Small pitch pixel detector for the CMS phase II upgrade

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Final Reports
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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 (100x150 μm²) 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 $100\times150\mu m^2$ 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

- 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.
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.

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

**Charge Sharing**: ~15 µm
18 μm x 13 μm capacitance with a SiO$_2$ thickness of 900 Å results on ~85 fF.

This capacitor can contribute to:
- capacitive load for the preamplifier
- spurious charge sharing between adjacent pixels
50x300 – Number of Clusters

- **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 2**: track is pointing to the top and bottom regions of the 4 cells.

Size 3

- **Size 3**: center of the region of the 4 cells structure.

Size 4

- **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

• We calculate the measured impact point with two different algorithm:

  **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

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

Linear fit on asimmetry to evaluate the measured impact point.
Resolution 100x150

All Clusters
- ~24 μm
- RMS without tails

Size 1
- ~25.8 μm
- Gaussian + flat distributions

Size 2
- ~11 μm
- ~7.5 μm
Resolution 50x300

Center of mass:  
- All Clusters: 12.68 μm  
- Size 1: 12.96 μm  
- Size 2: 11.25 μm  
- Size 2: 7.8 μm
Resolution 25x600

Center of mass:
- All Clusters: 9.89 μm
- Size 1: Negligible population
- Size 2: 8.78 μm

Asimmetry fit:
- Size 2: 7.4 μm
  Mean: -1.04 μm
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25x600

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.

Fermilab
**Resolution 25x600, Size 2**

Residuals from asymmetry fit for the four rows:

- **Row 1**: Mean: 1.9μm, Sigma: 6.4μm
- **Row 2**: Mean: -5.9μm, Sigma: 6.9μm
- **Row 3**: Mean: 2.8μm, Sigma: 6.4μm
- **Row 4**: Mean: -4.3μm, Sigma: 6.6μm

- 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).
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

• 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.
Questions?

Thank you
Cluster charge distributions

MPV ~ 23 ke

MPV ~ 22 ke

MPV ~ 22 ke

MPV ~ 23 ke

50x300

25x600

size2

size3

size4

~26 ke

~35 ke
Questions?

Thank you
Slope 3.08

Slope 3.33
Efficiency

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

**100x150**

- **99.75 %**

**50x300**

- **99.72 %**

**25x600**

- **99.58 %**
Back up

Size 4
Size2
Summary

Connections to transport charge

50x300

25x600
Future Plans

- 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 100x150 μm$^2$ are disposed in 52 columns and 80 rows
- Each pixel is bump bonded to the ROC
Cluster Size

Cluster: collection of adjacent pixels with signal.

Charge Sharing: \(\sim 15-20 \ \mu m\)