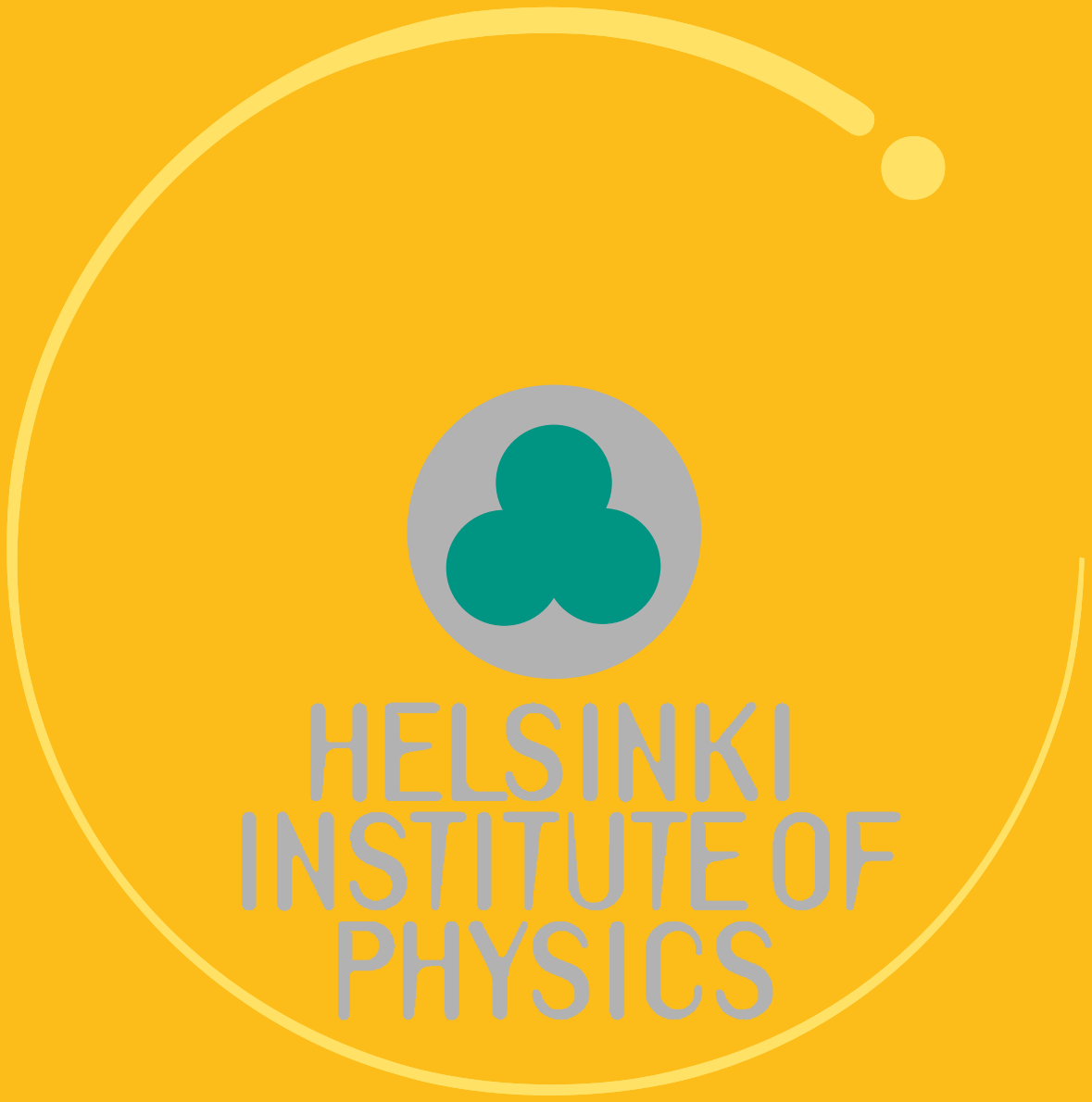

HELSINKI INSTITUTE OF PHYSICS

Annual Report 2016

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PSI researchers merging the CMS Barrel Pixel detector Layer 3 into Layer 4. The pixel modules produced in Finland are installed into Layer 3 and cover half of the whole layer. *(Photo courtesy of R. Horisberger/PSI).*

Annual Report 2016 Helsinki Institute of Physics

Contents

Preface

Paula Eerola

Research at the Helsinki Institute of Physics (HIP) addresses fundamental science questions from quarks to the Cosmos, as well as technologies from semiconductors to accelerators, medical applications, and climate research. HIP is operated by the University of Helsinki, Aalto University, the University of Jyväskylä and Lappeenranta and Tampere Universities of Technology. The Institute has, since 1997, had a national mandate from the Finnish Ministry of Education and Culture to co-ordinate the collaboration between CERN and Finland. HIP is also responsible for co-ordination of the Finnish activities at the planned international Facility for Antiproton and Ion Research (FAIR) in Darmstadt, Germany. A major milestone was reached in 2016 when the civil construction of FAIR was given the green light to proceed.

The research activities of HIP in 2016 consisted of four main research programmes: the Theory Programme; the CMS Programme including the CMS and TOTEM experiments; the Nuclear Matter Programme including involvements in the ALICE experiment, ISOLDE, and the FAIR facility; and the Technology Programme, with five applied research projects. In addition, there were two independent research projects, Planck-Euclid and CLOUD, and the Detector Laboratory.

The year 2016 witnessed remarkable advances in high energy physics. The Large Hadron Collider (LHC) at CERN provided unprecedented amounts of data. The Planck experiment published a large set of final results. Overall, the scientific output of HIP reached an all-time record with over 330 peer-reviewed publications in high impact journals, a significant increase from previous years.

The HIP operations are based on the Finnish CERN strategy, which emphasises, in addition to research and researcher training, the development of technology know-how for Finnish industry and business applications and the exploitation of CERN and FAIR research results in science education and literacy. The success of these outreach efforts is, for example, demonstrated by the great interest in CERN shown by Finnish high schools. In 2016 the Institute was able to host 18 science-study visits to CERN by 369 Finnish high school students. In addition, 11 teachers participated in a special one-week teachers' course. During 2016, 7 PhD degrees and 14 MSc and MSc (engineering) degrees were awarded by the HIP partner universities on the basis of work conducted within the research projects of the Institute. The summer student programme at CERN represents a key educational effort. During summer 2016, 15 Finnish university students worked at CERN as trainees in HIP research projects, and one student at ESRF as a pilot case.

Dr. Aleksi Vuorinen, the HIP High Energy Phenomenology in the LHC Era project leader, was awarded an ERC Consolidator grant. Dr. Matti Kortelainen from the CMS group, now a CERN fellow, obtained his second CMS Achievement Award. Jaana Heikkilä was chosen as the recipient of the Finnish Physical Society Young Physicist Honorary Award for her MSc thesis. Professor Paula Eerola was granted the E.J. Nyström prize by the Finnish Society of Sciences and Letters.

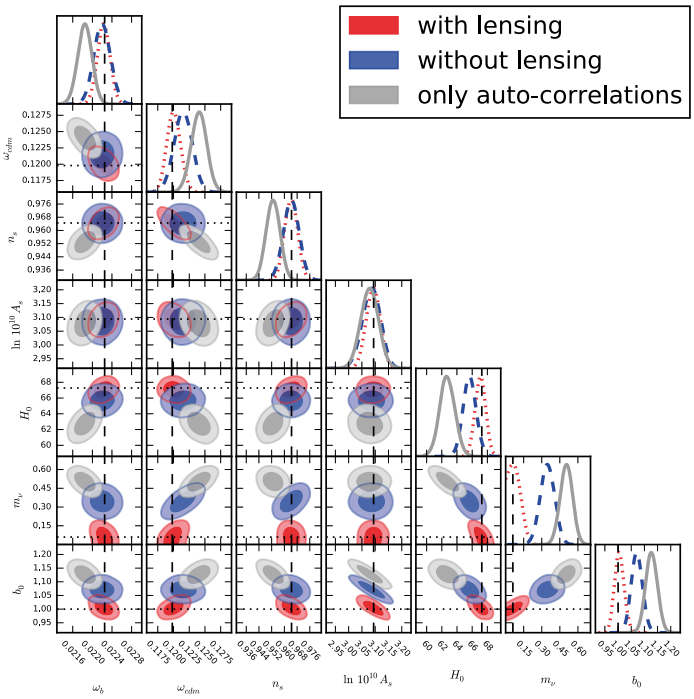
The year 2016 marked many changes in HIP. The status of HIP was changed into an independent institute within the Faculty of Science, University of Helsinki, as of the beginning of 2016. At the same time the University of Helsinki executed a major change in the organisation of the administration. All the administrative personnel were formally transferred to a new organisation, University Services. The number of administrative personnel was also reduced significantly.

Many of the long-time pillars of HIP operations retired in 2016: laboratory engineer Rauno Lauhakangas in May, senior researcher Ritva Kinnunen of the CMS Programme in June, the pioneer of the Finnish CERN school network, Riitta Rinta-Filppula, in July, and the former administrative head of HIP, Mikko Sainio, in August. Our devoted financial manager, Tarja Sandelin, moved to a new employer. I wish to thank all of them for their great contributions to the success of HIP. We welcome our new talents hired in 2016: Antti Väihkönen as the new research co-ordinator, holding together the strings of our multifaceted operations, and Pirkitta Koponen as the new laboratory engineer. We also welcome the team in University Services serving HIP: Tuulikki Laurila/administration, Heidi Kinnunen and Tuomo Palosaari/finances, Tuire Savolainen/human resources, and from the old HIP administrative personnel Taina Hardén, Tarja Heikkilä, Taina Onnela and Tuija Karppinen.

HIP celebrated its 20th anniversary with a seminar in November, with former HIP-affiliated persons reflecting on the impact of HIP on their careers. The speakers included Professor Johanna Björkroth, Professor Kari Eskola, Professor Edward Hæggström and Professor Ilpo Vattulainen, director Markku Oinonen, and senior consultant Matti Heikkurinen. The speakers in particular praised the opportunity given by HIP to "jump into something new and unknown". Indeed, raising tomorrow's research leaders is one of our most important missions.

HELSINKI INSTITUTE OF PHYSICS

Highlights of Research Results



Theory Programme

In the *Cosmology of the Early and Late Universe project*, we demonstrated the importance of including the lensing contribution in galaxy clustering analyses with large galaxy redshift surveys. Neglecting lensing in the autocorrelations severely biases parameter estimation leading to significant shifts for several parameters, notably the scalar spectral index and the neutrino mass scale. The latter is one of the main targets of future galaxy surveys.

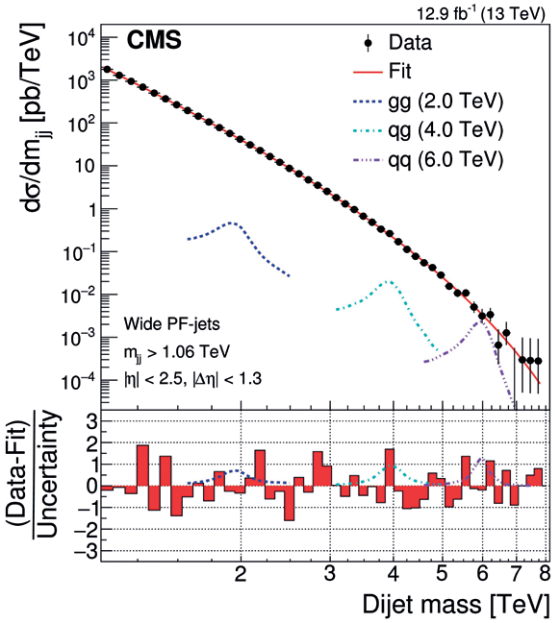
In the *High Energy Phenomenology in the LHC Era project* we have derived the first accurate Equation of State for ultradense quark matter at non-zero temperature. This is used for modelling the mergers of neutron stars, as temperatures up to 100 MeV may be reached in these violent phenomena. The computational methods developed in the paper pave the way towards extending the weak coupling expansion of the EoS to further orders at both zero and nonvanishing temperatures. The article was published as an Editor's Suggestion in Physical Review Letters.

A highlight of the *QCD and Strongly Interacting Gauge Theory project* was the publication of the new nuclear parton distribution set EPPS16. Due to the larger experimental dataset than its competitors and inclusion of LHC data, the analysis is the clear leader in the field. Significant progress was also made towards a comprehensive NLO analysis of small-x QCD scattering, concerning both the BK renormalization group equation and forward particle production.

In the *Nuclear Structure for Weak and Astrophysical Processes project* we have developed a strategy for CPU friendly computation of the nuclear photo-response. The response of the atomic nucleus to gamma radiation provides crucial information about its structure and the forces acting between constituent nucleons. It also plays an important role in various astrophysical scenarios. A newly developed method allows efficient computation of the response of the deformed superfluid nucleus, in the framework of microscopic nuclear density functional theory.

During the third year of the *Domain Wall Dynamics project* we have made significant progress in understanding the creep dynamics of domain walls (DWs) in narrow ferromagnetic strips, the complex nature of DW dynamics in wide permalloy strips, and coarsening dynamics of defects in permalloy thin films. Also, we found a novel mechanism which might explain observations of inter-event correlations in crackling noise.

CMS Programme



The Compact Muon Solenoid (CMS) is a particle physics experiment at CERN's Large Hadron Collider (LHC). The climax of LHC Run 1 (2010–2012) was the discovery of a Higgs boson. LHC Run 2 at 13 TeV continued in 2016 with a record luminosity of 41 fb^{-1}. The tentative 750 GeV diphoton signal in the 2015 data that had excited theorists was excluded by the 2016 data. By the end of 2016, the total number of published CMS physics papers was 495.

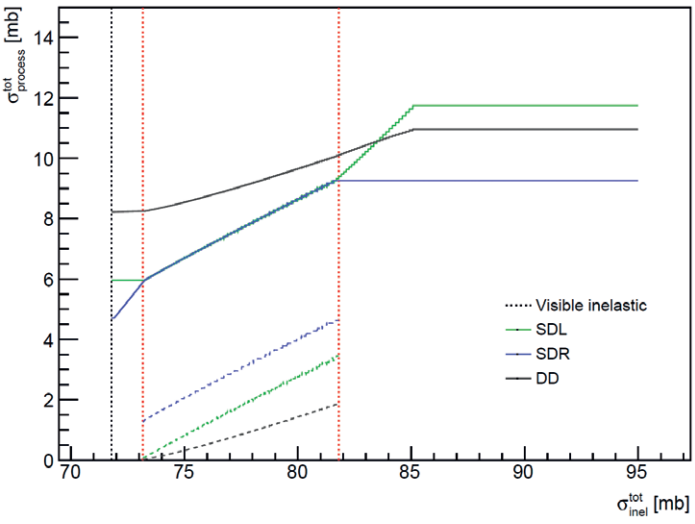
HIP researchers contributed especially to Higgs, jet, and B-physics analyses. The first CMS 13 TeV papers on new physics searches (dijet resonance search) and Standard Model measurements (inclusive jets) had HIP contributions. One of the CMS highlights at ICHEP was the updated dijet resonance search. The year 2016 also saw the first 13 TeV update on the charged Higgs search and the final Run 1 ATLAS and CMS combination of the Higgs properties with HIP involvement.

In 2016, the HIP CMS Upgrade group successfully completed their pixel detector Phase I Upgrade commitment, the production of 250 barrel pixel modules. The bare module construction in co-operation with Advacam Ltd. was made within the expected time and budget with excellent quality. Most of the full modules were constructed at CERN by fine-mechanics students from the Finnish School of Watchmaking. The new pixel detector will be installed in CMS before the 2017 LHC run.

The HIP TOTEM group contributed to the CMS-TOTEM precision proton spectrometer (CT-PPS) for diffractive measurements in high luminosity LHC runs. Using the TOTEM silicon strip detectors, the CT-PPS collected in 2016 15 fb^{-1}, the largest diffractive data set ever. The CT-PPS diamond detectors for precise proton time-of-flight measurement were commissioned with HIP involvement.

J. Heikkilä, M. Kortelainen and P. Eerola received the FPS Young Physicist Honorary Award, the CMS Achievement Award and the E.J. Nyström Prize, respectively.

Nuclear Matter Programme



Due to its negligible pile-up rates, excellent transverse momentum acceptance and particle identification capabilities, ALICE has unique characteristics for measuring soft physics processes. In diffractive physics, ALICE is producing new high quality measurements of inclusive diffractive cross sections. In the figure the the right, the single diffractive and double diffractive cross sections are shown as a function of the total inelastic proton-proton cross section.

The year 2016 saw the completion of HIE-ISOLDE Phase 1. The first radioactive beam ^{110}Sn at 4.5 MeV/u employing two superconducting cryomodules was sent to Miniball on 9th September.

This was followed by a successful operation and extensive physics campaign, paving the way for the upcoming HIE-ISOLDE Phase 2 upgrade.

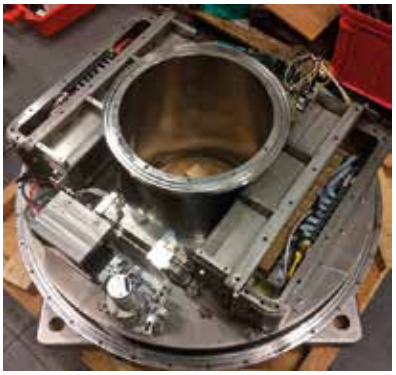
In 2016 the Super-FRS GEM-TPC tracking detector pre-commissioning was successfully carried out at the Accelerator Laboratory of the University of Jyväskylä and at GSI. The stability and count-rate capability was demonstrated. GEM-TPC is designed and manufactured in collaboration between the HIP and GSI detector laboratories.

Technology Programme

Accelerator technology: Application of graphene-based films for heavy-ion accelerator technology components, such as solid-state stripper foils for FAIR and Future Circular Collider, requires a good understanding of radiation damage by swift heavy ions. By developing further the theoretical framework of interaction of swift heavy ions via electronic excitations, we explained the formation of initial ion damage in graphene.

Computing performance: The Green Big Data project has focused on optimising energy consumption of scientific computing clusters used for HEP computing related to CERN experiments. In 2016, we developed models for estimating and controlling HPC energy-consumption and studied and prototyped solar energy driven distributed computing.

Medical imaging: In 2016, research was focused on the possible advantages of having an axial design for in-beam PET imaging, which would decouple the sensitivity from the spatial resolution. Monte Carlo simulations were used in order to evaluate the current performance of the partial ring, dual panel positron emission tomography (PET) configurations that are currently under development for treatment planning in proton therapy.



Business incubation: The first cases were processed and operations were outlined for BIC during 2016. Additionally, societal impact of big science studies were conducted as part of the technology commercialisation activities.

Radiation detection technology: The Passive Gamma-ray Emission Tomography (PGET) prototype was refurbished with new detectors, new electronics and a new data acquisition system by the International Atomic Energy Agency (IAEA). We participated in the successful commissioning at the Atominstitut in Vienna at the end of 2016.

Theory Programme

The HIP Theory Programme consists of five fixed term projects: Cosmology of the Early and Late Universe (leader Syksy Räsänen, University of Helsinki), High Energy Phenomenology in the LHC Era (leader Aleksi Vuorinen, University of Helsinki), QCD and Strongly Interacting Gauge Theory (leader Tuomas Lappi, University of Jyväskylä), Nuclear Structure for Weak and Astrophysical Processes (leader Markus Kortelainen, University of Jyväskylä), and Domain Wall Dynamics (leader Lasse Laurson, Aalto University). The present programmes were reviewed by external reviewers during 2016. In addition, Professor Mark Hindmarsh (Sussex University) continues his five-year part-time visiting professor position in Helsinki, shared by HIP and the Department of Physics.

Kari Rummukainen,
Theory Programme director

Cosmology of the Early and Late Universe

Inflation: We investigated the role of the Higgs field in inflation in various settings. In the case where the Higgs is the inflaton, we considered the dependence of the predictions on the matching between the low energy Standard Model limit and the inflationary regime. In the case when the Higgs is not the inflaton, we studied the instability of the electroweak vacuum, due to couplings between the Higgs and the inflaton. We also studied inflation in a model where the Higgs arises as a pseudo-Goldstone boson associated with the breaking of a global symmetry at a scale significantly larger than the electroweak scale.

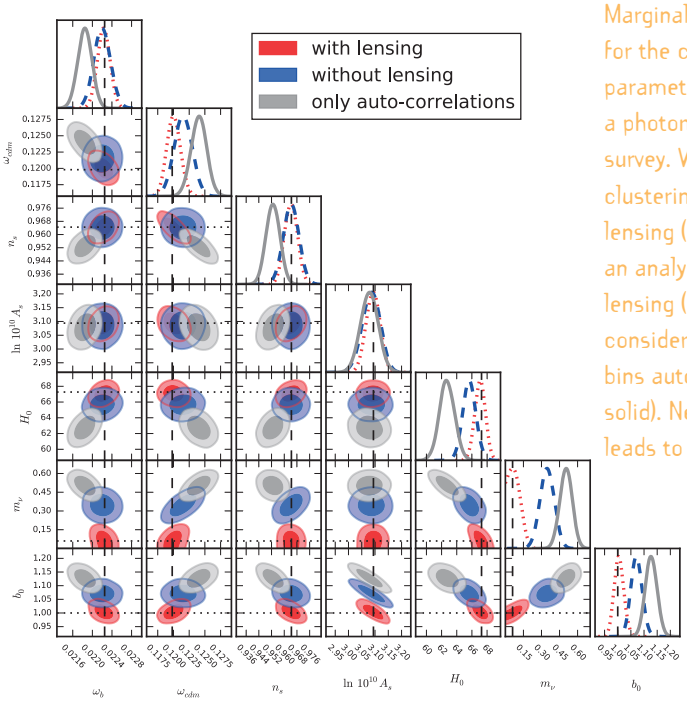
We studied the importance of correctly implementing renormalisation group running and choosing the renormalisation scale in inflation. We constrained scenarios where the Standard Model is reheated by the decay of hidden sector particles.

Dark Matter, baryogenesis and phase transitions: We investigated baryogenesis in a model with two Higgs doublets and a singlet scalar field and studied the gravitational wave signal from the electroweak phase transition with an extra scalar singlet. We showed how feebly interacting hidden sector models can be constrained by cosmological and astrophysical observations and studied how the field that drives inflation can also give a strong electroweak phase transition.

Observational cosmology: The Euclid satellite project continues to progress towards launch in 2020. We took part in reviewing the expected cosmology and fundamental physics constraints from Euclid, and studied the design strategy of the data quality control tools for the survey.

We also continued the development of the large scale structure theory needed for analysing the unprecedentedly precise data Euclid and other surveys will deliver. We showed that the lensing contribution is important for determining the neutrino mass in galaxy clustering analyses of large-scale redshift surveys. We demonstrated that significant shifts in the best-fit values of cosmological parameters are to be expected if magnification bias is not properly considered

Syksy Räsänen,
Cosmology of the Early and Late Universe project leader



Marginalised posteriors for the cosmological parameters inferred for a photometric Euclid-like survey. We show the full clustering analysis including lensing (red dotted), an analysis neglecting lensing (blue dashed), and considering only redshift bins autocorrelations (gray solid). Neglecting lensing leads to large biases.

in galaxy surveys. We analysed the impact of consistent modifications of gravity on the largest observable scales, focusing on relativistic effects in galaxy number counts and the cross-correlation between large scale structure and the cosmic microwave background.

On the more astrophysical side, we studied the distribution and evolution of the stellar mass and the star formation rate of the brightest group galaxies.

Other: We studied three-loop corrections to the high-energy growth of gauge theory scattering amplitudes in planar N=4 super Yang-Mills theory.

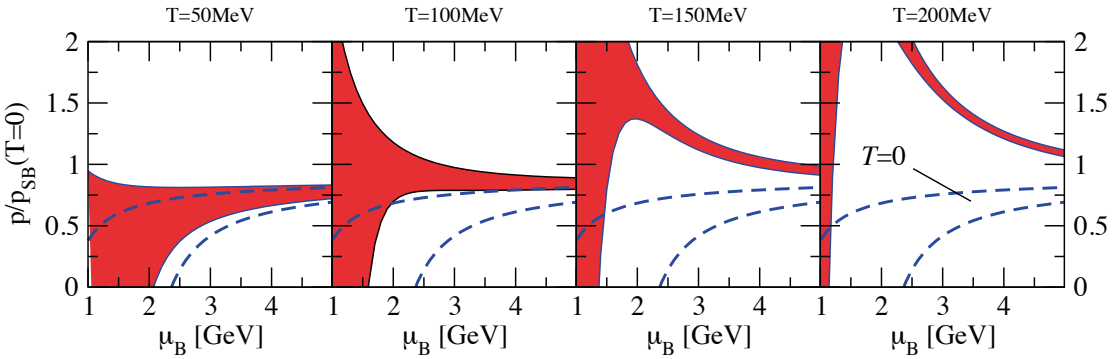
High Energy Phenomenology in the LHC Era

Aleksi Vuorinen, High Energy Phenomenology in the LHC Era project leader

The year 2016 witnessed remarkable observational and experimental advances in high energy physics. The announcement of the first detection of gravitational waves from a black hole merger by the LIGO collaboration marked the birth of a new era in astrophysics and cosmology by opening up a novel observational window into the Cosmos. At the same time, the disappearance of the hyped 750 GeV resonance at the LHC further strengthened the stance of the Standard Model in particle physics, with the continuous flow of data consistent with it placing further constraints on its possible extensions.

For the HIP High Energy Phenomenology project, 2016 was a very successful year, marked by several articles published in Physical Review Letters (PRL) and the PI of the project obtaining an ERC Consolidator grant at the end of the year. The observational advances of the year were reflected in the research conducted within the project, which in addition included fundamental research in various topics in quantum field theory and the gauge/gravity duality. Active work was carried out in particular on the physics of neutron stars and their collisions, the properties of various Beyond the Standard Model (BSM) theories, as well as topological defects in gauge theories. In the following, we give three brief examples of our work within these topics.

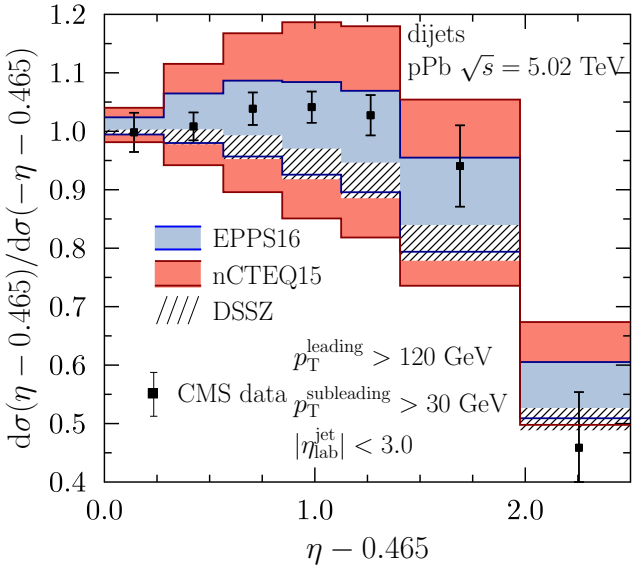
In the paper "Cool quark matter", published in PRL in the summer, A. Kurkela and A. Vuorinen generalised their current state-of-the-art perturbative Equation of State (EoS) for zero-temperature quark matter to non-zero temperatures. This is a very useful result for simulations of neutron star mergers and predictions of the gravitational wave signals emitted, as temperatures up to 100 MeV and extremely high energy densities can be reached in these events. In addition to perturbation theory, gauge/gravity duality has also been applied to the study of quark matter, producing another PRL article "Holographic quark matter and neutron stars" by N. Jokela, A. Vuorinen and co-authors, where the first realistic holographic EoS was derived for dense and cold quark matter.



The figure displays the temperature dependence of the pressure of deconfined quark matter as a function of the baryon chemical potential at four fixed values of temperature, and is taken from Kurkela, Vuorinen, PRL 117 (2016). The red band is the new perturbative result, with its width revealing the inherent uncertainty, while the blue dashed lines show the corresponding result at zero temperature.

In a third PRL article "New solutions for non-Abelian cosmic strings", published somewhat later in the year, M. Hindmarsh, K. Rummukainen, and D. Weir found new string solutions in SU(2) gauge theory, dubbed necklaces. These objects can be interpreted as monopoles trapped on strings, and their collective properties were further numerically studied in a later paper, which modelled a phase transition in the early universe. In simulations starting from random initial conditions, the authors saw that a system of necklaces exhibits similar properties to a network of ordinary cosmic strings, but that the dynamics of closed string loops is significantly affected.

Finally, a prime example of BSM research conducted in the project can be found in the article "Higgs-flavon mixing and h → μτ" by K. Huitu, V. Keus, N. Koivunen, and O. Lebedev. In this paper, the authors demonstrate that the excess observed in flavour violating decays of the Higgs boson at the LHC can be accommodated in a simple model featuring the mixing of the Higgs with the so-called flavon field, responsible for the flavour structure of the lepton sector in the Standard Model.



Comparison of the new EPPS16 and other nuclear parton distributions with CMS dijet data, showing both the good agreement with and the constraining power of the new data.

QCD and Strongly Interacting Gauge Theory

Our work revolves around different aspects of QCD at high energy and density. In addition to the phenomenology of high energy nuclear collisions at the LHC and RHIC, we are involved with physics studies for planned next generation DIS experiments. We use weak coupling QCD renormalization group equations to understand the energy and virtuality dependence of the partonic structure of hadrons and nuclei. An important specialty of our group is using this information to understand and model the formation of thermalized quark gluon plasma. The subsequent evolution of this plasma can then be modelled using relativistic hydrodynamics.

The DGLAP equations describe the scale dependence of proton or nuclear parton distributions (PDFs) required in computing hard-scattering cross sections. In 2016 we completed a new global analysis of nuclear PDFs, resulting in set EPPS16, which is the very first one constrained by LHC data (dijets, Z, W). Also neutrino-DIS and pion-nucleus Drell-Yan data were used as a new input. The data constraints now allow for a much greater parameterisation freedom, significantly reducing the bias in the error analysis. Related to nuclear hard processes, we also studied the neutron-skin effect at the LHC, and participated in the FCC physics studies.

The BK evolution equation, in turn, describes the energy dependence of QCD scattering cross sections at high energy. We included a resummation of transverse momentum logarithms in the next-to-leading order (NLO) BK equation, to achieve its first stable numerical solution. We also proposed a new way to calculate single inclusive particle production in forward rapidity proton-nucleus collisions at NLO. We also solved for the first time the corresponding evolution equations for the odderon, a parity-odd component of the scattering amplitude permitted by the symmetries of QCD.

We use two complementary QCD approaches to describe the formation of quark gluon plasma in the initial stages of a heavy ion collision. In

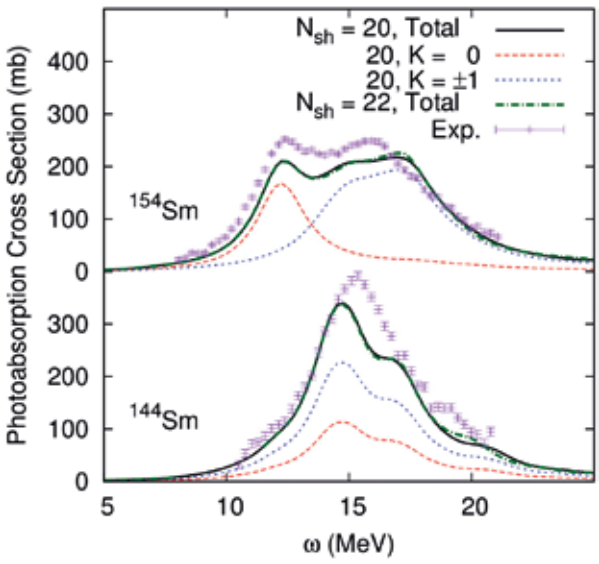
Tuomas Lappi, QCD and Strongly Interacting Gauge Theory project leader

the Colour Glass Condensate picture the process is described in terms of a strong classical gluon field, whose equilibration is characterized by the separation of the temperature and the plasmon mass scales which are initially the same. We developed new methods to measure the plasmon mass scale from classical gauge fields on the lattice and a new algorithm for a controlled study of linearised fluctuations around the classical gauge field. We also model the initial stages of heavy ion collisions starting from perturbative quark and gluon scattering, and using a saturation conjecture to control multiparticle production. Applying such initial conditions in our event-by-event hydrodynamical studies of heavy ion collisions, we computed various flow correlators for the LHC and RHIC experiments.

Markus Kortelainen, Nuclear Structure for Weak and Astrophysical Processes project leader

Nuclear Structure for Weak and Astrophysical Processes

Photo absorption cross section in rare earth nuclei: Collective excitations of atomic nuclei reflect properties of nuclear structure and the underlying interaction between nucleons. During 2016, we investigated giant dipole resonance (GDR) of heavy rare-earth isotopes by using the finite-amplitude-method quasiparticle random-phase-approximation (FAM-QRPA). The GDR is closely connected to the nuclear photo absorption cross section, having also an impact on the dynamics of various astrophysical processes. For most of the calculated cases, where experimental data existed, we could reproduce the measured photo absorption cross section well. With heavier rare earth isotopes there was some deficiency when comparing the values to the experimental data. We concluded that the construction of the next generation energy density functional (EDF) models should also incorporate data of GDR properties in order to improve the description of collective excitations.



Nuclear photo-absorption cross section in ^{144}Sm (spherical) and ^{154}Sm (deformed) nuclei, obtained with FAM-QRPA calculation with SkM* EDF.

No-core-configuration-interaction in multireference density functional theory: We used the recently developed no-core-configuration-interaction (NCCI) approach, rooted in multireference density functional theory, to conduct a pioneering study of beta-decay rates in light and medium mass T=1/2 mirror nuclei. The NCCI approach is capable of treating rigorously both the fundamental as well as approximate nuclear symmetries with a potentially unrestricted range of applicability throughout the nuclear chart. The calculated beta-decay rates were in good agreement with traditional valence space shell model predictions. In a second study, it was demonstrated that NCCI is capable of capturing many features of the low-lying energy spectra from light to medium mass nuclei. In addition, isospin breaking corrections for superallowed beta decay were computed for several nuclei.

Direct WIMP detection rates: Cosmological observations have provided plenty of evidence for the existence of dark matter. Presently, the weakly interacting massive particle (WIMP), motivated by various theoretical models going beyond the Standard Model, is a promising candidate to explain dark matter. In recent studies, we investigated elastic and inelastic scattering of the WIMP from target nuclei of ^{83}Kr and ^{125}Te. With inelastic scattering, in addition to detection of the nuclear recoil, the simultaneously observed de-excitation gamma ray would help to reduce the background signal. For the inelastic channel, we found that the nuclear response of ^{125}Te is more favourable to WIMP scattering compared to ^{83}Kr.

Domain Wall Dynamics

Domain wall dynamics in low-dimensional ferromagnetic structures is an active field of research driven by both numerous promising technological applications as well as fundamental physics interests. During 2016, we have made significant progress in understanding several key issues of domain walls (DWs) and their dynamics in various one- and two-dimensional systems.

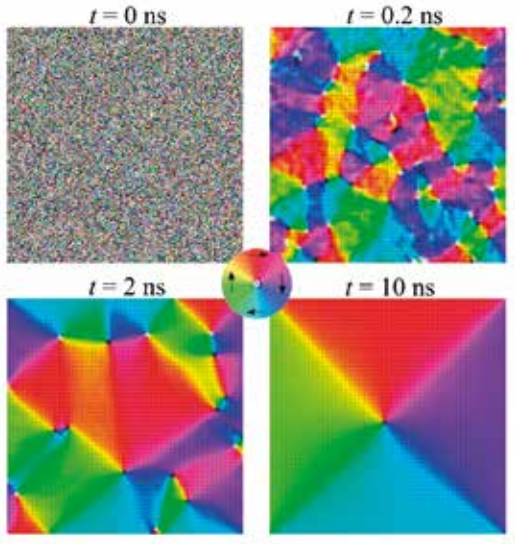
Linear creep dynamics in narrow ferromagnetic strips: The interplay of thermal fluctuations, the presence of various forms of quenched disorder (e.g., point defects and grain boundaries) interacting with DWs, and a weak external driving force is known to lead to slow, thermally activated creep motion of DWs. In a paper published in Scientific Reports, we show via a combination of extensive micromagnetic simulations and studies of a coarse-grained model, that in nanowire geometries the confined nature of the DWs leads to creep dynamics with the creep velocity linearly proportional to the driving force, in agreement with theoretical predictions, and in contrast to the highly non-linear relation encountered for extended DWs.

Domain wall dynamics in wide permalloy strips: To complement our earlier studies of the novel multi-vortex equilibrium DW structures occurring in wide permalloy strips, we have studied the magnetic field driven dynamics of such DWs. We have found a rich variety of dynamical behaviours, including dynamic transitions between different domain wall structures, periodic dynamics of a vortex core close to the strip edge, and the fact that for some combinations of the strip geometry and the driving field the system cannot support a compact domain wall.

Coarsening dynamics of topological defects in permalloy films: We have studied the dynamics of topological defects (vortices, antivortices and edge defects) in the magnetic texture of rectangular permalloy thin-film elements during relaxation from random magnetisation initial states. Our micromagnetic simulations reveal complex defect dynamics during relaxation towards the stable Landau closure domain pattern, manifested as temporal power-law decay of quantities such as the energy and defect densities. The related power-law exponents assume nontrivial values and are found to be different for the different defect types.

Apparent temporal correlations in crackling noise: A multitude of slowly driven systems respond by exhibiting bursting dynamics, which consist of a sequence of events with a broad event size distribution; an example is Barkhausen noise due to the field-driven jerky motion of DWs in disordered ferromagnets. Often, such systems are observed to exhibit temporal inter-event correlations. In a paper published in Physical Review Letters, and also featured by APS Physics, we show that these observations may be simply due to the way in which such events are defined: a finite detection threshold results in part of the avalanche activity "hiding" below such thresholds, and implies that the "true" bursts are broken into pieces by the thresholding process. Our theory, based on a description of the avalanche activity in terms of a stochastic process with specific properties, could be a possible explanation for the observed inter-event correlations in a large class of systems exhibiting crackling noise.

Lasse Laurson, Domain Wall Dynamics project leader



Coarsening dynamics of defects (vortices, antivortices and half-antivortex edge defects) in the magnetic texture of rectangular permalloy thin film elements studied via micromagnetic simulations. The initial state has a random magnetisation in each discretisation cell, and the system relaxes towards the stable Landau closure domain structure, with power-law temporal decay of the energy and defect densities (Phys. Rev. B 94 (2016) 144428).

CMS Programme

Kenneth Österberg,
CMS Programme director

The HIP CMS Programme is responsible for co-ordinating the Finnish participation in the CMS and TOTEM experiments at the Large Hadron Collider (LHC). The Compact Muon Solenoid (CMS) is a general purpose experiment covering detailed investigations of particles and interactions at LHC energies, the origin of electroweak symmetry breaking (Higgs bosons), and the search for signatures of new physics beyond the Standard Model of particle physics. The TOTEM experiment is a dedicated experiment, located at the same LHC interaction point as CMS, focusing on the scattering of particles at small angles ("forward"). The programme is divided into four projects: the CMS experiment, responsible for physics analysis and operations, the CMS upgrade, responsible for the Finnish contribution to the CMS upgrades, the Tier-2 and the TOTEM projects. The Finnish groups in CMS are: HIP (currently 12 authors), University of Helsinki (3 authors), and Lappeenranta University of Technology (2 authors). In TOTEM, there are 9 authors affiliated with HIP, out of which 5 are also affiliated with the University of Helsinki.

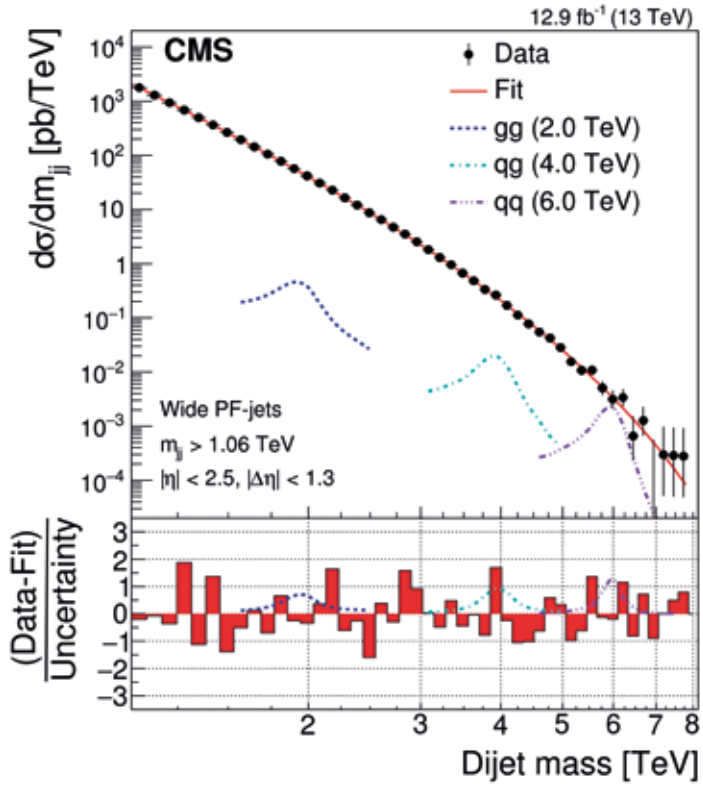
Mikko Voutilainen,
CMS Experiment
project leader

CMS Experiment

Introduction

The CMS experiment project is involved with detector operations on tracker alignment and jet energy corrections, and leads CMS efforts in data preservation. The physics analyses focus in particular on B physics, jet physics and Higgs searches. Significant work was done on all operation fronts in 2016, and the physics highlights from 13 TeV with HIP contributions include the first CMS papers on both new physics searches (dijet resonances) and Standard Model measurements (inclusive jets), as well as the first 13 TeV update on the charged Higgs search.

The year 2016 saw the publication of final Higgs properties from the LHC Run 1 and the disappearance of the tentative 750 GeV diphoton signal from December 2015 that had excited theorists. No tentative new physics signals were seen, but the LHC performance surpassed expectations, and CMS collected an excess of 40 fb^{-1} data, almost twice that in Run 1. J. Heikkilä, M. Kortelainen and P. Eerola were awarded the FPS Young Physicist Honorary Award, the CMS Achievement Award and the Prof. E.J. Nyström prize, respectively.



Mass spectrum (points) of the CMS dijet resonance search compared to a fitted parameterisation of the background (solid curve) for the high-mass region. The lower panel shows the difference between the data and the fitted parameterisation, divided by the statistical uncertainty of the data. Predicted signals from narrow gluon-gluon, quark-gluon, and quark-quark resonances are shown with cross sections equal to the observed upper limits at 95% CL.

Detector Operations

Tracker alignment: Geometrical alignment of the CMS Tracker and its 15148 modules is an essential ingredient for high-quality physics results. HIP has a long history in the Tracker Alignment group, and T. Lampén was its co-convener in 2016. In 2016, important features were taken into use, e.g., an automatic procedure correcting unexpected movements of pixel half-shells.

Jet Energy Corrections: Jet energy corrections (JEC) are critical for the performance of physics analyses involving jets, which encompasses most CMS analyses. HIP has contributed to the success of JEC since 2008, and M. Voutilainen was co-editor of the Run 1 legacy JEC paper submitted to JINST in 2016. Together with H. Siikonen, he participated in five updates of JEC for 2015+2016 Run 2 data.

Data preservation and open access: Led by K. Lassila-Perini, CMS made the second public release of research data in April, in total > 300 TB of data. In parallel, services were developed for the preservation of analysis details. HIP has prepared a pilot project to bring the scientific data to use in schools, and material is ready for Open data training for teachers, which will take place in 2017.

Physics Analysis

B physics: The B physics team was involved in the weak mixing phase ϕ_s and effective lifetime analyses of the decay channel $B_s \rightarrow J/\psi\, \phi$. The ϕ_s paper was published in PLB, while the effective lifetime measurement conducted by T. Järvinen entered CMS internal review and a paper on B-hadron lifetimes is expected to be published during 2017. G. Fedi completed his PhD thesis on studies of the B_s - $\bar{B}_s$ system in February.

Jet physics: From the jet physics team, J. Pekkanen was lead analyser in the first LHC new physics paper, the CMS dijet resonance search published in PRL in February and in the ICHEP update in August. H. Siikonen completed his MSc thesis on jet flavour algorithms, and started PhD studies on ultra-precise top quark mass measurement. M. Haapalehto started as research assistant on jets with CMS OpenData. Team leader M. Voutilainen co-convened the CMS Standard Model Physics / Jets group and assisted in the first CMS Standard Model measurement, the 13 TeV inclusive jet cross section published in EPJC in August.

Higgs physics: New results from the charged Higgs searches at 13 TeV centre-of-mass energy were made public using part of the data recorded in 2016. The searched mass range was extended to 3 TeV. The team (S. Lehti, S. Laurila, and J. Havukainen, who completed a MSc thesis and started PhD studies) continues the analysis with all the data recorded in 2016. The analysis with the whole 2016 data includes for the first time also the intermediate mass range, where the charged Higgs boson has a mass close to the top quark mass. In addition, the team was responsible for the development of the tau+MET trigger, used in the charged Higgs boson, W' and boosted WH searches. J. Heikkilä contributed to one of the central Run 1 results, the combined ATLAS and CMS measurements of the Higgs boson properties. The analysis was published in JHEP in August.

CMS Upgrade

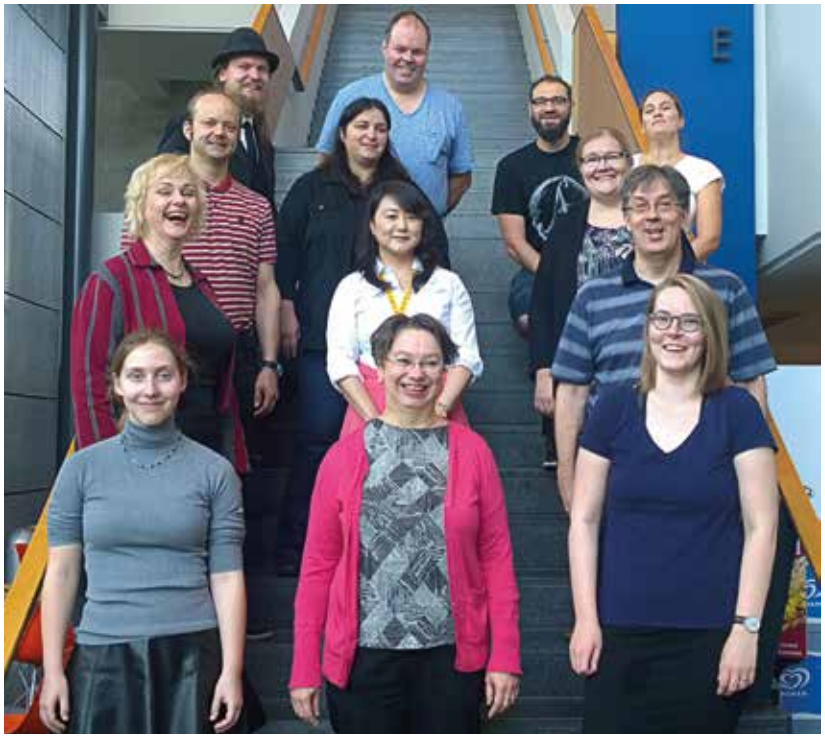
The CMS Upgrade project is responsible for the Finnish hardware contribution to the CMS experiment. Since 2013 the main activity has been the Phase I Upgrade of the pixel detector. The new detector will be installed into CMS during the winter technical stop at the beginning of 2017.

For the Phase I Upgrade, HIP committed to deliver 50% of the bare pixel detector modules for the third layer of the barrel pixel detector. This is 250 modules out of 1900 in total, and 4000 individual ROCs flip-chip bonded to the detectors. The project started in 2013 with a successful pre-series production together with Advacam Ltd. in the Micronova Centre for Micro and Nanotechnology in Espoo. The actual production took place from autumn 2014 until the beginning of 2016 and was successfully finished in the expected time and budget frame with an excellent quality of the module flip-chip bonding.

Panja-Riina Luukka, CMS Upgrade project leader

PSI researchers merging the CMS Barrel Pixel detector Layer 3 into Layer 4. The pixel modules produced in Finland are installed into Layer 3 and cover half of the whole layer. *(Photo courtesy of R. Horisberger/PSI).*

All the flip-chip bonded modules were shipped from Helsinki to CERN to the shared CERN/NTU/HIP module production centre after a preliminary quality assurance with a probe station set-up in the HIP Detector Laboratory. In the production centre, the bare modules were integrated into full modules containing all the interconnections and mechanics needed for their integration into the barrel support structure and full pixel detector data acquisition. In 2015, HIP started an exchange programme with the Finnish School of Watchmaking offering practical training at the CERN module production centre. Two fine-mechanics students from the school constructed most of the detector modules and developed several high-precision tools for improving the quality of the module production. The last full module of the HIP quota was produced by August and all modules were shipped to Zürich at the end of summer 2016 for the electrical reception tests and final integration into the pixel barrel support structure.



Some of the CMS programme personnel gathered on the stairs of Physicum.

In addition to the Phase I Upgrade work, the group also carried out research on novel detector and interconnection technologies aimed for the CMS Phase II Upgrade. In 2015, an R&D project together with two other CMS groups (DESY and University of Hamburg) for next generation silicon pixel detectors was launched. The project is benefitting from the earlier studies with the Laboratory of Inorganic Chemistry (UH), the Accelerator Laboratory (UH) and the Electron Physics Group (Aalto) on the use of Atomic Layer Deposition (ALD) to grow thin films in silicon strip detectors. The objective is to use the ALD thin films on thin p-type pixel detectors with very small pixel sizes, which will be needed in future high luminosity conditions. The design of the new detectors and test structures including diodes suitable for the CMS beam luminosity telescope was finalised in spring 2016, and the first wafers were received in autumn 2016. The processing was done at Micronova in collaboration with E. Tuovinen from VTT Technical Research Centre.

In autumn 2016, the HIP CMS Upgrade group started collaboration with the Radiation and Nuclear Safety Authority (STUK). The purpose is to investigate if the technology used in particle physics also can be used in nuclear safety and medical applications. Preliminary results of the first test beam in December were promising and encourage further investigations.

Lappeenranta activity: The CMS group at Lappeenranta University of Technology (LUT),

led by Professor T. Tuuva, participates in the design and construction of the readout electronics and data acquisition system for the CMS GE1/1 forward muon station. This new muon station of the CMS forward trigger system is using Gas Electron Multiplier (GEM) technology. LUT is in charge of 90 pieces of GE1/1 GEM electronics boards (GEBs) with VFAT2 readout hybrids. In 2016, the prototyping phase and slice tests of the GE1/1 on-detector electronics has been completed and the first wedge-shaped GEBs have been tested and installed at the CMS.

Tier-2

CMS 13 TeV analysis and simulation jobs were running on the HIP Tier-2 site during the second year of the LHC Run 2 with good performance ensured by the collaboration between HIP, CSC (IT Center for Science Ltd.) and the Nordic e-Infrastructure Collaboration (NeIC) Nordic DataGrid Facility (NDGF). T. Lindén represented HIP in the NeIC Nordic LHC Computing Grid steering committee.

CMS jobs were run at Kumpula on the Linux clusters Korundi (400 cores, 2008) and Alcyone (840 cores, 2011). The Jade cluster was moved to Aalto and the old HP D2600 disksystem to Kumpula. Work continued to take the CMS 5.5 M billing unit allocation on the Kajaani CSC cPouta cloud system into use. The University of Helsinki (UH) cluster Kale was taken into general use, but not yet for CMS.

The Nordic LHC network connection was upgraded from 10 to 20 Gb/s using MPLS technology. The new HPE Apollo 4510 disk system (2106) was able to saturate the 20 Gb/s WAN link. The dCache services at CSC ran very stably in 2016.

The collaboration between HIP and UH Department of Computer Science started in the cloud computing project Data Indirection Infrastructure for Secure HEP Data Analysis (DIIHEP) continued in 2016. The DIIHEP IEEE Transactions on Services Computing paper was presented at the 29th NORDUnet Conference.

The Tier-2 resources are operated, maintained and monitored by HIP, CSC and NDGF to spot problems early with Site Availability Monitoring jobs. According to the statistics, the Tier-2 resources were in the "ready" state 62.74% of the time (71.84% in 2015). The high load increased the "No Info" status to 18.49% from 2.88% in 2015. There were 23 GGUS tickets (27 in 2015) concerning HIP.

PhEDEx moved to HIP 1956 TB of production data (419 TB in 2015) and 400 TB of test data (361 TB in 2015). From HIP to elsewhere 1132 TB of production data (290 TB in 2015) and 216 TB of test data (211 TB in 2015) were moved. In total PhEDEx moved 3705 TB of data on the WAN (1281 TB in 2015). In total dCache transferred 6751 TB (3045 TB in 2015).

A total of 0.54 M CMS grid jobs (1.341 M in 2015) using 23.2 MHS06 CPU hours (26.7 MHS06 CPU hours in 2015) were run with an average CPU efficiency of 73.9% (68.0% in 2015).

TOTEM

The TOTEM project is responsible for co-ordinating the Finnish participation in the TOTEM experiment. The Helsinki group consists of a university lecturer (K. Österberg), an emeritus professor (H. Saarikko), a senior scientists (F. García), a post-doc (M. Berretti), three PhD students (T. Naaranoja, F. Oljemark and J. Welti) and two students (L. Martikainen and P. Helander). The project leader is also the TOTEM physics co-ordinator.

TOTEM is currently the leading forward physics experiment at LHC focusing mainly on elastic scattering, total cross section and diffraction. Using LHC Run 1 (2010–12) data, TOTEM has published 12 physics measurements, notably the total proton-proton (pp) cross section at $\sqrt{s}$ = 7 and 8 TeV and the differential elastic pp cross section over a wide $|t|$, momentum transfer squared, range. Lately the TOTEM physics programme has been extended to exclusive and hard diffractive processes through common data taking with CMS, both for special high β^* runs

Tomas Lindén,
Tier-2 Operations
project leader

Kenneth Österberg,
TOTEM
project leader

to access pb-nb cross sections (acceptance to all mass in exclusive processes) and for standard high luminosity running to access fb cross sections (mass acceptance > 300 GeV in exclusive processes), the CMS-TOTEM precision proton spectrometer (CT-PPS).

The start of CT-PPS was accelerated due to the indications by CMS and ATLAS of a possible 750 GeV resonance decaying to photon-photon (γγ) in their 2015 data. CT-PPS started to take data in June 2016 using the TOTEM silicon strip detectors and collected 15 fb^{-1}. The diamond detectors, consisting of four planes of scCVD diamond sensors, collected 2 fb^{-1} for commissioning. The data sample collected already constitutes the largest central diffractive (CD) sample ever collected. Several analyses are currently ongoing as searches for exclusive dileptons or γγ and the measurements of CD events with large missing masses.

The group continues to be responsible for the inelastic rate analysis for the cross sections measurements, both 2.76 (J. Welti) and 13 TeV (P. Helander), and play a leading role in the soft diffractive measurements: single diffraction at 7 TeV (F. Oljemark) and soft event classification at 8 TeV (J. Welti). The group (M. Berretti) is also involved in the CMS-TOTEM analysis for exclusive production of low mass resonances, which will allow the study of glueball candidates. HIP continues to maintain the T2 telescope. Finally, HIP is also actively involved in the diamond based proton time-of-flight (TOF) detector upgrade for both the vertical (special runs) and the horizontal RPs (CT-PPS). The Helsinki contribution is covered by infrastructure funding from the Academy of Finland.

In 2016, the group (M. Berretti) led the tests, the assembly and the installation of the diamond based TOF detector for CT-PPS. Eight diamonds planes, four per RP, were assembled. The installation of the two packages in the LHC tunnel was completed in June (see the figure above). First data was taken in October, once the data acquisition firmware was available. The group also led the R&D on novel double layer diamond detectors, which will allow improvement of the TOF performance by a factor of 1.7. Moreover, Ultra Fast Silicon Detectors (UFSD) were also tested to improve the TOF performance further. The installation of one UFSD plane in each CT-PPS arm is foreseen in spring 2017.

One of the CMS-TOTEM proton precision spectrometer diamond time-of-flight detector packages before installation in the LHC tunnel.

Nuclear Matter Programme

Ari Jokinen, Nuclear Matter Programme director

The Nuclear Matter Programme involves the participation of Finnish teams at CERN in studies of two aspects of nuclear and hadronic matter. These are cold exotic matter with the extreme composition of its proton and neutron numbers on the one hand and dense matter created in relativistic heavy ion collisions on the other hand. Exotic nuclei are studied at the ISOLDE facility while the study of quark gluon plasma and related phenomena takes place at ALICE. The Nuclear Matter Programme has also continued co-ordinating the Finnish participation in the planning and construction of the FAIR project in Darmstadt. FAIR stands for Facility for Antiproton and Ion Research. The Finnish involvement in FAIR includes participation in the construction of the Super-FRS facility and in the NUSTAR Collaboration for nuclear structure, reaction and astrophysics studies. Since the beginning of 2015, the Nuclear Matter Programme has also included the ALICE-Forward physics project.

ALICE

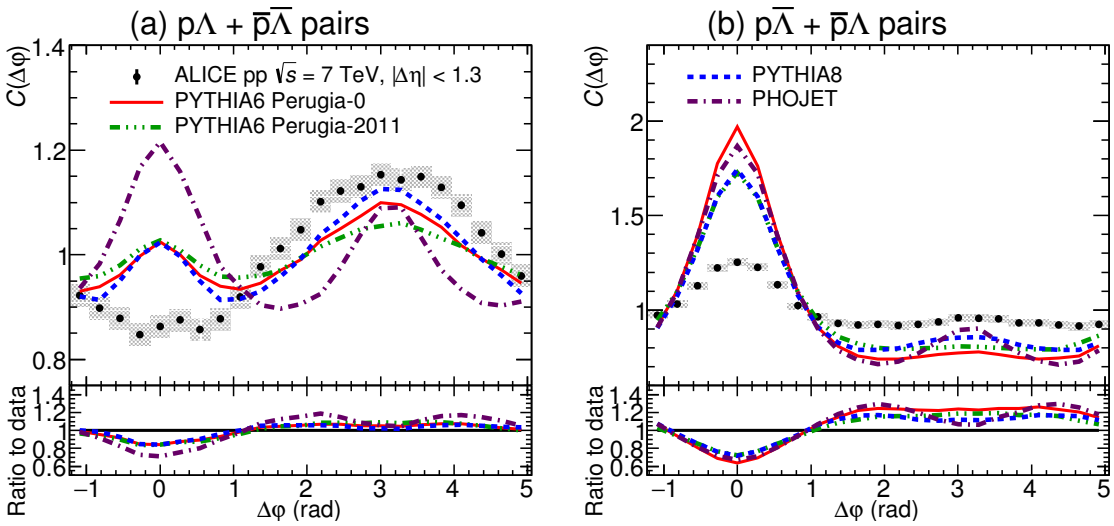
Jan Rak, ALICE project leader

In 2016 LHC continued to collect pp data at 13 TeV with very high luminosity and particularly the CMS and ATLAS experiments recorded an impressive amount of data. At the end the year the LHC delivered proton-lead collisions first at 5.02 TeV, as in the previous run, but at the end also with the record pPb centre-of-mass energy of 8 TeV. The collection of the pPb data was successful at ALICE. One highlight of our group was the excellent performance of the level-0 (L0) single photon EMCal trigger system used in the rare trigger data taking throughout the year.

On the hardware side, our group is also deeply involved in the upgrade of the Time Projection Chamber (TPC), and the Fast Interaction Trigger (FIT) system, the new ALICE forward detector to replace FMD, T0, and V0 after the Long Shutdown 2. Our main task within the TPC upgrade is to perform quality assurance studies for about 300 m^2 of Gas Electron Multiplier (GEM) foils, which will replace the old TPC readout chambers. Particularly, we measure gain uniformity and leakage currents via optical measurements in the HIP clean room. These studies have been successful and the Wigner Institute in Budapest decided to copy the same test set-up to their facilities. Our PhD student M. Vargyas has participated in building and performing measurements in Hungary.

The current main directions of the physics analysis performed by our group involve high-p_T triggered correlations and studies of the jet transverse structure. When studied in pp, pPb and PbPb collisions, the results provide insights into the QCD radiation and its modifications in cold nuclear matter and in the quark gluon plasma. We also study flow patterns via correlations among Fourier coefficients for detailing the azimuthal anisotropies of the final hadron momentum distributions in PbPb collisions. These correlations are used to constraint the transport properties of strongly interacting matter, like the shear viscosity to entropy ratio of QGP.

J. Viinikainen presented his studies on the transverse structure of jets via two-particle correlations in pp and pPb collisions at the Hard Probes 2016 Conference in Wuhan, China. D. J. Kim will present studies on flow correlations in the Quark Matter 2017 Conference in February in Chicago, USA. These two conferences are both large and highly valued in our field. Both Viinikainen and Kim will chair the paper committee on these results once ALICE will publish them.



Azimuthal correlation functions of identified baryon-baryon and baryon-anti-baryon pairs in proton-proton collisions compared to event generators.

One of the highlights of the scientific programme of ALICE is the detailed study of correlation functions among identified particles in pp collisions at 7 TeV [ALICE Collaboration, arXiv:1612.08975 [nucl-ex]].

The left panel of the figure above shows the depletion of the near side in the baryon-baryon correlations that none of the standard event generators can produce. This depletion is not seen in the baryon-anti-baryon correlations shown in the right panel. It turned out that the most used event generators, PYTHIA and Phojet, cannot reproduce these correlation functions although they provide a good description of the meson correlations. This implies that the baryon production mechanisms need to be revised in the event generators so they can provide insights into baryon production in fragmentation.

Janne Pakarinen, ISOLDE project leader

ISOLDE

In 2016, HIP-ISOLDE activities at CERN started in May with the NanoRad project, where HIP Adjoint Scientists K. Helariutta and U. Jakobsson conducted implantation of radionuclides in porous silicon wafers. The second HIE-ISOLDE campaign, again with the upgraded linear accelerator now providing radioactive beams up to 5.5 MeV per nucleon, reserved an impressive amount of 20% of ISOLDE beam time in 2016. The majority of it was devoted to Coulomb excitation experiments at MINIBALL, where the main focus was on the evolution of quadrupole collectivity at both ends of the Sn isotopic chain. After the radioactive beam campaign, the final commissioning of the SPEDE spectrometer was completed with a stable ion beam. Much of the related preparatory work was carried out during the summer by J. Ojala (HIP summer student) and D. Cox from the University of Jyväskylä. The SPEDE conversion electron spectrometer has been developed by an international collaboration led by Academy Research Fellow J. Pakarinen.

NanoRad Activities at ISOLDE

The *NanoRad* project develops radioactive mesoporous silicon nanovectors (PSi) for cancer theranostics. Porous silicon nanoparticles are implanted with a radioactive nuclide that can be used for tracing the migration of the drug-carrying

nanovector through nuclear imaging such as PET or SPECT. The radionuclide can, furthermore, be chosen so that its radiative properties can be used for tumour treatment as well.

Wafers of THCPSi type were implanted with the radioactive nuclide ^{159}Dy at the GPS separator. Close to 30 MBq was obtained in four wafers. The radionuclide ^{159}Dy has a half-life of 144.4 days, which makes it a good candidate for long stability studies. On its decay it emits low-energy conversion and Auger electrons, which could in addition generate a therapeutic effect to the surrounding tumour tissue. Dysprosium has, moreover, a high yield at ISOLDE due to the possibility of laser ionisation at the target.

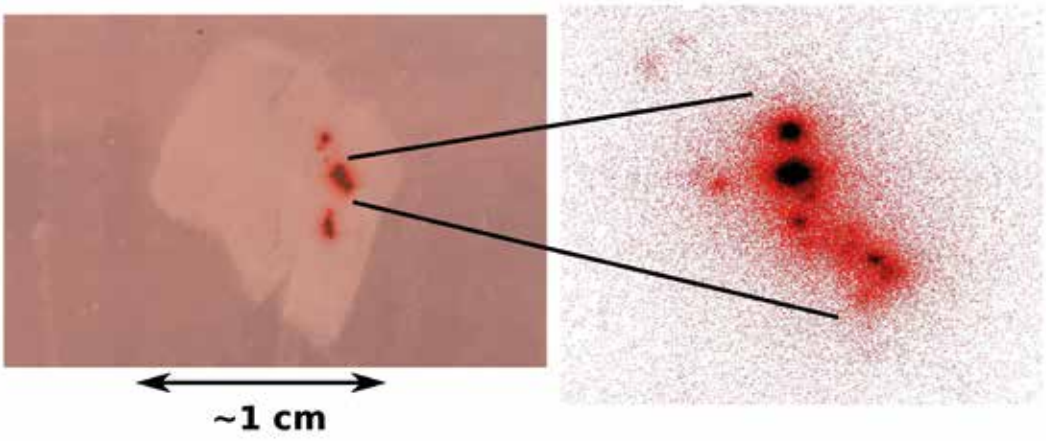
The wafers were post-processed into particle dispersion at the Department of Chemistry, University of Helsinki and injected into tumour bearing mice. The aim was to study the in vivo stability of the radioactive PSi when directly injected into tumour xenografts placed in nude mice. A stability study over three weeks was performed. The results of the project look very promising and will be published in the near future.

FAIR (Facility for Antiproton and Ion Research in Europe GmbH) Operations

Tuomas Grahn, FAIR
project leader

The FAIR facility civil construction moved ahead in 2016 and the Integrated Master Plan, which contains civil engineering, accelerator development and construction, and the scientific experiment co-ordination, was put together by the FAIR management. The Master Plan will serve as the basis for the realisation of FAIR and is a major milestone. The plan was approved by the shareholders in September 2016.

The FAIR management announced that the science programme of the FAIR Phase 0 will start in 2019 with the upgraded GSI facilities (SIS18 synchrotron). Therefore, in the September NUSTAR meeting, preparatory work for the physics cases for the science proposals started. Finnish researchers have currently strong contributions to the NUSTAR sub-collaborators of HISPEC/DESPEC and Super-FRS Experiment Collaboration with focus on the third nucleosynthesis r-process peak near the neutron number N=126.



Photograph of an example histological section of a tumour with a radiotomographic figure of the section superimposed on the photograph. The tumour has been injected with ^{159}Dy implanted PSi. (Left) The radioactive region on the section is indicated in red, with the activity growing toward black. The pixel size is 100 microm. (Right) A focus on the central active region, with the pixel size reduced to 3 microm reveals small-scale details.

The Super-FRS Experiment Collaboration is a sub-collaboration of NUSTAR. The collaboration focuses on the experiments that employ the Super-FRS (and existing FRS) fragment separator as a separator-spectrometer in low- and medium-energy nuclear physics experiments. HIP is deeply involved in the tracking detector development for Super-FRS. Professor emeritus J. Äystö is the chair of the Super-FRS Experiment Collaboration Board and T. Grahn is the deputy technical director.

Super-FRS Tracking and Diagnostics Detectors

Risto Orava, ALICE-Forward project leader

The Finnish main contribution to the Super-FRS separator is the beam tracking and diagnostics concept. It includes the GEM-TPC position detectors (developed by HIP in collaboration with GSI), MUSIC energy-loss detectors and SEM-Grid beam profile detectors.

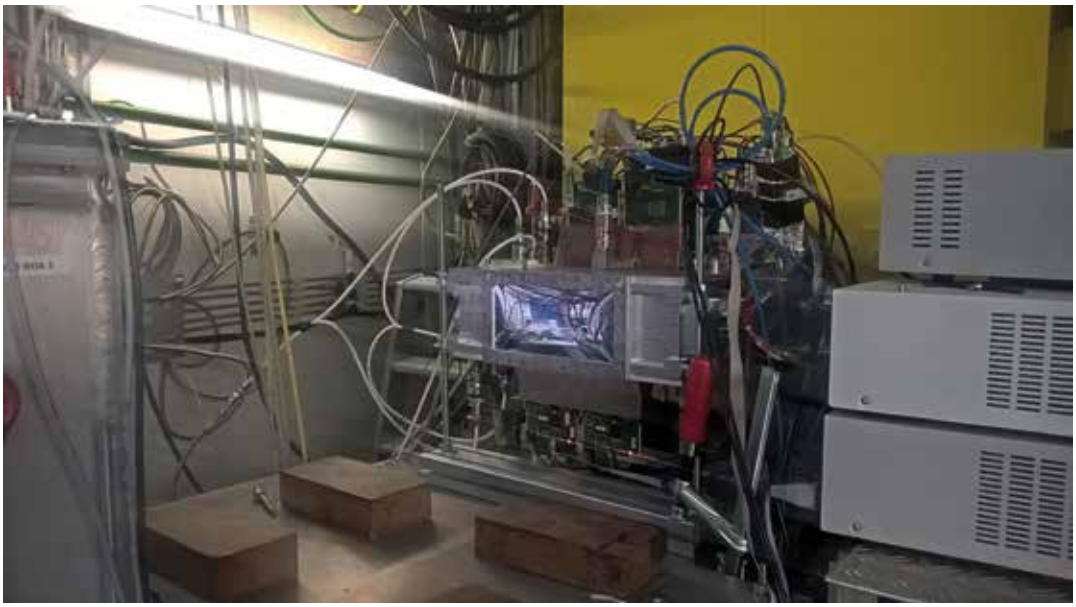
Pre-commissioning of the GEM-TPC tracking detector started in 2016, first in the experiment with the 55 MeV protons at the Accelerator Laboratory of the University of Jyväskylä followed by the experiments at the FRS at GSI with high-energy heavy-ion beams.

In addition, final tests of the prototype MUSIC energy-loss detector and especially new preamps were carried out with fragment beams at FRS. The MUSIC detector will be built in collaboration with GSI and CEA/DAM Bruyères-le-Châtel.

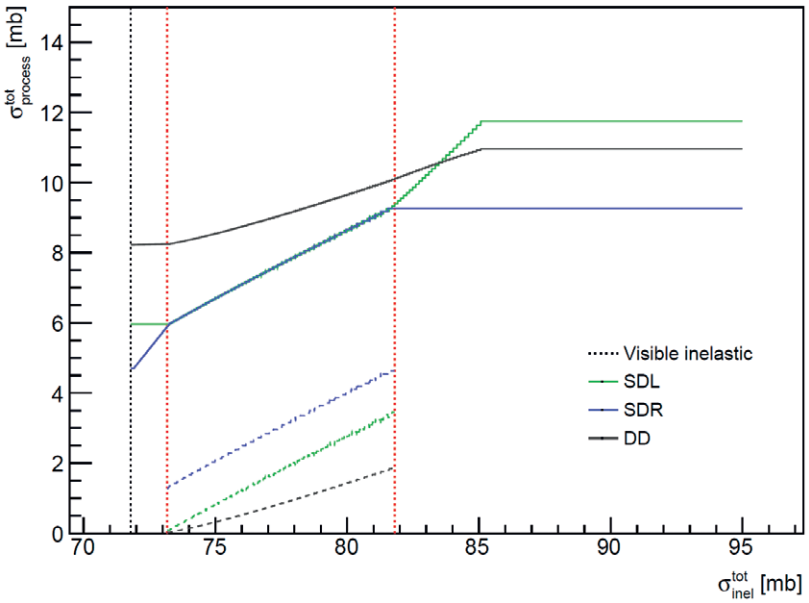
Collaboration has been initiated with Fermilab to produce the SEM-Grid beam profile detectors for Super-FRS. A prototype detector was received in 2016 that will be tested with readout modules developed by GSI.

Forward Physics in ALICE at the LHC

The Helsinki Forward Physics group concentrates on studies of the space-time structure of high energy hadron collisions. The ALICE experiment at CERN provides an ideal framework for these studies based on the set of central and forward detectors with their excellent tracking, particle identification, rapidity and transverse momentum coverage. Moreover, during the normal high luminosity proton-proton runs at the LHC, ALICE can continue collecting



The HGB4 GEM-TPC prototype detector installed at the S4 focal plane of FRS at GSI for the pre-commissioning studies.



The measured inclusive diffractive cross sections (σ_{SDL}, σ_{SDR}, σ_{DD}) as a function of the total inelastic proton-proton cross section (σ^{tot}_{inel}). The vertical red dashed lines indicate the allowed values of σ^{tot}_{inel}. Extrapolations of the measured visible cross sections (along the black vertical line) yield the invisible cross sections (shown by the dashed lines between a pair of red vertical lines). *[M. Mieskolainen, to be published.]*

precious forward physics data due to its special optics arrangement while the larger general purpose experiments, ATLAS and CMS, have to cope with large amounts of simultaneous collisions during the same bunch cross-overs (pile-up).

In diffractive physics, ALICE is producing new high quality measurements of inclusive diffractive cross sections. In the figure above, the single diffractive and double diffractive cross sections are shown as a function of the total inelastic proton-proton cross section.

By the end of the 2016 run periods, ALICE had collected about 0.5 pb^{-1} of proton-proton Double Gap events for the analysis of glueballs and exotic central states. During 2016, publications on inclusive diffractive cross sections, glueball analysis and partial wave analysis were completed, and presentations at several major conferences were given.

Using the LHC Ring for Tagging Forward Physics Events

In 2016, a proposal for using the LHC ring in forward physics event tagging was being completed (New Scientist, Daily News, 25 April 2016, http://arxiv.org/abs/1604.05778), and presentations were given at several major conferences.

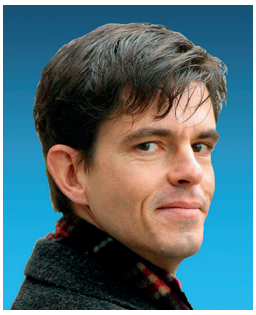
The proposal aims at configuring a new physics search facility based on the existing instrumentation of the LHC ring and the LHC experiments. The approach is novel, and uses the LHC Beam Loss Monitoring (BLM) and other LHC beam instrumentation devices for tagging the new physics event candidates in a model independent way. The physics potential of the proposed facility is huge.

A number of selected physics processes, based mainly on Central Exclusive Production (CEP) are studied. The CEP processes provide an ideal test ground for the proposal, with a pair of coincident final state protons – exiting the LHC beam vacuum chamber – being used to tag the event candidates. The fractional momenta of the final state protons are directly related to the invariant mass of the centrally produced system.

The Helsinki group is also involved in the CERN experiment MoEDAL, searching for magnetic monopoles, and the CDF experiment at the Fermilab Tevatron.

Technology Programme

Saku Mäkinen,
Technology Programme
director



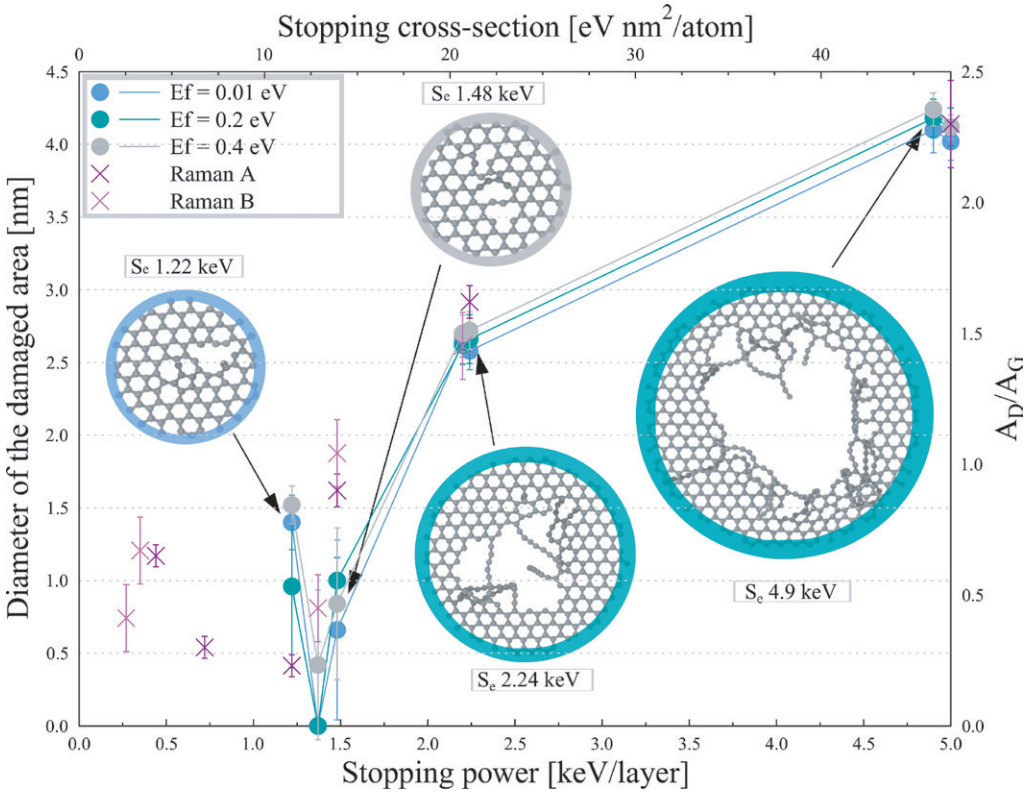
The Technology Programme aims to integrate the projects that have significant technology development, transfer and pre-commercialisation activities of HIP in the same programme. During 2016 the Technology Programme included five research areas supporting the HIP strategy and on-going activities, namely accelerator technology, computing performance and efficiency, medical imaging and pattern recognition, business incubation, and radiation-detection instrumentation.

Markus Aicheler,
Accelerator
Technology
project leader

Accelerator Technology (MAT/MSM)

In the group of Materials for Accelerator Technology (MAT) we investigate the modification of material properties in the harsh operational conditions of powerful accelerators used for cutting-edge technologies. The focus is to determine the cause of vacuum arcing, i.e., breakdowns, which are complex phenomena ranging from atomic diffusional processes to micrometer scale local plasmas. In 2016, we focused on diffusion on Cu and Fe surfaces, which are modelled as rigid lattices, with no relaxation included. We solved the problems by using approximations reasonable within the modelling framework. Thus, the energy barriers for the kinetic Monte Carlo model developed in the group were sufficient to describe the flattening of sharp surface protrusions and

Flyura Djurabekova,
University Researcher,
SIMAT



Defect size as a function of the energy deposited in the graphene layer. Simulation results of the average defect diameter (left y-axis) agree very well with the Raman results (right y-axis).

explained the formation of Fe nanocubes in an inert gas condensation magnetron sputtering chamber. The latter had been a long-standing puzzle for nanotechnology science. We also developed a couple of new algorithms to introduce in the molecular dynamic codes the electronic current and electric field effects. This year, we have transferred the experimental set-up for measurements of breakdown rates from CERN. Now, we will carry out new in-house experiments to validate our models. In 2016, we have achieved significant progress in understanding the interaction of swift heavy ions with graphene, the base material for solid state charge stripping foils for the accelerators at FAIR.

The MAT group consists of one University researcher (group leader, Dr. F. Djurabekova), 2 postdoctoral researchers (Dr. V. Jansson and Dr. A. Kyritsakis), 5 graduate students (E. Baibuz, M. Veske, A. Saressalo, S. Vigonski and H. Vázquez Muíños).

The Module, Structures and Manufacturing (MSM) group within the Accelerator Technology project collaborates strongly with various groups and projects at CERN and with FAIR: e.g., the Compact LInear Collider (CLIC) study at CERN is developing a two-beam technology for a multi-TeV electron positron collider in view of a decision on the future direction of the high energy frontier in the coming years. The CLIC study has entered a new phase of technical development and optimisation that will lead to a Technical Implementation Plan by 2019.

The focus of the HIP contribution is on a) R&D for the manufacturing of CLIC RF structures and the re-engineering of the so called CLIC module (the smallest modular entity containing all the sub-systems of the accelerator); b) ramping up an R&D activity related to Beam Instrumentation in close collaboration with the BI group at CERN leading up to a future PhD thesis; c) co-ordinating part of the Finnish in-kind contribution for FAIR; d) preparation for a new submission of the Compact-Light (former XbFEL) InfraDev proposal.

The work was executed in close collaboration with the CERN CLIC accelerating structures group of Dr. W. Wünsch and the CLIC module team of Dr. S. Döbert (co-led by Dr. M. Aicheler), and several Finnish industrial and academic partners. In 2016 the project had one MSc student (A. Moilanen), one researcher (J. Väinölä) and the project leader (Dr. M. Aicheler) at CERN plus two PhD students (A. Meriläinen and R. Montonen) and one MSc student (A. Holmström) based in Helsinki.

More details can be seen at: http://research.hip.fi/hwp/acctech/accelerator-technology/

Green Big Data

Jukka K. Nurminen, Green Big Data project leader

There are several new trends in scientific computing these days: a large part of computing tasks are processed in cloud computing centres using virtualisation technologies; the sizes of the data sets have become extremely large and complex causing challenges for data analysis; and energy consumption has become one of the main costs of computing, usually exceeding hardware and personnel costs. Therefore, there is an obvious need for new research to find more efficient hardware and software solutions for this big data analysis. Especially in computing intensive sciences, such as high energy physics (HEP), powerful but still energy-efficient solutions are essential. For example, it has been estimated that the computing needs of CERN LHC experiments will be ten times higher in 2020 than today.

The Green Big Data project has focused on optimising the energy consumption of scientific computing clusters used for HEP computing related to CERN experiments. In 2016, we contributed to this area of research by

- developing models for estimating and controlling HPC energy-consumption,
- performing data-analysis of data centre logs and power traces with machine learning techniques,
- studying and prototyping solar energy driven distributed computing,
- contributing to the *Scalable and Secure Infrastructures for Cloud Operations* Horizon 2020 project by leading the *High energy physics data processing* scenario.

Work on these items has continued in collaboration with Aalto University.

The personnel of the project included three part-time senior researchers, two PhD students (one of them finished at the end of spring when the publications for his thesis were completed) and two summer trainees during the summer. One MSc thesis was completed in the project (*Energy Efficiency in High Throughput Computing: Tools, techniques and experiments* by G. Pestana).

The project has submitted funding applications to NordForsk and to the WiFiUs-call of the Academy of Finland. Both of them are still under evaluation.

The goal for 2017 is to finalise the two on-going doctoral theses, continue research on modelling power consumption, exploit the results achieved, and prepare follow-up projects.

Professor H. Charaf from Budapest University of Technology and Economics performed a mid term evaluation of the project on the request of SAB. His report found that the Green Big Data project provides value and contributes to the goals of the ICT community.

AvanTomography

Ulla Ruotsalainen, Biomedical Imaging project leader

The Biomedical Imaging AvanTomography project aims to develop a dual panel positron emission scanner with axial PET geometry. In addition to the possible use of this dual PET scanner in mammography that was explored earlier, dual panel axial PET geometry was found also to be feasible for proton therapy. During proton therapy, the tumour (mostly in the brain) is irradiated with a proton beam. During the therapy, the beam is focused on the tumour, but nearby tissues are also affected. PET imaging is used during or after proton therapy in order to follow the dose deposition in the patient and make sure that critical areas/tissues that are sensitive to the radiation beam are unaffected. In-beam PET imaging refers to PET imaging during proton therapy. In this setting, the proton beam cannot be blocked by the PET detectors, leading to a partial PET ring. Dual panel scanners have been proven to have higher sensitivity than partial ring configurations as they are nearer to the patient and cover more area for radiation detection. However, similar to breast imaging, the trade-off between sensitivity and spatial resolution poses a problem also in proton therapy. A high sensitivity is needed to collect the most photons emitted from the patient, but high spatial resolution is also important because the distal edge of the proton beam need to be as accurate as 1–3 mm.

In 2016, research was focused on the possible advantages of having an axial design for in-beam PET imaging, which would decouple the sensitivity from the spatial resolution. Monte Carlo simulations were used in order to evaluate the current performance of the partial ring, dual panel positron emission tomography (PET) configurations that are currently under development for treatment planning in proton therapy. The future plan is to compare the imaging quality of the current dual panel PET scanners with the axial PET geometry, after optimising the axial PET for the size and space requirements of proton therapy applications. Data from the conducted simulations were collected in list-mode data format. Simple and more realistic phantoms were reconstructed using 3D iterative reconstruction algorithms, while optimising the reconstruction parameters for optimal time and a reasonable computational burden. Time-of-flight (TOF) information was also implemented in the reconstruction.

In order to investigate collaborators within academia for the project as well as to follow future trends towards personalised scanners, the following two conferences were visited: the ATTRACT Symposium and the IEEE Nuclear Science Symposium and Medical Imaging Conference. Additionally, the AvanTomography project was represented with a poster at the HD Tomo Days.

The project team in 2013–2017 included T. Zedda (MSc), S. Nazari Farsani (MSc), A. Moreno Galera (MSc), S. Moradi (MSc), S. Ylipää (MSc), D. Us (MSc), and Professor U. Ruotsalainen.

Finnish Business Incubation Center of CERN Technologies

The CERN Business Incubation Network aims to improve commercialisation, and therefore, social utilisation, of CERN-related technologies in each member state. The FBC (Finnish Business Incubation Center of CERN Technologies), the CERN BIC in Finland, was established in 2015. The FBC is operated under the Technology Programme at HIP. The focus of the FBC is to be very selective in its search for incubatees, the FBC is only selecting ideas, innovations, or incubatees that exhibit disruptive and business ecosystem changing technologies. During its first year in 2016 multiple screening cases were conducted and the first ones are under final stages in negotiations.

The aim of the Finnish Business Incubation Center of CERN Technologies is to support businesses and entrepreneurs in taking innovative CERN technologies from technical concept to market reality. Specifically, the aim is to find, screen, support and pre-incubate pre-commercialisation and/or the early commercialisation phase of ideas and technologies. The search and screening of ideas is done within the pool of ideas that are eligible if these are

- based on technologies developed at CERN or with direct contribution from CERN,
- companies developing technologies which could also be of interest to CERN,
- any innovative project that could clearly benefit from the support of CERN experts in their core fields of competences.

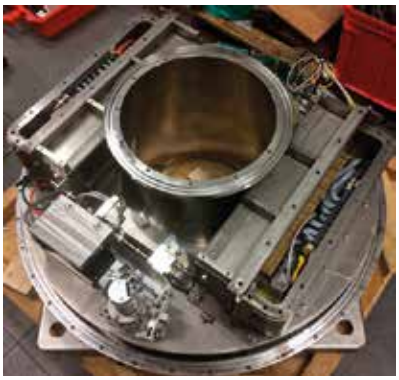
Initially it is envisioned that for the first 3-year period there would be an open call for proposals. The selection panel will be assessing the proposals according to strict and formally outlined criteria. The selection panel will consist of CERN, HIP/partner universities, and other relevant scientific, industry, venture capital etc. representatives as required. The objective of this selection process is to find 3 to 6 high-quality proposals during the first 3-year period. The Finnish CERN BIC is organised and managed by HIP and operations are carried out together with partner universities and as applicable also the incubation period for accepted proposals will be supported by partner universities as appropriate. *FBC website: http://www.hip.fi/bic*

Saku Mäkinen,
BIC project leader

Novel Instrumentation for Nuclear Safety, Security and Safeguards (NINS3)

Good stewardship of nuclear materials and an adequate response to threats that potentially involve nuclear materials are essential now and far into the future. In this context, the "Novel instrumentation for Nuclear Safety, Security and Safeguards" (NINS3) project performs R&D on passive tomography of spent nuclear fuel, alpha radiation threat detection and imaging from a distance, and active neutron interrogation of unknown objects. The project is an integral part of the National Radiation Safety Research Programme. The project partners are Helsinki Institute of Physics, the Finnish Radiation and Nuclear Safety Authority STUK, Tampere University of Technology and a consortium of companies in Finland involved in or in need of radiation measurements. Through the development of new technological concepts, the project will increase the technology readiness level in each of the R&D topics. Finnish industry will be strengthened by transferring the knowledge gained for implementation in new

Peter Dendooven,
NINS3
project leader



The refurbished Passive Gamma Emission Tomograph (PGET) during commissioning. In the upper left/ lower right, the two detector banks, each containing 87 CZT detectors, can be seen. Tomography is performed by rotating the detector banks around a spent nuclear fuel assembly positioned inside the central hole of the tomograph.

commercial products and services. The NINS3 project is funded through a FiDiPro – Finland Distinguished Professor – Programme financed by TEKES, the Finnish Funding Agency for Innovation. It runs from the beginning of 2015 until the end of 2018.

The Passive Gamma-ray Emission Tomography (PGET) prototype has been refurbished with new detectors, new electronics and a new data acquisition system by the International Atomic Energy Agency (IAEA). We participated in the successful commissioning at the Atominstitut in Vienna at the end of 2016. Measurements with the refurbished system in winter-spring 2017 have been planned in collaboration with the Finnish Radiation and Nuclear Safety Authority (STUK), IAEA and the European Commission.

We are working with two start-up companies on the design of an optimised system for the investigation of the contents of artillery shells by measuring neutron-induced gamma rays. Detailed Monte Carlo simulations of the neutron transport, gamma ray generation, gamma ray transport and gamma ray detection in the proposed system have been used to optimise the system with respect to the separation in time of fast and thermal neutrons as well as the background-free detection of gamma rays originating from the artillery shell. The experimental investigation of the system characteristics, focusing on the gamma ray detection and data analysis, was started in autumn 2016 at the premises of one of the commercial partners.

An experimental investigation into an optimised NaI detector for the detection of molten americium sources in the context of metal recycling plants was started.

The remote detection of alpha radiation is possible by measuring the ionization-induced fluorescence (radioluminescence) of the air molecules surrounding the alpha radiation source. We have investigated the viability of nitric oxide (NO) as a molecule for the remote detection of alpha radiation in the solar-blind region of the optical spectrum. Under suitable circumstances, the fluorescence of nitric oxide is as strong as that exhibited by molecular nitrogen in the visible part of the spectrum.

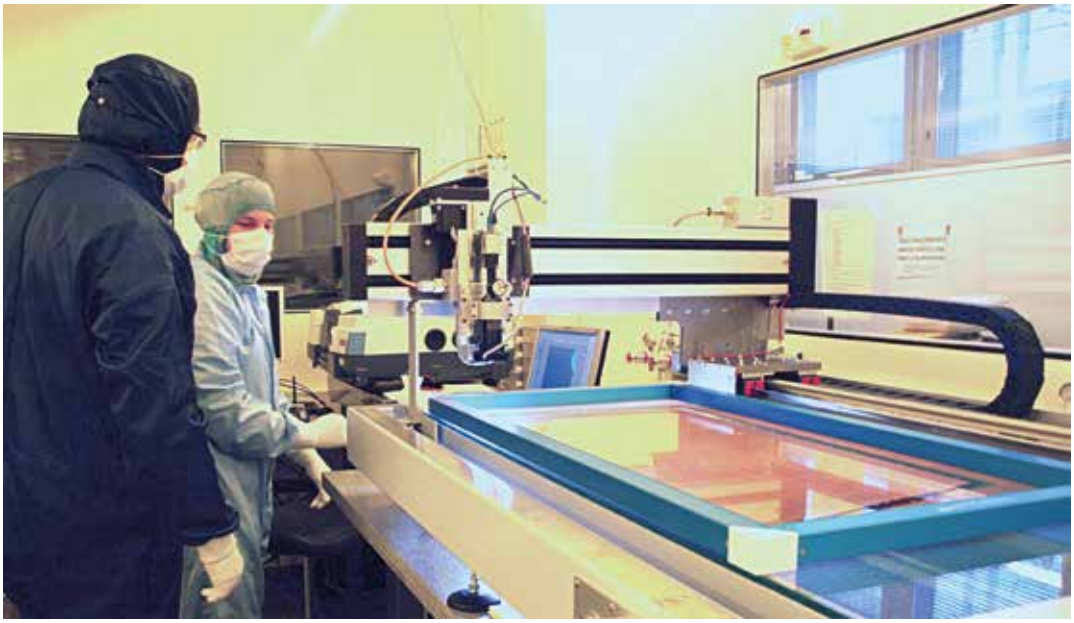
Detector Laboratory

The Helsinki Detector Laboratory is a national infrastructure specialised in the **instrumentation** of particle and nuclear physics. It is a joint laboratory run by the Helsinki Institute of Physics (HIP) and the Department of Physics of the University of Helsinki (UH/Physics), especially the UH Division of Particle and Astrophysics (PAP). The Laboratory provides premises, equipment, know-how and technical support for research projects that develop detector technologies. The Laboratory team has extensive expertise in the modelling, design, construction and testing of semiconductor and gas-filled radiation detectors. In addition, the personnel and scientists working in the Laboratory are active in educating the new generation of physicists. Activities are co-ordinated and priorities are set by the Detector Laboratory Steering Board.

All the Detector Laboratory projects have the objective to provide reliable instruments for large **international physics experiments**. The Laboratory is specialised in the quality assurance of detectors and their components and in detector prototyping. In 2016, the Laboratory hosted the activities of several experimental projects participating in the instrumentation of the CMS, TOTEM and ALICE experiments at CERN, and the NUSTAR experiment at FAIR. In addition, to maintain the outstanding expertise of the Laboratory, new detector technologies were developed in the framework of the CERN CMS, RD39, RD50 and RD51 Collaborations and with the Ruđer Bošković Institute from Croatia.

The Detector Laboratory has a wide network of **national collaboration**, especially in the form of sharing expertise, equipment and infrastructure. Its connections with the UH Electronics Research Laboratory are very tight in the field of optical imaging and interconnection technologies and with the UH Accelerator Laboratory in the field of radiation hard semiconductor detectors. Collaboration is active also with the University of Jyväskylä, Department of Physics; Lappeenranta University of Technology, School of Engineering Science; Aalto University, Micronova facility; and the Radiation and Nuclear Safety Authority (STUK). Furthermore, in 2016 the Laboratory had a project financed by the Finnish Funding Agency for Innovation (TEKES) for the development of black silicon photodiodes with the Aalto University Department of Micro and Nanosciences.

Eija Tuominen, Detector Laboratory coordinator



Quality Assurance of 300 m^2 Gas Electron Multiplier (GEM) foils for the CERN ALICE experiment takes place at the Detector Laboratory.

HIP doctoral student T. Järvinen presenting particle acceleration at the Observatory's Researchers' Night.

Providing **education** in the instrumentation of physics is of outmost importance to the Detector Laboratory. The scientists working in the Laboratory give lecture courses about semiconductor physics and detector technologies. Research-based hands-on exercises and special assignments are organised by the Laboratory. In addition, the Laboratory supervises the dissertation work of doctoral and Master's students, especially in the framework of the Doctoral Programme in Particle Physics and Universe Sciences (PAPU).

In the Detector Laboratory, special efforts are devoted to developing methods of **societal interaction** to ignite interest in physics among young people. One of the key outreach activities of the Laboratory is to demonstrate the instrumentation of particle physics for groups of visiting high-school students. In addition, in 2016, the Laboratory took an active part in all the outreach efforts organised by UH/Physics, e.g., CERN Master Class, Flora Day Celebration, "Science Bazaar" and EU Researchers' Night, co-ordinated nationally by HIP project leader J. Pakarinen from the University of Jyväskylä. Furthermore, a secondary school TET-trainee and a trainee from the Finnish School of Watchmaking worked in the Laboratory.

CLOUD

Background

The CLOUD (Cosmics Leaving OUtdoor Droplets) experiment at CERN is one of the most advanced laboratory set-ups for studying the formation and growth of atmospheric aerosol particles, which influence the Earth's radiative balance and therefore the whole climate system. This is caused by two mechanisms. First, aerosol particles can directly reflect or absorb solar radiation. Second, they can act as seeds for the formation of cloud droplets or ice crystals and thereby affect clouds' albedo, lifetime as well as precipitation. Measuring the underlying microphysics in controlled laboratory conditions is important for understanding the dynamical behaviour of ambient aerosol particles and cloud droplets, including the formation and growth processes of aerosols, cloud droplet activation and ice nucleation.

Indirect observations and theoretical studies have suggested that galactic cosmic rays GCR may influence the Earth's cloud cover and climate. The main proposed mechanisms are an enhancement of nucleation rates (i.e., the rate of formation of new particles from gas-phase precursors) or the formation of ice particles due to ionization by GCR. The CLOUD experiment aims to find possible pathways for this phenomena and evaluate their significance. By using the CERN proton synchrotron (PS), different levels of GCR can be simulated to investigate their influence on atmospheric processes.

The CLOUD Collaboration comprises 21 institutes with a strong Finnish contribution (the University of Helsinki, Helsinki Institute of Physics, the University of Eastern Finland and the Finnish Meteorological Institute).

Markku Kulmala,
CLOUD
project leader

Experiments in 2016: The CLOUD11 Campaign

During fall 2016, an 8-week intensive measurement campaign, CLOUD11, was organised to simulate particle formation in conditions relevant to the Amazonas, boreal forest and urban environments. The Finnish team made a major contribution, with a total of 20 persons working on site during the campaign, while the rest of the Helsinki team provided daily remote technical and data analysis support. The team was responsible for several important instruments such as particle counters and mass spectrometers.

L. Ahonen (MSc) from the University of Helsinki operating the remote access of the CLOUD11 daily science meeting, this allows researchers not present at CERN to attend the meeting remotely.

Data Analysis, Education and Reporting of Results

The analysis of the data collected during the CLOUD7-11 campaigns is continuously on-going within the institutes and cross-institute working groups. In May 2016 a press conference was organised at the University of Helsinki to celebrate 4 high impact publications related to CLOUD (Kirkby et al. 2016, Tröstl et al. 2016, Lehtipalo et al. 2016 and Bianchi et al. 2016). In June 2016, CLOUD invited 30 external scientists to participate in the CLOUD-TRAIN project final conference where the students presented their latest results. In 2016, CLOUD published in total 18 peer reviewed papers. For example, Duplissy et al. (JGR, 2016) present an experimental and theoretical study of ion-induced nucleation of a sulphuric acid - water system for a wide temperature range. Kuerten et al. (JGR, 2016) complemented this study with the effect of ammonia. These results were used to model the effect of ions on the global climate (Dunne et al., Science, 2016). Another new discovery by CLOUD is particle formation (Kirkby et al. Nature, 2016) and growth (Tröstl et al. Nature 2016) solely by organic vapours. Gordon et al. (PNAS, 2016) quantified the effect of this new mechanism on climate. CLOUD has also published important results on the ice nuclei capabilities of aerosol particles (Ignatius, 2016, ACP; Järvinen, 2016, ACP and Nichman, ACP, 2016).

Planck-Euclid

Hannu Kurki-Suonio, Planck-Euclid project leader

Planck and Euclid are the two cosmology missions of the European Space Agency. Planck measured the cosmic microwave background (CMB) with unprecedented accuracy to determine the properties of the universe.

Euclid will study the "Dark Energy Question" – why is the expansion of the universe accelerating? – photographing over one third of the sky, obtaining images of over a billion galaxies and spectra of tens of millions of galaxies. The Euclid Consortium will determine the 3-dimensional distribution of galaxies and dark matter in the universe, compare their statistics to cosmological models and thus constrain the law of gravity and the dark energy equation of state. Euclid and Planck complement each other in improving our understanding of the universe, its structure, composition, origin, and governing forces; Planck concentrates on the early universe and Euclid on its later evolution. Planck made observations from 2009 to 2013; Euclid will be launched in 2020.

Planck

In 2016 Planck data was reanalysed to prepare for the final release of Planck data in 2017, improving calibration, instrument beam determination, and correcting for bandpass differences between detectors. Calibration and map-making for the Planck Low Frequency Instrument (LFI) use codes from the Helsinki group, DaCapo and Madam, and we continued assisting in these tasks as well as in the determination of the residual noise covariance matrices of the maps. We did extensive numerical simulations to determine the matrix beam window functions for the LFI channels, to correct the temperature-polarization leakage due to the mismatch of the beams of the different polarization directions. We developed a method to determine the CMB angular power spectrum directly from time-ordered data, skipping the intermediate step of map-making. We also participated in preparation of a proposal for a new mission to follow Planck, CORE (Cosmic Origins Explorer), to be launched in 2029–2030. This mission would be optimised for CMB polarization.

Euclid

We operate one of the nine Euclid Science Data Centers, SDC-FI. It runs on virtual machines at the CSC Kajaani Data Center. Taking advantage of the FGCI (Finnish Grid and Cloud Infrastructure) acquisition in 2016 the capacity of SDC-FI was increased to 400 virtual CPUs and 22 TB of storage. We participated in the Euclid SDC IT and Science challenges, where Euclid software to produce simulated data and to implement the first steps of data analysis were installed at all SDCs and this pipeline was then run synchronously, the pipeline processing orders being sent from a central Euclid Archive System (EAS) to the different SDCs. After performing the analysis the SDCs then returned the metadata describing the output data to the EAS.

We have responsibilities for the development of two parts of the Euclid data analysis: production of simulated data (SIM) and the last step (Level-3) of the data analysis, which produces, e.g., galaxy correlation functions and their power spectra. We contributed to SIM by rewriting the True Universe library in C++ improving significantly its performance. We contributed to Level-3 by doing performance and scaling tests for the galaxy 2-point correlation function code and validating the code through running it on a large collection of simulated galaxy catalogues. This last task occupied most of the SDC-FI computing capacity for several months.

Artist view of the Euclid spacecraft. *(credit: Thales Alenia Space, Airbus Defence and Space)*

Joint Activities

Antti Väihkönen,
Research coordinator

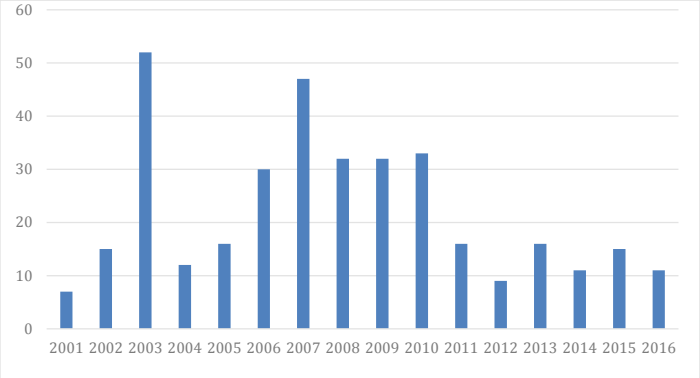
HIP is a joint institute of five universities. Its host, the University of Helsinki, implemented significant re-organisation in 2016. All the administrative personnel were formally transferred to a new organisation, University Services. The number of administrative personnel was also reduced significantly, including the retirement of the Institute's long time Administrative Manager, Mikko Sainio. In addition, the Institute has become part of the Faculty of Science since the beginning of 2016.

The graduate education of physics students continues to be one of the main tasks of the Institute. The HIP graduate students who take their degrees at the University of Helsinki belong to the Doctoral Programme in Particle Physics and Universe Sciences PAPU (http://blogs.helsinki.fi/papu-dp/) or the Doctoral Programme in Materials Research and Nanosciences MATRENA (http://blogs.helsinki.fi/matrena-dp/). In addition to the graduate students, a fair number of undergraduate students join the research groups and complete their Masters' theses work at the Institute. Many of them continue as graduate students in the Institute projects. In 2016 the traditional CERN summer student programme was broadened with a position at ESRF in Grenoble. During the period 2012–2016, 44 doctoral degrees and 71 Masters' degrees have been earned in HIP research projects.

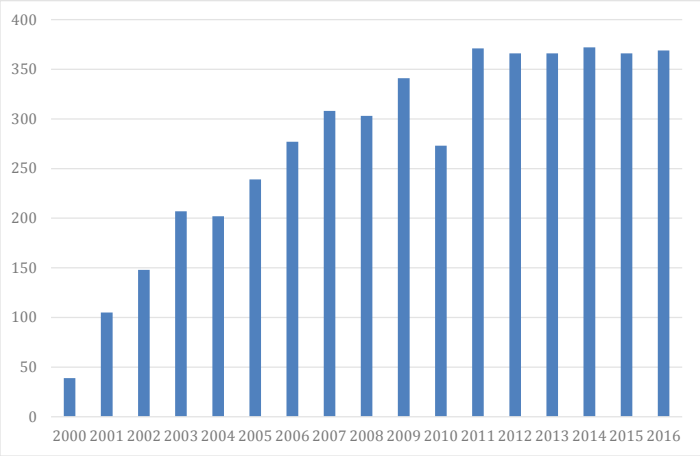
HIP continued its collaboration with the National Board of Education (Opetushallitus) and the education networks in strengthening the role of subatomic physics in school curricula in co-operation with CERN. The co-ordination of this renowned science study programme has now been taken over by Katri Lassila-Perini after the retirement of Riitta Rinta-Filppula, and she is assisted by Tuija Karppinen and Taina Onnela at CERN. In 2016 the programme attracted 369 Finnish students and 55 of their teachers. The science studies in school and the 3-day visit to CERN inspire and encourage students to study physics or other research oriented subjects. A related programme is being operated to bring high school physics teachers to CERN for continuing education courses. In 2016, 11 teachers participated in the programme.

Industrial activation was continued especially within the HIP Technology Programme and the Business Incubation Center, which aims to support new business innovations in the fields of CERN technologies.

Science Learning at CERN, teachers 2001 – 2016



Science Learning at CERN, students 2000 – 2016



Helsinki Institute of Physics 2007-2016

HIP finances (in M€)	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Budget exp.	4.09	4.11	4.39	4.19	4.44	4.63	4.91	4.73	5.09	4.12
External funding	0.63	0.72	0.77	0.79	1.04	1.06	1.24	0.80	1.97	1.31
Total	**4.72**	**4.83**	**5.16**	**4.98**	**5.48**	**5.69**	**6.14**	**5.53**	**7.07**	**5.42**
Budget exp. (SAP)	na	na	na	4.73	4.67	4.53	4.86	4.70	5.20	3.96
External (SAP)	na	na	na	0.84	1.51	1.15	1.28	0.83	1.86	1.46
Total (SAP)	**na**	**na**	**na**	**5.57**	**6.18**	**5.69**	**6.14**	**5.53**	**7.07**	**5.42**

The upper 3 lines are from the annual summaries to the Board (excluding the Ministry special funding for construction, e.g. of FAIR). The lower 3 lines are from the SAP accounting system. From 2012 on the Ministry special resources were moved away from HIP accounts. From 2015 on the contributions of Aalto, UJ, LTU and TTU were moved from basic (budget) funding to external funding. The remaining differences in the figures for basic and external funding are due to different handling of the overheads.

HIP manpower (in person years)	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Total	94.6	91.7	90.7	86.9	88.7	88.8	83.1	78.3	87.2	79.5
At CERN	23.8	23.8	24.1	25.9	23.9	21.0	20.1	12.6	12.7	12.9
Employees	na	na	na	62.9	67.1	68.3	63.8	63.2	67.9	62.6

Employees have a work contract with HIP.

HIP scientific activity	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
#refereed journ. articles	152	156	165	191	251	260	281	291	258	340
Coll. articles	52	52	66	92	154	172	167	155	141	210
HIP preprints, internal reports	77	50	35	44	39	37	33	42	45	44
Coll. notes	16	12	9	5	1	4	1	2	1	1
Seminars in Helsinki	41	38	47	41	40	41	31	48	43	37

Collaboration articles are included in the number of refereed articles.

Degrees granted in connection with the HIP research activities:

MSc/MSc (eng.)

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
UH	6	8	2	2	6	4	8	6	9	9
Aalto	2	6	3	1	1	3	2	2	4	1
UJ	5	1	3	1	3	4	2	-	1	4
LUT	-	1	-	-	-	-	2	-	1	-
TUT	-	1	1	2	3	1	-	3	2	-
Other	1	-	-	-	1	1	2	-	-	-
Sum	**14**	**17**	**9**	**6**	**14**	**13**	**16**	**11**	**17**	**14**

Doctoral degrees

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
UH	1	5	5	4	6	8	7	7	7	6
Aalto	3	3	2	1	2	-	1	-	-	-
UJ	-	2	2	3	1	1	2	3	1	1
LUT	-	1	1	-	-	-	-	-	-	-
TUT	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-
Sum	**4**	**11**	**10**	**8**	**9**	**9**	**10**	**10**	**8**	**7**

UH = Univ. Helsinki, Aalto = Aalto University (formerly TKK), UJ = Univ. Jyväskylä,
LUT = Lappeenranta Univ. of Technology, TUT = Tampere Univ. of Technology

High school visits to CERN

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
#students	308	303	341	273	371	366	366	372	366	369
#their teachers	50	44	48	48	60	64	61	54	57	55
#teachers in special courses (1 wk)	47	32	32	33	16	9	16	11	15	11

Participation of high school students and teachers in study periods at CERN.

Organization and Personnel

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PE, KR, KÖ, AJ, SM, TL, AV

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Research Coordinator
Antti Väihkönen

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- High Energy Phenomenology in the LHC Era — Aleksi Vuorinen
- QCD and Strongly Interacting Gauge Theory — Tuomas Lappi
- Nuclear Structure for Weak and Astrophysical Processes — Markus Kortelainen
- Domain Wall Dynamics — Lasse Laurson

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- CMS Experiment — Mikko Voutilainen
- CMS Upgrade — Panja-Riina Luukka
- Tier-2 Operations — Tomas Lindén
- TOTEM — Kenneth Österberg

Nuclear Matter
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- ALICE — Jan Rak
- ISOLDE — Janne Pakarinen
- FAIR — Tuomas Grahn
- ALICE-Forward — Risto Orava

Detector Laboratory
Eija Tuominen

Technology
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- Accelerator Technology — Markus Aicheler, Flyura Djurabekova
- Green Big Data — Jukka K. Nurminen
- Biomedical Imaging — Ulla Ruotsalainen
- BIC — Saku Mäkinen
- NINS3 — Peter Dendooven

- Planck-Euclid — Hannu Kurki-Suonio
- CLOUD — Markku Kulmala

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	Tuija Pulkkinen, Vice Rector (starting 2.9.2016) (Aalto University)
Members	**Mikko Alava**, Professor (starting 1.4.2016) (Aalto University)
	Kari J. Eskola, Professor (University of Jyväskylä)
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	Rauno Julin, Professor (University of Jyväskylä)
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	Mikko Ritala, Professor (University of Helsinki)
	Ulla Ruotsalainen, Vice Rector (Tampere University of Technology)
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Wolfram Weise,
Professor
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Barbro Åsman,
Professor
(U. Stockholm)

Personnel

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K. Rummukainen, prof., programme director
M. Hindmarsh, prof., adj. senior scientist
K. Kajantie, prof., adj. senior scientist
A. Krasheninnikov, adj. senior scientist

Cosmology of the Early and Late Universe

S. Räsänen, docent, proj. leader
K. Enqvist, prof., adj. senior scientist
K. Kainulainen, prof., adj. senior scientist
M. Herranen, scientist
F. Montanari, scientist
S. Rusak, adj. scientist
V.-M. Enckell, grad. student
G. Gozaliasl, grad. student
H. Jukkala, grad. student
K. Kettula, grad. student
H. Nyrhinen, grad. student
T. Tenkanen, grad. student
E. Tomberg, grad. student
V. Vaskonen, grad. student
P. Wahlman, grad. student

High Energy Phenomenology in the LHC Era

A. Vuorinen, docent, proj. leader
K. Huitu, prof., adj. senior scientist
O. Lebedev, prof., adj. senior scientist
E. Keski-Vakkuri, adj. senior scientist
K. Tuominen, adj. senior scientist
M. Heikinheimo, scientist
V. Keränen, scientist
A. Meroni, scientist
O. Taanila, scientist
T. Zingg, scientist
A. Amato, adj. scientist
I. Ghişoiu, adj. scientist
C. Gross, adj. scientist
N. Jokela, adj. scientist
V. Keus, adj. scientist
D. Weir, adj. scientist
J. Järvelä, grad. student
N. Koivunen, grad. student
A. Pönni, grad. student
J. Remes, grad. student
T. Tenkanen, grad. student
S. Tähtinen, grad. student
E. Annala, student
M. Säppi, student

QCD and Strongly Interacting Gauge Theory

T. Lappi, docent, proj. leader
K. J. Eskola, prof., adj. senior scientist
H. Paukkunen, scientist
Y. Zhu, scientist
H. Mäntysaari, grad. student
J. Peuron, grad. student
J. Suorsa, grad. student

Nuclear Structure for Weak and Astrophysical Processes

M. Kortelainen, Dr., proj. leader
J. Dobaczewski, prof., adj. senior scientist
W. Satuła, prof., adj. senior scientist
J. Niskanen, adj. senior scientist
T. Oishi, scientist
K. Petrik, scientist
T. Haverinen, grad. student

Domain Wall Dynamics

L. Laurson, Dr., proj. leader
V. Estévez Nuño, scientist
T. Herranen, grad. student

CMS Programme

K. Österberg, docent, programme director

CMS Experiment

M. Voutilainen, ass. prof., proj. leader
R. Kinnunen, senior scientist
T. Lampén, senior scientist
K. Lassila-Perini, senior scientist (at CERN)
S. Lehti, senior scientist
V. Karimäki, adj. senior scientist
J. Tuominiemi, adj. senior scientist
L. Wendland, scientist
G. Fedi, grad. student
J. Heikkilä, grad. student
T. Järvinen, grad. student
S. Laurila, grad. student
J. Pekkanen, grad. student
H. Siikonen, grad. student
M. Haapalehto, student
J. Havukainen, student
J. Juvalainen, trainee
P. Rikkilä, trainee

CMS Upgrade

J. Härkönen, Dr., proj. leader (until 30.4.2016)
P.-R. Luukka, Dr., proj. leader (starting 1.5.2016)
I. Kassamakov, senior scientist
E. Tuominen, senior scientist
T. Mäenpää, scientist
E. Tuovinen, scientist
T. Arsenovich, grad. student
A. Gädda, grad. student
T. Hakkarainen, grad. student
A. Karadzhinova, grad. student
J. Ott, grad. student
T. Peltola, grad. student
A. Winkler, grad. student
V. Pyykkönen, student
J. Juvelainen, trainee
A. Peltonen, trainee

Tier-2 Operations

T. Lindén, Dr., proj. leader, grid coordinator

TOTEM

K. Österberg, docent, proj. leader
M. Berretti, scientist
T. Naaranoja, grad. student
F. Oljemark, grad. student
J. Welti, grad. student
L. Martikainen, student
P. Helander, trainee

Nuclear Matter Programme

A. Jokinen, prof., programme director

ALICE

J. Rak, prof., proj. leader
D. J. Kim, senior scientist
S. S. Räsänen, senior scientist
E. Brücken, scientist
T. Hildén, scientist
B. Chang, grad. student
T. Snellman, grad. student
M. Vargyas, grad. student
J. Viinikainen, grad. student

ISOLDE

J. Pakarinen, Dr., proj. leader
P. Greenlees, prof., adj. senior scientist
I. Moore, adj. senior scientist
D. Cox, adj. scientist
K. Helariutta, adj. scientist
U. Jakobsson, adj. scientist

FAIR

T. Grahn, docent, proj. leader
J. Äystö, prof., director emeritus, adj. senior scientist
E. Tuominen, proj. coordinator
F. García, lab. engineer

ALICE-Forward

R. Orava, prof., proj. leader
M. Mieskolainen, grad. student

Technology Programme

S. Mäkinen, prof., programme director
J. Pascu, scientist (at CERN)

Accelerator Technology

M. Aicheler, Dr., proj. leader
F. Djurabekova, senior scientist
K. Nordlund, prof., adj. senior scientist
V. Jansson, scientist
A. Kyritsakis, scientist
S. Parviainen, scientist
V. Zadin, adj. scientist
E. Baibuz, grad. student
A. Korsbäck, grad. student
R. Montonen, grad. student
M. Parekh, grad. student
A. Saressalo, grad. student
H. Vázquez Muíños, grad. student
M. Veske, grad. student
J. Väinölä, grad. student
A. Holmström, student
J. Lahtinen, student

Green Big Data

J. K. Nurminen, prof., proj. leader
A.-P. Hameri, prof., senior scientist
T. Niemi, senior scientist (at CERN)
S. Heikkilä, scientist (at CERN)
K. Khan, grad. student
J. Kommeri, grad. student

Biomedical Imaging

U. Ruotsalainen, prof., proj. leader

Finnish Business Incubation Center of CERN Technologies (BIC)

S. Mäkinen, prof., proj. leader
P. Kauttu, grad. student

Novel Instrumentation for Nuclear Safety, Security and Safeguards (NINS3)

P. Dendooven, prof., proj. leader
C. Bélanger-Champagne, scientist
P. Peura, scientist
T. Kerst, grad. student

Detector Laboratory

E. Tuominen, lab. coordinator
J. Heino, lab. engineer
P. Koponen, lab. engineer
R. Lauhakangas, lab. engineer
M. Juntunen, research coordinator
R. Turpeinen, lab. technician
V. Vähänissi, grad. student
S. Adnan Hussein, trainee

CLOUD

M. Kulmala, prof., proj. leader
J. Duplissy, scientist

Planck-Euclid

H. Kurki-Suonio, docent, proj. leader
E. Keihänen, scientist
C. Kirkpatrick, scientist
J. Väliviita, scientist
M. Savelainen, adj. scientist
K. Kiiveri, grad. student
V. Lindholm, grad. student
A.-S. Suur-Uski, grad. student

Administration and Support

P. Eerola, prof., director
A. Väihkönen, research coordinator
M. Sainio, docent, adm. manager
T. Sandelin, financial manager
T. Hardén, secretary (starting 1.5.2016 University Services)
T. Heikkilä, secretary (starting 1.5.2016 University Services)
T. Karppinen, secretary (at CERN) (starting 1.5.2016 University Services)
T. Onnela, secretary (at CERN) (starting 1.5.2016 University Services)
R. Rinta-Filppula, ped. expert (at CERN)
J. Aaltonen, lab. engineer

Seminars

Seminars held in Helsinki

15th January T. Rantala (Tampere)
Path integral quantum Monte Carlo simulation of atomic matter

9th February F. Rennecke (Giessen, Germany)
From quarks and gluons to hadrons: chiral symmetry breaking in QCD

16th February M. Möttönen (Aalto)
Tying quantum knots

23rd February S. Moch (Hamburg, Germany)
Top-quark production at the LHC: theory status and perspectives

1st March K. Kajantie (HIP)
Physics of gravitational radiation

8th March J. Rantaharju (Odense, Denmark)
Lattice model of ideal walking

15th March R. Lauhakangas (HIP)
To the galaxy with the bubble chamber

4th April M. Berretti (HIP/Totem)
Exclusive processes with TOTEM and CT-PPS: results, perspectives and experimental challenges

12th April L. Lyons (Imperial College, UK)
Statistical issues in searches for new physics

14th April G. Moore (Darmstadt, Germany)
Relating the axion mass and dark matter density

19th April A. Meroni (Odense, Denmark)
Neutrino physics: status and quests for the future

26th April T. Konstandin (DESY, Gemany)
Effective actions in particle physics and cosmology

17th May M. Frandsen (Odense, Denmark)
Electroweak symmetry breaking, dark matter and the diphoton excess

19th May T. Zingg (HIP)
How I learned to stop worrying and love fractional spin: a systematic approach to holographic anyonization

31st May S. K. Rai (Allahabad, India)
Revisiting compressed SUSY at LHC

2nd June R. Kinnunen (HIP)
My experiences in large experiments

6th June J. Pedraza (Amsterdam, The Netherlands)
Spread of entanglement in holographic theories

7th June I. Vattulainen (Helsinki)
Cholesterol, tiny but tough! How membranes sense changes in cholesterol structure

9th June K. Schmidt-Hoberg (DESY, Germany)
The case for dark matter self interactions – evidence in Abell 3827?

14th June C. Carlson (College of William and Mary, Virginia, USA)
The proton charge radius puzzle

21st June M. Gronau (Technion, Haifa, Israel)
Precise perturbative flavor symmetry breaking in D decays

5th July A. Vuorinen (Helsinki)
Quark matter inside neutron stars

30th August M. Sainio (HIP)
From loops to knots – physics to bureaucracy

20th September T. Gorda (Helsinki)
Global properties of rotating neutron stars with QCD equations of state

27th September C. Ecker (TU Wien, Austria)
Exploring nonlocal observables in shock wave collisions

18th October C. Hoyos (Oviedo, Spain)
Towards a simpler description of holographic nuclear matter

25th October L. Visinelli (Stockholm, Sweden)
Axion cosmology

1st November T. Ala-Nissilä (Aalto)
The physics of this year's Nobel prize in physics – a personal point of view

11th November I. Vattulainen (Helsinki), K. J. Eskola (Jyväskylä), M. Oinonen (Helsinki), M. Heikkurinen (LMU Munich, Germany), E. Hæggström (Helsinki), J. Björkroth (Helsinki)
Helsinki Institute of Physics 20 years

15th November A. Meroni (HIP)
A radiatively induced elementary Goldstone Higgs

22nd November W. Buchmüller (DESY, Germany)
Grand unification and the early universe

24th November H. Waltari (Helsinki)
Collider signatures of sneutrino dark matter in left-right symmetric supersymmetry

29th November V. Leino (Helsinki)
The gradient flow running coupling in SU(2)

8th December H. Kirschenmann (CERN, Switzerland)
Searches of new physics at CMS

8th December Y. Ema (Tokyo, Japan)
Dynamics of Higgs during preheating epoch

13th December T. Graf (Nantes, France)
Quark mass effects in perturbative thermodynamics

13th December H. Haber (Santa Cruz, CA, USA)
Extended Higgs sectors and the alignment limit

20th December M. Järvinen (Paris, France)
Inverse magnetic catalysis in holographic QCD

Visitors

Theory Programme

Cosmology of the Early and Late Universe

A. Oksanen (Finland) 19.1.
J. Renk (Sweden) 8.–14.2.
M. Zumalacárregui (Sweden) 8.–14.2.
S. Kawai (South Korea) 15.2.–19.3.
F. Villaescusa-Navarro (Italy) 22.–24.2.
J. White (Japan) 3.–15.3.
T. Jacques (Italy) 14.–18.3.
S. Nurmi (Finland) 23.3.
M. Archidiacono (Germany) 5.–8.4.
M. Herranen (Finland) 12.–13.4.
A. Amara (Switzerland) 19.–21.4.
S. Hansen (Denmark) 27.–29.4.
T. Markkanen (UK) 2.–4.5.
F. Day (UK) 3.–6.5.
D. Wiltshire (New Zealand) 10.–12.5.
T. Takahashi (Japan) 10.–13.5.
M. Hindmarsh (UK/Finland) 12.–13.5.
S. Foffa (Switzerland) 17.–19.5.
E. Di Dio (Italy) 22.–29.5.
T. Koivisto (Sweden) 23.–27.5., 18.–24.9.
M. Krssak (Brazil) 25.–27.5.
D. Weir (Norway) 1.9.
H. Nersisyan (Germany) 10.–17.9.
A. Golovnev (Russia) 12.–16.9., 18.–24.9.
M. Viel (Italy) 26.–29.9.
F. Bezrukov (UK) 30.9.–5.10.
J. Cline (Canada) 17.–21.10.
L. Heisenberg (Switzerland) 18.–19.10.
M. Bruni (UK) 31.10.–3.11.
O. Cucciati (Italy) 7.–11.11.
S. Nesseris (Spain) 14.–17.11.
T. Garratt (Germany) 24.–28.11.
N. Christensen (USA/France) 28.11.–1.12.
S. Stopyra (UK) 28.11.–2.12.
A. Ricciardone (Norway) 3.–8.12.
A. Meroni (Sweden/Finland) 8.–9.12.
K. Tuominen (Finland) 8.–9.12.
M. Hindmarsh (UK/Finland)
T. Koivisto (Sweden)
A. Rajantie (UK)
O. Taanila (The Netherlands)
D. Weir (Norway)

High Energy Phenomenology in the LHC Era

F. Rennecke (Germany) 8.–10.2.
C. Hoyos (Spain) 6.–9.3., 17.–21.10.
D. Rodriguez (Spain) 6.–9.3., 17.–21.10.
J. Rantaharju (Denmark) 7.–10.3.
G. Moore (Germany) 14.–15.4.
A. Meroni (Denmark) 18.–20.4.
M. Frandsen (Denmark) 16.–18.5.
T. Gorda (USA) 23.–27.5.
J. Pedraza (The Netherlands) 1.–7.6.
B. DiNunno (USA) 1.6.–3.7.
K. Schmidt-Hoberg (Germany) 8.–10.6.
L. Visinelli (Italy) 25.–26.10.
W. Buchmüller (Germany) 21.–23.11.
T. Graf (France) 12.–14.12.
H. Haber (USA) 12.–16.12.
M. Järvinen (France) 15.–23.12.

QCD and Strongly Interacting Gauge Theory

H. Niemi (Germany) 8.1., 21.3., 8.–12.8.
P. Huovinen (Poland) 11.–15.1., 10.8.
D. Zaslavsky (China) 7.–10.2.
D. Rischke (Germany) 17.–29.2.
H. Mäntysaari (USA) 18.–22.4., 11.–15.11.
U. Wiedemann (Switzerland) 20.–21.4.
K. Boguslavski (Germany) 30.5.–4.6.
A. Kurkela (Switzerland) 8.–12.8.

Nuclear Structure for Weak and Astrophysical Processes

N. Hinohara (USA/Japan) 7.–25.3.
M. Konieczka (Poland) 8.–26.8.

Domain Wall Dynamics

L. Bergqvist (Sweden) 9.–10.5.

CMS Programme

A. Cerri (UK) 18.–20.2.
Z. Li (China) 10.–13.3.
L. Lyons (UK) 12.4.
A. Oskarsson (Sweden) 20.–21.10.
M. Heikkurinen (Germany) 11.11.
H. Kirchenmann (Switzerland) 7.–12.12.
J. Bendavid (USA) 14.–16.12.

Nuclear Matter Programme

ALICE

D. Varga (Hungary) 13.–15.4.
L. Boldizsár (Hungary) 13.–26.4.

ALICE-Forward

V. Khoze (UK) 7.–13.2.

Planck-Euclid

J. Mohr (Germany) 25.–27.5.

Conference participation, Talks and Visits by Personnel

Theory Programme

Cosmology of the Early and Late Universe

Spåtind 2016 – Nordic Conference on Particle Physics,
2–7 January, Gausdal, Norway (talk by V.-M. Enckell, talk by V. Vaskonen)

University of Geneva,
February – June, Geneva, Switzerland (talk by V.-M. Enckell)

Workshop on Relativistic Effects in Galaxy Surveys,
29 February, Cape Town, South Africa (talk by F. Montanari)

University of the Western Cape,
29 February – 4 March, Cape Town, South Africa (talk by F. Montanari)

Annual Meeting of the Finnish Physical Society,
29–31 March, Oulu, Finland (talk by T. Tenkanen)

NICPB,
4–5 April, Tallinn, Estonia (talk by T. Tenkanen)

Departmental Colloquium,
8 April, Jyväskylä, Finland (talk by K. Kainulainen)

University of Jyväskylä,
12–15 April, Jyväskylä, Finland (talk by T. Tenkanen)

11th Kosmologietag,
28–29 April, Bielefeld, Germany (talk by T. Tenkanen)

NORDITA,
1–5 May, Stockholm, Sweden (talk by F. Montanari)

University of Jyväskylä,
12–13 May, Jyväskylä, Finland (talk by M. Hindmarsh)

Workshop Why is there more Matter than Antimatter in the Universe?,
30 May – 10 June, MIAPP, Munich, Germany (talk by K. Kainulainen)

Workshop on Non-Standard Dark Matter,
2–5 June, Warsaw, Poland (talk by T. Tenkanen, talk by V. Vaskonen)

EPFL High Energy Theory Group Seminar,
6 June, Lausanne, Switzerland (talk by V.-M. Enckell)

Bethe Forum on Dark Matter Beyond Supersymmetry,
13–14 June, Bonn, Germany (T. Tenkanen)

Max-Planck-Institut für Physik,
15–17 June, Munich, Germany (talk by T. Tenkanen)

Workshop Strong and Electroweak Matter 2016,
11–15 July, University of Stavanger, Stavanger, Norway (plenary talk by S. Nurmi)

ICHEP 2016 Conference,
3–7 August, Chicago, IL, USA (T. Tenkanen)

COSMO-16 Conference,
8–12 August, Ann Arbor, MI, USA (talk by T. Tenkanen)

The Big Bang and the Little Bangs – Non-Equilibrium Phenomena in Cosmology and in Heavy-Ion Collisions,
15–25 August, CERN, Geneva, Switzerland (talk by K. Kainulainen)

UCI,
22–24 August, Irvine, CA, USA (talk by T. Tenkanen)

The Big Bang and the Little Bangs – Non-Equilibrium Phenomena in Cosmology and in Heavy-Ion Collisions,
22–25 August, CERN, Geneva, Switzerland (S. Nurmi)

Helsinki PAPU Meeting,
23 August, Helsinki, Finland (talk by F. Montanari)

UCLA,
25–29 August, Los Angeles, CA, USA (T. Tenkanen)

Particle Physics and Cosmology Meeting,
29–30 September, Tampere, Finland (K. Kainulainen, talk by O. Koskivaara, talk by L. Laulumaa, talk by J. Leskinen, S. Nurmi)

The Galaxy Life-Cycle Conference,
24–28 October, Venice, Italy (G. Gozaliasl)

Gravitational Wave Symposium,
26 October, London, UK (T. Tenkanen)

London Cosmology Discussion Meeting,
27 October, London, UK (talk by T. Tenkanen)

Kobe University,
1 November 2016 – 7 January 2017, Kobe, Japan (talk by S. Räsänen)

Dutch Cosmology Meeting,
3–5 November, Utrecht, The Netherlands (talk by K. Kainulainen)

Tuorla Observatory Seminar,
22 November, Turku, Finland (talk by G. Gozaliasl)

CosPA 2016 Conference,
28 November – 2 December, Sydney, Australia (talk by T. Tenkanen)

NORDITA,
30 November – 2 December, Stockholm, Sweden (K. Kainulainen)

Yukawa Institute Cosmology Seminar,
5 December, Kyoto, Japan (talk by S. Räsänen)

Hidden Sector Physics and Cosmophysics,
12–15 December, Kyoto, Japan (S. Räsänen)

Helsinki Higgs Forum,
14–16 December, Helsinki, Finland (talk by K. Kainulainen, talk by S. Rusak, T. Tenkanen)

High Energy Phenomenology in the LHC Era

Spring Retreat of the Research School Particles and Interactions,
8–10 April, Krems an der Donau, Austria (lectures by A. Vuorinen)

NBI Holography Workshop,
24 April – 1 May, Niels Bohr Institute, Copenhagen, Denmark (T. Zingg)

Workshop on Holography for Black Holes and Cosmology,
8–16 May, Solvay Institutes, Brussels, Belgium (T. Zingg)

Workshop Numerical Methods for Asymptotically AdS Spaces,
21–27 May, Haifa, Israel (talk by N. Jokela)

Workshop of the NewCompStar COST Network,
25–29 May, Istanbul, Turkey (talk by A. Vuorinen)

Workshop Why is there more Matter than Antimatter in the Universe?,
1–3 June, MIAPP, Munich, Germany (A. Vuorinen)

QCD MasterClass 2016,
5–18 June, Saint-Jacut-de-la-Mer, France (J. Remes)

Workshop Why is there more Matter than Antimatter in the Universe?,
13–24 June, MIAPP, Munich, Germany (T. Tenkanen)

University of Porto,
18 June – 8 July, Porto, Portugal (T. Zingg)

Numerical Relativity and Holography – NumHol2016,
26 June – 2 July, Santiago de Compostela, Spain (T. Zingg)

Workshop Strong and Electroweak Matter 2016,
11–15 July, University of Stavanger, Stavanger, Norway (M. Säppi, T. Tenkanen, talk by A. Vuorinen)

NORDITA Workshop – Black Holes and Emergent Spacetime,
7–23 August, Stockholm, Sweden (J. Remes)

NORDITA Workshop – Black Holes and Emergent Spacetime,
11 August – 4 September, Stockholm, Sweden (T. Zingg)

NORDITA Workshop – Black Holes and Emergent Spacetime,
22–27 August, Stockholm, Sweden (N. Jokela)

Research Visit,
24 August – 1 September, Brooklyn, NY, USA (talk by N. Jokela)

Stony Brook University,
29 August, Stony Brook, NY, USA (invited seminar by N. Jokela)

The XII International Conference Quark Confinement and the Hadron Spectrum,
29 August – 3 September, Thessaloniki, Greece (talk by A. Vuorinen)

Heraklion Workshop on Theoretical Physics,
4–11 September, Heraklion, Greece (N. Jokela)

University of Colorado,
12–16 September, Boulder, CO, USA (I. Ghişoiu)

Universidad del Bio-Bio,
19 September – 7 October, Chillan, Chile (invited seminar by I. Ghişoiu)

Tampere Fall Meeting,
29–30 September, Tampere, Finland (M. Säppi, A. Vuorinen)

Applications of Gauge-Gravity Duality,
2–5 October, Gothenburg, Sweden (talk by N. Jokela)

Niels Bohr International Academy (NBIA),
14–23 November, Copenhagen, Denmark (T. Tenkanen)

Particle Physics Days 2016,
25 November, University of Jyväskylä, Jyväskylä, Finland (talk by A. Vuorinen)

From Quarks to Gravitational Waves: Neutron Stars as a Laboratory for Fundamental Physics,
4–9 December, Geneva, Switzerland (E. Annala, talks by T. Gorda and N. Jokela, organised by A. Vuorinen)

QCD and Strongly Interacting Gauge Theory

Spåtind 2016 – Nordic Conference on Particle Physics,
2–7 January, Gausdal, Norway (organised by T. Lappi, talk by J. Peuron)

CERN,
18 January – 18 March, Geneva, Switzerland (J. Peuron)

CERN,
1–5 February, Geneva, Switzerland (seminar by T. Lappi)

New Observables in Quarkonium Production,
28 February – 4 March, Trento, Italy (talk by B. Ducloué)

DIS 2016 XXIV International Workshop on Deep-Inelastic Scattering and Related Subjects,
11–15 April, Hamburg, Germany (talk by B. Ducloué)

The 3rd International Conference on the Initial Stages in High-Energy Nuclear Collisions,
23–27 May, Lisbon, Portugal (K. J. Eskola, talks by T. Lappi, H. Paukkunen, Y. Zhu)

Fourth Annual Large Hadron Collider Physics Conference (LHCP2016),
13–18 June, Lund, Sweden (invited talk by T. Lappi)

IPhT, CEA,
20–23 June, Saclay, France (T. Lappi)

International HPC Summer School 2016,
26 June – 1 July, Ljubljana, Slovenia (J. Peuron)

The Big Bang and the Little Bangs – Non-Equilibrium Phenomena in Cosmology and in Heavy-Ion Collisions,
15–26 August, CERN, Geneva, Switzerland (Y. Zhu)

The XII International Conference Quark Confinement and the Hadron Spectrum,
29 August – 3 September, Thessaloniki, Greece (talks by T. Lappi, Y. Zhu)

J.W. Goethe University,
13–16 September, 24–25 September, Frankfurt, Germany (K. J. Eskola)

International School of Nuclear Physics, 38th Course, Nuclear Matter under Extreme Conditions – Relativistic Heavy-Ion Collisions,
16–24 September, Erice, Italy (invited talk by K. J. Eskola)

Hard Probes 2016,
22–27 September, Wuhan, China (talks by B. Ducloué, T. Lappi, Y. Zhu)

Theorie LHC France Workshop & Annual Meeting of the French GDR-QCD,
7–11 November, Orsay, France (invited talk by B. Ducloué)

Workshop on QCD and Diffraction – Saturation 1000+,
5–7 December, Cracow, Poland (invited talk by T. Lappi)

Nuclear Structure for Weak and Astrophysical Processes

Nuclear Physics Seminar,
24 May, Peking University, Beijing, China (talk by M. Kortelainen)

Nuclear Physics Seminar,
9 June, University of Warsaw, Warsaw, Poland (talk by M. Kortelainen)

CSC Summer School in High-Performance Computing,
28 June – 3 July, CSC, Espoo, Finland (T. Haverinen)

Talent Course on Density Functional Theory and Self-Consistent Methods,
17 July – 6 August, University of York, York, UK (T. Haverinen)

PHHQP16: Progress in Quantum Physics with Non-Hermitian Operators,
8–12 August, Kyoto University, Kyoto, Japan (talk by T. Oishi)

Euroschool on Exotic Beams 2016,
28 August – 3 September, Mainz, Germany (lectures by M. Kortelainen)

Shapes and Symmetries in Nuclei: from Experiment to Theory,
7–11 November, CNRS, Gif-sur-Yvette, France (talk by M. Kortelainen)

First Tsukuba-CCS-RIKEN Joint Workshop on Microscopic Theories of Nuclear Structure and Dynamics,
12–16 December, RIKEN/University of Tsukuba, Tsukuba, Japan (invited talk by M. Kortelainen)

Domain Wall Dynamics

Topological Patterns and Dynamics in Magnetic Elements and in Condensed Matter,
27 June – 8 July, Dresden, Germany (V. Estevéz Nuño, talk by T. Herranen)

Statphys26 Satellite Meeting "Statistical Physics of Materials",
29 June – 1 July, Aussois, France (organised by L. Laurson)

Statphys26,
18–22 July, Lyon, France (talk by L. Laurson)

Second Marie Curie School on Domain Walls and Spintronics,
11–16 September, Spetses, Greece (V. Estevéz Nuño, talk by T. Herranen)

CMS Programme

CMS Experiment

Spåtind 2016 – Nordic Conference on Particle Physics,
2–7 January, Gausdal, Norway (P. Eerola (organiser), talk by J. Heikkilä, S. Laurila, talk by J. Pekkanen (organiser), M. Voutilainen (organiser))

CERN,
25–29 January, Geneva, Switzerland (T. Lampén)

SMP-J Workshop,
27–28 January, CERN, Geneva, Switzerland (M. Voutilainen (organiser))

DPHEP/WLCG Workshop,
3–4 February, CERN, Geneva, Switzerland (K. Lassila-Perini)

Lake Louise Winter Institute 2016,
7–12 February, Alberta, Canada (talk by J. Pekkanen)

CMS Physics Week,
8–12 February, CERN, Geneva, Switzerland (J. Tuominiemi)

CMS Pixel Phase I Upgrade Days,
14–17 March, CERN, Geneva, Switzerland (T. Lampén)

Annual Meeting of the Finnish Physical Society,
29–31 March, Oulu, Finland (J. Heikkilä, talk by T. Järvinen, talk by S. Laurila)

CMS Tracker Alignment Camp,
18–21 April, CERN, Geneva, Switzerland (T. Lampén (organiser))

CMS Week,
18–22 April, CERN, Geneva, Switzerland (K. Lassila-Perini, J. Tuominiemi)

Beauty 2016, 16th International Conference on B-Physics at Frontier Machines,
1–6 May, Marseille, France (talk by T. Järvinen)

HEP Software Foundation Workshop,
2–4 May, Orsay, France (talk by K. Lassila-Perini)

European School of High-Energy Physics 2016,
15–28 June, Skeikampen, Norway (J. Pekkanen)

CMS Week,
20–24 June, CERN, Geneva, Switzerland (J. Heikkilä, K. Lassila-Perini, M. Voutilainen)

Second Machine Learning in High Energy Physics Summer School 2016,
20–26 June, Lund, Sweden (J. Havukainen)

2016 CTEQ-MCnet School,
6–16 July, Hamburg, Germany (J. Pekkanen, H. Siikonen, talk by M. Voutilainen)

CMS Tracker Week,
19–22 July, CERN, Geneva, Switzerland (J. Tuominiemi)

International Conference on High Energy Physics ICHEP 2016,
3–10 August, Chicago, IL, USA (parallel session convener P. Eerola)

SLAC Summer Institute 2016,
15–26 August, Stanford, CA, USA (J. Pekkanen)

QCD@LHC 2016,
22–26 August, Zurich, Switzerland (talk by M. Voutilainen)

CERN School of Computing,
28 August – 10 September, Mol, Belgium (J. Havukainen)

Higgs Hunting 2016,
31 August – 2 September, Paris, France (talk by J. Heikkilä)

CMS Data Analysis School,
19–23 September, Hamburg, Germany (J. Heikkilä, S. Laurila)

TOP 2016,
19–23 September, Olomouc, Czech Republic (H. Siikonen)

Prospects for Charged Higgs Discovery at Colliders,
3–6 October, Uppsala, Sweden (J. Havukainen, talk by S. Laurila)

Charged Higgs Workshop,
1–6 November, Boston, MA, USA (J. Havukainen, S. Laurila)

TOP @ 100 fb^{-1} Workshop,
8–9 November, CERN, Geneva, Switzerland (H. Siikonen)

Particle Physics Day,
25 November, Jyväskylä, Finland (T. Lindén, J. Tuominiemi, talk by M. Voutilainen)

CERN,
13–16 December, Geneva, Switzerland (T. Lampén)

The Helsinki Higgs Forum,
14–16 December, Helsinki, Finland (P. Eerola (organiser), J. Havukainen, J. Heikkilä, talk by S. Laurila, J. Tuominiemi, M. Voutilainen, K. Österberg)

CMS Upgrade

Vienna Conference on Instrumentation,
15–19 February, Vienna, Austria (J. Ott)

CMS Pixel Phase I Upgrade Days,
14–27 March, CERN, Geneva, Switzerland (P. Luukka)

CMS Phase II Days,
10–13 May, CERN, Geneva, Switzerland (P. Luukka)

Ruđer Bošković Institute,
15–18 June, Zagreb, Croatia (P. Luukka, E. Tuominen)

Deutsches Elektronen-Synchrotron (DESY),
22–31 July, Hamburg, Germany (J. Ott)

CMS Pixel Phase I Upgrade Days,
30 August – 1 September, Strasbourg, France (P. Luukka)

17th International Congress on Neutron Capture Therapy,
2–7 October, Colombia, MO, USA (A. Winkler)

CERN,
11–14 November, Geneva, Switzerland (J. Ott)

29th RD50 Workshop on Radiation Hard Semiconductor Devices for Very High Luminosity Colliders,
21–23 November, CERN, Geneva, Switzerland
(P. Luukka, E. Tuominen)

CMS Phase II Week,
5–9 December, CERN, Geneva, Switzerland
(talk by P. Luukka)

COMMAND 2016,
12–14 December, Sydney, Australia
(talk by T. Arsenovich)

Tier-2 Operations

Aalto Fusion Group Seminar,
3 March, Espoo, Finland (talk by T. Lindén)

29th NORDUnet Conference,
20–22 September, Helsinki, Finland (talk by T. Lindén)

Nuclear Science and Technology Symposium,
2–3 November, Helsinki, Finland (talk by T. Lindén)

TOTEM

CLIC Workshop 2016,
18–22 January, CERN, Geneva, Switzerland
(K. Österberg)

CMS FSQ Workshop 2016,
28–29 January, CERN, Geneva, Switzerland
(talk by K. Österberg)

Vienna Conference on Instrumentation,
15–19 February, Vienna, Austria (M. Berretti)

LHC Forward Physics Workshop,
16 March, CERN, Geneva, Switzerland (talk by M. Berretti)

Albanova, Stockholm University,
4–5 May, Stockholm, Sweden (K. Österberg)

3rd Forward Physics Workshop and TOTEM Collaboration Meeting,
27 May – 4 June, La Biodola, Elba Island, Italy
(talk by M. Berretti, talk by K. Österberg (organiser))

CERN,
9–16 June, Geneva, Switzerland (L. Martikainen, T. Naaranoja)

CERN,
20 July – 3 August, Geneva, Switzerland
(L. Martikainen, T. Naaranoja)

QCD at LHC: Forward Physics Workshop,
25–30 September, Trento, Italy (talk by K. Österberg)

Particle Physics Day,
25 November, Jyväskylä, Finland (talk by F. Oljemark)

LHCC Open Session,
30 November, CERN, Geneva, Switzerland
(talk by K. Österberg)

COMMAND 2016,
12–14 December, Sydney, Australia (talk by T. Naaranoja)

Meetings with the LHCC Referees of TOTEM and CT-PPS,
CERN, Geneva, Switzerland (talk by M. Berretti, talk by K. Österberg)

TOTEM Collaboration Meetings,
CERN, Geneva, Switzerland (talk by M. Berretti, F. García, T. Naaranoja, talk by K. Österberg)

TOTEM Physics and Analysis Meetings,
CERN, Geneva, Switzerland (talk by M. Berretti, talk by F. Oljemark, talk by J. Welti, K. Österberg (organiser))

CMS-TOTEM Combined Analysis Meetings,
CERN, Geneva, Switzerland (talk by M. Berretti, talk by J. Welti, K. Österberg (co-organiser))

Nuclear Matter Programme

ALICE

ALICE TPC Upgrade Planning Meeting,
4 February, Darmstadt, Germany (talk by E. Brücken)

GEM QA Meeting Budapest,
16 December, Budapest, Hungary (talks by E. Brücken and T. Hildén)

ALICE TPC Upgrade Working Group Meetings
(contributions by E. Brücken and T. Hildén)

ISOLDE

HIP SAB Meeting,
8 June, Helsinki, Finland (talk by J. Pakarinen)

HIE-ISOLDE Physics Collaboration Committee Meeting,
28 June, Helsinki, Finland (talk by J. Pakarinen)

Zakopane Conference on Nuclear Physics,
28 August – 4 September, Zakopane, Poland
(talk by D. Cox)

NRC9 Conference,
29 August – 2 September, Helsinki, Finland
(K. Helariutta, U. Jakobsson)

Shapes and Symmetries in Nuclei: from Experiment to Theory,
7–11 November, Gif-sur-Yvette, France
(talk by T. Grahn, talk by J. Pakarinen)

ICC Workshop on Simulation with NPTool,
29 November – 2 December, Caen, France (D. Cox)

NUSPRASSEN,
6 December, CERN, Geneva, Switzerland (T. Grahn, J. Pakarinen)

ISOLDE Users Meeting,
7–9 December, CERN, Geneva, Switzerland
(talk by T. Grahn, K. Helariutta, talk by U. Jakobsson, J. Pakarinen)

FAIR

MPGD Applications Beyond Fundamental Science Workshop and the 18th RD51 Collaboration Meeting,
17–19 March, Aveiro, Portugal (talk by F. García)

IEEE Nuclear Science Symposium,
29 October – 5 November, Strasbourg, France (talk by F. García)

ALICE-Forward

ALICE Week,
6–11 March, 15–17 March, 1–6 May, 29 May – 3 June, CERN, Geneva, Switzerland (contribution by R. Orava)

Physics Department Strategy Day,
26 April, Helsinki, Finland (contribution by R. Orava)

CERN,
5 June – 5 December, Geneva, Switzerland (R. Orava)

LOW-x Workshop,
6–11 June, Gyöngyös, Hungary (invited plenary talk by R. Orava)

MoEDAL Collaboration Meeting,
27–29 June, Valencia, Spain (invited plenary talk by R. Orava)

Diffraction 2016,
2–9 September, Catania, Italy (invited plenary talk by R. Orava)

ALICE Physics Working Group Meetings
(contribution by R. Orava)

ALICE AD Project Meetings
(contribution by R. Orava)

ALICE UD Physics Coordination Meetings
(contribution by R. Orava)

Technology Programme

Accelerator Technology

CLIC Workshop,
18–20 January, CERN, Geneva, Switzerland
(F. Djurabekova)

Mini-Workshop Mechanisms of Vacuum Arcing, MEVARC 2016,
20–23 March, CERN, Geneva, Switzerland
(F. Djurabekova, V. Jansson, talk by A. Kyritsakis)

Annual Meeting of the Finnish Physical Society,
29–31 March, Oulu, Finland (E. Baibuz, F. Djurabekova, H. Vázquez Muíños, M. Veske)

European Materials Research Society Spring Meeting,
2–6 May, Lille, France (symposium organiser F. Djurabekova, talk by V. Jansson, H. Vázquez Muíños)

Nanocluster Synthesis, Characterization & Applications Workshop,
15–20 May, Okinawa Institute of Science and Technology Graduate University, Okinawa, Japan
(E. Baibuz, invited talk by F. Djurabekova)

Technical Meeting on Ion Beam-Induced Spatiotemporal Stuctural Evolution of Matter,
23–27 May, Turin, Italy (talk by F. Djurabekova)

CLIC Test Facility 3 in CERN,
15 June – 15 July, Geneva, Switzerland (A. Saressalo)

International Conference Computer Simulations of Radiation Effects in Solids, COSIRES,
19–24 June, University of Loughborough, Loughborough, UK (talks by E. Baibuz, F. Djurabekova, V. Jansson)

Xi'an Jiaotong University,
5–8 July, Xi'an, China (talk by F. Djurabekova)

Summer School at Moscow Engineering Physics Institute,
11–15 July, MEPhI University, Moscow, Russia
(talk by F. Djurabekova)

International Nanoelectronics Conference (IVNC) 2016,
11–15 July, University of British Columbia, Vancouver, Canada (M. Veske)

CERN,
27–29 July, Geneva, Switzerland (F. Djurabekova, A. Kyritsakis)

Czech Institute of Physics,
15 September – 15 December, Prague, Czech Republic
(H. Vázquez Muíños)

5th International Congress on Energy Fluxes and Radiation Effects 2016,
2–7 October, Tomsk Technical University, Tomsk, Russia
(plenary talk by F. Djurabekova)

International Workshop on Radiation Effects in Extreme Condition,
27–30 October, Australian National University, Canberra, Australia (talk by F. Djurabekova)

International Conference on Ion Beam Modification of Materials,
31 October – 4 November, University of Wellington, Wellington, New Zealand (talk by F. Djurabekova)

Novel Instrumentation for Nuclear Safety, Security and Safeguards (NINS3)

KVI – Center for Advanced Radiation Technology, University of Groningen,
18 January – 12 February, Groningen, The Netherlands
(talk by C. Bélanger-Champagne, talk by P. Peura)

Annual Meeting of the Finnish Physical Society,
29–31 March, Oulu, Finland (T. Kerst)

Final Seminar for the REPO Project,
12 April, TEKES, Helsinki, Finland
(C. Bélanger-Champagne, P. Peura)

PGET Meeting,
14 April, IAEA, Vienna, Austria (C. Bélanger-Champagne, talk by P. Dendooven, P. Eerola)

IEEE SORMA West Conference,
23–27 May, Berkeley, CA, USA
(C. Bélanger-Champagne, P. Dendooven, P. Peura)

Optical Frequency Comb Workshop,
20 June, Helsinki, Finland (T. Kerst)

PGET Meeting,
20–21 June, STUK, Helsinki, Finland
(C. Bélanger-Champagne, P. Dendooven, P. Peura)

Euroschool on Exotic Beams,
28 August – 3 September, Mainz, Germany
(lectures by P. Dendooven)

STUK-KINAC Meeting,
29 August, STUK, Helsinki, Finland (talk by P. Peura, C. Bélanger-Champagne)

PGET Meeting,
6 October, IAEA, Vienna, Austria (P. Dendooven)

IEEE Nuclear Science Symposium,
31 October – 4 November, Strasbourg, France
(C. Bélanger-Champagne, P. Dendooven)

Finnish Nuclear Society Nuclear Science and Technology Symposium (NST2016),
2–3 November, Helsinki, Finland (talk by P. Peura)

CLAB,
9 November, Oskarshamn, Sweden
(C. Bélanger-Champagne, talk by P. Dendooven, P. Peura)

PGET Acceptance Testing and Calibration, IAEA and Atominstitut Vienna,
5–16 December, Vienna, Austria (P. Peura)

Symposium on the Future Prospect of Photonics 2016,
14–15 December, Tampere, Finland (T. Kerst)

CLOUD

CLOUD-TRAIN Final Conference,
14–16 June, Königstein, Germany (talk by M. Kulmala)

Planck-Euclid

Euclid OU-SIM Meeting,
13–15 January, Marseille, France (C. Kirkpatrick, H. Kurki-Suonio)

Planck LFI Core Team Meeting,
18–19 January, Bologna, Italy (talk by K. Kiiveri)

Euclid LE3 Galaxy Clustering Meeting,
25–27 January, Milano, Italy (H. Kurki-Suonio, V. Lindholm)

Euclid Garage Days,
10–12 February, Groningen, The Netherlands (H. Kurki-Suonio, V. Lindholm)

Planck LFI Core Team Meeting,
15–17 March, Ferrara, Italy (talk by H. Kurki-Suonio)

Euclid Consortium Board Meeting,
8 April, London, UK (H. Kurki-Suonio)

Euclid SGS System Team Meeting,
25–27 April, Lyon, France (E. Keihänen)

COrE/LiteCOrE Simulations and Foreground Meeting,
28–29 April, Bologna, Italy (K. Kiiveri)

Euclid C++ and Python Programming,
25–27 May, Paris, France (V. Lindholm)

Euclid Consortium Meeting,
30 May – 3 June, Lisbon, Portugal (C. Kirkpatrick, H. Kurki-Suonio, J.Väliviita)

Planck LFI Core Team Meeting,
5–7 June, Bologna, Italy (E. Keihänen)

Euclid Consortium Board Meeting,
27–28 June, Leiden, The Netherlands (H. Kurki-Suonio)

Euclid OU-SIM Meeting,
27–28 July, Toulouse, France (E. Keihänen, H. Kurki-Suonio)

Euclid Consortium Board Meeting,
30–31 August, London, UK (talk by H. Kurki-Suonio)

Planck LFI Core Team Meeting,
14–15 September, Bologna, Italy (H. Kurki-Suonio)

Oslo University,
27–30 September, Oslo, Norway (E. Keihänen)

Hitukosmopäivät,
29–30 September, Tampere, Finland (talk by K. Kiiveri)

Euclid SGS Organization Group and System Team Meeting,
3–5 October, Paris, France (C. Kirkpatrick, H. Kurki-Suonio)

Max Planck Institute for Astrophysics,
10–14 October, Garching, Germany (E. Keihänen)

Euclid Developers Workshop,
11–13 October, Munich, Germany (E. Keihänen, C. Kirkpatrick, V. Lindholm)

Planck LFI Core Team Meeting,
10–11 November, Bologna, Italy (K. Kiiveri)

Euclid SGS System Team Meeting,
5–6 December, Toulouse, France (H. Kurki-Suonio, V. Lindholm)

Publications

Theory Programme

Cosmology of the Early and Late Universe

T. Alanne, K. Kainulainen, K. Tuominen, and V. Vaskonen,
Baryogenesis in the two doublet and inert singlet extension of the Standard Model,
J. Cosmol. Astropart. Phys. 08 (2016) 057

F. Montanari in W. Cardona et al.,
Lensing convergence and the neutrino mass scale in galaxy redshift surveys,
Phys. Rev. D 94 (2016) 043007

F. Montanari in E. Di Dio et al.,
The bispectrum of relativistic galaxy number counts,
J. Cosmol. Astropart. Phys. 01 (2016) 016

F. Montanari in E. Di Dio et al.,
Curvature constraints from large scale structure,
J. Cosmol. Astropart. Phys. 06 (2016) 013

V.-M. Enckell, K. Enqvist, and S. Nurmi,
Observational signatures of Higgs inflation,
J. Cosmol. Astropart. Phys. 07 (2016) 047

K. Enqvist, M. Karčiauskas, O. Lebedev, S. Rusak, and M. Zatta,
Postinflationary vacuum instability and Higgs-inflaton couplings,
J. Cosmol. Astropart. Phys. 11 (2016) 025

K. Enqvist, S. Nurmi, S. Rusak, and D. J. Weir,
Lattice calculation of the decay of primordial Higgs condensate,
J. Cosmol. Astropart. Phys. 02 (2016) 057

K. Enqvist, T. Sekiguchi, and T. Takahashi,
Mixed inflaton and spectator field models: CMB constraints and μ distortion,
J. Cosmol. Astropart. Phys. 04 (2016) 057

M. Heikinheimo, T. Tenkanen, K. Tuominen, and V. Vaskonen,
Observational constraints on decoupled hidden sectors,
Phys. Rev. D 94 (2016) 063506

K. Kainulainen, S. Nurmi, T. Tenkanen, K. Tuominen, and V. Vaskonen,
Isocurvature constraints on portal couplings,
J. Cosmol. Astropart. Phys. 06 (2016) 022

K. Kainulainen, K. Tuominen, and V. Vaskonen,
Self-interacting dark matter and cosmology of a light scalar mediator,
Phys. Rev. D 93 (2016) 015016

T. Sekiguchi in K. Osato et al.,
Cosmological constraint on the light gravitino mass from CMB lensing and cosmic shear,
J. Cosmol. Astropart. Phys. 06 (2016) 004

F. Montanari in J. Renk et al.,
Gravity at the horizon: on relativistic effects, CMB-LSS correlations and ultra-large scales in Horndeski's theory,
J. Cosmol. Astropart. Phys. 07 (2016) 040

S. Räsänen, J. Väliviita, and V. Kosonen,
Testing distance duality with CMB anisotropies,
J. Cosmol. Astropart. Phys. 04 (2016) 050

T. Tenkanen,
Feebly interacting dark matter particle as the inflaton,
J. High Energy Phys. 09 (2016) 049

T. Tenkanen, K. Tuominen, and V. Vaskonen,
A strong electroweak phase transition from the inflaton field,
J. Cosmol. Astropart. Phys. 09 (2016) 037

T. Tenkanen and V. Vaskonen,
Reheating the Standard Model from a hidden sector,
Phys. Rev. D 94 (2016) 083516

High Energy Phenomenology in the LHC Era

A. Amato in G. Aarts et al.,
Spectral functions from anisotropic lattice QCD,
Nucl. Phys. A 956 (2016) 717

T. Alanne, A. Meroni, F. Sannino, and K. Tuominen,
Radiatively induced Fermi scale and unification,
Phys. Rev. D 93 (2016) 091701(R)

C. Gross and O. Lebedev in G. Arcadi et al.,
Multicomponent Dark Matter from gauge symmetry,
J. High Energy Phys. 12 (2016) 081

P. Bandyopadhyay, K. Huitu, and S. Niyog,
Non-standard charged Higgs decay at the LHC in Next-to-Minimal Supersymmetric Standard Model,
J. High Energy Phys. 07 (2016) 015

Y. Bea, N. Jokela, and A. V. Ramallo,
Quantum phase transitions with dynamical flavors,
Phys. Rev. D 94 (2016) 026003

S. Biswas, E. Gabrielli, M. Heikinheimo, and B. Mele,
Dark-photon searches via Higgs-boson production at the LHC,
Phys. Rev. D 93 (2016) 093011

M. Hindmarsh in C. Caprini et al.,
Science with the space-based interferometer eLISA. II: gravitational waves from cosmological phase transitions,
J. Cosmol. Astropart. Phys. 04 (2016) 001

S. Chakraborty, A. Datta, K. Huitu, S. Roy, and H. Waltari,
Light top squarks in a $U(1)_R$ lepton number model with a right handed neutrino and the LHC,
Phys. Rev. D 93 (2016) 075005

V. Keus in A. Cordero-Cid et al.,
CP violating scalar Dark Matter,
J. High Energy Phys. 12 (2016) 014

D. Daverio, M. Hindmarsh, M. Kunz, J. Lizarraga, and J. Urrestilla,
Energy-momentum correlations for Abelian Higgs cosmic strings,
Phys. Rev. D 93 (2016) 085014

M. D'Onofrio and K. Rummukainen,
Standard model cross-over on the lattice,
Phys. Rev. D 93 (2016) 025003

E. S. Fraga, A. Kurkela, J. Schaffner-Bielich, and A. Vuorinen,
QCD constraints on the equation of state for compact stars,
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Neutron star structure from QCD,
Eur. Phys. J. A 52 (2016) 49

M. Frank, K. Huitu, U. Maitra, and M. Patra,
Probing Higgs-radion mixing in warped models through complementary searches at the LHC and the ILC,
Phys. Rev. D 94 (2016) 055016

C. Gross, O. Lebedev, and M. Zatta,
Higgs-inflaton coupling from reheating and the metastable Universe,
Phys. Lett. B 753 (2016) 178

M. Hindmarsh,
Breaking symmetry, breaking ground,
J. Phys. A: Math. Theor. 49 (2016) 411001

M. Hindmarsh, K. Rummukainen, and D. J. Weir,
New solutions for non-Abelian cosmic strings,
Phys. Rev. Lett. 117 (2016) 251601

C. Hoyos, N. Jokela, D. Rodríguez Fernández, and A. Vuorinen,
Breaking the sound barrier in holography,
Phys. Rev. D 94 (2016) 106008

C. Hoyos, N. Jokela, D. Rodríguez Fernández, and A. Vuorinen,
Holographic quark matter and neutron stars,
Phys. Rev. Lett. 117 (2016) 032501

K. Huitu, V. Keus, N. Koivunen, and O. Lebedev,
Higgs-flavon mixing and $h \to \mu\tau$,
J. High Energy Phys. 05 (2016) 026

K. Huitu, T. J. Kärkkäinen, J. Maalampi, and S. Vihonen,
Constraining the nonstandard interaction parameters in long baseline neutrino experiments,
Phys. Rev. D 93 (2016) 053016

K. Huitu, K. Rao, S. D. Rindani, and P. Sharma,
Effective fermion-Higgs interactions at an e^+e^- collider with polarized beams,
Nucl. Phys. B 911 (2016) 274

M. Ihl, N. Jokela, and T. Zingg,
Holographic anyonization: a systematic approach,
J. High Energy Phys. 06 (2016) 076

G. Itsios, N. Jokela, and A. V. Ramallo,
Collective excitations of massive flavor branes,
Nucl. Phys. B 909 (2016) 677

N. Jokela, M. Järvinen, and K. Kytölä,
SLE boundary visits,
Ann. Henri Poincaré 17 (2016) 1263

N. Jokela, A. Pönni, and A. Vuorinen,
Small black holes in global AdS spacetime,
Phys. Rev. D 93 (2016) 086004

J. Järvelä, V. Keränen, and E. Keski-Vakkuri,
Conformal quantum mechanics and holographic quench,
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CP violating Two-Higgs-Doublet Model: Constraints and LHC predictions,
J. High Energy Phys. 04 (2016) 048

A. Kurkela and A. Vuorinen,
Cool quark matter,
Phys. Rev. Lett. 117 (2016) 042501

M. Hindmarsh in J. Lizarraga et al.,
New CMB constraints for Abelian Higgs cosmic strings,
J. Cosmol. Astropart. Phys. 10 (2016) 042

QCD and Strongly Interacting Gauge Theory

K. J. Eskola in J. L. Albacete et al.,
Predictions for p+Pb collisions at $\sqrt{s_{NN}}$ = 5 TeV: Comparison with data,
Int. J. Mod. Phys. E 25 (2016) 1630005

F. Arleo, É. Chapon, and H. Paukkunen,
Scaling properties of inclusive $W^\pm$ production at hadron colliders,
Eur. Phys. J. C 76 (2016) 214

H. Paukkunen in N. Armesto et al.,
An analysis of the impact of LHC Run I proton-lead data on nuclear parton densities,
Eur. Phys. J. C 76 (2016) 218

H. Paukkunen in N. Armesto et al.,
Re-weighting at the LHC: the p-Pb data impact,
Nucl. Phys. A 956 (2016) 525

R. Chatterjee, D. K. Srivastava, and T. Renk,
Triangular flow of thermal photons from an event-by-event hydrodynamic model for 2.76A TeV Pb + Pb collisions at the CERN Large Hadron Collider,
Phys. Rev. C 94 (2016) 014903

B. Ducloué, T. Lappi, and H. Mäntysaari,
Centrality-dependent forward J/ψ production in high energy proton-nucleus collisions,
EPJ Web of Conferences 112 (2016) 04002

B. Ducloué, T. Lappi, and H. Mäntysaari,
Nuclear modification of forward J/ψ production in proton-nucleus collisions at the LHC,
Nucl. Part. Phys. Proc. 276-278 (2016) 141

B. Ducloué, T. Lappi, and H. Mäntysaari,
Centrality dependence of forward J/ψ suppression in high energy proton-nucleus collisions,
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B. Ducloué, T. Lappi, and H. Mäntysaari,
Forward J/ψ production at high energy: Centrality dependence and mean transverse momentum,
Phys. Rev. D 94 (2016) 074031

B. Ducloué, T. Lappi, and Y. Zhu,
Single inclusive forward hadron production at next-to-leading order,
Phys. Rev. D 93 (2016) 114016

B. Ducloué, L. Szymanowski, and S. Wallon,
High-energy resummation effects in the production of Mueller-Navelet dijets at the LHC,
EPJ Web of Conferences 112 (2016) 02015

Y. Zhu in L. Keegan et al.,
Weak and strong coupling equilibration in nonabelian gauge theories,
J. High Energy Phys. 04 (2016) 031

A. Kurkela, T. Lappi, and J. Peuron,
Time evolution of linearized gauge field fluctuations on a real-time lattice,
Eur. Phys. J. C 76 (2016) 688

T. Lappi,
Initial state in heavy ion collisions,
Nucl. Part. Phys. Proc. 276-278 (2016) 29

T. Lappi,
Initial state azimuthal anisotropies in small collision systems,
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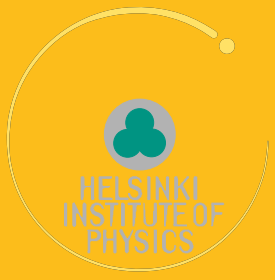

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