FASER Neutrino Results

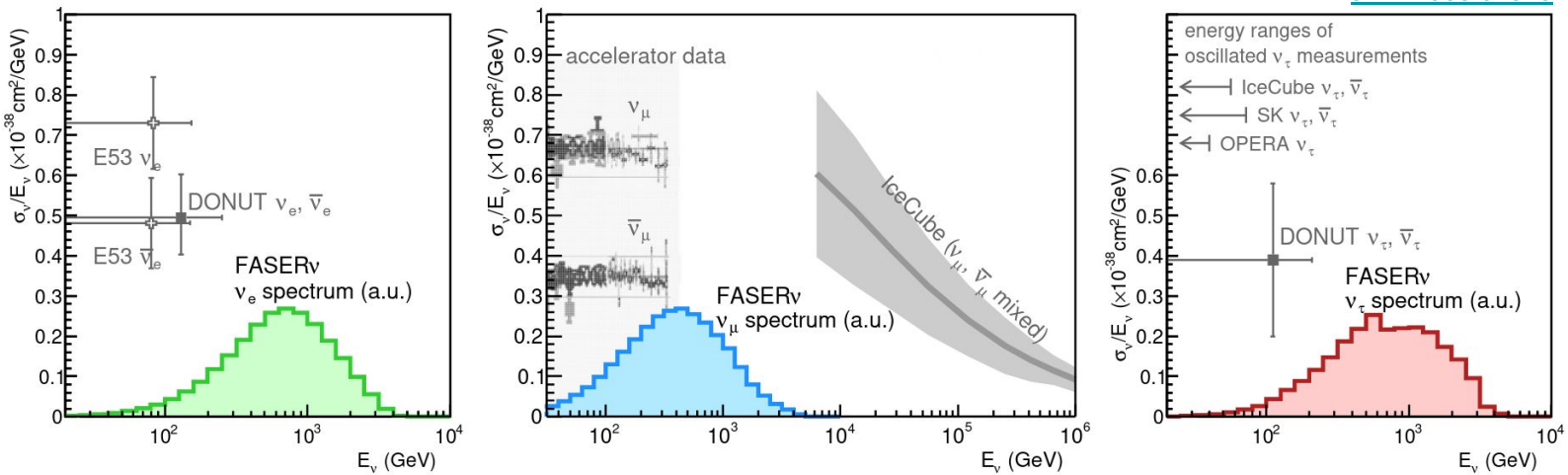
LHCP Conference, 22 - 26 May 2023, Belgrade

Tobias Böckh on behalf of the FASER collaboration

Collider Neutrinos

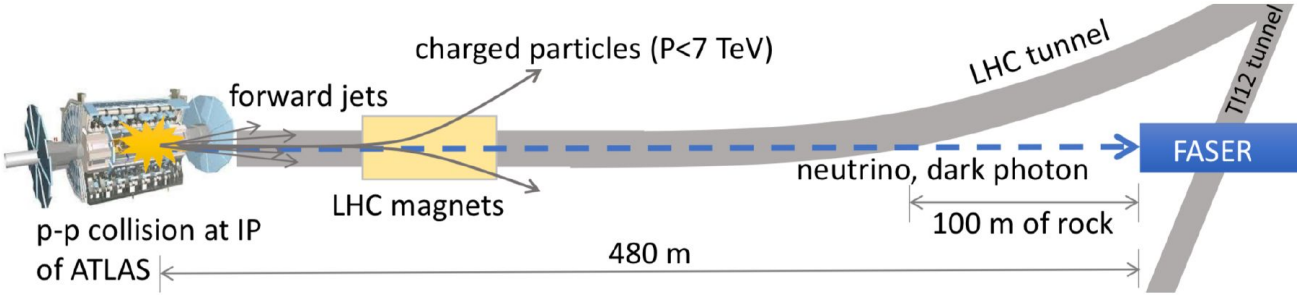
- Observed neutrinos from a variety of sources:
  nuclear reactors, beam dump experiments, cosmic rays, Sun, earth, supernovae, …
- Neutrinos produced copiously at hadron colliders, but no direct observation yet!
  - Neutrinos interact extremely weakly
  - Highest energy neutrinos produced in forward direction (parallel to beamline)
- Energy spectrum complementary to existing neutrino experiments
  - Measurement at highest man-made neutrino energies

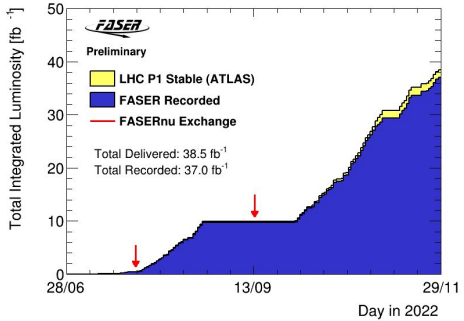
arxiv:1908.02310



The ForwArd Search ExpeRiment

- FASER is a new, small experiment at the LHC
  - Constructed and installed in 2019 - 2021
- Located 480 m downstream of ATLAS interaction point on collision axis line of sight
  - LHC magnets and 100 m of rock shield most backgrounds
- Targets long-lived BSM particles: A', ALPs, … (talk from Noshin Tarannum) and neutrinos (this talk)
- Successfully operated during all of 2022, restarted data taking in April 2023
  - All detector components perform excellently
  - Recorded 37.0 fb^{-1} of data in 2022 (96 % of delivered luminosity)
- Possible Future Upgrade: FASER2 at the proposed Forward Physics Facility (talk from Roshan Mammen Abraham)

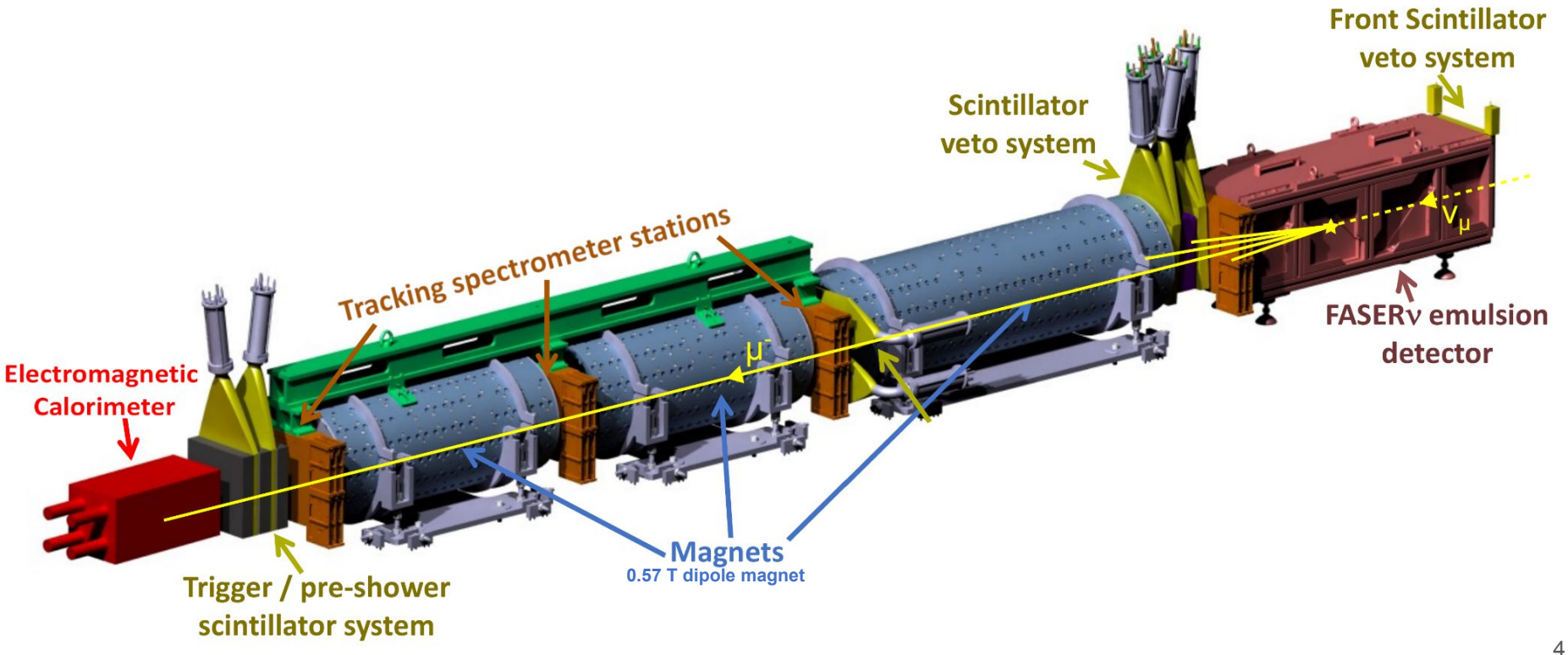




FASER Detector

arxiv:2207.11427

Aperture: 20 cm
Length: 7 m



Neutrino Signature in Emulsion Detector

arxiv:2207.11427

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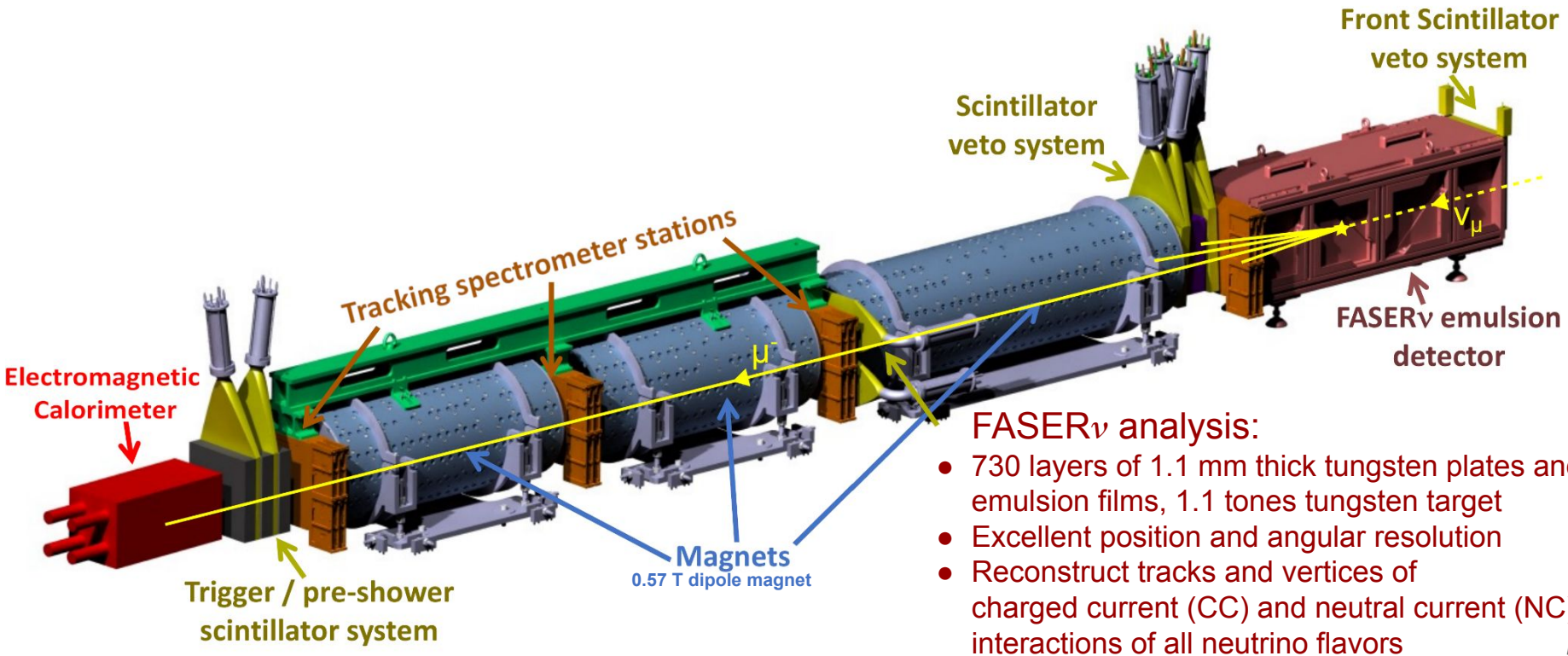


FASERν analysis:

- 730 layers of 1.1 mm thick tungsten plates and emulsion films, 1.1 tones tungsten target
- Excellent position and angular resolution
- Reconstruct tracks and vertices of charged current (CC) and neutral current (NC) interactions of all neutrino flavors
- Analysis still ongoing

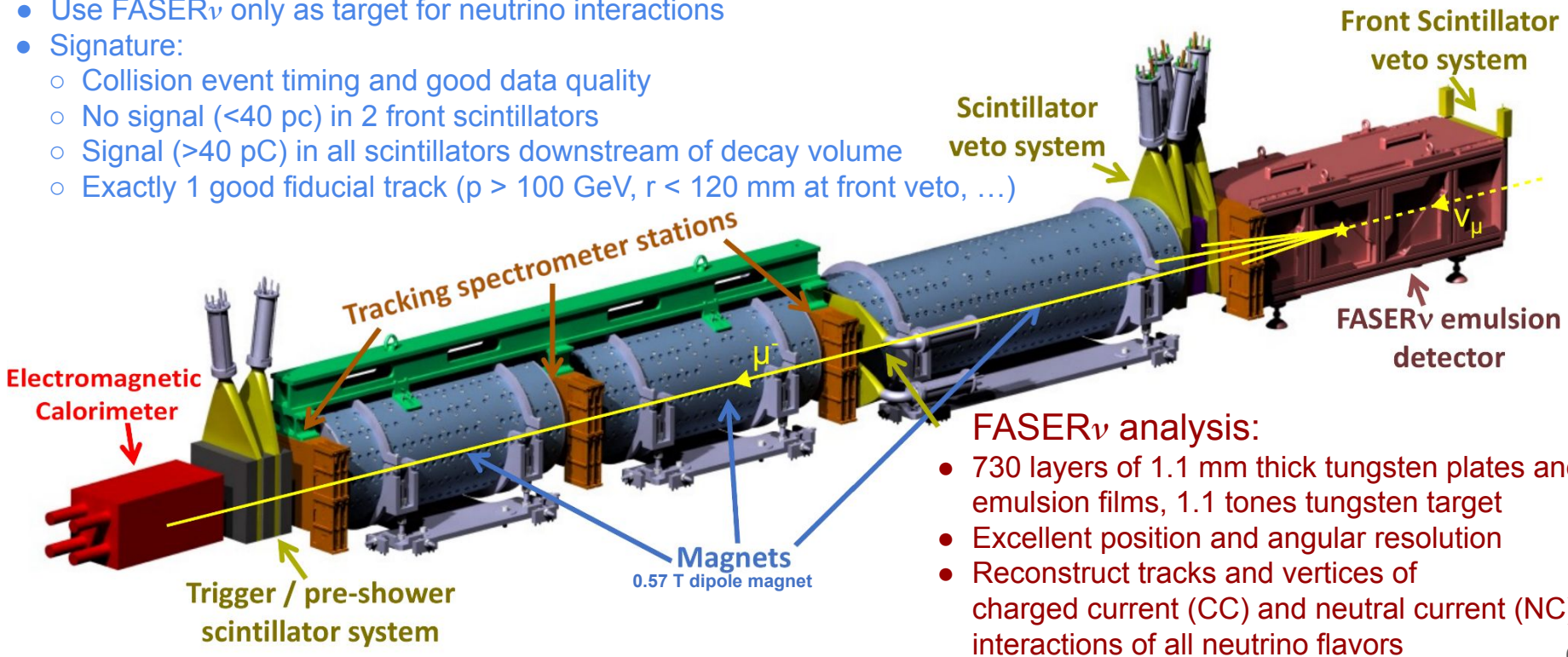
Neutrino Signature in Electronic Detector

arxiv:2207.11427

Electronic Neutrino analysis:

- Detect CC ν_μ interactions using spectrometer and scintillators
- Use FASERν only as target for neutrino interactions
- Signature:
  - Collision event timing and good data quality
  - No signal (<40 pc) in 2 front scintillators
  - Signal (>40 pC) in all scintillators downstream of decay volume
  - Exactly 1 good fiducial track (p > 100 GeV, r < 120 mm at front veto, …)

Aperture: 20 cm
Length: 7 m



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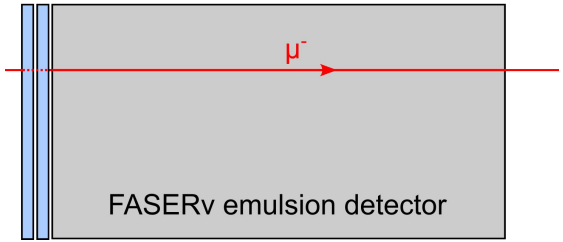
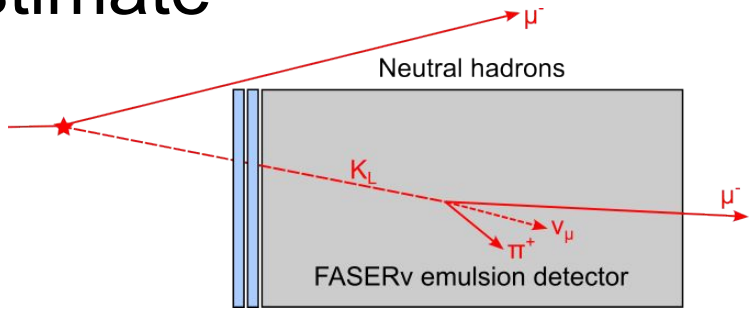
Background Estimate

Veto inefficiency

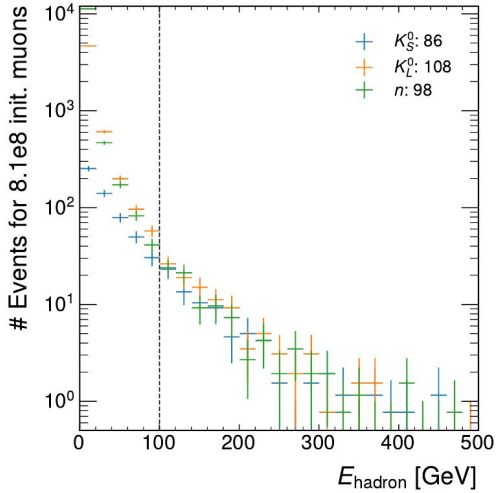


- Estimated from events with just one veto scintillator firing
- Expect (3.7±2.5) x 10^{-7} events

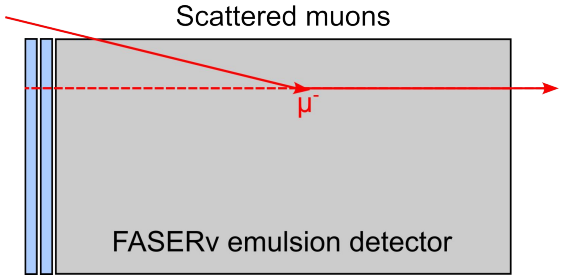
Neutral hadrons



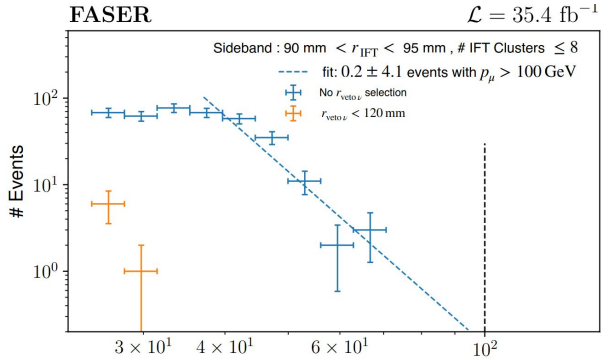
- Expect O(300) neutral hadrons with E > 100 GeV
- Most hadrons absorbed in tungsten (8 int. lengths)
- Estimate 0.11±0.06 events



Scattered muons



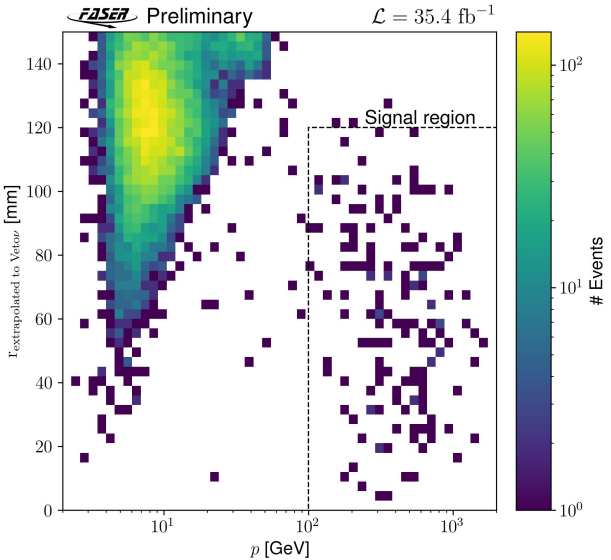
- Estimated from control region (90 < r < 95 mm, # clusters ≤ 8)
- Expect 0.08 ± 1.83 events

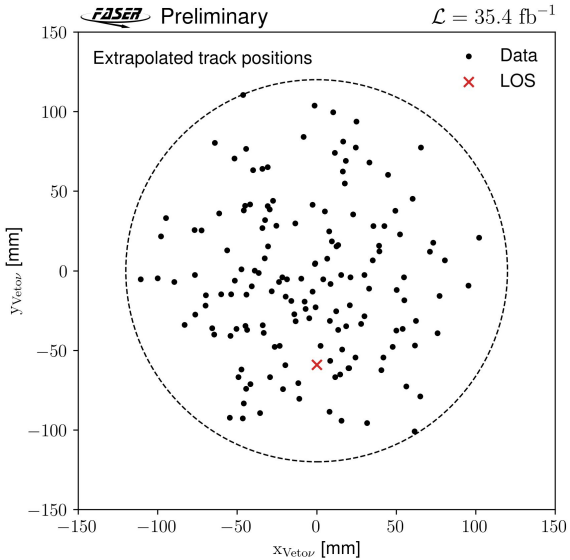


Neutrino Observation

- Based on GENIE simulation expect 151 ± 41 neutrino events
  - Uncertainty from difference between DPMJET and SIBYLL event generators
  - No experimental uncertainties → cannot translate to cross section / flux yet
- Observe 153 events with no veto signal with an expected background of 0.2 ± 1.8
- First direct observation of collider neutrinos!
  - Signal significance of 16 σ
  - Recently accepted by PRL

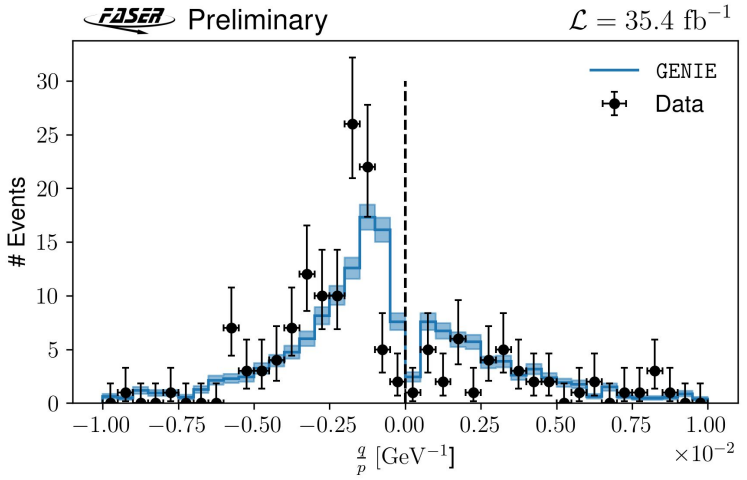
arxiv: 2303.14185

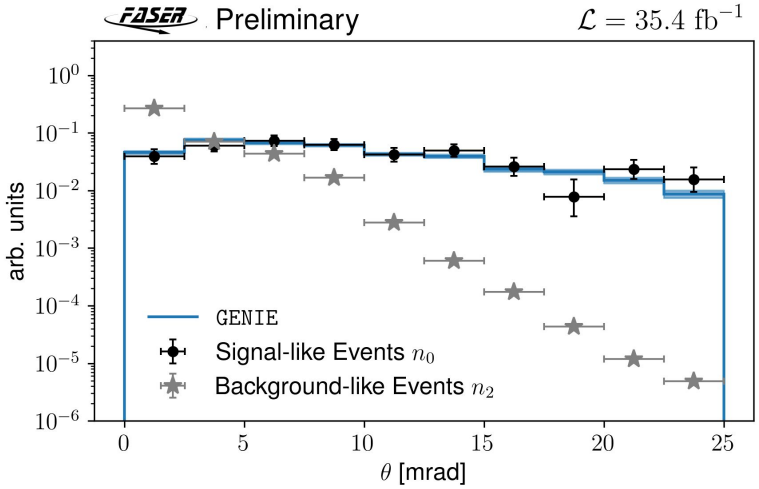


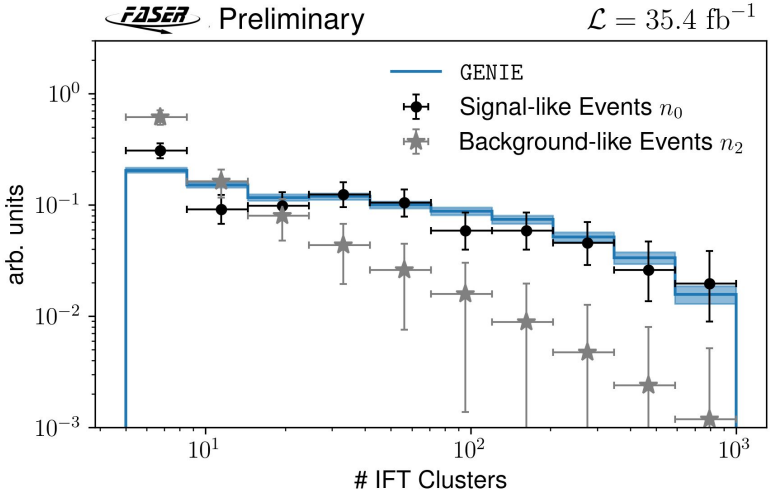


Neutrino Characteristics

- Neutrino events match expectations from simulation
  - Most events at high momentum (E_μ > 200 GeV)
  - More ν_μ than $\bar{\nu}_\mu$
  - High occupancy in front tracker station
  - Large angle θ with respect to line-of-sight
- No experimental uncertainties included in these plots!

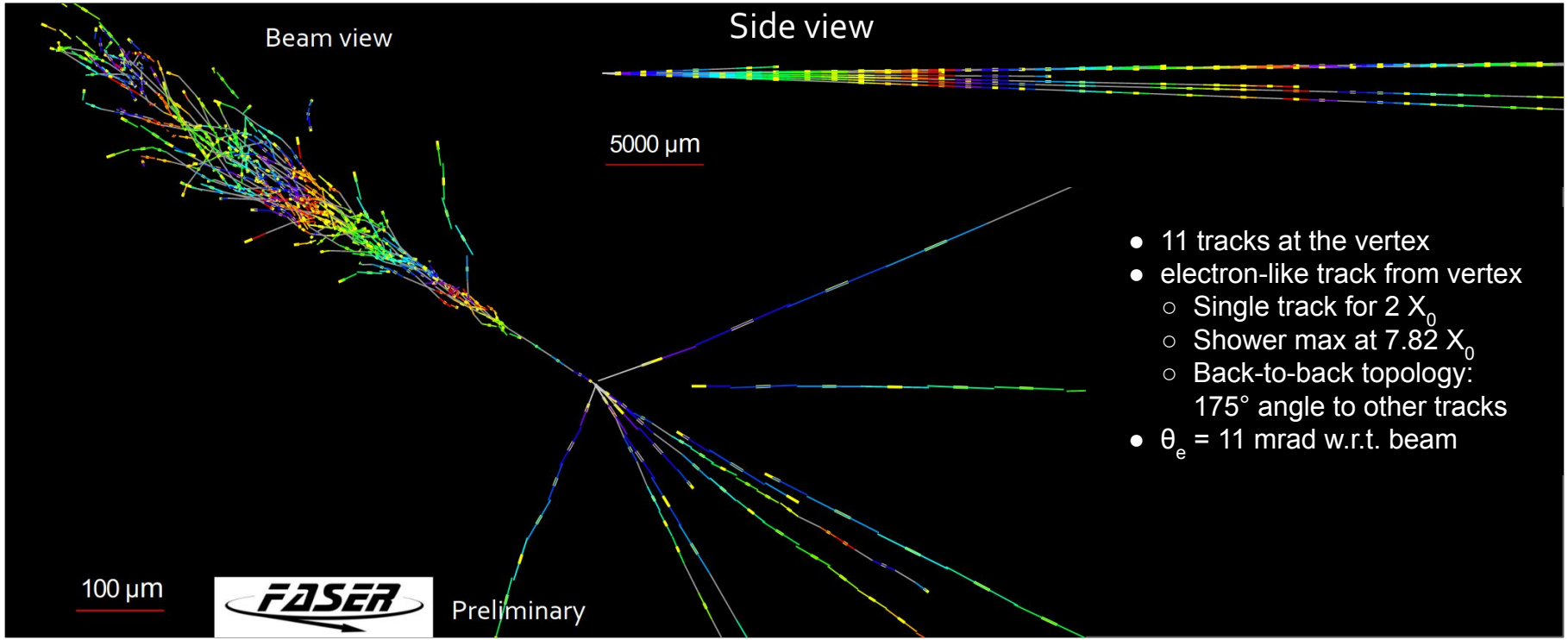






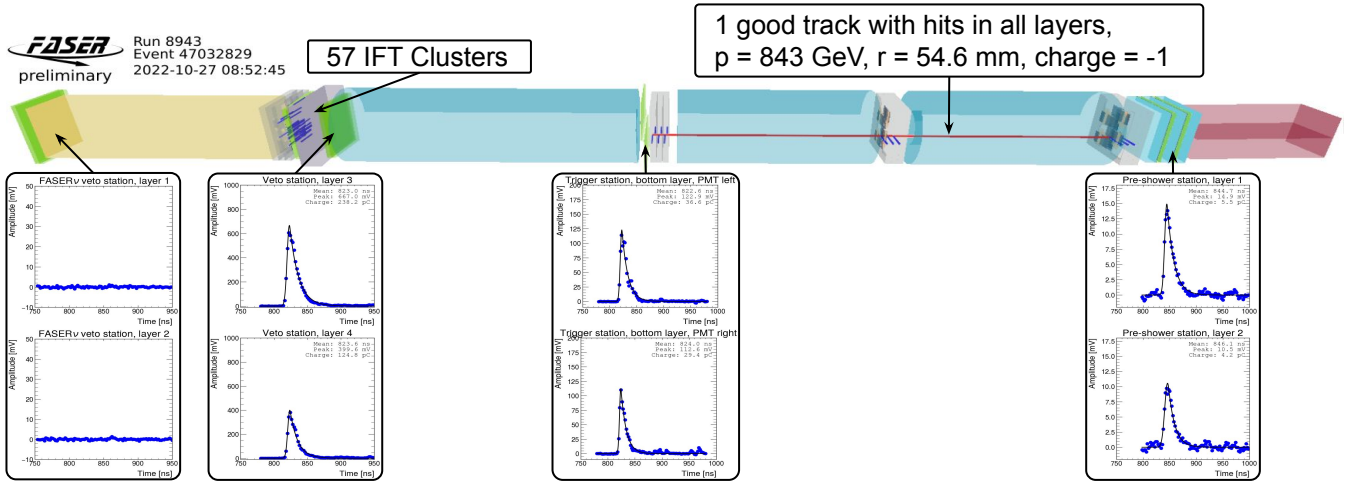
Neutrinos in FASERν

- Analysis of emulsion detector still ongoing
- Have multiple candidates, including highly ν_e like, high energy event:



Summary

- Observed 153 ν_μ CC interactions with electronic detectors
  - Many neutrinos with large momentum (E_μ > 200 GeV)
  - Charge indicates neutrinos and anti-neutrinos
  - First direct observation of collider neutrinos!
- Neutrino candidates from FASERν emulsion detector
- Plan to measure neutrino cross section and flux in future
- FASER operating well for start of the 2023 LHC run
- Up to an order of magnitude more data expected during LHC Run 3



Additional Slides

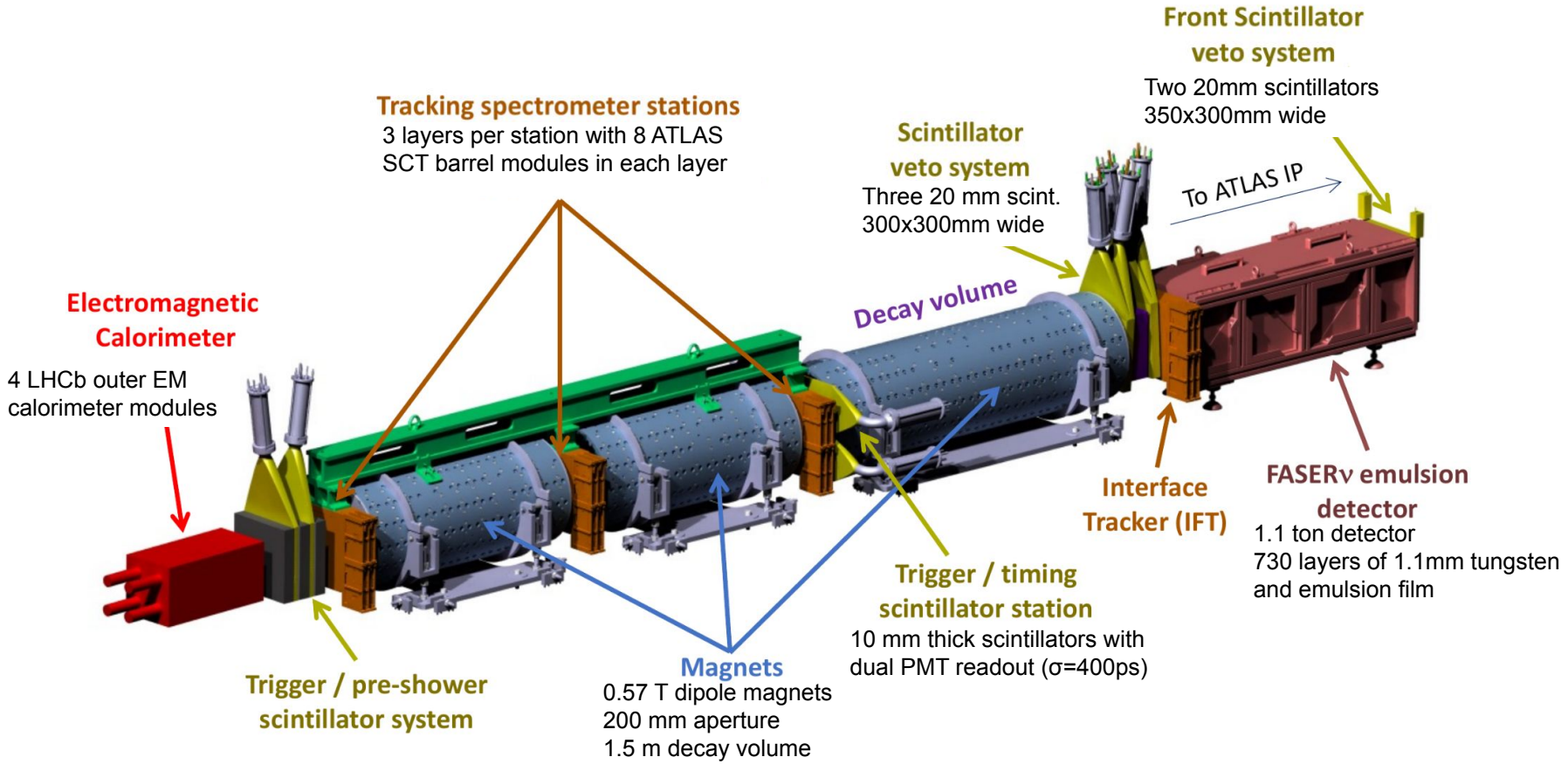
Acknowledgments

- FASER is supported by:

- Additionally would like to thank:
  - LHC for the excellent performance in 2022
  - ATLAS Collaboration for providing luminosity information
  - ATLAS SCT Collaboration for spare tracker modules
  - ATLAS for the use of their ATHENA software framework
  - LHCb Collaboration for spare ECAL modules
  - CERN FLUKA team for background simulation
  - CERN PBC and technical infrastructure groups for excellent support during design, construction and installation

FASER Detector

arxiv:2207.11427



- Detector installed between March – Nov 2021, ready for LHC run 3

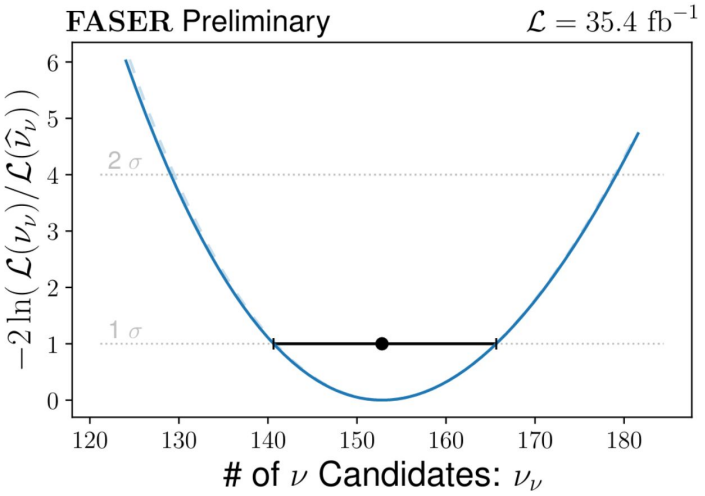
Neutrino Analysis

- Count number of events with hits in none, one or both front veto layers
  - n0: both scintillator layers have charge < 40 pC, signal, geom and hadronic background
  - n10, n01: only one of the two scintillators layers has charge > 40 pC, veto inefficiency background
  - n2: both scintillators layers have charge > 40 pC, background dominated
- Likelihood function is product of 4 Poisson terms for observables n_i and 3 Gaussian constraint terms for background:

$$\mathcal{L} = \prod_{i}^{4} \mathcal{P}(n_i|\nu_i) \cdot \prod_{j}^{3} \mathcal{G}_j$$

obs exp

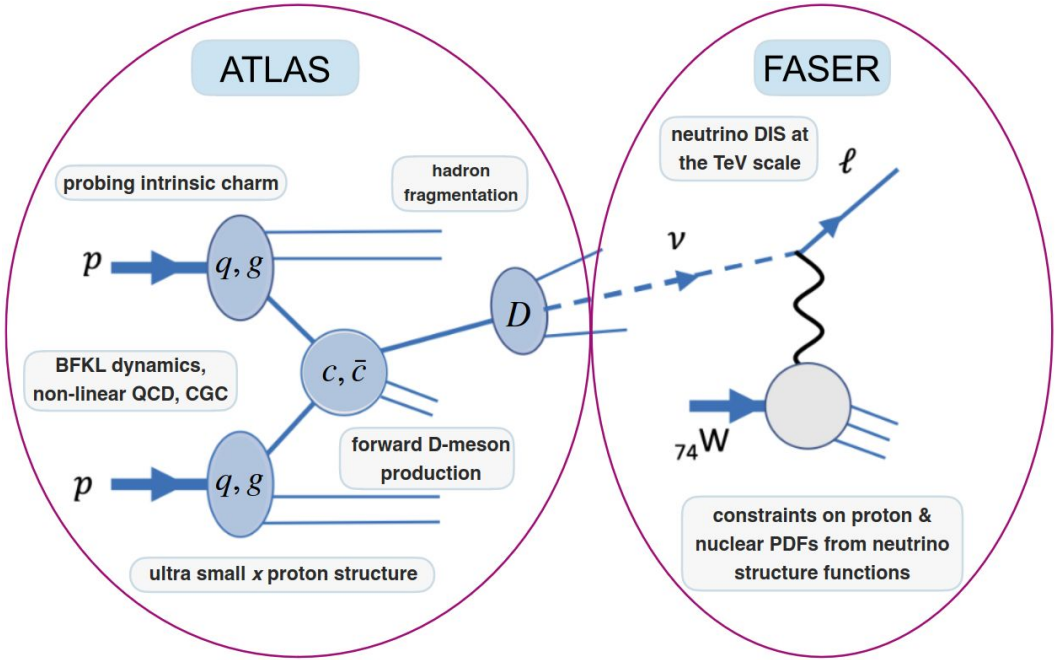
Category	Events	Expectation
n_0	153	$n_\nu + n_b \cdot p_1 \cdot p_2 + n_{\text{had}} + n_{\text{geo}} \cdot f_{\text{geo}}$
n_{10}	4	$n_b \cdot (1-p_1) \cdot p_2$
n_{01}	6	$n_b \cdot p_1 \cdot (1-p_2)$
n_2	64014695	$n_b \cdot (1-p_1) \cdot (1-p_2)$



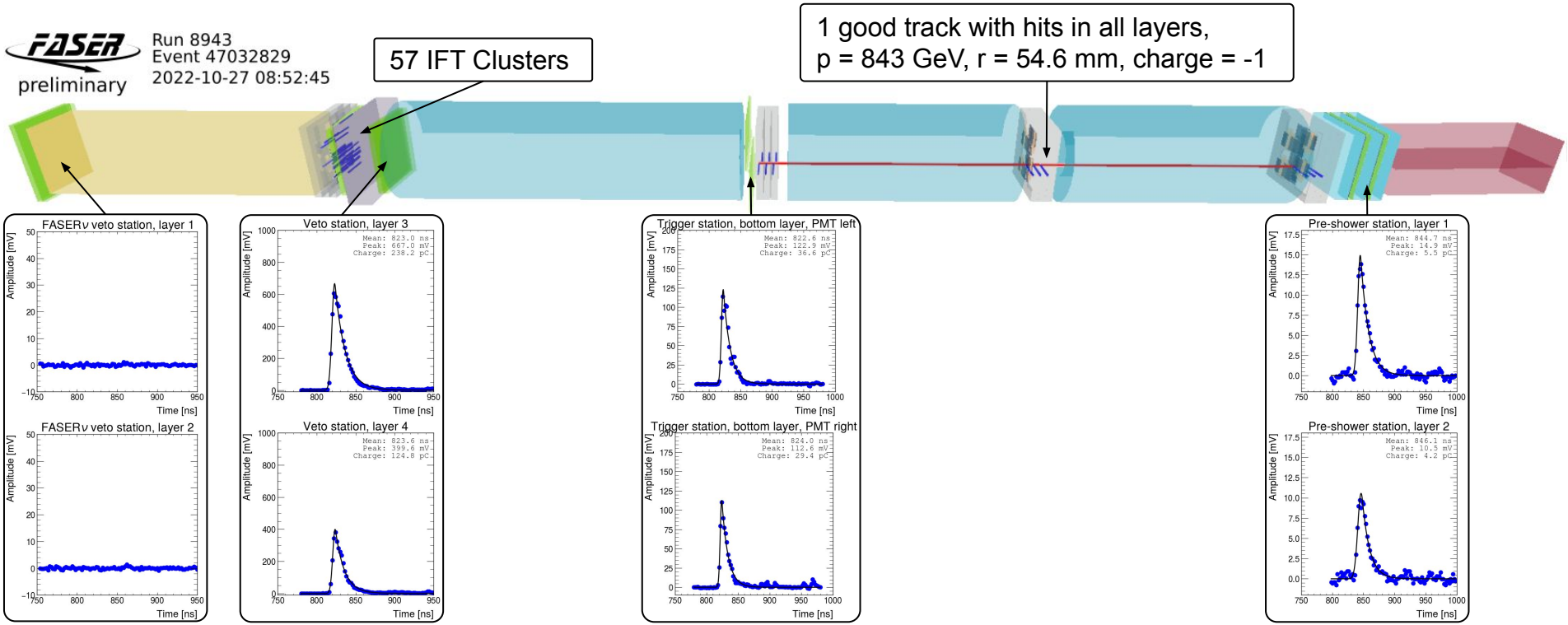
- Maximum likelihood fit gives 153 signal candidates

Physics Potential

- Study neutrino interactions at high energy
- Search for BSM physics in neutrino production, propagation and interaction
- Study PDFs by Deep Inelastic Scattering (DIS) of neutrino in the target
- Study forward hadron production via neutrino flux measurements (forward charm from high energy ν_e)

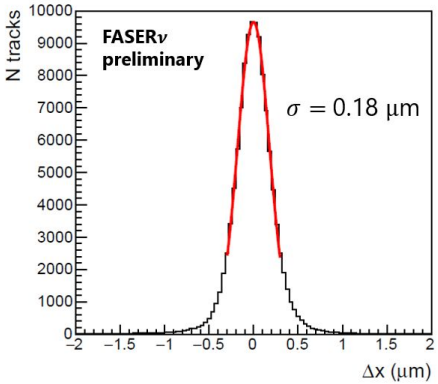


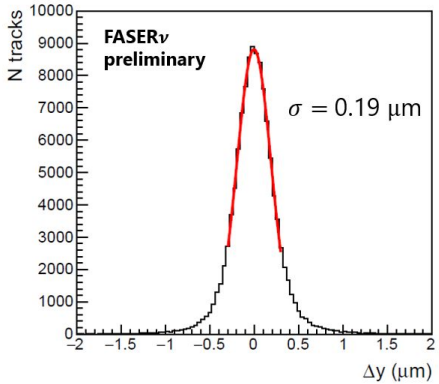
Event Display

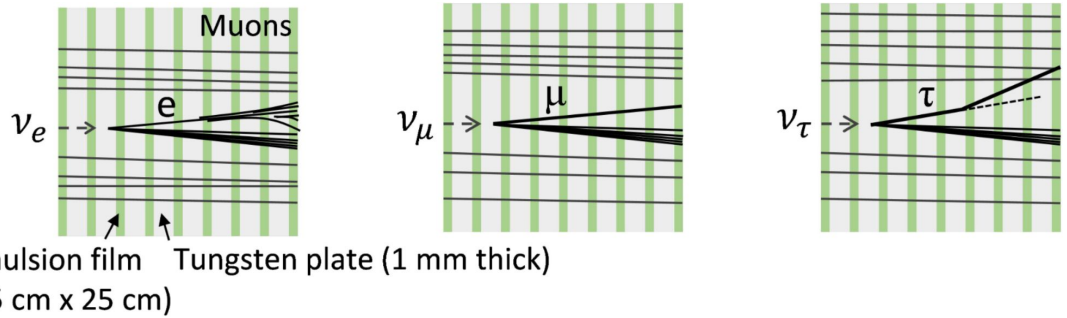


Detector Performance: Emulsion

- Track multiplicity measured in initial emulsion
  - Consistent with FLUKA simulation
- Excellent hit resolution (< 0.2 μm) after layer alignment

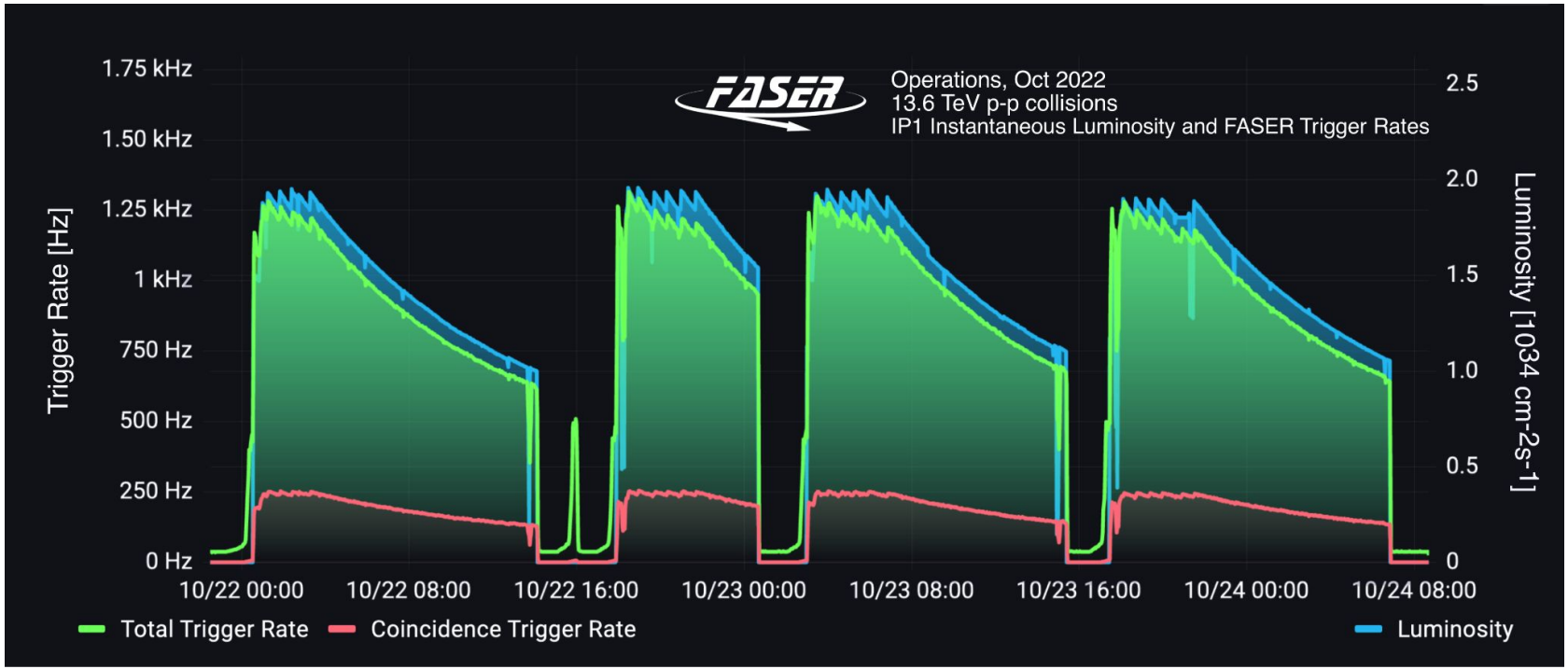






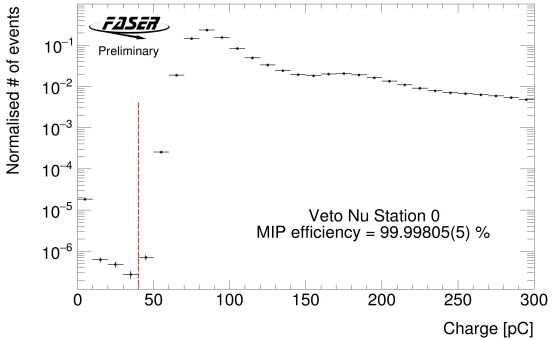
Detector Performance: Trigger + DAQ

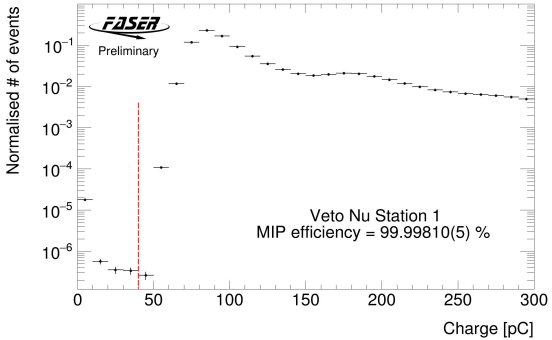
- DAQ running smoothly up to 1.3 kHz with deadtime only 1.3%
- Total trigger rate falls off faster than luminosity during run (higher beam-induced backgrounds) but coincidence trigger rate flat with respect to luminosity

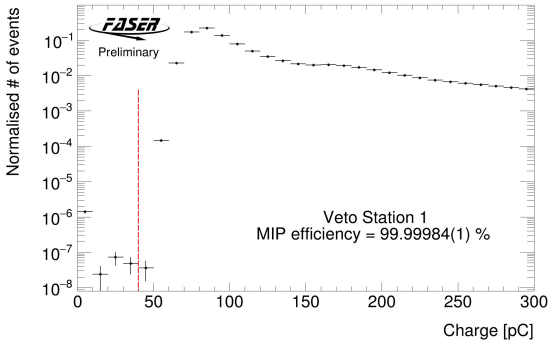


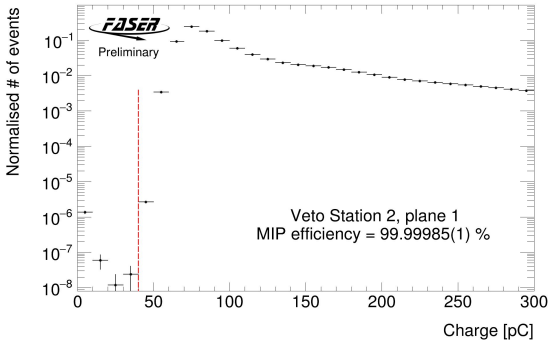
Detector Performance: Veto Scintillators

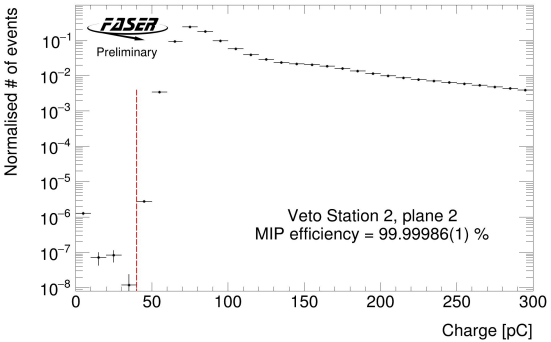
- All veto scintillator layers have inefficiencies < 2 x 10^{-5}
- Efficiencies measured by extrapolating tracks triggered in timing scintillator to layer, no requirement on other scintillator layers





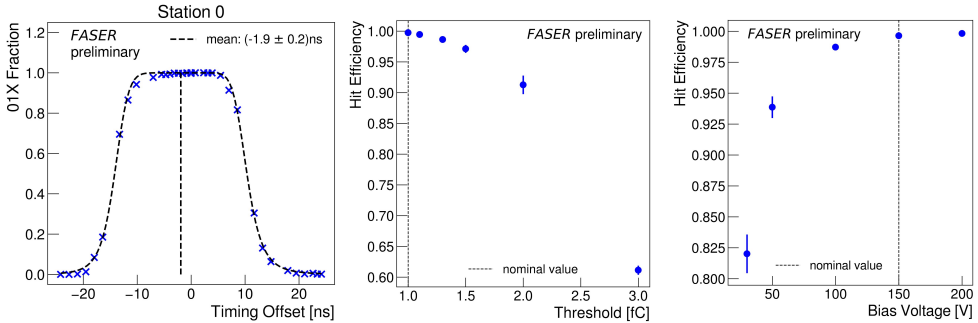






Detector Performance: Tracker

- Tracker fully timed in with respect to LHC clock
- Hit efficiency of 99.64 % at 150 V bias and 1 fC threshold



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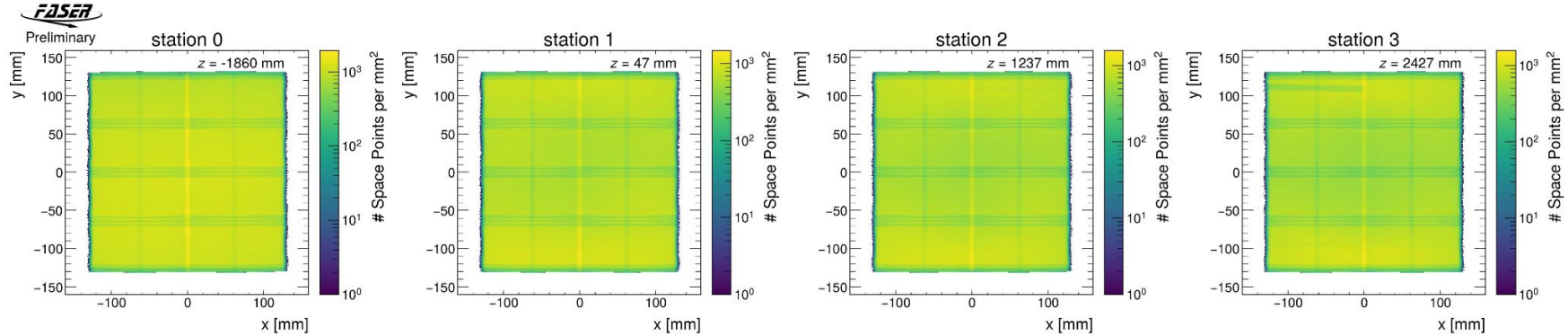
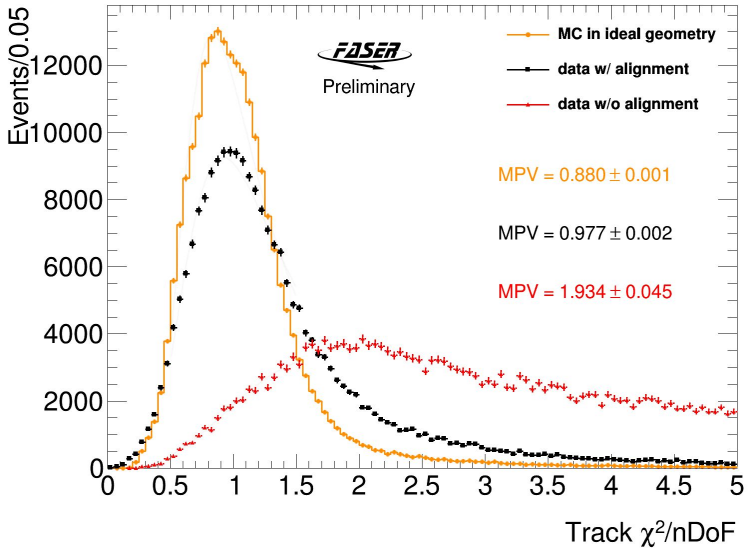
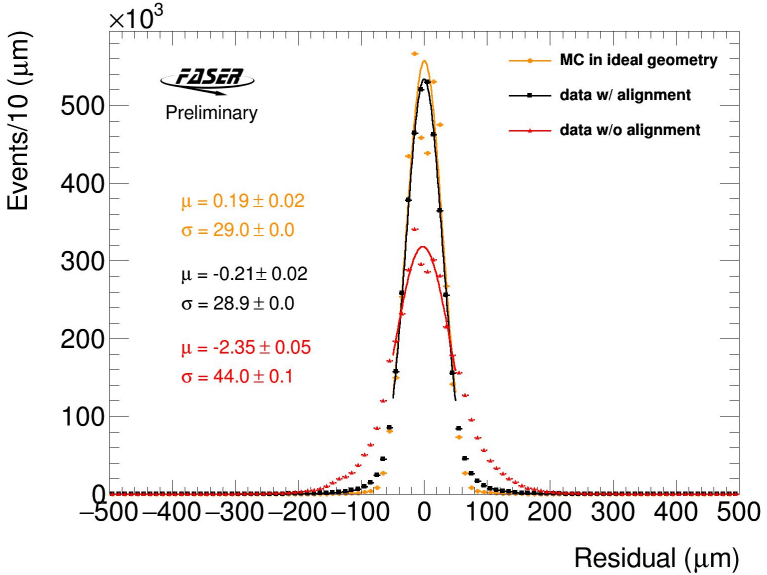


Detector Performance: Alignment

- Tracker modules aligned using local iterative χ^2 method
  - Validated using simulation with misalignments
- Currently only aligning two most sensitive parameters (vertical shift, in-plane rotation)
- Aligned resolution close to ideal geometry simulation





FASER Collaboration

- 87 members across 24 institutes from 10 countries

International laboratory covered by a cooperation agreement with CERN