Forward Physics Facility - Kickoff Meeting

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QCD and Neutrinos / 25

Probing Light Gauge Bosons with Tau Neutrino Experiments

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The tau neutrino is probably the least studied particle in the SM, with only a handful of interaction events being identified so far. This can in part be attributed to their small production rate in the SM, which occurs mainly through D_s meson decay. However, this also makes the tau neutrino flux measurement an interesting laboratory for additional new physics production modes. In this study, we investigate the possibility of tau neutrino production in the decay of light vector bosons. We consider four scenarios of anomaly-free U(1) gauge groups corresponding to the B-L, B-L_mu-2L_tau, B-L_e-2L_tau and B-3L_tau numbers, analyze current constraints on their parameter spaces and explore the sensitivity of DONuT and as well as the future emulsion detector experiments FASERnu, SND@LHC an SND@SHiP. We find that these experiments provide the leading direct constraints in parts of the parameter space, especially when the vector boson's mass is close to the mass of the omega meson.

Long-Lived Particles / 27

Long-lived Sterile Neutrinos at the LHC in Effective Field Theory

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We study the prospects of a displaced-vertex search of sterile neutrinos at the Large Hadron Collider (LHC) in the framework of the neutrino-extended Standard Model Effective Field Theory. The production and decay of sterile neutrinos can proceed via the standard active-sterile neutrino mixing in the weak current, as well as via higher-dimensional operators arising from potentially new, decoupled physics. We study scenarios where sterile neutrinos are predominantly produced via rare charm and bottom mesons decays at LHC experiments. If sterile neutrinos are long-lived, their decay can lead to displaced vertices which can be reconstructed. We investigate the search sensitivities for the ATLAS/CMS detector, the future far-detector experiments: AL3X, ANUBIS, CODEX-b, FASER, MATHUSLA, and MoEDAL-MAPP, and at the proposed fixed-target experiment SHiP. We focus on HNL production and decay from dimension-six operators involving quarks in the νSMEFT Lagrangian and perform simulations to determine the potential reach of high-luminosity LHC experiments in probing these EFT operators.

Long-Lived Particles / **28**

Long Lived Light Supersymmetric Neutralinos

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We have investigated the search sensitivity to long lived light neutralinos, with masses below a few GeV down to 10s of MeV, at various forward detectors. The can be produced at the LHC via rare decays of standard mesons or via rare Z-boson decays. The neutralinos decay to a lighter meson plus a charged lepton, which can be observed. We have studied a large set of proposed experiments: ANUBIS; AL3X; CODEX-b; Faser1,2; MATHUSLA, MOEDAL-MAPP1,2; SHiP; but also ATLAS.

Dark Sectors and Cosmology / **29**

FORMOSA & Forward-DUNE - Looking Forward to Millicharged Dark Sectors and New Neutrino Physics

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We identify potentially the world's most sensitive location to search for millicharged particles in the 10 MeV to 100 GeV mass range: the forward region at the LHC. We propose constructing a scintillator-based experiment, FORward MicrOcharge SeArch (FORMOSA) in this location, and estimate the corresponding sensitivity projection. We show that FORMOSA can discover millicharged particles in a large and unexplored parameter space, and study strongly interacting dark matter that cannot be detected by ground-based direct-detection experiments. The newly proposed LHC Forward Physics Facility (FPF) provides an ideal structure to host the full FORMOSA experiment.
This talk is based on arXiv:2010.07941 & arXiv:1812.03998.
I will also discuss the new idea of studying neutrino physics at FPF with the newly proposed Forward-DUNE experiment.

Long-Lived Particles / **30**

Opportunities for probing $U(1)_{T3R}$ with light mediators

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We consider strategies for using new datasets to probe scenarios in which light right-handed SM fermions couple to a new gauge group, $U(1)_{T3R}$. This scenario provides a natural explanation for the light flavor sector scale, and a motivation for sub-GeV dark matter. There is parameter space which is currently allowed, but we find that much of it can be probed with future experiments. In particular, experiments which search for displaced visible decay or invisible decay, cosmological and astrophysical observations, neutrino experiments can all play a role. Still, there is a small region of parameter space which even these upcoming experiments will not be able to probe.

Dark Sectors and Cosmology / **31**

Looking for light new particles with secondary production in the far-forward region of the LHC

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One of the primary aims of the Forward Physics Facility (FPF) would be to search for highly-displaced decays of light and long-lived particles (LLPs) produced in proton-proton collisions at the LHC. These searches are, however, limited to new particles with decay lengths similar to or larger than the baseline of the FPF. We will discuss how this basic constraint can be overcome in models that go beyond the simplest BSM scenarios thanks to a possible secondary production of LLPs right in front of the detector. A similar mechanism would allow one to treat the FPF as a high-energy neutrino beam-dump experiment to probe BSM couplings of the SM neutrinos.

Dark Sectors and Cosmology / **32**

Light Dark Matter at the Forward Physics Facility

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Light sub-GeV dark matter particles interacting through a kinetically mixed dark photon may be copiously produced in the far-forward region at the LHC. These dark matter particles may then be detected through their scattering off electrons. We show that thousands of scattering events may be detected in the HL-LHC era by a 10-ton emulsion detector placed on the beam collision axis 500 m from the ATLAS interaction point in the proposed Forward Physics Facility. We consider the leading backgrounds from neutrino-electron scattering, neutrino quasi-elastic scattering, charged current deep inelastic scattering, and muon-induced photon pair production. With an upstream magnet to mitigate low-energy muons and optimized cuts on the electron energy and direction, we find that such an emulsion detector can probe the entire thermal relic region for masses mA' between 10 and 100 MeV.

QCD and Neutrinos / **33**

Discovery potential of FASERnu with contained vertex and through-going events

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The FASERν detector is a newly proposed detector whose main mission is to detect neutrino flux from the collision of the proton beams at the ATLAS Interaction Point (IP) during run III of the LHC in 2021-2023. We show that this detector can also test certain beyond standard model scenarios, especially the ones in which the neutrino interaction with matter fields can produce new unstable particles decaying back into charged leptons. Such scenarios are also motivated by the MiniBooNE anomaly. The detector will be located 480 m away from the interaction point such that neutrinos have to cross 10 meters of concrete and 90 meters of soil before reaching the detector. We show that if the new physics involves multi-muon production by neutrinos scattering off matter fields, including the neutrino flux interactions in the rock before the detector in the analysis ({\it i.e.,} accounting for the through-going muon pairs) can significantly increase the effective mass of the detector to search for new physics. We develop a model that can give rise to such multi-muon signal.

QCD and Neutrinos / **34**

QCD measurements at the LHC to solve the Muon Puzzle in cosmic ray showers

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Long-Lived Particles / **35**

Search for sterile neutrino with light gauge interactions: recasting collider, beam-dump, and neutrino telescope searches

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We investigate features of the sterile neutrinos in the presence of a light gauge boson X that couples to the neutrino sector. The novel bounds on the active-sterile neutrino mixings $|U_{\ell 4}|^2$, especially for muon and tau flavors ($l = \mu, \tau$), from various collider and fixed target experiments in intensity frontiers are explored. Also, taking into account the additional decay channel of the sterile neutrino into a light gauge boson ($\nu_4 \to \nu_\ell e^+ e^-$), we explore and constrain a parameter space for low energy excess in neutrino oscillation experiments.

QCD and Neutrinos / **36**

High-energy muons at the Forward Physics Facility

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Muons produced at the LHC are the only Standard Model species besides neutrinos that can reach in large numbers the Forward Physics Facility. A combination of their typical high energy and very precise experimental tools to study their flux and interactions will open up a possibility for new exciting searches in this unique low-background environment. In the talk, we will mention a few such opportunities that could initiate further discussions about a possible far-forward muon-physics program at the LHC.

QCD and Neutrinos / **37**

Neutral Current Neutrino Interactions at FASERnu

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Charged current neutrino interactions have been extensively studied in the context of various experiments, including FASERν. The presence of a charged lepton in the final state allows for easy identification of candidate signal events and incoming beam energy reconstruction. Neutral current neutrino interaction on the other hand have a neutrino in the final state. This imposes two challenges: a) differentiating signal from background, which is primarily neutral hadron induced in FASERν and b) reconstructing incoming beam energy when the final state has missing energy. In this work we propose to use machine learning tools to identify and reconstruct signal events. We show how a suitable choice of event observables and proper training of the neural network can allow us to constrain NC neutrino cross-section in the 100GeV - a few TeV range. We convert this cross-section sensitivity to limits on neutrino NSI.

Long-Lived Particles / **38**

Dark Photon from Light Scalar Boson Decays at FASER

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FASER is one of the promising experiments which search for long-lived particles in beyond standard models.
In this paper, we focus on dark photon associating with an additional U(1) gauge symmetry, and also a scalar boson
breaking this U(1) gauge symmetry.
We study the sensitivity to the dark photon originated from U(1)-breaking scalar decays.
We find that sizable number of the dark photon signatures can be expected
in wider parameter space
than previous studies.

Long-Lived Particles / **39**

Pinning down the Flavour Structure of Hidden Photons

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Extensions of the Standard Model with an abelian gauge group are constrained by gauge anomaly cancellation, fermion masses and mixing angles. These constraints only allow for a limited number of $U(1)_X$ groups. We categorise these extensions and determine the allowed textures of Yukawa and Majorana mass matrices. If neutrinos are Dirac, the only possible choice satisfying all conditions is the $U(1)_{B-L}$ group, whereas all other $U(1)_X$ extensions require Majorana masses. This generically results in flavour changing couplings of the X gauge boson to neutrinos. In the future, FASERν 2 could play a crucial role in constraining these groups from searching for deviations of the flavour composition of the incoming neutrino flux from the SM prediction.

Dark Sectors and Cosmology / **40**

Collider signatures of minimal freeze in models

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We propose simple freeze-in models where the observed dark matter abundance is explained via the decay of an electrically charged and/or coloured parent particle into Feebly Interacting Massive Particles (FIMP). The parent particle is long-lived and yields a wide variety of LHC signatures depending on its lifetime and quantum numbers. We assess the current constraints and future high luminosity reach of these scenarios at the LHC from searches for heavy stable charged particles, disappearing tracks, displaced vertices and displaced leptons. We show that the LHC constitutes a powerful probe of freeze-in dark matter and can further provide interesting insights on the validity of vanilla baryogenesis and leptogenesis scenarios. We also discuss how future experiments like FASER and Mathusla can probe these models.

Long-Lived Particles / **41**

Probe Light Scalars in 2HDMs at FASER

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Two Higgs Doublet Model (2HDM) offers a prototype for models with an extended Higgs sector beyond that of the Standard Model. It provides a rich spectrum of scalars, some of them can be relatively light with relatively weak couplings. Complementary to the usual searches for extra scalars at high energy colliders, FASER offers a unique opportunity to study those relatively long lived light scalars. Given all the existing theoretical and experimental constraints, we consider the light CP-even and CP-odd scalars in the four different types of 2HDMs, and examine the parameter window which can be probed at FASER.

QCD and Neutrinos / **42**

Tau neutrino oscillations in the far forward rapidities

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In the very forward region of the LHC, a number of tau neutrinos can be produced mostly from the $D_s^{\pm}$ decay. For an integrated luminosity of 3000 fb^{-1} at the HL-LHC, thousands of charged current tau neutrino events are expected in a detector of m^3 size. It will allow the study of the mixing between sterile neutrinos and tau neutrinos with the fact that the possible specifics of the experiments at the Forward Physics Facility would be insensitive to oscillation between the standard model neutrinos. We will present a case-study of tau neutrino oscillations considering a 3+1 neutrino model with three active neutrinos and a sterile neutrino with a testable parameter set and discuss the potential and challenges for its investigation.

Dark Sectors and Cosmology / **43**

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.

Dark Sectors and Cosmology / **44**

Freeze-in Dark Matter in U(1) extended Standard Model and Lifetime Frontier Experiments

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In the context of a well-motivated gauged U(1) extension of the Standard Model, we introduce a non-thermal dark matter whose interaction is too weak to allow it to be in thermal equilibrium

with the Standard Model particles, and its relic density is determined by the freeze-in mechanism through a light mediator that is the extra U(1) gauge boson. We discuss a complementarity between the cosmological constraint on this dark matter physics and the planned/proposed Lifetime Frontier experiments to search for a long-lived particle.

QCD and Neutrinos / 45

DsTau (NA65) Experiment at CERN-SPS

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Tau neutrino is the least known particle of the Standard Model, first discovered by DONUT experiment in 2001. In DONUT, using tau neutrino interaction cross section was measured with large systematical (~50%) and statistical (~30%) errors. The main source of systematical error is due to a poor knowledge of the tau neutrino flux from Ds decays. The DsTau experiment at CERN-SPS has been proposed to measure an inclusive differential cross-section of a ⊠ production with a consecutive decay to tau lepton in p-A interactions. The goal of experiment is to reduce the systematic uncertainty from 50% to 10%. The accurate measurement of the cross-section is not only important for future neutrino experiments but also for testing the Lepton Flavour Universality (LFU) of Standard Model. In addition to the tau neutrino production study, DsTau can also study charmed particle production in proton interactions. About 10^5 charm events are expected to be detected in DsTau. The detector is based on nuclear emulsion providing a sub-micron resolution for the detection of short length and small "kink" decays. Therefore, it is very suitable to search for peculiar decay topologies ("double kink") of Ds$\longrightarrow\tau\longrightarrow$X.

After successful pilot runs and data analysis, CERN had approved the DsTau project as a new experiment NA65 in 2019. About an order of magnitude more data than the pilot runs will be collected in physics runs scheduled in 2021-2022. In this talk, the results of the pilot run data analysis will be presented and the prospect for physics runs in 2021-2022 will be given.

QCD and Neutrinos / 46

Prompt neutrinos in the forward region at the LHC

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We calculate the prompt muon and tau neutrino (and antineutrino) number of events in the far forward region at the LHC. In a region as such, the heavy quark decay dominates the tau neutrino production. The hadronic charm and bottom hadron production cross section is evaluated at the next-to-leading order in perturbative QCD. The intrinsic transverse momentum of the initial partons becomes important in this region and is modeled with a Gaussian function, with the parameter determined by fitting to the LHCb experimental data. The heavy quark fragmentation is described

by the Peterson fragmentation function. Thousands of charged current tau (anti)neutrino events can be expected for a 1 m long lead neutrino detector located 480 m down the stream for pp collision at a center-of-mass energy $\sqrt{s}$ = 14 TeV and an integrated luminosity L = 3000 fb^{-1}. However, the uncertainties from the perturbative QCD higher-order corrections are large in the neutrino event distribution.

Long-Lived Particles / **47**

LLP and neutrino mass models

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In this talk I will discuss the connection of different neutrino mass models with long-lived particles (LLPs). We will also discuss the prospects of the LHC and several recent experimental proposals to search for these LLPs.

Dark Sectors and Cosmology / **48**

Potential for BSM and Neutrino Physics at FORMOSA

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In this talk, I will present some additional physics potential of FORMOSA, that not only provides leading sensitivity to MCPs but also is extremely sensitive to other forms of exotica beyond the standard model (BSM), such as heavy neutrinos and DM with a large electric dipole moment (EDM). Furthermore, we expect a sizable number of interactions of TeV-energy neutrinos in FORMOSA, providing additional opportunities for neutrino physic in the far forward direction.

QCD and Neutrinos / **49**

Mueller-Navelet jets phenomenology

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We give a short review of recent Mueller-Navelet jets studies at the LHC and we propose new related observables to be used as probes of the BFKL dynamics.

Summary and Conclusions / **50**

Summary and conclusions

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