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Performance of the FASER tracker using testbeam data

June 23rd 2022
10th Beam Telescopes and Test Beams Workshop

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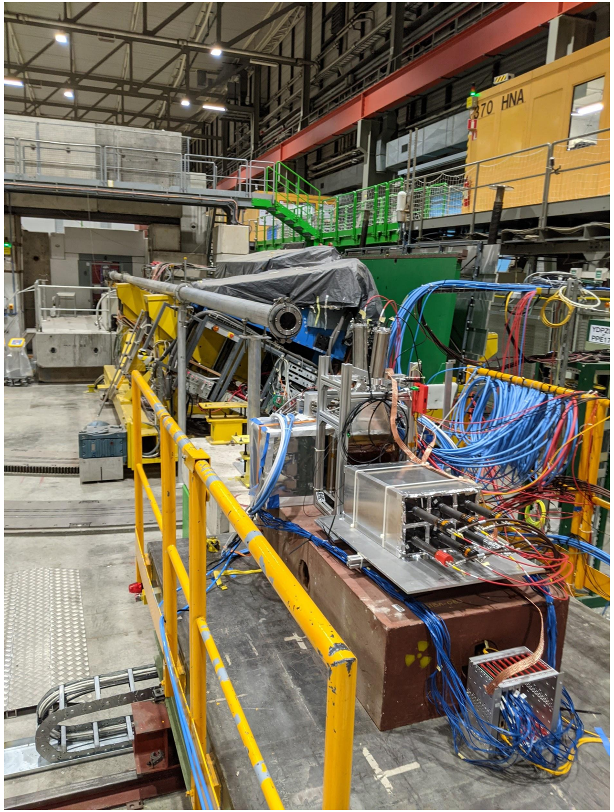
on behalf of the FASER collaboration

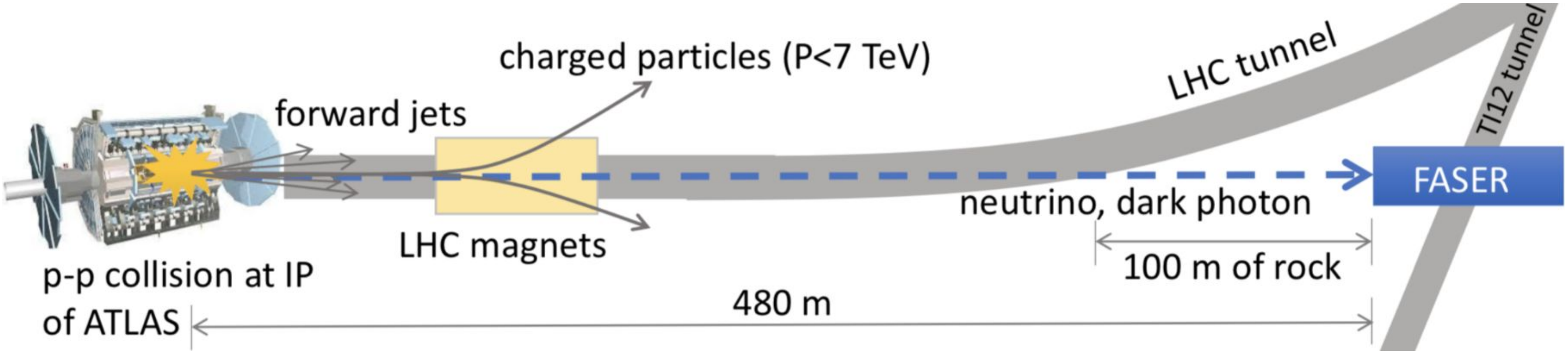
UNIVERSITÄT BONN



The FASER Experiment

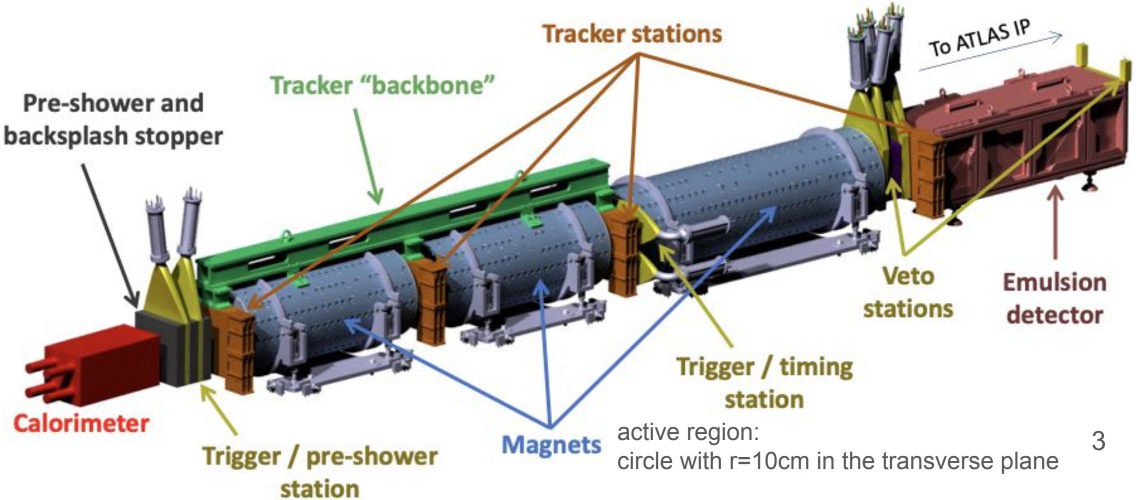
77 collaborators,
21 institutions,
9 countries

- FASER is a small experiment at the LHC and …
  - … located 480m from IP1, in the line-of-sight and low p_T spot of ATLAS.
  - … most backgrounds are greatly reduced by accelerator magnets and ~100m rock shielding.
  - … will take data during LHC Run-3 (2022-2024).
- FASER targets light, weakly-coupled new particles at low pT
- FASERν targets the measurement of neutrinos produced in pp collisions.



The FASER Experiment

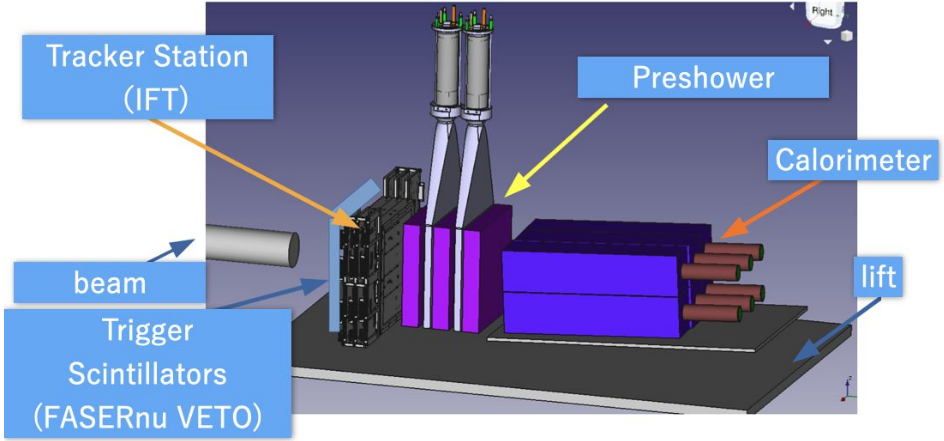
- Three 0.55 T permanent dipole magnets to separate charged particles from LLP decays.
- Veto, timing, and pre-shower scintillator stations to ensure LLPs decay inside of the decay volume or emulsion detector and triggering.
- Three tracking stations and an interface tracker to measure position and momenta of charged particles. [https://arxiv.org/abs/2112.01116]
- Electromagnetic calorimeter to measure particle energy and discriminate electrons from muons and triggering
- Tungsten/emulsion detector to detect all three neutrino flavors.
- Trigger with an expected rate of 500-1000 Hz, dominated by muons originating from collision in IP1. [https://arxiv.org/abs/2110.15186]

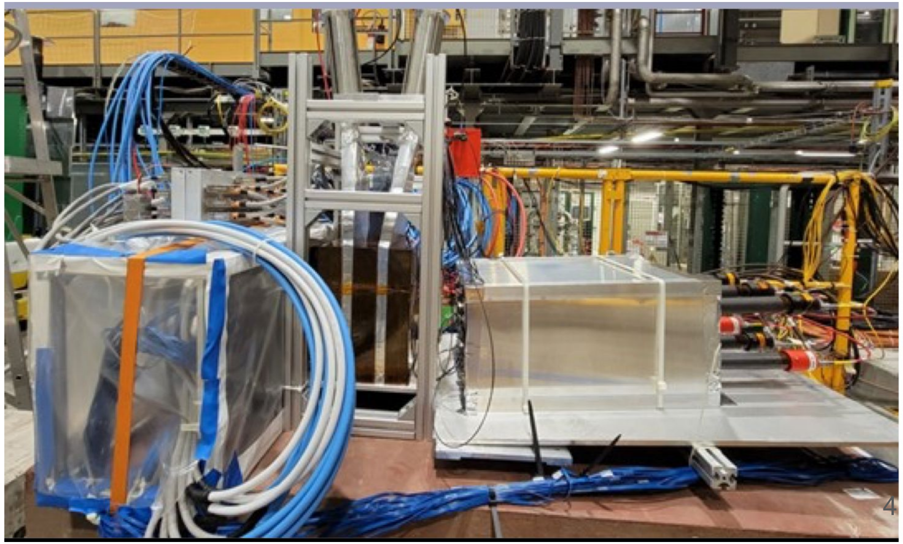


active region:
circle with r=10cm in the transverse plane

The 2021 FASER Test Beam

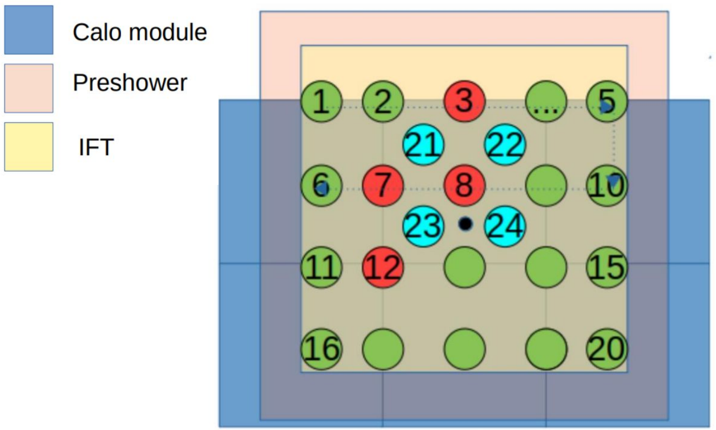
- CERN H2 beam line 28th July - 4th August 2021
- Purpose: energy calibration of preshower and calorimeter and check the performance of the detector
- Set up: two trigger scintillators, 3-layer tracker station, preshower and 6 calorimeter modules
- Tracker station used as telescope for the calorimeter measurements, but we also use the data to characterize the tracker

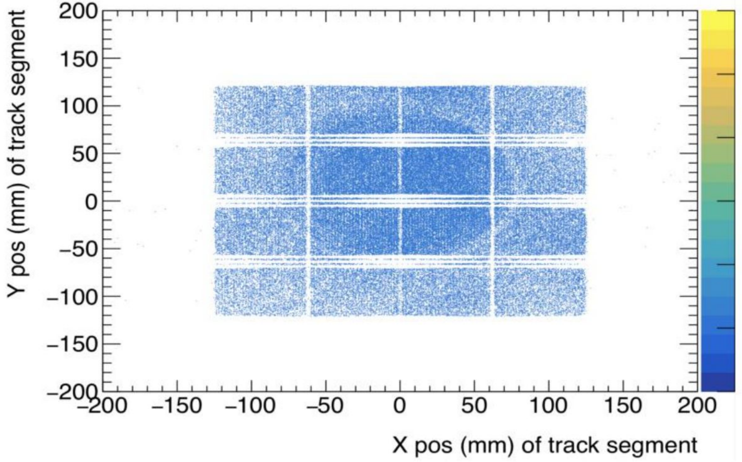




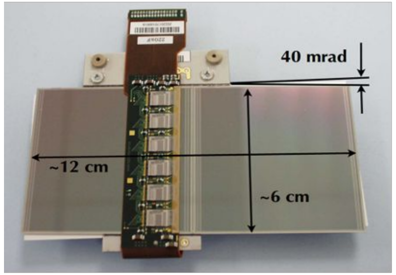
The 2021 FASER Test Beam

- Over 150 million events (1.8 TB) recorded
  - 24 individual spatial points of the detector
  - Different beam settings:
    - Electron: 5-300 GeV
      (primarily 30, 75 and 200 GeV)
    - Muon: 200 GeV, large beam size >5cm
    - Pion: 200 GeV
  - Various settings for the detector
    - Low, medium, and high PMT calo gain
      O(10^3) to O(10^^6)
    - Removal of optical filters in the calo
    - Removal of preshower material
- Today: Focus on Tracker and Preshower
- Studies are ongoing and everything shown today is preliminary and a work in progress…

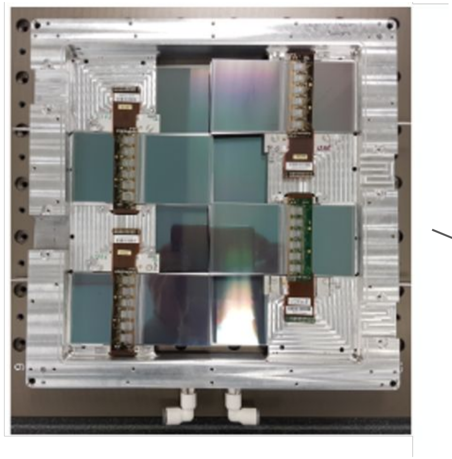




Tracker



8x



3x

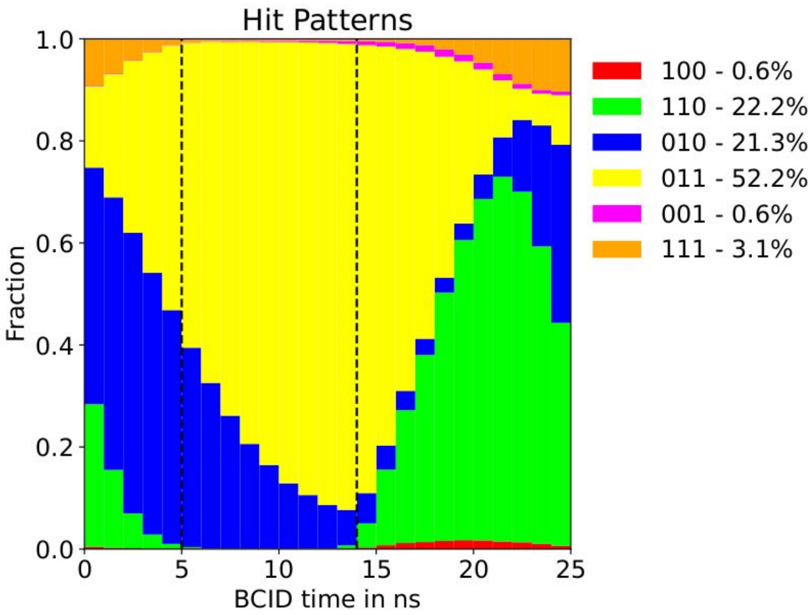
- spare ATLAS SCT modules
- 768 strips/layer, 80μm pitch
- 2 sensors layers w/ 40mrad stereo angle
  - ~17μm / 560μm resolution
  - 12 chips/module
- 2x4 modules per detector plane, 24x24cm^2 surface
- 3 planes per station

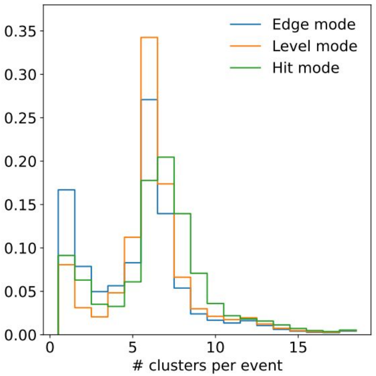
Tracker Readout

- Tracker reads out 3 bins of 25ns
- The test beam particles are asynchronous to the 40 MHz clock we used for the tracker
- We measure the arrival time with respect to the clock (BCID time) with the preshower scintillators

Tracker - Hit Modes and Patterns

- For BCID time between 5ns and 14ns, we almost exclusively see hit patterns 010 (20.6%) and 011 (78.6%)
- Hit pattern depends on the timing, but we see we can find a good timing window
- For real LHC beam particles the intrinsic time spread is only O(200ps) → optimal window can be found “easily”





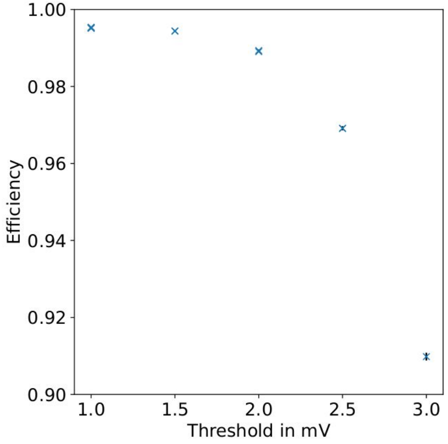
XXX	X1X	01X
Hit Mode	Level Mode	Edge Mode
7.12	6.77	5.86

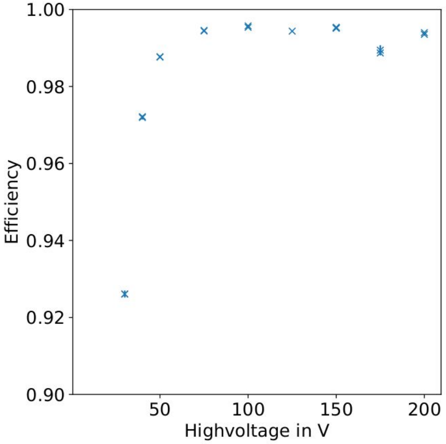
Tracker - Hit Efficiency

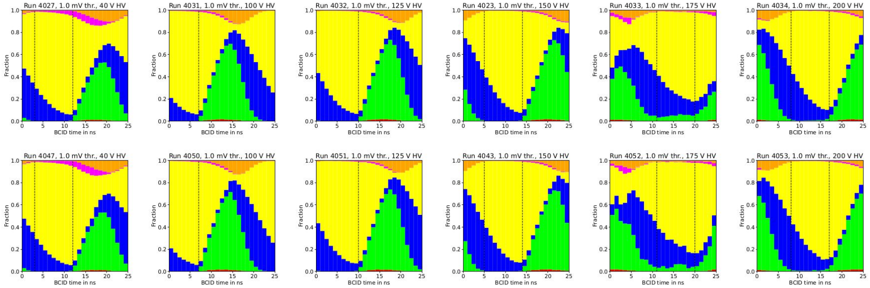
- Hit efficiency: Probability to find an additional strip with a distance smaller than 1.5 mm to the expected position when we create a track segment with the other five modules:
- Measured efficiency ϵ = (99.796 +- 0.006)%
- MC efficiency ϵ = 99.94 %
- ATLAS measured efficiency ϵ = (99.36 +- 0.42)%

Tracker - Voltage Dependence

- Lower thresholds lead to >50 hits
- BCID time / hit patterns and high voltage are correlated!
- No correlation with threshold
- Smaller efficiency for 175 V since hits with 110 hit pattern are missing
- Optimal time window moves (not the BCID time)

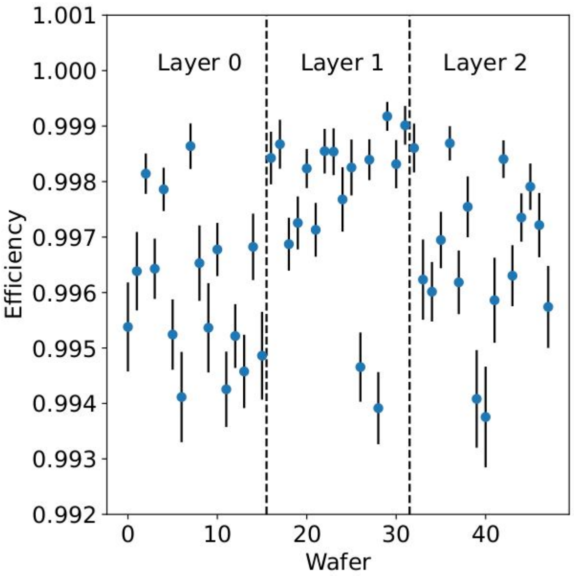


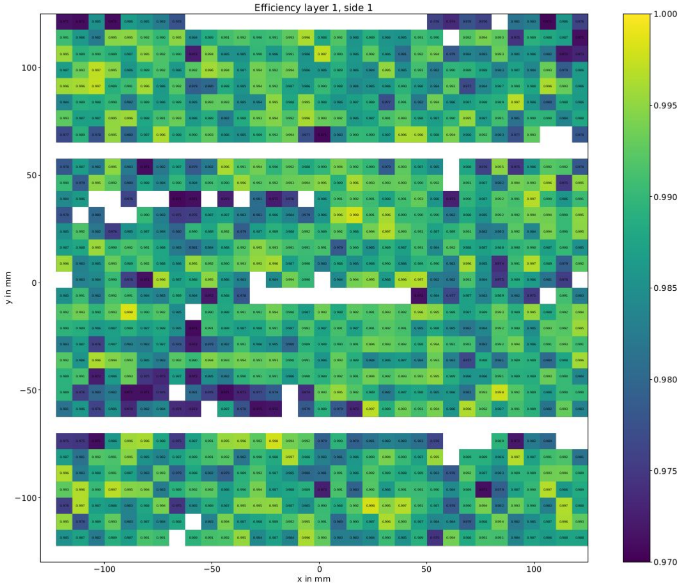




Tracker - Module Efficiency

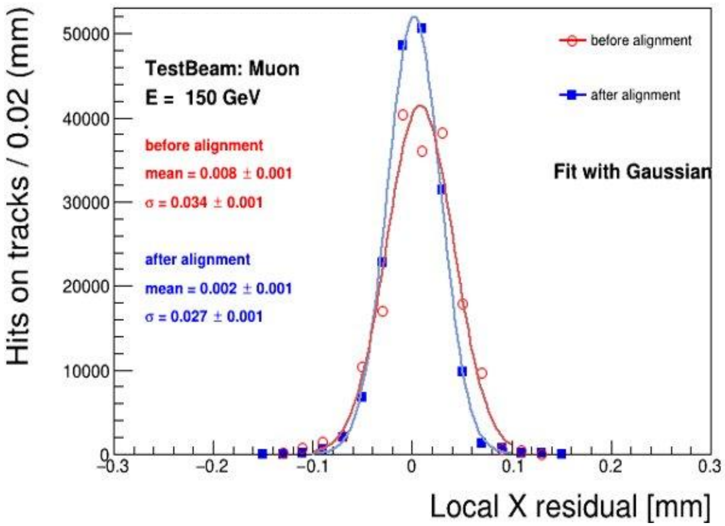
- No masked strips → expect similar efficiency for all wafers
- Uniform hit efficiencies for all layers/sides
- Layer gaps at y=+-60mm, +-5mm layer offsets w.r.t. center layer to avoid gaps

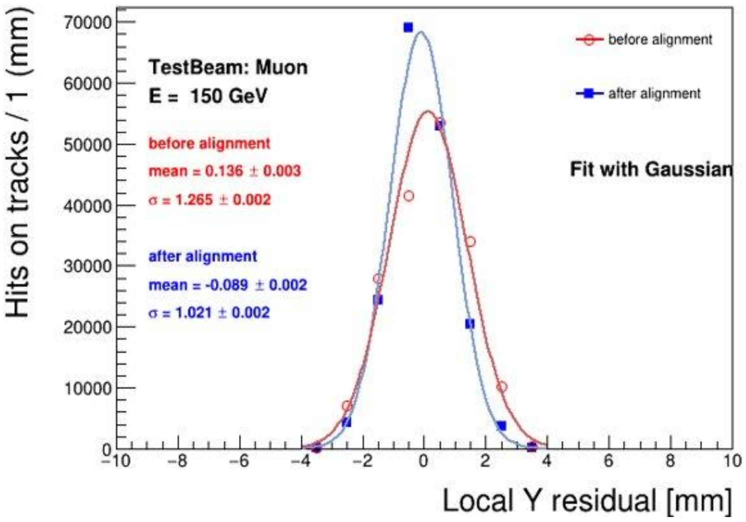




Tracker - Alignment

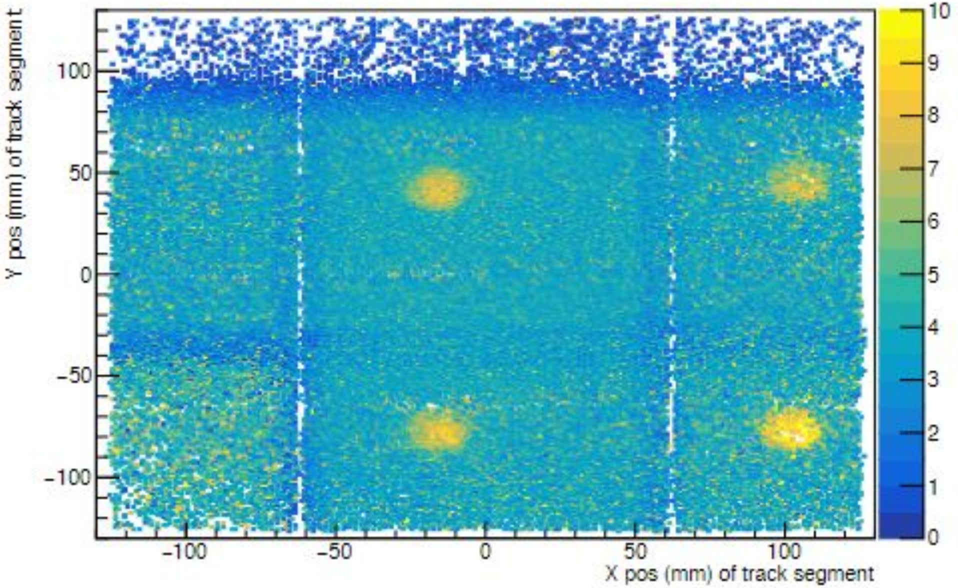
- Local Alignment of the middle layer demonstrates 20-30μm resolution
- Global Alignment approach in development
  - preliminary results indicate that the individual misalignment across all modules is consistent with expectation of ~100 μm shifts and ~2mrad rotations





Tracker + Calorimeter: Response

- Calorimeter response with respect to the track position
- Response increases greatly when muons traverse the PMT
- Note:
    - The tracker area does not fully cover calorimeter area.
    - The gaps originate from the tracker

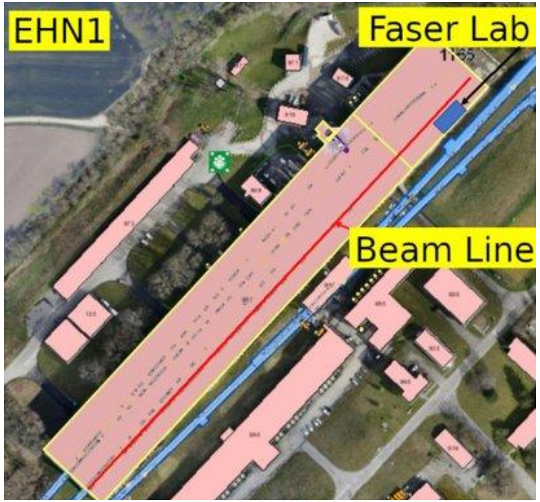


Tracker + Emulsion

Combined test run on the surface with scintillator, emulsion module and the IFT

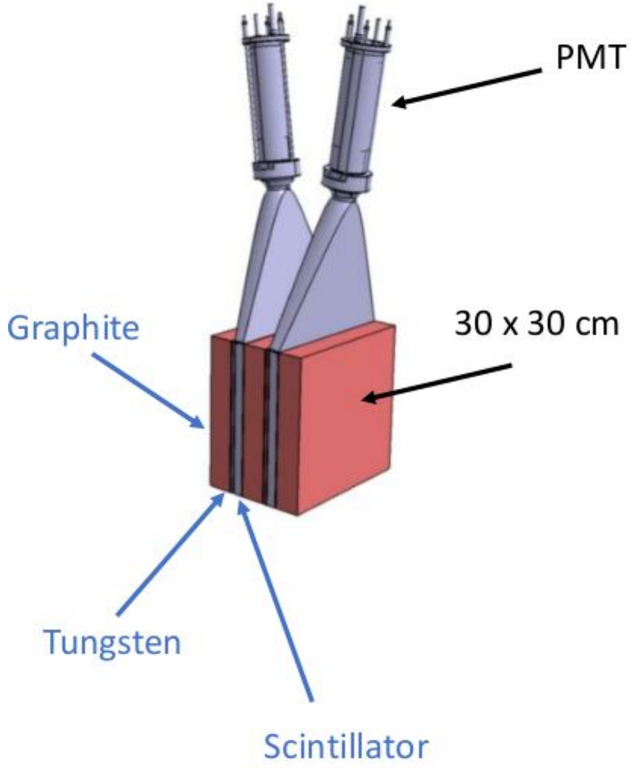
- make use of low rate of scattered muons from test beam line from SPS which can be detected from our lab (about 6m away)
- 1.5 million tracks expected over time
- the track density in reconstructed emulsion is consistent with the expected counts

Emulsion-IFT track matching study is ongoing



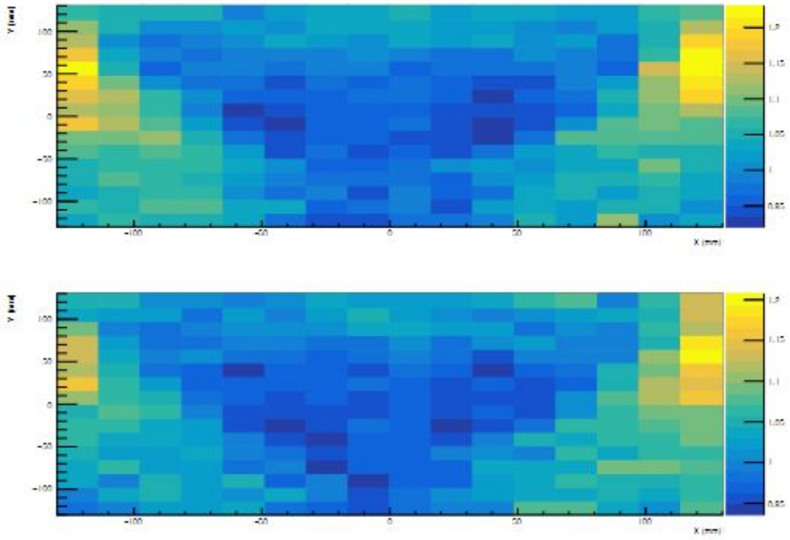
Preshower

- 2 scintillator stations w/ single PMT for readout
- ~3mm tungsten radiators, roughly ~2 radiation lengths
- ~5cm graphite to reduce backsplash from the calorimeter
- PMT module provides readout pulses



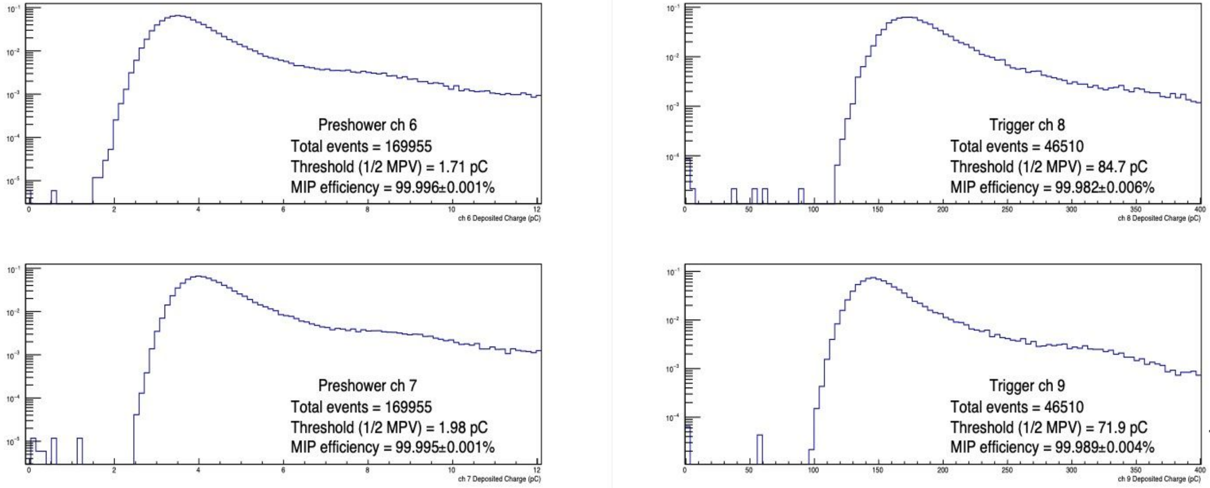
Preshower Response

- Measure light collection efficiency using track position and preshower response from muons.
- Expected: Straight MIP tracks should generate uniform amount of light independent of position.
- Light collection non-uniformity varies by +- 15% across the area of the preshower.
- Triangular shape can be explained by the triangular light guide.



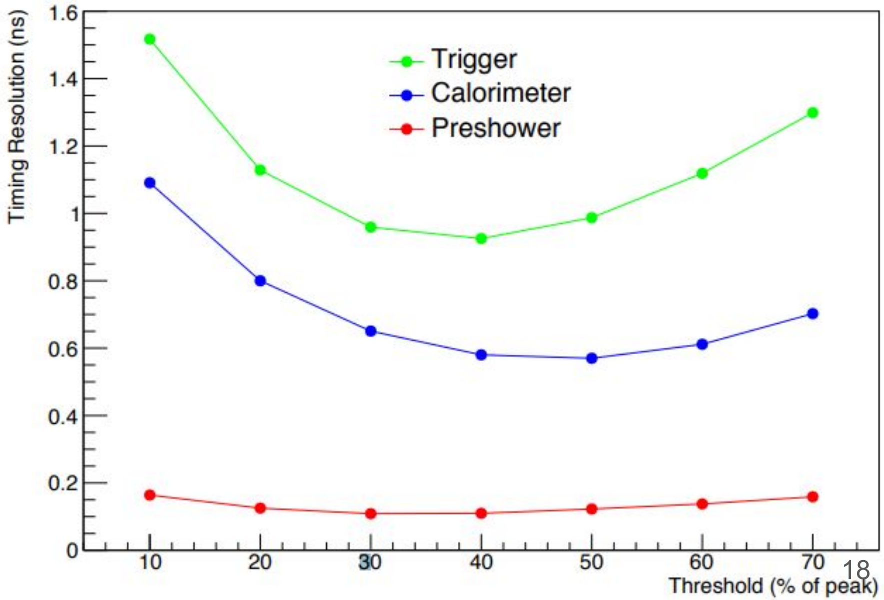
Scintillator Efficiency

- Use clean muon events to measure MIP efficiency of each preshower and trigger scintillating layer
- A special run was taken where we triggered with the preshower layers, to have an unbiased sample for the trigger layers
- MIP efficiency >99.98% for all scintillating layers, defining a threshold at half the MIP signal
- MIP efficiency within the specification for the experiment

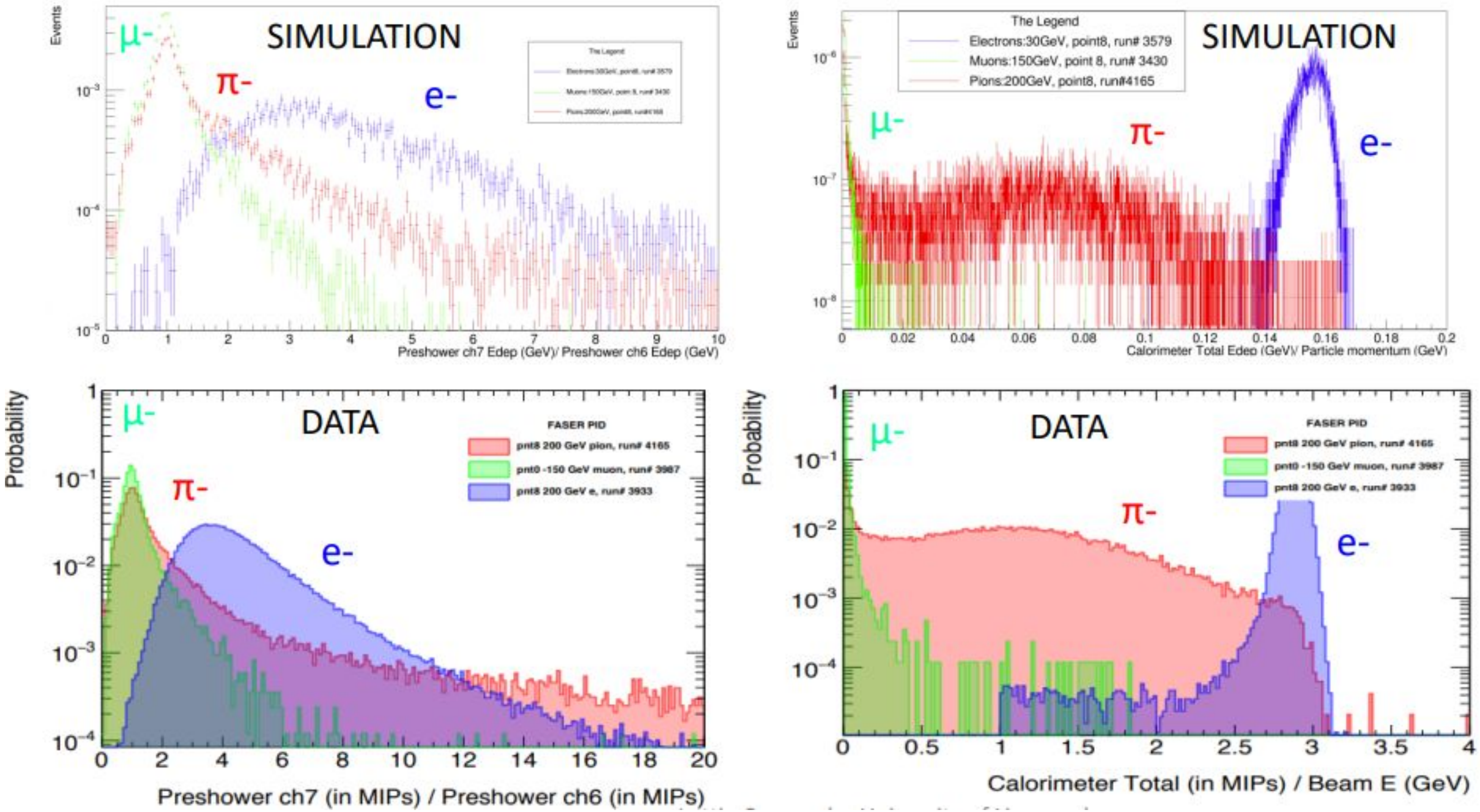


Scintillator Timing Resolution

- Timing resolution measured with the 200 GeV electron data
- Crystal ball fit of the waveforms, and backing out the time of the waveform at constant fraction threshold of the peak height
- Subtract these measured times of other detectors of the same type
- Distribution of time difference fitted with a Gaussian (time resolution)
- Optimal constant fraction threshold for timing resolution of each detector type:
  - 577±1 ps for the calorimeter
  - 110±1 ps for the preshower
  - 929±2 ps for the trigger
- Measured time resolution is within the specification of the experiment (better than 1ns)



PID capabilities



Summary & Outlook

- We had a successful test beam campaign with a small scale detector system.
- Plenty of recorded data, and analysis is still ongoing for some aspects.
- The individual components behave within the specifications for the experiment
- Performance agrees with measurements from other experiments and simulations
- Paper on the testbeam results is in preparation

- The full FASER detector has been installed in the LHC tunnel
- In-situ commissioning still ongoing, we are recording first events from LHC commissioning
- Ready for the coming data taking period