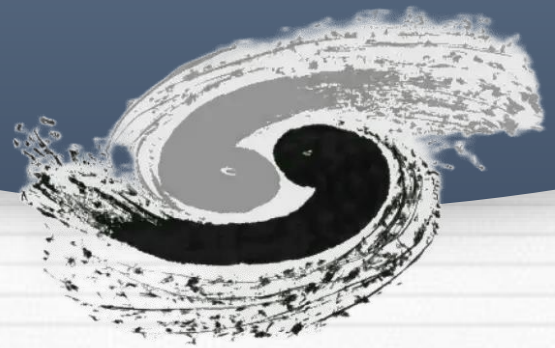

# Digitization of TaichuPix-3 silicon pixel detector based on AllPix-Squared framework

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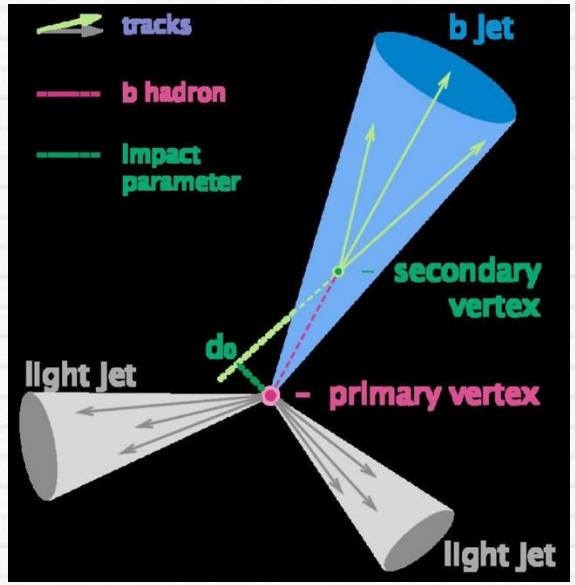
**Reporter: Hancen LU**

# Intro: CEPC VXD

High-precision vertex detectors are crucial for the realization of the CEPC physics goals

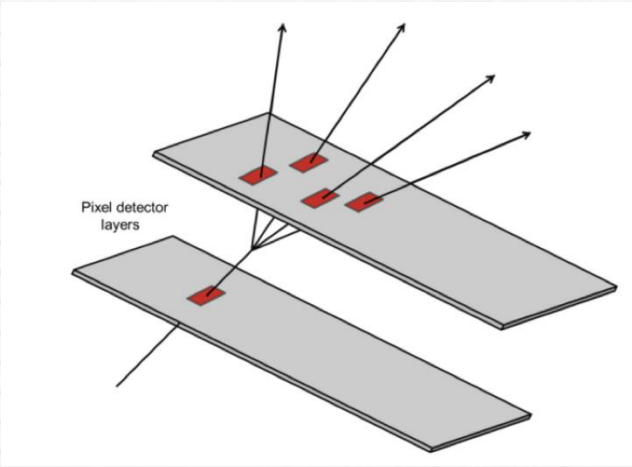
- Flavor physics (a large number of $b/c$ quark jets, $\tau$ leptons)
- Higgs physics ( $H \to bb/cc/gg$ and $H \to \tau\,\tau$)




Goal: $\sigma$(IP) ~5$\mu m$ for high P track

CDR design specifications

- Single point resolution ~ 3$\mu m$
- Low material (0.15% $X_0$/Layer)
- Low power (< 50mW/$cm^2$)
- Radiation hard (1 Mrad/year)



# Intro: TaichuPix-3



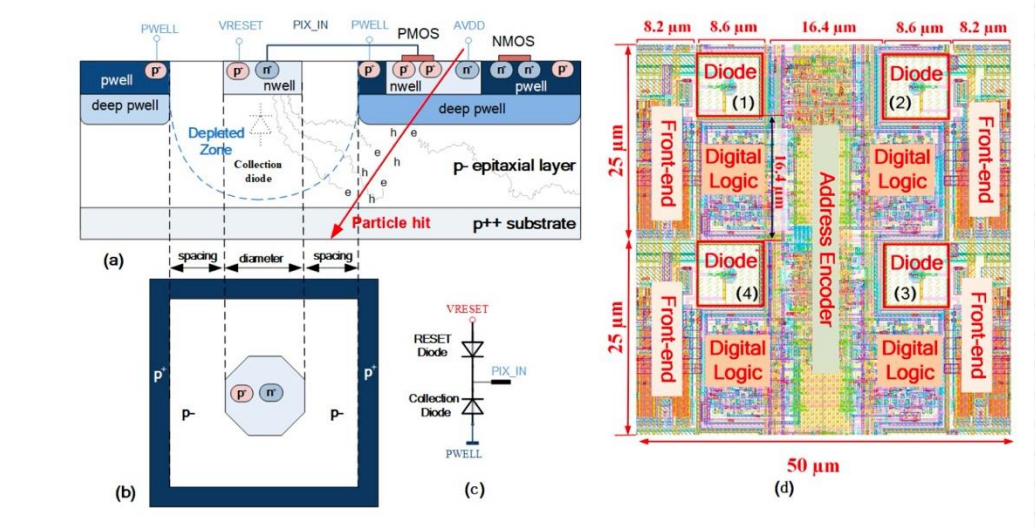
Requirements of the CEPC for VXD

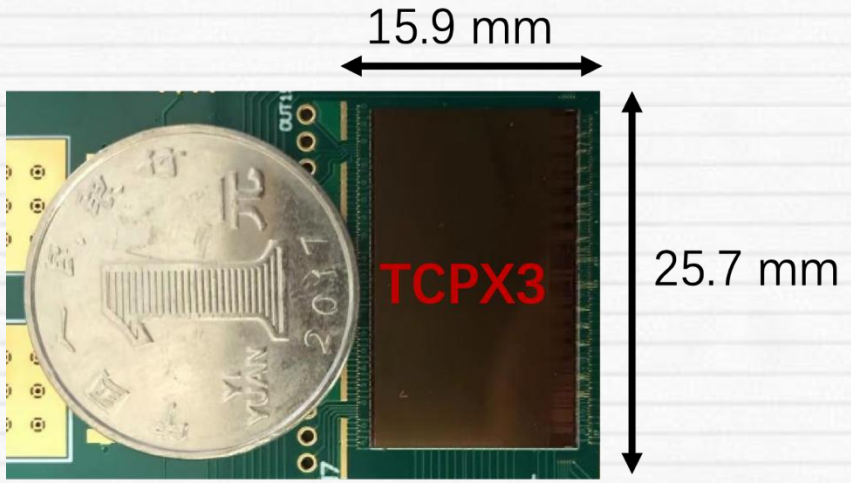
CEPC VXD team

TaichuPix

- Data-dirven
- Fast-readout
- monolithic active

| Specification | Index |
|---|---|
| Pixel size | 25 μm × 25 μm |
| Dimension | 15.9 mm × 25.7 mm |
| Techonology | CIS 180 nm |
| Dead time | < 500 ns |
| Power density | < 200 mW $cm^{-2}$ |
| Max. hit rate | $36 \times 10^6$ $cm^{-2}$ $s^{-1}$ |
| Bunch spacing | Higgs: 680 ns; W: 210 ns; Z: 25 ns |



# Intro: AllPix-Squared



A generic simulation framework for semiconductor tracker and vertex detectors:

- Reflect the physics:
  - A run consists of several sequential events. A single event here refers to an independent passage of one or multiple particles through the setup.
  - Detectors are treated as separate objects for particles to pass through.
  - All relevant information must be contained at the end of processing every single event (sequential events).
- Ease of use:
  - Simple, intuitive configuration and execution (“does what you expect”).
  - Clear and extensive logging and error reporting capabilities.
  - Implementing a new module should be feasible without knowing all details of the framework.
- Flexibility
- ……

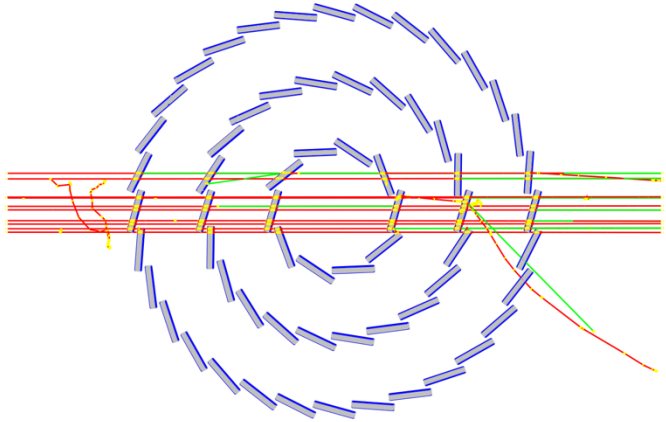
Provide a complete and easy-to-use package to us for simulating the performance of detectors from incident ionizing radiation until the digitization of hits in the detector chip.

# Intro: VXD Prototype Beam Test



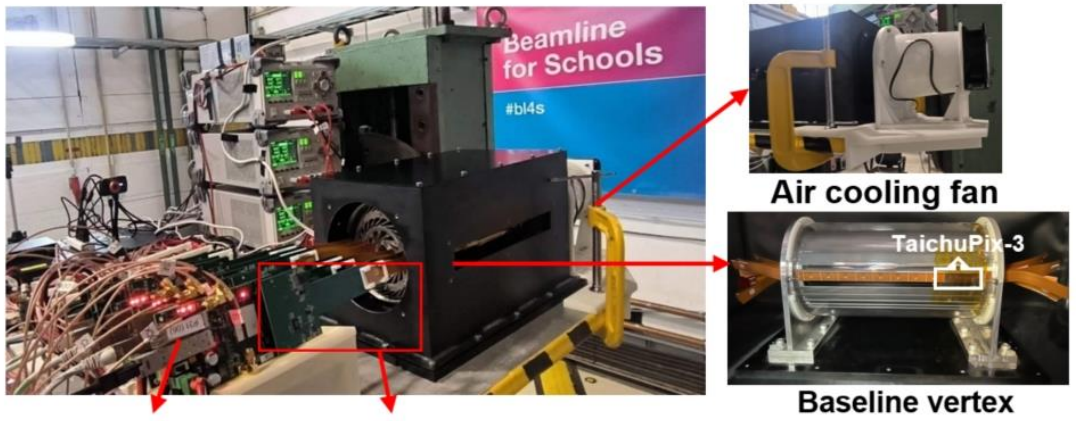
## We run the beam test of VXD Prototype in 2023.4

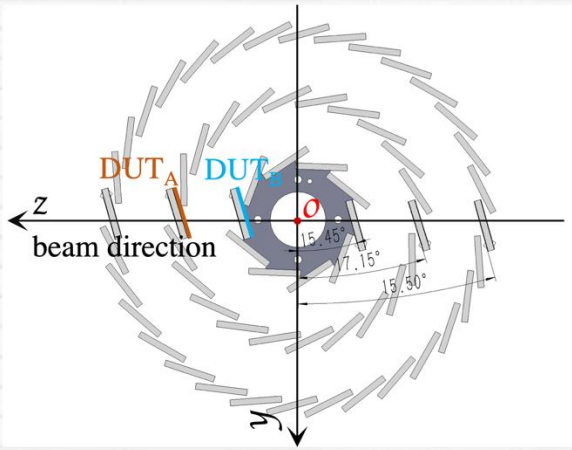
- The 4 - 6 GeV electron beam provided by DESY II.
- The cooling system brought the temperature of the prototype from 40° C to 28° C, ensuring the prototype's good performance.

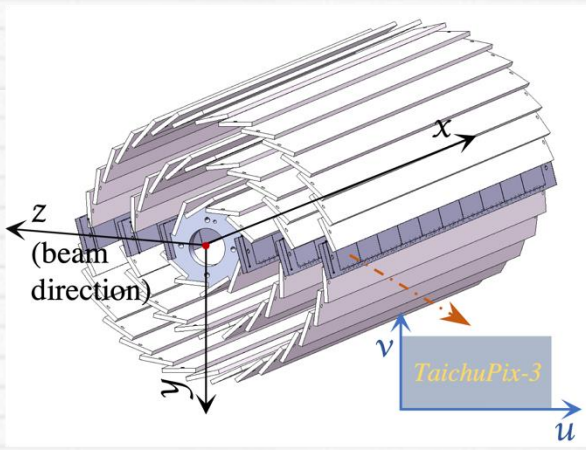


## During the data collection period

- The electronic readout system and data acquisition system operated stably.
- Maximum data rate 18Mb/s



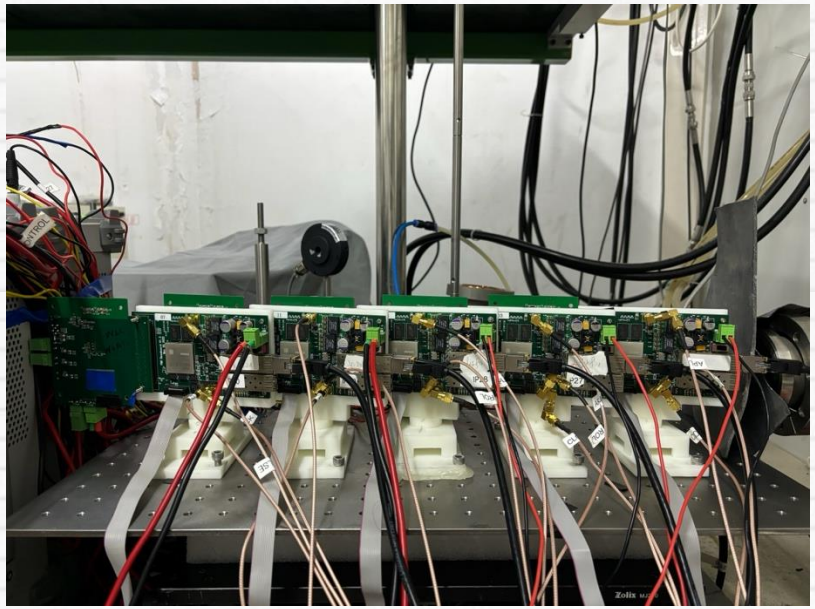



# Intro: Angle Beam Test

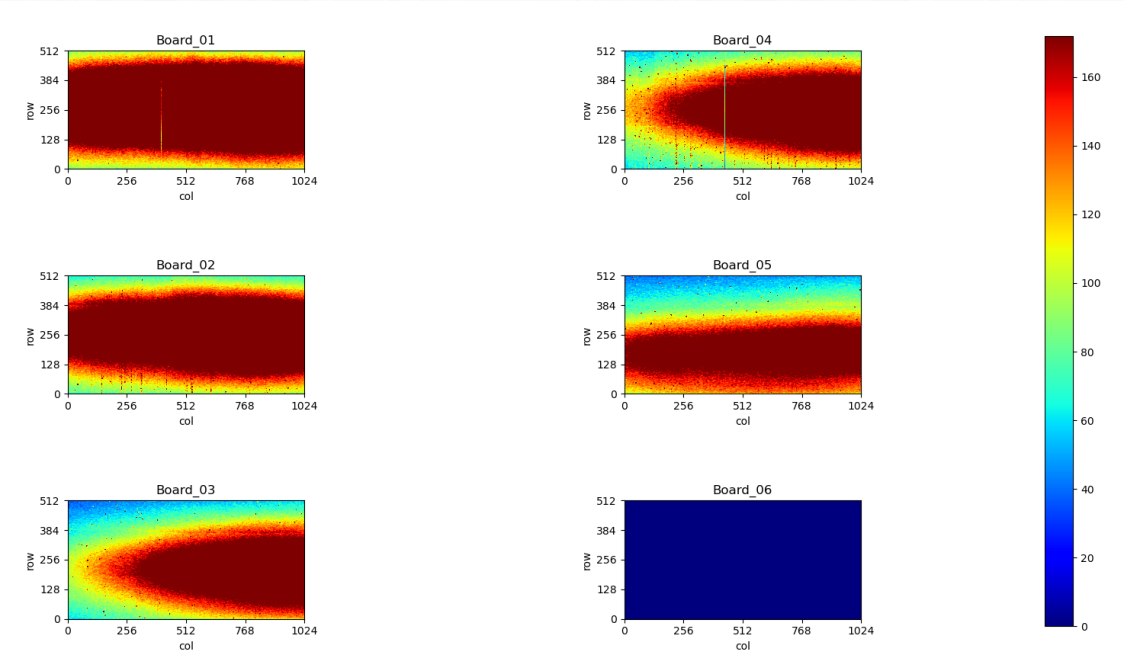


Setup the TaichuPix-3 telescope with tilt angle (80°, 70°, 60°)

- Synchrotron pattern (about 0.5 mm Pb to shield the X ray)
- 2.5 GeV $e^-$ (data rate: ~ 4-7 Mb/s)
- Tilt angle of 5 test boards: ( 80°, 70°, 60° ) *5
- Threshold of 5 test boards: 32, 32, 32 (64, 96), 32, 32



There is no much room to put sixth test board

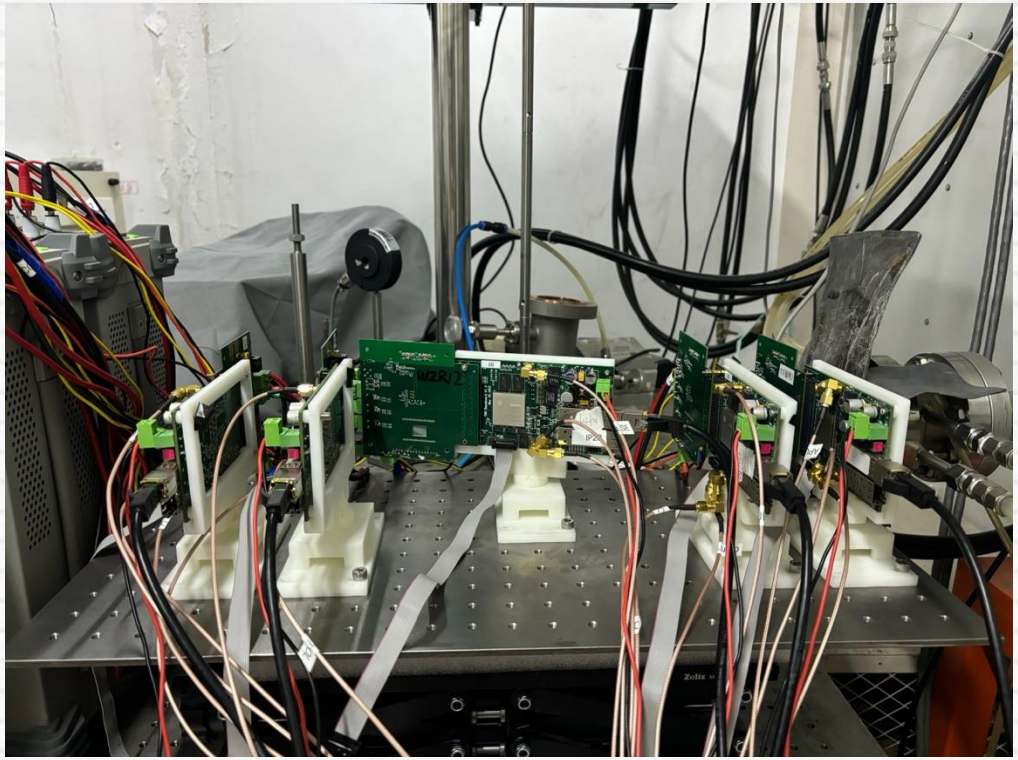


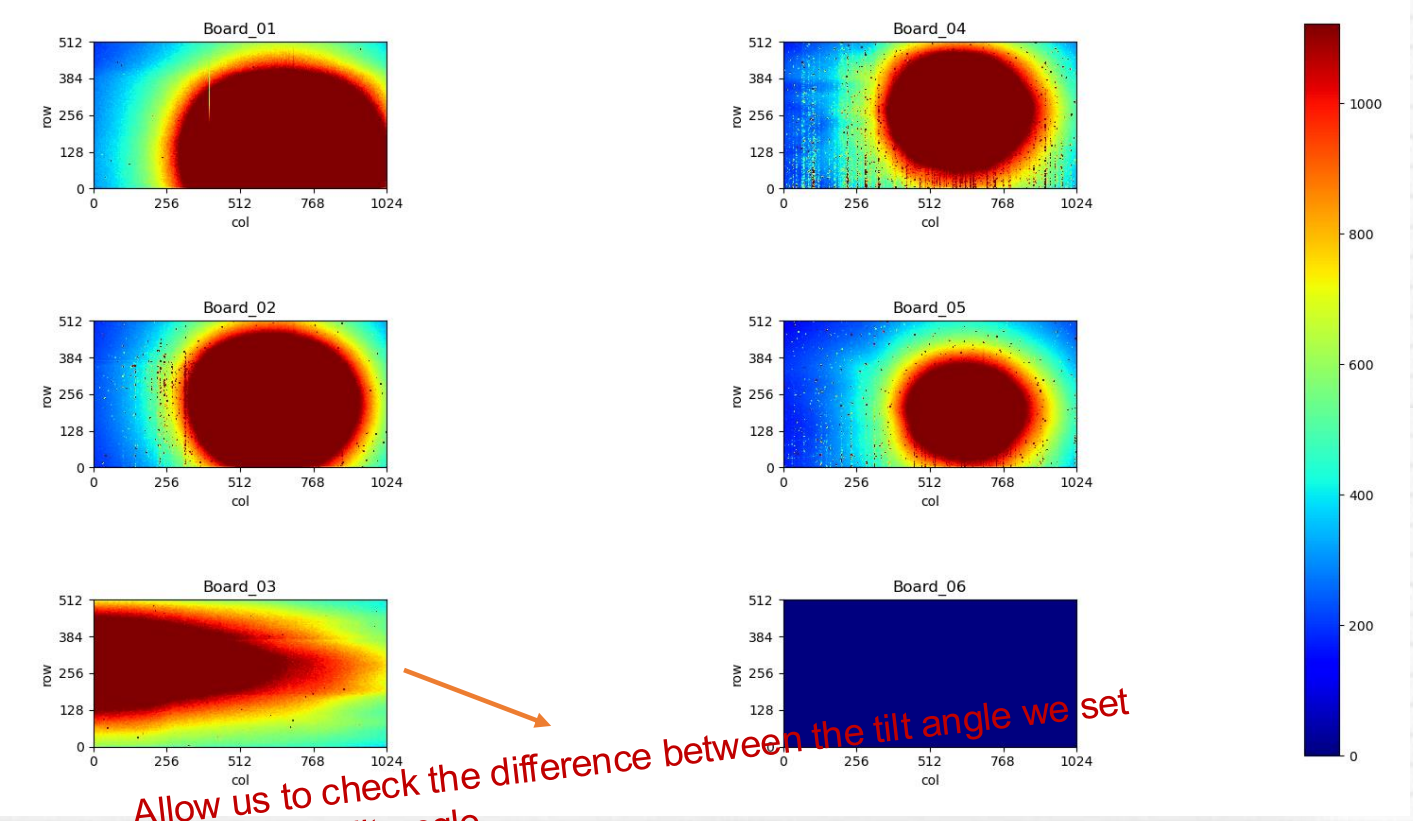
# Intro: Angle Beam Test



- Tilt angle: 0°, 0°, 80°, 0°, 0°
- Threshold: 32, 32, 32 (64, 96), 32, 32

Multiple scattering from the medium PCB board, which makes it difficult to reconstruct the tracks.

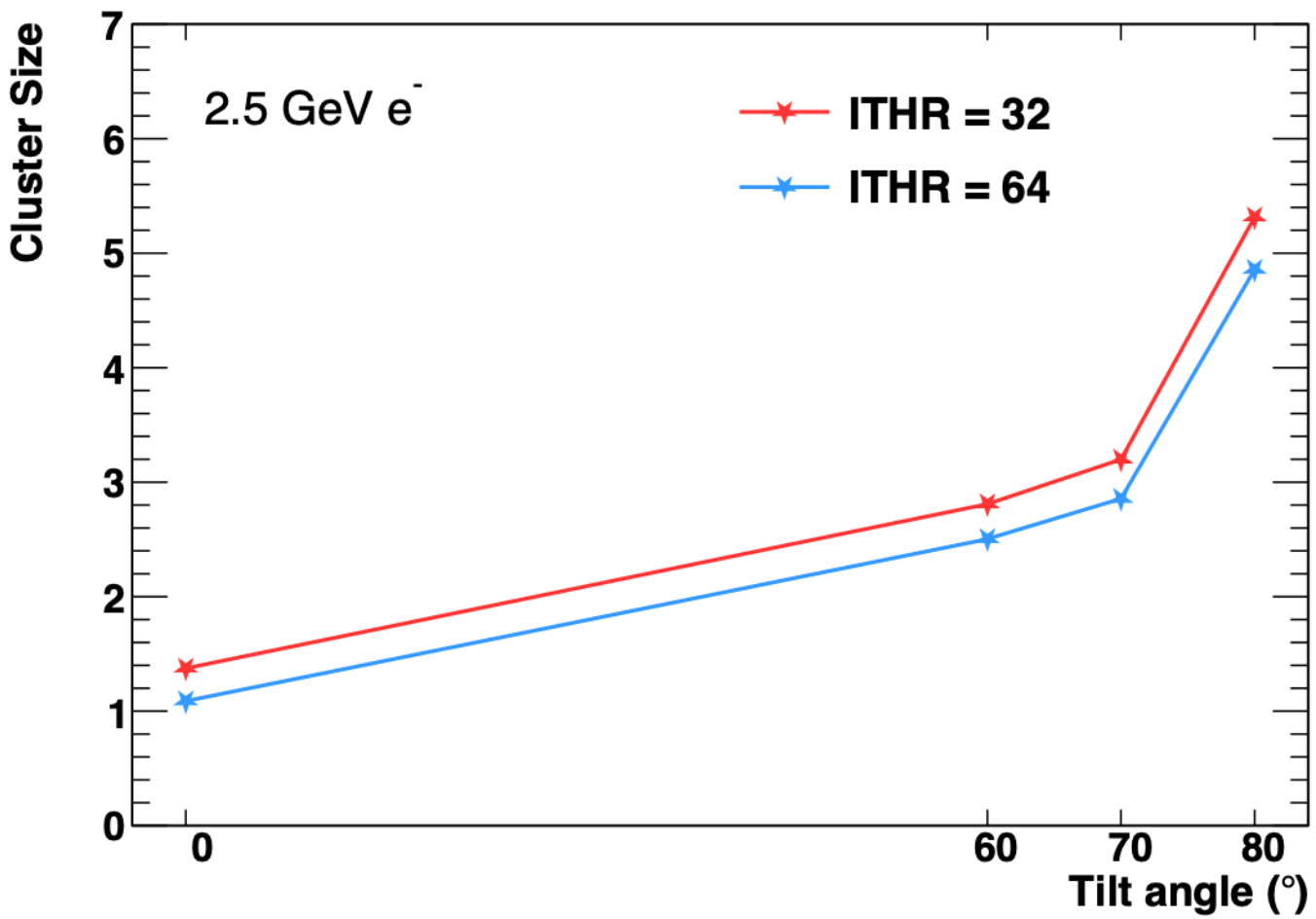





Allow us to check the difference between the tilt angle we set and the real tilt angle

# Result: Beam Test(Cluster Size)






| Angle | ITHR32 | ITHR64 |
|---|---|---|
| 0° | 1.561 | 1.469 |
| 16° | 1.645 | 1.478 |
| 60° | 2.809 | 2.504 |
| 70° | 3.199 | 2.856 |
| 80° | 5.315 | 4.857 |

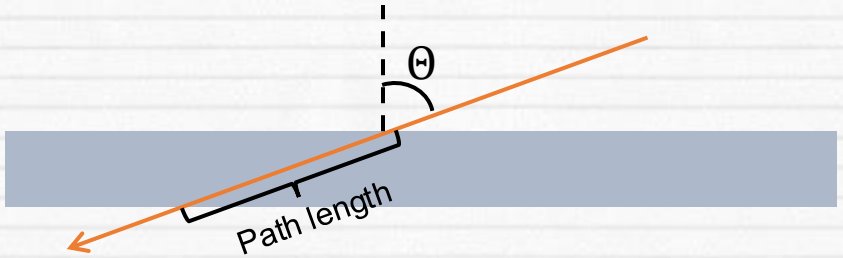
from prototype beam test at DESYII.

Test environment at DESYII is similar with this time. It can be used for analysis.

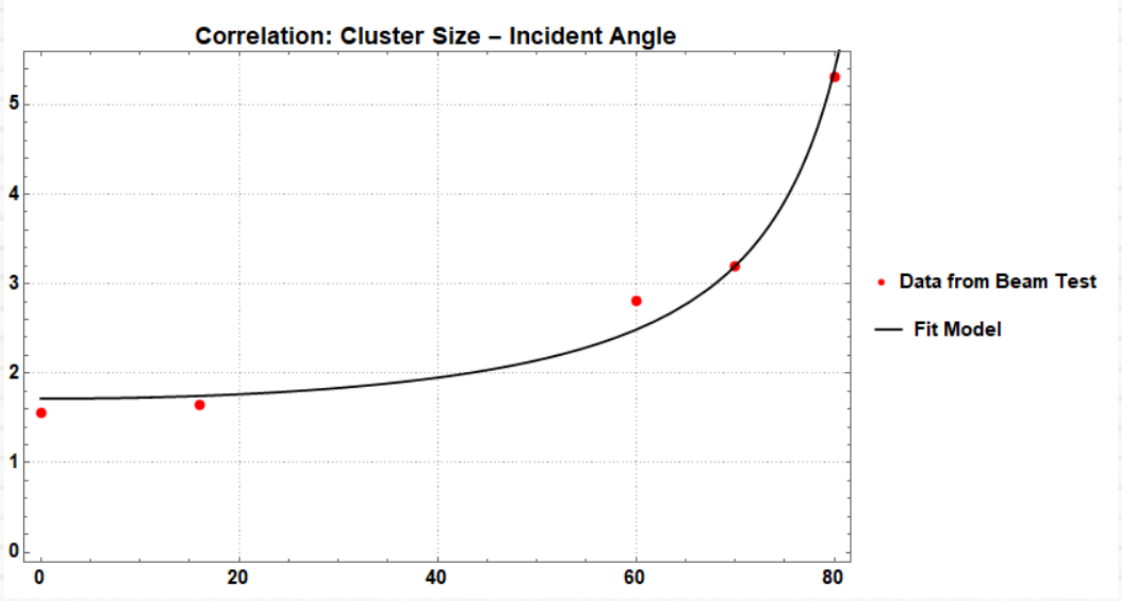
# Analysis: Beam Test(Cluster Size)



Cluster size correlate with the length of a particle's path through the detector.




Cluster size $= a \sec\theta + b$



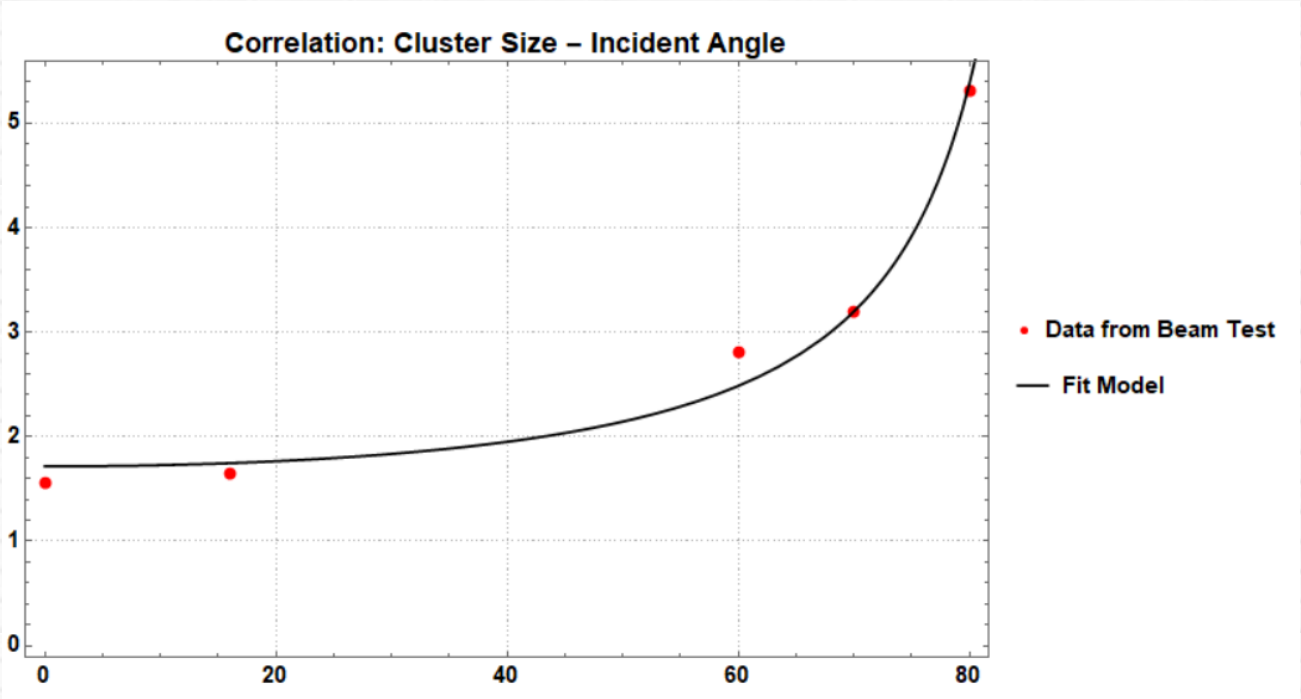

x-axis label is incident angle in degree, and y-axis label is cluster size.

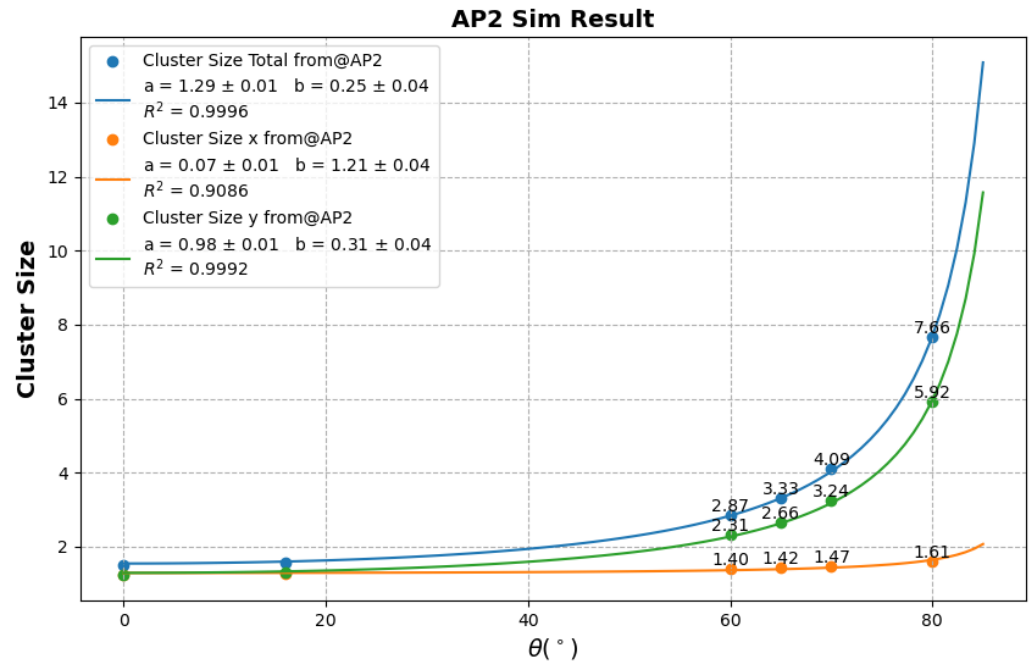
| Param | Estimate | Std Error | RSquared |
|---|---|---|---|
| b | 0.945 | 0.172 | 0.9972 |
| a | 0.770 | 0.056 | |

Still a certain gap between the $R^2$ value and the expectation

# Analysis: Cross validation





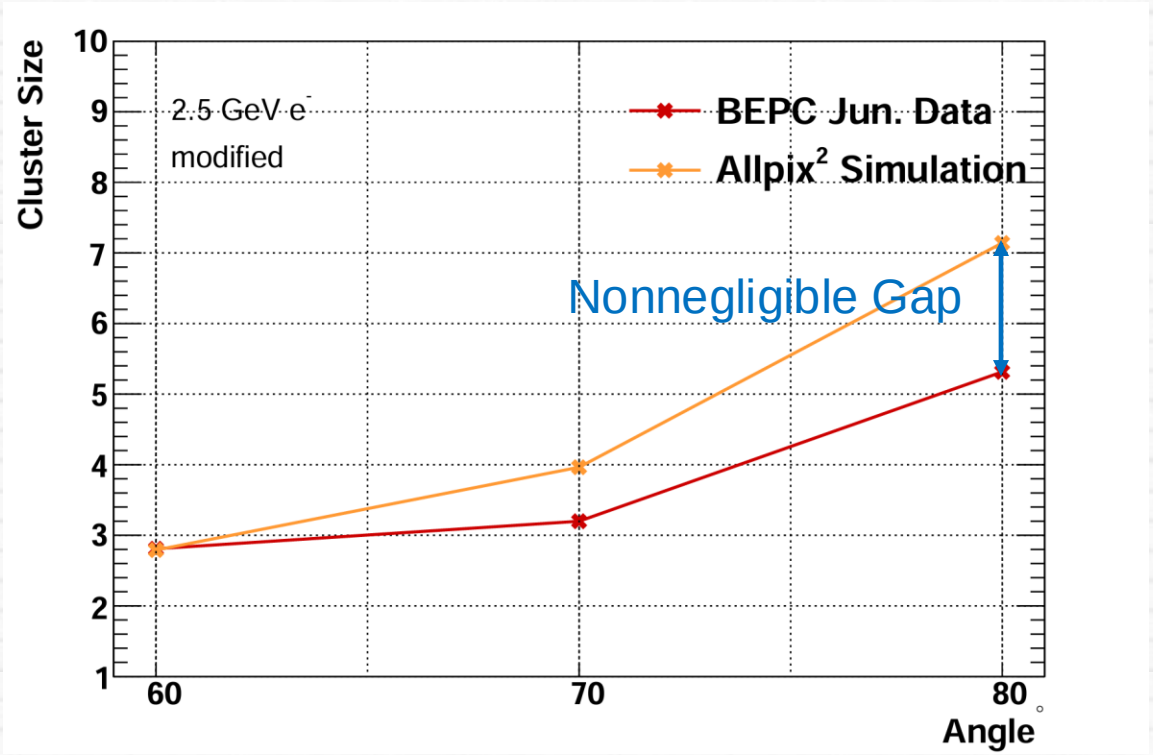

The picture at right hand is the data generated by AllPix-2 to verify our model.

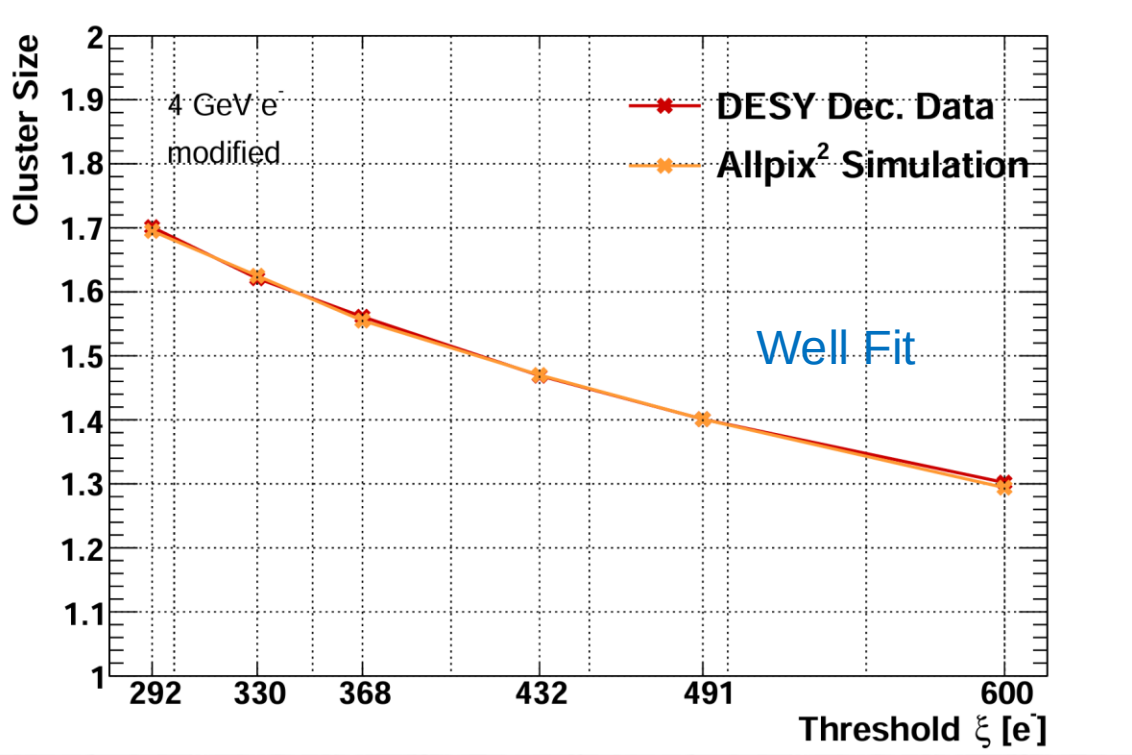
The setting of the tilt angle may have some errors compared to the expectation.

Gives us reason to re-examine the actual value.

# Analysis: BeamTest vs. AllPix-2






AP2 sim requirement:

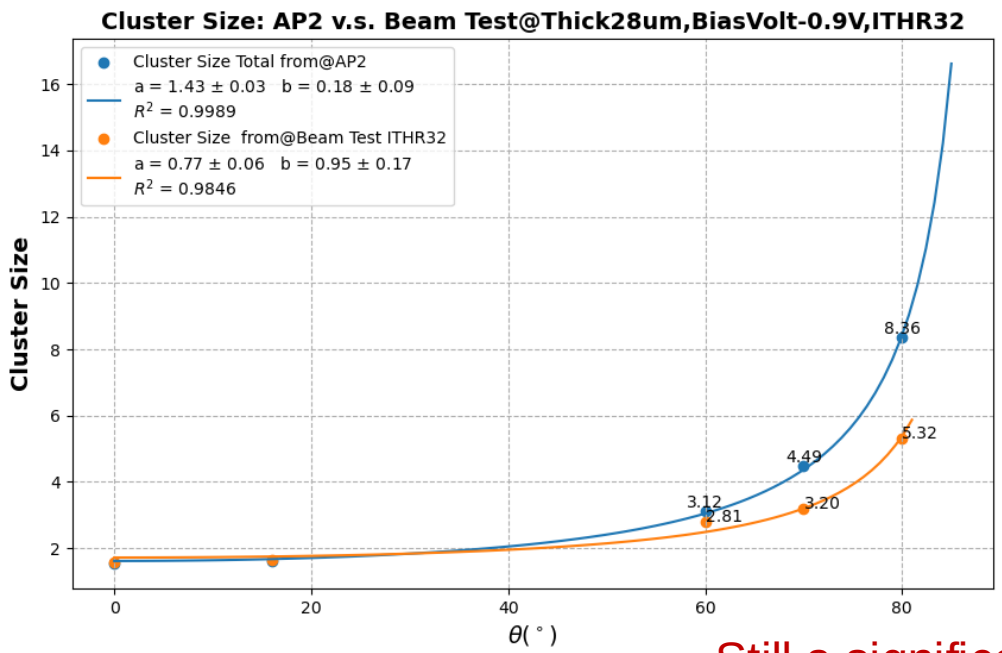
- Electric field distribution
- Sensor geometry
- Support geometry
- Source energy
- ……

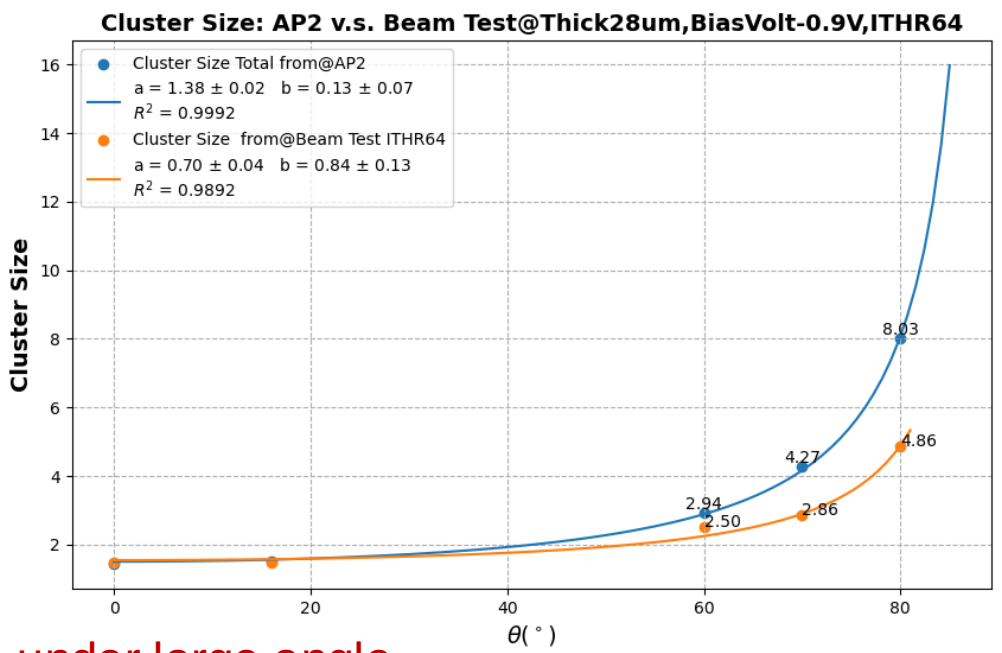
Main parameters:

- Linear, bias voltage: -0.9V → employed as an approximation
- Sensor thickness: 28um, angle…
- Threshold: 368$e^-$ → ITHR32, 432$e^-$ → ITHR64 …
- ……

# Analysis: Further Attempts





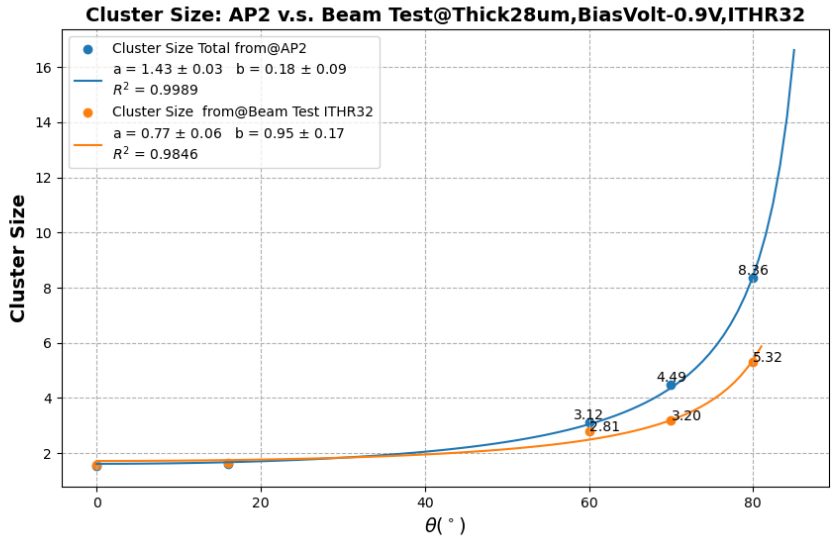

Still a significant difference under large angle.

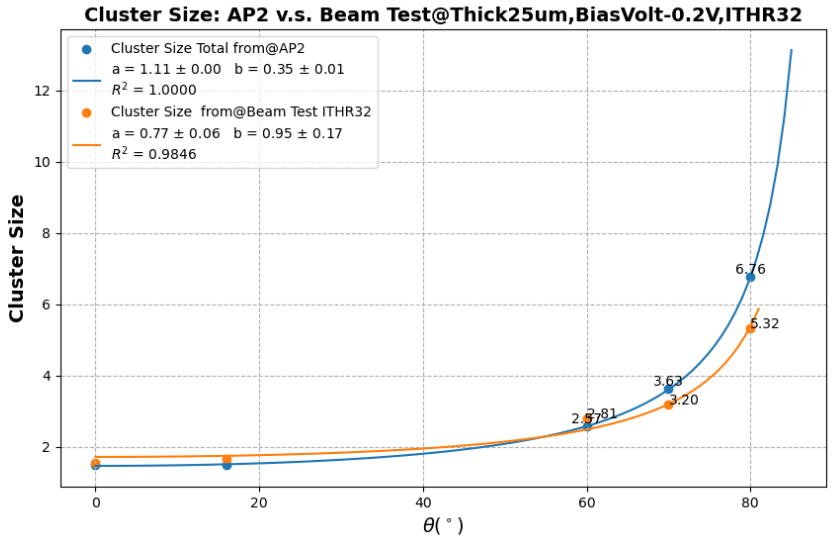
- In AllPix-2, signals produced by substrate does not contribute.
- Due to electric field distributions, the effective sensitive thickness may differ from the marked thickness.

Adjusting the thickness parameter is acceptable.

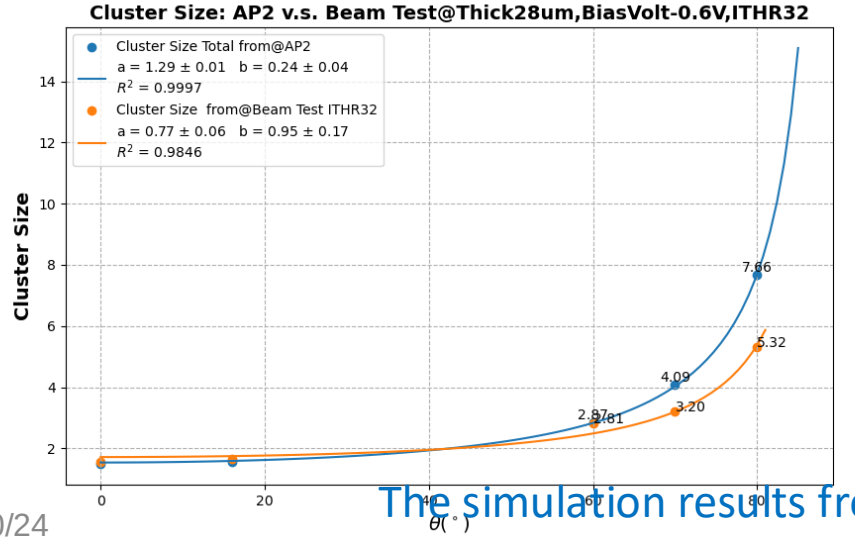
# Analysis: Further Attempts

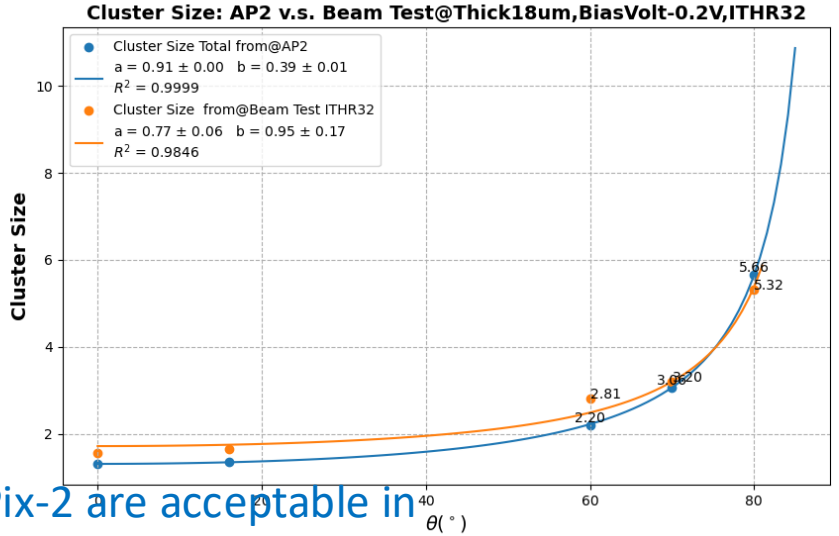





Reducing the thickness and bias voltage




Reducing the electric field bias

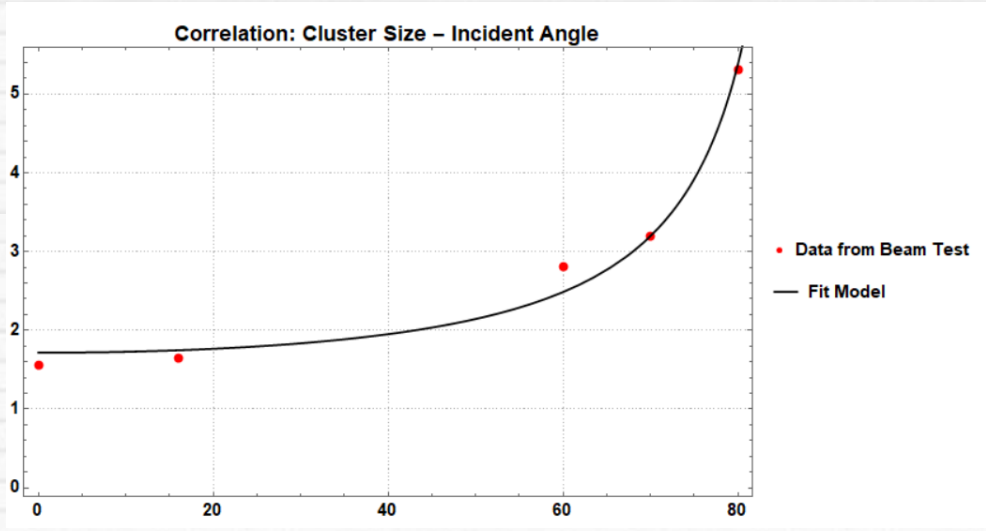
The simulation results from AllPix-2 are acceptable in comparison to the experimental measurement results.

# Weakness & Improvement



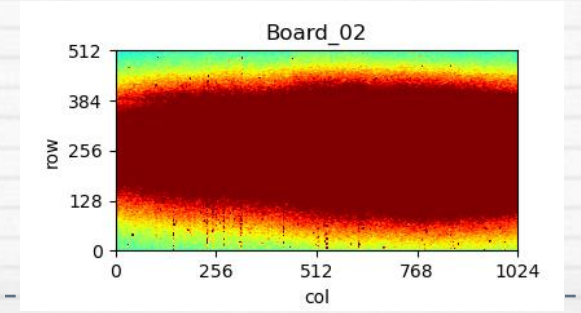
Regarding the differences in the simulation results, our analysis has following weakness:

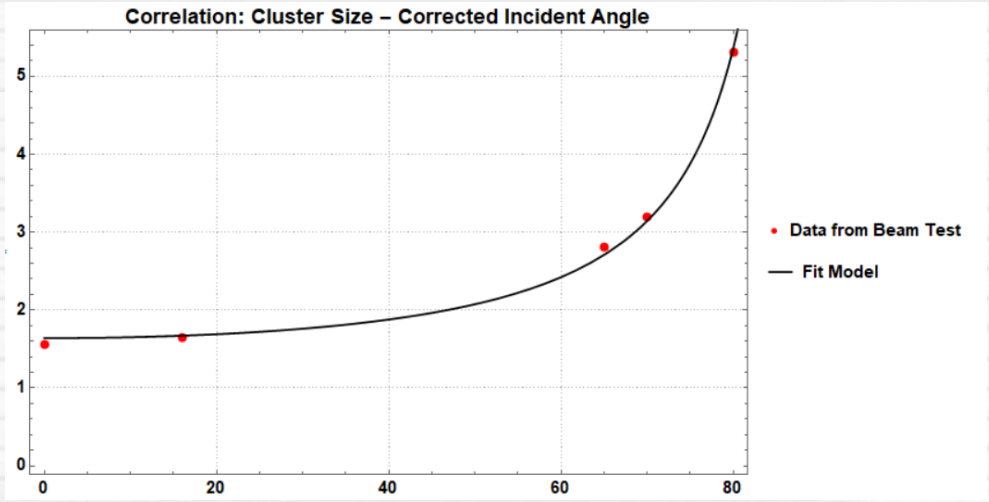
- Electric field distribution is unclear now.
- The true value of the incident angle may differ from the currently adopted value.
- The geometrical details of the supporting structure and other components are not refined.




What's more, the following improvements can be made in the future:

- Electric field distribution should be measured or calculated precisely.
- Verify the incident angle and other relevant information through the hit map.
- Refined the current geometry.



# Future Plan

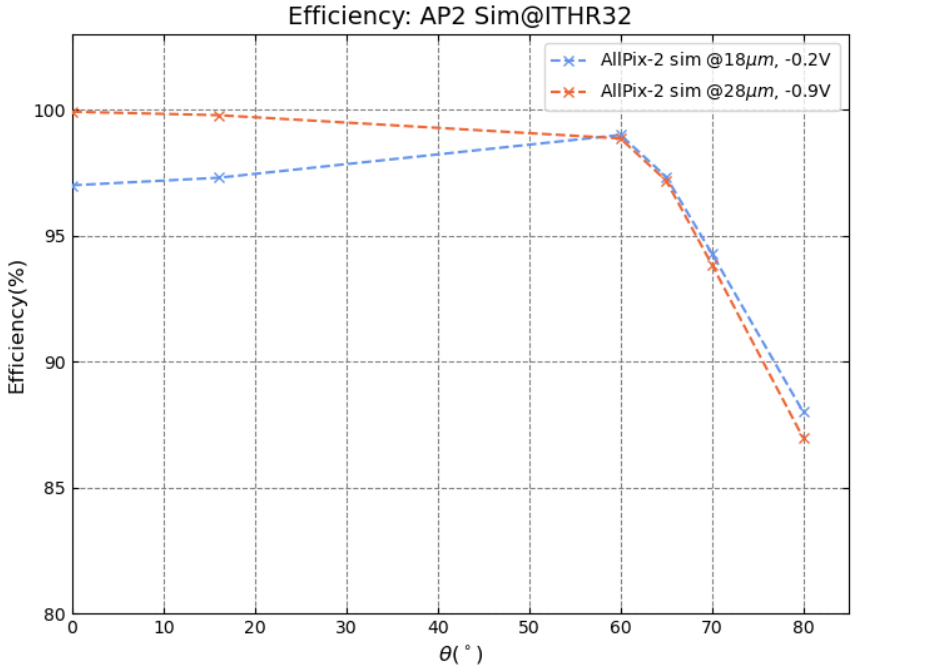


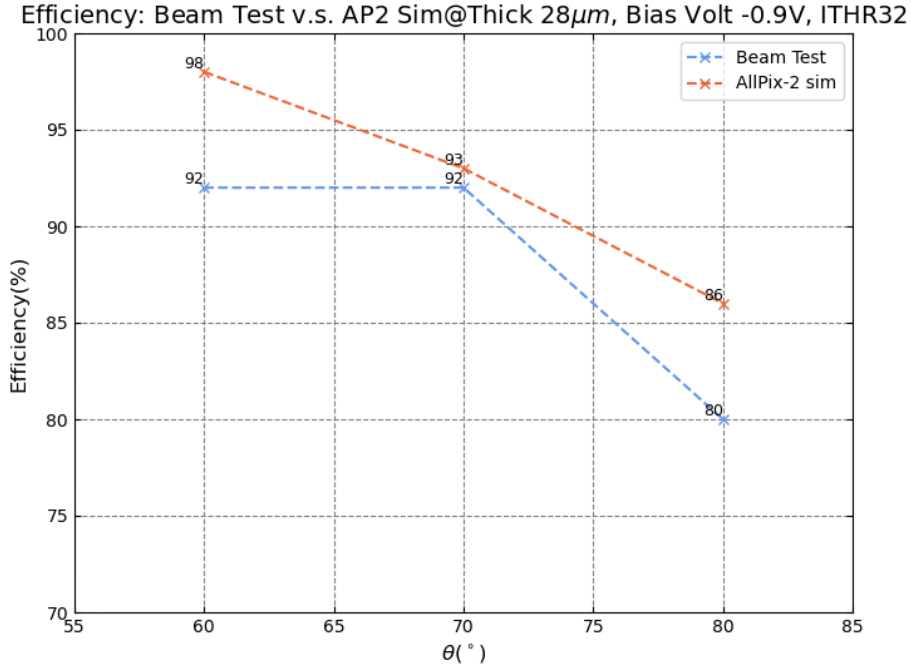
- Conduct more in-depth tests on TaichuPix-3:
  - Incident Angle - Efficiency,
  - Incident Angle - Spatial Resolution,
  - Cluster Size - Spatial Resolution
- Conduct more precise measurements at refined angles.
- Connect AllPix-Squared with CEPCSW for digitization.
- ……

# Efficiency



Due to issues with the experimental environment, the alignment of the experimental data could not be performed this time, making it impossible to calculate the efficiency precisely. The actual results are expected to be higher than the current calculated results. The experimental data provided here are for reference only.



# Thanks for Your Attention!