Performance of the STCF MPGD-based inner tracker prototype in magnetic field

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On behalf of STCF ITKW Group

Outline

1. Inner tracker in STCF
2. MPGD-based ITK prototype
3. Beam test in magnetic field
4. ASIC research progress
5. Summary

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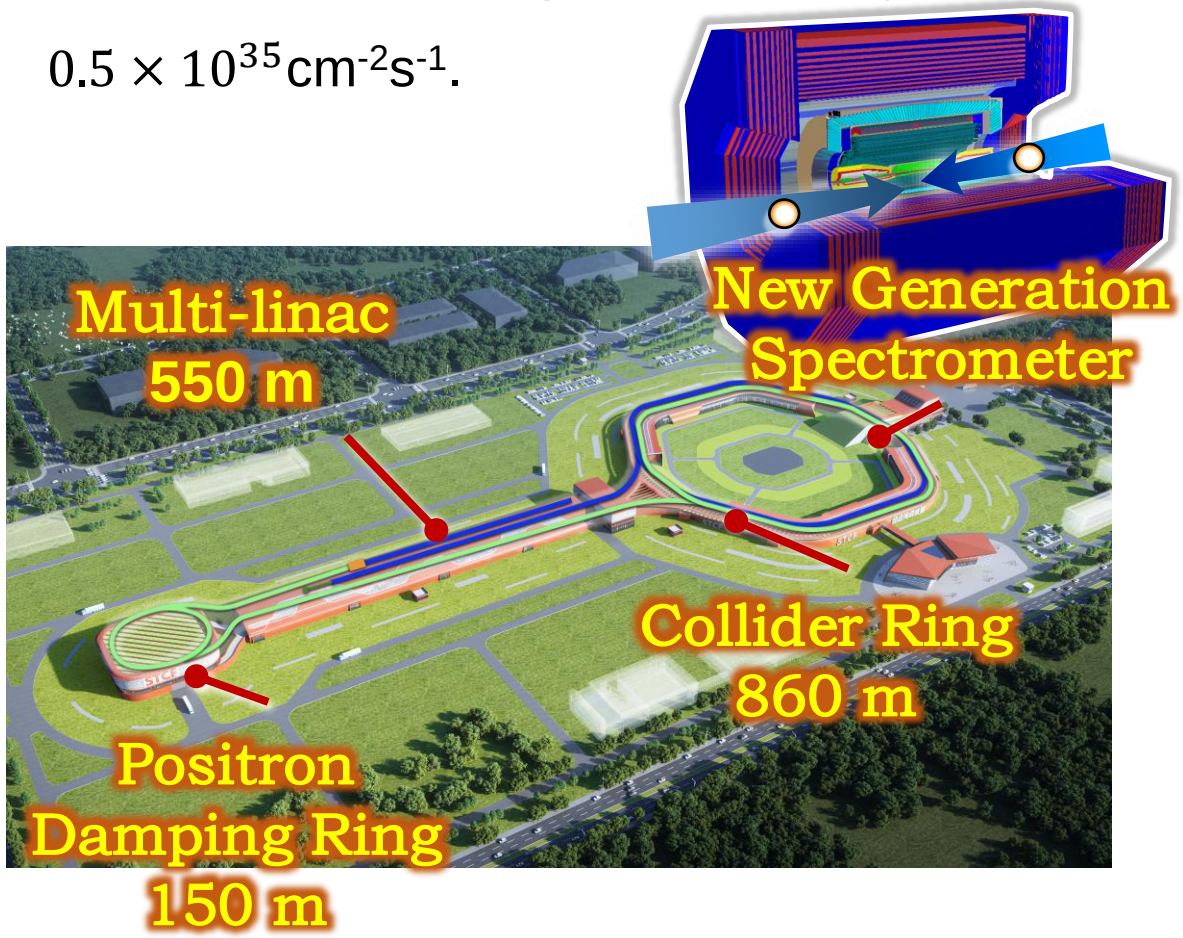
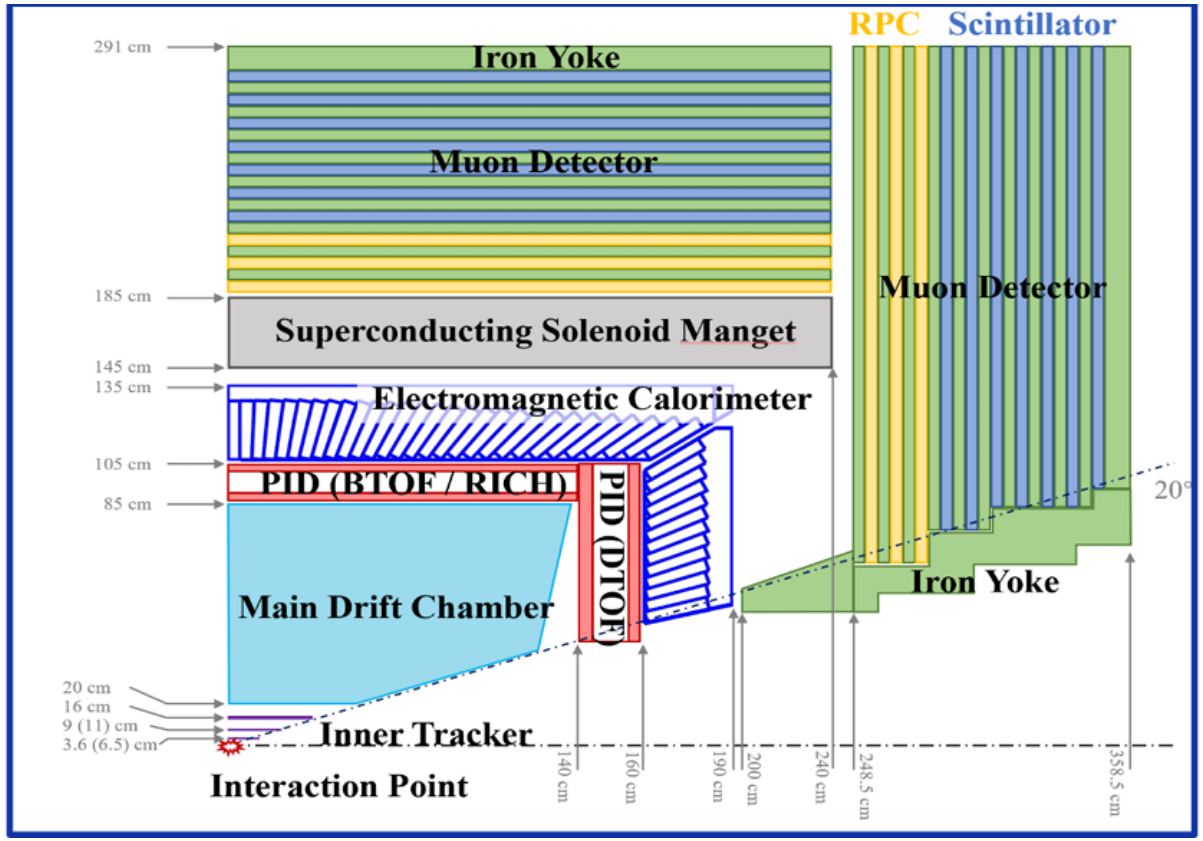
Super Tau-Charm Facility

STCF is an e + e- collider operating at $\sqrt{s}$=2～7 GeV with a peak luminosity of 0.5×10^{35}cm^{-2}s^{-1}.



Inner tracker (ITK): the inner most part of the tracker system in spectrometer



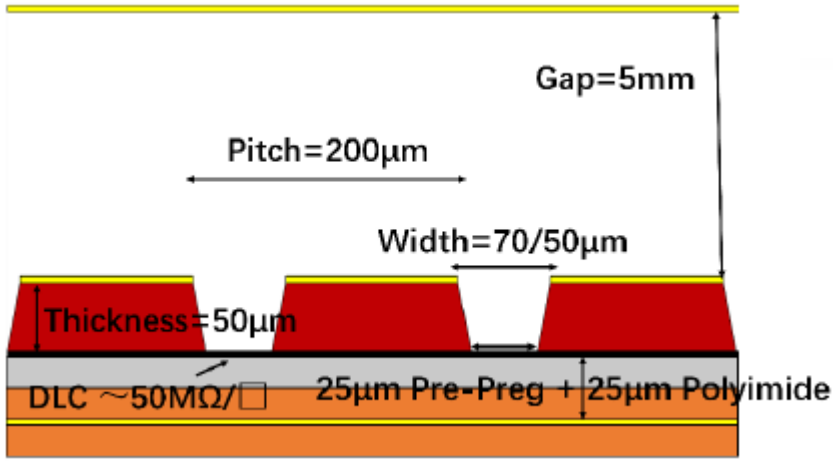
MPGD-based ITK

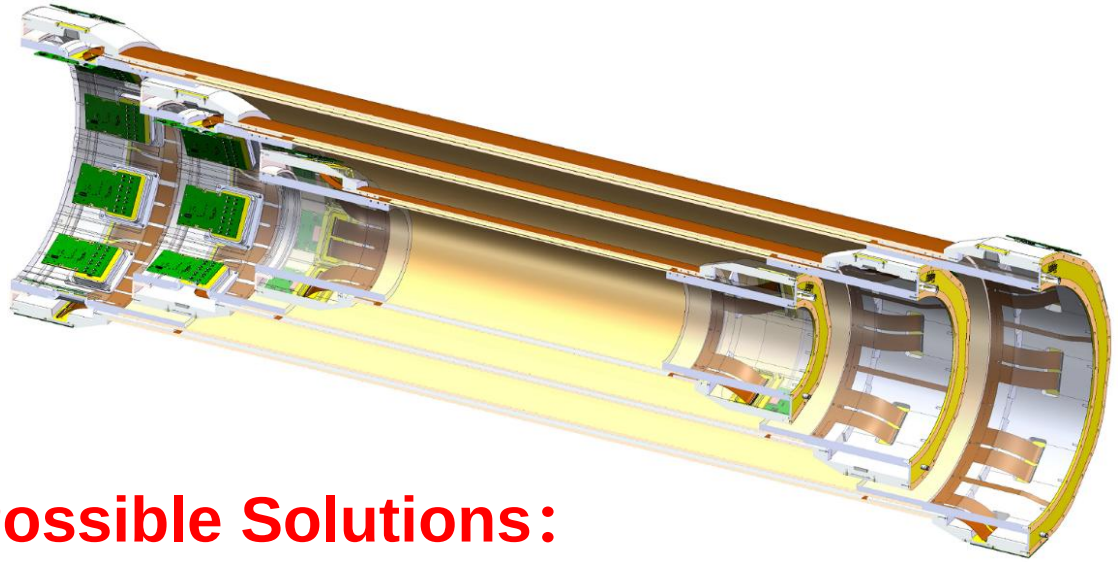
Requirements for ITK:

- Ultra-low material budget (<**0.3%X_0**)
- Good spatial resolution (<**100μm**)
- Handle **high occupancy**
- ……

Advantages of MPGD:

- Scalable to large area
- Low material budget
- ~100 μm spatial resolution
- Support C.C. and μ-TPC mode





Possible Solutions:

3-layers Cylindrical MPGDs

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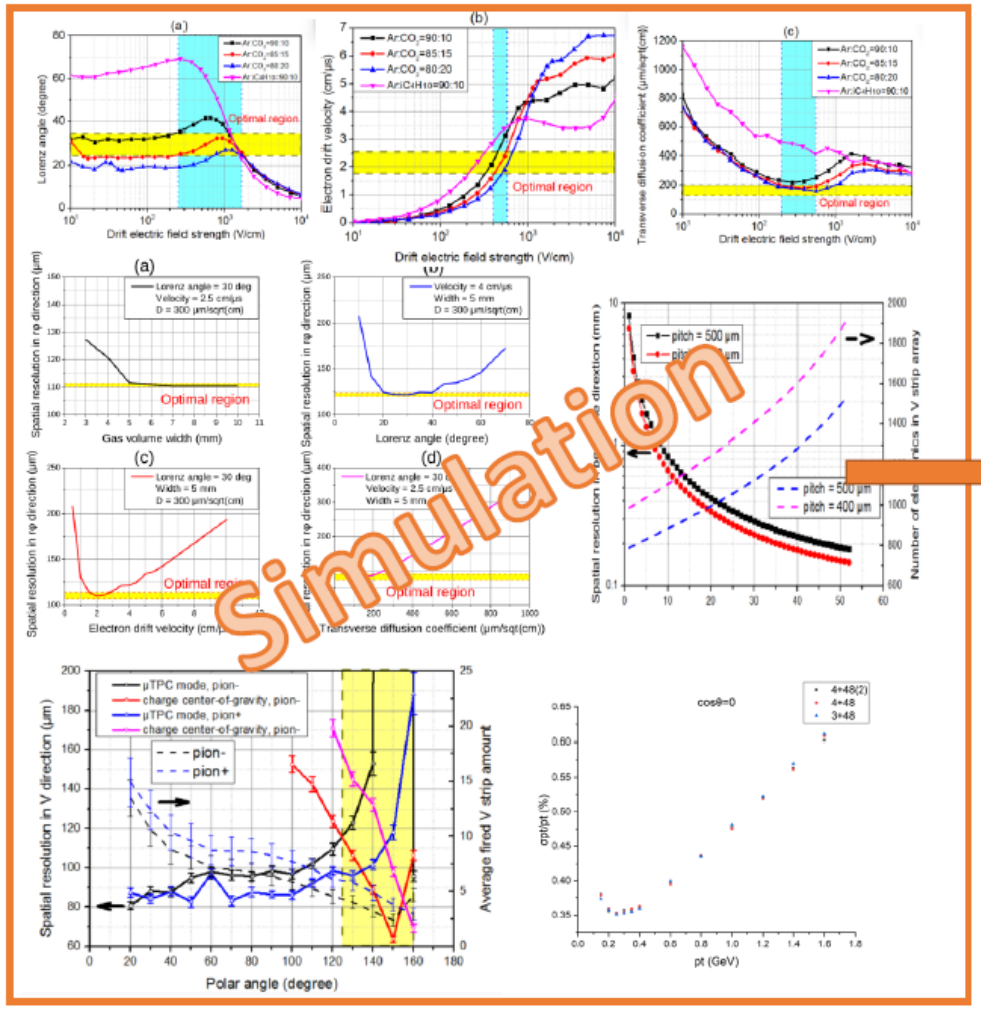
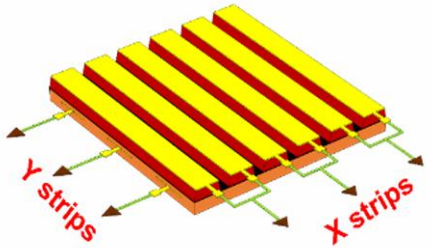
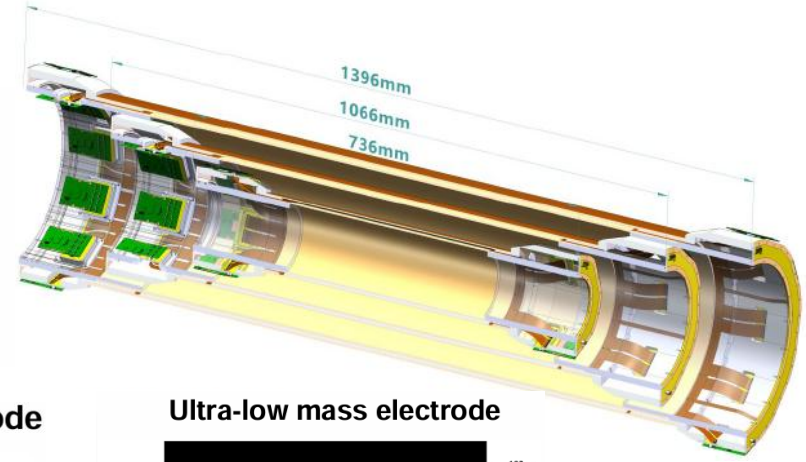
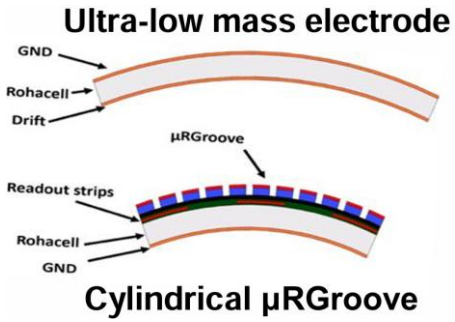
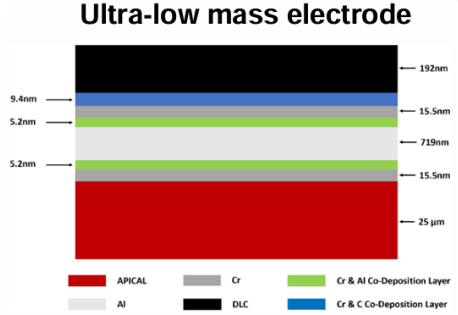
MPGD-based inner tracker design: C-μRGroove





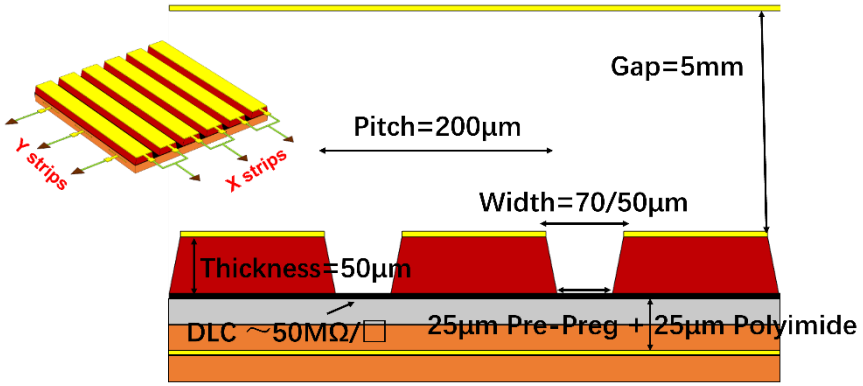


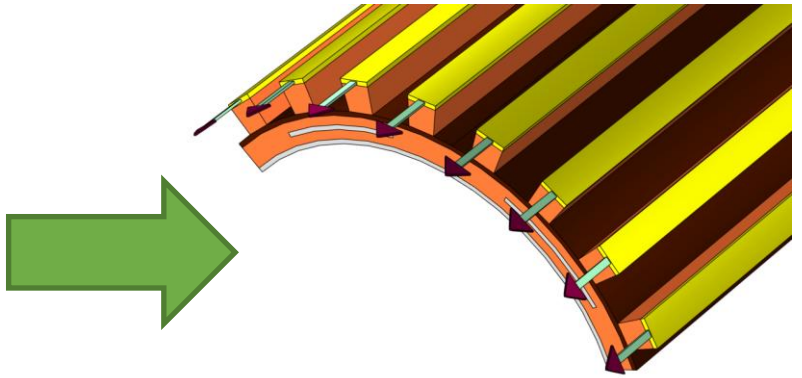


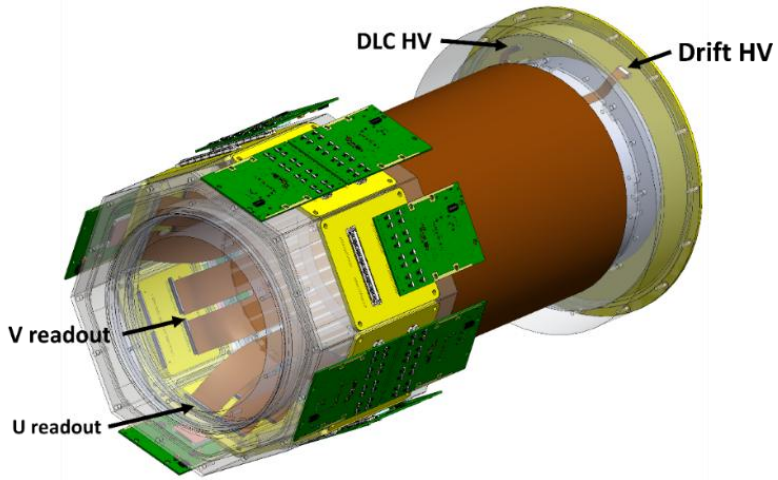


- 3 layers of independent cylindrical detector
- R_{in} = 65.5 mm, 115 mm, 164 mm respectively
- 5 mm gas gap with 400 μm pitch XV readout strips
- Ar:CO_2:CF_4 = 45:15:40 working gas
- Low budget design (0.23% X_0 for 1st layer)

MPGD-based inner tracker prototype



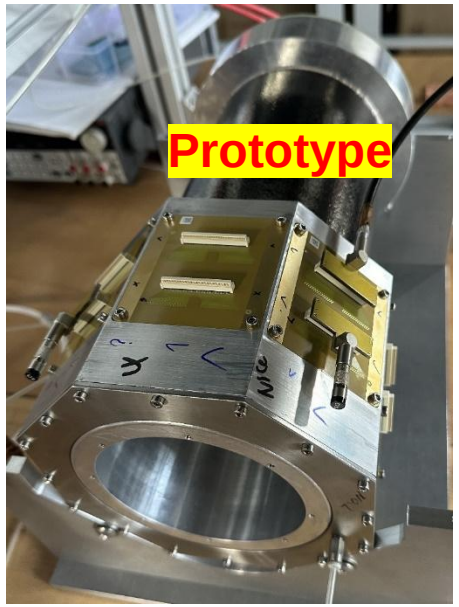


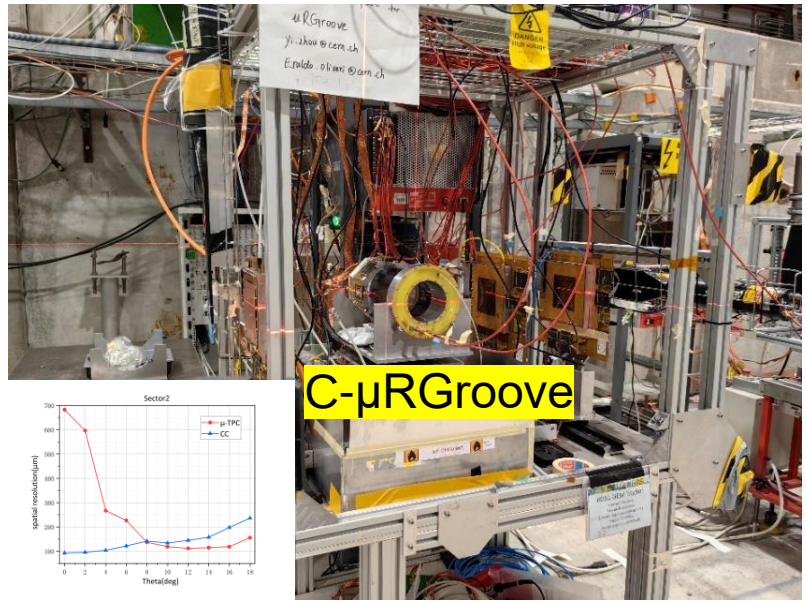


1st prototype:

- D = 131.0mm, L = 100.0mm;
- Spatial resolution without magnetic field:
  - ✓ <100 μm for perpendicular tracks
  - ✓ <120 μm for Oblique incident tracks

Test detector performance in magnetic field!





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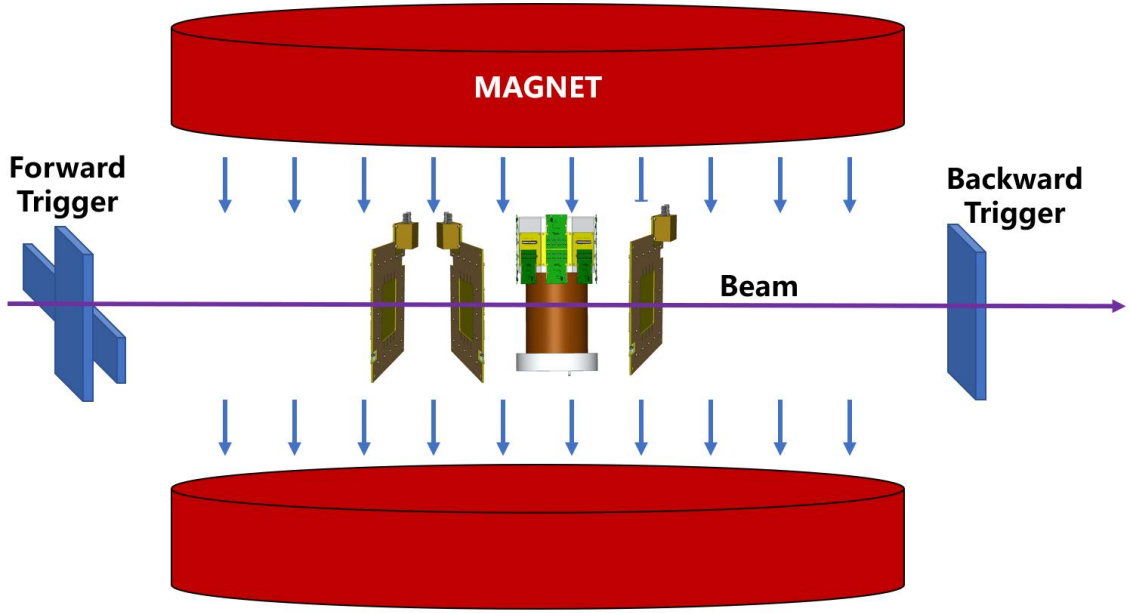
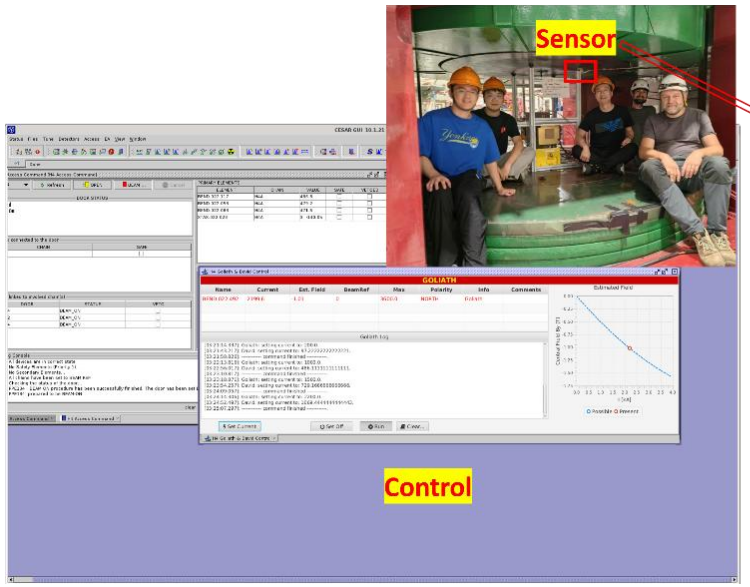
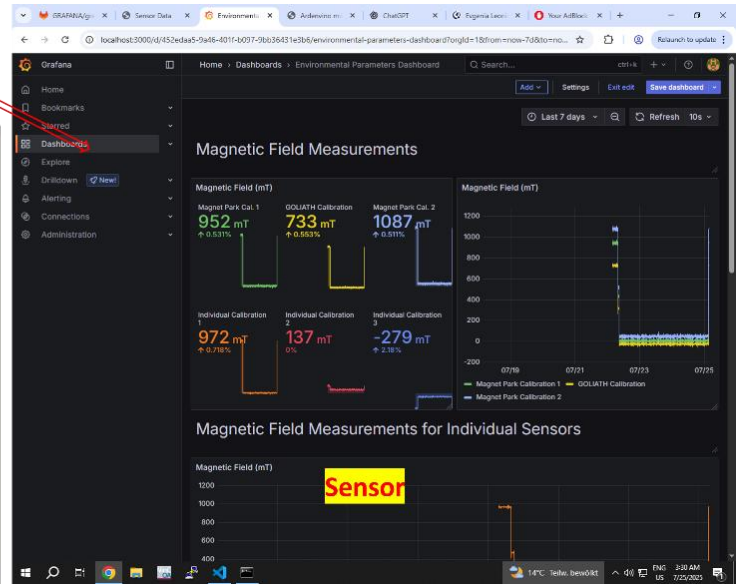
Experiment setup

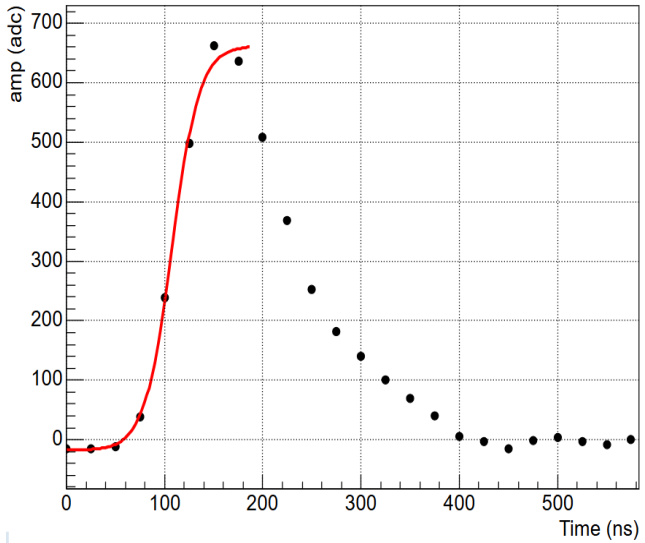
- Goliath magnet at SPS-H4, B = 1T
- Trackers: μRGroove, Ar/iC_4H_{10}(98/2), 3 kV/cm drift field, Lorentz angle: ~6°
- **MPGD-ITK**: Ar/CF_4/CO_2(45/40/15), 0.5 kV/cm drift field, Lorentz angle: ~22°
- APV25 + SRS + mmDAQ

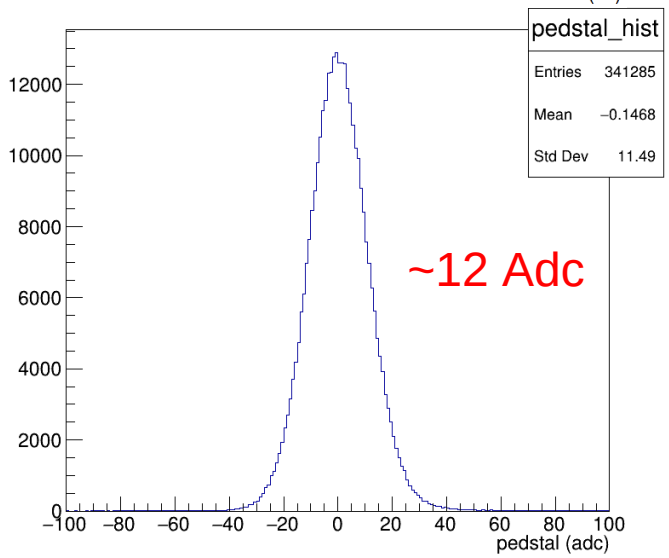




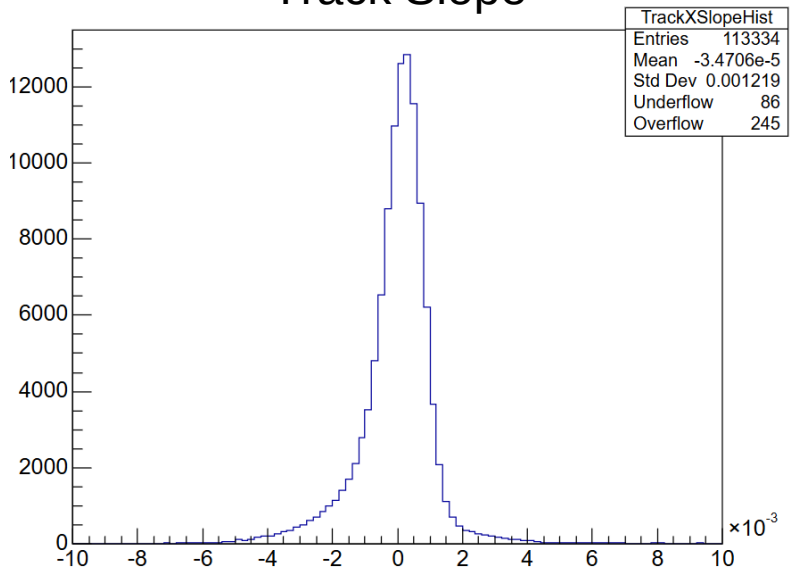


Analysis workflow of raw data

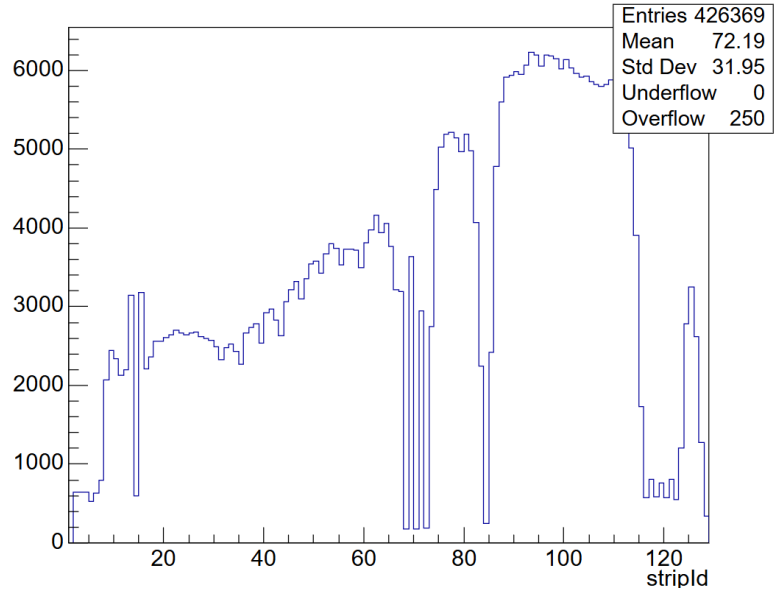




Track Slope



HitID for MPGD-ITK



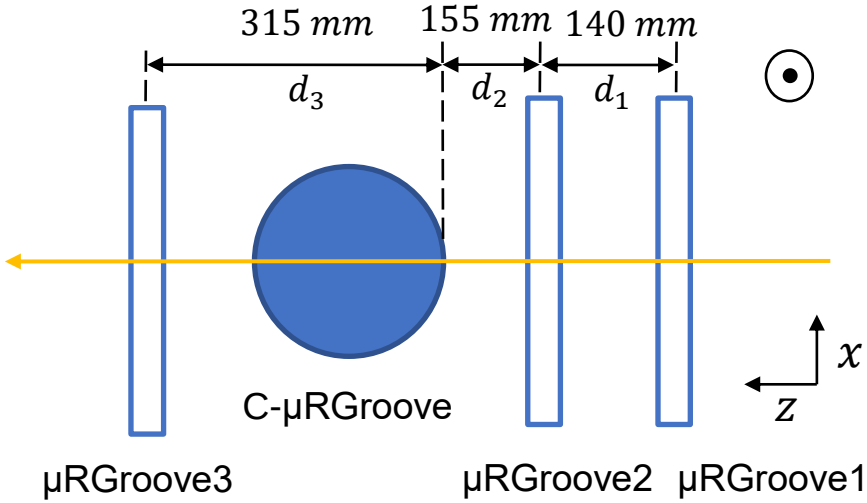
Beam Analysis Workflow

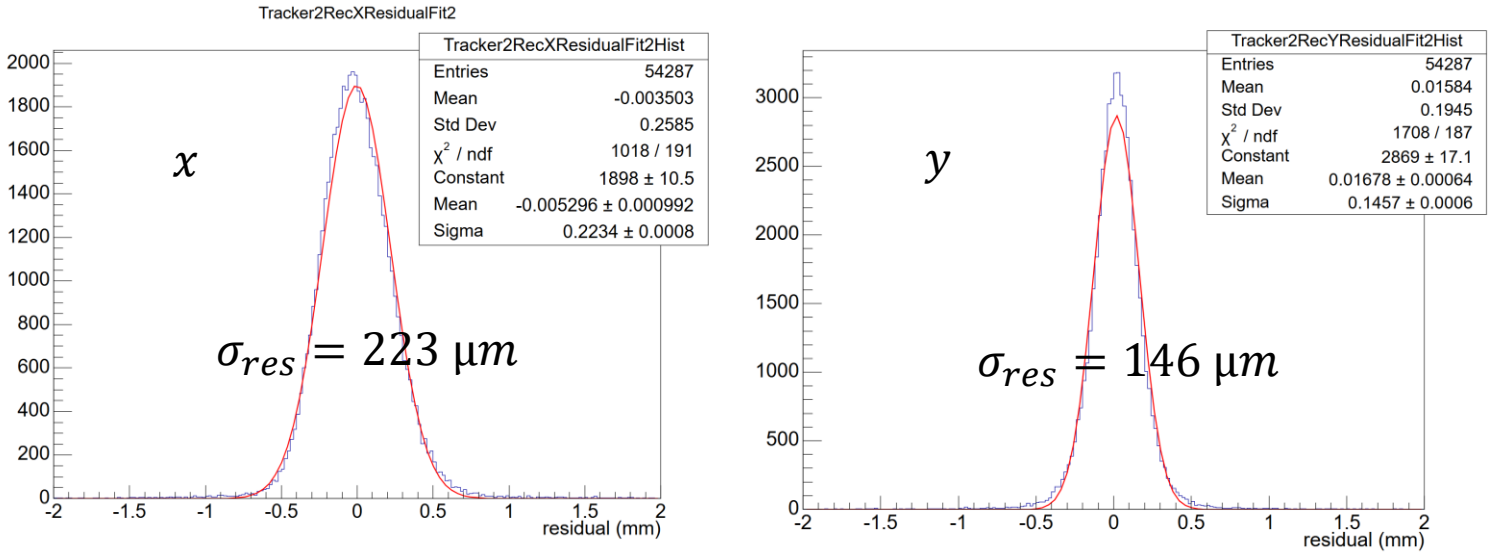
1. **Waveform Process**: extract charge and time with fit the leading edge
2. **Clustering**: group neighboring fired strips, allow one missing strip
3. **Event Selection**: allow only one hit per tracker, keep tracks with $\chi^2 < 10$
4. **DUT Matching**: get hit point and find nearest cluster in the DUT
5. **Reconstruction**

Tracking system alignment

- Align trackers by minimizing track residuals χ², mainly x/y translations and rotation around the z-axis.
- Built track from **μRGroove1 & 3**, then compute residuals to **μRGroove2** and estimate track error
- Assume all trackers have the same spatial resolution $\sigma_{tracker}$,

$$\sigma_{res}{}^2 = \left[1 + \left(\frac{d_2+d_3}{d_1+d_2+d_3}\right)^2 + \left(\frac{d_1}{d_1+d_2+d_3}\right)^2\right] \sigma_{tracker}{}^2$$

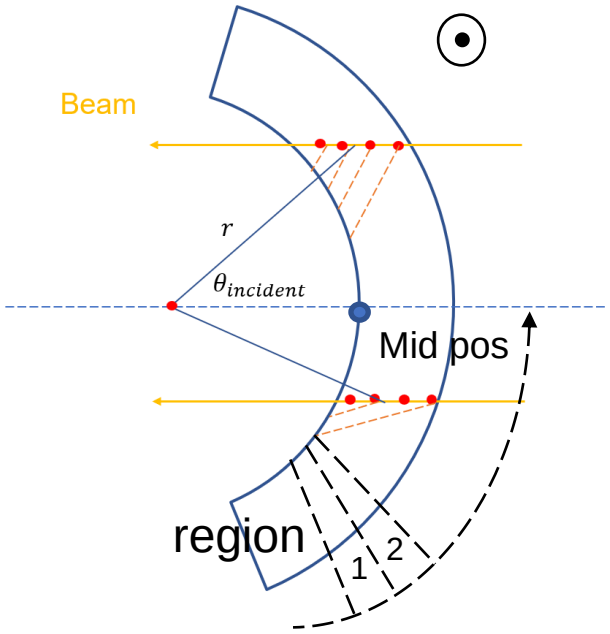




- Estimate the track error(fitted from three trackers) via error propagation
- C-μRGroove placed at the position with minimum $\sigma_{track} \sim \sigma_{tracker}/\sqrt{3}$
- C-μRGroove position track error:

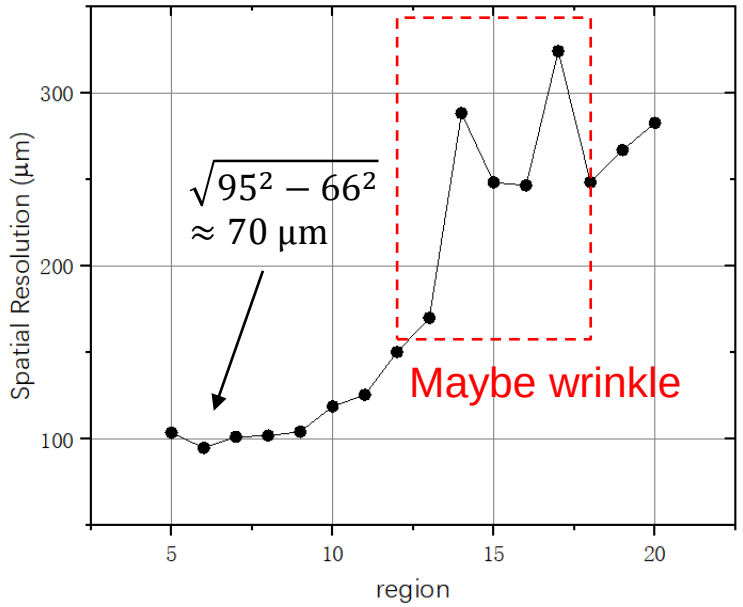
  x: ~100 μm, y: ~66 μm

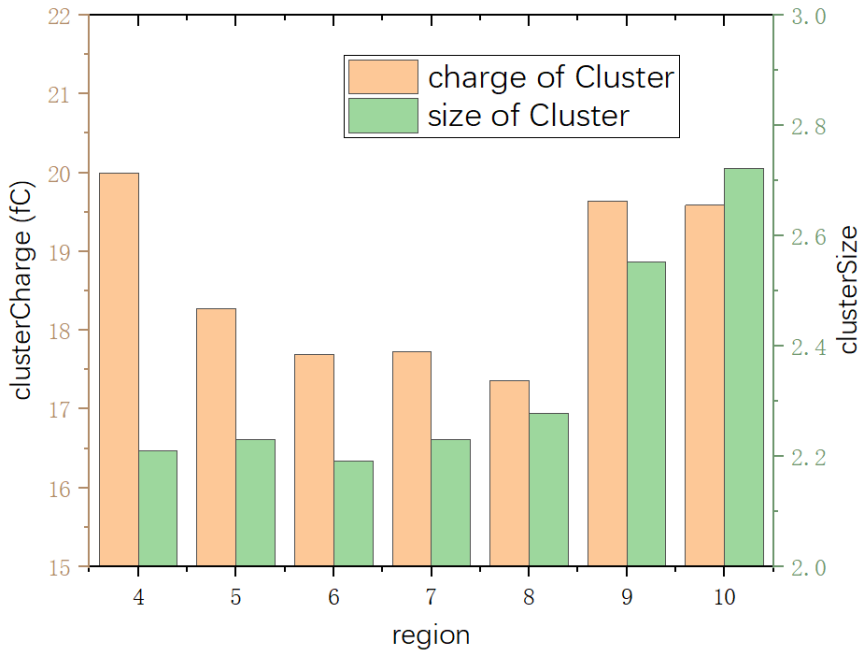
Spatial resolution @B = 0T



Divide the cylindrical surface into regions along the arc per 2°

charge centroid Residual RMS

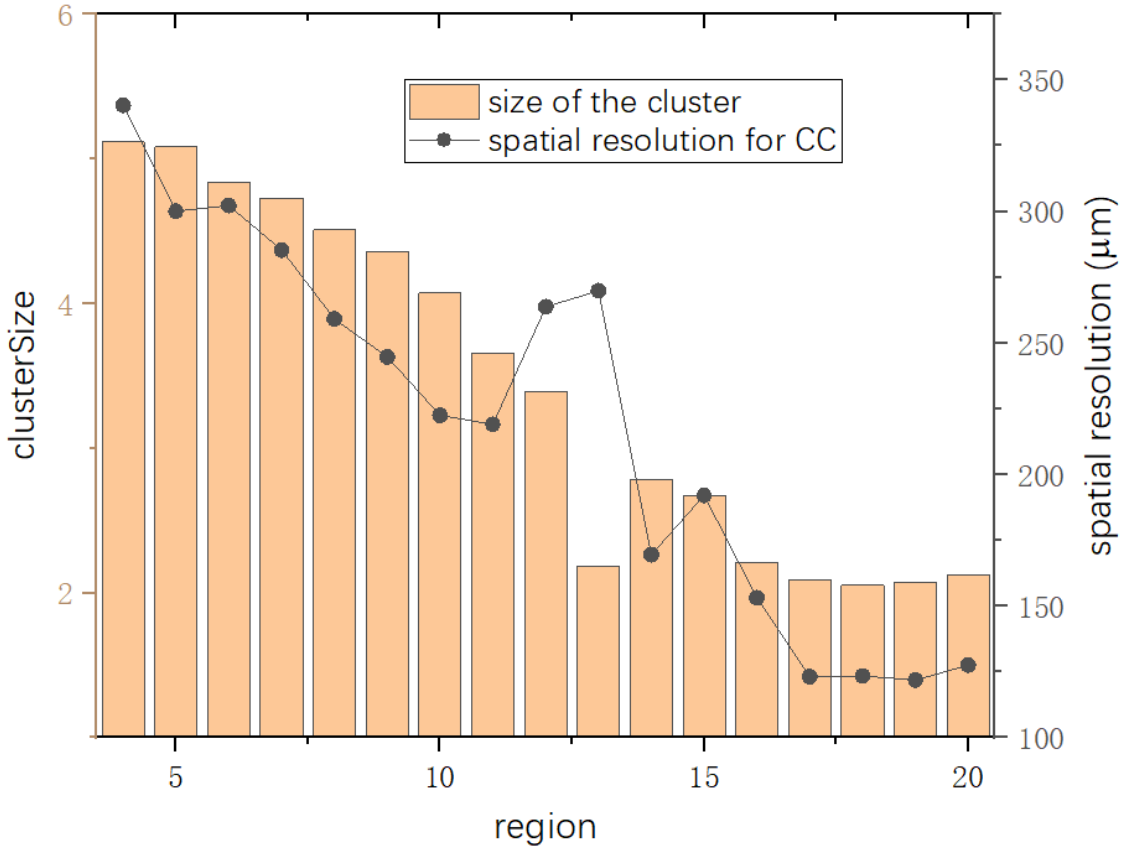


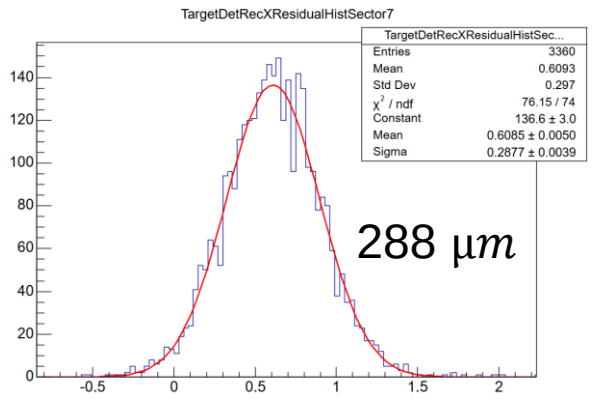


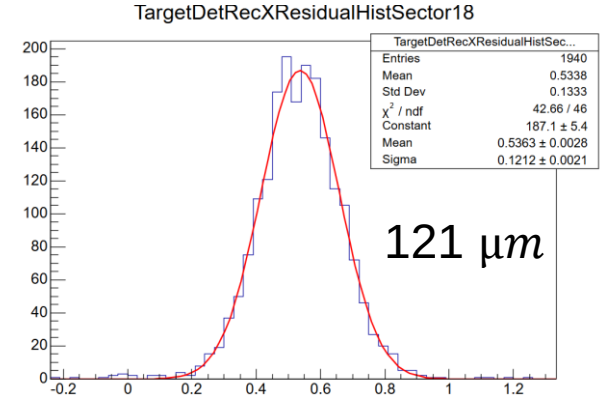
The center is determined with 2° error

- Different hit positions lead to different incident angles through the cylindrical detector
- Test the detector performance and determine the **center position at B=0 T**

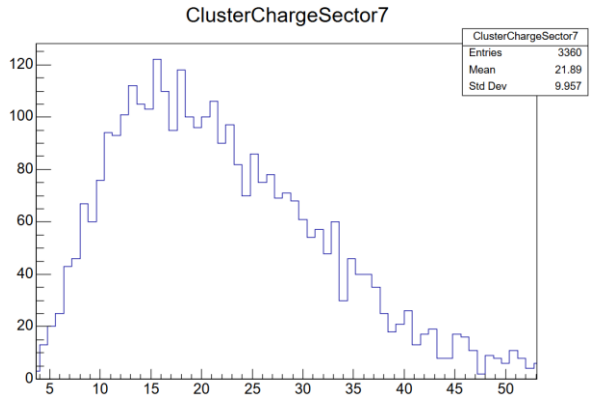
Charge-centroid @B = 1T

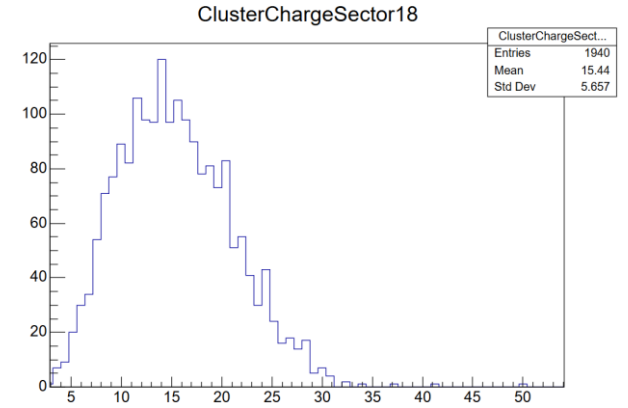






$incident\ angle \approx 0°$ $incident\ angle - Lorentz \approx 0°$



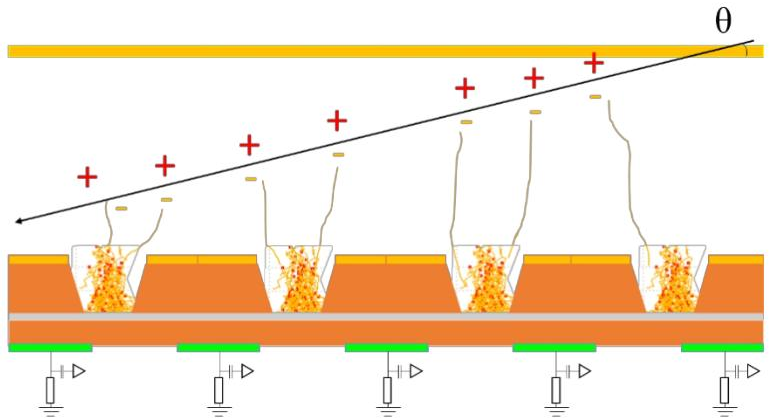


(Θ – Lorentz angle ≈ 0°) ≈ 70 μm correct for track error

→ consistent with **B = 0 T**.

The micro-TPC mode

- The time information of the hits can be used with the drift velocity to reconstruct
- For large incident angles or with magnetic field, micro-TPC is stronger than the charge centroid

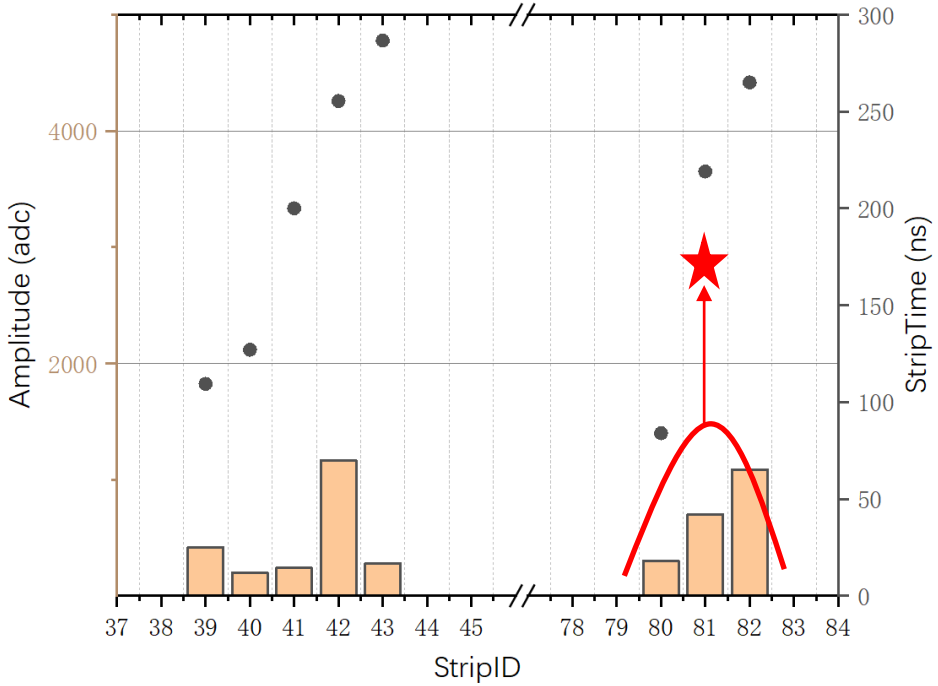


A new combination of CC and μTPC Method

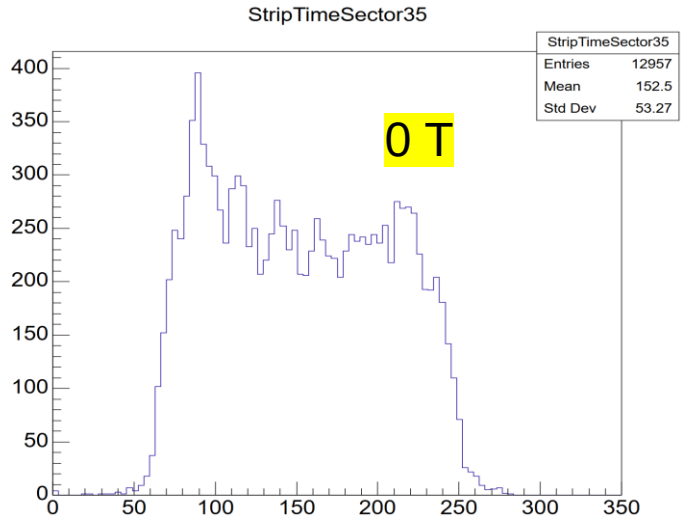
- Add the CC-reconstructed point as an **extra point** in the μ-TPC linear fit
- In the micro-coordinate, the extra point:

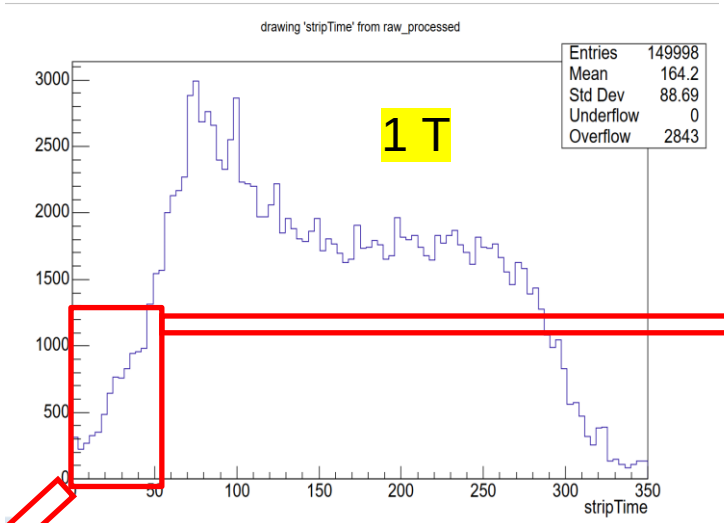
$$(charge\ centroid,\ \frac{Gasgap}{2})$$

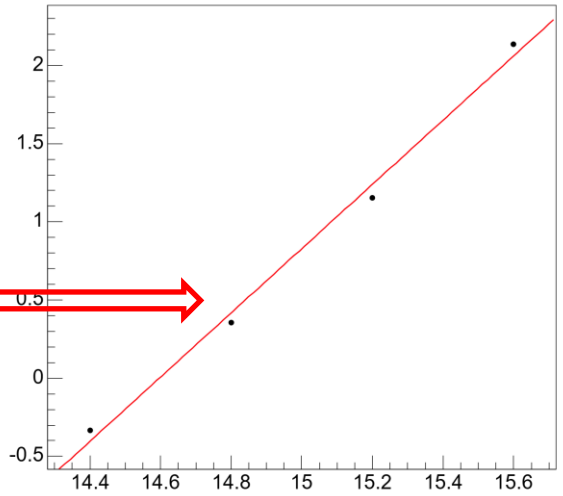
- Provides more stable fits in low-statistics events while keeping μ-TPC advantages



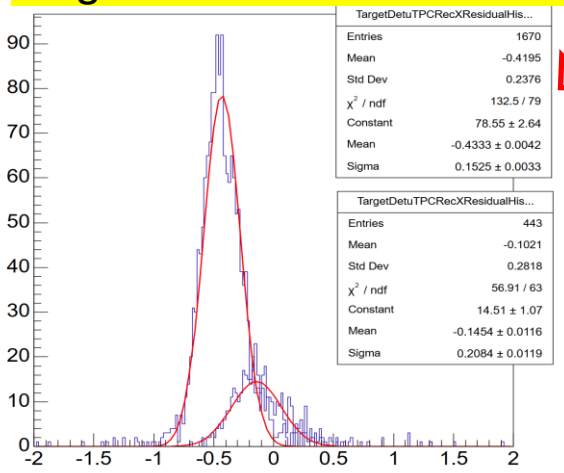
Time shift correction in magnetic field



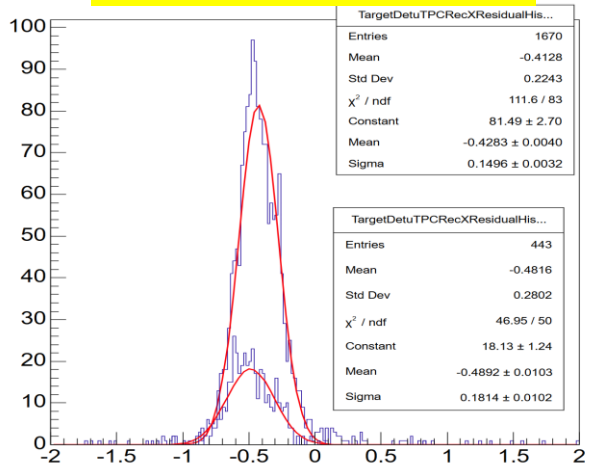




Origin residual distribution



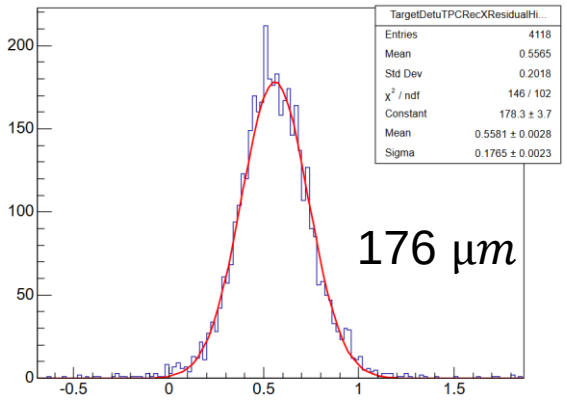
corrected distribution



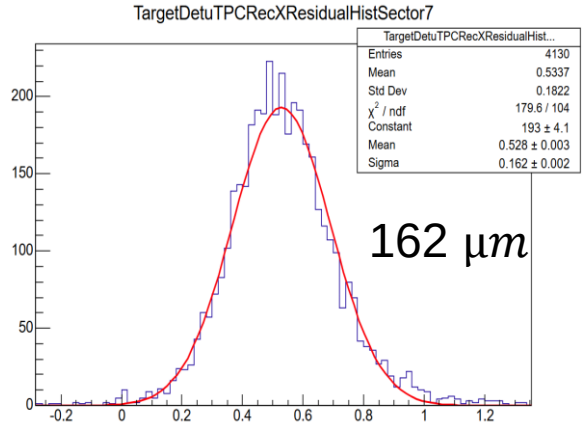
- Observed abnormal events, introducing a **timing shift** affecting all points
- Applying a **global time offset** to points during abnormal events

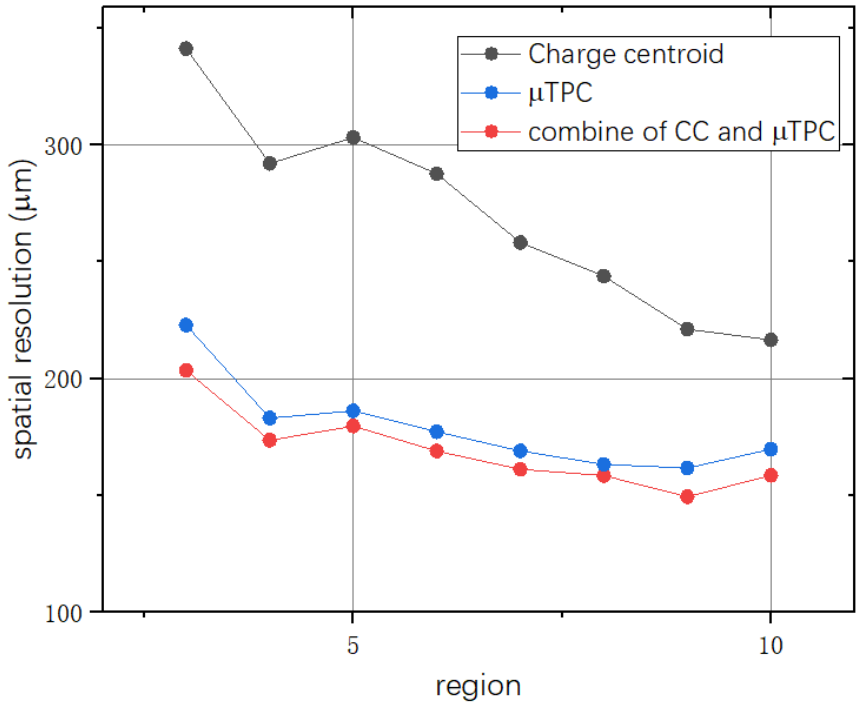
Result in magnetic field

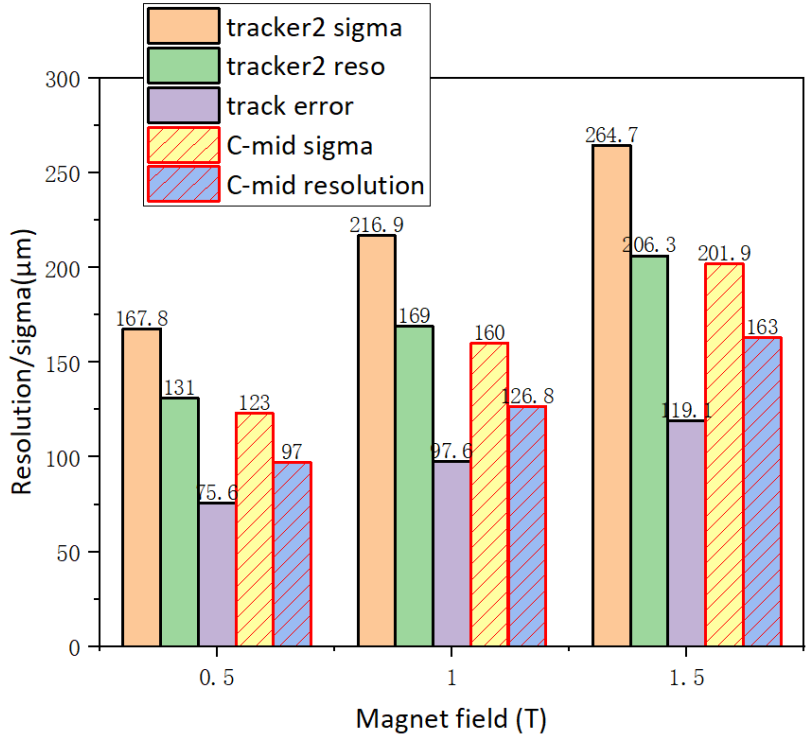
Micro-TPC



Combine of CC and Micro-TPC







- At incident angle ≈ 0°: ~127 μm by μ-TPC (without track error)
- New CC + μTPC combination improves resolution
- Resolution degrades with increasing magnetic field

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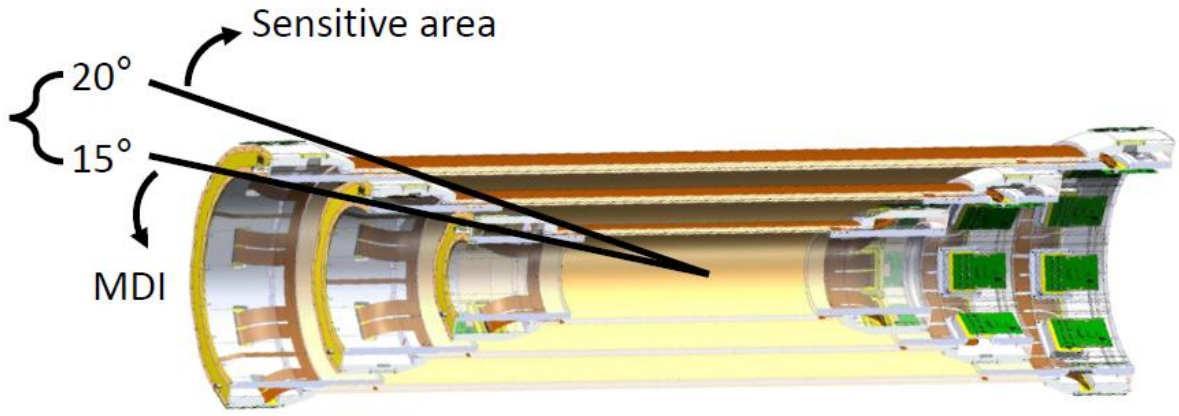
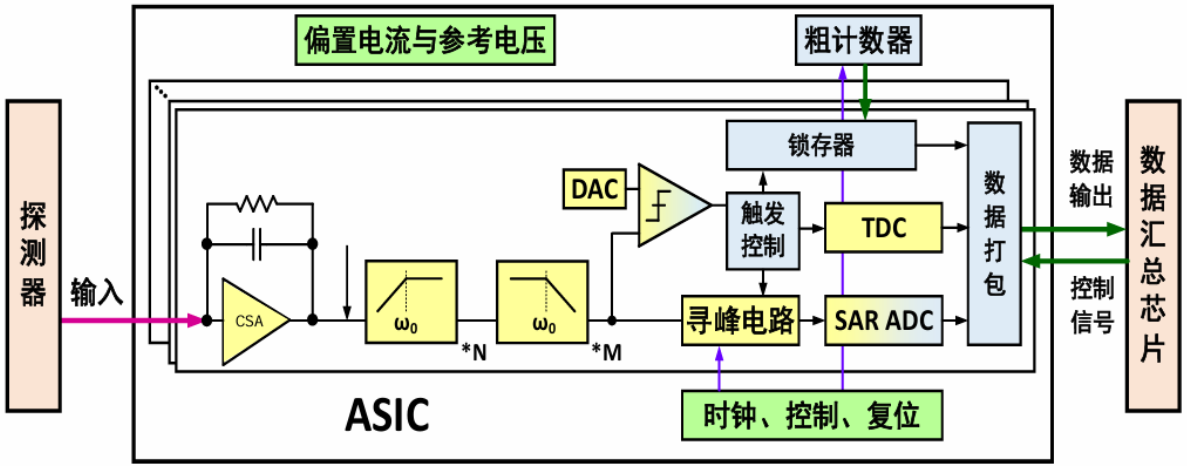
Front-end readout ASIC for C-μRGroove

Challenges to front-end readout ASIC:

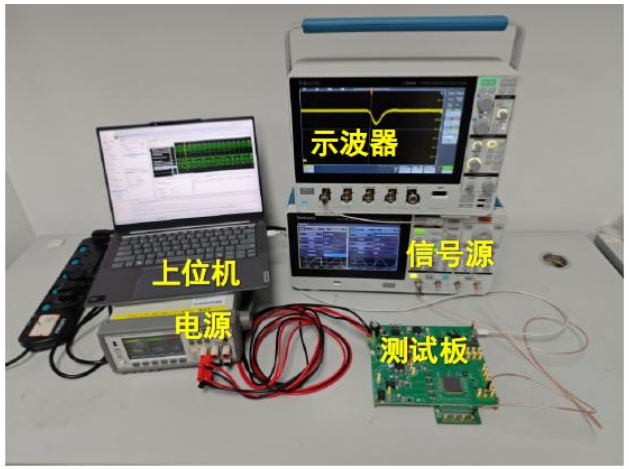
- High count rate (Max ~ 4MHz/channel)
- Highly integrated design required
- Weak Signals (~ fC)
- Large input capacitance (tens of pF)

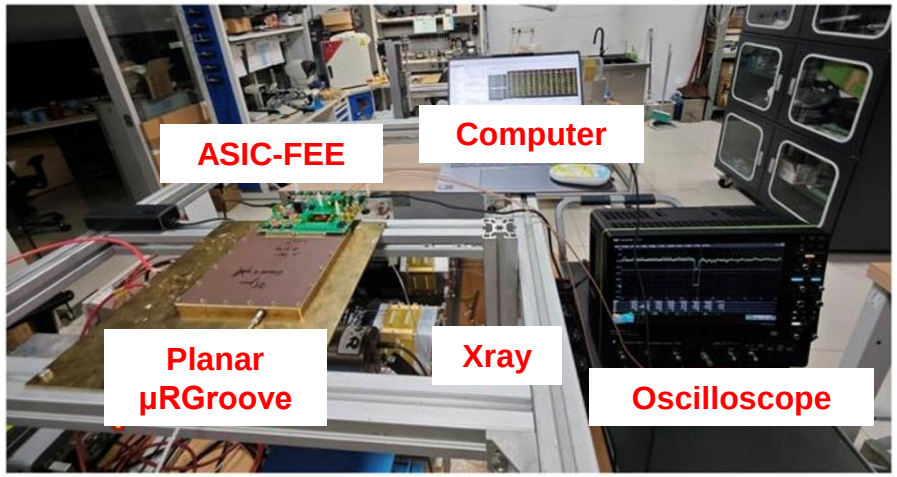




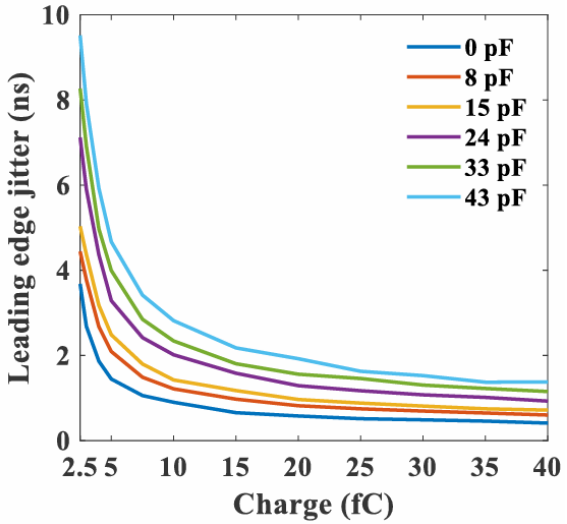
ASIC Specs	Demands
Charge Range	40 fC
Charge precision	~ 1 fC RMS
Time precision	< 10 ns RMS
Max. event rate	4 MHz

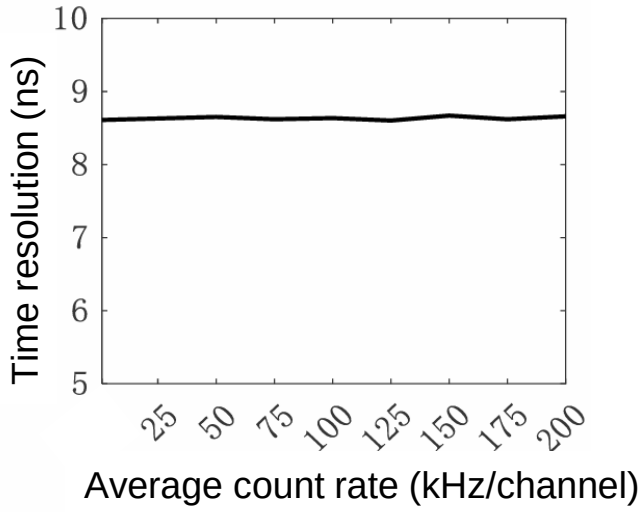
Front-end readout ASIC test with planar μRGroove detector



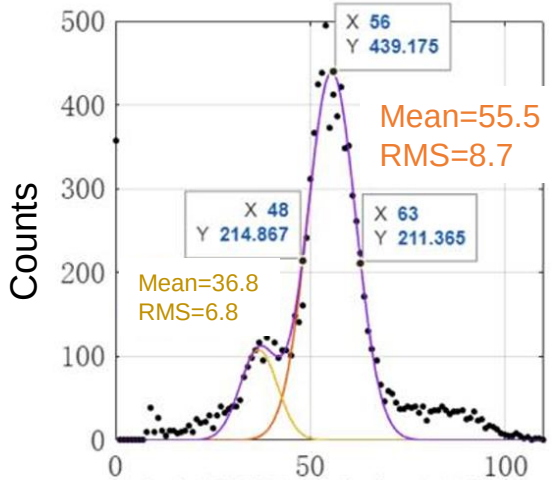


Time resolution

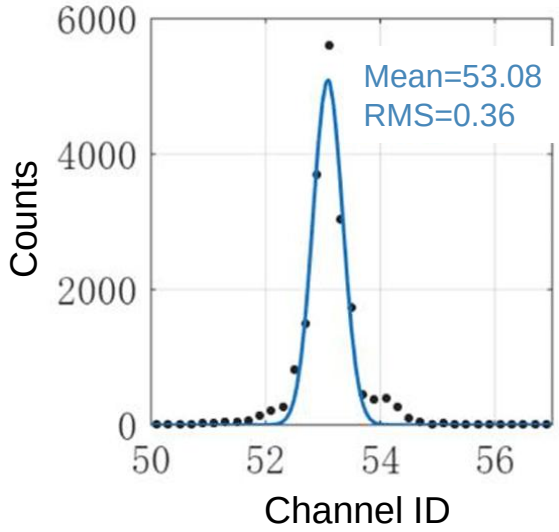




Spectrum of 8.9 keV Xray



Hits distribution



Outline

1. Inner tracker in STCF
2. MPGD-based ITK prototype
3. Beam test in magnetic field
4. ASIC research progress
5. **Summary**

Summary

The MPGD-based ITK prototype is validated in magnetic field

- Verified detector performance at **B = 1 T**
- At normal incidence: **<130 μm spatial resolution** achieved
- Proposed a **new combination method**, which further improves resolution

Front-end readout ASIC for MPGD-based ITK

- A 32-channel prototype ASIC chip is manufactured and tested with a detector
- Several ns **time resolution** achieved
- Preparing for the further optimization

Thanks~