

# Characterization of a 180nm CMOS pixel sensor prototypes for the CEPC vertex detector



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## Introduction

### CEPC ?

- Circular Electron Positron Collider<sup>[1]</sup> 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**

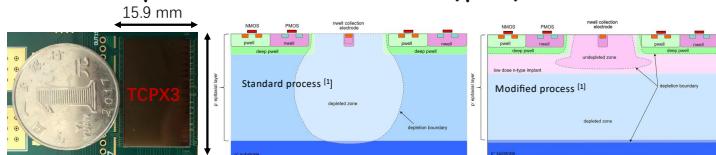
### Vertex detector ?

- $H \rightarrow bb$  precise **vertex reconstruction**
- $H \rightarrow uu$  precise **momentum measurement**

High spatial resolution (3~5  $\mu\text{m}$ )  
Radiation hard ( $> 1 \text{ Mrad}$ )

### CMOS pixel sensor prototypes?

- **TaiChuPix3 pixel sensor developed for the vertex detector**  
 $1024 \times 512$  Pixel array  
 $25\text{um} \times 25 \mu\text{m}$  per pixel → high spatial resolution
- **Process: TowerJazz CIS 180nm process**  
Standard process (baseline option)  
Modified process<sup>[2]</sup> (an extra low dose n-type layer) modified process: faster charge collection

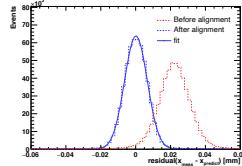
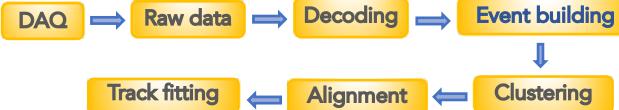


## Beam test @ DESY

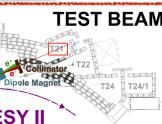
### DESY TB21 beam line<sup>[3]</sup>

- 4 ~ 6 GeV electron beam

### Offline data analysis flow



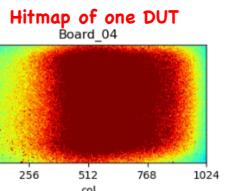
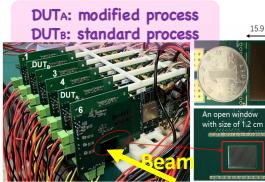
- **Clustering:** geometric center of the gravity of the neighboring fired pixels
- **Alignment:** Millipede<sup>[4]</sup>
- **Track fitting:** Straight line fit and General broken line fit<sup>[5]</sup>



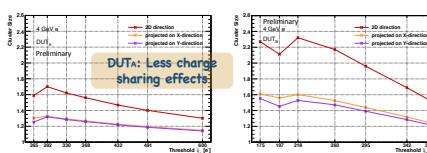
## Test beam on pixel sensor prototype

### Setup

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



### Cluster size



The higher the threshold, the smaller the cluster size

### Spatial resolution

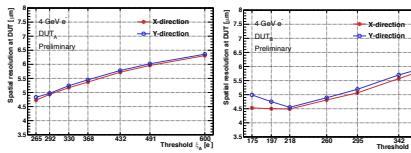
#### Estimation of intrinsic resolution<sup>[6]</sup>

$$\text{pull}_b \equiv p_b = \frac{r_b}{\sqrt{\sigma_{int}^2 - \sigma_{t,b}^2}}.$$

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

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

### Resolution vs. Threshold

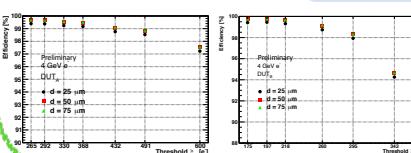


Higher threshold → less cluster size → less charge sharing effects → worse spatial resolution

### Efficiency

$$\epsilon = \frac{N_{\text{matched Tracks}}}{N_{\text{tel}}^{N_{\text{Tracks}}}}$$

$d$ :  $x, y_{\text{measured}} - x, y_{\text{predicted}}$   
 $N_{\text{tel}}$ : Number of tracks of telescope  
 $N_{\text{matched Tracks}}$ : matched tracks on DUT within d



The efficiency for both process can reach 99.4% at lowest threshold

## 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



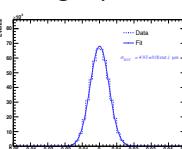
### Beam test setup



Biggest collimator available ( $2.5 \times 2.5 \text{ cm}^2$ ) focus on the installed chips



### Single point resolution



- **6 GeV** electron beam
- Spatial resolution < 5  $\mu\text{m}$
- The resolution varies along the x and y axis

## Conclusions

- The spatial resolution of TaiChuPix3 sensors can < 5  $\mu\text{m}$  for both processes
- The efficiency is ~ 99.4% for both processes of TaiChuPix3 sensors.
- The vertex detector prototype and DAQ can work well under different thresholds and energies

## 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. Seery, 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:<https://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, Nucl. Inst. Meth. A 566 (2006) 5–13, 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. Dreiling-Eschweiler, H. Ehrlichmann, I. Gregor, U. Kotz, U. Krämer, N. Meynert, N. Potylitsina-Kube, A. Schütz, S. 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). doi:<https://doi.org/10.1140/epjti/e04085-016-0033-2>.