



MRPC of SPD-TOF

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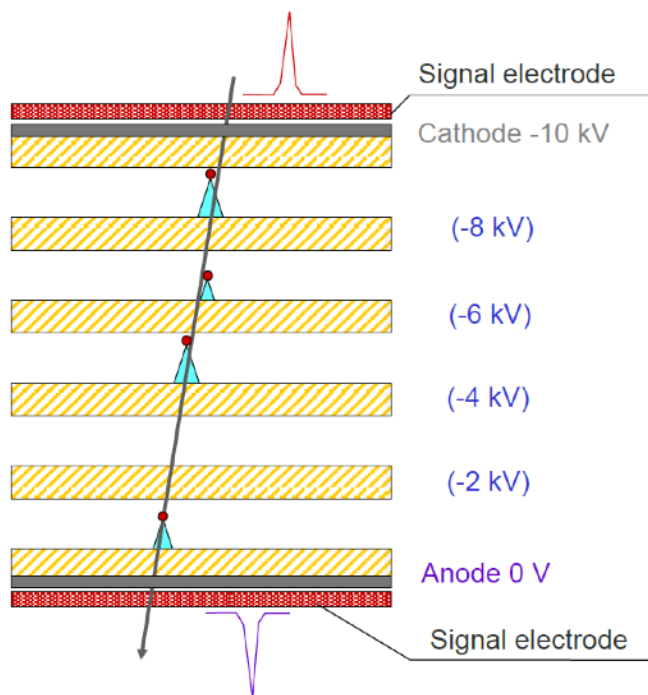


Outline

- Multigap Resistive Plate Chamber (MRPC)
- MRPC: at the R&D frontier: high rate + high time resolution
- MRPC for SPD-TOF
- Conclusions

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)x 32.8	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	20k

The next generation MRPC applications mark the higher **counting rate** and **time precision**.

Expanding the MRPC rate capability

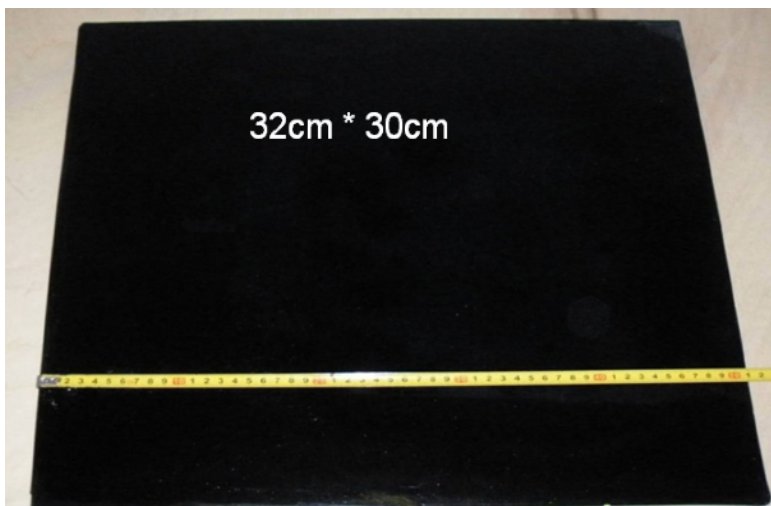
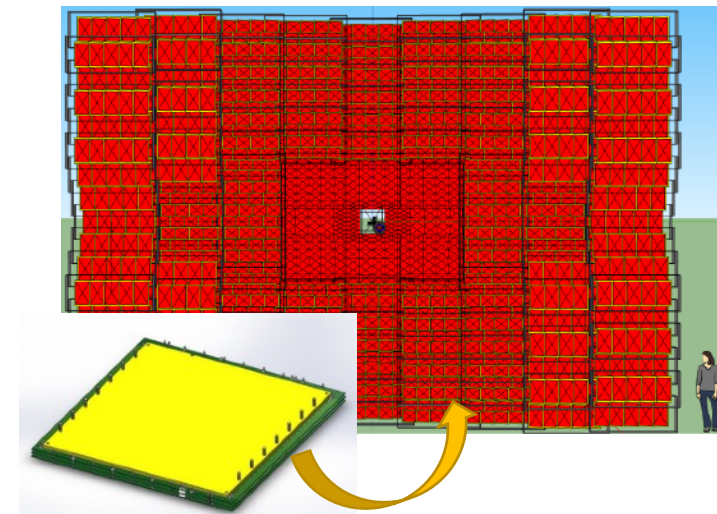
- One must control the voltage drop (efficiency loss) when incident flux goes up.

$$V_{gap} = V_{ap} - \bar{V}_{drop}$$

$$\bar{V}_{drop} = \bar{I}R = \bar{q}\Phi\rho d$$

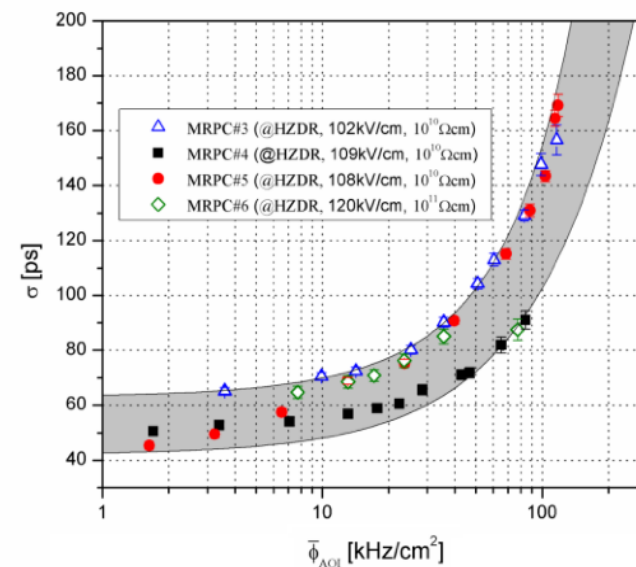
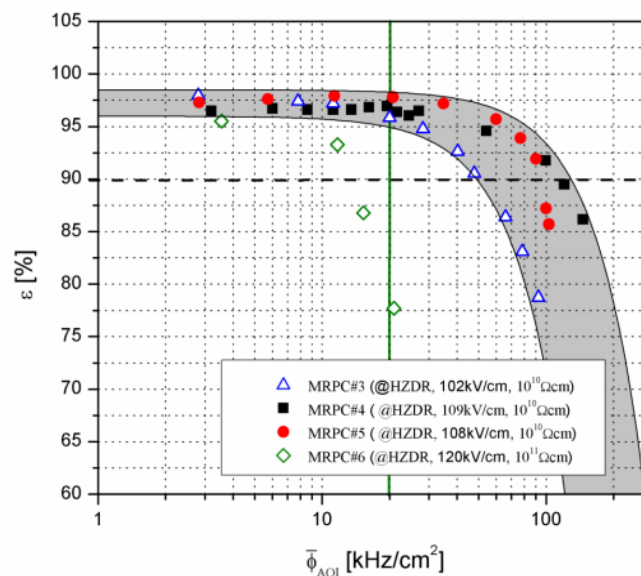
Decrease the resistivity of the electrodes

- MRPC2 with low-resistive glass will be applied in CBM-TOF wall, and has been operating at FAIR-Phase 0 programs like STAR-eTOF and mCBM



With the low-resistive glass developed in Tsinghua, resistivity has decreased by 2 orders of magnitude. (common float glass: $10^{12} \Omega\text{cm}$, low-resistive: $10^{10} \Omega\text{cm}$)

Rate capability verified through beam test: 93%, 80ps@70kHz/cm²

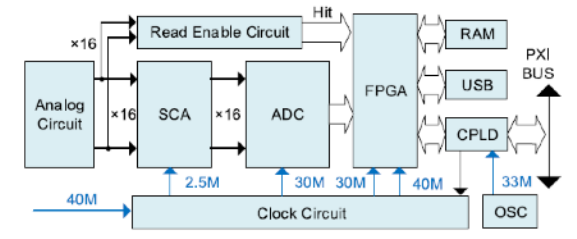
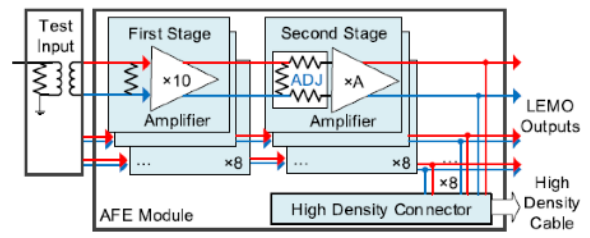
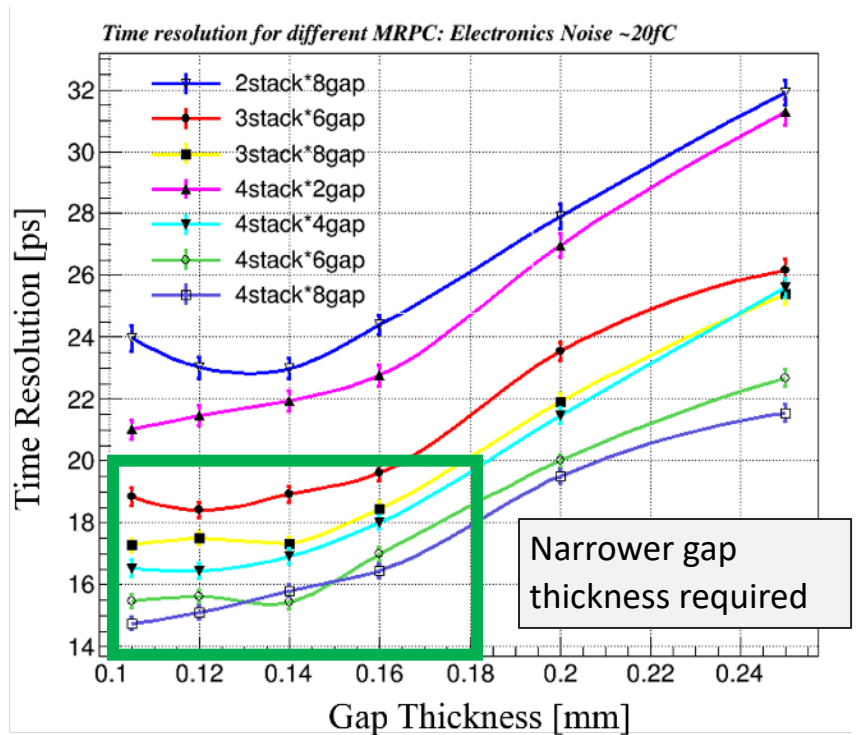


Towards a time precision < 20 ps

Time over Threshold (ToT) method
– Leading and trailing time

Simulation indicates proper ways to design the gap thickness and arrange the stacks

Waveform sampling technology



Nucl. Instrum. Meth. A 925 (2019) 53.

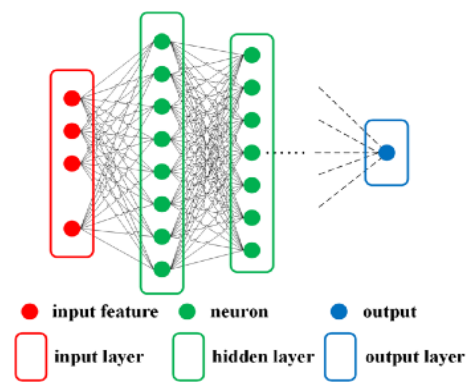
σ_t Fast-End Electronics:
Bandwidth: 1.4 GHz
Gain: 26-40 dB
Noise (NSD): < 1.5 nV/√Hz



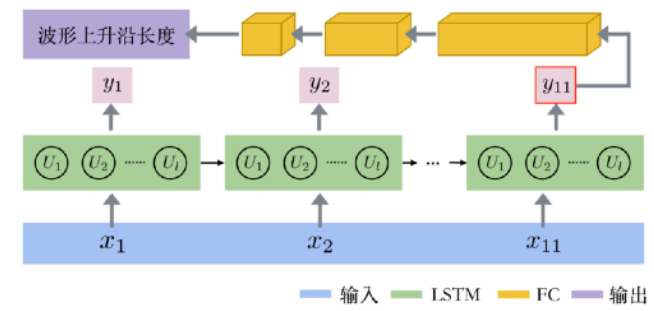
σ_t Waveform Digitization:
Sampling freq.: 5 GS/s < 5 ps
Noise ampl.: 0.5 mV

Waveform provides detailed information of avalanche that allows more calibration methods.

Besides the 'intrinsic' time resolution of the detector, it is also crucial to develop an **advanced readout technique**.



An MLP neural network for position calibration

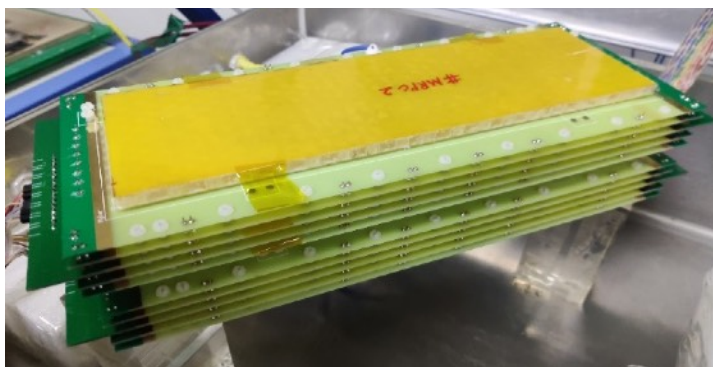


An LSTM model for signal leading edge recognition and time calibration

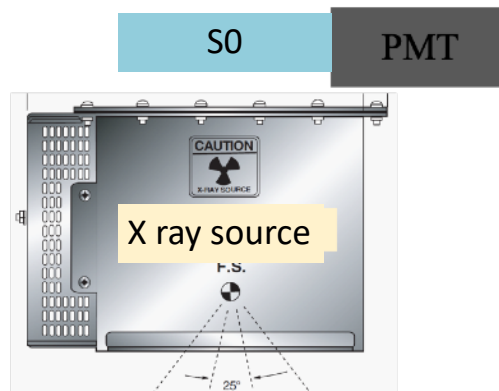
The high-rate high-resolution prototype

Two prototypes have been assembled and tested.

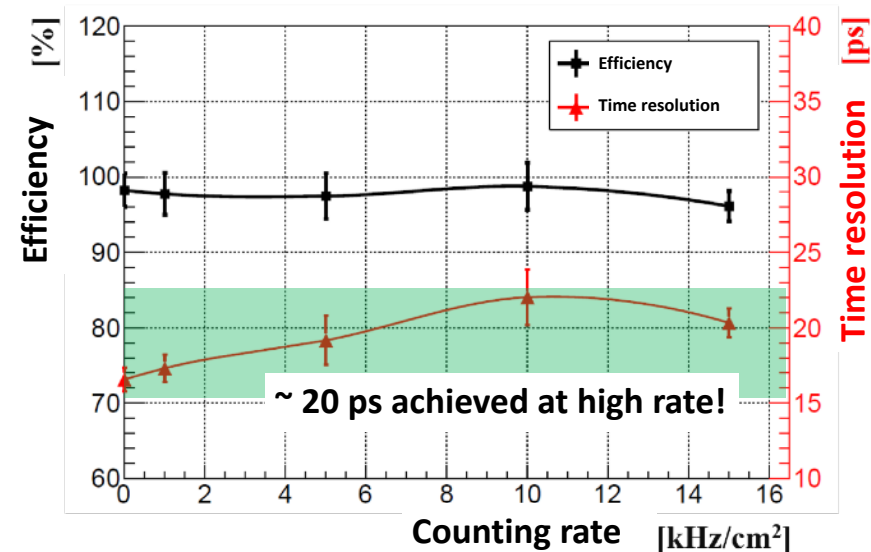
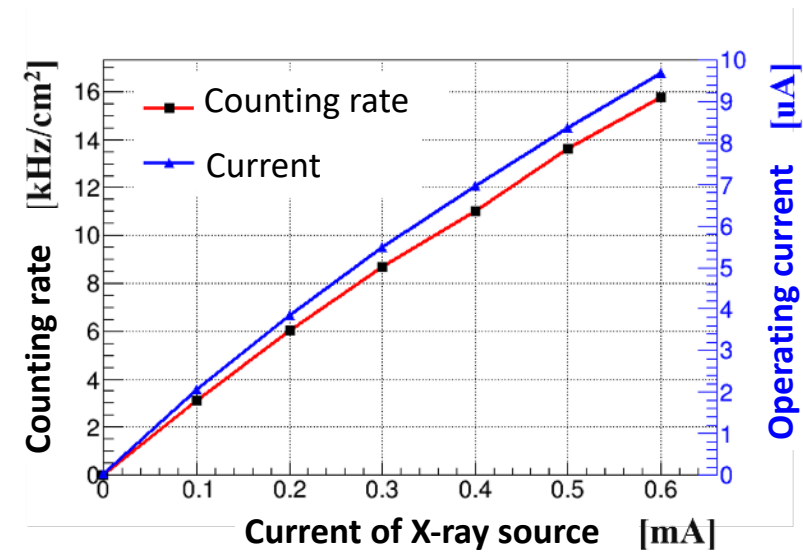
Parameter	Value
Gap thickness (mm)	0.128
N of gaps	4 x 8
glass	Low-resistive
Glass thickness(mm)	0.4
Strip interval (cm)	0.5 width + 0.2 gap



The high rate test is carried out by discriminating cosmic event in X-ray irradiation.



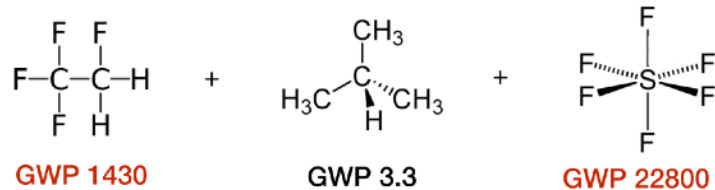
Top MRPC
Bot MRPC



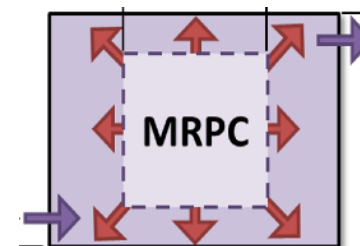
Gas-related challenges of MRPC

Regulations against greenhouse gases causes uncertainty:

availability, cost, eco-impact, ...

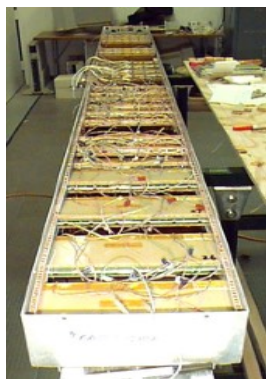


Gas pollution effect in high rate conditions



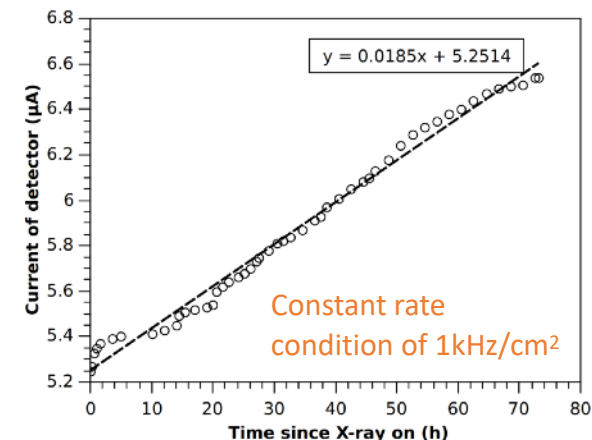
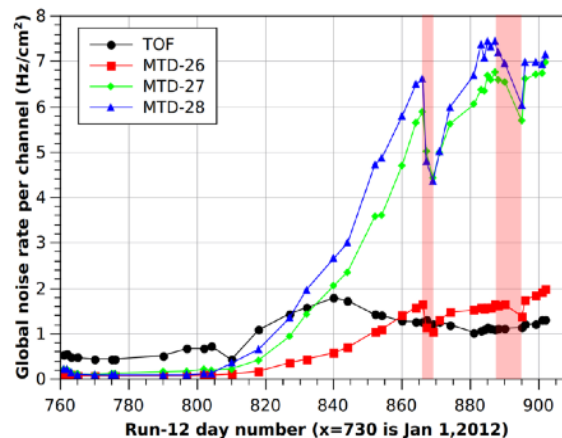
Narrow gap of MRPC and large gas volume --- ionization products exchanged slowly by **diffusion**

Application with large area: gas flow, cost, leakage, ...



STAR-TOF (left) and CBM-TOF (right) detectors in gas boxes forming a module

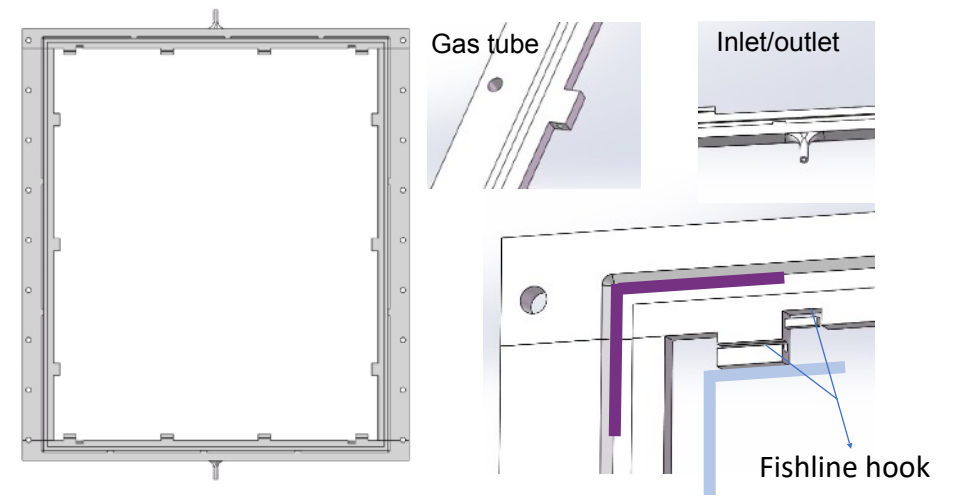
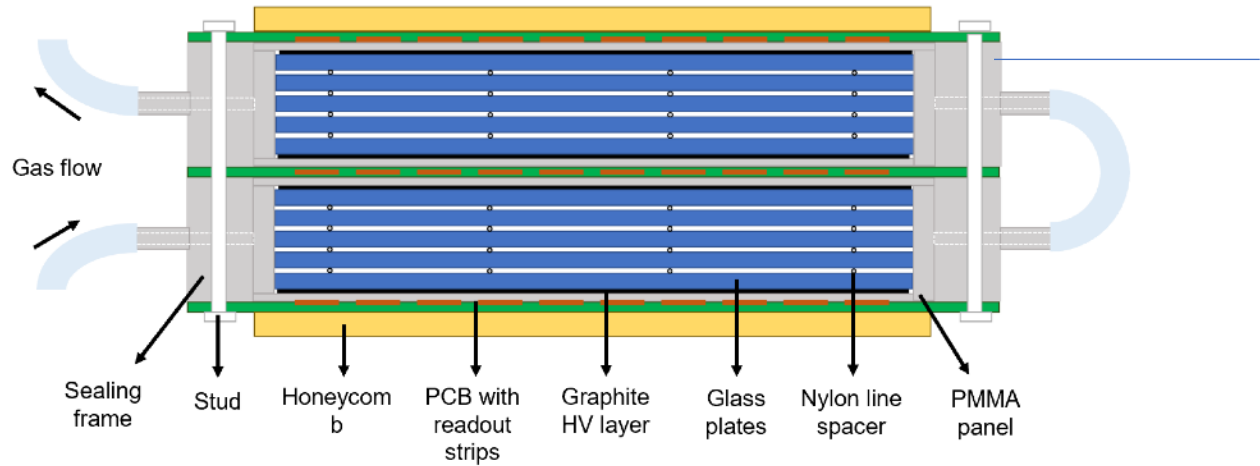
...observed in HEP experiments and lab tests.



Pollution caused noise and current rise

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

Sealed MRPC

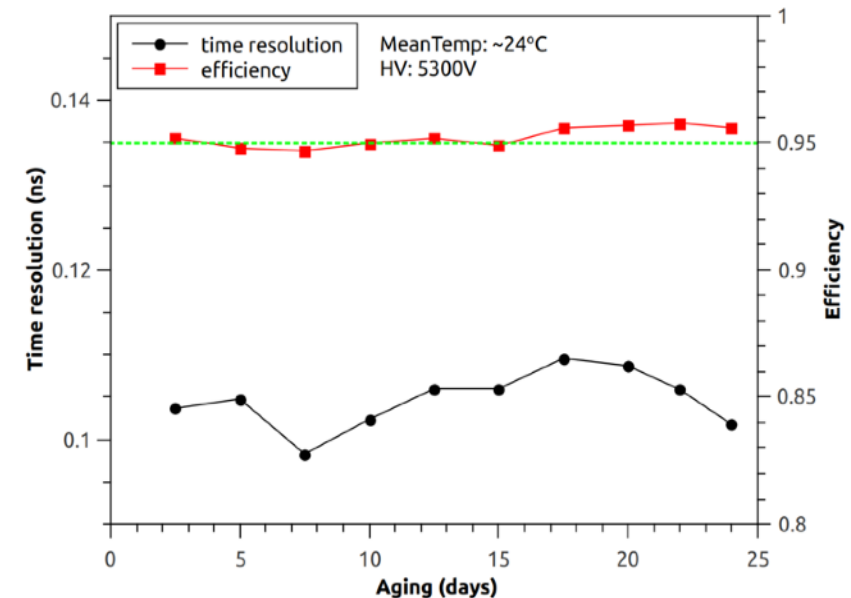


3D printed sealing frame with Good strength, insulation and radiation persistency

- With the lateral side mostly enclosed, the counter itself becomes a gas box. The sealed design brings the features of:

1. **Gas saving:** 20 sccm/m² gas flow with common practice

With cosmic ray test of a counter, 1 mL/min flow is examined with stable operation for the tested 24 days!



Sealed MRPC

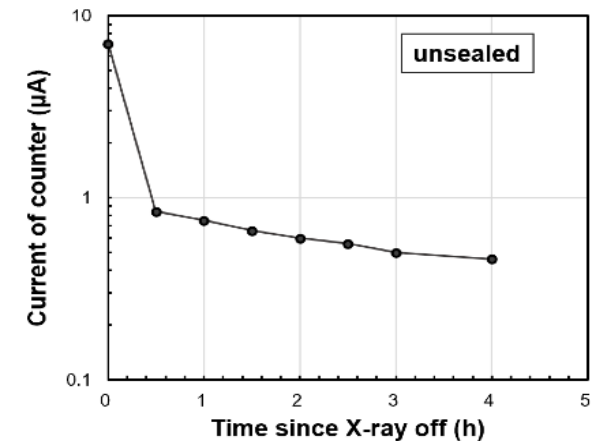
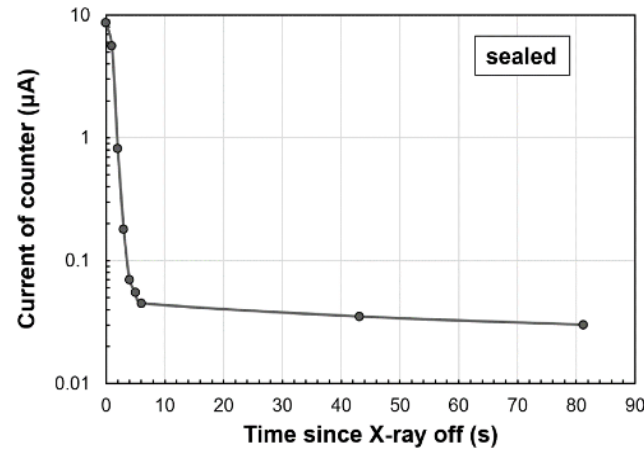
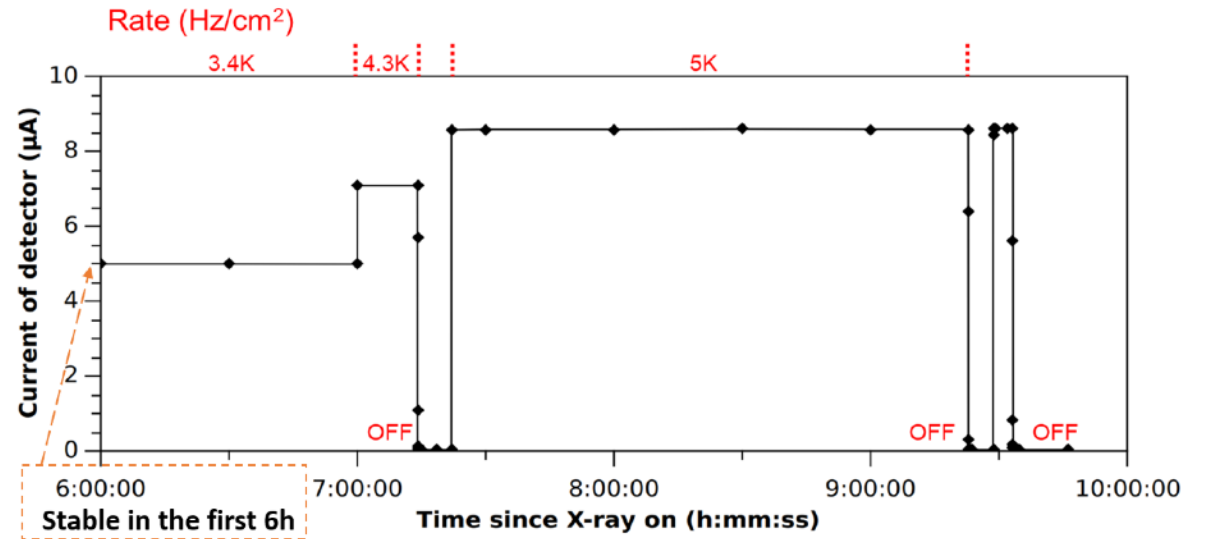
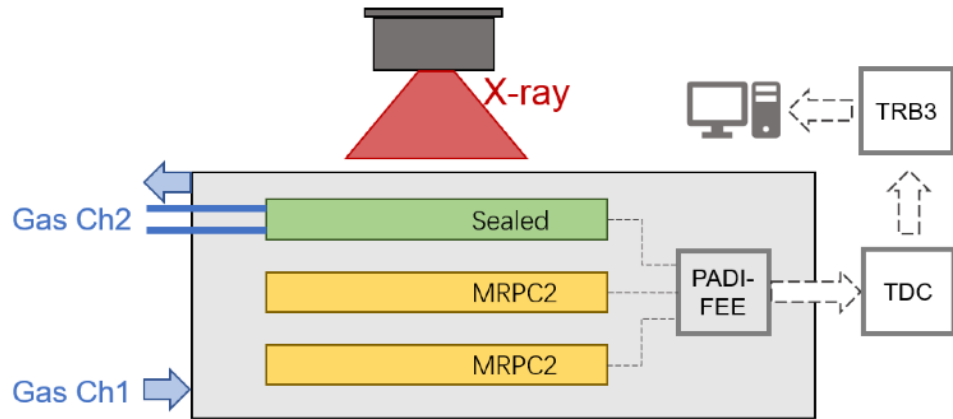
2. Promoted gas exchange

Decrease the wait time of gas purging:

- Reach the working HV in 2h since flowing the gas

Excellent current behavior under high rate irradiation:

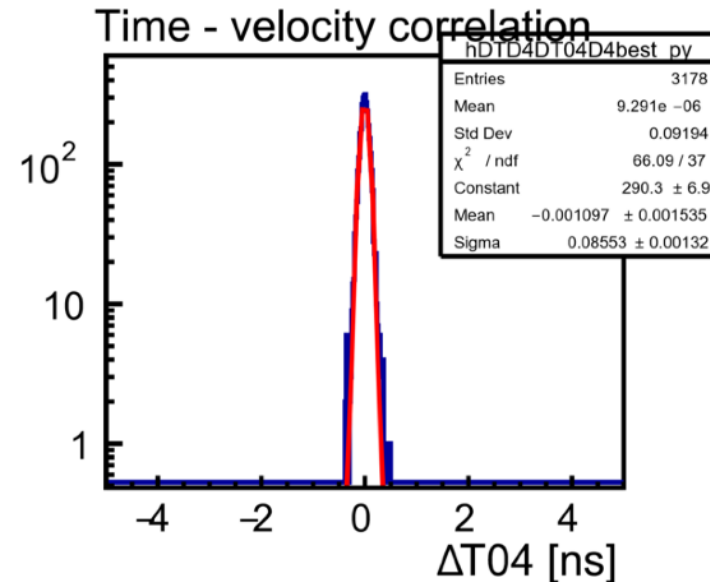
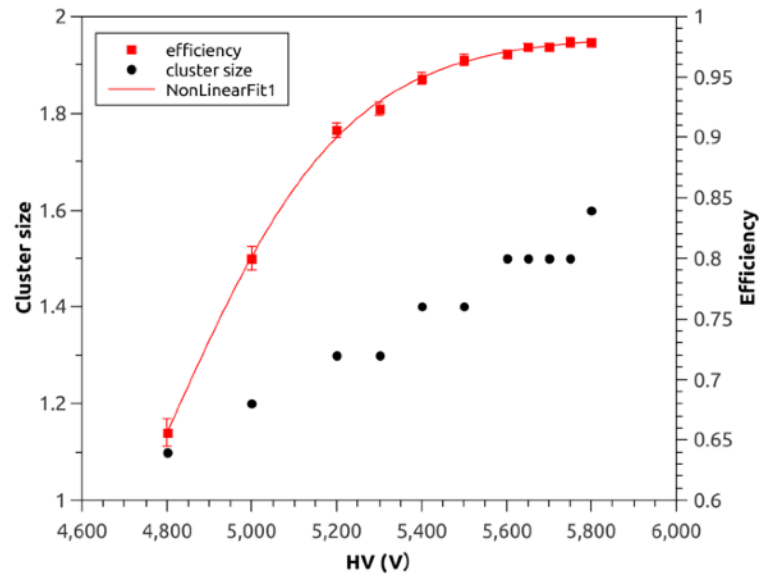
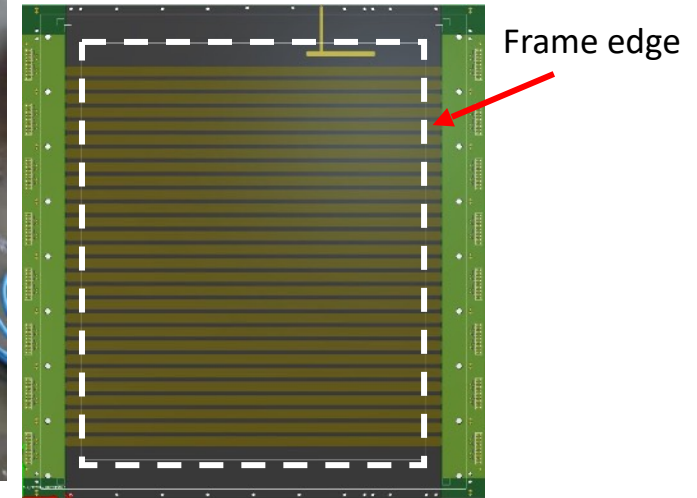
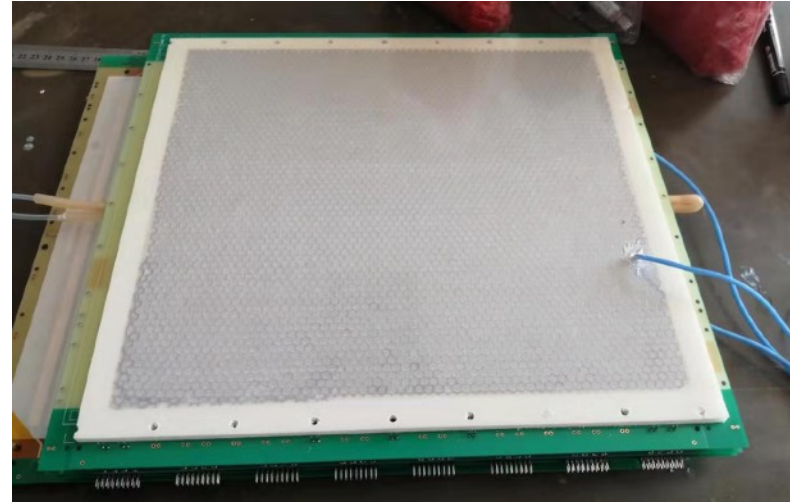
- Stable current with constant rate condition.
- Fast decay of dark current since when X-ray is off



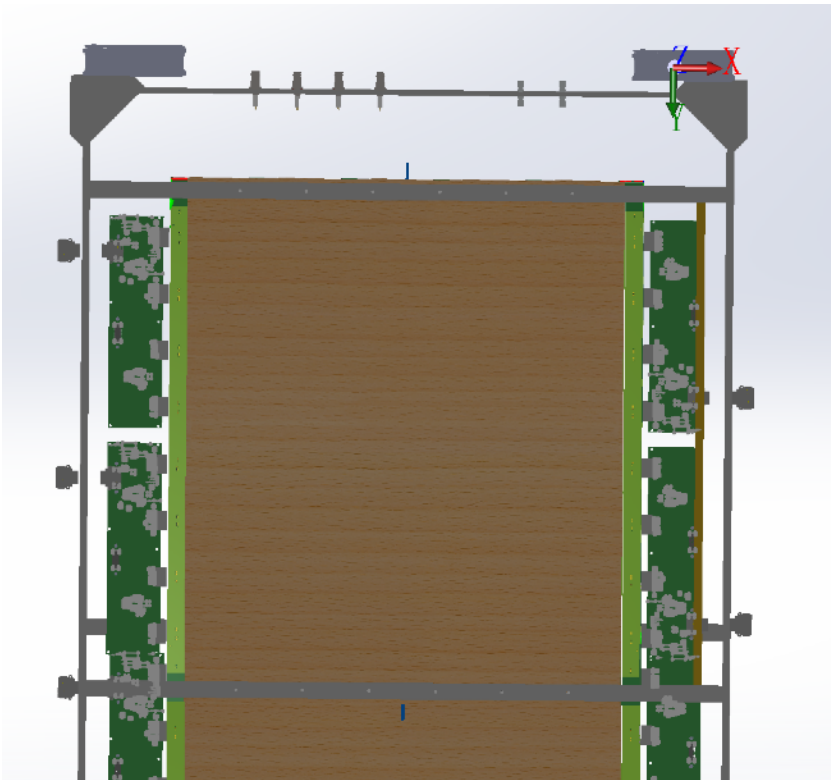
The real prototype for CEE-eTOF

Structure of sealed MRPC prototype

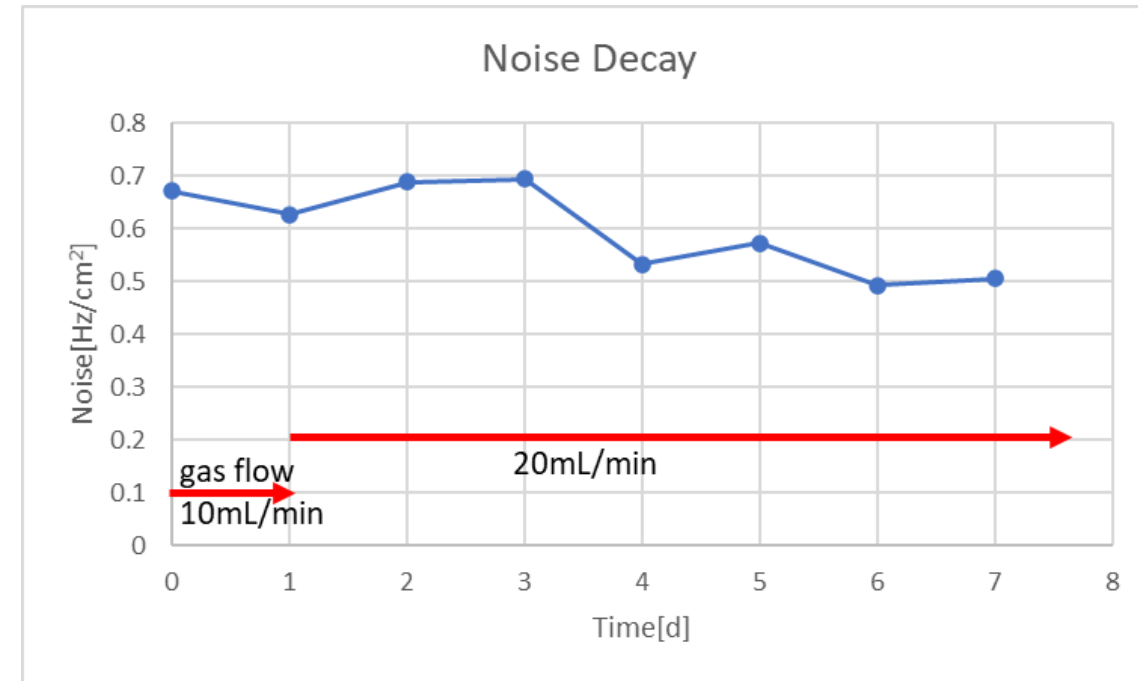
- 2 stack * 5 gas gap * 0.25mm
- Float glass plates of 0.7mm width
- 32 channels, differential signal
- 2-end readout
- Strip length 27cm, 7mm width+3mm gap
- Sealed design, total gas volume ~170ml



The super module with 4 MRPC



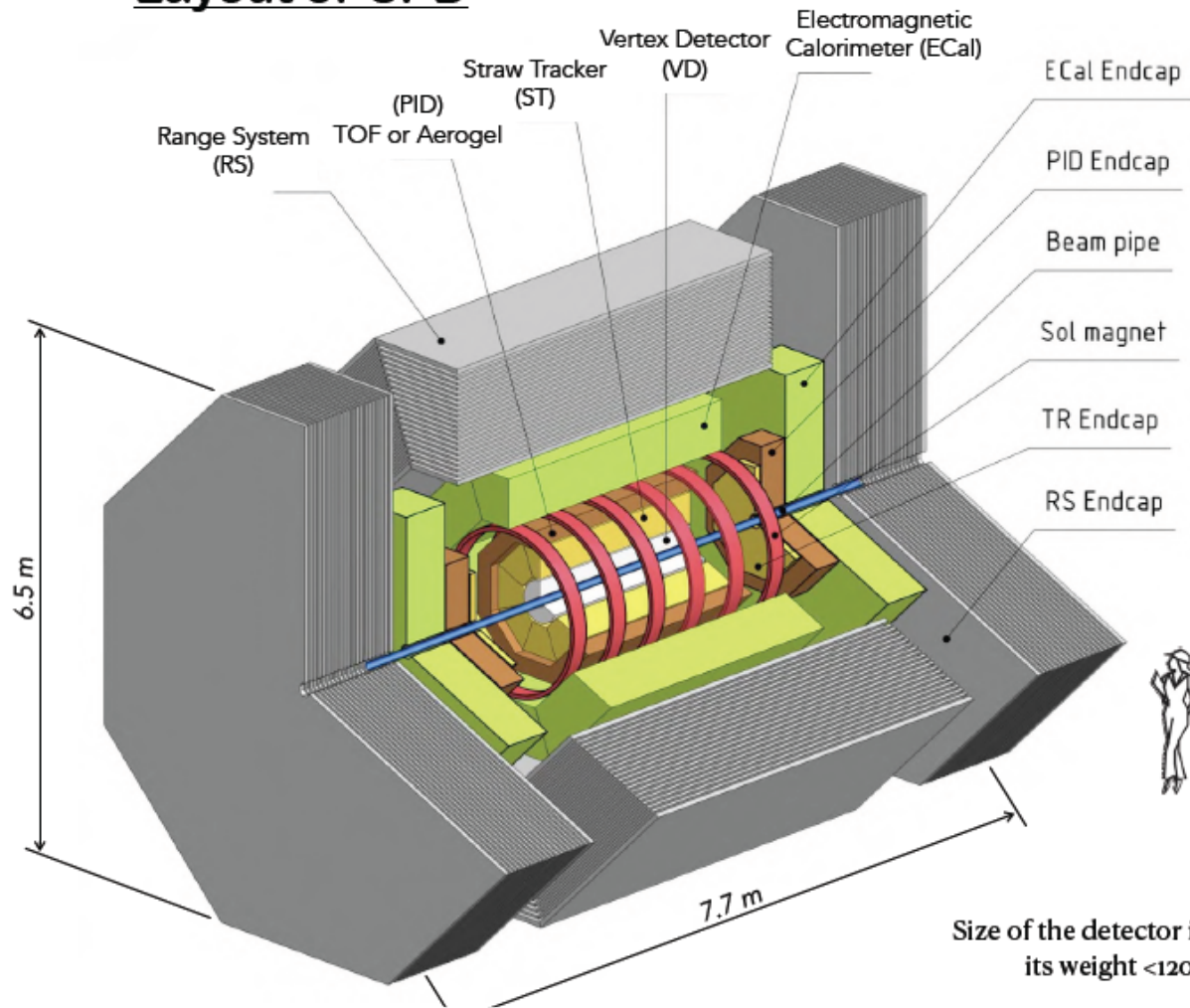
- Four MRPCs, total detection area $\sim 1\text{m}^2$
- Working gas: Freon, 20sccm
- HV: $\pm 6.5\text{kV}$
- Total dark current: 70nA



- Noise level $< 0.5\text{ Hz/cm}^2$
- Become better after long time training

Layout of SPD

Layout of SPD



Size of the detector is limited by its weight <1200 ton

Requirement for TOF system

- PID : e few GeV at distance of 108cm
- Time resolution: 70ps
- Particle rate: 100Hz/cm²
- Total area: 27m²

Structure of barrel TOF

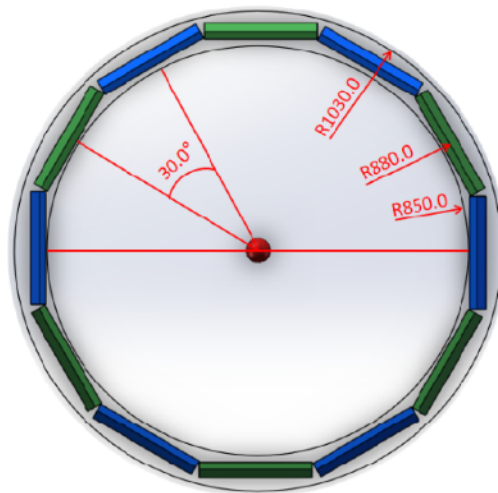
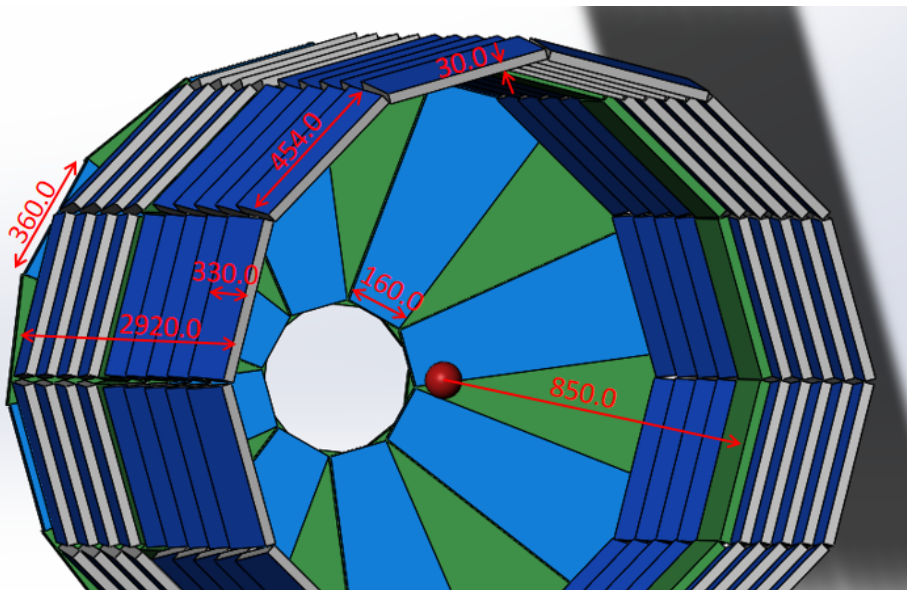
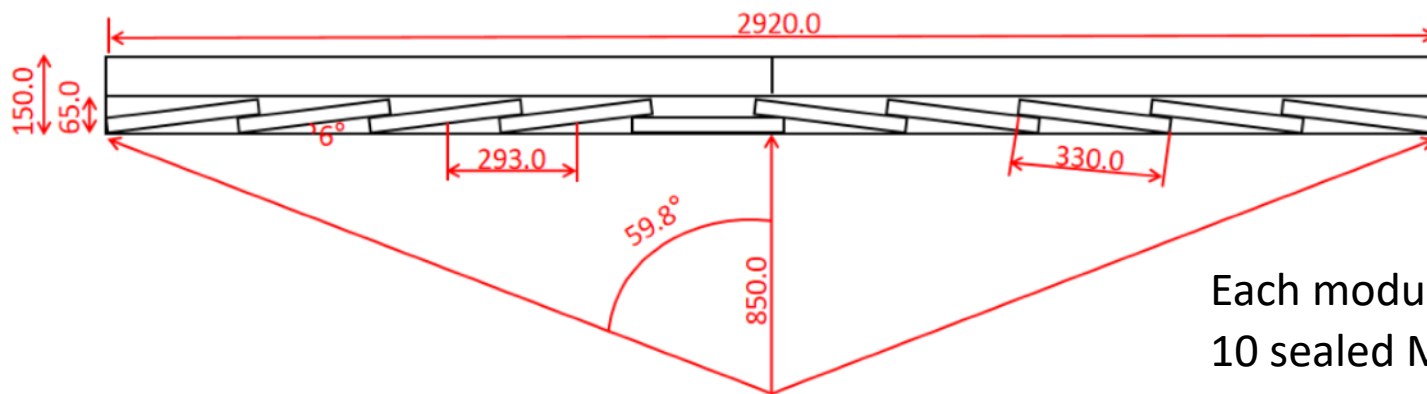


Figure 1.1 Main sizes of the TOF barrel in ϕ direction.

12 module for
one circle

Table 1.2 Main parameters of one MRPC detector in the Barrel

Name of component	Dimensions (mm)	Quantity
Honeycomb	$300 \times 450 \times 6$	2
PCB	$330 \times 454 \times 0.8$	5
Mylar	$300 \times 450 \times 0.25$	8
Float glass	$300 \times 450 \times 0.3$	28
Gas gap	0.128	24
Readout strip	$454 \times (10+2.5)$	24



Each module consists of
10 sealed MRPC

Figure 1.2 Arrangement of MRPCs inside the box along the beam direction.

Structure of end-cap TOF

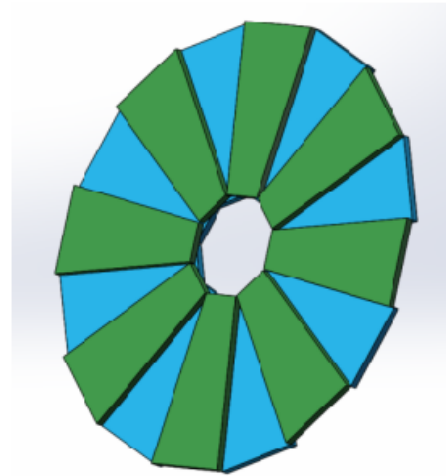
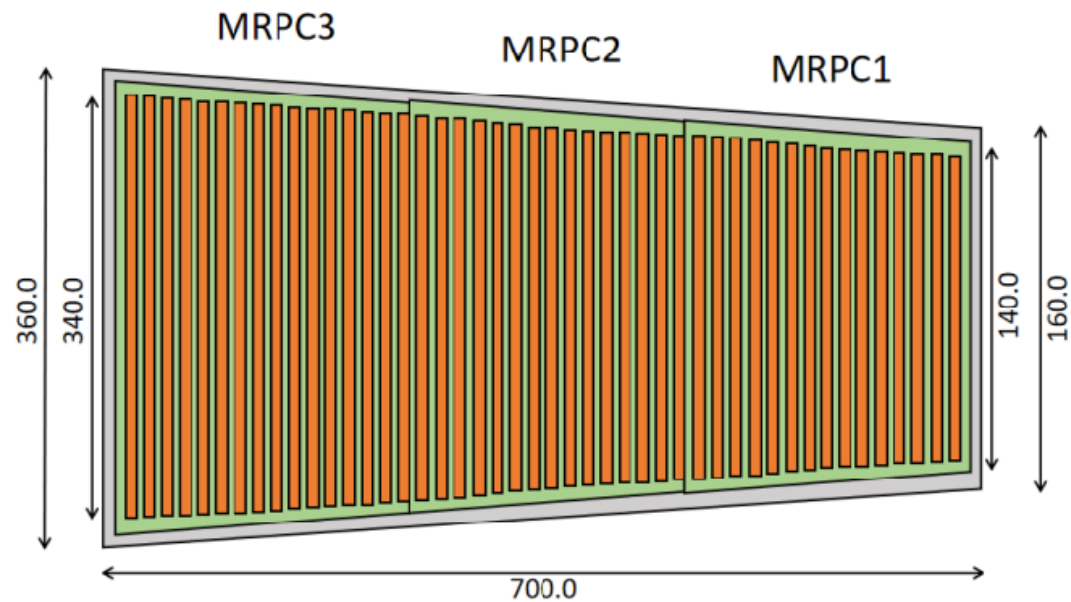


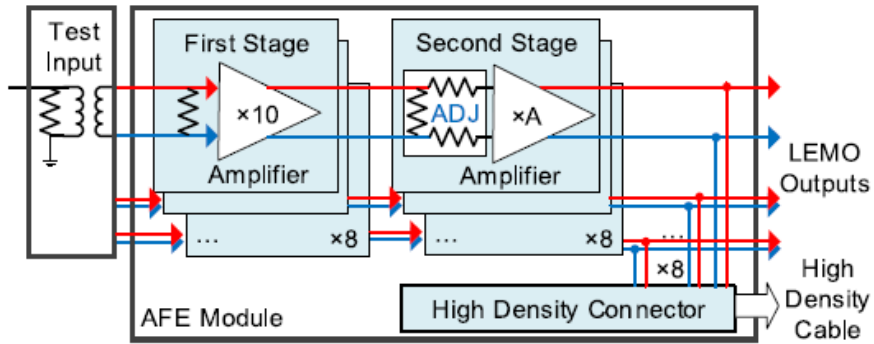
Table 1.3 Main parameters of one MRPC detector in the End-cap

Name of component	Dimensions (mm)	Quantity
Honeycomb	$216 \times (336 \sim 136) \times 6$	2
PCB	$246 \times (340 \sim 140) \times 0.8$	5
Mylar	$216 \times (336 \sim 136) \times 0.25$	8
Float glass	$216 \times (336 \sim 136) \times 0.3$	28
Gas gap	0.128	24
Readout strip	$(340 \sim 140) \times (10 + 3.5)$	16

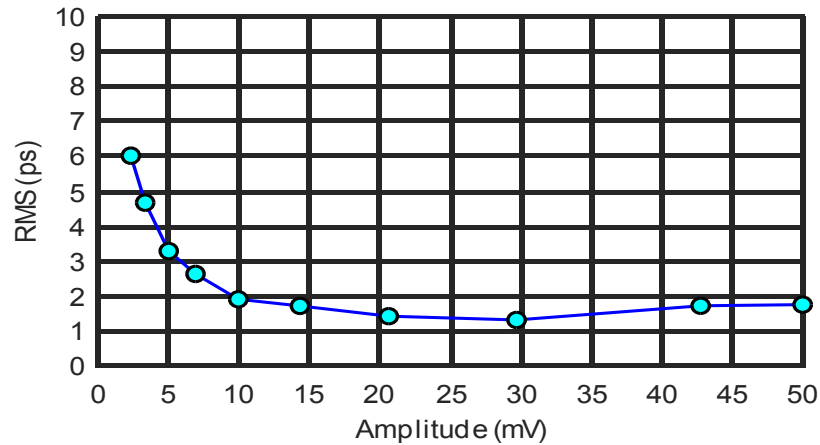
Figure 1.3 Arrangement of MRPCs inside the box in the End-cap.

eTOF consists of 16 modules and each module consists of 3 sealed MRPC.

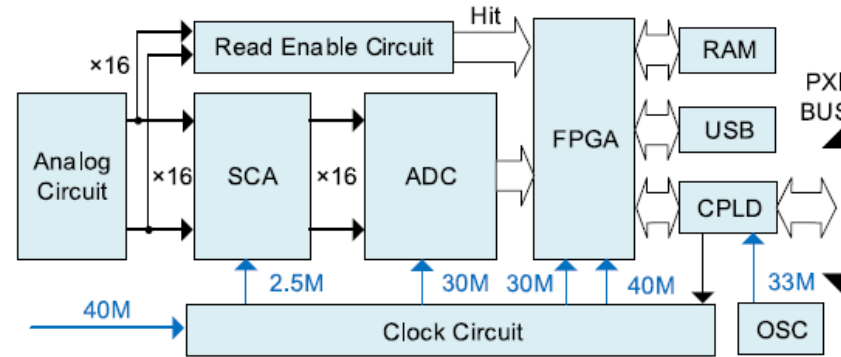
Fast amplifier+Pulse shape digitizer



Fast FEE by USTC



- Gain: 26 dB~40 dB
- Band width: 1.4 GHz
- Time jitter: 4 ps



Time digitizer

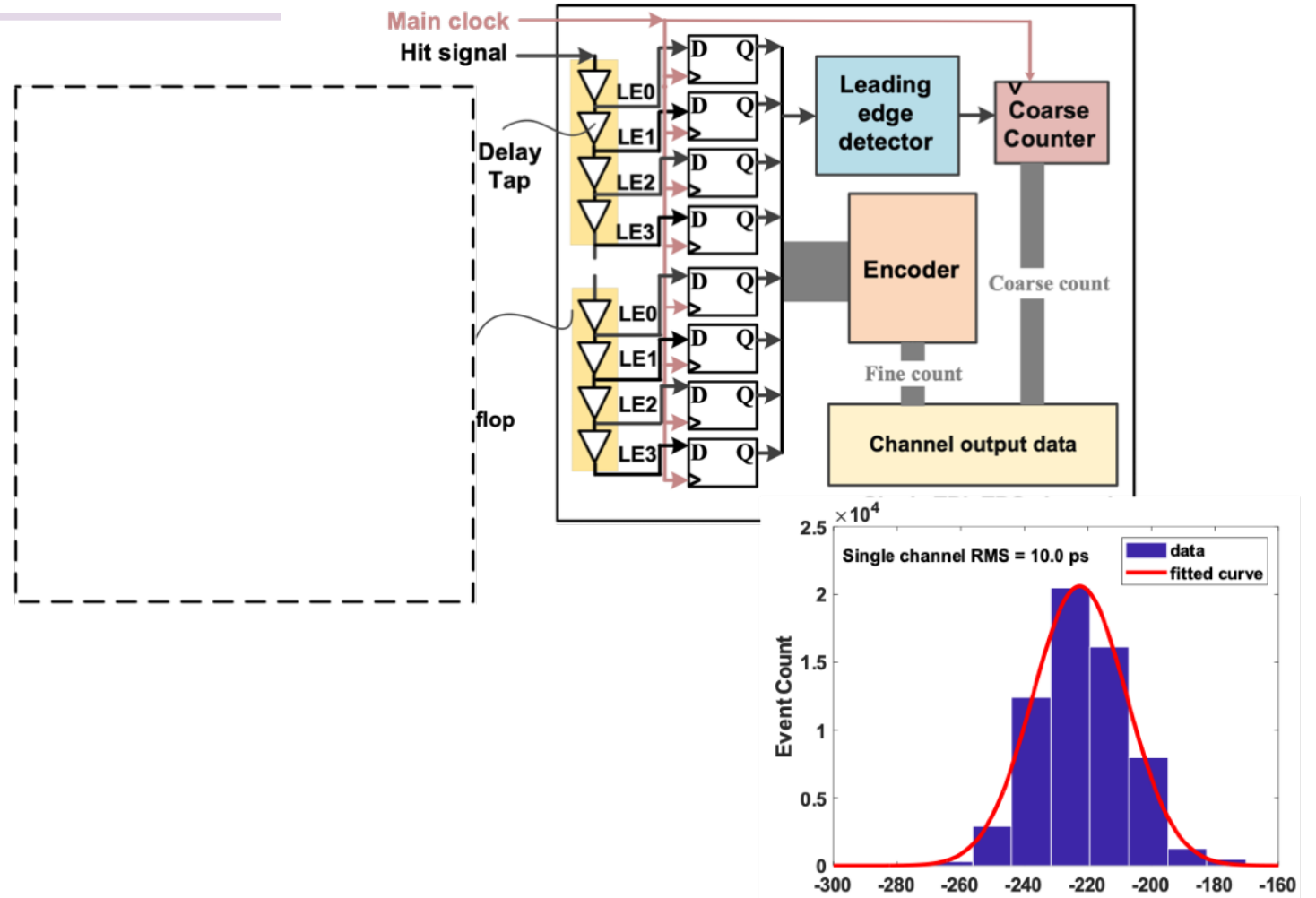
- SCA (DRS4): 1024 sampling capacitor
- Max sampling rate: 5.12 GHz
- Noise: 0.5 mV
- Time jitter: 3 ps

Nucl. Instrum. Meth. A 925 (2019) 53.

Ninos + FPGA-TDC

Ninos Asic specifications

Parameter	Value
Number of channels	8
Peaking time	1 ns
Supply voltage	2.5 V
Power consumption	27 mW/ch
Input signal range	30 fC – 2 pC
Noise (with detector)	$< (2.5 - 5) \times 10^3$ e- rms
Discriminator threshold	10 fC to 100 fC
Differential input impedance	$40 \Omega < Z_{in} < 75 \Omega$
Timing precision	< 10 ps jitter
Outputs	LVDS



Time precision is about 10ps !

Summary

- Future HEP experiments calls for MRPCs with high rate capability and excellent time resolution.
- Low-resistive electrodes help expand the rate capability.
- Narrow gap width and advanced readout chain help improve the timing performance.
- Prototype has been examined its 96% efficiency and 20 ps resolution at 20 kHz/cm² rate condition.
- MRPC faces gas related challenges which motivates an enhanced gas exchange.
- Sealed MRPC with low gas volume can be used in SPD-TOF.

Thank you !