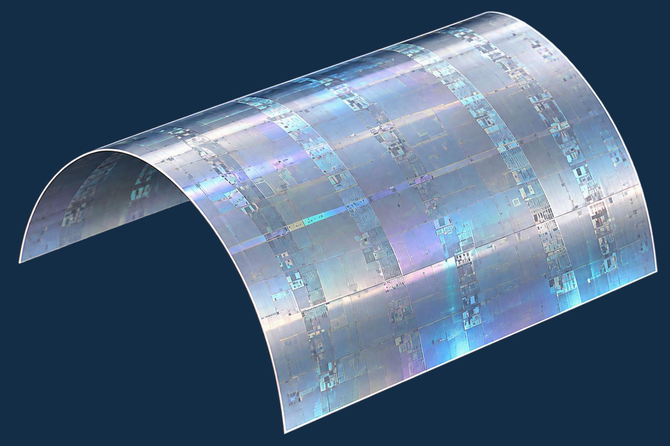
CEPC Workshop 2026, Shanghai

Simulation and Beam-Test Studies of TaichuPix

for the CEPC Vertex Detector



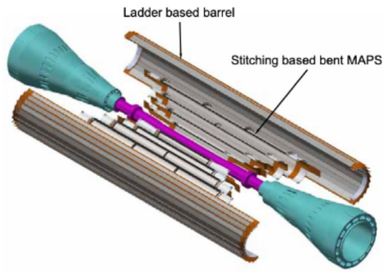
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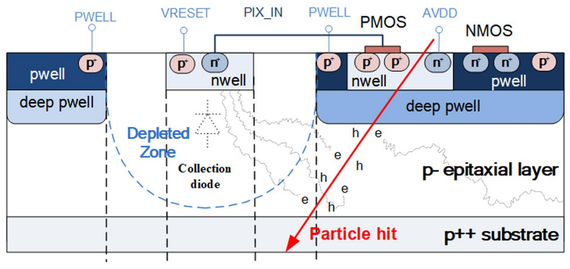
CEPC Vertex Detector R&D

CEPC vertex detector and TaichuPix

01

Precision vertexing at CEPC supports flavour tagging and heavy-flavour physics. Large incidence angles enhance charge sharing among neighbouring pixels.
TaichuPix-3 is a monolithic active pixel sensor in a 180 nm CMOS imaging process. [3]





25 µm pitch 1024 × 512 pixels
DESY test, 150 µm chip: resolution <5 µm, efficiency >99.5%. [3]

Illustrative vertex concept [4]. TaichuPix cross-section, not to scale. [3]

Simulation and digitization

02

Allpix² combines Geant4 energy deposition with electron/hole drift and diffusion in imported 3D fields. Endpoint charges feed threshold digitization and eight-connected clustering. Shockley–Ramo signal diagnostics remain a separate validation step. [1,2]

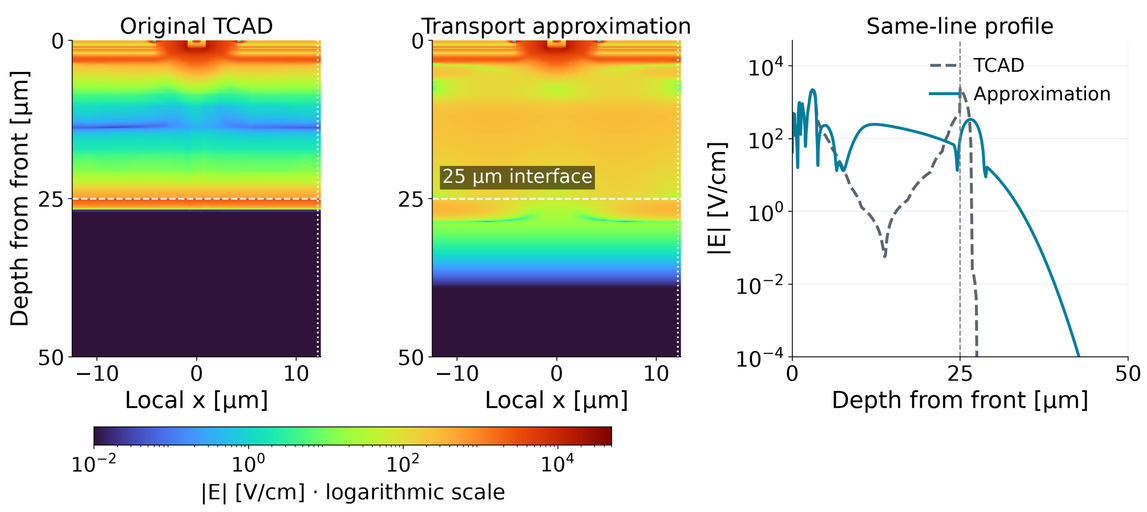
Current endpoint study	Fixed configuration
Beam / angles	2.5 GeV e⁻; 0°, 60°, 65°, 70°, 80°
Statistics / silicon	1000 per angle; 25 + 25 µm
Node / P-well / temperature	+1 / 0 V; 293 K
Packet / step / integration	50 e / 1 ps / 3 µs
Threshold / spread / noise	368 / 50 / 20 e; no reflection

Angles are measured from the sensor normal. Full 50 µm silicon includes 25 µm of epitaxial silicon and 25 µm of substrate.

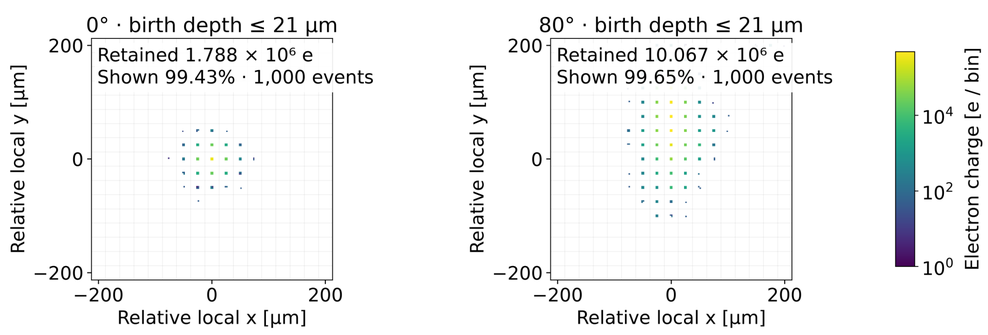
TCAD baseline and approximate field

03

The n10 TCAD baseline has a sharp field feature at the 25 µm epitaxial/substrate interface. The approximation combines a screened surface field, a smooth concentration-gradient potential (L = 5 µm sensitivity case) and weak focusing.
A = 0.10 V and D = 24 µm were **selected using 0° BSRF** cluster-size and width distributions. The scan penalized an endpoint electron fraction outside 30–40% and any-hit probability below 99%. The selected field gave 55.9% before depth selection in the 100-event selection sample. Independent calibration remains pending.



Section y = −0.2348 µm, profile x = 12.153 µm; depth = −TCAD Z. Dashed line: 25 µm interface. This approximation changes interface and bulk response. A self-consistent process/device solution remains pending.



Allpix transport before electronics threshold; 2.5 µm square bins; fixed original event centroid.
21 µm is a birth-depth selection, not a depletion depth. Response uses no new field or trajectories.

Selected endpoint electrons (birth depth ≤21 µm), weighted by collected charge. The empirical depth selection adds no new trajectories or field changes.

[1] S. Spannagel et al., NIM A 901 (2018) 164. [2] S. Agostinelli et al., NIM A 506 (2003) 250.
[3] T. Wu et al., NIM A 1059 (2024) 168945. [4] H. Lu et al., arXiv:2503.05415 (2025).

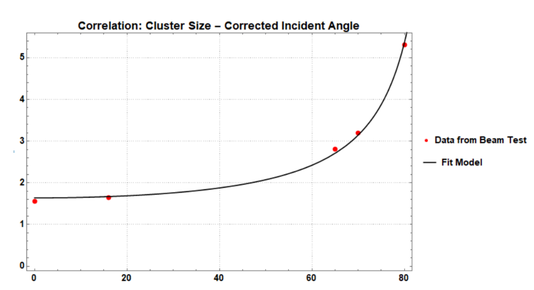
Earlier beam-test parameterization

04

Previous beam-test measurements suggest an empirical parameterization of mean cluster size versus incidence angle. [4]

$$\langle C \rangle(\theta) = a \sec\theta + b$$

a = 0.783 ± 0.022 b = 0.856 ± 0.069
Historical fit: $R^2 = 0.9995$



Historical beam-test fit, not a validation of the present simulation. Its corrected-angle convention does not calibrate the current beam angles.

BSRF beam test and simulation

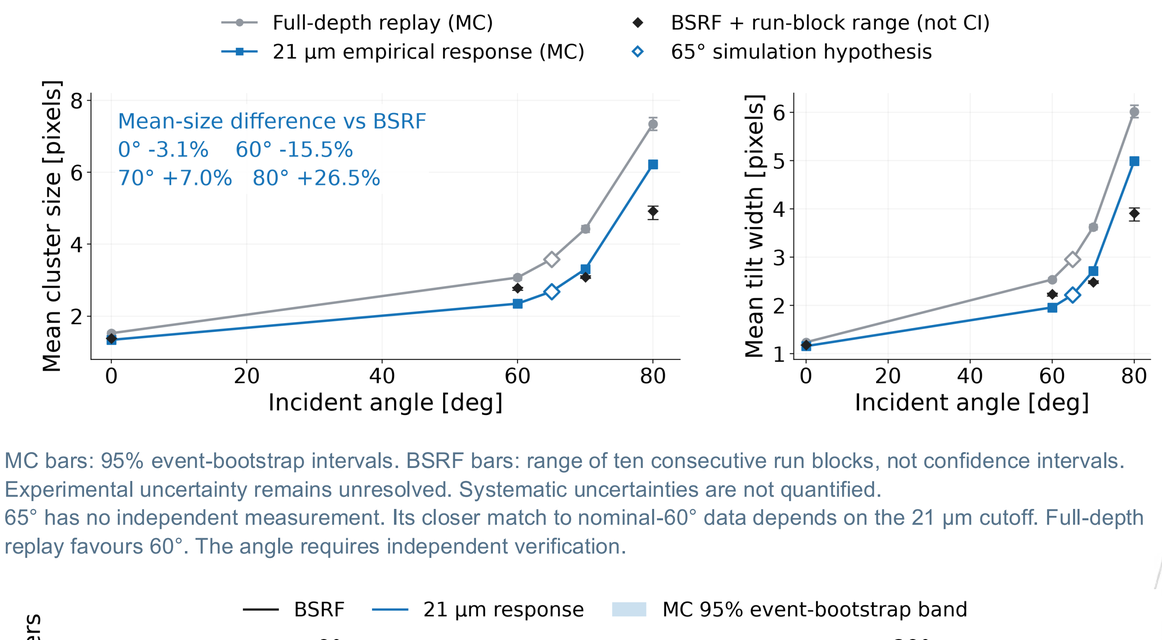
05

BSRF: ITHR32, nominal 0°, 60°, 70° and 80°, provisional DUT plane 2. Allpix²: 2.5 GeV electrons, 1000 events at each of 0°, 60°, 65°, 70° and 80°, with fixed field and readout.

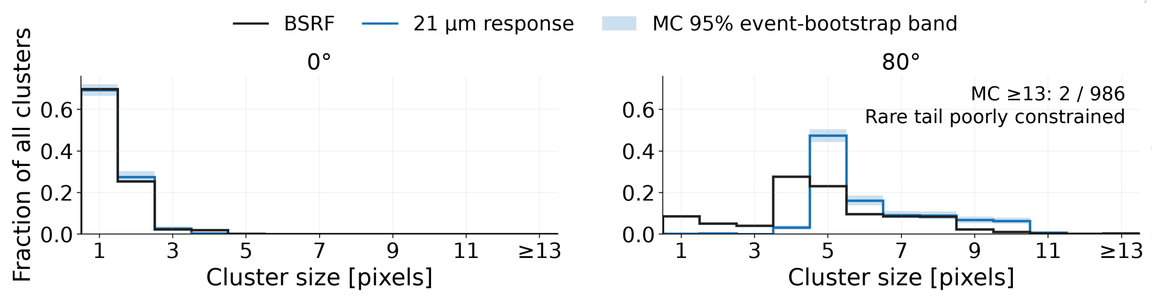
The 18/21/24 µm scan reused 0°/80° samples. The 21 µm choice balanced a 30–40% electron-fraction target with hit retention and BSRF comparisons. This empirical, model-dependent choice is **not an independent prediction**.
After transport, it selects collected electrons born within 21 µm of the front. Original hole contributions stay unchanged. The **effective collected-electron fraction** divides selected electrode-endpoint electrons by all electrons generated in the full 50 µm silicon. The cutoff is not a measured depletion depth and differs from the 25 µm epitaxial thickness and D = 24 µm focusing depth.

Angle	Effective e⁻ fraction	Seed med. [e]	⟨C⟩ sim.	⟨C⟩ BSRF
0°	38.33%	1048	1.342	1.385
60°	39.34%	1677	2.349	2.781
65°	38.38%	1767	2.686	N/A
70°	39.04%	1887	3.309	3.092
80°	39.19%	2377	6.225	4.921

Eight-connected components are formed per generated event in simulation and within each stored cluster ID in data. Means include all non-empty components. Zero-hit events contribute none. Event selections are not matched.



MC bars: 95% event-bootstrap intervals. BSRF bars: range of ten consecutive run blocks, not confidence intervals. Experimental uncertainty remains unresolved. Systematic uncertainties are not quantified.
65° has no independent measurement. Its closer match to nominal-60° data depends on the 21 µm cutoff. Full-depth replay favours 60°. The angle requires independent verification.



Conclusions and outlook

06

Mean cluster size differs from BSRF by −3.1% (0°), −15.5% (60°), +7.0% (70°) and +26.5% (80°). These data-informed comparisons remain model dependent.
At 80°, the two 500-event halves give means of 6.34 and 6.11. Only two clusters have ≥13 pixels, so rare tails remain poorly constrained.
Next steps: self-consistent TCAD with dopant diffusion, matched event selections, independent depth-response constraints and Ramo/front-end validation.

The collected-electron fraction is distinct from a Ramo signal efficiency.