

# **Forward Physics Facility Theory Workshop**

## **Report of Contributions**

Contribution ID: 2

Type: **not specified**

## Probing Reheating Cosmology at FORMOSA and FPF: Cosmic Millicharged Background

*Monday 18 September 2023 17:55 (15 minutes)*

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 reheating scenarios and can set limits on the maximum temperatures of the SM particles during the reheating process.

**Primary authors:** TSAI, Yu-Dai (University of California, Irvine); GAN, Xucheng (New York University)

**Presenter:** TSAI, Yu-Dai (University of California, Irvine)

**Session Classification:** BSM Physics Parallel Session

Contribution ID: 3

Type: **not specified**

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

Monday 18 September 2023 16:25 (15 minutes)

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  $\sim$ 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.

**Primary author:** JODLOWSKI, Krzysztof

**Presenter:** JODLOWSKI, Krzysztof

**Session Classification:** BSM Physics Parallel Session

Contribution ID: 4

Type: **not specified**

## Forward D-meson production

*Monday 18 September 2023 17:10 (15 minutes)*

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.

**Primary authors:** XIE, Keping (University of Pittsburgh); GUZZI, Marco (Kennesaw State University); Prof. NADOLSKY, Pavel (Southern Methodist University)

**Presenter:** XIE, Keping (University of Pittsburgh)

**Session Classification:** SM Physics Parallel Session

Contribution ID: 5

Type: **not specified**

## CT18 Fitted Charm: possibilities at the Forward Physics Facility

*Monday 18 September 2023 17:25 (15 minutes)*

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.

**Primary author:** HOBBS, TIMOTHY J (Argonne National Laboratory)

**Co-authors:** GUZZI, Marco (Kennesaw State University); XIE, Keping (University of Pittsburgh); HUSTON, Joey (Michigan State University (US)); Prof. NADOLSKY, Pavel (Southern Methodist University); YUAN, C.-P. (Michigan State University)

**Presenter:** HOBBS, TIMOTHY J (Argonne National Laboratory)

**Session Classification:** SM Physics Parallel Session

Contribution ID: 6

Type: **not specified**

## ISR and FSR of Dark Photons

*Monday 18 September 2023 17:10 (15 minutes)*

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.

**Primary author:** REIMITZ, Peter (University of Sao Paulo)

**Presenter:** REIMITZ, Peter (University of Sao Paulo)

**Session Classification:** BSM Physics Parallel Session

Contribution ID: 7

Type: **not specified**

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

*Monday 18 September 2023 17:55 (15 minutes)*

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.

**Primary author:** MAMMEN ABRAHAM, Roshan

**Presenter:** MAMMEN ABRAHAM, Roshan

**Session Classification:** SM Physics Parallel Session

Contribution ID: 8

Type: **not specified**

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

*Monday 18 September 2023 16:25 (15 minutes)*

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.

**Primary authors:** KLING, Felix (DESY); Dr TROJANOWSKI, Sebastian (NCBJ, Astrocent); MAKELA, Toni (NCBJ)

**Presenter:** MAKELA, Toni (NCBJ)

**Session Classification:** SM Physics Parallel Session



Contribution ID: 9

Type: **not specified**

## Benchmarking Proton Bremsstrahlung for Dark Sector Production

*Monday 18 September 2023 17:25 (15 minutes)*

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.

**Primary author:** FOROUGHI-ABARI, Saeid (University of Victoria)

**Co-author:** RITZ, Adam

**Presenter:** FOROUGHI-ABARI, Saeid (University of Victoria)

**Session Classification:** BSM Physics Parallel Session

Contribution ID: 10

Type: **not specified**

## Forward Neutrinos from Charm at Large Hadron Collider

*Monday 18 September 2023 16:55 (15 minutes)*

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.

**Primary author:** Dr BHATTACHARYA, Atri (University of Liège)

**Co-authors:** STASTO, Anna (Penn State); KLING, Felix (DESY); SARCEVIC, Ina

**Presenter:** Dr BHATTACHARYA, Atri (University of Liège)

**Session Classification:** SM Physics Parallel Session

Contribution ID: 11

Type: **not specified**

# Tuning Pythia for Forward Particle Production at the FPF

*Monday 18 September 2023 17:40 (15 minutes)*

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 its 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.

**Primary author:** FIEG, Max

**Co-authors:** KLING, Felix (DESY); SJOSTRAND, Torbjorn (Lund University (SE))

**Presenter:** FIEG, Max

**Session Classification:** SM Physics Parallel Session

Contribution ID: 12

Type: **not specified**

## The Swampland and Neutrino Physics

*Monday 18 September 2023 16:40 (15 minutes)*

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.

**Primary author:** ANCHORDOQUI, Luis

**Presenter:** ANCHORDOQUI, Luis

**Session Classification:** SM Physics Parallel Session

Contribution ID: 13

Type: **not specified**

## Welcome and Introduction

*Monday 18 September 2023 14:00 (20 minutes)*

**Presenters:** KLING, Felix (DESY); KOPP, Joachim (CERN)

Contribution ID: 14

Type: **not specified**

## **Talk: QCD & Generators for FPF**

**Presenter:** ISAACSON, Joshua

Contribution ID: 15

Type: **not specified**

## **FPF Connection to Astro-Particle Physics**

*Monday 18 September 2023 14:20 (30 minutes)*

**Presenter:** Prof. SARKAR, Subir (University of Oxford)

Contribution ID: **16**

Type: **not specified**

## **Physics with Muons at the FPF**

*Monday 18 September 2023 15:00 (1 hour)*

**Presenters:** SANDROCK, Alexander; KLING, Felix (DESY); Dr CRUZ MARTINEZ, Juan M. (CERN); TROJANOWSKI, Sebastian



Contribution ID: 17

Type: **not specified**

## **BSM: ISR and FSR of Dark Photons**

**Presenter:** REIMITZ, Peter

**Session Classification:** BSM Physics Parallel Session

Contribution ID: **18**

Type: **not specified**

## **SM: Neutrinos EM Properties and Weak Mixing Angle at the FPF**

**Presenter:** MAMMEN ABRAHAM, Roshan

**Session Classification:** SM Physics Parallel Session

Contribution ID: 19

Type: **not specified**

## **BSM: Looking forward to photon-coupled sub-GeV long-lived particles**

**Presenter:** JODLOWSKI, Krzysztof

**Session Classification:** BSM Physics Parallel Session

Contribution ID: 20

Type: **not specified**

## **BSM: Benchmarking Proton Bremsstrahlung for Dark Sector Production**

**Presenter:** FOROUGHI-ABARI, Saeid (University of Victoria)

**Session Classification:** BSM Physics Parallel Session

Contribution ID: 21

Type: **not specified**

## **BSM: Probing Reheating Cosmology at FORMOSA: Cosmic Millicharged Background**

**Presenter:** TSAI, Yu-Dai (University of California, Irvine)

**Session Classification:** BSM Physics Parallel Session

Contribution ID: 22

Type: **not specified**

## **SM: Forward D-meson production**

**Presenter:** XIE, Keping (University of Pittsburgh)

**Session Classification:** SM Physics Parallel Session

Contribution ID: 23

Type: **not specified**

## **SM: CT18 Fitted Charm - possibilities at the FPF**

**Presenter:** Dr HOBBS, TIMOTHY J (Argonne National Laboratory)

**Session Classification:** SM Physics Parallel Session

Contribution ID: 24

Type: **not specified**

## **SM: Forward Neutrinos from Charm at LHC**

**Session Classification:** SM Physics Parallel Session



Contribution ID: 25

Type: **not specified**

## **SM: Tuning Pythia for Forward Particle Production at the FPF**

**Presenter:** FIEG, Max

**Session Classification:** SM Physics Parallel Session

Contribution ID: 26

Type: **not specified**

## **SM: Investigating the reach of FPF using multi-differential neutrino spectra**

**Presenter:** Dr MAKELA, Toni (NCBJ)

**Session Classification:** SM Physics Parallel Session

Contribution ID: 27

Type: **not specified**

## Neutrino Cross Sections at TeV Energies

*Tuesday 19 September 2023 14:00 (30 minutes)*

**Presenters:** Dr RABEMANANJARA, Tanjona R. (NIKHEF & VU Amsterdam); JEONG, Yu Seon (Chung-Ang University (KOR))

Contribution ID: 28

Type: **not specified**

## Neutrino Interaction Tools for the FPF

*Tuesday 19 September 2023 14:30 (30 minutes)*

**Presenter:** Dr GARCIA SOTO, Alfonso Andres (NIKHEF)

Contribution ID: 29

Type: **not specified**

## **BSM Physics Opportunities with LHC Neutrino Beams**

*Tuesday 19 September 2023 15:00 (30 minutes)*

**Presenter:** KELLY, Kevin James (Texas A&M University)

Contribution ID: **30**

Type: **not specified**

## **Hadronic Physics in Neutrino Interactions and Complementarities to the EIC**

*Tuesday 19 September 2023 15:30 (30 minutes)*

**Presenter:** Dr VITEV, Ivan

Contribution ID: **31**

Type: **not specified**

## **WG1 Summary: Neutrino Interactions and DIS**

*Tuesday 19 September 2023 16:30 (15 minutes)*

**Presenter:** Dr ROJO, Juan (VU Amsterdam and Nikhef)

Contribution ID: **32**

Type: **not specified**

## **WG2 Summary: Forward Charm Production**

*Tuesday 19 September 2023 16:45 (15 minutes)*

**Presenter:** STASTO, Anna (Penn State)



Contribution ID: 33

Type: **not specified**

## **WG3 Summary: Light Hadron Production and Astroparticle Connections**

*Tuesday 19 September 2023 17:00 (15 minutes)*

**Presenters:** SOLDIN, Dennis; ANCHORDOQUI, Luis

Contribution ID: **34**

Type: **not specified**

## **WG4 Summary: BSM Physics**

*Tuesday 19 September 2023 17:15 (15 minutes)*

**Presenter:** TROJANOWSKI, Sebastian

Contribution ID: 35

Type: **not specified**

## Discussion and Next Steps

*Tuesday 19 September 2023 17:30 (30 minutes)*

**Presenters:** KLING, Felix (DESY); KOPP, Joachim (CERN)

Contribution ID: 36

Type: **not specified**

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

*Monday 18 September 2023 17:40 (15 minutes)*

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.

**Primary authors:** OVCHYNNIKOV, Maksym (KIT & Leiden University); TASTET, Jean-Loup (UAM-IFT); MIKULENKO, Oleksii (Leiden University); BONDARENKO, Kyrylo (IFPU, SISSA & INFN Trieste)

**Presenter:** TASTET, Jean-Loup (UAM-IFT)

**Session Classification:** BSM Physics Parallel Session

Contribution ID: 37

Type: **not specified**

## **BSM: The Swampland and Neutrino Physics**

**Presenter:** ANCHORDOQUI, Luis

**Session Classification:** BSM Physics Parallel Session

Contribution ID: **38**

Type: **not specified**

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

**Presenter:** TASTET, Jean-Loup (UAM-IFT)

**Session Classification:** BSM Physics Parallel Session

Contribution ID: 39

Type: **not specified**

## Quirks at the Forward Physics Facility

*Monday 18 September 2023 16:55 (15 minutes)*

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  $p_T$ , but since they are tied together by a color string, the quirk–anti-quirk system has vanishing total  $p_T$  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

**Primary author:** FENG, Jonathan Lee (University of California Irvine (US))

**Presenter:** FENG, Jonathan Lee (University of California Irvine (US))

**Session Classification:** BSM Physics Parallel Session

Contribution ID: 40

Type: **not specified**

## **BSM: Quirks at the FPF**

**Presenter:** FENG, Jonathan Lee (University of California Irvine (US))

**Session Classification:** BSM Physics Parallel Session



Contribution ID: 41

Type: **not specified**

## Light Scalars at FASER

*Monday 18 September 2023 16:40 (15 minutes)*

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  $10^7$ , extending beyond the constraints of the other existing experiments.

**Primary author:** SONG, Huayang (ITP)

**Presenter:** SONG, Huayang (ITP)

**Session Classification:** BSM Physics Parallel Session