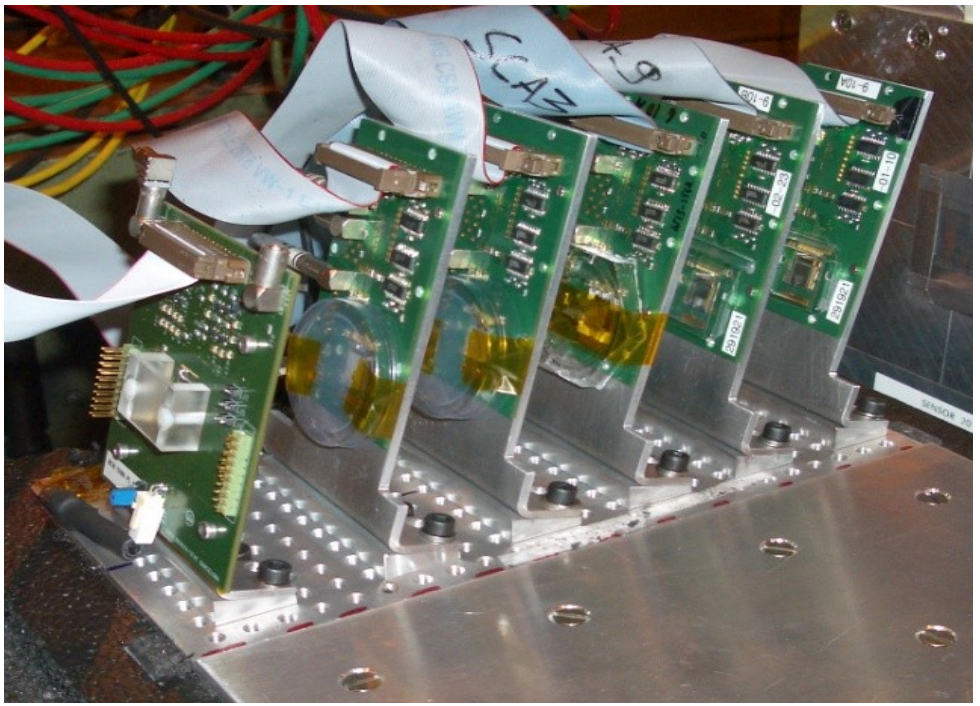
Characterization and beam tests of Barcelona FE-I3 planar n-in-p and 3D double sided devices



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RD-50 Workshop
23-25 May 2011

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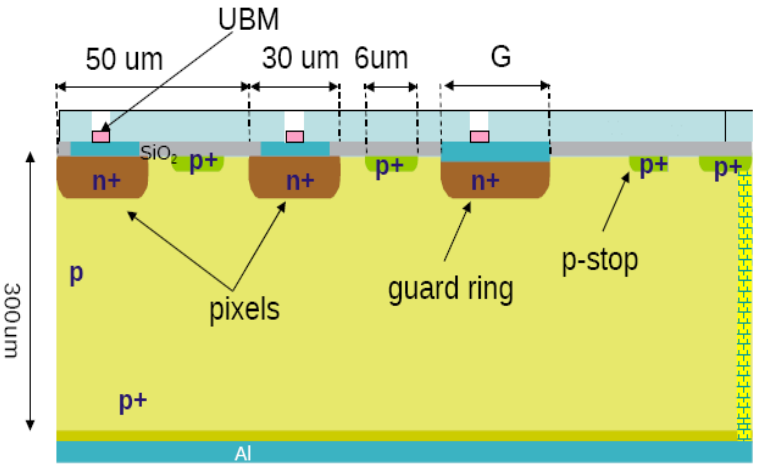
Layout

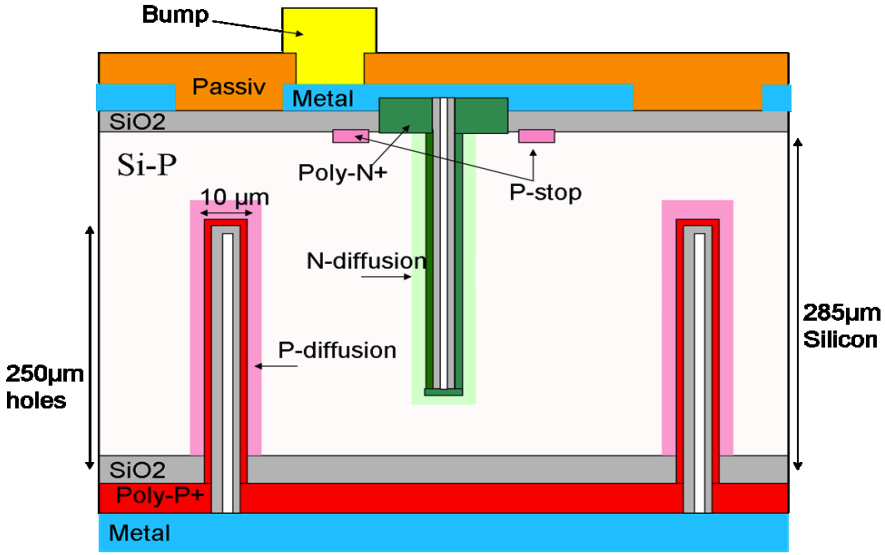
This talk will consist of four parts:

- Brief introduction
  - Sensor technologies.
  - Description of the FE-I3 read-out chip.
- Characterization
  - Results from the characterization in laboratory at IFAE.
- Test beam studies
  - Results and interpretation of the beam test studies.
- Conclusions

Introduction to CNM FE-I3 devices

- **Planar n-in-p**
  - Planar n^+ in p sensors in a 300 μm deep substrate.
  - No bias grid present in CNM devices.
  - p-stop isolation, 11 guard ring design.
- **3D double sided**
  - Electrodes etched into the bulk, perpendicular to the wafer's surface.
  - Double sided: columns etched from opposite sides of the wafer for each electrode type.
  - Columns are 250 μm deep in a 300 μm thick p-substrate.





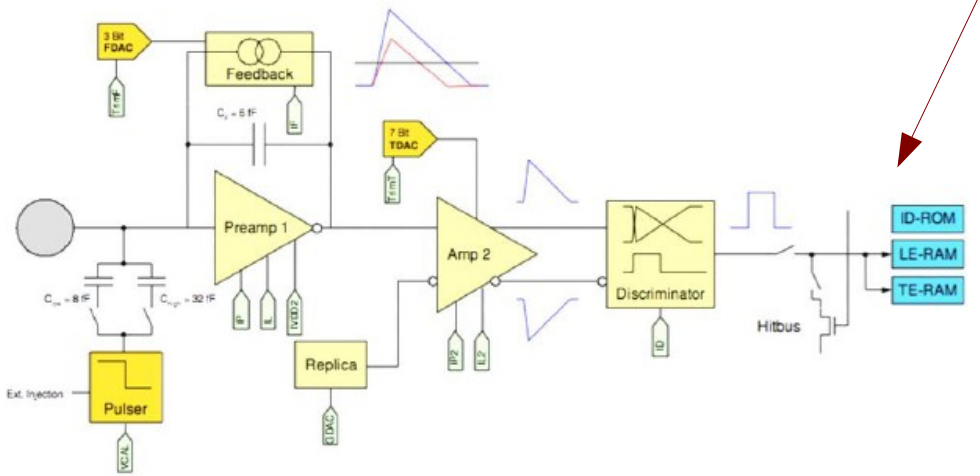
Nomenclature

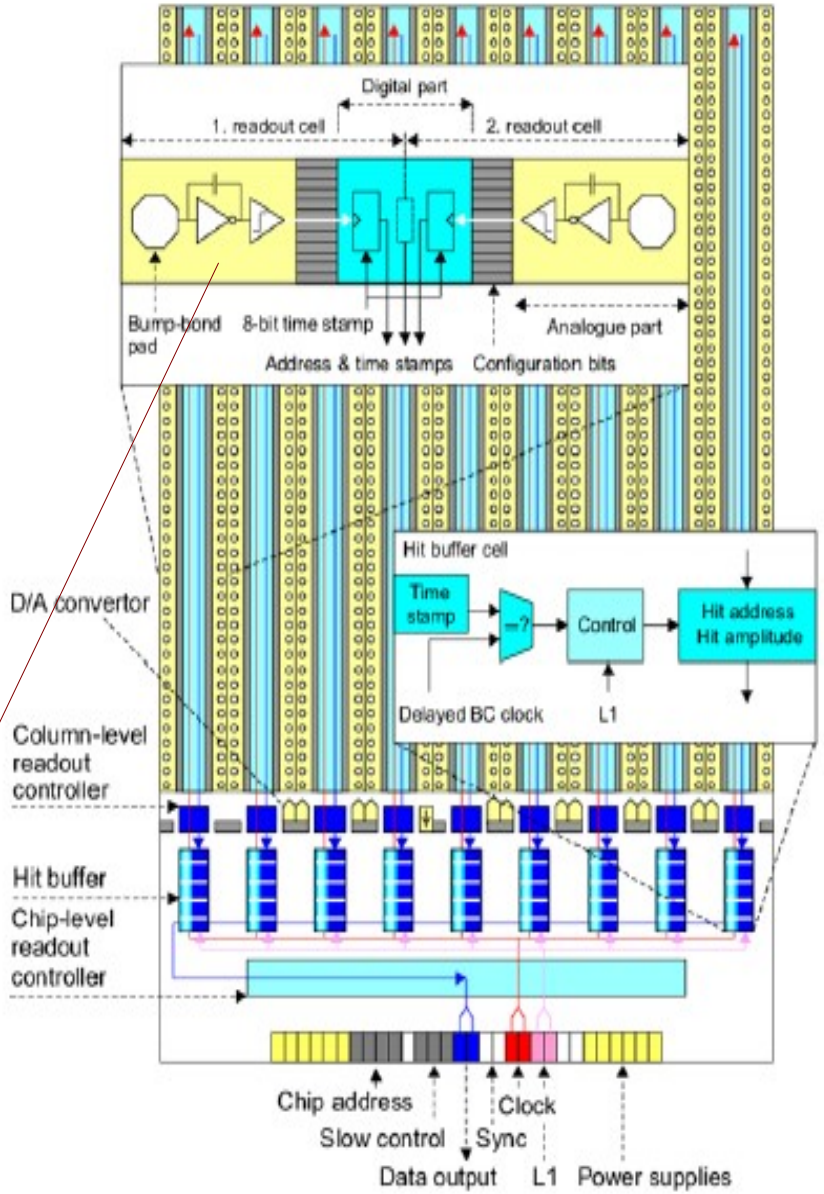
The nomenclature used for the devices is:

(Mounting)_(production)_(type)_(number), i.e. BCN_CNM_PL_04

Readout chip

- The pixel sensors studied are bump-bonded at Barcelona on the FE-I3 readout chip (currently used in ATLAS).
- 2880 cells of 400 x 50 μm^2 size, arranged in 160x18 matrix (same as sensors).
- Both the threshold and the Time over Threshold (ToT, related to the charge deposited in a pixel) can be tuned by varying DAC values.
  - In all the characterized devices, the tuning is: 30 ToT units = $20 \cdot 10^3 e^-$.

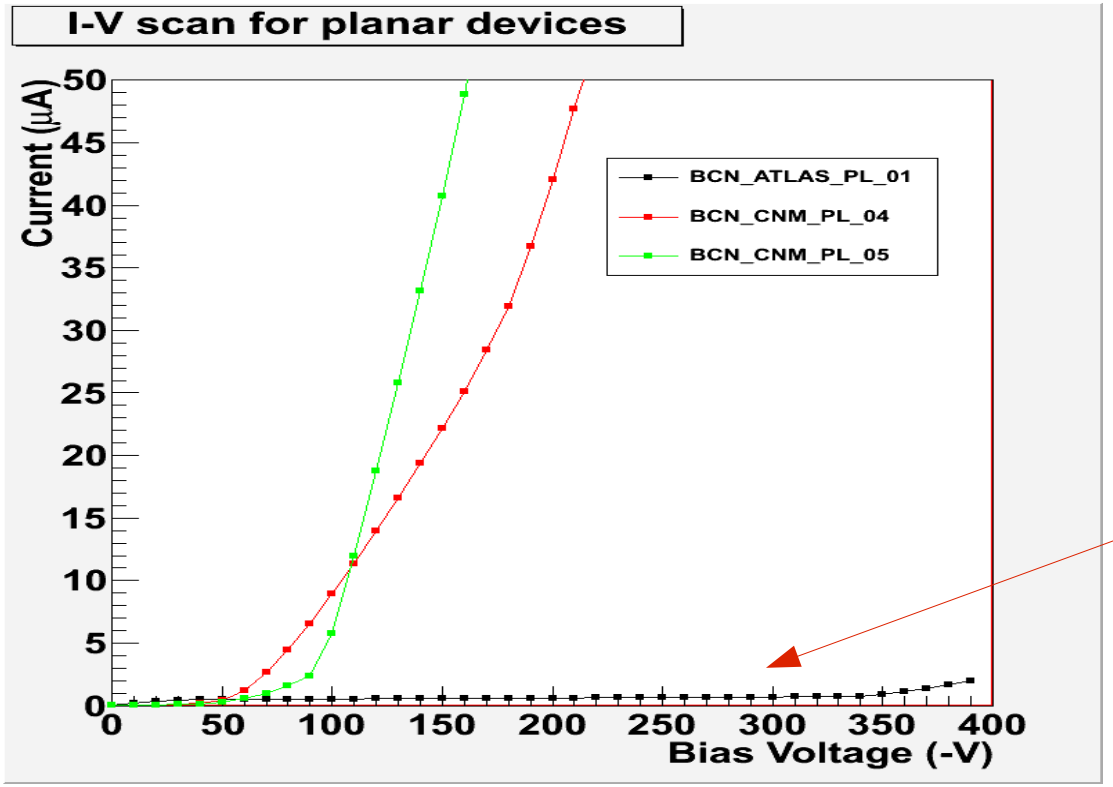




Characterization

Planar n-in-p (1)

- First step in characterization procedure: IV measurement.
- Results for BCN_CNM_PL_04 and 05 are shown and compared to BCN_ATLAS_PL_01 (n-on-n).
- Breakdown voltage around -100V for the CNM devices, full depletion around -65 V (measured at CNM).

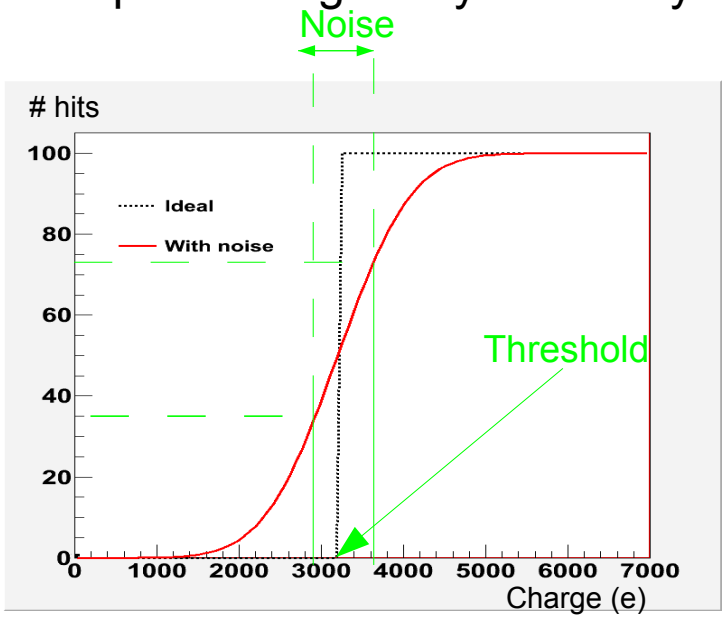


- Low breakdown voltage for CNM devices.
- Probably due to high p-stop dose.

BCN_ATLAS_PL_01 has much higher breakdown voltage (~400 V).

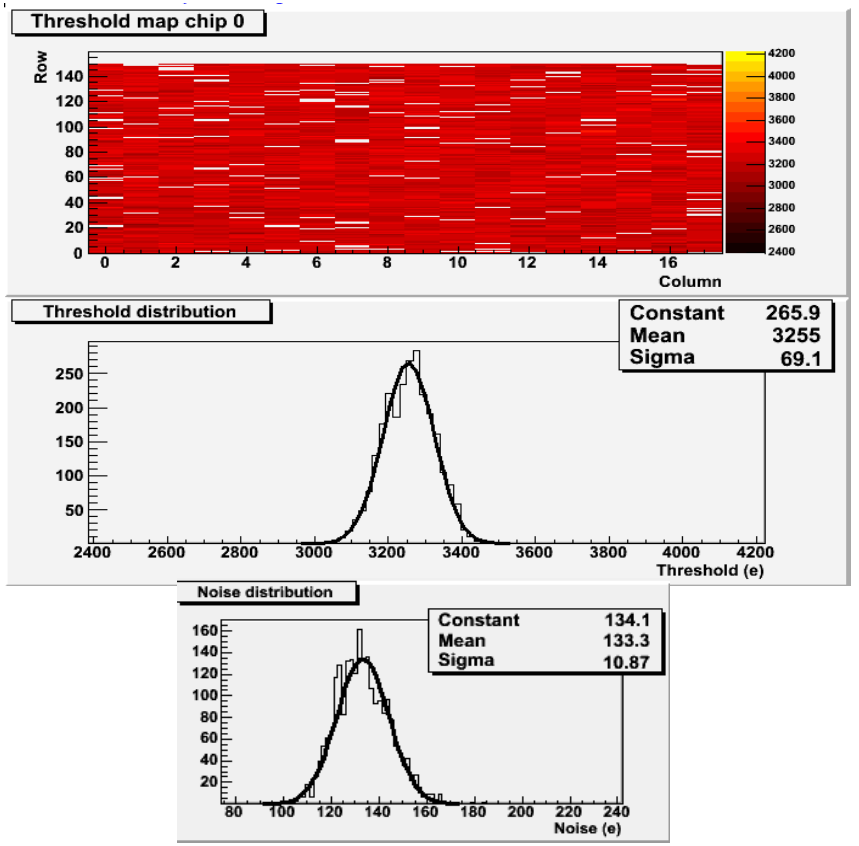
Planar n-in-p (2)

- Threshold scan: Different amount of charge injected into each pixel, 100 times.
- Threshold for each pixel set at 3200 e^-.
- The top rows both for planar and 3D are floating (not connected), to simplify the processing. They will always appear masked.



Expected curve shape for each pixel

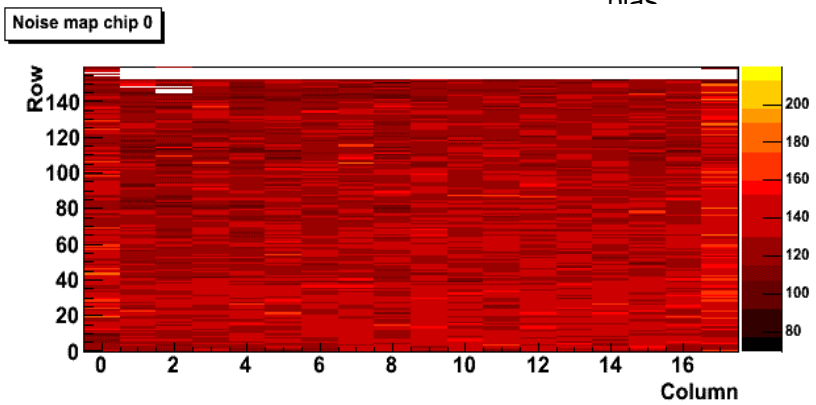
- The threshold has been adjusted successfully for CNM planar n-in-p devices

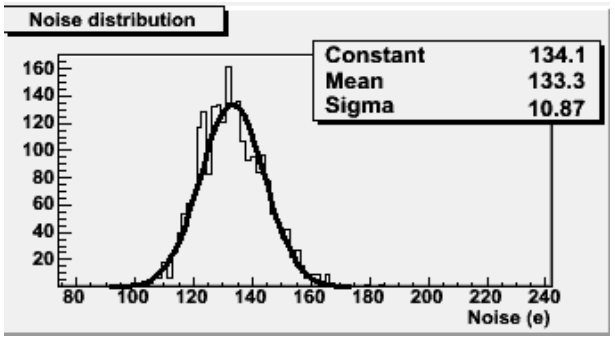


Threshold and noise for all the pixels in BCN_CNM_PL_04 at V_{bias} = -50V.

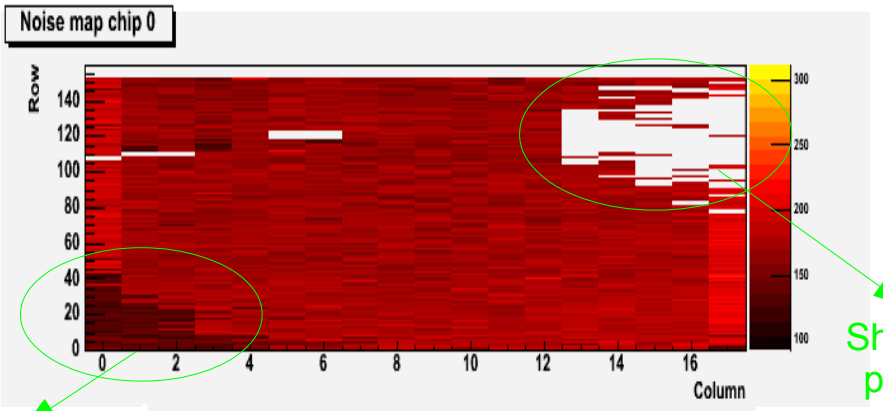
Planar n-in-p (3)

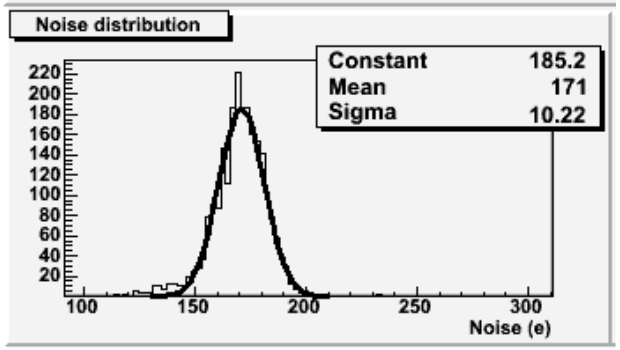
- Noise measurement: Different observations can be made:
  - BCN_CNM_PL_04: All pixels OK (~140 e^- at V_{bias} = -50 V).
  - BCN_CNM_PL_05: Found shorted and unconnected pixels. Central pixels OK (~170 e^- at V_{bias} = -50V).





Noise for BCN_CNM_PL_04 at V_{bias} = -50V.

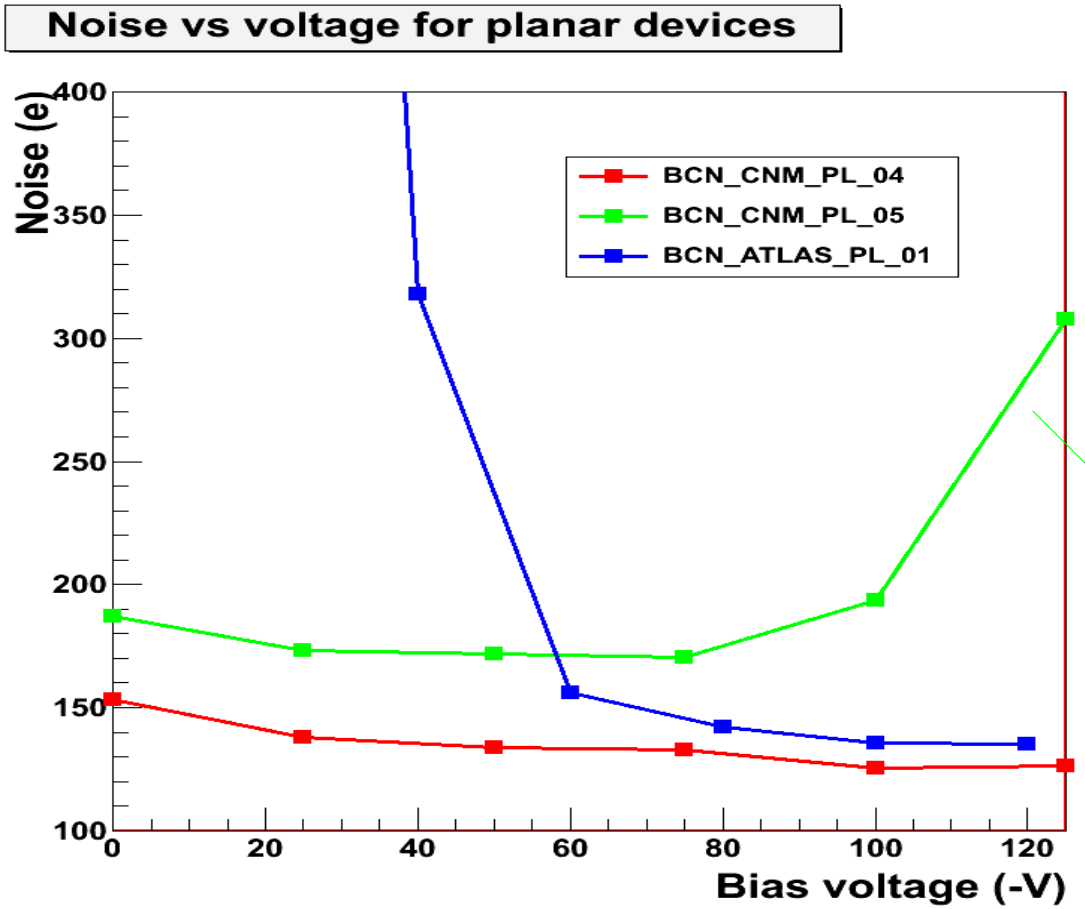


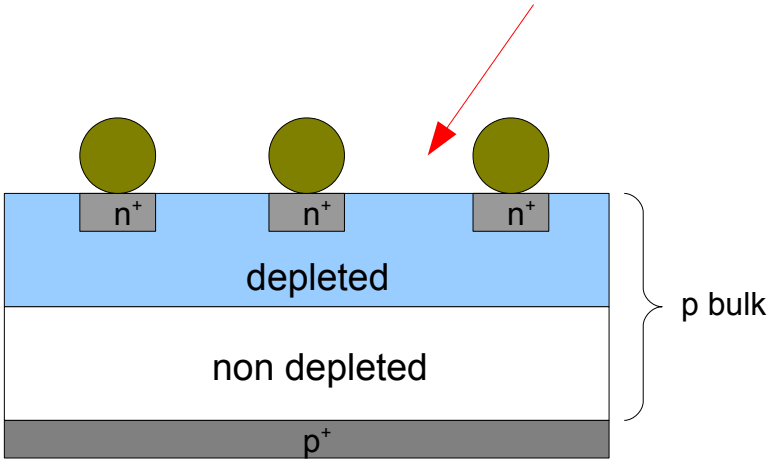


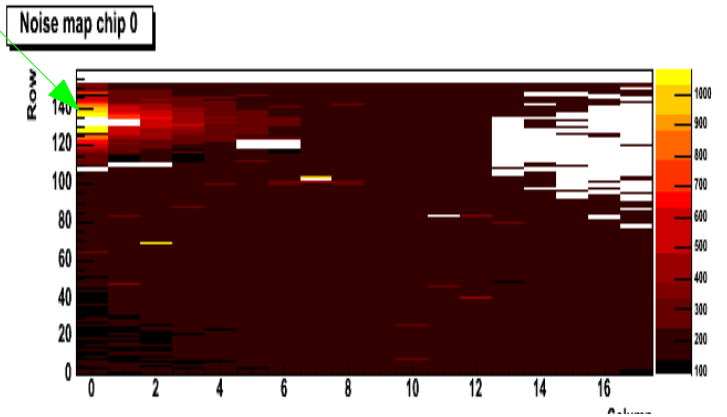
Noise for BCN_CNM_PL_05 at V_{bias} = -50V.

Planar n-in-p (4)

- “Hot” noisy spot in BCN_CNM_PL_05 appears for V < -95 V.
- N-in-p have low noise for V < $V_{depletion}$ → Depletion region grows from the pixel.

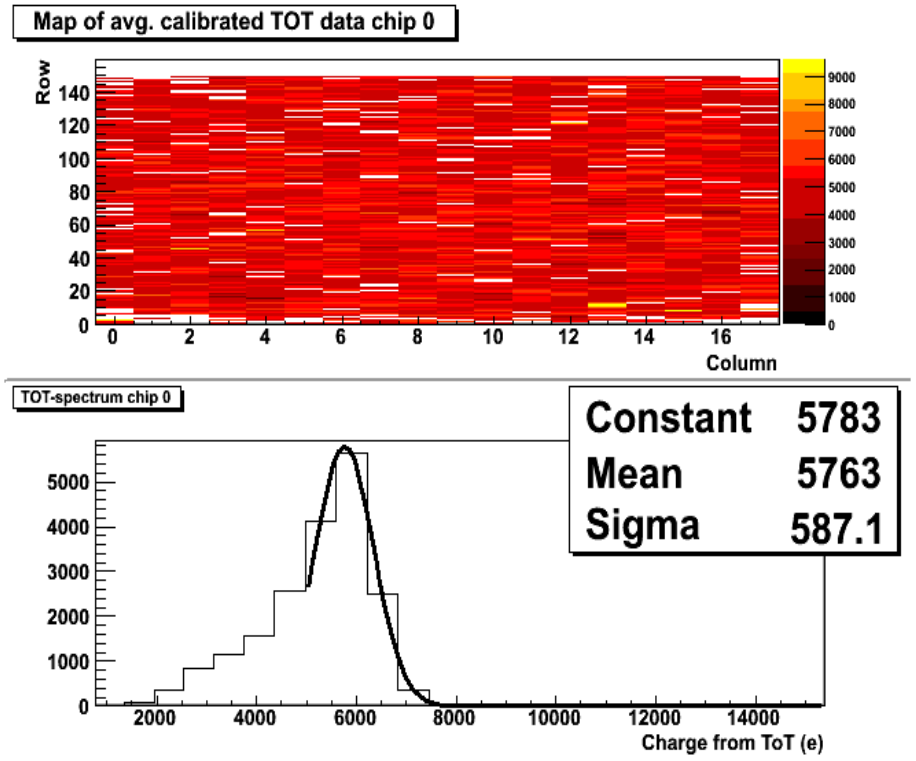




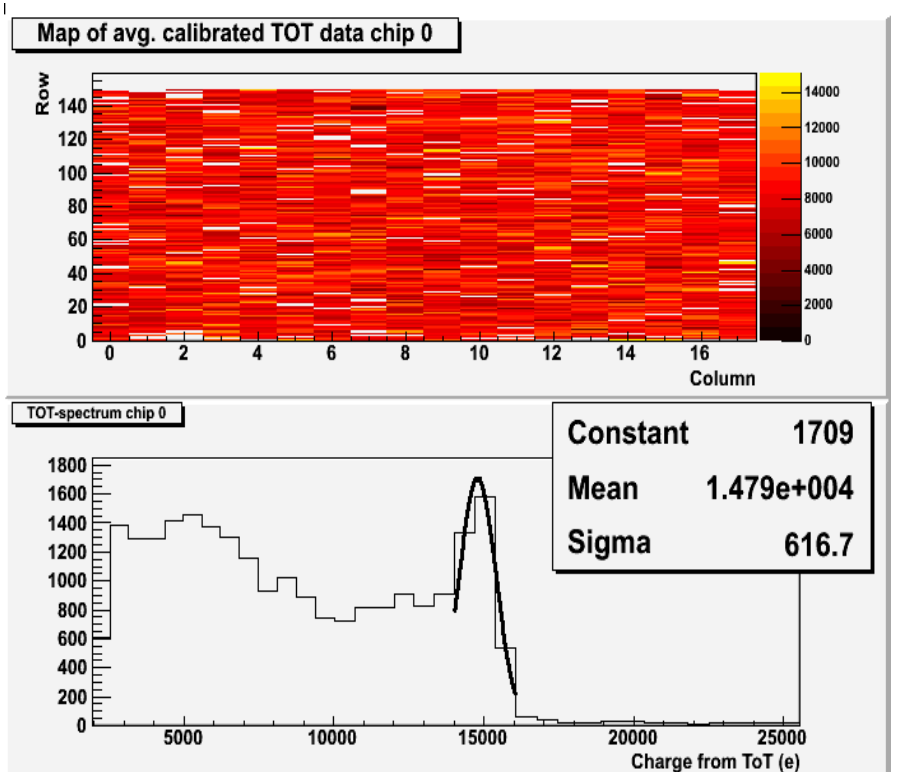


Planar n-in-p (5)

- To see that the devices work, check that they collect charge.
- Source scan with Cd-109 (21.4 KeV photons) and Am-241 (60 KeV photons).
- Found a peak around 6000 e^- (Cd-109) and 15000 e^- (Am-241), as expected.



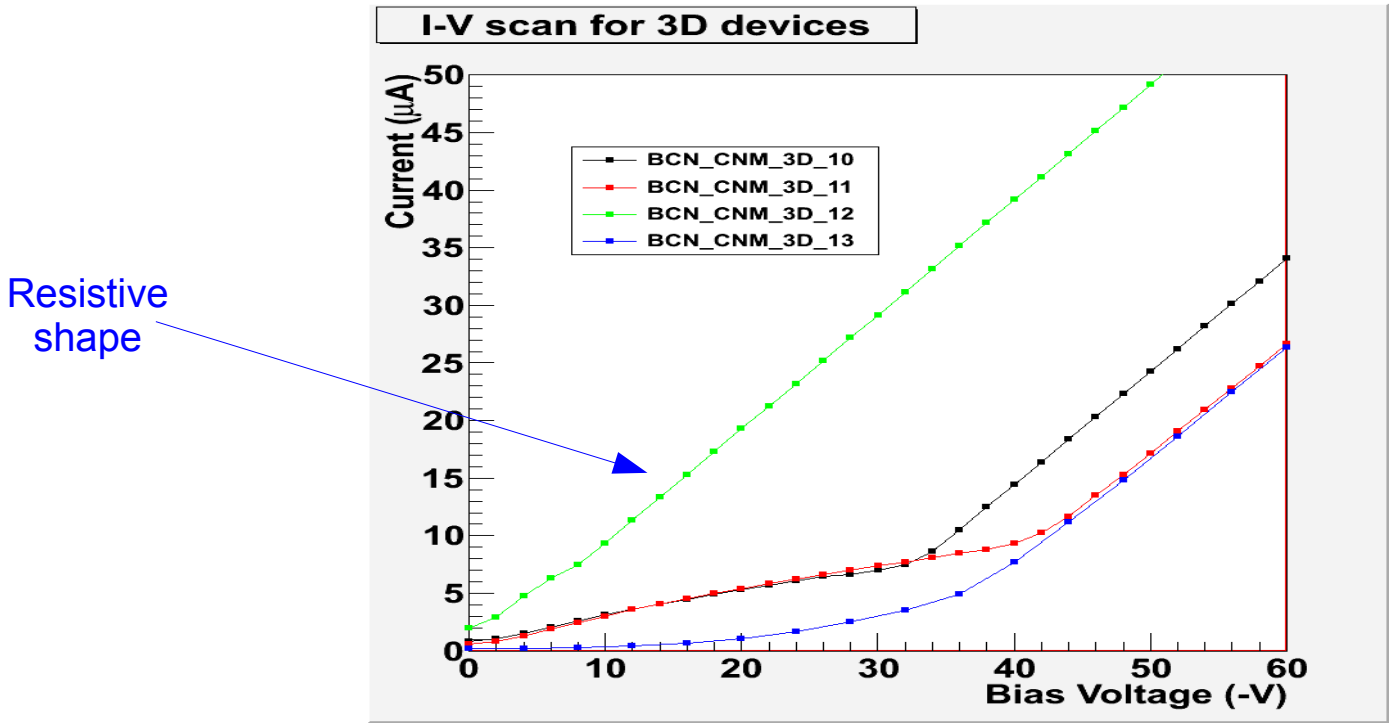
Cd-109 source scan in BCN_CNM_PL_04 at V_{bias} = -50V



Am-241 source scan in BCN_CNM_PL_04 at V_{bias} = -50V

3D devices (1)

IV scan shows a low breakdown voltage (~ 35 V).



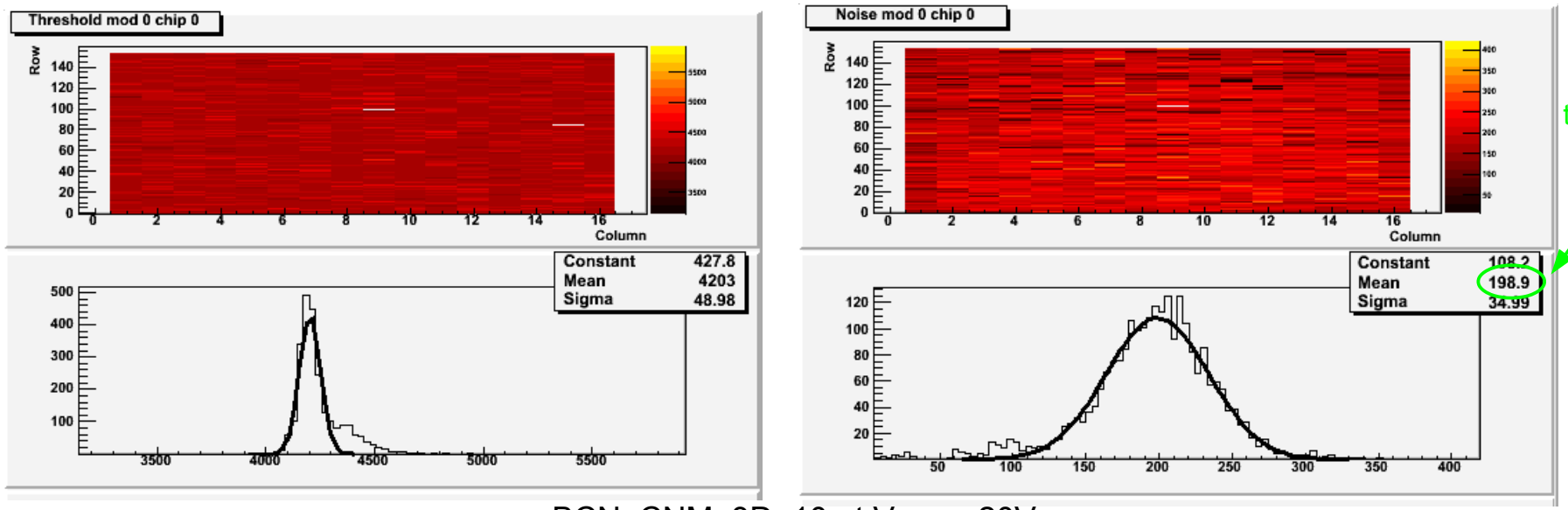
- BCN_CNM_3D_12 has a resistive shape. We are investigating this device.

3D devices (2)

- Threshold for each pixel set higher than for planars: ~4000 e^-.

Threshold

Noise



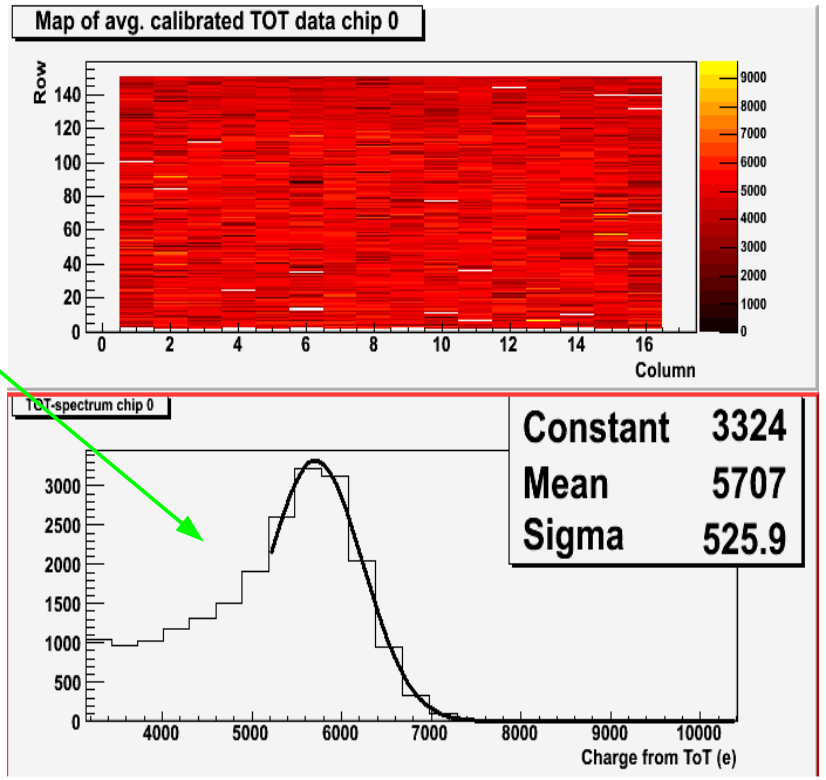
BCN_CNM_3D_10 at V_{bias} = -20V.

- All 3D devices are found to be noisy (200 – 400 e^-).
- The production run was problematic; also high p-stop might cause microdischarges.

3D devices (3)

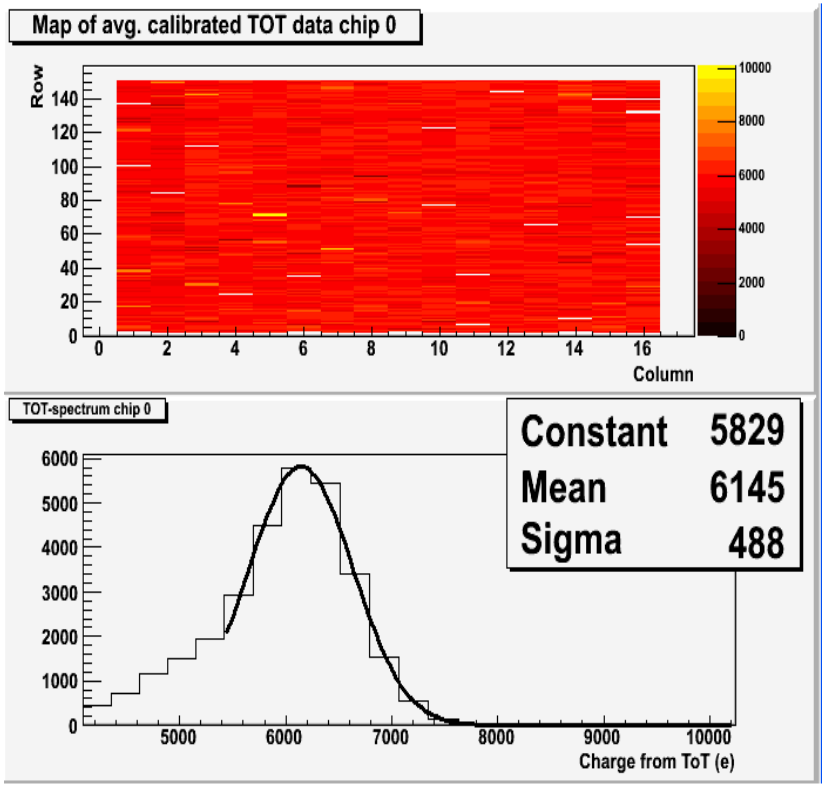
- Source scan for Cd-109 shows similar results than for planar devices. Verified charge collection although the devices are noisy.
- A “noisy tail” appears when “low” thresholds are set.

Threshold = ~3500 e⁻



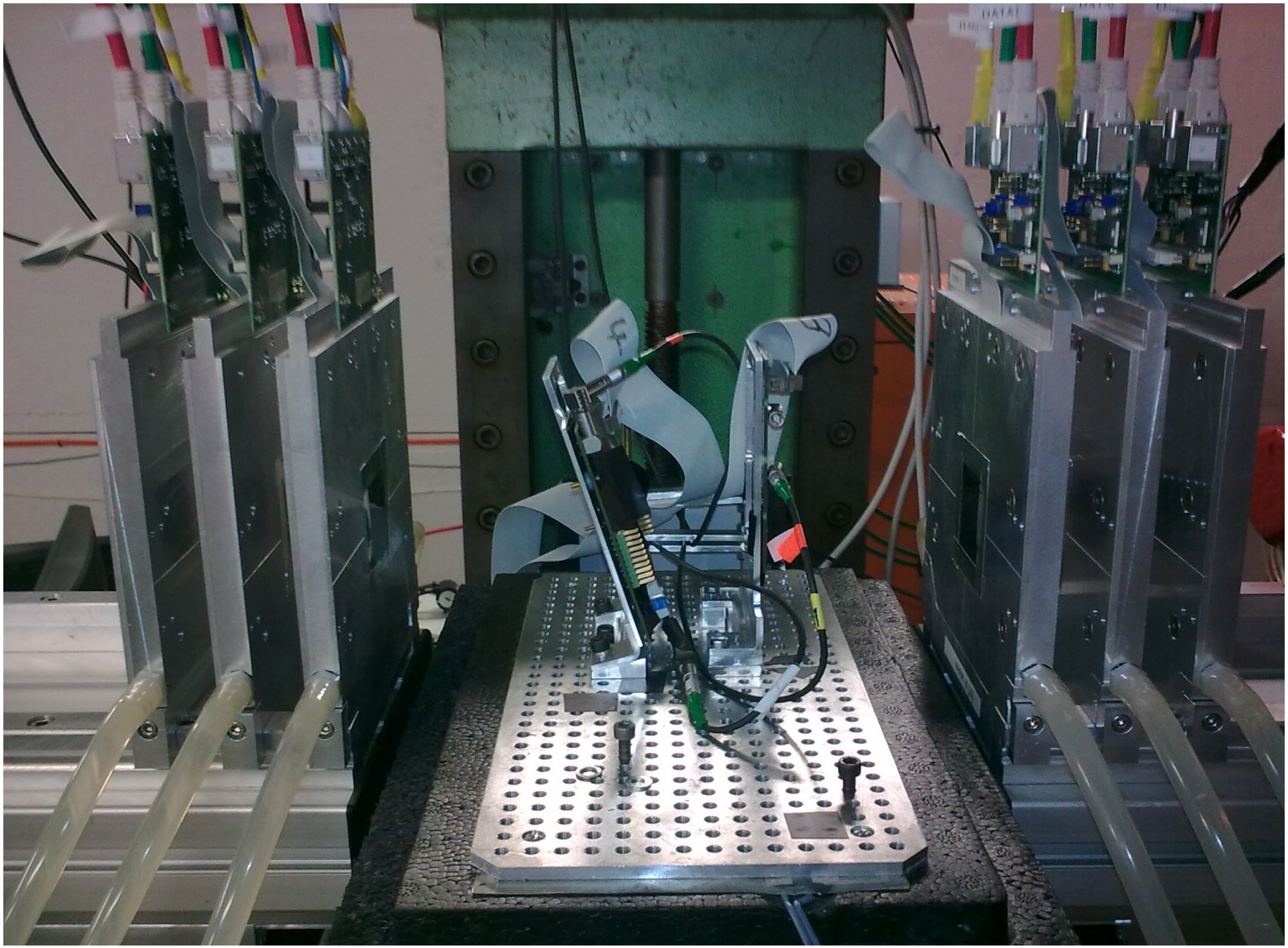
Noisy tail

Threshold = ~4500 e⁻



Source scans with Cd-109 (21.4 KeV) for BCN_CNM_3D_11 at V_{bias} = -20 V

Test Beam studies



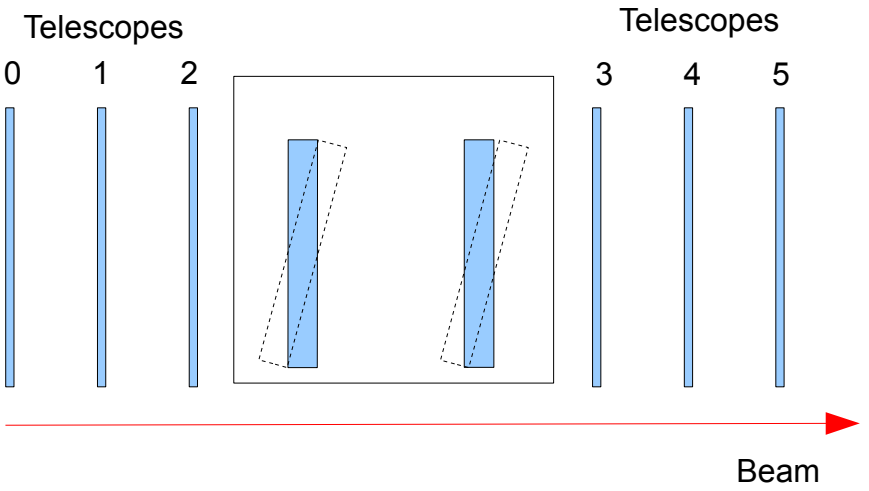
3D CNM device at DESY

General information

- After characterization in lab, the working devices were brought to different testbeams:
  - BCN_CNM_PL_04 → 2010 July test beam at CERN.
  - BCN_CNM_PL_05 → 2010 October test beam at CERN
  - BCN_CNM_3D_13 → 2011 April test beam at DESY.

- The sensors were placed under a beam with energies:
  - CERN testbeams → 120 GeV charged pions.
  - DESY testbeam → 4 GeV electrons.

- The resolution of the telescopes is:
  - CERN testbeams → few μm.
  - DESY testbeam → ~ 20 μm.



- The devices were placed with a normal incidence and with a 15 deg incidence (with respect to the beam axis).

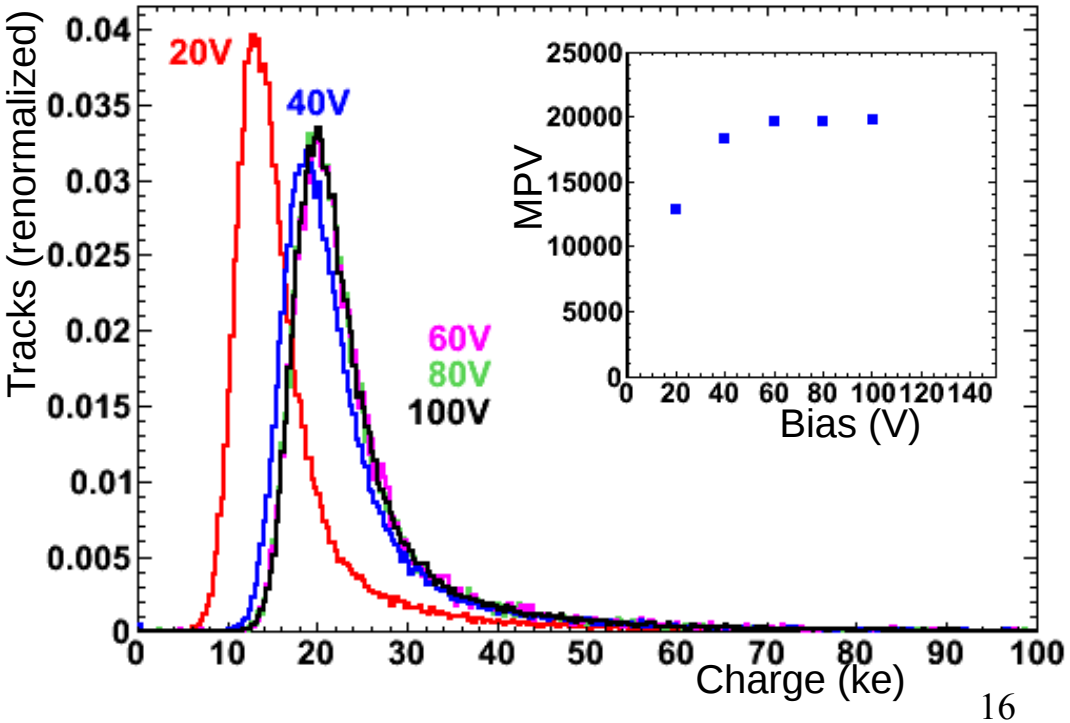
- The results for the BCN_CNM_3D_13 are still PRELIMINARY.

Planar n-in-p (1)

Cluster spectrum with all pixel

- The charge deposit for each reconstructed cluster is plotted.
- The peak is found around $20 \cdot 10^3$ e^- (as expected, since $dE_{m.i.p}/dx \sim 1$ MeV)

- For the sensor under depleted, less charge is detected.
- Results are compatible with a depleted sensor at -60 V (as measured by CNM).



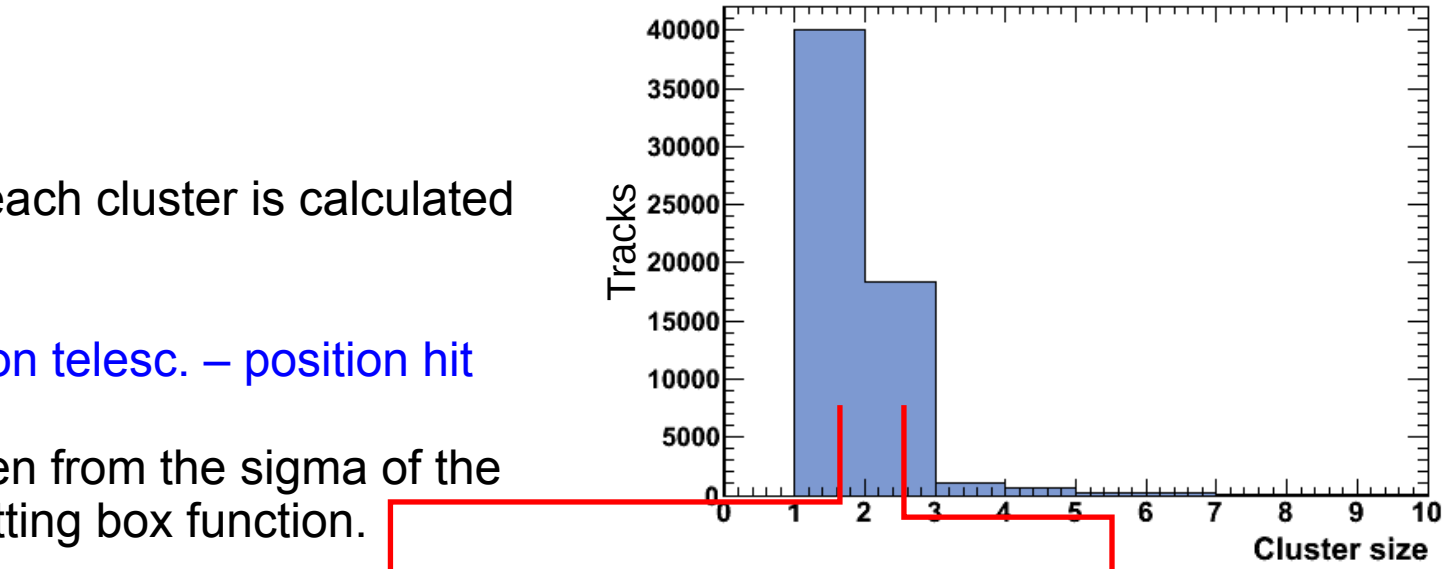
Planar n-in-p (2)

Resolution

- The residual for each cluster is calculated with:

  Residual = position telesc. – position hit

- Resolution is taken from the sigma of the gaussian in the fitting box function.

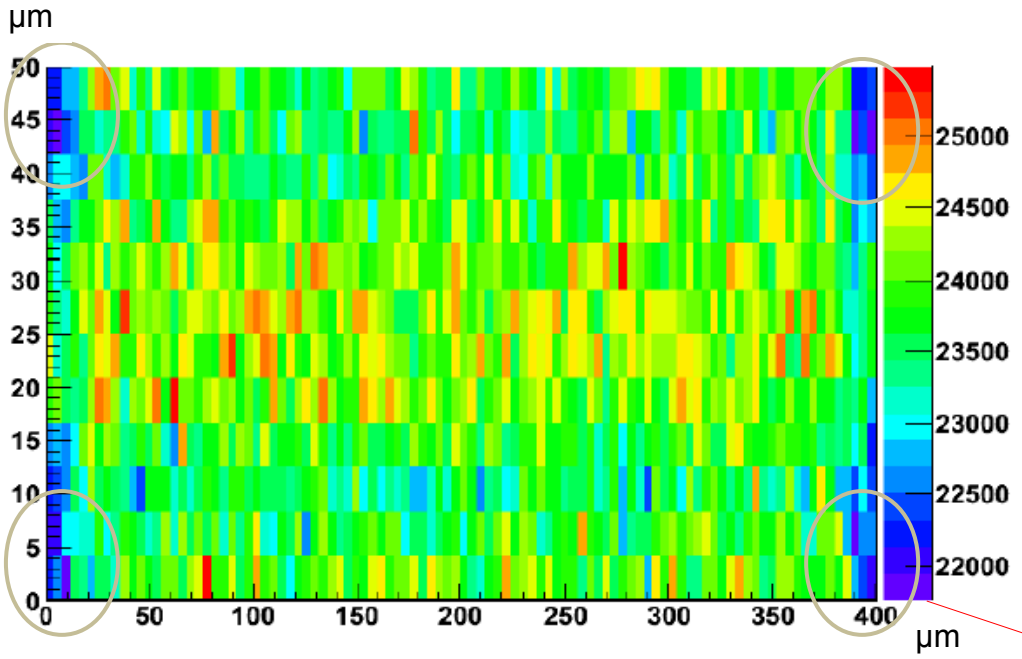


- Single and double pixel resolution (~ 5 μm), consistent with other devices (current n-in-n ATLAS sensors).

Planar n-in-p (3)

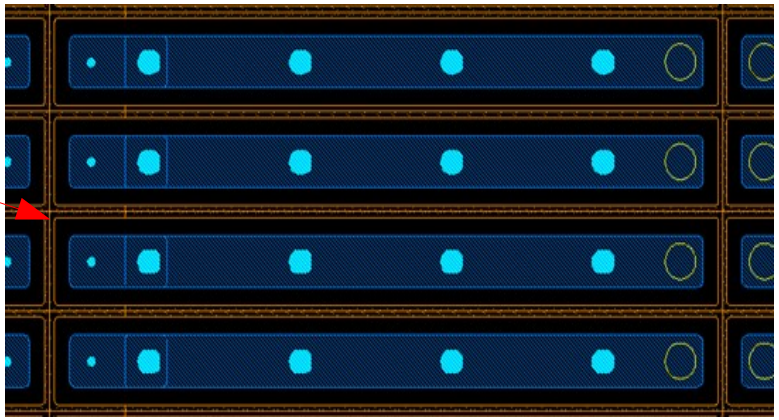
Charge collection

- The position of the collected charge is associated to the track matched to the cluster. Then, summed all pixels.



Charge collection distribution in one pixel for BCN_CNM_PL_04.

- Low charge deposited in the edges.
- At these points, part of the charge is lost in the space between pixels.



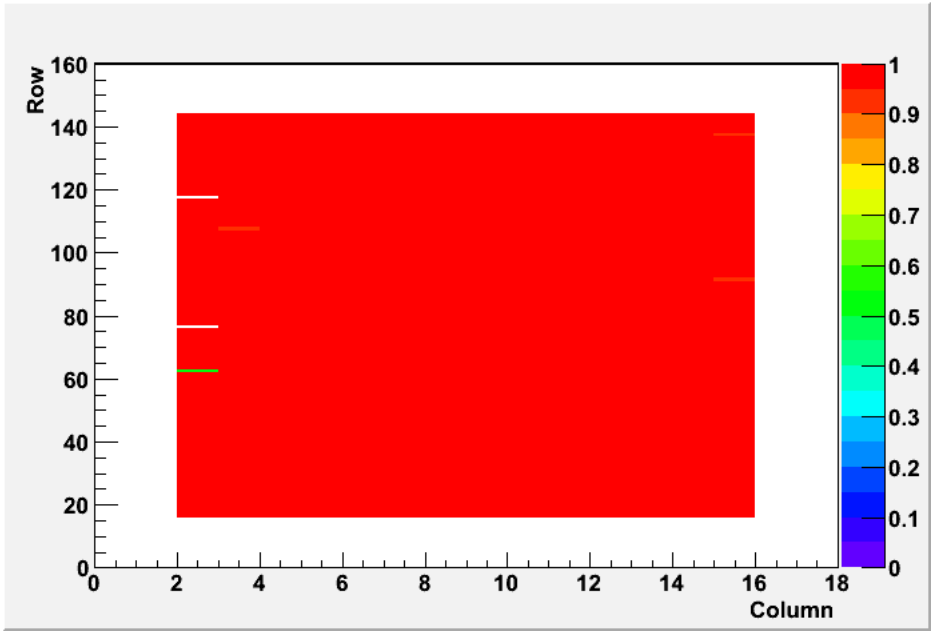
Planar n-in-p (4)

Efficiency map

- The efficiency is calculated for each pixel in the central region:

$$\varepsilon = (N_{hits}) / (N_{tracks\ matched})$$

- The efficiency for BCN_CNM_PL_04 is shown.

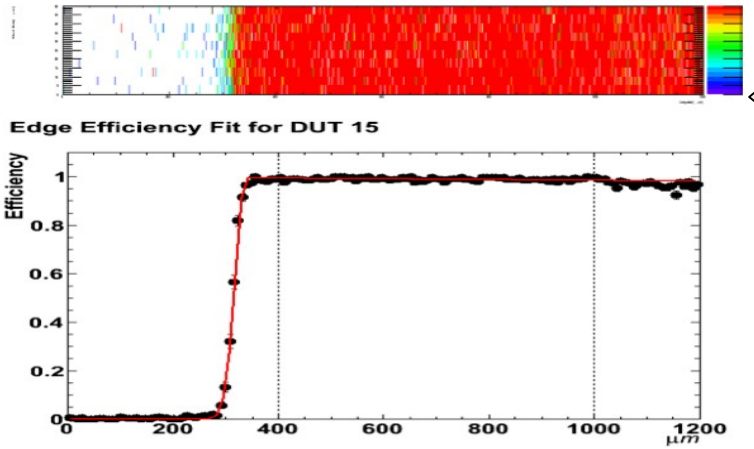


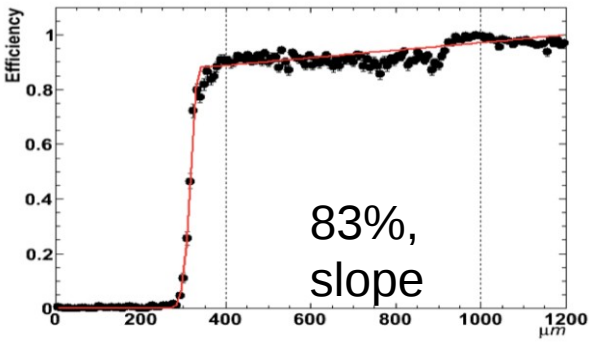
Efficiency map for BCN_CNM_PL_04
ε = 0.997

Planar n-in-p (5)

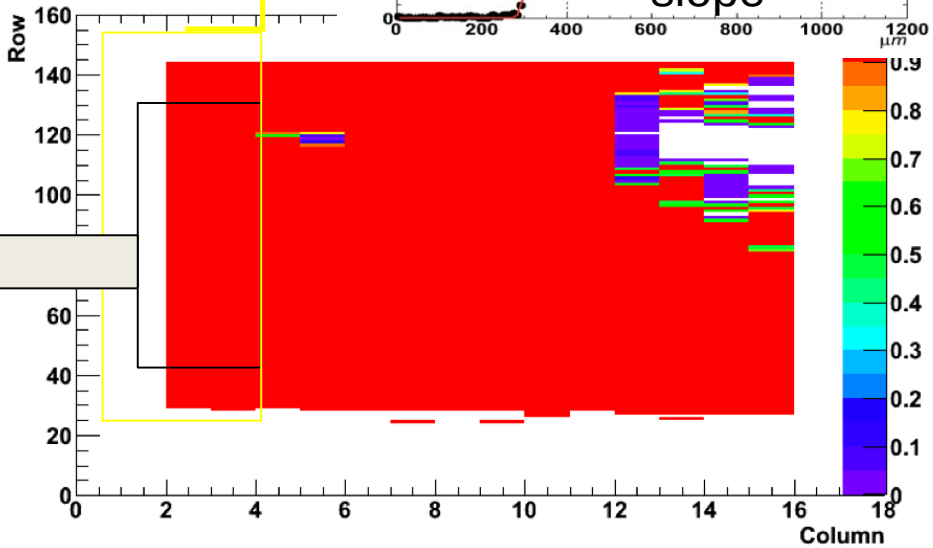
Edge efficiency

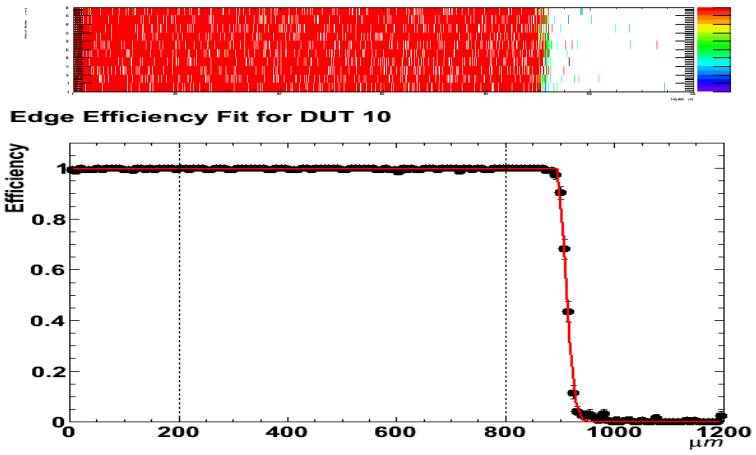
- The edge efficiency measures the efficiency in the pixels on columns 1, 2, 17 and 18 (1 and 18 have longer pixels: 50 x 600 μm^2.)





83%, slope





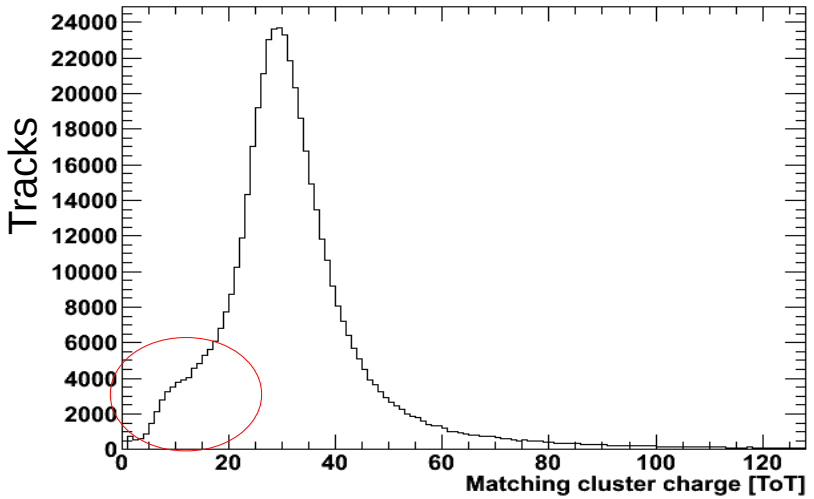
- The edge efficiencies for the CNM planar devices are:
  - BCN_CNM_PL_04: ε = 0.996
  - BCN_CNM_PL_05: ε = 0.999

3D devices (1)

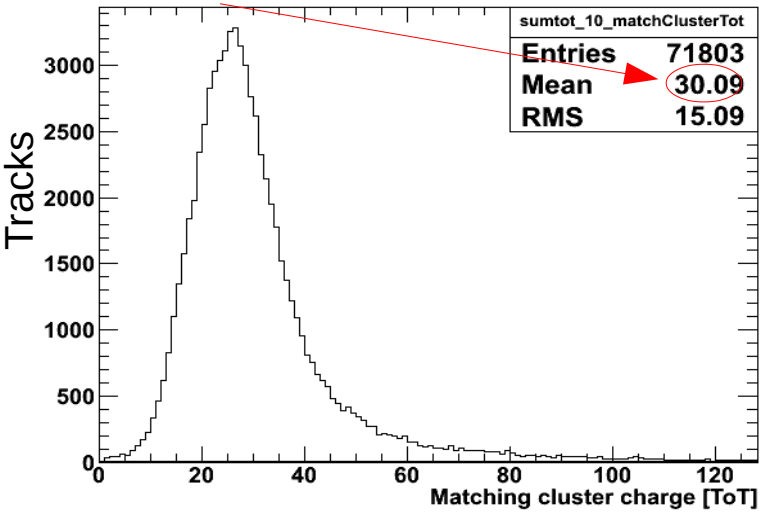
Cluster spectrum with all pixels

- Differences observed between normal and 15 deg incidence:
  - The curve shape for normal incidence is different because of hits in the electrode area .

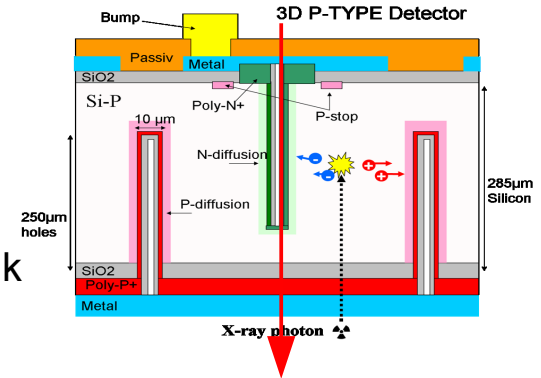
30 ToT = 20 ke$^-$



Normal incidence



15 deg incidence

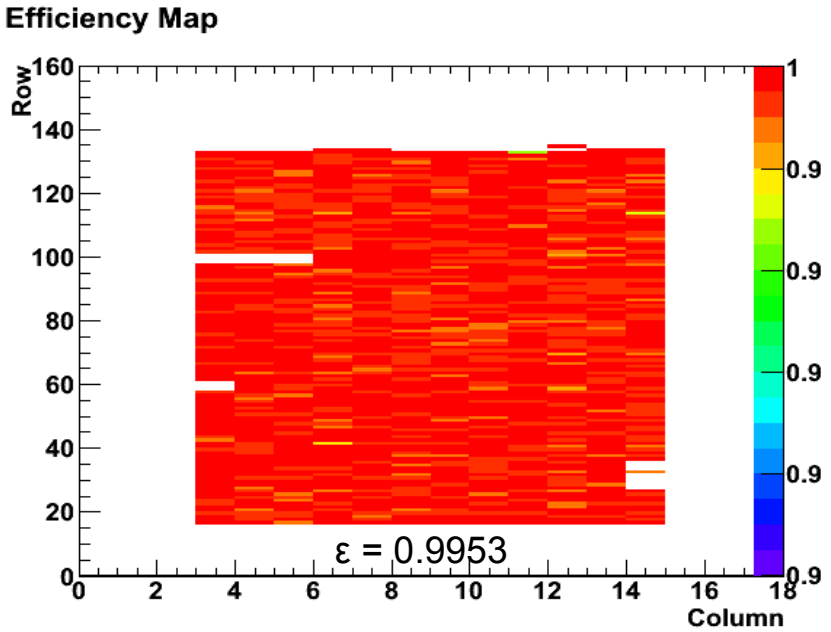


The beam doesn't traverse the p-bulk

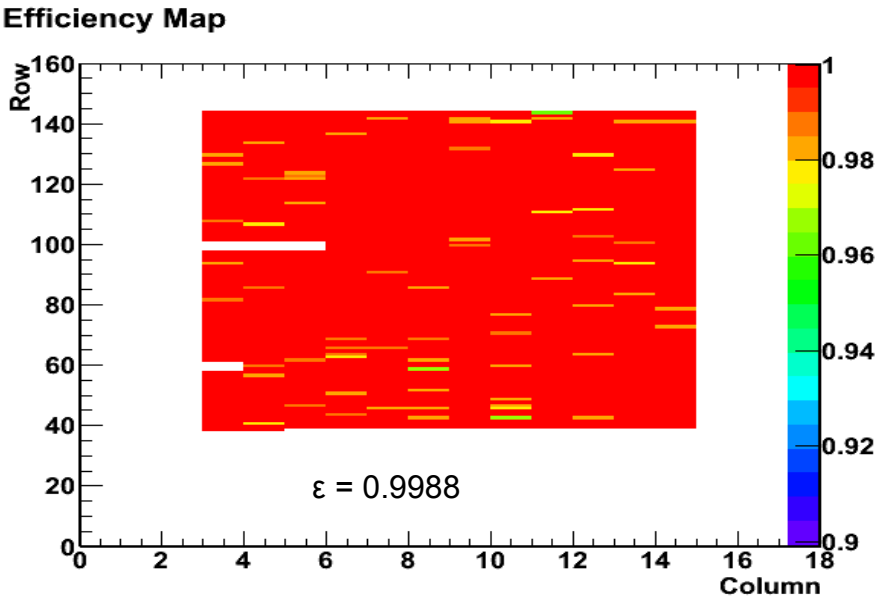
3D devices (2)

Efficiency map

- The efficiency for BCN_CNM_3D_13 is shown for normal incidence and 15 degrees.



Normal incidence



15 deg incidence

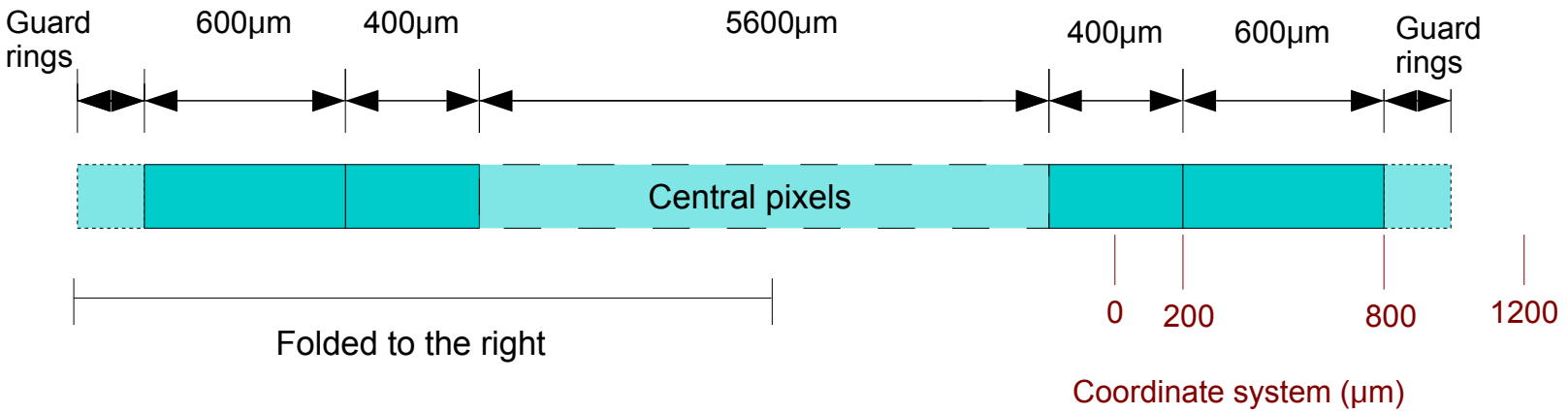
- Lower efficiency under normal incidence: hits in the pixel's column area are lost.

Conclusions

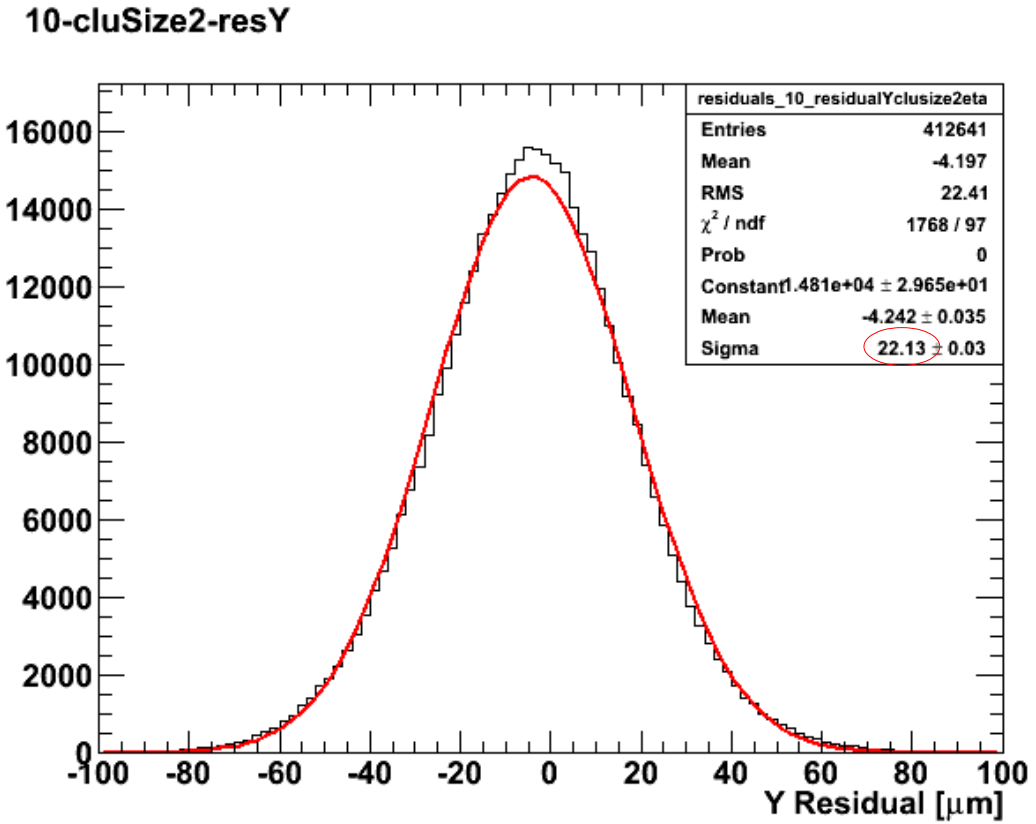
- First FE-I3 production from CNM for n-in-p planar and 3D double sided was tested at IFAE and in test beams.
- The devices were able to detect charge.
- Several issues in the production made these devices not optimal. It translated into low breakdown and noisy pixels. However, the performance in terms of efficiency and resolution is as good as standard devices.
- This problems are solved for the new 3D sensors from CNM.
- These productions are an essential step for the ATLAS IBL qualification production. Giulio is going to talk about this in a moment.

Backup slides

Coordinate system for edge efficiency



Residuals for clusters of 2 pixel size for BCN_CNM_3D_13.



Residuals for BCN_CNM_3D_13

- The pixel resolution is ~ 9 μm.

$\sigma^2_{pixel} = \sigma^2_{telesc} - \sigma^2_{fit}$