ALICE Forward Calorimeter

Physics Program and Expected Performance

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for the ALICE Collaboration

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ALICE FoCal upgrade

FoCal is an upgrade of the ALICE experiment at the LHC, to be installed during **Long Shutdown 3** for data-taking in **Run 4**.

Publications and public notes:

FoCal LOI: CERN-LHCC-2020-009

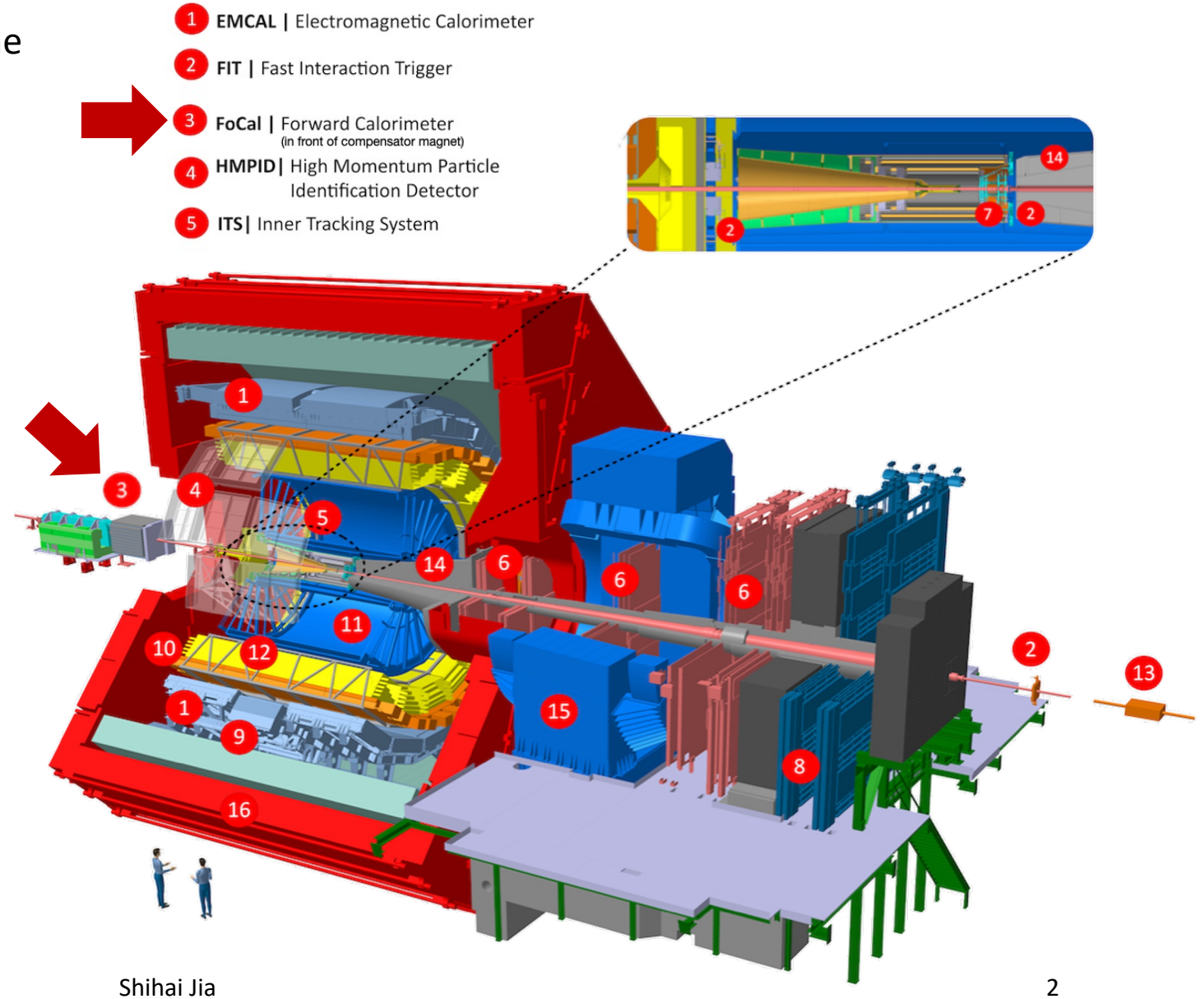
FoCal TDR: CERN-LHCC-2024-004

Physics of FoCal: ALICE-PUBLIC-2023-001

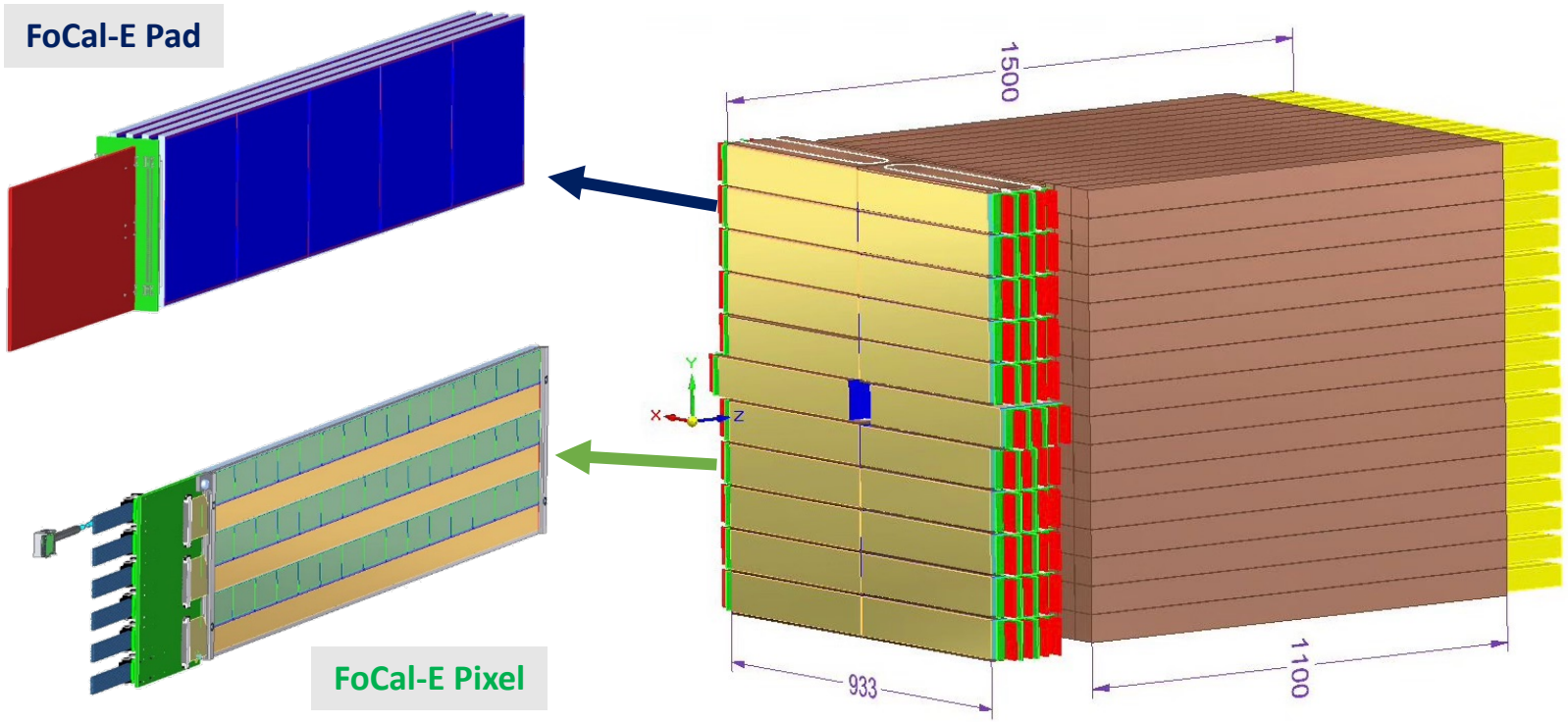
Physics performance: ALICE-PUBLIC-2023-004

Pixel layer performance: arXiv:2504.03018

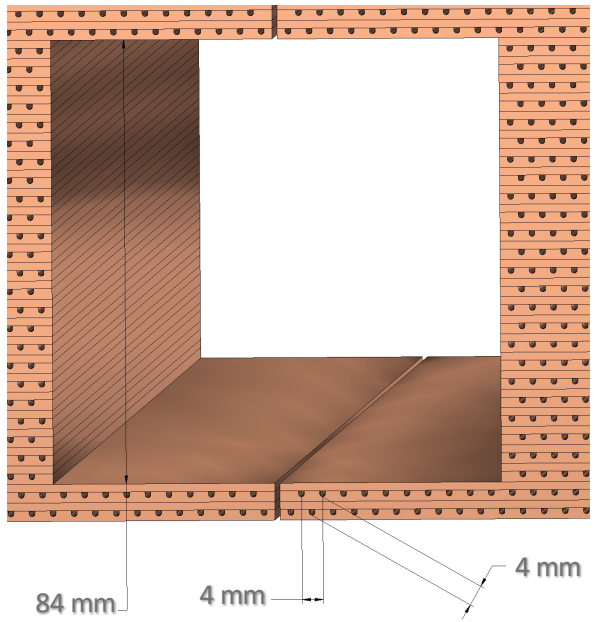
FoCal beam test: arXiv:2311.07413



FoCal sub-detectors



FoCal-H



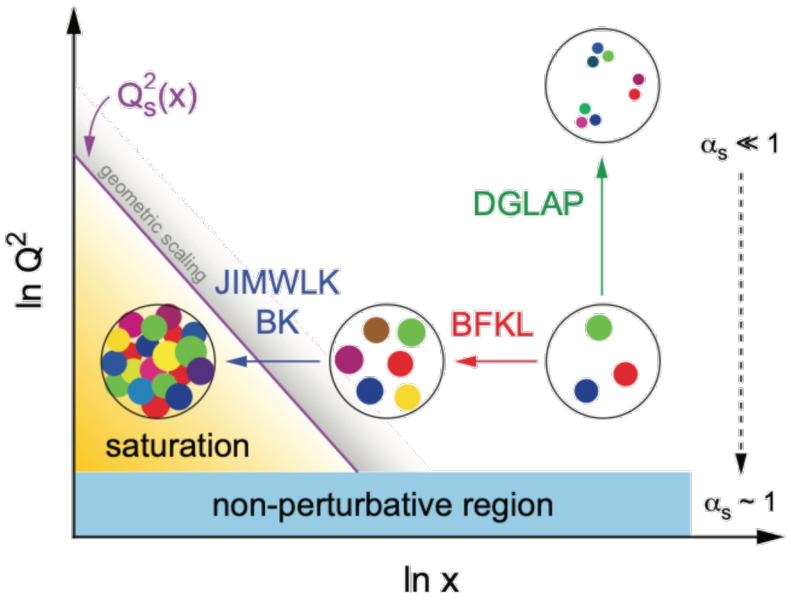
FoCal-E – electromagnetic part:

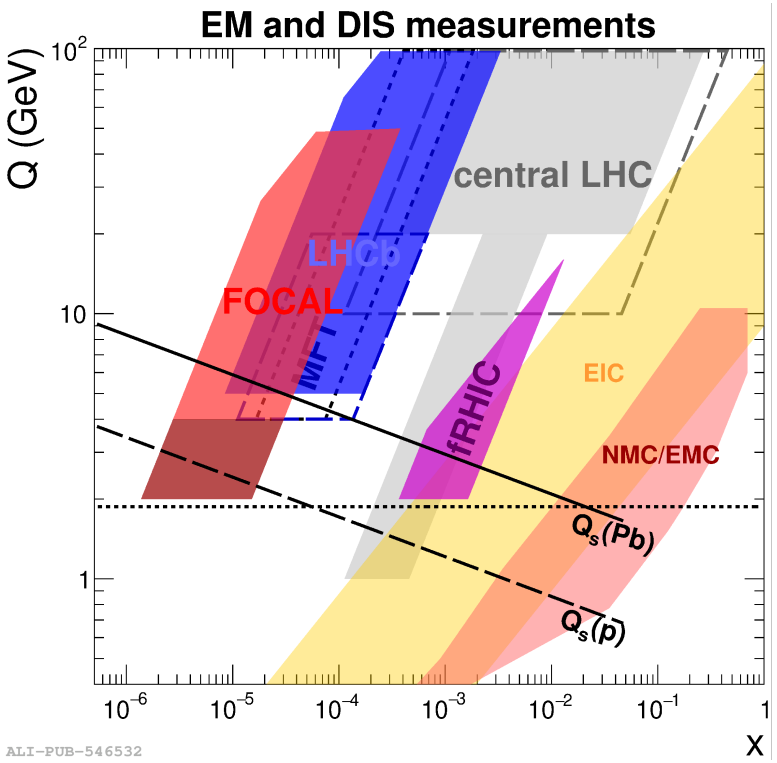
- A **tungsten-silicon** calorimeter
- **18 pad layers** (1 cm x 1 cm)
- **Photons, electrons, π^0, …**
- **2 high-granularity pixel layers**
  - ~ 30 µm x 30 µm pixels
  - on the 5th and 10th layer

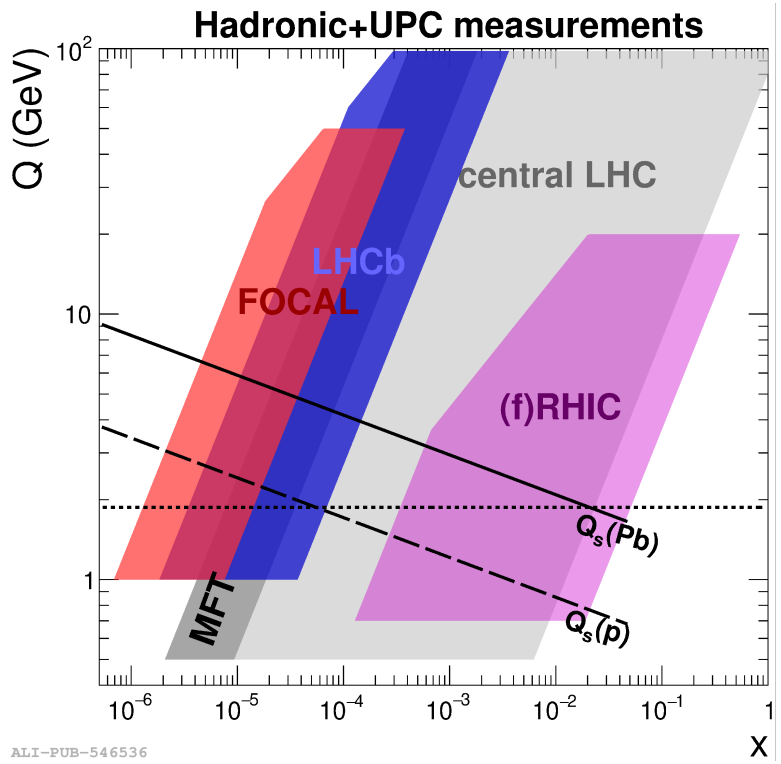
FoCal-H – hadronic part:

- A **copper-scintillator** calorimeter:
- Upcoming new prototype with copper sheets and scintillating fibers
- **Photon isolation**
- **Jet measurements**

FoCal physics

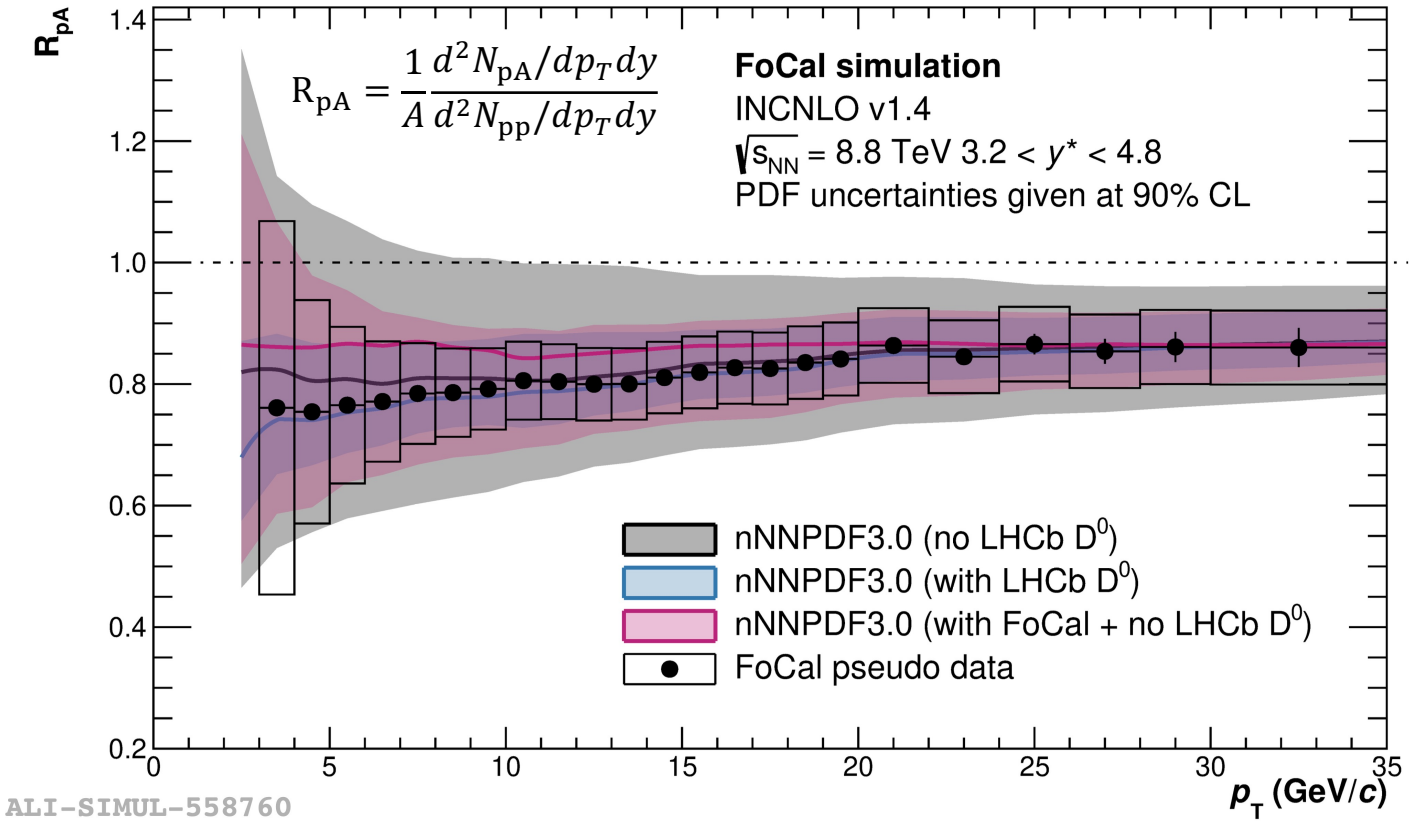






- FoCal extends ALICE's reach to **forward rapidity ($3.2 < \eta < 5.8$)**, enabling precision direct photon measurements at small-x, and unlocking novel studies of QCD dynamics in hadronic and ultra-peripheral collisions down to $x \sim 10^{-6}$.
- Main observables include **prompt photons**, jets, neutral mesons, J/ψ, gamma-hadron correlations

Physics program – prompt photons



- Prompt photon directly produced in $qg \rightarrow \gamma q$ is a **direct probe** of the gluon PDF, with no final-state effects.
- FoCal pseudo data shows a **$\sim 50\%$ reduction** in the nPDF uncertainty.

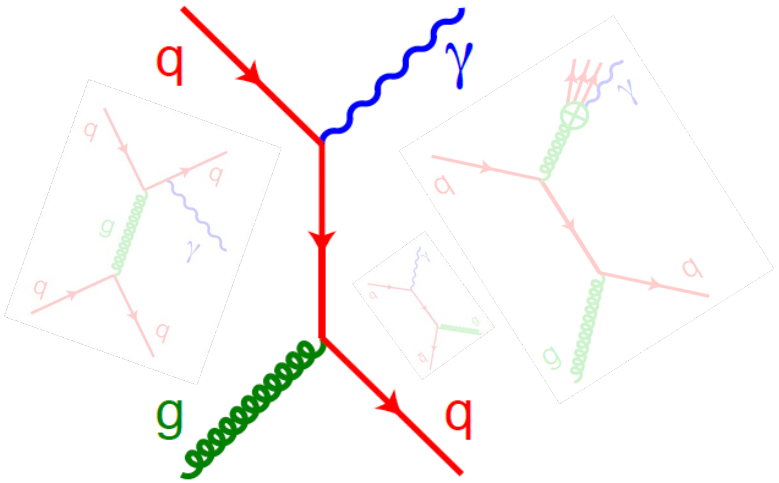
The main background is from π^0 decay.

By using:

- Isolation
- Invariant mass
- Shower shape

Next slide

The signal fraction is increased by **a factor of 11**



Physics program – prompt photons

Invariant Mass

- **π^0 decay photons** have a clear peak on cluster pairs invariant mass.
- Applying a cut ($0.07 - 0.18\ \mathrm{GeV}/c^2$) significantly improves the signal-to-background ratio.

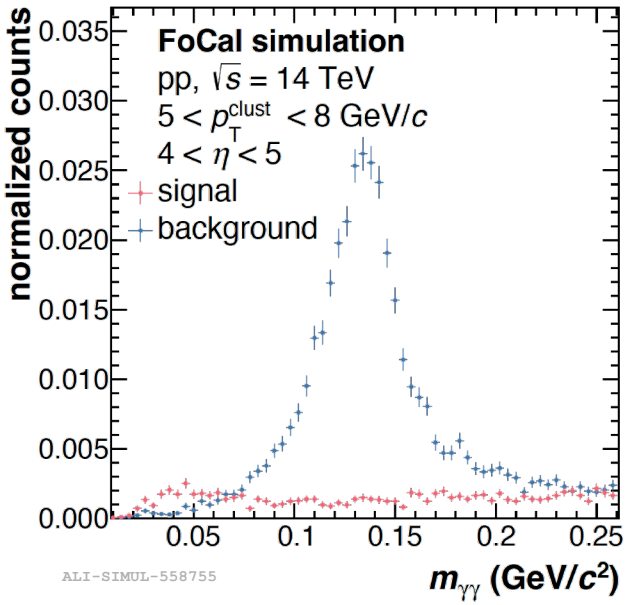
Shower Shape

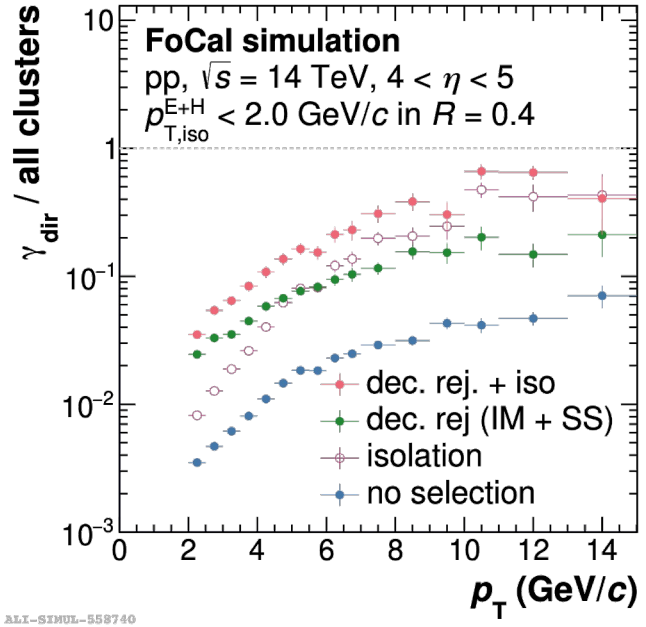
- Clusters from the background sample are **elongated** with respect to signal photons

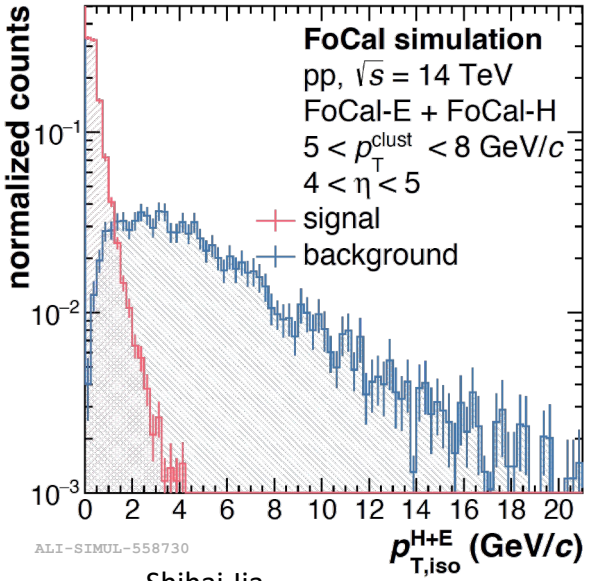
Isolation

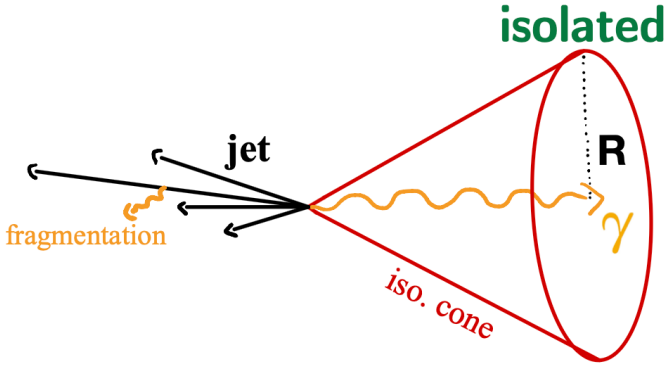
Applying an **isolated cone**, only accept photons with no neighboring particles.

- Collinear fragmentation
- Decay photons come with hadronization products







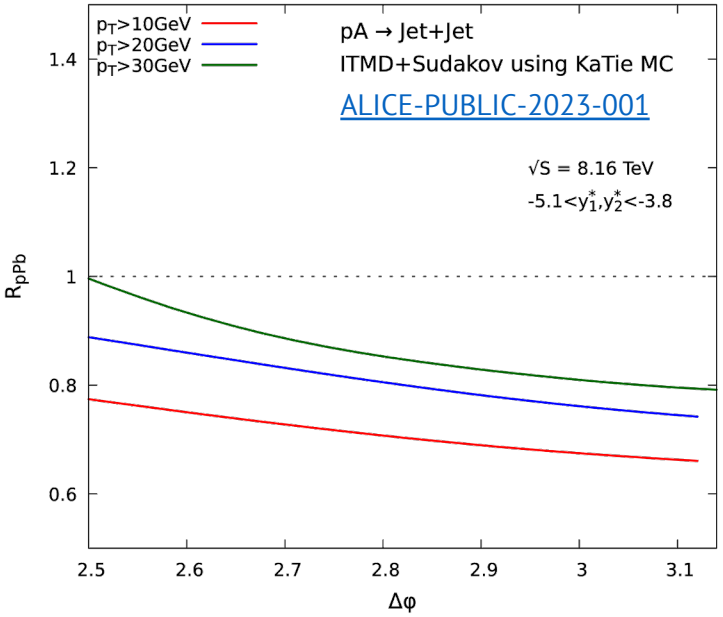


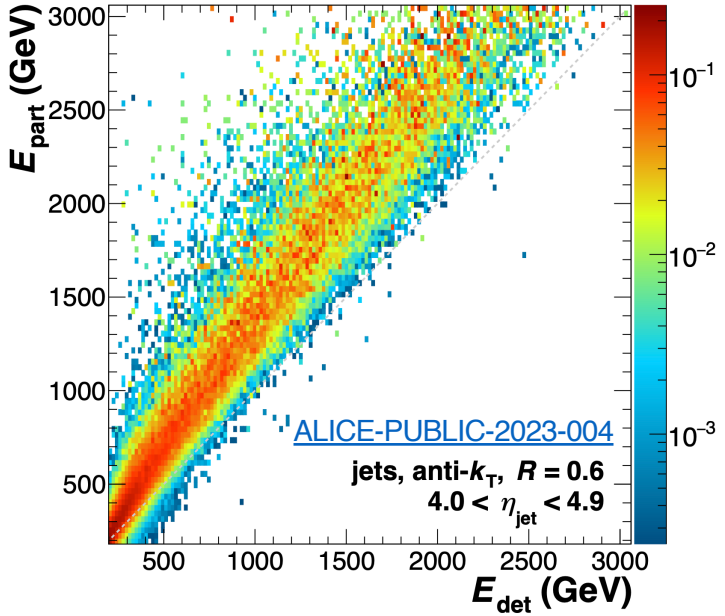
Physics program – jets, neutral mesons

Jets

- Forward jets, dijets, and γ+jet observables are sensitive to different **transverse momentum dependent (TMD) gluon distributions**.
- Provide crucial insight into **gluon saturation** and the nonlinear regime of QCD at small-x.
- Q_{sat} can be probed using the **momentum imbalance k_{T}**

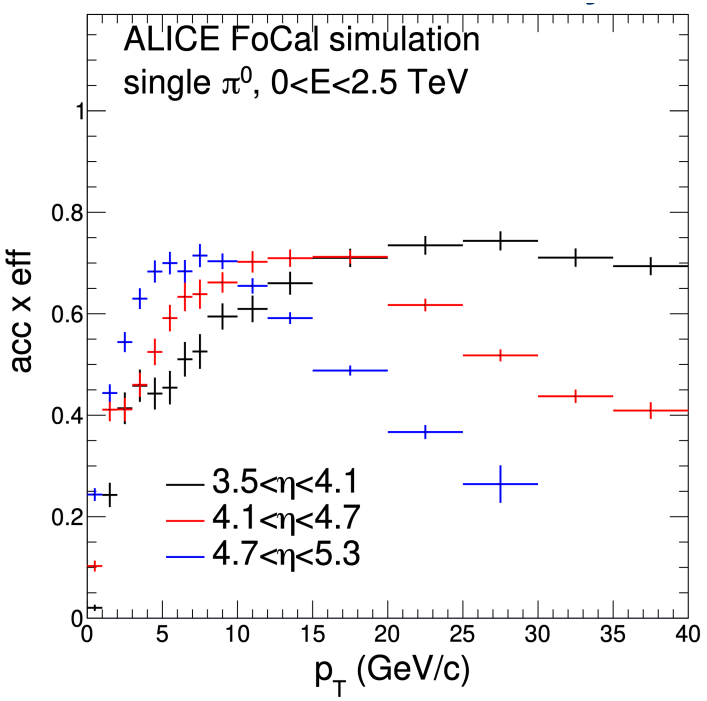
$$k_T = \left|\boldsymbol{p}_{T,1} + \boldsymbol{p}_{T,2}\right| \approx p_{T,1}\sin(\Delta\varphi)$$



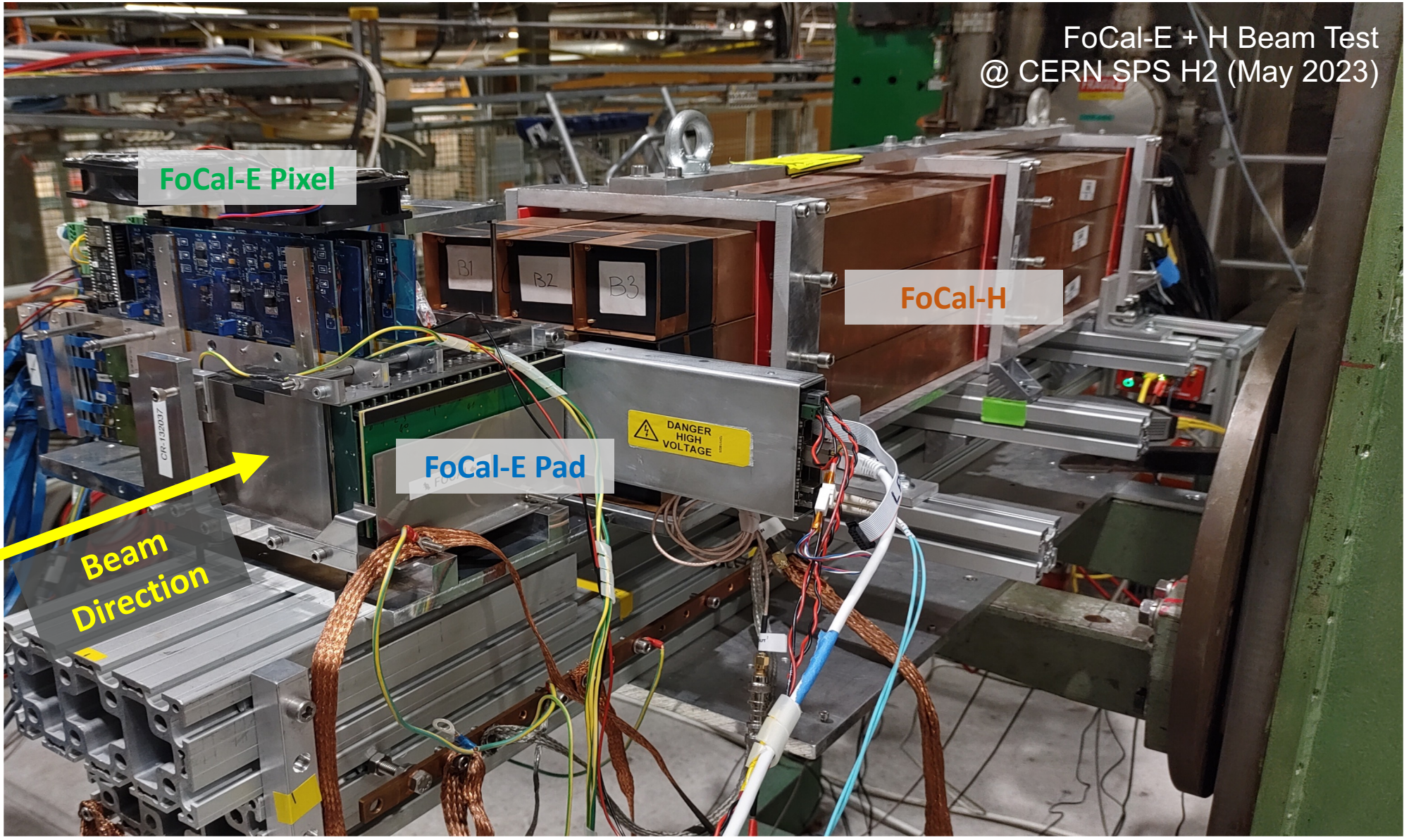


Neutral Mesons

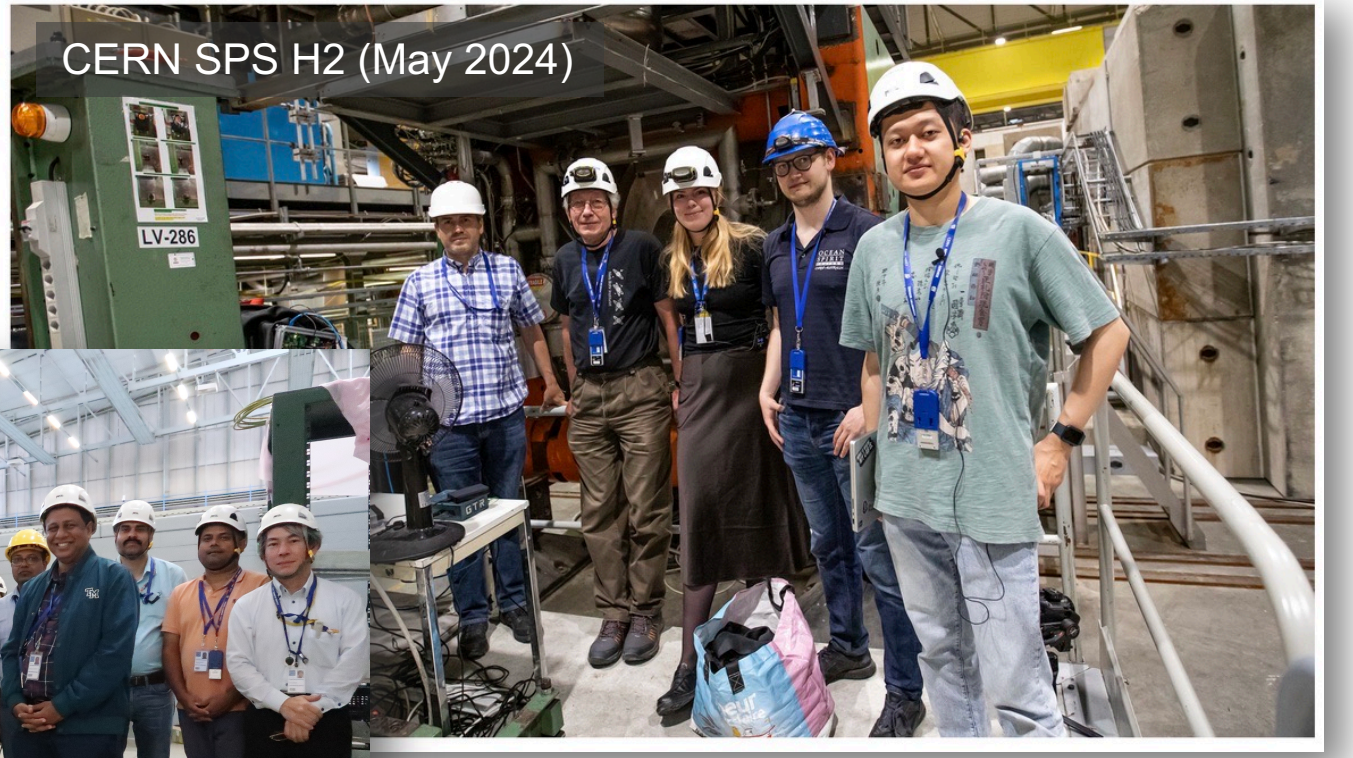
- Simulation studies have been carried out for meson measurements**.**
- FoCal-E pixels give high **reconstruction efficiency** and provide good spatial separation.



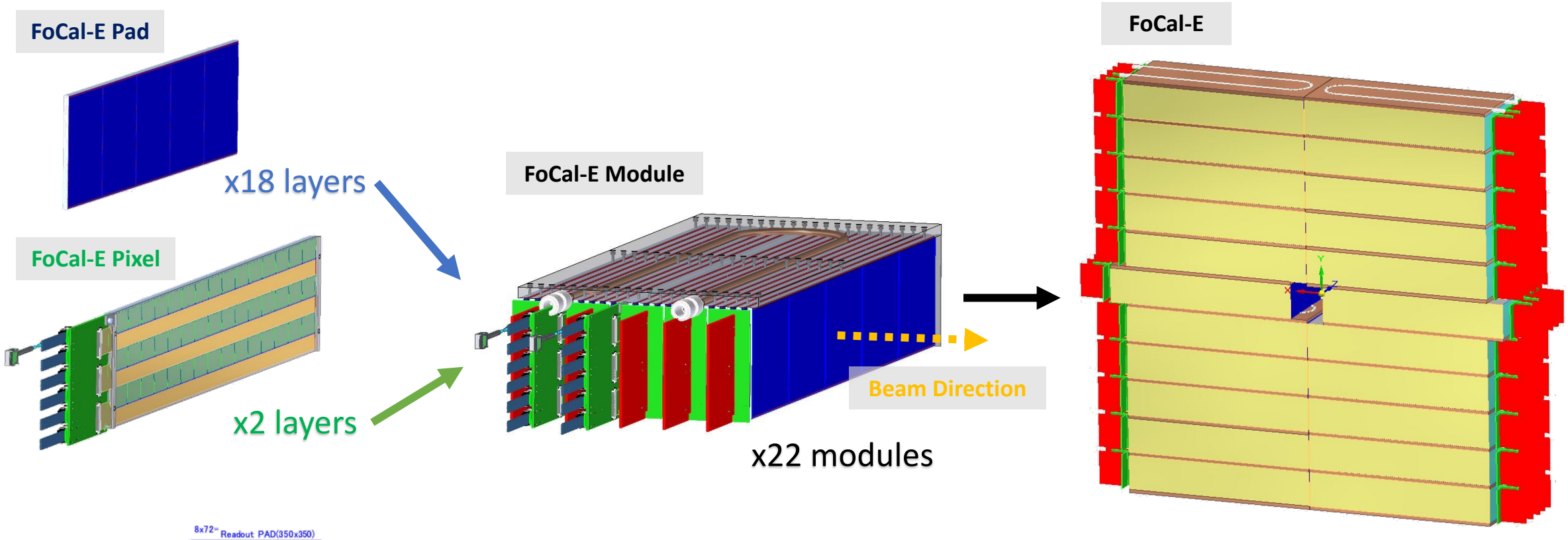
FoCal beam test setup

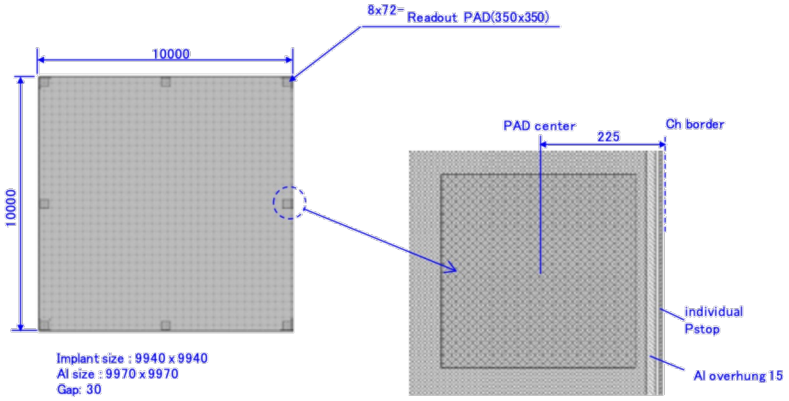


FoCal beam test campaigns

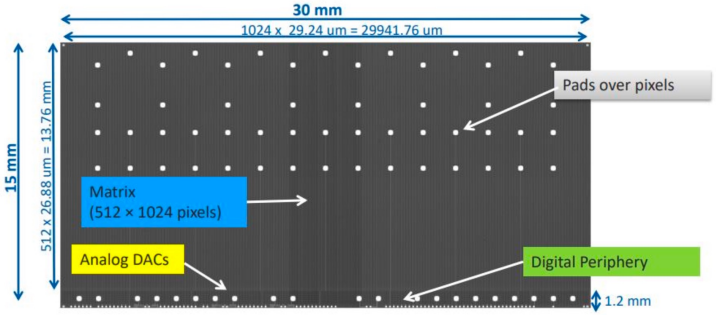


FoCal-E development





One selected pad sensor is made by Hamamatsu. The main sensor module is 9 cm x 8 cm, with 72 main cells and 2 calibration cells.

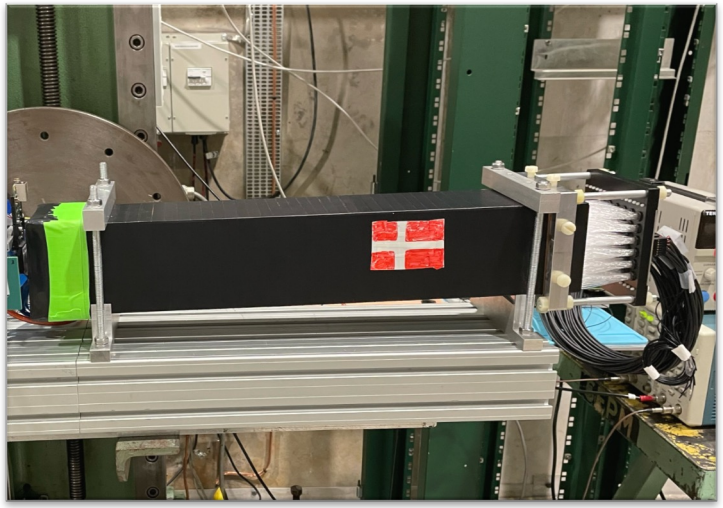


ALPIDE is the pixel sensor used. It is using 180 nm technology, containing 1024 x 512 pixels in a single sensor.

FoCal-H development

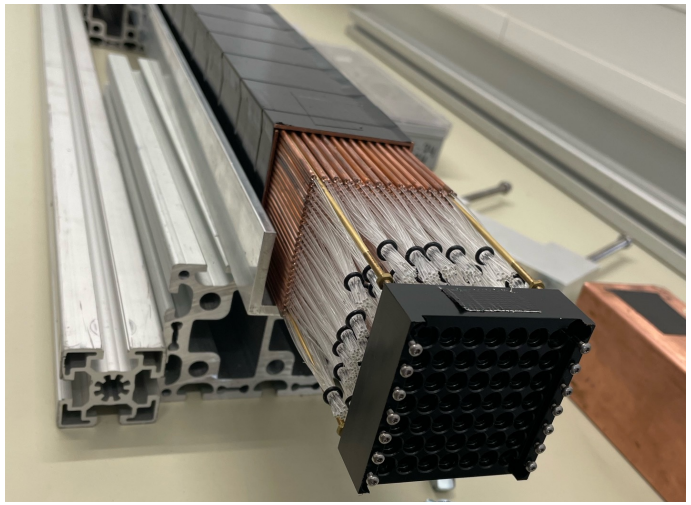
Prototype 1

- One module
- 9.5 cm x 9.5 cm x 50 cm
- **Scintillating fibers + Capillary tubes**
- 30 fibers bundled into one readout channel



Prototype 2

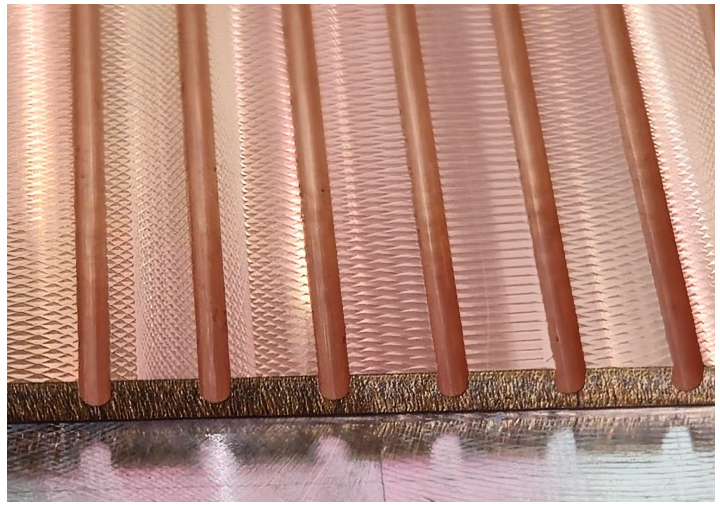
- **9 modules**
- 6.5 cm x 6.5 cm x 110 cm per module
- 49 SiPMs for central module
- 25 SiPMs for each outer module
- Tested in 2023 and 2024



Prototype 3

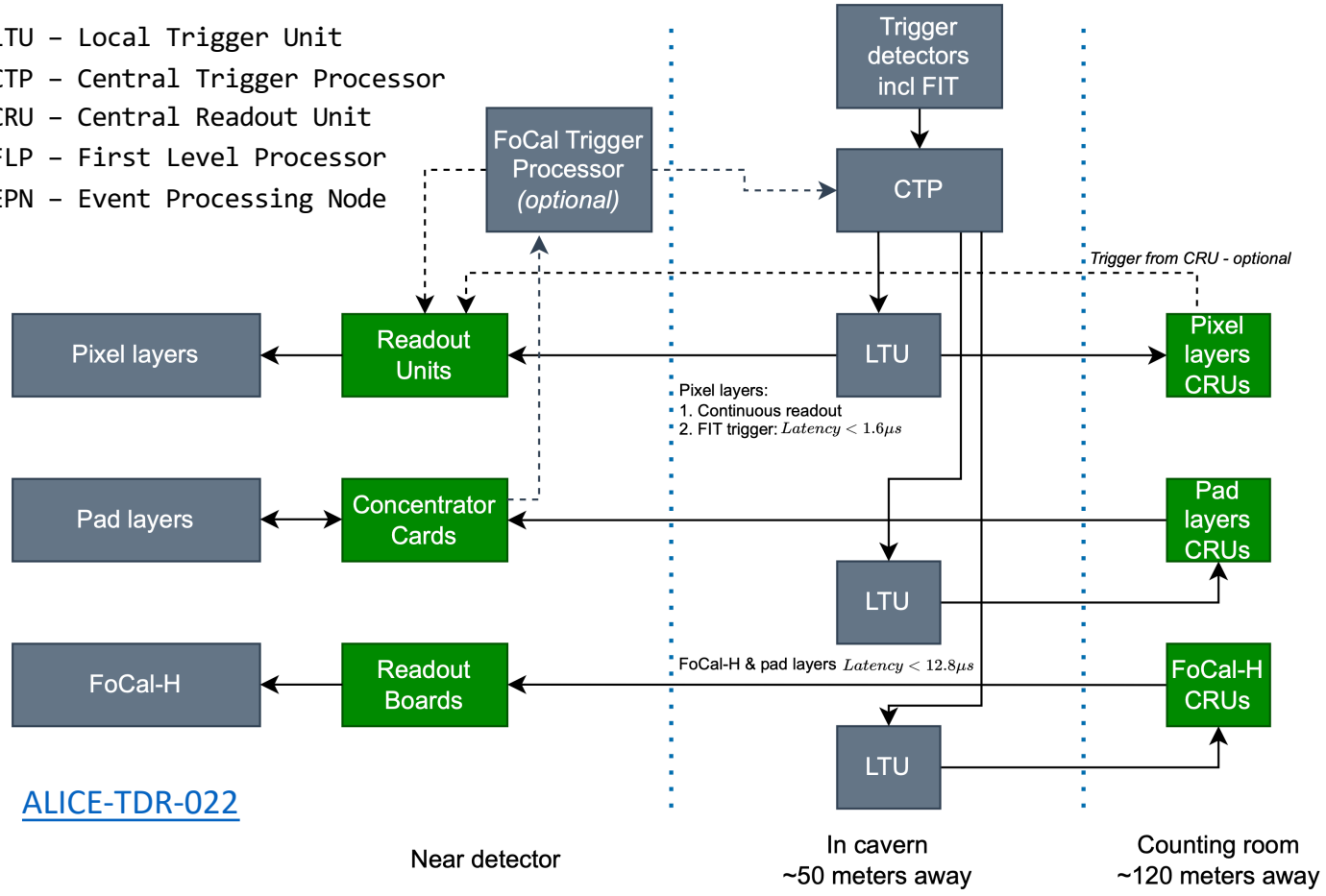
FoCal-H prototype 3 is being manufactured, and is planned to be tested in the beam in 2025

- Scintillating fibers + **Copper sheets**
- Simulation shows better performance



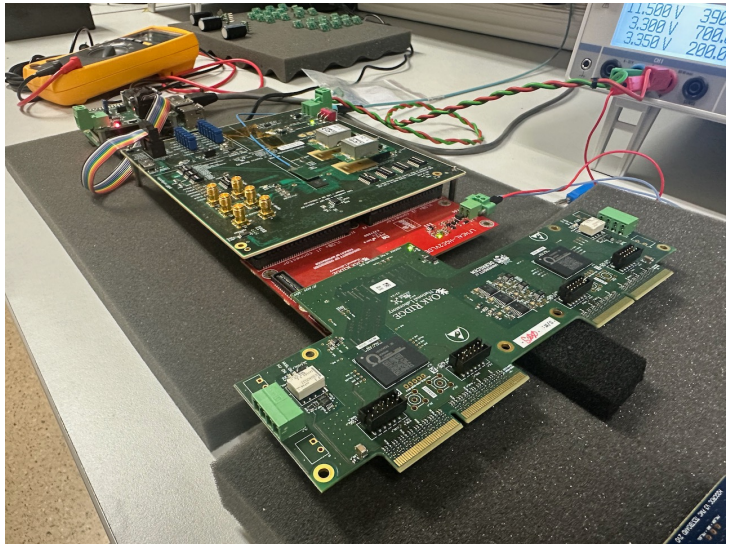
FoCal readout

LTU – Local Trigger Unit
CTP – Central Trigger Processor
CRU – Central Readout Unit
FLP – First Level Processor
EPN – Event Processing Node

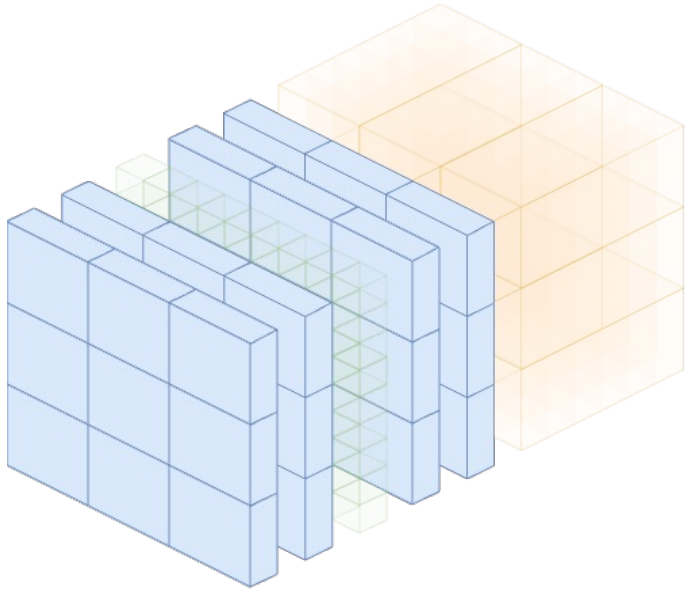


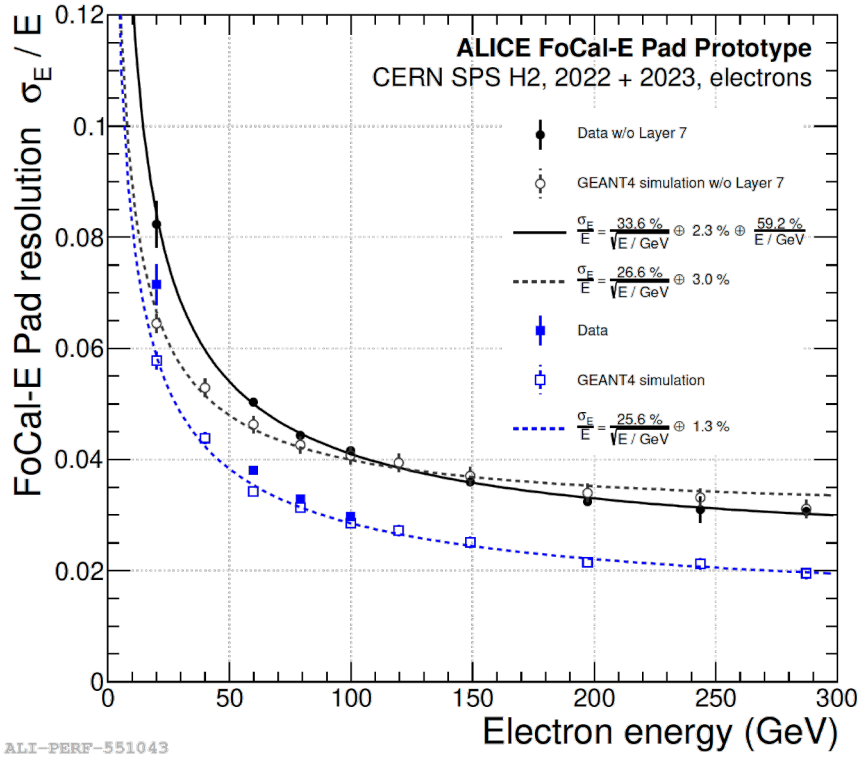
Subsystem	Number of CRUs	Data rate per CRU	Total data rate
FoCal-E pixel layers	7	10–50 Gbps	65–320 Gbps
FoCal-E pad layers	10	11–17 Gbps	110–170 Gbps
FoCal-H (non-zero supp.)	2	175 Gbps	344 Gbps
Total	19		519–834 Gbps

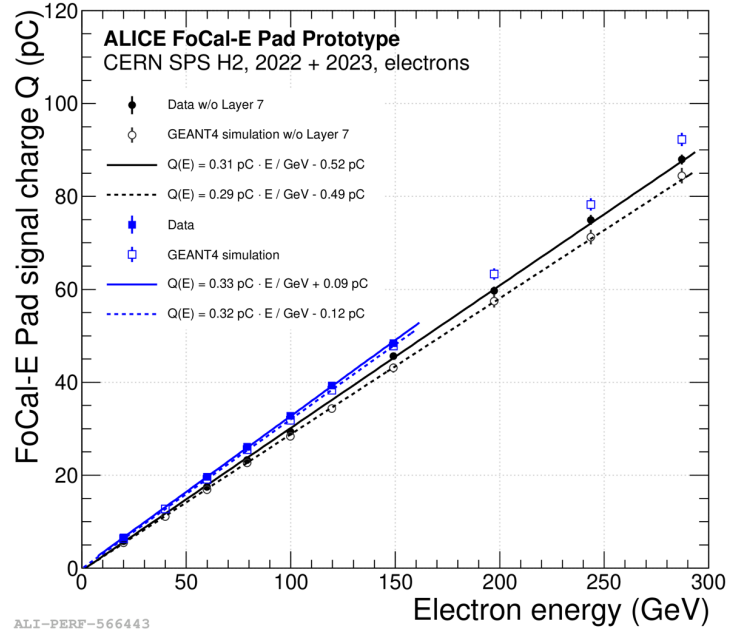
- All FoCal sub-detectors will be read out using the **standard ALICE readout** chain.
- A total of **19 CRUs** are foreseen, supporting an overall input data rate up to 830 Gbps.
- Data is processed by the FLPs and EPN farm using the ALICE O^2 infrastructure.

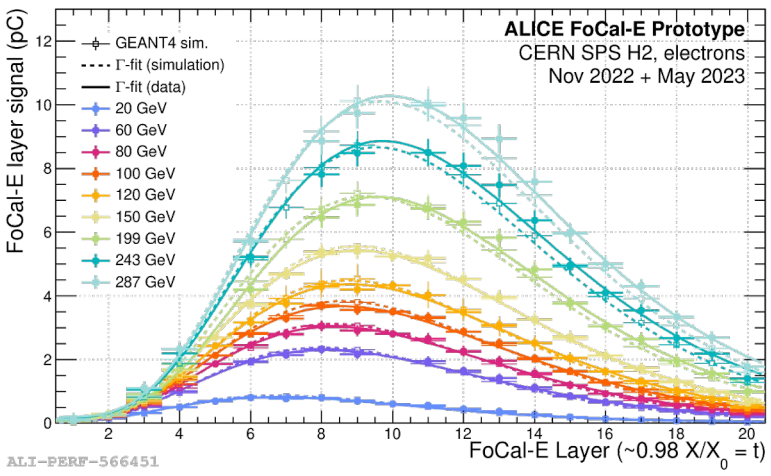


FoCal-E pads performance







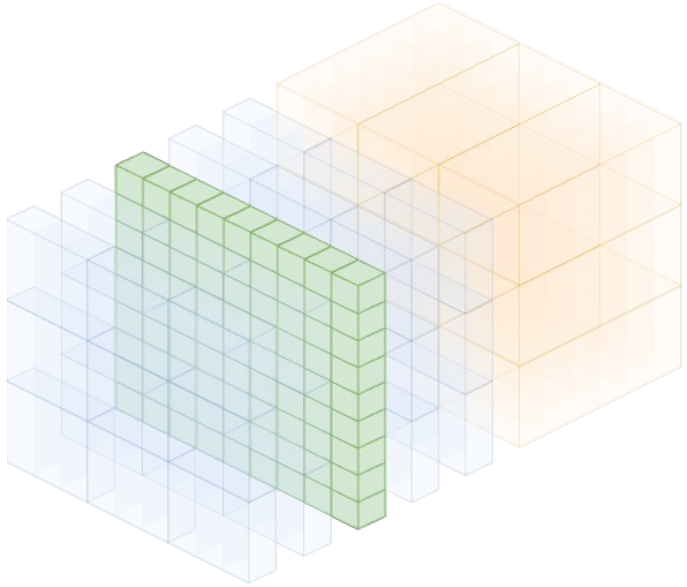


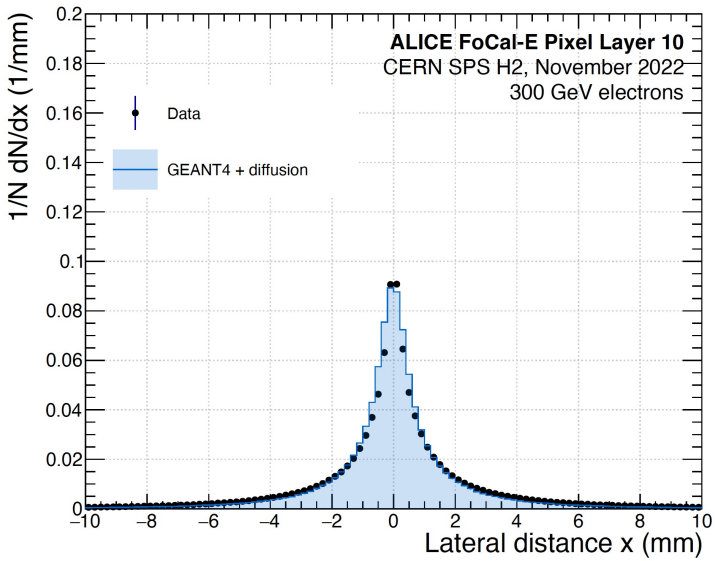
- The **energy resolution** is given by:

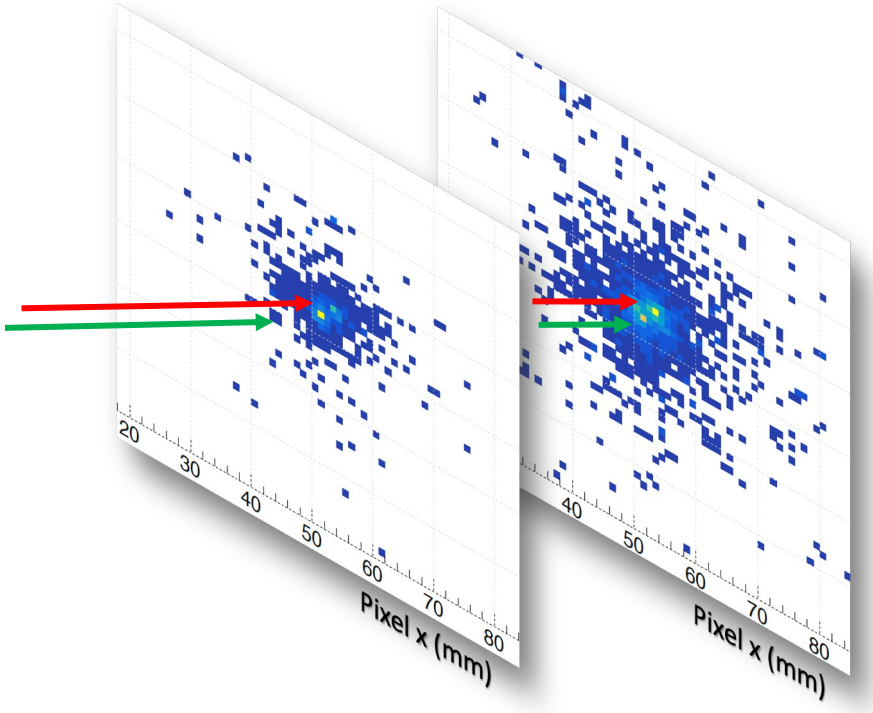
$$\frac{\sigma_E}{E} = \frac{\sigma_{\text{stoch.}}}{\sqrt{E/\text{GeV}}} \oplus \sigma_{\text{const.}} \oplus \frac{\sigma_{\text{noise.}}}{E/\text{GeV}}$$

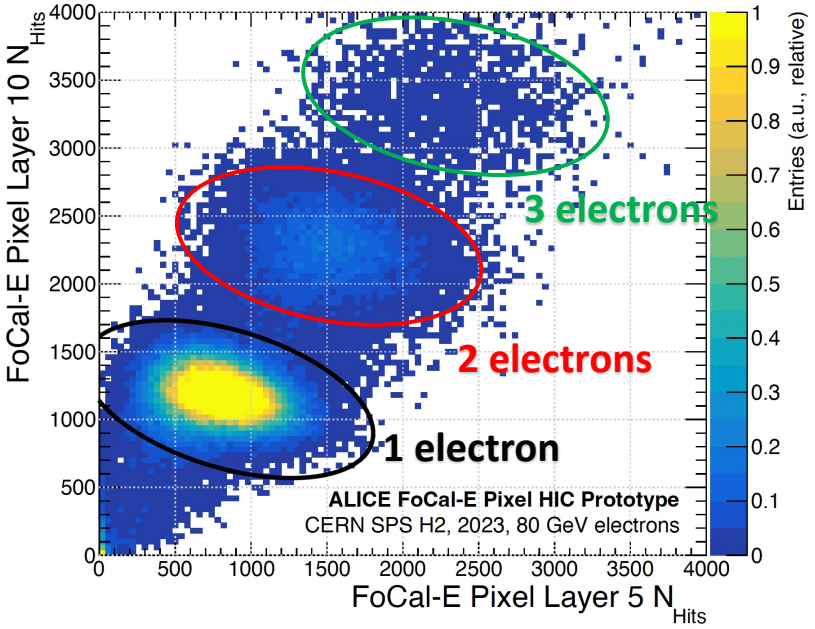
  - (2022 beam test w/o layer 7) $\sigma_{\text{stoch.}} = (33.6 \pm 1.4)\%$, $\sigma_{\text{const}} = (2.27 \pm 0.10)\%$, $\sigma_{\text{noise}} = (59.20 \pm 35.3)\%$
  - (2023 beam test with layer 7) $\sigma_{\text{stoch.}} = 25.6\,\%$, $\sigma_{\text{const}} = 1.3\%$

FoCal-E pixels performance



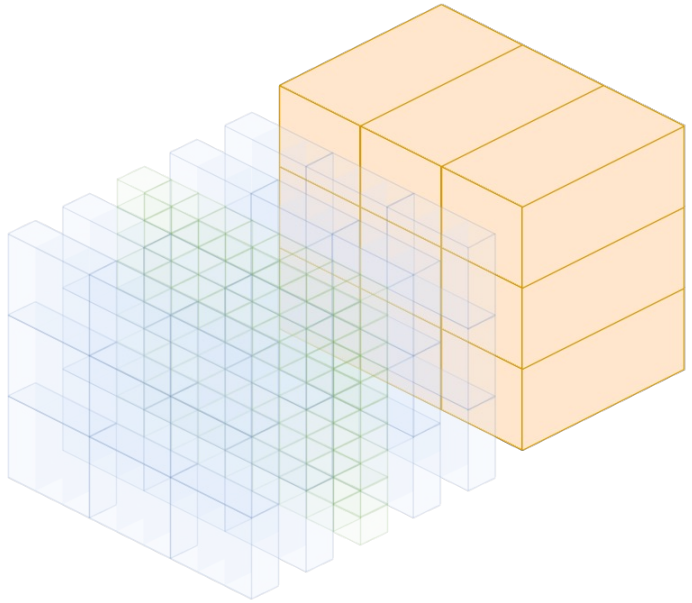


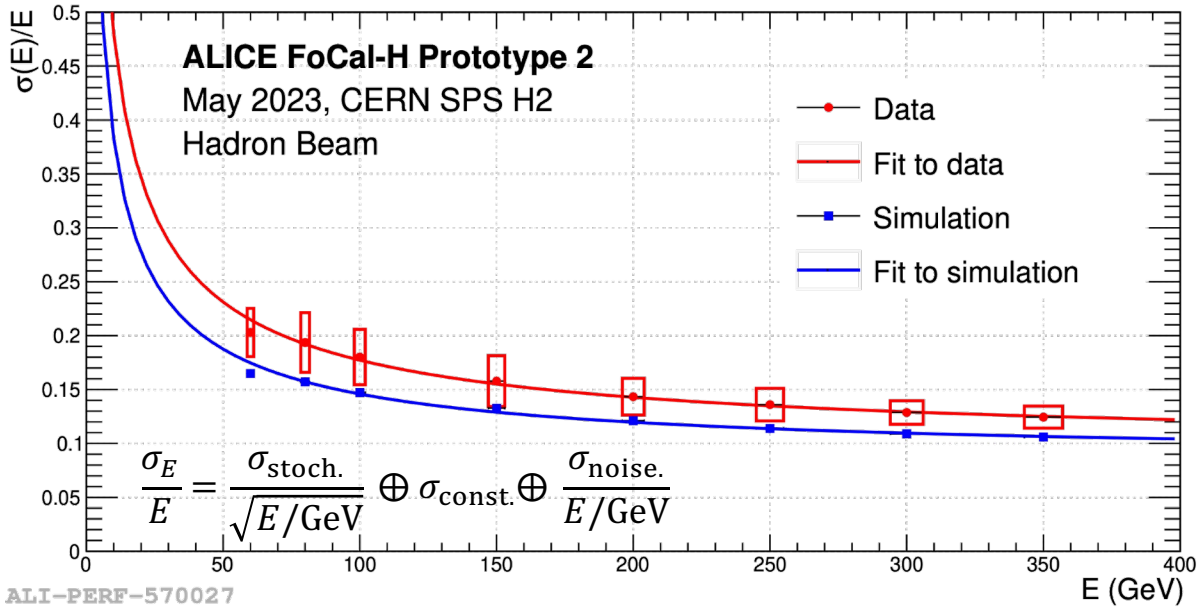




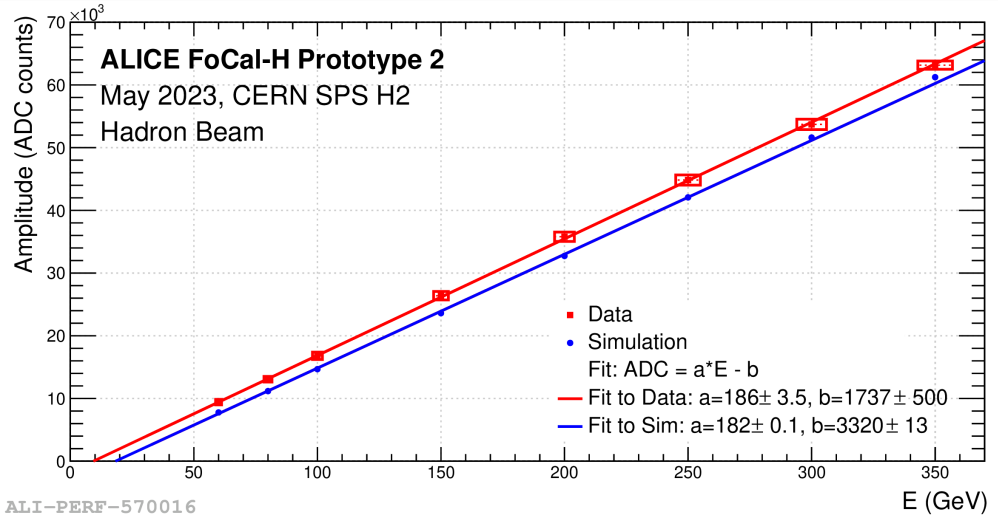
- The **electron shower profile** from beam test data matches the simulation.
- In the N_{Hits} correlation between the two pixel layers, the regimes of **one-electron, two-electron, and three-electron** events can be clearly identified.
- Increasing the back bias voltage can reduce the mean cluster size, therefore reducing the **pixel occupancy.**

FoCal-H performance





- **The energy resolution** is evaluated:
  - $\sigma_{\text{stoch.}} = \left(148 \pm 2_{\text{stat}} \pm 22_{\text{syst}}\right)\%$
  - $\sigma_{\text{const}} = \left(10.0 \pm 0.13_{\text{stat}} \pm 0.7_{\text{syst}}\right)\%$
  - Meets the requirements in the LOI (25% @ 100 GeV, 11% constant term)
- The **nonlinearity** is within 2% from 60 – 350 GeV



Summary

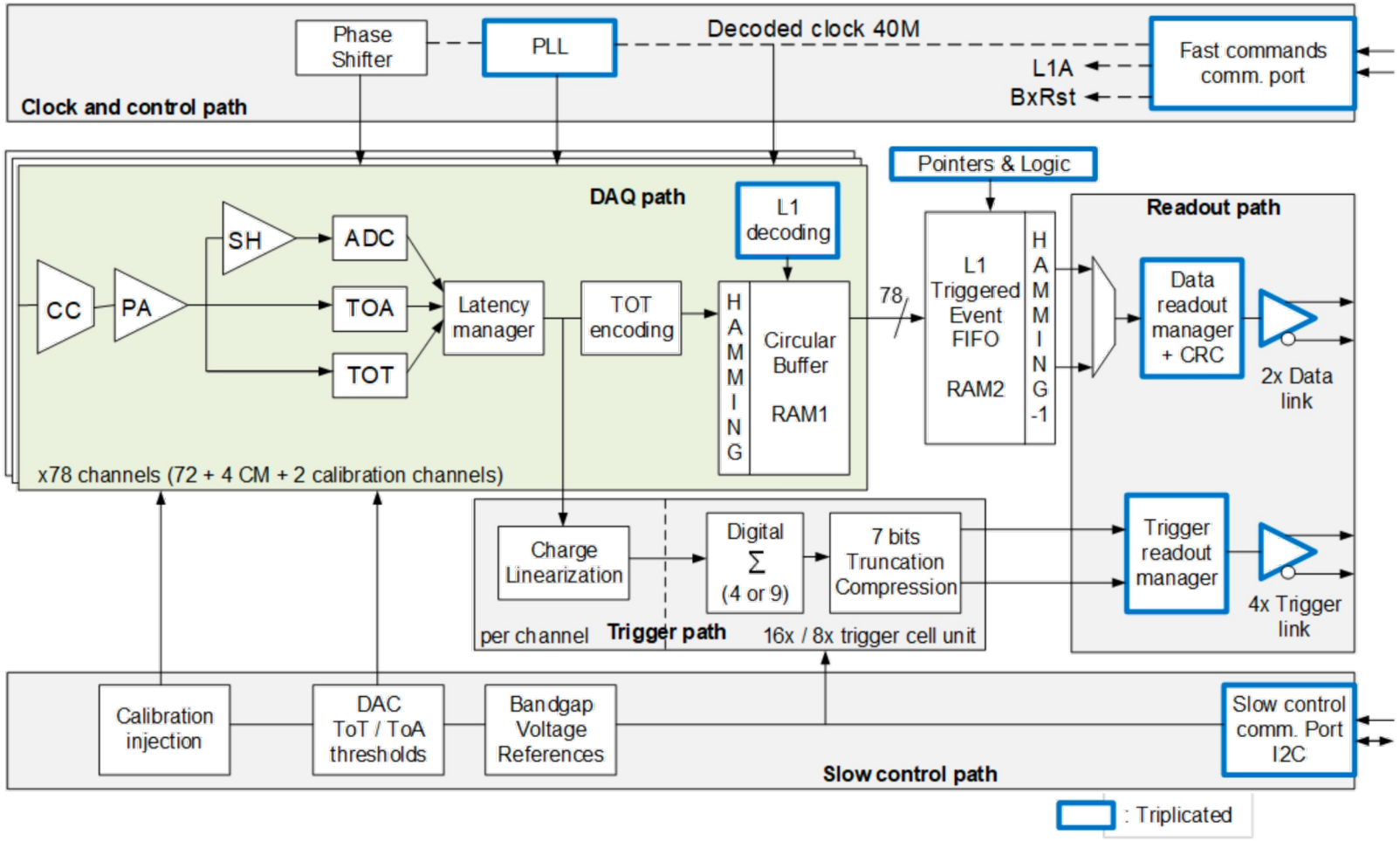
- The ALICE FoCal project has a unique capability to study nonlinear QCD at **small-x**. It will be a powerful tool for exploring gluon distribution in Run 4.
- FoCal-E pixels, FoCal-E pads, and FoCal-H have undergone multiple beam test campaigns, and all sub-systems **demonstrate the required performance**.

Status

- Several **beam tests** at CERN are planned in 2025 to further study new detector and readout electronics prototypes.
- The mechanical and cooling design is progressing rapidly, and the collaboration is evaluating options for assembly and large-scale production.
- The final FoCal detector will be **fully characterized by 2028 and installed in July 2028.**

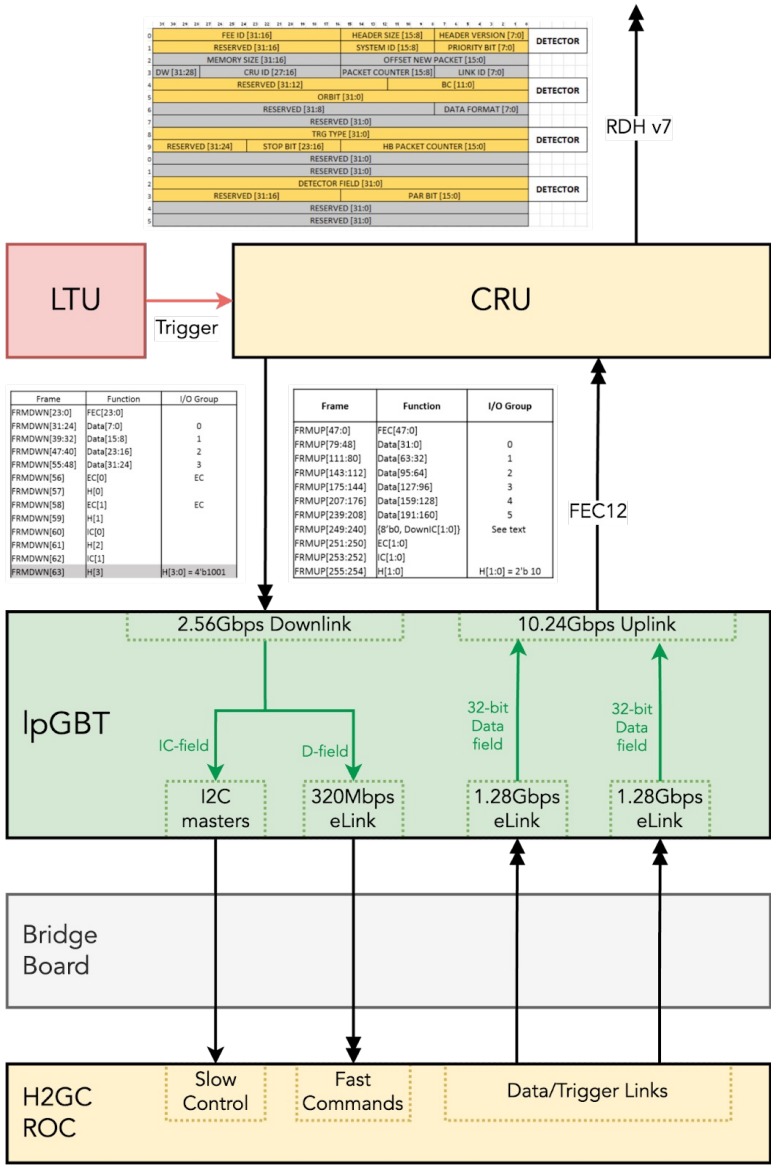
Backup

HGCROC/H2GCROC ASIC



- 72 readout channels
- Interfaces:
  - (out) 2x data links
  - (out) 4x trigger links
  - (in) fast commands
  - (io) slow control
- Measurements:
  - ADC for ‘low range’ energy
  - ToT (time-over-threshold) for ‘high range’ energy
  - ToA (time-of-arrival) for timing
- Current conveyor (CC) for SiPM operation

Back-end data flow



In ALICE FoCal, the data flow from/to H2GCROCs is done via data concentration ASICs (lpGBT, ECON-D, ECON-T)

- One lpGBT can aggregate the data lines from 3 H2GCROCs
- Data rate (uplink) is boosted from 1.28 Gbps to 10.24 Gbps by lpGBT
- Slow control and fast commands are commonly issued by the downlink (IC-field and D-field in the data frame)