Ultimate position resolution of pixel clusters with binary readout for particle tracking

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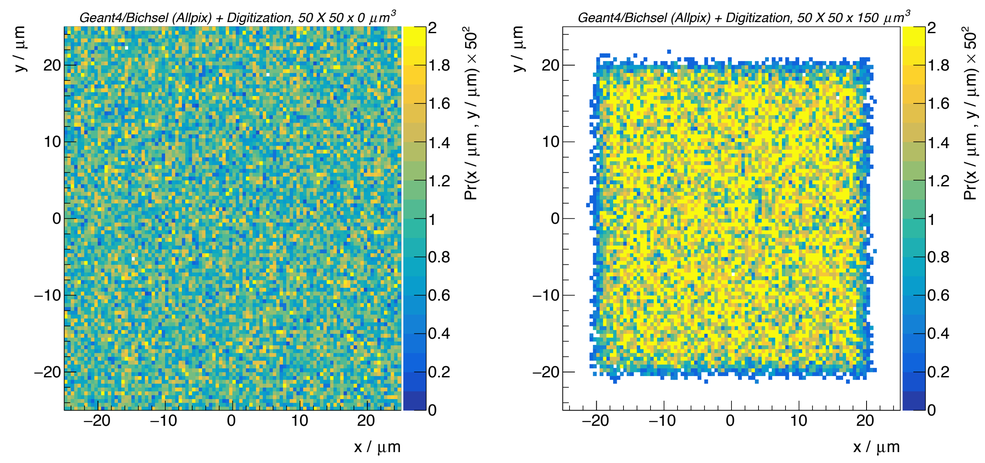
Motivation

- There is significant literature on the position resolution obtained from interpolation of charge measurements.
- A comprehensive study of the resolution obtainable with binary readout is lacking and commonly assumed to be $pitch/\sqrt{12}$, which is the worst case upper limit.
- We study the best achievable resolution for minimum ionizing particles in binary readout pixels using simulation

Why is $pitch/\sqrt{12}$ a worst case upper limit?

A. The cluster distributions that the hit belongs to.

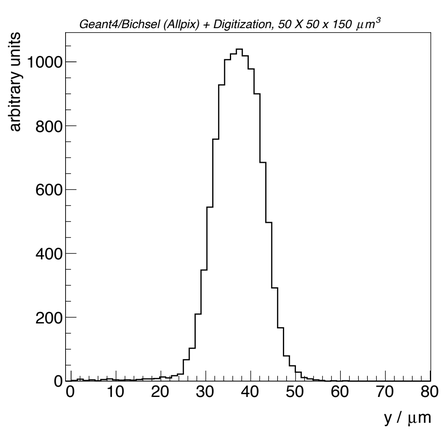
B. Approximate incidence angles of the track producing the hit.

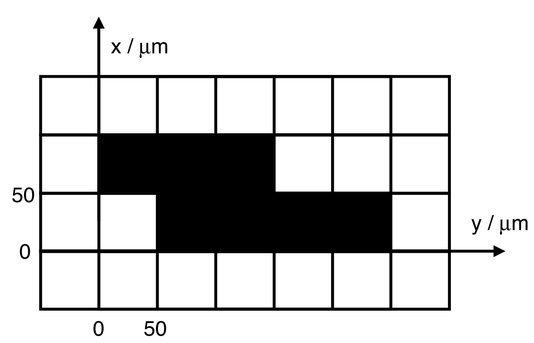


- Tracks near the edge of the pixel will produce 2-pixel clusters instead of 1-pixel clusters.
- The RMS of the actual distribution is $0.78 \times pitch/\sqrt{12}$.

Shape classification and RMS calculation

- Histogram the true entrance point independently for each cluster shape and compute the mean and RMS of the distribution.



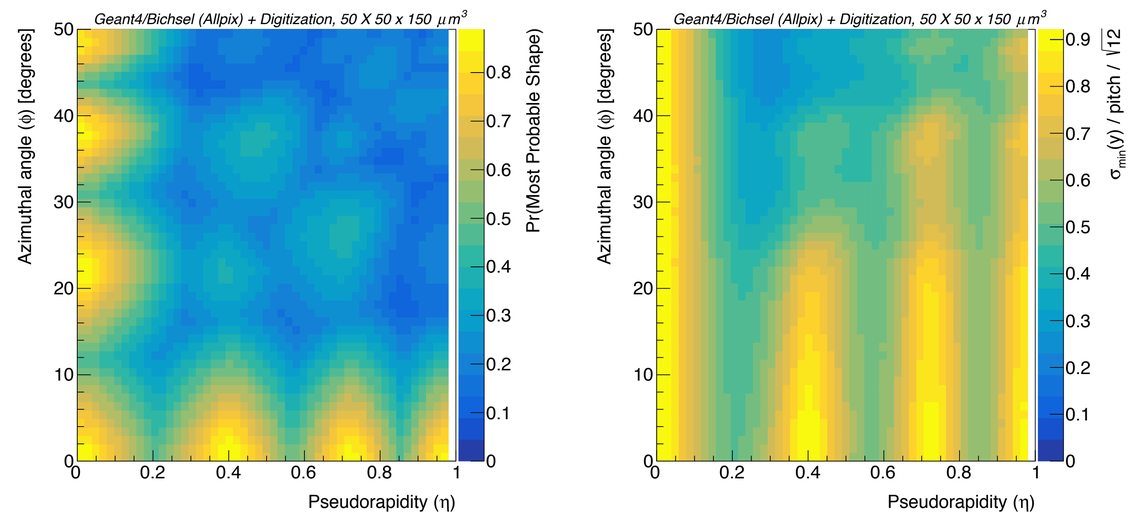


$$\sigma^2 \min(x) \equiv \min(dx)^2 = \sum_{shapes\ s} \Pr(s)\left\langle\left(x_{true} - \langle x_{true} \mid s\rangle\right)^2\right\rangle$$

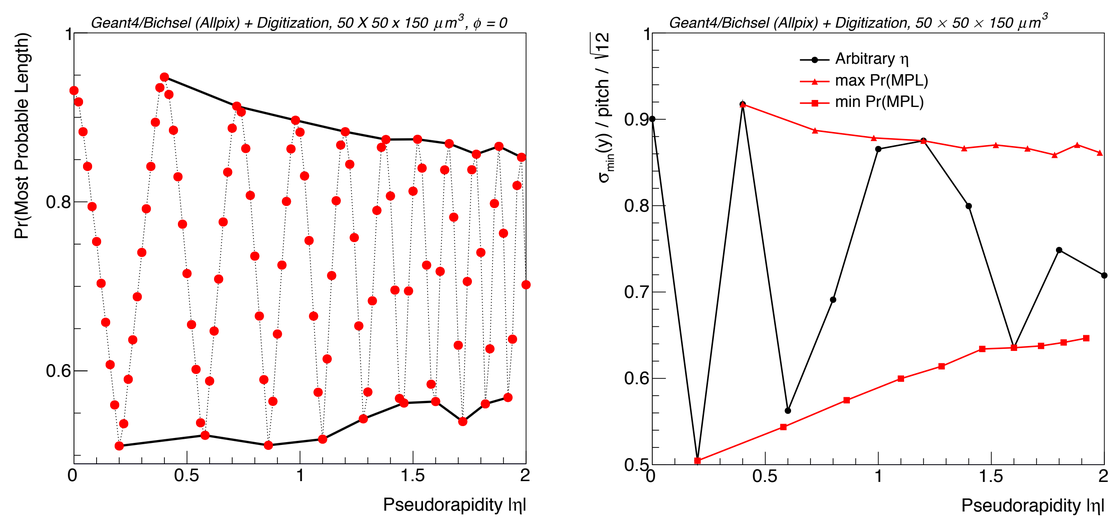
Resolution and the variety of clusters

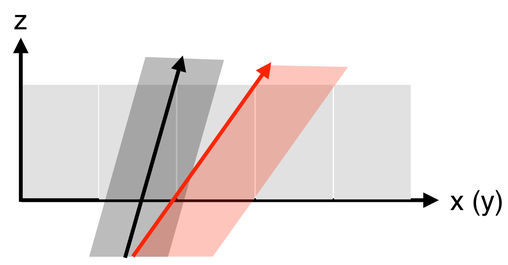
The position resolution ⟷ The variety of cluster shapes ⟷ Incidence angle

- The resolution is best when Pr(Most Probable Shape) is small.
- $50 \times 50 \times 150\ \mu m^2$ pixel sensor



- The resolution envelopes for different ϕ are always below 90% $pitch/\sqrt{12}$ across the entire $|\eta|$ range



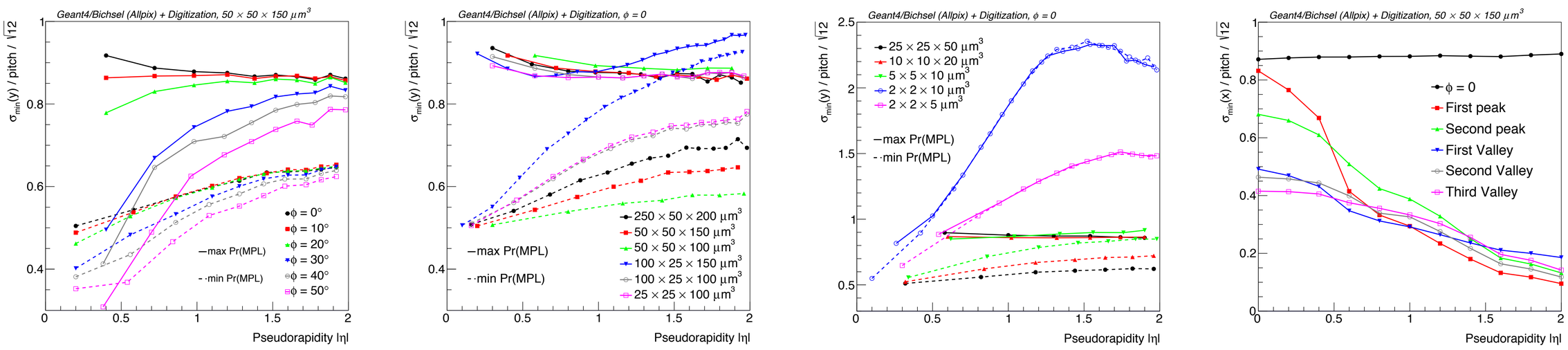


Red arrow: no matter where along a pixel the particle enters the sensor, the MIP will always traverse two pixels.

Black arrow: When the particle enters to the left of the black arrow the cluster length will most likely be 1 pixel, while when the particle enters to the right the length will most likely be two.

Position Resolution in the x and y direction

- Resolution was calculated for the peaks and valleys of the Pr(Most Probabl Length).



- Large pixel: peak depends little on the size and $|\eta|$; valley depends strongly on the size and $|\eta|$
- Small pixel: both the peak and valley depend strongly on the size and $|\eta|$, and the resolution can even exceed $pitch/\sqrt{12}$
- Resolution in the x (non-zero ϕ incidence) benefits significantly from the longer cluster-size as $|\eta|$ increases.

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