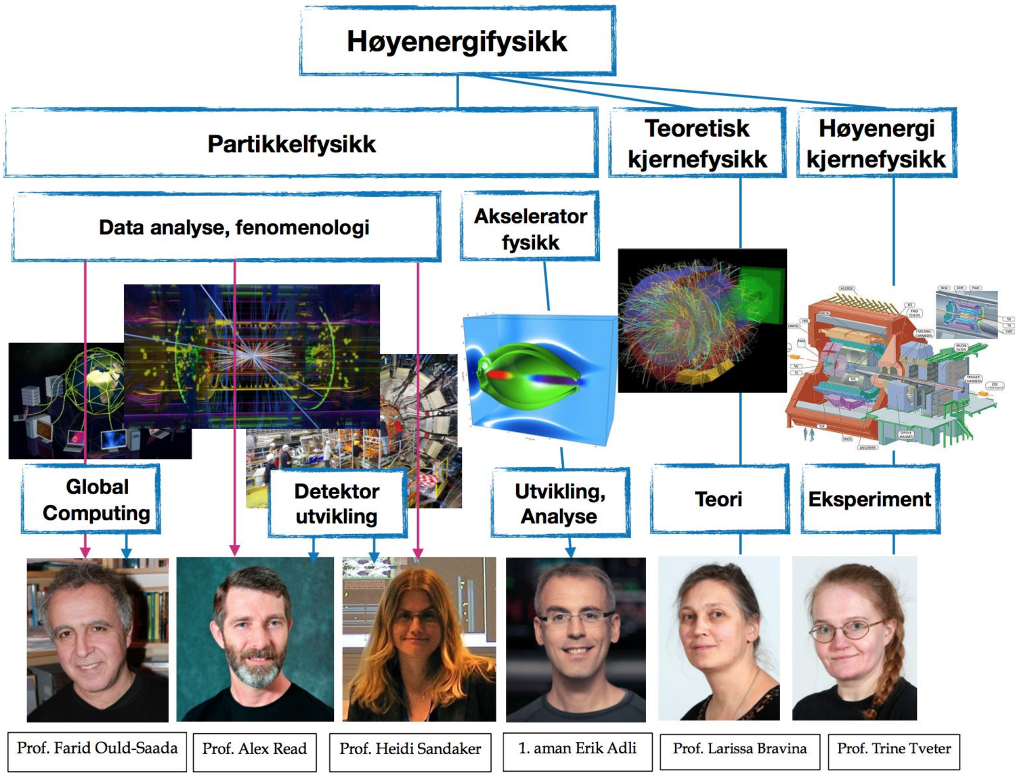
MSc prosjekter i høyenergifysikk (HEP) - 2018



WELCOME !

In the High Energy Physics (HEP) Section we research the fundamental particles and forces of nature under extreme conditions, at the current time mainly through the observation of proton-proton and heavy ionized nuclei in the ATLAS and ALICE experiments on the Large Hadron Collider (LHC) at the world's leading laboratory for HEP at CERN, in Geneva Switzerland. One of the leading questions in HEP after the discovery of the Higgs boson at CERN in 2012 is the nature of the vast amount of dark matter in the universe. In addition to the measurements and particle searches we do at CERN, several of which are highly relevant to the dark matter question (is it a weakly interacting particle?), the role of gravity at the subatomic scale, and the unification of fundamental forces, the Section is involved in preparations of the Cherenkov Telescope Array (CTA), which among other quests will look for indirect evidence of dark matter annihilation out in the universe.

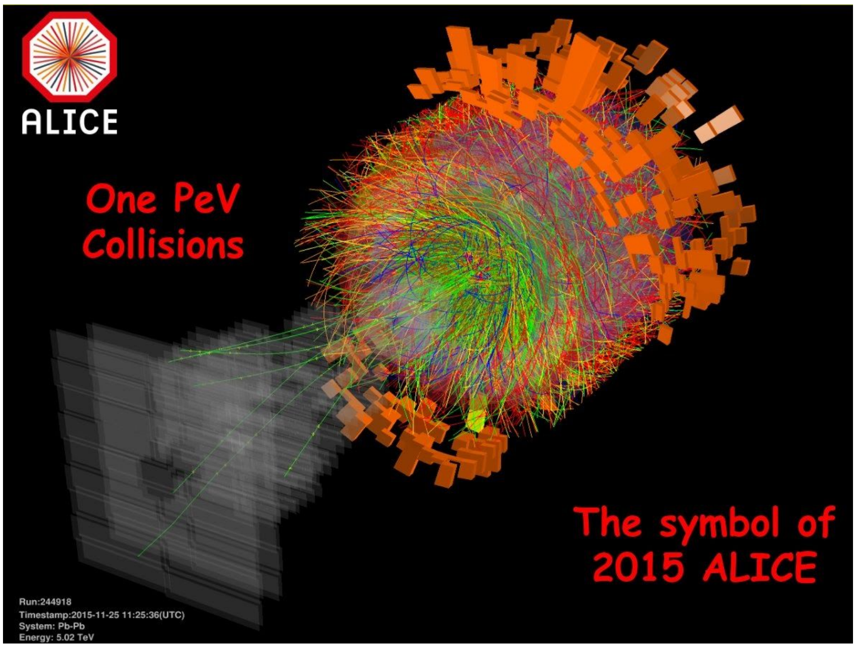
We offer master projects from the full spectrum of activities of HEP activity: experimental and computational studies of future particle accelerators; experimental, phenomenological and computational studies of the quark-gluon plasma; and precision measurements and searches for new phenomena with proton-proton collisions. In addition we have strong activities in developing educational material and new distributed computational and data storage management systems for HEP, and developing and constructing electronics systems and advanced particle detection systems for HEP experiments (currently the upgrades of the ALICE and ATLAS experiments as well as particle beam monitoring for the upcoming European Spallation Source in Lund, Sweden).

There are plenty of details about our current portfolio of MSc projects below, and we don't expect you to *grasp them all at once - please feel welcome to approach any of the supervisors to ask questions!*

Heavy ion physics

Studies of charmonium production in the di-electron decay channel with the ALICE experiment at the LHC

Primordial matter, existing until ~10 microseconds after the Big Bang, was a Quark-Gluon Plasma (QGP), an extremely hot and dense phase of strongly interacting matter consisting of deconfined quarks and gluons (partons). The QGP is currently recreated in ultra-relativistic heavy-ion collisions at LHC (Large Hadron Collider). The main physics objective of the ALICE experiment at LHC is the detailed exploration of QGP properties, using as prime probes charmonia and other hadrons containing heavy quarks.



Charmonia, mesons built from a charm-anti-charm quark pair, are among the main probes of QGP characteristics, and display a complex and interesting behaviour in the nuclear medium.The data material so far has shown strong indications of a novel QGP signature, charmonium production through a recombination mechanism, permitted by the high density of charm-anti-charm quark pairs in this unprecedentedly hot plasma and competing with thermal dissociation of the bound state. A particular challenge in this investigation is the disentanglement of final-state (QGP) and initial-state (cold nuclear matter, CNM) medium effects. Those can be evaluated by comparison of data from different systems, where Pb-Pb, p-Pb and p-p collisions represent the hot QGP and the CNM / vacuum baseline, respectively.
The ALICE-Oslo group has extensive experience with charmonium physics and analysis. The charmonium state measured is the J/psi meson reconstructed in its di-electron decay channel using ALICE charged particle tracking detectors. We currently offer the following specific master projects:

i) Modification of J/psi production in the QGP
Late autumn 2018, the ALICE experiment will collect a high-statistics data set with Pb-Pb collisions at a centre-of-mass energy of 5.02 TeV. High-quality reference data from p-p collisions at the same energy is already available. This will allow a precise determination of the medium-induced modification of the charmonium production in the heavy system, as a function of collision centrality and transverse momentum. Earlier data sets have revealed tantalizing hints of charmonium enhancement in central collisions and at low transverse momenta, and the large upcoming data sample will strongly reduce experimental uncertainties.

Comparison with theoretical model calculations may allow to discriminate between different recombination scenarios: statistical regeneration at the phase transition from QGP to hadron gas, versus dynamical interplay between melting and regeneration processes throughout the evolution of the hot system.

Prof. Trine S. Tveter, FV317, t.s.tveter@fys.uio.no

ii) Elliptic flow of J/psi

The QGP behaves like a low-viscosity liquid and exhibits a collective, multi-harmonic azimuthally anisotropic expansion pattern (flow), which can be described in terms of a Fourier series. The various Fourier components v_n originate from pressure gradients, due to the collision geometry in non-central collisions (typically the quadrupole component v_2, called elliptic flow) or to fluctuations in the initial nucleon density (typically triangular flow v_3 and higher order components). Non-zero elliptic flow has been observed for the J/psi meson, providing further evidence that the charm quarks are thermalized and participate in the collective flow of the plasma, as expected in a recombination scenario. The elliptic flow at higher transverse momenta, where a significant contribution from primordial J/psi is expected, is not well described by model calculations and presently not well understood. The new Pb-Pb data will allow detailed investigations of the flow pattern as a function of collision centrality and transverse momentum, which may give additional information on the interactions of charm quarks with the plasma and the balance between different J/psi production mechanisms.

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iii) Photoproduction of J/psi in hadronic collisions

Heavy nuclei at ultrarelativistic speeds are sources of intense electromagnetic fields, interacting with the other nucleus and leading to photoproduction of charmonium states at very low transverse momenta. A very strong excess of J/psi mesons in this transverse momentum region has been observed by ALICE in peripheral (hadronic) to ultraperipheral Pb-Pb collisions, with and without nuclear overlap. Detailed studies of this phenomenon might offer information on both hot and cold medium effects. The charmonium photoproduction cross section is sensitive to the gluon nuclear parton distribution function, which depends on initial-state CNM effects like nuclear shadowing and / or gluon saturation. Furthermore, photoproduced charmonia will interact with the plasma, and the differential yield of this very distinctive component as a function of transverse momentum and centrality, plus its elliptic flow, could be exploited as a relatively clean probe of final-state hot matter (QGP) effects.

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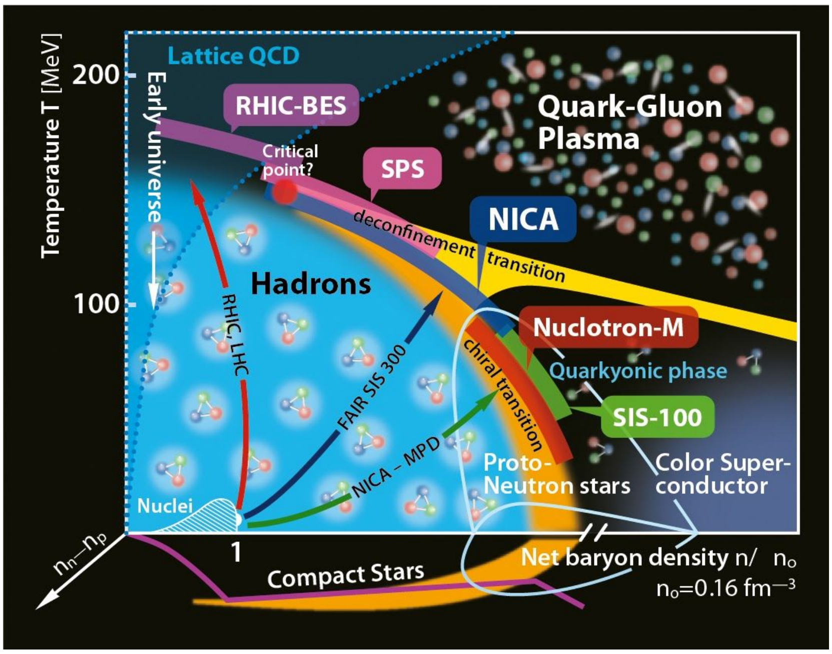
Development of Monte Carlo programs for relativistic hadronic and heavy-ion collisions.

Predictions and comparison with experimental data (e.g. from the ALICE experiment).

Ultra-relativistic heavy-ion collisions (UrHIC) offer a unique opportunity to study the nuclear phase diagram at high temperatures and densities. The matter under such extreme conditions probably has existed in the early Universe within the first few fm/*c* after the Big Bang. Therefore, it is very tempting to investigate the properties of the *Little Big Bang* in the laboratory, and to search for a new state of matter, predicted by the fundamental theory of strong interactions - Quantum Chromodynamics (QCD), namely, a plasma of deconfined quarks and gluons or quark-gluon plasma (QGP).



The only "first principles" calculations of the bulk properties of hadronic matter are lattice QCD calculations. As the temperature crosses some critical value T_C, the energy density rapidly increases and reaches the black body limit for $T > T_C$, indicating that the system has turned into the QGP phase. According to the current status, the transition is second order in SU(2) and first order in SU(3). However, lattice calculations at finite baryon density remain a very complicated problem, the masses of the light quarks are not strictly zero, and the non-perturbative effects are still present in the QGP phase. Also, during the evolution of the fireball formed in UrHIC, the number of produced particles dramatically increases, while the mean energy of a collision between secondaries rapidly decreases, implying that "soft" processes appear to dominate over the hard ones. To describe such complex phenomenon one has to rely on phenomenological models, which can be subdivided into macroscopic, i.e. thermal and hydrodynamic, and microscopic Monte Carlo models, incorporating partonic and hadronic degrees of freedom in a consistent fashion. These models are indispensable for the comparison with the experimental data coming from the working heavy-ion accelerators and for planning the new machines such as Facility for Antiproton and Ion Research (FAIR) at GSI, Nuclotron-based Ion Collider fAcility (NICA) at JINR, and Future Circular Collider which is widely discussed nowadays.

In Oslo we use several MC models at our disposal, namely, Ultra-relativistic Quantum Molecular Dynamics (UrQMD) and Quark-Gluon String Model (QGSM) for description of various hadronic and nuclear collisions, and HYDrodynamics with JETs (HYDJET++) model for simulation of heavy-ion collisions at energies of RHIC and LHC.

The list of possible topics for MS Thesis can be formulated as follows:

(1) relaxation of hot and dense nuclear matter to thermal and chemical equilibrium; extraction of transport coefficients (shear and bulk viscosity):

(2) development of anisotropic flow (directed, elliptic, triangular and so forth) in expanding fireball at energies from few GeV to several TeV;

(3) directed and elliptic flow in proton-proton collisions;

(4) gluon shadowing and other cold nuclear matter effects;

(5) forward-backward multiplicity correlations in proton-proton and heavy-ion collisions;

(6) event-by-event fluctuations;

(7) investigation of the role of geometric and dynamic anisotropy in heavy-ion collisions.

During your study you will get a chance to visit leading scientific centers, meet top-class physicists, attend scientific conferences throughout the world and present results of your study there. *Prof. Larissa Bravina, FV305, Larissa.Bravina@fys.uio.no*

Instrumentation and computing

Particle detector development for the European Spallation Source : The European Spallation Source (ESS) is currently under construction in Lund, Sweden. The Oslo group is building an advanced telescope inside the radioactive nuclear core of ESS in order to image the proton beam before it hits the neutron spallation target. As MSc work on this topic, you will help our team finding novel scintillators for imaging charged particle beams in high-radiation environments. You will perform experimental tests of coated luminescent samples using lasers and at some occasions the Oslo Cyclotron. You may have the possibility to participate in experiments using proton test beams abroad as well. You may also aid our team on building the telescope which will image the ESS beam.

1. aman Erik Adli, FØ382, Erik.Adli@fys.uio.no

Computing and software at the Exascale are crucial parts of the LHC physics experiments. The NorduGrid Advanced Resource Connector (ARC) middleware increases in popularity due its simplistic design and ease of deployment. This makes it the preferred choice of middleware for new and many existing sites particularly in Europe and Asia. ARC and its Control Tower allow seamless access to heterogeneous resources: ***Grid, High Performance Computers and Clouds***. Moreover, ATLAS@home, based on BOINC and ARC, allow to access opportunistic resources made of personal computers. The requirements imposed on software during the coming LHC runs will be as stringent as those on the computing resources. The data throughput that will have to be achieved exceeds anything that our community has managed to date. Such performance can only be attained by combining a number of techniques - ***multi-threading and parallel processing*** of events - as well as novel algorithms and optimisation of existing software.
We propose master thesis subjects on development of new computing software tools, distributed data management systems, and data models that will address the challenges of future LHC extreme conditions. This involves various aspects of software and algorithm development including modern techniques making use of ***machine learning and anomaly detection***. 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.

Prof. Farid Ould-Saada, FØ377, Farid.Ould-Saada@fys.uio.no

Utvikling av pixel detektorer for å oppgradere ATLAS detektoren på CERN. Når LHC blir oppgradert til høyere intensitet må mange av detektorene i ATLAS byttes. I Norge deltar vi i utviklingen av pixel detektorer og vi får nye sensorer Desember 2018 som skal bygges til moduler og testes. Studenten kan velge mellom følgende oppgaver:

- Modulbygging av SINTEF 3D sensorer;
- Delta i ATLAS-testbeam på CERN og bidra til analyse av testbeam-data;
- Videreutvikle en metode (basert på Compressed Sensing) for 3-D målinger av pixel sensorer;
- Karakterisering av nye tynne 3-D pixel sensorer produsert av SINTEF og bygging av detektor-moduler.

Studentene utvikler kunnskap om detektorutvikling, sensorutvikling i samarbeid med SINTEF, silisumdetektorer, dataanalyseverktøy, elektronikk. Studentene får anledning til kortere eller lengre utenlandsopphold ved CERN, f.eks. gjennom CERNs sommer skole, trening og testbeam aktiviteter.

Prof. Heidi Sandaker, FØ384, Heidi.Sandaker@fys.uio.no
Prof. Alex Read, FØ381, a.l.read@fys.uio.no

Utvikling av silisium detektorer for å studere anti-materie ved AEGIS på CERN. Vi vet ikke ennå om antimaterie faller oppover eller nedover i jordens magnetfelt. Vår gruppe utvikler detektorer for å studere anti-Hydrogen. Master studenten skal bidra til byggingen av en silisium detektor for AEGIS samt samle data i testbeam på CERN og analysere disse. Vi har også et prosjekt som er å utvikle simuleringsverktøy av anti-materie annihilasjoner i silisium detektorer og sammenligne med data. Studenten utvikler kunnskap om detektorutvikling, sensorutvikling i samarbeid med SINTEF, silisumdetektorer, dataanalyseverktøy, elektronikk. Studenten får anledning til kortere eller lengre utenlandsopphold ved CERN, f.eks. gjennom CERNs sommer skole, trening og test-beam aktiviteter.

Prof. Heidi Sandaker, FØ384, Heidi.Sandaker@fys.uio.no

Accelerator physics

Particle accelerator physics studies for the European Spallation Source: The European Spallation Source (ESS) is currently under construction in Lund, Sweden. We participate in the study of how the proton beam is accelerated and focused in the ESS accelerator. As MSc work on this topic, you will perform beam dynamics studies of the proton beam, and help our team to predict the shape and impact of the proton beam as it interacts with the neutron spallation target at high energy (see also the previous description). You may also aid our team on building up an advanced telescope to image the beam you will be simulating.

1. aman Erik Adli, FØ382, Erik.Adli@fys.uio.no

The AWAKE experiment: Plasma wakefield acceleration is a new concept for building more powerful particle accelerators. We participate in the Advanced WAKEfield Experiment (AWAKE)accelerator R&D project based at CERN. As MSc work on this topic, you will perform beam-plasma numerical simulation studies of the acceleration process. You will have the chance of traveling to CERN to participate in the experimental studies, together with the AWAKE team.

1. aman Erik Adli, FØ382, Erik.Adli@fys.uio.no

Plasma-based linear colliders: Plasma wakefield acceleration is a new concept for building more powerful particle acceleration. We participate in studies on how to design a future, Teraelectronvolt linear collider using plasma acceleration. As MSc work on this topic, you will use numerical simulations to study how one can improve a the CERN compact linear collider concepts, CLIC, using plasma technology. The work will be done in collaborations with experts at CERN.

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Particle physics at the LHC with the ATLAS Experiment

Studies of the Higgs boson, searches for Dark Matter and new physics phenomena, and path for education, research and discovery.

The Higgs boson, the last ingredient of the particle physics theory known as the Standard Model (SM), has been discovered by the ATLAS and CMS experiments at the Large Hadron Collider (LHC). The next step is to measure the Higgs boson properties and nature. Is it the long-awaited SM particle? Is it the first in a long series of scalar particles? With the advent of higher energies and higher collision rates the Large Hadron Collider (LHC) continues the exciting voyage towards ***new physics phenomena***, allowing physicists all over the world to explore a previously unknown territory full of promise. The ambitious LHC physics programme may shed light on some of the greatest mysteries in physics today: (i) the nature of dark matter (DM), and (ii) the behaviour of the gravitational force at the microscopic scale.

The studies proposed below may include a search optimization, analysis of ATLAS data at 13 TeV center-of-mass energy, comparison to simulation, and interpretation of results, making use of new theoretical models, statistical tools, and constraints from particle physics, astrophysics and cosmology. In proton-proton collisions at the LHC, new particles (signal) are often produced together with other known particles (denoted X below), thus assuring various known conservation laws and taking account of higher order effects. The "**signal**" process we search for is very often hidden by competing "**background**" due to SM processes and/or misidentifications caused by some detector imperfections.

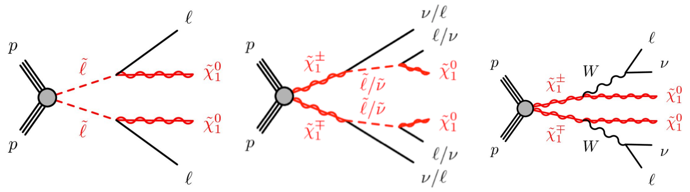
You will quickly get acquainted with ATLAS analysis and simulation tools, often C++ and Python-based: (i) ROOT, a modular scientific software framework using C++, python and R languages, provides all functionalities needed to deal with big data processing, statistical analysis, visualisation and storage; (ii) ATLAS software tutorial over 4 days covering ATLAS computing and analysis tools, as well as latest recommendations for data analysis, (iii)Monte Carlo (MC) generation programs for the SM and new physics.

Throughout your master project you will be working within ATLAS physics working groups and/or other related groups, such as the LHC DM forum or the International Particle Physics Outreach Group (IPPOG). If you have not been to CERN or would like to pay other visits, here is your chance.

1. **Precision measurements of Higgs boson production** in the decay channel to two photons in the ATLAS experiment at the LHC. Although the first measurements of the properties of the Higgs boson discovered at CERN in 2012 are consistent with the SM, the uncertainties are large and there are many physically motivated models that would give small deviations from the SM predictions. MSc projects in this activity include (a) the study of robust statistical models for the data-driven estimation of the background under the Higgs boson signal peak in the two-photon mass spectrum, (b) development of a procedure to optimize the use of computing-intensive detailed simulations of the detector, (c) search for additional mass peaks below and far above the established mass peak at 125 GeV, (d) precision measurement of the Higgs boson mass, and (e) measurement of the transverse momentum spectrum of the Higgs boson. You will work with data taken during the 2015-18 runs of the LHC at 13 TeV, nearly twice the center of mass energy compared to 2011-12 (7 and 8 TeV). You will join the Hgamma working group in ATLAS, participate in the ongoing development of the data analysis strategies and code, learn, further develop and apply advanced statistical techniques, and, thus, contribute to furthering our understanding of the Brout-Englert-Higgs (mass-generating) mechanism and test whether there is new physics beyond the SM (such as dark matter). *Prof. Alex Read, FØ381, a.l.read@fys.uio.no*

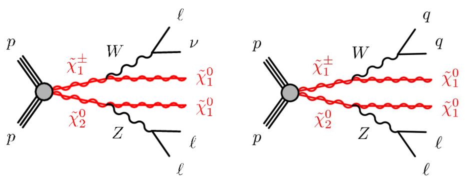
2. ***Search for Supersymmetry and Dark Matter (DM).*** Symmetries play a crucial role in physics. Supersymmetry (SUSY) relates integer spin particles (bosons) and half-integer spin particles (fermions). It allows unification of the electroweak and strong interactions, proposes ***dark matter*** candidates, and predicts ***five Higgs bosons*** (3 neutral and 2 charged ones). Processes of interest involve superpartners of the leptons, of the gauge and Higgs boson(s), as well as a dark matter particle, which is predicted to be the lightest supersymmetric particle (LSP). *How will you be involved in searches for SUSY and Dark Matter?*
    a. Search for sleptons, hypothetical supersymmetric partners of leptons, in the process $pp \rightarrow \tilde{l}^{+}\tilde{l}^{-}+X \rightarrow l^{+}l^{-}+\chi\chi+X$, where the DM candidate χ is the lightest neutralino (a mixture of photino, zino and higgsino), leading to a pair of leptons ($e^{+}e^{-}$ or $\mu^{+}\mu^{-}$) and missing transverse energy (MET). The main SM background comes from, $pp \rightarrow W^{+}W^{-}+X \rightarrow l^{+}l^{-}+\nu\nu$bar (MET)+X, $pp \rightarrow Z(\rightarrow l^{+}l^{-})\ Z(\rightarrow \nu\nu$bar$)+X \rightarrow l^{+}l^{-}$+MET+X and top quark-pair production. Among others, the following variables help extracting the signal: di-lepton invariant mass M_{ll}, missing transverse energy (MET), transverse mass. The results will be interpreted within

SUSY simplified models having slepton and DM masses as free parameters. *Prof. Farid Ould-Saada, FØ377, Farid.Ould-Saada@fys.uio.no, Prof. Heidi Sandaker, FØ384, Heidi.Sandaker@fys.uio.no*



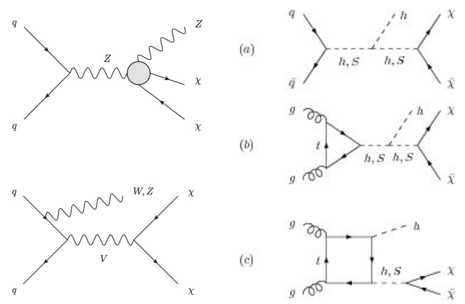
b. The same final state (l^+l^-+MET+X) above may be due to the production of a pair of lightest charginos $\chi^{\pm}_1$ (mixture of wino (W-superpartner) and charged higgsino (charged Higgs super-partner) through the process pp→ $\chi^+_1\chi^-_1$+X, followed by (i) $\tilde{l}^+\tilde{l}^-$+ννbar+χχ+X or (ii) W^+W^-+χχ+MET+X. Further variables and analyses, including multivariate techniques based on neural networks and machine learning (ML) help separate various new physics scenarios on one hand and known SM physics on the other hand. *Prof. Farid Ould-Saada, FØ377, Farid.Ould-Saada@fys.uio.no , Prof. Heidi Sandaker, FØ384, Heidi.Sandaker@fys.uio.no*

c. Another promising search for electro-weakinos (superpartners of electroweak gauge bosons, 4 neutralinos and 4 charginos) is through the process pp→ $\chi^{\pm}_1\chi^0_2$+X, followed by $W^{\pm}Z^0$+χχ+MET+X ~ ending with the final states 2-jets+l^+l^-+χχ+X or $l^{\pm}$ ν+l^+l^-+χχ+X. *Prof. Farid Ould-Saada, FØ377, Farid.Ould-Saada@fys.uio.no, , Prof. Heidi Sandaker, FØ384, Heidi.Sandaker@fys.uio.no*



3. ***Search for DM in mono-Z and mono-Higgs final states.***

DM can also be searched for within so-called simplified (non-SUSY) models. These simplified models assume, in addition to DM candidates, some DM mediator which can be, among others, a scalar (h,S) or a vector (V, Z'). The signature consists in detecting a well known SM particle recoiling against missing energy-momentum carried away by DM, more precisely 2 DM particles.



a. ***Mono-Higgs.*** *Prof. Alex Read, FØ381, a.l.read@fys.uio.no, Prof. Heidi Sandaker, FØ384, Heidi.Sandaker@fys.uio.no*

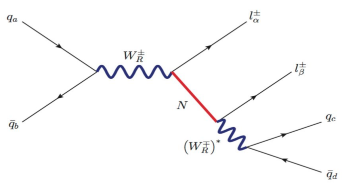
b. ***Mono-Z.*** *Prof. Farid Ould-Saada, FØ377, Farid.Ould-Saada@fys.uio.no, Prof. Heidi Sandaker, FØ384, Heidi.Sandaker@fys.uio.no*

4. **Search for new gauge bosons.** Do ***new fundamental forces*** show up at the LHC the way the Z and Higgs bosons did? According to superstring theories, which proposes to unify all fundamental forces, including gravity, there is room for new forces to be mediated by new gauge bosons, known as Z' and W'. The W' boson is also predicted by theories aiming at restoring parity (left-right) symmetry at high energies. This work consists in: (i) a detailed study and implementation into MC generators of various

theories beyond the SM, (ii) an analysis of ATLAS data, taken at the highest available energies, and a comparison to simulation data. *You will make use of one of the following processes:*

a. **Search for Z'**: pp → Z'+X → l^+l^-+X. The so-called Drell-Yan process constitutes the main SM background. The analysis consists in searching for a bump in the distribution of invariant mass of di-leptons M_{ll}. At high masses top pair production is non-negligible. Two strategies are followed to determine the SM background: (i) using MC simulation and (ii) making use of data-driven methods. With the latter method you will investigate the best functions or make use of the so called "sliding-window" method to fit the data. In addition to searching for new particle resonances you can look for other phenomena, one of which is the investigation of lepton substructure at some high energy scale, leading to a non-resonant excess at high masses. Eventually, you will interpret the data in terms of various Z' or substructure models. If you are more interested in theory/phenomenology, you can investigate new models, by studying their free parameters, implement the interesting models into MC generators, and perform feasibility studies at the LHC. If you are fast and still eager you can test some models yourself with real data at hand. *Prof. Farid Ould-Saada, FØ377, Farid.Ould-Saada@fys.uio.no*

b. **Search for W' (and heavy Majorana neutrino)**: pp → W'+X → $l^\pm$+ν+X → $l^\pm$+MET+X. You will follow a similar procedure as above. Due to the missing neutrino the signal is less prominent than in the resonance structure expected for a Z'. The distorted resonance shape is known as a Jacobian peak and, instead of the invariant mass, you will deal with the transverse mass built from the measured lepton and missing energy. The most important background stems from the real and virtual production of the W boson. You will interpret your results within W' models, the Sequential SM one and the W_R predicted by left-right symmetric models. What about the option to search for a heavy Majorana neutrino, N. For example in decays of a W_R where the N decays to a charged lepton and 2 jets through a virtual W_R. You need to master both leptons and jets. As a bonus the SM background is expected to be very small as the 2 leptons in the final state have the same electric charge, in contrast to the cases above.



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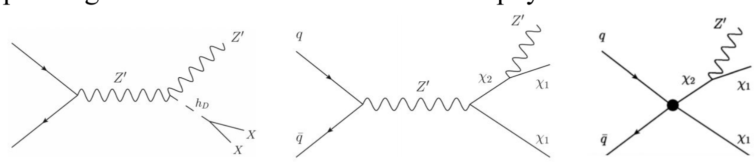
c. **Search for a DM-aware new Z' gauge boson.** You will search simultaneously for a new gauge boson Z' and DM through the process pp→Z'+MET+X→ l^+l^-+MET+X, the missing transverse energy MET being due to DM particles. Non-SUSY simplified models assume, in addition to DM, some mediator which can be, among others, a scalar or a vector. A new search mechanism, a generalisation of the mono-Z search to arbitrary vector boson mass, is proposed along 3 production mechanisms: (Left) Dark Higgs model, with a Z' in association with a dark Higgs h_D coupling to DM; (Middle) Light vector model with a Z' coupling to dark states χ_1 (DM) and χ_2 (unstable); (Right) Light vector with inelastic Effective Field Theory model operating at an unknown new scale of new physics Λ.



i. If you are interested in theory/phenomenology, you can investigate the DM models above by studying their free parameters: variation of the Z' and DM masses within ranges compatible with experimental, astrophysical and cosmological constraints.

You will work within the LHC DM group where experimental physicists from ATLAS, CMS and non-LHC experiments, together with theoreticians, collaborate to shed light on DM. You may implement new interesting models into MC generators and perform feasibility studies at the LHC by comparing to SM expectations. If you are fast and still eager you can test some models yourself with real data at hand.

ii. You can also start the other way around: analyse real data, search for Z' and DM, and interpret your results in terms of the simplified models above. See for example the Z' analysis above.
Prof. Farid Ould-Saada, FØ377, Farid.Ould-Saada@fys.uio.no

5. ***Extra space dimensions and microscopic Gravity.*** Gravity as we know it is negligible at the subatomic level. The addition of *n* space dimensions affect the behaviour of the gravitational force, changing from $1/r^2$ to $1/r^{(2+n)}$, thus enhancing its strength at very short distances *r*. A way to search for signatures of gravity at the LHC, and thus reveal the existence of ***microscopic space dimensions***, is to look for **graviton excitations** and/or **microscopic black holes**. Both would decay into SM particles, measurable in particle detectors. Advanced analysis and statistical methods are crucial to distinguish these new phenomena from competing standard processes, on one hand, and from other resonances such as Z' described above. In addition to the variables and search methods detailed above, you will make use of the fact that the Graviton is spin-2, the Z' spin-1 and the Higgs spin-0. The decay angle distribution of the measured lepton in the centre of mass of the decaying resonance is expected to have a characteristic shape in each of the cases. *Prof. Farid Ould-Saada, FØ377, Farid.Ould-Saada@fys.uio.no*

6. The various scenarios of new physics theories discussed above may show up in a given process at the LHC. ***Model independent searches for new physics*** are proposed in final states with leptons recorded with the ATLAS detector. New methods and tools involving neural networks and machine learning algorithms are to be used and optimized, using real data as well as simulated data based on various theoretical implementations, in order to correctly interpret any signal of new physics and distinguish it from regular SM electroweak and strong processes. *Prof. Farid Ould-Saada, FØ377, Farid.Ould-Saada@fys.uio.no*

7. Are you interested in **sharing ATLAS data, research excitement and possibly discoveries with other students**, and explaining to them modern physics concepts? Join the ***Path for education, research and discovery!*** The ambition to bring to the "classrooms" important LHC discoveries is already realized using the discovery of the Higgs boson in 2012. Approximately 10% of the ATLAS discovery data were made available for students to search themselves for the Higgs boson. Promises of new discoveries in the 13 TeV LHC era and opportunities offered by the CERN open data portal have triggered new educational materials. We have room for 2 students to work on development of educational material based on new high energy particle physics research data and possible coming discoveries. You will target high school as well as university students, including bachelor, master and PhD levels. In preparing these educational materials you follow the LHC 'heartbeats' with the ambition to influence textbooks and teaching methods. You will integrate the resulting material as part of a dynamic, standalone, web-based library. This "student-based research project" is supported by the Thon Foundation. For more information you are invited to visit the Zpath http://www.mn.uio.no/fysikk/english/research/projects/zpath/ . You will be working in close contact with the International Particle Physics Outreach and the ATLAS collaboration. *Prof. Farid Ould-Saada, FØ377, Farid.Ould-Saada@fys.uio.no*

Astro-particle physics and dark matter

Søk etter mørk materie med Cherenkov Telescope Array (CTA). CTA er et nytt observatorium som har byggestart i 2017. Master studenten skal se på simuleringer av kosmiske stråler som kommer til å treffe CTA teleskopene for å finne ut hvor godt vi kan observere mørk materie fra forskjellige steder i universet og hvor mye data som trengs for å kunne gi et bedre resultat enn dagens teleskoper. Studenten utvikler kunnskap om partikkelfysikk, astrofysikk, cherenkov detektorer, simuleringsverktøy, statistikk.

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