Forward Physics Facility Theory Workshop

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Book of Abstracts

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BSM Physics Parallel Session / 2

Probing Reheating Cosmology at FORMOSA and FPF: Cosmic Millicharged Background

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We demonstrate that the searches for dark sector particles can provide probes of reheating scenarios, focusing on the Cosmic Millicharge Background (CmB) produced in the early universe. We discuss two scenarios of millicharge particles (mCPs), with or without kinetic mixing, as they have different theoretical motivations and cosmological signatures. The mCP without an accompanying dark photon can be an indirect test of GUTs and string compactifications, and we discuss its overproduction and CMB constraints with different reheating temperatures as an attempt to identify a region to search for it. The millicharged particle from kinetic mixing also has important constraints regarding different reheating temperatures. In both cases, FORMOSA and FPF provide excellent probes of these rehearing scenarios and can set limits on the maximum temperatures of the SM particles during the reheating process.

BSM Physics Parallel Session / 3

Looking forward to photon-coupled sub-GeV long-lived particles

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Many Dark Sector models contain photon-coupled long-lived particles. An outstanding example is an axion-like particle decaying into two photons. The forward physics detectors at the LHC, e.g., FASER, were shown to be particularly suitable for hunting ˜sub-GeV ALPs thanks to numerous photons produced in pp collisions, which in turn are efficiently converted into ALPs by the Primakoff scattering. We consider a few of beyond the SM physics scenarios in which similar processes can occur, in particular *massive spin-2 portal and inelastic DM with EM form factors*. We find that FASER2 and SHiP experiments will cover a significant part of the available parameter space for each of them. Moreover, we show that secondary production of LLPs at FASER2 can improve the coverage of parameter spaces in the regime of smaller lifetimes.

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Forward D-meson production

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The heavy-flavor production at the hadron collider provides an important venue to test our understanding of the strong interaction. Due to the large heavy-flavor mass, this process is perturbatively

calculable in quantum chromodynamics. In this work, we apply our recently developed Simplified-ACOT scheme with massive phase space (S-ACOT-MPS) to the D-meson production, which can be directly measured very well at the LHC. Meanwhile, the D-meson decay in the far-forward region provides an important neutrino resource directly detected in the FASER experiment as well as other forward physics facilities.

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CT18 Fitted Charm: possibilities at the Forward Physics Facility

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As the lightest of the heavy flavors, the charm quark occupies a liminal space in QCD, transgressing the boundary separating perturbative and nonperturbative dynamics. Charm thus plays a central role in efforts to refine QCD and our corresponding understanding of proton structure for experiments at the LHC and elsewhere. We outline a stubborn problem in the theory of nucleon structure: the open question of whether the proton contains a significant nonperturbative charm component. We also discuss some of the theoretical ambiguities that have kept this challenge alive while summarizing the findings of a recently published CTEQ-TEA analysis, the CT18 Fitted Charm (FC) study, which identified a need for more data from experiments like the Forward Physics Facility to resolve this question.

BSM Physics Parallel Session / **6**

ISR and FSR of Dark Photons

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We study the relevance of Initial- and Final-State radiation in QCD processes at the LHC as a production mechanism for dark photons. We implement dark photon splitting functions to quarks into the Monte-Carlo Generator Herwig and add it to the forward and backward evolution of the parton shower in LHC events. We simulate the most relevant forward physics processes, and identify in which way ISR and FSR radiations contribute to the overall production of dark photons in forward physics experiments like FASER/FASER2.

SM Physics Parallel Session / **7**

Electromagnetic Properties of Neutrinos and the Weak Mixing Angle at the FPF

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The recent observation of collider neutrinos by the FASER collaboration highlights the potential the forward direction at the LHC has for neutrino physics. In the HL-LHC era, we expect a significant number of neutrinos of all flavors in the forward direction, opening the way for precision studies using collider neutrinos at the proposed Forward Physics Facility (FPF). In this talk, I will present some phenomenological studies of the electromagnetic properties of neutrinos, namely magnetic moment, milli-charge, and charge radius, that can be done at the FPF. Making use of this intense flux of neutrinos, FPF will be able to provide highly competitive and world leading bounds on these neutrino properties. Furthermore, the weak mixing angle can be measured to about 3% precision at the FLArE detector. The ability to measure the weak mixing angle with this high precision sets an important benchmark for the design of the FPF neutrino detectors.

SM Physics Parallel Session / **8**

Investigating the reach of FPF via information geometry using multidifferential neutrino spectra

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Based on a broad selection of existing predictions to cover the phase space as well as possible, we investigate the highest achievable precision for the neutrino spectra expected at the FPF. The spectra are presented as a function of neutrino energy and the spatial radius of the interaction vertex, separately for each outgoing charged lepton flavor, thus demonstrating the increase in precision due to the use of multidifferential distributions. This allows assessing the ultimate experimental reach of the FPF, and as particular examples we investigate the constraints that can be set on neutrino charged current non-standard interactions and enhanced forward kaon production.

BSM Physics Parallel Session / **9**

Benchmarking Proton Bremsstrahlung for Dark Sector Production

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Proton beams at high luminosity colliders and fixed-target facilities offer remarkable sensitivity to new light weakly coupled degrees of freedom in the dark sector. In a recent study, we revisited the production of dark photons and dark scalars via proton bremsstrahlung for a range of beam energies, including those relevant to the proposed Forward Physics Facility (FPF) at the High Luminosity LHC.

In this talk I will present some new results from work in progress, assessing the effectiveness of current methods for calculating the proton bremsstrahlung rate by comparing and benchmarking the bremsstrahlung distribution with very forward particle production rates within the SM. In the case of the vector portal, we analyze and compare the bremsstrahlung spectrum with data on the inclusive forward production of neutral vector mesons.

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Forward Neutrinos from Charm at Large Hadron Collider

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The currently operating FASER experiment and the planned Forward Physics Facility (FPF) will detect a large number of neutrinos produced in proton-proton collisions at the LHC. In addition to neutrinos from pion and kaon decays, a significant contribution is expected from the decay of charmed hadrons, particularly for electron and tau neutrino flavors. In this talk, we shall discuss two QCD formulations for the production of charm quarks in pp collisions: the next-to-leading order collinear factorization and the k_T-factorization approach. We use state of the art fragmentation schemes to obtain hadron cross-sections and validate them against current LHCb data. These calculations are then used to predict the forward neutrino flux from charm hadron decays. We further scrutinize the impact of varying QCD parameters, such as scales, the selection of parton distribution functions, and the modeling of fragmentation, on these predictions. Among these factors, the modeling of fragmentation has a particularly significant impact on the neutrino flux at FASER.

SM Physics Parallel Session / 11

Tuning Pythia for Forward Particle Production at the FPF

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Event generators have largely been used for central physics predictions at the LHC and parameters regarding hadron production in these generators have been tuned using central physics data. In particular, Pythia has proven to be a reliable generator for central measurements, but it's prediction for forward particle production shows disagreement with LHCf data, which points to a need for a Pythia tune for the FPF. Furthermore, flux uncertainty predictions at the FPF have been obtained by using the spread of different event generators which is a pragmatic but statistically ungrounded approach. In this talk, I discuss our work to obtain a Pythia tune for future forward physics studies. Using LHCf data we tune a subset of Pythia's parameters to more accurately reproduce the forward particle flux without spoiling the success in the central region, and we also obtain a flux uncertainty in a data-driven way. This tune can be used for future studies both within and beyond the Standard Model.

SM Physics Parallel Session / 12

The Swampland and Neutrino Physics

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I will discuss constraints imposed by swampland conjectures on neutrino masses and mixing, focussing attention on the region of the parameter space to be probed by FPF experiments.

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Discussion and Next Steps

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SensCalc: public and unified calculations of sensitivities to feebly interacting particles

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The idea that new physics could take the form of feebly interacting particles (FIPs) —particles with a mass below the electroweak scale, but which may have evaded detection due to their tiny couplings or very long lifetime —has recently gained a lot of traction. A wide variety of experiments have

been proposed to search for this type of particles. However, the assumptions made about the models or acceptance can differ greatly between sensitivity studies, making it difficult to do an apples-to-apples comparison between those experiments. To address this issue, we have developed *SensCalc*, a Mathematica package designed to consistently compute the expected signal across a broad range of models and experiments (both at colliders and beam dumps) while keeping the assumptions under control. In this talk, I will introduce *SensCalc*, compare it with related packages, discuss its strengths and limitations, and finally show how the sensitivity can change when some core assumptions are varied.

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BSM: The Swampland and Neutrino Physics

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BSM: SensCalc -public and unified calculations of sensitivities to feebly interacting particles

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Quirks at the Forward Physics Facility

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Quirks are a generic prediction of strongly-interacting hidden sectors with low Lambda. Such particles can be produced in large numbers at the LHC with high initial pT, but since they are tied together by a color string, the quirk–anti-quirk system has vanishing total pT and so propagates down the beam pipe into forward detectors. We show that quirks produce a spectacular signature of two simultaneous, slow or delayed, charged tracks, allowing FPF detectors to probe deep into quirk parameter space

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BSM: Quirks at the FPF

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Light Scalars at FASER

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FASER, the ForwArd Search ExpeRiment, is a currently operating experiment at the Large Hadron Collider (LHC) that can detect light long-lived particles produced in the forward region of the LHC interacting point. In this talk, we show the prospect of detecting light CP-even and CP-odd scalars at FASER and FASER 2. Considering a model-independent framework describing the most general interactions between a CP-even or CP-odd scalar and SM particles using the notation of coupling modifiers in the effective Lagrangian, we develop the general formalism for the scalar production and decay. We then analyze the FASER and FASER 2 reaches of light scalars in the large tan beta region of the Type-I two Higgs doublet model as a case study, in which light scalars with relatively long lifetime could be accommodated. Both FASER and FASER 2 can probe a large part of the parameter space in the large tan beta region up to 10ˆ7, extending beyond the constraints of the other existing experiments.