Towards First Data from FASER: Simulation to Electromagnetic Calorimeter Test Beam Studies

Liverpool HEP Meeting 19th – 20th May 2022

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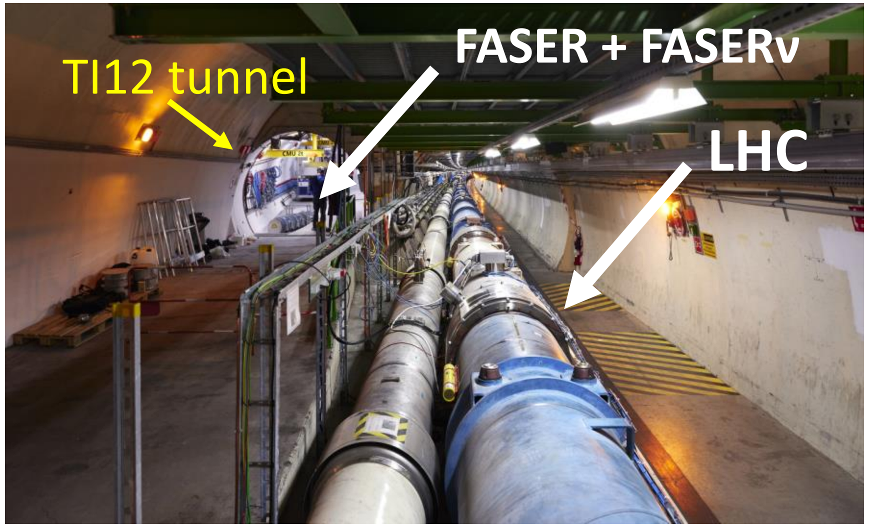
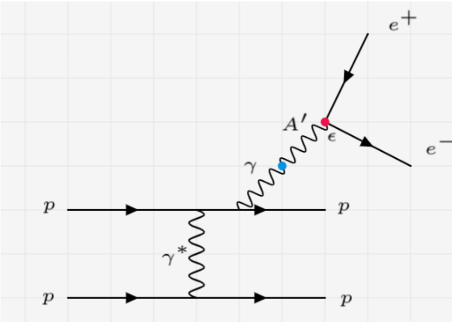
FASER: Introduction

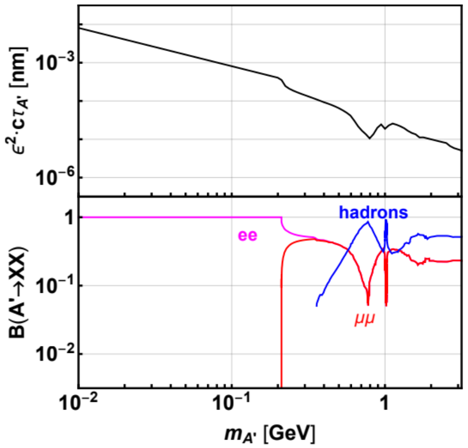
- There is evidence to suggest the existence of Dark Sectors which may contain new, light, weakly-coupled particles that interact only very weakly with ordinary matter
- FASER is designed to detect potentially long-lived particles (LLPs) produced at the ATLAS Interaction Point in the forward region $pp \to \text{LLP} + X, \quad \text{LLP travels} \sim 480\text{ m}, \quad \text{LLP} \to e^+e^-, \mu^+\mu^-, \pi^+\pi^-, \gamma\gamma, \ldots$

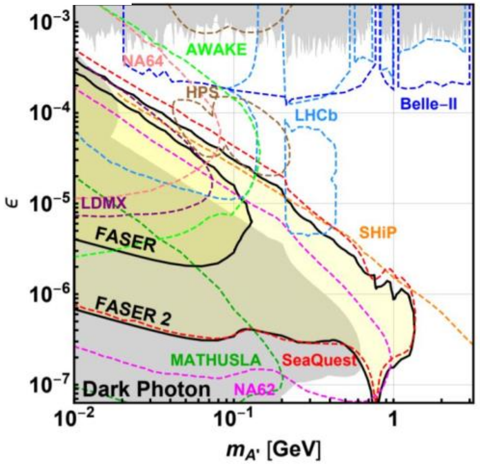
See Carl's talk tomorrow for detector details



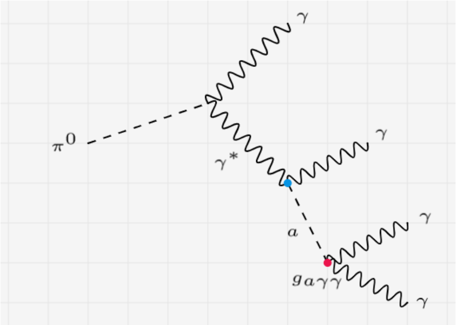
Dark Photon (A') production and decay:

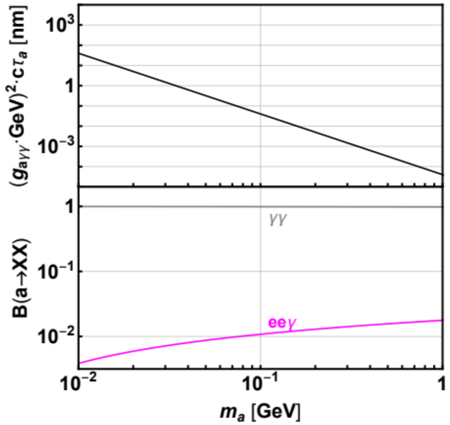


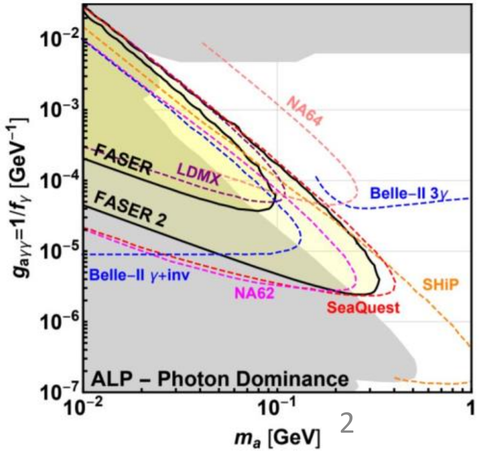




ALP (a) production and decay:



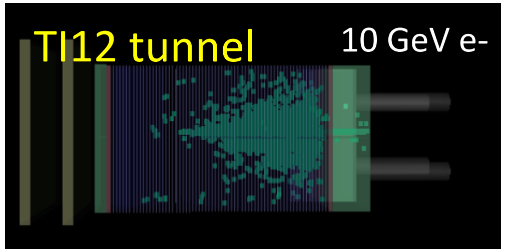


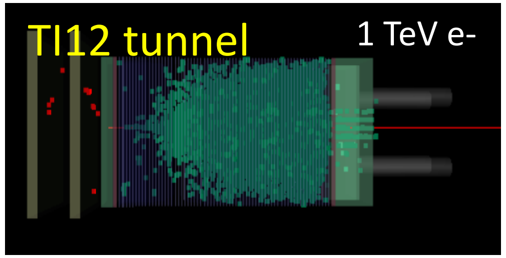


Current Status

My presentation last year gave details of the simulation studies in the TI12 geometry

- Simulation based on the Geant4
- Before we were able to validate with our own test beam, the simulation was based on LHCb test beam results
- Various additions and corrections were studied in order to find the "best" setup



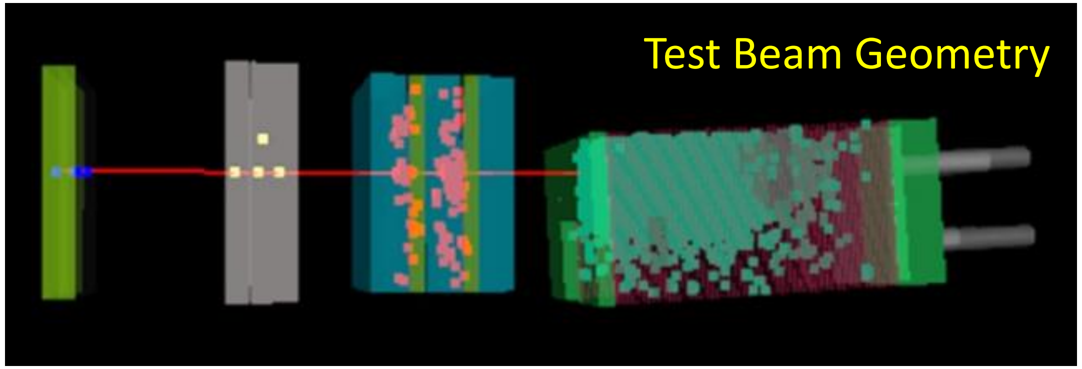


Since last summer's test beam, focus has been on simulation and analysis of this data

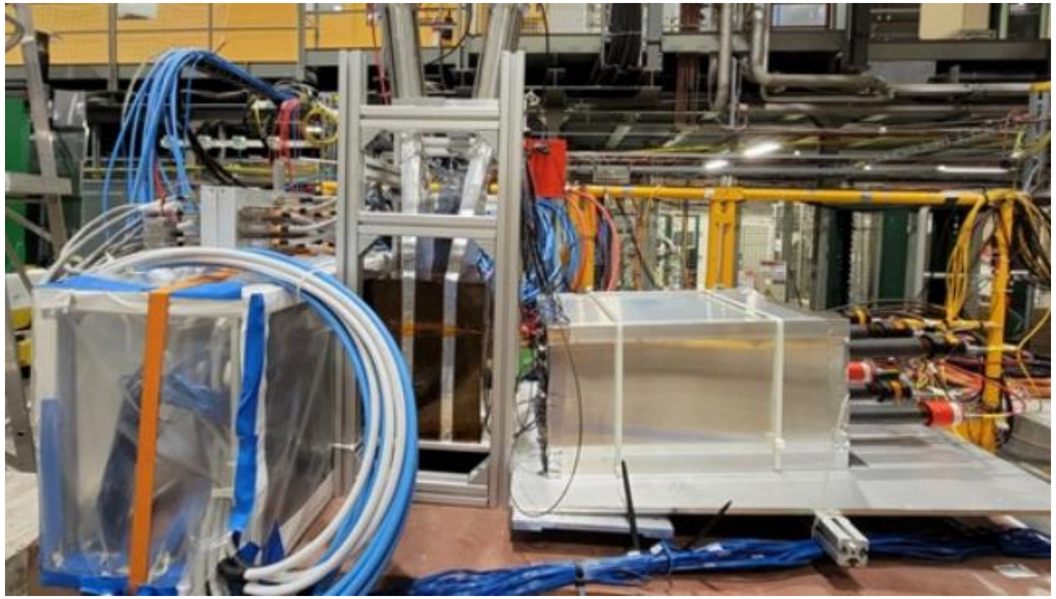
- A dedicated framework was developed for the test beam simulation
- So far more than 2 million events have been simulated in the test beam geometry that mimic test beam runs
- Reconstruction and digitization steps are being finalised

Now we are shifting to preparations for Run 3 data taking

- Return to TI12 geometry, generate realistic signal samples
- See Carl's talk for details of Mock Data Challenge



The 2021 FASER Calorimeter Test Beam

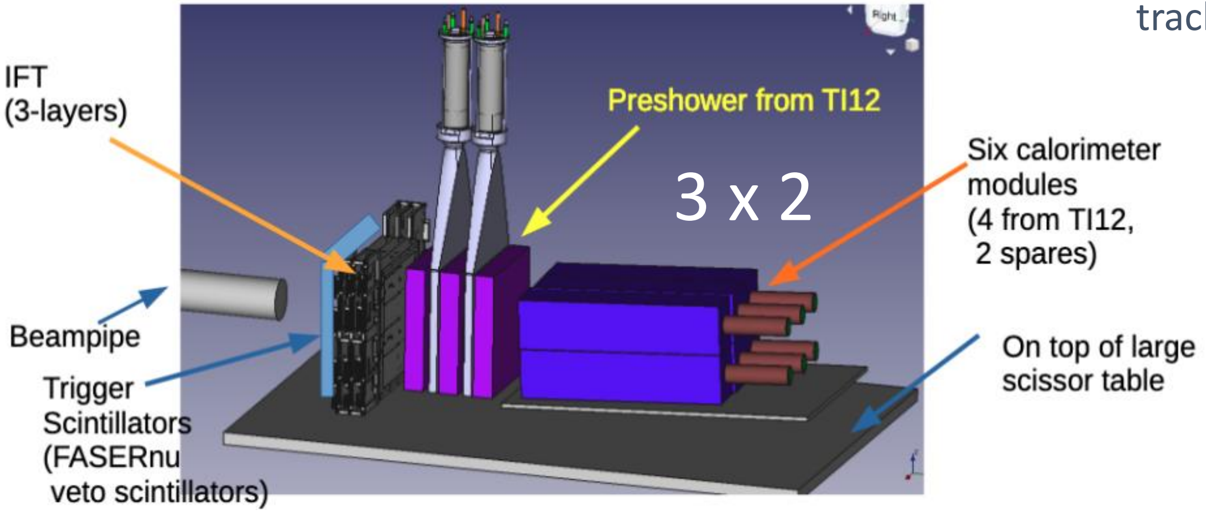


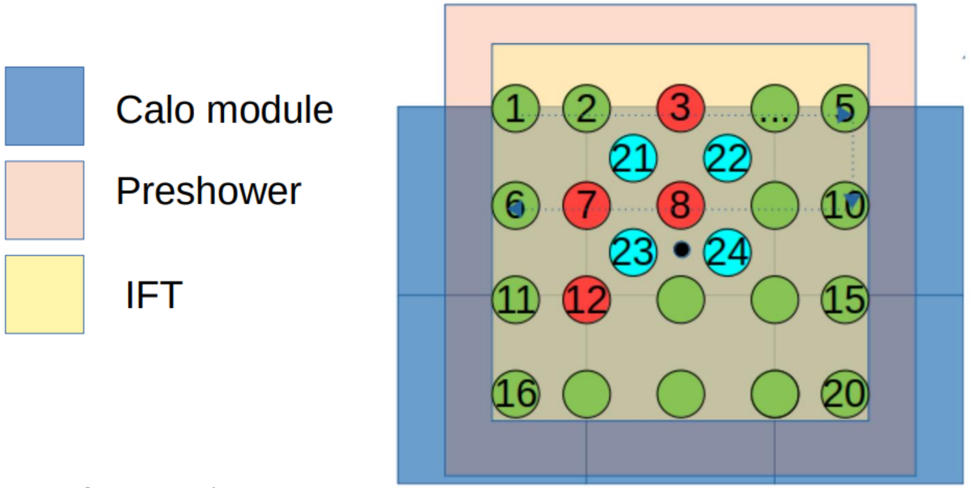
CERN H2 beam line 28th July – 4th August 2021

The aims of the test beam were to:

- Calibrate the calorimeter and preshower modules
- Study electron response
- Perform muon response to study uniformity of MIP response
- Perform pion scan to study hadronic response

Secondary goal: operation and performance measurement of interface tracker (IFT) station in actual beam conditions

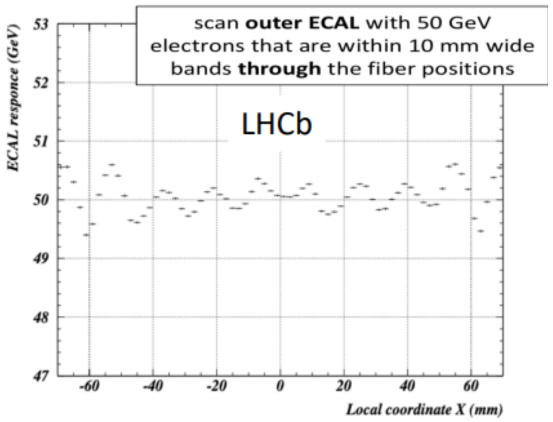


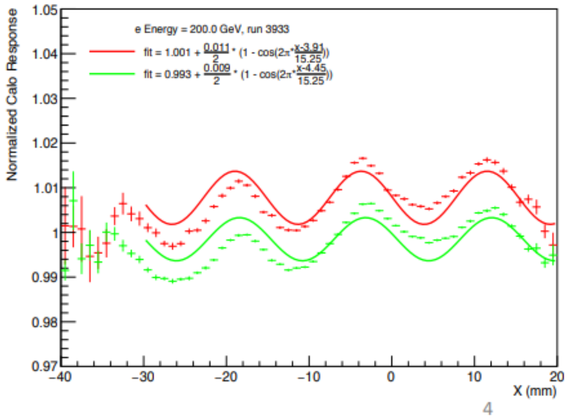


Calorimeter Studies: Local Effects and Corrections

WLS Fibre effects

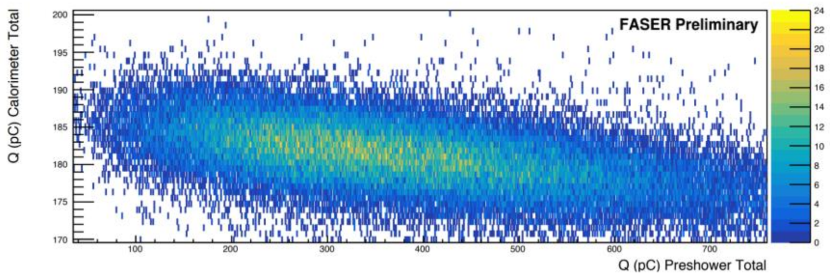
- Light collection improves when near a fibre
  - This effect is at a similar scale to what LHCb saw in their studies
- **This is not currently implemented in simulation**
  - Can now add this to simulation based on measurements in data





Preshower Correction

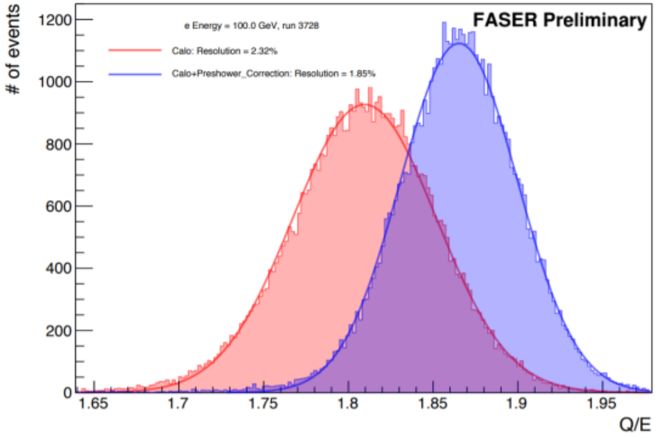
- The preshower steals a portion of the EM shower from the calorimeter
- This needs to be corrected for on an event by event level
- **This has now been applied to the simulation**



Preshower correction

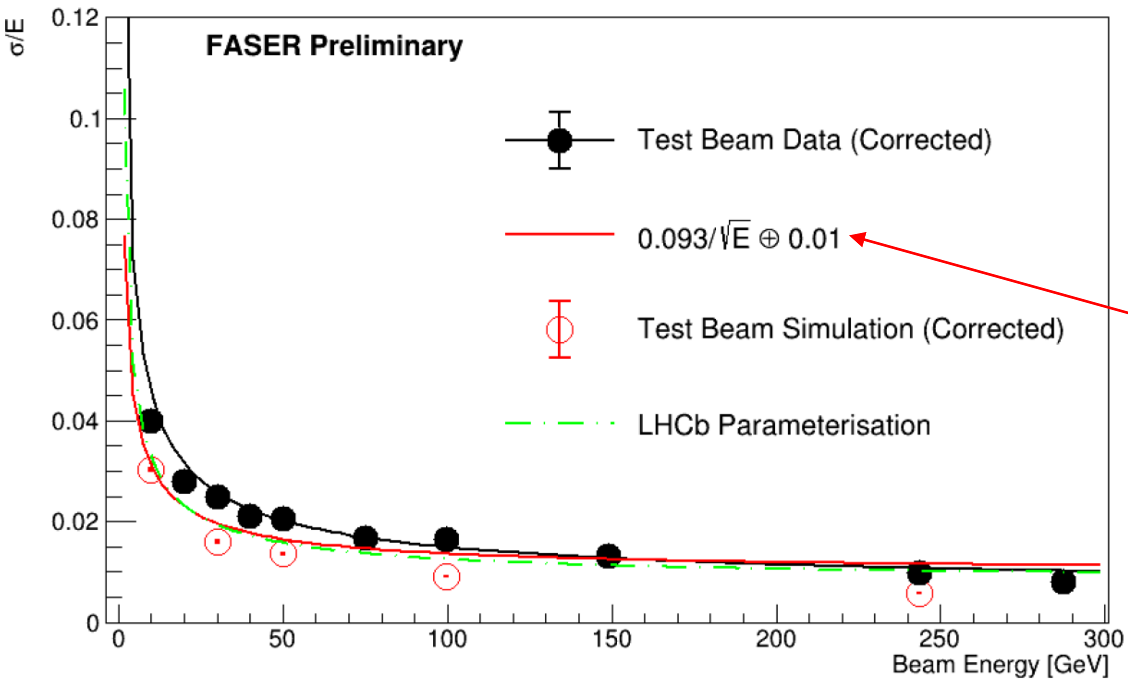
m = slope of $Q_{preshower}$ vs Q_{calo} plot

$$Q_{corrected} = Q_{calo} + m * Q_{preshower}$$



Data and Simulation

- Comparing energy resolution of corrected data measurements with corrected simulation
- Aim to fully understand the differences
  - Some effects aren't yet implemented in simulation



$$\sigma_E/E = a/\sqrt{E} \oplus b/E \oplus c$$

	a	b	c
Data (Corrected)	0.134	0.151	0.0065
Data	0.196	0.151	0.0057
Simulation (Corrected)	0.093 ± 0.003	-	0.0000 ± 0.0004
Simulation	0.135 ± 0.001	-	0.0000 ± 0.0017
LHCb	0.094 ± 0.004	0.108 ± 0.029	0.0083 ± 0.0002

- A noise term (b/E) improves the fit in the case of data
  - Calculated from the measured noise of digitizer signal using the same data being studied at the moment
- The simulation does not have a way to replicate the value of the constant (c) term
  - 1% was chosen to study the impact on the resolution fit on plot
  - Brings tail end of distribution higher, towards data and LHCb's measurement

Outlook

- Test Beam
  - We saw efficient data taking with good overall beam quality and purity
  - Most of FASER's physics signal will be at energies above the test beam, the resolution that we see in data and simulation is more than sufficient for what we need

- Simulation and Analysis
  - The plan moves towards simulating more realistic signal samples to prepare for dark photon analysis
  - The mock data challenge will ensure FASER is prepared for data taking

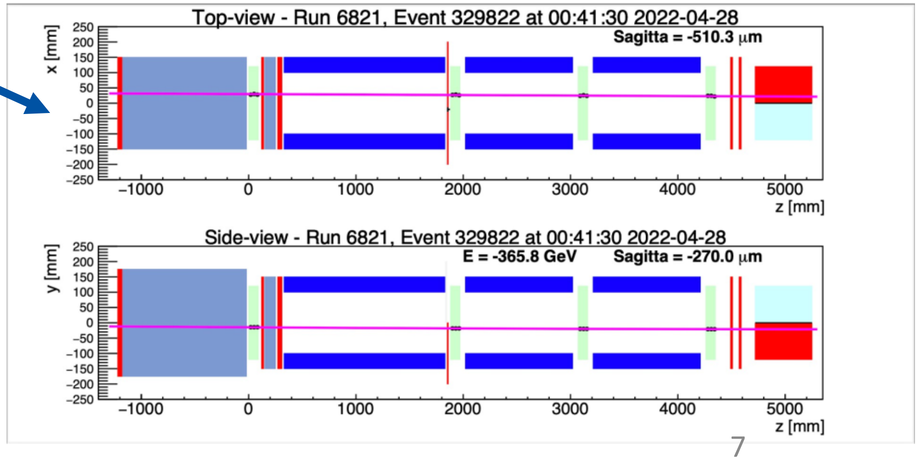
- Detector once again situated in TI12, Run 3 data taking has started and we have first results!

- I have presented preliminary results at IoP and CALOR22 conferences

- Now starting to work on preparation for real data analysis which will focus on searches for dark photons

- Will hopefully start my LTA at CERN in October

Background (beam) muon traversing the full FASER detector and leaving signals in all detector systems:



Thanks!

Backup Slides

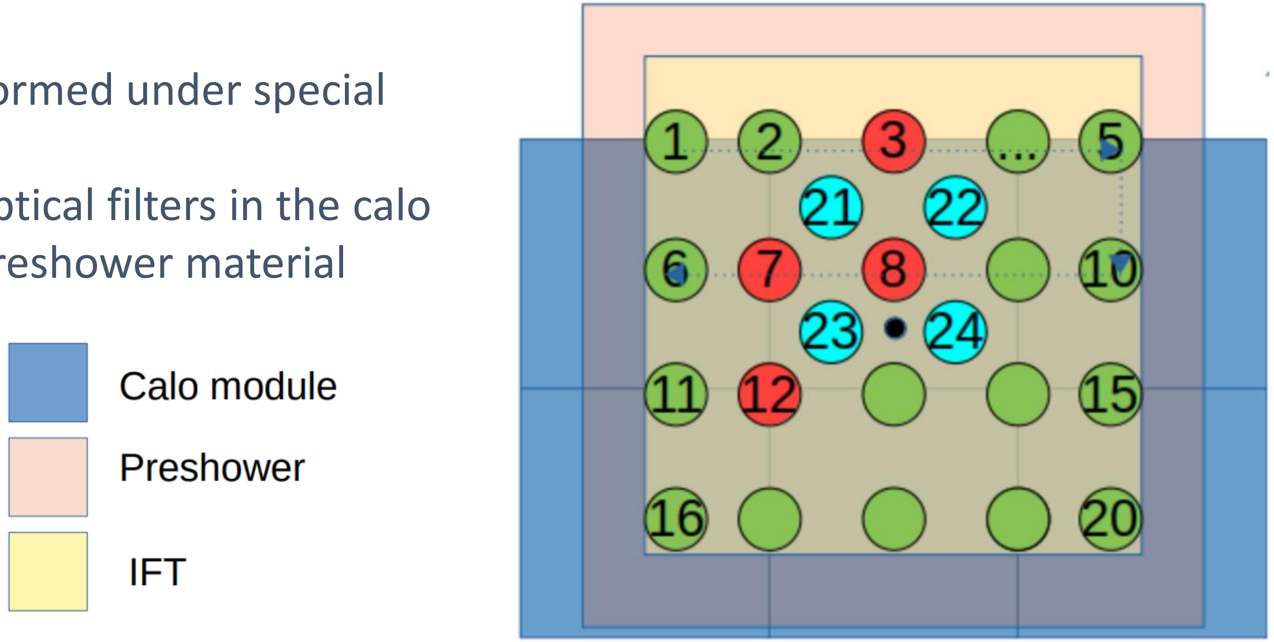
Test Beam Overview

Over 150 million events (1.8 TB) recorded, scanning through 24 spatial points across 6 ECAL modules

- Electron, μ-, π- beams at different energies and settings
- Low, medium and high calo PMT gain settings
  - Gain offsets: 0 V – 500 V in 50 V steps

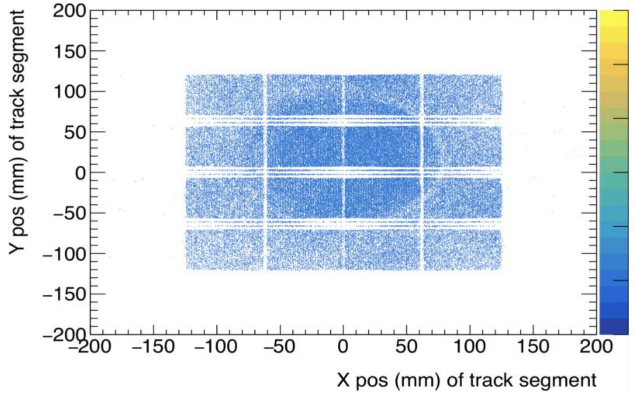
Some runs were performed under special conditions:

- Removal of optical filters in the calo
- Removal of preshower material



Electron beam
- 12 energies: 5 – 300 GeV
- Primarily used 30, 75 and 200 GeV

Muon beam
- 200 GeV
- Large beam size (> 5 cm)

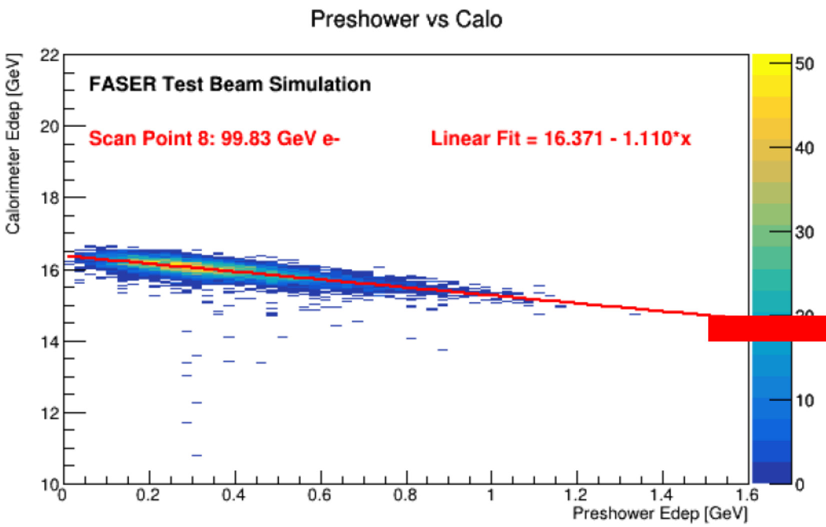


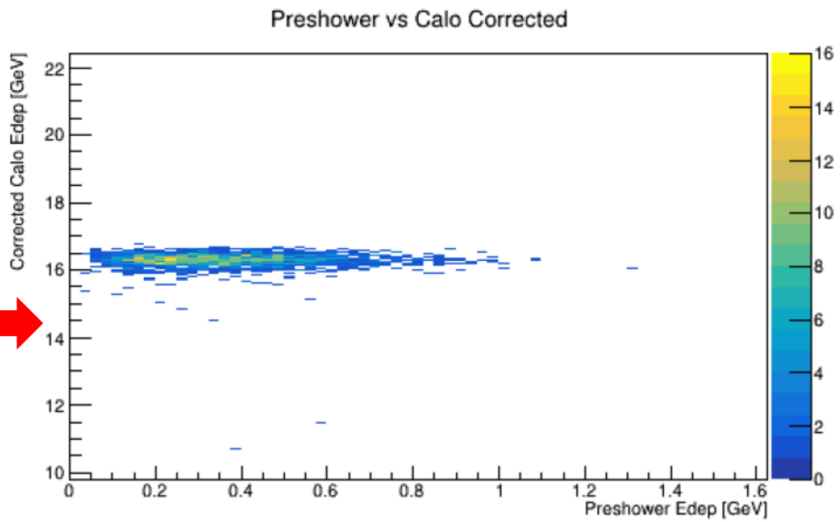
Pion beam
- 200 GeV
- Study hadronic response

Test Beam Simulation: Preshower Correction

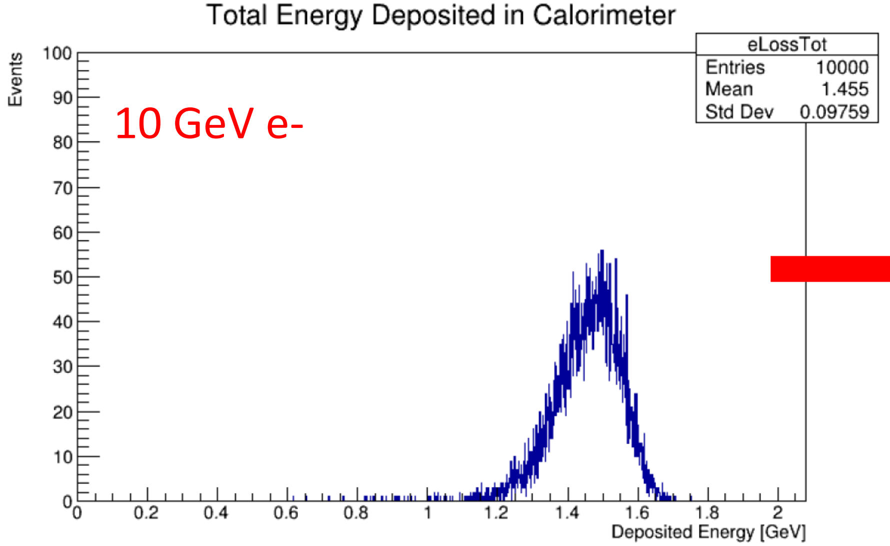
Preshower correction
m = -1.11

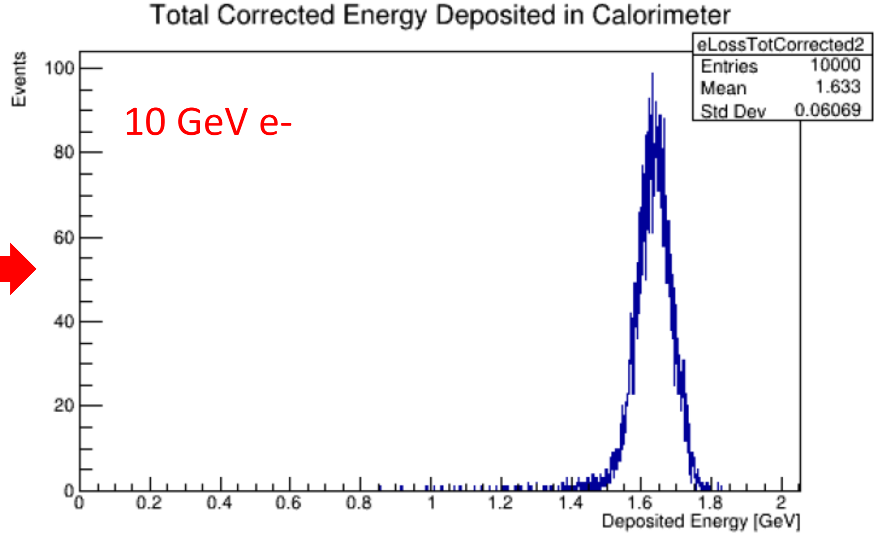
Ecorrected = Ecalo + m*Epreshower





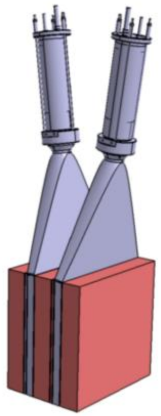
- We can also apply a preshower correction to the simulation
- Changes distribution
- Important note: simulation gives deposited energy rather than deposited charge

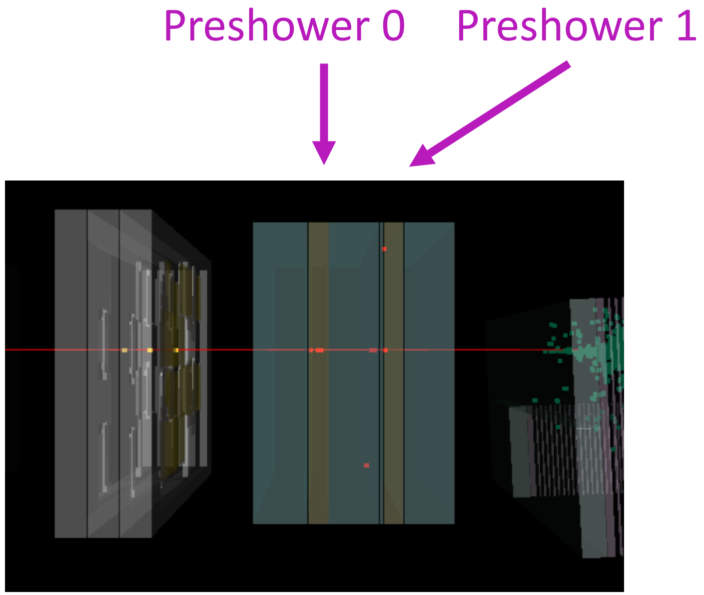


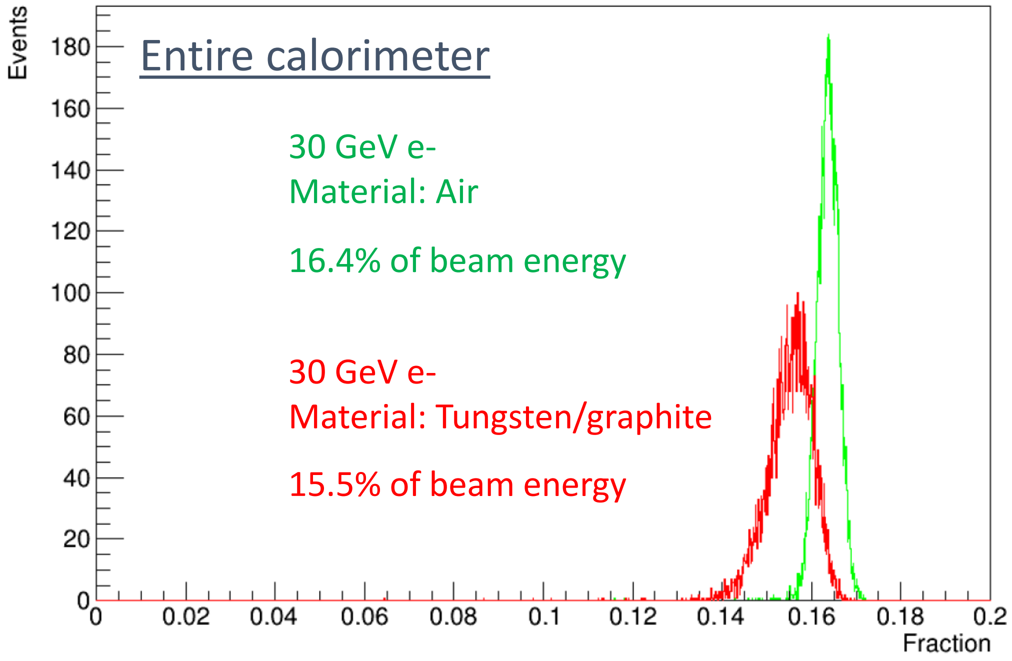


Test Beam Simulation: Preshower Material

- Some test beam runs were performed with the preshower material (tungsten/graphite blocks) removed
- This was also carried out in simulation, and the change in edep % was studied
- We can compare with results from preshower correction







This was validated by data:

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