WG3: Working Group for Light Hadron Production

FPF Theory Days 2023

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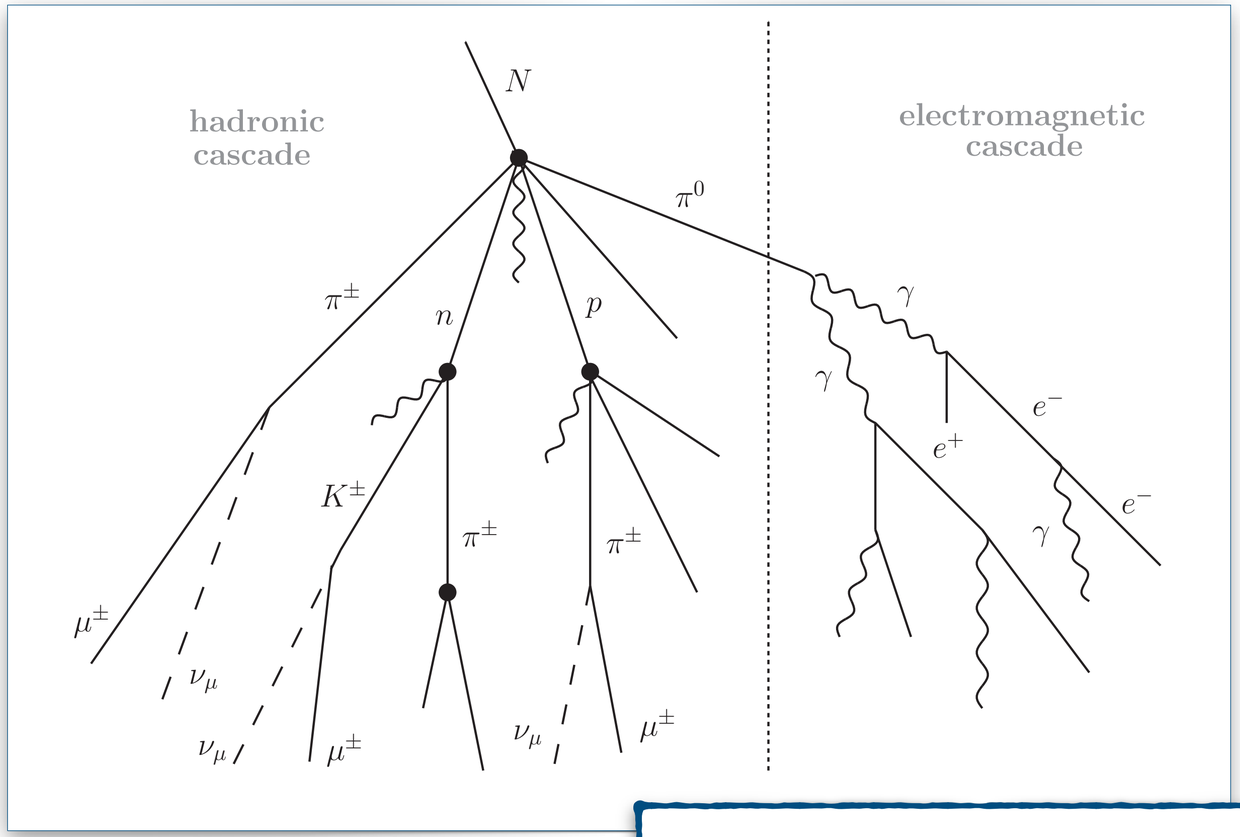
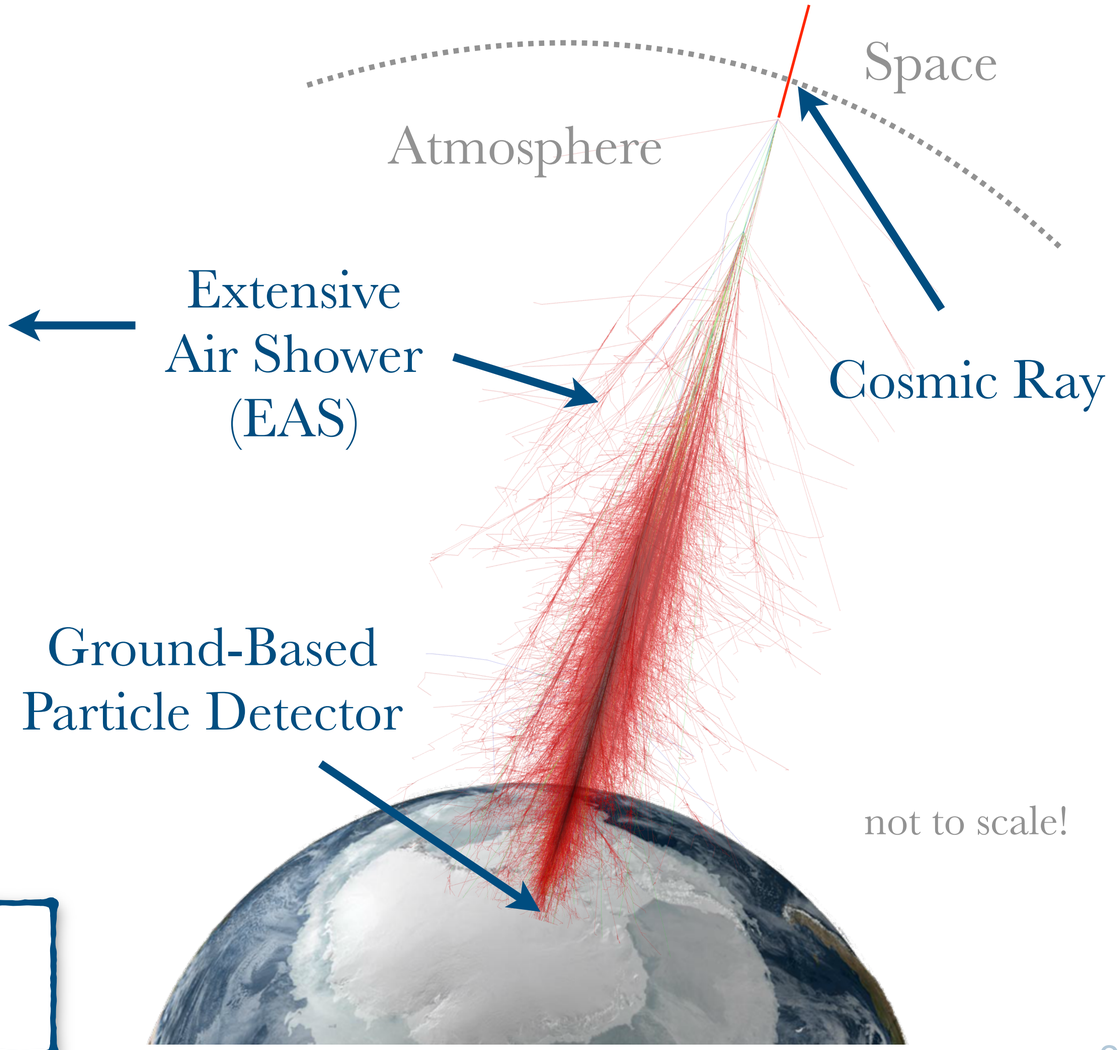
Motivation I

- Large motivation to study light hadron production at the FPF arises from observations of extensive air showers (EAS)





See also Subir's talk

Motivation I

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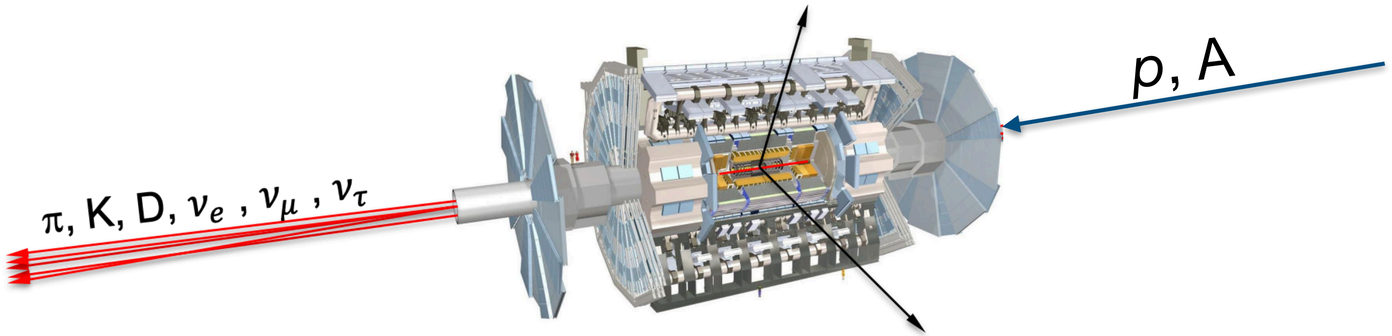
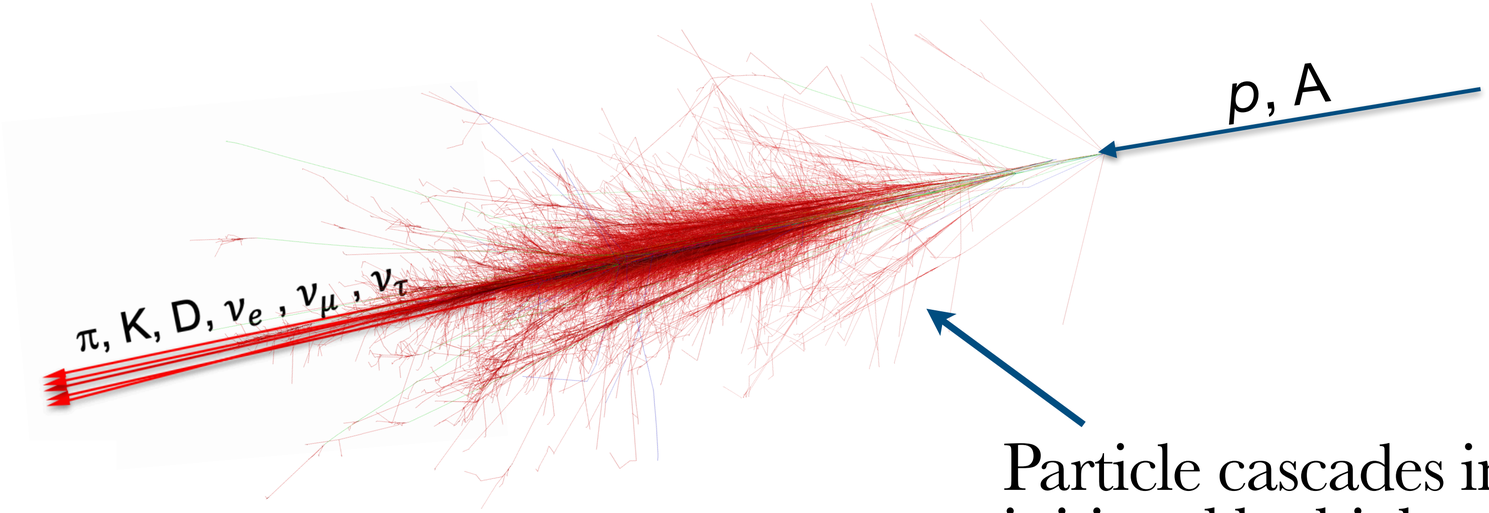
- <u>LHC:</u>



- <u>EAS:</u>

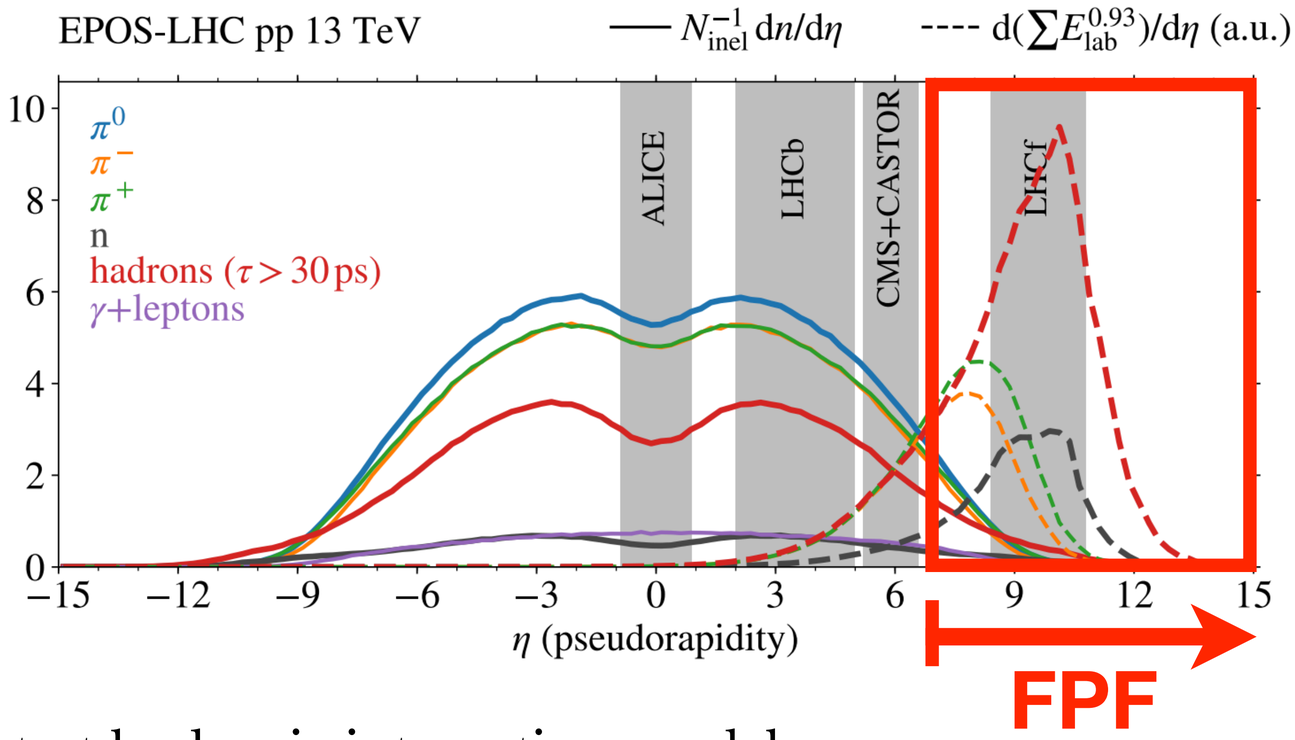


Particle cascades in the atmosphere initiated by high-energy cosmic rays

Motivation I

- Extensive air showers:
  - Particle production in the far-forward region
  - Low momentum transfer
  - Non-perturbative regime
  - Complex particle composition
  - Energies range over many orders of magnitude
- Modeling of particle interactions based on phenomenological models developed for EAS simulations

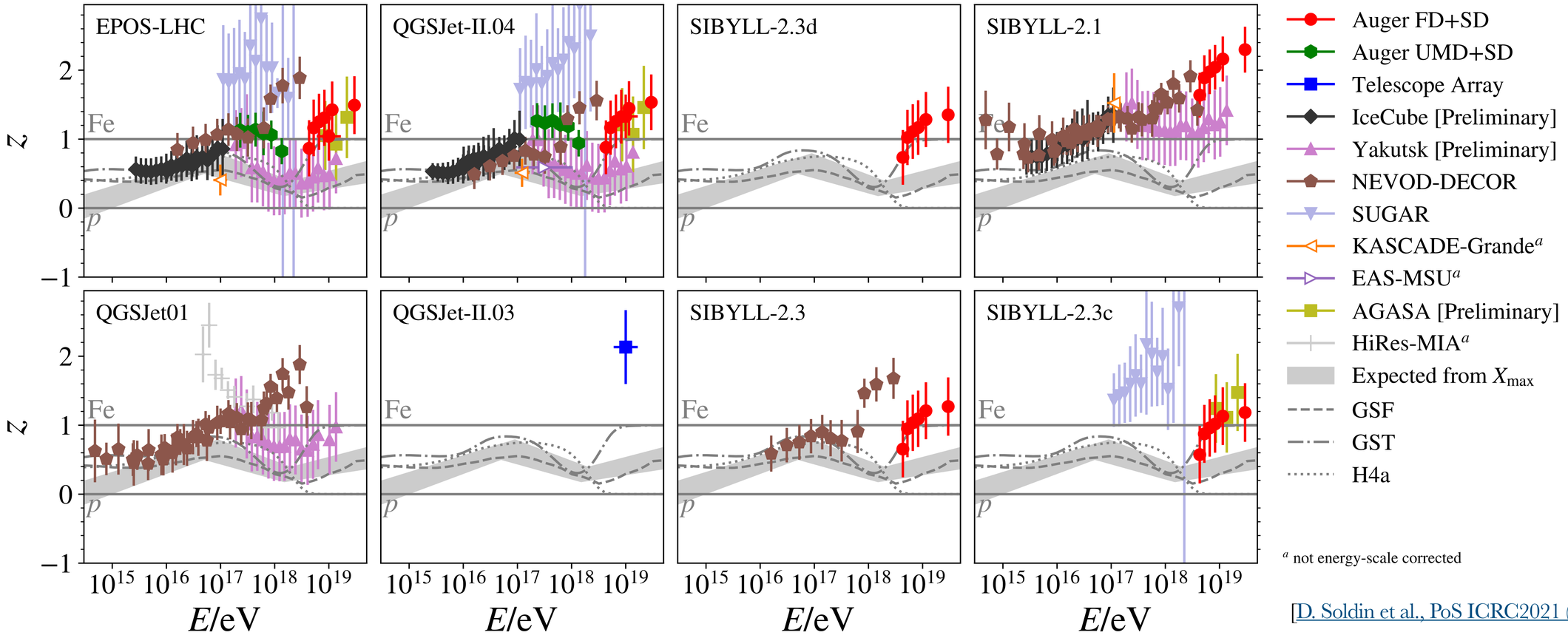
[J. Albrecht et al., Astrophys. Space Sci. 367 (2022)]



- FPF will provide unique opportunities to test hadronic interaction models

Motivation I

- Large discrepancies between data and MC observed in extensive air showers (EAS)



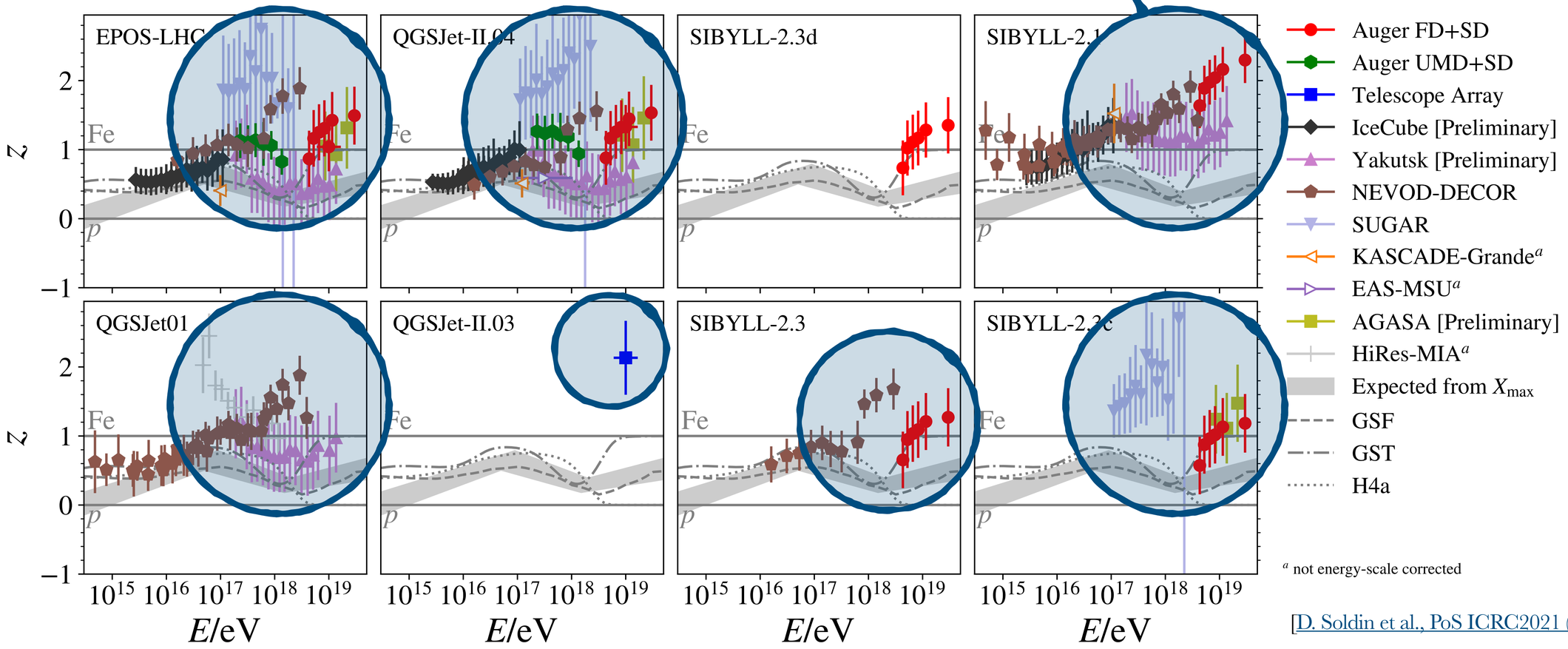
[D. Soldin et al., PoS ICRC2021 (2021) 349]

- Muon measurements and models indicate composition heavier than iron at high energies!

Motivation I

Muon Puzzle

- Large discrepancies between data and MC observed in extensive air showers (EAS)



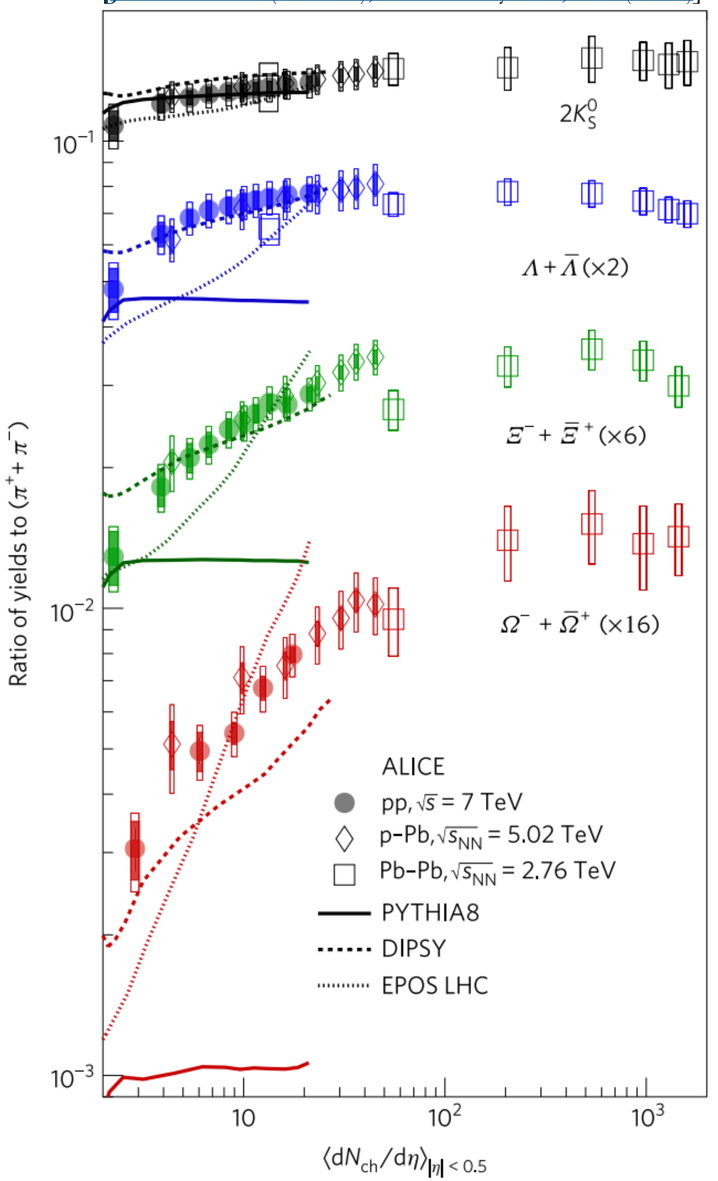
[D. Soldin et al., PoS ICRC2021 (2021) 349]

- Muon measurements and models indicate composition heavier than iron at high energies!

Motivation II

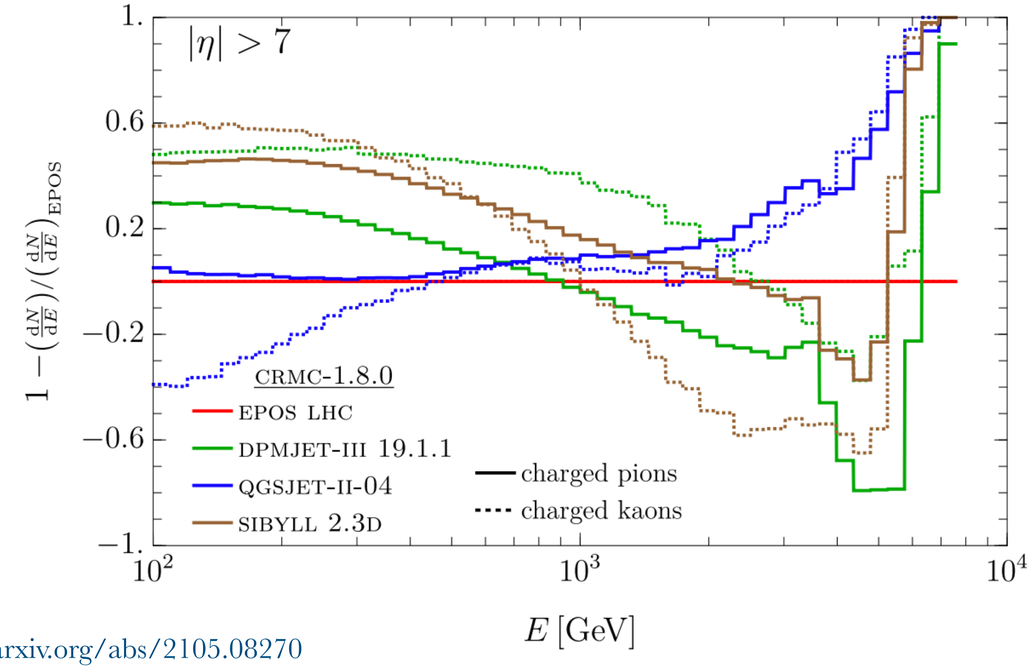
- Evidence for strangeness enhancement reported by ALICE
- Universal enhancement of strangeness production in high-multiplicity events at mid-rapidity ($|y| < 2$)
- Depends on the multiplicity of the event at mid-rapidity, not on the details of the collision system!
- Can this effect also be seen in hadrons produced at forward rapidities?
- Possible explanation for the Muon Puzzle in EAS…
- <u>FPF provides unique opportunities for testing the forward rapidity region!</u>

[J. Adam et al. (ALICE), Nature Phys. 13, 535 (2017)]



WG3 Science Topics I

- Neutrino fluxes at the FPF:
  - Ratio of electron and muon neutrinos is a proxy for the ratio of charged pions and kaons
  - Electron and muon neutrino fluxes populate different energy regions which will help to disentangle them
  - Neutrinos from pion and kaon decays have different rapidity distributions which will help to disentangle them
  - Fast simulation package* available (F. Kling)
  - Further studies needed:
    - MC based on different generators
    - Neutrino fluxes in different detectors
    - Tests of dedicated muon (e.g. strangeness) enhancement models

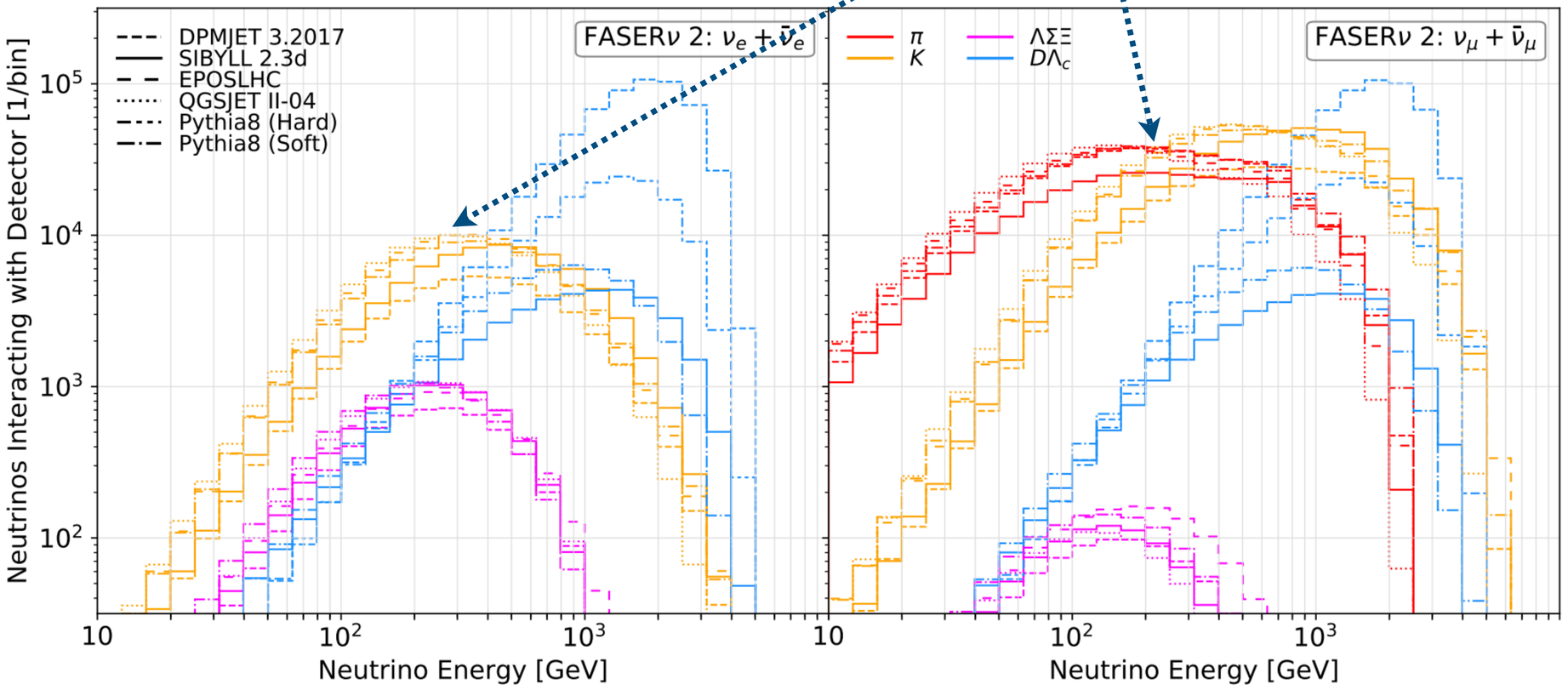


* Simulation code available at: https://github.com/KlingFelix/FastNeutrinoFluxSimulation, see also https://arxiv.org/abs/2105.08270

WG3 Science Topics I

- Neutrino fluxes at FASERν2:

low energy region relevant!



- Predictions differ by a factor of up to 2, much bigger than the anticipated FPF uncertainties

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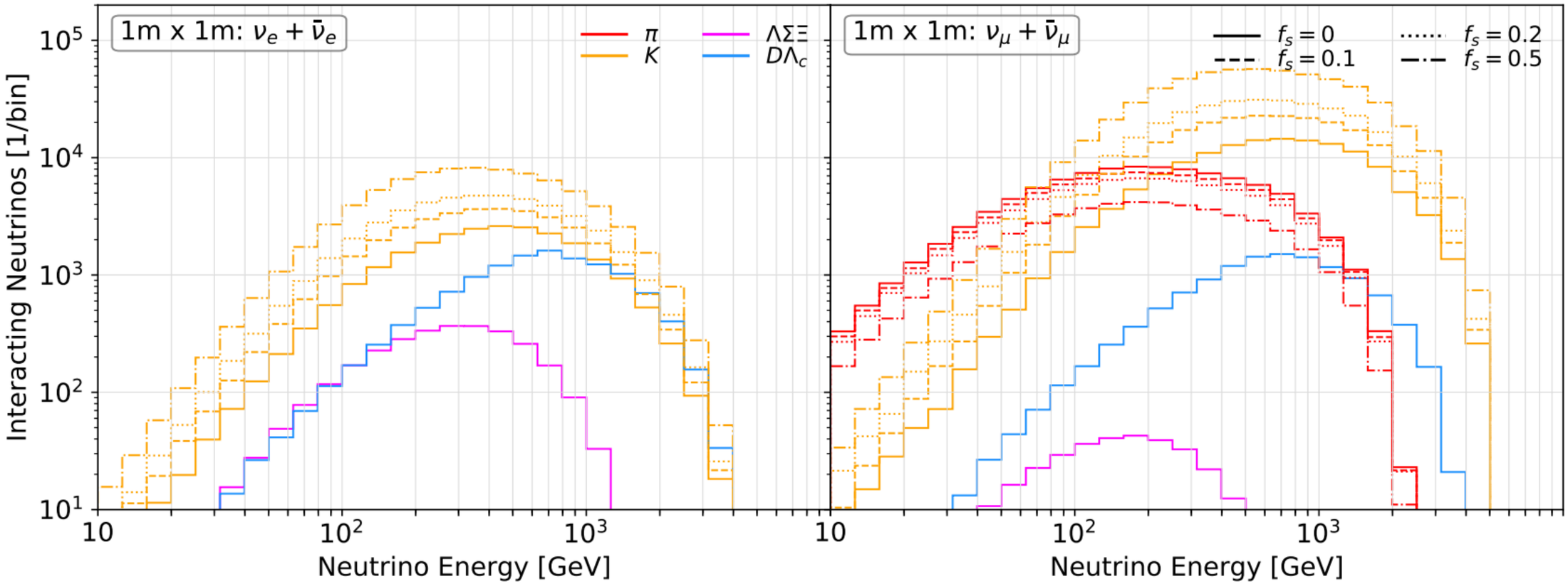
WG3 Science Topics I

- Neutrino fluxes at FLArE:



- Example: strangeness enhancement toy model [L. Anchordoqui et al., JHEAp 34 (2022)]

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WG3 Plans

- Comprehensive MC library of event generators / models to be tested:
  - PYTHIA
    - Monash tune
    - Forward physics tune
  - HERWIG/SHERPA
  - DIPSY
  - DPMJet
    - DPMJet-II
    - DPMJet-III
  - QGSJet
    - QGSJet-II.04
    - QGSJet-III (?)
  - EPOS
    - EPOS-LHC
    - EPOS-LHCr (?)
    - ~~EPOS 3~~
    - EPOS 4 (?)
  - Sibyll
    - Sibyll-2.1
    - Sibyll-2.3
      - ρ^0-enhancement
      - Baryon enhancement
      - pi-K swap model
      - Manshanden-Sigl-Garzelli model

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    - EPOS-LHCr (?)
  - ρ^0-enhancement
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If you want additional models to be tested, please let us know!

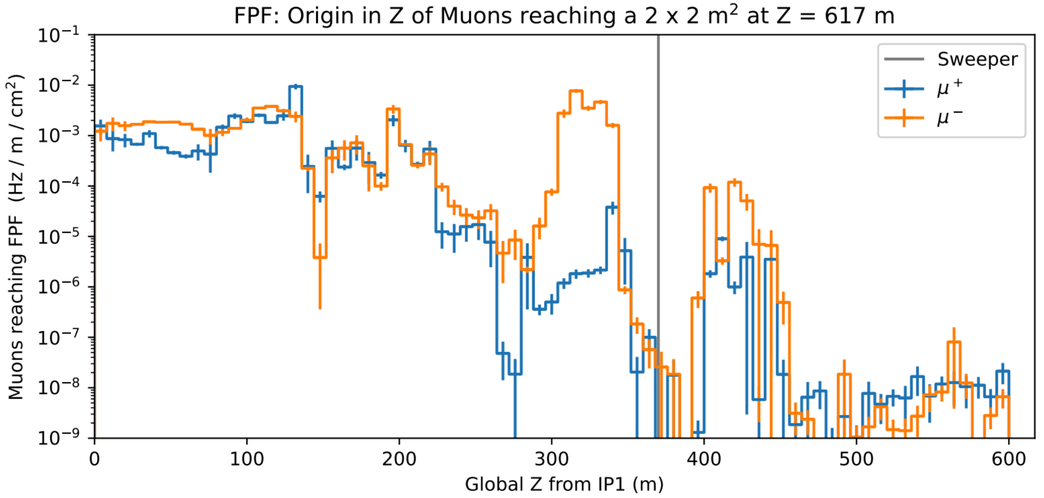
WG3 Plans

- Current status:
  - We're in the process of contacting all model authors at the moment
  - Production of comprehensive MC library (partially) in progress
  - WG3 report to be prepared (journal paper?):
    - Detailed model comparisons
      - Energy spectra
      - Rapidity spectra
      - K/pi ratios (?)
      - More..?
    - Recommendations / benchmark models for FPF science
    - Discussion: How to treat model uncertainties for FPF measurements?
  - This effort needs some coordination with WG2 (e.g. some models include charm)

WG3 Science Topics II

- Muon fluxes at the FPF:
  - Large muon flux at the FPF, e.g. ~1 Hz per cm^2 in FASER
  - Challenging to study as the origin of production is uncertain…
  - BDSIM/Geant4 simulations available, including full muon history (L. Nevay)
  - Open questions:
    - Can we use muons to study light hadron production?
    - Can we measure the muon charge ratio?
    - Can we measure muon cross-sections?
    - What can we learn from muon fluxes measured at FASER and SND@LHC?
  - Dedicated studies of the muon yield at the FPF (incl. full muon history) needed!

See yesterday's session



Summary

- Studies of light hadron production in the forward region important!
- Goal:
  - Quantify how well we can test/constrain certain models/generators
- Plan:
  - Produce comprehensive MC library with large variety of models
  - Study particle distributions at the FPF in close collaboration with model builders
  - Recommendations for FPF benchmark models and systematics
- Status:
  - We're reaching out to all model builders at the moment
  - Production of HepMC files for all models (where to store them?)

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If you want to contribute, please get in touch with us!

Thanks!