Study of time resolution of MRPC for cosmic rays and 0.511MeV photons

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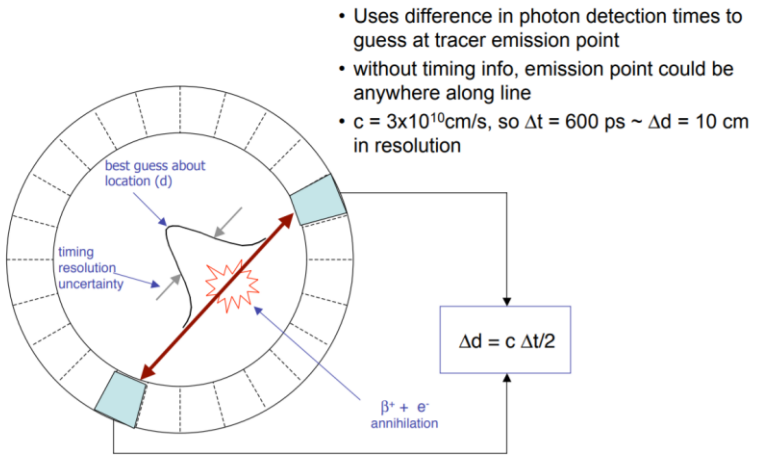
2022-9-28

Research background

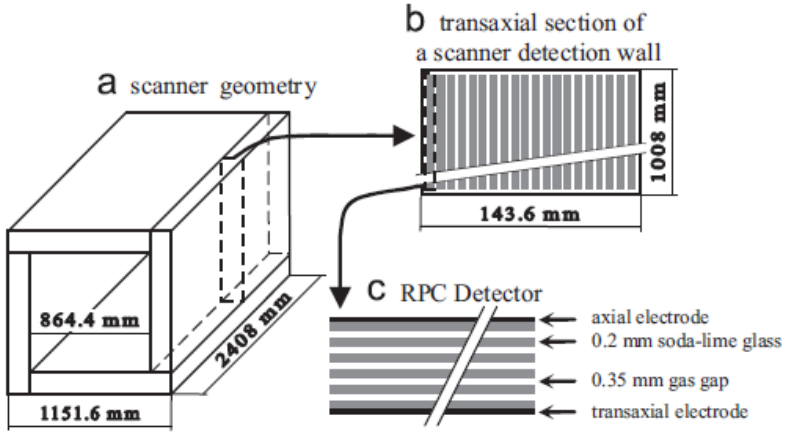


■ Traditional TOF-PET

Scintillator detector + PMT

- ➢ Time resolution is not high > 50ps
- ➢ Thickness of the scintillator > 3cm
- ➢ Low reception, information is wasted

→ Long detection time, poor accuracy



[M. Couceiro et al. Portugal 2012]

■ MRPC TOF-PET

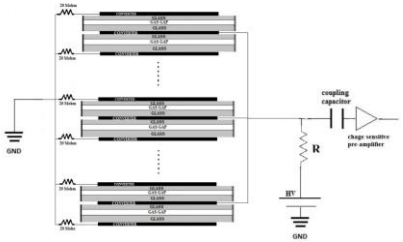
Advantages

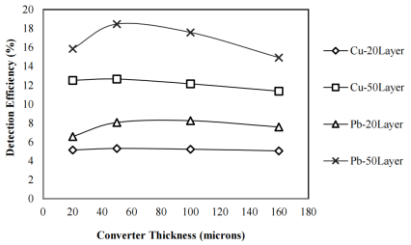
- ➢ Excellent time resolution < 20ps
- ➢ Ultrathin sensitive zone ~ 100μm
- ➢ Large area → whole body PET

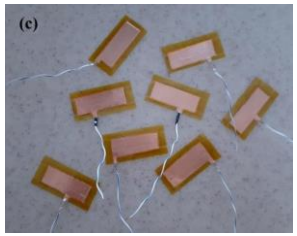
→ Make up for the low efficiency for γ

Others' work

- **20 gas gaps double-stack MRPC with Multi-layer Copper Converters**







[S. Razaghi et al. 2021]

- **Monte Carlo simulation study of RPC-based 0.511MeV photon detector**

[W. Zhou et al. 2014]

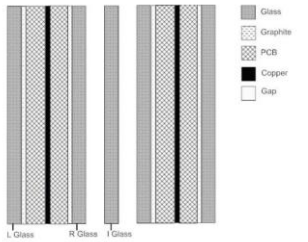
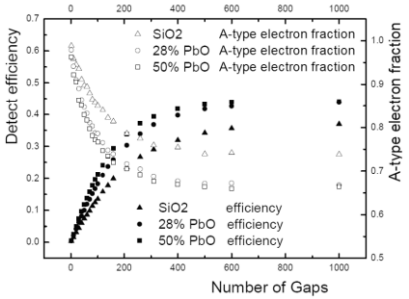
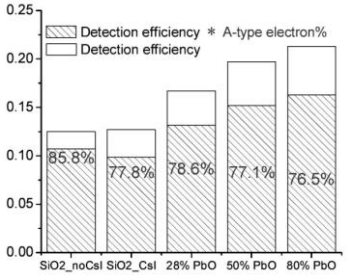
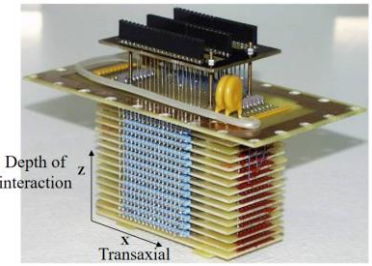


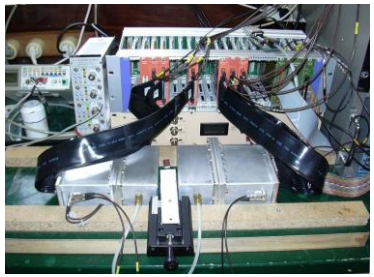
Figure 1. Detector structure of the RPC-based PET unit.

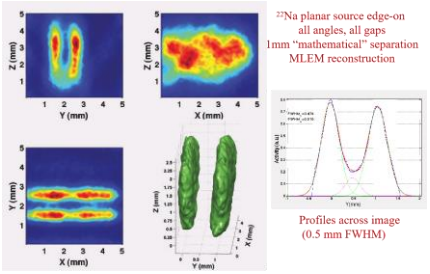




- **RPC-PET for small animals**







[Paulo Martins et al. 2014]

Improve the detection efficiency by increasing the number of converters and gas gaps

→ low time resolution, poor positioning accuracy, high cost for too many electronic channels

Our research route

★ **Develop a 4-stack 8-gap MRPC prototype with 128μm gas gap**

☑ Time resolution for cosmic rays < 20 ps ; for gamma < 70 ps

★ **Make a thin 8-gap MRPC prototype with 128μm gas gap**

☑ Sensitive area thickness < 5mm

☐ Time resolution for cosmic rays < 20 ps ; for gamma < 20 ps

★ **Build a TOF PET system**

Place Ten 8-gap MRPCs on each side of 22Na for positioning

The electronics of each MRPC are read out separately

☐ Positioning accuracy < 3mm

★ **Create a high efficiency, high time resolution RPC prototype**

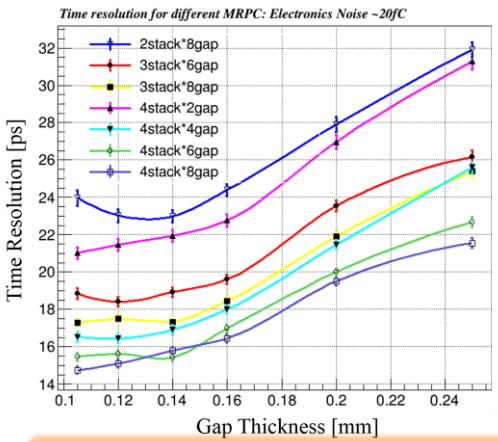
☑ Sensitive area thickness < 3mm

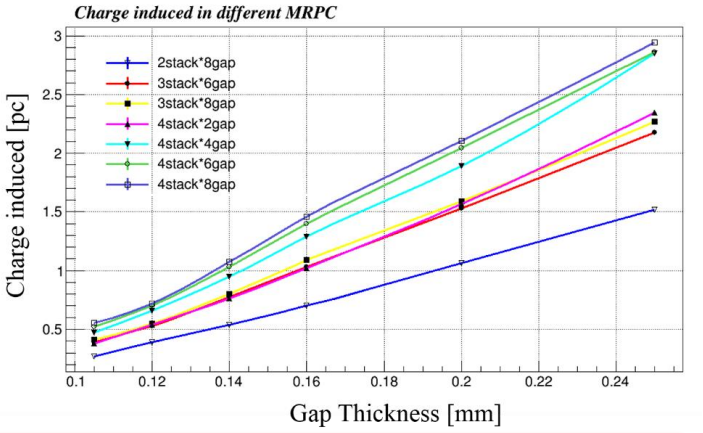
☐ Time resolution < 20 ps

☐ Detection efficiency > 10%

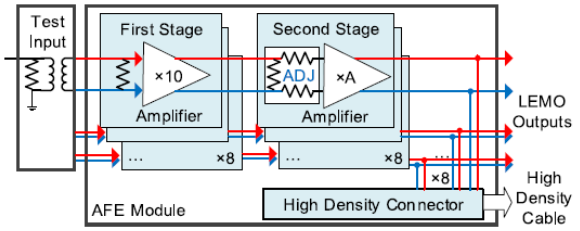
☐ Energy resolution < 20%

Our studies

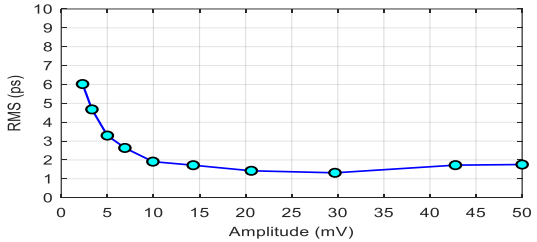




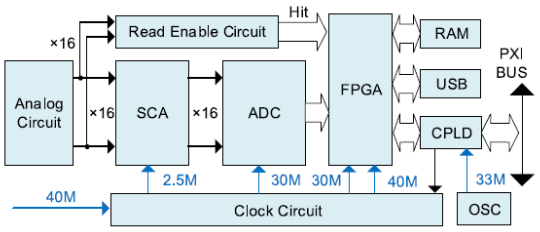
- Gas thickness < 160μm， numbers of chamber > 3 ，
  numbers of gas gap in each chamber > 4 → **20ps**
- The thinner the gas gap thickness or the more the number of gas gaps, can't significantly improve the time precision.
- Optimize MRPC ~ Gas thickness 104μm → **128μm**



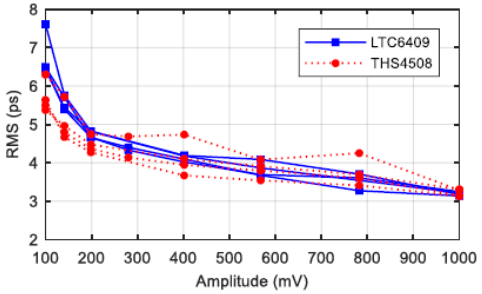
front-end electronics module



- Gain is 26 dB ~ 40 dB
- Bandwidth is 1.4 GHz
- Time jitter < 4 ps



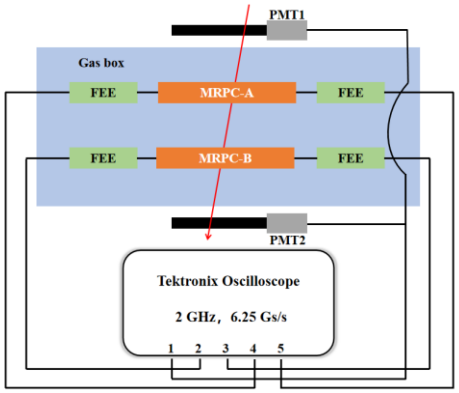
waveform digitization module

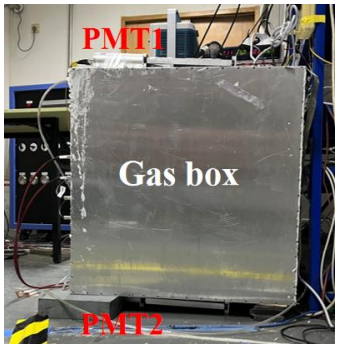


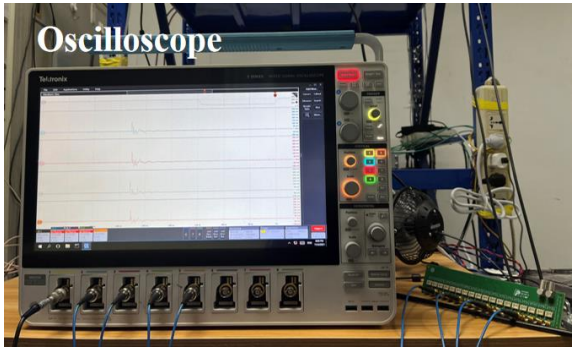
- Switched Capacitor Array ~1024 sampling capacitors
- Maximum sampling frequency ~ 5.12 GHz
- noise ~ 0.5 mV
- Time jitter < 8 ps

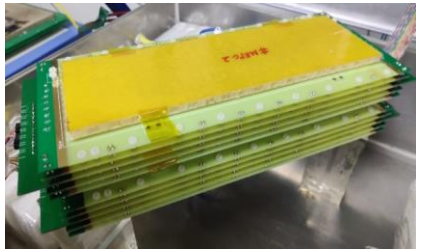
Cosmic ray test

MRPC prototype + Fast amplifier + Waveform digitization module

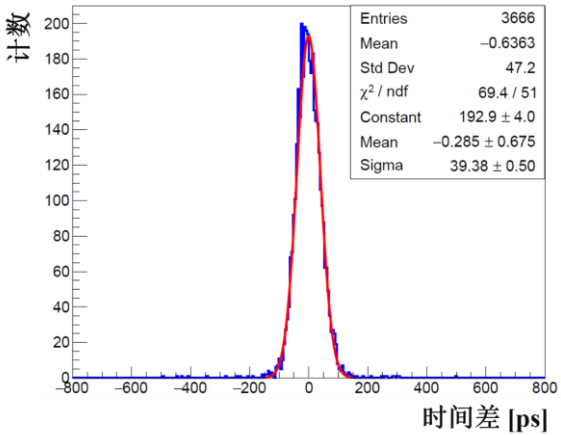




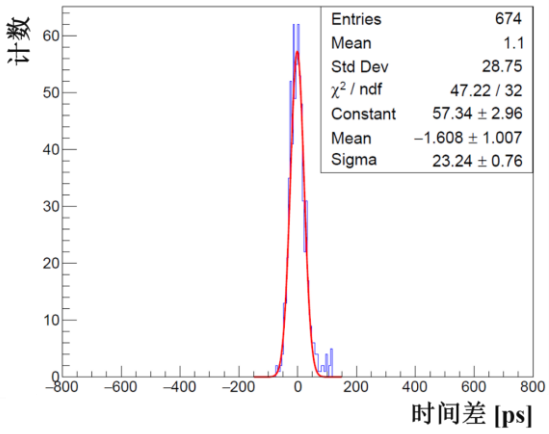




	MRPC prototype
gas gap thickness	128 μm
number of gas gaps	4 chambers × 8 gaps
glass material	**low resistivity glass**
glass thickness	400
readout strips	5 mm in width (2 mm clearance)

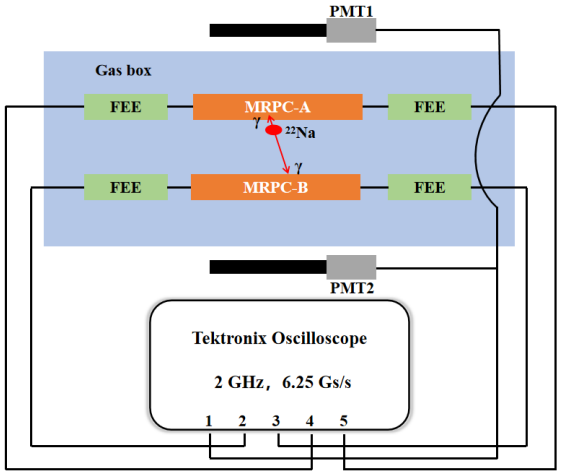


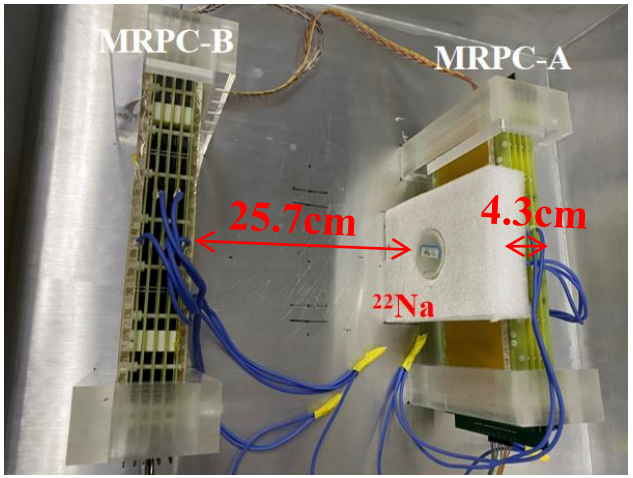
time resolution ~ 27 ps



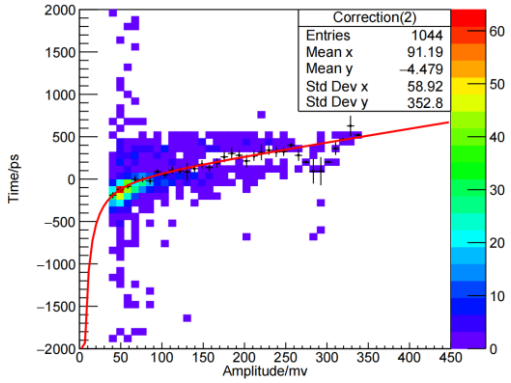
Time resolution after vertical case selection ~ 16.44 ps

Gamma test

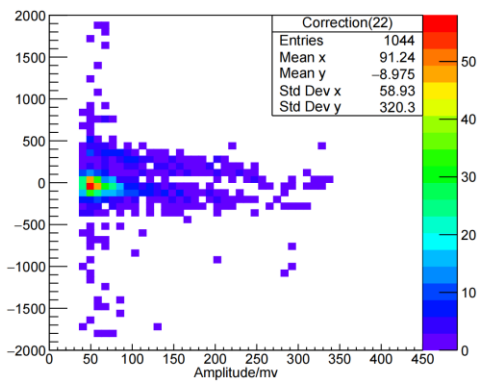




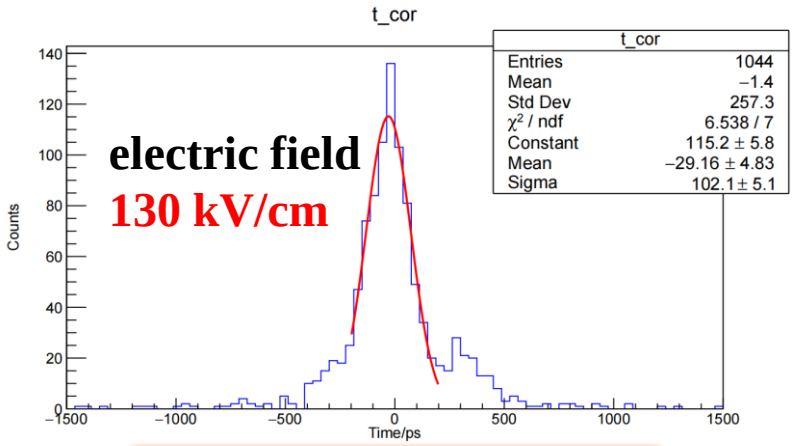
Activity
~ 3.73×10⁵ Bq



before time amplitude correction



after time amplitude correction



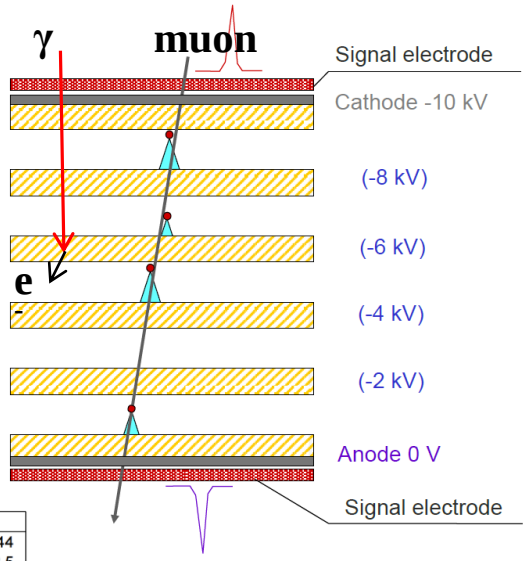
time resulution ~ 72 ps

Gamma test

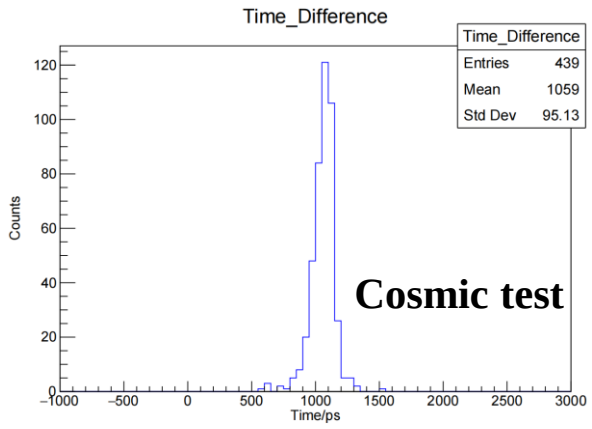
Effect of thickness of MRPC on time resolution

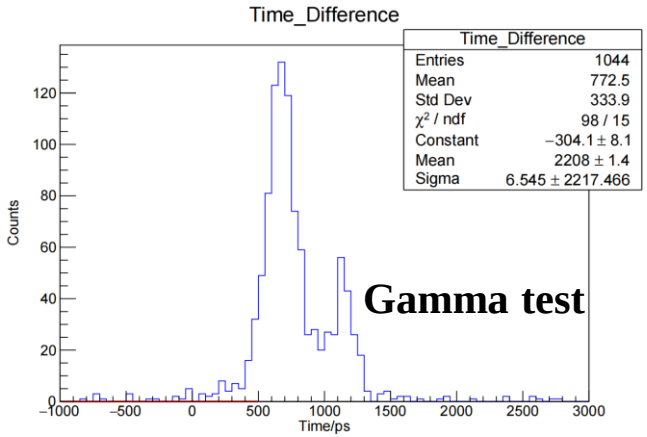
$$\sigma_{\Delta L}{}^2 = \sigma_{\Delta t}{}^2 + 2\sigma_x{}^2, \quad \sigma_x = 2*(\text{thickness of mrpc}/\sqrt{12})/c$$

The effective thickness of MRPC should be less than 7.4mm.



Verification of ^{22}Na placement



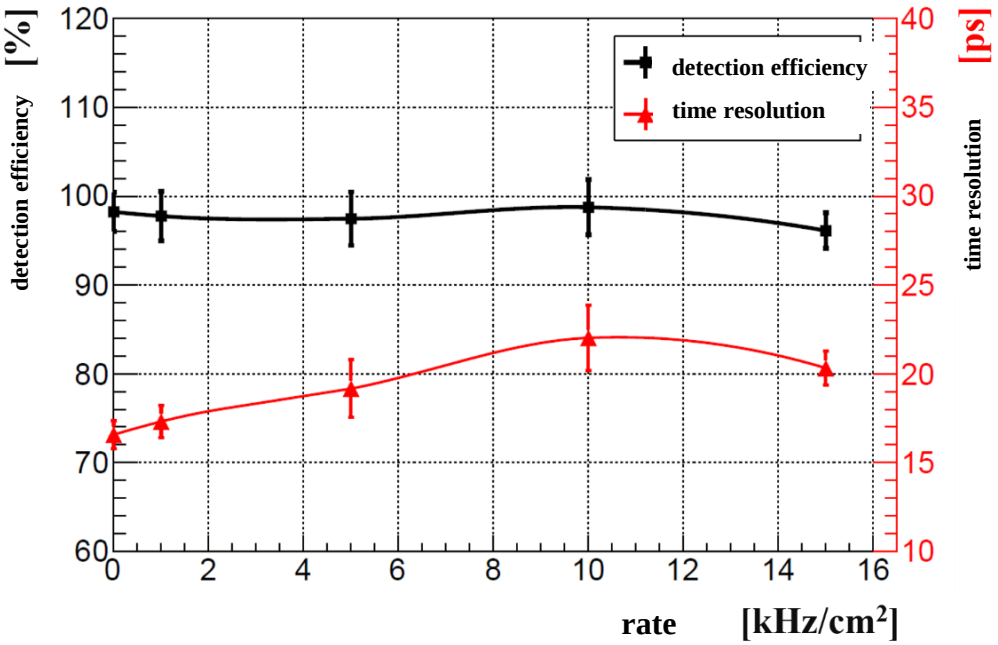


Distance between two mrpc is 30cm

The real time difference for gamma test is 773-59=714ps → 21.4cm ☑

X ray test

MRPC prototype + Fast amplifier + Lecroy Scintillation



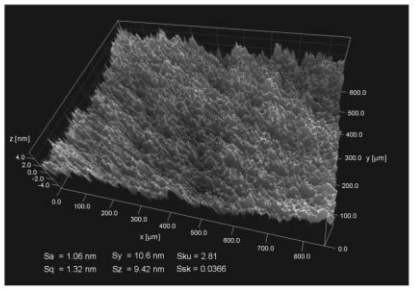


Figure 7.4: Scanned 2-D image of a glass plate.

Maximal dimension	32cm × 30cm
Bulk resistivity	10^{10} Ωcm
Standard thickness	0.7, 1.1mm
Thickness uniformity	20 μm
Surface roughness	< 10nm
Dielectric constant	7.5 - 9.5
DC measurement	Ohmic bebavior stable up to 1 C/cm^2

Table 7.1: Specific parameters of the low-resistive glass.

A new RPC

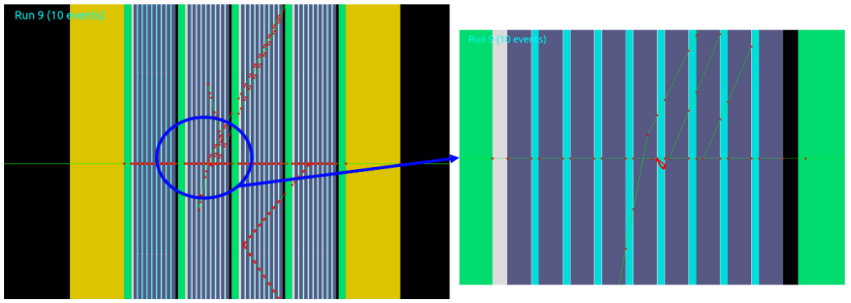
Ultrathin, high efficiency, high time resolution RPC

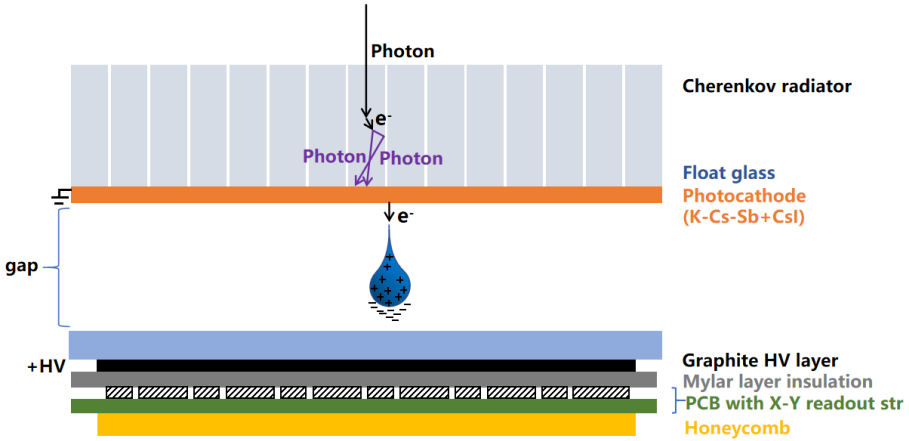
- **Detection efficiency for γ (128μm gas gap)**

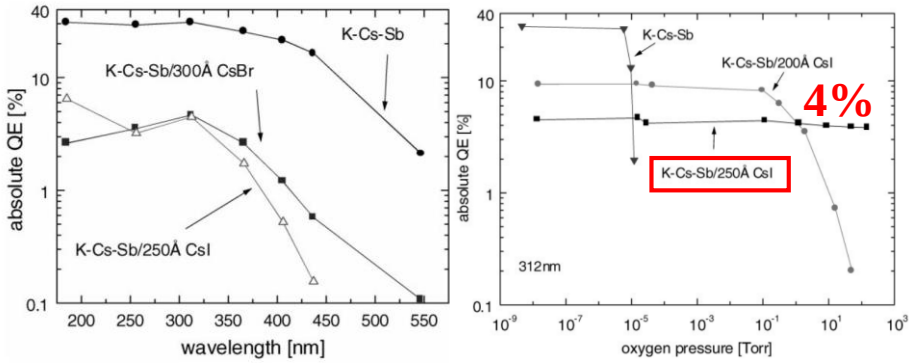
  1-chamber 1-gap ~ 0.2%

  1-chamber 8-gap ~ 1.5%

  4-chamber 32-gap ~ 6.3%







[A. Breskin et al. Israel 2000]

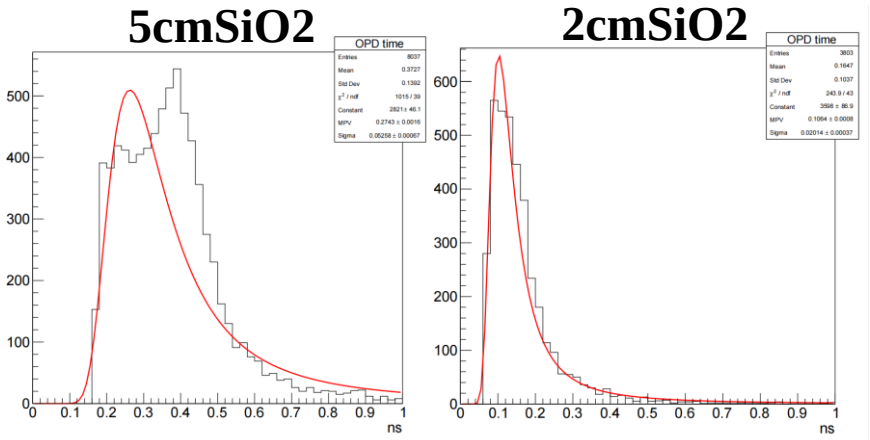
- **Performance indicators**

  time resolution < 20ps，detection efficiency ~ 6.4%

  sensitive area thickness < 3mm，energy resolution < 20%

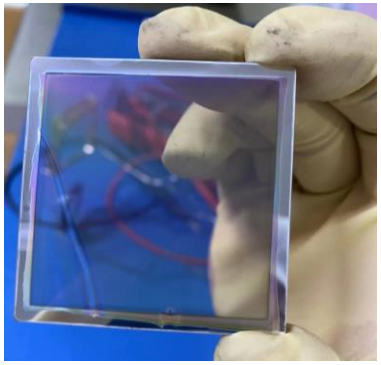
A new RPC

- Calculation of optical path difference in Cerenkov radiator (SiO_2)

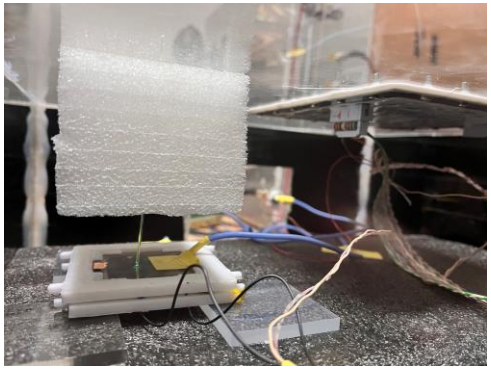


thickness of SiO_2	Time in SiO_2 (average)	Time in SiO_2 σ	Detection efficiency
7cm	491ps	70ps	16%
5cm	372ps	52ps	13%
3cm	241ps	32ps	8.7%
2cm	**164ps**	**20ps**	**6.4%**
1cm	80ps	8ps	3.2%

- Fabrication of the new RPC



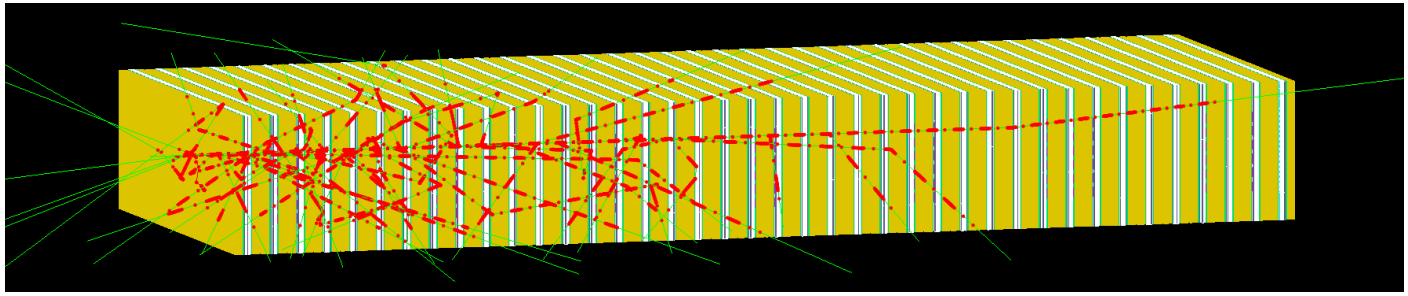
K-Cs-Sb+CsI

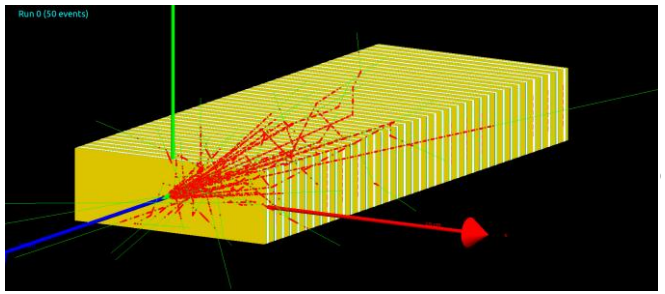


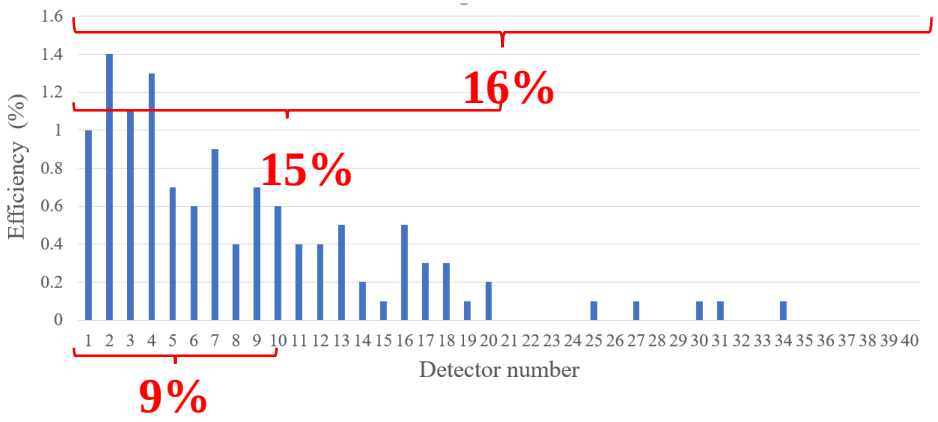
electric field ~ 180 kV/cm， dark current ~ 0.04μA、0.03μA

Research plan

- **Ten 8-gap MRPCs are placed on each side of ^{22}Na for positioning**







- **Develop the high efficiency, high time resolution RPC prototype**

  Consider a more appropriate Cerenkov photon-to-electron conversion
  Improve the coating process

Conclusion

- **A 4-chamber 8-gap MRPC prototype has been developed**
  - time resolution for cosmic rays ~ 27ps
  - time resolution for 0.511MeV gamma ~ 72ps
  - the thickness of MRPC affects the time resolution for gamma
  - The effective thickness of MRPC should be less than 7.4mm

- **A Ultrathin, high efficiency, high time resolution RPC was proposed**
  - use converters to improve detection efficiency → limited improvement
  - increase the number of gas gaps → poor positioning accuracy
  - use Cerenkov radiator + composite photocathode → 6.4% efficiency for one gap

Thanks For Your Attention!

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