4th Forward Physics Facility Meeting

Monday, 31 January 2022 - Tuesday, 1 February 2022

Book of Abstracts

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Excess of Tau events at SND@LHC, FASERν and FASERν2

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During the run III of the LHC, the forward experiments FASERν and SND@LHC will be able to detect the Charged Current (CC) interactions of the high energy neutrinos of all three flavors produced at the ATLAS Interaction Point (IP). This opportunity may unravel mysteries of the third generation leptons. We build three models that can lead to a tau excess at these detectors through the following Lepton Flavor Violating (LFV) beyond Standard Model (SM) processes: (1) $\pi^+ \to \mu^+ \nu_\tau$; (2) $\pi^+ \to \mu^+ \bar{\nu}_\tau$ and (3) $\nu_e + \text{nucleus} \to \tau + X$. We comment on the possibility of solving the $(g-2)_\mu$ anomaly and the τ decay anomalies within these models. We study the potential of the forward experiments to discover the τ excess or to constrain these models in case of no excess. We then compare the reach of the forward experiments with that of the previous as well as next generation experiments such as DUNE. We also discuss how the upgrade of FASERν can distinguish between these models by studying the energy spectrum of the tau.

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Dark matter freeze-in from semi-production

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We study a novel dark matter production mechanism based on the freeze-in through semi-production, i.e. the inverse semi-annihilation processes. A peculiar feature of this scenario is that the production rate is suppressed by a small initial abundance of dark matter and consequently creating the observed abundance requires much larger coupling values than for the usual freeze-in. We provide a concrete example model exhibiting such production mechanism and study it in detail, extending the standard formalism to include the evolution of dark matter temperature alongside its number density and discuss the importance of this improved treatment. Finally, we confront the relic density constraint with the limits and prospects for the dark matter indirect detection searches. We show that, even if it was never in full thermal equilibrium in the early Universe, dark matter could, nevertheless, have strong enough present-day annihilation cross section to lead to observable signals.

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Searching for rich dark sectors in the FPF through secondary production and in indirect dark matter searches

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Light new physics has become a particularly active research direction, in particular with the proposed dedicated Forward Physics Facility at CERN, as well as with the upcoming FASER detector measurements. In the talk, we will describe how the small lifetime regime of light long-lived particles in the non-minimal BSM scenarios based on renormalizable portals can be covered in the FPF using the secondary particle production. Additionally, we will describe prospects of indirect detection (ID) of long-lived particles in a model employing heavy thermal DM particle, LLP and a light mediator. The resulting non-local ID effects distinguish such a scenario from ordinary searches for WIMPs, while complementary FPF searches for the light mediator will allow us to explore even such an extended scenario.

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TeV neutrino cross sections

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There are no neutrino cross-section measurements from 400 GeV to 10 TeV. Nevertheless, experiments like FASERnu estimate interaction rates that will allow us to measure the cross section in this unexplored region. Neutrinos with energies above a few hundred GeV will primarily interact via Deep Inelastic Scattering. We compare different model predictions in this energy range.

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Searching for Light Dark Matter at the Forward Physics Facility

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Light sub-GeV dark matter and dark sector particles can be copiously produced in the far forward direction at the LHC. The proposed FLArE, FASERnu2, and FASER2 experiments, housed in the Forward Physics Facility, can be sensitive to a variety of dark matter scattering and other associated

dark sector signatures during the HL-LHC era. This talk will provide an overview of this possibility, including a review of the light dark matter models of interest, the various dark sector signatures, the potential Standard Model backgrounds and mitigation strategies, and the anticipated experimental reach.

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4-fermion operators and their UV completion at FASERv

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The high-luminosity of neutrinos at FASERv and FASERv2 makes them excellent facilities for neutrino studies. In this talk, after briefly reviewing very interesting physics from the 4-fermion operators, I will then present sensitivities to them at FASERv and FASERv2 model independently in the EFT framework. Time permitting, the corresponding implications on specific phenomenologically interesting UV models will also be discussed.

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Decays (and Production) of Light Vectors

Author: Peter Reimitz[None]

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We provide a robust calculation of hadronic decays of light vector particles ($m < 2$ GeV) into an extensive set of final state configurations of mesons and baryons. We improve currently considered mesonic decay channels as included in DarkCast, and complement them by a large list of additional channels, especially in the range of excited ρ, ω, and ϕ states above $m > 1$ GeV. We show the effect on the branching ratios and lifetime of the vector particles and in which way this affects current limits and future sensitivities. Our results help extending experimental searches to hadronic signatures. While our calculations can be used for arbitrary vector mediator models with couplings to quarks, we focus on models that couple to baryon number as for example the B model, or anomaly-free models like $B - L$ or $B - 3L_i$ models. We provide the results in a python package called DeLiVeR. I will also comment on possible additional production mechanisms for vector particles.

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Bremming Enhanced ALP Productions and FPF Sensisivity

Authors: Kunfeng Lyu[1]; Zhen Liu[None]

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The searches of axion-like particles (ALP) are strongly motivated by the general dark sector, strong CP problem and axiom quality problem etc. We focus on the gluonic coupling to ALP which is relevant to the strong CP puzzle and is of great importance. We propose the axion as the bremsstrahlung radiation off the proton in the typical proton-proton collision which has not been incorporated in the previous studies. The splitting function is calculated for the axion emitted off the proton and then convoluted with the proton-proton non-single diffractive cross section. Due to the large scattering cross section of the proton-proton collision we may observe the axion decay signals in the FPF detectors. The inclusion of the bremsstrahlung production process significantly extends the FPF coverage for ALP in a broadclass of models.

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Dark states with electromagnetic form factors at FLArE

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Similar to millichagred particles, dark states with electromagnetic form factors can be probed at FLArE by scattering signals with SM particles in the detector. I will discuss details of production channels and the detection mechanism. Finally, I will present the projected sensitivity of FLArE.

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BDSIM Studies

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FLArE

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Long-Lived Particles

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Dark Matter

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Milli-Charged Particles

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Overview of QCD Activities for the FPF Whitepaper

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BFKL effects in Forward D-meson Production

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Neutrino Data in Proton and Nuclear Global PDF Fits

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High-Energy QCD via an FPF+ATLAS Tight Timing Coincidence

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Neutrino Fluxes and Cross Sections

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Neutrino Event Generators

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BSM Physics with Neutrinos

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Parton distribution function uncertainties in theoretical predictions for far-forward tau neutrino fluxes at the Large Hadron Collider

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Far-forward tau neutrinos and antineutrinos come predominantly from Ds± production in pp collisions, followed by the leptonic decay of these mesons. At such large pseudorapidities, theoretical predictions rely on parton distribution functions (PDFs) in a combination of very small and large parton–x values. We evaluate the 3-flavor PROSA PDF uncertainties in a next-to-leading order (NLO) QCD calculation of the flux of tau neutrinos plus antineutrinos. The scale uncertainties are much larger than the PROSA PDF uncertainties in general. The predictions with the central PDFs from other 3-flavor NLO PDF sets, i.e., the CT14, ABMP16 and NNPDF3.1 PDF sets are also shown. The Forward Physics Facility in the high luminosity LHC era will provide data capable of constraining NLO QCD evaluations with these PDF sets.

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Oscillations and sterile neutrinos

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Sterile neutrinos are hypothetical massive neutral leptons, which mix with the neutrinos of the Standard Model, and which are singlets of the SM gauge symmetry. Therefore their mass term can be included directly in the Lagrangian, assuming they are Majorana fermions. They are motivated by their potential to explain the origin of dark matter, light neutrino masses and oscillations, and baryonic asymmetry of the universe (leptogenesis). The mass and mixing of a sterile neutrino to active flavours are free parameters which can be probed in the Forward Physics Facility on very large mass window, improving the current experimental bounds significantly. My envisioned contribution

to the BSM physics section of FPF whitepaper consists of a short summary of the seesaw mechanism (the most common way of light neutrino mass generation), active-to-sterile neutrino mixing, present experimental bounds on sterile neutrino mixing for sterile neutrino mass on MeV and GeV scale, and the prospects of FPF improved bounds.

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Searching for dark photons at the FPF

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In the search for new physics, the dark photon is one of the most studied targets. It is often invoked as a mediator connecting the SM to a secluded dark sector charged under a novel dark $U(1)_X$ symmetry. However, beyond the minimal secluded dark photon model there is a myriad of anomaly-free U(1) extensions of the SM, which originate from gauging combinations the accidental global flavour symmetries of the SM. In this talk I want to review some of the most prominent examples of these minimal U(1) extensions and discuss their phenomenology, as well as the potential to search for them at the future Forward Physics Facility.

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Resonant anti-neutrino electron scattering at the FPF

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We discuss detection prospects for Standard Model resonances at FASERν and FLArE. The primary channel of interest is the production of ρ^- resonances which yield two-pion final states, $\pi^-\pi^0$, with no additional hadronic activity and no leptons in the final state. We conclude that FASERν (and especially FASERν-2) have the best detection prospects due to their nuclear emulsion detector technology.

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Radiative Decay of sub-GeV Supersymmetric Neutralinos from Light Mesons

Authors: Dominik Köhler[None]; Herbi Dreiner[None]; Saurabh Nangia[None]; Zeren Simon Wang[None]

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In certain supersymmetric scenarios, no existing mass bounds apply to the lightest neutralino. In the case of broken R-parity, such very-light neutralinos —produced via rare decays of mesons — may decay radiatively over macroscopic timescales leading to a single boosted-photon signature in the far-forward region at the LHC. We consider various R-parity Violating Supersymmetry (RPV-SUSY) scenarios involving a sub-GeV neutralino, and show that a search for such a signal at FASER

and FASER2 allows us to probe RPV couplings to values beyond current constraints by orders of magnitude.

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Neutrino cross sections in the SIS-DIS transition region

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Neutrino experiments of the FPF will be able to measure different types of neutrino interactions due to its broad energy range. In this talk, we discuss neutrino cross sections in the transition region between the shallow- and deep- inelastic scattering focusing on the impact of W_{min} and Q^2.

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An explanation of the muon puzzle of ultrahigh-energy cosmic rays and the role of the Forward Physics Facility for model improvement

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We investigate the observed muon deficit in air-shower simulations when compared to ultrahigh-energy cosmic ray (UHECR) data. We assume that the enhancement of strangeness production in high-energy hadronic collisions reported by the ALICE Collaboration is the keystone to resolve the muon anomaly and study the concomitant $\pi \leftrightarrow K$ swap impact on the shower development. We construct a toy model in terms of the $\pi \leftrightarrow K$ swapping probability F_s. We present a parametrization of F_s in terms of the pseudorapidity that can accommodate the UHECR data. Looking to the future, we explore potential strategies for model improvement using the massive amounts of data to be collected at the Forward Physics Facility (FPF). We calculate the FPF sensitivity to F_s and show that FASERν2 will be able to probe the model phase space.

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Cosmic ray physics and the muon puzzle

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Cosmic ray hadronic interaction models

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Atmospheric neutrino flux and prompt neutrinos

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The Muon Puzzle in Cosmic Ray Physics

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Freeze-in sterile neutrino dark matter in a class of U$(1)'$ models with inverse seesaw

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We consider a general, anomaly free U$(1)'$ extension of the Standard Model (SM) where the neutrino mass is generated at tree level from the inverse seesaw mechanism.
After U$(1)'$ symmetry breaking the mass of a neutral beyond the SM (BSM) gauge boson (Z') is originated which can be produced it at high energy colliders.
The model contains three generations of heavy neutrinos which can interact with Z' and could be produced in pair at colliders.
A trilepton signature is very unique and clean when such pair production occurs at electron positron colliders from a TeV scale Z'.
In this model we assign one pair of the degenerate sterile neutrinos as Dark Matter (DM) candidate whose relic density is generated by freeze-in mechanism. To reproduce the correct relic abundance we consider different mass regimes of the DM candidate and the Z'. The production of DM can occur at different reheating temperatures in various scenarios depending on Z' and DM masses. Additionally, if the DM mass is greater than 1 MeV and Z' is heavier than DM, the DM may decay into positron explaining the galactic 511 keV line in the Milky Way observed by the INTEGRAL satellite.

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Tuning Pythia for Forward Physics

Authors: Max Fieg[None]; Felix Kling[1]; Holger Schulz[2]; Torbjorn Sjostrand[None]

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The event generator, Pythia, has been invaluable in making predictions at colliders like the LHC. However, Pythia was tuned with central (η<5) measurements, and so it should not be expected to reproduce forward physics data, such as what the LHCf collaboration has obtained (η>10). If new physics is to be probed at the proposed FPF, one must sufficiently understand the incoming shower of standard model particles. Here, I will discuss an ongoing effort to tune Pythia for the FPF.

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Synergies Between the FPF and Neutrino Observatories

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Details will follow.

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The effect of forward charm production modelling on prompt neutrino flux estimates

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Hunting Inflaton at FASER

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We consider the nonminimal quartic inflation in a classically conformal $U(1)_X$ extended SM. We show that if the inflaton mass and its mixing angle with the SM Higgs field lie in a suitable range, the FASER experiment can search for the inflaton at the High Luminosity (HL)-LHC. Also because of the classical conformal invariance, the inflationary predictions and the LHC search for the $U(1)_X$ gauge boson (Z') resonance are complementary. Therefore, three independent experiments, namely, the inflaton search at the FASER, the Z' boson resonance search at the HL-LHC and the precision measurement of the inflationary predictions, are complementary to test our inflation scenario.