Beam test of a baseline vertex detector for the CEPC

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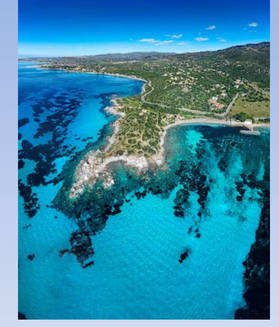
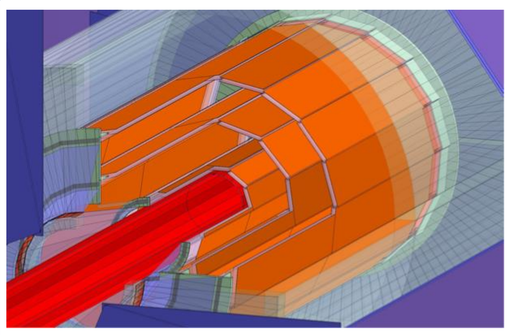


Abstract

- The proposed Circular Electron Positron Collider (CEPC) presents challenges for the vertex detector in terms of material budget, spatial resolution, readout speed, and power consumption.
- A Monolithic Active Pixel Sensor (MAPS) prototype called TaichuPix has been implemented, which has been characterized by a spatial resolution of less than 5 μm and a detection efficiency better than 99 %.
- The baseline vertex detector is proposed with a three-ladder architecture, which is double-sided with TaichuPix sensors.
- Six ladders were installed on the barrel, and the beam test was conducted at the DESY II TB21 facility.

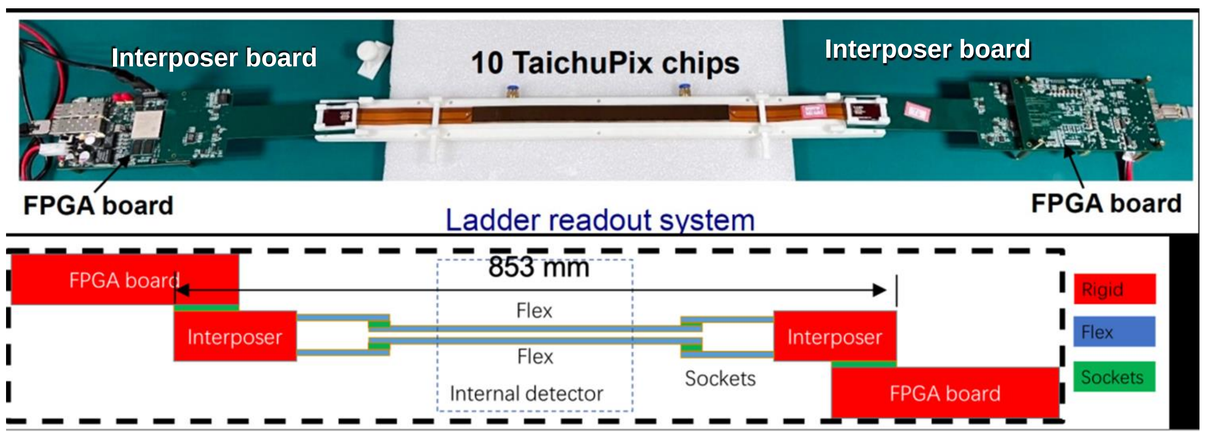


Schematic of a baseline vertex detector for the CEPC

https://doi.org/10.48550/arXiv.1811.10545

Motivated from CEPC CDR:
- Critical to provide excellent impact parameter resolution
- First layer located at a radius: ~1.6 cm.
- Single-point resolution : <3 μm. ~16 μm pixel pitch
- Material budget :<0.15% X0/layer.
- Power consumption： <50 mW/cm^2,if air cooling used
- Radiation hardness : 1Mrad/year

CEPC baseline vertex detector prototype:
- three-ladder architecture
- Double-sided pixel sensors to each ladder
- Six precise reconstruction points

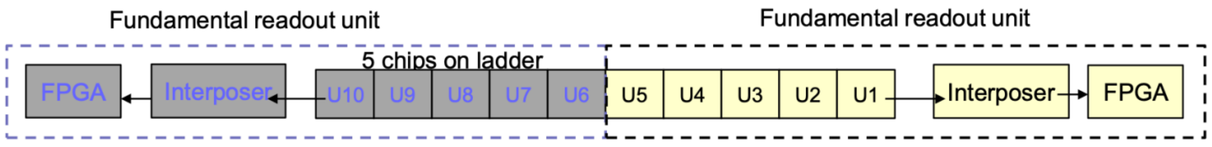


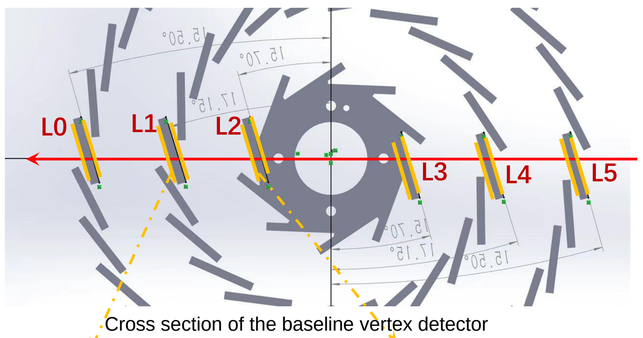
- A detector module includes 10 sensors, flexible PCB, interposer board, support structure, and a monitoring FPGA board.
- One ladder is made of two detector modules, which are glued to the front and back sides of a carbon fiber support.
- Sensors are glued and wire bonded to the flexible PCB.
- Signal, clock, control, power, ground will be handled by monitoring FPGA board through flexible PCB.

Challenge:
- Long flex cable brings some issue with power distribution and delay
- Limited space for power and ground placement

Solution: Readout from both ends, readout compose of three parts, careful design on power placement

→ A full ladder includes two identical fundamental readout units, each contains 5 TaichuPix chips, an interposer board, a FPGA readout board





Cross section of the baseline vertex detector

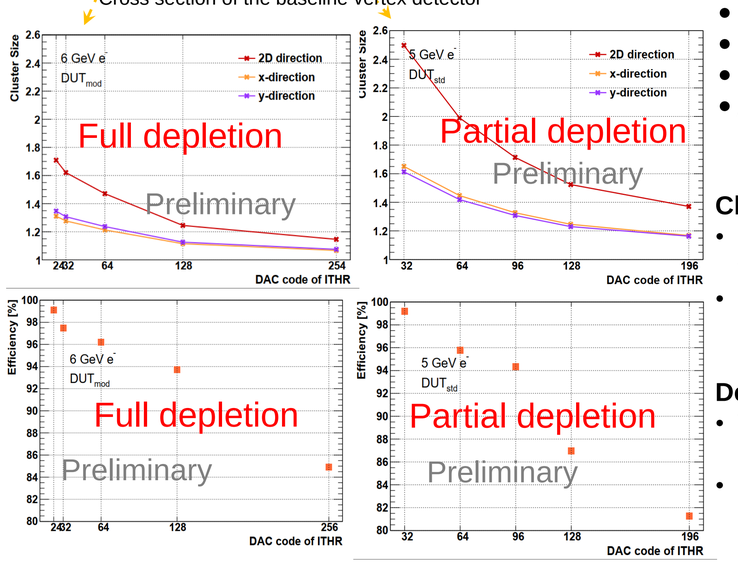
	L0-L1	L1-L2	L2-L3	L3-L4	L4-L5
Space(mm)	21.2	20.6	37.46	20.6	21.2

- Totally six ladders are assembled in the baseline vertex detector.
- The space between each ladder not the same.

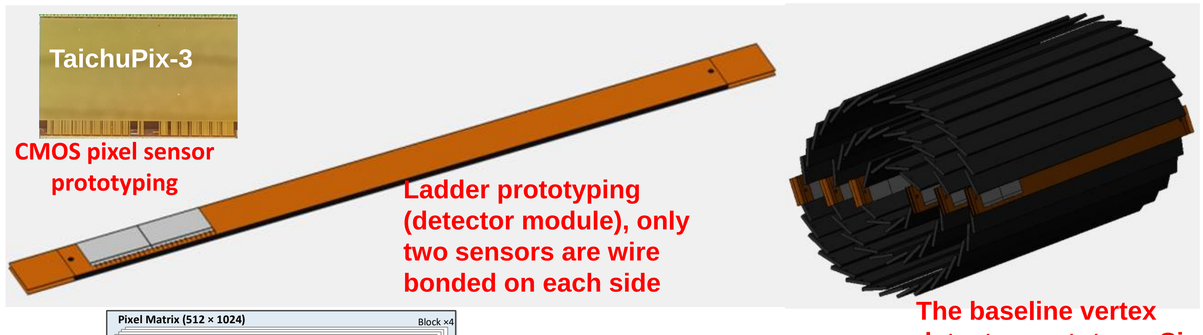
Track Reconstruction:
- No magnetic field
- Least squares fitting (Straight line fit)
- No considering multi-scattering
- Alignment is accomplished by using Millepede (c++ version) matrix method

Cluster
- Cluster size decreases with rising threshold.
- Overall cluster size of full depletion is smaller.

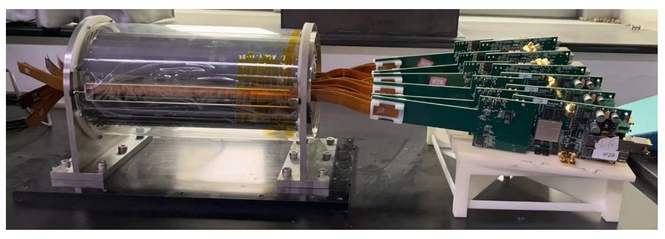
Detection efficiency
- With increasing threshold, the efficiency decrease
- Maximum eff. for DUT_{mod} is 99.1%, maximum eff. for DUT_{std} is 99.2%.



Cluster size and detection efficiency of both processes

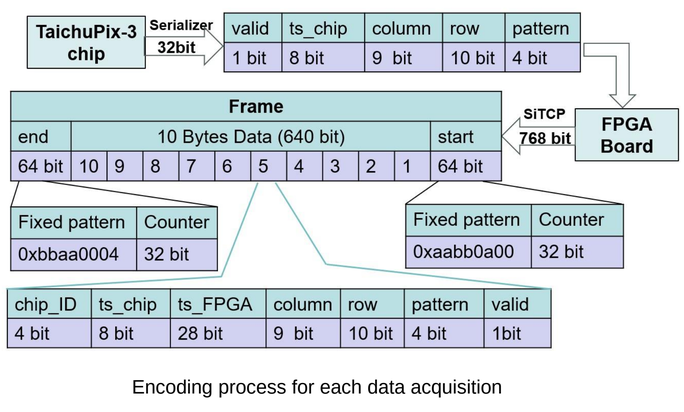


TaichuPix-3
- Chip size：~1.4 ×2.56 cm^2
- Pixel size： 25 μm × 25 μm
- Pixel matrix: 512x1024
- Technology：180nm CIS process, including partial depletion and full depletion process.
- Readout: Column-drain readout for pixel matrix, two-level FIFO architecture
- Trigger-less and Trigger mode are compatible (max.160Mbps for trigger mode & max. 3Gbps for triggerless)
- Power density: Max. 200mW/cm^2



Baseline vertex detector prototype with readout boards

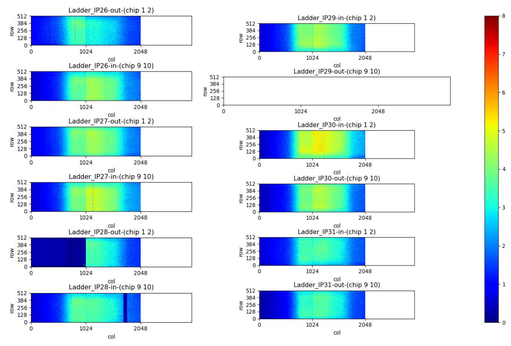
- For beam test, only one end of ladder are readout.
- TaichuPix-3 is set with triggerless mode
- The peaking data rate to DAQ system is about 18 MB/s



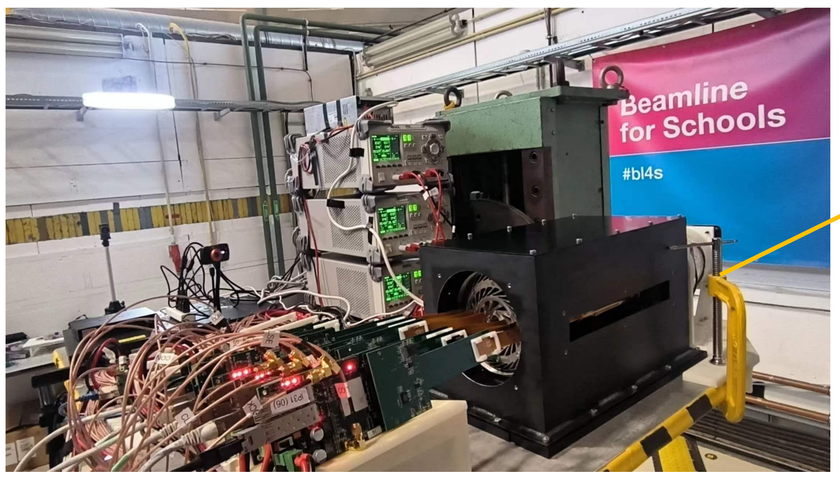
Encoding process for each data acquisition

- valid: data available flag, "1" valid , "0" invalid
- ts_chip: timestamp from pixel array
- column: column address of the firing pixel
- row: row address of the firing pixel
- pattern: pattern for data compression
- ts_FPGA: timestamp from FPGA
- chip_ID: ID number of each TaichuPix-3

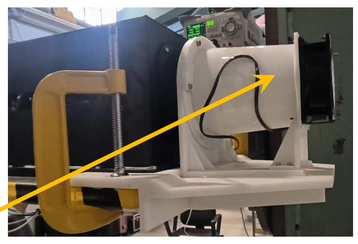
- All equipment fits in the 3D stage at DESY II TB21 hut.
- A bigger collimator (2.5x2.5cm^2) is used to focus on the center of two TaichuPix-3 chips.
- Three sensors are not working correctly, and they were completely shielded.
- Threshold scan for inner layer ladder and middle layer ladder on 4 GeV, 5 GeV and 6 GeV beamline
- Operating 21 sensors together with different energies.



Online hitmap acquired by DAQ



Beam test setup



Air cooling fan

The outermost layer temperature was reduced to 28℃ from 40℃ with the fan or dry ice.

Conclusion

- Full size TaichuPix-3 prototype is developed and tested, which shows a spatial resolution less than 5 μm.
- Over 800 million valid tracks are collected during beam test.
- First CEPC silicon vertex detector prototype was realized
- Beam test results of both processes indicate a detection efficiency better than 99 %.
- More analysis is undergoing.

Acknowledgement

The research was supported and financed in large part by the National Key Research and Development Program of China under Grant No. 2018YFA0404302 from the Ministry of Science and Technology. The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF). Additional support was provided by the Youth Scientist Fund from the National Natural Science Foundation of China under Grant No. 12205313, China Postdoctoral Science Foundation under Grant No.2021M693182 and State Key Laboratory of Particle Detection and Electronics under Grant No. SKLPDE-ZZ-202315.