Simulation of CMOS Strip Sensors

Naomi Davis on behalf of the CMOS Strips Collaboration

5th Allpix Squared User Workshop

May 23rd, Oxford UK

HELMHOLTZ technische universität dortmund Fachhochschule Dortmund University of Applied Sciences and Arts universität freiburg UNIVERSITÄT BONN DESY.

Single-Vendor Problem

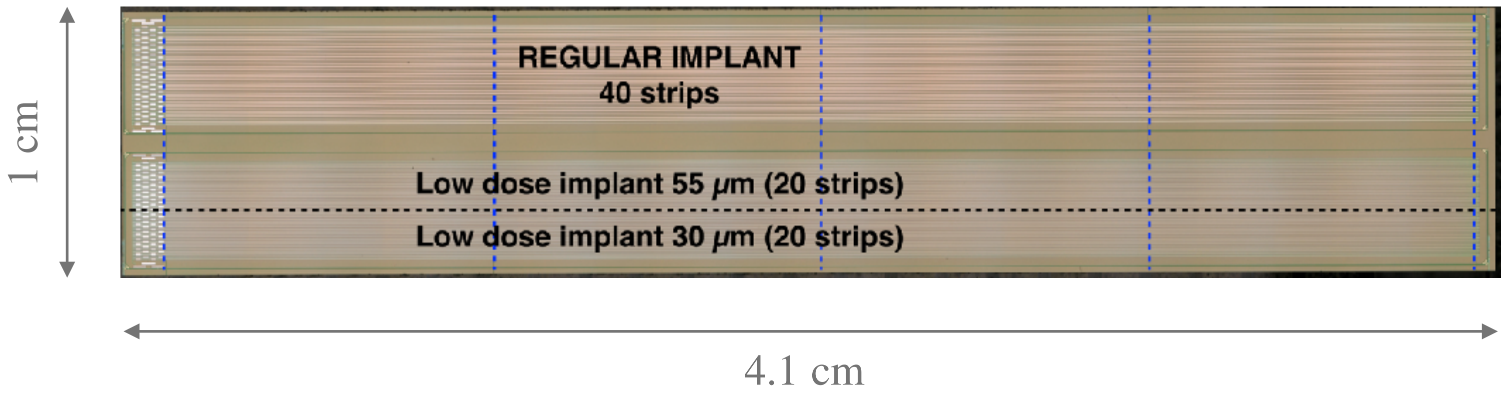
- Silicon sensors have become indispensable in high energy physics.
- … only available from few foundries

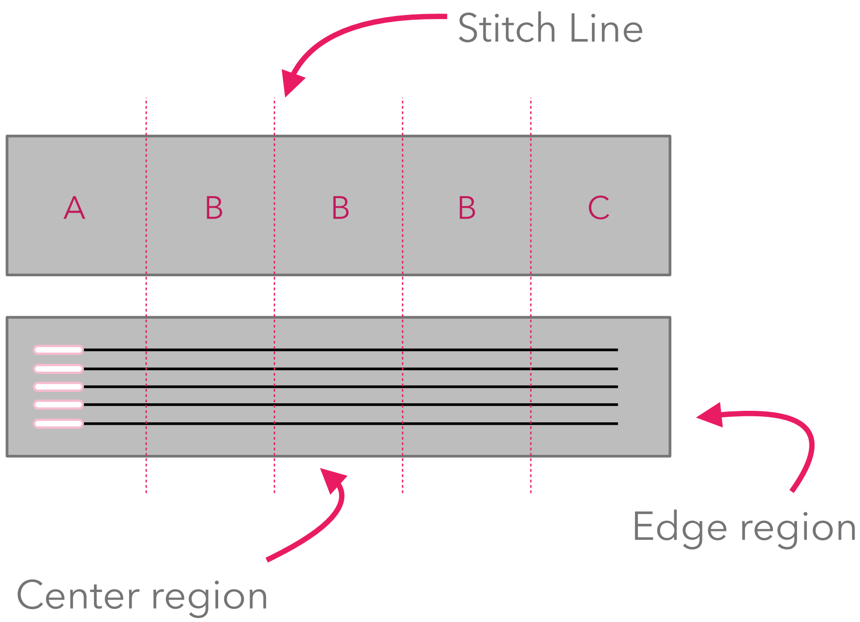
Alternative vendors ?

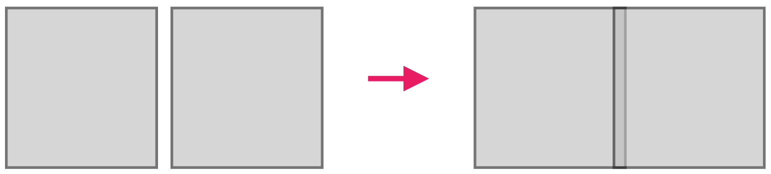
- Vendor diversification through standardised industrial CMOS process
- Fast, cheap and large-scale production

CMOS Strip Sensors

- n-in-p sensor, 150 nm LFoundry technology
- 150 ± 10 um thickness, 75.5 um strip pitch
- Different formats through stitching technique





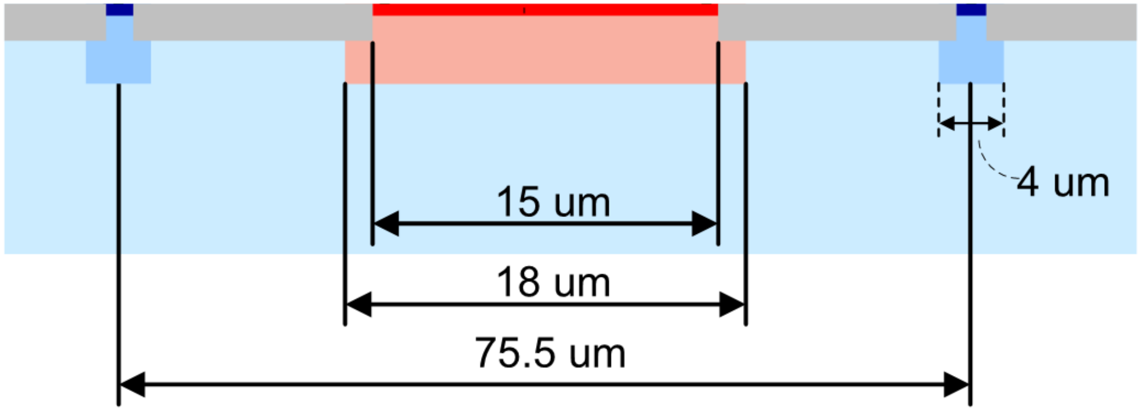


L. Diehl et al., NIMA, Vol 1022 (2022), https://doi.org/10.1016/j.nima.2022.166671

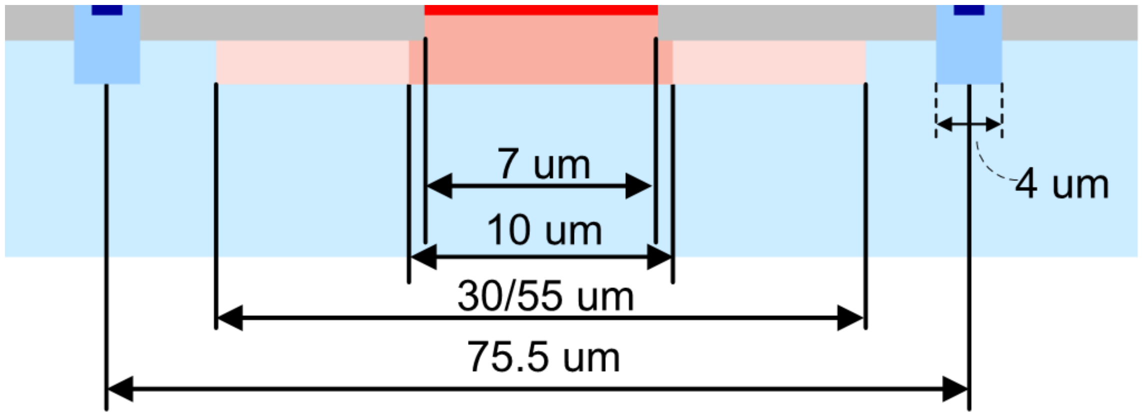
CMOS Strip Sensors

- Strip-implant varies in width and doping concentration

Regular strip implant



Low Dose (LD) 30/55 strip implant



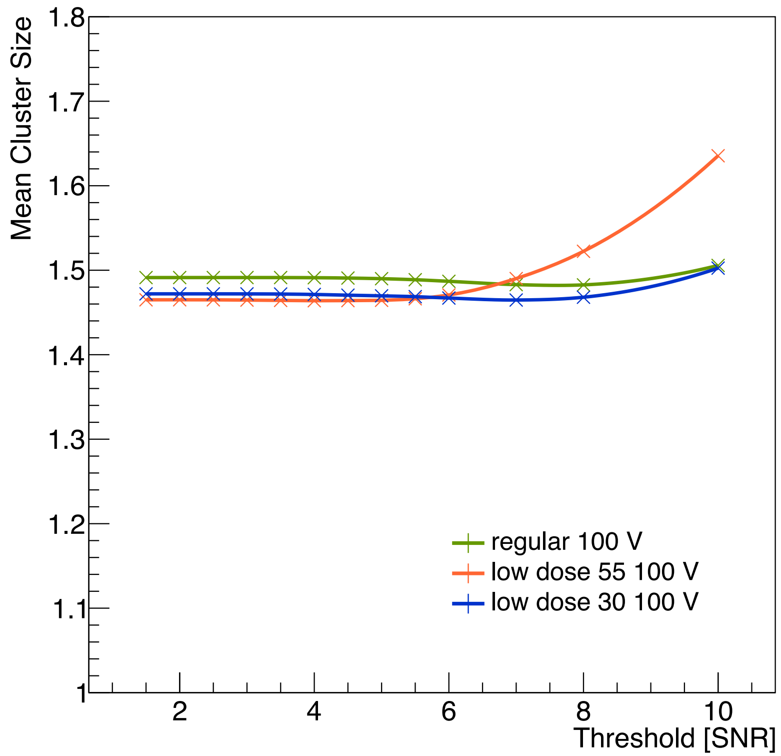
L. Diehl et al., NIMA, Vol 1022 (2022), https://doi.org/10.1016/j.nima.2022.166671

Why are we doing simulations?

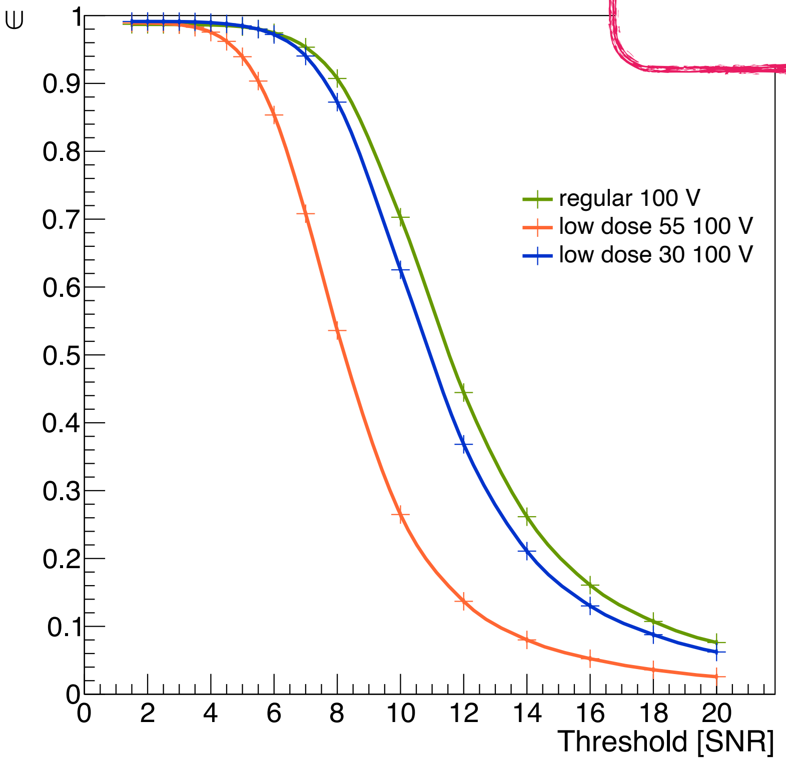
Performance differences of strip layouts in test beam data

- Lower cluster sizes and efficiency drop for Low Dose designs

Mean Cluster Size



Efficiency



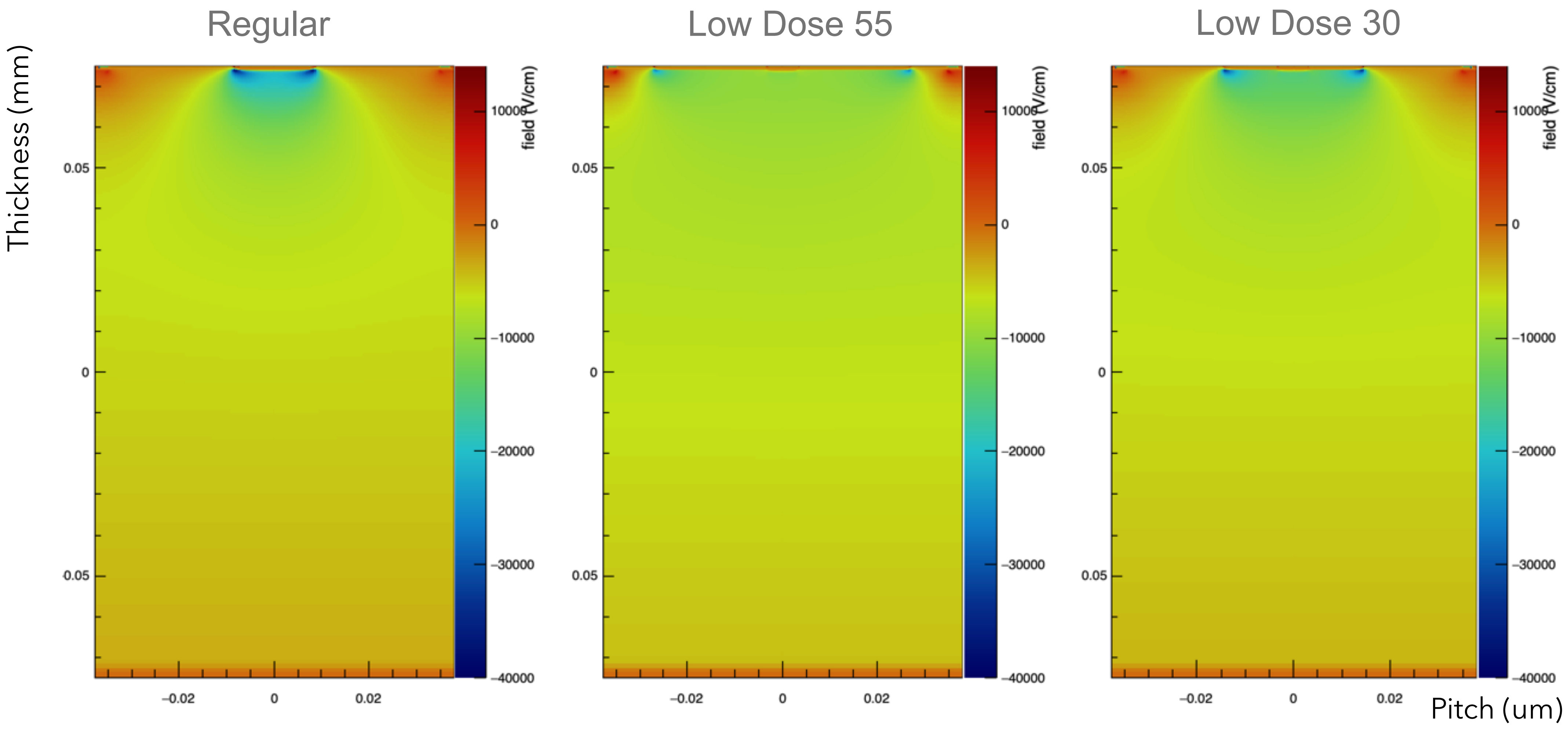
Test Beam Data of unirradiated sample

D. Dannheim et al., J. Instr. 16 (2021), https://doi.org/10.1088/1748-0221/16/03/P03008

Electric Field Strength

Simulation of the electric field within the sensor @100V

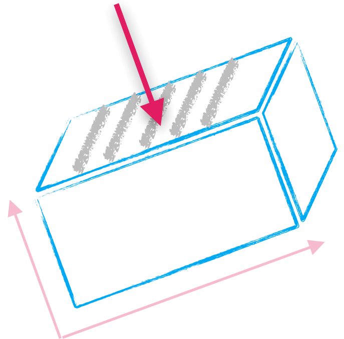
- Input: Electrostatic TCAD simulation @100V bias (*)



(*) By Iveta Zatocilova

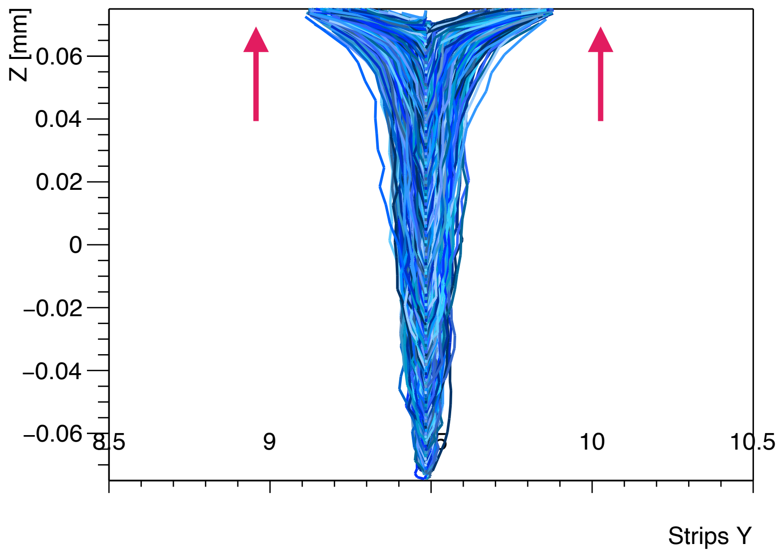
Charge Carrier Propagation

Simulation of charge carrier motion within the sensor

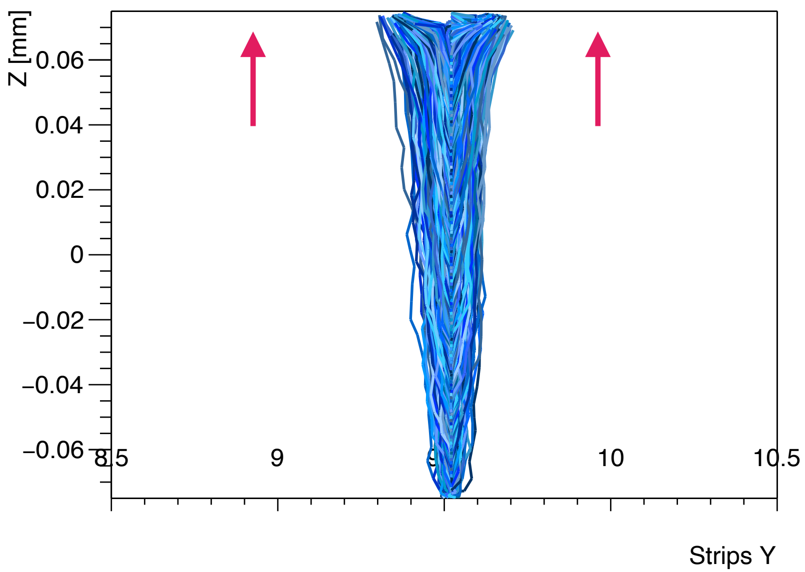


- Regular & Low Dose 30: strong drift towards collection electrode

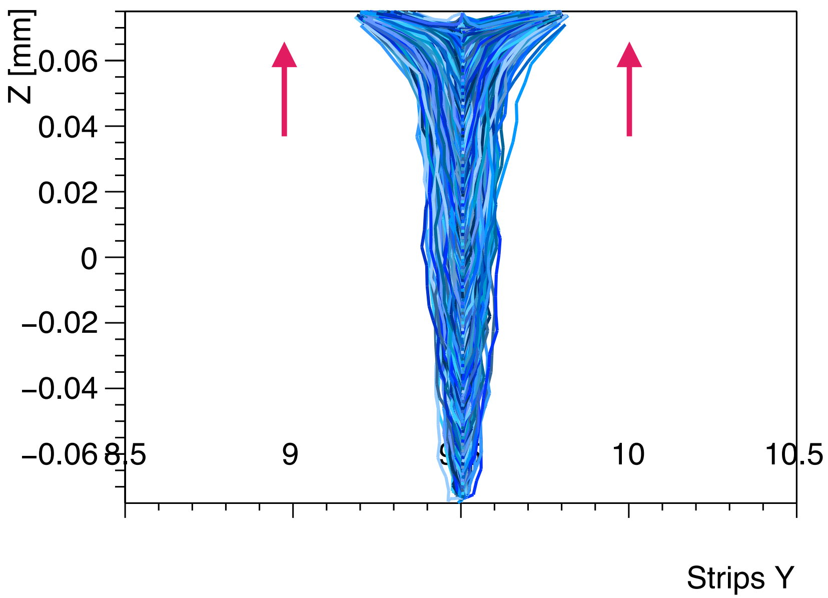
Regular



Low Dose 55

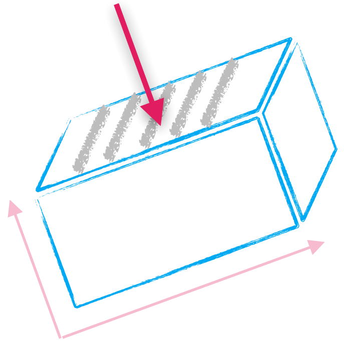


Low Dose 30



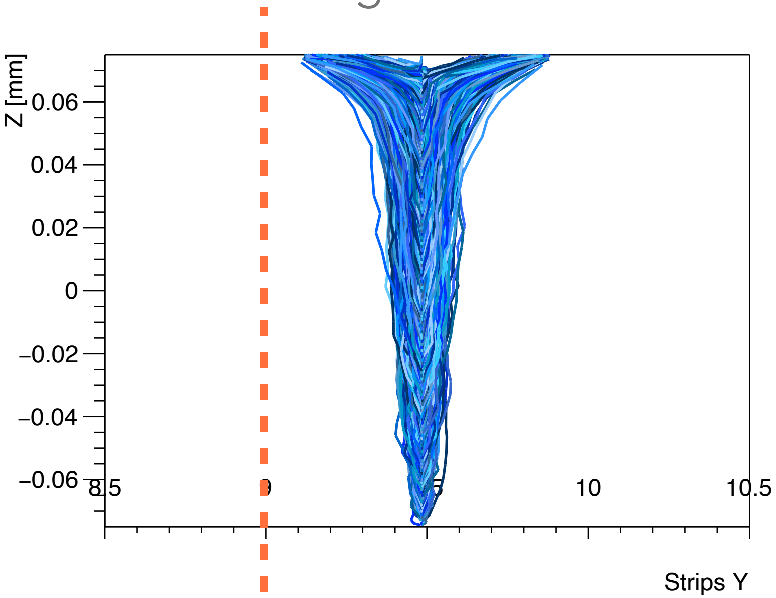
Charge Carrier Propagation

Simulation of charge carrier motion within the sensor

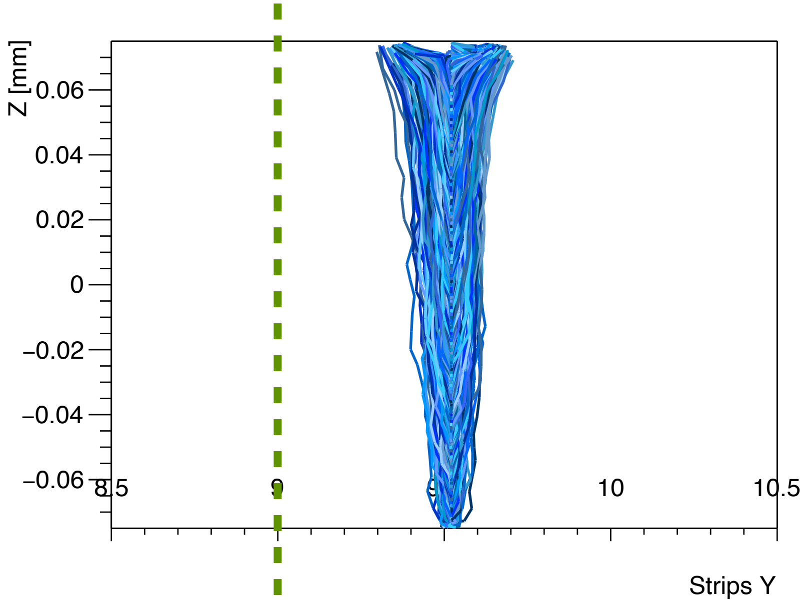


- Regular & Low Dose 30: strong drift towards collection electrode

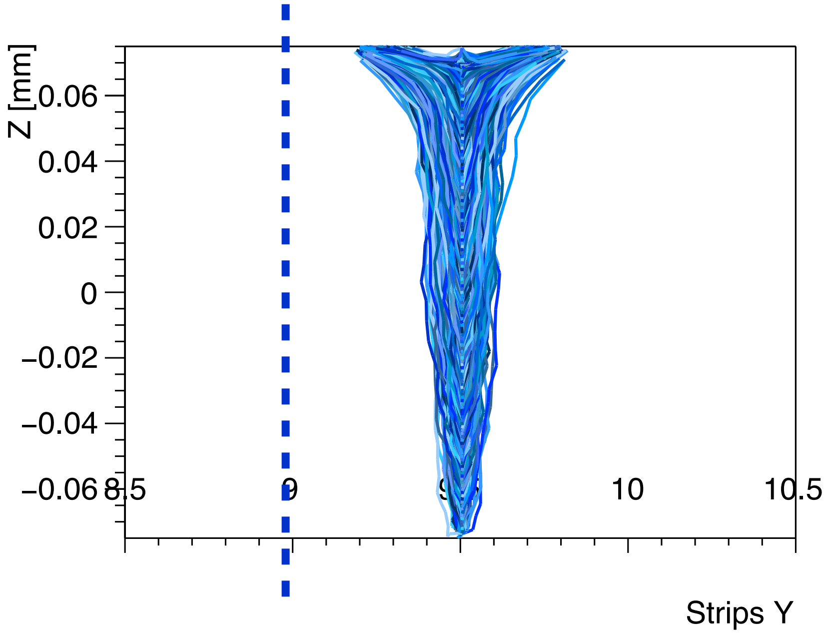
Regular



Low Dose 55



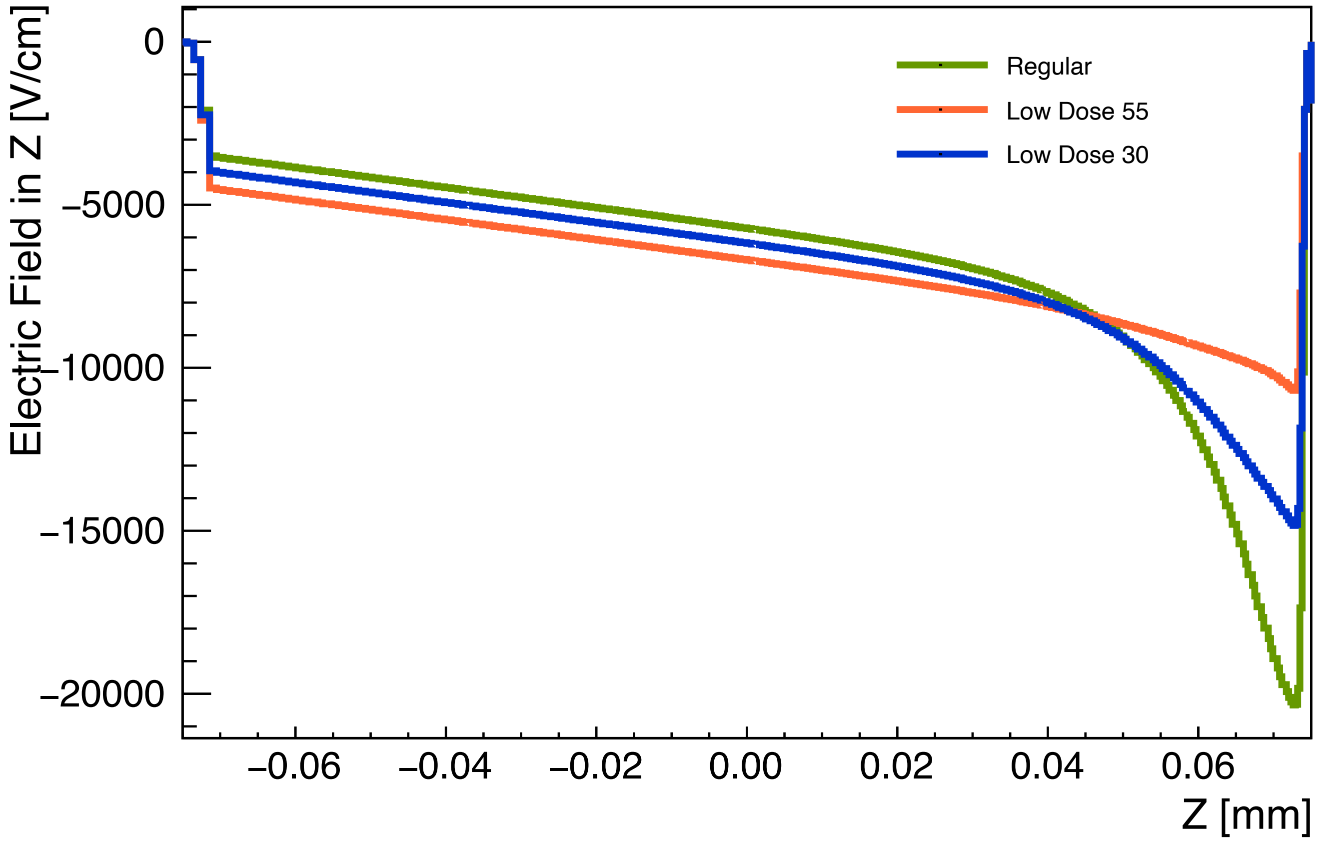
Low Dose 30



Charge Carrier Propagation

Simulation of the charge carrier path within the sensor

- Low Dose: decreasing field strength with implant width
- Regular: highest field strength around electrode
- trend towards higher cluster sizes in Regular and LD30 data

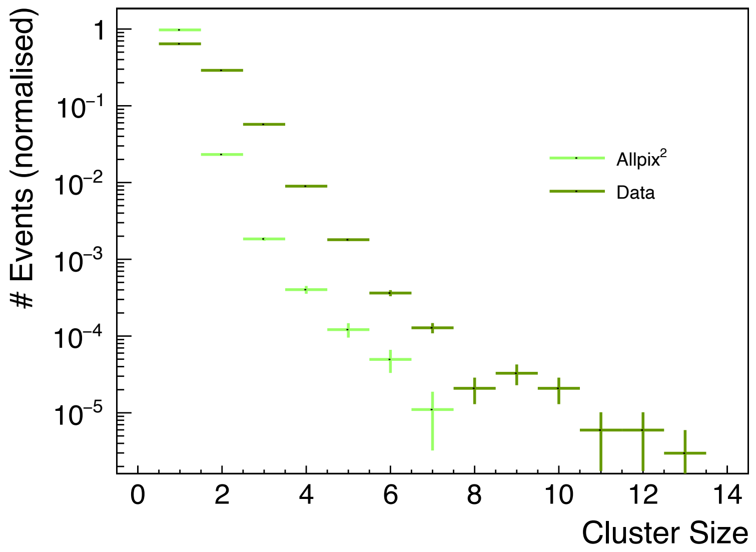


Cluster Size

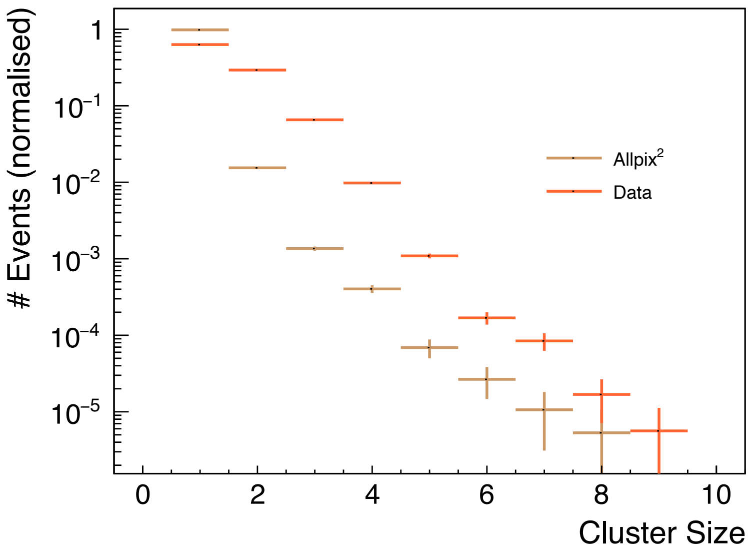
Comparing Simulation results to test beam data

- Large deviations and higher cluster sizes in Regular layout data
- Optimisation of TCAD fields needed e.g. based on electrical characterisation

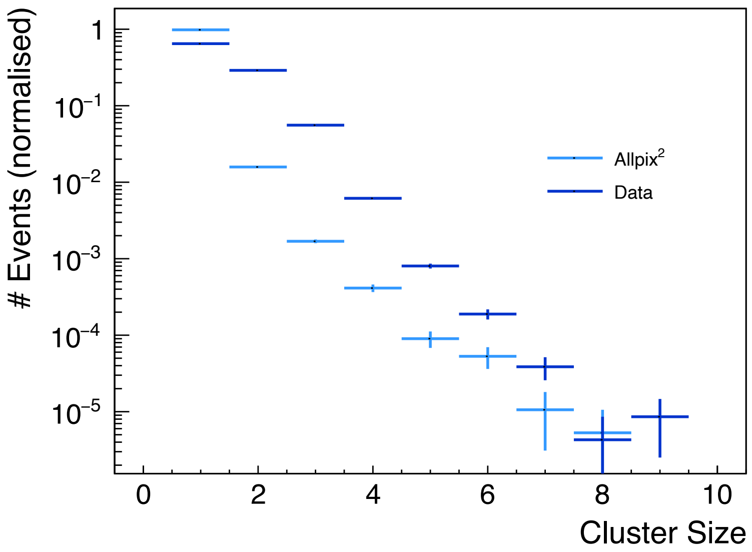
Regular



Low Dose 30



Low Dose 55



!1077 Beam Shape Variety in DepositionGeant4 Module

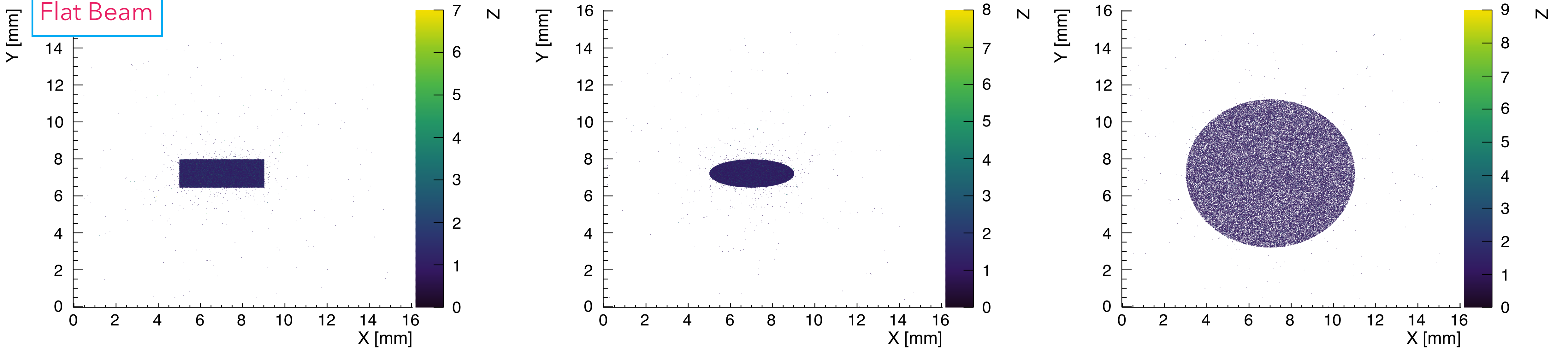
- `rectangle`, `ellipse` and circle beams in DepositionGeant4 (flat and gaussian)
- `incident_track_position` visualises the beam in 2D
- `beam_size` parameter defines dimension in (x, y)
- backwards capability: circle beam with one `beam_size` value for beam sigma in r

```
enum class BeamShape {
   CIRCLE, ///< Circular beam
   ELLIPSE, ///< Elliptical beam
   RECTANGLE, ///< Rectangular beam
};
```

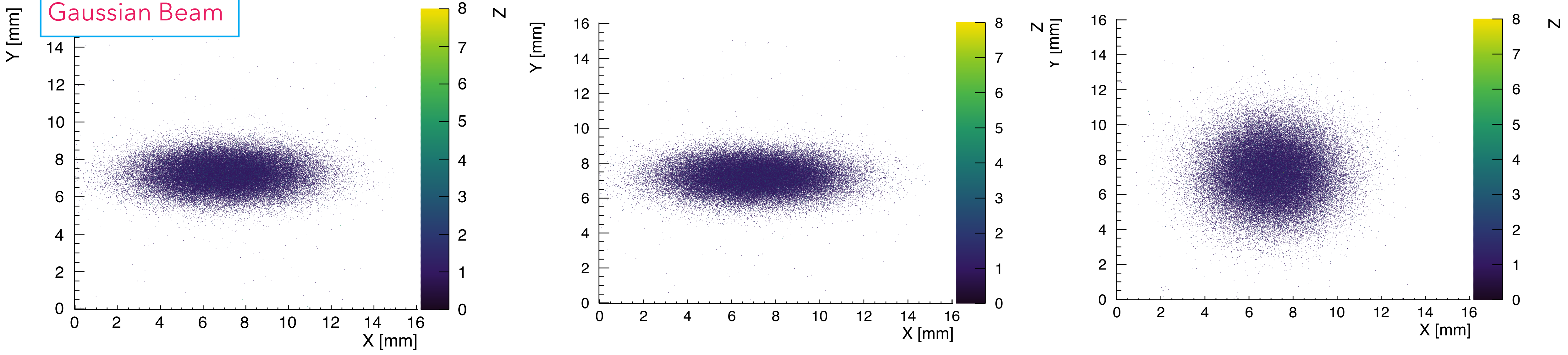
```
[DepositionGeant4]
source_type = "beam"
flat_beam = true
particle_type = "e-"
source_energy = 5GeV
beam_size = 3mm 4mm
beam_shape = Rectangle
beam_direction = 0 0 1
model = "fixed"
source_position =  0 0 -10mm
output_plots = true
```

!1077 Beam Shape Variety in DepositionGeant4

Flat Beam



Gaussian Beam



Conclusion & Outlook

What we have learned and what's next ...

- Investigating performance differences of strip layouts
  - Different cluster sizes and efficiency drop for Low Dose designs
- New beam shape varieties

- Further Investigations:
  - Optimisation of TCAD input
  - Detailed comparison to test beam data

Thank you,

Questions?

Naomi Davis, Jan-Hendrik Arling, Marta Baselga, Leena Diehl, Jochen Dingfelder,
Ingrid M. Gregor, Marc Hauser, Fabian Hügging, Tomasz Hemperek, Karl Jakobs, Michael Karagounis,
Roland Koppenhöfer, Kevin Kröninger, Fabian Lex, Ulrich Parzefall, Arturo Rodriguez, Birkan Sari,
Niels Sorgenfrei, Simon Spannagel, Dennis Sperlich, Tianyang Wang, Jens Weingarten, Iveta Zatocilova

The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF).

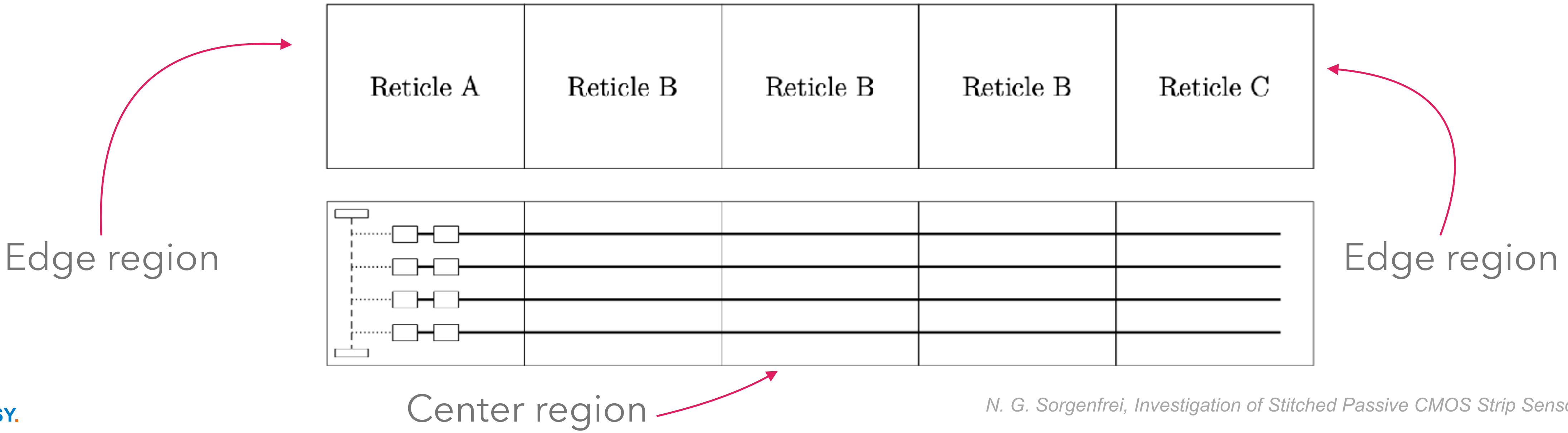
Backup

Stitching for Silicon Sensors

Connection of neighbouring reticles

- Sensor is divided into small(er) parts
- Different reticles used to imprint these parts
- Reticle B: is imprinted, moved, imprinted…

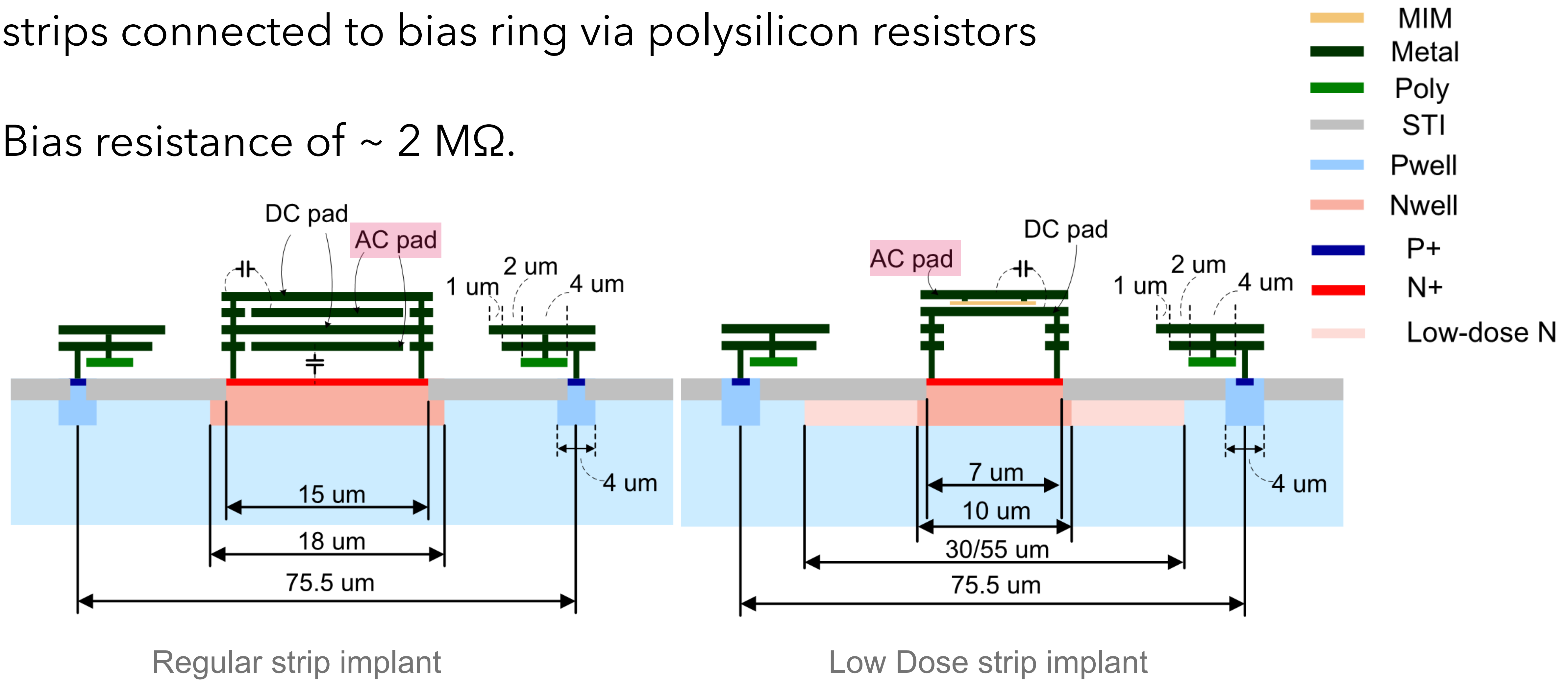
Stitching is possible in both dimensions!



N. G. Sorgenfrei, *Investigation of Stitched Passive CMOS Strip Sensors*

Full Sensor Layout

- strips connected to bias ring via polysilicon resistors
- Bias resistance of ~ 2 MΩ.

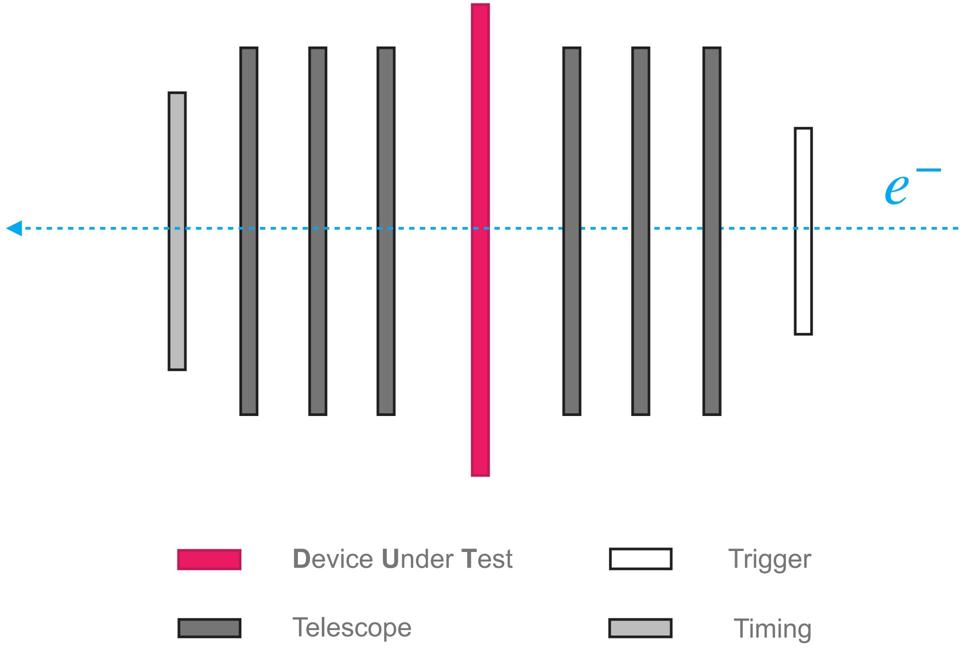


Test Beam Measurements at DESY II

- ADENIUM telescope with 6 ALPIDE planes as reference + timing plane
- e^- beam energy: $4.2\ \mathrm{GeV}$
- ALiBaVa readout system for DUT
- Corryvreckan: data reconstruction and analysis

Unirradiated short sample,

fully depleted @100V bias



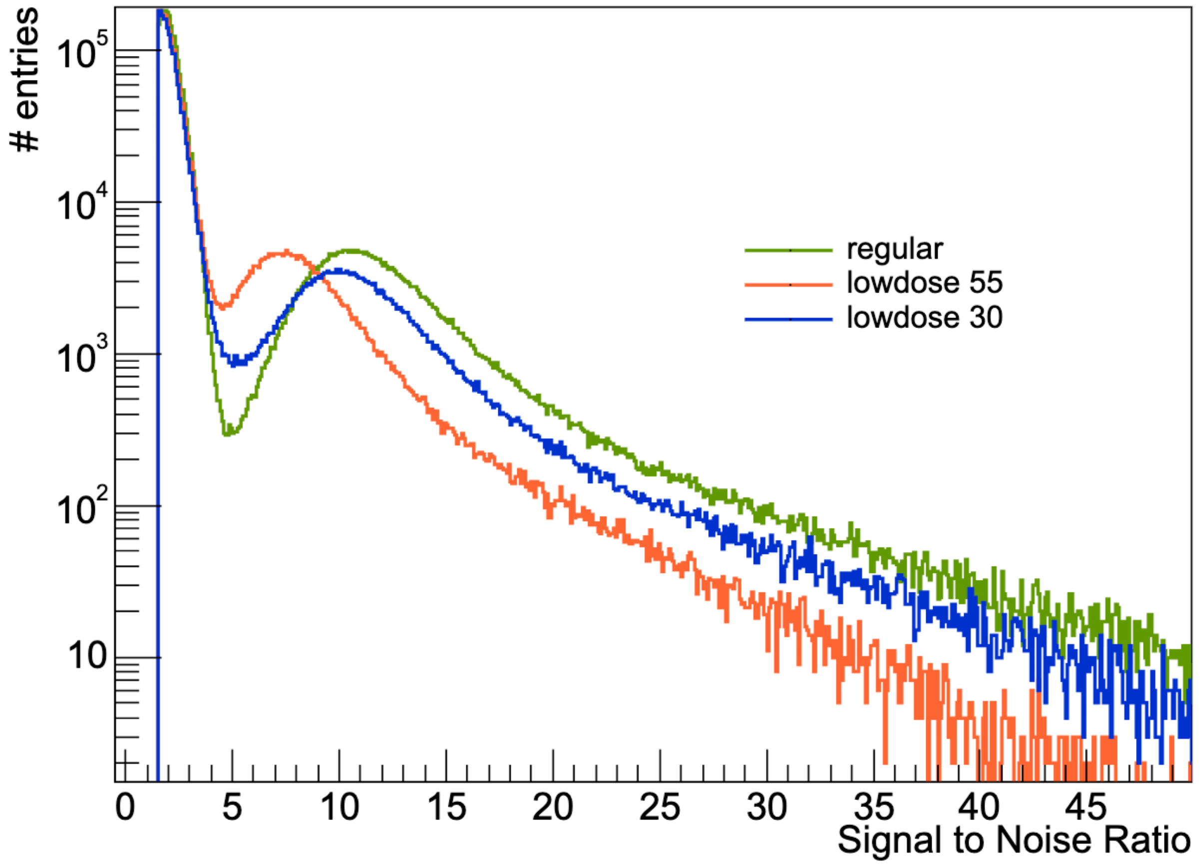
J. Dreyling-Eschweiler et al., NIMA, Vol 922 (2019), https://doi.org/10.1016/j.nima.2018.11.133
H. Jansen et al. , EPJ Techn Instrum 3 (2016), https://doi.org/10.1140/epjti/s40485-016-0033-2

Clustering

SNR distribution

$$SNR = \frac{\text{Signal}}{\text{Noise}}$$

- Clustering Algorithm based on SNR
- Iteratively includes strips above threshold
- Threshold: cut in SNR distribution for definition of seed and neighbour strip



Total Hit Detection Efficiency

Hit detection efficiency of an unirradiated sample

Unirradiated Sample

@100V bias, short

- Seed Cut Value:
  - Clustering Algorithm based on SNR distribution
  - Threshold: cut in SNR distribution for definition of seed and neighbour strip
- High efficiency region at low seed cuts