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# Small pitch pixel detector for the CMS phase II upgrade

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**Supervisor: Gino Bolla,  
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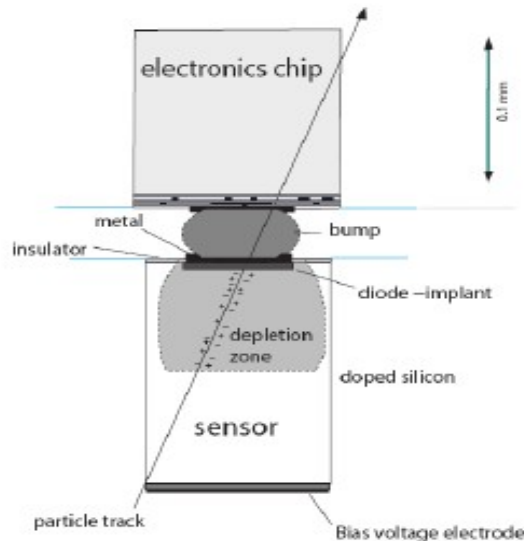
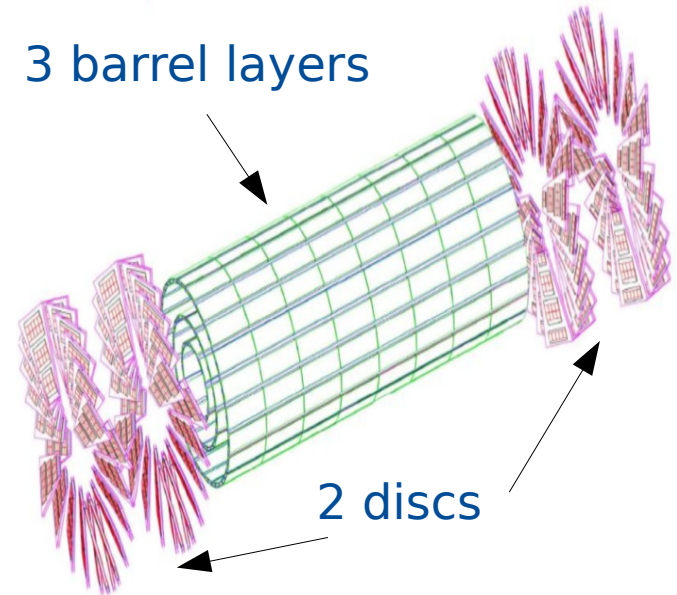
Final Reports

22 September 2015



# CMS Silicon Pixel Detector

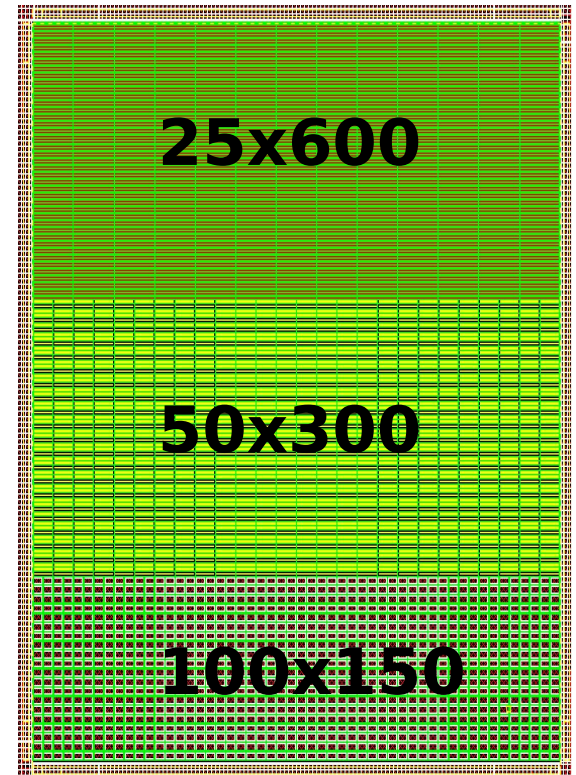
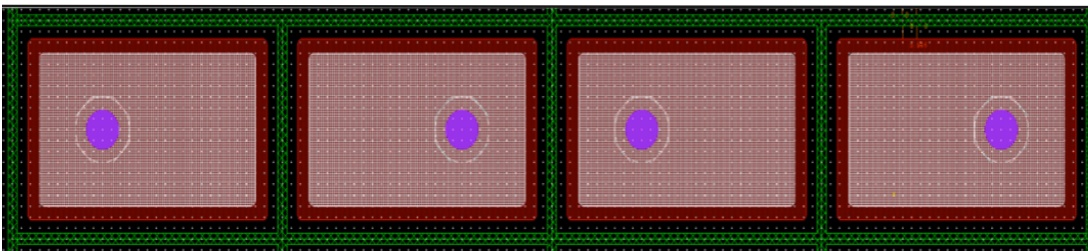
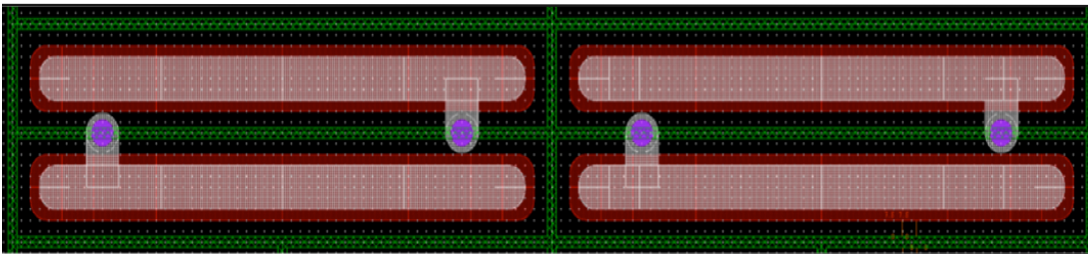
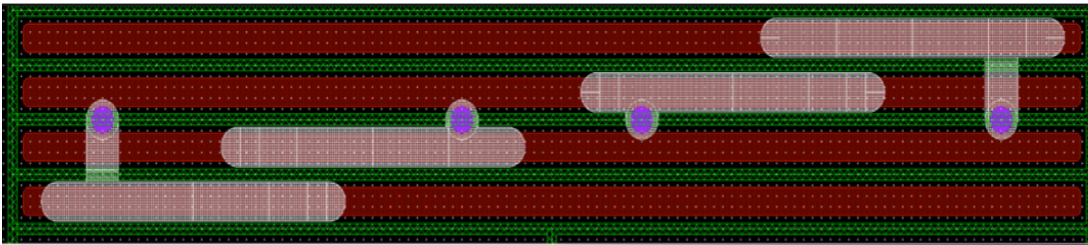
- It is the innermost and most precise part of the CMS tracking system.
- 1 barrel detector module is composed of 16 Read Out Chips (ROCs).
- 1 ROC has 4160 pixels.
- Pixels of standard dimension ( $100 \times 150 \mu\text{m}^2$ ) are arranged in 52 columns and 80 rows



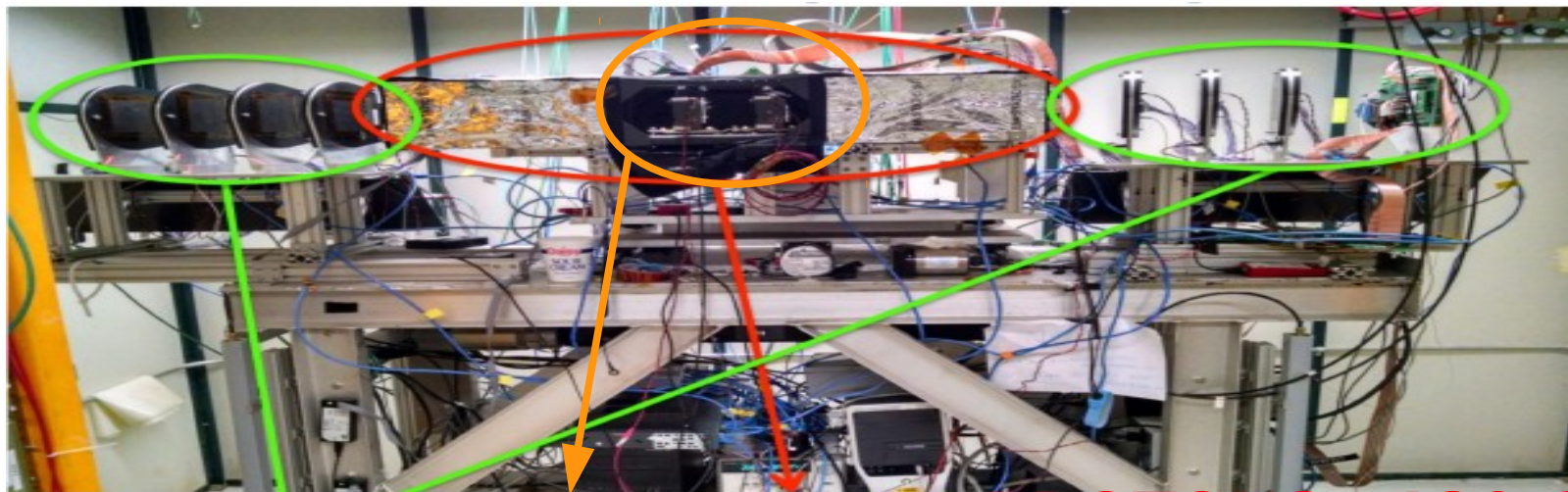
- Each pixel is bump bonded to the ROC

# Small Pitch Prototype Design

- Maintained the same pixel area  $100 \times 150 \mu\text{m}^2$  that is implemented in the Phase-I design
- Single ROC sensors split in 3 regions with 3 different pitches



# June Test beam and data acquisition

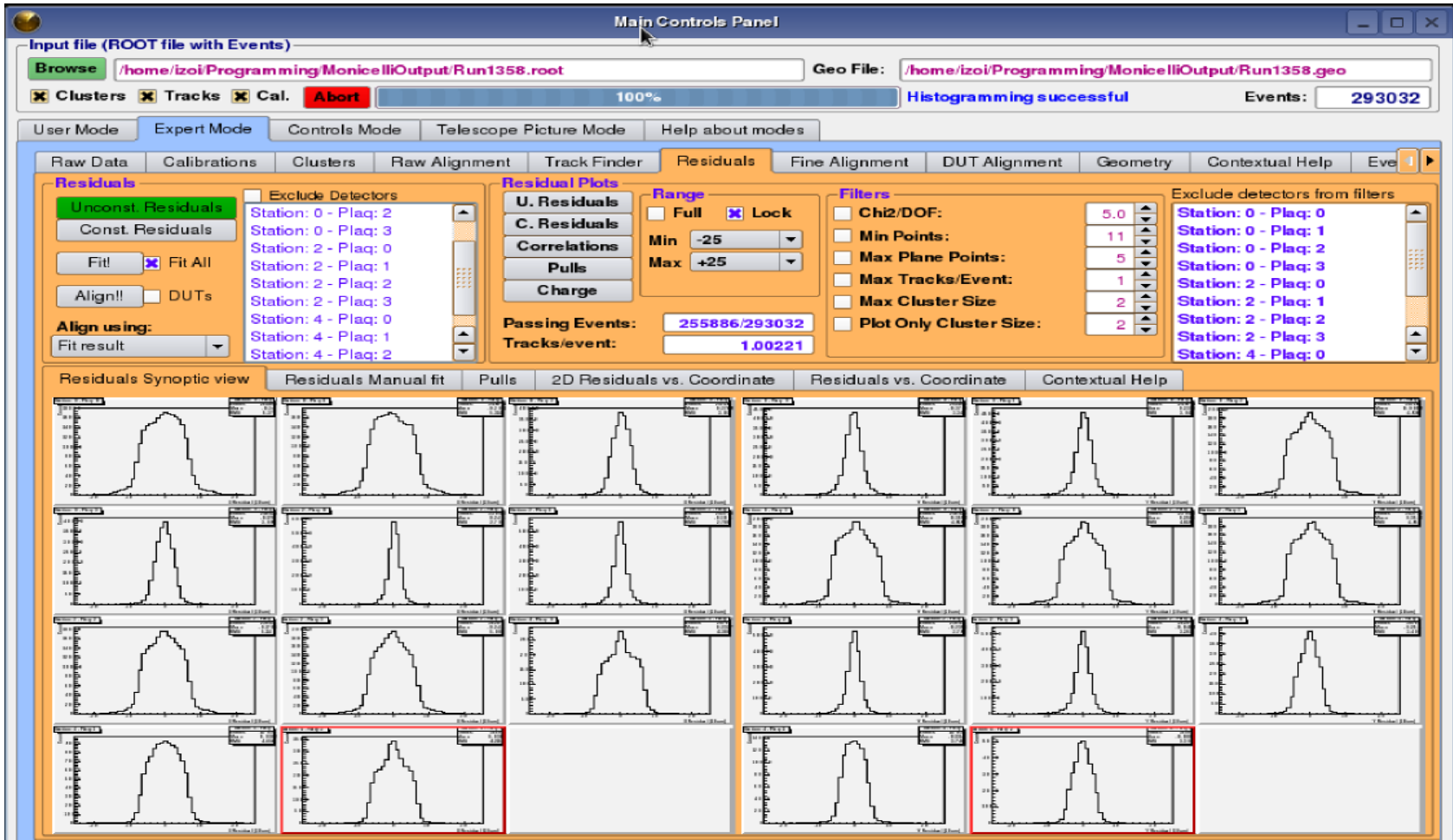


Strip telescope **DUTs** Pixel Telescope **PROTONS@120 GeV**

- Hits in the pixel detectors are grouped together according to the trigger number.
- The data acquired are first analyzed by a tracking program (Monicelli) that aligns the detectors and reconstructs tracks.
- Then another program (Chewie) is used to analyze the reconstructed tracks.

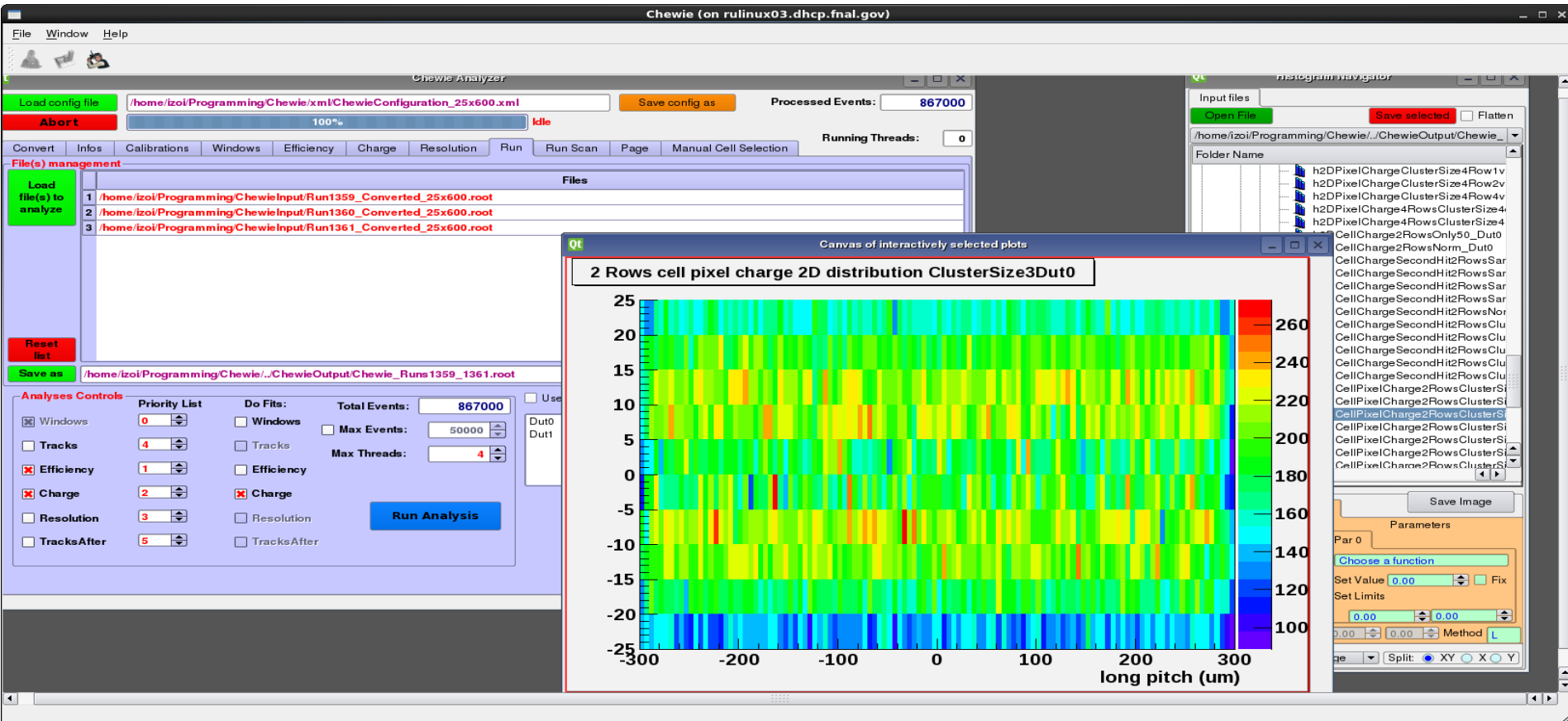
# Monicelli

My first task was to complete the alignment of the DUTs in order to reconstruct the tracks.



# Chewie

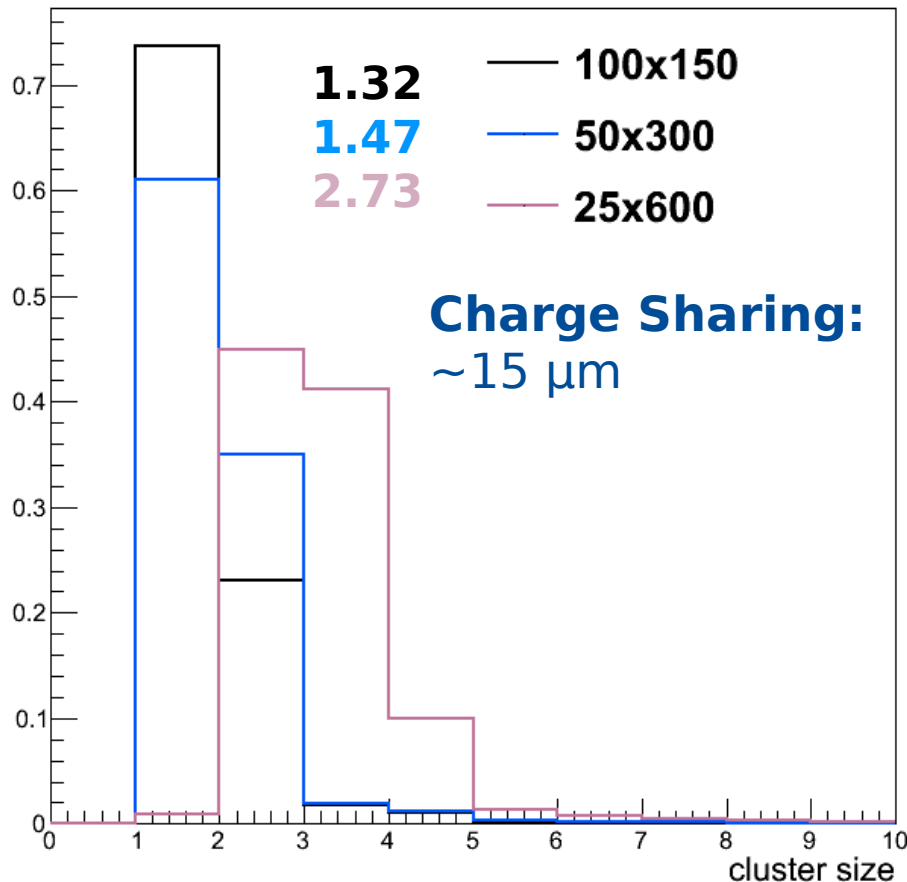
My second task is to modify the Chewie code in order to analyze the data obtained from the three different zones of the DUTs.  
I worked on the measurement of the collected charge and the resolution.



# Cluster size

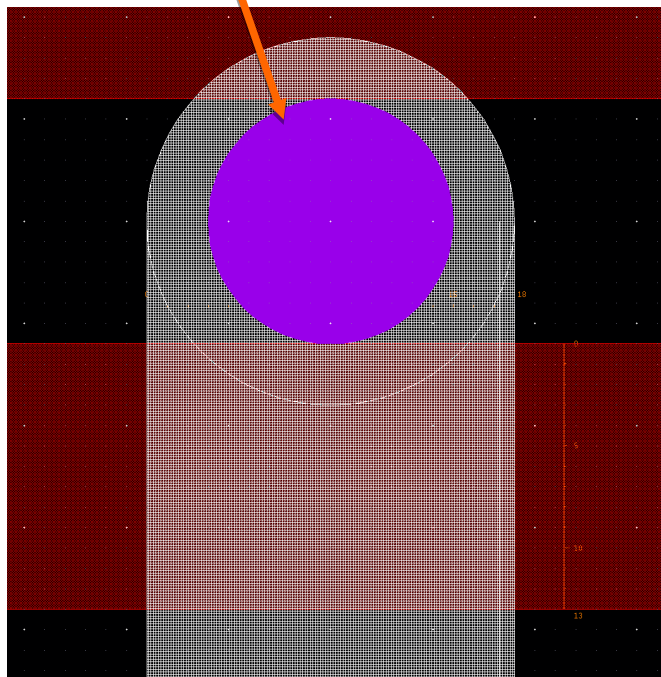
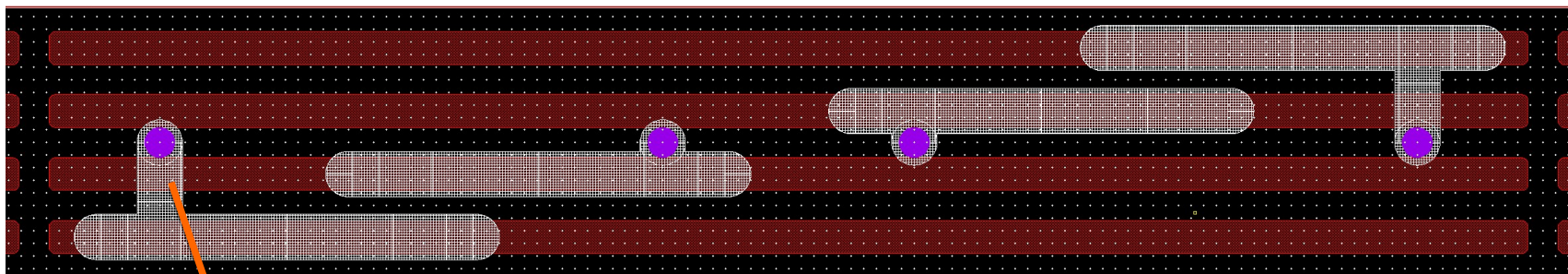
**Cluster:** collection of adjacent pixels with signal.

Test Beam FNAL, June15, Dut0=SPb2a V=120V



- **Cluster size increases as pixel pitch decreases.**
- 100 and 50  $\mu\text{m}$  pitch pixel behave according to expectations.
- For the **25  $\mu\text{m}$**  pitch:
  - No more single pixel clusters.
  - Several (10%) clusters of size 4
  - **maybe it is a consequence of the capacitors.**

# 25x600, closer look at the bonding



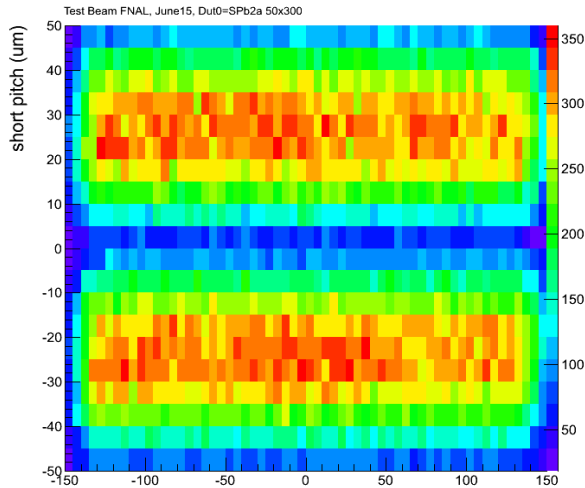
18  $\mu\text{m}$  x 13  $\mu\text{m}$  capacitance with a  $\text{SiO}_2$  thickness of 900  $\text{\AA}$  results on  $\sim 85$  fF.

This capacitor can contribute to:

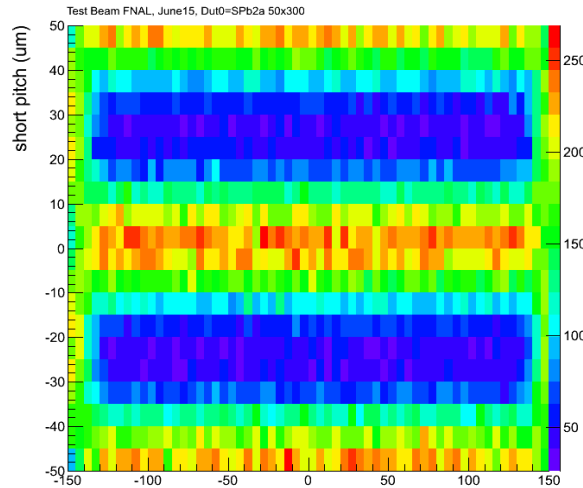
- capacitive load for the preamplifier
- spurious charge sharing between adjacent pixels



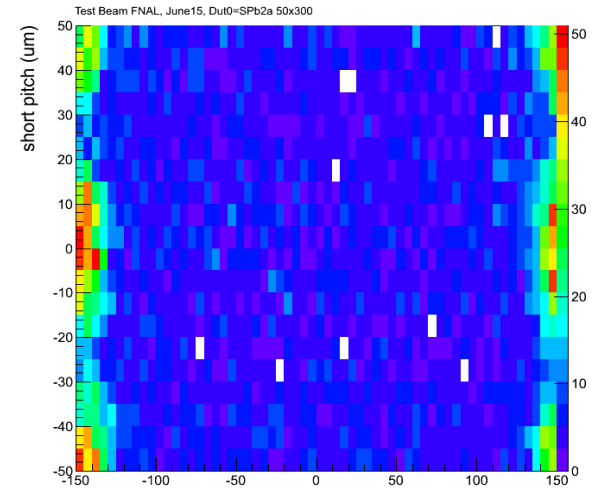
# 50x300 – Number of Clusters



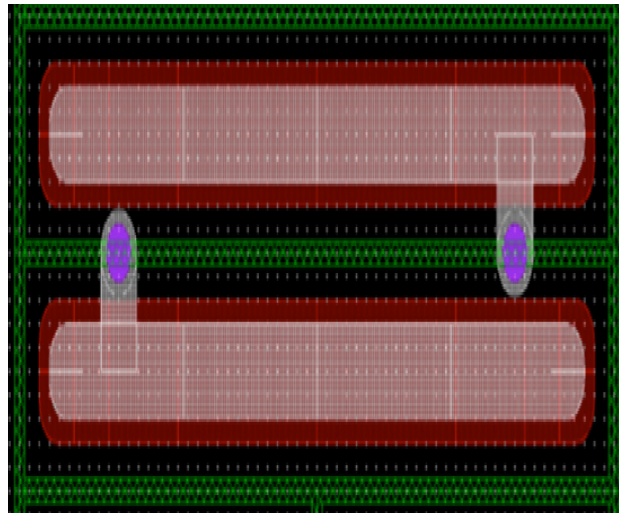
Size 1



Size 2



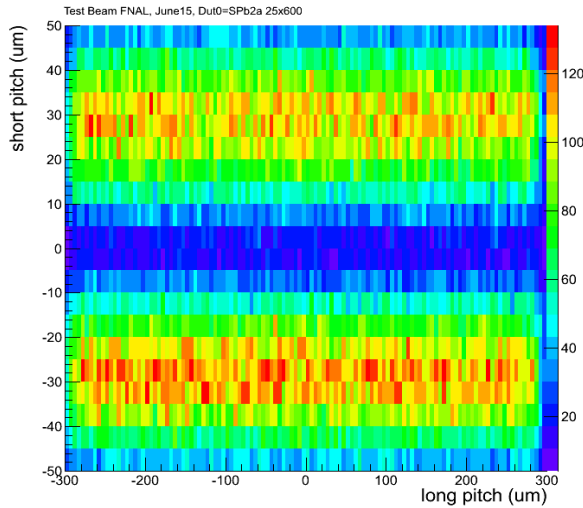
Size 3



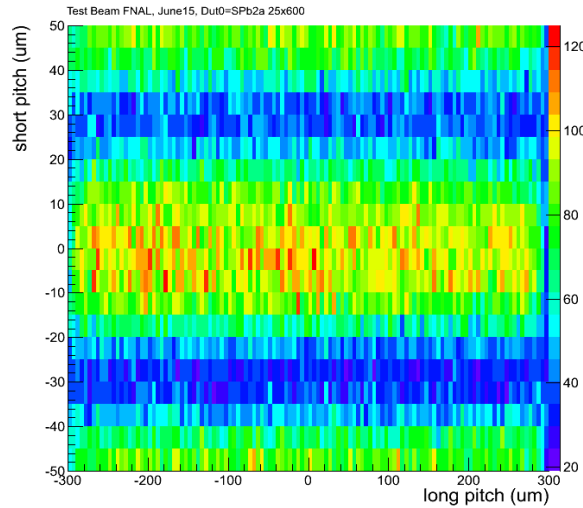
- **Size 1:** track is pointing at the center of the pixel.
- **Size 2:** edge between two adjacent pixels.

Pixels behave in the same way.

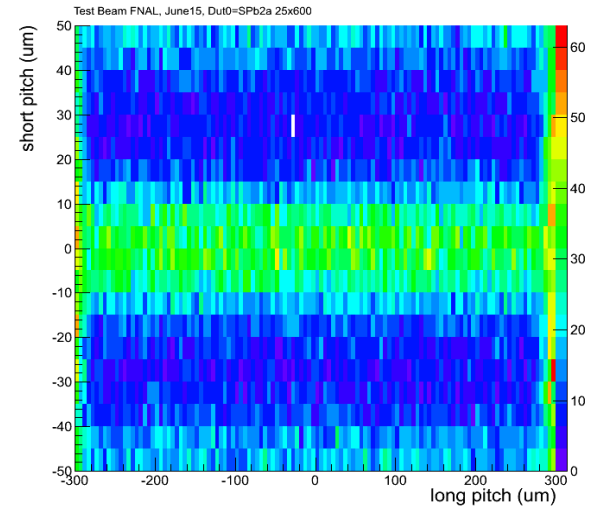
# 25x600 – Number of Clusters



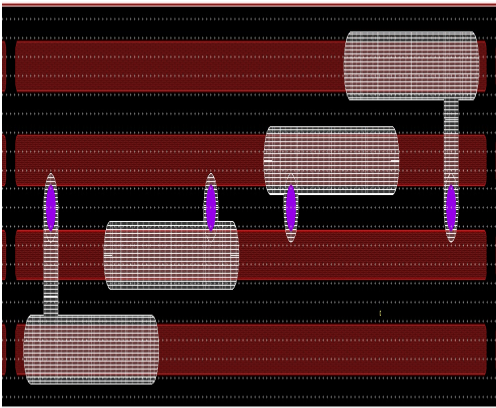
Size 2



Size 3



Size 4

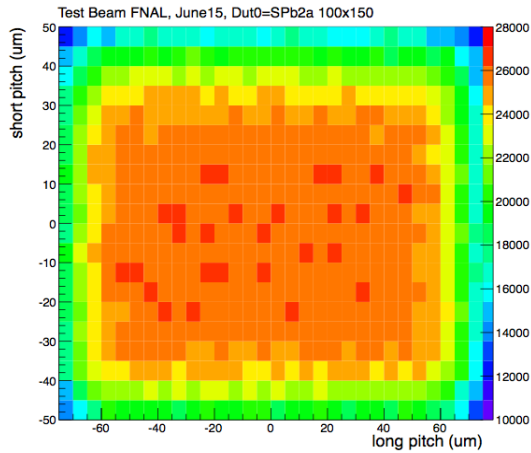


- **Size 2:** track is pointing to the top and bottom regions of the 4 cells.
- **Size 3:** center of the region of the 4 cells structure.
- **Size 4:** edge between the second and third row.

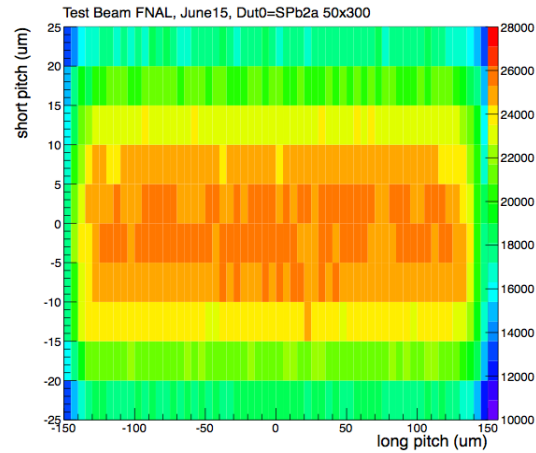
Pixels behave in different ways.

# Pixel and Cluster Charge Map

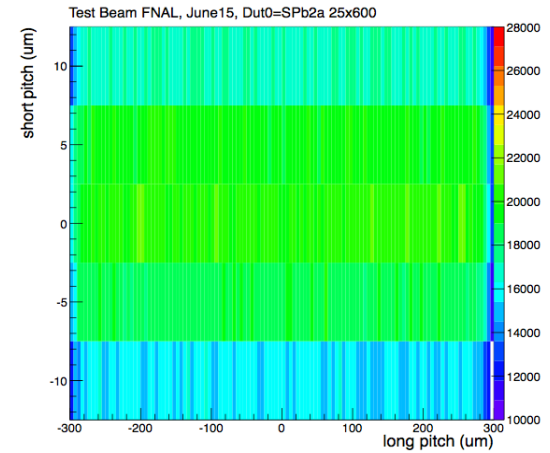
## 100x150



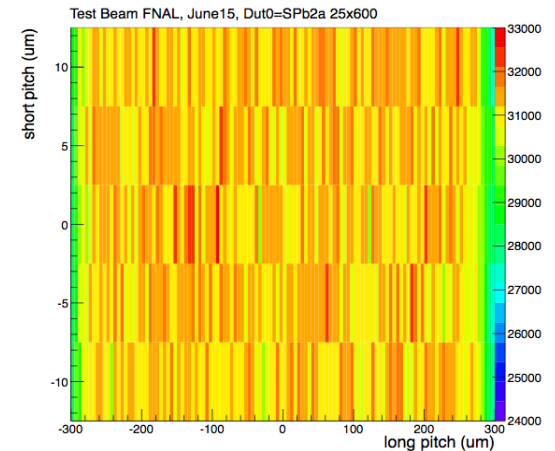
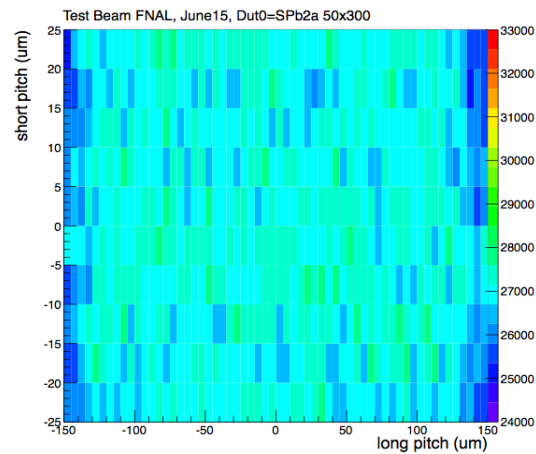
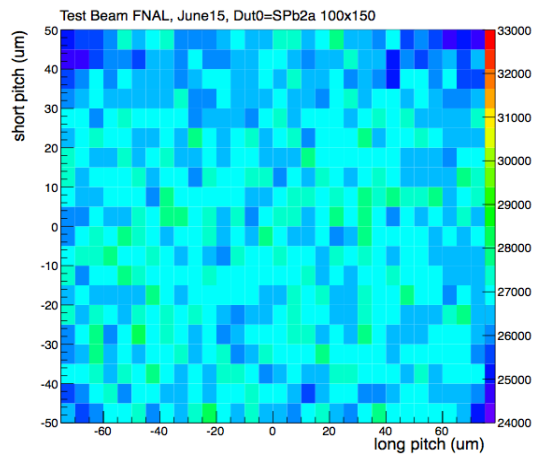
## 50x300



## 25x600

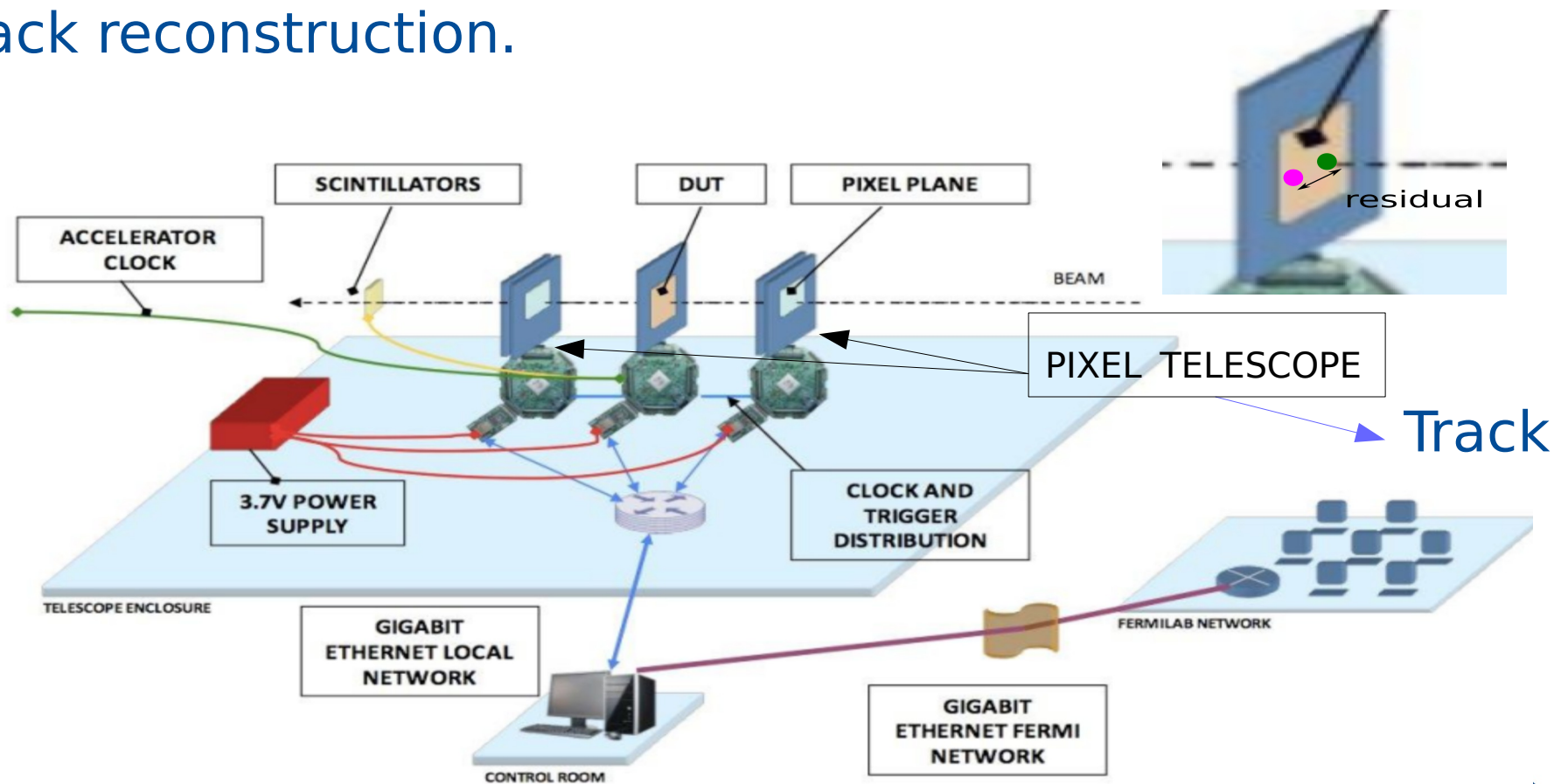


Always Charge Sharing



# Spatial Resolution

- Spatial resolution is calculated using the **residuals**.
- A residual is the difference between the **measured impact point** and the **predicted impact point** from the track reconstruction.



# Spatial Resolution

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- We calculate the measured impact point with two different algorithms:

## Center of mass

## Asimmetry fit

- The resolution is quantified using the sigma of a gaussian fit on the residuals distribution.  
In both cases we applied cuts on the collected charge and on the quality of the tracks.

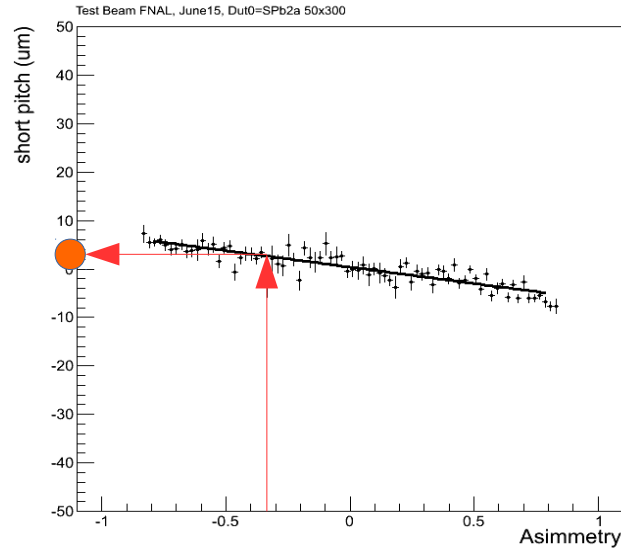
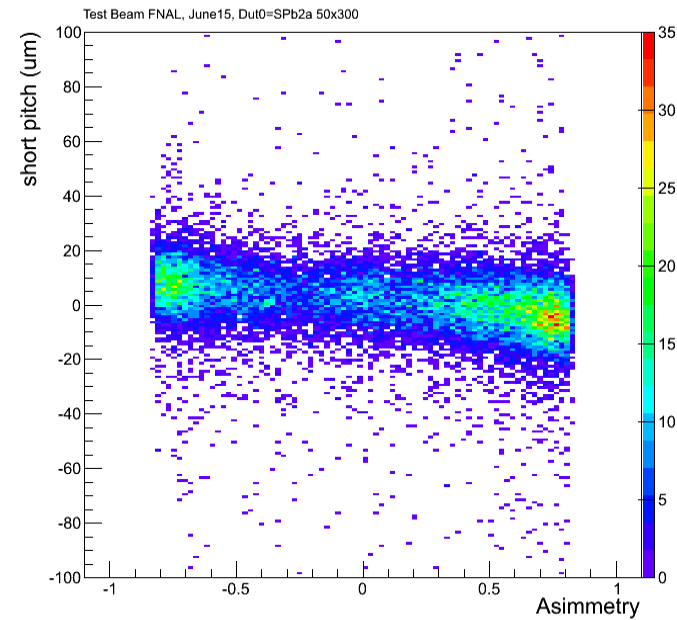
# Asimmetry

$Q_{up}$

$Q_{down}$

size 2

$$\text{asimmetry} = \frac{Q_{down} - Q_{up}}{Q_{down} + Q_{up}}$$

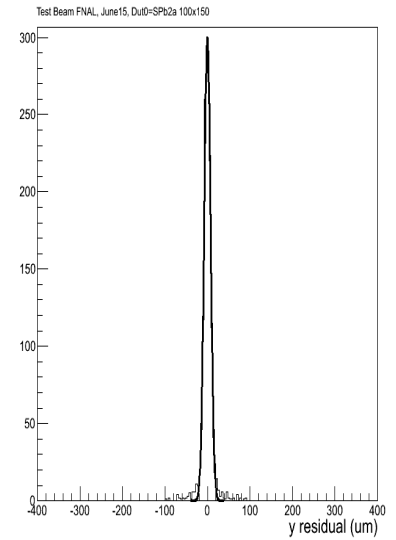
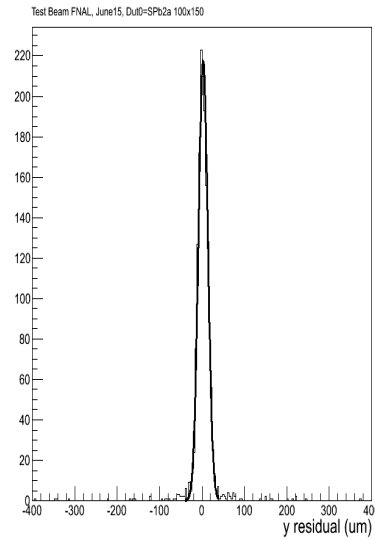
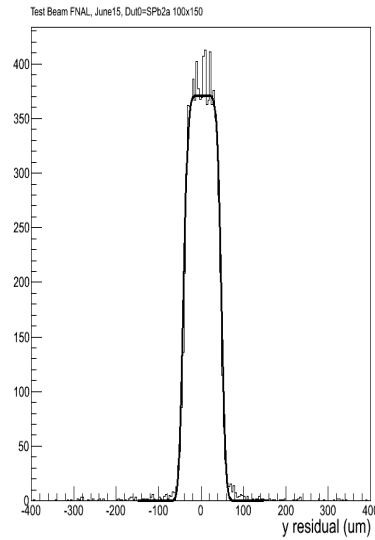
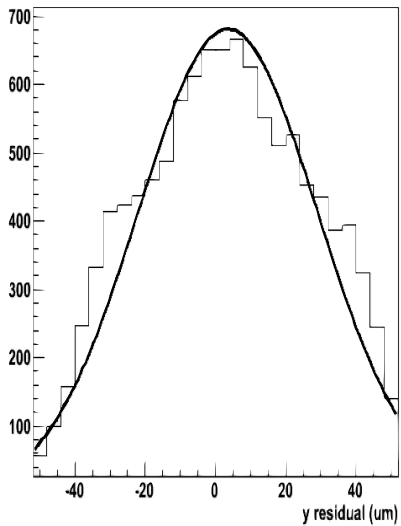


Linear fit on asymmetry to evaluate the measured impact point.

# Resolution 100x150

Center of mass:

Asimmetry fit:



All Clusters

~24  $\mu\text{m}$

RMS without  
tails

Size 1

~25.8  $\mu\text{m}$

Gaussian +  
flat  
distributions

Size 2

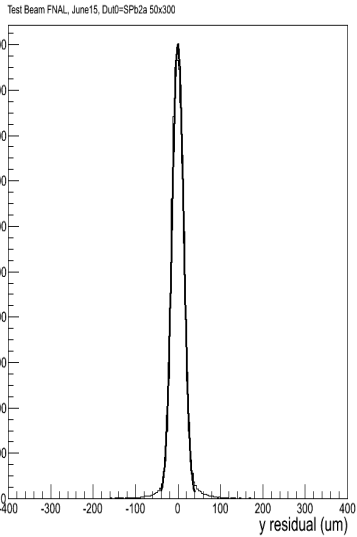
~11  $\mu\text{m}$

Size 2

7.5  $\mu\text{m}$

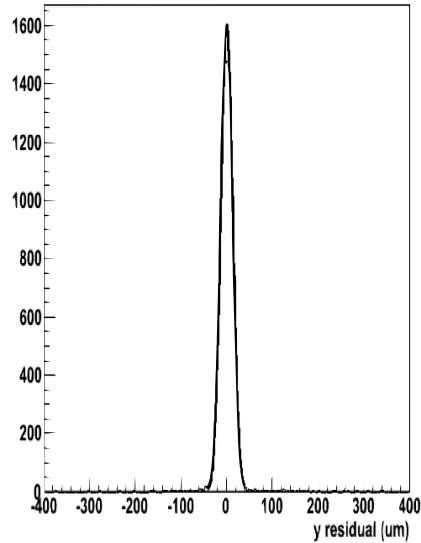
# Resolution 50x300

Center of mass: Asimmetry fit:



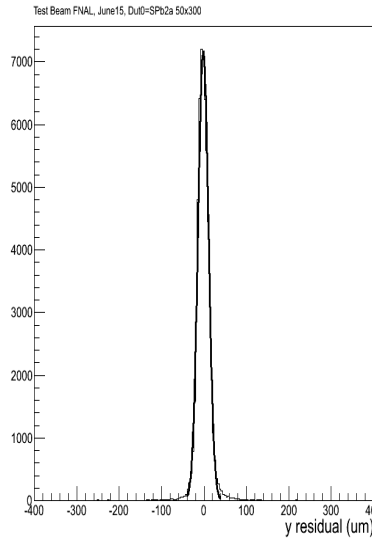
All Clusters

12.68  $\mu\text{m}$



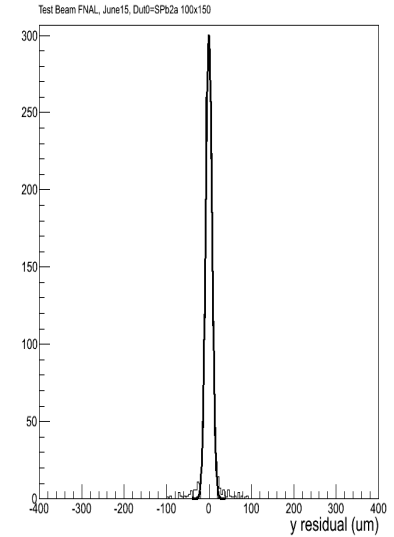
Size 1

12.96  $\mu\text{m}$



Size 2

11.25  $\mu\text{m}$



Size 2

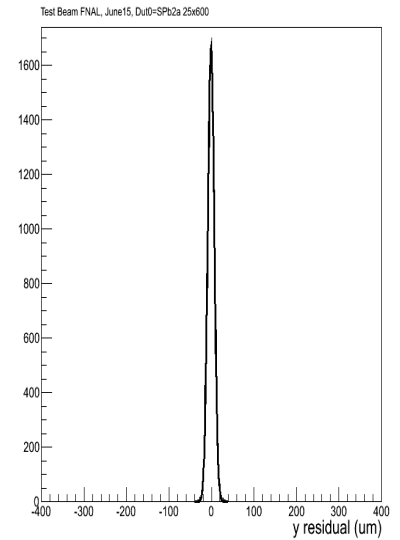
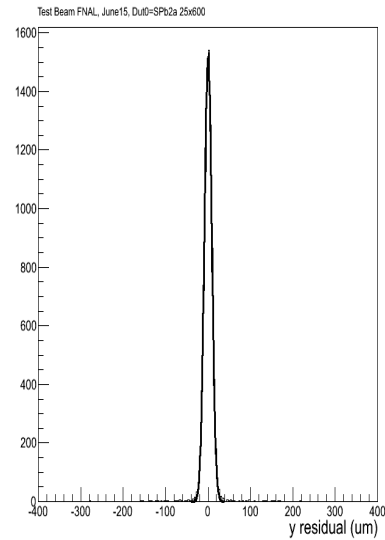
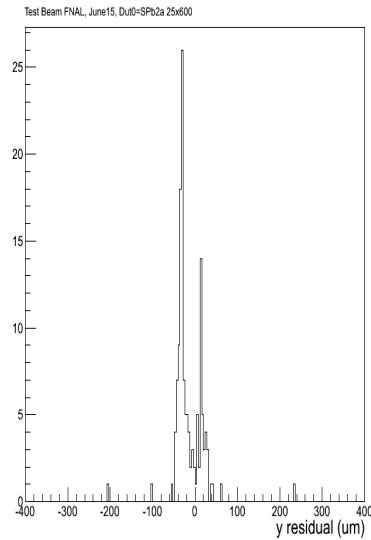
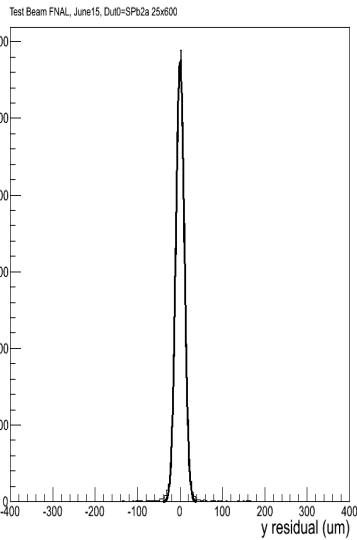
7.8  $\mu\text{m}$



# Resolution 25x600

Center of mass:

Asimmetry fit:



All Clusters

Size 1

Size 2

Size 2

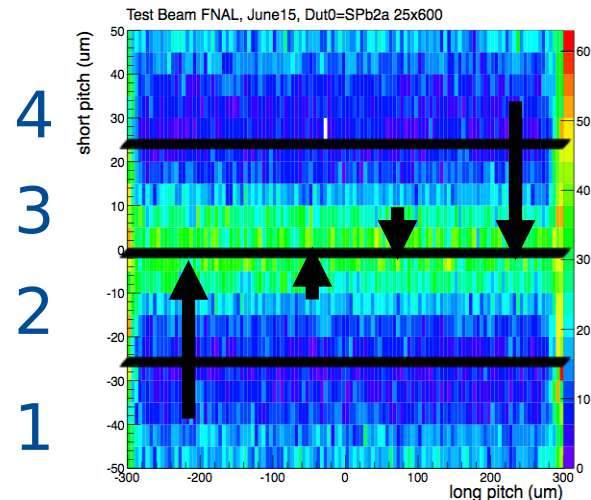
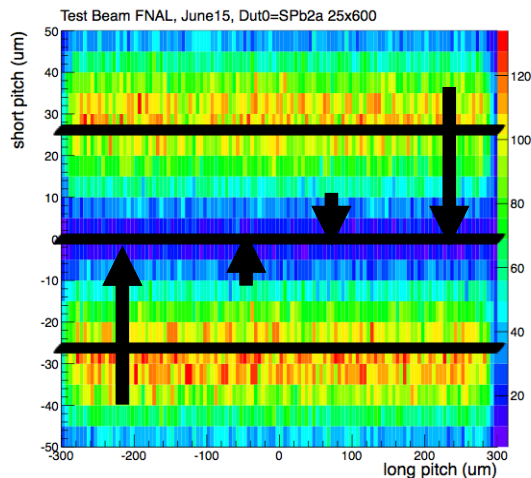
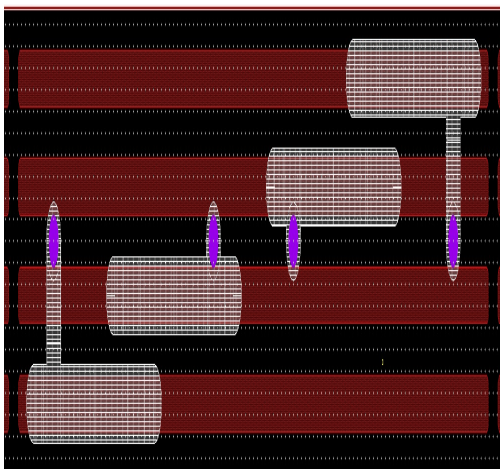
9.89  $\mu\text{m}$

Negligible  
population.

8.78  $\mu\text{m}$

7.4  $\mu\text{m}$   
Mean:-1.04  $\mu\text{m}$

# 25x600

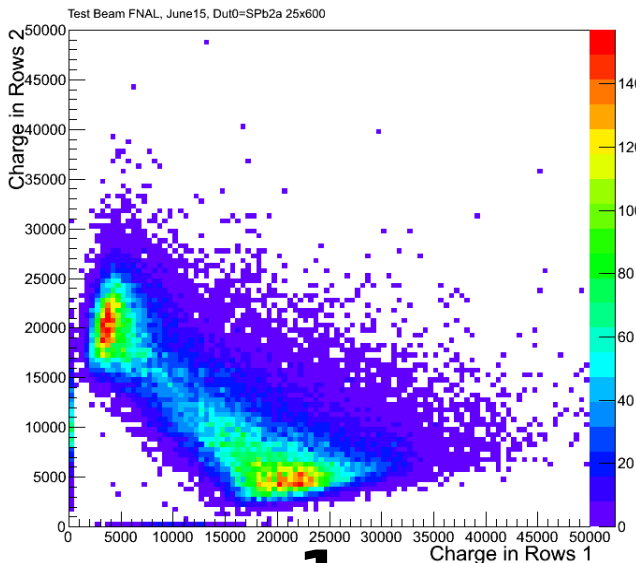


size 2

size 4

Missing highest charge in row 2: Cluster of size 4

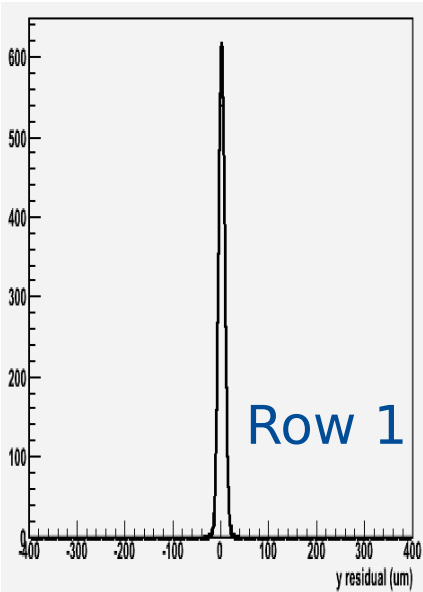
We are trying to estimate in a quantitative way the correlation between the charge in this two rows.



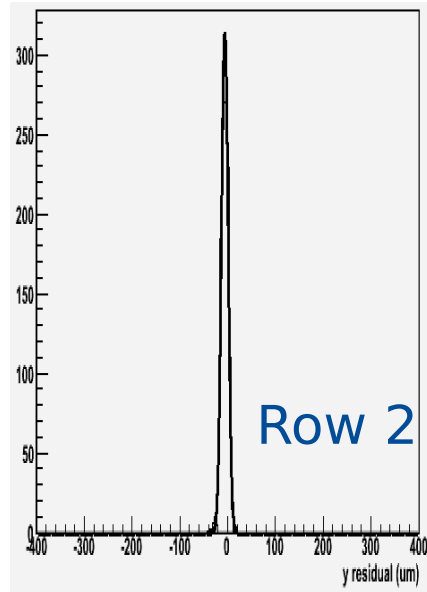
1

# Resolution 25x600, Size 2

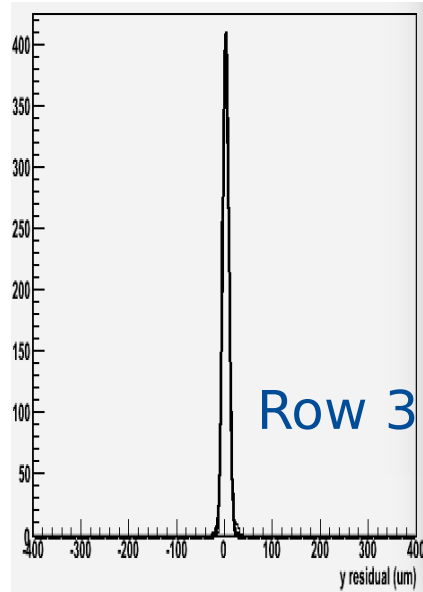
Residuals from asymmetry fit for the four rows:



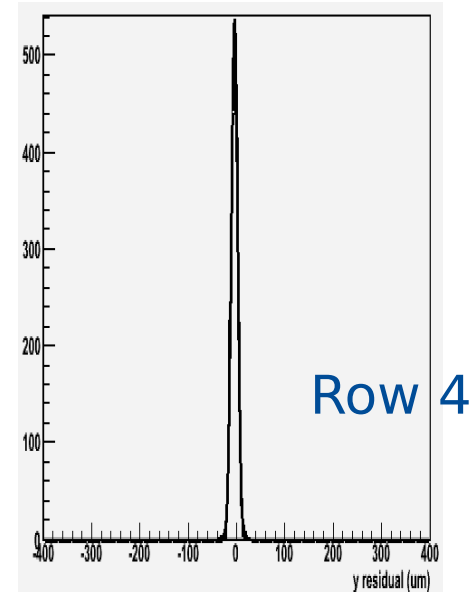
Mean:  $1.9\mu\text{m}$   
Sigma:  $6.4\mu\text{m}$



Mean:  $-5.9\mu\text{m}$   
Sigma:  $6.9\mu\text{m}$

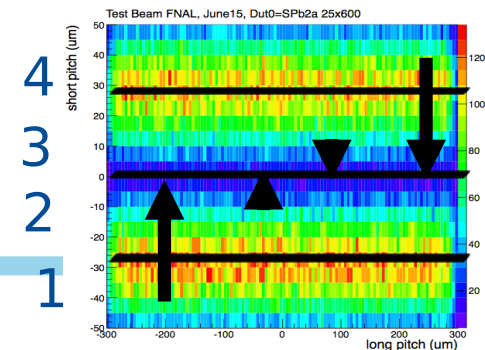


Mean:  $2.8\mu\text{m}$   
Sigma:  $6.4\mu\text{m}$

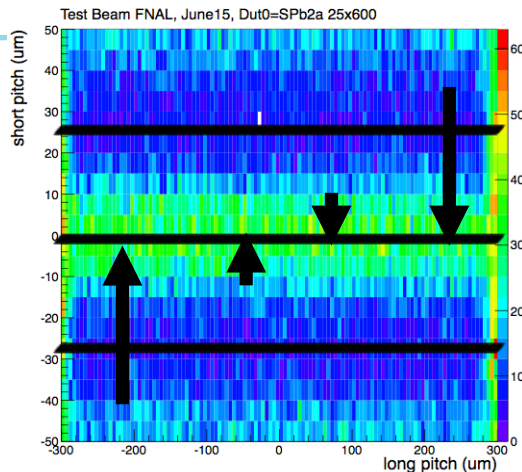
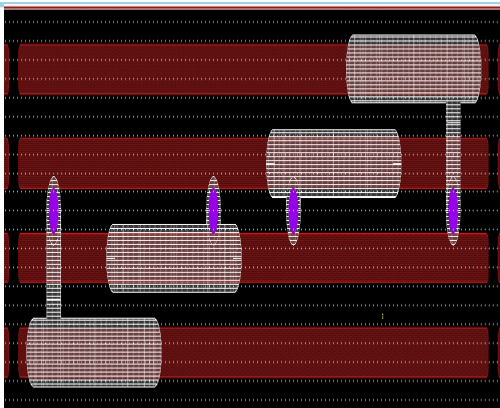


Mean:  $-4.3\mu\text{m}$   
Sigma:  $6.6\mu\text{m}$

- The gaussian distribution for the residuals of size 2, calculated from the asymmetry fit, is the sum of these 4 gaussians.
- Gaussians are not centered in zero because of the asymmetric behavior of the pixel 1(4) and 2(3).

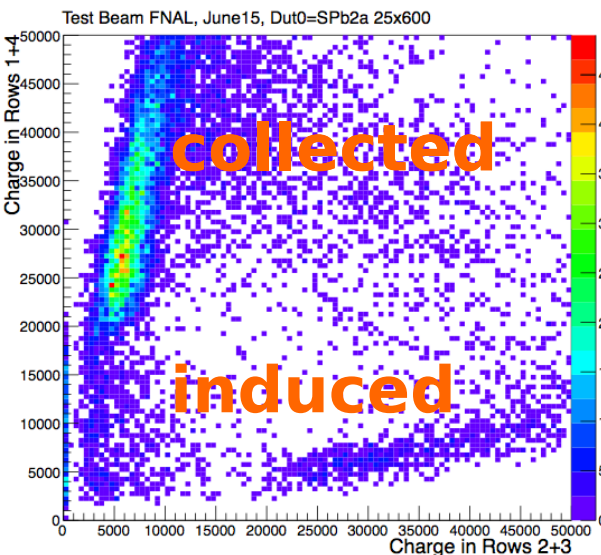


# 25x600

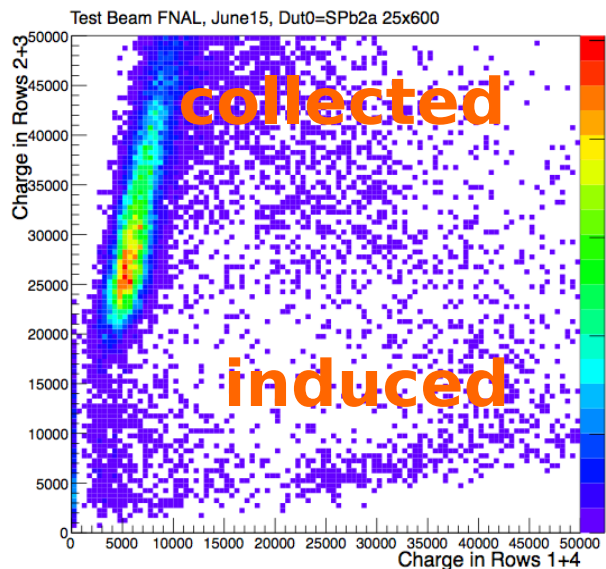


4  
3  
2  
1

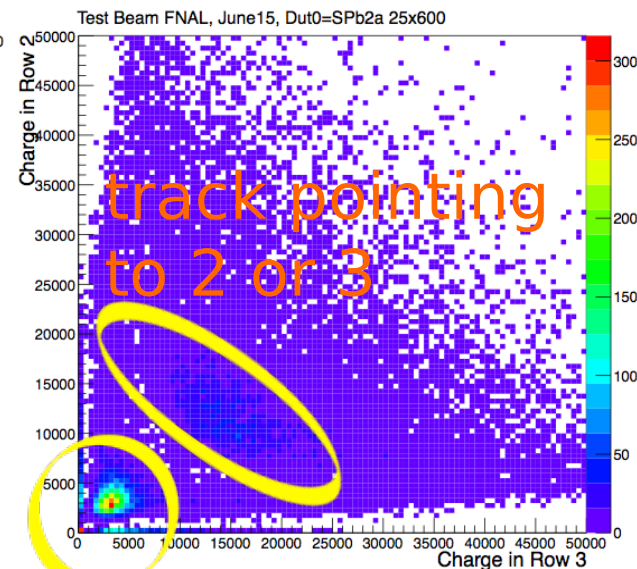
Clusters of size 4



track is pointing to 1 or 4



track is pointing to 2 or 3



track is pointing to 1 or 4

# Conclusions and plans

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- The devices are fully efficient independently of the pitch.
  - Cluster size varies with the pitch as expected, except for 25x600.
  - We are working to understand the impact of the extra capacitance.
  - We are working on the corrections to be applied.
  - Calculate the telescope resolutions.
  - Calculate the errors on the resolution.
- 
- After this experience I've learned more about the use of ROOT.
  - I studied pixel detector and I have a better understanding on the track reconstruction.
  - I learned how to analyze data on a prototype.

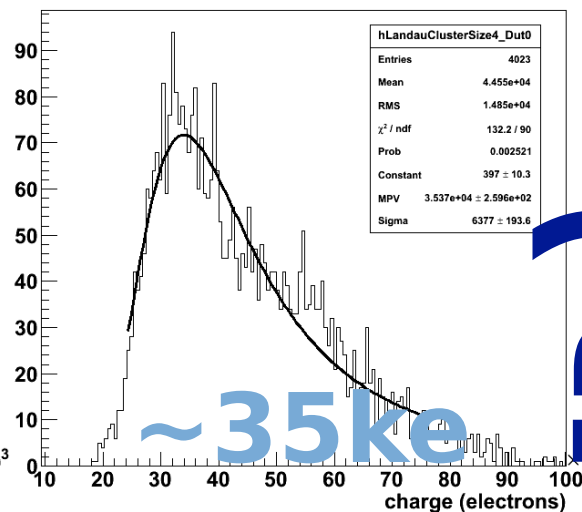
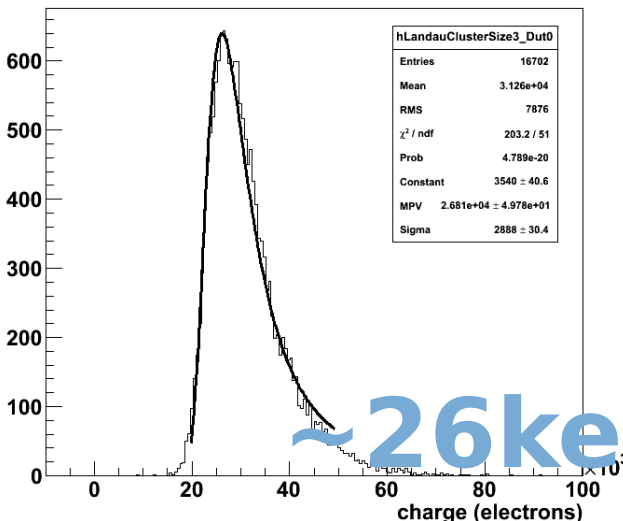
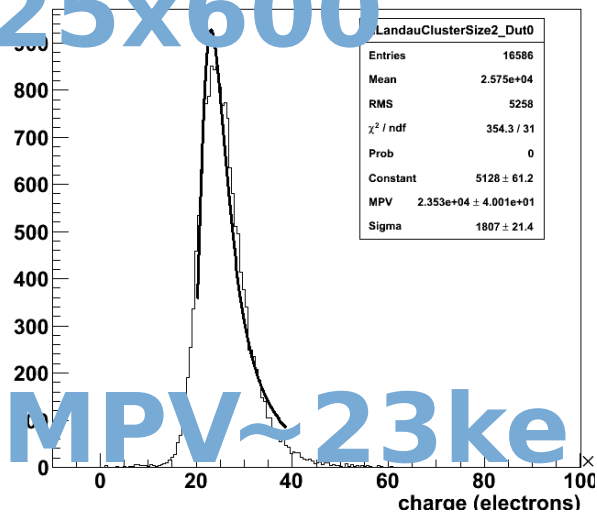
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•Questions?

**Thank you**

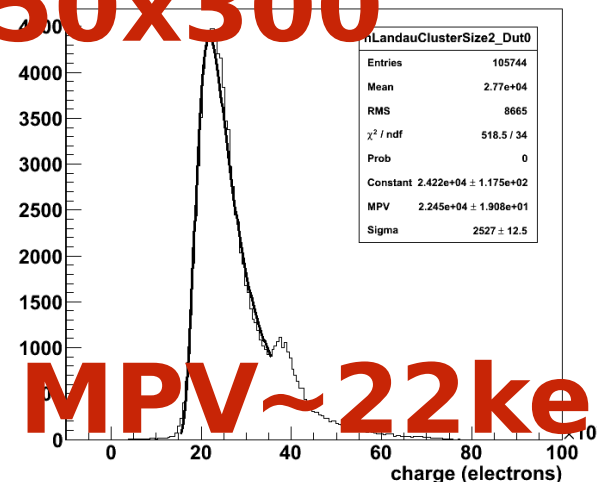
# Cluster charge distributions

25x600

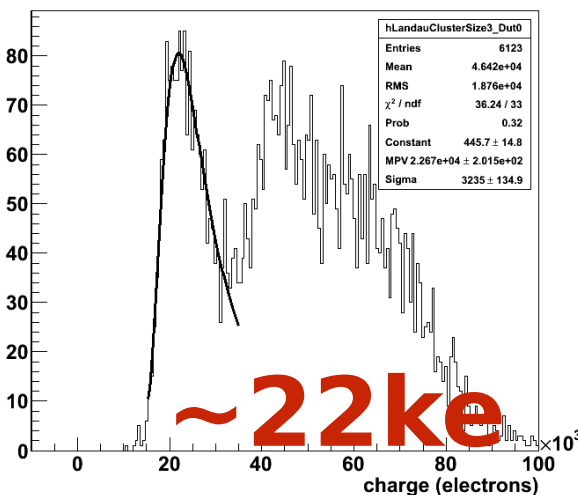


size2

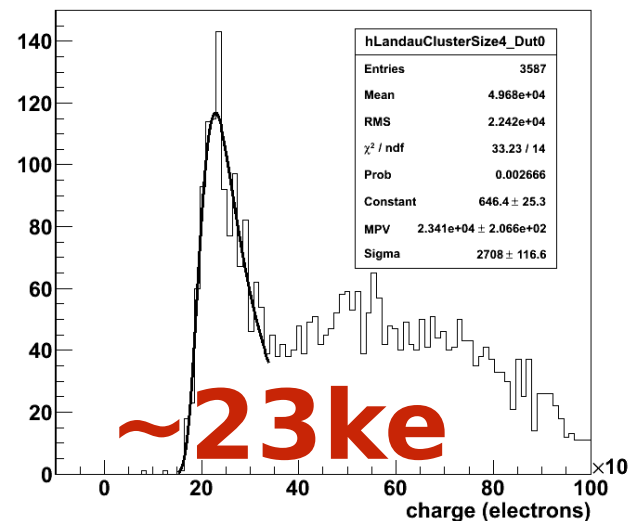
50x300



size3



size4



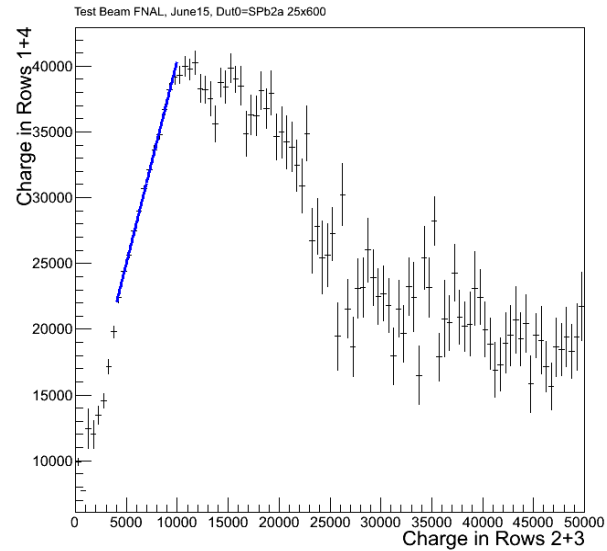
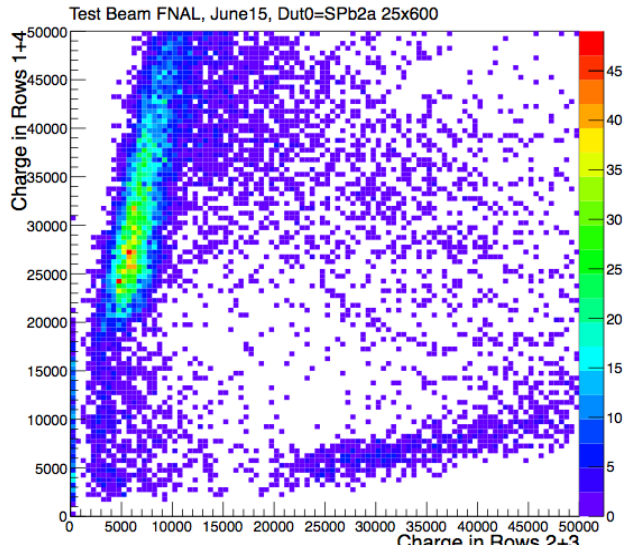
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•Questions?

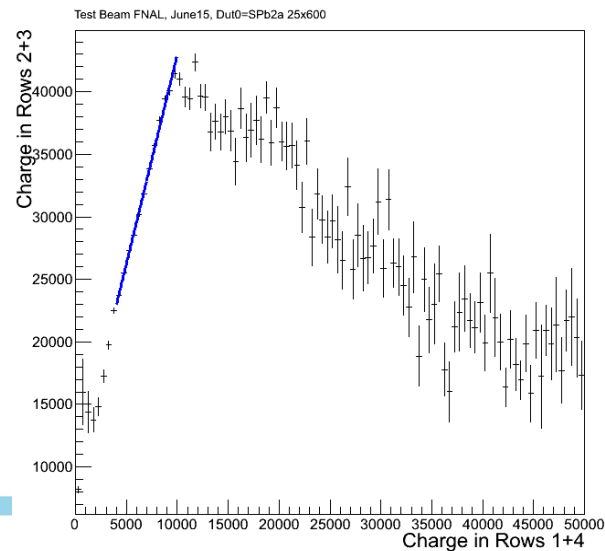
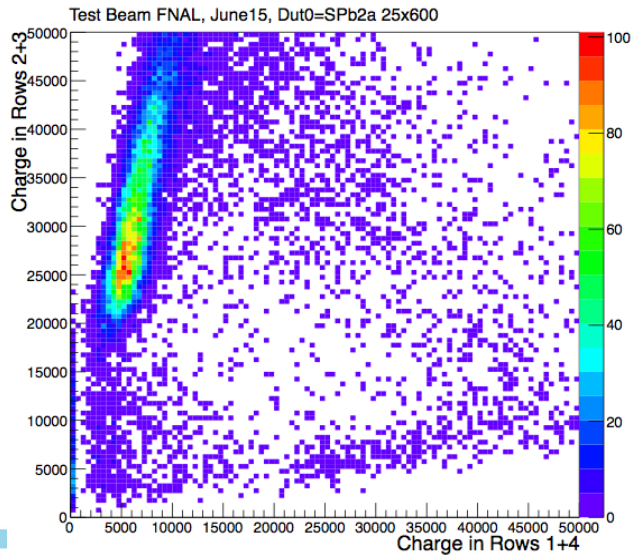
**Thank you**



# 25x600



Slope 3.08



Slope 3.33

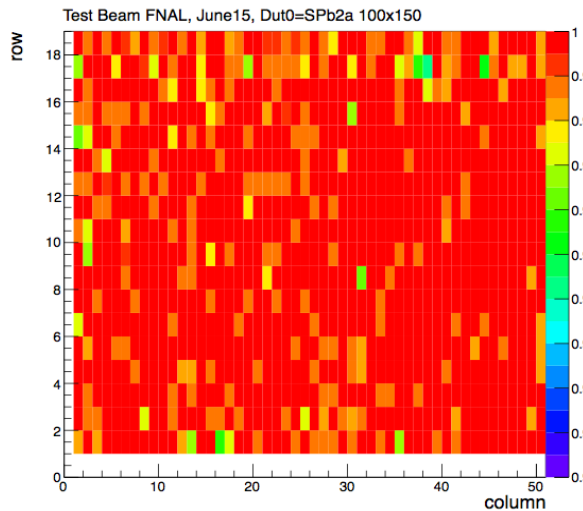
# Efficiency

- Efficiency is computed excluding first and last row/column.

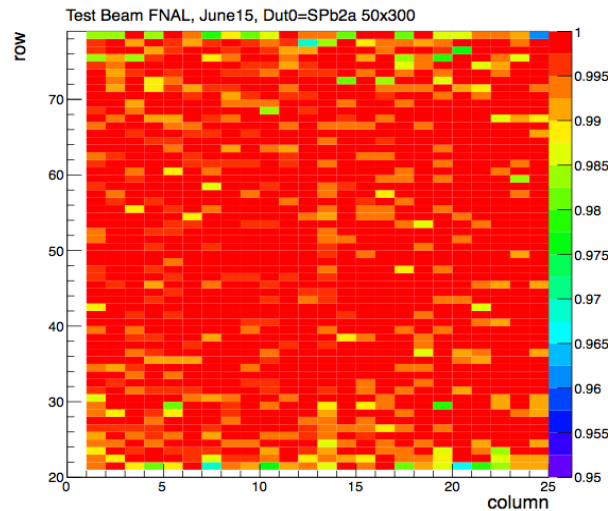
## 100x150

## 50x300

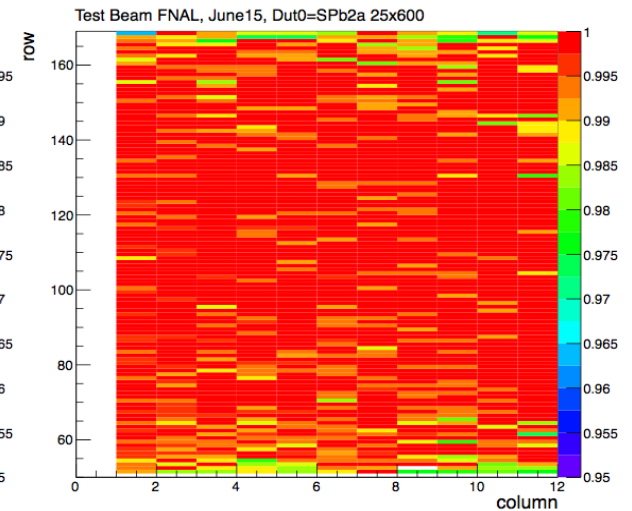
## 25x600



99.75 %

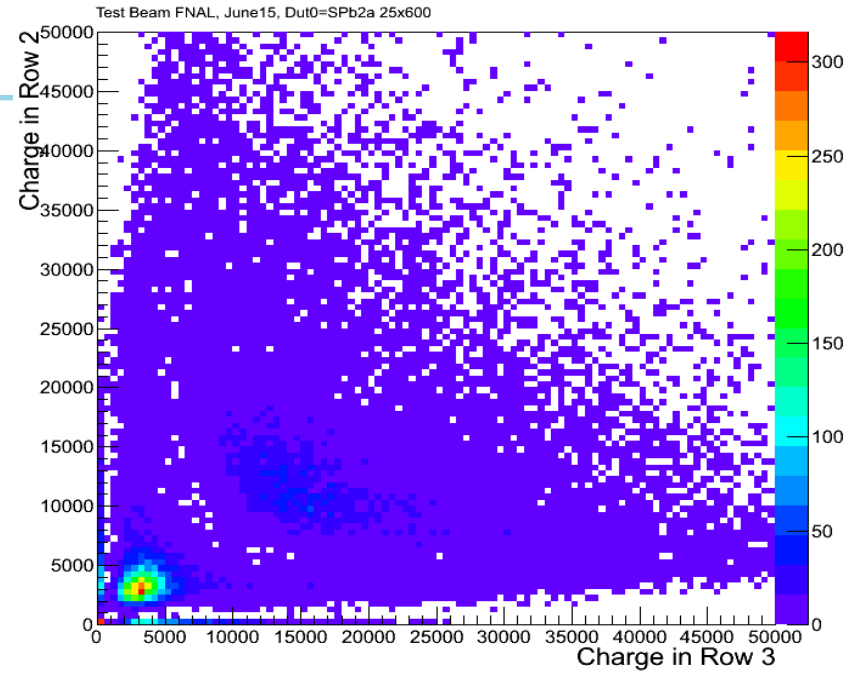
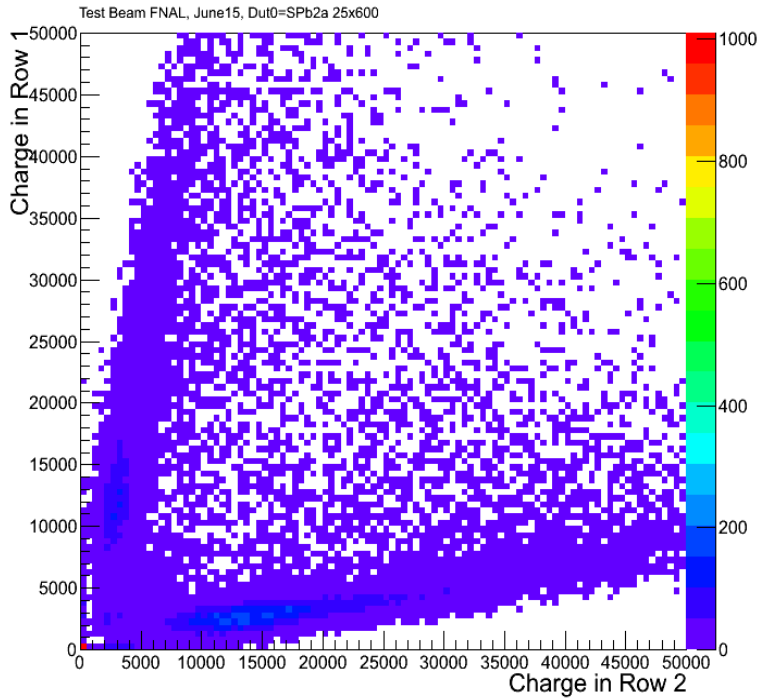


99.72 %

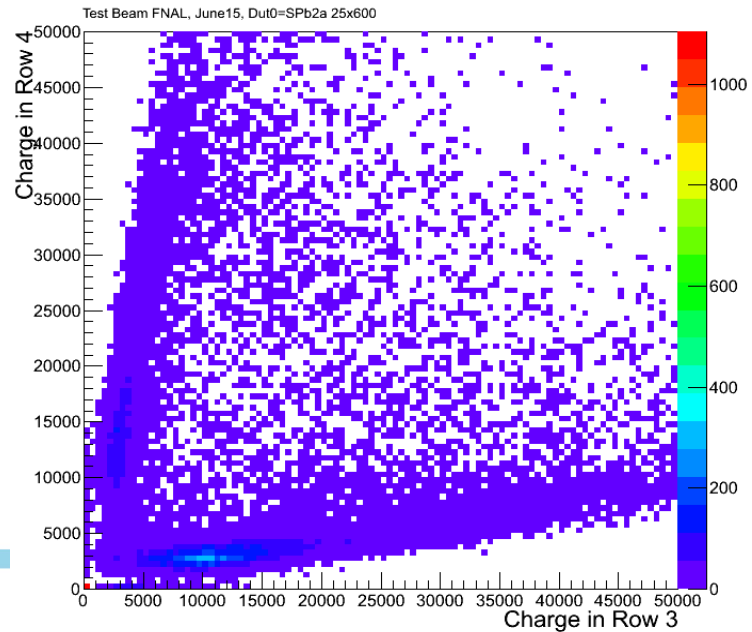


99.58 %

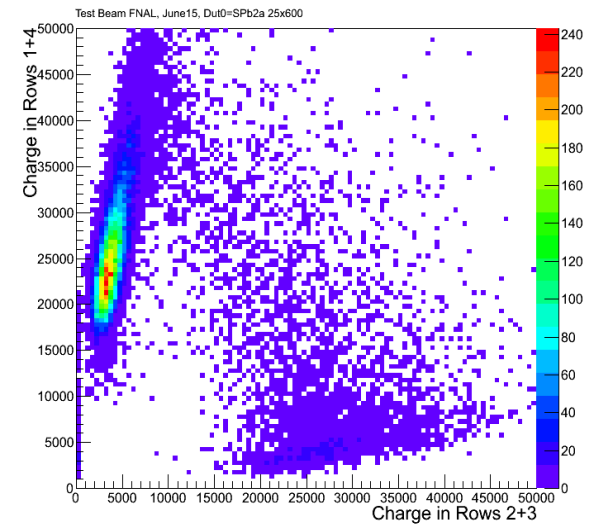
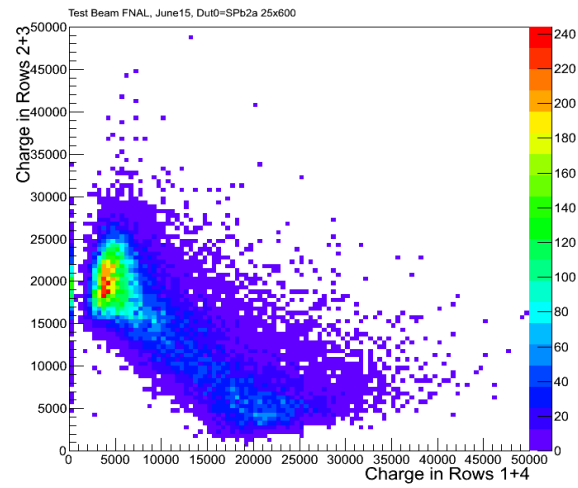
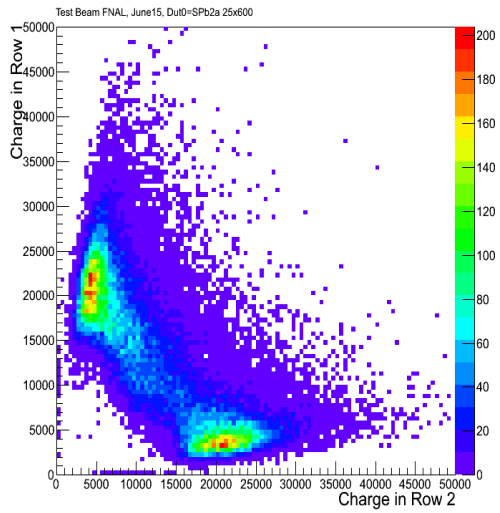
# Back up



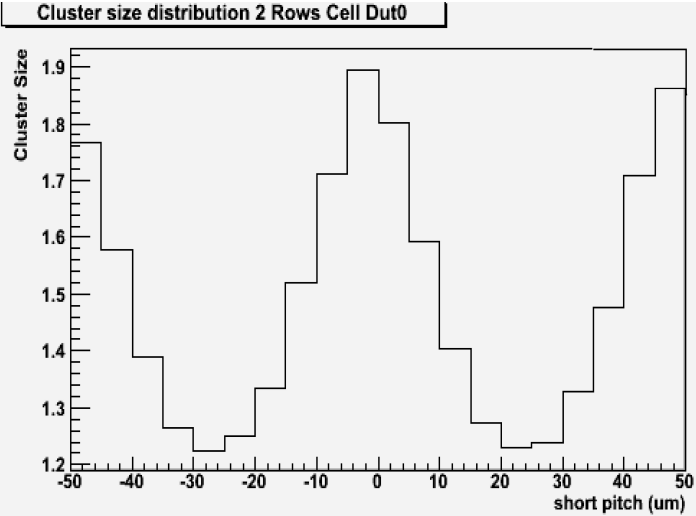
Size 4



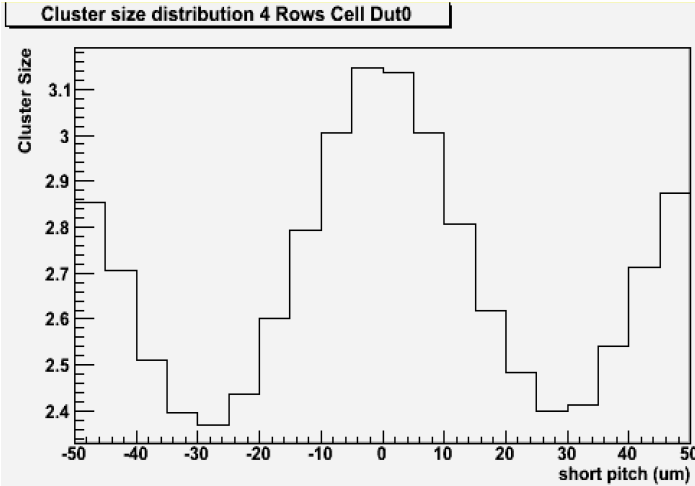
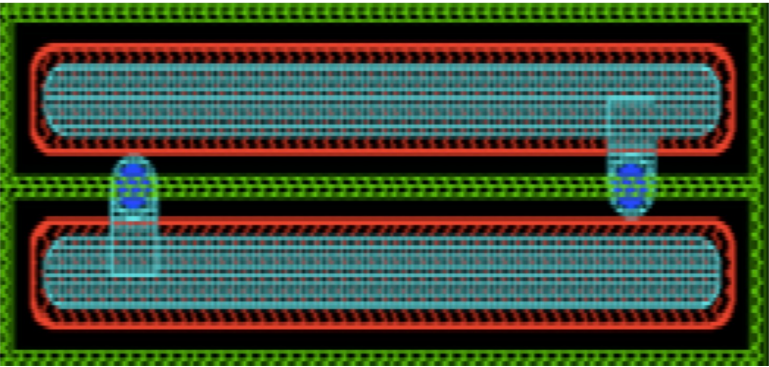
# Size2



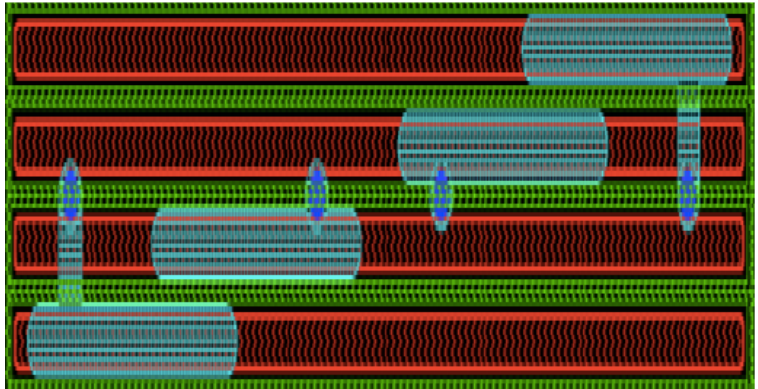
# Summary



50x300



25x600



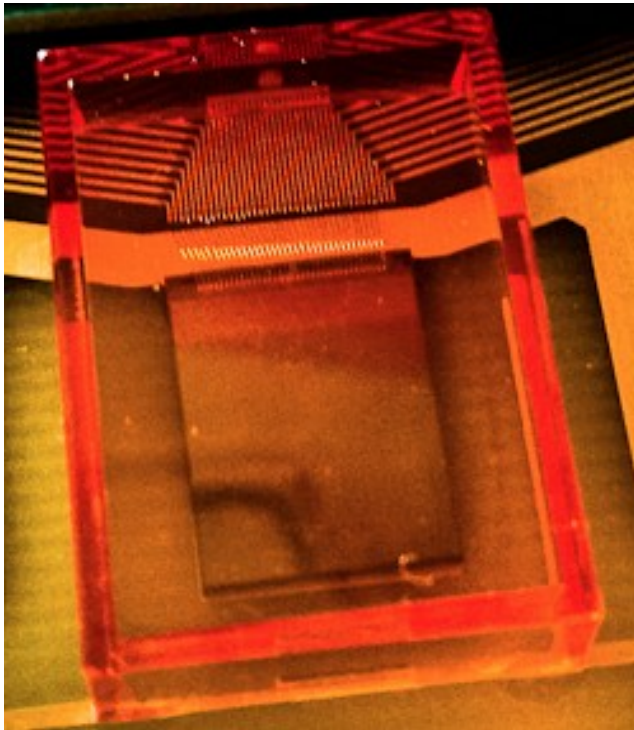
# Future Plans

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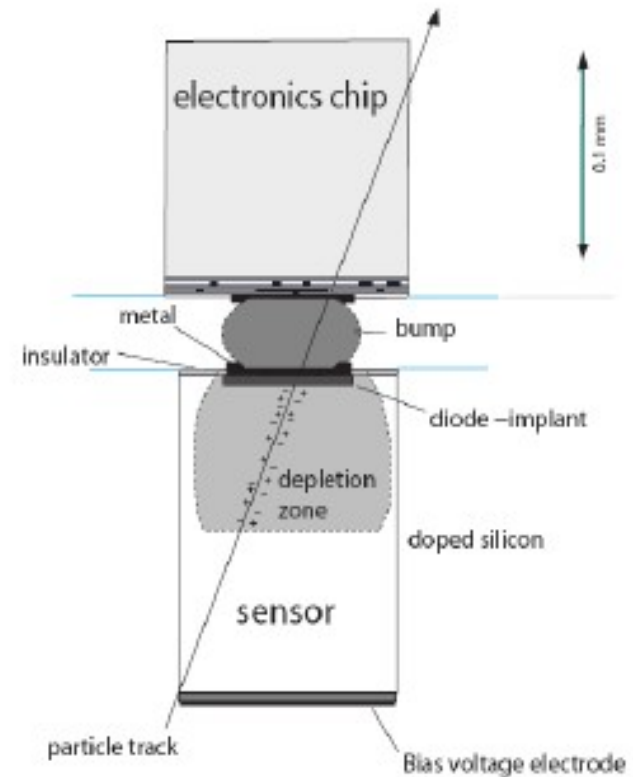
- Keep working on the analysis of the Small Pitch Sensors to have a better understanding of their behavior.
- In particular, I'll focus my studies on the **charge** and the **resolution**.

# CMS Pixel Detector Design

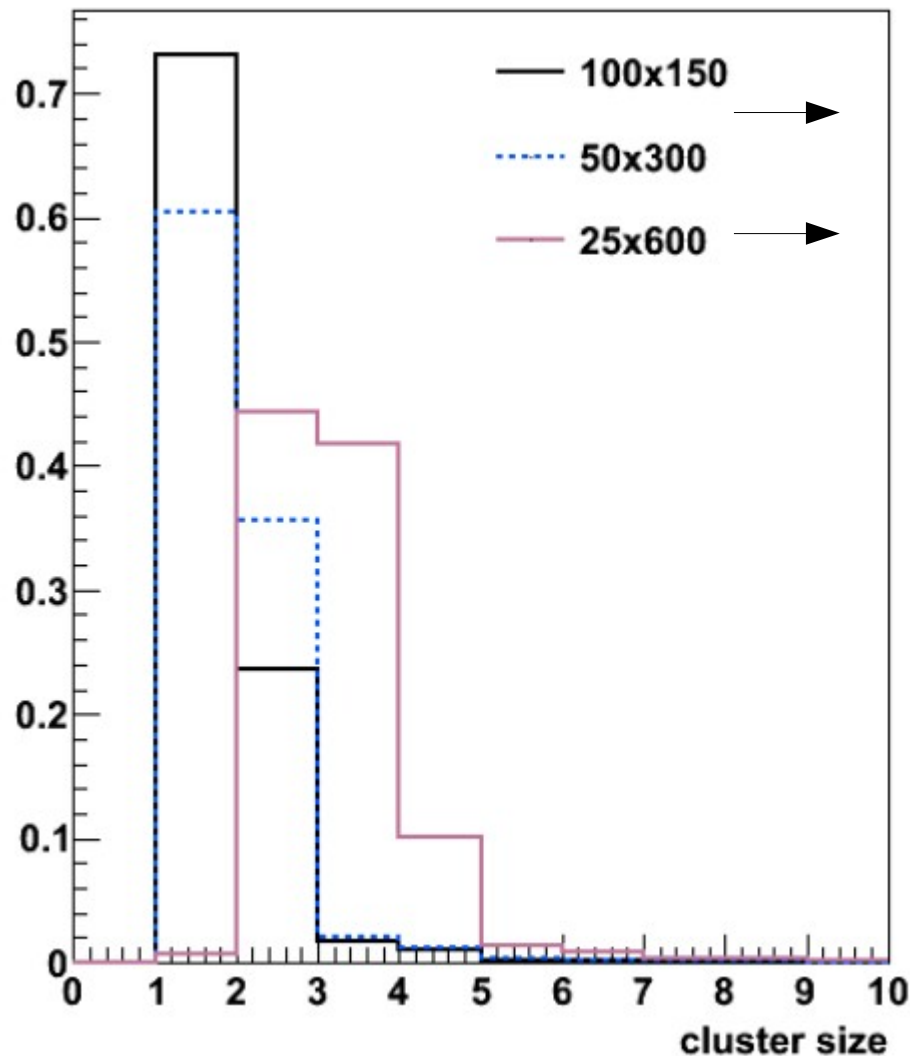
- 1 ROC has 4160 pixels
- Pixels of  $100 \times 150 \mu\text{m}^2$  are disposed in 52 columns and 80 rows



- Each pixel is bump bonded to the ROC



# Cluster Size



Size 1 and 2

Size 2, 3 and 4

**Cluster:** collection of adjacent pixels with signal.

**Charge Sharing:**  
~15-20  $\mu\text{m}$