Recent results and prospects of The FASER experiment -Input for CR physics-

Hiroaki MENJO
ISEE, Nagoya University
on behalf of the FASER collaboration

FASER - New experiment at the LHC Run3

FASER has started operation since July 2022

FASER collaboration

121 members, 28 institutions
11 countries

FASER Management

- Spokespersons: Jonathan Feng (UC Irvine), Jamie Boyd (CERN)
- Collaboration Board Chair: Monica D'Onofrio (Liverpool)
- Executive Board: Akitaka Ariga (Chiba), Tomoko Ariga (Kyushu), Frank Raphael Cadoux (Geneva), Dave Casper (UC Irvine), Tomohiro Inada (Kyushu), Enrique Kajomovitz (Technion), Felix Kling (DESY), Brian Petersen (CERN), Michaela Queitsch-Maitland (Manchester), Eric Torrence (Oregon), Stefano Zamibito (Geneva)

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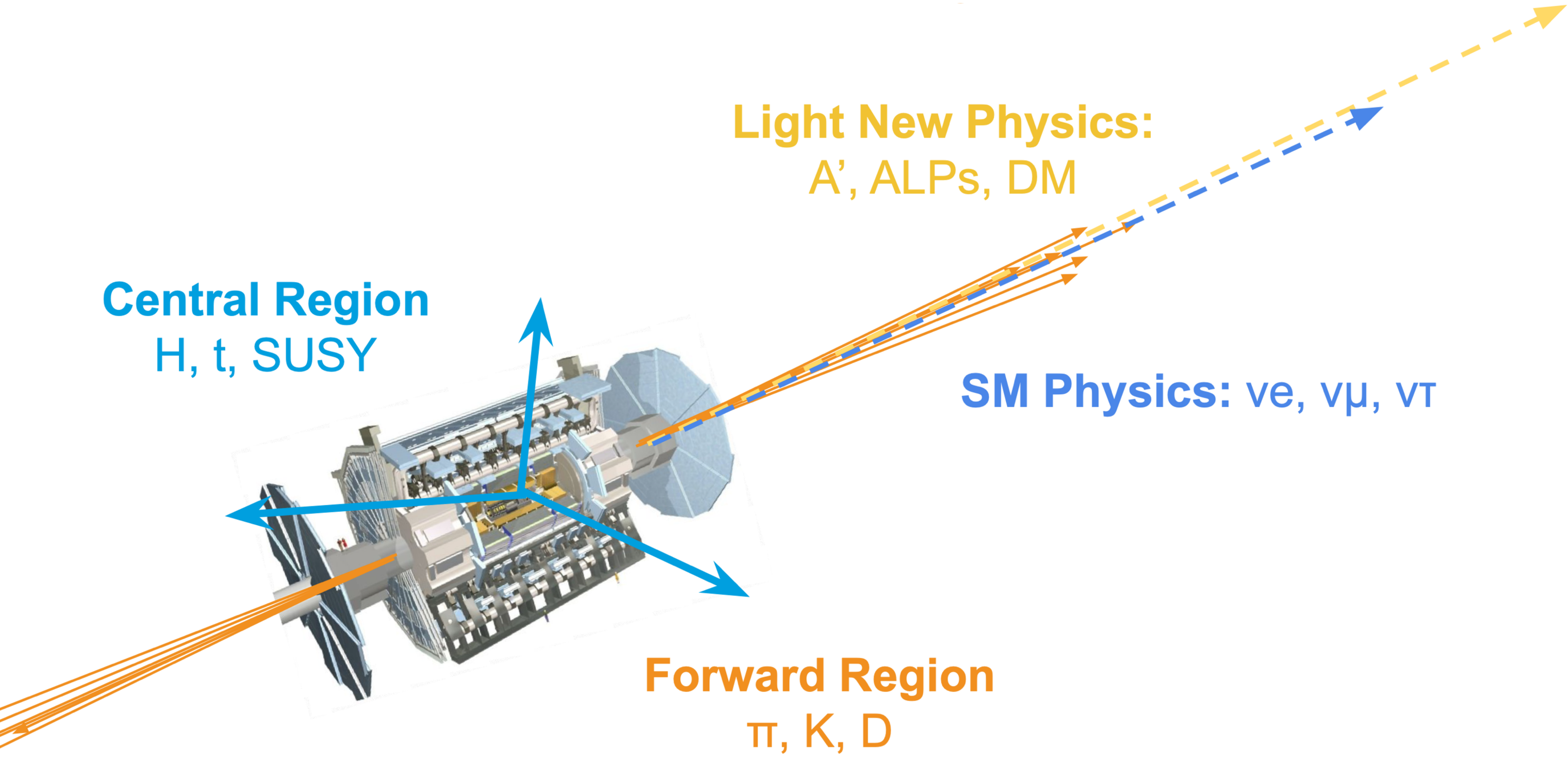
Administrative support for the collaboration is provided by Veronique Wedlake (CERN, EP Secretariat) and Alison Lara (UC Irvine)

International laboratory covered by a cooperation agreement with CERN

We are growing up!

Physics at Very Forward Region



Explore a rich and broad physics programs **in the far forward region**

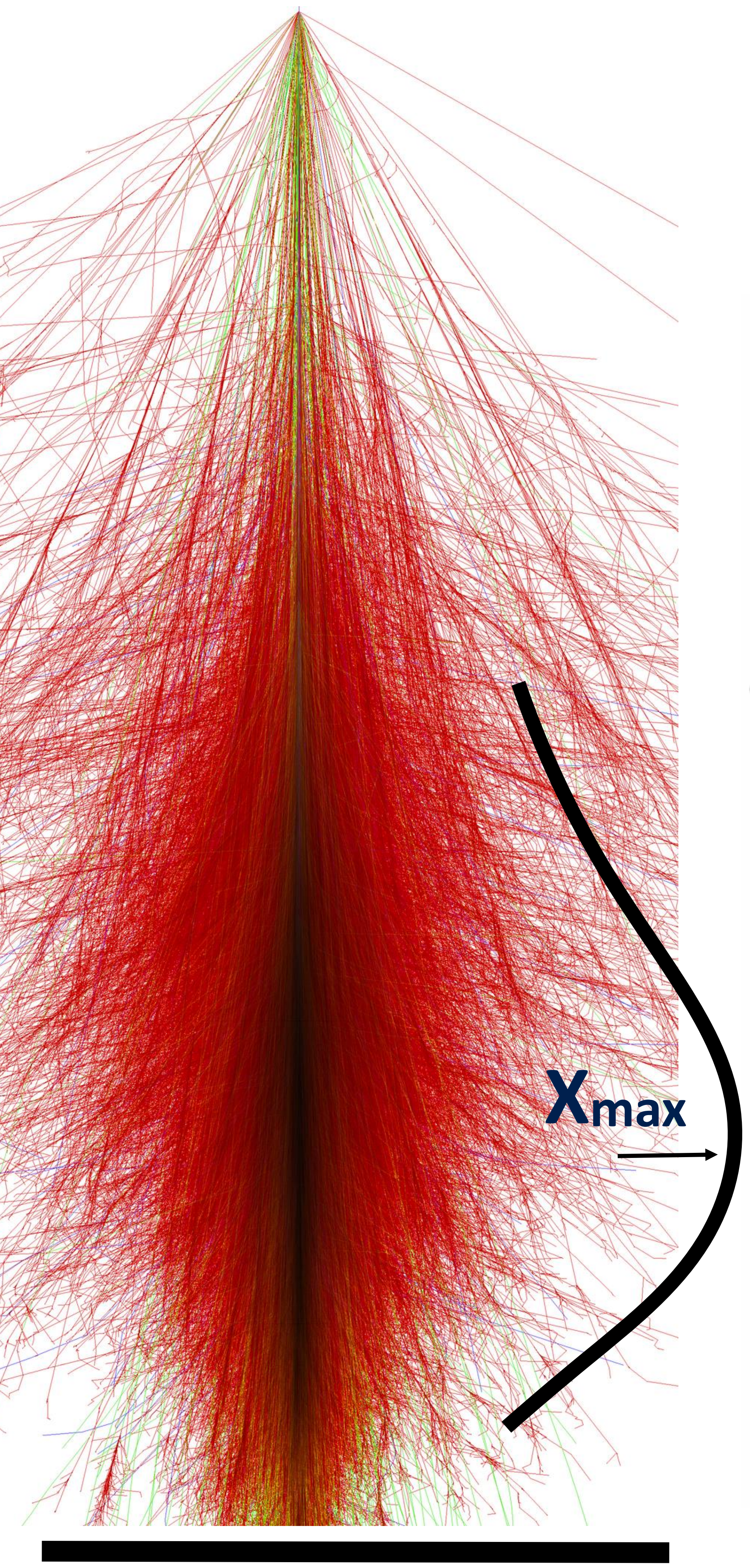
BSM physics
- Light new particle; A', ALPs

Cosmic-ray physics / QCD physics
- π, K production via neutrino
  → Muon production in EAS
- Charmed hadron (D) production
  → Prompt atmospheric neutrinos

TeV Neutrino beams
- Neutrino interactions at highest-E
- Neutrino DIS

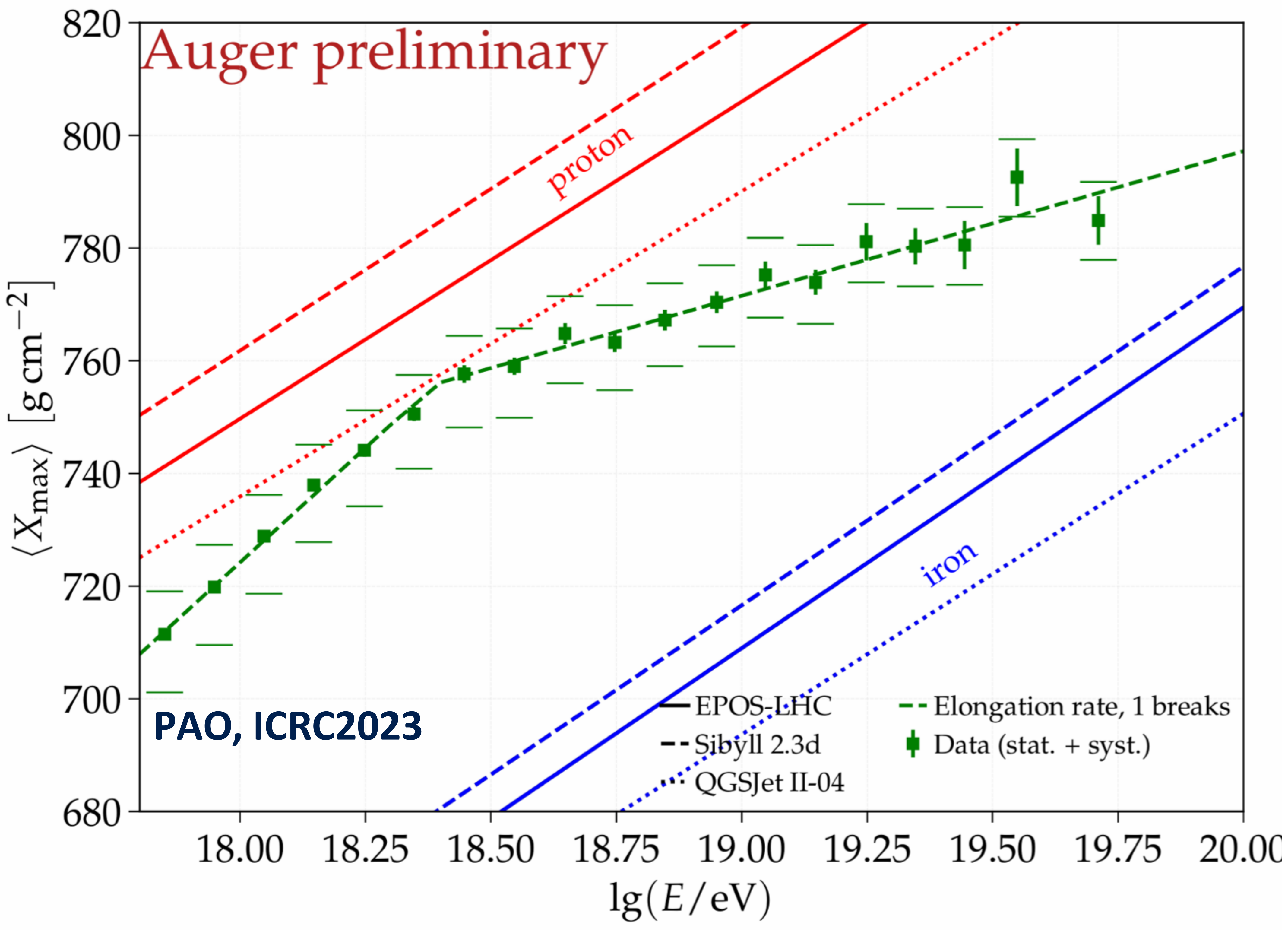
TeV Muon beams
- Muon DIS

Composition measurement on EAS



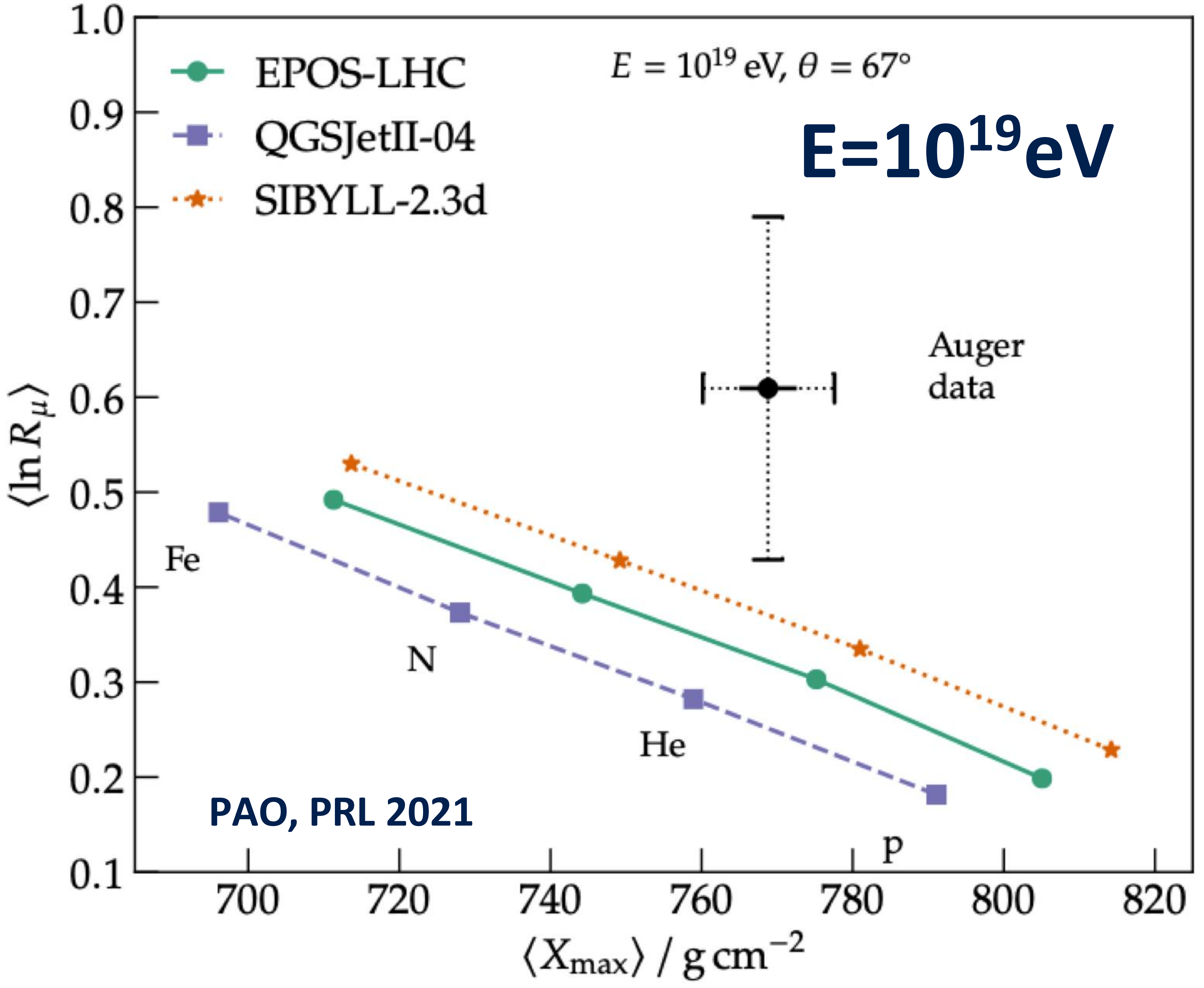
N_μ

Shower Maximum Depth $< X_{MAX} >$



Interaction model uncertainty > Experimental uncertainty

Muon Number N_μ



N_μ: Data > MC (30-50%)

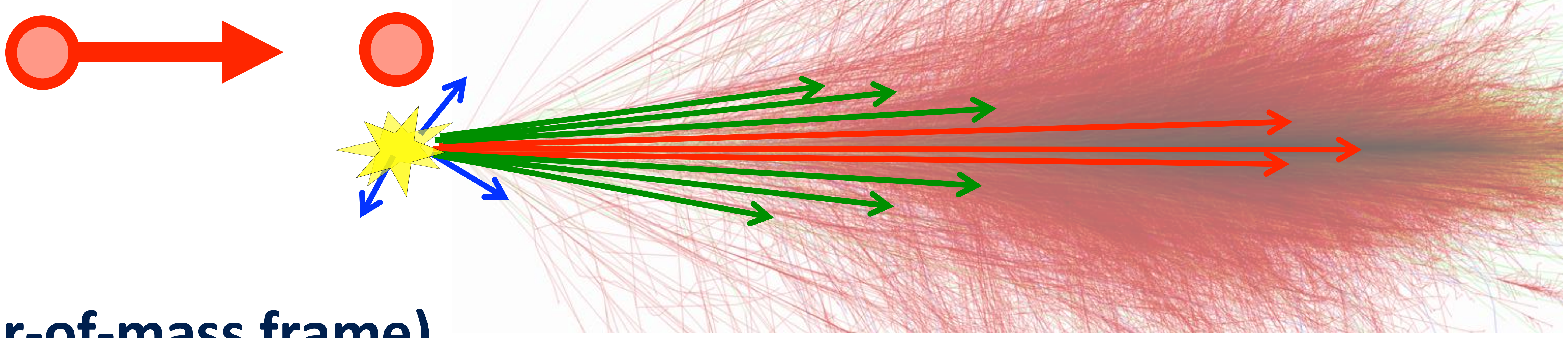
Muon puzzle

Physics at Very Forward Region

Cosmic-ray (target-rest frame)

CR, 10^{17} eV

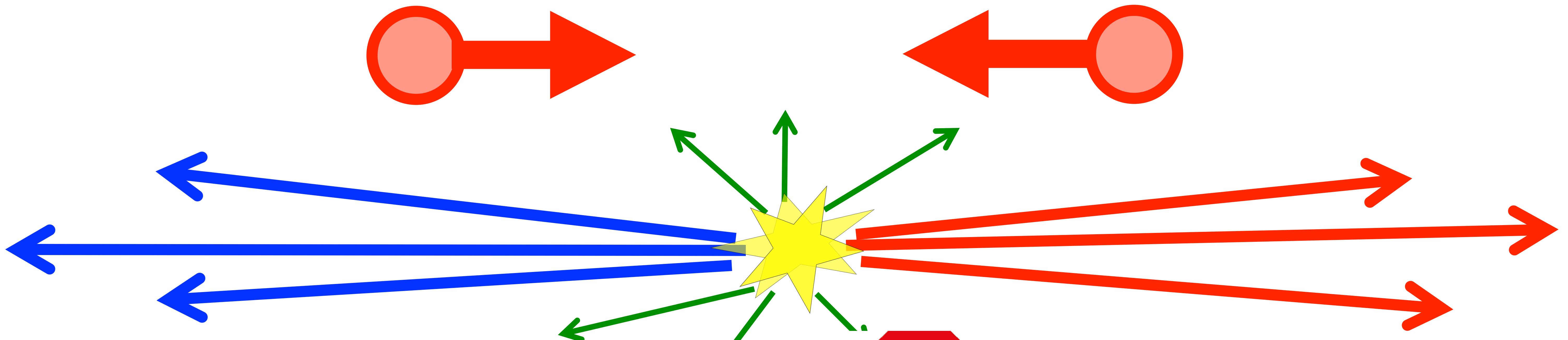
N,O



LHC(Center-of-mass frame)

proton, 7×10^{12} eV

proton, 7×10^{12} eV



- Limited due to conflict with beam pipes
- FASER and SND@LHC opened new program to measure chaged meson via neutrinos

Scattered proton

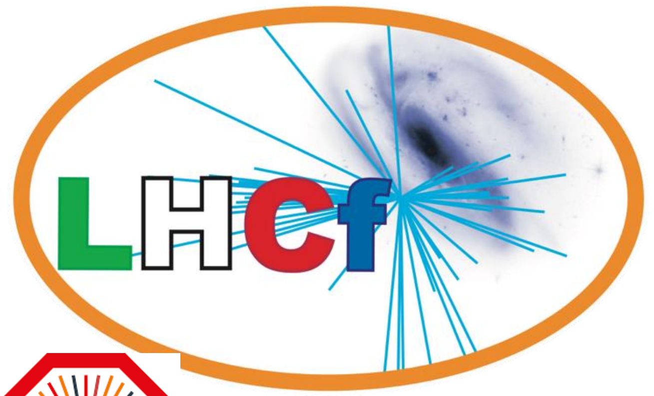
$\rightarrow \sigma_{total}$

$\nu_{e,\mu,\tau}$

$\rightarrow K/\pi$

γ, π^0, n

$+ K^0, \Lambda$



(for AA collisions)

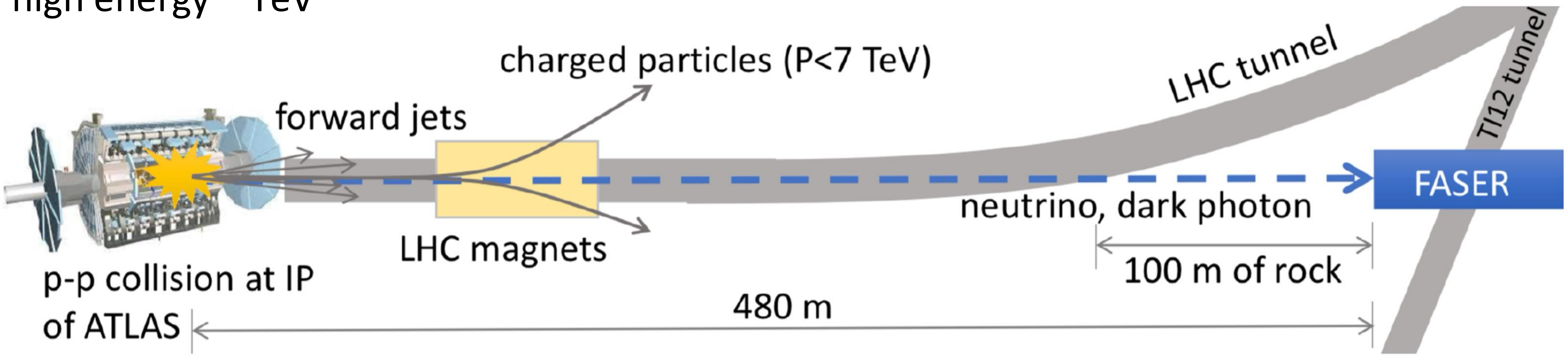
Scattering and Neutrino Detector at the LHC

FASER

- **ForwArd Search ExpeRiment (FASER) at the LHC**
  - Placed **480 m downstream of the ATLAS IP** on the beam axis
  - Started the **operation** from July 2022 (LHC run3)

- **Only weekly interacting particles arrives**
  - New Particles, Neutrinos, and muons
    Others are absorbed in the rock
  - Very high energy ~ TeV

- **Unique location**
  - **Very low background from collision**
    - **Only high-energy muon** at about $1/cm^2/sec$
  - **Low radiation level from the LHC**
    - 4×10^6 1-MeV neutron/cm^2/year



FASER detector

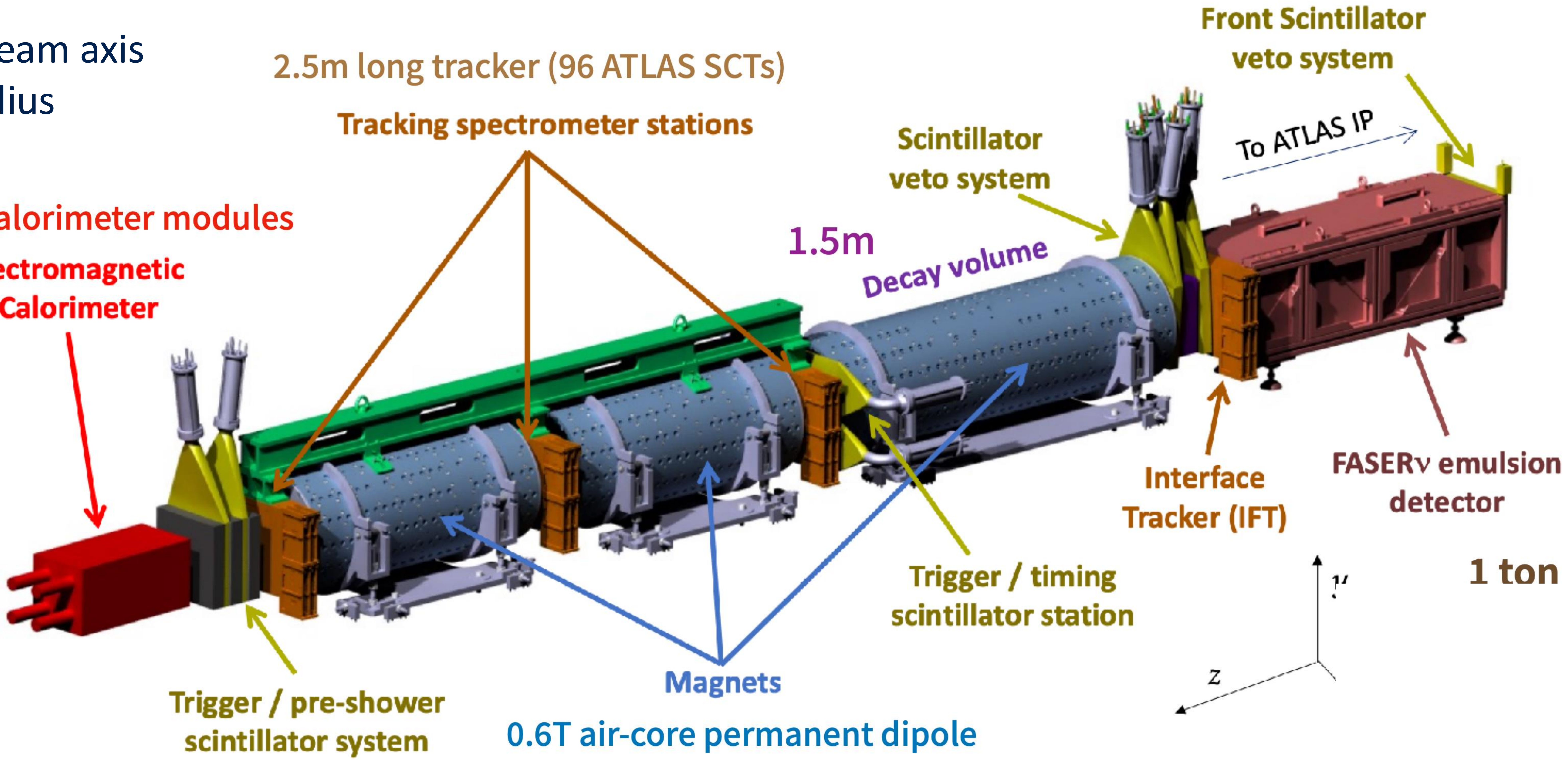
JINST 19 (2024), P05066

On the beam axis
10cm radius
7m long

2.5m long tracker (96 ATLAS SCTs)

4 LHCb calorimeter modules

1.5m



1 ton

0.6T air-core permanent dipole

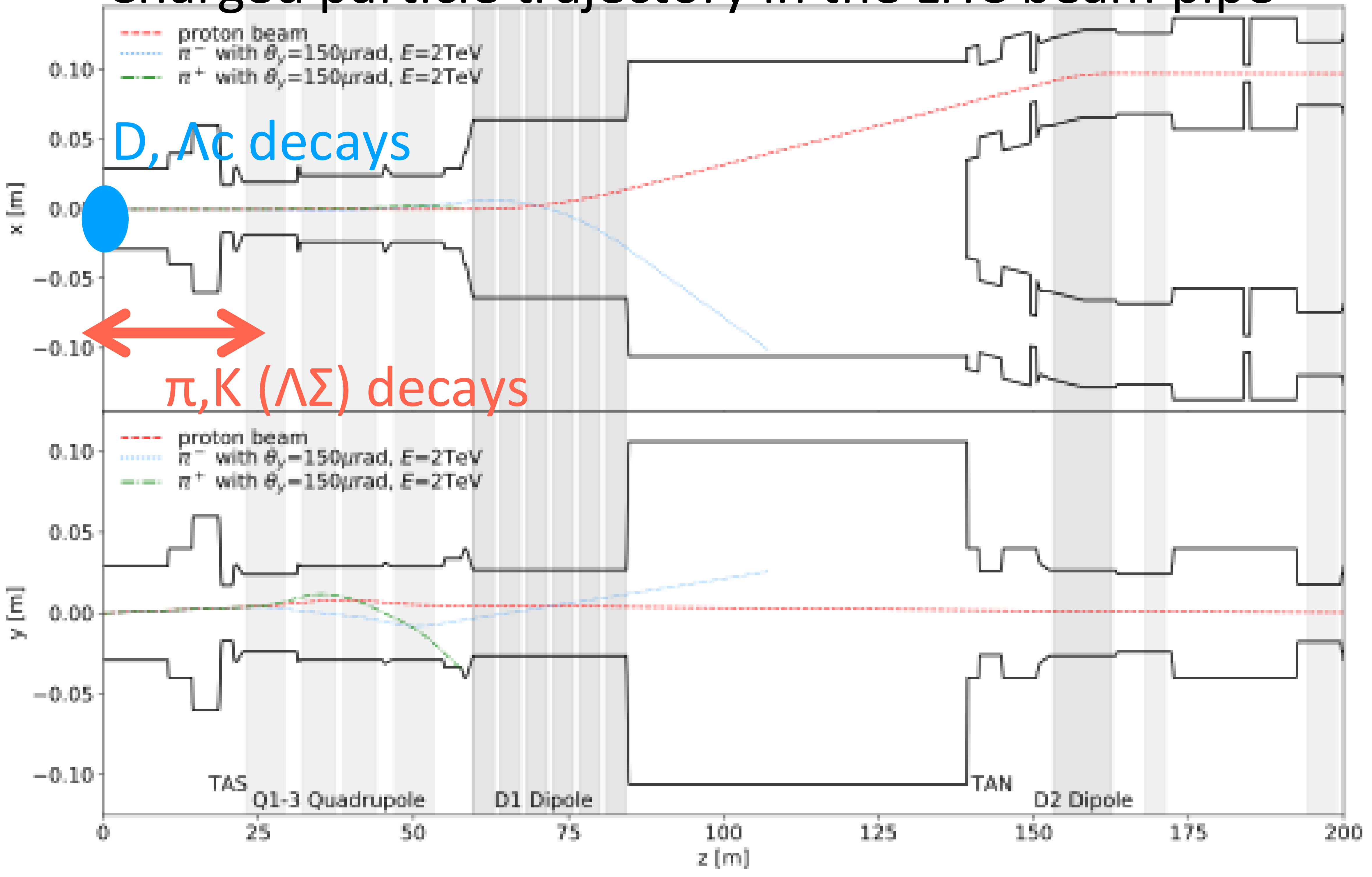
Scintillators for veto, trigger, and
preshower (particle ID)

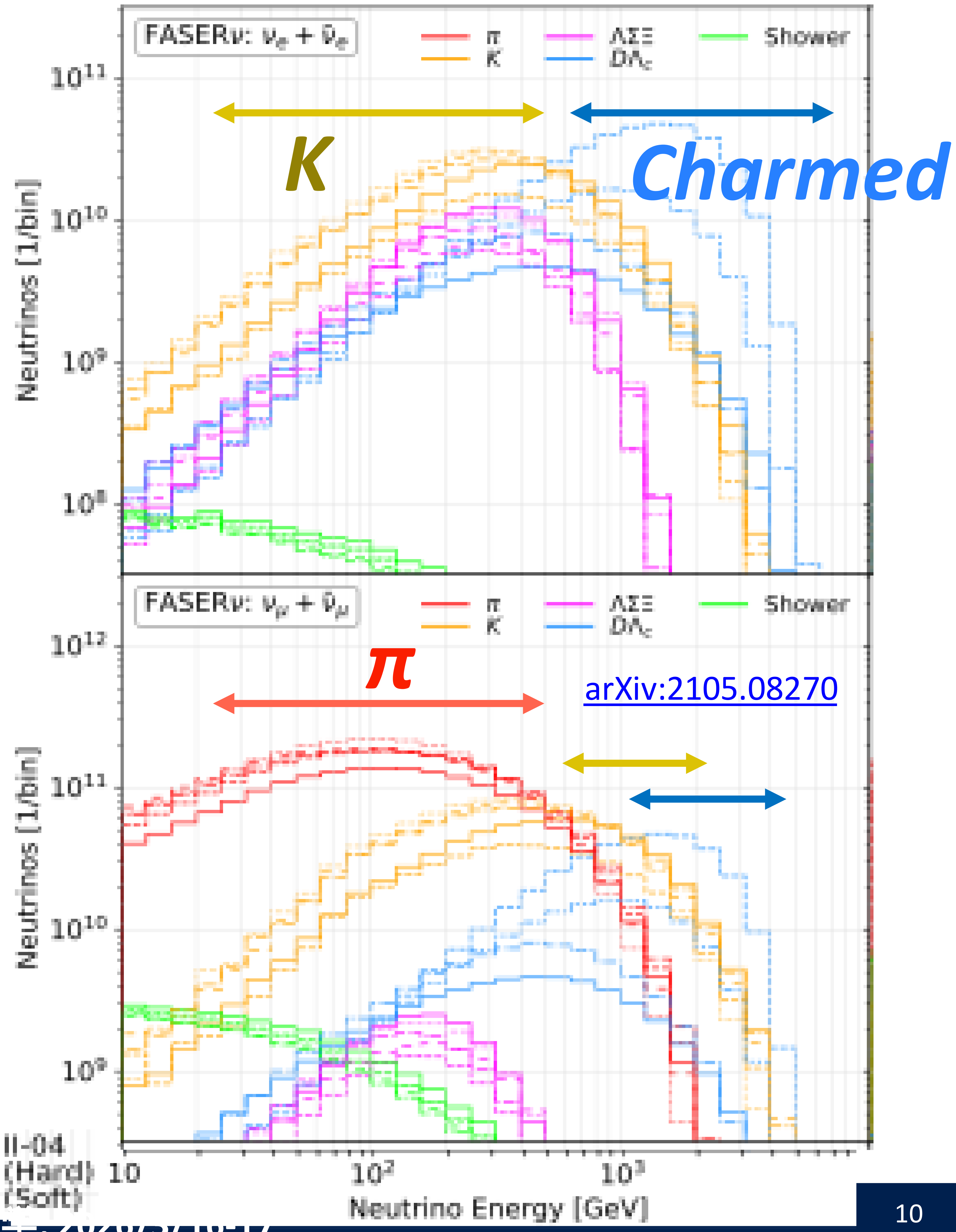
5

All detector components are successfully installed in T12 in March 2022

Neutrinos from LHC collisions

Charged particle trajectory in the LHC beam pipe

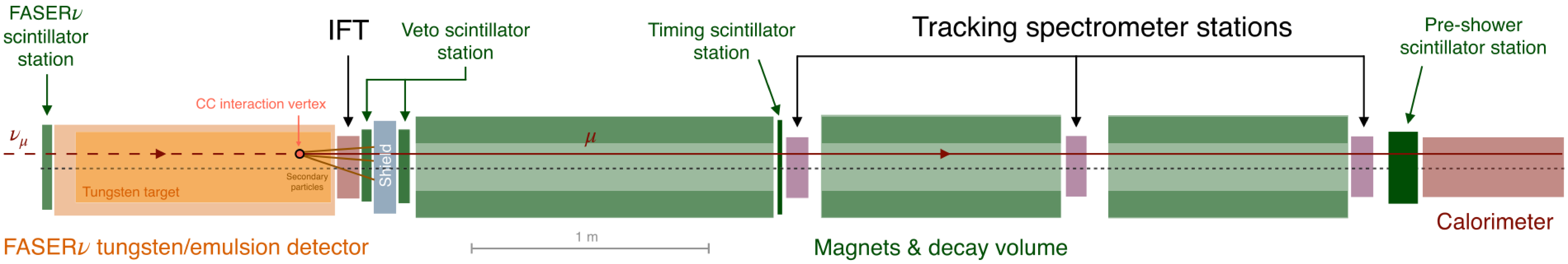




- $\pi \rightarrow \nu_\mu$
- $K \rightarrow \nu_e, \nu_\mu$
- $D \rightarrow \nu_e, \nu_\mu, \nu_\tau$

Neutrino measurements = Probe of forward hadron productions

Analysis strategy of neutrino measurement

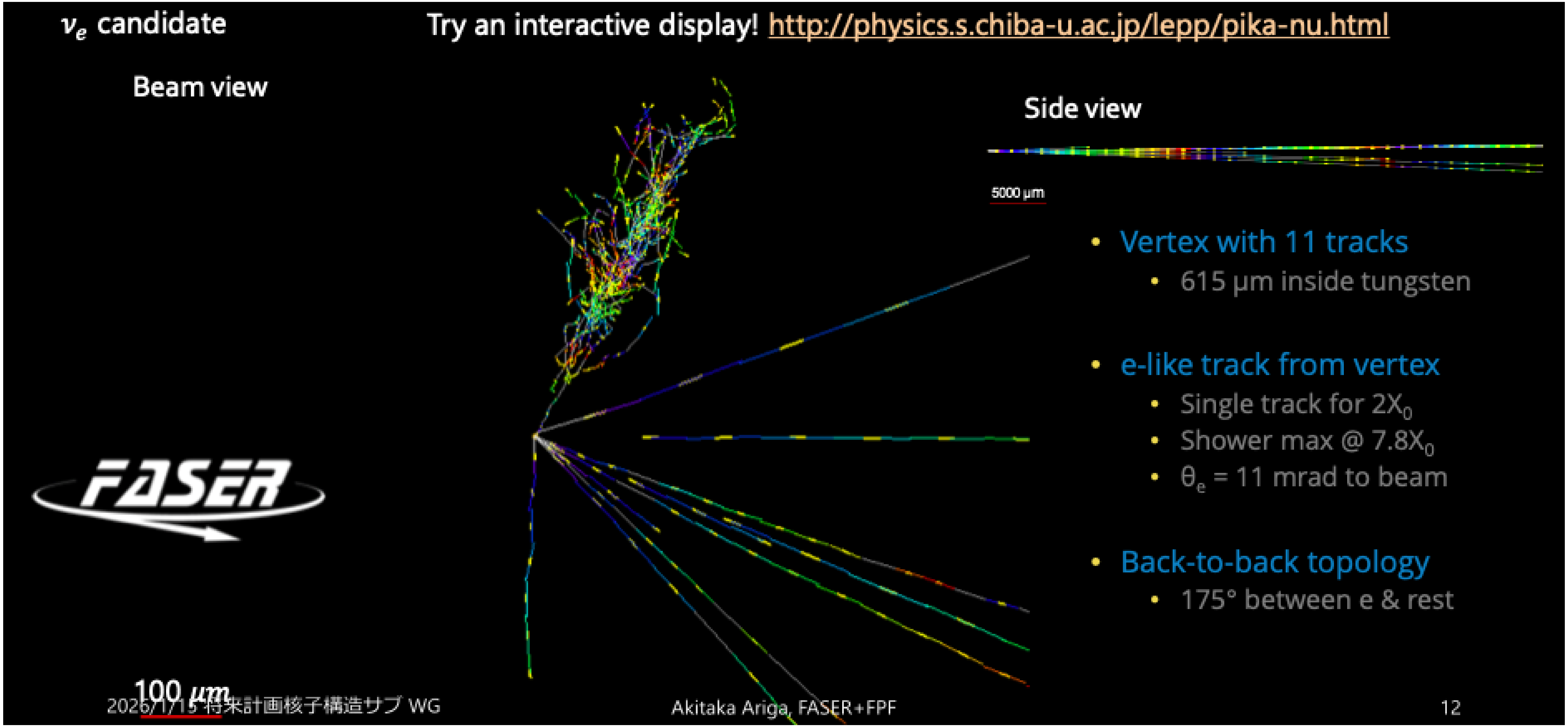


Two approaches in FASER

- Use **electronic detector**: tracking spectrometer, scintillators, calorimeter
  - No signal in FASERν veto, track in spectrometer, MIP-like signal in downstream scintillators
  - Only access to muon (anti)neutrinos
- Use **emulsions detector** detector: FASERν
  - Develop films (slow process), reconstruct tracks, and analyse data

Results of the FASER from Run3

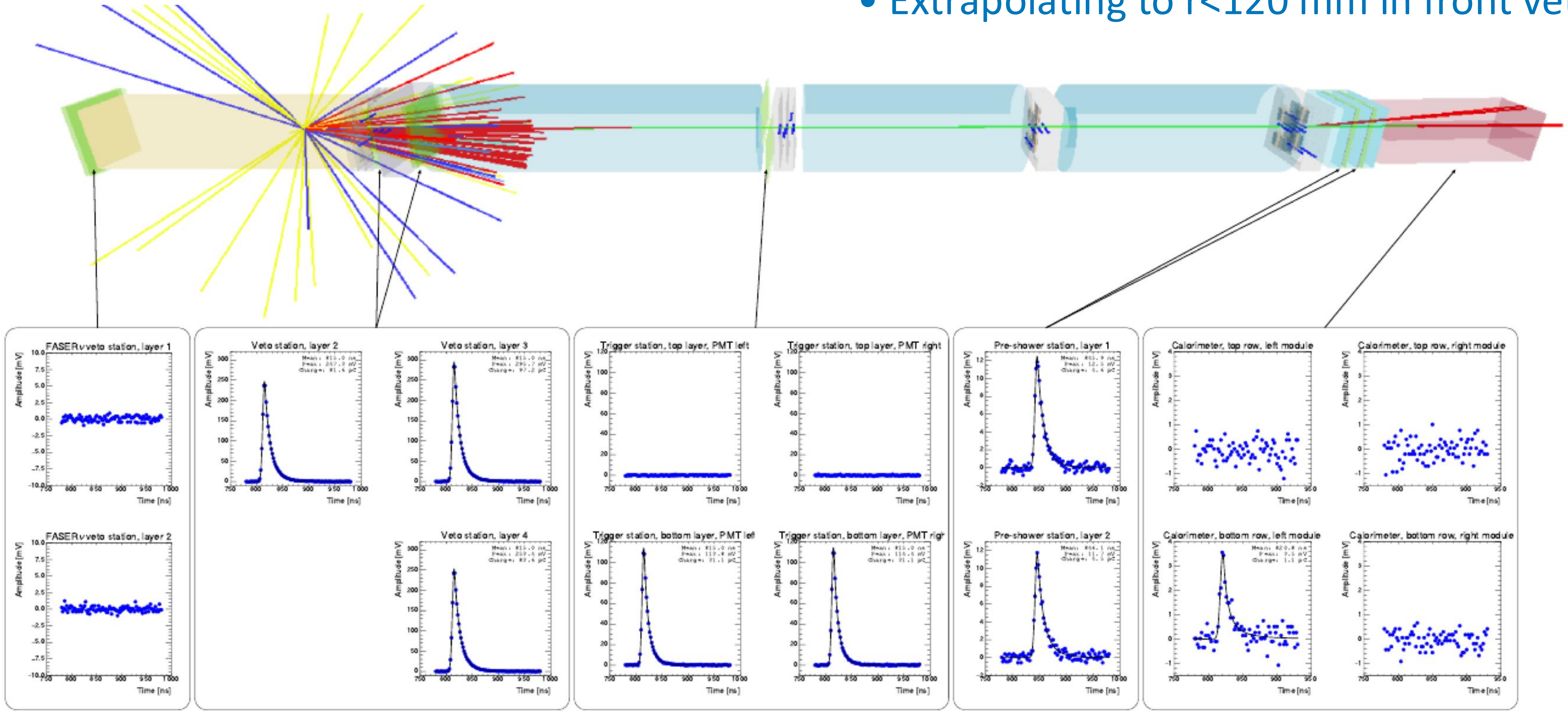
Neutrino event in FASER emulsion



Observing Neutrino in FASER spectrometer

- Try to make a first observation of neutrinos using trackers and veto system
- Signal: **no signal in two front veto** and **one high momentum track** in the rest of detector

1. Good collision events
2. No signal (<40 pc) in 2 front vetos
3. Signal (>40 pC) in other 3 vetos
4. Timing and preshower consistent with ≥1 MIP
5. Exactly **1 good fiducial** (r < 95 mm) track
   - p_T>100 GeV and θ<25 mrad
   - Extrapolating to r<120 mm in front veto



Expect **151 ± 41 signals** from **GENIE simulation**

- Uncertainty from DPMJET vs SIBYLL
- No experimental errors

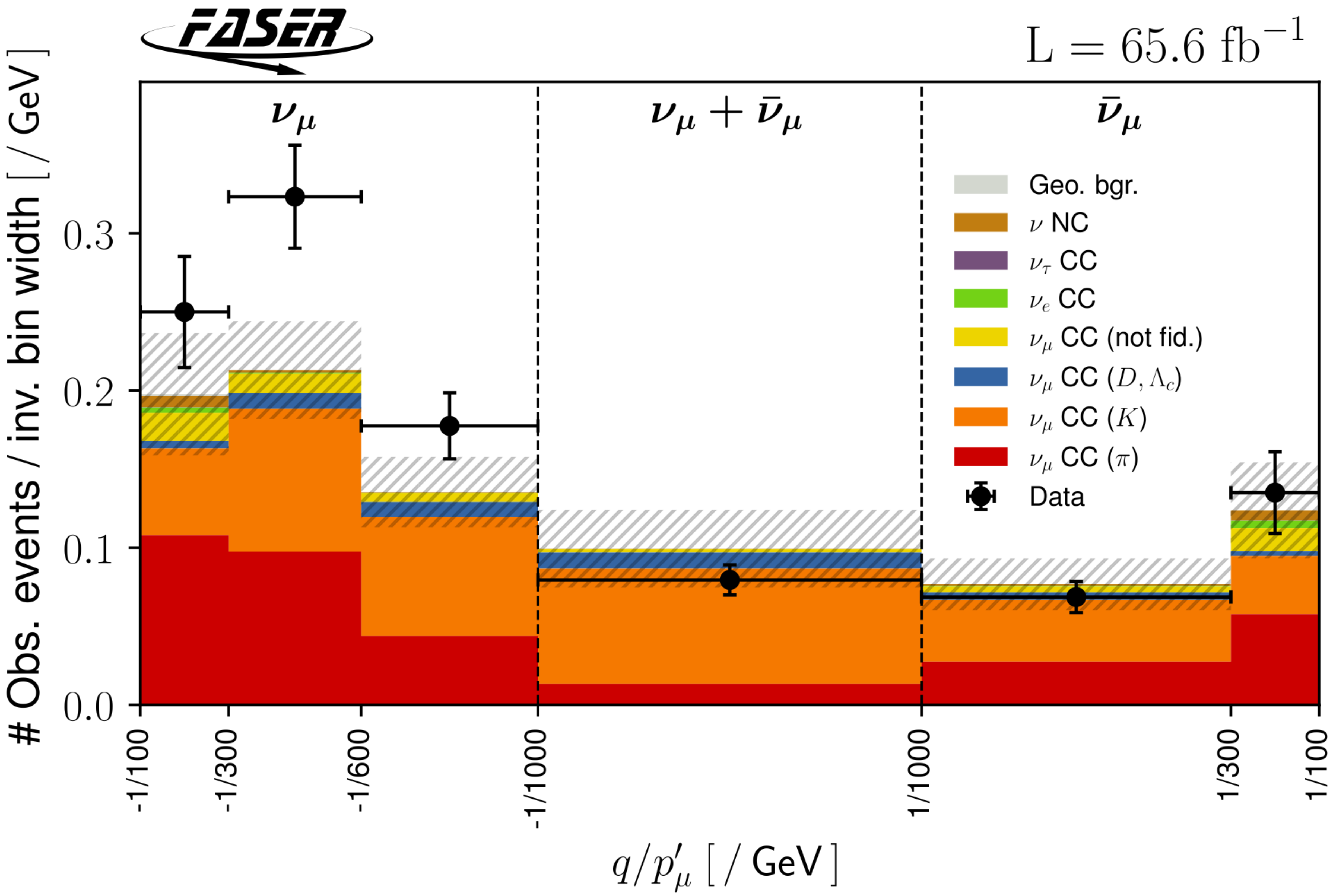
Background

- Veto inefficiency: negligible
- Neutral hadrons: **0.11±0.06** events (MC)
- Scattered large-angle muons: **0.08±1.83** events (sideband)

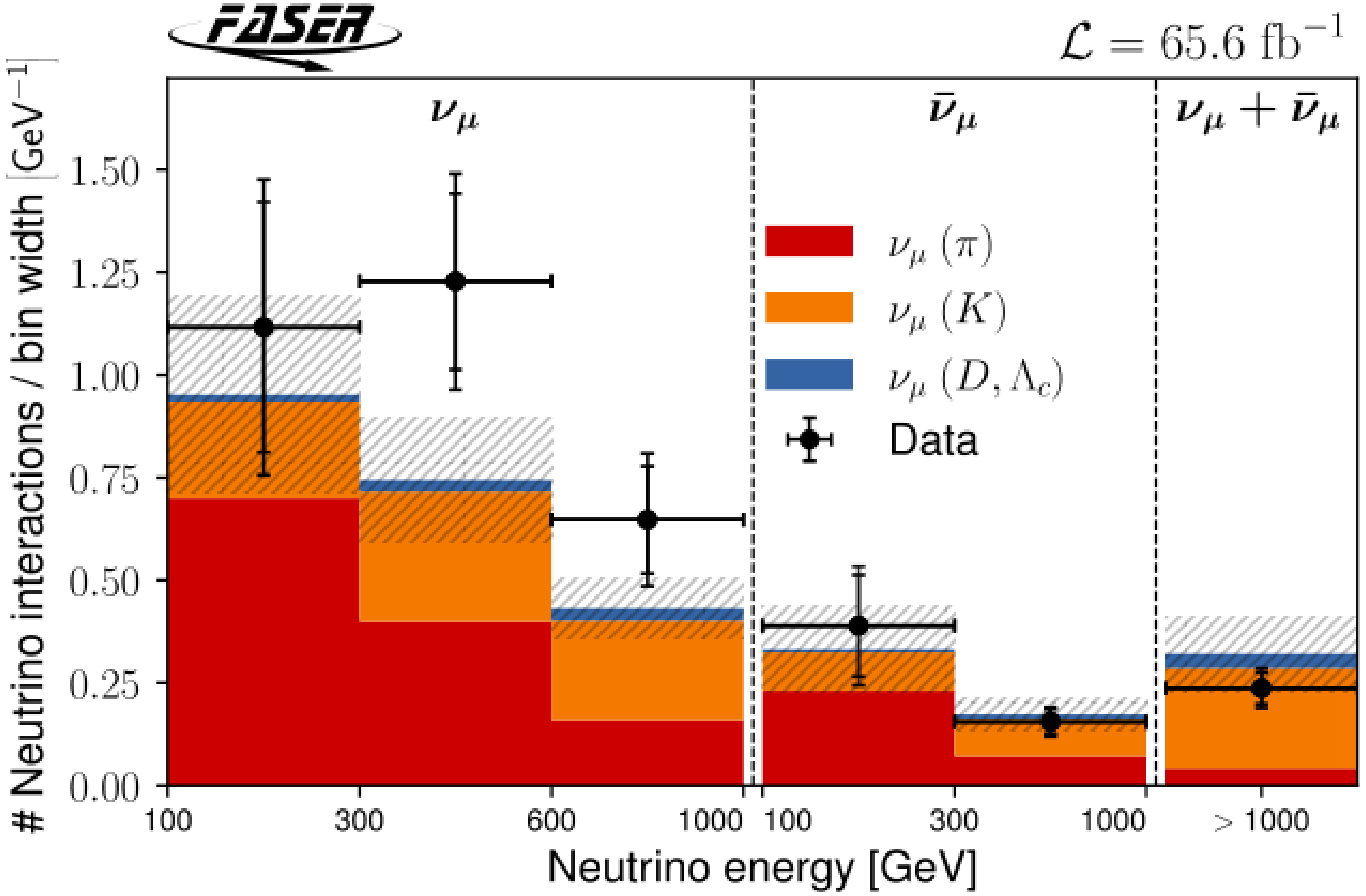
Updates in 2025: Observed events and kinematics

Phys. Rev. Lett. 134, 211801 (2025)

338.1 ± 21.0 ν_μ CC observed
(298.4 ± 42.6 ν_μ CC expected)

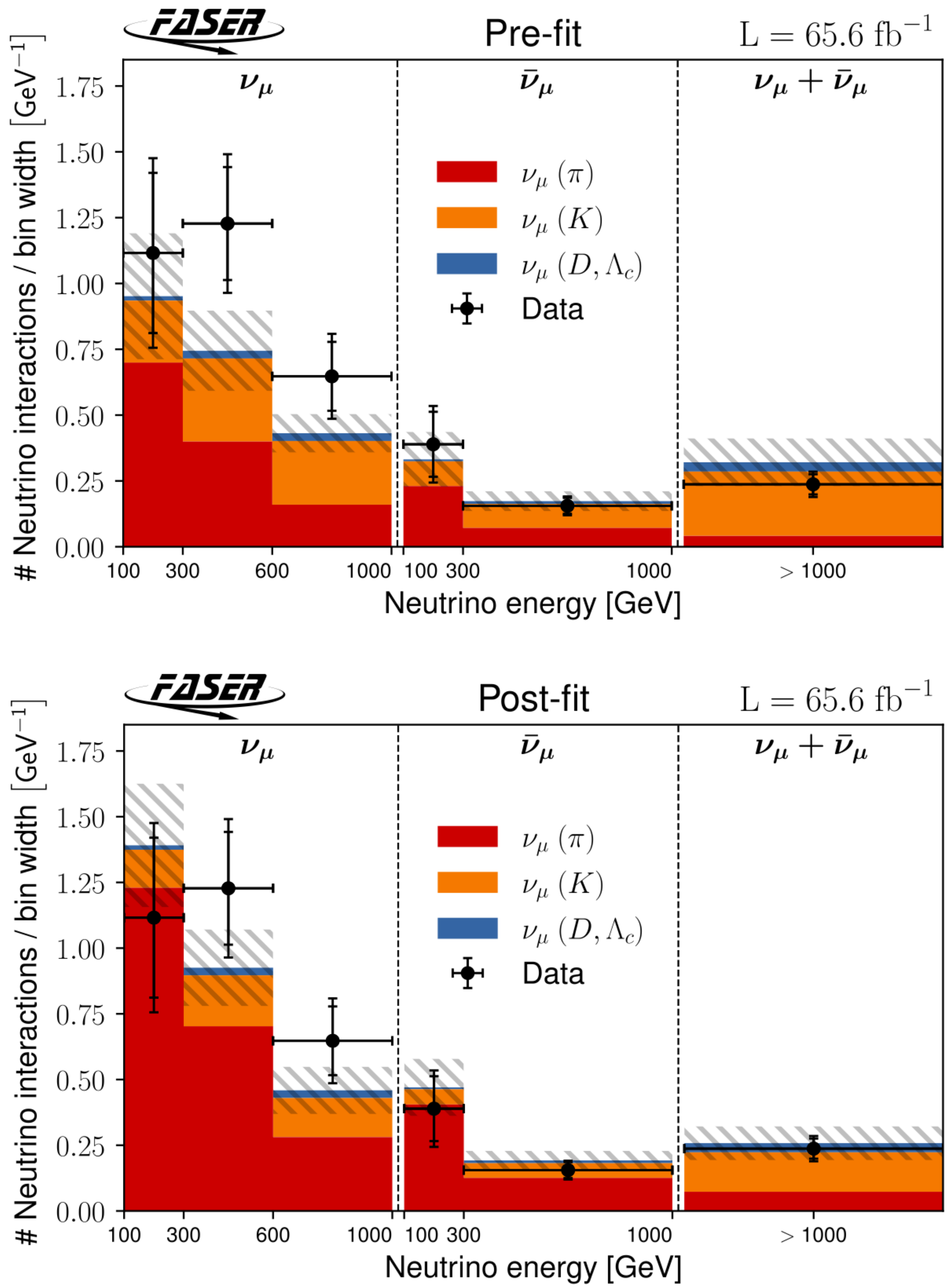


Muon momentum is unfolded into neutrino energy with $\nu_\mu/\overline{\nu_\mu}$ separation



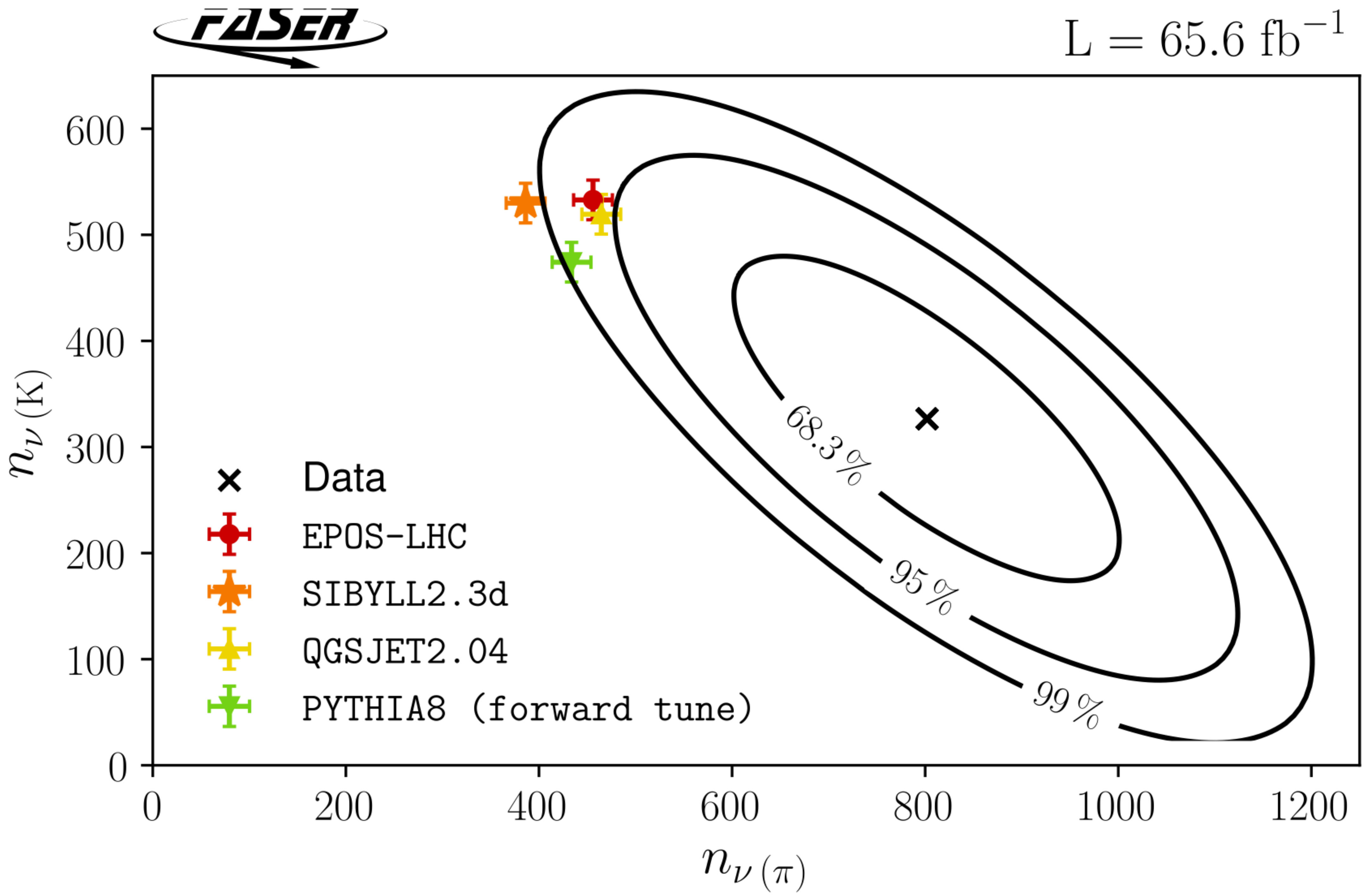
Implication on π and K production

Phys. Rev. Lett. 134, 211801 (2025)



Performed template fit to neutrino interactions

Free parameters: normalization for π and K



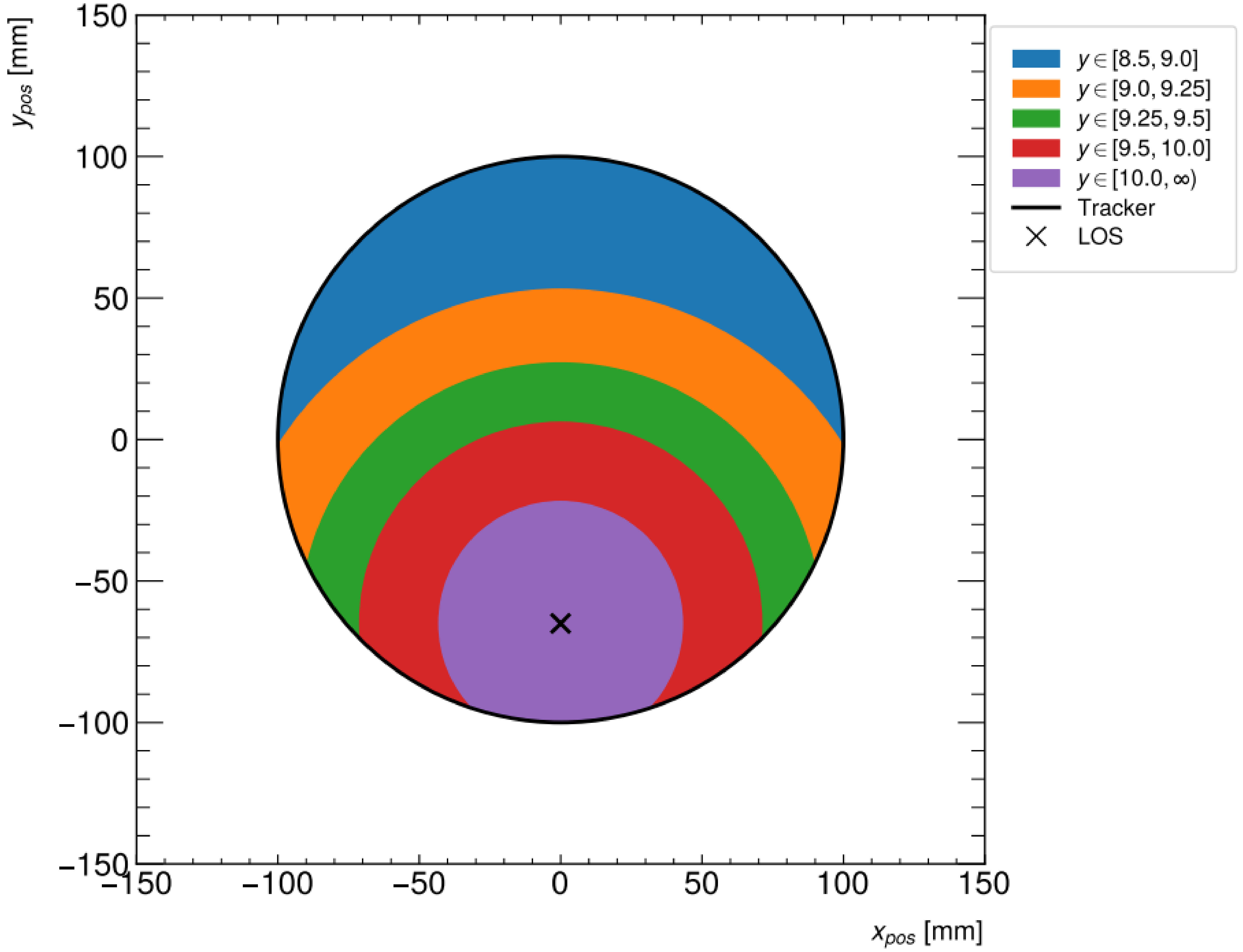
Start validating hadron production models

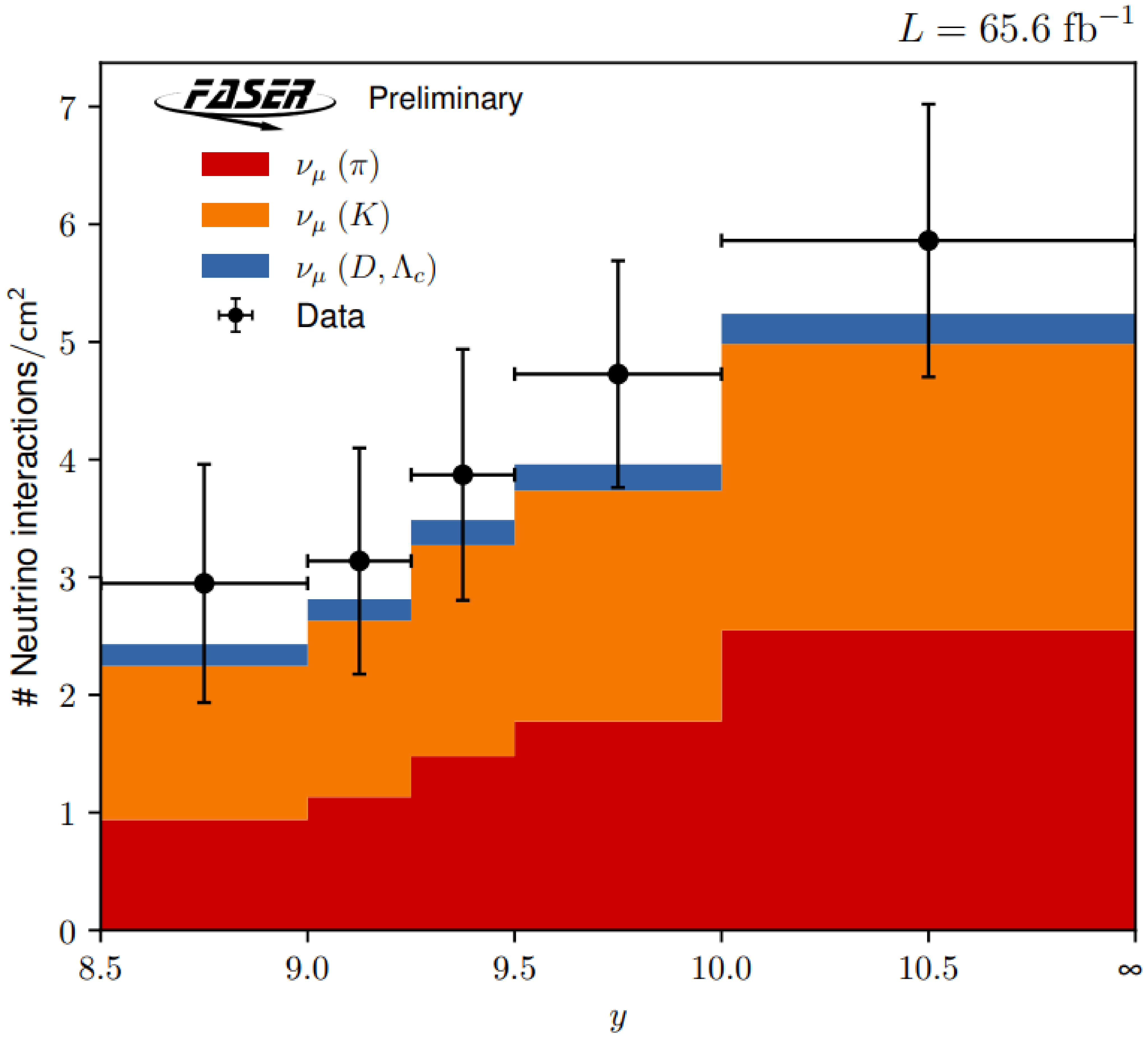
Implication to strange enhancement scenario?

Stay tuned

Neutrino measurement with rapidity distribution

- To study the characterization of forward hadron production at the LHC [CERN-FASER-CONF-2025-001]
  - Define five rapidity bins (annular regions) around line of sight (black cross)
  - Rapidity from transverse position of reconstructed muon, then unfolded to neutrino rapidity
    - Rapidity y = -ln tan(θ/2)





Forward hadron production Study

- Experimental test of forward pion, Kaon, and Charm production at the LHC

CERN-FASER-CONF-2025-004

Forward hadron production Study

- Experimental test of forward pion, Kaon, and Charm production at the LHC
  - Model dependence (e.g. EPOS-LHCr) more comparisons:

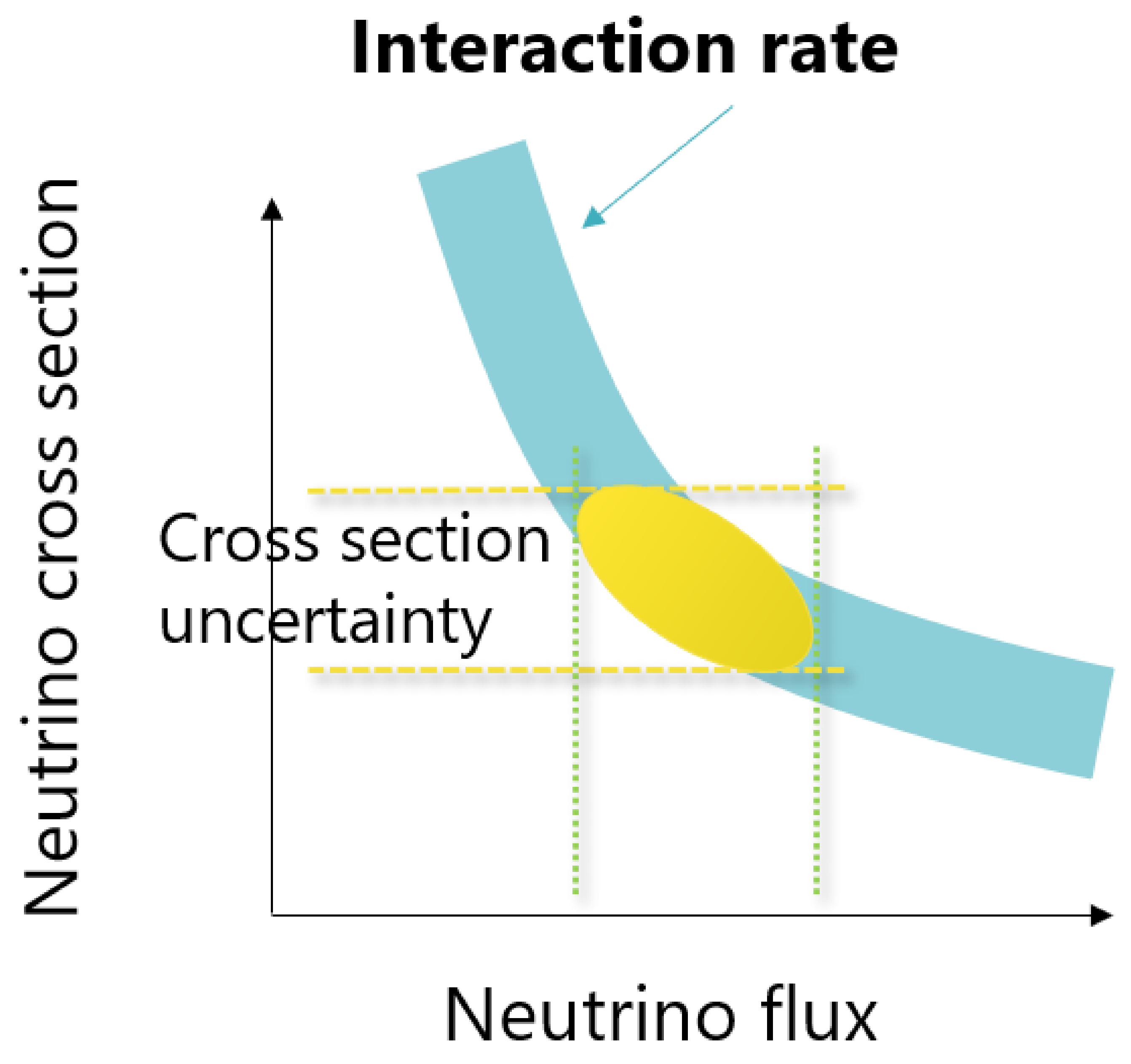
CERN-FASER-CONF-2025-004

FASER Prospects

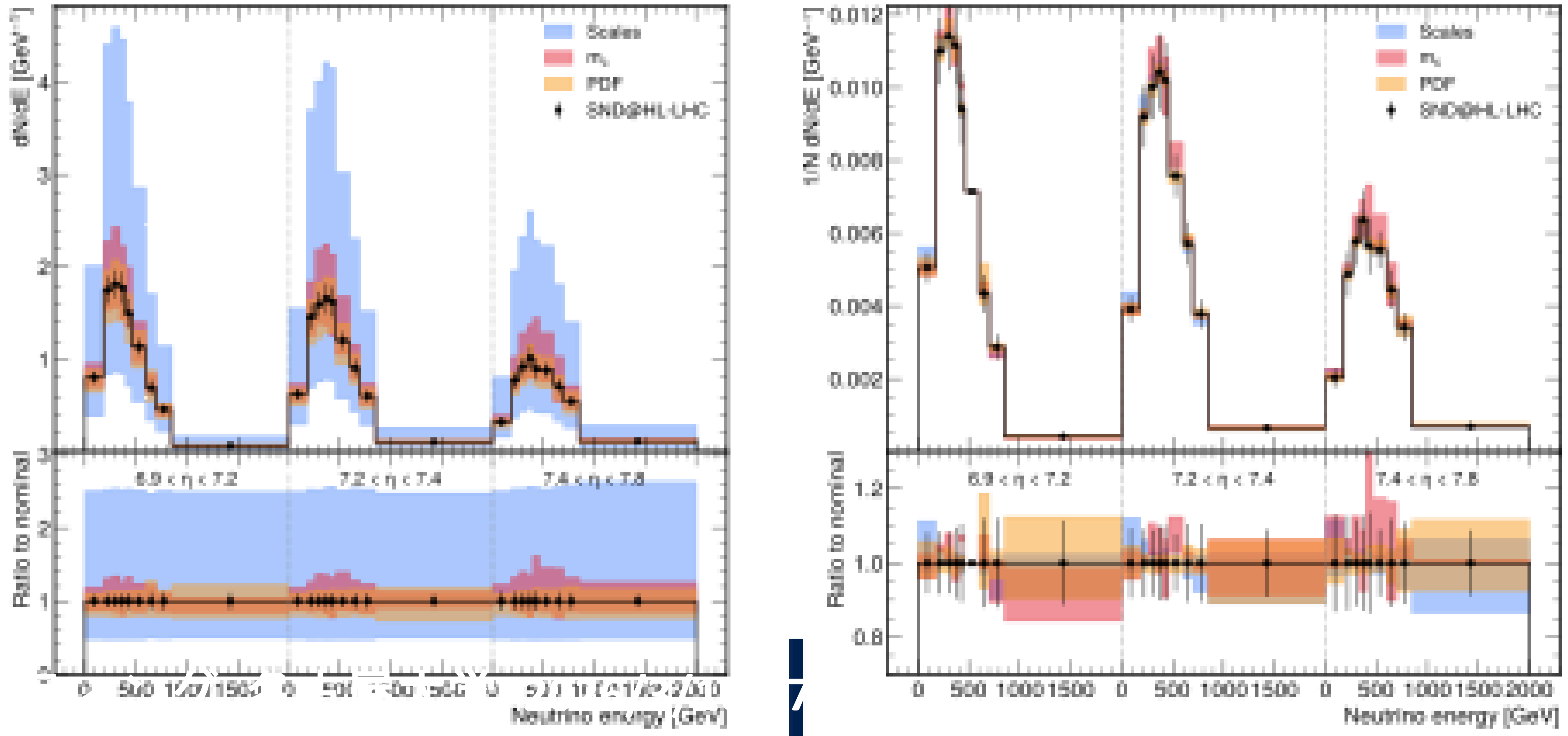
Key measurement for cosmic-ray physics

- High statistics of neutrino events for all flavors

- K/π ratio measurement via ν_e/ν_μ ratio
  → interaction rate = (σ_ν) x (ν flux)
  suppress uncertainty of σ_ν using ratio
  Very important for solving muon puzzle



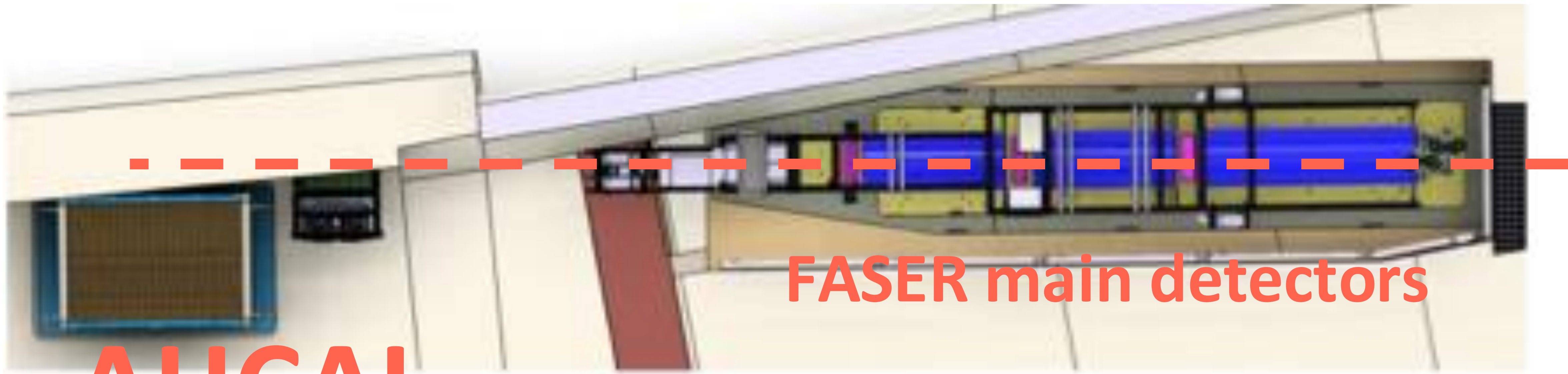
- Pseudo-rapdity dependency measurement
  → E and η distribution shape
  can address detail study of
  charm production
  Improve high energy atmospheric neutrino flux prediction



Study by SND
arXiv:2503.24233v1

Extension to the off-axis region in 2026

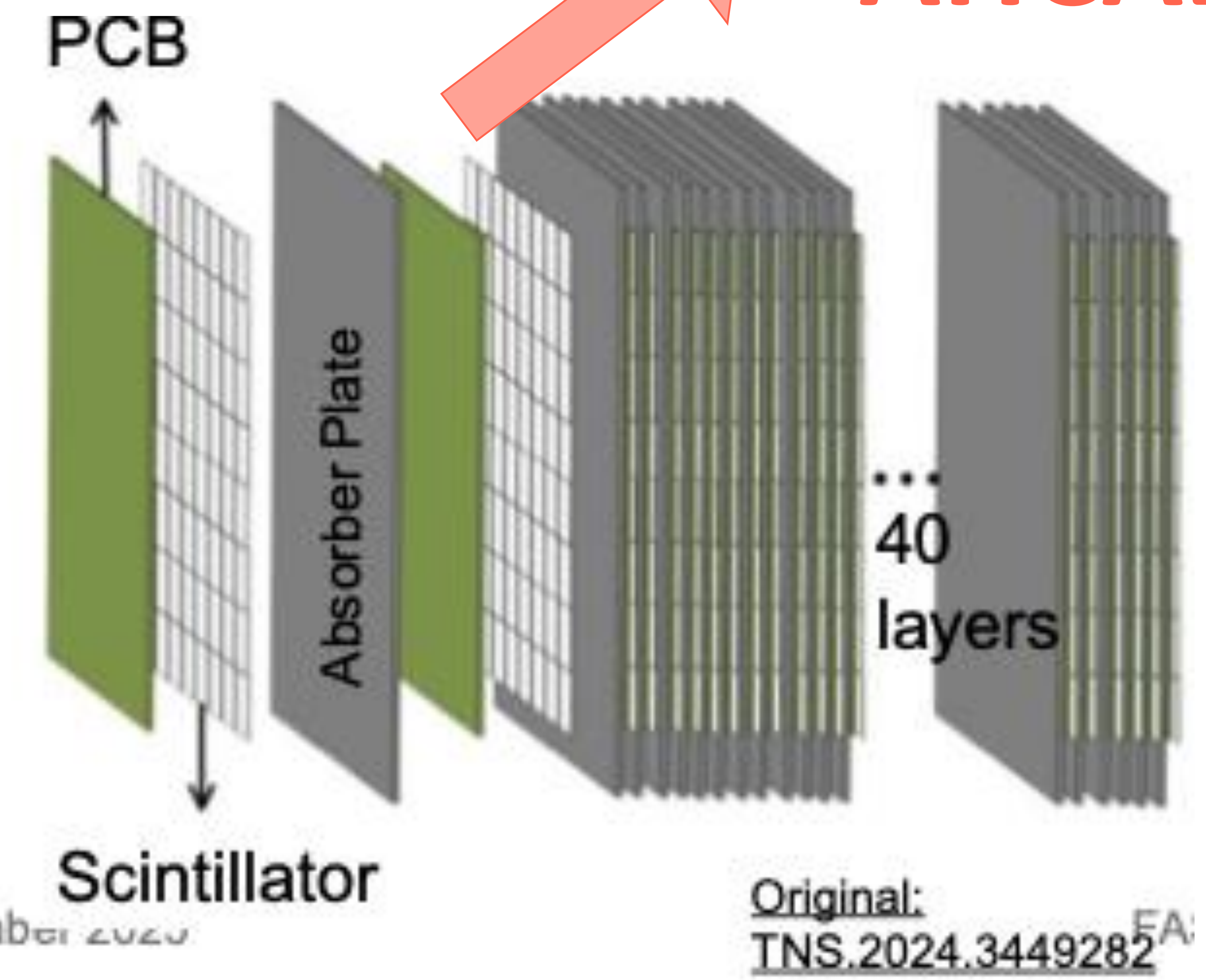
The region 7<η<8 can be addressed only by neutrinos with SND@LHC (similar experiment as FASER) and a new off-axis FASER detector



AHCAL

AHCAL

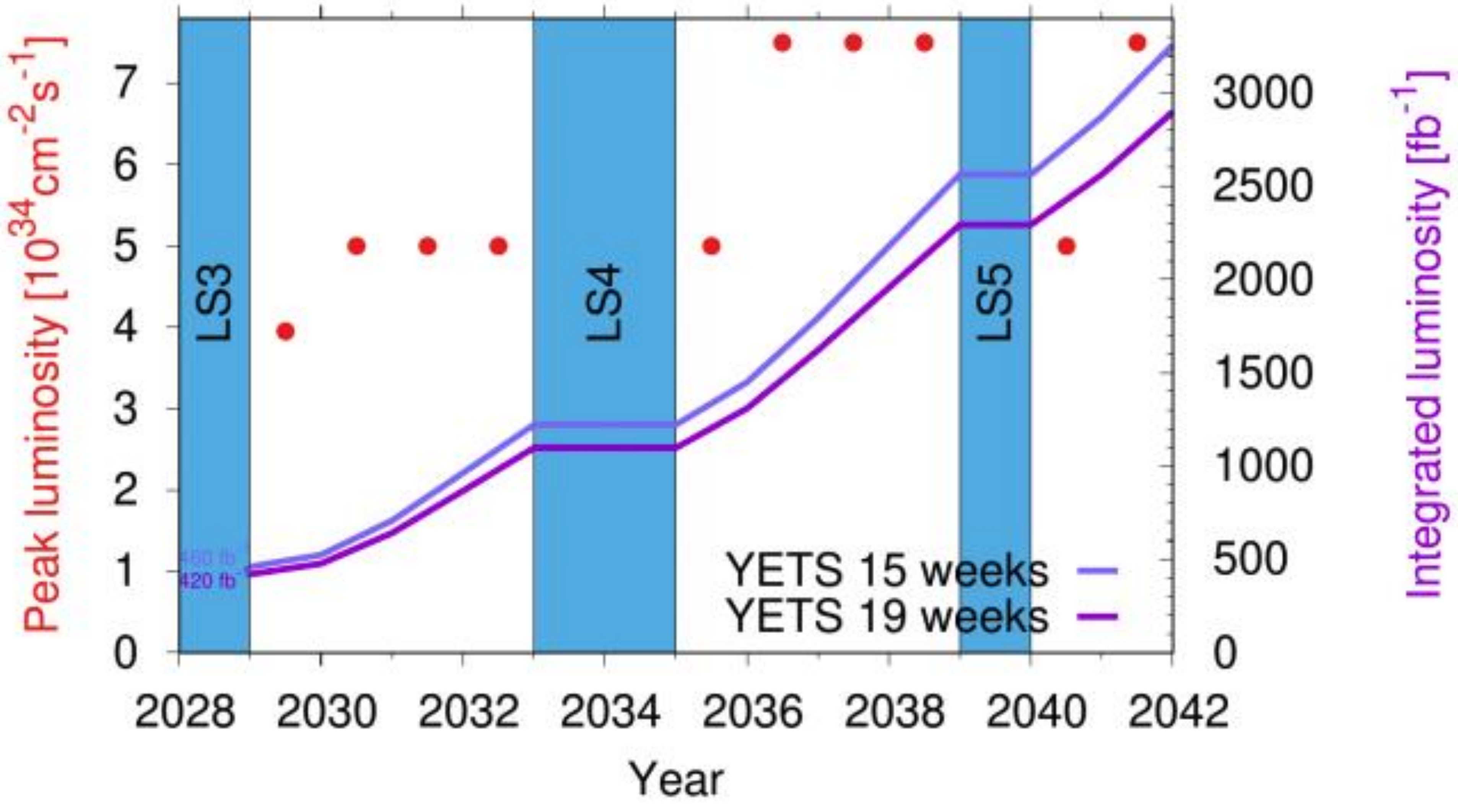
- Sampling calorimeter with Iron layers + scintillator tiles
- Originally developed for CEPC by USTC (China)
- Target of ν_e measurement in $6.5 < \eta < 7.6$
  ~100 ν_e events are expected in 2026 operation

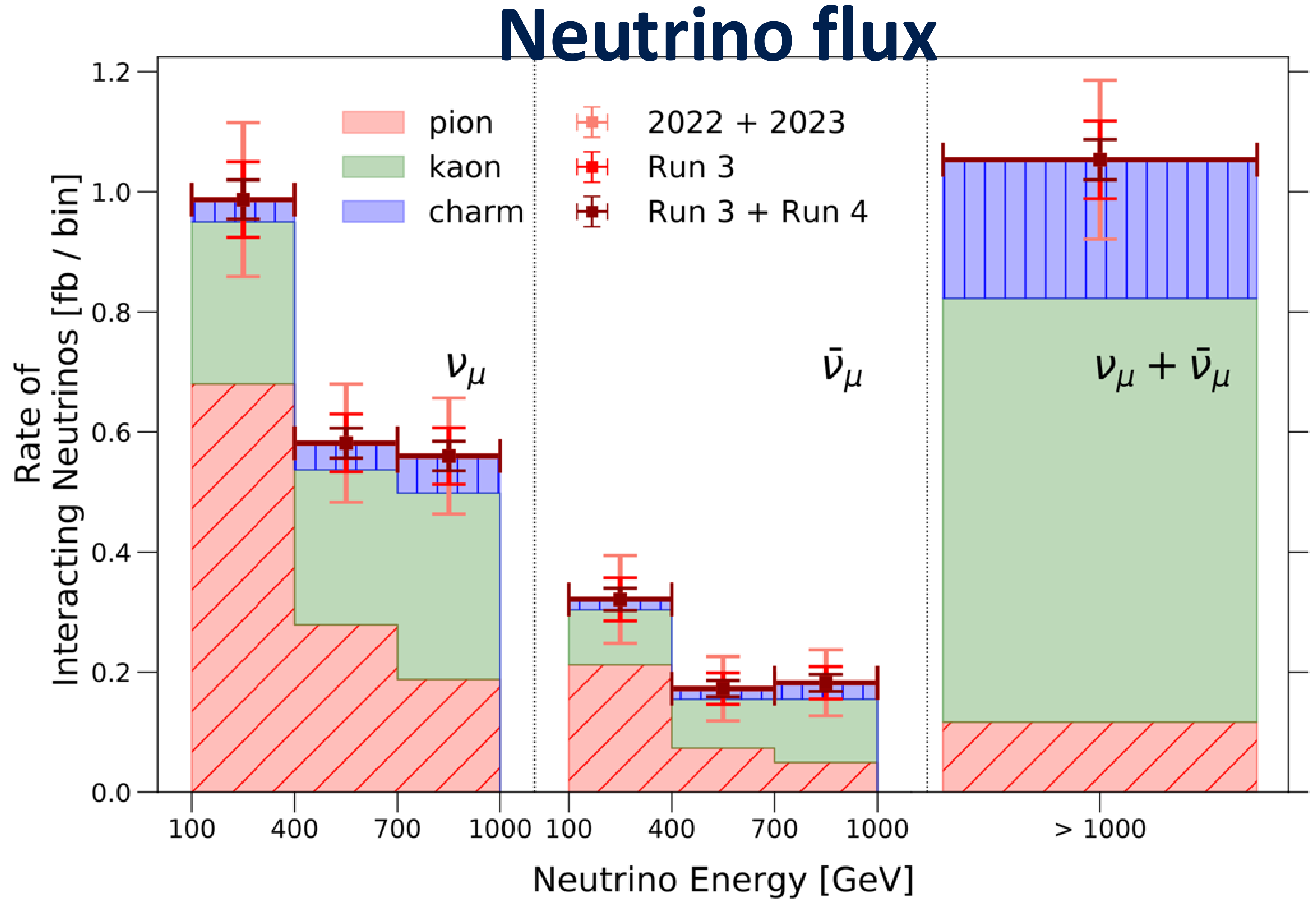


FASER in Run4

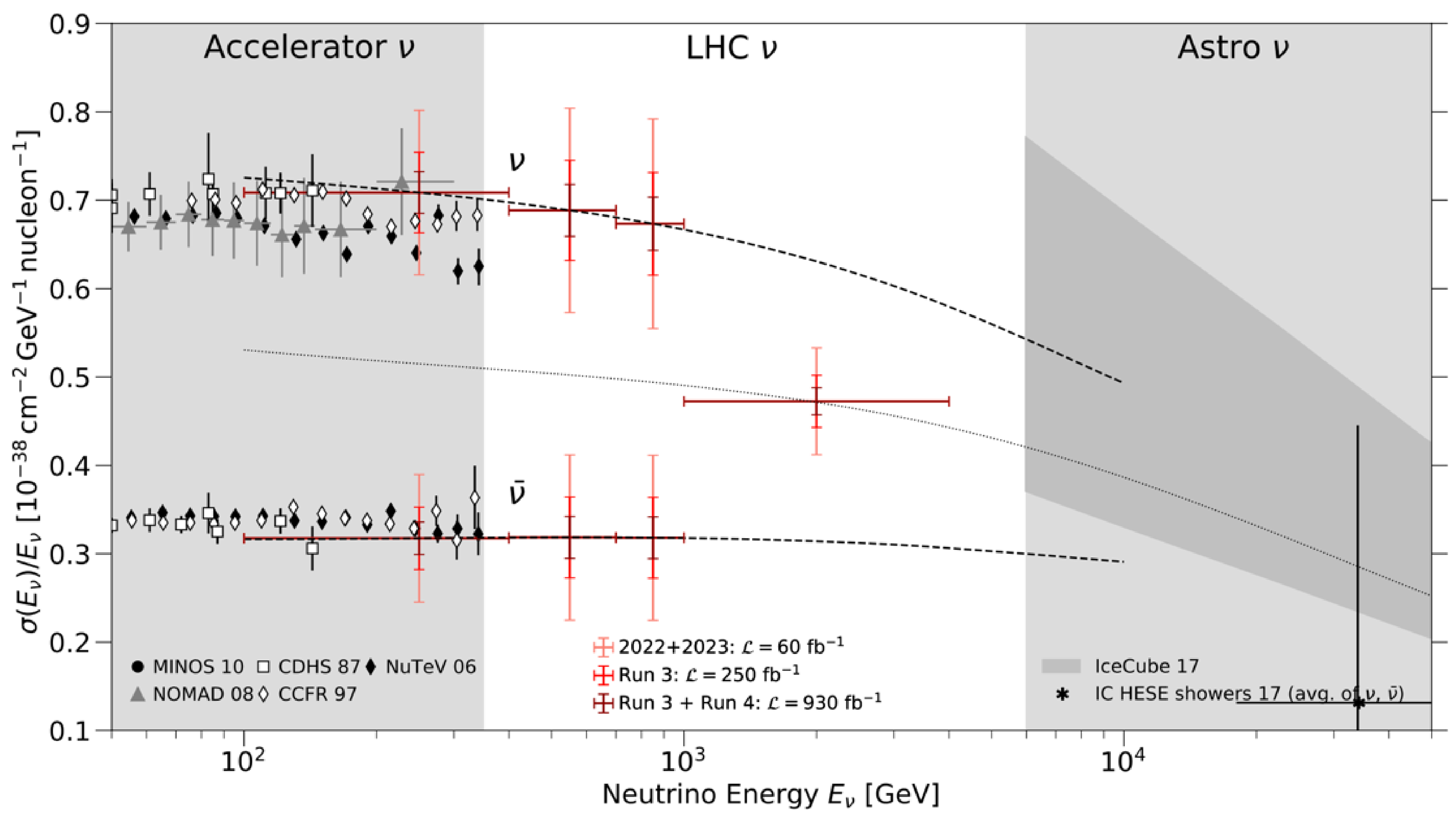
Operation proposal is already approved: [CERN-LHCC-2023-009]()

Increase statistics of neutrino events is expected in Run 4
Improvement and addition of detectors are under discussion





Neutrino cross-section




CERN-FASER-2025-001

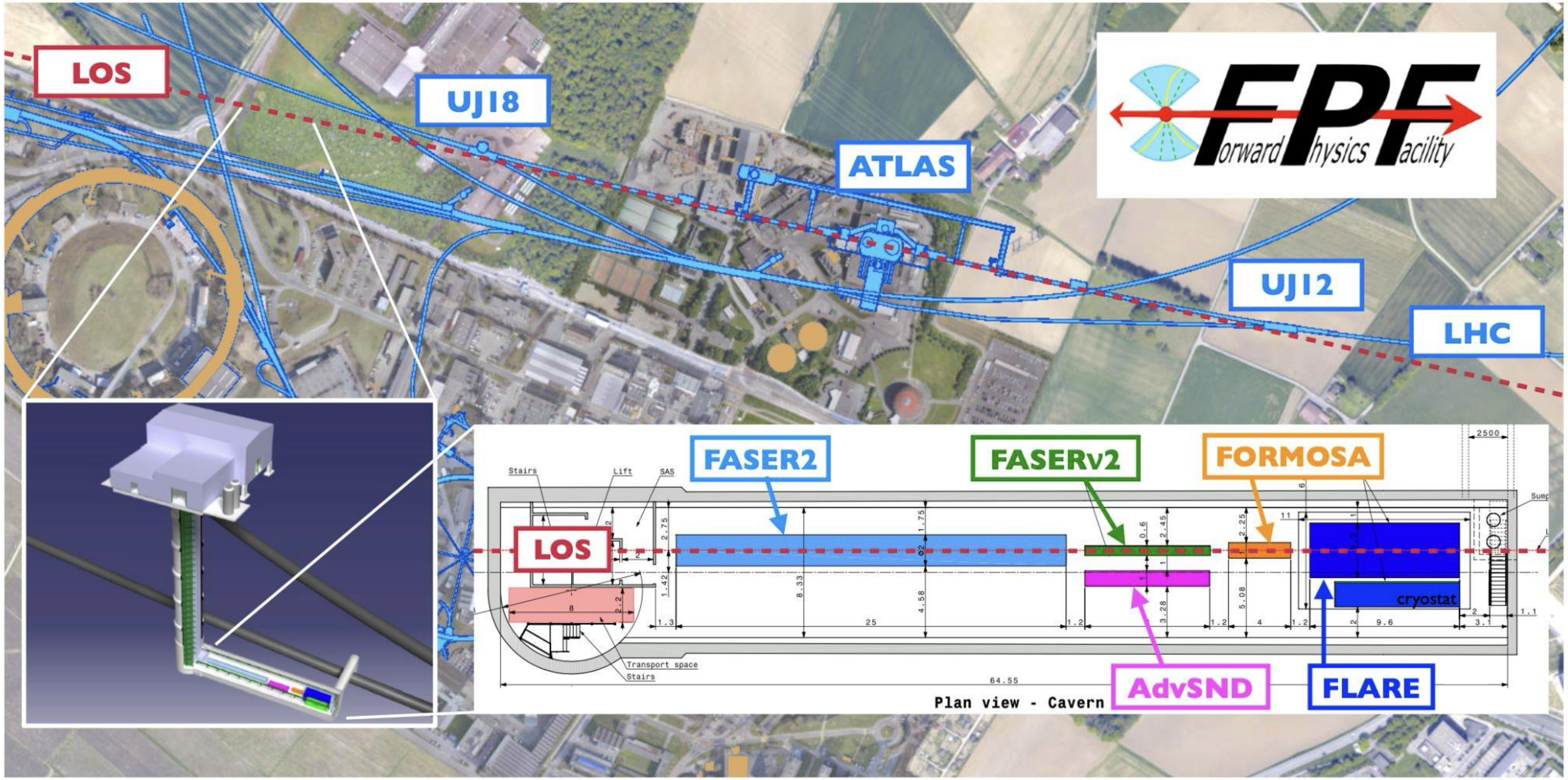
Prospects and Opportunities with an upgraded FASER Neutrino Detector during the HL-LHC era: Input to the EPPSU

FASER Collaboration

arXiv:2503.19775v1 [hep-ex] 25 Mar 2025

Forward Physics Facility

Continuation of this program envisioned for **HL-LHC era (2030s)**.
Proposal to create a dedicated **Forward Physics Facility (FPF)** for the HL-LHC:



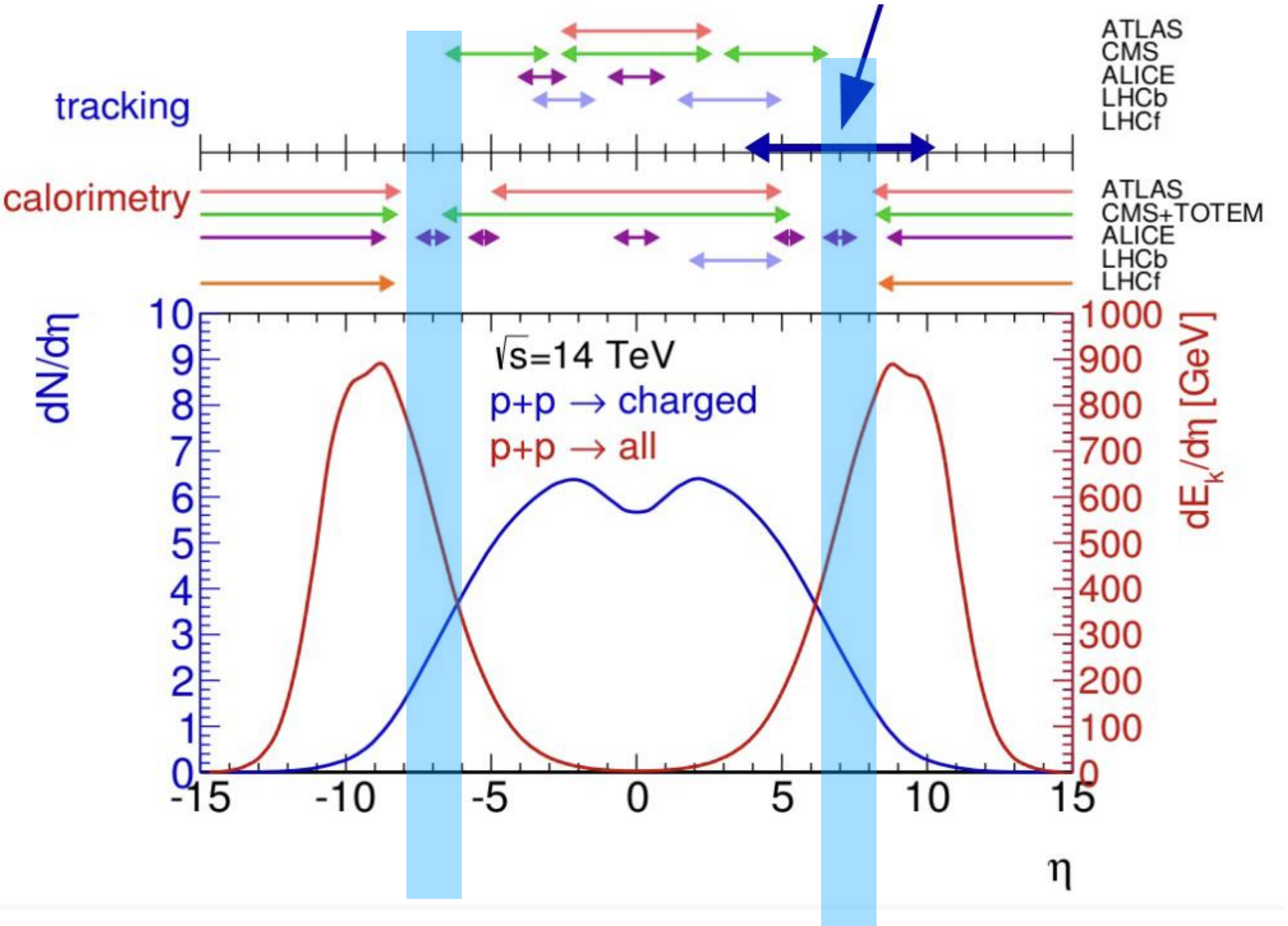
Summary

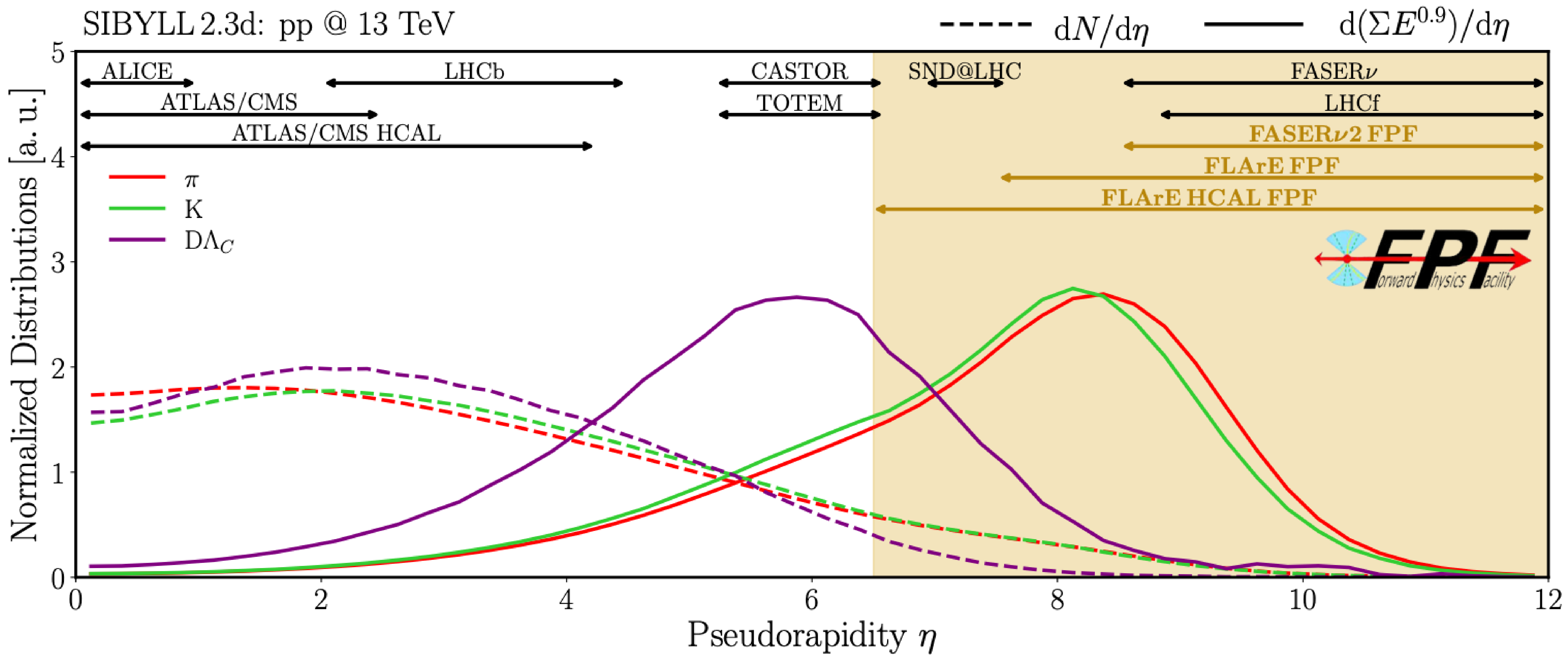
- Wide physics programs can be explored at the very forward region of LHC
- Neutrino measurements enable us to address the unexplored region of hadron production, which contribute to understand hadronic interaction significantlly.
- Several results from Run 3 data were already available.
  The newest results will open in this afternoon
  Moriond 2026, https://indico.in2p3.fr/event/39055/
- FASER will extend the program in LHC-Run4 periond and in FPF era.

Back

Up

Extension to the off-axis region



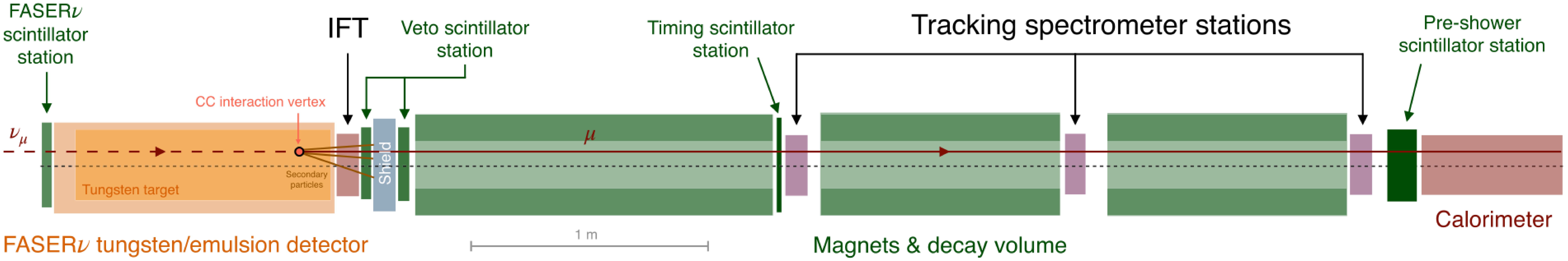


Hadron production at the pseudo-rapidity region **7<η<8**
is not explored yet due to conflict with the beam pipe configuration.

**The region 7<η<8 can be addressed by neutrinos
with SND@LHC (similar experiment as FASER)
and a new off-axis FASER detector, called AHCAL**

<u>Advantage of off-axis measurement</u>

- Better purity of charm contribution in ν_e
- Large pT coverage 1-2 GeV/c
  → Address semi-hard region
- Measurement of pseido-rapidity dependency

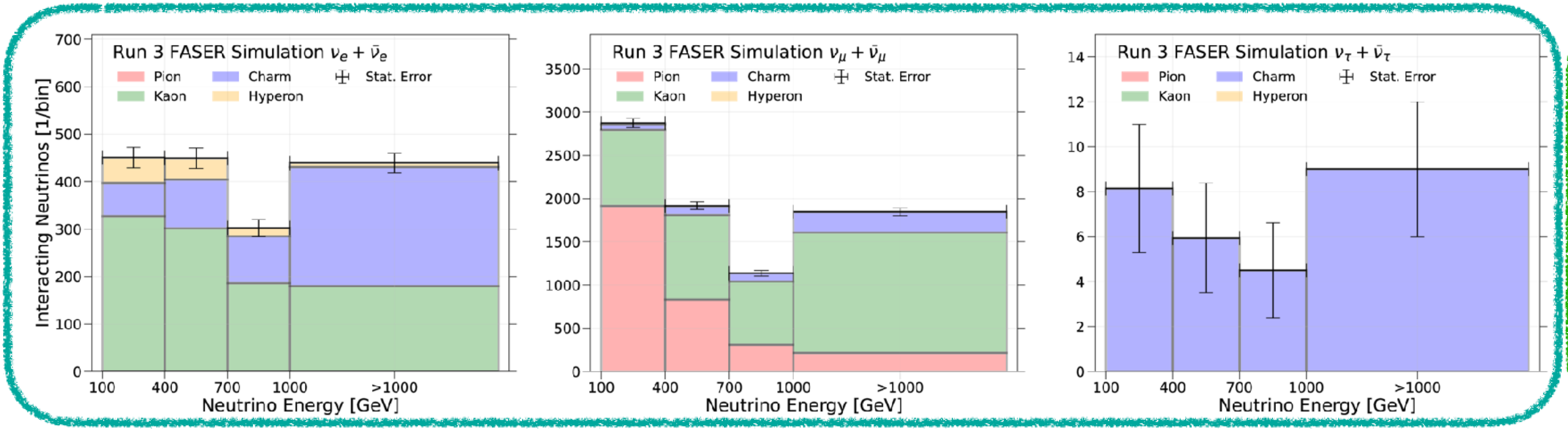


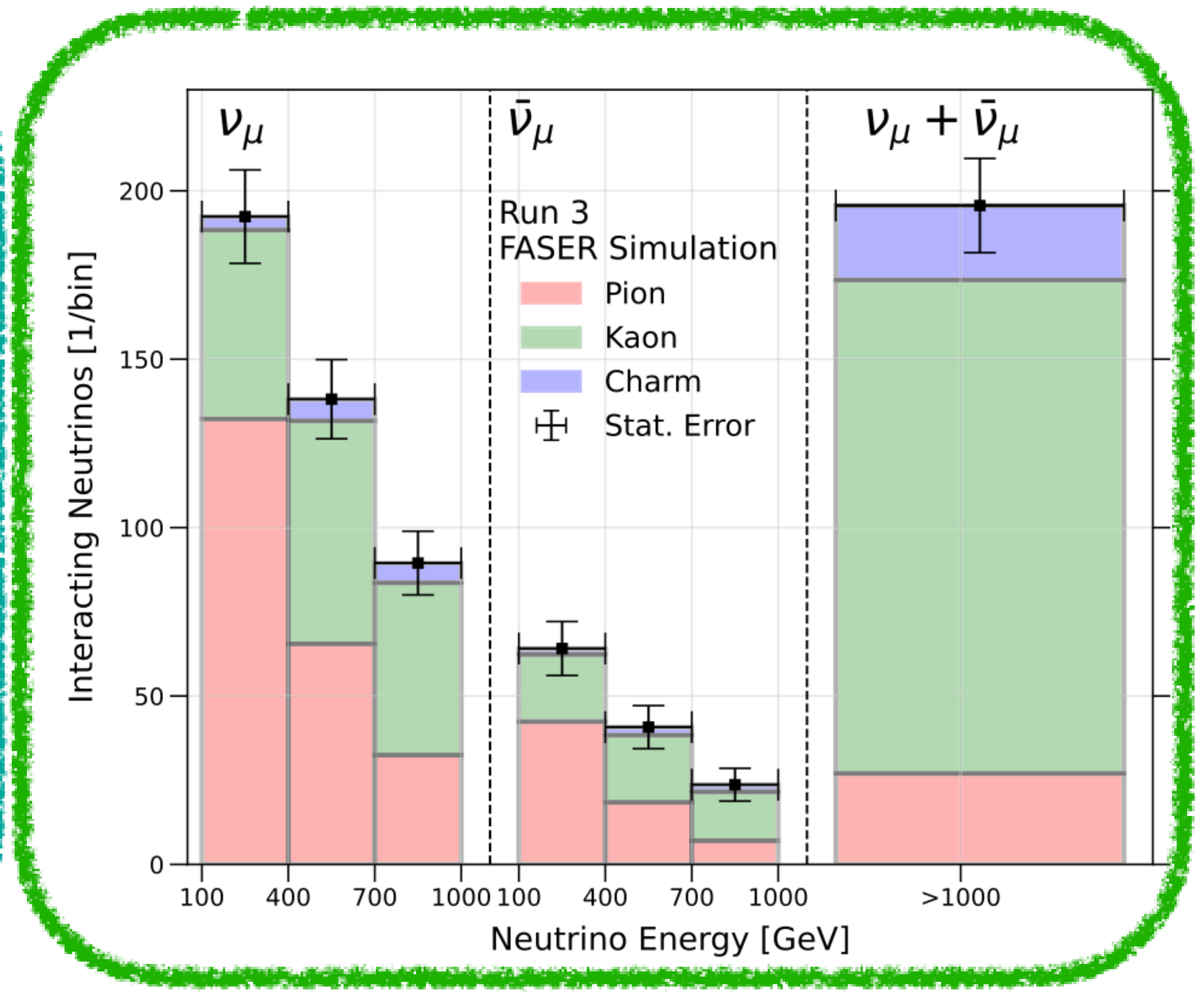
FASERν (Emulsion-based detector)

Sensitive to all 3 flavors

“Electric” detector technique

Charge separation $\nu_\mu/\nu_{\bar{\mu}}$



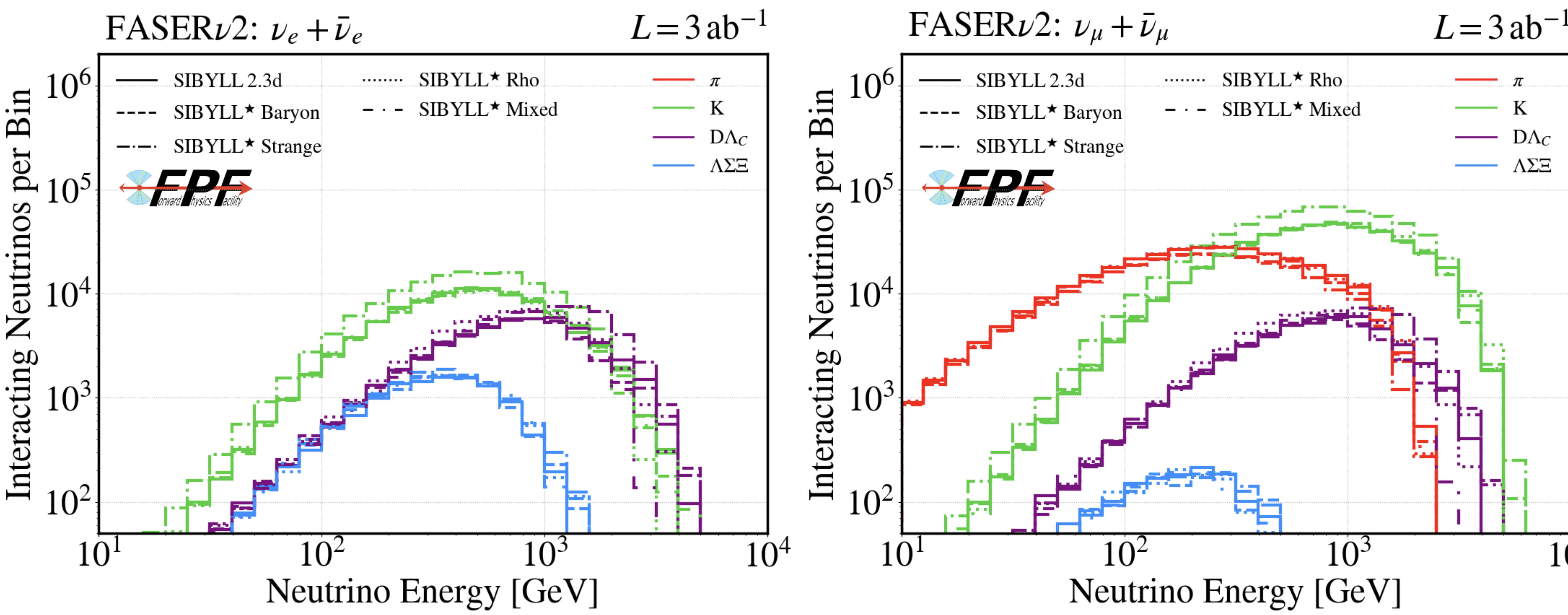


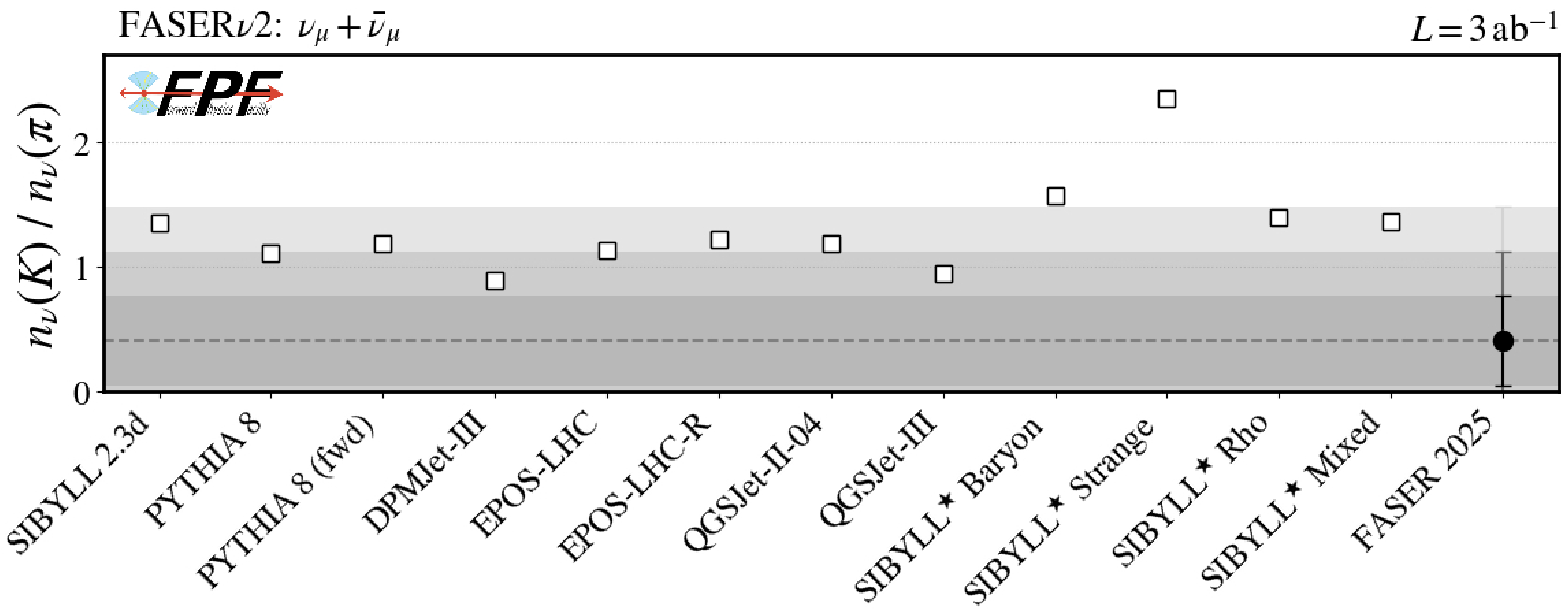
~10,000 neutrinos should be collected in LHC Run 3 (2022-2026)

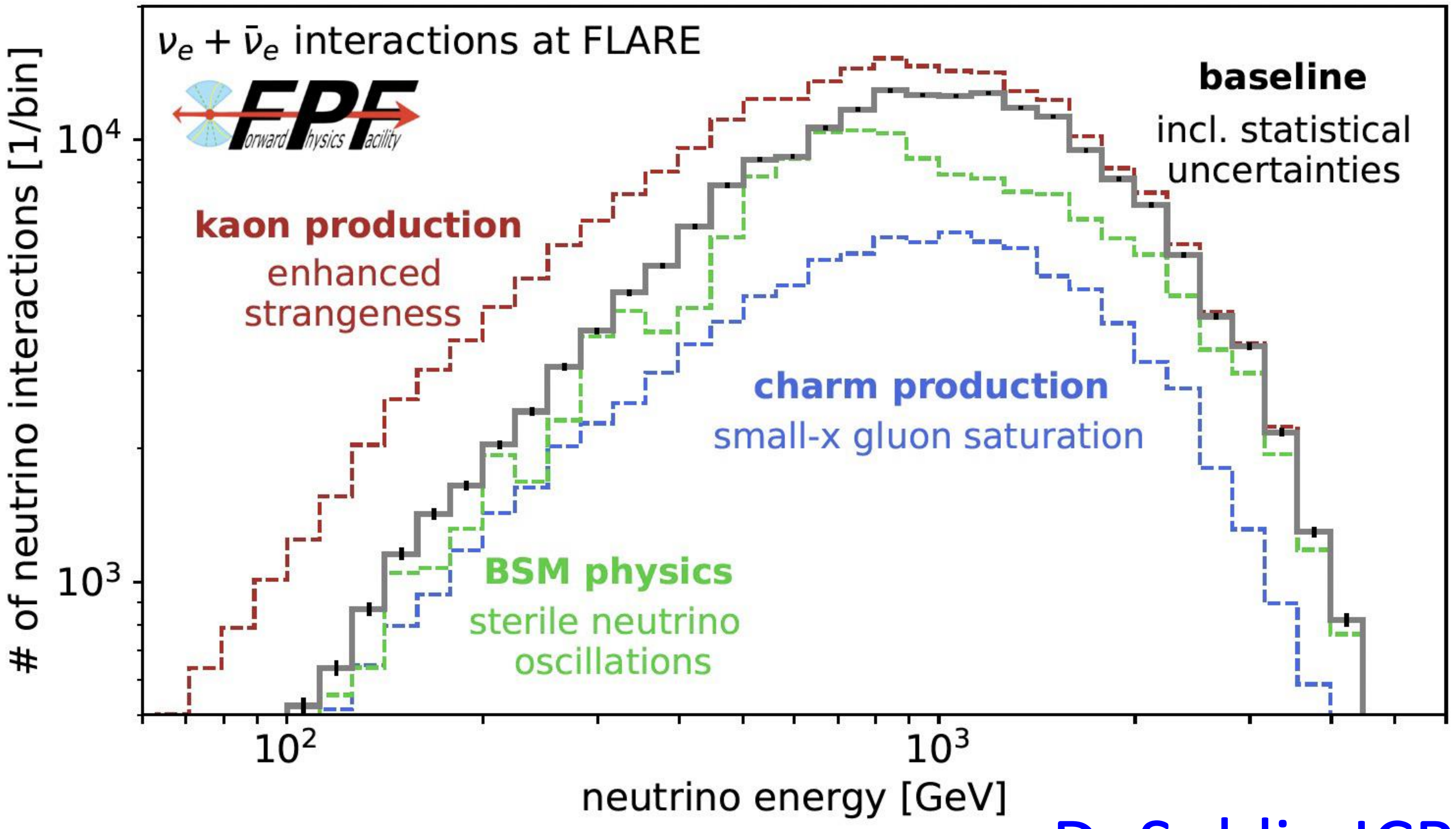
[Phys. Rev. D 110, 012009]

FPF with astroparticle physics

- 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
- Unique position to test $n_\nu(K)/n_\nu(\pi)$ with high statistical significance





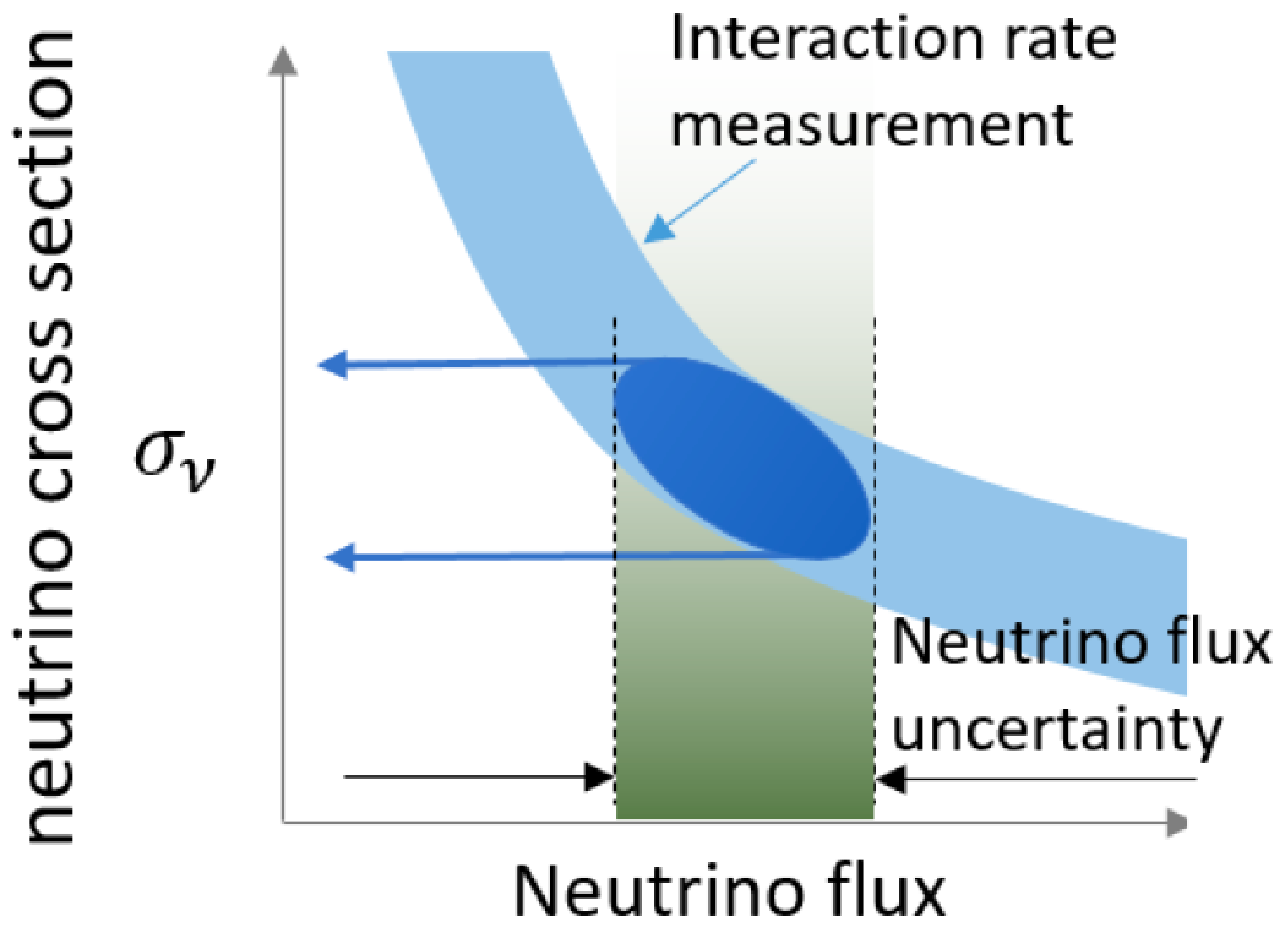


[D. Soldin ICRC2025]

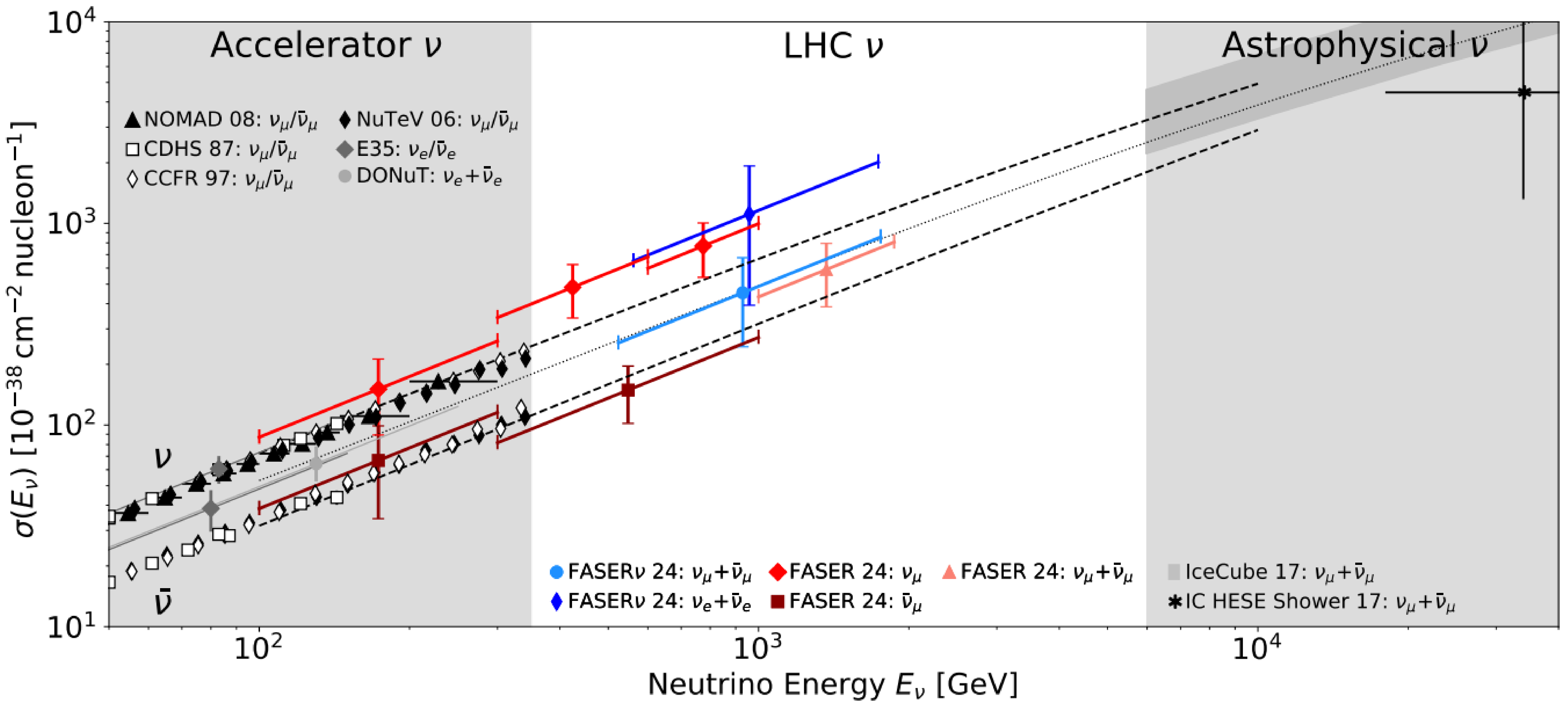
Interpretations of ν_μ interaction rate

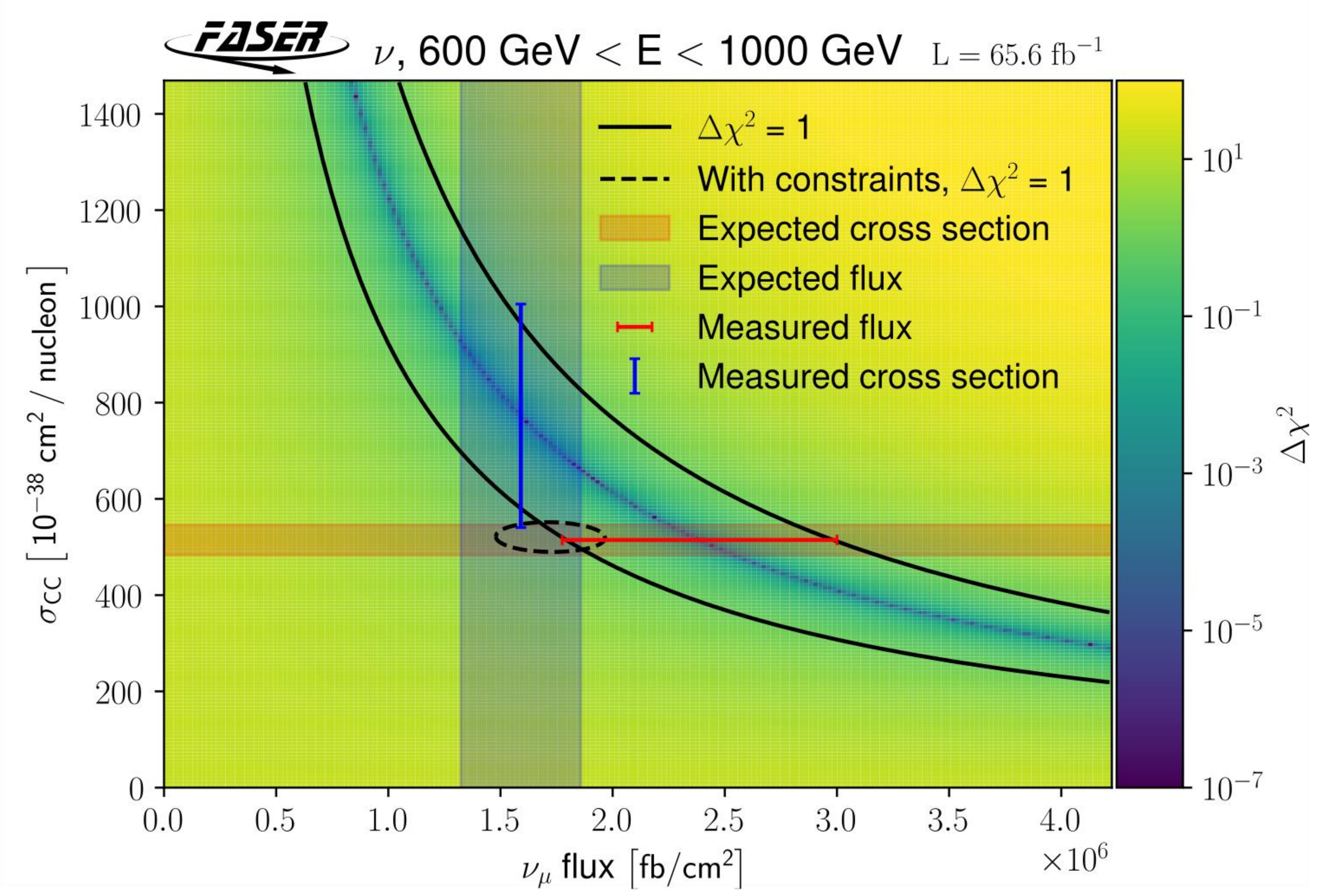
- FASER's result can be interpreted in two ways
  - Neutrino Cross-sections
  - Flux measurements・hadron production measurements

Achieved first $\overline{\nu_\mu}$ cross-section measurements!!



[Phys. Rev. Lett. 134, 211801](#)



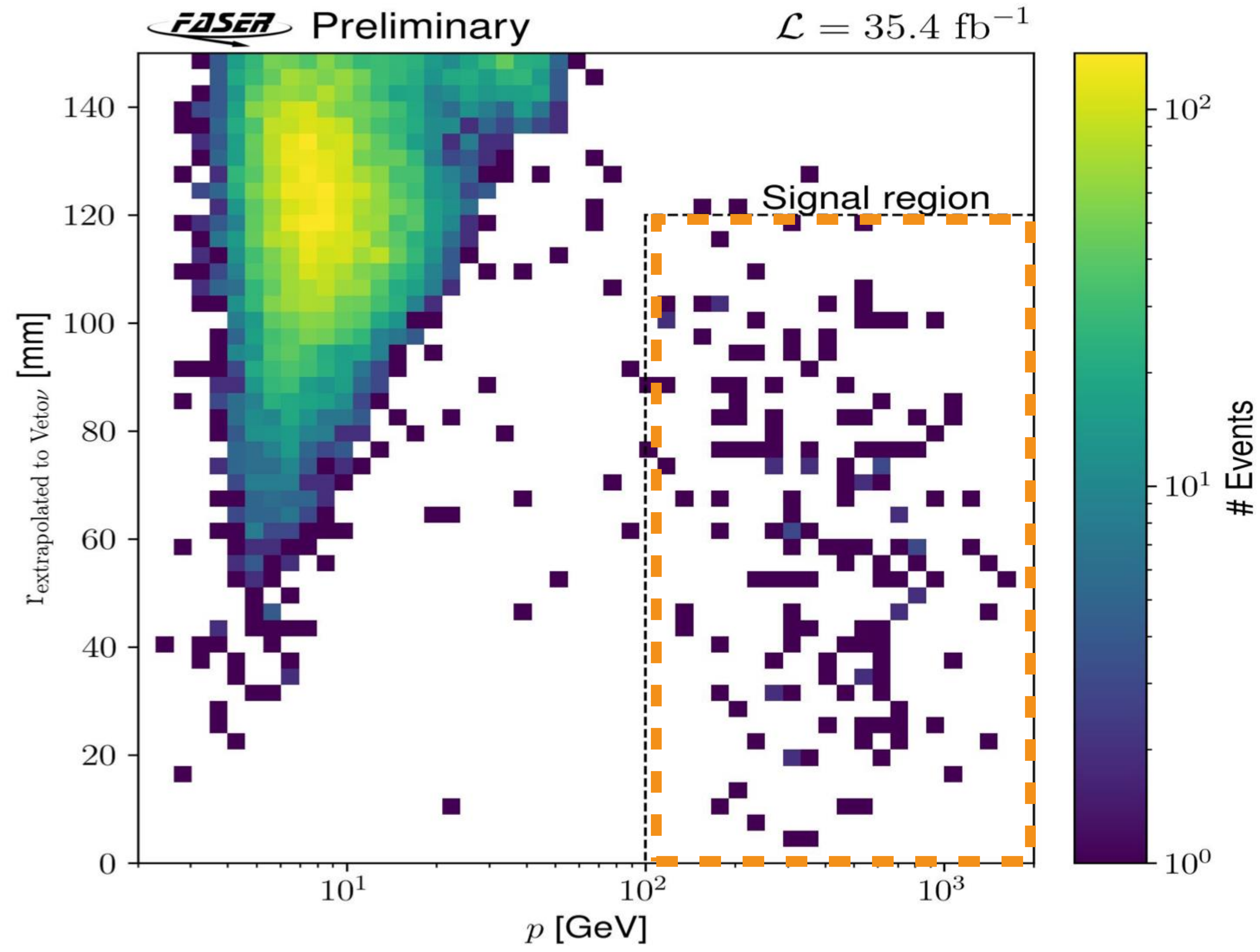


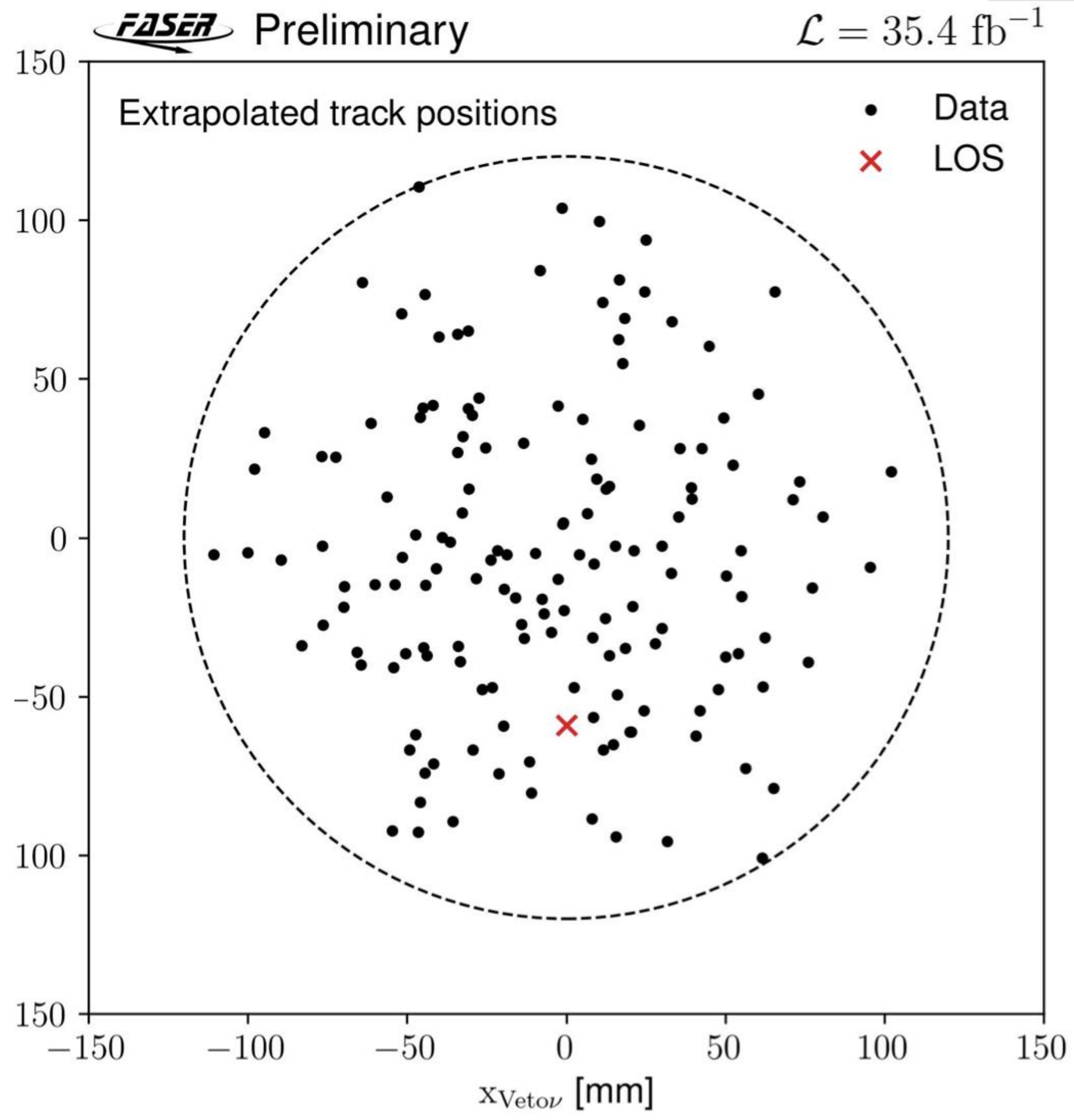
First detection of collider neutrino

Phys. Rev. Lett. 131, 031801 (2023)

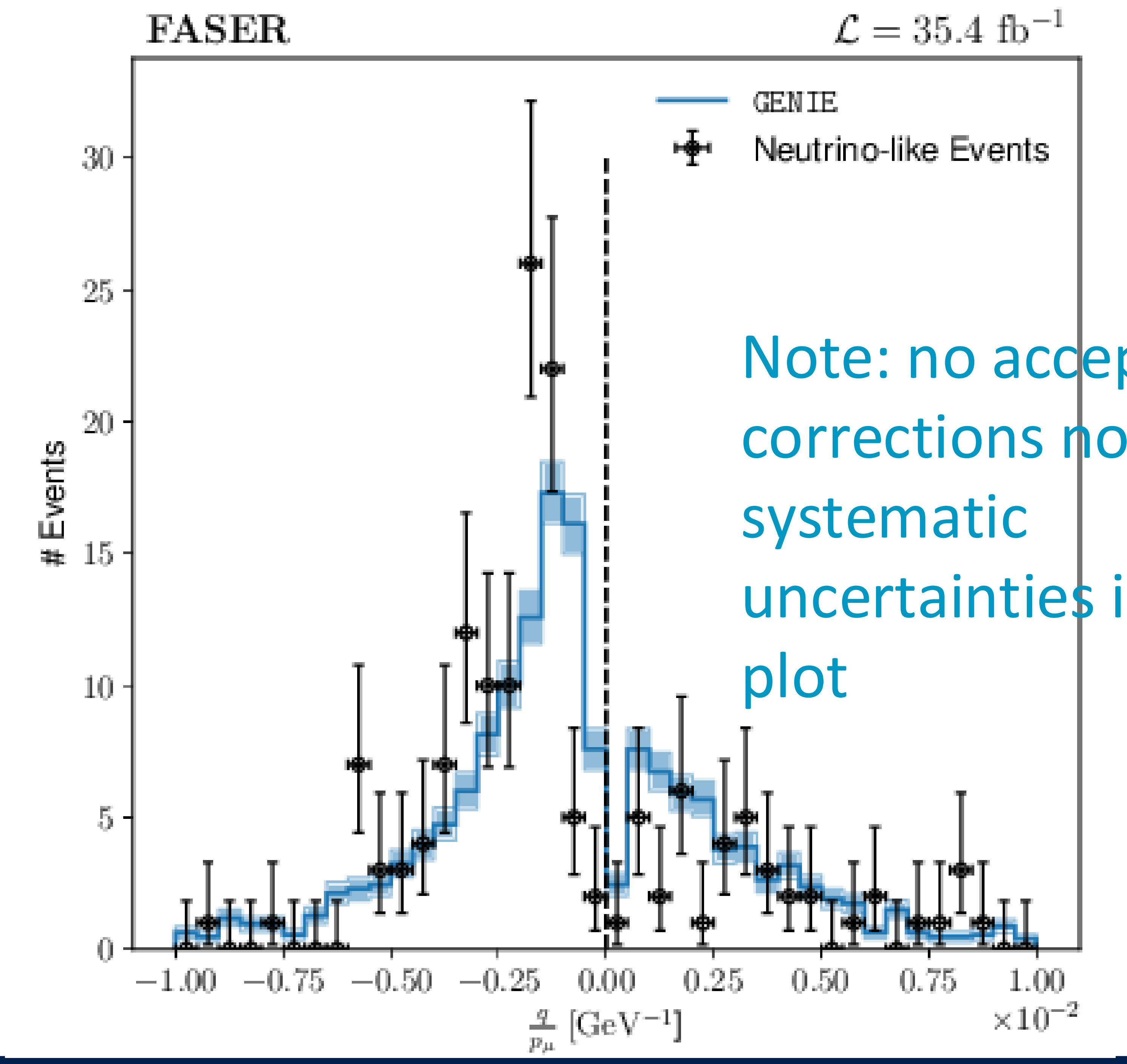
- Upon unblinding find **153 events** with no veto signal
  - Just 10 events with one veto signal
- **First direct detection of collider neutrinos!**
  - **With signal significance of 16σ**
- Candidate neutrino events match expectation from signal
  - Observed both neutrinos and anti-neutrinos as we expected

Candidate	Events
ν enriched Events (Passed all event selection)	153, (151±41, MC)
Events (1 veto signal at the first layer))la	4
Events (1 veto signal at the second layer)	6
Events (Veto signals for both layers)	64014695





Track momentum distribution

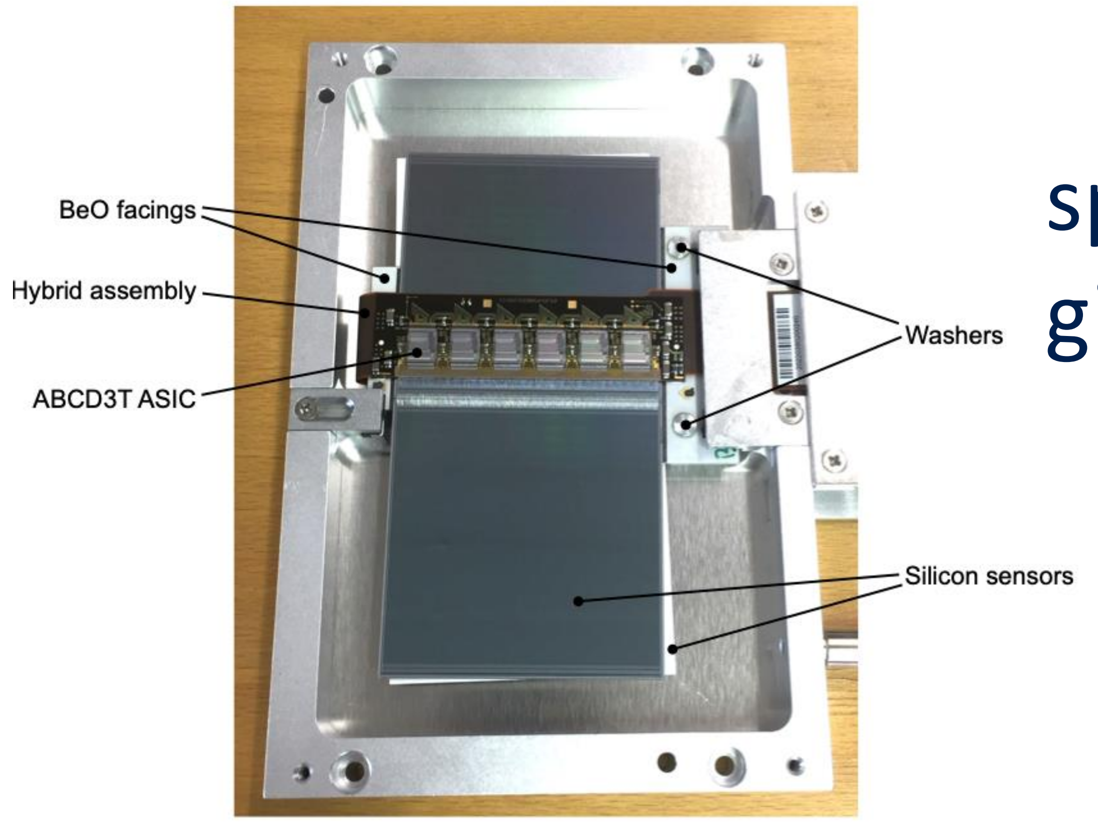


Note: no acceptance corrections nor systematic uncertainties in the plot

FASER Tracking components

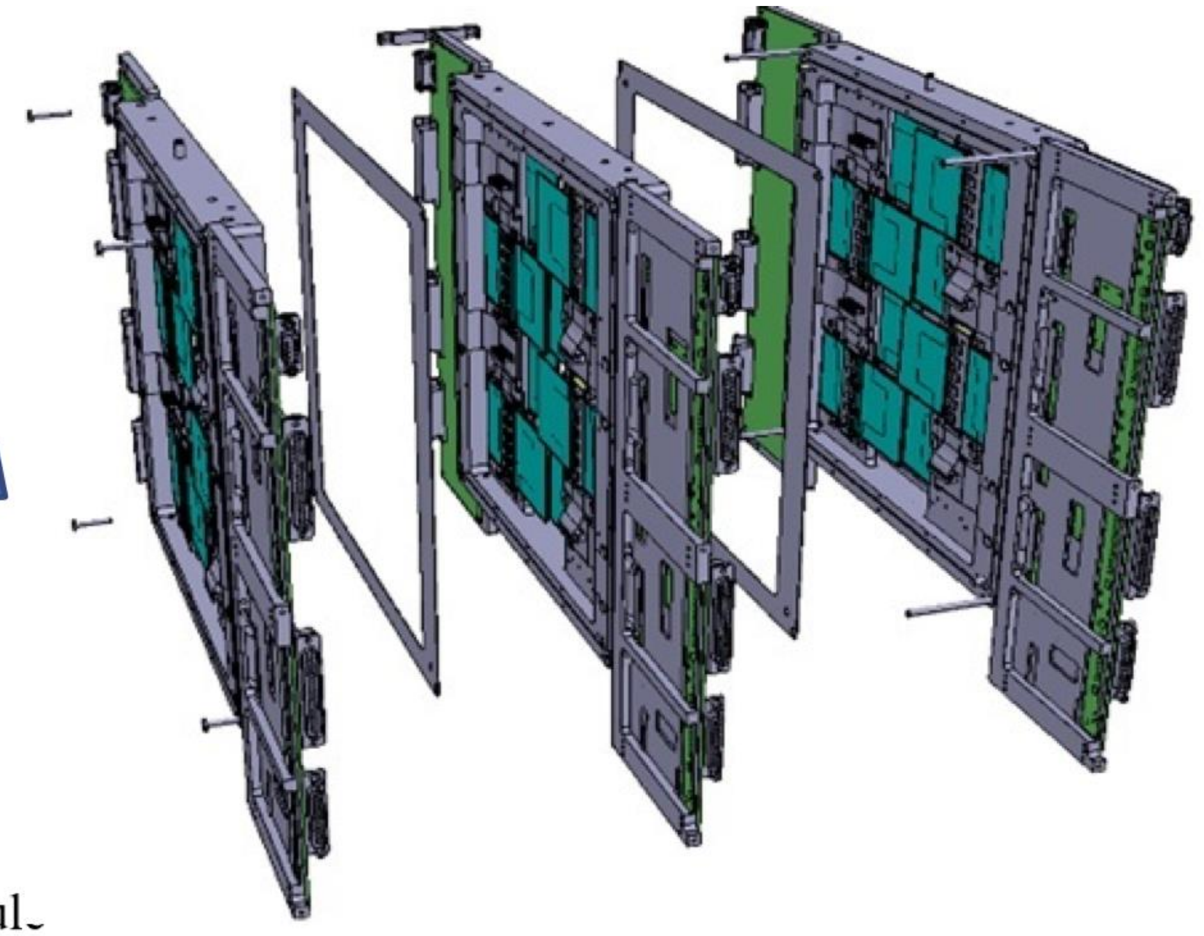
3 tracker stations + Interface tracker placed after the FASERν emulsion detector

Semiconductor Tracker (SCT) modules
→8 modules per tracker plane

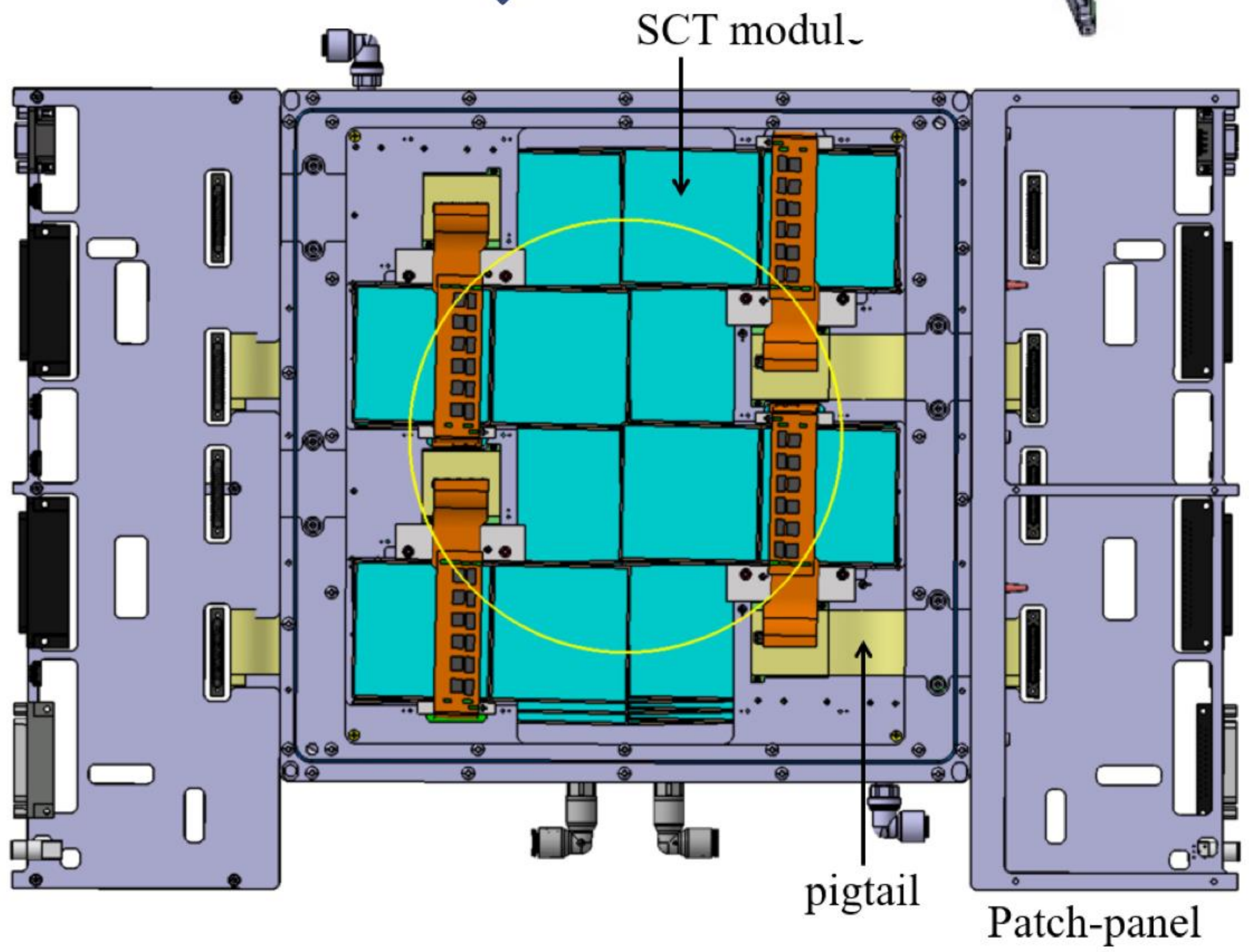


spare modules given by ATLAS

Tracker Station



Tracker Plane

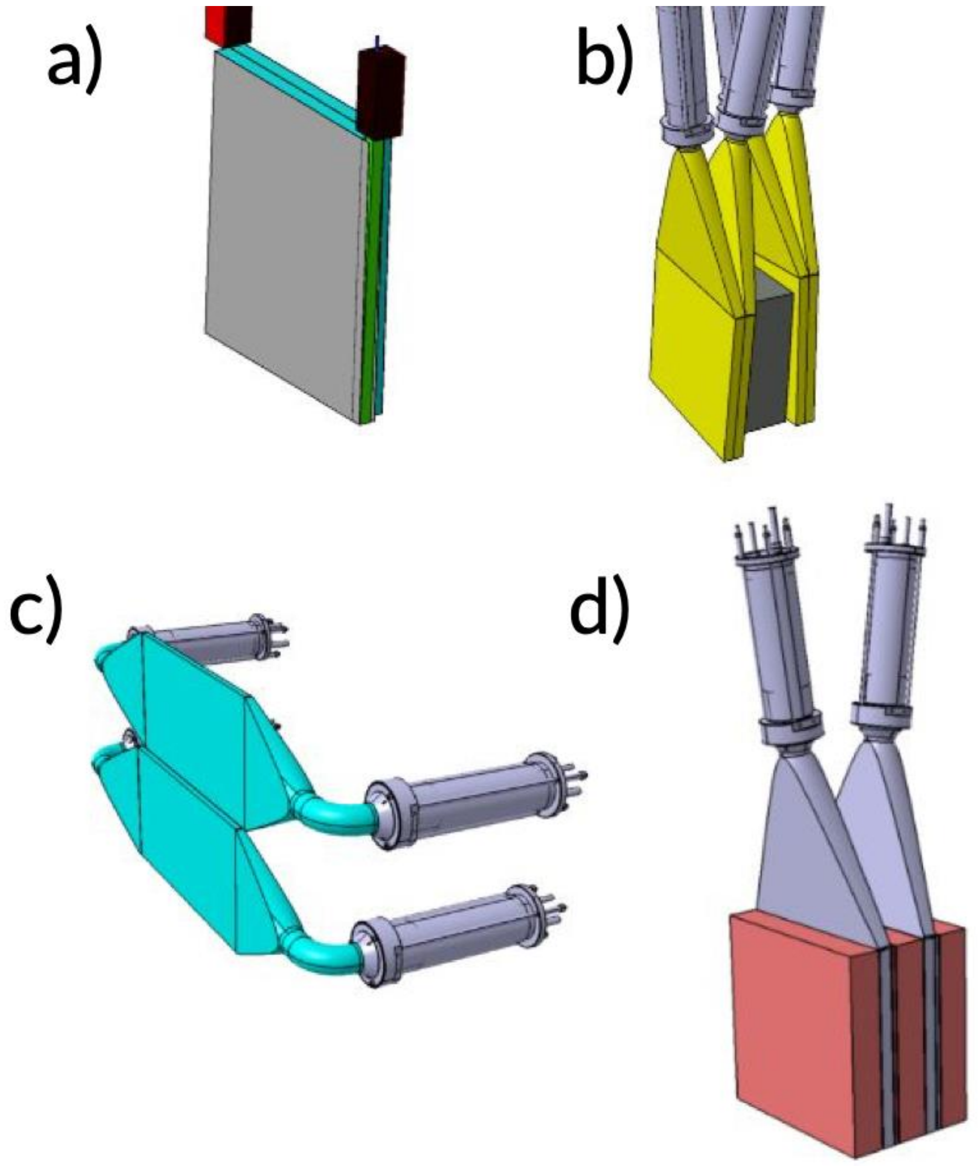


3 Tracker planes per station (12 in total)

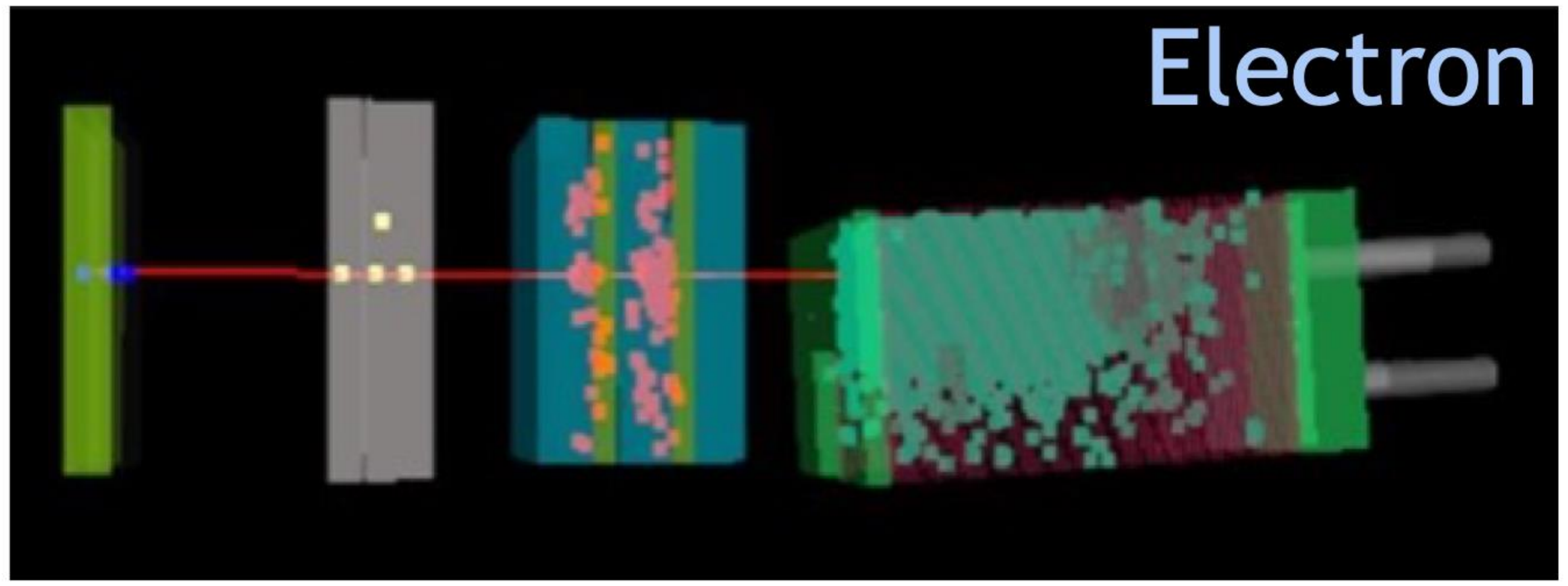
- 80μm strip pitch, 40mrad stereo angle (17μm / 580μm resolution)
  - precision measurement in bending (vertical) plane
  - 8 SCT modules give a 24cm x 24cm tracking layer

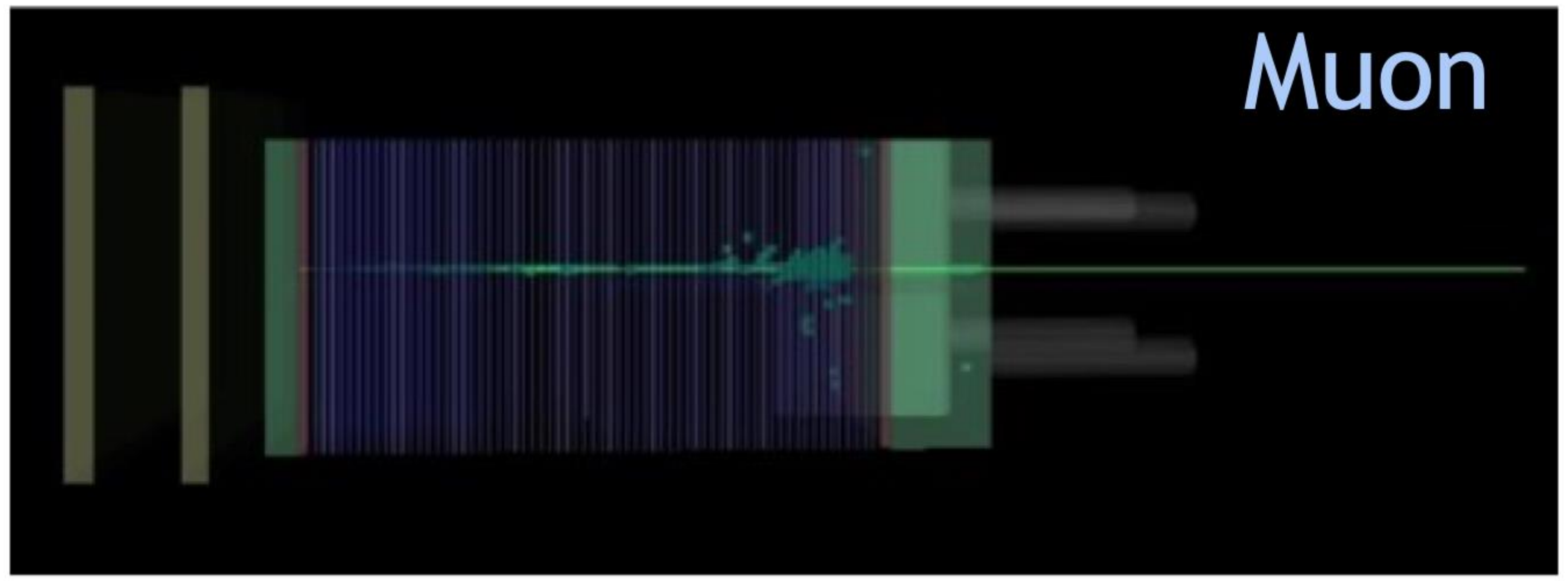
FASER calorimeter, pre-shower and scintillator systems

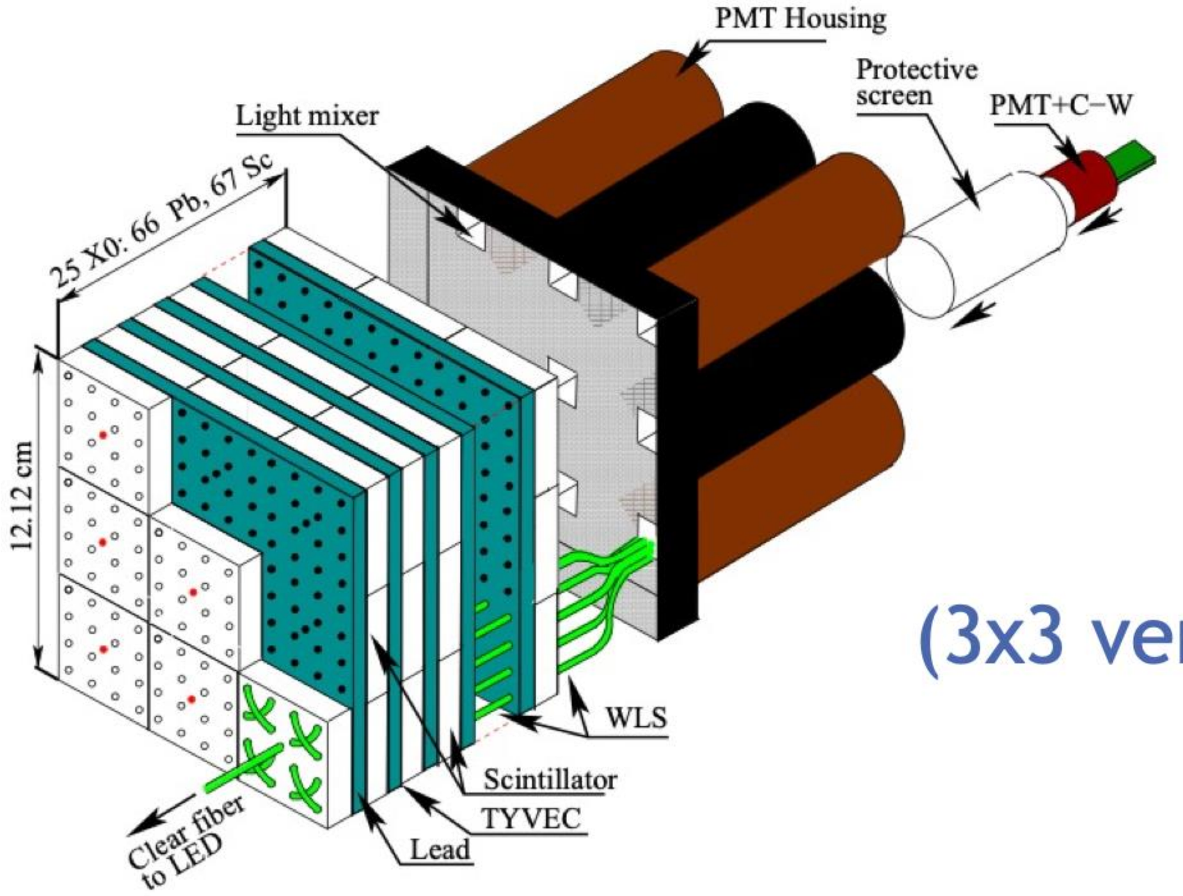
- **Four scintillator stations**
  - (a) FASERν (b) Interface Veto, (c) Timing, & (d) Preshower
  - **>99.98 % efficiency**, sufficient to **veto all incoming muons**
  - photo-multiplier tubes to detect the scintillation signals.



- **Electromagnetic calorimeter** made of spare **LHCb modules**
  - 66 layers of lead-scintillator plates read by 2x2 array of PMTs
  - 12 cm x 12 cm (25 X_0)
  - Simulated deposits for electrons and muons



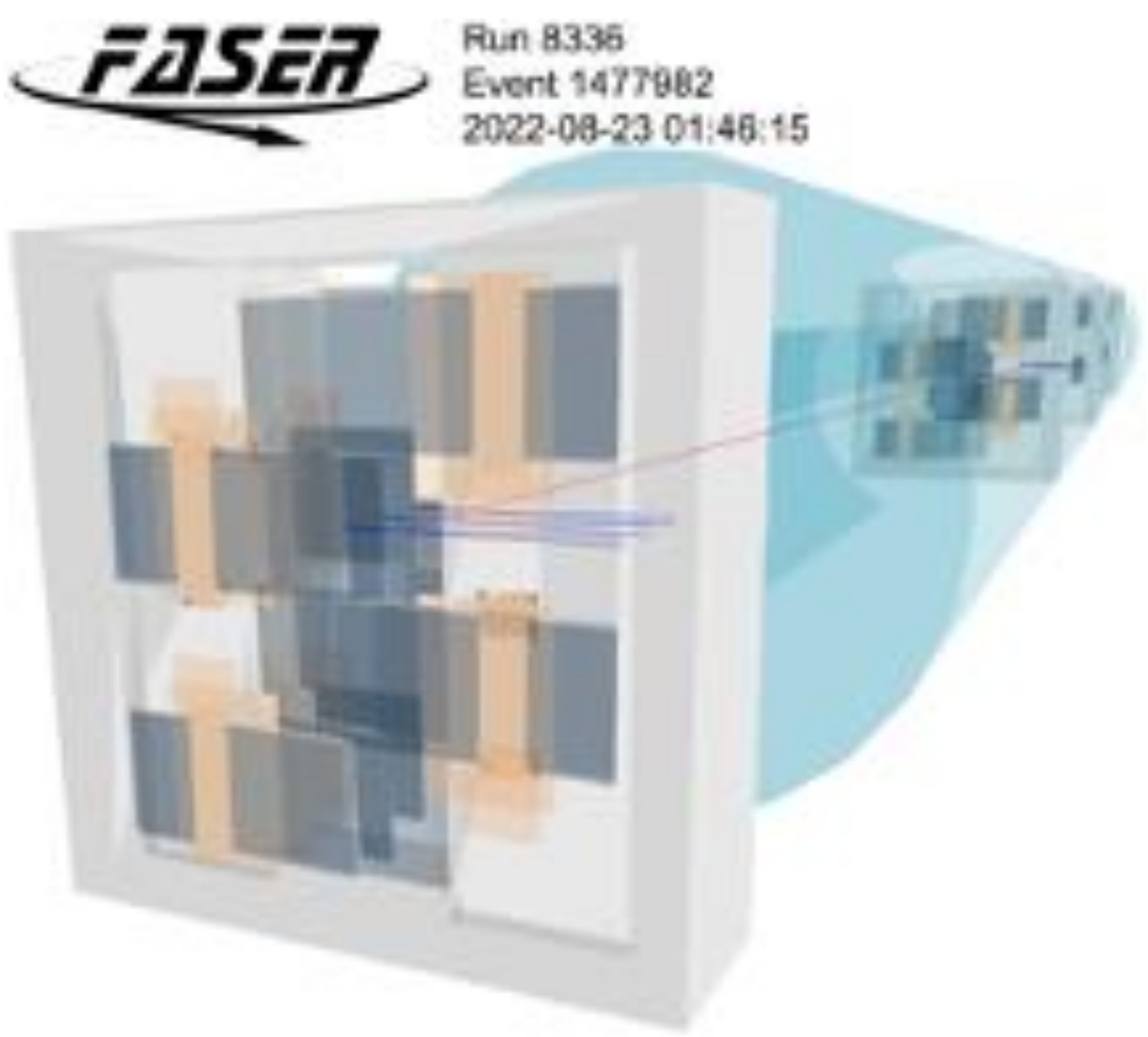


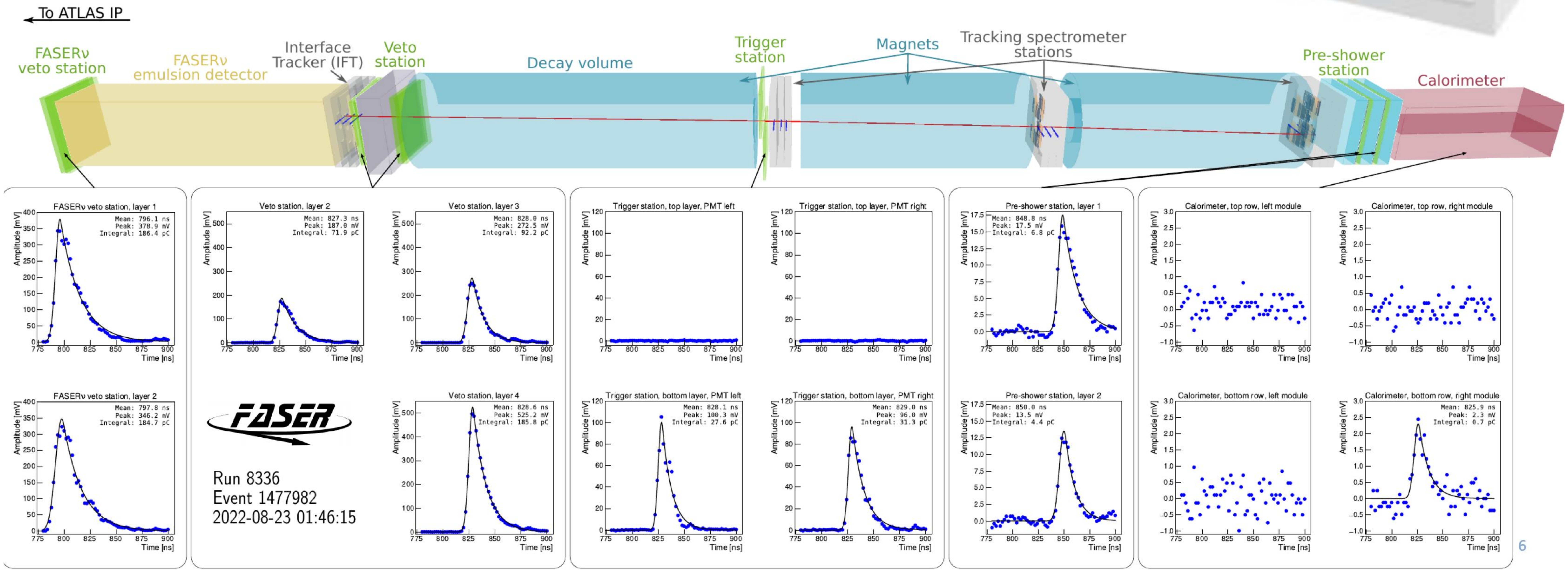


LHCb
(3x3 version)

Example Collision Event

- **More than 350M single-muon events recorded**
  - Example:muon leaving track passing through full detector + scintillator deposits consistent with MIP





Expected neutrino flux

- Expected number of CC interactions in FASERν in LHC Run 3
- The detector is **installed to the beam on-axis** to maximize the event rate
- **High E ν_e and ν_τ derived from charmed meson decay**

Expected number of neutrino interaction events obtained from different MC generators

Generators		FASERν		
light hadrons	heavy hadrons	$\nu_e + \bar{\nu}_e$	$\nu_\mu + \bar{\nu}_\mu$	$\nu_\tau + \bar{\nu}_\tau$
SIBYLL	SIBYLL	901	4783	14.7
DPMJET	DPMJET	3457	7088	97
EPOSLHC	Pythia8 (Hard)	1513	5905	34.2
QGSJET	Pythia8 (Soft)	970	5351	16.1
Combination (all)		1710^{+1746}_{-809}	5782^{+1306}_{-998}	$40.5^{+56.6}_{-25.8}$
Combination (w/o DPMJET)		1128^{+385}_{-227}	5346^{+558}_{-563}	$21.6^{+12.5}_{-6.9}$

arXiv:2105.08270