HGCROC v2 readout chip characterization and radiation tolerance for FoCal-E pad detector in ALICE

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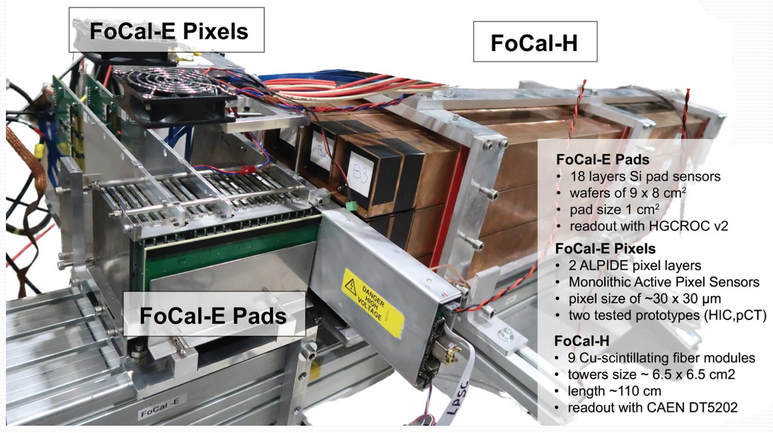
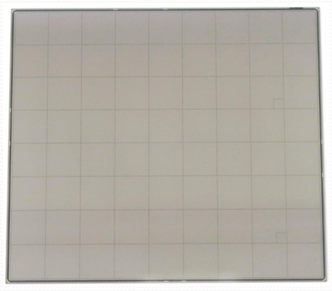
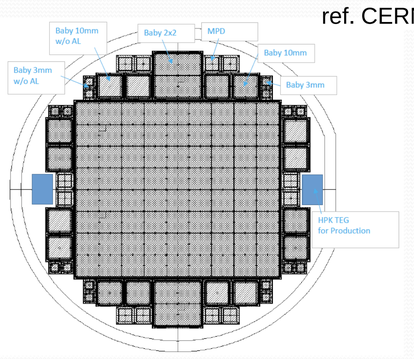
Introduction: FoCal E-pad detector

- The Forward Calorimeter (FoCal) detector is scheduled for installing in the ALICE experiment for the LHC-Run4 upgrade (2029-2032).
- The FoCal-E is a detector based on a Si sensor and tungsten to measure electromagnetic/hadronic shower profile in the forward region.

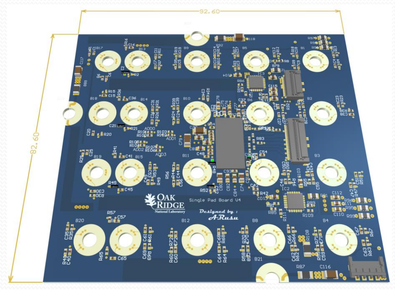


ref. CERN-LHCC-2024-004 ; ALICE-TDR-022





Hamamatsu p-type, S162111-1665 main sensor and Layout



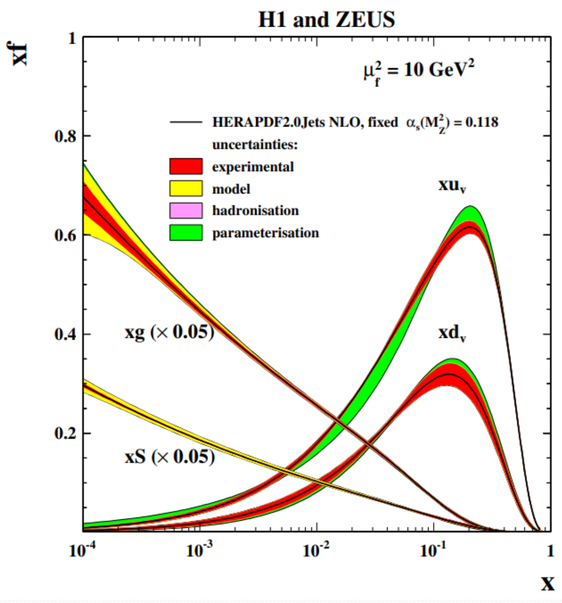
The PCB with HGCROC for a single pad Si sensor

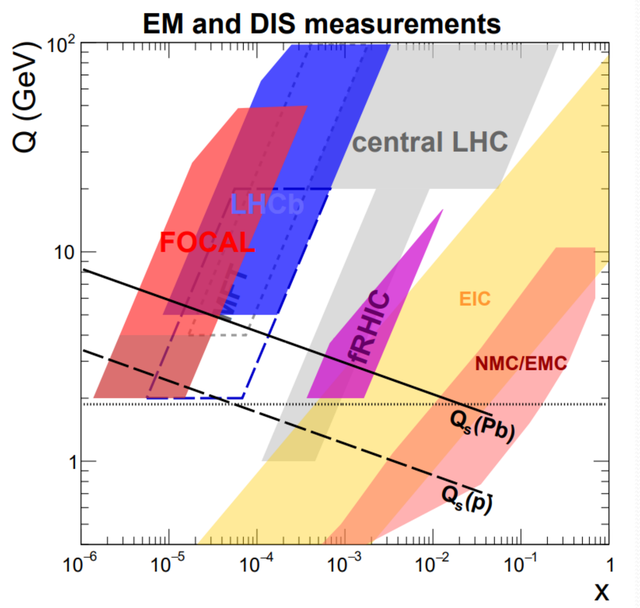
- Si pad sensor has 9 x 8 = 72 main cells (pad size $1\ cm^2$) and two calibration cells
  Thickness : $320 \pm 15\ \mu m$
  Full depletion voltage : min 120 V / max 270 V
- HGCROC (developed by OMEGA) dynamic range :
  Low Range (1MIP≅2 MeV~) : ADC (Analog to Digital Converter), 10 bits 1024ch
  High Range (~1 TeV) : TOT (Time Over Threshold), 12 bits 4096ch

ref. CERN-LHCC-2017-023 ; CMS-TDR-019

- It's important to check the HGCROC chip performance and the variability.

Physics motivation: elucidate small-x

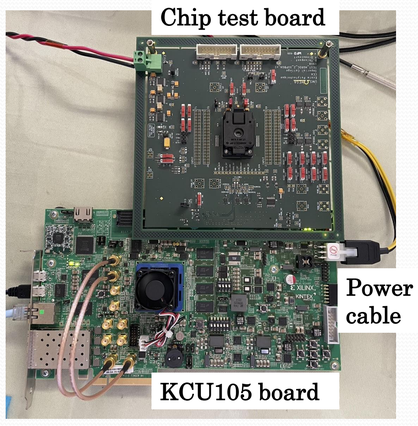


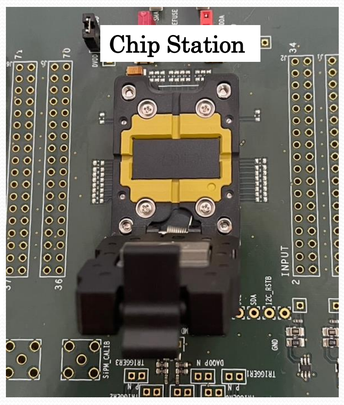


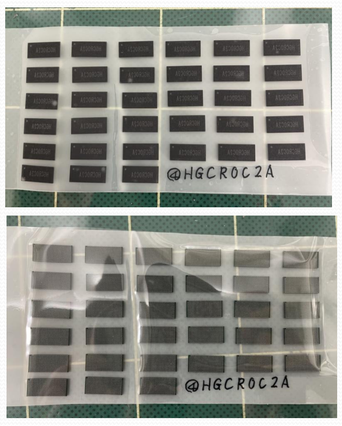
Cf. A Forward Calorimeter (FoCal) in the ALICE experiment https://cds.cern.ch/record/2719928/files/LHCC-I-036.pdf

- Nuclear Parton Distribution function (nPDF) for gluon increases at small x
- Only known up to $x \approx 10^{-4}$, and even smaller values are not known
- FoCal aims to measure nPDF for gluons at small x from 10^{-6} to 10^{-4} and gluon saturation

Experimental Setup







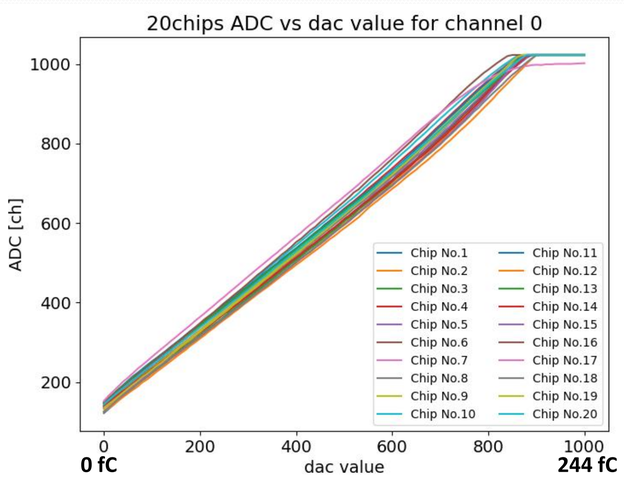
HGCROC2A chip package

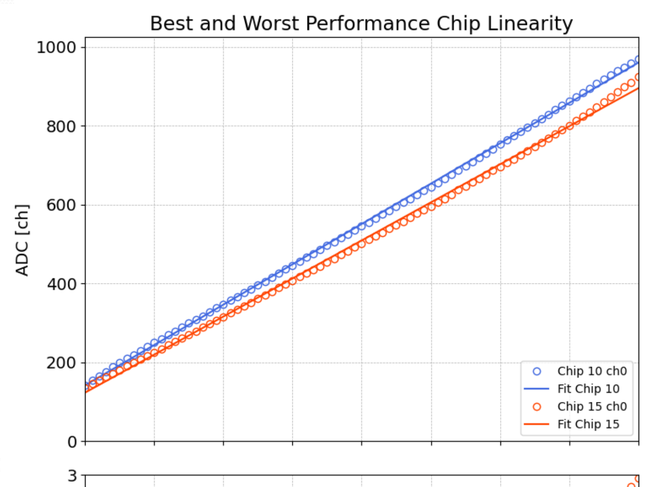
- Put the HGCROC chip into the socket of chip station
- Easily communicate with the chip without soldering
- New HGCROC2 and 2A were packaged in Japan (total 344 chips)

*2A is a slightly upgraded version of 2

- ADC and TOT values were measured by DAC scan with internal charge injection.
- Preamp Gain Settings :
  Cf=300 fF, Cf_comp=100 fF, Rf=25 kΩ (high gain, 0.22 fC / 1ch ADC)

Result: ADC Linearity





- DAC scan results with low injection
- Fitted range: 0 to 800 (0 ~ 195 fC)
- Best chip (blue) linearity :
  $-1\% \sim +1\%\ (< 2\%)$
- Worst chip (red) linearity :
  $-1\% \sim +3\%\ (< 4\%)$
- HGCROC2 Datasheet :
  $-3\% \sim +1\%\ (< 4\%)$

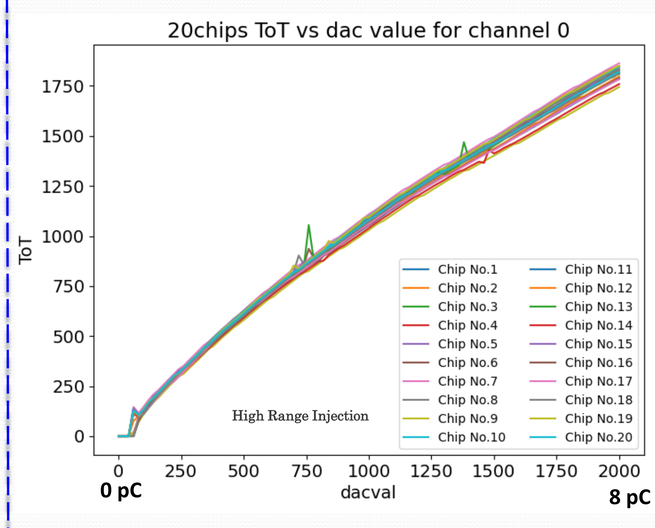
$$INL = \frac{data\ val\ - fit\ val}{1024} \times 100\ [\%]$$

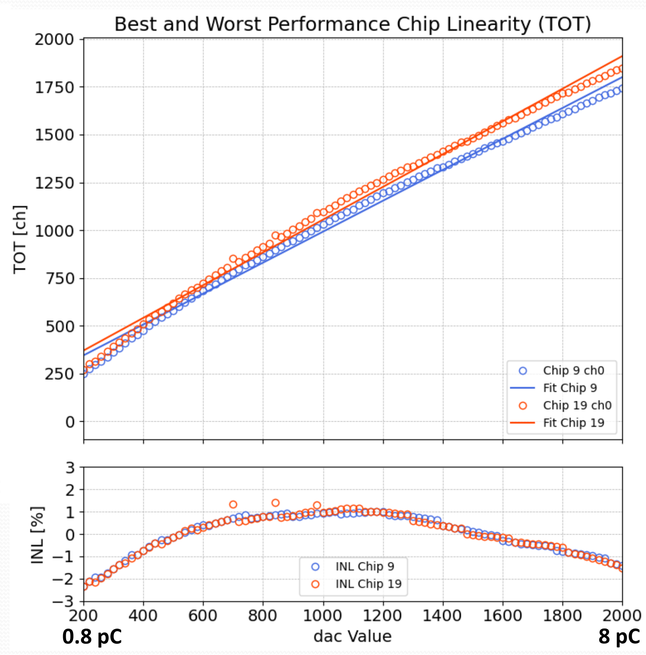
(Integral Non-Linearity)

ADC : 10bits

→All chips ADC satisfies FoCal's requirements ($< 4\%$).

Result: TOT Linearity





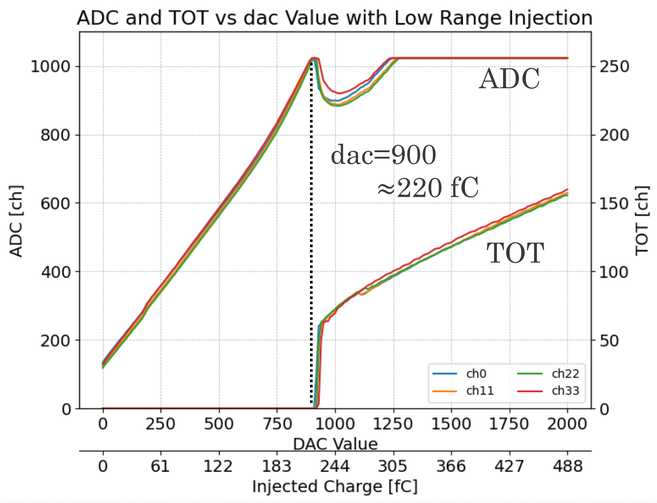
- DAC scan results with high injection
- Fitted range: 200 to 2000 (0.8 ~ 8 pC)
- Due to a test board issue, 36~71ch could not be tested
- Small channel-to-channel variation
- The Best and Worst chip linearity :
  $-2\% \sim +1\%\ (< 3\%)$
- HGCROC2 Datasheet :
  $-2\% \sim +1\%\ (< 3\%)$

$$INL = \frac{data\ val\ - fit\ val}{4096} \times 100\ [\%]$$

TOT : 12bits

→All chips TOT also satisfies FoCal's requirements ($< 3\%$).

Result: Gap between ADC and TOT



- TOT starts when ADC saturates
  ADC range : 0 ~ 220 fC
  TOT range : 220 fC ~ 8 pC
- When the TOT stands up, the ADC gets warped.
  → Cannot have overlap
  → Improvements planned for HGCROC3

Summary and Future Plan

- Linearity of all chips was sufficient for FoCal.
- Evaluate the performance by using external charge injection
- Performance study for the irradiated chip.
- Establish a test system for 2000 chips.
- Compare between HGCROC2 and HGCROC3 chips
  →Set up the test environment for HGCROC3 chip