Newest development of MRPC

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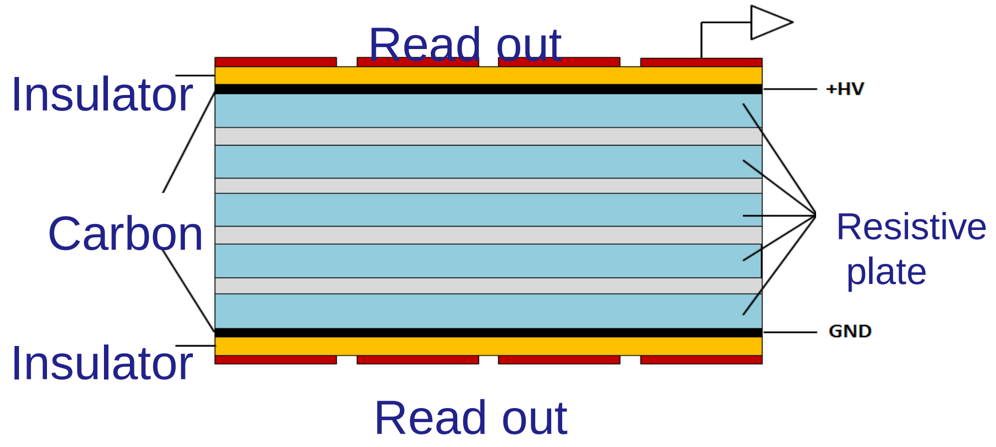
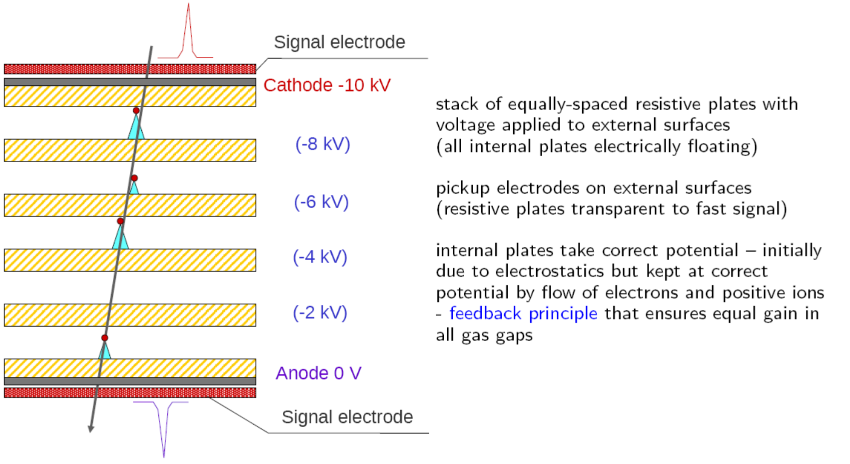
Abstract:

- Introduction of MRPC
- Introduction of three generation MRPC TOF
- Status of newest technology
- Conclusion

MRPC introduction



MRPC structure



Main specification:

Time resolution: ~tens ps

Spatial resolution: <1mm

Efficiency：>98%

Cost effective, large area

Long time stability

MRPC application：

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

MRPC used in TOF system

	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	32 x 0.128
Gas mixtures ($C_2H_2F_4$/ C_4H_{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	140
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**

→ higher **counting rate** and **time precision**.

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!

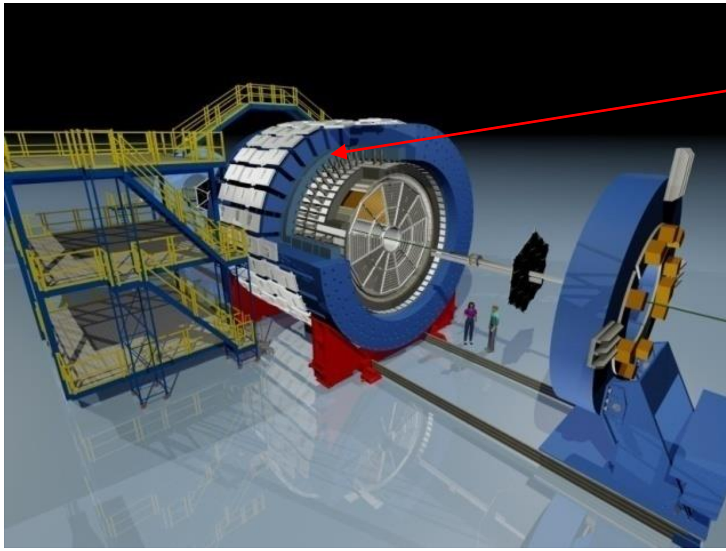
Two main ways to improve rate capability:

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

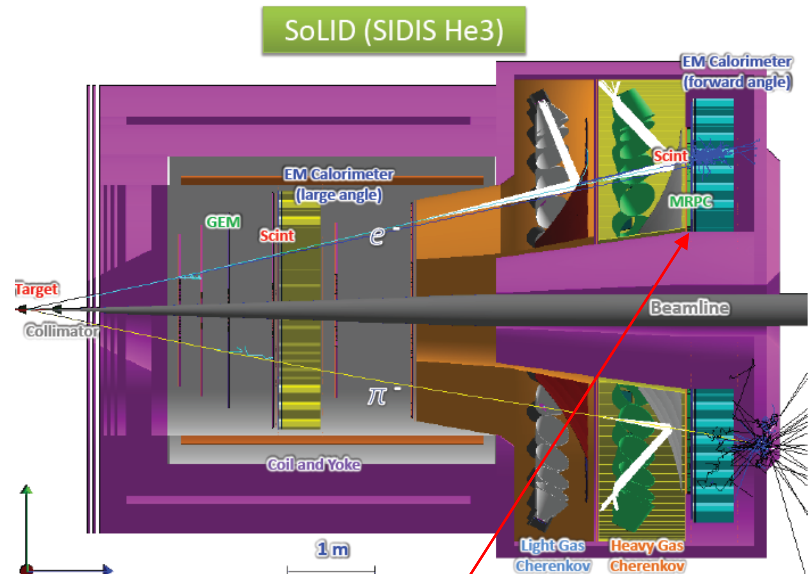
Other methods:

- Reducing the thickness of glass
- Warming the detector

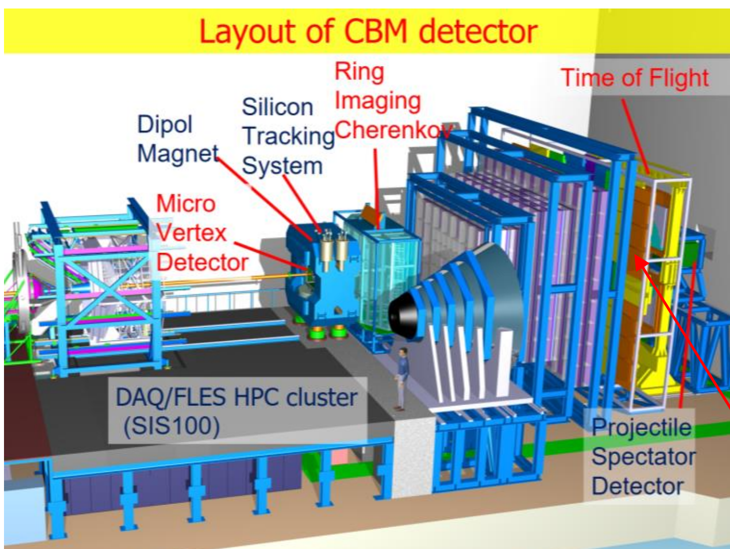
Typical MRPC TOF



RHIC-STAR TOF
Float glass



JLab-SoLID TOF
High rate and 20ps resolution



FAIR-CBM TOF
High rate- low resistive glass

Key technology

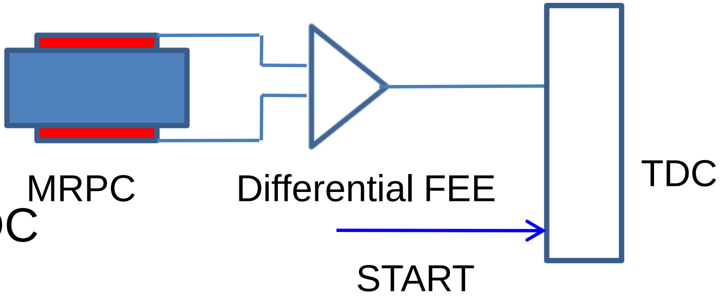
1st generation TOF (from 2000):

Requirement: Time resolution: <80ps

Rate : <1kHz/cm^2

Technology: common glass MRPC+NINOs +HPTDC

Analysis method: TOT slewing correction



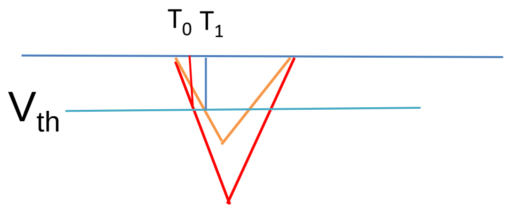
2st generation TOF (from 2008):

Requirement: Time resolution: <80ps

Rate : 30kHz/cm^2

Technology: low resistive glass MRPC+PADI +GET4

Analysis method: TOT slewing correction



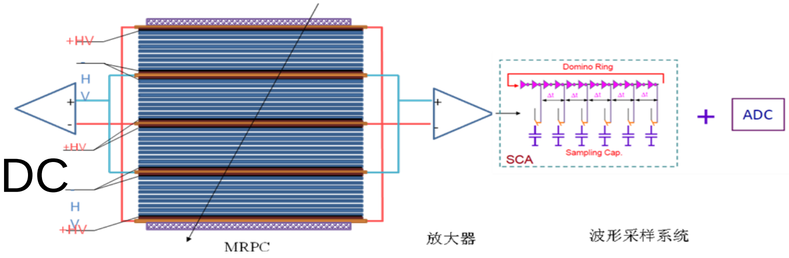
3st generation TOF (from 2012):

Requirement: Time resolution: <20ps

Rate : 20kHz/cm^2

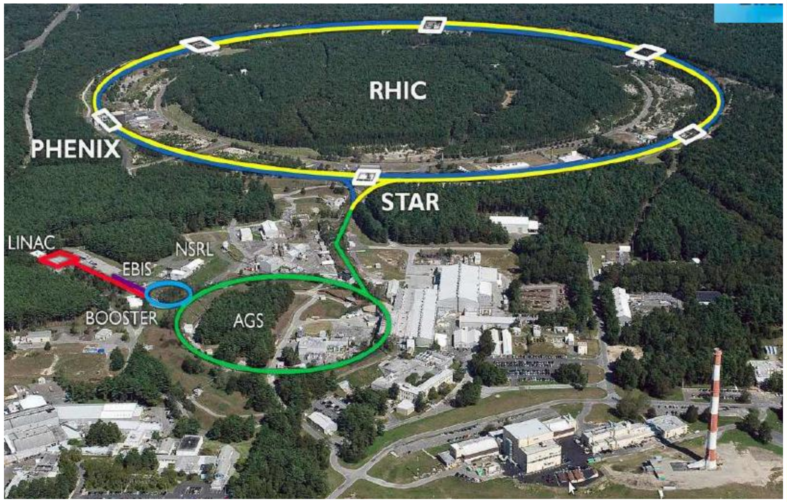
Technology: low resistive glass MRPC+SCA +ADC

Analysis method: TOT slewing correction

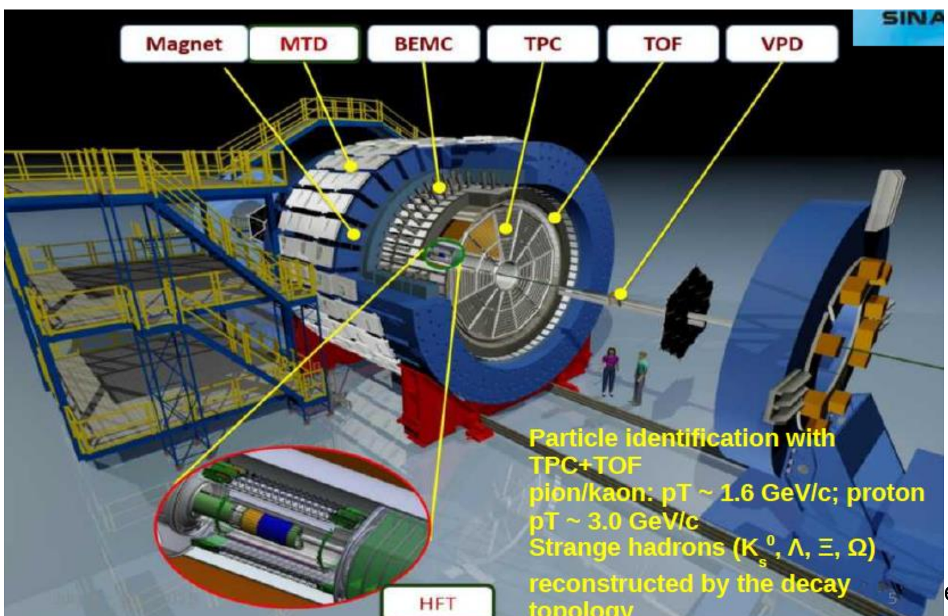


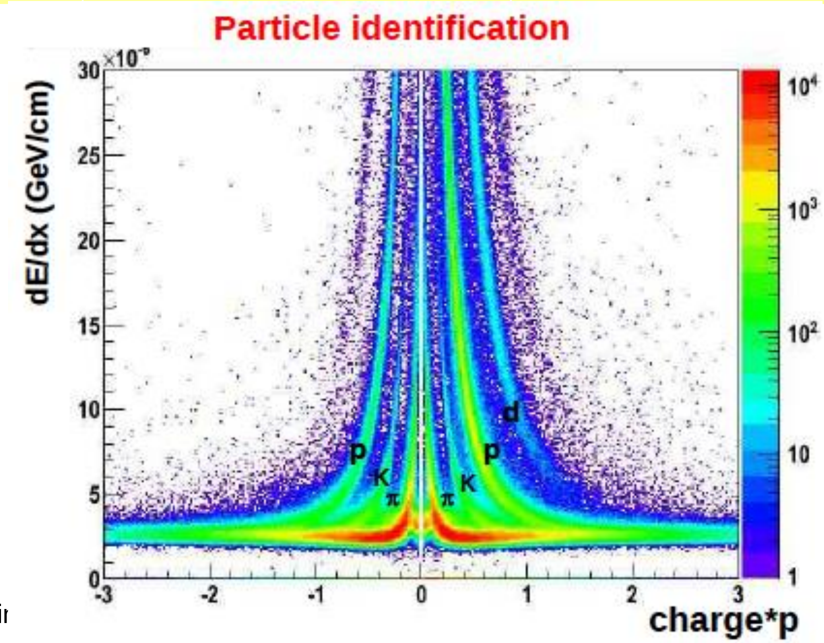
Deep learning+ Neural network

RHIC-STAR

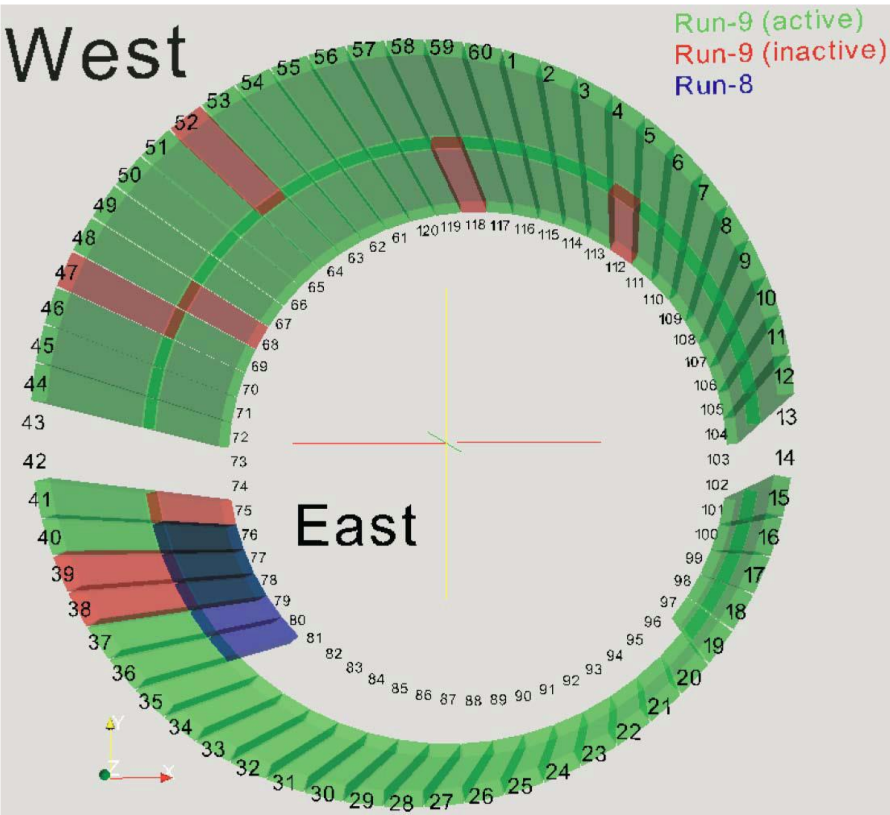


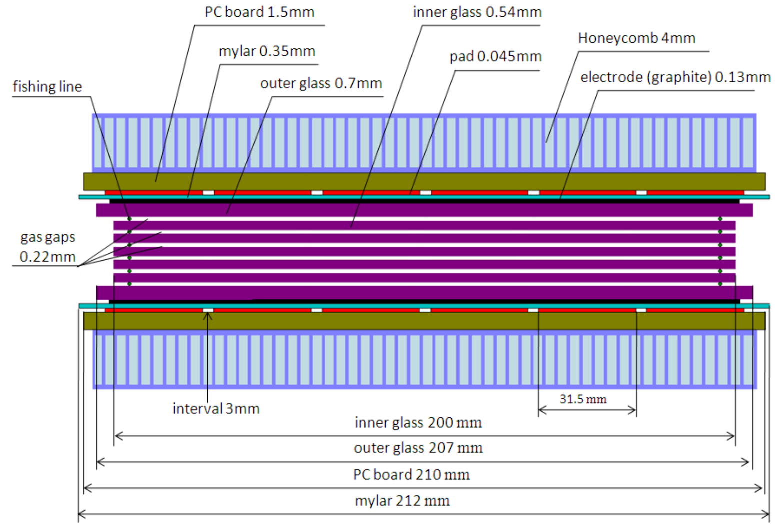
Collision species	C.M. Energy per nucleon pair (GeV)	Physics
Polarized p+p	510, 200, 150	Spin physics
Au+Au	200, 130, 62.4, 39, 27, 19.6, 14.5, 11, 7.7	Quark Gluon Plasma properties, QCD Critical point search
Cu+Cu, Cu+Au	200, 62.4, 19.6, 22.4	Study initial conditions
d+Au	200	Cold nuclear matter
U+U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





STAR-TOF structure

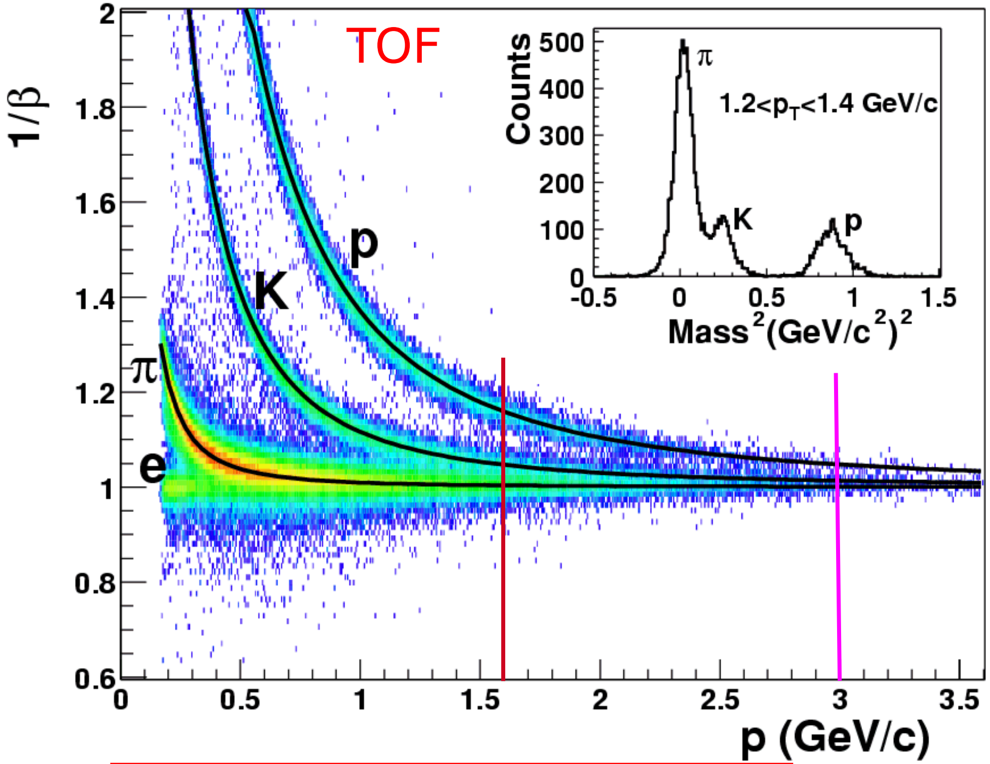


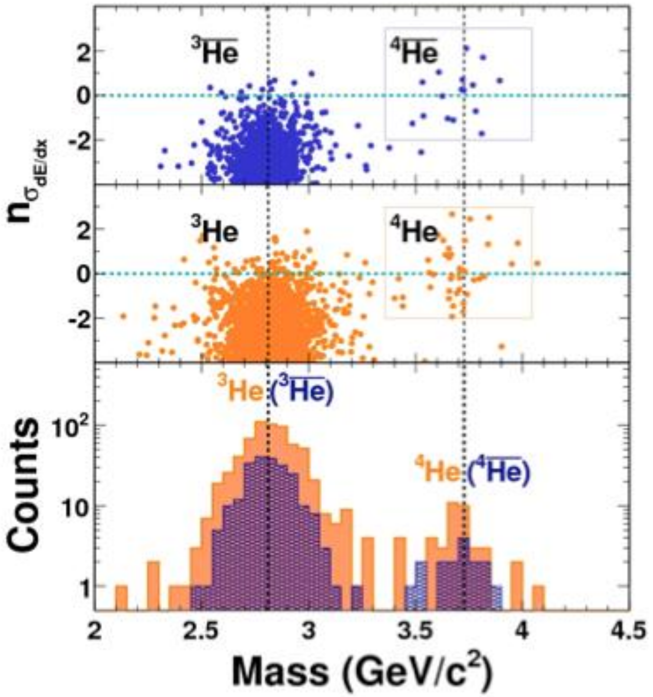


The structure of MRPC

MRPC + NINOs + HPTDC

PID of STAR-TOF





TOF PID:

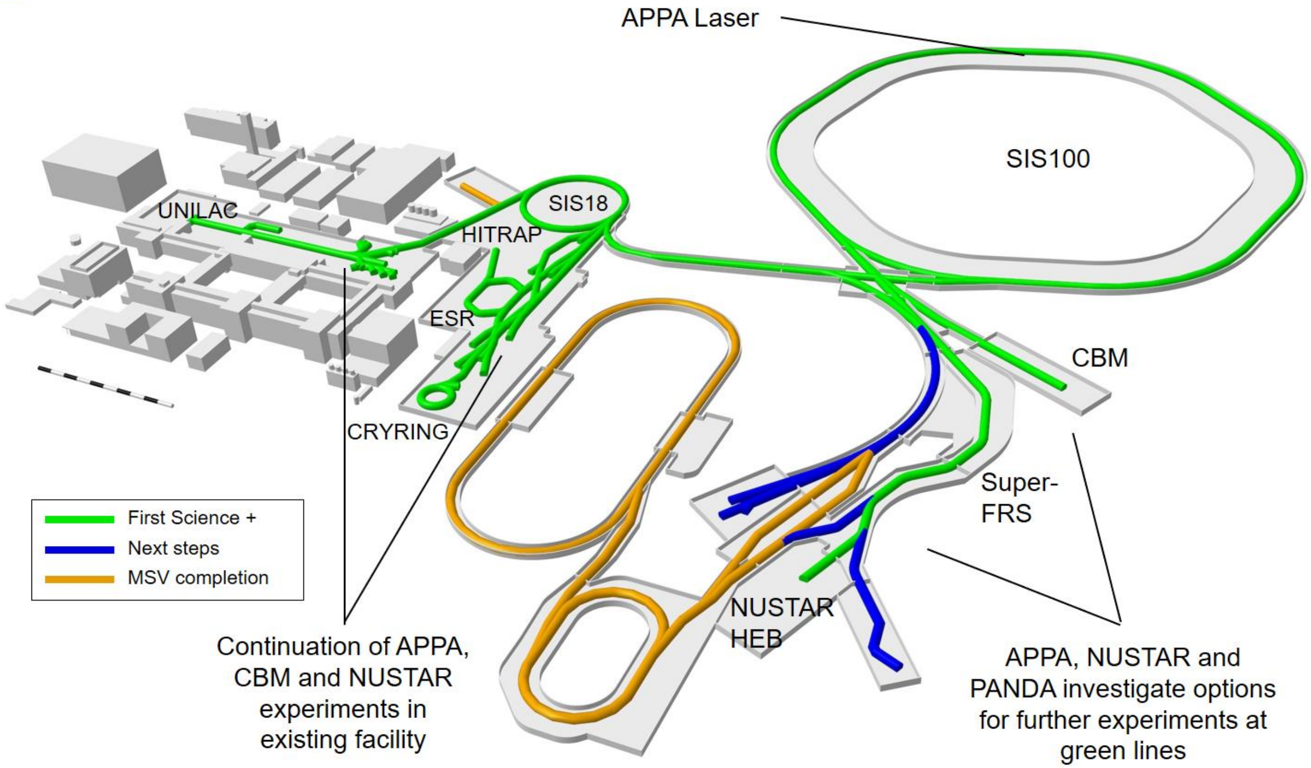
π /k ~1.6 GeV/c,

(π,k)/p ~ 3.0 GeV/c

Observation of the antimatter helium-4 nucleus

The STAR Collaboration* ***Nature 473 (2011) 353***

FAIR 2028

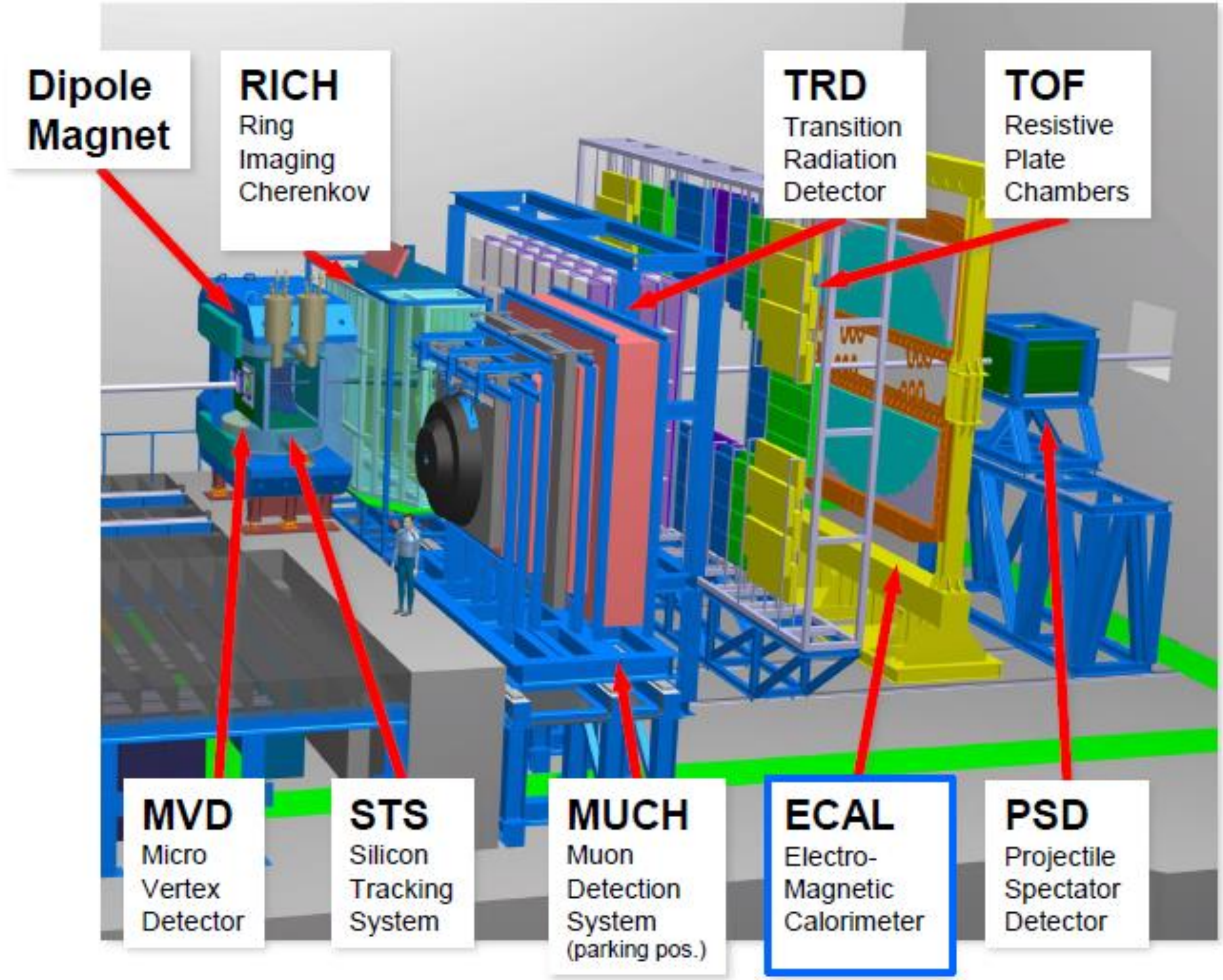


Primary Beams

- 10^{12}/s; 1.5 GeV/u; $^{238}U^{28+}$
- 10^{10}/s $^{238}U^{73+}$ up to 35 GeV/u
- 3×10^{13}/s 30 GeV protons

- The „**FAIR 2028**“ science program will include:
  - **CBM** at the ***new cave with SIS100 beams***, and ***HADES at SIS18***
  - **APPA** experiments ***at the low-energy rings***, ***at SIS100***, at the ***caves at SIS18 and UNILAC*** with and at ***PHELIX*** and a limited set of experiments which could be hosted at all the ***caves served by SIS100***

Layout of CBM detector



- Tracking acceptance: $2^{o} < \theta_{lab} < 25^{o}$
- Free streaming DAQ
- R_{int} = 10 MHz (Au+Au)

  $R_{int} \approx 0.5$ MHz
  full bandwith:
  Det. – Entry nodes
  reduced bandwidth
  Entry nodes – Comp. farm

  with
  R_{int} (MVD)=0.1 MHz
- Software based event selection

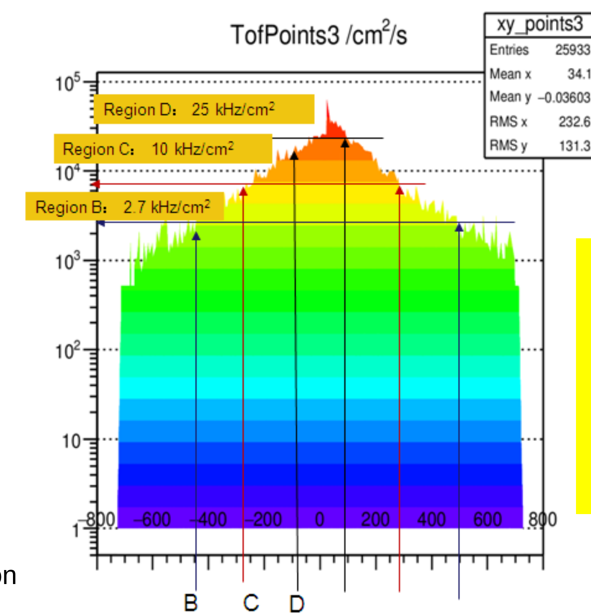
Day-1 setup = MSV setup – Compute Performance - ECAL
Phase-1 = MSV = Day1 with full Compute Performance + ECAL

Day-1 funding: ~ 90% secured

The structure of CBM-TOF wall

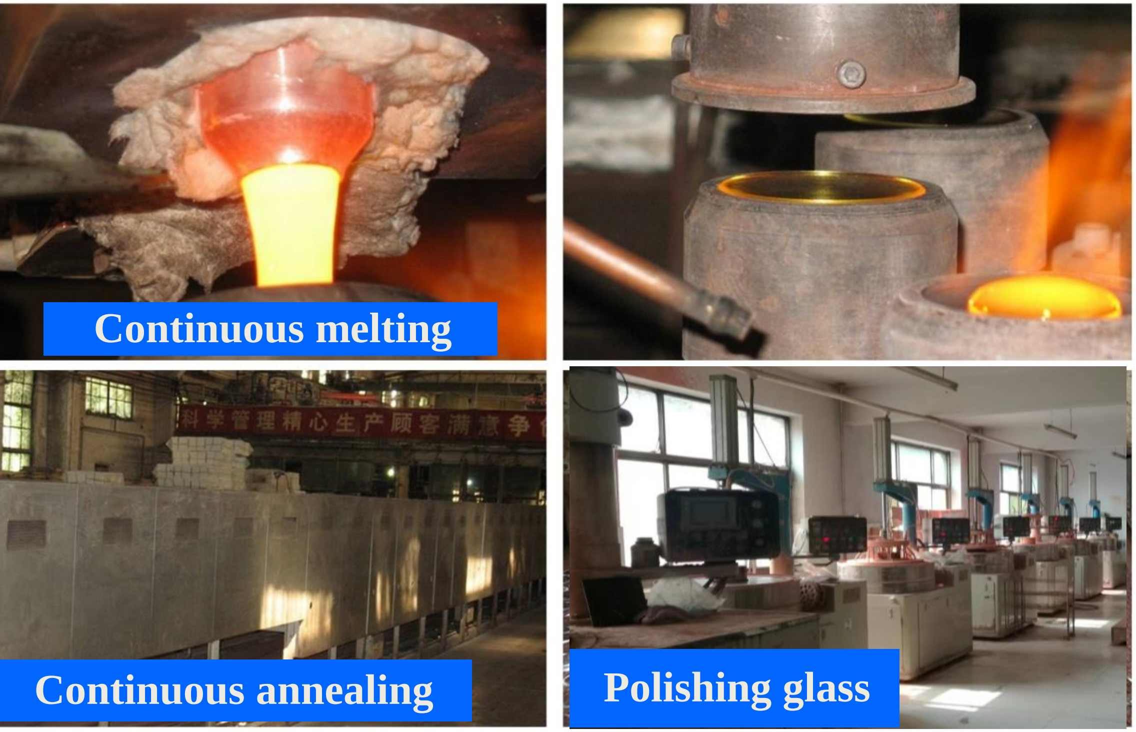
CBM-ToF Requirements

- **Full system time resolution σ_T ~ 80 ps**
- **Efficiency > 95 %**
- **Rate capability ≤ 30 kHz/cm^2**
- **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

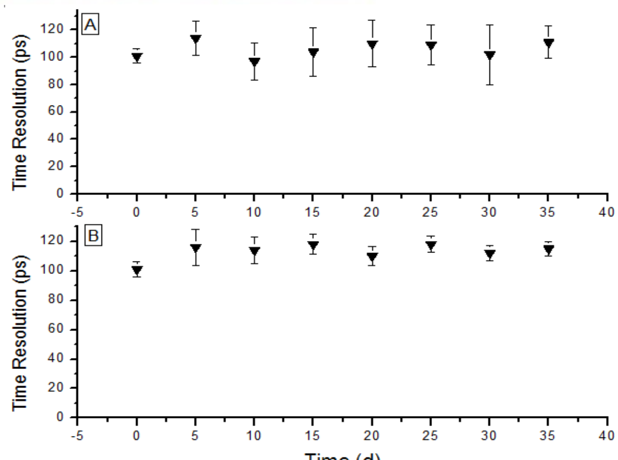
Development of low resistive glass



Glass mass production
Yield >100m^2/month

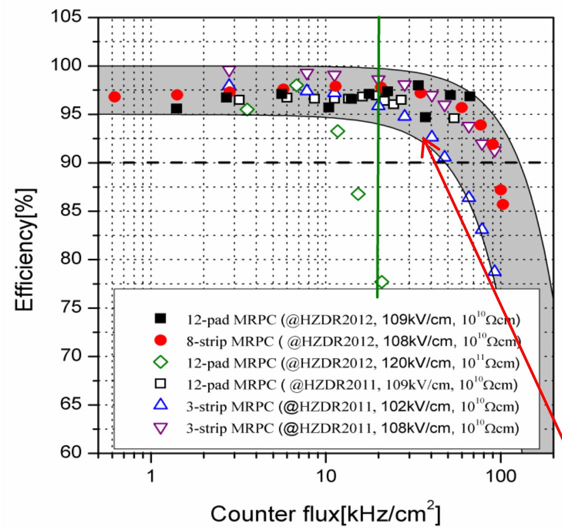
Performance of the glass

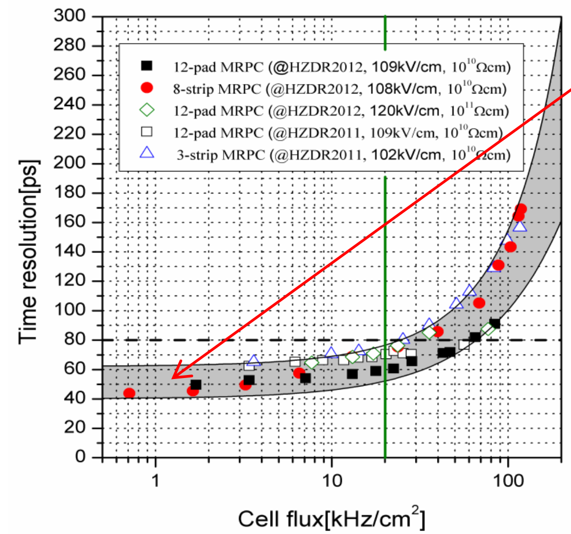
Maximal dimension	32cm $\times$ 30cm
Bulk resistivity	10^{10} Ωcm
Standard thickness	0.7, 1.1mm
Thickness uniformity	20 μm
Surface roughness	$<$ 10nm
Dielectric constant	7.5 - 9.5
DC measurement	Ohmic bebavior stable up to 1 C/cm^2



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.

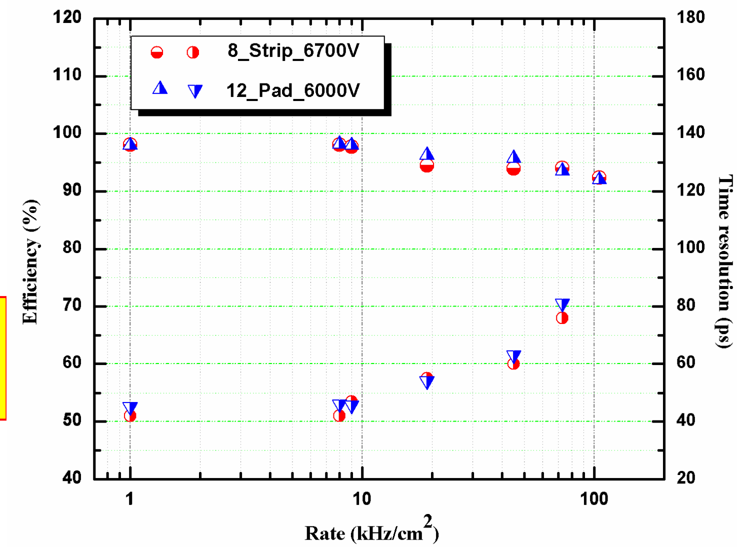
Rate capability of high rate MRPC





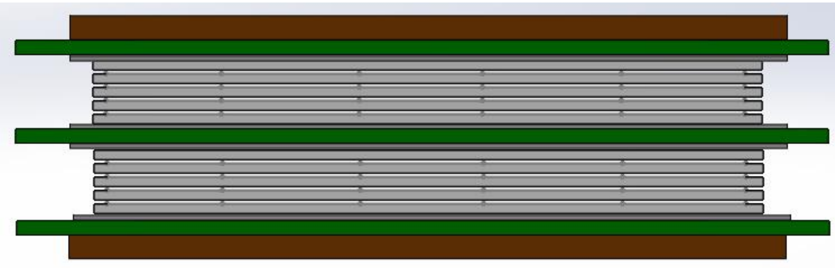
Rate: 70kHz/cm^2
Time resolution: 40 ps

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

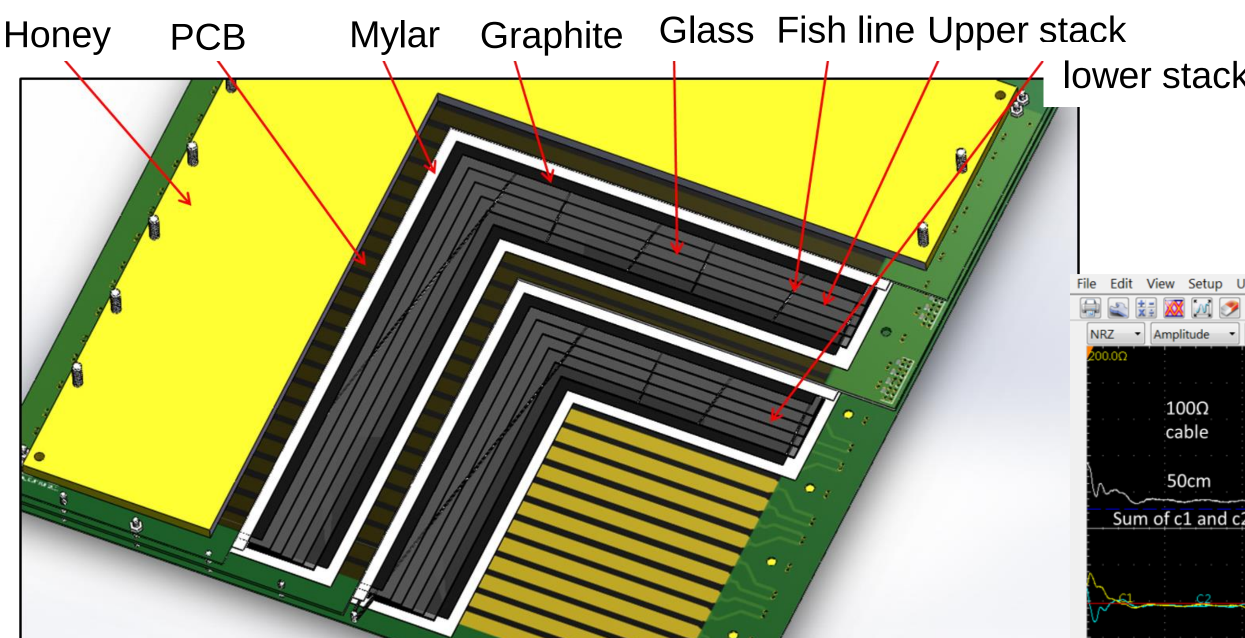


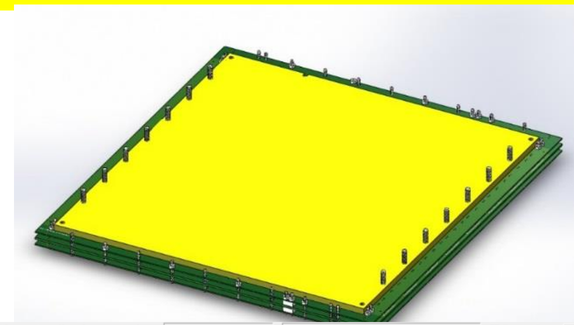
Glass: low resistive glass

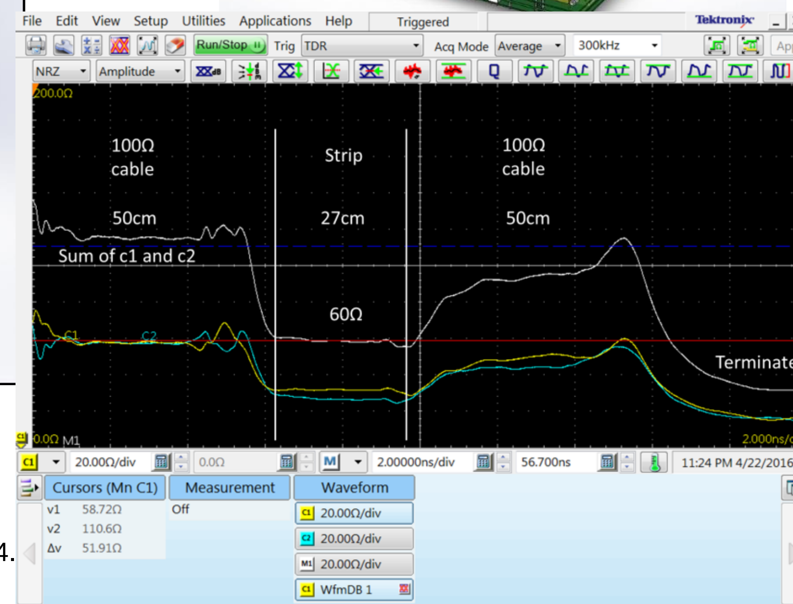
0.7mm thick, 33cm x 27.6cm

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

Gas gap: 8 x 0.25mm, two stacks

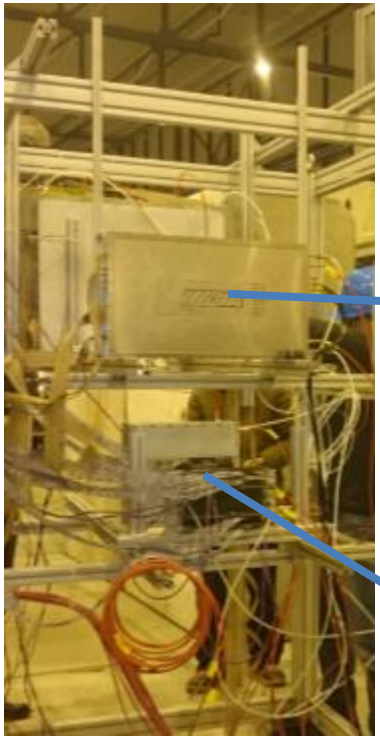






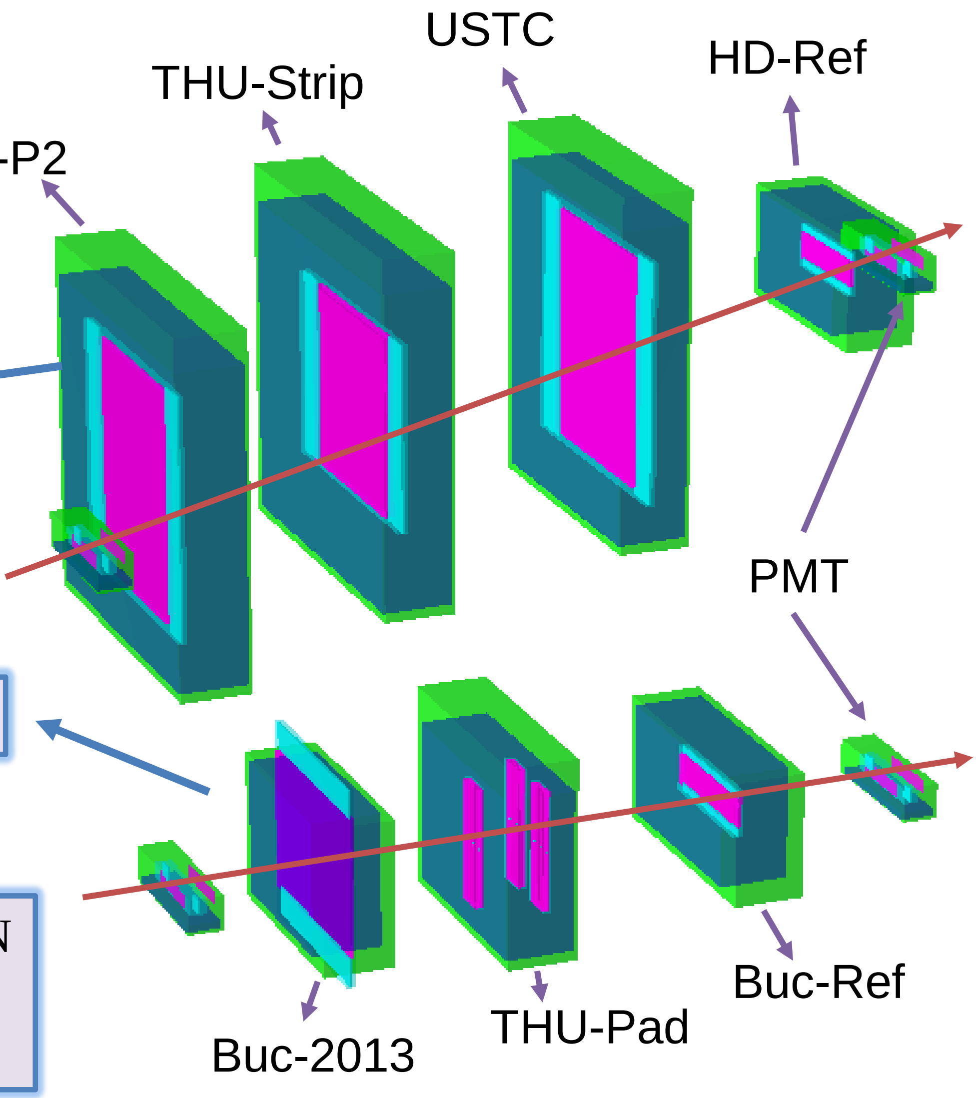
Beam test @ SPS Feb 2015

Experimental Setup:



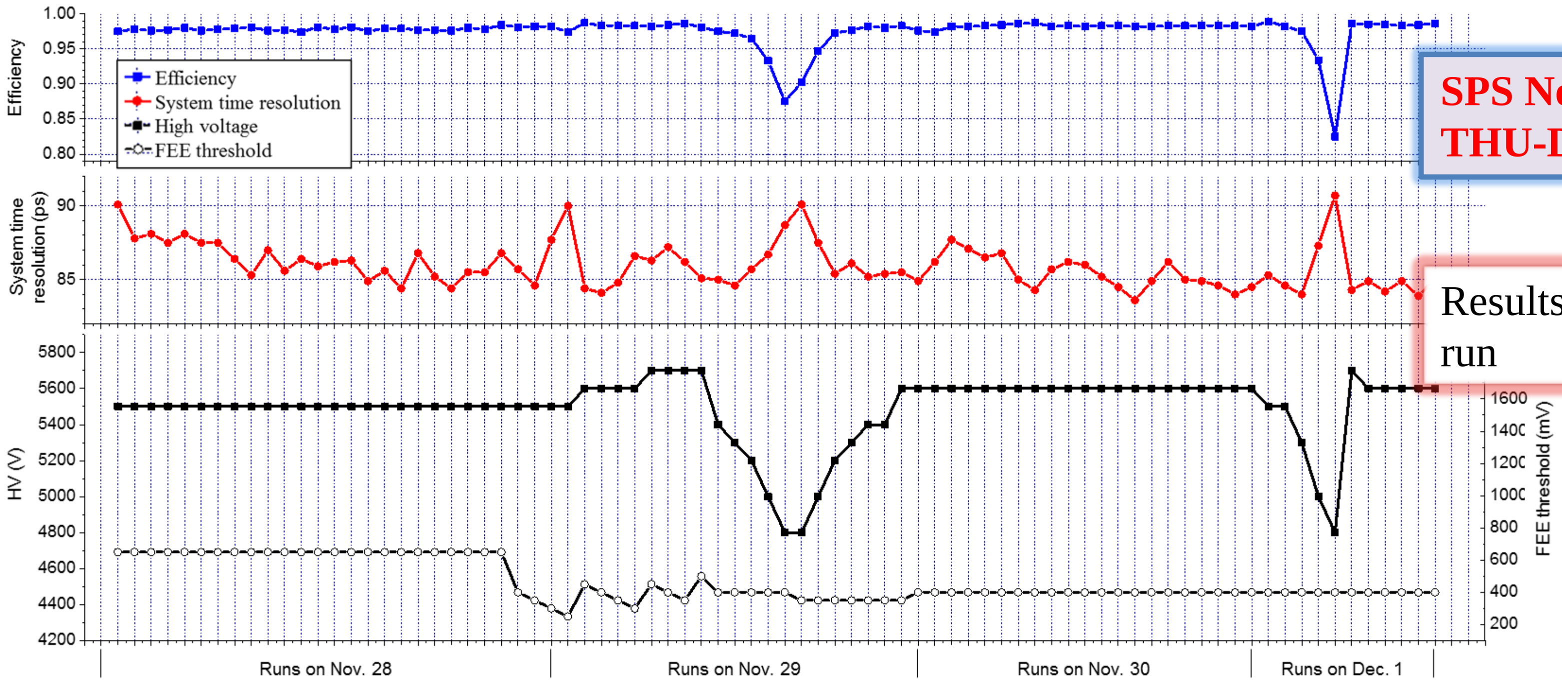
Up setting

Down setting



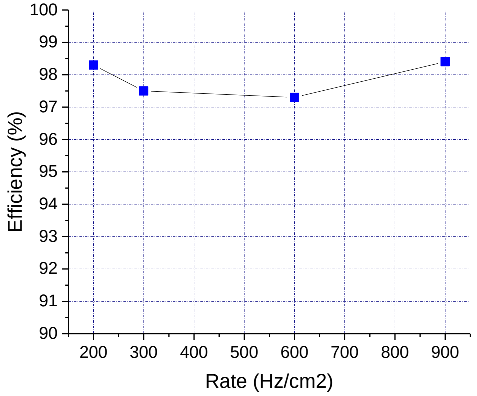
High rate test in February 2015 at SPS CERN
13 GeV Ar beam
Flux rate **around 1kHz/cm^2**

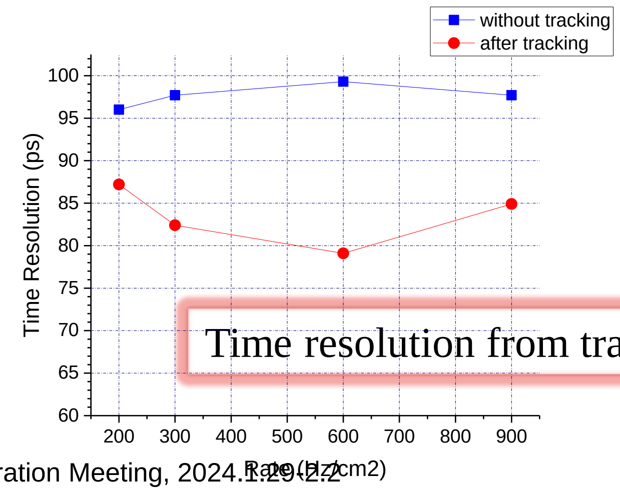
Performance of the prototype



SPS Nov 2015 THU-DU results

Results of each run

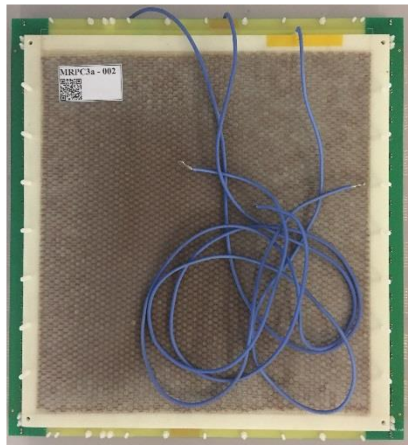


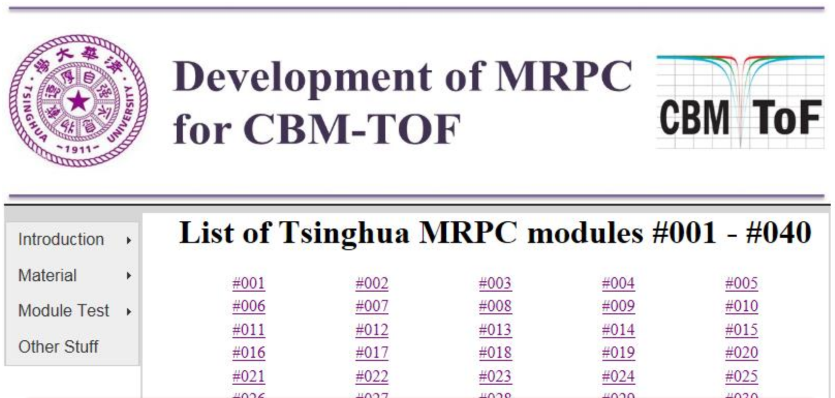


Time resolution from tracking method

Mass production of high rate MRPC

Two-dimensional code of MRPC



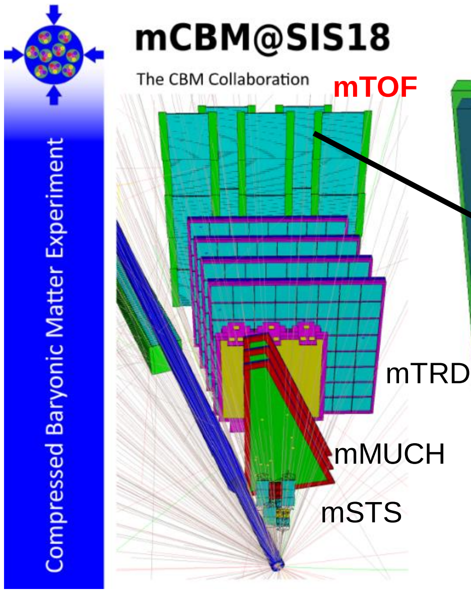


Producttion website:
http://hepd.ep.tsinghua.edu.cn/CBM_TOF/

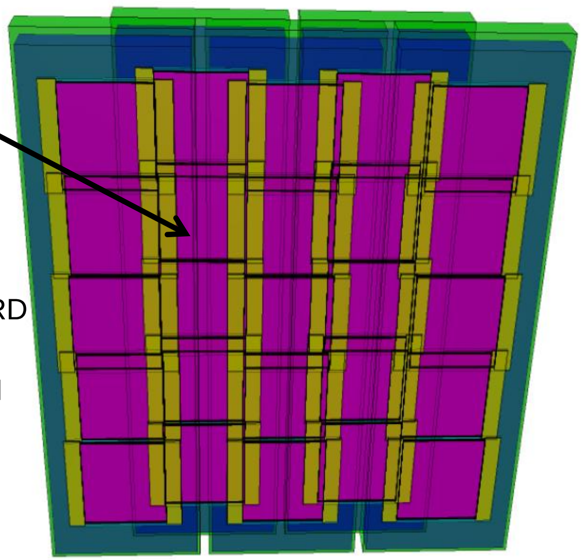
MRPC生产记录表 / MRPC3a Quality Assurance Table

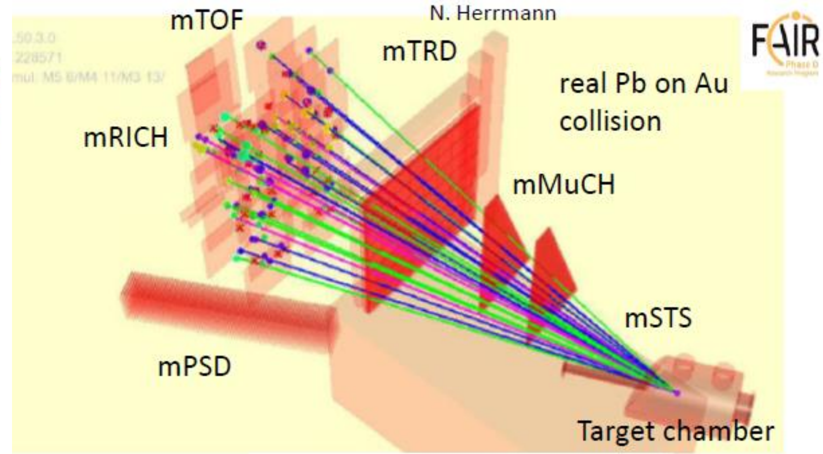
MRPC ID	MRPC3a - 005							
玻璃 / Glass	来自箱号与批次 / Glass Batch No.			NO.9 151225	用料数量/Amount			6
	来自箱号与批次 / Glass Batch No.			NO.11 151225	用料数量/Amount			4
	来自箱号与批次 / Glass Batch No.				用料数量/Amount			
电极玻璃 / Electrode	面电阻 / Surface Resistance (MΩ/sq)			Point 1	Point 2	Point 3	Point 4	Point 5
	电极玻璃1 / Electrode 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								

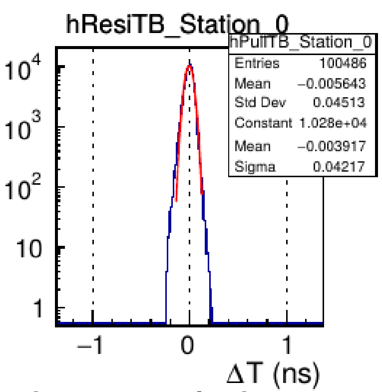
Results in mCBM@SIS18



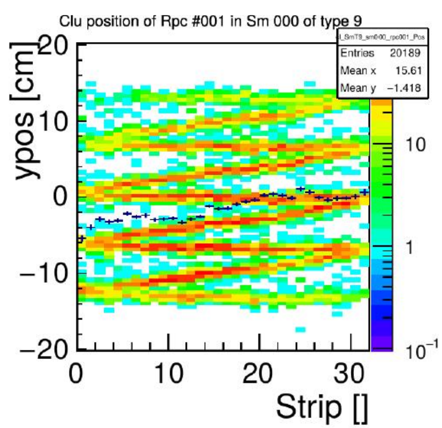
mTOF-wall

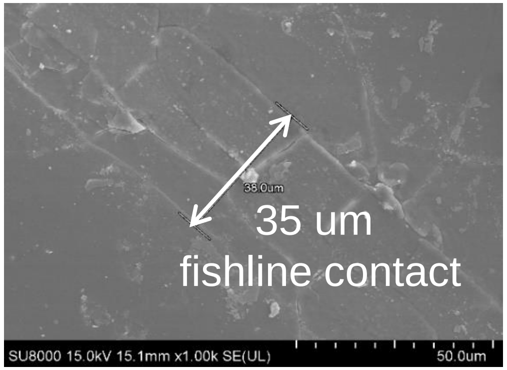






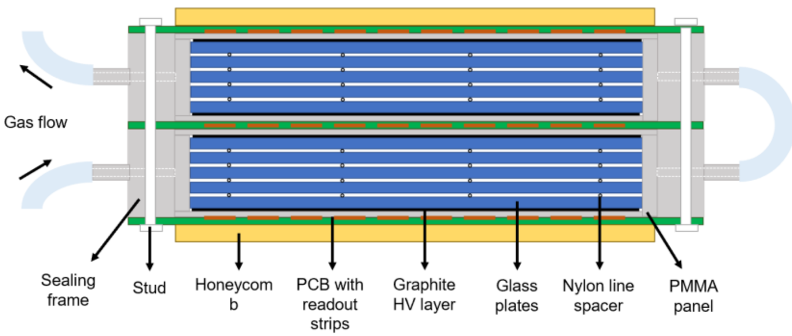
Time resolution: 42ps

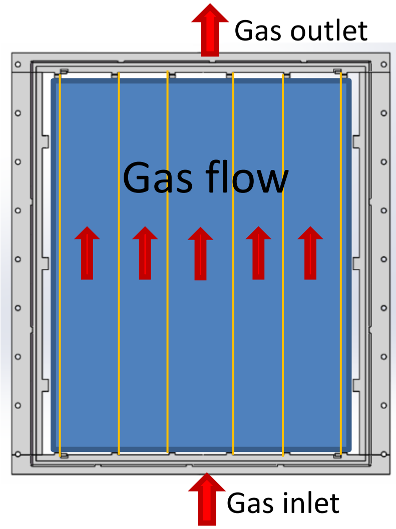


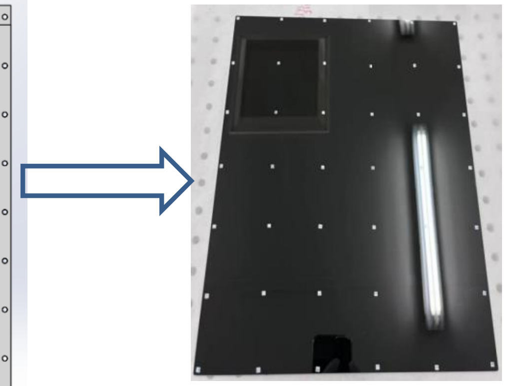


Obvious gas pollution effect is observed

Development of sealed pad-spacer MRPC

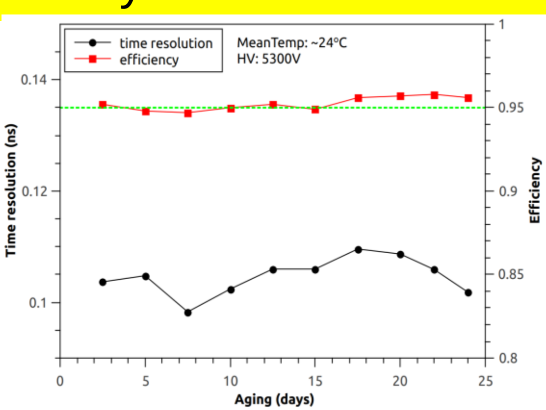


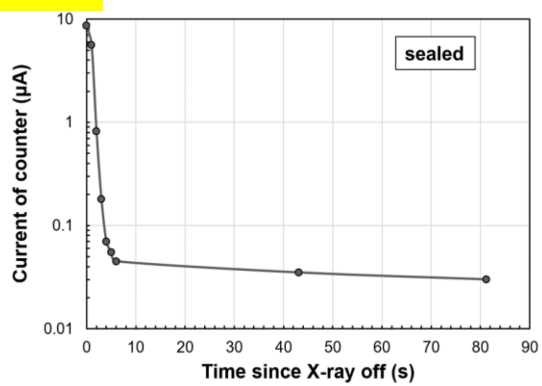


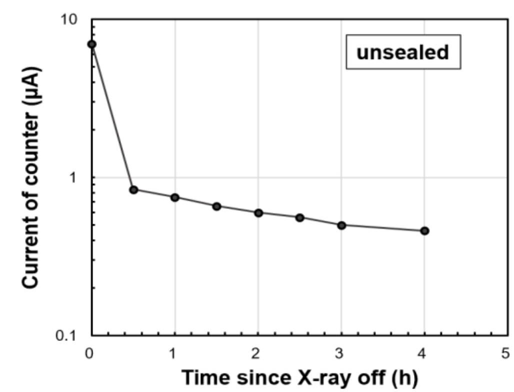


1. **Gas saving :** stable operation under < 10 sccm/m^2 gas flow in cosmic ray test

2. **Speedup gas exchange and reduce creepage on the spacer**







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

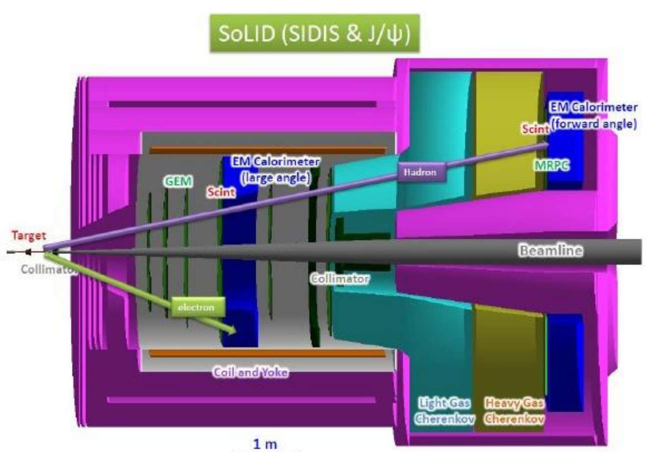
  Reach ultimate precision for SIDIS (TMDs), PVDIS in high-x region and threshold J/ψ

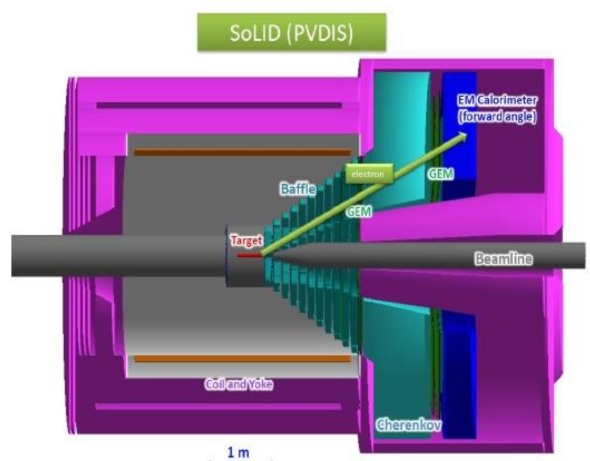
- 5 highly rated experiments approved (+3)

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

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

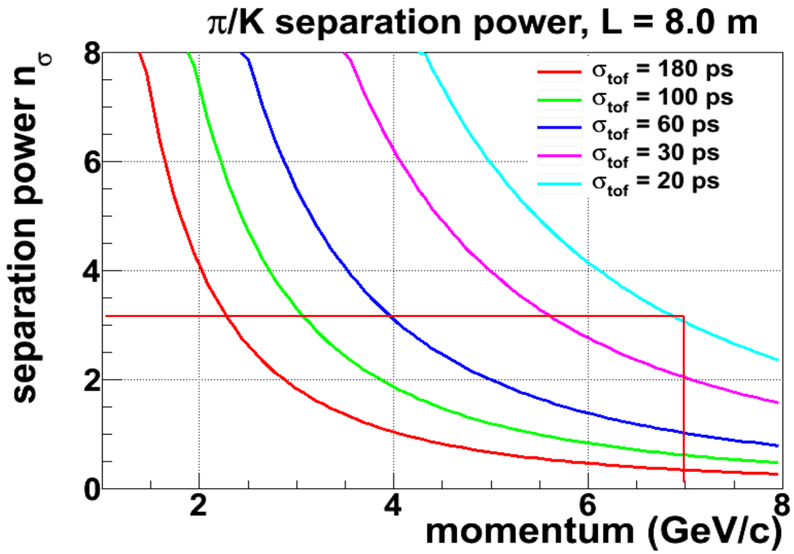
  Significant international contributions (Chinese collaboration)

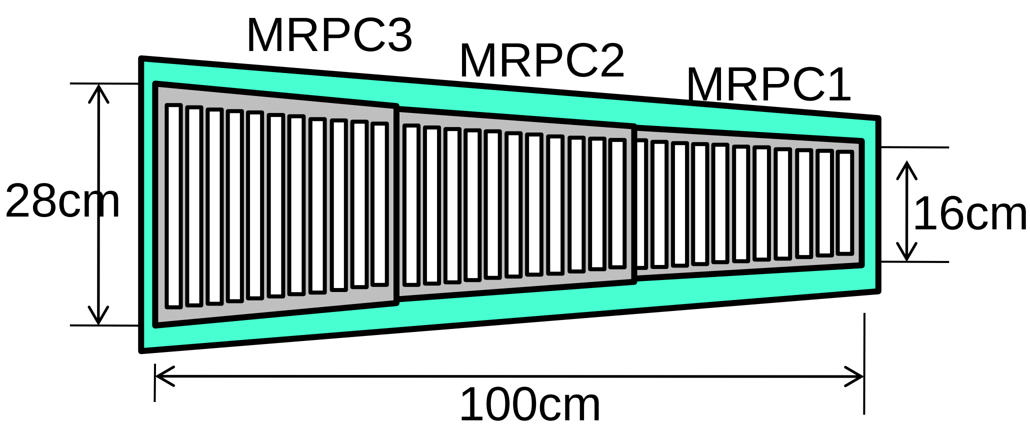




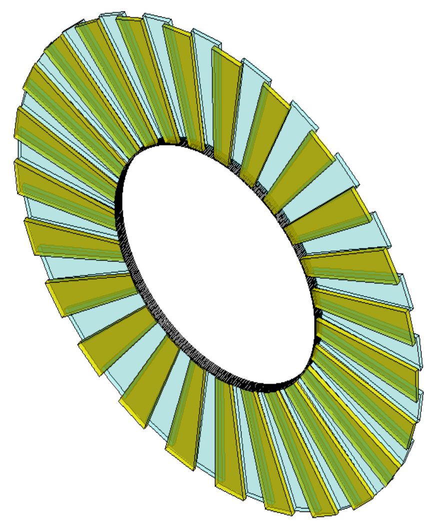
SoLID-TOF structure

- 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/cm^2



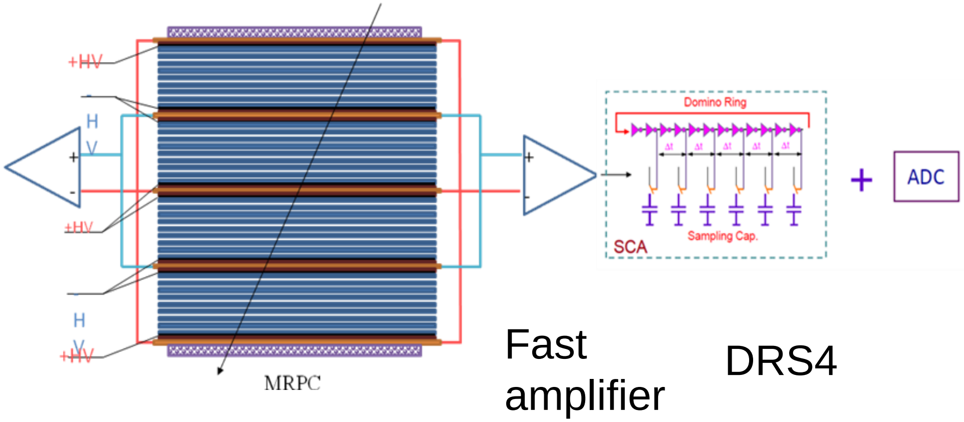


SoLID-TOF super module



SoLID-TOF structure

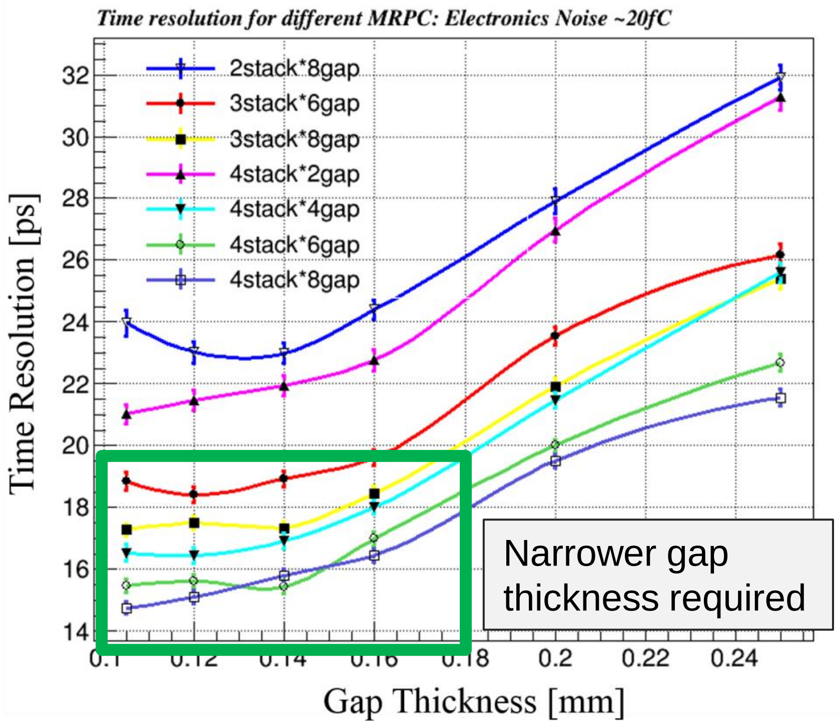
Toward 20ps resolution: narrow gap MRPC



$$\sigma_{TOF} = \sqrt{\sigma_{MRPC} + \sigma_{electronics}}$$

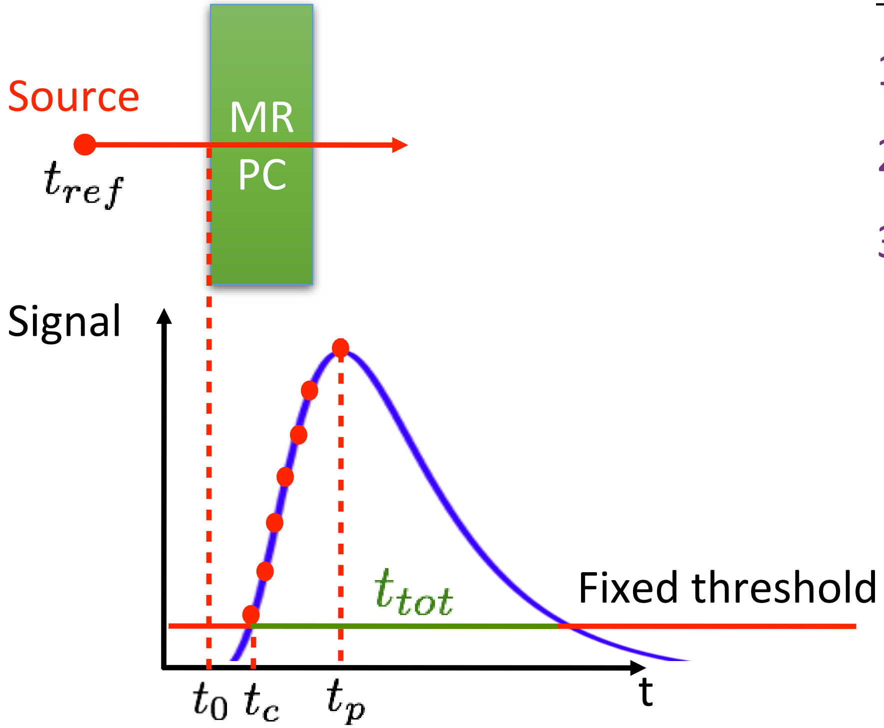
σ_{TOF} <20 ps， the intrinsic resolution of narrow gaps MRPC is around 15ps，so the time jitter of readout electronics <13~15 ps。

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



σ_{MRPC} <20 ps， the gas gap: <0.18mm
gap number: >16

NN can get the first interaction time t_0



Simulation dataset :

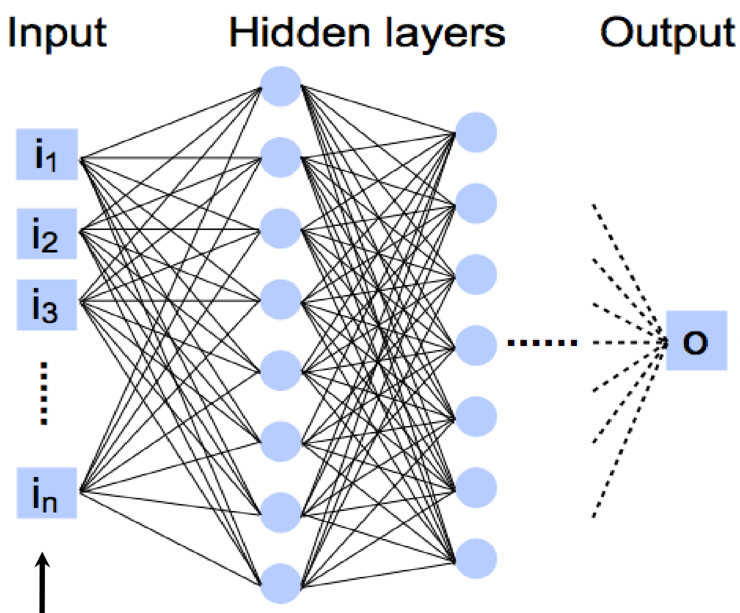
1. t_0: first interaction happens
2. t_p: the signal reach the peak
3. 7 uniformly distributed points along the leading edge

NN method can avoid avalanche time jitter compared with TOT method.

One NN： Multilayer perception (MLP)

- Multilayer perceptron (MLP)

$$\underbrace{F_i(\vec{x})}_{\text{Output}} = h(\sum_j(\omega_{ij}^2 g(\ldots g(\sum_k(\omega_{jk}^1 g(\sum_l(\omega_{kl}^0 \underbrace{x_l}_{\text{Input}} + \chi_k^0)\ldots + \chi_j^1) + \chi_i^2)$$



- Activation function: g and h —— tanh
- Weights: $\omega^{0,1\ldots}, \ \chi^{0,1\ldots}$
- "Dropout": avoid overfitting

The length of the leading edge t_l

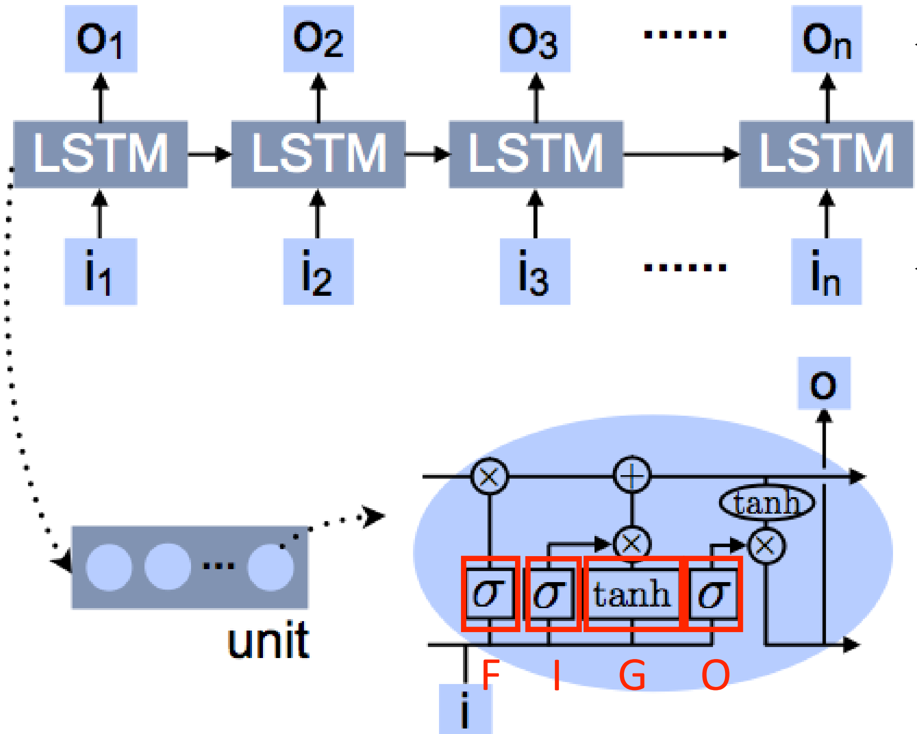
Several uniformly distributed points along the leading edge

Time of the very first interaction: $t_0 = t_p - t_l$

- Train/validate/test set: 20/10/10 k
- Tensorflow & GPU: GTX 1080 Ti
- ~ 10 mins for training

Another NN: LSTM

- Recurrent neural networks(RNN): Long Short Term Memory network(LSTM)



The length of the leading edge t_l

Several uniformly distributed points along the leading edge

f : forget gate: Whether to erase

I : Input gate, whether to write

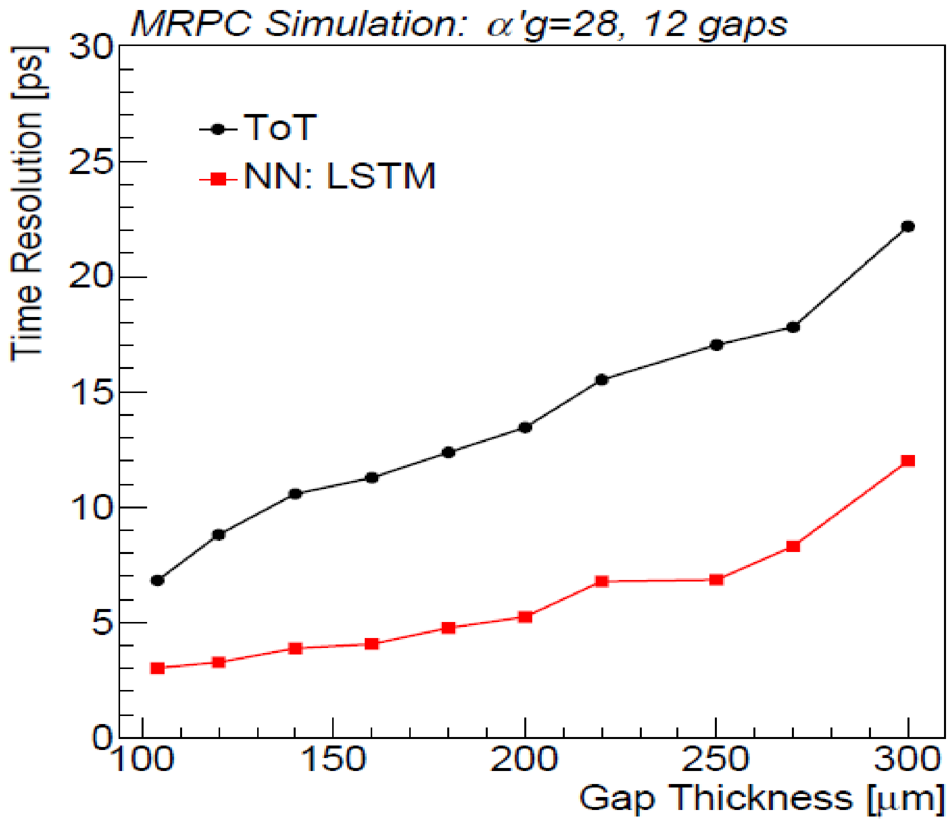
g: gate gate, How much to write

o: output gate, How much to reveal

- Train/validate/test set: 20/10/10 k
- Tensorflow & GPU: GTX 1080 Ti

> 30 mins for training

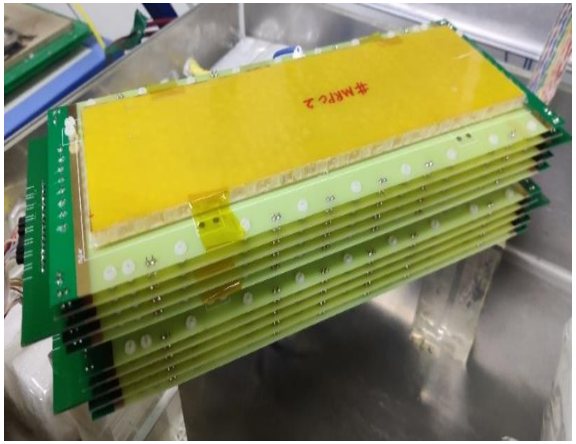
Comparison of ToT and NN

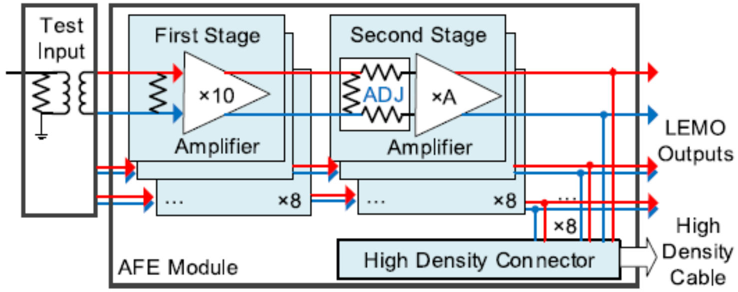


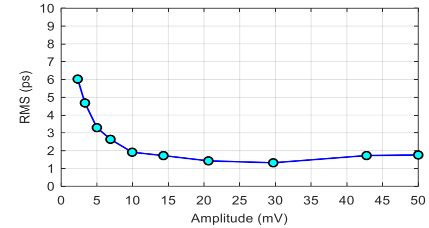
Time reconstruction algorithms:
The traditional algorithm:
ToT (Time-over-Threshold)
Neural network:
LSTM(Long Short Term network)

The resolution result with the new reconstruction algorithm is even better

A prototype of 20ps MRPC



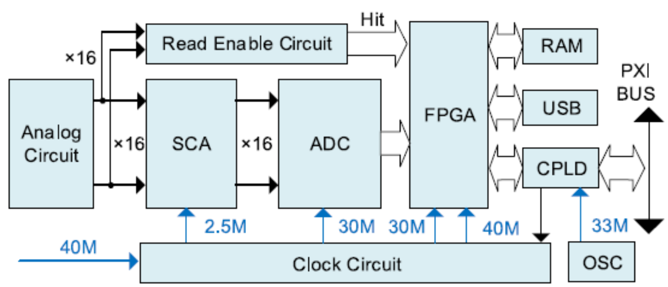


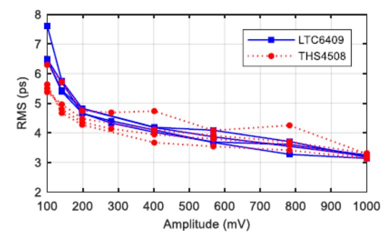


Fast amplifier
Bandwidth=1.4GHz

	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)

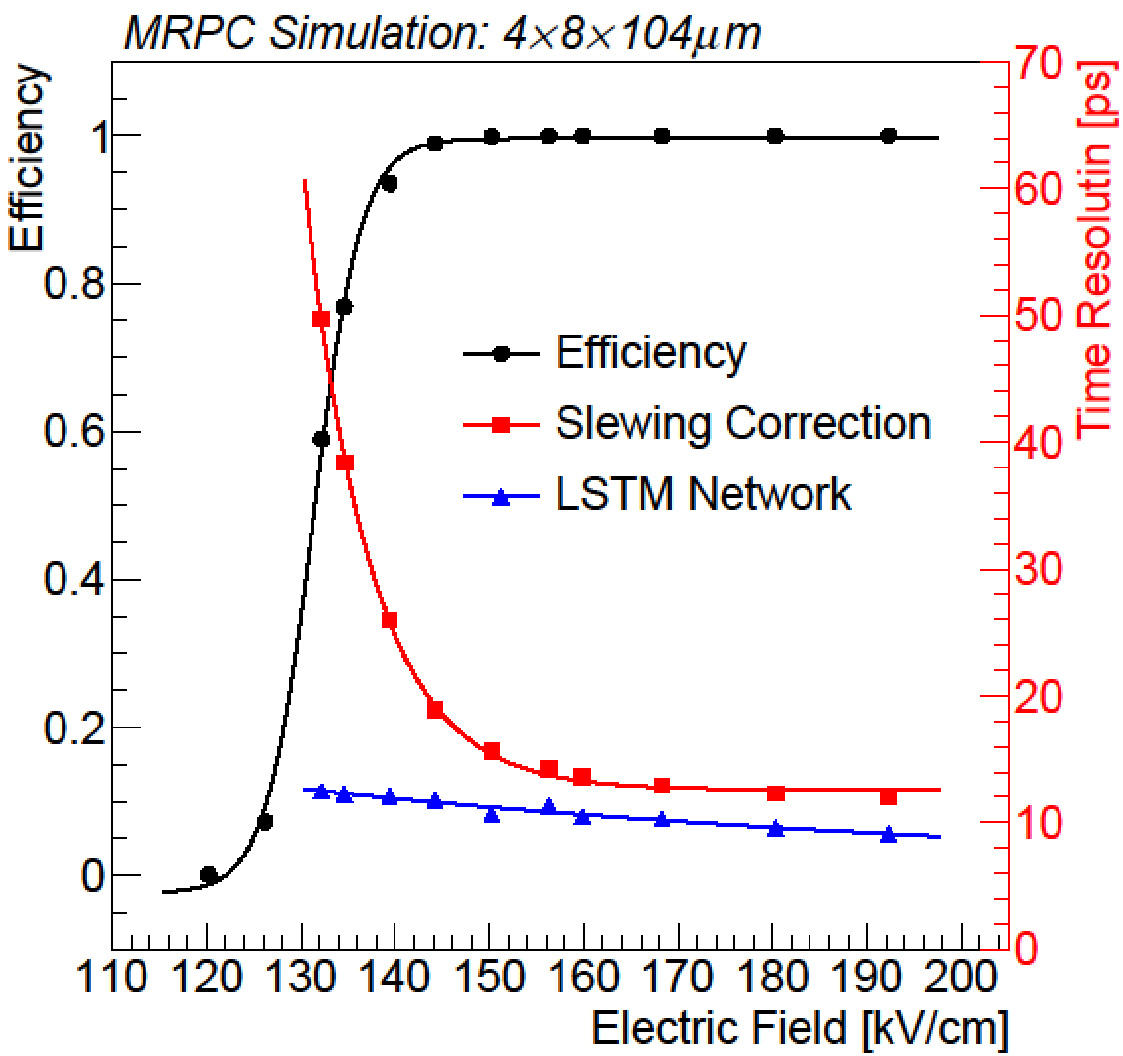
Total material: $<0.1X_0$





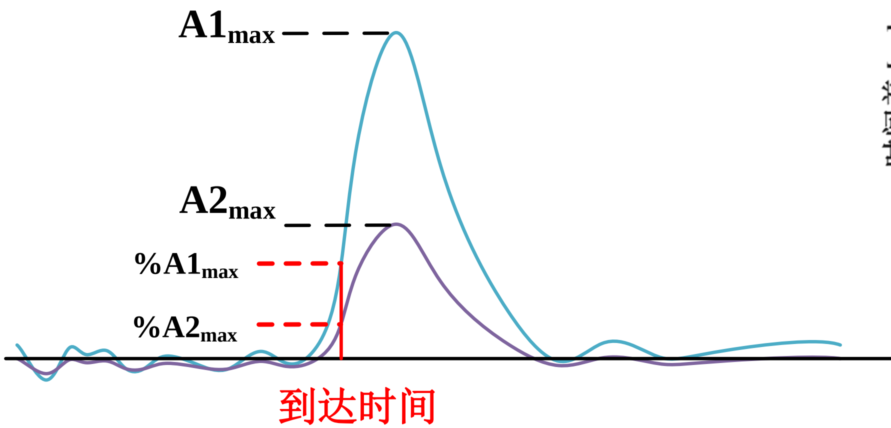
Waveform sampling
Based on DRS4
Sampling freq=5 GS/s

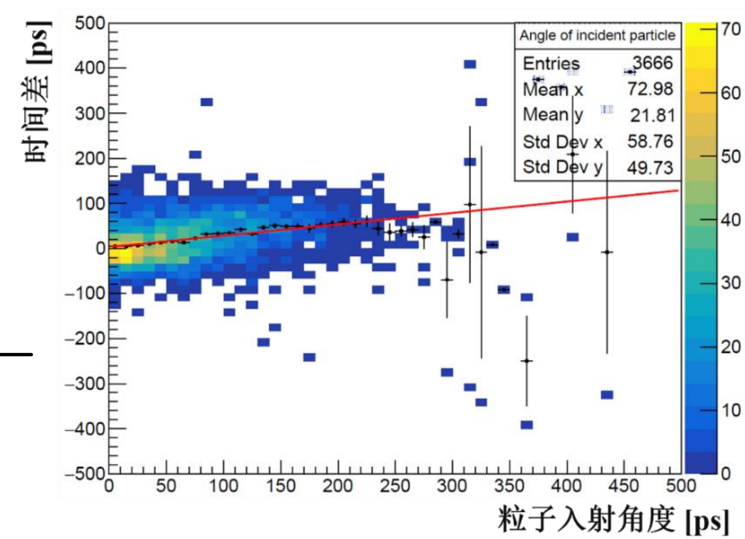
Simulated efficiency and time resolution



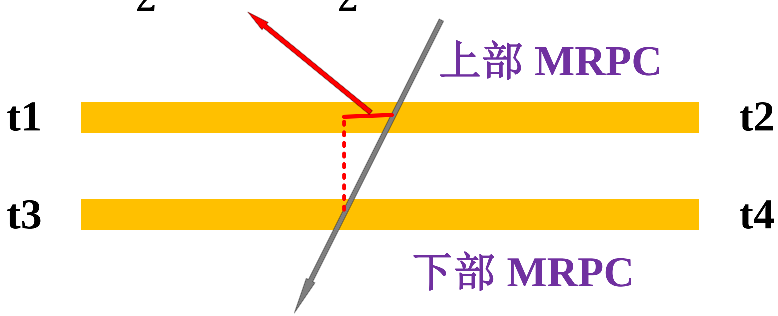
Cosmic test

MRPC + fast amplifier + DRS4



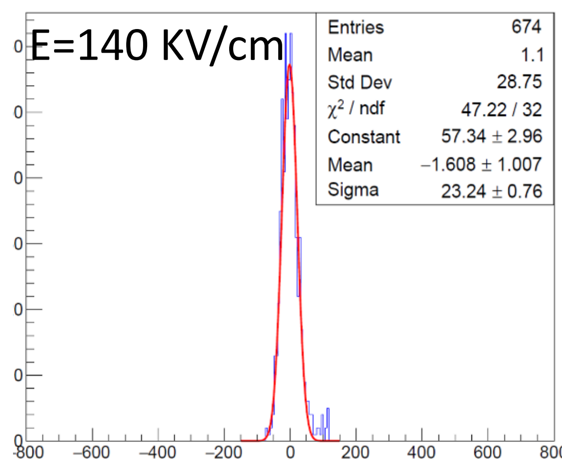


$$cut = \left[\frac{(t1 - t2)}{2} - \frac{t3 - t4}{2}\right] < 3\sigma_{\Delta t}$$



$$\Delta t = (t1 + t2)/2 - (t3 + t4)/2$$

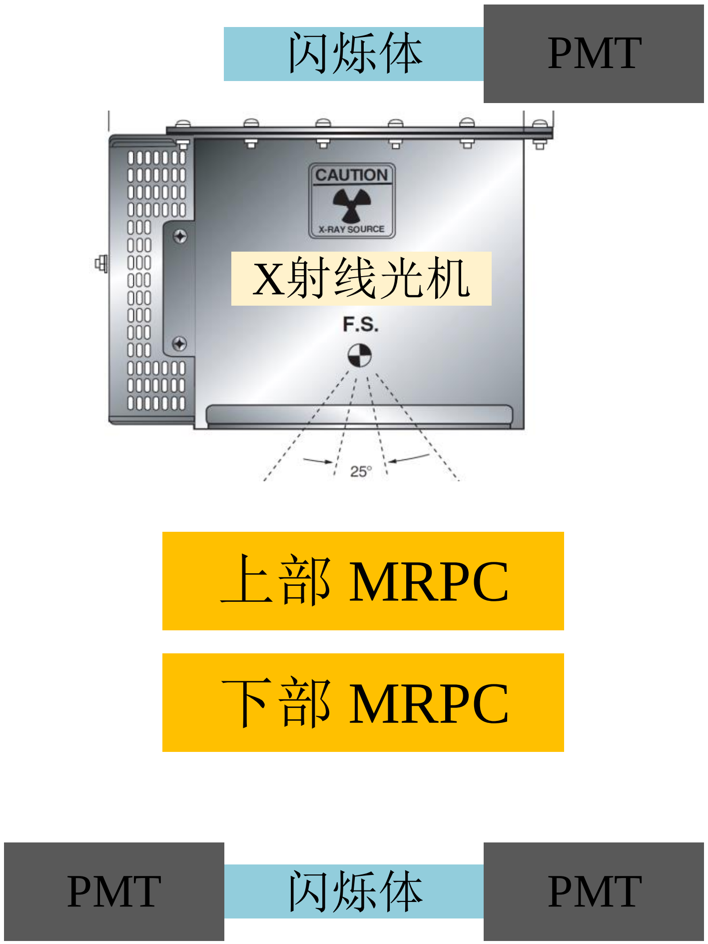
$$\sigma_{MRPC} = \sigma_{\Delta t}/\sqrt{2}$$

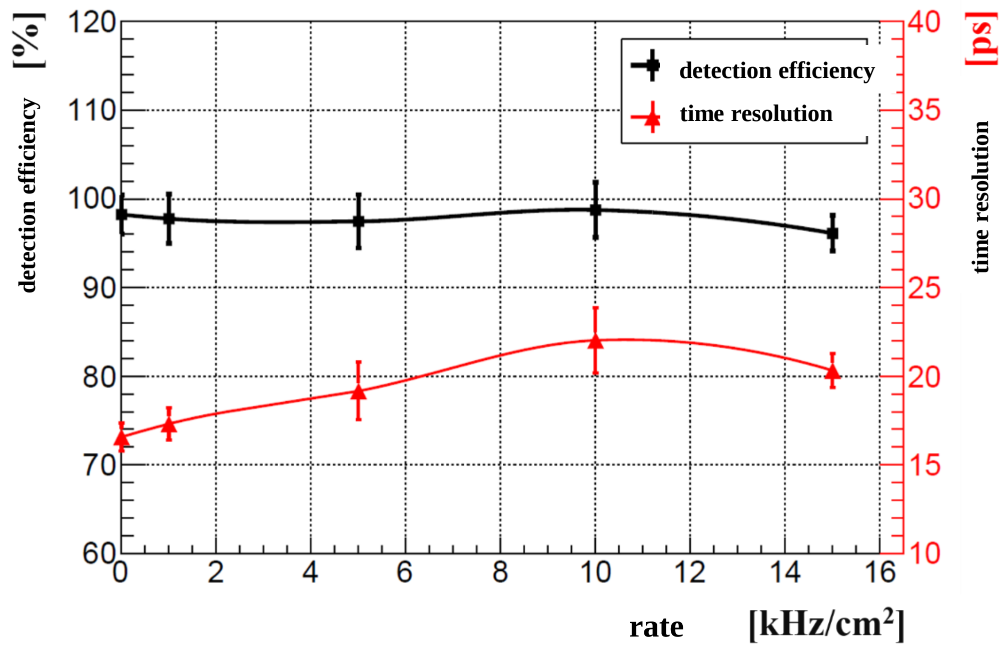


- Time resolution:

$$\sigma = \frac{23.24\text{ps}}{\sqrt{2}} = 16.43\text{ps}$$

20ps@15kHz/cm² MRPC



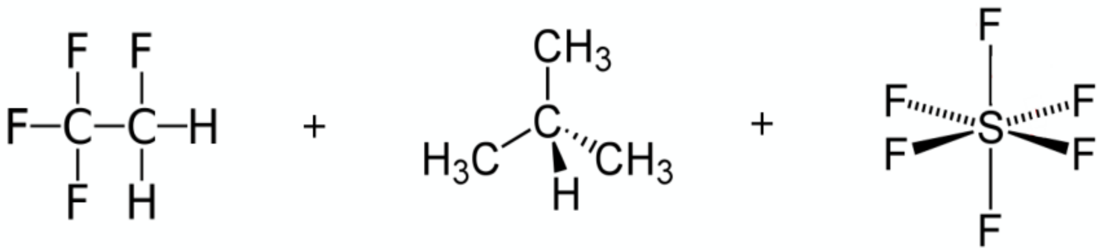


Find Eco-gas

- 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.

Candidation of Eco-gas

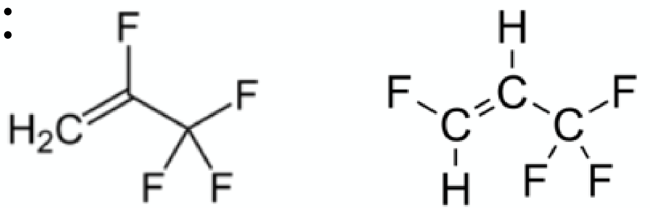
~95% | 4-5% | 0.3%



GWP 1430 | GWP 3.3 | GWP 22800

Eco-gas replacements:

-for Freon:



HFO-1234yf (flam) | HFO-1234ze

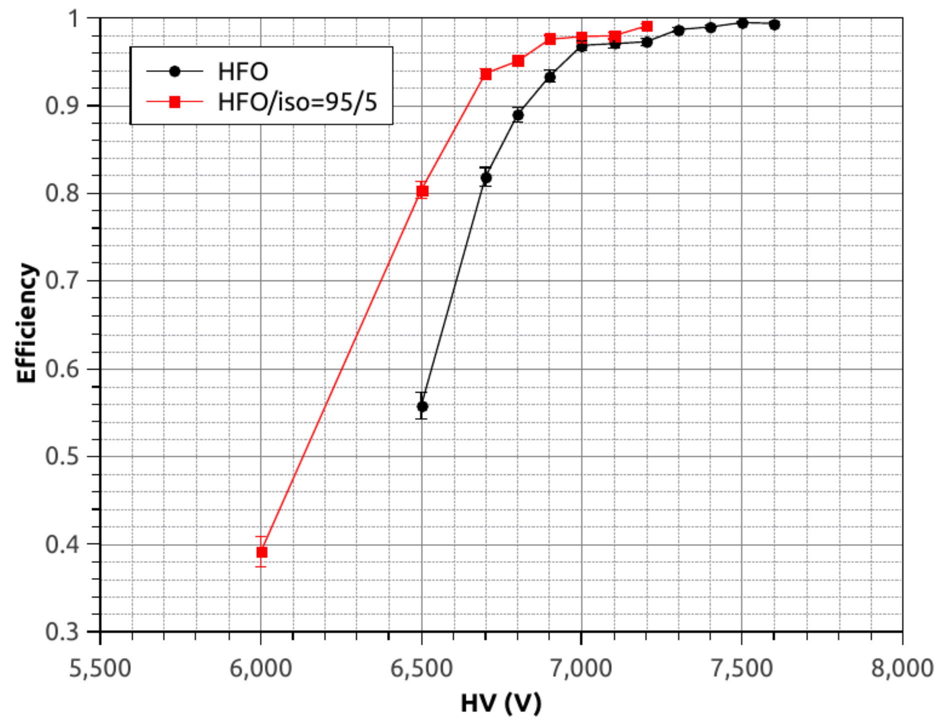
GWP 4 6

Preliminary results

- Pure HFO and HFO/iC_4H_{10} 95/5 tests completed
- Efficiency Curve:
- Pure HFO:

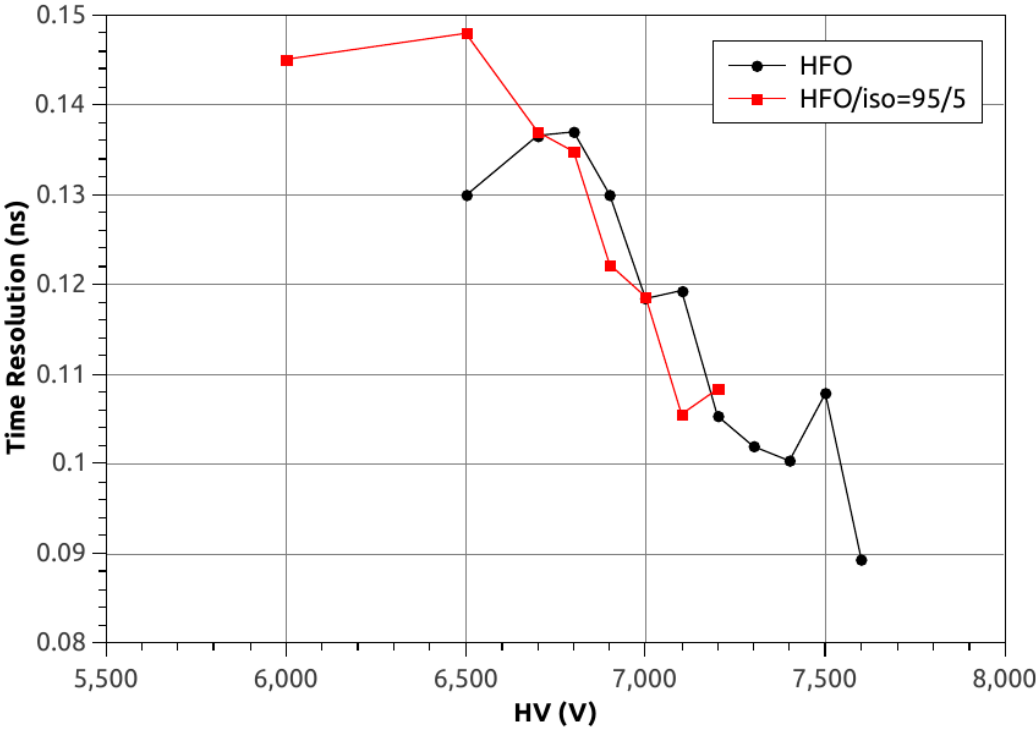
  96.9%@7000V
- HFO/iC_4H_{10} 95/5:

  97.6%@6900V



Preliminary results

- Time resolution:
- ~120ps at working point, not as good as standard gas (100ps)
- Increasing the HV may help improve the timing performance, but should mind the streamer.



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.**

- ✓ **New technology were developed such as :**

  New material :low resistive glass;

  New MRPC structure: sealed pad-spacer for high rate-MRPC;

  New electronics : switched capacitor array (SCA) and high precision TDC) ;

  New analysis method : deep learning technology.

- ✓ **A prototype of 20ps resolution MRPC was designed and the time is around 16ps.**

- ✓ **New topics such as Eco-gas, industrial and medical usage…**

Thanks for your attention!