Silicon pad array detector development for high energy electromagnetic calorimeter application

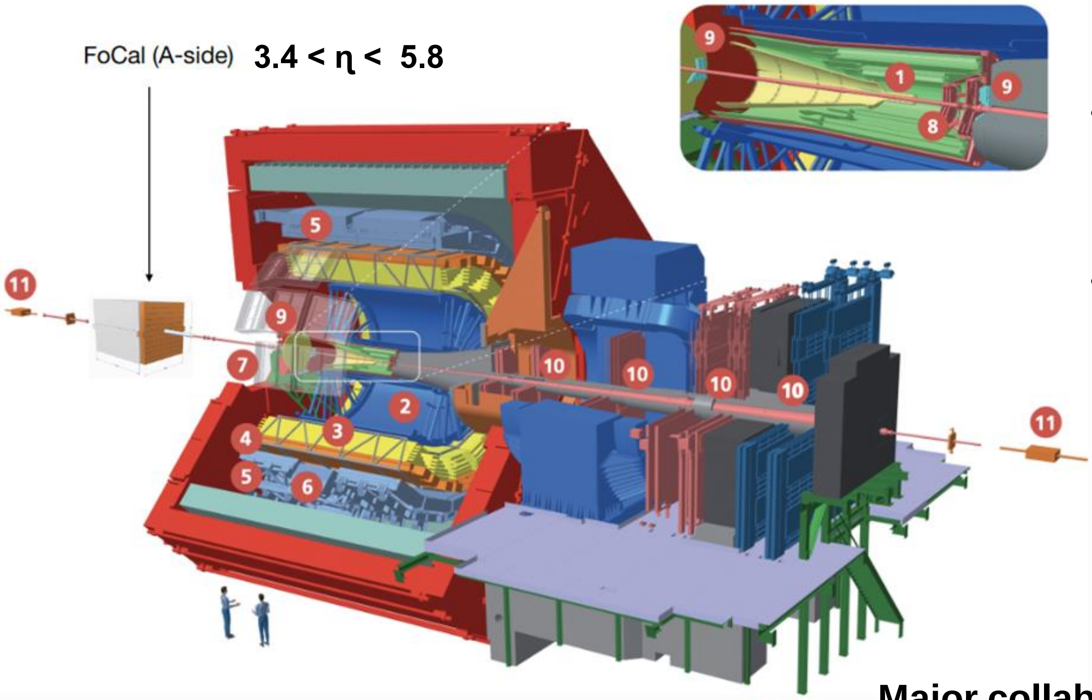
Ganesh Tambave, Ranbir Singh, Bedangadas Mohanty

NISER, Bhubaneswar, India

Introduction

- Fabricating Silicon (Si) pad array detectors on 6’’ Si wafers in India at Bharat Electronics Limited (BEL), Bangalore. The array dimension is of 8x9 cm^2 containing 72 Si pads (each 1x1 cm^2 active area)
- The prime goal of this development is to employ Si Pad arrays in high-energy electromagnetic (EM) calorimeter application such as
  - Forward calorimeter of ALICE experiment
  - Possibly be used in Zero Degree Calorimeter (ZDC) of EPIC experiment planned at EIC (electron ion collider) in USA
  - Societal applications - proton Computed Tomography (pCT)
- The EM calorimeter will be build using several layers of Si-W (tungsten) sandwich structure where silicon is the active material and W is absorber

Introduction to ALICE detector



Ref. Letter-of-Intent: https://cds.cern.ch/record/2719928

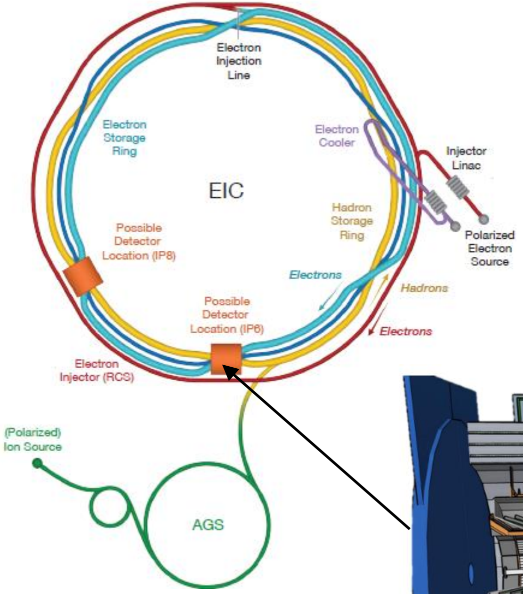
Forward Calorimeter (FoCal)

- Main physics goal:
  - study nuclear structure at very low Bjorken-x down to 10^{-5} and in η > 3.4
- Key observables:
  - Direct photons (pt~5 to 10GeV)
  - Mesons, π0
  - J/ψ, Y, Z, W
  - Jets
  - Correlations

Major collaborations: VECC (India), LPSC, Grenoble (France), Tsukuba university (Japan)

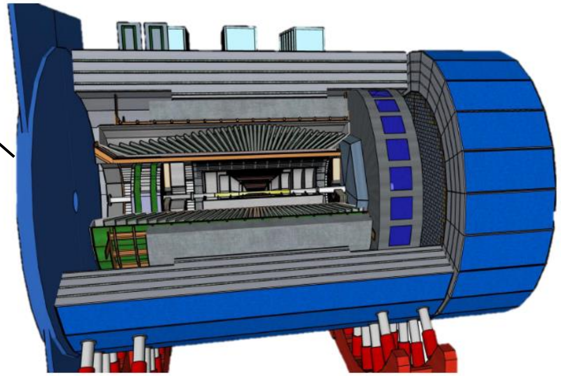
Electron Ion Collider (EIC) – EPIC detector: ZDC

RICH facility at BNL, USA



Ref. EIC EPIC LOI

EPIC detector



Zero Degree Calorimeter (ZDC)

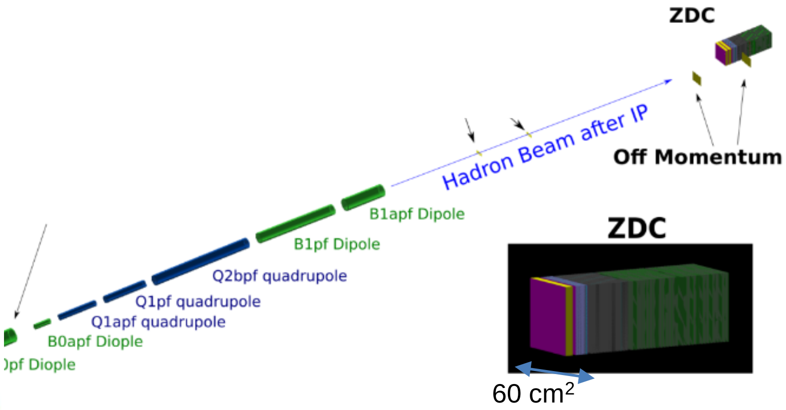
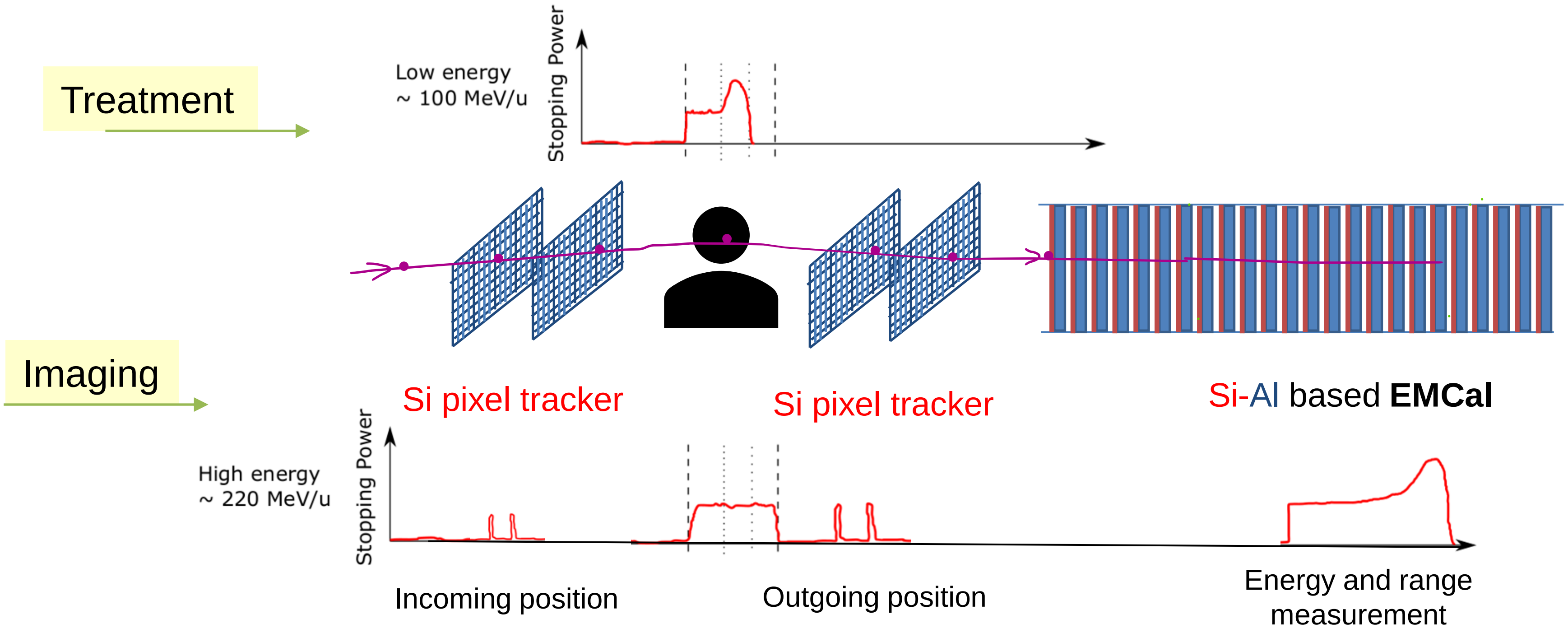


Figure 2.23: The layout of the EIC Far-Forward region.

ZDC is planned to be placed
at about 25 m in far forward region

Ref.: Developing a High Resolution ZDC for the EIC, https://digitalcommons.odu.edu/cgi/viewcontent.cgi?article=1441&context=physics_fac_pubs

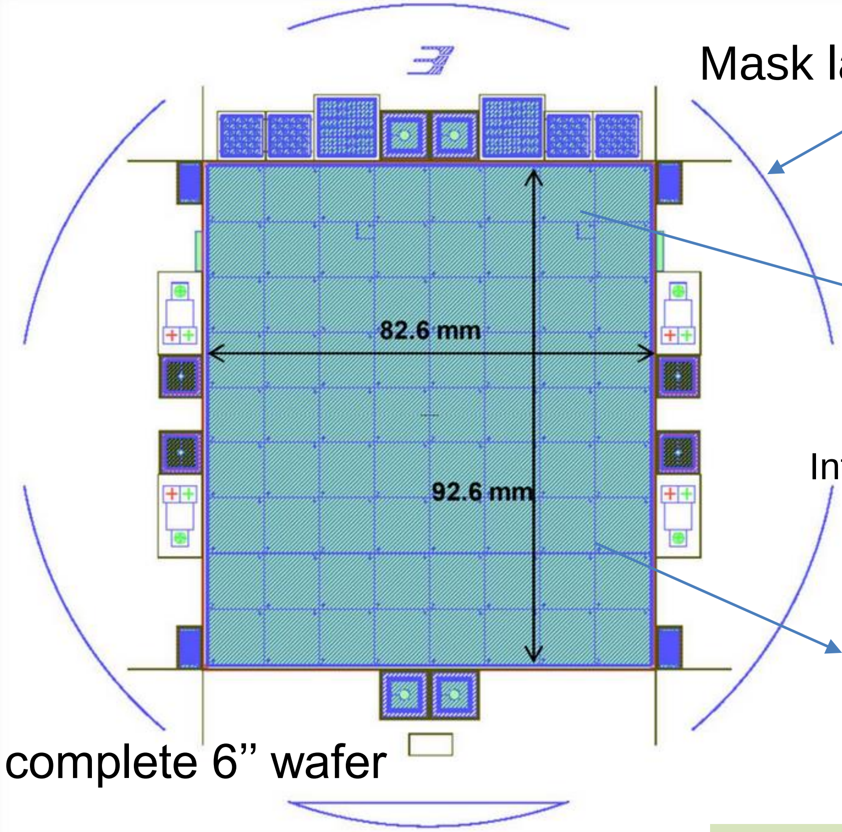
proton Computed Tomography (pCT)



- Imaging: Identify individual proton trajectories through the patient by means of Si tracking planes, and obtain energy using EMcal
- Using proton Imaging, it is possible to reduce the Error on RSP of protons and hence improve the dose planning while treatment

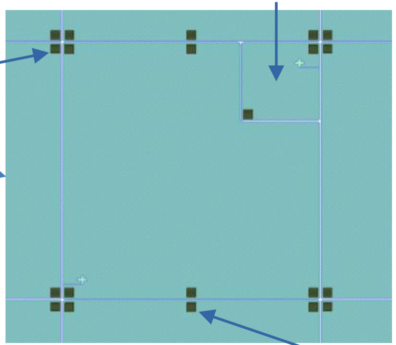
FoCal-E R&D in NISER – n-type

Mask layout design of 8x9 pad array

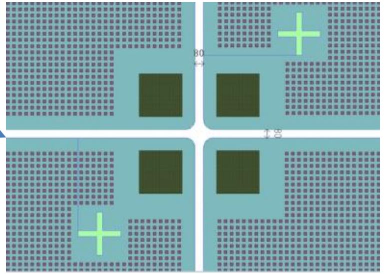


complete 6” wafer

one pad (1x1 cm^2)



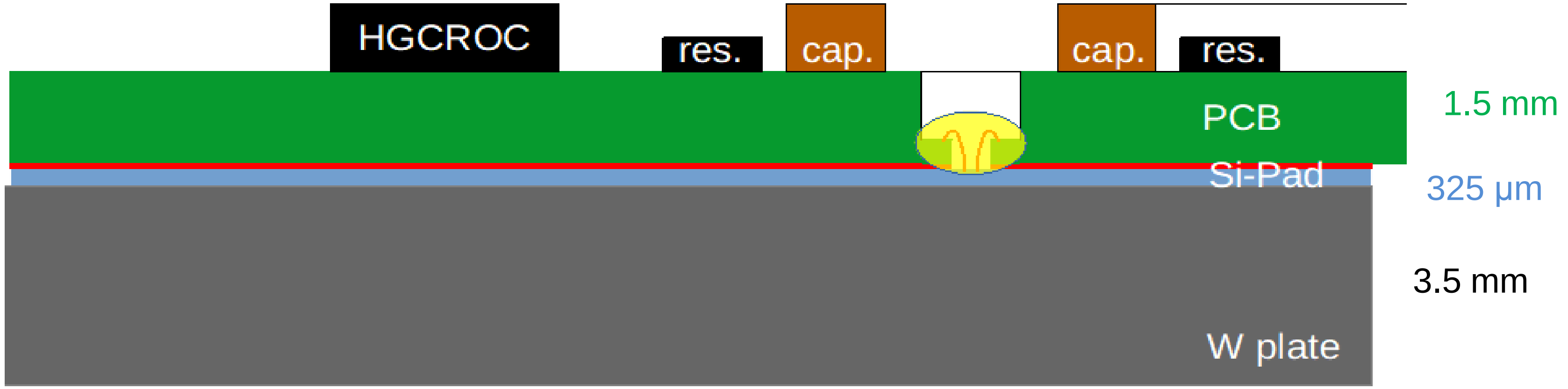
Inter-pad distance (80 μm)



Ref.: All the Mask layout images are taken from slides of Indian Fab Engineer, BEL, Bangalore

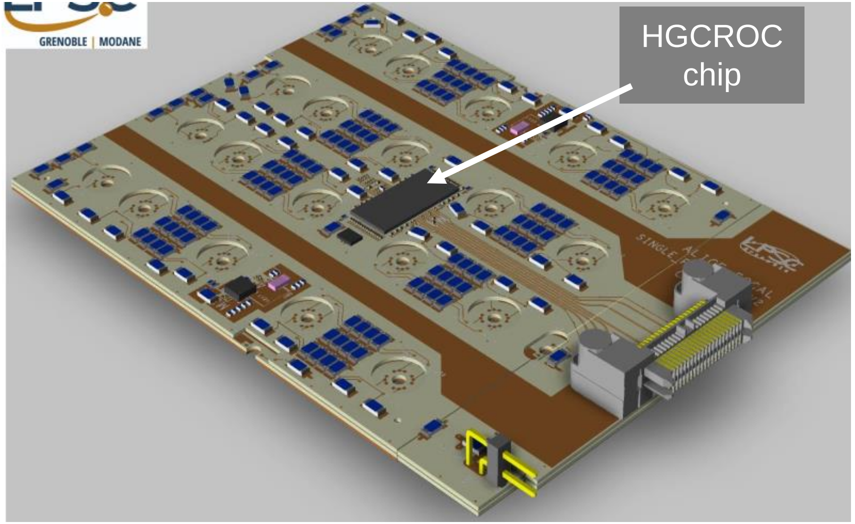
25 n-type 8x9 pad array detector ready by March 2023

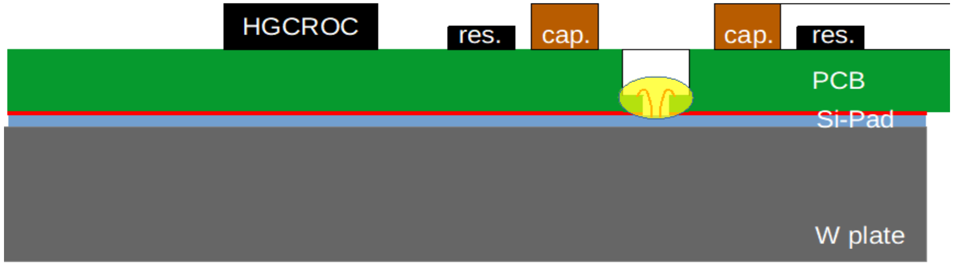
Single pad array assembly with Front-end Electronics



PCB fabrication and assembly order is given to one Indian company, Assembled PCB will be delivered by April 2023, PCB is designed by LPSC Grenoble, France for ALICE FoCal prototype.

Fabrication of Front-end Electronics board

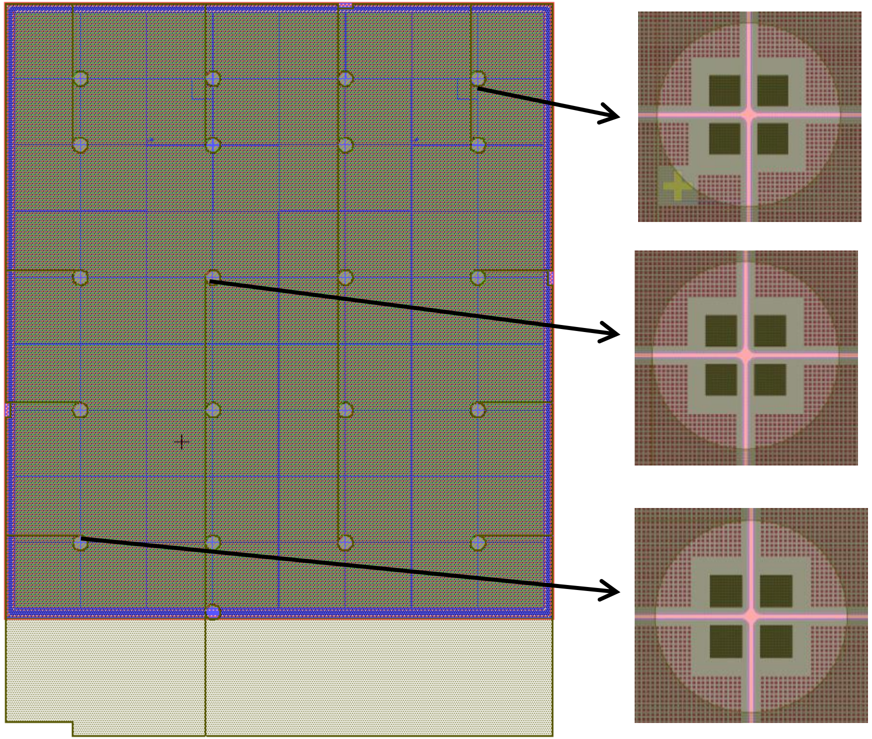


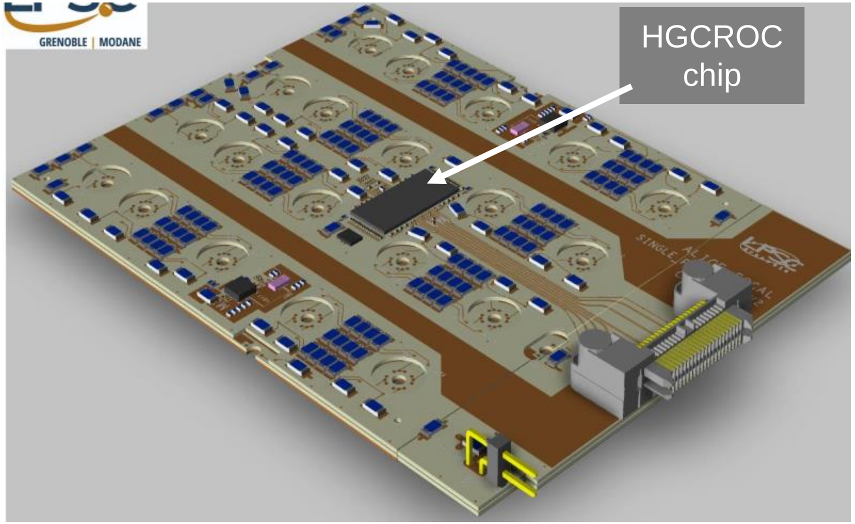


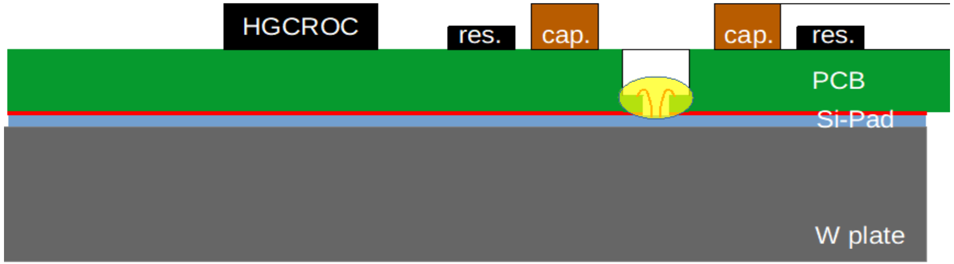
Ref. LPSC Grenoble, France

Fabrication of Front-end Electronics board

PCB and Pad array nicely aligned



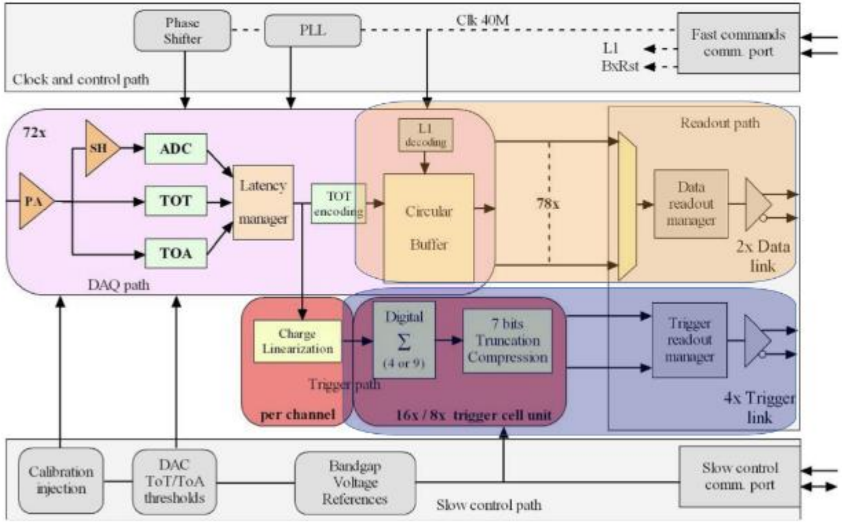




Ref.: All the Mask layout images are taken from slides of Indian Fab Engineer, BEL, Bangalore

Ref. LPSC Grenoble, France

HGCROCv2 Front-end chip



HGCROC_v2 block diagram

FoCal-E front end:

- Low noise and large dynamic range 0.2 fC to 10 pC
- Linearity better than 1% on the full range
- Fast shaping time (peak time < 20 ns)
- High speed readout links (1.28 Gb/s)
- Low power budget < 20 mW
- High radiation resistance

HGCROC (Developed by CMS Collaboration)**:**

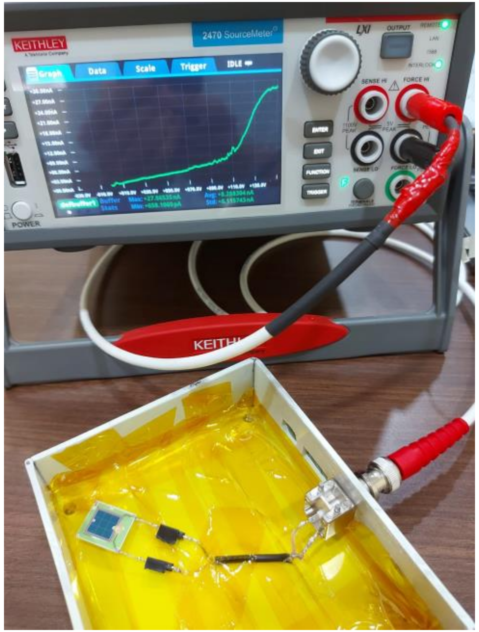
- 76 data channels (72 ch, 4 common noise, 2 calibration)
- ADC for low charge - 10b (10 bit, 40 MHz, SAR-ADC)
- TOT for high charge - 12b

This chip is originally developed for CMS experiment

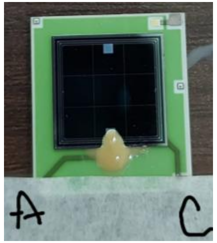
NISER will get 25 HGCROC chips from our ALICE FoCal Collaboration

n-type pad – IV test setup

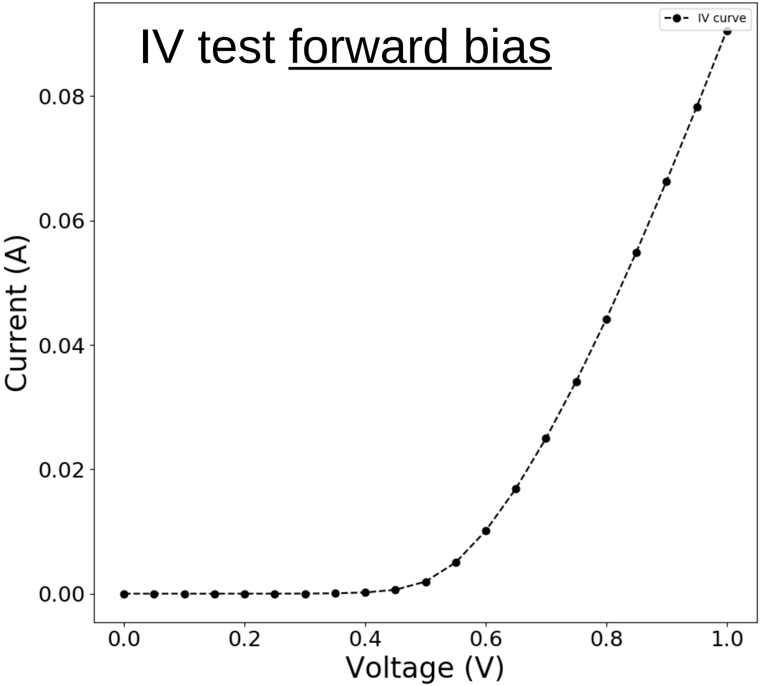
- Used Keithley 2470 source meter unit
- Simple python script sweeps the voltage and measure the leakage current and plots, copy data to file.



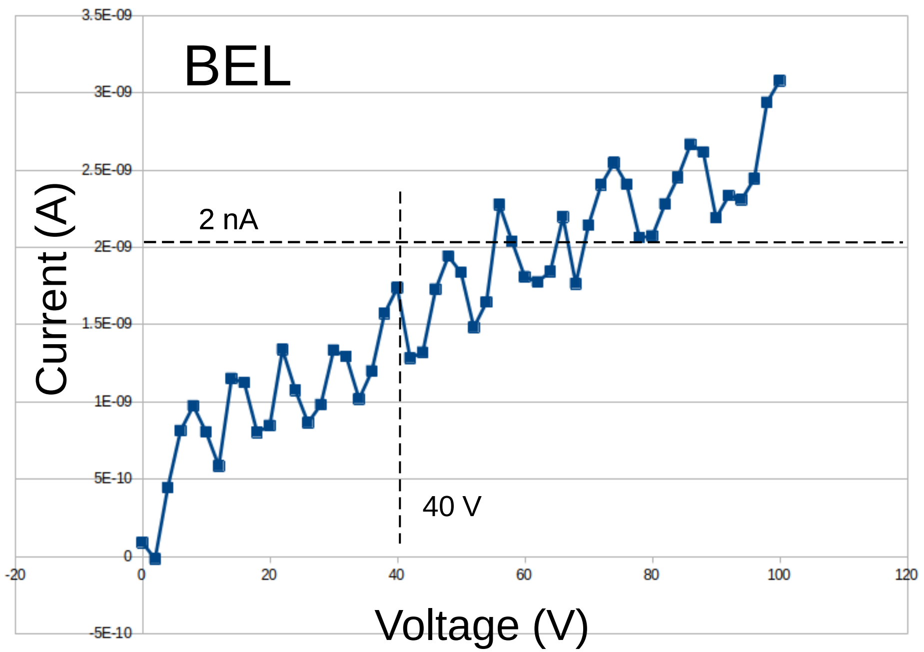
n-type si detector
(1x1 cm^2)

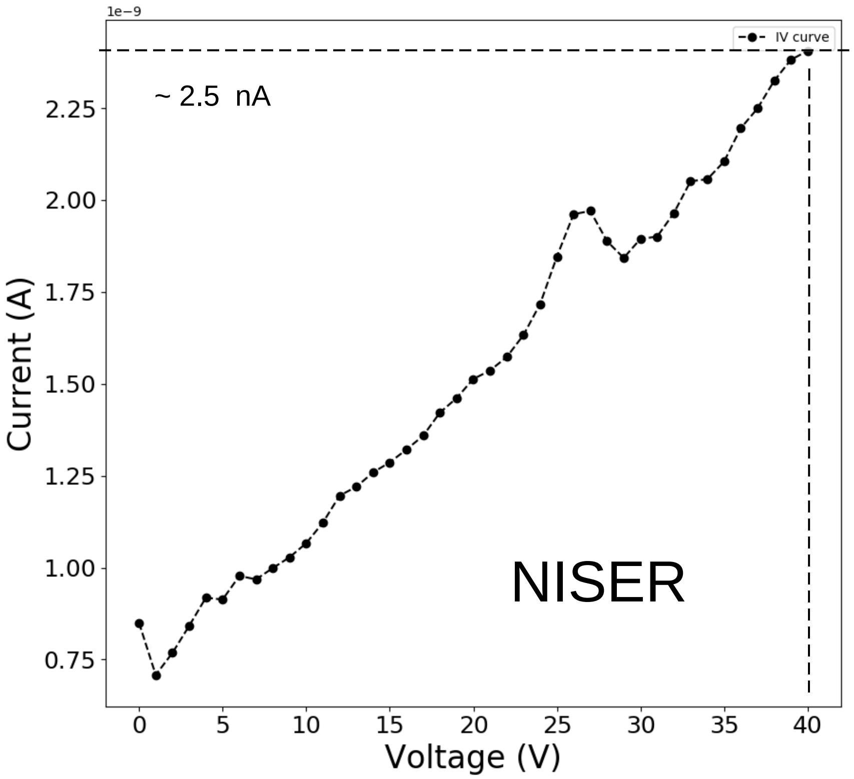


IV test forward bias



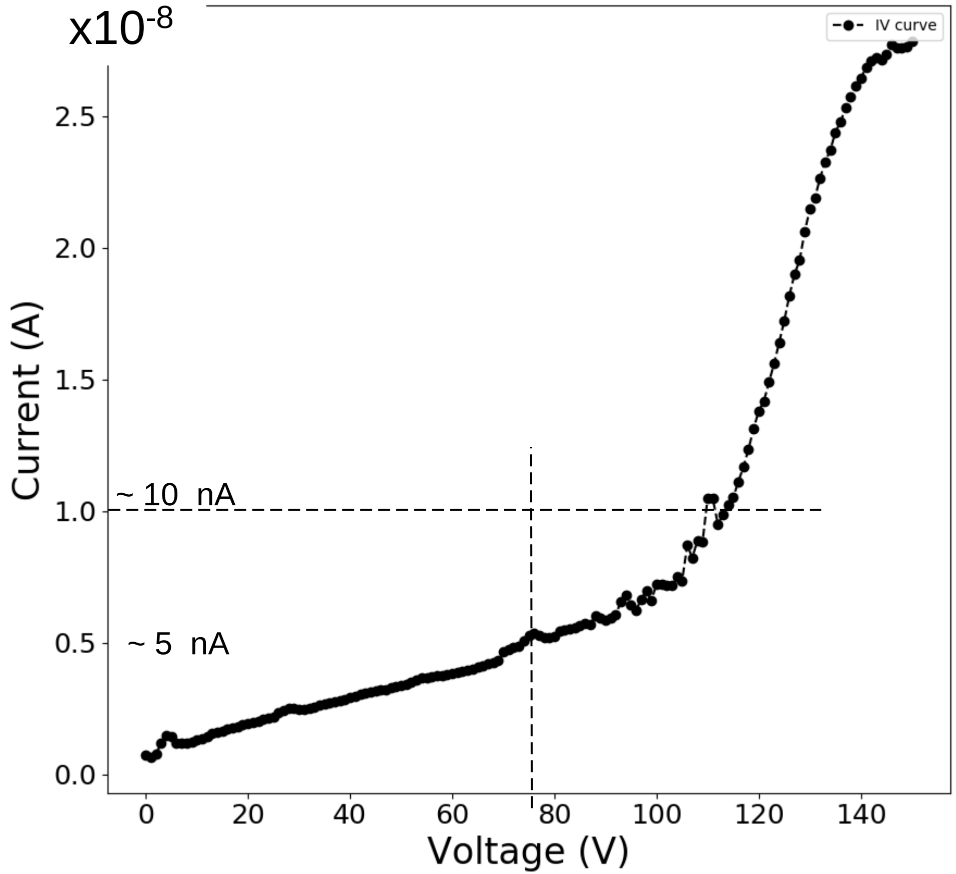
IV curves (Reverse bias) – BEL vs NISER



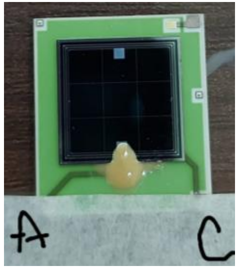


- Leakage current values are comparable
- Required specification: I < 10 nA at Full depletion (~45 V)

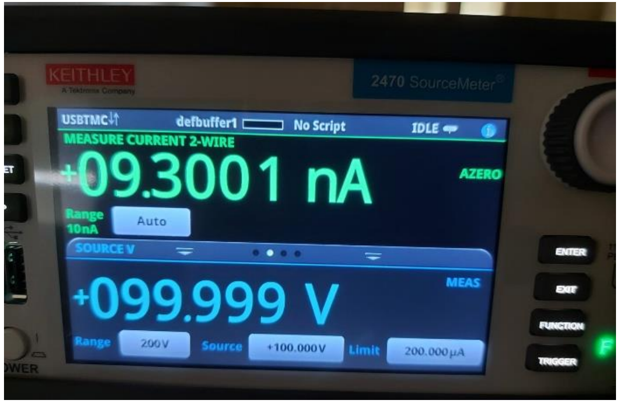
IV curves (Reverse bias) – up to 150 V_{bias}



n-type Si detector (1x1 cm^2)

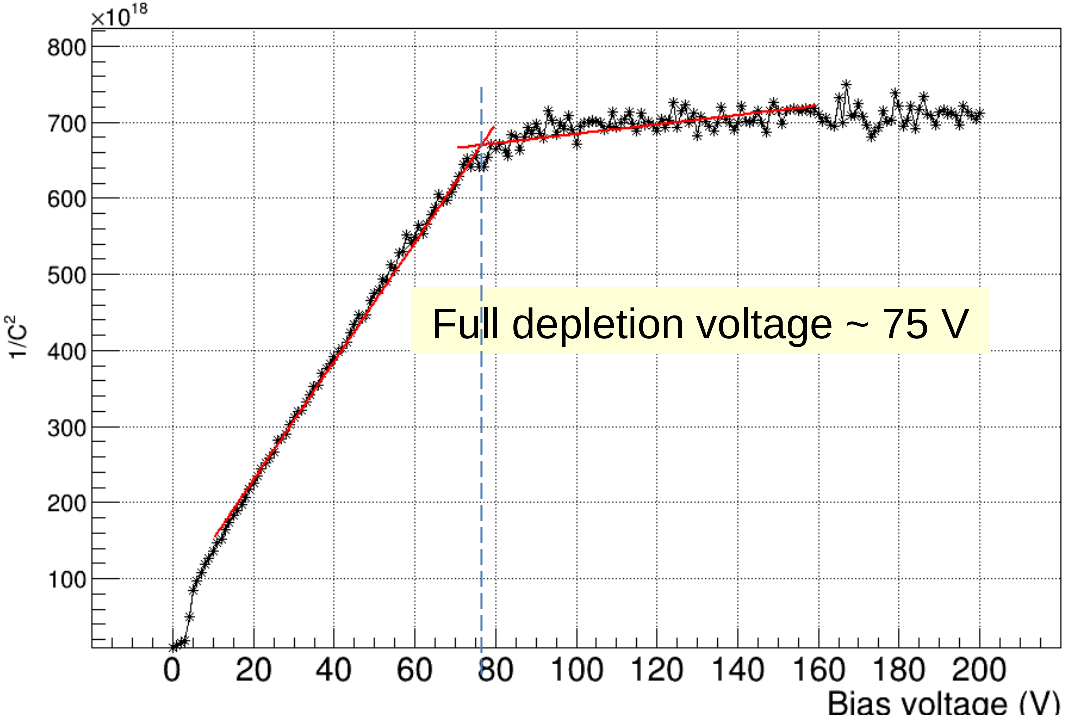


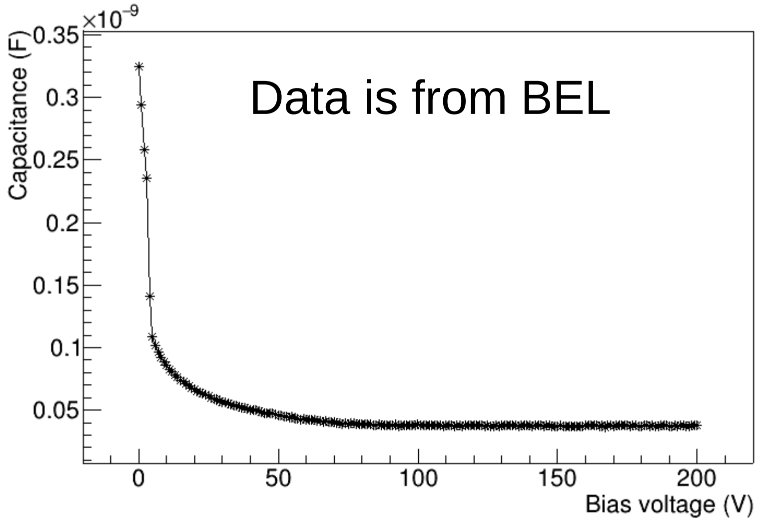
Wafer resistivity (~ 4 kΩ.cm)



n-type pad – CV test

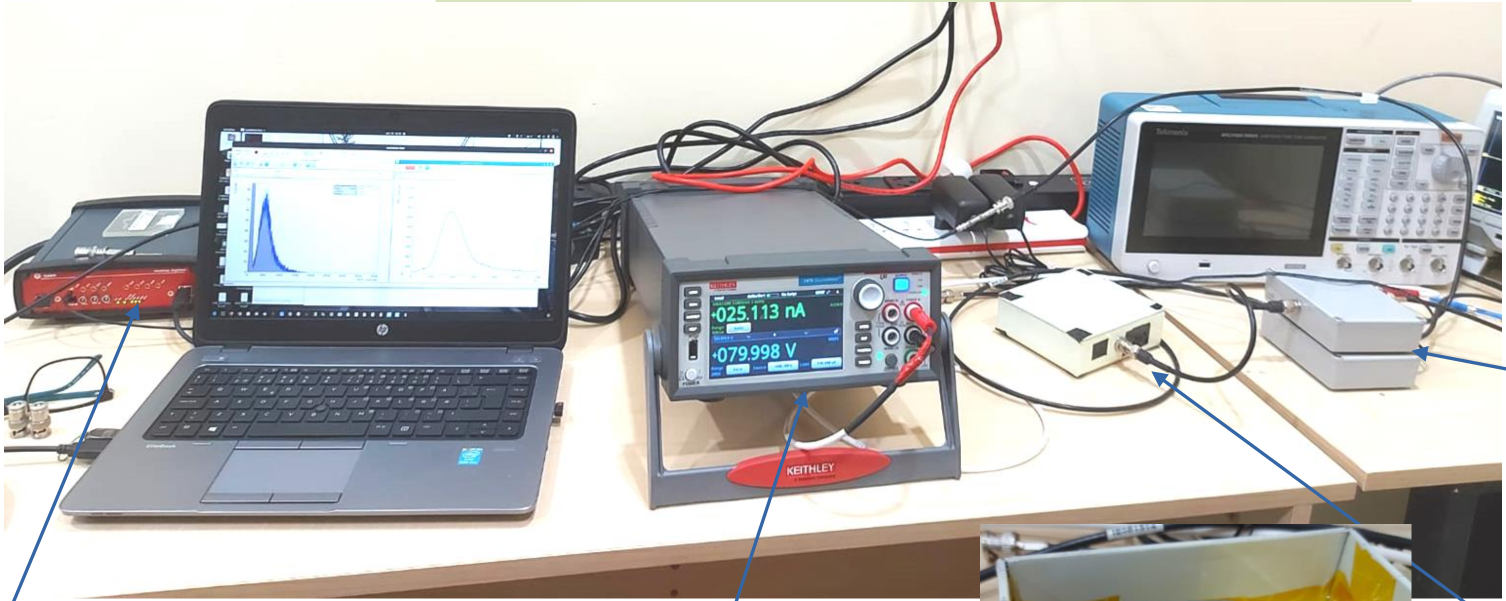
- Done to find out full depletion voltage (FDV)
- Operating voltage is usually chosen to be slightly higher than FDV





Aim to achieve FDV ~ 45V using high resistivity wafer (~ 8kΩ.cm)

n-type pad – test setup at NISER



CAEN Digitizer (DT5730)
8 ch, 14 bit resolution,
500 MS/s sampling rate,
2Vpp dynamic range

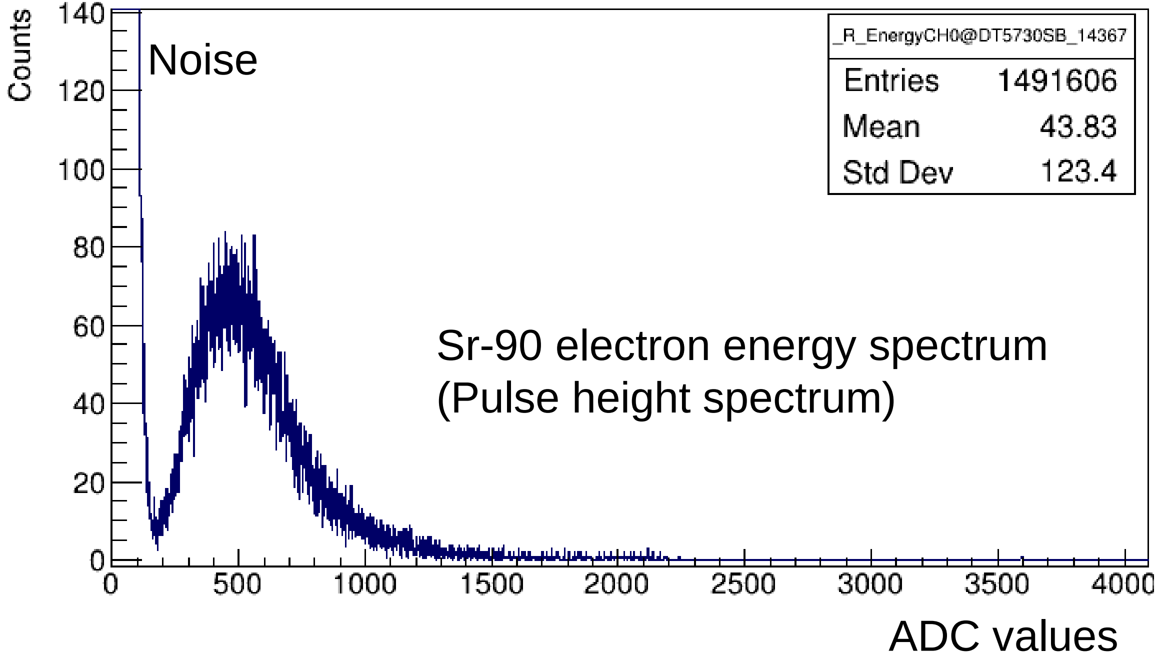
Detector bias supply
(Keithley 2470 SMU)

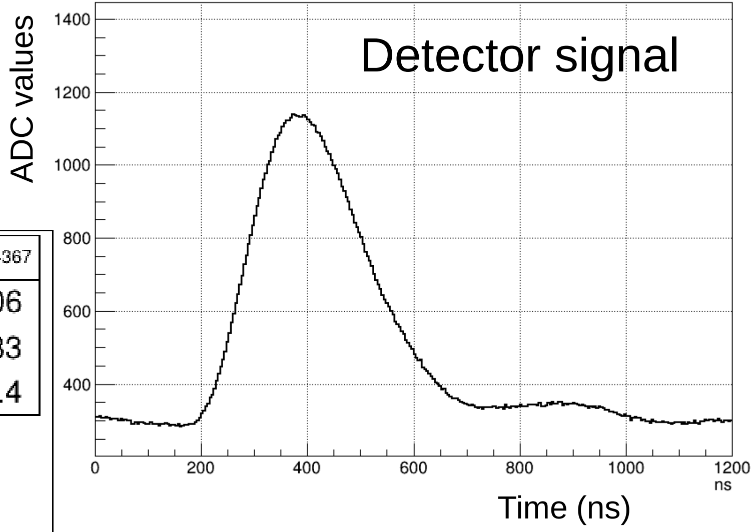
Detector box

Preamp
(cremat 110) and
Shaping amplifier
(cremat 200)

n-type pad – Sr90 response (beta source)

Pad size: 1x1 cm^2:
detector operated at 80 V bias



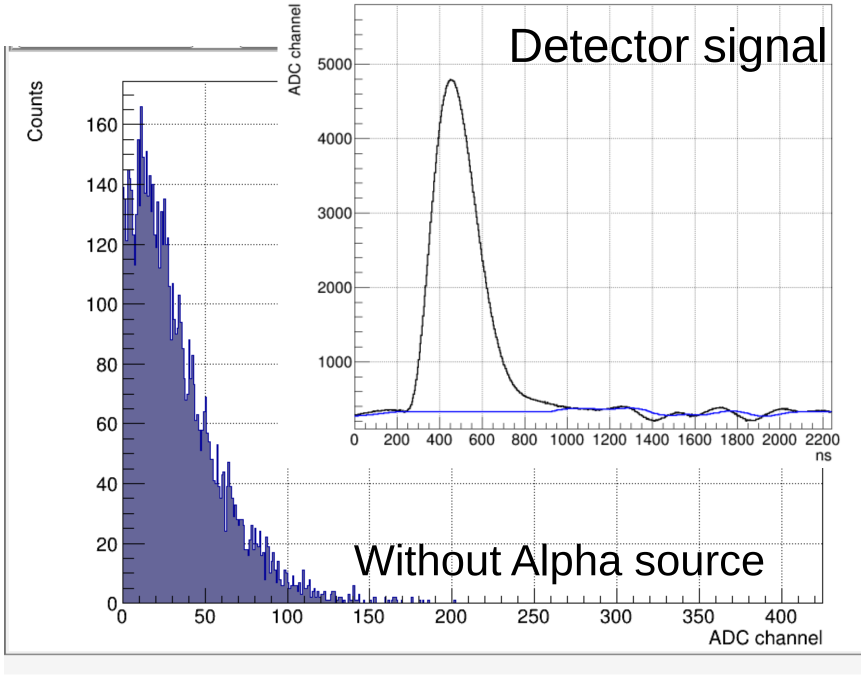


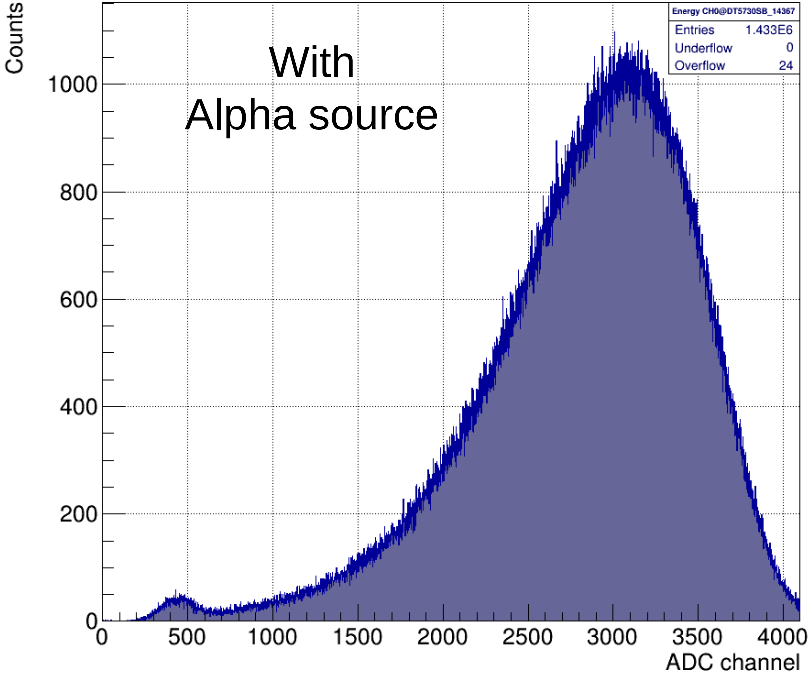
Sr90 beta source emits electrons upto 2.2 MeV, activity ~ 3.7 kBq

n-type pad – Am241 response (alpha source)

Pad size: 1x1 cm^2: detector operated at 80 V bias

Am241 source: 33 kBq, emits alpha of 5.48 MeV,
source kept at 3 cm from the detector, test done in air





Summary

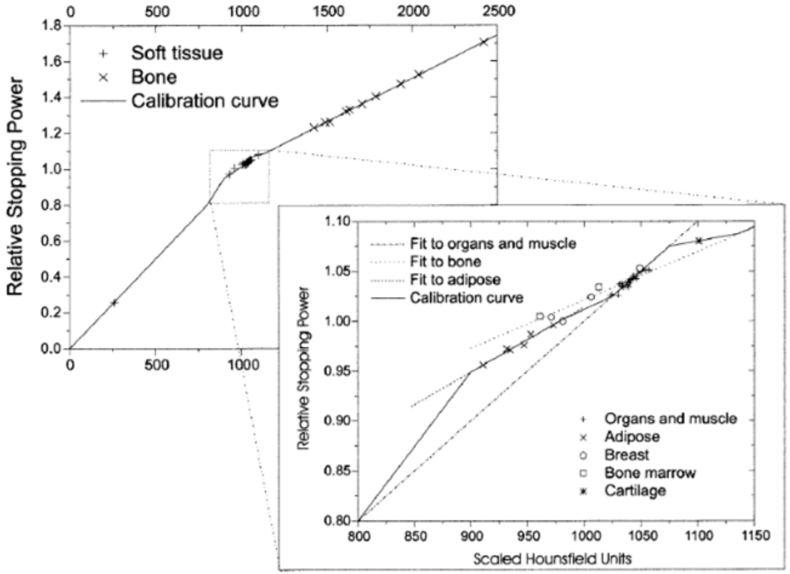
- Fabricating n-type 8x9 Si pad array detectors at BEL, Bangalore
- Plan to use them as EMCal for high energy physics experiments:

  → ALICE FoCal, EIC-EPIC ZDC and medical application - pCT
- Reported test results of first n-type Si detector sample (1x1 cm^2)

  → results look promising

Thanks.

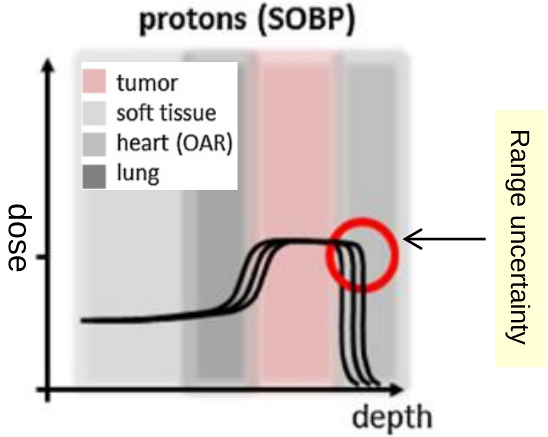
proton Computed Tomography (pCT) – Need?



Relative Stopping Power (RSP) = $[dE/dx]^{tissue} / [dE/dx]^{water}$

- Source of RSP error: Variations in HU from CT system in the form of noise, volume size, scan energy, and technique, positioning, and tissue composition at the treatment site

- Proton RSP from X-ray CT unit
- Conversion leading to systematic range errors (3-5%) for soft tissues and higher for tissues with low or high density (lung, bone) or high z metal artifacts
- As example, Breast cancer treatment with proton: errors in RSP can lead to dose beyond (heart, lung) the target due to proton range error



Ref: Antje-Christin Knopf, Phys. Med. Biol.58 (2013) R131–R160 OAR: Organ at Risk, Phys Med Biol, (1998), 43(6), p1579-92

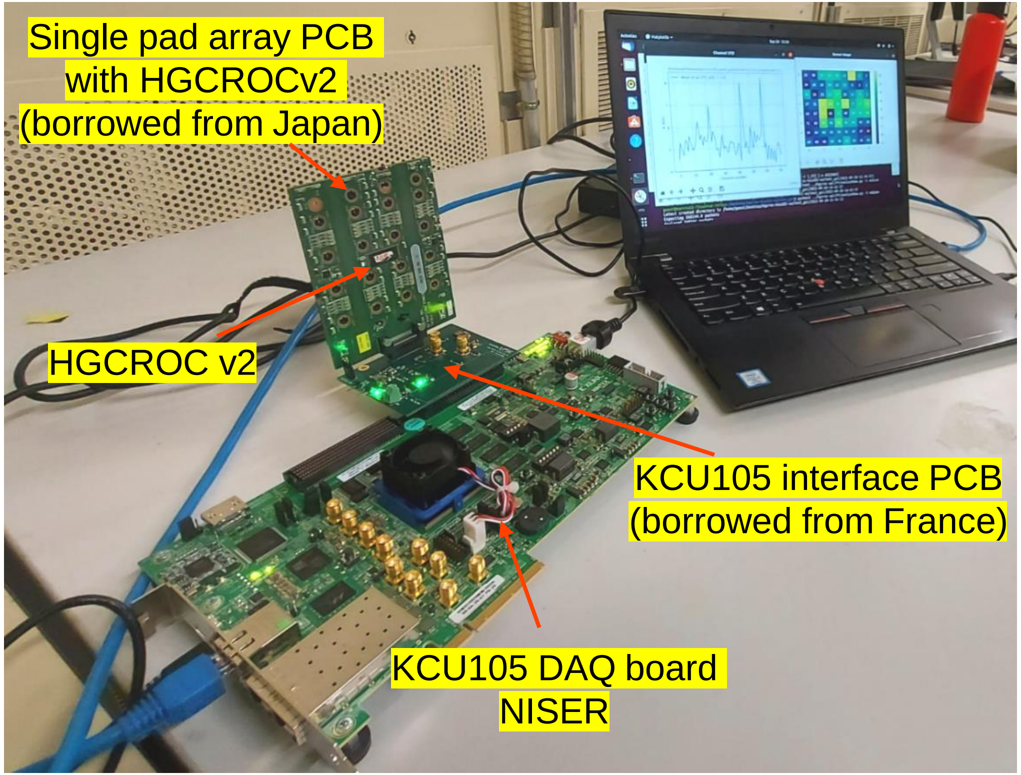
HGCROCv2 – test setup

Backup

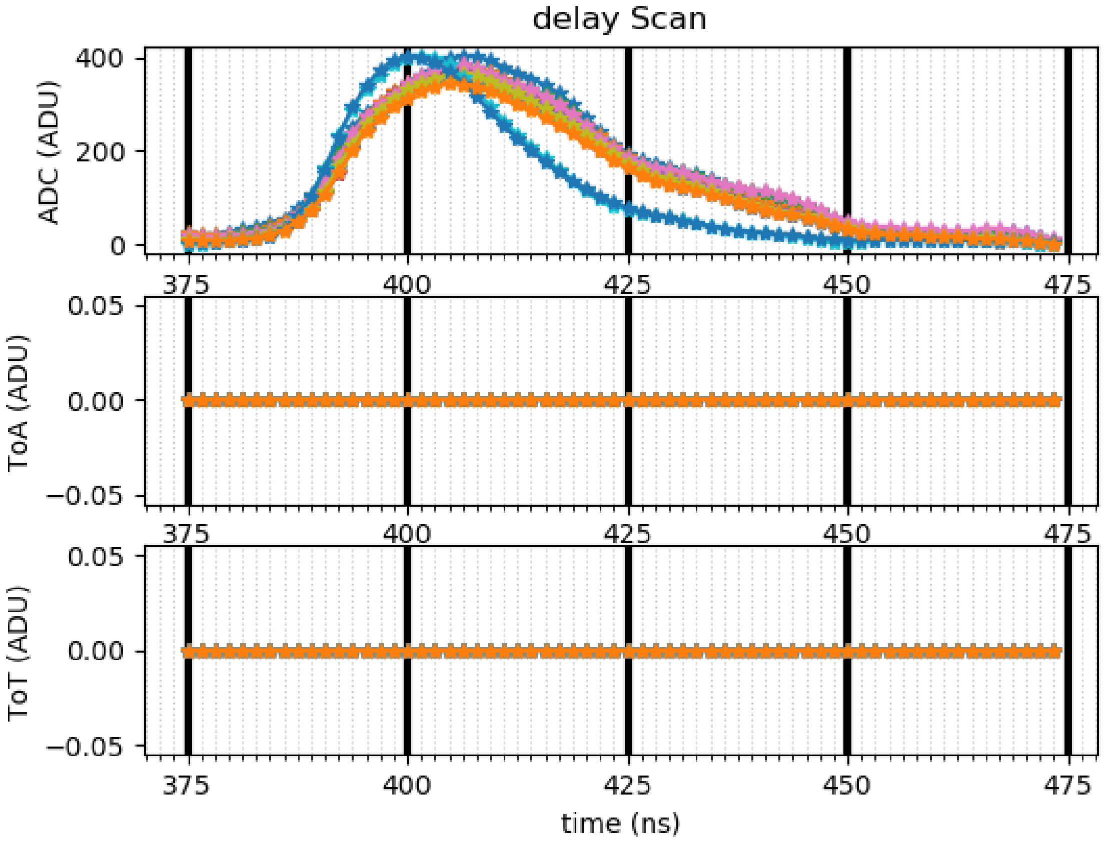
- Mainly prepared for performance testing of the packaged untested chips before gluing their carrier boards to the detector pad arrays, make sure the KCU105 board works (my motivation!)

- 25 single pad array PCB production is in progress

- Test results in the following slides are produced using a test framework developed by LPSC, Grenoble team

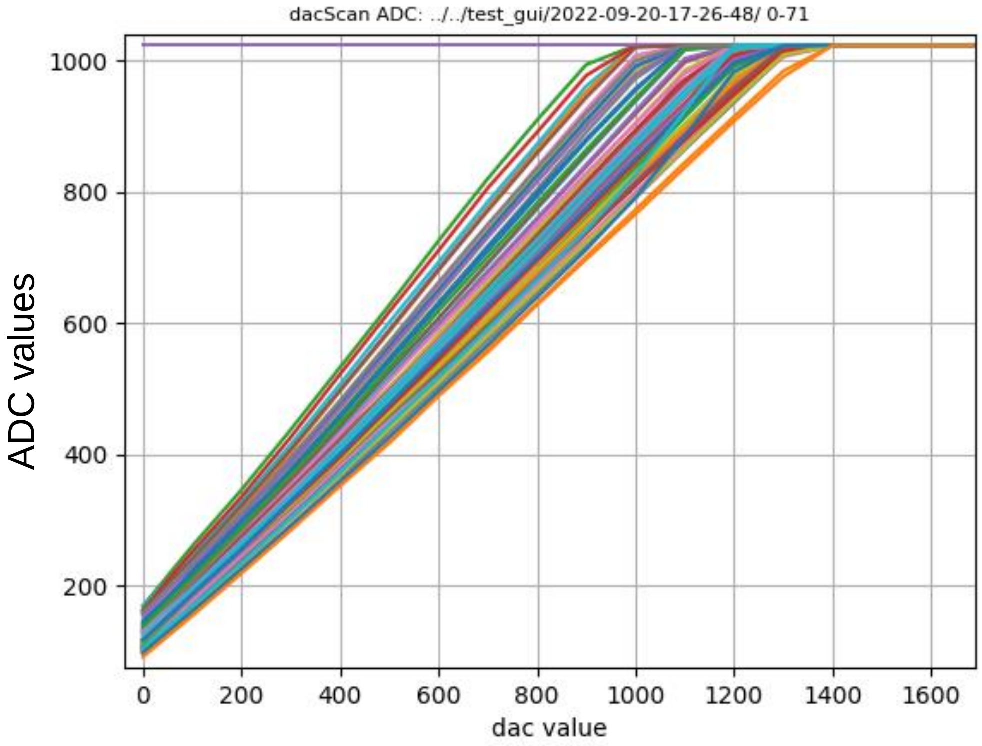


Pulse shapes – Internal injection



Pulse shape for low internal injection, ToA and ToT were turned off

ADC linearity – Internal injection



ADC response is linear for the 71 readout channels

IDEAs ASIC and DAQ system

Product Features

Detectors	Silicon
Application	Imaging, Spectroscopy, Calorimetry
Number of inputs	128
Input charge range	-250 fC to +250 fC
Shaping time	0.5 µs
Nominal capacitive load	6 pF
Equivalent Noise Charge (ENC)	398e + 5e/pF
Trigger threshold	Adjustable
Trigger outputs	Common trigger output for all channels
Outputs	Multiplexed pulse height
Test and calibration	Internal calibration circuit
Power consumption	2.2 mW / channel

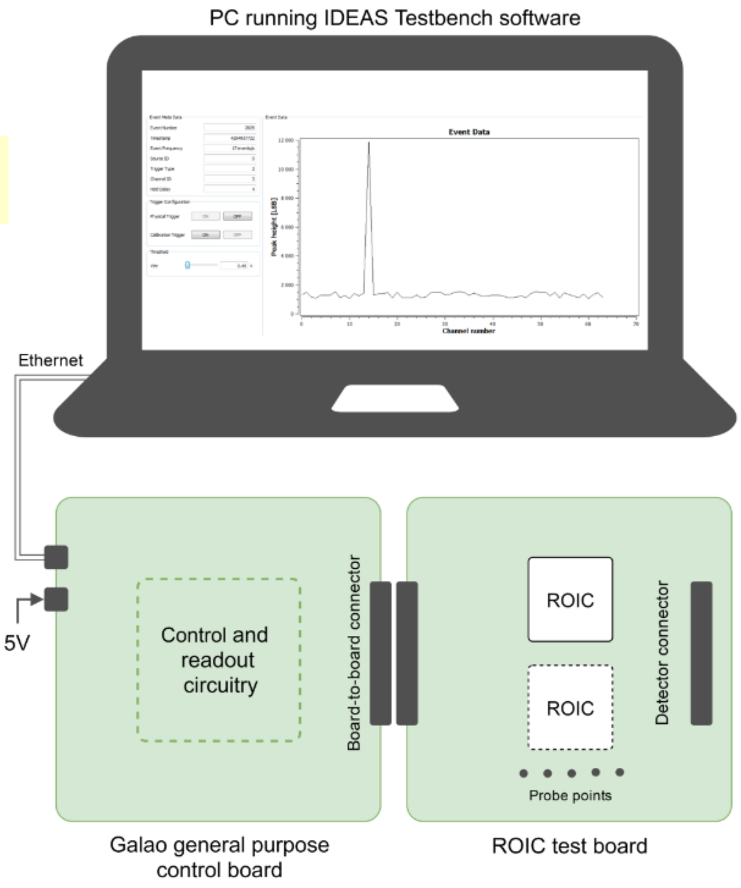


Figure 1: Galao ROIC development kit overview