LIV.INNO

UNIVERSITY OF LIVERPOOL

Latest Collider Neutrino Measurements with the FASER detector

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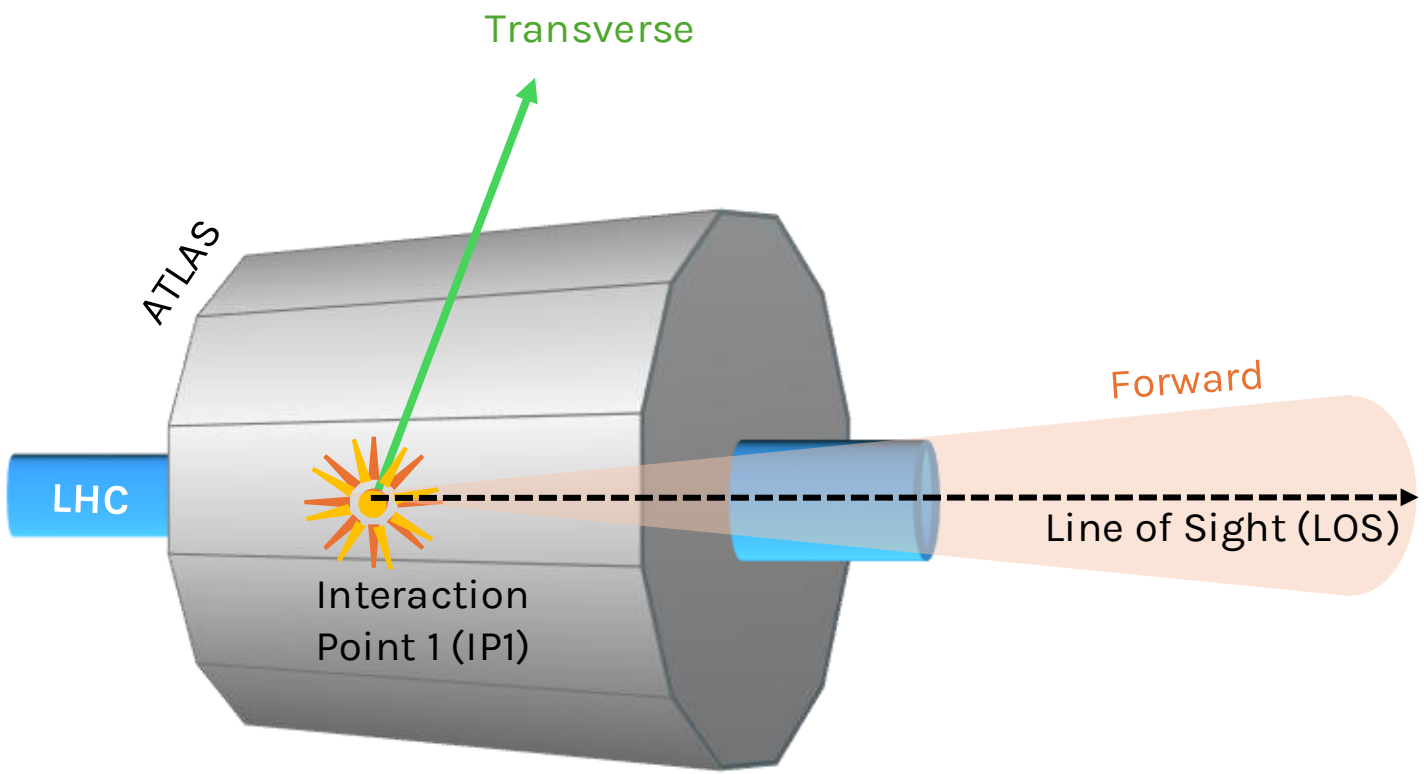
FASER

CERN

Forward Physics at the LHC



Detectors at the LHC have **traditionally focused** on events that have:

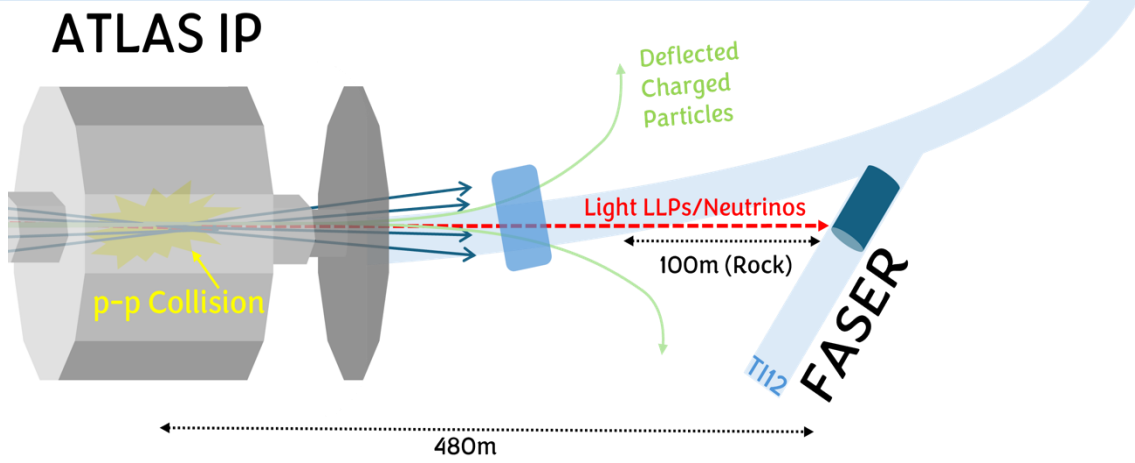
- **High** transverse momentum (p_T)
- **Strongly interacting** particles
- **Small pseudorapidity** (η)

Located around interaction points (IPs), these detectors typically **miss events** that have:

- **Low** p_T
- **Feebly interacting** particles (FIPs)
- **Large** η

ForwArd Search ExpeRiment (FASER)

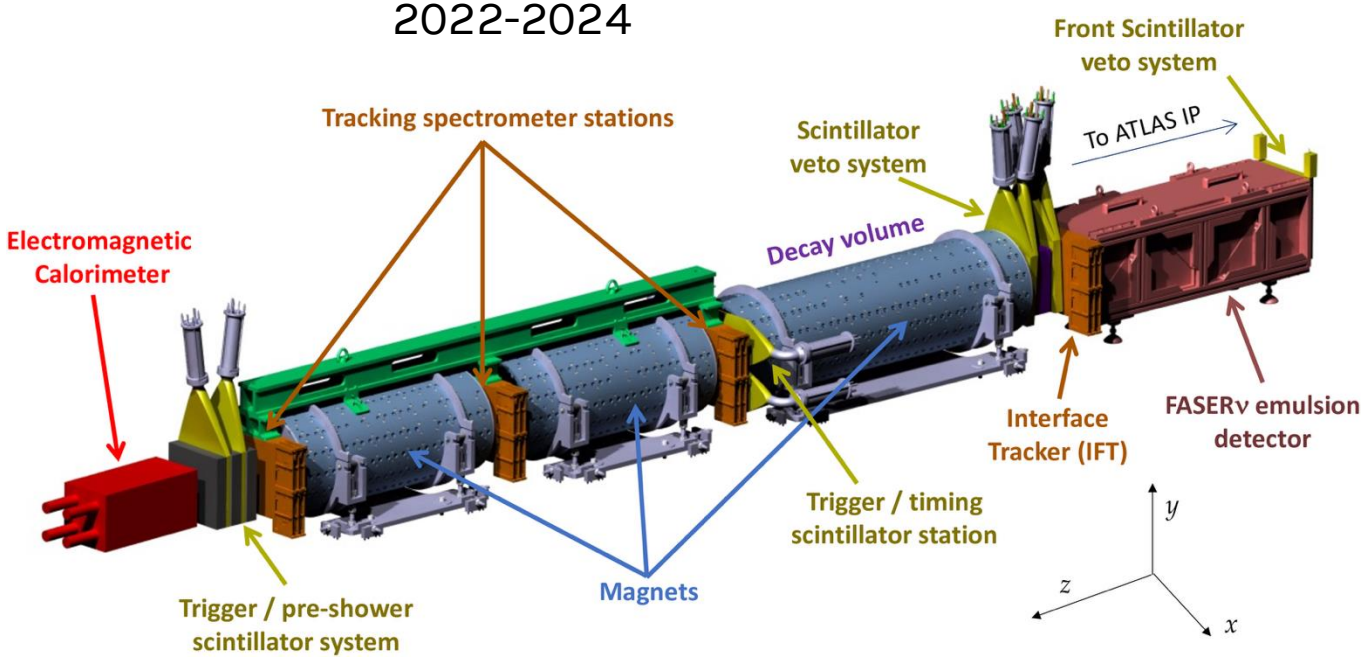
- Purposefully designed to:
  - **Search for BSM particles** i.e. Feebly-Interacting Particles (FIPS)
  - **Study** properties of collider-produced **neutrinos** at high energies
- Located **480m downstream**, on the line-of-sight (LOS) of the ATLAS IP
- Benefits from highly collimated flux of light hadrons along line of sight



FASER Detector
Detector Layout

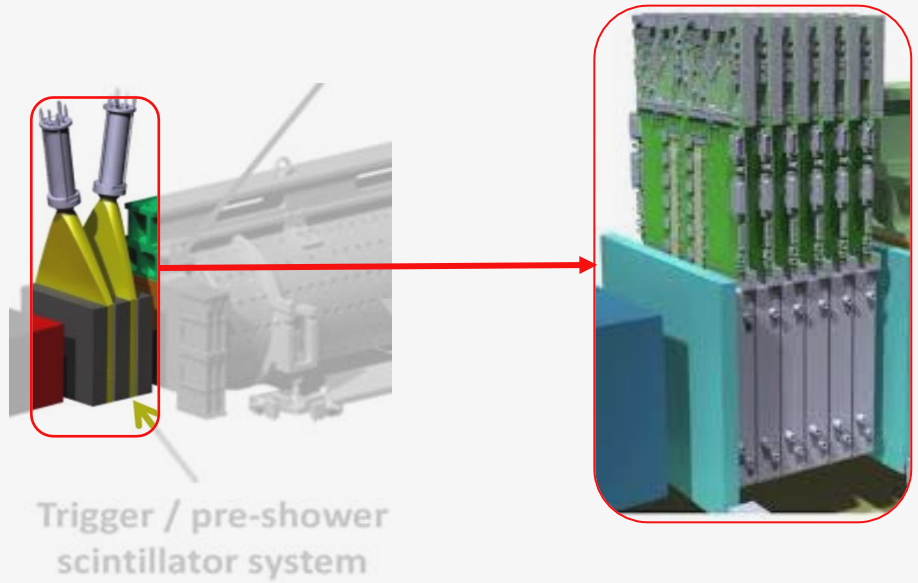
FASER Detector Paper

2022-2024



2025 - Present

Preshower upgraded with pixel-based detector



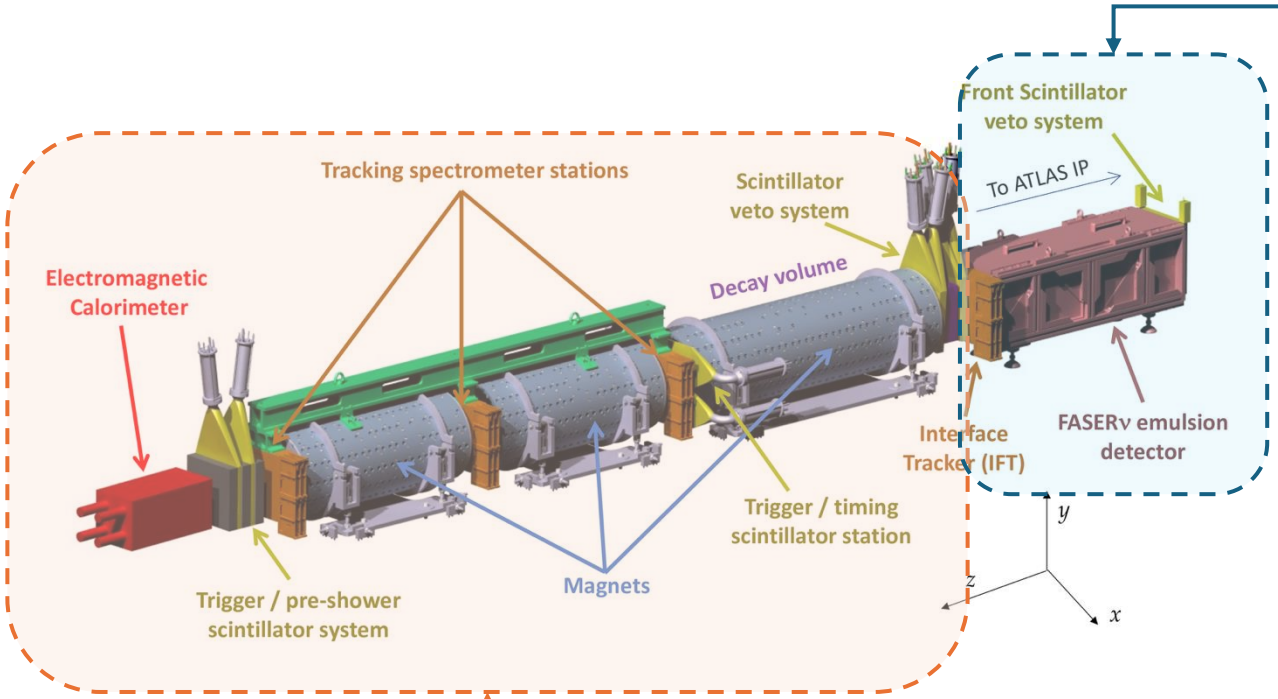
FASER detector comprised of:

- Electronic Spectrometer
- Neutrino emulsion detector (FASERν)

Both of these can be used to **detect neutrinos independently**

FASER Detector

FASER Detector Paper



Emulsion Detector

Slow to analyze
- Each film must be processed by hand and digitized before analysis

Exceptional resolution (~0.3 μm)
- Emulsion films interleaved with tungsten plates

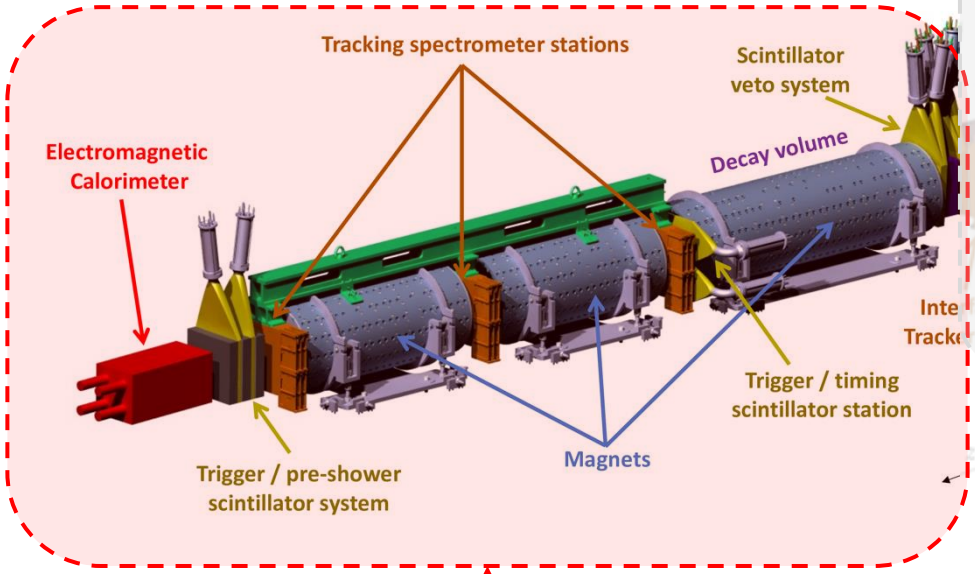
Electronic Detector

Faster to analyze
- Uses only electronic components of detector
- Benefits from prompt data reconstruction

Can **separate** neutrino decays by **charge**
- Can differentiate neutrino and anti-neutrino

FASER Detector

FASER Detector Paper



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Focus of This Talk

Electronic Detector

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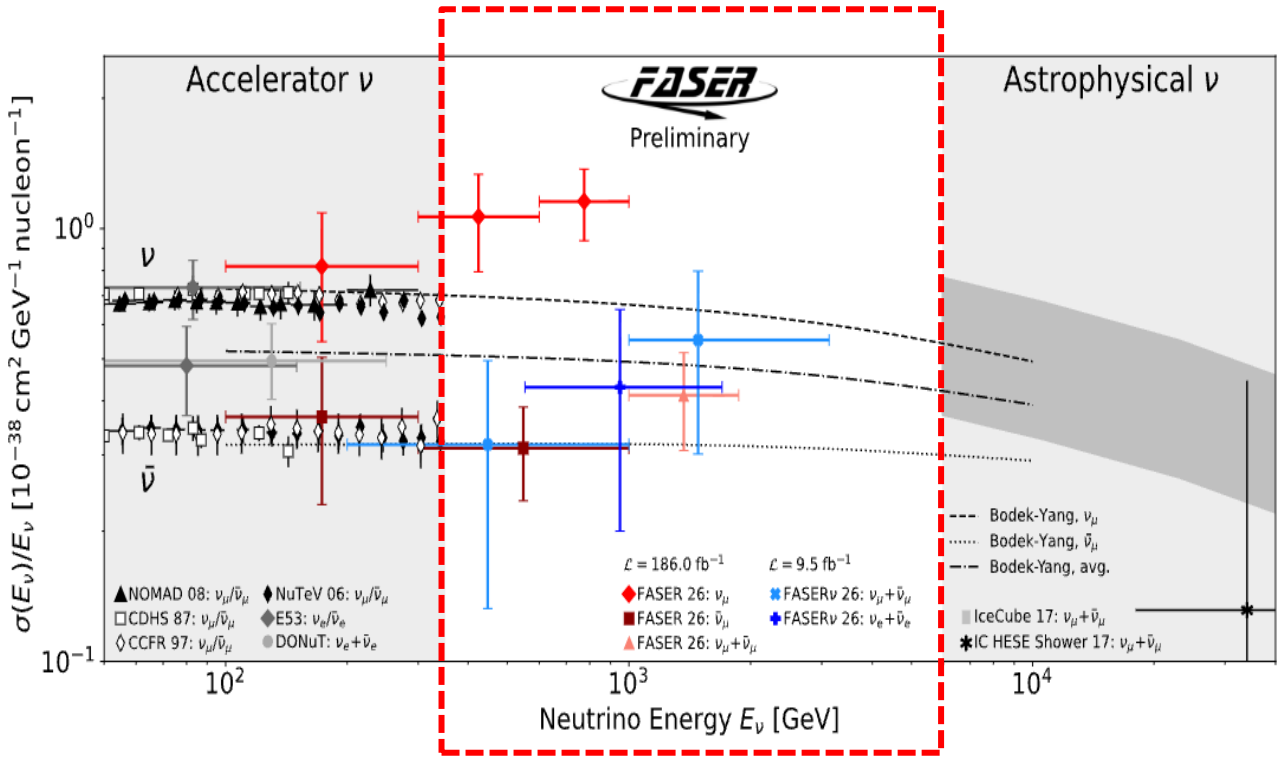
Can **separate** neutrino decays by **charge**
- Can differentiate neutrino and anti-neutrino

Neutrinos @ FASER

- **Highest energy man-made neutrinos**
- Produced through **light/charm decays due** to high flux of light hadrons along LOS
- Exist in the **energy gap** between neutrinos from fixed-targets and astrophysical processes
- **First direct detection by FASER (2023)**

FASER continues to constrain cross-sections in the energy gap



First Collider Neutrino Detection Paper

Muon Neutrinos

Neutrinos are **produced upstream of FASER** :

- Through both light & charm **hadron decays**
- High flux in forward direction along the LOS

ν_μ **first** flavour to be studied using **only FASER's electronic detector**

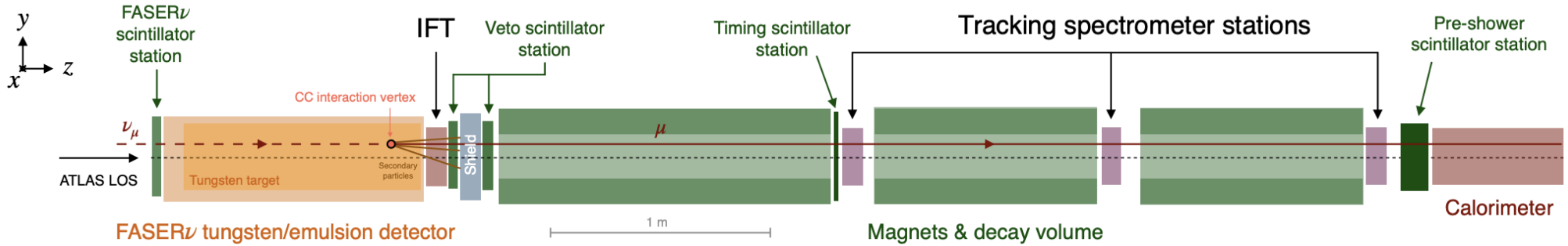
Signal

- **Interactions** occur in the **tungsten** target of FASERν
- Resulting in a **highly collimated muon track**
- Measured by FASER's **electronic sub-detectors**

Background

Main source of background due to:

- High momentum muons that miss veto scintillators



Muon Neutrino
Previous Measurements

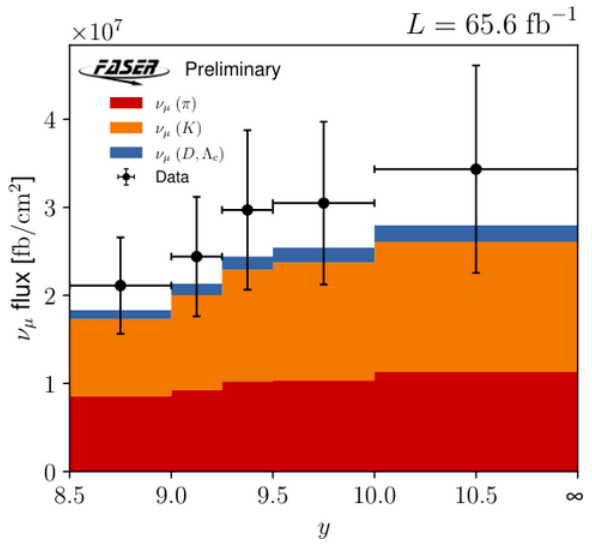
Previous measurements of ν_μ with FASER's electronic detector include:

- ν_μ flux and differential cross section measurement
- Rapidity measurement

All previous measurements :

- **Measured one variable**
- Constrained the others using **MC predictions**
- Example: measuring the cross section with a fixed neutrino flux

Rapidity Measurement



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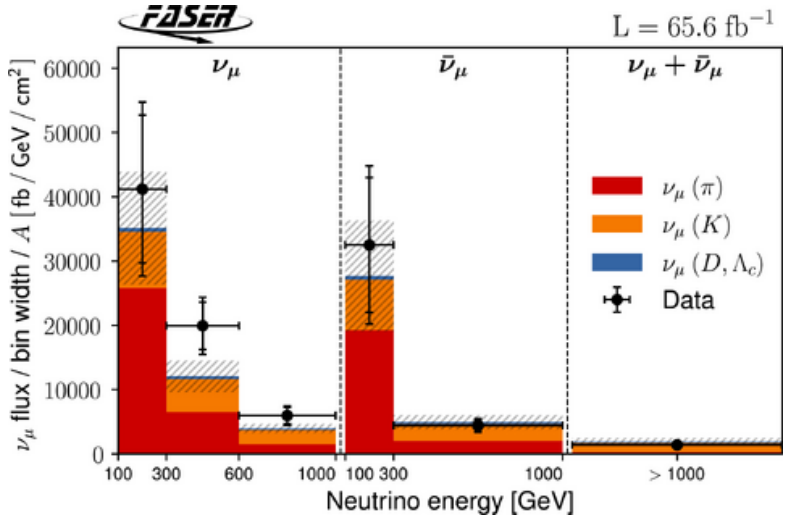
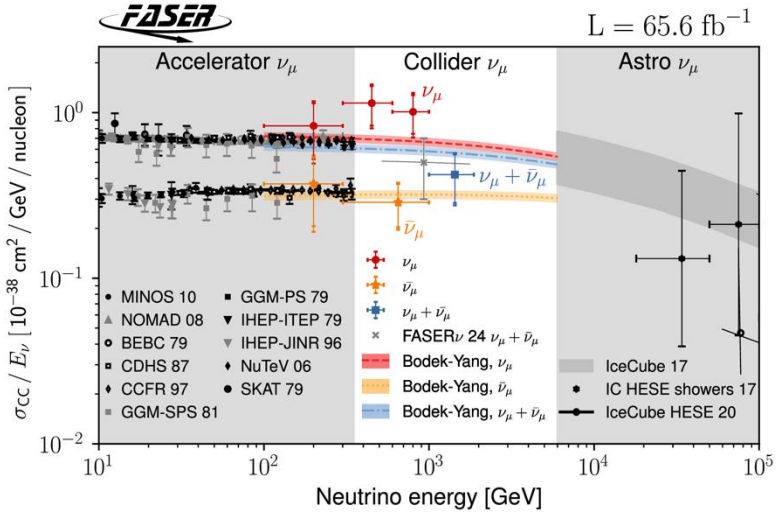
Flux and Differential Cross Section Measurement





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Muon Neutrino
Results

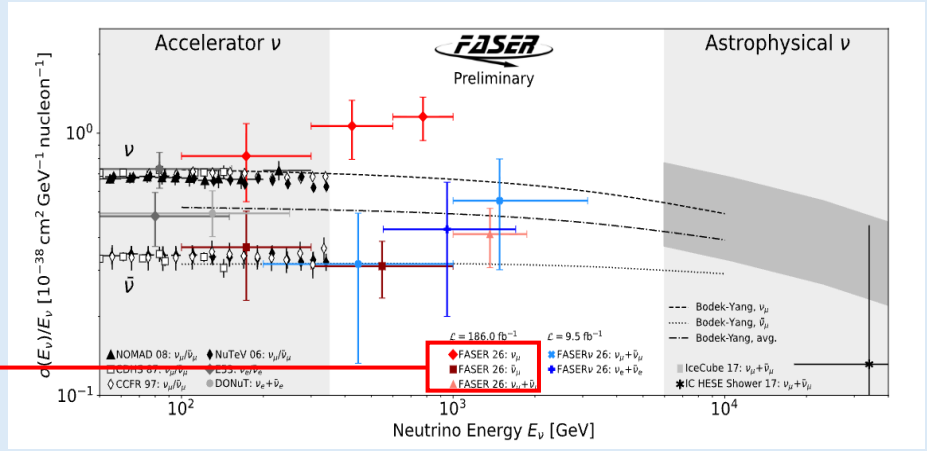
New Measurement:

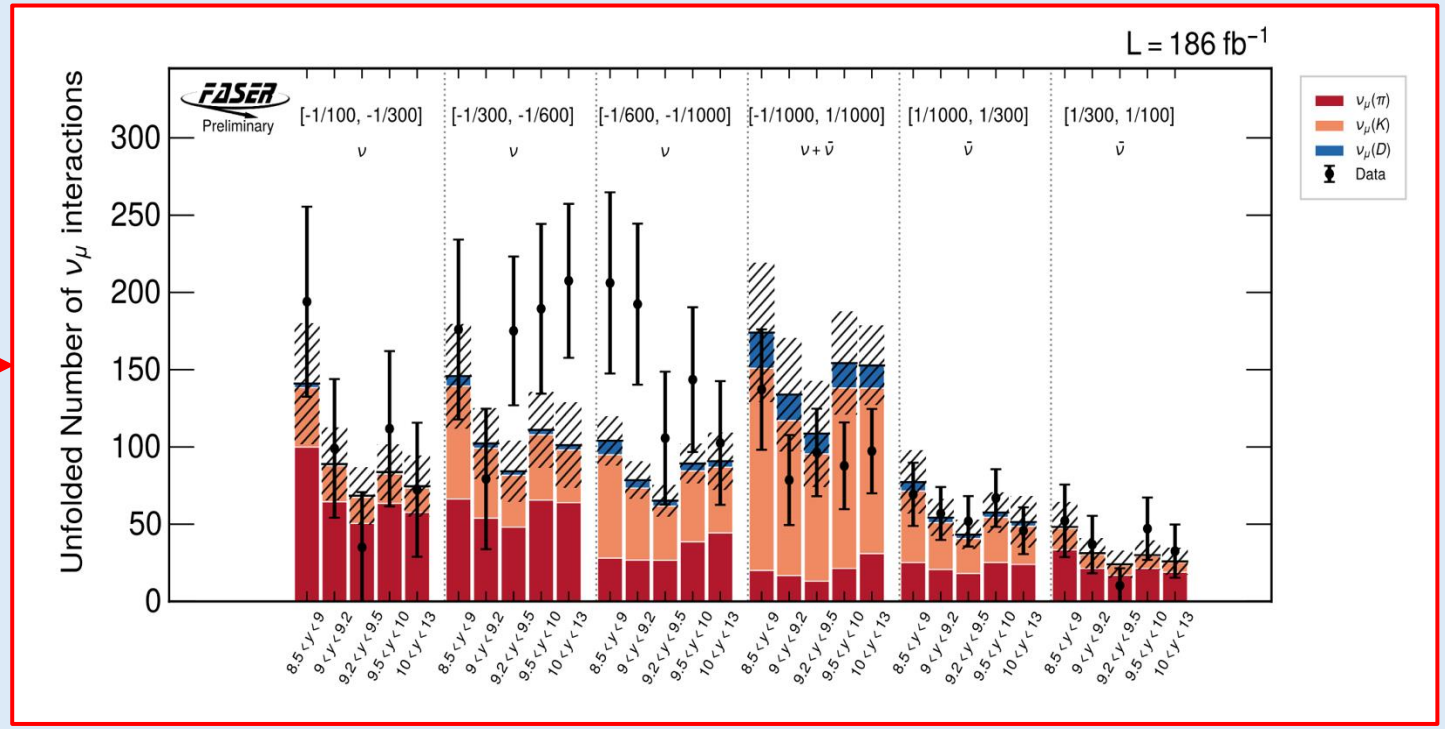
- **Combines previous measurements** to extract a double-differential cross section
- Expressed as a function of both in **energy and rapidity**

Events observed :

766.8 ± 28.7 (stat.) ± 7.3 (syst.)

Result complements and expands upon measurements taken using FASERν





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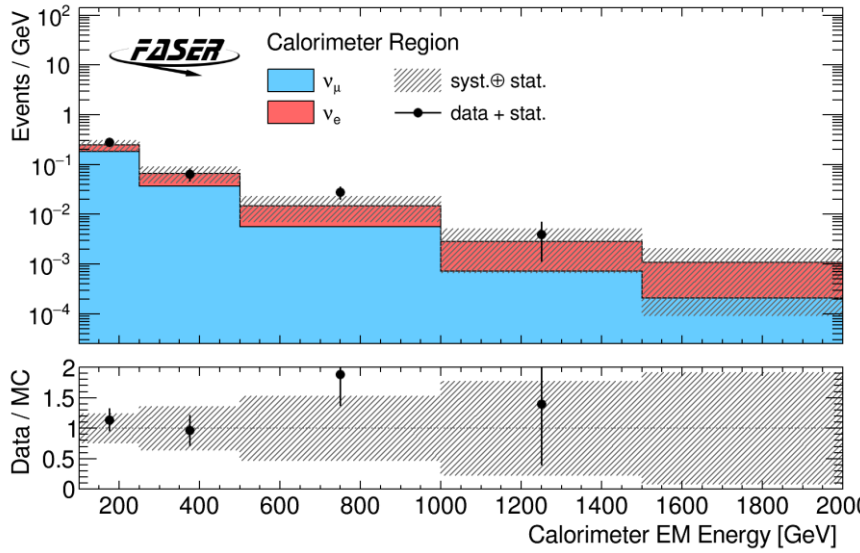
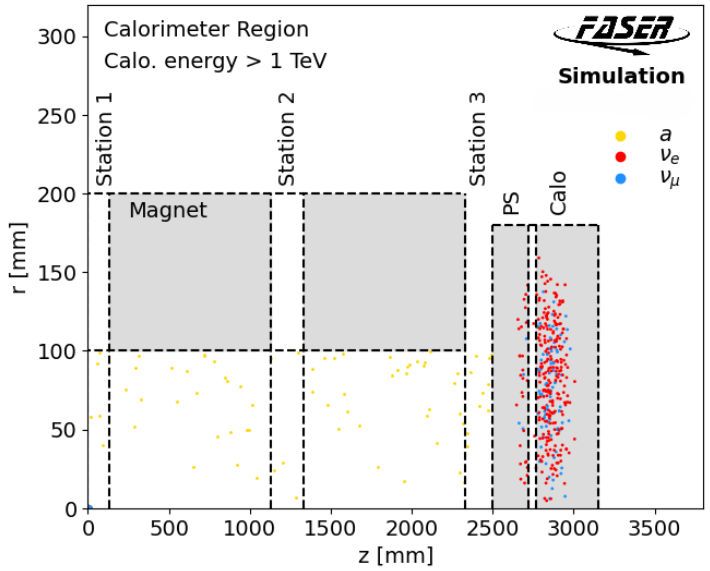
Electron Neutrinos

- While ν_μ **interactions** are most **abundant**, **other flavours** are also able to **detected**
- Control regions of previous BSM search for axion-like particles (ALPs) dominated by ν_e interactions
- Demonstrated **potential to measure** ν_e with the electronic detector
- This analysis exploits these control regions to isolate ν_e interacting in the detector

ALPS Paper

Control Region (Calorimeter) in FASER's ALP Search (2024)



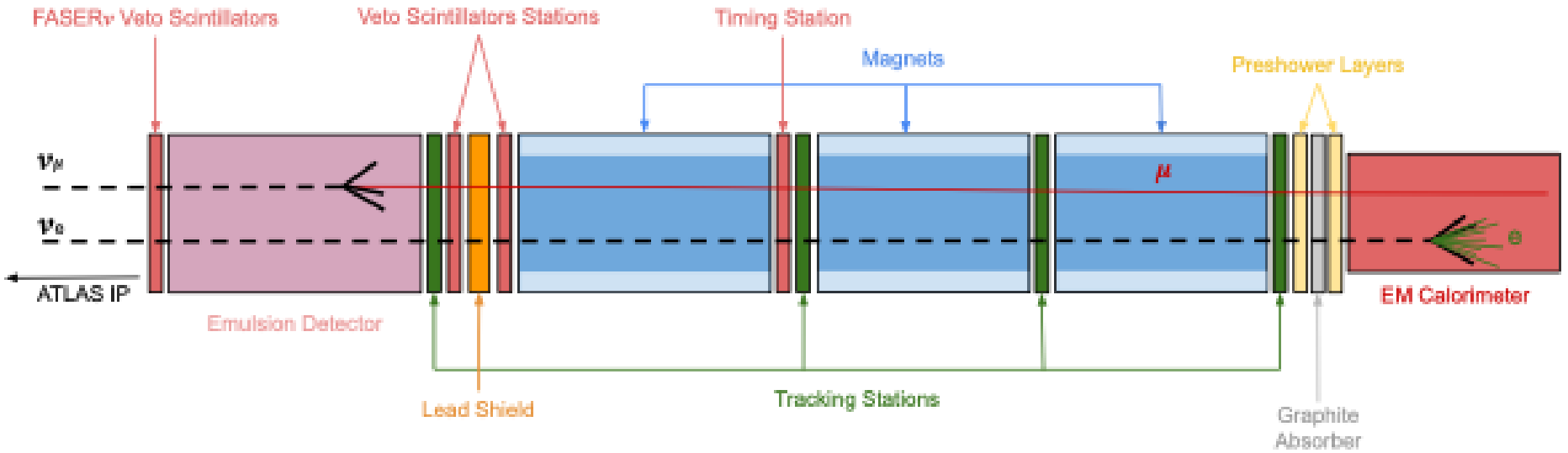


Electron Neutrinos
Event Selection

- **176.8 fb^{-1}** of data
  - Collected by FASER in 2022-2024 (inclusive)
  - **Only** uses data from **electronic spectrometer**
  - **Targets ν_e** produced in both charged-current (CC) and neutral-current (NC) interactions in the calorimeter

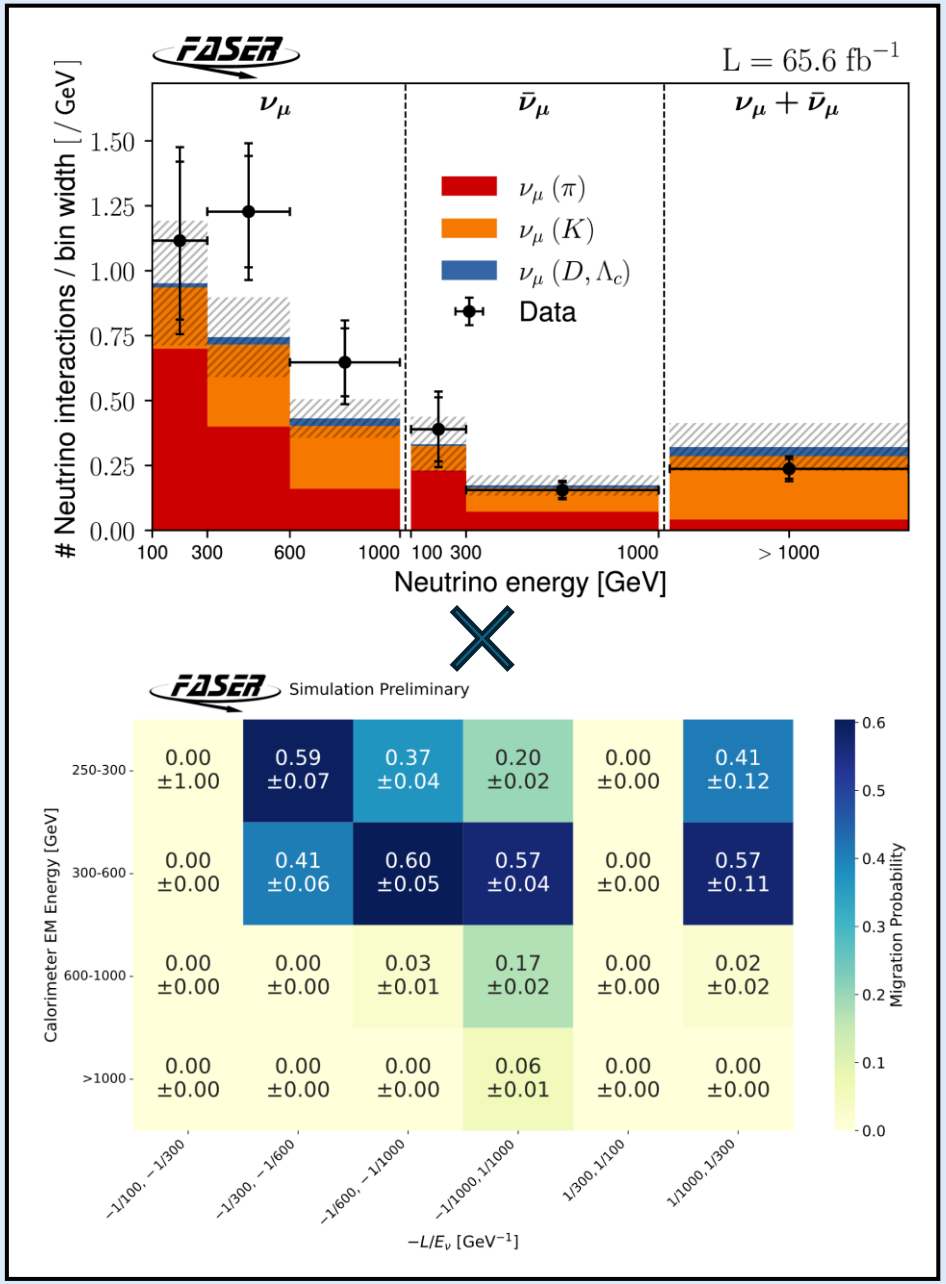
Signal

- **No charge** in either **veto or timing scintillators**
- **No signal** in **preshower** scintillator
- Large **energy deposit in calorimeter** (>250 GeV)



Electron Neutrinos
Background Estimation

- Dominate **background** is **muon neutrinos**
- ν_μ interactions deposit less energy in calorimeter than ν_e interactions
  - Introducing a **250 GeV energy requirement** in the calorimeter significantly **suppresses the muon neutrino background**
- Using **previous ν_μ cross-section measurement**:
  - Background can be further constrained using data
  - Requires migration-matrix to obtain ν_μ energy from data



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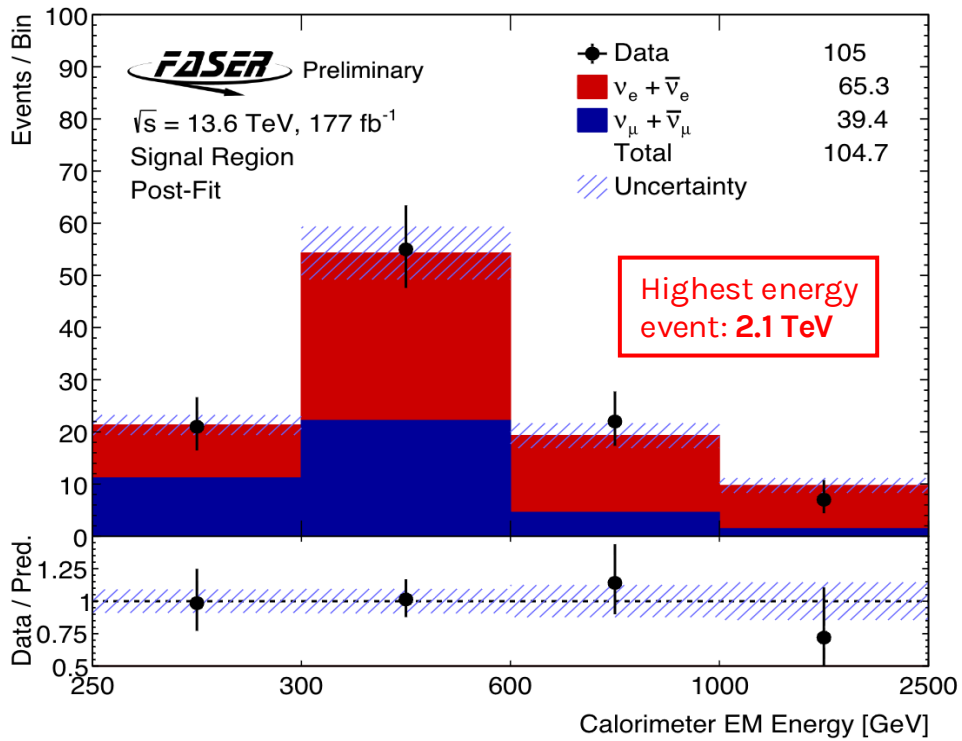
Electron Neutrinos
Results

- **Observation** of electron neutrinos in FASER's EM calorimeter
  - Significance of $\mathbf{5.5\ \sigma}$
- Observed : $\mathbf{65 \pm 12}\ \boldsymbol{\nu_e}$ (CC +NC) events
- Expected : $\mathbf{42 \pm 27}\ \boldsymbol{\nu_e}$ (CC+ NC) events

First measurement of ν_e using FASERs electronic detector !



Backgrounds

E_{Calo} [GeV]	[250-300]	[300-600]	[600-1000]	[+1000]	Total
Nominal ($\nu_e + \bar{\nu}_e$)	6.52	20.6	9.44	5.32	41.9
Flux Unc.	3.20	12.5	6.97	4.36	27.0
GEANT4 Unc.	0.73	0.77	0.33	0.24	2.07
Calorimeter	0.36	1.13	0.52	0.29	2.29
PS Layer 1	0.22	0.70	0.32	0.18	1.42
Luminosity Unc.	0.12	0.39	0.18	0.10	0.80
Statistical Unc.	0.34	0.60	0.41	0.31	1.66
Total	6.52 ± 3.32	20.6 ± 12.6	9.44 ± 7.01	5.32 ± 4.40	41.9 ± 27.3

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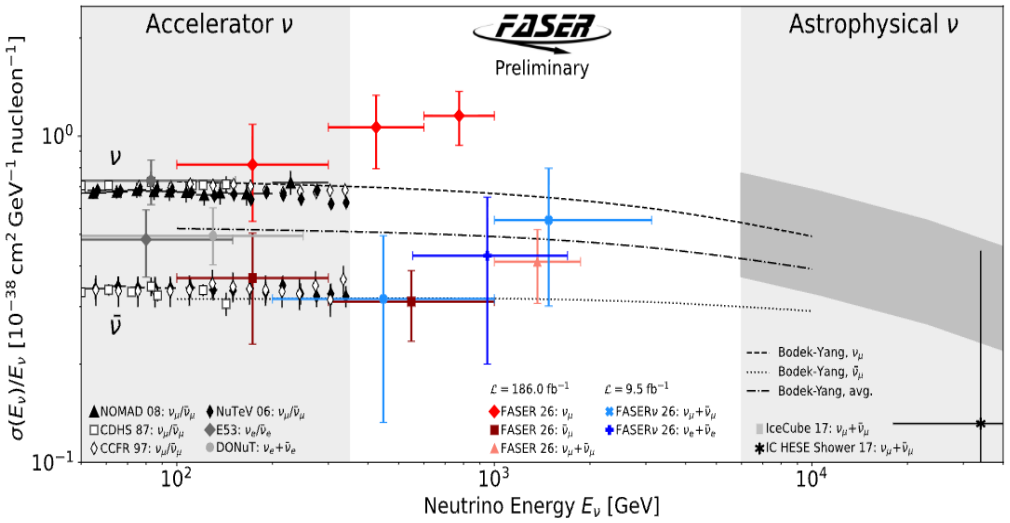
Summary

- **New measurement of muon neutrinos** with FASER's electronic detector
- **First observation of electron neutrinos achieved** solely with FASER's electronic sub-detectors
- Together with measurements from FASER's emulsion detector, this work further bridges the gap between neutrinos from fixed-target experiments and astrophysical processes



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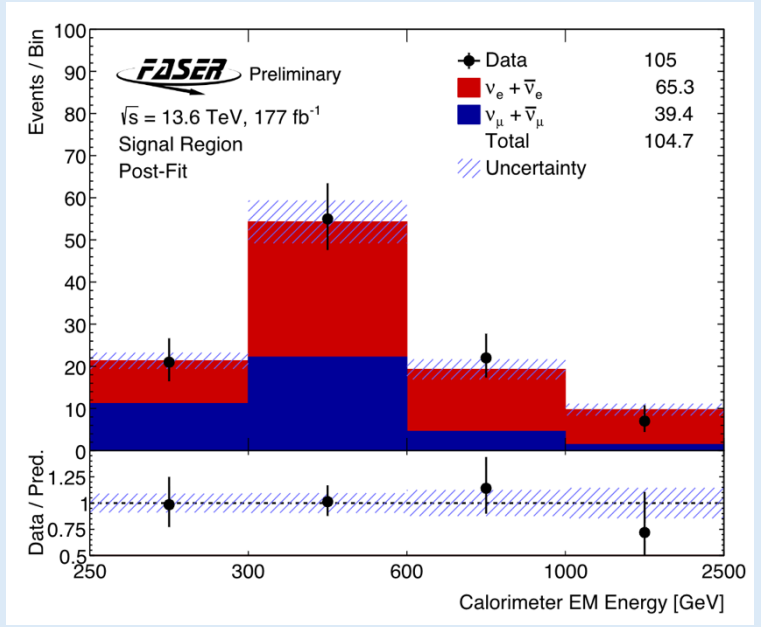

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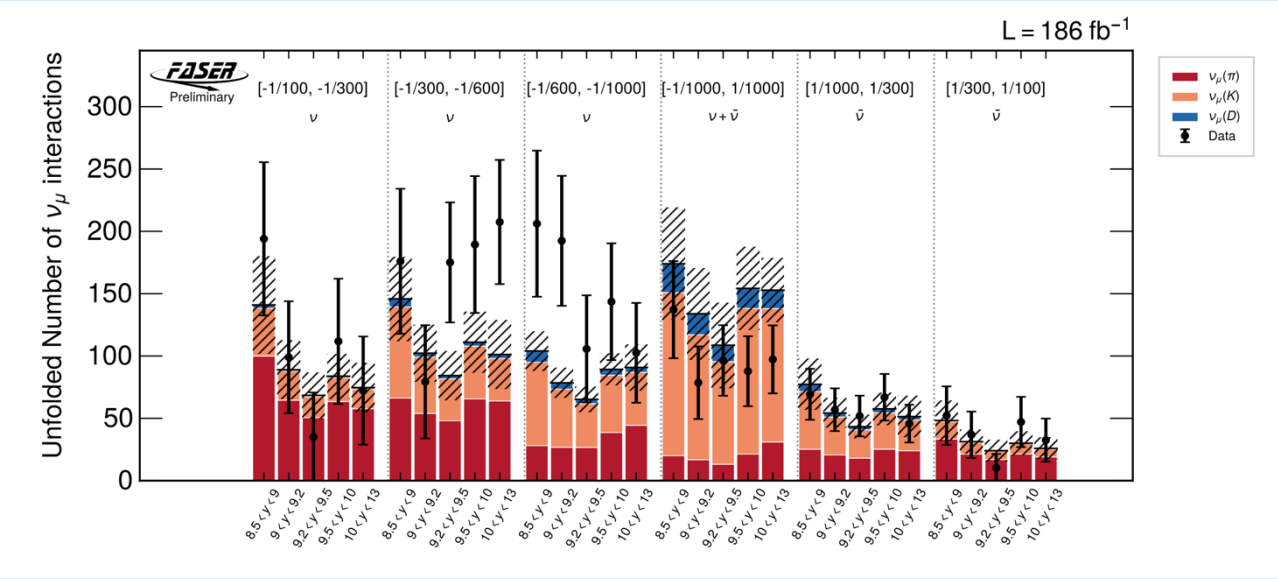

Back up

Background Estimation

Additional backgrounds include:

- Large angle muons
  - Only account for a small number of events < 250GeV
  - Negligible > 250 GeV
- Neutral hadrons
  - Negligible with signal selection applied
- Veto system inefficiency
  - Negligible
- Non-collision backgrounds
  - Beam background does not correspond to colliding bunches
  - No events observed in cosmic muon data
  - i.e. Negligible
- Tau Neutrinos
  - Expected contribution is very small

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