Prototype test beam results and design of the future Forward Calorimeter in ALICE

Max Rauch for the ALICE Collaboration

7th edition of the International Conference
on the Initial Stages in High-Energy Nuclear Collisions

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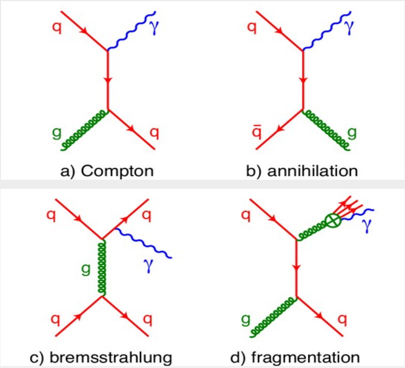
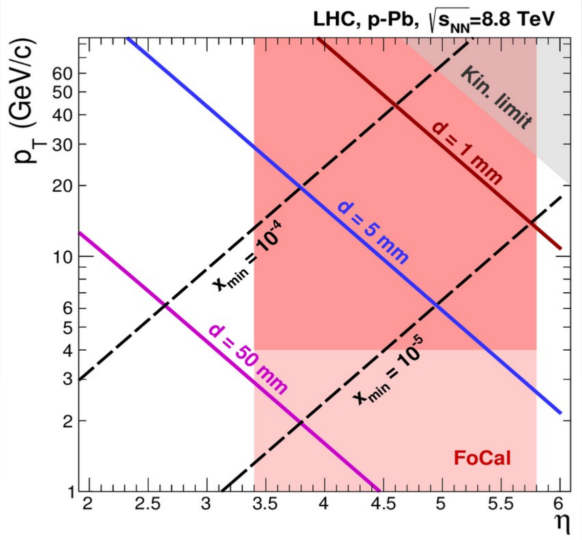
ALICE

UNIVERSITAS BERGENSIS

Single isolated photon signal events



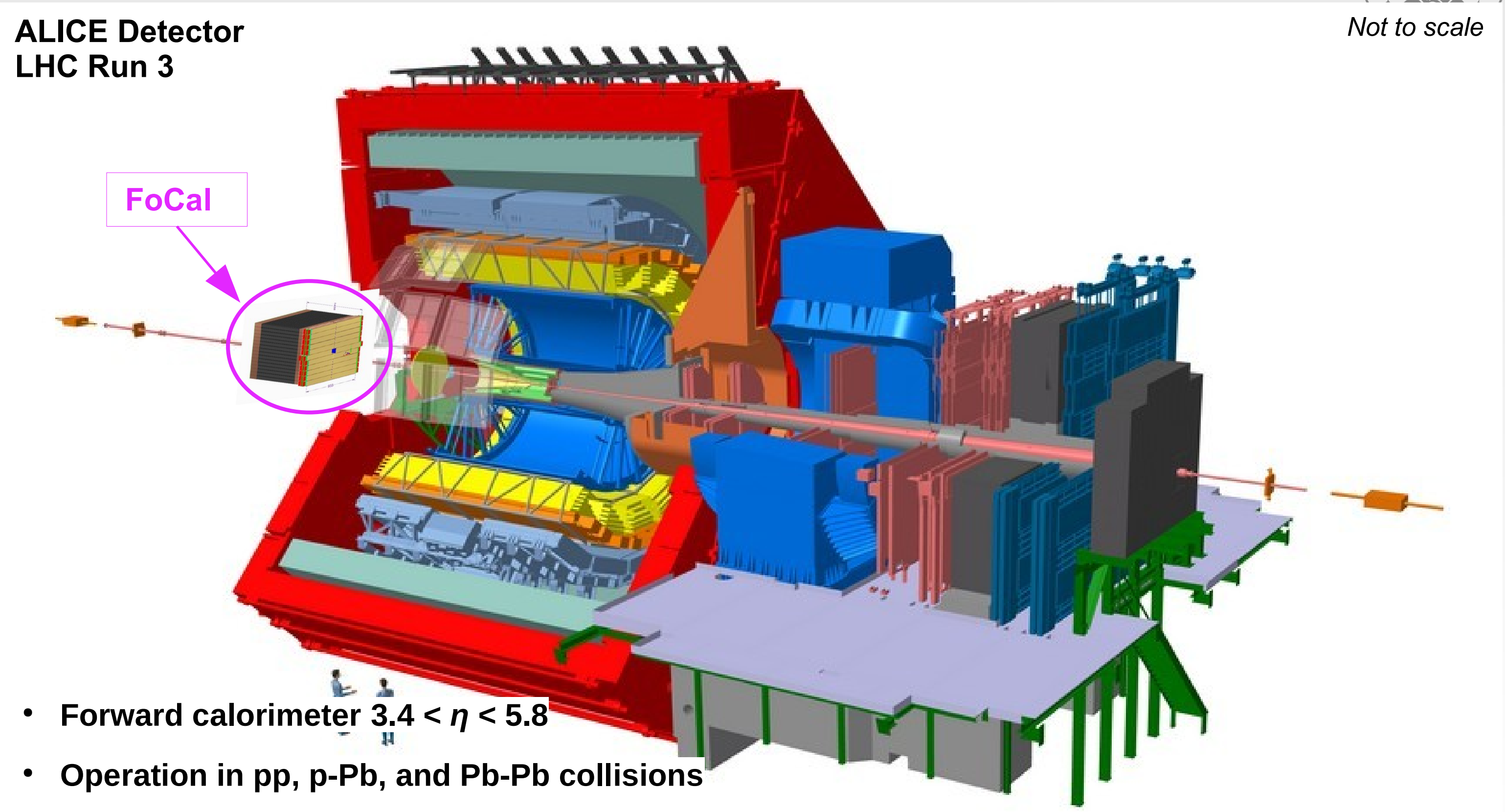


Thanks to Peter Jacobs for the nice overview of the ALICE FoCal physics program.

- Flagship measurement: single isolated photons
  - Very forward direction 3.4 < η < 5.8
  - Exploration of low-x regime
- Electromagnetic calorimeter
  - High photon detection efficiency
  - **< 5 % resolution at high energies**
  - Discrimination of π^0 decay into two ɣ by electromagnetic **shower separation d < 5mm**
- Hadronic calorimeter
  - **< 25 % resolution at lower energies for isolation measurement**
  - **< 15 % resolution at high energies for energy measurement**
- **ALICE For**ward **Cal**orimeter → **ALICE FoCal**

This talk is on the instrumentation and prototyping of such a detector.

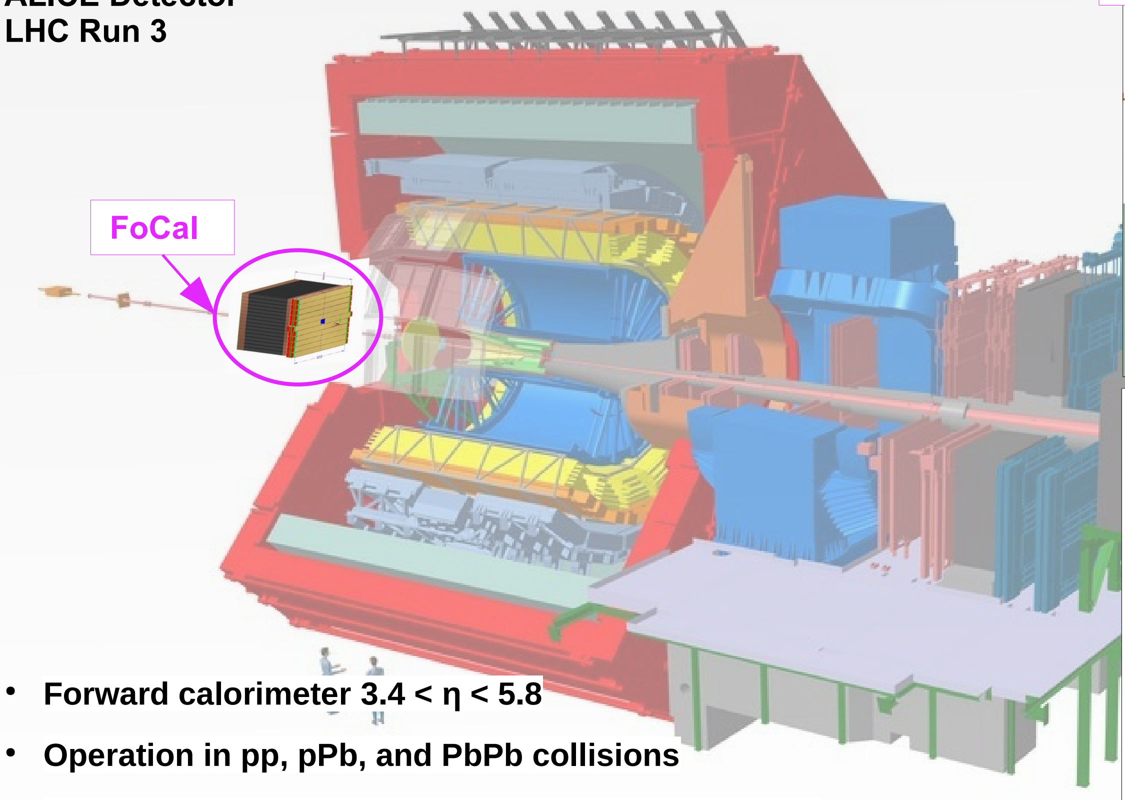
The FoCal detector in ALICE

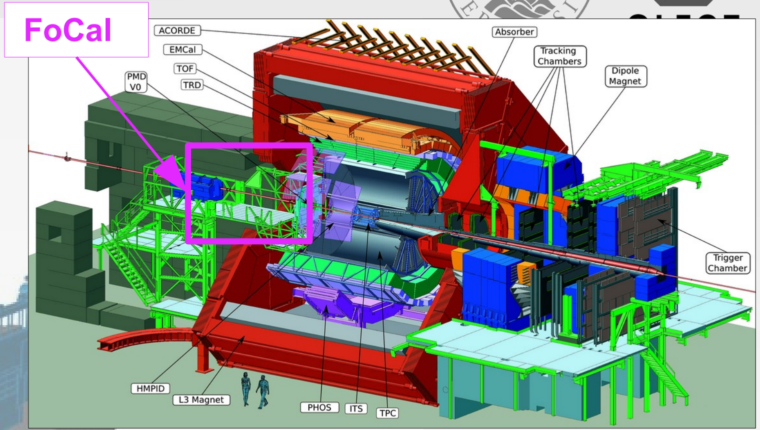


- **Forward calorimeter 3.4 < η < 5.8**
- **Operation in pp, p-Pb, and Pb-Pb collisions**
- **Installation in ALICE foreseen for LHC Run 4 (2029)**

The FoCal detector in ALICE

ALICE Detector
LHC Run 3





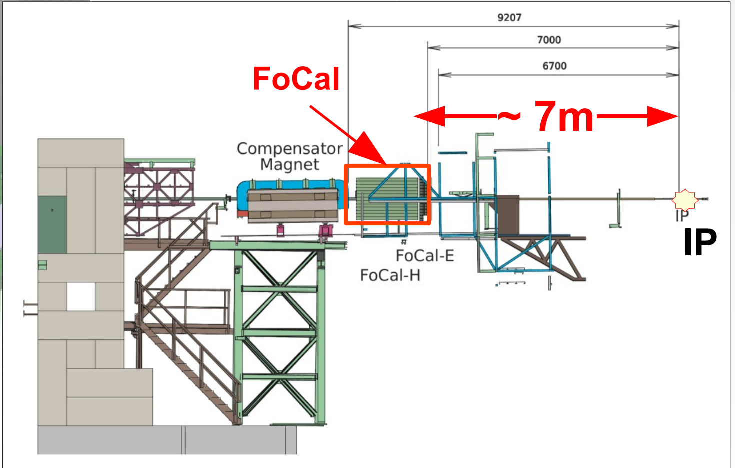
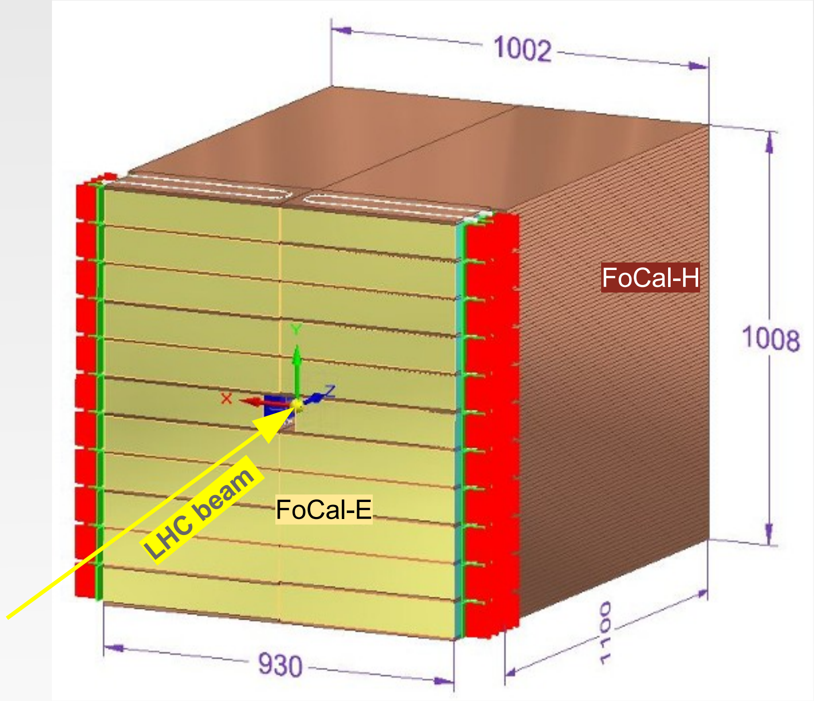
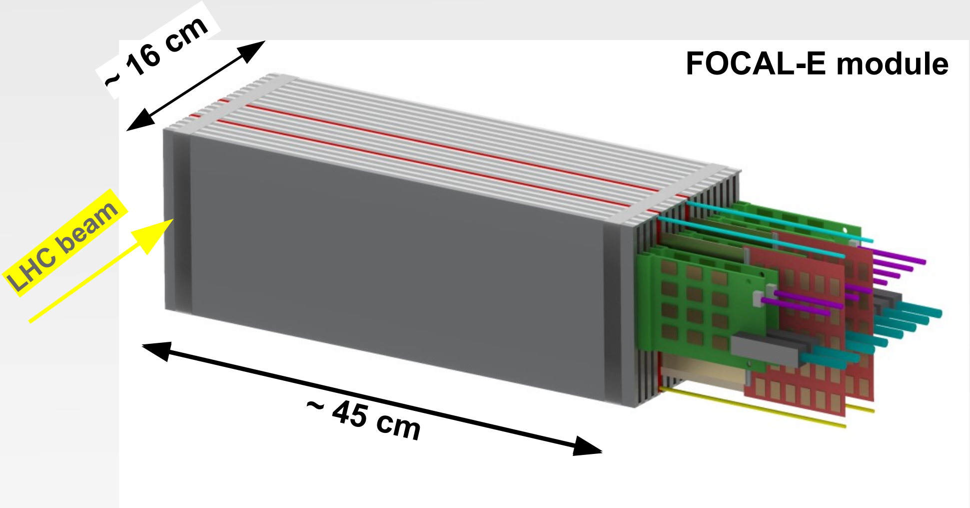


Fig. 19: Installation of the FoCal at the 7m location with FoCal-E and FoCal-H detectors.

- **Forward calorimeter 3.4 < η < 5.8**
- **Operation in pp, pPb, and PbPb collisions**
- **Installation in ALICE foreseen for LHC Run 4 (2029)**

ALICE FoCal detector design





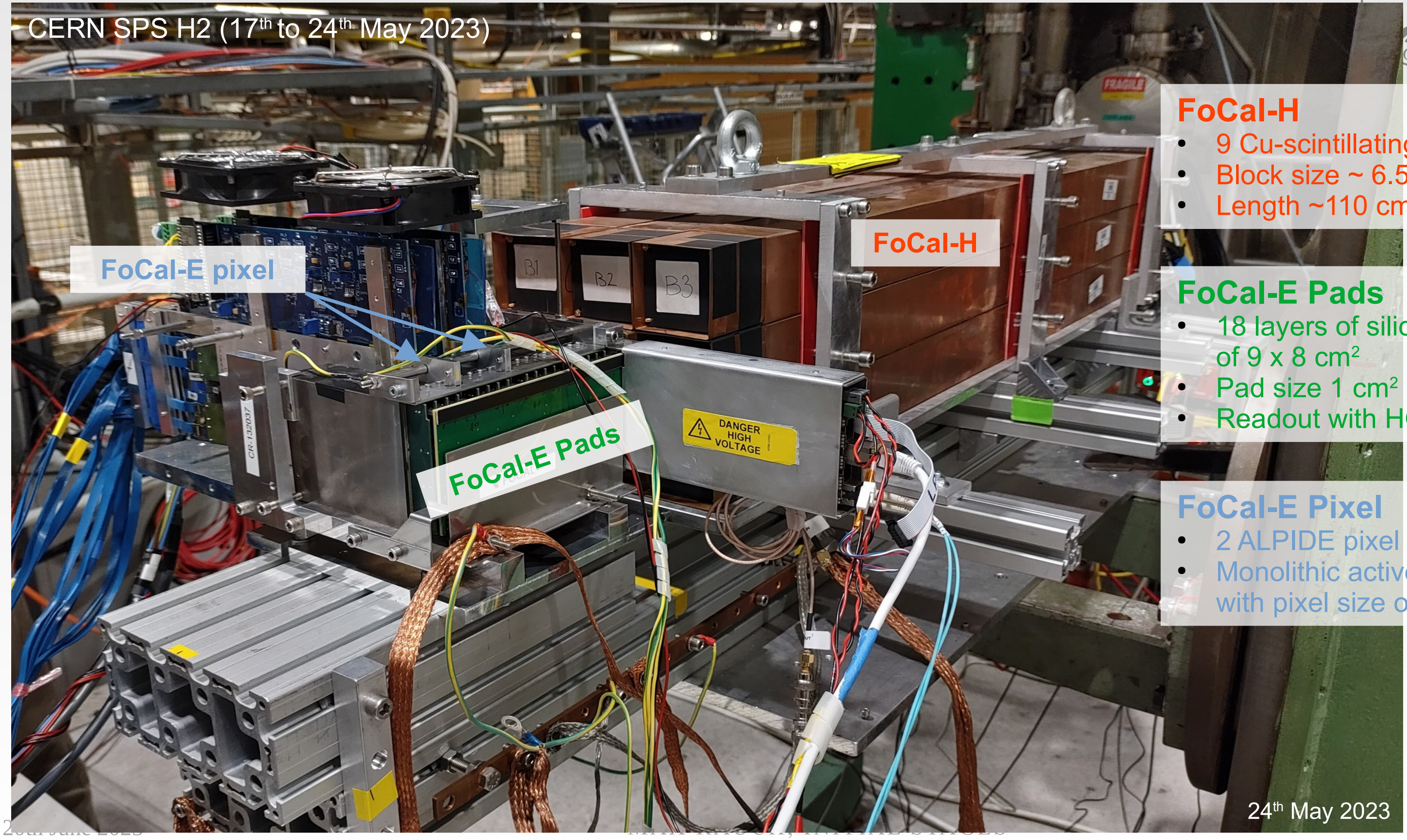
Hadronic calorimeter FoCal-H

- Transversally segmented calorimeter, total length ~ 6 λ_{had}
  - Spaghetti Cu-scintillating fibre design
  - Located directly behind FoCal-E (reduce shower blow-up)

Electromagnetic calorimeter FoCal-E

- 20 layers W absorbers (~ 20 X_0), longitudinally segmented
- Si-W sampling calorimeter (18 low-granularity layers + 2 high-granularity pixel layers)

ALICE FoCal prototype installed at CERN SPS H2

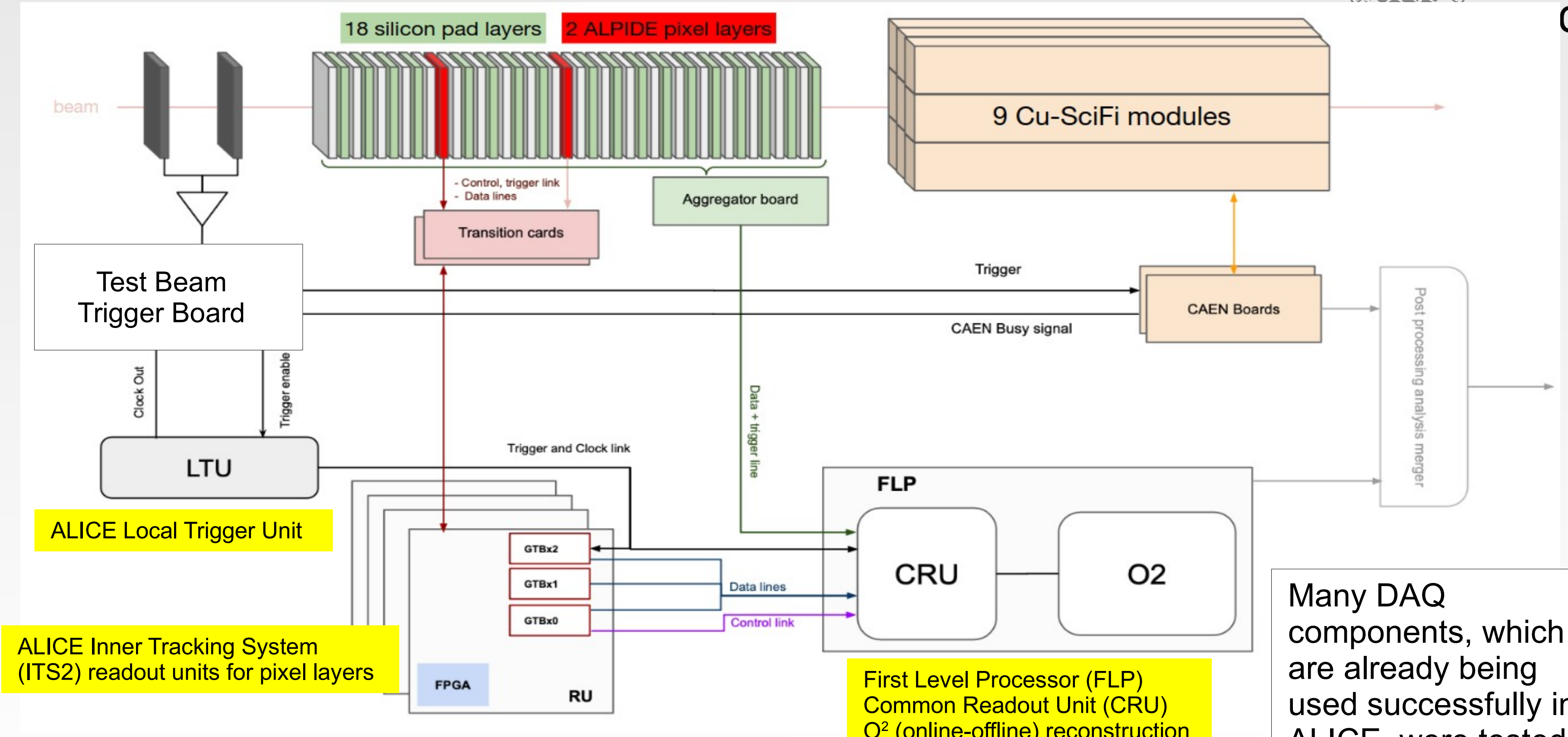


FoCal-H
- 9 Cu-scintillating fiber blocks
- Block size ~ 6.5 x 6.5 cm^2
- Length ~110 cm

FoCal-E Pads
- 18 layers of silicon pad sensors of 9 x 8 cm^2
- Pad size 1 cm^2
- Readout with HGCROC v2

FoCal-E Pixel
- 2 ALPIDE pixel layers
- Monolithic active pixel sensors with pixel size of ~30 x 30 μm^2

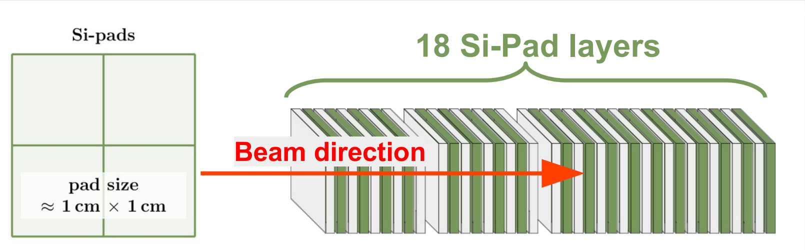
FoCal prototype DAQ May 2023

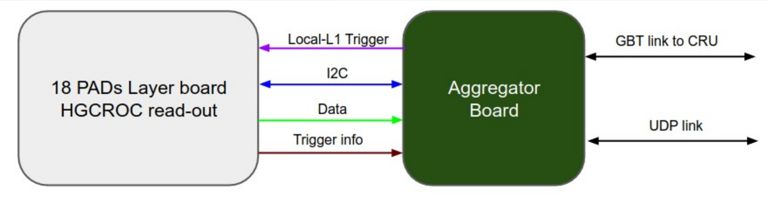


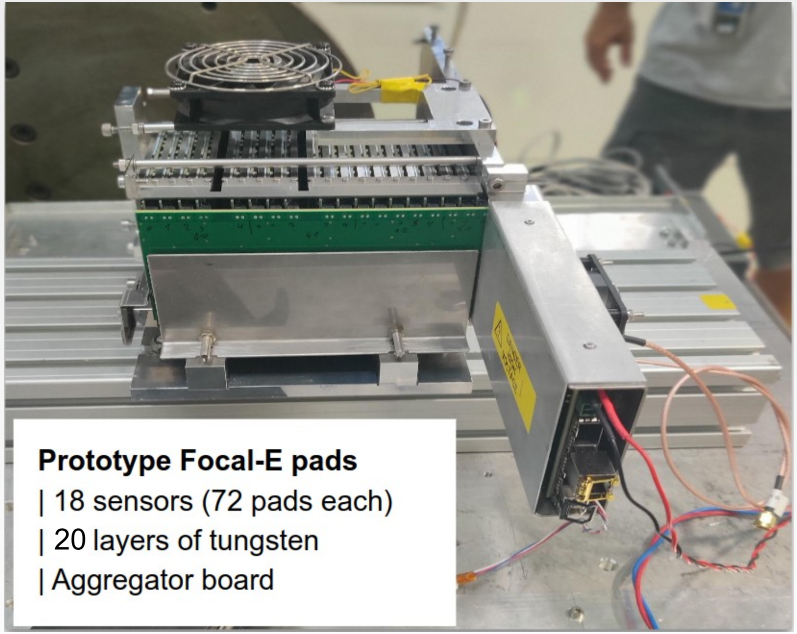
Many DAQ components, which are already being used successfully in ALICE, were tested

FoCal-E Pad prototype

- 18 layers of 9 x 8 silicon pad sensors (pad size 1 x 1 cm^2)
- Charge measurement per pad with ADC, ToT, and ToA
- High dynamic range: MIP ↔ 10 pC
- Fast trigger signal derived from HGCROCv2
- Longitudinal shower profile information for each layer



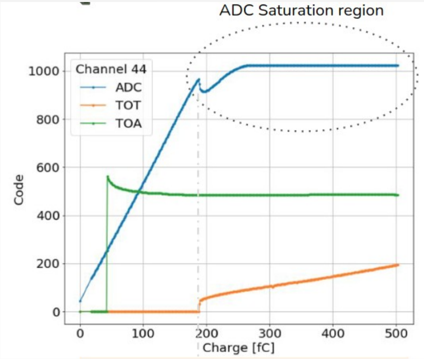




Analog-digital converter (ADC): 0 – 200 fC

Time over threshold (TOT): 0.2 – 10 pC

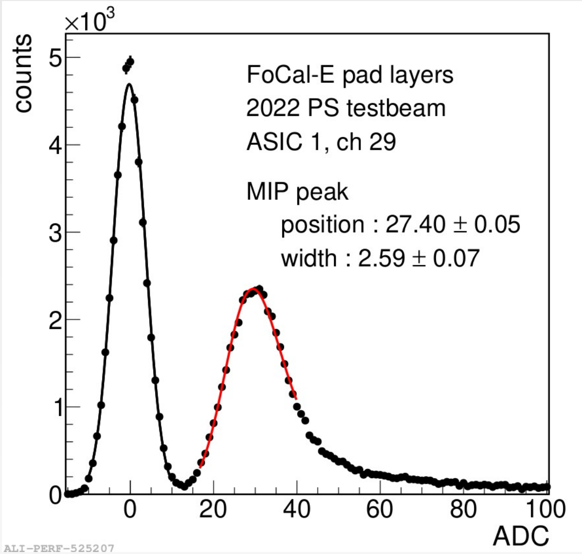
Time of arrival (TOA): 25ps resolution

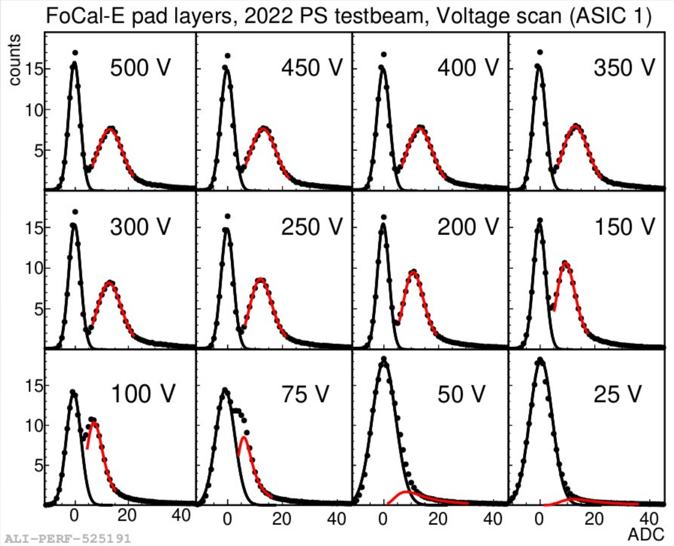


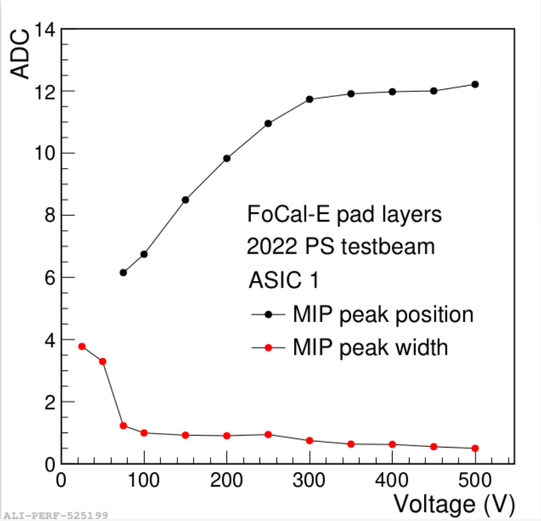
[1] Performance study of HGCROC-v2: the front-end electronics for the CMS High Granularity Calorimeter, D. Thienpont and C. de La Taille 2020 JINST 15 C04055

[2] Prototype electronics for the silicon pad layers of ALICE experiment at the LHC, O. Bourrion et al 2023 JINST 18 P04031

FoCal-E Pad MIP response

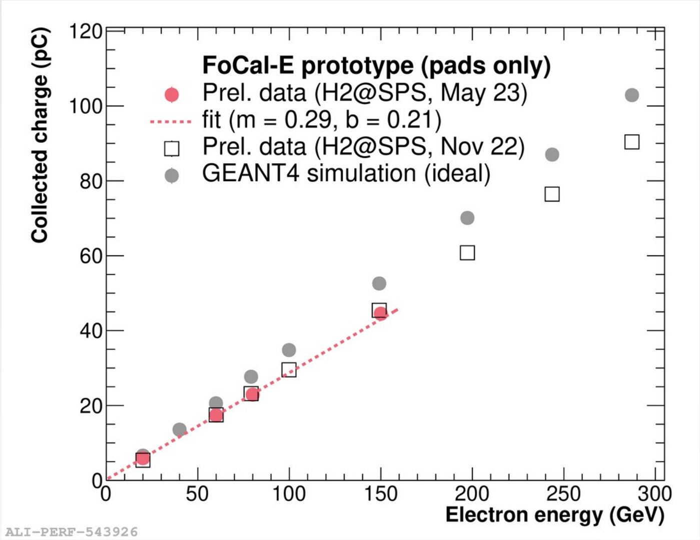


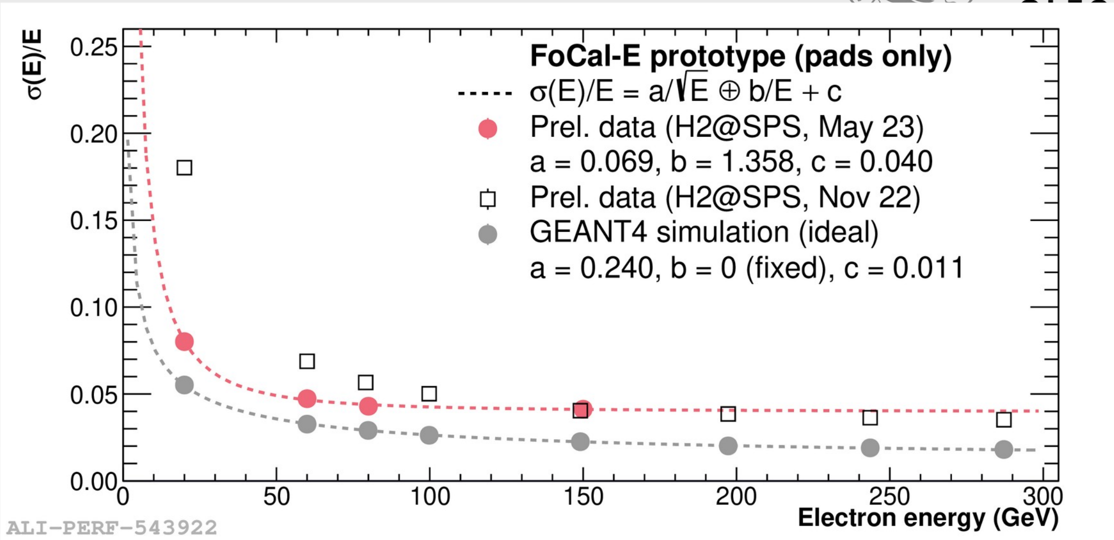


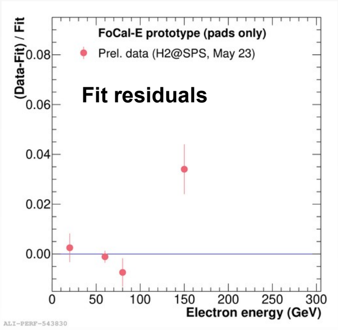


- Clear separation of MIP peak and pedestal noise measured in ADC distribution
  - → Sensitivity to a single MIP
- Separation measured in HV scan from 0 V to 500 V
- MIP Peak position stable at full depletion (~300V)

FoCal-E Pad linearity and resolution



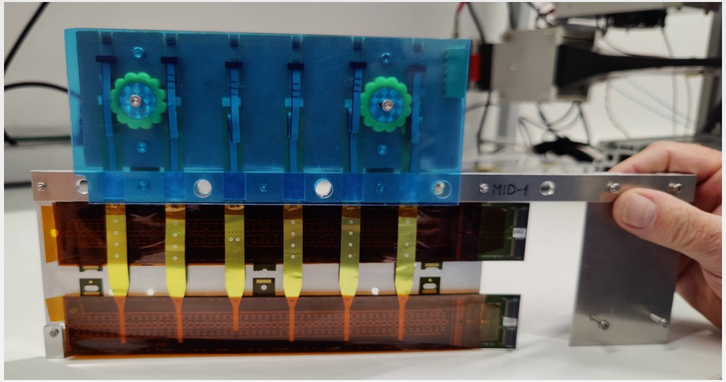


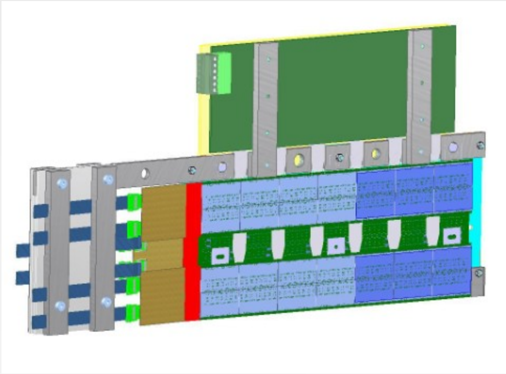


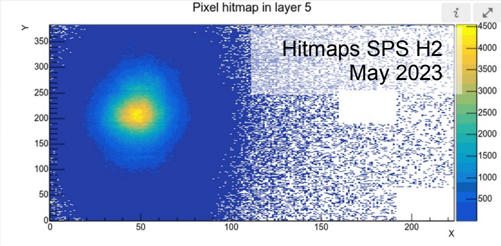
- Linear response of detector in two energy regimes
  - Connection of two regimes to be studied
- Good resolution for high energies: 3 – 4 %
- Resolution for 20 GeV measured to be ~ 8%

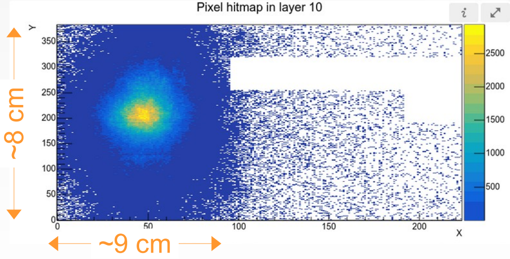
FoCal-E Pixel prototype + event displays

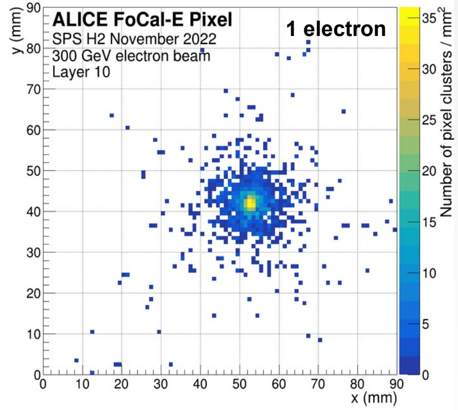
- Two-photon separation (≤ 5mm shower distance)
- Pixel pitch of 30 x 30 μm^2
- Two prototype layers built from ALICE ITS2 Outer Barrel modules (HICs)
- 42 ALPIDEs per layer
- 18 ALPIDEs per layer in active region (in tungsten tower)
- Final design with flex PCB strings, and SpTAB bonding techniques

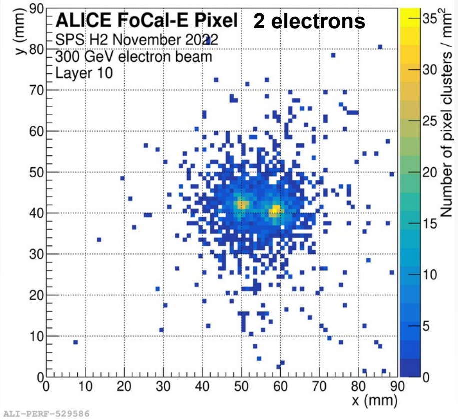


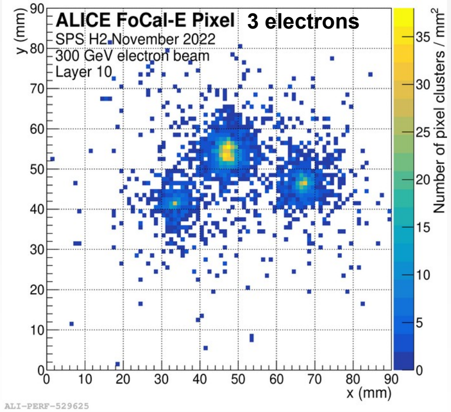




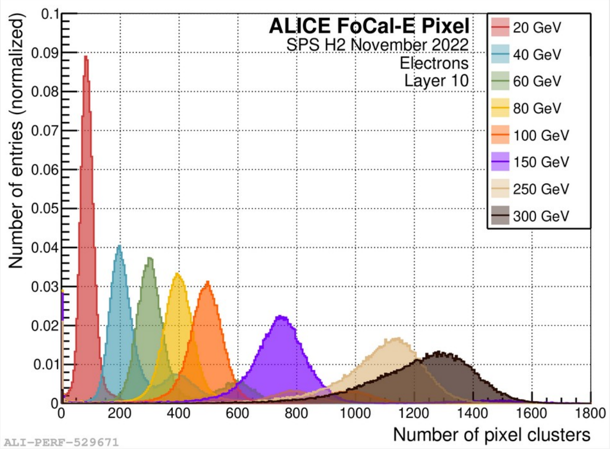


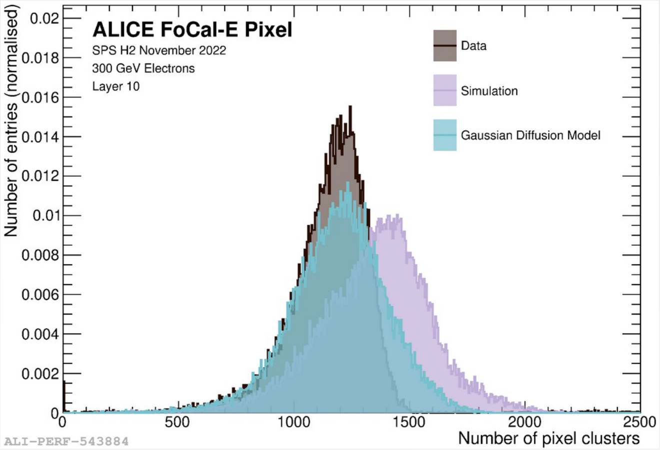


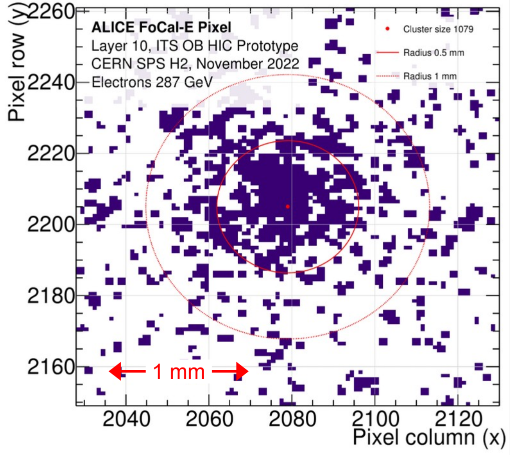




FoCal-E Pixel electromagnetic showers



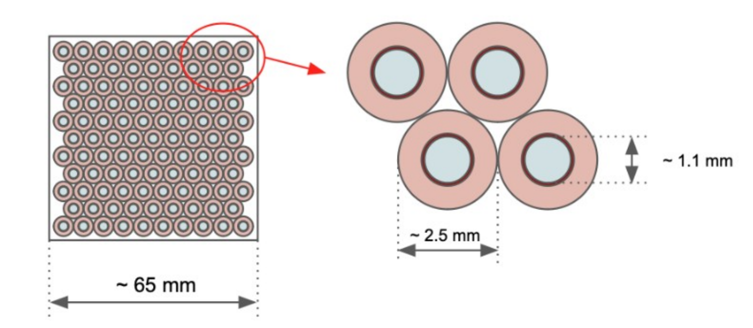


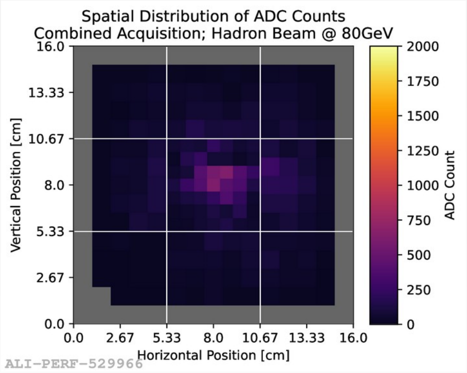


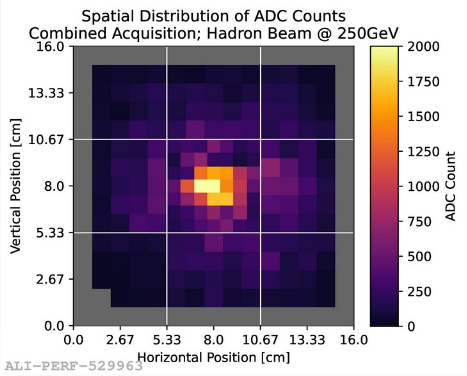
- Electron shower events at beam energies between 20 and 300 GeV
  - Very pure beams, nearly no hadron contamination
- First strategy: use pixel clusters (one particle activates more than one adjacent pixels) as measure for shower energy
- Saturation of pixel cluster density observed for the highest energies
  - Ongoing work for modelling with a Gaussian diffusion model
  - Develop method to use hits (not pixel clusters) for high energy information

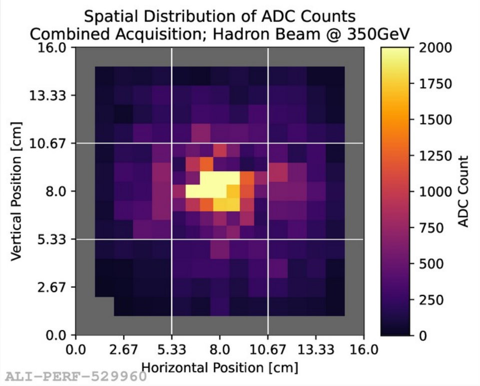
FoCal-H Prototype 2

- Prototype 2 ready for testing in 2022
- 9 full length modules at 6.5 cm x 6.5 cm x **110 cm**
- Copper tubes filled with BCF12 scintillating fibers
- Fibres grouped to bundles of SiPMs
  - 49 readout bundles in central modules
  - 25 readout bundles for each outer module
- Readout with CAEN DT5202 boards
- Overall weight > 300 kg

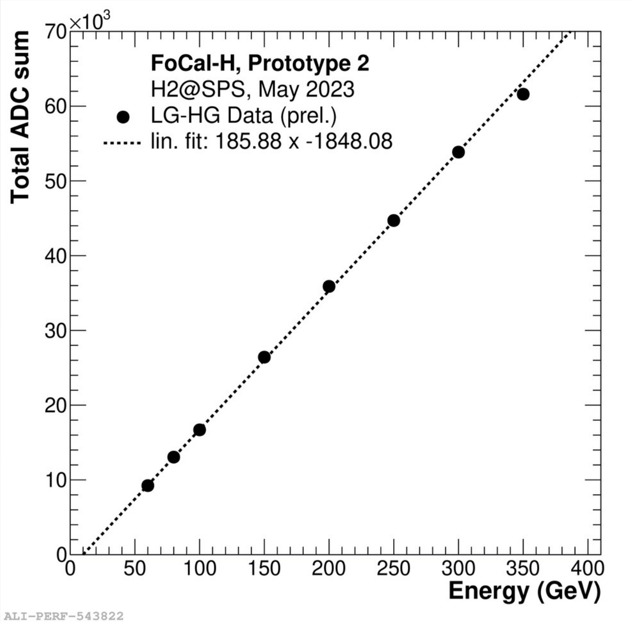


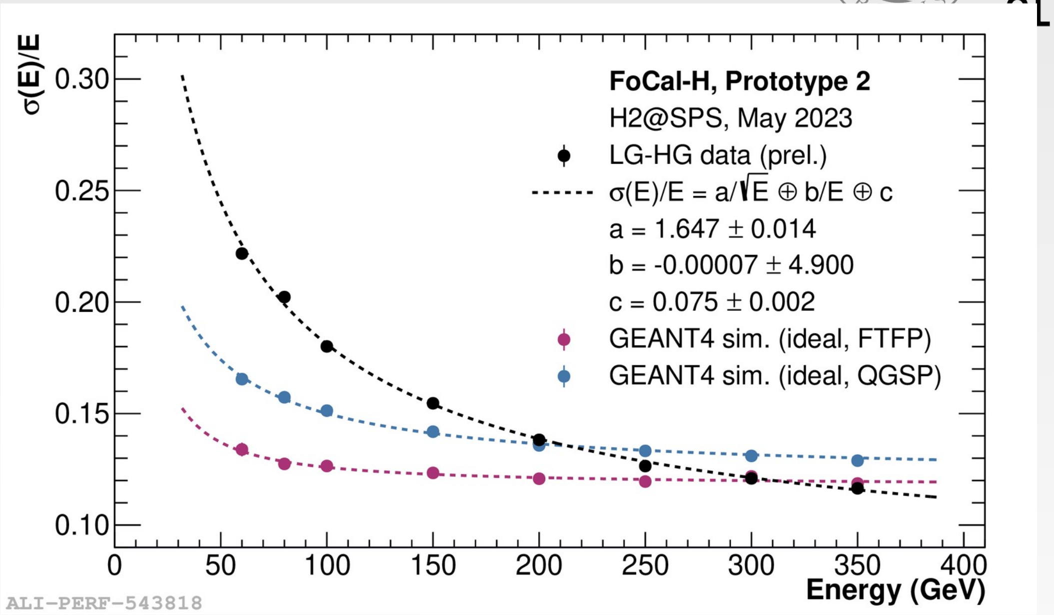






FoCal-H linearity and resolution





- Resolutions simulated in GEANT4 with two different physics lists: QGSP + FTFP: Constant term ~12%
- Measured resolutions show different behavior, to be investigated
  - Resolution **< 25 %** for hadrons > 60 GeV
  - Resolution **< 15 %** for hadrons > 200 GeV

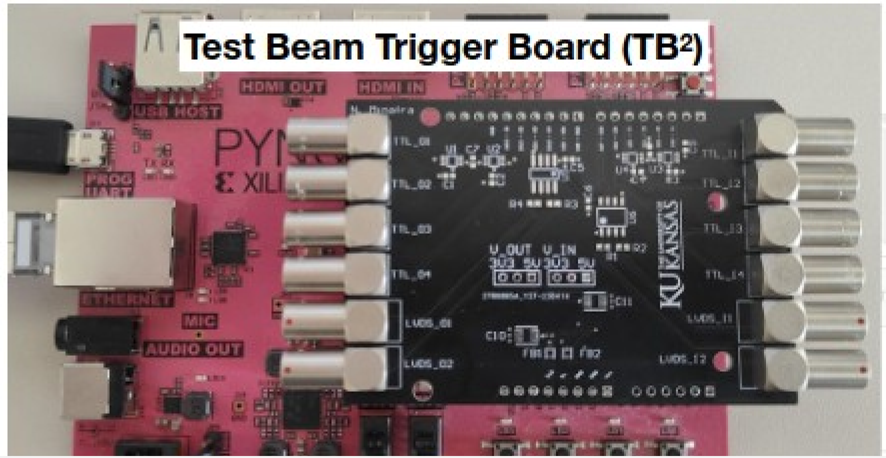
Summary

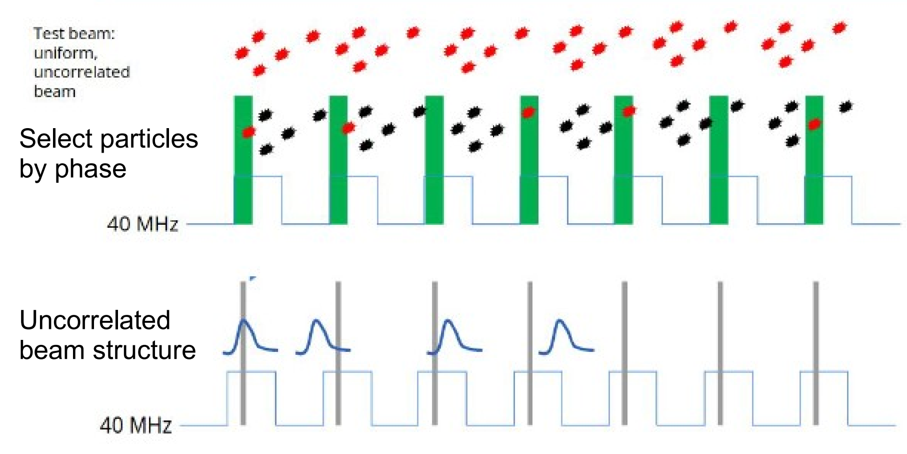
- FoCal prototype detectors show required performance
  - FoCal-E Pads resolution with constant term **< 5% feasible**
  - FoCal-E Pixel electromagnetic shower separation **< 5mm possible**
  - FoCal-H **resolution < 15%** for energies > 200 GeV
- Extensive tests at CERN SPS and PS beam facilities during 2021, 2022 and 2023
- Combined acquisitions of all subsystems
  - Open analysis topics: combination of subdetector information for complete FoCal events

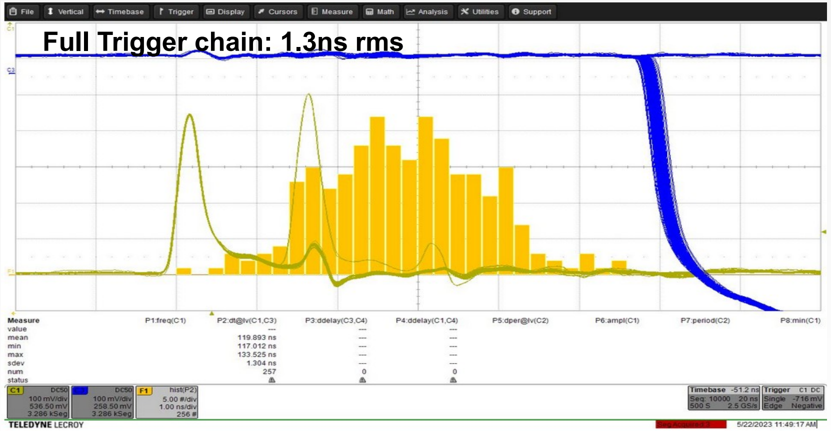
ALICE FoCal Technical Design Report
aimed for end of 2023

Additional Material

Test Beam Trigger Board

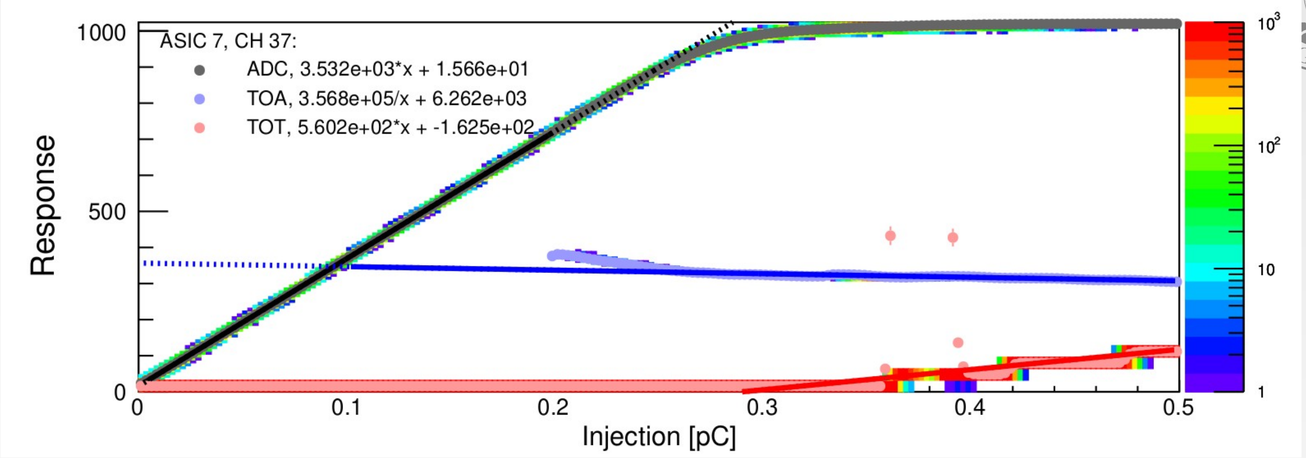


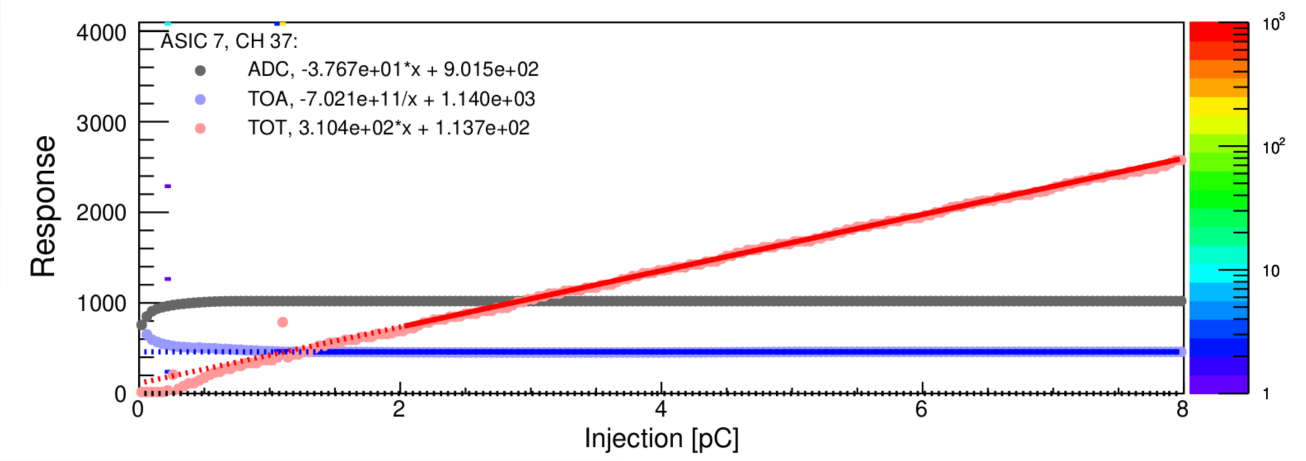




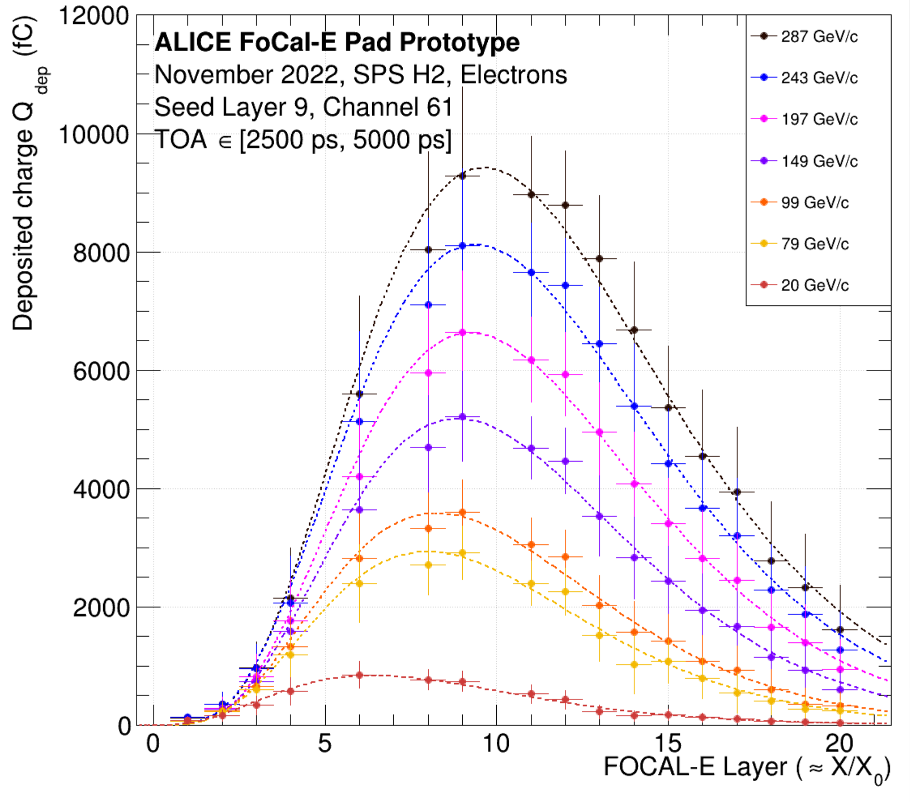
- At LHC, particles arrive synchronously with 40 MHz clock
- Beam particles at CERN NA beamlines arrive asynchronously
- Test beam trigger board phase locks triggers from incoming particles to a window of 2.5ns
- Sampling of detector signal at constant phase possible → reproducibility of results
- Handles busy veto logic and trigger delay for FoCal-H and FoCal-E pixels

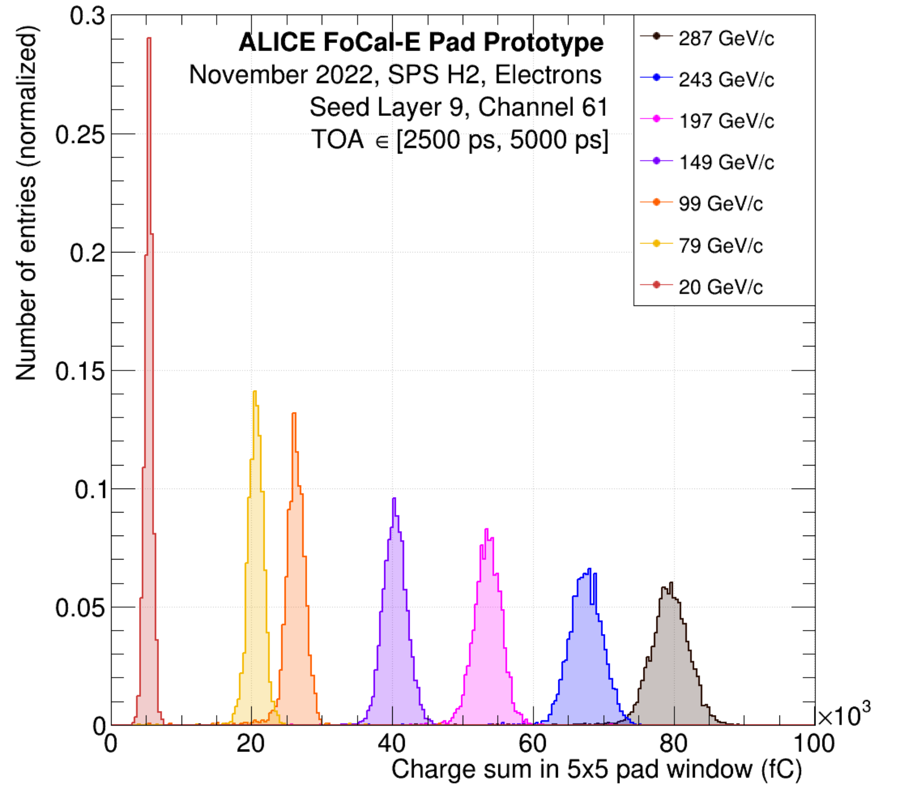
HGCROC Channel Calibration





FoCal-E Pads Signal + Longitudinal Shower Profile





FoCal-E Pads Linearity