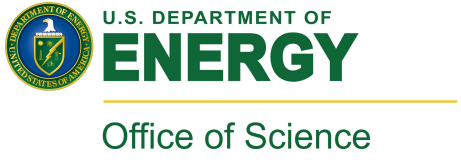
A Large Ion Collider Experiment

FoCal: a high-granularity forward calorimeter

at the ALICE experiment

Tommaso Isidori

for the ALICE Collaboration



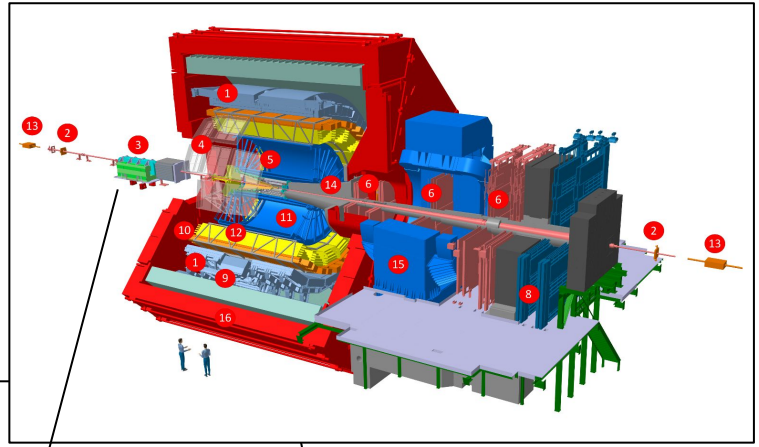
The FoCal detector at the ALICE experiment

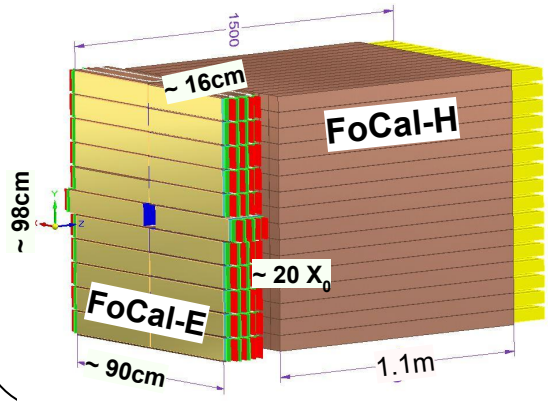
Forward Calorimeter (FoCal)

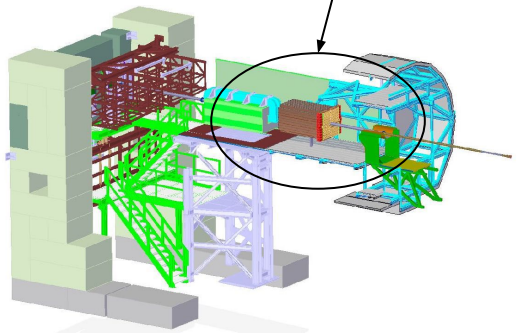
| Part of the ALICE upgrade for Run 4 (starting from 2029)

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

| covering **$3.4 < \eta < 5.8$**







Letter of Intent: A Forward Calorimeter (FoCal) in the ALICE experiment

The FoCal detector at the ALICE experiment

FoCal Physics Program

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

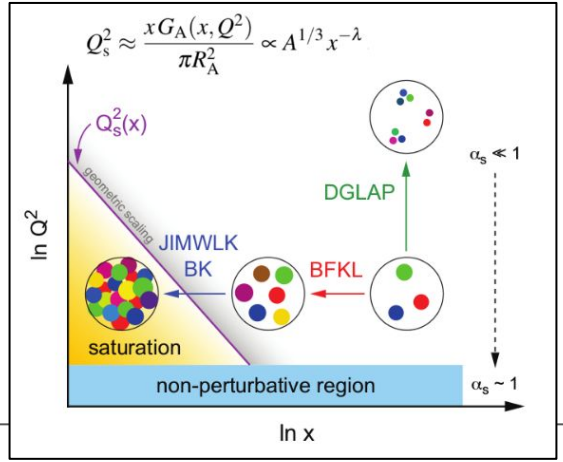
… Measure Gluon density in protons and Pb nuclei

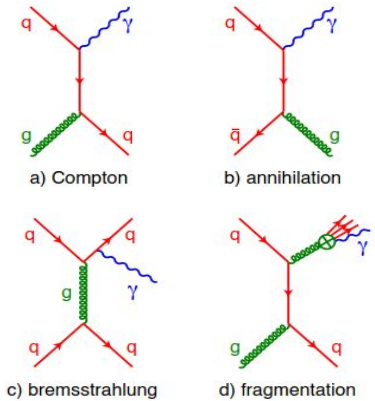
… Investigate origin of shadowing effects

… Ultra-peripheral heavy-ion collisions

… Jet quenching at forward rapidity

… Investigate long range correlation in pp and p-Pb





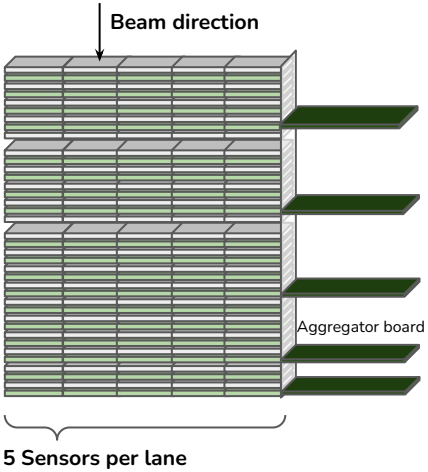
Direct photons (a,b) couple to the partons → **probe of the nuclei structure**

| direct constraint of the gluon density and its x-dependence (not fit-dependent)

| Azimuthal correlation of Π_0- Π_0 vs γ-Π_0

| Direct study of non-linear effects of the hadronic structure at low-x and Q^2

FoCal-E pads design concept



18 layers of Si Pad sensors interleaved with Tungsten absorbers

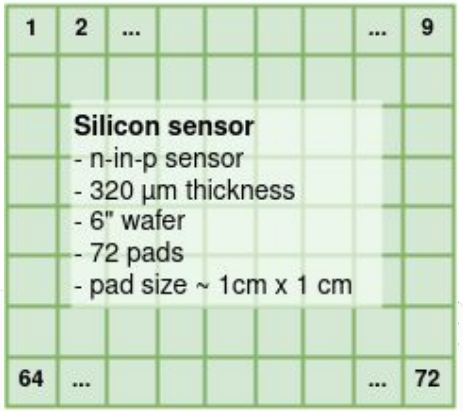
| (Coarsely) samples the longitudinal development of EM showers |

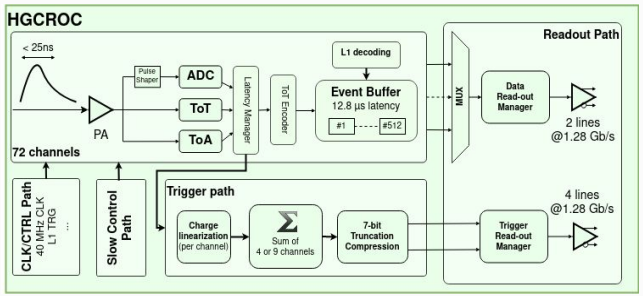
> Si pads size **~1 x 1 cm^2**

> 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 :: HGCROC chip

| provides ADC, ToT, ToA, 25ps time information

| 40MHz trigger pulse

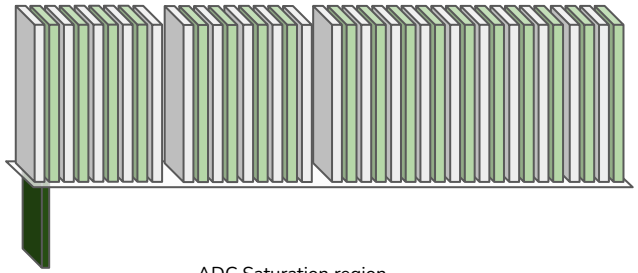
| dynamic range MIP ~ 10 pC

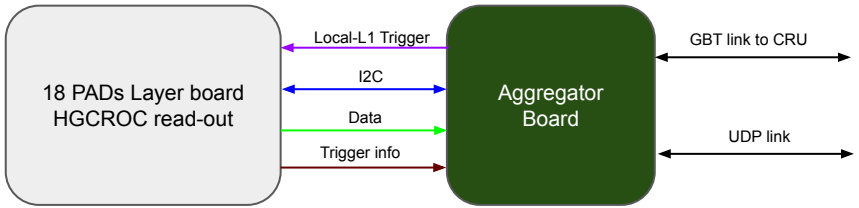
| data transfer ~ 960KHz with internal buffer

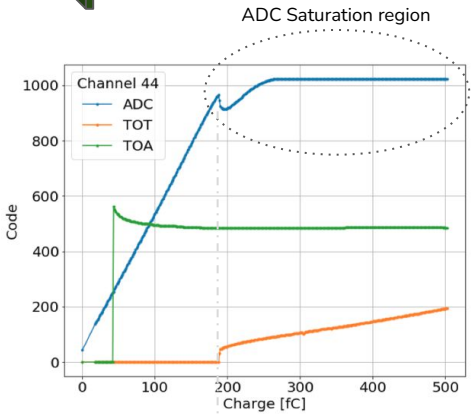
ALICE FoCal A Forward Calorimeter for the ALICE Experiment - max Rauch for the ALICE collaboration - ICHEP 2022

The FoCal-E Pad prototype

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







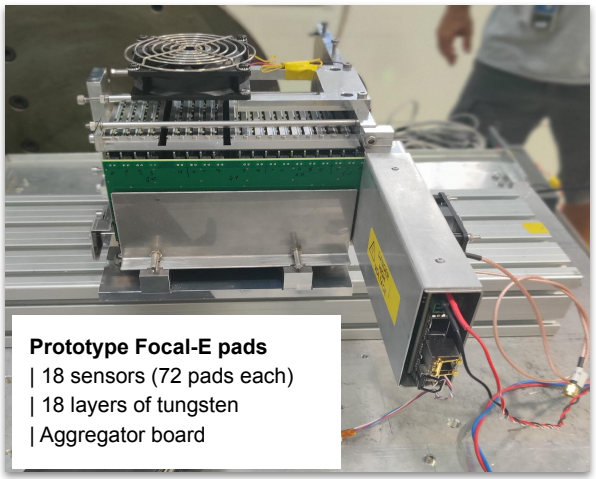
Time Over Threshold (TOT)
Starts firing when ADC saturates

HGCROC

Energy measurement performed using the ADC and TOT values

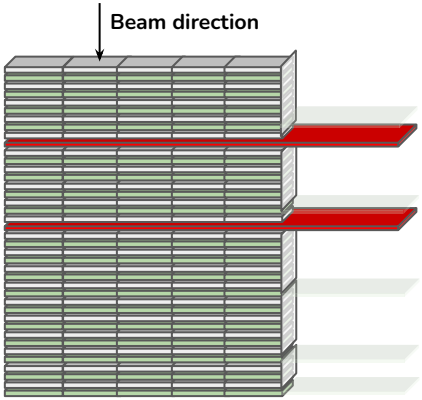
| TOT used to linearize the charge response

| 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

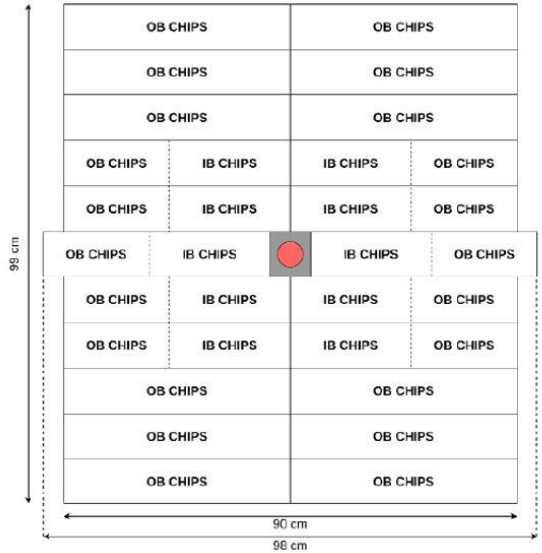
| two-photon separations (~5mm): isolated photons from π_0 decay photons |

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

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

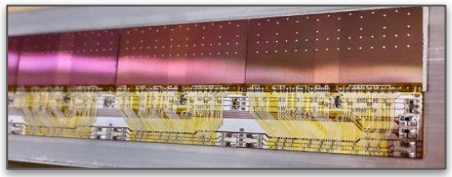
>**1024 x 512 pixels per chip**

> pixel size **~ 30µm x 30µm**



| ITS ALPIDE modes:

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



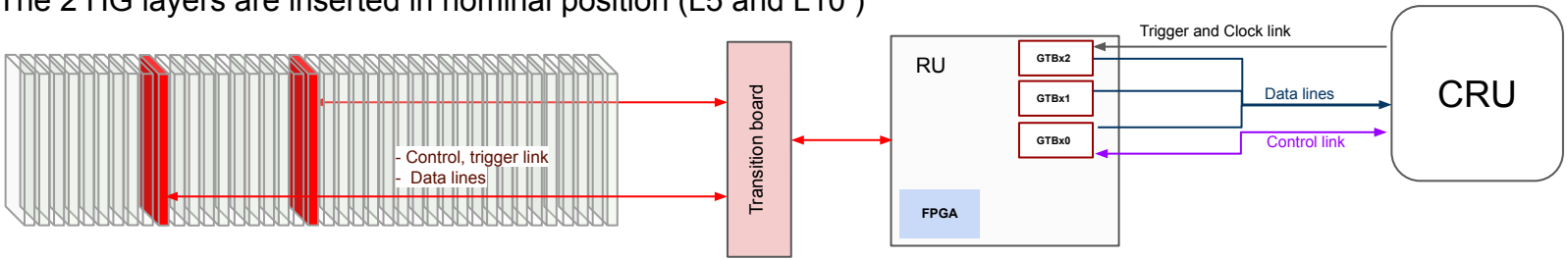
> Design inherited from proton CT project

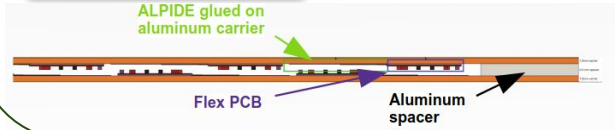
> 3 strings of 15 ALPIDEs per aluminum carrier

> 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)





IB Layers

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

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

| Full layer connected to a Transition Card

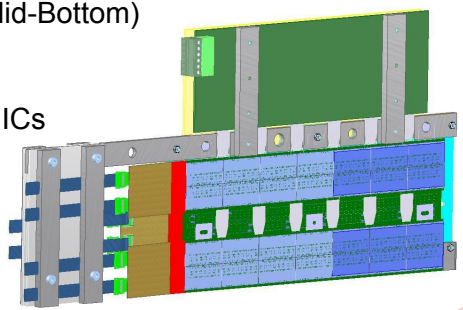
BACKUP SOLUTION

OB Hybrid Integrated Circuit (HICs) Layers

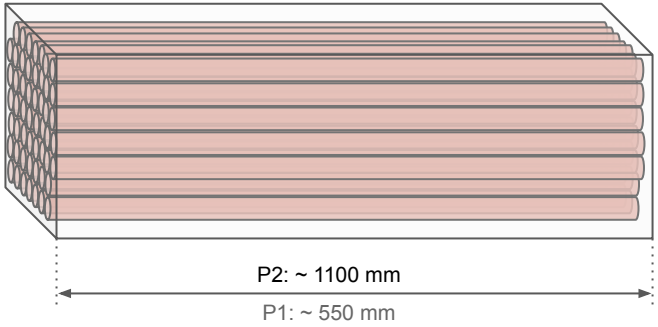
| Three HICs perLayer (Top-Mid-Bottom)

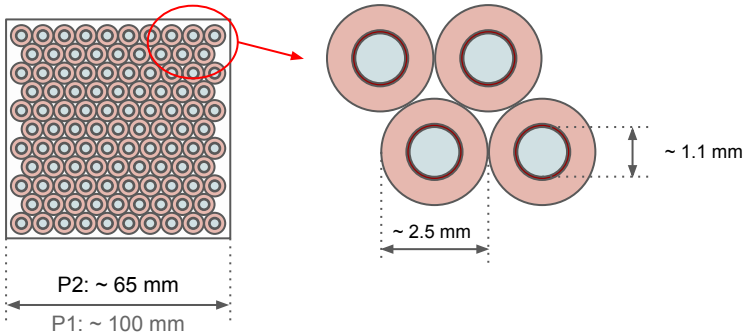
| Wire bonded to FPC

| 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

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

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)

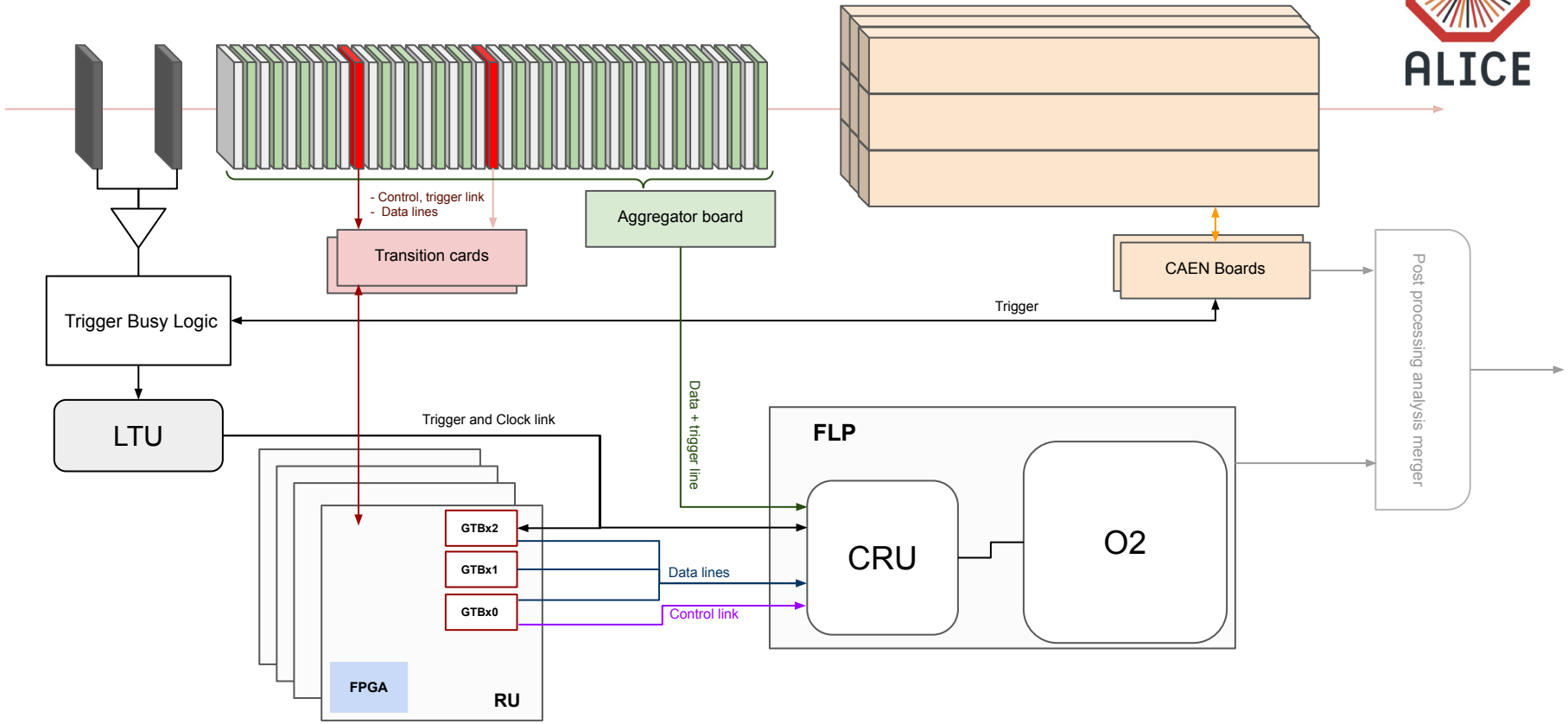
FoCal-H

| Characterization of energy collection

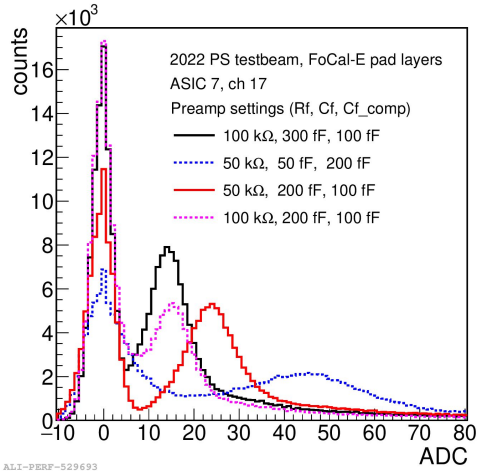
| Energy scans (Hadrons) with 9 stacked modules prototype

| Position dependence and resolution

Test Beam setup 2022



Test Beam results - FoCal-E Pads

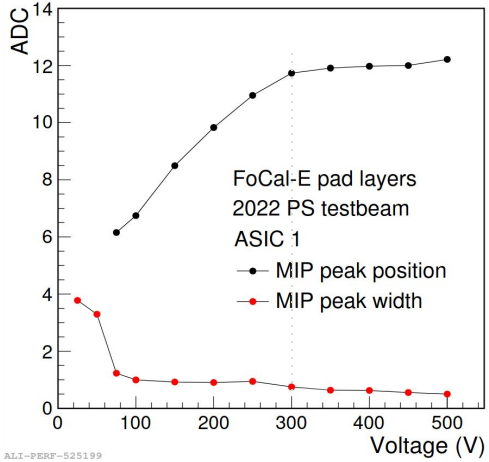


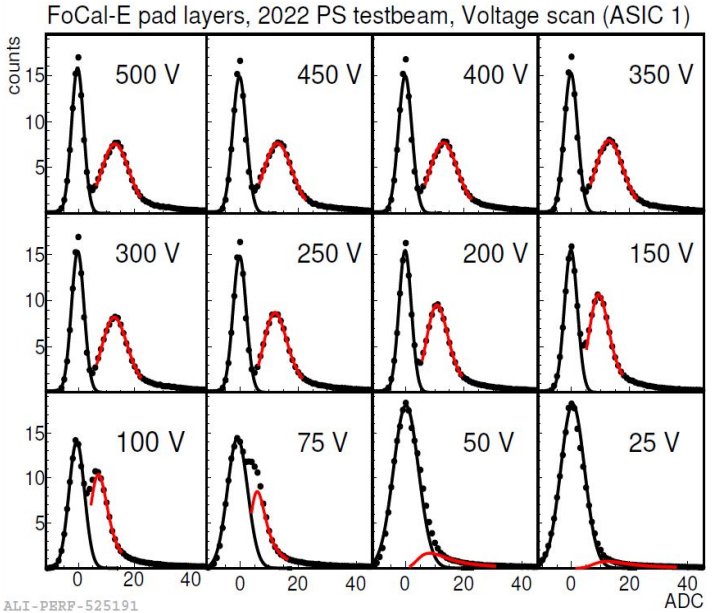
Gain calibrations

| Characterization of the MIP/noise separation

| Validate simulation results

| optimize energy resolution





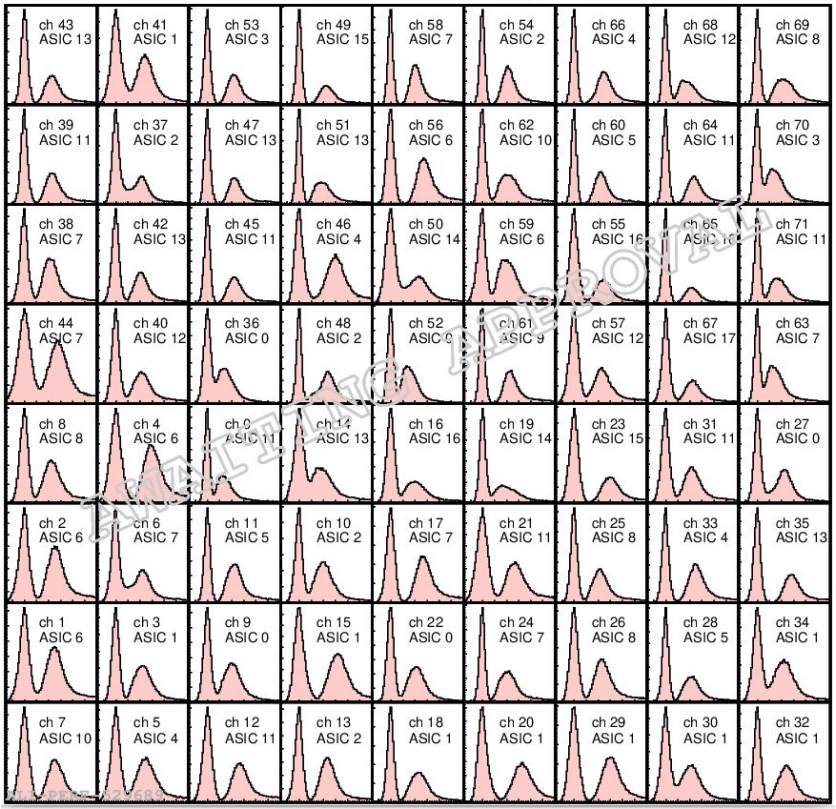
Voltage scan

| 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 with hadron beams

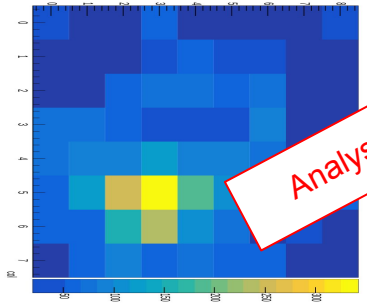
| most of the cells displays clear MIP peak |

|Study of pads edge-effect

| Compare two p-type Si pads productions

| Compare Pads within the same sensor

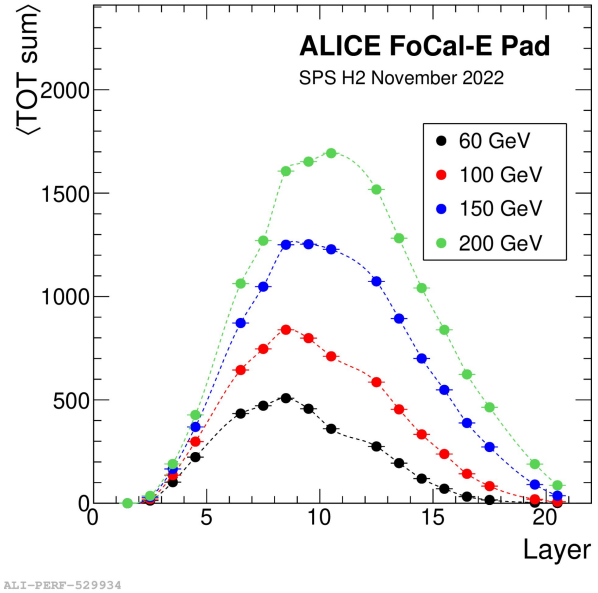
Position scan performed with 100 GeV hadrons



Analysis ongoing

43	41	53	49	58	54	66	68	69
39	37	47	51	56	62	60	64	70
38	42		46	50	59	55	65	71
			48	52	61	57	67	63
			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

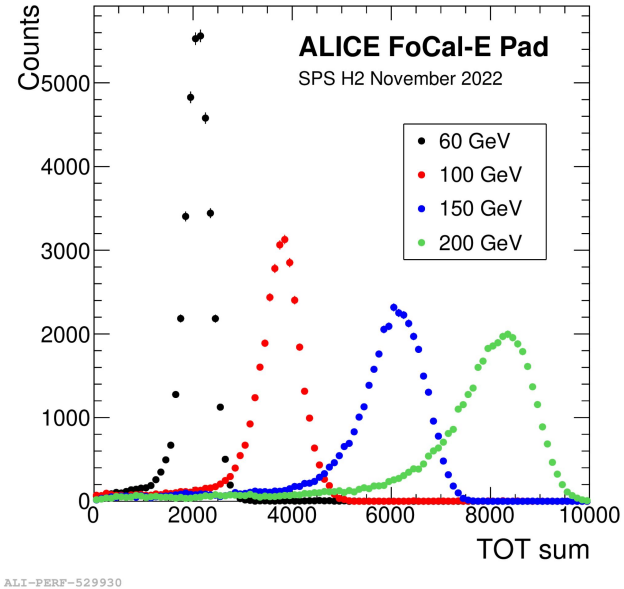
Test Beam results - FoCal-E pads



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

| TOT ∝ total deposited charge

| Qualitative description of the longitudinal shower development

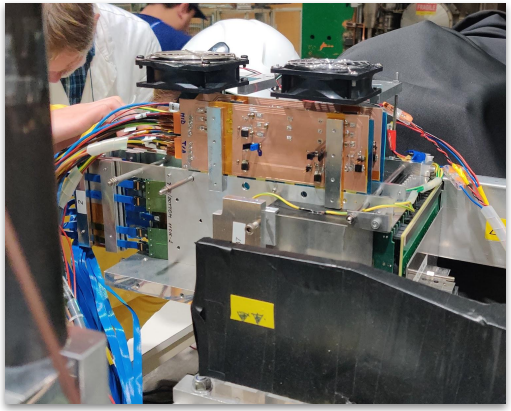


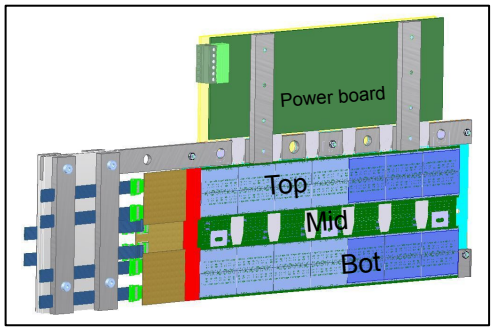
Total TOT distribution per beam energy
SPS electron beam | Energies (60 GeV - 200 GeV)

| Characterizes detector response to the charge deposit

| MPV of the distributions ∝ collected charge

Test Beam results - FoCal-E pixels

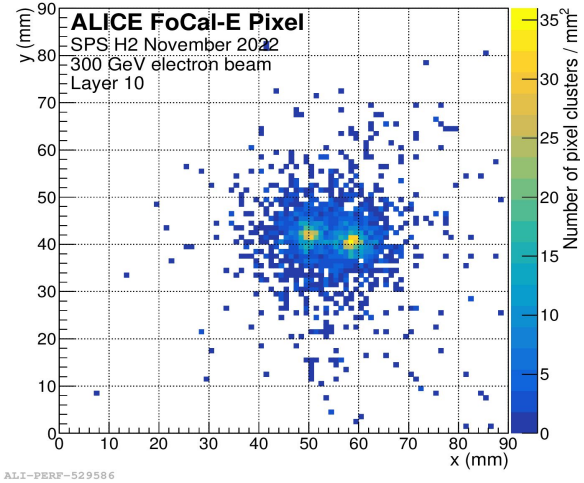


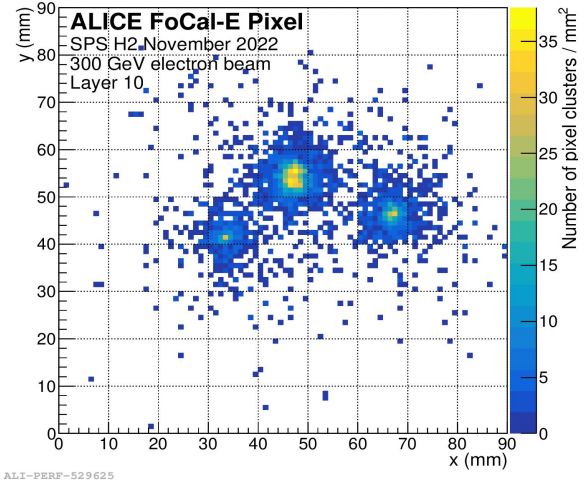


Successful commissioning of the HICs

| Global hitmaps monitored using O2 QC

| Double and triple electron signature identified in preliminary analysis

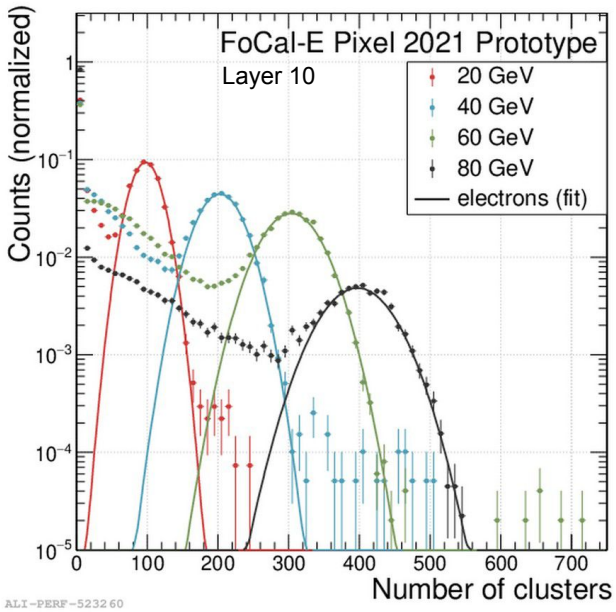




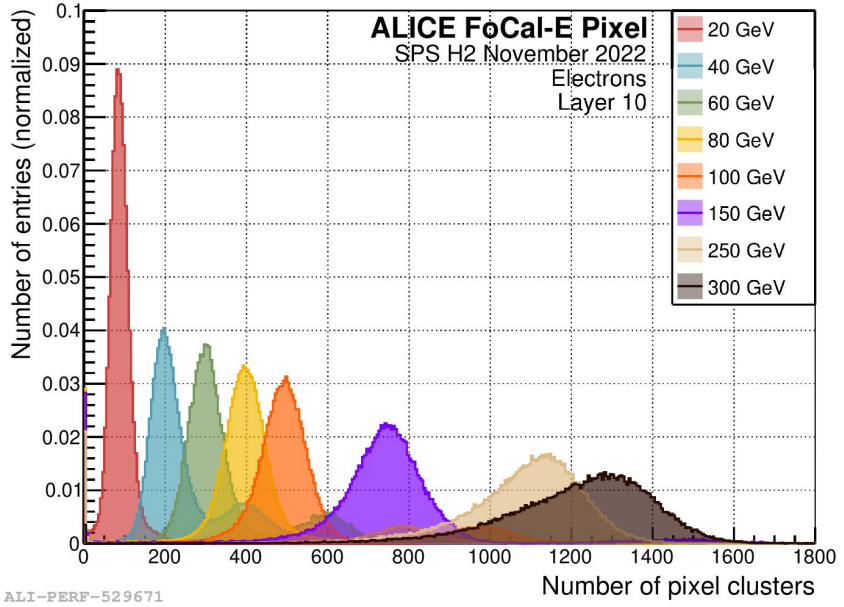
Test Beam results - FoCal-E pixels

2021 Results [IB pCT layers] - Layer 10

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

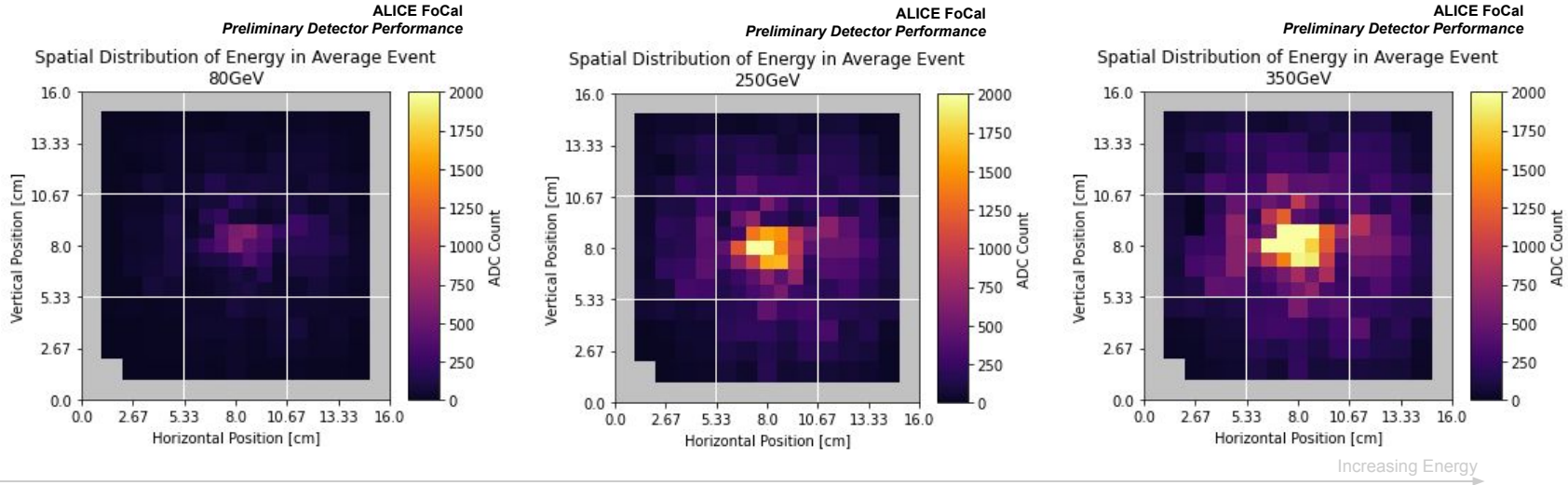


2022 preliminary results [HICs layers] - Layer 10



Test Beam results - FoCal-H prototype

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



| Energy deposited increasing with the beam energy

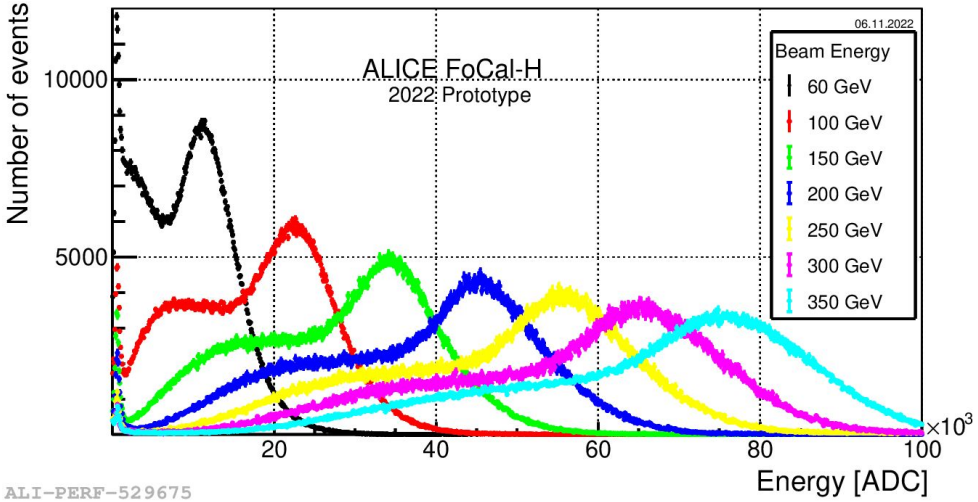
| Grey bands → Non instrumented SiPMs (3 CAEN DT5202 boards used)

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

Summary

| **FoCal** is part of the **upgrade project** of ALICE during **Run 4** (starting from 2029)

| FoCal will enable a **unique physics program** at the LHC, investigating the region of

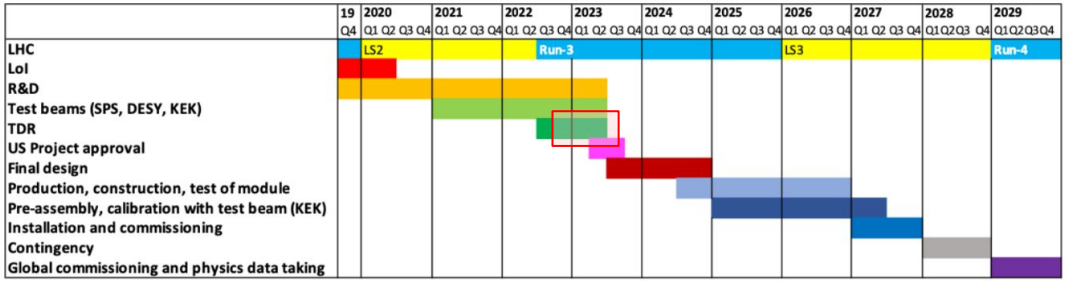
small-x and low Q^2 through a comprehensive set of measurements

| Test Beam campaigns **validated the functionality of the individual systems and** the commissioning of **newer prototype versions**

| Demonstrated the **successful integration** of the subsystems **in combined acquisitions**

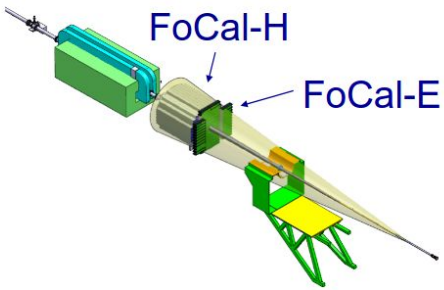
| The collected **data** (2021, 2022) are **currently being analyzed** and **compared to simulation** results

| The FoCal collaboration is now preparing for the internal review of the TDR (early 2023)



BACKUP

The FoCal detector at the ALICE experiment



FoCal-E

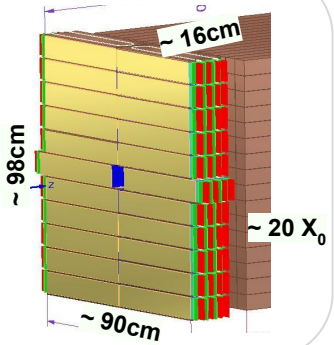
| Si+W EM calorimeter (2 subsystems)

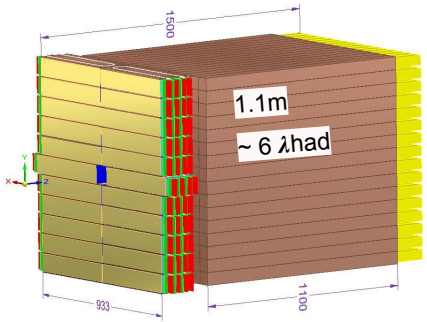
| enable photons separation (~ 5mm distance)

| Designed for:

measurement of direct photons

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





FoCal-H

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

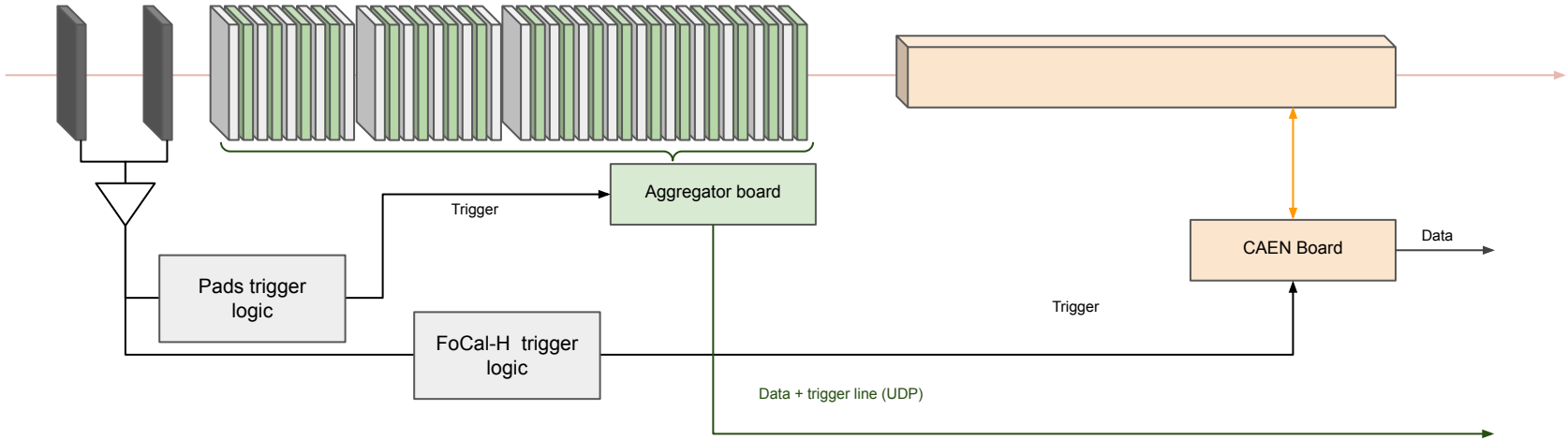
| Scintillating fibers enclosed in Cu capillary-tubes, readout by SiPMs

| Designed to:

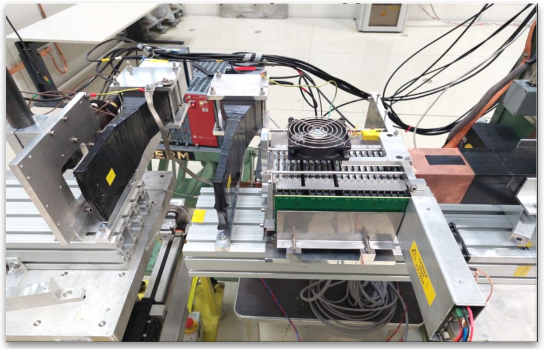
Study the dynamics of hadronic matter in measurements with photons and jets.

Good Jet isolation capabilities (single hadron res ~ 20-25%)

The test beam setup - June 2022 (PS T9)



Test beam June 2022 (PS,T9) - Results

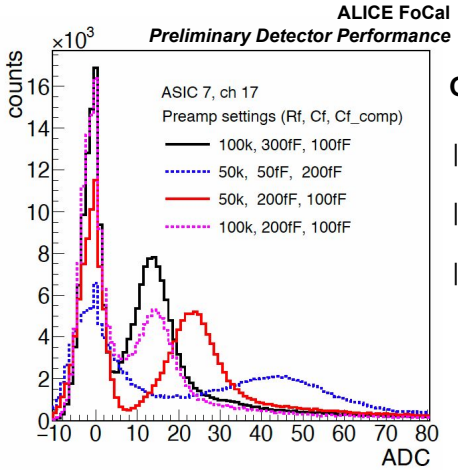


Run List

Beam Type	Energy [GeV]
positive hadrons	15
electrons	1
electrons	2
electrons	3
electrons	4
electrons	5

Goals

- positive hadrons (15 GeV) → | Tracking MIP peak in the Pad layers (position scan)
- electrons (1–5) → | Characterization shower development (after internal calibrations)
- electrons (1–5) → | Validation of FoCal-H 2nd prototype



Gain calibrations

| Characterization of the MIP/noise separation

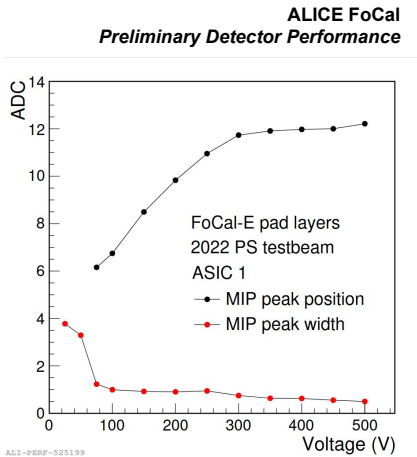
| Validate simulation results

| optimize energy resolution

Voltage scan

| Dependance of MIP peak position

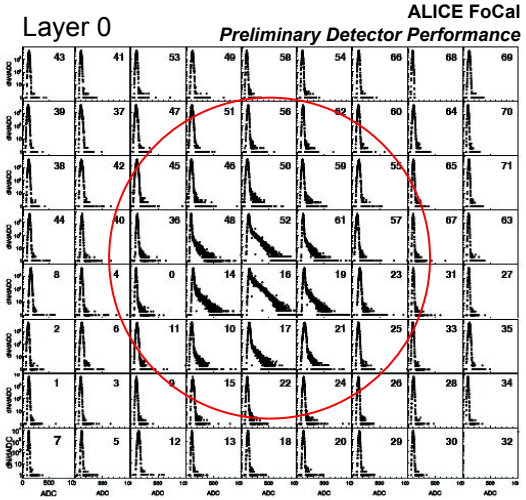
| Depletion reached @ ~ 300V

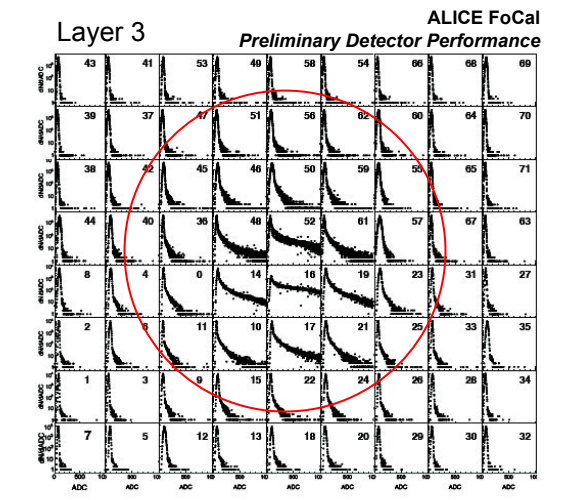


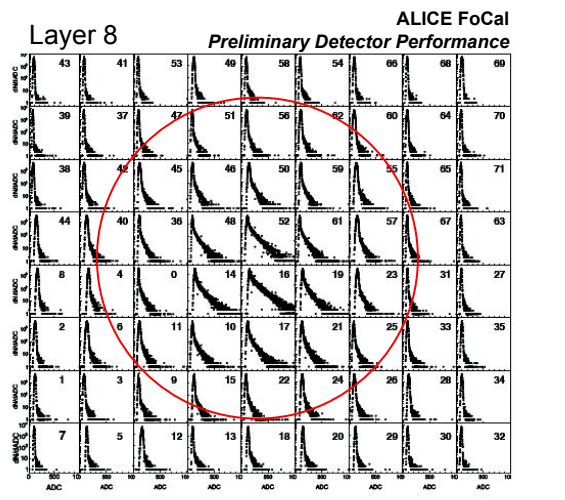
Test beam campaign 2022 - Results

EM Shower development over 3 Pad Layers: 5 GeV electrons @ PS T9 (June 2022)

Plots to be approved





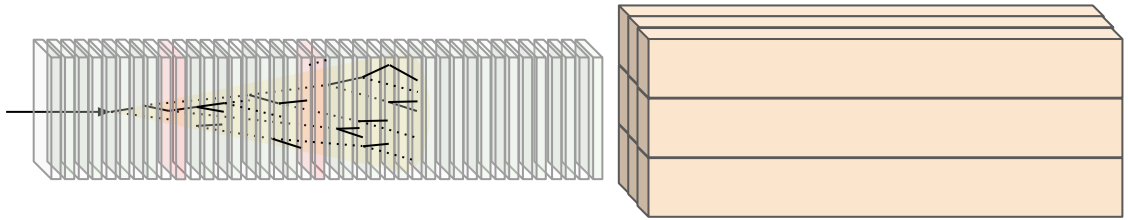


Test Beam requirements

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

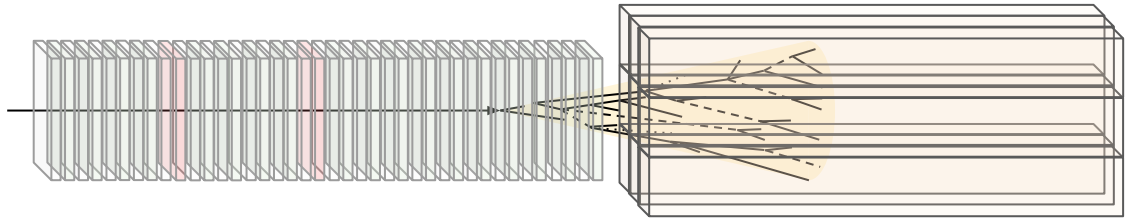
| EM showers fully contained in FoCal-E

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



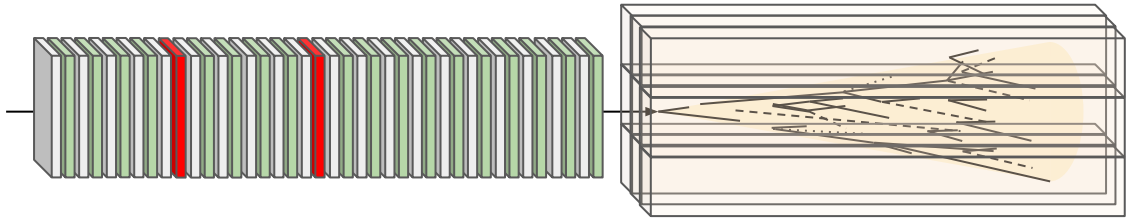
| EM showers NOT fully contained in FoCal-E

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

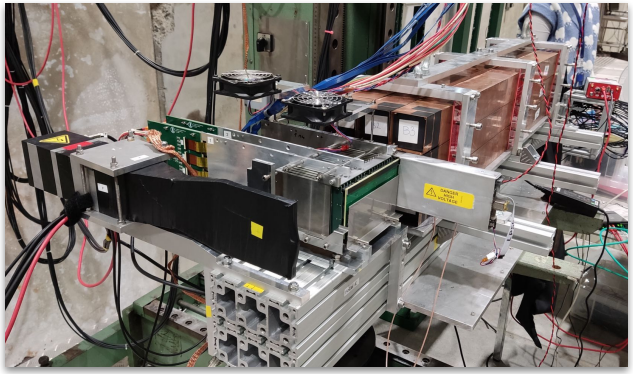


| Hadronic showers fully contained in FoCal-H

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

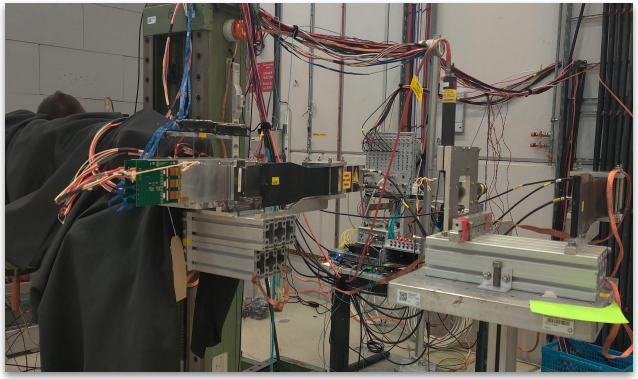


Test beam September 2022 (SPS H6, PS T10)



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)

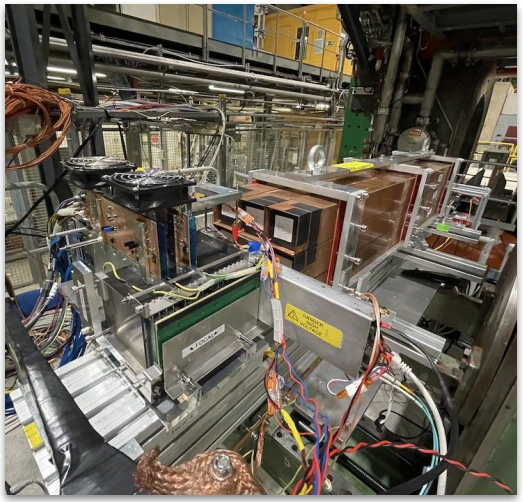
FoCal-H

| Installation of FoCal-H 3 x 3 quadratic modules

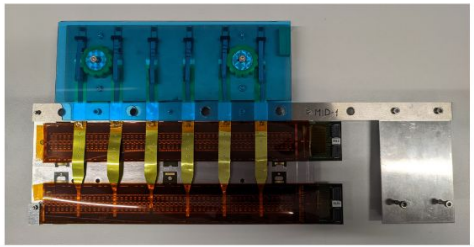
| Test of CAEN commercial electronic ad high rates

| 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