First performances of EICROC ASIC to read-out pixelated AC-LGAD sensors for the Electron-Ion Collider (EIC)

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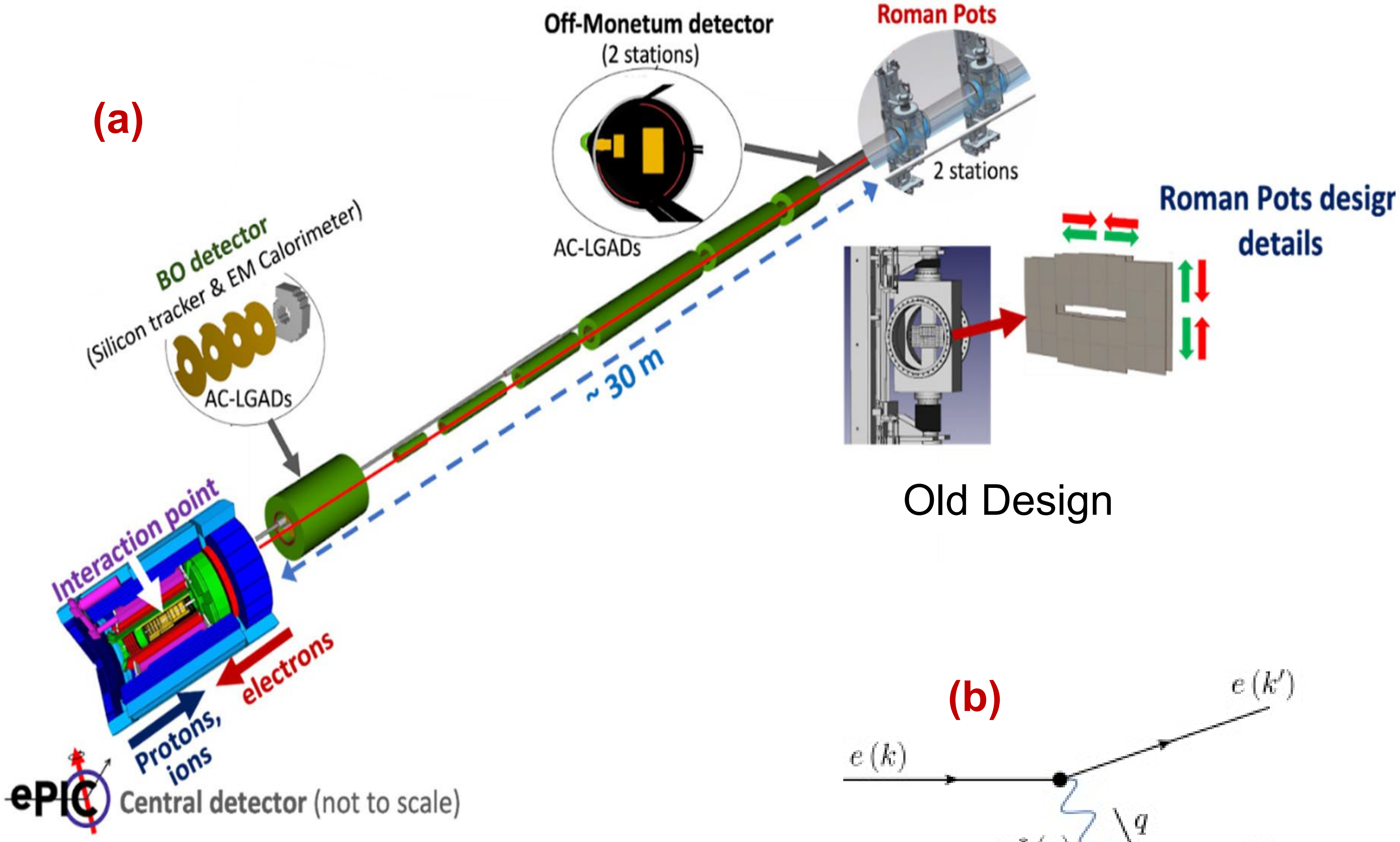
- Overview of EICROC
- EICROC Characterization via Internal Charge Injection
- Initial Testing with Beta Source: PA Measurements
- Beta Source testing with Digital readout across all channels

Summer 2025 EICUG/ePIC Collaboration Meeting, July 14-18, Thomas Jefferson National Accelerator Facility, United States

Roman Pots: Essential for exclusive processes



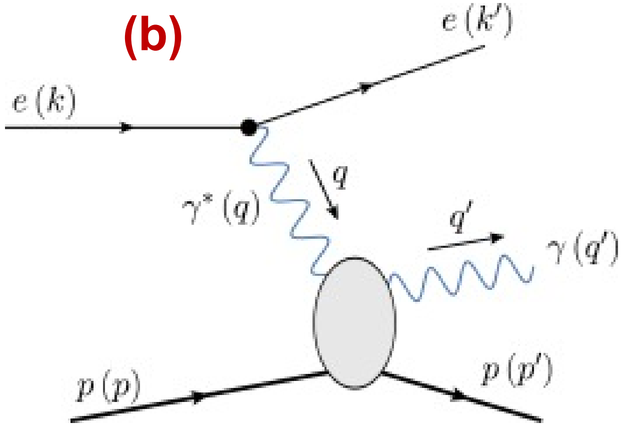


Fig: (a) Roman pots at far-forward angles in the beamline, (a) Deep Virtual Compton Scattering (DVCS) process.

- Aim is to identify and characterize exclusive, diffractive, and tagged events using detectors integrated with the outgoing hadron beamline, (**far-forward detectors**).
- Scattered angle < 5 mrad
- To be placed directly in vacuum around the hadron beam to detect intact hadrons with transverse momenta down to a couple hundred MeVs.

Essential Features:

- Obtain a position resolution of ~50 µm.
- Time resolution ~30 ps to account for head on collision between the electron and proton beam.

EICROC Project

Design & performance characterization of EICROC2 (32x32) chip intended to readout large surface pixelated AC-LGAD (Simultaneous time and spatial study)

- Design challenge is to fit all the components within a 0.5x0.5 mm^2pad.
- Challenge to accommodate for low sensor capacitance (< 1 pF), low electronic noise (~ 1 mV/channel) and jitter to reach the required timing resolutions (20-30 ps),sensitivity to small charges (~ 3 fC) per pixel, and to estimate the amplitude of the central hit pixel for time-walk correction but also of its neighbors (containing the induced cross-talk and charge sharing).
- Achieve good position resolution (~ 20 microns) while ensuring a very low power dissipation, << 1mW/channel.
- Cooling mechanism in vacuum: studies being performed @ IJCLab.
- EICROC0: 1st ASIC prototype has 16 channels

Design Credit for ASIC Development: @ OMEGA withTDC @ CEA/Irfu/DEDIP, ADC @ AGH Krakow.

EICROC0 1st prototype (4x4 pads)

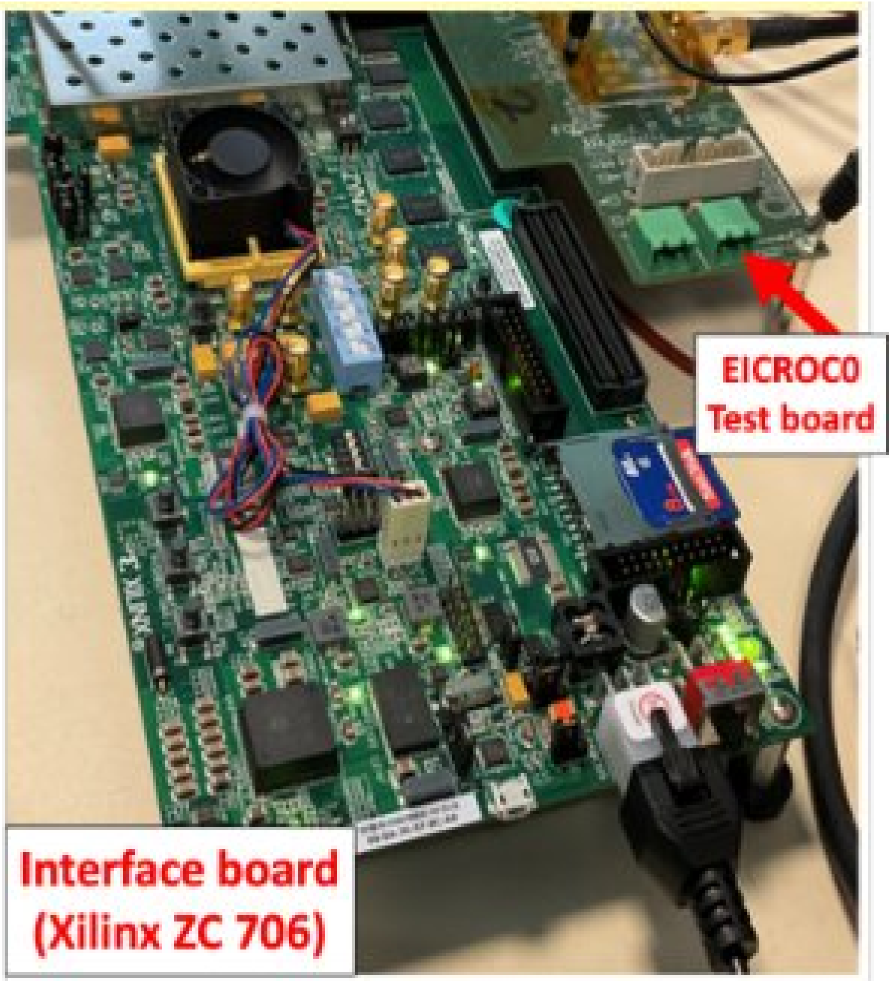
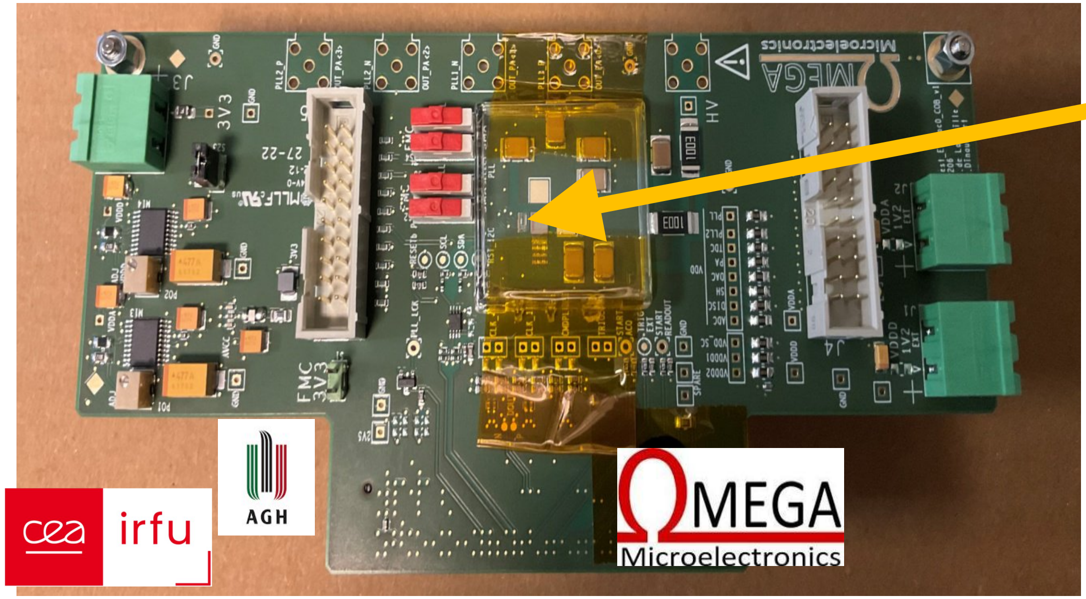
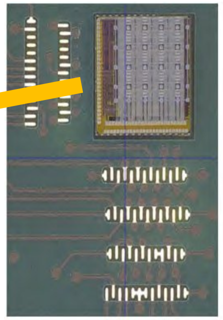


Fig.: EICROC0 Testbench

Fig.: EICROC0 Testboard setup.



EICROC0 chip



Pixel / Channel Mapping	Column 0	Column 1	Column 2	Column 3
Line 0	Pixel (0,0) #00	Pixel (1,0) #04	Pixel (2,0) #08	Pixel (3,0) #12
Line 1	Pixel (0,1) #01	Pixel (1,1) #05	Pixel (2,1) #09	Pixel (3,1) #13
Line 2	Pixel (0,2) #02	Pixel (1,2) #06	Pixel (2,2) #10	Pixel (3,2) #14
Line 3	Pixel (0,3) #03	Pixel (1,3) #07	Pixel (2,3) #11	Pixel (3,3) #15

Fig.: EICROC0 chip channel map.

EICROC0 features

- An analogical fast Transimpedance (TZ) pre-amplifier and a discriminator taken from ALTIROC ASIC design (ATLAS/HGTD).
- 10-bit Time-to-Digital Converter (TDC) measuring the Time-of-Arrival (ToA), designed by CEA/Irfu/DEDIP.
- 8-bit (40 MHz) Analogical-to-Digital Converter (ADC), designed and adapted by AGH University of Science and Technology (Krakow, Poland) from the HGCROC 10 bit ADC.
- Compared to the ALTIROC chip, holding 2 TDCs, one to measure the TOA and the second one associated to the Time-over-Threshold, an ADC has been preferred to measure the signal amplitude to avoid nonlinear behavior of a ToT TDC as a function of injected charge.
- I^2C communication (firmware + software developments)
- Digital readout: FIFO depth 8(200ns)
- 5 slow control bytes per pixel:

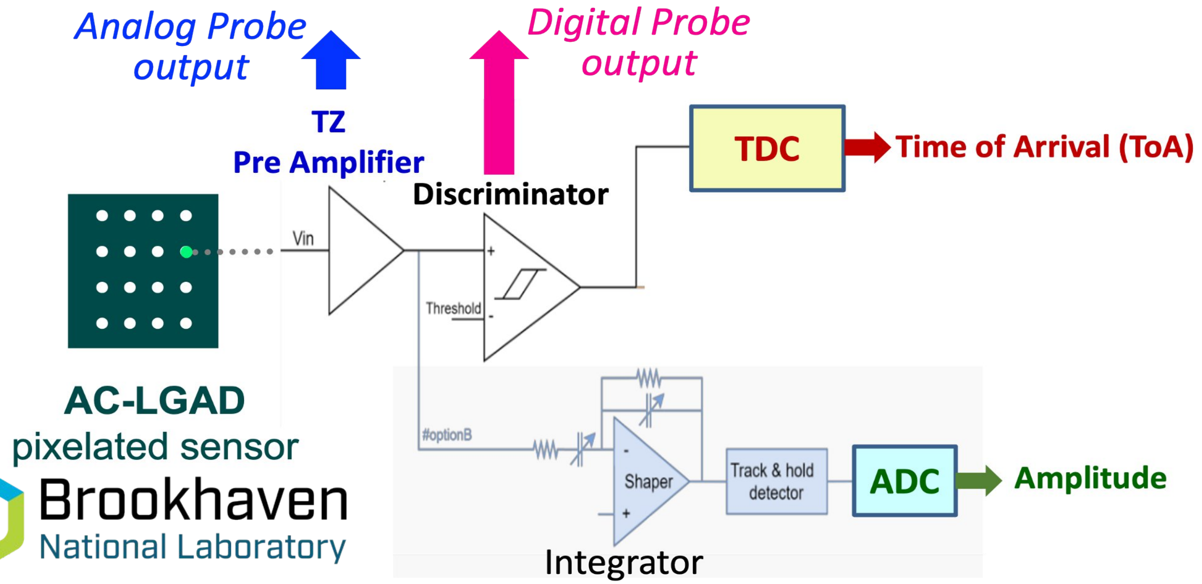
➢ 6 bits local threshold,

➢ 6 bits ADC pedestal,

➢ 16 TDC calibration bits,

➢ several on/off and probes.

1 channel (1 pixel) schematics



Brookhaven National Laboratory

EICROC Characterization

Results presented in EIC France 2024 Meeting

1. Charge injection system, referred as CMD Pulse signal (**0.7-25 fC**).
2. Preamplifier signal divided and sent to Discri/TDC (ToA) and to ADC (measure signal amplitude).
3. Digital output data consist of 8 time samples;
   [TDC, ADC, Hit bit] / time sample for each of the 16 channels.
4. Discriminator threshold correction is performed by measuring S-curve, i.e., efficiency as a function of threshold.
5. TDC calibration performed.
6. TDC is characterized by measuring average time and jitter as a function of injected charge.
7. Determination of minimum detectable charge (plotting efficiency as a function of charge).
8. ADC waveforms studied with pedestal subtraction.

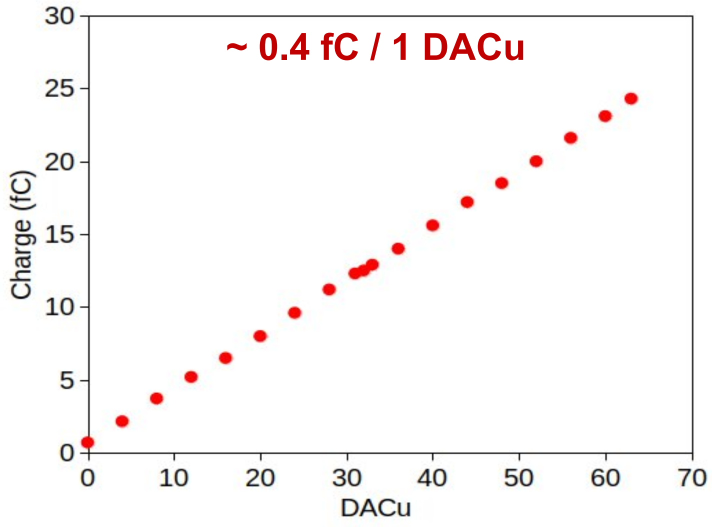


Fig.: Internal Injected charge calibration.

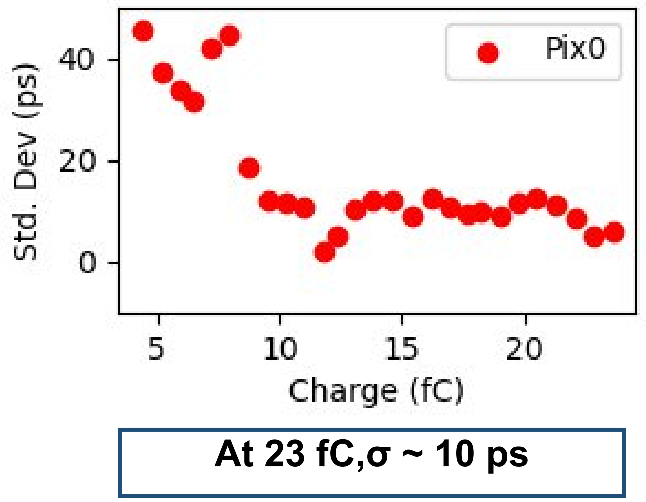


Fig.: Jitter study as a function of charge.

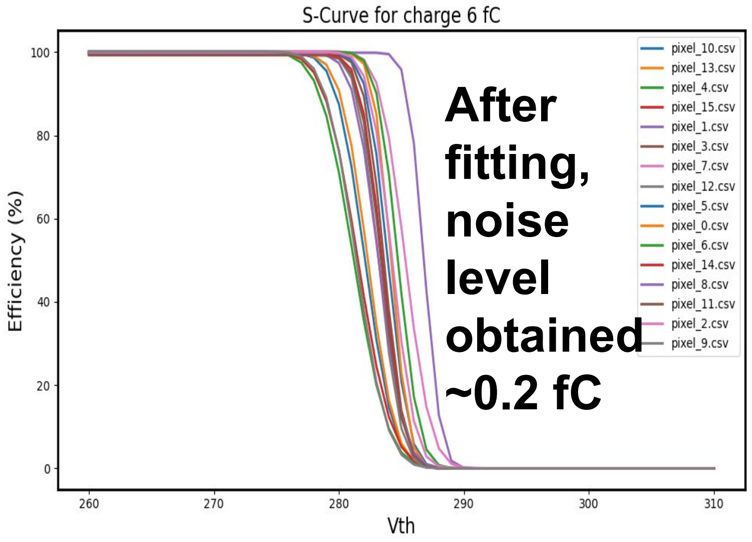


Fig.: Discriminator threshold optimization.

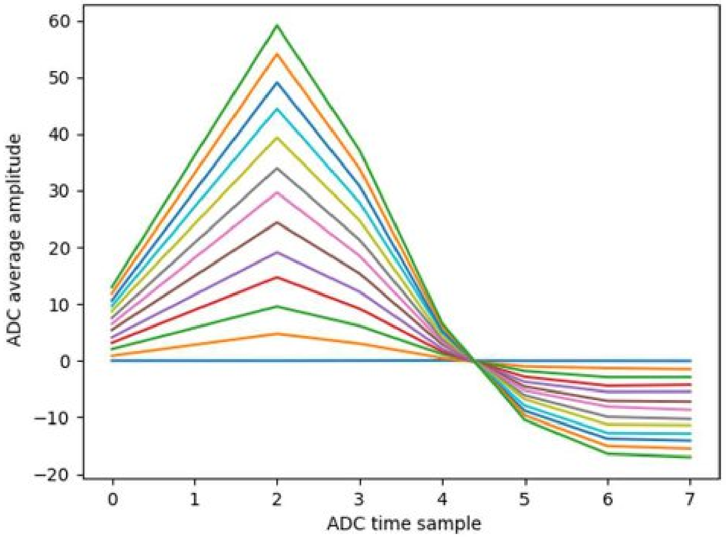


Fig.: ADC waveform studies for different charge injected.

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PA Measurements with ^{90}Sr β source

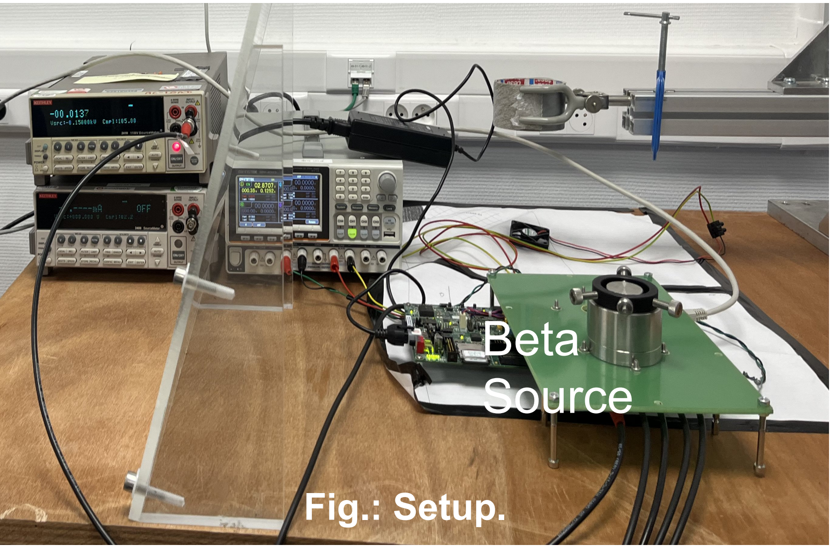
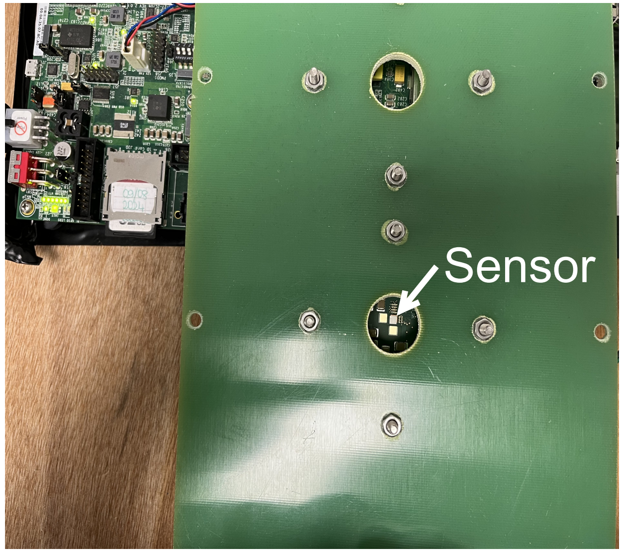


Fig.: Setup.



Results presented in ePIC Collaboration Meeting, Jan 2025

Charge sharing ratio normalised to maximum amplitude measured for the reference pixel ⇒ 100 %

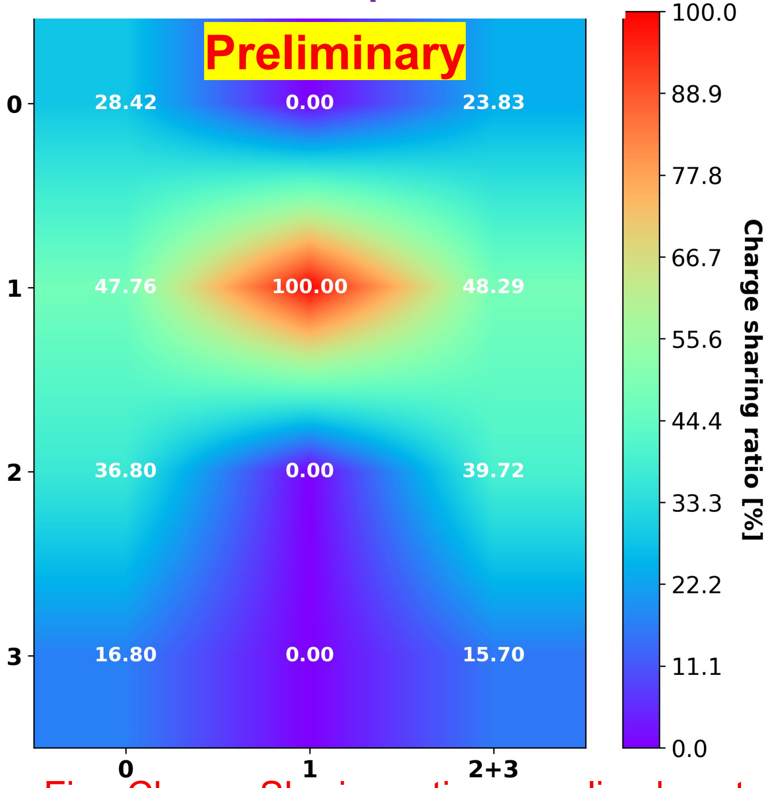


Fig.: Charge Sharing ratio normalized w.r.t. Pix 05 (Triggered Channel) for HPK WB.

- **Probe Pre-Amplifier signal on oscilloscope**

  Cons:
  - 4 channels only at a time
  - Only 1 channel per column
  - Difficulty as signal maximum can come from other channel.
  - **Very complicated analysis: selection of good events**

	0	1	2	3
0	C4	Pixel (1,0) #04	C2	C1
1	C4	C3	C2	C1
2	C4	Pixel (1,2) #06	C2	C1
3	C4	Pixel (1,3) #07	C2	C1

Fig.: Channel map for scope.

- **ADC + TDC data**

  Pros:
  - 16 channels at a time
  - Require a specific firmware

Updated Firmware : Acquiring TDC and ADC data for all 16 channels when **at least** a hitbit is set to 1 among all 16 channels (meaning that PA signal amplitude passes the discriminator threshold). (courtesy: Beng-Yun Ky)

Measurements with ^{90}Sr β source : Digital Readout

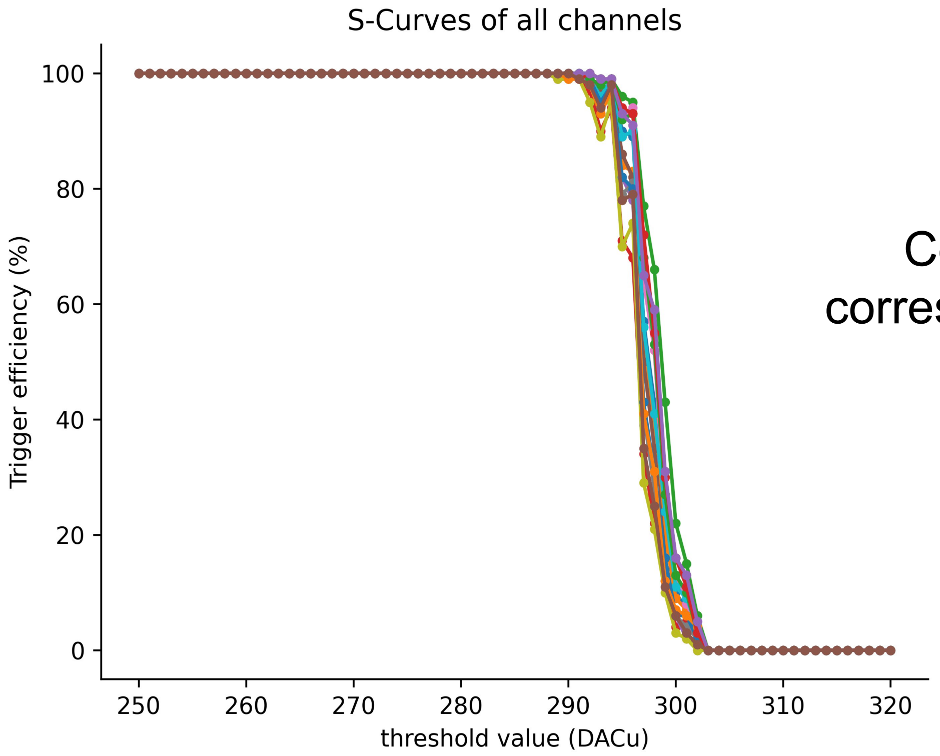
Pix-to-Pix Adjustment

- **Threshold adjustment** channel-by-channel performed.
- **Baseline adjustment** channel-by-channel done.

EICROC0 + wire-bonded BNL AC-LGAD

Detector Bias = -200 V
I ~ 0.06 microA

Adjustments performed for lower charge DAC Pulser 12 (~5 fC) [CMD pulse] and setting global threshold 300 DACu



Color map corresponds to all pixels

Computed data
50% value = 297.4
50% spread = 2.21

Fig.: Discriminator threshold optimization for all channels.

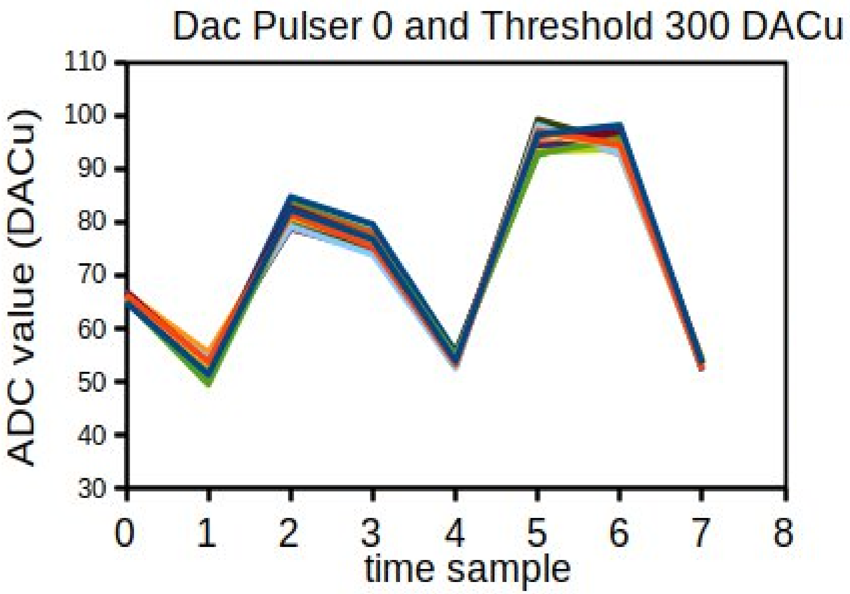


Fig.: ADC offset correction for all channels.

Event Filtering in Digital Readout: Hit Map Evaluation

- An event in any pixel is recorded when Discriminator crosses the threshold.
- **Event Selection**: Hit Map (hit bit = 1) for one of the pixels + same pixel has maximum amplitude recorded after pedestal subtraction.

Condition: Hitbit for Pix 5=1 and Pix 5 with Max Amp

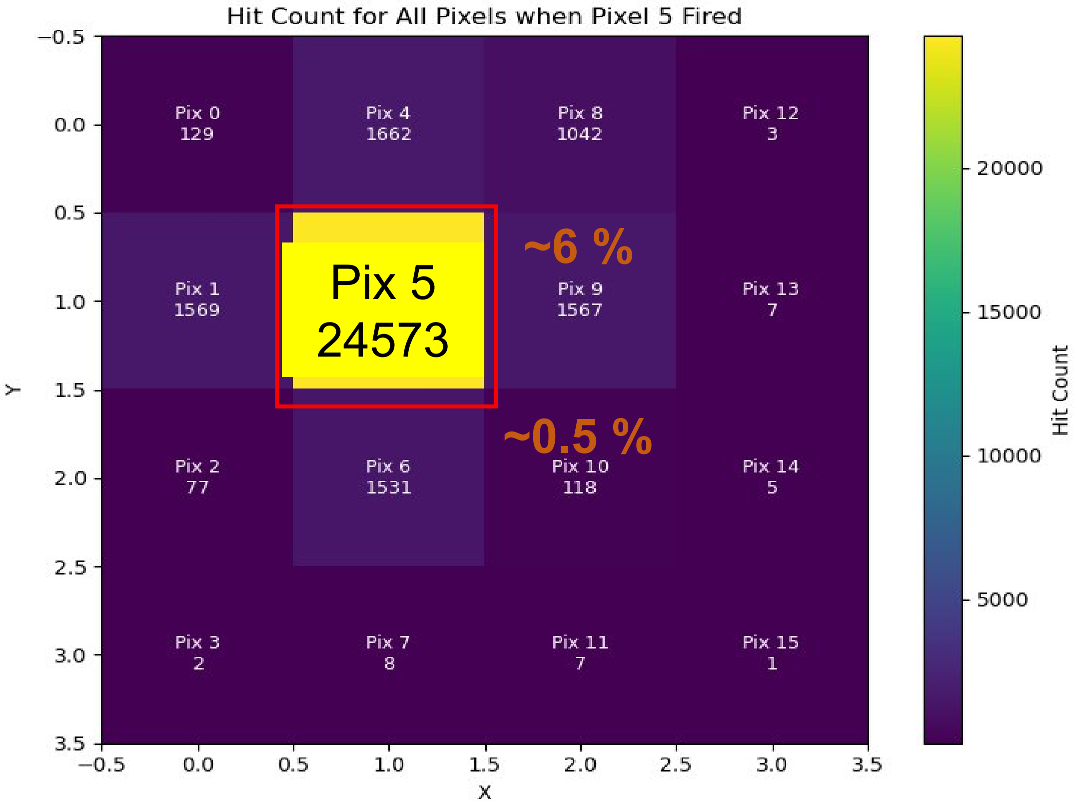


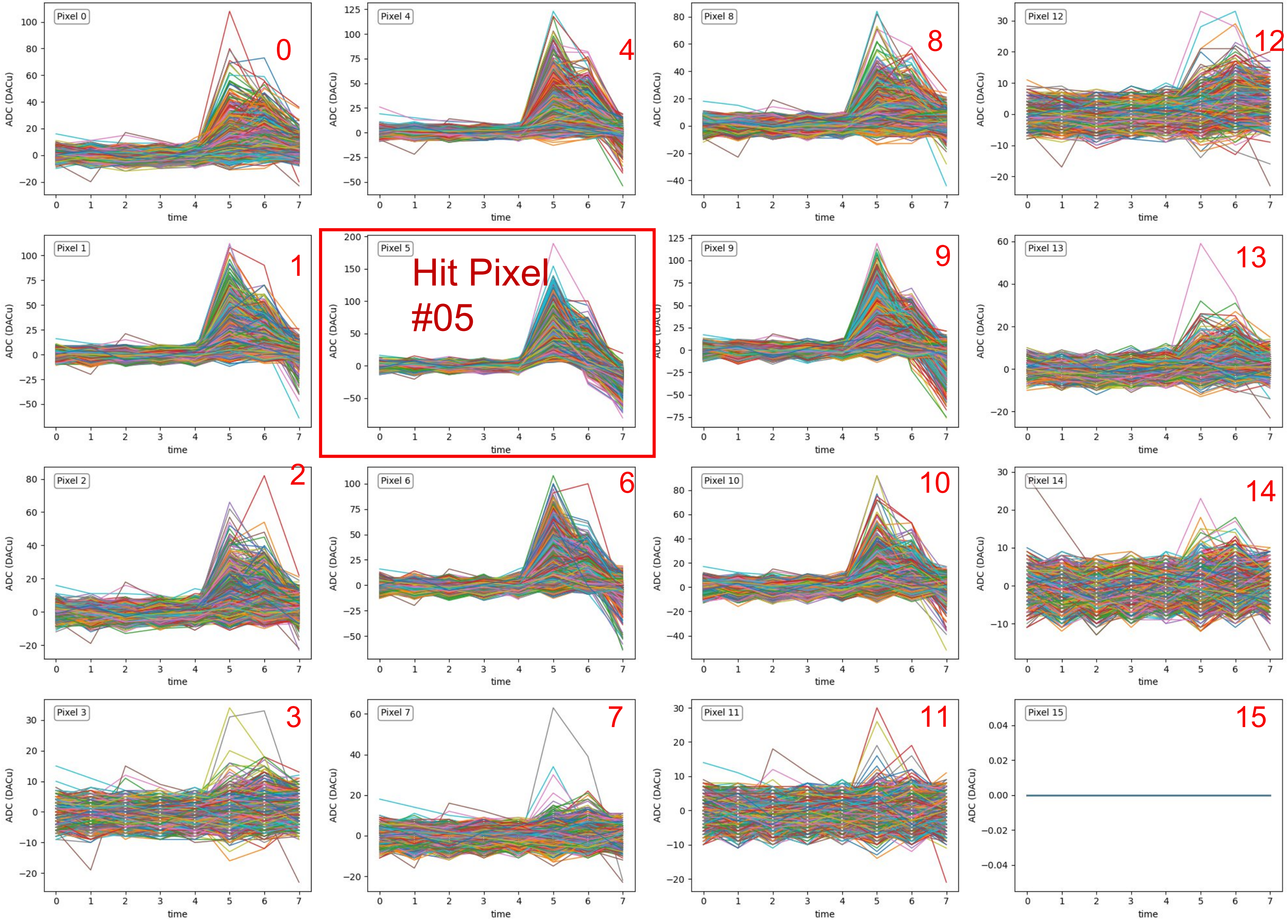
Fig.: Hit Map for event selection in Pix 05 (hit bit = 1 and maximum amplitude).

- Only 4% of the events remaining after the selection of events with **hit bit =1 in pixel 5 and has max amplitude**.
- With this condition the first neighbors having hit bit = 1 ~ 6%. (Clearly we need more statistics)
- The far neighbor, almost never crosses the threshold -> **The ADC data corresponds to the noise** and can be used for pedestal subtraction.

ADC Waveform (Beta Measurements): Pedestal Subtracted

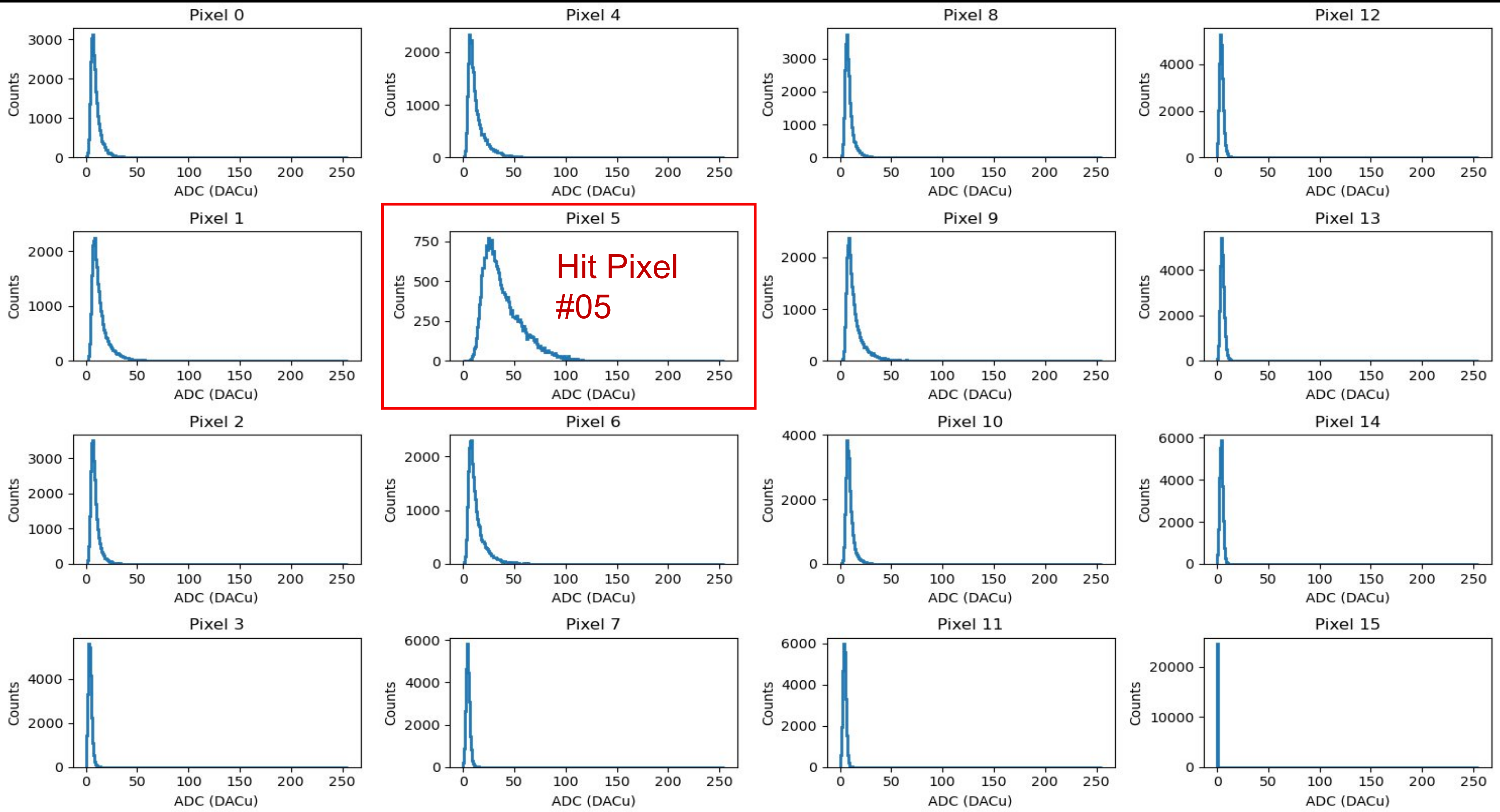
Fig: ADC waveform for each pixel with a condition Pix 5 has hit bit = 1 and max amplitude.

- Code adapted to select events with specific channel with a hit bit = 1 and same channel has maximum amplitude. No condition on the rest of the channels.
- Pedestal Subtraction for ADC performed using a Pix far from the hit pixel on **event-by-event basis**.
- Clearly, we start to see maxima in each pixel **->**ADC waveform is dominated by the noise that can be subtracted using a far pixel.



Energy spectrum : After Pedestal Subtracted

(1DACu = 5 mV)



- The Maximum amplitude in the neighboring channels is less as compared to the hit pixel.
- The Width of the spectrum is reduced for pixels away from the hit pixel.

Fig.: Max ADC distribution for hit in Pix 05 (represented by red rectangle).

ADC vs ADC (Correlation study between different neighbors)

Pixel / Channel Mapping	Column 0	Column 1	Column 2	Column 3
Line 0	Pixel (**0**,0) **#00**	Pixel (**1**,0) **#04**	Pixel (**2**,0) **#08**	Pixel (**3**,0) **#12**
Line 1	Pixel (**0**,1) **#01**	Pixel (**1**,1) **#05**	Pixel (**2**,1) **#09**	Pixel (**3**,1) **#13**
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Line 3	Pixel (**0**,3) **#03**	Pixel (**1**,3) **#07**	Pixel (**2**,3) **#11**	Pixel (**3**,3) **#15**

Fig.: Channel Map. Selected Hit Pix #05 represented in red rectangle.The neighboring pixels selected for correlation study in this slide are represented in blue rectangle.

ADC vs ADC (Correlation study between different neighbors)

Pix 4 vs Pix 5 (I neighbor)

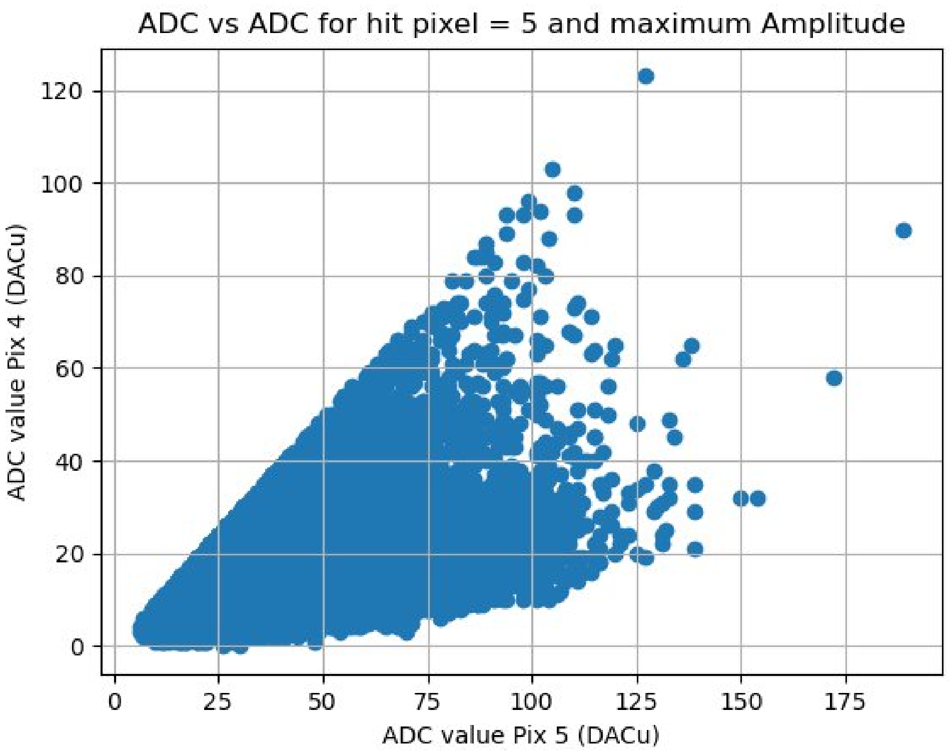

Fig.: ADC 4 vs ADC 5 for hit in Pix 05.

Pixel / Channel Mapping	Column 0	Column 1	Column 2	Column 3
Line 0	Pixel (0,0) #00	Pixel (1,0) #04	Pixel (2,0) #08	Pixel (3,0) #12
Line 1	Pixel (0,1) #01	Pixel (1,1) #05	Pixel (2,1) #09	Pixel (3,1) #13
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Fig.: Channel Map. Selected Hit Pix #05 represented in red rectangle.The neighboring pixels selected for correlation study in this slide are represented in blue rectangle.

ADC vs ADC (Correlation study between different neighbors)

Pix 4 vs Pix 5 (I neighbor)

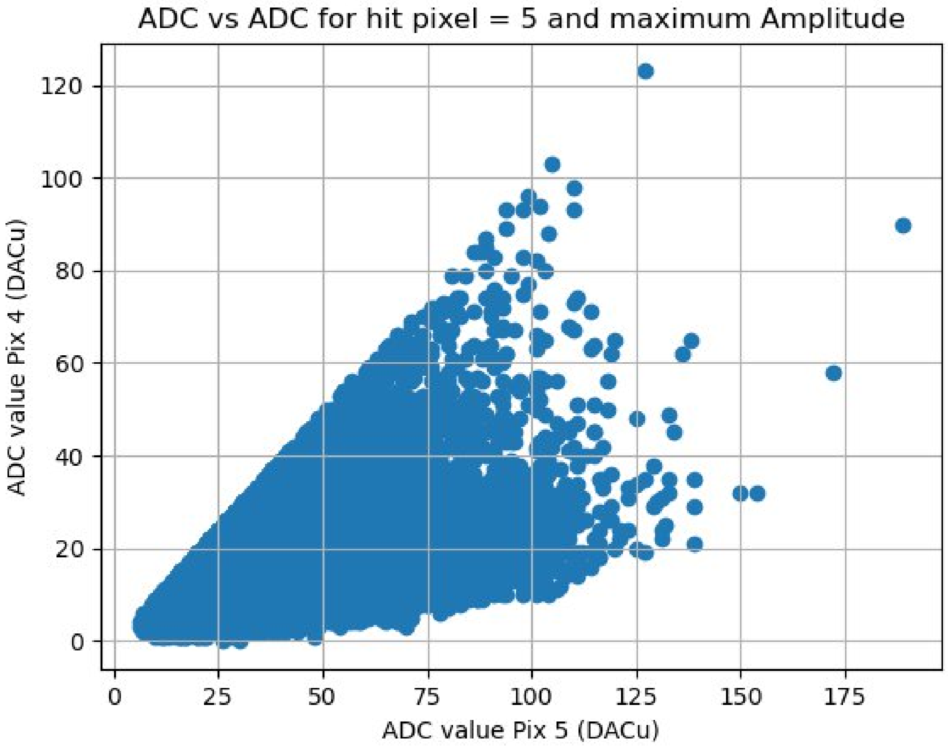

Fig.: ADC 4 vs ADC 5 for hit in Pix 05.

Pixel / Channel Mapping	Column 0	Column 1	Column 2	Column 3
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Line 3	Pixel (**0**,3) **#03**	Pixel (**1**,3) **#07**	Pixel (**2**,3) **#11**	Pixel (**3**,3) **#15**

Fig.: Channel Map. Selected Hit Pix #05 represented in red rectangle.The neighboring pixels selected for correlation study in this slide are represented in blue rectangle.

Pix 3 vs Pix 5 (far neighbor)

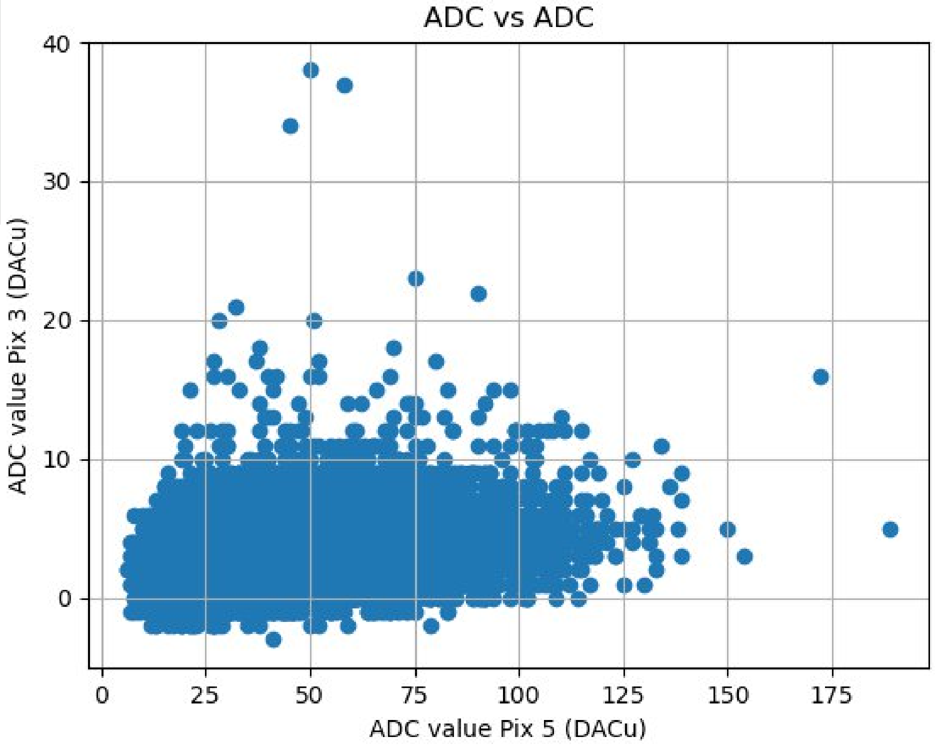


Fig.: ADC 3 vs ADC 5 for hit in Pix 05.

- The results appear consistent with the scope data.
- The correlations are neighbor order dependent, i.e., first neighbor shows clear correlations with hit pixel.

Normalized ADC spectrum w.r.t. hit pixel 5

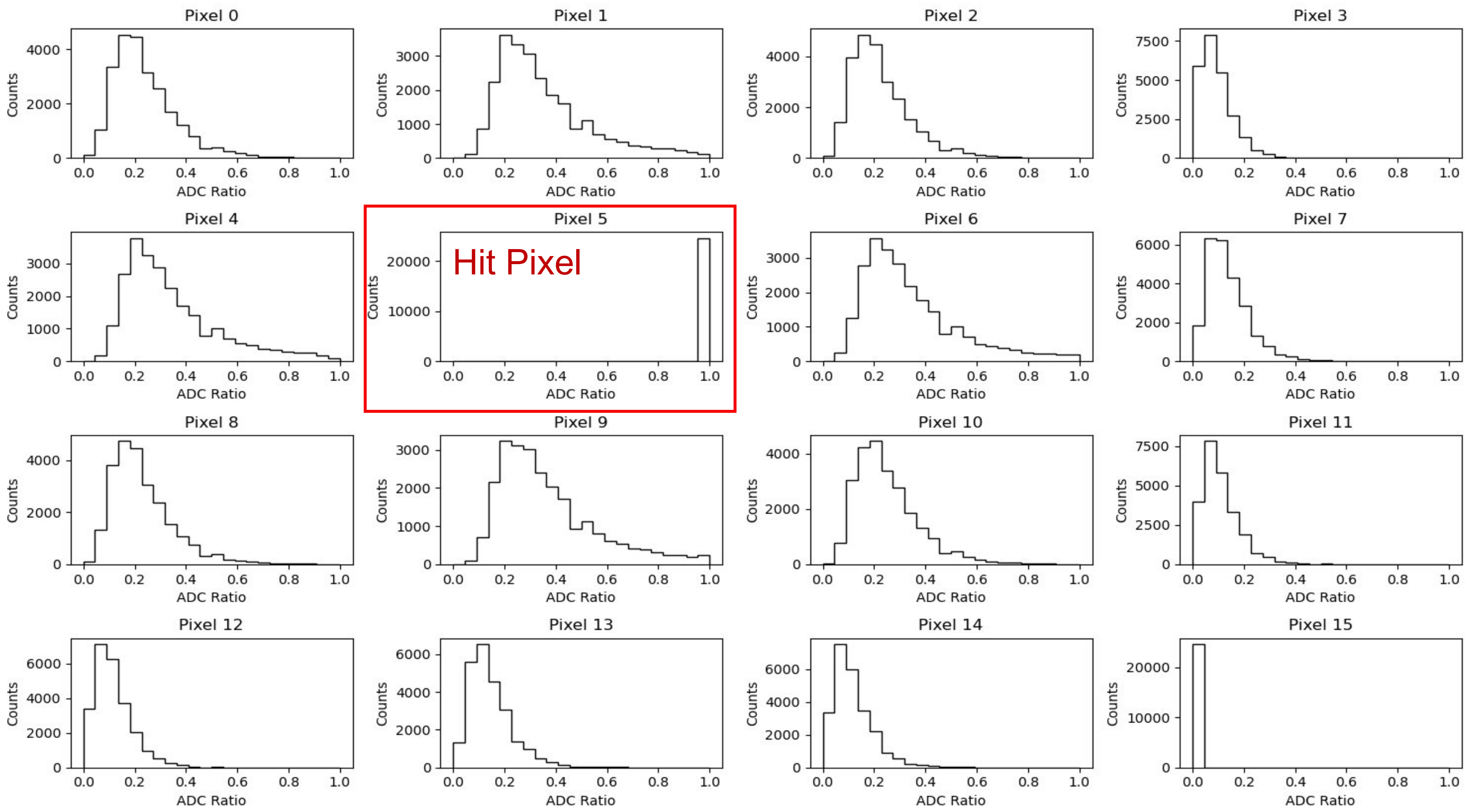


Fig.: Normalized ADC distribution w.r.t. Pix 05 for hit in Pix 05.

#The first neighbors show more tailing, and it reduces for pixels away from the hit pixel..

Charge sharing using MPV from Landau Fit

- **Event Selection: Hitbit for Pix 5=1 and Pix 5 with Max Amp after Pedestal subtraction.**
- **Landau Fitting to ADC distribution Normalized w.r.t. amplitude in Pix #05.**

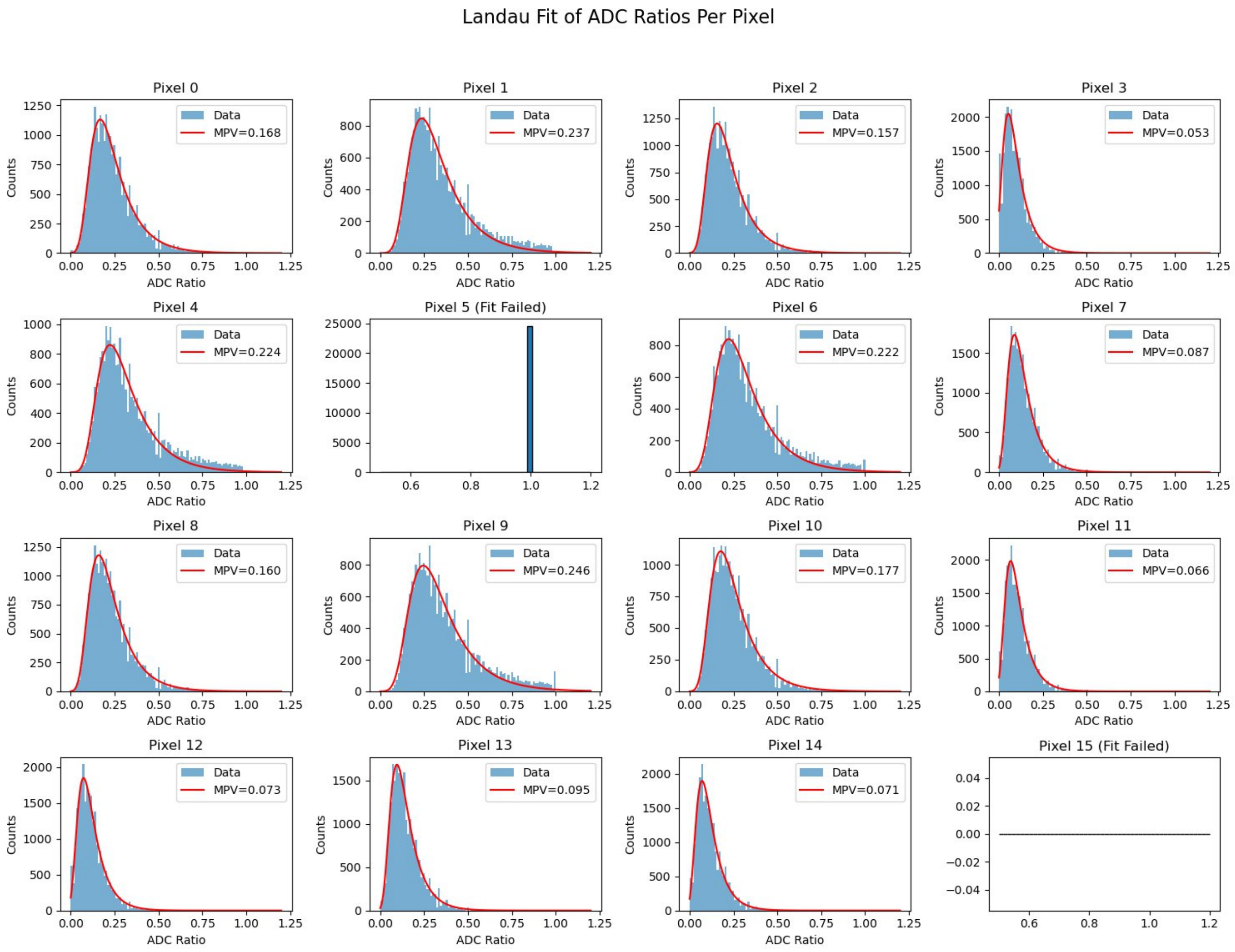
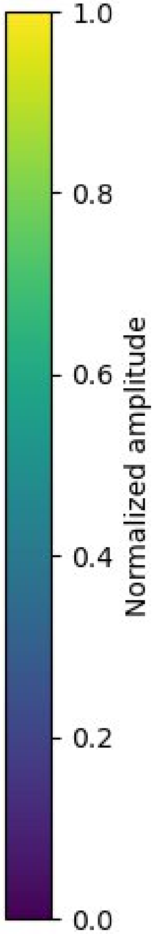


Fig.: Charge Sharing ratio for hit in Pix 05.



Charge sharing:
~23 % for first neighbors
~ 16% for first diagonal neighbors.

Fig.: Landau Fit to Normalized ADC distribution for hit in Pix 05. Fit is represented in red color.

Comparison between Pix0, Pix5 and Pix9 as hit pixels

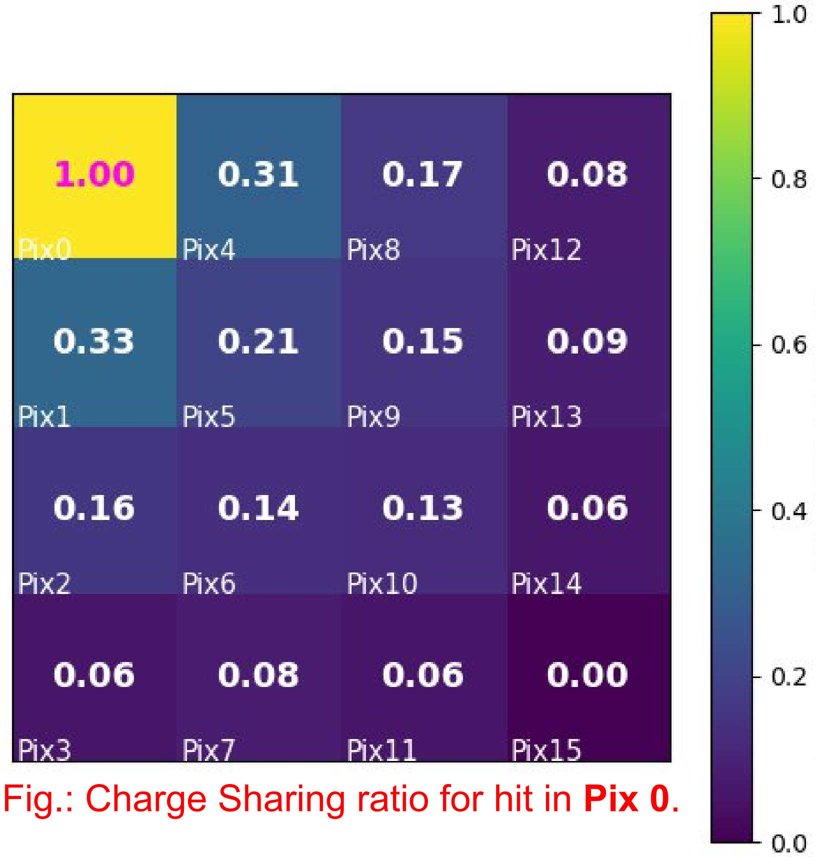


Fig.: Charge Sharing ratio for hit in **Pix 0**.

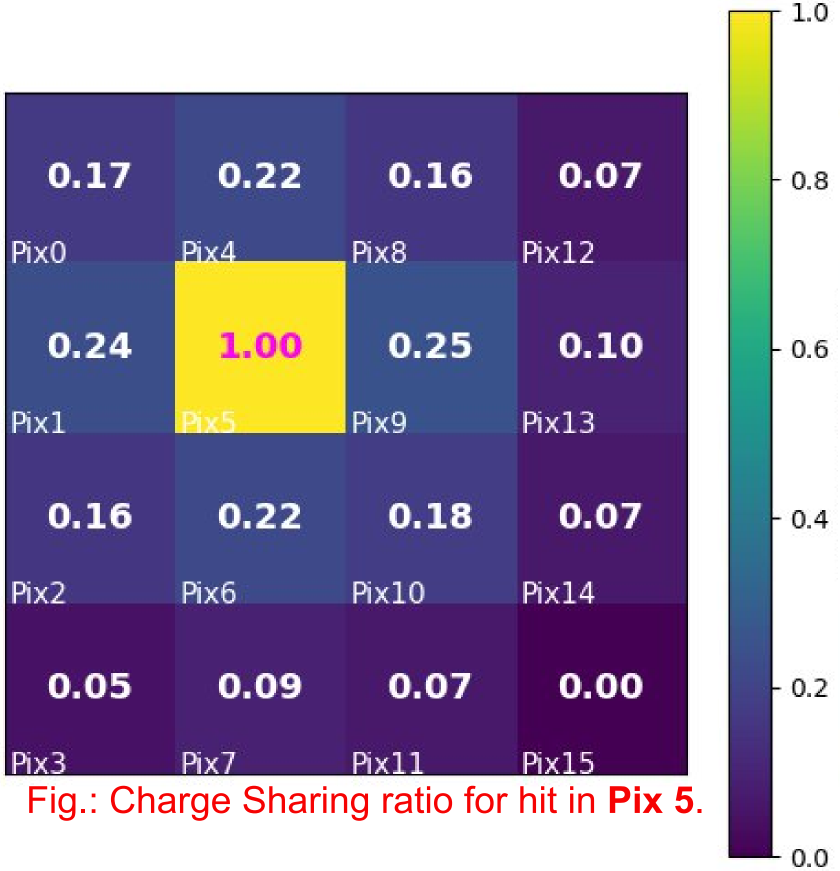


Fig.: Charge Sharing ratio for hit in **Pix 5**.

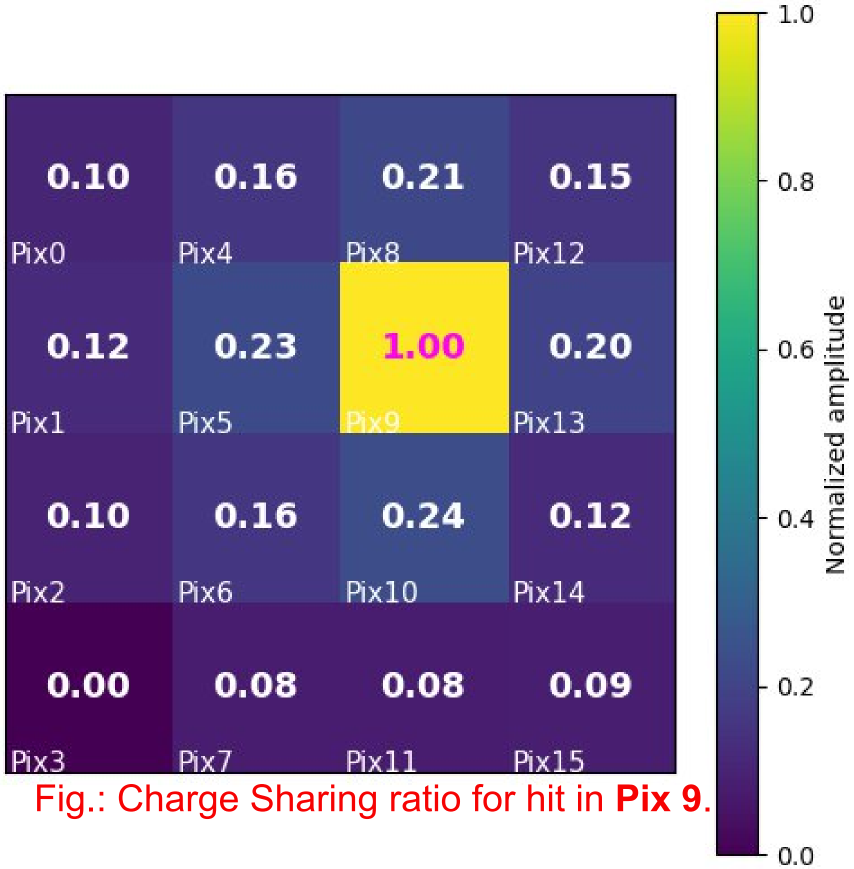


Fig.: Charge Sharing ratio for hit in **Pix 9**.

- For central hit pixel Charge sharing is ~23 % for I neighbors ~ 16% for I diagonal neighbors. For edge hit pixel Charge sharing is ~32 % for I neighbors.
- For all cases, diagonals have approximately 60 % of the charge sharing as compared it direct neighbor, as expected.

Conclusions

- ✓ Beta source measurements performed with BNL 4x4 pixelated sensor Wire-Bonded to EICROC0 ASIC.
- ✓ 95 % of the events are cut with event selection cut (hit bit =1 in pixel of interest and has max amplitude).
- ✓ For pedestal subtraction, the far pixel chosen, which almost never crosses the threshold (implying corresponds to the noise).
- ✓ The analysis shows consistency with the scope data, while the method is more reliable.
- ✓ Charge sharing studied using Landau fitting.
- ✓ For central hit pixel Charge sharing is ~23 % for first neighbors ~ 16% for first diagonal neighbors. For edge hit pixel Charge sharing is ~32 % for first neighbors ~ 20 % for first diagonal neighbors.
- ✓ For all cases, diagonals have approximately 60 % of the charge sharing as compared to direct neighbor.

Future perspectives

- ➢ Further analysis Ongoing to determine charge sharing in all pixels and timing resolution.
- ➢ Ongoing measurements to acquire data for more statistics.
- ➢ Exhaustive study of all the sensor boards (BNL Flip Chip + BNL and HPK Wire-Bonded). (Future: Flip Chip Sensor without metallization for LASER setup)
- ➢ LASER setup completed; measurements commenced to investigate detector position and timing resolution.

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