IIHE

Annual Report

2016

ANNUAL REPORT
2016

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ULB Director
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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 2016

The present report presents the research performed at the IIHE in 2016, 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 2016 the IIHE published with its national and international research partners about 130 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.

During 2016, 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 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.

In parallel, the IIHE initiated its participation to the JUNO experiment, designed to establish the neutrino mass hierarchy.

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.

With the arrival of a new faculty, the IIHE joined the Pierre Auger Collaboration to study cosmic rays.

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 and ARA). 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 DAQ systems for a TPC prototype for a future linear collider detector, for the ARA experiment, and for the upgrade of the CMS 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 world-wide LHC computing grid, with very high performance and stability.

On October 19th 2016, 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 Jan Debruyne was celebrated at his occasion.

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, the European Union (FP7). Additional supports comes from our collaboration with the Institut de Recherche de l’Institut Supérieur Industriel de Bruxelles (IRISIB) and Ion Beam Applications S.A. (IBA) for proton therapy.

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 2016

1.3.1 The ULB personnel

Academic and scientific personnel

Juan Antonio AGUILAR SANCHEZ	Chargé de cours	IceCube, ARA
Isabelle ANSSEAU	PhD student (Assistante ULB)	IceCube
Diego BEGHIN	PhD student (Aspirant F.R.S.-FNRS) since October	CMS
Daniel BERTRAND	Directeur de Recherche F.R.S.-FNRS; past IIHE co-director; honorary, and Professeur de l’Université	IceCube
Hugues BRUN	Post-doc (IISN)	CMS
Cécile CAILLOL	PhD student (Aspirant F.R.S.-FNRS) until July	CMS
Barbara CLERBAUX	Chargée de Cours ULB, Directeur de Recherche F.R.S.-FNRS honoraire	CMS, JUNO
Hugo DELANNOY	PhD student (FRIA)	CMS
Gilles DE LENTDECKER	Maître de Recherche F.R.S.-FNRS; Maître d’Enseignement	CMS, DAQ R&D
Valérie DE SMET	PhD student (FREDONE) until September	Instrumentation
Jianmeng DONG	”PhD student (CSC scholarship) Co-tutelle with IHEP University”	CMS DAQ R&D
Wenxing FANG	”PhD student (CSC scholarship) Co-tutelle with BUAA University”	CMS
Giuseppe FASANELLA	”PhD student (FRIA) 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	Post-doc (PAI) until September; Chargé de Recherche F.R.S.-FNRS since October	CMS
Georgia KARAPOSTOLI	Post-doc (PAI)	CMS
Thomas LENZI	PhD student until December; Post-doc since December (Aspirant F.R.S.-FNRS)	CMS
Alexandre LÉONARD	Logisticien de Recherche F.R.S.-FNRS until September; Logisticien de Recherche ULB since October	CMS
Jelena LUETIĆ	Post-doc (PAI) since January	CMS
Thierry MAERSCHALK	PhD student (IISN) until August	CMS, DAQ R&D
Pierre MARAGE	Professeur ordinaire émérite; Professeur de l'Université; past IIHE co-director	CMS, Hist. of Sc.
Andrey MARINOV	Chargé de Recherche F.R.S.-FNRS	CMS, DAQ R&D
Kevin MEAGHER	Post-doc (IISN)	IceCube
David NDAYIZEYE	PhD student (Burundi grant)	Instrumentation
Aongus O'MURCHADHA	Chargé de Recherche F.R.S.-FNRS until October	IceCube, ARA
Yves PIERSEAUX	collaborateur scientifique	Hist. of Science
Elisa PINAT	PhD student (IISN)	IceCube
Nicolas POSTIAU	PhD student (Assistant ULB)	CMS
Christoph RAAB	PhD student (IISN)	IceCube
Aidan RANDLE-CONDE	Post-doc (PAI) until March	CMS
Tomislav SEVA	Post-doc (PAI until October)	CMS
Rachel SIMONI	PhD student (Amsterdam University); collaborateur scientifique	
Zixuan SONG	"PhD student (CSC scholarship) Co-tutelle with CCNU University"	CMS, DAQ R&D
Raffaella TONCELLI	collaborateur scientifique	
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
Ryo YONAMINE	Chargé de Recherche F.R.S.-FNRS until October	CMS, DAQ R&D
Florian ZENONI	PhD student (IISN) until September	CMS, DAQ R&D
Fengwangdong ZHANG	"PhD student (CSC scholarship) Co-tutelle with PKU University"	CMS

Master students

Diego BEGHIN	physics, since September	CMS
Hugo DEWITTE	physics, since September	CMS DAQ R&D
Camille GIAUX	physics, since September	CMS DAQ R&D

Nadège IOVINE	physics, since September	IceCube
Jérôme LEMAIRE	physics, since September	CMS DAQ R&D
Louis MOUREAUX	physics, since September	CMS
Jason ROSA	physics, since September	CMS DAQ R&D

Engineers, Technical and Logistic Personnel

Samir AMARY	Computer scientist
Abdelhakim BOUKIL	Computer scientist
Patrick DE HARENNE	Technician, general support
Michael KORNTHEUER	Electronics
Fatimé PERO	Secretariat, 1/2-time until August
Shkelzen RUGOVAC	Computer scientist
Audrey TERRIER	Technician, 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)	CMS
Lana BECK	FWO scientific collaborator (PhD)	CMS
Freya BLEKMAN	ZAP hoofddocent	CMS
Douglas BURNS	FWO scientific collaborator (PhD student) since June	CMS
Andries COONE	FWO scientific collaborator (PhD student)	Pheno
Nadir DACI	FWO scientific collaborator (post-doc)	CMS
Isabelle DE BRUYN	FWO scientific collaborator (PhD)	CMS
Karen DE CAUSMAECKER	FWO aspirant (PhD)	Pheno
Catherine DE CLERCQ	Professor-emeritus	IceCube
Jarne De Clercq	FWO scientific collaborator (PhD) since October	CMS
Krijn DE VRIES	FWO research fellow (postdoctoraal onderzoeker)	IceCube
Gwenhael DE WASSEIGE	FWO scientific collaborator (PhD)	IceCube
Kevin DEROOVER	FWO scientific collaborator (PhD)	CMS
Jorgen D'HONDT	ZAP hoogleraar; IIHE director	CMS & SoLid
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)	IceCube
Giuliano MAGGI	FWO scientific collaborator (PhD)	IceCube
Alberto MARIOTTI	VUB scientific collaborator (post-doc) until September ZAP docent since October	Pheno
Kentarou MAWATARI	10% ZAP research professor	Pheno

Seth MOORTGAT	FWO aspirant (PhD student)	CMS
Lieselotte MOREELS	FWO scientific collaborator (PhD)	CMS
Quentin PYTHON	FWO scientific collaborator (PhD)	CMS
Olaf SCHOLTE	10% ZAP Research Professor	IceCube
Dominic SMITH	FWO scientific collaborator (PhD)	CMS
Kirill SKOVPEN	FWO scientific collaborator (post-doc) in September FWO research fellow (postdoctoraal onderzoeker) since October	CMS
Stefaan TAVERNIER	Professor-emeritus	Crystal Clear
Simona TOSCANO	FWO scientific collaborator (post-doc)	IceCube
Walter VAN DONINCK	Professor-emeritus	CMS
Nick VAN EIJNDHOVEN	ZAP hoogleraar	IceCube
Petra VAN MULDERS	FWO research fellow (postdoctoraal onderzoeker) 10% ZAP research professor	CMS, SoLid
Isis VAN PARIJS	FWO scientific collaborator (PhD)	CMS
Simon VERCAEMER	IUAP scientific collaborator (PhD) VUB–UA	SoLid
Mathias VEREECKEN	FWO aspirant (PhD)	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

Jan DEBRUYNE	Technician, general support, 1/2 time, till October
Olivier DEVROEDE	Computer scientist
Stéphane GERARD	Computer scientist - VSC
Marleen GOEMAN	Secretariat
Abdelhak OUCHENE	Computer technician, till November
Rosette VANDENBROUCKE	Computer scientist - VSC

With our greatest gratitude

Jan Debruyne joint the IIHE in its early days in 1972 as a job student. Since 1974 he was hired as a technician at the VUB which he continued to be for the following 42 years. His passion for fundamental science and physics in particular made him an all-round technician valuable for the construction and maintenance of several novel instruments in high-energy physics as well as in its medical applications.

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, Prof. Dr. Hannes Jung, Dr. Sunil Bansal, Dr. Igor Cherednikov, Dr. Xavier Janssen, Dr. Benoit Roland, Dr. Albert Knutsson, Jasper Lauwers, Pieter Taels, Merijn Van Der Klundert, Sara Alderweireldt, Tom Cornelis, Sten Luyckx, Tom Mertens, Silvia Ochesanu, Frederik Van Der Veken, Hans Van Haevermaet, Sarah Van Mierlo, Alex Van Spilbeeck, Ir. Wim Beaumont, Ir. Eric De Langhe, Ir. Dmirty Druzhkin.

The following members of the Particle Physics Group of Mons University (UMons) are closely associated to the IIHE activities through the Académie Wallonie-Bruxelles (ULB-UMons):

Dr. Evelyne Daubie, Dr. George Kohnen, Nikita Beliy, Thierry Caebergs, Martine Fracas, Joseph Hanton, Francis Lequeux.

1.5 New Professors

Educated as a researcher in mathematical physics Alberto Mariotti continued his research in the direction of phenomenological aspects in the interplay between theory and experiment. For example with a fellowship at the University of Durham. Since October 2016, he was awarded a tenured track professorship at the VUB to lead the phenomenological research in high energies. The phenomenological research brings together themes from all high-energy physics groups at the VUB, namely theoretical particle physics, experimental particle physics (collider and neutrino), high-energy astrophysics and astro-particle physics. The research is strongly embedded within the framework of the HEP@VUB Strategic Research Program at the VUB.

In October 2016 Ioana Mariş joined the ULB Physics Department and the IIHE as an associate professor (chargé de cours). Ioana Mariş, Romanian, obtained her Master in Physics in 2004 at the University of Bucharest (RO). In 2008 she obtains her PhD at the University of Karlsruhe (D) with a thesis on "Measurement of the Ultra High Energy Cosmic Ray Flux using Data of the Pierre Auger Observatory".

As a post doctoral researcher, she pursued her career in the field of Ultra High Energy Cosmic Rays (Pierre Auger Observatory), in accelerator experiments (NA61/SHINE, AMY), at the Karlsruhe Institute of Technology (D), in Paris at the LPNHE and the Institut Lagrange and at the University of Granada (E) where she obtained a Marie Curie fellowship for career development in 2013. She became one of the experts within the Pierre Auger Collaboration concerning the surface detectors and played leading roles for the measurement of the cosmic rays flux. Being constantly interested in new techniques for measuring the air-showers and in improvements of current detectors, she contributed to the design of two experiments aimed at measuring the MHz and GHz emissions of air-showers and has been responsible for building a new surface detector in the framework of AugerPrime, the Pierre Auger Observatory upgrade. Shortly before joining ULB, Ioana Mariş had I have the opportunity to participate in the direct dark matter searches with an experiment that is currently being commissioned, XENON 1T, in parallel with developing an X-Ray fluorescence portable detector for the analysis of the cultural heritage artworks.

2 Research activities, development and support

2.1 The CMS experiment at the CERN LHC

(S. Abu Zeid, L. Beck, D. Beghin, F. Blekman, H. Brun, D. Burns, C. Caillol, B. Clerbaux, J. D'Hondt, I. De Bruyn, J. De Clercq, N. Daci, G. De Lentdecker, H. Delannoy, K. Deroover, J. Dong, W. Fang, G. Fasanella, L. Favart, X. Gao, R. Goldouzian, A. Grebenyuk, G. Karapostoli, T. Lenzi, D. Lontkovskyi, S. Lowette, A. Léonard, J. Luetic, T. Maerschalk, P. Marage, A. Marinov, S. Moortgat, L. Moreels, N. Postiau, Q. Python, A. Randle-Conde, T. Seva, K. Skovpen, D. Smith, Z. Song, D. Strom, S. Tavernier, W. Van Doninck, P. Van Mulders, I. Van Parijs, C. Vander Velde, P. Vanlaer, D. Vannerom, Q. Wang, Y. Yang, R. Yonamine, F. Zenoni, F. Zhang)

The following members of Antwerp and Mons universities are also members of CMS: S. Alderweireldt, S. Bansal, W. Beaumont, N. Belyi, K. Cerny, T. Cornelis, E. Daubie, Th. Caebergs, E. De Langhe, A. Deroeck, E. De Wolf, D. Druzhkin, X. Janssen, H. Jung, A. Knutsson, J. Lauwers, S. Luyckx, S. Ochesanu, B. Roland, P. Taels, M. Van Der Klundert, H. Van Haevermaet, P. Van Mechelen, N. Van Remortel, A. Van Spilbeeck

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 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 Standard Model (SM) and to search for new physics beyond the Standard Model. About 500 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. The Run 2 will continue in 2017 and 2018, with an total expected luminosity of about 120/fb. While the discovery of the SM scalar boson is definitely the highlight of Run 1, the high-energy and high-intensity Run 2 dataset opens a totally new 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 (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 the 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 2016 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 the past the IIHE team lead the analysis of the $ZH \to l^+l^-\tau^+\tau^-$ channel, and contributed to the $WH \to e\nu\tau_h\tau_h$ channel. These associated production channels of the scalar boson with a Z/W boson are important ways to measure the coupling of the scalar boson to fermions. One of the IIHE PhD student was responsible of the combination of all searches for the SM scalar boson decaying to tau leptons in the associated production mode. In year 2016, 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: (i) a search for a heavy pseudoscalar A boson in the $A \to Zh \to ll\tau\tau$ channel interpreted in the MSSM and in a 2HDM model; (ii) an analysis of a light pseudoscalar produced in association with a bb pair, $bbA \to bb\tau\tau$; (iii) a search for an exotic decays of the $h(125)$ GeV into light pseudoscalars $h \to aa \to \mu\mu\tau\tau$. The results of all these analyses have been published by the CMS Collaboration. 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.

- **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 the full 2016 dataset is being prepared, 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 off-shell production and decay of the SM scalar:** The ZZ production cross section has a tiny but characteristic contribution from decays of off-shell SM scalars. This contribution being closely related to the properties of the scalar boson, it can be exploited in a variety of ways. For instance, an upper limit on the off shell cross section can be reinterpreted as an upper limit on the decay width of the scalar boson, that is two orders of magnitude better than a direct measurement of the line shape. This measurement is complementary to the direct search for new decay modes of the SM scalar, and also puts a constraint on anomalous couplings of the SM scalar with SM particles. The IIHE has contributed in a leading way to setting the world best constraints on the decay width of the scalar boson using off-shell decays. In 2015 and 2016, an IIHE member performed studies on how the theory prediction for the off-shell cross section depends on the choice of parameters of the computation (factorization and renormalization scales, α_S and parton densities). This work is now published in the $4th$ volume of the LHC Higgs cross section working group reports.

- **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. In 2016 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. An internal CMS note was written describing this study.

Searches for high-mass resonances

Many scenarios beyond the Standard Model (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 electron-muon decay channel; they are detailed below. These analysis are considered as HPA (High Priority Analysis) by CMS in particular at the Run 2 data taking where the new high energy frontier of 13 TeV allows to open considerably the phase space for discovery of massive new 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. An important contribution concerns 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. For both the diphoton and the dilepton analyses, preliminary results have been presented at conference and have been published or are in preparation for publication.

- **Search for heavy resonances decaying to a photon pair:** The IIHE contributed to the analysis searching for new phenomena in the diphoton spectrum at mass above 500 GeV, with in particular a dedicated development of the CMS electromagnetic calorimeter (ECAL) calibration. Simple selection criteria were optimised, requiring two high p_T and isolated photons in the final state. A small excess of events was observed at a mass of about 750 GeV both by the CMS and ATLAS experiments when analysing the 2015 data at 13 TeV. This excess has triggered many discussions in the particle physics community. The CMS results have been published in Phys. Rev. Lett. and was highlited as a "Editor's Suggestion". The excess was however not confirmed when analysing the data collected in 2016. Figure 1 presents the observed background-only p values for narrow-width scalar resonances in the diphoton decay channel as a function of the resonance mass m_X, for the analyses of the 2015 and 2016 datasets, as well as their combination. the An IIHE member, Prof. Barbara Clerbaux, was chairing the Analysis Review Committee (ARC) in CMS for the analyses of the 2015 and 2016 datasets, leading to 2 important CMS publications.

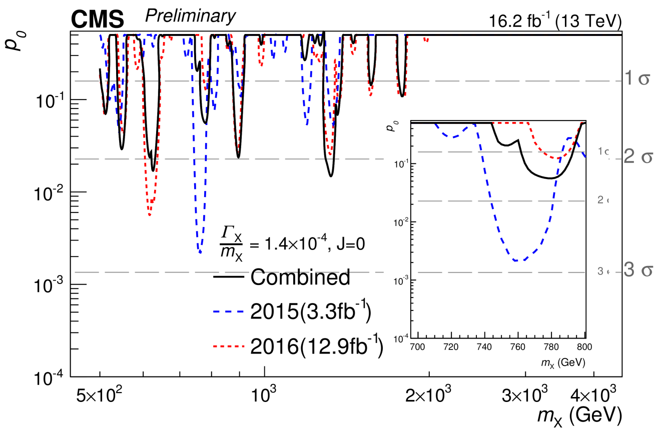

Figure 1: Observed background-only p values for narrow-width scalar resonances in the diphoton decay channel as a function of the resonance mass m_X, for the analyses of the 2015 and 2016 datasets, as well as their combination. The inset shows an expanded region around $m_X = 750$ GeV.

- **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. The group participated to the Run 2 data taking and analysis (data collected in 2015 and 2016). No excess was observed in the Run 2 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.

- **Searches for electron-muon resonances:** In collaboration with ULB theorists, an additional analysis was performed to search for high mass resonances decaying into electron-muon pairs using the Run 2 dataset. The data were found to be in agreement with the SM expectation, and limits on new physics parameters for different models have been put. The CMS results on the Run 1 data analysis have been published in 2015, and the results on the run 2 dataset are being prepared for publication.

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 have a leading role in the CMS collaboration in improving the b jet identification algorithms and developing charm quark identification algorithms as well as to commission heavy flavour tagging variables with the 13 TeV proton collision data. Under the leadership of FWO postdoc Petra Van Mulders as convener 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. New postdoctoral researchers such as FWO postdoc Kirill Skopven are also heavy flavour experts and active as sub-conveners in the BTV group.

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.

- **Cross section of top quark pair processes:** A previously developed method to simultaneously measure the b-tagging efficiency and the cross section after b-tagging was used for the publication of the top quark pair production cross section measurement on 8 TeV, in collaboration with the Universiteit Gent. To provide a final conclusion of the LHC Run 1 top quark physics programme, the final publication also included a measurement of the cross section ratio of top quark pair production in 7 and 8 TeV proton-proton collisions. In addition IIHE members are now preparing a differential measurement of the top quark production cross section in collaboration 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 $t \rightarrow Hc$ and $t \rightarrow Zc$, 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 is performing a direct measurement of the top quark width in an attempt to constrain theories beyond the standard model. 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.

- **Search for displaced production of top quarks:** One of the possibilities why no new physics has been observed at the LHC is hypothesising that the Supersymmetry particles have a longer than expected lifetime before they decay. Such events would be rejected by nominal searches, which require that the SM decay products originate from the collision point. The analysis looking for these hypothetical particles using the 13 TeV data was published as a preliminary result and the paper on this the analysis searching for these signatures including some that were not examined by CMS before is currently in preparation.

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.

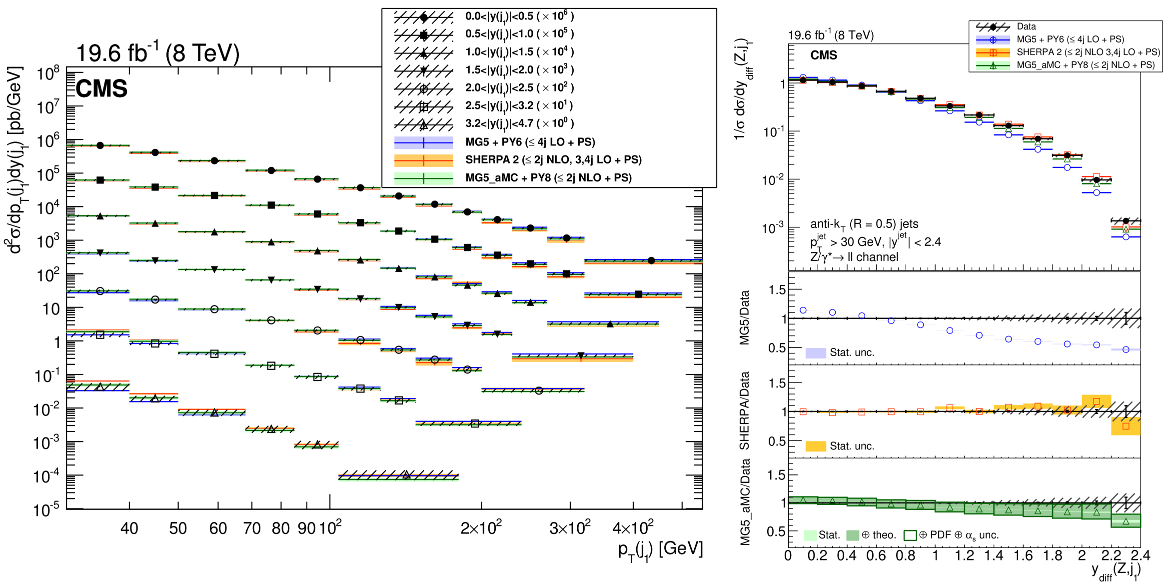

Figure 2: Measured cross section for Z + 1 jet at 8 TeV. a) doubly differential in first jet transverse momentum and rapidity, b) differentially in the difference of rapidity between the Z and the first jet. The error bar represents the statistical uncertainty and the grey hatched band represents the total uncertainty including systematic and statistical uncertainties. The measurements are compared to different predictions.

- **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 8 TeV (2012 data) and 13 TeV (2015-16 data) measuring the Z+jet cross section for up to 7 jets with transverse momenta above 30 GeV and compared it to different Monte Carlo predictions (MadGraph, aMC@NLO, Sherpa and Powheg). The jet multiplicity as well as the different transverse momentum distributions are measured. Some results are shown in Fig. 2.

Dark matter production at the Large Hadron Collider

Since 2013, the IIHE is actively involved in the search for signatures of direct dark matter (DM) production at the LHC. In 2016, the CMS physics management responded to the grown interest by grouping all dark matter searches into the more coherent Exotica MET+X subgroup, of which an IIHE member became the first convener. The group proved very successful, with more than 10% of the CMS results that became public at the ICHEP 2016 conference (and later were or are being published) to be from this MET+X group alone, as such recovering the historical lag with respect to ATLAS, and going beyond. For the analyses itself, the IIHE dark matter team participated in 2016 in three consecutive analyses cycles of the so-called "monojet" search, for which the ICHEP 2016 result with about a third of the 2016 dataset has been submitted for publication. Also, the previous phenomenology work on dark matter in the form of strongly interacting massive particles has started to be transformed into a full-blown CMS data analysis. Finally, first steps were taken to translate the results from a dilepton top squark search into limits on dark matter produced through a (pseudo)scalar mediator, a simplified model for which associated production with top quarks is expected to provide the best sesntivity.

2.1.2 Tracker operation

As in previous years, several of the PhD students 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, many 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, many offline software developments were done in the area of Data Quality Monitoring (DQM) for the tracker. In particular, two of our students were appointed 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. Finally, we continued the analysis of measurements taken in 2015 using the so-called DCU chip (also by IIHE people) with the goal of establishing fully calibrated temperature (and other) measurements for long-term historical monitoring of the tracker.

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 (G. De Lentdecker, J. Dong, M. Korntheuer, A. Marinov, Th. Lenzi, A. Leonard, Th. Maerschalk, Y. Yang, R. Yonamine, F. Zenoni)

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 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 3 shows one fully equipped Triple-GEM prototype that is going to be installed in CMS, with 9 others, as a demonstrator, during the winter 2016-2017. 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).

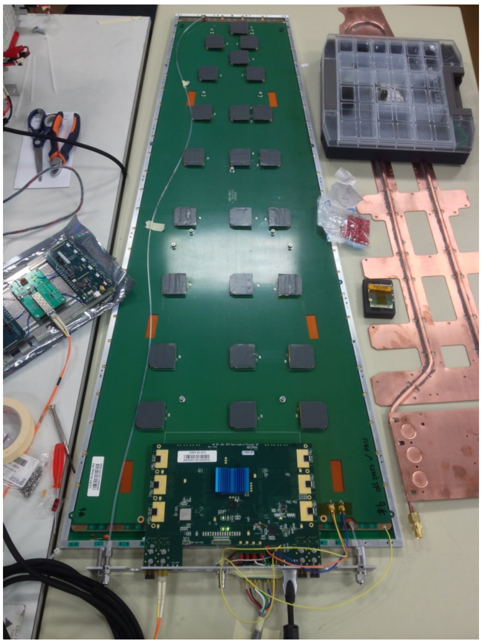

Figure 3: One of 10 Triple-GEM prototypes before its installation in CMS during the 2016-2017 LHC shutdown. The detector is equipped with its new electronics. The opto-hybrid board designed at the IIHE is located on the long base of the detector.

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 will be based on the micro-TCA standard as well as the new optical link, called Versatile Link, and the GBT chipset, both developed by CERN for the CMS tracker 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, while 10 prototypes will be operated inside the CMS experiment, the IIHE will pursue the developments of the final electronics system, including a new front-end chip, the VFAT3, for 2019-2020 installation.

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 is now finalising the technical design report (TDR) describing the baseline technical choices for the building of the phase-2 tracker. It will be submitted to the LHCC review committee beginning of July 2017.

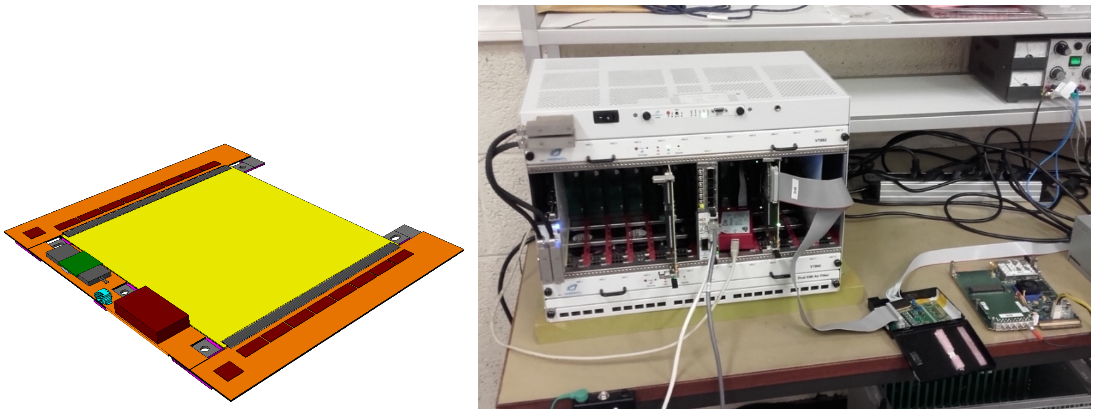

Figure 4: Left: Schematic view of a 10x10 cm^2 module of the type that will be assembled at the IIHE. Right: Migration from a table-top GLIB board to a data acquisition based on a μTCA crate housing an FC7 board.

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 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 **??**). 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.

In preparation for the construction phase, 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 readout 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 also contributes to the development of the FEH test system, within the CMS Tracker phase-2 electronics working group. This system consists in a test box with temperature and humidity control, that allows thermal cycles to be made betweeen the assembly temperature, 20, and the operation temperature, -35, 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. So far, we developed the graphical user interface for the prototype system developed at CERN. We have started to copy the CERN prototype system in Brussels and to optimize 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 developments of the tracker phase-2 local reconstruction and validation software.

At the Belgian level, regular Tracker phase-2 workshops are being held, to organise work and monitor progress of the different teams. Seven such workshops have been held in 2016.

2.2 The H1 experiment - Study of ep collisions at HERA

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

Deep-inelastic lepton-nucleon scattering has played a key role in understanding the structure of the nucleons since the late 1960. The results of these experiments led to the development and verification of Quantum Chromodynamics (QCD), the gauge field theory of the strong interaction.

HERA (Hadron-Electron-Ringanlage) 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 and ZEUS, were magnetic spectrometers with a nearly hermtic coverage, allowing a complete measurement of the lepton and hadronic final states.

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 closedown in 2007 HERA produced another 560 pb^{-1}. The analysis of the data is still ongoing and represents more than 25 FTE in 2015 in H1.

For the first HERA operation phase, the Belgian groups 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 took the responsability for the construction, installation, and running of the very forward spectrometer (VFPS). The detector composed of two movable stations - Roman pots - consists of scintillating fibre detectors allowing the reconstruction of low track multiplicity events. The stations are only moved close to the beam when the beam conditions are stable.

In recent years, the main activity of the group concerns the analysis of the VFPS data. In a first instance and prior to any physics analysis is the extraction of the diffractive track information from many datasets in which beam conditions and background change and different beam approches have to be accounted for. The VFPS calibration and kinematic reconstruction results have been published in 2014 in [1].

Applying the VFPS selection and the proton kinematic reconstruction algorithm, the cross section of dijets in deep-inelastic and photo production processes have been measured and their ratio determined. They confirm with better precision that the QCD-factorisation in photoproduced jets is broken and that this breaking is unrelated to diffractive proton disociation process. The results have been published [2] in 2015.

Further results obtained by the H1-collaboration are:

- Signals of QCD instanton-induced processes have been searched for in neutral current deep-inelastic scattering in the kinematic region of Bjorken-scaling variable $x > 10^{-3}$, the inelasticity $0.2 < y < 0.7$ and the photon virtuality $150 < Q^2 < 15000$ GeV^2, corresponding to an integrated luminosity of 351 pb^{-1}. No evidence for the production of QCD instanton-induced events is observed. Improved upper limits on the cross section for instanton-induced processes between 1.5 pb and 6 pb, at 95% confidence level, have been obtained depending on the kinematic domain in which instantons could be produced.

- A precision measurement of jet cross sections in neutral current deep-inelastic scattering for photon virtualities $5.5 < Q^2 < 80$ GeV^2 and inelasticities $0.2 < y < 0.6$ has been performed, using an integrated luminosity of 290 pb^{-1}. Double-differential inclusive jet, dijet and trijet cross sections are measured simultaneously. Jet cross sections are extended to low transverse jet momenta $5 < P_T < 7$ GeV. The data are compared to predictions from perturbative QCD in up to next-to-next-to-leading order in the strong coupling. Using also the recently published H1 jet data at high values of Q^2, the strong coupling constant is determined in next-to-leading order (see figure 5).

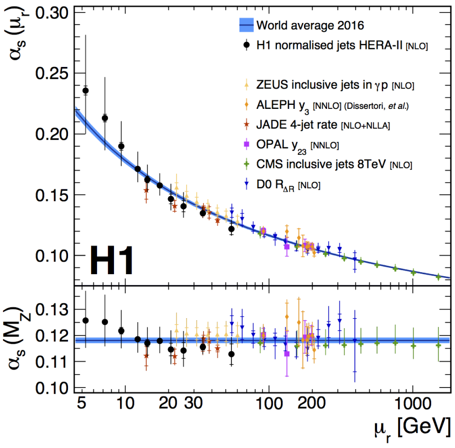

Figure 5: The strong coupling constant extracted from the normalised inclusive jet, dijet and trijet cross sections using NLO predictions compared to values extracted from other jet data.

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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 corresponds 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].

In a total sample of 5408 fully analysed neutrino interactions, 5 ν_τ candidate events have been observed where respectively (2.64 ± 0.53) signal and (0.25 ± 0.05) background events are expected. $\nu_\mu \to \nu_\tau$ oscillation in the appearance mode is therefore established with a statistical significance of 5.1 σ [3]. With this discovery, the primary scientific goal the OPERA experimental project has been reached.

OPERA is a finishing experiment but the study of several physics topics have been finalised or are still under progress, among which: an improved method allowing measuring the sign of the muon charges by the magnetic spectrometers with an efficiency exceeding 99.5% [4]; the multivariate analysis of a larger sample of ν_τ candidate events using looser kinematic and topological selection cuts; a first reasonably accurate measurement of $|\Delta m^2_{32}|$ in an appearance experiment; new limits on the search for an exotic $\nu_\mu \to \nu_e$ oscillation signal, a possible signature for the existence of sterile neutrinos – the article is being finalised; a global analysis of the three oscillation channels $\nu_\mu \to \nu_{\mu,e,\tau}$; the study of charged hadrons multiplicities at neutrino CC interaction vertices – the article is being finalised; the parametrisation of the annual modulation of the rate of cosmic muons; etc.

In 2016, the OPERA Collaboration included about 150 physicists from 30 institutions in 11 countries.

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2.4 Astroparticle Physics with the IceCube Neutrino Observatory

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

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.

2.4.1 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. 6) 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. However, based on theoretical calculations the cosmic sources of interest are expected to yield an E^{-2} power law energy spectrum for the produced neutrino flux, whereas most of the neutrinos originating from dark matter particles are also expected to have energies below the IceCube detection threshold. This implies that extending the sensitivity to lower energies will provide a significant increase in the neutrino detection potential.

Sensitivity to lower energies can be obtained by a smaller spacing between adjacent sensors and to achieve this, the original IceCube detector has been extended with a dense core located at the deepest parts of the detector. This

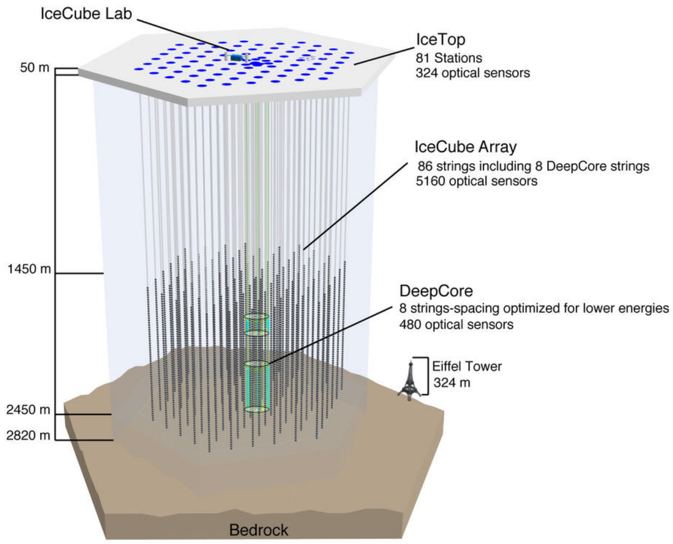

Figure 6: The IceCube observatory.

so called DeepCore detector consists of 8 strings arranged around the central IceCube string such that the distance between adjacent strings is 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. With this DeepCore extension the lower energy threshold has been pushed down by an order of magnitude to about 20 GeV. Furthermore, located at these large depths and completely surrounded by standard IceCube strings, an efficient trigger and veto system may be developed such that the DeepCore sensors provide sensitivity over the full 4π solid angle. This allows investigation of sources in the Southern hemisphere, including the Galactic center and the black hole within it.

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. The analysis of three years of data using sophisticated veto techniques resulted in an astrophysical neutrino flux of the level of 10^{-8} GeV cm^{-2} s^{-1} sr^{-1} per neutrino flavor (Science **342** (2013) 1242856). This achievement was awarded the title *Breakthrough of the year 2013* by the Physics World magazine. Since then, about 50 high additional energy neutrinos from astrophysical origin have been observed. The level of this flux implies a much richer hadronic activity in the non-thermal Universe than previously expected. However, 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. 7).

2.4.2 Research areas at the IIHE

In 2016 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

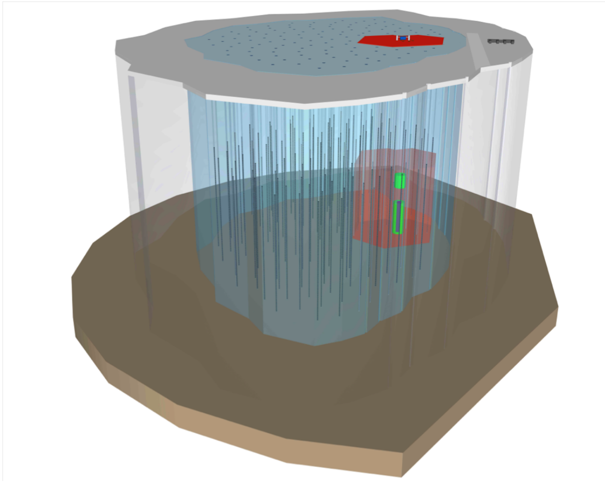

Figure 7: A possible *IceCube-Gen2* configuration. IceCube, in red, and the infill subdetector DeepCore, in green, show the current configuration

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.

  - **Fast-response analysis.**
    In the same context of transient phenomena, but with a different approach, at IIHE developed an analysis to provide a fast-response from IceCube in case of an important astronomical event. Examples of past events of this nature are the tidal disruption event (GRB 110328A/Swift J1644+57), the Gravitational Wave detection (GW150914) or the intense flare from Blazar 3C 279 in June 2015. These events required a fast response to the astronomical community in order to provide the necessary input to evaluate the possibility of triggering follow-up observations. As a real example on April 26 of 2016 a HESE event was sent out to our follow-up partners. The optical telescope Pan-STARRS found a supernova compatible with a Ic type. The fast response analysis was initiated to using the found SN candidate to look for a neutrino excess of low energy events. These results, as well as the methodology, will be presented at the International Cosmic Ray Conference in 2017.

- **Search for cosmic point sources.**
  Apart from the correlation studies mentioned above, this research also comprises a full sky search for "hot spots" of neutrino production. Identification of such "hot spots" on the neutrino sky would enable us to locate the sources of the most energetic cosmic ray particles.

  - **Search for neutrino emission from Obscured Flat Spectrum Radio AGN**
    At the IIHE we are interested in Blazars. As already mentioned these are a special class of AGNs where the jet is pointing towards the Earth. However, instead of selecting the sources which are brightest in γ-rays as was done in previous analyses, we focus on the ones which are bright in radio flux but rather dim at more energetic radiation. This condition is a signature of Blazars in which the x-ray luminosity has been obscured by a column of matter. These dust obscured Blazar are very interesting sources of neutrino emission since the dust provides an additional target for high-energy neutrino production. Together with a novel statistics method which has been developed at the IIHE we intend to achieve a better sensitivity for neutrino detection of these objects.
  - **Search for extended neutrino emission.**
    During 2016 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 analysis to search for this extended regions is an evolution of the point source analysis in which the source is now assumed to cover a significant extension of the sky (from 1° up to 5°). In 2016 a new likelihood formalism was implemented for this analysis to account for the signal contamination in the background estimate when dealing with large extended regions of signal emission.

- **Dark matter searches.**
  If dark matter is a particle it is possible to search for annihilations 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.
  - **Dark matter from the Galactic Center**
    The Galactic Center yields the highest signal expectation from dark matter annihilation. Unfortunately, IceCube being located at the South Pole is not in privileged position to observed the Galactic Center. 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.

- **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. A new analysis proposed at the IIHE is studying the feasibility of using IceCube to search for solar flare neutrinos in coincidence with observations of electromagnetic radiation (i.e. X-rays, gamma rays and radio) from these events. Although related to a different astrophysical phenomenon, the analysis technique shares many aspects with the supernova neutrino analysis. Detection of neutrinos from solar flares will open a new window on these phenomena and increase our insight in the underlying physical processes.
- **Detection of Ultra-high energy cosmogenic neutrinos.**
  The most energetic cosmic ray particles will be destroyed by interactions with the Cosmic Microwave Background Radiation (CMBR) on their journey through the Universe. These interactions should be a source of very energetic cosmogenic neutrinos, but given the measured cosmic ray flux at high energies, the associated neutrino flux is expected to be extremely low. Consequently, a very large detector area is required to detect a substantial amount of these particles. To achieve this, a detector R&D program has been initiated to investigate the feasibility of using an area of about 80 km^2 equipped with radio detection systems to observe these GZK neutrinos. At the IIHE two efforts have been on-going during 2016. 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. The IIHE has participated in the development of the timing and data acquisition system and in the commissioning of the first detector elements as well as in the analysis of the data obtained with these first detector stations. Participation in the ARA project was however ended during 2016 given the depart of the senior postdoc A. O'Murchadha.

  A feasibility study and exploration of a novel detection principle based on the radio scattering by plasma induced by the neutrino interaction in ice is also pursued at the IIHE since 2015. This RADAR detection principle is a complementary detection technique that will fill up the energy gap between the IceCube high energy edge and the ARA detector. Several promising experimental tests have been done at the facilities of the Telescope Array observatory in Utah the last one in December 2016.
- **R&D and design studies for IceCube-Gen2**
  The discovery of cosmic high-energy neutrinos has triggered feasibility studies for the extension of the existing IceCube observatory towards higher energies (so-called High Energy Array of IceCub-Gen2). On the other hand, in view of neutrinos oscillation studies and in particular the investigation of the neutrino mass hierarchy, also an extension towards lower energies (the so called PINGU project) is being examined. Both these extensions involve extensive detector R&D efforts in which the IIHE team participates. Currently IIHE members are exploring the veto capabilities of several proposed designs for the future IceCube-Gen2. A coordinated R&D effort to exploit

the potential offered by new technology, specially in photo-detection, has also started in IceCube. At IIHE we are interested in the possibilities offered by SiPMs and its application to a future IceCube-Gen2 design.

2.4.3 Radio efforts at the IIHE: Towards the detection of the EHE cosmic neutrino flux

The main goal for the IceCube neutrino telescope was the discovery of the high-energy cosmic-neutrino flux and its sources. This flux was expected to rise above the atmospheric neutrino background in the TeV-PeV region, where indeed IceCube has discovered a flux of extra-terrestrial neutrinos. Due to the steeply falling energy spectrum and the rather low interaction probability, a cubic kilometer volume was needed to fulfill this goal. Nevertheless, at even higher energies, above several PeV, the flux becomes extremely small and IceCube runs out of statistics. Therefore, to detect cosmic neutrinos at these energies, an even larger detection volume than the one cubic kilometer currently probed by IceCube is needed.

Due to its large attenuation length, the radio signal is an ideal probe to cover such large volumes in a cost-efficient way. The IIHE investigations to use the radio detection technique to probe the cosmic neutrino flux at the highest energies are two-fold. Firs there is the direct radio detection technique to probe the radio emission from a high-energy neutrino induced particle cascade. Secondly, we investigate the indirect RADAR detection technique to actively probe the ionization trail which is left behind after such a particle cascade traverses the medium.

Askaryan radio emission

The direct radio detection technique is based on the so-called Askaryan radio emission. When a particle cascade traverses the medium electrons are swept up from the medium and a net negative charge builds up in the high-energy cascade front. The time variation of this excess charge in combination with Cherenkov effects induces a radio signal which is coherent over the typical dimensions of the particle cascade leading to strong radio emission in the MHz-GHz region. To detect this signal, the Askaryan Radio Array (ARA) is currently under construction at the South-Pole, where three detector stations have been constructed. The daily ARA monitoring is overseen by Aongus O'Murchadha, who left the IIHE in September 2016. The disadvantage for detecting the direct radio emission is its relatively high energy threshold, around 10^{17} eV. With its current set-up, the ARA detector is close to the single event detection threshold , and additional detector stations are expected in the near future. Besides the ARA detector operations performed at the IIHE, a theoretical study has been performed to predict the effects of a possible (background) signal from cosmic-ray-induced air showers in Askaryan radio detectors. For this, both the in-air radio emission, the in-ice radio emission, as well as the transition radiation from the particle cascade traversing between air and ice was investigated. It follows that such a signal should indeed be visible by the currently operating Askaryan radio detectors. This signal allows the Askaryan radio detectors not only to study cosmic-ray air showers, but should also provide an excellent on-site calibration signal.

Besides studies for the Askaryan radio detectors, at the IIHE also sensitivity studies are performed 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.

Feasibility studies for the RADAR detection technique

Where IceCube runs out of statistics at several PeV, the Askaryan radio detectors only become sensitive in the EeV region. It follows there is an energy gap in the PeV-EeV region. To fill this gap, the RADAR detection technique is investigated at the IIHE. 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.

2.5 Data acquisition systems RD activities

(G. De Lentdecker, J. Dong, M. Korntheuer, A. Marinov, Th. Lenzi, A. Leonard, Th. Maerschalk, E. Pinat, Z. Song, Y. Yang, R. Yonamine)

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 2.8) for more details).

Finally the IIHE is studying the possibility to develop a digital prompt-photon camera, using powerful FPGAs, for protontherapy applications. A first proof of concept has been performed in 2016 with some commercial FPGA kit. The study of a first prototype should start in 2017.

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

(G. De Lentdecker, V. De Smet, 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.

2.7 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. Two fibers pass through each cube to read it out, which provides a precise localization of where the interaction happened. The light is collected at the fiber end using MPPCs. An other advantage of this novel detector design is that it is easily scalable.

In 2016, we have made major contributions to the data analysis for the first submodule (SM1). These analyses include: determination of the channel gains (S. Vercaemer), cosmic muon induced background studies (L. Kalousis), algorithms for neutron identification (S. Vercaemer) and determination of the neutron identification efficiency (S. Vercaemer and L. Kalousis). L. Kalousis was also leading the neutron group in the SoLid collaboration. In addition, since November 2016, L. Kalousis is leading the oscillation analysis group based on his expertise on this topic and his effort for building the framework for the oscillation analysis and the sensitivity contours. Around the same time scale, P. Van Mulders was appointed as leader of the background group in the experiment. Major steps have been made in understanding the atmospheric and muon-induced spallation neutron background using SM1.

We are also actively participating in the construction of the full-scale Phase 1 detector, in particular during the construction shifts at the University of Ghent where we are taking the lead in the number of shifts performed per author.

2.8 The JUNO experiment at Jiangmen (China)

(B. Clerbaux, J. Dong, Y. 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 and Solid experiments. 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, in particular being responsible to design studies on the back-end electronics (BEC) system. In parallel, physics activities and potential of the JUNO experiment is beeing investigated by the group. ULB became an official member of the JUNO Collaboration in January 2015. An JUNO equipment FNRS funding was requested in June 2016 (IISN new project) and successfully obtained. The budget covers the cost of the design, prototype building and tests of the BECs, as well as the final production of the 435 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 and has as main goal to determine the neutrino mass hierarchy, after 6 years of data taking. The detector 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 currently being decommissioned, in which IIHE has been a contributor. The JUNO civil construction started in 2015 and the RD for the detector is ongoing. The start of the data taking is expected at the end of 2020.

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, attached to each PMT and 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 options were studied and proposed by the ULB team in 2015 for the back-end electronics. 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 system 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. The design is still ongoing but the general concept has been accepted by the JUNO collaboration. The second prototype design at the IIHE is shown in Figure 8. The group participated to a first combined test in December 2016 in Aachen. In particular the 125 MHz clock transfer and the power injection were successfully tested. 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. ULB organised the JUNO electronics workshop at the IIHE in November 14-16, 2016, with about 50 participants.

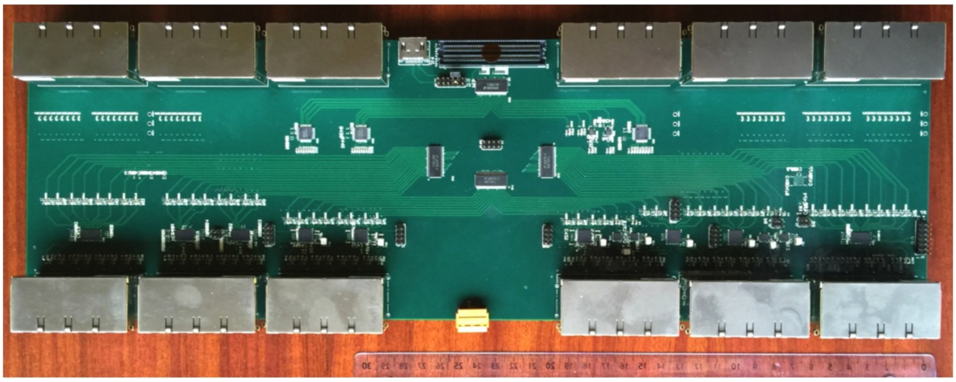

Figure 8: Second version of the JUNO Back-End Card (BEC) built at the IIHE. At the top and the bottom of the board, the ethernet connectors (RJ45) are visible, together with the equalizers. At the centre of the board, the translators and drivers are displaced. The main connector for the mezzanine card for the FPGA is placed at the top centre of the board.

2.9 Phenomenology

(K. De Causmaecker, 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 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), and Theoretical high-energy physics (TENA).

In 2016 the Pheno group comprised one 10% Prof. - 90% PostDoc A. Mariotti (now 100% ZAP member at VUB), one 10% Prof. K. Mawatari (90% PostDoc in LPSC Grenoble), three PhD students (K. De Causmaecker, D. Coone and M. Vereecken). The PhD student K. De Causmaecker concluded her PhD thesis in August 2016 [1].

During 2016 the members of the pheno group have produced 11 scientific papers published on international peer reviewed Journals [2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12], one preprints [13], one proceeding [14] and participated to two working group reports [16, 15]. They have pursued different lines of research in BSM phenomenology achieving important results in a broad range of subjects.

One central topic of investigation has been the formulation of simplified models for dark matter and their signatures at collider and in direct/indirect detection experiments [2, 3, 4, 14]. In particular in [2], a joint collaboration among the pheno group and the CMS group at IIHE has studied a simplified model for dark matter exhibiting flavour violation in the top sector. The investigation showed that such dark matter model can explain the GCE excess in gamma rays observed by Fermi-LAT and also identified the most characteristic signatures to be looked for at the LHC.

The pheno group has achieved results with great impact in the interpretation of a recent LHC excess in diphoton final states [3, 5, 6, 7], being e.g. the first to propose a dark matter model to accommodate such excess [3].

Other relevant topics of investigation include inflation in Plateau-like models with non minimal coupling to gravity [8], and the detailed study of an unconventional model to address naturalness, i.e. the Twin Higgs, focusing on its supersymmetric incarnation [9].

Furthermore, 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. The sources studied so far are obscured flat spectrum radio AGN, binary black hole mergers and solar flares. The different works [10, 13], achieved in collaboration with external researchers, illustrate themselves within the multi-messenger framework, using electromagnetic and gravitational wave detection to predict the neutrino counterpart.

Finally, the group has also performed investigations on the subject of the Brout-Englert-Higgs boson characterization [11, 12], for instance studying at NLO the impact of dimension six operators in vector boson fusion production mechanism of the H boson at the LHC [12].

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2.10 Computing and networking

(S. Amary, R. Rougny, F. Blekman, A. Boukil, O. Devroede, J. D'Hondt, S. Gérard, A. Ouchene, S. Rugovac, P. Vanlaer, R. Vandenbroucke)

2.10.1 Local computing resources

The IIHE hosts a range of general IT services like a web server, DNS and DHCP servers. Most servers have been migrated to a virtual environment based on VMWARE. The implemented solution consists of 3 hypervisors running the virtual machines. The disk images are kept on a central NAS server. To guarantee the machines against short power breaks, the infrastructure was connected to an 8kVA UPS (uninterruptible power supply).

2.10.2 Large scale and grid computing

The IIHE operates a computing cluster that can be used through a local batch system (PBS) as well as via the grid. The computing cluster is offering resources to several large experiments (CMS, IceCube, Solid). In 2016, the Brussels HTC/grid team counted five IT scientists (S. Rugovac, F.R.S.-FNRS; O. Devroede, VUB; S. Gérard, VSC, part time; Romain Rougny, UA; Samir Amary, ULB). Pascal Vanlaer (ULB) is in charge of the Belgian federated Tier-2 sites and is the representative to the W-LCG and CMS computing boards. O. Devroede is the technical coordinator of the Belgian Tier-2 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.

IceCube

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

Until May 2016, the IceCube collaboration maintained a dedicated, separate, cluster for their calculations and mass storage. For scaling issues and easier maintenance, the IceCube cluster was integrated into our larger cluster that is mainly used for CMS. Due to this integration, the cluster became fully grid enabled and as such was able to handle a substantial fraction of the computing demand of the IceCube collaboration. Since its integration, we were able to process ∼25% of the simulation needs of the entire IceCube Collaboration on top of the computing needs of the local users.

Large scale computing for CMS

The Brussels CMS Tier-2 contributes significantly to the computing resources of the CMS collaboration. It hosts the contributions of the UA, UGent, UMons, ULB and VUB universities, and is funded by the F.R.S.-FNRS and by the FWO. It is part of Belgian federated Tier-2 computing resources, together with another Tier-2 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 2016, the T2 had ∼4700 job slots for a total of 50 TFLOPS (or 38.000 HepSpec06 units). Attached to this, a mass storage system of 2.3 PB is found.

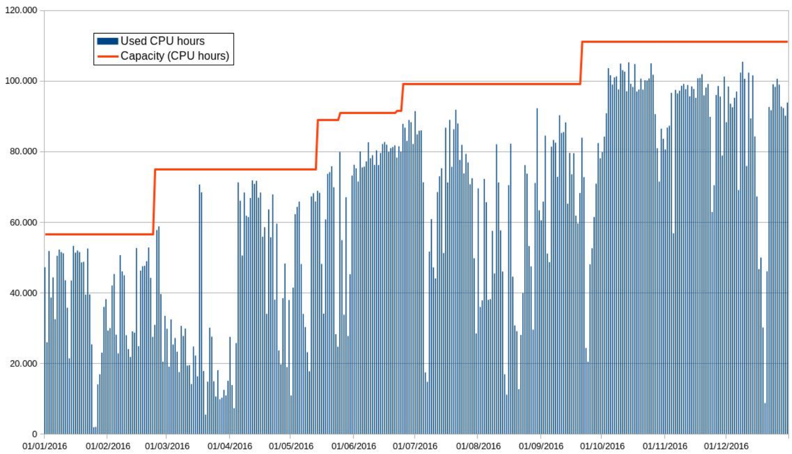

Figure 9: Daily capacity of the site (in CPU*Hours) and the the capacity actually used, between January 1st, 2016 and December 31st, 2016.

Figure 9 shows the capacity of the T2 during 2016. The red line represents the available capacity per day, expressed in CPU*Hours. The blue histograms show what was used in that particular day (in the same units). The increase in capacity in May and July correspond to the gradual insertion of the IceCube calculation nodes into the Tier-2. The increases in March and October correspond to the addition of computing power needed for the CMS experiment. Figure 9 clearly demonstrates that the growing capacity of the site is made to good use by the local users and experiments. Increasing the capacity also increases the usage, clearly indicating the growing need for computing power. Over the whole year 2016, the cluster was used for almost 70% of its full capacity. This number also includes downtimes due to necessary software updates or outages. A detail per month can be seen in Figure 10. The lesser usage in March-April 2016 is due to the change in technology from single to multi core pilot jobs, which generated lots of unforeseen errors.

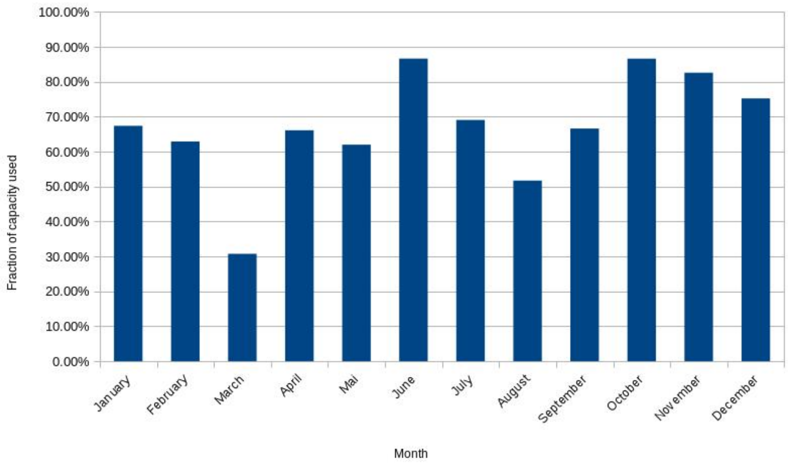

Figure 10: Fraction of the capacity of the site used, per month, in 2016.

2.11 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. The participation to the international Master Classes in Particle Physics is a prime example. At the VUB, these are organised by Freya Blekman in the framework of IPPOG, the International Particle Physics Outreach Group. At the ULB, they are organized twice a year by Gilles De Lentdecker for about 60 students. 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.

Several members of the IIHE have been awarded for science communication. For her continuous science communication via social media Freya Blekman was awarded one of the year prizes in 2016 of the Royal Academy of Belgium (KVAB) for Science Communication.

To celebrate the discovery of gravitational waves, Simona Toscano and Gwen de Wasseige organized in 2016 a public lecture (more than 200 participants), followed by a dedicated symposium.

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.

Barbara Clerbaux participated in the publication of a booklet, summarizing the discussion and reflections that took place during two sessions of interdisciplinary workshops "Penser la Science", with the participation of all French-speaking universities in Belgium, the FNRS and the EU. Reference: E. Zaccai, B Timmermans, M. Hudon, B. Clerbaux B. Leclercq, H. Bersini, "Penser la science: L'évaluation de la recherche en question(s)", actes complets publiés par l'Académie Royale des Sciences, des Lettres et des Beaux-Arts de Belgique, Collection 8, IVe série, tome VII, numéro 2113, 2016.

Stefaan Tavernier is member of and was previously spokesperson (1995-2010) of Crystal Clear, an international collaboration active on research and development on inorganic scintillation materials for novel ionizing radiation detectors, for high-energy physics, medical imaging and industrial applications. Recent publications are "Validation of a highly integrated SiPM readout system with a TOF-PET demonstrator" (just accepted in JINST) and "A new method for depth of interaction determination in PET detectors" (Phys.Med.Biol. 61(12):4679-98, 2016).

Jorgen D'Hondt obtained funding from the Brussels region to participate and sponsor the development of the documentary "Kwantumrevolutie" which was recently selected for the 360 Science Film Festival in Moscow as well as for a Film Festival in Kopenhagen.

2.12 Technical and administrative work

2.12.1 Workshop

(J. De Bruyne, P. de Harenne, M. Korntheuer, R. Vanderhaeghen and Y. Yang ; coordinator : G. De Lentdecker).

Y. Yang was responsible for the development of a test DAQ system based on the recent micro-TCA technology in the framework of the preparation of new detectors for future experiments. He was involved in the design of an FPGA based board. He also participated to the development of the readout of the ARA neutrino detector.

R. Vanderhaeghen and M. Korntheuer were in charge of the maintenance of the electronic workshop.

2.12.2 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 J. De Bruyne, P. De Harenne and F. Pero.

J. De Bruyne and P. De Harenne provided daily support for numerous tasks; F. Pero was in charge of ULB travels until August 2016.

3 Activities

3.1 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 Coordination Committee

Freya Blekman

- Member of CMS Supersymmetry group Publication Committee

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

- Calibration of the Tracker DCU chips
- Chair of the Young Scientist Committee
- DQM: Use TH2Poly objects in Tracker Maps
- DQM: implement Phase 2 Upgrade Outer Tracker plots
- Shift Leader shifts
- Tracker DQM convener
- Tracker on-call shifts

Catherine De Clercq

- Belgian liaison in the IceCube International Oversight and Finance Group, IOFG
- PI of VUB in the IceCube collaboration board

Gilles De Lentdecker

- CMS Tracker Institution Board member
- 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, on site data taking.

Gwenhaël De Wasseige

- Gravitational Wave HitSpool coordination + contact person
- SFNews coordination + contact person
- Snow depth measurements for IceTop coordination + contact person
- South Pole deployment: snow sensor installation

Laurent Favart

- Internal H1 referee
- 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

Georgia Karapostoli

- Coordinator of the CMS Higgs Working Group: $H \to ZZ \to 2l2v$
- Coordinator of the CMS Trigger operations group STEAM (Strategy for Trigger Evolution and Monitoring)

Giuliano Maggi

- Member of the IceCube Software Strike Team since June 2015

Lieselotte Moreels

- CMS Tracker: DCU Calibration
- CMS Tracker DOC shifts
- CMS Tracker DQM-on-call shifts
- DQM: Phase II outer tracker plots
- General DQM maintenance for the CMS silicon strip tracker

Christoph Raab

- Performed checks on Pass 2 data at Muon L3
- Referee of the IC86-II-II-IV Time-Dependent Analysis for the point source working group
- Referee of the Monthly Time-Dependent Analysis for the point source working group

Petra Van Mulders

- Convener of the BTV POG in the CMS collaboration

- 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)
- Promotor-spokesperson of the FNRS IISN convention CMS Phase 2 upgrade (UCL-ULB)

Gaston Wilquet

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

Fengwangdong Zhang

- Jet Energy Correction at High Level Trigger for CMS data taking in 2016

3.2 Completed Master and PhD theses

Barbara Clerbaux

- Diego Beghin
  Search for new physics in final states with tau-leptons at the LHC Run2 with the CMS detector
  Master thesis, ULB, June 2016.
- Cécile Caillol
  Study of the Brout-Englert-Higgs boson in the di-tau final state at the LHC
  Phd thesis, ULB, April 2016.

Jorgen D'Hondt

- Annik Olbrechts
  Measuring the anomalous couplings in the Wtb vertex using the Matrix Element Metho d at the LHC
  Phd thesis, VUB, February 2016.
- Karen De Causmaecker
  Unconventional signatures of supersymmetry
  Phd thesis, VUB, August 2016.

Gilles De Lentdecker

- Camille Giaux
  Deconvolution-based gamma-camera for proton therapy: design and test of the data-acquisition chain
  Master thesis, ULB, June 2016.
- Thomas Lenzi
  Development of the DAQ System of Triple-GEM Detectors for the CMS Muon Spectrometer Upgrade at LHC
  Phd thesis, ULB, December 2016.
- Jerome Lemaire
  Exploring FPGA hardening solutions at the detector level for the future high luminosity phase of the CMS experiment at the LHC
  Master thesis, ULB, September 2016.
- Hugo Dewitte
  Implementation of an FPGA based calibration procedure at the detector level for the future high-luminosity phase of the CMS
  Master thesis, ULB, June 2016.

- Valerie De Smet
  Neutron measurements in a proton therapy facility and comparison with Monte Carlo shielding simulations
  Phd thesis, ULB, September 2016.
- Thierry Maerschalk
  Study of Triple-GEM detector for the upgrade of the CMS muon spectrometer at LHC
  Phd thesis, ULB, July 2016.
- Florian Zenoni
  Study of Triple-GEM detectors for the CMS muon spectrometer upgrade at LHC and study of the forward-backward charge asymmetry for the search of extra neutral gauge bosons
  Phd thesis, ULB, April 2016.

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

- 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
- WT2 (physics) funding review panel of the FWO, Flanders, Belgium

Barbara Clerbaux

- Adviser for the NWO for the Innovational Research Incentives Scheme
- President of the Jury FRIA of the Belgian FNRS

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

- 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)

Pascal Vanlaer

- Representative of the ULB in the CECI interuniversity high-performance computing infrastructure (FUNDP, UCL, ULB, ULg, UMons)

Fengwangdong Zhang

- Secretary of CMS Young Scientist Committee

3.4 Diffusion of scientific results

3.4.1 Oral presentations at conferences and schools

Juan Antonio Aguilar Sánchez

- Highlights form IceCube, 6th Rome International Conference on AstroParticle Physics (RICAP) - Rome, Italy from 21/06/2016 to 24/06/2016
- Highlights from IceCube, Seminar at University of Bonn - Bonn, Germany 16/06/2016

Freya Blekman

- BSM physics at the LHC, Spaatind 2016 - Nordic conference of Particle Physics - Spaatind, Norway 05/01/2016
- Top physics at the FCC-ee, Workshop on physics at the Future Circular Collider - CERN 04/02/2016

Barbara Clerbaux

- BSM Physics at the High-Lumi LHC with ATLAS and CMS, LHC Physics (LHCP) - Lund University, Sweden from 13 June 20 to 18 June 20
- Beyond the Standard Model: A selection of the latest LHC results, Invited review talk at the conference "Theory LHC France - IPN Orsay, France from 7 November to 9 November

Andries Coone

- Inflation with a random nonminimal coupling to gravity, Theory at sea - Oostende from 25/05/2016 to 26/05/2016

Krijn De Vries

- Radar detection of high- energy neutrino induced particle cascades in ice, ARENA 2016 - Groningen, The Netherlands from 07/06/2016 to 10/06/2016

Gwenhaël De Wasseige

- On the study of solar flares with neutrino observatories, The 51th Rencontres de Moriond - Session electroweak interactions and unified theories - La Thuile, France from 12/03/2016 to 19/03/2016

Laurent Favart

- Low-x and Diffraction, 24th International workshop on Deep-Inelastic Scattering (DIS 2016) - Hamburg (D) from 11/04/2016 to 15/04/2016

Georgia Karapostoli

- CMS Trigger rates and physics menu, ECFA High Luminosity LHC experiments Workshop 2016 - Aix-Les-Bains, France 06/10/2016

- HLT Rates and Timing report, CMS Trigger Studies Group Workshop - INFN Milano Biccoca, Milan , Italy 17/02/2016
- Study of Higgs production in the bosonic decay channels, SUSY2016 - Melbourne, Australia 04/07/2016

Alberto Mariotti

- Beyond Standard Model signatures at the LHC, VUB - Kobe symposium - VUB 08/11/2016
- The Di-photon excitement at the LHC: TH, IAP meeting - UCL 17/06/2016
- Twin Higgs meets SUSY, GDR TeraScale - Jussieu Paris from 23/11/2016 to 25/11/2016

Seth Moortgat

- Charm jet identification at the CMS experiment, VIII International Workshop On Charm Physics - Bologna, Italy from 01/08/2016 to 05/08/2016

Elisa Pinat

- Extended sources search with the IceCube detector, IceCube Collaboration Meeting, plenary session - Mainz, Germany 30/09/2016
- Search for extended sources with IceCube, IceCube Collaboration Meeting, parallel session - Stony Brook, USA 20/04/2016

Petra Van Mulders

- CMS: Achievements and plans, LHCC - CERN, Geneva, Switzerland 21/09/2016
- CMS experiment: status and recent highlights , LHCP - Lund, Sweden from 13/06/2016 to 18/06/2016
- Getting to the “bottom” of precision measurements and/or new physics, iAP - UCL, Louvain-la-Neuve, Belgium 17/06/2016

Pascal Vanlaer

- Practical statistics for searches, Belgian-Dutch-German graduate school of particle physics - Antwerpen from 03/09/2016 to 06/09/2016
- Recent results on BSM scalar boson searches at CMS (Run 1 and Run 2), Rencontres de Blois 2016 - Blois 01/06/2016

Fengwangdong Zhang

- Associated production of vector bosons and jets in CMS, QCD@LHC 2016 - UZH Zurich, Switzerland from 22/08/2016 to 26/08/2016
- Vector Boson Production in association with Jets and Heavy Flavor Quarks from CMS, XXIV International Workshop on Deep Inelastic Scattering and Related Subjects - DESY Hamburg, Germany from 11/04/2016 to 15/04/2016
- Vector boson production in association with jets from CMS, Second China LHC Physics Workshop - PKU Beijing, China from 17/12/2016 to 19/12/2016

3.4.2 Poster presentations at conferences and schools

Isabelle De Bruyn

- Search for Dark Matter in the Monojet and Hadronic Mono-V Final States at CMS, BPS meeting - Gent 18/05/2016
- Simplified SIMPs and the LHC, Dark Matter at LHC workshop - Amsterdam from 30/03/2016 to 01/04/2016

Krijn De Vries

- Interpretation of the cosmic-ray air shower signal in Askaryan radio detectors, ARENA 2016 - Groningen, The Netherlands from 07/06/2016 to 10/06/2016

Giuliano Maggi

- Dust Obscured Blazars as sources of high-energy neutrinos, Active Galactic Nuclei: what's in a name? - ESO, Garching, Germany 27/06/2016

Christoph Raab

- Exploring Dark Matter Models with PINGU Events, General Scientific Meeting 2016 of the Belgian Physical Society - Gent 18/05/2016

Zixuan Song

- Study of Hardware Implementation of Fast Tracking Algorithms, TWEPP 2016 - Topical Workshop on Electronics for Particle Physics - Karlsruhe Institute of Technology (KIT) from 26/09/2016 to 30/12/2016

David Vannerom

- Search for dark matter with jets and missing transverse energy at 13 TeV, LHCP - University of Lund, Sweden from 13/06/2016 to 18/06/2016

3.5 Scientific training

3.5.1 Attendance to conferences and workshops

Shimaa Abu Zeid

- The 9th International Workshop on Top Quark Physics (TOP 2016) - Olomouc - Czech Republic from 19/09/2016 to 23/09/2016

Samir Amary

- 21st Quattor Workshop - IIHE - Brussels from 22/03/2016 to 24/03/2016
- 22nd Quattor Workshop - London from 04/10/2016 to 06/10/2016
- HTCondor / ARC CE Workshop - ALBA Synchrotron - Barcelona from 29/02/2016 to 04/03/2016

Isabelle Ansseau

- IIHE symposium LIGO - LIGO discovery of Gravitational Waves - Bruxelles 09/03/2016

Freya Blekman

- SEARCH - BSM sensitivity of Standard Model measurement in CMS - Oxford from 30/08/2016 to 03/09/2016
- ICHEP2016 - Presentation on FCC-ee top physics and media presence - Chicago from 06/08/2016 to 12/08/2016

Barbara Clerbaux

- General meeting of IUAP - Fundamental interactions - VUB 21/12/2016
- JUNO electronics workshop - JUNO - IIHE-ULB, Belgium from 14/11/2016 to 16/11/2016
- European JUNO meeting - JUNO - Tuebingen, Germany from 06/10/ 201 to 08/10/2016
- JUNO collaboration meeting - JUNO - Xiamen, China from 09/01/2016 to 16/01/2016
- Funding meeting - JUNO - Roma from 25/10/2016 to 26/10/2016

Andries Coone

- Utrecht cosmology Symposium - Cosmology - Utrecht from 27/06/2016 to 01/07/2016

Catherine De Clercq

- Gravitational Waves: the Discovery and Outlook - ULB, Brussels, Belgium 09/03/2016
- General Scientific Meeting of the Belgian Physical Society - Gent, Belgium 18/05/2016

Jarne De Clercq

- IAP meeting - Brussels 21/12/2016
- CMS tracker week - CERN, Geneva, Switzerland from 18/07/2016 to 20/07/2016
- IAP meeting - Louvain-La-Neuve, Belgium 17/06/2016
- CMS tracker week - CERN, Geneva, Switzerland from 25/01/2016 to 28/01/2016
- Tracker phase II days - CERN, Geneva, Switzerland from 09/05/2016 to 13/05/2016

Catherine De Clercq

- IDM2016 - Identification of Dark Matter - Sheffield, UK from 17/07/2016 to 22/07/2016

Krijn De Vries

- IceCube collaboration meeting - Mainz, Germany from 23/09/2016 to 30/09/2016
- ARENA 2016 - Groningen, The Netherlands from 07/06/2016 to 10/06/2016

Gwenhaël De Wasseige

- Inter-university Attraction Pole IAP on fundamental interactions - General meeting of the IAP - Louvain-la-Neuve 17/06/2016
- Session electroweak interactions and unified theories - The 51th Rencontres de Moriond - La Thuile, France from 12/03/2016 to 19/03/2016

Laurent Favart

- Workshop on Resummation, Evolution, Factorization (REF2016) - member of organizing and scientific committees - Antwerp from 07/11/2016 to 10/11/2016

Stéphane Gérard

- Belnet Networking Conference 2016 - Belnet Networking Conference - Brussels 25/10/2016
- Digital Infrastructures for Research 2016 - Digital Infrastructures for Research - Krakow from 27/09/2016 to 30/09/2016
- HTCondor - ARC Workshop - Grid Middleware - ALBA Synchrotron in Bercelona from 29/02/2016 to 04/03/2016
- EGI Conference 2016 - Opening science in Europe and in the World - Science Park in Amsterdam from 06/04/2016 to 08/04/2016

Alberto Mariotti

- CERN Institute - Charting the Unknown: interpreting LHC data from the energy frontier - CERN from 25/07/2016 to 30/07/2016

Seth Moortgat

- Connecting the Dots 2016 - Machine Learning and Tracking - Vienna, Austria from 22/02/2016 to 26/02/2016

Lieselotte Moreels

- TOP2016 - Olomouc, Czech Republic from 18/09/2016 to 23/09/2016
- IAP meeting - Vrije Universiteit Brussel 21/12/2016
- BPS - Belgian Physical Society meeting - Universiteit Gent 18/05/2016

Elisa Pinat

- IIHE Symposium: Gravitational Waves - IIHE Symposium: Gravitational Waves - IIHE, Brussels 09/03/2016
- IceCube Fall Collaboration Meeting - IceCube - Mainz, Germany from 24/09/2016 to 30/09/2016
- IceCube Spring Collaboration Meeting - IceCube - Stony Brook, USA from 16/04/2016 to 23/04/2016

Christoph Raab

- IceCube Collaboration Spring Meeting 2016 - Stony Brook, USA from 19/04/2016 to 23/04/2016
- IceCube Collaboration Fall Meeting 2016 - Mainz, Germany from 24/09/2016 to 30/09/2016
- Statistics Class by Kevin Meagher - Brussels from 07/06/2016 to 16/08/2016
- IceCube Software Bootcamp - Workshop on software development and IceCube software - New York, USA from 16/04/2016 to 18/04/2016

Romain Rougny

- Condor Workshop - Alba Syncrotron, Barcelona from 29/02/2016 to 04/03/2016

Zixuan Song

- Designing for FPGAs (2nd ed.) - the training cover various topics around FPGAs and VHDL design for FPGAs - IIHE from 18/01/2016 to 22/01/2016

Pascal Vanlaer

- ECFA High Luminosity LHC Experiments Workshop - 2016 - ECFA High Luminosity LHC Experiments Workshop - Aix-les-Bains from 30/05/2016 to 03/06/2016
- Rencontres de Blois 2016 - Particle and astroparticle physics - Blois from 03/10/2016 to 06/10/2016
- Belgian Physical Society meeting - Physics and particle physics - Gent 18/05/2016

David Vannerom

- Trigger workshop - University of Milano-Bicocca from 16/02/2016 to 18/02/2016

Matthias Vereecken

- IceCube Collaboration Meeting fall 2016 - IceCube Collaboration Meeting - Mainz from 26/09/2016 to 30/09/2016

3.5.2 Attendance to schools

Isabelle Ansseau

- ISCRA : International School of Cosmic Ray Astrophysics - Particle, Gamma-ray and Neutrino Astrophysics in the 21st Century - Erice, Italy from 01/08/2016 to 07/08/2016

Andries Coone

- ICTP summer school in cosmology - Cosmology - Triest from 06/06/2016 to 17/06/2016

Isabelle De Bruyn

- Hadron Collider Physics Summer School - Fermilab from 11/08/2016 to 20/08/2016

Jarne De Clercq

- BND school - Experimental particle phyiscs: strong interaction physics calorimeters - Antwerp, Belgium from 29/08/2016 to 09/09/2016

Seth Moortgat

- MLHEP summer school - Machine Learning in HEP - Lund, Sweden from 20/06/2016 to 26/12/2016

Christoph Raab

- 2nd MERCUR Winter School - Cosmic ray detection, interactions, transport - Bad Honnef, Germany from 06/03/2016 to 11/03/2016

David Vannerom

- CMS Data Analysis School - Fermilab, Batavia, Illinois, USA from 11/01/2016 to 15/01/2016
- BND School - University of Antwerp, Belgium from 28/08/2016 to 09/09/2016

Fengwangdong Zhang

- BND Summer School on Particle Physics - BND Summer School on Particle Physics - University of Antwerp from 29/08/2016 to 09/09/2016

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-103 : Physique, (0/24/0/12) BA1 Physics Exercices for BA1 Info
- ULB - PHYS-F-205 : Physique 2, (0/0/44/20) BA2 Physics Laboratory for BA2 BIO
- ULB - PHYS-F-205 : Physique 2, (0/0/44/20) BA2 Physics Laboratory for BA2 Géo
- 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

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

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

Andries Coone

- VUB - 1015238ANR : Fysica: trillingen, golven en thermodynamica, (0/36/0/0) BA1

Isabelle De Bruyn

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

Jarne De Clercq

- VUB - WE-DNTK-... : Fysica: Inleiding mechanica, (0/0/8/10) BA1
- 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

Gwenhaël De Wasseige

- VUB - WE-DNTK-006329 : Experimentele fysica, (0/0/84/0) BA1 Labs
- VUB - WE-DNTK-6331 : Subatomic Physics I : Introduction to Nuclear and Particle Physics, (0/26/0/0) BA3 Exercises

Kevin Deroover

- VUB - WE-DNTK-1001388CNR : Experimentele stralings- en kwantumfysica, (0/0/48/40) BA2
- VUB - WE-DNTK-1015332ANR : Fysica: inleiding mechanica, (0/0/22/14) BA1
- VUB - WE-DNTK-1010221BNR : Statistische verwerking van experimentele gegevens, (0/0/0/2) BA2

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

Alberto Mariotti

- VUB - 4015689FNR : Subatomic Physics 2, (26/0/0/0) MA1

Seth Moortgat

- VUB - WE-DNTK-11330 : Fysica: Inleiding Mechanica, (0/32/0/0) BA1 Introductory course on Physics for non-physics students (biology, bio-ingeneer,...): Exercises

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

Christoph Raab

- ULB - PHYS-F311 : Physique des astroparticules - Laboratoires, (0/0/26/0) BA3 Tutored students for their data analysis. Helped a bit with preparation and supervision in the lab.
- ULB - PHYS-F482 : Techniques avancées de physique expérimentale, (0/2/8/12) MA1 Developed and 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

Pascal Vanlaer

- ULB - PHYS-F420 : Détection de particules, acquisition et analyse de données, (12/0/24/0) MA1 MA2 Physique
- ULB - PHYS-F205 : Physique 2: Electricité et magnétisme, (24/0/0/0) BA2 Biologie, Géographie, Géologie
- 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-F104 : Physique Générale, (0/2/0/0) BA1

Matthias Vereecken

- VUB - 004134 : Elektrodynamica en speciale relativiteit, (0/26/0/0) BA2

Fengwangdong Zhang

- ULB - PHYS-F312 : Particle Physics Laboratory, (0/20/20/20) BA3 Cosmic muon arch experiment

3.6.2 Membership to academic juries of Master and Phd theses

Juan Antonio Aguilar Sánchez

- Phd thesis, - Universite Paris Diderot, November 2016 - Rodrigo G. Ruiz : Search for populations of unresolved sources of high energy neutrinos with the ANTARES neutrino telescope.
  Referee
- Phd thesis, - ULB, June 2016 - Thierry Maerschalk : Study of Triple-GEM detector for the upgrade of the CMS muon spectrometer at LHC
  Referee

Freya Blekman

- Master thesis, - VUB, January 2016 - Secretary of Examination Council : As secretary of MSc (and BSc) examination council I am a member of all MSc juries at the VUB
  Secretary

Barbara Clerbaux

- Phd thesis, - ULB-theory, June 2016 - Simon Mollet : Exploration of 6-dimensional models with non trivial topology and their predictions for fermions masses and mixings, neutrino physics, flavour changing interactions and CP violation
  President
- Phd thesis, - UA, January 2016 - Sara Alderweireldt : Study of the standard model scalar boson decaying to b quarks and produced via vector boson fusion
  Referee
- Phd thesis, - UCL, October 2016 - Adrien Caudron : The final state with two b jets and two leptons at the LHC as a probe of the scalar sector
  Referee
- Master thesis, - ULB, September 2016 - Sacha Ferrari : Théorie de grande unification et matière noire
  Referee

Gilles De Lentdecker

- Phd thesis, - UCL, March 2016 - Bob Velghe : Development and Commissioning of the Silicon Pixel GigaTracker for the NA62 Experiment at CERN
  Referee
- Master thesis, - ULB, June 2016 - Diego Beghin : Etude des leptons taus et recherche de nouvelle physique avec le detecteur CMS
  Referee

Krijn De Vries

- Phd thesis, - University of Groningen, September 2016 - Stefano Messina : Extension to lower energies of the cosmic-ray energy window at the Pierre Auger Observatory
  Referee

Laurent Favart

- Phd thesis, - Université Libre de Bruxelles, December 2016 - Thomas Lenzi : Development of the DAQ System of Triple-GEM Detectors for the CMS Muon Spectrometer Upgrade at LHC
  President
- Phd thesis, - Université catholique de Louvain, April 2016 - Laurent Forthomme : Measurement of exclusive two-photon processes with dilepton final states in pp collisions at the LHC
  Referee
- Phd thesis, - CEA/Orsay, France, June 2016 - Matthias Saimpert : Mesure de la section efficace de production de paires de photons isolés dans l'expérience ATLAS au LHC et étude des couplages à quatre photons
  Secretary
- Phd thesis, - Université Libre de Bruxelles, August 2016 - Valérie De Smet : Neutron measurements in a proton therapy facility and comparison with Monte Carlo shielding simulations
  President
- Phd thesis, - Université Libre de Bruxelles, April 2016 - Florian Zenoni : Study of Triple-GEM detectors for the CMS muon spectrometer upgrade at the LHC and study of the forward-backward charge asymmetry for the search of extra neutral gauge bosons
  President

Alberto Mariotti

- Phd thesis, - Vrije Universiteit Brussel, August 2016 - Karen De Causmaecker : Unconventional signatures of supersymmetry
  Referee

Petra Van Mulders

- Phd thesis, - Vrije Universiteit Brussel, February 2016 - Annik Olbrechts : Measuring the anomalous couplings in the Wtb vertex using the Matrix Element Method at the LHC
  Referee

Pascal Vanlaer

- Phd thesis, - ULB, December 2016 - Thomas Lenzi : Development of the DAQ System of Triple-GEM Detectors for the CMS Muon Spectrometer Upgrade at LHC
  Secretary
- Phd thesis, - VUB, February 2016 - Annik Olbrechts : Measuring the anomalous couplings in the Wtb vertex using the Matrix Element Method at the LHC
  Referee
- Master thesis, - ULB, August 2016 - Diégo Bardiaux : Review of spectral methods
  Referee
- Phd thesis, - ULB, April 2016 - Cécile Caillol : Scalar boson decays to tau leptons : in the standard model and beyond
  Secretary
- Phd thesis, - ULB, July 2016 - Thierry Maerschalk : Study of Triple-GEM detector for the upgrade of the CMS muon spectrometer at LHC
  President

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 pedagogic committee, ULB
- Member of the ULB Funding Committee (commission finance), ULB

- Member of the administrative ULB committee (commission administrative), ULB
- Members of Faculty full time academic position search committee, ULB
- Representative of the ULB rector at the Scientific Olympiads proclamation, ULB

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

Nick Van Eijndhoven

- Member of the Education Board of the VUB Faculty of Science, 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
- President of the users committee of the ULB-VUB computing center, ULB

3.7 Vulgarisation and outreach

Samir Amary

- CERN visit with BA students - CERN, from 15/03/2016 to 17/03/2016

Isabelle Ansseau

- Expo Science festival by jeunesses scientifiques - Bruxelles, 29/04/2016
- IceCube Masterclasses - Bruxelles, IIHE, 02/03/2016

Juan Antonio Aguilar Sánchez

- Gravitational Waves: The discovery and outlook. - ULB, 09/03/2016
- IceCube Masterclass - IIHE , 02/03/2016

Freya Blekman

- "Jaarprijs Science Communication" of the Royal Flemish Academy of Belgium for the Arts and Sciences (KVAB) for Promotion of particle physics on social media, particularly twitter and youtube - Brussels, 14/11/2016

Barbara Clerbaux

- Outreach campaign, - ULB, 01/03/2016
- Penser la Science : - Académie Royale des Sciences, 07/04/2016

Jarne De Clercq

- CMS masterclass - VUB, 11/02/2016

Catherine De Clercq

- Organisation of the IceCube Masterclass 2016 - I.I.H.E., Brussels, 02/03/2016
- Organisation of the contest for schools *90 South: your experiment at the South Pole* - VUB and ULB, Brussels, from 01/09/2016 to 17/02/2017

- Speaker at the *Science Bar Brussel: Donkere Materie* - RITCS café, Brussels, Belgium, 13/12/2016

Jarne De Clercq

- VUB VOETendag - VUB, 08/03/2016

Krijn De Vries

- Dag van de Wetenschap: IceCube - VUB campus Jette, 27/11/2016
- High school campus visit: IceCube, neutrinos vangen op Antarctica - VUB/IIHE, 23/02/2016
- High school campus visit: IceCube, neutrinos vangen op Antarctica - VUB/IIHE, 15/03/2016
- IceCube Masterclass - VUB/IIHE, 02/03/2016
- VUB Voetendagen: IceCube, neutrinos vangen op Antarctica - VUB/IIHE, 22/11/2016

Gwenhaël De Wasseige

- 90 degrees South experiment contest for primary and high-school students - Brussels-SouthPole, from 01/09/2016 to 31/12/2016
- Antarctikaartjes: greetings exchange between Belgian citizens and South Pole scientists - Belgium-South Pole, from 15/10/2016 to 31/12/2016
- Co-organizor of a public event to celebrate the first direct observation of gravitational waves - Brussels, 08/03/2016
- Collaboration with Moulinsart: Tintin at the South Pole - South Pole, from 01/12/2016 to 31/12/2016
- Masterclass IceCube 2016 organization + activities - Brussels, 02/03/2016
- Multiple interviews in the written press as well as for the national radio La Première and Nostalgie - Belgium, from 01/09/2016 to 31/12/2016
- Several outreach articles about (astro)particle physics actuality in Wntschp.be - Brussels, 2016
- Several visits to primary and high-schools - Brussels, from 01/09/2016 to 31/12/2016

Elisa Pinat

- IceCube Masterclasses - IIHE, Brussels, 02/03/2016
- Neutrini astrofisici e l'origine dei raggi cosmici. - Trieste, Italy, 13/06/2016

Christoph Raab

- Helped with IceCube Masterclass - Brussels, 02/03/2016

Petra Van Mulders

- CERN: zoektocht naar de fundamentele bouwstenen van het universum - ie-net, Antwerpen, Belgium, 20/10/2016
- Curiosity-driven science - VUB congres, Brussel, Belgium, 24/05/2016
- Eén theorie voor alles: zou dat niet fantastisch zijn? Een ontdekkingsreis naar de bouwstenen van het universum - Artemis Kempen, Turnhout, Belgium, 17/02/2016
- Waarvan zijn de sterren eigenlijk gemaakt? Ontdekkingsreis naar de bouwstenen van het heelal - Technopolis, Mechelen, Belgium, 17/01/2016

Pascal Vanlaer

- Une bosse suspecte dans les données au LHC ? - Radio Campus, 22/02/2016

David Vannerom

- "Recherche de Matière Noire au CERN" - "10 minutes pour comprendre", Festival du Film Scientifique de Bruxelles, 15/03/2016

4 Publications

4.1 Refereed journals and conference proceedings

4.1.1 CMS

1. Υ(nS) *polarizations versus particle multiplicity in pp collisions at* $\sqrt{s} = 7$ *TeV*
   Khachatryan, V et al. [CMS Collaboration]
   Phys.Lett. B761 (2016) 31-52

2. *A search for pair production of new light bosons decaying into muons*
   Khachatryan, V et al. [CMS Collaboration]
   Phys.Lett. B752 (2016) 146-168

3. *Angular analysis of the decay* $B^0 \to K^{*0}\mu^+\mu^-$ *from pp collisions at* $\sqrt{s} = 8$ *TeV*
   Khachatryan, V et al. [CMS Collaboration]
   Phys.Lett. B753 (2016) 424-448

4. *Azimuthal decorrelation of jets widely separated in rapidity in pp collisions at* $\sqrt{s} = 7$ *TeV*
   Khachatryan, V et al. [CMS Collaboration]
   JHEP 1608 (2016) 139

5. *Combined search for anomalous pseudoscalar HVV couplings in VH(*$H \to b\bar{b}$*) production and* $H \to VV$ *decay*
   Khachatryan, V et al. [CMS Collaboration]
   Phys.Lett. B759 (2016) 672-696

6. *Correlations between jets and charged particles in PbPb and pp collisions at* $\sqrt{s_{\mathrm{NN}}} = 2.76$ *TeV*
   Khachatryan, V et al. [CMS Collaboration]
   JHEP 1602 (2016) 156

7. *Decomposing transverse momentum balance contributions for quenched jets in PbPb collisions at* $\sqrt{s_{\mathrm{N\,N}}} = 2.76$ *TeV*
   Khachatryan, V et al. [CMS Collaboration]
   JHEP 1611 (2016) 055

8. *Event generator tunes obtained from underlying event and multiparton scattering measurements*
   Khachatryan, V et al. [CMS Collaboration]
   Eur.Phys.J. C76 (2016) 155

9. *Evidence for exclusive* $\gamma\gamma \to W^+W^-$ *production and constraints on anomalous quartic gauge couplings in pp collisions at* $\sqrt{s} = 7$ *and 8 TeV*
   Khachatryan, V et al. [CMS Collaboration]
   JHEP 1608 (2016) 119

10. *Forward–backward asymmetry of Drell–Yan lepton pairs in pp collisions at* $\sqrt{s} = 8$ TeV
    Khachatryan, V et al. [CMS Collaboration]
    Eur.Phys.J. C76 (2016) 325

11. *Inclusive and differential measurements of the* $t\bar{t}$ *charge asymmetry in pp collisions at* $\sqrt{s} = 8$ *TeV*
    Khachatryan, V et al. [CMS Collaboration]
    Phys.Lett. B757 (2016) 154-179

12. *Measurement of* $\mathrm{t\bar{t}}$ *production with additional jet activity, including* b *quark jets, in the dilepton decay channel using pp collisions at* $\sqrt{s} = 8$ *TeV*
Khachatryan, V et al. [CMS Collaboration]
Eur.Phys.J. C76 (2016) 379

13. *Measurement of differential and integrated fiducial cross sections for Higgs boson production in the four-lepton decay channel in pp collisions at* $\sqrt{s} = 7$ *and 8 TeV*
Khachatryan, V et al. [CMS Collaboration]
JHEP 1604 (2016) 005

14. *Measurement of differential cross sections for Higgs boson production in the diphoton decay channel in pp collisions at* $\sqrt{s} = 8\,TeV$
Khachatryan, V et al. [CMS Collaboration]
Eur.Phys.J. C76 (2016) 13

15. *Measurement of dijet azimuthal decorrelation in pp collisions at* $\sqrt{s} = 8\,\mathrm{TeV}$
Khachatryan, V et al. [CMS Collaboration]
Eur.Phys.J. C76 (2016) 536

16. *Measurement of electroweak production of a W boson and two forward jets in proton-proton collisions at* $\sqrt{s} = 8$ *TeV*
Khachatryan, V et al. [CMS Collaboration]
JHEP 1611 (2016) 147

17. *Measurement of inclusive jet production and nuclear modifications in pPb collisions at* $\sqrt{s_{\mathrm{NN}}} =$ *5.02 TeV*
Khachatryan, V et al. [CMS Collaboration]
Eur.Phys.J. C76 (2016) 372

18. *Measurement of long-range near-side two-particle angular correlations in pp collisions at* $\sqrt{s}$ *=13 TeV*
Khachatryan, V et al. [CMS Collaboration]
Phys.Rev.Lett. 116 (2016) 172302

19. *Measurement of spin correlations in* $t\bar{t}$ *production using the matrix element method in the muon+jets final state in pp collisions at* $\sqrt{s} = 8$ *TeV*
Khachatryan, V et al. [CMS Collaboration]
Phys.Lett. B758 (2016) 321-346

20. *Measurement of the* $\mathrm{Z}\gamma \rightarrow \nu\bar{\nu}\gamma$ *production cross section in pp collisions at* $\sqrt{s} = 8$ *TeV and limits on anomalous* $\mathrm{ZZ}\gamma$ *and* $\mathrm{Z}\gamma\gamma$ *trilinear gauge boson couplings*
Khachatryan, V et al. [CMS Collaboration]
Phys.Lett. B760 (2016) 448-468

21. *Measurement of the* $\mathrm{W^+W^-}$ *cross section in pp collisions at* $\sqrt{s} = 8$ *TeV and limits on anomalous gauge couplings*
Khachatryan, V et al. [CMS Collaboration]
Eur.Phys.J. C76 (2016) 401

22. *Measurement of the* $\mathrm{t\bar{t}}$ *production cross section in the all-jets final state in pp collisions at* $\sqrt{s} = 8$ *TeV*
Khachatryan, V et al. [CMS Collaboration]
Eur.Phys.J. C76 (2016) 128

23. *Measurement of the charge asymmetry in top quark pair production in pp collisions at $\sqrt(s) = 8$ TeV using a template method*
Khachatryan, V et al. [CMS Collaboration]
Phys.Rev. D93 (2016) 034014

24. *Measurement of the CP-violating weak phase ϕ_s and the decay width difference $\Delta\Gamma_s$ using the $B_s^0 \to J/\psi\phi(1020)$ decay channel in pp collisions at $\sqrt{s} = 8$ TeV*
Khachatryan, V et al. [CMS Collaboration]
Phys.Lett. B757 (2016) 97-120

25. *Measurement of the differential cross section and charge asymmetry for inclusive* $\mathrm{pp} \to \mathrm{W}^{\pm} + X$ *production at $\sqrt{s} = 8$ TeV*
Khachatryan, V et al. [CMS Collaboration]
Eur.Phys.J. C76 (2016) 469

26. *Measurement of the differential cross sections for top quark pair production as a function of kinematic event variables in pp collisions at $\sqrt{s}$=7 and 8 TeV*
Khachatryan, V et al. [CMS Collaboration]
Phys.Rev. D94 (2016) 052006

27. *Measurement of the double-differential inclusive jet cross section in proton–proton collisions at $\sqrt{s} = 13\,TeV$*
Khachatryan, V et al. [CMS Collaboration]
Eur.Phys.J. C76 (2016) 451

28. *Measurement of the inclusive jet cross section in pp collisions at $\sqrt{s} = 2.76\,TeV$*
Khachatryan, V et al. [CMS Collaboration]
Eur.Phys.J. C76 (2016) 265

29. *Measurement of the inelastic cross section in proton–lead collisions at $\sqrt{s_{NN}} = 5.02$ TeV*
Khachatryan, V et al. [CMS Collaboration]
Phys.Lett. B759 (2016) 641-662

30. *Measurement of the integrated and differential $t\bar{t}$ production cross sections for high-p_t top quarks in pp collisions at $\sqrt{s} = 8$ TeV*
Khachatryan, V et al. [CMS Collaboration]
Phys.Rev. D94 (2016) 072002

31. *Measurement of the mass of the top quark in decays with a J/ψ meson in pp collisions at 8 TeV*
Khachatryan, V et al. [CMS Collaboration]
JHEP 1612 (2016) 123

32. *Measurement of the ratio $B(B_s^0 \to J/\psi f_0(980))\ /\ B(B_s^0 \to J/\psi\phi(1020))$ in pp collisions at $\sqrt{s} = 7$ TeV*
Khachatryan, V et al. [CMS Collaboration]
Phys.Lett. B756 (2016) 84-102

33. *Measurement of the t-tbar production cross section in the e-mu channel in proton-proton collisions at sqrt(s) = 7 and 8 TeV*
Khachatryan, V et al. [CMS Collaboration]
JHEP 1608 (2016) 029

34. *Measurement of the top quark mass using charged particles in pp collisions at $\sqrt{s} = 8$ TeV*
Khachatryan, V et al. [CMS Collaboration]
Phys.Rev. D93 (2016) 092006

35. *Measurement of the top quark mass using proton-proton data at $\sqrt{(s)} = 7$ and 8 TeV*
Khachatryan, V et al. [CMS Collaboration]
Phys.Rev. D93 (2016) 072004

36. *Measurement of the top quark pair production cross section in proton-proton collisions at $\sqrt{(s)} = 13$ TeV*
Khachatryan, V et al. [CMS Collaboration]
Phys.Rev.Lett. 116 (2016) 052002

37. *Measurement of the W boson helicity fractions in the decays of top quark pairs to lepton + jets final states produced in pp collisions at $\sqrt{s} = 8TeV$*
Khachatryan, V et al. [CMS Collaboration]
Phys.Lett. B762 (2016) 512-534

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