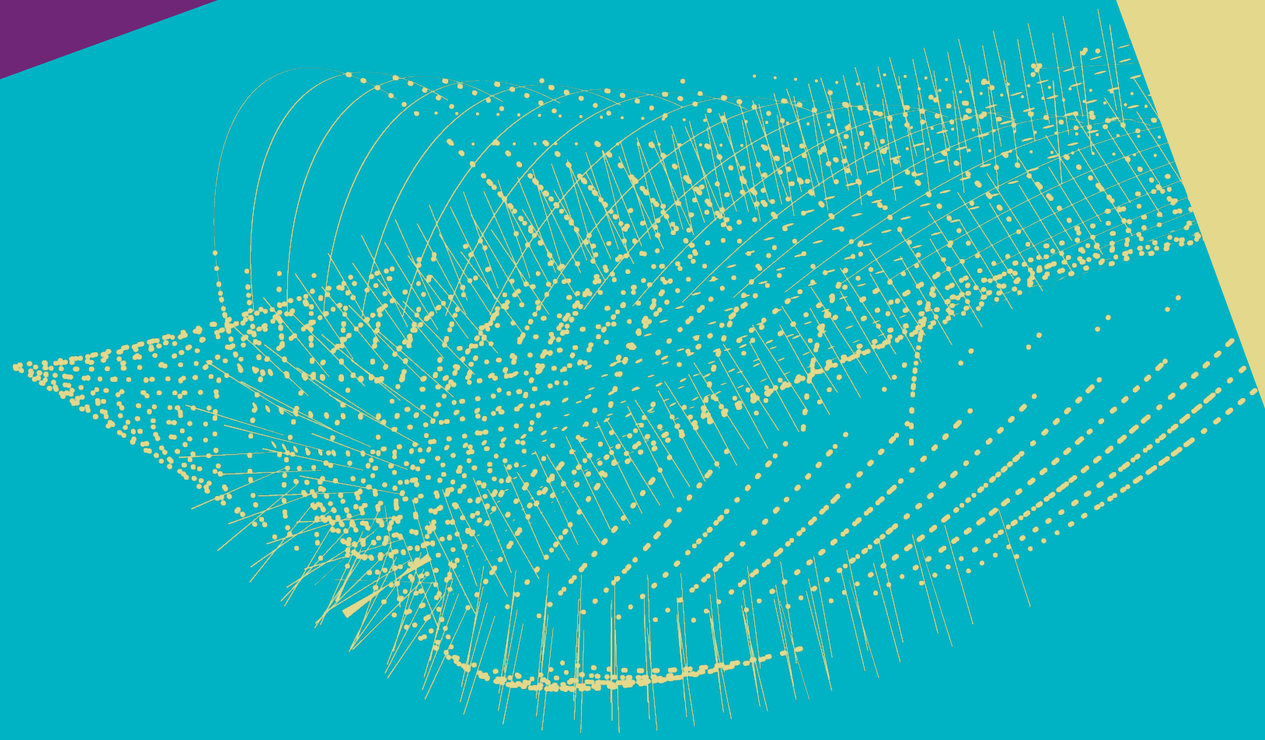
Nikhef



FASTER CONSORTIUM
NIJMEGEN 2025

CLUSTERING CONTINUED

by Andrej Sarnatskiy

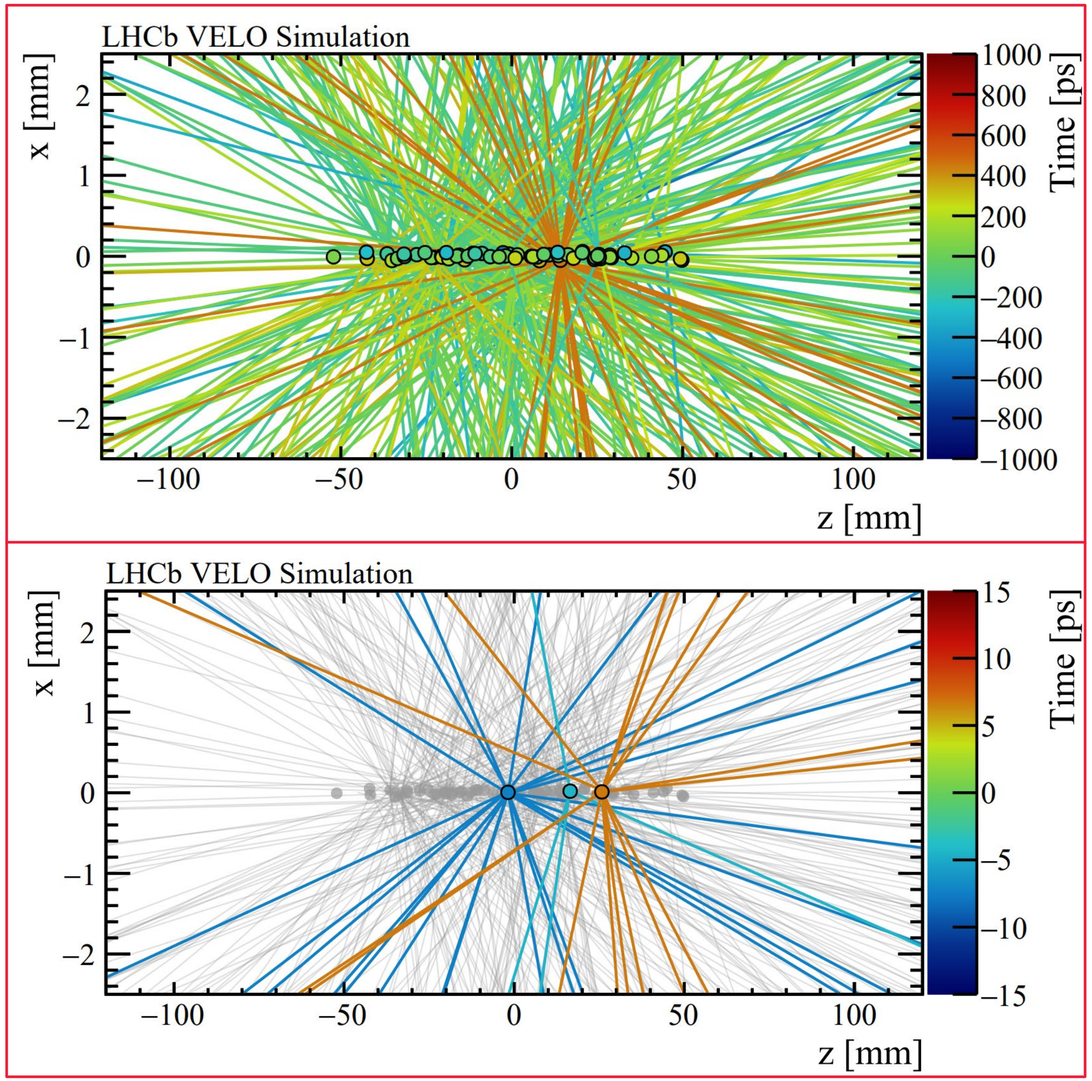
LHCb

university of groningen

RECAP FROM LAST TIME

Update II of VELO faces many challenges due to increased pile-up (5 → 40):

- More hits on sensor occupies more data bandwidth.
- More possible tracks will delay reconstruction.



COURTESY: R. E. GEERTSEMA

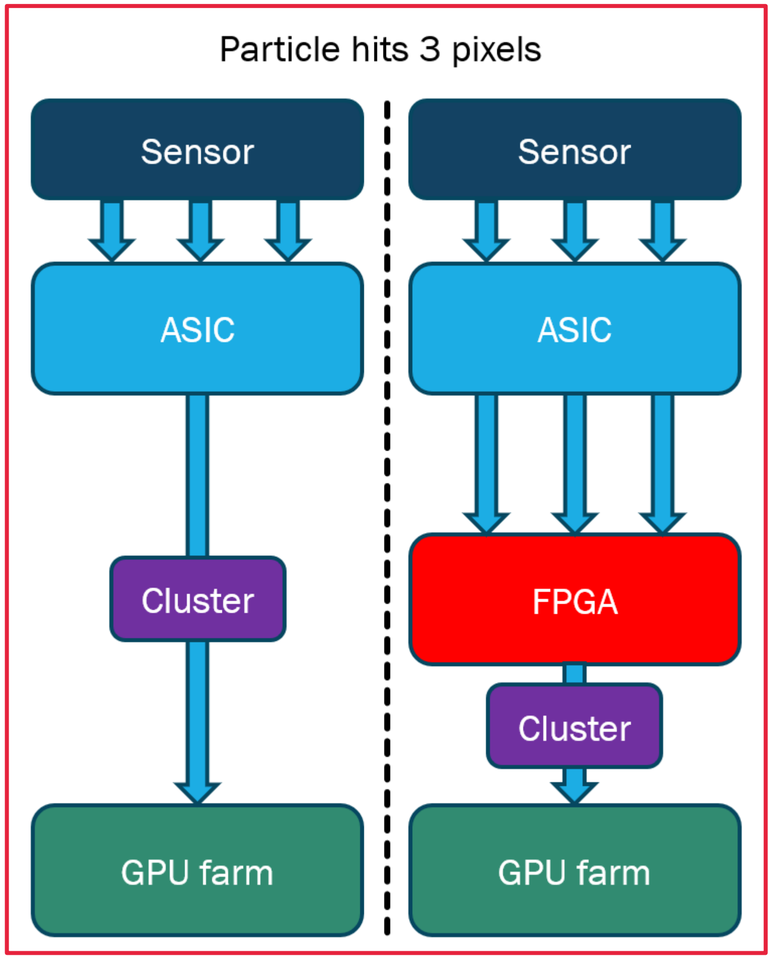
RECAP FROM LAST TIME

Possible solutions:

- Compress data ASAP, e.g. cluster hits on chip.

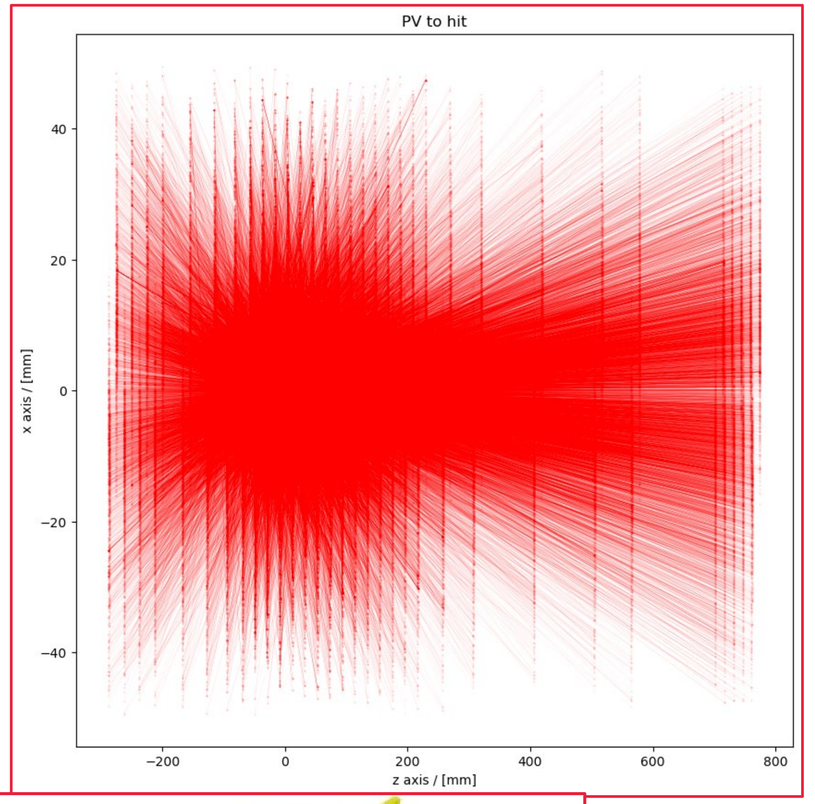
  Opportunity to add corrections.

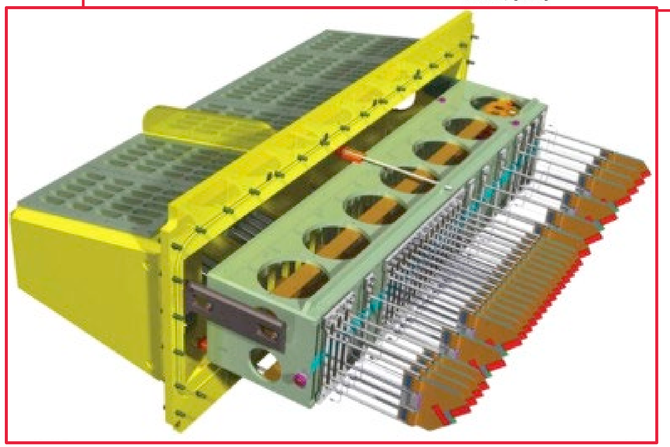
- Add precise timing to disentangle track reconstruction.



LHCB SIMULATION

- LHCb run5 simulation is used to analyse impact of algorithms.
- Using current geometry of the VELO.
- Planar 200 um sensors
  (3D sensors incoming)





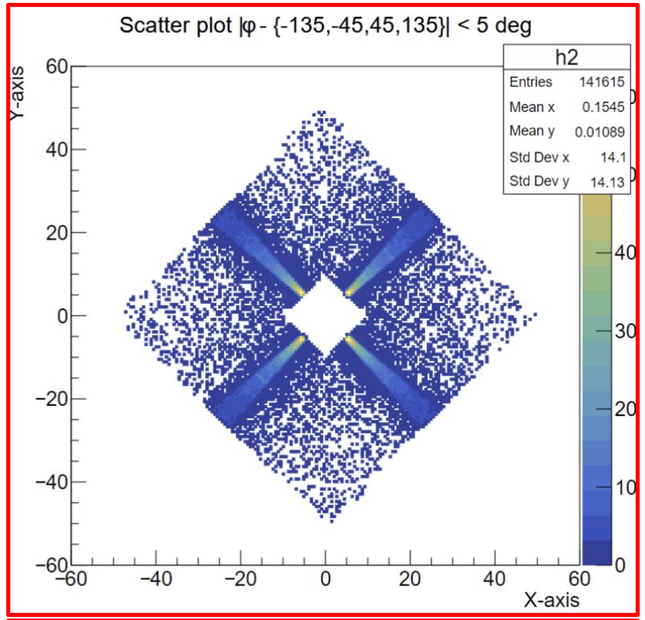
LHCB SIMULATION

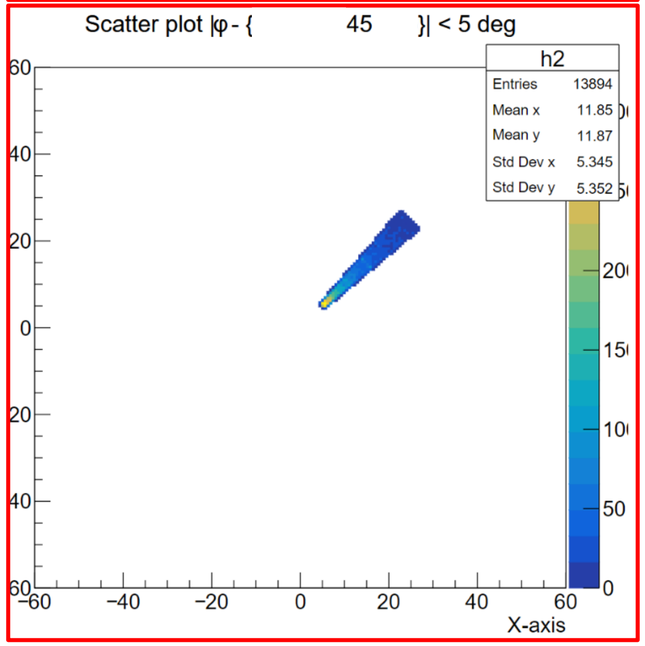
- Following results based on following cut:

$$\left|\phi_{\vec{p}} - 45°\right| < 5° \quad \cap \quad \left|\phi_{\vec{x}} - 45°\right| < 5°$$

  in order to disentangle overlapping effects.

- Therefore incident particles travel in plane along the columns on chip.





RECAP: CLUSTERING METHODS

Three methods previously mentioned:

- **Binary:**

  Equal weight for every pixel in cluster

$$(\bar{x}, \bar{y})_{bin} = \frac{1}{N} \sum_{i}^{N} (x_i, y_i)$$

- **CoG:**

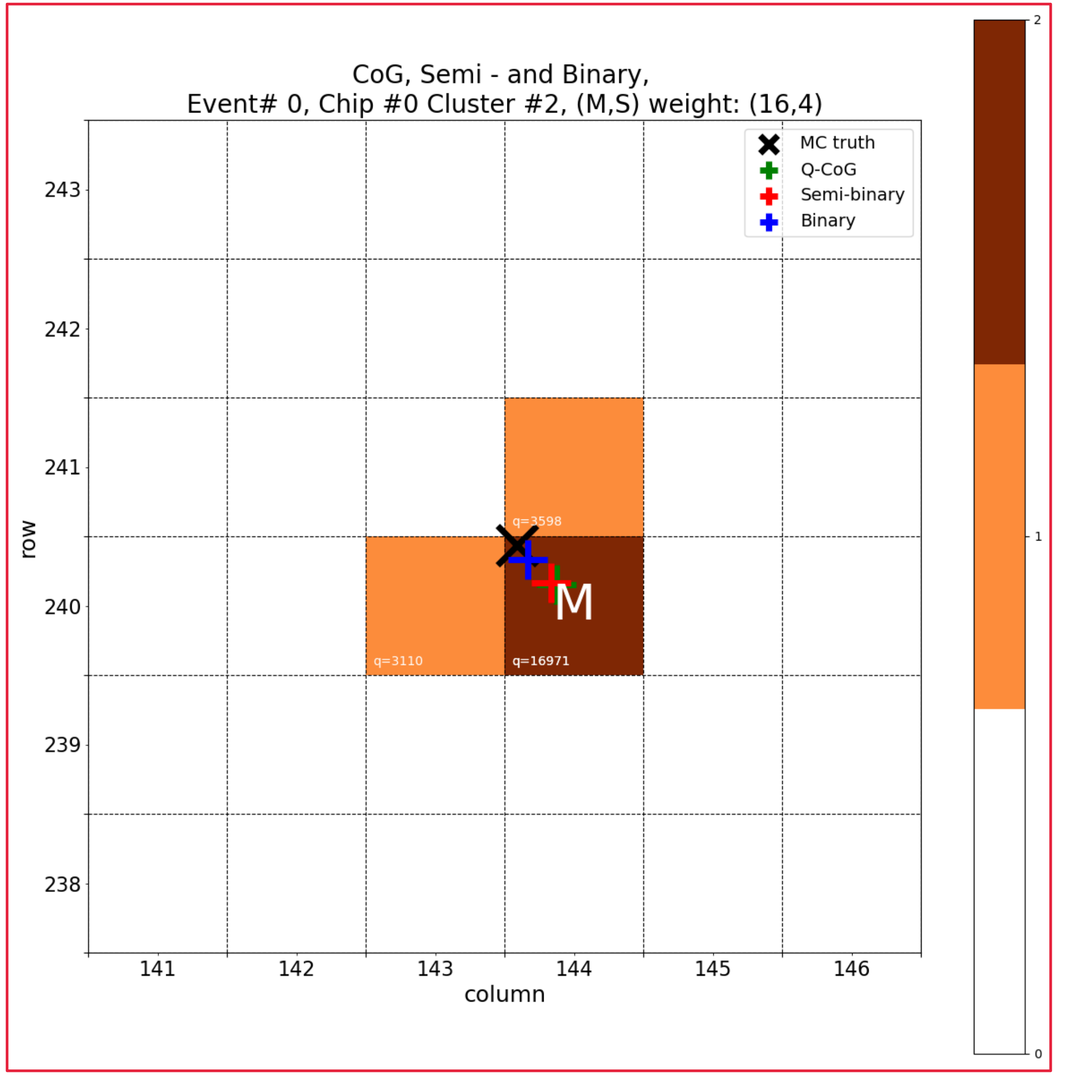
  charge weighted centre-of-gravity

$$(\bar{x}, \bar{y})_{CoG} = \frac{1}{N} \sum_{i}^{N} q_i \cdot (x_i, y_i)$$

- **Semi-binary:**

$$(\bar{x}, \bar{y})_{sbin} = \frac{1}{M+S} \left(M \cdot (x, y)_{main} + S \cdot \sum_{i}^{spec} (x_i, y_i) \right)$$

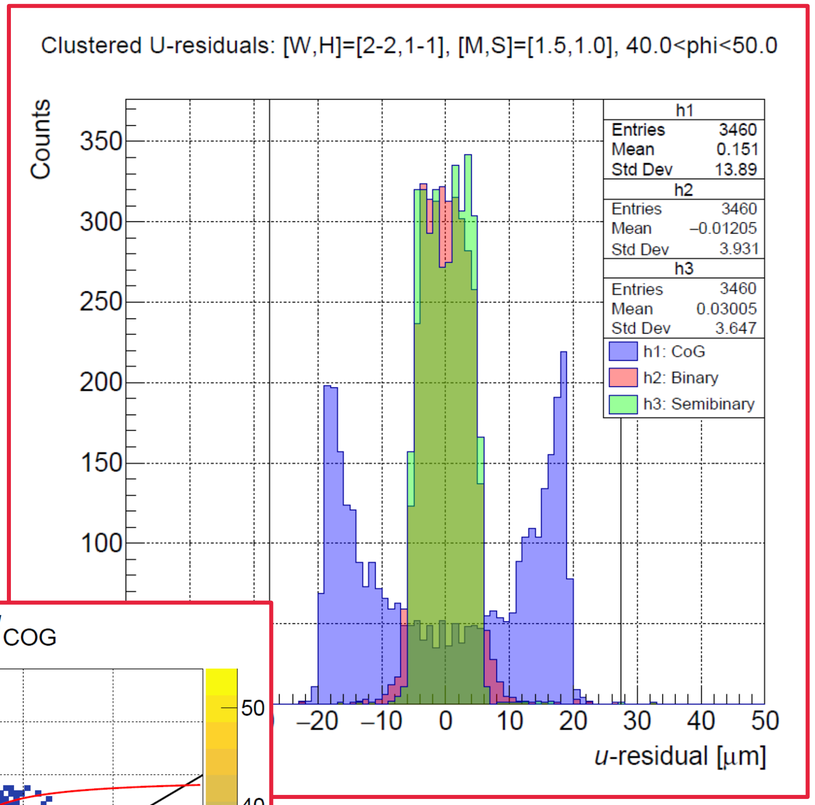
  Main pixel (M) with highest collected charge weighted more than Spectators (S).

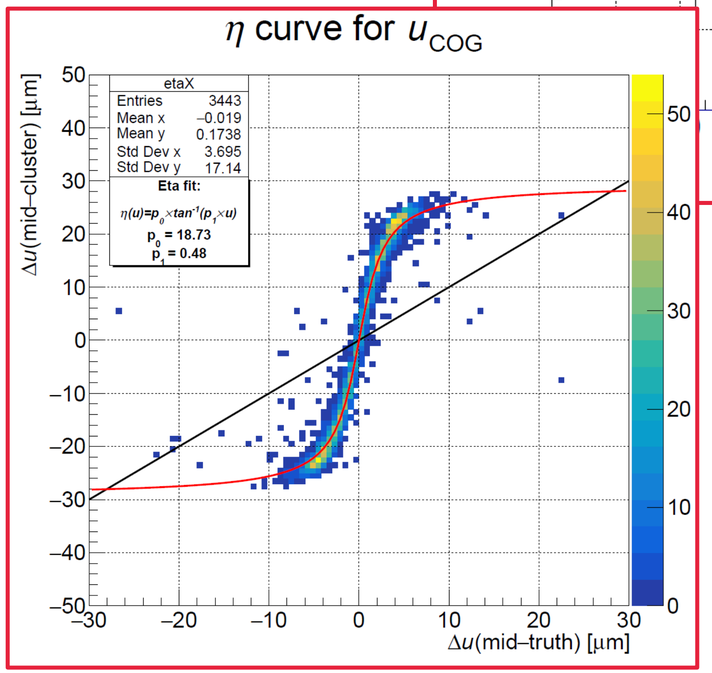


ETA CORRECTION

- Non-linear charge sharing degrades resolution of charge weighted centre-of-gravity.

- Improved by applying an eta-correction

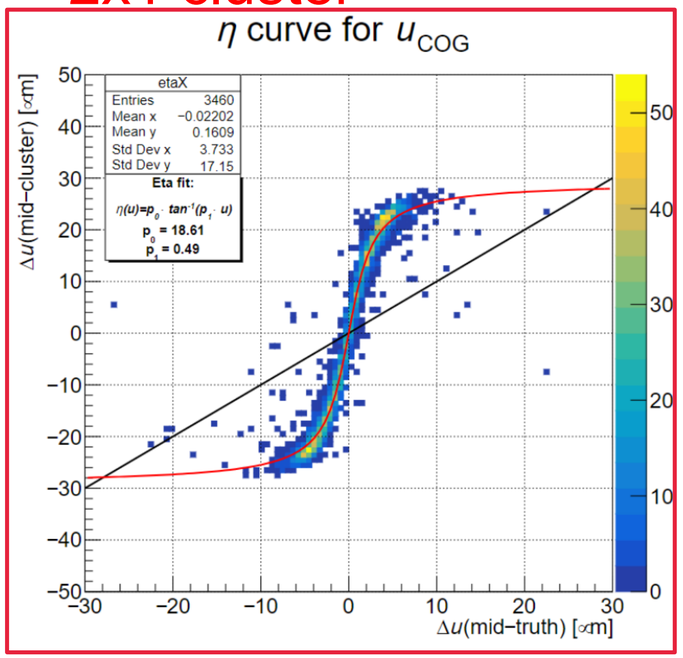




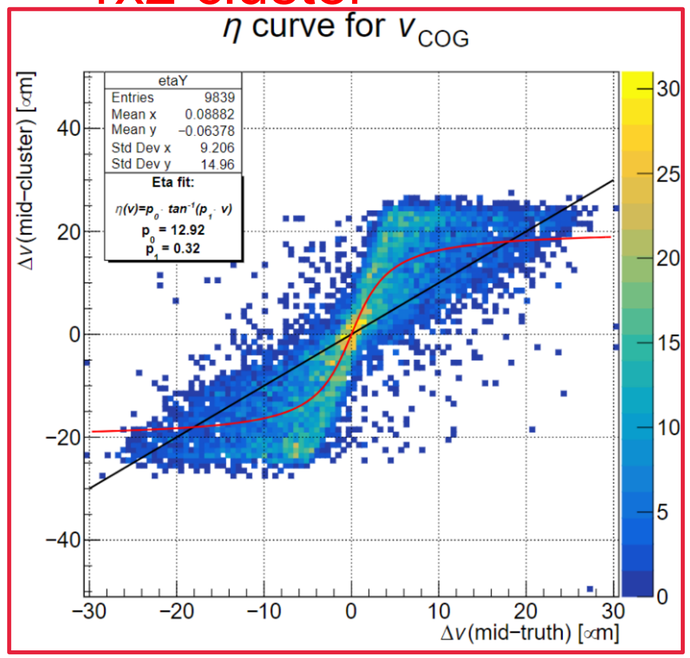
ETA CORRECTION

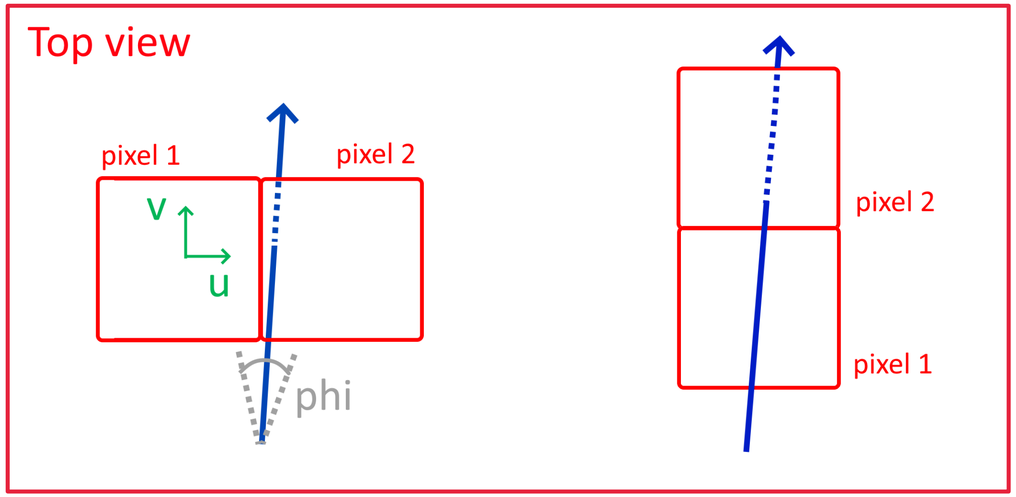
- Caveat: angle dependent

2x1 cluster



1x2 cluster



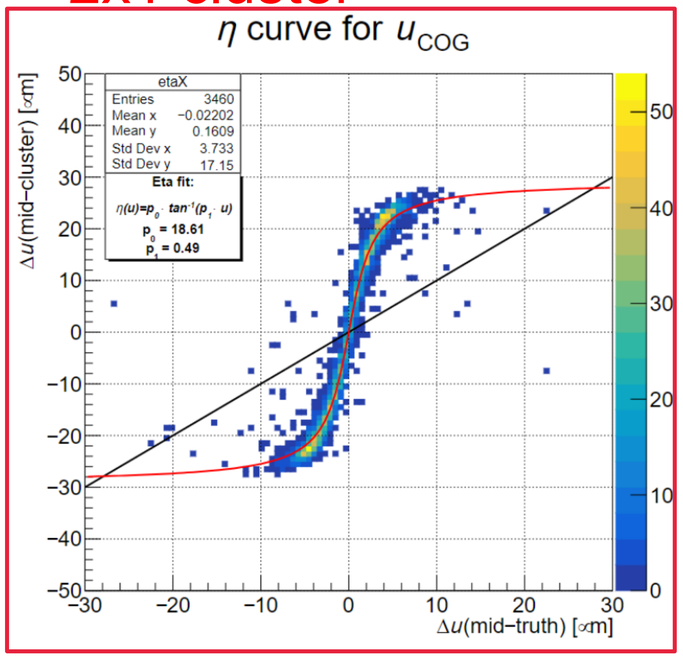


ETA CORRECTION

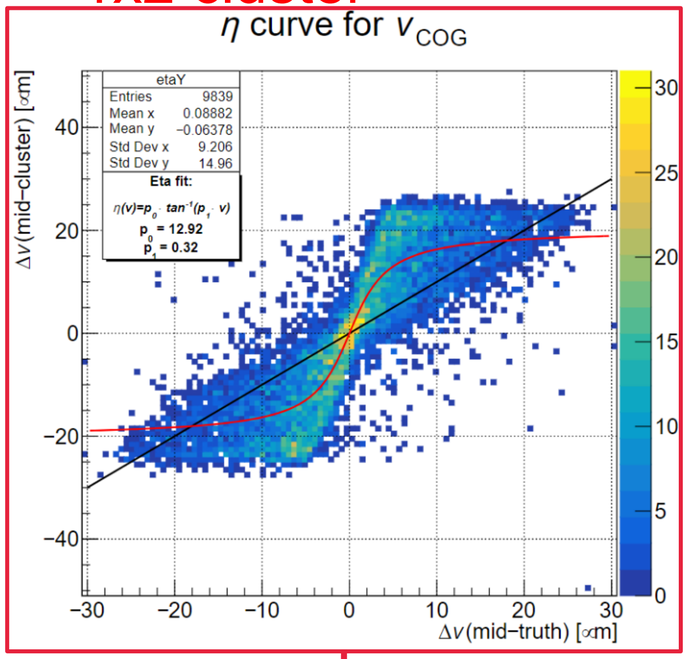
- Caveat: angle dependent.
- Decomposition in theta.
- At larger angles, linearity is recovered.

Only useful if direction is known.
After track reconstruction such correction is possible.

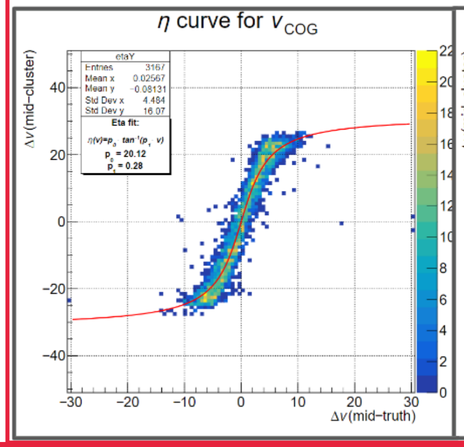
2x1 cluster



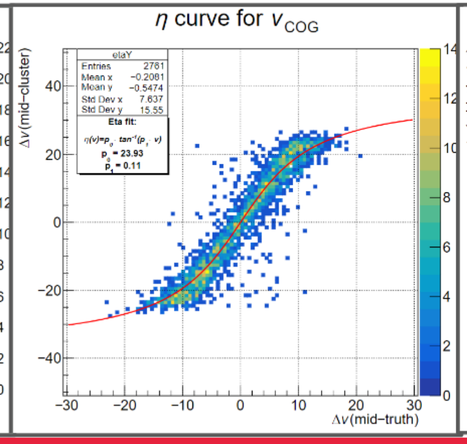
1x2 cluster



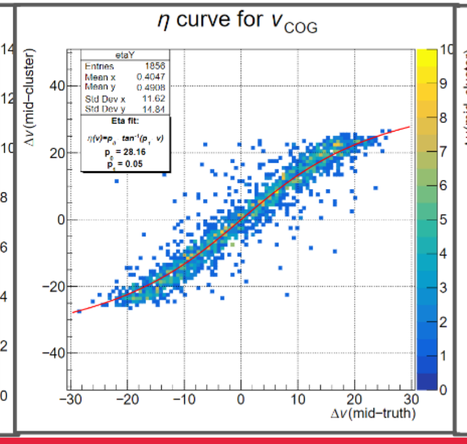
0 < theta < 5 deg



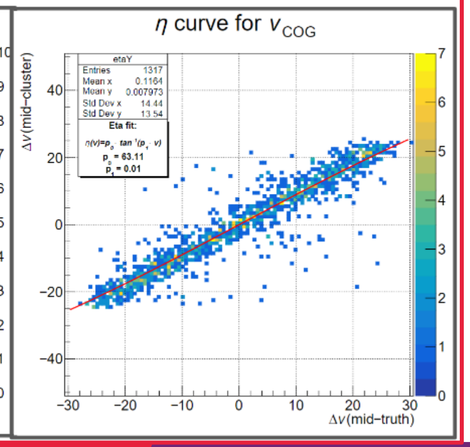
5 < theta < 10 deg



10 < theta < 15 deg



15 < theta < 20 deg



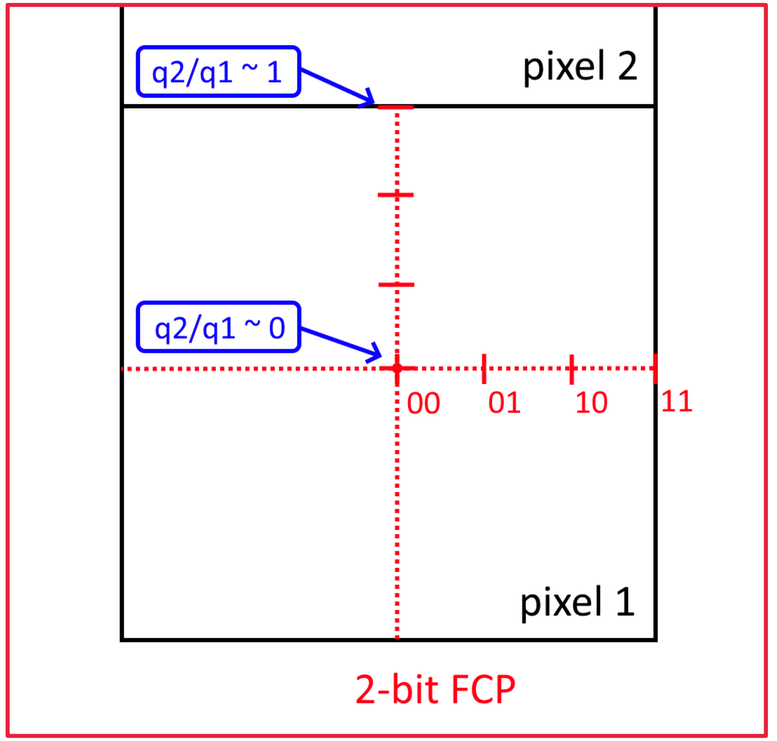
FRACTIONAL CHARGE POSITION (FCP)

Unrealistic to transfer charge information in floating point precision.

Charge information packaged as time-over-threshold (11 bits). FCP condenses this information.

Two neighbouring pixels collect charges q_1 and q_2.
Use digitized q_1/q_2 for intrapixel position.

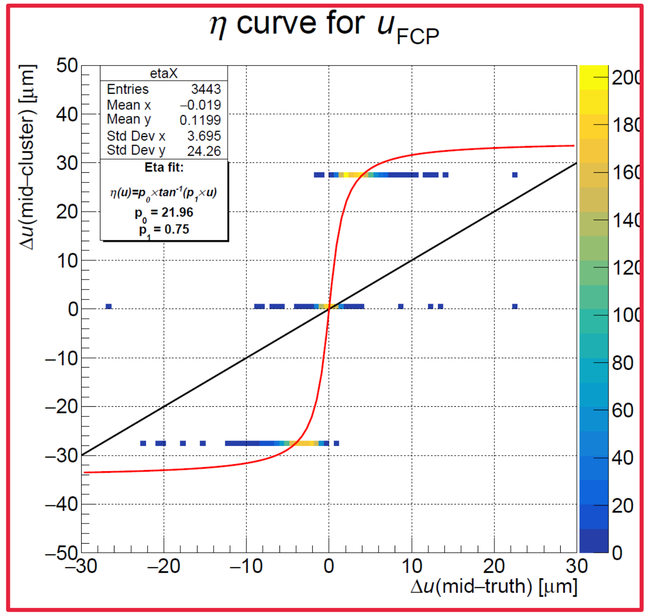
Example shown uses 8 bits total, with 00 being 4-fold degenerate.

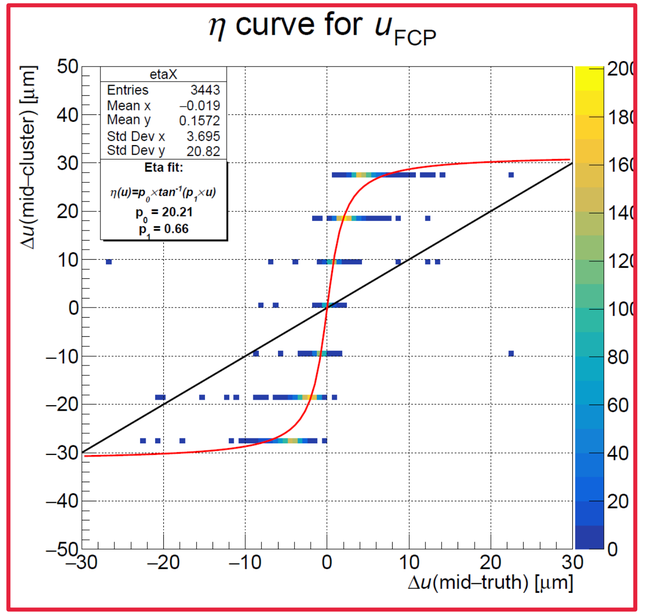


Note: charge calibration and equalisation makes this complicated to implement

FRACTIONAL CHARGE POSITION

Same eta correction is applied in the FCP method.

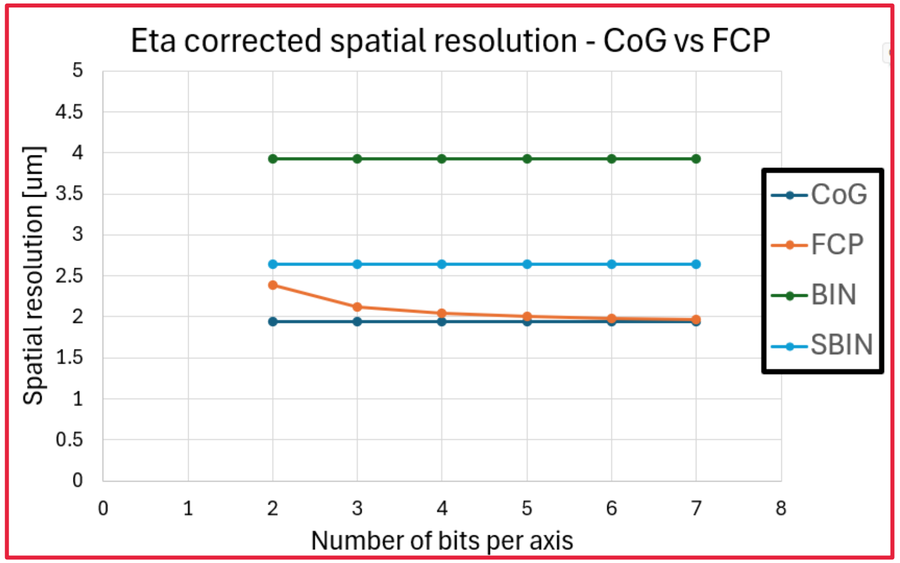


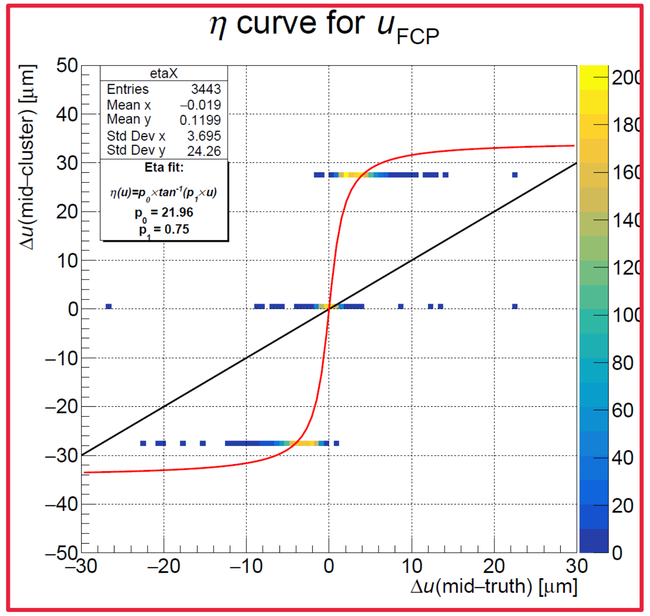


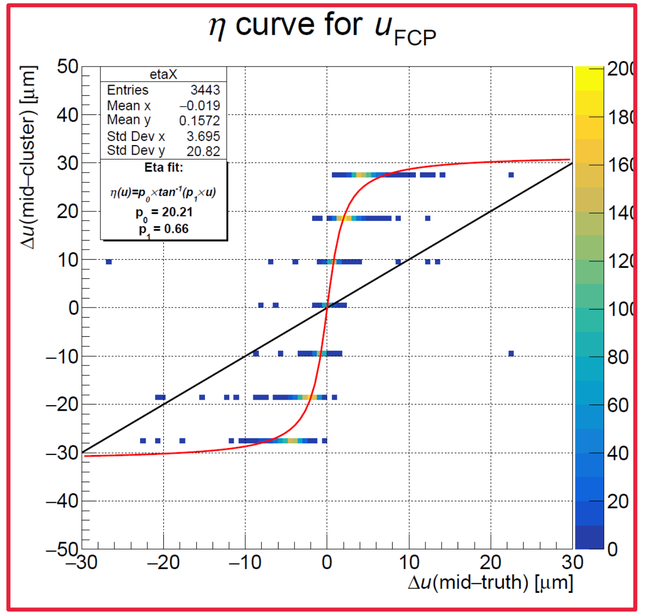
FRACTIONAL CHARGE POSITION

Same eta correction is applied in the FCP method.

Naturally FCP converges to CoG.

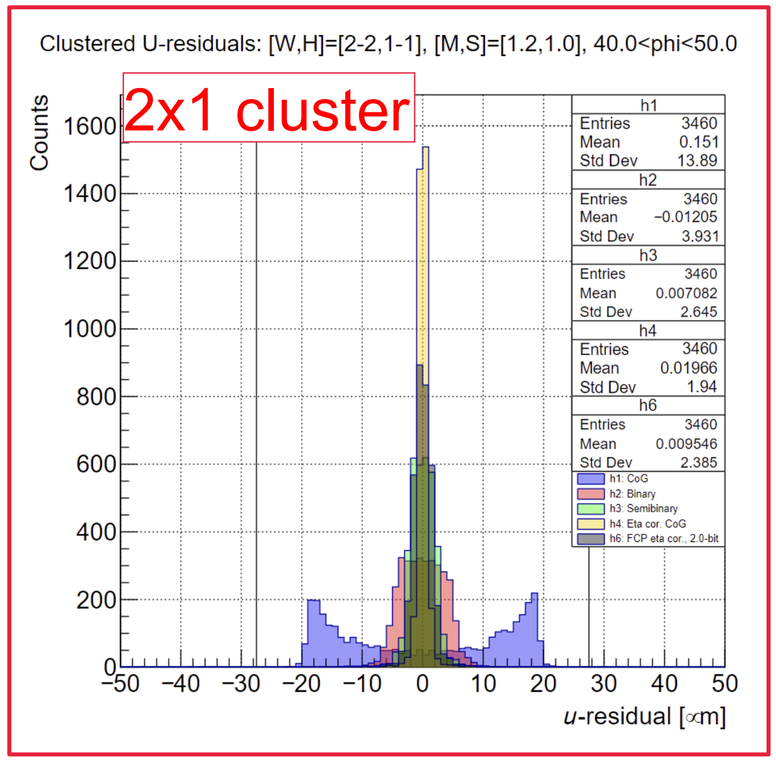


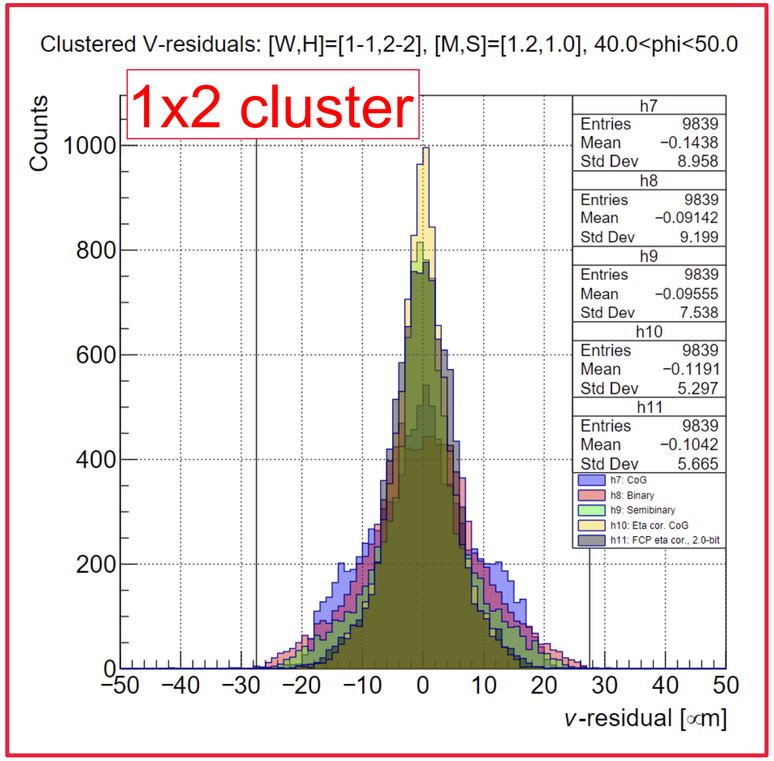


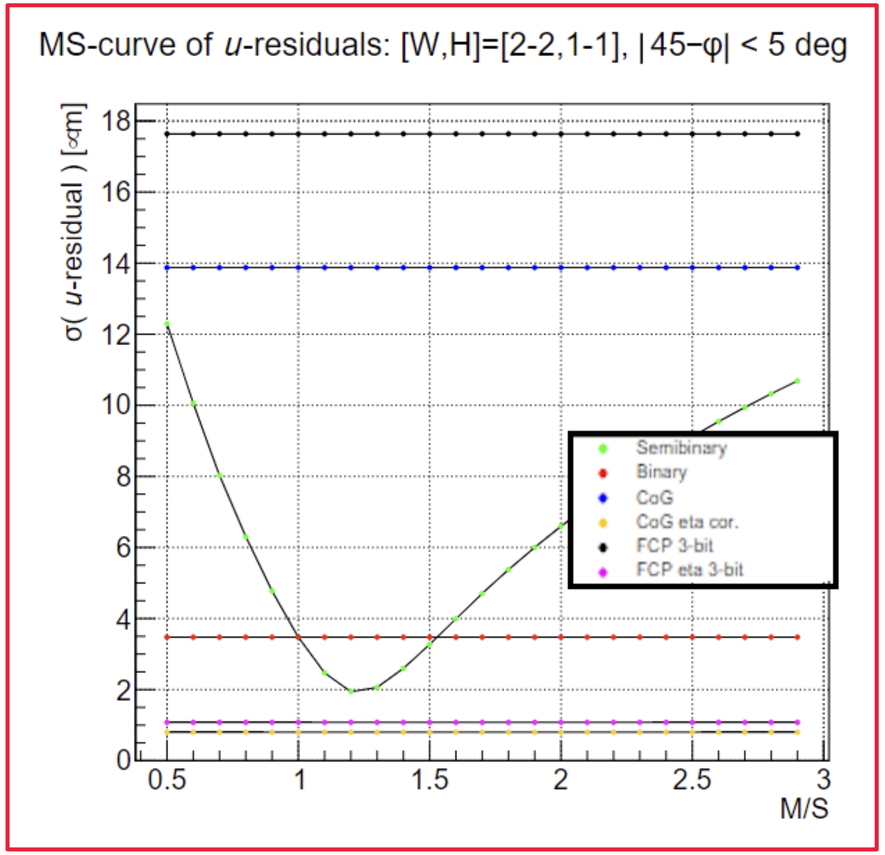


RESULTS

- Study is wrapping up. Next step is to make it publishable.





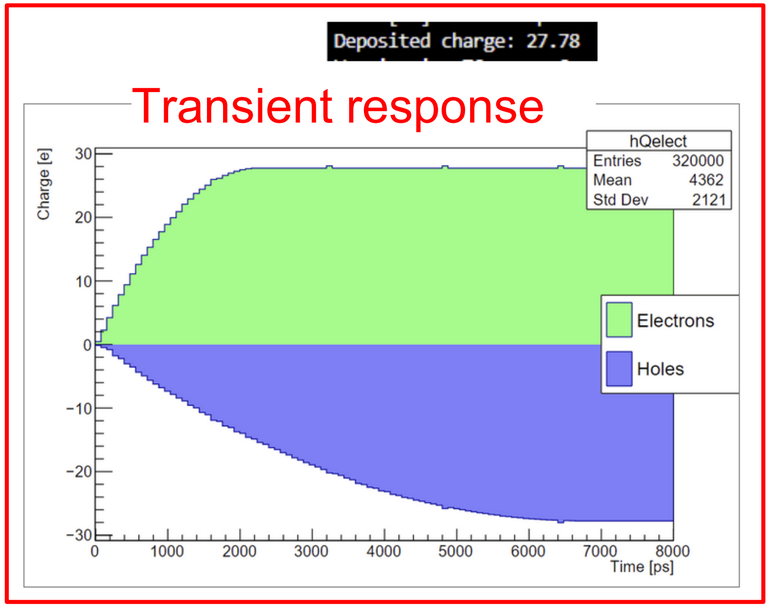


TIMING

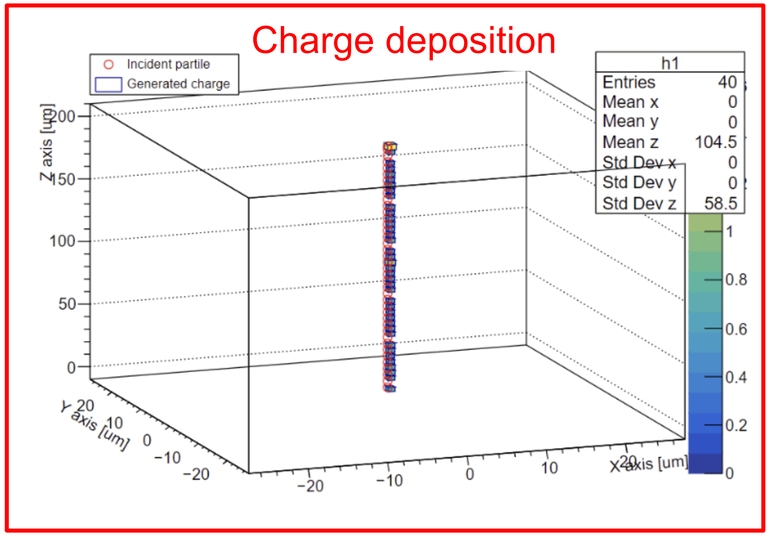
- Toy model created, which is in pre-preliminary phase.
- Several issues need to be addressed/polished:

- Implementation of a simplified but accurate weighting field.
- Electronic response, e.g. discharge.

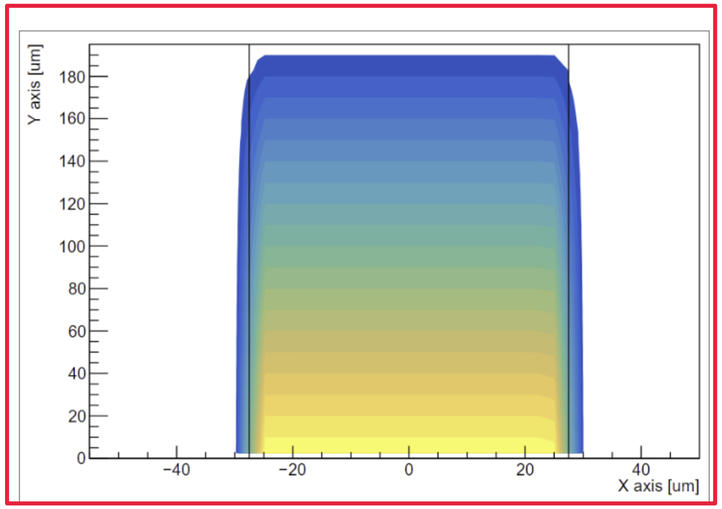
Transient response



Charge deposition



Weighting field



TIMING

Plans timing analysis testbeam:

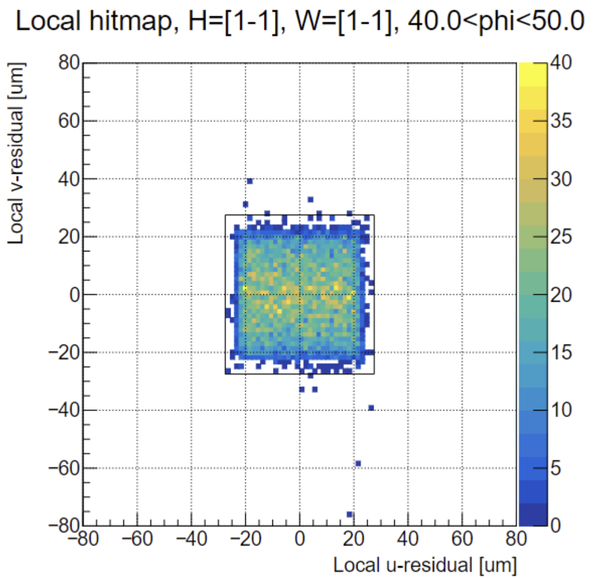
- Number of operations need simplification. Try to limit bit usage.
- VCO-correction, time-walk and charge calibration.

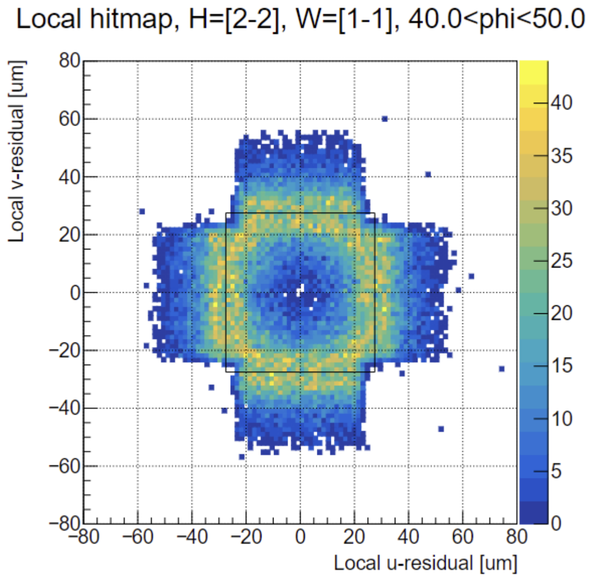
$$ToT = p_0 + p_1 q + \frac{p_2}{q - p_3}$$

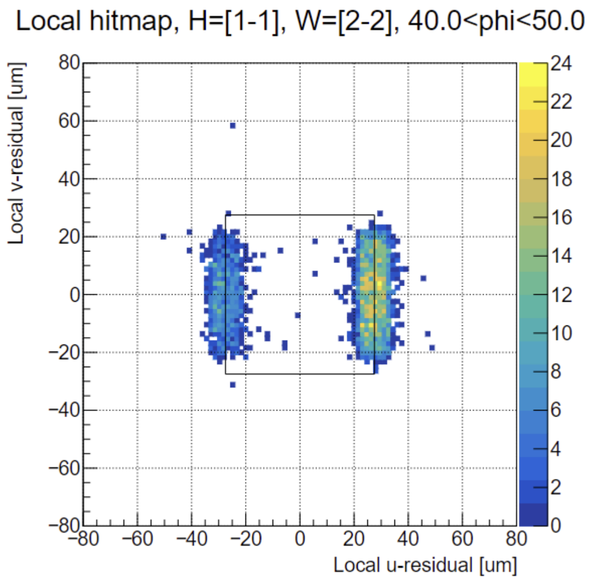
$$t_w = bt_0 + \frac{\frac{Q}{a}}{(Q - Q_{th})^c}$$

THANK YOU

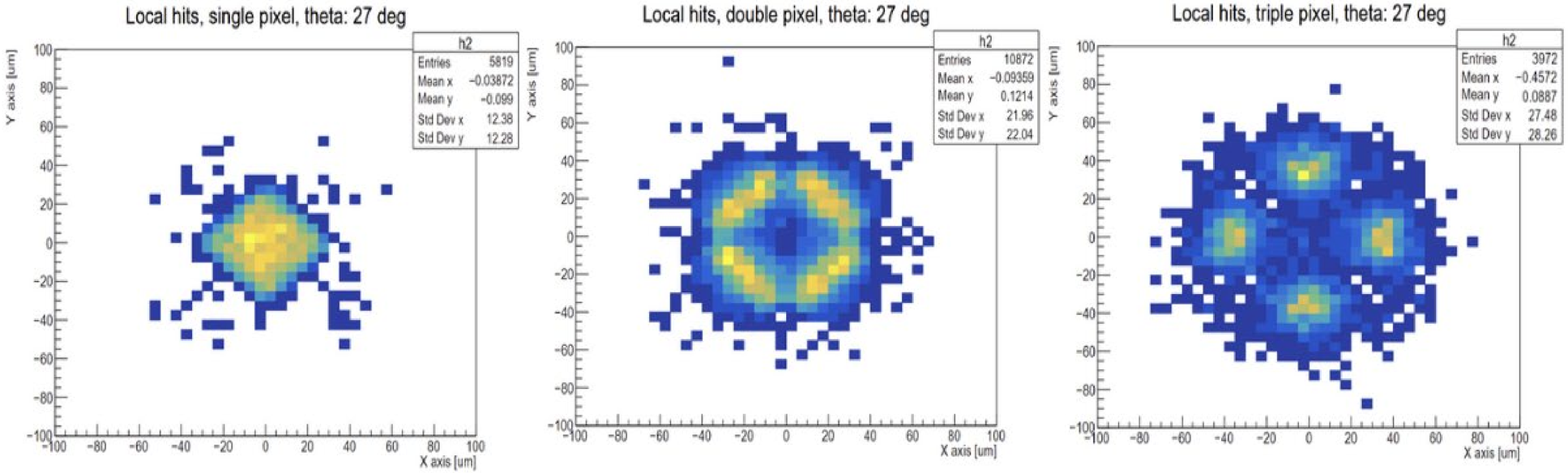
BACKUP


Local hitmap, H=[1-1], W=[1-1], 40.0<phi<50.0
Local v-residual [um]
Local u-residual [um]

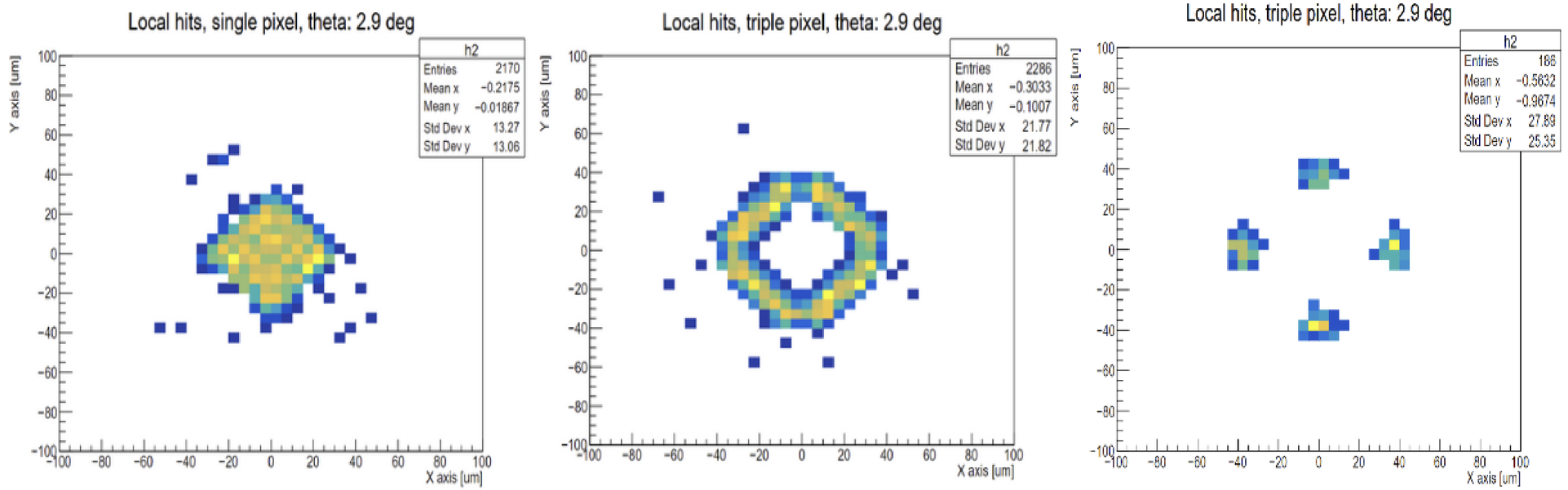

Local hitmap, H=[2-2], W=[1-1], 40.0<phi<50.0
Local v-residual [um]
Local u-residual [um]

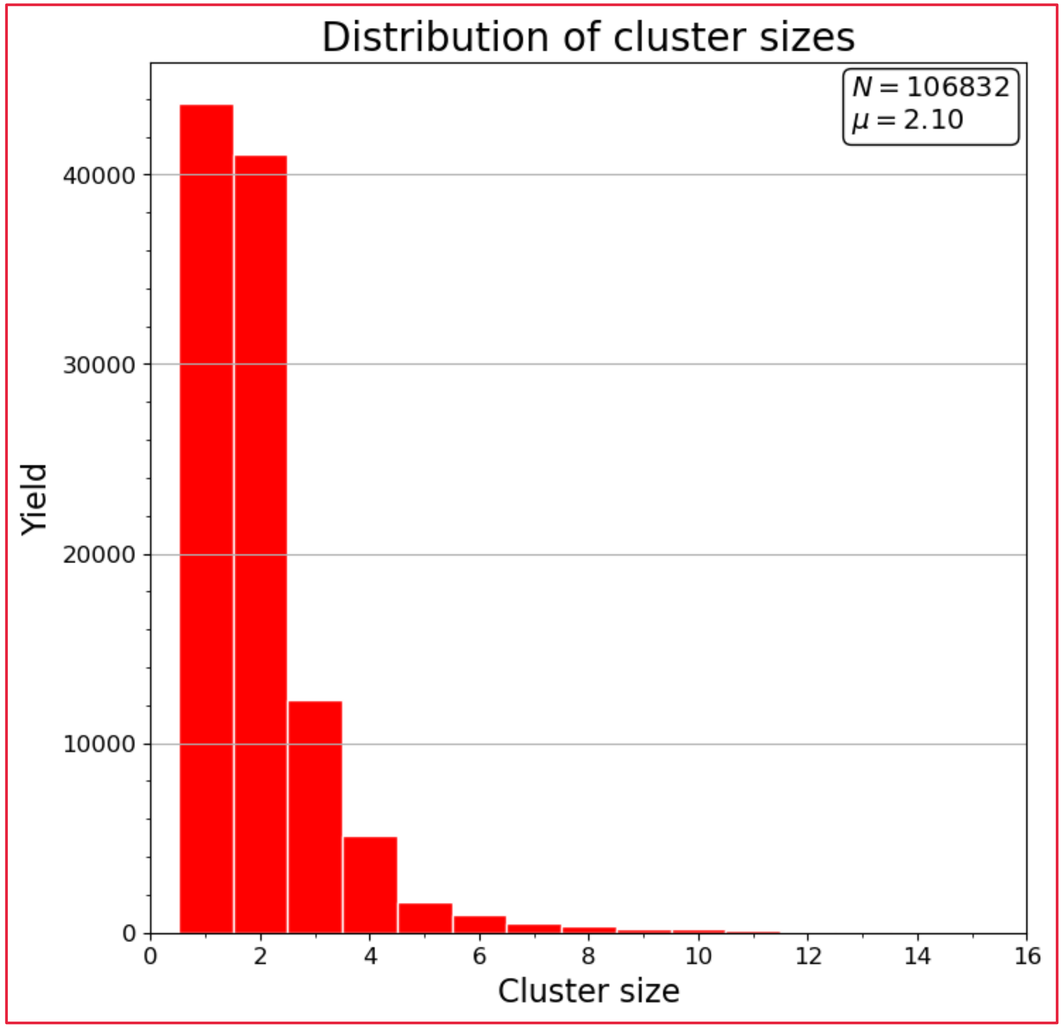

Local hitmap, H=[1-1], W=[2-2], 40.0<phi<50.0
Local v-residual [um]
Local u-residual [um]

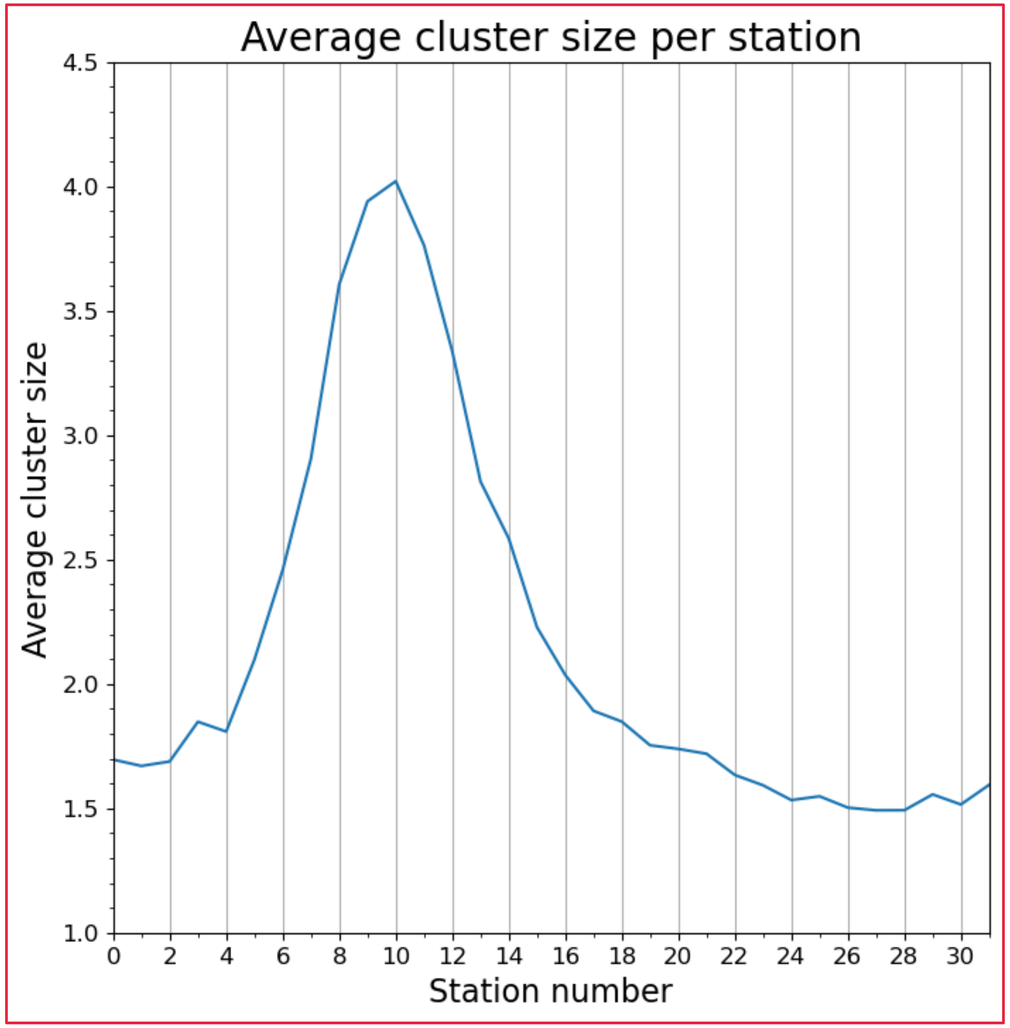
theta < 27 deg



theta < 2.9 deg

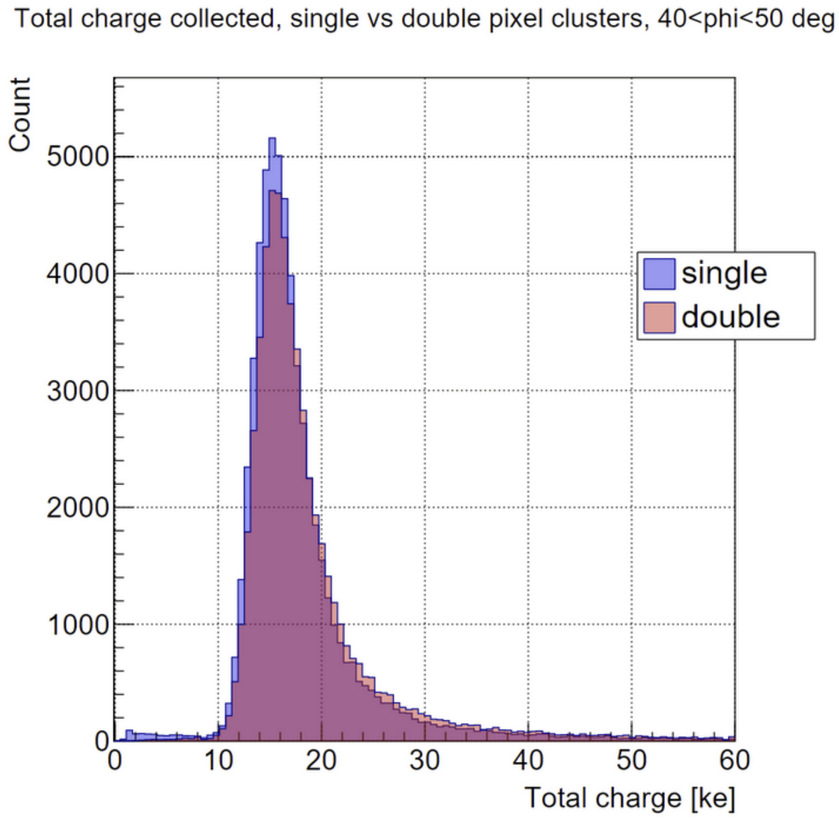



Distribution of cluster sizes
$N = 106832$
$\mu = 2.10$
Yield
Cluster size
0
10000
20000
30000
40000
0
2
4
6
8
10
12
14
16


Average cluster size per station
Average cluster size
Station number
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30

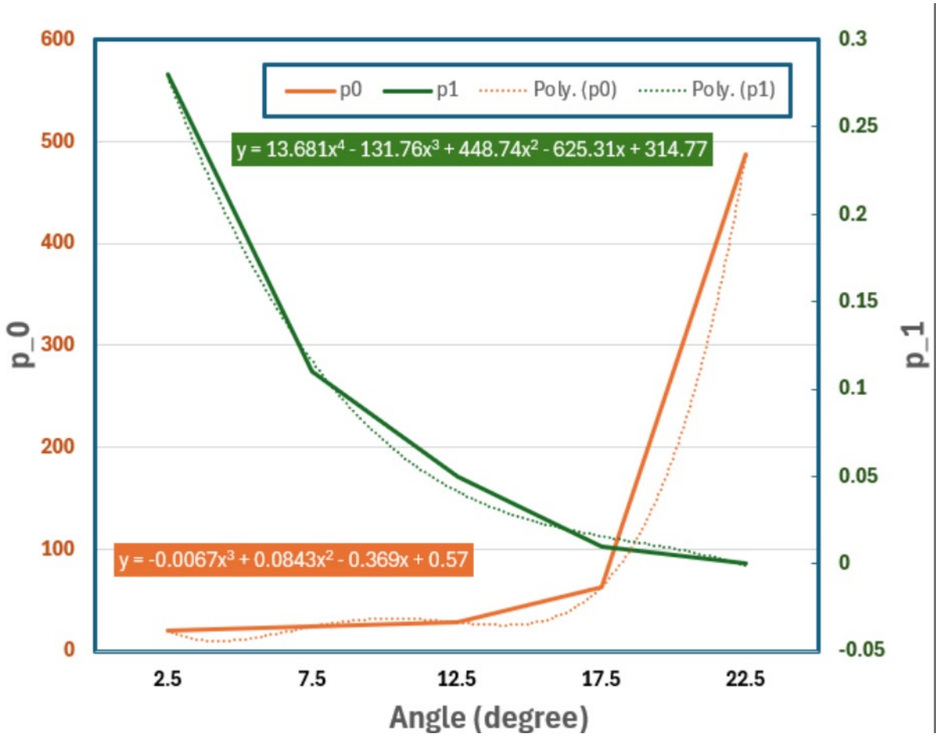
Total charge collected:

Single vs double pixel clusters

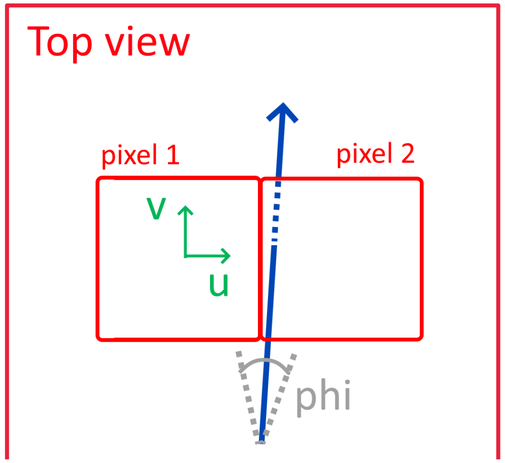


Angle dependence eta-correcting using tangent function.

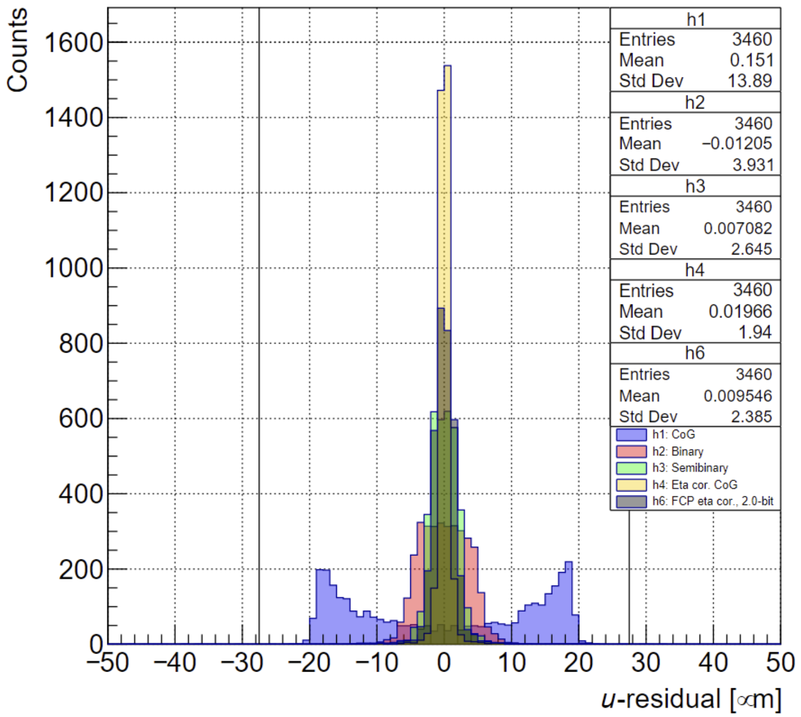
F(x) = p0 tan(p1 x)



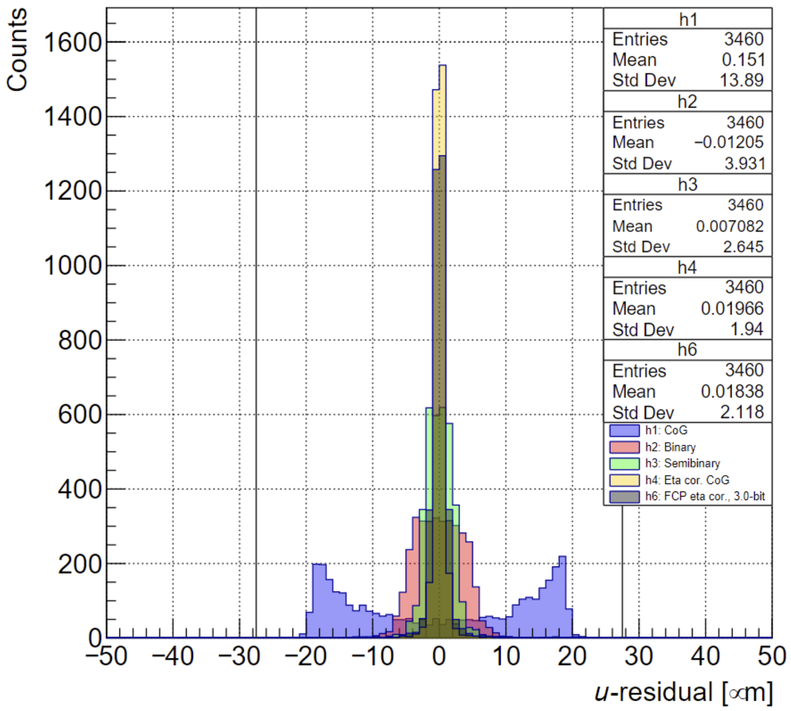
2x1 cluster



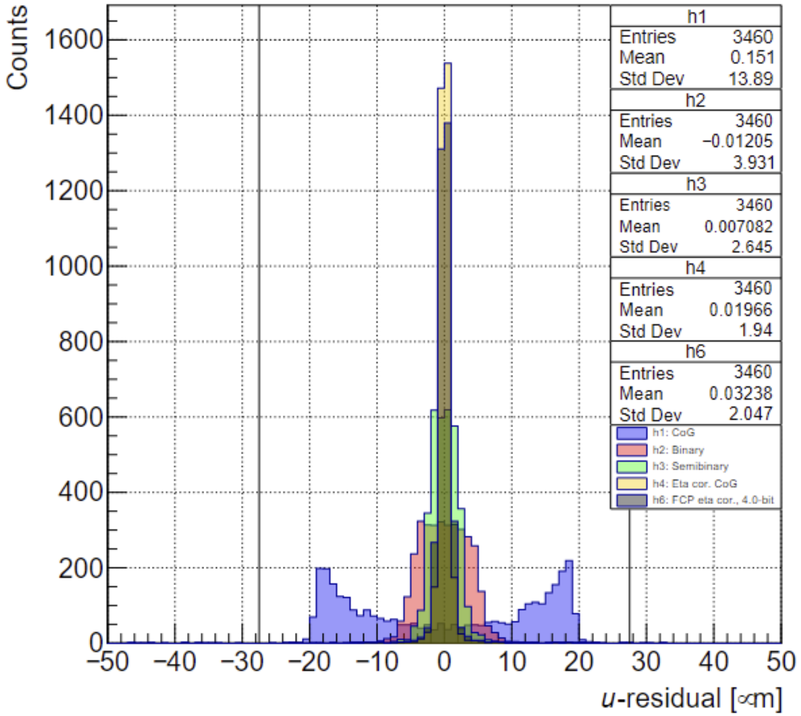
Clustered U-residuals: [W,H]=[2-2,1-1], [M,S]=[1.2,1.0], 40.0<phi<50.0



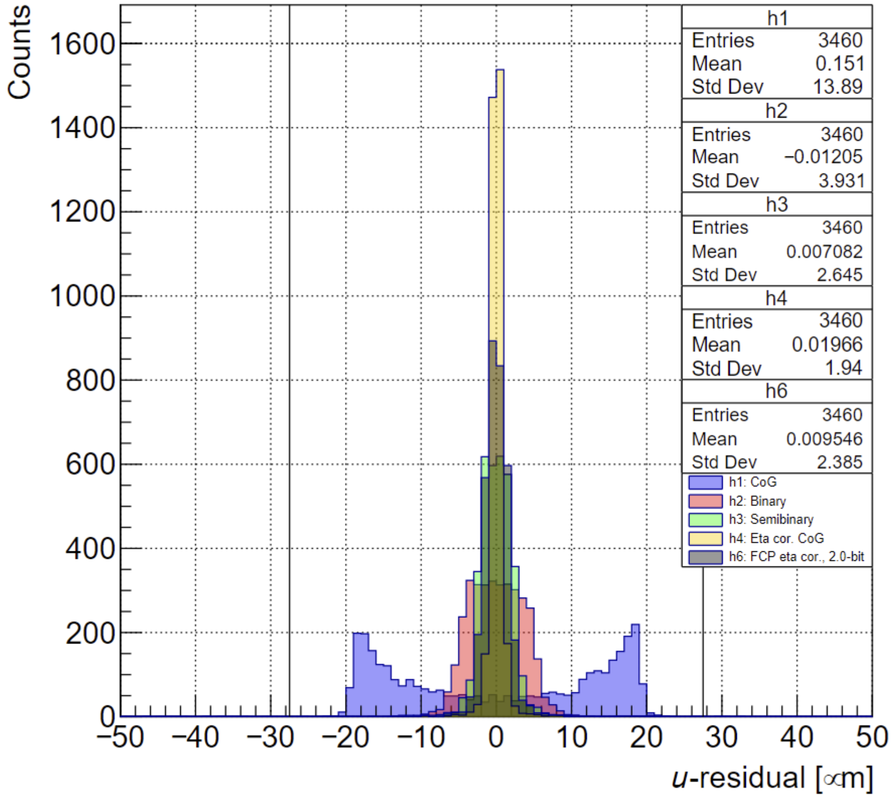
Clustered U-residuals: [W,H]=[2-2,1-1], [M,S]=[1.2,1.0], 40.0<phi<50.0



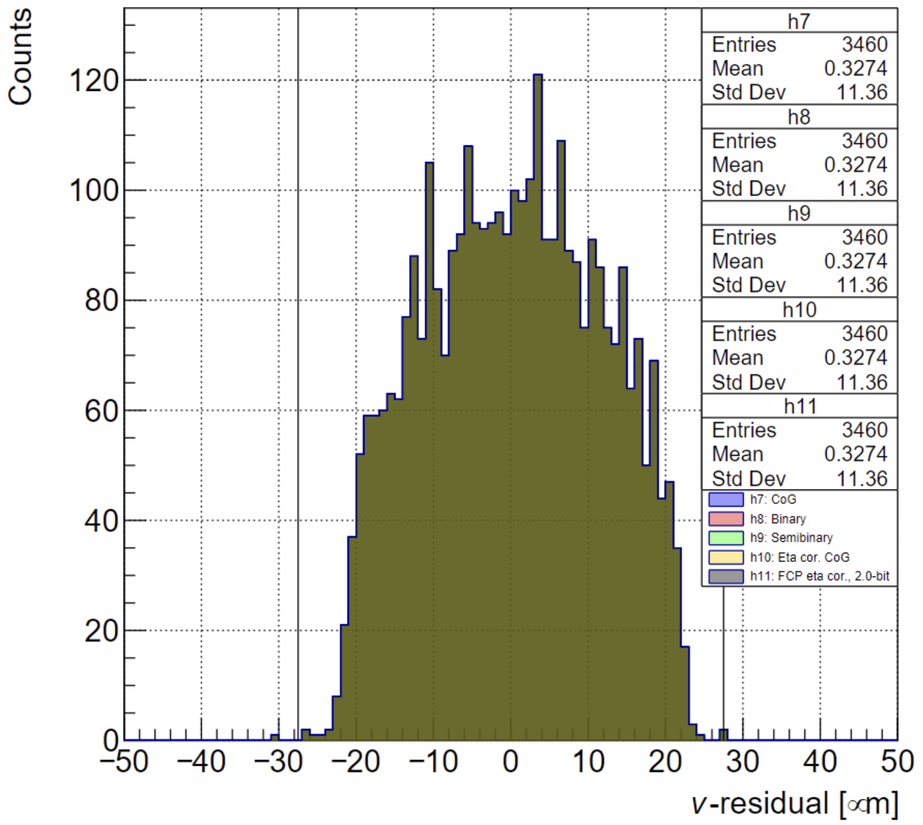
Clustered U-residuals: [W,H]=[2-2,1-1], [M,S]=[1.2,1.0], 40.0<phi<50.0



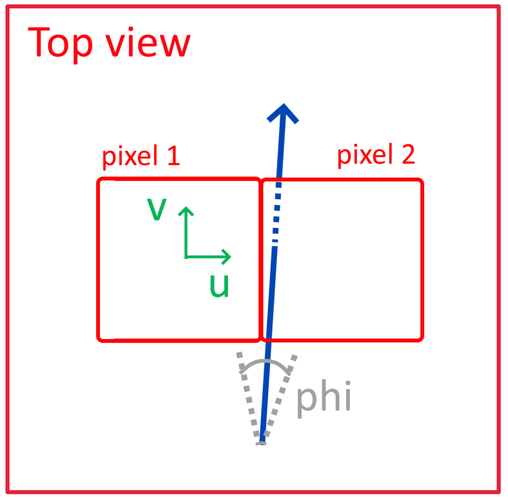
Clustered U-residuals: [W,H]=[2-2,1-1], [M,S]=[1.2,1.0], 40.0<phi<50.0



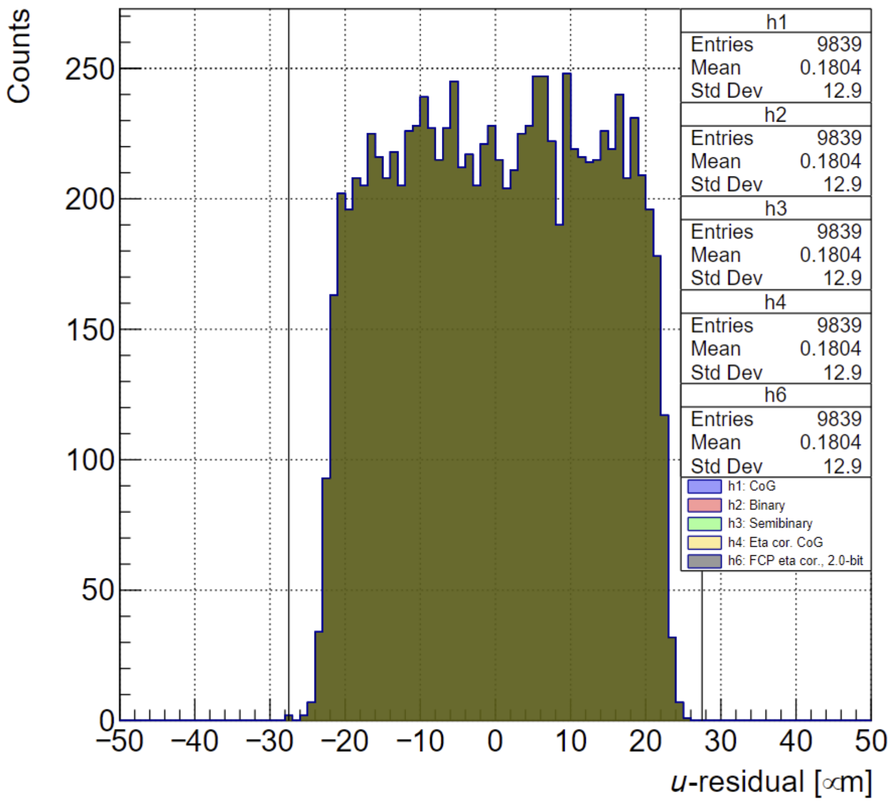
Clustered V-residuals: [W,H]=[2-2,1-1], [M,S]=[1.2,1.0], 40.0<phi<50.0



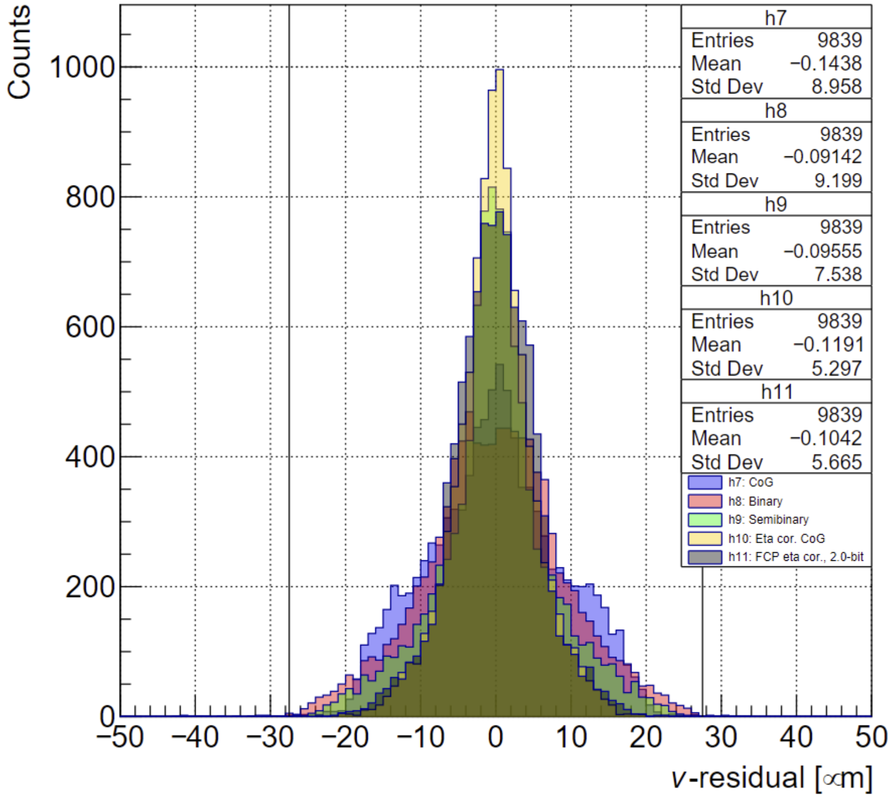
2x1 cluster



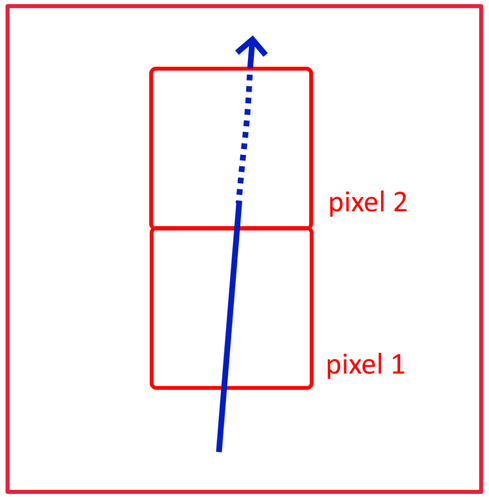
Clustered U-residuals: [W,H]=[1-1,2-2], [M,S]=[1.2,1.0], 40.0<phi<50.0



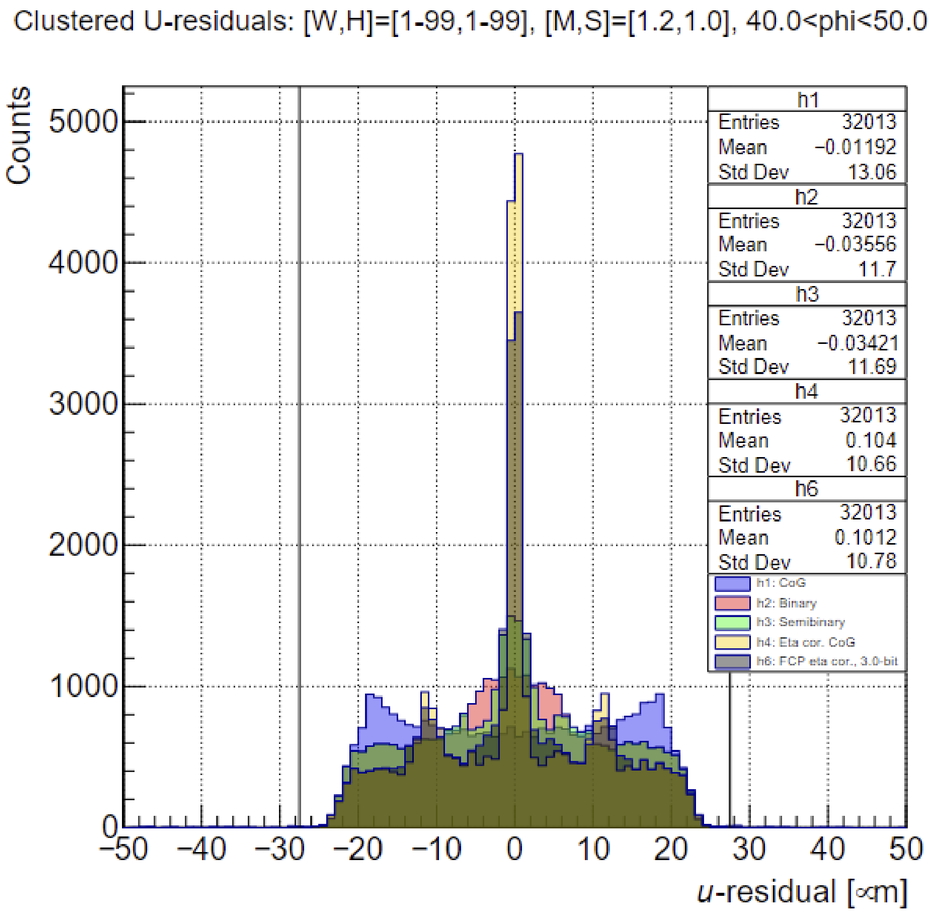
Clustered V-residuals: [W,H]=[1-1,2-2], [M,S]=[1.2,1.0], 40.0<phi<50.0

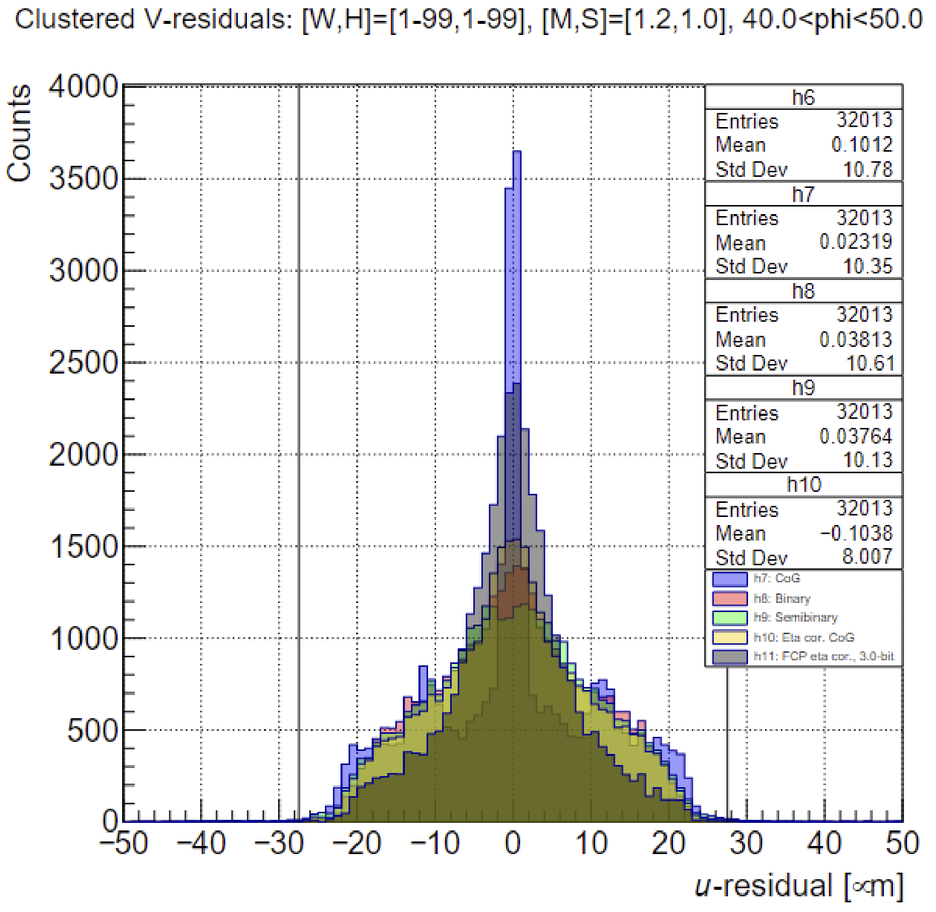


1x2 cluster



All clusters





MS-curve of *u*-residuals: [W,H]=[2-2,1-1], |45−φ| < 5 deg