ALICE

The FoCal detector

at the ALICE collaboration

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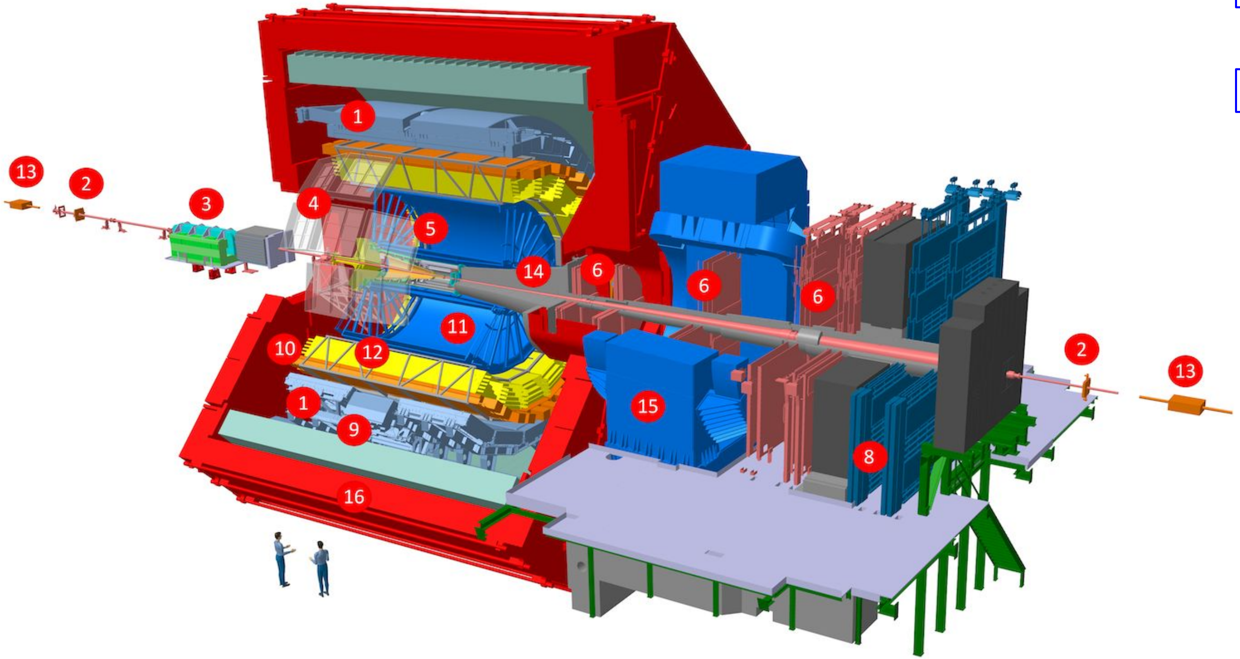
U.S. DEPARTMENT OF ENERGY
Office of Science

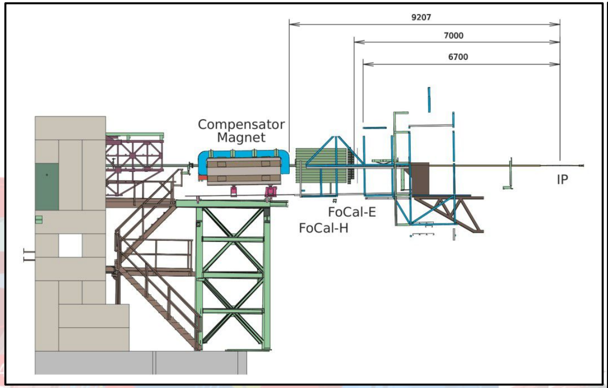
The FoCal detector at the ALICE experiment

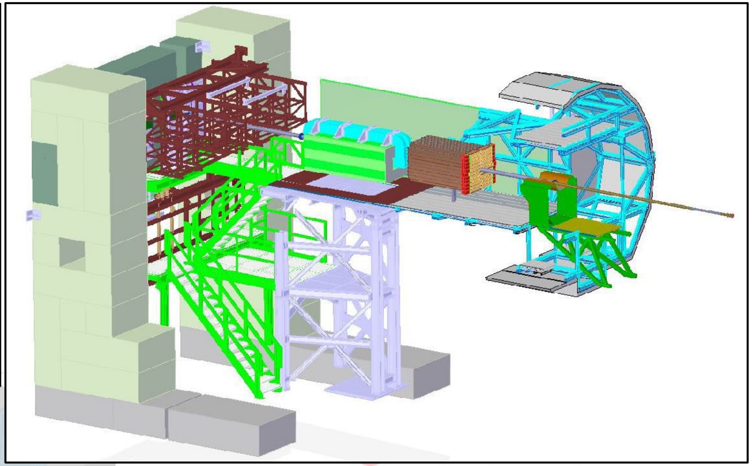
The upgraded detector (post LS3)

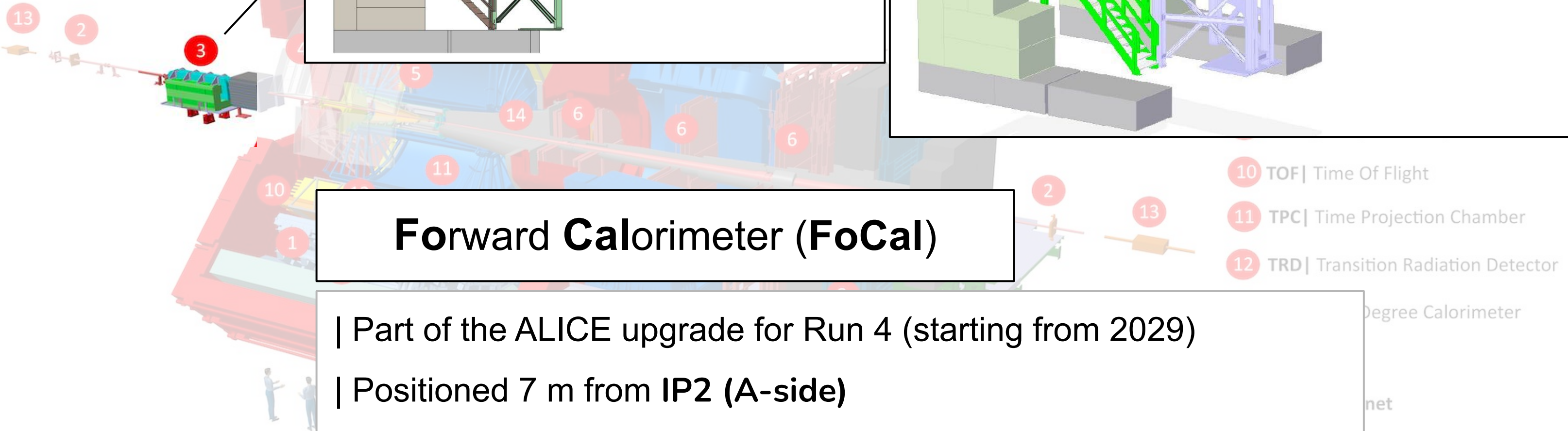


1. **EMCAL** | Electromagnetic Calorimeter
2. **FIT** | Fast Interaction Trigger
3. **FoCal** | Forward Calorimeter
4. **HMPID**| High Momentum Particle Identification Detector
5. **ITS**| Inner Tracking System
6. **MCH**| Muon Tracking Chambers
7. **MFT**| Muon Forward Tracker
8. **MID**| Muon Identifier
9. **PHOS/CPV**| Photon Spectrometer
10. **TOF**| Time Of Flight
11. **TPC**| Time Projection Chamber
12. **TRD**| Transition Radiation Detector
13. **ZDC**| Zero Degree Calorimeter
14. **Absorber**
15. **Dipole Magnet**
16. **L3 Magnet**

The FoCal detector at the ALICE experiment







Forward **Cal**orimeter (**FoCal**)

| Part of the ALICE upgrade for Run 4 (starting from 2029)

| Positioned 7 m from **IP2 (A-side)**

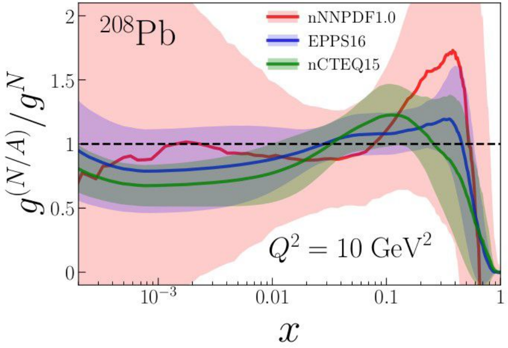
| covering $\mathbf{3.4 < \eta < 5.8}$

The FoCal physics program

Measure the gluon density in protons and lead nuclei at small x and Q

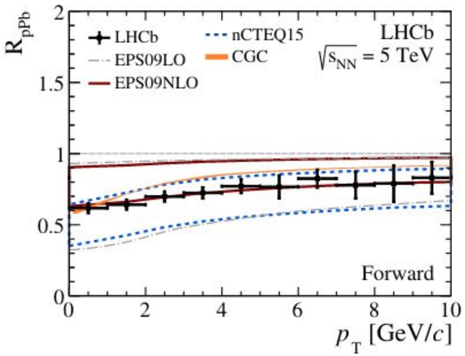
DIS, DY and electroweak boson production constrain the PDFs.

→ Direct probe of quark density in nuclei BUT gluon structure determined indirectly from fits to Q^2 evolution



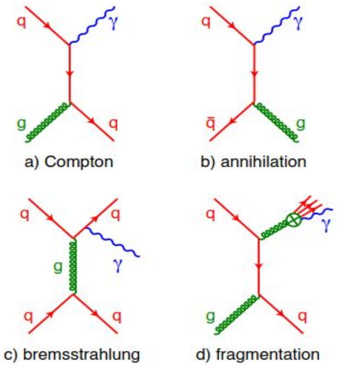
At low x and Q^2 uncertainties are larger than 20%

nuclear modification effects



D-Meson production (p-Pb) at high rapidity (dominated by gg->cc) is the most precise evidence of strong gluon shadowing at low-x

However, affected by hadronic final state effects (rescattering)

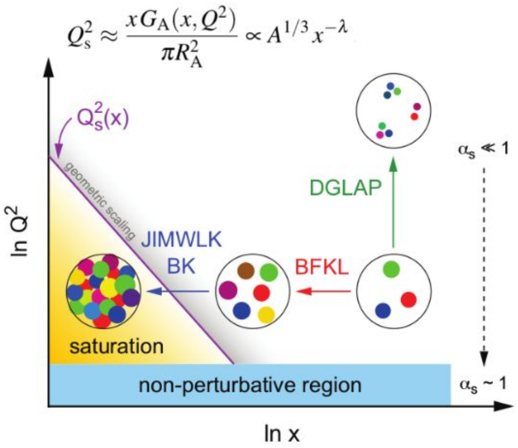


| FoCal explores **x ~ 10^{-6}** and low transferred momenta **Q^2 ~ 4 GeV/c** |

Observables: Study of isolated photon spectra at forward rapidity in pp and p–Pb

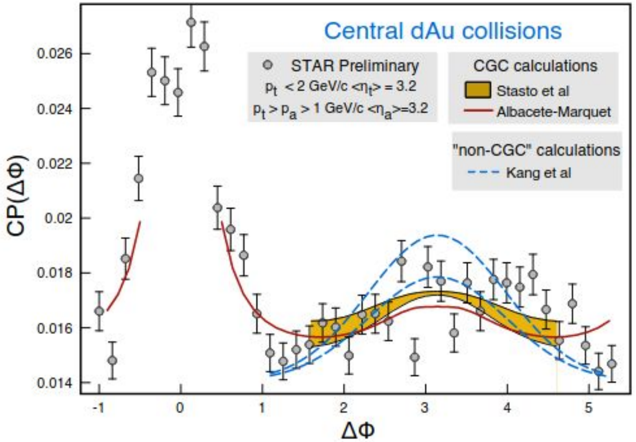
The FoCal physics program

Investigate non-linear QCD evolution at small x and Q^2



The momentum scale of nuclei the parton structure is described by linear QCD evolution equations (DGLAP,BFKL)

At low-x the evolution is non-linear due to the high gluon densities (CQC, where single partons scatter off gluons)



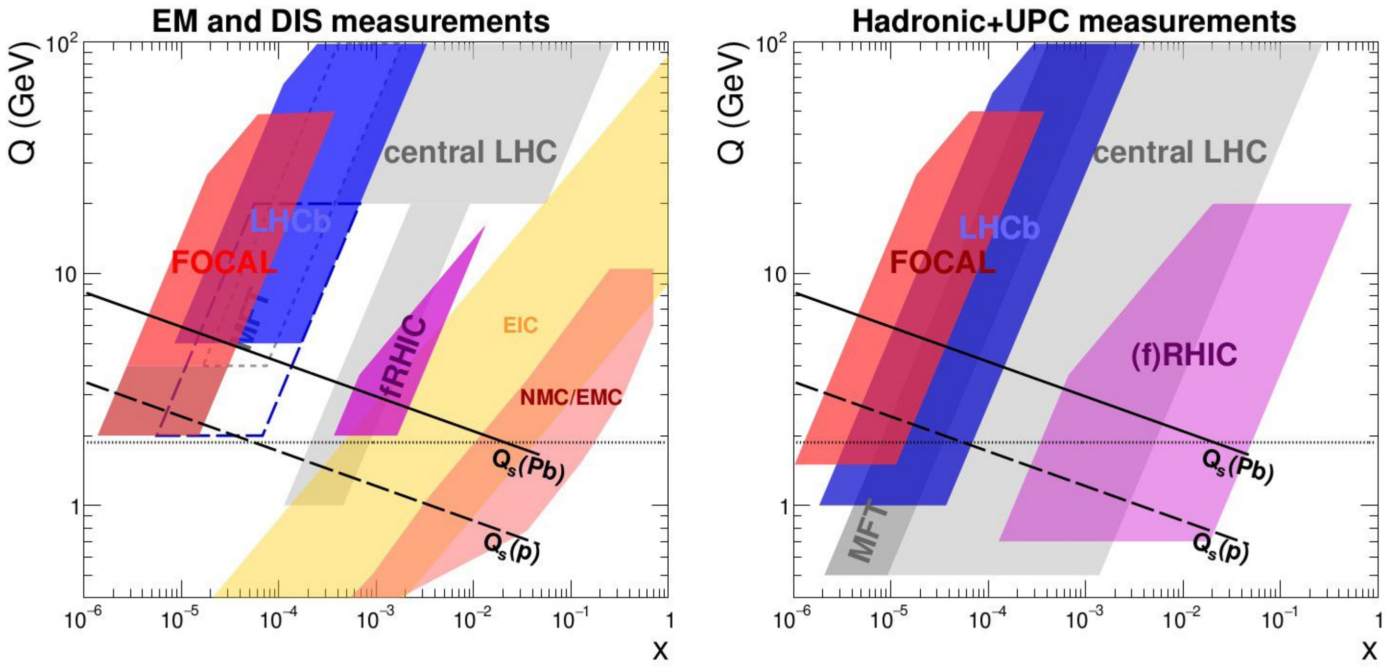
Observable effects in coincidence measurements

Azimuthal correlation of π_0- π_0 vs γ - π_0 (also γ - jets and π_0 - jets)

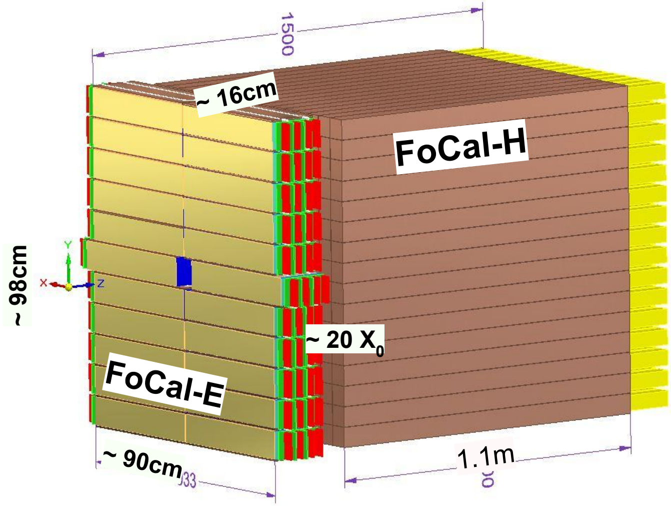
1. Test of the x and Q2 dependence of QCD evolution
2. Validate consistency of the theory, with saturation studies

The FoCal physics program

FoCal extends the experimentally accessible Q-x-domain, complementing present and future experiment (EIC) in studying evolution of saturation effects with high precision



The FoCal detector design



FoCal-E

| 20 Layers (LG + HG Si detectors + W absorbers). Tot (~ 20 X_0)

| Dimensions ~ 90cm x 98cm x 20cm

| Designed for:

measurement of direct photons

Measurement of high p_t neutral pions (Pb-Pb vs p-p)

| Granularity optimized to enable photons separation (~ 5mm distance)

FoCal-H

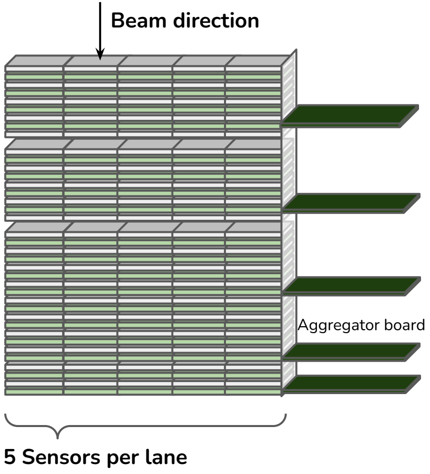
| Transversally segmented calorimeter Tot thickness ~ 6 λhad

| located behind FoCal-E (reduce shower blow-up)

| Designed for:

Studying the dynamics of hadronic matter with photons and jets (isolation capabilities (single hadron res ~ 20-25%))

FoCal-E pads design concept



18 layers of Si Pad sensors interleaved with Tungsten absorbers

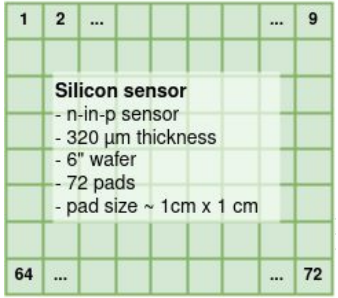
| samples the longitudinal development of EM showers |

> Si pads size **~1 x 1 cm^2**

> Absorber: **3.5 mm Tungsten** (= 1 X_0), R_M~ 1 cm

> Each sensor: **8_{rows} x $9_{columns}$ pads**

> **5 aggregator** (+interface) **boards** per stack.



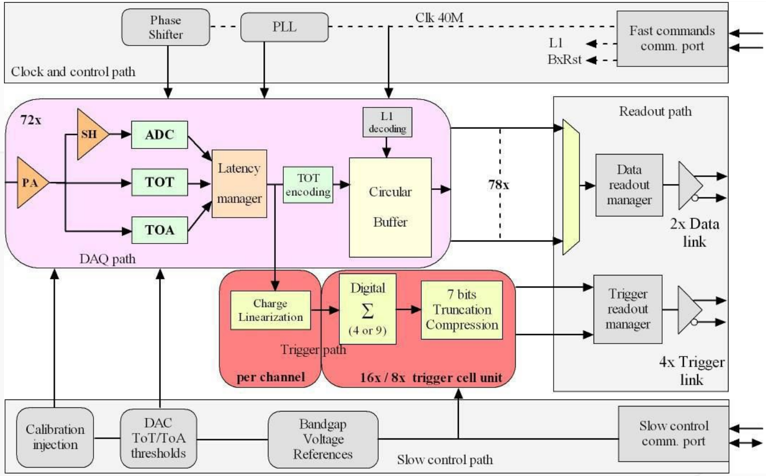
Read-out :: HGCROCV2 chip

| provides ADC, ToT (12bit, lsb:50ps), ToA (10bit, lsb:25ps)

| 40MHz trigger pulse

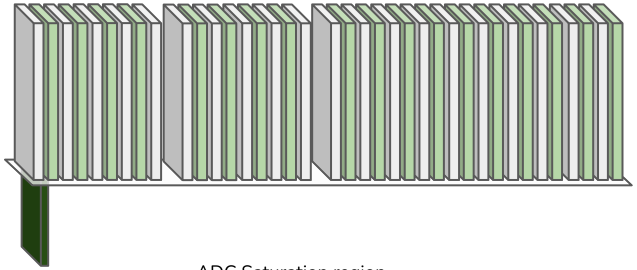
| dynamic range MIP ~ 10 pC

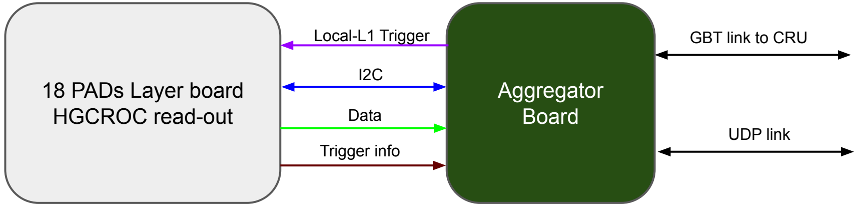
| data transfer ~ 960 KHz with internal circular buffer

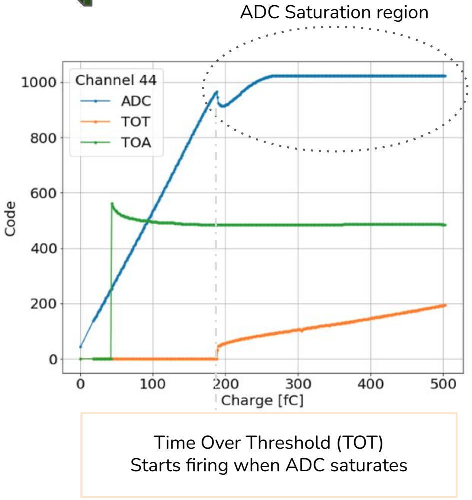


The FoCal-E Pad prototype

Tower with 18 layers of individual Si Pad sensors + 1 aggregator board





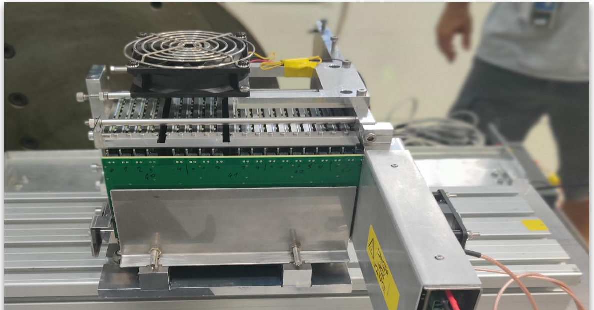


HGCROCV2

Energy measurement performed using the ADC and TOT values

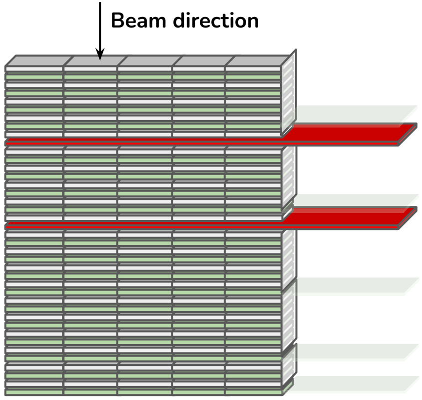
| TOT used to linearize the charge response

| Data buffer binned in time interval relative to the received trigger



Prototype Focal-E pads
| 18 sensors (72 pads each)
| 18 layers of tungsten
| Aggregator board

FoCal-E pixels design concept



2 High granularity layers (L5, L10) of Si pixels

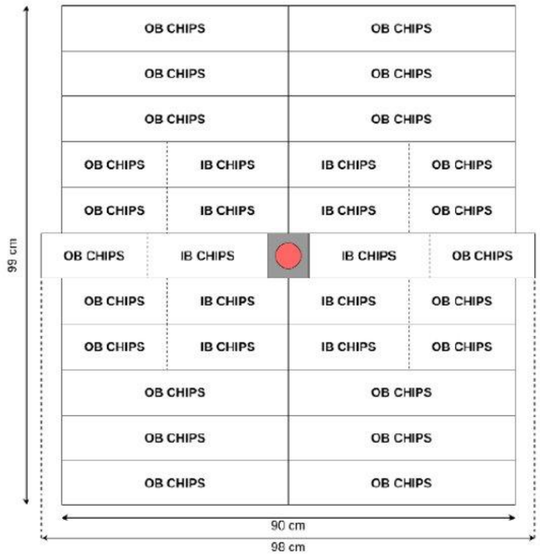
| two-photon separations (~5mm): isolated photons from π_0 decay photons |

ALICE **PI**xel **DE**tector **(ALPIDE) M**onolithic **A**ctive **P**ixel **S**ensor (**MAPS**)

| Chip size **~30mm x 15mm**

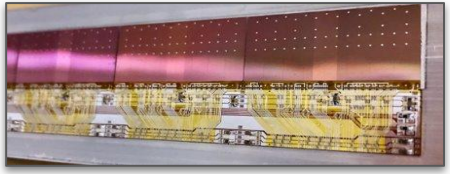
>**1024 x 512 pixels per chip**

> pixel pitch **~ 30µm x 30µm**



| ITS ALPIDE modes:

Inner **B**arrel (**IB**) and **O**uter **B**arrel (**OB**)



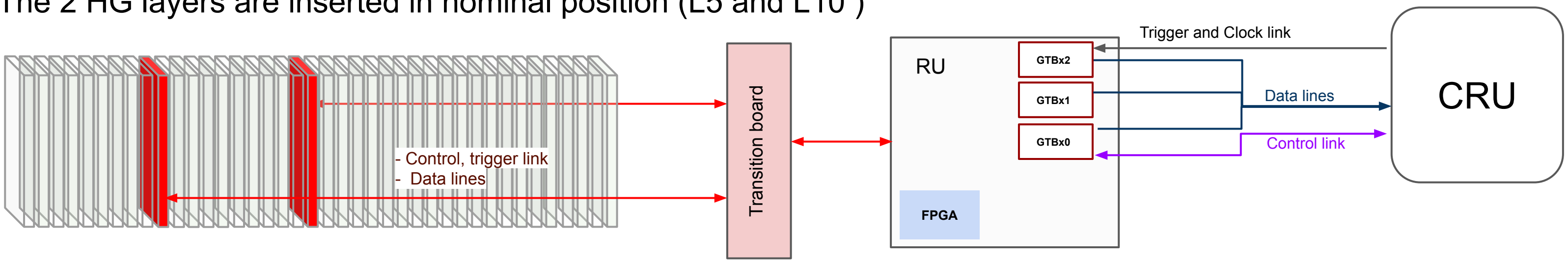
> Design inherited from proton CT project

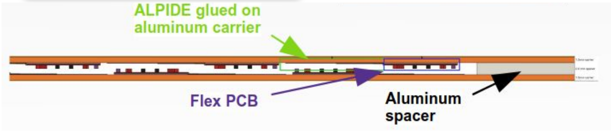
> 3 strings of 15 ALPIDEs per aluminum carrier

> 2 carries folded together so that ALPIDEs cover the pad area

The FoCal-E pixel prototype

The 2 HG layers are inserted in nominal position (L5 and L10)





pCT - IB Layers

| **Two** folded **half layers** (back and front)

| Total of **6x3 ALPIDEs** in the beam region

| Full layer connected to a Transition Card

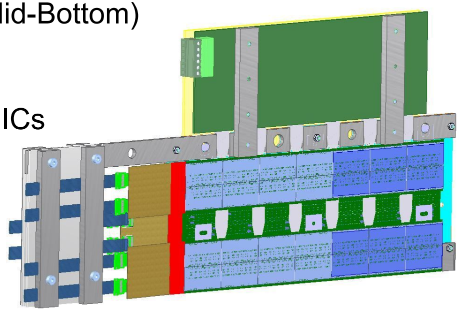
BACKUP SOLUTION

OB Hybrid Integrated Circuit (HICs) Layers

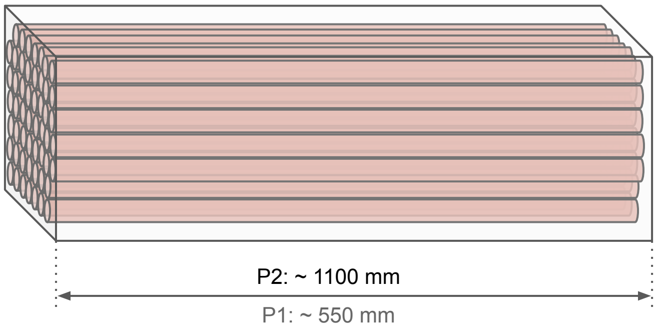
| Three HICs perLayer (Top-Mid-Bottom)

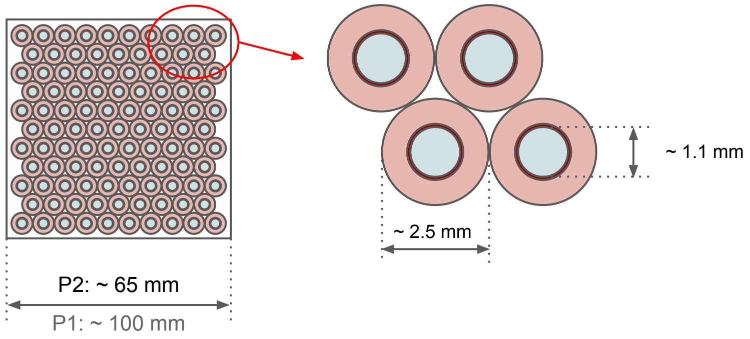
| Wire bonded to FPC

| Overlap between adjacent HICs



FoCal-H design concept and prototypes





Cu capillary-tubes enclosing BCF scintillating fibers

| Collect energy of the hadronic shower deposits |

> final dimensions 90 cm x 90 cm x 110 cm

Advantages:

Modularity: different tower sizes at different rapidities

Simplicity: easy assembly, Cu tubes commercially available

Possibility of upgrade with quartz fibers (dual readout)

Gaps can be filled with copper powder and epoxy

FoCal-H design concept and prototypes

Prototype 1 (used during 2021 tests)

| 10cm x 10cm x 5cm

| 1480 fibers per module

| 1 mm BCF10 scintillating fiber

| Single module

| 48 ONsemi: MicroFC-SMA-60035-GEVB

| CAEN A1702 readout boards

Prototype 2 (used during 2022 tests)

| 6.5 cm x 6.5 cm x 110 cm

| 1 mm BCF12 scintillating fiber

| 49 (central), 25 (sides) Hamamatsu: S13360-6025PE

| 2/3 CAEN DT5202 boards (2xCitiroc-1A chips)

| alternative custom VMM-based readout (with SRS system)

Test beam requirements

Hadron and electron beams needed to explore every expected topology (PS ad SPS)

| Photons converting in the Tungsten layers starting EM showers fully contained in FoCal-E

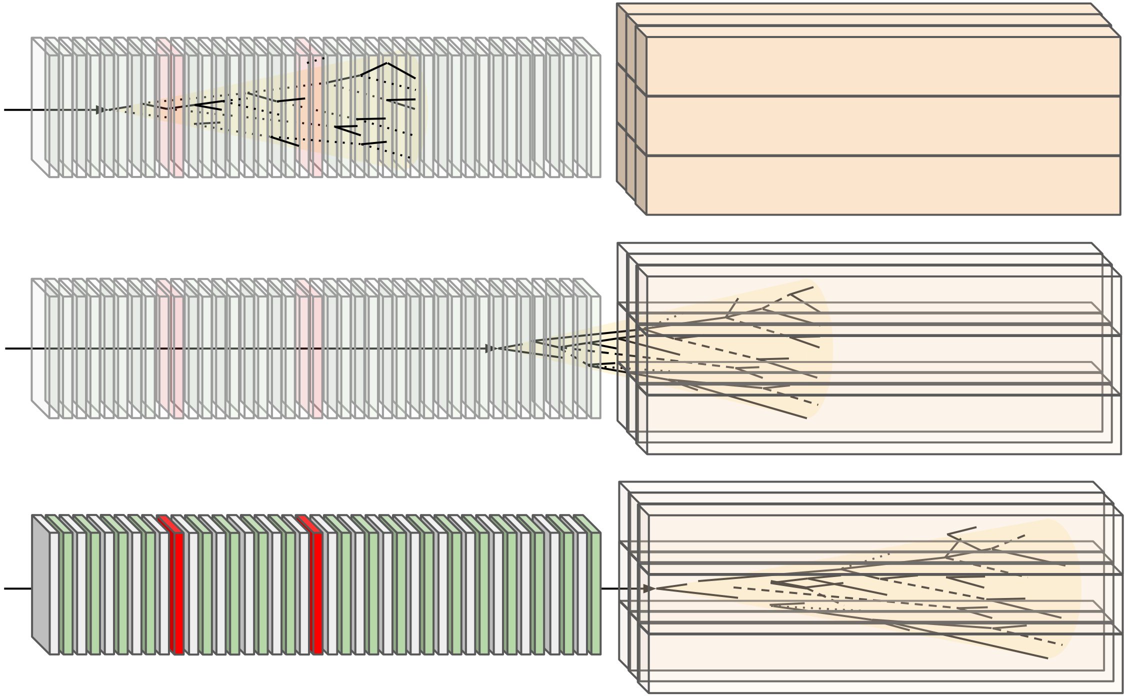
>> lower Energy electron beams (1-15 GeV) <<

| Photons converting in the Tungsten layers starting EM showers NOT fully contained in FoCal-E

>> higher Energy electron beams (up to 300 GeV) <<

| Hadrons converting in the copper starting Hadronic showers fully contained in FoCal-H

>> Hadron beams (up to ~350 GeV) <<



Test Beam campaign 2022

Proton Synchrotron (PS)	
Beam Type	**Energy [GeV]**
positive hadrons	1 - 15
electrons	1 - 5
Super Proton Synchrotron (SPS)	
positive hadrons	20 - 350
electrons	20 - 300

General

| Focus on FoCal-E and FoCal-H combined acquisition

| Data needed for **T**echnical **D**esign **R**eport (**TDR**) of FoCal

FoCal-E

| Commissioning of OB HICs Layers

| Characterization of HGCROC ADC at different electron energies

| Energy and position scans (hadrons and electrons)

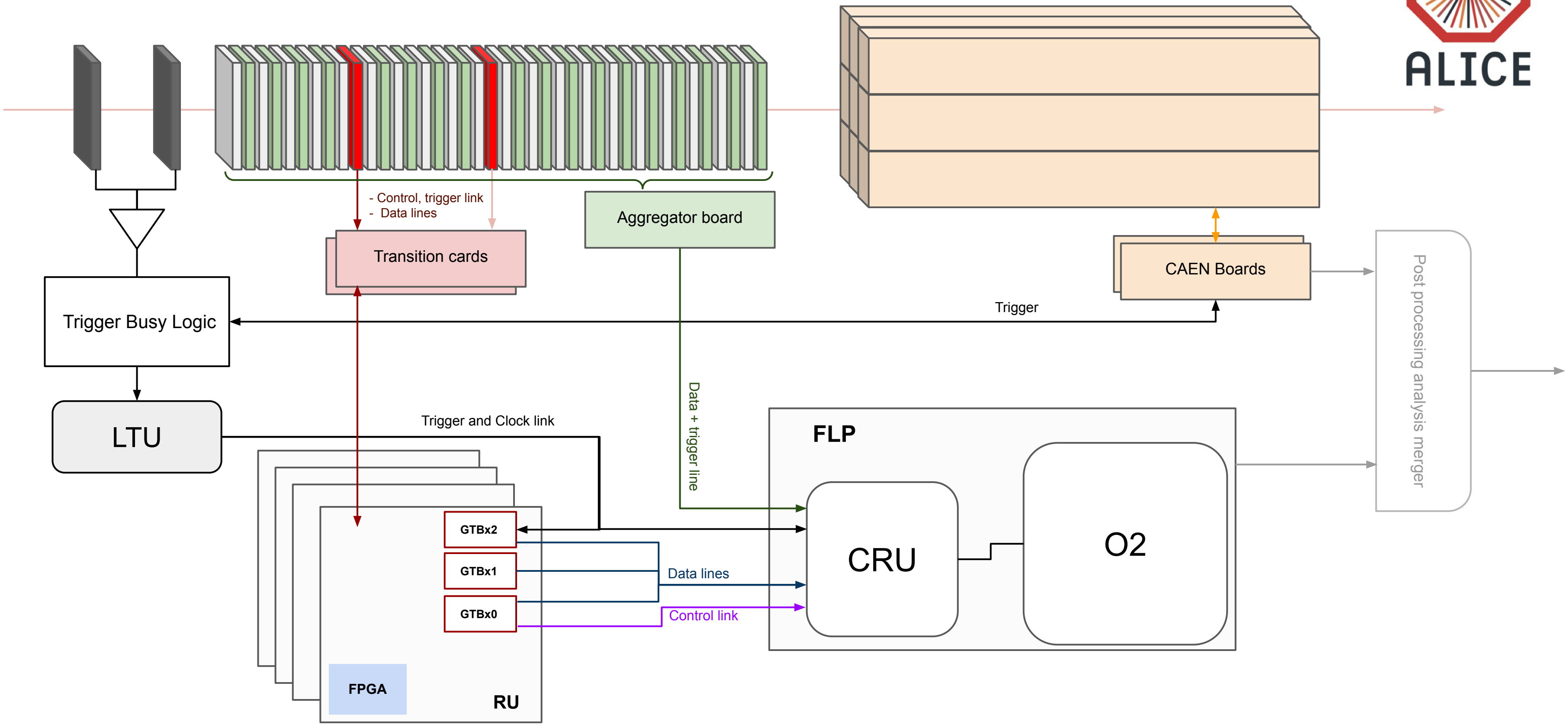
FoCal-H

| Characterization of energy collection

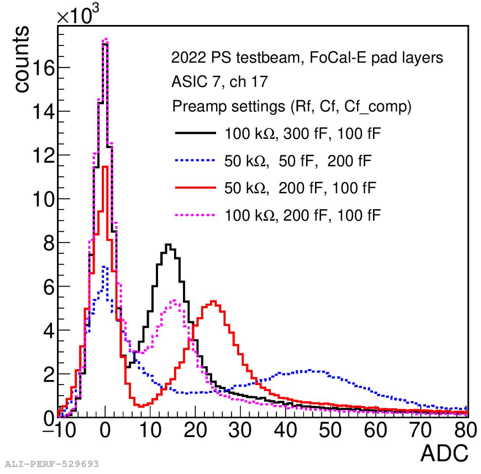
| Energy scans (Hadrons) with 9 stacked modules prototype

| Position dependence and resolution

The test beam setup 2022



Test Beam results - FoCal-E pads

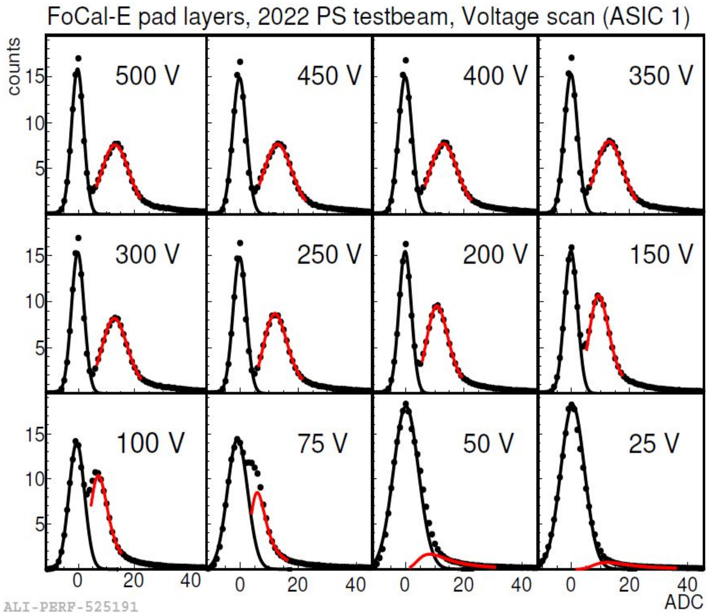


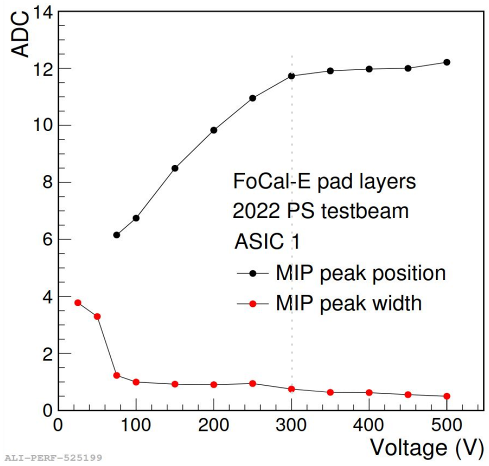
Gain calibrations

| Characterization of the MIP/noise separation

| Validate simulation results

| optimize energy resolution





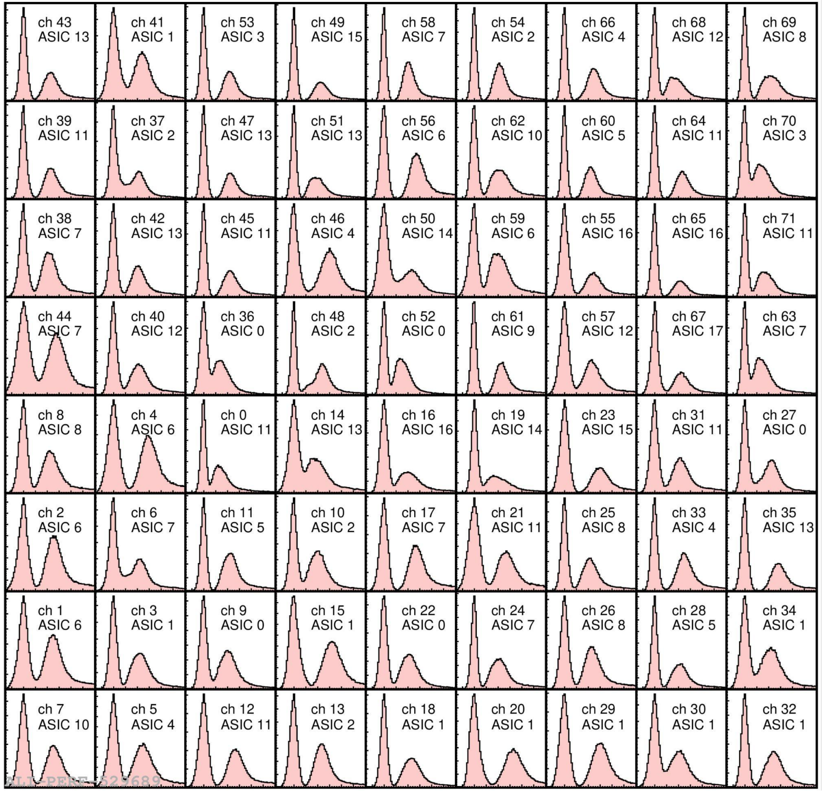
Voltage scan

| Dependance of MIP peak position

| Depletion reached @ ~ 300V

Test Beam results - FoCal-E pads

Position scan, 2022 PS testbeam, FoCal-E pad layers



Position scan 15 GeV hadron beams

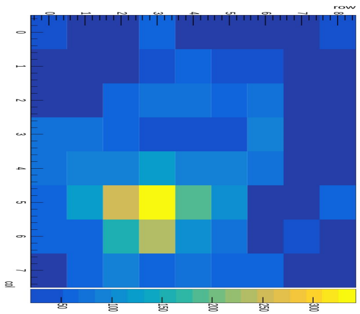
| most of the cells displays clear MIP peak |

|Study of pads edge-effect

| Compare two p-type Si pads productions

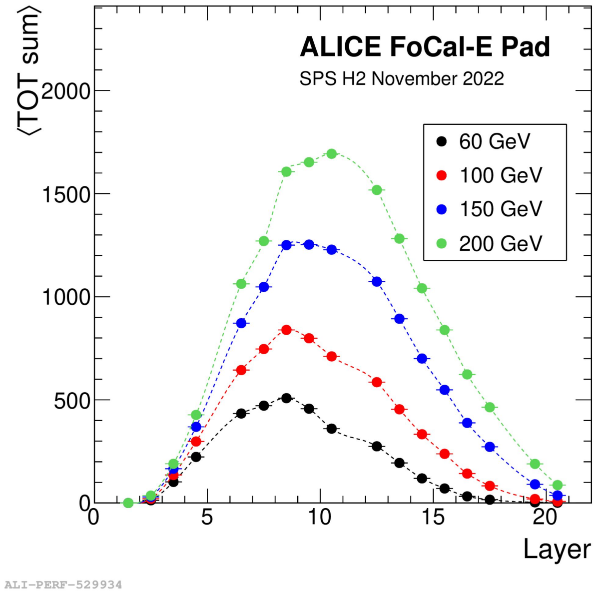
| Compare Pads within the same sensor

Position scan performed with 100 GeV hadrons



43	41	53	49	58	54	66	68	69
39	37	47	51	56	62	60	64	70
38	42	45	46	50	59	55	65	71
44	40	36	48	52	61	57	67	63
8	4	0	14	16	19	23	31	27
2	6	11	10	17	21	25	33	35
1	3	9	15	22	24	26	28	34
7	5	12	13	18	20	29	30	32

Test Beam results - FoCal-E pads



Total Time Over Threshold (TOT) per layer
SPS electron beam | Energies (60 GeV - 200 GeV)

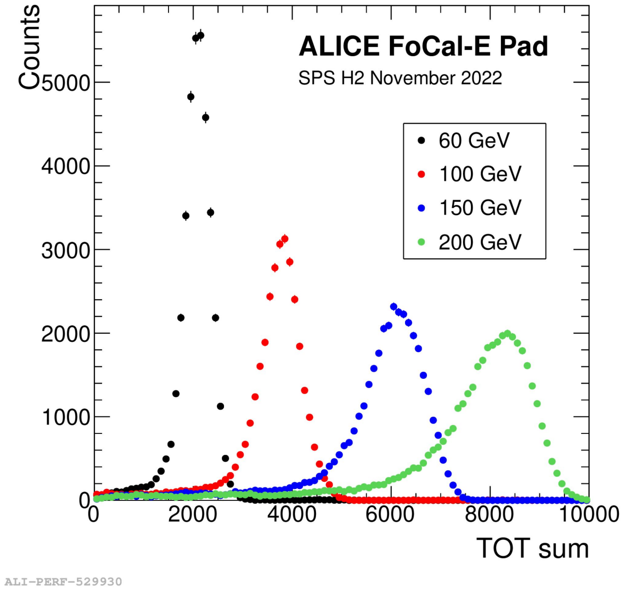
| TOT ∝ total deposited charge

| Qualitative description of the shower longitudinal development

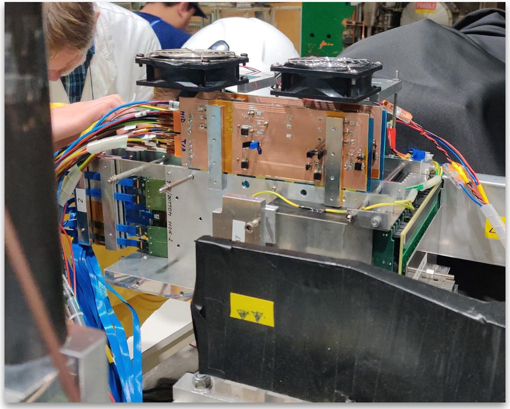
Total TOT distribution per beam energy
SPS electron beam | Energies (60 GeV - 200 GeV)

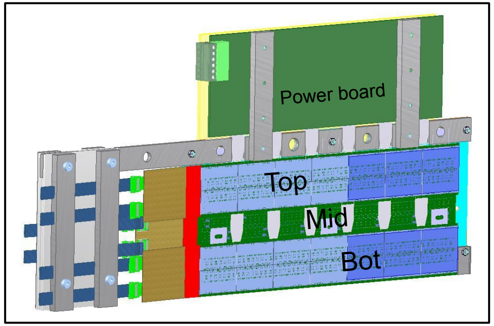
| Characterizes detector response to the charge deposit

| MPV of the distributions ∝ collected charge



Test Beam results - FoCal-E pixels



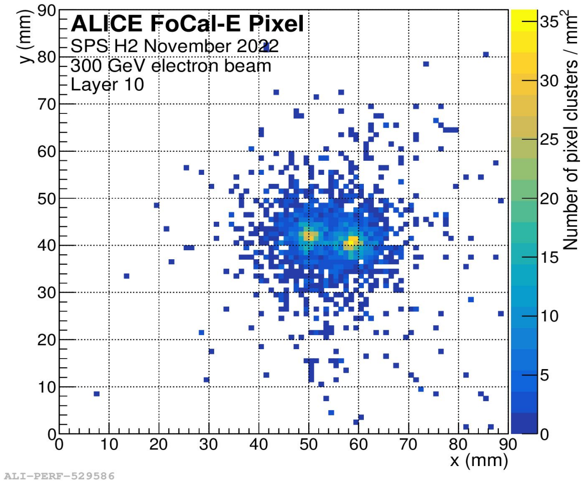


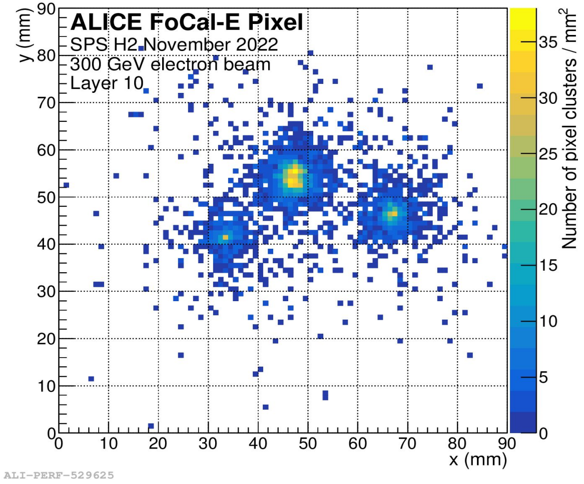
Successful commissioning of the HICs

| recover complete nominal acceptance (faulty line in L5) |

| Global hitmaps monitored using O2 QC

| Double and triple electron signature identified in preliminary analysis

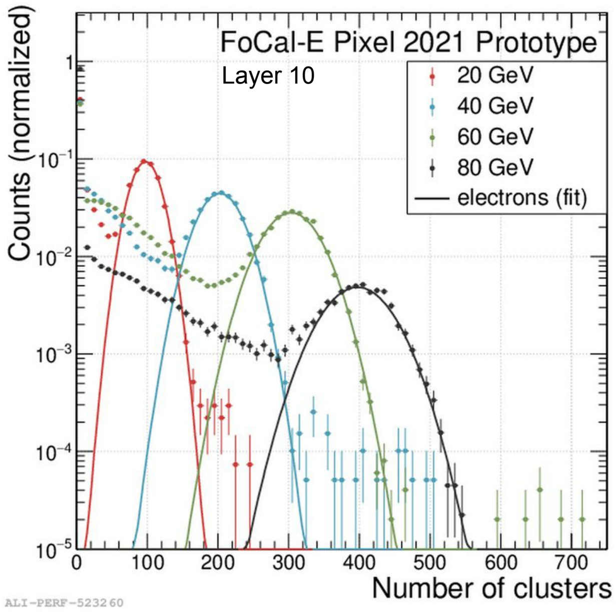




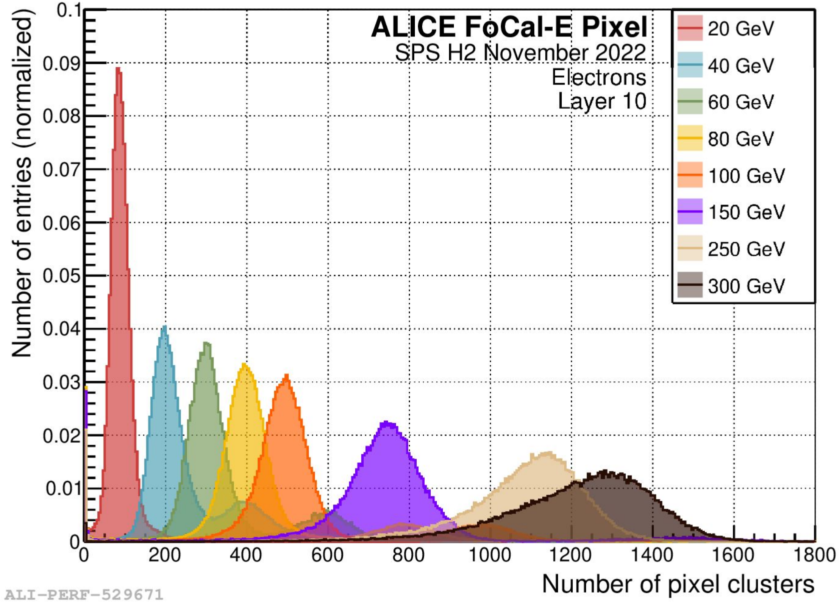
Test Beam results - FoCal-E pixels

2021 Results [IB pCT layers] - Layer 10

| clusters distributions fitted with Gaussians
| Deviation between data and simulation within 10%

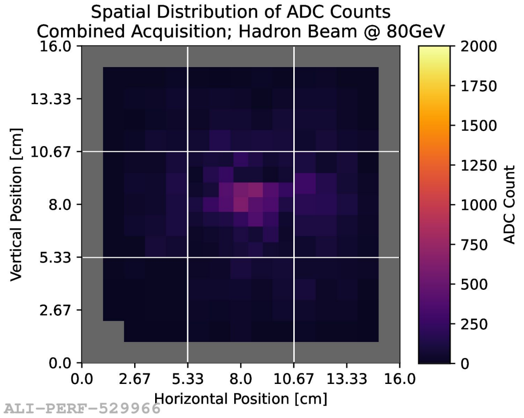


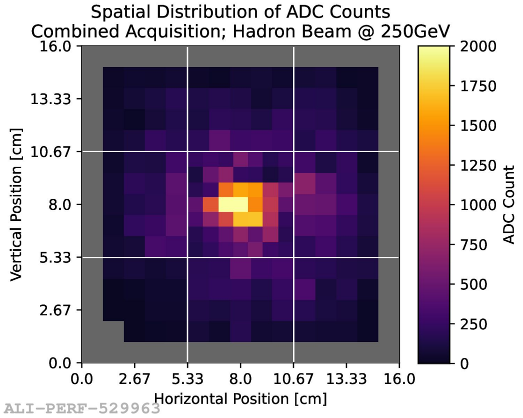
2022 preliminary results [HICs layers] - Layer 10

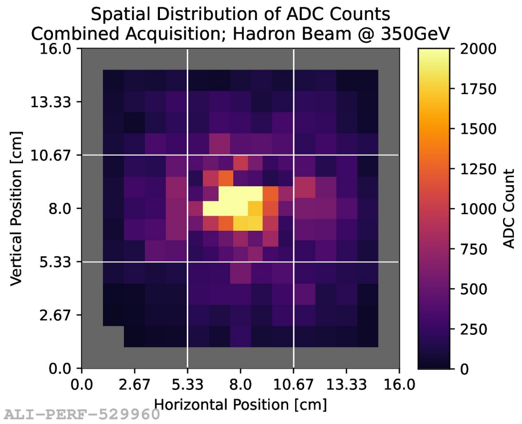


Test Beam results - FoCal-H prototype

FoCal-H (9 modules) 2D hitmaps with hadron beam @ different energies







Increasing Energy →

| Energy deposited increasing with the beam energy

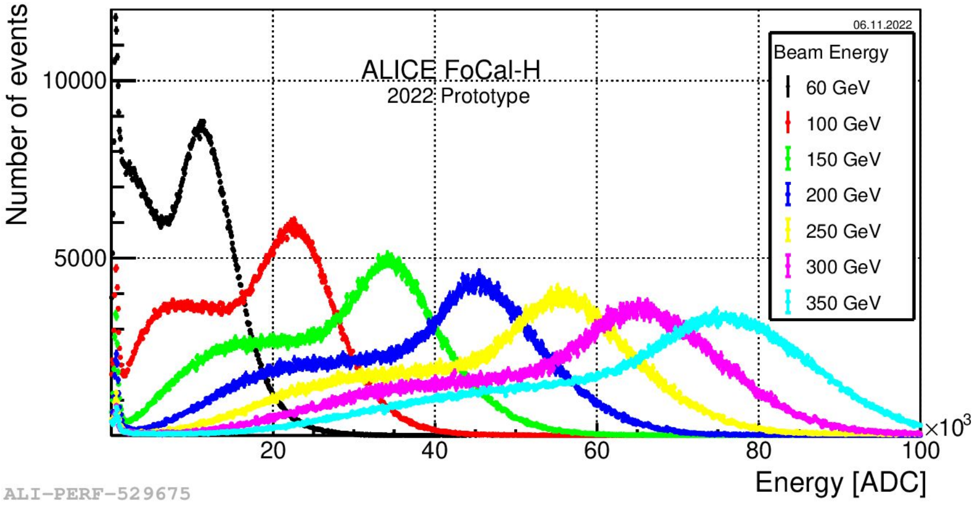
| Grey bands → Non instrumented SiPMs (3 CAEN DT5202 boards used)

| 49 (central) + 25x8 (sides) SIPMs, photosensitive area: 6x6 mm, pixel size: 25 μm

Test Beam results - FoCal-H prototype

Reconstructed charge in the FoCal-H prototype [ADC counts/energy]

SPS positive hadron beam | Energies (60 GeV - 350 GeV)



| Distributions qualitatively follow the expected trends

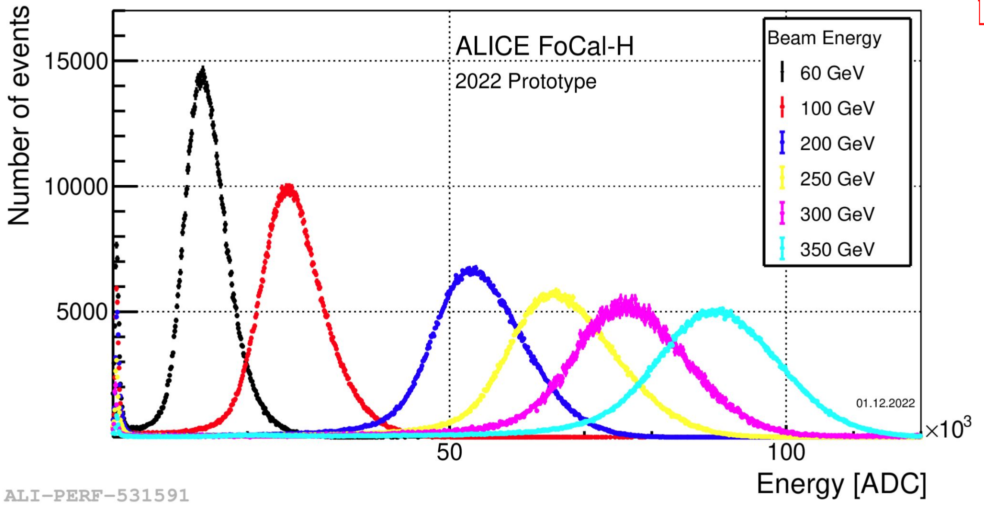
| MIP peak (centered around 0) is at the same position for each beam energy

| The position of the second peak move according to the beam energy.

Test Beam results - FoCal-H prototype

Reconstructed charge in the FoCal-H prototype [ADC counts/energy]

SPS positive hadron beam | Energies (60 GeV - 350 GeV)



w/o FoCal-E infront

| The tails at lower En deposit disappear (conversion in Focal - E)

| The plot display good energy resolution in data

|Under investigation check potential effect from saturation (electronic or SiPM)

Summary

| **FoCal** is part of the **upgrade project** of ALICE during **Run 4** (starting from 2029) for investigating unexplored regions of **small-x and low Q^2**

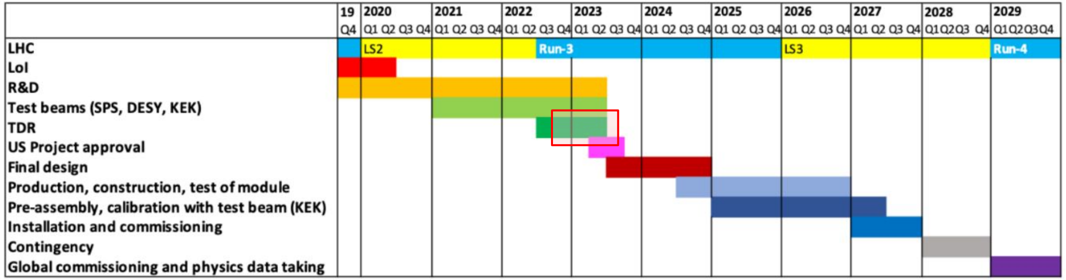
| Successful Test Beam campaigns during 2021 and 2022. Now preparing for june 2023

| **Successful integration** of the subsystems **in combined acquisitions**

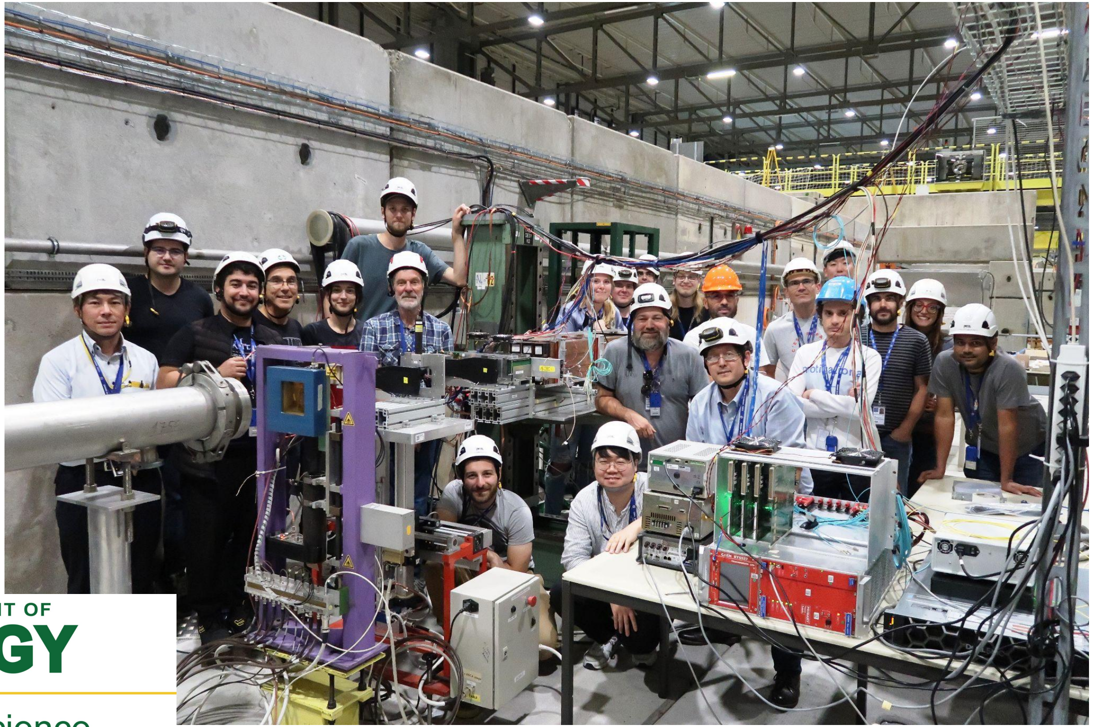
| The collected **data** (2021, 2022) **currently being analyzed** and **compared to simulations**

| Focus on design readout and trigger design

| **The FoCal collaboration is preparing the TDR**



Thank you for your attention



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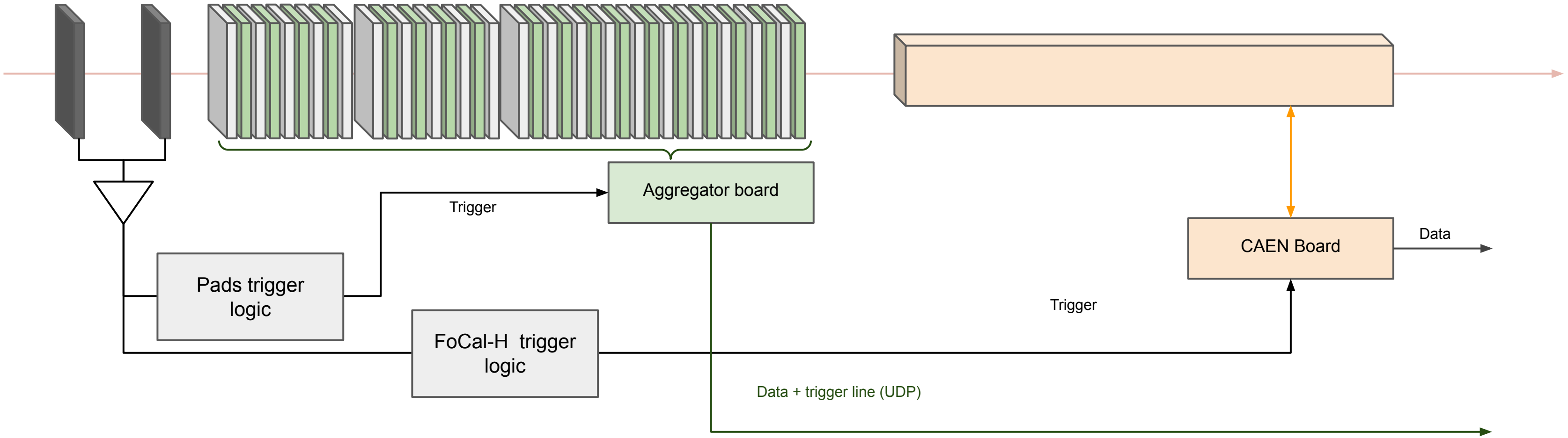
THE UNIVERSITY OF KANSAS

The test beam setup - June 2022 (PS T9)

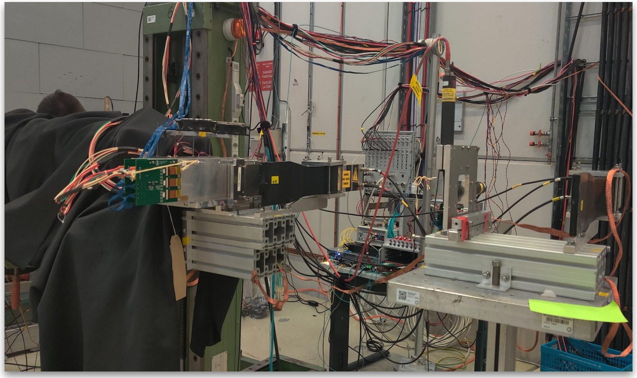


Test beam September 2022 (SPS H6, PS T10)

ALICE

SPS H6

Beam Type	Energy [GeV]
positive hadrons	20
	40
	60
	80
	100
	120
electrons	20
	40
	60
	80



PS T10

Beam Type	Energy [GeV]
positive hadrons	1
	2
	3
	4
	5
	6
	7
	8
	9

General

| Focus on FoCal-E and FoCal-H combined acquisition

| Full system triggered through LTU to attempt evt matching

| Energy scan for energy resolution

FoCal-E

| Commision of FoCal-E Pixels (IB pCT layers)

| Data acquisition of FoCal-E through O2 workflow (FLP+CRU)

| match reconstructed tracklets (pixels) to MIP peak (pads)

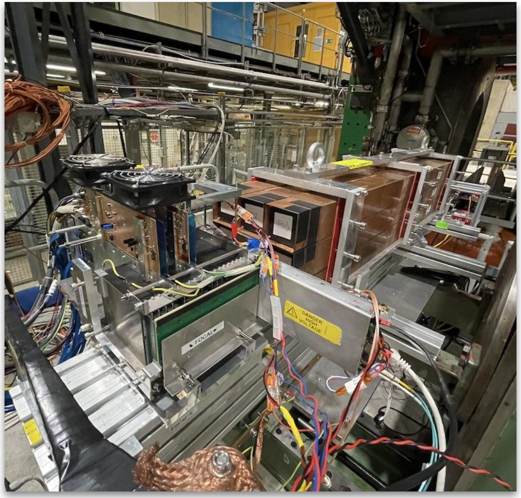
FoCal-H

| Installation of FoCal-H 3 x 3 quadratic modules

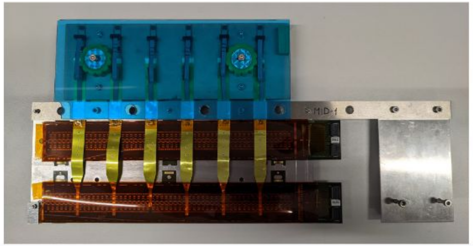
| Test of CAEN commercial electronic ad high rates

| Test of VMM custom made read-out

Test beam November 2022 (SPS H2)



HIC-based module



SPS H2

Beam Type	Energy [GeV]
positive hadrons	60
	80
	100
	150
	200
	250
	300
	350
electrons	20
	40
	60
	80
	100
	150
	200
	250
	300

General

| Focus on FoCal-E and FoCal-H combined acquisition

| Data needed for **T**echnical **D**esign **R**eport (**TDR**) of FoCal

FoCal-E

| Commissioning of OB HICs Layers

| Integration of O2 **Q**uality **C**ontrol (**QC**)

| Characterization of HGCROC ADC at different electron energies

| position scan of the Pads

FoCal-H

| Characterization of energy collection
> CAEN readout
> VMM readout

| Energy scans (Hadrons) with new prototype

| Position dependence and resolution