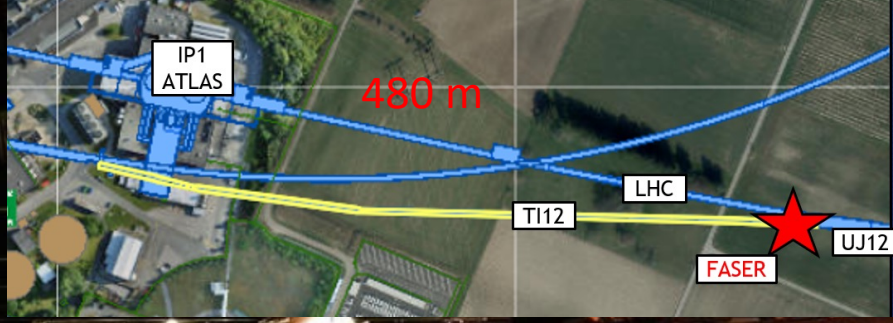
Neutrino Studies with FASER

Yuxiao WANG

on behalf of the FASER Collaboration

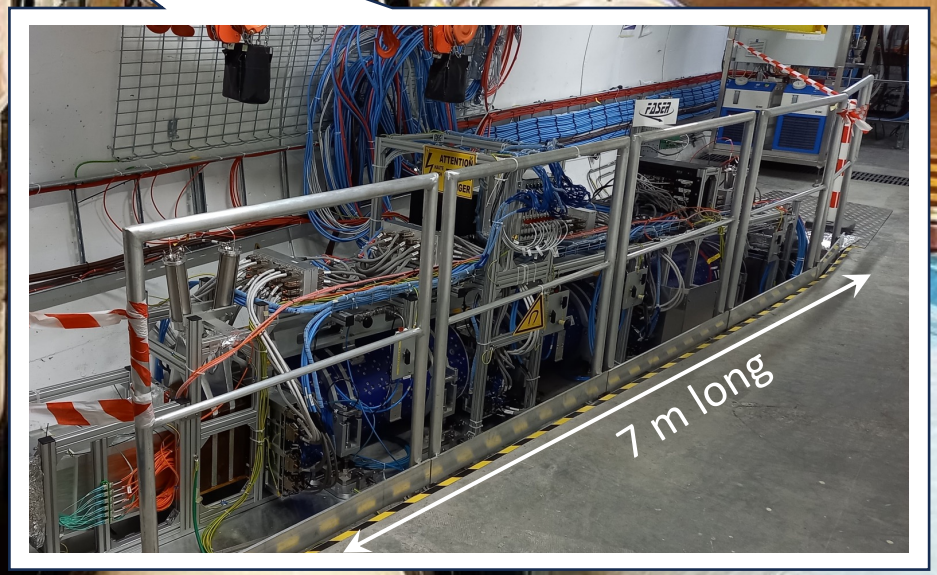
ForwArd Search ExpeRiment

FASER at TI12 tunnel



We are here!

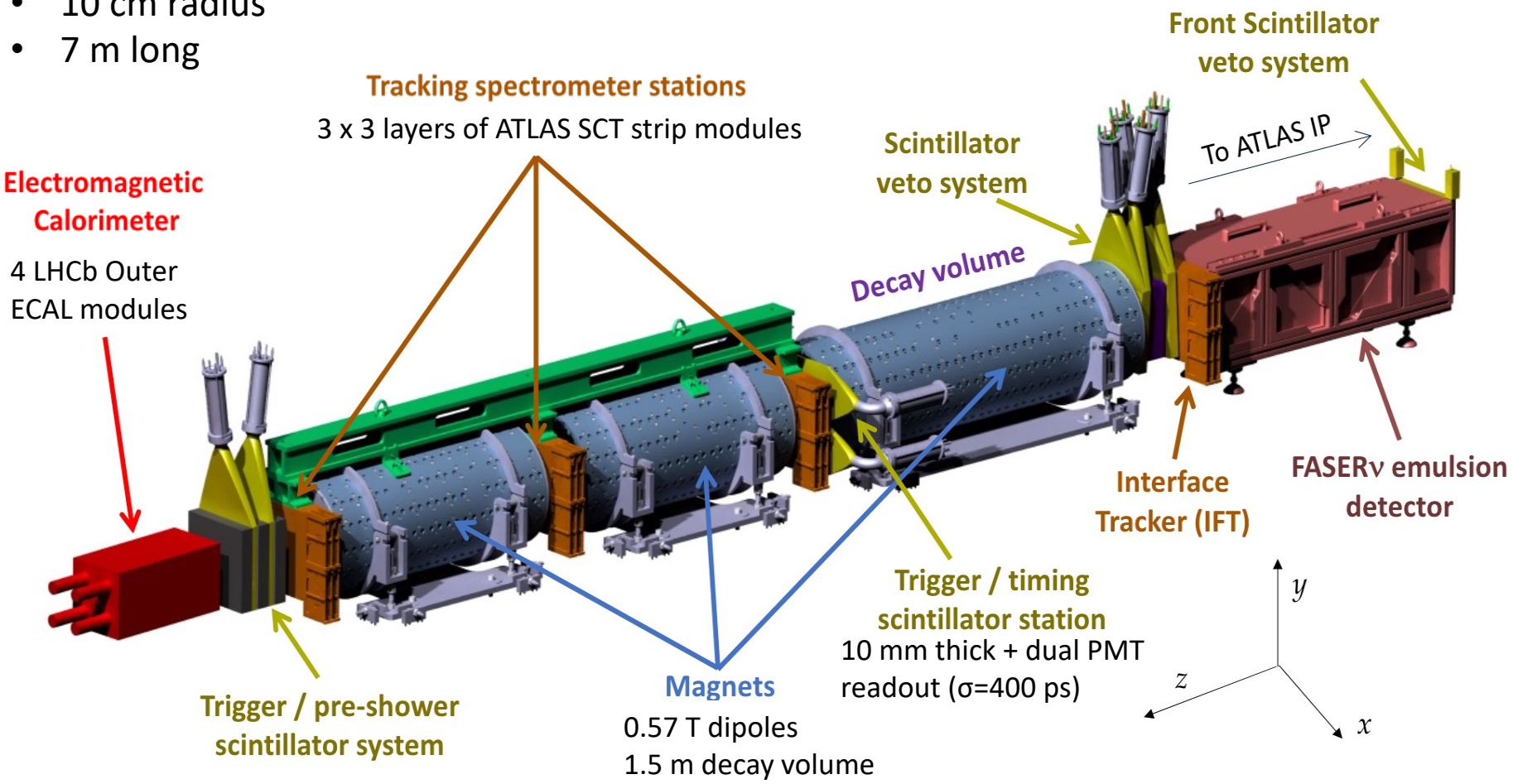
TI12 tunnel



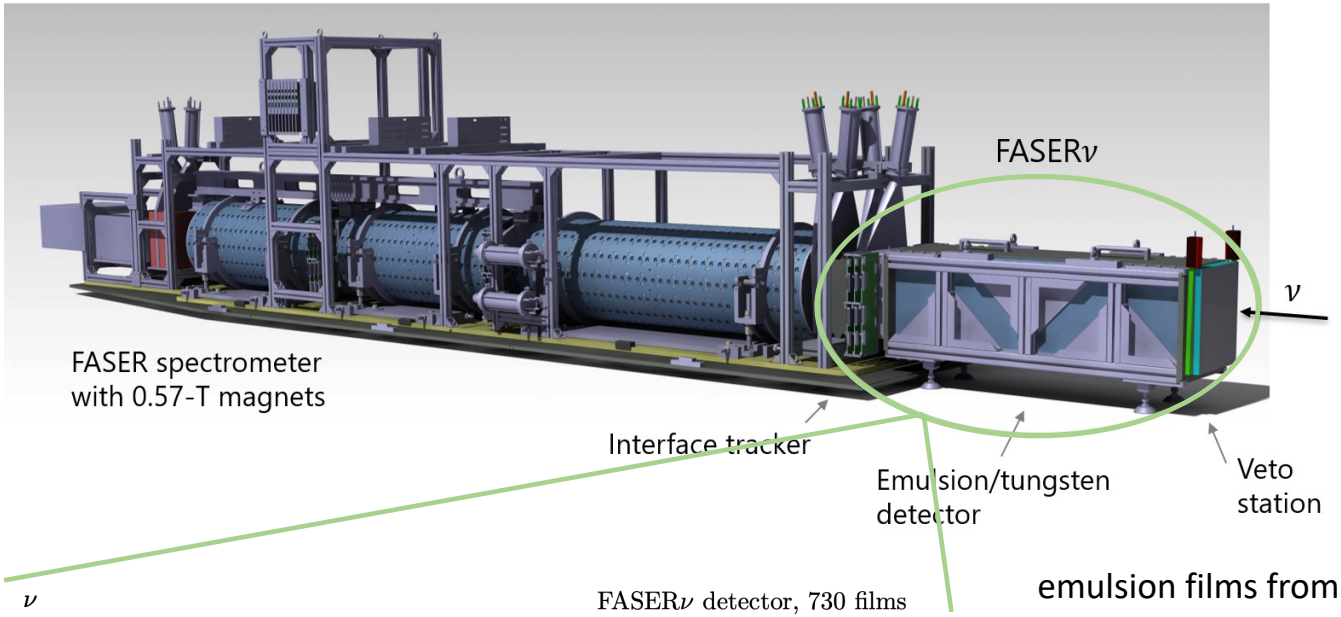
The FASER Detector

10.1088/1748-0221/19/05/P05066

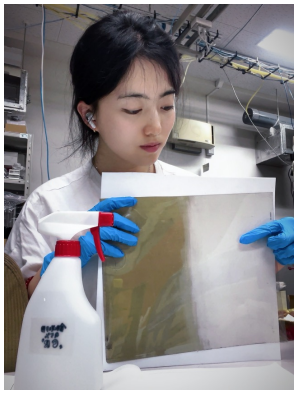
- 10 cm radius
- 7 m long



FASERν Emulsion Detector



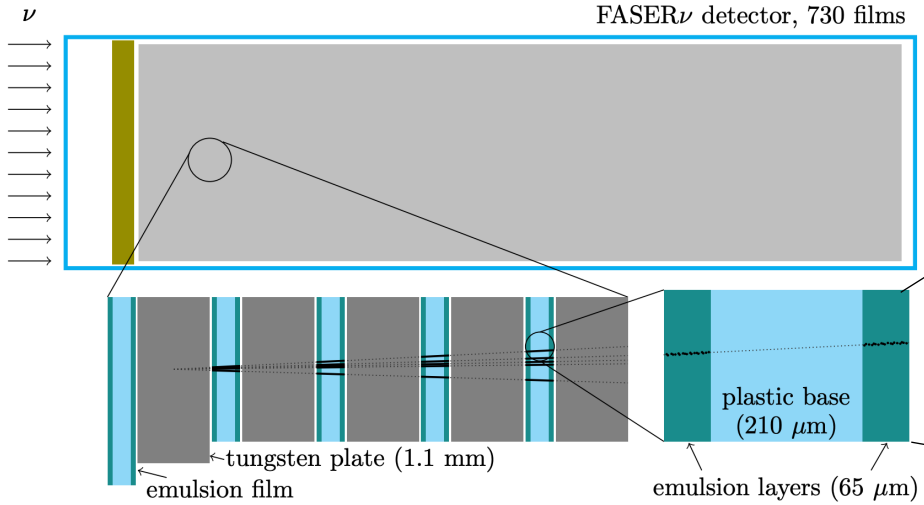
- 730 layers of 1.1 mm tungsten plates interleaved with emulsion films
- $25\times30\text{cm}^2$, 1.1 m, 1.1 t
- Exchange emulsions ~ 3 times a year

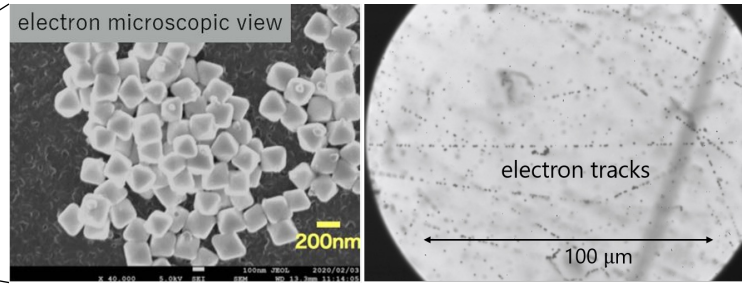


emulsion films from Japan

arXiv:2504.13008

50 nm intrinsic position resolution





silver bromide crystals

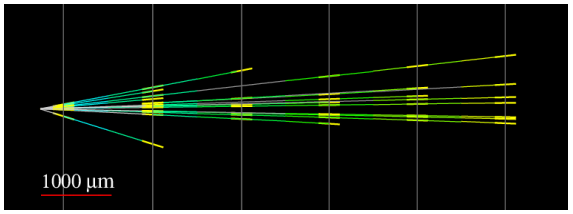
Neutrino at FASER

FASERν emulsion detector

105 fb^{-1} data collected by 2024

Neutrino candidates with Run2 data

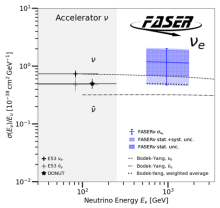
PhysRevD.104.L091101

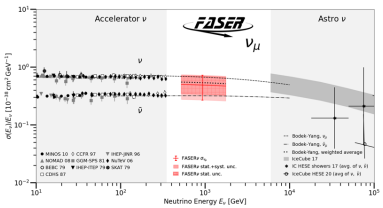


First ν_e, ν_μ cross section measurements

PhysRevLett.133.021802

PRL editor's suggestion





Update with increased statistics

CERN-FASER-CONF-2025-002

Run 2

2018

2019

2020

2021

Run 3

2022

2023

2024

2025

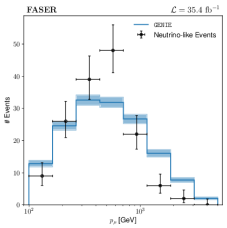
FASER electronic detector

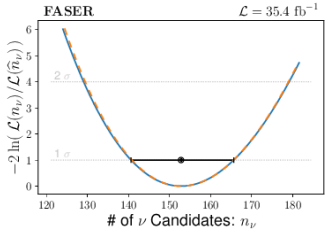
190 fb^{-1} data collected by 2024

First observation of collider neutrinos

PhysRevLett.131.031801

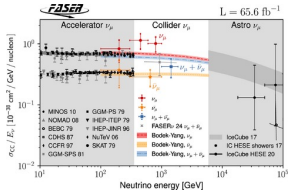
PRL editor's suggestion





Differential ν_μ cross section and flux measurements as a function of energy

PhysRevLett.134.211801



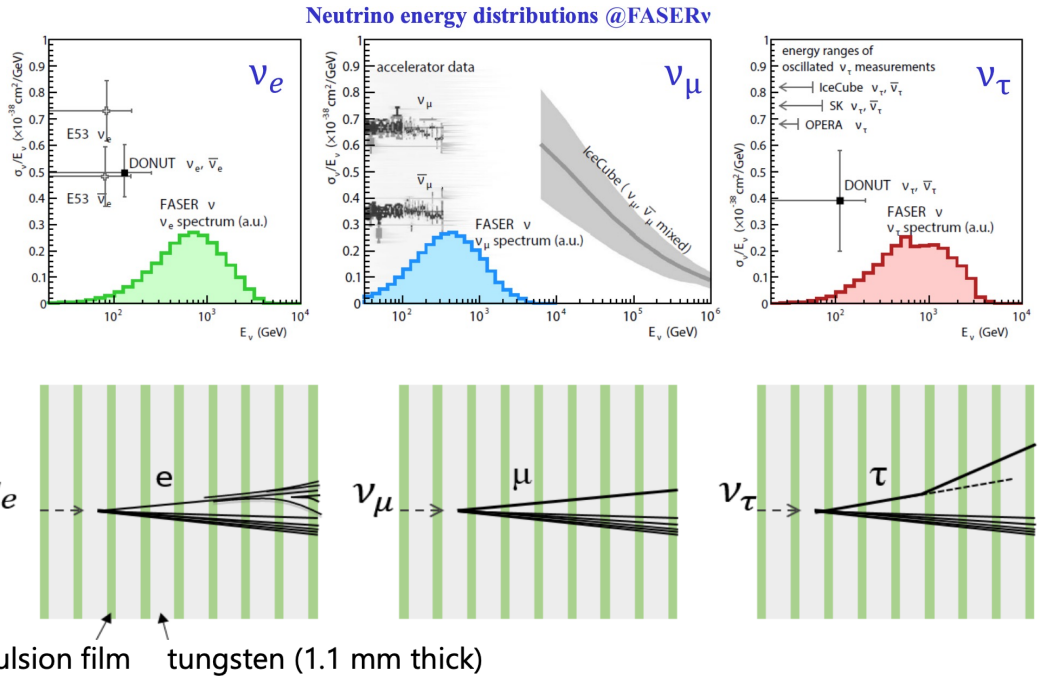
Neutrino rapidity measurements

CERN-FASER-CONF-2025-001

Neutrino at FASERν

- Measure neutrino cross-sections at TeV-scale;
- From charged current (CC) interaction;
- Flavor tagging: ν_e, ν_μ, ν_τ
- Expected event number for 250 fb^{-1}, Run3: Phys.Rev.D 110, 012009

  ν_e~1700, ν_μ~8500, ν_τ~30

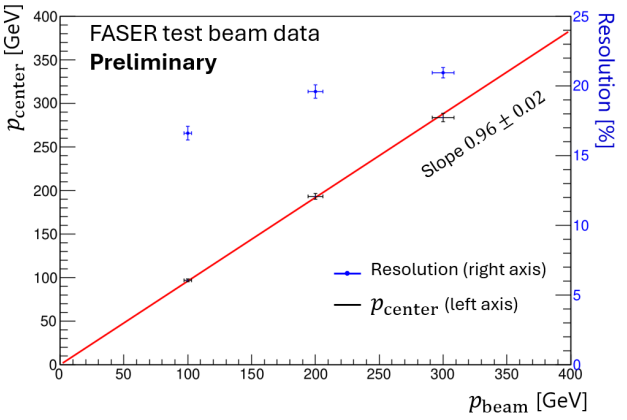


Latest results: CERN-FASER-CONF-2025-002

	ν_e CC	ν_μ CC
Expected signal	2.8–7.2	16.2–28.7
Expected background	$0.06^{+0.04}_{-0.02}$	$0.54^{+0.22}_{-0.17}$
Observed events	5	20

Performance validation
- 2024 testbeam data
- SPS (H8 beamline)

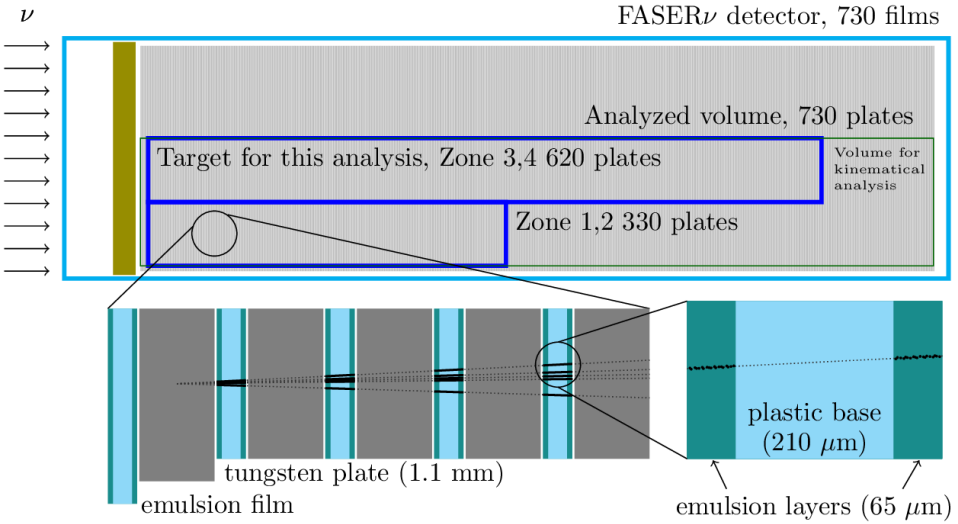
~ 20% resolution at 200 GeV

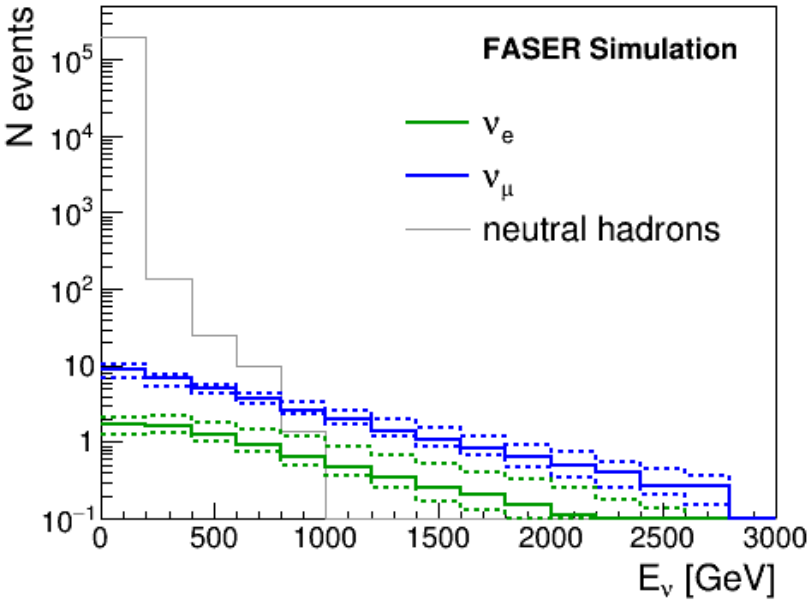


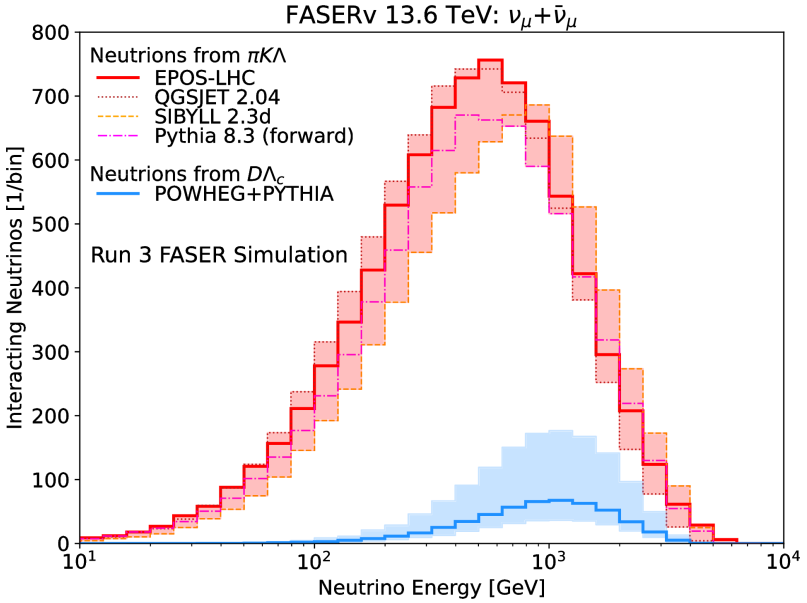
Data Set and Simulations

CERN-FASER-CONF-2025-002

- Data Sets:
  - 9.5 fb^{-1}, LHC Run 3
  - Target mass: 314.7 kg in latest analysis
- MC Samples:
  - Light hadron production (4 samples: EPOS-LHC, QGSJET II-04, SIBYLL 2.3d, PYTHIA 8)
  - Charm hadron production (1 sample: POWHEG+PYTHIA 8)

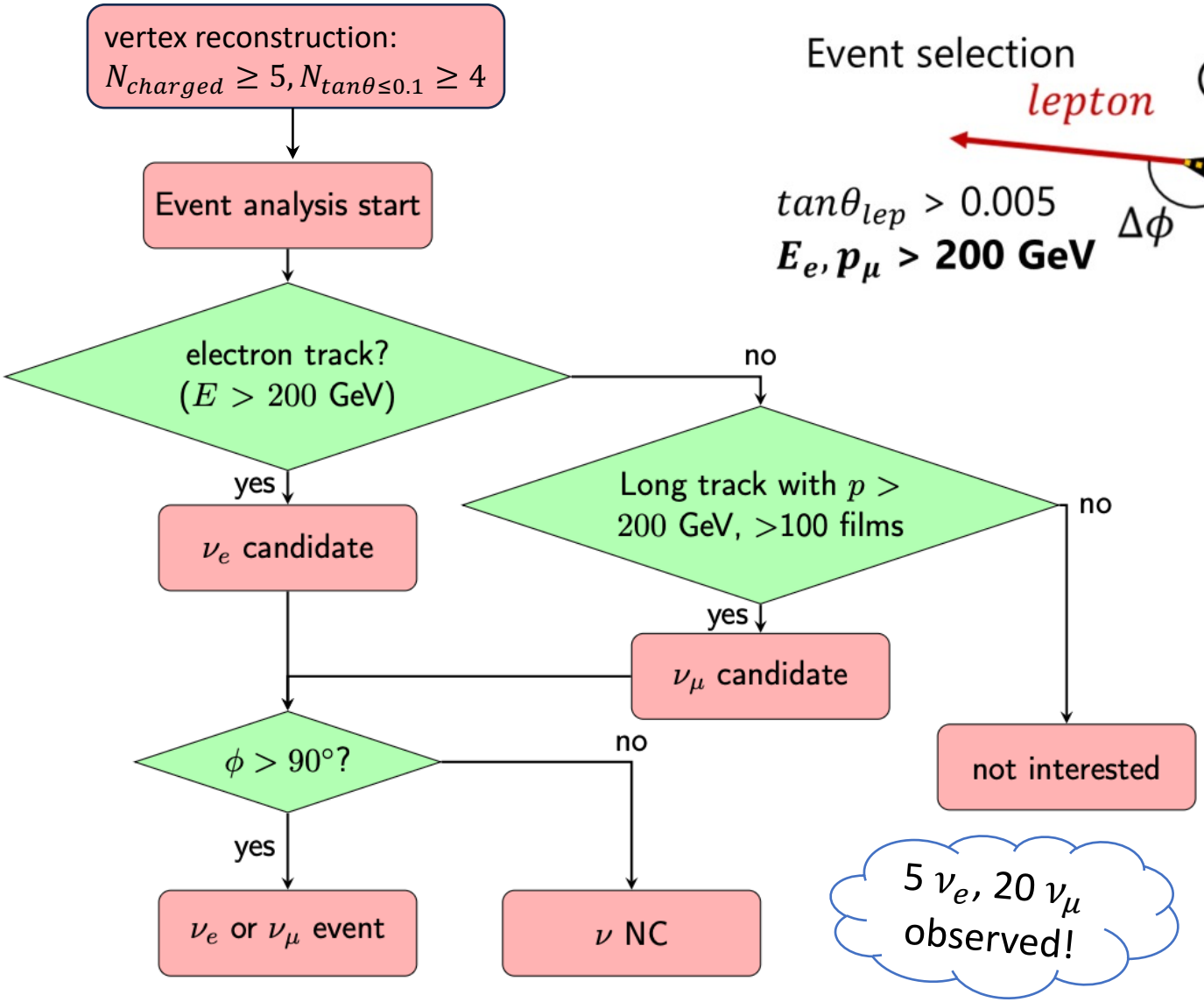


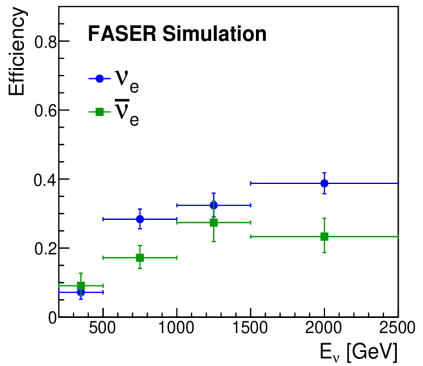


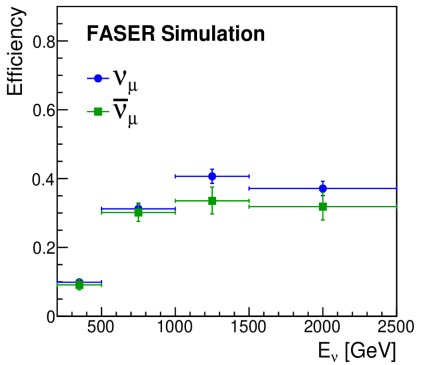


Neutrino Event Selection

PhysRevLett.133.021802



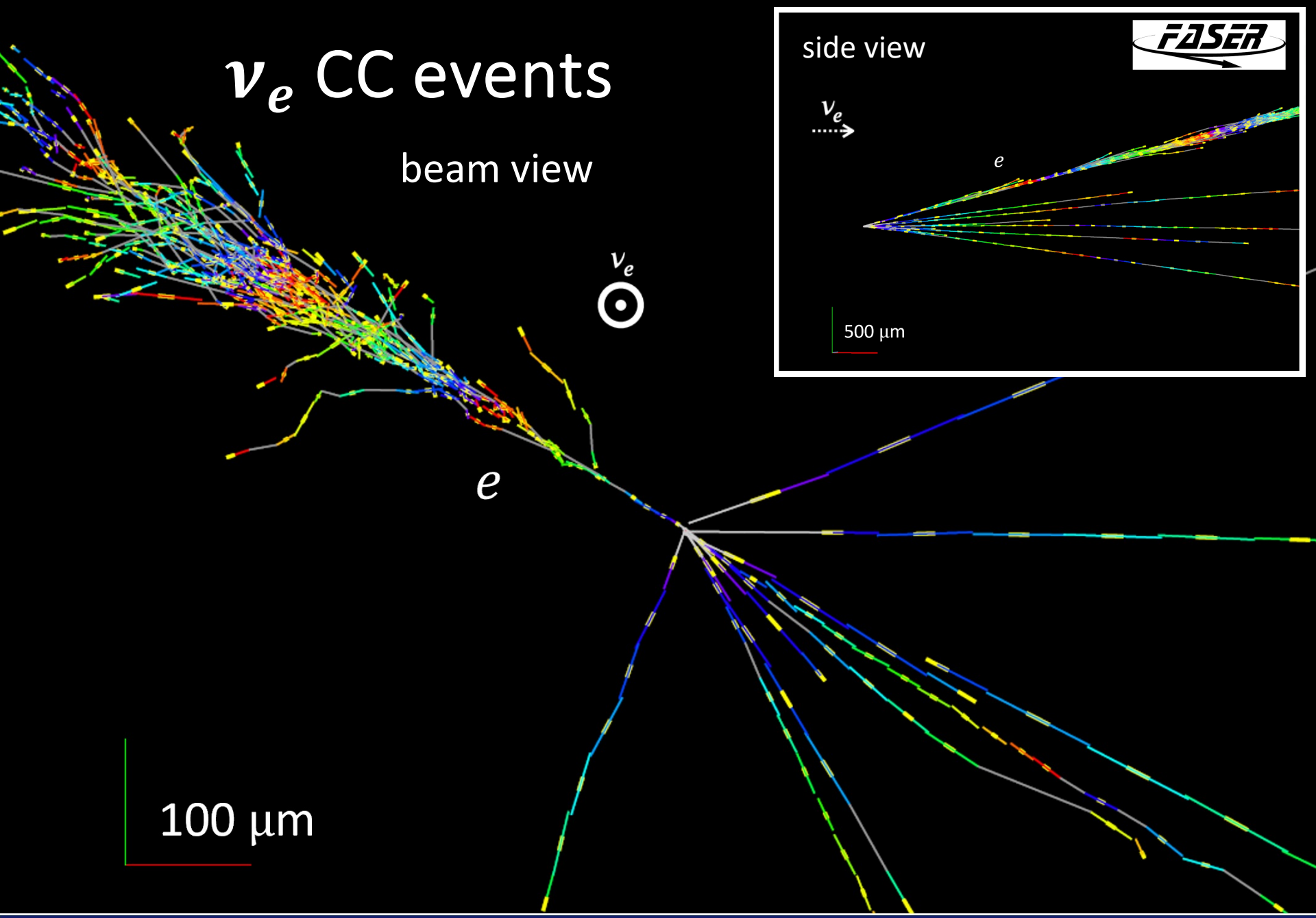




5 ν_e, 20 ν_μ observed!

ν_e CC events

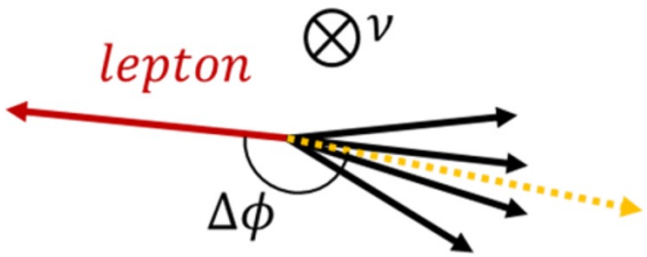
beam view



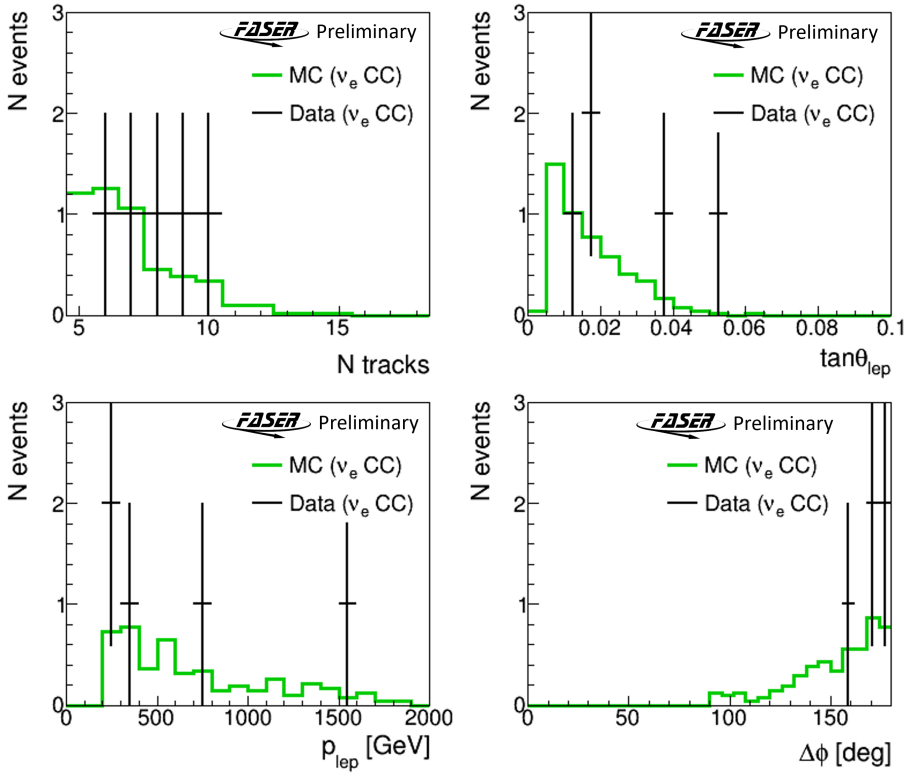
ν_e CC events

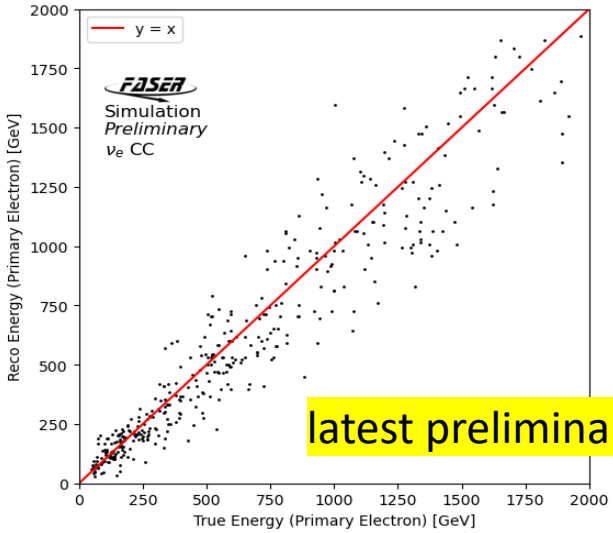
CERN-FASER-CONF-2025-002

ν_e event characteristics

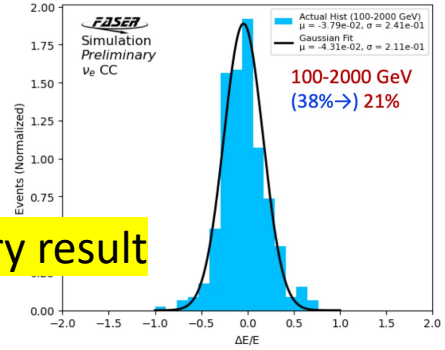


- E_e= 1.5 TeV, highest ν_e measured.
- MC normalized to number of observed events.





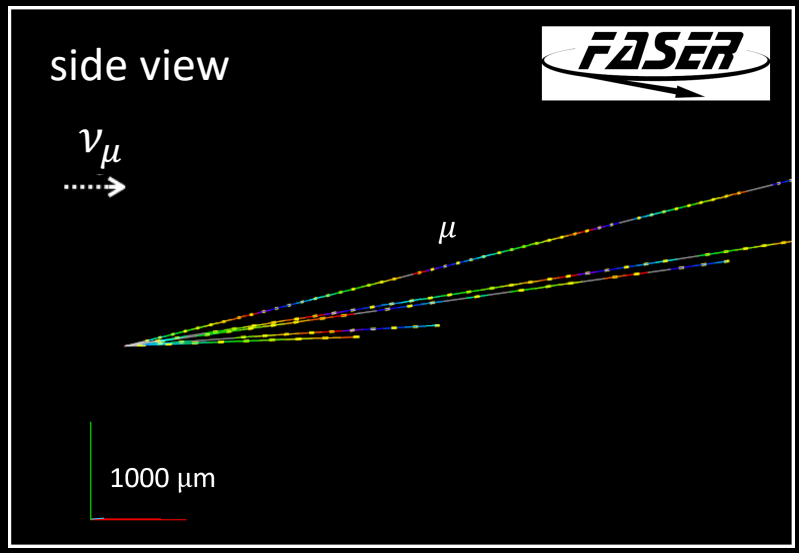
latest preliminary result



Electron energy found using multiplicity in core of EM shower:
$\Delta E/E$ at (100, 2000) GeV ~ 0.21

My presentation at WIN2025

ν_μ CC events



ν_μ

beam view

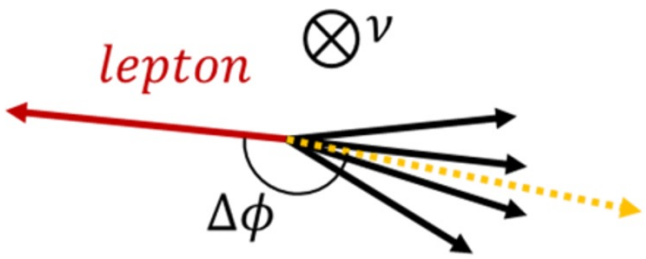
μ

200 µm

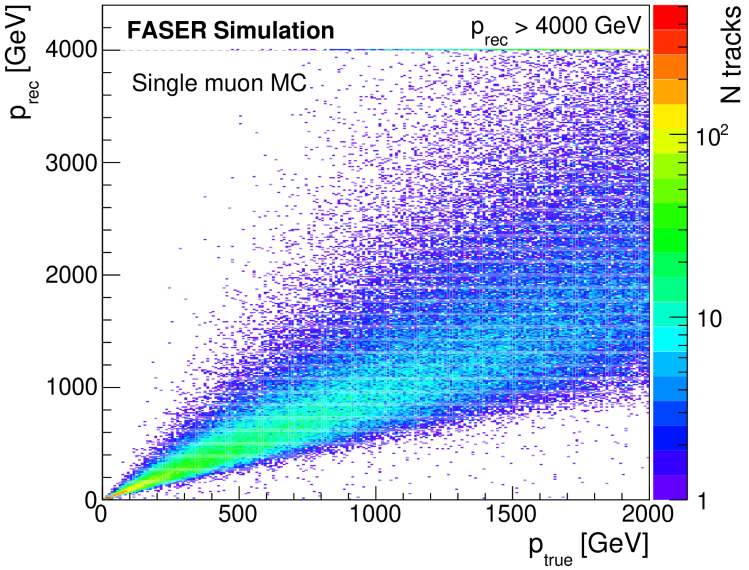
ν_μ CC events

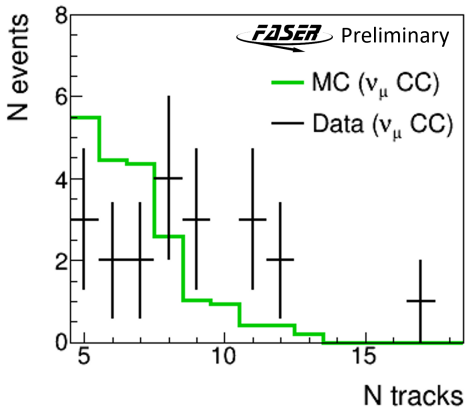
CERN-FASER-CONF-2025-002

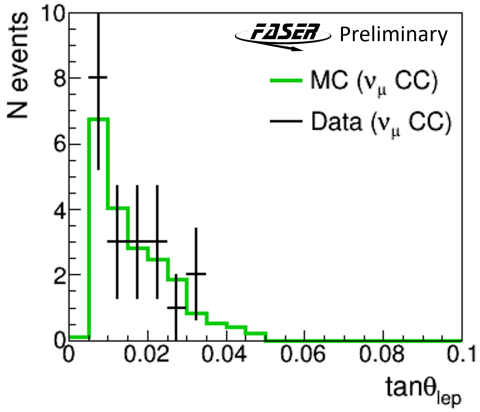
ν_μ event characteristics

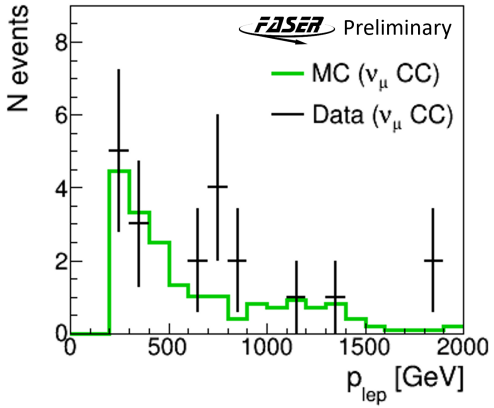


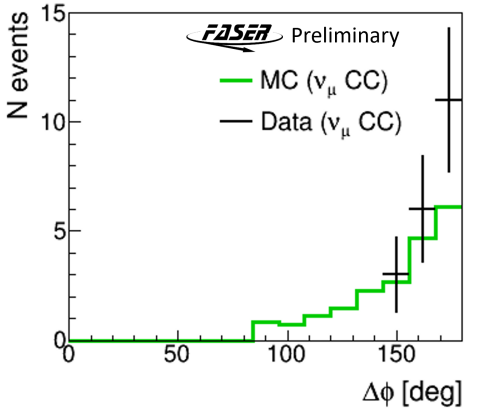
- p_μ= 360 GeV.
- MC normalized to number of observed events.





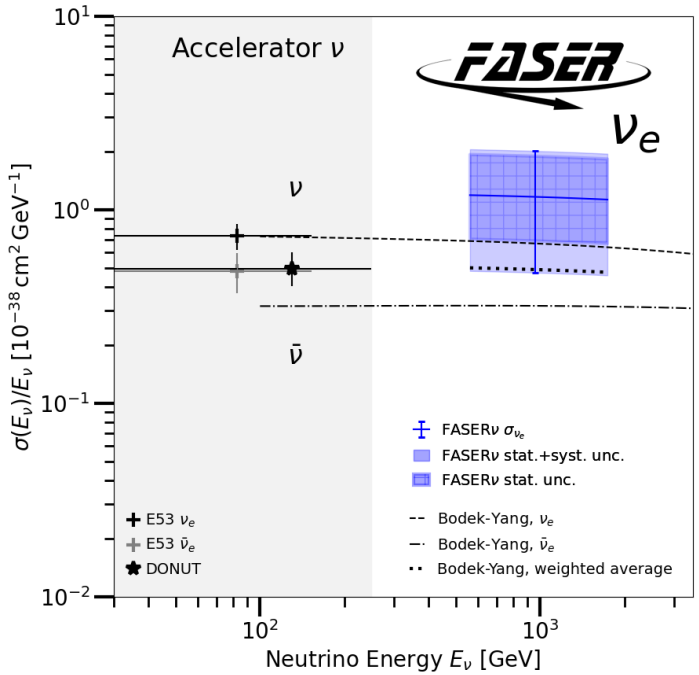


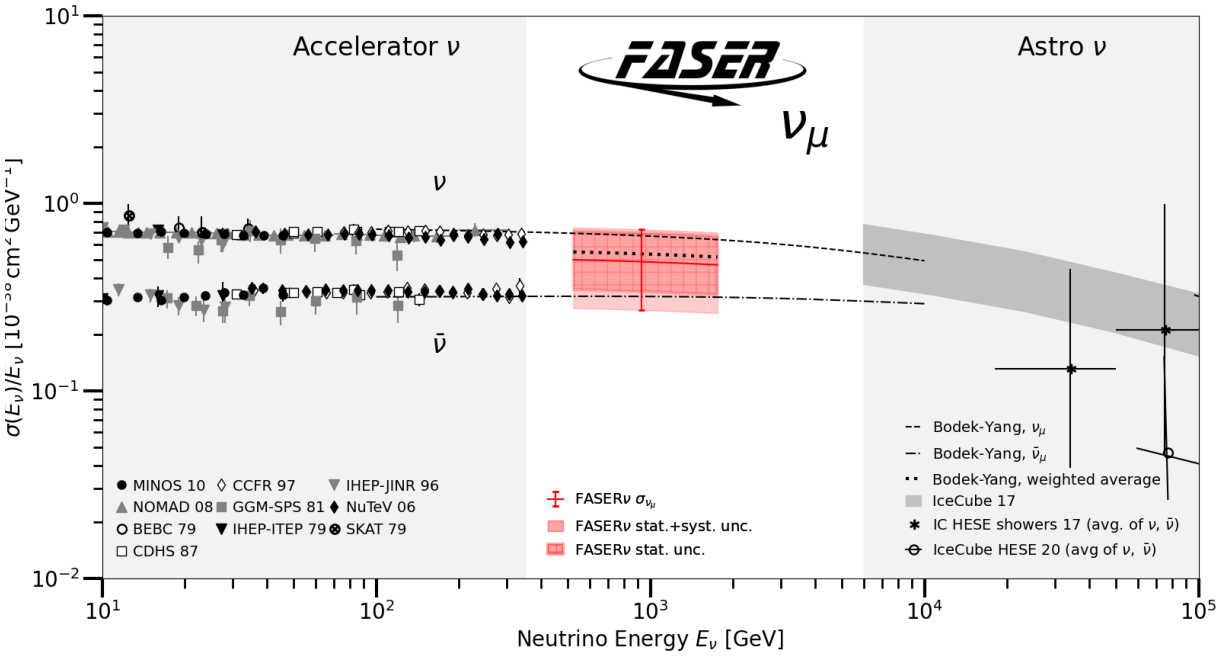




- Good linearity even above 1 TeV
- Based on multiple Coulomb scattering of charged particle

Neutrino Cross Section Measurements



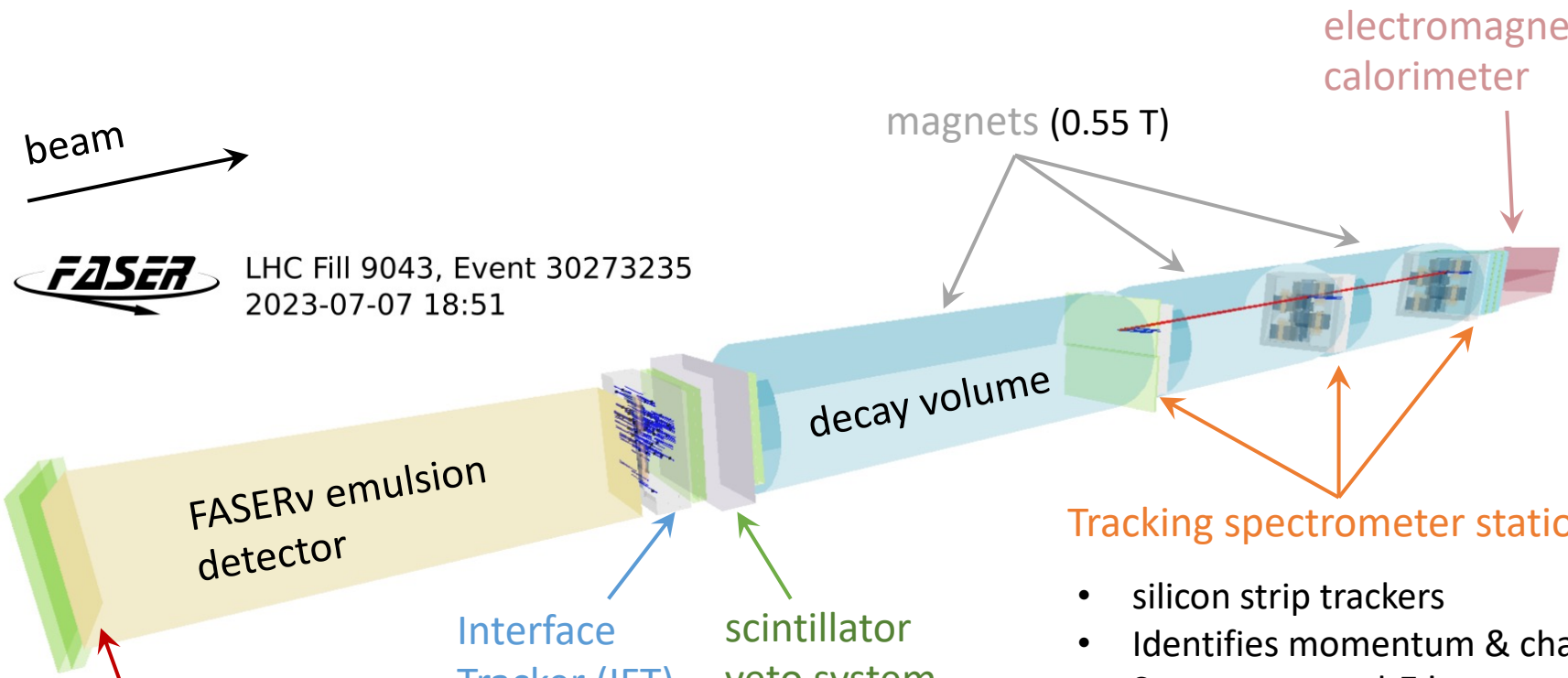


- First observation of ν_e at the LHC (2023)
- First neutrino cross-section measurement in the TeV range (2024) [PRL.133.021802](PRL.133.021802)

target mass 128.6 kg, 4 ν_e + 8 ν_μ

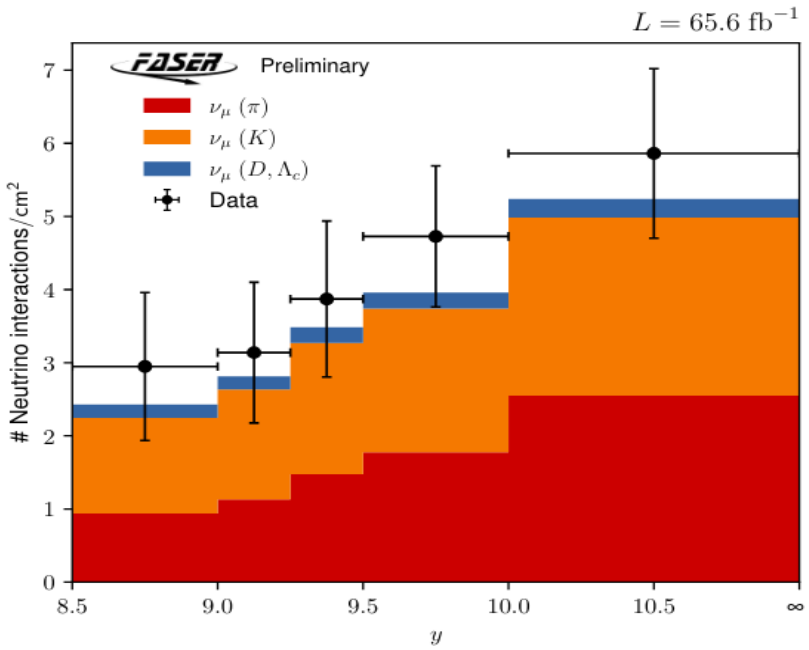
- Working on a differential cross section measurement with the full 1.1 tons detector volume for 9.5 fb^{-1} data (2025) CERN-FASER-CONF-2025-002

FASER Electronic Detector

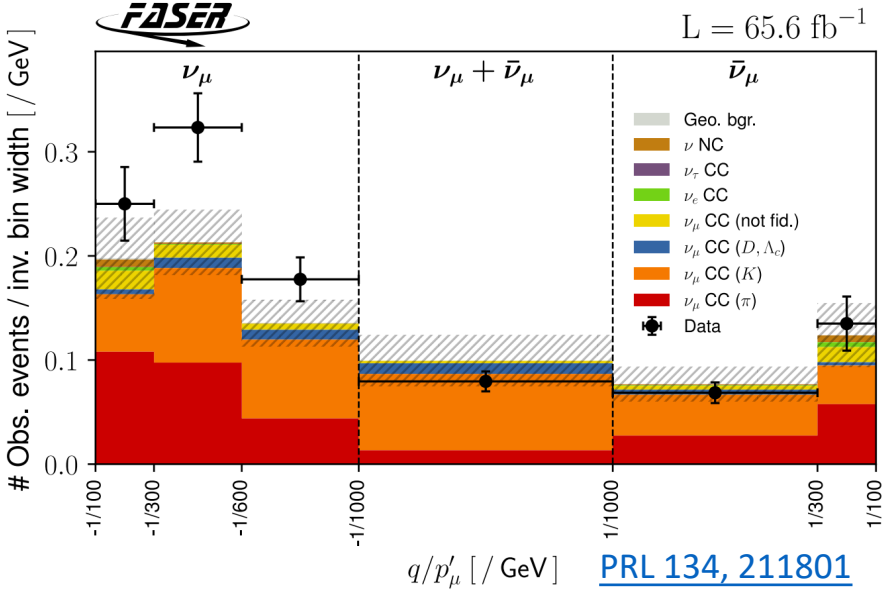


- silicon strip trackers
- Identifies momentum & charge
- Seperates ν and $\bar{\nu}$!
- Focus on high-p_T muons

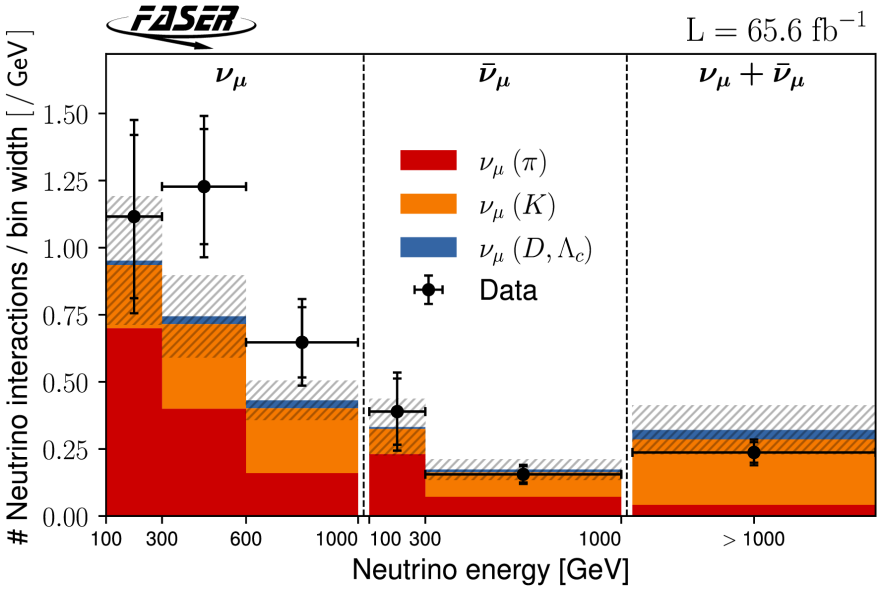
Neutrino at FASER Electronic Detector



CERN-FASER-CONF-2025-001



PRL 134, 211801



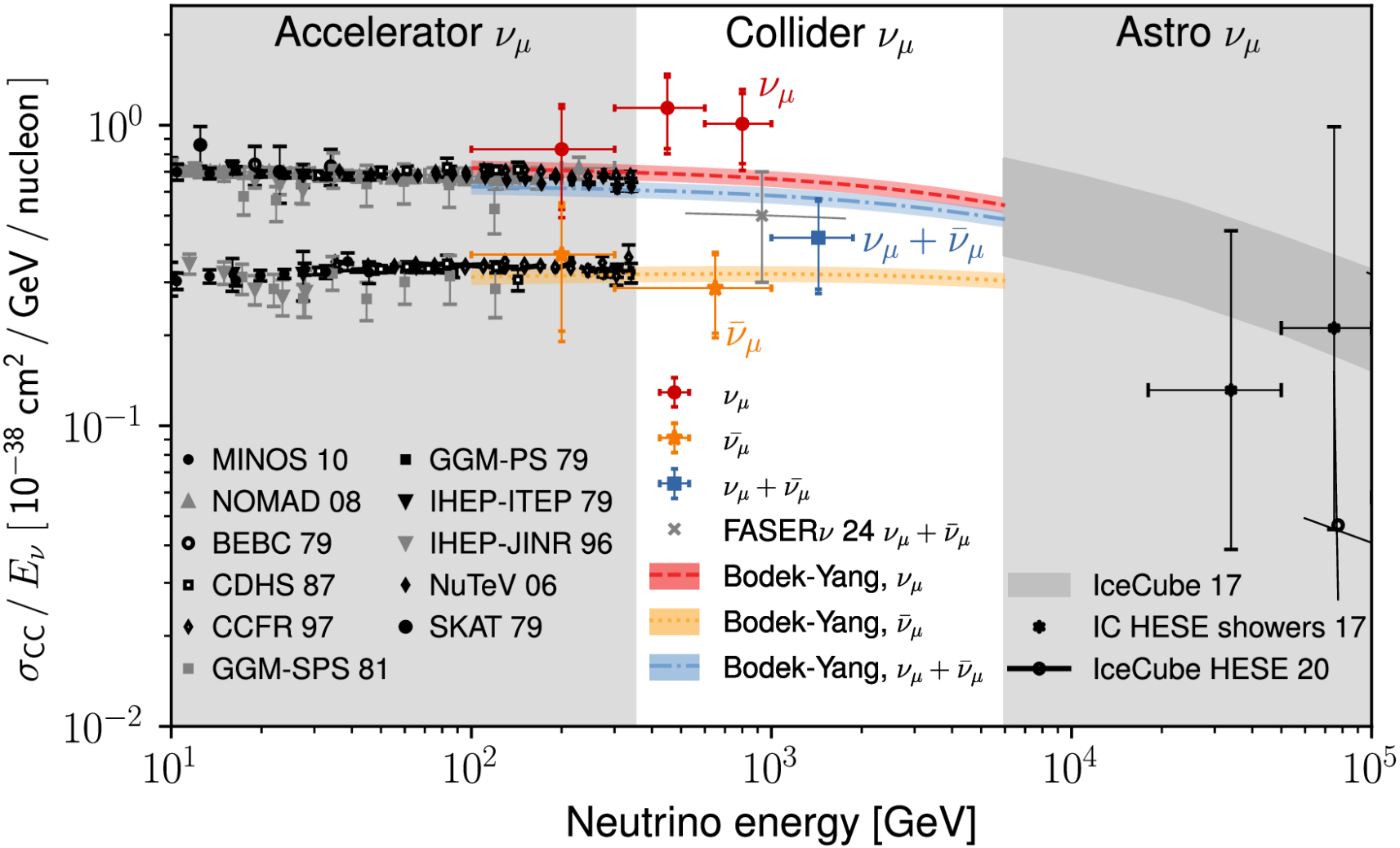
Muon momentum is unfolded into

- ν_μ energy (3 bins),
- $\bar{\nu}_\mu$ energy (2 bins),
- a high energy bin for $\nu_\mu + \bar{\nu}_\mu$.

Latest neutrino results at FASER electronic detector

ν_μ cross section measurement

$\mathrm{L} = 65.6\ \mathrm{fb}^{-1}$



Summary and Outlook

- FASER historic achievements:
  - first neutrinos observed at a particle collider
  - first detection of ν_μ and ν_e at the LHC
  - first neutrino cross-section measurements in the TeV range

- Current data taking:
  - Run3 expectations: ~10,000 neutrino interactions
  - 200 times more events with full Run3 dataset
  - FASER continues through LHC Run4

- Future: Forward Physics Facility ArXiv 2503.19010
  - Ambitious upgrade program for HL-LHC (FASER2 & FASERv2)
  - Target: ~1,000,000 high-energy neutrino interactions

Acknowledgement

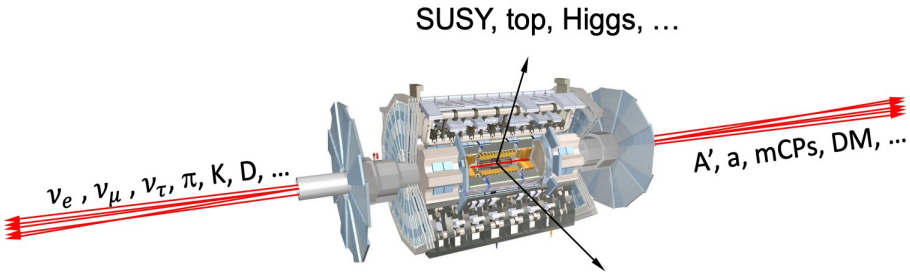
- FASER is supported by:

- We also thank:
  - ❖ LHC for the excellent performance
  - ❖ 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 the background simulation
  - ❖ CERN PBC and technical infrastructure groups for the excellent support

BACKUP

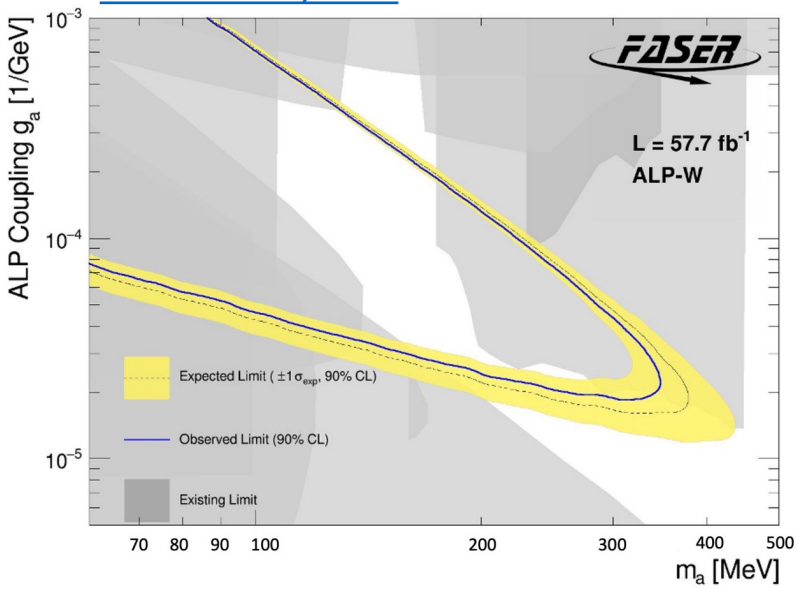
FASER Physics Targets

- **Explore forward physics**
  (particles in very forward region not seen by ATLAS/CMS)
- **Search for new light, long-lived particles**
  (dark photons, ALPs, etc.)

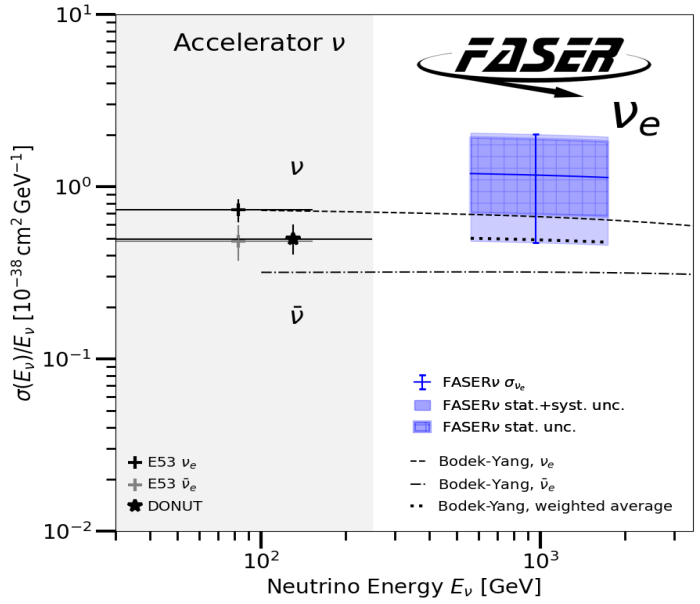


- **Detect and study collider neutrinos**
  (first-ever TeV neutrinos at LHC)

JHEP 2025, 199

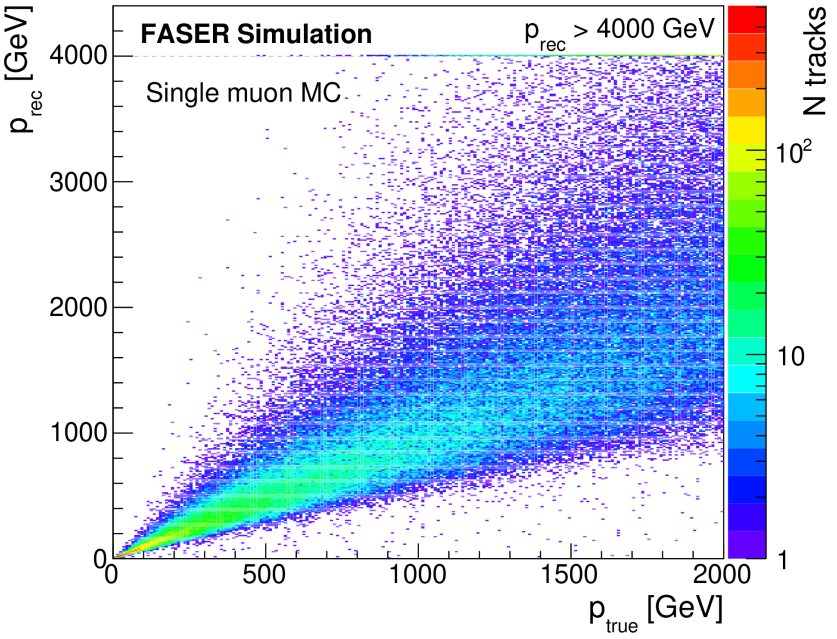


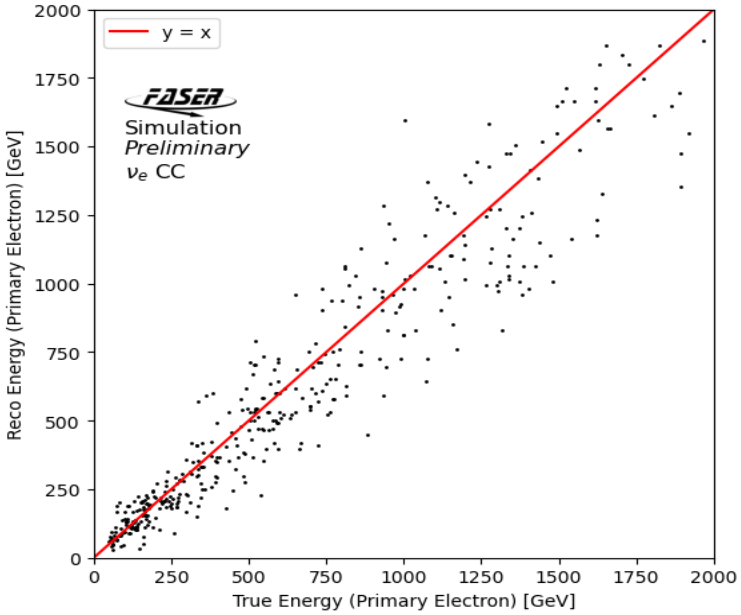
PRL 134.211801



Kinematic Tools Performances

- 300 nm position resolution has been achieved -> 0.04 mrad angular resolution for a 1 cm track.
- Momentum measurement from Multiple Coulomb Scattering (MCS): $\Delta P/P$ at 200 GeV $\sim$ 0.30
- EM shower energy found using segment multiplicity in core of EM shower: $\Delta E/E$ at 200 GeV $\sim$ 0.21



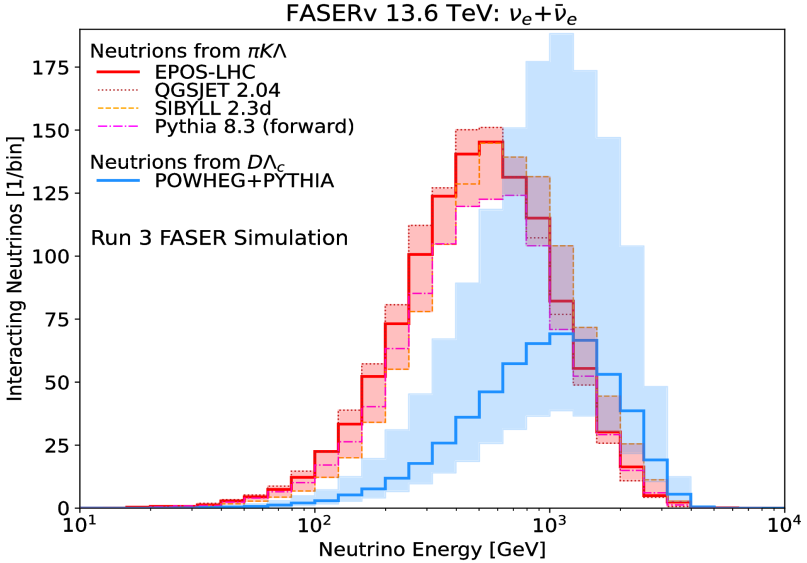


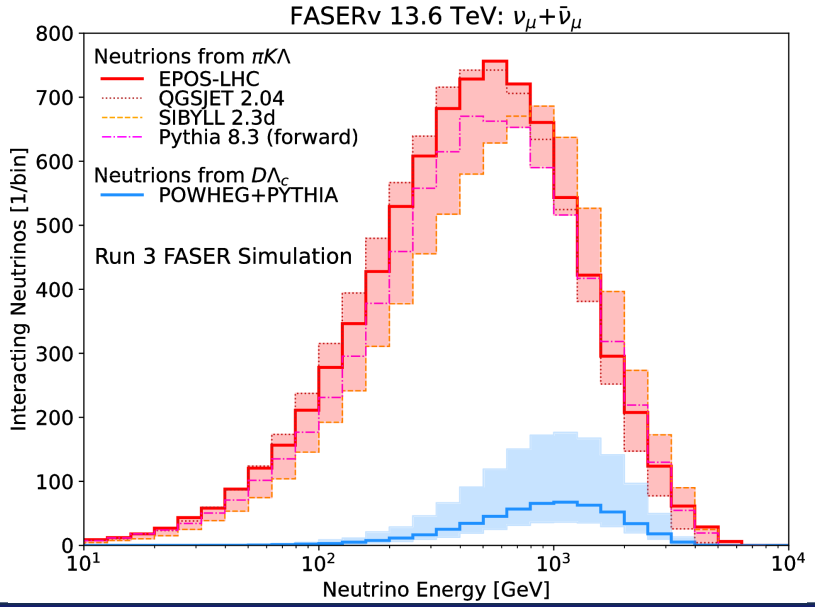
Data Set and Simulations

- Data Sets:
  - -2022 second module → 9.5 fb^{-1}
  - -Target mass: 128.6 kg
  - -~1.7% of the data collected to date.
- MC Samples:
  - -Light hadron production (4 samples: EPOS-LHC, QGSJET II-04, SIBYLL 2.3d, PYTHIA 8)
  - -Charm hadron production (1 sample: POWHEG+PYTHIA 8)

Differences between the generators checked with the same propagation model (RIVET-module)

	DPMJET	SIBYLL	Pythia8
ν_e , $\bar{\nu}_e$	3390 , 1024	800 , 452	826 , 477
ν_μ , $\bar{\nu}_\mu$	8270, 2391	6571 , 1653	7120 , 2178
ν_τ , $\bar{\nu}_\tau$	111 , 43	16 , 6	22 , 11





Systematic Uncertainties

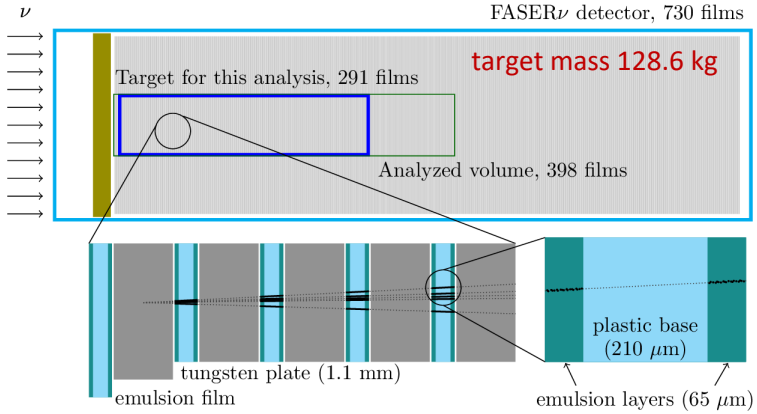
- several factors of systematic uncertainties have been considered.
- total systematics: sum in quadrature.

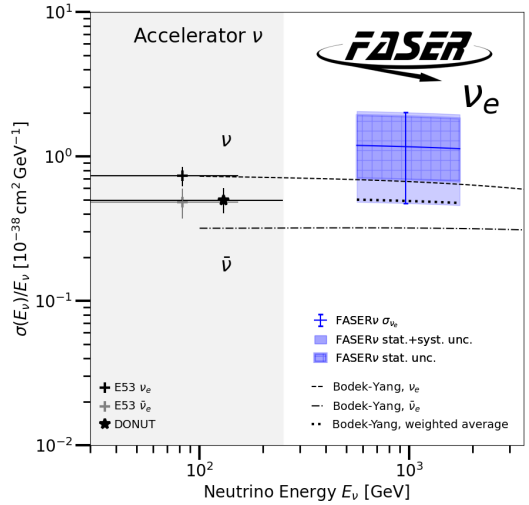
Source	Relative uncertainty	
	ν_e	ν_μ
Luminosity	2.2%	2.2%
Tungsten thickness	1%	1%
Interactions with emulsions	$^{+3.6}_{-0}$%	$^{+3.6}_{-0}$%
Flux uncertainty	$^{+70}_{-22}$%	$^{+16}_{-9}$%
Line of sight position	$^{+2.1}_{-2.4}$%	$^{+1.9}_{-2.5}$%
Efficiency from hadronization	$^{+22}_{-5}$%	$^{+23}_{-5}$%
Efficiency from reconstruction	20%	20%
Efficiency from MC statistics	4.9%	2.8%
Total	$^{+70}_{-22}$% (flux) $^{+30}_{-21}$% (other)	$^{+16}_{-9}$% (flux) $^{+31}_{-21}$% (other)

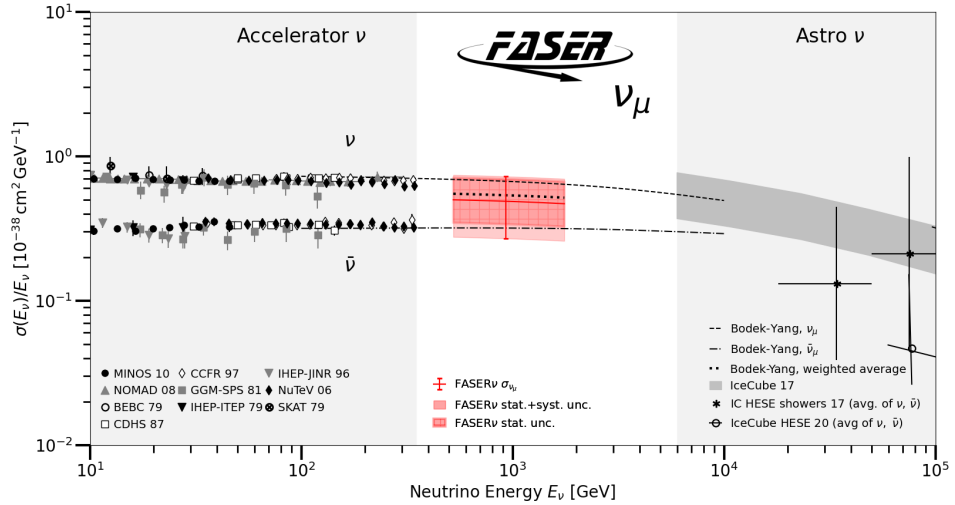
First X-section Measurements

PhysRevLett.133.021802

- First observation of ν_e at the LHC (2023)
- First neutrino cross-section measurement in the TeV range (2024)
- Large uncertainty from neutrino flux.







- 4 ν_e observed
- expected background $0.025^{+0.015}_{-0.010}$
- significance: 5.2σ

- 8 ν_μ observed
- expected background $0.22^{+0.09}_{-0.07}$
- significance: 5.7σ

ν NC Cross Sections

- FASERν also measures cross-section of Neutral Current (NC) neutrino interactions [arXiv: 2012.10500].
- Non-Standard Interaction (NSI) can be explored in conjunction with measurement of CC cross-section.