WIN 2025

9–13 June 2025
University of Sussex, Brighton, UK

WiN 25

EM Shower Identification Reconstruction with Testbeam 2023 at the FASERν

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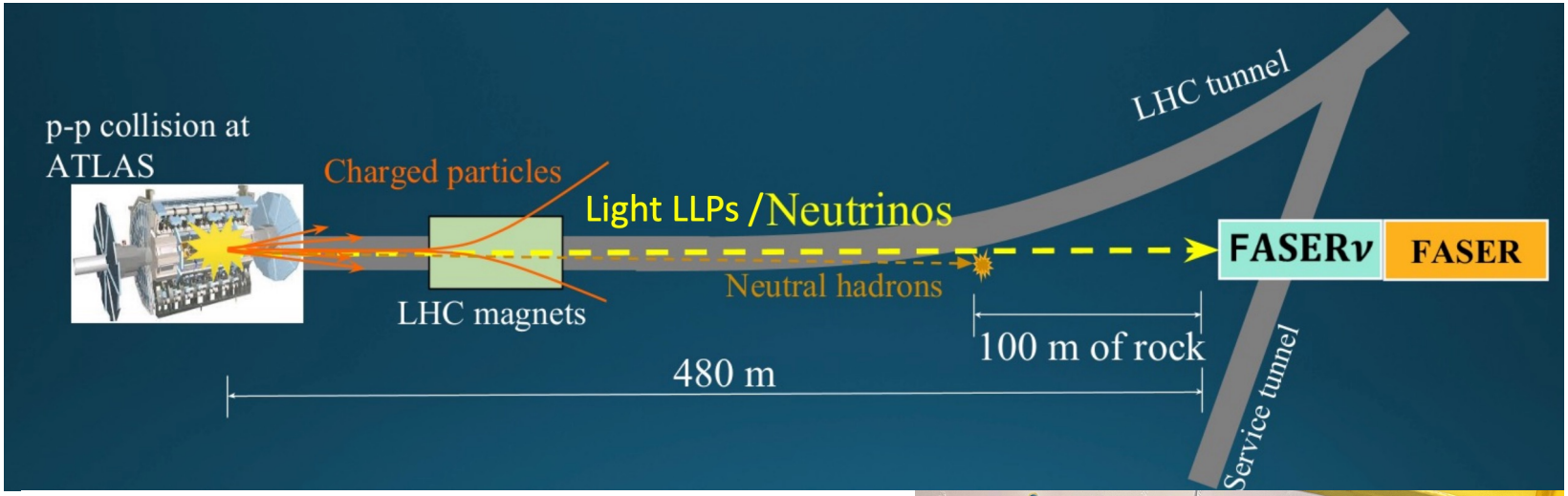
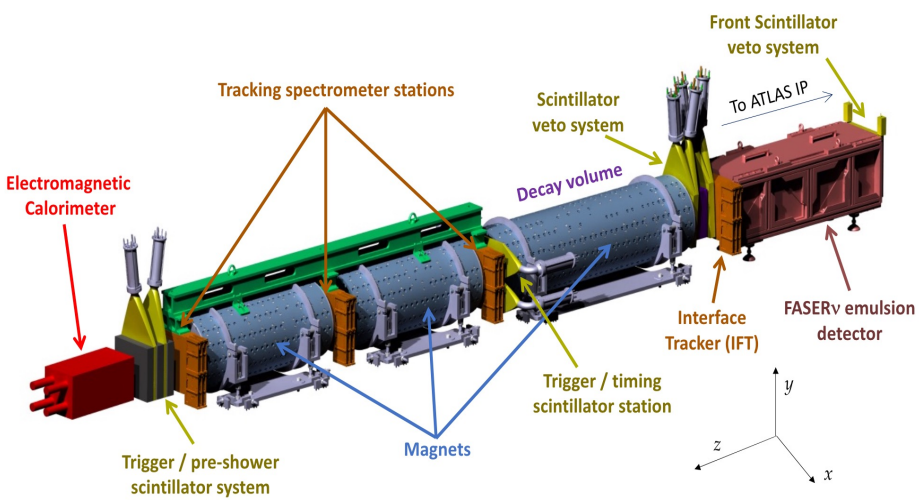
on behalf of the FASER Collaboration

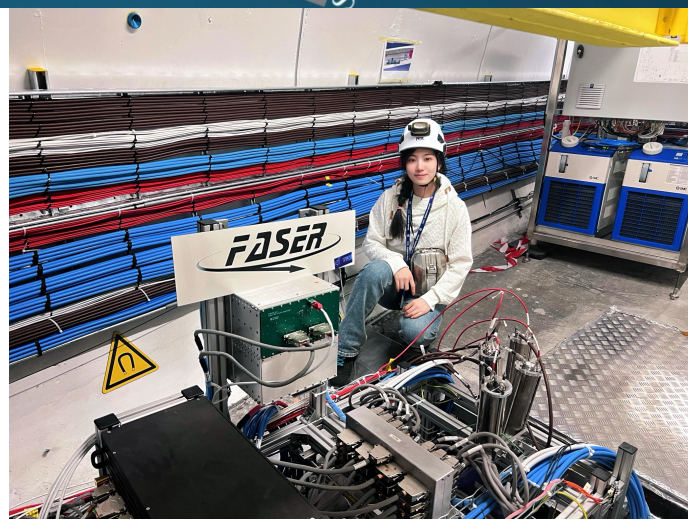
Tsinghua University

The FASER Experiment at the LHC

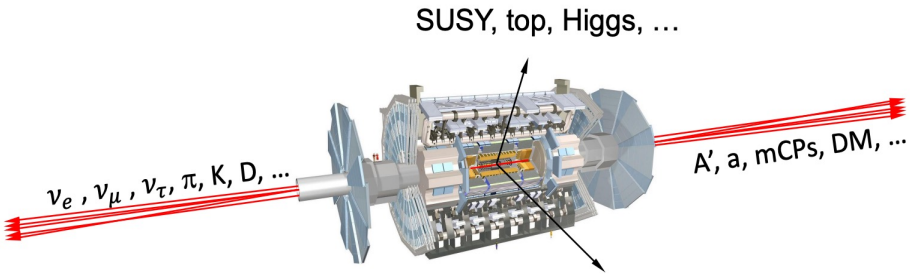
- FASER: ForwArd Search ExpeRiment





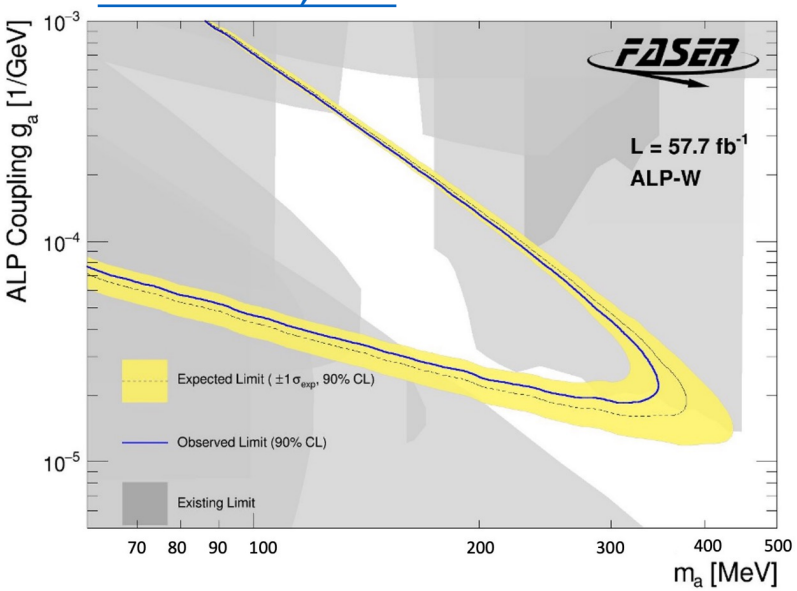


FASER Physics Targets



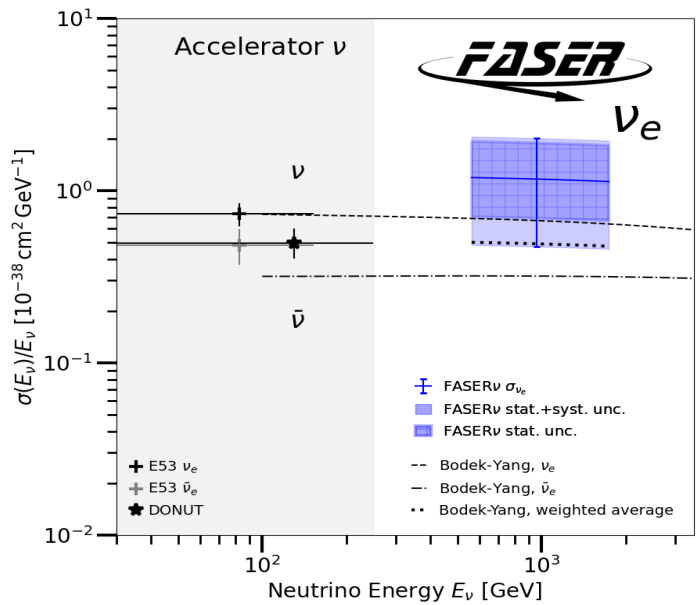
- **Explore forward physics**
  (particles in very forward region not seen by ATLAS/CMS)
- **Search for new light, long-lived particles**
  (dark photons, ALPs, etc.)

JHEP 2025, 199



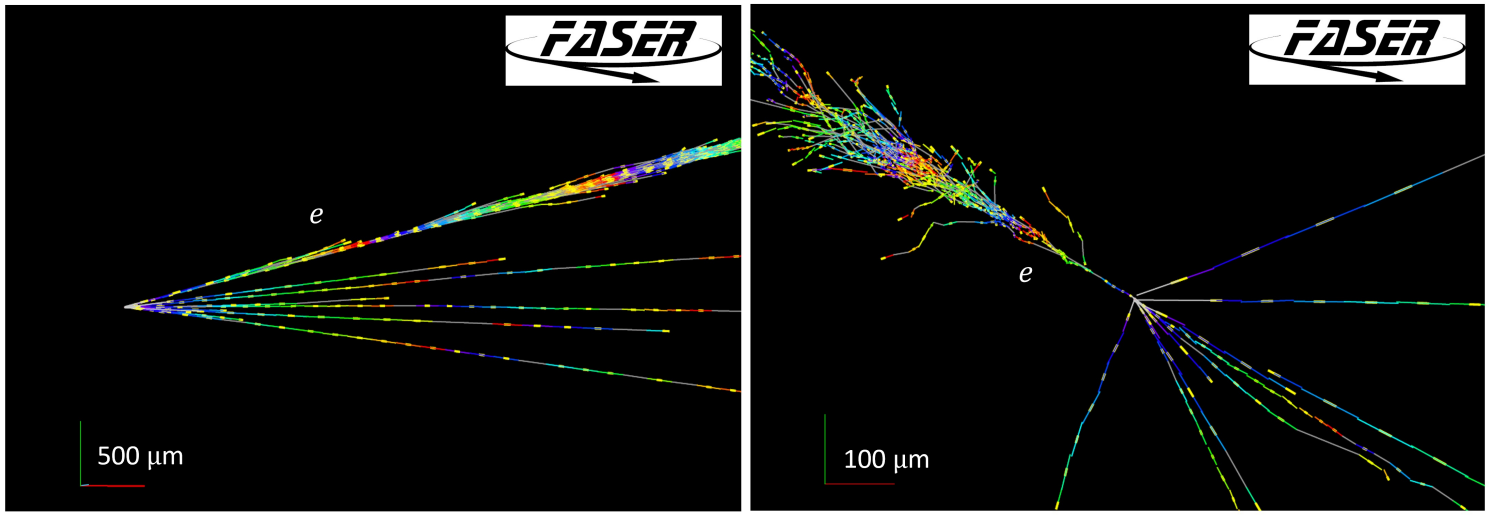
- **Detect and study collider neutrinos**
  (first-ever TeV neutrinos at LHC)

PRL 134.211801

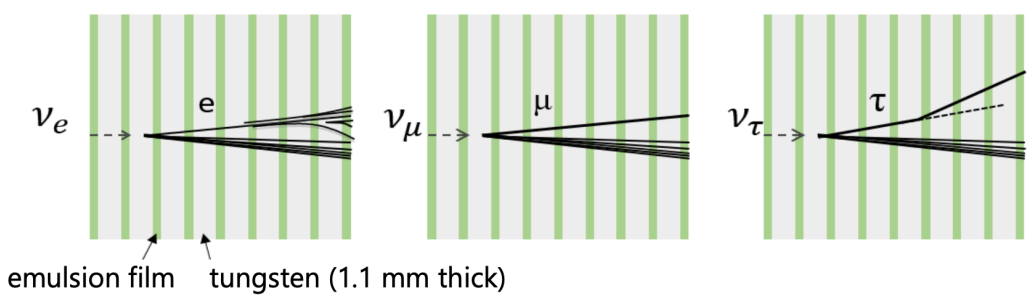


Neutrino at FASER

- First observation of collider neutrinos at the LHC (PRD 104, L091101, PRL 131, 031801).
- First Measurement of the ν_e and ν_μ Interaction Cross Sections at the LHC (PRL 133, 021802).

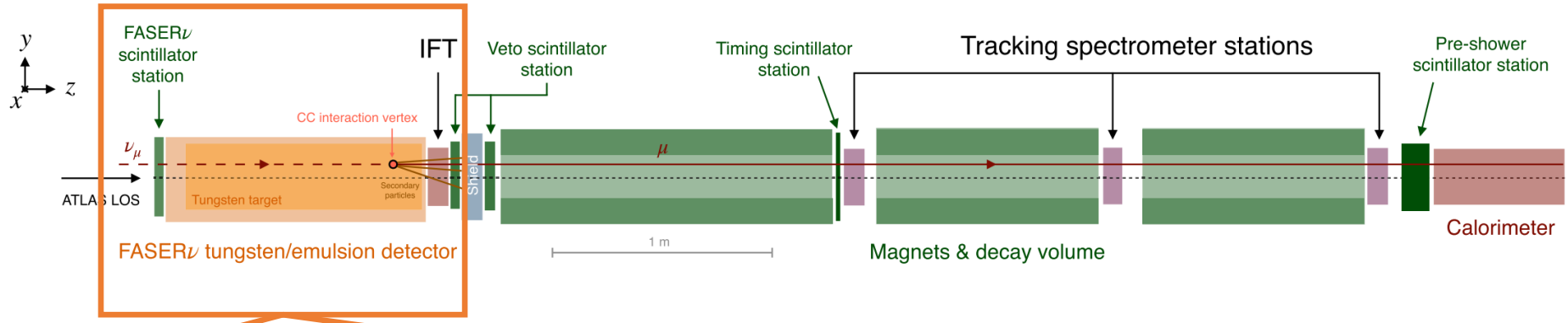


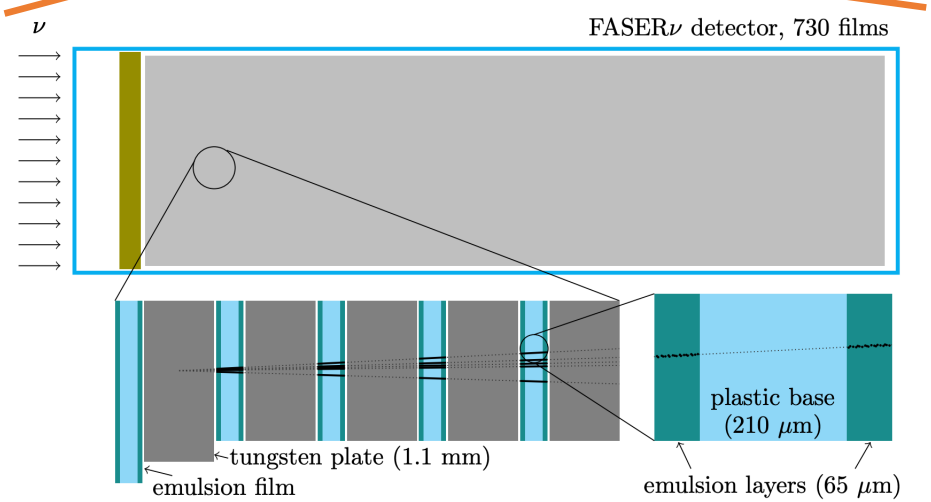
- Studies ongoing:
  - Neutrino cross-section measurements.
  - Flavor tagging: ν_e, ν_μ, ν_τ.
  - New physics: non-standard neutrino interactions.



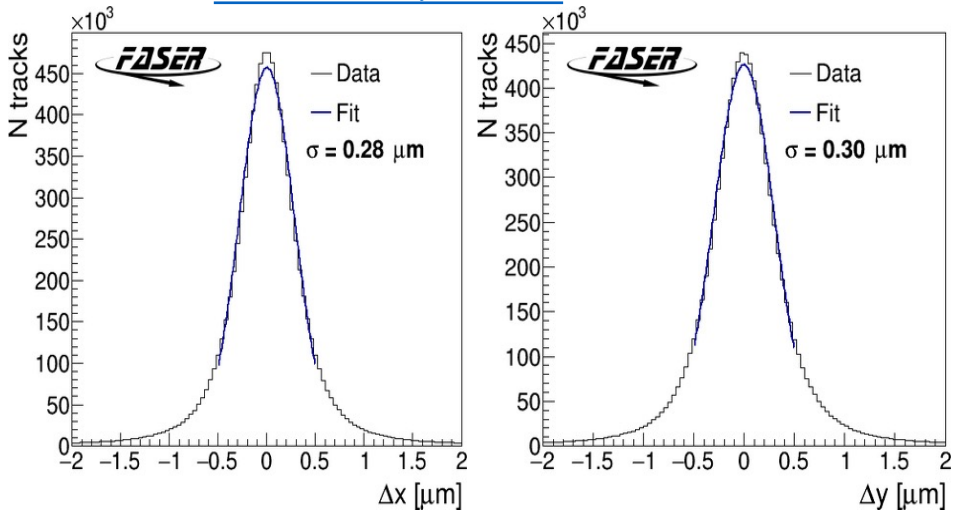
FASERν and the Emulsion Detector arXiv 2504.13008

FASERν: Dedicated neutrino detector within the FASER experiment



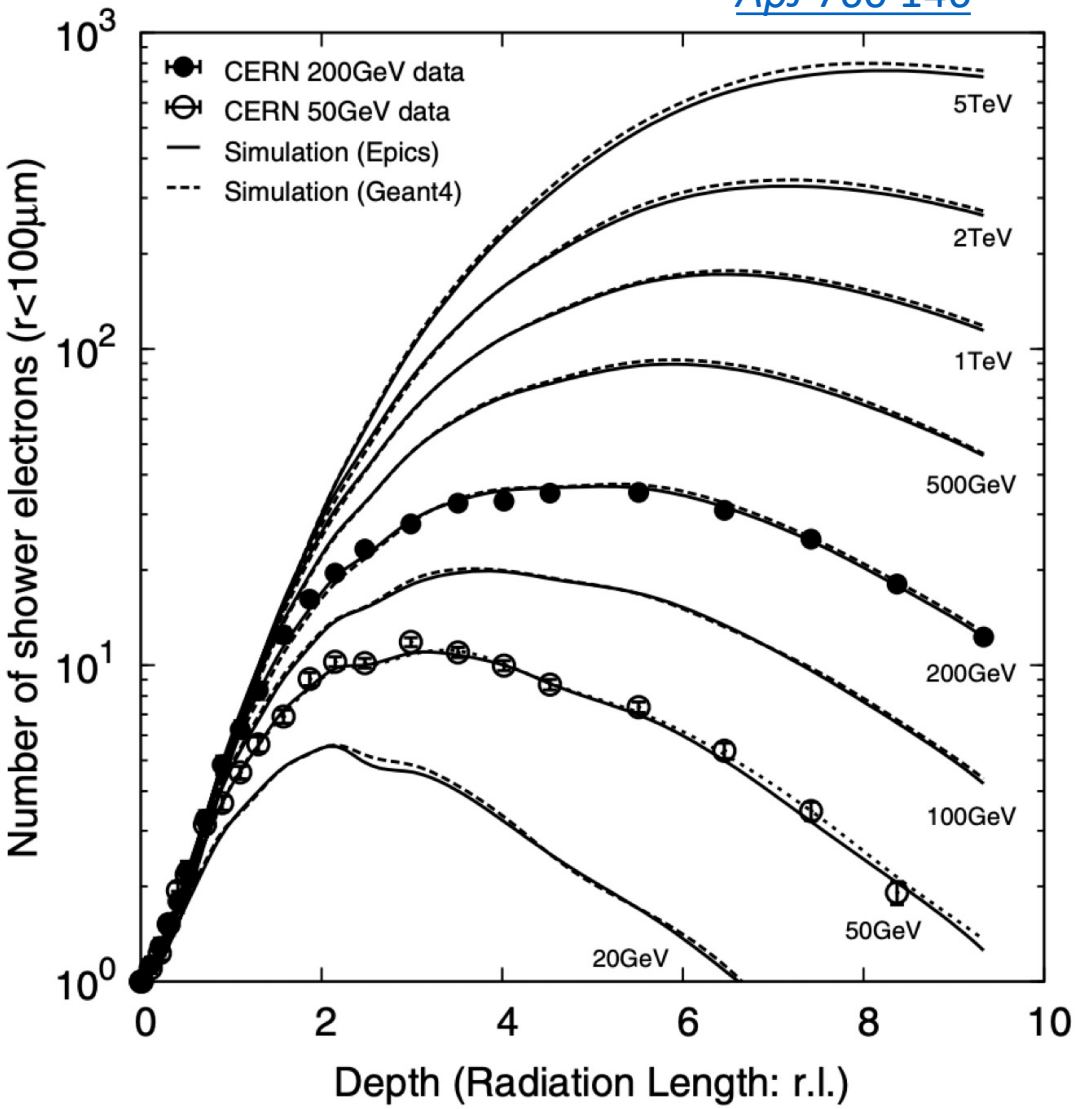


arXiv 2504, 13008

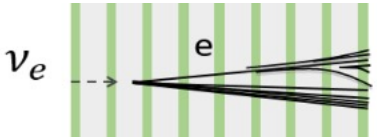


EM Shower Introduction

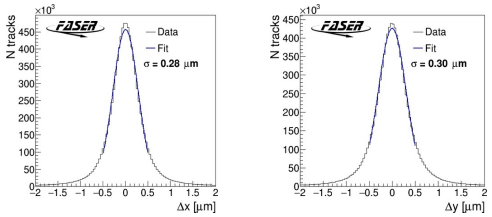
ApJ 760 146



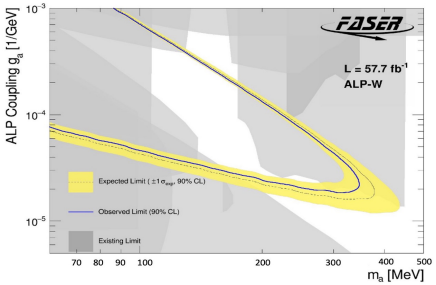
- ν_e identification studies & interaction cross section measurements



- Energy resolution & Detector performance



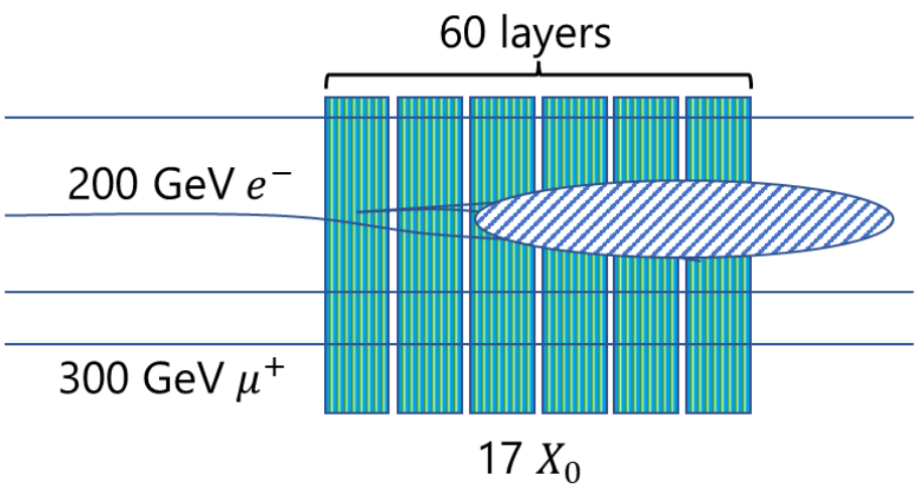
- New Physics Exploration

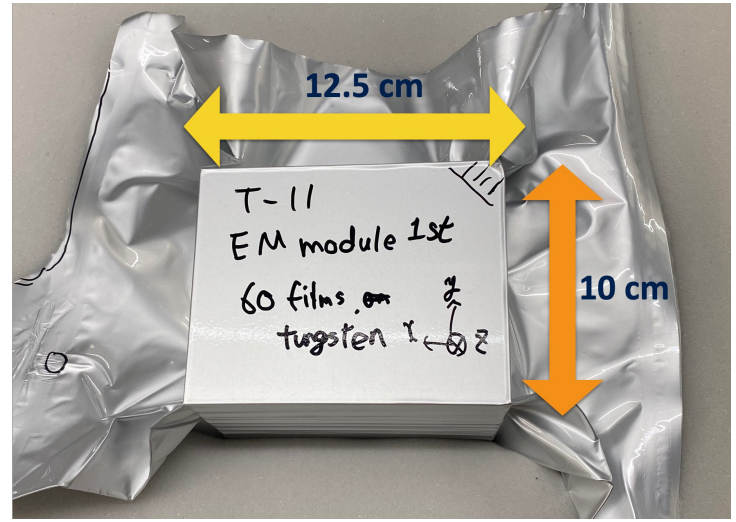


Dataset

Test beam data:

- To test the performance of electron energy reconstruction at 200 GeV
- Test beam at SPS (H4 beamline)
- 300 GeV muons injected for alignment
- Analyzed region ~ 8.6 cm × 6.6 cm, 60 layers
- Electron density ~ 8 / cm^2
- Muon density ~ 1500 / cm^2

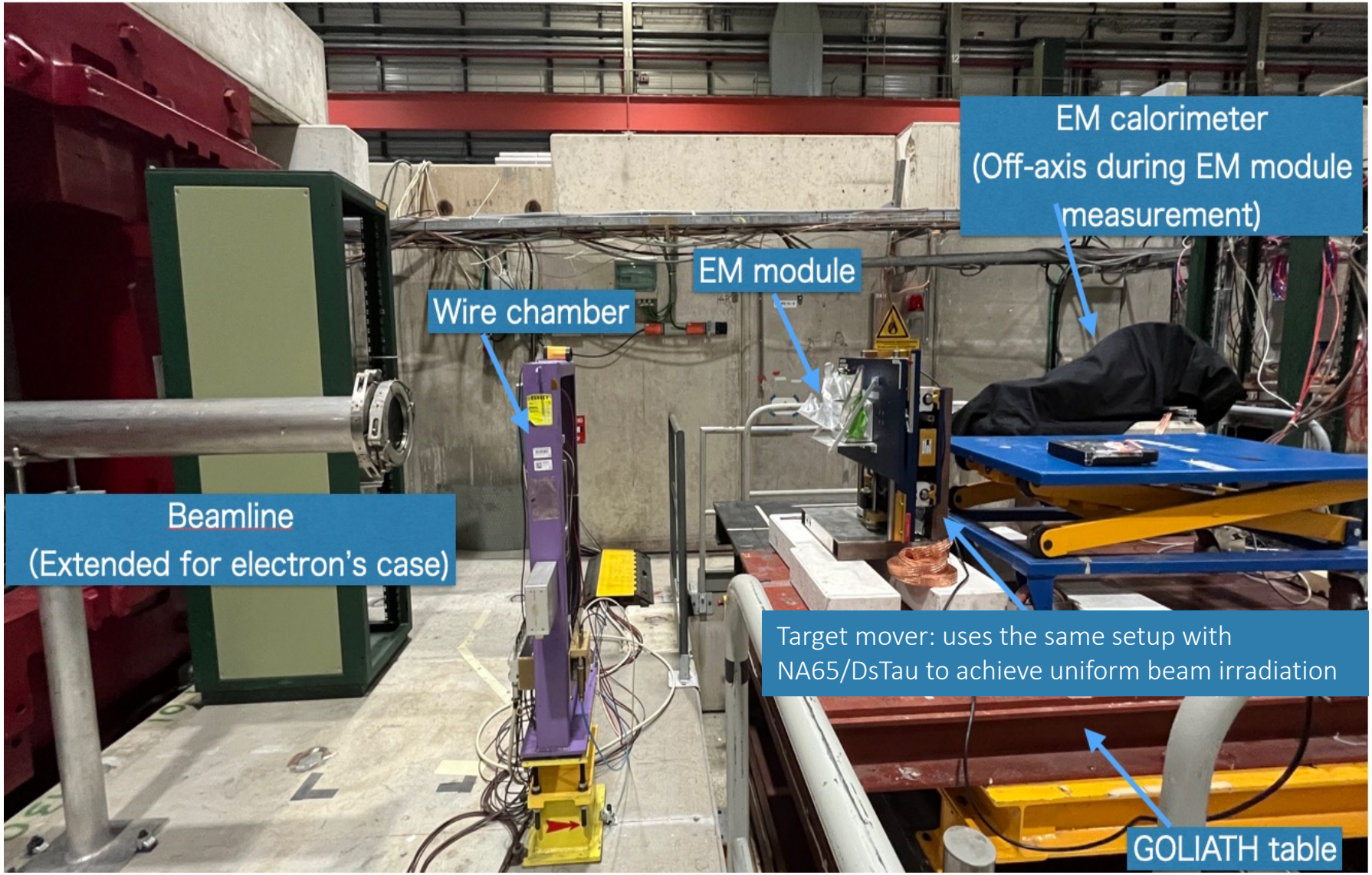




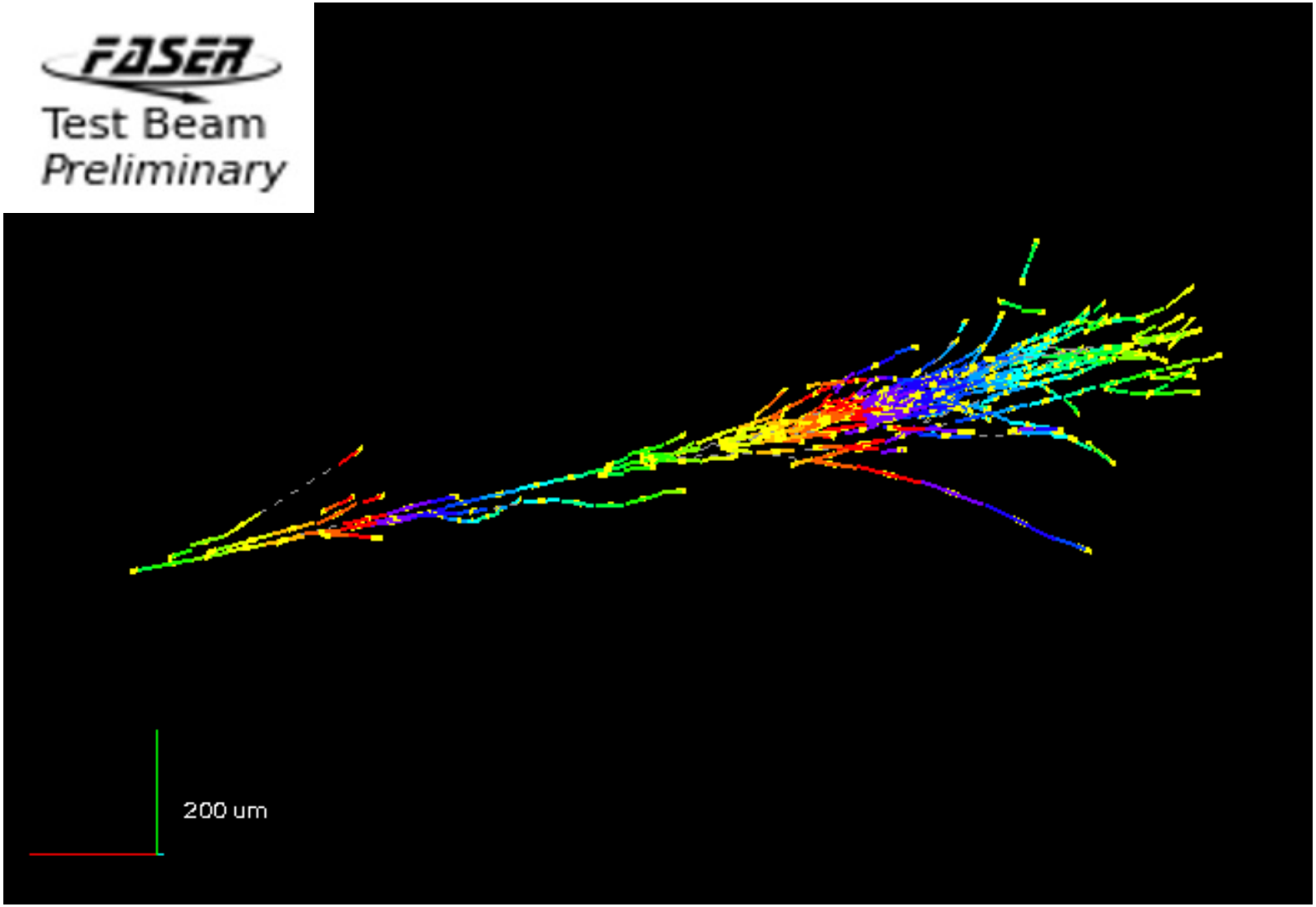
Simulations:

- ν_e CC MC sample (ν_e Charged Current)
- 200 GeV electron MC sample by GEANT4

Test Beam Setup

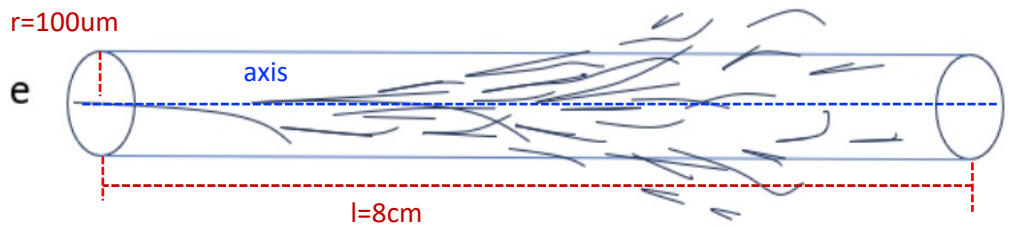


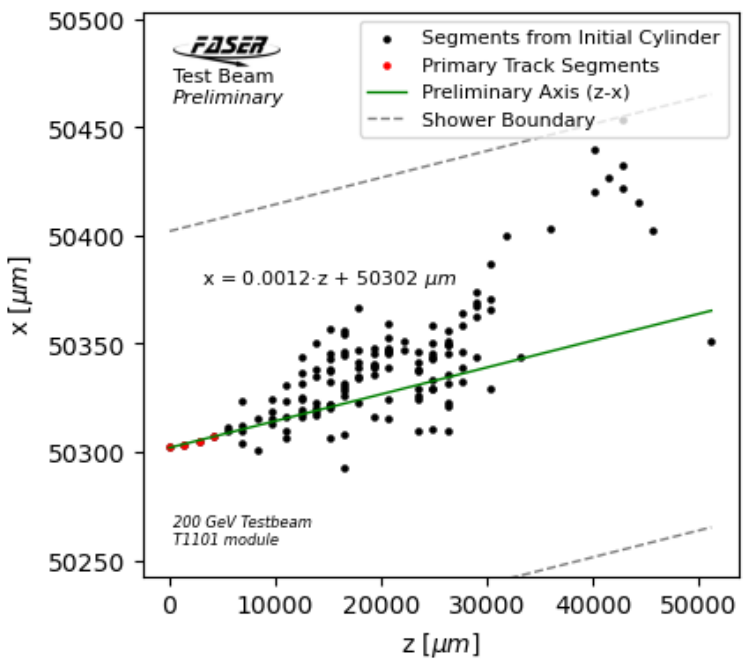
EM Shower Event Display

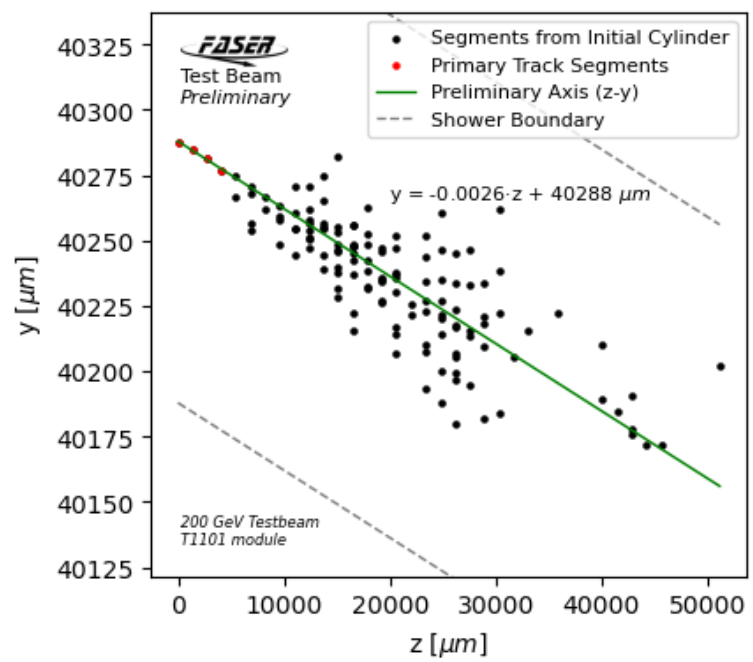


Reconstruction Algorithm

1. Select tracks starting from the 1st plate -> primary tracks
2. Use the first 4 hits in each primary track to fit an initial axis, and open a cylinder

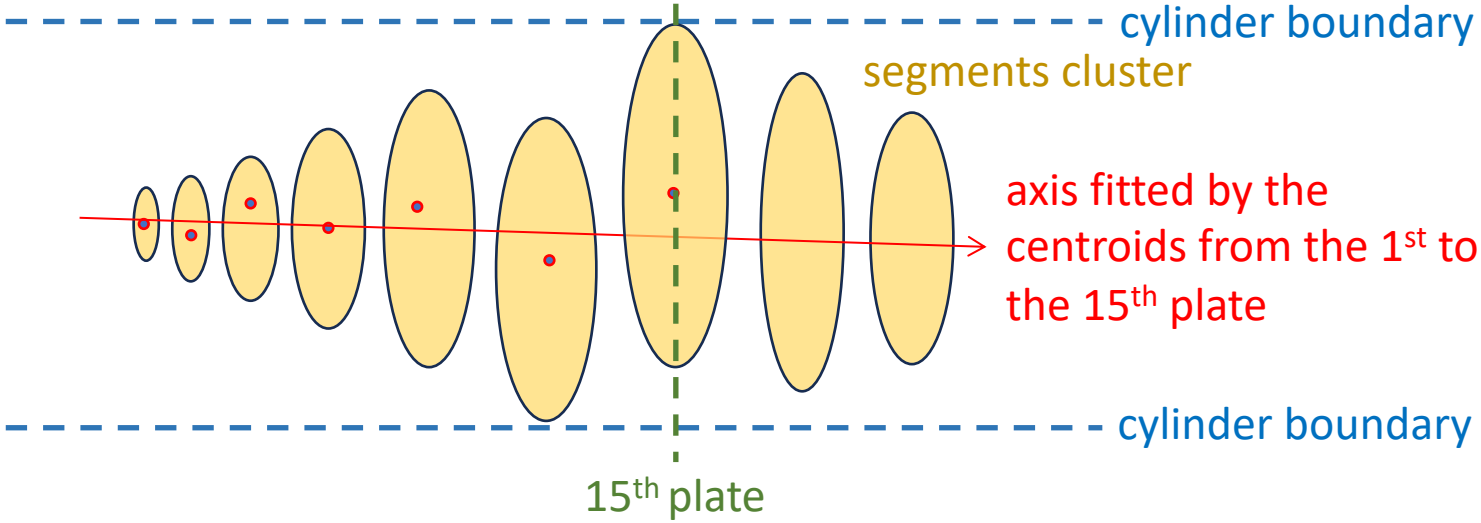




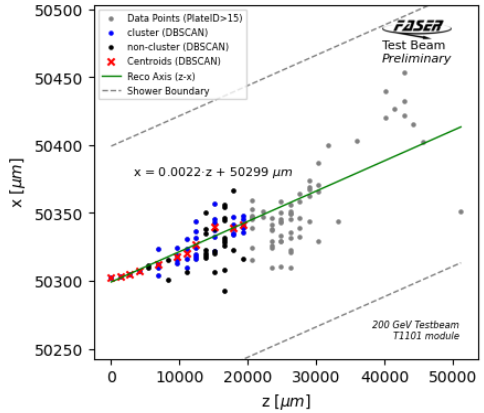


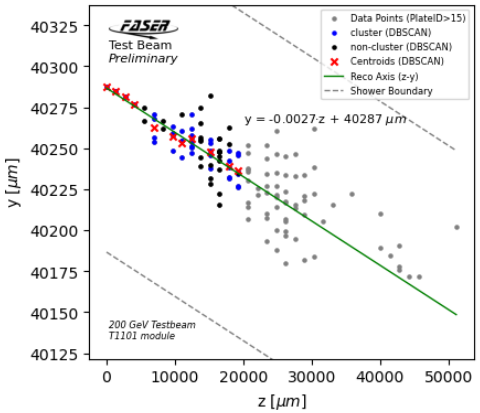
Reconstruction Algorithm

3. For each cylinder, get the shower clusters on each plate by the DBSCAN clustering algorithm.



4. For each cluster on each plate, define centroid as:
   - PlateID < 4: centroid = (mean_X (all seg), mean_Y (all seg))
   - PlateID >= 4: centroid = (mean_X (seg in cluster), mean_Y (seg in cluster))





Reconstruction Algorithm

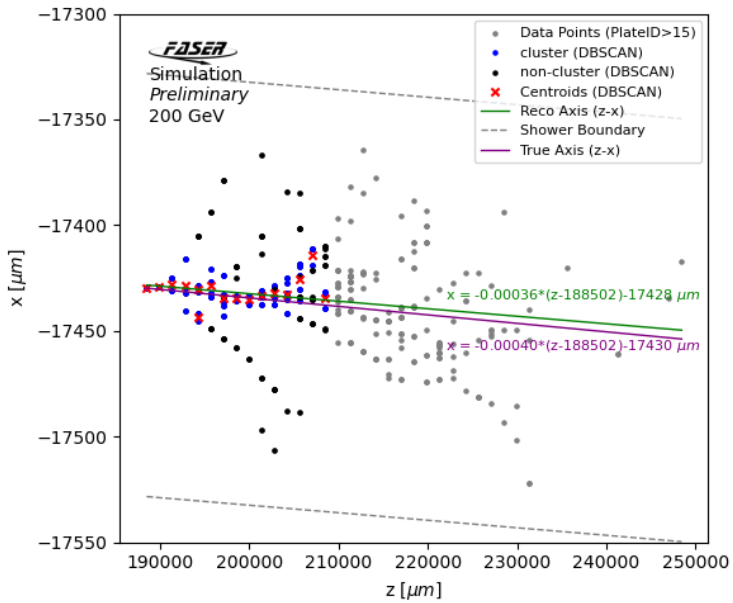
5. Do a robust fit on all the centroids and get the re-fitted axis.

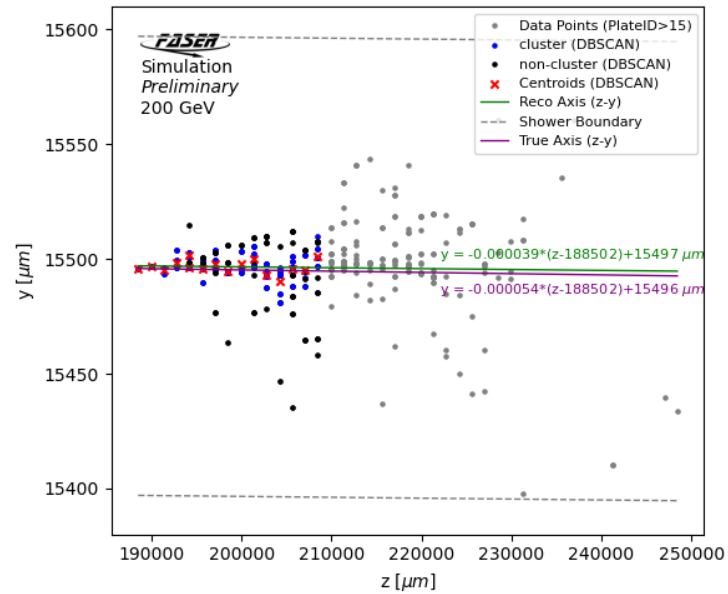
$x - x_0\ [\mu m] = \tan\theta_{xz} \cdot (z - z_0)\ [\mu m]$

- Truth axis:
  $\tan\theta_{xz} = -0.00040, x_0 = -17430\ \mu m$
- Reco axis:
  $\tan\theta_{xz} = -0.00036, x_0 = -17428\ \mu m$

$y - y_0\ [\mu m] = \tan\theta_{yz} \cdot (z - z_0)\ [\mu m]$

- Truth axis:
  $\tan\theta_{yz} = -0.00054, y_0 = 15496\ \mu m$
- Reco axis:
  $\tan\theta_{yz} = -0.00036, y_0 = 15497\ \mu m$





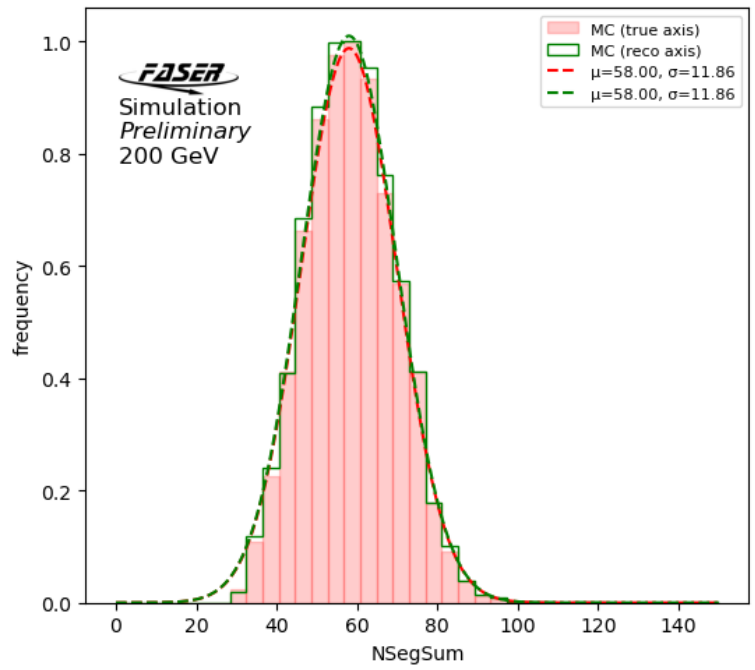
6. Along this axis, from the initial segment, re-open a cylinder.

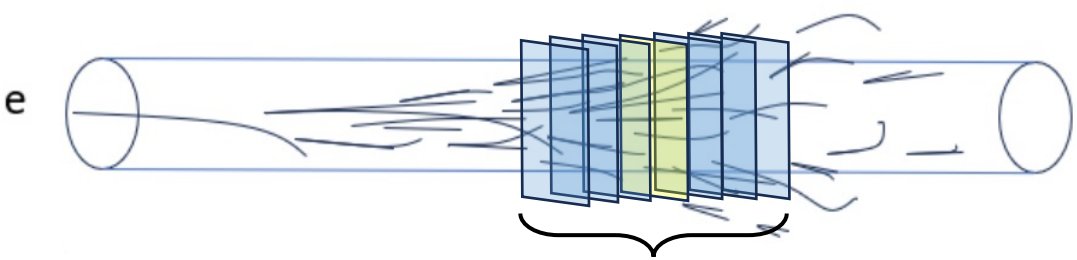
7. The segments inside the reconstructed cylinder are seen as shower.

EM Shower Identification

Crucial Shower Variables

- Shower Max: Highest segment count on any plate in the shower
- Shower Max PlateID: Plate ID where Shower Max occurs.
- NSegSum: Total segments on 7 plates centered at Shower Max PlateID (±3 plates).





NSegSum: sum of segments on 7 layers around the shower max

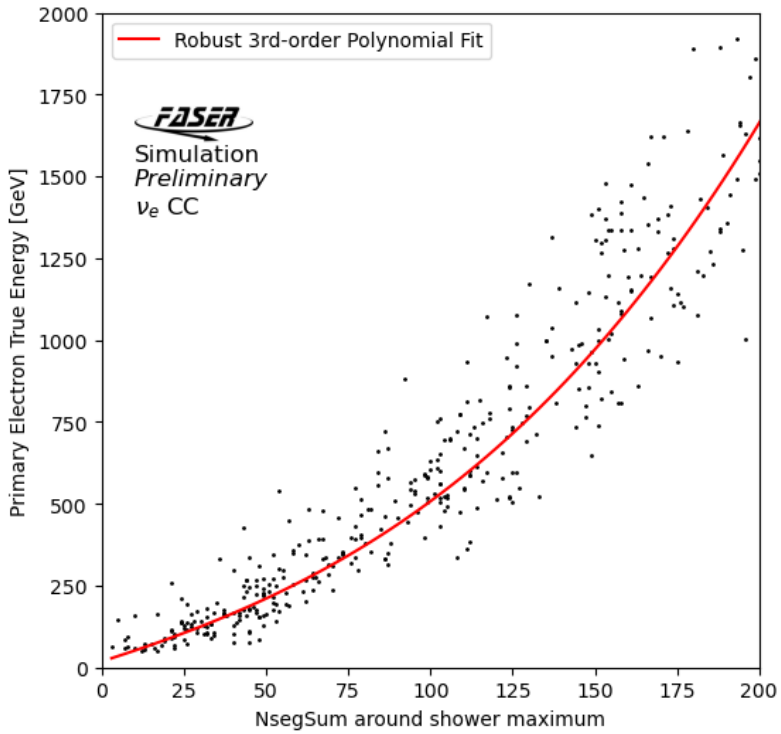
200 GeV EM Shower Identification:

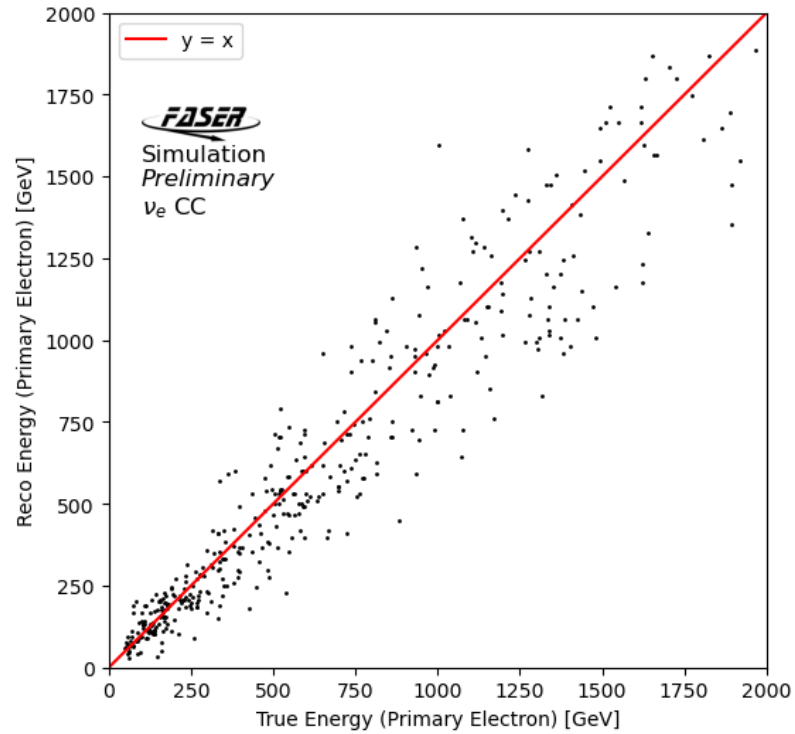
- NSegSum > 30
- Shower Max > 5
- Shower Max PlateID in (7, 32)

Energy Estimation

- Estimated by the ν_e CC simulation sample
- The optimal energy estimator: NSegSum (Total segments on 7 plates around shower max)
- Reconstructed energy (E_{rec}) vs NSegSum (S) is modelled by

$$E_{rec} = 18.7 + 3.20 \cdot S + 0.0087 \cdot S^2 + 0.0000821 \cdot S^3$$





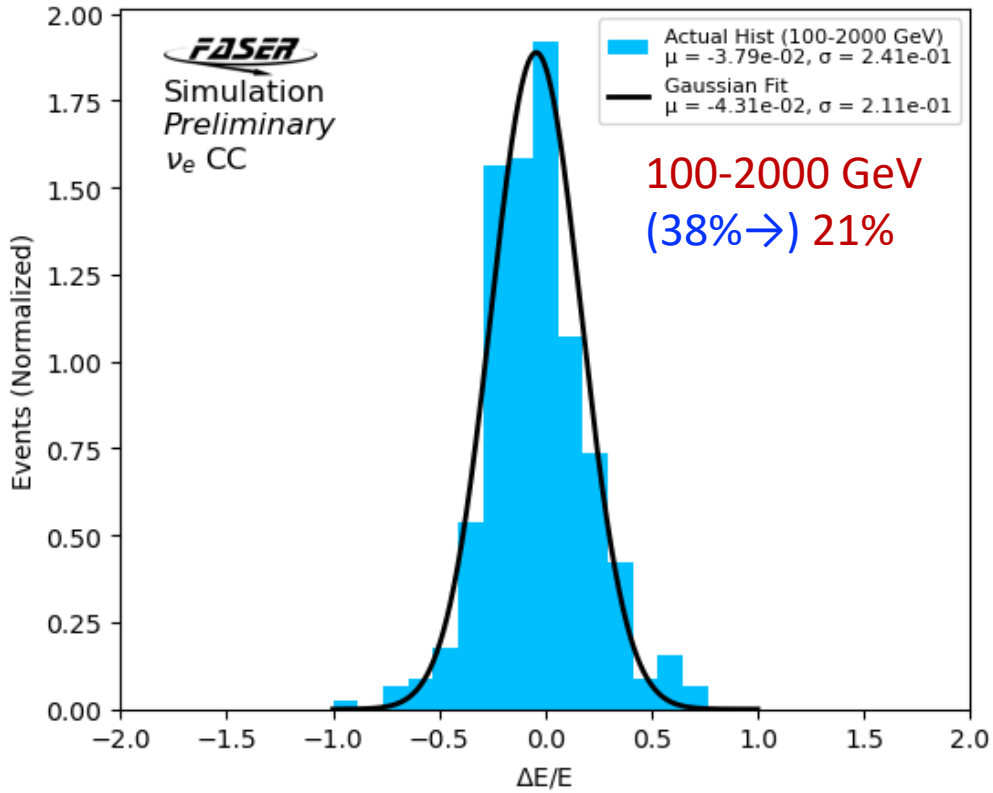
Energy Resolution

- Estimated by the ν_e CC simulation sample
- Relative uncertainty (ε_R) from reconstruction

$$\varepsilon_R = \frac{E_{rec} - E_{true}}{E_{true}}$$

where E_{rec} is reconstructed energy, E_{true} is the truth energy

- Energy resolution $\sigma_E = \sigma(\varepsilon_R) = \sigma((E_{rec} - E_{true})/E_{true})$



Conclusion

FASER and FASERν at the LHC

- Forward physics program dedicated to high-energy neutrino detection and searches for BSM signatures (ALPs, dark photons).

First high-precision EM shower axis reconstruction in FASERν emulsion detector

- Cylinder-plus-DBSCAN algorithm achieves angular alignment with truth within $< 4\times10^{-4}$ rad

Robust electron energy estimator for high-energy electrons

- Estimator based on NSegSum provides 21% energy resolution for electrons (100-2000 GeV).
- Performance sufficient for neutrino energy reconstruction at the 30%-35% level

Physics Impact

- Enables precision ν_e cross-section measurements.
- Boosts sensitivity to BSM physics signatures (ALPs, dark photons).

FASER Acknowledgement

- FASER is supported by:

HEISING-SIMONS FOUNDATION
SIMONS FOUNDATION
CERN
erc
科研費 KAKENHI
NSF
Swiss National Science Foundation

- 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

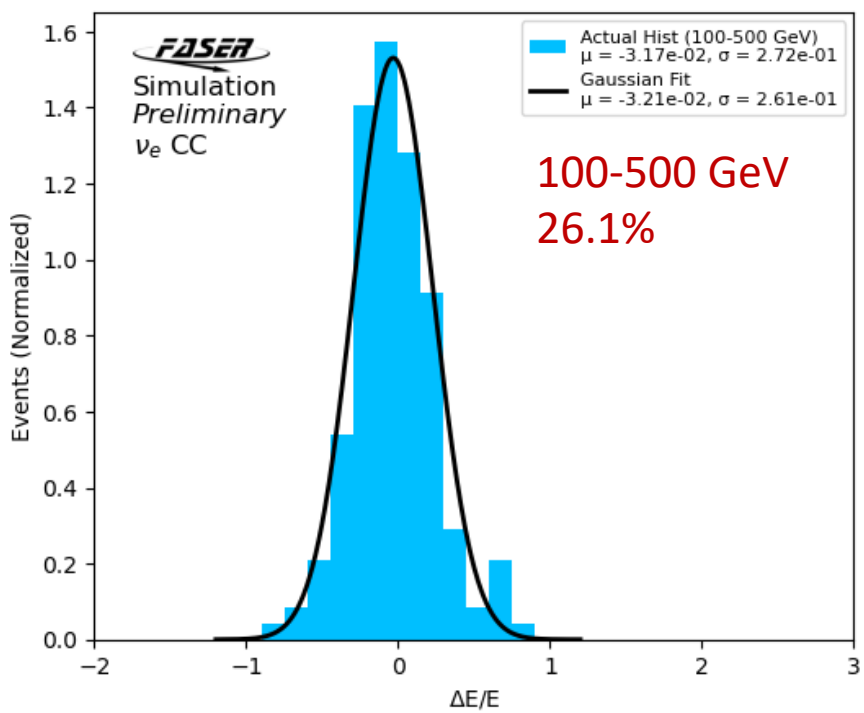
THANKS!

BACKUP

Energy Resolution

- Estimated by the ν_e CC simulation sample
- Relative uncertainty (ε_R) from reconstruction

$$\varepsilon_R = \frac{E_{rec} - E_{true}}{E_{true}}$$

where E_{rec} is reconstructed energy, E_{true} is the truth energy

- Energy resolution $\sigma_E = \sigma(\varepsilon_R) = \sigma((E_{rec} - E_{true})/E_{true})$