SIMULATION OF A HEAVILY IRRADIATED 3D PIXEL DETECTOR

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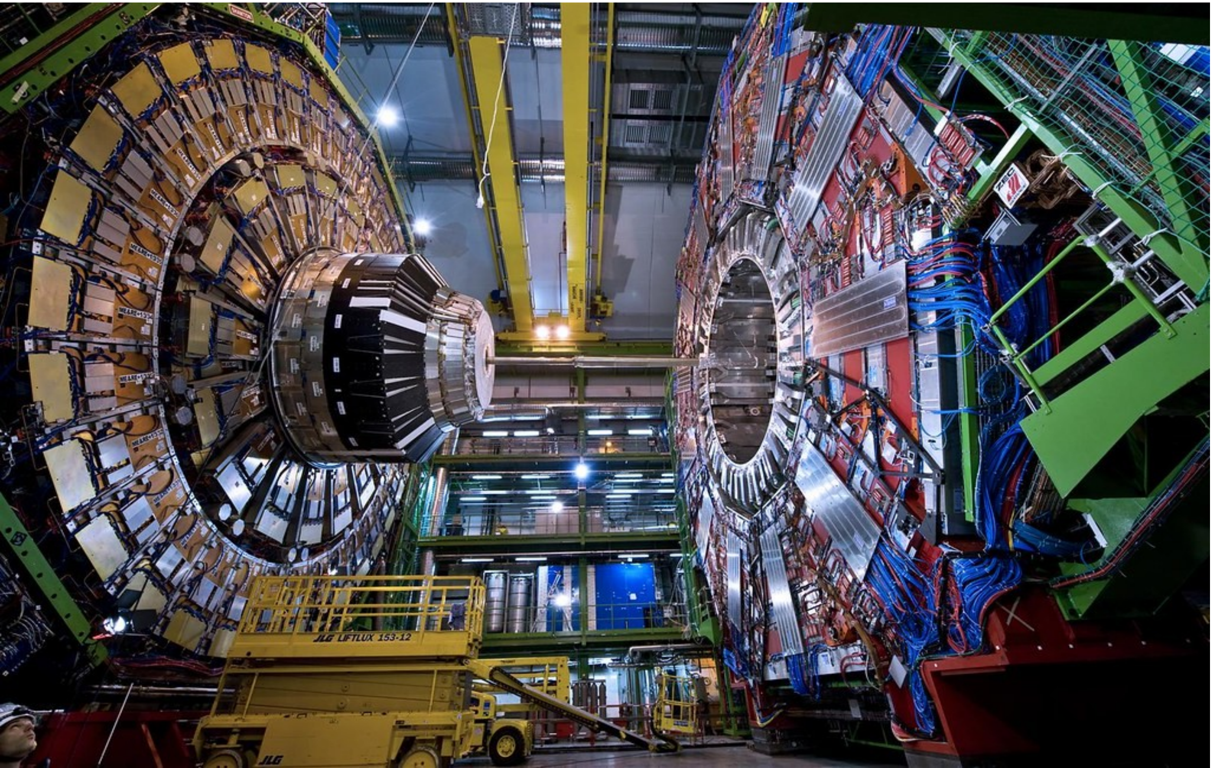
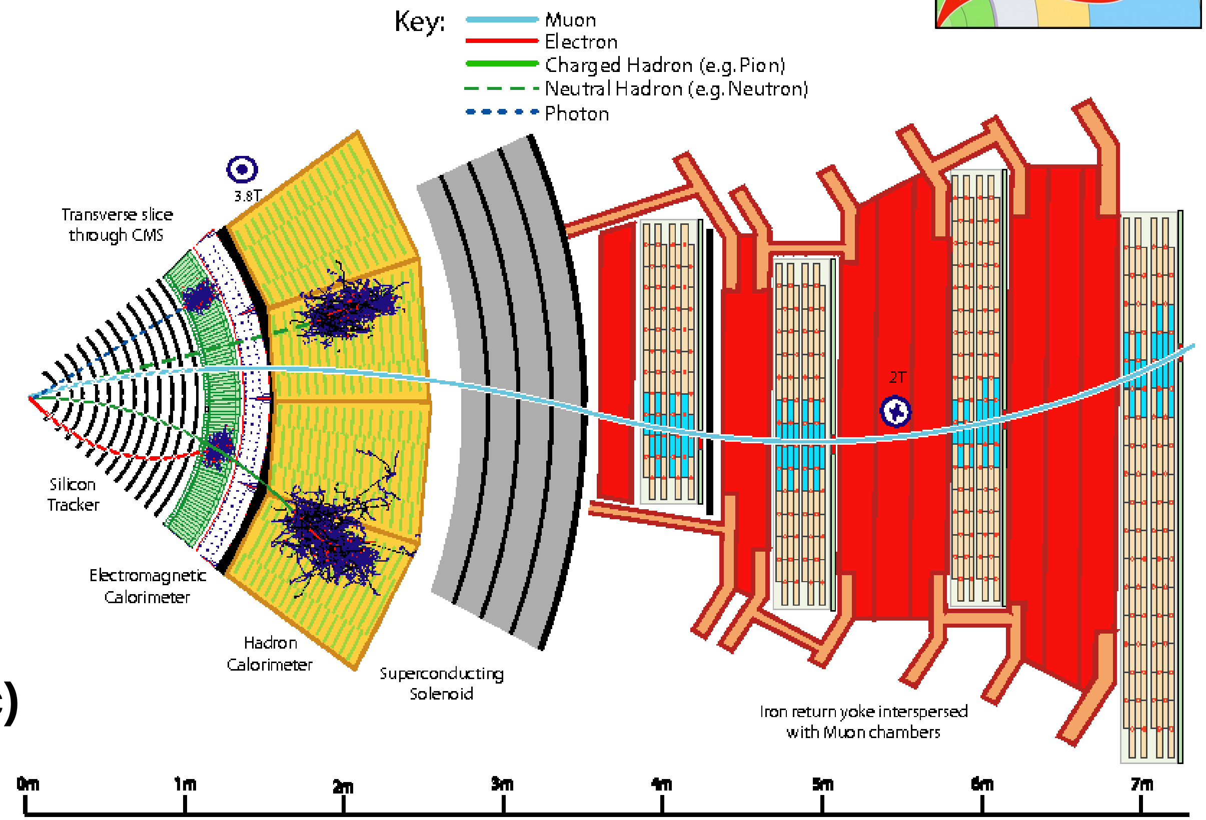


- **CMS introduction**
- **3D pixel detector**
- **DESY test beam**
- **Model**
- **Summary**

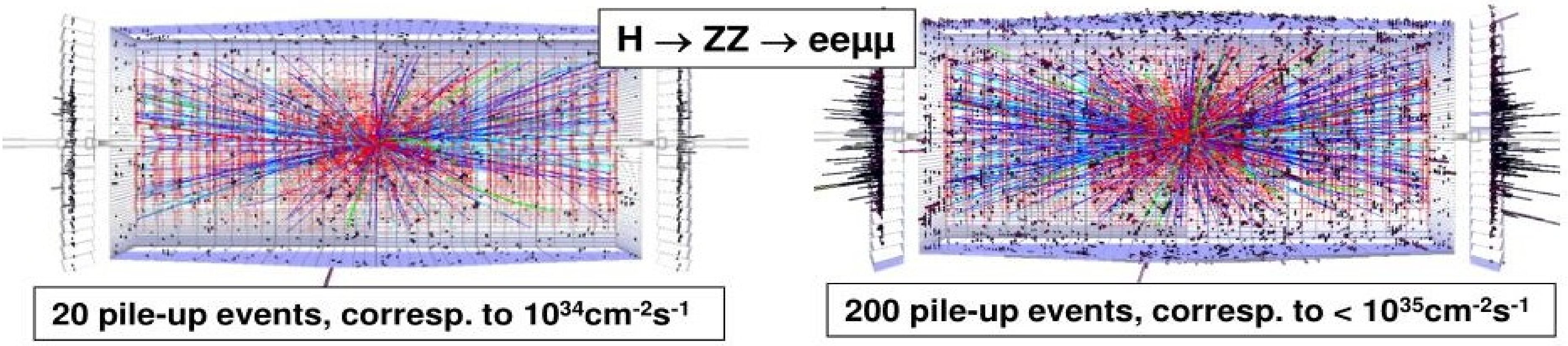
CMS Introduction

- **CMS is one of the large collider experiments at LHC, CERN.**
- **Realized to detect new particle (Higgs boson…).**
- **Onion structure with different layers :**
  - **tracker (pixel and strips)**
  - **calorimeter (electronic, hadronic)**
  - **muon chamber**



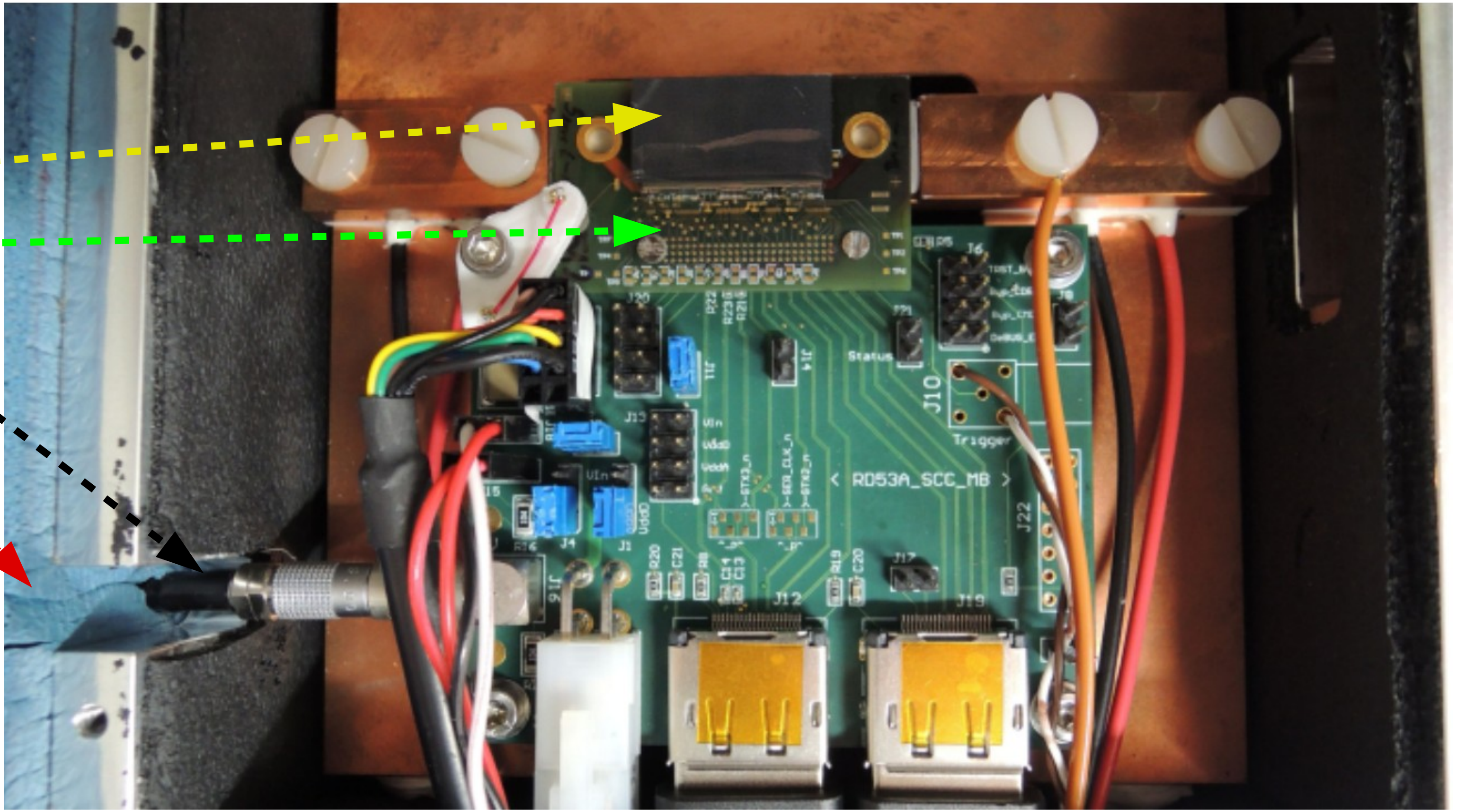
CMS Upgrade : Phase II

- **Increase in LHC luminosity (by up to a factor of five).**
- **Expected more pile-up:**
  - **selection at tracker level faster**
  - **high radiation tolerance required**
- **Proposed 3D pixels in inner tracker layers.**

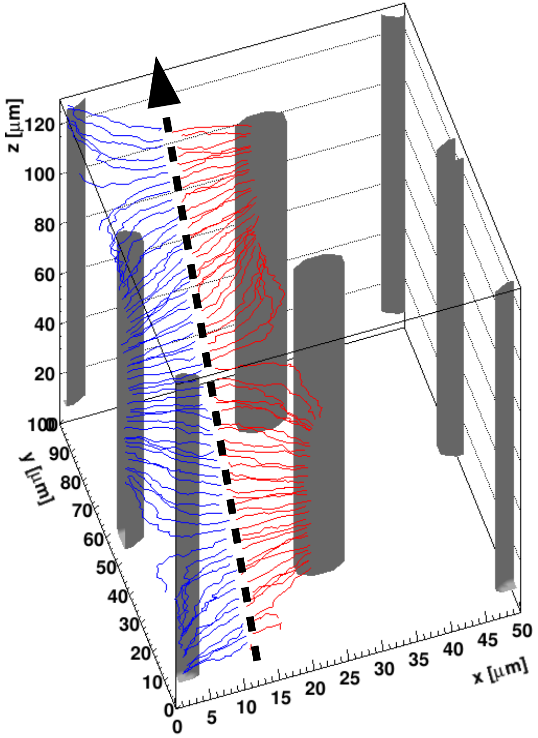


3D Pixel Test Set-up

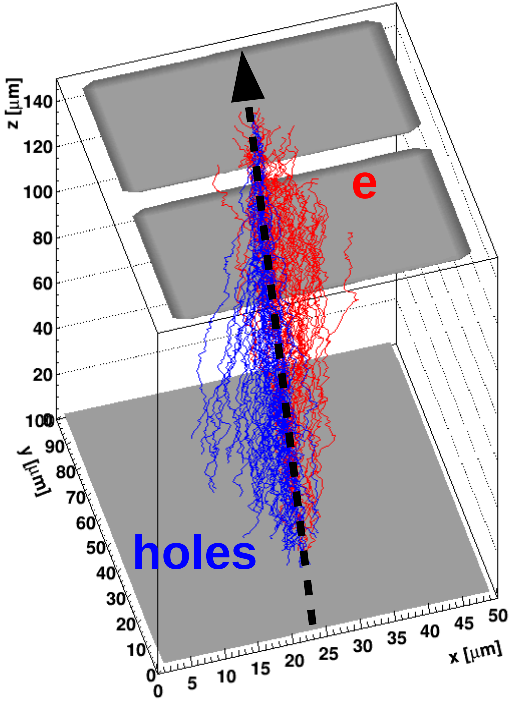
- 3D pixel
- power and signal routing
- bias voltage
- cooling box



3D Vs Planar Pixel Sensors

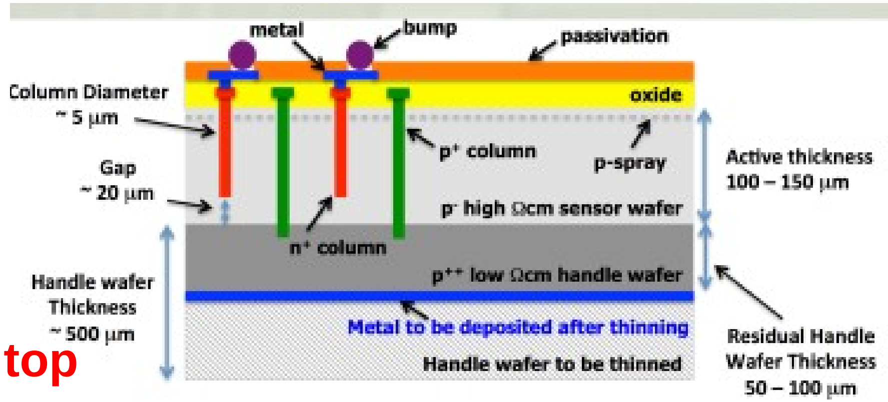


bias voltage between central and corner electrodes



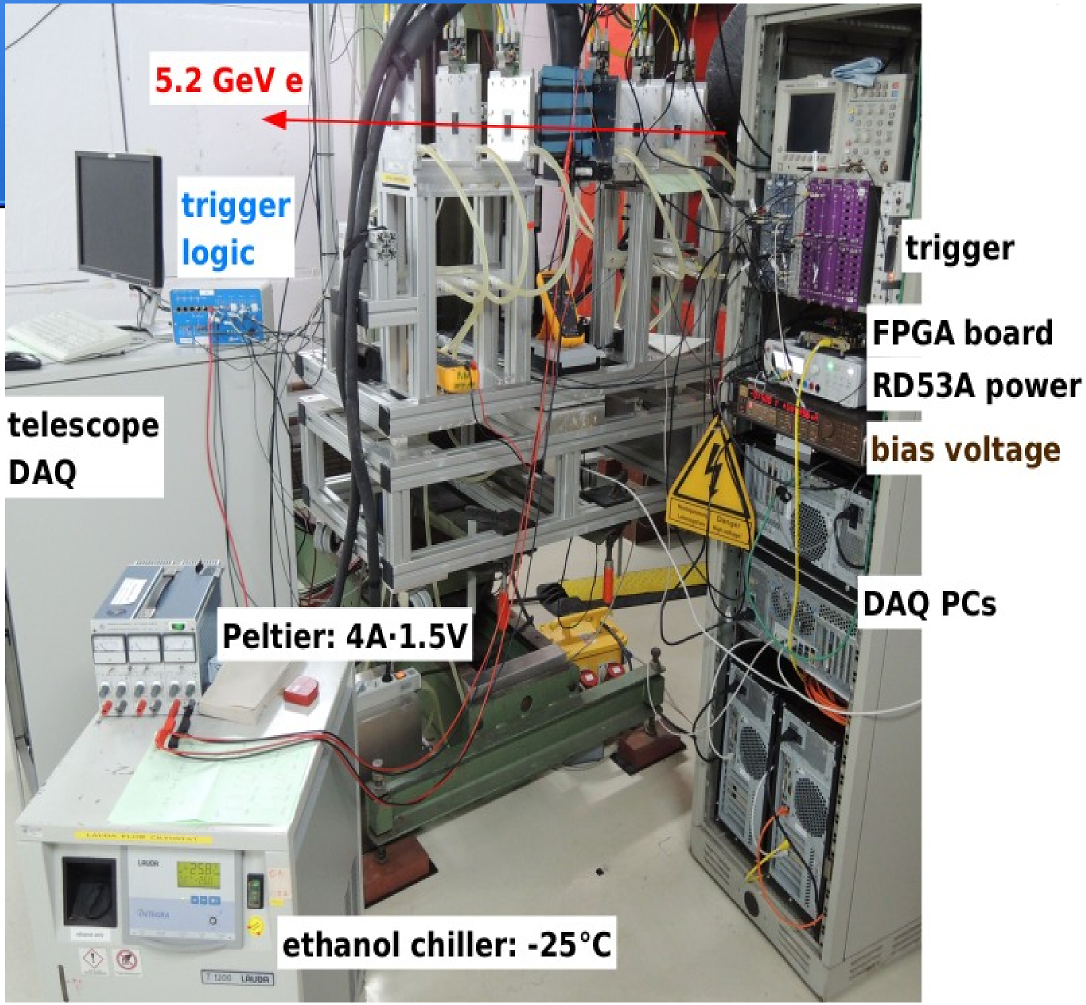
bias voltage between top and bottom implants

3D Pixel is a silicon detector used for tracking particles. The main difference with planar ones are the columns etched into the silicon instead of implanting a layer at the surface.



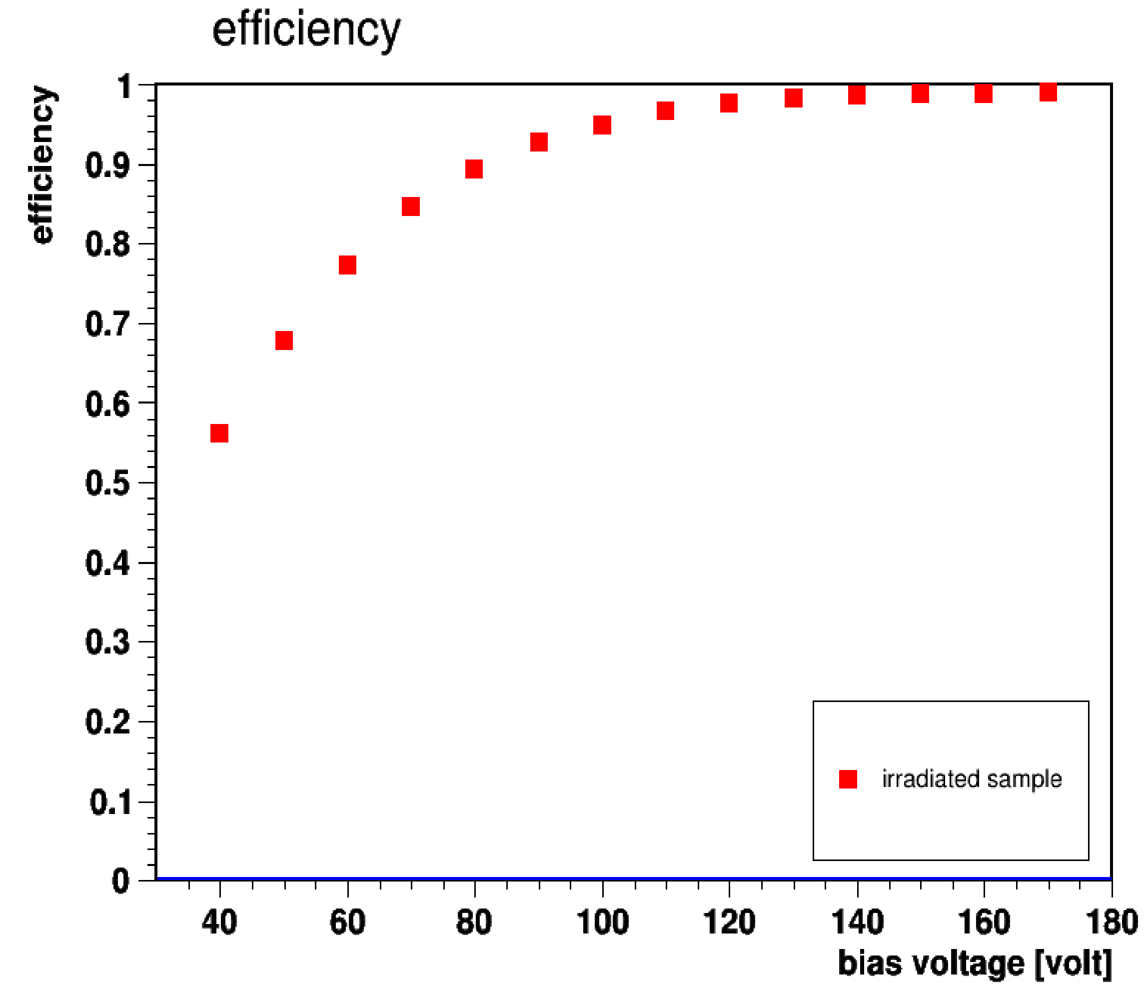
DESY Beam Test

- 3D module irradiated at CERN to $10^{16}/cm^2$ (half life fluence for layer 1 at phase II)
- measured here at DESY (in April) with the Mimosa test beam telescope.
- Data analysis made with eudaq53 software: clustering, alignment, and track reconstruction



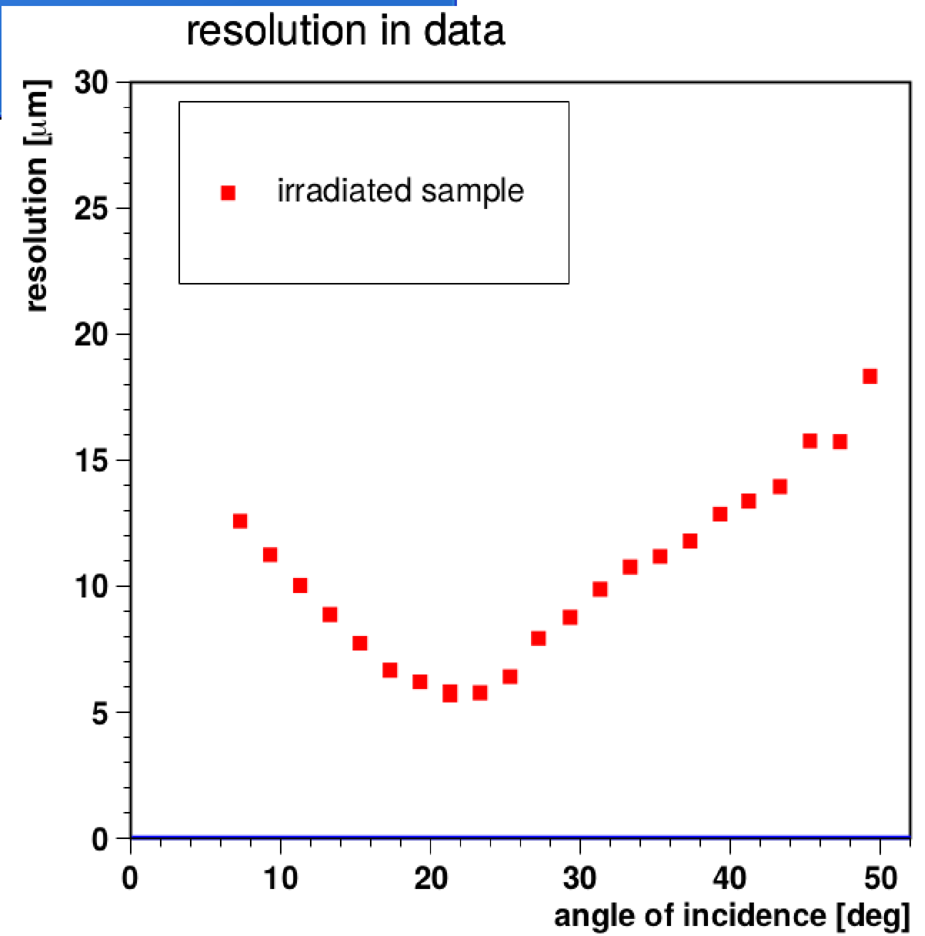
Efficiency Vs Bias

- vertical incidence
- irradiated 3D module:
  - efficiency relative to telescope tracks
- need 140 V for 97% efficiency
  - (planar would need about 500 V)



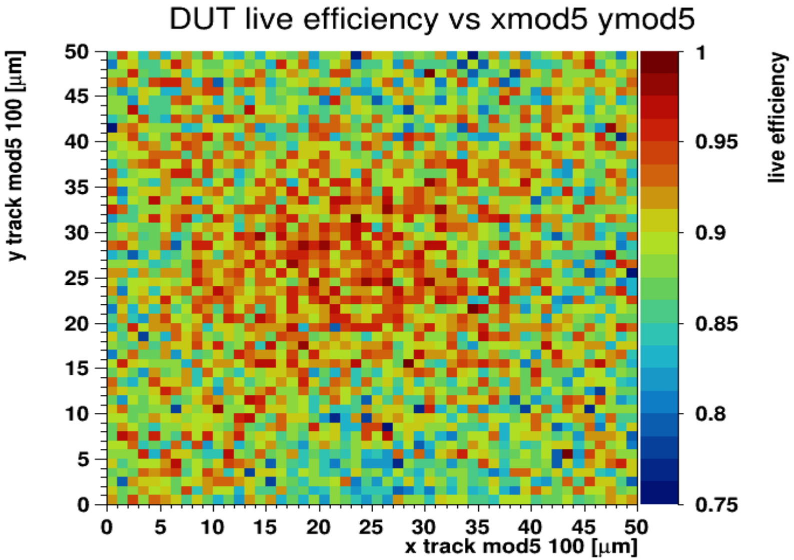
Resolution Vs Angle

- **resolution from hit – track residual width**
  - **telescope contribution subtracted (with ~2 µm systematics)**
- **best charge sharing at 21°:**
  - **atan(pixel width / sensor thickness)**
  - **reaching 6 µm resolution (with 50 µm pixel size)**



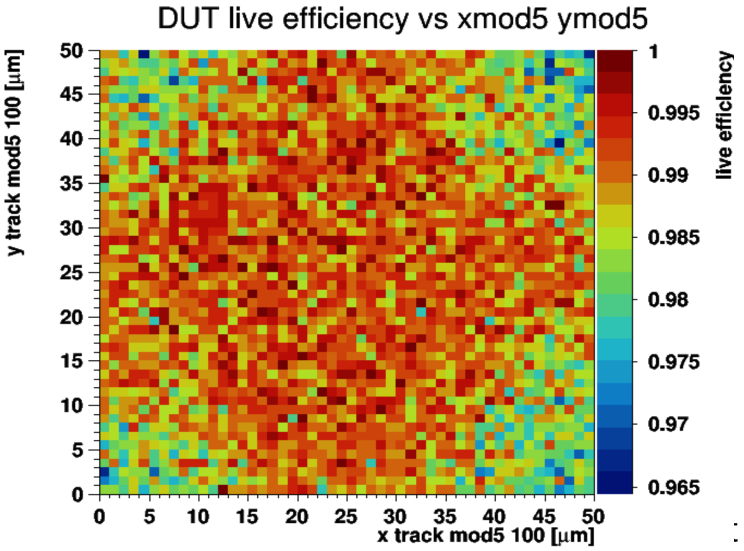
Charge Collection In Data

- Data efficiency reduced to a single pixel:
- medium voltage: “cloverleaf” extending between the electrodes
- high voltage: good efficiency except inside corner electrodes (at vertical incidence)



80 Volt

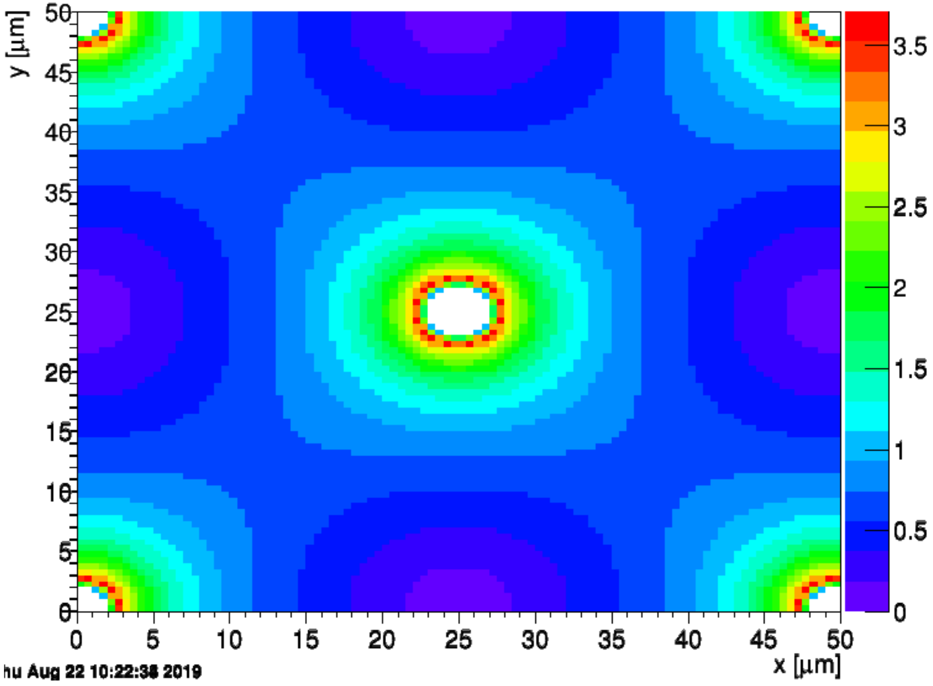
170 Volt



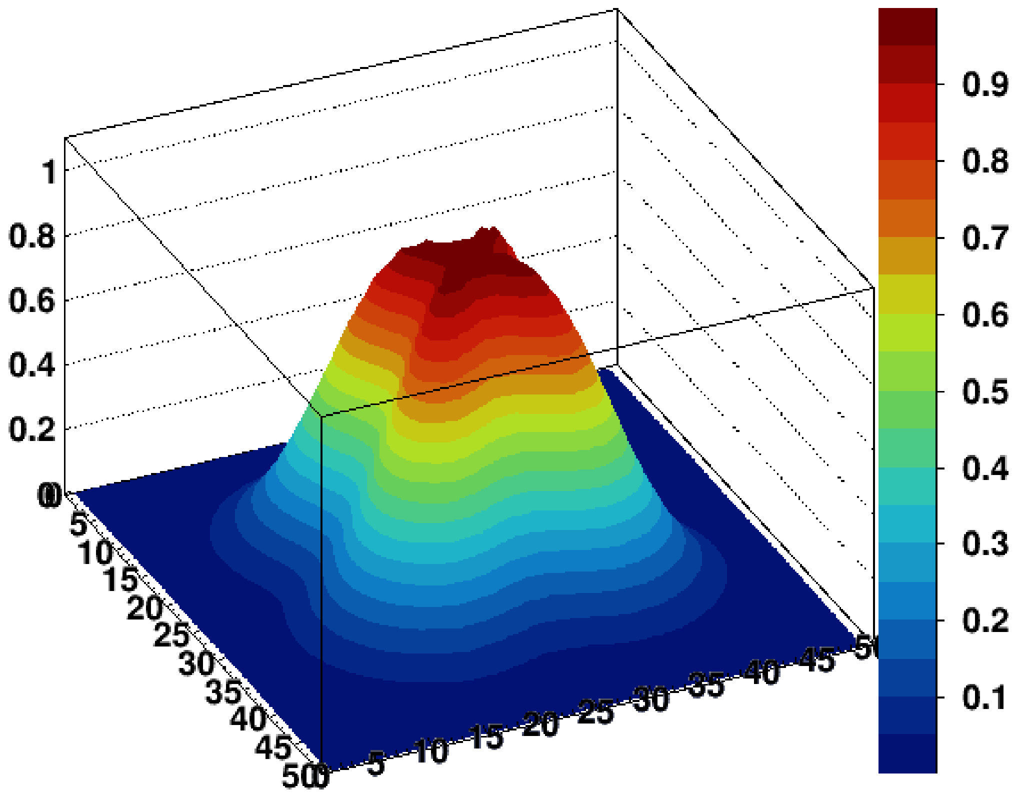
KDetSim Model

- from `kdetsim.org`
- KDetSim is a library, based on ROOT, which solves the Poisson equation in 3 dimensions, and from there produces a MC simulation of the charge transport inside the semiconductor detector.
- impose periodic boundary conditions on all (six) sides.

electric field map [V/μm]



Model Charge Density Function

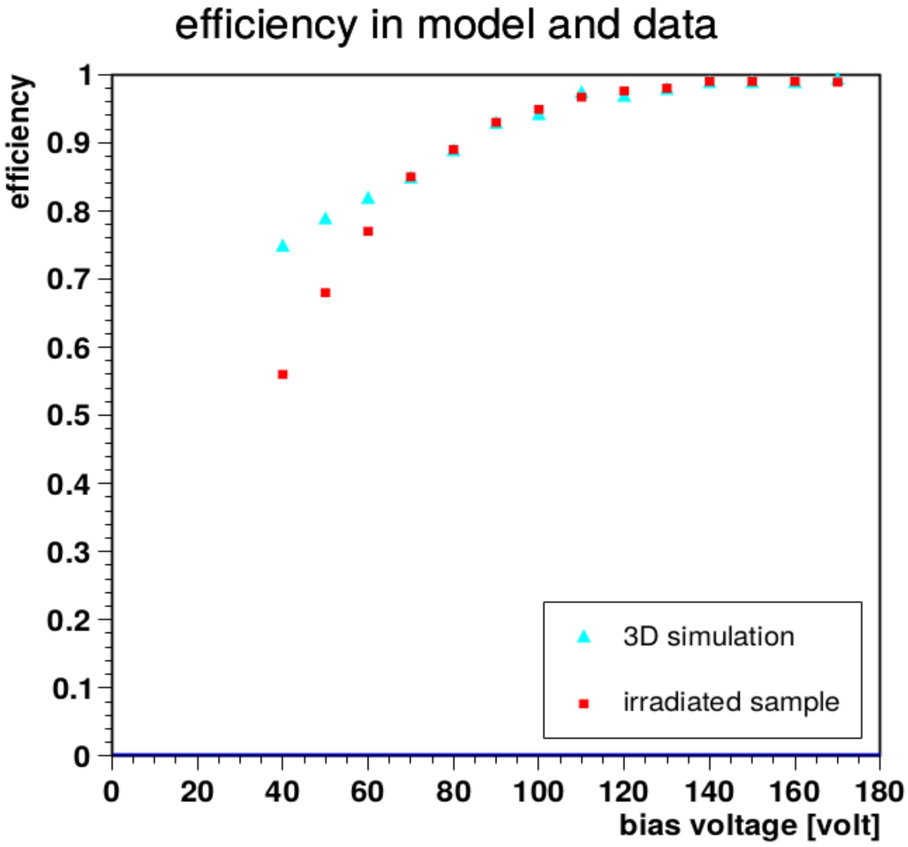


- **Space charge in irradiated silicon detectors from trapped leakage current.**
- **Our model:**

$$Q\ \exp\left(-\frac{R^2}{\delta^2}\right)\left(p_2+\frac{R^2}{\delta^2}\sin^2(2\phi)\right)$$

- **scale δ, Space Charge Q and p_2 are effective parameters of the model in pixel polar coordinates R, ϕ.**

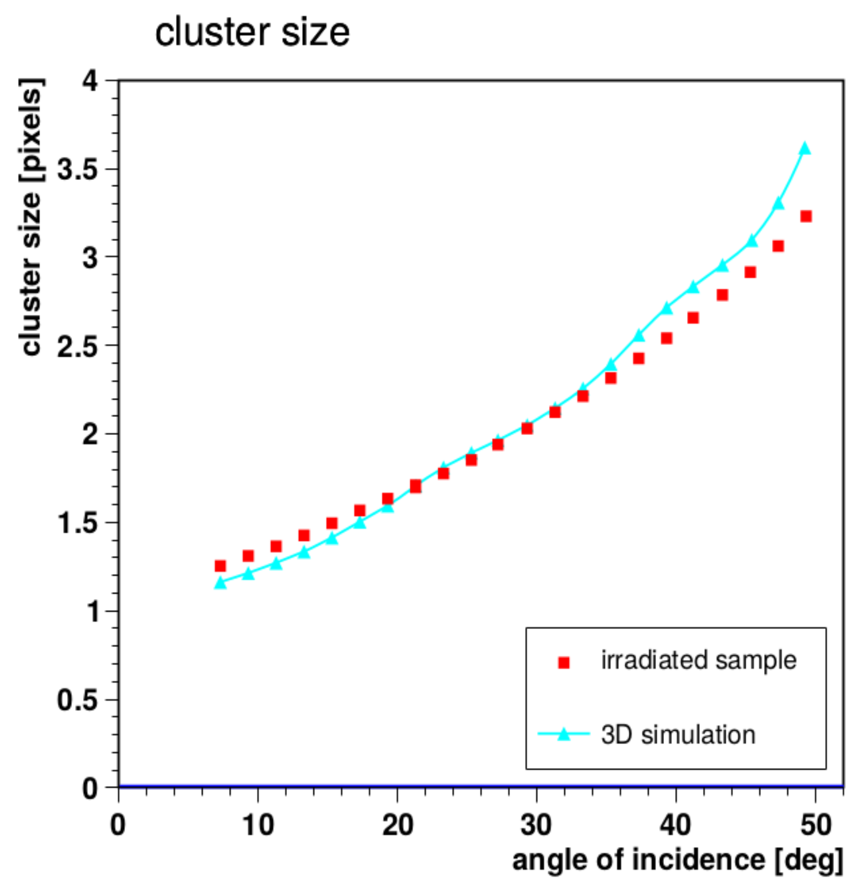
Efficiency In Model Vs Data



- **Trapping of free charge carriers taken from planar sensor studies**
- **Space charge Q tuned for each bias voltage (within boundary conditions)**
- **good description above 70 V**

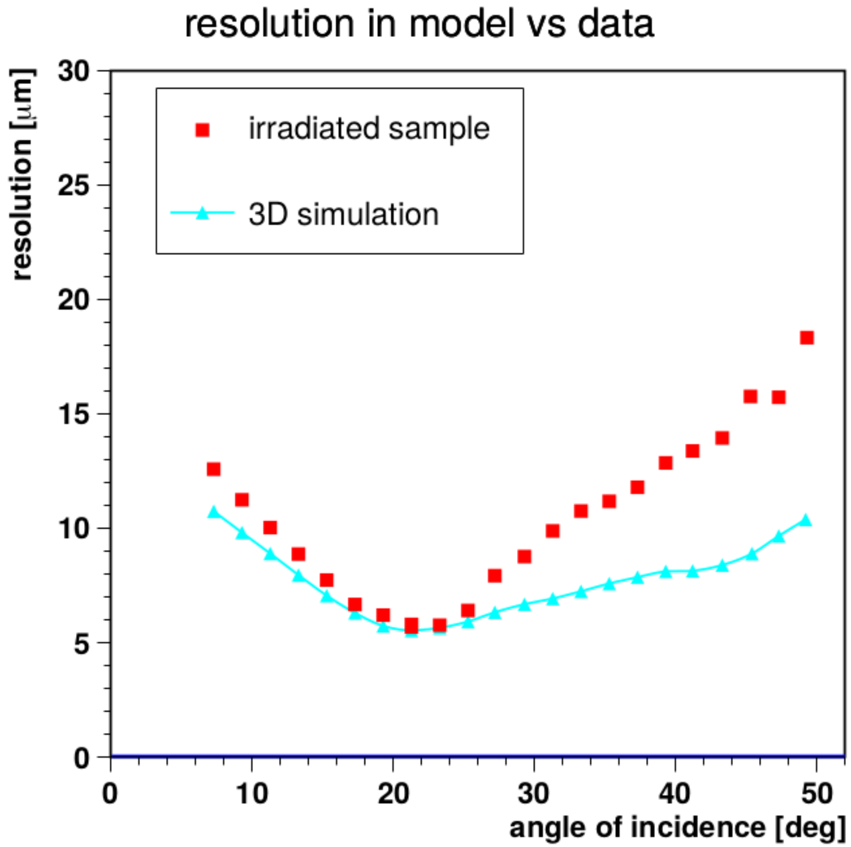
Cluster Size In Model And Data

- **cluster size:**
  - **number of pixels above threshold linked to a track**
  - **increases with angle of incidence**
  - **~ (1 + tan(angle)) from geometry**
- **well described with 1.7 ke threshold**



Resolution In Model And Data

- **bias 170 V**
- **fairly good description (within systematics) around the minimum and at small angles**
- **deviation at high angles to be understood (further measurements)**



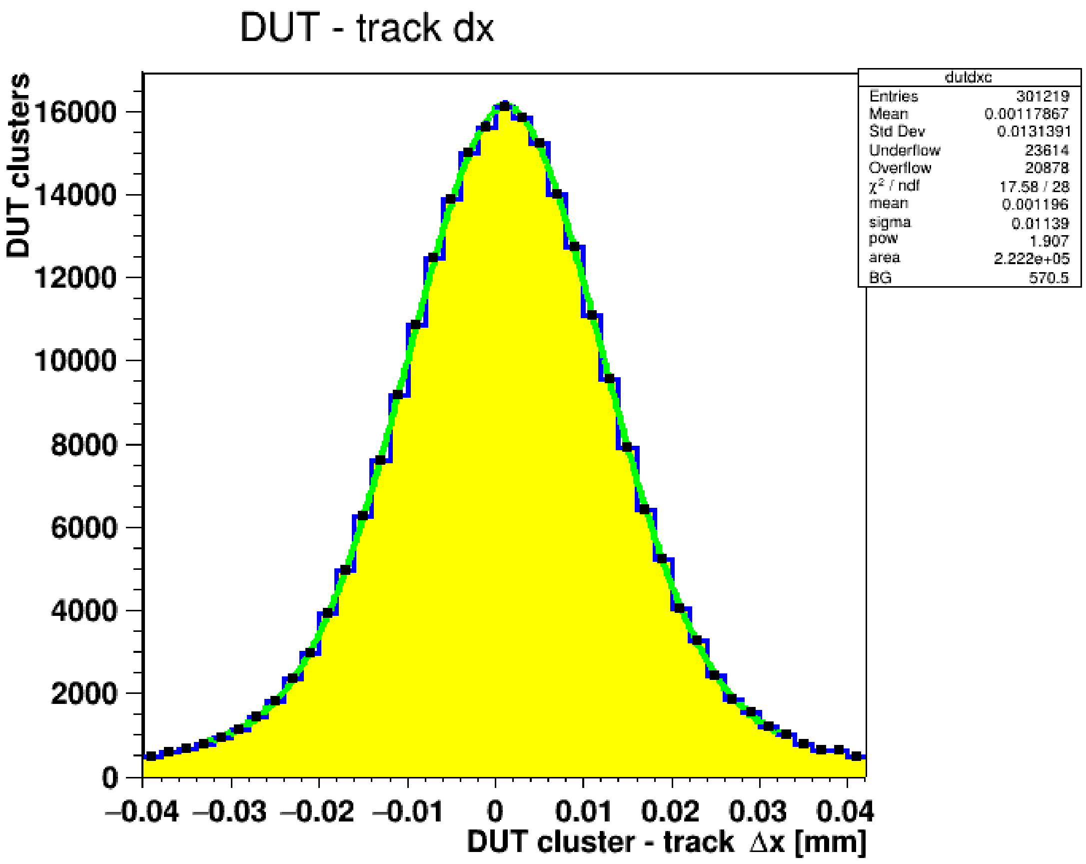
Summary

- Analysed test beam data of an irradiated 3D silicon pixel detector:
  - efficiency above 98%, resolution reaches 6 μm
- Development of a first model for an irradiated 3D pixel detector:
  - cloverleaf space charge model
  - tuning of model parameters (space charge, threshold, noise)
- Comparison:
  - gross features described, deviations in the extremes
- Future plan:
  - fine tuning of simulation
  - take more data with different fluences

Thank you to everyone for your time

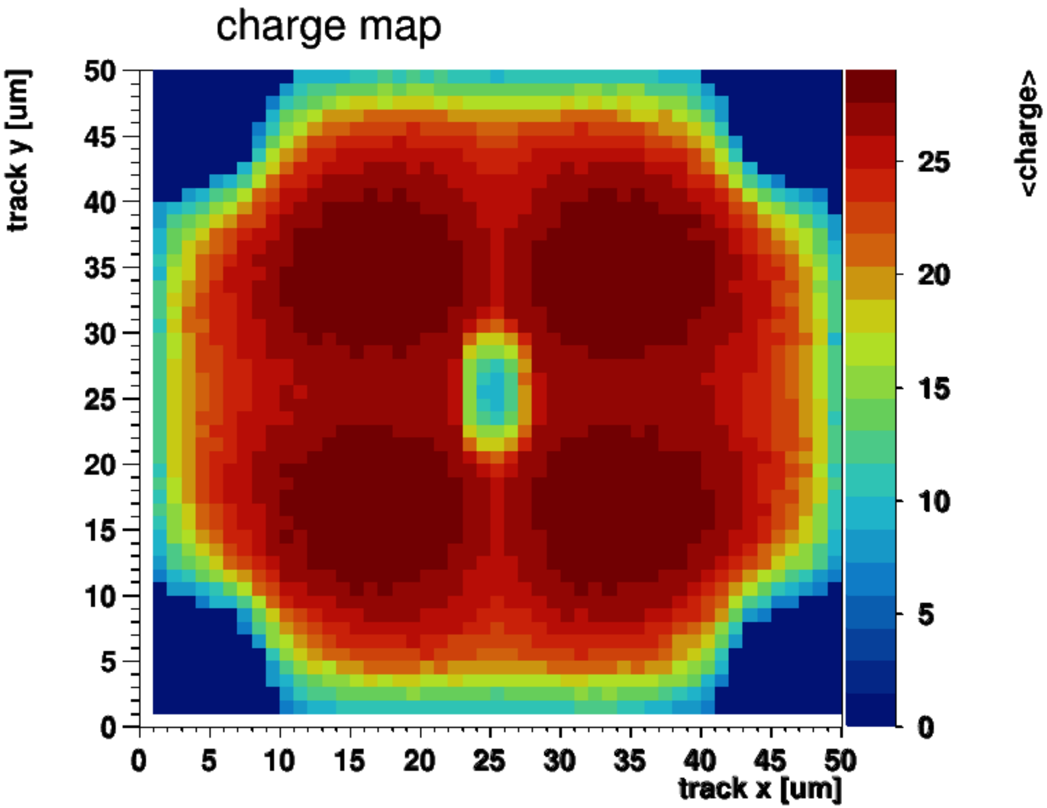
Back-up slides

- **raw data residual in x after a cut on y**
- **fitted through general exponential**
- **residual calculated in 3 sigma**
- **resolution computed from residual subtracting telescope contribute**

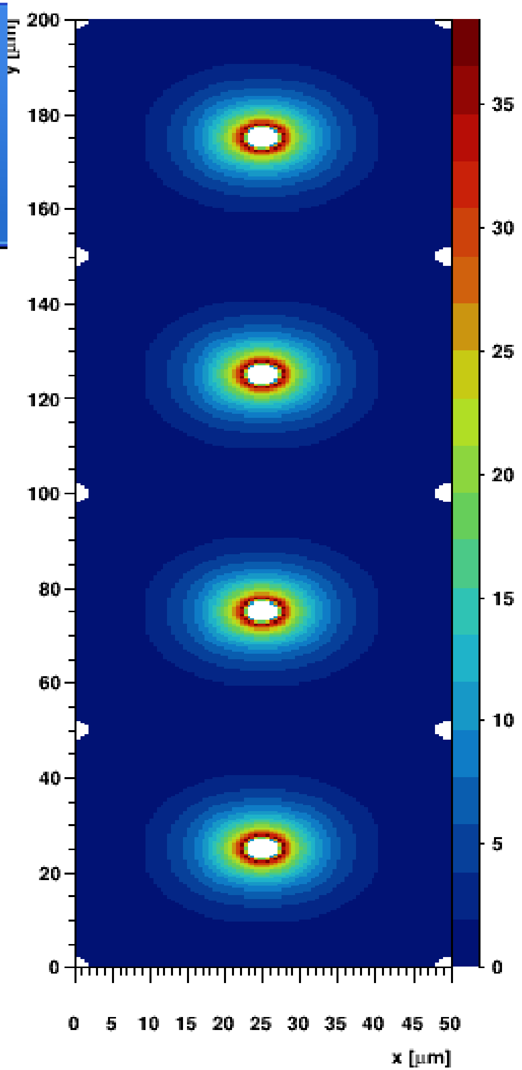


Charge Collection In The Model

With this choice of density function, that's the single pixel's collected charge with bias voltage 80 volts.

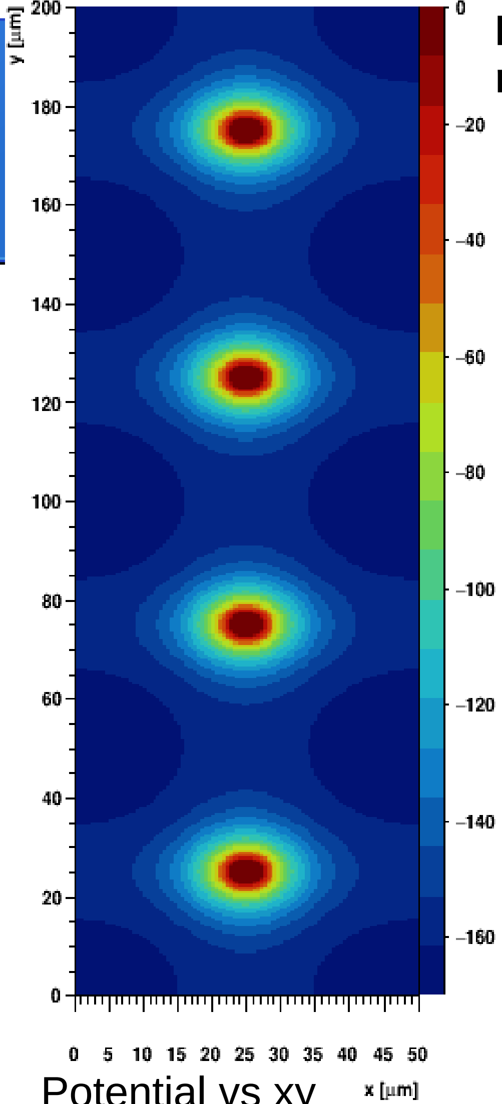


Model must be doubled and quadrupled in order to consider the charge sharing between pixels



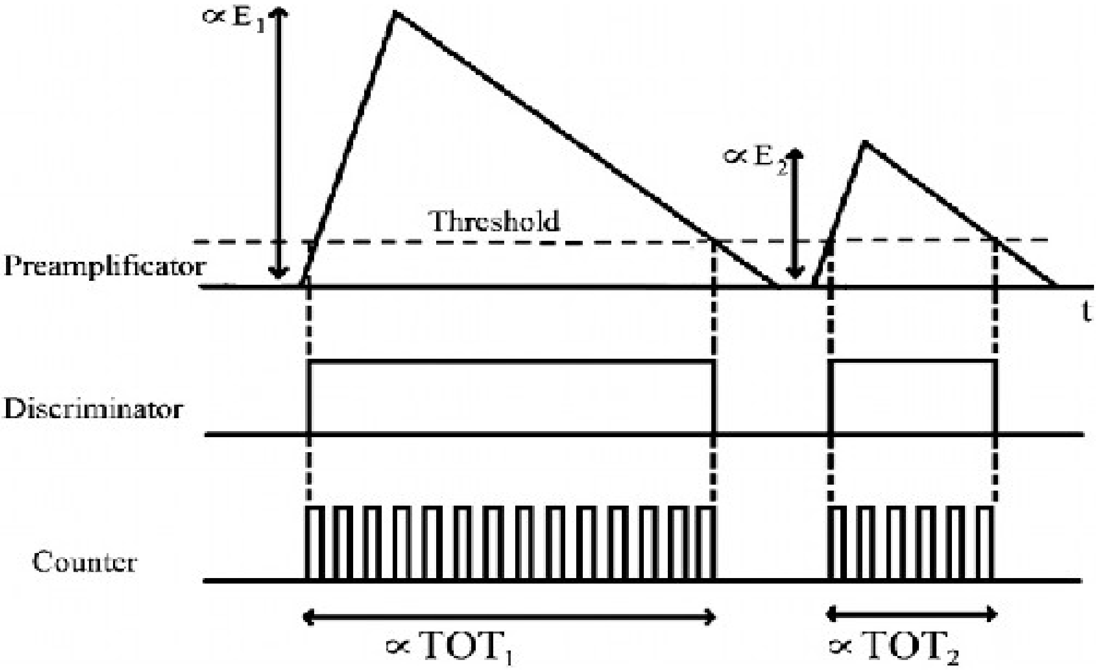
Electric field map [V/ #um]

Electric field vs xy

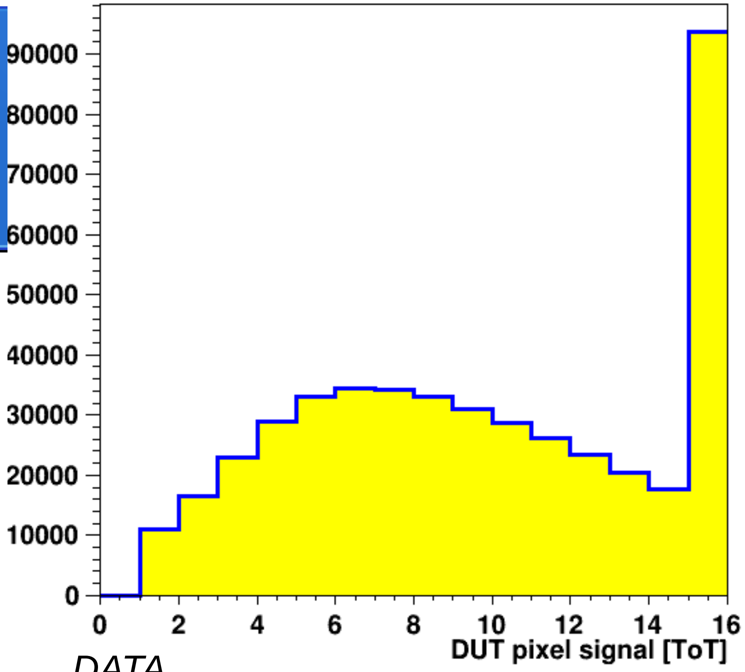


Potential map [V]

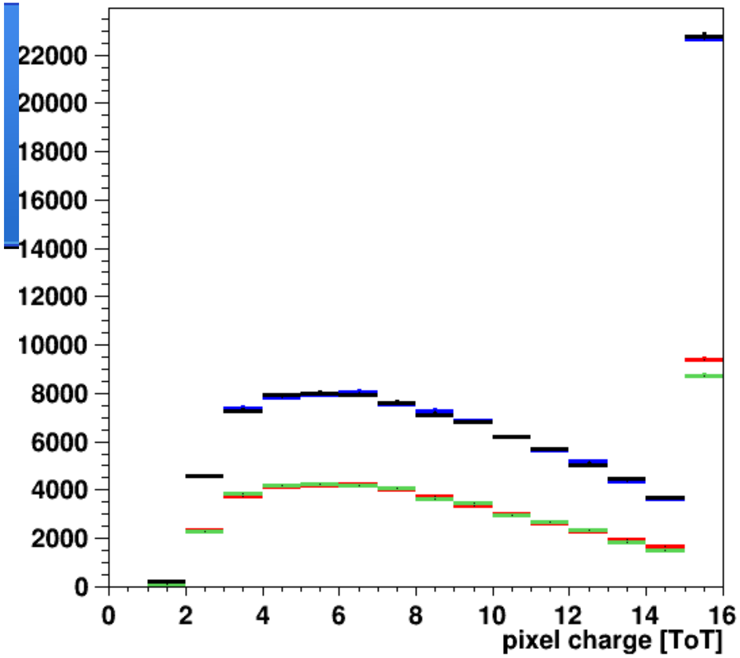
Potential vs xy



- **It is necessary to consider also the threshold, the electronics and the conversion from analogue signal to a digital one.**
- **Collected charge must be converter in an integer to remind the behaviour of the ToT (time over threshold).**

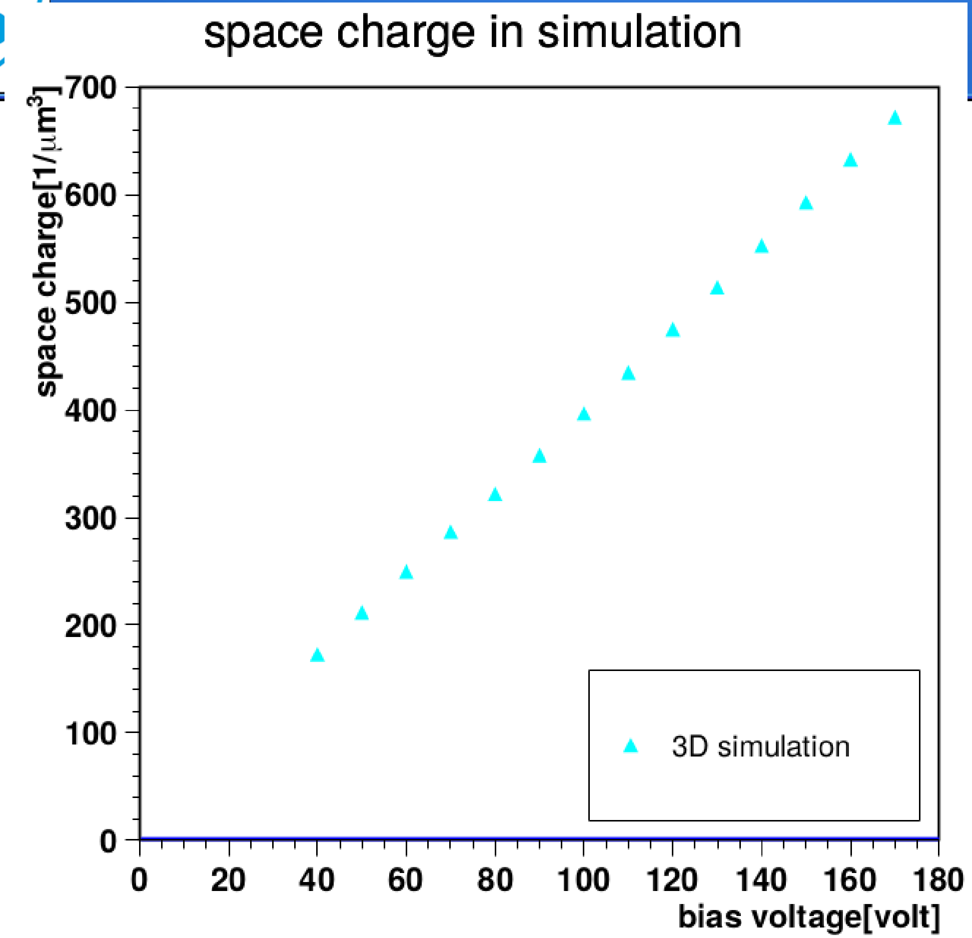


DATA



MODEL

- **Effects that must be taken in account**
  - **the gaussian smearing of signal due to different responses of the amplifiers**
  - **the electronic noise which contributes with another gaussian term**
- **In the plot above are shown the result in collected charge in each pixel (in ToT unit) for data and model at 21 degrees.**



- **unexpected linear proportion between bias and efficiency**
- **chance to optimize the simulation using the slope of this line**
- **linear dependence comes from the request to maintain a physical potential in the model**

Parameter of the model

	Fixed value	Upper limit	Lower limit
Thickness	142	150	130
Threshold	1.7	1.8	0.5
Fluence	10 E 15	15 E15	10 E15
Gamma e	0.2	0.2	0.2
Gamma h	0.33	0.33	0.33
Radius of column	2.5	3	2
Space charge	615	1817	2
delta	12	20	10
p2	1	0.3	1
sigmaTrack	7.7/8.7	8.7	7.7
ToTscale	0.7	0.5	1.2
smear ToT	0.2*threshold	0.2*threshold	0.2*threshold
noise	0.3*threshold	0.3*threshold	0.3*threshold