MRPC technology used in muon tomography

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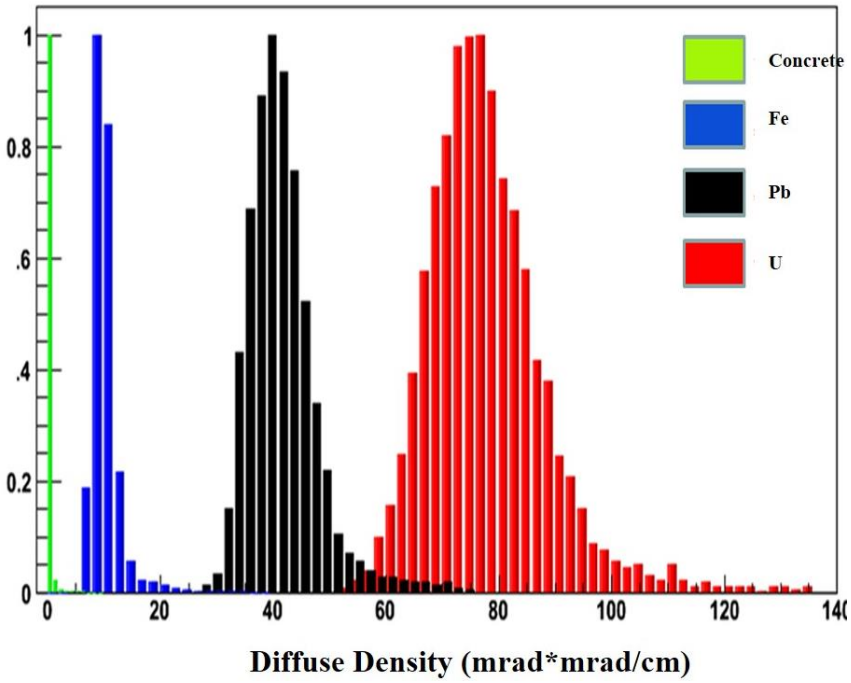
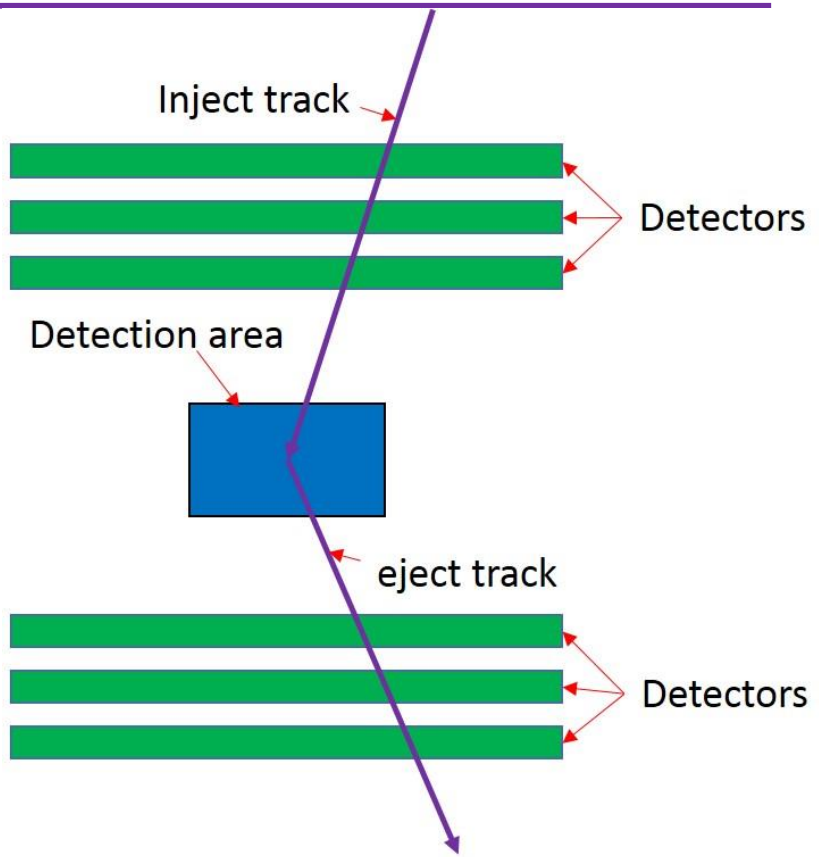
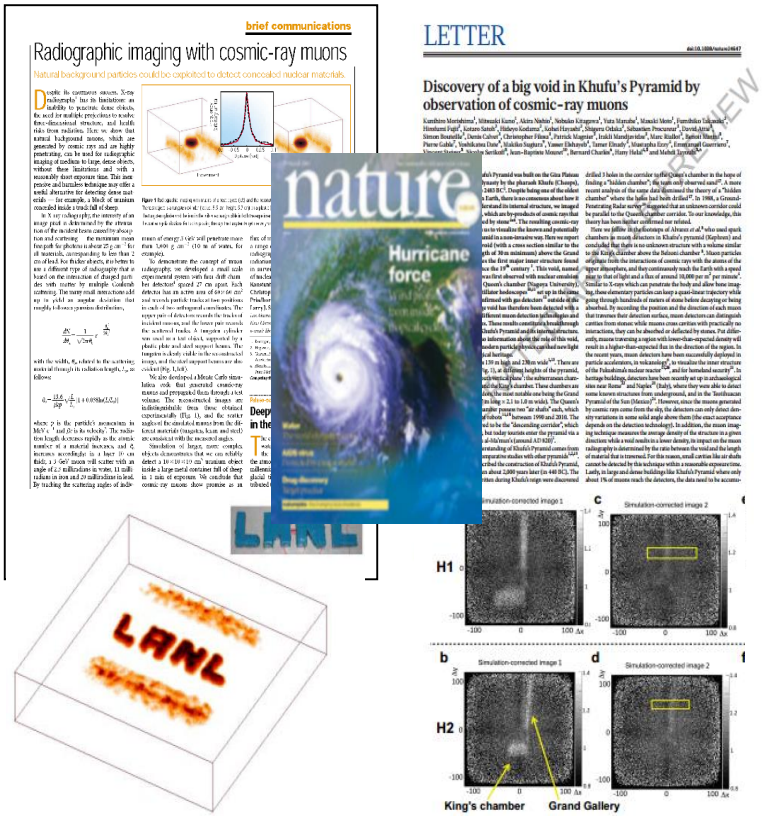
What's muon tomography





- When muon past through H-Z object, big diffuse angle
- Through track detector get inject and eject tract
- Get the diffuse angle and scatter point, reconstruction detection area information
- The key point is track detector

Muon tomography system in the word



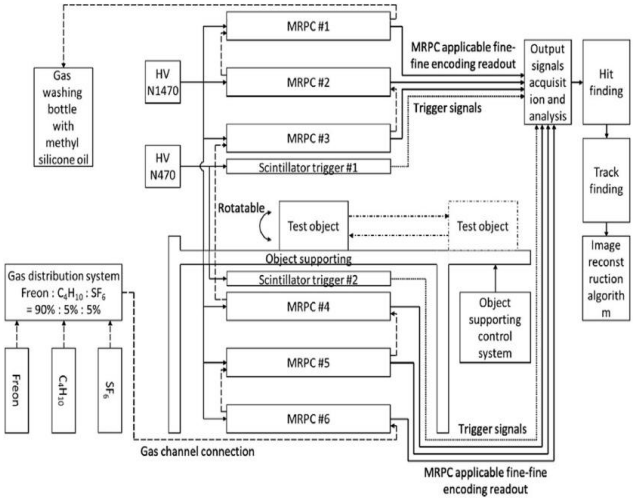
LANL and Khufu's Pyramid muon tomography system

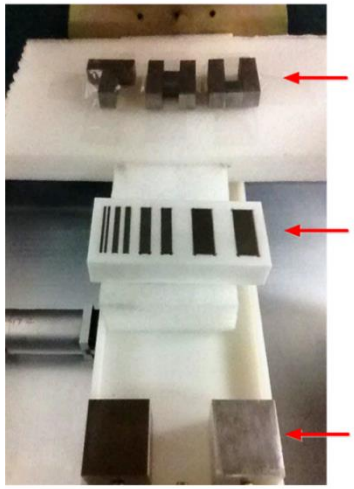
	Institution	Detector
USA	LANL	Drift tube
	FIT	GEM
Russia	IHEP	Drift tube
Italy	INFN	Drift chamber
Canada	AECL(CRIPT)	Scintillator and Drift chamber
UK	AWE	RPC

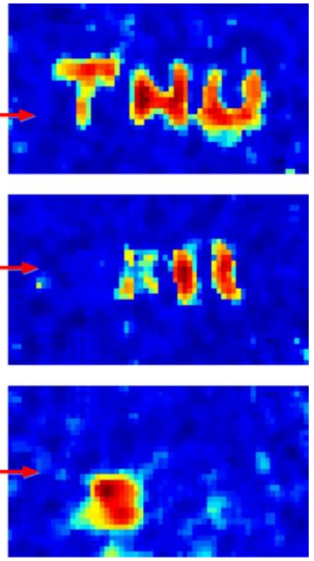
Different system and track detector

- K. N. BOROZDIN, et al., "Radiographic Imagingwith Cosmic Ray Muons," *Nature, 422, 277 (2003).*
- Morishima K, Kuno M, Nishio A, et al. Discovery of a big void in Khufu's Pyramid by observation of cosmic-ray muons[J]. Nature, 2017.

Tsinghua university TUMUTY



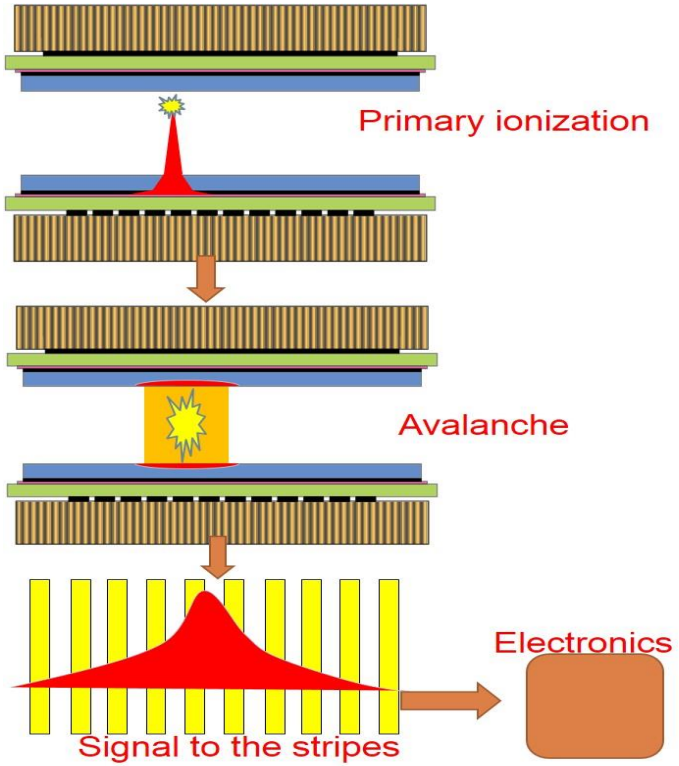




The “TUMUTY” system and imaging results

- Height: 3 m
- 6 groups of detectors
- Each group includes 2 MRPCs, can realize the 2D readout.
- Detector area: 720mm×720mm
- 2cm lead get imaging result “THU”
- the 10 mm line pairs can be distinguished
- the tungsten cube can be identified while the aluminum cube is invisible due to its small density

Position resolution MRPC



$$x = \frac{\sum_i (channel_i \times Q_i)}{\sum_i (Q_i)}$$

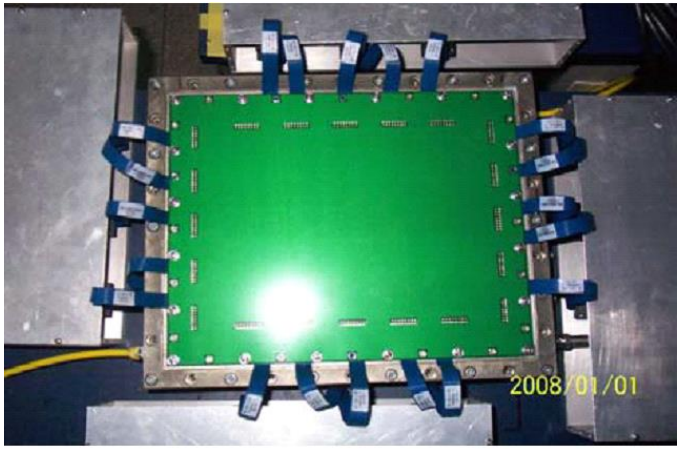
RPC-type detector for position resolution

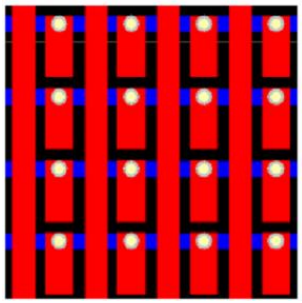
Time	Scientist	Type	Size	Gap	Strip width	Result
2003	T. Francke	RPC	5cm×5cm 10cm×10cm	0.1-4mm	30μm-50μm	50μm
2012	A. Blanco	MRPC	8cm×8cm	0.35mm×5 +0.8mm×2	4mm	70μm
2012	M. Petris	MRPC	46cm×180cm	0.14mm×14	2.54mm	~500μm
2012	P. Baess	RPC	58cm×58cm	2mm	1.5mm	800μm
2013	Li Qite	RPC	20cm×20cm	2mm	2.54mm	900μm

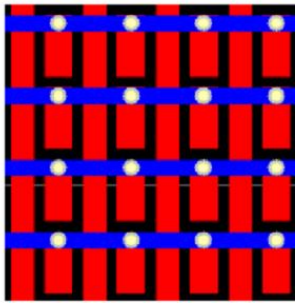
Position resolution RPC-type detector development history

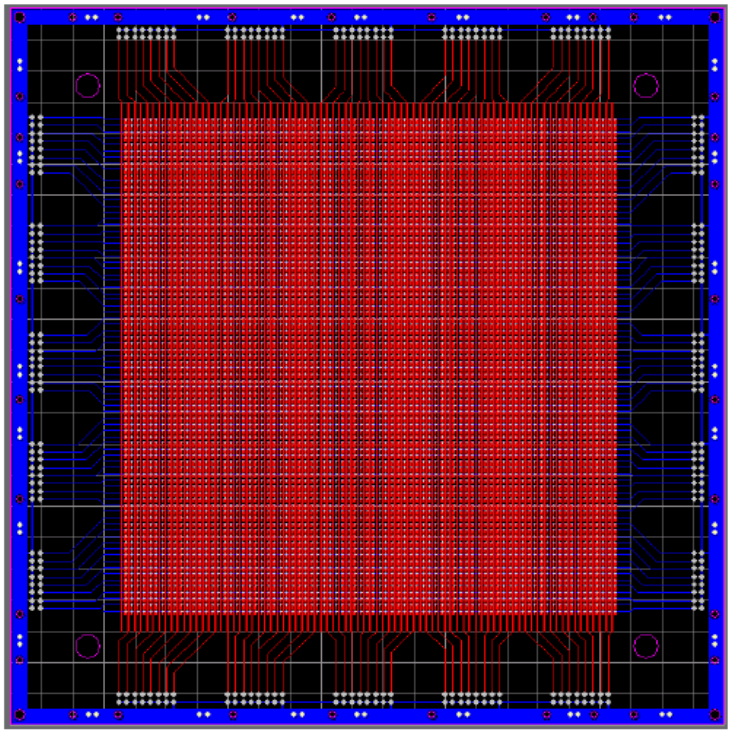
- RPC-type detector can develop for position resolution
- Can reach position resolution under mm level
- Low cost, high efficiency, easy production, large sensitive area

MRPC for tomography





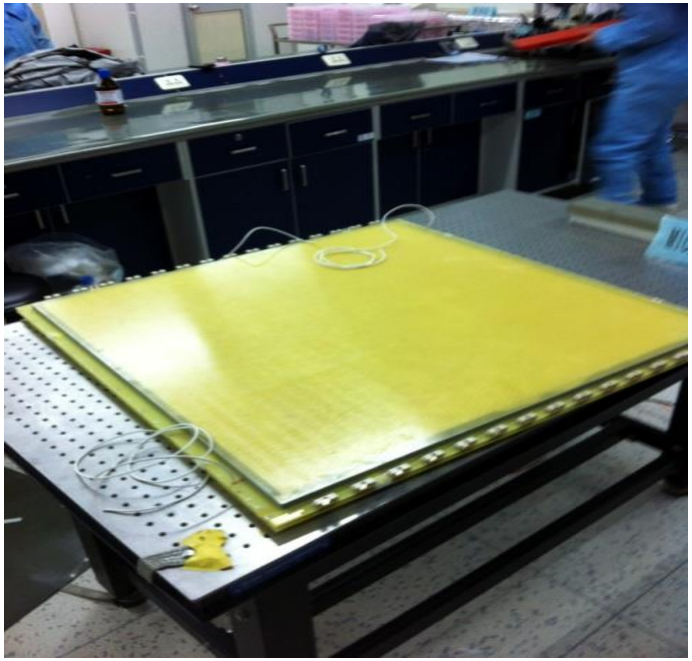


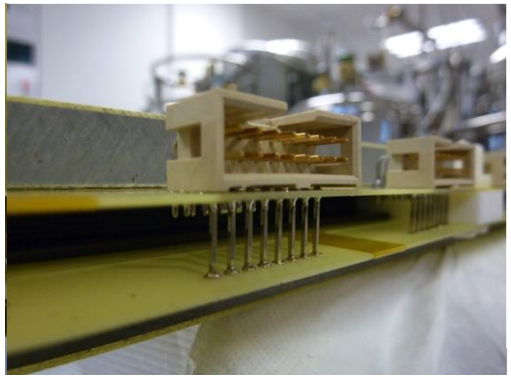


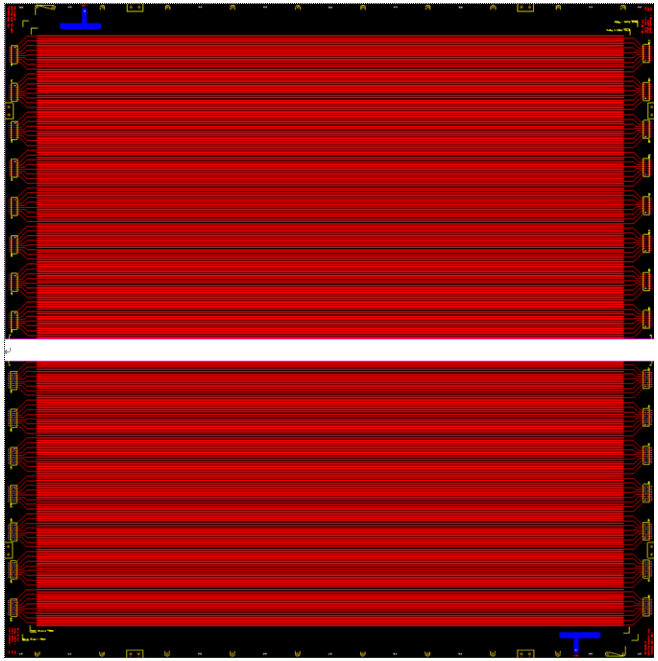
Ye Jin MRPC and PCB board design

- One PCB board for X-Y readout, strip for X , block for Y, center distance 2mm
- Size:50cm*50cm,5 gaps, gap size:0.33mm, Position resolution reach 500 μm
- Study about influence carbon film resistivity to MRPC signal
- PCB design is complex and hardly reach more larger sensitive area

Large sensitive area position resolution MRPC



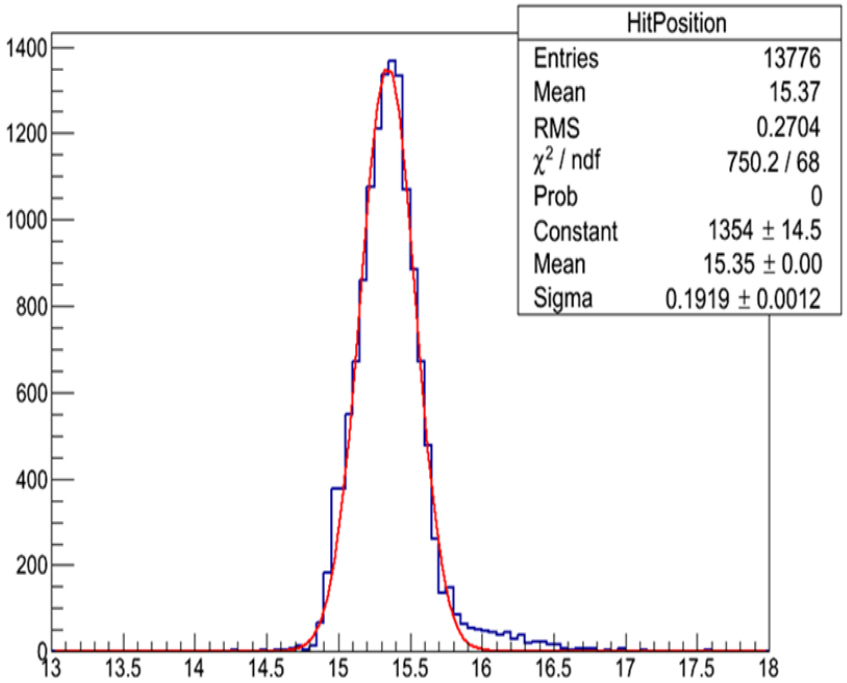




TUMUTY MRPC and readout PCB

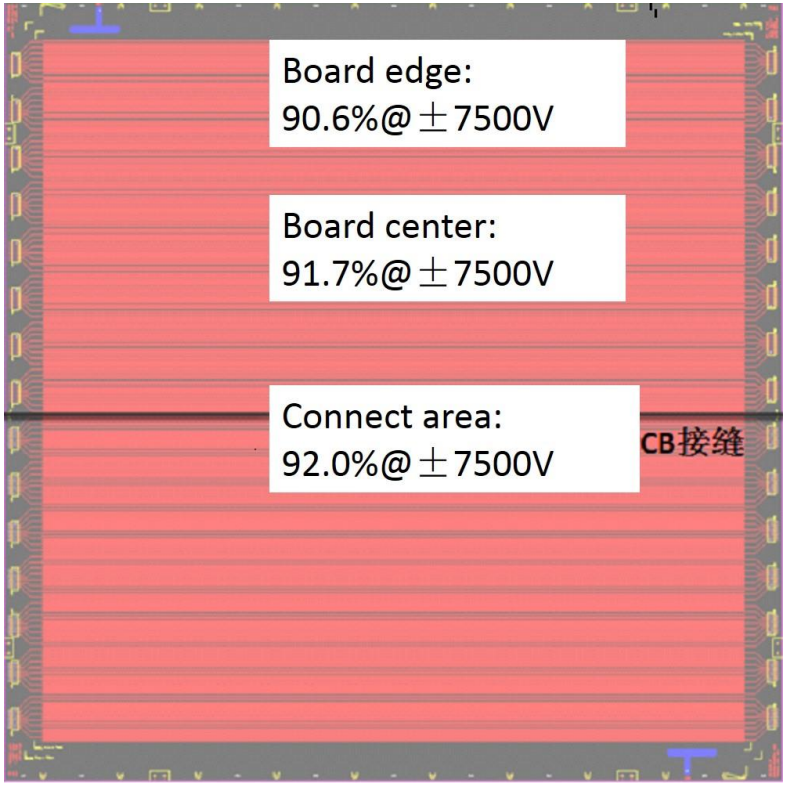
- Single MRPC 1 dimension readout, 1 set two MRPCs for X-Y readout
- Size 800mm*800mm, sensitive area 720mm*720mm
- 6 gaps, gap size 0.25mm,strip pitch:2mm+1mm
- Readout electrode consists of two PCB boards

Study on TUMUTY MRPC



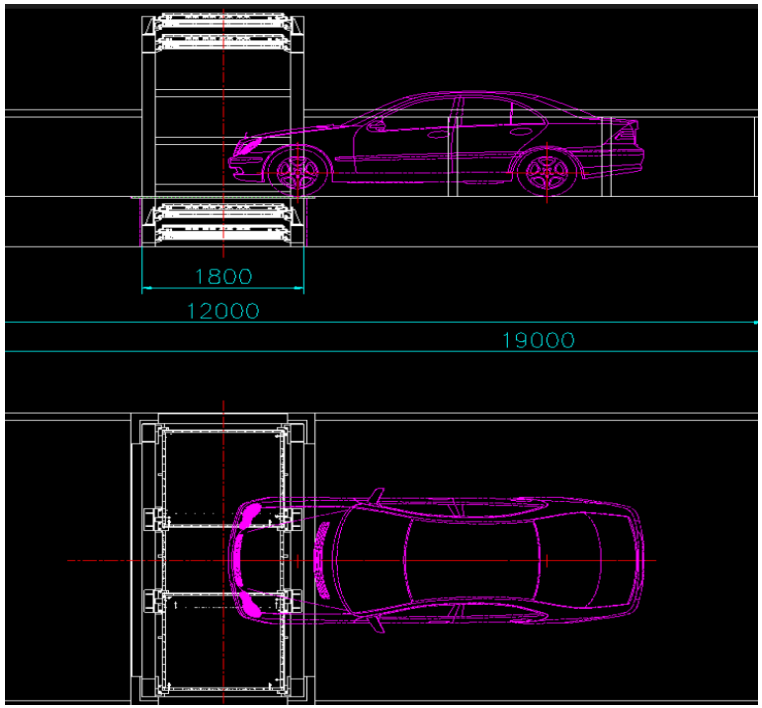
$$\sigma_{MRPC} = \sqrt{\sigma_{all}^2 - \sigma_{slit}^2}$$

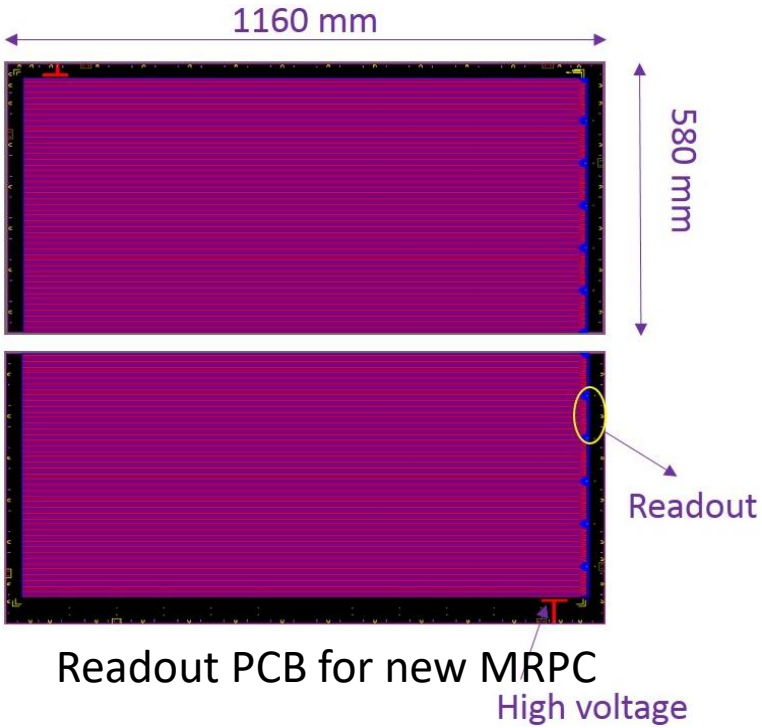
$$= \sqrt{(0.1919 \times 3)^2 - \frac{0.126^2}{12}} = 0.575\ (\text{mm})$$



- Position resolution reach 575μm@±7900V
- Two PCB connect area have good efficiency
- Big sensitive area have detection uniformity

Second generation MRPC for car detection





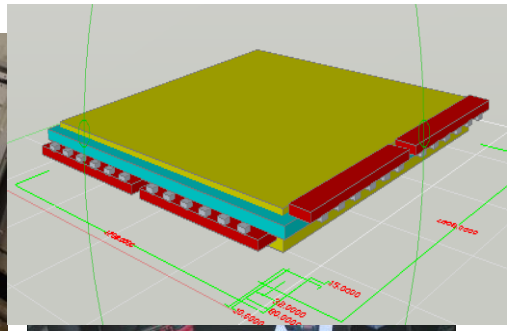
Readout PCB for new MRPC

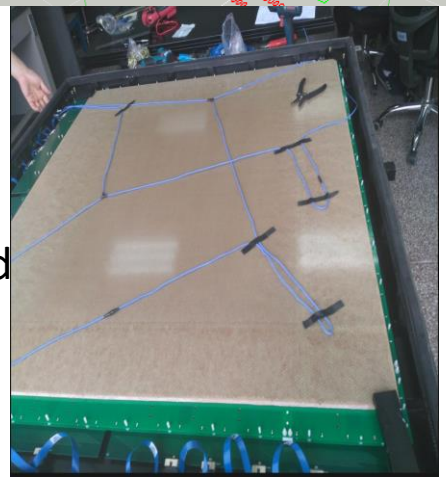
Car detection for industrial application

- Project has four layers, each layer sensitive area reach 1m*3m
- Need: larger sensitive area and smart structure to MRPC
- Work stably at difference temperature
- Also two board in one readout electrode

TUMUTY MRPC and Car detection project MRPC

	TUMUTY MRPC	New MRPC
Pats of MRPC	Size（mm）	
PCB	800*800	1160*1160
Sensitive area	720*720	1072*1072
Mylar	750*750	1110*1110
Honeycomb panels	750*750	1100*1100
Inner glass	736*736	1100*1100
Outer glass	756*756	1100*1100
Carbon film	740*740	1092*1092
Read out strip	2	1.44
Gap	1	1.1
Gas gap	0.25	0.25



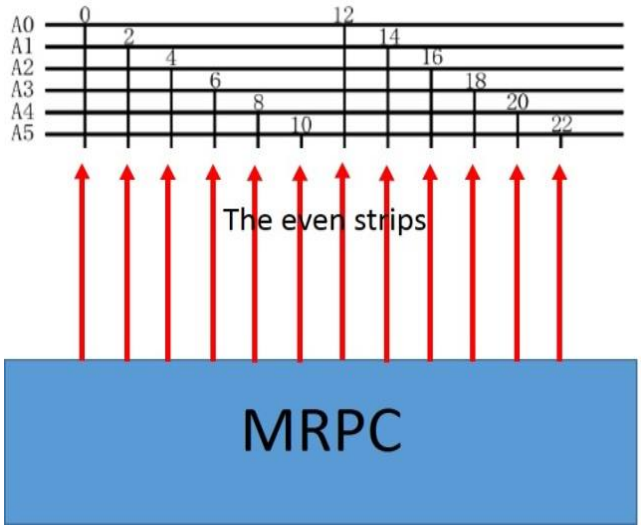


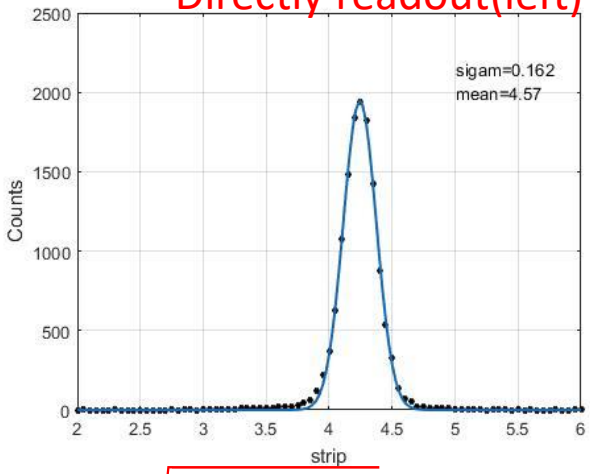
TUMUTY MRPC and new MRPC

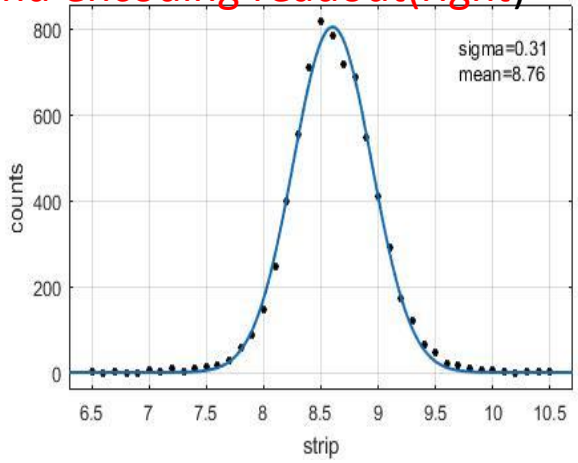
- Large sensitive area reach 1 m^2
- Single MRPC for X-Y two dimension readout
- Take encoding readout device in the box for stably data transmission

Encoding readout to MRPC

Directly readout(left) and encoding readout(right)





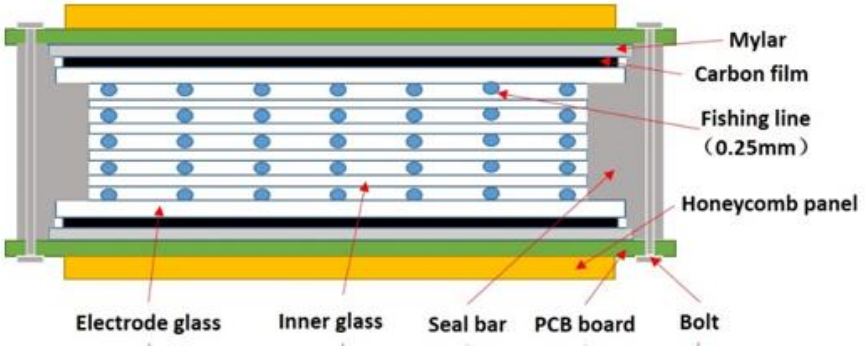


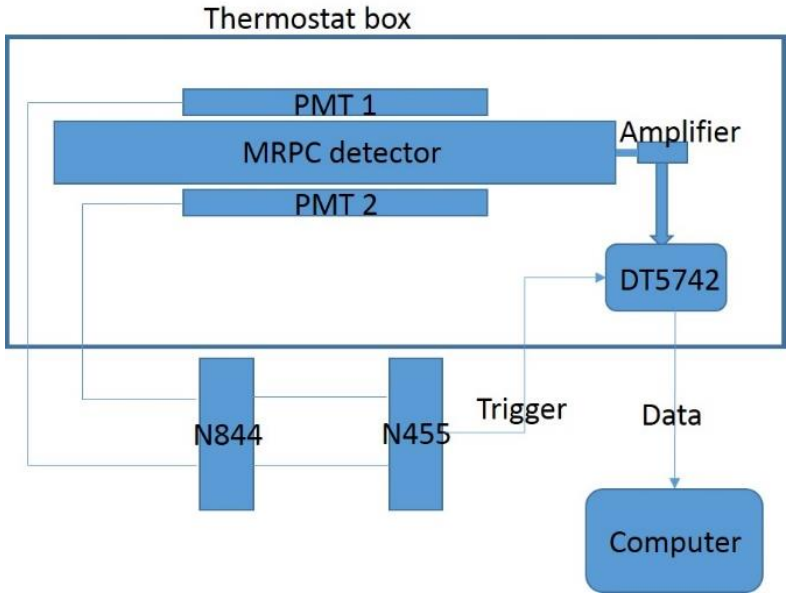
$$\sigma_{MRPC-E} = \sqrt{\sigma_{all-E}^2 - \sigma_{slit}^2} = \sqrt{(0.31 \times 2.54)^2 - (0.126/\sqrt{12})^2} = 0.787\ (\text{mm})$$

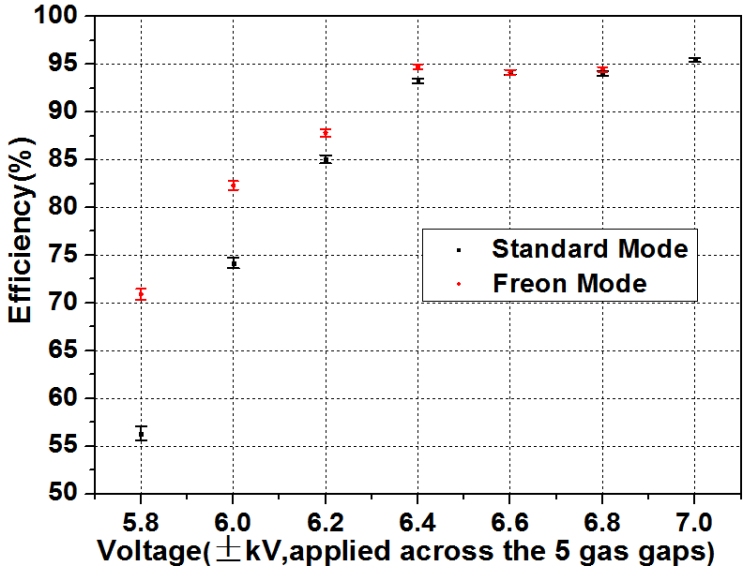
$$\sigma_{MRPC-D} = \sqrt{\sigma_{all-D}^2 - \sigma_{slit}^2} = \sqrt{(0.16 \times 2.54)^2 - (0.126/\sqrt{12})^2} = 0.405\ (\text{mm})$$

- Muon: low rate, at sea level about 10000 m^{-2} min^{-1}; system: big mount of readout (each MRPC 864 strips)
- use $2 \times n + 2$ electric channel readout $n \times (n + 2)$strips
- Will Significantly decrease MRPC readout channels under the encoding readout
- To each MRPC:864 MRPC strips only 120 electric channels, Significantly reduce system costs and complex

Temperature study about MRPC

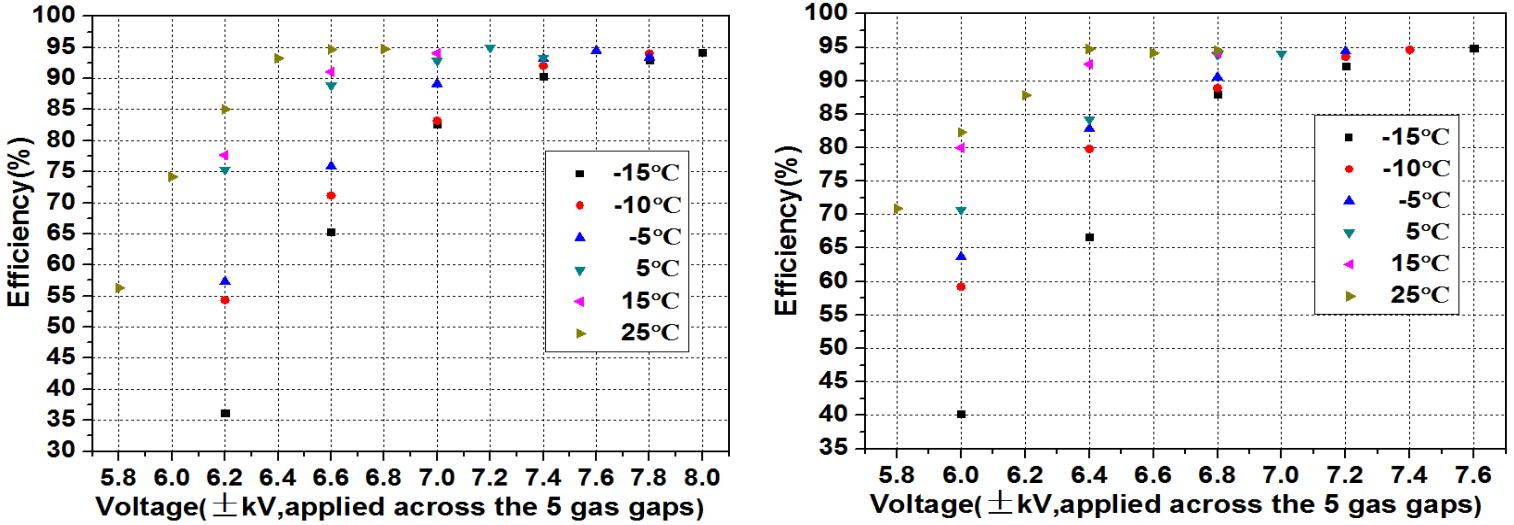




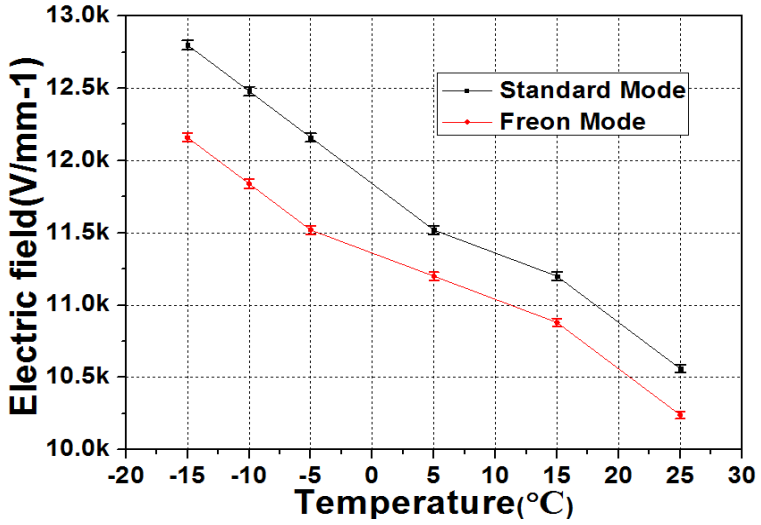


- Important set right working point at different temperature for muon tomography system
- Prototype: 5 gaps, 0.25mm gap width
- Through thermostat precise control MRPC working temperature.
- Learn MRPC performance under two gas mode at different temperature from -15℃ to 25 ℃

MRPC at different temperature



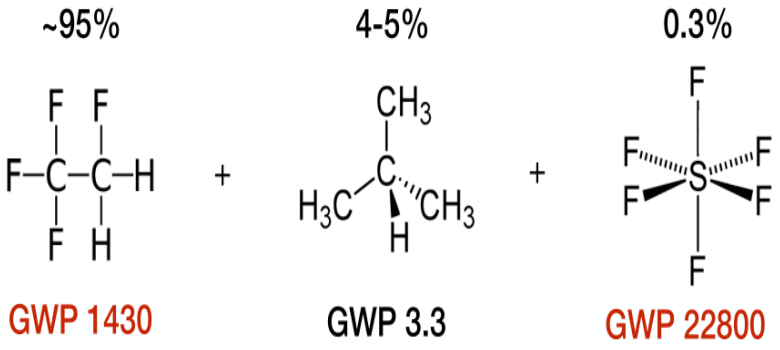
Efficiency at different temperature(left: standard gas; right: Freon gas)



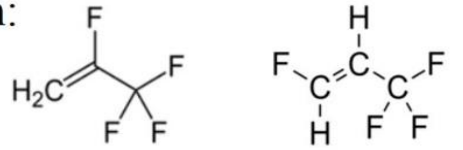
- Low temperature make efficiency curve right shift
- Freon gas mode has lower working voltage than standard gas mode
- About 320V/mm electric field change for 5℃ temperature change based on 25 ℃

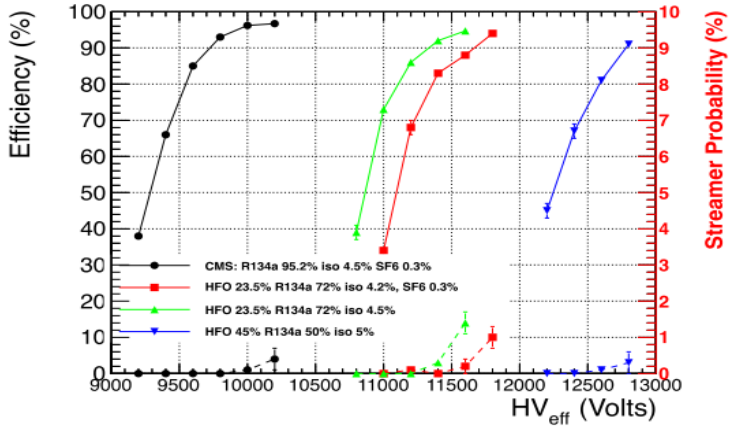
SMRPC(sealed MRPC) development

Motivation:



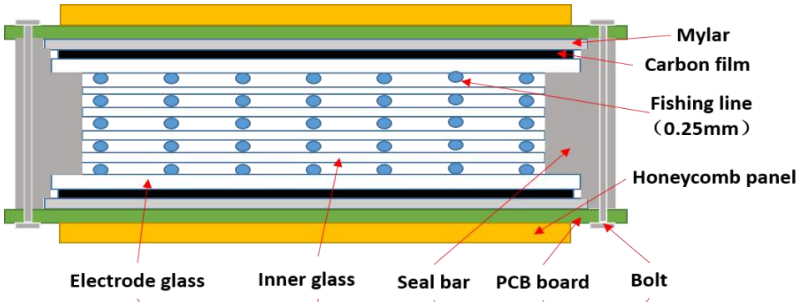
Eco-gas replacements:
-for Freon:

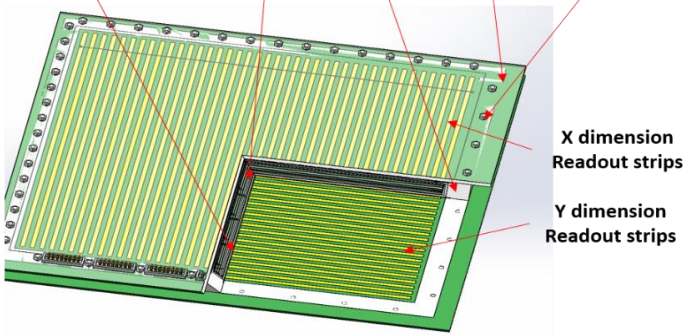


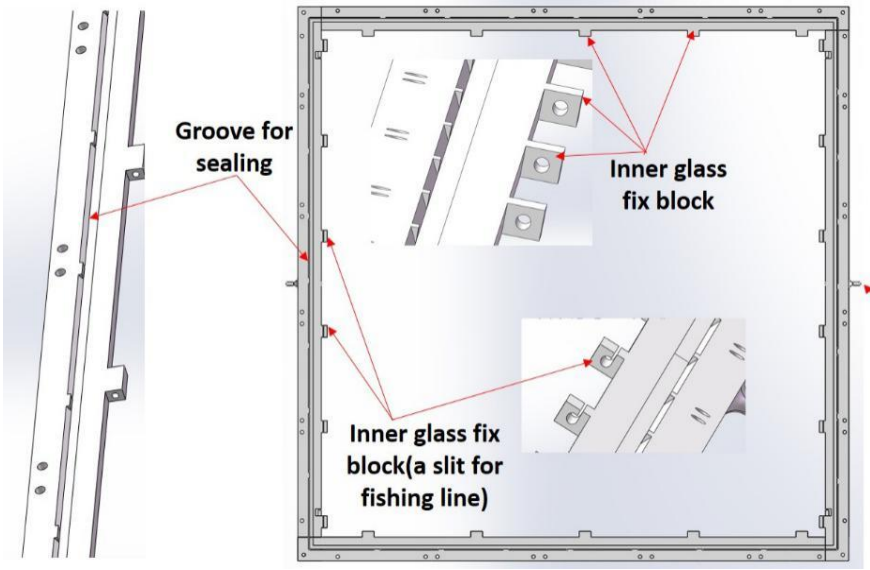


- European Union “F-gas regulation”: Limiting the total amount of F-gases that can be sold in the EU; Banning the use of F-gases in many new types of equipment; Preventing emissions of F-gases from existing equipment
- High working point
- High cost, 5-7 times cost than Freon
- Eco-gas still on study

SMRPC design

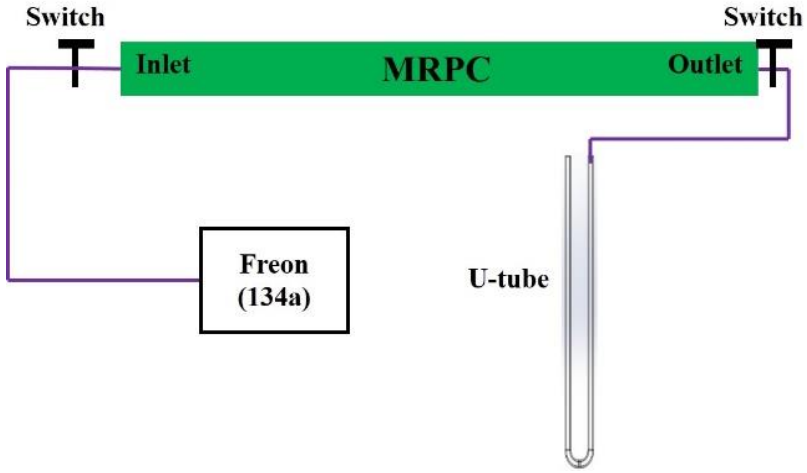


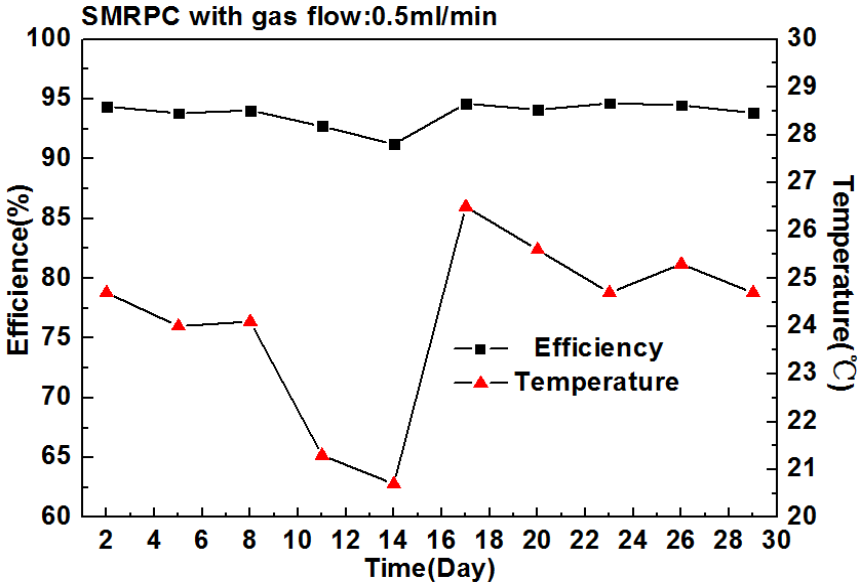


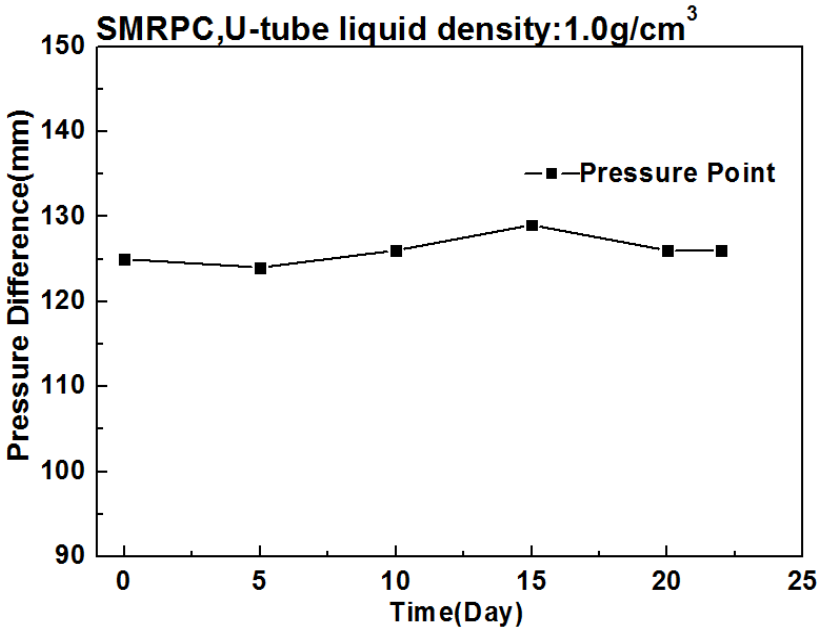


- Through low inlet gas flow to reduce the F-gas pollution
- Low rate muon at sea level, low avalanche pollution for the detector gas
- Through design reduce MRPC self component outgas pollution the MRPC working gas
- Seal bar and outside glass make space for MRPC working
- Made by 3D printer
- 5 gaps, gap thickness 0.25mm,sensitive area 420mm*420mm

Tightness and extremely gas flow performance

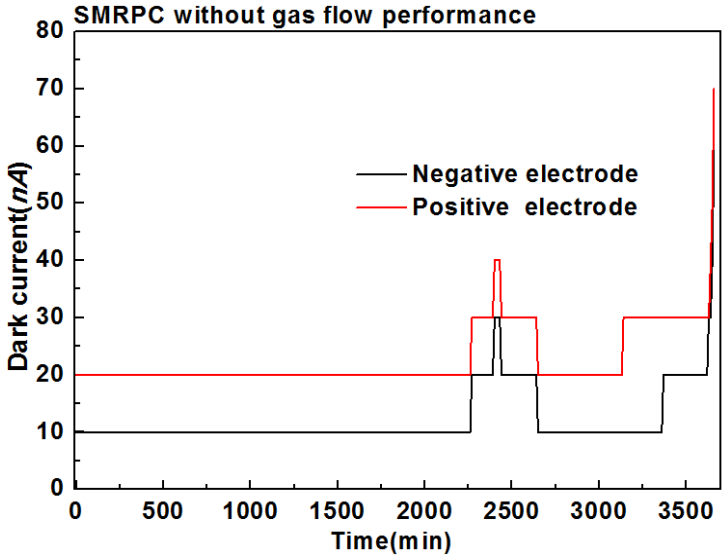


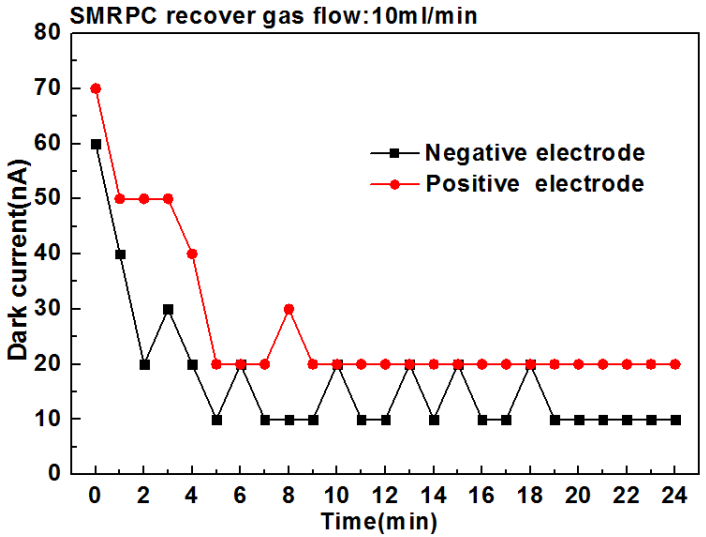


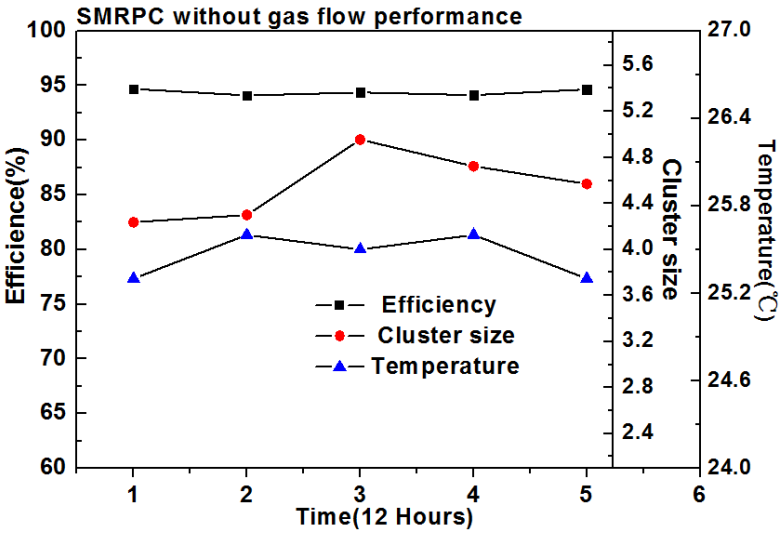


- Show good tightness in about 22days test
- Test at Freon gas mode
- Working stably at working point(±6400V) at gas flow 0.5ml/min for more than one month
- Efficiency around 95%

No gas exchange







- No gas exchange can work more than 60 hours
- Efficiency around 95%
- Re-inject gas total volume equal capacity of detector chamber (220ml),detector works can recover
- In the no gas exchange mode, Equivalent to average gas flow reduce 0.05ml/min

Position resolution MRPC for future

The frame of MRPC simulation

- the particle source, type, position and angle of the incident particles
- particles impinging on the detector and the primary interactions
- the drifting and the signal induction in the MRPC
- the electronics response to the induced current signal

The first and second process by GEANT4

The current signal induced on an electrode by Shockley-Ramo:

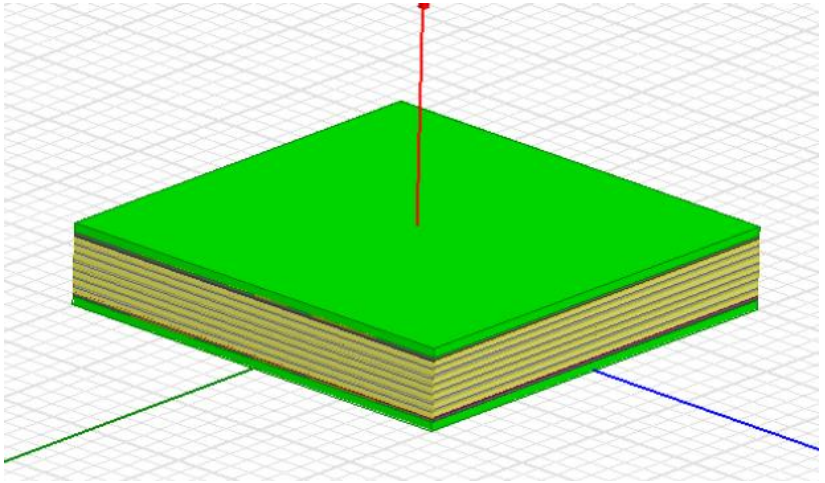
$$i(t) = \frac{E_w \cdot v}{V_w} e_0 N(t)$$

E_w/V_w is weighting field, v is the drift velocity, e_0 is the electron charge, $N(t)$ is the number of electrons at time t

Front- end electronics response:

$$f(t) = A\left(e^{-t/\tau_1} - e^{-t/\tau_2}\right)$$

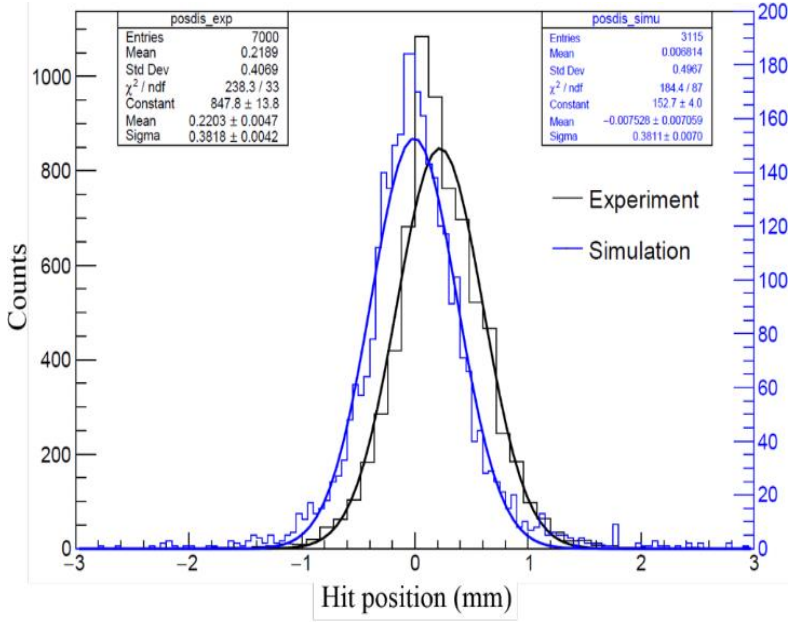
A is the amplification factor, and τ_1, τ_2 correspond to the time constants of the RC circuits in the electronics



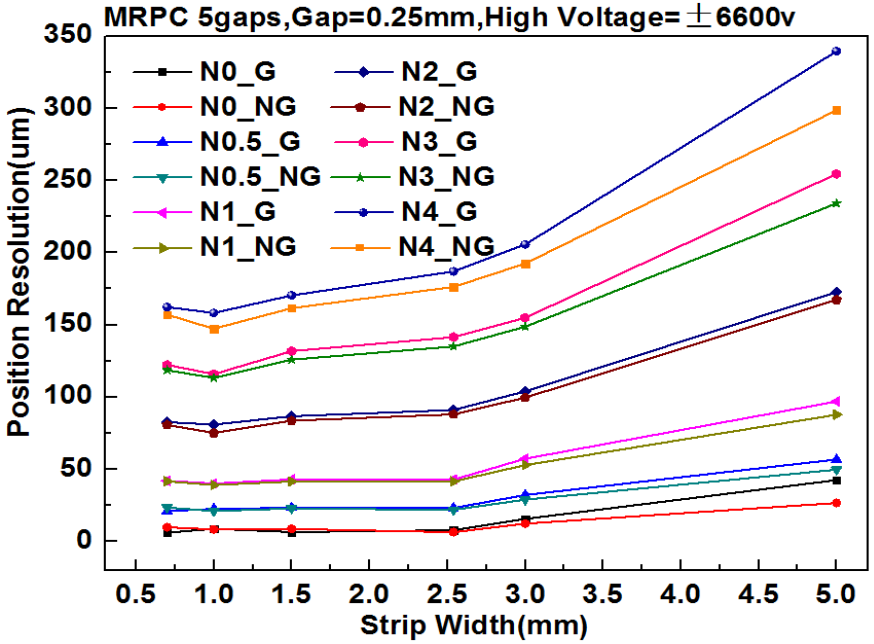
The realistic configuration of a six-gap MRPC modeled with ANSYS Maxwell

- Get weighting field in the MRPC

Position resolution simulation



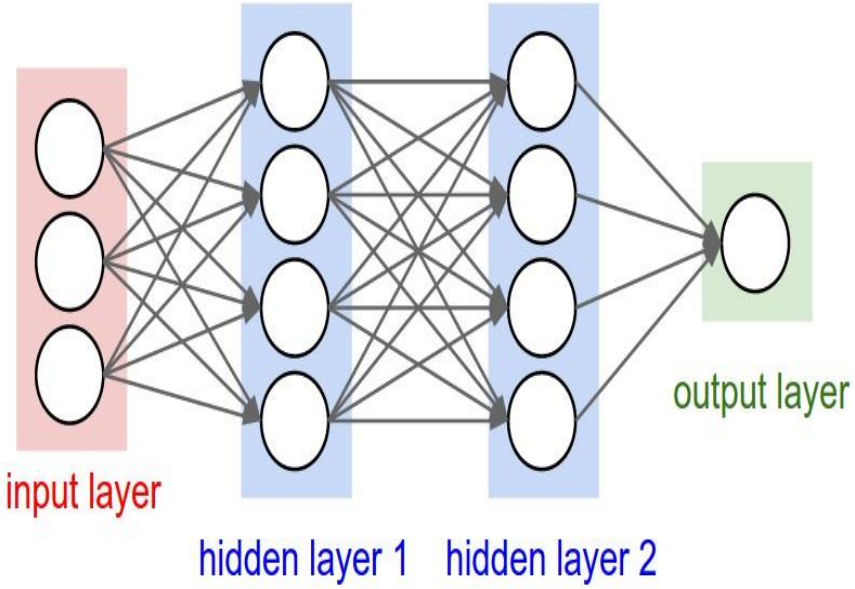
The position resolution of MRPC. The blue lines simulation,black lines are experiment

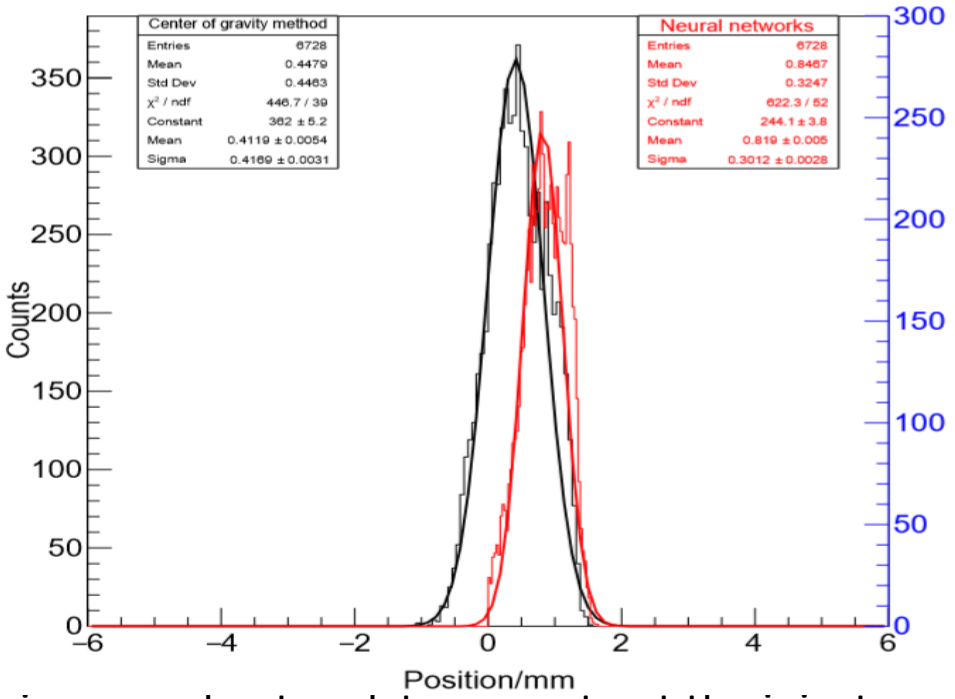


MRPC position resolution to Strip width under different noise

- Simulation and experiment result fit very well
- MRPC mode with 5 gaps and gap width 0.25mm with difference strip width at different noise was simulated
- Nosie have a great affect to MRPC position resolution, strip width 1mm can get better position resolution
- Other influence of the position resolution to MRPC can also study by this simulation frame, such as gap width, copper width in the strip

Machine learning to position resolution MRPC





- New analysis method —— introducing neural network to reconstruct the inject muon position.
- Simulation data used for training, experiment data for testing.
- Position resolution can be much improved! 416μm position resolution for old method, and 301μm for neural network .

More details see talk of Yancheng Yu: A neural network based algorithm for MRPC position reconstruction

Summary

- MRPC is cheap, robust structure, high position resolution, easy large sensitive produce, make it very suitable for muon tomography.
- The MRPC for muon tomography developed for three stages in our study. Large sensitive area to more large sensitive area, and environment friendly low cost.
- Many key technology study for MRPC to muon tomography application
- Position resolution MRPC simulation by ANSYS Maxwell+GEANT4 was built for the our future MRPC design.
- New analysis method—neural network was introduced to reconstruct the inject particle position in our study.

THANKS FOR YOU LISTENING