Spåtind 2023 - Nordic Conference on Particle Physics

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Book of Abstracts

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Supermassive black holes as detectors for ultralight bosons

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Ultralight bosons behave like coherent waves when the occupation number is large enough. If they are coupled to the Standard Model sector of the particle physics, such an oscillating background can induce a tiny signal. Near a fast rotating black hole, ultralight bosons within one order of the mass window can accumulate through superradiance with a large density expected. If linearly polarized radiation is emitted near the black hole, axion can contribute to birefringence effect that shifts the position angle periodically, making the polarimetric measurements of the Event Horizon Telescope on M87*a powerful way to look for ultra-light axions. On the other hand, the superradiance phase where black hole spin decreases exponentially can leave imprints on the shadow contour drift or azimuthal angle lapse of photon ring autorrelations, which makes future observations of SgrA* optimal to look for such signals. Finally, gravitational atoms can induce oscillating metric perturbations that modify the geodesics of photons, creating a new observation channel for the future precise measurement of supermassive black holes.

Contributed Talks VII / 11

Gaussian Process-based calculation of look-elsewhere trials factor

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In high-energy physics it is a recurring challenge to efficiently and precisely (enough) calculate the global significance of, e.g., a potential new resonance. We propose a new method that models the significance in the search region as a Gaussian Process (GP). The kernel of the GP is approximated with a covariance matrix and is calculated with a carefully designed set of background-only data sets, comparable in number to the random background-only data sets used in a typical analysis that relies on the average upcrossings of the significance. The trials factor for both low and moderate significances can subsequently be calculated to the desired precision with a computationally inexpensive random sampling of the GP. In addition, once the covariance of the GP is determined, the average number of upcrossings can be computed analytically. In our work we give some highlights of the analytic calculation and also discuss some peculiarities of the trials factor estimation on a finite grid. We illustrate the method with studies of three complementary statistical models.

Contributed Talks VI / 12

Status of the HIBEAM-NNNAR experiment at the European Spallation Source

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The HIBEAM-NNBAR program is a proposed two-stage experiment at the European Spallation Source (ESS) designed to search for neutrons converting, or oscillating, into antineutrons and/or sterile neutrons. Such an observation would indicate baryon number violation, a fundamental Sakharov condition for baryogenesis, or act as a sign of a potential dark sector. The experiment would increase the sensitivity to neutron conversion probabilities by three orders of magnitude compared with previous free neutron searches, being sensitive to a scale of new physics substantially in excess of that available at colliders. HIBEAM-NNBAR is a cross-disciplinary experiment with a clear particle physics goal. The community encompasses physicists from large collider experiments and low energy nuclear physics experiments, together with scientists specialising in neutronics and magnetics. In this talk I summarize the current status of the experiment and provide an outlook for the future of the experiment, both from a short and long term perspective.

Contributed Talks III / 13

Inverse Compton emission from heavy WIMP annihilations in the Galactic Centre

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In gamma-ray astronomy typically only the direct photon component is considered as signal when searching for annihilating WIMPS. This means that only photons that are produced during the WIMP annihilation and the consecutive hadronisation are taken into account. There is however also a non-negligible contribution to the gamma-ray signal that arises from the electrons that are produced in the annihilation. They can enhance the WIMP signal through high energy photons produced e.g. in inverse Compoton processes. In this talk, I want to highlight this contribution as expected in the Galactic Centre region and encourage people to account for this component when searching for WIMP annihilation using gamma-rays.

Contributed Talks I / 14

Recent ALICE results on charmonium production in Pb-Pb collisions

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The ALICE detector is specifically designed for allowing a precise characterization of the quark-gluon plasma (QGP), a deconfined phase of nuclear matter which can be formed in heavy-ion collisions. Heavy quarks, i.e. charm and beauty, are created in the hard partonic scatterings at the early stage of the collision, prior to QGP formation, and could thus experience energy loss, transport, thermalisation and hadronisation during the QGP phase. Charmonia, bound states of charm and anti-charm quarks, are sensitive probes of the deconfined medium, exhibiting a rich phenomenology.

In this talk, I will present recent results from the ALICE Collaboration on the production of the charmonium state J/ψ in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, at mid- and forward rapidity, exploiting the full Run 2 data sample. In particular, I will report on the nuclear
modification factor for inclusive, prompt and non-prompt J/ψ, defined as the yield in heavy-ion collisions normalized to the binary scaled yield measurement in pp collisions at the same energy. The J/ψ anisotropic azimuthal distribution (flow), indicating a
hydrodynamic expansion pattern, will also be presented. Novel results on the excited charmonium state $\psi(2S)$, measured at forward rapidity, will also be discussed. The talk will conclude with a brief summary of our current physics understanding and an outlook regarding foreseen charmonium measurements during the Run 3 of the LHC.

Contributed Talks V / 15

SMARTHEP network: Studies on online vs. offline jet energy corrections at CMS

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SMARTHEP is an Innovative Training Network, bringing together researchers from all major four LHC collaborations and partners from industry, all working on real-time analysis. In this contribution, I will present work on intertwining the online and offline calibration of jets at CMS. We investigate the transverse momentum response between high level trigger (HLT) and several types of offline jets. We conduct our analysis in the coffea framework, a columnar analysis tool.

While the online reconstruction is simplified compared to the offline reconstruction, an increasing amount of analyses exploit the extended phase space accessible with scouting data also for complex analyses. Performing statistics-limited parts of the jet calibration with online jets and merging it with high-precision offline reconstructed jets promises improved calibrations for both online and offline analyses.

Contributed Talks VII / 16

Overcoming limitations to parameter inference using Neural Ratio Estimation

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In the hunt for new physics phenomena, such as dark matter, it is crucial to compare experimental data to theoretical models. During this step, the most likely values of the model's parameters —such as particle masses and cross sections —are inferred. However, a rigorous statistical treatment of such an inference is oftentimes not practically feasible without making significant simplifying assumptions. In many cases, this may dramatically decrease the sensitivity and reliability of the inference analysis. Recently, new inference techniques based on machine learning have emerged to help overcome these limitations. In particular, "Neural Ratio Estimation"(NRE) stands out with its reported accuracy and efficiency. NRE achieves such success by avoiding explicit integration or optimization over large parameter spaces, which are typical in traditional inference techniques. Instead, in NRE, a neural network is trained to distinguish between the likely and the unlikely parameter values of any given observation. The training set consists of model simulations, which implicitly contain the necessary information for an inference. In this contribution, I will discuss how NRE, and some of its variants, can be applied to problems in gamma-ray astroparticle physics. Its applications in forward-folding problems and the inclusion of nuisance parameters will also be addressed. In particular, I will apply NRE to the search for Axion-like particles (ALPs) with the upcoming Cherenkov Telescope Array (CTA). This analysis is particularly relevant, because ALPs are popular dark matter candidates, whose detection (or exclusion) in gamma-ray observations is especially difficult using conventional inference techniques.

Contributed Talks V / 17

Top quark mass measurement in lepton and jets final state at the CMS experiment

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Our analysis is a direct top quark mass measurement where the mass is extracted from the reconstruction of the top quark decay products.The analysis operates on a lepton and jets final state in top quark pair event topology. Our analysis is based on a binned profile likelihood method which has been introduced to the top quark mass measurements at CMS during the LHC Run II data taking period.

This analysis strategy shows a great promise for an accurate direct top quark mass measurement. The connection to the top quark pole mass is however left as a somewhat open question.

Contributed Talks V / 18

Effective Field Theory interpretation of the search for Higgs boson pair production in the two bottom quarks plus two photons final state with the ATLAS detector

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Measuring Higgs pair production will give us information about the Higgs self coupling, which is key to determine the shape of the Higgs potential at higher order O(3).

The leading production mode is gluon gluon fusion, with a cross section of 31.05 fb at a centre of mass energy of 13 TeV. Given the small cross section, Higgs pair production has not yet been observed. However, despite its low branching fraction, the search for Higgs boson pair production in the two bottom quarks plus two photons final state (HH->bbyy) exploits the great diphoton mass resolution of the ATLAS detector to set very competitive upper limits to the HH production cross section.

The search for HH->bbyy with 2015-2018 data recorded by the ATLAS detector sets observed (expected) upper limits to the HH cross section of 4.1 (5.5) times the SM cross section. These are the most stringent upper limits published by ATLAS up to date.

Assuming no new unknown particles are produced at the LHC energy, different interpretations can be used to measure deviations from the SM predictions due to new physics produced at much higher energies. These interpretations of the HH->bbyy search can help us to understand whether the observed result is best described by Higgs self-interaction or other processes that give similar signatures.

Contributed Talks VII / 19

Combined collider constraints on SUSY with a light gravitino

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I will present the latest physics results from the GAMBIT Collaboration, focusing on a recent study of how the current combined set of LHC SUSY searches and LHC measurements of SM signatures constrain SUSY scenarios with multiple light neutralinos and charginos, and a near-massless gravitino. Through a large-scale global fit, with full Monte Carlo simulations of LHC searches and measurements at each sampled SUSY parameter point, we have investigated how the interplay and complementarity of the many LHC SUSY searches and SM-signature measurements impact this class of non-simplified SUSY scenarios. Our results demonstrate that while much of the parameter space is constrained, there are several still-viable scenarios which predict a phenonemonlogically rich and detectable sector of multiple sub-TeV neutralinos and charginos, with masses down to around 200 GeV.

Contributed Talks I / 20

Characterizing the initial conditions of heavy-ion collisions with correlations between mean transverse momentum and anisotropic flow

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The study of the initial conditions of relativistic heavy-ion collisions and the subsequent development of hot and dense nuclear matter at the LHC is fundamental for the understanding of the strong nuclear force. The traditional approach of comparing observables with hydrodynamical models based on different initial conditions typically fails to isolate the effects of the initial conditions due to the sensitivity of the observables to the collective behaviour of the expanding system. Correlations of the mean transverse momentum [pT] and the anisotropic flow Fourier coefficients v_n have been shown to serve as a unique probe of the initial conditions of the heavy-ion collisions with little to no bias from final state effects.
In this talk, correlations between [pT] and v_2 or v_3 are presented as a function of centrality in Pb–Pb and Xe–Xe collisions at √sNN = 5.02 TeV and √sNN = 5.44 TeV, respectively. The observables are compared between data and hydrodynamical models using IP-Glasma or TRENTo initial conditions. The former is based on Color Glass Condensate effective theory with gluon saturation and the latter is a parameterized model with nucleons as the relevant degrees of freedom. The data is best described by models using IP-Glasma initial conditions, whereas the TRENTo based models fail to describe the data regardless of the parametriza- tion. It is argued that the nucleon width, w, plays an essential role in describing the measured correlations.

Contributed Talks I / 21

Light-flavour hadron production in $\sqrt{s} = 13$ TeV pp collisions as a function of the underlying event activity

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Multiple measurements of high-multiplicity pp and p-A collisions at LHC energies have revealed that these small collision systems exhibit some of the quark-gluon plasma features, e.g.\ collective behaviour and strangeness enhancement, formerly thought to be achievable only in heavy-ion collisions. The dependence on multiplicity is indicative of significant final-state interactions. A proposed method to narrow down the origin of the phenomena is to study the effect of Multi-Parton Interactions (MPIs). Although the MPIs cannot be measured directly, the event observable $R_{\rm T}$, quantifying the magnitude of the underlying event, has been suggested as an experimental proxy.

In this presentation, we report on the identified light-flavour hadron transverse momentum spectra as a function of $R_{\rm T}$ in pp collisions at $\sqrt{s} = 13$˜TeV measured with the ALICE detector at the LHC. The results are also compared with MC predictions of theoretical models, for which our measurements have an excellent discriminatory potential.

Contributed Talks VI / 22

Norwegian accelerator research towards future colliders

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I will present the Oslo group's involvement in towards a future collider at the Energy Frontier, with focus on advanced accelerator technology, including plasma wakefield accelerators and plasma lenses. I will also elude to how the technological advances may be used for medical applicaitons.

Contributed Talks III / 23

Glueball Dark Matter revisited

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We revisit the possibility that Dark Matter is composed of stable scalar glueballs of a confining dark $\mathrm{SU}(3)$ gauge theory coupled only to gravity. The relic abundance of dark glueballs is studied for the first time in a thermal effective theory accounting for strong-coupling dynamics. An important ingredient of our analysis is the use of an effective potential for glueballs that is fitted by lattice simulations. We predict the relic abundance to be in the range $0.12\zeta_T^{-3}\Lambda/(137.9eV) < \Omega h^2 < 0.12\zeta_T^{-3}\Lambda/(82.7eV)$, with Λ being the confinement scale, ζ_T the visible-to-dark sector temperature ratio and the uncertainty is coming from the fit to lattice data. This prediction is an order of magnitude smaller than the existing glueball abundance results in the literature. Our framework can be easily generalised to different gauge groups and modified cosmological histories paving the way towards consistent exploration of strongly-coupled dark sectors and their cosmological implications.

Contributed Talks I / 25

Multi-particle correlations for the new decade of QGP studies

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Multi-particle correlations have been compelling tools to probe the properties of the Quark-Gluon Plasma (QGP) created in the ultra-relativistic heavy-ion collisions. In this seminar, I will present a generic recursive algorithm for multi-particle cumulants, which enables the calculation of arbitrary order multi-particle cumulants. Among them, I will emphasize a particular series of mixed harmonic multi-particle cumulants, which measures the general correlations between any moments of different flow coefficients. The study of these new multi-particle cumulants in heavy-ion collisions will significantly improve the understanding of the initial event-by-event geometry fluctuations and the hydrodynamic response in the final state. This will pave the way for more stringent constraints on the initial state and help extract more precise information on how the created hot and dense matter evolves. Last but not least, I will show the most recent study of correlations between anisotropic flow and mean transverse momentum in terms of multi-particle correlations/cumulants. I will show how we can directly access the initial conditions of heavy-ion collisions using the latest experimental measurements at the LHC and discuss the critical challenge of the state-of-the-art QGP studies via Bayesian analyses.

Contributed Talks I / 26

Spin polarization measurements in relativistic heavy-ion collisions

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The extreme temperatures and energy densities generated in the ultrarelativistic nuclear collisions produce a state of partonic matter, the quark-gluon plasma (QGP), which behaves almost like an ideal fluid. The created system may possess large orbital angular momentum leading to the global polarization of particles perpendicular to the reaction plane. Also, local asymmetries in the velocity fields due to anisotropic flow can generate vorticity and particle spin polarization along the beam direction. In parity-violating weak decays of hyperons, the momentum direction of the decay baryon is correlated with the hyperon spin. This feature can be used to measure the hyperon spin polarization and estimate the global and local vorticity of the system created in relativistic heavy-ion collisions. The spin polarization, being sensitive to the hydrothermal (flow velocity and temperature) gradients, is unique compared to conventional observables that are sensitive to the hydrothermal fields only. Hence, the recent measurements of global and local hyperon spin polarization at the Large Hadron Collider (CERN, Geneva) and Relativistic heavy ion collider (RHIC, USA) provides a unique opportunity to probe the QGP substructure with finer details.
This talk will present the recent experimental measurements of the hyperon spin polarization in heavy-ion collisions at the LHC and RHIC. The comparison of the measured global and local polarization with the hydrodynamic model calculations, including competing contributions from thermal and shear-induced vorticity will be discussed.

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Primordial gravitational waves from phase transitions

Author: David Weir[1]

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In many extensions of the Standard Model, the electroweak transition is first order - in some cases, strongly so. The ensuing phase transition would result in collisions of bubbles of the new Higgs phase. These collisions, and the associated interactions of sound waves in the plasma, are substantial sources of gravitational waves. For a phase transition at or around the electroweak scale, these gravitational waves may be detectable by future missions such as LISA. They can indirectly provide a probe of particle physics beyond the Standard Model, complementary to future colliders.

However, concrete predictions of the resulting gravitational waves will require good understanding both of the particle physics models themselves, as well as the non-equilibrium physics of the transition. In other words, we need accurate studies of the phase diagrams in the underlying particle physics theories, as well as good predictions of the expected gravitational wave signal from simulations. These feed into one another, forming a so-called 'pipeline'.

The stronger the phase transition, the better the chance of being detected (or constrained) by future missions like LISA. However, strong transitions are also the most poorly understood. In this talk I will discuss some recent results from different points along the 'pipeline', with a focus on the consequences for strong first-order phase transitions.

Contributed Talks V / 28

Constraints on spin-0 dark matter mediators and invisible Higgs decays using ATLAS 13 TeV pp collision data with two top quarks and missing transverse momentum in the final state

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This paper presents a statistical combination of searches targeting final states with two top quarks and invisible particles, characterised by the presence
of zero, one or two leptons, at least one jet originating from a b-quark and missing transverse momentum.
The analyses are searches for phenomena beyond the Standard Model consistent with the direct production of dark matter in pp collisions at the LHC, using 139 fb⁻¹ of data collected with the ATLAS detector at a centre-of-mass energy of 13 TeV.
The results are interpreted in terms of simplified dark matter models with a spin-0 scalar or pseudoscalar mediator particle. In addition,
the results are interpreted in terms of upper limits on the Higgs boson invisible branching ratio, where the Higgs boson is produced
according to the Standard Model in association with a pair of top quarks.
For scalar (pseudoscalar) dark matter models, with all couplings set to unity, the statistical combination extends the mass range
excluded by the best of the individual channels by 50 (25) GeV, excluding mediator masses up to 370 GeV.
In addition, the statistical combination improves the expected coupling exclusion reach by 14% (24%), assuming a scalar (pseudoscalar) mediator mass of 10 GeV.
An upper limit on the Higgs boson invisible branching ratio of 0.38 (0.30^{+0.13}_{-0.09}) is observed (expected) at 95% confidence level.

Contributed Talks VII / 29

Geometry Calibration in IceCube

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The IceCube Neutrino Observatory at the South Pole has instrumented one cubic kilometer of ice by deploying digital optical modules (DOMs) in 86 drill holes, each containing a string of DOMs So far IceCube has used the GPS-determined location of the drill tower for the positions of DOMs in the transverse directions (x and y) while the depth (z) is calibrated in situ. The large inter-string spacing makes higher precision (˜1m) localization of the x and y positions of the DOMs in the ice challenging. This talk presents a new method for calibrating the positions of the DOMs. For a large selection of muon tracks, a maximum likelihood-based approach is used to determine the positions of DOMs. As a proof of concept, four central strings are studied to keep systematic uncertainties as low as possible. The method can find x and y positions to 0.2m as found using simulation corresponding to four days of data. In four days of real data, we find that for the x and y positions the results are consistent with nominal positions except for string 36. I will discuss how this method in combination with additional developments in IceCube calibration will provide improved event reconstructions, applicable to both existing and future data.

Contributed Talks I / 30

Precise description of medium-induced emissions

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The high quality experimental data on hard probes in heavy-ion collisions call for a more precise theoretical description of jet evolution in a quark-gluon plasma. To accomplish that we study jet

fragmetation via 1 ⟶ 2 final-state parton splittings in the medium. In earlier works [1, 2] the authors have usually calculated these processes by invoking one or two approximations: the large-Nc and the eikonal approximations. We want to develop methods to do the calculations without using these approximations, and to quantify the error that is introduced by employing them.
As partons go through the medium their color continuously rotates, an effect that is encapsulated in a Wilson line resumming multiple medium interactions along their trajectory. When calculating observables, one typically has to calculate correlators of several Wilson lines. For 2- or 3-point correlators, analytical solutions exist. However, correlators of 4 or more lines are usually dealt with in the literature by invoking the large-Nc limit. In our work [3], we showed how correlators of multiple Wilson lines appear, and developed a method to calculate them numerically to all orders in Nc. This result is quite general, and can be used to calculate Wilson line correlators that appear in many areas of particle physics.
In our previous paper we made use of the eikonal approximation, meaning that the partons are assumed to travel in straight lines through the medium. This is a good approximation for hard, balanced splittings. For soft and imbalanced splittings the produced partons can be kicked around by the medium, which is described mathematically by a path integral. We show how the full problem can be transformed into solving a set of coupled Schrödinger equations describing a set of mutually interacting color representations, with the aforementioned Wilson line correlators acting as the potential term. These results are relevant for high-pT jet processes, multi-gluon emissions in the QGP [4] and initial stage physics [5] at the LHC.

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Contributed Talks II / 31

Improving Bayesian parameter estimation with the latest RHIC and LHC data including a new initial conditions model

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The evolution of the strongly interacting medium is modelled with hydrodynamic models, which are driven by a large number of parameters quantifying the properties of the medium. The need to find model parameters which give the best description of the experimental data imposes a multidimensional optimization problem. The Bayesian analysis has shown to be very effective in constraining the parameter values[1], and the combined inclusion of LHC Pb-Pb 5.02 and 2.76 TeV data with additional flow observables has greatly narrowed down the uncertainties[2].

In this talk, we present our latest study in inferring the transport properties of QGP by an improved Bayesian analysis using the RHIC Au-Au collision data in addition to the previous studies[1,2] where only the LHC data were used. Additionally, the initial conditions are in our study now described with a dynamical initial conditions model called EKRT. With the addition of RHIC data and the change of initial conditions model we aim to get a better understanding of the initial conditions' and transport properties' dependence on the system's size and energy scale. Furthermore, we will quantify

the sensitivities of newly developed flow observables, Asymmetric Cumulants and Symmetry Plane Correlations[3] as well as the $\rho(v_n^2,\ [p_T])$ correlation to model parameters.

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Contributed Talks V / 32

Searches for baryon number violation via neutron conversions at the European Spallation Source

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The observation of neutrons converting to antineutrons and/or sterile neutrons would demonstrate Baryon Number Violation (BNV) for the first time. BNV is an essential condition needed to produce the matter/anti-matter asymmetry in the universe and appears in a number of theories beyond the Standard Model. The existence of sterile neutrons would address the issue of a possible dark sector of particles. The HIBEAM/NNBAR project is a proposed series of experiments for the European Spallation Source (ESS), in Lund, Sweden, that can open up a discovery window for BNV by observing free neutrons transforming to antineutrons and/or sterile neutrons. A series of competitive searches are planned with an ultimate improvement in sensitivity of three orders of magnitude compared with the previous free neutron to anti-neutron search at Institut Laue-Langevin. This talk describes the HIBEAM/NNBAR experiment. The motivation for the experiment and theories predicting neutron conversions are described, followed by a description of the ESS and those ESS facilities which can be exploited for the experiment. The set-ups and sensitivities of the neutron conversion searches are shown. Special focus is placed on the annihilation detector which would use a Time Projection Chamber and calorimeter system exploiting scintillators and lead-glass. Geant-based simulations of the annihilation signature within a detector are shown and compared with background predictions

Contributed Talks VII / 33

Radiation Hard 3D Silicon Pixel Sensors for use in the ATLAS Detector at the HL-LHC

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The High Luminosity LHC (HL-LHC) upgrade requires the planned Inner Tracker (ITk) of the ATLAS detector to tolerate extremely high radiation doses. Specifically, the innermost parts of the pixel system will have to withstand radiation fluences above $1 \times 10^{16}\ n_{eq}cm^{-2}$. Novel 3D silicon pixel sensors offer a superior radiation tolerance compared to conventional planar pixel sensors and are thus excellent candidates for the innermost parts of the ITk.

The University of Bergen (UiB) is actively collaborating with the Norwegian ATLAS project and has a research group which is also a part of the ITk project. At UiB, we are testing irradiated modules, and building a facility to perform Quality Assurance (QA) and Quality Control (QC) qualifications on production modules for installation in the ITk.

Results from the electrical characterisation of 3D pixel samples done at the testing facility at UiB will be shown. Sensors have also been mounted on the RD53A prototype readout chip. Test Beam

results are presented for unirradiated as well as heavily irradiated sensors. For particles passing at perpendicular incidence, it is shown that average efficiencies above 96% are reached for sensors exposed to fluences of $1 \times 10^{16}\ n_{eq} cm^{-2}$ when biased to 80 V.

The talk is on behalf of the Norwegian ITk group.

Contributed Talks II / 34

Challenges of flow harmonic analysis in LHC collisions from large to small systems

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One of the primary goals of heavy-ion physics is to understand the transport properties of the quark-gluon plasma (QGP), which is composed of the smallest constituents of matter, the quarks and gluons, and which filled up our universe a few microseconds after the Big Bang.
The present most challenging question in this research field is to pin down the critical point of the QGP, where the shear viscosity over entropy ratio is at its minimum. As of now, the QGP has the smallest observed value of η/s, close to the theoretical minimum of $1/4\pi$. Significant advances based on flow harmonic analysis have recently been made. There are, however, still a few remaining challenges in both experiment and theory to constrain the temperature dependence of η/s and ζ/s of the QGP. In this talk, I will highlight the latest results from LHC experiments in this regard and discuss aforementioned challenges.

Contributed Talks IV / 35

Using computer-vision inspired techniques for end-to-end event classification on ATLAS data

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The ATLAS detector is, in its most abstract form, a cylindrical camera. It captures the energy deposits left in the detector material from particles produced in high-energy particle collision events. Traditional methods of analysing this data rely on the reconstruction of the particle collision. This process transforms the high-dimensional, low-level data from the detector into lower-dimensional, high-level data. By treating the low-level energy deposit data as part of a panoramic (360 degrees) image, we aim to skip the reconstruction event and classify the event based on this "energy fingerprint"using machine learning algorithms specifically designed for image recognition.

Contributed Talks III / 36

Implementation of XGBoost for a SUSY tau analysis

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The application of machine learning has become popular in high energy physics within recent years. In addition to standard cut-based analyses, more and more effort is put to develop new strategies. One of a highly effective and widely recognised machine learning ensemble method are gradient boosted decision trees. This talk presents the current implementation of an optimized gradient boosting framework called XGBoost for binary and multiclass classification in a search for supersymmetry in events with large missing transverse momentum jets and at least one hadronically decaying tau lepton. In addition, neural networks will be introduced to compare both approaches.

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Search for squarks and gluinos using machine learning in tau-rich final states using Run2 and Run 3 data from the ATLAS detector

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New physics has proven quite elusive, hence more data and increasingly sophisticated techniques are required to probe it. With Run 3 of the LHC started and major developments in modern machine learning techniques, we face a very interesting new era of experimental physics. We aim to quantify the gain in sensitivity by using the highly effective XGBoost framework in searches for supersymmetry by gluino and squark production with a tau-rich signature at the LHC using Run 2 and developing Run 3 data. This approach will be a reference of the relative gain in sensitivity by utilizing machine learning methods in comparison to traditional methods, while in addition being used to set competitive bounds on squark/gluino production and constrain the parameter space of new physics.

Contributed Talks IV / 38

Search for beyond Standard Model Higgs resonances with a parametrised neural network in ATLAS

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Several beyond Standard Model theories predict the existence of heavy scalars which could decay into the Standard Model (SM) Higgs boson. This analysis focuses on the search for resonant heavy scalar X decaying to a lighter scalar S and the SM Higgs boson H in a final state with two photons and 2 b-jets. A neural network (NN), parametrised on the resonant X and S masses, is used to discriminate signal from background and a likelihood fit to the NN discriminant is performed to set expected upper limits to a wide range of X and S masses.

Contributed Talks III / 39

Robustness and interpretability of machine learning models applied to LHC data

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Modern machine learning (ML) methods are widely used in LHC analyses, but considerably more time is invested in training ML models, than in understanding them. We present a small review of interpretation and explanation techniques relevant to ML classifiers used in collider experiments, and motivate why they should be consulted. Further, we present ongoing work on the related topic that is robustness, meaning how the output of a classifier is affected by changes in the input data. Different types of distribution shifts in data may affect the classifier output in nontrivial ways, which calls for systematic studies of model behaviour. We discuss plans for developing model-agnostic methods to quantise robustness under different types of perturbations in data.

Contributed Talks III / 40

Use Artificial Intelligence to pinpoint Dark Matter at the LHC

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Høgskulen på Vestlandet (HVL) has over the last couple of years built up a strong group working on machine learning (ML) for data analysis in collider experiments.

With the project "Use Artificial Intelligence to pinpoint Dark Matter at the LHC", financed by the Research Council of Norway, we focus on dark matter searches in the tau lepton sector of the LHC phase space in ATLAS data analyses. This talk will present the overall aim of the project, methods, approaches and challenges we face when applying machine learning in BSM searches and event classification.

The lack of new discoveries over the past decade motivates the use of ML methods to increase search sensitivity, which can be done in different ways. We aim to approach the task from two different angles –one following a traditional ML-based analysis, and one that reformulates the data into a computer vision task. The details will be covered in separate presentations, but we take a look at the benefits and disadvantages and discuss open problems in both approaches. Although ML-based analysis is by now well established, there is still a troublesome lack of consensus on certain points in strategy and implementation, which we wish to both highlight and offer solutions to.

Invited Talks I: Heavy Ion Physics / 41

The theory roadmap in heavy-ion physics

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Invited Talks I: Heavy Ion Physics / 42

Overview of experimental results in heavy Ion physics

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Invited talks II: Multimessenger landscape / 43

Theory and interpretation of multimessenger physics

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Highly relativistic nuclei, known as cosmic rays, bombard the Earth every second. These particles reach energies that go well beyond the ones that can be produced here at Earth, i.e. reaching up to 10ˆ20˜eV in the lab. In this talk, the state of the art of what we can learn from the interaction of these highest-energy particles will be reviewed. The first part of the talk will focus on what information about the cross section we can extract from hadronic interactions in the Earth atmosphere. The second part of the talk will go into the interpretation of the combination of cosmic-ray, neutrino, photon, and gravitational wave data of the Universe, and how these combined signatures help us learn about the origin of cosmic-rays.

Invited talks II: Multimessenger landscape / 44

Overview of experimental and observational aspects of multi-messenger astronomy

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Multi-messenger astronomy combines astronomical measurements of photons, neutrinos, and gravitational waves. I will introduce this field and will review its main breakthroughs. I will then discuss future prospects and highlight important planned future observatories, which promise exciting science.

Invited Talks III: Neutrino physics / 45

Current topics in neutrino physics theory

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Neutrino masses and mixing are a direct evidence that the standard model of elementary particles is incomplete. Furthermore, neutrinos are different from other fermions since, first, their masses are many orders of magnitude smaller in comparison, and second, their mixing angles are significantly larger in comparison to the mixing of the quarks. This brings significant challenge in creating the underlying theory that can successfully explain neutrino masses along with other observations. Two of the other observational evidences for beyond standard model physics are the observed dark matter density and the baryon asymmetry of the universe. A consistent theory to explain all three simultaneously. Such a theory generally will also predict other new physics features in the neutrino sector which could be observed in future experiments. We will outline the status of neutrino masses and mixing and look briefly at what the future holds for neutrino oscillation phenomenology. We

will then discuss some models for neutrino masses and mixing and how they can be connected to dark matter and baryogengesis via leptogenesis.

Invited Talks III: Neutrino physics / 46

Experimental neutrino physics: latest results and a glimpse to future

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The precision era of neutrino physics has started in 2012 with the first measurement of the size of theta_13. Since then, we have witnessed major advances nearly every year. In this talk, I will review the most impressive achievements gathered in the last two years through a wealth of high-precision experiments. These experiments are based on artificial (accelerator and reactor neutrinos) and natural sources (solar and atmospheric neutrinos), and they are key to pinning down the lepton Yukawa sector of the Standard Model. I will discuss measurements of the most critical unknown parameters of this sector (CP violation, mass-ordering, and the octant of theta_23) and the experiments that will address them soon. The only parameters that cannot be accessed by neutrino oscillations are currently investigated by absolute mass measurements, observational cosmology, and neutrinoless double beta decay. I will review advances in this field and discuss the opportunity to test the Majorana nature of neutrinos in the decade to come.

Invited talks IV / 47

Probing fundamental physics with gravitational waves

One of the most remarkable possibilities of General Relativity concerns gravitational collapse to black holes, leaving behind a geometry with light rings, ergoregions and horizons. These peculiarities are responsible for uniqueness properties and energy extraction mechanisms that turn black holes into ideal laboratories of strong gravity, of particle physics (yes!) and of possible quantum-gravity effects. The latest progress in testing strong-field gravity, and of using black holes as particle detectors will be discussed.

Invited talks IV / 48

New developments in machine learning in particle physics

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As datasets in particle physics get progressively larger, algorithms to swiftly and accurately process this data have become increasingly complex. Machine Learning (ML) has emerged as a solution to tackle several of the challenges experiments face: to efficiently select and reconstruct interesting observational data, to enhance sensitivity to increasingly rare processes and to efficiently generate accurate simulations of complex physical systems.

In this talk, I will give an overview of how ML is becoming an integral part of how we do particle physics research; from contributing to the discovery of the Higgs boson in 2012, to helping experiments at the future High Luminosity LHC process an amount of data comparable to 5% of the total internet traffic. We will especially focus on the role of Deep Learning in tackling future computational challenges in high energy physics.

Invited talks V / 49

Primordial Gravitational Waves, Higgs, Phase Transitions

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In many extensions of the Standard Model, the electroweak transition is first order - in some cases, strongly so. The ensuing phase transition would result in collisions of bubbles of the new Higgs phase. These collisions, and the associated interactions of sound waves in the plasma, are substantial sources of gravitational waves. For a phase transition at or around the electroweak scale, these gravitational waves may be detectable by future missions such as LISA. They can indirectly provide a probe of particle physics beyond the Standard Model, complementary to future colliders.

However, concrete predictions of the resulting gravitational waves will require good understanding both of the particle physics models themselves, as well as the non-equilibrium physics of the transition. In other words, we need accurate studies of the phase diagrams in the underlying particle physics theories, as well as good predictions of the expected gravitational wave signal from simulations. These feed into one another, forming a so-called 'pipeline'.

The stronger the phase transition, the better the chance of being detected (or constrained) by future missions like LISA. However, strong transitions are also the most poorly understood. In this talk I will discuss some recent results from different points along the 'pipeline', with a focus on the consequences for strong first-order phase transitions.

Invited talks V / 50

Overview of experimental results in the Higgs sector: precision, BSM and diHiggs

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The 2012 discovery of the Higgs boson by the ATLAS and CMS experiments at CERN's Large Hadron Collider (LHC) marked the completion of the Standard Model (SM). Since then the experiments have collected more than ten times the amount of data, which are being used to carefully map the properties of the Higgs boson and to search for additional scalars. Looking ahead, one of the main goals of the high-luminosity upgrade of the LHC will be to measure the Higgs boson self-couping which will shed light on the shape of the Higgs potential. Given the unique role that the Higgs boson plays in the SM, it is linked to many fundamental questions such as the vacuum stability and the matter-antimatter asymmetry. This talk will summarize what the LHC has taught us about the Higgs boson over the past ten years and what measurements and searches lie ahead at current and possible future colliders.

Invited talks VI / 51

Effective theories in the Higgs sector

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A general and conceptual introduction to effective field theories (EFT) is given and applied to EFT extensions of the Standard Model. The focus of the talk is on on the Higgs sector and examples of recent LHC experimental constraints from single and di-Higgs production are discussed. To be exploited to its full power EFTs requires complex analysis techniques involving multiple measurements, and the implementations of these are currently under very active development.

Invited talks VI / 52

Beyond-SM Higgs at the LHC

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An extended Higgs sector, with a structure richer than the single Higgs doublet field of the Standard Model (SM), could solve many shortcomings of the SM. Experimentally, it could manifest as production of additional, beyond-SM scalar bosons at the LHC, as well as deviations from SM predictions for the SM-like 125 GeV Higgs boson. In this talk, a selection of recent experimental results from the LHC experiments is presented, showcasing various extended Higgs sector models, their experimental signatures, and constraints from the LHC data. Novel experimental methods that allow unprecedented reach for these analyses are highlighted. Implications for future beyond-SM Higgs searches are discussed.

Invited talks VII / 53

Theoretical frameworks for dark matter and the dark sector

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A selection of "theoretical frameworks" that are currently used in the analysis of dark matter (DM) search experiments is presented. These frameworks are divided into two classes: those extending the Standard Model (SM) by a DM candidate only, and those extending the SM by a new particle mediator in addition to a DM candidate ("dark sectors"). For each framework, examples are provided for how it can be used in the interpretation of experimental data. Doing so, the emphasis is placed on the interdisciplinary input from, e.g., particle, nuclear and solid state physics that the use of each framework explicitly requires.

Invited talks VII / 54

Direct search for Dark Matter

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Dark matter makes up 80% of the total matter content in the universe, but has so far only been observed through its gravitational pull on ordinary matter. Direct detection experiments aim to discover dark matter interacting with their detector, and these detectors have provided rapidly improving sensitivity to the popular WIMP dark matter model. This talk gives an overview of the concepts and techniques used in direct detection experiments, some recent experimental results and some prospects for further searches.

Invited talks VIII / 55

Future experimental programs in HEP and the ECFA detector R&D roadmap

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In 2020, after a wide consultation of the community, the update of the European Strategy outlined an ambitious and visionary scientific program for HEP. It considers, over decades, a global experimental endeavour to discover and study phenomena beyond the predictions of the Standard Model; in direct or indirect searches, at accelerators, nuclear reactors or cosmic ray facilities. In this context, ECFA developed two roadmaps for a realistic planning of the accelerator and detector R&D that should ensure the success of these programs. The presentation provides an overview of the instrumentation challenges. It highlights technical innovations that can pave the path toward timely delivered detectors of unprecedented performance.

Contributed Talks II / 56

Search for the Chiral Magnetic Wave in Heavy-ion Collisions

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The interplay of the chiral anomaly and the strong magnetic field ($\sim 10^{15}$ T) created in heavy-ion collisions could give rise to a collective excitation in the quark–gluon plasma called the Chiral Magnetic Wave (CMW). This effect can be experimentally sought by the charge asymmetry (A_{ch}) dependence of elliptic flow v_2. However, non-CMW mechanisms such as local charge conservation (LCC) coupled with collective flow can also lead to a similar dependence of v_2 on A_{ch}. The triangular flow (v_3) measurement serves as a reference as it is not expected to be affected by the CMW. The v_2 and v_3 of charged hadrons as a function of A_{ch} measured in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 2.76 and 5.02 TeV are presented. In addition, the event-shape engineering (ESE) technique is adopted for the first time to quantitatively disentangle the CMW signal and the LCC background. The results indicate that the background effects dominate the CMW measurements.

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A multimessenger view on the high-energy Universe

Author: Julia Tjus[None]

Highly relativistic nuclei, known as cosmic rays, bombard the Earth every second. These particles reach energies that go well beyond the ones that can be produced here at Earth, i.e. reaching up to 10^{20}~eV in the lab. In this talk, the state of the art of what we can learn from the interaction of these highest-energy particles will be reviewed. The first part of the talk will focus on what information about the cross section we can extract from hadronic interactions in the Earth atmosphere. The second part of the talk will go into the interpretation of the combination of cosmic-ray, neutrino, photon, and gravitational wave data of the Universe, and how these combined signatures help us learn about the origin of cosmic-rays.

Contributed Talks VII / 58

Conference summary & Close out