Norwegian High Energy Particle Physics research with the ATLAS detector at the Large Hadron Collider.

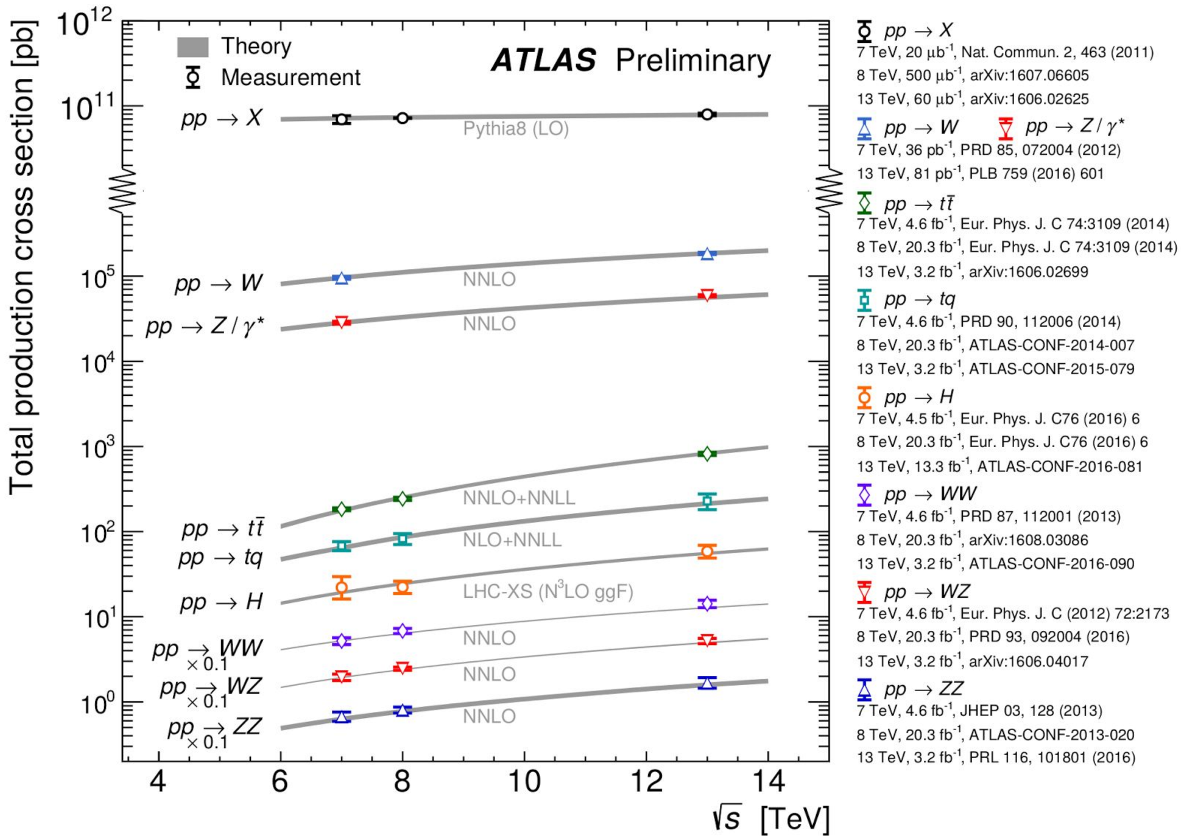
HEPP 2016-2019

Norwegian Research Council
Project Number 255182/F50

October 1st 2016 – September 30th 2017

Project Status, Activity Summary, Highlights

F. Ould-Saada et al.,30-09-2017



Introduction

The Large Hadron Collider (LHC) and the ATLAS experiment have so far been hugely successful. The discovery of the Higgs particle and the painstaking search for new physics in all possible corners of the data are the highlights so far. The project 'High Energy Particle Physics at LHC Run 2´ aims to collect and exploit 13 TeV data until end of 2018. This ambitious physics programme may shed light on two of the greatest mysteries in physics today: the nature of dark matter and the behaviour of the gravitational force at the microscopic scale. Our strong team of experts in physics analysis, software and computing, detector technology and statistics, proposes a way to refine the ATLAS detector, strengthen the computing infrastructure and tools, and innovate in analysis methods, in order to take part in this revolution in understanding the basic laws of nature. Theoretical particle and astroparticle physicists in Oslo, Bergen and Trondheim work closely with us, creating synergies in interpretation of results and widening the scope for new physics searches.

With the restart of the experimental programme at higher collision energies and luminosities, data rates will increase dramatically, posing new challenges for distributed computing. Continued contributions to and adaptation of the Worldwide LHC Computing Grid infrastructure (WLCG), novel algorithms, and software optimisation are mandatory and provide experience at the forefront of computing technology. To run at even higher luminosities and energies necessitates the upgrade of the ATLAS detector. Our experience in developing novel 3D silicon sensors is instrumental for the final sensor technology to be employed by the new all-silicon tracker (ITk), which will replace the current Inner Detector. The R&D necessary for the ITk is now approaching its final phases. Last but not least, we aim to educate tomorrow's experts - master and PhD students - and share the excitement, data and discoveries with students and the public.

Manpower situation and financing status

Manpower situation

The staff members involved in the HEPP project are listed below.

Permanent staff

Thirteen professors (two have retired) take part in the HEPP project at levels varying between 10% and 50%. In general people are involved in at least one more activity – R&D, computing, AeGIS, CTA (Cherenkov Telescope Array), etc. Two permanent researchers at UiO and more recently one at UiB, rely on external funding, currently mainly funded by the Research Council (RCN). In 2017 Trygve Buanes, researcher until 2016, and Therese Sjursen (PhD in 2015) became associate professors at the Western Norway University of Applied Sciences (previously Høgskolen i Bergen). Both intend to collaborate with the UiB ATLAS group. Garonne, and Buanes and Sjursen are now listed as permanent staff members starting from 2017. Four engineers and technicians help with the ATLAS upgrade.

Name	***Affiliation***	***Period***	***Funding***
Prof. Farid Ould-Saada	UiO Exp.	2006 -	UiO
Prof. Alex L. Read	UiO Exp.	2006 -	UiO
Prof. Heidi Sandaker	UiO Exp.	2015 -	UiO
Prof. Gerald Eigen	UiB Exp.	2006 -	UiB
Prof. Anna Lipniacka	UiB Exp.	2006 -	UiB
Prof. Bjarne Stugu	UiB Exp.	2006 -	UiB
Ass. prof. Trygve Buanes	UiB Exp.	2017-	WNUAS
Ass. prof. Therese Sjursen	UiB Exp.	2017-	WNUAS
Dr. Ole Røhne	UiO Exp.	2012 -	RCN (25% ESS)
Dr. David Cameron	UiO Comp.	2012 -	RCN (50% ATLAS)
Bertrand Martin Dit Latour	UiB Exp.	2017 -	RCN, HEPP
Dr. Maiken Pedersen	UiO Comp.	2016 -	USIT/NeIC
Dr. Vincent Garonne	UiO Exp.	2017 -	USIT/NeIC
Kjell Martin Danielsen	UiO Eng.	2006 -	UiO
Ole Dorholt	UiO Eng.	2006 -	UiO
Attiq Ur Rahman (50%)	UiB Eng.	2015 -	UiB
Prof. Torsten Bringmann	UiO Theory	2014 -	UiO
Prof. Are Raklev	UiO Theory	2012 -	UiO
Prof. Jan Olav Eeg	UiO Theory	2015 -	retired
Prof. Jörn Kersten	UiB Theory	2014 -	UiB
Prof. Per Osland	UiB Theory	2015 -	retired
Prof. Michael Kachelriess	Ntnu Theory	2016 -	NTNU
Prof. Are Strandlie	HiG Exp.	2006 -	HiG/NTNU

Postdocs and researchers

The following people are mostly funded by RCN through the HEPP project, with contributions from RCN Free Programme grants (theory), UiO (theory and experiment) and ATLAS (computing).

Name	***Affiliation***	***Period***	***Funding***
Eirik Gramstad	UiO	01.16 - 10.18	RCN, HEPP
James Catmore	UiO	01.16 - 12.17	RCN, HEPP
Magnar Kopangen Bugge	UiO	05.16 - 04.19	RCN, HEPP

Vincent Garonne	UiO Exp.	01.15 - 06.17	ATLAS (1/6 HEPP)
Cedric Serfon	UiO Exp.	10.15 - 09.18	ATLAS (10% HEPP)
NN	UiO Exp.	01.18 - 12.19	RCN, HEPP
Bertrand Martin Dit Latour	UiB Exp.	01.16 - 12.16	RCN, HEPP
Zongchang Yang	UiB Exp.	01.16 - 12.17	RCN , HEPP
NN	UiB Exp.	01.18 - 12.19	RCN, HEPP
NN	UiB Exp.	01.18 - 12.19	RCN, HEPP
Dr. Tomas Gonzalo	UiO Theory	10.15 - 09.18	RCN, FRIPRO
Dr. Andrzej Hryczuk	UiO Theory	10.13 - 09.17	UiO, SDI

Owing to excellent contributions to software and distributed computing, we could benefit a maximum return from the annual HEPP contributions to ATLAS Maintenance & Operations funds. This is further strengthened by an effective collaboration with NeIC and USIT.

In addition to researcher David Cameron, see permanent staff list above, who was partly funded by the HEPP project with contributions from NeIC, then ATLAS through the M&O and common funds, two additional researchers, software and computing experts, have been affiliated to UiO for 3 years in January 2015 (Vincent Garonne 5/6 ATLAS and 1/6 HEPP) and October 2015 (Cedric Serfon, 90% ATLAS, only 10% contribution from HEPP). The Norwegian contributions to these positions are covered by this HEPP project period, although only parts of the spendings is effective in the 2016 project period. Jon Nilsen and Dmytro Karpenko (no longer in the HEPP project and not listed) have permanent positions at USIT. They still make valuable contributions to the distributed computing activities through the Nordic WLCG Tier 1. More recently, Maiken Pedersen (PhD in 2015) holds a permanent position at USIT (co-funding from NeIC) as ARC developer. She is now listed as permanent staff. Garonne has also obtained a permanent position (USIT/NeIC) as storage expert. He moved to Oslo in August 2017.

PhD students

Name	***Affiliation***	***Period***	***Supervisor***	***Funding***
Kristian Bjørke	UiO Atlas	08.16-08.20	Read, Raklev	UiO SDI
Laura Franconi	UiO Atlas	01.13-12.17	Røhne, Read	Talent
Vanja Morisbak	UiO Atlas	08.13-12.18	Ould-Saada, Read	UiO HEPP
Simen Hellesund	UiO Atlas	08.16-08.20	Ould-Saada, Bugge	UiO HEPP
Henrik Oppen	UiO Atlas	08.15-08.19	Sandaker, Catmore, Ould-Sa	UiO HEPP
Knut OH Vadla	UiO Atlas	08.15-08.19	Ould-Saada, Gramstad, Sand	UiO SDI
Eli B. Rye	UiO Atlas	08.17-08.21	Sandaker, Ould-Saada	UiO HEPP
Andreas L. Heggelund	UiO Atlas	08.17-08.21	Read, Røhne, Sandaker	UiO HEPP
Nikolai Fomin	UiB Atlas	01.16-12.19	Lipniacka, Martin dit Latour	UiB HEPP
Steffen Mæland	UiB Atlas	01.14-12.17	Stugu, Eigen	UiB HEPP

Justas Zalieckas	UiB Atlas	08.12-11.16	Eigen, Stugu	UiB HEPP
Jeriek v.d. Abeele	UiO Theory	08.16-08.19	Raklev, Read	UiO SDI
Parampreet Walia	UiO Theory	10.13-01.18	Bringmann, Mota	UiO
Inga Strümke	UiB Theory	05.15-04.19	Kersten, Raklev	UiB
Anastasia Sokolenko	UiO Theory	10.16-09.19	Bringmann, Mota	UiO

Master students

Name	***Affiliation***	***Period***	***Supervisor***
Anne-Marthe Hovda	UiO Atlas	08.15-06.17	Read
Even Simonsen Håland	UiO Atlas	08.15-06.17	Ould-Saada, Gramstad
Anders Huse Pedersen	UiO Atlas	08.15-02.18	Sandaker, Gramstad
Børge Tranøy Hovden	UiB Atlas	01.16-11.17	Lipniacka, Martin dit Latour
Magne Lauritzen	UiB Subatom	08.15-06.17	Lipniacka, Stugu
Håkon Kolstø	UiB Atlas	08.16-06.18	Eigen
Are Træet	UiB Atlas	08.15-09.17	Eigen
Andreas Løkken Heggelund	UiB Atlas	08.15-06.17	Stugu
Eli Bæverfjord Rye	UiO Theory	08.14-12.16	Raklev
Mari Røysheim	UiO Theory	08.14-12.16	Raklev
Thomas Haaland	UiO Theory	08.15-12.17	Raklev
Jon Vegard Sparre	UiO Theory	08.16-02.18	Raklev
Ingrid Angélica Holm	UiO Theory	08.16-05.18	Raklev
Thorbjørn Vidvei Larsen	UiO Theory	08.16-05.18	Gonzalo, Raklev
Martin Breistein	UiB Subatom	01.16-12.16	Kersten
Håkon Høines	UiB Subatom	01.16-12.16	Kersten
Hans Heum	UiB Subatom	08.15-11.17	Kersten
Daniel Alvestad	UiB Subatom	08.16-06.18	Kersten
Marie Tamber Løbach	UiB Subatom	01.17-11.18	Kersten
Anton Kuncinas	UiB Subatom	08.17-06.19	Kersten
Ask Markestad	UiO Theory	08.15-05.17	Bringmann, Hryczuk
Alessio Pizzini	UiO Theory	08.16-05.18	Bringmann, Hryczuk
August Geelmuyden	UiO Theory	08.16-05.18	Bringmann, Hryczuk
Kristian Joten Andersen	NTNU	09.16-05.17	Kachelriess
Petter Taule	NTNU	09.16-05.18	Kachelriess
Martin Hornkjoel	NTNU	09.16-05.18	Kachelriess
Kristian Bryhn Myhre	NTNU	09.16-05.18	Kachelriess

Financing situation

There is no overall change to the RCN (Research Council of Norway) total budget. The project is being implemented in accordance with the following funding plan:

	Amount (kNOK)	2016	2017	2018	2019
Research Council	44 000	7 809	17 150	10 127	8 914
Own financing	56 159	12 706	16 148	13 849	13 456
Total financing	100 159	20 515	33 298	23 976	22 370

We will report on the 2017 budget at a later stage. Due to uncertainties on the upgrade and computing - see more information on the infrastructure project below - some expenses might be moved from 2017 to 2018 and/or 2019.

The NFR funding covers the following areas:
- post-doc and researcher positions in a sustained way
- the ATLAS maintenance and operations and other common funds
- detector R&D and hardware contributions to ATLAS, including renting of laboratory space and instruments
- travel and subsistence (CERN, conferences and workshops worldwide, long-term stays)
- a small contribution to outreach activities and organisation of project workshops and local conferences
- the Norwegian part of the Nordic WLCG Tier-1 computing infrastructure

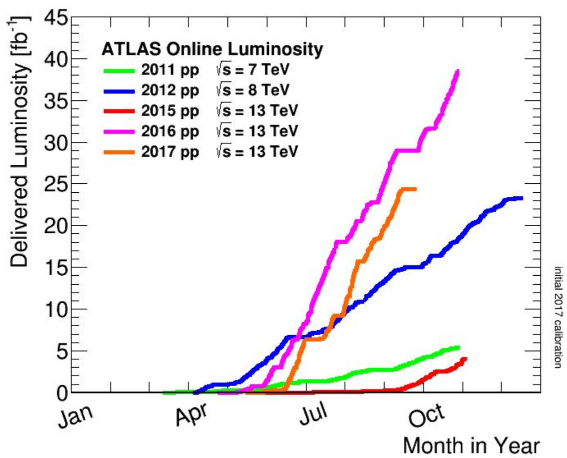
The own contributions by UiO and UiB are about 50%. They cover mainly salaries of permanent staff, including technicians and engineers, occasionally post-docs or researchers, and PhD grants. Given the popularity of and the interest in our research field we still wish to have an increase of the number of PhD grants. Payroll and indirect expenses make the bulk of the project expenses, followed by operating expenses, travel and computing hardware, and, finally, other equipments (silicon detectors for R&D and beam tests, staves and flexes for IBL and AFP) .

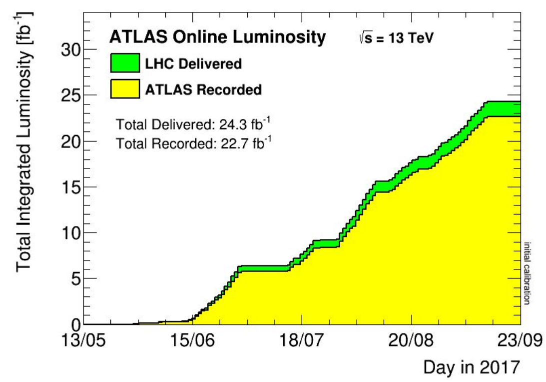
The 5-year infrastructure project - NorLHC - will be funded by the RCN with the goal to cover the ATLAS and ALICE detector upgrades as well as the computing needs of the 2 experiments.. Unfortunately we have only received 60% of the sought budget. We entered negotiations with the RCN in September 2017 with the challenge to deal with the 40% cut. We consider both reducing the scope of the project and deferring some expenses to a second phase, with the hope to apply for an extension of the infrastructure project and/or apply within the next period of the HEPP project. Note that computing is an inherent challenge which necessitates a long-term solution beyond the NorLHC project period, see further in the computing section.

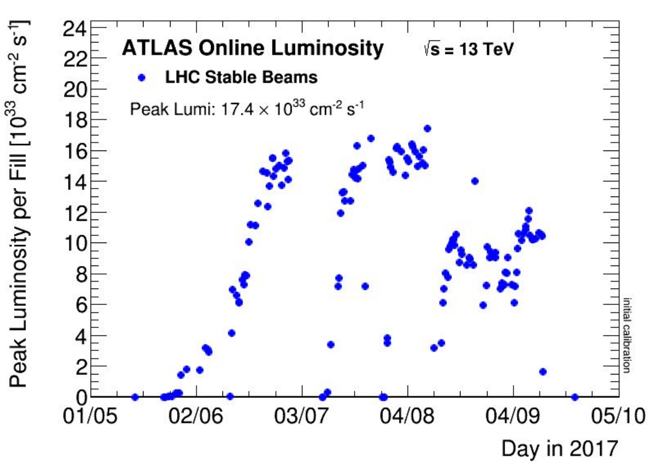
Performance and highlights

The LHC delivered high quality data; ATLAS recorded 93%

In terms of number of collisions per second, a peak luminosity of 17.4×10^{33} $cm^{-2}s^{-1}$, above the LHC design luminosity of 10×10^{33}, was reached. The integrated luminosity (Figures below) recorded by ATLAS in 2017 – so far 22.7 fb^{-1} at 13 TeV and a collision rate frequency of 25 MHz, instead of 50 during Run 1 – exceeds 93% of that delivered by LHC.







About 95% of the data recorded by ATLAS in 2016 and 2017 is used for physics measurements and results. This proves the very good performance of the detector.

The current challenge is to collect as much luminosity as possible and push the LHC machine to its limit before the long LHC shutdown 2 in 2019 and 2020: an instantaneous luminosity surpassing 10^{34} $cm^{-2}s^{-1}$ and energy of 13 TeV at a collision rate frequency of 25 ns, instead of 50 ns during Run 1.

Total integrated and peak luminosities in 2017.

The ATLAS detector had control over high pile-up in 2016 Run 2

The event display in below, showing a proton-proton collision, is a proof that the tracking system of ATLAS, which includes an important Norwegian contribution (Semi Conductor Tracker, SCT, and the Pixel B-layer), functioned very well during the LHC Run 2.

A display of a candidate Higgs boson event from proton-proton collisions recorded by ATLAS at 13 TeV. The Higgs boson candidate is reconstructed in a beam crossing with 25 additionally reconstructed primary vertices from the minimum bias interactions. The candidate event is reconstructed in the 2μ2e final state. The invariant mass of the four lepton system is 119 GeV. In the left display, the red lines show the path of the two muons including the hits in the muon spectrometer, the green lines show the paths of the two electrons together with the energy deposit in the electromagnetic calorimeter.

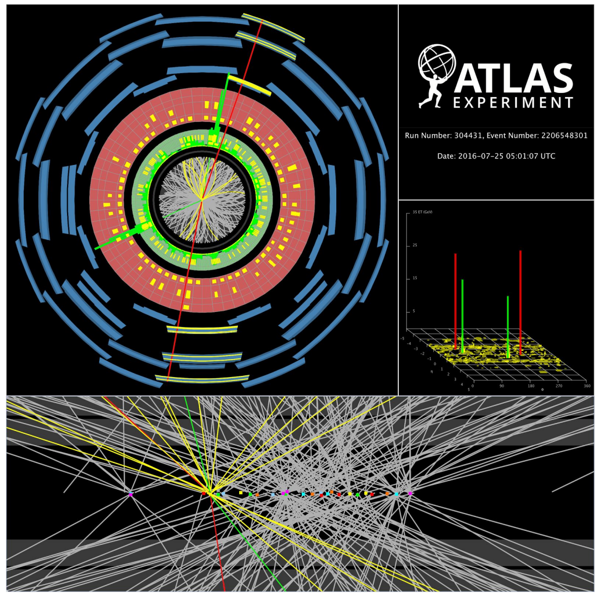


Figure. Higgs boson event candidate during the high pile-up data taking period in 2016.

In fact, the entire ATLAS detector functioned well despite operating at pile-up conditions tougher in 2017 than 2016 and more than a factor of 2 larger in 2017 than in 2015.

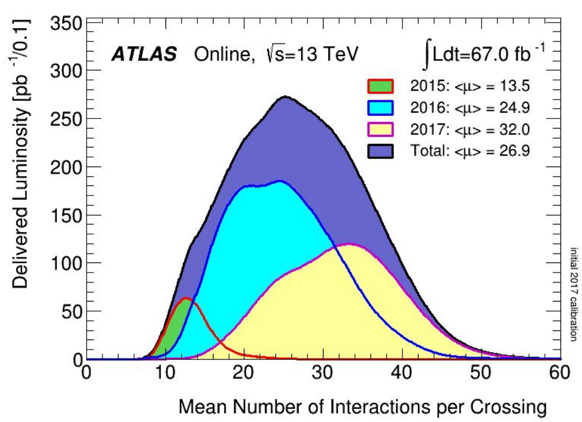


Figure. Number of proton-proton interactions per beam crossing in 2015, 2016 and 2017 (luminosity weighted).

A strong contribution to publications

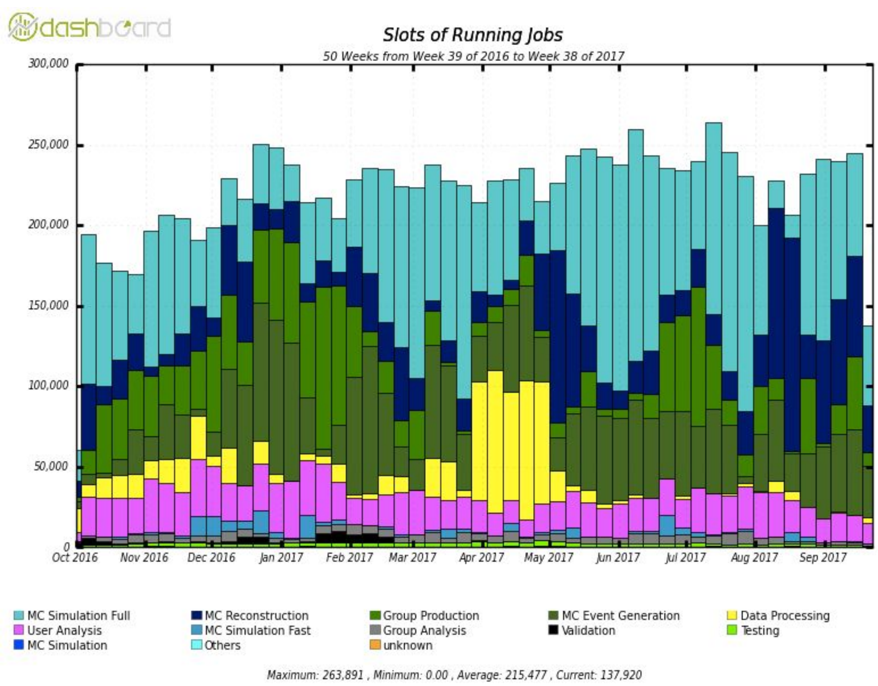
The physics publications cover extensive searches, at energies of 7, 8 and 13 TeV, for new physics phenomena and measurements of Standard Model processes (Higgs boson and Bottom quark physics). By the end of 2016 ATLAS has produced about 660 publications in refereed journals and more than 40 have been submitted; we have made direct contributions to about 10%

of these, have acted as editorial board members or internal referees for some of them, and have presented Run1 and Run2 results at international conferences and workshops.

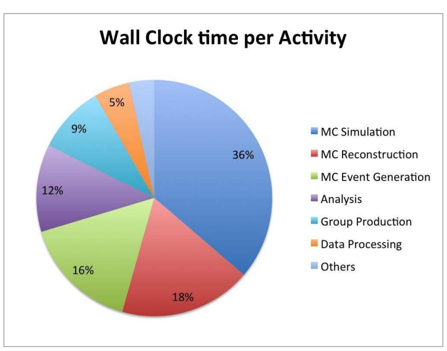
Distributed computing made it possible

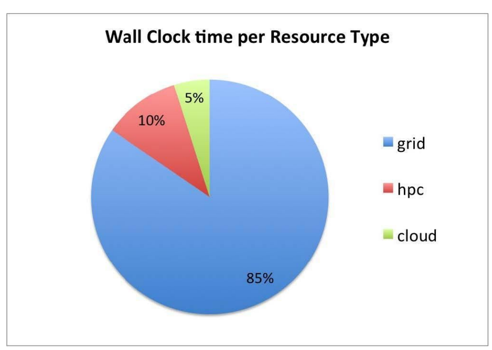
A significant contribution is made to the central and worldwide computing and Grid operation, including distributed data production, management and analysis. The operation of the Nordic Tier-1 is done in collaboration with USIT (University of Oslo IT department) and Uninett Sigma2 within the Nordic eInfrastructure Collaboration (NeIC).

The number of concurrent CPU-cores used by ATLAS jobs on the WLCG in the last year, around 20% of which are running on NorduGrid ARC-enabled resources.

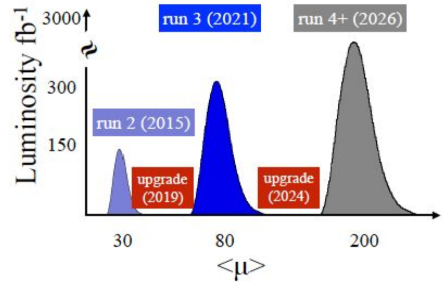


As the charts below show, the majority of jobs are Monte Carlo (MC) event generation and simulation, closely followed by physics analysis. Most of the jobs run on the Grid, followed by HPC centres and Clouds. To date 300 PetaBytes of data have been recorded on disk (195) and tape (105).



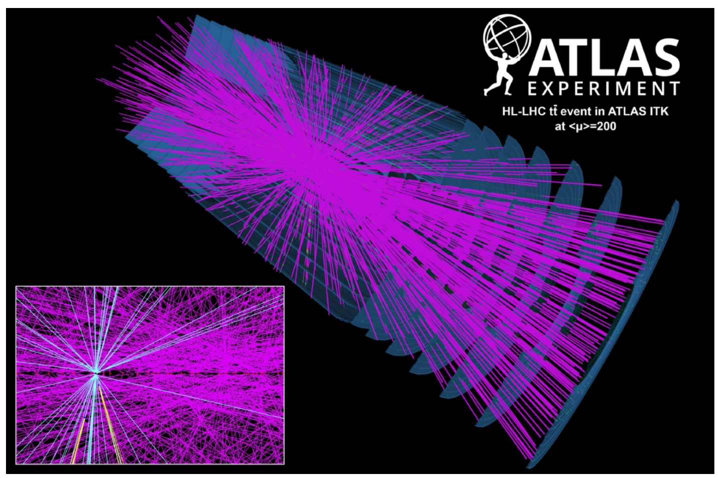


Both the ATLAS detector and computing and software will be challenged during the next running periods. Integrated luminosities of 150 fb^{-1} (300, 3000) will be accumulated at 13 and/or 14 TeV with a mean pile-up of 30 (respect. 80 and 200) during Run 2 (respec. Run 3 and Run 4).



The conditions that will prevail at the high-luminosity LHC are demonstrated through the simulated top-antitop event at a mean pile-up of 200 (Figure below). High track densities will be a challenge for the new Inner Tracker (Itk) made of silicon strips and pixels.

Figure. Simulated top-antitop event in the new ITk tracker at a mean pile-up of 200



ATLAS Detector Upgrade

The technical design report of the Strip part of the new Inner Tracker (Itk) was ready end of 2016. The Pixel Itk TDR, with Norwegian contribution, is due end of 2017.

2017 was an important year for the ATLAS upgrade in Norway. After finishing the infrastructure application autumn 2016, a lot of work has been put into the preparation of the next steps of the Norwegian ATLAS upgrade programme. The infrastructure application includes the core costs of ATLAS upgrade as well as participation in the construction of the Inner Tracker. The outline of the proposed upgrade plan is to participate in the construction of pixel modules and their mounting onto staves as well as substantial fraction to common items, in line with our previous application in 2014 and the project proposals of the Norwegian CERN related research program for ATLAS.

In July 2017 we received positive feedback from the research council. We entered negotiations with the RCN in September 2017 with the challenge to deal with the 40% cut in the overall budget. We are considering both reducing the scope of the project and deferring some expenses to a second phase, with the hope to apply for an extension of the infrastructure project and/or apply for additional funding within the next period of the HEPP project on top of the current envelope. Meanwhile, we are very much looking forward to the formal start of the LHC infrastructure project, hopefully by the end of 2017, and the continuation of the R&D upgrade programme within the HEPP project.

Contributions to AFP

After successfully contributing to two deliverables to AFP (ATLAS Forward Protons)[1], flexes and mechanical support structure, in 2016 (see Figure below) we completed in 2017 the final deliveries. In AFP, the sensors are installed very close to the beam, far downstream from the interaction point in a very harsh radiation environment. Now in total 40 flex-hybrids have been successfully developed, assembled and tested in Oslo, and delivered to AFP. Bergen has been responsible for developing a mechanical support structure for holding four 3D sensors in AFP in its final position. In addition, we have contributed to the decoding of the raw sensors data including the interface to ATLAS software (bytestream converter) and the installation of cables underground. In total we have contributed to 4 roman pots, and now in 2017 they have been completed, installed underground and are in operation. Bergen has organized and held ALFA/AFP general meeting 11-14 September 2017.

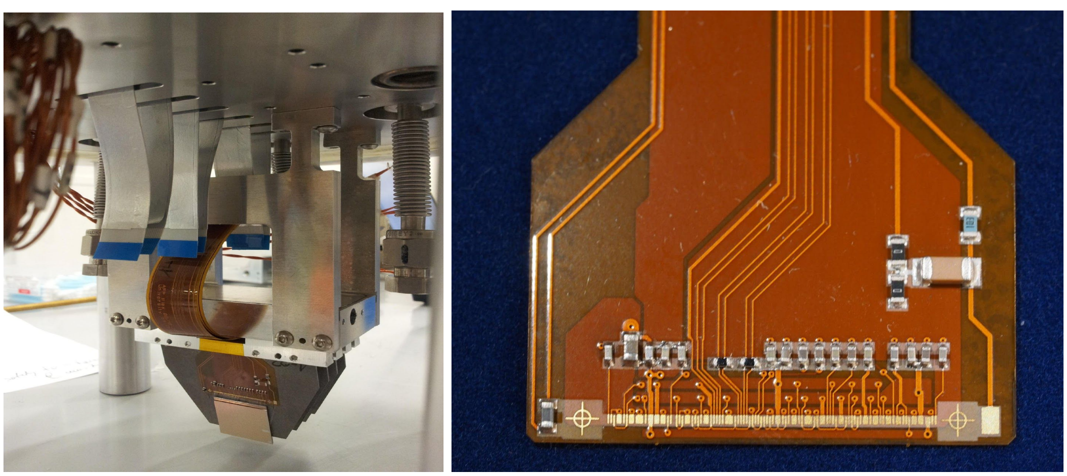


Figure. Left, an arm of the silicon pixel system for the AFP mounted in the lab. The Norwegian groups have contributed with the flat readout flexible cables as well as with the mechanical support structure for mounting four 3D sensor modules in AFP. Note that the modules are mounted at an angle in order for the 3D sensors to detect the incident protons with full efficiency.

[1] S. Grinstein, O. Dorholt, O. Rohne, B. Stugu et al., Module production of the one-arm AFP 3D pixel tracker, PIXEL 2016 proceedings; Submitted to JINST, 2016, Instrumentation and Detectors in High Energy Physics Experiment

3D sensor R&D

The Oslo and Bergen groups have further researched radiation hard 3D silicon sensors, currently in use in AFP and IBL, for the ATLAS Inner Tracker. In 2017 we have continued our analysis of tested sensors developed with SINTEF (Run 3) with pion beams during the 2015 and 2016 spring and autumn campaigns. This design consists of vertical electrodes in a planar silicon wafer, and has been shown to be fully operational at very low bias voltages, even after substantial irradiation. First results have been presented at ATLAS upgrade weeks and we have been able to demonstrate that the efficiency profile of the sensors is as expected (See Figure below). Currently we are working on a publication of these testbeam results showing the performance of these sensors.

Our work towards a new 3D sensor run (Run 4) with SINTEF has progressed significantly this year. Investigations at SINTEF during 2016 revealed what may be at the origin of their low production yield in past fabrication runs. SINTEF's R&D run was finished in 2016 and production only started mid-autumn 2016, with a delay of around 6 months. Further delays happened early 2017 due to equipment malfunction and replacement of old equipment in the SINTEF laboratory. Currently SINTEF is about to finish their wafer processing and we expect to have first results from the test metal layer October 2017.

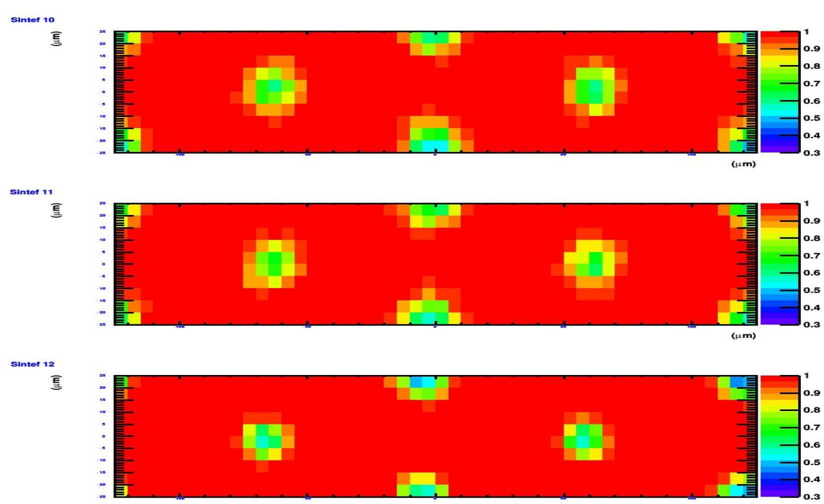


Figure. Average single pixel efficiencies of three prototype sensors, as measured by the Bergen and Oslo groups in a pion beam.The pixel size is 0.05 x 0.25 mm^2. The regions with low efficiency correspond to the position of the electrode implants in sensors.

Site qualification

The preparation for the ITK site qualification is well on its way in Oslo. The new cleanroom has been completed and furnishing has started. The 10 year old Kulicke-Soffa 8090 bonding machine, which was temporarily recommissioned during 2016, was declared unmaintainable and finally decommissioned in the spring of 2017. Leiested funds were used to purchase a new

Delvotec G5 2017 machine. The new machine will arrive November 2017. The old machine was successfully used to bond detectors from other projects as a first step before being used to demonstrate module assembly for ATLAS. This will now be done with the new machine. A granite table is installed and will house an assembly robot, which together with the newly purchased laser system has been set early 2017. A full silicon module for AEGIS has already been built in this new laboratory and we look forward to start building ATLAS 3D modules as the next step.

Further contributions

PhD student Laura Franconi (supervisors Read, Røhne) is finishing her thesis. Since February 2017 she has been working, within the ATLAS Pixel Offline group, on the evaluation of the performance of the 3D sensors instrumenting the IBL, in terms of pixel cluster properties (e.g. pixel cluster size, efficiency, resolution..). The study is of interest because it is the first time 3D sensors instrument an LHC experiment. Laura made comparison between the IBL planar and the IBL-3D properties and assessed the variation of these properties as a function of the luminosity. She also compared collision data with MC simulations. This work aims at being part of a publication on the pixel performance.

PhD student Nikolai Fomin's (supervisor A. Lipniacka) qualification work was to provide "Bytestream converter for the ATLAS AFP tracking detector", converting stream of bytes resulting from hits into physics data. The digital format can then be further processed in xAODs. The bytestream converter was completed and validated and is presently working in line with expectations enabling physics data analysis from AFP. The next step is to write a database interface related with calibration(s), but that requires more preparation and discussion from the AFP side.

Steffen Mæland has continued to contribute to pixel and IBL analysis and software, by continuing to maintain the bytestream converter code, and studying the development of the depletion depth in the sensors. Results from these studies using 2016 and 2017 data have been presented at the Pixel general meeting and in a dedicated pixel performance meeting.

MSc student Andreas Heggelund (supervisor B. Stugu) worked on testbeam data and has also set up the testbeam and sensor simulation tool (called 'allpix'). The simulation and subsequent reconstruction chain worked well with planar pixel sensors. Heggelund's thesis includes TCAD field maps for the simulation of 3D sensors, as well as specialised studies of the efficiency profiles of the edges of the sensors (so-called 'active edge') Heggelund graduated in June 2017[2]. During August 2017, Andreas Heggelund was hired as PhD student at the University of Oslo.

[2] A. Heggelund "Analysis of 3D Pixel Detectors for the ATLAS Inner Tracker Upgrade." http://bora.uib.no/handle/1956/16039

Zongchang Yang has been involved in R&D of 3D silicon pixel sensors for the ATLAS upgrade. He participated in two test beams at the CERN North Area in 2016. A good amount of data were collected, and first results were presented at the 5th Test Beam Workshop in Jan 2017. More data analysis and detailed studies of the 3D pixel sensor efficiencies will be included in an article. Zongchang chairs the weekly ATLAS detector upgrade meeting common to Oslo and Bergen.

Electronics engineer Attiq Rehman has, together with B. Stugu, made contact with the RD53 collaboration, which is developing radiation hard pixel readout chips for LHC experiments upgrades. A newly graduated MSc student from Bergen, Magne Lauritzen[3], is staying in Berkeley for six months (from end of September 2017) to take part in testing the first prototype chips that will be received in November 2017. The plan is that Lauritzen and Rehman start setting up a chip testing system in Bergen from March 2018 based on the experience acquired in Berkeley. Rehman is looking into contributing to the design of the final front-end readout chip that is to be used in ATLAS ITk. Lauritzen is an excellent candidate for the engineering position at UiB that is planned to be announced within the recently approved LHC infrastructure project.

Computing and Software

Computing

Computing is a crucial part of the LHC physics experiments. The ATLAS computing model relies on a geographically distributed framework which facilitates management of more than 300 PB of data, gives access to around 250 000 promised cores (and peaks of up to 300 000, including opportunistic cores) and is the daily working tool for more than 1000 physicists.

The ATLAS Distributed Computing (ADC) activity manages and coordinates the operation of this distributed system, with members of UiO taking several key roles in the organisation. During LS1, two major ADC components, handling data and workflow management, underwent complete rewrites building on the experience of Run 1. These systems came to maturity during 2015 at the start of Run 2 and proved extremely capable of handling the larger than expected requirements of data taking in the last two years.

The ATLAS Distributed Data Management (DDM) system in particular has evolved drastically since the Rucio software fully replaced the previous system before the start of Run 2. With the exceptional LHC performance in 2016 and 2017, the ATLAS DDM system manages now more

[3] Magne Lauritzen: “A Silicon Photomultiplier Based Readout System For A Cosmic Muon Telescope; Design And Implementation” MSc thesis. (http://bora.uib.no/handle/1956/16044).

than 300 petabytes spread on 130 storage sites. DDM has been operating robustly, stably and effectively since the beginning of 2016 and ATLAS is using all the available resources at full scale. The focus of 2017 has been the integration of new technologies such as object stores, and offering new features mainly related on performance and automation, while preparing the long term evolution plans of the ATLAS data management.

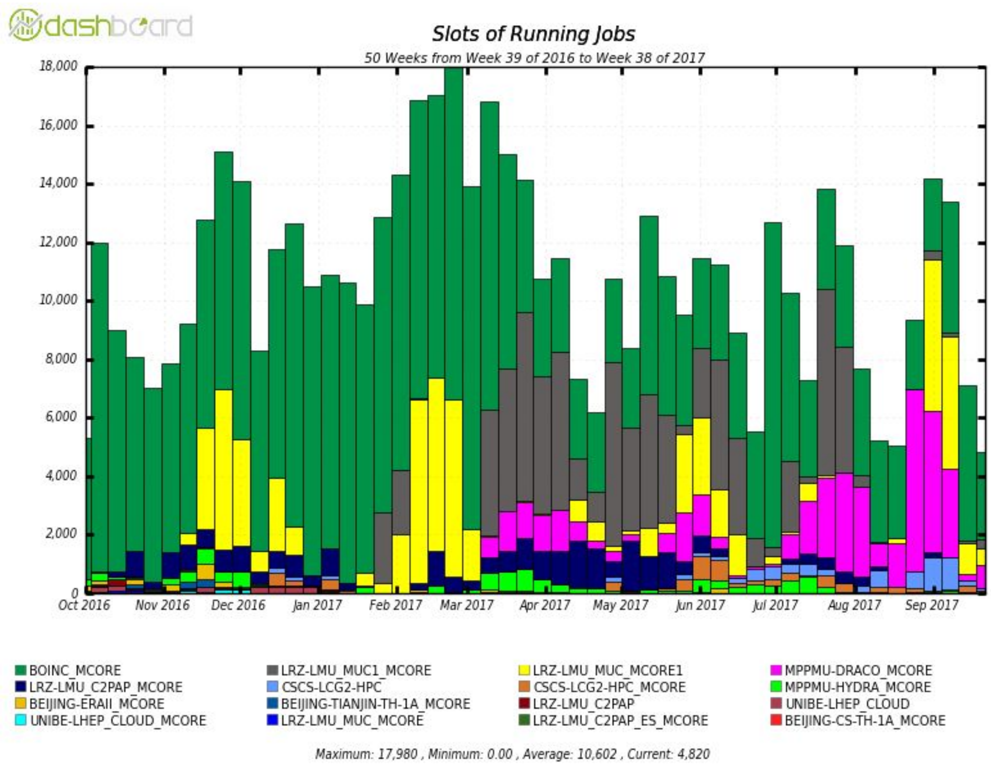
Along with Rucio software development, a parallel effort exists to operate and manage the running system. The DDM operations duties include ensuring data replication follows the computing model, helping commission/decommission storage sites, implementing the data lifetime model, integration with other ADC systems, user support, and in general ensuring a smooth running system with no bottlenecks such as full disks at sites. HEPP members have important roles in leading the DDM project (Vincent Garonne) and leading the DDM operations effort (Cedric Serfon).

The NorduGrid ARC middleware continues to increase in popularity outside its traditional Nordic roots. The simplistic design, ease of deployment and good support make it the preferred choice of middleware for new and many existing sites particularly in Europe and Asia. At the moment ARC is either fully deployed or in the process of being deployed at 5 out of 11 ATLAS Tier-1 sites, and countries such as Germany and the UK are moving towards deploying ARC on all their sites. The ARC software has proven to be very stable and recent development consists mainly of implementing minor new features and bug fixes.

Many of the ARC sites are managed by the ARC Control Tower (aCT), which is a service at CERN sitting between the PanDA workload management system and the ARC Compute Elements (CE). This service is required to allow ATLAS jobs to run on restrictive environments such as High Performance Computing centres because it provides the mechanisms to handle data staging and communication with PanDA outside the job worker node. Increasingly, aCT is also used for other "regular" grid sites, because the model allows more efficient use of the batch systems and simplifies the administration of the site setup within ATLAS systems. Today aCT manages up to 20% of all ATLAS jobs worldwide from a single machine.

As mentioned above, ARC is a key component in exploiting HPC centres, where the environment is quite different from the rest of the grid sites. Members of HEPP have been working for several years with colleagues at the Institute for High Energy Physics in Beijing to use Chinese HPCs for ATLAS. This effort has led to significant fractions of ATLAS workload being produced there opportunistically when the HPCs are not being used by other users. HEPP members have also been working closely with the SuperMUC HPC in Munich, again using ARC to exploit both allocated and opportunistic computing cycles. There have also been the first tentative steps to use ARC at HPCs in Taiwan, France and the UK. An ATLAS qualification task which started near the end of 2016 aims to simplify the setup for HPCs to make ARC even easier to deploy.

Figure. Running jobs on ARC-enabled opportunistic resources from October 2016 to September 2017. BOINC is ATLAS@Home and the rest are HPC centres in Germany, Switzerland and China.



ATLAS@Home is a volunteer computing project where members of the public run ATLAS simulation tasks on their home PCs. It also uses the ARC/aCT infrastructure, in particular to avoid sending sensitive credentials to volunteers. Since the start of the project in 2014, the number of volunteers has steadily grown and the platform now contributes around 2% of ATLAS simulation events globally. In addition to the free computing resources, ATLAS@Home is important for outreach, making people feel like they are part of the ATLAS experiment. During 2017 there were several developments designed to expand the use of the platform such as the use of containers instead of virtual machines to run the jobs, allowing the exploitation of idle CPU cores in T2 sites as well as ADC service hosts.

Derivation Production

HEPP members have continued their commitment to the derivation production within the ATLAS Train Coordination team also in 2016 & 2017. The work primarily involves following up and coordinating production request from physics groups, configuring and submitting derivation trains to the production system in ATLAS, overseeing the production as it runs and following up and fixing problems. The derivation production manager gives weekly reports to the Atlas Distributed Computing team on the progress and/or bottlenecks related to derivation jobs in the ATLAS production system. The bookkeeping of the available and recommended derivations to be used by analysers at any given time has also been an important duty for the production coordinators. Cleaning up obsolete derivations through the monthly "list of obsolescence" has been an important task in 2016 and 2017. Another important duty has been to look at derivation job statistics, performance etc. to be used in various reports and overview talks, but also to understand better the performance of the production and to identify potential improvements

Software

Members of the UiO high energy physics group have made very significant contributions to the ATLAS software project. In particular the group has had responsibility for the maintenance and development of the derivation framework software, which is used to reduce the output of the reconstruction (AOD) down to the “derived” data formats (DAODs) used by physicists for their analysis. In 2017 the entire ATLAS software has been migrated to Git, involving not just a change in the repository itself, but also in the software development workflow. Oslo group members have performed this migration, validated the resulting software, set up the workflows for the physics and combined performance groups to follow, and given relevant training. . Group members have presented at two ATLAS meetings per working week on this topic (derived data production coordination meeting, and analysis software coordination meeting).
Group members continue to play an important role in the management of the analysis model in general. We provide shifters for analysis release building and Git merge request reviewing, and a member of the group has co-chaired the task force to reduce the overall size of the AOD formats by 30%. This work began in late 2016 and concluded early in 2017, with the relevant software modifications being deployed in time for the 2017 data taking and MC campaigns. The resulting size savings will have a considerable impact on ATLAS’s resource usage, as well as increasing the efficiency of the data processing chain that automatically comes with smaller per-event sizes. The same task force, under the same Oslo-based co-chair, is now addressing the DAOD sizes and should conclude in October 2017. Group members have chaired and presented at 20 of these ATLAS meetings, and have also presented the recommendations to the ATLAS management and the plenary collaboration meetings.

Oslo physicists have recently become involved with formal “physics validation” (that is, statistical comparisons) of new software releases.The AOD size reduction strategy has included dropping a number of reconstructed object containers (mostly jets and flavour tagging) and transferring this to the DAOD building stage. This requires physics validation to be performed on DAODs, which has not been done before. To expedite this group members, in collaboration with the ATLAS physics validation team, have proposed and implemented a new workflow which involves the production of a new “master” DAOD containing all of the reconstructed object containers used at all points in the physics analysis chain. Validation is performed on these objects rather than directly on the AOD, as was done previously. This new workflow will be used for the first time in late 2017 to validate the software release used for reprocessing the 2017 data.

The importance of Multi-variate analysis or "Machine Learning" in High Energy Physics continues to increase, for applications as diverse as reconstruction, physics analysis, data quality monitoring and distributed computing. Members of the Oslo group have been experimenting in 2016 and 2017 with a variety of software tools and techniques, including deep and shallow neural networks, auto-encoders, decision trees and support vector machines. These have been applied particularly in supersymmetry analyses and in data quality monitoring, with the aim of introducing them into published analyses and the ATLAS workflow during Run 2. Particular attention has also been paid to anomaly detection as a means of detecting abnormalities in the data. An ATLAS qualification task has also begun within the EPF group, to make more use of machine learning techniques in reducing the workload on shifters monitoring the distributed computing system.. Group members have presented at two of the internal ATLAS machine learning forum meetings. Furthermore, Steffen Mæland from Bergen tested different Machine learning algorithms to optimise the sensitivity to the CP properties of the Higgs particle in the decay to two tau-lepton. (He presented the status of his work in an ATLAS machine learning forum 2nd March 2017).

Are Strandlie has been working on the development of algorithms for charged particle track reconstruction. During the project period, special emphasis has been put on further development of a so-called Riemann track fitting method, following up work pioneered more than 15 years ago. New achievements include more precise estimates of track parameters, as well as a more general approach to the determination of the uncertainties of estimated track parameters. The work has been documented in two publications [4].

Members of the Oslo group are also involved with training new members of the collaboration in the use of the collaboration's software. They have been involved in three tutorials at CERN.

People

David Cameron is a core ARC developer and member of the NorduGrid Technical Coordination Board, which steers the development of the ARC middleware. He is currently part-funded by ATLAS to work on ATLAS Distributed Computing (ADC) developments and operations. He

[4] R. Fruhwirth and A. Strandlie, A new Riemann fit for circular tracks. J Phys.: Conf. Ser. 762 (2016) 012032.
A. Strandlie and R. Fruhwirth, Exploration and extension of an improved Riemann track fitting algorithm. Nucl. Inst. Meth. A 867 (2017) 72.

contributes to daily ADC operational matters and since March 2016 he is co-chair of the ADC Technical Coordination Board, which oversees ADC developments and provides a forum for various ADC projects and activities to interact. He has worked on ATLAS@Home since the beginning and is currently leading the project. He is a developer and maintainer of the ARC Control Tower and implemented many new features as required by changes in ATLAS computing workflows (for example integration with ATLAS Event Service).

Vincent Garonne is the ATLAS Distributed Data Management (DDM) project leader. Vincent Garonne's responsibilities are the coordination of the development team (~10 persons); support of the system; and the development of the system project, called Rucio. He is also responsible of the system architecture, contributing as the core developer and release coordinator of the project. He recently joined the NDGF Tier-1 team as a storage expert and the Dcache development team.

Cedric Serfon is the coordinator of ATLAS DDM operation group as well as the DDM activity. He’s involved in the day to day operation of the DDM service, which includes, managing space at the sites (rebalancing/lifetime model), user support, interaction with the other ADC services/activities, preparing Rucio infrastructure changes. He is also one of the core developer of Rucio and is responsible of maintaining some core components like the subscriptions interface, recovery service, etc. He has developed new a new user interface to manage the subscription and requests exceptions to the deletion policy (aka Lifetime Model). He took Computing Coordinator shifts in 2017.

Aleksandr Konstantinov is a core ARC developer funded by the NordForsk project. In 2017 he implemented numerous bug fixes and performance enhancements. He especially focused on enhancing stability and security of the A-REX Web Service interface. The support for Ganglia Monitoring System was also expanded and VO awareness of the A-REX service was increased. He will continue working on job processing performance and reaction time enhancements for the A-REX service. As well as providing support for bug fixing and overall code maintenance.

Maiken Pedersen has since September 2016 had the role of ARC release manager and developer. As ARC release manager Pedersen has pushed for increased release frequency and is working on implementing new release testing procedures. In addition the codebase is being migrated from the revision control system SVN to Git in form of GitLab which has a whole set of useful tools for testing, building and code review. This is expected to improve quality of the releases. As ARC developer Pedersen has been working on her ATLAS authorship qualification task which implements the possibility for aCT to run locally at sites alongside ARC. This will allow HPC resources with strict access policies to be integrated transparently into the ATLAS production system.

Eirik Gramstad has been working as derivation production manager, being responsible for following up and coordinate production request from physics groups as well as configuring and submitting derivation trains to the production system in ATLAS. A large part of the work has also been to validate and test new features before being finally implemented in the production system and to manage the procedure by which obsolete datasets are deleted.
Having a good overview of the ongoing and planned derivation production has been of crucial importance in order to meet various deadlines set by the physics conferences. Gramstad has given weekly reports with a day-by-day status as well as larger summary talks during 2016 and 2017.

Bertrand Martin Dit Latour works as SUSY group derivation production manager since December 2016.

James Catmore has a variety of responsibilities in computing and software in ATLAS. He designed, developed and implemented the Derivation Framework used by ATLAS to produce all of the data formats used by analysts (DAOD). Working closely with E. Gramstad (see above), he has continued during 2016 and 2017 to develop and debug the software as it is used in large scale production, and in particular to manage the transition form SVN to Git. In September 2017 he took on the overall responsibility for the derived physics data, as coordinator of the DPD production group He has also continued to maintain and develop the software which writes and manages the Monte Carlo truth record in the reconstruction output (AOD) and analysis formats (DAOD). On the computing side, he is closely involved with data placement and replication policies as a member of CREM. He is also co-chair of the task force given responsibility for reducing the disk footprint of the AOD and DAOD. He has also run a number of ATLAS software tutorials in Scandinavia (Norway and Denmark) and has contributed to similar events at CERN.

Henrik Oppen finished his qualification task, which involved comparing the output of GEANT4 simulation from Intel and AMD chips, on an event-by-event basis. This is a highly relevant topic due to the mix of CPU architectures in use across the grid, on which the simulation is usually run. His extensive investigations identified a flaw in the treatment of low energy neutrons, leading to different results depending on the CPU architecture used. Whilst these differences would not affect physics results (which are at much higher energies) they do affect bitwise comparisons, meaning that more serious problems can be missed (and the problem was a genuine bug in the neutron transport). Henrik presented his findings to an ATLAS simulation meeting which was also attended by GEANT4 authors. This presentation [5] led to his qualification as ATLAS author.

[5] H. Oppen, "Geant4 Output on Intel vs AMD Chips", ATLAS simulation group meeting, 13.12.2016

Knut Vadla made the final presentation of his work for the ATLAS authorship qualification on 4 April 2017. The task was to investigate reproducibility of Monte-Carlo production steps in heterogeneous distributed environments. This consisted of running simulation jobs on different combinations of computing sites on the LHC computing grid, with different CPU architectures – Intel sites, AMD sites and sites with a mix of both – and comparing the results. The goal was to set the initial conditions for various production steps to be the same on per-event basis regardless of the execution platform.

As part of his ATLAS qualification work Simen Hellesund is involved in a project which aims to make an anomaly detection system for file transfers on the worldwide LHC computing grid. The first part of the project involved becoming acquainted with the basic software tools required, and learning how to "scrape" useful information from the key databases recording the state of the system. This was a major task since the information is spread across several databases in different locations. The main part of the project - studying the failed and successful transfers and implementing an anomaly detection system - followed three routes. The first involved correlating the state of the system during failed transfer attempts with tickets filed by human shifters, in the hope that the algorithm could learn from the human actions. This idea was abandoned since the number of tickets was insufficient, and were not in a form that could be readily parsed by a computer without very significant work beyond the scope of the qualification task. The second route involved the study of the time evolution of the failure rates, in the hope that an anomaly detection mechanism could be triggered if the failure rate (correlated with other parameters of the system) went out of some pre-determined range. This was also unsuccessful as the distributions proved too noisy to make any conclusions. [6]. The third, and most promising avenue of study, involved using a multivariate classifier to predict whether or not a file transfer is likely to fail, based on the state of the system and the size file being transferred across the grid [7]. This work is still ongoing.

Farid Ould-Saada coordinates the HEPP software & computing activities. He interacts with the ATLAS S&C management and is active in the International Computing Board (ICB). The operation of the Nordic Tier-1 is done in collaboration with USIT (University of Oslo IT department), NOTUR and Uninett-Sigma within the Nordic eInfrastructure Collaboration (NeIC). Strong contributions to ATLAS are made possible through an efficient collaboration with NorduGrid ARC developers, as well as NeIC and USIT system administrators and developers. The synergy between the various activities has been instrumental in the success of ARC and ARC Control Tower and their use in heterogeneous resources worldwide.

[6] https://indico.cern.ch/event/653669/contributions/2682415/attachments/1503585/2342421/Analytics020817.pdf
[7] https://indico.cern.ch/event/665949/contributions/2720774/attachments/1522900/2379898/AnalyticsMultivariate.pdf

We recently submitted an application for a research project with the aim to develop Archestrate[8], a complete system for intelligent distributed computing in the big data era, that will orchestrate complex dataflows and computational tasks in a secure and robust manner, enabling rapid deployment of critical systems for research and public services. The resulting system will be an intelligent, generic and flexible solution for distributed computing with the ability to manage huge amounts of data and utilise a range of resources: HPC, HTC, virtualized cloud and volunteer resources. The focus will be on research into intelligent data scheduling algorithms and machine learning techniques to allow these algorithms to self-improve over time, using analytics techniques to effectively mine historical data. Through a collaborate with Sigma2, NeIC, IT centres and NorduGrid, the result of this project, if funded, will be help building a future, sustainable, heterogeneous, cost-effective computing infrastructure, serving the WLCG and other fields.

Physics and related

We first describe some combined performance studies, followed by searches for new physics and Standard Model measurements performed. A summary of the theory activities closes this chapter.

Combined performance studies

ATLAS physicists in Oslo and Bergen have made important contributions to combined performance (CP) studies during 2016. These analyses measure the precision and efficiency of the detector and software at reconstructing the final-state particles and multi-particle objects which are used as the basis of all physics measurements and searches. In all cases, the Norwegian activities in these domains have been relevant to the physics analyses being done in the two institutes.

Since the beginning of LHC Run 2, the Bergen group has been involved with tau lepton performance studies, and is in charge of deriving tau energy scale corrections based on calorimeter information. These corrections consist of two steps. The energy contribution originating from soft proton-proton interactions is first subtracted from the measured tau lepton energy. A response correction is then applied to account for the energy lost in front of the calorimeter, and improve the initial calibration of electromagnetic and hadronic clusters that corrects for the non-compensation of the ATLAS calorimeters. The Bergen group has also

[8] Archestrate: a complete system for intelligent distributed computing in the big data era, Project description, RCN “FRINATEK” program, D. Cameron, J. Catmore, A. Konstantinov, F. Ould-Saada, C. Serfon, S. Hellesund, K. Vadla, Fysisk Institutt, UiO, V. Garonne, D. Karpenko, J. K. Nilsen, M. Pedersen, G. Thomassen, T. Thorbjørnsen, USIT, UiO, Oslo, 24 May 2017

proposed a multivariate technique for calibrating the tau lepton energy which dramatically improves the energy resolution at low energy. This method, which exploits shower shapes in the calorimeter as well as the reconstruction of charged and neutral hadrons from the tau decay, has been adopted by the Tau Performance group, and it is becoming the recommended calibration for tau leptons in ATLAS. The group has provided supervision and guidance to the PhD student carrying out the final studies. Calibrations have also been derived in the context of ATLAS upgrade studies, where the tau lepton reconstruction capability will be extended up to $|\eta|=4.0$ instead of $|\eta|=2.5$ in the current detector layout. As of 2017, Bergen will be taking yearly commitments in the Tau Performance group at the level of 0.2 FTE.

The Bergen group is also taking part in the Release 21 Scrutiny Task Force, which is in charge of scrutinizing data recorded in 2017 and reconstructed with a new software release. A member of the group has been appointed as contact person for Tau Performance matters. The taskforce has uncovered several features due to bugs in the reconstruction and analysis software, as well as deeper problems such as a bias in the track alignment due to a weak-mode deformation not corrected for in the current alignment procedure. The taskforce will be dismissed in October 2017 after its successful investigations.

The Oslo group has a strong focus on searches for New Physics involving muons, and so the CP studies have focused on combined muon reconstruction. The W' searches are particularly exposed to any issues in the muon reconstruction at high transverse momentum, since high p_T muons form the tail of the transverse mass distribution that is used to assess the presence or otherwise of signal, and set cross section and mass limits. Mismeasurements in such muons can have a direct and severe effect on the reported limits. Furthermore, significant revisions to the muon software have been applied for Run 2, and the 2016 data was the first opportunity to expose this revised reconstruction scheme to large numbers of very high p_T muons. Members of the Oslo group have investigated the performance of the reconstruction on a muon-by-muon basis, and have uncovered and helped to diagnose a number of issues, including with the muon quality selections, and alignment-related problems in the combination of the muon system and inner detector measurements that together produce the final muon measurement.

Searches for Supersymmetry

Supersymmetry (SUSY) is one of the most studied extensions to the Standard Model (SM), due to its ability to provide an elegant solution to the SM Hierarchy problem. In its minimal realisation (the Minimal Supersymmetric Standard Model, or MSSM), it predicts a new bosonic (fermionic) partner for each fundamental SM fermion (boson), as well as an additional Higgs doublet. If R-parity is conserved the lightest supersymmetric particle (LSP) is stable. This is typically the lightest neutralino which can then provide a natural candidate for dark matter. If produced in the decay of heavier SUSY particles, a neutralino LSP would escape detection in ATLAS, leading to an amount of missing transverse momentum significantly larger than SM processes, that can be exploited to extract SUSY signals.

We participate in the following searches, all focused on leptons:

- SUSY with τ leptons (strong production) – Bergen
- Electroweak (EW) SUSY production with e and μ leptons – Oslo

Project members are involved in various searches for supersymmetric particles and made strong contributions to several publications involving light leptons and taus.

Electroweak production

The coloured sparticles (squarks and gluinos) have significantly larger production cross sections (strong production) than non-coloured sparticles of equal masses such as the electroweakinos and the sleptons. The direct production of electroweakinos or sleptons can dominate SUSY production at the LHC if the masses of the gluinos and squarks are significantly heavier. The current searches from the ATLAS and CMS collaborations during LHC Run II excluded gluino (squark) masses up to 1.8 TeV (1.3 TeV).

The group plays an important role in the searches for 2 and 3 leptons and missing transverse energy from direct production of electroweakinos and sleptons at the LHC. People within the HEPP project have in particular contributed to the estimation of the backgrounds coming from leptons originating from either jets or conversion processes. These processes are poorly modelled by the available Monte Carlo simulations and thus needs to be extracted from data using a method known as the Matrix Method. We have also been involved in the designing of signal regions to optimize the sensitivity for specific SUSY scenarios. A conference note was published and presented at the SEARCH conference in September 2016 has been superseded by this year's contribution to the LHCP conference [9] in, Shanghai, May 2017. Searches for the electroweak production of neutralinos, charginos and sleptons decaying into final states with exactly two or three electrons or muons and missing transverse momentum are performed using 36.1/fb of $\sqrt{s}$=13 TeV proton-proton collisions. Three different search channels are considered. The 2l and no jets channel targets direct $\chi^+_1 \chi^-_1$ pair production where each $\chi^\pm_1$ decays via an intermediate slepton $\tilde{l}$ and neutralino χ^0_1, and direct $\tilde{l}^+\tilde{l}^-$ pair production. The 2l+jets channel targets associated $\chi^\pm_1 \chi^0_2$ production where each sparticle decays via a SM gauge boson giving a final state with two leptons consistent with a *Z* boson and two jets consistent with a *W* boson. No significant excess above the SM expectation is observed in any of the signal regions considered across the three channels, and the results are used to calculate exclusion limits in several

[9] E. Gramstad, E. Håland, F. Ould-Saada, K. Vadla, Search for electroweak production of supersymmetric particles in the two and three lepton final states at √s = 13 TeV with the ATLAS detector, ATLAS-CONF-2017-039

simplified model scenarios. For associated $\chi^{\pm}_1 \chi^0_2$ production with $\tilde{l}$-mediated decays, masses up to 1150 GeV are excluded for a 200 GeV χ^0_1. Both the 2l+jets and 3l channels place exclusion limits on associated $\chi^{\pm}_1 \chi^0_2$ production with gauge-boson-mediated decays. For a massless χ^0_1, $\chi^{\pm}_1 / \chi^0_2$ masses up to approximately 580 GeV are excluded in the 2l+jets channel. In the 2l and no jets channel, for direct χ^+_1 χ^-_1 pair production with decays via intermediate $\tilde{l}$ to a χ^0_1, massesupto750GeV are excluded for a massless χ^0_1 and for $\tilde{l}\tilde{l}$ pair production masses up to 500 GeV are excluded for a massless χ^0_1 assuming degenerate left-handed and right-handed sleptons. The Figure below shows the new limits.

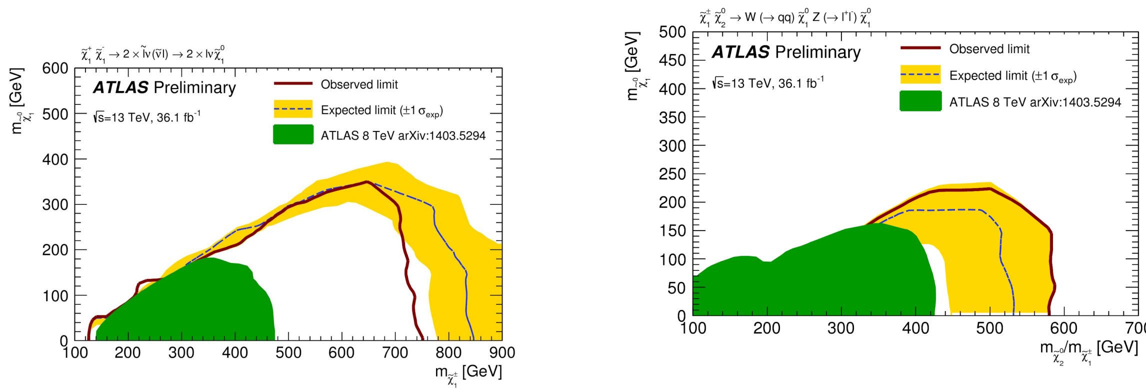


Figure. Observed and expected exclusion limits on the chargino 1 / neutralino 2 and lightest neutralino masses in the context of SUSY scenarios with simplified mass spectra for direct chargino 1 (left) and chargino 1 neutralino 2 (right) pair production using the two-lepton signal regions. The observed limits obtained from ATLAS during LHC Run I are also shown

PhD student Knut Vadla (supervis. Ould-Saada, Gramstad) studies the production of dark matter in final states with 2 leptons within the 2/3 lepton SUSY subgroup. His contribution to the SEARCH and LHCP conferences was through the study of the electroweak production of chargino pairs via sleptons using 2015 and part of 2016 data at 13 TeV (feasibility studies, signal regions, background estimation). Knut went on to study the production of pairs of chargino1-neutralino2 leading to a final state with 2 jets (from W) and l^+l^- (from Z). The signal model in question was pair-production of a lightest chargino and a next-to-lightest neutralino, decaying via the SM gauge bosons W and Z, where the W further decays to two jets and the Z to two leptons (electrons or muons). The final state then consists of two leptons, two jets and missing transverse energy from two lightest neutralinos which are assumed to be stable. His work included defining and optimizing signal region selections targeting medium and large mass-splittings between the pair-produced supersymmetric particles (assumed to be mass-degenerate) and the lightest neutralino.

The master thesis of Even Håland (supervis. Ould-Saada, Gramstad) is based on the search for pairs of sleptons leading to a pair of same-flavour opposite charge leptons l+l- and missing transverse energy carried by two lightest neutralinos. He analysed the entire 13

TeV data set recorded in 2015 and 2016. He contributed to the study of various signal regions as well as the determination of the SM background. His work was part of a contribution to LHCP 2017.

PhD student H. Oppen (supervis. Sandaker, Ould-Saada, Catmore) is looking for dark matter in supersymmetric final states with 2-3 leptons. He concentrates on chargino 1 pair production (C1C1) via WW, leading to opposite sign dilepton pairs l+l- and missing transverse energy-momentum stemming from 2 neutrinos and 2 lightest neutralinos. He has developed a cut and count analysis and is currently implementing machine learning techniques to possibly improve the overall analysis and results.

Master student A.H. Pedersen (supervis. Sandaker, Gramstad) searches for supersymmetric signals in view of finding out what dark matter can be. He is contributing to the 2-3 lepton group and is looking at C1C1 decays to leptons via WW production.

PhD student Eli B. Rye (supervis. Sandaker, Ould-Saada) started August 2017 and will contribute to the SUSY 2-3 lepton group.

Strong production

In most supersymmetry models, light third-generation squarks and gluinos at the TeV scale are favoured by naturalness arguments, as their contribution would regulate the large radiative corrections to the Higgs boson mass without fine-tuning the free parameters of the models. With the increased centre of mass energy of 13 TeV achieved by the LHC in 2015, and the large increase in the integrated luminosity of the 2016 dataset, the ATLAS experiment can explore kinematic regimes never probed before. In regions of the parameter space where scalar taus (SUSY partner of the tau lepton) are lighter than scalar electrons and scalar muons, tau leptons are expected to be produced more abundantly than electrons and muons in the cascade decay of gluinos and squarks. These models often assume R-parity conservation, and therefore provide a good candidate for dark matter, either the lightest neutralino or a very light gravitino.

The Bergen group plays a leading role in the search for squarks and gluinos with tau leptons, jets and missing transverse momentum in the final state [10]. The analysis optimisation is performed using a simplified model of gluino pair production with decays involving scalar taus, which gives sensitivity to a large class of SUSY models featuring light scalar taus, without relying on the very details of the models. A gauge-mediated SUSY breaking model is also considered, where squark pair production and associated squark-gluino production dominate. The two

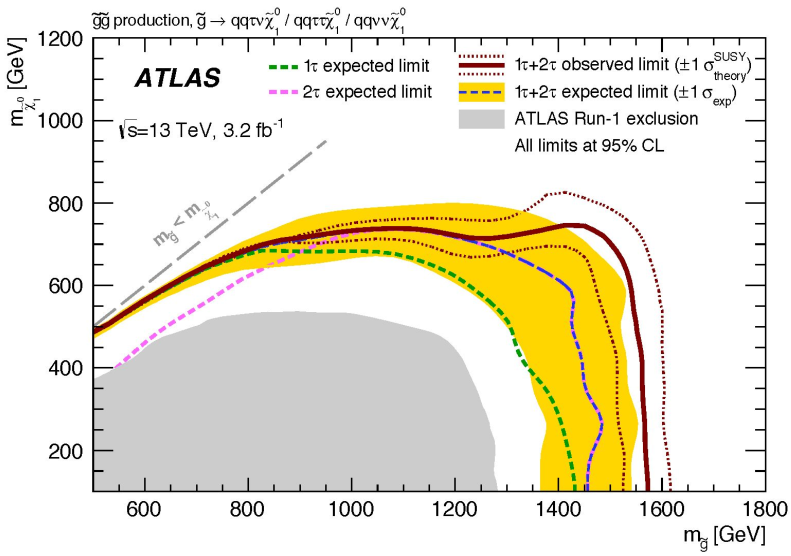
[10] Search for squarks and gluinos in events with hadronically decaying tau leptons, jets and missing transverse momentum in proton-proton collisions at sqrt(s) = 13 TeV recorded with the ATLAS detector, Eur. Phys. J. C (2016) 76:683, arXiv: 1607.05979 [hep-ex]

analysis channels requiring either one or at least two tau leptons are separately optimised to maximise the sensitivity to SUSY signals. Special attention is paid to parameter space regions with compressed SUSY mass spectra, leading to soft gluino decay products. No excess over the Standard Model expectation was observed in 2015 data. Exclusion limits obtained with 3.2 fb-1 of proton-proton collision data recorded by ATLAS at $\sqrt{s}$ = 13 TeV are shown in the Figure below, and greatly surpass previous results. The analysis based on 2015+2016 data uses an improved fit setup, with a multi-bin signal region in the 2τ channel giving increased sensitivity to high-mass gluino signals. Results have been approved by the SUSY group and a paper is in preparation.

The group has contributed in a decisive way to most of the analysis aspects, including the entire development of the analysis software, the production of data and simulation samples, the full analysis chain in the 1τ channel, a very strong involvement in writing the publication, and an active coordination role within the analysis group.
PhD student N. Fomin (supervis. Lipniacka, Martin Dit Latour) has carried out the Level-1 and High-Level Trigger efficiency measurement of the missing transverse-momentum trigger used in the analysis. Besides, he is in charge of deriving the acceptance of SUSY signals for the various signal regions, which will be delivered in the HEPData format as part of the publication on 2015+2016 data. The software that computes signal acceptance at truth level will also be used to re-interpret our SUSY search results in the framework of the more generic 19-dimension phenomenological Minimal Supersymmetric Standard Model (pMSSM), as was done in Run 1.

In addition, the Bergen group is initiating a new effort in the search for supersymmetry within ATLAS. PhD student N. Fomin is designing an analysis which will target the production of scalar bottom (sbottom) pairs, assuming that the sbottom decays to a bottom quark and the next-to-lightest neutralino, the latter decaying to a Higgs boson and the lightest neutralino. The analysis will focus on final states with tau leptons, b-tagged jets and missing transverse momentum. Based on a dedicated trigger strategy, we aim at probing a kinematically-challenging region that was not excluded by ATLAS in Run 1 of the LHC. Signal characteristics have been studied, discriminating variables identified, and tentative signal regions have been designed.
We consider exploiting advanced techniques such as boosted-object reconstruction, to identify more efficiently boosted Higgs bosons decaying to a b-bbar pair. Feasibility studies will be carried out by Master student B. Hovden (supervis. Lipniacka, Martin Dit Latour).

Figure. Exclusion contours at the 95% confidence level for the simplified model of gluino pair production, based on results from the 1τ and 2τ channels.



Searches for Exotic Phenomena

In spite of the enormous success of the Standard Model, there are reasons to look for physics beyond it. There is no place in the SM for the graviton (G), the postulated mediator of gravity. Any unification of the fundamental forces could lead to extended gauge symmetries. For these reasons, many models going beyond the Standard Model have been proposed that predict the existence of new exotic particles: new gauge bosons W', Z', excited gauge bosons W^*, Z^*, gravitons G, …

In ATLAS we performed searches in the di-lepton and lepton-neutrino mass spectra, where the leptons are electrons or muons, with proton-proton data at 7 TeV, 8 TeV, and 13 TeV.
F. Ould-Saada, M. Bugge and J. Catmore, together with two PhD students, V. Morisbak and S. Hellesund, take part in two exotics sub-groups where we have already contributed to several ATLAS publications, conferences notes as well as internal notes:

- Lepton + missing transverse energy (LMET)[11] [12]: Search for new charged gauge bosons – W'→lν. Magnar Bugge took over as analysis contact in spring 2016 for the ICHEP 2016 conference note and Moriond 2017 paper. He has also had the main responsibility for the muon channel as well as the statistical analysis. Furthermore, he has been working on validation for m_T-binned diboson samples. James Catmore is editor for both the ICHEP 2016 conference note and the Moriond 2017 paper. Magnar has continued as analysis

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[11] M. Aabout, M.K. Bugge, J. Catmore, F. Ould-Saada, et al., Search for a new heavy gauge boson resonance decaying into a lepton and missing transverse momentum in 36 fb^{-1} of pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS experiment, ATLAS-CONF-2017-016

[12] M.K. Bugge, J. Catmore, F. Ould-Saada, et al., Search for a new heavy gauge boson resonance decaying into a lepton and missing transverse momentum in 36 fb^{-1} of pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS experiment, arXiv:1706.04786 [hep-ex], submitted to EPJC

contact after the finalization of the 2016 data result, and has contributed to the validation of a new version of reconstruction software to be used for upcoming publications.

- Lepton + X (L+X): Model independent search for new high mass dilepton resonances (neutral gauge bosons – Z’, excited Z^*, Graviton, …)[13][14].

Detailed studies involve

- Fake lepton (QCD and others) estimations, which are common to SUSY multi-lepton searches
- Lepton efficiencies, common to SUSY multi-lepton searches and in collaboration with the performance studies with muons
- Statistical analysis to claim discovery or set exclusion limits, which are common to various Higgs, SUSY and other searches.

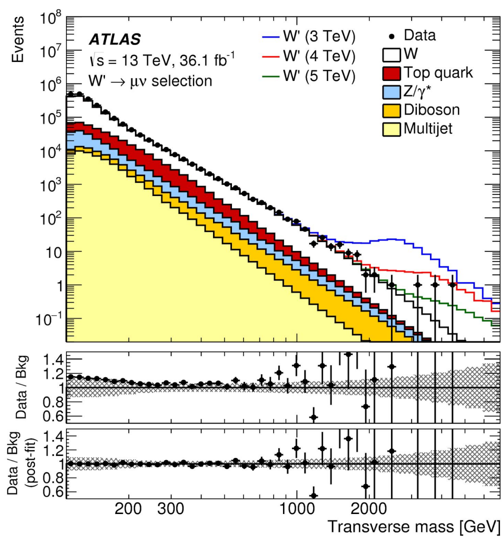

Figure. Transverse mass of events with a muon and missing transverse energy.

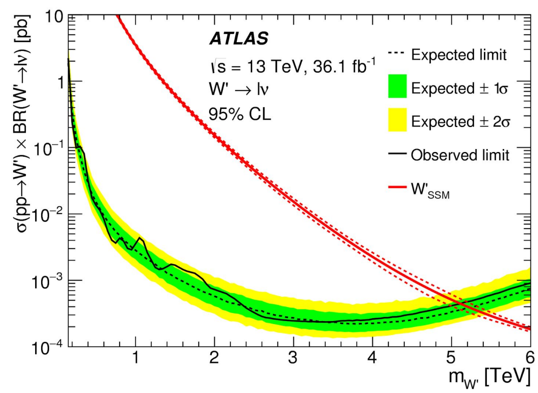

Figure. Median expected (dashed black line) and observed (solid black line) 95% CL upper limits on cross-section times branching ratio (σ × BR) in the combined channel, along with predicted σ × BR for W' SSM production (red line).

[13] M. Aabout, J. Catmore, V. Morisbak, F. Ould-Saada, et al., Search for new high-mass phenomena in the dilepton final state using 36.1 fb^{-1} of proton-proton collision data at $\sqrt{s}$= 13 TeV with the ATLAS detector, ATLAS-CONF-2017-027

[14] J. Catmore, V. Morisbak, F. Ould-Saada, Search for new high-mass phenomena in the dilepton final state using 36.1 fb^{-1} of proton-proton collision data at $\sqrt{s}$ = 13 TeV with the ATLAS detector, arXiv:1707.02424 [hep-ex], submitted to JHEP

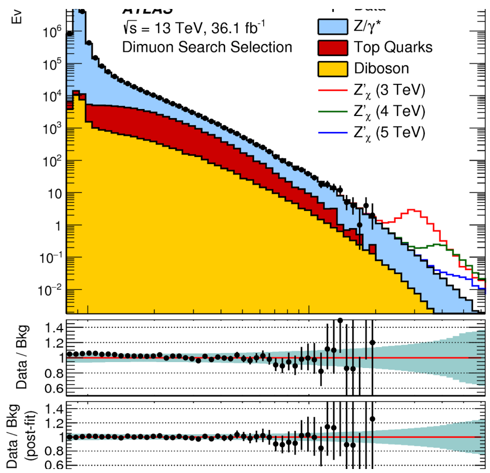

Figure. Dimuon reconstructed invariant mass distribution

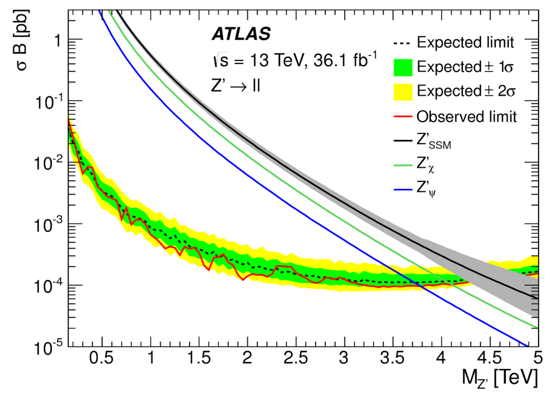

Figure. Upper 95% C.L. limits on the Z' production cross section times branching ratio to two leptons as a function of Z' pole mass (MZ').

S. Hellesund (supervis. Ould-Saada, Bugge) started a PhD thesis in August 2016 with the title "Model-independent search for Dark Matter and New Phenomena in di-lepton final states". In addition to the interpretation in terms of new Z' (gauge) bosons and excited graviton resonances, the aim is also to expand the analysis to a more inclusive dilepton analysis, opening up the possibility for dark matter interpretations like the ones mentioned above. For this a data-driven approach to background estimation will be the key.
Contributions to the Moriond 2017 exotic dilepton search paper consisted in analysing the di-muon data and in cross checking the frequentist significance calculations using the Bayesian Analysis Toolkit (BAT) framework. Furthermore, results with the log-normal parametrization of systematic uncertainties was cross checked against a simpler Gaussian parametrization.

For the paper submitted for publication Simen did a validation study of the statistical framework, specifically recalculating the local and global (accounting for the Look Elsewhere Effect) significance. For the analysis of the data collected in 2017 he started applying data-driven methods to determine the SM background, moving from the Monte Carlo (MC) based method of background estimation used in the previous publications. This proceeds by fitting a predetermined function to the dilepton invariant mass spectrum in the search region. Instead of performing one single fit to the whole dimuon search range, smaller subsections, called windows, will be studied. The dilepton group hosted a workshop at CERN on August 30th 2017 to lay down a common strategy and organise the analysis work. Simen was heavily involved in the preparations and made a presentation on "Model independent search and high mass extrapolation" [15], including a study on how to include a search for non-resonant physics signatures in the high mass region. He also contributed to the analysis overview, using the new

[15] https://indico.cern.ch/event/655316/contributions/2702634/attachments/1515653/2365248/ModelDependentSimen-2.pdf

SWiFt (sliding window fit) background estimation, and introduced some new search for a Z' gauge boson in association with missing transverse energy (dark matter) or di-jets.
In addition to the dilepton analysis Simen carries out a service qualification task within the ATLAS Distributed Computing group (ADC), with Mario Lassnig as technical supervisor and J. Catmore as local qualification supervisor. The title is "Automating ATLAS Computing Operations Using Machine Learning Algorithms". The aim is to automate distributed computing workflows that are currently done by human shifters, possibly by using machine-learning algorithms. The latter will be applied to the independent search for new phenomena and dark matter in di-lepton final states.

Standard model and Higgs physics

Higgs

Justas Zalieckas (supervisor: Gerald Eigen) completed his PhD thesis in November 2016. One topic consisted of the analysis of the Higgs decay to four leptons via the ZZ^* intermediate state with run 2 data using 3.87/fb collected in 2015 and 12.8/fb collected in 2016 to which we contributed. The goal consisted of measuring the cross section for Higgs production via gluon-gluon fusion, vector boson fusion and associated production with vector boson mechanism. Four final states were selected, four electrons, four muons, two electrons plus two muons and two muons plus two electrons where the latter two final states distinguish between the decays $Z \rightarrow ee$ and $Z \rightarrow \mu\mu$. Boosted-decision trees were trained to distinguish between the different production mechanisms.
Zongchang Yang continued the analysis with run 2 data in 2017. With 36.1/fb of LHC pp collision data at $\sqrt{s} = 13$ TeV, 95 events were observed compared to 77±4 expected in the mass range of 118-129 GeV. The data are shown to be consistent with the SM hypothesis, with the largest deviations of about 2σ due to the excess of observed event.

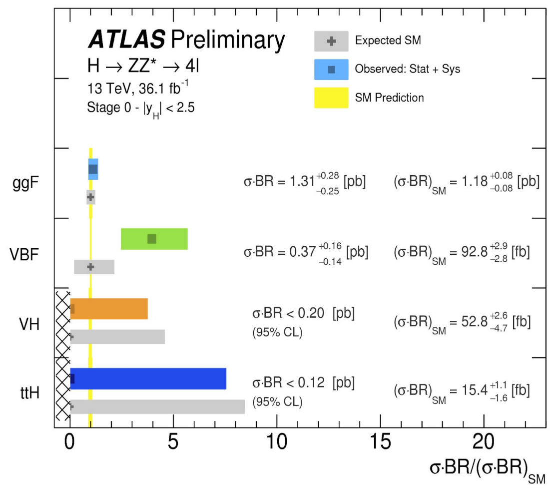

Figure. The observed and expected SM values of the cross section ratios σ·BR normalized by the SM expectation $(\sigma{\cdot}BR)_{SM}$

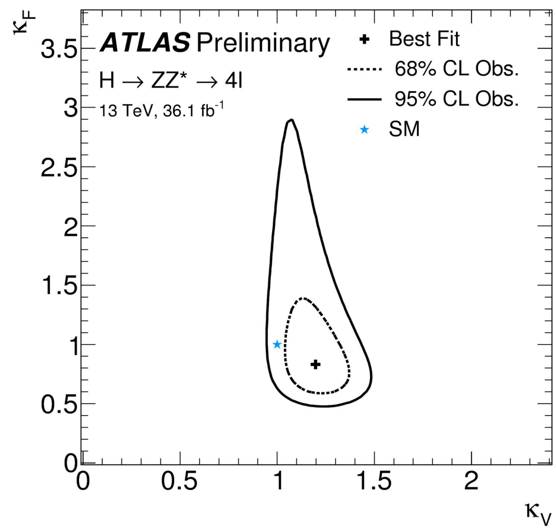

Figure. Likelihood contours at 68% CL (solid line) and 95% CL (dashed line) in the k_V - k_F parameter plane.

Zongchang Yang also contributed to the measurements of the inclusive and differential fiducial cross sections in the H→ZZ→4-leptons decay channel. With 36.1/fb of collision data, the inclusive fiducial cross section in the H→ZZ*→4-lepton decay channel is measured to be in agreement with the Standard Model prediction.

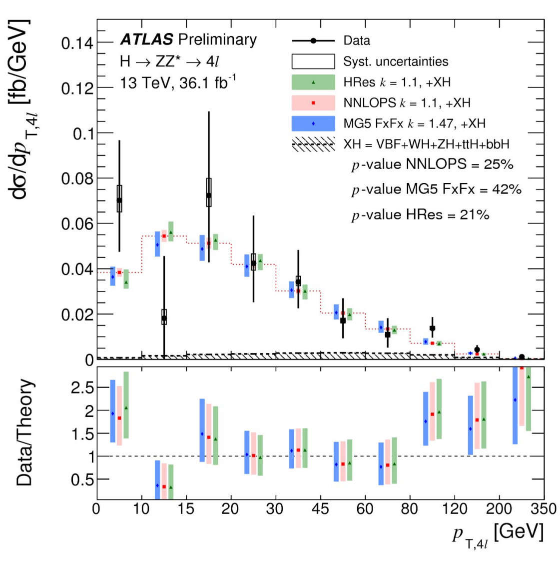

Figure. Differential fiducial cross sections, for the transverse momentum of the Higgs boson.

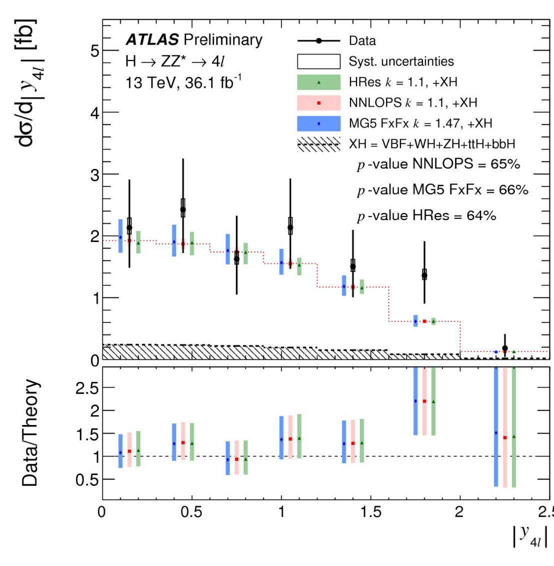

Figure. Differential fiducial cross sections, for the absolute value of the rapidity of the Higgs boson.

Alex Read contributed to the publication of a textbook (a chapter[16] and an appendix[17]) for graduate students summarizing the state of the art in Higgs boson physics after the discovery of the Higgs boson and the first measurements of its properties were published.

Anne-Marthe Hovda (supervisor A. Read) worked on her MSc thesis during 2016 but results will first be available during late 2017-2018. The goal of her thesis is to evaluate the residual systematic uncertainty on the amplitude of the Higgs boson signal in the di-photon decay channel when the background parameterisation is implemented via the "discrete profiling method" introduced by CMS colleagues and compare this in detail to the results obtained by ATLAS by selecting specific functions that meet certain criteria designed to minimize the total uncertainty on the signal amplitude.

Kristian Bjørke (supervisor A. Read) began his PhD thesis (funded by SDI) in August 2016. He will work on precision measurements of the Higgs boson decays to the di-photon final state and the interpretation of these results in global fits, including a fit that will set a combined limit on invisible Higgs boson decays, thus having some sensitivity to various models of dark matter. He will also contribute to the analysis and interpretation of Higgs bosons (detected by the di-photon signature) produced in association with missing transverse energy, again contributing to tests of models involving both the Higgs boson and dark matter candidates.
Kristian participates in the mono-H(gg) (mono-higgs to diphoton) working group in ATLAS (subgroup of Higgs to diphoton group). He contributes to the mono-H(gg) analysis of a Two Higgs Doublet Model with an additional pseudoscalar mediator to be included in the Dark Matter Summary paper by ATLAS. Current status is that parameter space of the model has been evaluated by multiple working groups focusing on different channels in order to agree on benchmark parameter set for the analysis. Based on this a MC sample request has been submitted. Further work will include reweighing of MC samples and other preparations in vue of the full analysis of Run 2 data. Kristian will soon become the contact person between mono-H(gg) group and Dark Matter Summary paper group.

The qualification task of Kristian consists in the implementation of unit testing and code optimization of the SCT offline ByteStream converter package. Some progress has been made, but this will be a focus of the last term of 2017.

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[16] Igo-Kemenes, P.; Read, A.L., "Searches for the Standard Model Higgs boson at the LEP collider", in "Discovery of the Higgs Boson", World Scientific, ISBN 9814425877, pp. 45-70 (2016).
[17] Junk, T. R.; Korytov, A.; Read, A.L., "Appendix A - Statistical methods" in "Discovery of the Higgs Boson", World Scientific, ISBN 9814425877, pp. 415-433 (2016).

Steffen Mæland (Supervisor B. Stugu) has been very active in studies aimed at studying the sensitivity to the Higgs CP properties in tau tau decays. The status of all parts of the analysis was presented by Steffen at the combined Tau Performance and Higgs to Leptons Workshop in Sheffield 24-28 October 2016.[18] The analysis is further optimised throughout 2017, in particular by introducing machine learning algorithms to the sensitivity optimisation. Prospects for increasing sensitivity to the spin/CP analysis using neural networks was presented at the ATLAS Machine Learning Workshop in June. Mæland has also contributed strongly to develop a software framework to be shared with the main H→ττ coupling analysis. Thus the results both on the CP study and the coupling analysis will be released simultaneously, hopefully by the end of 2017.

B Physics

PhD student Justas Zalieckas (supervisor: Gerald Eigen) also finished the analysis of the measurement of the ratio of b-quark fragmentation fractions into a strange quark with respect to that of a down quark, fs/fd. Using 2.47/fb of pp data at 7 TeV in the ATLAS experiment, he extracted fs/fd from the yields of the decays $B_s \rightarrow J/\psi$ phi and $B_d \rightarrow J/\psi\ K^{*0}$. The result, fs/fd=0.240±0.004(stat)±0.010(sys)±0.017(th), is in good agreement with LHCb measurements and was published in Physical Review Letters. In addition, Zalieckas studied the dependence of fs/fd on transverse momentum and pseudorapidity. The ATLAS data are consistent with uniform distribution

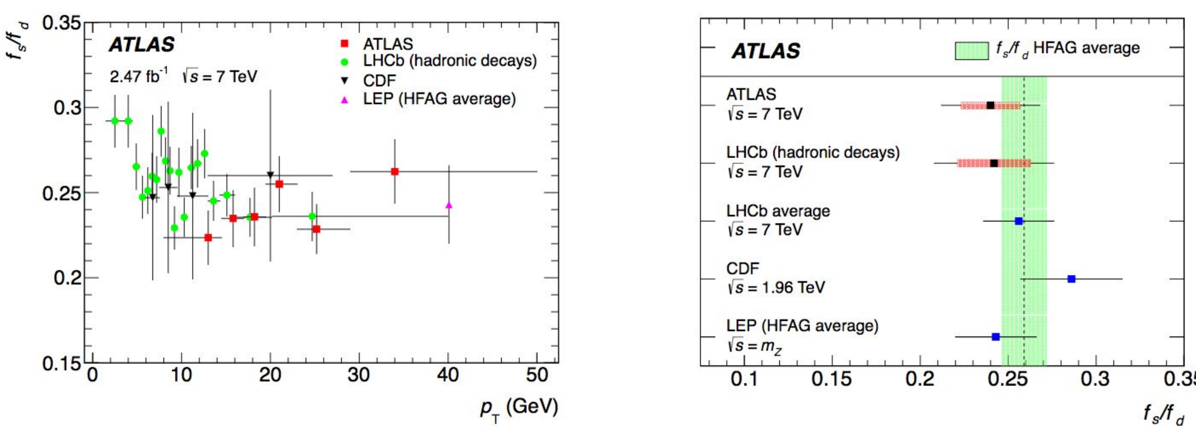

Figure. (Left) Measurements of f_s/f_d versus B meson p_T for CDF, LHCb and ATLAS, where the ATLAS data points are plotted at average p_T of the events in each bin. The error bars show statistical and systematic errors added in quadrature. The LEP ratio is plotted at an average pT value in Z decays. (Right) Measurements of f_s/f_d (black and blue points with error bars) from LEP, CDF, LHCb and ATLAS. The total experimental error (thin black) is added linearly to the theory error (red thick). The green-shaded region shows the HFAG average obtained using the blue points.

[18] Mæland S., "Higgs CP decay analysis fit model and sensitivity", ATLAS combined tau performance and Higgs to leptons workshop, Sheffield (24.10-28.10), https://indico.cern.ch/event/559951 (2016).

Master student Are Træet (supervisor: Gerald Eigen) measured the fragmentation ratio fc/fu, the fragmentation fraction into a charm quark to that into a u quark, and the Bc mass in his master thesis using ATLAS pp data at 13 TeV. The strategy consists of measuring the ratio of yields of $B_c^+ \rightarrow J/\psi\ \pi^+$ and $B^+ \rightarrow J/\psi\ K^+$ decays at 13 TeV. From the B+ cross section measurement at 13 TeV by CMS, one can determine the cross section for Bc production at 13 TeV . This is the first B_c^+ studies at 13 TeV. Due to delays in the data processing the cross section measurement will be done soon. Further plans include to measure the lifetime.

Master student Håkon Kolstø (supervisor: Gerald Eigen) started his master thesis. His topic is measure the branching fraction of $B_c^+ \rightarrow J/\psi\ 3\ \pi$. The idea is to measure the ratio of yield in $B_c^+ \rightarrow J/\psi\ \pi\pi\pi$ to $B_c^+ \rightarrow J/\psi\ \pi$ from which the $B_c^+ \rightarrow J/\psi\ \pi\pi\pi$ branching fraction can be extracted.
Gerald Eigen has updated the Scan method to include measurements of $B_{s,d} \rightarrow \mu\mu$ and $B \rightarrow D^{(*)} \tau\nu$. New results have been presented at the Flavor and CP Violation conference (FPCP) at Caltech in June.

Master student Are Træet (supervisor: Gerald Eigen) measured the B_c mass and ratio of efficiency-corrected B_c to B^+ events yields in his master thesis using ATLAS pp data at 13 TeV. He further computed the ratio of fragmentation fractions into a charm quark to that into a u quark, f_c/f_u. The B_c is reconstructed in the $B_c \rightarrow J/\psi\ \pi^+$ decay and the B^+ in the $B^{++} \rightarrow J/\psi\ K^+$ decay. Due to delays in the ATLAS data processing, some goals were postponed such as the the determination of the B_c production cross section by using the B^+ cross section measurement at 13 TeV from CMS and the measurements of the B_c lifetime. These are the first B_c results at 13 TeV. The plan is to complete the cross section and B_c lifetime measurements and publish them.

Master student Håkon Kolstø (supervisor: Gerald Eigen) is working on the analysis of the *B* rare decay $B^+ \rightarrow K^+\mu^+\mu^-$. This is the first step in testing lepton flavour universality in *B* rare decays by measuring the ratio R_K of branching fractions $B(B^+ \rightarrow K^+\mu^+\mu^-)$ to $B(B^+ \rightarrow K^+e^+e^-)$. During the summer 2017 interest in this measurement and related lepton flavour ratios $R_{K*} = B(B^0 \rightarrow K^{*0}\mu^+\mu^-)/B(B^0 \rightarrow K^{*0}e^+e^-)$ and $R_f = B(B^0_s \rightarrow \varphi\mu^+\mu^-)/ B(B^0_s \rightarrow \varphi\ e^+\ e^-)$ has grown since LHCb found more than two standard deviation discrepancies for R_{K*} and R_K with respect to the Standard Model predictions.

Theory: short summary and highlights of activities

Theoretical calculations and predictions complement the experimental activities of the project. Areas of particular interest are supersymmetry (SUSY), dark matter, and cosmic rays. We have studied the phenomenology of physics beyond the Standard Model, aiming to constrain model parameters, to evaluate their discovery potential, and to determine how to reconstruct the parameters in the case of a discovery.

An important outcome of this work is the GAMBIT software (gambit.hepforge.org), released in May 2017, which allows a comprehensive statistical analysis of new physics models. We have completed six papers describing the software, and another three papers with physics applications, studying the scalar singlet model, SUSY models inspired by GUT-relations, as well as a SUSY model defined at the weak scale. In addition, we performed a detailed investigation of QCD as well as electroweak corrections to neutralino annihilation relevant for dark matter searches, and pointed out that transitions between excited meson states may give rise to a new type of dark matter signatures in MeV gamma rays. Another project, whose main contributors were master student N. Murphy (supervis. Kersten) and PhD student I. Strümke (supervis. Kersten, Raklev), determined the parameter space of gaugino-mediated SUSY breaking compatible with the observed Higgs mass and LHC SUSY searches. We also pointed out that the standard method of calculating the relic density of thermally produced dark matter can lead to predictions that are wrong by up to an order of magnitude, and we provided an improved way of solving the Boltzmann equation in these cases.

Several projects investigated scenarios with self-interacting dark matter. Among other things, we performed a simplified model analysis of cases where cold dark matter particles could mimic warm dark matter, without being subject to the phenomenological constraints that the latter are subject to; the most important part of this analysis was performed by master student H. T. Ihle and PhD student P. Walia (supervis. Bringmann). Furthermore, we pointed out that a large class of self-interacting dark matter models often considered in the literature is actually strongly disfavored by CMB observations.

Four PhD students contribute to the theory activity. J. v. d. Abeele (supervis. Raklev, Read) works on dark matter indirect detection, LHC phenomenology, global fits, and machine learning. I. Strümke (supervis. Kersten, Raklev) investigates LHC phenomenology and SUSY. P. Walia (supervis. Bringmann, Mota) works on the phenomenology of SUSY and dark matter. A. Sokolenko (supervis. Bringmann, Mota) studies dark matter and collider phenomenology.

Education and Outreach

We continued sharing the excitement, data and discoveries with students and the public through various events, ranging from exhibitions, lectures, articles and interviews in media, visits at CERN, international masterclasses, etc. In 2017, project members have received grants from the Thon foundation, teaching prize for A. Raklev and research education grant for M. Bugge, E. Gramstad and F. Ould-Saada.

International Masterclasses at UiO in 2017

A total of close to 380 teachers and students from various high schools all around Norway participated in the International Masterclasses held at the University of Oslo during spring 2017. A similar event was organised in Bergen.

The Masterclass-day starts with two lectures of about 45 minutes each, introducing both theoretical and experimental concepts of particle physics. After lunch the students get a quick introduction to the experimental measurement they are going to perform later. The so-called "Z-path" allows the students to analyse real collision data recorded by the ATLAS experiment at the LHC. Groups of two students study event displays of 50 collisions each and identify di-lepton, 4-lepton or di-photon final states. To look for known (J/Psi, Upsilon, Z, Higgs) and unknown particles (Z', Graviton) they use the invariant mass of the objects they identify.

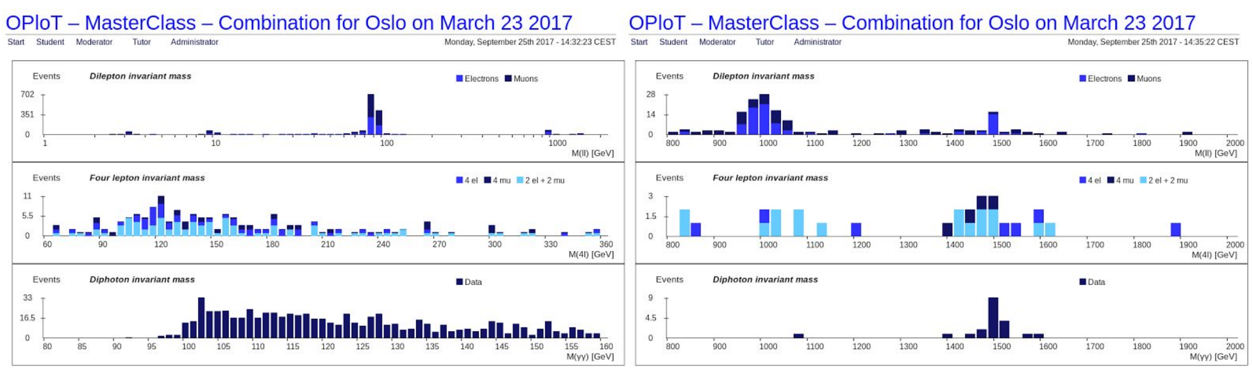

Figure. Invariant mass of di-photon and dilepton combinations from one of the two IMC events in Oslo spring 2017. The left and right plots differ only in the choice of x-axis ranges, with emphasis on the high-mass region in the right plot.

The results from each group of students are uploaded to a web-based database and analysis tool so that they can be combined with the other students visiting the local institute, but also with all participating students, from institutes all around the world.

At the end of the day results are discusses with people at CERN and the other 4 participating institutes through a video connection. Here students get the opportunity to ask all sorts of questions to the people at CERN.

The Z-path educational package and some of the accompanying tools have been developed at the University of Oslo and is under constant development. The aim is to always follow the "heart beats" of LHC and bring the most recent discoveries to the students. Right after the official announcement of the Higgs discovery, Higgs boson candidates were added to the Z-path program. Last year the Graviton was added and got some extra, unforeseen relevance with the infamous 750 GeV di-photon excess observed by ATLAS and CMS in late 2015 (later proved to be only a statistical fluctuation).

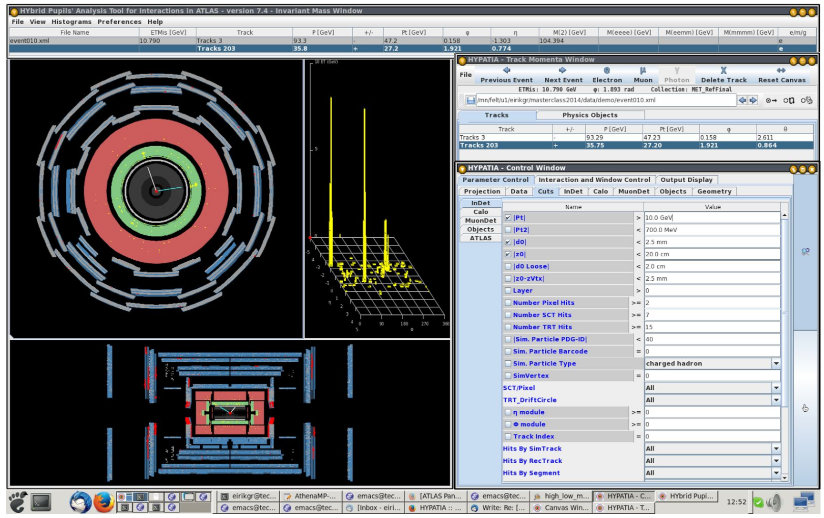

Figure. Hypatia ATLAS event display

The challenge of explaining new physics concepts and phenomena

With the advent of higher energies and higher collision rates the LHC continues the exciting voyage towards new physics, allowing physicists all over the world to explore a previously unknown territory full of promise. IPPOG's International Masterclasses are very popular, and year after year teachers keep coming back with their students who find it exciting to learn more about particle physics, and especially to experience research at the very forefront of science. So far the masterclass developers, with the help of physicists and in close contact with teachers, have been successful in designing educational material and in engaging high school students to work, with real LHC data, on current hot topics, such as the discovery of the Higgs boson.

One of the current challenges is to convey advanced physics concepts and to introduce new ideas beyond today's theoretical framework describing the content of the Universe and its evolution. How can we influence the teaching at schools in order to provide a better basis for attending masterclass-like events, and in general for understanding experimental results and new theoretical ideas? An IPPOG initiative deals with effective ways of explaining new physics. Moreover, physicists, in close contact with high school teachers and university departments of education, are investigating a more professional and research-based view on methods and ideas for introducing and explaining new physics concepts. A program plan together with relevant material must be created and incorporated to suit the high school curriculum and even replace the ordinary text book on the subject. We suggest how educational material could be improved and extended to cover crucial topics and concepts and to better accommodate real learning at the Masterclasses and similar events, and to facilitate the understanding of new results as they keep streaming from the LHC and other current and future research instruments. This is crucial in explaining new physics concepts and related enigmas such as dark matter, the role of gravity at the quantum scale, the possible unification of all fundamental forces and the physics of the early Universe.

Since May 2017 the Z-path receives funding from the Olav Thon Foundation as a "Student active research project"[19]. The aim is to:

- develop research projects adapted to students as a support to current courses
- develop new course based on measurements and discoveries at LHC and other research infrastructures
- convey advanced physics concepts and phenomena and introduce new ideas beyond today's theoretical framework describing the content of the Universe and its evolution.

PhD and Master theses

The following students finished their PhD (1) or MSc (9) thesis during the project period 1.10.2016 - 30.9.2017.

1. J. Zalieckas, "Determination of the ratio of b-quark fragmentation fractions fs/fd and study of the Higgs boson production and couplings with the ATLAS detector in pp collisions", UiB, PhD thesis, supervisors: G. Eigen, B. Stugu, November 2016
2. Eli Bæverfjord Rye, "Making SUSY Natural Again - Investigating the Naturalness Reach of the International Linear Collider", Master thesis, UiO, supervisor A. Raklev, examined 19.12.16.
3. Mari Røysheim, "Exploring Naturalness in Supersymmetry at the High-Luminosity Large Hadron Collider", Master thesis, UiO, supervisor A. Raklev, examined 05.01.17.
4. Håkon Høines, "Gravitino Dark Matter with Entropy Production constrained by Big Bang Nucleosynthesis", Master thesis, UiB, supervisor J. Kersten, examined 16.01.17.
5. Martin Breistein, "Late Time Entropy Production in Leptogenesis Scenarios", Master thesis, UiB, supervisor J. Kersten, examined 27.01.17.
6. Are Træet, "Study on viability of Gain Stabilization of SiPMs and determination of b-quark fragmentation fraction ratio fc/fu in pp collisions at $s=\sqrt{13}$ TeV with the ATLAS detector", Master thesis, UiB, supervisor G. Eigen, examined 08.09.2017.
7. Ask Markestad, "Dark Matter Bound State Formation for Pseudo-Scalar Mediators", supervisors: T.Bringmann, A. Hryczuk, examined 15.06.2017.
8. Even Simonsen Håland, "Search for direct production of sleptons in proton-proton collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector", Master thesis, UiO, supervisor F. Ould-Saada, E. Gramstad, examined 06.17.
9. Magne Lauritzen, " A Silicon Photomultiplier Based Readout System For A Cosmic Muon Telescope; Design And Implementation", Master thesis, Supervisor A. Lipniacka and B.Stugu, examined 14.06.17
10. Andreas Lokken Heggelund, "Analysis of 3D Pixel Detectors for the ATLAS Inner Tracker Upgrade." http://bora.uib.no/handle/1956/16039 , supervisor B. Stugu, examined 15.06.17.

[19] http://www.mn.uio.no/fysikk/english/research/projects/zpath/

Responsibilities, special positions and duties

Below are listed the special positions held by project members and their duties in the current project reporting period.

1. M.K. Bugge, Analysis contact for the W' analysis team in the ATLAS exotics group
2. T. Bringmann is referee for Physical Review Letters, Physical Review D, Physics Letters B, Journal of High Energy Physics, Journal of Cosmology and Astroparticle Physics, Astrophysical Journal and Monthly Notices of the Royal Astronomical Society.
3. T. Bringmann is member of CTA, GAMBIT (co-lead of dark matter group) and DarkSUSY (main current code developer).
4. T. Bringmann is the deputy leader of the "strategic dark matter initiative" (SDI) at UiO.
5. T. Bringmann organizes the seminar series of the Theory Section at the physics department, UiO.
6. T. Bringmann organizes the weekly "dark matter lunch" series for SDI and related students.
7. D. Cameron is project leader of ATLAS@Home
8. D. Cameron is ATLAS Distributed Computing Technical Coordination Board co-chair
9. D. Cameron is ATLAS representative in the WLCG Middleware Readiness Working Group
10. D. Cameron is a member of the NorduGrid Technical Coordination Group
11. J. Catmore is the derivation production coordinator and is also one of the ATLAS derivation framework software developers
12. J. Catmore is a member of the ATLAS Computing Resources Management board (CREM2)
13. J. Catmore is data placement co-coordinator for ATLAS
14. J. Catmore is a member of the ATLAS Collaboration Board Chair Advisory Group from 2016
15. J. Catmore is co-chair of the (D)AOD Size Reduction Task Force
16. J. Catmore is an ATLAS representative of the CERN Collaborative Environments board (LCEB) since 2015
17. J. Catmore, ATLAS Editorial Board member, B physics, Exotics
18. J. Catmore, Co-convener, Lepton+X Exotics group
19. G. Eigen is chief referee of LHCb in LHCC
20. G. Eigen is referee for Physical Review Letters and Physical Review D.
21. G. Eigen is referee for Nuclear Instruments and Methods, JINST
22. G. Eigen is referee for the Particle Data Group
23. G. Eigen is the Norwegian representative in the restricted ECFA committee.

24. G. Eigen, ATLAS Editorial Board member, B physics
25. G. Eigen is the local ATLAS contact in Bergen to organize readings of ATLAS publications.
26. G. Eigen is convenor for the LCC conference talks committee.
27. V. Garonne is ATLAS data management (Rucio) project leader since October 2014 (as member of HEPP)
28. E. Gramstad, associated member of the International Particle Physics Outreach Group (IPPOG) since 2015.
29. E. Gramstad, coordinator of the derivation production in the Train Coordination Team from autumn 2014
30. E. Gramstad, National contact for CERN's Beamline for Schools since 2016
31. M. Kachelriess, member of the Commission on Astroparticle Physics (C4) of the IUPAP, 2015 -
32. M. Kachelriess, Vice-President of the Norwegian Physical Society, 2016 -
33. M. Kachelriess, member of the steering committee of "ISAPP: International School on AstroParticle Physics European Doctorate School", 2006 -
34. M. Kachelriess, member of the organizing committee of the workshop ``Sources of Galactic cosmic rays", Paris 2016
35. J. Kersten and A. Raklev are members of the Management Committee of COST Action CA15108 "Connecting Insights in Fundamental Physics".
36. J. Kersten is member of the Nordita Research Committee for High-Energy Physics.
37. J. Kersten is leader of the Subatomic Physics group of the Department of Physics and Technology, UiB.
38. J. Kersten is member of the Steering Committee of the international workshop series "Dark Side of the Universe".
39. J. Kersten organizes the colloquium of the Department of Physics and Technology, UiB.
40. J. Kersten is referee for Physical Review Letters, Physical Review D, Journal of High Energy Physics, and Journal of Cosmology and Astroparticle Physics.
41. A. Lipniacka is a deputy member of the Department Board.
42. A. Lipniacka is a senior editor of Particle and Nuclear Physics Section of COGENTOA
43. A. Lipniacka is a board member of European Physical Society HEP section
44. A. Lipniacka was an organizing committee member of HEP EPS2017 conference 2016-2017
45. A. Lipniacka, ATLAS Editorial Board member, SUSY, TOP, Direct stau upgrade
46. A. Lipniacka is a member of Master degree evaluation committee at the Department.
47. A. Lipniacka is Bergen CTA contact person.
48. A. Lipniacka is a reviewer for Academy of Finland
49. A. Lipniacka was a member of a steering group of the NeIC project, "Investigating options for the future Nordic Tier1", 2015-2016.

50. B. Martin dit Latour, ATLAS Editorial Board member, SUSY
51. B. Martin dit Latour, Analysis group contact and editor for the search for squarks and gluinos with taus in ATLAS
52. B. Martin dit Latour, Derivation Manager for the ATLAS SUSY group
53. B. Martin dit Latour, Contact person for the Tau Performance group within the Release 21 scrutiny group
54. B. Martin dit Latour, Deputy member of the Physics Institute Council at UiB
55. P. Osland is a member of Plenary ECFA.
56. P. Osland is an expert for Marie Sklodowska-Curie actions.
57. P. Osland is co-chair of the Scientific Advisory Committee for The European Physical Journal.
58. F. Ould-Saada is Leader of CERN-related Norwegian HEPP Project since 2006
59. F. Ould-Saada is ATLAS Oslo University Team leader and Collaboration Board member since 2005
60. F. Ould-Saada is National contact physicist within ATLAS since 2006
61. F. Ould-Saada is Norwegian member ATLAS International Computing Board (ICB) since 2005.
62. F. Ould-Saada is deputy member at the LCG Grid Deployment Board (GDB) since 2005
63. F. Ould-Saada is member of the ATLAS education and outreach speakers and publications committee since 2015
64. F. Ould-Saada is member of the ATLAS outreach data and tools group since 2015
65. F. Ould-Saada is the Norwegian representative at the International Particle Physics Outreach Group (IPPOG) since 2006.
66. F. Ould-Saada is member of the Masterclasses and Conferences Steering groups in IPPOG since 2010.
67. F. Ould-Saada is member of the IPPOG speakers and publications committee since 2011
68. F. Ould-Saada is member of the IPPOG working group "New discoveries" since 2012
69. F. Ould-Saada is NorduGrid Chairperson since 2004.
70. F. Ould-Saada is leader of NordForsk-funded project ARC for e-Infrastructures since 2014
71. F. Ould-Saada is member of the Advisory Committee for CERN-related NDGF activities (now NeIC) since 2006.
72. F. Ould-Saada, ATLAS Editorial Board member, Exotics, DM
73. F. Ould-Saada, MC member of the COST Action CA15139, EuroNuNet since 2016
74. F. Ould-Saada, leader of the "Student active research" project ZPATH, Thon grant, since 2017
75. M. Pedersen is NorduGrid ARC release manager starting in 2016
76. A. Raklev is the deputy leader of the Norwegian Physical Society's group for Subatomic Physics and Astrophysics.

77. A. Raklev is section leader for the Theory Section, Department of Physics, UiO.
78. A. Raklev is STSM Coordinator for the COST Action CA15108.
79. A. Raklev is a member of the Program Board for the Master of Physics program, UiO.
80. A. Read is leader of the High Energy Physics section, UiO.
81. A. Read is a member of the board of the Department of Physics at UiO.
82. A. Read is a referee for Journal of Instrumentation and JHEP.
83. A. Read is chairman of the CERN-related Projects Committee.
84. O. Rohne was co-coordinator of the ATLAS/IBL: Stave working group
85. O. Rohne was co-leading Work package 5: Performance and System integration of FP7/ITN TALENT
86. H. Sandaker is deputy head of department, research leader
87. H. Sandaker is member of the department board
88. H. Sandaker is member of the department hiring committee
89. H. Sandaker is leader of the Strategic Dark Matter Initiative (SDI) at UiO
90. H. Sandaker is leader of AEGIS in Norway
91. H. Sandaker is member of the Cherenkov Telescope Array and PI for Norway
92. H. Sandaker is board member of the NanoNetwork national research school
93. H. Sandaker is member of the STREAM ITN network
94. H. Sandaker is member of the ATLAS pixel extended institute board
95. C. Serfon, Responsible of ATLAS Distributed Data Management operation activity.
96. A. Strandlie is active referee for Journal of Instrumentation
97. A.Strandlie is active referee for Nuclear Instruments and Methods in Physics Research A
98. A. Strandlie is a member of the Advisory Committee for CERN School of Computing
99. B. Stugu is Bergen representative in ATLAS Collaboration Board, ID, ITK and SCT boards.