A study of 3D Silicon pixel sensors using ROC4sens read-out chip in a DESY test beam

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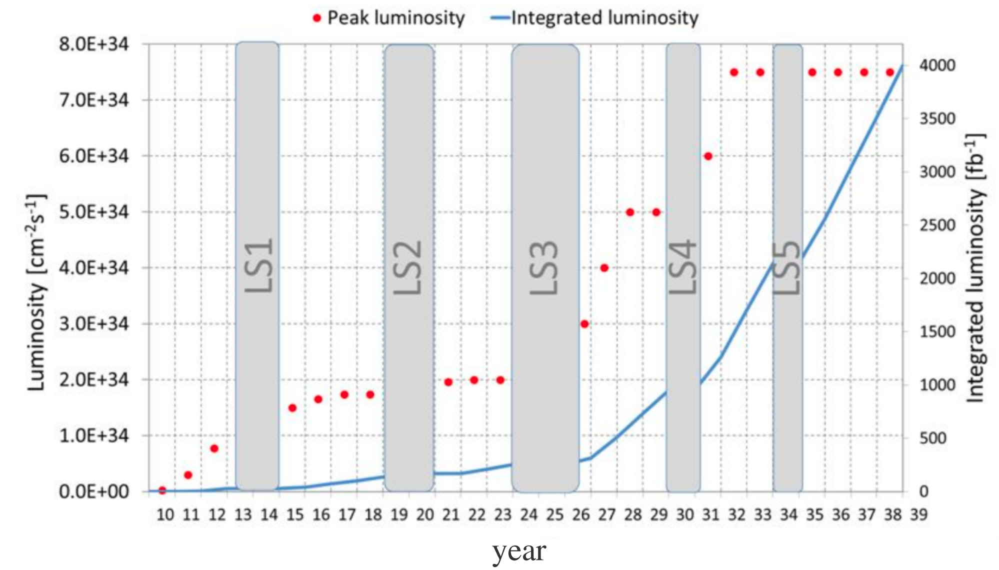
31st RD50 Workshop
Radiation hard semiconductor devices for very high luminosity colliders
CERN, 20-22 November 2017

Motivation: CMS Upgrade (HL-LHC)

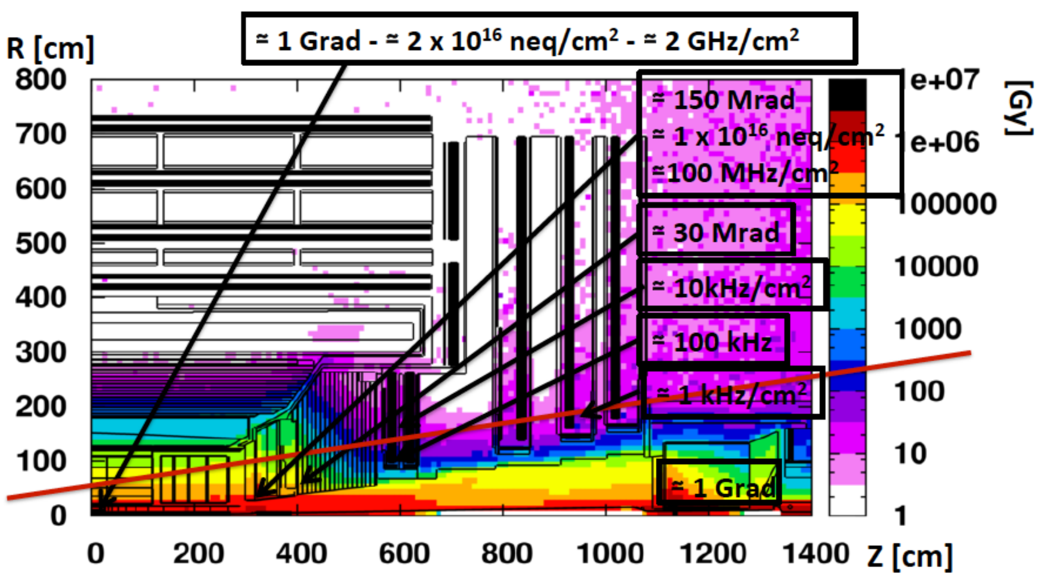


Pile-up ~ 200

Higher occupancy: Increases combinatorial complexity and rate of fake tracks. Increases amount of data to be read out in each bunch crossing.

Mitigation

High granularity detectors: needed to identify particles associated with the primary hard scatter collision vertex with high efficiency.



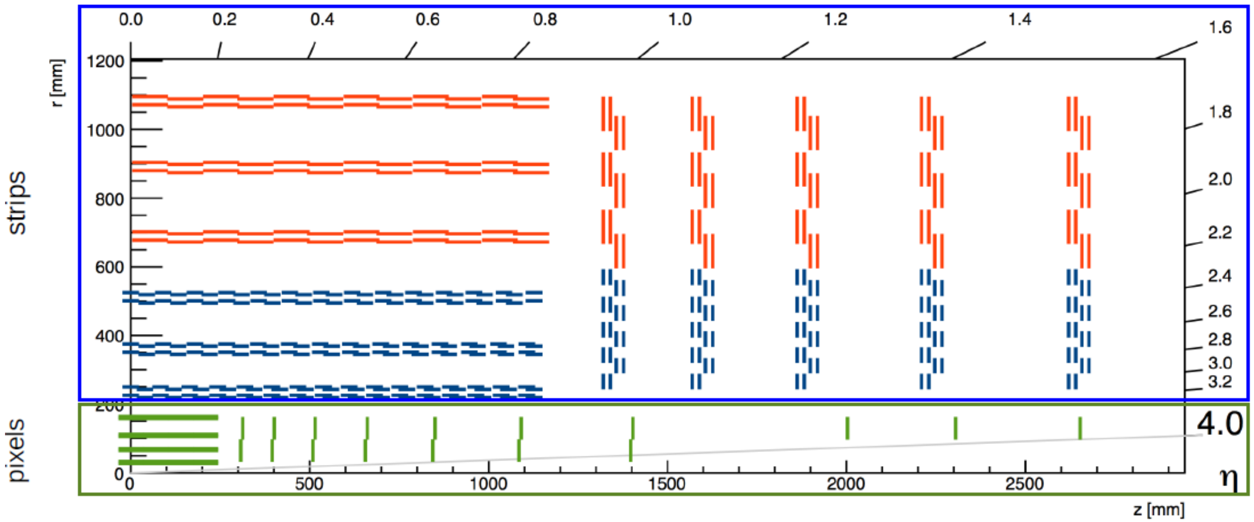
Radiation damage ~ $2x10^{16}$ n_{eq}/cm^2

Detector elements and electronics exposed to high radiation dose. Degrades signal & limits life time of detectors.

Mitigation

Completely new tracker with radiation hard sensors and readout chips.

CMS Phase II Pixel Upgrade



Small pitch

- 50x50 or 25x100 um²
- 1/6 of current size
- Sensor area 2x2 cm²

Current Sensor Options:
Thin planar
3D pixels

Inner barrel & endcap layers need to be very rad-hard!
Radius = 29 mm: close to beam.
Innermost barrel layer ~0,2 m², ~500 sensors.

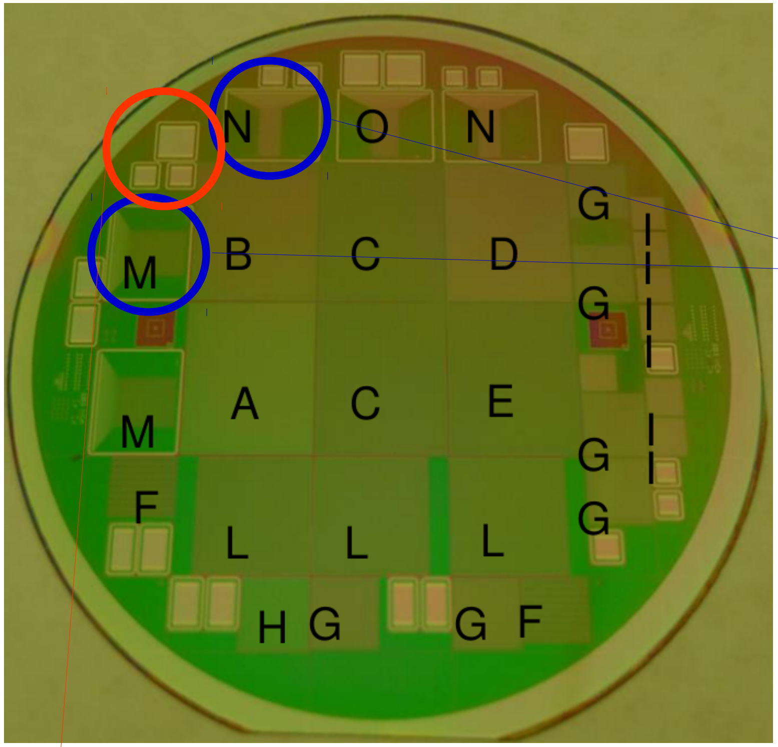
Advantages:

- Electrode distance decoupled from sensitive detector thickness.
  - Lower depletion voltage.
  - Shorter drift distance.
    - ✓ Less trapping, rad hard.
- Active or slim edges are a natural feature of 3D technology.

Challenges:

- Complex production process.
- Higher capacitance.
- Non-uniform response in columns and low field regions.

CNM small pitch double sided 3D run (7781)



Previous studies done and presented in the last RD50 workshop:

Strips: 50x50x230 μm^3 (M).
25x100x230 μm^3 (N).

Completed

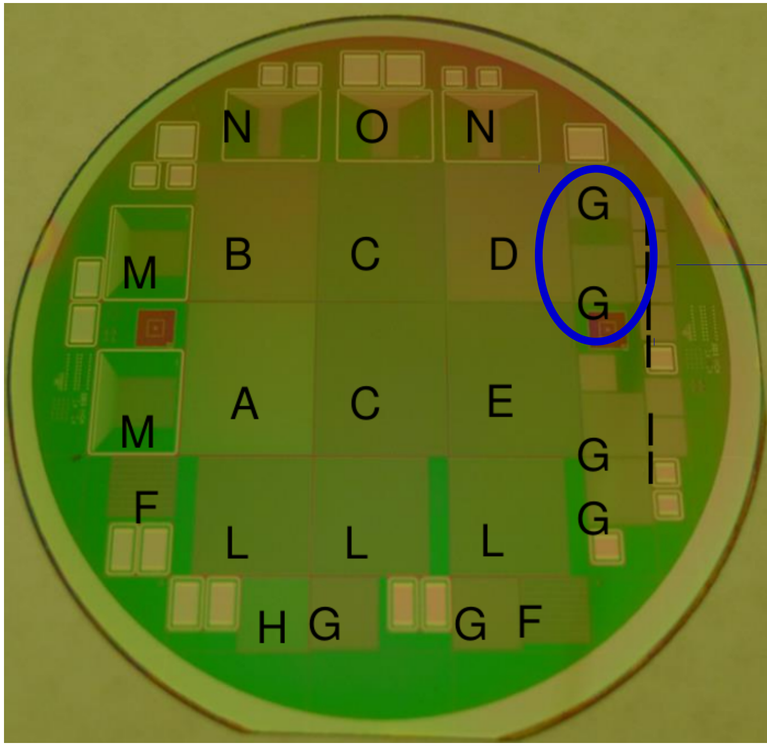
Read out using Alibava.
Irradiated up to 1E16 n_{eq}/cm^2.
Tested in a test beam at CERN (SPS).
Measured with Sr-90 source.
IV/Power studies done.

Pads: 50x50x230 μm^3 .
25x50x230 μm^3.

On going

Irradiation campaign up to 2E16 n_{eq}/cm^2 in three steps.
First step at 5E15 n_{eq}/cm^2 done.
Measurements with Sr-90 source in progress ...
IV/CV characterization and TCT measurements in progress ...

CNM small pitch double sided 3D run (7781)



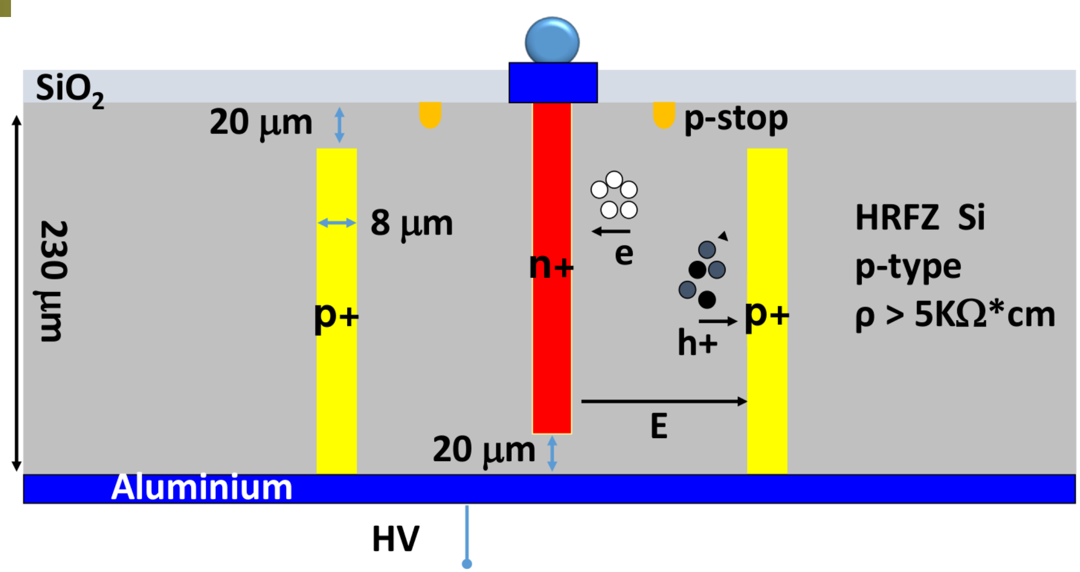
This study focuses on **unirradiated** 3D pixel (G) readout using ROC4sens chip:

► G: pixel 50x50x230 μm^3 (1E).

Produced in 2016 within the RD50 collaboration.

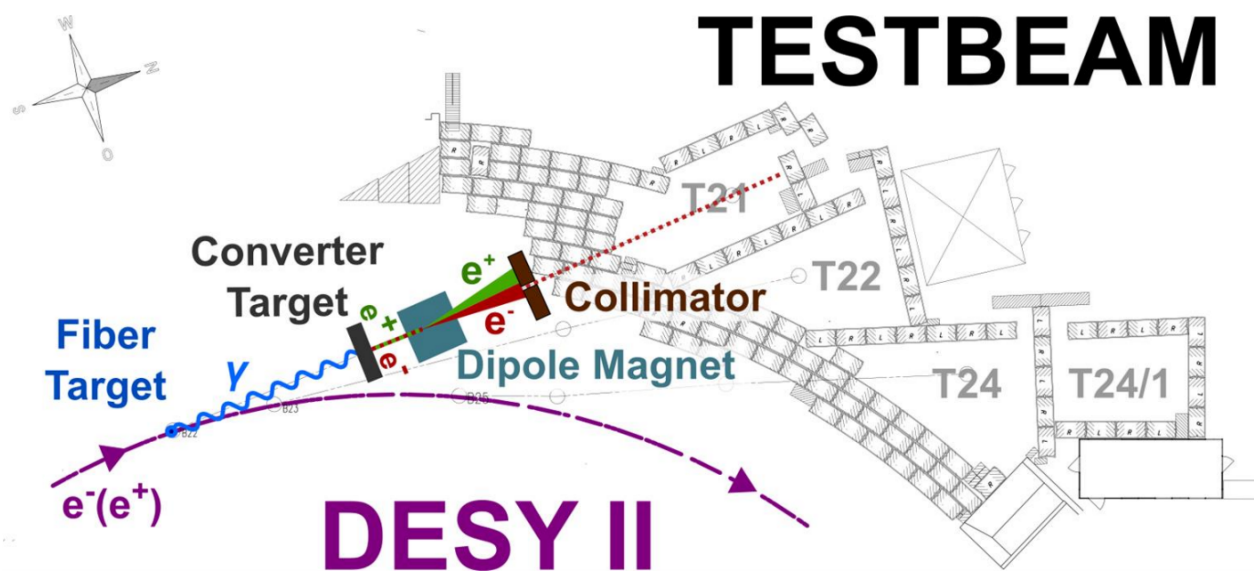
CNM double sided 3D process:

Cross section.

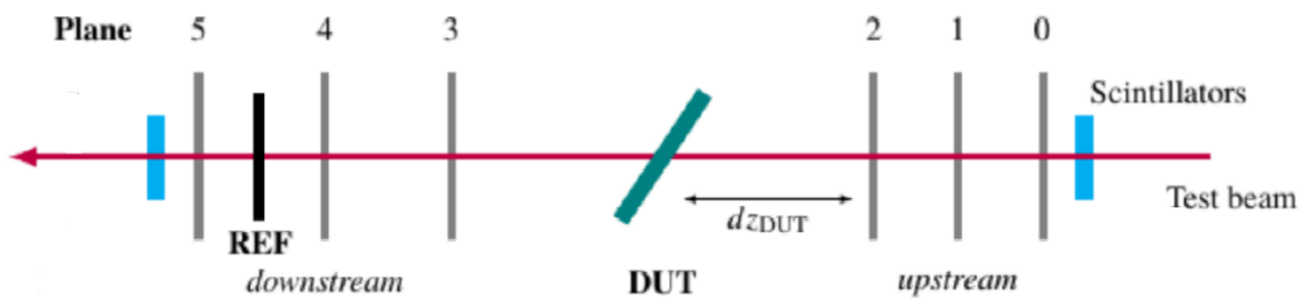


The set-up (T21 area)

November 2017

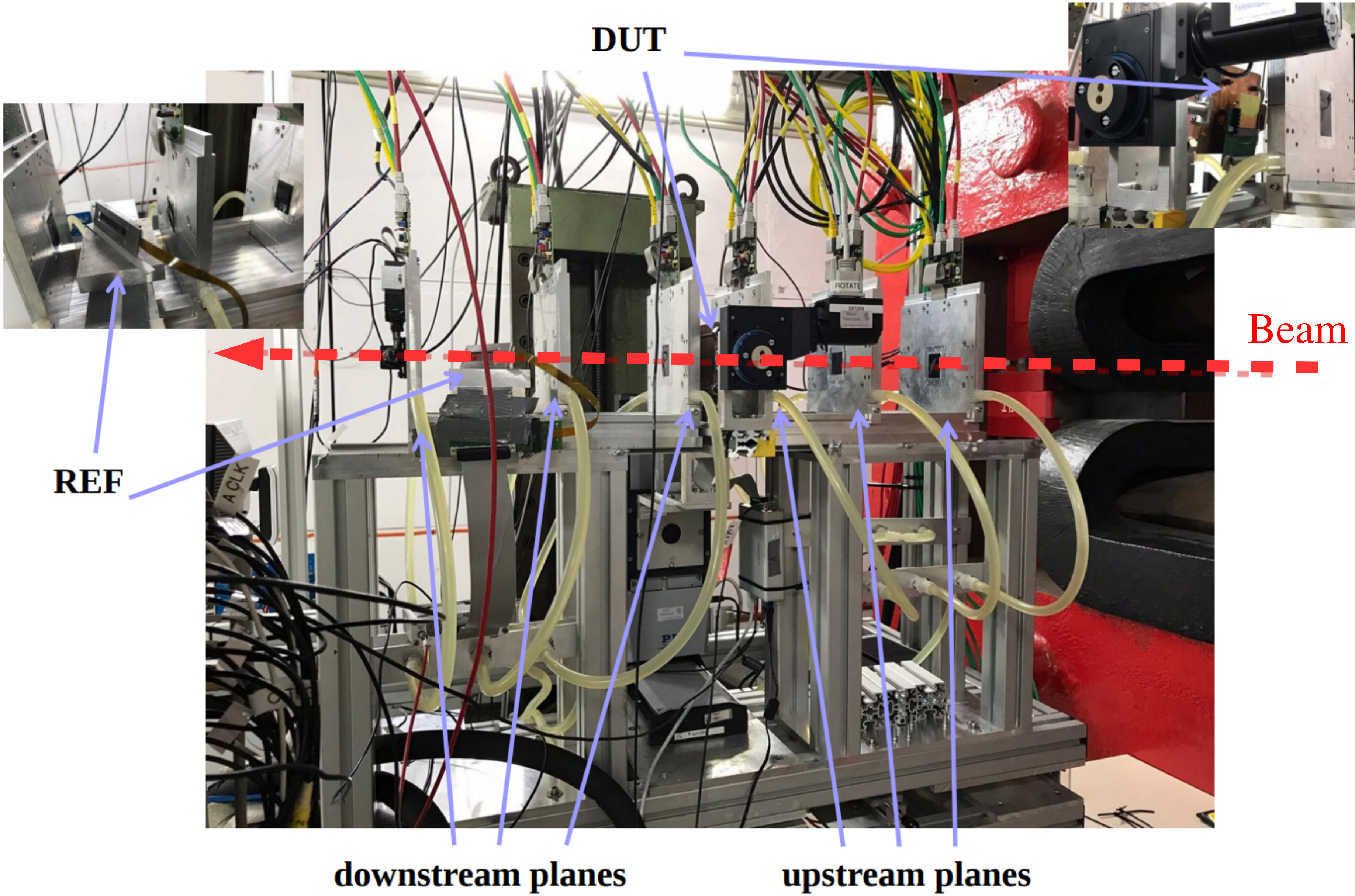


Electrons at 5.6 GeV

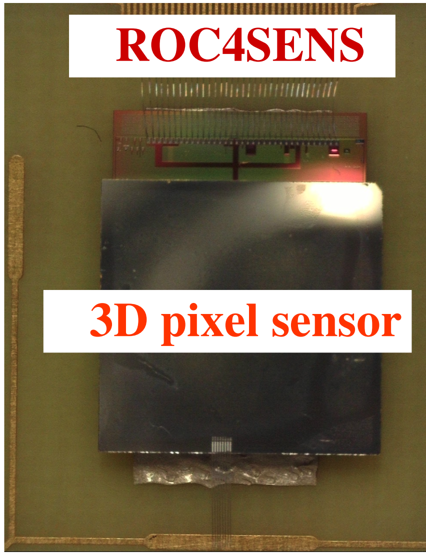


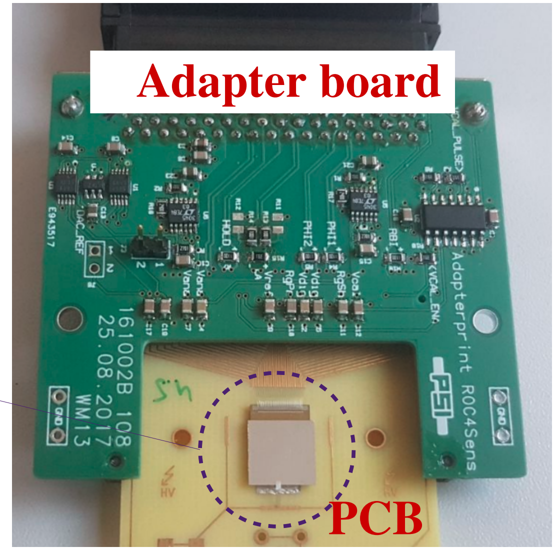
EUDET DATURA telescope for tracking.
Multiple scattering effect → telescope reconstruction in two legs.
Scintillators for triggering.
DUT like **REF**erence plane for timing (efficiency measurements).
Device **U**nder **T**est (3D pixel sensor + ROC4sens chip).

The set-up (Pictures)

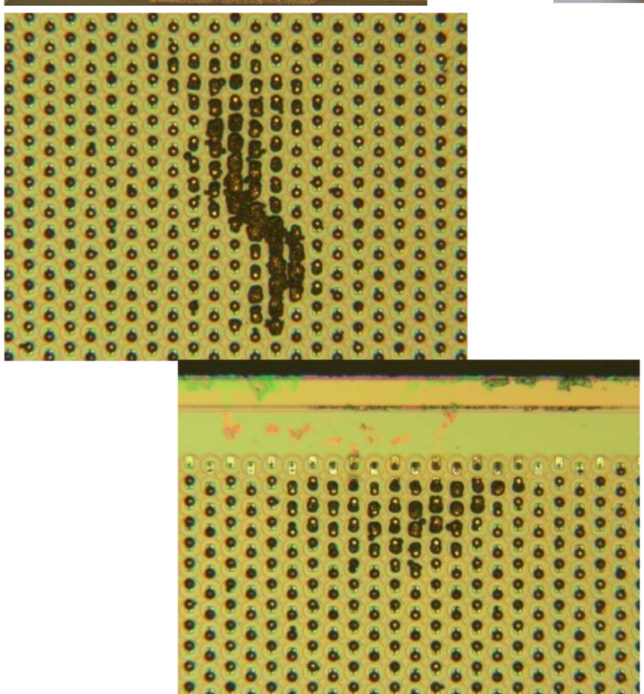


Device Under Test



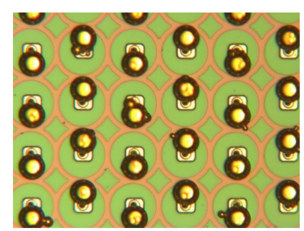


Based on CMS pixel-dtb:
- Widely used within CMS.
- Limitations in readout speed.



7781-DET-3 G5

Electroless **U**nder **B**ump **M**etallization in chips "G" ROC4sens at CNM.



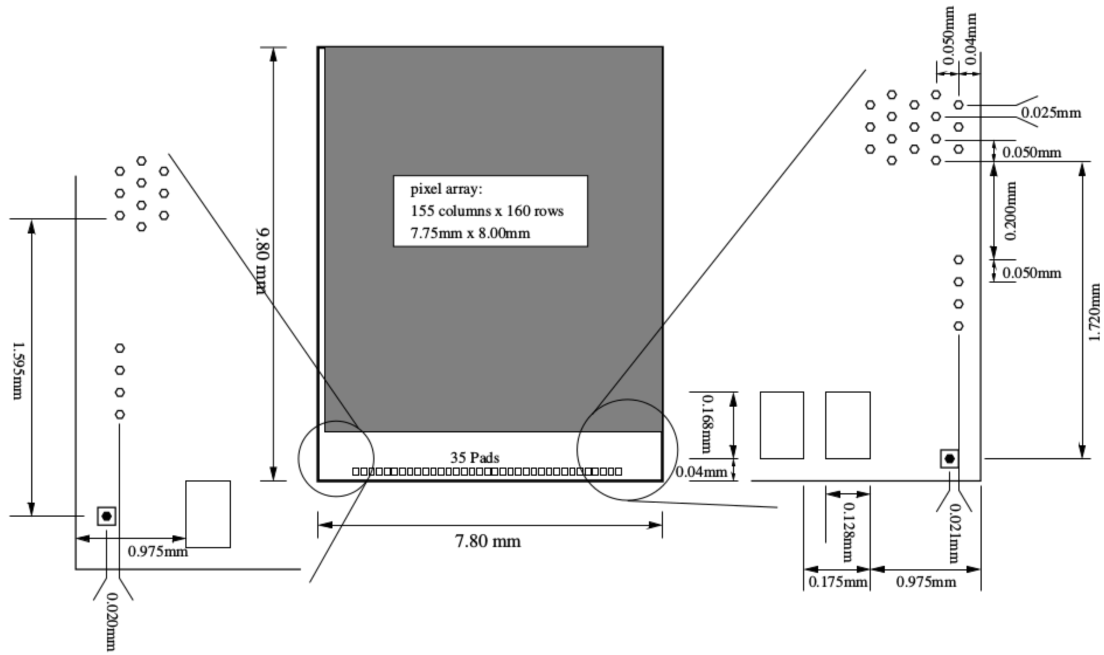
Flip-chipping of ROC4sens on 3D sensors done at IZM.

CMS R&D ROC: ROC4SENS

More information on Tilman's talk tomorrow → “ROC4SENS -- a generic readout chip for sensor studies”

Size: $9.80 \times 7.80\ mm^2$.

- $155 \times 160 = 24800$ pixels.
- Bump pads staggered.
- Pattern fits Phase 0 sensors.
- 2×4 bump pads for guard ring connection.
- 35 wire bond pads with pitch 175 um.
  - 2 power lines, 2 GNDs.
  - 4 reference Voltages.
  - 5 LVDS signals in.
  - 3 digital inputs.
  - 2 LVDS signals out.

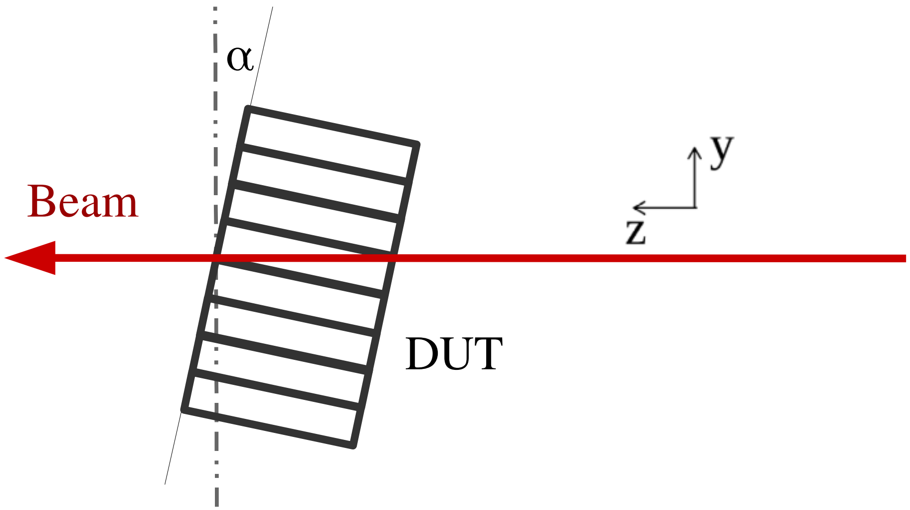


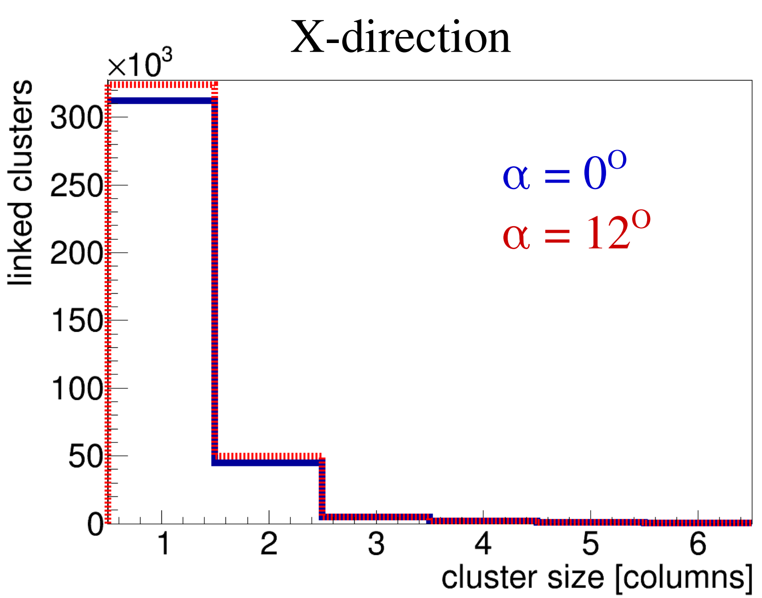
- Analogue signal transmission.
- Simple operation.
- Small pitch for phase II sensor development: $50 \times 50\ um^2$.
- Expected to be as radiation hard as the tested sensors.

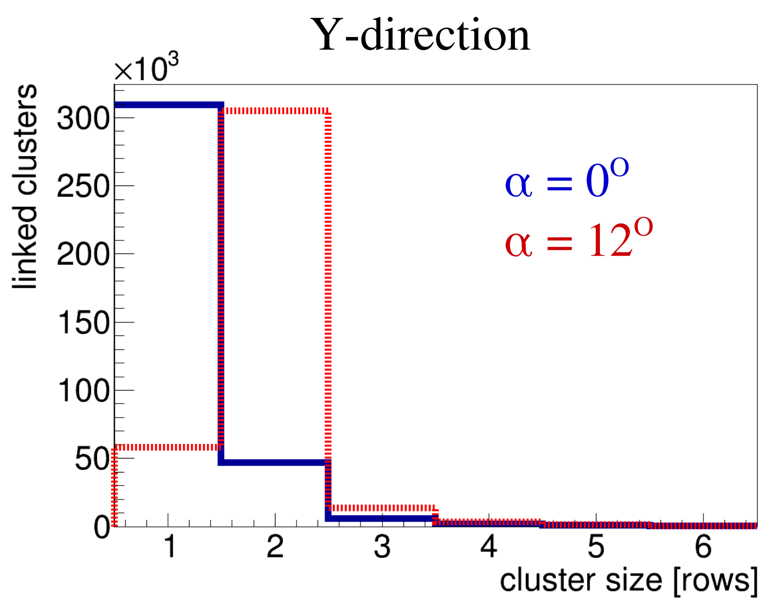
Test beam results

$$\arctan\left(\frac{pitch}{thickness}\right) = \arctan\left(\frac{50}{230}\right) = 12.26$$

- Available data for two assemblies.
- High statistics at $\alpha = 0^{o}$ (perpendicular incidence) and $\alpha = 12^{o}$(optimal incidence angle).
    Efficiency, charge collection, spatial resolution …
- Angle scan for one assembly.
    DUT resolution vs track incidence angle.
- Room temperature.
- Vbias = 25 V (fully depleted above 10 V).

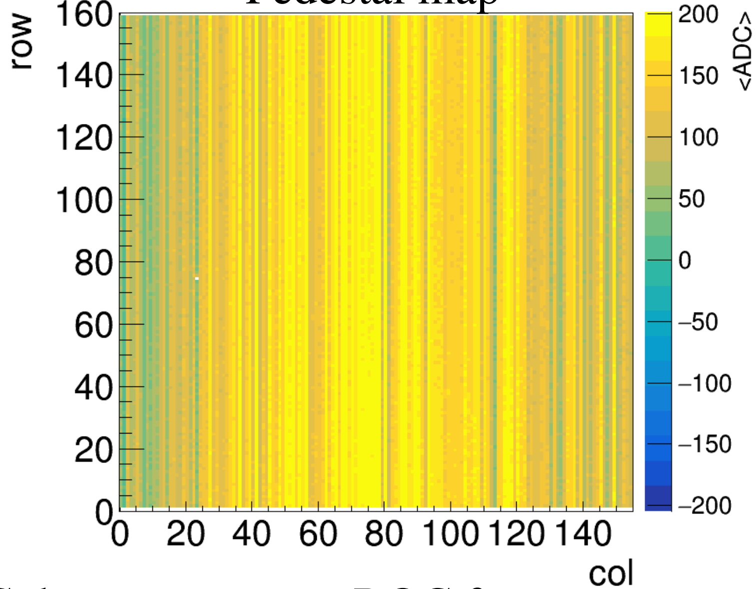




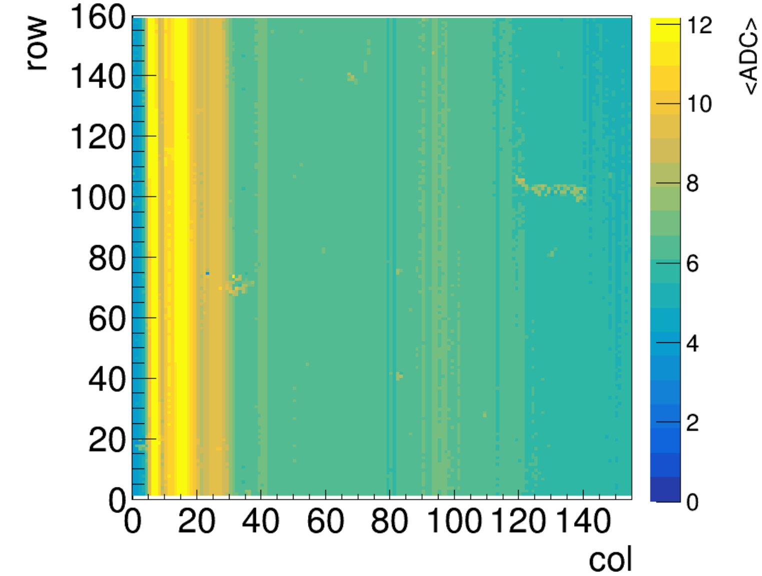


Test beam results

Pedestal map

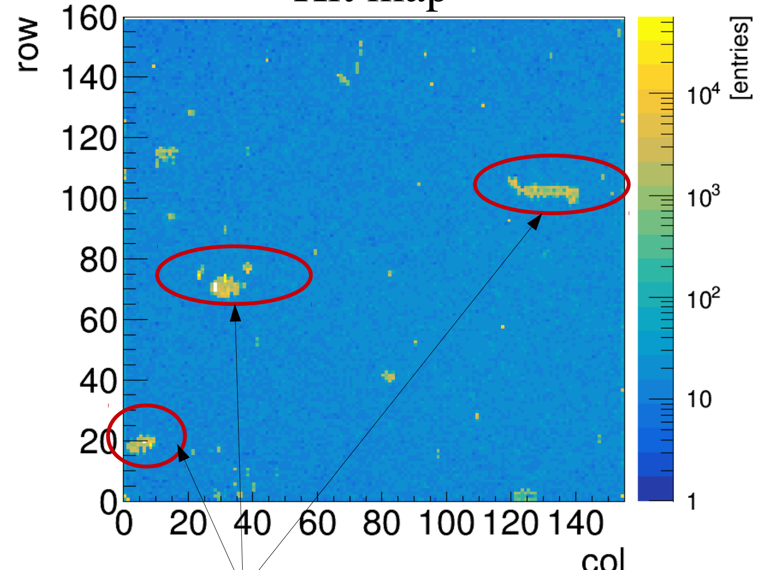


Noise (RMS)

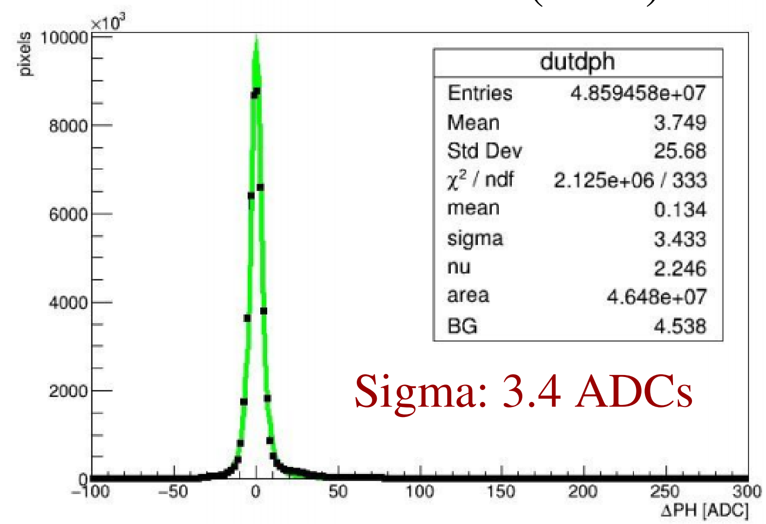


Column pattern → ROC feature: gyrator circuit variation at the end of each column.

Hit map

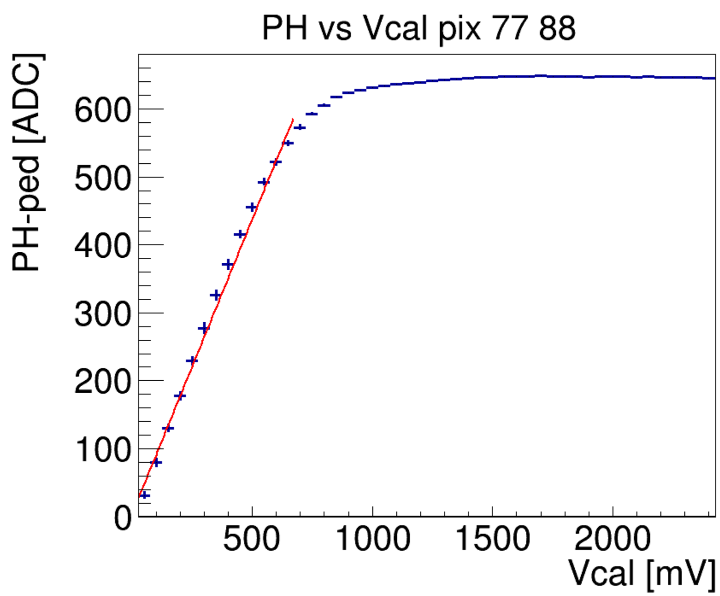


Noise distribution (RMS)

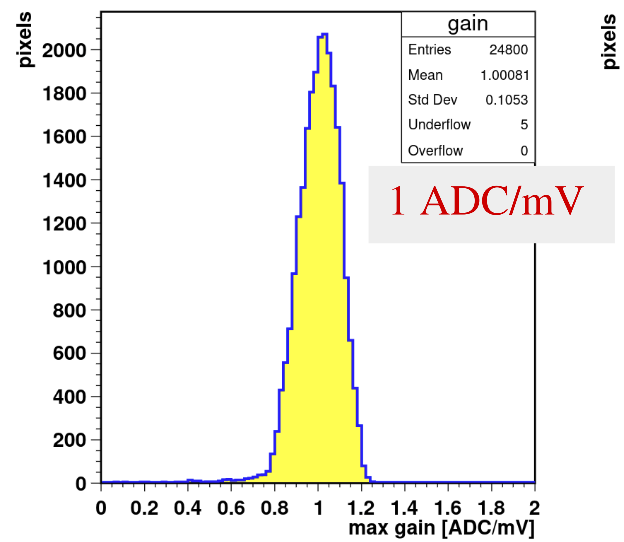


Bad areas on the hit map due to the UBM process.

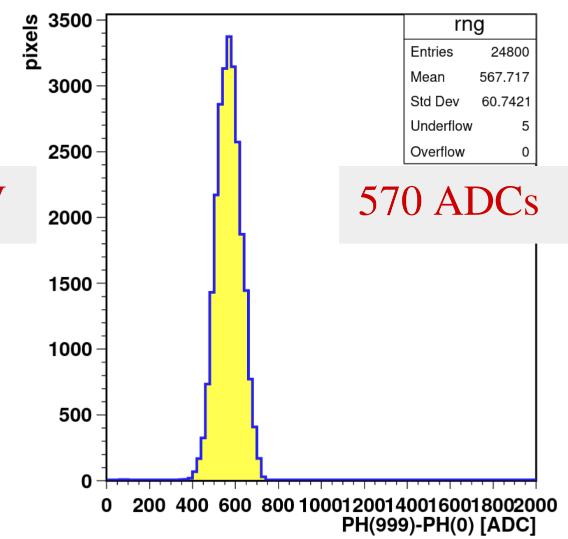
Test beam results: charge distribution



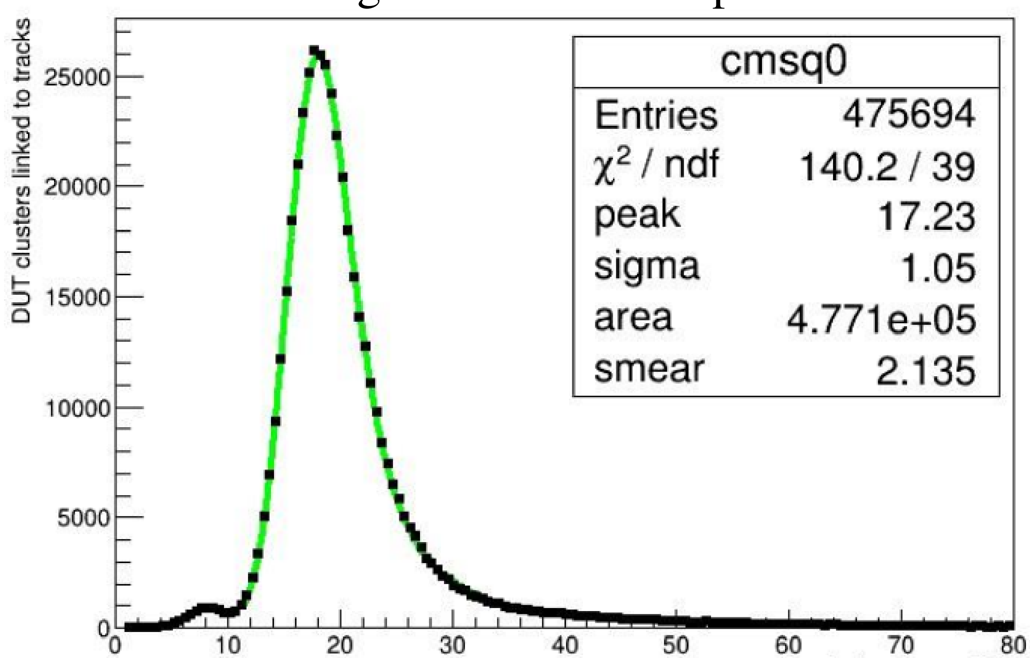
Gain calibration



Dynamic range



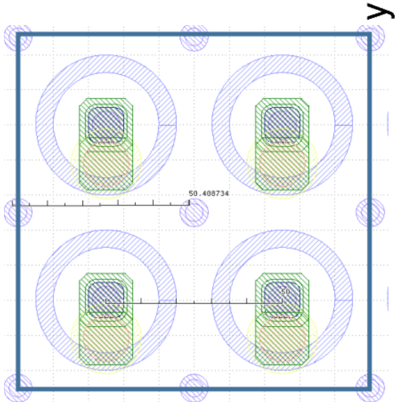
Charge distribution shape

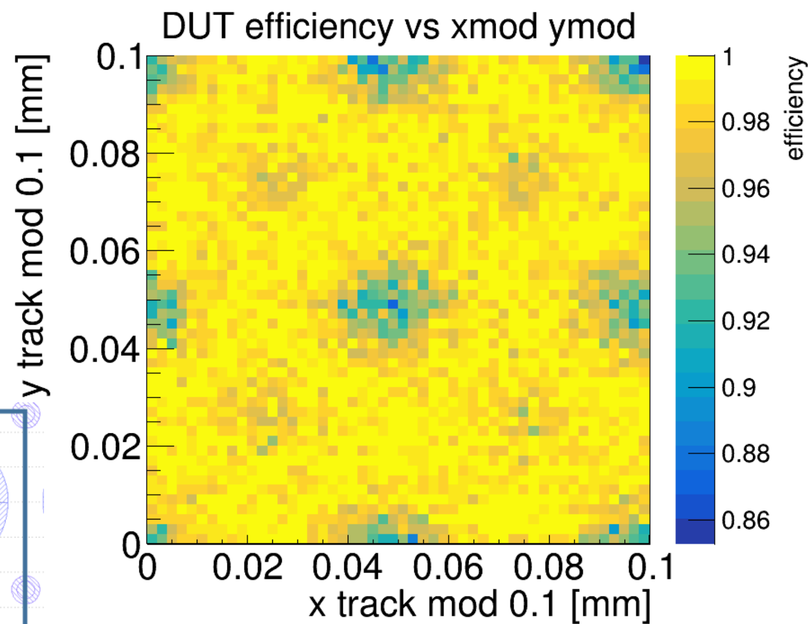


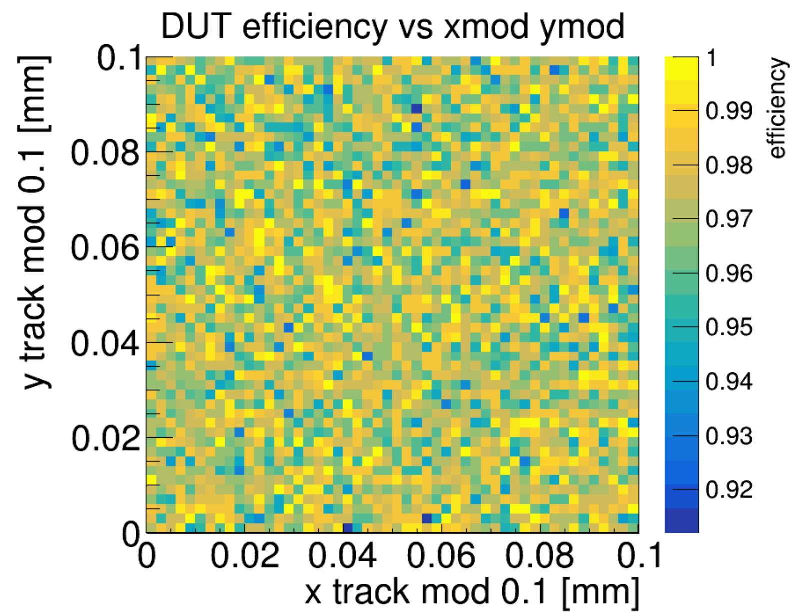
a.u.

Test beam results: efficiency measurements

Sensor 1



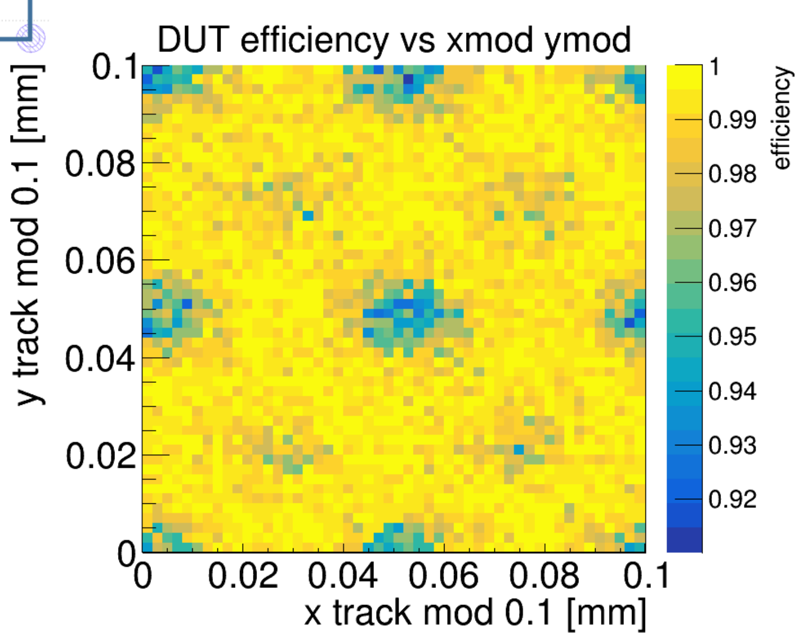


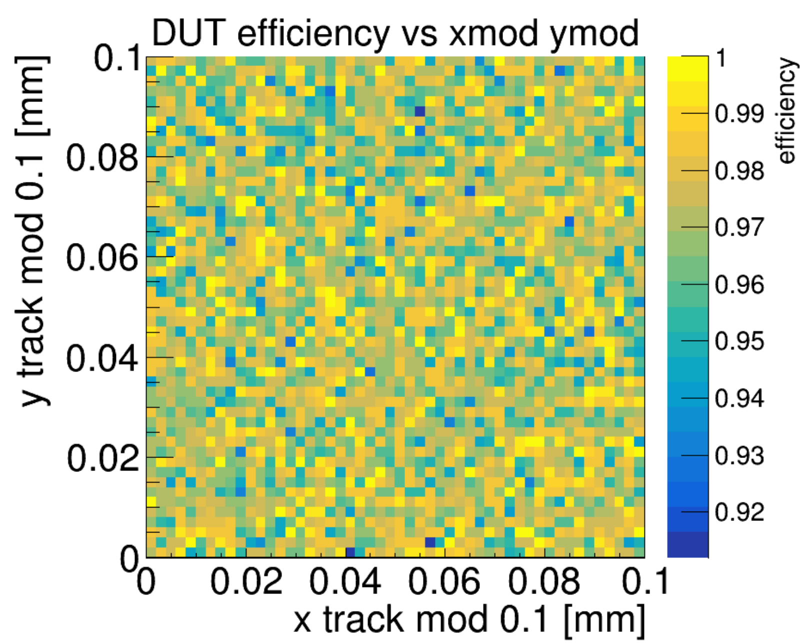


0^{o}

12^{o}

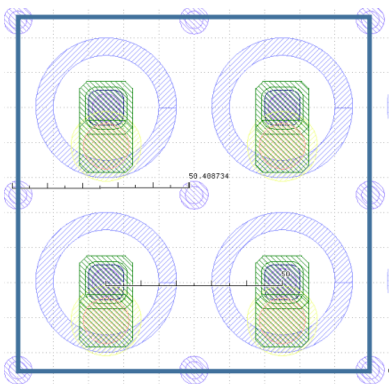
Sensor 2

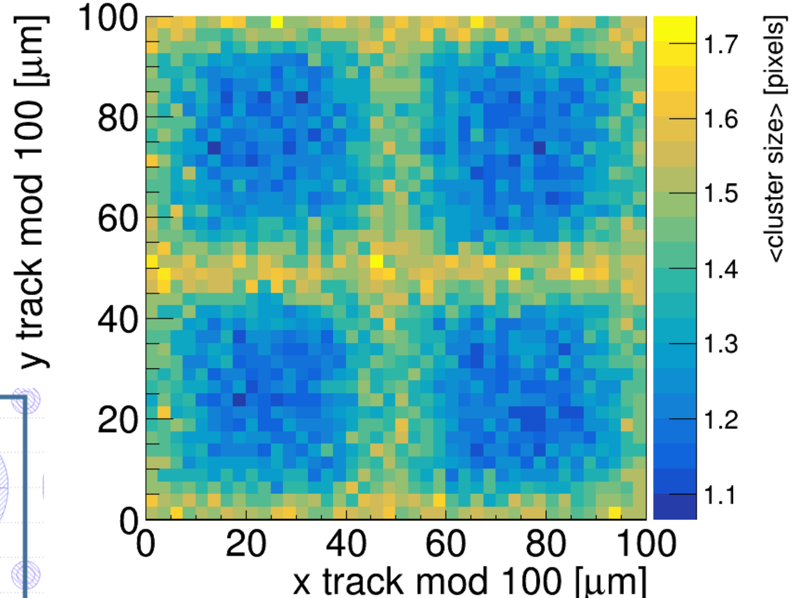


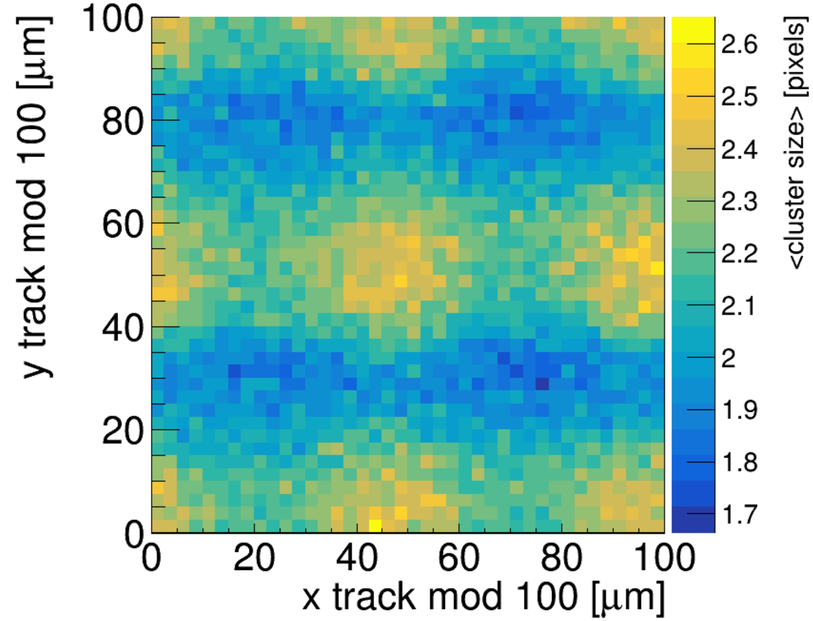


Test beam results: cluster size

Sensor 1



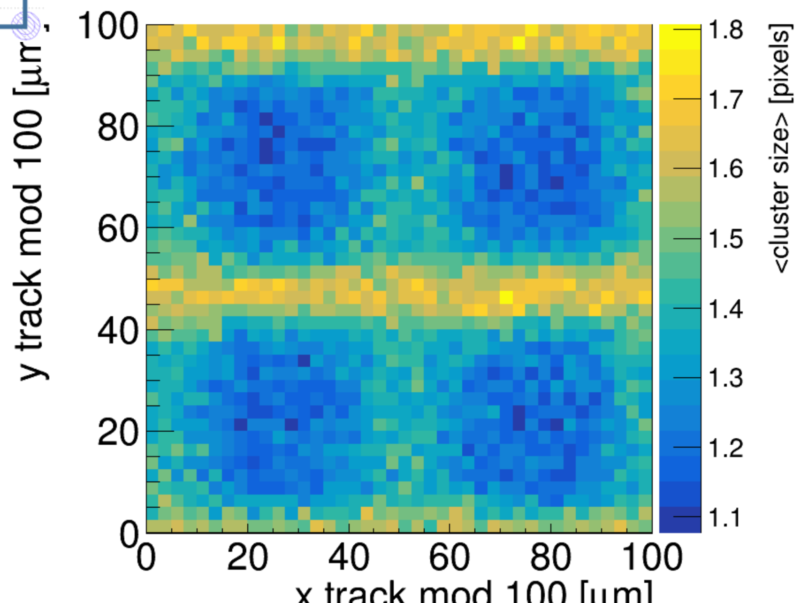


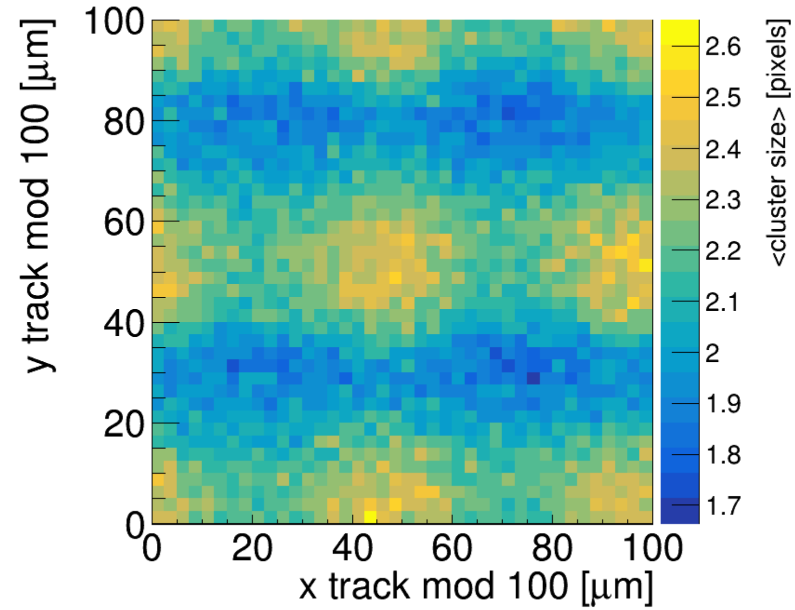


0^o

12^o

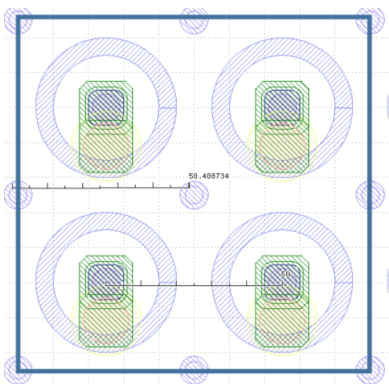
Sensor 2

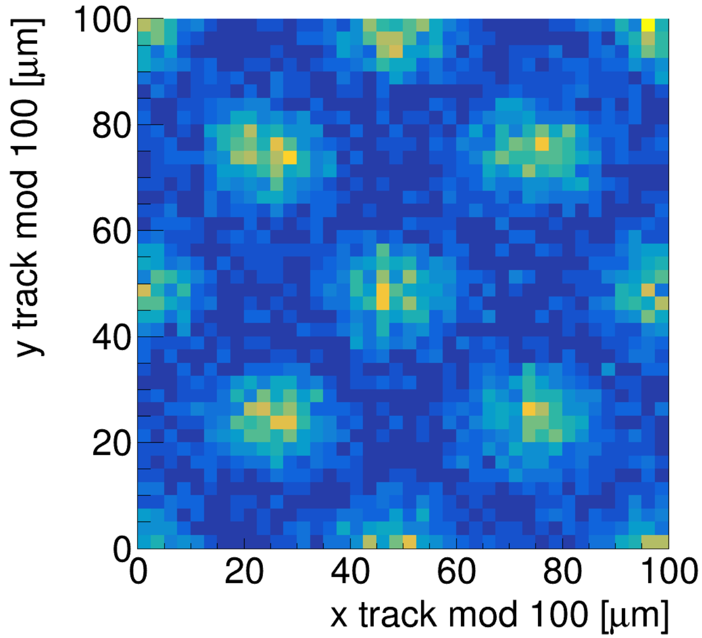


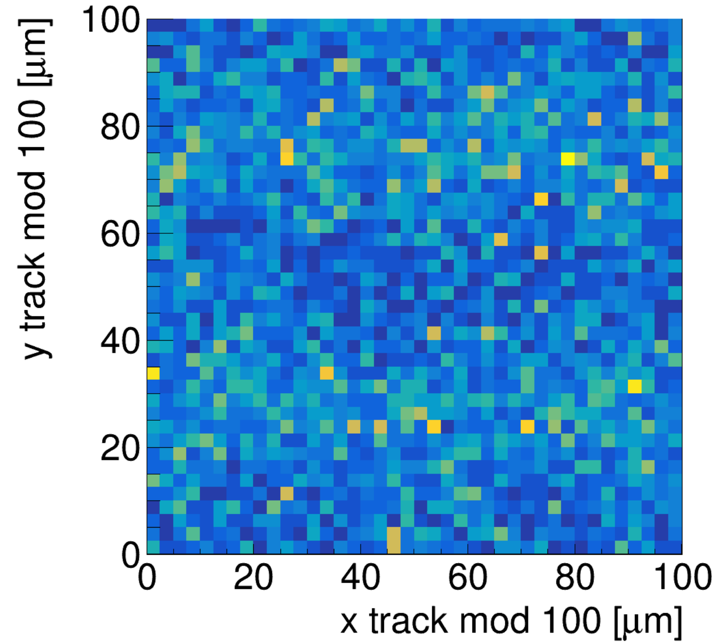


Test beam results: cluster charge (a.u.)

Sensor 1



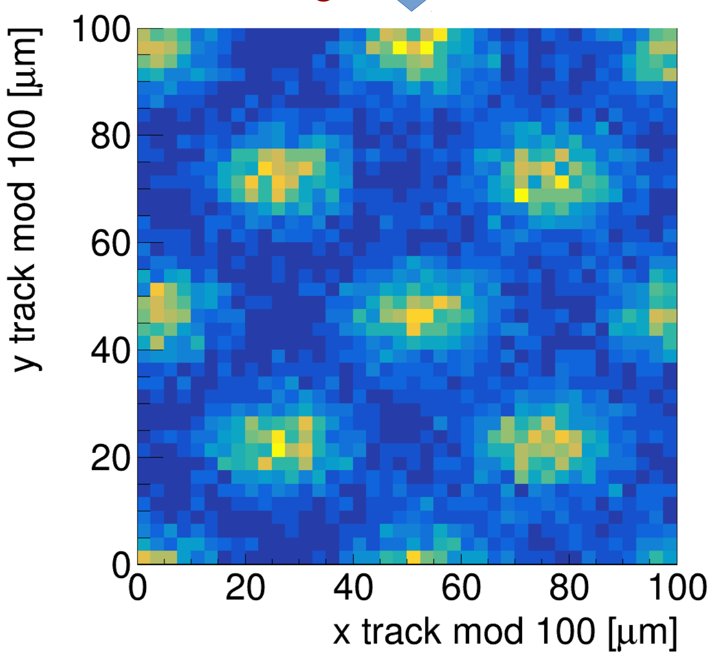


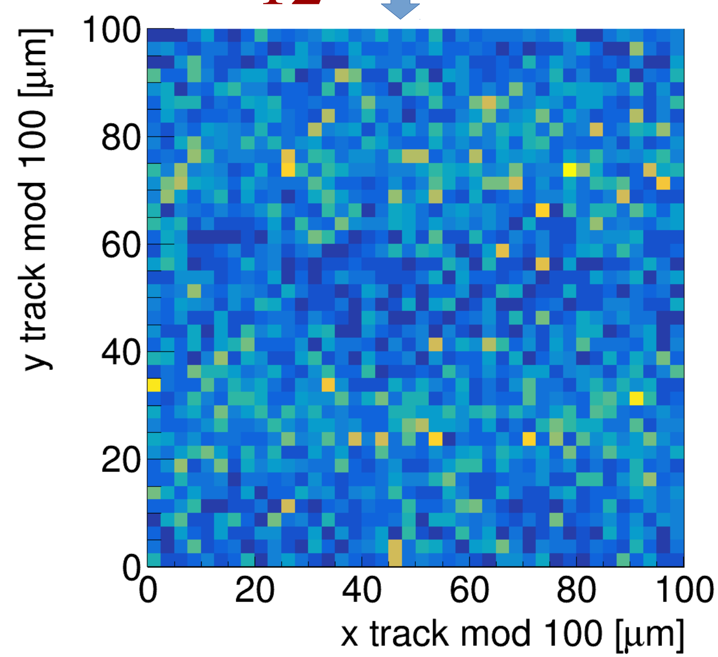


0^{o}

12^{o}

Sensor 2

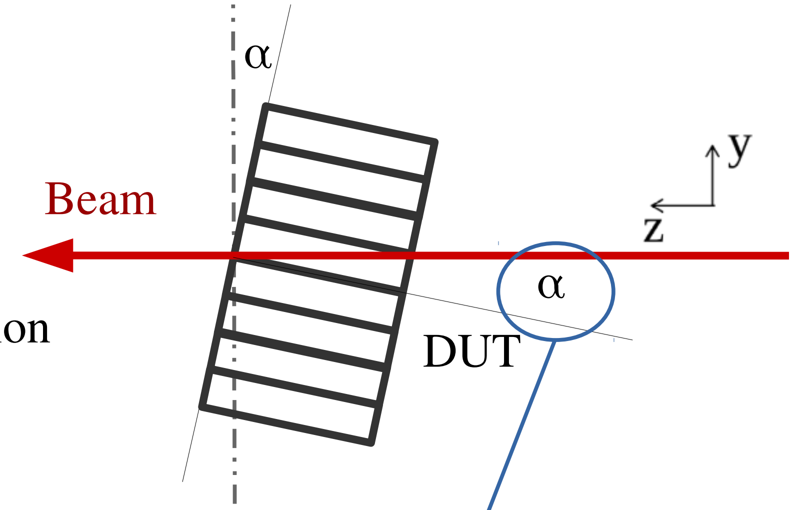


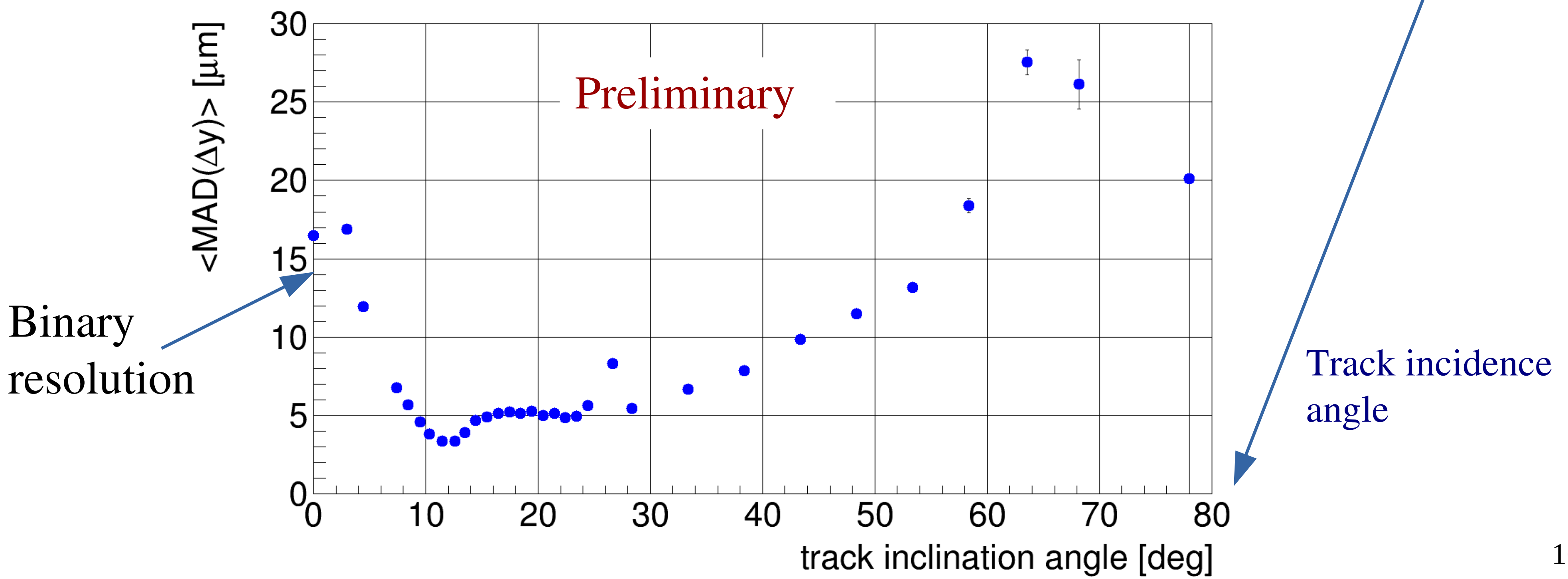


Test beam results:
spatial resolution vs track incidence angle

- Extrapolation of upstream and downstream tracks to the DUT
- Residuals: cluster position (DUT) – track extrapolation

- DUT spatial resolution:
  width of the residual distribution ⊖ telescope spatial resolution
- Only clusters within the Landau peak.





Summary and next steps

First results of small pitch unirradiated 3D pixel sensors were presented.

The ROC4sens read-out chip works as expected.

The characterization presented here: spatial resolution, charge collection, efficiency and noise are very promising.

The two assemblies have been already irradiated at 3E15 n_{eq}/cm^2 and we will try to measure them again this December at DESY test beam.

Acknowledgments

We would like to give our special thanks to Tilman Rohe and Beat Meier (PSI).

PAUL SCHERRER INSTITUT

PSI