The Performance of the AstroPix Sensor: Bench Test and Beam Test

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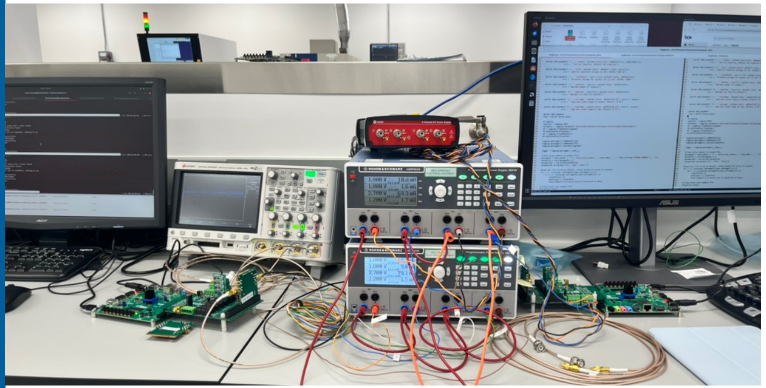
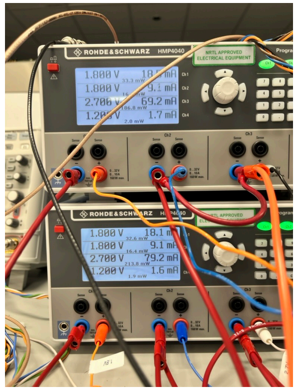
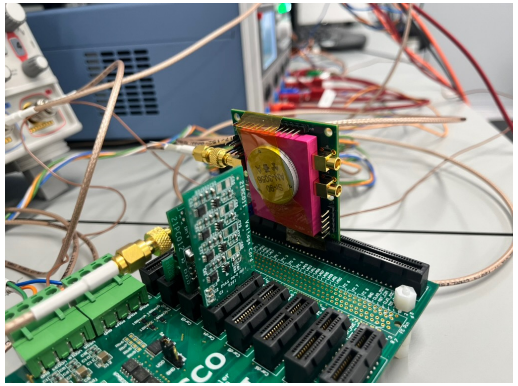
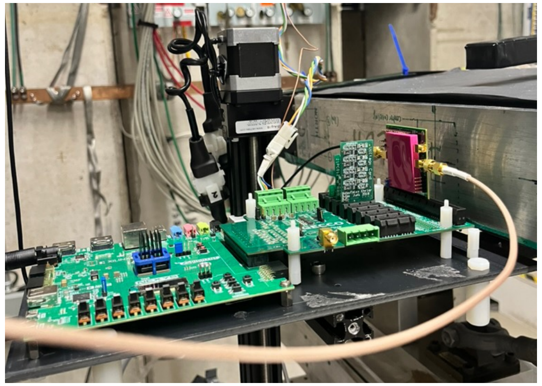
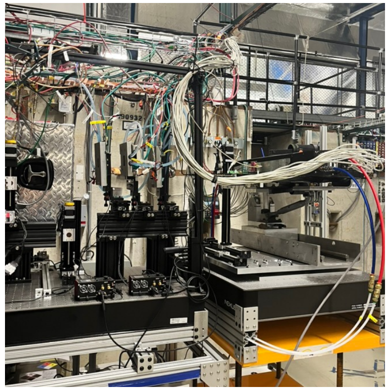
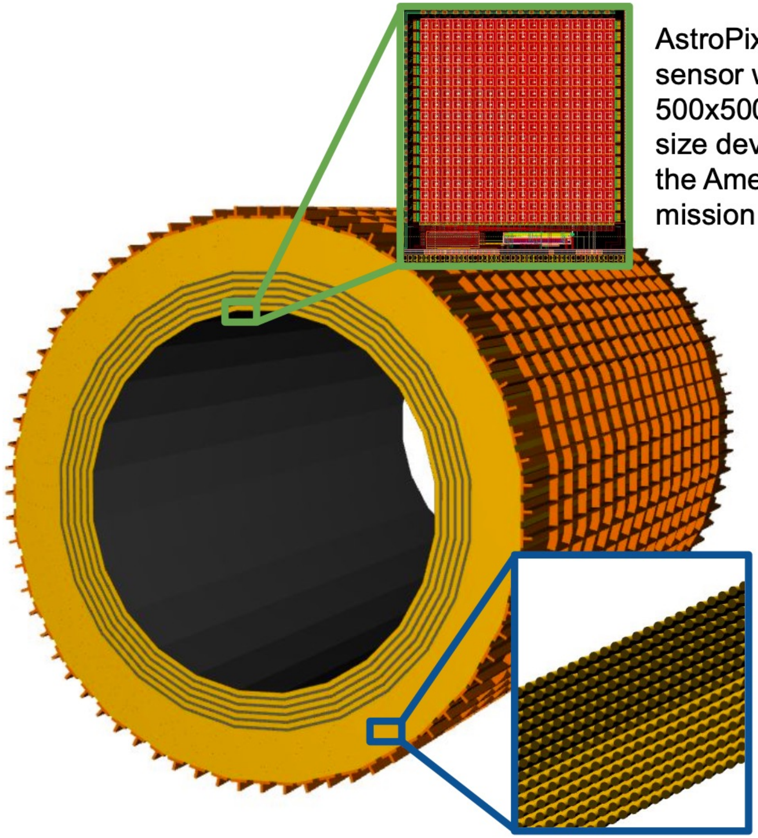
Contents

- Astropix Sensor
- Bench Test at ANL
  - Noise scan result
  - Injection scan result
  - Source test result
- Beam Test at FANL: 120 GeV proton
  - Astropix sensor
  - Astropix + Baby bcal
  - Double layer using Astropix sensor
- Summary

Barrel Imaging Calorimeter in EIC detector



- The electromagnetic calorimeter is the main detector for electron-pion separation in the barrel region.
  - Detection of electrons/photons to measure energy and position
- Requirements for Barrel EM Calorimeter
  - Require moderate **energy resolution** $(7-10)\%/\sqrt{E} \oplus (1-3)\%$
  - Require **electron-pion separation up to 10^4** at low momenta in combination with other detectors
  - Discriminate between **π^0 decays and single ɣ up to ~ 10 GeV**
  - **Low energy photon** reconstruction ~ 100 MeV
- 4(+2) layers of Astropix sensors interleaved with the first 5 Pb/SciFi layers
- Followed by a **large section of Pb/ScFi section**
- Total radiation thickness ~ 17.1 X_0 at η=0
- Sampling fraction ~ 10%

R&D goals for FY24

- Commissioning and characterizing a small Pb/SciFi calorimeter prototype, termed Baby BCAL, using mixed electron/pion and proton beams at the Fermilab Test Beam Facility (FTBF)
- Testing the first integration of the AstroPix v3 single chip with the Pb/SciFi system and the double layer using Astropix v3 single chips

Astropix sensor: Introduction

AstroPix R&D for BIC

- v3: Application in larger NASA payloads
  - Not final version for BIC
  - Single chip and quad chip: under test at ANL
- v4: Currently under test in NASA
- v5: Just submitted engineering run in mid June
  - For use in BIC
  - Similar to AstroPix v3

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<tr><th>v3</th><th>v4</th><th>v5</th></tr>
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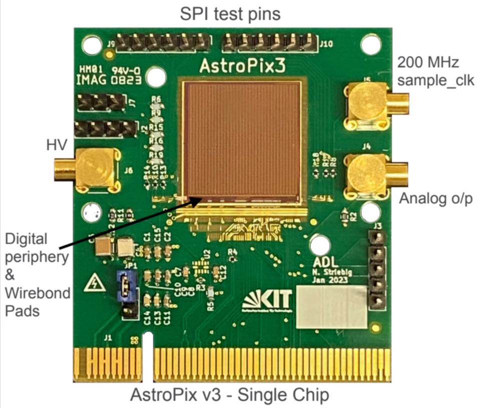
<td>
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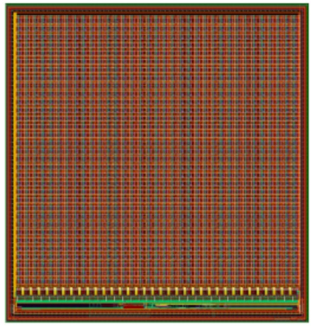
<td></td>
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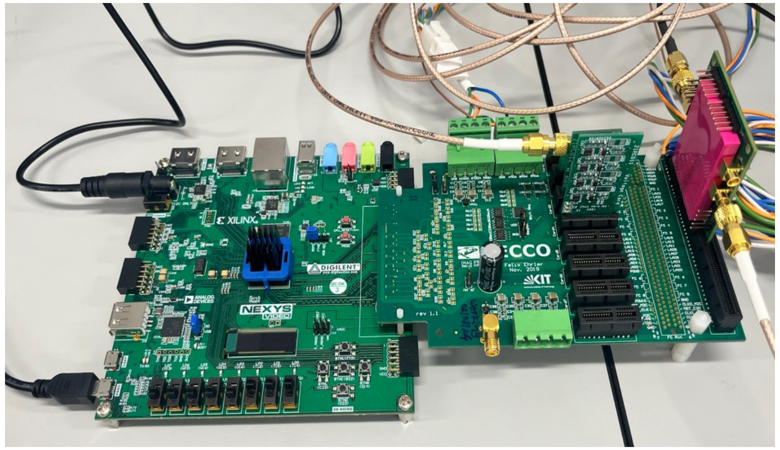
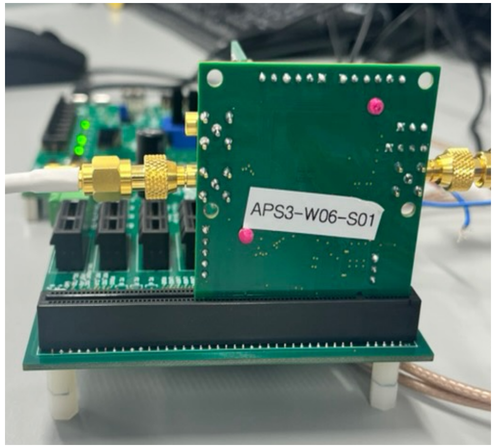
<tr>
<td>• Full size 2 x 2 cm^2 array
• 500 x 500 µm^2 pixel pitch
• 35 x 35 pixels</td>
<td>• 1 x 1 cm^2 array
• 500 x 500 µm^2 pixel pitch
• 16 x 13 pixels</td>
<td>• Full size 2 x 2 cm^2 array
• 500 x 500 µm^2 pixel pitch
• 35 x 33 pixels</td>
</tr>
</table>

AstroPix v3 single chip

- 2×2 cm^2 -size with 35 × 35 pixel matrix, 500 µm × 500 µm pixel pitch, 720 µm thickness
- Very low power dissipation < 1.5 mW/cm2
- The good energy resolution (< 10% @ 60 keV)
- Timestamp clock: 2 MHz (500 ns), 8-bit (0-255)
- ToT (Time over Threshold) clock: 200 MHz (5 ns), 12-bit (0-4,096)
- 10-byte data frame per hit
  - Header including Layer ID
  - 5 Bytes of hit information from sensor (chip ID, pixel location, time stamp, Time over threshold)
  - 4 Bytes of FPGA timestamp

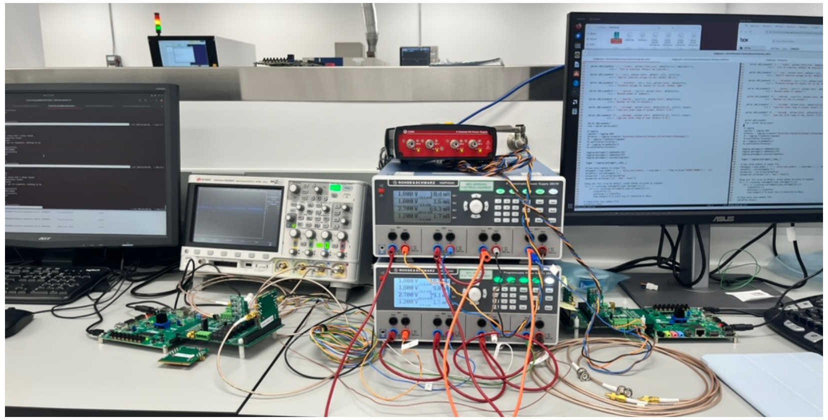


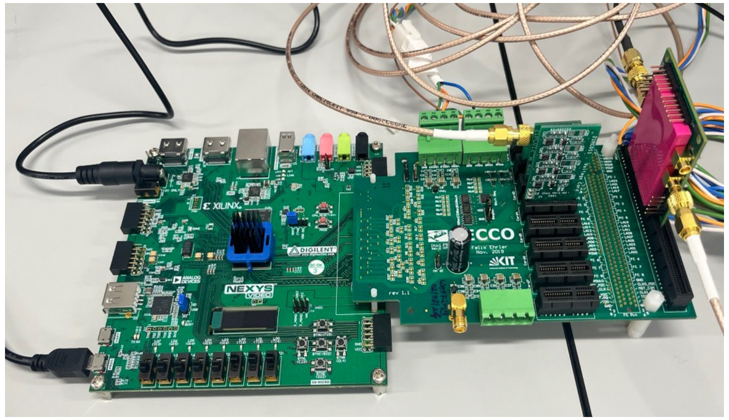


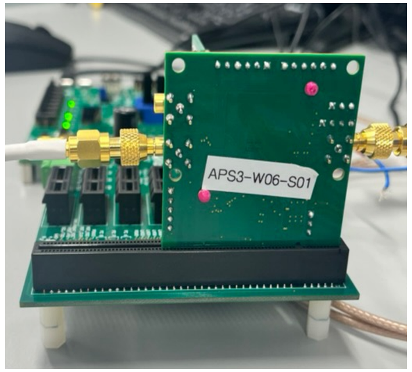
R&D Goal

- M2: AstroPix chips prepared at the bench

1-1. Noise Scan
with respect to threshold



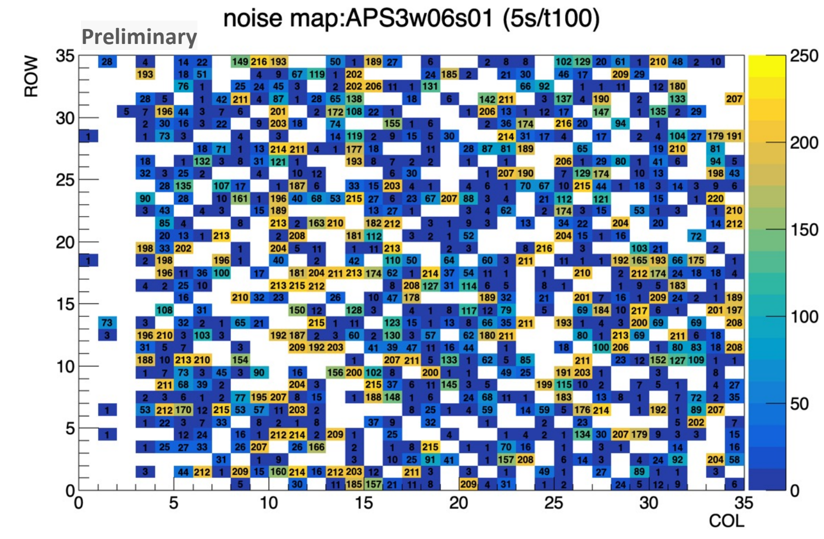




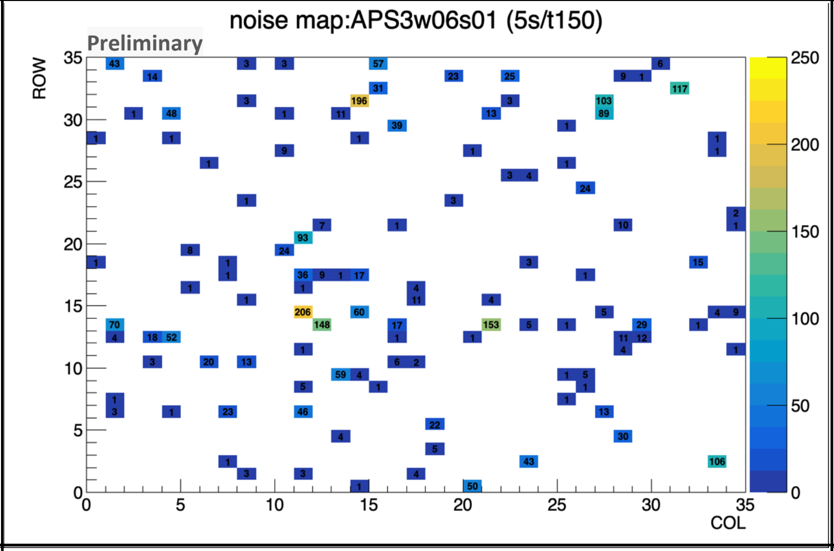
- Used Astropix v3 single chips: APS3w06s01
- Bias voltage: - 150 V
- LV supply
  - Digital and analog: 1.8 V
  - Gecco board: 2.7 V
  - Amplifier: 1.2 V
- Time windows: 5 secs
- Threshold: 100, 150, 175, 200, 250, and 300 mV

Noise Scan with respect to threshold [100 mV – 300 mV]

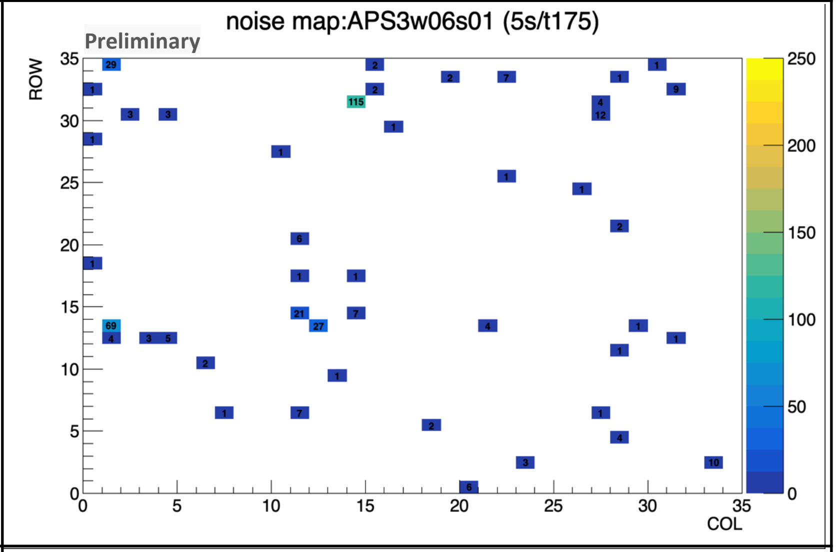
100 mV



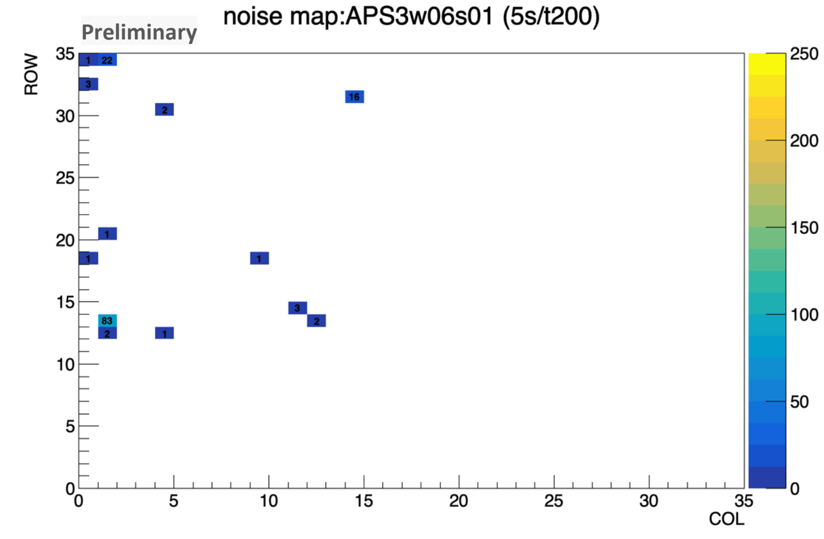
150 mV



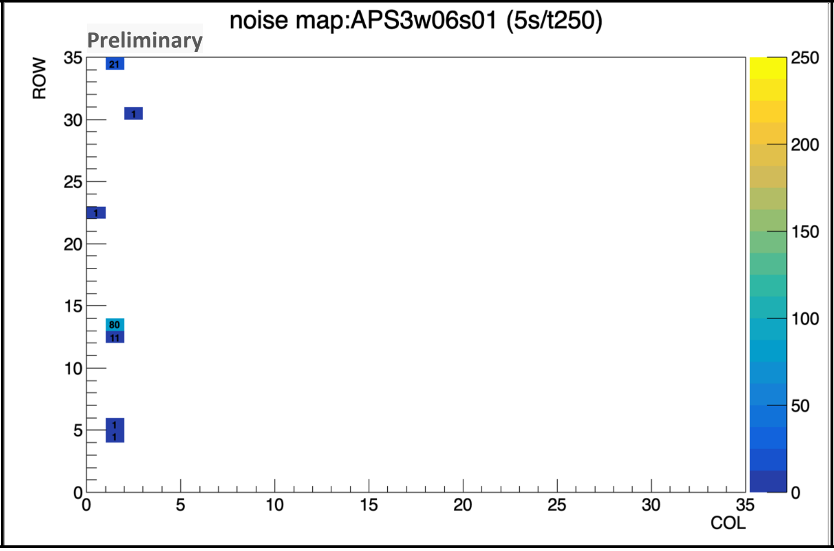
175 mV



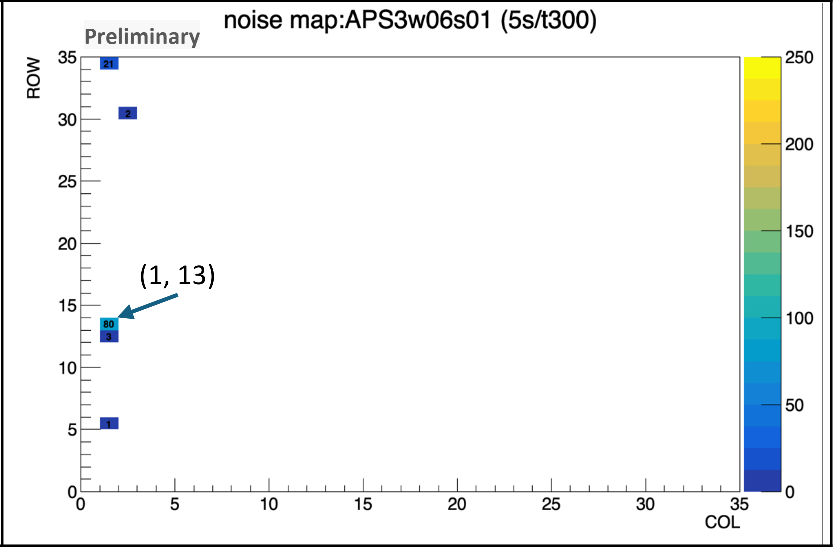
200 mV



250 mV



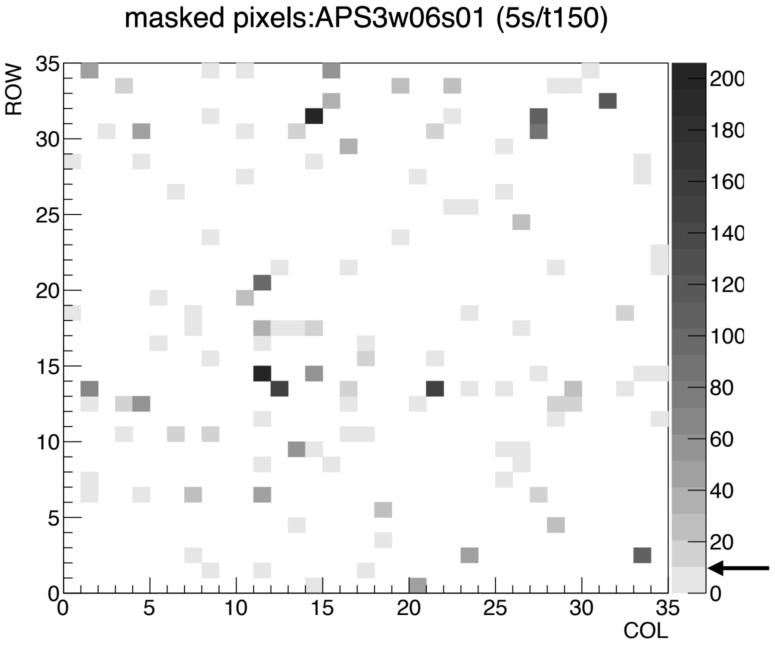
300 mV



Noise Scan: Masked Pixels

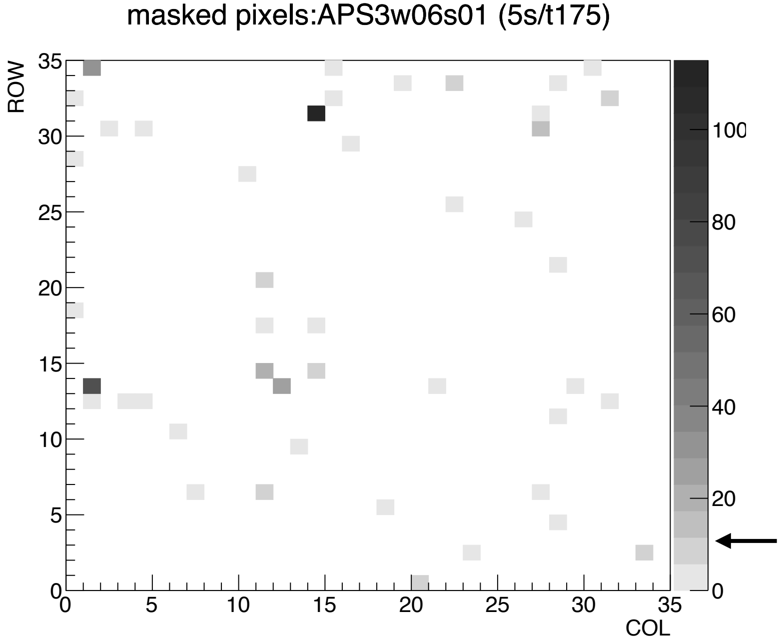
- Disable pixel : Noise > 10
- Used 200 mV threshold for source test and beam test

V_{th}= 150 mV



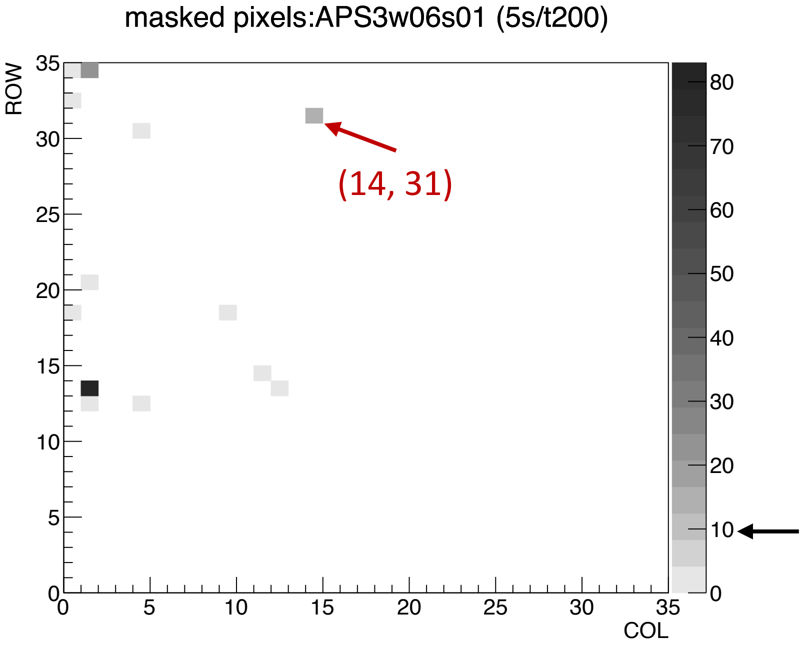
- Active pixels: ~ 96.5%
- 43/1225 pixels are disable.

V_{th}= 175 mV



- Active pixels: ~ 99.5%
- 6/1225 pixels are disable.

V_{th}= 200 mV



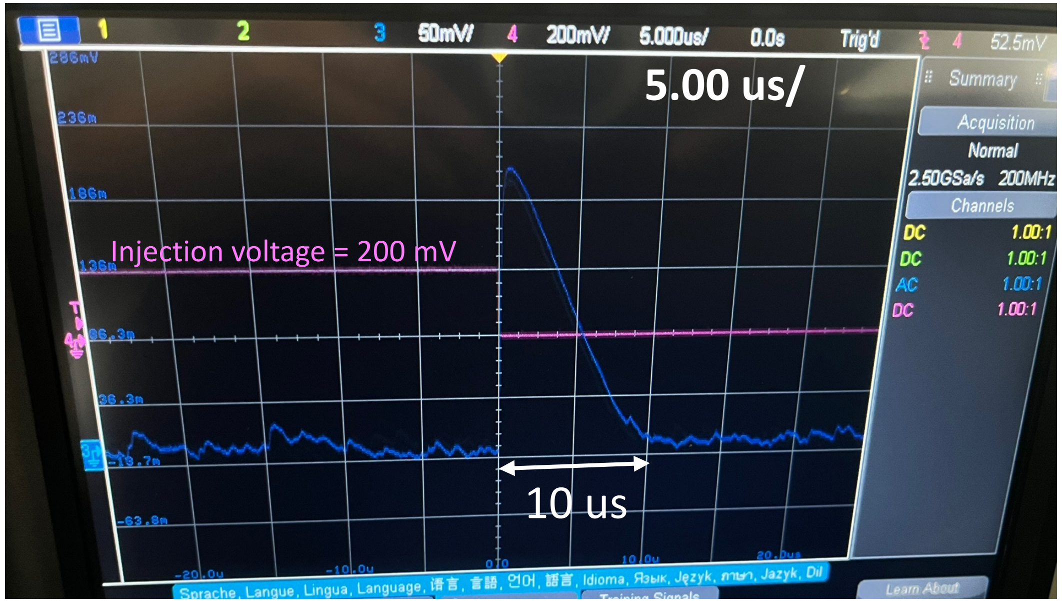
- Active pixels: ~ 99.8%
- 3/1225 pixels are disable.

→ Masked noisy pixel (14, 31)

R&D Goal

- M2: AstroPix chips prepared at the bench

1-2. Injection Scan

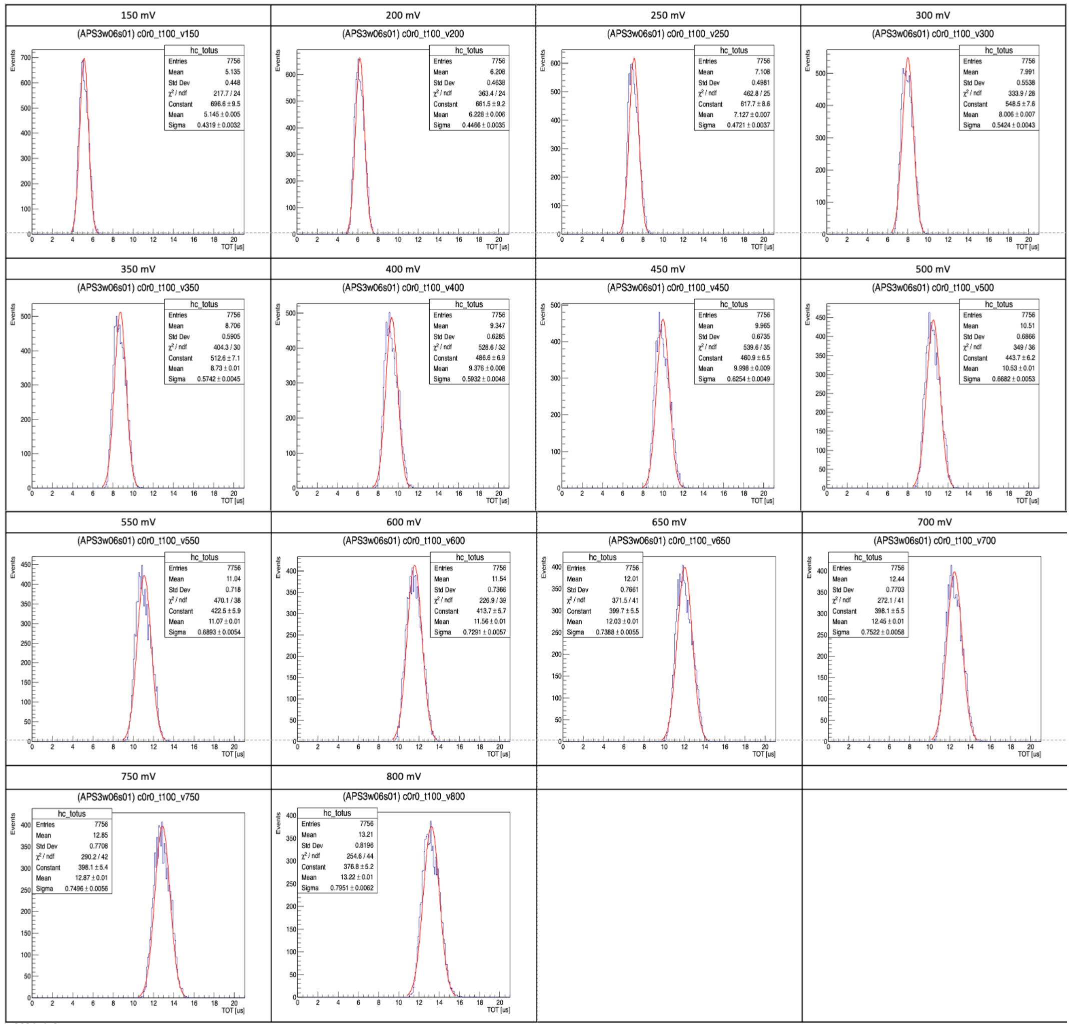


- Used Astropix v3 single chips: APS3w06s01
- Bias voltage: - 150 V
- LV supply
    - Digital and analog: 1.8 V
    - Gecco board: 2.7 V
    - Amplifier: 1.2 V
- Threshold: 100 mV
- With respect to injection voltages at (COL #, ROW #)
    - Column (0, 1, 2, 3, 4, 5, 6) & Row 0
    - 150 mV – 800 mV in steps of 50 mV
    - Time windows: ~ 90 secs for 1k events

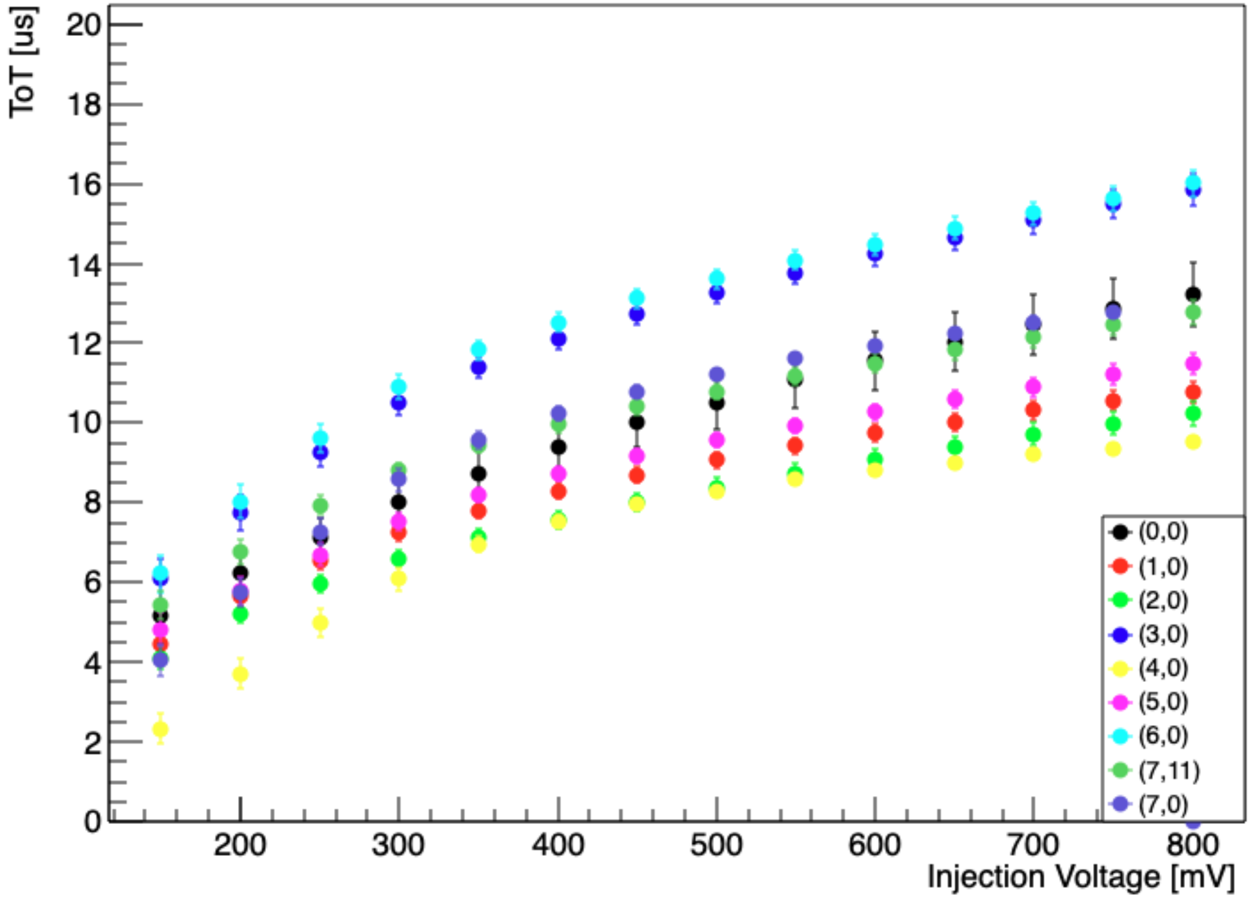
Injection Voltage vs ToT [us]

- Column (0, 1, 2, 3, 4, 5, 6) & Row 0
- ToT [us] as a function of injection voltages from 150 mV to 800 mV in steps of 50 mV.
- Fitting using gaussian function then mean and sigma values from fitting results are plotted.

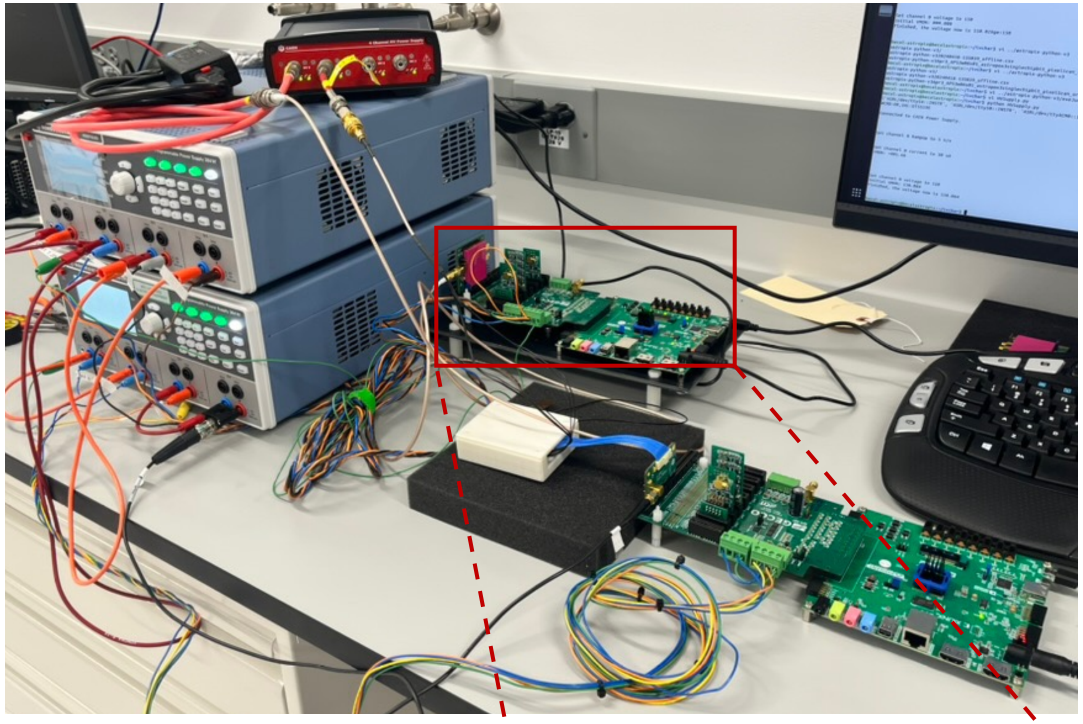
- ToT spectra w.r.t various injection voltages at pixel (0, 0)



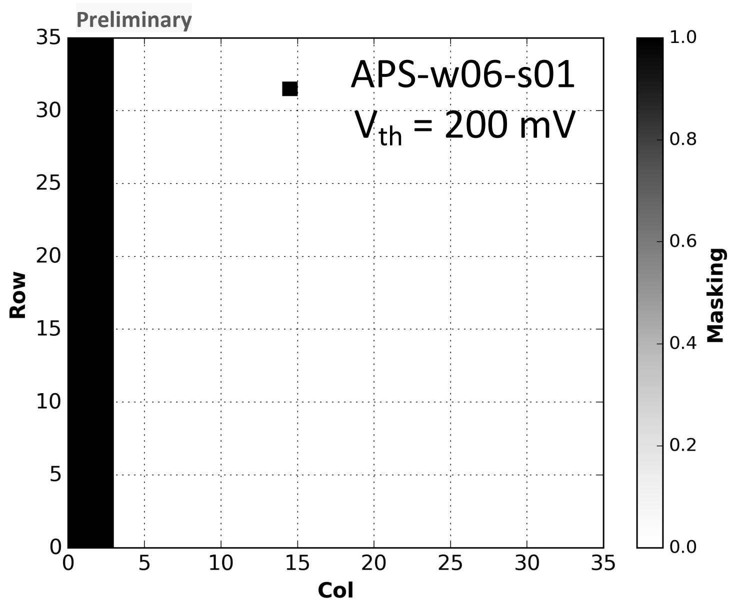
- ToT mean values as a function of various injection voltages

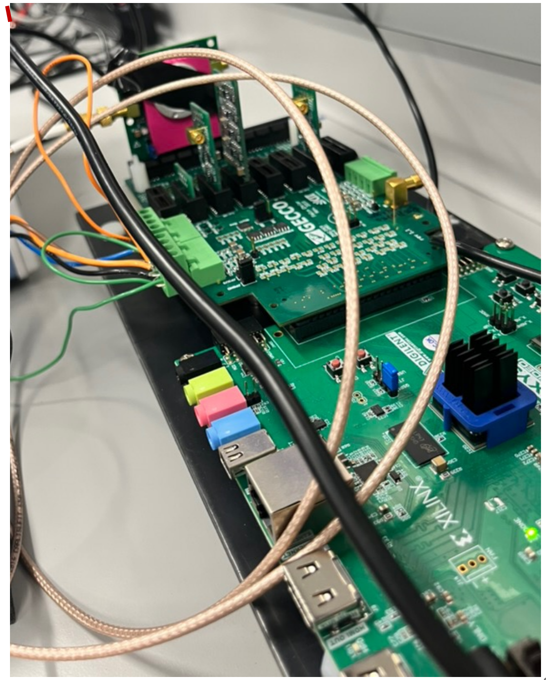


1-3. Source test using Am-241

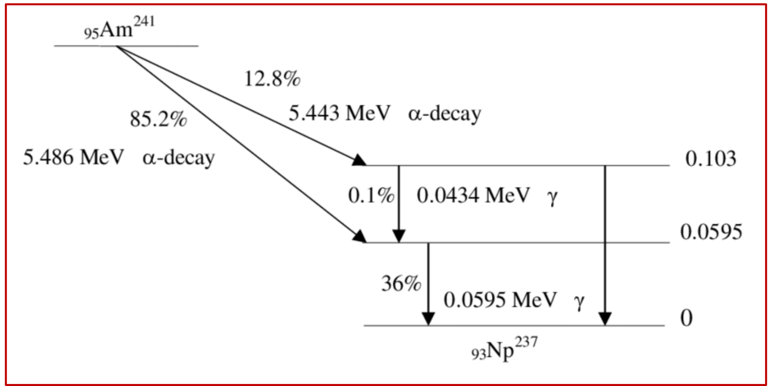


- Used Astropix v3 single chips: APS3w06s01
- Bias voltage: - 150 V
- LV supply
    - Digital and analog: 1.8 V
    - Gecco board: 2.7 V
    - Amplifier: 1.2 V
- Used threshold = 200 mV
- Masked first three column pixels





Am-241 Result: 32 × 35 pixels

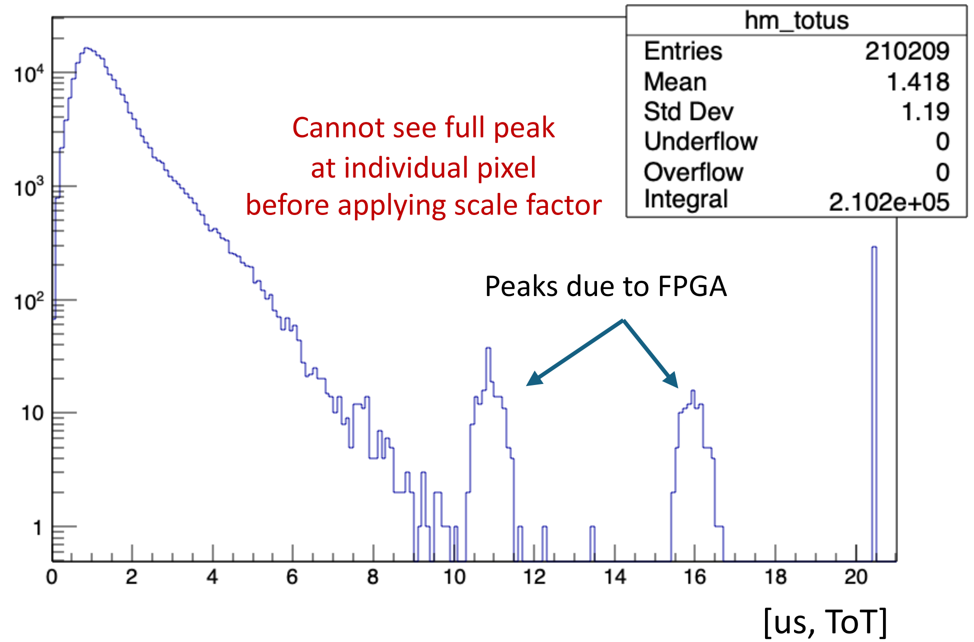


- Data-taking for 12 hours with 32 × 35 pixels (1,120 pixels)
- ToT distribution for all pixels after applying to scale factor (from proton result)
- Full peak, fitted with gaussian function

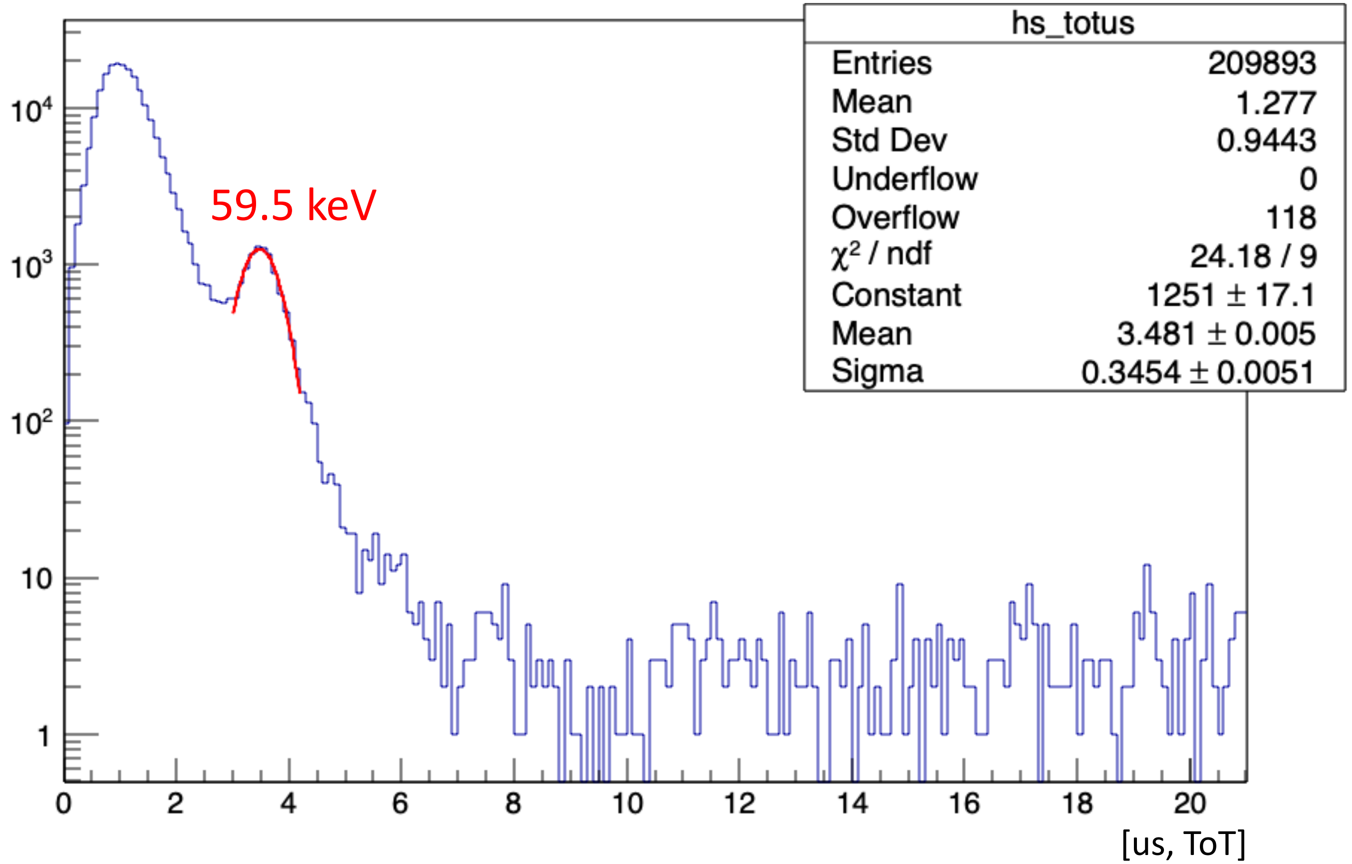
- A **calibration constant** is calculated:
  59.5 [keV] /3.481 [us, TOT]= 17.09 [keV]/[us, ToT]

- **E$_{res}$ (FWHM)** = $2.35 \times \frac{Sigma}{Mean}$ = 23.3 % @ 59.5 keV

ToT distribution of all pixels **before** applying scale factor

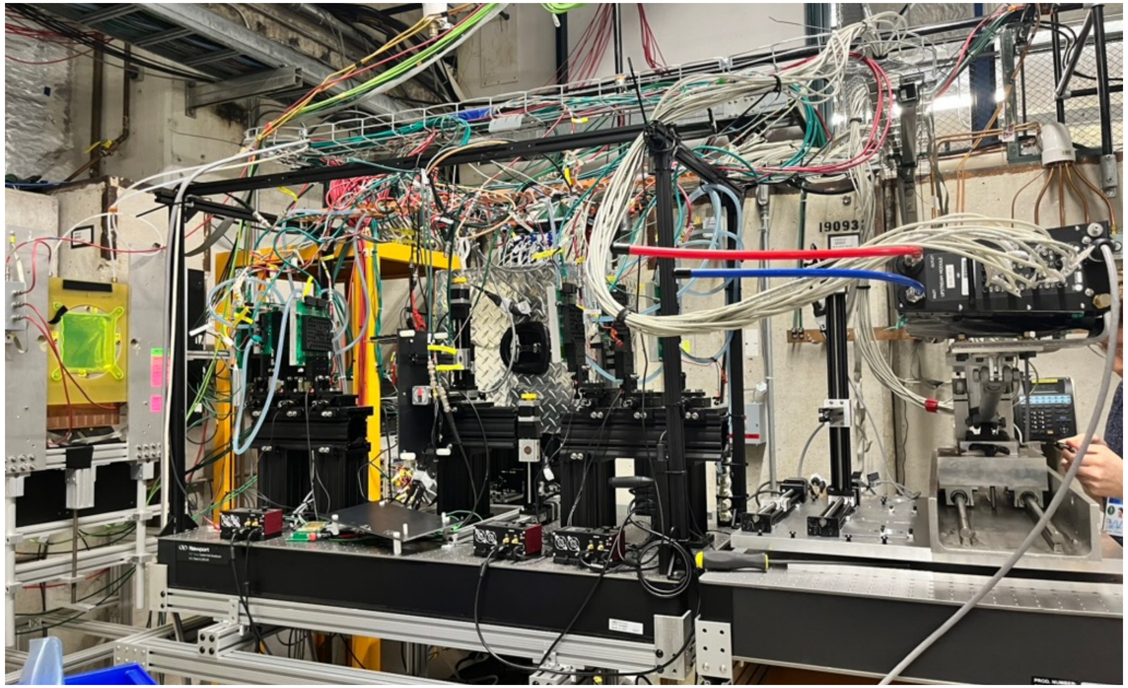


ToT distribution of all pixels after applying scale factor



Beam Test R&D Goal

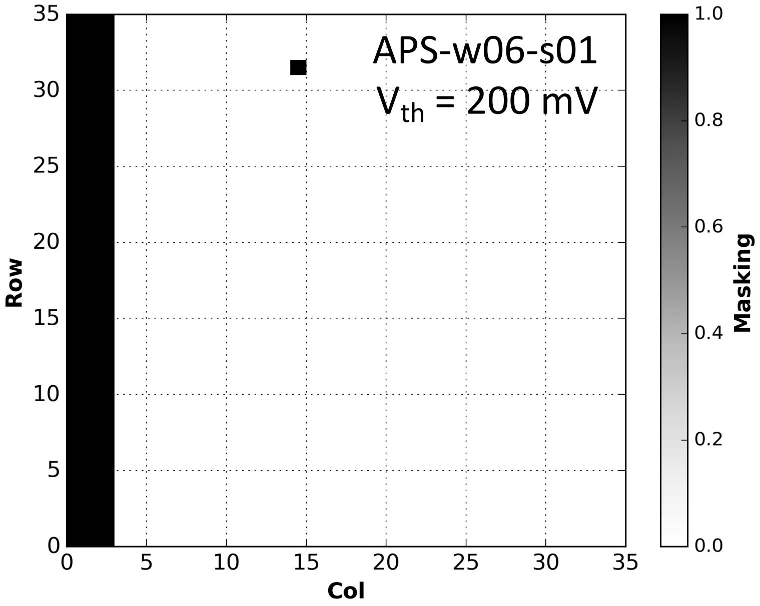
- M6: Integrated system commissioned with proton beam
  - Single AstroPix v3 chip with Baby BCal
  - Two AstroPix v3 chips daisy-chained



2. Beam Test at FNAL

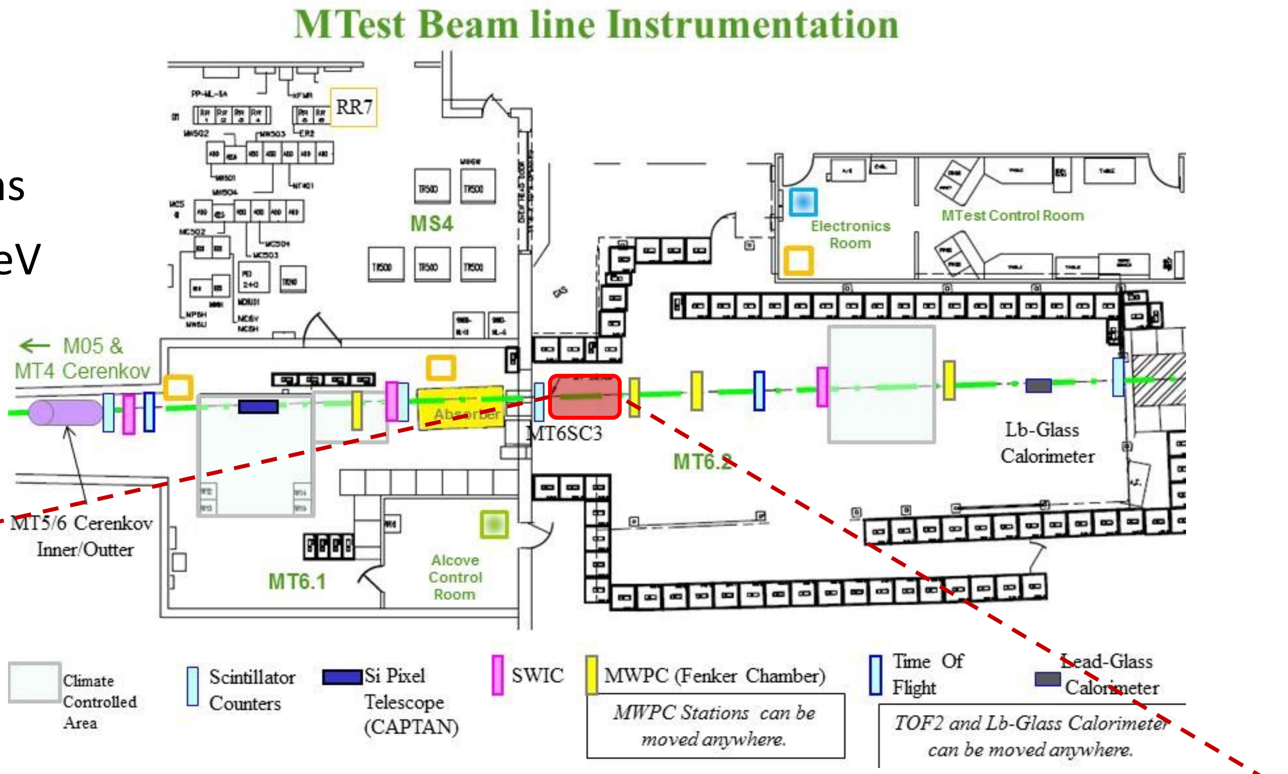
On June 13-18

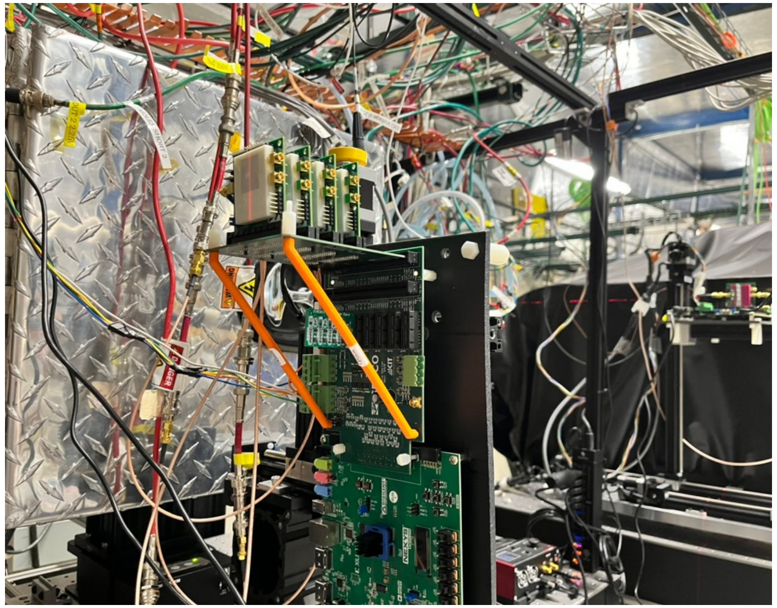
1. Single layer in front of Baby Bcal
   1. MIP response
   2. Astropix+Baby Bcal: coincident event
2. Double layer using two v3 single chips
   1. Coincident hits

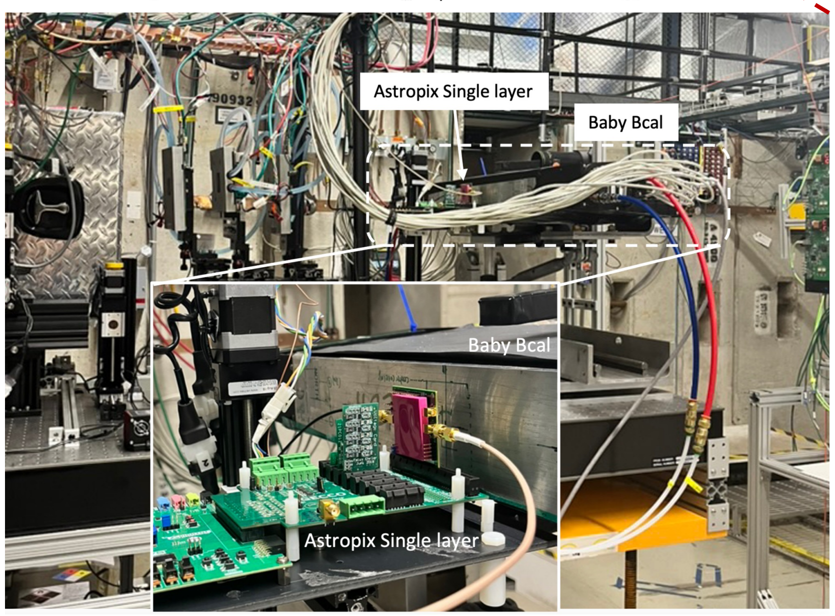


Beam Test Setup @FNAL

- ‘Mtest’ Beam line provides particles from 120 GeV protons to secondaries (electrons, muons, and pions) of ~ 200 MeV
  - Single 4.2 s long spill per every 60 seconds
- FNAL instrumentation system
  - Segmented Wire Ionization Chambers (SWICs); 2 mm wire spacing
  - Scintillator counter
  - Two Cherenkov detectors for PID

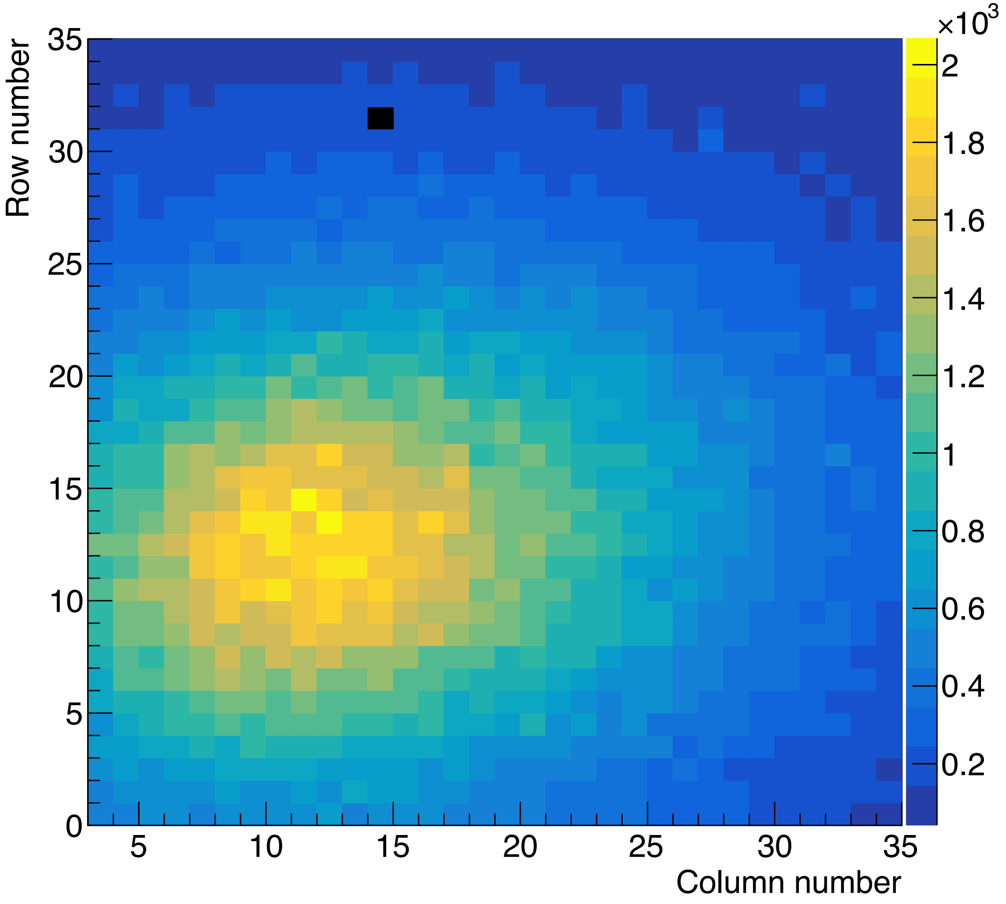


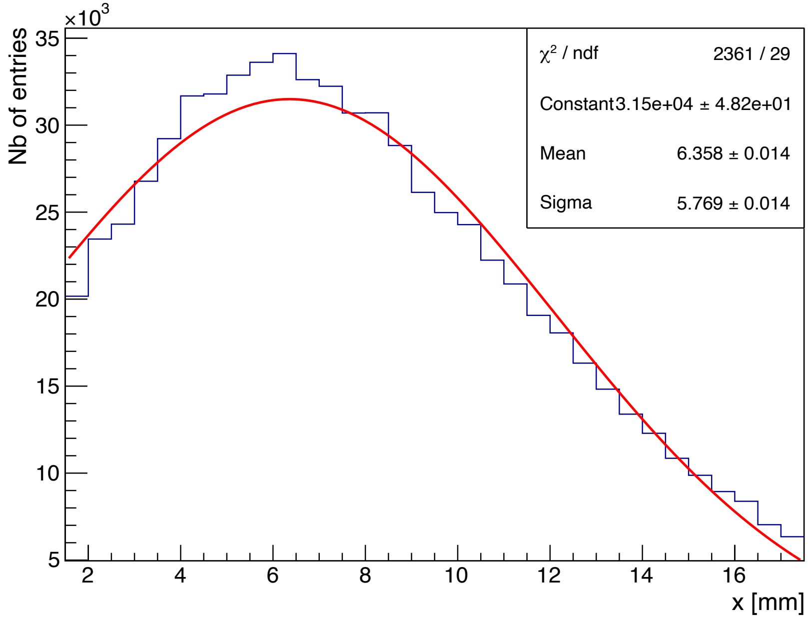


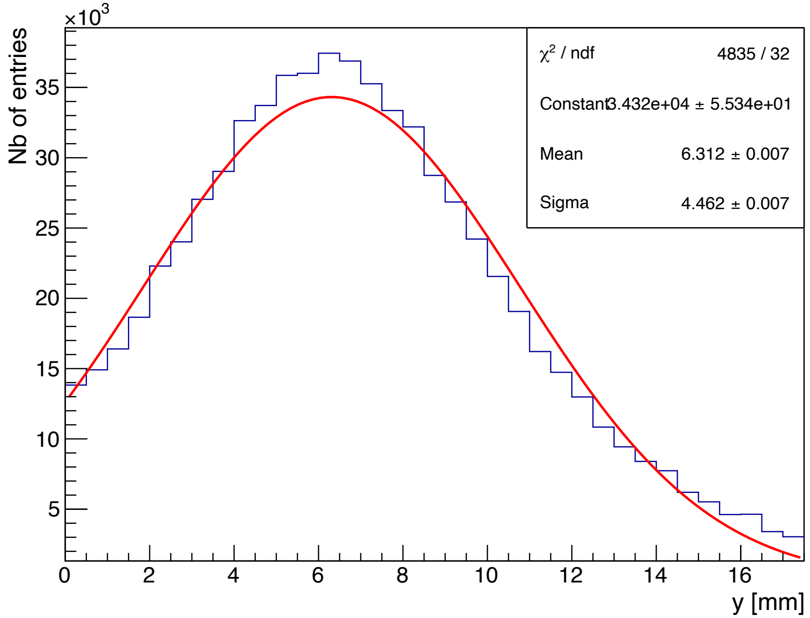


120 GeV Proton: Astropix, the beam profile

- The width of the beam profile is extracted from the beam hit map
- Position resolution: 500 um
- $\sigma_x \times \sigma_y$ = 5.8 mm × 4.5 mm

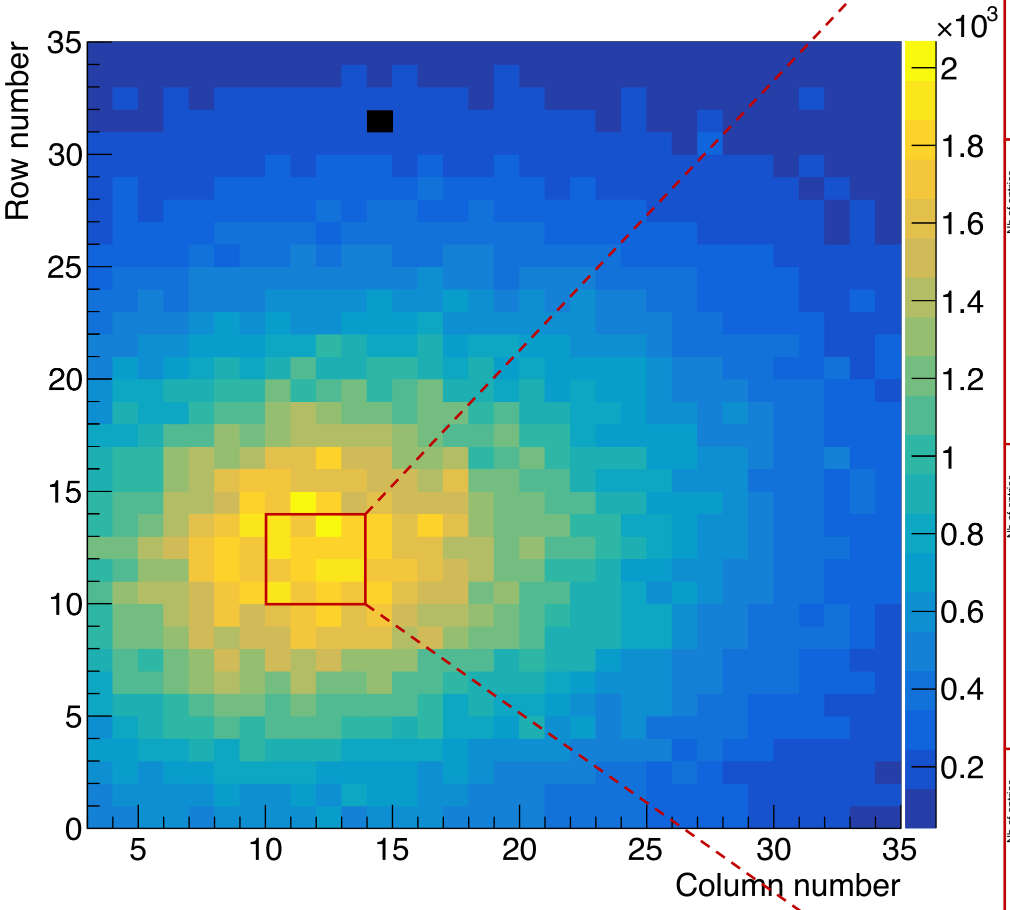


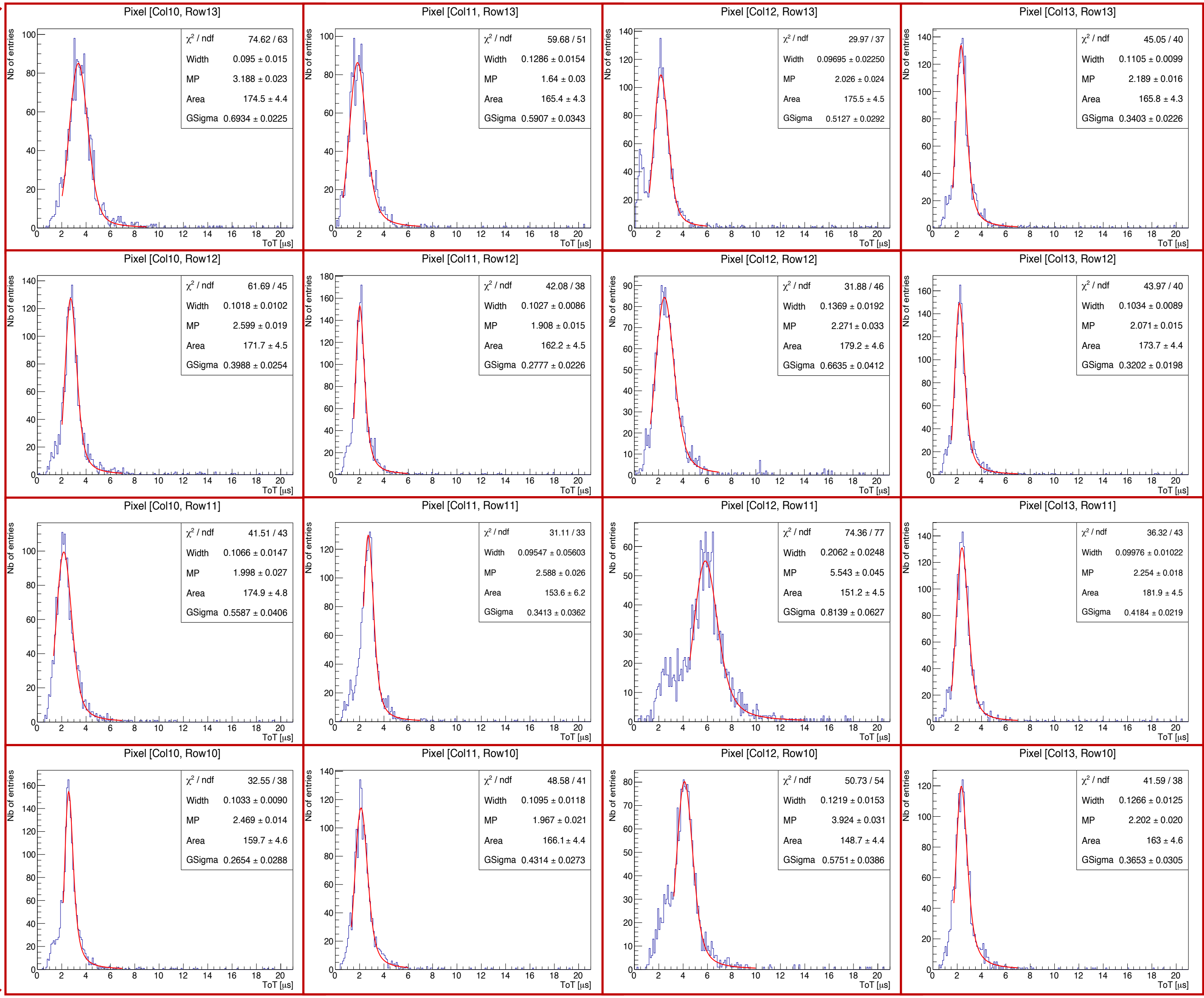




120 GeV Proton: Astropix, ToT Distributions of 4 × 4 pixels

- Fit with landau convoluted with gaussian function on ToT distribution



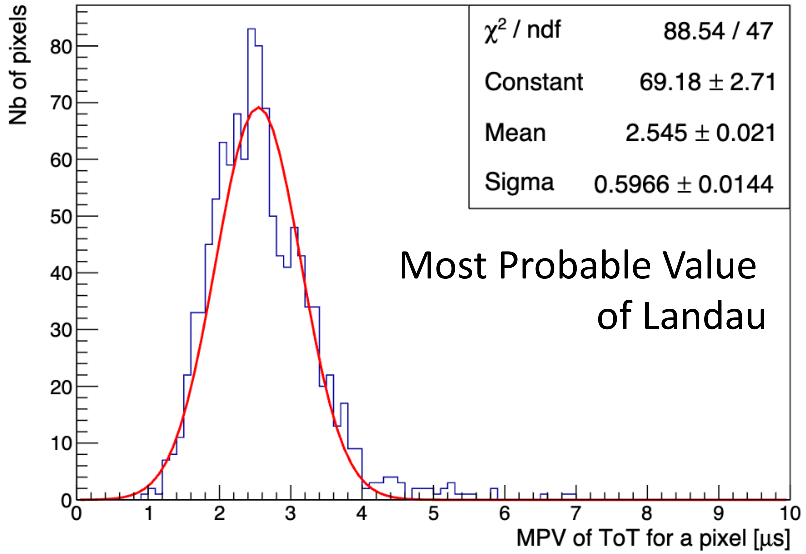


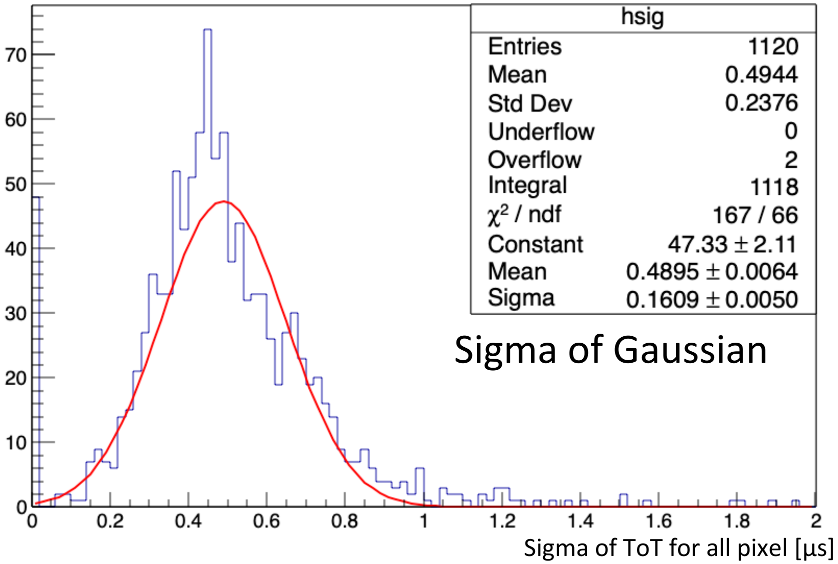
- 4 × 4
  - Col 10 – 13
  - Row 10 - 13

120 GeV Proton: Astropix, 32 × 35 pixels

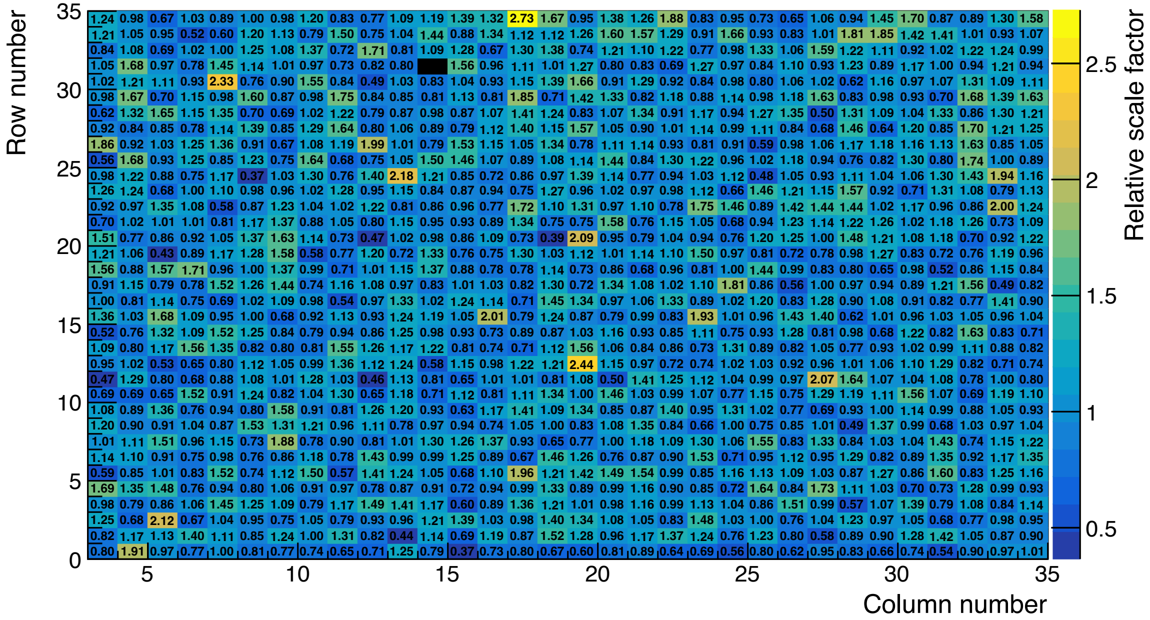
- 32 × 35 (1,120 pixels)
  - Col 3 – 24
  - Row 0 - 35

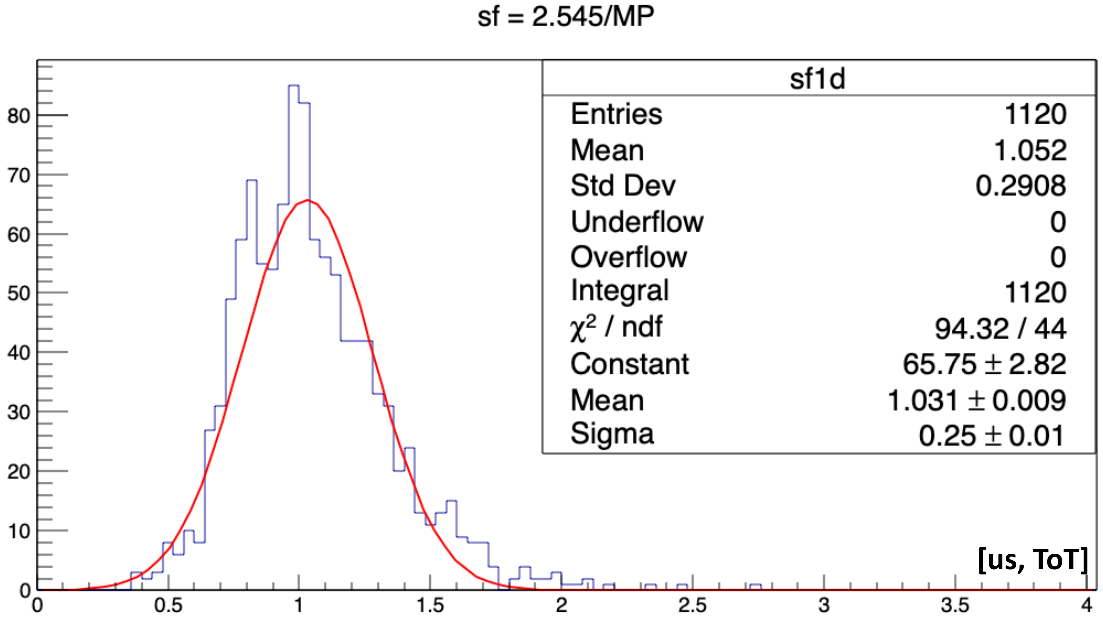
- Fit with landau convoluted with gaussian function on ToT distribution for all pixels





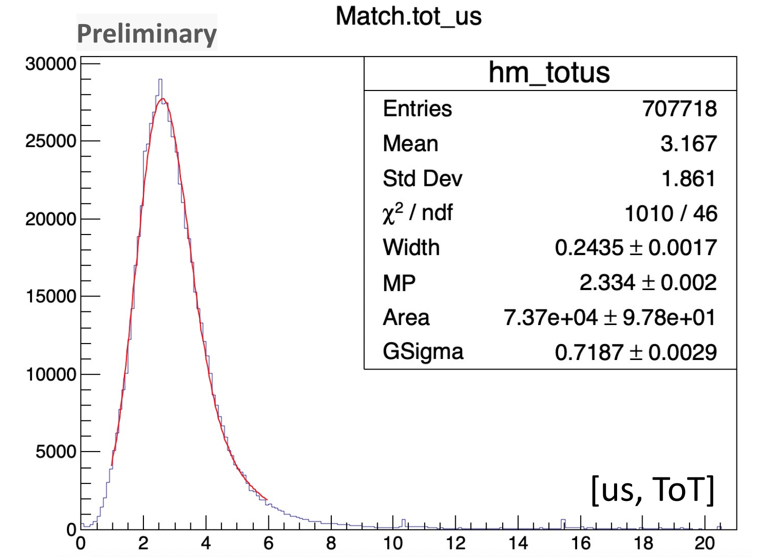
- Scale factor (sf), defined as mean of Most probable value for all pixels/Most probable value of each pixel

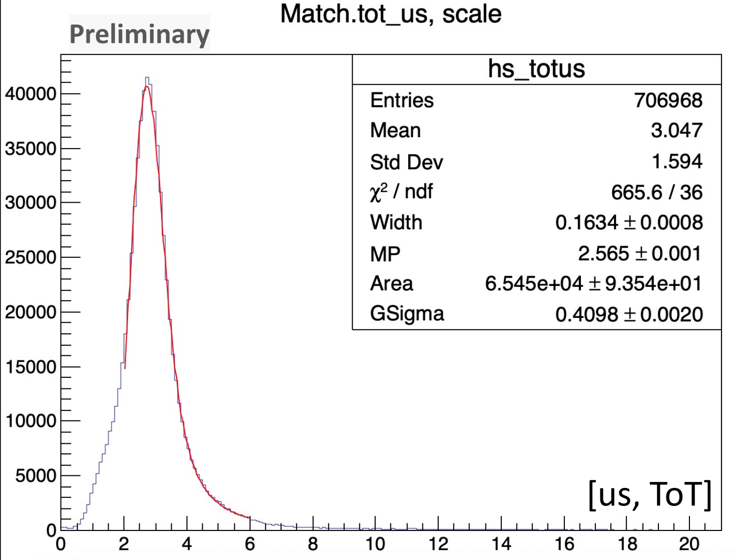


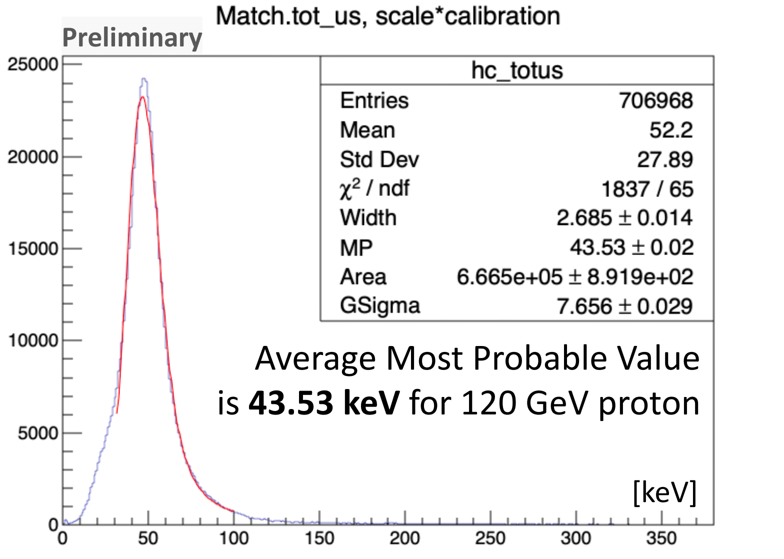


120 GeV Proton: Astropix, Energy Distribution of 32 × 35 pixels

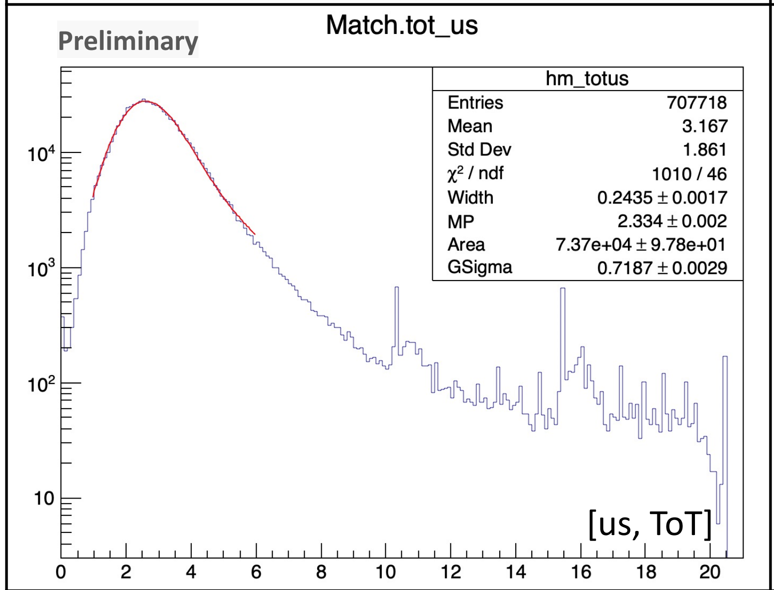
Before applying scale factor	After applying scale factor	After applying scale factor and calibration constant

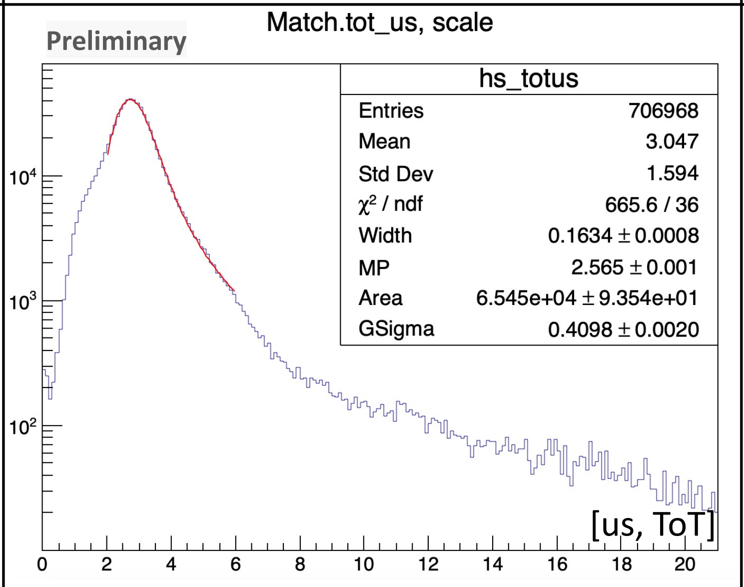


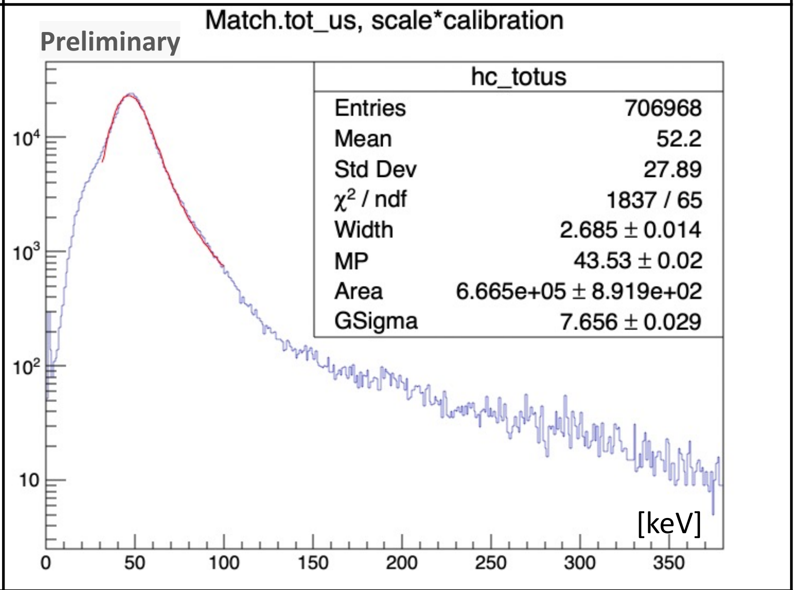




Average Most Probable Value is **43.53 keV** for 120 GeV proton

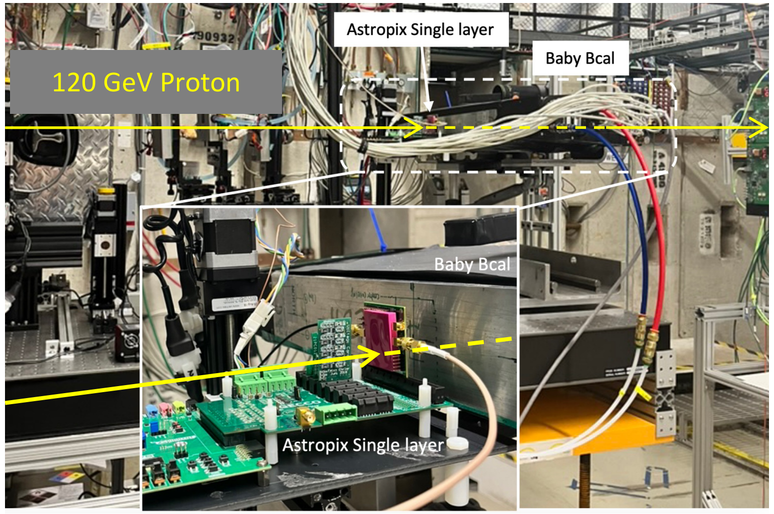


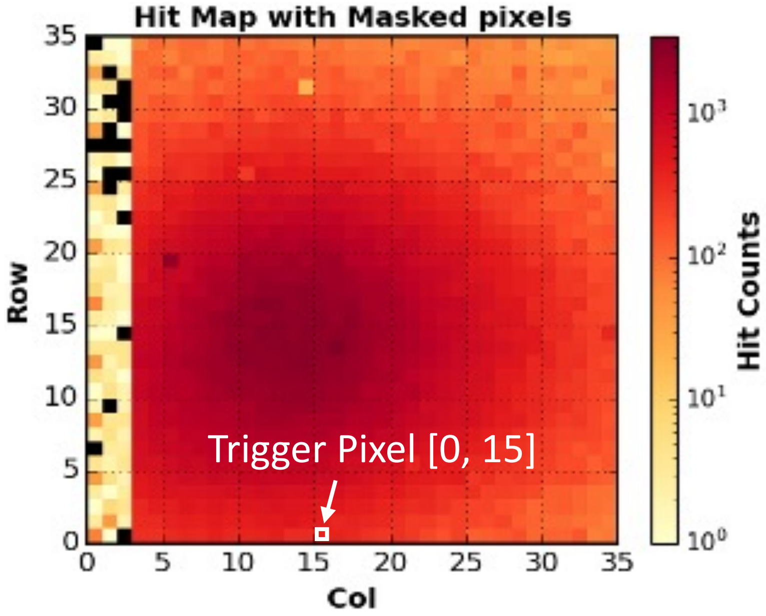




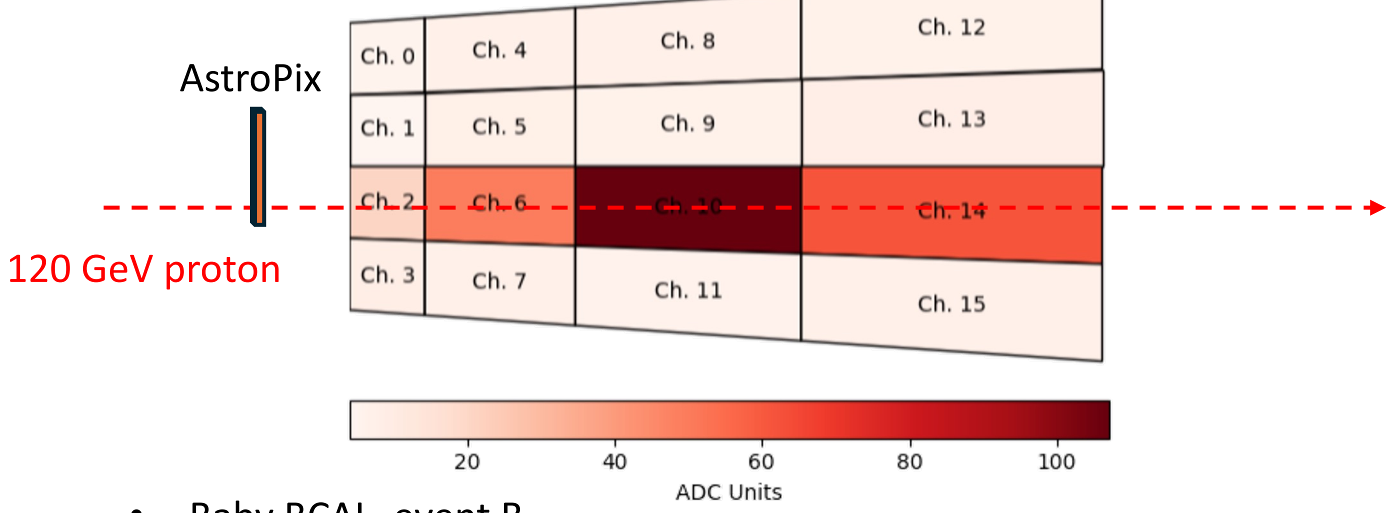
120 GeV Proton: Coincident Event Display of Baby BCAL and AstroPix

- Baby BCAL triggered by analog signal from [0, 15] pixel of Astropix

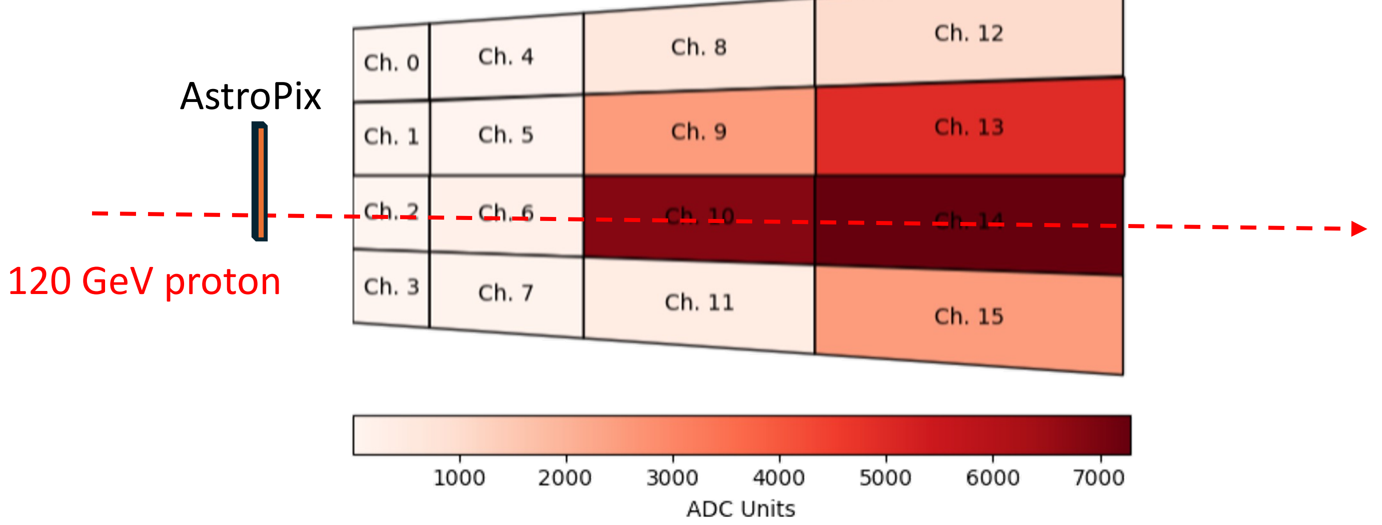




- Baby BCAL, event A

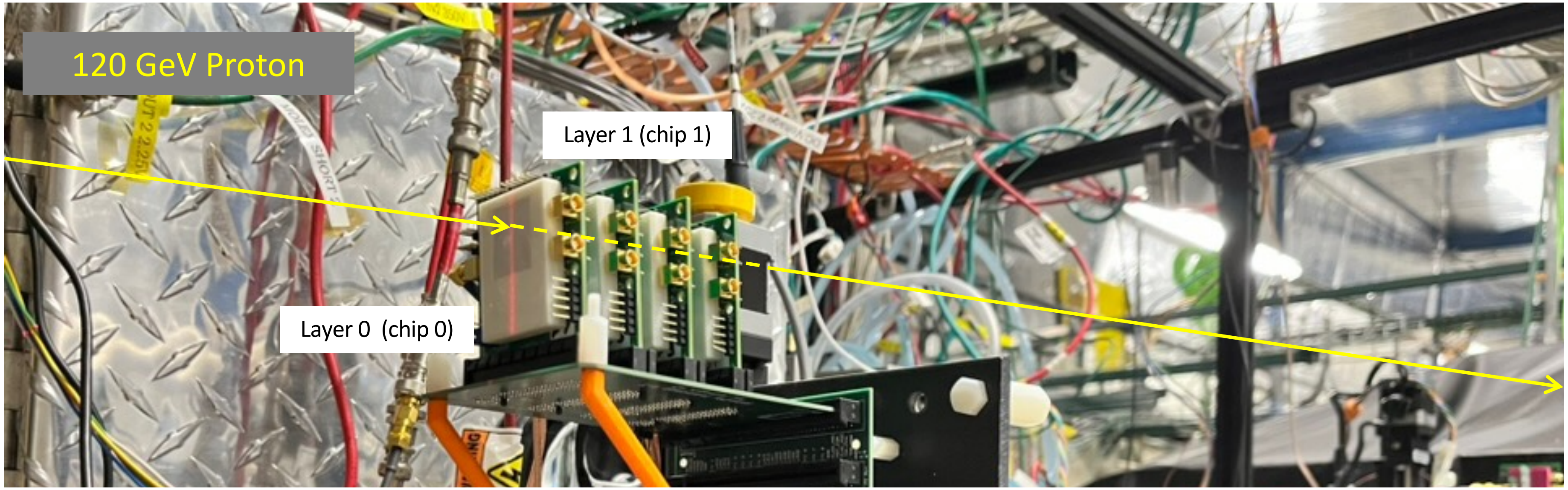


- Baby BCAL, event B

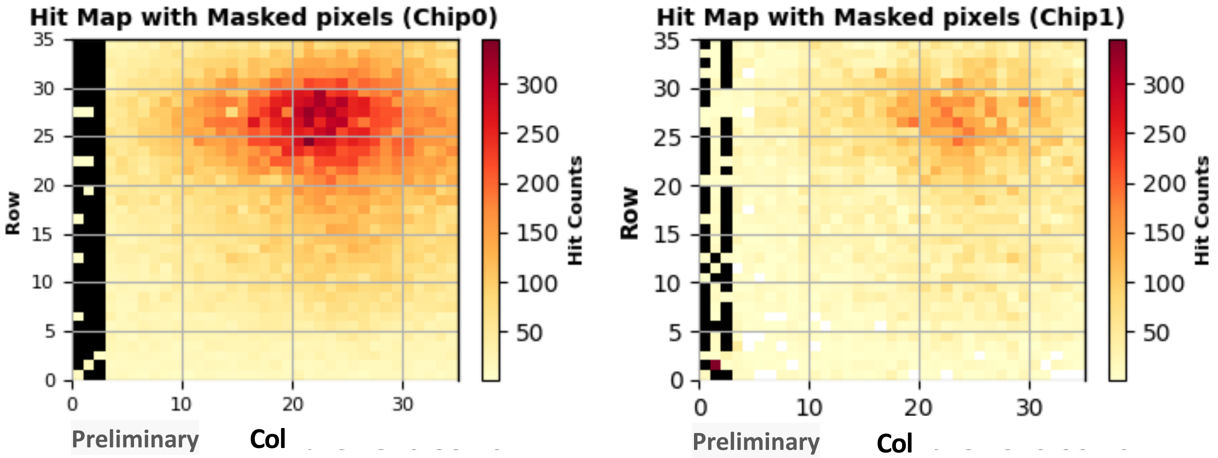


*Example plot of 120 GeV proton event display from an integrated system of Baby BCAL and a single-layer AstroPix v3 chip by Henry Klest

120 GeV Proton: Double Layer, Hit Map of Coincident Hit

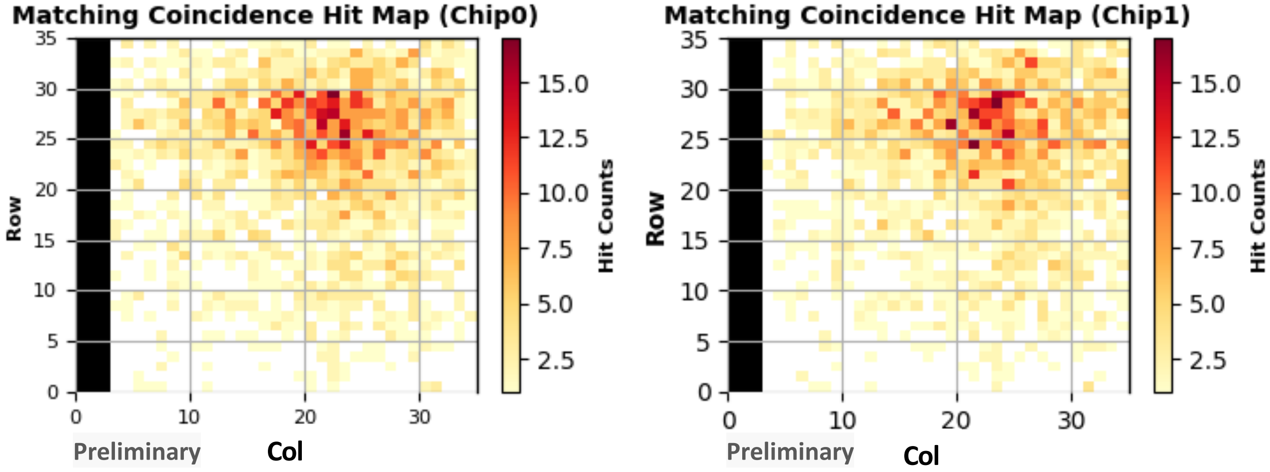


- Matching hit using col&row information on same chip



  - Matching hits with time stamp <2 and ToT error < 10%

- Matching coincident hit between chip0 and chip1



  - Matching hits with location difference < 3 and time stamp difference < 5

Summary

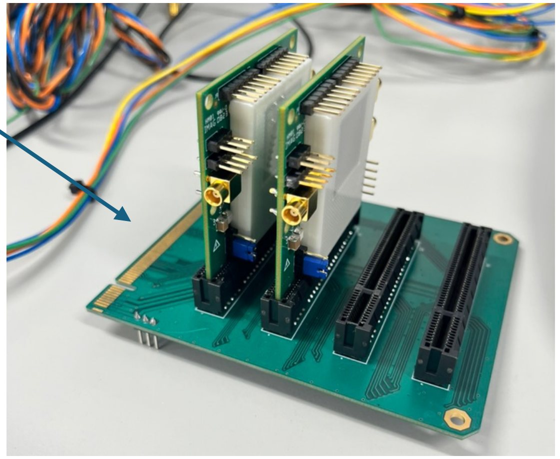
- The performance of Astropix v3 single chip is measured at ANL:
  - Noise scan: measured noisy pixels
  - Injection scan: measured a relation between injection voltage and individual pixel output
  - Source test: measured a calibration constant of 17.09 [keV]/[us, ToT]
- Using 120 GeV proton beam at FNAL
  - Astropix v3 single chip,
    - Measured beam position by hit map and average MIP deposited energy of 43.53 keV

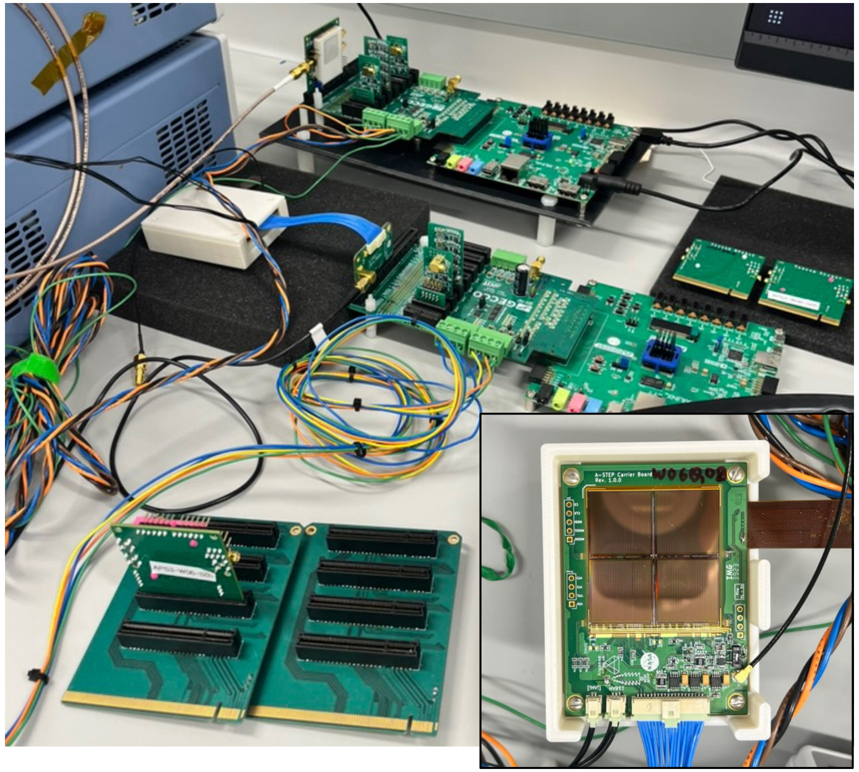
    → Extract MIP response. Need to cross-check with simulation
  - Astropix and Baby BCAL,
    - Measured coincident hits between Astropix and Baby BCAL

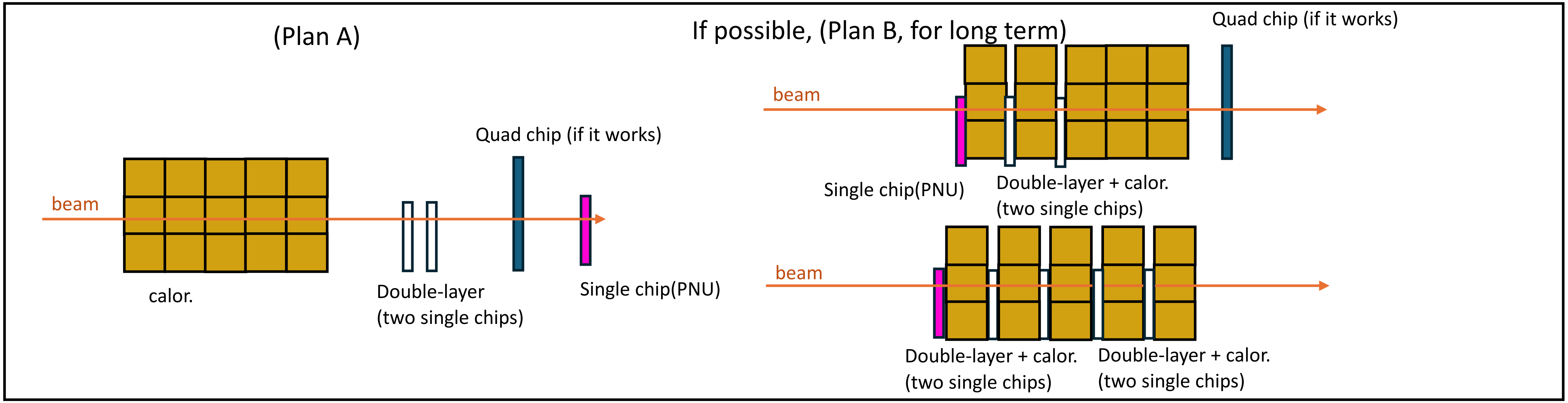
    → Proof-of-concept tested in the beam
  - Double layer of two Astropix v3 single chips
    - Measured coincident hits between double layer
- Collaboration paper is in progress during this summer.

For Beam Test at CERN

- Two GECCO+FPGA boards
- Two multi-layer boards
  - Confirmed that Double-layer is working.
- Three single chips
  - APS-W08s05
  - w01s07
  - w01s06
- One Quad chip: need to check operation
  - W06Q08
  - Only two chips on bottom are connected.







Thank you