IIHE
Annual Report
2017

Interuniversity Institue for High Energy

ANNUAL REPORT
2017

J. D'Hondt - L. Favart
Directors

http://www.iihe.ac.be

Contents

1 Introduction

1.1 The Interuniversity Institute for High Energies

The IIHE (ULB-VUB) was created in 1972 at the initiative of the academic authorities of the Université Libre de Bruxelles and the Vrije Universiteit Brussel. It is devoted to experimental research in elementary particle physics, using mainly high energy particle accelerators, and, more recently, in astroparticle physics with non-accelerator experiments.

The main goal of the experiments at accelerators, notably the CERN LHC, is the understanding of the strong, electromagnetic and weak interactions between the elementary building blocks of matter, which forms the standard model of particle physics, precision measurements of its parameters, the search for missing pieces in the standard model (notably untill recently the Brout-Englert-Higgs boson and neutrino oscillations), and the search for physics beyond the standard model, possibly related to the dark matter in the Universe and to cosmology. Astroparticle physics is devoted to the study of the structure of the Universe, using particles as messengers of astrophysical activity in the Universe and using the techniques developed in particle physics. All these experiments are performed in the framework of large to very large international collaborations (several hundreds to several thousands of physicists and engineers).

Fundamental contributions to the understanding of the Universe, particle and astroparticle physics experiments imply major R&D developments concerning particle detectors, computing and networking systems, frontier technologies in various fields (electronics, superconductivity, cryogenics, etc.), which lead to break-through progress in industrial and medical applications.

1.2 Overview of 2017

The present report presents the research performed at the IIHE in 2017, that spans from the smallest accessible scales, below 10^{-19} m for e.g. the Brout-Englert-Higgs boson, quarks and neutrinos, to the largest scales above hundreds of thousands of light years for the source of ultra high energy neutrinos detected by IceCube. During the year 2017 the IIHE published with its national and international research partners about 180 journal papers.

The IIHE is deeply involved in the CMS experiment since its design phase in the early 1990's, and actively contributed to all aspects of this experimental project, i.e. building, operating and maintaining the CMS detector as well as to the data analysis for searches for new physics and precision measurements of the fundamental interactions and particle properties. All aspects of this work are done in collaboration with other Belgian and international teams. Since the first collisions in 2009, the LHC has performed extremely well, with steadily increasing luminosity. The so-called Run 1, started in 2010, accumulated proton collisions with a collision energy up to 8 TeV and has been ended in February 2013. Data taken in proton-proton collision mode were complemented Pb-Pb and proton-Pb data. After a two-year upgrade, the LHC began the so-called Run 2, in June 2015, with a collision energy of 13 TeV — the highest energy ever achieved in a laboratory. In the year 2016 in total around 40 fb^{-1} of proton collision data was collected by the CMS experiment and 49.8 fb$-$1 in 2017.

During 2017, in addition to operational activities around the detector and its continuous survey and calibration, the Brussels team in CMS contributed to physics analyses with a continuous development of reconstruction methods for objects detected in the final state as well as the identification and trigger techniques to differentiate the physics objects. With these reconstructed objects physics measurements and searches are performed related to the Brout-Englert-Higgs boson, top quark physics, dark matter, supersymmetry and in general new physics phenomena. Precision measurements of the strong interaction (QCD) and the electro-weak interaction (EW) provided as well numerous new results.

The H1 experiment at the HERA electron-proton collider of DESY at Hamburg has taken data from 1992 to 2007, with major contributions of the IIHE team to detector building, operating and upgrading, in particular in the very forward proton spectrometer (VFPS). The measurements of H1 and ZEUS at HERA deeply modified our understanding of the proton structure in terms of quarks and gluons. Since the accelerator shut-down in 2007, the data analysis of the Brussels group focuses on the finalisation of the VFPS related measurements, providing new insights in Quantum Chromodynamics. The contribution of the IIHE to H1 has been closed in 2017. A short summary of the H1 experiment and its related physics results is given in the present report.

The IIHE has a long history of research in the field of neutrino (ν) physics. The IIHE has initiated together with national and international colleagues the SoLid experiment at the BR2 nuclear reactor at the SCK-CEN (Mol, Belgium). A new detector has been deployed in 2014, followed shortly by the start of data taking. These data are being analysed to commission the experiment for future reactor cycles. The intention is to measure neutrino oscillation processes at very short distances between 5 and 10 meter from the reactor source.

The JUNO experiment consist in a large liquid scintillator detector aiming to measure antineutrinos issued from nuclear reactor at a distance of 53 km and having as main goal to determine the neutrinos mass hierarchy after 6 years of data taking. Located in China, the detector will be at 700 m overburden and consists of 20 kton of liquid scintillator contained in a 35 m diameter acrylic sphere, instrumented by more than 17000 20-inch photomultiplier tubes (PMT). The required energy resolution to discriminate between the normal and inverted neutrinos hierarchies at 3-4 sigma of CL for about 6 years of data taking is 3energy of 1 MeV. This put strong constraints on the detector component quality in particular on the PMT characteristics. The international collaboration of JUNO was established in 2014, the civil construction started in 2015 and the RD/production phase for the detector is ongoing. The start of the data taking is expected at the end of 2021/beginning of 2022. The IIHE joined JUNO in 2016 and is contributing to the development and the construction of the readout electronic system.

In the field of astro-particle physics, the IIHE has been involved in the search and measurement of interactions of ultra-high energy neutrinos from cosmic origin in the South Pole ice, since the start of this quest in the late 1990's with the AMANDA and IceCube experiments. Since 2011 the fully deployed IceCube detector operates as the largest ever built particle detector (1 km^3). The major research topics of the IIHE team are: the search for cosmic point sources, dark matter, high-energy neutrinos from transient events, from supernovae and from solar flares. The first hints of extra-terrestrial high-energy neutrinos came in April 2012 with the observation of two very high energy events (above 1000 TeV). Since then, with an intensified search more events have been found. This achievement marks the birth of neutrino astronomy.

Since 2016, the IIHE has joined the Pierre Auger Collaboration to study cosmic rays. The IIHE group analyses the ultra high energy cosmic rays, which are messengers of the most violent phenomena in the Universe, to elucidate the origin of cosmic ray by performing mass-enhanced anisotropy studies and mass composition studies.

For the detection in the South Pole ice of "GZK" neutrinos, from the scattering of ultra-high energy cosmic rays off the cosmic microwave background, a sound-wave technique is being developed for the ARA experiment. A major activity at the IIHE in conjunction with the R&D group of the IIHE has been the development of a digital communication circuit to permit the deployment of digitization electronics under particularly stringent conditions. To cover the energy gap between IceCube and the Askaryan radio detectors, the IIHE initiated its investigations to use radar detection techniques.

Being devoted to experimental particle physics, the IIHE has always been very active in technical developments and instrumentation. This tradition points back to automatized bubble chambers and nuclear emulsion measurements, with important contributions to detectors at highest energy particle colliders (DELPHI at LEP, H1 at HERA and CMS at the LHC), in neutrino oscillation experiments (CHARM II, CHORUS, OPERA, JUNO, SoLid) as well as in the more recent astroparticle experiments (AMANDA, IceCube, ARA and AUGER). Over the recent years, R&D activities are centred on the development of multi-purpose, very high-rate, robust and low-cost, industry-based data acquisition systems, aimed to particle and astroparticle experiments. The contributions have taken place in the framework of generic DAQ systems for future experiments at colliders, for the ARA experiment, and for the upgrade of the CMS central tracker and muon spectrometer in the forward region. Also in the medical area the IIHE keeps on contributing to neutron metrology for future proton therapy centres.

To link the activities of their theoretical physics (TENA) and experimental particle physics (ELEM) groups, a phenomenology group has been settled by the VUB in 2014 through a Strategic Research Program, namely HEP@VUB. The main topics of research are new physics models and their signatures at the LHC, as well as early universe physics and the phenomenology of cosmic rays propagation.

Finally, large computing resources are requested by the experiments, in particular IceCube and CMS. The IceCube collaboration uses the IIHE cluster for large simulations of the ice optical structure. For CMS computing, a "Tier- 2" cluster installed at the ULB-VUB Computing Centre is fully integrated in the worldwide LHC computing grid, with very high performance and stability.

On November 22th 2017, all the IIHE members attended the IIHE annual meeting, where a review of the activities in the different experiments, in computing and in R&D were presented and discussed, together with the development plans for the coming years. The retirement of Prof. Walter Van Doninck was celebrated at his occasion.

Walter Van Doninck obtained his PhD in 1977 at the VUB with a thesis on the experimental discovery of the weak neutral currents with the Gargamelle experiment in 1973 at the CERN PS neutrino beam. After leading roles in the Big European Bubble Chamber (BEBC) and DELPHI experiment at LEP, he initiated in 1992 the Belgian involvement in the CMS experiment at the LHC. Since 2000 he was on leave of absence from Belgium and stationed at CERN where he coordinated the work on the forward RPC detectors of the CMS experiment. His career culminated in the election as vice-president of the CERN Council.

Research at IIHE has been supported by the Université Libre de Bruxelles (ULB), the Vrije Universiteit Brussel (VUB), the Fonds de la Recherche Scientifique (F.R.S.-FNRS), the Fonds voor Wetenschappelijk Onderzoek-Vlaanderen (FWO), the Fonds pour la Formation à la Recherche dans l'Industrie et dans l'Agriculture (FRIA), the Instituut voor de Aanmoediging van Innovatie door Wetenschap en Technologie in Vlaanderen (IWT), the Belgian Federal Science Policy Office, the Odysseus programme.

Since 2015 the IIHE benefits from the support of the China Scholarship Council (CSC) through the agreement between them and ULB, providing PhD scholarships to Chinese students to achieve their PhD at ULB.

1.3 The IIHE team in 2017

1.3.1 The ULB personnel

Academic and scientific personnel

Juan Antonio AGUILAR SANCHEZ	Chargé de cours	IceCube
Isabelle ANSSEAU	PhD student (Assistante ULB)	IceCube
Diego BEGHIN	PhD student (Aspirant F.R.S.-FNRS)	CMS
Bugra BILIN	Post-doc (IISN) since September	CMS
Hugues BRUN	Post-doc (IISN)	CMS
Barbara CLERBAUX	Chargée de Cours	CMS, JUNO
Hugo DELANNOY	PhD student (FRIA)	CMS
Gilles DE LENT-DECKER	"Maître de Recherche F.R.S.-FNRS; Maître d'Enseignement"	CMS, DAQ R&D
Wendi DENG	"PhD student (CSC scholarship) since September Co-tutelle with CNNU University"	CMS, DAQ R&D
Jianmeng DONG	"PhD student (CSC scholarship) Co-tutelle with IHEP-China"	CMS DAQ R&D
Brian DORNEY	Post-doc (IISN) since March	CMS
Wenxing FANG	"PhD student (CSC scholarship) Co-tutelle with BUAA University"	CMS
Giuseppe FASANELLA	"PhD student (FRIA) until September Co-tutelle with Rome University"	CMS
Laurent FAVART	"Directeur de Recherche F.R.S.-FNRS; part-time Chargé de Cours; IIHE director"	H1, CMS
Xuyang GAO	"PhD student (CSC scholarship) Co-tutelle with BUAA University"	CMS
Reza GOLDOUZIAN	Post-doc (IISN)	CMS
Anastasia GREBENYUK	Chargé de Recherche F.R.S.-FNRS	CMS
Zigfried HAMPEL-ARIAS	Post-doc (BAEF grant) since November	IceCube
Amandeep Kaur KALSI	Post-doc (IISN) since November	CMS
Georgia KARAPOSTOLI	Post-doc (PAI) until June	CMS
Thomas LENZI	"Post-doc until September (Aspirant F.R.S.-FNRS) Post-doc (PAI) from September until December"	CMS, DAQ R&D
Alexandre LÉONARD	Logisticien de Recherche ULB until April	CMS
Jelena LUETIĆ	Post-doc (PAI) until December	CMS
Pierre MARAGE	"Professeur ordinaire émérite; Professeur de l'Université; past IIHE co-director"	Hist. of Science
Andrey MARINOV	Chargé de Recherche F.R.S.-FNRS until September	CMS
Ioana MARIS	Chargé de Cours since January	IceCube, Auger
Kevin MEAGHER	Post-doc (IISN)	IceCube

Louis MOUREAUX	PhD student (Assistant ULB) from September until December	CMS
David NDAYIZEYE	PhD student (Burundi grant)	Instrumentation
Yves PIERSEAUX	collaborateur scientifique	Hist. of Science
Elisa PINAT	PhD student (IISN) until June	IceCube
Nicolas POSTIAU	PhD student (Assistant ULB)	CMS
Christoph RAAB	PhD student (IISN)	IceCube
Rachel SIMONI	"PhD student (Amsterdam University); collaborateur scientifique"	
Zixuan SONG	"PhD student (CSC scholarship) Co-tutelle with CCNU University"	CMS, DAQ R&D
Elizabeth STARLING	PhD student (FRIA) since January	CMS
Laurent THOMAS	Chargé de Recherche F.R.S.-FNRS since September	CMS
Raffaella TONCELLI	collaborateur scientifique	Hist. of Science
Catherine VANDER VELDE	Professeur de l'Université	CMS
Pascal VANLAER	Chargé de Cours	CMS
David VANNEROM	PhD student (Aspirant F.R.S.-FNRS)	CMS
Qun WANG	"PhD student (CSC scholarship) Co-tutelle with PKU University"	CMS
Gaston WILQUET	"honorary Maître de Recherche F.R.S.-FNRS; Professeur invité"	OPERA
Fengwangdong ZHANG	"PhD student (CSC scholarship) until June Co-tutelle with PKU University"	CMS

Master students

Nadège IOVINE	physics, until September	IceCube
Louis MOUREAUX	physics, until September	CMS
Pierre-Alexandre PETITJEAN	physics, since September	CMS
Laurent PÉTRÉ	physics, since September	CMS
Morgane Raphaëlle RIGAUX	physics, since September	CMS
Jason ROSA	physics, until September	CMS DAQ R&D

Engineers, Technical and Logistic Personnel

Samir AMARY	computer scientist
Yannick ALLARD	Logisticien de Recherche ULB (half-time) since October
Abdelhakim BOUKIL	computer scientist until June
Patrick DE HARENNE	technician, general support
Benoît DENÈGRE	technician, electronics (half-time) since January
Michael KORNTHEUER	electronics
Shkelzen RUGOVAC	computer scientist
Adriano SCODRANI	computer scientist since September
Audrey TERRIER	secretariat
René VANDERHAEGEN	technician, electronics
Yifan YANG	ULB electronics/computing

1.3.2 The VUB personnel

Academic and scientific personnel

Shimaa ABU ZEID	ERASMUS MUNDOS (PhD student)	CMS
Freya BLEKMAN	ZAP hoofddocent	CMS
Emil BOLS	FWO scientific collaborator (PhD student) since November	CMS
Douglas BURNS	FWO scientific collaborator (PhD student)	CMS
Andries COONE	FWO scientific collaborator (PhD student)	Pheno
Paul COPPIN	FWO scientific collaborator (PhD student) since October	IceCube
Pablo CORREA	FWO aspirant (PhD student) since October	IceCube
Isabelle DE BRUYN	FWO scientific collaborator (PhD student)	CMS
Catherine DE CLERCQ	Professor-emeritus	IceCube
Jarne De Clercq	FWO scientific collaborator (PhD student)	CMS
Krijn DE VRIES	FWO research fellow (postdoctoraal onderzoeker)	IceCube
Gwenhael DE WASSEIGE	FWO scientific collaborator (PhD student)	IceCube
Kevin DEROOVER	FWO scientific collaborator (PhD student) until September	CMS
Jorgen D'HONDT	ZAP hoogleraar; IIHE co-director	CMS, SoLid
Giannis FLOURIS	FWO scientific collaborator (post-doc) until October	CMS
Leonidas KALOUSIS	FWO scientific collaborator (post-doc)	SoLid
Denys LONTKOVSKYI	FWO scientific collaborator (post-doc)	CMS
Steven LOWETTE	ZAP docent	CMS
Jan LUNEMANN	FWO scientific collaborator (post-doc) until July	IceCube
Giuliano MAGGI	FWO scientific collaborator (PhD student) until June	IceCube
Ivan MARCHESINI	FWO scientific collaborator (post-doc) from July	CMS
Alberto MARIOTTI	ZAP docent	Pheno
Kentarou MAWATARI	10% ZAP research professor until September	Pheno
Seth MOORTGAT	FWO aspirant (PhD student)	CMS
Lieselotte MOREELS	FWO scientific collaborator (PhD student)	CMS
Quentin PYTHON	FWO scientific collaborator (PhD student)	CMS
Olaf SCHOLTE	10% ZAP professor	IceCube
Kirill SKOVPEN	FWO research fellow (postdoctoraal onderzoeker)	CMS
Dominic SMITH	FWO scientific collaborator (PhD student)	CMS
Stefaan TAVERNIER	Professor-emeritus	Crystal Clear
Walter VAN DONINCK	Professor-emeritus	CMS
Nick VAN EIJNDHOVEN	ZAP hoogleraar	IceCube
Petra VAN MULDERS	FWO research fellow (postdoctoraal onderzoeker) 10% ZAP professor	CMS, SoLid
Isis VAN PARIJS	FWO scientific collaborator (PhD student)	CMS
Simon VERCAEMER	IUAP scientific collaborator (PhD student) 1/2 VUB – 1/2 UA	SoLid
Mathias VEREECKEN	FWO aspirant (PhD student)	Pheno

Master students

Paul COPPIN	Student in physics	IceCube
Matthias STUCKENS	Student in physics	CMS
Pablo CORREA	Student in physics	IceCube

Engineers, Technical and Logistic Personnel

Olivier DEVROEDE	computer scientist
Stéphane GERARD	computer scientist - VSC
Marleen GOEMAN	secretariat
Annemie MOREL	engineer (since September)

1.4 Associated institutes

The following members of the Particle Physics Group of Antwerp University (UA) have been working in close collaboration with the IIHE Institute:

Prof. Em. Dr. Eddi De Wolf, Prof. Dr. Pierre Van Mechelen, Prof. Dr. Nick Van Remortel, Prof. Dr. Albert De Roeck, Dr. Francesco Hautmann, Dr. Xavier Janssen, Dr. Hans Van Haevermaet , Jasper Lauwers, Pieter Taels, Merijn Van Der Klundert, Sarah Van Mierlo, Alex Van Spilbeeck, Ir. Wim Beaumont, Ig. Tim Viaene, Davide Di Croce, Maxim Pieters, Senne Van Putte, Yamiel Abreu, Maja Verstraeten, Ibrahin Pinera, Simon Vercaemer.

2 Research activities, development and support

2.1 The CMS experiment at the CERN LHC

(S. Abu Zeid, Y. Allard, D. Beghin, F. Blekman, E. Bols, H. Brun, D. Burns, B. Clerbaux, J. D'Hondt, I. De Bruyn, J. De Clercq, G. De Lentdecker, H. Delannoy, W. Deng, K. Deroover, O. Devroede, J. Dong, B. Dorney, W. Fang, G. Fasanella, L. Favart, G. Flouris, X. Gao, R. Goldouzian, A. Grebenyuk, A. K. Kalsi, G. Karapostoli, M. Korntheuer, T. Lenzi, D. Lontkovskyi, S. Lowette, A. Léonard, J. Luetic, P. Marage, I. Marchesini, A. Marinov, S. Moortgat, L. Moreels, L. Moureaux, N. Postiau, Q. Python, S. Rugovac, K. Skovpen, D. Smith, Z. Song, E. Starling, D. Strom, S. Tavernier, L. Thomas, W. Van Doninck, P. Van Mulders, I. Van Parijs, C. Vander Velde, P. Vanlaer, D. Vannerom, Q. Wang, Y. Yang, F. Zhang)

The following members of Antwerp university are also members of CMS: W. Beaumont, K. Cerny, T. Cornelis, A. De Roeck, E. De Wolf, D. Di Croce, D. Druzhkin, F. Hautmann, X. Janssen, H. Jung, J. Lauwers, S. Luyckx, P. Taels, M. Van Der Klundert, H. Van Haevermaet, P. Van Mechelen, S. Van Mierlo, S. Van Putte, N. Van Remortel, A. Van Spilbeeck, T. Viaene

One of the two general-purpose detectors at CERN's Large Hadron Collider (LHC) is the Compact Muon Solenoid (CMS) experiment. The LHC provided proton-proton collisions during the so-called Run 1 in years 2010, 2011 and 2012, at a centre-of-mass energy of 7 and 8 TeV, corresponding to a total integrated luminosity of about 29/fb delivered by the machine to the experiments. The most important result in the LHC Run 1 is beyond doubt the observation of the last missing part of the Standard Model (SM), the BEH scalar boson predicted by R. Brout, F. Englert and P. Higgs, at a mass of 125 GeV/c^2. In addition, the analysis of the Run 1 data allowed physicists to perform precision tests of the SM and to search for new physics beyond the Standard Model. About 650 CMS publications are based on the LHC Run 1 data in international scientific journals.

During the years 2013 and 2014, a long shutdown period took place to upgrade the LHC machine and the detectors in view of the high-energy and high intensity run. The Run 2 data taking started in year 2015 at a record energy of 13 TeV. The year 2015 was key in the optimisation of the new machine condition running at high energy and high intensity, with a 25 ns bunch crossing time separation, a factor two smaller compared to the Run 1 running condition. The data accumulated in 2015 correspond to an integrated luminosity of 4.2 delivered by the LHC. The full power of the machine was develop in year 2016, with a record integrated luminosity of 40.8/fb delivered by the LHC. In 2017 in total 49.8/fb of integrated luminosity was delivered to the CMS experiment, with peak luminosities reaching far above the design values and producing up to about 60 simultaneous proton-proton collisions. The Run 2 will continue until end 2018, with an total expected luminosity of about 120/fb. While the discovery of the SM scalar boson (Higgs particle) is definitely the highlight of Run 1, the high-energy and high-intensity Run 2 dataset extends the phase space for discoveries. It allows physicists to study in detail the newly-discovered scalar particle, to search for possibly additional scalar particles, to make precise SM measurements in various sectors, and to search for new physics beyond the SM, among others for dark matter candidates.

CERN foresees to increase gradually the luminosity of the LHC: up to twice the design luminosity in 2017 and 2018 (with a corresponding Phase-1 upgrade programme for the experiments), and up to 10 times the design luminosity in 2026 (the so-called HL-LHC project, HL stands for High-Luminosity, with a corresponding Phase-2 upgrade of the experiments). The aim is to allow a precise study of the scalar sector, as well as extending the discovery potential of the LHC for rare beyond-the-standard-model processes. The HL-LHC was formally approved by the CERN council in June 2016, and is among the "landmark projects" in the European strategy roadmap for research infrastructures (ESFRI roadmap 2016). The IIHE is strongly involved in these activities, coordinating the electronics of the GEM Phase-1 upgrade of the Muon system, and taking a leading rôle in the Phase-2 upgrade of the silicon tracker.

Members of the IIHE were selected or elected for top-level managerial positions in the CMS Collaboration. Amongst others the position of Chairperson of the CMS Collaboration Board by Prof. Jorgen D'Hondt.

2.1.1 Data analysis

Study of scalar bosons and of multi-boson production

Since the existence of the SM scalar was confirmed in 2012, the study of the SM scalar now involves questions such as whether this particle is the only element to be added to the SM in order to give masses to the particles, and questions regarding the consistency of the discovered particle with respect to SM predictions. The SM scalar could also interact with particles yet to be discovered, such as dark matter particles. Measurements of the properties of the SM scalar are thus essential to address. The 2016 dataset taken at 13 TeV provides a significant increase in sensitivity. To maximize the discovery power, the understanding of the background processes, in particular diboson production interfering with the production of a scalar particle, is crucial up to the highest possible precision.

The IIHE group contributed in 2017 to the SM scalar boson studies on several important areas: 1) the search for additional scalar(s) in the $\tau^+\tau^-$ final state, 2) the search for additional massive scalars in the l^+l^- plus missing energy channel, 3) the search for invisible decays of the light scalar boson in the l^+l^- plus missing energy channel, 4) the study of the off-shell production and decay of the SM boson, and 5) the study of higher-order electroweak contributions to diboson production. These studies are detailed below.

- **Studies of the $H \to \tau^+\tau^-$ channel:** In 2016 and 2017, the IIHE team was involved in the search for a massive A/H/h boson decaying into a pair of tau leptons predicted by models with an extended scalar sector. This is the most powerful channel to uncover an MSSM scalar sector at the LHC. The team contributed to the decay channel where both taus decay into hadrons and a neutrino. In addition, three new Beyond the Standard Model (BSM) searches were performed for the first time using the 8 TeV data. These analyses are supported by a detailed study of the performance of tau lepton reconstruction and selection algorithms: the selection efficiency and fake rate measurements are estimated using Drell-Yan $Z \to \tau\tau$ events, both for the 8 TeV and the 13 TeV CMS datasets. These activities provide leading contributions from the IIHE to the recent CMS publication on the tau-lepton reconstruction and identification performance during Run 2. This tau lepton reconstruction expertise is also used in the search for heavy resonances in the dilepton final state (search for new resonances with lepton flavor violation decay), as explained later in this section.

Cécile Caillol, a IIHE PhD student, made leading contributions in these activities and was awarded the 2016 prize of the CMS PhD thesis competition.

- **Search for a high-mass scalar in the $H \to ZZ \to l^+l^-\nu\bar{\nu}$ channel:** The $H \to ZZ \to l^+l^-\nu\bar{\nu}$ decay channel is a sensitive final state for the possible observation of an additional heavy scalar with SM-like couplings, thanks to its large branching ratio compared to the decay into four charged leptons, and to the smaller background compared to the $l^+l^-q\bar{q}$ channel. The IIHE team is strongly involved in this search, and is co-convening $H \to ZZ \to l^+l^-\nu\bar{\nu}$ working group. A joint paper combining the $H \to ZZ \to 4l$, $H \to ZZ \to l^+l^-\nu\bar{\nu}$ and $H \to ZZ \to l^+l^-q\bar{q}$ channels with 36fb^{-1} of data at 13 TeV, was finalized, with an IIHE member as a co-editor.

- **Search for invisible decays of scalars in the $ZH \to l^+l^- + MET$ channel:** Being susceptible to couple to all massive particles, the scalar boson could decay into yet-undiscovered non-interacting particles such as those postulated to be responsible for the dark matter of the universe. The IIHE contributes to the search for such decays in the $ZH \to l^+l^-$ plus missing energy channel. We contributed to the estimation of the instrumental background from Z+jet events using the γ+jet control triggers that we designed. We also provide tables of NLO electroweak corrections to the ZZ and WZ background processes.

- **Study of the diboson background:** Such searches and measurements require excellent control of the SM diboson background. IIHE members were the first to introduce electroweak corrections into the modeling of the ZZ differential cross section in an analysis at the LHC. An IIHE PhD student also estimated electroweak corrections to the WZ process, which include a contribution from the photon density in the proton, poorly known until the study was performed.

Searches for high-mass resonances

Many scenarios beyond the SM are expected to be manifest through the production of new heavy resonances, typically above 1 TeV. For example, massive gravitons or new massive gauge bosons, Kaluza-Klein recurrences, are expected in the framework of extra spatial dimension models, as well as new heavy Z bosons in Grand Unified Theories. Additional scalar sector (spin-0) resonances are also investigated. Several final states are being analysed by the IIHE team: the diphoton final state, the dilepton final state and the lepton flavour violation (LFV) decay channels; they are detailed below. These analyses are considered as HPA (High Priority Analysis) by CMS in particular for the run 2 data taking period where the new high energy frontier of 13 TeV allows to open considerably the phase space for discovery of new massive particles.

The electromagnetic calorimeter of CMS, the ECAL, is the main detector used in the diphoton and dilepton analyses. Expertise has been acquired in the ECAL calibration, resolution and linearity measurement. Important contributions concern the ECAL energy scale and energy resolution estimation and corrections, in particular using the Z peak events from SM Drell-Yan process. In addition, the Brussels group has designed and developed a method based on the ECAL shower shape to cross check the ECAL calibration and linearity, and to correct for ECAL electronic readout saturation at very high energy. This sophisticated method is the only one available at very high energy and is crucial for the control of the ECAL response in view of the search for new physics at high energy.

- **Search for heavy resonances decaying to a lepton pair:** Since 2006, physicists from the IIHE play a leading role in this channel; they initiated the creation of the HEEP (High Energy Electron Pairs) working group and were strongly involved in every step of the run 1 CMS data analysis at 7 TeV and 8 TeV, as well as on the run 2 data taking and analysis (data collected in 2015-2018) at 13 TeV. No excess was observed in the 2015-17 datasets and limits at 95% Confidence Level (CL) on the new resonance production cross section have been determined. The dielectron and dimuon channel results were combined. The results on the CMS data at 13 TeV taken in year 2015 and part of the 2016 dataset have been published. Updated results using the full 2016 dataset have been recently published and preliminary results on the 2017 data analysis have been presented at the Moriond 2018 conference. Figure 1 presents the recent results obtained by the HEEP group : the dielectron invariant mass distribution resulting from the analysis of the 2017 CMS data (on the left side) and the upper limits on the spin-1 resonance production (on the right side).

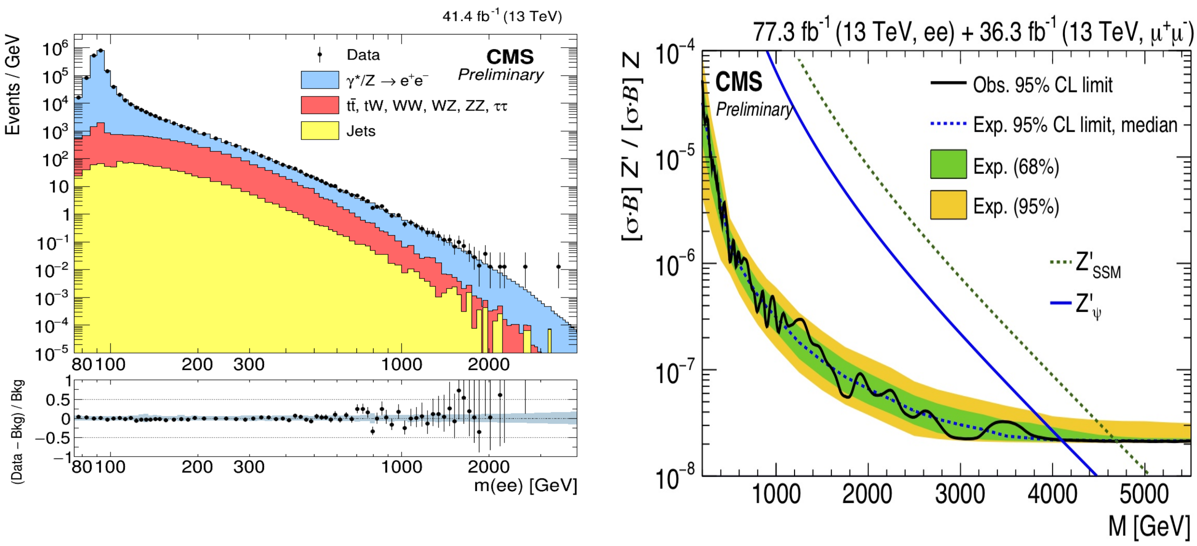


Figure 1: Left: The invariant mass spectrum of the dielectron events using the CMS data collected in 2017. Right: The 95% CL upper limits on the production cross section times branching fraction for a spin-1 resonance with a width equal to 0.6% of the resonance mass, relative to the production cross section times branching fraction for a Z boson, for the dielectron channel using the 2017 dataset in combination with the 2016 dataset (dielectron and dimuon channels).

- **Searches for new heavy resonances decaying with LFV:** In collaboration with ULB theorists, an additional analysis was performed to search for high mass resonances decaying with lepton flavor violation (LFV) into an electron-muon pair, using the 8 TeV dataset. The analysis was also performed using the data collected in 2015 and in 2016, leading to 2 CMS publications. The data were found to be in agreement with the SM expectation, and stringent limits on new physics parameters for different models have been put. The group is presently extending the search for LFV Z with final states including a tau lepton: the electron-tau and muon-tau final states, using both the 2016 and 2017 datasets.

Heavy flavour jet identification

A crucial ingredient for many analyses in CMS is the accurate identification of jets originating from b quarks. The importance of this topic is illustrated by the fact that about one third of all CMS publications relies on heavy flavour jet identification. At the IIHE, particularly the subjects of SM scalar and top quark physics, as well as many searches for beyond the standard model phenomena, rely heavily on the identification of heavy flavour jets. IIHE members had a leading role in the CMS collaboration in improving the b jet identification algorithms (S. Abu Zeid, K. Deroover, Q. Python, S. Moortgat) and developing charm quark identification algorithms (S. Moortgat) as well as to commission heavy flavour tagging variables with the 13 TeV proton collision data (K. Deroover). S. Moortgat also contributed profoundly to the validation of the simulation using the data. As a result of all of his contributions, S. Moortgat was appointed as coordinator of the performance and validation activities within the BTV group in the CMS collaboration, which is truly remarkable for a second-year PhD student. Under the leadership of postdoc Ivan Marchesini (2016-2018) and FWO postdoc Kirill Skovpen (2017-2018) as conveners of the vertexing and heavy flavour identification group (BTV) in the Physics Coordination of the experiment, CMS managed to smoothly and successfully complete the many challenges in heavy flavour jet identification, especially related to the new tracker installed in 2017. An important achievement of the BTV group is the publication of around 100 pages summarizing the state of the art of heavy-flavour jet identification in the CMS experiment for the LHC Run 2 for which FWO postdoc P. Van Mulders was the editor.

Top quark physics

During the 2016 run of the Large Hadron Collider, at 13 TeV centre of mass energy, the CMS experiment collected an enormous sample containing top quarks in pair production as well as single production. In addition the precision measurements using the datasets collected in 2015 and 2012 at $\sqrt{s} = 8$TeV are still ongoing.

IIHE physicists are measuring and studying very diverse aspects of the top quark sector, focusing not only on the SM but also on searches for physics beyond the SM. IIHE physicists remained visible in a leading role in the LHC top physics working group with ex-IIHE postdocs in leading roles as convener and multiple sub-conveners.

Using the 2012 and 2015 datasets the IIHE group are involved in the preparation of legacy papers on the high precision measurements of the production and decay properties of the top quark (some of these will not be possible to be performed as accurately in future LHC runs due to the high luminosity conditions) as well as searches for new physics in top-like final states. This results in a physics programme that reveals going from SM measurements via BSM-sensitive top quark physics to direct searches, with substantial roles in CMS by senior IIHE members in the internal peer-review inside the collaboration.

- **Differential cross section of top quark pair processes:** The final publication providing an overview of the Run 1 data analysis also included a measurement of the cross section ratio of top quark pair production in 7 and 8 TeV proton-proton collisions that was an IIHE contribution. Using the 2015 and 2016 datasets, a differential measurement of the top quark production cross section are being measured by D. Burns, PhD student at the IIHE in a shared doctoral agreement with the University of Bristol in the UK.

- **Flavour-Changing Neutral Currents in the top quark sector:** If new physics can not be directly observed at the LHC, it would in many cases still be possible to find evidence of such new physics processes through deviations to Standard Model rare processes. IIHE physicists coordinated by FWO postdoc Kirill Skopven, are preparing an inclusive approach using the full LHC Run 2 dataset at 13 TeV centre of mass energy, where all final states in top quark physics sensitive to Flavour-Changing Neutral Currents (FCNC) such as the rare decays $t \to Hc$ and $t \to Zc$, are examined and these processes are accurately measured in all possible final states. This work relies heavily on identification of b- and charm quarks so the same team is also developing the CMS experiment charm quark tagger for the 13 TeV LHC run.

- **Using precision techniques to measure the width of the top quark:** A team of IIHE physicists was involved with the direct measurement of the top quark width. The top quark width is extracted by performing a likelihood template fit on the scaled top quark mass distribution, defined as the reconstructed top quark mass divided by the average top quark mass. With this strategy the dependency on the jet energy scale uncertainty is largely reduced. As a result, the dominant uncertainty is expected to come from modelling uncertainties. The large amount of data allows to employ tight selection requirements for instance on the number of observed jets to reduce the dependency on these uncertainties. In addition, the sensitivity of the analysis is enhanced by weighting each event taking into account the resolution on their reconstructed object four-momenta.

- **Search for production of four tops:** The production of four top quarks, which in the SM is a very rare process with a cross section of the order of $1fb$ at 8 TeV and $9fb$ at 13 TeV, could be greatly enhanced by many new physics models, including Supersymmetry, but also more exotic models where gluon couplings are enhanced due to additional particles in the QCD sector. Depending on the physics model, these signatures will not display the typical Supersymmetry signature with large transverse missing energy. The an IIHE team with postdoc Denys Lontkovskyi published an extremely competitive limit on Standard Model top quark production as a preliminary result with expected expected publication in early 2017.

- **Search for third generation supersymmetric particles:** Supersymmetry is a popular extension of the SM, but invokes a large set of new parameters. Simplified benchmark models are developed to allow a general interpretation. There are many different scenarios, and IIHE members are involved in searches for the production of top squark pairs using boosted techniques and related searches in jets+missing energy and monojet final states, which are included in the PhD thesis of Dominic Smith who was also involved with searches for new physics in the jets+missing energy signature.

SM precision measurements

To exploit the full discovery potential of CMS and to achieve the maximal precision on the BEH boson properties measurement, it is essential to reach the highest level of precision possible in SM physics area. For these reasons, the jet production associated to the Drell-Yan process is identified as a High Priority Analysis in CMS.

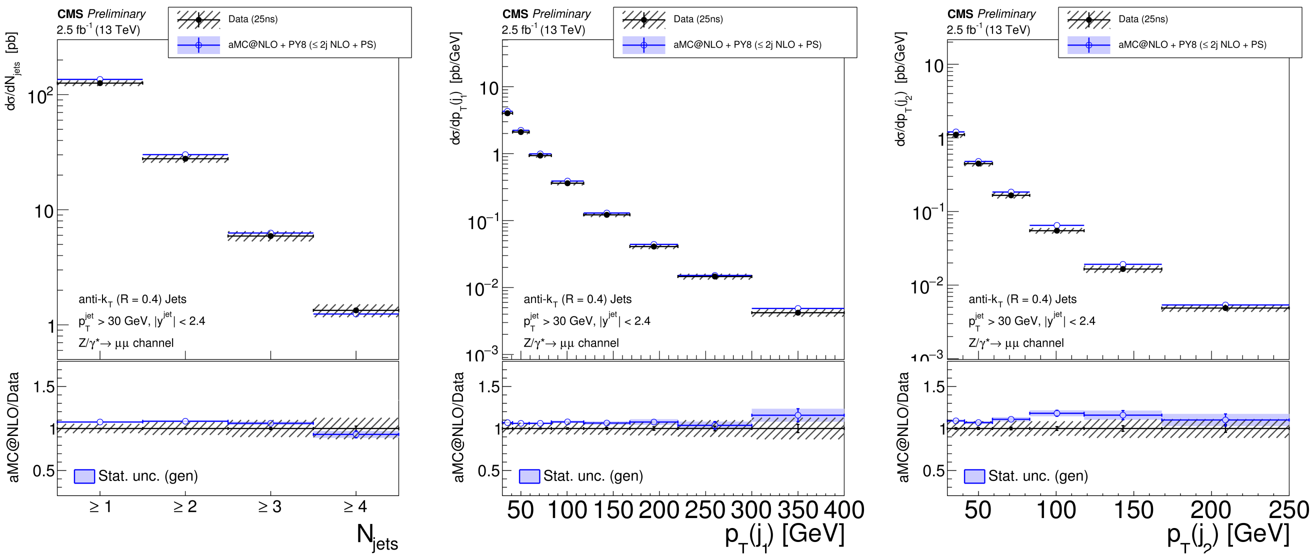


Figure 2: Measured cross section for Z+jets, using 13 TeV proton-proton data collected in 2015, are shown as a function of the jet multipicity, the leading and the sub-leading jet transverse momenta, compared to prediction at NLO from aMC@NLO Monte Carlo.

- **Drell-Yan production associated with jets:**

  The Drell-Yan production cross section on the Z peak with jet production is one of the central reference measurement at the LHC. The leptonic decay of the Z boson provides a background free and unbiased data selection to study in details the jet production and the reliability of its Monte Carlo simulation. The Drell-Yan cross section being known at NNLO in QCD for 1 jet process, the confrontation of the measurement to theoretical predictions provides a stringent test of perturbative QCD. Furthermore, the very high energy of the LHC allows producing many jets in the events. In particular Z events with more than 2 jets are frequently produced but beyond the scope of NNLO predictions. Alternative approaches are developed in Monte Carlos to predict many jets production. The IIHE group is leading the analysis at 13 TeV (2015-2017 data) measuring the Z and $Z + jet$ cross sections for up to 4 jets with transverse momenta above 30 GeV and compared it to different Monte Carlo predictions. In 2017, first results (preliminary) at 13 TeV have been obtained (see Fig.2 based on 2.5fb^1 of luminosity collected in 2015, for Z boson decaying in two muons.

Dark matter and long-lived particle searches

Since many years, the IIHE is actively involved in the search for signatures of direct dark matter production at the LHC. Through participation in the flagship search for a jet recoiling against a dark matter pair escaping the detector without interacting, an IIHE member became the first convener of the so-called Exotica MET+X group that very successfully grouped all searches for direct dark matter production from 2016 onwards. In 2017, the prior investments beared ample fruit, with active IIHE contributions to the CMS searches in $t\bar{t}(2\ell)$+MET, VBF+MET (invisible BEH boson) and jets+MET signatures each wrapped or wrapping up for publication using the full 2016 CMS dataset. As an example result, the state-of-the-art of limits on the existence of dark matter produced through a scalar mediator is shown in Fig. 3, where both red and blue curves originate from analyses IIHE participated in, as mentioned above. This summary, shown at the important EPS 2017 conference, represented the best world limits at that time on this benchmark model.
Additionally, new avenues in more exotic dark matter searches were initiated at IIHE, looking beyond into new physics from dark sectors in general. A search for strongly interacting dark matter was continued and is nearing completion

by PhD student Isabelle De Bruyn; a new search for sexaquarks was started up in the context of the PhD of Jarne De Clercq as well as a master thesis, searching for a soft hadronic signature from a bound state made of 6 quarks that could compose standard-model dark matter; and a search for long-lived fractionally charged particles was started by PhD student David Vannerom, linking the previously investigated jets+MET searches with the realm of new long-lived physics. These signatures are indeed all examples of searches for long-lived particles, a topic with increasing impact in the LHC search program. Also here, an IIHE member took the lead mid-2017 and was appointed convener of the overall Exotica long-lived analysis group.

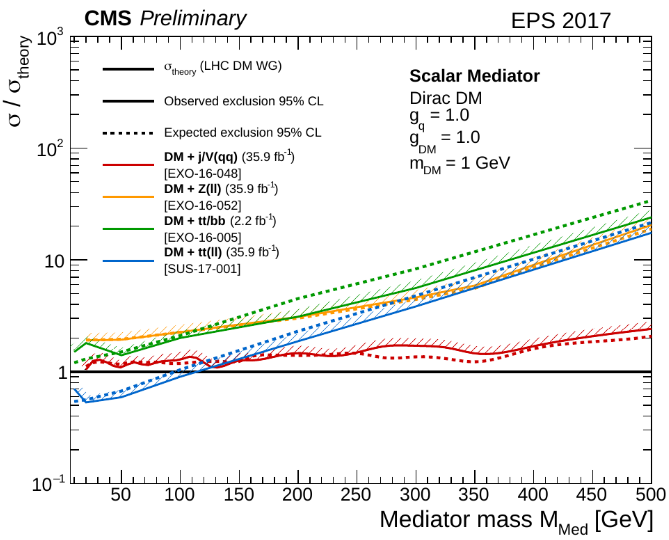


Figure 3: Normalized cross section upper limits on the production of dark matter through a scalar mediator, featuring the limits from the jets+MET and $t\bar{t}(2\ell)$+MET final states the IIHE helped analyze.

2.1.2 Tracker operation

As in previous years, several of the PhD students, postdocs and senior physicists have contributed to the running of the current CMS tracker detector, either at the detector, in data quality monitoring, or through specific offline system monitoring. For the online activities, several weeks of Detector-On-Call shifts were performed, an intense monitoring and problem-solving task first in line when problems occur during data taking. Similarly, weeks of shifts as on-call or shift leader were taken for the monitoring of the quality of the data taken in the previous days and promptly reconstructed. Also, offline software developments were done in the area of Data Quality Monitoring (DQM) for the tracker. In particular, two of our students continued their roles as tracker DQM co-conveners, managing the group both for the organization of the shift work and follow-up of lessons learned, as well as for what concerns the longer-term offline software developments. As these students neared thesis completion, these tasks were eventually handed over.

2.1.3 Contributions to the CMS upgrades

In the years 2020 and beyond, CERN will further increase the LHC luminosity. In these extremely intense experimental conditions, new detector technologies are needed, to which IIHE physicists are contributing.

GEM (GE11) upgrade

Since July 2011, the IIHE is contributing to the upgrade of the forward region ($1.5 < |\eta| < 2.2$) of the CMS muon spectrometer for the LHC high luminosity phase. The project called GE11 aims at installing 144 Triple-GEM detectors in the first ring of the first muon endcap disk, during the 2nd long LHC shutdown in 2019-2020. Fig 4 shows one of the 10 fully equipped Triple-GEM prototypes that has been installed in CMS, as a demonstrator, in February 2017. The 1m-long detector has a trapezoidal shape and it is subdivided into 3 × 8 sectors, each read-out by a front-end chip (black rectangles on the picture). These 24 chips are connected through a large PCB (green) to an FPGA-based board, the opto-hybrid (sitting on the long base of the detector).

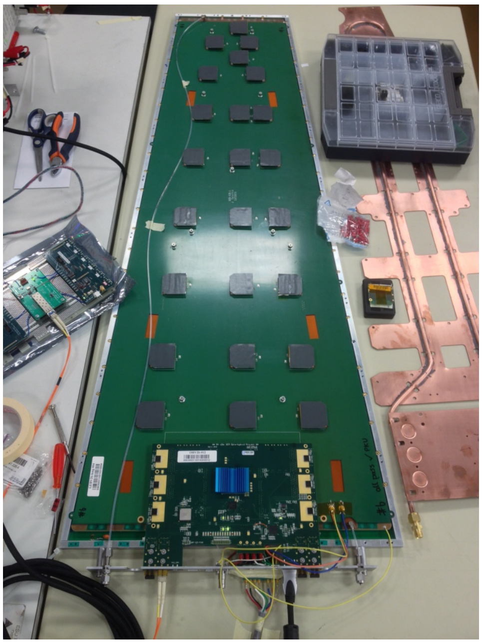


Figure 4: One of 10 Triple-GEM prototypes before its installation in CMS during the 2016-2017 LHC shutdown. The detector is equipped with its new electronics. The opto-hybrid board designed at the IIHE is located on the long base of the detector.

In this project the IIHE is leading the design of the trigger and data acquisition (DAQ) system of the new detectors. The new readout system is based on the micro-TCA standard as well as on the new optical link, called Versatile Link, and the GBT chipset, both developed by CERN for the LHC upgrade. In addition to the overall readout architecture the IIHE is also responsible for the design of the opto-hybrid. The board is equipped with an FPGA connected on one side to 24 front-end VFAT2 front-end chips and on the other side to the backend micro-TCA electronics through several optical fibers. This board being located on the detector, it has to be tolerant to the radiation. The IIHE group has developed the largest part of the firmware of the readout system, in particular for the opto-hybrid, including Single Event Upset (SEU) mitigation techniques.

In 2017, the IIHE has largely contributed to the installation and the commissioning of these 10 detectors in CMS and has pursued the developments of the final electronics system, including a new front-end chip, the VFAT3. The production of the final electronics and the assembly of the GE11 detectors will take place in 2018.

Tracker Phase-2 upgrade

From 2026 on, CERN has the goal to further increase the LHC luminosity by a factor 5-7 above the present design parameters. The aim is to allow a precise study of the scalar sector, as well as extending the discovery potential of the LHC for rare beyond-the-standard-model processes.

To meet the challenging data taking conditions at the HL-LHC, the CMS tracker must be completely replaced, for 3 reasons: first, the silicon sensors and their readout electronics must be more radiation-tolerant than those of the current tracker; second, the tracker data must be used in real time at the first level of event selection (L1 trigger) every 25 ns; and third, the tracker coverage must be extended towards the beam line (up to a pseudo-rapidity range $|\eta| < 4$) to optimize the potential of the experiment. The use of tracker data at L1 trigger level sets stringent requirements on the reliability of the outer tracker.

After a proof of concept documented in the CMS phase-2 upgrade technical proposal, the Tracker phase-2 community has finalised the technical design report (TDR) describing the baseline technical choices for the building of the phase-2 tracker. It was submitted to the LHCC review committee beginning of July 2017, and approved in December

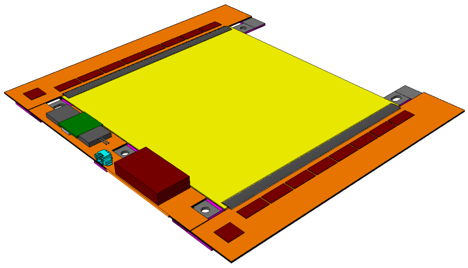
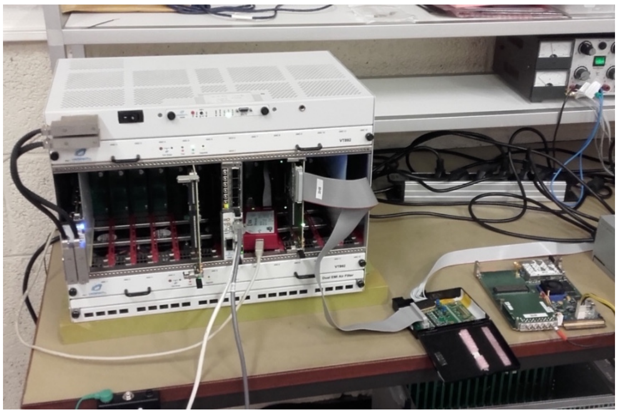
 

Figure 5: Left: Schematic view of a 10x10 cm^2 module of the type that will be assembled at the IIHE. Right: Migration from a table-top GLIB board to a data acquisition based on a μTCA crate housing an FC7 board.

2017. The LHCC committee also recommended that the final R&D phase be supported as strongly as possible to meet the upgrade schedule.

The Belgian groups from the IIHE (ULB-VUB), from Universiteit Antwerpen, the Université Catholique de Louvain-la-Neuve, and from Universiteit Gent have decided to build together one endcap of the phase-2 outer tracker. At the IIHE, about 2000 modules + spares will be assembled and tested, before they are integrated onto the tracker endcap support structures. These modules are composed of a stack of 2 silicon sensors of about 10x10 cm^2 size, read out on each side by a front-end hybrid (FEH) equipped with 8 amplifier ASICs of the CBC type, with 254 channels each, and serviced by a powering and optical transceiver hybrid (see Fig 5). It is the correlation of the signals from both sensors inside the CBC chips that allows the measurement of the particle incident angle and therefore the measurement of the particle momentum at the L1 trigger level.

To connect the sensors to their readout electronics, an industrial bonding machine capable of making 3 to 7 microscoping bonds per second with a wire of 25 μm diameter will be deployed end 2018. The market survey was completed in 2017 and the call for tender was prepared to be launched in 2018.

To readout the modules that will be built in Brussels, the IIHE team has installed a first version of a data acquisition (DAQ) system based on a GLIB board, and was provided with a prototype mini-module with 5 cm long n-type sensors read out with 2 prototype CBC chips (CBC2 type). This module was successfully tested with a ^{90}Sr source. The IIHE team then upgraded the DAQ using components complying to the modern telecommunication standard called micro-TCA (μTCA), which are closer to the components that will be used in module assembly centers for module testing and validation. Among those, we deployed an FC7 board, equipped with a powerful Kintex7 FPGA chip. The IIHE team contributes to the development of the firmware for this board in the context of the CMS Tracker phase-2 DAQ and system test working group.

The IIHE team contributes to the development of the FEH test system, within the CMS Tracker phase-2 electronics working group. This system should allow thermal cycles to be made between the assembly temperature, 20^o, and the operation temperature, -35^o, while reading out the CBC chips. Such cycles may be needed for each hybrid before they are assembled into a module. Only a physicist can determine the adequate sampling rate of FEH production batches, as well as the test procedures guaranteeing the reliability of these components. We have successfully copied the CERN prototype system in Brussels, and we now contribute to the optimization of the components and procedures to meet the CMS requirements.

The IIHE team participates to the research and development of successive versions of the tracker modules by contributing to test beams at CERN, both on DAQ and on data analysis aspects. Recent tests focused on the performance of real-size, irradiated sensors. The results from these test beams are included in the Tracker phase-2 TDR. A common Belgian test beam was also performed at the Cyclotron Resource Center in Louvain-la-Neuve, allowing to test modules in uncommon situations. No new failure mode appeared on 2CBC2 mini-modules.

The IIHE team also contributes to the preparation of the module assembly procedures. We started developing a dosing system for the different glue components, with the goal to simplify this step of the module assembly logistics.

At the Belgian level, regular Tracker phase-2 workshops are being held, to organise work and monitor progress of the different teams.

2.2 The H1 experiment - Study of *ep* collisions at HERA

(L. Favart, X. Janssen, R. Roosen, and P. Van Mechelen)

HERA (Hadron-Electron-Ringanlage) (see figure 14-left) was the first machine in which leptons collided with protons in a storage ring. Operating with electrons/positrons of 27.5 GeV and protons of 820/920 GeV, the center-of-mass energy in these collisions was increased by a factor ten over the previous fixed-target experiments. The two main detectors installed in the interaction regions, H1 (see figure 14-right) and ZEUS, were magnetic spectrometers with a nearly hermetic coverage, allowing a complete measurement of the lepton and hadronic final states.

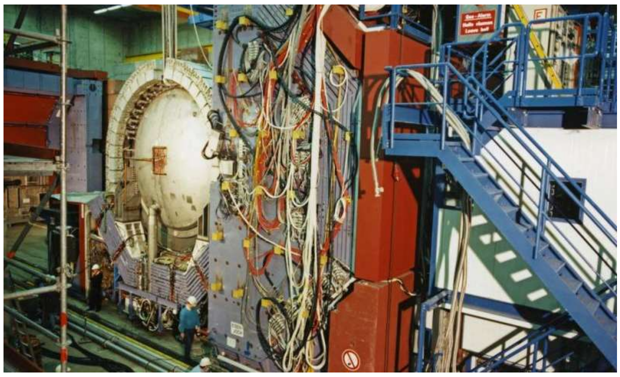


Figure 6: left: View of the HERA tunnel. On top the superconducting proton line, on the bottom, the electron line.right: View of the H1 detector during assembly. In white, the liquid Ar calorimeter cryostat surrounded by muon chambers.

HERA started in 1992 and during phase I, which lasted until 2002, delivered about 200 pb^{-1}. During phase II which started in 2004, after a 4-fold luminosity upgrade, until the close down in 2007 HERA produced another 560 pb^{-1}.

Deep-inelastic lepton-nucleon scattering (DIS) has played a key role in understanding the structure of the nucleons since the late 1960. The measurements in DIS at HERA (H1 and ZEUS) confirmed the nature of the Strong force as it was predicted by physicists Davis Gross, David Politzer and Frank Wilczek for which they received the 2004 Nobel Prize. But further, they completely changed our understanding of the proton structure, that went from a static vision to a dynamic dominated one, with the important role of the gluon density, much larger than expected. It opened the way to a new field of low x physics [1] - see figure 7. The data yield a detailed picture of the vacuum structure in the proton in terms of quarks and gluons dynamics, described by the quantum chromodynamics (QCD), a precise extraction of the strong coupling constant and a demonstration of the chiral structure of the weak interaction. The similarity of the weak and electromagnetic interactions at high energies has been also beautifully demonstrated [2], supporting the hypothesis of unification into one electroweak force (see figure 8-left).

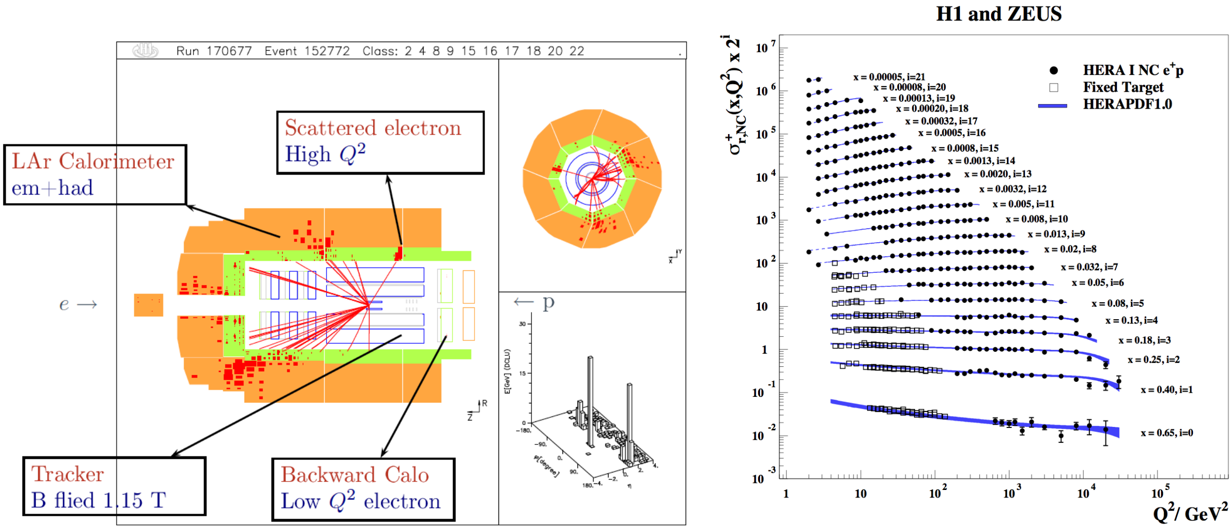


Figure 7: left: display of one H1 DIS event candidate. right: H1 and ZEUS combined DIS cross section measurements as a function of Q^2.

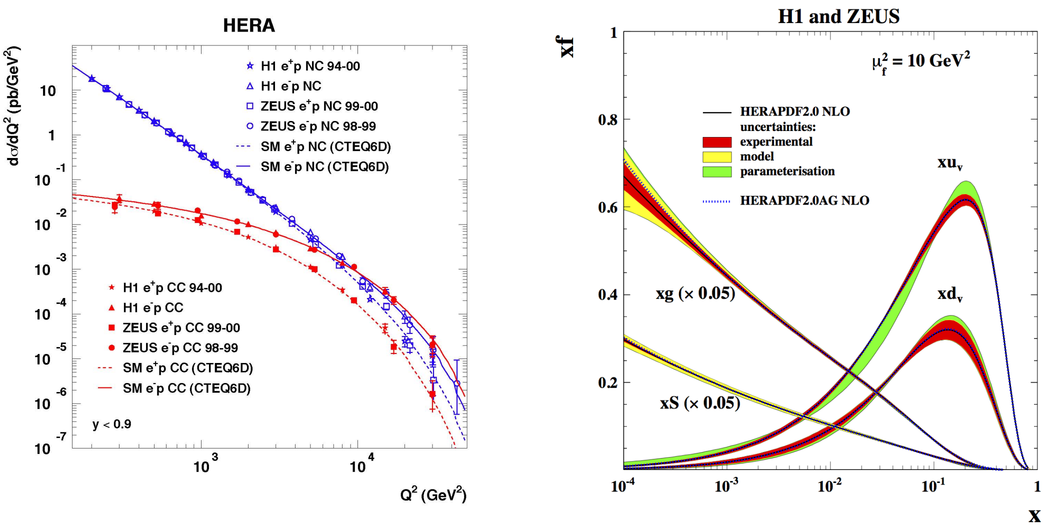


Figure 8: left: H1 and ZEUS measurements for (a) $e^{+}p$ and (b) $e^{-}p$ scattering compared to the Standard Model (green band) as well as limits on the radius of quarks (lines). right: Parton distributions as a function of the variable Bjorken x, according to HERAPDF2.0, at a scale of 10 GeV^2.

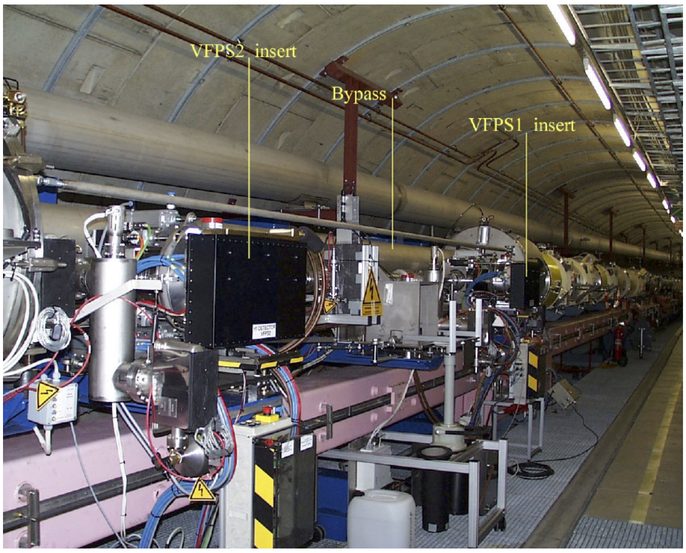
The high-precision data provided the so far most detailed understanding of the structure of the proton [3] encoded in parton distribution function (PDF), in particular in the H1 and ZEUS combined data leading to a new set of parton distribution functions, HERAPDF2.0 [4] - see figure 8-right. This precise knowledge is essential for physics at the LHC.

Many more important results have been obtained by the H1 experiment in strong interaction, in electroweak and in terms of limits in searched for new physics. Among those, should be mentioned, the important role in :
- benchmarking jet algorithms and jet substructure
- measurement and understanding of charm and bottom quarks
- showing how to handle diffractive processes in QCD

- value of the electroweak mixing angle and the W mass
- coupling of the Z boson to u and d quarks
- upper limit for the quark radius of $R_q < 0.43\,10^{-18}m$
- photon structure, hadronisation corrections, underlying event, BFKL searches ...

In total H1 published over 300 papers and trained 500s of young people.

In 1987, the IIHE and the UA joined H1 Collaboration. They had important contributions to all levels of the experiment, from the detector R&D, construction, commissioning, data taking, data analysis and management. In total, 18 PhD were defended based on H1 detector development and data analysis.



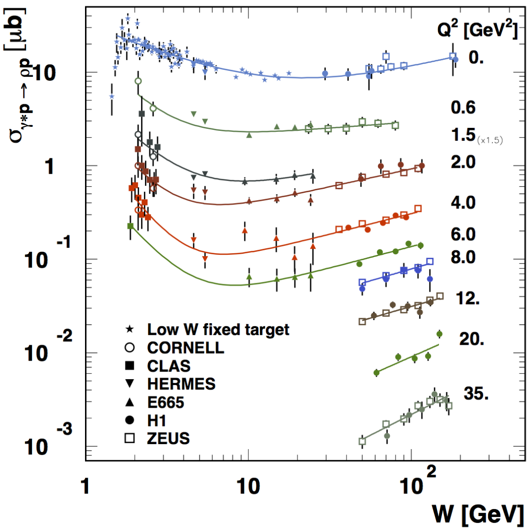


Figure 9: left: View of the HERA tunnel at 220m from the H1 interaction point after the installation of the VFPS detectors. right: World compilation of exclusive ρ production - figure from [5]

For the first HERA operation phase, the IIHE group built the central outer proportional chamber, COP, and designed and built the readout for all MWPC's in H1 and related software. During phase II, the Belgian groups (IIHE and UA) took the responsibility for the construction, installation, and running of the very forward spectrometer (VFPS) [6] - see figure 9-left. The detector composed of two movable stations - Roman pots - consists of scintillating fiber detectors allowing the reconstruction of low track multiplicity events. The stations are only moved close to the beam when the beam conditions are stable.

The Belgians groups contributed to data analysis mainly in the fields of structure functions (F_2 and F_L measurements), diffraction (exclusive vector meson production - see figure 9-right, diffractive structure functions, jet production,...) and other QCD studies.

References

[1] C. Adloff *et al.* [H1 Collaboration], "Deep inelastic inclusive e p scattering at low x and a determination of alpha(s)," Eur. Phys. J. C **21** (2001) 33 [hep-ex/0012053].

[2] C. Adloff *et al.* [H1 Collaboration], "Measurement and QCD analysis of neutral and charged current cross-sections at HERA," Eur. Phys. J. C **30** (2003) 1 [hep-ex/0304003].

[3] F. D. Aaron *et al.* [H1 and ZEUS Collaborations], “Combined Measurement and QCD Analysis of the Inclusive e+- p Scattering Cross Sections at HERA,” JHEP **1001** (2010) 109 [arXiv:0911.0884 [hep-ex]].

[4] H. Abramowicz *et al.* [H1 and ZEUS Collaborations], “Combination of measurements of inclusive deep inelastic $e^{\pm}p$ scattering cross sections and QCD analysis of HERA data,” Eur. Phys. J. C **75** (2015) no.12, 580 [arXiv:1506.06042 [hep-ex]].

[5] L. Favart, M. Guidal, T. Horn and P. Kroll, “Deeply Virtual Meson Production on the nucleon”, Eur. Phys. J. A (2016) 52:158 arXiv:1511.04535 [hep-ph].

[6] A. Astvatsatourov at al., Nucl. Instrum. Meth. A376(2014) 46-65.

2.3 OPERA experiment (CERN CNGS1)

P. Vilain, G. Wilquet

The OPERA long baseline neutrino oscillation experiment has been designed to discover for the first time the direct appearance of ν_τ in a ν_μ beam with a large signal/noise ratio through the identification of the τ^- lepton produced in their CC interactions. The domain of parameters space tested is the one primarily indicated by the atmospheric neutrinos experiments: compatible with full $\nu_\mu - \nu_\tau$ mixing and $|\Delta m^2_{32}| \approx 2.4\ eV^2$. The detector was installed in the underground Gran Sasso Laboratory of INFN (LNGS) and exposed from spring 2008 to December 2012 to the CERN CNGS ν_μ beam over a baseline of 730 km, the achieved integrated neutrino beam flux corresponding to 18×10^{19} protons on target. Detailed information on the detector and the analysis procedure may be found in previous reports and respectively in [1] and [2].

A new strategy has been used in the study of the $\nu_\mu \to \nu_\tau$ channel. Looser selection criteria in conjunction with a multivariate approach for event identification have produced 10 ν_τ candidate events where respectively 6.8 and 2.0 signal and background events were expected. A total of 5 events were observed in previous analyses based on event counting. The discovery of ν_τ appearance will be confirmed with a further improved significance that should reach 6 σ. $|\Delta m^2_{32}|$ will be measured for the first time in appearance mode with a reasonable accuracy of about 20%. The ν_τ CC cross-section will also be measured for the first time as well as the direct observation of the ν_τ lepton number. When completed, this analysis will close the mainstream scientific programme of the OPERA experiment [3].

The study of several other physics topics is in progress and will be submitted to publication in 2018, among which:
- New limits will be placed on the search for an exotic $\nu_\mu \to \nu_e$ oscillation signal, a signature for the existence of a hypothetical sterile neutrino. OPERA is the only experiment able to exclude, in appearance mode, the allowed parameter space observed by the LSND and MiniBooNE experiments, at values of $|\Delta m^2|$ smaller than 5 eV^2 [4].
- The evaluation of the high significance of an event compatible with the production of a charmed particle in a ν_τ CC interaction is being completed. This will be the first observation of such an event, difficult to produce, detect and identify against several background sources [5].
- The measurement of the cosmic ray muon flux seasonal variation and its correlation to the high atmosphere temperature is being completed [6].
- Charged hadrons multiplicity distributions at ν_μ CC interaction vertices have been measured and shown to be compatible with extended KNO scaling. This result has been accepted for publication [7].

In 2017, the OPERA Collaboration included about 150 physicists from 30 institutions in 11 countries.

References

[1] The OPERA Collaboration, R. Acquafredda et al., JINST 4 (2009) P04018

[2] The OPERA Collaboration, N. Agafonova et al., Eur. Phys. J. C 74 (2014) 2986

[3] ”Final results of the OPERA experiment on ν_τ appearance in the CNGS neutrino beam”, in preparation for submission to Phys. Rev. Lett.

[4] ”Final results of the search for $\nu_\mu \to \nu_e$ oscillations with the OPERA detector in the CNGS beam”, in preparation for submission to JHEP

[5] "First observation of a tau neutrino candidate event with charm production in the OPERA experiment", in preparation for submission to JHEP

[6] "Measurement of the cosmic ray muon flux seasonal variation with the OPERA detector", in preparation for submission to JCAP

[7] "Study of charged hadron multiplicities in charged-current neutrino–lead interactions in the OPERA detector", The OPERA Collaboration, N. Agafonova et al., arXiv:1706.07930v1 [hep-ex], accepted for publication by Eur. Phys. J. C.

2.4 Astroparticle Physics with the Pierre Auger Observatory

(Ioana C. Mariş)

2.4.1 The Pierre Auger Observatory

Extremely energetic particles, ultra high energy cosmic rays UHECRs, are entering the Earth's atmosphere constantly. Cosmic rays together with gamma rays and neutrinos are part of the multi-messenger approach to investigate the highest energy phenomena in the Universe. After a century of experimental toil, the origin, the mass and the acceleration mechanisms of cosmic ray particles to energies above 10^{20} eV still constitutes one of the main puzzles of modern astrophysics. Besides the astrophysical importance, these particles provide a unique way to study fundamental physics, like testing the Lorentz invariance violation and to study particle physics interactions at center of mass energies beyond the ones reached by man-made accelerators.

The flux of cosmic rays decreases rapidly with the energy: above 10^{19} eV the rate of these particles is about one particle per square kilometer per year. Therefore large detectors are needed to accumulate the statistics required to understand their nature and origin and to perform particle-physics research at ultra-high energies.

The Pierre Auger Observatory located in the province of Mendoza, Argentina, and covering a surface of 3000km2 is a state-of-the-art experiment to measure the ultra-high energy cosmic rays. The commissioning of the experiment was completed in 2008. The results published by the Pierre Auger collaboration have contributed significantly in the understanding of cosmic rays. The propagation and the origin of cosmic rays influence the number of particles that enter the Earth's atmosphere. The evolution of the flux with energy, measured with the Pierre Auger Observatory, exhibits at the highest energies two features: the ankle, a flattening of the flux at about 4×10^{18} eV, and a strong suppression above 5×10^{19} eV. The flux suppression can be explained by the Greisen-Zatsepin-Kuzmin effect: during their propagation cosmic rays lose energy in the interaction with the cosmic microwave background radiation or it might be due to the maximum acceleration power at sources. The ankle can originate from either the transition from the galactic to the extragalactic components or from the production of $e^{\pm}$ by protons interacting with the cosmic microwave background. These hypothesis can not be distinguished from the spectral shape, but they differ by the mass composition of the cosmic rays that reach the Earth and their anisotropy properties. The cosmic rays suffer deflections during their trajectory from the source to the Earth depending on the strength of the magnetic fields and their mass. Nevertheless at the highest energies protons should point at their sources. Therefore it is not trivial to observe point-like correlations between UHECRs and sources and to find the specific origin of these particles. Nevertheless above 8×10^{18} eV the cosmic rays exhibit a dipolar structure with an amplitude of 6%. Moreover the direction of this dipole does not coincide with the Galactic center, which proves that above this energy the cosmic rays are extragalactic. The interpretation of the Auger measurements in terms of the mass composition indicate the presence of a heavier component, but a considerable change in the hadronic interaction models at ultra-high energies could make the measurement compatible with a pure light composition.

The Pierre Auger collaboration has also published the measurement of the proton-air and proton-proton cross-sections at a center of mass energy of 57 TeV well above the energies reached at LHC, which allows this collaboration to test fundamental interactions at energies never reached by laboratory experiments.

After the entrance in the atmosphere the cosmic ray interacts with air nuclei and generates a cascade of secondary particles, a so called air-shower. Currently two complementary techniques are employed to measure the air-showers: the observation of the fluorescence signal produced by the secondary particles in the atmosphere and the measurement of a sample of the particles that reach the ground. The Pierre Auger Observatory is built as a hybrid detector: the longitudinal development of the air-showers is observed with 24 fluorescence telescopes (FD), and the distribution of particles on the ground is measured with 1664 water-Cherenkov detectors (SD).

To advance in answering the remaining questions an upgrade of the Pierre Auger Observatory is currently being deployed. The most stringent information is the determination of the mass composition of the UHECRs with high statistics and a very good resolution. Currently the FD measurements provide a good sensitivity to for the mass composition studies, but as they can be operated only during moonless nights with a duty cycle of only about 10%, they cannot provide the required statistics. The upgrade of the Observatory, Auger Prime, aims at increasing the resolution of the surface detector (100% duty cycle) towards mass composition determination.

2.4.2 Research areas at IIHE

The IIHE has joined the Pierre Auger collaboration in February 2017. The research is focused on the data analysis of the upgrade detectors with a final goal of determining the mass composition. A previous work on the energy spectrum of the UHERCs is also continued, with a focus on the comparison with the Telescope Array measurements.

Analysis of the data from Auger Prime. The upgrade of the surface detector of the Pierre Auger Observatory has started in 2017. The plan of the collaboration is to deploy scintillators on top of the current Water-Cherenkov detectors and in the same time to update the readout electronics. A first analysis of the data from the prototype array has been performed by the summer student Zhang Tianliang. He has assessed the stability of the calibration constants of the new detectors and he has checked the possible changes in the signals due to the new faster electronics. This work will be continued at IIHE. The final goal, after the understanding of the response of the new detectors is to contribute to the determination of the mass composition of the UHECRs.

Full sky measurements of UHECRs. The second line of research at IIHE comprises of combining the measurements of the Telescope Array and the Pierre Auger Observatory with the aim at a mass-composition enhanced anisotropy study. This work is done in collaboration with Peter Tinyakov (ULB), member of the Telescope Array collaboration. The energy spectra of the two experiments show a different flux shape at the highest energies. The group has been involved in understanding the differences between the two experiments: is it due to the observation of different parts of the sky or is it an experimental effect? The results are not conclusive by now, and the analysis is ongoing. In the context of this work a workshop on the energy spectrum has been organised in Brussels in November 2017 with the participation of members from both collaborations.

2.5 Astroparticle Physics with the IceCube Neutrino Observatory

(J. A. Aguilar, S. Amary, I. Ansseau, C. De Clercq, P. Coppin, P. Correa, N. Van Eijndhoven, N. Iovine, J. Lünemann, G. Maggi, I. C. Mariş, K. Meagher, E. Pinat, C. Raab, O. Scholten, K. D. de Vries, G. De Wasseige)

Astroparticle Physics revolves around phenomena that involve (astro)physics under the most extreme conditions. Black holes with masses a billion times greater than the mass of the Sun, accelerate particles to velocities close to the speed of light. The produced high-energy particles may be detected on Earth and as such provide us insight in the physical processes underlying these cataclysmic events.

Having no electrical charge and interacting only weakly with matter, neutrinos are special astronomical messengers. Only they can carry information from violent cosmological events at the edge of the observable universe directly towards the Earth. Furthermore, since they are hardly hindered by intervening matter, they are the only messengers that can provide information about the central cores of cosmic accelerators like Gamma Ray Bursts (GRBs) and Active Galactic Nuclei (AGN), which are believed to be the most violent cosmic events and the sources of the most energetic Cosmic Rays. Identification of related neutrino activity would unambiguously indicate hadronic activity and as such provide clues to unravel the nature of these mysterious phenomena.

Another mystery of the Universe is the illustrious Dark Matter, which has not yet been identified but which would explain various observed phenomena. According to some models, this dark matter may consist of Weakly Interacting Massive Particles (WIMPS) which can annihilate among themselves. In these annihilation processes some of the produced particles are high-energy neutrinos. Since these WIMPS are expected to get trapped in gravitational fields, there may be large concentrations of them at the center of massive objects like the Earth, the Sun or the Galactic

Center. Consequently, observation of high-energy neutrinos from these objects could provide indirect evidence for the existence of these dark matter particles.

At the IIHE, we are involved in a world wide effort to search for high-energy neutrinos originating from cosmic phenomena or from dark matter particles. For this we use the IceCube neutrino observatory at the South Pole, the world's largest neutrino telescope which has now been taking data for several years.

2.5.1 The IceCube observatory

IceCube (http://www.icecube.wisc.edu) is a neutrino telescope consisting of an array of optical sensors, located in the icecap of the South Pole at depths between 1450 and 2450 m. The sensors are arrayed on vertical cables, called strings, each of which comprises 60 sensors spaced by 17 m. In the horizontal plane, the strings are arranged in a triangular pattern such that the distance between adjacent strings is always 125 m. The overall configuration (see Fig. 10) exhibits a hexagonal structure, which is the result of extensive optimization procedures based on simulation studies. At the end of 2010 the full 86-string detector, including its DeepCore extension (see here after), was completed and started taking data, representing an operational observatory with an instrumented volume of 1 km^3. Due to the geometrical configuration outlined above, the energy sensitivity for IceCube is ranging from a few hundred GeV up to several PeV.

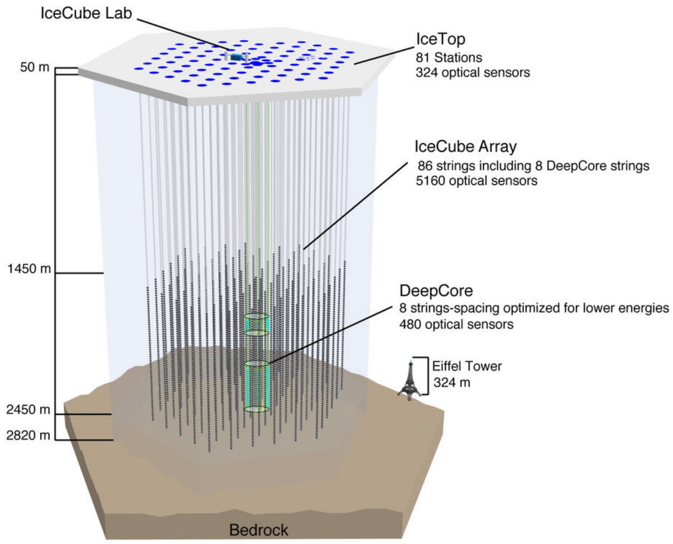


Figure 10: The IceCube observatory.

Sensitivity to lower energies can be obtained by a smaller spacing between adjacent sensors. IceCube is equipped with a denser sub-array called DeepCore consisting on 8 strings arranged around the central IceCube volume with an inter-strings spacing of 72 m as opposed to the 125 m standard IceCube string spacing. Each DeepCore string has 50 sensors at 7 m spacing covering depths between 2100 and 2450 m and 10 sensors at 10 m spacing between 1750 and 1860 m. Aside the in-ice instrumentation IceCube is also equipped with a surface cosmic-ray detector called IceTop. This surface array consists of 162 tanks of ice, each instrumented with two standard IceCube sensors, to detect showers of secondary particles generated by interactions of high-energy cosmic rays in the atmosphere.

Most of the high-energy neutrinos detected in IceCube originate from cosmic-ray particle interactions in the Earth's atmosphere. However, in 2013 IceCube detected a neutrino flux component incompatible with the atmospheric background hypothesis. This achievement was awarded the title *Breakthrough of the year 2013* by the Physics World magazine. Since then IceCube has observed a total of 103 cosmic neutrino candidates of which 60 have deposited energies > 60 TeV incompatible with an atmospheric origin beyond the commonly accepted 5 sigma detection threshold. The level of observed extraterrestrial neutrino flux of 10^{-8} GeV cm^{-2} s^{-1} sr^{-1} per neutrino flavor (Science **342** (2013) 1242856) implies a much richer hadronic activity in the non-thermal Universe than previously expected. The neutrino energy density matches the one observed for photons, indicating a much larger role of protons relative to electrons than previously anticipated.

The origin of these astrophysical neutrinos is not yet known. Clustering analysis performed on the sample are thus far unable to resolve statistically significant hot spots, or areas of events accumulation beyond the expectation of an isotropic flux. However, the recent observation of a gamma-ray flare from a blazar (an active galaxy with a jet pointing at Earth) in spatial and temporal coincidence with a high-energy neutrino observed by IceCube may be the first evidence of an extragalactic cosmic ray source.

The current size of the IceCube observatory limits its ability to identify the sources of these high energy neutrinos. For this reason expansions of the current detector are already planned. The second generation of IceCube, *IceCube-Gen2*, will be a future installation including a 10 km^3 volume expansion of detection volume of the clear Antarctic ice (Fig. 11) as well as a Surface Veto array for cosmic-ray detection, and a Radio Array to explore the highest energies.

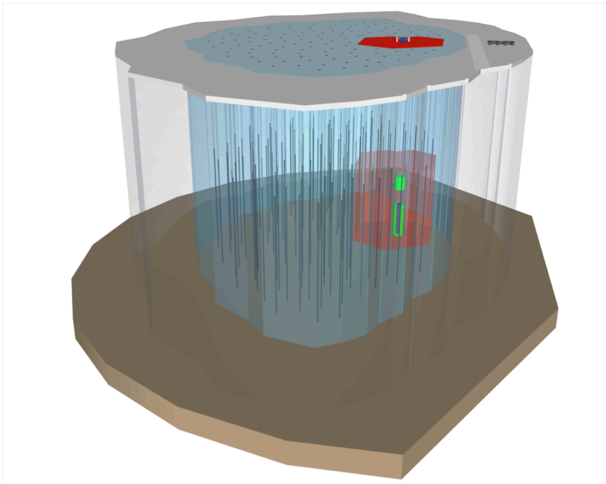


Figure 11: A possible *IceCube-Gen2* configuration. IceCube, in red, and the infill subdetector DeepCore, in green, show the current configuration

2.5.2 Research areas at the IIHE

In 2017 the IIHE was involved in the following IceCube related (astro)physics topics:

- **Search for high-energy neutrinos from transient events.**
  This study is aimed at the identification of high-energy neutrino production in relation with Gamma Ray Bursts, flares from Active Galactic Nuclei or any transient phenomena. The activities of the IIHE in this field are several:
  - **Stacking search for AGNs flares.**
    Active Galactic Nuclei are among the main candidates for particle acceleration to the highest energies of the Cosmic Ray spectrum. They are also sources of violent transient phenomena, in particular AGNs with jets pointing to us (called Blazars) exhibit a high variability in their photon flux with sudden sequences of multiple flares that may last from minutes to months. Starting in 2015 we initiated an analysis using the light-curve information from γ-ray as a time-template to search for neutrinos. The novelty of this analysis compared to previous analyses in IceCube, is that the list of AGNs is also stacked in order to search for a combined signal of all selected AGNs during their flaring periods. The analysis for individual sources has already been implemented and the stacking is on-going. The interest of this analysis is further increased given the recent correlation of a flaring blazar and one of the high energy neutrinos of IceCube. If flaring blazars are sources of cosmic rays then the question is why there have not been observed before. One possible answer is that this particular blazar belongs to a special sub-category of blazars, or that only a small fraction of the IceCube astrophysical flux comes indeed from flaring blazars.
  - **Fast-response analysis.**
    In the same context of transient phenomena, but with a different approach, at IIHE we developed an

analysis to provide a fast-response from IceCube in case of an important astronomical event. The fast response analysis was implemented on April 2016. Soon after, on April 26 of 2016 a HESE event alert was sent out to our follow-up multimessenger partners. The optical telescope Pan-STARRS found a supernova compatible with a Ic type. This interesting finding triggered the fast response analysis, which was run pointing to the SN candidate coordinates to search for an additional excess of low energy neutrinos. Although no additional neutrinos were found, this was the first time the IceCube provided a fast response to an astronomical event. The fast response analysis has run 24 times since its implementation. One remarkable event was the neutrino star merger event detected by LIGO on September 2017 and associated with a short Gamma-Ray-Burst (sGRB) observed by Fermi two seconds after. This correlation proved for the first time, that the engines behind sGRB are neutrino start mergers. IceCube, ANTARES and Pierre Auger performed a follow-up analysis to search for neutrinos. The fast-response analysis was also used in this search. Although no neutrinos were found, this result was compatible with an off-axis GRB as the electromagnetic observations seemed to indicate.

  - **GRB searches.**
    A first analysis (Nature 484 (2012) 351) has shown that the detected Gamma Ray Bursts (GRBs) cannot be the sole sources of the very energetic cosmic rays observed at Earth. This, rather shocking, result has ruled out a large number of mainstream theoretical models describing GRBs. The limits set by IceCube however only constrain neutrino emission during the prompt phase of GRBs. Since observations of precursor photon flashes occurring before the prompt phase suggest that neutrinos are emitted during the GRB precursor, we at the IIHE study the emission of neutrinos during the phase leading up the the prompt flash of gamma-rays. Likewise, the afterglow of GRBs are investigated, as these often contain high-energy X-ray flares which are an excellent candidate for neutrino production.

- **Search for steady sources of neutrino emission.**
  Apart from the correlation studies using timing information at the IIHE we also worked on analysis searching for steady sources of neutrino emission. Here the strategy is to search for accumulation of events in a particular direction of the sky in a way incompatible with the isotropic atmospheric background. The identification of such "hot spots" or "hot regions" on the neutrino sky would enable us to locate the sources of the most energetic cosmic ray particles.

  - **Search for neutrino emission from Dust Obscured Sources**
    The energy budget of astrophysical neutrinos is equivalent to that of gamma-rays seen by Fermi. Since most of these sources in the Fermi diffuse flux are blazars from which we did not find any neutrino correlation, there is a slight tension between gamma-ray data and neutrinos. The tension could be resolved if the neutrino sources are opaque to gamma-rays.

    As mentioned before, blazars are a special class of AGN with their jets pointing towards Earth. These objects are very bright in the gamma-ray sky, and very variable. However some of these blazars might be opaque to gamma-rays. At the IIHE we developed a different approach and focused instead on a sub-category of blazars which appear bright in radio frequencies, but are rather dim when observed with more energetic radiation. The reason for this condition is that such a signature could indicate that X-ray luminosity has been obscured by a column of matter, such as dust. The latter could also provide an additional target for high-energy neutrino production. In 2017 the IceCube data was unblinded for this analysis and no significant excess from these dust-obscured blazars was found. In the meanwhile another subclass of sources that could explain the gamma-ray, neutrino discrepancy are Ultra-Luminous Infrared Galaxies (ULIRGs). With an infrared luminosity that exceeds $L_{\odot}^{12}$, ULIRGs have a vast energy budget with which to possibly accelerate cosmic rays, which will on their turn produce gamma-rays and neutrinos. Moreover, the bright infrared luminosity indicates the presence of large amounts of dust, which will block the gamma-rays on their way out of the sources while enhancing the neutrino production. As such, in 2017 an analysis was started at the IIHE to search for IceCube neutrinos originating from these ULIRGs.

  - **Search for extended neutrino emission.**
    During 2017 an analysis focusing on neutrino emission from extended regions was performed at the IIHE. Some models predict neutrinos from extended regions like accelerators close to molecular-clouds or nearby star forming regions like the Cygnus region as a whole. The goal of the extended source analysis is an extension of the point source analysis in which the source spatial distribution is now assumed to cover a significant extension of the sky (from 1° up to 5°) instead of only a point source. In 2017 the unblinding of the data was performed using this analysis. No significant hot region was found, and upper limits on neutrino emission from different extensions were set.

- **Search for low-energy GeV neutrinos**
  IceCube is primarily optimized to search for signatures of neutrinos from energies of around TeV. However, this does not mean that neutrinos of lower energies scales of about GeV are not under the scientific scope of IceCube. To detect GeV neutrinos novel event selections, as well as different treatment of the noise, were developed. With these new techniques, the energy threshold of IceCube can be lowered to about $\sim$ GeV, opening the window to a different kind of astrophysical observations.

  - **GeV neutrinos from solar flares.**
    Since the end of the eighties and in response to an increase in the total neutrino flux in the Homestake experiment in apparent coincidence with major solar flares, solar neutrino experiments are trying to identify neutrinos produced during these sudden flashes of energy. To date no confirmation of an increase in the neutrino rate due to solar flares has been found. Detection of neutrinos from solar flares would open a new window on these phenomena and increase our insight in the underlying physical processes. A new analysis proposed at the IIHE searched for low energy neutrinos in IceCube in coincidence with observations of gamma rays detected by Fermi-LAT. The results, recently obtained, have allowed to set the first experimental constraints on the flux of GeV neutrinos emitted during solar flares. This first effort within the IceCube Collaboration will be pursued and other analysis techniques will be developed in view of improving the current state-of-the-art.
  - **GeV neutrinos from GRBs** While TeV neutrinos are predicted as a consequence of the internal shocks in the prompt phase of the GRBs, GeV neutrinos should be produced by neutron and proton collisions following decoupling. A neutrino search in the GeV energy range would therefore be complementary to the existing limits that have been set by neutrino telescopes in the TeV range. Some models also predict the neutrino emission before, or after the prompt phase. In this analysis we searched for an excess of GeV neutrinos in time windows from 3 s to 1000 s around gravitational wave events as possible counterparts of short GRBs. While all the time regions showed a p-value consistent with the pure background hypothesis, one significantly case deviates with a p-value of 9.33×10^5. The corresponding gravitational wave event was labeled GW170608 by the LIGO Collaboration. Interestingly, during the follow-up campaign triggered last June by the LIGO observation, Fermi-LAT has observed gamma rays inside the LIGO probability map 1200 s after the merger time. The first checks performed in our analysis show that IceCube was stable at the moment of the merger. However, more detailed investigations are required, and currently ongoing, to understand the origin of the potential extra events observed in IceCube.

- **Dark matter searches.**
  In addition to astrophysical neutrino searches, IceCube has proved to be an excellent beyond-Standard-Model detector producing very interesting and competitive results on dark matter searches and sterile neutrinos. At the ULB we are also working on indirect searches of dark matter from the center of the Galaxy and the center of the Earth. If dark matter is a particle it is possible to search for annihilation signals of these particles from massive celestial objects in which an excess of dark matter is expected. The products of these annihilations are standard model particles among which we can find neutrinos. The dark matter searches in IceCube focused on the search of neutrino signatures from the center of our Earth, the Sun or the Galactic Center.

  - **Dark matter from the center of the Earth**
    In recent years the IIHE group focused on the search for neutrino signals from WIMP annihilation in the center of the Earth. Initial results using one year of data provided limits that were one order of magnitude better compared to the previously published AMANDA (predecessor of IceCube) results. The results of this first IceCube analysis were accepted for publication on December 2016 in the European Physical Journal C. Efforts to extend this analysis to combine several years of data are also on-going. In which we plan to explore a unified event selection, while exploring all the astrophysical uncertainties that could boost a neutrino signal, such as the existence of a dark disc.
  - **Dark matter from the Galactic Center**
    The Galactic Center region yields the highest signal expectation from dark matter annihilation, due to the high density of dark matter present at the center of the Milky Way. Unfortunately, IceCube being located at the South Pole is not in a privileged position to observed the Galactic Center since it has to beat the large amount of atmospheric muon background. IceCube limits in this regard are comparable to a much smaller detector located in the Mediterranean Sea, the ANTARES neutrino telescope. For this reason, we have initiated a working group to combine data from both telescopes in order to enhanced the discovery potential (or put stringier limits) of dark matter from the Galactic Center. Preliminary results not only

showed a benefit of combining the two data sets, it also solved many of the ambiguities and assumptions that different experiments apply when calculating limits of a velocity averaged dark matter annihilation cross-section.

- **R&D for future upgrades**
The discovery of cosmic high-energy neutrinos has triggered feasibility studies for the extension of the existing IceCube observatory by an order of magnitude in size. This new facility will increase the event rates of cosmic events from hundreds to thousands over several years making possible to identify the sources of astrophysical neutrinos as well as possibly the detection of cosmogenic neutrinos generated by ultra-high energy cosmic rays interactions during their travel towards the Earth. This major neutrino observatory facility has been dubbed IceCube-Gen2 a name that builds on the idea of a step forward in neutrino astronomy from the successful results of IceCube. In addition to the in-ice extension, the future observatory envisages as well the construction of a major Surface Veto array on the surface. This Surface Veto array will consist on scintillator panels deployed to measure cosmic air showers and explore the vetoing capabilities in order to reduce the large contamination of the atmospheric muons background in the Southern Sky. The facility also seeks to improve the sensitivity to to neutrinos in the $10^{16} - 10^{20}$ eV energy range with the construction of Radio Array. Because of the kilometer–scale attenuation length of radio waves in ice, a radio array that explores the coherently enhanced radio emission due to the Askaryan effect, can be built in a cost-effective way to detect neutrinos of energies about ~ 100 PeV.

  - **Surface Veto and SiPM**
  As part of the IceCube-Gen2 facility a Surface Array of 75 km^2 is being proposed. With an infill factor of 10^{-3} this implies the deployment of 5000 to 7000 stations of at least 10 m^2 effective surface. Since such an area will be impossible to cover with the current technology used in IceTop, ie water tanks, the collaboration is exploring the possibility of using scintillator panels with a read-out consisting on SiPMs. A first step will consist on upgrading the current IceTop detector with 37 scintillator pannels. Currently two prototypes of these panels have been deployed at the South Pole. At the IIHE we interested in the characterization and study of the charge response of these novel photodetector devices, the SiPMs. To this end, an optical lab is being installed at the IIHE where SiPM measurement will take place.
  - **Radio Detection Techniques** The Askaryan Radio Array (ARA) is a radio detector being deployed at the South Pole aiming at the radio detection of cosmogenic neutrino interactions with the antarctic ice at above ~ 100 PeV. On the other hand, IceCube is sensitive to high energy neutrinos of several PeV, following that an energy region between PeV-EeV is strongly unexplored. To fill this gap at the IIHE a novel detection technique, dubbed RADAR, is being investigated. A detailed model for the radar scattering off the high-energy ionization plasma induced by neutrino induced particle cascade in ice has been developed. There are however several unknown parameters which are crucial for the detection method, with the main parameters being the lifetime and the free charge collisional damping rate. Since it is very hard to model these parameters, they have to be determined experimentally. To do so, in December 2016, in combination with groups from the University of Madison, Kansas University, and the University of Utah, an experiment has been performed at the Telescope Array Electron-Light-Source (TA-ELS) facility. This facility directs a high-energy electron beam in the air to mimic a cosmic-ray air shower. During this experiment the electron beam was directed in a block of ice placed on top of the beam exit. Consequently a RADAR set-up was installed to probe a possible scatter off the induced ionization plasma. Good data was obtained, which is currently being analyzed.

  Besides studies for the Askaryan radio detectors, a groupt at the IIHE is also working on sensitivity studies for the future GRAND detector. This detector aims to detect the radio footprint from tau-induced particle cascades in air. The tau itself originates from the charged current interaction of an extremely ($>$ EeV) energetic Earth skimming tau neutrino which interacts with Earth matter. The GRAND detector aims to cover a roughly 10^5 km^2 surface area with $10^4 - 10^5$ radio antennas. The main goal is to discover and determine the properties of the ultra-high-energy ($>$ EeV) cosmic neutrino spectrum. These studies will be incorporated in the GRAND white paper, which is currently under development.

2.6 Data acquisition systems RD activities

(Y. Allard, G. De Lentdecker, W. Deng, J. Dong, M. Korntheuer, A. Marinov, Th. Lenzi, A. Leonard, E. Pinat, Z. Song, Y. Yang)

Since 2007, the IIHE has started an RD program in the field of data acquisition (DAQ) and digital electronic systems for future experiments in particle and astro-particle physics. Modern technologies allow to design a DAQ architecture independent of the detector to which the DAQ system will be connected, providing freedom to the choice of the future experiment as well as the possibility to re-use components in several projects.

Since the beginning the IIHE has started to study the most advanced technologies from the telecommunication and the digital programmable electronic industries: the Advanced Telecom Computing Architecture (ATCA or micro-TCA) standard and Field Programmable Gate Arrays (FPGA). The choice of the IIHE to start such a RD program has been driven by the fact that the laboratory has a large expertise in the development of DAQ systems for the major experiments in particle and astro-particle physics (DELPHI, H1, CMS, ICECube).

The first developments were carried out within the LCTPC project which aims to build a large prototype of Time Projection Chamber (TPC) that could be installed at a future linear electron-positron collider (ILC or CLIC), where the FPGAs and ATCA technologies will be largely used. The experience the IIHE gained by developing DAQ systems in this framework was a valuable asset to start other new projects.

Since 2011, the IIHE is leading the design of the trigger and DAQ system of the new Triple-GEM detectors to be installed in the CMS forward muon spectrometer, during the 2nd long LHC shutdown in 2019-2020. Some details of the developments can be found in section 2.1.3. Since this project uses components common with the CMS tracker upgrade, naturally the IIHE started in 2016 to contribute to the electronics developments for this major upgrade planned for the 3rd LHC long shutdown. Related to that project the IIHE is also studying and developing fast track reconstruction algorithms like Retina to be processed on FPGAs for track trigger applications.

Since 2015 the IIHE is also involved in the electronics development for the JUNO experiment, in particular the lab has the responsibility to design and produce the back-end cards (BEC) which is a kind of signal concentrator and a bridge between the front-end electronics and the DAQ and Trigger systems (see section 2.9 for more details).

Finally the IIHE is studying the possibility to develop a digital prompt-photon camera, using powerful FPGAs, for protontherapy applications (see section 2.7). A first proof of concept has been performed in 2016 with some commercial FPGA kit. The study of a first prototype should start in 2018.

2.7 Measurement of the high-energy neutron dose in proton therapy

(G. De Lentdecker, D. Ndayizeye)

Proton therapy uses proton beams with energies typically between 50 and 230 MeV to treat cancerous tumors very efficiently, while protecting as much as possible surrounding healthy tissues from radiation damage. Protons interacting with matter inevitably induce secondary radiation from which all people inside the proton therapy center have to be protected. The ambient dose equivalent H*(10) in such a facility is mainly due to neutrons, which can have energies up to 230 MeV. Although various dose monitoring systems sensitive to high energy neutrons have already been developed, the response function of these detectors is often insufficiently characterized, and so are the calibration factors appropriate for the specific neutron spectra encountered inside a proton therapy facility.

Since 2012 the IIHE is collaborating with the Institut de Recherche de l'Institut Supérieur Industriel de Bruxelles (IRISIB) and Ion Beam Applications S.A. (IBA) to study the response function of the extended-range rem meter WENDI-2 from thermal energies up to 5 GeV. Extensive Monte Carlo simulations using the MCNPX software are now routinely been running on the IIHE cluster.

A first part of this study focused on the study of the WENDI-2 response function and its comparison with the fluence-to-H*(10) conversion coefficients, to theoretically assess the accuracy in terms of H*(10) of our WENDI-2 measurements performed in proton therapy facility. Our experimental validation of the WENDI-2 response function is based on measurements performed with ^{252}Cf and AmBe sources as well as with quasi-monoenergetic neutron beams at the TSL at peak energies of 21.8 MeV, 93.1 MeV and 173.4 MeV. The measurements tend to be lower than the simulated responses but smaller discrepancies were obtained than with previous experimental results. A detailed sensitivity study was also carried out with respect to the physics models for the proton and neutron interactions above 150 MeV.

Finally, since the WENDI-2 can not inform us on the accuracy of the simulated neutron fluence, especially above 100 MeV, spectrometry measurements have been performed with a WENDI-2 and an extended-range Bonner Sphere Spectrometer (BSS) in a proton therapy facility. The WENDI-2 measurements agree with the BSS H*(10) rates within 10%. It thus confirmed that the WENDI-2 allows measuring H*(10) with satisfactory accuracy in these neutron fields.

In the near future, the research in this field will move towards the developments of a prompt-gamma detector, equipped with a new full digital electronics to improve the spatial resolution on the proton beam location with respect to the tumor being irradiated. After the study of the concept of the new electronics and of the gamma pulse processing algorithm to be run on this electronics, the development of a first prototype should start in 2018.

2.8 The SoLid experiment

(J. D'Hondt, L. Kalousis, P. Van Mulders, S. Vercaemer)

The SoLid collaboration unites about 45 researchers from 10 institutes in the UK, France, US and Belgium. The researchers involved in the SoLid experiment aim to search for Short baseline neutrino Oscillations with a novel Lithium-6 composite scintillator (SoLid). The highly segmented plastic scintillation detector coated with Lithium-6 is designed to provide a measurement of the rate of electron antineutrinos at very short baseline distances between 5 and 11 metres from the BR2 research reactor core in SCK-CEN at Mol. This measurement will provide confirmation or exclusion of the so-called reactor anomaly present in the ratio of the observed to predicted number of electron antineutrino events at short baseline distances.

The detector consists of PVT scintillator cubes of 5cmx5cmx5cm coated with $^6LiF : ZnS$ to detect $\bar{\nu_e}+p \rightarrow n+e^+$. The antineutrinos produced by the reactor interact with the protons of the detector material and produce a neutron and positron. The positron will quickly annihilate with one of the electrons in the detector. While the neutron will be captured by the Lithium-6 ($n +^6 Li \rightarrow^3 H + \alpha + 4.78\ MeV$). The combination of the signal from the positron annihilation and the delayed neutron capture allows for a clear identification of the antineutrino interaction. Fibers pass through each cube to read it out in two directions, which provides a precise localization of where the interaction happened. The light is collected at the fiber end using MPPCs. More details about the detector technology can be found in Ref. [0].

In 2017 we have made major contributions to the data analysis for the first submodule (SM1). In particular, despite the inferior quality of the data, a better understanding of the background was obtained under the leadership of P. Van Mulders who coordinated these studies. All the findings based on the SM1 detector are summarized in Ref. [0]. Based on this knowledge and the changes to the detector design, predictions for the background composition and rates were obtained for the full-scale Phase 1 detector. An oscillation analysis framework has been developed by L. Kalousis. Together with S. Vercaemer, sensitivity studies were performed varying several of the design detector parameters.

The group in Brussels was also vital in the construction of the full-scale Phase 1 detector, in particular to assemble the 12800 cubes, to equip the 50 detector planes. The detector was installed at the BR2 reactor in November 2017 and commissioning and calibration data has started to be collected.

Y. Abreu *et al.* [SoLid Collaboration], "A novel segmented-scintillator antineutrino detector," JINST **12**, no. 04, P04024 (2017) doi:10.1088/1748-0221/12/04/P04024 [arXiv:1703.01683 [physics.ins-det]].

Y. Abreu *et al.* [SoLid Collaboration], "Performance of a full scale prototype detector at the BR2 reactor for the SoLid experiment," JINST **13**, no. 05, P05005 (2018) doi:10.1088/1748-0221/13/05/P05005 [arXiv:1802.02884 [physics.ins-det]].

2.9 The JUNO experiment at Jiangmen (China)

(Barbara Clerbaux, Jianmeng Dong, Pierre-Alexandre Petitjean, Yifan Yang)

Neutrino physics today is one of the major challenges of our understanding of nature, and is a very active research area, in particular related to the observation of neutrino oscillations, with the 2015 Nobel prize of physics awarded to Takaaki Kajita and Arthur McDonald for this discovery. The very nature of these particles is still unknown and some key measurements still need to be performed. The IIHE laboratory has a long tradition in long baseline neutrinos physics with the participation to the CHARM2, CHORUS and OPERA experiments using neutrino beams from CERN, and it is presently very active in the IceCube neutrino telescope located at the South Pole, and in the SOLID experiment, a very short baseline neutrino experiment presently running at the BR2 MTR research reactor in Mol. In addition to its strong tradition in neutrino physics, the IIHE has a recognized expertise in detector R&D and instrumentation, in particular in state-of-the-art electronics and data acquisition system (DAQ). Since 2015, IIHE-ULB is participating to the Jiangmen Underground Neutrino observatory (JUNO) experiment, based in China, being responsible for design studies on the back-end electronics system, in particular for the back-end card. A JUNO equipment FNRS funding was requested in June 2016 and successfully obtained for the period 2017-2020. The budget covers the cost of the design, prototype building and tests of the BECs, as well as the final production of the BEC boards, their shipping and installation in the experiment.

The JUNO experiment uses a large liquid scintillator detector aiming at measuring antineutrinos issued from nuclear reactors at a distance of 53 km. The precise measurement of the antineutrino energy spectrum will allow determining the neutrino mass hierarchy (NMH) and reducing the uncertainty below 1% on solar oscillation parameters, after 6 years of data taking. Moreover, sterile neutrinos with small Δm^2 value and at large mixing angle θ_{41} could be identified through a precise measurement of the antineutrino energy spectrum. The JUNO detector is also capable of observing neutrinos/antineutrinos from terrestrial and extra-terrestrial sources, including geoneutrinos, atmospheric neutrinos, solar neutrinos, supernova neutrinos, and diffuse supernova neutrino background.

The detector is located at 700 m underground and consists of 20 ktons of liquid scintillator contained in a 35 m diameter acrylic sphere, instrumented by more than 17000 20-inch photomultiplier tubes (PMT). Two vetoes are foreseen to reduce the different backgrounds: a 20 ktons ultrapure water Cerenkov pool around the central detector instrumented by 2000 20-inch PMTs will tag events coming from outside the neutrino target, and a muon tracker will be installed on top of the detector (top muon veto) in order to tag cosmic muons and validate the muon track reconstruction. The top muon veto will use the OPERA experiment target tracker, in which IIHE has been a contributor. The JUNO civil construction started in 2015 and the production has started for the main components (as for example the PMTs). The start of the data taking is expected at the end of 2021/beginning of 2022.

The JUNO electronics system will have to cope with signals from 17000 large (20-inch) PMTs and 25000 small (3-inch) PMTs of the central detector as well as 2000 PMTs installed in the surrounding water pool. It consists of mainly two parts: (i) the front-end electronics system performing analog signal processing, and (ii) the back-end electronics system, sitting outside water and consisting of DAQ and trigger units for digital signal processing. Several schemes were studied and discussed inside the JUNO electronics teams. The schemes differ on the usage of the Ethernet cables and on the method used to provide the power supply. An important challenge is to ensure very high reliability of the system. Due to the big amount of connections between the front-end and back-end electronics systems and the complexity of the signal combination, the ULB group proposed to use back-end cards (BEC) as a concentrator and a bridge between the two parts, and concentrated on the design and the tests of the BECs. The two key requirements for the BECs are to implement a 250 Mb/s bi-directional data transfer and to deliver 48-W low voltage power.

1-The BX scheme:

During the years 2016-17, the option called the “BX scheme” was intensively studied, where one long cable is connected to one PMT, with the front-end electronics directly attached to the PMT, see Figure 12 (left). A first prototype was designed at ULB with two kinds of equalizers and cable drivers to verify the 250 Mb/s data link over 100 m Ethernet cable, and a second prototype was design to verifying the 48 channel data transfer as well as the power injection and communication with the DAQ and trigger system, see Figure 13 (left). The BEC prototype version 2 was working fine. Few issues were observed and resolved (lower the noise, improve the power distribution, channel crosstalk mitigation). Each BEC will handle signals from 48 PMTs, and in total 355 back-end cards are needed to read the 17000 PMTs. A first full prototype chain, including the BEC (version 2), was assembled in Padova in spring 2017, and tested successfully (100 Mb/s Ethernet for DAQ and Slow Control). This option was providing good signal to noise ratio, as the signal processing is performed on the PMT side. However this option had to be reconsidered because of the following three issues: (i) fragility issue when potting the electronics on the PMT, (ii) potentially high power consumption, and (iii) installation difficulty to manipulate the PMTs with its electronics and the 100 m cable attached to it. To mitigate these issues, the use of an underwater box was unavoidable, implying the presence of underwater connectors.

2-The 1F3 scheme:

Since fall 2017, the so-called “1F3 scheme” was adopted as the new baseline design for the JUNO electronics, see Figure 12 (right). The main modification is the addition of underwater (UW) boxes that will collect, for each of them, the signals of 3 PMTs, via 3 short (about 1 m long) coax cables. One UW box will host 3 ADC, and one GCU, and will be connected to the outside water system via 2 Ethernet cables. Each BEC will handle signals from 48 underwater boxes. To test this new scheme, a BEC version 3 has been designed, see Figure 13 (right). This version is optimised to be flexible and can test both the BX and 1F3 schemes. The idea is to have a baseboard and various mezzanine cards. The details of the these options and the BEC version 3 design are described in a poster sent to IEEE conference and in the corresponding proceeding. Various tests have been performed. Currently we have tested the 250 Mb/s bi-directional data transfer (most importantly for synchronized link), the 15 W power delivery with resettable fuse protection, and the 1 Gb/s data transfer over the combined 4 asynchronized links. All the tests above were successful. The results of the tests have been sent as a contribution to the TWEPP conference in September 2018.

The ULB work in JUNO is appreciated and visible in the collaboration. Y. Yang is presently officially responsible (L3 manager) for the DLU (Data Link Unit) for JUNO and B. Clerbaux is the ULB representative at the JUNO institutional board and at the JUNO financial board. The ULB team has organized two JUNO electronics workshops at the IIHE (on 14-16 November 2016 and on 14-15 May 2018) with about 50 participants.

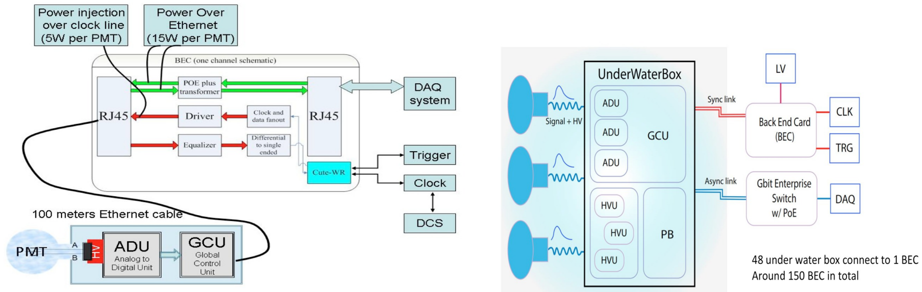


Figure 12: Schematic view of the JUNO readout with the front-end part (PMT, ADU, GCU – under water) and the back-end part (BEC, DAQ, trigger). Left: the first option with one GCU and one long cable per PMT ; Right: the latest version with 3 PMTs connected to one GCU via an underwater box.

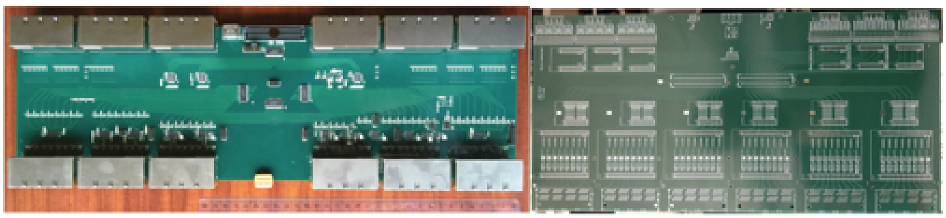


Figure 13: The baseboard of the BEC developed at the ULB (v2 on the left and v3 on the right).

2.10 Phenomenology

(D. Coone, A. Mariotti, K. Mawatari, M. Vereecken)

The phenomenology of Beyond Standard Model physics is nowadays an elemental topic of investigation in high energy physics. The Large Hadron Collider (LHC) at CERN is exploring the fundamental physics at very high energy and will provide new informations about the dynamics at the base of the electroweak scale. At the same time, several experiments are looking for understanding the nature of the dark matter that populates our universe, through direct and indirect detection. The Pheno group at IIHE pursues outstanding research on Beyond Standard Model phenomenology, including supersymmetry and its signals at the LHC, as well as simplified models for dark matter and their experimental signatures.

The Pheno group has started in 2010 under the initiative titled "Supersymmetric models and their signatures at the Large Hadron Collider" financed through a five-year "Geconcerteerde Onderzoeksactie" (GOA) research project at the VUB. Now it is part of the Strategic Research Program "High Energy Physics" (HEP@VUB) whose purpose it to strengthen the research activity in high energy physics among the existing groups at VUB: Collider physics (CMS), Astroparticle physics (IceCube), High-energy Astrophysics (LOFAR), and Theoretical high-energy physics (TENA).

In 2017 the Pheno group comprised one VUB 100% ZAP member Prof. A. Mariotti, one 10% Prof. K. Mawatari (90% PostDoc in LPSC Grenoble and subsequently Research Assistant Professor at Osaka University), two PhD students (D. Coone and M. Vereecken).

During 2017 the members of the pheno group have produced 5 scientific papers published on international peer reviewed Journals [1, 2, 3, 4, 5] three proceedings [6, 7, 8] and participated to one working group report [9]. They have pursued different lines of research in BSM phenomenology achieving important results in a broad range of subjects.

One important topic of investigation has been the study of axion-like particle phenomenology. In particular, in the paper published in PRL [2], it has been shown that the existence of a pseudo-nambu goldstone boson associated to the spontaneous breaking of R-symmetry is generic in supersymmetric extension of the Standard Model. The phenomenology of this unconventional sign of supersymmetry at colliders has been also investigated. With the aim to explore the reach of the LHC to light axion-like particles, in [4] it has been also shown how current LHC cross section measurements can constrain the existence of light (pseudo)scalar resonances decaying into diphotons, providing the most stringent existing bound on such new physics states.

Another relevant subject of studies has been the connection of supersymmetry breaking and inflation. In [3] it has been proposed a concrete model where both successful inflation as well as supersymmetry breaking in the MSSM can be realized. The predictions on the superparticle spectrum and on the inflation observables have then been derived and compared with experimental constraints from collider physics and from astrophysical observations on the CMB.

Furthermore, the group has also contributed to the research on simplified models of dark matter and their signatures at colliders [1, 9], and to the study of the Brout-Englert-Higgs boson characterization at the LHC [8], in the framework of the Effective Field Theory extension of the Standard Model.

Finally, the experimental searches carried out by the IIHE IceCube group have triggered several phenomenological efforts to understand the neutrino production in astrophysical events. These projects have been studying the source itself and its environment as well as the consequent effects on the neutrino emission. So far, these studies have focussed on objects obscured in gamma rays by matter (obscured flat spectrum radio AGN and ULIRGs) and binary black hole mergers. The different works [5, 6, 7], achieved in collaboration with external researchers, illustrate themselves within the multi-messenger framework, using electromagnetic and gravitational wave detection to predict the neutrino counterpart.

References

[1] S. Kraml, U. Laa, K. Mawatari and K. Yamashita, "Simplified dark matter models with a spin-2 mediator at the LHC," Eur. Phys. J. C **77** (2017) no.5, 326 doi:10.1140/epjc/s10052-017-4871-0 [arXiv:1701.07008 [hep-ph]].

[2] B. Bellazzini, A. Mariotti, D. Redigolo, F. Sala and J. Serra, "R-axion at colliders," Phys. Rev. Lett. **119** (2017) no.14, 141804 doi:10.1103/PhysRevLett.119.141804 [arXiv:1702.02152 [hep-ph]].

[3] R. Argurio, D. Coone, L. Heurtier and A. Mariotti, "Sgoldstino-less inflation and low energy SUSY breaking," JCAP **1707** (2017) no.07, 047 doi:10.1088/1475-7516/2017/07/047 [arXiv:1705.06788 [hep-th]].

[4] A. Mariotti, D. Redigolo, F. Sala and K. Tobioka, "New LHC bound on low-mass diphoton resonances," doi:10.1016/j.physletb.2018.06.039 arXiv:1710.01743 [hep-ph].

[5] K. D. de Vries, G. de Wasseige, J. M. Frère and M. Vereecken, "Constraints and prospects on gravitational-wave and neutrino emissions using GW150914," Phys. Rev. D **96** (2017) no.8, 083003 doi:10.1103/PhysRevD.96.083003 [arXiv:1612.02648 [astro-ph.HE]].

[6] K. D. de Vries, G. de Wasseige, J. M. Frere and M. Vereecken, "Constraints and prospects on gravitational wave and neutrino emission using GW150914," PoS ICRC **2017** (2017) 959 [arXiv:1709.04880 [astro-ph.HE]].

[7] K. D. de Vries, G. de Wasseige, J. M. Frere and M. Vereecken, "Implications of GW related searches for IceCube," arXiv:1709.07430 [astro-ph.HE].

[8] K. Mimasu, C. Degrande, B. Fuks, K. Mawatari and V. Sanz, "Electroweak Higgs production in Standard Model effective field theory at next-to-leading order in QCD," PoS DIS **2017** (2018) 298. doi:10.22323/1.297.0298

[9] A. Albert *et al.*, "Recommendations of the LHC Dark Matter Working Group: Comparing LHC searches for heavy mediators of dark matter production in visible and invisible decay channels," arXiv:1703.05703 [hep-ex].

2.11 Computing and networking

(S. Amary, F. Blekman, O. Devroede, S. Gérard, S. Rugovac, R. Rougny, A. Scodrani, P. Vanlaer, R. Vandenbroucke)

2.11.1 Local computing services

The IIHE hosts a range of general IT services like DNS and DHCP servers for internet connectivity, web servers for the official website as well as all the intranet services. Most servers have been migrated to a virtual environment based on FOSS software: RedHat based OS, KVM virtualization, OpenNebula orchestrator. In order to rationalize resources, a single infrastructure shared with the large scale cluster is used, with several hypervisors for redundancy as well as a High Availability (HA) storage.

The IIHE computing room also serves as a disaster-recovery backup solution, where important user data is preserved in case something happens to the main SISC (The VUB-ULB Shared ICT Service Center) datacenter.

2.11.2 Large scale and grid computing

The IIHE operates a computing cluster that can be used through a local batch system (PBS), to which a large scale storage solution is attached, both accessible via the Grid. The computing cluster offers resources and support to several large experiments (CMS, IceCube, Solid, Auger, ENMR).

In 2017, the Brussels HTC/Grid team was comprised of five IT scientists (S. Rugovac, F.R.S.-FNRS; O. Devroede, VUB; S. Gérard, VSC, part time; Romain Rougny, UGent; Samir Amary, ULB). Pascal Vanlaer (ULB) is in charge of the Belgian federated Tier2 sites and is the representative to the WLCG and CMS computing boards.

O. Devroede is the technical coordinator of the Belgian Tier2 sites. In addition, IIHE members act as representatives of ULB and VUB in regional bodies promoting the deployment of large computing infrastructures in Belgium: the Consortium des Equipements de Calcul Intensif (CECI) in the Wallonia-Brussels Federation, and the Vlaams Supercomputer Centrum (VSC) in Flanders.

With the integration of the IceCube cluster in 2016 and the ramp-up of the SoLid experiment, the cluster shifted away from its CMS-centric operations to a fully multi-purpose Grid computing cluster.
Overview per Experiment

SoLid: In order to transfer data from the experiment in SCK-CEN to our mass storage, as well as access, monitor and control resources on-site, a dedicated 1Gbps network link was implemented by BELNET between the SoLid experiment and the Tier2 in Brussels. Since then, daily data transfers occur at full link speed: a day's worth of data-taking is transferred in approximately 8 hours. The DIRAC grid tools are used for transferring and cataloging the files, which allows easy replication of this critical data to ensure its safekeeping: copies are made on tape at the Tier1 in RAL (UK) and the Tier1 in Lyon (FR), and on disks at the Tier2 at Imperial College (UK).

The computing and storage needs of the SoLid experiment have increased significantly in 2017. The experimental data collected, along with the Monte-Carlo simulations, take more than 100TB of storage in 2017. More than 50 users from the SoLid collaboration have access to our infrastructure, either to use the cluster or manage the experiment. They represent 1.6% of the overall non grid computing time, totalling 108'981 hours of computing done in 2017.

IceCube: The IceCube collaboration relies on its collaborating institutions to provide computing resources to generate simulated data sets. Producing these data sets requires vast amounts of CPU. In addition, specialized graphics processing units (GPU), containing the Tesla processing engine from NVIDIA, are used to simulate photon propagation in ice.

Since the integration of IceCube in 2016 with the Grid cluster, its use of Grid-enabled computing has been greatly beneficial to both the IceCube collaboration and the Tier2 itself, representing 21.7% of the computing time allocated to Grid experiments with 7.9M hours of computing done in 2017. The computing usage of local IceCube users also increased significantly, as efforts were done to help these users migrate from the Madison infrastructure - which is the central resource of the collaboration - to the Belgian Tier2. With 1.9M hours of compute done in 2017, they represent 28.2% of the overall non grid computing time.

CMS: The Brussels Tier-2 contributes significantly to the computing resources of the CMS collaboration. It hosts the contributions of the UA, UGent, ULB and VUB universities, and is funded by the F.R.S.-FNRS and by the FWO. It is part of the Belgian federated Tier2 computing resources, together with another Tier2 site at UCL. The two sites support the analyses of the ∼100 Belgian CMS physicists, and have been a crucial tool to allow Belgian physicists to contribute in an important way in the analyses of the LHC data.

By the end of 2017, the Tier2 had ∼6700 job slots dedicated to CMS, for a total of 80 TeraFLOPS (or 51.000 HepSpec06 units). The Grid-enabled storage system hosted 3.7 PB of CMS data, from centrally managed datasets comprising of real collisions or Monte-Carlo simulations, to data produced by Belgian researchers. The CMS usage of the cluster through the Grid infrastructure represented 78.3% of the computing time allocated to Grid experiments with 28.5M hours of computing performed. Albeit an extremely well integrated usage of the Grid infrastructures by the CMS end-users, with tools like CRAB, a small portion of the analysis steps are performed locally on the Tier2 with non-Grid means, mainly to allow rapid feedback when looking at the final results. With 4.8M hours of compute done in 2017, this usage represented 70.2% of the overall non grid computing time.

The analysis performed by the users has gradually become more and more I/O intensive, with sometimes tens of Terabytes read by a single researcher, as collected data at the LHC keeps increasing. Therefore, the network of the cluster has been upgraded, with the aggregated bandwidth between the worker nodes performing the calculations and the storage system increasing drastically to ∼400Gbps in 2017, in order to sustain the CMS analyses.

Also, although it has been predicted for years, the pool of IPv4 addresses has slowly been exhausted worldwide, with an important milestone reached end of 2017. Consequently some new Tier2s can only have connectivity through the new IPv6 protocol. In order to maintain the fully meshed grid of Tier1s and Tier2s, we took part in the migration to a dual stack storage: all our data stored on our mass storage is as of end 2017 accessible though IPv4 and IPv6.

2.12 Communication and outreach

The IIHE continuously stimulates and supports researcher to initiate and participate in activities to disseminate our research results. Numerous members of the IIHE therefore had the opportunity to give public lectures on both small and large scale, and at a variety of venues in Belgium. We have also welcomed many groups of young students from secondary schools to follow workshops and lectures in our institute.

Every year the IIHE organise Master Classes in astroparticle and in Particle Physics for between 60 and 80 pupils from secondary school. A common session is taking place in english for all pupils and later separated session (in FR and NL) with practicles.

We also participate in national and international programs concerning science communication, and our researchers do follow regularly courses to disseminate their research to a wider audience. Members of the IIHE are active in valorisation activities on social media such as Youtube videos, google hangouts and twitter, with particularly the video activities regularly reaching tens of thousands of views.

Our researchers have also guided many groups for visits at CERN, ranging from children to politicians. Every year we also take the physics students from both the ULB and VUB for a detailed visit to CERN.

Figure 14: Picture taken during the ULB BA3 student CERN visit 2017.

During the summer 2017, 8 US undergrad students came to the IIHE to perform their undergrad research project, within the frame of the IceCube education and outreach office program (NSF funding). At the same period one Chinese undergrad student from Tsinghua University joined the group, to realize a research project.

Gwenhael de Wasseige, a PhD student of the IIHE, has been selected to visit the IceCube neutrino observatory at the South Pole. In addition to the scientific goal of this mission, the IIHE has used the opportunity of this trip to communicate about the science achieved by IceCube in general and about the Brussels group in particular. Using the attractiveness of Antarctica and IceCube to trigger curiosity, we have developed, in collaboration with the science communication team of the ULB and the VUB, several activities adapted for different target audience. We were searching through these activities to sensitize Belgian citizens to science and scientist's life.

2.13 Technical and administrative work

2.13.1 Workshop

(Y. Allard, P. de Harenne, B. Denègre, M. Korntheuer, A. Morel, R. Vanderhaeghen and Y. Yang ; coordinator : G. De Lentdecker).

Our electronic and mechanic workshops are used for the development of the ongoing research projects CMS, IceCube and JUNO, where important developments are taking place, and for the preparation of new detectors for future experiments.

2.13.2 Secretariat

The secretarial work and the general administrative and logistic support of the experiments were in charge of A. Terrier and M. Goeman, with the collaboration of P. De Harenne.

P. De Harenne provided daily support for numerous tasks.

3 Activities

3.1 Contributions to experiments

3.1.1 Responsibilities in experiments

Shimaa Abu Zeid

- CMS Cenetral shifts - Detector Central Shifts (DCS)

Isabelle Ansseau

- contact person for the BSM L3 filter
- contact person for the Vertical Event Filter

Juan Antonio Aguilar Sánchez

- IceCube Muon Group coordinator
- IceCube local group leader and IceCube Institutional Board member
- Member of the IceCube Publication Committee

Bugra Bilin

- Participation in central shifts; DAQ and shift-leader

Freya Blekman

- Chairperson of CMS Supersymmetry group Publication Committee

Hugues Brun

- CMS muon POG convener (from January to September)

Douglas Burns

- Contact person for the analysis 'Measurement of differential top pair cross sections as a function of kinematic event variables at 13 TeV at CMS'
- Work on standalone simulation of the 'HIP' effect in the readout chip of the CMS tracker

Barbara Clerbaux

- Member and Chair of various Analysis Review Committees (ARC) in EXO and Higgs groups in CMS
- Member of the JUNO Financial Board
- Member of the publication committee board (PUBCOM) for the EXOTICA and B2G groups
- ULB Deputy representative at the CMS board
- ULB representative at the JUNO board

Jorgen D'Hondt

- Chairperson of the CMS Collaboration Board
- Chairperson of the CMS International Committee
- Member of the CMS Collaboration Board
- Member of the CMS Executive Board
- Member of the CMS Management Board
- Member of the CMS Steering Committee of the Tracker Phase-2 Upgrade
- Member of the International Advisory Committee for CMS Schools

Isabelle De Bruyn

- Chair of the Young Scientist Committee
- Tracker DQM convener

Jarne De Clercq

- CMS central technical shifts
- Contribution to firmware developments for CMS tracker phase II test systems

Catherine De Clercq

- PI of VUB in the IceCube collaboration board

Jarne De Clercq

- Test beams for CMS phase II tracker

Gilles De Lentdecker

- Convener of the CMS GEM DAQ & Electronics Working Group

Krijn De Vries

- Radar scattering experiment TA-ELS, Delta, Utah, United States: Coordination of simulations and analysis

Gwenhaël De Wasseige

- Gravitational Wave HitSpool coordination + contact person
- SFNews coordination + contact person
- Snow depth measurements for IceTop coordination + contact person

Hugo Delannoy

- Tracker DQM: convener, developer, expert on-call, shift leader and shifter

Wenxing Fang

- Done 13 CMS DQM shifts
- Main author for paper : Search for high-mass resonances in dilepton final states in proton-proton collisions at sqrt(s)=13 TeV, https://doi.org/10.1007/JHEP06(2018)120

Giuseppe Fasanella

- EXO contact for HEEP electron identification
- Energy calibration of the ECAL detector with the ECALELF framework
- Shift leader at CMS point 5 (14 shifts)

Laurent Favart

- Internal referee for CMS (ARC)
- Member of the CMS Publication Committee Board FSQ and PRF
- Member of the H1 Physics Board
- Shift Leader - CMS data taking

Reza Goldouzian

- Electron/photon contact and expert of the CMS exotica group

- Internal peer reviewer for CMS analyses (TOP-17-014, HIG-17-013)

Leonidas Kalousis

- Coordinator of the Final Fit (FF) working group (WG)
- Member of the Publication Committee

Georgia Karapostoli

- Coordinator of the CMS Trigger operations group STEAM (Sep 2015 - Sep 2017)
- Editor of the CMS paper HIG-17-012 published in JHEP: JHEP06(2018)127
- Leader of the CMS HZZ2l2nu Higgs Working Group (Nov 2015 - Sep 2017)

Amandeep Kaur Kalsi

- CMS Exotica workshop 2017, Brussels
- HCAL Calibration with muons

Denys Lontkovskyi

- Four top production using 2016 data
- MC request manager in PPD/PdmV group (L3 convener)

Steven Lowette

- CMS delegate to the CERN Dark Matter Working Group
- Convener of the CMS Exotica Long-Lived Particle search group
- Member of the CMS SUSY Publication Board
- VUB representative to the CMS Tracker Institution Board

Ioana Maris

- Task leader for the Long term perfomance of the Pierre Auger Observatory

Seth Moortgat

- L3 convener of the BTV performance and validation group

Lieselotte Moreels

- DQM: Phase II outer tracker plots
- General DQM maintenance for the CMS silicon strip tracker

Nicolas Postiau

- Validator for High-level Triggers for the SMP analysis group

Christoph Raab

- Referee of the 3C279 analysis for the point source working group

Kirill Skovpen

- ARC member for TOP-17-018 and B2G-17-006
- Contact person for top-Higgs FCNC (H-¿bb) analysis
- L2 coordinator of the b tagging group at CMS
- L3 coordinator of the b tagging performance group at CMS

Elizabeth Starling

- GEM DOC (shifter and trainer)

Petra Van Mulders

- Convener of the background group in the SoLid collaboration
- Member of the institutional board of the SoLid collaboration

Pascal Vanlaer

- Academic person in charge of the ULB-VUB CMS Tier-2 computing cluster
- CMS ULB team leader
- Member and chair of CMS analysis review committees (ARCs)
- Member of the CMS Tracker Institution Board
- Promotor-spokesperson of the FNRS IISN convention CMS Phase 2 upgrade (UCL-ULB) 4.4502.17
- co-promotor of FNRS IISN convention Frontier physics at the LHC 4.4502.15

Gaston Wilquet

- Internal referee for OPERA publications
- Member of the OPERA Collaboration Board

3.1.2 Presentations in collaboration meetings

Isabelle Ansseau

- An update of the Earth Wimp Analysis - IceCube - Madison 04/05/2017

Juan Antonio Aguilar Sánchez

- HIghlights from the Muon Working Group - IceCube Collaboration Meeting - Berlin, Germany 03/10/2017

Diego Beghin

- Search for high mass particles with lepton flavour violating decays - CMS - EXO Workshop - Brussels 02/12/2017
- Towards the trigger menu for 2017: data-mc comparison - CMS - CMS Week - CERN 05/04/2017

Douglas Burns

- Preapproval talk for 'Measurement of differential top pair cross sections as a function of kinematic event variables at 13 TeV at CMS' - CMS - CERN 01/05/2017
- Summary of CMS Physics at Bristol - CMS Bristol - Bristol, UK 01/07/2017
- Summary of top physics in the UK (CMS) - CMS UK - Imperial College London, UK 01/02/2017

Gwenhaël De Wasseige

- GeV astrophysical neutrino searches - IceCube - Madison 05/04/2017

Wenxing Fang

- EGM workshop on 2017 performance and plans for 2018. - CMS - CERN 21/11/2017

Leonidas Kalousis

- Final Fit group status and roadmap - SoLid - Mol, Belgium from 14/09/2017 to 15/09/2017
- Final Fit working group status - SoLid - Gent, Belgium from 30/05/2017 to 31/05/2017

- Final Fit working group status - SoLid - Antwerp, Belgium from 20/02/2017 to 22/02/2017

Ioana Maris

- The energy spectrum of UHECRs: comparison of the TA and Auger measurements - Pierre Auger collabarotion - Paris from 06/06/2017 to 10/06/2017

Christoph Raab

- Blazar Flare Stacking Analysis update - IceCube - Madison, USA 03/05/2017
- Flare Stacking - IceCube - Berlin, Germany 18/09/2017
- PINGU DM Paper Update - IceCube - Madison, USA 01/05/2017

Kirill Skovpen

- Approval of top-Higgs FCNC analysis (TOP-17-003) - CMS - CERN 01/08/2017

Qun Wang

- Measurement of the differential cross section for Z boson production in association with jets at 13 TeV - CMS - CERN 22/06/2017

Yifan Yang

  - Backend Card status$_0212-JUNO-Zhuhaifrom11/02/2017to12/02/2017BackendCardstatus_0715-JUNO-Beijingfrom15/07/2017to16/07/2017$

- Back end card status$_0420-JUNO-Padovafrom20/04/2017to21/04/2017studyofBECcrosstalk_1106-JUNO-J\ddot{u}lich06/11/2017$

3.2 Completed Master and PhD theses

Juan Antonio Aguilar Sánchez

- Nadège Iovine
  Combined Search for Neutrinos from Dark Matter Annihilation in the Galactic Centre using IceCube and ANTARES
  Master thesis, ULB, September 2017.
- Elisa Pinat
  The IceCube Neutrino Observatory: search for extended sources of neutrinos and preliminary study of a communication protrocol for its future upgrade
  Phd thesis, ULB, June 2017.

Barbara Clerbaux

- Giuseppe Fasanella
  Search for new physics in dielectron and diphoton final states at CMS
  Phd thesis, ULB, September 2017.

Laurent Favart

- Louis Moureaux
  Etude de la production exclusive du meson ρ dans les données proton-plomb prises à CMS en 2013 à $\sqrt{S_{NN}} = 5.02$ TeV
  Master thesis, ULB, June 2017.
- Fengwangdong Zhang
  Measurement of jet production in association with a Z boson at the LHC and jet energy correction and calibration at high level trigger in CMS
  Phd thesis, ULB, June 2017.

Kirill Skovpen

- Kevin Deroover
  A search for flavour changing neutral currents involving a top quark and a Higgs boson with the CMS experiment
  Phd thesis, VUB, September 2017.

Nick Van Eijndhoven

- Pablo Correa
  Comparison of Statistical Methods to Evaluate the IceCube Discovery Potential for Steady Point Sources
  Master thesis, VUB, June 2017.
- Paul Coppin
  InIce Veto Studies for the IceCube-Gen2 Neutrino Observatory
  Master thesis, VUB, June 2017.
- Giuliano Maggi
  Search for High-Energy Neutrinos from Obscured Flat Spectrum Radio AGN using the IceCube Neutrino Observatory
  Phd thesis, VUB, June 2017.

3.3 Representation in scientific councils and committees

Juan Antonio Aguilar Sánchez

- Member of the Scientific Committee of the Centre de Physique des Particules de Marseille (CPPM) France

Freya Blekman

- Chairperson ATLAS-Canada Standing Review Committee, Natural Sciences and Engineering Research Council of Canada (NSERC), Canada
- Review panel on subatomic physics, space physics and astronomy (NT-3), Swedish Research Council, Sweden
- Vice-Chairperson of WT2 (physics) funding review panel of the FWO, Flanders, Belgium

Barbara Clerbaux

- External referee (expert) for ANR (Agence Nationale de la Recherche), France
- President of the Jury FRIA of the Belgian FNRS
- Referee for the Phys. Lett. B Journal

Jorgen D'Hondt

- Belgian representative in Restricted European Committee for Future Accelerators (RECFA)
- FWO delegate in the International Oversight Funding Group (IOFG) of the IceCube experiment
- Member of the FWO Committee for International Collaboration
- Member of the NWO selection committee for the VICI grants
- Member of the VUB committee for Future Education Innovations
- Member of the VUB selection committee for grants for Education Projects
- Member of the VUB steering group for setting up an Honour Program
- Permanent member of the International Advisory Board of the workshop series
- Promotor of the Strategic Research Program

Catherine De Clercq

- Member of the FNRS scientific committee *Hautes et Basses Energies*

- Representative of FWO in the APPEC General Assembly
- Representative of FWO in the CERN-CMS Resources Review Boards

Gilles De Lentdecker

- Referee for the Agence Nationale de Recherche (ANR), France
- Referee for the IEEE Journal
- Vice-President of the Belgian Physical Society

Laurent Favart

- Adviseur for EUROTALENTS - Marie Curie Actions FP7 EU
- FNRS delegate to the IOFG (International Oversight and Finance Group) of the IceCube experiment
- Member of the Belgian committee for the selection of CERN fellows
- Representative of the FNRS at the ApPEC (Astroparticle Physics European Consortium)

Steven Lowette

- Member of the organizing committee for the Belgian-Dutch-German Graduate School in Particle Physics

Nick Van Eijndhoven

- Adviser for the National Research Foundation (NRF) of South Africa
- Belgian representative in the HEP board of the European Physical Society
- Member of the IceCube Collaboration Board
- Scientific Programme Committee member of the International Cosmic Ray Conference

Catherine Vander Velde

- Member of the CMS Thesis Awards Committee
- Member of the IISN committee Low and High Energy
- Member of the SUSY Publication Committee of the CMS experiment

Pascal Vanlaer

- Referee for Physics Letters B
- Representative of the ULB in the CECI interuniversity high-performance computing infrastructure (FUNDP, UCL, ULB, ULg, UMons)

3.4 Diffusion of scientific results

3.4.1 Oral presentations at conferences and schools

Juan Antonio Aguilar Sánchez

- COMBINED SEARCH FOR NEUTRINOS FROM DARK MATTER ANNIHILATION IN THE GALACTIC CENTRE USING ICECUBE AND ANTARES, MANTS 2017 - Marseille, France from 07/10/2017 to 08/10/2017
- Indirect searches of dark matter with IceCube, Seminar at University of Padua - Padua, Italy 12/10/2017

Hugues Brun

- H-¿VV decays and Higgs measurements, Multi-Boson Interactions 2017 - Karlsruhe from 28/12/2017 to 30/12/2017

Barbara Clerbaux

- Highlights from the CMS experiment, Seminar at Laboratori Nazionali di Frascati (LNF) - Frascati, Italy 29/06/2017
- Physics prospects of the JUNO experiment, The 19th international Workshop on Neutrinos from Accelerators (NUFACT2017) - Uppsala, Sweden from 25/09/2017 to 30/09/2017
- Search for charged lepton flavour violation processes heavy neutrinos at CMS, The 19th international Workshop on Neutrinos from Accelerators (NUFACT2017) - Uppsala, Sweden from 25/09/2017 to 30/09/2017

Isabelle De Bruyn

- Searches for long-lived particles decaying in the detector, Large Hadron Collider Physics (LHCP) conference 2017 - Shanghai from 15/05/2017 to 20/05/2017

Jarne De Clercq

- CMS tracker phase II test system DAQ architecture, CMS phase II DAQ workshop - Brussels, Belgium from 11/07/2017 to 13/12/2017

Krijn De Vries

- Coherent radio emission from the electron beam sudden appearance, International Cosmic Ray Conference 2017 - Busan, South Korea from 10/07/2017 to 20/12/2017
- Coherent transition radiation at radio frequencies from the electron beam sudden appearance, IPA 2017 - Madison, Wisconsin, United States from 08/05/2017 to 10/05/2017

Gwenhaël De Wasseige

- Search for GeV neutrinos associated with solar flares with IceCube, ICRC2017 - BUSAN, SOUTH KOREA from 10/07/2017 to 22/07/2017
- Search for GeV neutrinos associated with solar flares with IceCube materials, Fermi Symposium - Garmisch-Partenkirchen from 15/10/2017 to 20/12/2017

Hugo Delannoy

- CMS Tracker performance in 2016, BPS - Mons (Belgium) 05/05/2017
- Performance of the silicon tracker of the CMS experiment for the 2016 LHC data taking, TIPP - Beijing (China) 22/05/2017

Wenxing Fang

- Search for high mass ee/$e\mu$ resonances in CMS, CLHCP - China 22/12/2017

Laurent Favart

- Belgium HEP Overview, RECFA - open session - Brussels 21/04/2017
- High Energy Physics in Belgium, ESS Science Seminar in Belgium - Brussels 14/09/2017

Reza Goldouzian

- High mass Z' search in ee channel, CMS Exotica Workshop - Brussels, Belgium from 30/11/2017 to 02/12/2017
- Search for new physics via single top quark production, CMS Workshop on Top Quark Physics - CERN from 14/11/2017 to 15/12/2017
- Single Top Quark Properties Measurements, 10th International Workshop on Top Quark Physics - Braga, Portugal from 17/12/2017 to 22/12/2017

Denys Lontkovskyi

- Four top production at CMS, BPS2017: General Scientific Meeting of the Belgian Physical Society - Mons, Belgium from 17/05/2017 to 18/05/2017

- Top quark physics at CMS, La Thuile 2017: XXXI Les Rencontres de Physique de la Vallée d'Aoste - La Thuile, Italy from 05/03/2017 to 11/03/2017

Steven Lowette

- Dark Matter Searches at ATLAS and CMS, ALPS2017 - Obergurgl, Austria 20/04/2017
- Dark Matter Searches at ATLAS and CMS, Rencontres de Blois 2017 - Blois, France 01/06/2017
- Dark Matter Searches at CMS, CP3 Dark Matter Workshop - Louvain-la-Neuve, Belgium 06/12/2017
- Neutral Jets at the LHC from Stable SIMPs, LHC LLP Workshop - CERN, Geneva, Switzerland 26/04/2017

Jelena Luetic

- The CMS Outer Tracker Upgrade for the High Luminosity LHC, Vertex 2017 - Las Caldas, Spain from 10/09/2017 to 15/12/2017

Alberto Mariotti

- Lectures on Quantum Field Theory, BND graduate school 2017 - Callantsoog – Nikhef from 04/09/2017 to 08/09/2017
- SUSY @ CLIC, Physics at CLIC - CERN from 17/07/2017 to 18/07/2017
- SUSY@LHC: theory perspective, CMS SUSY Workshop 2017 - Ghent from 10/04/2017 to 12/04/2017

Ioana Maris

- Recent results from the Pierre Auger Observatory, Lomonosov conference - Moskow from 24/08/2017 to 30/12/2017

Kirill Skovpen

- Searches for FCNC, TOP2017 - Braga from 17/09/2017 to 22/09/2017
- Search for SM deviations in top precision studies at CMS, Blois2017 - Blois from 28/05/2017 to 02/06/2017
- Search for top-Higgs FCNC at LHC, 4th CMS single top workshop - Karlsruhe from 08/06/2017 to 10/06/2017
- Search for top-Higgs FCNC at LHC, BPS 2017 - Mons 17/05/2017

Petra Van Mulders

- b tagging in CMS: challenges and prospects, - Geneva 04/12/2017

Pascal Vanlaer

- Recent results from CMS on the scalar sector, invited seminar - Peking University, Beijing, China 07/06/2017
- Recent results from CMS on the scalar sector, invited seminar - Peking University, Beijing, China 07/06/2017
- VBF H, VH and HH results from the LHC, Multi-Boson Interactions workshop - Karlsruhe Institute of Technology, Germany from 28/08/2017 to 30/08/2017
- VBF H, VH and HH results from the LHC, Multi-Boson Interactions workshop - Karlsruhe Institute of Technology, Germany from 28/08/2017 to 30/08/2017

David Vannerom

- Dark Matter searches with the CMS detector, Meeting of the Belgian Physical Society - Université de Mons 17/05/2017
- Energy recovery methods for ECAL dead cells, CMS JetMET workshop - University of Helsinki from 10/05/2017 to 12/05/2017

Matthias Vereecken

- Implications of GW related searches for IceCube, - Moriond from 18/03/2017 to 25/03/2017

Qun Wang

- Vector Boson production in association with jets at CMS, DIS2017 - Birmingham 04/04/2017

Fengwangdong Zhang

- EWK & QCD measurements, The 21st Particles & Nuclei International conference - Beijing, China from 01/09/2017 to 05/09/2017
- Vector boson production in association with jets from CMS, TeV Physics Workshop - Zhengzhou, China from 22/07/2017 to 24/07/2017

3.4.2 Poster presentations at conferences and schools

Isabelle Ansseau

- Search for Dark Matter in the center of the Earth with the IceCube detector, ICRC - Busan, Korea 11/07/2017

Juan Antonio Aguilar Sánchez

- Combined Search for Neutrinos from Dark Matter Annihilation in the Galactic Center using IceCube and ANTARES, International Cosmic Ray Conference - Busan, South Korea from 12/07/2017 to 20/07/2017
- Search for a cumulative neutrino signal from blazar flares using IceCube data, International Cosmic Ray Conference - Busan, South Korea from 12/07/2017 to 20/07/2017

Diego Beghin

- The CMS experiment's High Level Trigger, BPS - Mons 17/05/2017

Douglas Burns

- 'Measurement of differential top pair cross sections as a function of kinematic event variables at 13 TeV at CMS', ESHEP - Evora, Portugal 01/09/2017

Isabelle De Bruyn

- Search for SIMPs using Trackless Jet at the CMS Experiment, Large Hadron Collider Physics (LHCP) conference 2017 - Shanghai from 15/05/2017 to 20/05/2017

Krijn De Vries

- Probing the radar scattering cross-section for high-energy particle cascades in ice, International Cosmic Ray Conference 2017 - Busan, South Korea from 10/07/2017 to 20/12/2017
- The GRANDproto35 experiment, International Cosmic Ray Conference 2017 - Busan, South Korea from 10/07/2017 to 20/07/2017
- Towards the sensitivity for the radar scattering technique to probe neutrino induced particle cascades in ice: The radar cross-section, International Cosmic Ray Conference 2017 - Busan, South Korea from 10/07/2017 to 20/07/2017

Gwenhaël De Wasseige

- A better communicator is always a better scientist, or the reason why every PhD student should engage in science outreach, ICRC2017 - BUSAN, SOUTH KOREA from 10/07/2017 to 22/07/2017
- Constraints and prospects on gravitational wave and neutrino emission using GW150914, ICRC2017 - BUSAN, SOUTH KOREA from 10/07/2017 to 22/07/2017

Hugo Delannoy

- Search for a spin-zero high mass resonance with the Z(ll)Z(vv) final state in 2016 with CMS, EPS - Venezia (Italy) 05/07/2017

Wenxing Fang

- Search for heavy resonances in the dilepton final state with the CMS detector, BPS2017 - Belgium 17/05/2017
- Search for heavy resonances in the dilepton final state with the CMS detector, BPS2017 - Belgium 17/05/2017

Xuyang Gao

- Search new physics in e, BPS2017:General Scientific Meeting of the Belgian Physical Society - UMons, Mons(Belgium) 17/05/2017

Nadège Iovine

- Combined Search for Neutrinos from Dark Matter Annihilation in the Galactic Center using IceCube and ANTARES, ICRC2017 - Bexco, Busan, Korea from 10/07/2017 to 20/07/2017

Seth Moortgat

- c-jet identification, 2017 EUROPEAN SCHOOL OF HIGH-ENERGY PHYSICS - Evora, Portugal from 06/09/2017 to 19/09/2017

Christoph Raab

- Search for a cumulative neutrino signal from blazar flares using IceCube data, ICRC 2017 - Busan, Korea from 10/07/2017 to 20/07/2017

Rachel Simoni

- Upper limits on gamma-ray emission from supernovae serendipitously observed with H.E.S.S., ICRC 2017 - Busan South Korea from 12/07/2017 to 20/07/2017
- Upper limits on gamma-ray emission from supernovae serendipitously observed with H.E.S.S., IAUS331 - La Reunion France from 20/02/2017 to 24/02/2017

David Vannerom

- How to detect the invisible: Dealing with missing energy in the CMS detector, Meeting of the Belgian Physical Society - Université de Mons 17/05/2017

3.5 Scientific training

3.5.1 Attendance to conferences and workshops

Isabelle Ansseau

- Workshop steriles neutrinos - Workshop steriles neutrinos - VUB 18/01/2017

Juan Antonio Aguilar Sánchez

- International Cosmic Ray Conference - Busan, Korea from 12/07/2017 to 20/07/2017

Diego Beghin

- BPS - Mons 17/05/2017
- EXO Workshop - Brussels from 30/11/2017 to 02/12/2017
- CMS Week - CERN from 05/04/2017 to 07/04/2017

Bugra Bilin

- Resummation, Evolution, Factorization 2017 - Resummation, Evolution, Factorization 2017 - Madrid Spain from 13/11/2017 to 16/11/2017

Barbara Clerbaux

- JUNO Collaboration funding comittee meeting - Aachen, Germany 15/11/2017
- JUNO electronics workshop - Padova from 19/04/2017 to 22/04/2017
- JUNO Collaboration meeting - Zhuhai, China from 09/02/2017 to 18/02/2017
- Belgian Physical Society, BPS - General meeting - University of Mons 17/05/2017
- IUAP network - General meeting - ULB 21/12/2017
- CMS EXOTICA Workskop - Organiser of the CMS EXOTICA Workshop in Brussels - ULB from 30/11/2017 to 02/12/2017

Paul Coppin

- IAP meeting - Brussels 21/12/2017
- IceCube collaboration conference - Berlin from 30/09/2017 to 06/10/2017

Pablo Correa

- IceCube Collaboration Meeting Fall 2017 - Humboldt University, Berlin, Germany from 30/09/2017 to 06/10/2017
- IAP (Final) Meeting - ULB, Brussels, Belgium 21/12/2017

Catherine De Clercq

- MANTS meeting - Marseille, France from 06/10/2017 to 09/10/2017

Gilles De Lentdecker

- Topical Workshop on Electronics for Particle Physics (TWEPP 17) - The DAQ and Electronics system of the CMS GE11 upgrade - Santa Cruz (CA) USA from 11/09/2017 to 15/09/2017

Krijn De Vries

- 35th International Cosmic Ray Conference - 35th International Cosmic Ray Conference - Busan, South Korea from 10/12/2017 to 20/12/2017
- IceCube collaboration meeting - IceCube Collaboratoin meeting - Madison, Wisconsin, United States from 02/05/2017 to 06/12/2017
- IPA 2017 - Particle Astrophysics - Madison, Wisconsin, United States from 08/05/2017 to 10/05/2017

Hugo Delannoy

- CMS Statistics Committee Mini-Workshop + Higgs Combine Tutorial - CERN from 29/11/2017 to 30/11/2017
- BPS - Mons (Belgium) 05/05/2017
- TIPP - Beijing (China) from 22/05/2017 to 26/05/2017
- EPS - Venezia (Italy) from 05/07/2017 to 12/07/2017

Laurent Favart

- DIS 2017 - 25th International Workshop on Deep Inelastic Scattering and Related Topics - Birmingham (GB) from 03/04/2017 to 07/04/2017
- Workshop on Resummation, Evolution, Factorization (REF17) - Member of Organizing and scientific committees - - Madrid (E) from 13/11/2017 to 16/11/2017

Stéphane Gérard

- Digital Infrastructures for Research conference - Digital Infrastructures for Research - Brussels from 30/11/2017 to 01/12/2017
- EGI Conference 2017 and INDIGO Summit 2017 - EGI and INDIGO - Catania (Italy) from 09/05/2017 to 12/05/2017

- ELIXIR Belgium Launch event - ELIXIR - Zwijnaarde 09/02/2017
- VSC Users Day - VSC - Brussels 02/06/2017
- VSC all hands meeting - VSC - Brussels 21/02/2017

Steven Lowette

- 52nd Rencontres de Moriond EW 2017 - Session chair - La Thuile, Italy from 18/03/2017 to 25/03/2017

Seth Moortgat

- Symposium: A matter of flavor - Flavor physics and dark matter - Mainz, Germany from 19/02/2017 to 22/02/2017
- Chaire Georges Lemaitre in CP3 2017 : Prof. K. Cranmer Lectures - Machine Learning - Louvain-La-Neuve Universite (UCL) from 27/11/2017 to 01/12/2017

Rachel Simoni

- H.E.S.S. Collaboration Meeting - Paris Palaiseau from 27/03/2017 to 31/03/2017
- H.E.S.S Collaboration Meeting - Erlangen from 09/10/2017 to 13/10/2017

David Vannerom

- IIHE annual meeting - Brussels, Belgium 22/11/2017
- HEP@VUB workshop: "CrossTalk Workshop: The Fate of Sterile Neutrinos" - IIHE 18/01/2017
- CMS Exotica Workshop - ULB from 30/11/2017 to 01/12/2017

Matthias Vereecken

- IceCube Collaboration Meeting - Berlin from 02/10/2017 to 06/10/2017

Qun Wang

- REF workshop - Madrid from 13/11/2017 to 16/11/2017

3.5.2 Attendance to schools

Diego Beghin

- CMS Data Analysis School - Fermilab from 09/01/2017 to 13/01/2017
- BND - Callantsoog (NL) from 04/09/2017 to 15/12/2017

Douglas Burns

- ESHEP - Advanced particle physics theory summer school for late-stage PhD students/postdocs - Evora, Portugal 01/09/2017

Barbara Clerbaux

- Formation Practice ULB - Formation for enhencing your teaching skills - La Roche en Ardennes from 01/02/2017 to 03/02/2017

Paul Coppin

- BND Graduate School - Callantsoog, Netherlands from 04/09/2017 to 15/12/2017

Seth Moortgat

- 2017 EUROPEAN SCHOOL OF HIGH-ENERGY PHYSICS - High-Energy phsyics - Evora, Portugal from 06/09/2017 to 19/09/2017

Louis Moureaux

- CERN Summer School - Particle Physics in general + GEM Detector - CERN from 28/06/2017 to 30/08/2017

Christoph Raab

- International School on Astroparticle Physics 2017 - Arenzano, Italy from 13/06/2017 to 24/06/2017

Elizabeth Starling

- BND School - Callantsoog, Netherlands from 04/09/2017 to 15/09/2017

David Vannerom

- CMS Data Analysis School - Facilitator for the DAS - Fermilab from 09/01/2017 to 13/01/2017

Qun Wang

- BND summer school - Amsterdam from 04/09/2017 to 15/12/2017
- MC school - Hamburg from 13/03/2017 to 17/03/2017

3.6 Teaching and academics activities

3.6.1 Teaching activities

Isabelle Ansseau

- ULB - XP : Experimentarium, (0/0/36/0) BA1 Hour at the museum of physics - for high school student
- ULB - PHYS-F-205 : Physique 2, (0/0/44/20) BA2 Physics Laboratory for BA2 Géo
- ULB - PHYS-F-205 : Physique 2, (0/0/44/20) BA2 Physics Laboratory for BA2 BIO
- ULB - PHYS-F-110 : Physique I, (0/0/16/8) BA1 Physics laboratory for BA1 PHYS
- ULB - PHYS-F-210 : Physique II, (0/0/72/30) BA2 Physics laboratory for BA2 PHYS
- ULB - PHYS-F-205 : Physique générale, (0/0/0/24) BA2 coordination pour le cours de physique
- ULB - PHYS-F-110 : Physique générale 1 et 2, (0/0/40/20) BA1 Physics Laboratory for BA1 CHIM

Juan Antonio Aguilar Sánchez

- ULB - PHYS-F314 : Electronique, (12/0/0/0) BA3
- ULB - PHYS-F210 : Laboratoires, statistique appliquée à la physique expérimentale et projet, (0/0/72/40) BA2
- ULB - PHYS-F311 : Laboratoires et Stage de recherche , (0/0/72/30) BA3
- ULB - PHYS-F467 : Physique des Astroparticules , (24/24/0/24) MA1 MA2

Diego Beghin

- ULB - PHYS-F104 : Physique Générale, (0/24/0/0) BA1

Freya Blekman

- VUB - WE-DNTK-mobility : Coordinator external mobility, (0/0/0/20) MA1 MA2 coordinate the assignment of the obligatory mobility courses (6 ECTS credits)
- VUB - WE-DNTK-12965 : EXPERIMENTELE FYSICA, (10/0/70/40) BA1 This is the obligatory experimental physics laboratory for students in the first year of the Ba1
- VUB - IR-BIO-6763 : Measurement Techniques in Nuclear Science, (20/0/0/40) MA1 MA2 Optional course for students in the Master Biomedical Engineering

- VUB - WE-DNTK-7136 : Simulation of Physics Phenomena and Detectors in Modern Physics, (15/25/10/20) MA1 MA2 Course preparing students for their masters project, combining simulation/computing with physics to

Hugues Brun

- ULB - PHYS-F-110 : Physique Général, (0/40/0/0) BA1 Tutorials

Barbara Clerbaux

- ULB - PHYS-F416 : Interactions fondamentales et particules, (18/12/12/0) MA1
- ULB - PHYS-F311 : Laboratoires et stage de recherche, (0/0/12/36) BA3
- ULB - PHYSF-311 : Organisation of the CERN visit for the BA3 students, (0/0/0/36) BA3 From 21 to 23 March 2017
- ULB - PHYS-F104 : Physique Générale, (0/24/0/0) BA1

Pablo Correa

- VUB - WE-DNTK-6406 : Subatomic Physics I: Introduction to Nuclear and Particle Physics, (0/26/0/0) BA3

Isabelle De Bruyn

- VUB - WE-DNTK-006317 : Fysica: trillingen, golven en thermodynamica, (0/0/34/30) BA1

Jarne De Clercq

- VUB - VUB - WE-DNTK-006317 : Fysica: trillingen, golven en thermodynamica, (0/24/6/30) BA1

Gilles De Lentdecker

- ULB - PHYS-F314 : Electronics, (12/6/18/0) BA3 Introduction to electronics
- ULB - PHYS-F205 : General Physics II, (0/12/0/0) BA2 Exercices of electromagnetism for Biologists
- ULB - PHYS-F312 : Particle Physics Laboratory, (0/0/36/0) BA3 Laboratory in Particle Physics
- ULB - PHYSF482 : Techniques Avancées en Physique Expérimentale, (4/0/0/0) MA1

Krijn De Vries

- VUB - WE-DNTK-6508 : High Energy Astrophysics, (0/18/0/0) MA1

Hugo Delannoy

- ULB - PHYS-F110 : Laboratoire de Physique générale, (0/0/84/0) BA1
- ULB - PHYS-F311 : Laboratoires et Stage de recherche, (0/0/72/0) BA3

Olivier Devroede

- VUB - WE-DNTK-14101 : Experimentele Fysica, (0/12/0/0) BA1 First Matlab Course
- VUB - 4015950FNR : Object Oriented Programming (C++) for Physicists, (12/12/12/60) MA1 MA2

Laurent Favart

- ULB - PHYS-F305 : Introduction à la Physique des Particules, (24/0/0/0) BA3 Physique
- ULB - PHYS-F477 : Physique auprès des collisionneurs, (24/0/0/0) MA1 MA2 Physique
- ULB - PHYS-F311 : Visite annuelle du CERN, (0/0/0/24) BA3 Physique

Anastasia Grebenyuk

- ULB - PHYS-F311 : Laboratoires et Stage de recherche, (0/0/40/0) BA3

Leonidas Kalousis

- VUB - PHYS-Fxxx : Statistical physics, (0/12/0/0) BA3

Steven Lowette

- VUB - 4015948FNR : Experimental Techniques in Particle Physics, (36/0/0/20) MA1 MA2
- VUB - 4012730CNR : Extensions of the Standard Model, (24/12/0/0) MA2
- VUB - 4015029ENR : External Mobility B, (0/0/0/0) MA1 MA2
- VUB - 1019736ANR : Seminarie Actuele Wetenschappen en Samenleving, (13/13/0/13) BA1

Alberto Mariotti

- VUB - 1015267BNR : Statistical Physics, (26/0/0/0) BA3
- VUB - 4015689FNR : Subatomic Physics 2, (26/0/0/0) MA1

Ioana Maris

- ULB - PHYS- F-311 : Laboratoires et Stage de recherche , (0/0/36/0) BA3

Lieselotte Moreels

- VUB - WE-DNTK-1001388CNR : Experimentele stralings- en kwantumfysica, (0/0/48/32) BA2 Lab sessions in which the students prepare and perform some of the basic experiments related to radi
- VUB - WE-DNTK-1015332ANR : Fysica: Inleiding Mechanica, (0/14/0/52) BA1 Introductory Mechanics course for non-physicists
- VUB - WE-DNTK-1010221BNR : Statische verwerking van experimentele gegevens, (0/10/0/8) BA2 Introduction to statistical concepts concerning data analysis

Louis Moureaux

- ULB - PHYS-F210 : Laboratoire de physique générale, (0/0/36/0) BA2
- ULB - PHYS-F110 : Physique Générale I et II, (0/40/32/0) BA1
- ULB - PHYS-F104 : Physique I, (0/72/0/12) BA1 Exercices+Coordination

Nicolas Postiau

- ULB - PHYS-F-104 : Physique Générale, (0/48/0/0) BA1 Students in BA1 Pharma/Biol/Géog
- ULB - PHYS-F-110 : Physique Générale I, (0/44/0/0) BA1 Students in BA1 Math
- ULB - PHYS-F-110 : Physique Générale II, (0/95/23/0) BA1 Students in BA1 Phys/Chim
- ULB - PHYS-F-201 : Thermodynamique, (0/24/0/0) BA2 Students in BA2 Phys

Christoph Raab

- ULB - PHYS-F311 : Physique des astroparticules - Laboratoires, (0/0/26/0) BA3 Tutored students for their data analysis.
- ULB - PHYS-F310 : Supervising stagiair Bertrand Raysz, (0/0/16/8) BA3
- ULB - PHYS-F482 : Techniques avancées de physique expérimentale, (0/2/8/4) MA1 Led exercises/lab on statistical data analysis.

Nick Van Eijndhoven

- VUB - WE-DNTK-6406 : Experimental Study of the Micro and Macrocosmos, (13/13/0/0) BA3
- VUB - WE-DNTK-6331 : Subatomic Physics I : Introduction to Nuclear and Particle Physics, (26/26/0/0) BA3

Petra Van Mulders

- VUB - 1010183ANR : WPO Mechanica, (0/22/0/22) BA1

Catherine Vander Velde

- ULB - PHYS-F-416 : Physique des particules, (16/4/0/0) MA1

Pascal Vanlaer

- ULB - PHYS-F420 : Détection de particules, acquisition et analyse de données, (12/0/24/0) MA1 MA2 Physique
- ULB - PHYS-F110 : Physique générale, (0/0/24/0) BA1 laboratoires de physique section Chimie
- ULB - PHYS-F482 : Techniques avancées de la physique expérimentale, (24/0/24/0) MA1

David Vannerom

- ULB - PHYS-F305 : Introduction à la physique des particules, (0/8/0/0) BA3
- ULB - PHYS-F416 : Physique des particules élémentaires, (0/12/0/0) MA1
- ULB - PHYS-F104 : Physique générale (1er semestre 2017-2018), (0/20/0/0) BA1
- ULB - PHYS-F104 : Physique générale (2e semestre 2016-2017), (0/16/0/0) BA1

Matthias Vereecken

- VUB - 004134 : Elektrodynamica en speciale relativiteit, (0/26/0/0) BA2
- VUB - WE-DNTK-1015332ANR : Fysica: inleiding mechanica, (0/14/0/0) BA1

3.6.2 Membership to academic juries of Master and Phd theses

Juan Antonio Aguilar Sánchez

- Phd thesis, - Universitat de València, March 2017 - Christoph Tönnis : The indirect search for dark matter in the Sun and the Galactic Center with the ANTARES neutrino telescope
  President

Barbara Clerbaux

- Phd thesis, - ULB - service de physique théorique, September 2017 - Federica Giacchino : A Dark Matter through the Vector-like Portal
  President
- Phd thesis, - ULB, June 2017 - Elisa Pinat : The IceCube Neutrino Observatory: search for extended sources of neutrinos and preliminary study of a communication protocol for its future upgrade
  President

Catherine De Clercq

- Phd thesis, - Université Libre de Bruxelles, June 2017 - Elisa Pinat : The IceCube Neutrino Observatory: search for extended sources of neutrinos and preliminary study of a communication protocol for its upgrade
  Referee

Gilles De Lentdecker

- Phd thesis, - ULB, September 2017 - Piotr ANTONIK : Application of FPGA to Real-Time Machine Learning: Hardware Reservoir Computers and Software Image Processing
  President
- Master thesis, - ULB, June 2017 - Jason ROSA : Characterizing the VFAT3 chip for the DAQ electronics of the CMS detector
  Referee

- Phd thesis, - ULB, July 2017 - Elisa PINAT : The IceCube Neutrino Observatory: search for extended sources of neutrinos
  Secretary

Krijn De Vries

- Master thesis, - VUB, January 2017 - Pablo Correa : Comparison of statistical methods to evaluate the icecube discovery potential for steady point sources
  Referee
- Phd thesis, - VUB, June 2017 - Giuliano Maggi : Search for high-energy neutrinos from obscured flat spectrum radio AGN using the IceCube neutrino observatory
  Referee

Laurent Favart

- Master thesis, - ULB, June 2017 - Jérome Vandecasteele : Effets des corrections de la chromodynamique quantique sur la recherche de indirecte d'un candidat de matière noire
  Referee
- Phd thesis, - Middle East Technical University, Turkey, June 2017 - Bugra Bilin : Measurements of Standard Model heavy particle production in association with jets using proton-proton collision data at 8 and 13 TeV with the CMS experiment at the LHC
  Referee
- Phd thesis, - Université catholique de Louvain, October 2017 - Brieuc François : Search for reasonant di-Higgs production in CMS and development of a model independent approach to look for new physics at the LHC
  Referee
- Phd thesis, - Universiteit Antwerpen, June 2017 - Alex Van Spilbeeck : Study of the very forward jet energy spectrum in proton-proton collisions at $\sqrt{s} = 7$ TeV with the CASTOR calorimeter at the CMS experiment
  Referee

Denys Lontkovskyi

- Master thesis, - VUB, May 2017 - Matthias Stuckens : SEARCH FOR SUPERSYMMETRIC PARTNERS OF THE TOP QUARK IN EVENTS WITH TWO DISPLACED MUONS USING THE 2016 DATA FROM THE CMS EXPERIMENT
  Referee

Steven Lowette

- Phd thesis, - Universite Catolique de Louvain-la-Neuve, September 2017 - Antony Martini : Dark matter searches in the context of simplified models
  Referee

Alberto Mariotti

- Phd thesis, - VUB, September 2017 - Kevin Deroover : A search for flavour changing neutral currents involving a top quark and a Higgs boson with the CMS experiment
  Referee
- Phd thesis, - VUB, June 2017 - Giuliano Maggi : Search for high-energy neutrinos from obscured flat spectrum radio AGN using the IceCube neutrino observatory
  Referee

Pascal Vanlaer

- Phd thesis, - Vrije Universiteit Brussel, September 2017 - Kevin Deroover : A search for flavour changing neutral currents involving a top quark and a Higgs boson with the CMS experiment
  Referee

- Phd thesis, - cotutelle ULB-Peking University, June 2017 - Fengwandong Zhang : Measurement of jet production in association with a Z boson at the LHC and jet energy correction calibration at high level trigger in CMS
Secretary
- Phd thesis, - cotutelle ULB-Université de Rome La Sapienza, September 2017 - Giuseppe Fasanella : Search for new physics in dielectron and diphoton final states at CMS
Secretary

3.6.3 Representation in academic councils and committees (in universities)

Isabelle Ansseau

- Bureau du conseil du département de physique, ULB
- Commission Enseignement du département de physique, ULB
- Commission Plan stratégique du département de physique, ULB
- Conseil de faculté des sciences, ULB
- Conseil du département de physique, ULB

Freya Blekman

- IIHE website coordinator, Other
- Organiser open days etc Department of physics, VUB
- PR chairperson VUB faculty of science and bio-engineering, VUB
- Secretary Bachelors Exam Committee, VUB
- Secretary Masters Exam Committee, VUB
- Seminar organiser IIHE, Other

Barbara Clerbaux

- Elected as the representative of Academic Staff at the ULB Assemblée plénière (AP) , ULB
- Elected as the representative of Academic Staff at the ULB university board (CA), ULB
- Member of the Faculty committee of restructuration of the , ULB
- Member of the Science Faculty pedagogic committee, ULB
- Member of the ULB Funding Committee (commission finance), ULB
- Member of the ULB committee for the University strategic plan, ULB cap 2030, ULB
- Member of the administrative ULB committee (commission administrative), ULB
- Member of the search Science Faculty committee for the professor position in experimental condensed matter , ULB
- Representative of the ULB rector at the Scientific Olympiads proclamation, ULB

Catherine De Clercq

- VUB representative in the Board of the School of Arts KCB, Other

Gilles De Lentdecker

- Membre de la commission enseignement du d'epartement de physique, ULB
- Membre de la commission finance du d'epartement de physique, ULB

Laurent Favart

- Membre de la commission du Plan stratégique, ULB

Steven Lowette

- DNTK delegate to the faculty's doctoral committee, VUB
- DNTK delegate to the faculty's internationalisation committee, VUB

Zixuan Song

- Development of Sophisticated Tracking Algotithms on FPGAs for the CMS Trigger Upgrade, ULB

Nick Van Eijndhoven

- Chair of the curriculum board of the VUB dept. of Physics and Astronomy, VUB
- Chair of the educational board of the VUB dept. of Physics and Astronomy, VUB
- Member of the education council of the VUB Faculty of Science, VUB
- President or member of various PhD committees, VUB
- Responsible for plagiarism control of the VUB dept. of Physics and Astronomy, VUB

Pascal Vanlaer

- Coordinator of the Physics department in the AEQES higher-education quality assessment process in the French community, ULB
- Member of the Observatory of the 1st year bachelor studies in sciences, ULB
- Member of the Physics department committee for teaching assistants hirings, ULB
- Member of the panel kwaliteitsbeoordeling opleidingen fysica en sterrenkunde, VUB

3.7 Vulgarisation and outreach

Isabelle Ansseau

- IceCube Masterclasses - Bruxelles, 08/03/2017

Juan Antonio Aguilar Sánchez

- IceCube Masterclass - IIHE, Brussels, 08/03/2017

Barbara Clerbaux

- Conférence au Collège de Belgique : - Collège de Belgique, à Namur, 10/05/2017
- Member of the interdisciplinary committee "Penser la Sciences" at the ULB, since 09/2017 - ULB, 01/09/2017

Paul Coppin

- IIHE IceCube masterclass - Brussels, 08/03/2017

Pablo Correa

- IceCube Masterclass - IIHE, Brussels, Belgium, 08/03/2017
- The South Pole Experiment Contest - IIHE, Brussels, Belgium, from 01/10/2017 to 31/12/2017

Jarne De Clercq

- CMS masterclass - VUB, Brussel, 29/03/2017

Catherine De Clercq

- Particle and Astroparticle physics Masterclass coordination - IIHE, 08/03/2017
- SPExperiment competition for schools - organiser for Belgium - IIHE, from 10/11/2017 to 31/12/2017

Jarne De Clercq

- VUB voetendag: particle physics - VUB, Brussels, 28/03/2017

Catherine De Clercq

- organiser of the *90degrees South* competition - exhibition day - Vrije Universiteit Brussel, 17/02/2017

Krijn De Vries

- IceCube Masterclass - IIHE, 08/03/2017
- TADA toekomstatelier wetenschap - IIHE, 18/02/2017

Gwenhaël De Wasseige

- 90 degrees South - VUB, from 01/01/2017 to 28/02/2017
- South Pole Experiment Contest - VUB, from 15/08/2017 to 31/12/2017
- VUB week van - VUB, from 26/02/2017 to 04/03/2017

Giuseppe Fasanella

- CMS guides, introducing the CMS detector for undergraduate students - CMS point 5, from 01/03/2017 to 31/03/2017

Nadège Iovine

- IceCube Masterclass - Brussels, 08/03/2017

Steven Lowette

- Campusbezoek - VUB, 09/02/2017
- Campusbezoek: VOETendagen - VUB, 16/11/2017

Lieselotte Moreels

- Jury member for the scientific prize for the project '90 degrees South: Your Experiment at the South Pole' - VUB, 17/02/2017

Christoph Raab

- Developed skymap paper model visualization - Brussels, from 16/03/2017 to 23/03/2017
- Helped with IceCube Masterclass - Brussels, 08/03/2017
- Produced localized versions and coordinated translation of IceCube paper model - Brussels, from 01/05/2017 to 06/05/2017

Kirill Skovpen

- Public lecture 'A Big Bang in the Lab', 1h45m - Maria-Boodschaplyceum, 04/05/2017

Zixuan Song

- Study of hardware implementation of fast tracking algorithms - proceeding on Journal of instrumentation 2017 JINST12C02068, 22/02/2017

Elizabeth Starling

- CMS Guide - CMS, CERN, from 18/05/2017 to 31/12/2017

Nick Van Eijndhoven

- Exploring the Most Powerful Cosmic Phenomena - VUB Brussels, Belgium, 31/05/2017

- Various campus visits of secondary school students - VUB Brussels, Belgium, 15/03/2017

Pascal Vanlaer

- Osons le boson ! - Festival du Film Scientifique de Bruxelles, ULB, 21/03/2017
- Que nous apporte la physique des particules et la découverte du boson de Brout-Englert-Higgs ? - séminaire CEPULB, 07/02/2017

4 Publications

4.1 Refereed journals and conference proceedings

4.1.1 CMS

1. *A search for new phenomena in pp collisions at sqrts* $= 13, extTeV$ *in final states with missing transverse momentum and at least one jet using the* $alpha_{mathrmT}$ *variable*
   Khachatryan, V et al. [CMS Collaboration]
   Eur.Phys.J. C77 (2017) 294

2. *Charged-particle nuclear modification factors in PbPb and pPb collisions at* $sqrts_{mathrmN;mathrmN} = 5.02\ TeV$
   Khachatryan, V et al. [CMS Collaboration]
   JHEP 1704 (2017) 039

3. *Coherent J/psi photoproduction in ultra-peripheral PbPb collisions at* $sqrts_{NN} = 2.76$ *TeV with the CMS experiment*
   Khachatryan, V et al. [CMS Collaboration]
   Phys.Lett. B772 (2017) 489-511

4. *Combination of searches for heavy resonances decaying to WW, WZ, ZZ, WH, and ZH boson pairs in proton–proton collisions at sqrts* $= 8$ *and 13 TeV*
   Sirunyan, A et al. [CMS Collaboration]
   Phys.Lett. B774 (2017) 533-558

5. *Constraints on anomalous Higgs boson couplings using production and decay information in the four-lepton final state*
   Sirunyan, A et al. [CMS Collaboration]
   Phys.Lett. B775 (2017) 1-24

6. *Cross section measurement of* t*-channel single top quark production in pp collisions at sqrts* $=$ *13 TeV*
   Sirunyan, A et al. [CMS Collaboration]
   Phys.Lett. B772 (2017) 752-776

7. *Evidence for collectivity in pp collisions at the LHC*
   Khachatryan, V et al. [CMS Collaboration]
   Phys.Lett. B765 (2017) 193-220

8. *Inclusive search for supersymmetry using razor variables in pp collisions at sqrts* $=$ *13TeV*
   Khachatryan, V et al. [CMS Collaboration]
   Phys.Rev. D95 (2017) 012003

9. *Jet energy scale and resolution in the CMS experiment in pp collisions at 8 TeV*
   Khachatryan, V et al. [CMS Collaboration]
   JINST 12 (2017) P02014

10. *Measurement and QCD analysis of double-differential inclusive jet cross sections in pp collisions at sqrts* $= 8$ *TeV and cross section ratios to 2.76 and 7 TeV*
    Khachatryan, V et al. [CMS Collaboration]
    JHEP 1703 (2017) 156

11. *Measurement of charged pion, kaon, and proton production in proton-proton collisions at sqrts* $= 13$ *TeV*
Sirunyan, A et al. [CMS Collaboration]
Phys.Rev. D96 (2017) 112003

12. *Measurement of differential cross sections for top quark pair production using the lepton+jets final state in proton-proton collisions at 13 TeV*
Khachatryan, V et al. [CMS Collaboration]
Phys.Rev. D95 (2017) 092001

13. *Measurement of double-differential cross sections for top quark pair production in pp collisions at sqrts* $= 8$ $, extTeV$ *and impact on parton distribution functions*
Sirunyan, A et al. [CMS Collaboration]
Eur.Phys.J. C77 (2017) 459

14. *Measurement of electroweak-induced production of Wgamma with two jets in pp collisions at sqrts* $= 8$ *TeV and constraints on anomalous quartic gauge couplings*
Khachatryan, V et al. [CMS Collaboration]
JHEP 1706 (2017) 106

15. *Measurement of inclusive jet cross sections in pp and PbPb collisions at* $sqrts_{NN} = 2.76$ *TeV*
Khachatryan, V et al. [CMS Collaboration]
Phys.Rev. C96 (2017) 015202

16. *Measurement of prompt and nonprompt* $mathrmJ/psi$ *production in* $mathrmpmathrmp$ *and* $mathrmpmathrmPb$ *collisions at* $sqrts_{mathrmNN} = 5.02, extTeV$
Sirunyan, A et al. [CMS Collaboration]
Eur.Phys.J. C77 (2017) 269

17. *Measurement of the* B^{pm} *Meson Nuclear Modification Factor in Pb-Pb Collisions at* $sqrts_{NN} = 5.02 extextmathrmTeV$
Sirunyan, A et al. [CMS Collaboration]
Phys.Rev.Lett. 119 (2017) 152301

18. *Measurement of the tart production cross section using events with one lepton and at least one jet in pp collisions at sqrts = 13 TeV*
Sirunyan, A et al. [CMS Collaboration]
JHEP 1709 (2017) 051

19. *Measurement of the tart production cross section using events in the emu final state in pp collisions at sqrts = 13 TeV*
Khachatryan, V et al. [CMS Collaboration]
Eur.Phys.J. C77 (2017) 172

20. *Measurement of the cross section for electroweak production of Zgamma in association with two jets and constraints on anomalous quartic gauge couplings in proton–proton collisions at sqrts* $= 8$ *TeV*
Khachatryan, V et al. [CMS Collaboration]
Phys.Lett. B770 (2017) 380-402

21. *Measurement of the differential cross sections for the associated production of a* W *boson and jets in proton-proton collisions at sqrts* $= 13$ *TeV*
Sirunyan, A et al. [CMS Collaboration]
Phys.Rev. D96 (2017) 072005

22. *Measurement of the inclusive energy spectrum in the very forward direction in proton-proton collisions at* $sqrts = 13\ \ TeV$
Sirunyan, A et al. [CMS Collaboration]
JHEP 1708 (2017) 046

23. *Measurement of the jet mass in highly boosted* $mathrmtoverlinemathrmt$ *events from pp collisions at* $sqrts = 8\ , extTeV$
Sirunyan, A et al. [CMS Collaboration]
Eur.Phys.J. C77 (2017) 467

24. *Measurement of the mass difference between top quark and antiquark in pp collisions at* $sqrts = 8\ \ TeV$
Chatrchyan, S et al. [CMS Collaboration]
Phys.Lett. B770 (2017) 50-71

25. *Measurement of the production cross section of a W boson in association with two b jets in pp collisions at* $sqrts = 8, mathrmTeV$
Khachatryan, V et al. [CMS Collaboration]
Eur.Phys.J. C77 (2017) 92

26. *Measurement of the semileptonic* $mathrmtoverlinemathrmt\ +$ *production cross section in pp collisions at* $sqrts = 8\ \ TeV$
Sirunyan, A et al. [CMS Collaboration]
JHEP 1710 (2017) 006

27. *Measurement of the top quark mass in the dileptonic* $tart$ *decay channel using the mass observables* M_{bell}*,* M_{T2}*, and* M_{bellu} *in pp collisions at* $sqrts = 8TeV$
Sirunyan, A et al. [CMS Collaboration]
Phys.Rev. D96 (2017) 032002

28. *Measurement of the top quark mass using single top quark events in proton-proton collisions at* $sqrts = 8\ \ \ TeV$
Sirunyan, A et al. [CMS Collaboration]
Eur.Phys.J. C77 (2017) 354

29. *Measurement of the total and differential inclusive* B^+ *hadron cross sections in pp collisions at sqrts = 13* TeV
Khachatryan, V et al. [CMS Collaboration]
Phys.Lett. B771 (2017) 435-456

30. *Measurement of the transverse momentum spectra of weak vector bosons produced in proton-proton collisions at* $sqrts = 8\ \ TeV$
Khachatryan, V et al. [CMS Collaboration]
JHEP 1702 (2017) 096

31. *Measurement of the transverse momentum spectrum of the Higgs boson produced in pp collisions at* $sqrts = 8$ TeV *using* $HoWW$ *decays*
Khachatryan, V et al. [CMS Collaboration]
JHEP 1703 (2017) 032

32. *Measurement of the triple-differential dijet cross section in proton-proton collisions at* $sqrts = 8, extTeV$ *and constraints on parton distribution functions*
Sirunyan, A et al. [CMS Collaboration]
Eur.Phys.J. C77 (2017) 746

33. *Measurement of the WZ production cross section in pp collisions at sqrt(s) = 13 TeV*
Khachatryan, V et al. [CMS Collaboration]
Phys.Lett. B766 (2017) 268-290

34. *Measurement of the WZ production cross section in pp collisions at sqrts = 7 and 8 ,extTeV and search for anomalous triple gauge couplings at sqrts = 8,extTeV*
Khachatryan, V et al. [CMS Collaboration]
Eur.Phys.J. C77 (2017) 236

35. *Measurement of vector boson scattering and constraints on anomalous quartic couplings from events with four leptons and two jets in proton–proton collisions at sqrts = 13 TeV*
Sirunyan, A et al. [CMS Collaboration]
Phys.Lett. B774 (2017) 682-705

36. *Measurements of differential cross sections for associated production of a W boson and jets in proton-proton collisions at sqrts = 8 TeV*
Khachatryan, V et al. [CMS Collaboration]
Phys.Rev. D95 (2017) 052002

37. *Measurements of differential production cross sections for a Z boson in association with jets in pp collisions at sqrts = 8 TeV*
Khachatryan, V et al. [CMS Collaboration]
JHEP 1704 (2017) 022

38. *Measurements of jet charge with dijet events in pp collisions at sqrts = 8 TeV*
Sirunyan, A et al. [CMS Collaboration]
JHEP 1710 (2017) 131

39. *Measurements of properties of the Higgs boson decaying into the four-lepton final state in pp collisions at sqrts = 13 TeV*
Sirunyan, A et al. [CMS Collaboration]
JHEP 1711 (2017) 047

40. *Measurements of the mathrmtoverlinemathrmt production cross section in lepton+jets final states in pp collisions at 8 ,extTeV and ratio of 8 to 7 ,extTeV cross sections*
Khachatryan, V et al. [CMS Collaboration]
Eur.Phys.J. C77 (2017) 15

41. *Measurements of the associated production of a Z boson and b jets in pp collisions at sqrts = 8,extTeV*
Khachatryan, V et al. [CMS Collaboration]
Eur.Phys.J. C77 (2017) 751

42. *Measurements of the charm jet cross section and nuclear modification factor in pPb collisions at* $sqrts_{NN}$ *= 5.02 TeV*
Sirunyan, A et al. [CMS Collaboration]
Phys.Lett. B772 (2017) 306-329

43. *Measurements of the pp oWgammagamma and pp oZgammagamma cross sections and limits on anomalous quartic gauge couplings at sqrts = 8 TeV*
Sirunyan, A et al. [CMS Collaboration]
JHEP 1710 (2017) 072

44. *Mechanical stability of the CMS strip tracker measured with a laser alignment system*
Sirunyan, A et al. [CMS Collaboration]
JINST 12 (2017) P04023

45. *Multiplicity and rapidity dependence of strange hadron production in pp, pPb, and PbPb collisions at the LHC*
Khachatryan, V et al. [CMS Collaboration]
Phys.Lett. B768 (2017) 103-129

46. *Observation of Upsilon(1S) pair production in proton-proton collisions at* $sqrts = 8\ TeV$
Khachatryan, V et al. [CMS Collaboration]
JHEP 1705 (2017) 013

47. *Observation of charge-dependent azimuthal correlations in p-Pb collisions and its implication for the search for the chiral magnetic effect*
Khachatryan, V et al. [CMS Collaboration]
Phys.Rev.Lett. 118 (2017) 122301

48. *Observation of the decay* $B^{+}opsi(2S)phi(1020)K^{+}$ *in pp collisions at sqrts = 8 TeV*
Khachatryan, V et al. [CMS Collaboration]
Phys.Lett. B764 (2017) 66-86

49. *Observation of top quark production in proton-nucleus collisions*
Sirunyan, A et al. [CMS Collaboration]
Phys.Rev.Lett. 119 (2017) 242001

50. *P-Type Silicon Strip Sensors for the new CMS Tracker at HL-LHC*
Adam, W et al. [CMS Collaboration]
JINST 12 (2017) P06018

51. *Particle-flow reconstruction and global event description with the CMS detector*
Sirunyan, A et al. [CMS Collaboration]
JINST 12 (2017) P10003

52. *Principal-component analysis of two-particle azimuthal correlations in PbPb and pextPb collisions at CMS*
Sirunyan, A et al. [CMS Collaboration]
Phys.Rev. C96 (2017) 064902

53. *Pseudorapidity dependence of long-range two-particle correlations in pPb collisions at* $sqrts_{NN}$ *= 5.02 TeV*
Khachatryan, V et al. [CMS Collaboration]
Phys.Rev. C96 (2017) 014915

54. *Relative Modification of Prompt (2S) and J/ Yields from pp to PbPb Collisions at* $sqrts_{NN} = 5.02\,TeV$
Sirunyan, A et al. [CMS Collaboration]
Phys.Rev.Lett. 118 (2017) 162301

55. *Search for mathrmtoverlinemathrmt resonances in highly boosted lepton+jets and fully hadronic final states in proton-proton collisions at* $sqrts = 13\ TeV$
Sirunyan, A et al. [CMS Collaboration]
JHEP 1707 (2017) 001

56. *Search for a heavy composite Majorana neutrino in the final state with two leptons and two quarks at sqrts* $= 13$ TeV
Sirunyan, A et al. [CMS Collaboration]
Phys.Lett. B775 (2017) 315-337

57. *Search for a heavy resonance decaying to a top quark and a vector-like top quark at sqrts* $= 13$ TeV
Sirunyan, A et al. [CMS Collaboration]
JHEP 1709 (2017) 053

58. *Search for a light pseudoscalar Higgs boson produced in association with bottom quarks in pp collisions at sqrts* $= 8$ TeV
Sirunyan, A et al. [CMS Collaboration]
JHEP 1711 (2017) 010

59. *Search for anomalous couplings in boosted* $mathrmWW/WZoellumathrmqarq$ *production in proton-proton collisions at sqrts = 8 TeV*
Sirunyan, A et al. [CMS Collaboration]
Phys.Lett. B772 (2017) 21-42

60. *Search for anomalous Wtb couplings and flavour-changing neutral currents in t-channel single top quark production in pp collisions at sqrts = 7 and 8 TeV*
Khachatryan, V et al. [CMS Collaboration]
JHEP 1702 (2017) 028

61. *Search for associated production of a Z boson with a single top quark and for tZ flavour-changing interactions in pp collisions at sqrts* $= 8$ TeV
Sirunyan, A et al. [CMS Collaboration]
JHEP 1707 (2017) 003

62. *Search for associated production of dark matter with a Higgs boson decaying to mathrmboverlinemathrmb or gammagamma at sqrts* $= 13$ TeV
Sirunyan, A et al. [CMS Collaboration]
JHEP 1710 (2017) 180

63. *Search for black holes in high-multiplicity final states in proton-proton collisions at sqrts =13 TeV*
Sirunyan, A et al. [CMS Collaboration]
Phys.Lett. B774 (2017) 279-307

64. *Search for Charged Higgs Bosons Produced via Vector Boson Fusion and Decaying into a Pair of* W *and* Z *Bosons Using pp Collisions at sqrts* $= 13extextmathrmTeV$
Sirunyan, A et al. [CMS Collaboration]
Phys.Rev.Lett. 119 (2017) 141802

65. *Search for CP violation in toverlinet production and decay in proton-proton collisions at sqrts* $= 8$ TeV
Khachatryan, V et al. [CMS Collaboration]
JHEP 1703 (2017) 101

66. *Search for Dark Matter and Supersymmetry with a Compressed Mass Spectrum in the Vector Boson Fusion Topology in Proton-Proton Collisions at sqrts = 8TeV*
Khachatryan, V et al. [CMS Collaboration]
Phys.Rev.Lett. 118 (2017) 021802

67. *Search for dark matter produced in association with heavy-flavor quark pairs in proton-proton collisions at sqrts* $= 13$ *TeV*
Sirunyan, A et al. [CMS Collaboration]
Eur.Phys.J. C77 (2017) 845

68. *Search for dark matter produced with an energetic jet or a hadronically decaying W or Z boson at sqrts* $= 13$ *TeV*
Sirunyan, A et al. [CMS Collaboration]
JHEP 1707 (2017) 014

69. *Search for direct production of supersymmetric partners of the top quark in the all-jets final state in proton-proton collisions at sqrts* $= 13$ *TeV*
Sirunyan, A et al. [CMS Collaboration]
JHEP 1710 (2017) 005

70. *Search for electroweak production of a vector-like quark decaying to a top quark and a Higgs boson using boosted topologies in fully hadronic final states*
Sirunyan, A et al. [CMS Collaboration]
JHEP 1704 (2017) 136

71. *Search for electroweak production of charginos and neutralinos in WH events in proton-proton collisions at sqrts* $= 13$ *TeV*
Sirunyan, A et al. [CMS Collaboration]
JHEP 1711 (2017) 029

72. *Search for electroweak production of charginos in final states with two leptons in pp collisions at sqrts* $= 8$ *TeV*
Khachatryan, V et al. [CMS Collaboration]
JHEP 1704 (2017) 018

73. *Search for Evidence of the Type-III Seesaw Mechanism in Multilepton Final States in Proton-Proton Collisions at sqrts* $= 13 extextmathrmTeV$
Sirunyan, A et al. [CMS Collaboration]
Phys.Rev.Lett. 119 (2017) 221802

74. *Search for heavy gauge W' boson in events with an energetic lepton and large missing transverse momentum at sqrts = 13 TeV*
Khachatryan, V et al. [CMS Collaboration]
Phys.Lett. B770 (2017) 278-301

75. *Search for heavy neutrinos or third-generation leptoquarks in final states with two hadronically decaying au leptons and two jets in proton-proton collisions at sqrts* $= 13$ *TeV*
Khachatryan, V et al. [CMS Collaboration]
JHEP 1703 (2017) 077

76. *Search for heavy resonances decaying into a vector boson and a Higgs boson in final states with charged leptons, neutrinos, and b quarks*
Khachatryan, V et al. [CMS Collaboration]
Phys.Lett. B768 (2017) 137-162

77. *Search for heavy resonances decaying to tau lepton pairs in proton-proton collisions at sqrts* $= 13$ *TeV*
Khachatryan, V et al. [CMS Collaboration]
JHEP 1702 (2017) 048

78. *Search for heavy resonances that decay into a vector boson and a Higgs boson in hadronic final states at sqrts* $= 13$ $, extTeV$
Sirunyan, A et al. [CMS Collaboration]
Eur.Phys.J. C77 (2017) 636

79. *Search for Higgs boson pair production in the bbauau final state in proton-proton collisions at sqrt*$(s) = 8extextmathrmTeV$
Sirunyan, A et al. [CMS Collaboration]
Phys.Rev. D96 (2017) 072004

80. *Search for high-mass mathrmZgamma resonances in proton-proton collisions at sqrts = 8 and 13 TeV using jet substructure techniques*
Sirunyan, A et al. [CMS Collaboration]
Phys.Lett. B772 (2017) 363-387

81. *Search for high-mass diphoton resonances in proton–proton collisions at 13 TeV and combination with 8 TeV search*
Khachatryan, V et al. [CMS Collaboration]
Phys.Lett. B767 (2017) 147-170

82. *Search for high-mass Zgamma resonances in* $mathrme^+mathrme^-gamma$ *and* mu^+mu^-gamma *final states in proton-proton collisions at sqrts = 8 and 13 TeV*
Khachatryan, V et al. [CMS Collaboration]
JHEP 1701 (2017) 076

83. *Search for leptophobic Z bosons decaying into four-lepton final states in proton–proton collisions at sqrts =8TeV*
Khachatryan, V et al. [CMS Collaboration]
Phys.Lett. B773 (2017) 563-584

84. *Search for light bosons in decays of the 125 GeV Higgs boson in proton-proton collisions at sqrts* $= 8$ *TeV*
Khachatryan, V et al. [CMS Collaboration]
JHEP 1710 (2017) 076

85. *Search for Low Mass Vector Resonances Decaying to Quark-Antiquark Pairs in Proton-Proton Collisions at* $sqrts = 13extextmathrmTeV$
Sirunyan, A et al. [CMS Collaboration]
Phys.Rev.Lett. 119 (2017) 111802

86. *Search for massive resonances decaying into WW, WZ or ZZ bosons in proton-proton collisions at sqrts = 13 TeV*
Sirunyan, A et al. [CMS Collaboration]
JHEP 1703 (2017) 162

87. *Search for narrow resonances in dilepton mass spectra in proton-proton collisions at sqrts = 13 TeV and combination with 8 TeV data*
Khachatryan, V et al. [CMS Collaboration]
Phys.Lett. B768 (2017) 57-80

88. *Search for new phenomena in events with high jet multiplicity and low missing transverse momentum in proton–proton collisions at sqrts* $= 8$ *TeV*
Khachatryan, V et al. [CMS Collaboration]
Phys.Lett. B770 (2017) 257-267

89. *Search for new phenomena with multiple charged leptons in proton–proton collisions at* $sqrts = 13\ , extTeV$
Khachatryan, V et al. [CMS Collaboration]
Eur.Phys.J. C77 (2017) 635

90. *Search for new phenomena with the* $M_{mathrmT2}$ *variable in the all-hadronic final state produced in proton–proton collisions at* $sqrts = 13\ , extTeV$
Sirunyan, A et al. [CMS Collaboration]
Eur.Phys.J. C77 (2017) 710

91. *Search for new physics in the monophoton final state in proton-proton collisions at* $sqrts = 13\ TeV$
Sirunyan, A et al. [CMS Collaboration]
JHEP 1710 (2017) 073

92. *Search for new physics with dijet angular distributions in proton-proton collisions at* $sqrts = 13\ TeV$
Sirunyan, A et al. [CMS Collaboration]
JHEP 1707 (2017) 013

93. *Search for pair production of vector-like T and B quarks in single-lepton final states using boosted jet substructure in proton-proton collisions at* $sqrts = 13\ TeV$
Sirunyan, A et al. [CMS Collaboration]
JHEP 1711 (2017) 085

94. *Search for physics beyond the standard model in events with two leptons of same sign, missing transverse momentum, and jets in proton–proton collisions at* $sqrts = 13, extTeV$
Sirunyan, A et al. [CMS Collaboration]
Eur.Phys.J. C77 (2017) 578

95. *Search for R-parity violating supersymmetry with displaced vertices in proton-proton collisions at sqrts = 8 TeV*
Khachatryan, V et al. [CMS Collaboration]
Phys.Rev. D95 (2017) 012009

96. *Search for single production of a heavy vector-like T quark decaying to a Higgs boson and a top quark with a lepton and jets in the final state*
Khachatryan, V et al. [CMS Collaboration]
Phys.Lett. B771 (2017) 80-105

97. *Search for single production of vector-like quarks decaying into a b quark and a W boson in proton-proton collisions at sqrts = 13 TeV*
Sirunyan, A et al. [CMS Collaboration]
Phys.Lett. B772 (2017) 634-656

98. *Search for single production of vector-like quarks decaying to a Z boson and a top or a bottom quark in proton-proton collisions at* $sqrts = 13\ TeV$
Sirunyan, A et al. [CMS Collaboration]
JHEP 1705 (2017) 029

99. *Search for standard model production of four top quarks in proton-proton collisions at sqrts = 13 TeV*
Sirunyan, A et al. [CMS Collaboration]
Phys.Lett. B772 (2017) 336-358

100. *Search for Supersymmetry in pp Collisions at sqrts* = 13*extextmathrmTeV in the Single-Lepton Final State Using the Sum of Masses of Large-Radius Jets*
Sirunyan, A et al. [CMS Collaboration]
Phys.Rev.Lett. 119 (2017) 151802

101. *Search for supersymmetry in events with at least one photon, missing transverse momentum, and large transverse event activity in proton-proton collisions at sqrts* = 13 *TeV*
Sirunyan, A et al. [CMS Collaboration]
JHEP 1712 (2017) 142

102. *Search for supersymmetry in events with one lepton and multiple jets in proton-proton collisions at sqrts = 13 TeV*
Khachatryan, V et al. [CMS Collaboration]
Phys.Rev. D95 (2017) 012011

103. *Search for supersymmetry in events with photons and missing transverse energy in pp collisions at 13 TeV*
Khachatryan, V et al. [CMS Collaboration]
Phys.Lett. B769 (2017) 391-412

104. *Search for supersymmetry in multijet events with missing transverse momentum in proton-proton collisions at 13 TeV*
Sirunyan, A et al. [CMS Collaboration]
Phys.Rev. D96 (2017) 032003

105. *Search for supersymmetry in the all-hadronic final state using top quark tagging in pp collisions at sqrts* = 13 *TeV*
Khachatryan, V et al. [CMS Collaboration]
Phys.Rev. D96 (2017) 012004

106. *Search for third-generation scalar leptoquarks and heavy right-handed neutrinos in final states with two tau leptons and two jets in proton-proton collisions at sqrts* = 13 *TeV*
Sirunyan, A et al. [CMS Collaboration]
JHEP 1707 (2017) 121

107. *Search for top quark decays via Higgs-boson-mediated flavor-changing neutral currents in pp collisions at sqrts* = 8 *TeV*
Khachatryan, V et al. [CMS Collaboration]
JHEP 1702 (2017) 079

108. *Search for top quark partners with charge 5/3 in proton-proton collisions at sqrts* = 13 *TeV*
Sirunyan, A et al. [CMS Collaboration]
JHEP 1708 (2017) 073

109. *Search for top squark pair production in compressed-mass-spectrum scenarios in proton-proton collisions at sqrts = 8 TeV using the alpha*$_T$ *variable*
Khachatryan, V et al. [CMS Collaboration]
Phys.Lett. B767 (2017) 403-430

110. *Search for top squark pair production in pp collisions at sqrts* = 13 *TeV using single lepton events*
Sirunyan, A et al. [CMS Collaboration]
JHEP 1710 (2017) 019

111. *Searches for invisible decays of the Higgs boson in pp collisions at sqrts = 7, 8, and 13 TeV*
Khachatryan, V et al. [CMS Collaboration]
JHEP 1702 (2017) 135

112. *Searches for pair production of third-generation squarks in* $sqrts = 13\ ,extTeV$ *pp collisions*
Sirunyan, A et al. [CMS Collaboration]
Eur.Phys.J. C77 (2017) 327

113. *Searches for W bosons decaying to a top quark and a bottom quark in proton-proton collisions at 13 TeV*
Sirunyan, A et al. [CMS Collaboration]
JHEP 1708 (2017) 029

114. *Study of Jet Quenching with* $Z+extjet$ *Correlations in Pb-Pb and pp Collisions at* $sqrts_{NN} = 5.02 extextmathrmTeV$
Sirunyan, A et al. [CMS Collaboration]
Phys.Rev.Lett. 119 (2017) 082301

115. *Suppression and azimuthal anisotropy of prompt and nonprompt* $mathrmJ/psi$ *production in PbPb collisions at* $sqrts_{_{extNN}} = 2.76\ ,mathrmTeV$
Khachatryan, V et al. [CMS Collaboration]
Eur.Phys.J. C77 (2017) 252

116. *Suppression of* $Upsilon(1S), Upsilon(2S)$ *and* $Upsilon(3S)$ *production in PbPb collisions at* $sqrts_{mNN}$ *= 2.76 TeV*
Khachatryan, V et al. [CMS Collaboration]
Phys.Lett. B770 (2017) 357-379

117. *The CMS trigger system*
Khachatryan, V et al. [CMS Collaboration]
JINST 12 (2017) P01020

4.1.2 H1

1. *Determination of the strong coupling constant* $alpha_s(m_Z)$ *in next-to-next-to-leading order QCD using H1 jet cross section measurements*
Andreev, V et al. [H1 Collaboration]
Eur.Phys.J. C77 (2017) 791

2. *Measurement of* D^* *production in diffractive deep inelastic scattering at HERA*
Andreev, V et al. [H1 Collaboration]
Eur.Phys.J. C77 (2017) 340

3. *Measurement of Jet Production Cross Sections in Deep-inelastic ep Scattering at HERA*
Andreev, V et al. [H1 Collaboration]
Eur.Phys.J. C77 (2017) 215

4.1.3 ICECUBE

1. *All-sky Search for Time-integrated Neutrino Emission from Astrophysical Sources with 7 yr of IceCube Data*
Aartsen, M et al. [ICECUBE Collaboration]
Astrophys.J. 835 (2017) 151

2. *Constraints on Galactic Neutrino Emission with Seven Years of IceCube Data*
   Aartsen, M et al. [ICECUBE Collaboration]
   Astrophys.J. 849 (2017) 67

3. *Extending the search for muon neutrinos coincident with gamma-ray bursts in IceCube data*
   Aartsen, M et al. [ICECUBE Collaboration]
   Astrophys.J. 843 (2017) 112

4. *First search for dark matter annihilations in the Earth with the IceCube Detector*
   Aartsen, M et al. [ICECUBE Collaboration]
   Eur.Phys.J. C77 (2017) 82

5. *Measurement of the* u_{mu} *energy spectrum with IceCube-79*
   Aartsen, M et al. [ICECUBE Collaboration]
   Eur.Phys.J. C77 (2017) 692

6. *Measurement of the multi-TeV neutrino cross section with IceCube using Earth absorption*
   Aartsen, M et al. [ICECUBE Collaboration]
   Nature 551 (2017) 596-600

7. *Multi-messenger Observations of a Binary Neutron Star Merger*
   Abbott, B et al. [ICECUBE Collaboration]
   Astrophys.J. 848 (2017) L12

8. *PINGU: A Vision for Neutrino and Particle Physics at the South Pole*
   Aartsen, M et al. [ICECUBE Collaboration]
   J.Phys. G44 (2017) 054006

9. *Search for annihilating dark matter in the Sun with 3 years of IceCube data*
   Aartsen, M et al. [ICECUBE Collaboration]
   Eur.Phys.J. C77 (2017) 146

10. *Search for astrophysical sources of neutrinos using cascade events in IceCube*
    Aartsen, M et al. [ICECUBE Collaboration]
    Astrophys.J. 846 (2017) 136

11. *Search for High-energy Neutrinos from Binary Neutron Star Merger GW170817 with ANTARES, IceCube, and the Pierre Auger Observatory*
    Albert, A et al. [ICECUBE Collaboration]
    Astrophys.J. 850 (2017) L35

12. *Search for High-energy Neutrinos from Gravitational Wave Event GW151226 and Candidate LVT151012 with ANTARES and IceCube*
    Albert, A et al. [ICECUBE Collaboration]
    Phys.Rev. D96 (2017) 022005

13. *Search for Neutrinos from Dark Matter Self-Annihilations in the center of the Milky Way with 3 years of IceCube/DeepCore*
    Aartsen, M et al. [ICECUBE Collaboration]
    Eur.Phys.J. C77 (2017) 627

14. *Search for sterile neutrino mixing using three years of IceCube DeepCore data*
Aartsen, M et al. [ICECUBE Collaboration]
Phys.Rev. D95 (2017) 112002

15. *The contribution of Fermi-2LAC blazars to the diffuse TeV-PeV neutrino flux*
Aartsen, M et al. [ICECUBE Collaboration]
Astrophys.J. 835 (2017) 45

16. *The IceCube Neutrino Observatory: Instrumentation and Online Systems*
Aartsen, M et al. [ICECUBE Collaboration]
JINST 12 (2017) P03012

17. *The IceCube Realtime Alert System*
Aartsen, M et al. [ICECUBE Collaboration]
Astropart.Phys. 92 (2017) 30-41

4.1.4 JUNO

1. *Atmospheric neutrinos in JUNO*
Guo, W et al. [JUNO Collaboration]
J.Phys.Conf.Ser. 888 (2017) 012205

2. *Background suppression in the JUNO experiment*
Gornushkin, Y et al. [JUNO Collaboration]
PoS ICHEP2016 (2017) 974

3. *Jiangmen Underground Neutrino Observatory: Status and Prospectives*
Li, Y et al. [JUNO Collaboration]
MISSING INFORMATIONS

4. *JUNO Central Detector and its Calibration System*
Zhang, Q et al. [JUNO Collaboration]
PoS ICHEP2016 (2017) 967

5. *JUNO PMT system and prototyping*
Wang, Z et al. [JUNO Collaboration]
J.Phys.Conf.Ser. 888 (2017) 012052

6. *Large photocathode 20-inch PMT testing methods for the JUNO experiment*
Anfimov, N et al. [JUNO Collaboration]
JINST 12 (2017) C06017

7. *Offline Data Processing Software for the JUNO Experiment*
Huang, X et al. [JUNO Collaboration]
PoS ICHEP2016 (2017) 1051

8. *Precision Oscillation Measurements with Next Generation Reactor Neutrinos*
Garfagnini, A et al. [JUNO Collaboration]
PoS NOW2016 (2017) 023

9. *Solar, supernova, atmospheric and geo neutrino studies using JUNO detector*
Salamanna, G et al. [JUNO Collaboration]
PoS ICHEP2016 (2017) 1239

10. *Status and prospects of the JUNO experiment*
Ranucci, G et al. [JUNO Collaboration]
J.Phys.Conf.Ser. 888 (2017) 012022

11. *Status of the JUNO reactor anti-neutrino experiment*
Lu, H et al. [JUNO Collaboration]
Nucl.Part.Phys.Proc. 287-288 (2017) 143-146

12. *The Application of SNiPER to the JUNO Simulation*
Lin, T et al. [JUNO Collaboration]
J.Phys.Conf.Ser. 898 (2017) 042029

13. *The design of the JUNO veto system*
Lu, H et al. [JUNO Collaboration]
J.Phys.Conf.Ser. 888 (2017) 012088

14. *The JUNO experiment*
Jollet, C et al. [JUNO Collaboration]
Nuovo Cim. C39 (2017) 318

4.1.5 OPERA

1. *Discovery of $u_a u$ appearance and recent results from OPERA*
Fukuda, T et al. [OPERA Collaboration]
Nuovo Cim. C39 (2017) 315

2. *High precision reconstruction of electromagnetic showers in the nuclear emulsions of the OPERA experiment*
Laudisio, F et al. [OPERA Collaboration]
PoS EPS-HEP2017 (2017) 640

3. *Latest results from the OPERA experiment*
Duchesneau, D et al. [OPERA Collaboration]
J.Phys.Conf.Ser. 888 (2017) 012004

4. *Latest results of OPERA*
Meregaglia, A et al. [OPERA Collaboration]
Nucl.Part.Phys.Proc. 285-286 (2017) 8-13

5. *More results from the OPERA Experiment*
Gornushkin, Y et al. [OPERA Collaboration]
PoS ICHEP2016 (2017) 952

6. *Results from the OPERA experiment*
Di Crescenzo, A et al. [OPERA Collaboration]
EPJ Web Conf. 164 (2017) 01025

7. *Results from the OPERA experiment at the CNGS beam*
   Mauri, N et al. [OPERA Collaboration]
   EPJ Web Conf. 164 (2017) 01026

8. *Search for sterile neutrino mixing in the* v_m*uo* v_a*u appearance channel with the OPERA detector*
   Tenti, M et al. [OPERA Collaboration]
   MISSING INFORMATIONS

4.1.6 SOLID

1. *A novel segmented-scintillator antineutrino detector*
   Abreu, Y et al. [SOLID Collaboration]
   JINST 12 (2017) P04024

2. *IBD Selection for the 288kg Prototype SoLid Module*
   Saunders, D et al. [SOLID Collaboration]
   J.Phys.Conf.Ser. 888 (2017) 012179

3. *Light yield and energy resolution studies for SoLid phase 1*
   Boursette, D et al. [SOLID Collaboration]
   J.Phys.Conf.Ser. 888 (2017) 012090

4. *SoLid Detector Technology*
   Labare, M et al. [SOLID Collaboration]
   J.Phys.Conf.Ser. 888 (2017) 012180

5. *SoLid: An innovative anti-neutrino detector for searching oscillations at the SCK•CEN BR2 reactor*
   Abreu, Y et al. [SOLID Collaboration]
   Nucl.Instrum.Meth. A845 (2017) 467-470

6. *The SoLid anti-neutrino detector's readout system*
   Arnold, L et al. [SOLID Collaboration]
   JINST 12 (2017) C02012

7. *The SoLid experiment*
   Kalousis, L et al. [SOLID Collaboration]
   J.Phys.Conf.Ser. 888 (2017) 012181

4.2 Refereed public and internal documents