Status of MRPC TOF technology

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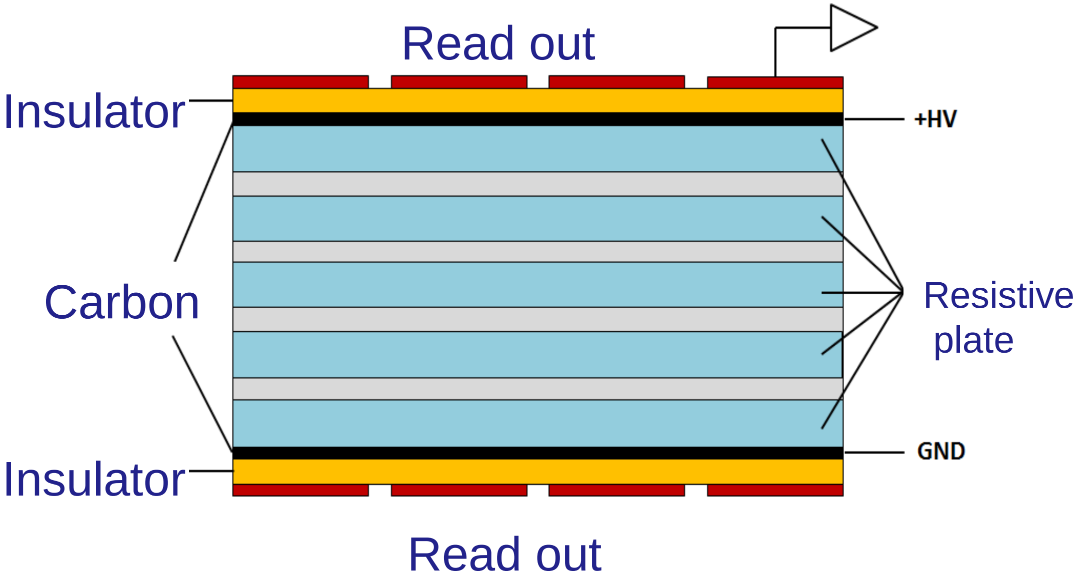
Abstract:

- Introduction of MRPC
- Introduction of three generation MRPC TOF
- Status of TOF of STAR, CBM and SoLID
- Conclusion

MRPC introduction



MRPC structure

Standard parameters:

Resistivity of glass: ~10^{12} Ω.cm

Working gas:

90%Freon+5%iso-butane+5% SF6

Time resolution <100ps

Efficiency >95%

Charge: a few PC

Dark current: a few nA

Noise ~$1 Hz/cm^2$

Rate <$100 Hz/cm^2$

Large area, low cost

MRPC application：

1. Application in nuclear physics experiments
2. Application in industry（Muon tomography)
3. Application in medicine（TOF-PET）

How to increase rate of MRPC

The voltage drop in the gas gap:

$$\bar{V}_{drop} = V_{ap} - \bar{V}_{gap} = \bar{I}R = \bar{q}\phi\rho d$$

The smaller the voltage drop, the higher efficiency and higher rate capability!

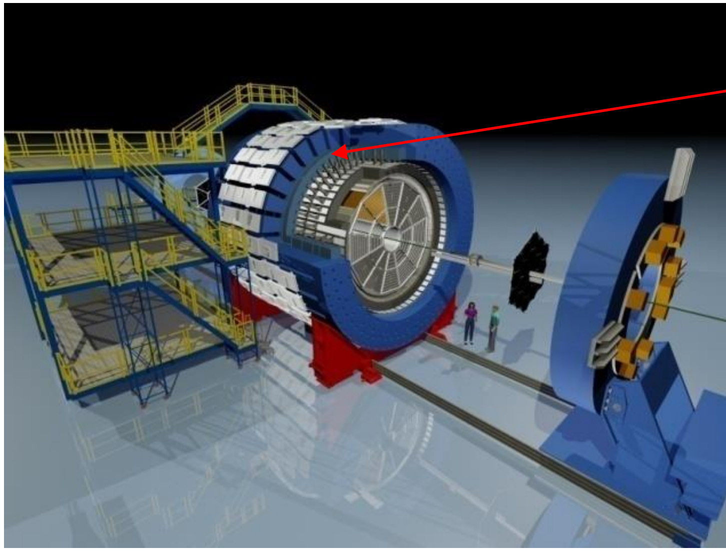
Two main ways to improve rate capability:

- Reducing bulky resistivity of electrode glass (CBM)
- Reducing the avalanche charge (ATLAS)

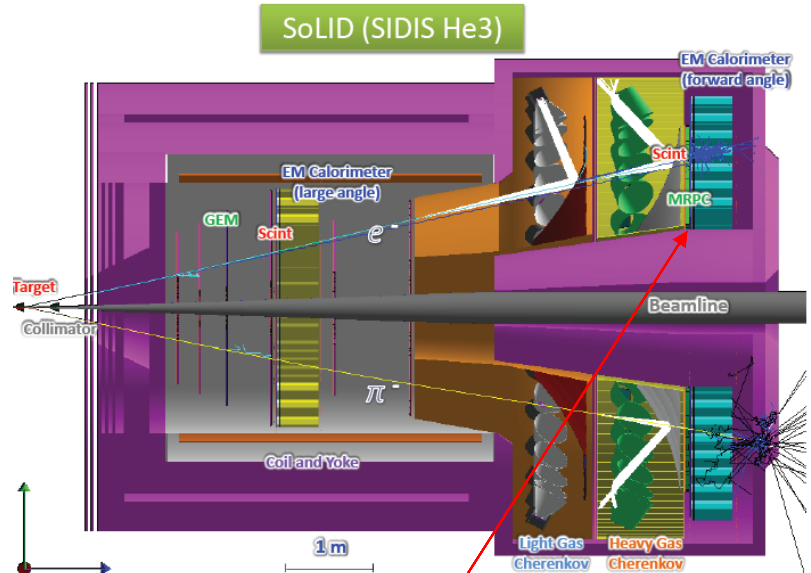
Other methods:

- Reducing the thickness of glass
- Warming the detector

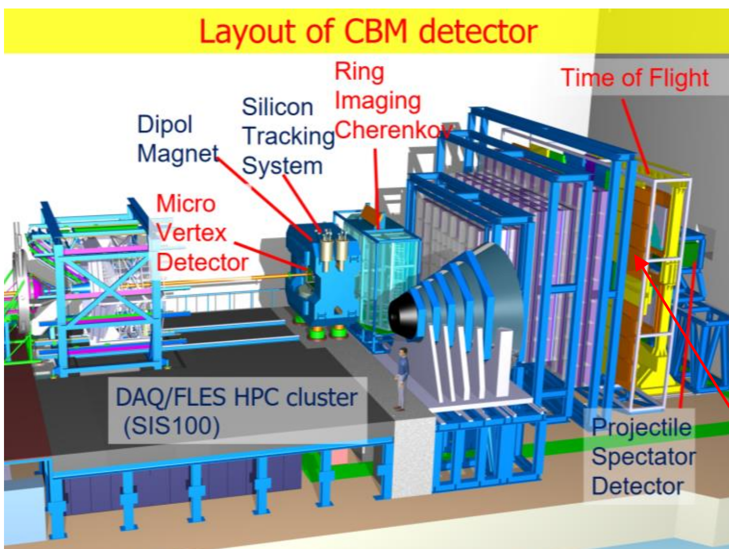
Typical MRPC TOF



RHIC-STAR TOF
Float glass



JLab-SoLID TOF
High rate and 20ps resolution



FAIR-CBM TOF
High rate- low resistive glass

Key technology

1st generation TOF:

Requirement: Time resolution: <80ps

Rate : <1kHz/cm^2

Technology: common glass MRPC+NINOs +HPTDC

Analysis method: TOT slewing correction

2st generation TOF:

Requirement: Time resolution: <80ps

Rate : 30kHz/cm^2

Technology: low resistive glass MRPC+PADI +GET4

Analysis method: TOT slewing correction

3st generation TOF:

Requirement: Time resolution: <20ps

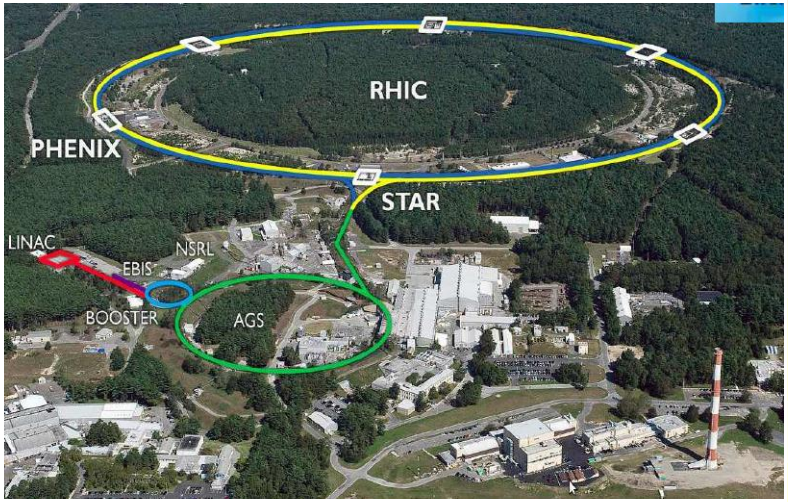
Rate : 20kHz/cm^2

Technology: low resistive glass MRPC+SCA +ADC

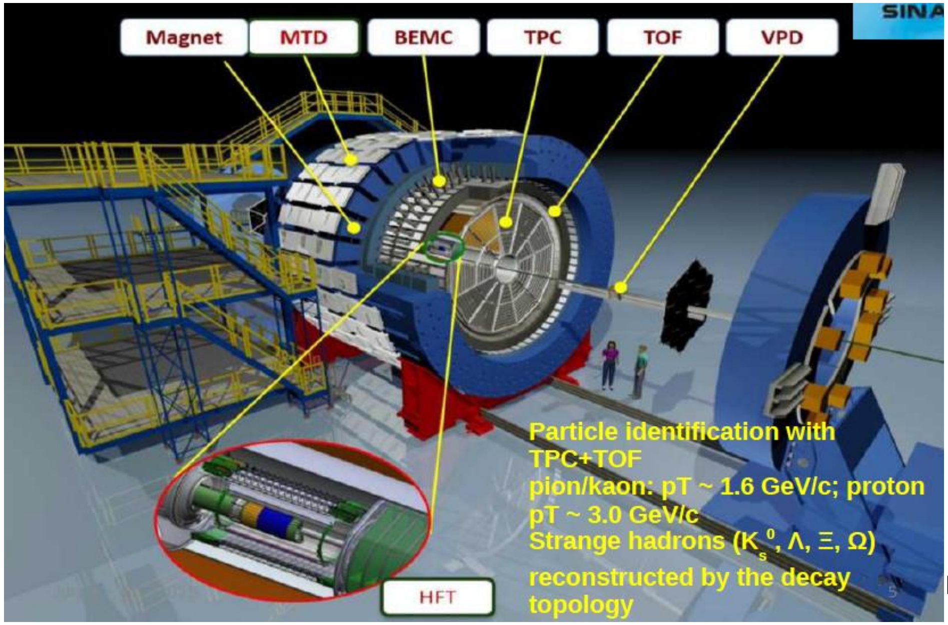
Analysis method: TOT slewing correction

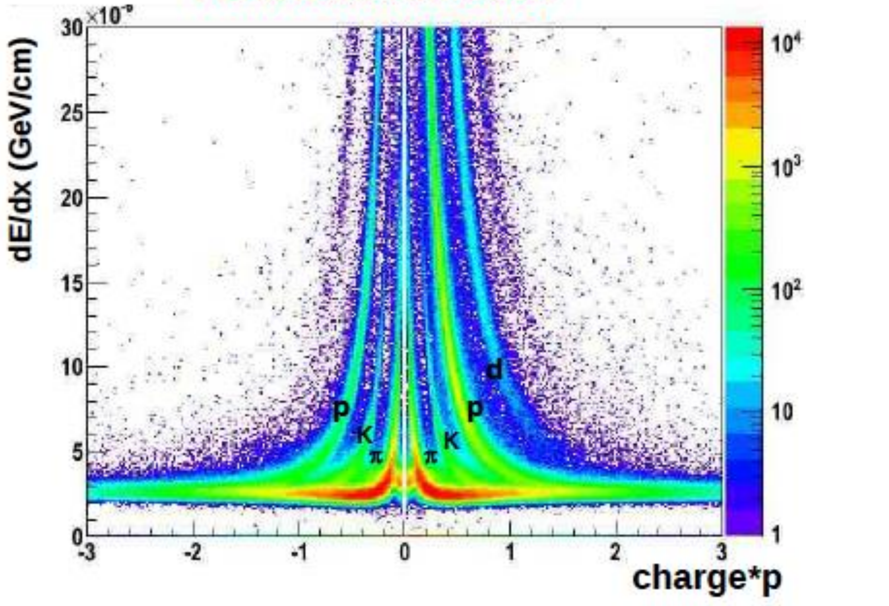
Deep learning+ Neural network

RHIC-STAR

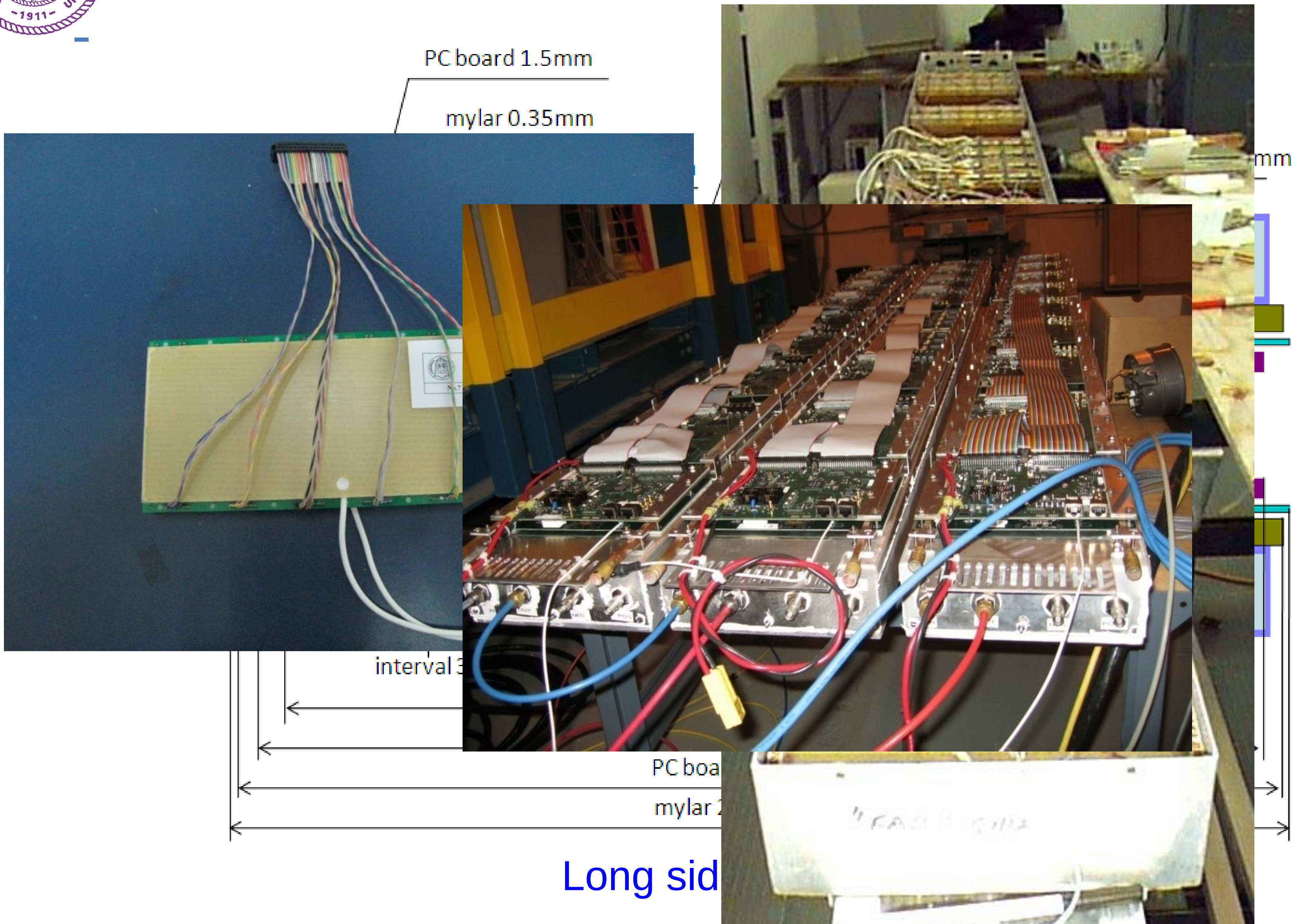


Collision species	C.M. Energy per nucleon pair (GeV)	Physics
Polarized p+p	510, 200, 150	Spin physics
Au+Au	200, 130, 62.4, 39, 27, 19.6, 14.5, 11, 7.7	Quark Gluon Plasma properties, QCD Critical point search
Cu+Cu, Cu+Au	200, 62.4, 19.6, 22.4	Study initial conditions
d+Au	200	Cold nuclear matter
U+U	193	Study initial conditions

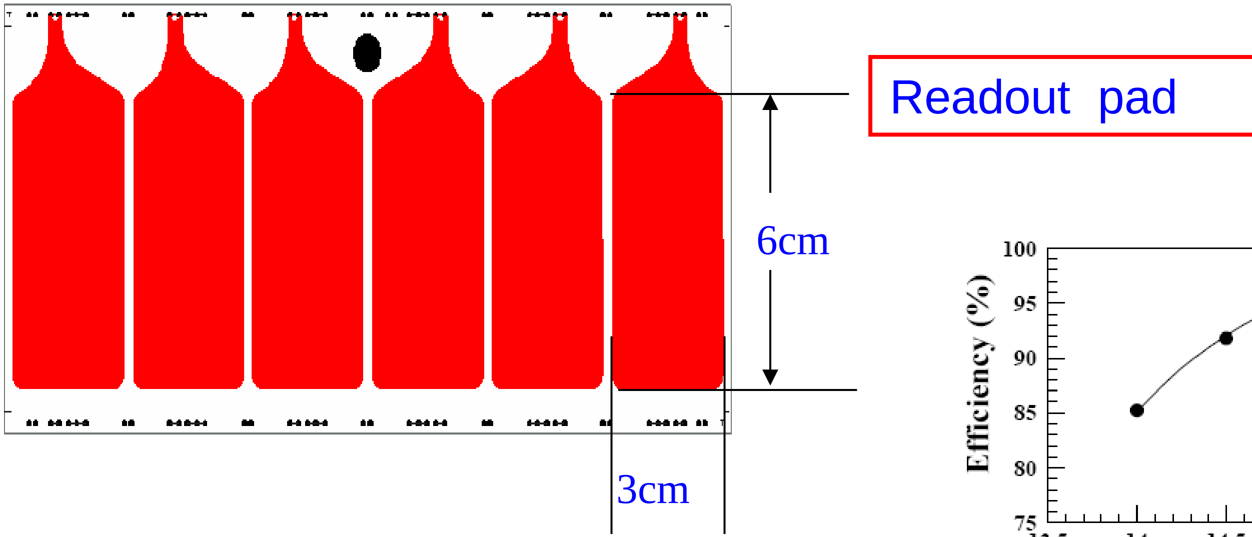


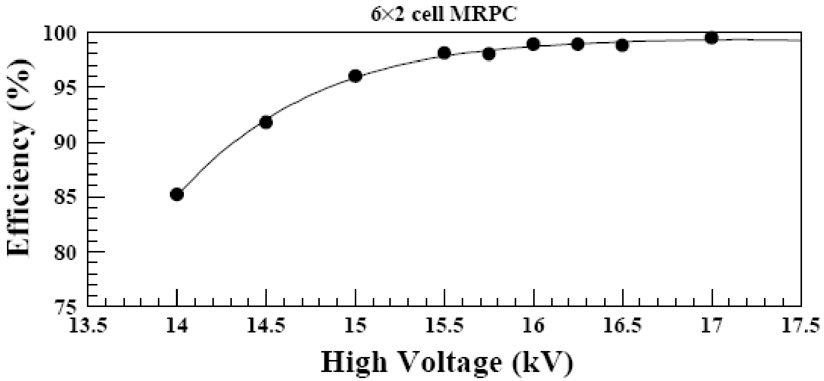


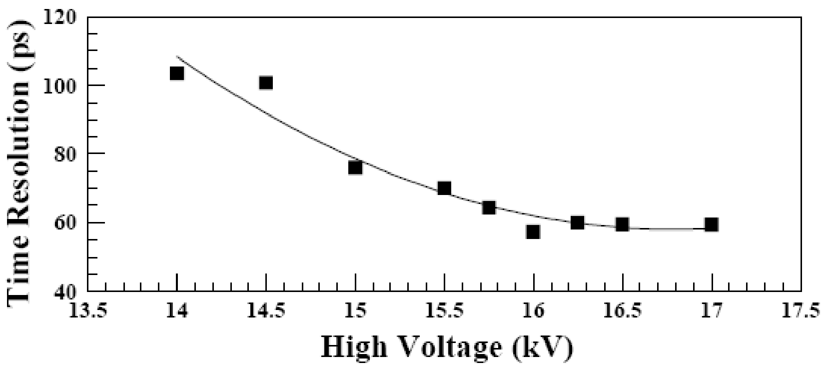
STAR-TOF MRPC



STAR MRPC performance

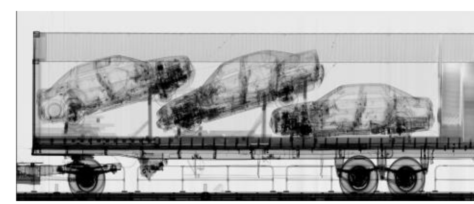






Glass: ～4×10^{12}Ω.cm
Carbon tape: 500k Ω/□
Gas gap: 6×0.22mm
Working gas: 95% F134a+5% iso-butane
Time resolution: 70ps
Efficiency >90%
Rates capability: <500Hz/cm^2 !

MRPC mass production



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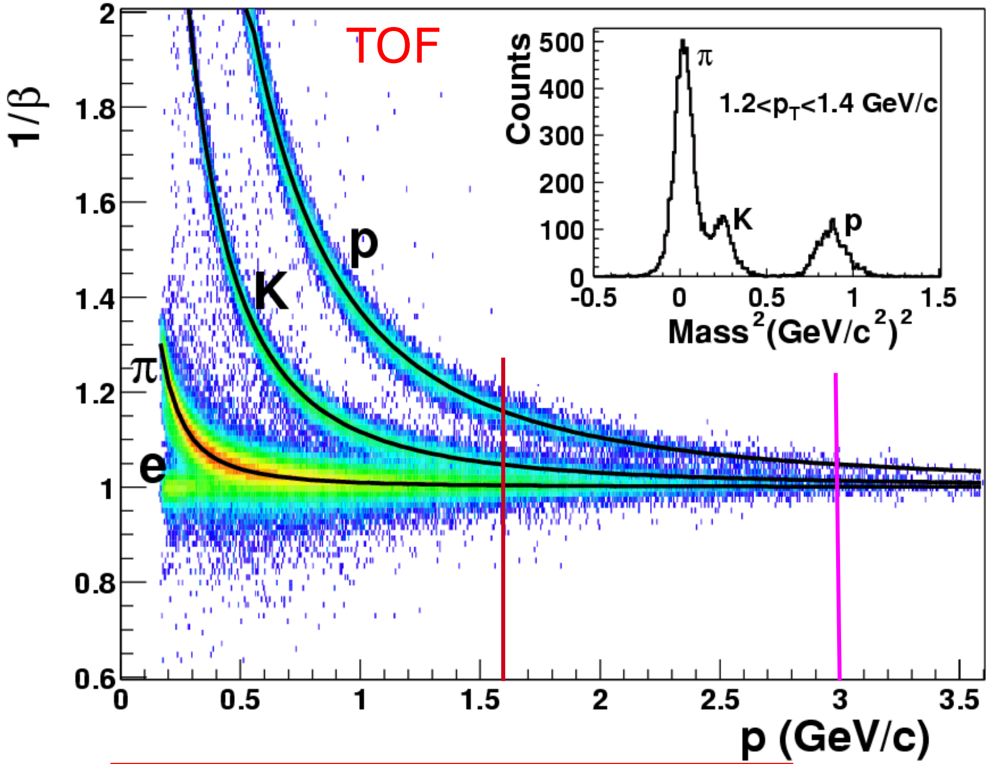
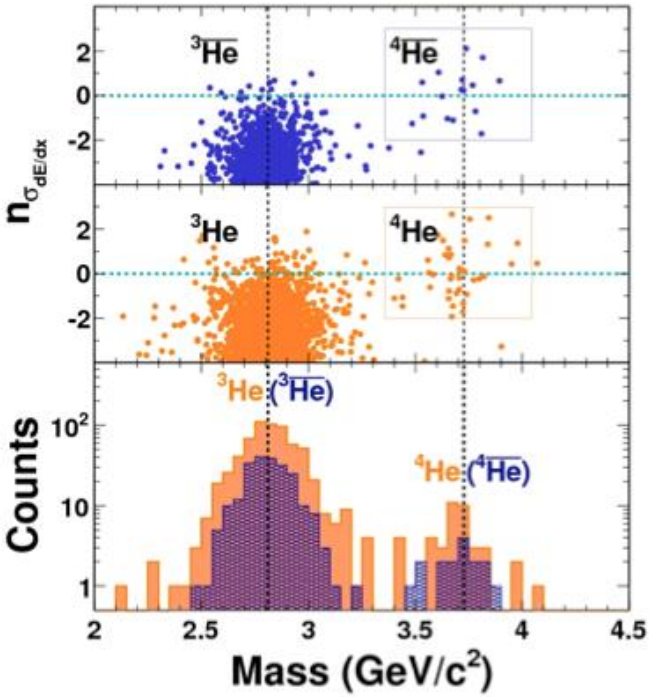
PID of STAR-TOF





TOF PID:

π /k ~1.6 GeV/c,

(π,k)/p ~ 3.0 GeV/c

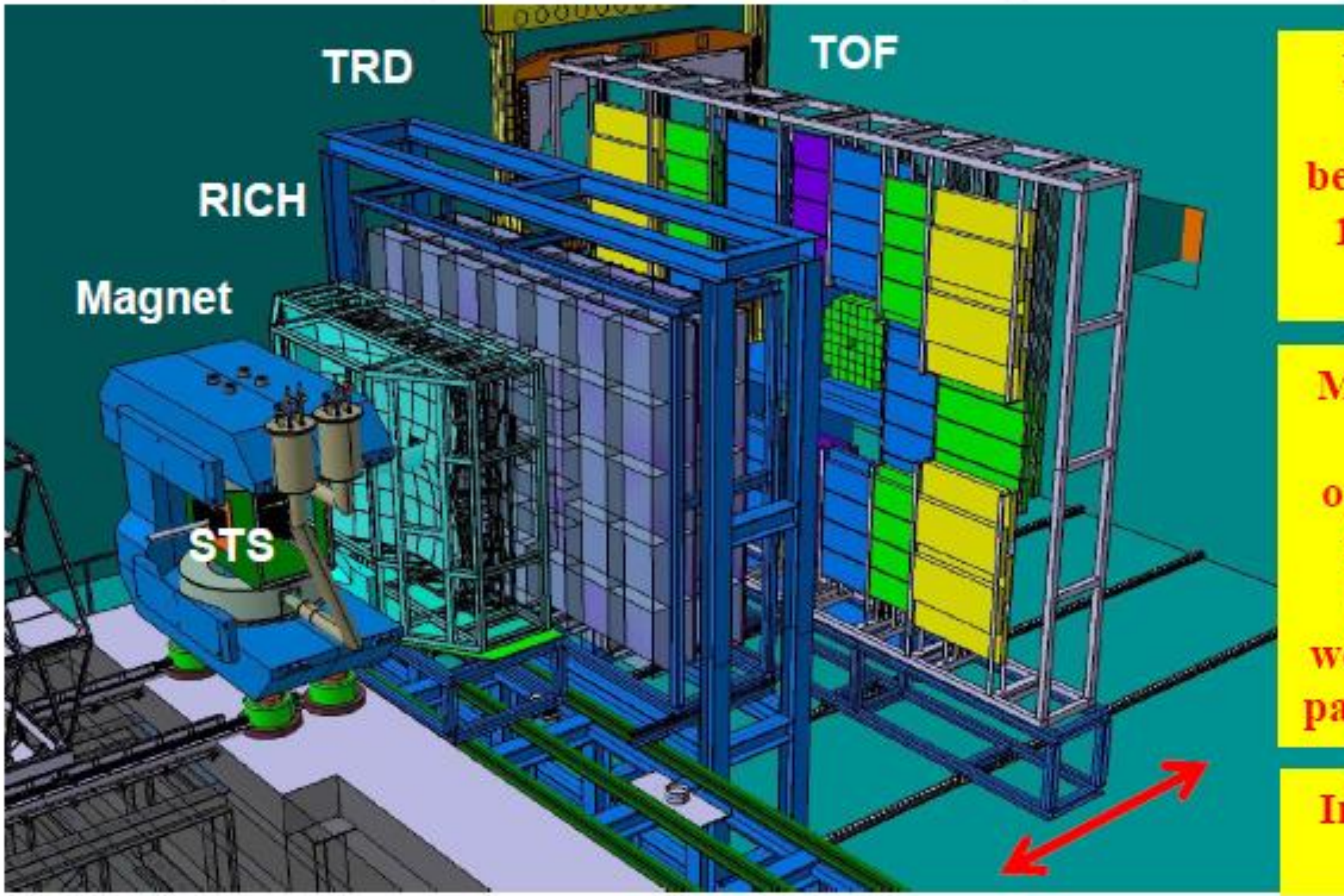
Observation of the antimatter helium-4 nucleus

The STAR Collaboration*

Nature 473 (2011) 353

Layout of CBM detector

Engineering design of the CBM experiment



Nominal ToF position is between 6 m and 10 m from the target

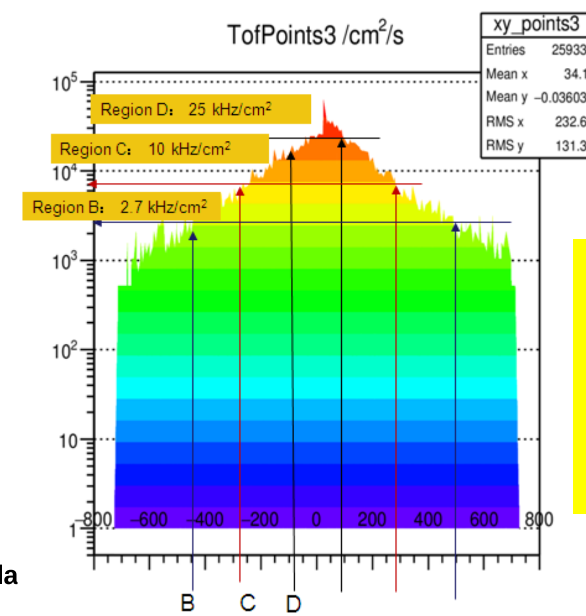
Movable design allows for optimization of the detection efficiency of weakly decaying particles (Kaons)

Interaction rate 10 MHz

The structure of CBM-TOF wall

CBM-ToF Requirements

- Full system time resolution σ_T ~ 80 ps
- Efficiency > 95 %
- Rate capability ≤ 30 kHz/cm²
- Polar angular range 2.5° – 25°
- Occupancy < 5 %
- Low power electronics (~100.000 channels)
- Free streaming data acquisition

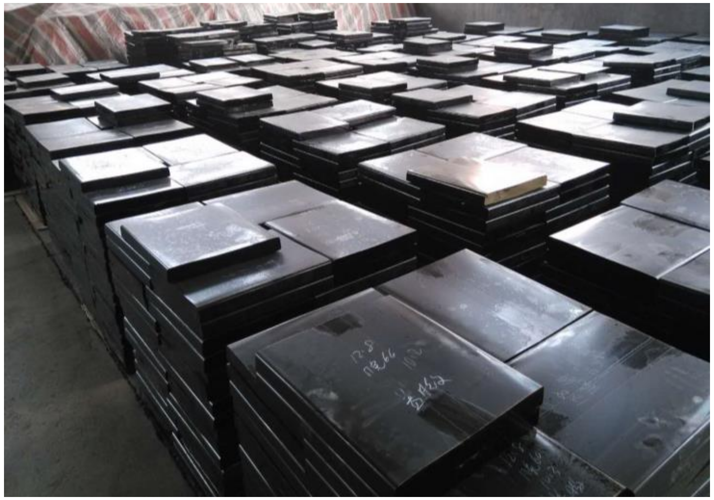


Au+Au, Center, 10AGeV Simulated with CBM ROOT

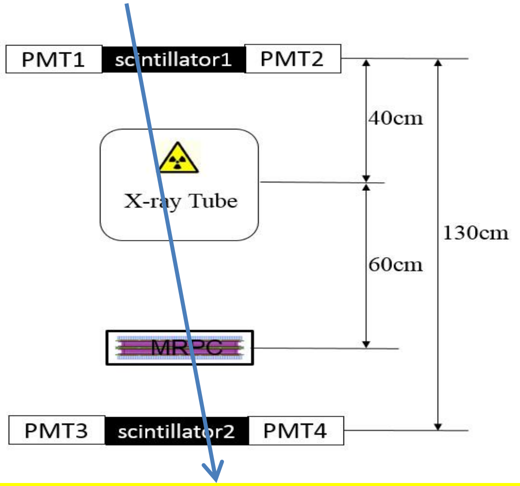
Development of low resistive glass

Performance of the glass

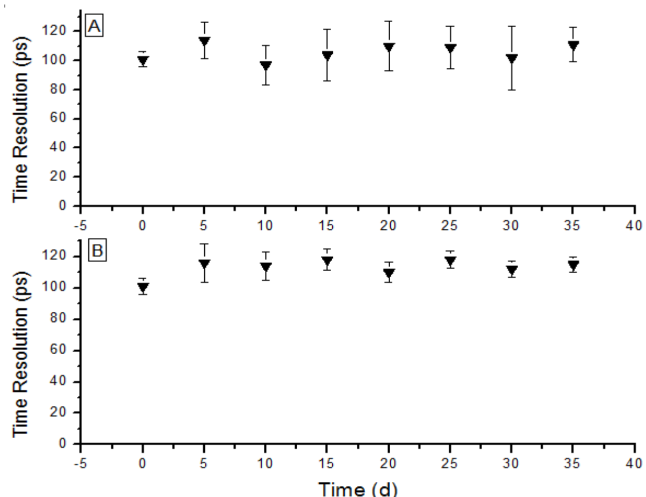
Maximal dimension	32cm $\times$ 30cm
Bulk resistivity	10^{10} Ωcm
Standard thickness	0.7, 1.1mm
Thickness uniformity	20 μm
Surface roughness	$<$ 10nm
Dielectric constant	7.5 - 9.5
DC measurement	Ohmic bebavior stable up to 1 C/cm^2



Glass mass production
Yield >100m^2/month

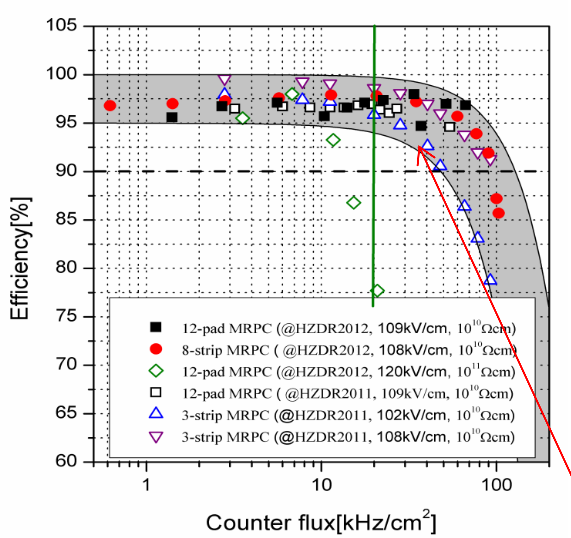


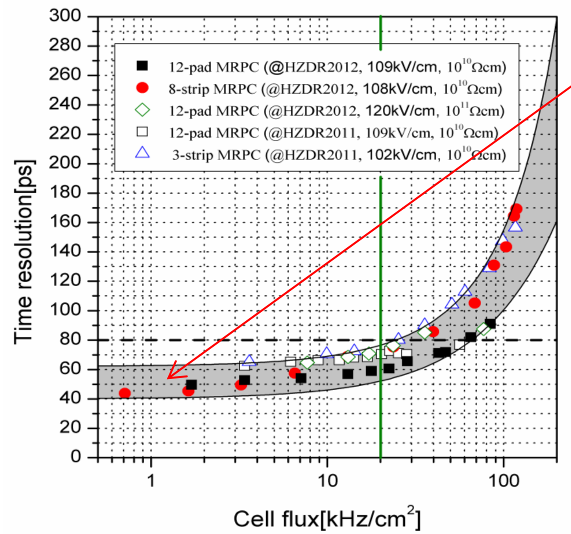
Aging test with X-ray source



Online test system. The efficiency and time resolution can be obtained by cosmic ray while irradiated by X-rays. 0.1C/cm^2 charge is accumulated in 35 days.

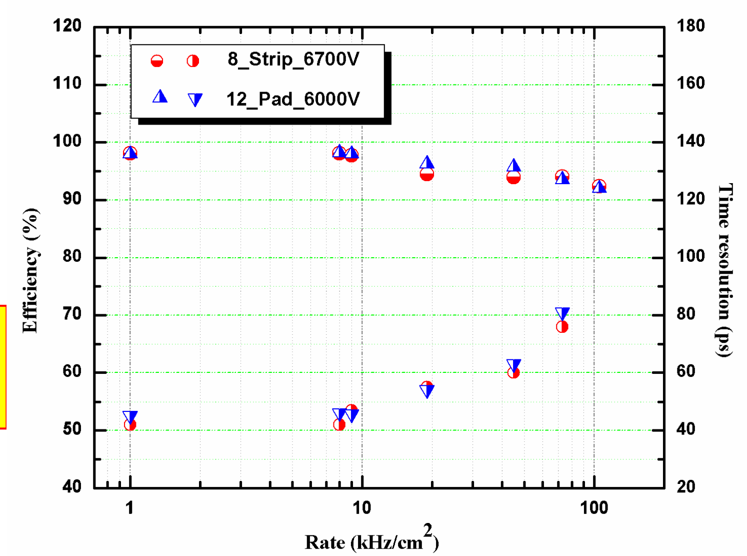
Rate capability of high rate MRPC





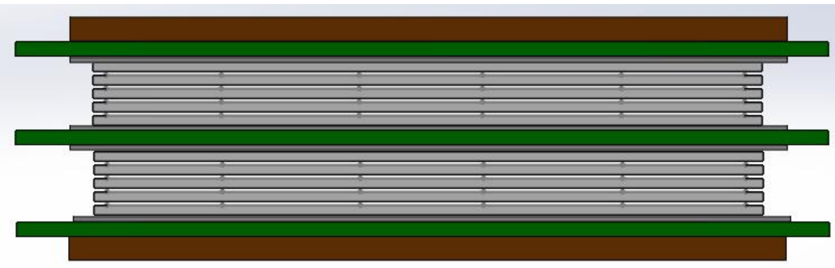
Rate: 70kHz/cm^2
Time resolution: 40 ps

Test results at Nuclotron, Dubna，2013



Even though the rate is 70kHz/cm^2, the efficiency is still higher than 90% and the time resolution is about 80ps.

Design of strip-MRPC for high rate region

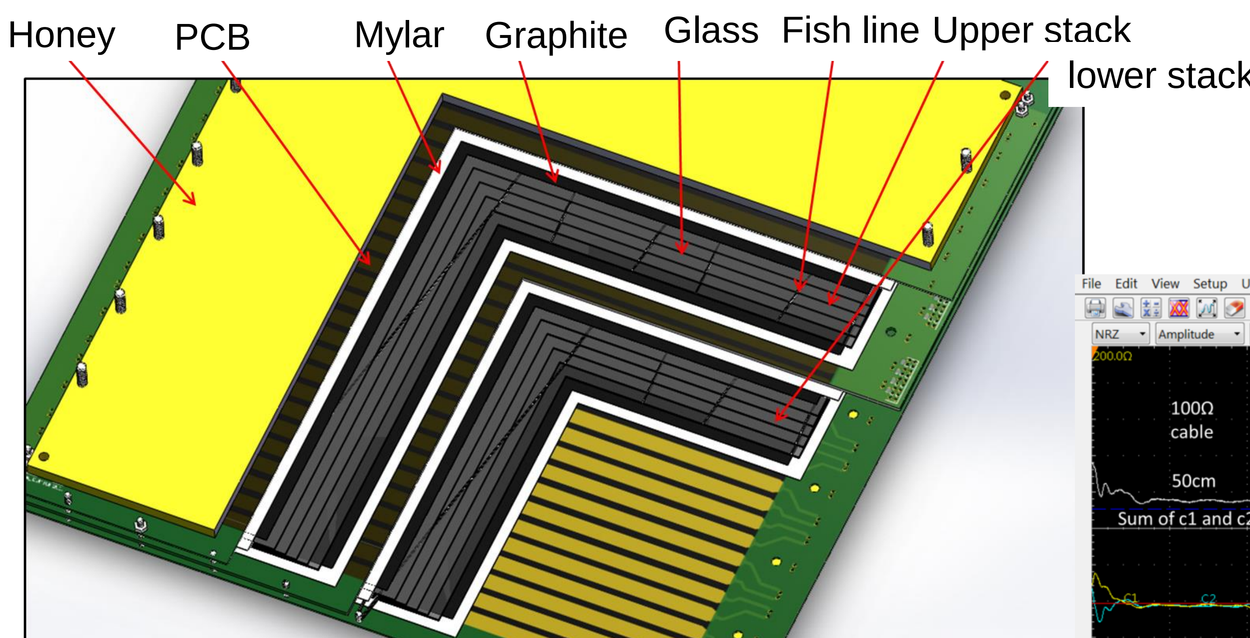


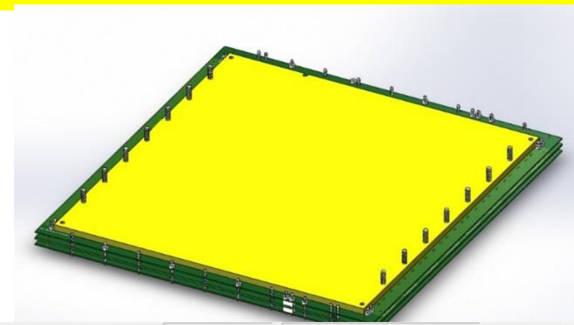
Glass: low resistive glass

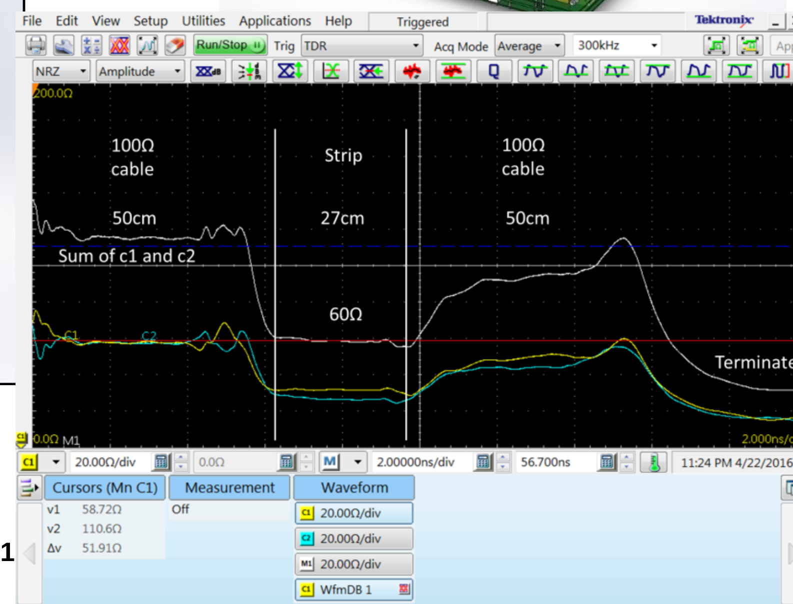
0.7mm thick, 33cm x 27.6cm

Strip: 27cm x 0.7cm, 0.3cm interval, 32 strips

Gas gap: 8 x 0.25mm, two stacks

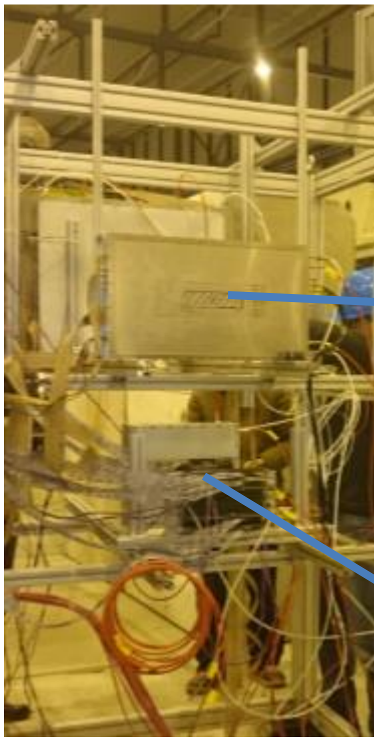






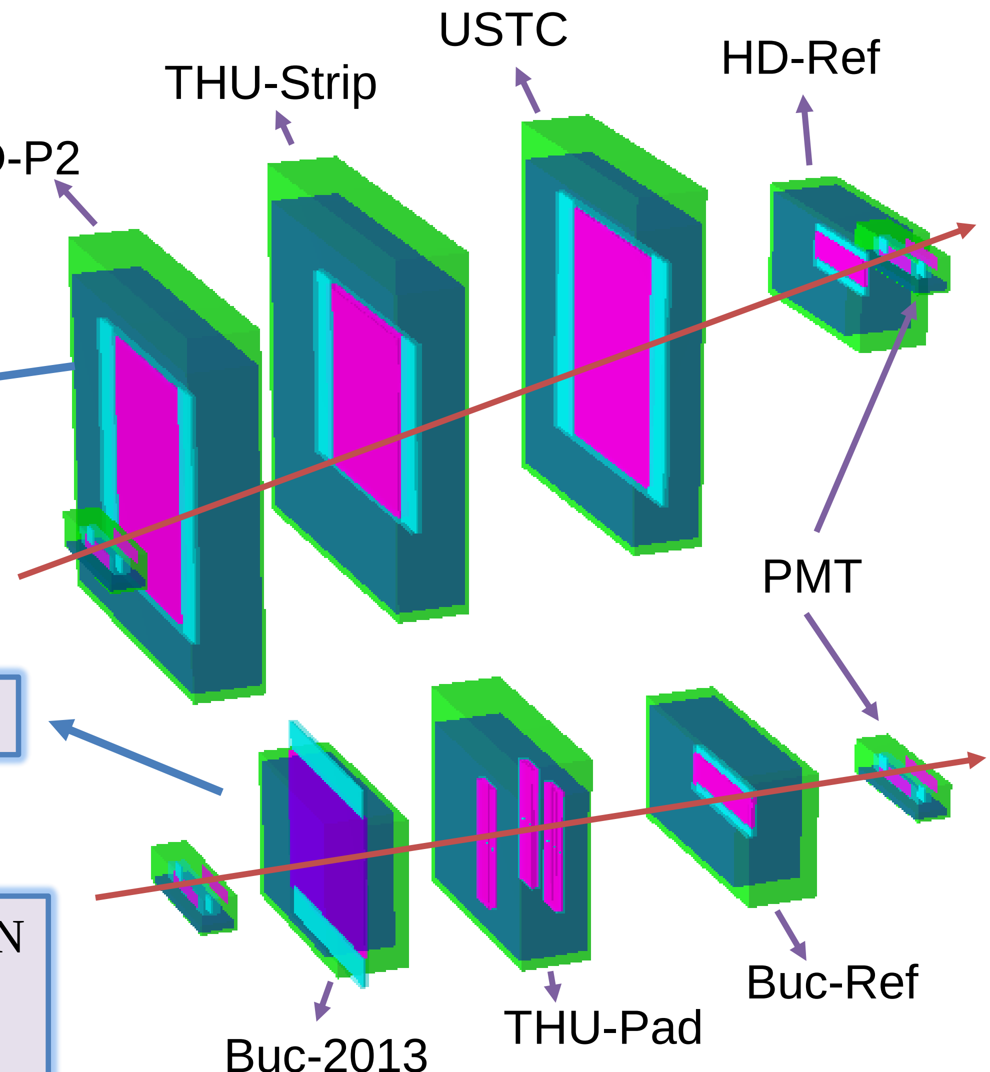
Beam test @ SPS Feb 2015

Experimental Setup:



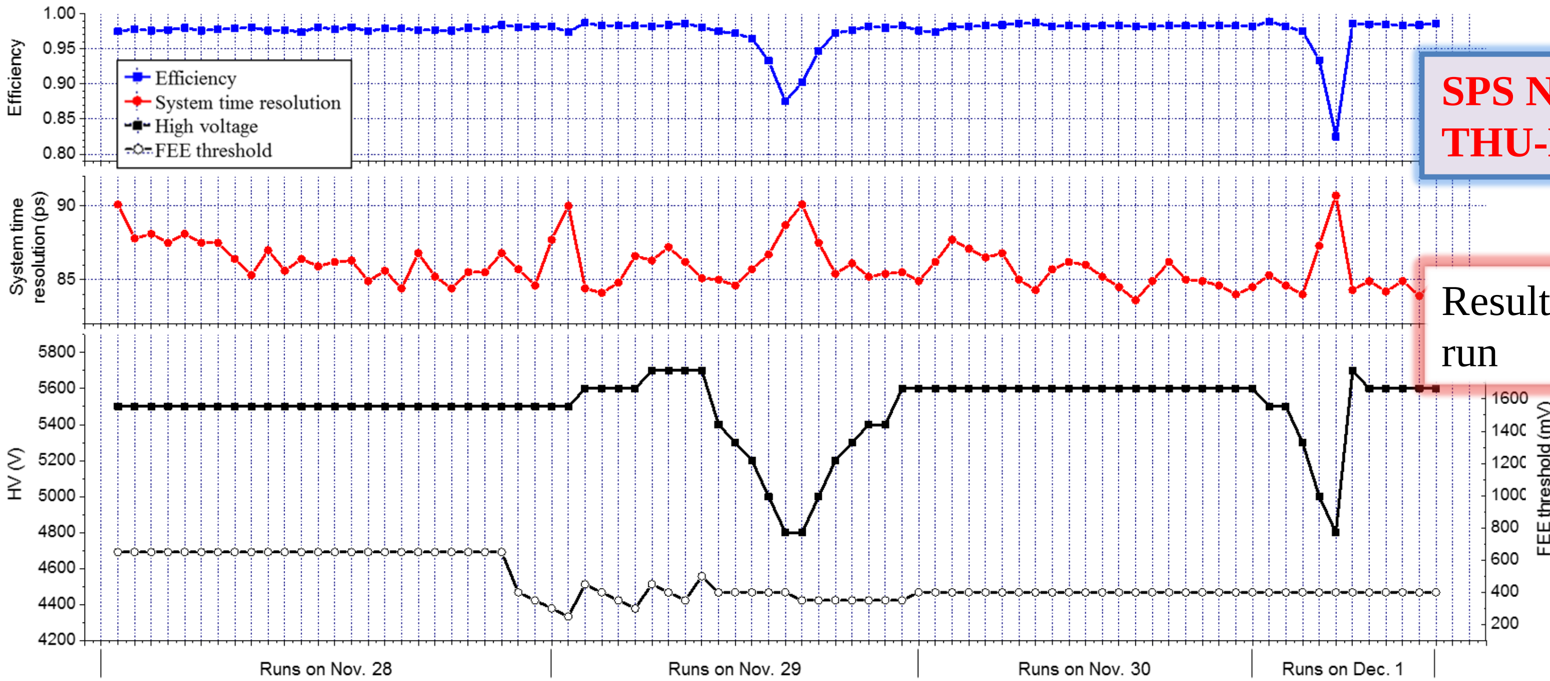
Up setting

Down setting



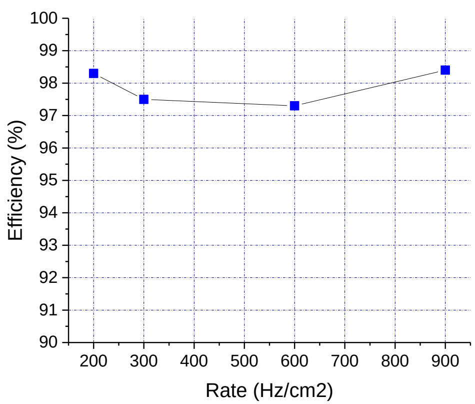
High rate test in February 2015 at SPS CERN
13 GeV Ar beam
Flux rate **around 1kHz/cm^2**

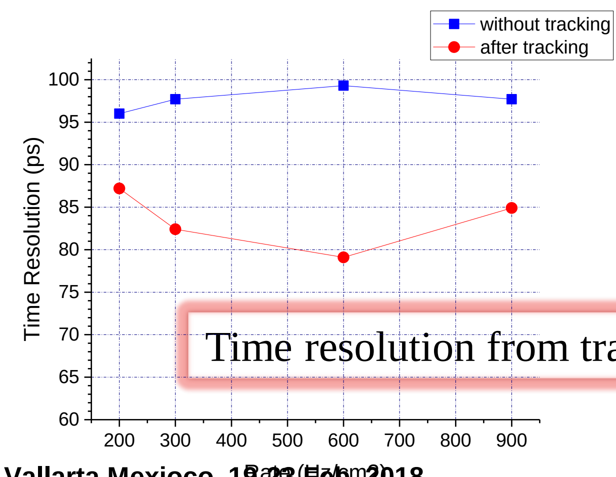
Performance of the prototype



SPS Nov 2015 THU-DU results

Results of each run

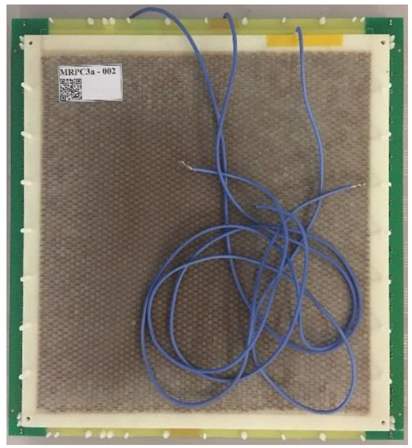


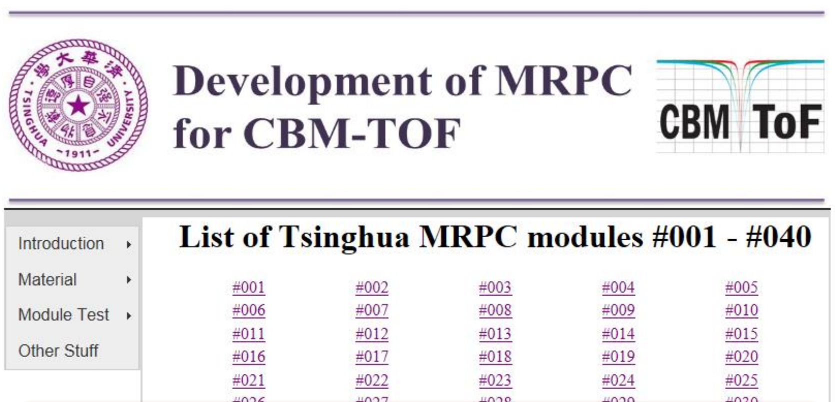


Time resolution from tracking method

Mass production of high rate MRPC

Two-dimensional code of MRPC





Producttion website:
http://hepd.ep.tsinghua.edu.cn/CBM_TOF/

MRPC生产记录表 / MRPC3a Quality Assurance Table

MRPC ID	MRPC3a - 005							
玻璃 / Glass	来自箱号与批次 / Glass Batch No.			NO.9 151225	用料数量/Amount			6
	来自箱号与批次 / Glass Batch No.			NO.11 151225	用料数量/Amount			4
	来自箱号与批次 / Glass Batch No.				用料数量/Amount			
电极玻璃 / Electrode	面电阻 / Surface Resistance (MΩ/sq)			Point 1	Point 2	Point 3	Point 4	Point 5
	电极玻璃1 / Electrode 1			8	2	3	7	7
	电极玻璃2 / Electrode 2			3	3	4	3	3
	电极玻璃3 / Electrode 3			5	8	5	8	5
	电极玻璃4 / Electrode 4			8	4	3	5	5
蜂窝板 / Honeycomb	√							
PCB上下板 / Top & Bottom PCB	√							
PCB中间板 / Middle PCB	焊接保护电阻 / Protection Resistor		外侧64路信号与地之间电阻是否均为100kΩ / Resistance Measured on Outside Resistor			√	问题数量 / Unqualified	0
			内侧64路信号与地之间电阻是否均为200kΩ / Resistance Measured on Inside Resistor			√	问题数量 / Unqualified	0
	焊接双排插针 / Connector		16个插座与电路板的厚度是否均<6.7mm / Thickness of the connectors			√	问题数量 / Unqualified	0
Mylar膜 / Mylar	√							
PCB上下板高压 / Top & Bottom HV	√							
PCB中间板高压 / Middle HV	√							
鱼线 / Spacer	√							
厚度 / Thickness	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8
上下PCB / Between Top & Bottom PCB	11.44	11.47	11.44	11.41	11.57	11.45	11.59	11.52
上中PCB / Between Top & Middle PCB	4.61	4.77	4.67	4.76	4.66	4.79	4.72	4.77
下中PCB / / Between Bottom & Middle PCB	4.63	5.03	5.02	4.87	4.96	4.84	4.84	4.74
总厚度 / Total Thickness	25.98	25.92	26.11	26.12	26.03	26.13	26.15	26.05
组装人员签字 / Signature	杨泽林							
日期 / Date	08/09/2017							
备注 / Note								

Overview of SoLID

Solenoidal Large Intensity Device

- Full exploitation of JLab 12 GeV Upgrade

  → A Large Acceptance Detector AND Can Handle High Luminosity (10^{37}-10^{39})

  Take advantage of latest development in detectors , data acquisitions and simulations

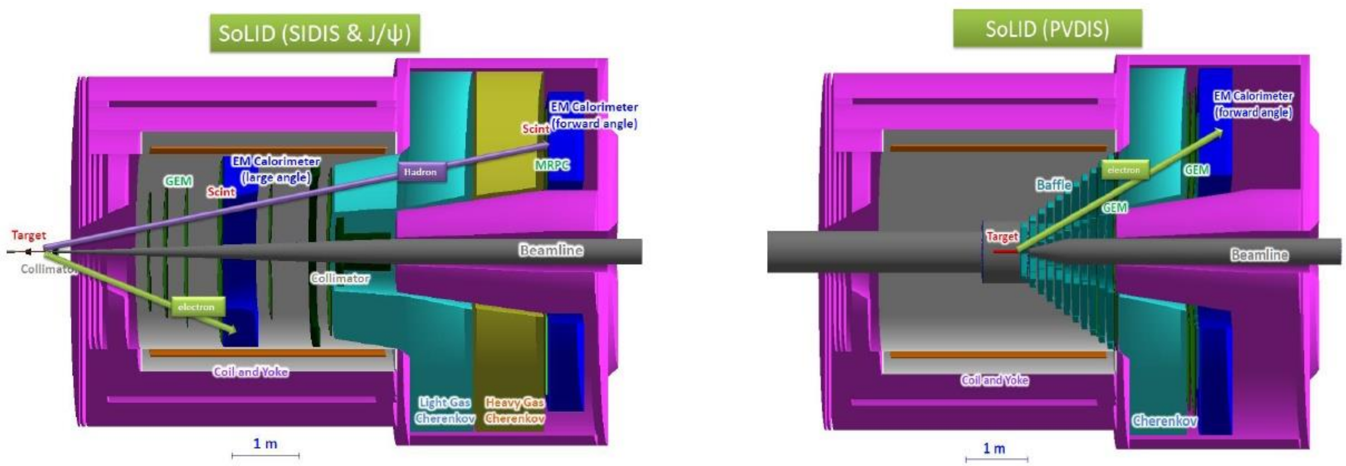
  Reach ultimate precision for SIDIS (TMDs), PVDIS in high-x region and threshold J/ψ

- 5 highly rated experiments approved (+3)

  Three SIDIS experiments, one PVDIS, one J/ψ production (+ three run group experiments)

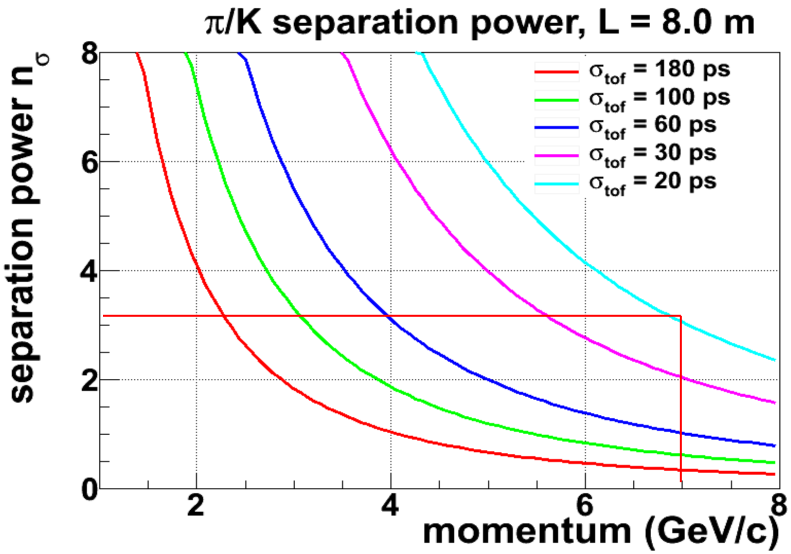
- Strong collaboration (250+ collaborators from 70+ institutes, 13 countries)

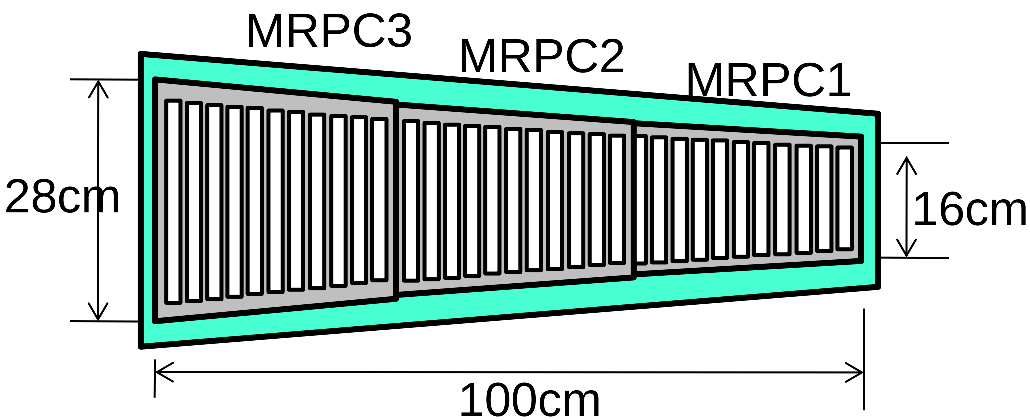
  Significant international contributions (Chinese collaboration)



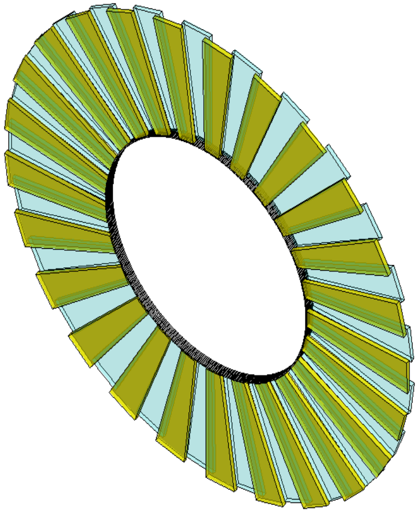
SoLID-TOF structure

- The MRPC is developed for the TOF of SoLID
- Main Requirements for TOF:
  - π/k separation up to 7GeV/c
  - Time resolution < 20ps
  - Rate capability > 20kHz/cm²





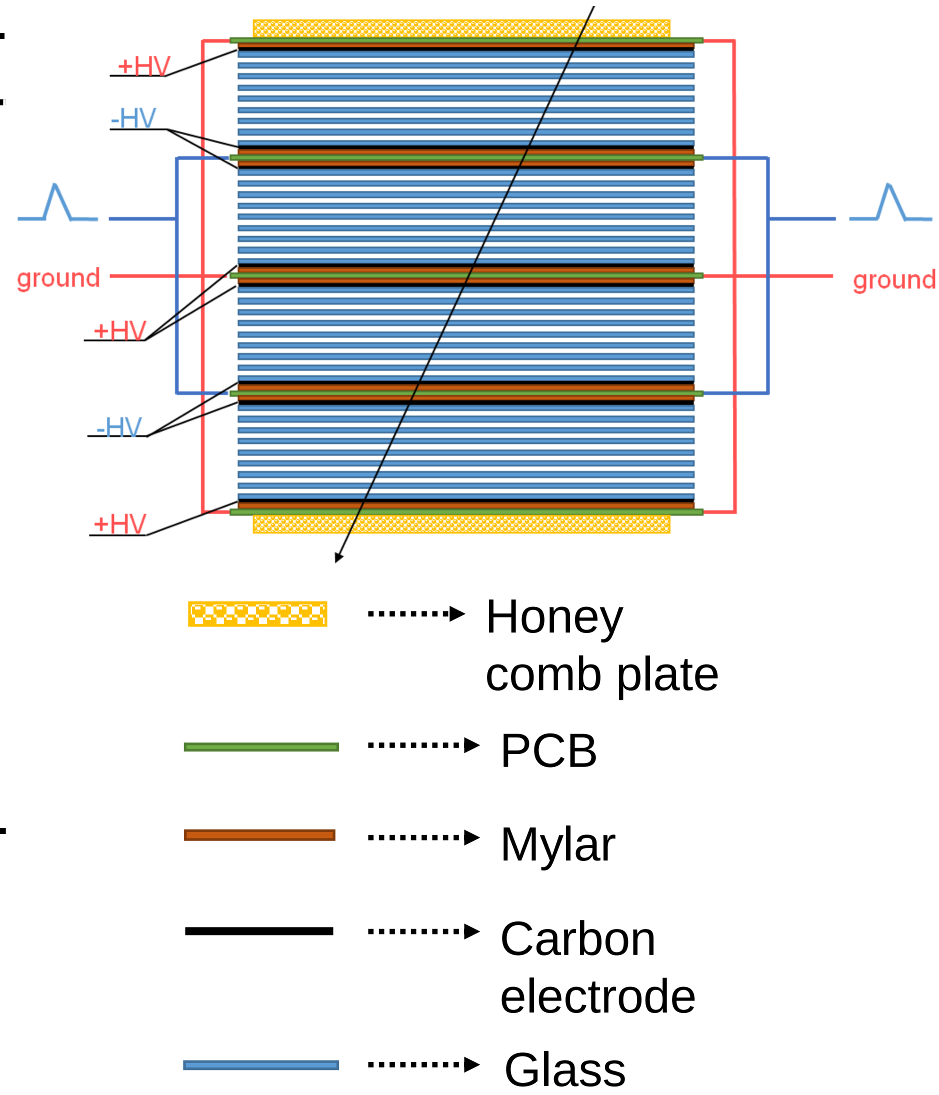
SoLID-TOF super module



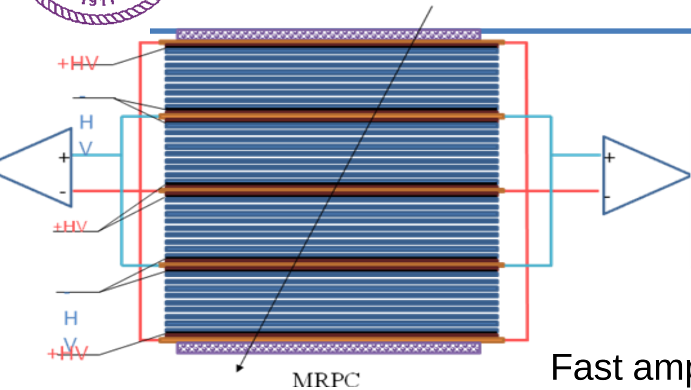
SoLID-TOF structure

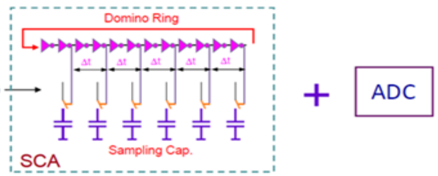
Design of 3^{g} MRPC for SoLID

Item	dimension/mm
Honeycomb	90×265×7.5
Outer PCB	120×298×0.6
Middle PCB1	120×298×1.2
Middle PCB2	120×328×1.2
Strip length	268
Strip width	7
Mylar	90×268×0.25
Glass	80×258×0.5
Carbon	72×250
Gas gap width	0.104
Number of gas gap	32

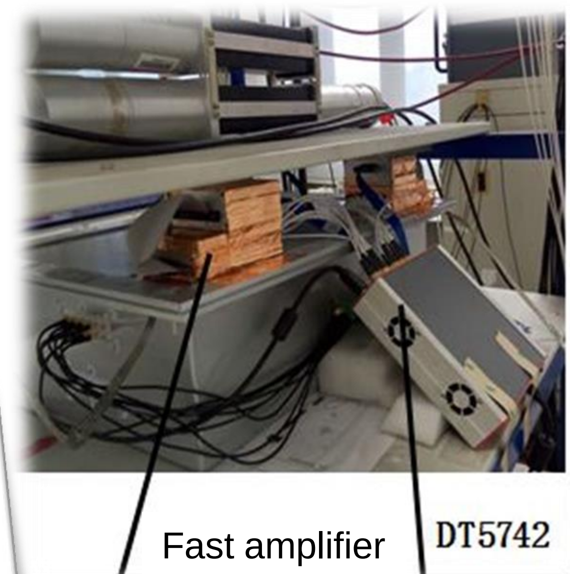


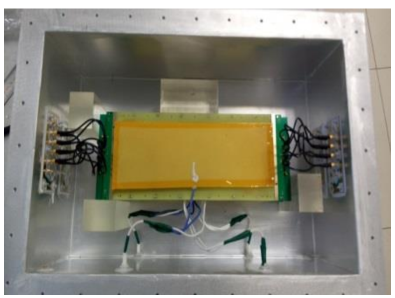
Readout chain



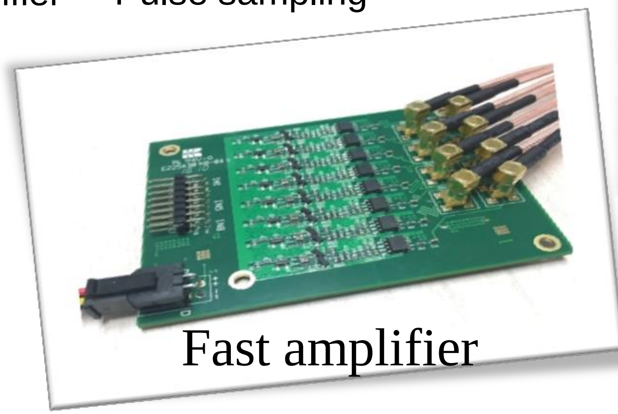


Fast amplifier Pulse sampling





Gas box



Waveform Digitizer DT5742

- DRS4-V5 chip
- 16 channels
- 12bit 5GS/s
- ~ 8 points for leading edge of MRPC

Typical wave form sampling chip

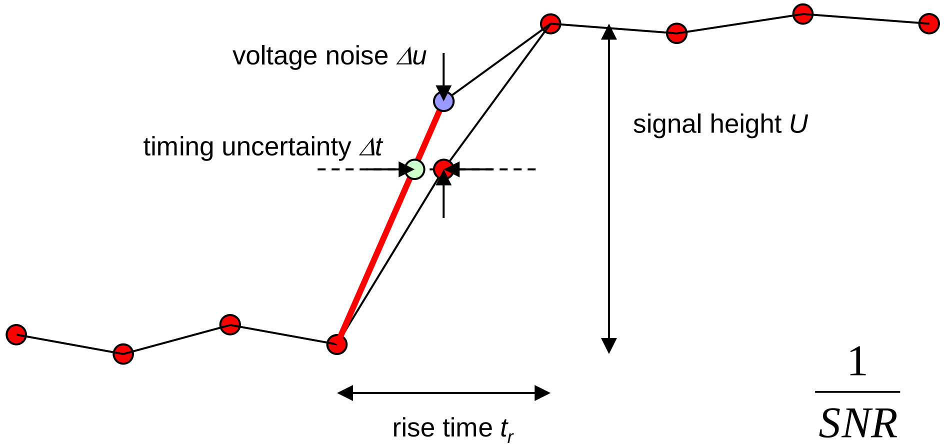
Chip	Sampling Frequency (GHz)	Bandwidth GHz	Number of samples	Number of channels	Readout frequency (MHz)	Resolution (ps)
PSEC4	4 to 15	1.5	256	6	40 to 60	9
SAMPIC	3 to 8.2	1.6	64	16 – 8 (at 10 GHz)	80	5
DRS4	0.7 to 5 GHZ	0.950	1024	9	33	1
DRS5	10	3	4096	32	300	5
PSEC5	5 to 15	1.5 to 2	32768	4	500	5

Deep learning and Neural network

- **Artificial neural networks(NN) are powerful tools for solving complex pattern recognition problems characterized by significant non–linearity**
- **Widely used in high energy physics**
- **For example, several sets of NN are used in the tracking reconstruction in ATLAS experiment**
- **Introduce NN to MRPC ?**
- **Training the NN with simulation data, and test with experiment data**

Comparison

Threshold method

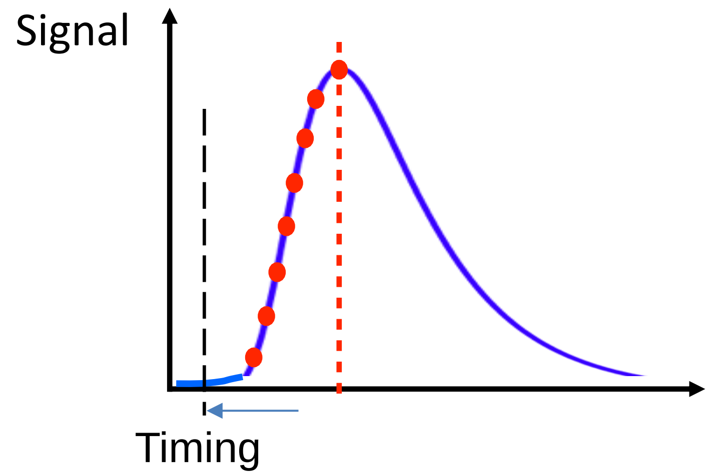


$$\frac{1}{SNR}$$

$$\Delta t = \frac{\Delta u}{U}\cdot t_r = \frac{\Delta u}{U\sqrt{n}}\cdot t_r = \frac{\Delta u}{U}\cdot\frac{t_r}{\sqrt{t_r\cdot f_s}} = \frac{\Delta u}{U}\cdot\frac{\sqrt{t_r}}{\sqrt{f_s}}$$

number of samples on slope

Neural network



From leading edge-→Particle incident time

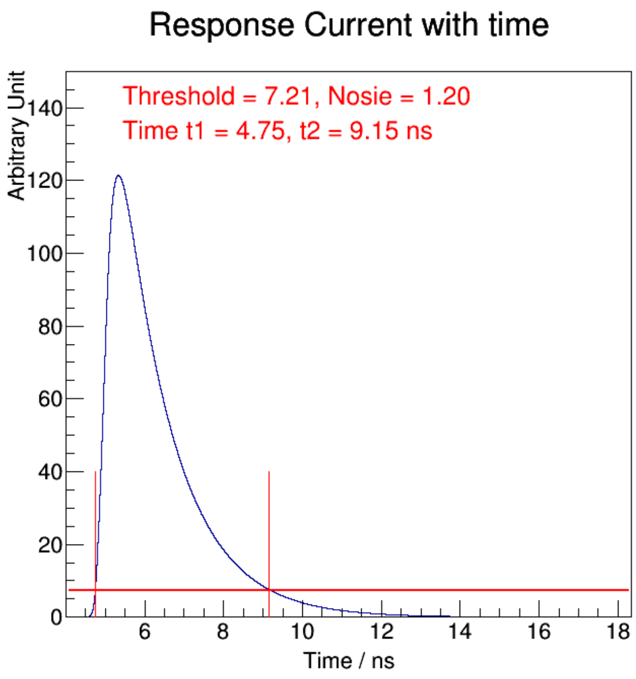
- Avalanche progress
- Charge induce
- Shaped by electronics

Neural network analysis method

- Determine structure of MRPC
- Construct NN
- Detector simulation->Pulse shape
- Training NN
- Input measured pulse-> Timing

MRPC simulation

- Physics model——primary ionization:
- Photo Absorption Ionization(PAI) model
- Induced charge signal
- Shaped by electronics
- Train neural network

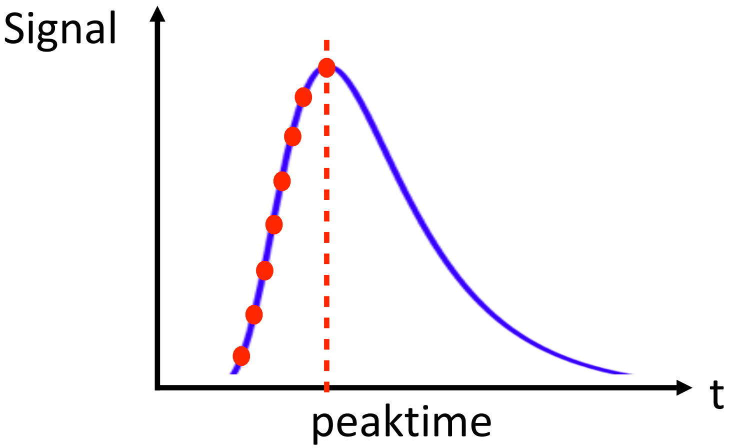


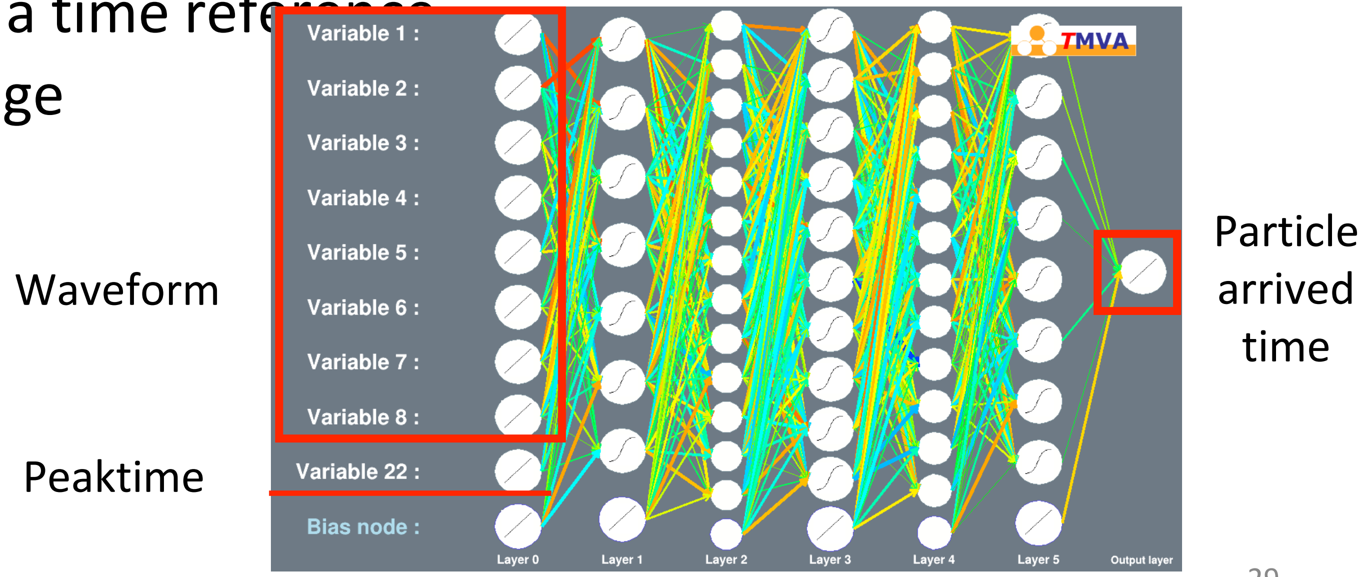
See Fuyue's poster:

A neural network based algorithm for MRPC time reconstruction

Analysis with neural network

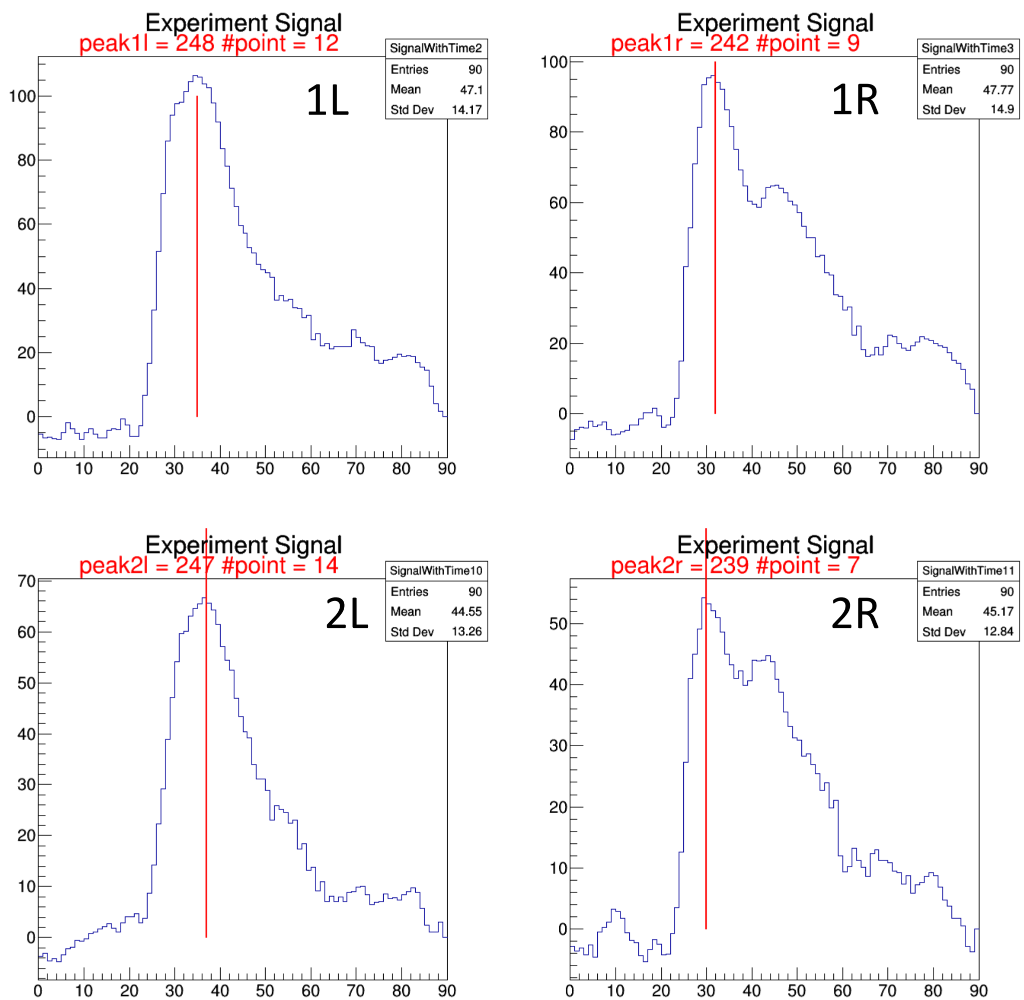
- Feed the waveform into a fully connected neural network
- 5 hidden layers
- 8 points along the leading edge
- Peaktime as a time reference
- TMVA package

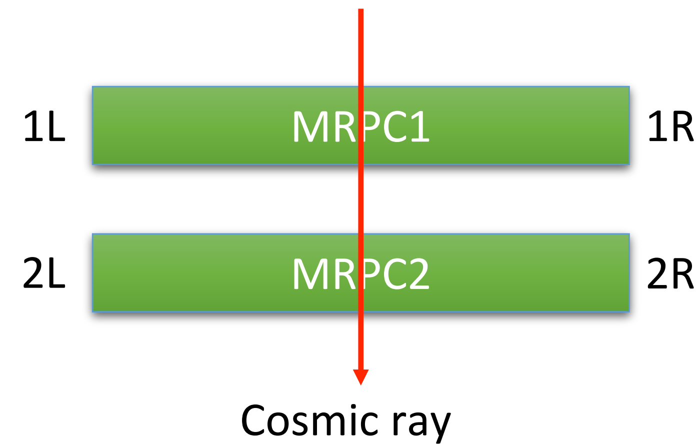




Analysis with neural network

- Test the model with the experiment data and get the estimated time





For 1L,1R,2L,2R, we will get

$$t_{est1} = \frac{t_{estimated1L} + t_{estimated1R}}{2}$$

$$t_{est2} = \frac{t_{estimated2L} + t_{estimated2R}}{2}$$

Analysis with neural network

- Test system: 2 MRPC

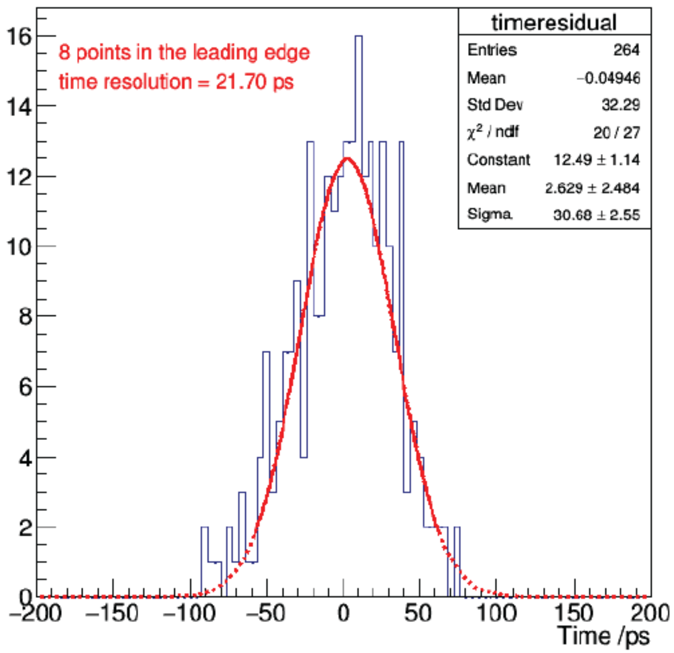
$$\sigma(\Delta t) = \sigma(t_{res1} - t_{res2}) = \sqrt{\sigma^2(t_{resi1}) + \sigma^2(t_{resi2})} = \sqrt{2\sigma^2_{MRPC}}$$
$$= \sigma(t_{true2} - t_{est2} - t_{true1} + t_{est1}) = \sigma(t_{est1} - t_{est2})$$
$$= \sigma(\frac{t_{est1l} + t_{est1r}}{2} - \frac{t_{est2l} + t_{est2r}}{2})$$

$$\sigma_{MRPC} = \frac{\sigma(\Delta t)}{\sqrt{2}}$$

- SCA+ADC waveform sampling
- Train with simulation data, test with experiment data
- Plot

$$Time = \frac{t_{est1l} + t_{est1r}}{2} - \frac{t_{est2l} + t_{est2r}}{2}$$

- The time resolution can reach 20 ps



Conclusions

- ✓ **Time of flight system (TOF) based on MRPC technology is widely used and played an important role in modern high energy nuclear physics experiments.**
- ✓ **With the increase of accelerator energy and luminosity, many experiments have increasingly demand on the TOF for particle identification to have high resolution TOF under high data rate environment.**
- ✓ **New technology such as New material (low resistive glass), New electronics (switched capacitor array (SCA) and precision TDC) will be used in TOF system. New analysis method such as deep learning technology will play an very important role!**

Thanks for your attention!