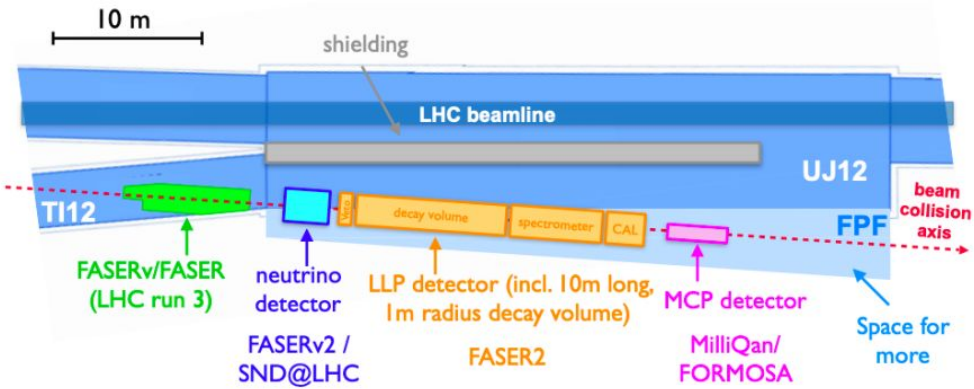
Forward Physics Facility kickoff meeting

Summary talk

Felix Kling

SLAC NATIONAL ACCELERATOR LABORATORY



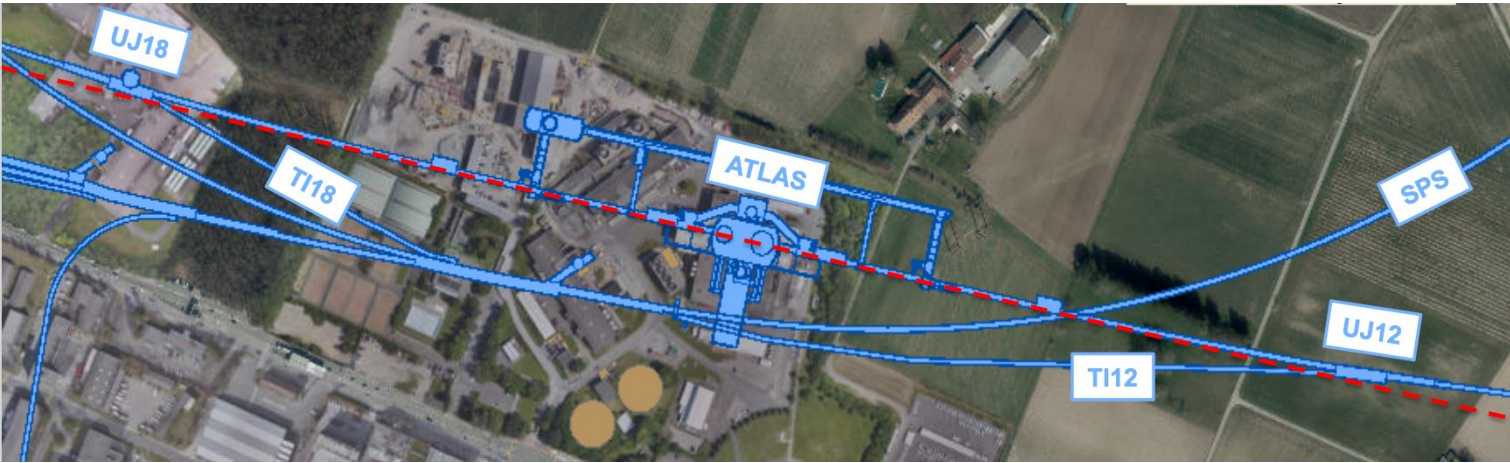
The Forward Physics Facility

see Jonathan Feng's talk

In recent years, it has become clear that there is a rich SM and BSM physics program that remains to be explored in the far forward region.

The proposal: create a Forward Physics Facility for the HL-LHC to house a suite of experiments that will greatly enhance the LHC's physics potential for neutrinos, LLP searches, QCD, dark matter, dark sectors, and cosmic ray physics.

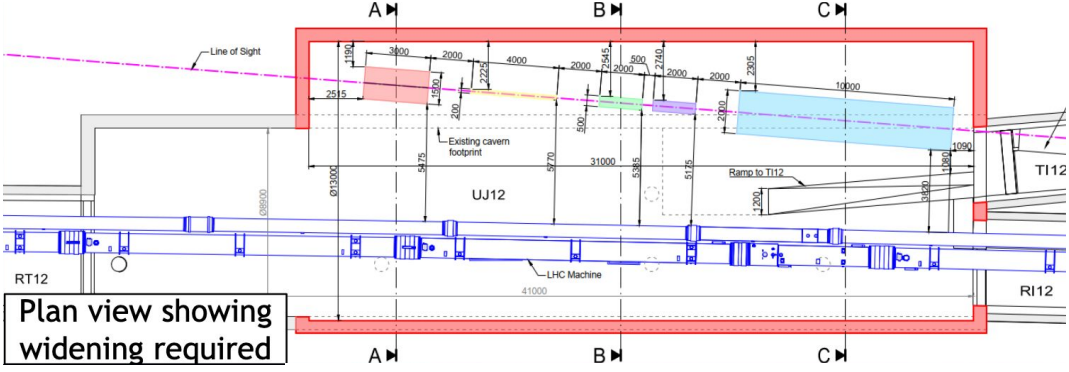
Two promising locations: caverns UJ12 and UJ18, each ~500 m from ATLAS and shielded from the ATLAS IP by ~100 m of rock, creating extremely quiet environments.



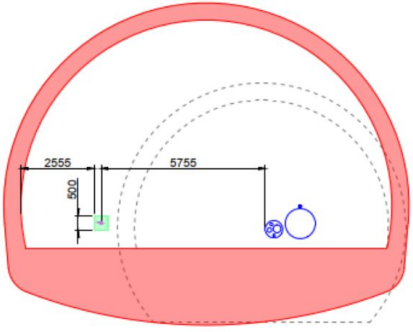
Civil Engineering

see Jonathan Gall's talk

A first design/feasibility study was performed. Widening of TI12 is one option.

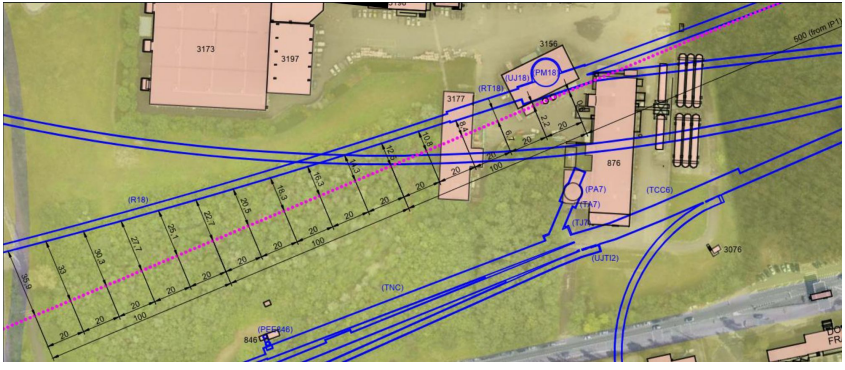


Plan view showing widening required



B–B

A new shaft/experimental area will be considered.



Next Steps

- Choose option(s) to progress
- Further discussions with integration, CERN coordination, Transport, etc
- Produce full concept design
- Confirm outline feasibility
- Schedule / Cost estimate

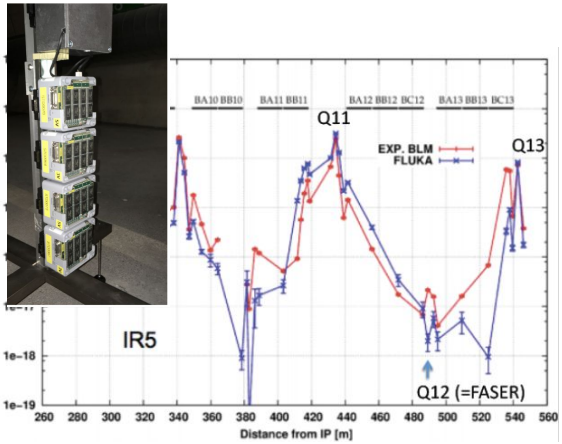
Environment and Services

see Jamie Boyd's talk

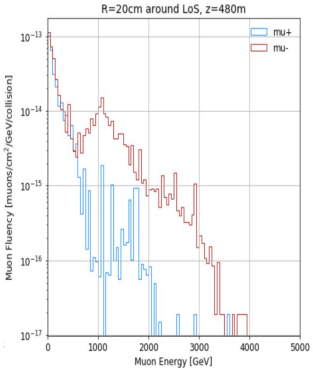
In preparation for FASER, particle fluxes and radiation were studied in TI12/TI18 with simulations and measurements

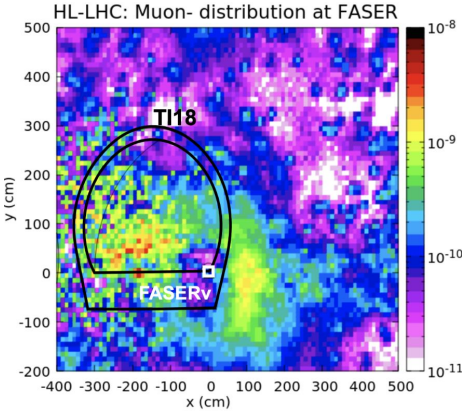
TI12 /TI18 are ideal to place experiments – and the FPF in UJ12 / UJ18 would likely be similar

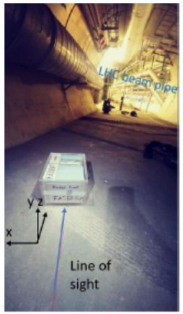
The installation of common services for the FPF would be a big advantage for preparing the experiments

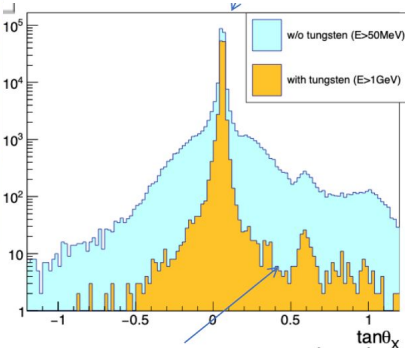


Muon flux: FLUKA









BSM Physics

see Ahmed Ismail's talk

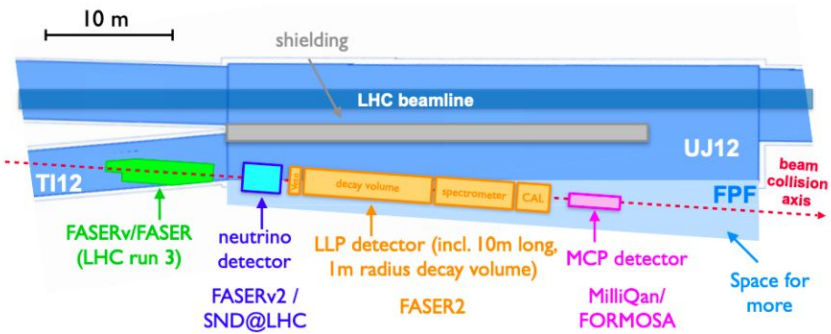
Myriad probes of BSM physics

Long-lived particles

Neutrinos

Dark matter

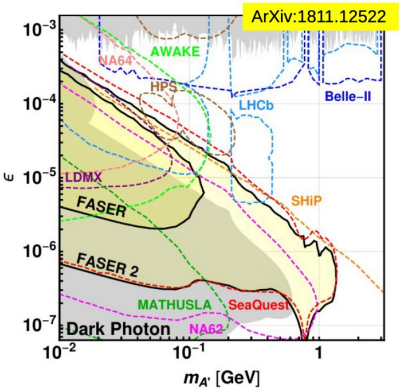
Millicharged particles

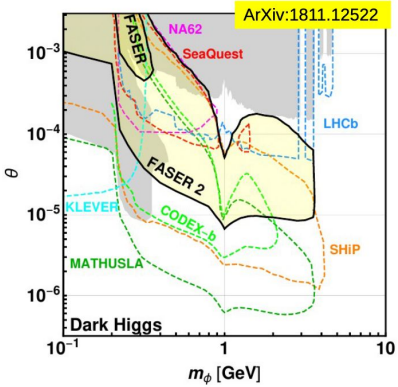


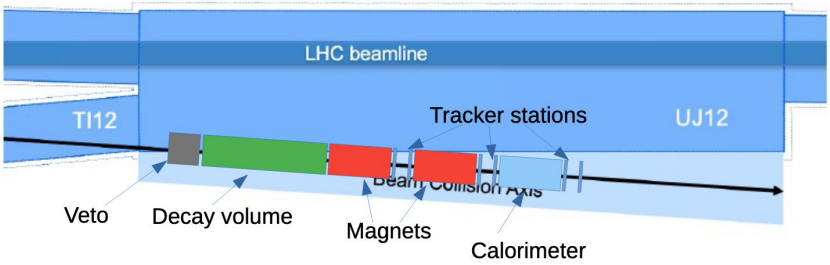
Long-Lived Particles: FASER 2

see Brian Peterson's talk

FASER 2 would be sensitive to a large range of LLP models. Its sensitivity mostly complements or matches other proposed LHC and fixed target experiments





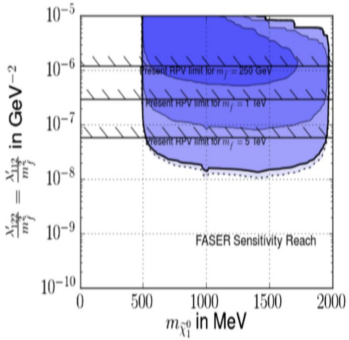


Example FASER 2 layout in FPF

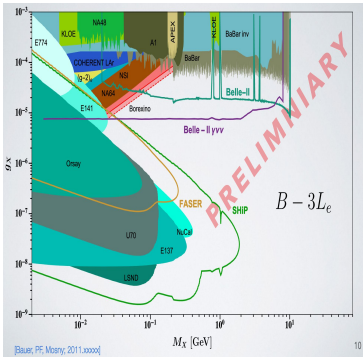
more long lived particles @ FPF

see LLP parallel session

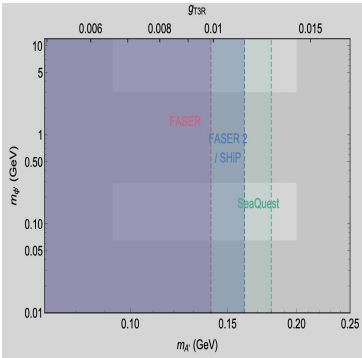
Many non-minimal LLP models can be probed as well.



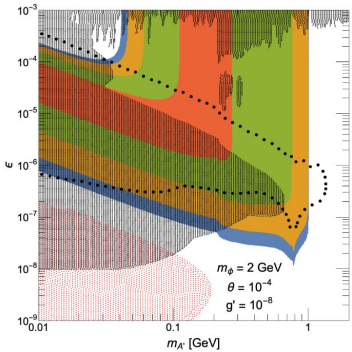
Herbi Dreiner
RPV Neutralino



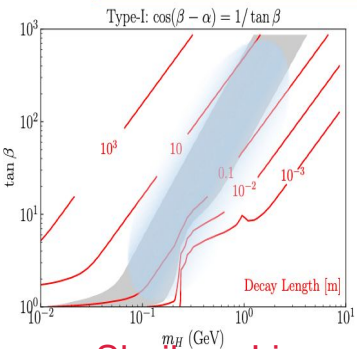
Patrick Foldenauer
Hidden Photons



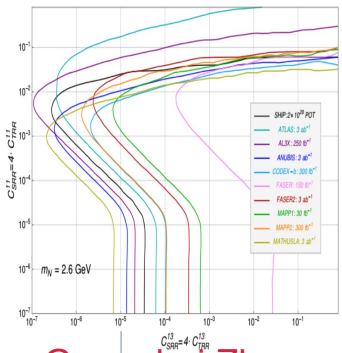
Sumit Ghosh
U(1)T3R Bosons



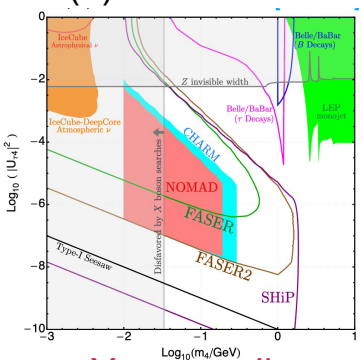
Takashi Shimomura
A' from dark Higgs



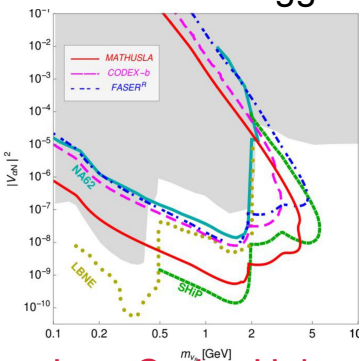
Shailong Li
2HDMs



Guanghui Zhou
HNLs + dim6 operators



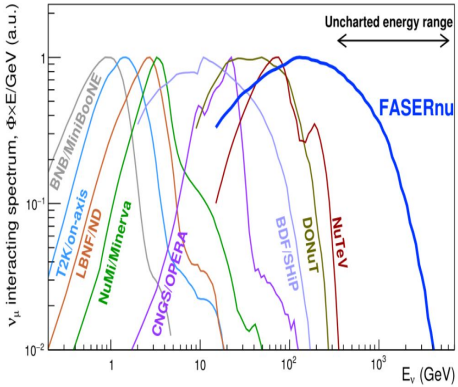
Yongsoo Jho
HNLs + A'



Juan Carlos Helo
HNL & ν masses

Neutrinos: FASERnu 2 & SND@LHC

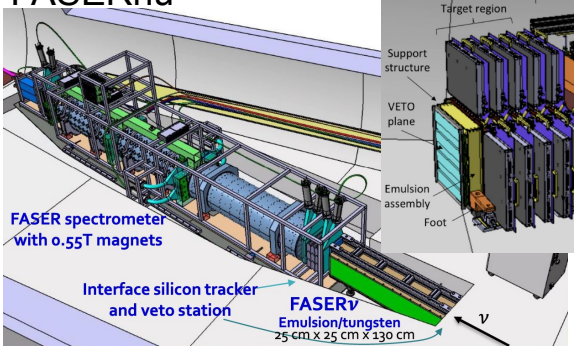
see Aki Ariga's and Giovanni De Lellis talk

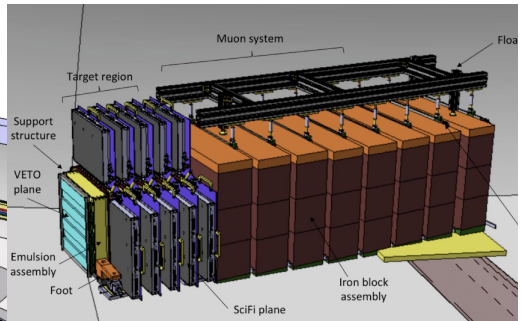


LHC provides high energy neutrino beam

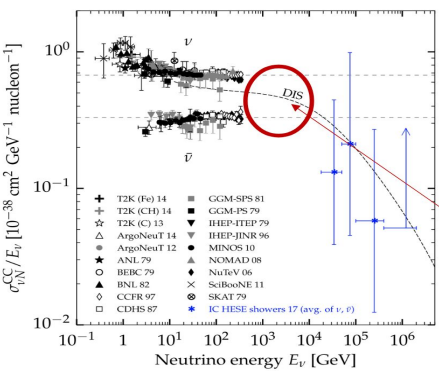
2 experimental collaborations propose experiments

FASERnu





SND@LHC



broad spectrum of possible neutrino physics probed

Production

14 TeV p-p collision ≡ 100 PeV int in fixed target ($\sqrt{s}$ ~ 10 TeV)

Prompt neutrino production → Input for neutrino telescopes

QCD (charm/gluon PDF, intrinsic charm)

Propagation

Unique energy and baseline, $L/E \sim 10^{-3}$ m/MeV

Neutrino oscillation at $\Delta m^2 \sim 1000$ eV^2

Interaction

Neutrino cross sections, LU

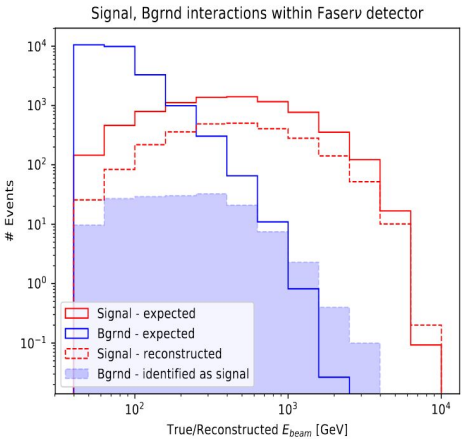
Nuclear PDFs (strangeness)

Heavy flavor physics (τ, charm, beauty)

New physics effects
Non standard interactions

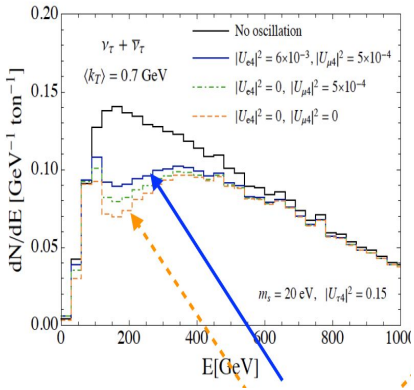
more physics with neutrino detectors @ FPF

see Neutrino and QCD session



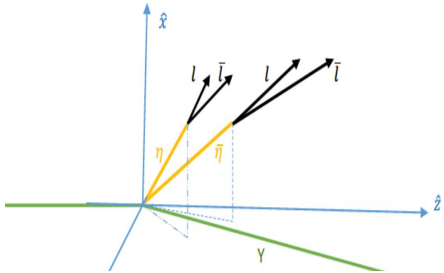
Roshan Abraham

Neutral Current Interactions



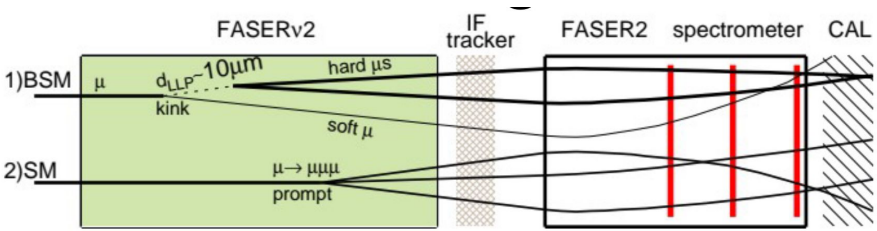
Yu Seon Jeong

neutrino oscillations



Yasaman Farzan

long-lived particles



Incident muon (front veto activation)

vertex reconstruction

←matching

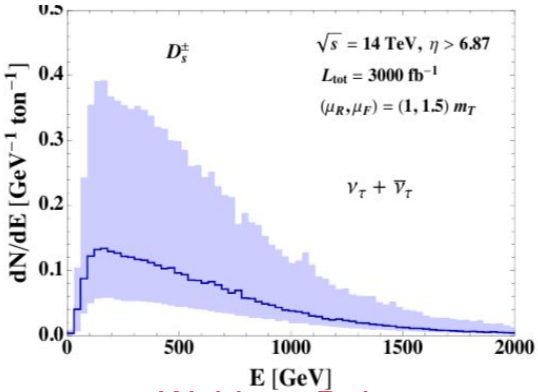
3 muons going through the detector

Sebastian Trojanowski

FASERv as muon beam dump

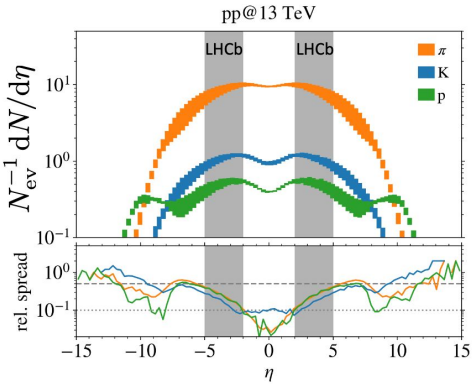
QCD considerations @ FPF

see Neutrino and QCD session



Weidong Bai

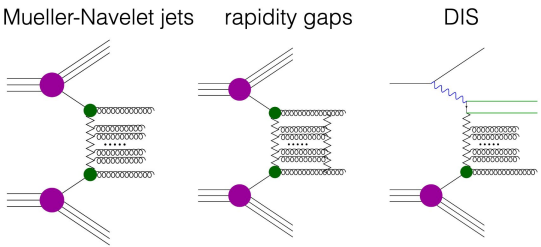
neutrino fluxes in pQCD



Hans Dembinski

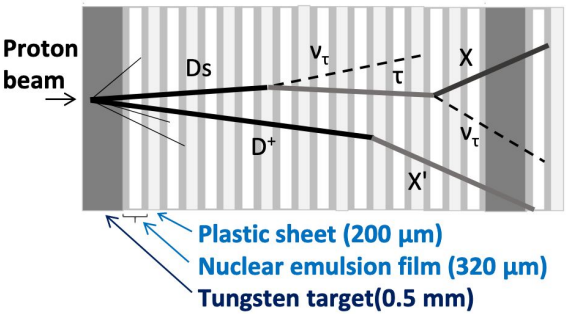
Forward QCD and Muon Puzzle

Rich phenomenology, e.g.



Grigorios Chachamis

Rich phenomenology of forward QCD

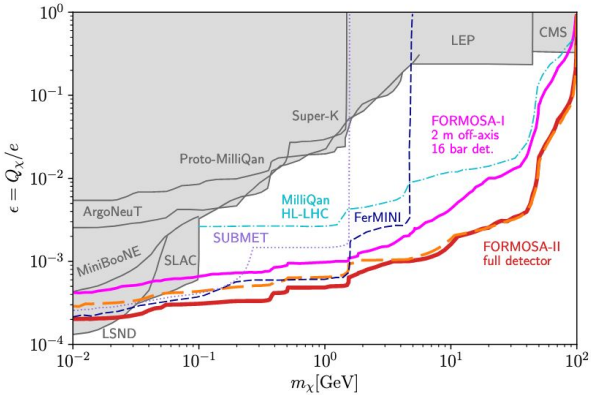


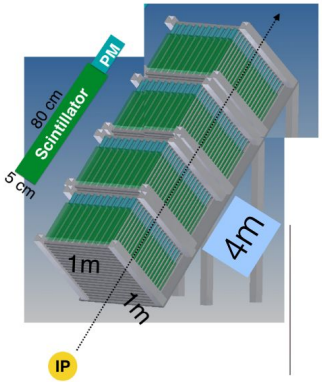
Osamu Sato

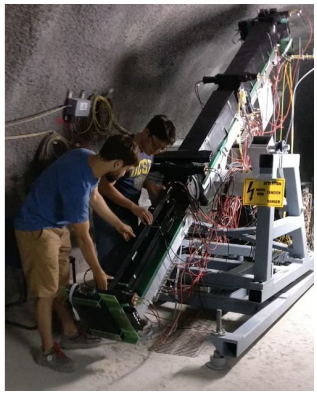
Constrain charm production with DsTau

Millicharged Particles & MilliQan/FORMOSA

see Chris Hill's, YuDai Tsai's & Saeid Foroughi's talk







With a more advantageous location and free of spatial constraints, installing a milliQan-like detector in the FPF for HL-LHC is an obvious next step for this type of experiment

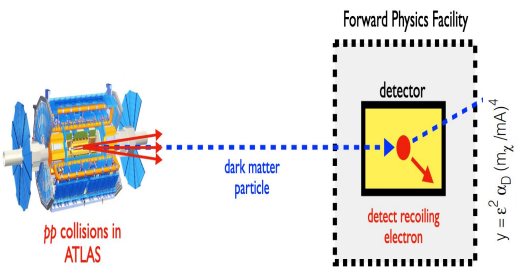
- *Baseline design of 1 m x 1 m x 4 m device would easily provide world-leading sensitivity over a large portion of relevant parameter space*
  - **Highly configurable detector, potential to do even better**
- Can confirm understanding of backgrounds by relocating milliQan demonstrator to FASER cavern

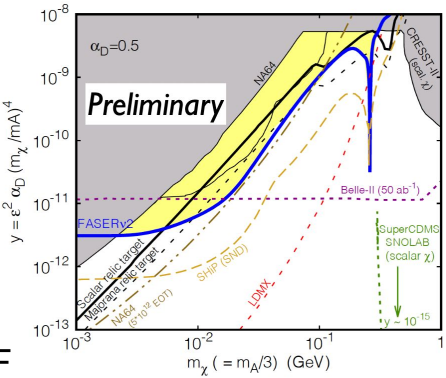
more physics potential:

- Heavy Neutrino EDM
- Tau Neutrino MM
- Neutrino Interactions

and even more physics opportunities

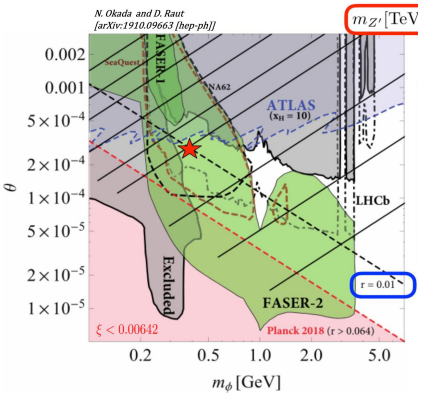
see Dark Sector and Cosmology session





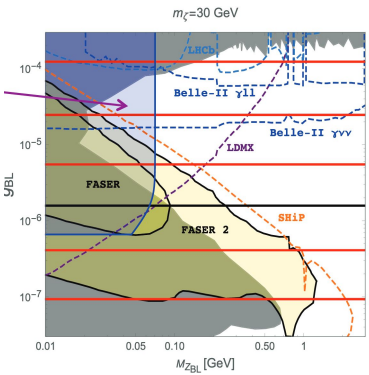
Brian Batell

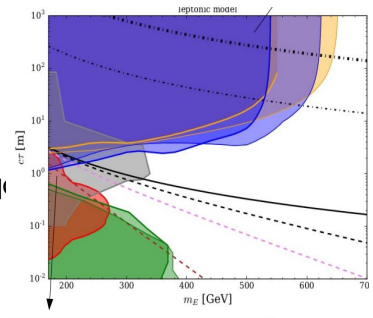
Dark Matter Scattering @ FPF



Digesh Raut

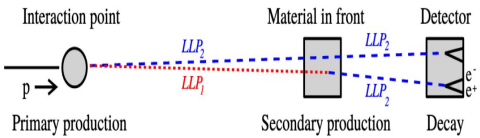
Probing Models of Inflation

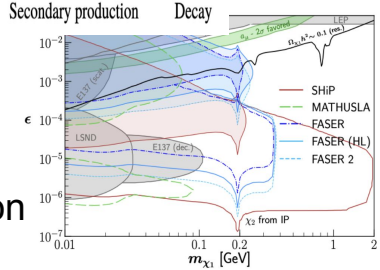




Nobuchika Okada & Dipan Sengupta

probing freeze in DM Models @ FPF



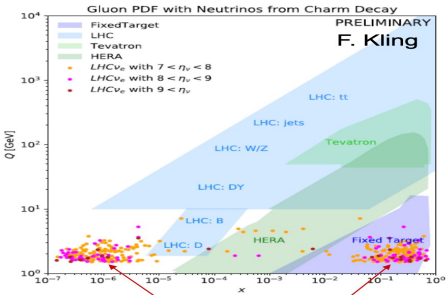


Krzysztof Jodlowski

secondary particle production

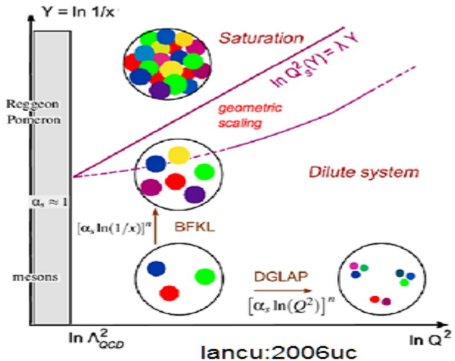
PDFs @ FPF

see Pavel Nadolsky's and Maria Garzelli's talk

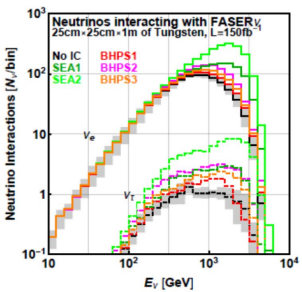


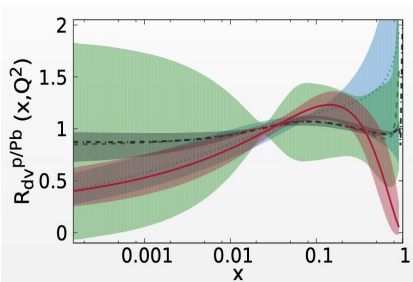
Neutrino experiments @ FPF will test QCD in novel kinematic regimes where little or no experimental measurements exist

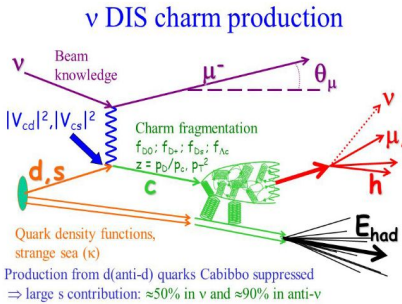
We don't know which QCD formalism(s) are appropriate in these regimes

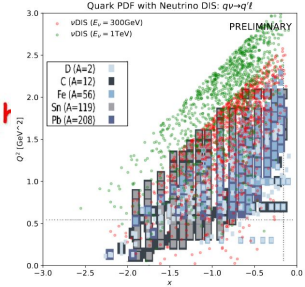


We can test transition to small-x factorization, higher-twist enhancements in charm production, DIS on heavy nuclei, strange sea PDFS









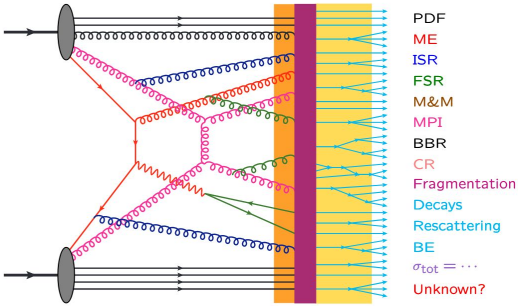
PDFs measurements at the FPF will be most successful as a part of a larger physics program that includes efforts at LHCb, the EIC, and possibly LHeC.

General Purpose Generators @ FPF

see Torbjorn Sjostrand's and Frank Krauss talk

Frank: "forward physics often overlooked (certainly true for SHERPA)"

An event consists of many different physics steps to be modelled:



Fragmentation can include clusters, strings, ropes, QGP, shove, ...

Torbjorn: "forward physics is extensively modelled in PYTHIA ... but little tested"

Holger: "Is it a tuning or a modelling problem?"

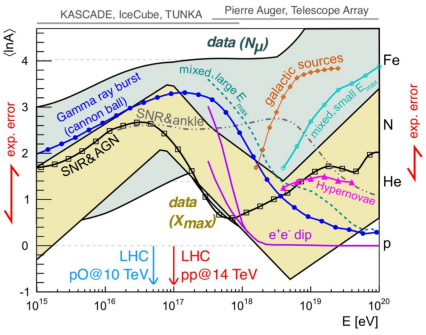
- in the absence of (quantitative) 1st principles, need data
- tool-chain considerations:
  general-purpose MC $\longrightarrow$ RIVET $\longleftarrow$ HEPDATA
- absence of data/analysis code for some core meadurements from HERA, Cosmic Rays, fixed target ...
  $\longrightarrow$ would be great to fix this
- Compare DIS and pp forward spectra
- Compare rate of different forward baryons (p, n, Λ, ...) and mesons (π^+, π^-, K^0_S, ...)
- Correlate central and forward activity

FPF data can help

- forward physics driven by low-$p_\perp$ QCD
  $\longrightarrow$ link with MPI and their (perturbative) modelling
  $\longrightarrow$ link with BFKL/saturation physics (?)
- diffraction added "ad hoc"
  $\longrightarrow$ no true first-principles model to link with perturbative QCD
  $\longrightarrow$ must improve (links with) theory
- add-on: hadronization & beam remnants
  $\longrightarrow$ phenomenological models only
- from a theory point of view:
  wild dream: construct an integrated QCD-inspired parton-based model to combine soft and perturbative physics

CRMCs @ FPF

see Sergey Ostapchenko's and Tanguy Pierog's talk



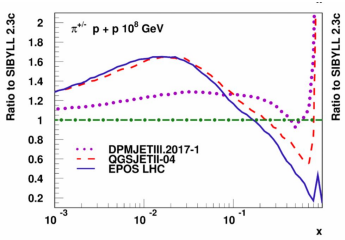
Based on Kampert & Unger, Astropart. Phys. 35 (2012) 660

Tanguy: with muons current CR data are impossible to interpret: Mass from muon data incompatible with mass from Xmax.

New input from LHC crucial to reproduce EAS data consistently: too large uncertainties in model for forward spectra and light ion interactions.

Of highest importance for very high energy cosmic ray studies have been LHC measurements

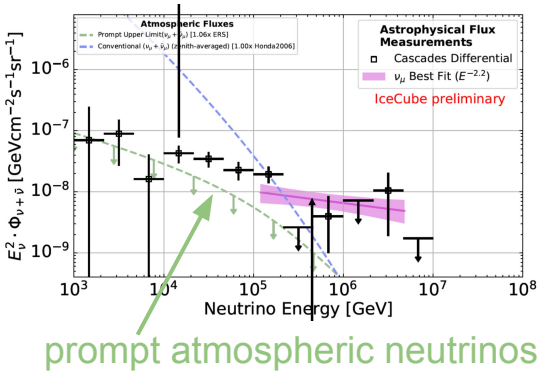
- **Most "natural" explanation given by a change in pion charge ratio.**
  - Other possibilities limited by X_{max} (multiplicity, inelasticity)
- **Large differences observed in hadronic interaction models.**
  - Different type of hadronization (string like or satistical decay)
  - Different energy spectra
- **More data are necessary to constrain the model in relevant kinematic space.**
- **Possibilities open by FPF to be studied**
  - Muon charge ratio ?
  - Neutrino flavor ratio ?



2. Combined studies with forward & central LHC detectors may
   - reveal the origin of the discrepancy between the results on σ_{pp}^{SD}, obtained using Roman Pots & rapidity gap techniques
   - disentangle the contributions of low & high mass diffraction
   - discriminate between the very basic model approaches to the treatment of constituent parton Fock states

Cosmic Neutrinos @ FPF

see Francis Halzen's and Dennis Soldin's talk

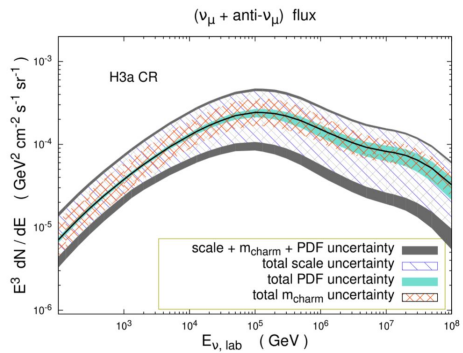


prompt atmospheric neutrinos

in order for IceCube to:

- make precise measurements of the flux of cosmic neutrinos,
- measure neutrino oscillations at PeV energy over cosmic distances,

we need accelerator measurements of the high energy and large rapidity charm production cross sections,



[PROSA Collaboration, JHEP 04 (2020) 118]

Large uncertainties in prompt flux models due to scale, PDF, charm mass, CR flux

Summary & Conclusions

- Lepton energies relevant for large-scale neutrino telescopes, including transition region of conventional, prompt, astrophysical fluxes, accessible by existing accelerators!
- Multi-particle production in the forward region ($x_{lab} = \gtrsim 0.2$) crucial for air shower models
- Lepton measurements at Forward Physics Facility:
  - Better understanding of high-energy lepton production in the forward region, e.g.
    - Lepton parent multiplicity / composition (i.e. pion, kaon, prompt)?
    - Nuclear effects..?
  - Reduced uncertainties in conventional/prompt neutrino flux predictions
    - → Better understanding of the transition region conv./prompt/astro.
  - Reduced uncertainties in muon production
    - → Reduced uncertainties in CR mass composition measurements
    - → Improved muon (lepton) flux estimates (especially prompt/unflavored)

Thank You!

Summary

We would like to thank all speakers for the very interesting discussions.

The FPF opens up many new opportunities for neutrino physics, long lived particle searches, milli-charged particle searches, PDFs, dark matter and dark sectors, and cosmic rays, significantly extending the LHC's physics program.

We would also like to thank all participants for the nice and valuable discussions.

Outlook

Snowmass Contribution
Forward Physics Facility

1. Overview
2. Facility
   - Location / Design
   - Cost / Schedule estimates
3. Experiments at the FPF
   - LLP Searches: FASER2
   - Neutrinos: FASERv2
   - Neutrinos: SND@LHC
   - Millicharged Particles: MilliQan/FORMOSA
   - …
4. Physics Potential: BSM Physics
   - Long-lived particles
   - Dark Matter
   - Neutrinos
   - MCPs
   - …
5. Physics Potential: SM
   - Implications for PDFs
   - Implications for MC generators
   - Implications for cosmic rays and neutrinos
   - …

The work discussed in this (and the following) meetings will contribute to a whitepaper for the Snowmass 2021 community study and the FPF proposal.

We will have an FPF follow up meeting in February, to report progress on open questions raised in this meeting and to plan the FPF whitepaper.

We hope to see all of you again in the next meeting!