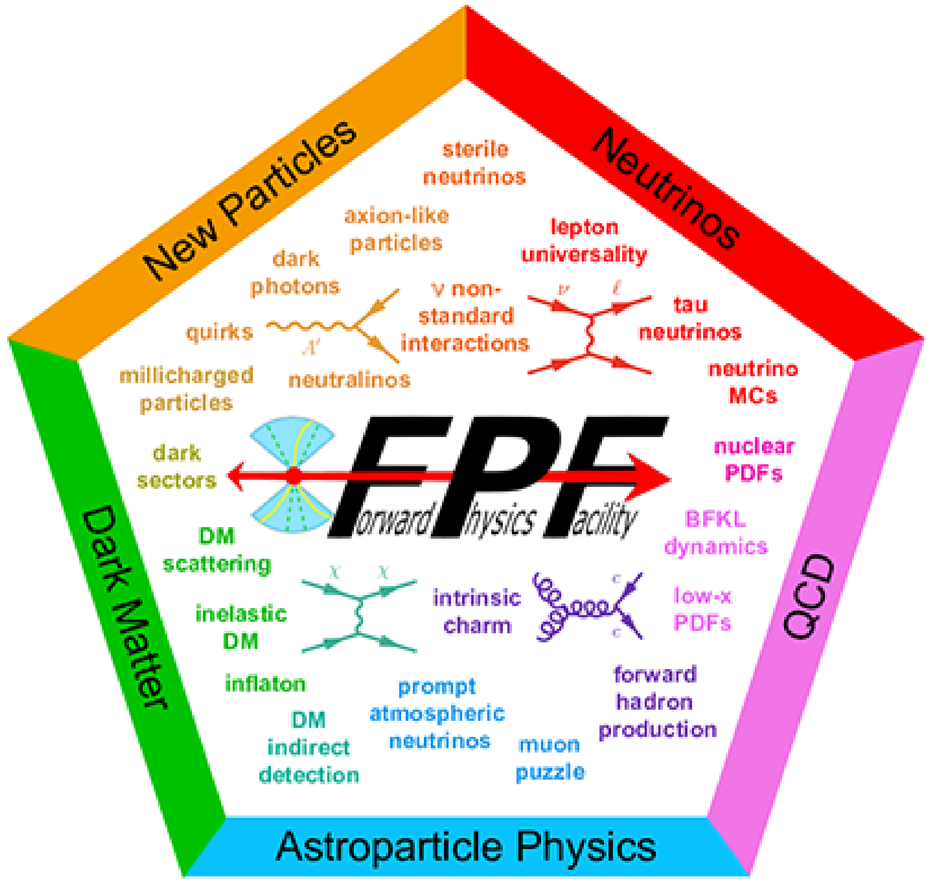
And many university collaborators from US, Europe, and Asia

Physics and Project planning for Forward Physics Facility

Milind V. Diwan (Brookhaven National Laboratory) on behalf of the FPF working group under the PBC/CERN

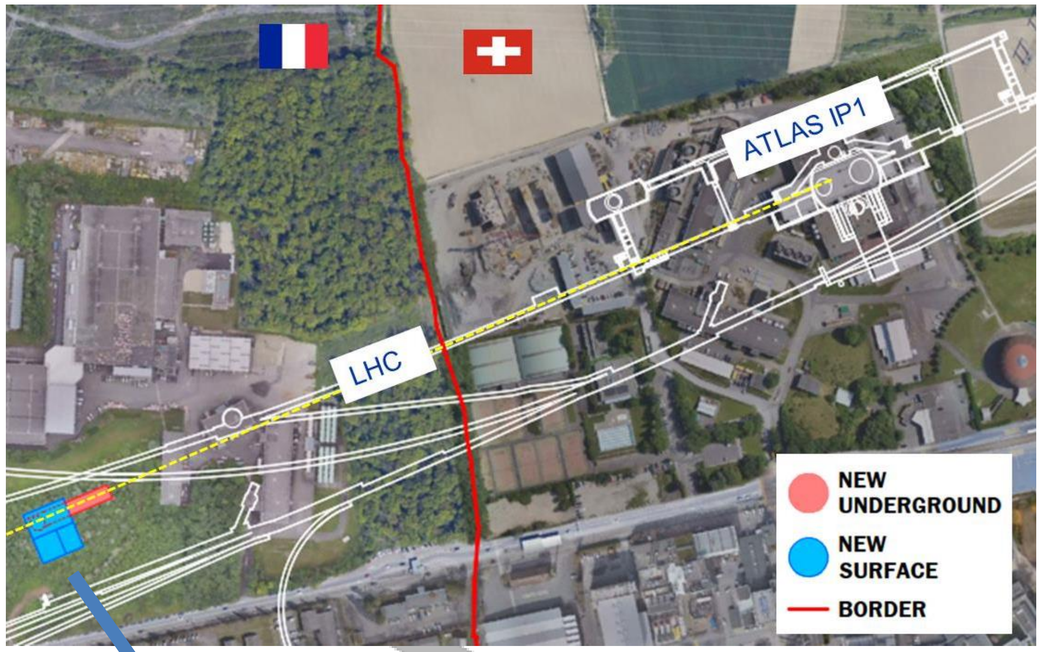
The 2025 Canadian Association of Physicists Congress (June 9-13, 2025), University of Saskatchewan



Forward Physics Facility (FPF) is for neutral long lived particles emerging in the forward direction from the LHC collisions.

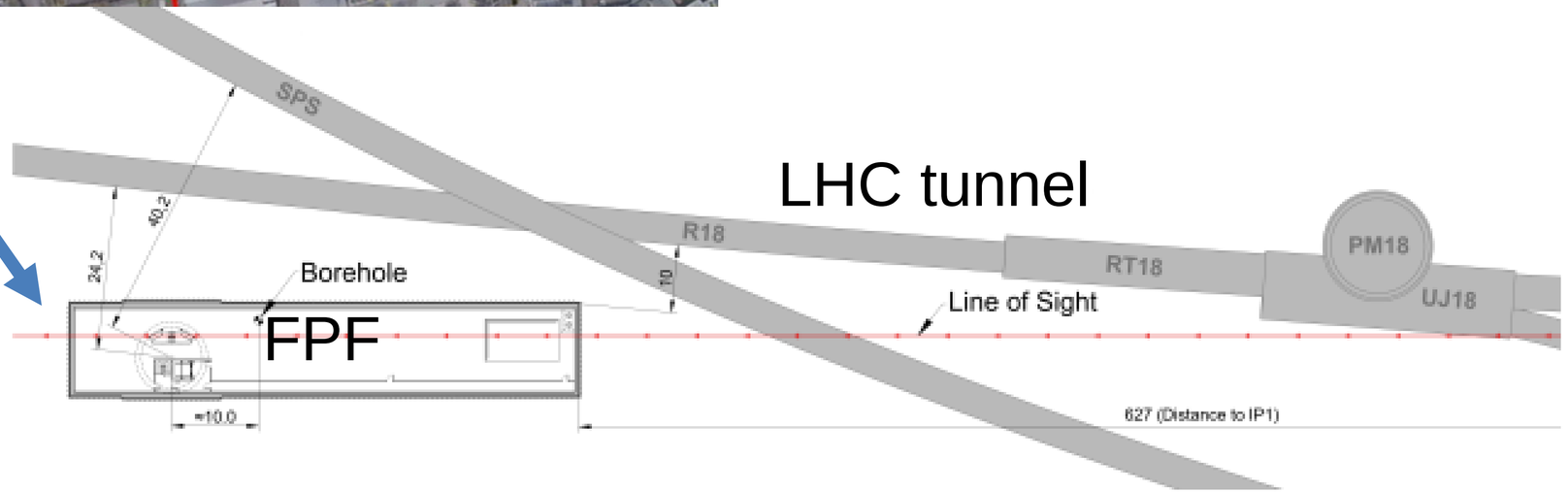
ENGINEERING DEPARTMENT

Forward Physics Facility cavern conceptual design

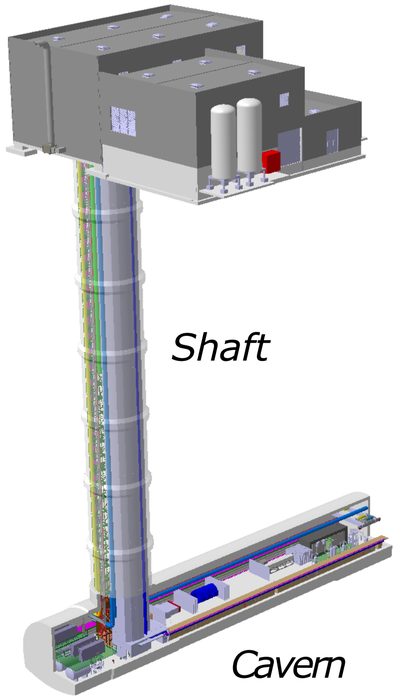


- FPF - Forward Physics Facility:

- Final location to respect constraints:
  - ✓ 627 m from ATLAS IP1 on the French side of CERN land
  - ✓ 90 m depth; 75 meter long/ 12 meter wide.
  - ✓ 10 m away from the LHC tunnel
  - ✓ Suite of 4 experiments have been designed.



Surface building



Shaft

Cavern

Recent detection of neutrinos (FASER/FASERnu) from the LHC has opened a new opportunity for physics. The FPF will allow full exploitation of this opportunity.

Community and References

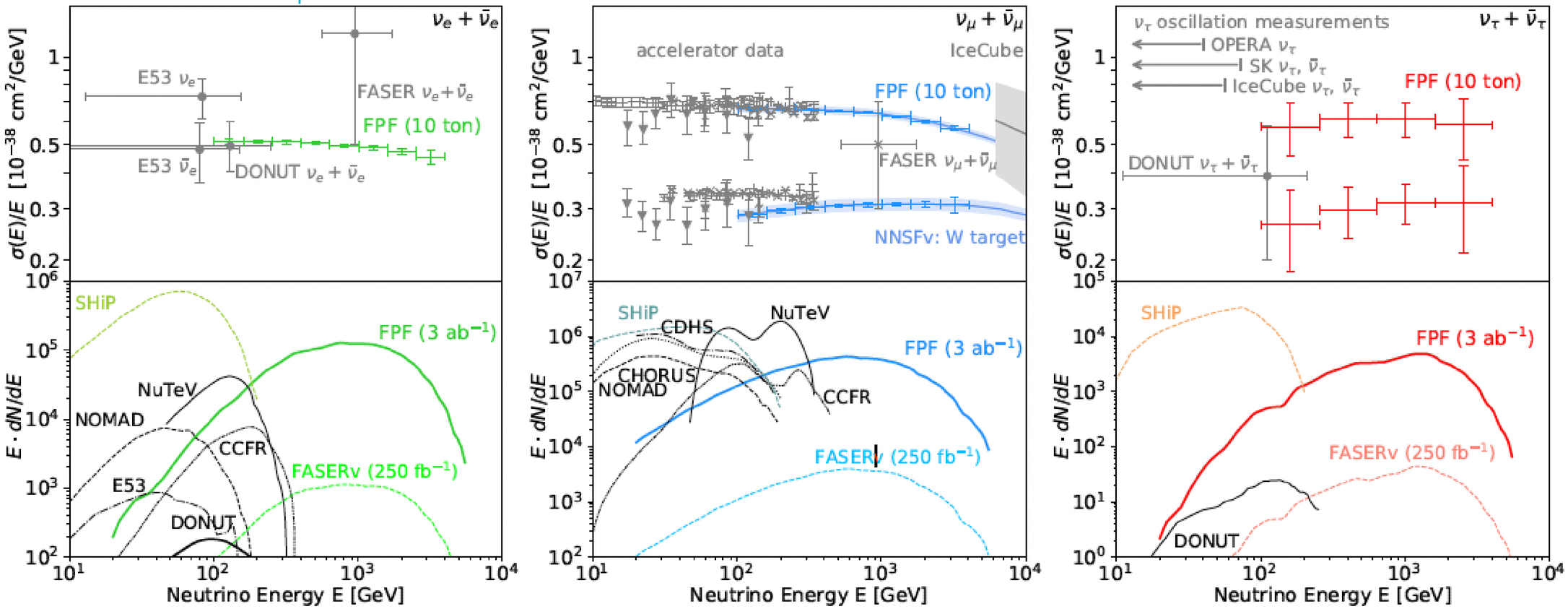
- **This talk is on behalf of the working group under the Physics Beyond Colliders PBC@CERN**
- **Science and Project Planning for the Forward Physics Facility in Preparation for the 2024-2026 European Particle Physics Strategy Update: https://arxiv.org/abs/2411.04175**
- **Engineering effort supported from CERN and other institutions.**
- **Several workshops have resulted in the design. FPF8 Jan 21-22, 2025**
- **Snowmass white paper has ~ 400 authors and contributors.**
- **Snowmass Energy Frontier Report: Our highest immediate priority accelerator and project is the HL-LHC, the successful completion of the detector upgrades, operations of the detectors at the HL-LHC, data taking and analysis, including the construction of auxiliary experiments that extend the reach of HL-LHC in kinematic regions uncovered by the detector upgrades.**

The scientific case for the Forward Physics Facility

- Standard Model and Neutrinos
  - Expected data set ~10^6 ν_μ ~10^5 ν_e and ~10^4 ν_τ interactions from HL-LHC. x 100 compared to estimates for the current program with FASER/FASERnu and SND@LHC
  - Unique impact on HL-LHC discovery potential, QCD, astrophysics, and neutrino physics.
- Broad program for Discovery Science or BSM physics, and rare phenomena
  - Search for dark sector decays to SM particles: dark photons, dark higgs, heavy neutral leptons, axion-like particles.
  - Unique sensitivity to inelastic dark matter. Decays of dark matter into lighter DM and SM particles.
  - DM scattering with electrons or nuclei.
  - Millicharged particles.

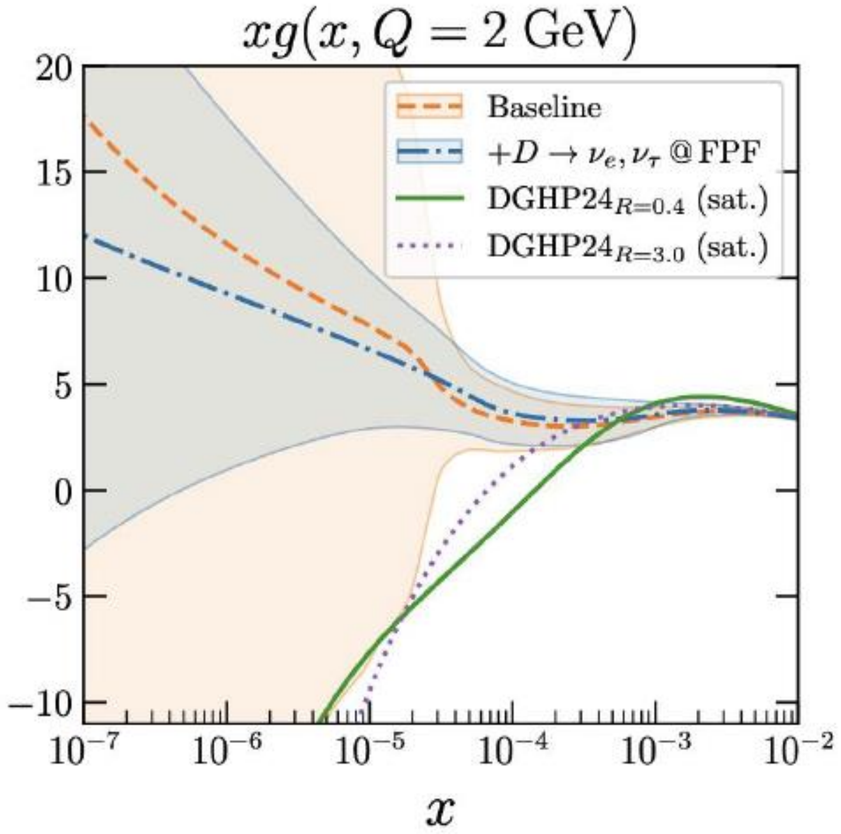
Neutrinos and SM physics

Production → kaons | charm pions | kaons charm



- **FPF experiments detects highest energy laboratory neutrinos. ~10^6 ν_μ ~10^5 ν_e and 10^4 ν_τ from HL-LHC.**
- **Rates ~ 20-50 events/ton/day.**
- **This data allows 1) SM cross sections for astrophysics (e.g. to understand the cosmic ray muon puzzle), 2) Lepton flavor studies with tau, 3) constraints on anomalous neutrino properties. 4) QCD studies to constrain parton distributions down to $x \sim 10^{-7}$**

Enhancing the HL-LHC discovery potential



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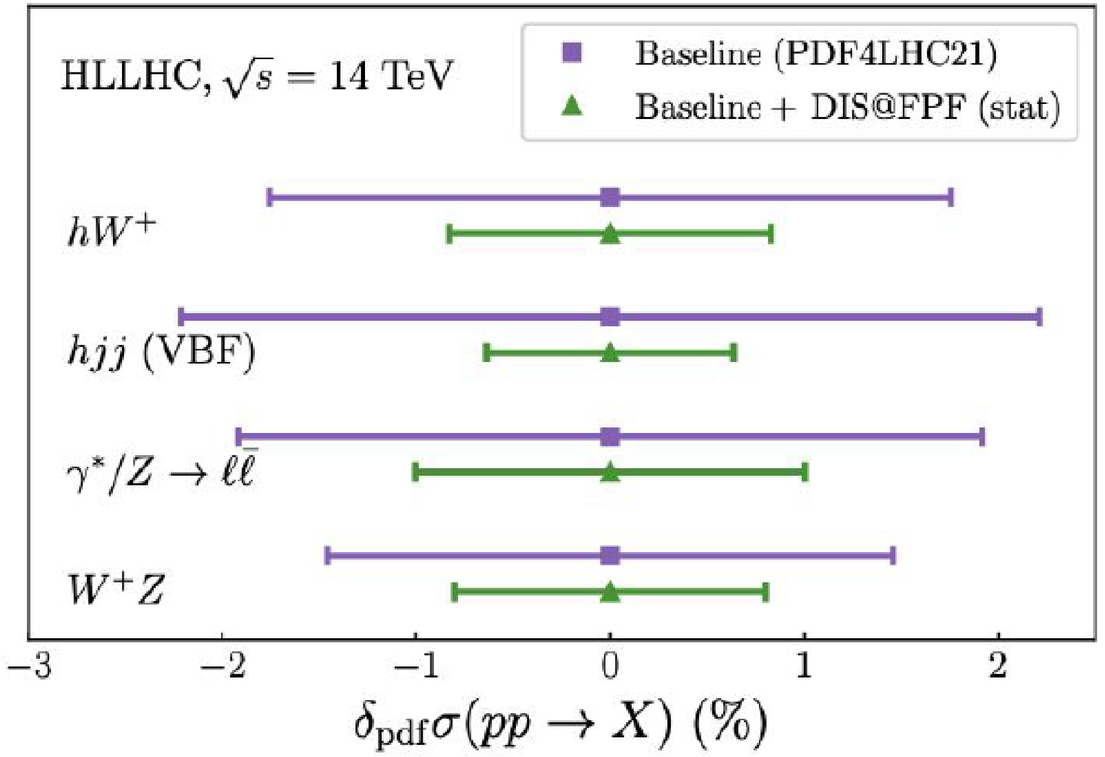

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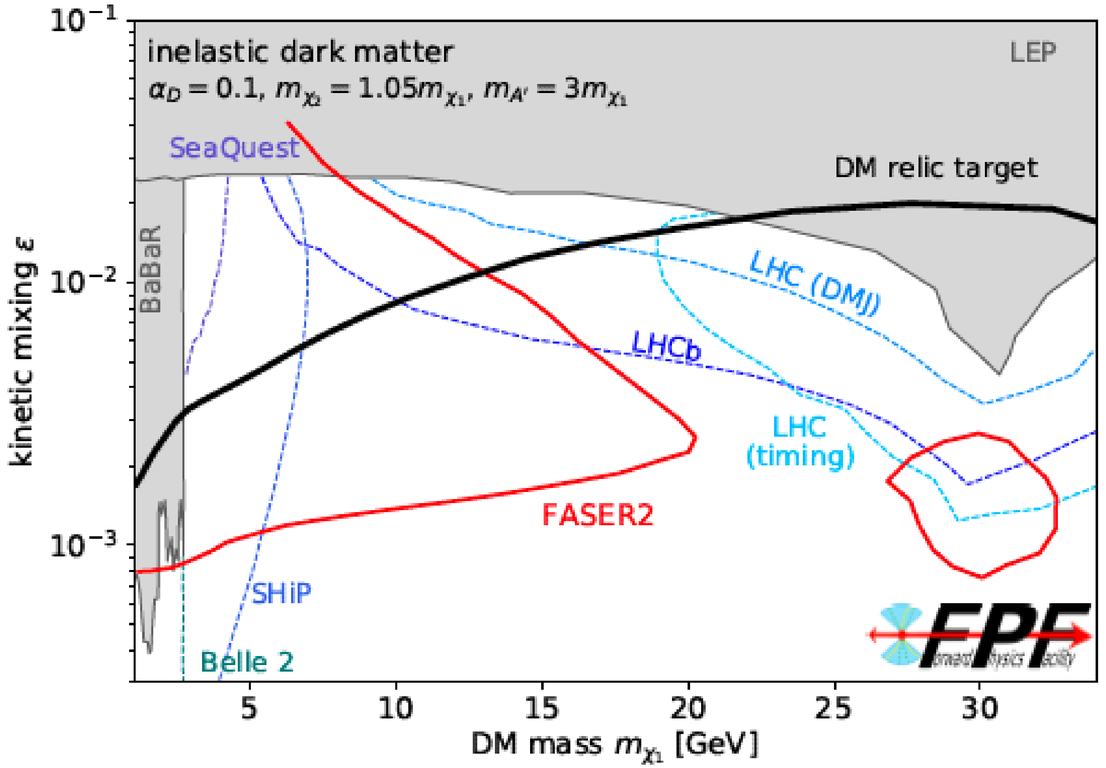
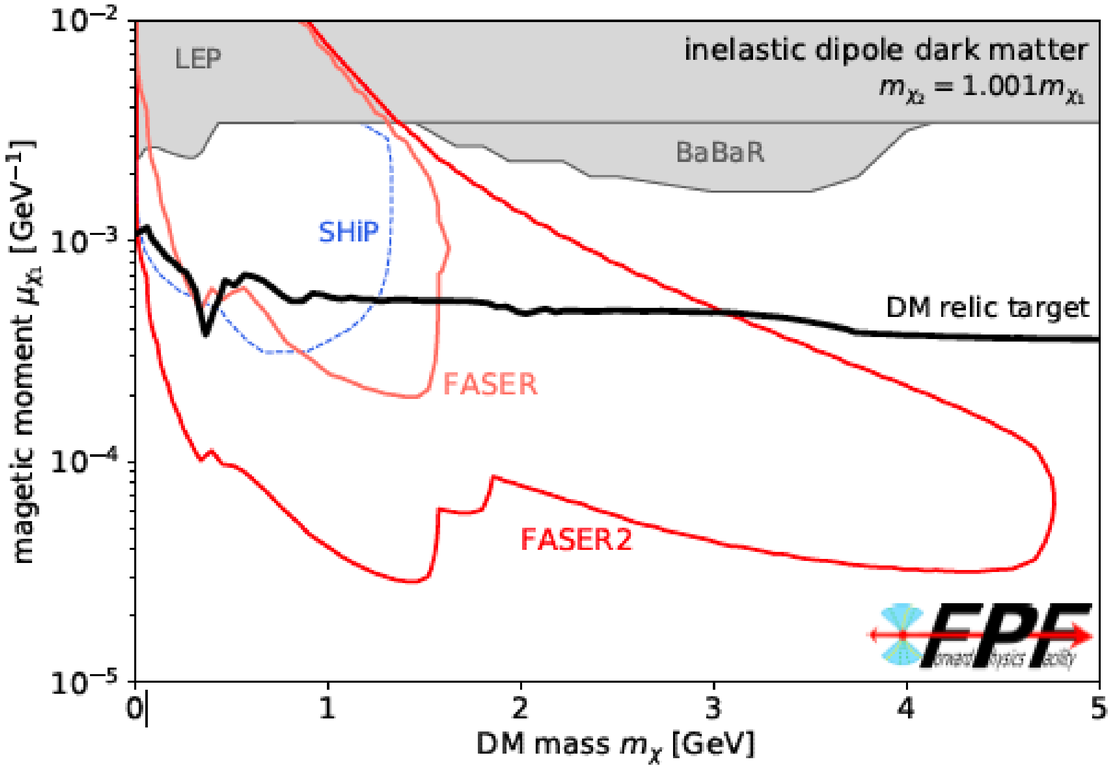
- **The expected ν_e and ν_μ interactions provide PDF constraints in (x, Q^2) regions that affect the core SM processes at the HL-LHC.**
- **Left: small-x QCD at FPF, ability to constraint gluon PDFs at low x.**
- **Right: fit to simulated pseudo-data from FPF detectors to constrain PDF inputs for HL-LHC core processes. Only Statistical uncertainty improvements are shown.**

Dark Sector searches (examples from a wide BSM program)





Example for inelastic DM (almost degenerate states with SM emission)
Signature is a pair of SM leptons. Left: for high mass advantage due to high CM energy.
Right: low mass advantage due to large boost. https://arxiv.org/pdf/1810.01879

Millicharged particles and Quirks (examples from a wide BSM program)

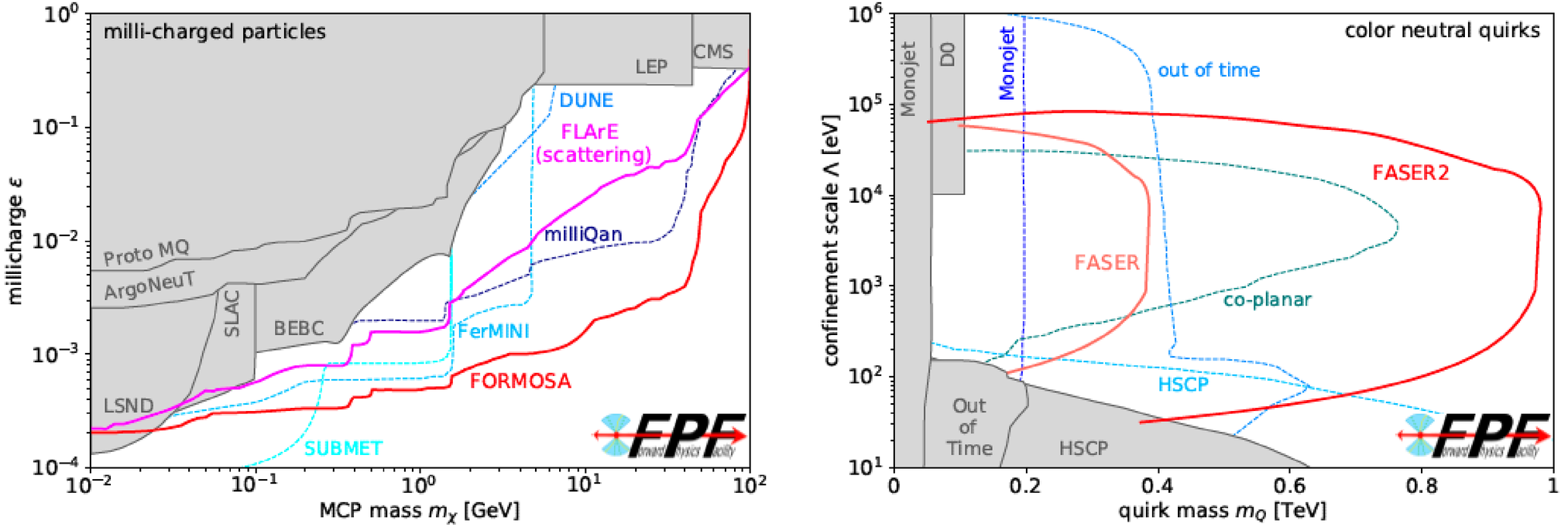


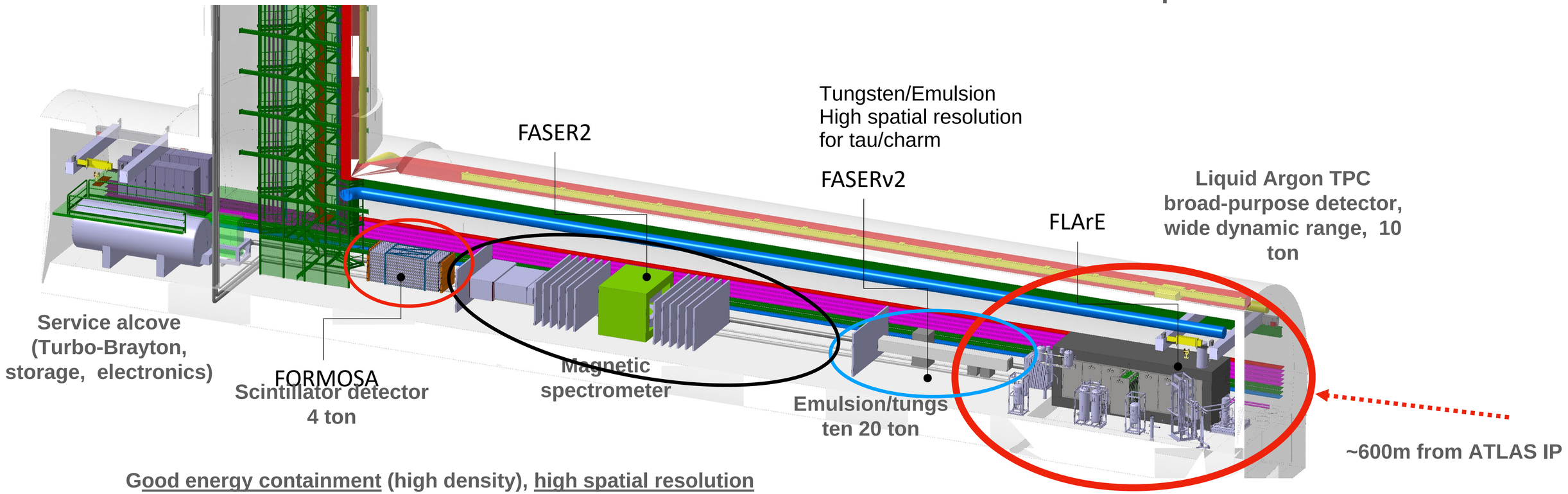
FIG. 5. **New particle searches at the FPF.** Left: The discovery reach of FORMOSA and FLArE for millicharged particles [13, 19]. Right: The discovery reach of FASER and FASER2 for color-neutral quirks [20]. In both panels, we also show existing bounds (gray shaded regions) and projected sensitivities of other experiments (dashed contours).

https://arxiv.org/pdf/2203.05090

Experiments in Forward Physics Facility

Baseline design

FPF covers η > 5.5, experiments on LOS cover η ≳ 7



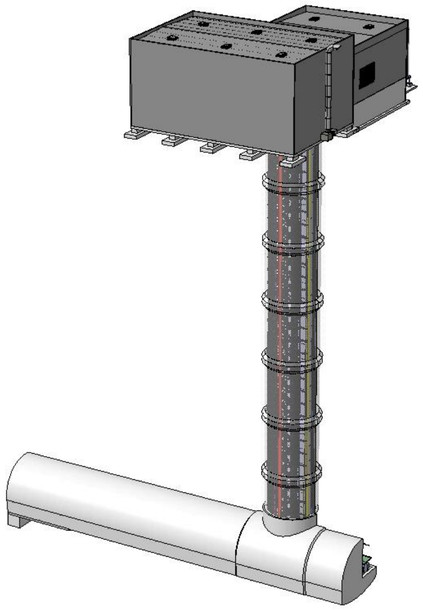
Good energy containment (high density), high spatial resolution (for τ neutrinos) and low threshold (for DM scattering)

Detector parameters and physics (summary)

Detector	Design/Parameter	Standard Model Physics	Discovery and Rare Phenomena Physics
FLArE	Liquid argon TPC/10 ton active target/~ns timing/Fe-Scin hadronic calorimeter(40 ton)	High eff. Muon/Electron neutrino spectrum. wider eta coverage, Low purity Tau neutrinos spectrum	LLP interactions with low threshold. Inelastic DM, DM scattering, mCP interactions. Neutrino Tridents
FASERnu2	Tungsten/emulsion/20 ton/high spatial resolution <1micron.	High eff Tau neutrino detection. Charm detection. Muon/electron neutrino spectra at high eta	DM scattering, Neutrino Tridents
FASER2	Magnetic Spectrometer/SciFi/~4 T-meter/aperture ~ 3mx1m; dp/p ~ 5% @ TeV	High acceptance Muon spectrometer for FLArE and FASERnu2	Dark sector decays of neutral LLPs, Inelastic DM, Quirks
FORMOSA	Plastic Scintillator Array/high resolution dE/dx (4 layers, 4 tons)	—	Millicharged particles with sensitivity q~10^{-3} Quirks

Each detector is designed to have unique scientific reach. System of detectors enhance the scientific case for the facility. Simulations are in progress to evaluate acceptances and resolutions.

Status of Technical Studies and Integration



ENGINEERING DEPARTMENT

CERN beam physics group: Vibration/tunnel movement are not expected to be an issue either during construction or operation.

CERN radioprotection group: Can access cavern for trained personnel during beam operations.

Muon backgrounds: CERN fluke team, muon flux will be < 1 Hz/cm^2 in a region 1 meter around LOS. Generally acceptable for experiments.

CERN site investigation: Geological conditions appear good for proposed excavation.

CERN safety: Addition of over-pressure safety corridor allows a single access point (no physical connection to LHC).

The cryo system to be separated underground; has an industrial cooler(Turbo Brayton), LAr and LN2 storage ; all sized to be installed thru shaft.

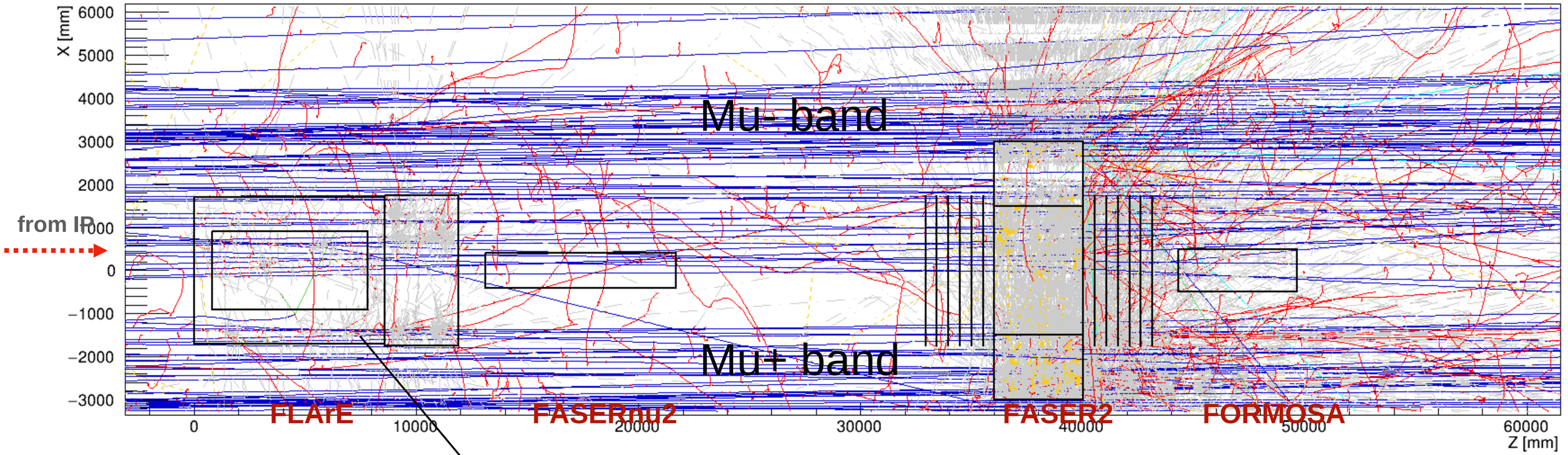
Conceptual installation plan for all services and detectors developed at FPF8.

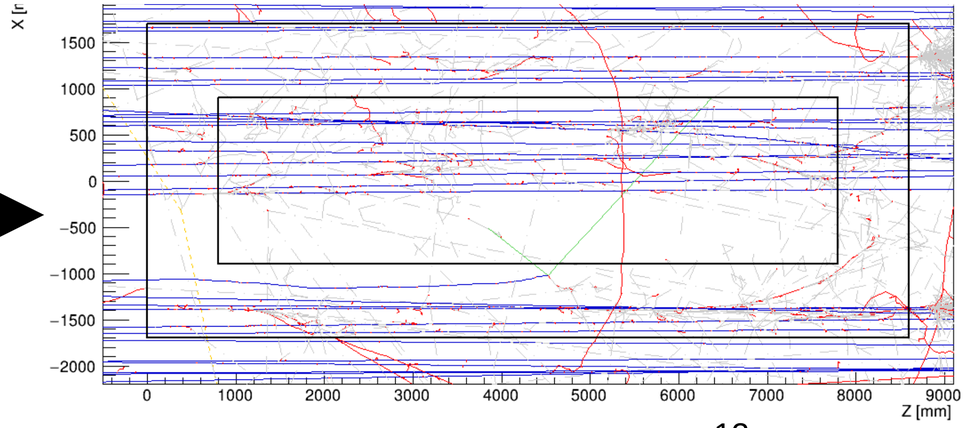
Full simulation of muon backgrounds shows that detector background rates on LOS are manageable

Event display from G4 simulations

ZX Projection

Overlayed background events in **187.5 us** (FLArE acquisition window)





Zoom on FLArE volume

The muon rates (0.5 Hz/cm^2) and space charge effects are manageable around the line of sight.

$\mu^{\pm}$: blue
$e^{\pm}$: red
n: orange
γ: gray
p: black
π^{0}: magenta
$\pi^{\pm}$: cyan
other: green

Conclusion

- **A scientific opportunity with Forward Physics Facility is ready with excellent design for a new underground hall and an initial suite of experiments. https://arxiv.org/pdf/2411.04175**
  - **Headline physics interest for FPF experiments is world class.**
    - **Neutrinos in the 1 TeV range: ~200-500 events/ 10 ton/day**
    - **Tau neutrino flux and associated heavy flavor physics: ~1-2 events/10 ton/day**
    - **And discovery science with BSM searches and rare phenomena.**
- **After 8 dedicated workshops and technical meetings, most integration, safety issues are understood and documented.**
- **Unique experimental features: A. There will be no interference to HL-LHC during construction or operation. B. The LHC magnets provide shielding from MUONs, C. location has over 200 meters of rock shielding. D. The boost from LHC energy provides excellent experimental signatures.**
- **A preliminary cost estimate for the facility (from CERN experts) is ~49MCHF and detector core costs of ~40 MCHF. A schedule can be developed rapidly.**
- **This project is for young capable international physicists who are needed for the future.**

Photograph from FPF8 workshop at CERN Jan 25 (114 registrants)

Information Sheet

- Effort Name: Forward Physics Facility and Experiments at the High Luminosity LHC.
- Short Abstract: The **Forward Physics Facility (FPF)** is a proposed new underground cavern at the Large Hadron Collider (LHC) that will host a suite of new experiments during the High-Luminosity LHC (HL-LHC) era. The existing large LHC detectors have un-instrumented regions along the beam line, and so miss the rich physics opportunities provided by the enormous flux of particles produced in the far-forward direction. A diverse set of experiments are planned to detect millions of neutrinos and a wide range of new physics possibilities.
- Contact: https://fpf.web.cern.ch/
- Useful Link: https://pbc.web.cern.ch/ , https://pbc.web.cern.ch/fpf-resources
- White papers: https://arxiv.org/abs/2411.04175