



Beam Test Results of the Sealed MRPC Prototype for CEE-eTOF

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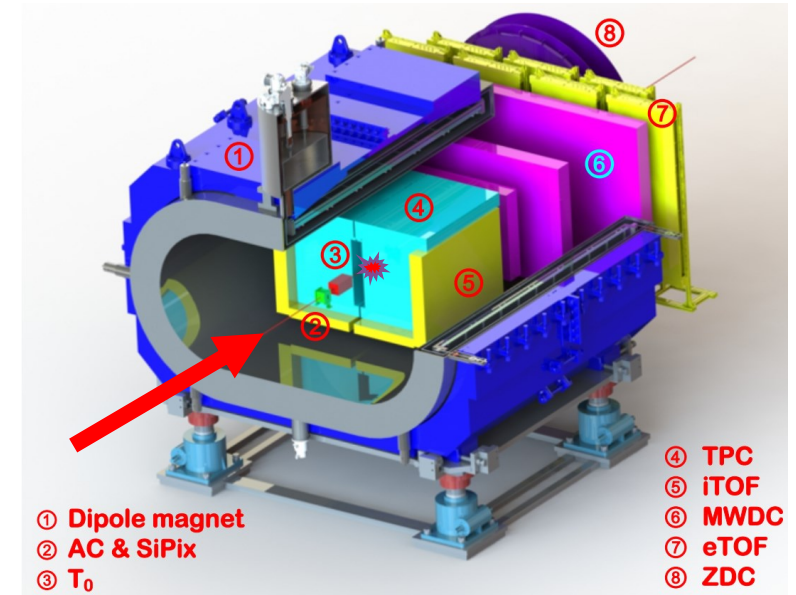
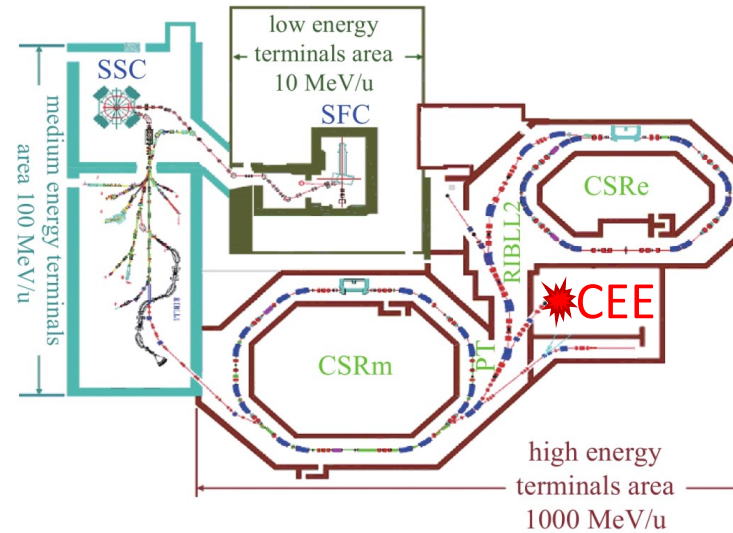


Outline

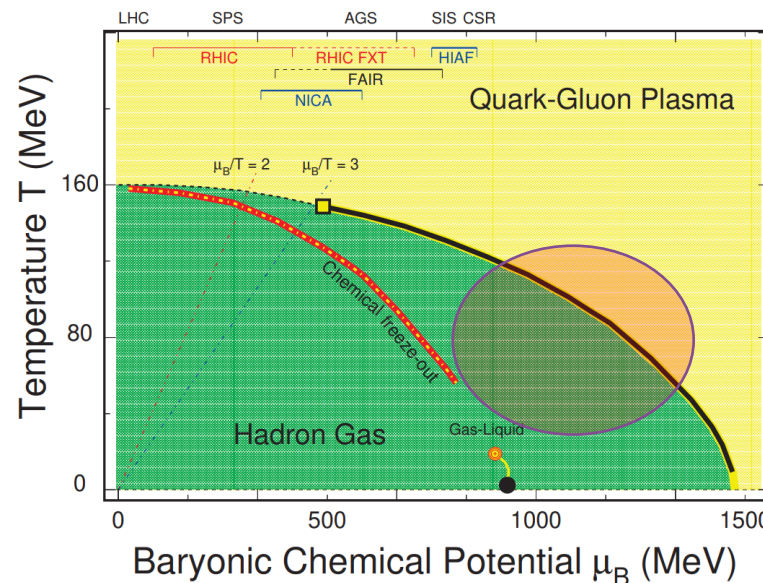
- CSR External-target Experiment (CEE) at Lanzhou, China
- Multigap Resistive Plate Detector (MRPC)
- External Time-Of-Flight wall (eTOF) and the sealed MRPC
- Beam test on Apr 2023
- Reconstruction and analysis
- Beam test results
- Conclusion

CSR External-target Experiment (CEE)

- CEE is under construction for the studies of the Equation of State (EoS) of nuclear matters
 - QCD phase structure
 - EoS and Asymmetry energy
 - Hyperon and features
 - Take data from 2025



- CEE is a spectrometer which measures the secondary particles in heavy ion collisions with Time-Of-Flight (TOF) methods
 - Front angle: MWDC+eTOF
 - Large angle: TPC+iTOF
 - Multigap Resistive Plate Chamber (MRPC) technology

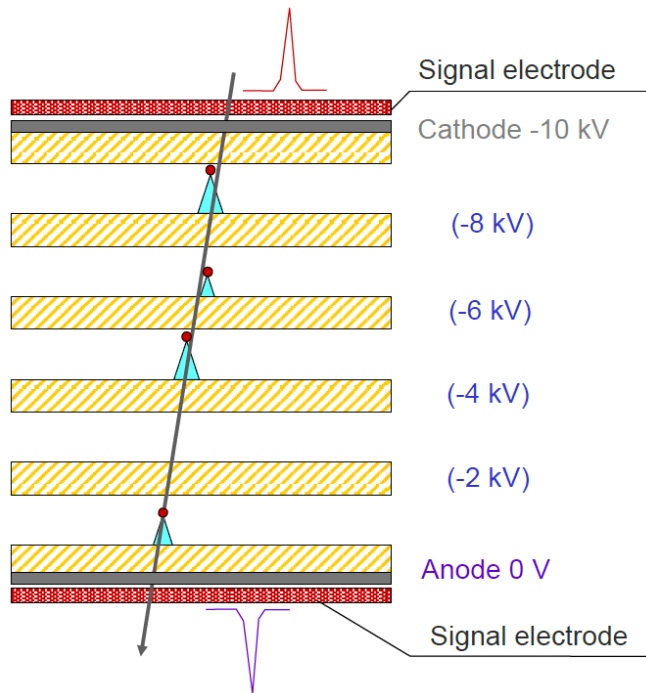


Item	value
Maximum beam energy	0.5GeV/u(U) – 2.8GeV(p)
Beam type	$p \sim U$
Maximum event rate	10 kHz
Acceptance	> 50%
Total channel number	20k

$$n_{\sigma TOF} = \frac{|t_1 - t_2|}{\sigma_{TOF}} = \frac{Lc}{2p^2 \sigma_{TOF}} |m_1^2 - m_2^2|$$

Multigap Resistive Plate Chamber

First proposed by E. C. Zeballos



The multigap structure brings:

- Narrow gap thus high time precision
- Necessary gap thickness for good efficiency

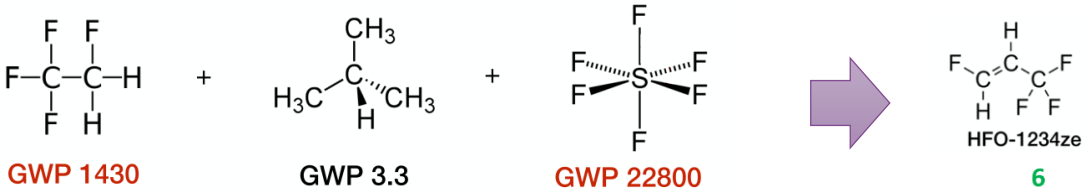
MRPC has been broadly adopted to construct the Time of Flight (TOF) systems in HEP experiments.

					In construction	Proposed
	ALICE	STAR	FOPI	BESIII	CBM	SoLID
Active area per detector (cm)	120 x 13	22 x 8.4	90 x 4.6	0.5x(9.2+14.8) x32.8	33 x 27.6	--
Total active area (m ²)	141	50	5	1.33	120	10
Pad size (cm)	3.7 x 2.5	6.3 x 3.1	90 x 0.3	(9.1~14.1) x 2.4	27 x 1.0	(16~28) x 2.5
Gap × thickness(mm)	10 x 0.25	6 x 0.22	6 x 0.3	12 x 0.22	10 x 0.25	10 x 0.25
Gas mixtures (C ₂ H ₂ F ₄ / C ₄ H ₁₀ /SF ₆)	90/5/5	95/5/0	85/5/10	90/5/5	90/5/5	90/5/5
Operating field (kV/cm)	96	107	110	109	110	106
Efficiency	99.9%	95-97%	97 ± 3%	99%	97%	98%
Time resolution(ps)	40	60	73 ± 5	60	60	20 ps
Max rate (Hz/cm ²)	50	10	50	50	30k	10k

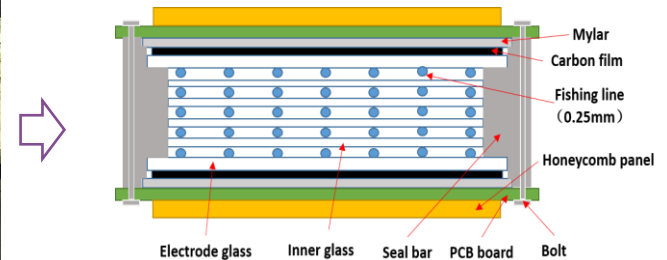
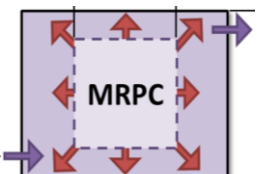
Gas-related challenges of MRPC

- Regulations against greenhouse gases causes uncertainty: availability, cost, eco-impact, ...

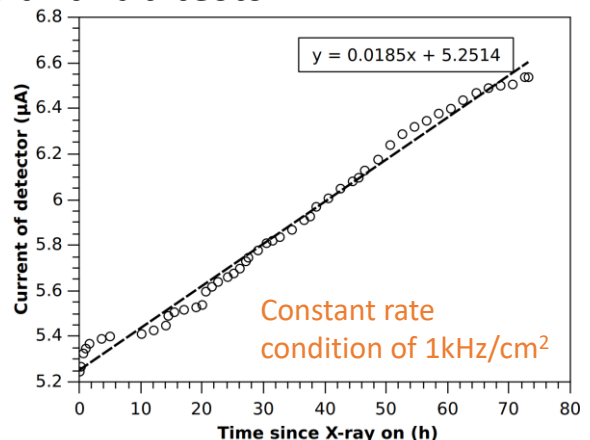
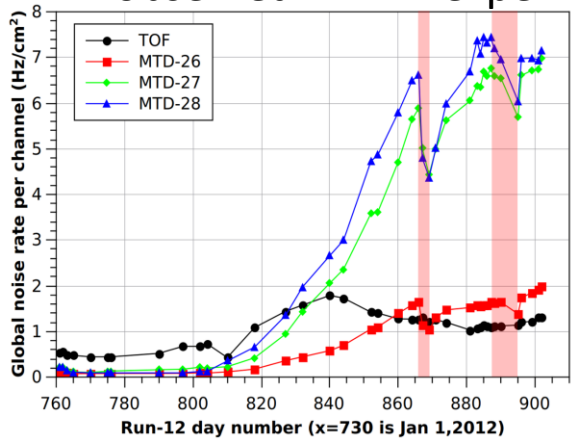
Motivation: A wise design of the gas volume shall promote the gas exchange and decrease the gas consume.



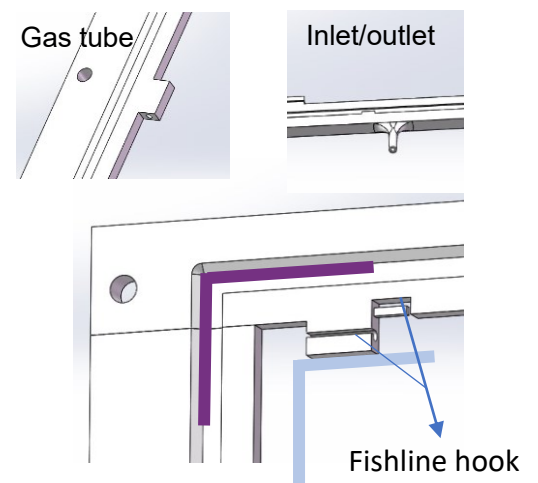
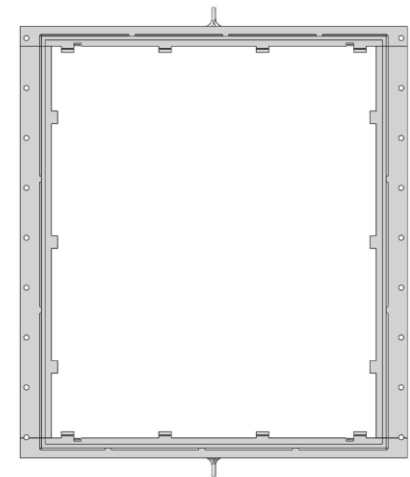
- Gas pollution effect in high rate conditions
- Narrow gap of MRPC and large gas volume --- ionization products exchanged slowly by **diffusion**



...observed in HEP experiments and lab tests.



Pollution caused noise and current rise



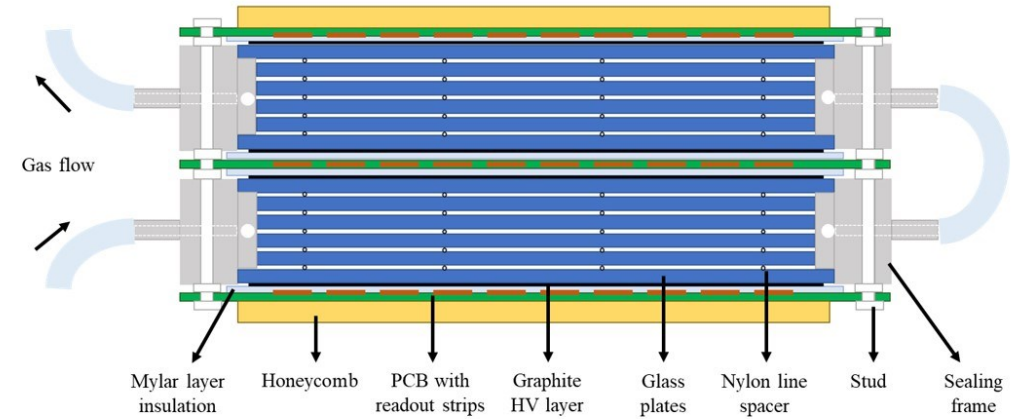
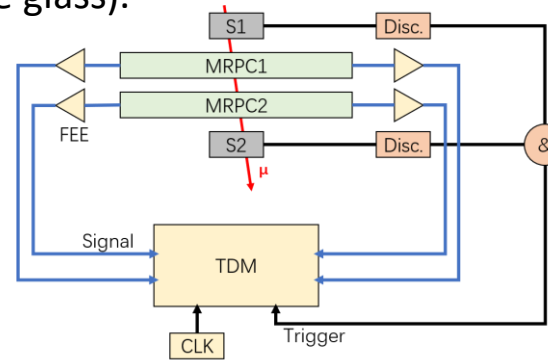
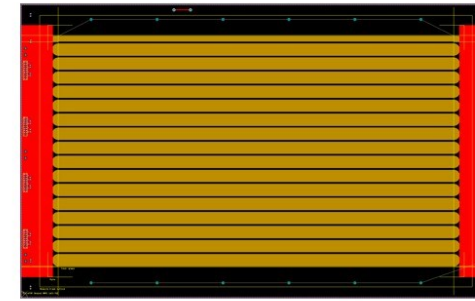
The sealed MRPC for eTOF

Features of the *Sealed MRPC*:

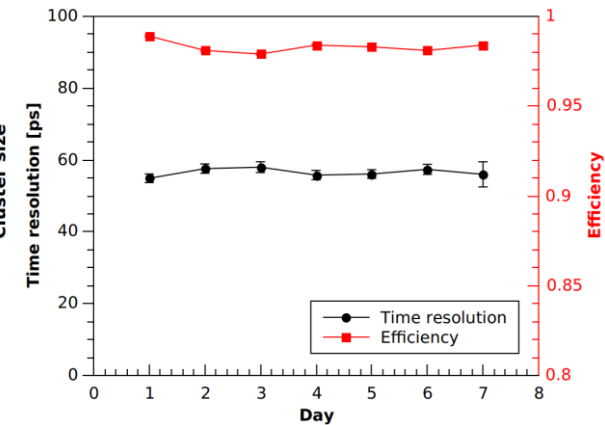
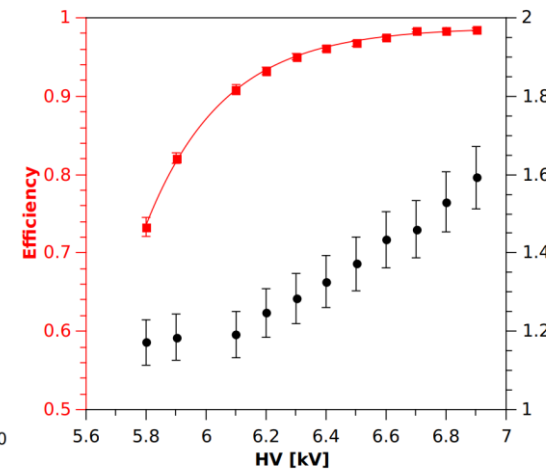
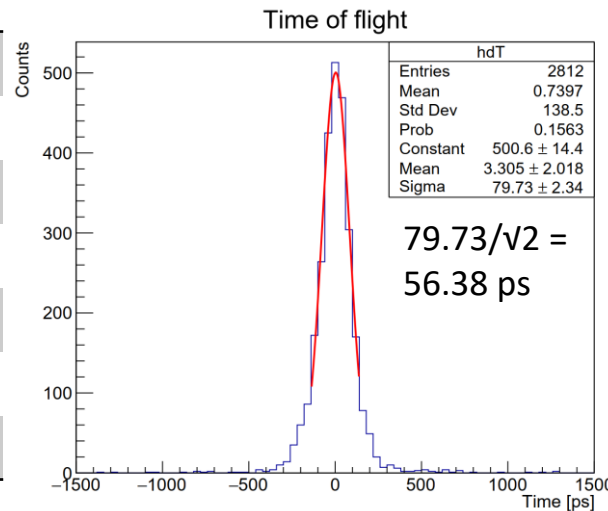
1. Novel structure: 3D-printed sealing frame
2. Gas saving: 10 sccm/m² active area in common rate conditions
3. Fast preparation: 2 h from gas-purging to working HV.
4. Promoted gas exchange: invisible gas pollution effect at 10 kHz/cm² counting rate (MRPC built with low resistive glass).

Cosmic test results:

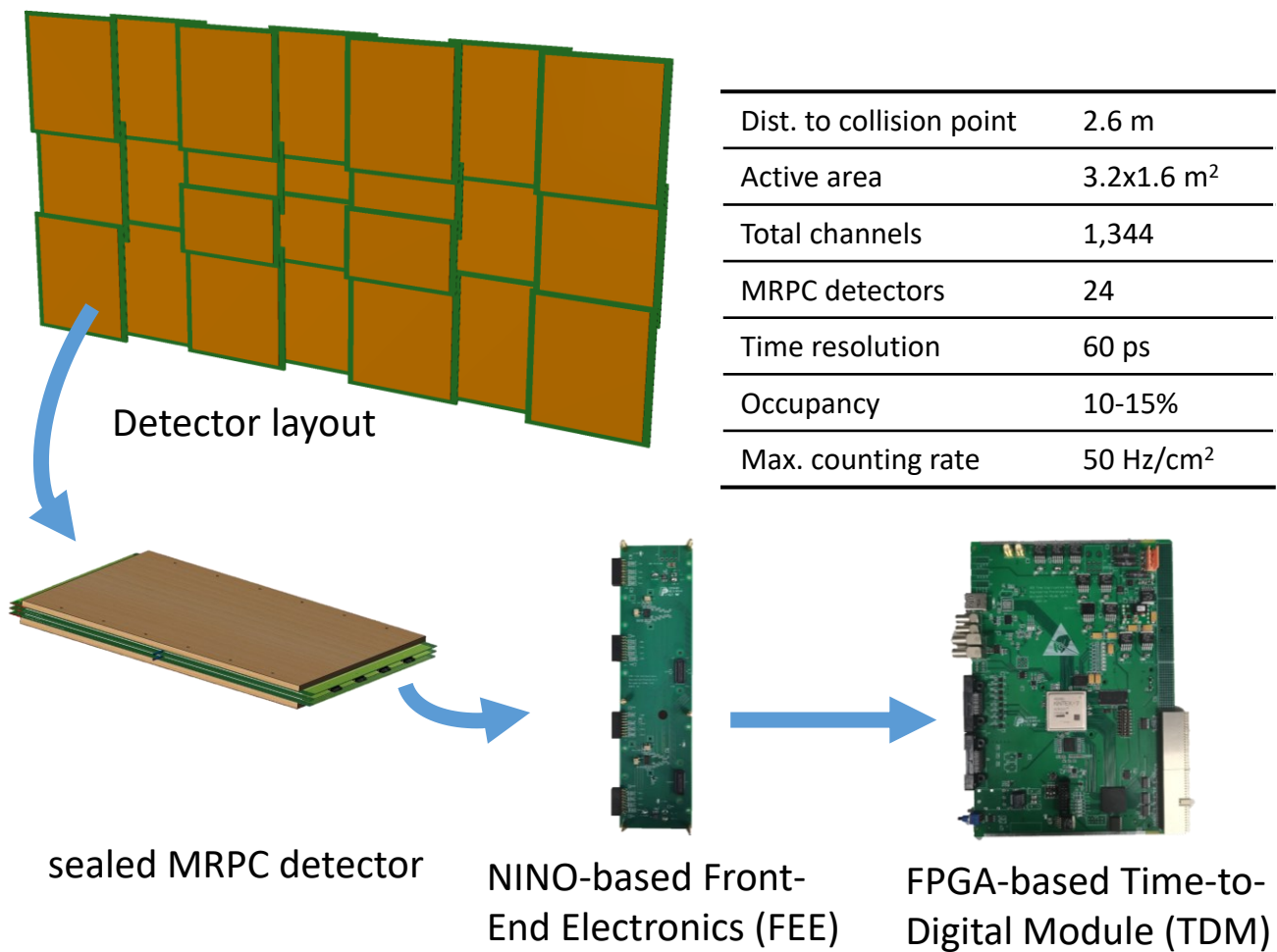
1. Over 97% efficiency at 6.9 kV (110 kV/cm).
2. 56 ps time resolution at working point.
3. Stable behavior in tested 7 days.



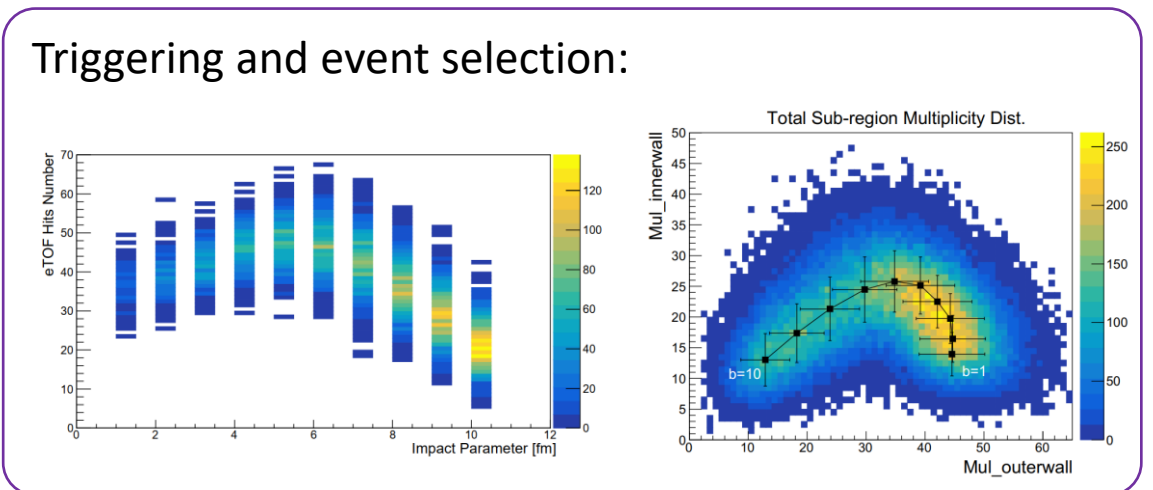
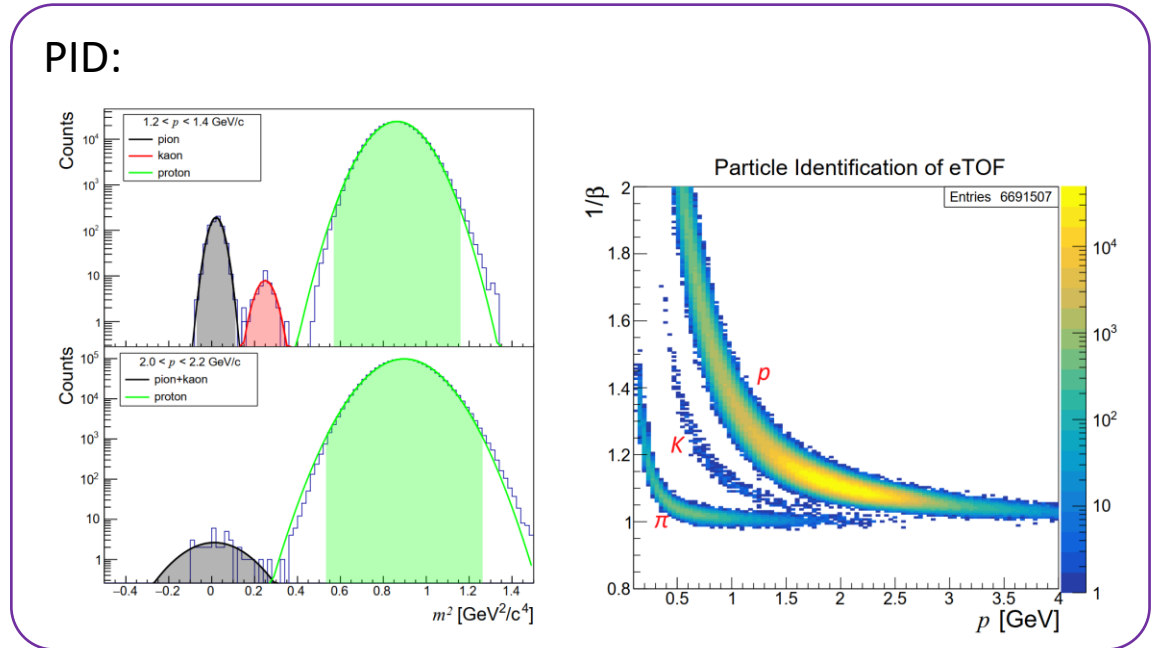
Detector parameters	values
Gas gaps	2x5
Gas gap thickness	0.25 mm
Glass thickness	0.5 mm
Readout strips	32 or 16
Strip size	48 cm x 1.5 cm
Strip gap	0.2 cm
Gas flow	10 sccm



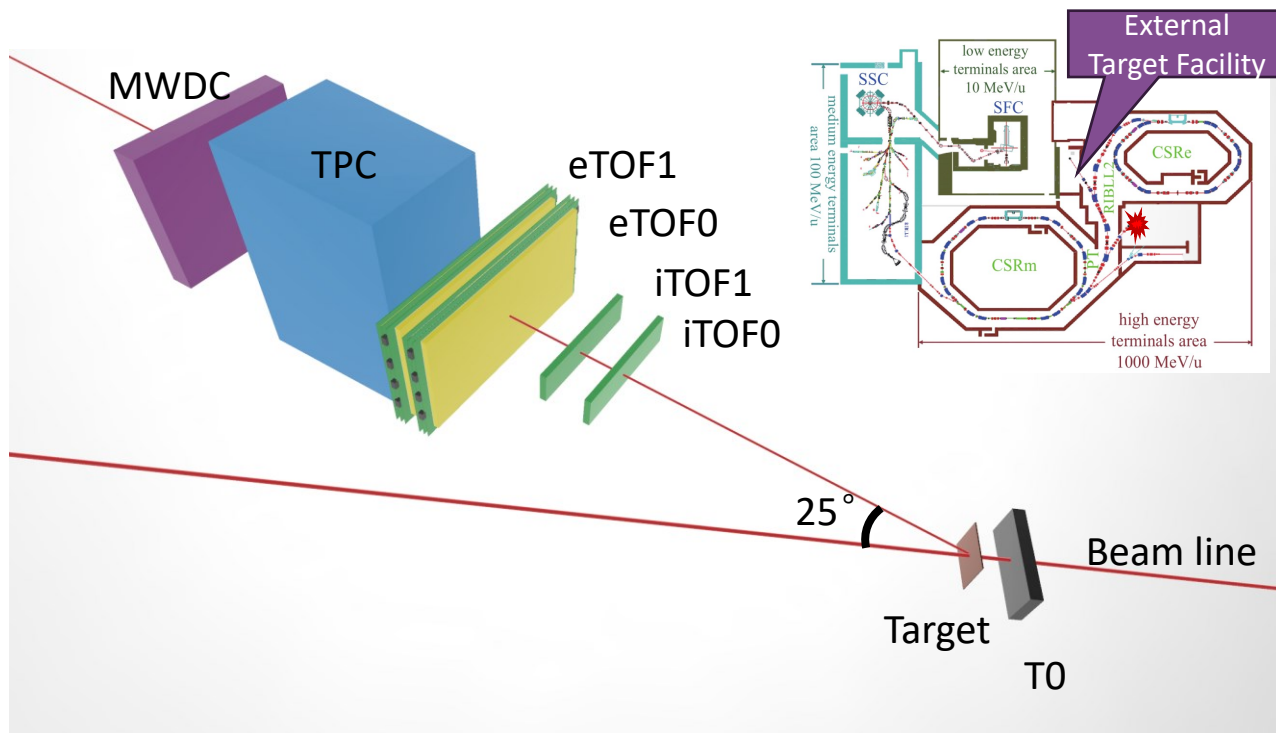
The external TOF wall (eTOF)



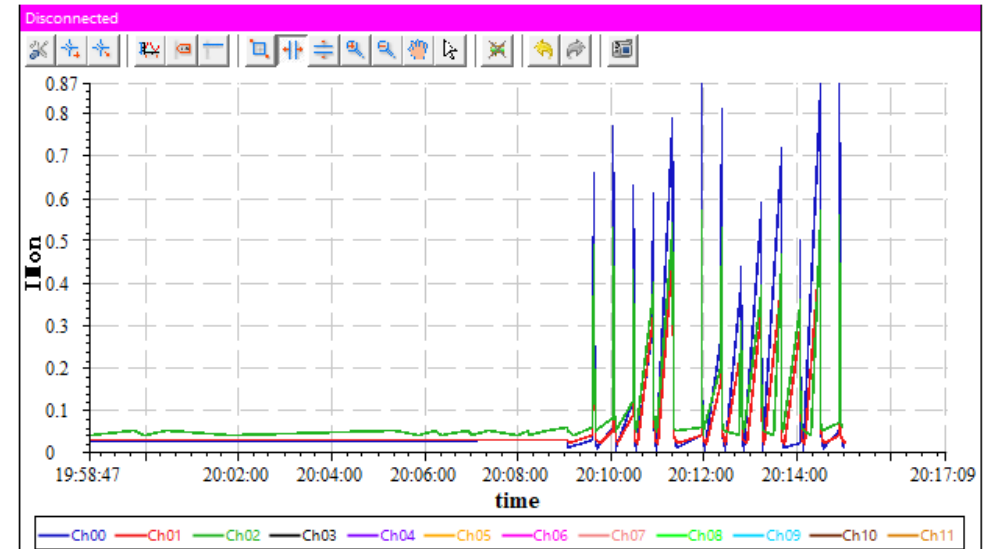
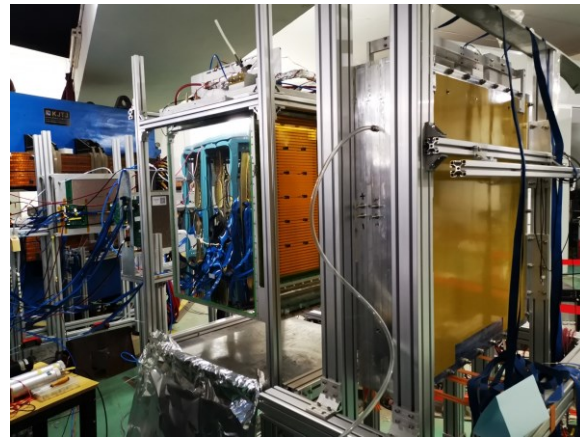
Wang, B., Xu, H., Chen, X. et al. The external time-of-flight wall for CEE experiment. Eur. Phys. J. C 83, 817 (2023). <https://doi.org/10.1140/epjc/s10052-023-11806-2>



Beamtime setup



Collision system	Fe-Fe
Beam energy	300 MeV/u
TOF readout channels	64
eTOF distance to target	137 cm
Trigger criterion	$Mul_{TOF} \geq 4 \ \& \ T0$
Trigger time window	75 ns
Acquisition time window	5 μ s
Triggered event rate	2000 s ⁻¹ max.



Reconstruction and analysis

- Reconstruction:

- X: position along the strip, reconstructed from the both-end signal times
- Y: position across the strips.
- Z: position of the detector.
- T: average signal time from both ends

- Correction:

- Position correction
- Time-slewing correction

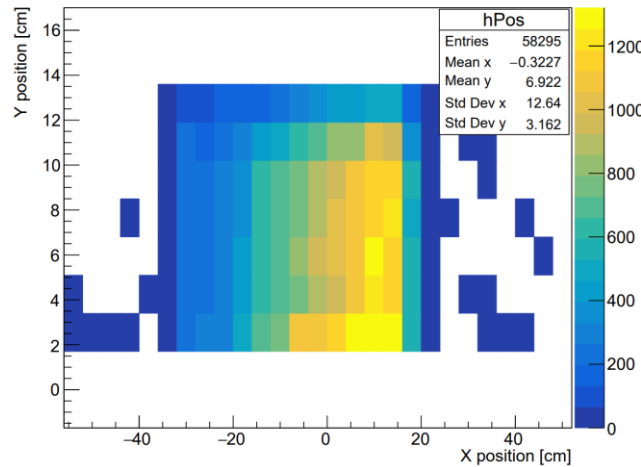
- Tracking:

- Chi2 discrimination
- Merge hits into tracks

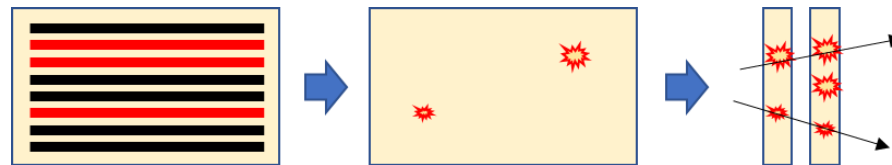
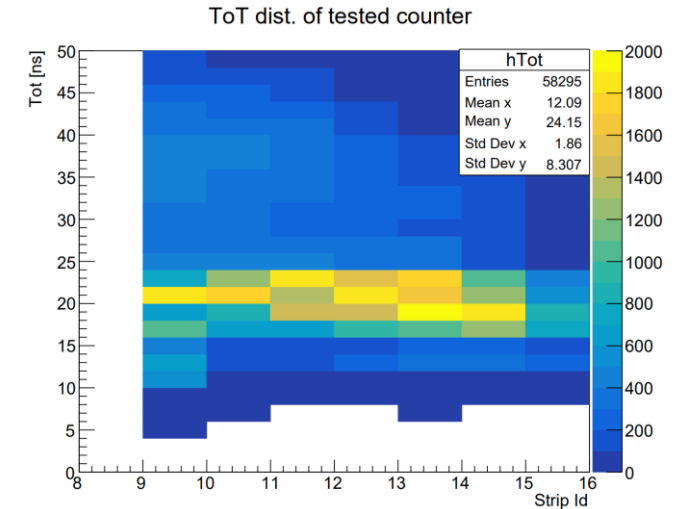
- Analysis:

- Efficiency, time resolution, etc.
- Event display

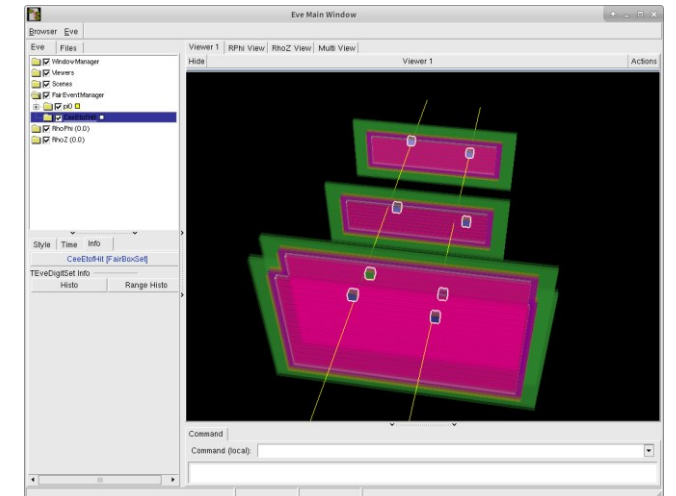
Position of tested counter



Time over 250 mV Threshold

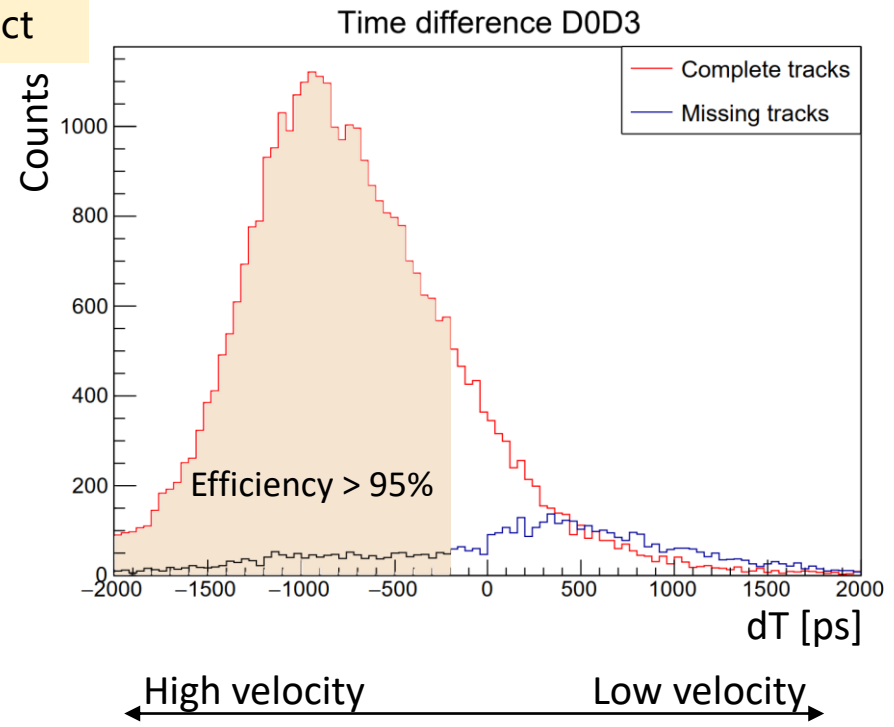
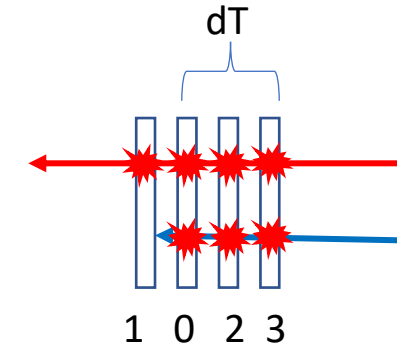
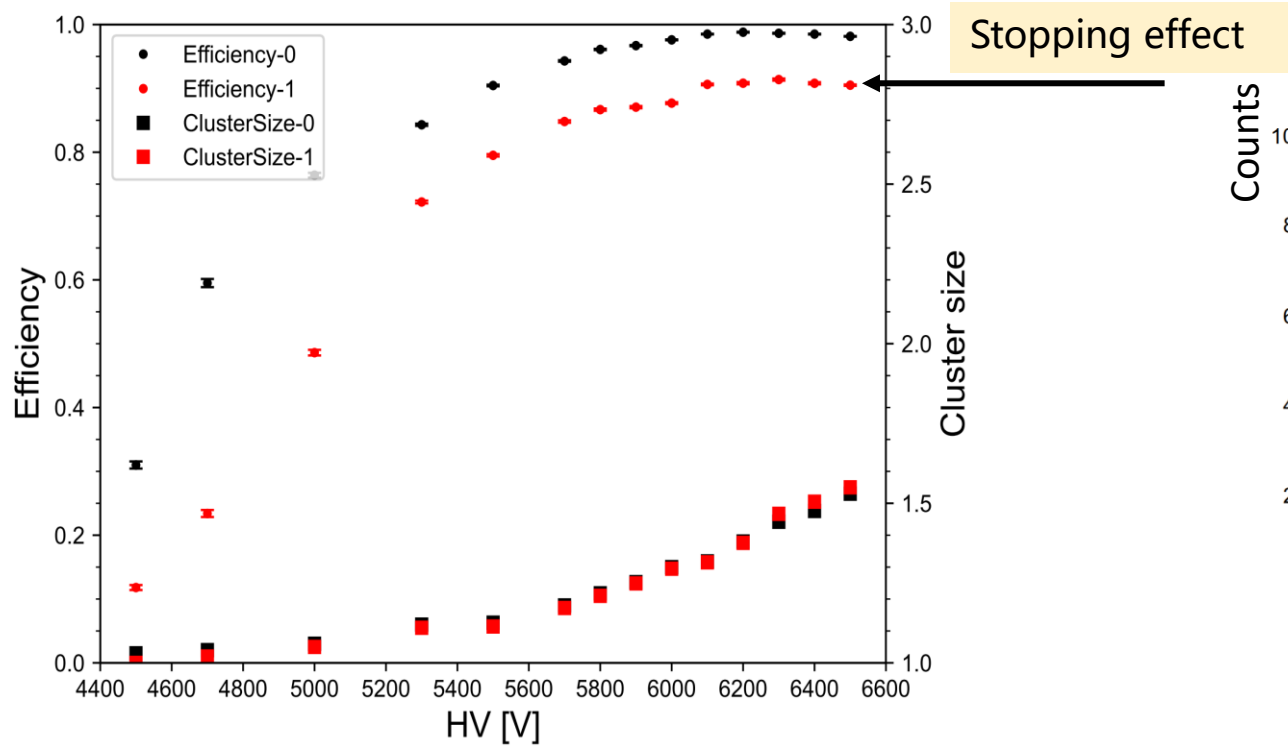


$$\chi^2 = \frac{1}{3} \left[\left(\frac{X_1 - X_0}{\sigma_x} \right)^2 + \left(\frac{Y_1 - Y_0}{\sigma_y} \right)^2 + \left(\frac{t_1 - t_0}{\sigma_t} \right)^2 \right]$$



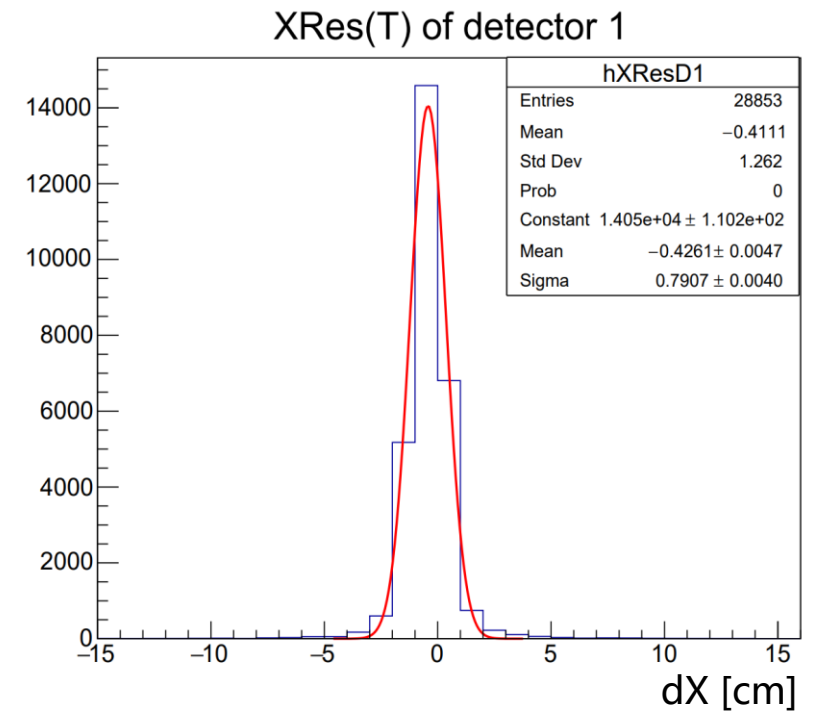
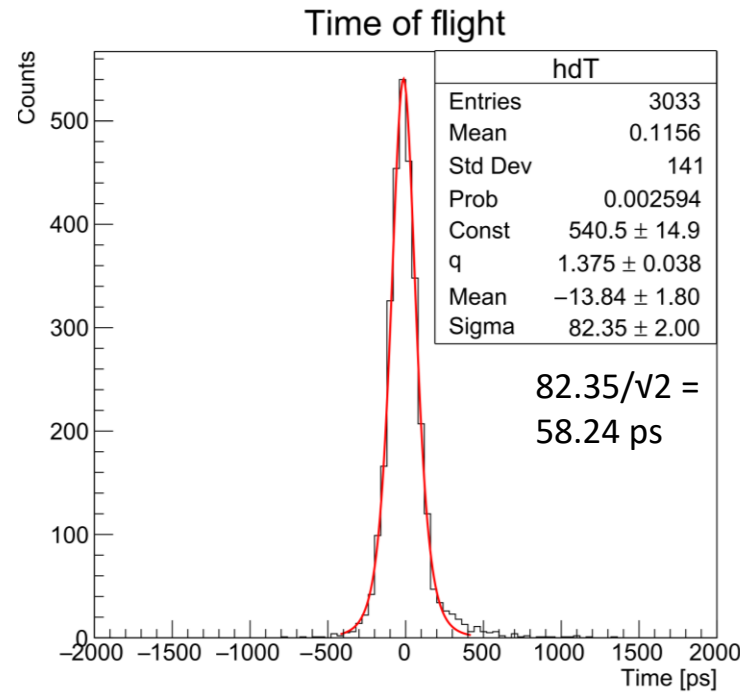
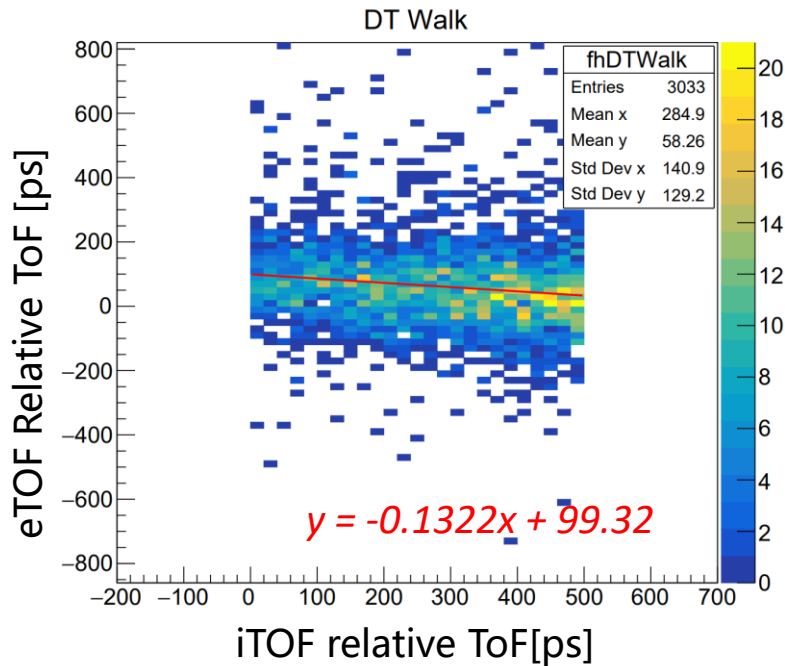
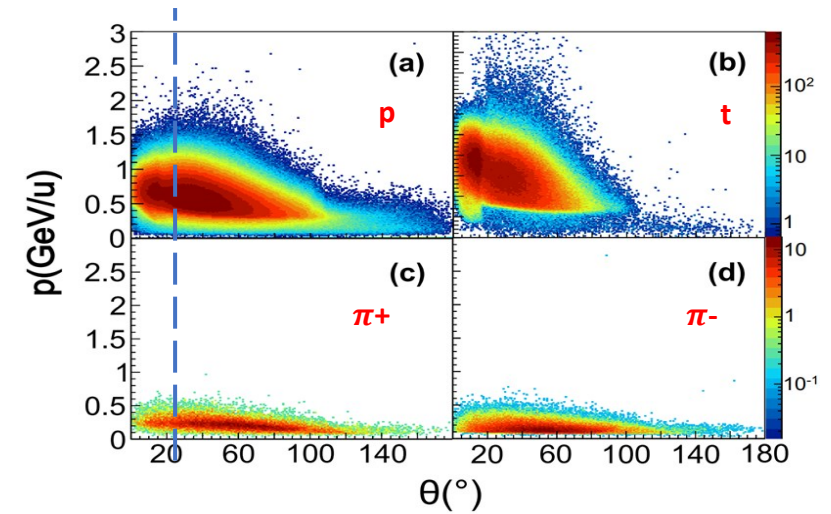
Beam test results

- HV scan conducted with >30k events in each run.
- Intrinsic efficiency: 98% @6.4 kV (1.024 kV/cm).
- Stopping effect observed on the farthest detector.
- Cluster sizes indicate similar performances.



Beam test results

- Time resolution: around 60 ps, after velocity correction.
- Position resolution: <1 cm

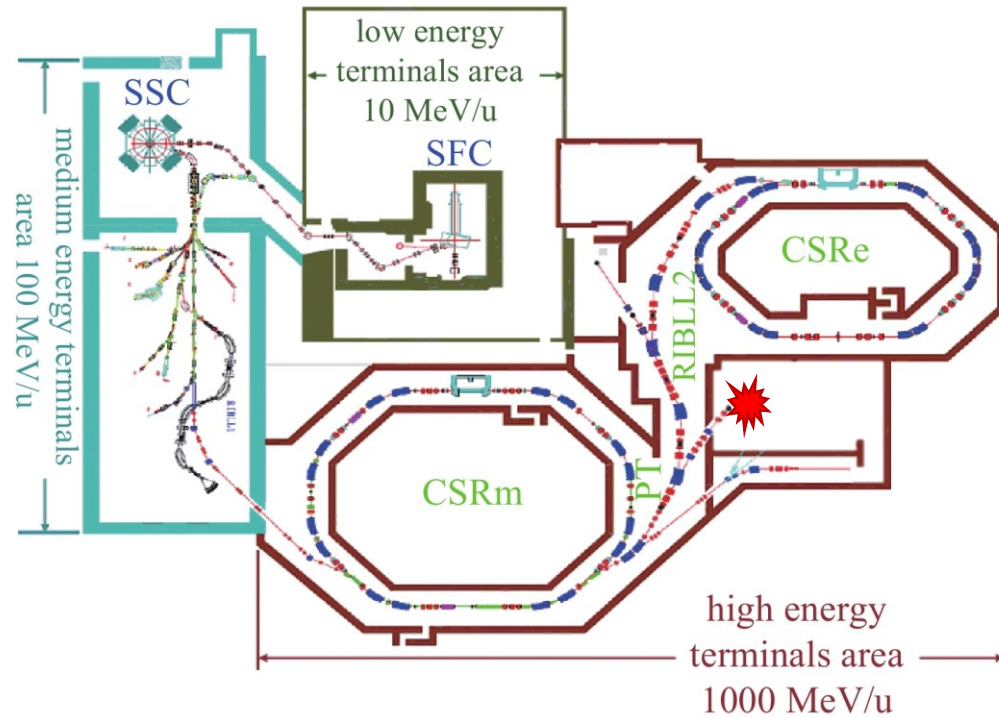


Conclusion

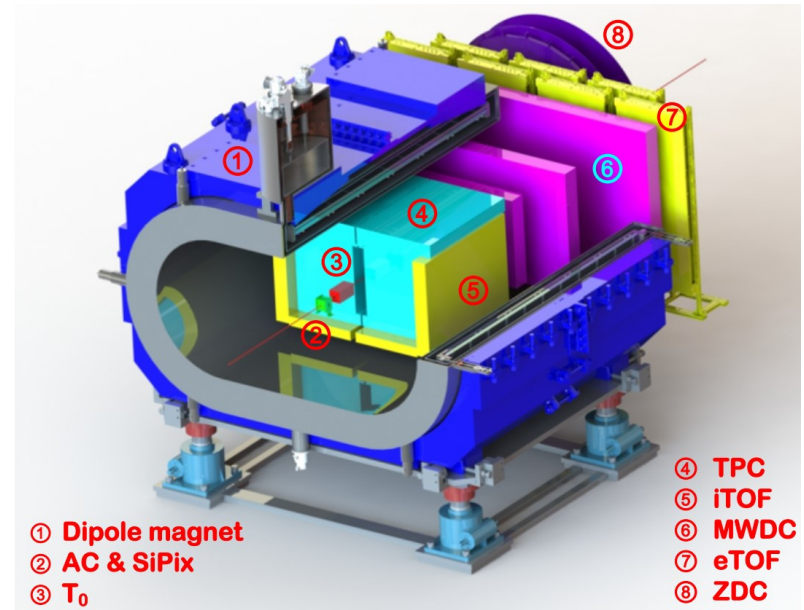
- Sealed MRPCs are applied to the eTOF wall of CEE with a time resolution requirement of 60 ps.
- Beam test was carried out for the examination of the prototypes.
- Tracking analysis was built and implemented on eTOF detectors.
- 98% efficiency and 60 ps resolution obtained, with stopping effect and velocity dependence observed.
- The beam test results strongly validate the design for CEE-eTOF. Mass production is scheduled.

Thank you!

Backup: facility



HIRFL: Heavy Ion Research Facility in Lanzhou
CSR: Cooler Storage Ring



Backup: time-slewing correction

