Performance of the ALICE FoCal electromagnetic calorimeter using hadron and electron beam at SPS

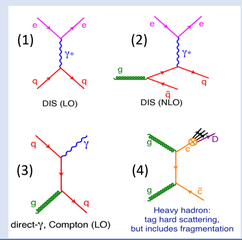
Hanseo Park for the ALICE collaboration
hapark@cern.ch
University of Tsukuba, Japan

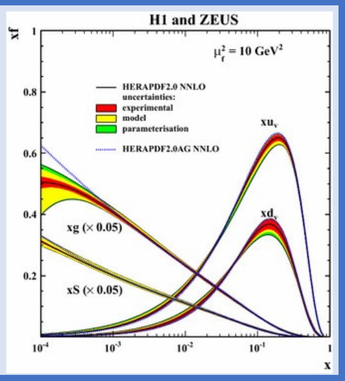
Physics Motivation

Nuclear PDF (nPDF)

- **quantify the nuclear modification of the gluon density in nuclei at small-x and Q^2 by measuring isolated photons in pp and p–Pb collisions**

1. It is not sensitive to the gluon PDF in the LO
2. Gluons from NLO
3. **Photon production in hadronic collision:**
   - **Sensitive to the gluon PDF** in the LO via the QCD Compton scattering
4. Heavy quark production is dominated by gluon fusion





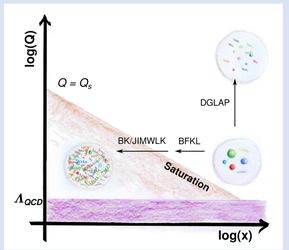
Color Glass Condensaste (CGC)

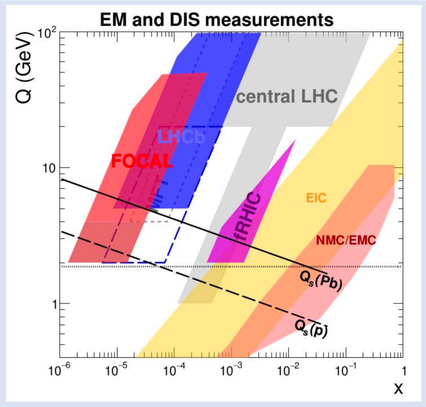
- **Investigate non-linear QCD evolution by measuring azimuthal $\pi^0 - \pi^0$ correlations and isolated $\gamma - \pi^0$ corrrelations in pp and p-Pb collisions**

- Linear QCD BFKL: gluon emission
- Nonlinear QCD BK/JMWLK: gluon recombination
- When these two processes are in **equilibrium**, the number of gluons is constant

$$Q_S^2 \approx \frac{xG_A(x,Q^2)}{\pi R_A^2} \propto A^{\frac{1}{3}} x^{-\lambda}$$

Saturateted gluon field: CGC



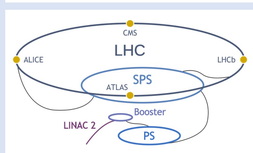


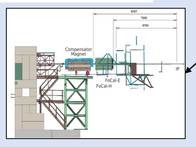
Detector

ALICE experiment

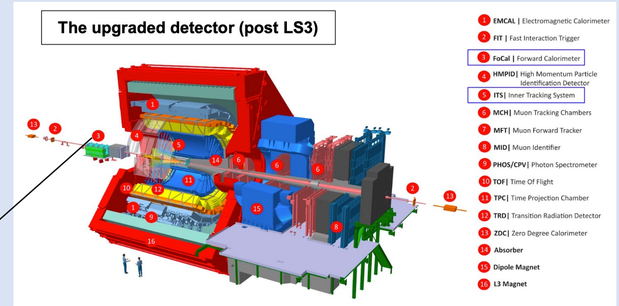
Forawd Calorimeter (FoCal)

- Part of the ALICE upgrade for Run 4 (starting from 2029)
- Positioned 7 m from IP2 (A-side)
- Covering $3.4 < \eta < 5.8$



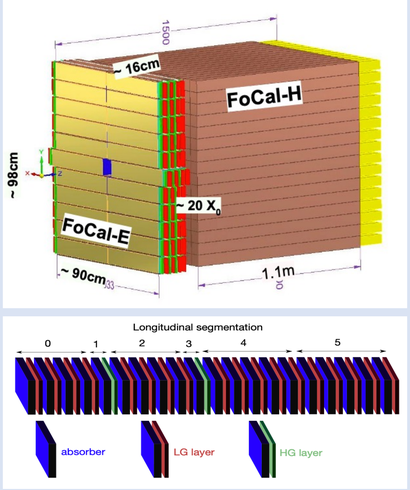


The upgraded detector (post LS3)



- **ALICE** (A Large Ion Collider Experiment) is a detector dedicated to heavy-ion physics at the Large Hadron Collider (LHC)
- It is designed to study the physics of strongly interacting matter at extreme energy densities, where a phase of matter called quark-gluon plasmas forms.

FoCal detector design



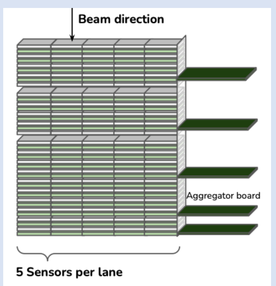
FoCal-E

- 20 Layers (LG+HG Si detectors + W absorbers)
- Dimensions ~ 90 cm × 98 cm × 20cm
- Disigned for :
  - ✓ Measurement of **direct photons**
  - ✓ Measurement of **high p_T neutral pions** (PbPb vs pp)
- Granularity optimized to enable photon separation (~ 5mm distance)

FoCal-H

- Transversally segmented calorimeter thickness ~6 λ
- Located behind FoCal-E (reduce shower blow up)
- Designed for:
  - ✓ Studying the dynamics of hadronic matter with photons and jets (isolation capabilities (single hadron ~ 20-25%))

FoCal-E Pad design concept



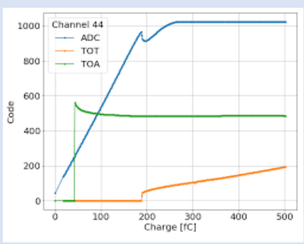
- **FoCal-E pad layers are designed for measuring very high energy photons and good separation from decay photons**

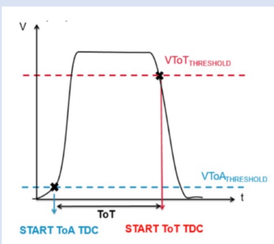
18 layers of Si Pad sensors interleaved with Tungsten absorbers

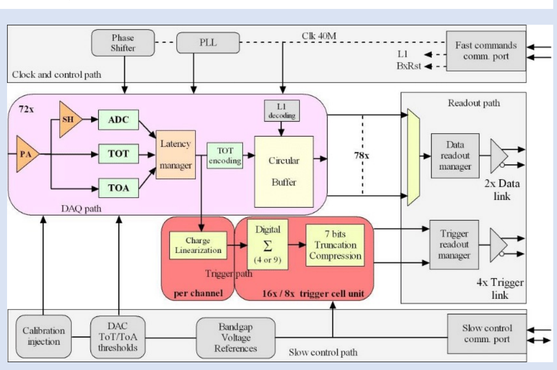
- Samples the longitudinal development of EM showers
- Si pad layers size ~ 1 × 1 cm^2
- Absorber: 3.5 mm Tungsten
- Each sensor: $8_{rows} \times 9_{columns}$ pad layers
- 5 aggregator (+interface) boards per stack

Read-out: HGCROCV2 chip

- Provides ADC, TOT (12bit, lsb:50ps), TOA (10bit, lsb:25ps)
- 40MHz trigger pulse
- Dynamic range MIP ~ 10pC
- Data transfer ~ 960 KHz with internal circular buffer



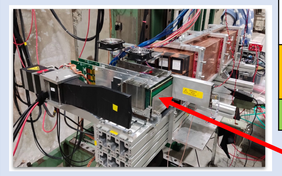




ADC: Analog to digital converter
TOT: Time of threshold
TOA: Time of arrival

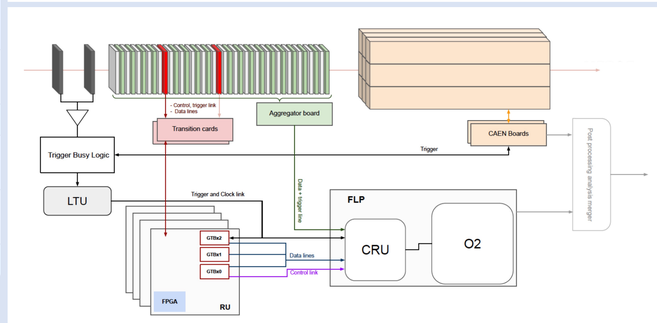
Experiment

Test Beams in 2022



Proton Synchroton (PS)	
Beam Type	Energy [GeV]
Positive hadrons	1 - 15
Electrons	1 - 5
Super Proton Synchrotron (SPS)	
Positive hadrons	20 - 350
Electrons	20 - 300

Test beam setup



- Test beam experiment on PS and SPS with hadron and electron beam at CERN in 2022
- There were a number of engineers and scientists representing the FoCal-E and FoCal-H groups
- Data needed for Technical Design Report (TDR) of FoCal

*For **FoCal E-Pad** …*
Characterization of HGCROCV2 ***ADC*** and ***TOT*** at different electron energies

- **Energy Linearity** and **Energy Resolution** using ADC and TOT

First results

PADs MIP Response at PS using hadron beam

(1) Position scan 15 GeV hadron beams

- Most of the cells display clear MIP peak

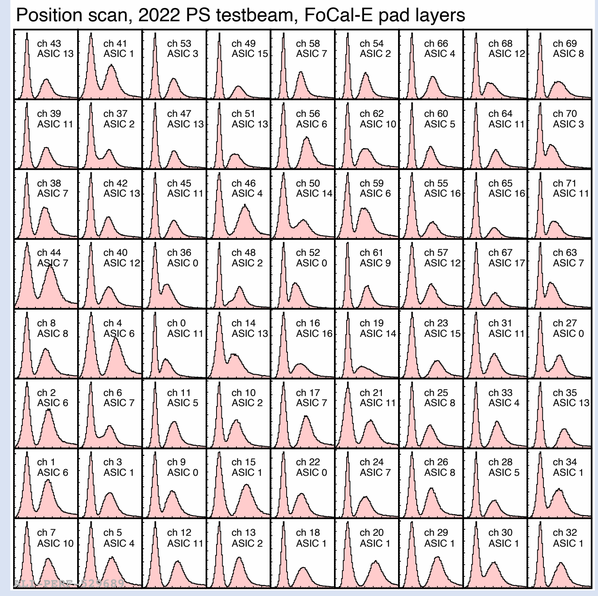
(2) Testing the HGCROC2 capabilities:

- Gain tests (128 possible setups)
- Testing MIP peak and background
- Optimization of the bunch crossing phases
- Validate simulations results

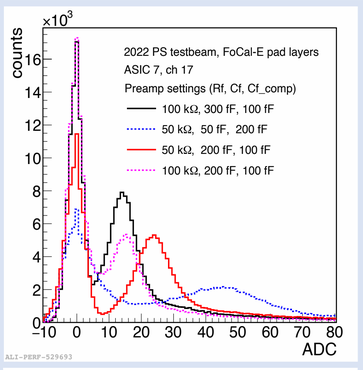
(3) Test of the silicon response and full depletion voltage:

- Testing the p-type Hamamatsu sensors for FoCal
  - p-type was increased for better performance
- Voltage scan from 0-500 V
- Full depletion of this sensor reached at > 300 V

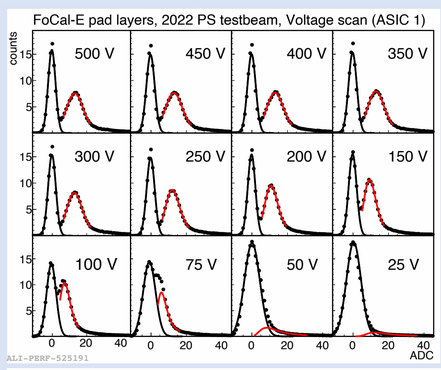
Position scan, 2022 PS testbeam, FoCal-E pad layers



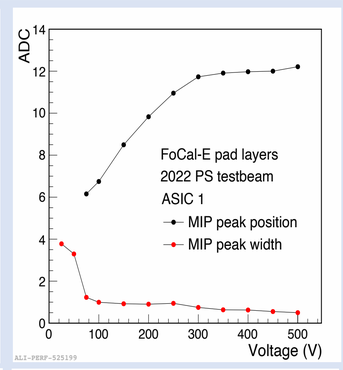
(1) Best choice of MIP with all channel and layers



(2) Gain scan



(3) Volatage scan with MIP



(3) Voltage scan

Test Beam Results at SPS using electron beam

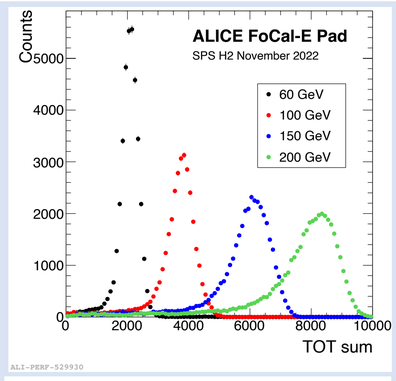
- TOT (∝ total deposited charge) with electron beam energy scan 60– 200 GeV
- Study of full response of HGCROC ongoing (needs combination of TOT and ADC)

(4) Energy response for different energies

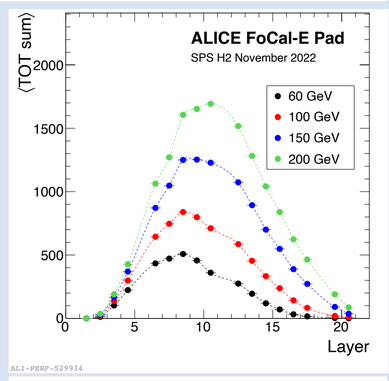
- Shows expected energy dependence

(5) Longitudinal shower development

- Shape consistent with expectations



(4) Energy response



(5) Longitudinal shower

Summary & Outlook

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

ALICE FoCal upgrade proposal is well on track

- Successful Test Beam campaigns during 2022. Now preparing for June 2023
- Preparations for Technical design report (TDR) ongoing
- Design of all components complete

Prototypes of all components constructed and tested successfully

- Analysis ongoing
- FoCal-E pad with HGCROC readout has energy resolution with constant term < 5%

Reference

A Forward Calorimeter (FoCal) in the ALICE experiment

- https://cds.cern.ch/record/2696471
- https://doi.org/10.22323/1.414.0317

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