Spatial resolution of SOI pixel detectors with binary readout

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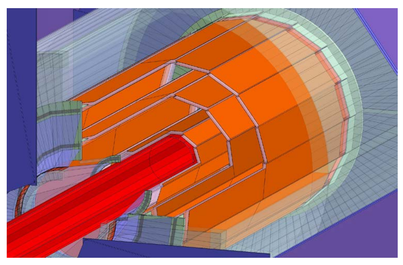
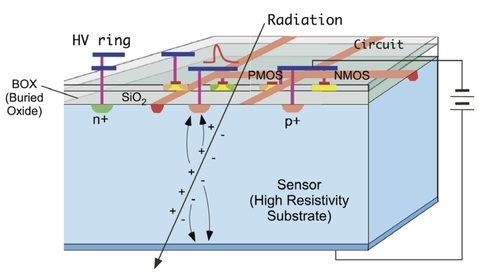
Introduction

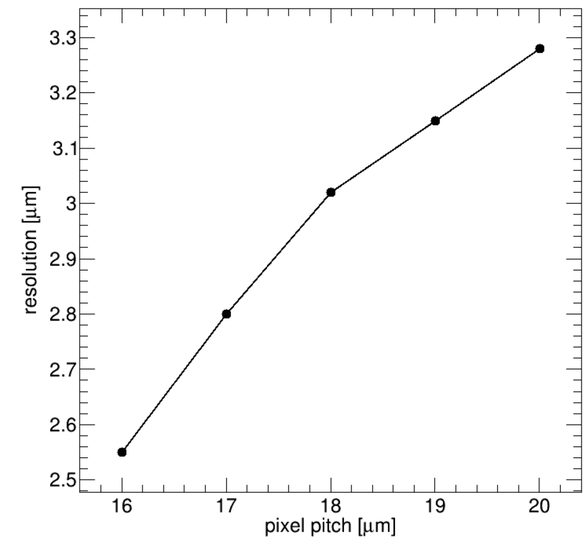
- Silicon pixel detector is the innermost part of the detector system at CEPC. It's spatial resolution is one of the most important parameters . In the concept design report, the vertex detector should comply with the following specification: a spatial resolution near the IP better than 3 um [1].
- SOI (silicon on insulator) pixel detector with binary readout is one possible way to achieve this target. It features the fully depleted sensor and standard CMOS circuit.
- This study aims to exploit the key factors influencing the spatial resolution of SOI pixel detector using simulation method.
- A generic pixel detector simulation framework Allpix[2] is used.





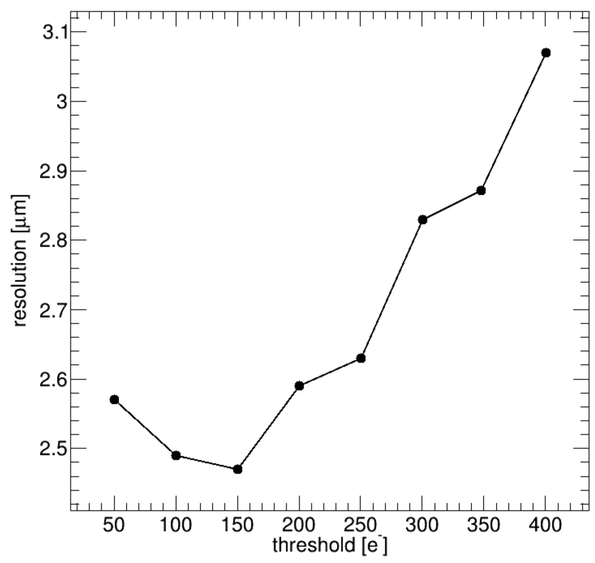
Pixel pitch

- The resolution for pixel detector with binary readout is usually considered to be $\frac{pitch}{\sqrt{12}}$. Due to the charge sharing between two adjoining pixels, the resolution will be better than $\frac{pitch}{\sqrt{12}}$, and worse than $\frac{pitch}{2\sqrt{12}}$ [2].
- The resolution decreases with pitch decreasing as we expected.



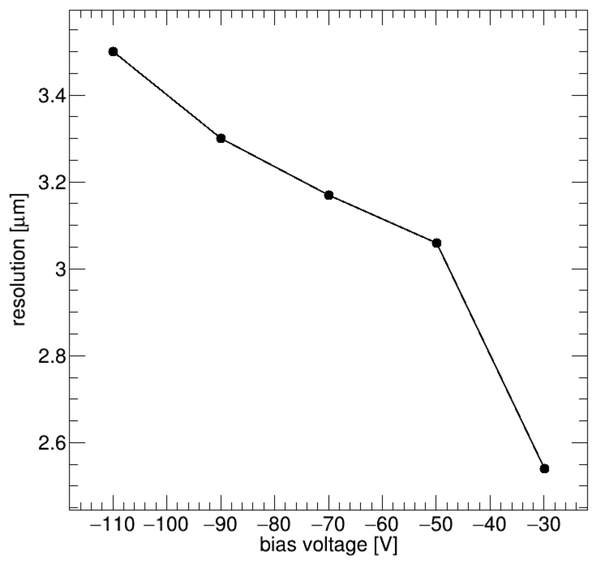
Threshold

- A high enough threshold is necessary to suppress noise hits and reduce the fake hitting rate.
- However, a pixel with relative small charge collected will not be recorded due to a high threshold. This may lead to a resolution decreasing.
- The resolution first decreases and then increases with threshold decreasing.



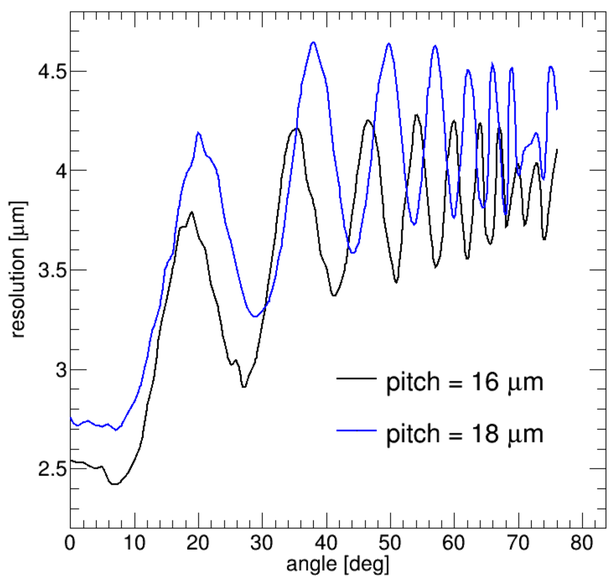
Bias voltage and doping concentration

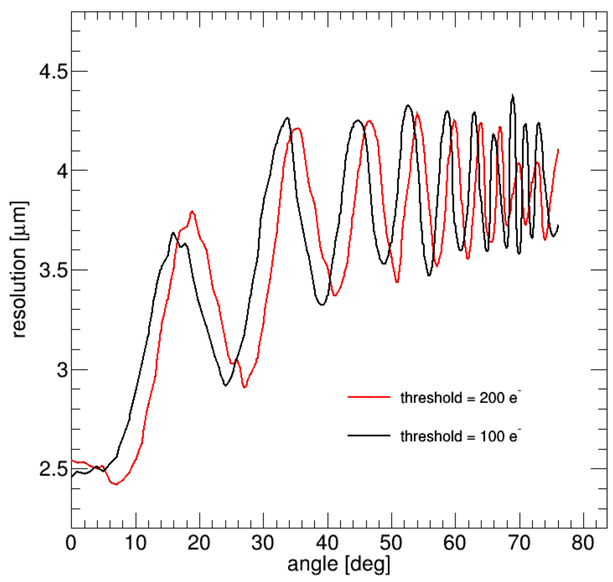
- A bias voltage is applied to fully deplete the SOI sensor. The value of fully depleted voltage can be calculated using P-N junction approximation: $V = \frac{eN_D d^2}{2\varepsilon_0 \varepsilon_{Si}}$.
- The time to collect the electrons is decided by the bias voltage and the position.
- The diffusion of the electrons is a random walk like process. The transverse spread distance can be calculated as : $\sigma = \sqrt{2Dt}, D = \frac{kT}{q}\mu$.
- A small V_{bias} will be beneficial for improving resolution. A high resistance thus low doping concentration sensor is more appreciated.

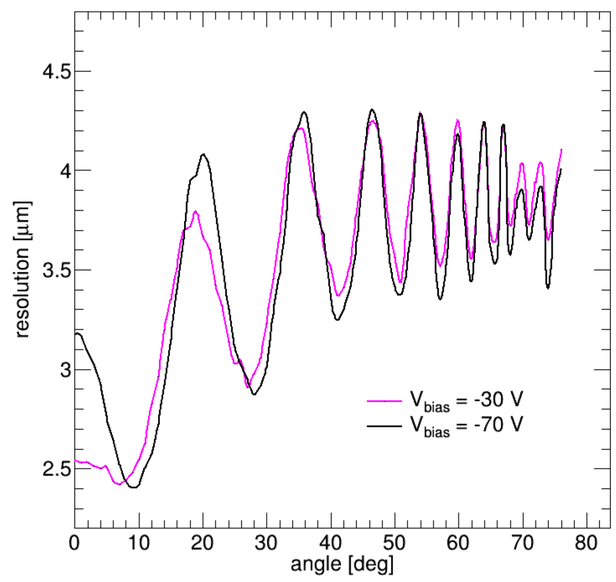


Angle

- All the simulations above are done for the case where the particle goes through the detector perpendicularly. This is also the conventional way to measure the resolution of a pixel detector.
- However, many interesting events pass through the detector with a large angle.
- Resolution shows upward trend with the angle of incidence increasing.
- The change of the threshold will shift the waveform. Bias voltage will not influence the resolution at a relatively large angle. Reducing the pixel pitch is almost the only way to improve the resolution in the whole angle range.

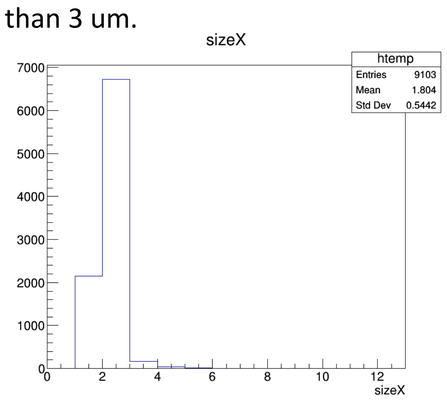




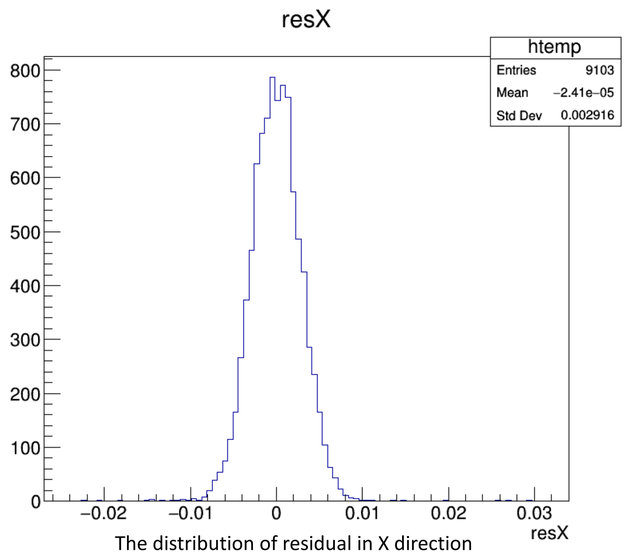


For CEPC

- SOI pixel detector with a size of 16×16 um^2, a noise less than 20 e$^-$, and high resistance substrate can achieve a resolution better than 3 um.



The distribution of cluster size in X direction



The distribution of residual in X direction

Acknowledgement

This work is supported by the CAS Center for Excellence in Particle Physics (CCEPP) and the National Nature Science Foundation of China, Grant 11575220.

Reference

[1] CEPC CDR, http://http://cepc.ihep.ac.cn/CEPC_CDR_Vol2_Physics-Detector.pdf
[2] Rossi, L., Fischer, P., Rohe, T., & Wermes, N. (2006). Pixel detectors: From fundamentals to applications. Springer Science & Business Media.