Test Beam Studies of the performance of Timepix Hybrid Pixel Detector

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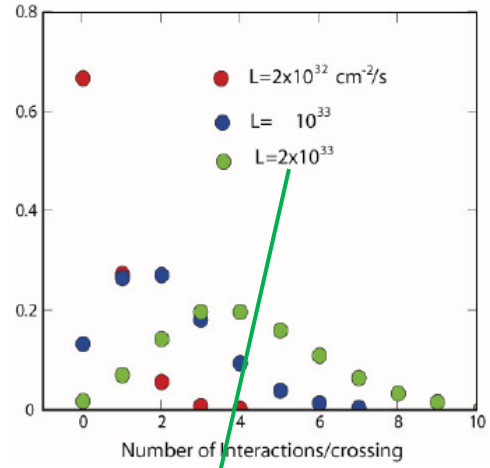
Outline

- Motivation:
  a new vertex detector concept for the LHCb upgrade
- The TIMEPIX ASIC
- Test beam experimental set-up
- Preliminary Results:
  - Charge calibration
  - Charge collection studies
  - Cluster characteristics
  - Spatial resolution

Motivation

- The high luminosity challenge ($\mathcal{L}$=2x10^{33}cm^{2}s^{-1}) requires faster electronics (40MHz readout) and better pattern recognition capabilities (better segmentation) [Current VELO triggered at 1MHz]
- Novel pixel based vertex detector meets these challenges
- Key to success front end electronics: present VELOPIX concept will be derived from TIMEPIX2 (evolution of present TIMEPIX ASIC)
- Starting point: understand features of existing TIMEPIX device

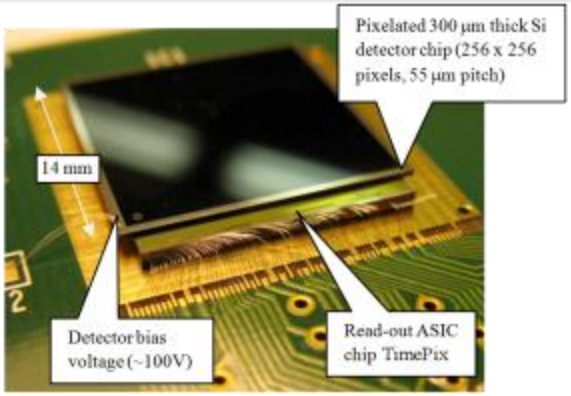


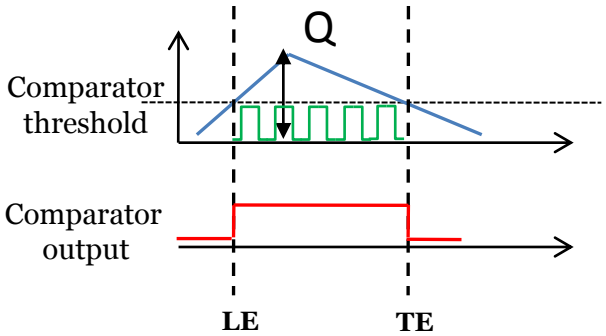
Mean # of interactions per crossing is 4.6 and all crossings have at least 1 interaction

The TIMEPIX ASIC

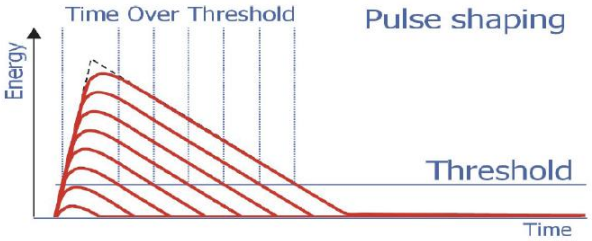
- The Timepix is a pixel read out chip, based on Medipix2.There are 256 by 256 pixels of 55 μm by 55 μm square and the overall dimensions of the active area of the chip are 14mm x 14mm. Each pixel digitizes the charge by measuring the Time Over Threshold (TOT)
- Time Over Threshold(TOT) Principle:

  Preamp has fast peaking time (90ns) but slow (500ns -2500ns) constant-return to zero time. (programmable Ikrum)



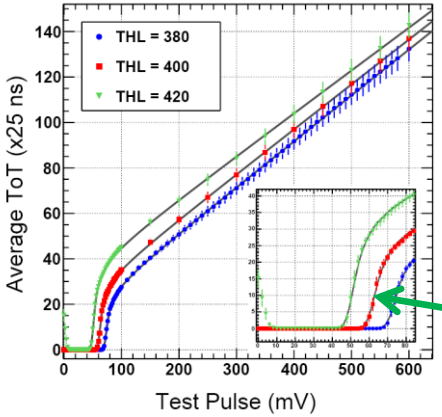


ToT = TE - LE



$$TOT = f(Q, threshold) \propto Q$$

Response Function



- non zero offset
- non linear turn-on behavior

Charge Calibration

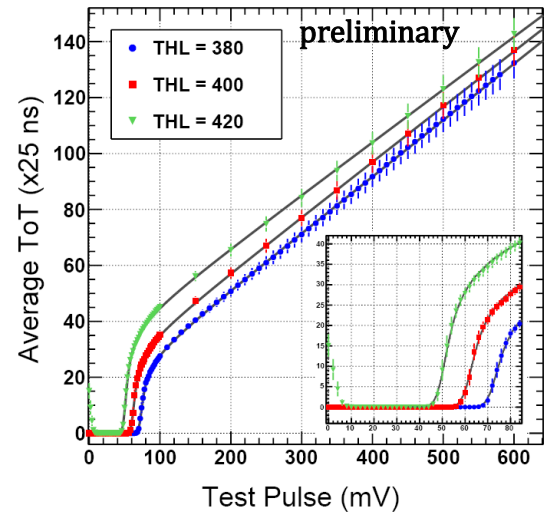
- We used test pulse to obtain the explicit from of surrogate response function for each of total 64k pixel cells

$$TOT = Gain \bullet TestPulse(mv) + Tot0 - \frac{C}{TestPulse(mv) - T}$$
$$= f(TestPulse(mv))$$

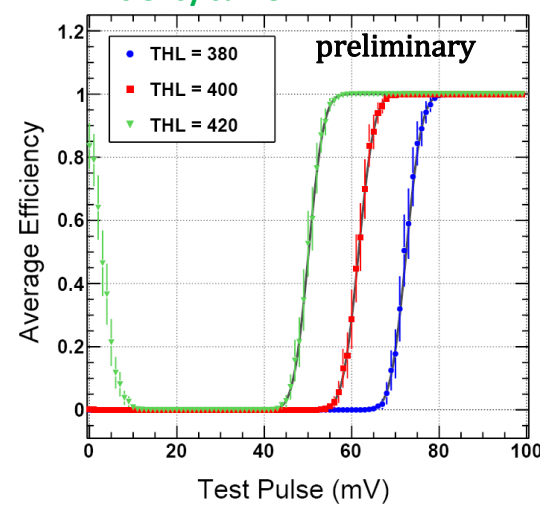
- Effective Threshold :
  - (1)response function (TOT=0)
  - (2)efficiency curve (TIMEPIX working in counting mode), 50% efficiency point
- Apply inverse surrogate function to convert TOT into charge
- Calibrate individual pixel cell because of pixel-to-pixel gain variation

THL	420	400	380
Threshold (mV)	21.90	33.04	43.56
Threshold (e)	1027	1549	2042
Noise (mV)	2.570	2.653	2.566
Noise (e)	120	124	120

Surrogate convoluted with Gaussian fit

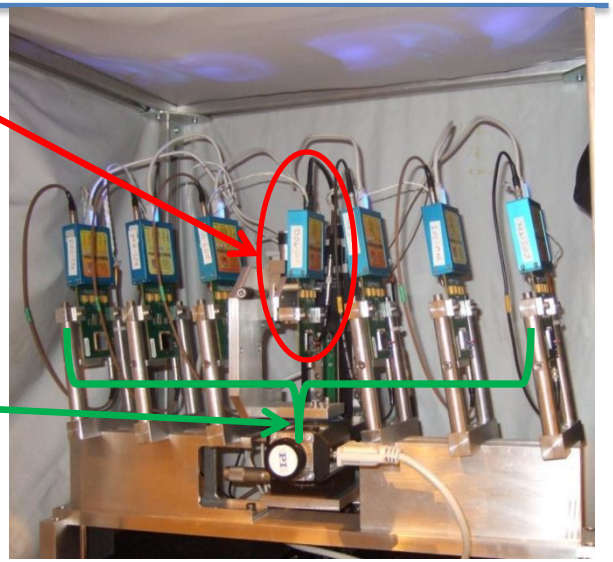


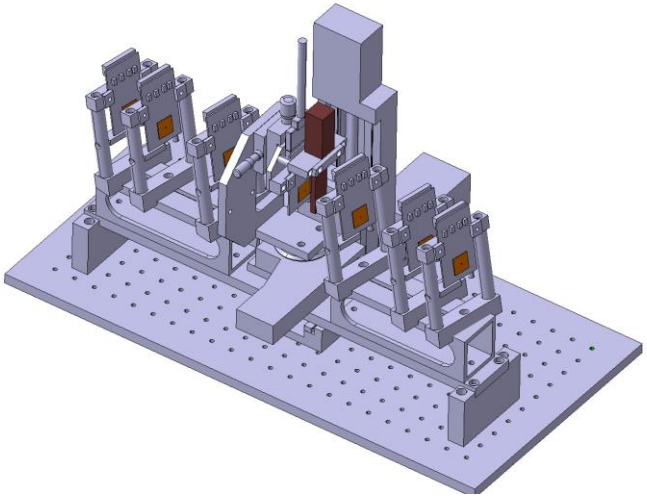
Efficiency curve



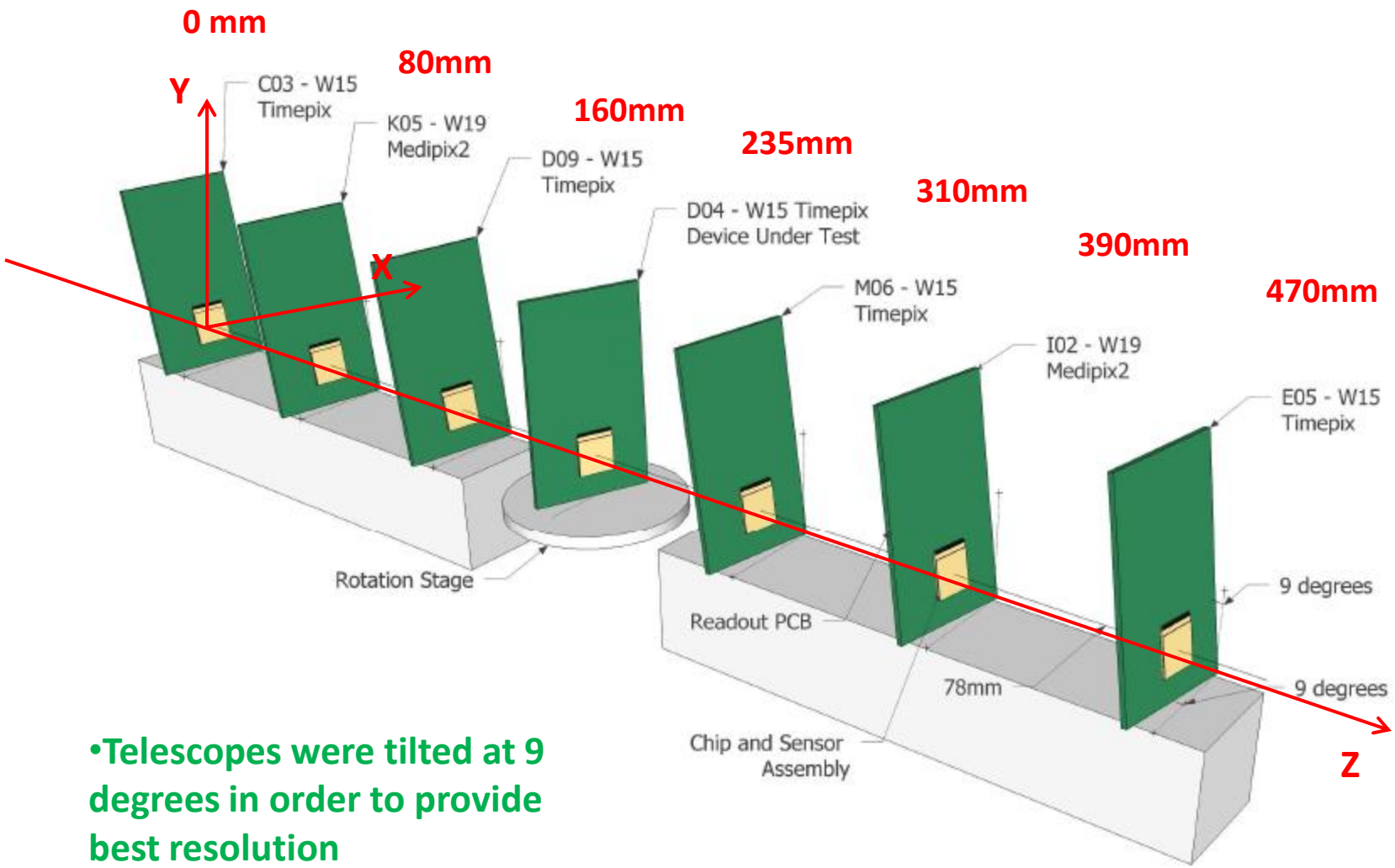
Beam Test Set-up

- Dedicated Timepix/Medipix telescope system was constructed with 6 planes(double angled 9 deg). 4 Timepix and 2 Medipix sensors were used.
- 120 GeV pion beam
- Medipix2 planes only provide binary information
- Pattern recognition &Track fitting ignore the DUT to generate unbiased spatial resolution





Global coordinate system for the whole analysis framework

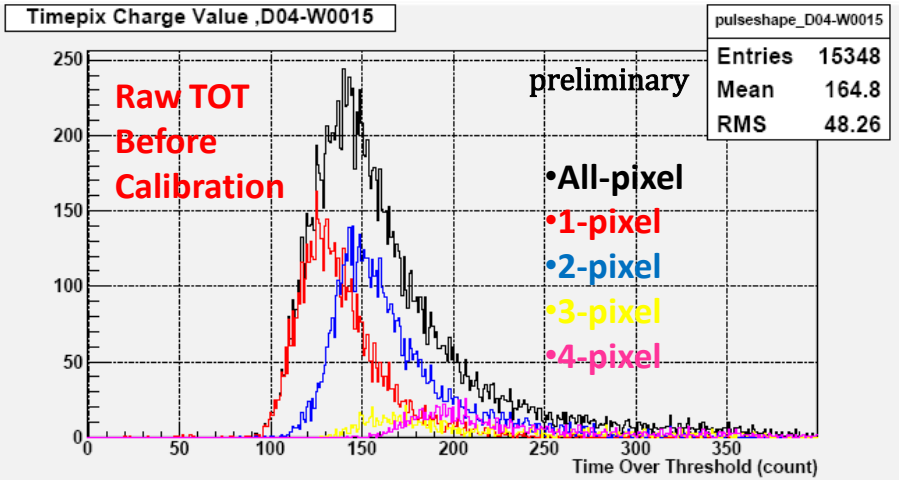


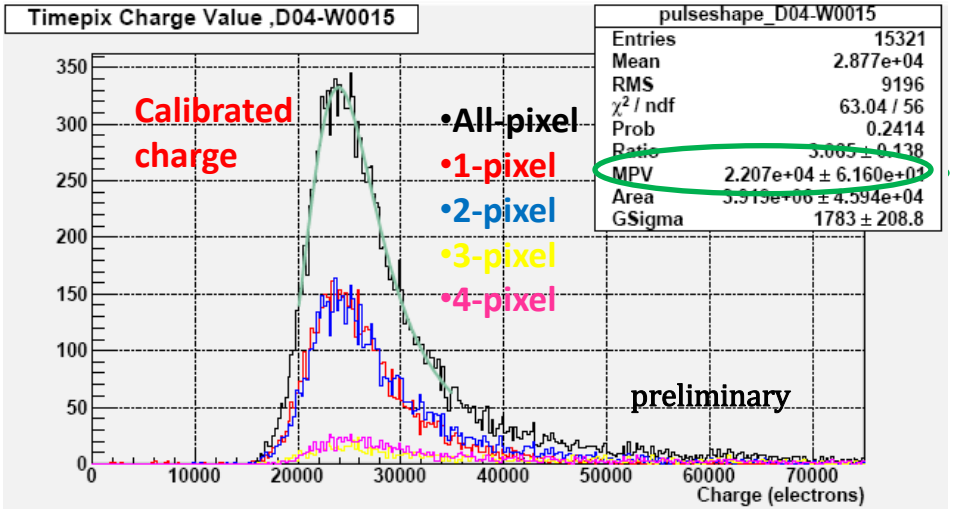
- Telescopes were tilted at 9 degrees in order to provide best resolution

Landau

- TOT of the clusters increases incrementally with each additional pixel, with most probable values of 123,148,171, and 200 TOT counts for the 1,2,3, and 4 pixel clusters respectively.

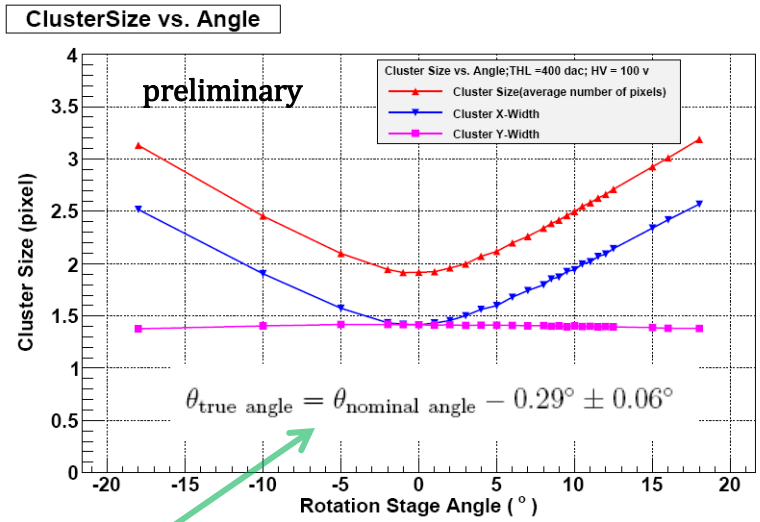
- Proper calibration enables to extract the correct charge information of each pixel, and will improve the spatial resolution
- LanGaus model fit to the charge :example data with M.I.P ~ 22ke (300 um silicon thickness)

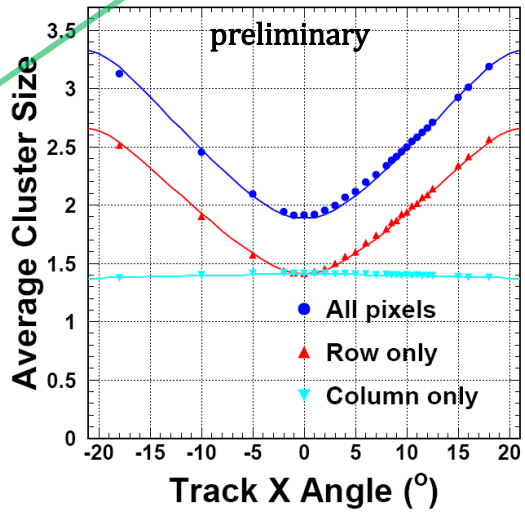




Spatial Resolution Studies (angle scan)

- Motivation: understand whether resolution expected on the basis of geometry (angle) and diffusion process (normal incidence) is achieved
- Angle scans : Using the motion stage the DUT was rotated about the y-axis, causing the clusters to spread in the x direction
- Approximately 30 different angles were taken, concentrating on the region between zero and the optimal angle of around 10 deg, increasing to a largest angle of 18 deg
- Although the rotation stage can move and reproduce the angle of the DUT with very high precision, there is an uncertainty on the absolute calibration of the angle



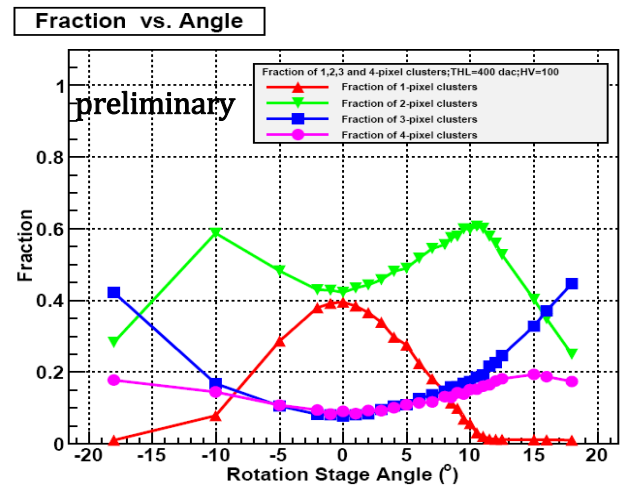


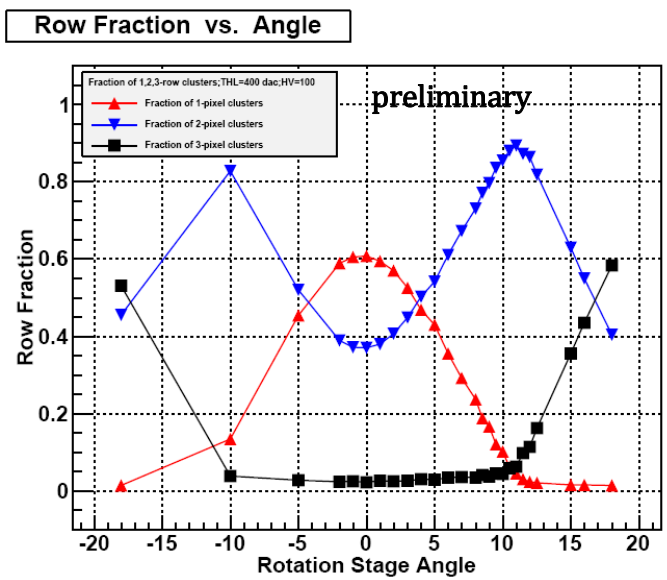
•Good agreement with a dedicated simulation

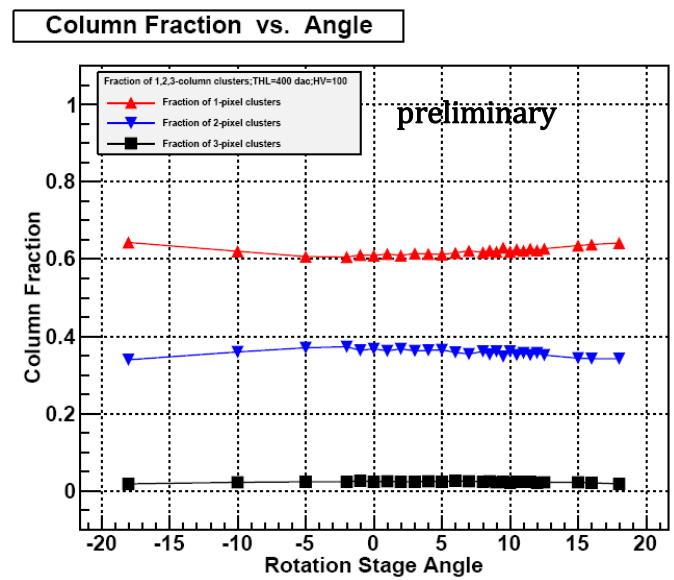
Angle Scans Continued

- Fraction of clusters split into row and column direction(1,2, and 3 row/column cluster)
- DUT not rotated in column direction(Y direction)

~10 degree is the optimal angle which has maximum charge sharing

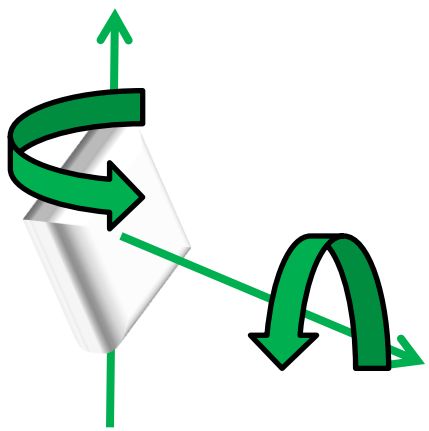




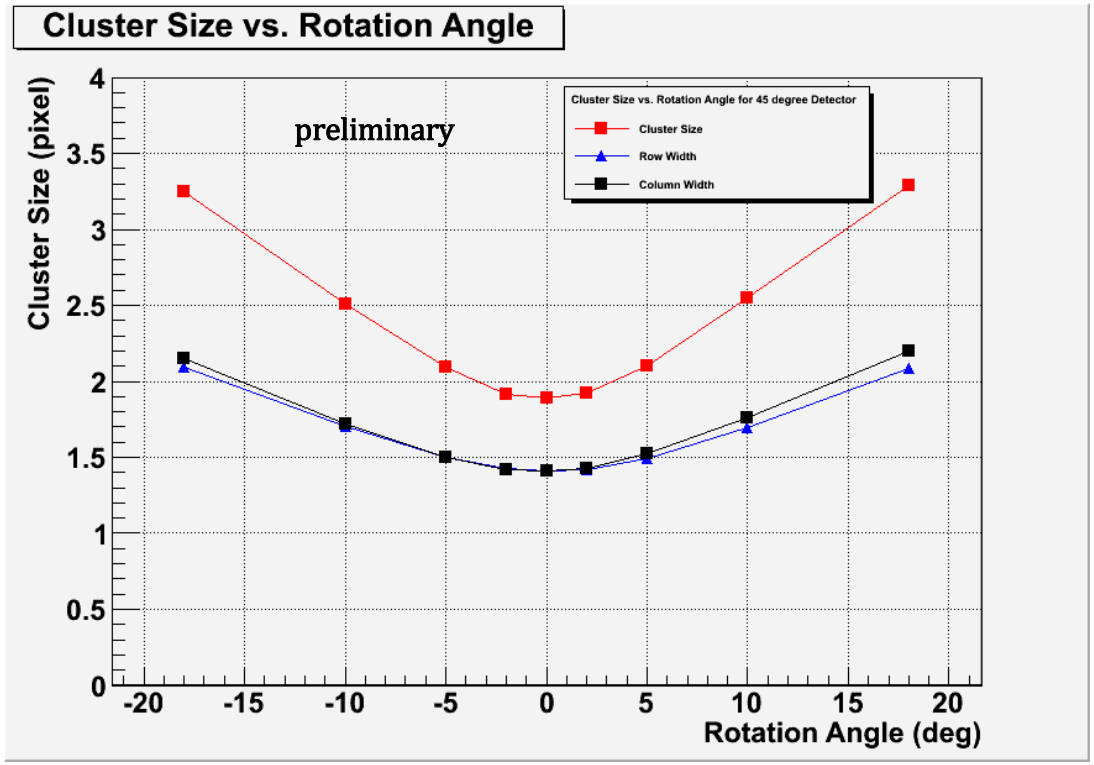


2-Dimensional Rotation

- DUT was rotated by 45 deg *about the z axis,* and a further angle scan performed
- Same behavior in row and column direction



Rotation about Z&Y axis



Track Fit & Alignment

➢**Pattern recognition** does not contain DUT, for the majority of the analysis, it is required that each track has a cluster from each of the 6 telescope planes.

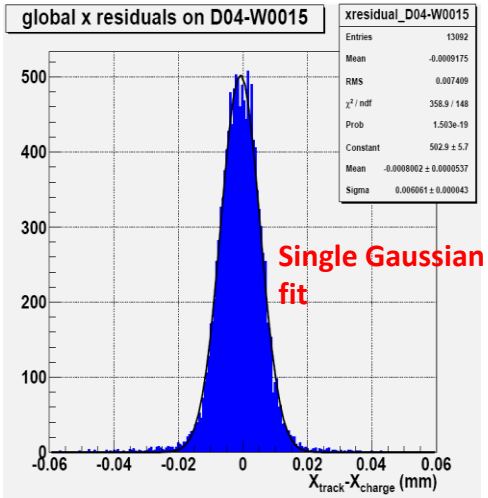
➢**Straight line track fit** is performed on the clusters selected in the telescope. Due to the fact that the planes equipped with Medipix sensors are expected to have lower resolution than the Timepix planes, the track fit takes into account the errors in order to weight the clusters appropriately in the fit.

$$y_{pred(n)} = \sum_i y_i \cdot A(z_n, i)$$

$$A(z_n, i) = \frac{\sum_j \frac{(z_j)^2 + z_n \cdot z_i}{(\sigma_j)^2 \cdot (\sigma_i)^2}}{\sum_j \frac{1}{\sigma_j^2} \sum_j \frac{z_j^2}{\sigma_j^2}}$$

➢**Plain charge weighting** (linear) to reconstruct the hit position X_{charge}
Further non-linear weighting also applied

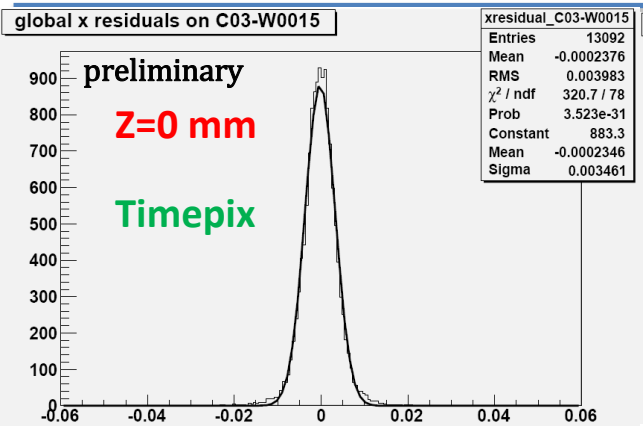
Unbiased residual for angled tracks

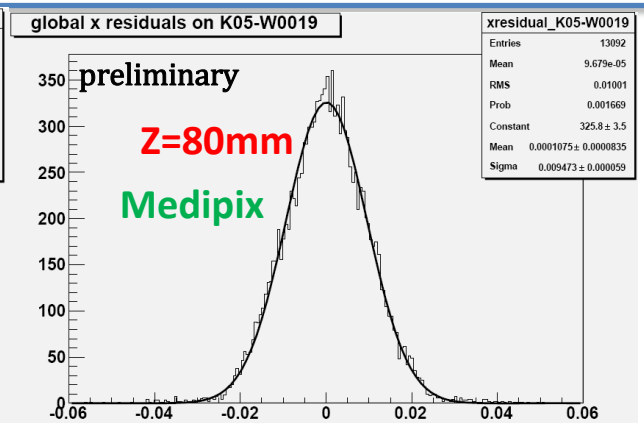


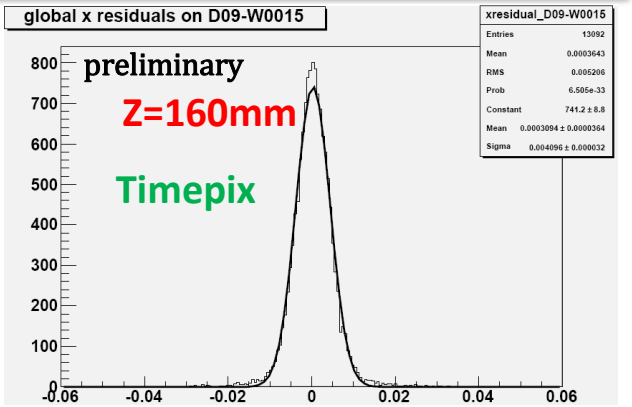
➢**Software Alignment**

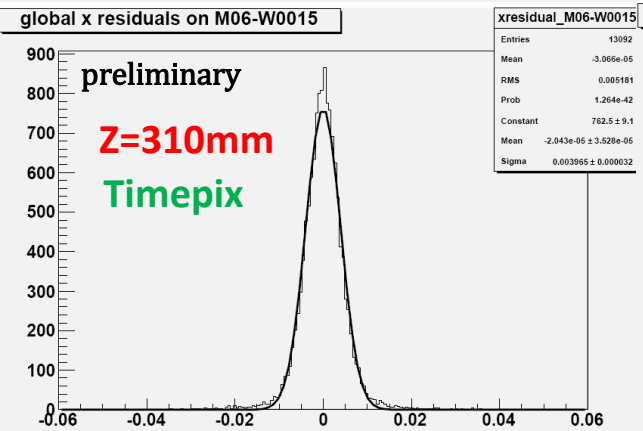
- the only input being the rough z positions and inclinations of the planes
- A multistep offline procedure is used to refine the sensor positions ($x, y, z, \theta_x, \theta_y, \theta_z$)

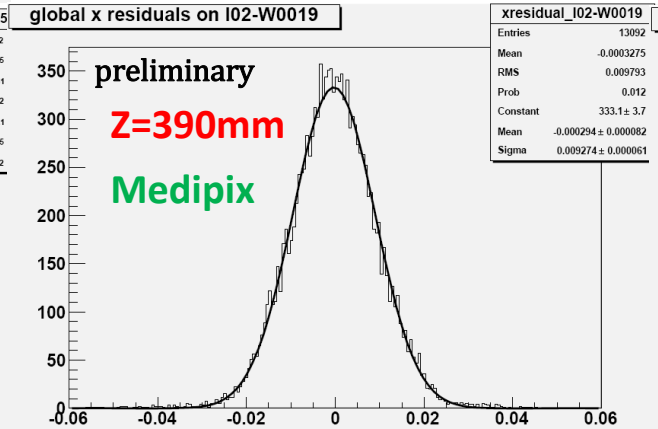
Telescope Resolution

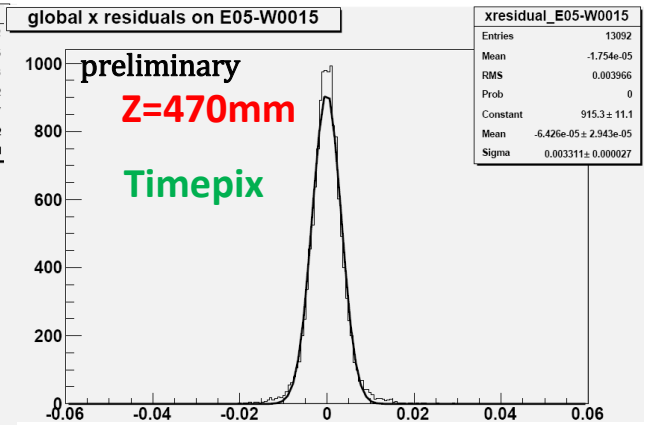












- Medipix produces a lower resolution, they were placed in the least sensitive positions

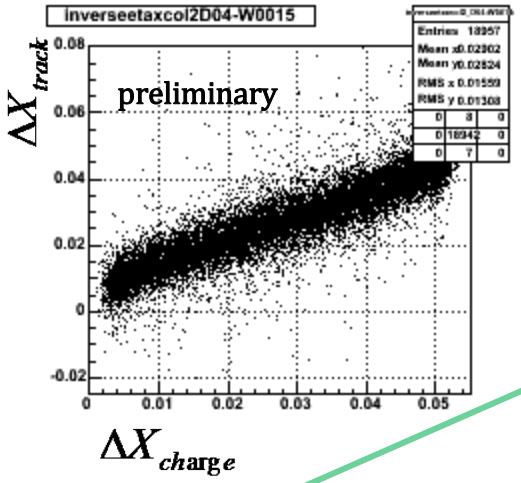
Eta Correction

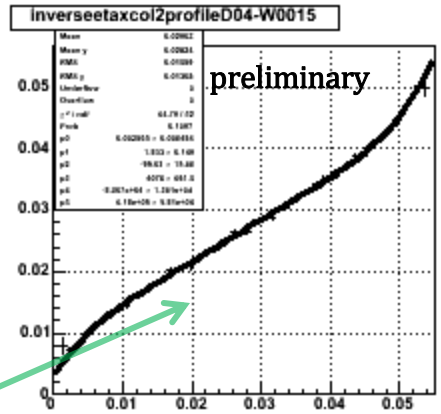
- pixel pitch is large compared to the diffusion width of drifting holes , *the charge sharing between cells is not perfect and the simple* weighted charge is not expected to reproduce precisely the track position.

- This effect is a very strong function of angle. (a set of angles are scanned)
- By comparing the weighted charge position to the track position the effect can be corrected , the resulting histogram is fitted with a five order polynomial, which is later used to correct the weighted charge position in the data.

Non-linear charge weighting

$$\Delta X = f(\eta) \cdot Pitch$$

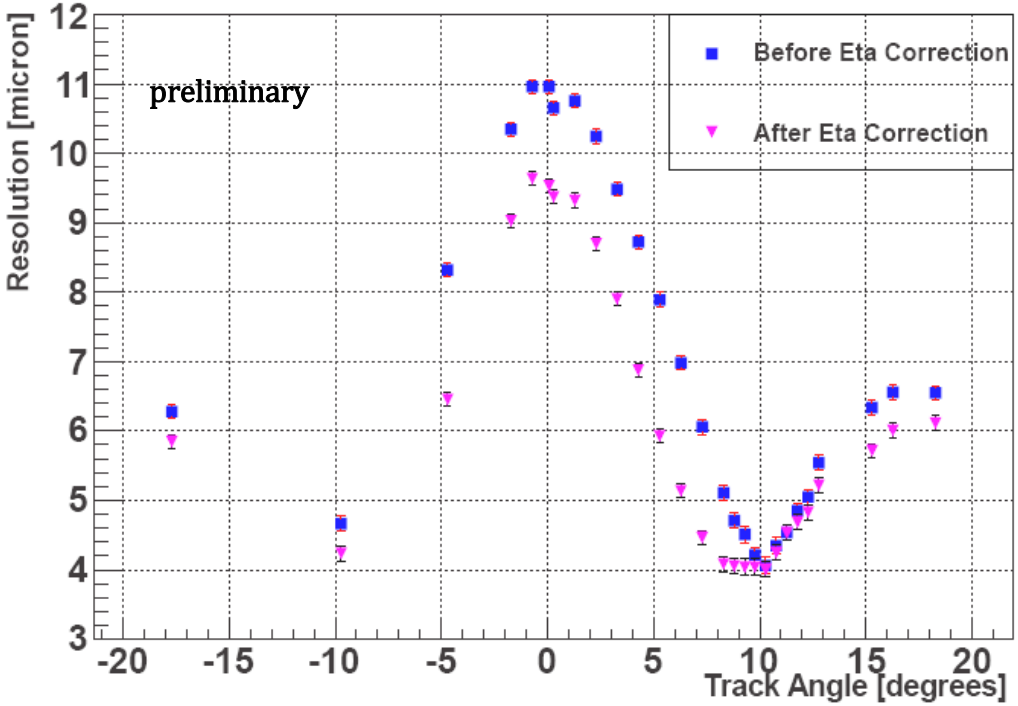


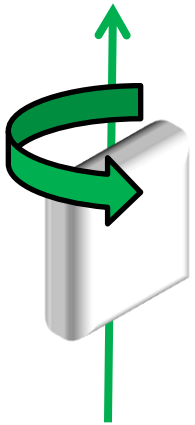


$$\Delta x_{track} = f(\Delta x_{charge})$$
$$= a \cdot \Delta x_{charge}^{5} + b \cdot \Delta x_{charge}^{4} + c \cdot \Delta x_{charge}^{3} + d \cdot \Delta x_{charge}^{2} + e \cdot \Delta x_{charge} + f$$
$$= \Delta x_{charge}^{corrected}$$

Resolution

- Best resolution of **4~5 micron meter** has been achieved
- Results are compared before and after eta correction

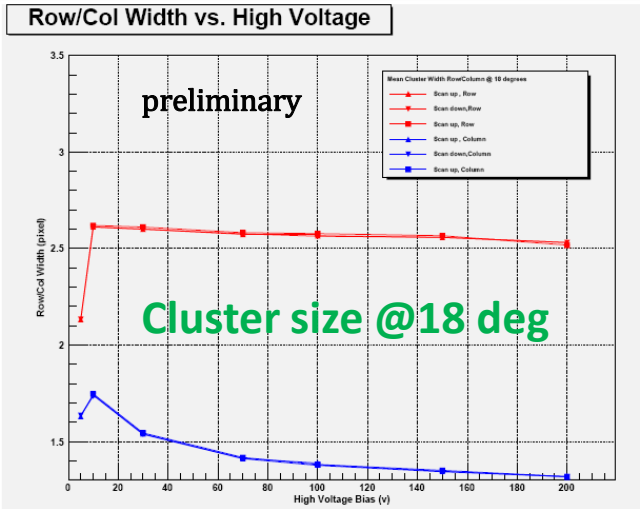


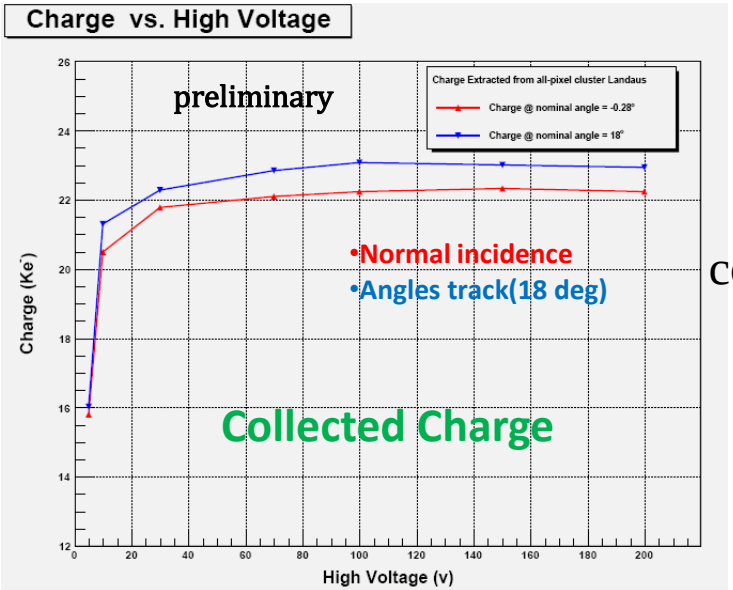


Rotation about Y axis

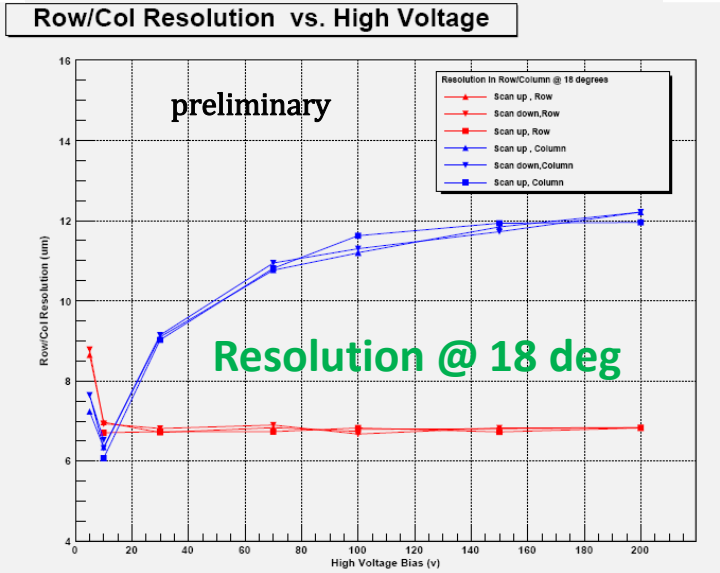
High Voltage Study

- The HV was varied between 5 and 200V to investigate the cluster characteristics and resolution of the DUT.
  resolution performance highly depends on cluster size & cluster categories (charge sharing)
- These scans were performed at three different angles: 0, *10, and 18 deg.*





$\cos\theta$ **dependence**



Conclusion

- Timepix has been demonstrated to be an excellent tracking device for HEP applications
- R&D towards the LHCb upgrade aimed at VELOPIX (faster front end, high speed data transfer, radiation hardness up to 3.7 MRad per fb^{-1})