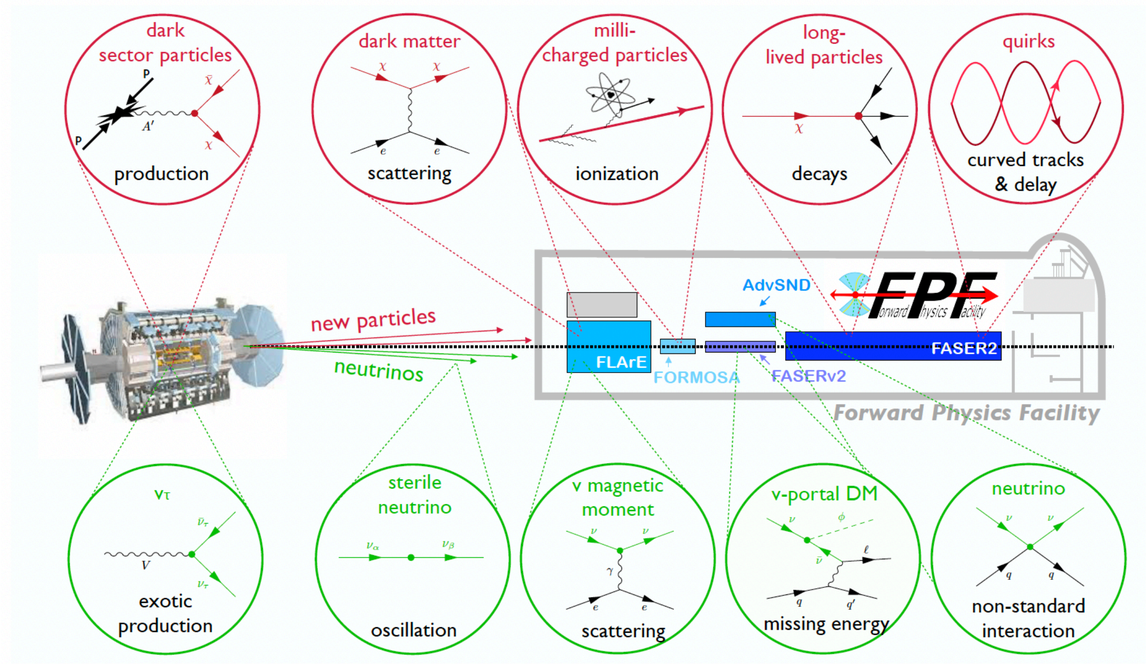
Forward Physics Facility (FPF)
Working Group (WG4) — BSM Physics

Brian Batell & Sebastian Trojanowski (WG4 conveners)
with input from
Reuven Balkin and Jinmian Li

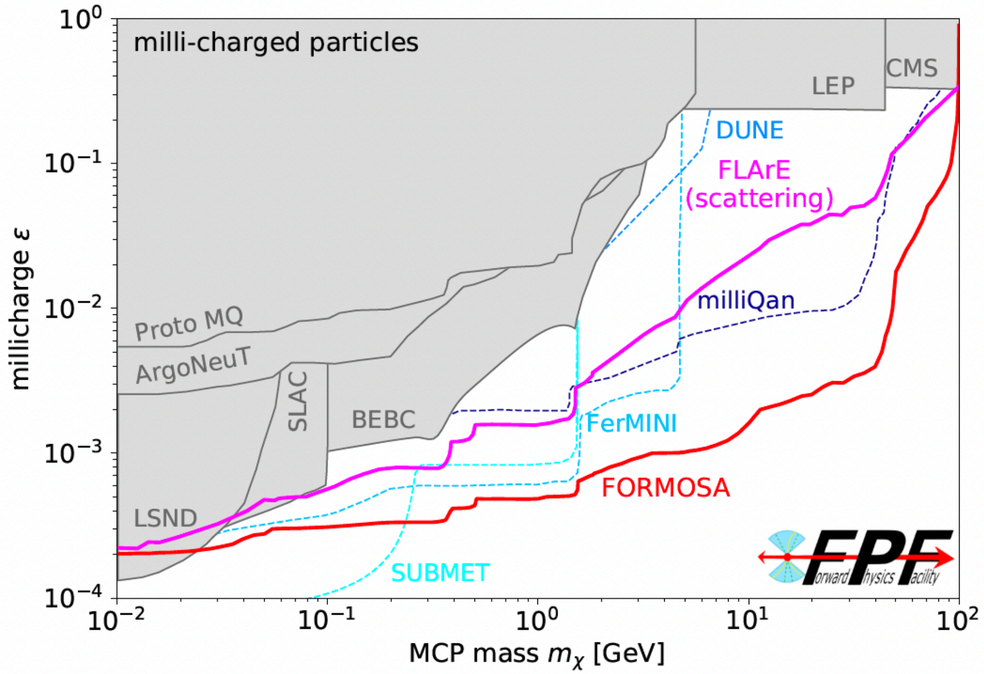
6th Forward Physics Facility Meeting, June 8-9, 2023

BSM physics at FPF

- There is a diverse, compelling BSM physics case for the FPF
- LLPs, dark matter, millicharged particles, neutrino BSM, quirks, and many other examples
- Large, international community of physicists (~several hundred) interested in BSM at FPF



Figures from P5 FPF Summary Document, F. Kling



[Foroughi-Abari, Kling, Tsai, 2010.07941]

Working Group 4: BSM Physics

- Extensive BSM physics case already established and surveyed in FPF whitepapers, 2109.10905, 2203.05090

- Goals of WG4 include studies of less well-explored BSM opportunities and simulation tool development/refinement. Some examples:
  - Further detailed simulation development, coverage of relevant benchmark models (FORESEE)
  - Neutrino-philic BSM (e.g., active-sterile oscillations, tridents, neutrino-coupled forces, neutrino-DM interactions…)
    - Requires detailed understanding of neutrino fluxes — see Toni Makela's talk next
  - BSM physics opportunities with muons traversing the FPF
  - Exploiting unique FPF experimental capabilities,
    - e.g., high LHC energies, lowering thresholds, timing, …

Recent BSM at FPF Highlights

FORESEE – tool for estimating sensitivity in new physics searches in the far-forward region
hep-ph/2105.07077 can be used for FASER, FPF, & future pp colliders

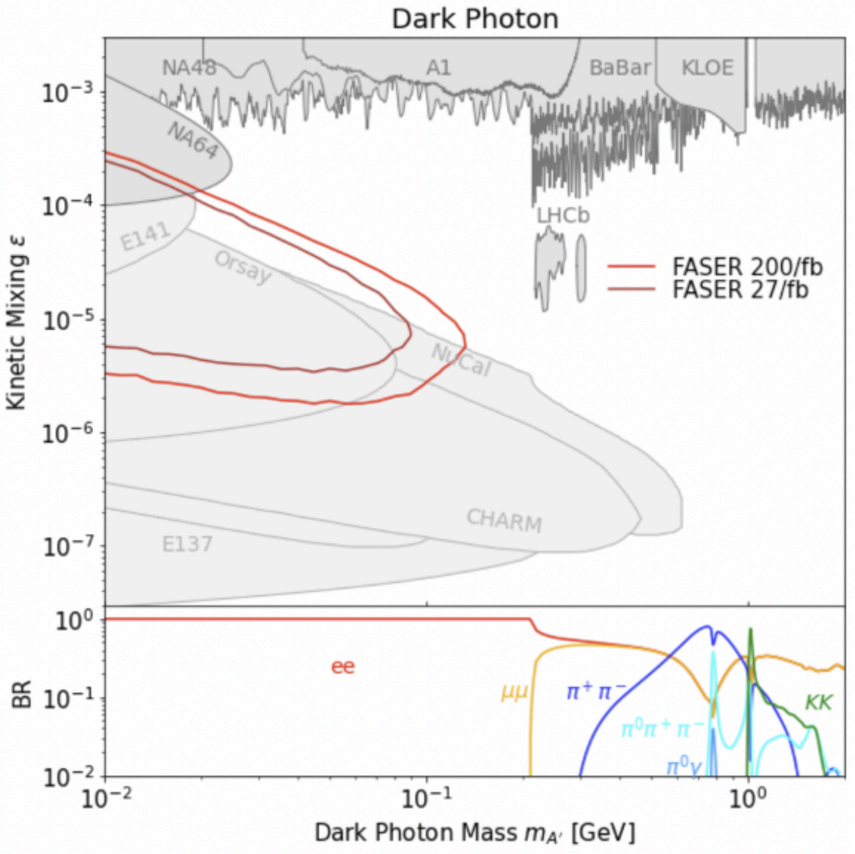
Team: F. Kling (DESY)
J. Adhikary (NCBJ, Warsaw)
S. Trojanowski (NCBJ, Warsaw)
to join: R.M. Abraham (→ UC Irvine)

FORESEE updates (partially **done** + ongoing work & plans):

a) BSM model library:
- new models constantly added
- adding production modes (e.g., **Primakoff for ALP-γ-γ**)
- adding estimates of modeling uncertainties
- introducing new signatures (**DM scattering**, mCPs, semi-visible decays)
- unifying scripts

b) Improvements in the HEPMC output format:
- add decay modes beyond 2-body
- multiple event weights for flux uncertainty estimates

c) General improvements:
- add detection efficiencies
- use more scikit-hep libraries
- reduce file size



SEARCH FOR LLPs
– semi-visible decays

Inelastic DM & FASER: A. Berlin, F. Kling, 1810.01879
Recently: K. Dienes, J.L. Feng, M. Fieg, F. Huang, S.J. Lee, 2301.05252;
K. Jodlowski, 2305.16781

- Light long-lived particles – important target for FASER
- Large activity in the field – many ongoing & proposed experiments
- Efforts towards identifying good (~unique) physics cases for FPF
- Important advantages of the FPF employing large LHC energies:
  – heavier BSM particles can be produced
  – large LLP energies → more room for detectable signals in semi-visible decays
- Idea: inelastic dark matter, two states χ_1 (DM), χ_2, + assume dark photon mediator

Small mass splitting: $\Delta = (m\chi_2 - m\chi_1) / m\chi_1$

Heavier state decays semi-visibly: $\chi_2 \rightarrow \chi_1 + (e^+e^-$ or $\mu^+\mu^-, \ldots)$

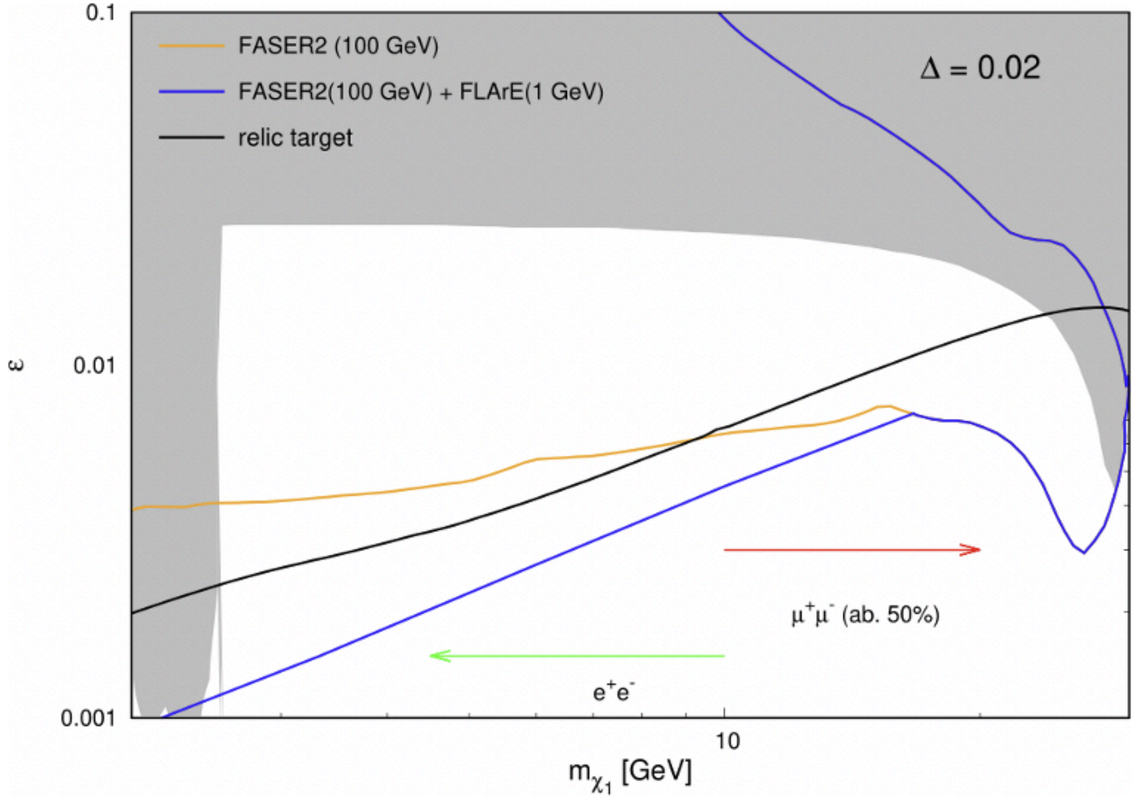
For $\Delta << 1$, only a small fraction of energy goes into visible particles

Questions:

- how low can the energy threshold be in FASER2?

- can FLArE help? (soft e^+e^- or $\mu^+\mu^-$, ~ GeV)

Working on the topic: J. Adhikary, S .Trojanowski, …



Hunting muonic forces at emulsion detectors

Ariga et al. 2305.03102

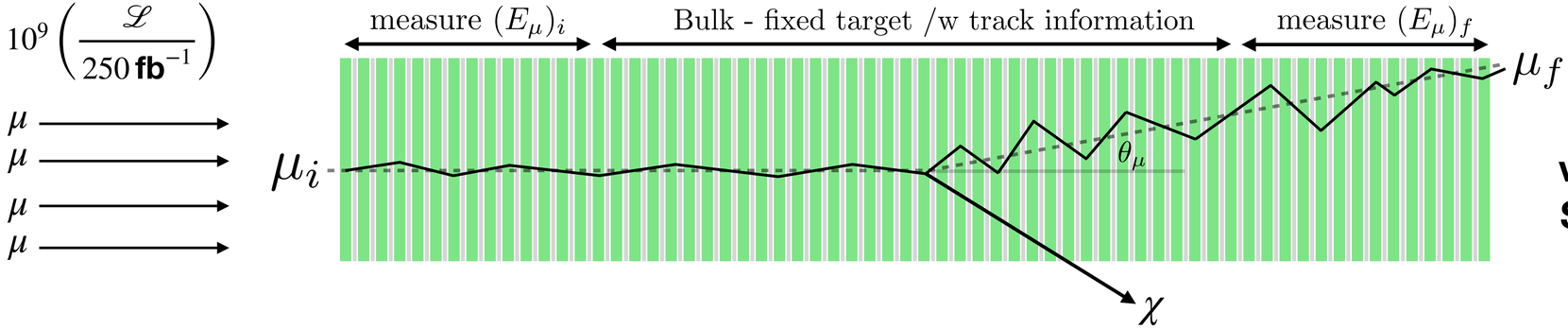
Large muon flux

$E_\mu \gtrsim 100\,\textbf{GeV}$

$\mathscr{L} \supset g\chi\bar{\mu}\mu$

Basic idea: use FASERν as a instrumented fixed target

$N_\mu \sim 2\times 10^9 \left(\frac{\mathscr{L}}{250\,\textbf{fb}^{-1}}\right)$

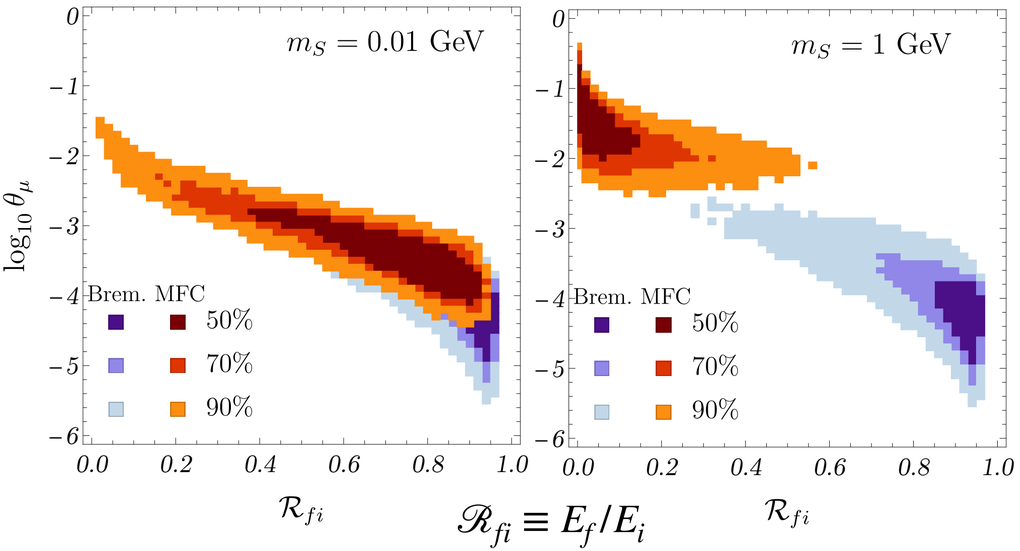


BG strategy #1 : kinematic cuts

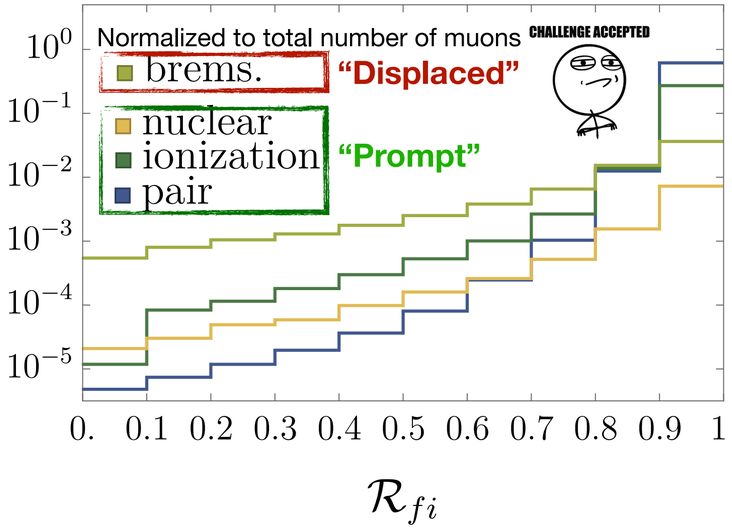
BG strategy #2 : veto BG by identifying SM energy deposition

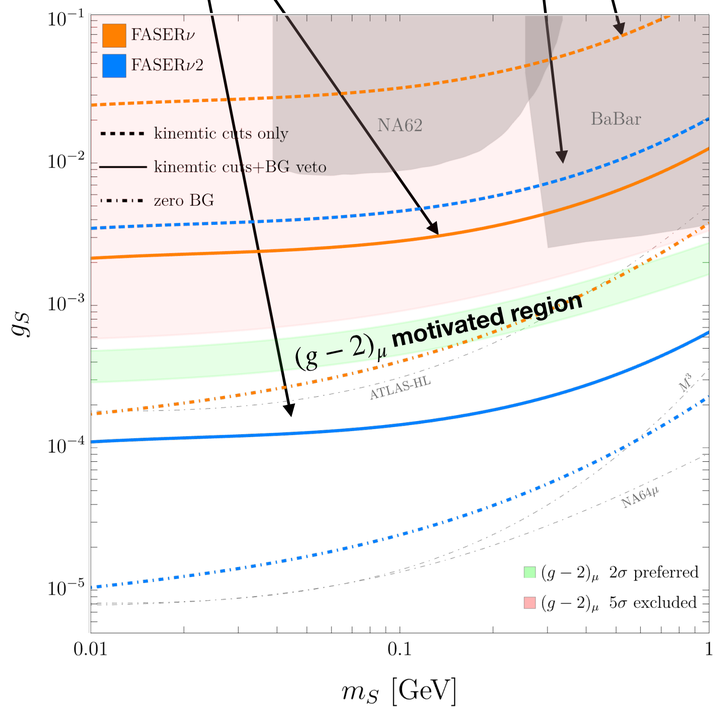
Light MFC : SM-like

Heavy MFC : well-separated



Background : rare SM processes





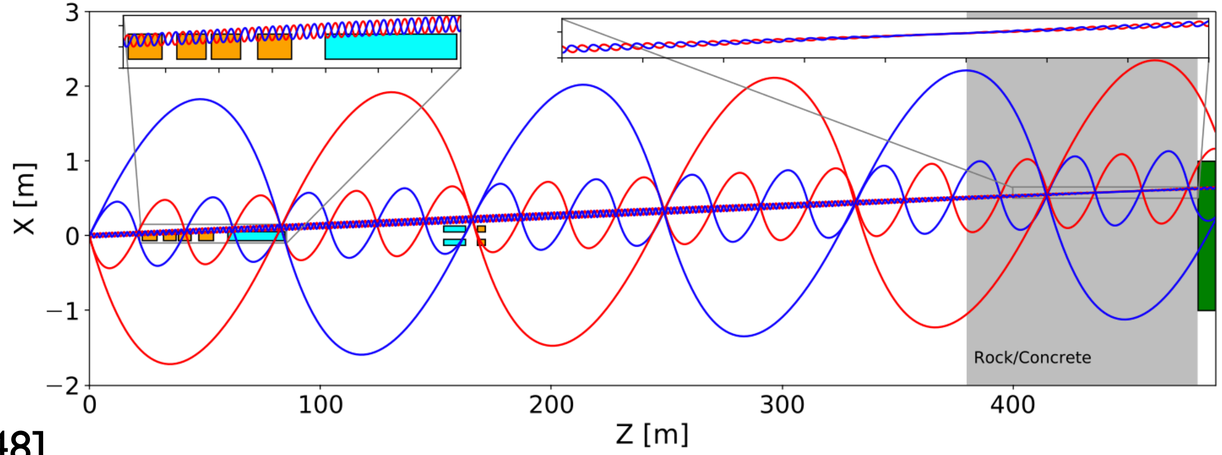
Slide from R. Balkin

Quirks at FASER, FASER2

- Quirks: exotic particles that carry SM charges and form bound states of macroscopic size due to a dark non-Abelian force.

- Previous studies focused on detailed simulation of the quirk trajectory and passage through material en route to FASER(2)

[J. Li, J. Pei, L. Ran, W. Zhang, 2108.06748]

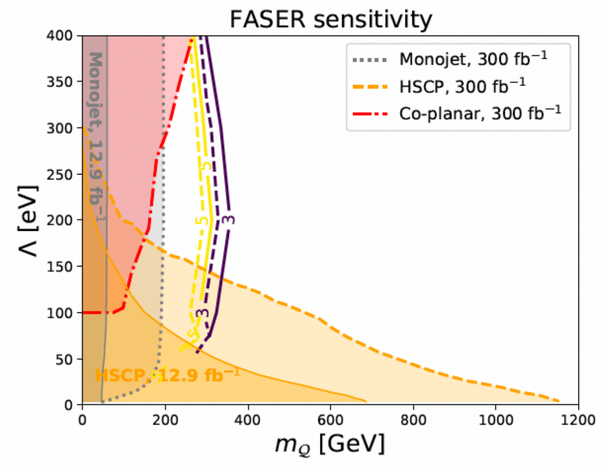


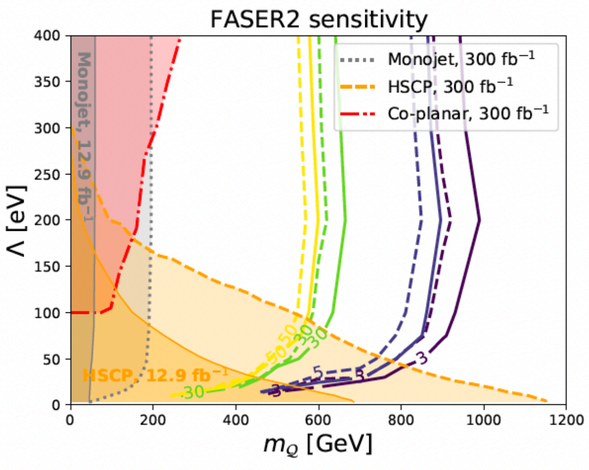
- New, ongoing work: new, powerful quirk search strategies using timing to mitigate backgrounds:

[J. Li, J. Feng, J. Pei, X. Liao, in progress]

1. Search based on arrival time of the quirk-antiquirk pair (dashed)

2. Search using time difference between quirk passage through front and back scintillators (solid)





Figures, input from Jinmain Li

OTHER BSM HIGHLIGHTS

- Neutrinos:

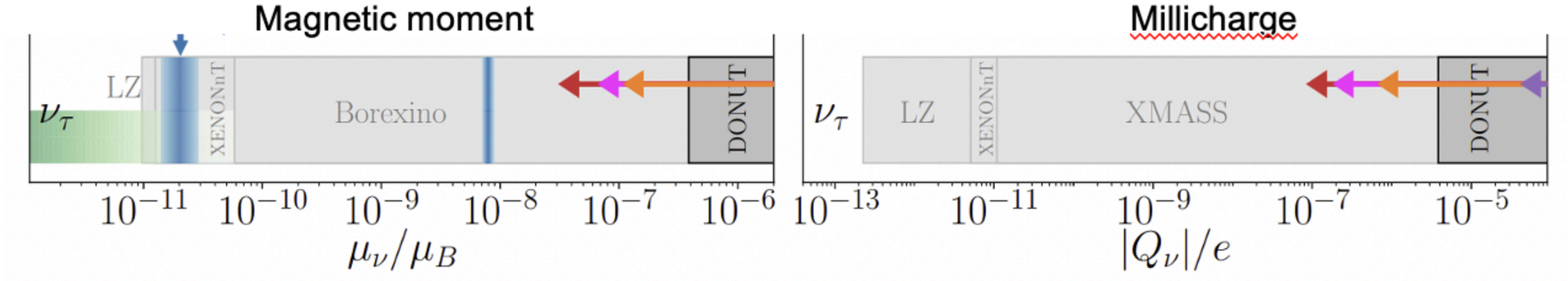
a) Tridents – extensive simulations of SM events (di-, tri-, quad-muon) **Bei Zhou** (FPF event analysis, ongoing work ST)

b) Neutrino oscillations: analyses in 1908.02310, 2203.05090 (P. Denton)
Currently work on the tool for physics analyses using expected FPF neutrino data → talk: **Toni Makela**
Next: use the tool refine oscillation analyses

c) Other neutrino BSM

Signatures: ve → ve (a-la DM)
also $\sin^2\theta_W \leftrightarrow \nu$ NC scatterings

R.M. Abraham, S. Foroughi-Abari, F. Kling, Y.-D. Tsai, 2301.10254



- Dark matter – refine & update of far-forward production of light DM, DM detection with very low thresholds (~MeV – tens of MeV)

ST
etal

Outlook

- A broad and exciting BSM physics case has been developed for the FPF.
- BSM at FPF continues to be a active research direction, with many recent works since the FPF whitepapers, e.g.,
  - Photon-coupled LLPs, lepton number violation, lepton flavor violation, leptoquarks, neutrino-dipole portal, axion-like particles, heavy QCD axions, light neutralinos and RPV,…
- There is discussion of organizing a FPF Theory Day meeting to highlight recent theoretical developments related to FPF physics.
- We (B. Batell, M. Diwan, S. Trojanowski) organize monthly meetings on Forward Physics, with a focus on FLArE, but also of more general interest — please reach out to one of us if you would like to follow these meetings.