# FASER Detector Characterization with a Test Beam

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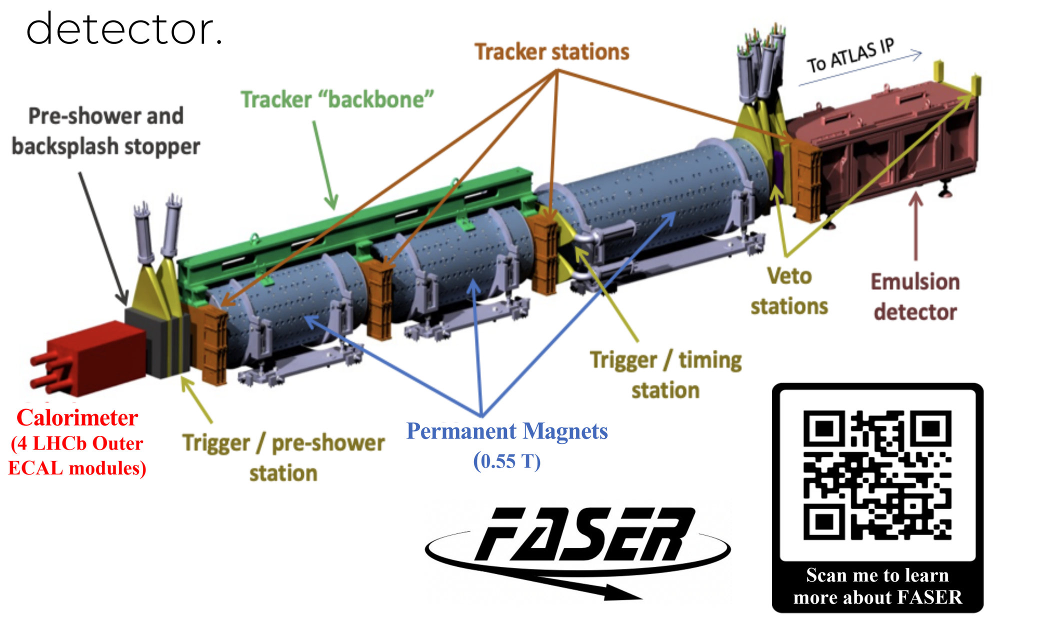
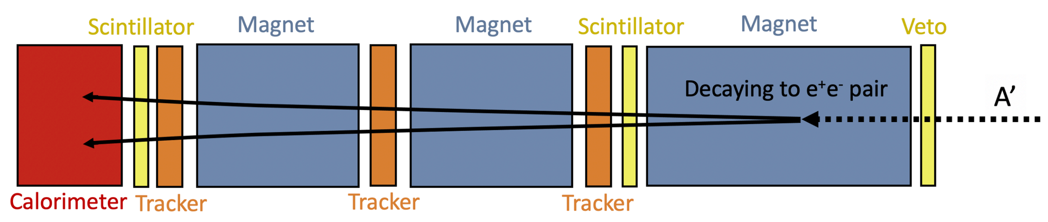
## FASER

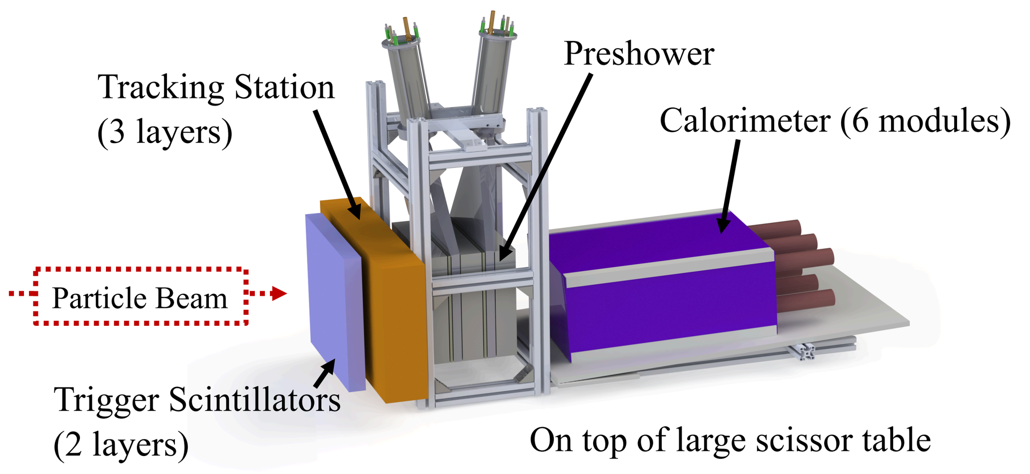
FASER is a new experiment at CERN dedicated to searching for long-lived and weakly interacting particles beyond the standard model, such as the dark photon. Though extremely rare, such particles may be produced copiously at the LHC in the far-forward region and leave a unique signal characterized by two oppositely charged tracks in the multi-TeV range that emanate from a common vertex inside of the detector.

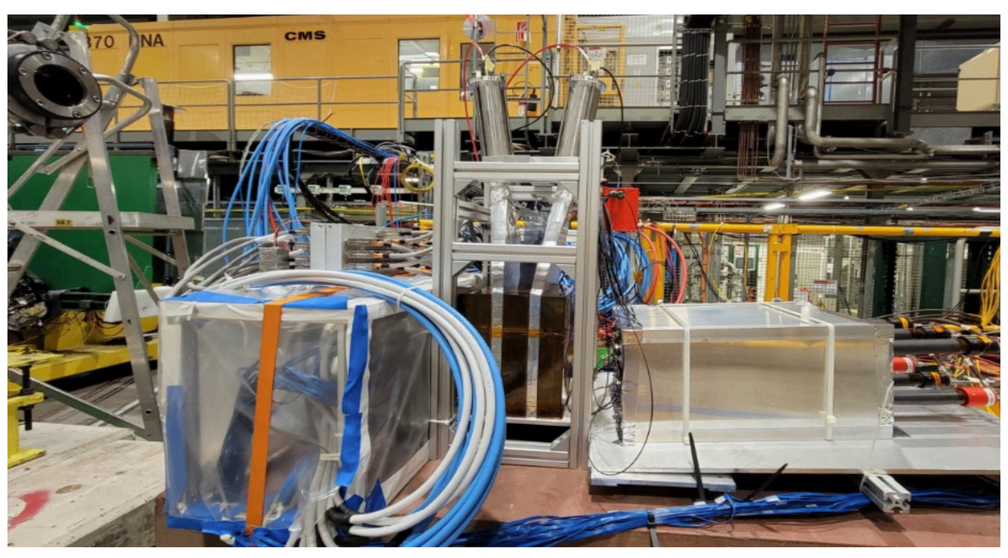



## Test Beam

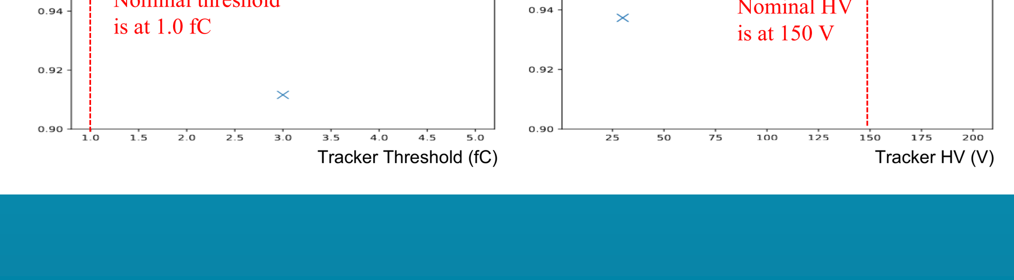
A subset of the FASER detector was stuck in front of one of the CERN SPS beam lines from July 28th to August 4th, 2021. Placed in the test beam was a FASER tracking station composed of spare ATLAS SCT modules, followed by a simple preshower system consisting of two-layers of tungsten and scintillator, and lastly a 3x2 stack of spare LHCb electromagnetic calorimeter modules. Beams of electrons with energies between 10 and 300 GeV, as well as high energy muons and pions, were scanned across the entire face of the setup, resulting in over 150 million recorded events.



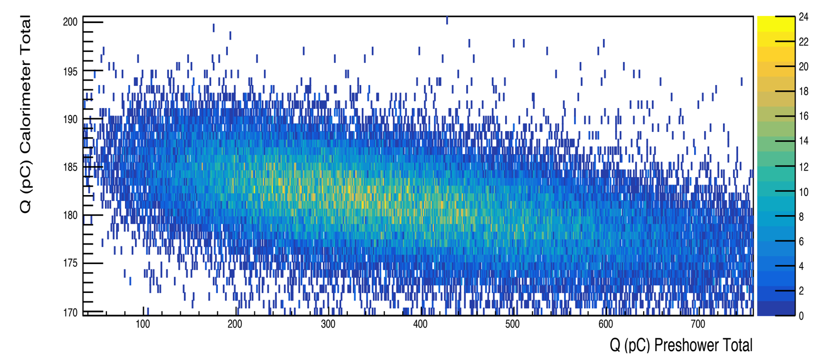
## Tracker

Clean muon tracks were used to measure a tracker cluster efficiency of 99.86 ± 0.04 % which agrees well with MC and ATLAS (99.74 ±0.04 %). For more information about the FASER tracker, see the poster titled "The Tracking Detector of the FASER Experiment."




## Calorimeter Response and Preshower Correction

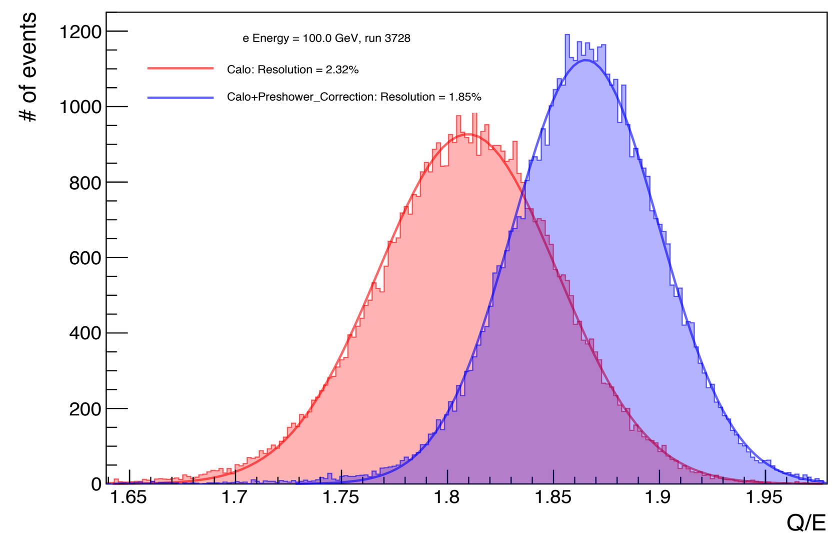
The preshower has ~2 $X_0$ of tungsten and thus steals some of the EM shower from the calorimeter. Plotting the correlation between the calorimeter and preshower shows that when the preshower sees more charge than the calorimeter sees less charge. This sampling variation degrades the Calorimeter's energy resolution.




To correct for this, we can use the slope (m) of the correlation to add the stolen charge back into the calorimeter for each event:

$$Q_{Corrected} = Q_{Calo} + |m| * Q_{preshower}$$

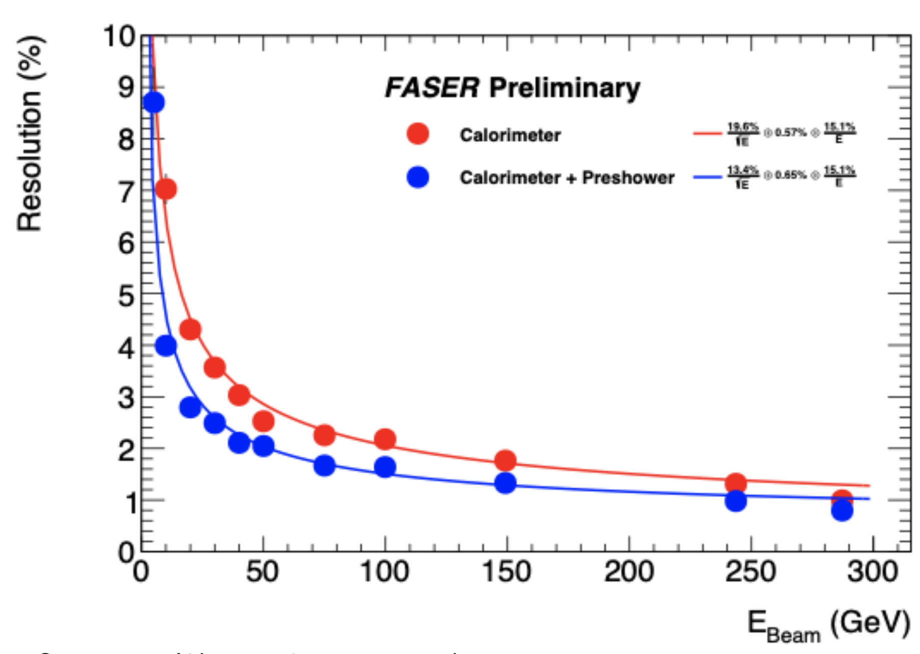
As you can see in the following plot, this correction increases the mean response of the calorimeter and decreases its width.



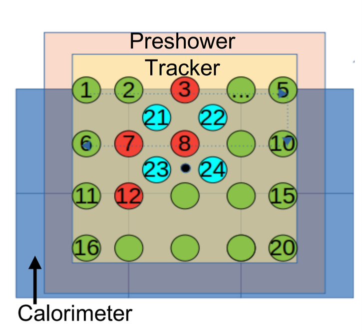

In order to validate the preshower correction, we took special runs where the tungsten (W) and graphite (C) were physically removed from the preshower in the test-beam setup. Comparing the calorimeter resolution with the preshower material removed and with the preshower present but corrected for, shows that the correction completely accounts for the losses in the preshower.

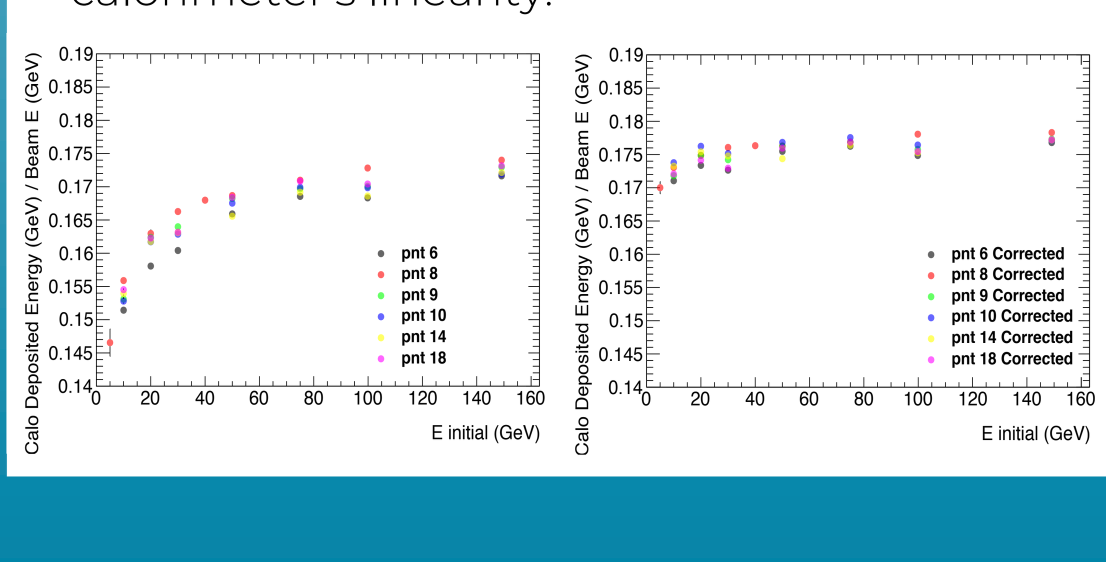
| | With Preshower | W and C removed | With Preshower + correction |
|---|---|---|---|
| Resolution (30 GeV e⁻) | 3.76 ± 0.03 % | 2.84 ± 0.02 % | 2.88 ± 0.02 % |
| Resolution (200 GeV e⁻) | 1.89 ± 0.01 % | 1.67 ± 0.01 % | 1.66 ± 0.01 % |

Plotting the calorimeter's resolution for various electron beam energies shows that the preshower correction improves the resolution from 19.6%/√E to 13.4%/√E.



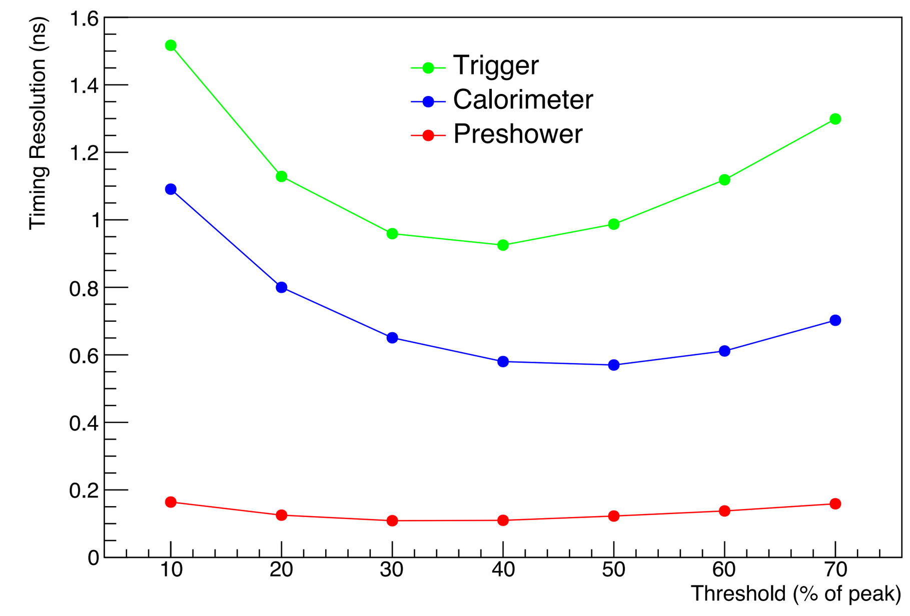

After calibrating each calorimeter module with the MIP signal, we can compare the calorimeter response at several different beam positions. As you can see, the response only varies by a few percent and correcting for the preshower helps to restore the calorimeter's linearity.



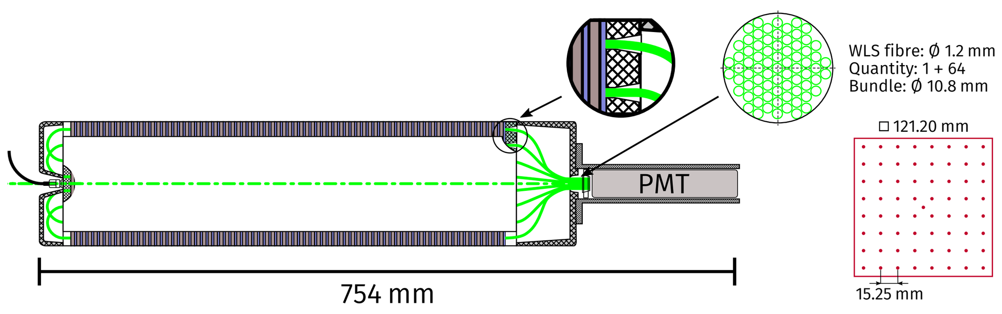

## Timing Resolution

After fitting the scintillator waveforms with a CrystalBall function, we can back out the time of the event for various given thresholds with respect to the peak of the waveform. Subtracting the event times between similar detector types allows us to measure the timing resolution of each detector type and determine the optimal threshold for measuring the event time. As you can see, the best timing resolution for each detector type occurs at different thresholds from 30-50% of the peak and results in a timing resolution of < 1 ns for all detector types.

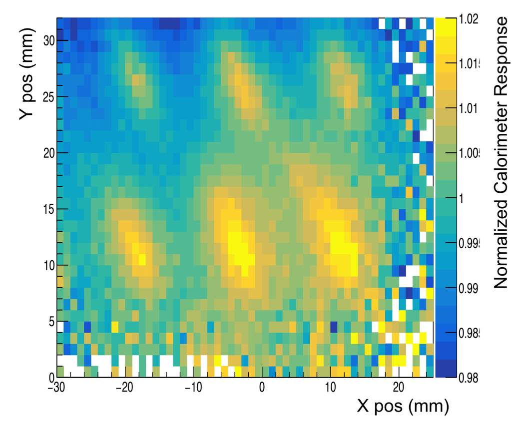



## Light Collection Efficiency

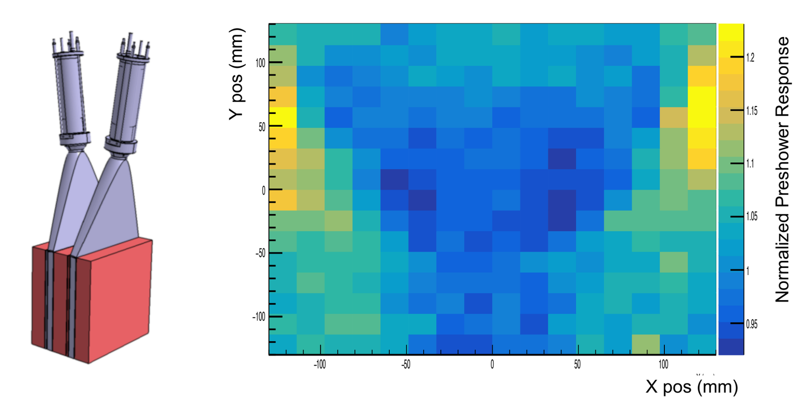
The calorimeter modules have wavelength-shifting fibers that penetrate the entire length of the module in order to carry light from the scintillating planes to the PMT.




Plotting the calorimeter response from a 200 GeV e- shows that the light collection efficiency increases by ~1% when near a fiber.




A similar plot can be made to measure the light collection of the preshower layers. Looking at the normalized preshower response to muons across the area of the preshower shows that there is a ±15% change in the light collection efficiency. This large non-uniformity is due to the number of reflections needed for the light to reach the PMT being dependent upon the geometry, with the response clearly reflecting the triangular shape of the light guide.




## Particle Identification

We can demonstrate our ability to distinguish between electrons, muons, and pions using the response of the calorimeter and preshower. Both the total deposited energy of the particle and the longitudinal distribution of the shower allow for good separation between particle types.