The monolithic ASIC for the high precision preshower detector of the FASER experiment at the LHC

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on behalf of the Preshower upgrade team

11th Beam Telescopes and Test Beams Workshop

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FASER

ForwArd Search ExperRiment

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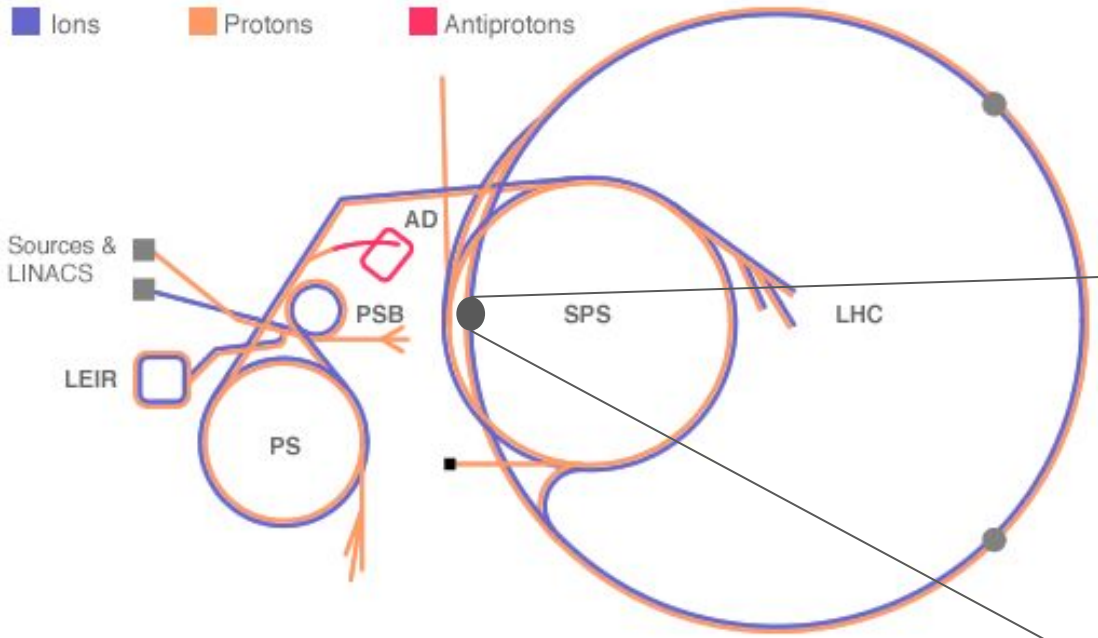
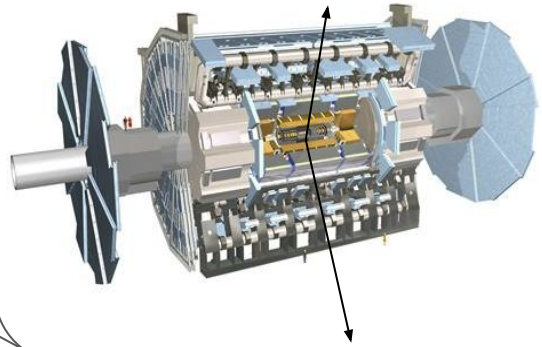
Large Hadron Collider: proton-proton collisions at 13.6 TeV

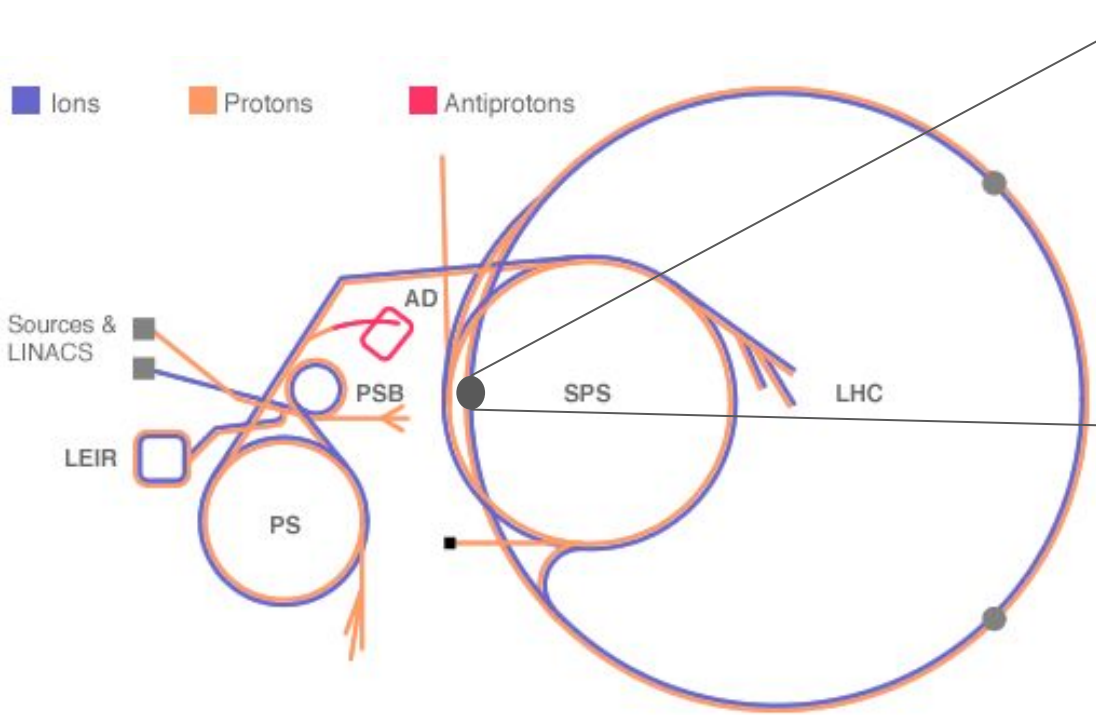


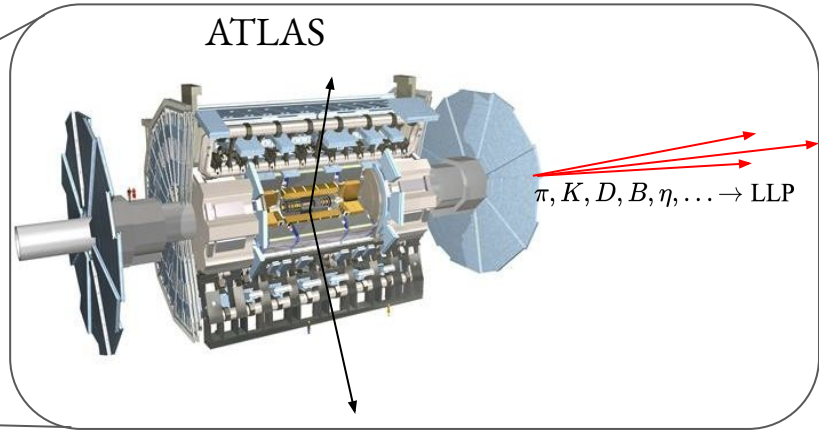
- Proton-proton collisions at $\sqrt{s}$ = 13.6 TeV
- Main detectors at the LHC look at high momentum particles in the transverse plane

ATLAS



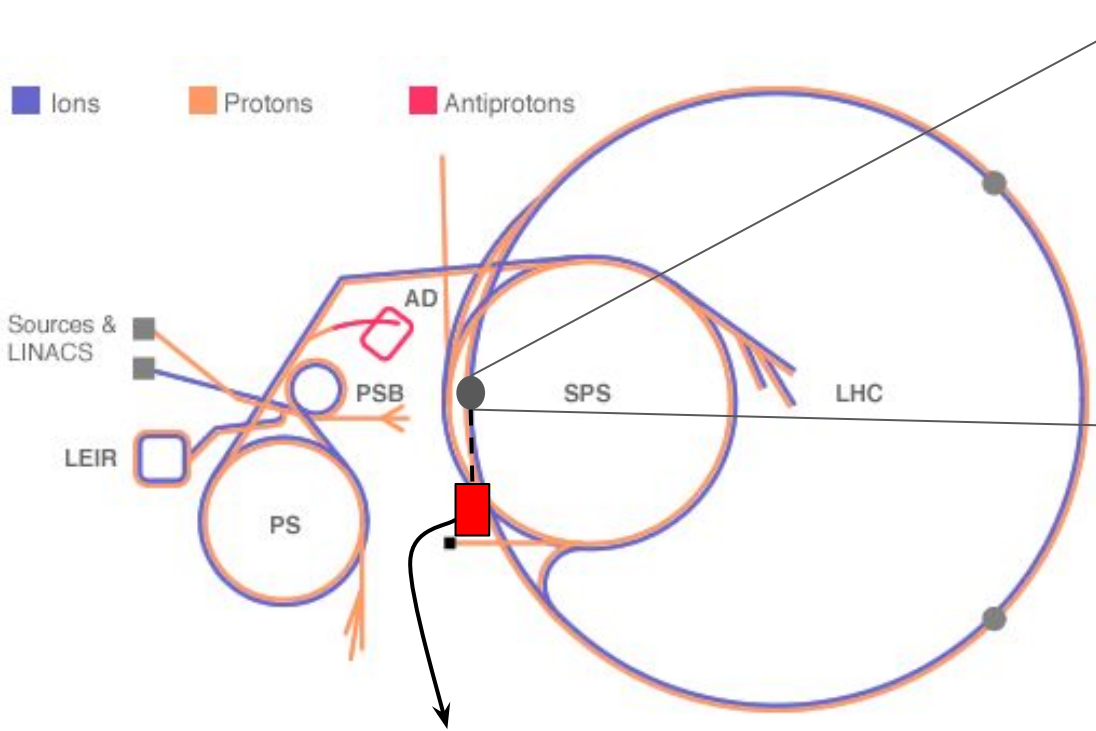
Forward physics at the LHC

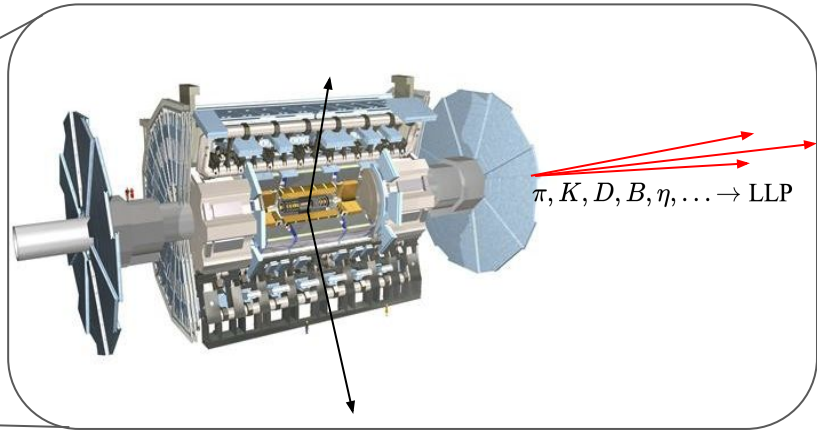




- Pion production at the LHC mainly in forward direction → large forward cross section unused

Forward physics at the LHC and the FASER experiment



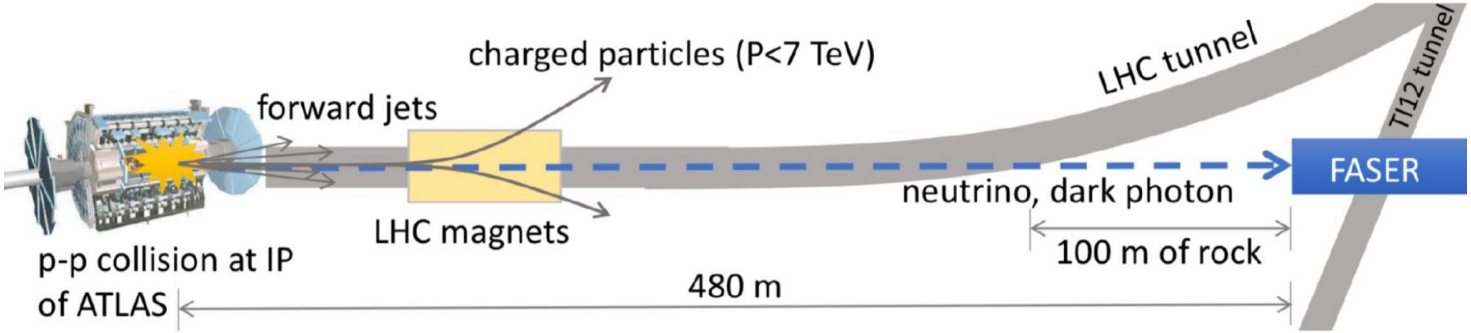


Forw**A**rd **S**earch Expe**R**iment (FASER)

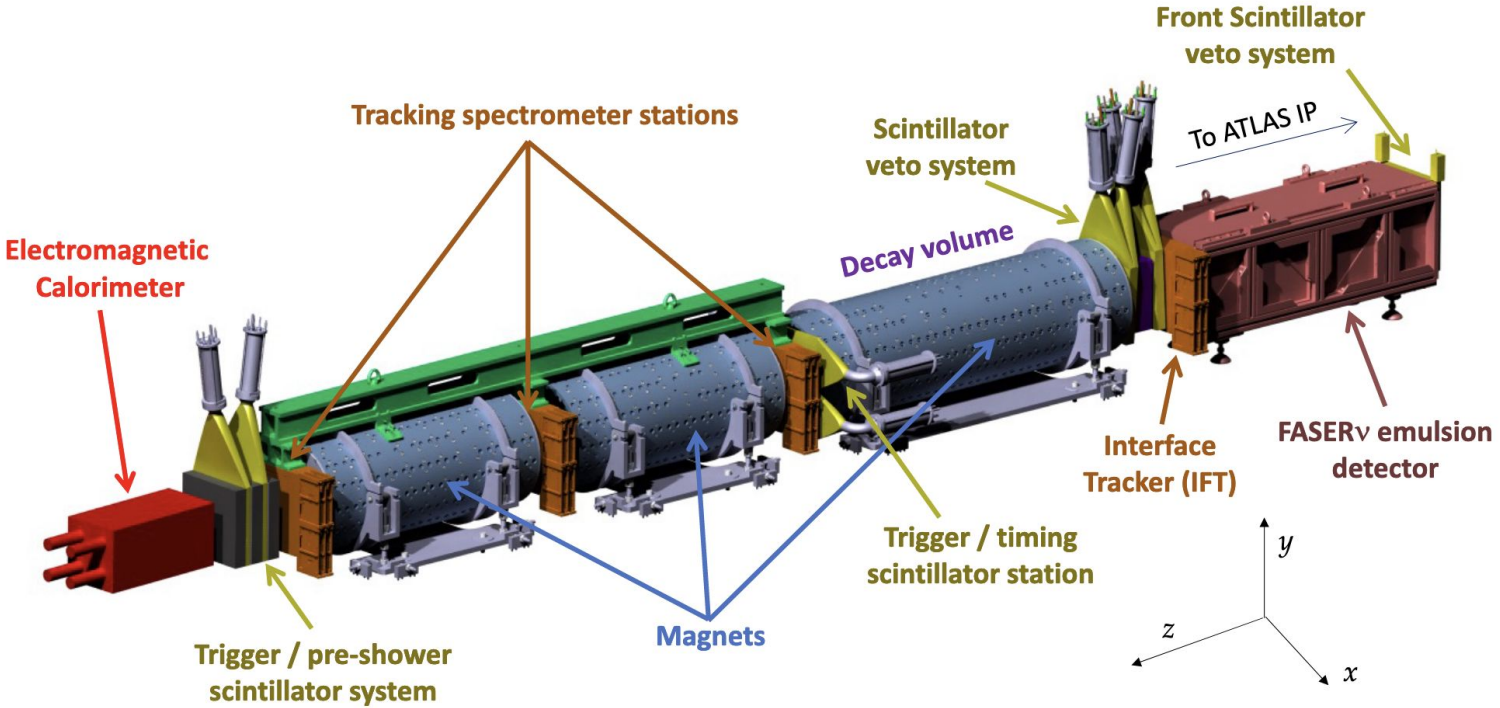
- Pion production at the LHC mainly in forward direction → large forward cross section unused
- Locate a detector to exploit the forward cross section: **FASER**

Forward physics at the LHC and the FASER experiment

- FASER located at 480m away from ATLAS interaction point
- Mesons may decay into long-lived Beyond Standard Model Particles (LLP)
- LLPs can decay within the FASER detector volume
- FASER capable of detecting the products from the LLP decays (and neutrinos)
- Almost background-free searches, main background: neutrinos

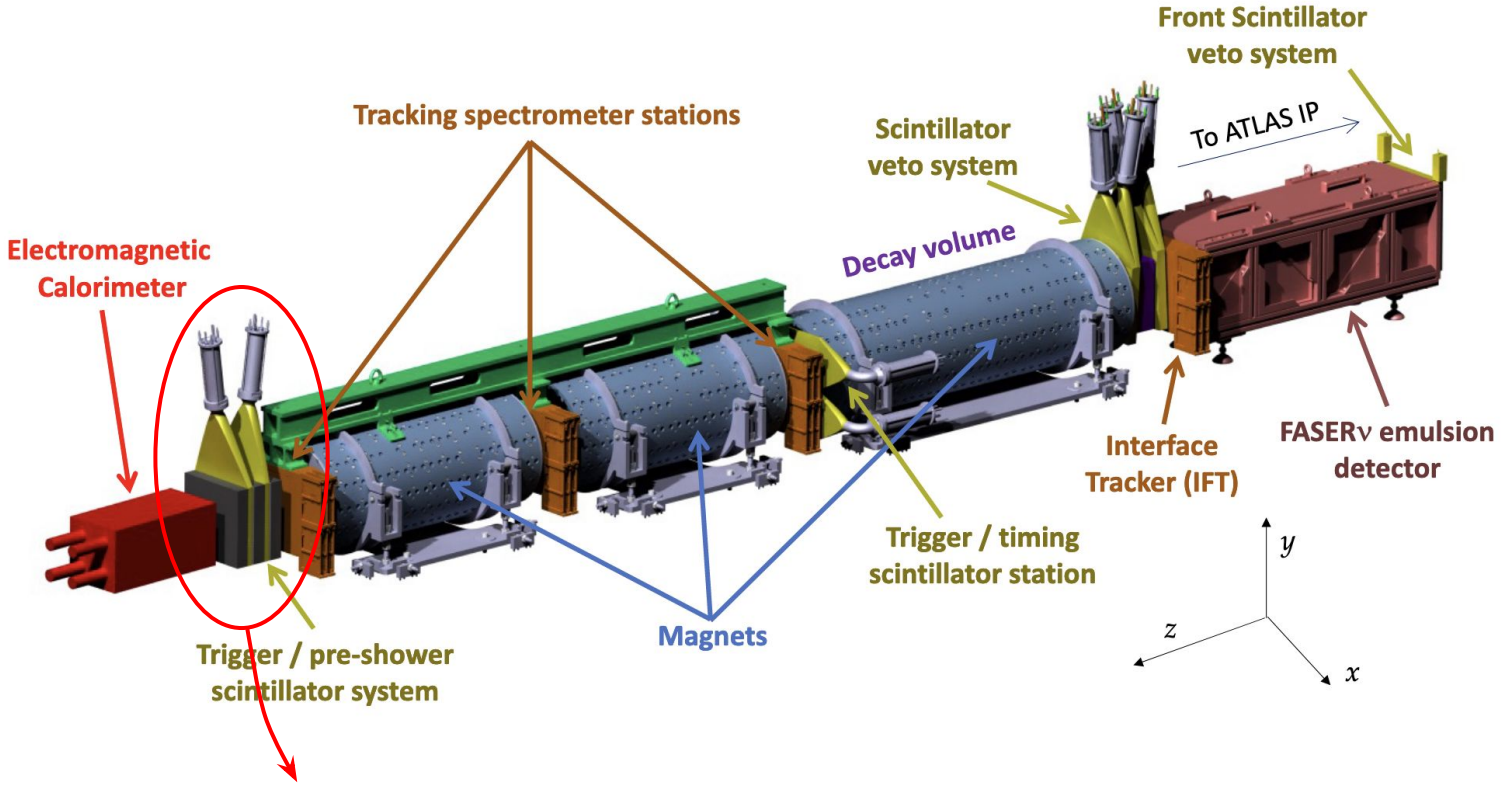


The FASER experiment



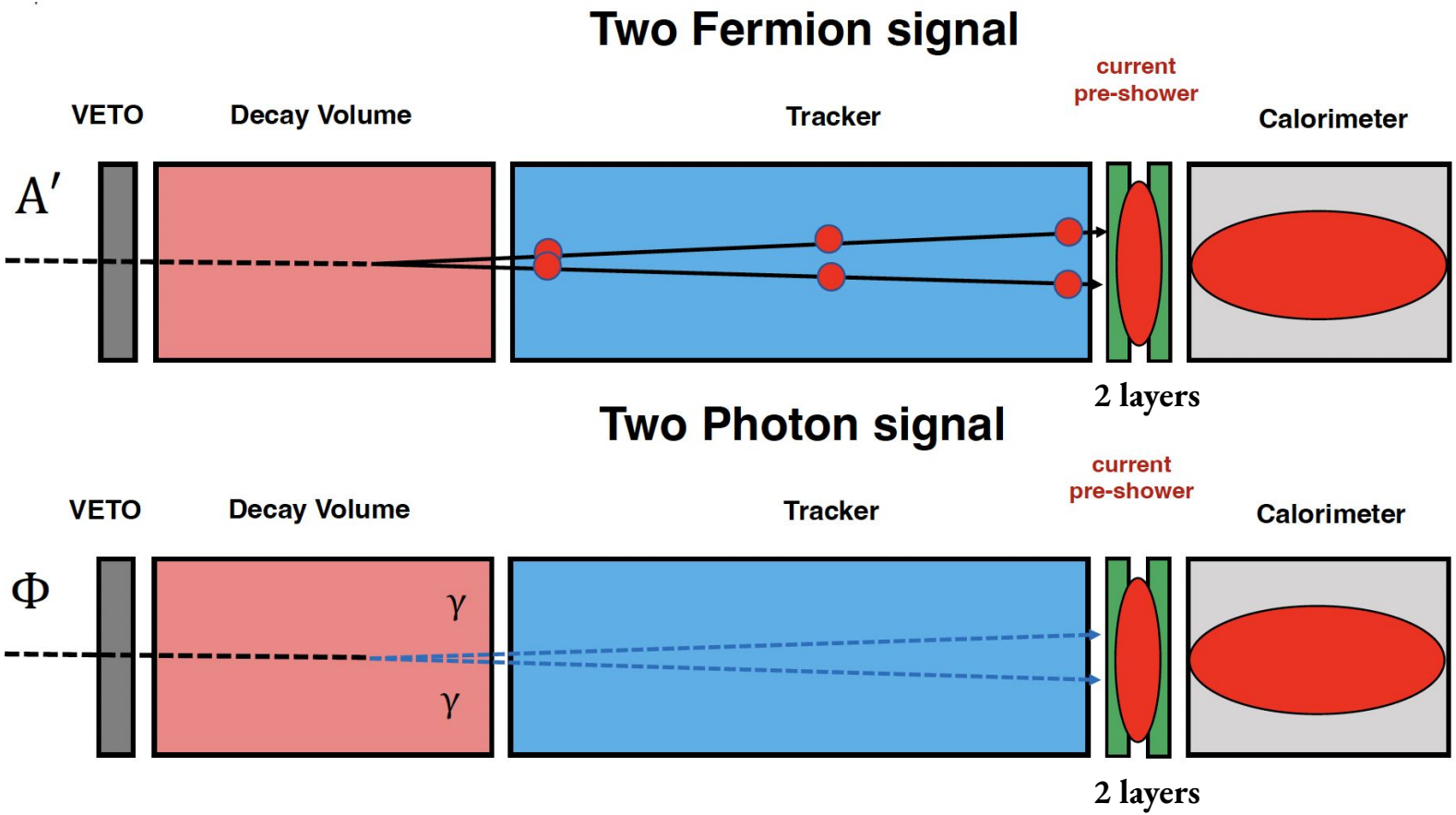
5m length, 2cm magnet aperture (0.57 T)

The FASER experiment

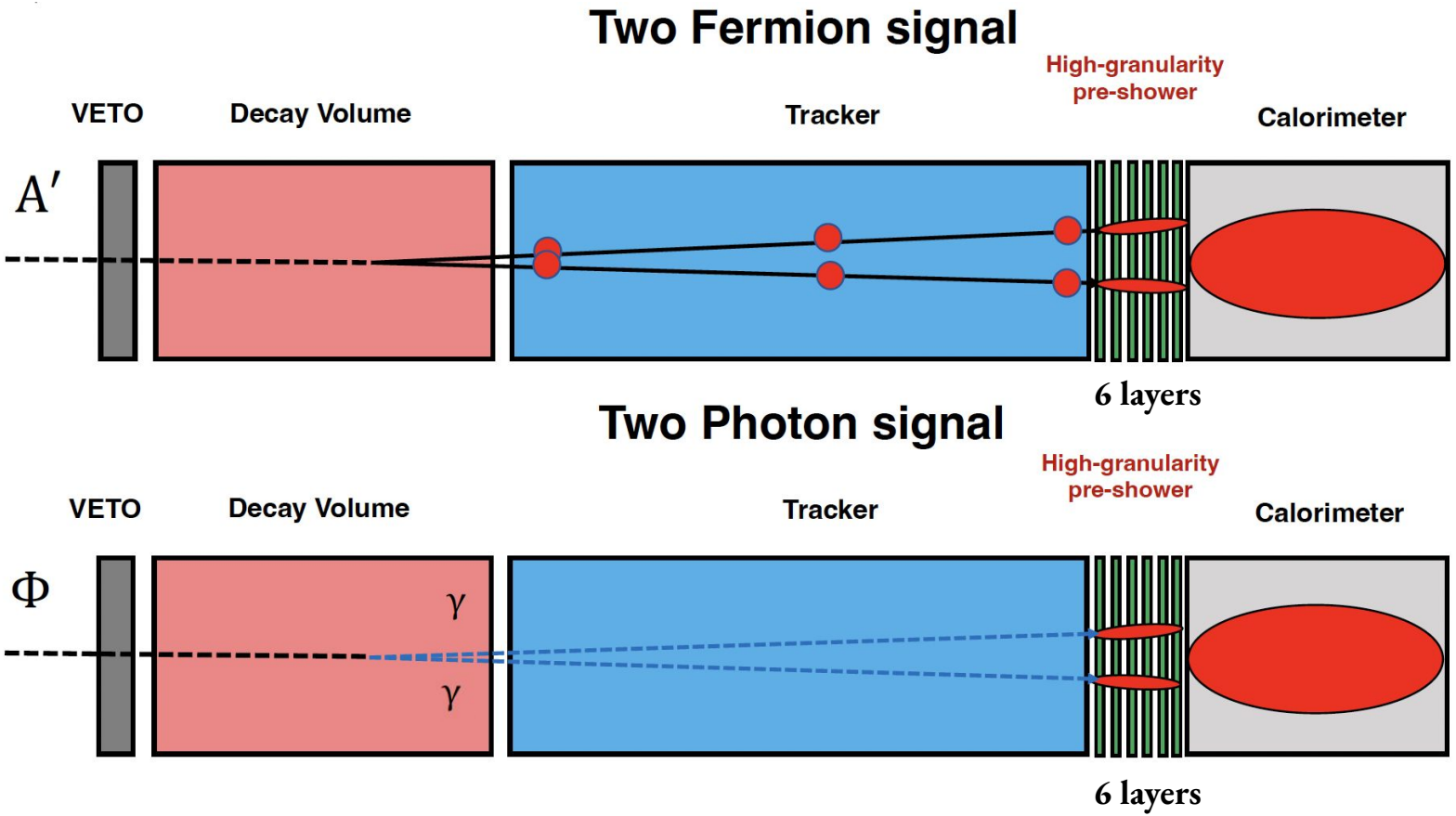


2 tungsten ($2X_0$) + 2 scintillator layers (+3 graphite layers)

Current physics signatures in FASER

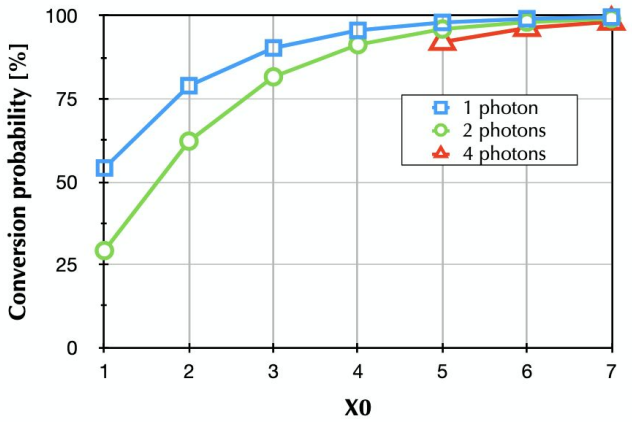


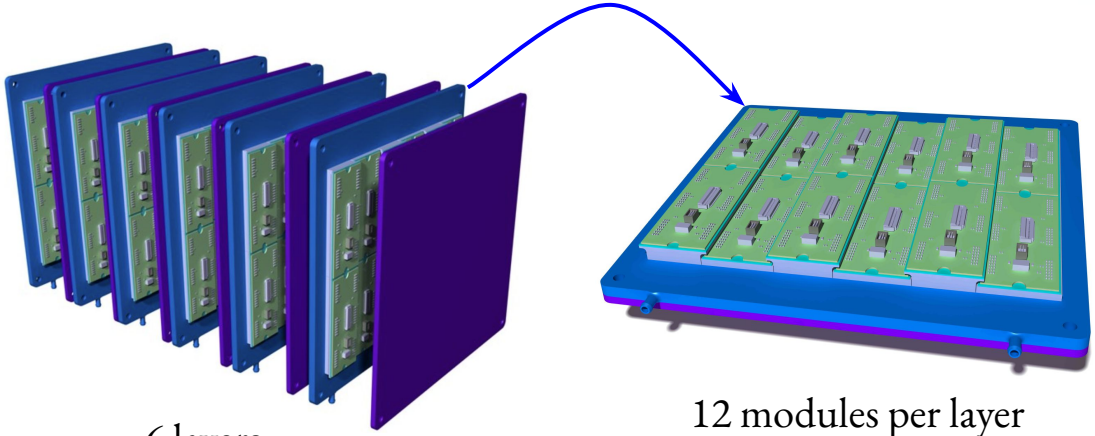
Desired physics signatures in FASER



Preshower layout

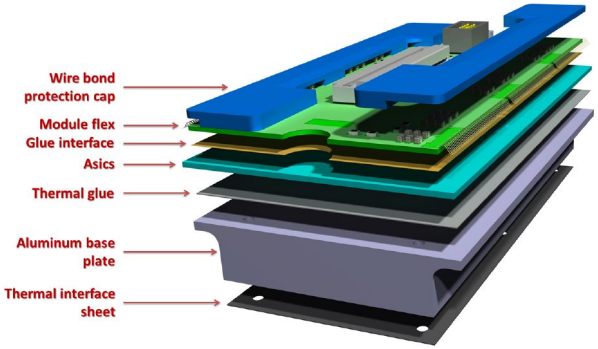
- Layout: 6 layers of silicon + 6 tungsten layers ($1X_0$ per layer)
  → Conversion probability after 6 X_0 > 98% for 2 photons
- 12 modules per layer, each module consisting in 6 monolithic pixel ASICs
  → 432 ASICs, 11.5M (hexagonal) pixels





6 layers

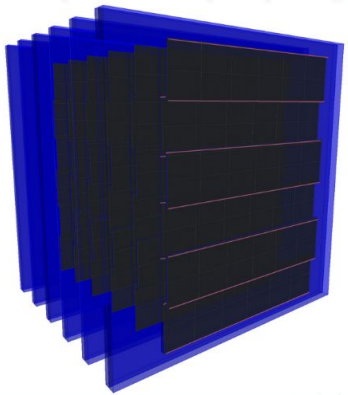
12 modules per layer on cooling plate

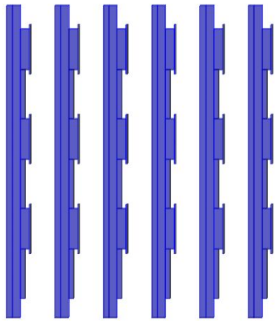


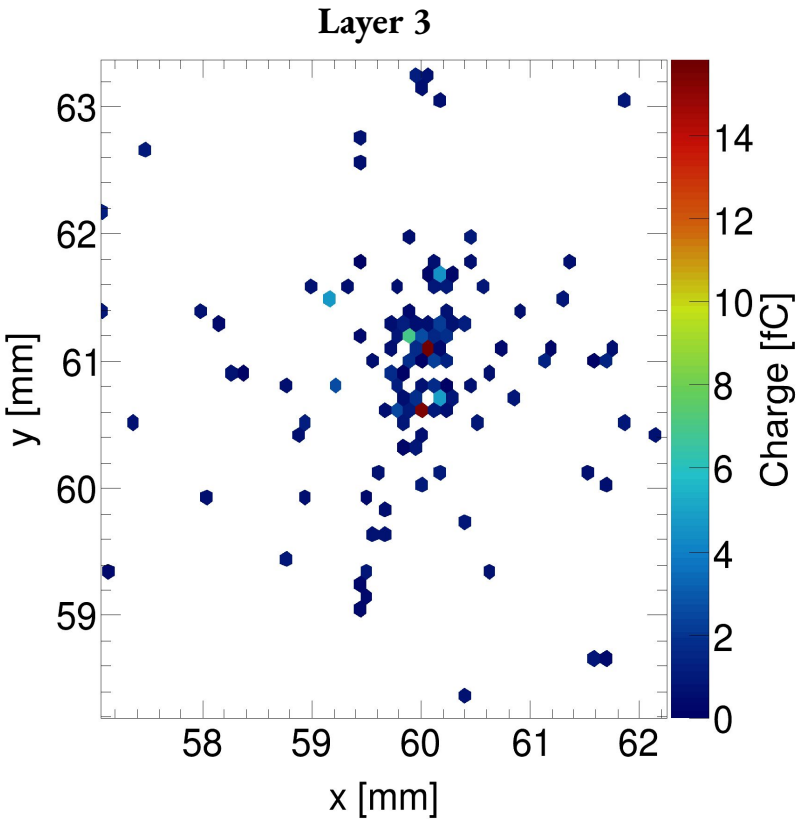
Module stack

Preshower simulation: 2 photon signature

Two photons
E = 1 TeV, ΔR = 500 μm







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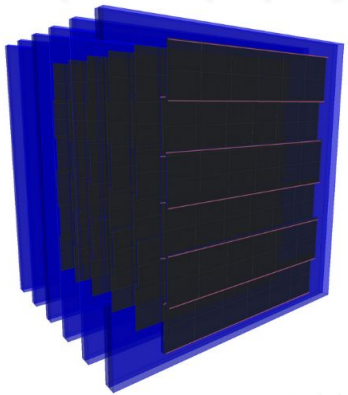

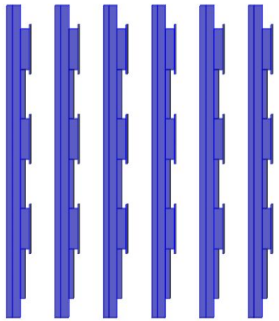

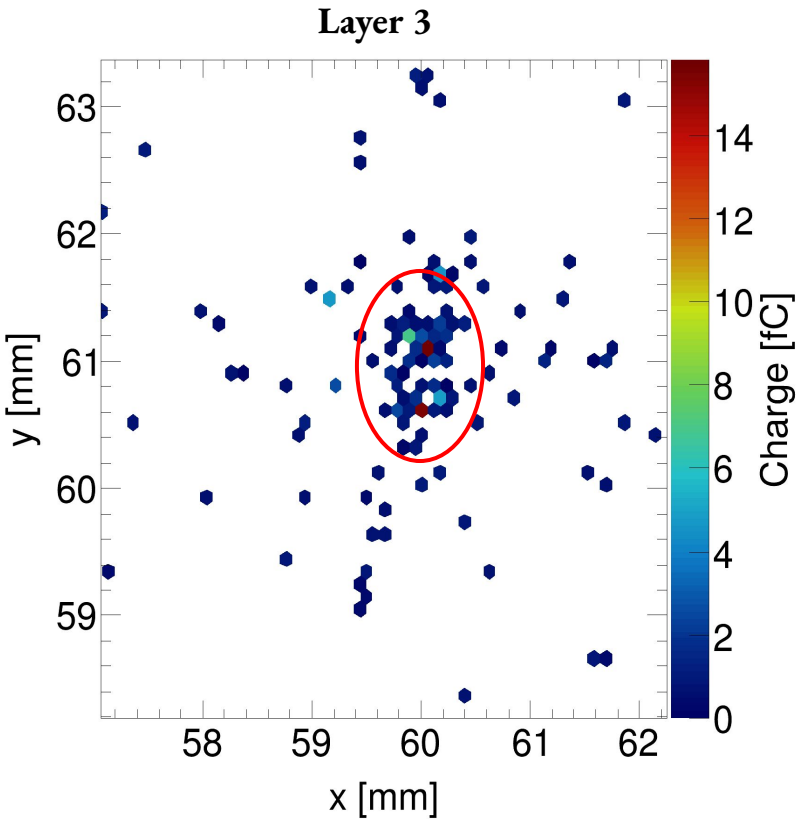

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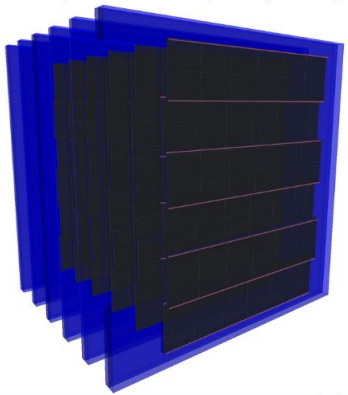

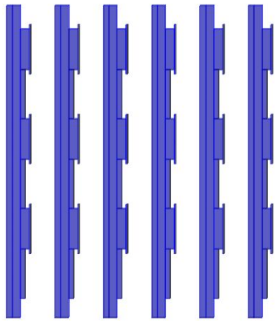

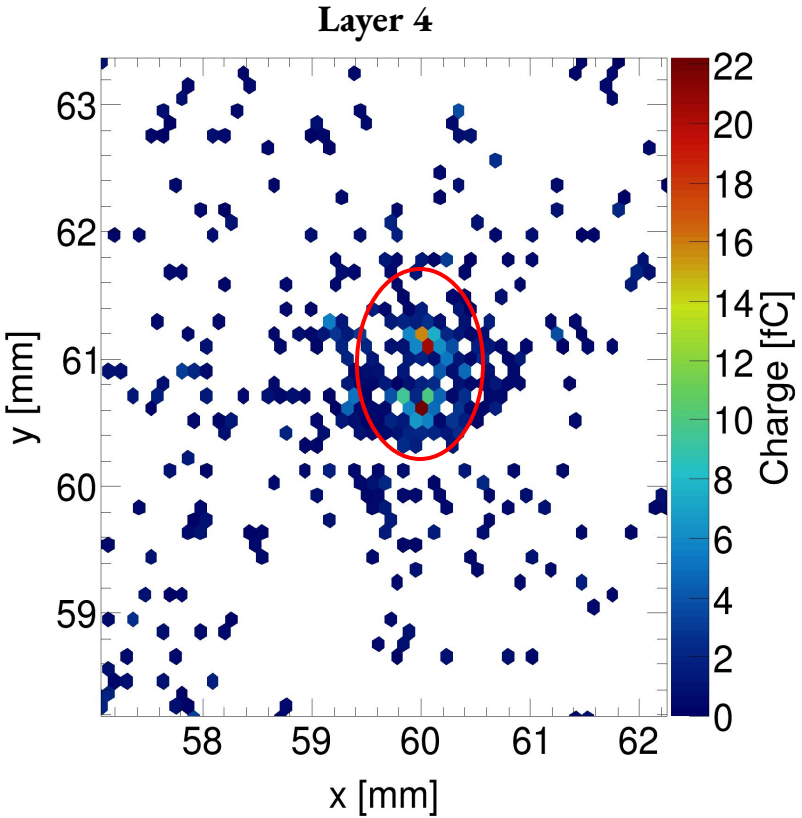

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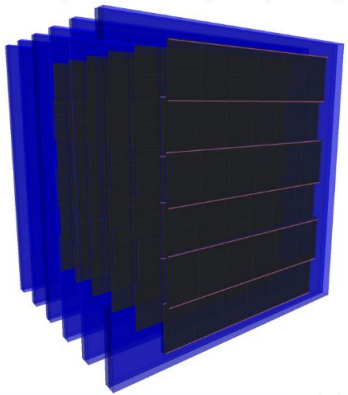

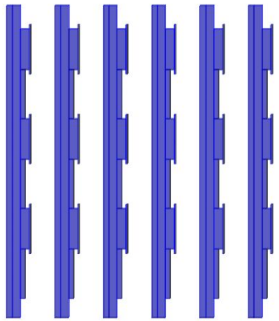

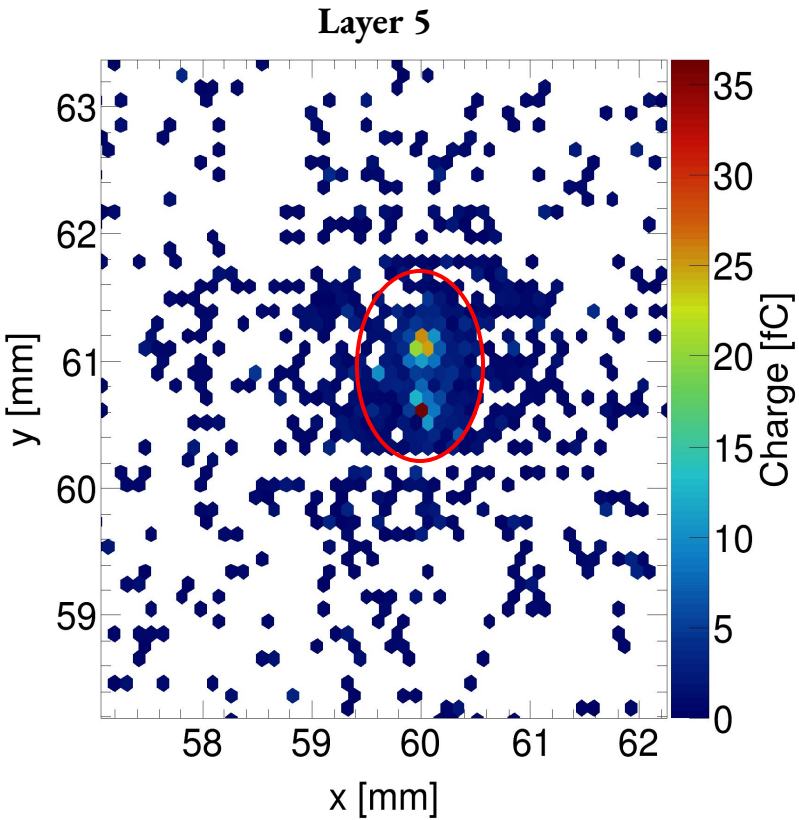

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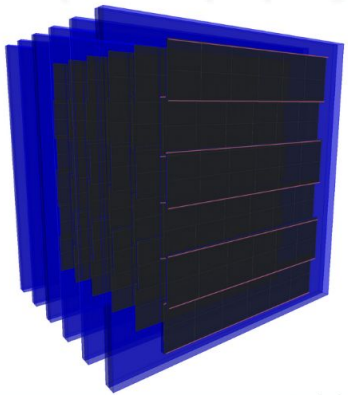
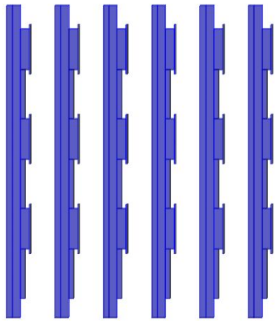
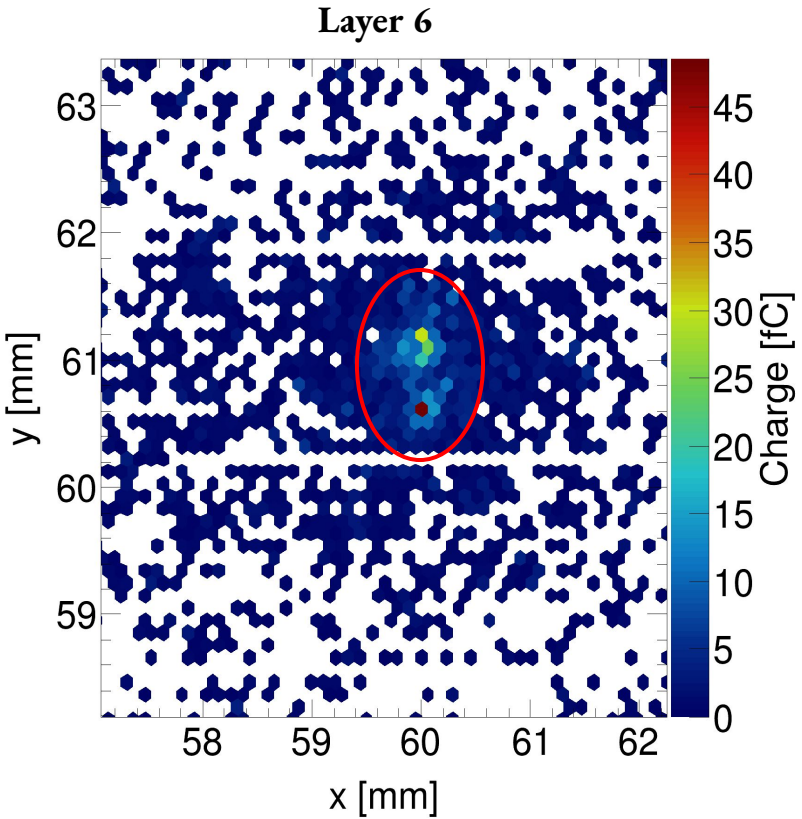


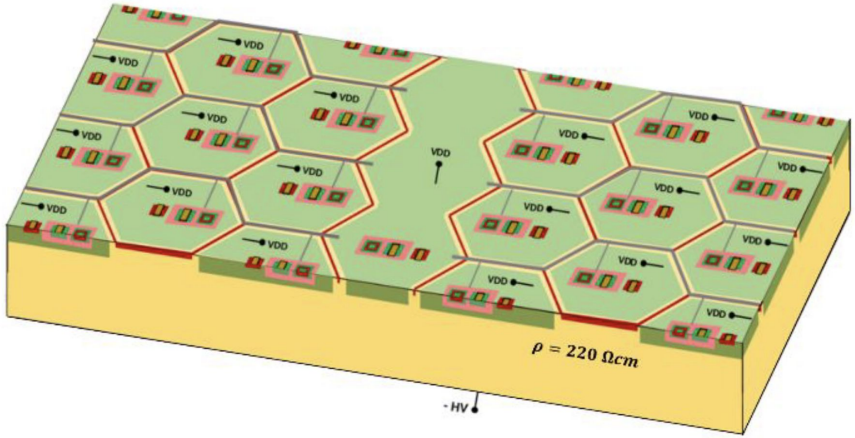




Monolithic pixel ASIC: Sensor

130 nm SiGe BiCMOS technology (IHP SG13G2)

- 220 Ωcm resistivity substrate, 130 µm thick
- Hexagonal pixels integrated as triple wells; pixel capacitance 80 fF
- 100 µm pitch



Main specifications	
Pixel Size	65 µm side (hexagonal)
Pixel dynamic range	0.5 ÷ 65 fC
Cluster size	O(1000) pixels
Readout time	< 200 µs
Power consuption	< 150 mW/cm^2
Time resolution	< 300 ps

Pre-production prototype

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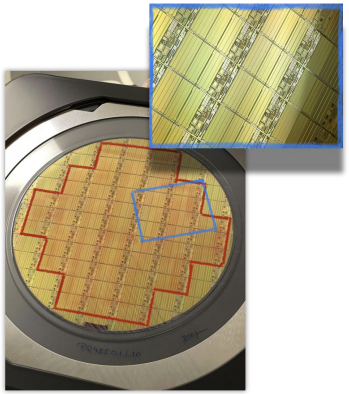
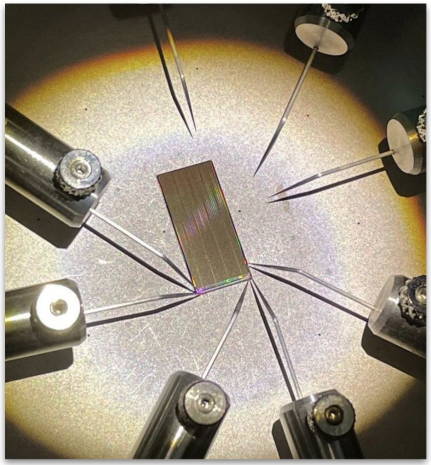
Wafers with pre-production prototype chips received on June 13th, 2022

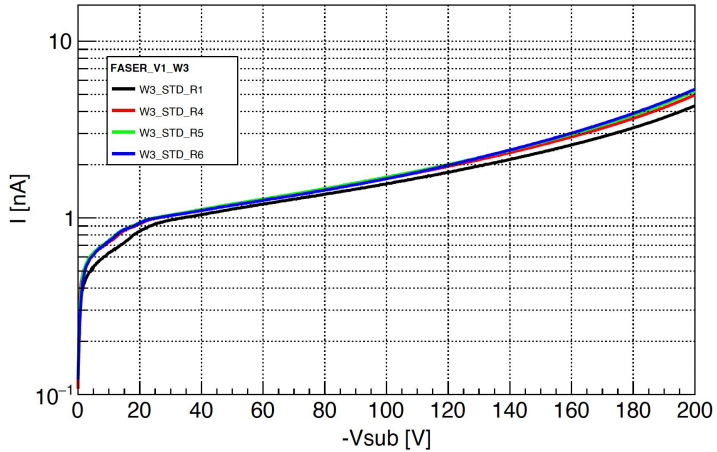
- 3 Standard wafers, 50 Ωcm resistivity substrate



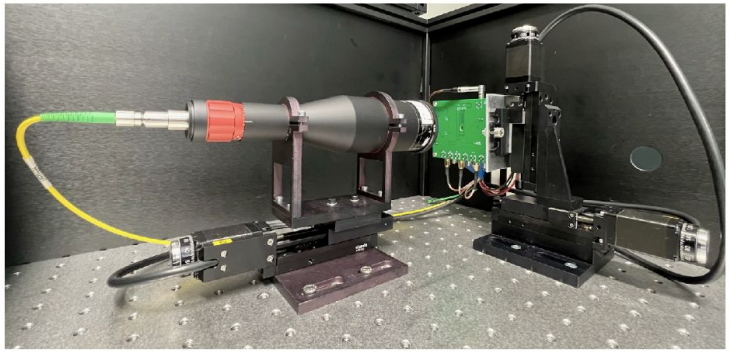
Good results in I-V characterization at probe station

- Reaching >200 V with innermost guard ring connected to ground



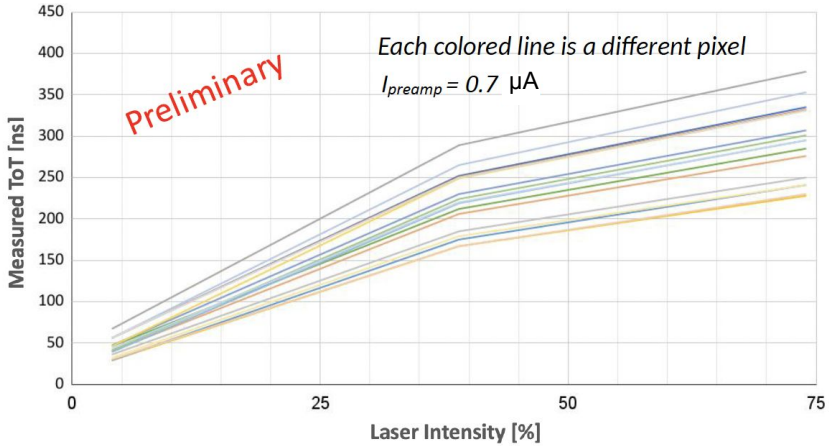


Pre-production chip ToT (charge) mismatch



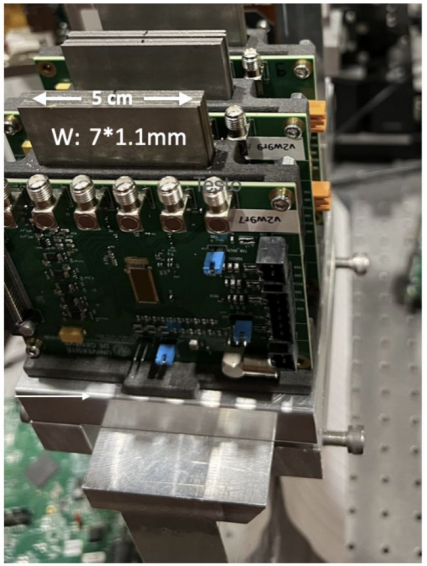
Evaluating charge response with infrared laser

- Measuring ToT via Fast-OR signal on the scope
- Varying per-pixel injected charge via laser attenuator
- Some mismatch observed → improved in the final chip

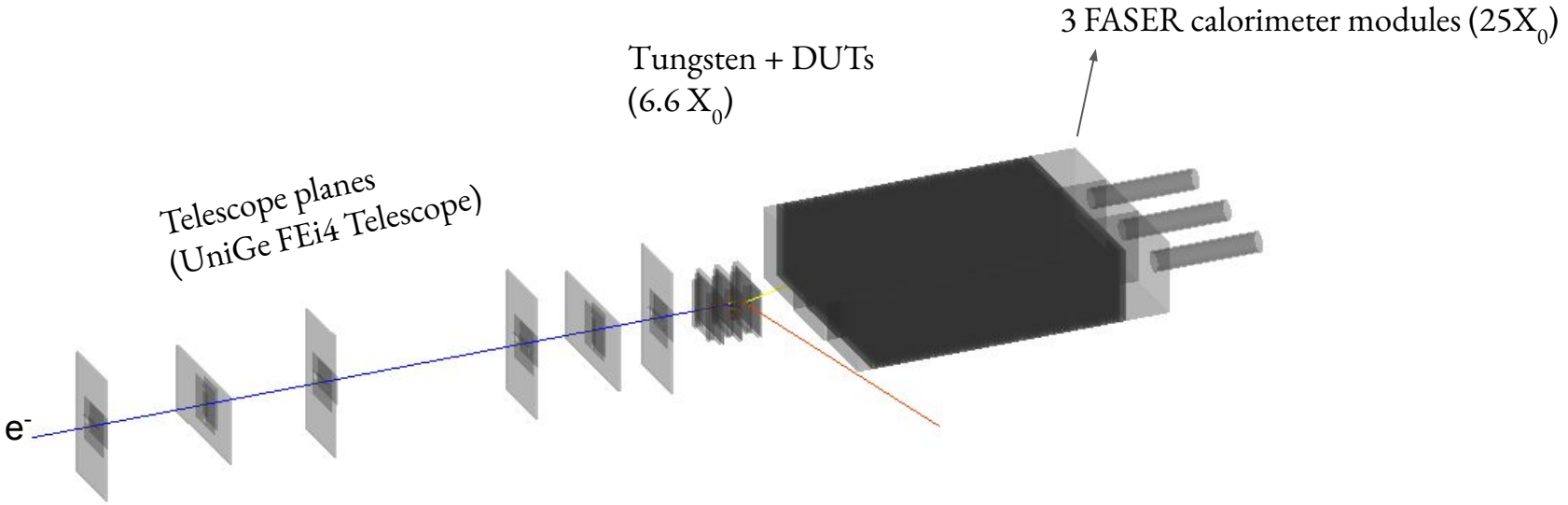


Testbeam September 2022

- Testbeam at CERN SPS (H2 beamline) to study
  - The behaviour of the preproduction chip → used mainly for debugging for final production chip
  - The calorimeter response after 6.6X0
- Setup consists of
  - 6 telescope planes
  - 3 DUT planes, each after 2.2X0 of tungsten: 6.6X0 in total
  - 3 FASER calorimeter modules (next to each other) at the end of the setup
- Electrons of E = 20, 50, 80, 100 and 150 GeV



Testbeam setup



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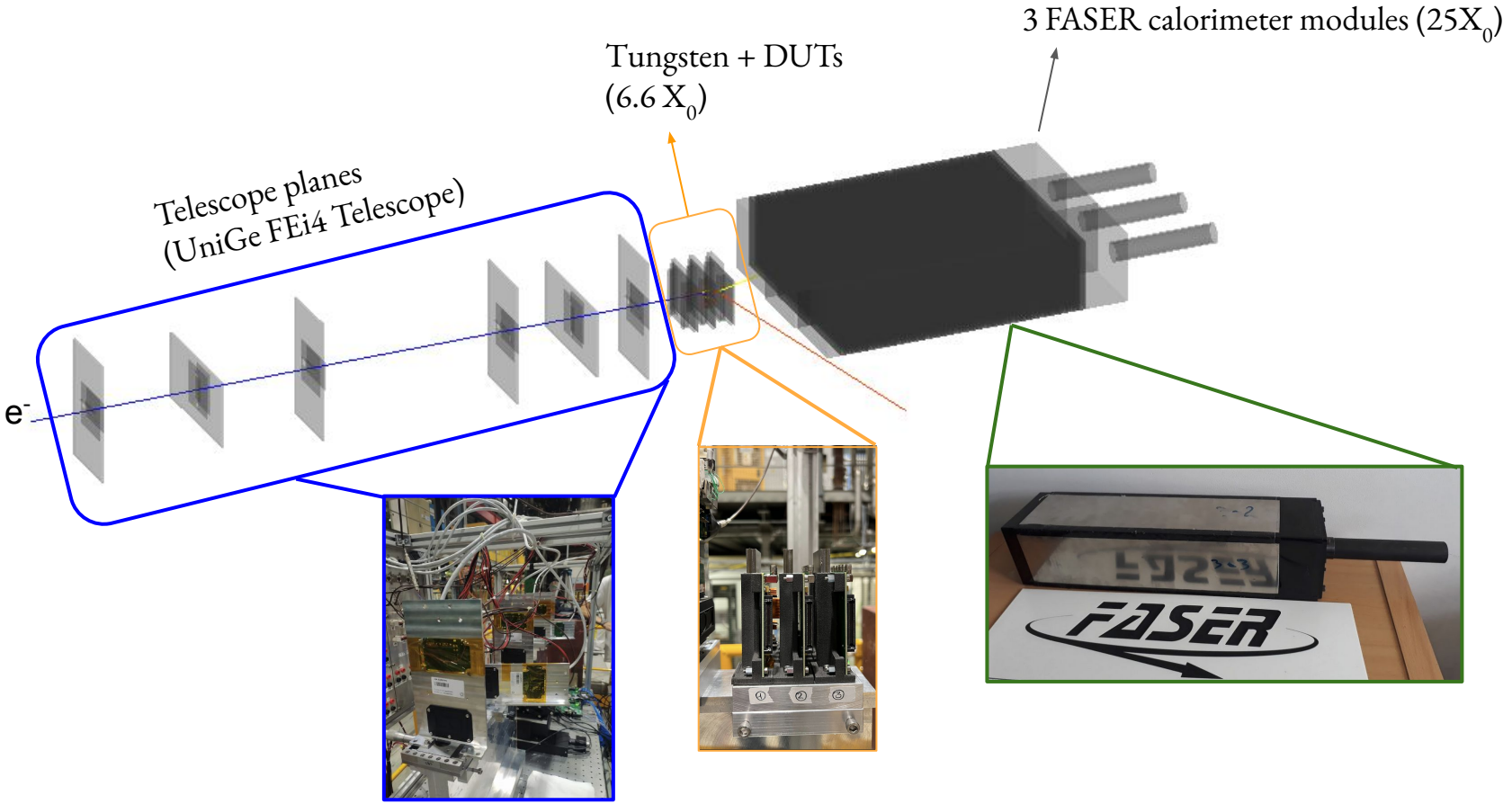
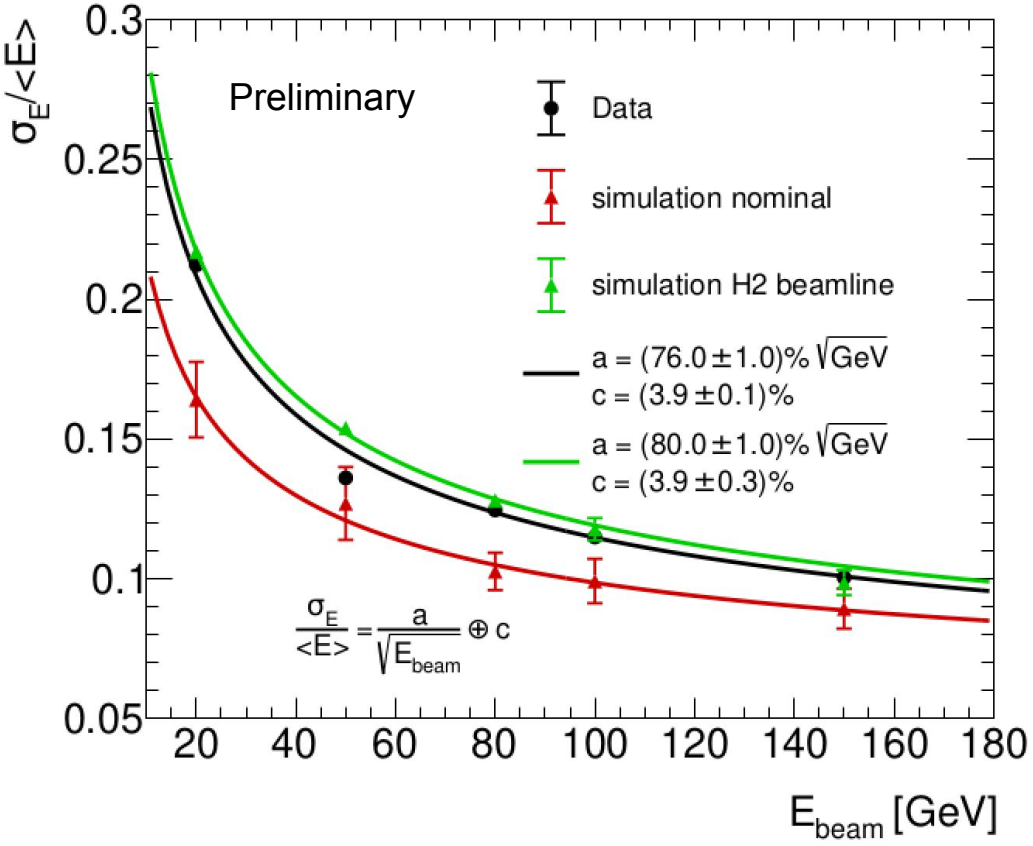


Calorimeter resolution data and simulation



- Early analysis showed data/mc discrepancies
- Simulations were pointing to missing material upstream in simulation (NA61, magnets, pipes,..) → degraded resolution
- Material upstream simulation with G4Beamline provided by authors of [1]
- Good description of the calorimeter response by simulation

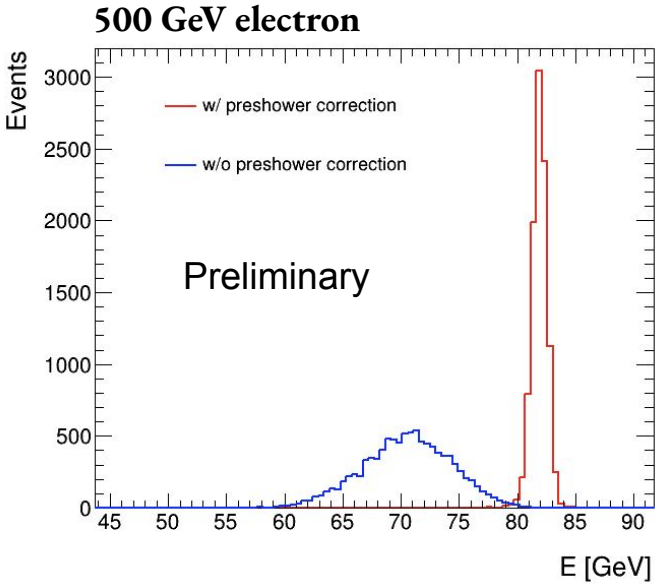
[1] arXiv:2111.06855.

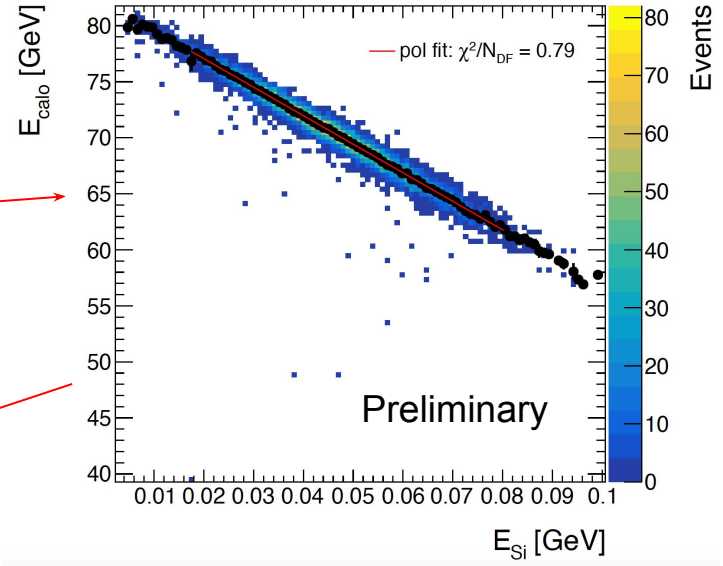
Special thanks to Ali Eren Simsek and Nikolaos Charitonidis

Energy measurement in FASER calorimeter + preshower

$$E_{tot} = E_{calo} + \gamma E_{Si}$$

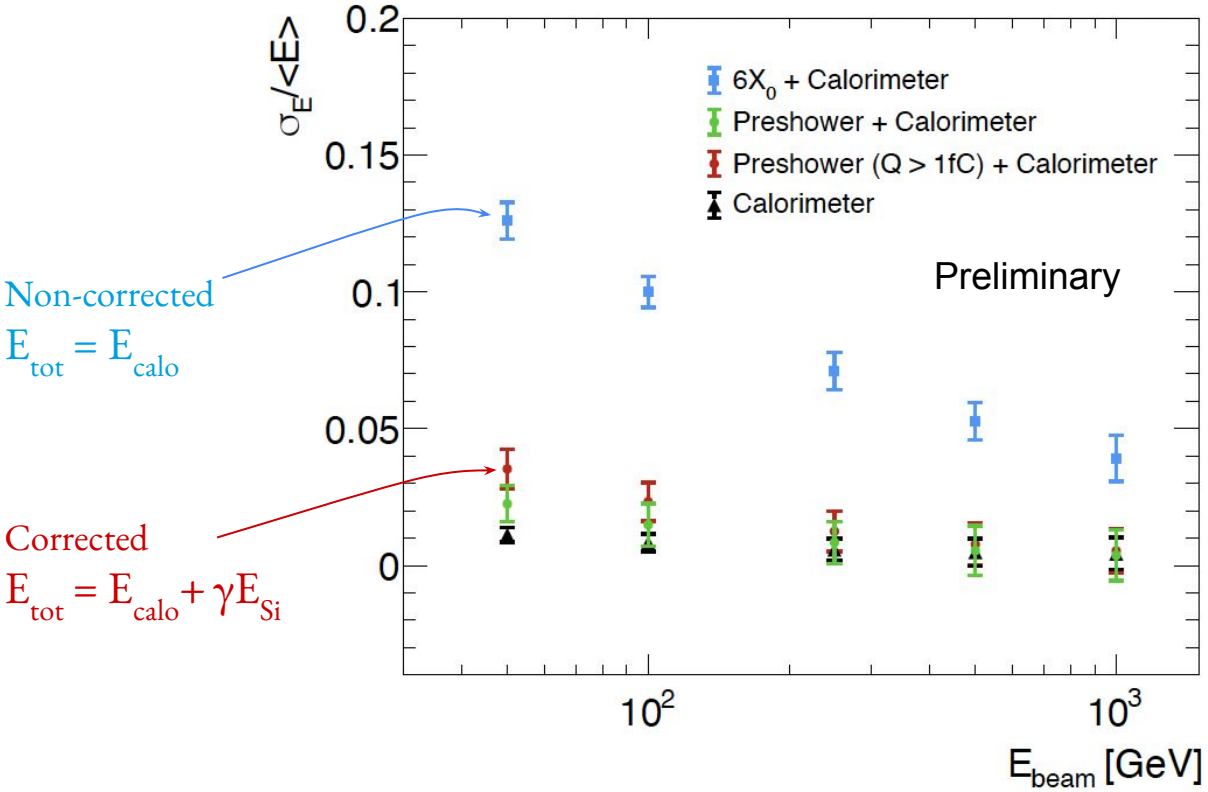
Calculated from E_{calo} vs E_{Si}





γ is stable within 10% from 50 GeV to 2 TeV for charge threshold > 1fC

Calorimeter + preshower energy resolution



Summary & outlook

A new preshower detector is being developed for the FASER experiment

- Discriminating very collimated photons from LLP decays
- Installation targeted for in 2024, data-taking at end of Run 3

Chips received June 2022

- IV characteristics OK, chip operated up to 200V
- Possible improvements planned e.g. ToT mismatch
- Tests on single chips and first assembled modules ongoing

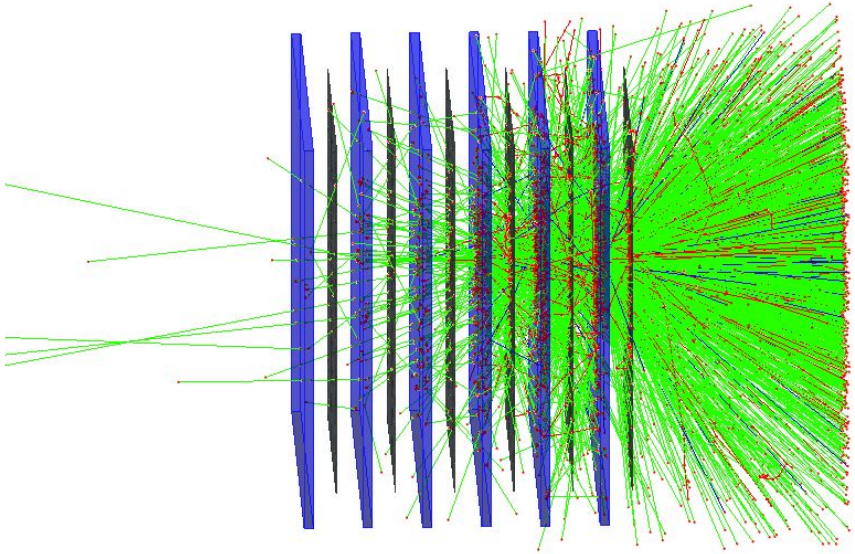
TestBeam September 2022

- Useful to debug pre-production chip and prepare for final chip submission
- Calorimeter data used to validate simulation and study resolution
- Preshower correction able to recover the calorimeter resolution at high energies

[1] arXiv:2111.06855.

Special thanks to Ali Eren Simsek and Nikolaos Charitonidis

Backup

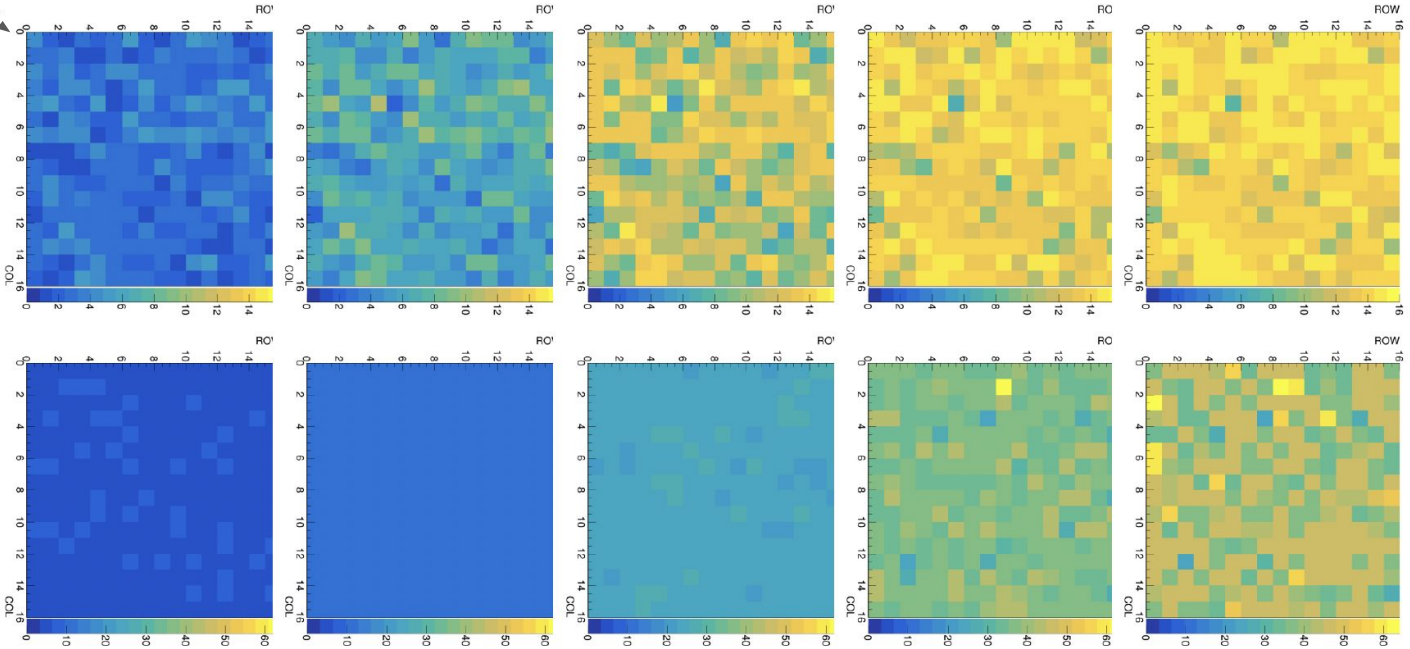


Test with full readout: charge calibration

One superpixel
(16x16 pixels)

Before calibration

After calibration



Color map ⇒ ADC response: [0-15] before calibration, [0fC-65fC] after calibration

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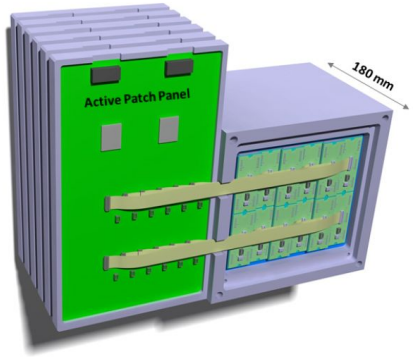
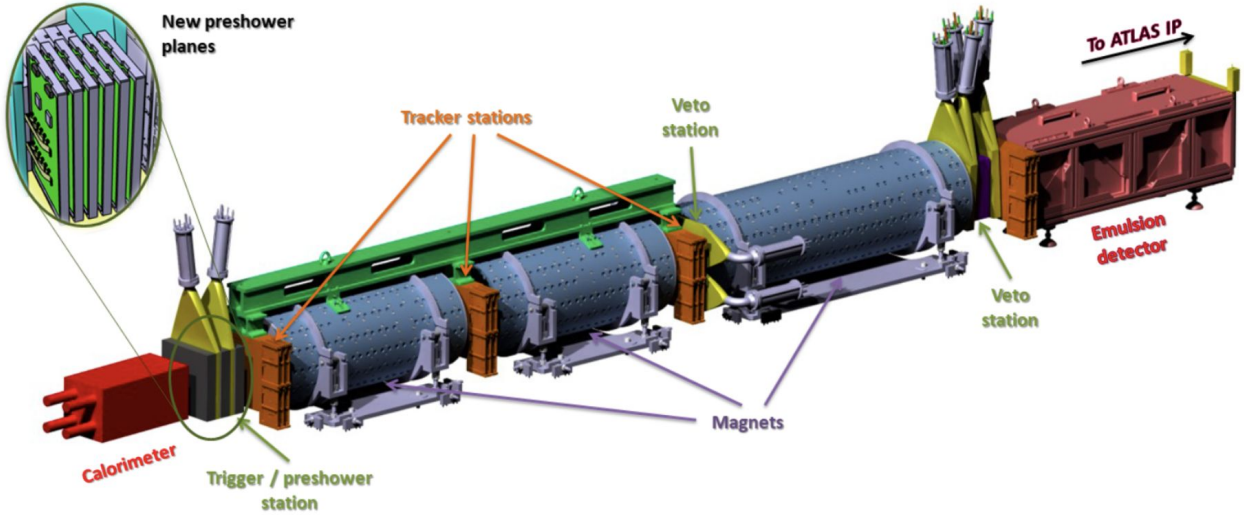
Acknowledgements

The development of the new pre-shower by the FASER collaboration was funded by a Swiss National Science Foundation (SNSF) grant at the University of Geneva, with financial contributions also from KEK, Kyushu University, Mainz University, Tsinghua University and the Heising-Simons Foundation.

Preshower layout





Technical proposal reconstruction algorithm