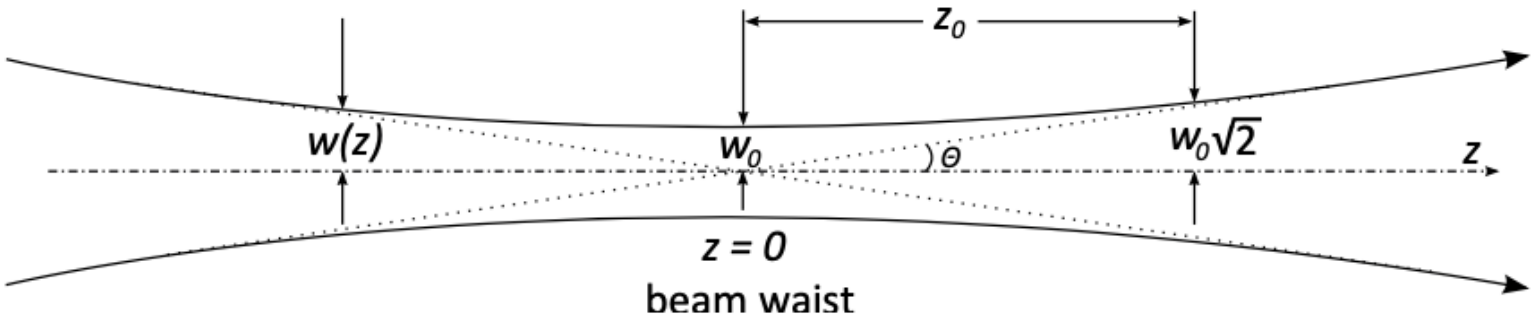
JadePix3芯片空间分辨率激光测试

卢云鹏
中科院高能物理研究所

董胜，汪虎林
华中师范大学

2021年4月2日

Laser Characterization



- Wavelength: 1064 nm
  - Attenuation length in silicon ~1036 $\mu m \gg$ epitaxial layer thickness ~20 μm
- Beam waist $w_0 \sim 1.7\ \mu m$
  - 2σ in 2D gaussian, contains ~86.5% of beam power
- Rayleigh range $z_0 \sim 8.5\ \mu m$
- Divergence angle $\theta = \sim 11°$, $\tan(\theta) \sim 0.19$
- Laser pulse duration ~100 ps $\ll$ charge collection time ~O(10) ns

Threshold, N charge, and Resolution

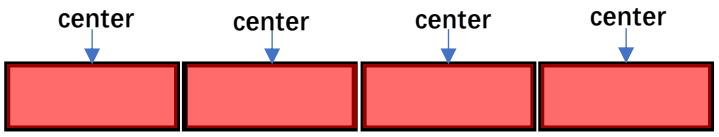
The spatial resolution lies beneath the sensor threshold and number of ionization charges. Or in its normal usage, given N charges, the threshold is tuned to achieve optimal resolution.

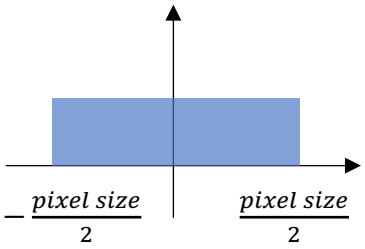
Somewhere in between:

$$\frac{pixel\ size}{2\sqrt{12}} < \sigma < \frac{pixel\ size}{\sqrt{12}}$$

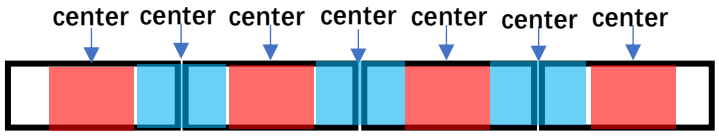
Single Hit

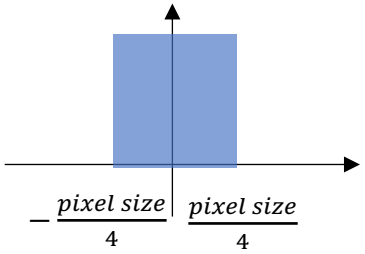
Double Hits



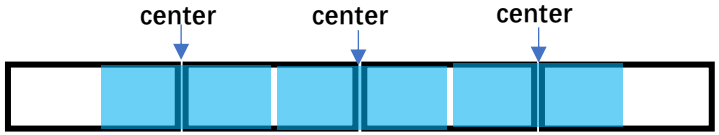


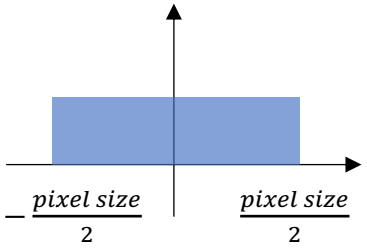
- $\sigma = \frac{pixel\ size}{\sqrt{12}}$
- Mean(N Hits)=1





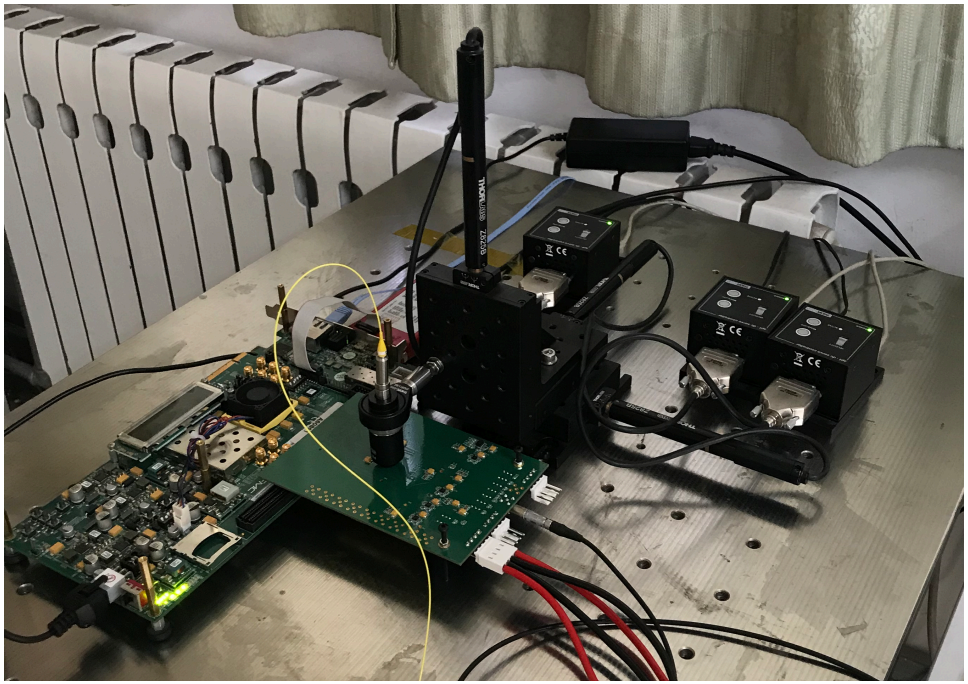
- $\sigma = \frac{pixel\ size}{2\sqrt{12}}$
- Mean(N Hits)=1.5





- $\sigma = \frac{pixel\ size}{\sqrt{12}}$
- Mean(N Hits)=2

Operations and nomenclatures

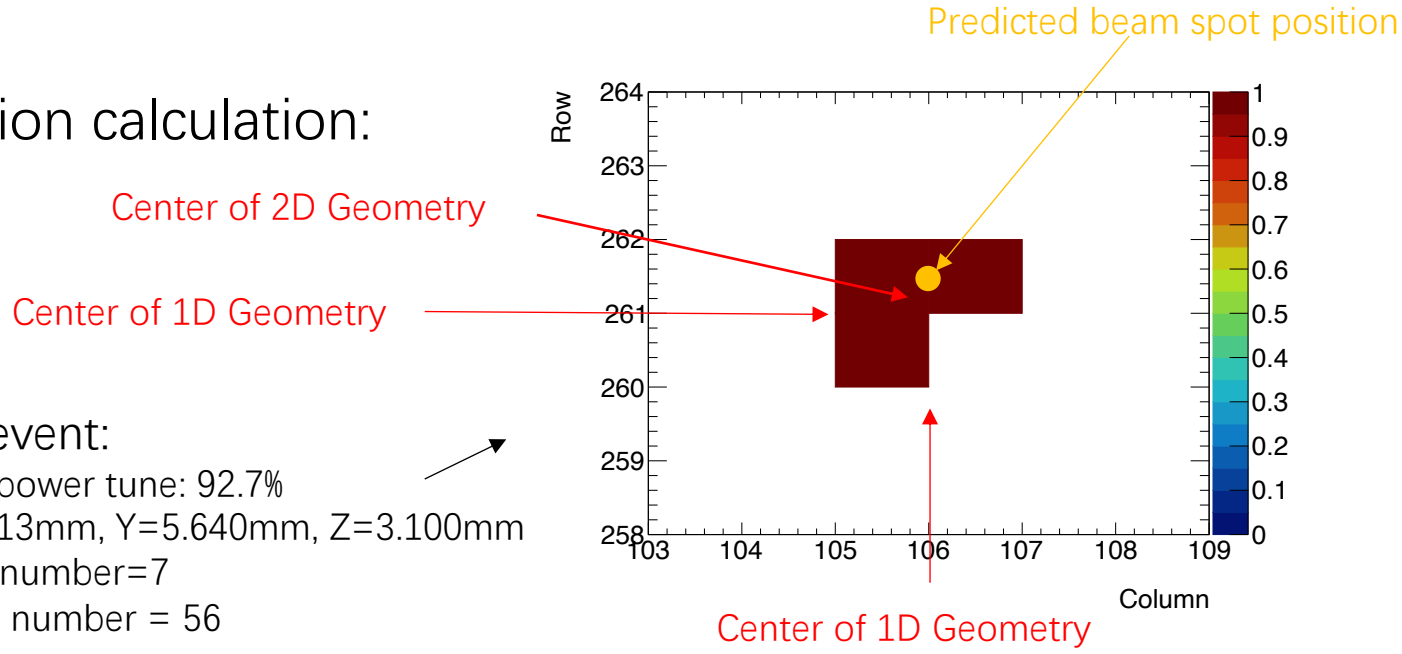


- Laser Power Tune:
  - 0% : maximum power; 100% : minimum power
  - For final results, use 92.7%, 92.9%, 93.3%, 93.5%, 93.7%
  - 92.7% ~ 4 × threshold (threshold set to ~220 e^-)
  - 93.7% ~ 2 × threshold

Operations and nomenclatures

- Use pixels in sector 2
  - $16\ \mu m \times 23.11\ \mu m$.
  - $16\ \mu m$ side: Y axis, row; $23.11\ \mu m$ side: X axis, column
  - X scan: from one pixel center (X_0, Y_0) to (X0+22μm, Y0) with 1 μm step. ~1000 events (frame with laser) per step
  - Y scan: from one pixel center (X_0, Y_0) to (X0, Y0+15 μm) with 1 μm step. ~1000 events (frame with laser) per step

- Position calculation:

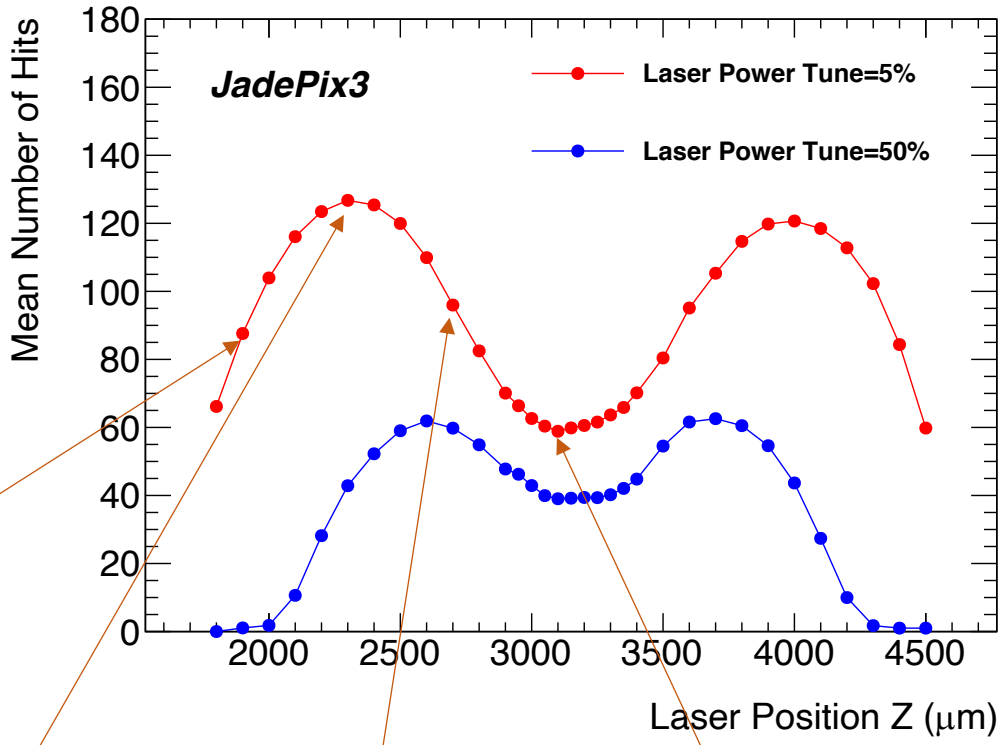


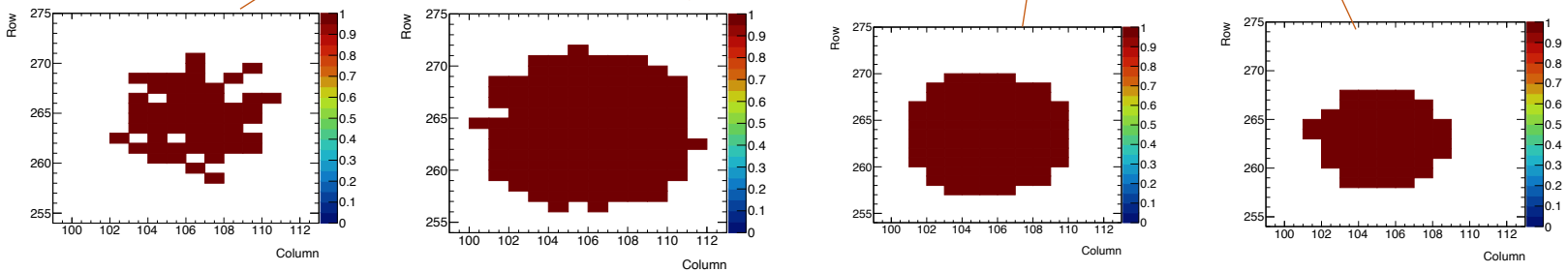
X scan event:
- Laser power tune: 92.7%
- X=0.713mm, Y=5.640mm, Z=3.100mm
- Event number=7
- Frame number = 56

Vertical (Z) adjustment

Vertical adjustment method:

- Scan the Z position with large laser power
- The number of hits VS Z position will display a "double peak" shape, due to the fixed sensor threshold
- The local minimum between the two peaks means the focal point lies within the epitaxial layer (or close to it)
- Due to time constraint, the Z scan step around the local minimum is 50 μm with ~1000 events.



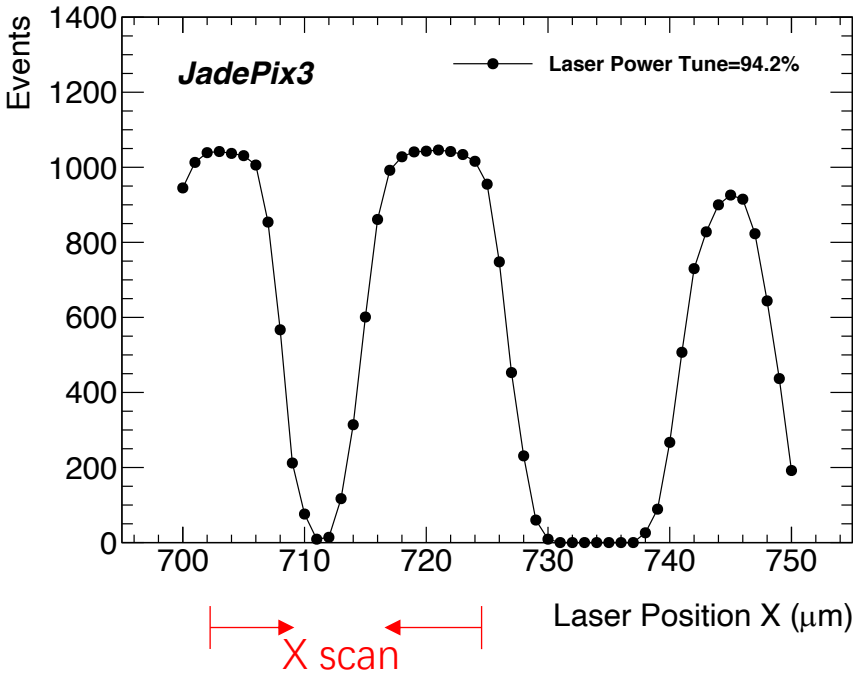


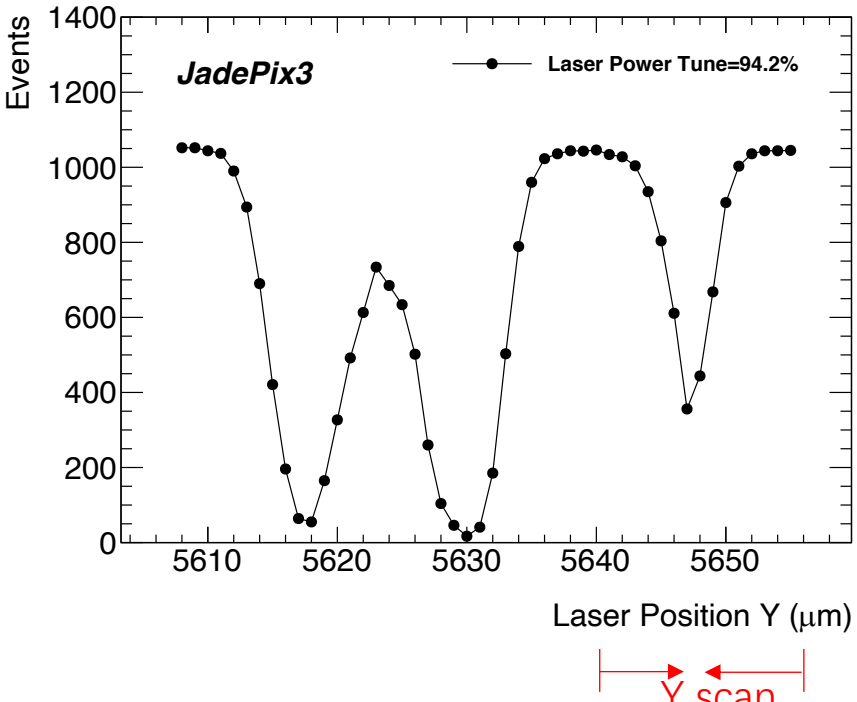
focal point

Locating X and Y

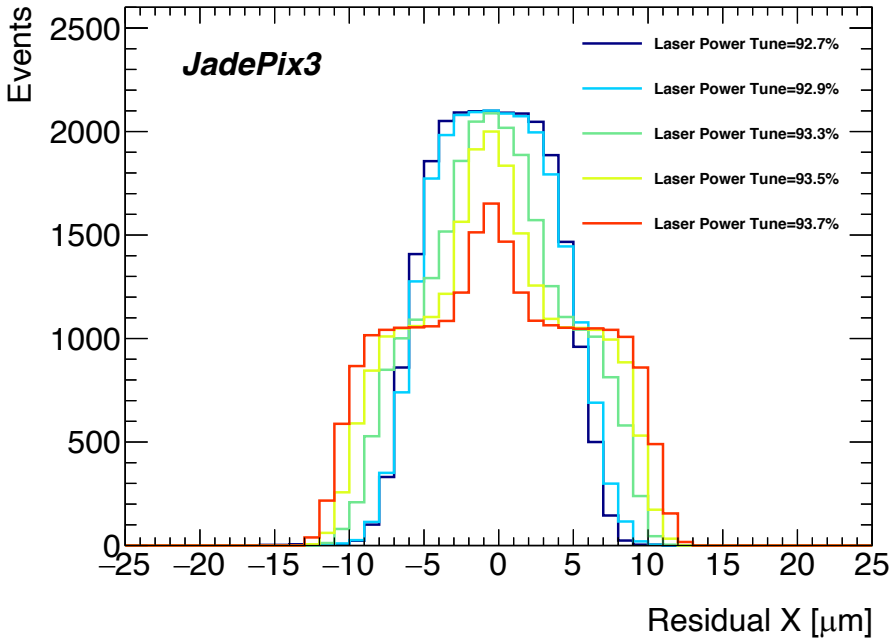
Horizontal coordinates determination method:

- Scan the X or Y position with laser power slightly over 1 × threshold
- Due to the charge sharing between adjacent pixels, the efficiency ($\frac{N\ frames\ with\ hits}{N\ frames\ with\ laser}$) decreases as laser spot move near the pixel edge
- The minimum and maximum corresponds to pixel center and edge respectively, roughly speaking.

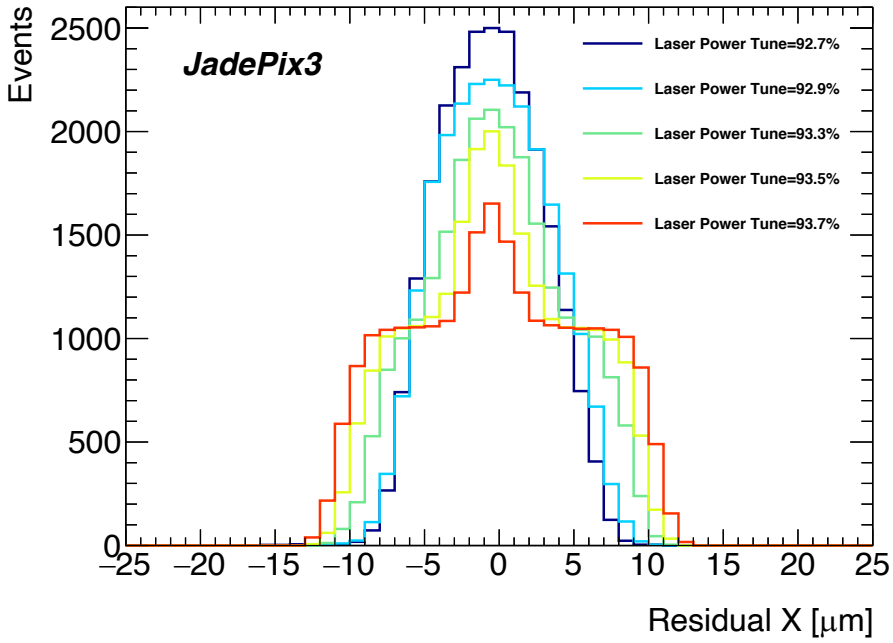




Residual in X (23.11 μm side)



Center of 1D Geometry



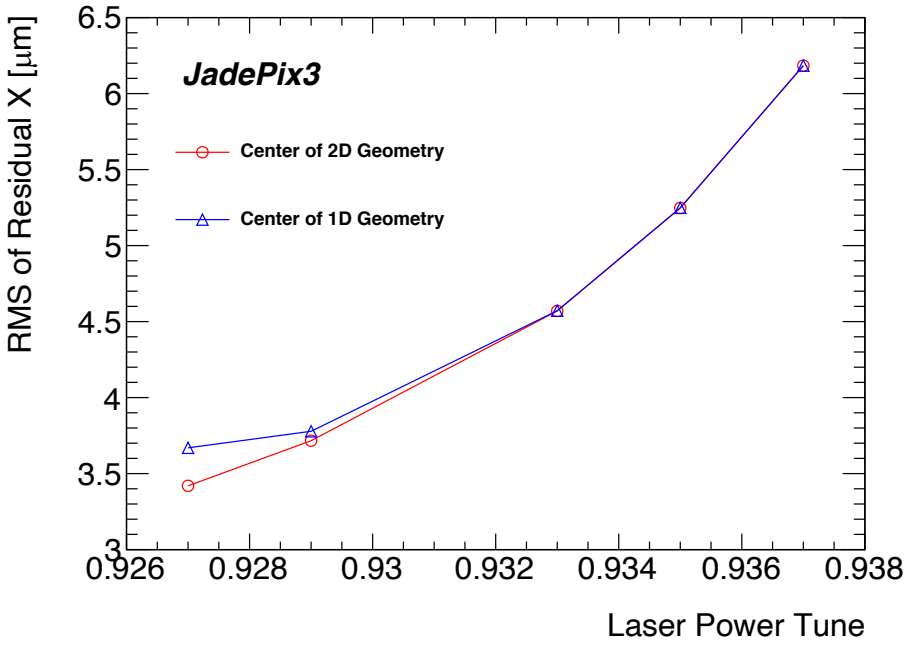
Center of 2D Geometry

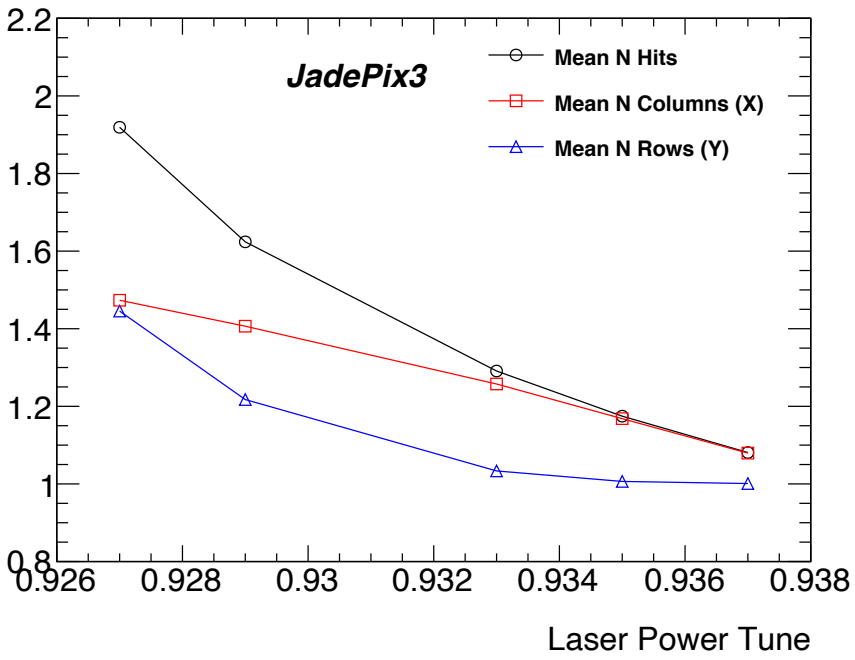
Theoretical boundaries:

$$\frac{23.11\ \mu m}{2} = 11.56\ \mu m$$

$$\frac{23.11\ \mu m}{4} = 5.78\ \mu m$$

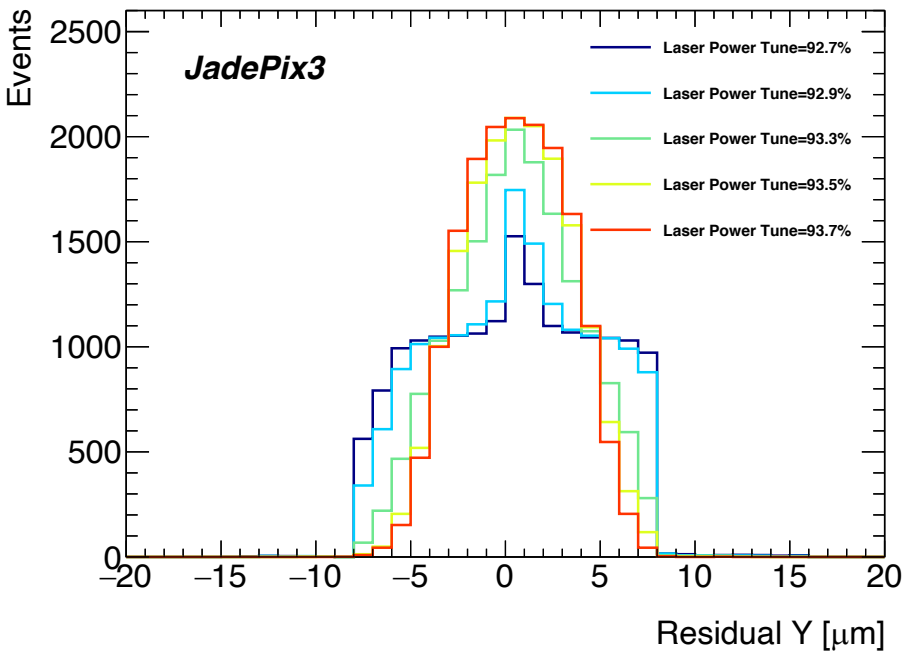
Resolution and N (Hits/Columns/Rows) in X Scan



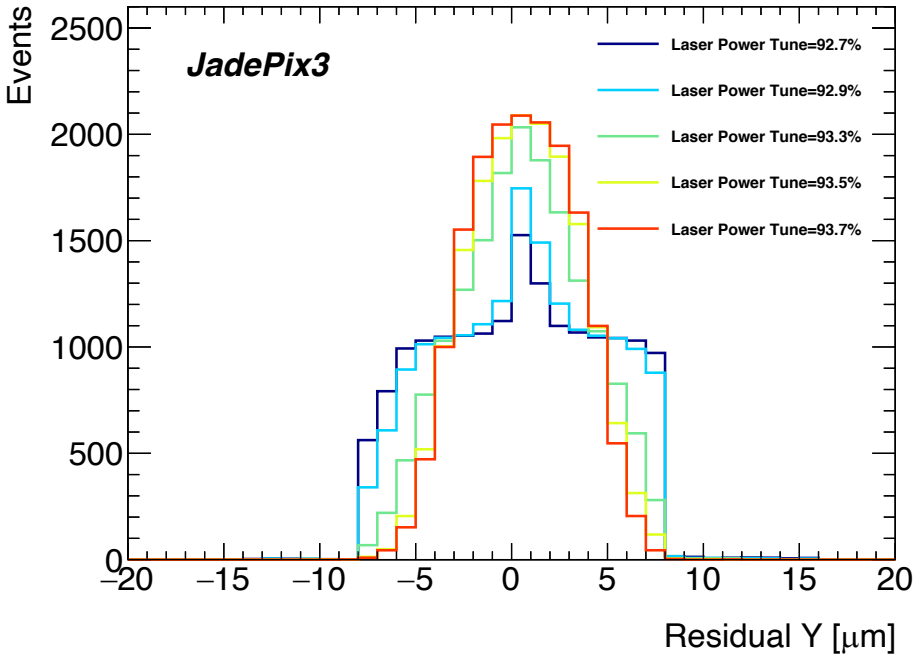


Theoretical values: $\frac{23.11\ \mu m}{2\sqrt{12}} = 3.34\ \mu m$ $\frac{23.11\ \mu m}{\sqrt{12}} = 6.67\ \mu m$

Residual in Y (16 μm side)



Center of 1D Geometry



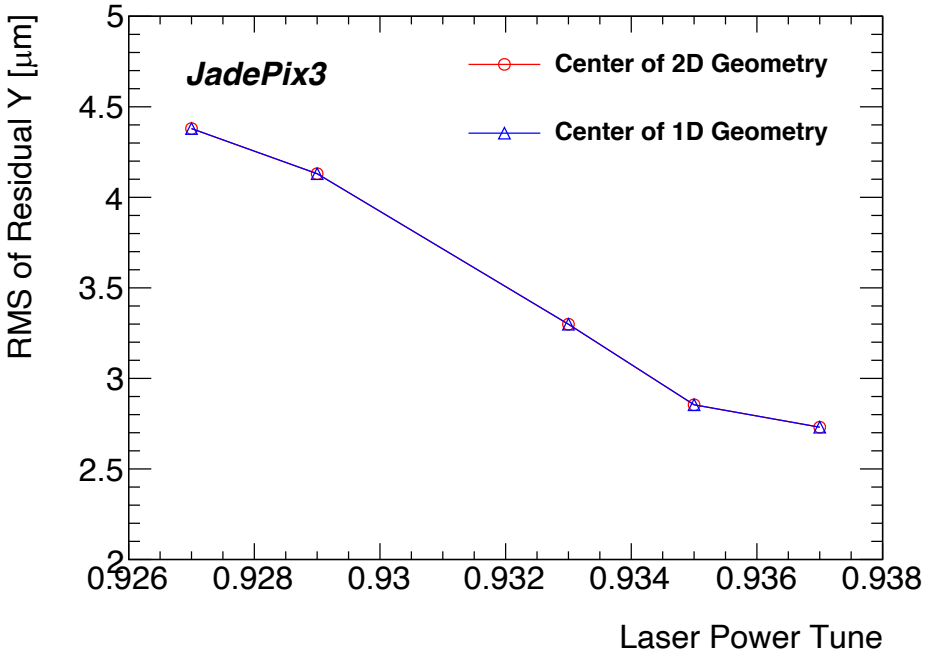
Center of 2D Geometry

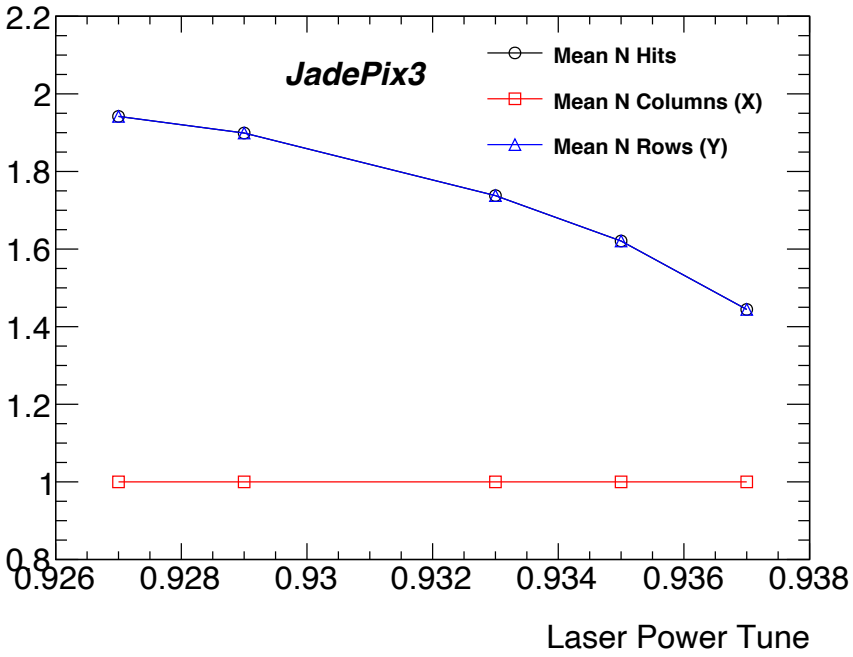
Theoretical boundaries:

$$\frac{16\ \mu m}{2} = 8\ \mu m$$

$$\frac{16\ \mu m}{4} = 4\ \mu m$$

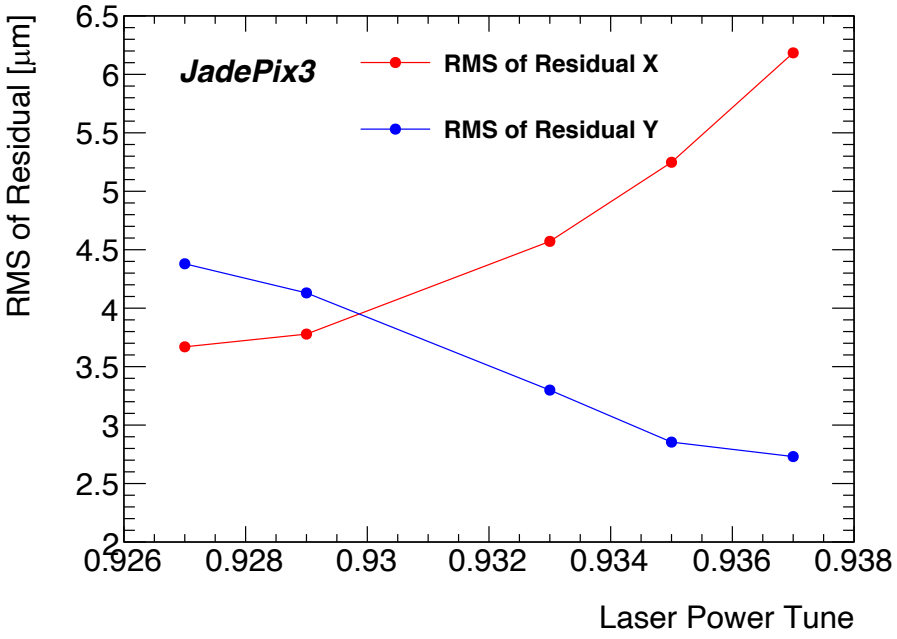
Resolution and N (Hits/Columns/Rows) in Y Scan



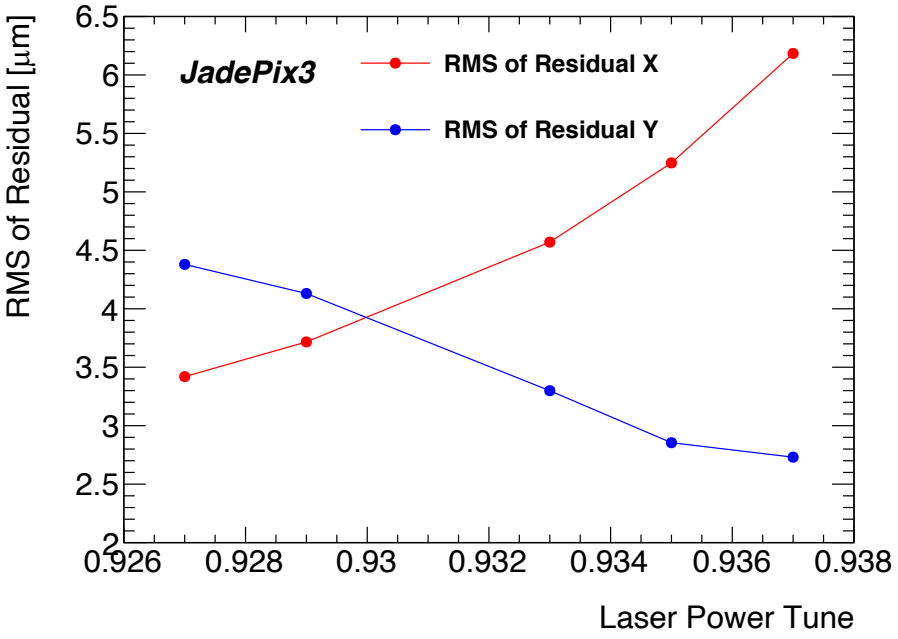


Theoretical values: $\frac{16\ \mu m}{2\sqrt{12}} = 4.62\ \mu m$ $\frac{16\ \mu m}{\sqrt{12}} = 2.31\ \mu m$

Resolution Summary



Center of 1D Geometry



Center of 2D Geometry

Summary

- Obtained spatial resolution of JadePix3 with laser beam, results fit predictions, behaviours understood. Some further improvements and subtler understanding could be accomplished, if demanded.

- It can be reasonably anticipated that for a diffusion-dominated CMOS sensor like JadePix3, laser and particle beam tests should yield similar results, provided that the same condition regarding threshold and number of ionized charges apply.