Offline analysis for the beam test of CEPC vertex detector prototype

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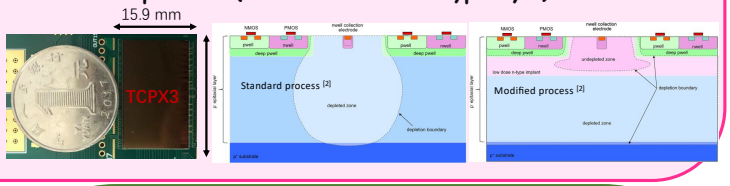
Introduction

- **CEPC ?**
  - **Circular Electron Positron Collider**[1] proposed by Chinese particle physics community
  - Double-ring collider with **electron and positron** beams circulated in opposite directions in separate beam pipes
  - Precise measurement of properties of **Higgs, W and Z bosons**
- **Vertex detector ?**
  - H → bb precise vertex reconstruction
  - H → uu precise momentum measurement

High spatial resolution (3~ 5 μm)
Radiation hard (>1 Mrad)

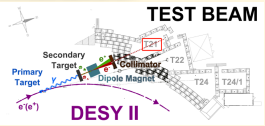
- **CMOS pixel sensor prototypes?**
  - **TaiChuPix3 pixel sensor developed for the vertex detector**
    1024 x 512 Pixel array
    25um x 25 μm per pixel → high spatial resolution
  - **Process: CIS 180nm process**
    Standard process (baseline option)
    Modified process[2] **(an extra low dose n-type layer)**

modified process: faster charge collection



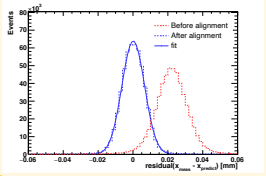
Beam test @ DESY

- **DESY TB21 beam line** [3]
  - 4 ~ 6 GeV electron beam



- **Offline data analysis flow**

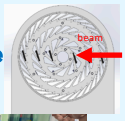
DAQ → Raw data → Decoding → Event building → Clustering → Alignment → Track fitting



- **Clustering:** geometric center of the gravity of the neighboring fired pixels
- **Alignment:** Millipede[4]
- **Track fitting:** Straight line fit and General broken line fit[5]

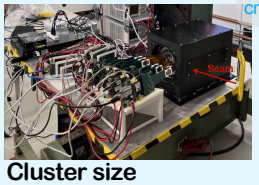
Test beam on vertex detector prototype

- **Mechanical prototype assembly**
  - Doubled ladder with **2 TaichuPix3 chips on each side**
  - **6 ladders** mounted on the mechanical prototype

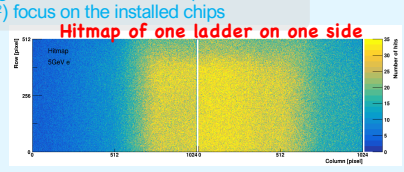


- **Beam test setup**

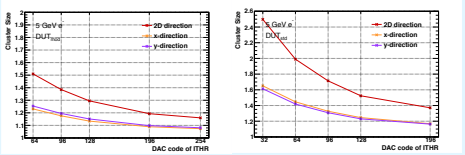
Biggest collimator available (2.5 x 2.5 cm²) focus on the installed chips



Hitmap of one ladder on one side

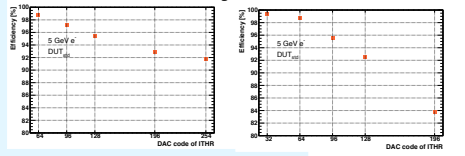


- **Cluster size**



The DUT with the standard process shows more charge-sharing effects

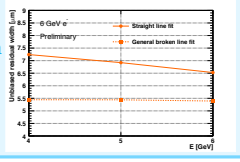
- **Detector efficiency**



The detection efficiency also can reach 99% for the vertex detector prototype at the lowest setting threshold

- **Unbiased residual width**

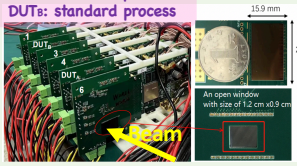
The unbiased residual width before and after correction for multiple scattering



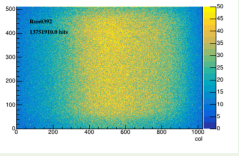
Test beam on pixel sensor prototype

- **Setup**
  - 6 equally spaced (4cm) detector module with TaichuPix3

DUTA: modified process
DUTB: standard process



Hitmap of one DUT



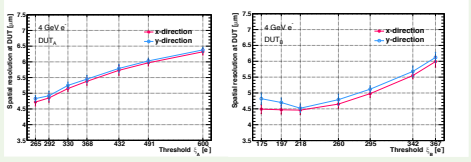
- **Spatial resolution**
  - **Estimation of intrinsic resolution**[6]

$$pull_b \equiv p_b = \frac{r_b}{\sqrt{\sigma_{int}^2 - \sigma_{t,b}^2}}$$

r_b: biased residual
σ_{int}: intrinsic resolution
$\sigma_{t,b}$: biased track uncertainty

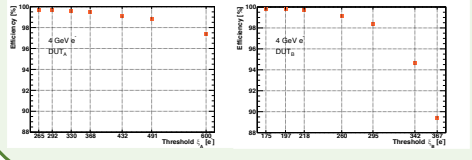
- $pull_b \sim N(0,1)$, if accurate estimate of the intrinsic resolution and scattering angle
- The standard deviation of $pull_b$ iteratively used to update the estimate σ_{int}

- **Resolution vs. Threshold**



Higher threshold → less cluster size → less charge sharing effects → worse spatial resolution

- **Detection efficiency**



The detection efficiency for both process can reach 99% at the lowest threshold

Conclusions

- The spatial resolution of TaichuPix3 sensors can be < 5 μm for both processes
- The detection efficiency is larger than 99% for both processes of TaichuPix3 sensors.
- The vertex detector beam test results show nearly identical results to the sensor beam test.

References

[1] The CEPC Study Group, CEPC Conceptual Design Report: Volume 2 - Physics Detector (11 2018). doi:https://doi.org/10.48550/arXiv.1811.10545.

[2] W. Snoeys, et al., A process modification for CMOS monolithic active pixel sensors for enhanced depletion, timing performance and radiation tolerance, Nucl. Instrum. Meth. A 871 (2017) 90–96. doi:http://dx.doi.org/10. 1016/j.nima.2017.07.046

[3] V. Blobel, Software alignment for tracking detectors, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 566 (1) (2006) 5–13, tIME 2005. doi:https://doi.org/10.1016/j.nima.2006.05.157.

[4] Kleinwort C (2012) General broken lines as advanced track fitting method. Nucl Instr Meth Phys Res A 673:107–110

[5] R. Diener, J. Dreyling-Eschweiler, H. Ehrlichmann, I. Gregor, U. Kötz, U. Krämer, N. Meyners, N. Potylitsina-Kube, A. Schütz, P. Schütze, M. Stanitzki, The DESY II test beam facility, Nucl. Instrum. Meth. A 922 (2019) 265–286. doi:https://doi.org/10.1016/j.nima.2018.11.133

[6] Jansen, H., Spannagel, S., Behr, J. *et al.* Performance of the EUDET-type beam telescopes. *EPJ Techn Instrum* **3**, 7 (2016). https://doi.org/10.1140/epjti/s40485-016-0033-2