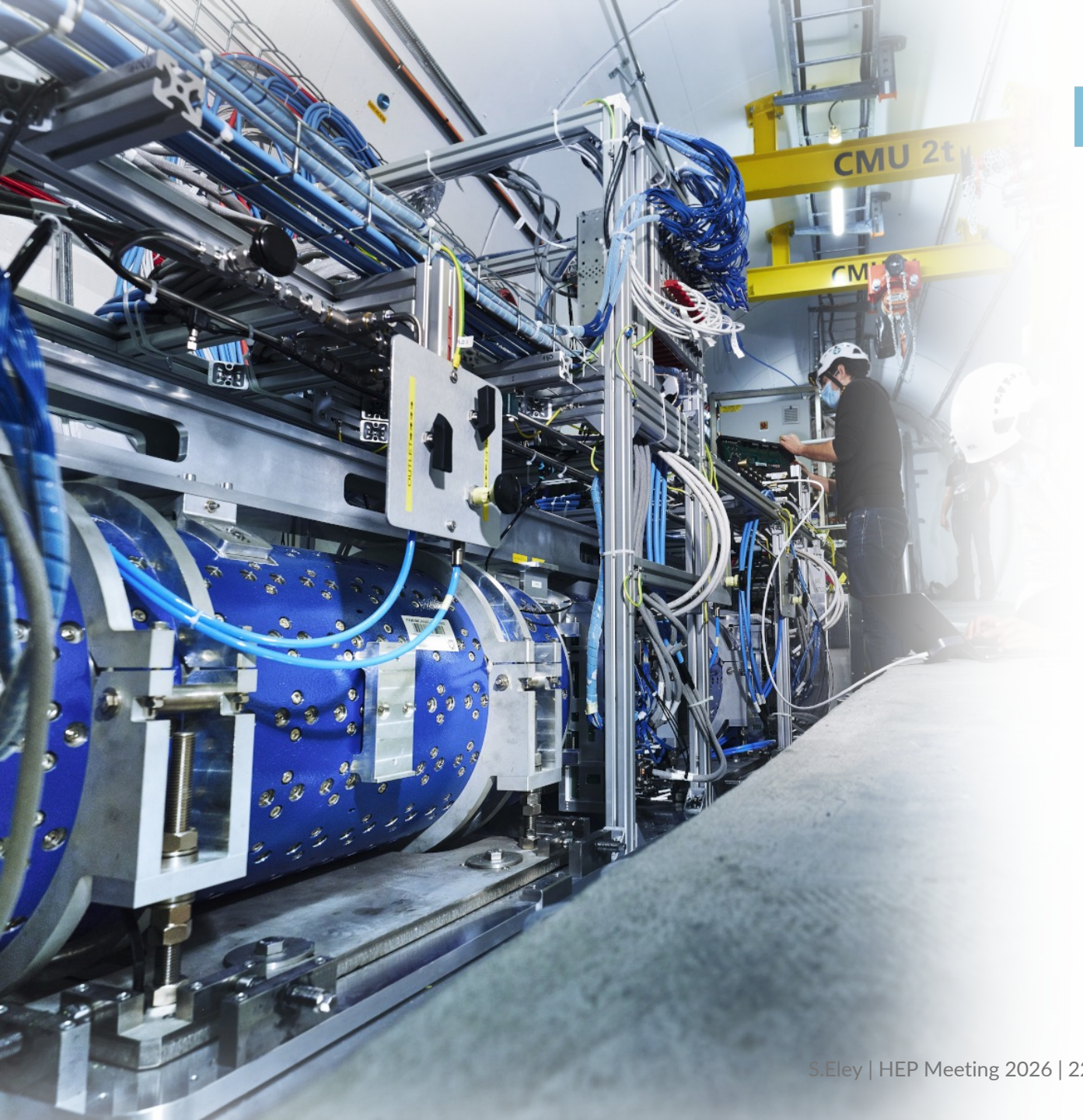


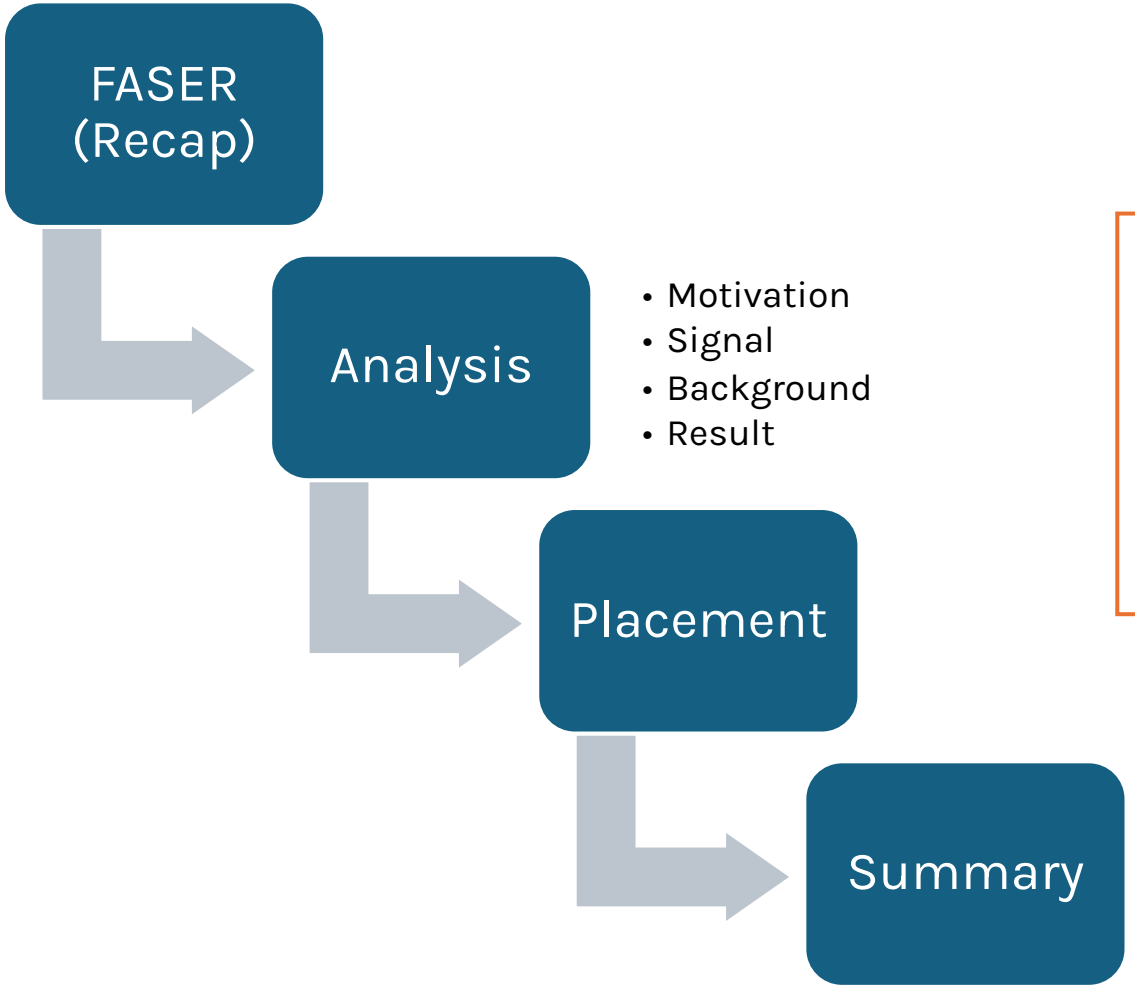
Studying Electron Neutrinos with FASER's Electronic Spectrometer

HEP Annual Meeting
Friday 22nd May 2026

Sinead Eley

Supervised by:
Prof. Carl Gwilliam, Prof. Monica D'Onofrio,
(& Dr . John Anders)

Overview



Recap

- Finished LTA @ CERN in October
- Focusing on analysis to get result (March 2026)
- Placement @ The Guardian (since Jan 2026)
- Aiming for full unfolding of analysis by end of year

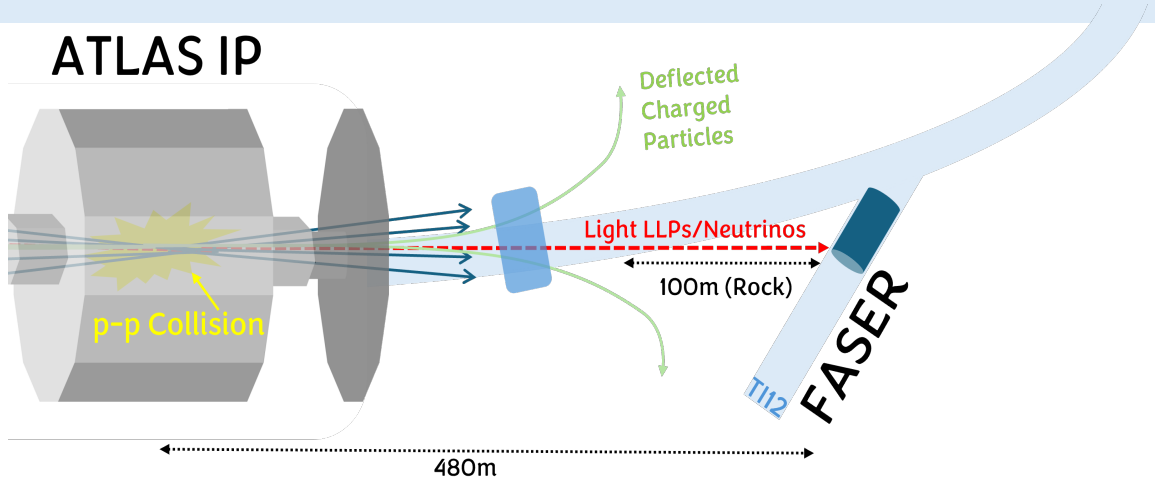
ForwArd Search ExpeRiment (FASER)

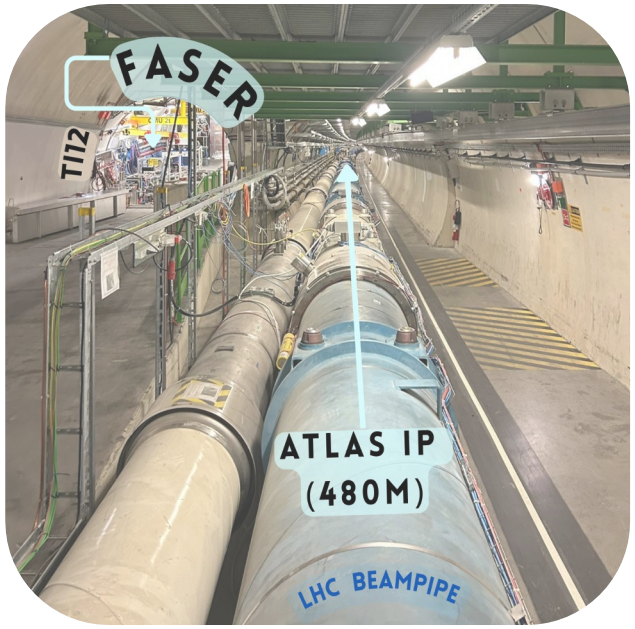
Purposefully designed to:

- **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

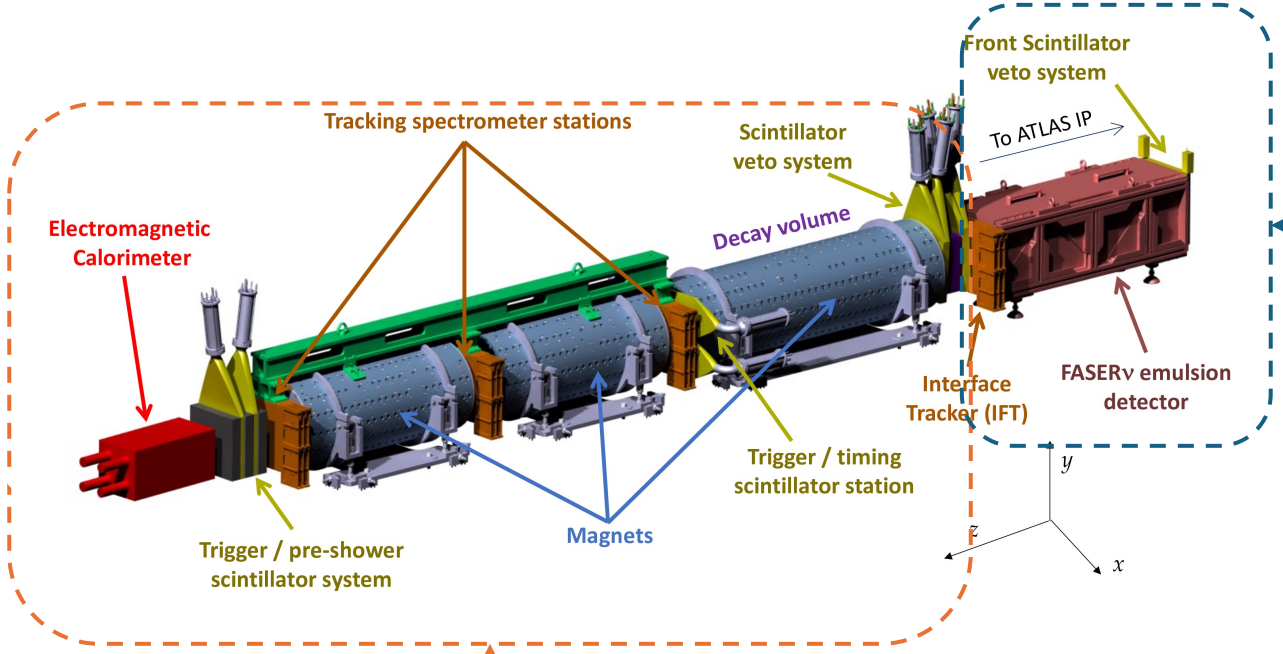




For more info on:
BSM Searches --> See **Pawan's** talk here
FASER --> See **John's** talk here

FASER Detector

Two Complementary Neutrino Detection Methods



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

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

OPERATIONS

- Running since start of LHC Run 3 (2022)
- >333 fb-1 Recorded
  - 97% of IP1 delivered luminosity
- Successful Run 3 operations
- Detector controlled fully remotely

Contributions

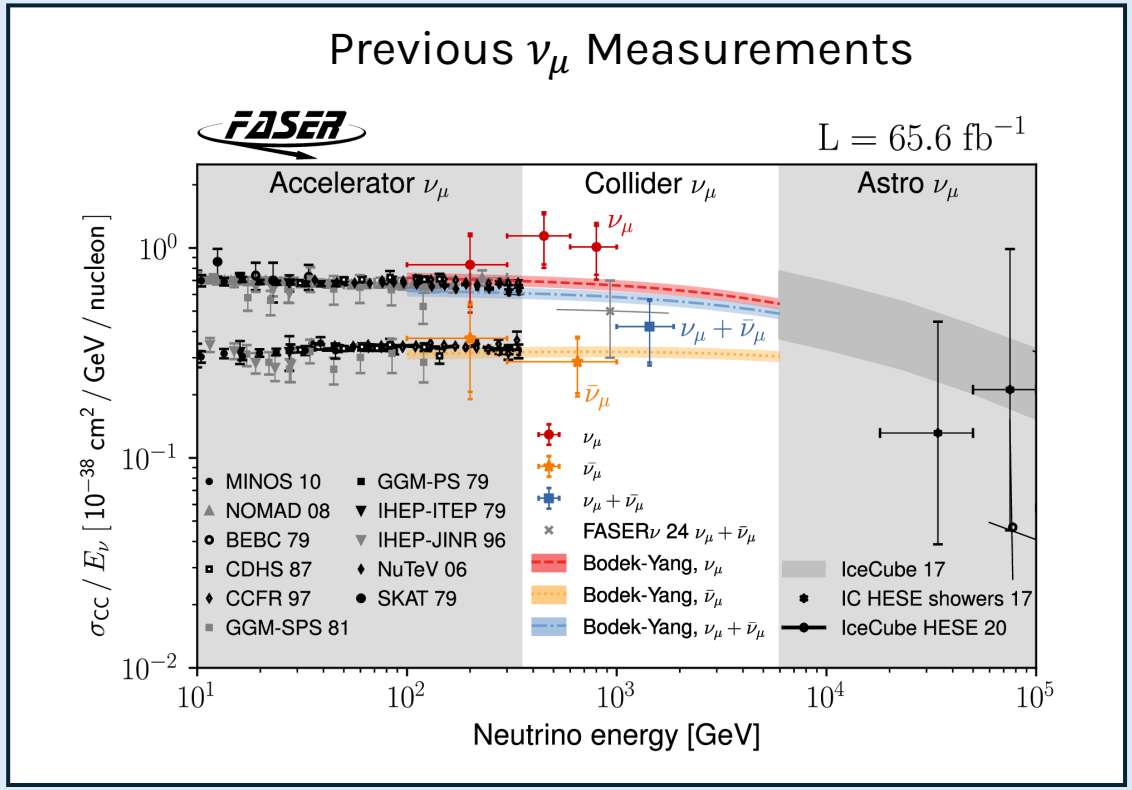
- Contributed to operations as Run Manager
- Responsible for coordinating detector operations during shifts

FASER Detector Paper
FASERNu Reco & Performance Paper

Neutrinos @ FASER

Gap between accelerator & astrophysical production

- **Collider neutrinos are the 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
- Only studied since 2023
  - First direct detection of a collider neutrino occurred at FASER
- Measurements in this gap key to:
  - Improve theory predictions
  - Constrain light and charm hadron production



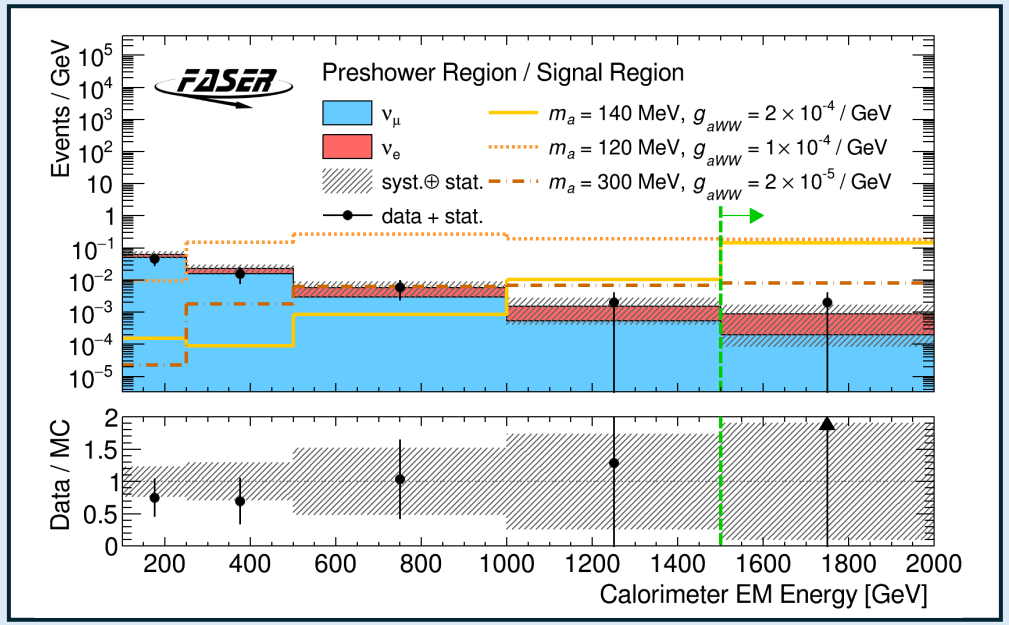
First Collider Neutrino Detection Paper
Electronic ν_μ Cross Section Paper
Latest FASERν Cross Section Paper

From ALPs to Neutrinos

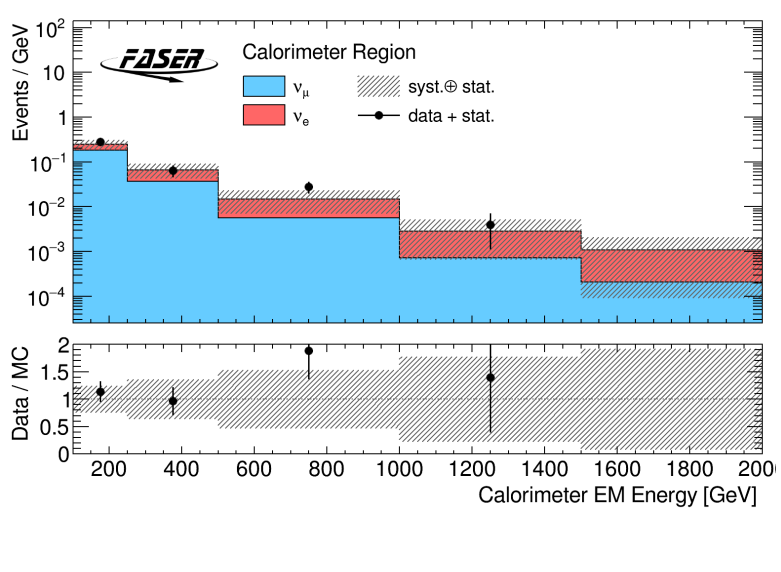
- FASER's search for axion-like Particles (ALPS) published in 2024
  - Led by **Lottie** (previous Liverpool PhD student)
- Result showed 1 event consistent with SM predictions
- High calorimeter energy requirement (>1.5 TeV) to reduce neutrino background

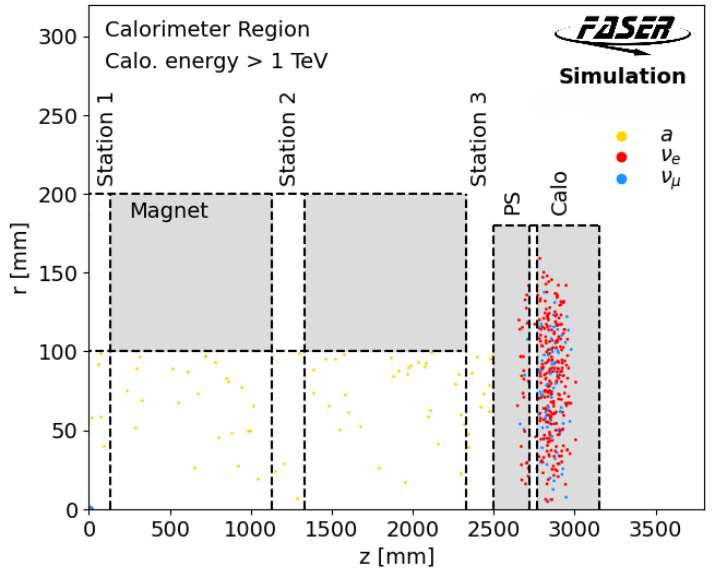
- Control regions (especially calorimeter) dominated by ν_e interactions
- Demonstrated **potential to measure ν_e** with the electronic detector

Signal Region (Preshower)



Control Region (Calorimeter)





ALPS Paper

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

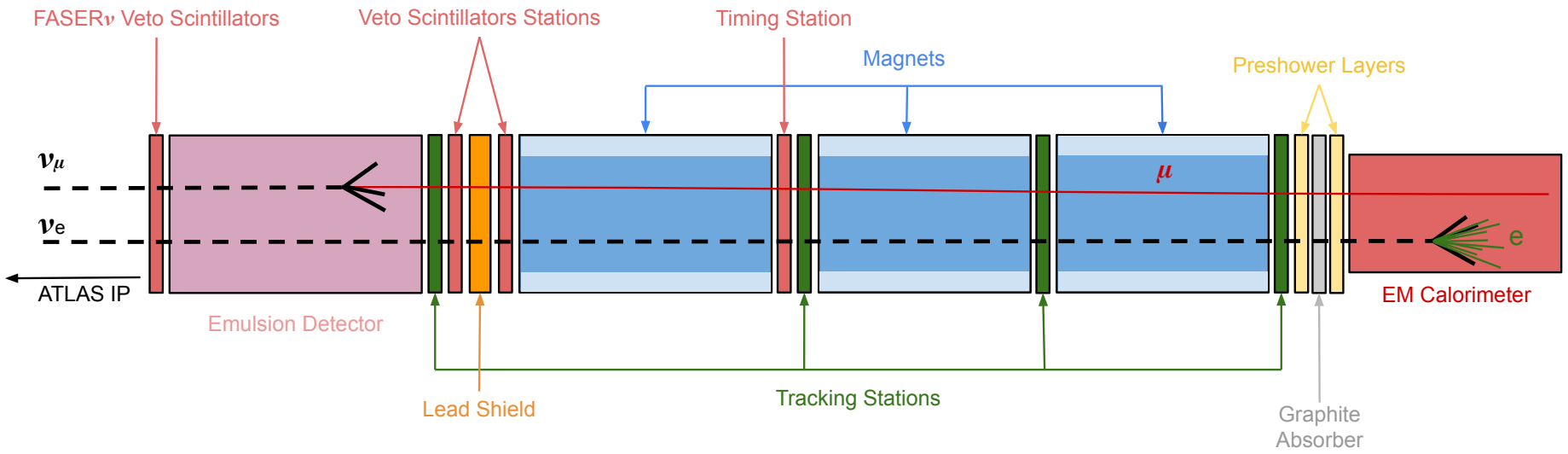
Signal Selection

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

Energy cut reduced from ALPs search

↓

Multiple energy bins required in signal region



Electron Neutrinos
Backgrounds

Contributions

Large Angle Muon Study
Neutral Hadron Study
Preshower Systematic Calculations
Data Cross Checks

Main Background

Muon Neutrinos

- Reduced by 250 GeV energy cut
- Further constrained using data & previous ν_μ measurement

Additional Backgrounds

Large Angle Muons

Accounts for small number of events < 250 GeV
Negligible > 250 GeV

Neutral Hadrons

Negligible

Non-Collision Backgrounds

Occurs when beam background does not correspond to colliding bunches
Negligible

Veto System Inefficiencies

Negligible

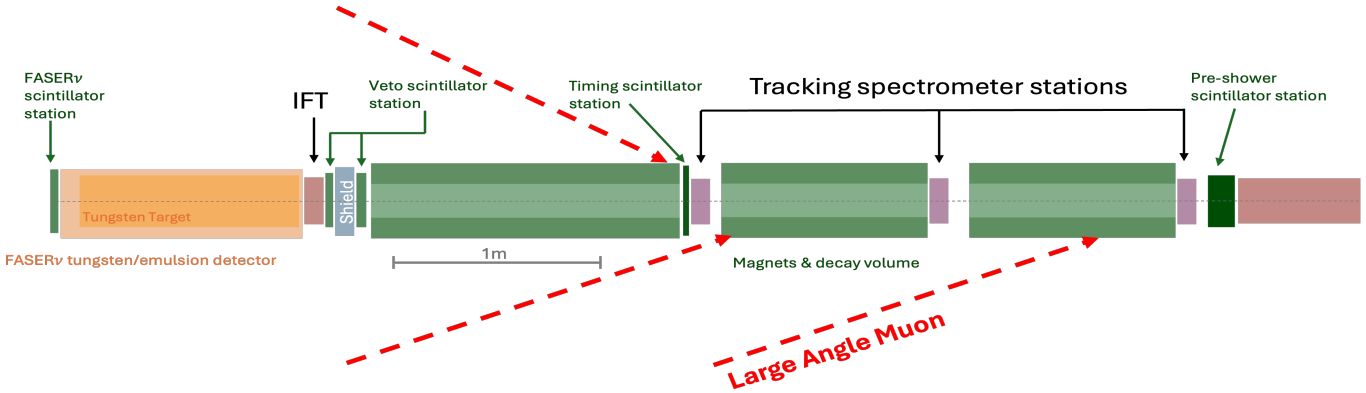
Tau Neutrinos

Expected contribution very small

Large Angle Muons

Large angle muons can bypass the veto systems

Not all muons that enter FASER necessarily pass through all veto scintillators



Requires data driven background prediction

- Using two uncorrelated variables [Veto Signal & Calorimeter Energy]
- Used to define control regions to predict number of large angle muon events in signal region

Signal extraction

- For each control region (CR)

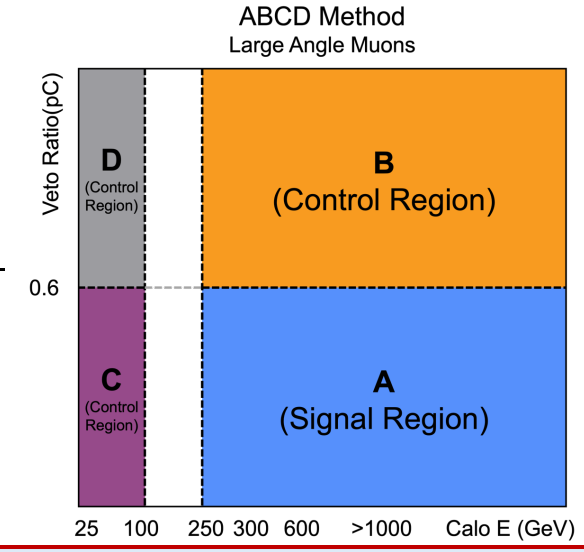
$$N_{CR} = N_{CR}^{Data} - N_{CR}^{\nu\mathrm{MC}}$$

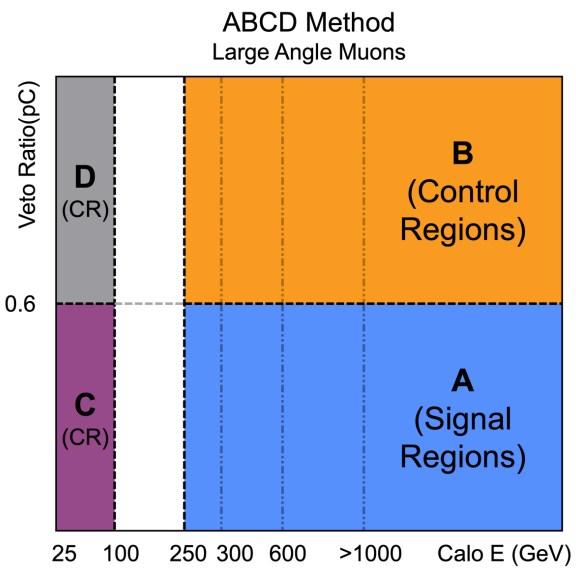
Neutrino MC contribution subtracted from data

A (signal region) and B (CR) are divided in multiple energy bins

Large Angle Muons are a negligible background above 250 GeV

$$N_{SR} = N_B * \frac{N_C}{N_D}$$





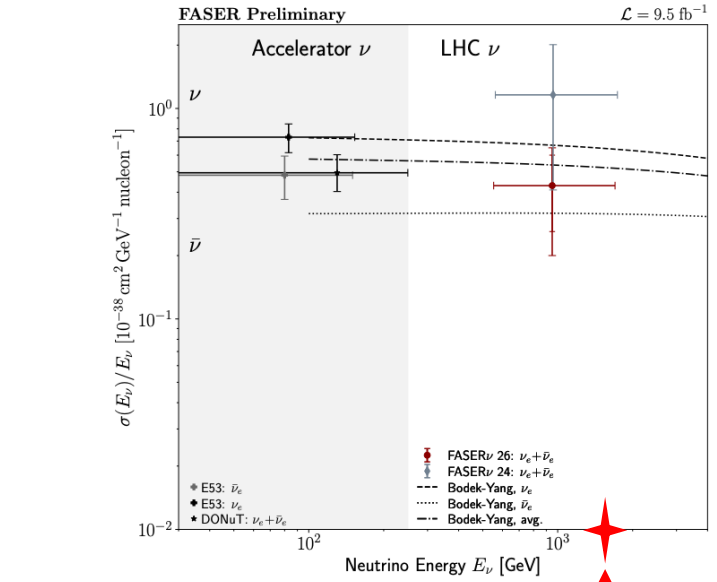
$$N_{SR,i} = (N_{B,i}^{Data} - N_{B,i}^{MC}) * \frac{(N_C^{Data} - N_C^{MC})}{(N_D^{Data} - N_D^{MC})}$$

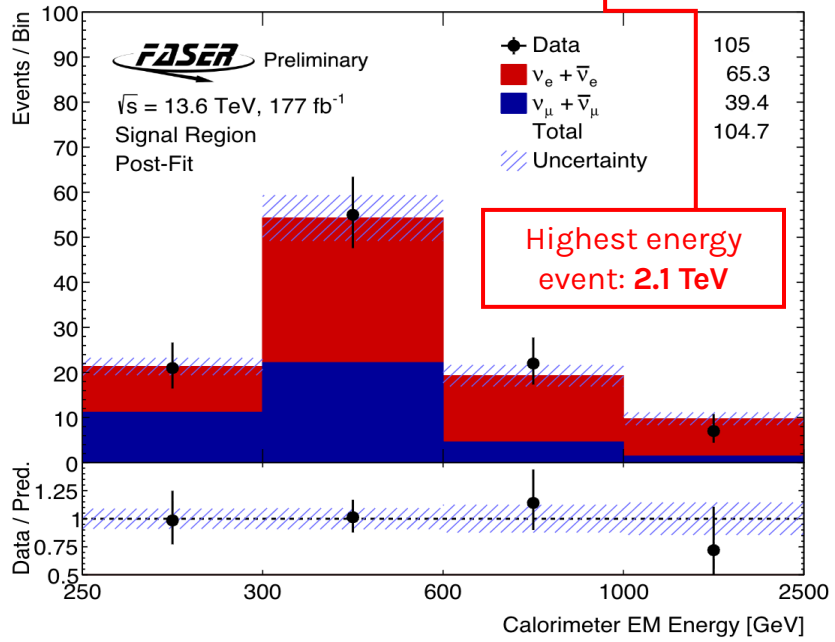
Electron Neutrinos
Observation Results

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

- Impact of results of collider neutrino measurements:
  - Inform future theoretical modelling of neutrino properties
  - Provides input for neutrino telescopes
  - Constrain light hadron production

First measurement of ν_e using FASERs electronic detector !

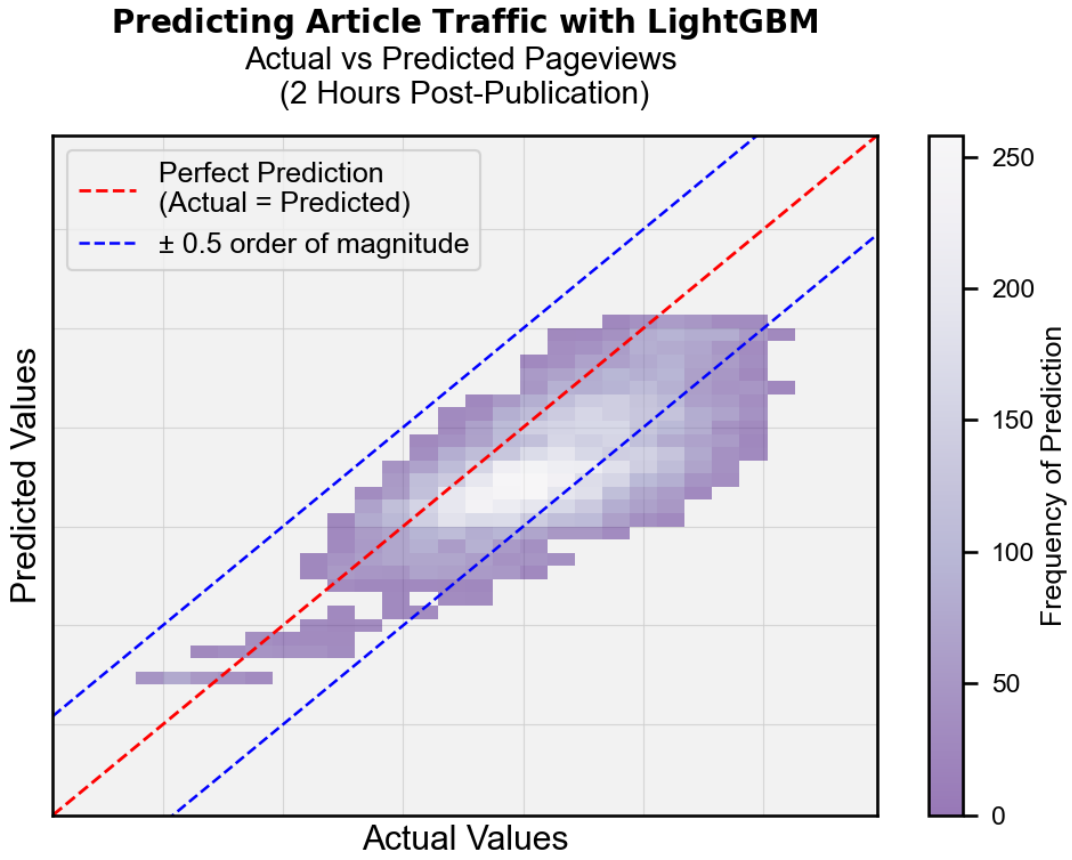




Placement @ The Guardian

Using Machine Learning to Model Online Traffic

AIM: Predict online traffic to an article at point of publication



Finish placement at The Guardian in Sep 2026

Approaches taken (so far):

- Exploratory Data Analysis (EDA)
- Applying an unsupervised learning algorithm (clustering) to time series profiles
- Engineering features from data available at (and after) point of article publication
- Building and optimizing a regression Gradient BDT model to predict traffic

Developing experience in :

- Applied ML workflow development
- Large-scale NLP data processing
- Model optimization and feature engineering
- Cloud computing with Google Cloud Platform (GCP)
- Large-scale database querying using SQL

Summary

- Contributed to background and systematic studies for FASER's **first observation of electron neutrinos with the electronic detector**
- Together with measurements from FASER's emulsion detector, this work further bridges the gap between neutrinos from fixed-target experiments and astrophysical processes

Next steps:

- Working towards unfolding to a cross-section measurement for collider electron neutrinos
- Reinterpreting these results in the form of a new ALPs search

Work ongoing with the Data Science team at The Guardian

- Aiming to pivot towards testing ideas of a deliverable product soon

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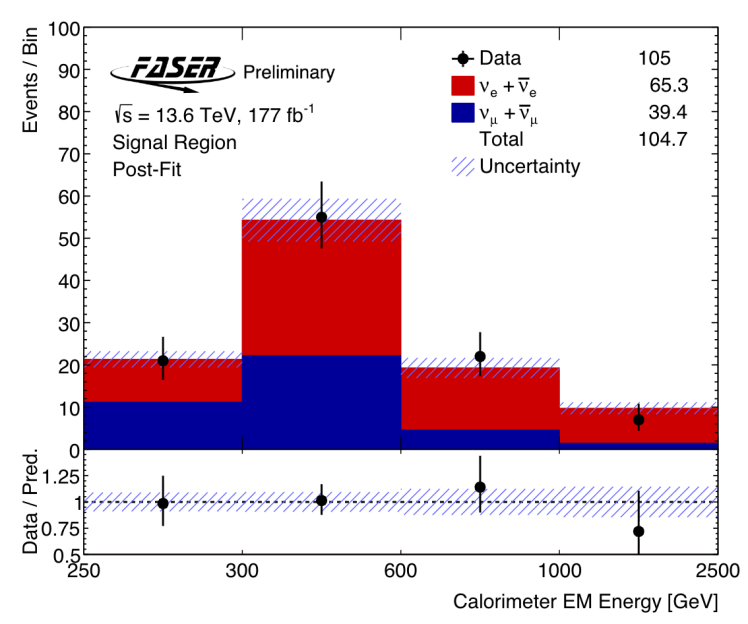


Back up

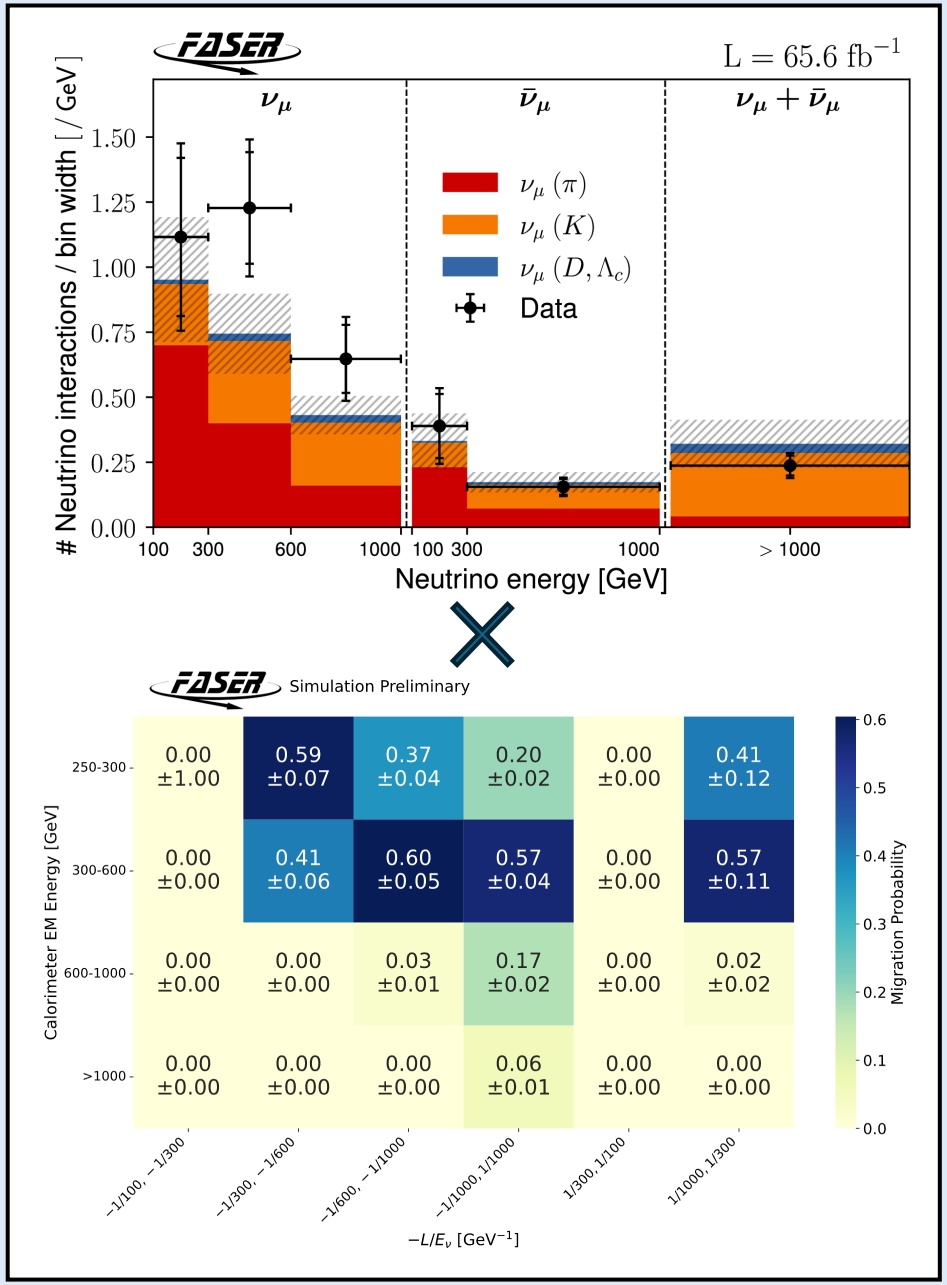
Electron Neutrinos
Estimation of Muon Neutrino Background

Main Background:
Muon Neutrinos

Unconstrained Muon Neutrino Background → Apply Calorimeter Energy Requirement (Calo E > 250 GeV) → Strong Suppression of ν_μ background → Background further constrained using data

ν_μ interactions deposit less energy in calorimeter than ν_e interactions

Previous ν_μ cross-section measurement alongside associated muon neutrino energy



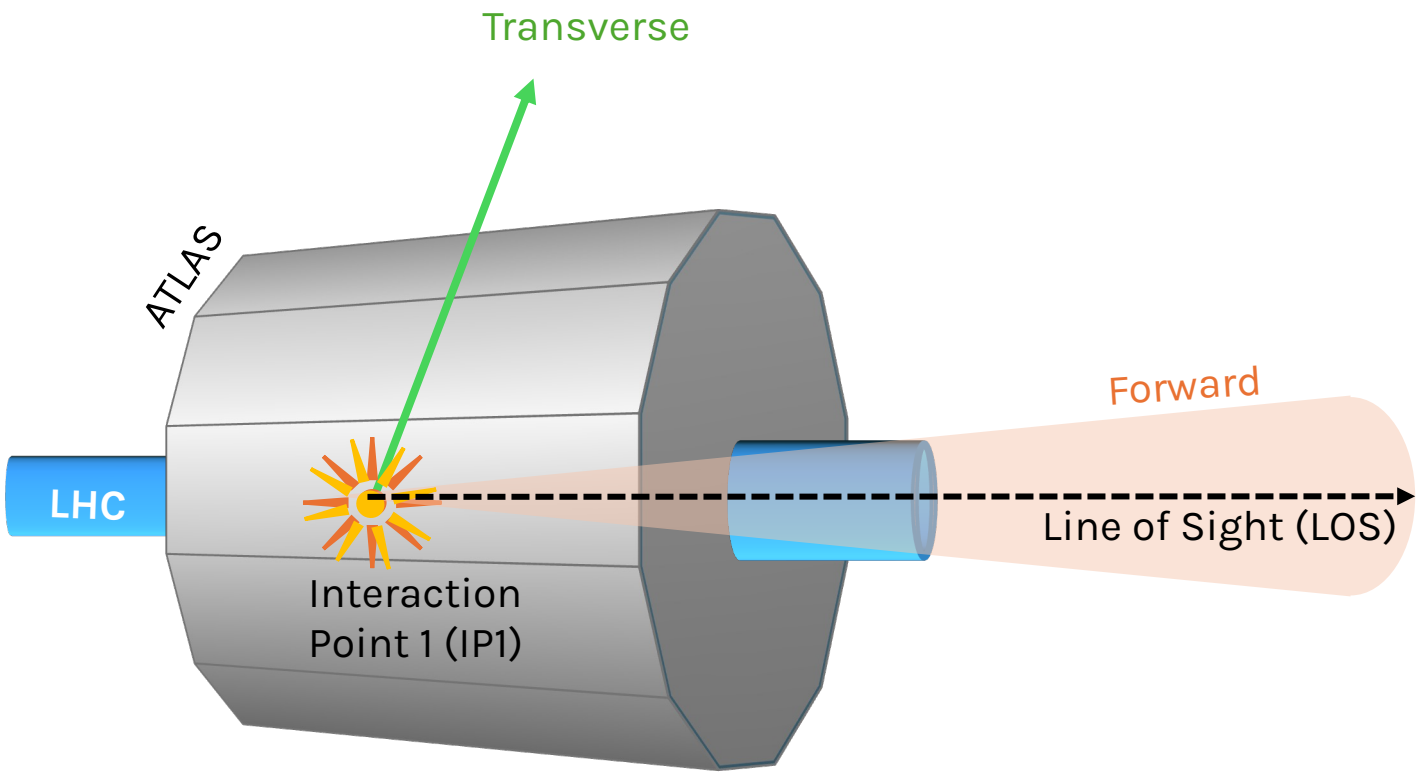
Background Estimation

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

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

Forward Physics at the LHC



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

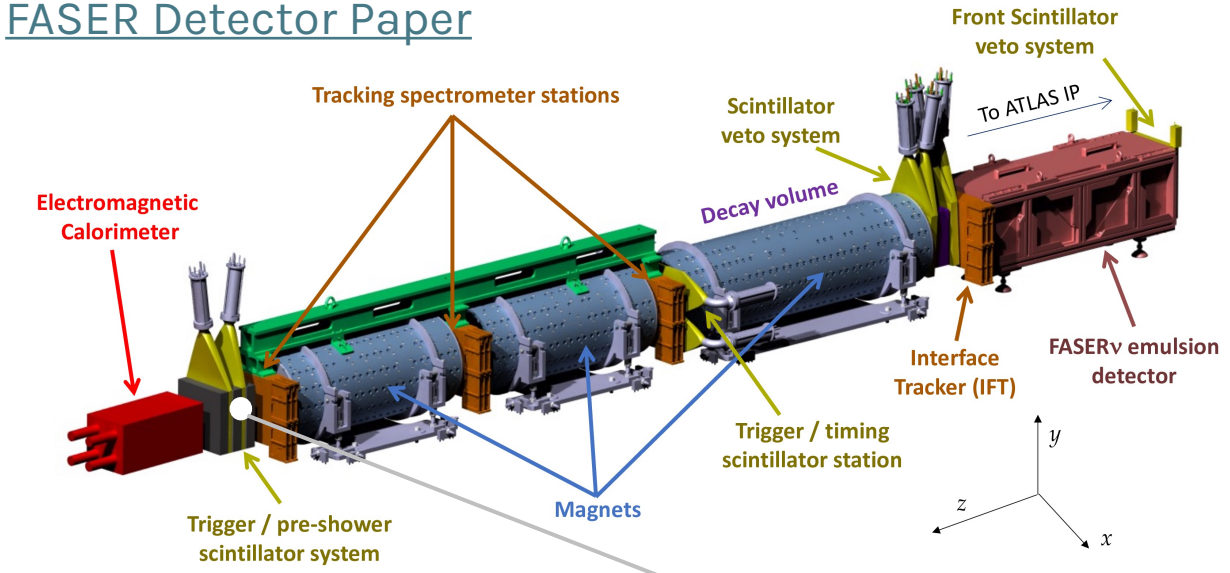
- **High** transverse momentum (p_T)
- **Strongly interacting** particles
- **Small pseudorapidity** (η)

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

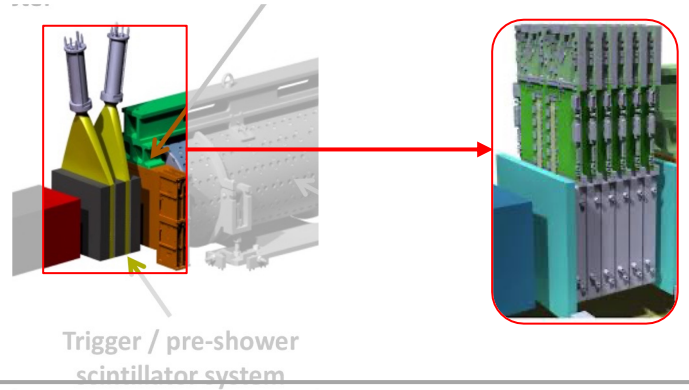
- **Low** p_T
- **Feebly interacting** particles (FIPs)
- **Large** η

FASER Detector
Overview & Operations

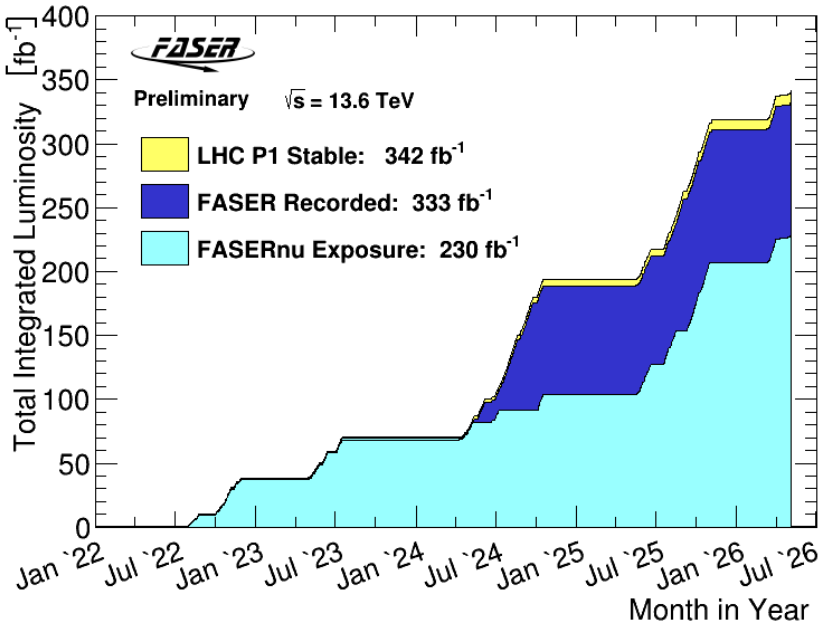
FASER Detector Paper



Winter 24/25
Preshower upgraded with pixel-based detector



OPERATIONS



- Running since start of LHC Run 3 (2022)
- 333 fb-1 Recorded
  - 97% of IP1 delivered luminosity
- Successful Run 3 operations
- Detector controlled fully remotely

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**

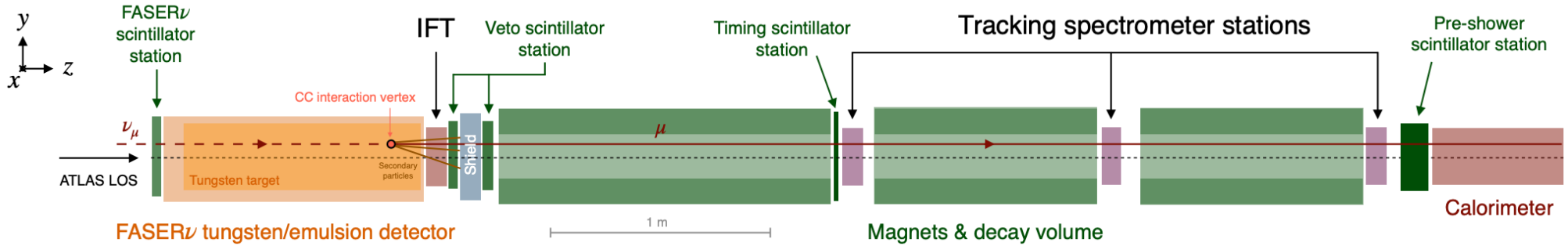
Signal

- **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

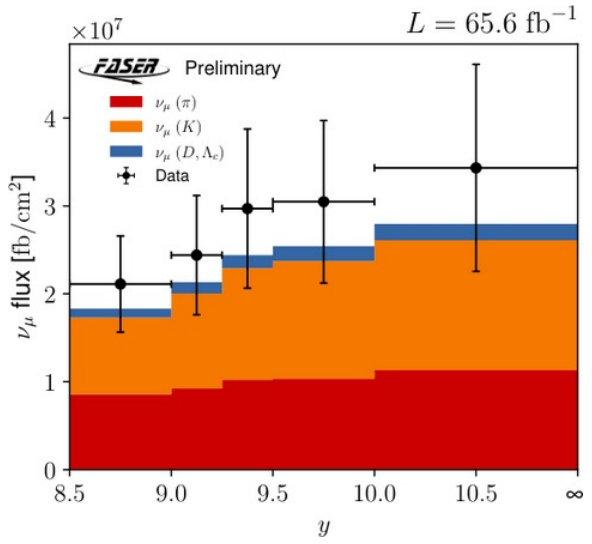
Previous measurements of ν_μ with FASER's electronic detector include:

- 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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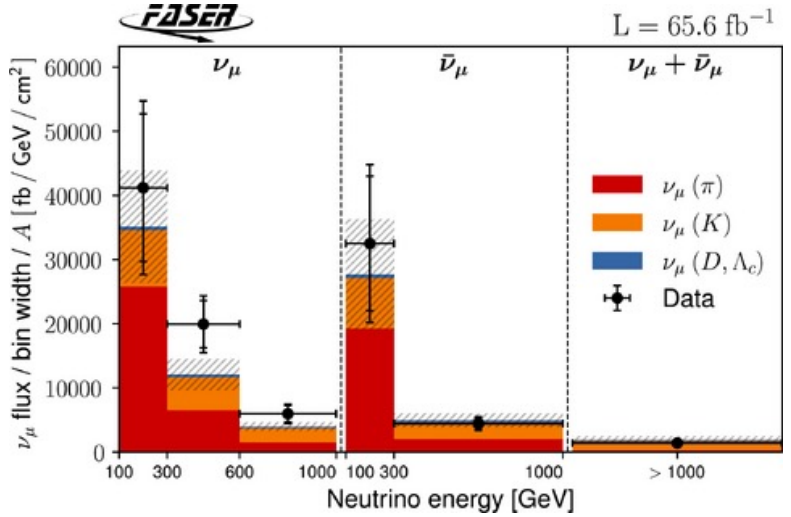
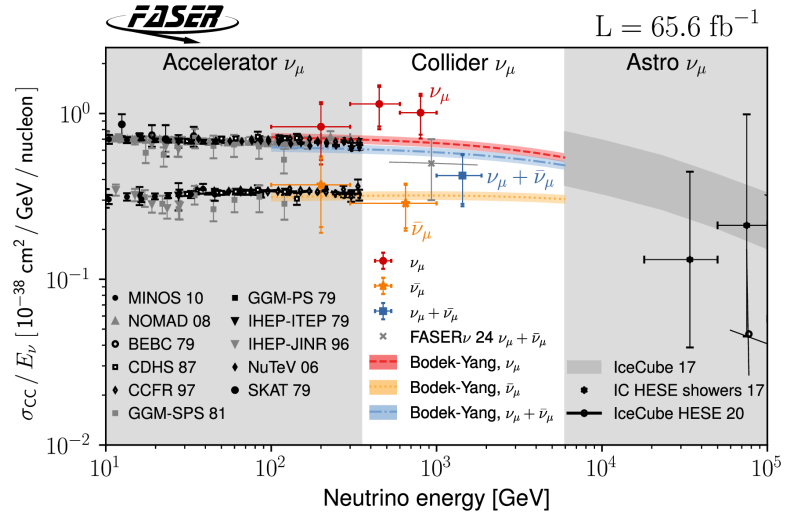
Flux and Differential Cross Section Measurement





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Muon Neutrino
Results

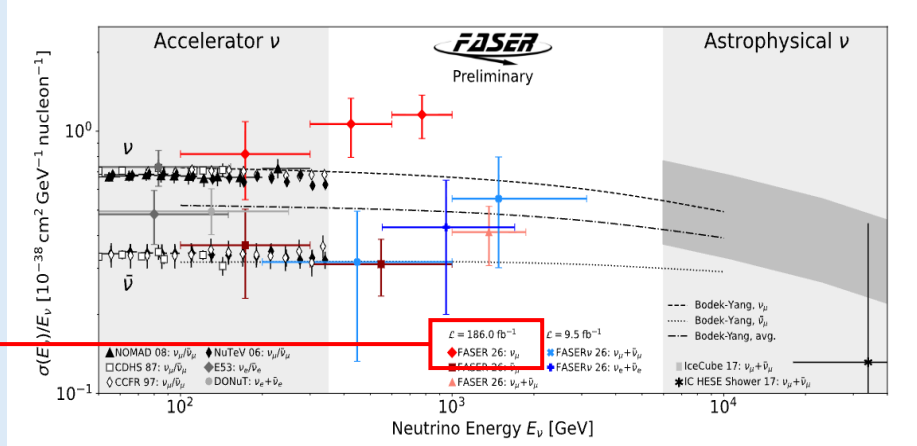
New Measurement:

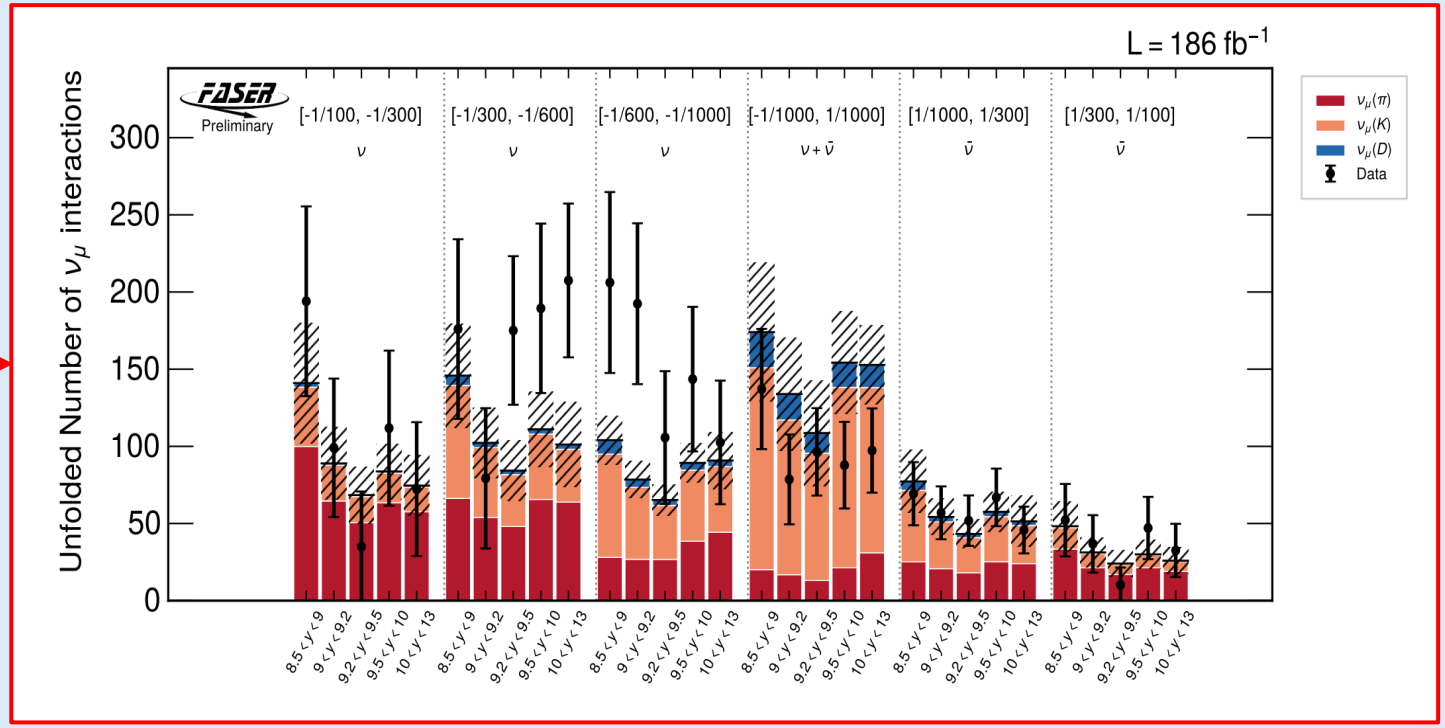
- **Combines previous measurements** to extract a double-differential cross section
- Expressed as a function of both in **energy and rapidity**

Events observed :

766.8 ± 28.7 (stat.) ± 7.3 (syst.)

Result complements and expands upon measurements taken using FASERν





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