R&D and production of timing RPC

Outline:

- **Introduction of timing RPC**
- **MRPC for RHIC STAR-TOF**
- **High rate MRPC for CBM-TOF**
- **MRPC mass production**
- **Conclusions**

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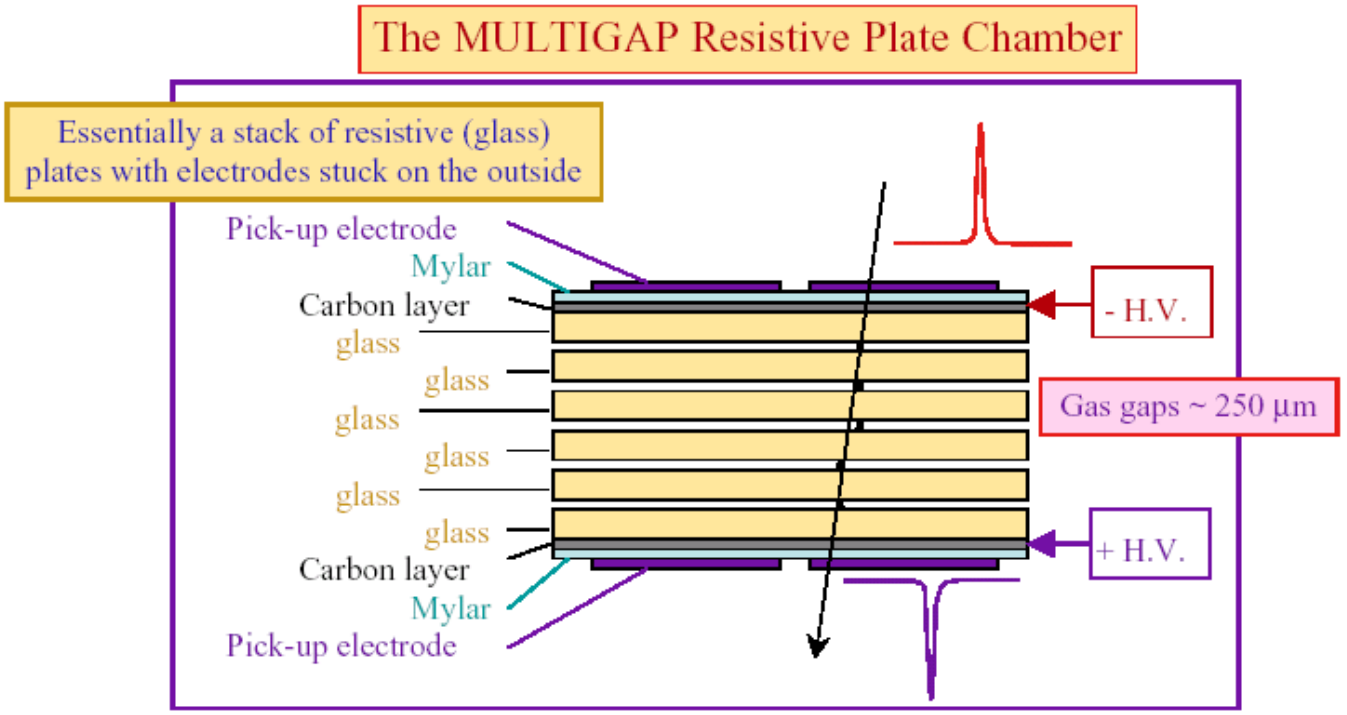
Introduction of timing RPC



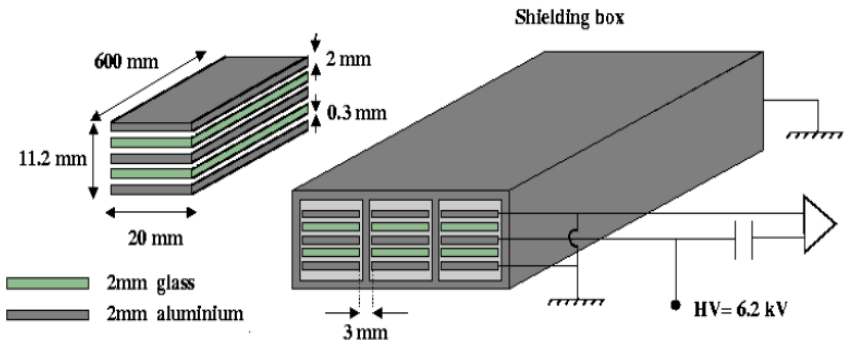
Note 1: internal glass plates electrically floating - take and keep correct voltage by electrostatics and flow of electrons and ions produced in gas avalanches

Note 2: resistive plates transparent to fast signals - induced signals on external electrodes is sum of signals from all gaps

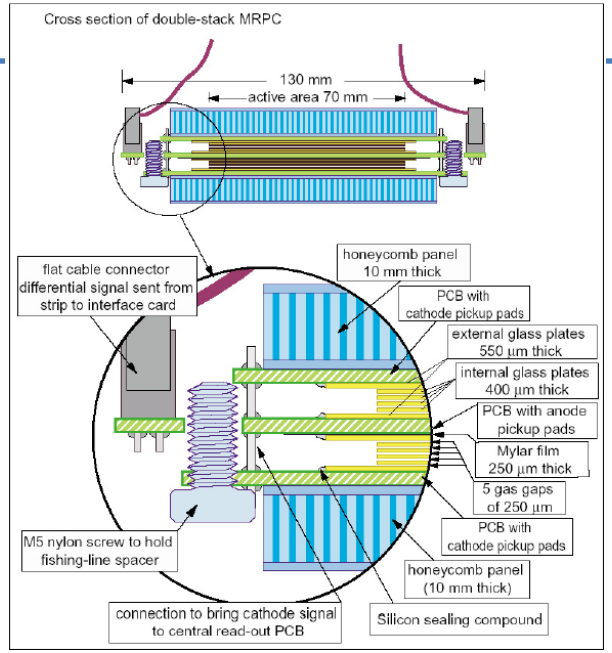
Large area, high granularity
Good time resolution<80ps
High efficiency> 95%
Low cost

ALICE, STAR, FOPI, HADES
HARP, CBM and NICA-MPD

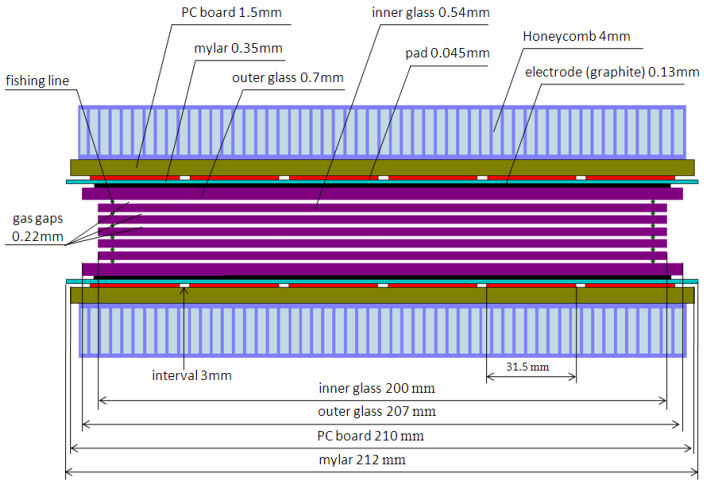
Four kinds of MRPC prototypes



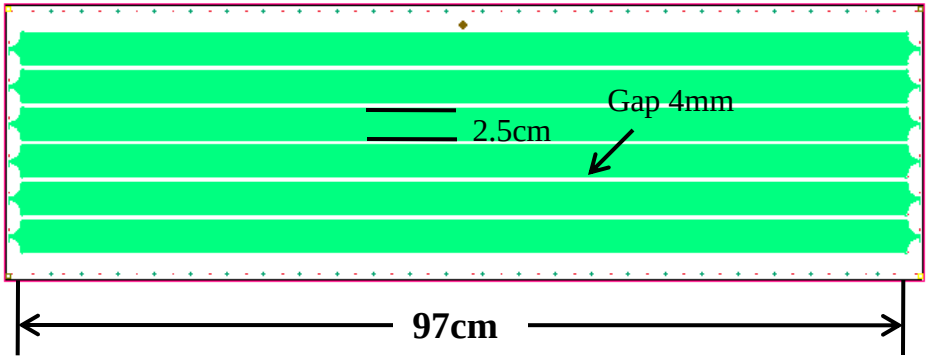
- Used in HADEs-TOF



- Used in ALICE-TOF



- Used in STAR-TOF

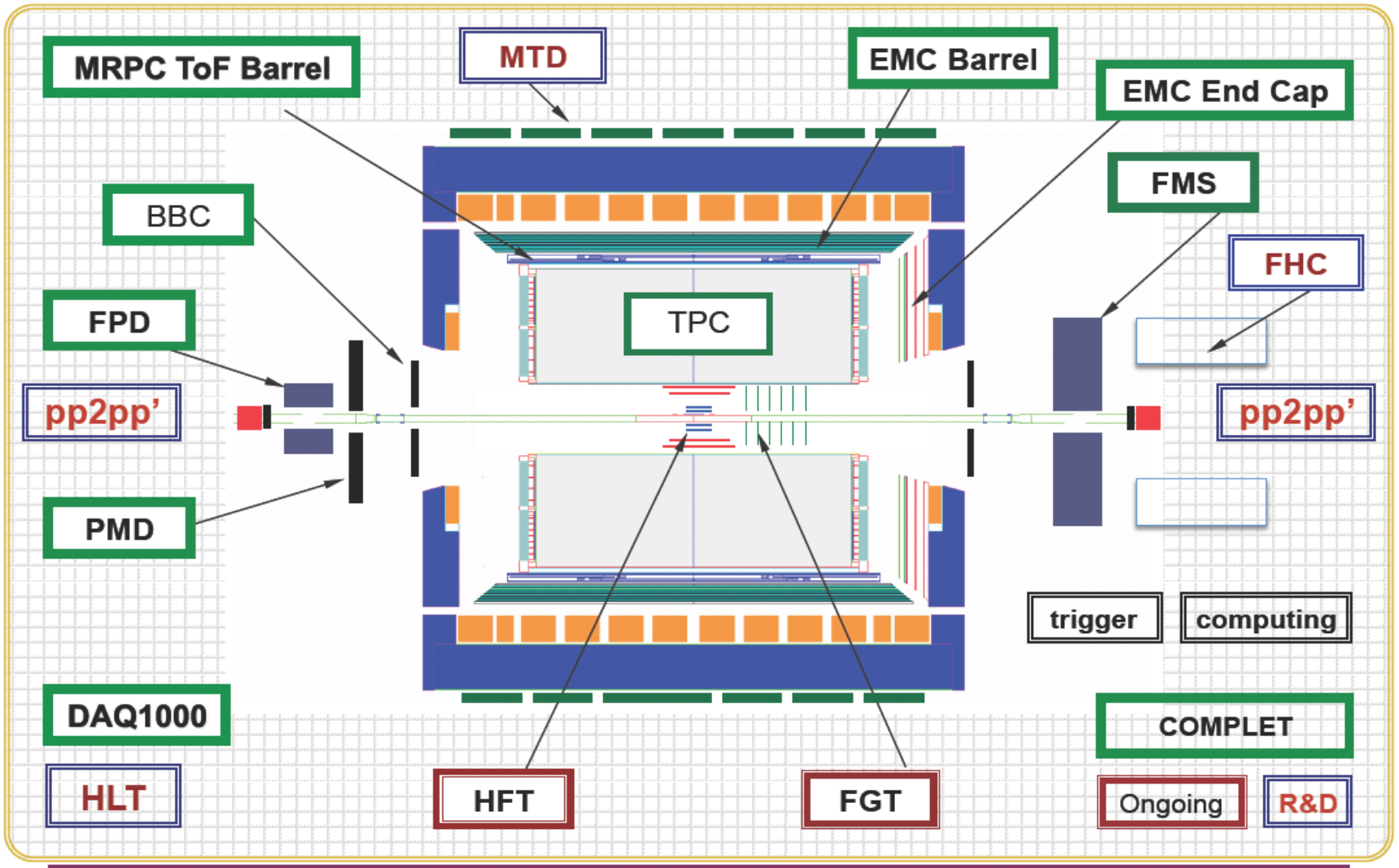


- Used in STAR-MTD

MRPCs used in hadron experiment

Detector	HARP	ALICE	STAR	FOPI	HADES
N_{gaps}	4	10	6	6	4
gap size [mm]	0.3	0.25	0.22	0.3	0.3
gas[$C_2F_4H_2/SF_6/C_4H_{10}$]	90/5/5	90/5/5	90/5/5	85/10/5	98.5/1/0.5
electric configuration	cat-an-cat	cat-an-cat	an-cat	cat-an-cat	cat-an-cat
cell size [cm×cm]	22×10.6	2.5× 3.7	6.3× 3.1	90×0.34	60×2
detector size	10 m^2	150 m^2	60 m^2	5 m^2	8 m^2
$N_{channels}$	368	160000	$\simeq$ 30000	5000	$\simeq$ 2100
HV/gap	3.0 kV	2.4 kV	2.35 kV	3.3 kV	3.2 kV
ε	99%	99.9%	95-97%	97 $\pm$ 3%	>95%
plateau length	300 V	2000 V	500 V	600 V	$\gtrsim$ 200 V
σ_T	-	90 ps	120 ps	-	100 ps
σ_T (after slewing corr.)	150 ps	40 ps	60 ps	73 $\pm$ 5 ps	70 ps
cross-talk/neighbor	< 10%	-	-	-	< 0.5%
3-σ tails	-	-	-	< 2%	6%
space resolution [cm^2]	-	-	-	-	0.6×0.6
experiment rates	1 Hz/cm^2	50 Hz/cm^2	10 Hz/cm^2	50 Hz/cm^2	700 Hz/cm^2
dark rate [Hz/cm^2]	< 0.1	-	< 0.3	< 1	2–3
rate capability [Hz/cm^2]	$\leq$ 2000	$\leq$1000	-	-	350
$\rho\ d$ [$10^{12}\ \Omega \times cm^2$]	10 × 0.105	- × 0.04	5 × 0.055	- × 0.15	5 × 0.1
$\bar{q}$	-	2 pC	-	-	-
$\bar{q}_{prompt}$	-	-	-	-	0.7 pC
material budget (x/X_o)	-	-	-	-	12-24%
resistive material	float glass	float glass	float glass	float glass	float glass

STAR Experiment



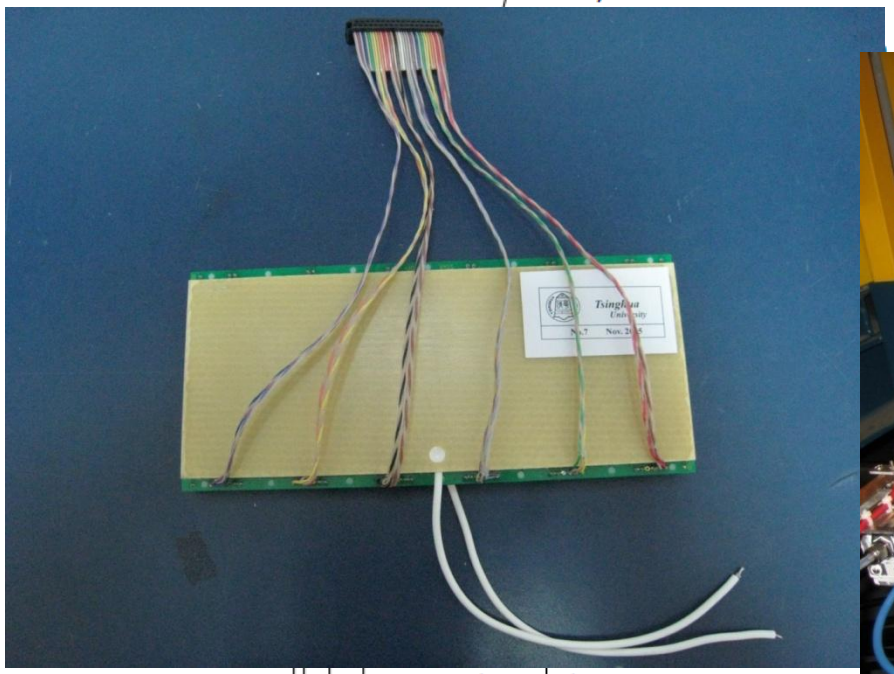
Requirement for STAR-TOF

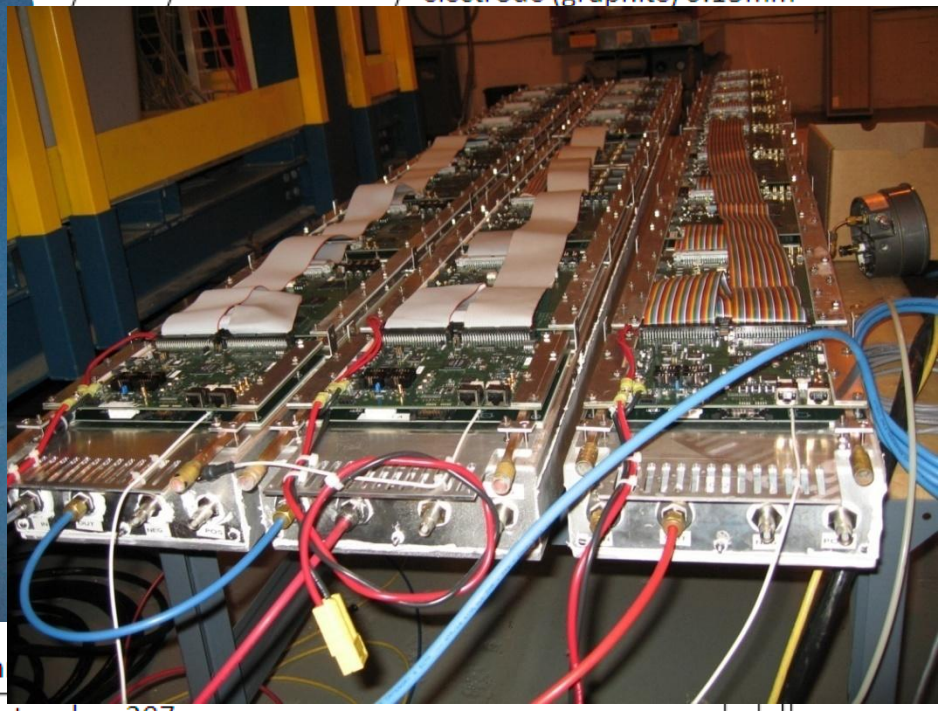
Large acceptance TOF detector to dramatically extend STAR's scientific reach through enhanced PID.

120 Trays of MRPC modules to cover acceptance of the STAR TPC.

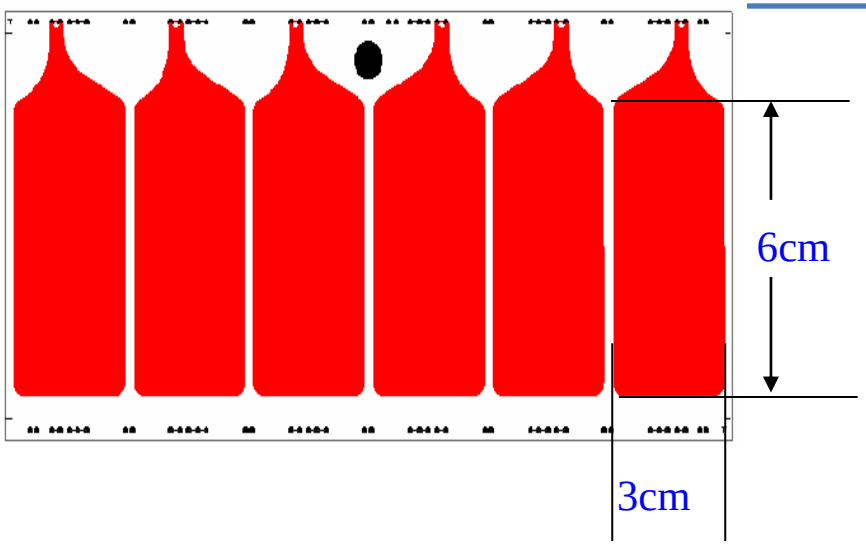
- The total resolution after all corrections must be less than 100 ps.
- The detector segmentation : the occupancy per channel is below 10-15%.
- The system must fit into the space for the present CTB system.
- The system must be able to operate at particle fluxes up to ~300 Hz/cm^2

MRPC used in STAR barrel TOF





Long side view



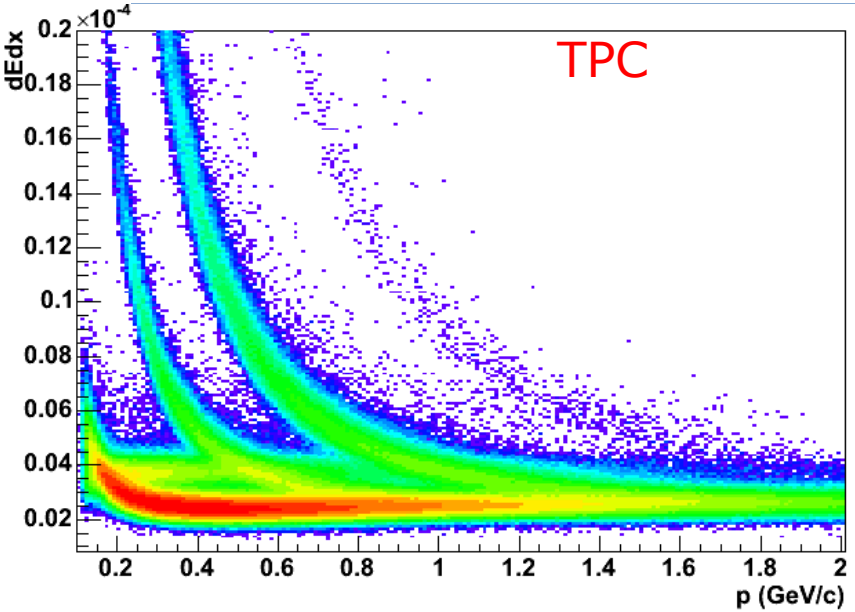
Readout pad

Glass: ～$4\times10^{12}\Omega$.cm
Carbon tape: 500k Ω/□
Gas gap: 6×0.22mm
Working gas: 95% F134a+5% iso-butane
Time resolution: <80ps
Efficiency >90%
Rates capability: <500Hz/cm^2 !

Time performance of MRPC-TOF

Operation condition			Time resolution（ps）		
			Start time	Overall	Stop time
Run III	200GeV d+Au		~85	~120	~85
	200GeV p+p		~140	~160	~80
Run IV	62GeV Au+Au		~55	~105	~89
	200GeV Au+Au	FF/RFF	~27	~74	~70
		HF	~20	~74	~71
RunV	200GeV Cu+Cu (TOT)		~50	~92	~75
	64GeV Cu+Cu (TOT)		~82	~125	~94
Run VIII 5 Trays	200GeV d+Au		NA	NA	NA
	200GeV p+p (TOT)		~83	~112	~75
Run IX 86 Trays	500GeV p+p (TOT)		~85	~117	~78

PID of STAR-TOF



Only TPC:

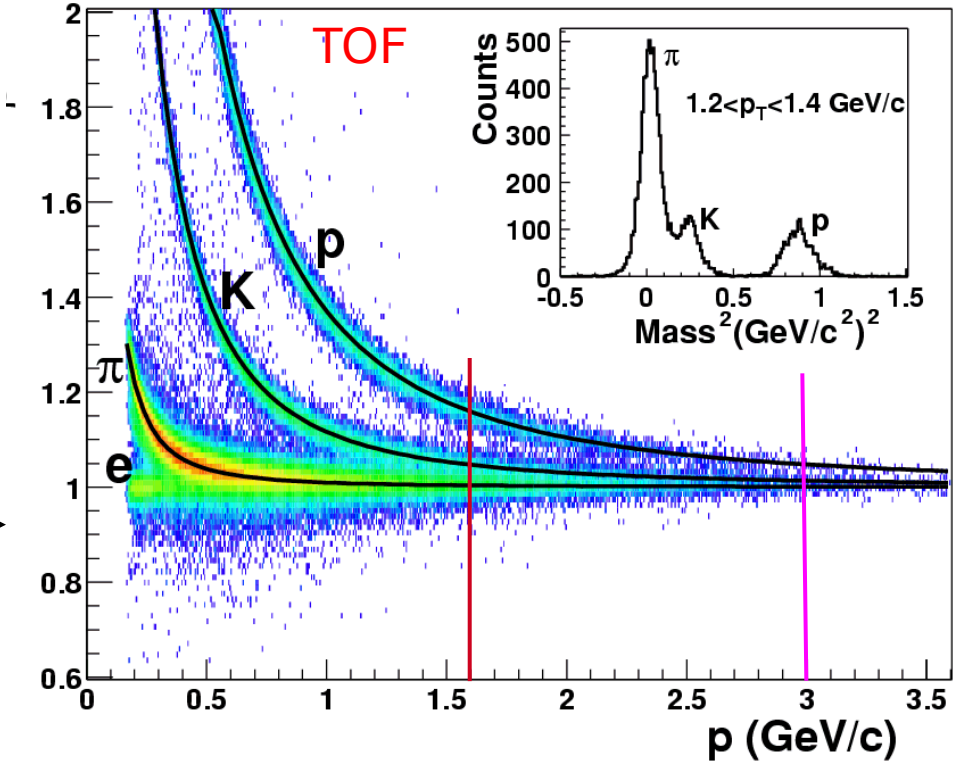
π/k ~0.7 GeV/c,

(π,k)/p ~1.1 GeV/c

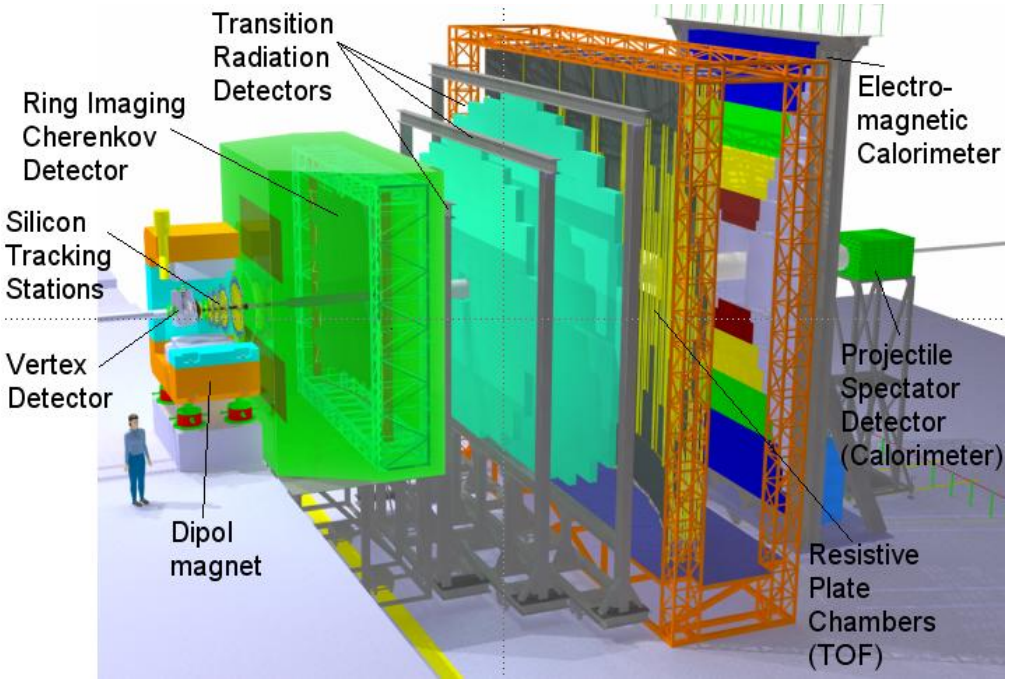
Only TOF:

π /k ~1.6 GeV/c,

(π,k)/p ~ 3.0 GeV/c



FAIR-CBM TOF



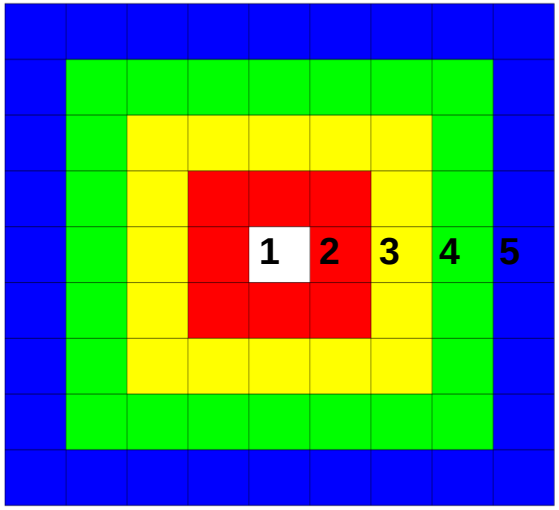
- Full system time resolution σ_T ~ 80 ps
- Efficiency > 95 %
- Rate capability < 20 kHz/cm^2
- Acceptable cross-talk and charge-sharing
- Pile-up < 5%
- Occupancy < 5 %
- Spatial resolution

CBM-TOF requirement

5 different **regions** were defined, with 5 different cell sizes:

- **Pad** region (1): 2.0 x 2.0 cm^2 (27072 channels, A=11 m^2).
- **Strip** region (2): 2.0 x 12.5 cm^2 (3840 x 2 channels, A=10 m^2).
- **Strip** region (3): 2.0 x 25.0 cm^2 (5568 x 2 channels, A=28 m^2).
- **Strip** region (4): 2.0 x 50.0 cm^2 (6150 x 2 channels, A=62 m^2).
- **Strip** region (5): 2.0 x 100.0 cm^2 (2900 x 2 channels, A=58 m^2).

TOTAL (**63988** channels, **A=170 m^2**).



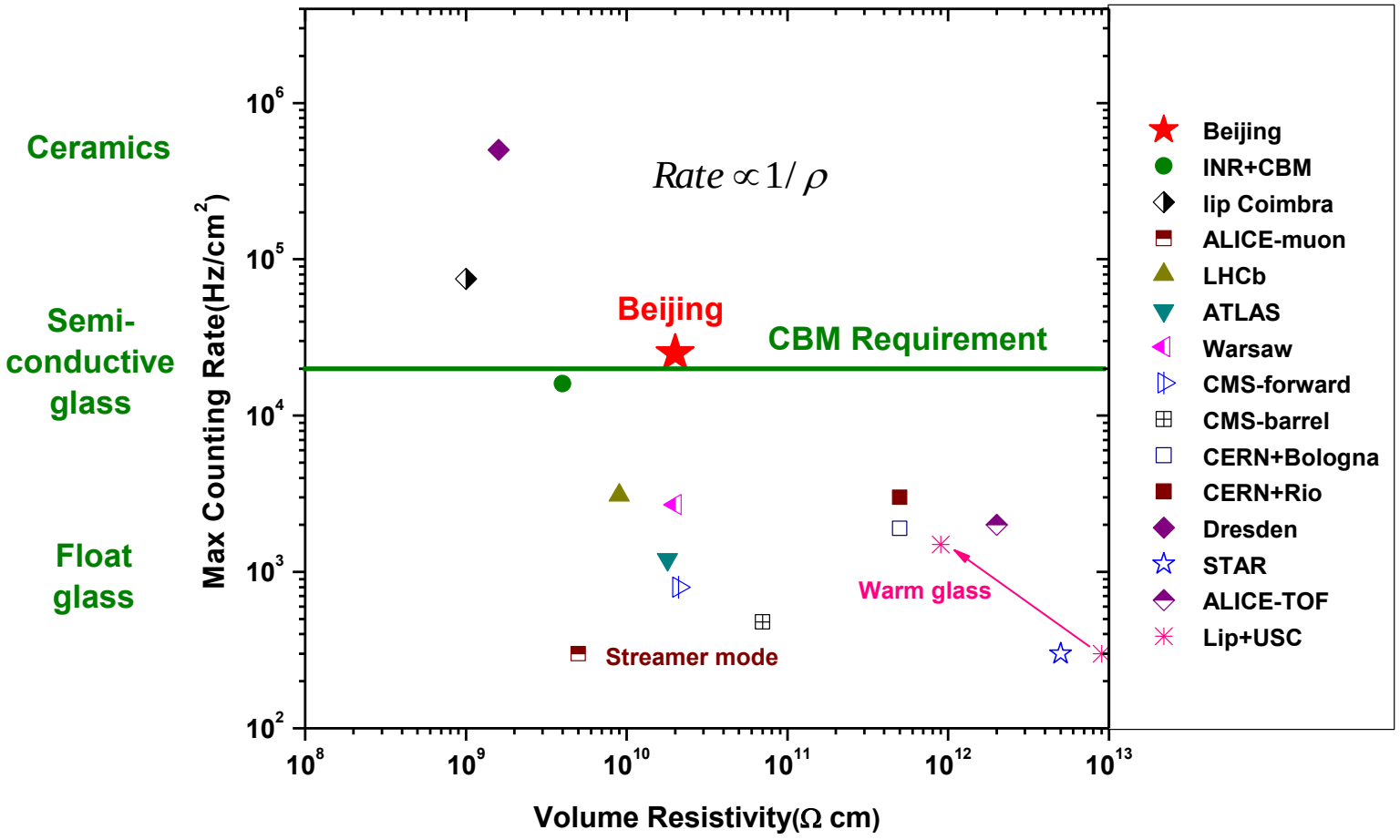
Possible Solution:

– Timing RPC with low resistivity glass ~10^{10} Ωcm

– Center: pad-readout

Outside: strip-readout

Timing RPC world map

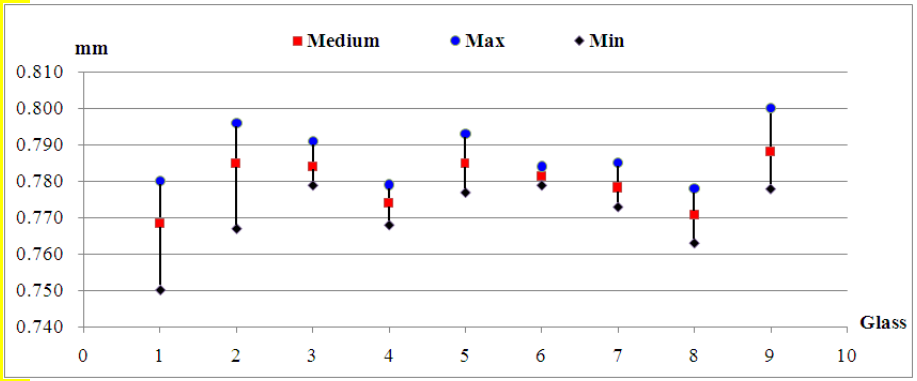


Development of low resistive glass

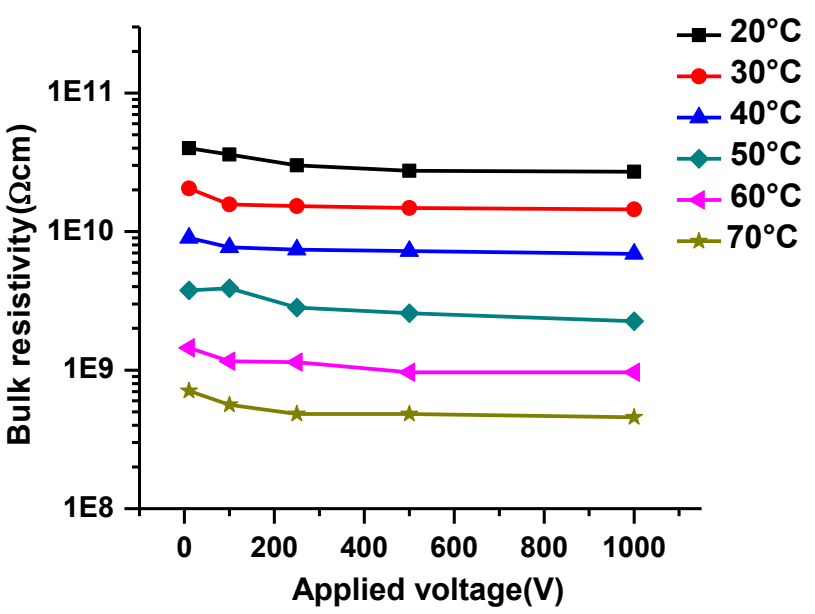
Specifications:

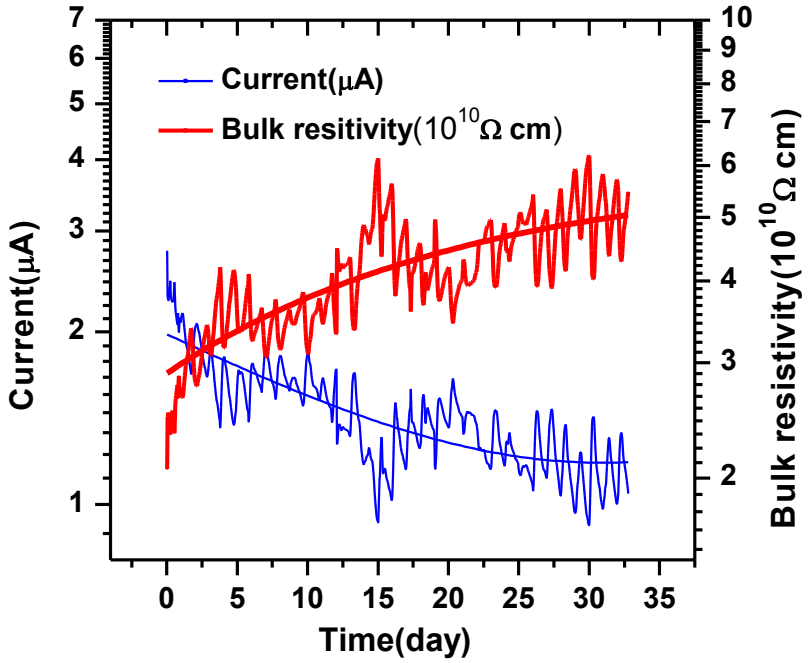
Maximal dimension: 50cm × 50cm
Bulk resistivity: ~$10^{10}\Omega$.cm
Standard thickness: 0.5mm--2mm
Thickness uniformity: ±0.02mm
Dielectric constant: ~10
Surface roughness: <10nm
DC measurement: very stable

Thickness distribution



Performance test of glass



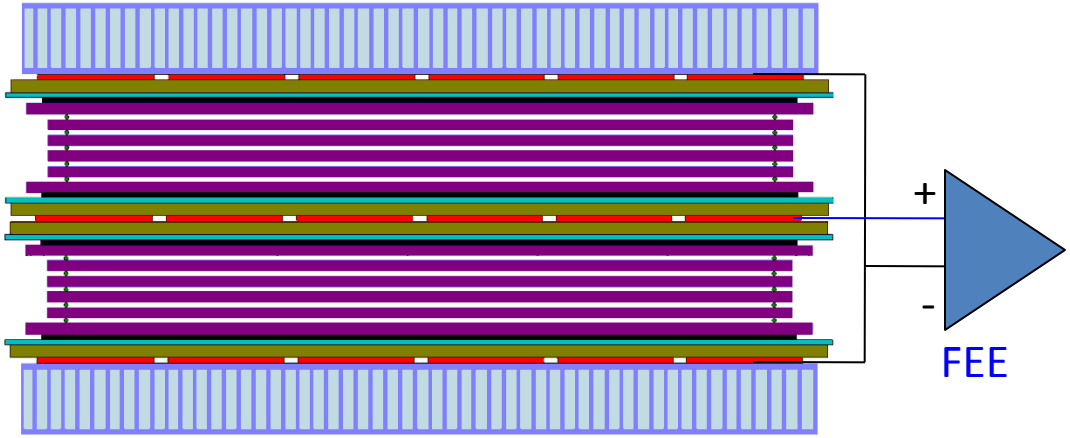


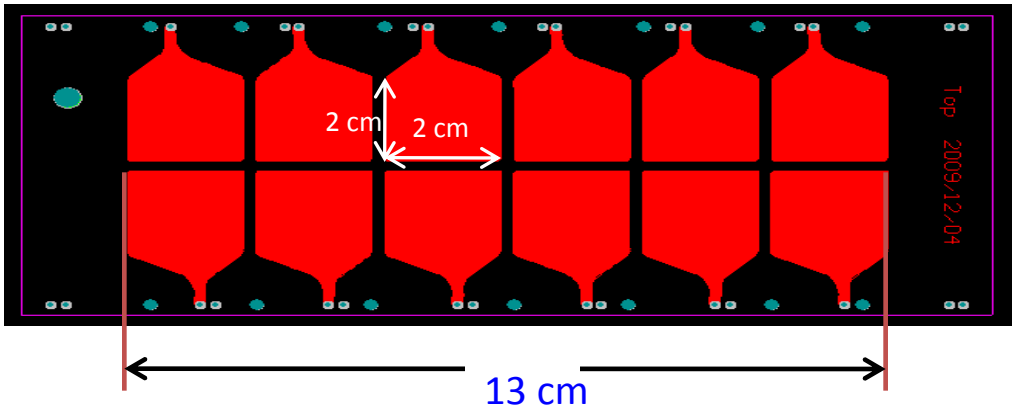
- Resistivity decreases with temperature
- Resistivity is very stable in DC measurement

This glass was applied with 1000V for about 32days, integrated charge: 1 C/cm^2

--roughly corresponding to the CBM life-time over 5 years operation at the maximum particle rate.

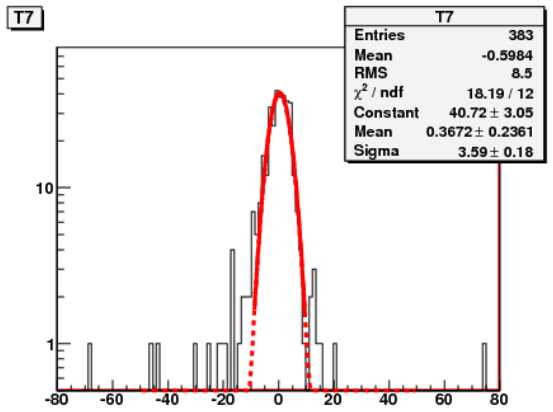
Prototype of high rate MRPC (pad-readout)

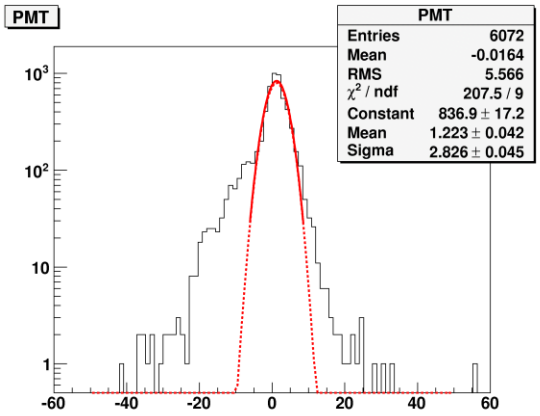


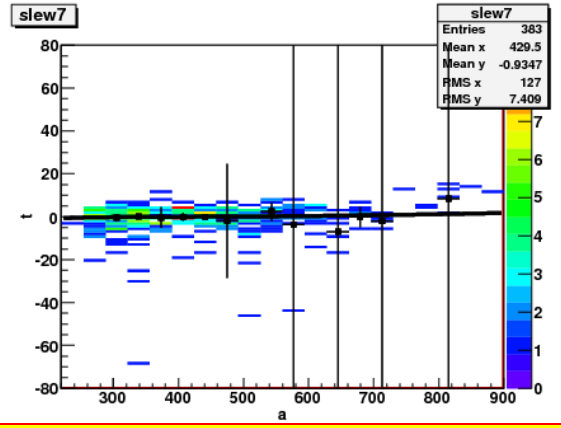


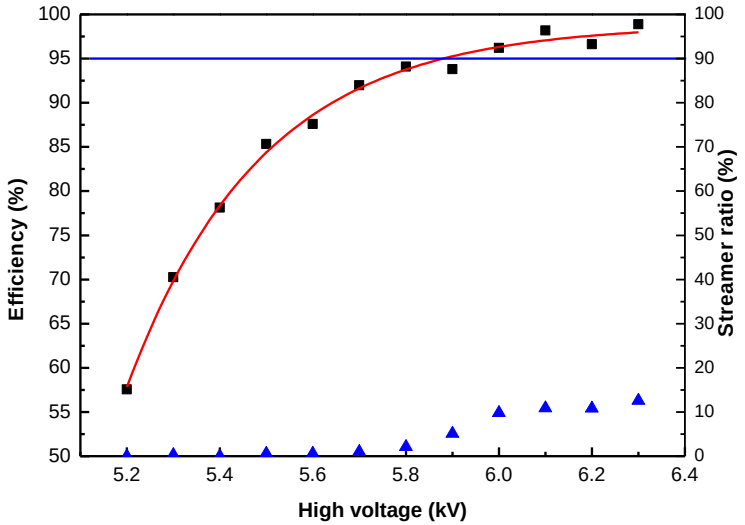
Colloidal graphite: 2M Ω/□
Gas gap: 10×0.25mm
10×0.22mm
Glass: 0.78mm,1mm
Resistivity: ～10^{10}Ω.cm
Working gas: 96% F134a+3%
iso-butane+1%SF6

Cosmic ray test





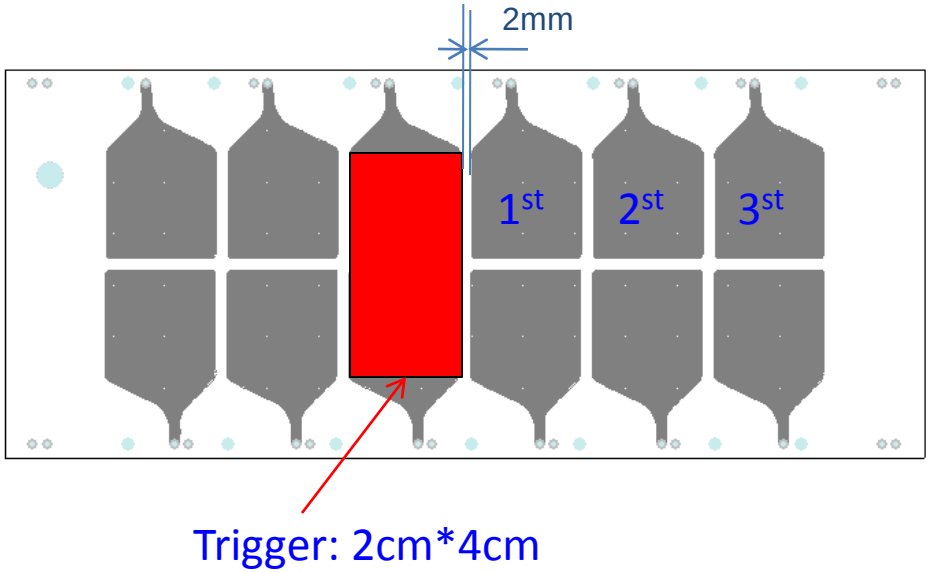


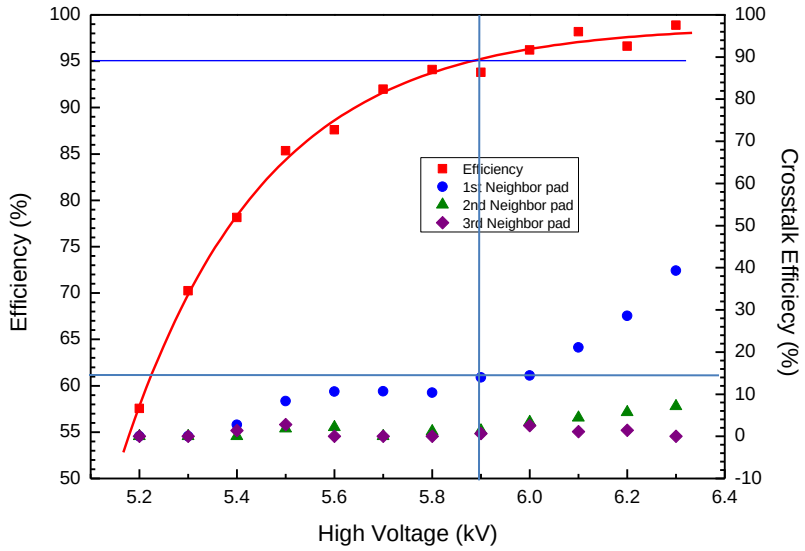


Cosmic ray test:

- Time resolution: ~80ps
- Efficiency: >95%

Cosmic ray test

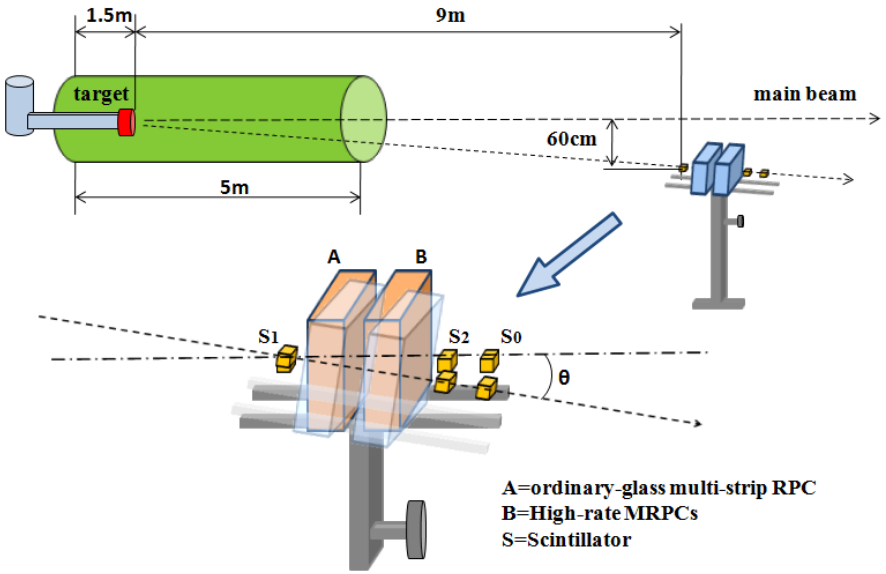


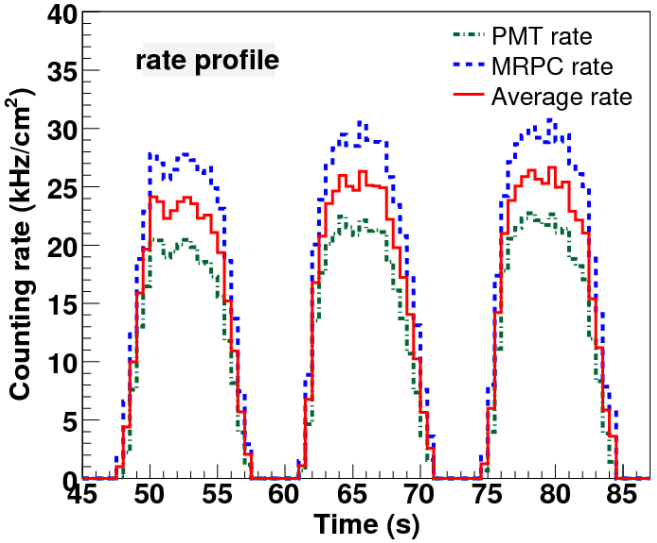


1st neighboring pad: charge sharing + crosstalk

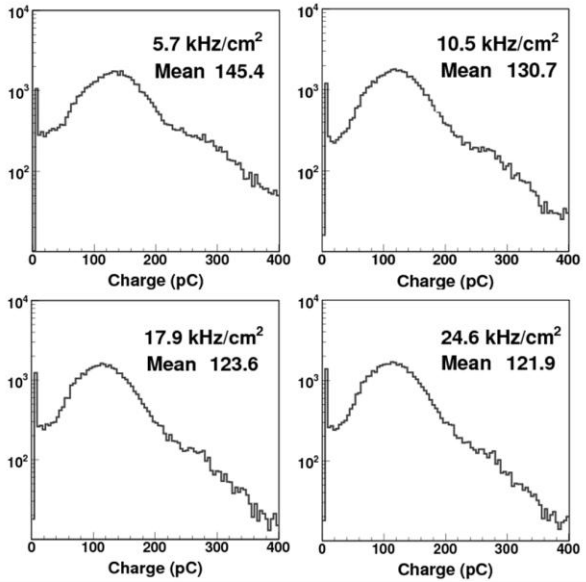
2st and 3st: only crosstalk <5%

Beam test for rate capability



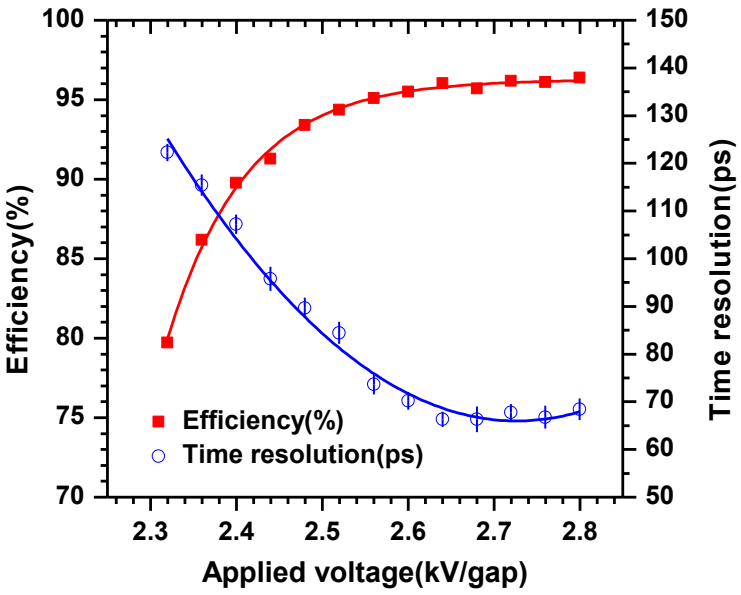


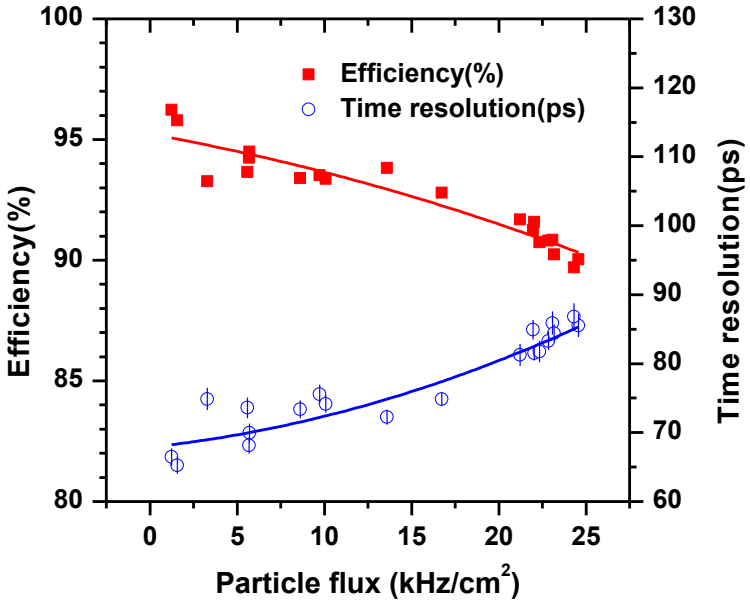
PMT: 0.8-20 kHz/cm^2
MRPC: 2-30 kHz/cm^2



Charge distributions of the 10-gap RPC for different particle fluxes at 2.64 kV/gap

Performance of high rate MRPC

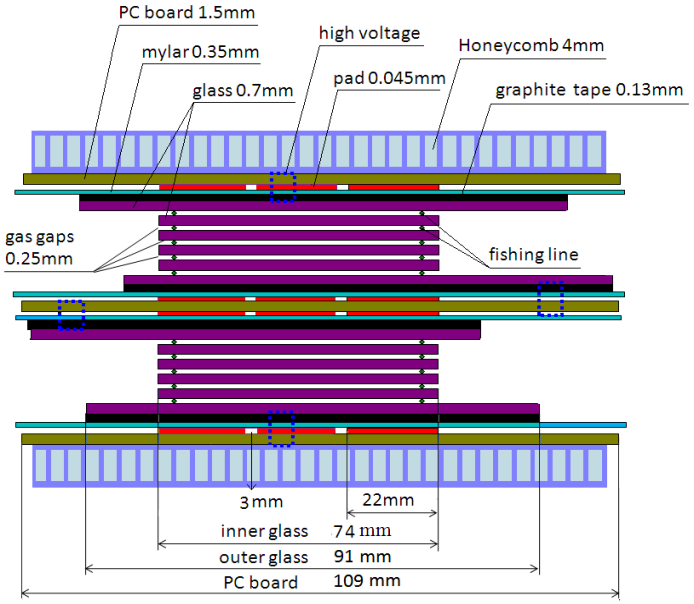


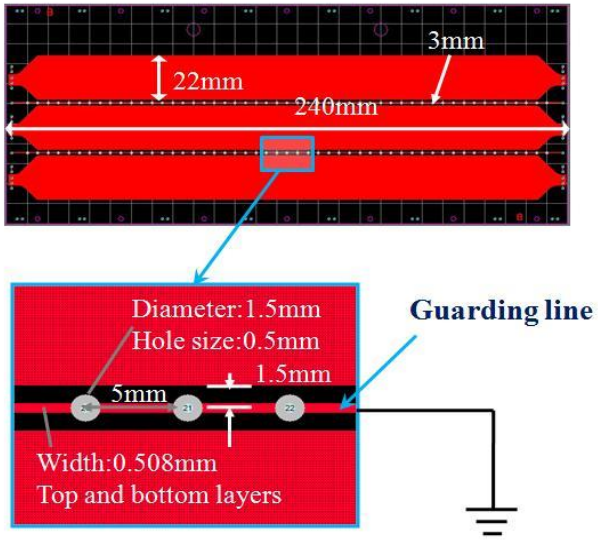


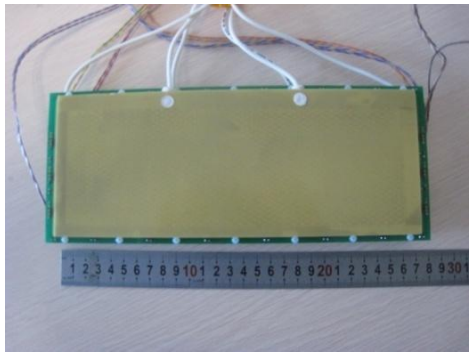
Efficiency and time resolution as a function of high voltage at a rate of about 800Hz/cm^2

When the particle flux increases every 5 kHz/cm^2, the efficiency decreases by 1% and the time resolution deteriorates by 4 ps.

Prototype of high rate MRPC (strip-readout)

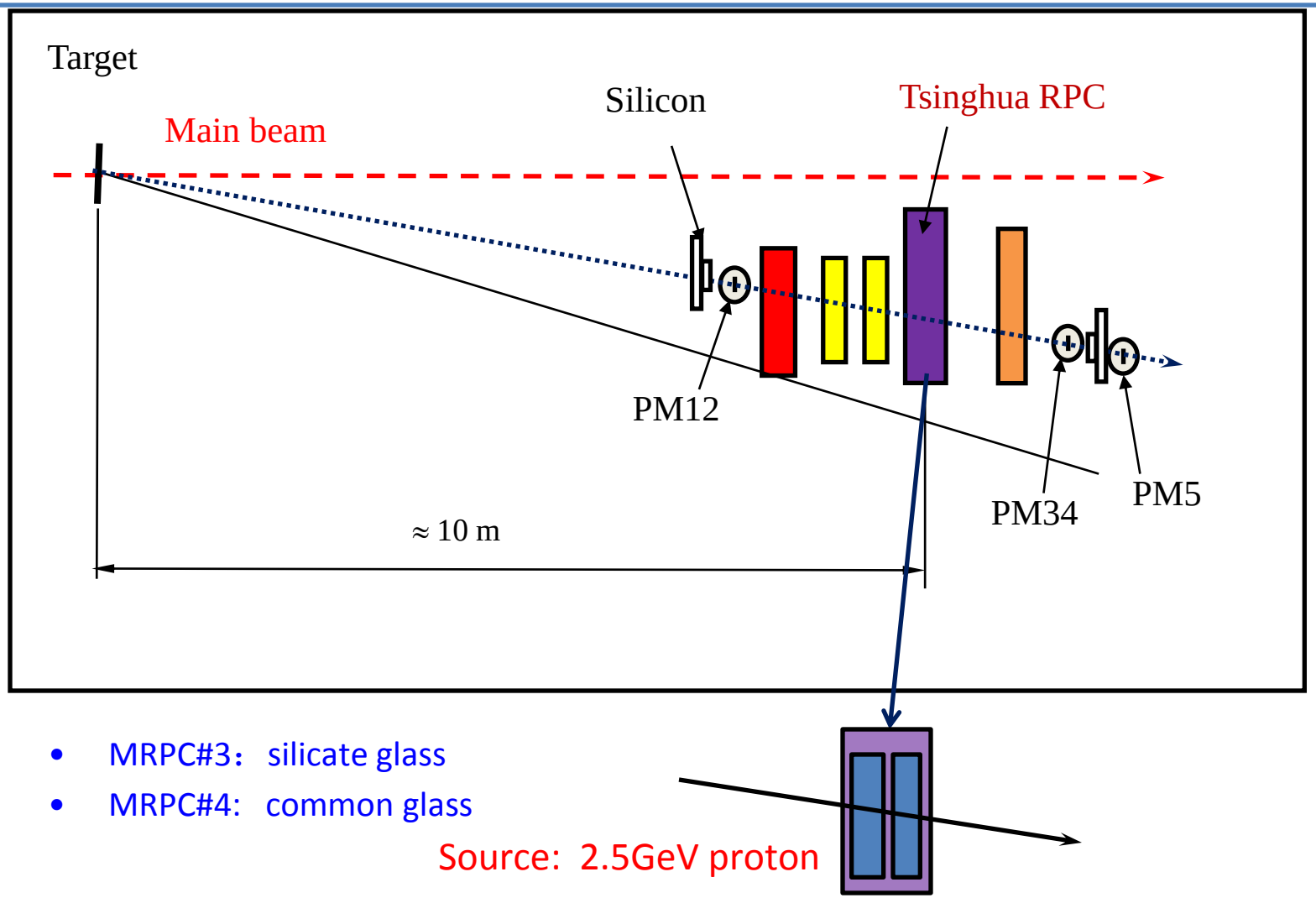






Colloidal graphite: 1M Ω/□
Gas gap: 10×0.25mm
Glass: 0.78mm,1mm
resistivity: ~10^{10}Ω.cm
Gas mixture:
Freon/iso-butane/SF6
96.5%/3%/0.5%

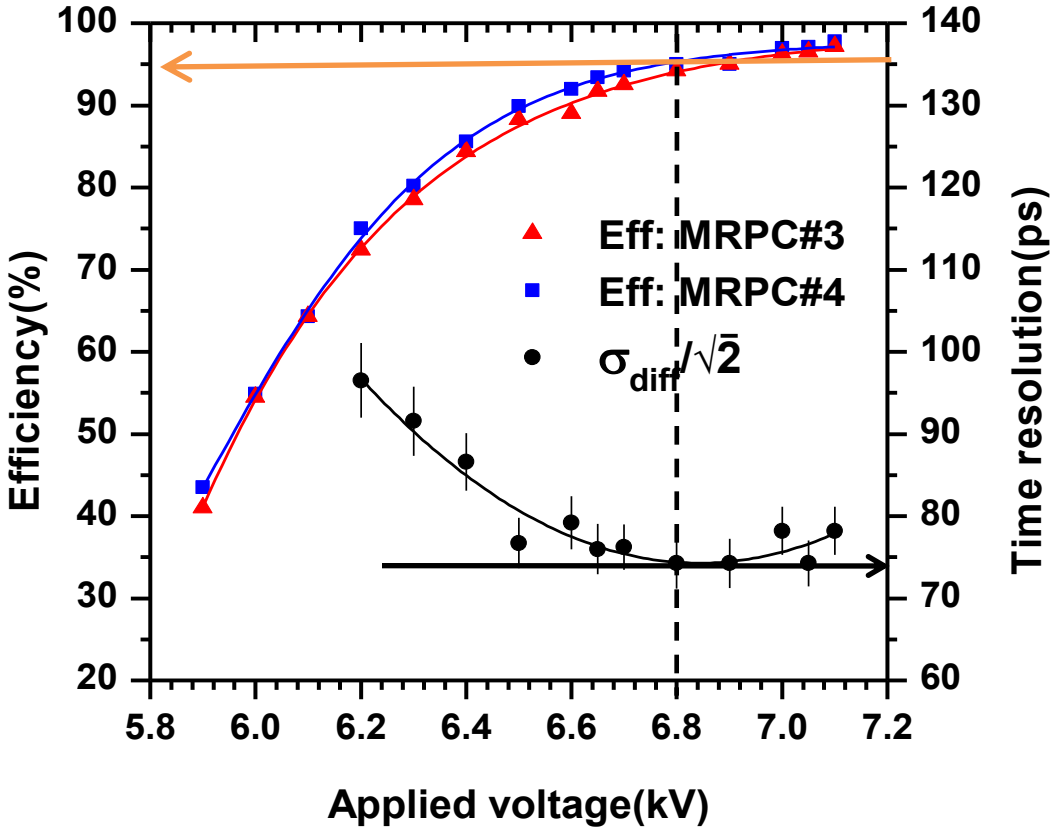
Test Setup



- MRPC#3：silicate glass
- MRPC#4: common glass

Source: 2.5GeV proton

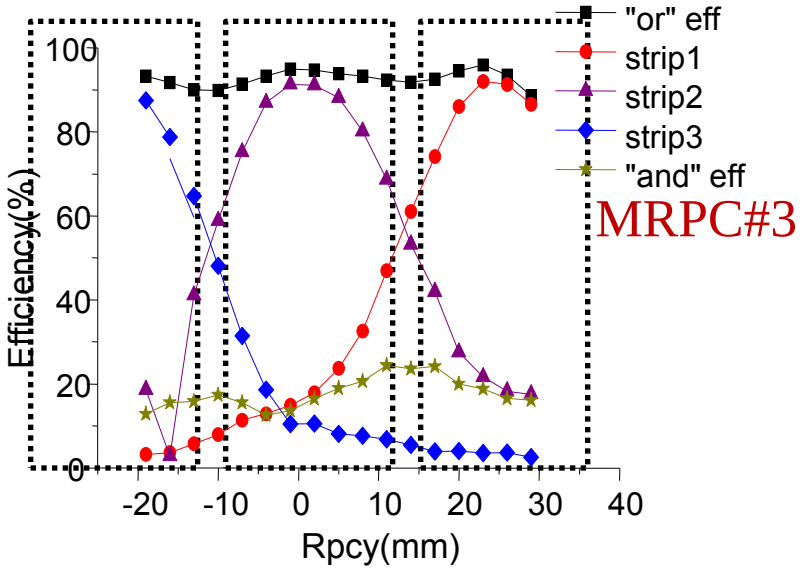
HV scan

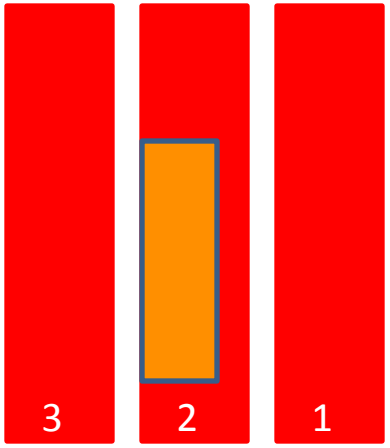


$T_{diff} = T_{MRPC\#3} - T_{MRPC\#4}$,

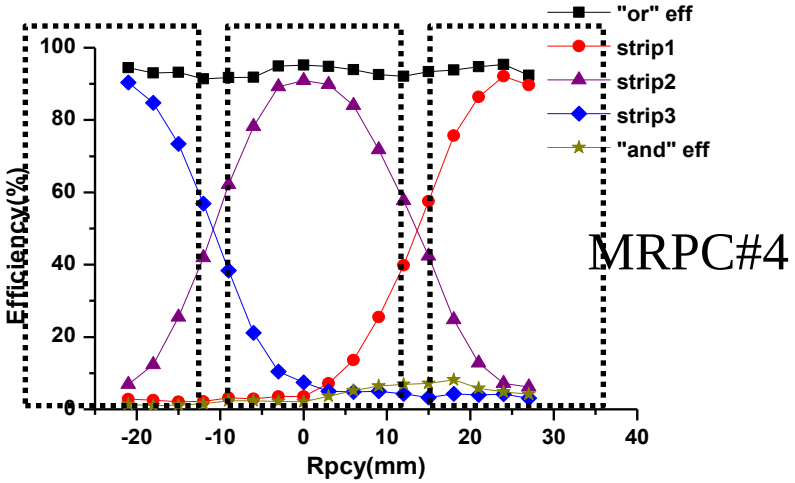
$\sigma_{MRPC\#3} \approx \sigma_{MRPC\#4} \approx \sigma_{diff} / \mathrm{sqrt}(2)$

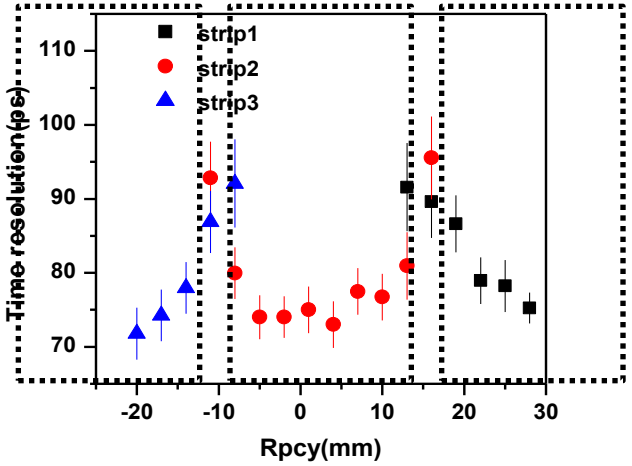
Position Scan



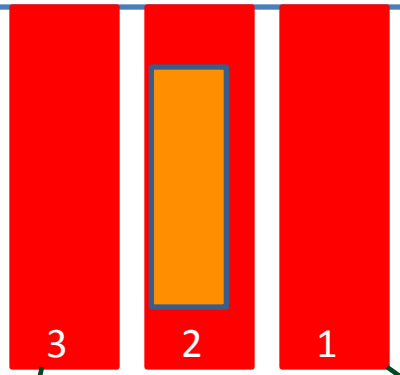


Rpcy



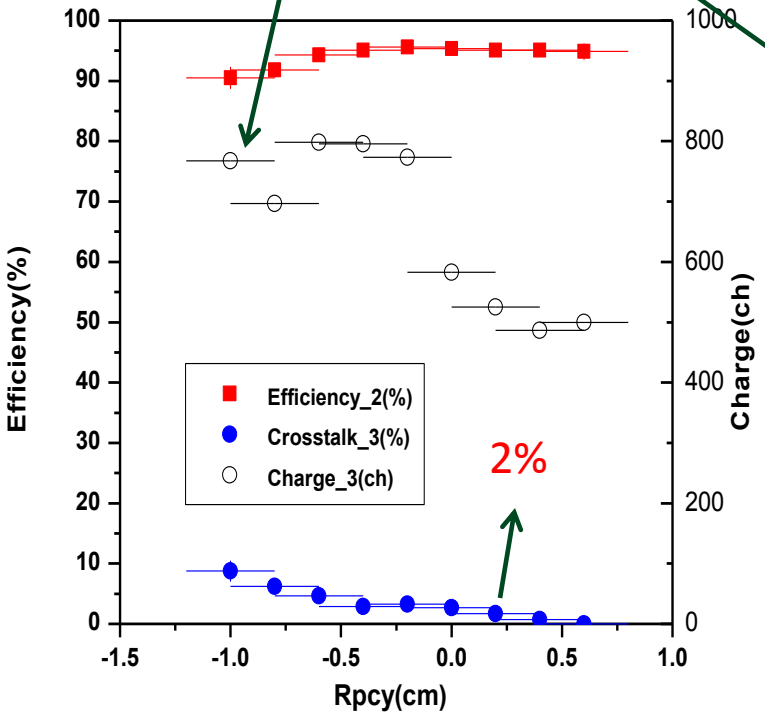


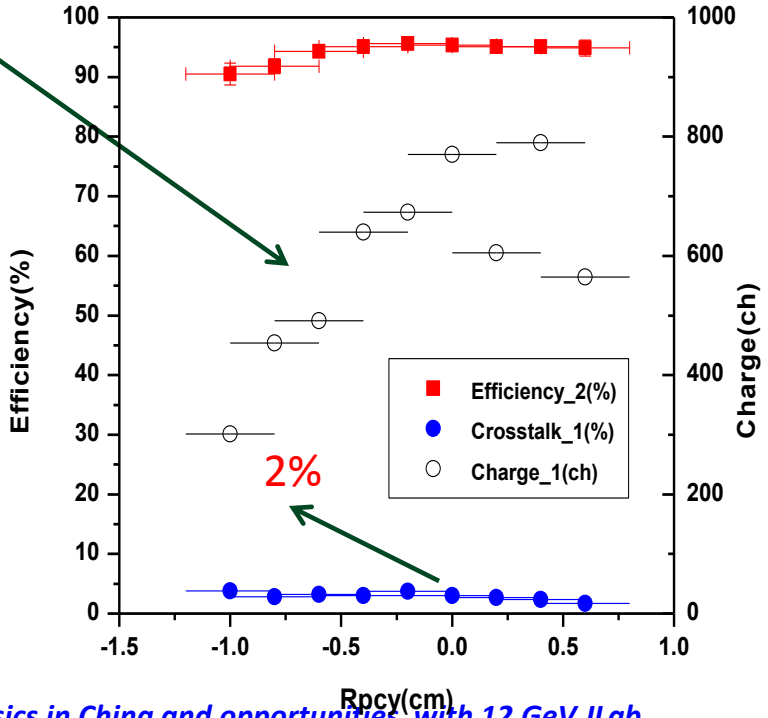
Crosstalk & charge sharing



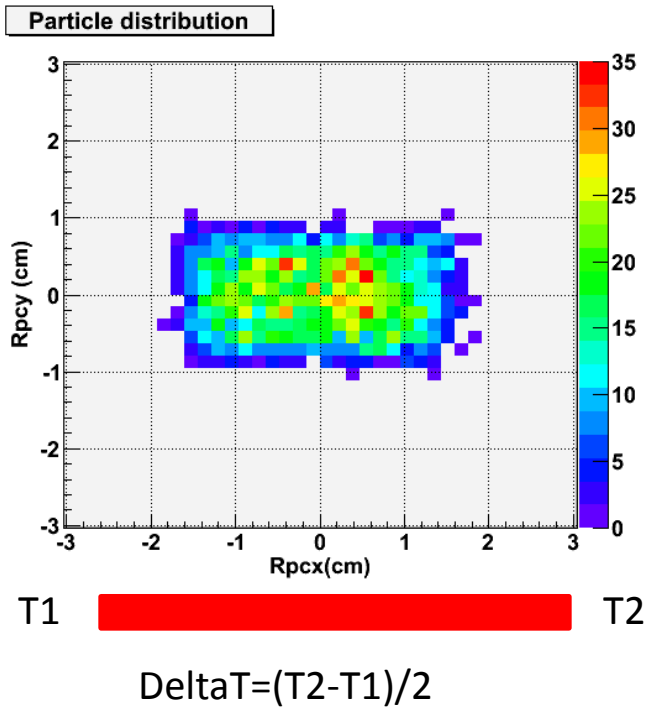
Rpcy (cm)

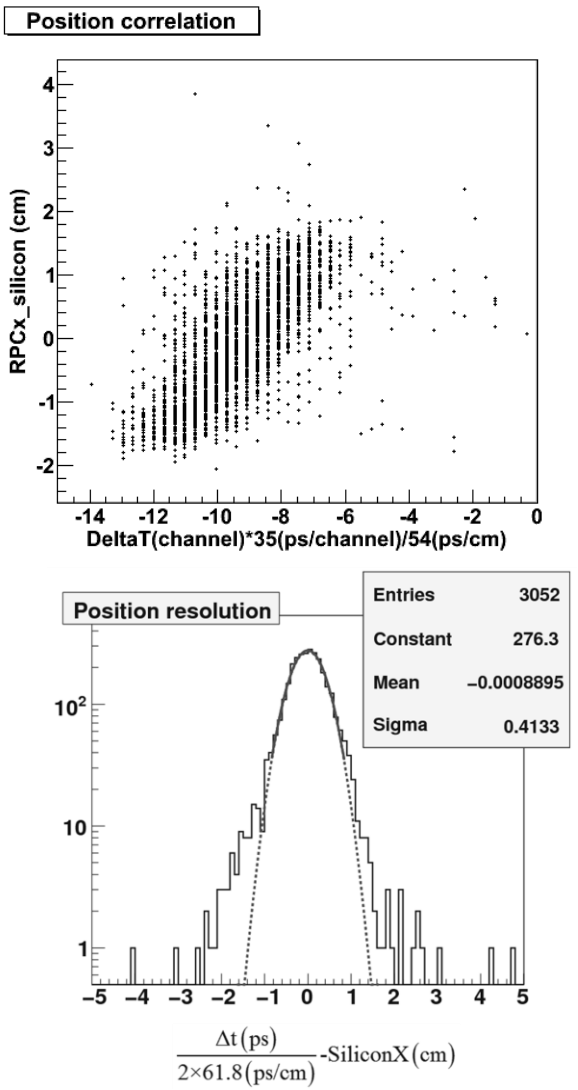
Crosstalk_1=counts(T2>0 && T1>0) / counts(trigger)





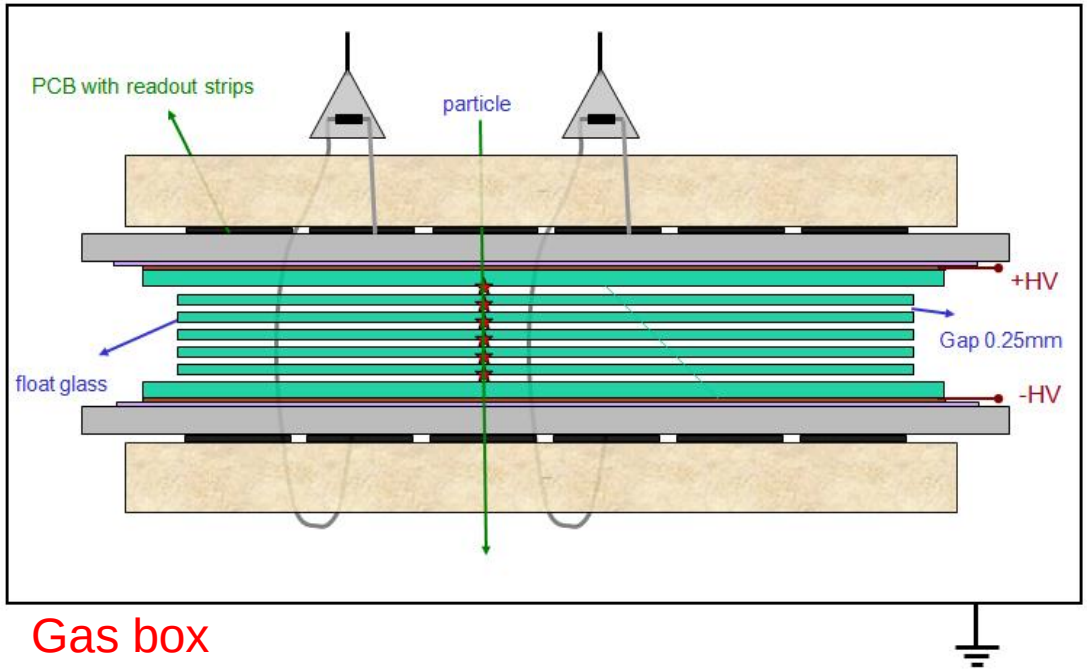
Position resolution





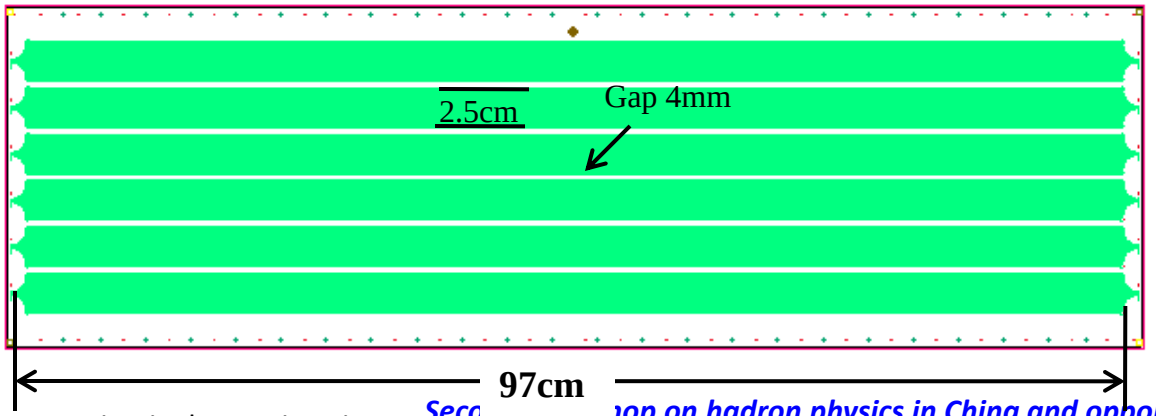
- Using the tracking, we get the signal propagation velocity:
  ~ 61ps/cm
- Position resolution:
  <5mm

Structure of 1m-long counter

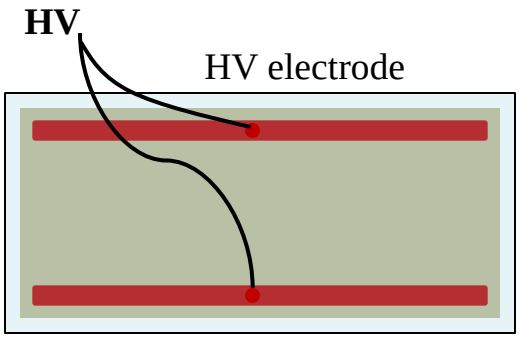


Gas box

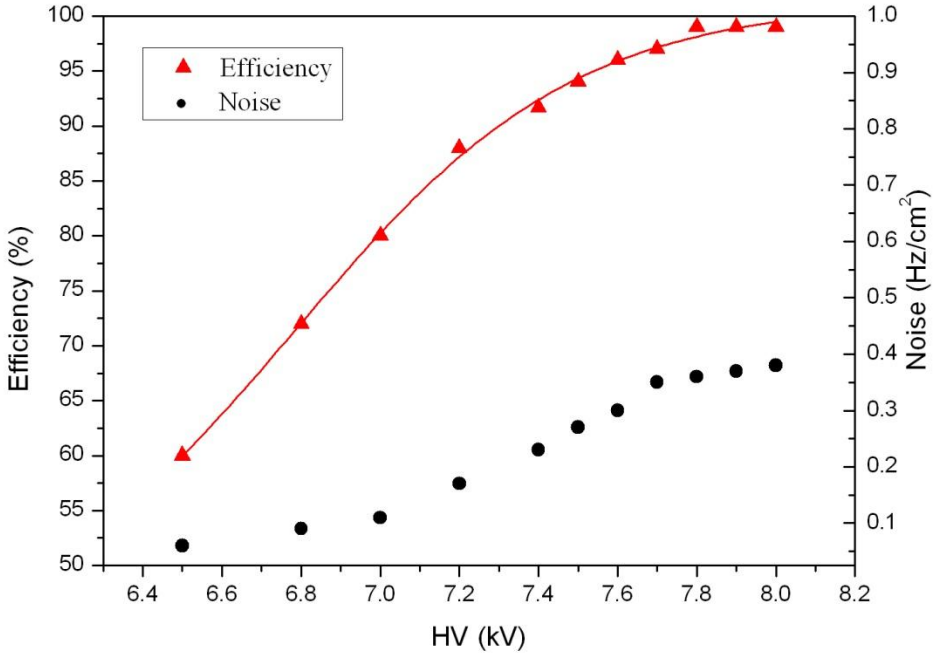
- Readout strips: 2.5 cm x 1m
- Gaps between strips: 4 mm
- Gas gaps: 6 x 0.25 mm
- Outer glass: 1.1 mm
- Inner glass: 0.7 mm
- HV electrode: colloidal graphite ~5 MΩ/□
- Gas mixture: 90%/5%/5% Freon/iso-butane/SF6
- Gas flux: 50ml/min



Strips

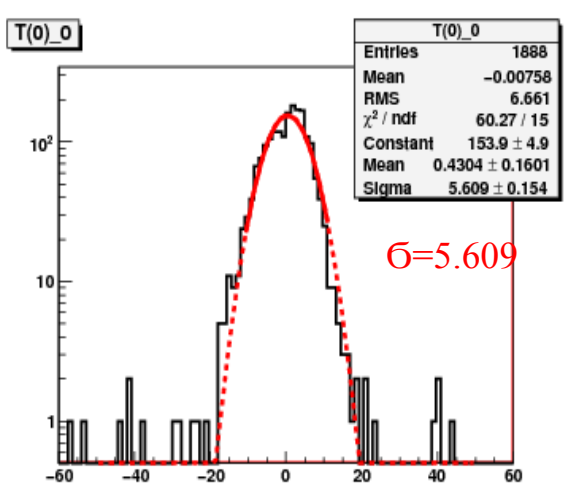


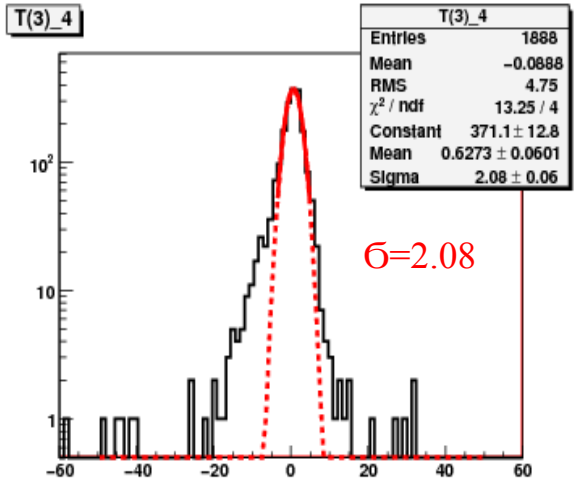
Performance of 1m-long counter



This detector can be used in STAR-MTD and CBM-TOF.

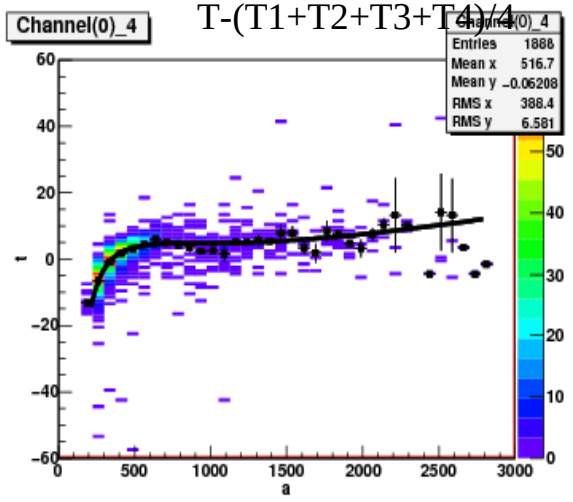
MRPC calibration-Time resolution



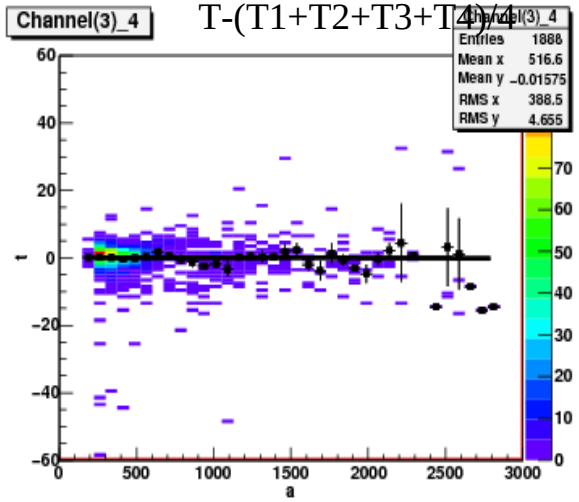


$$\sigma_{rpc} = \sqrt{2.08^2 - 1.033^2}$$
$$= 63.8\,ps$$

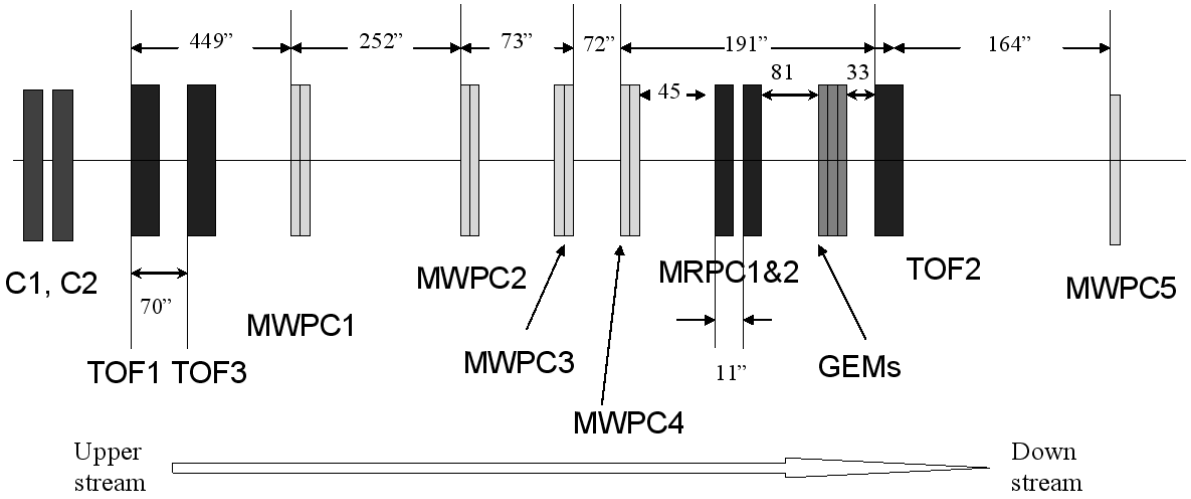
T-(T1+T2+T3+T4)/4

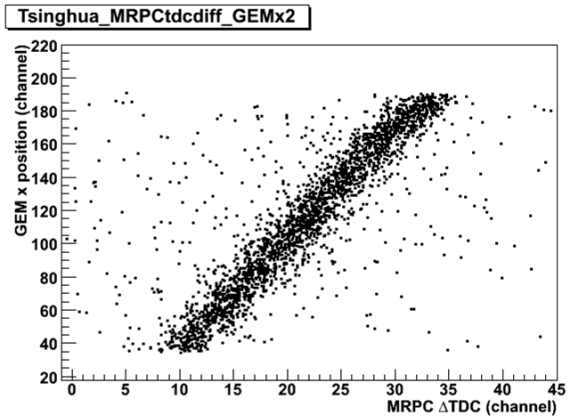


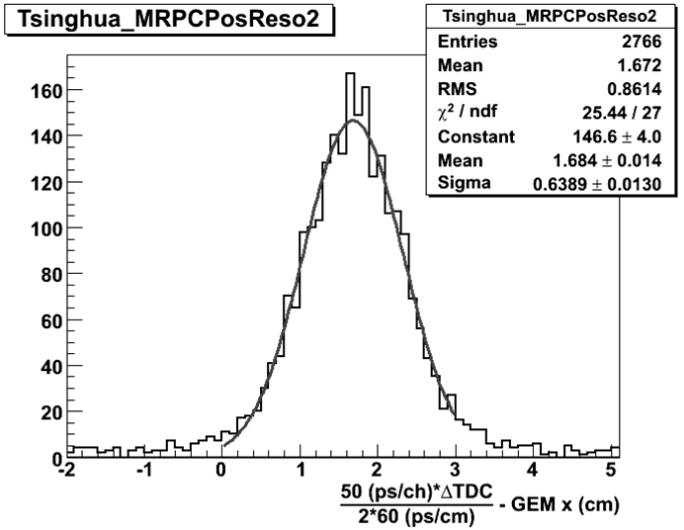
T-(T1+T2+T3+T4)/4



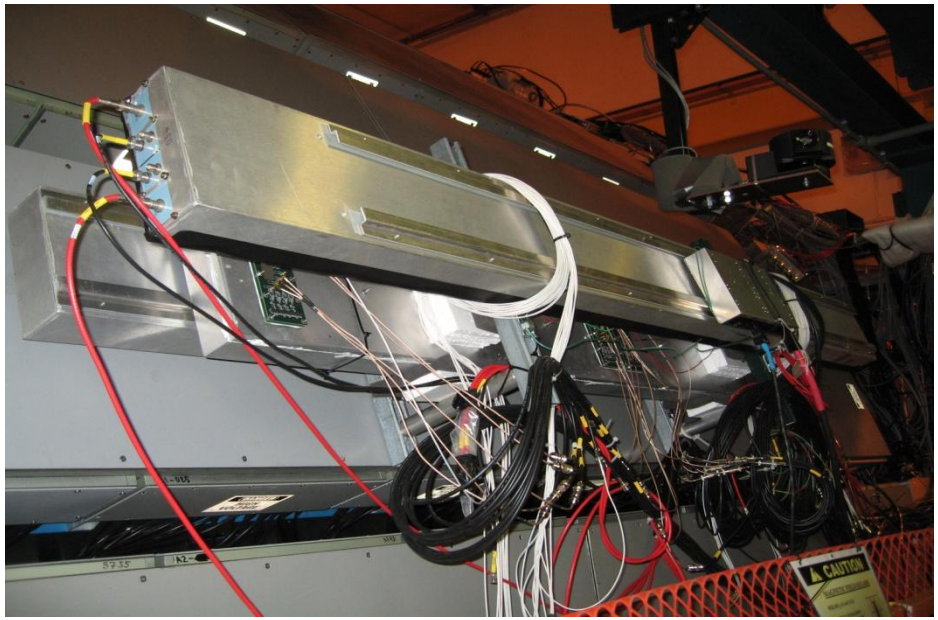
Spacial resolution

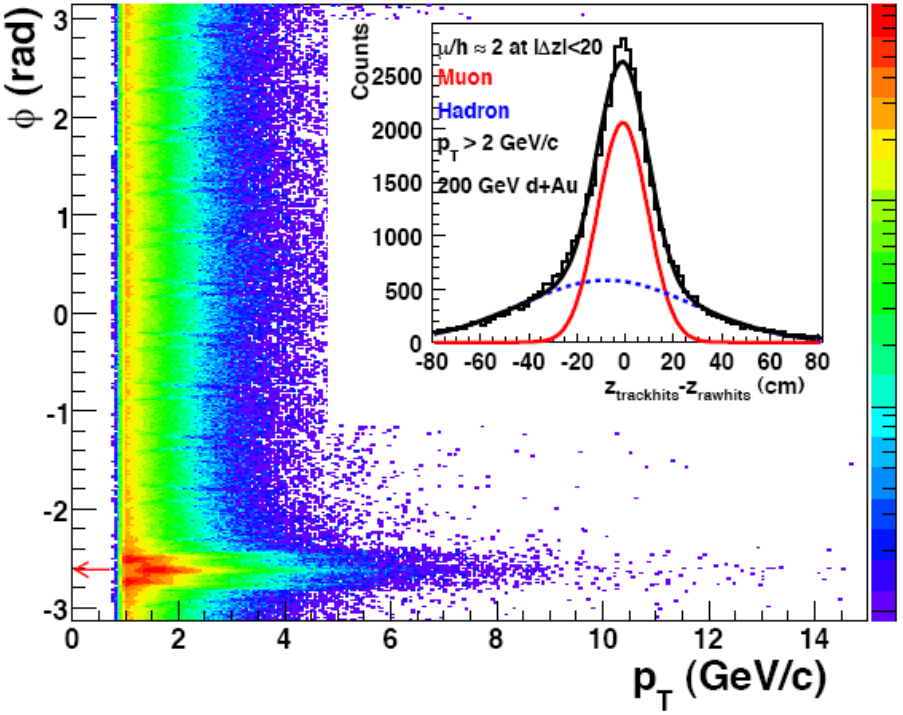






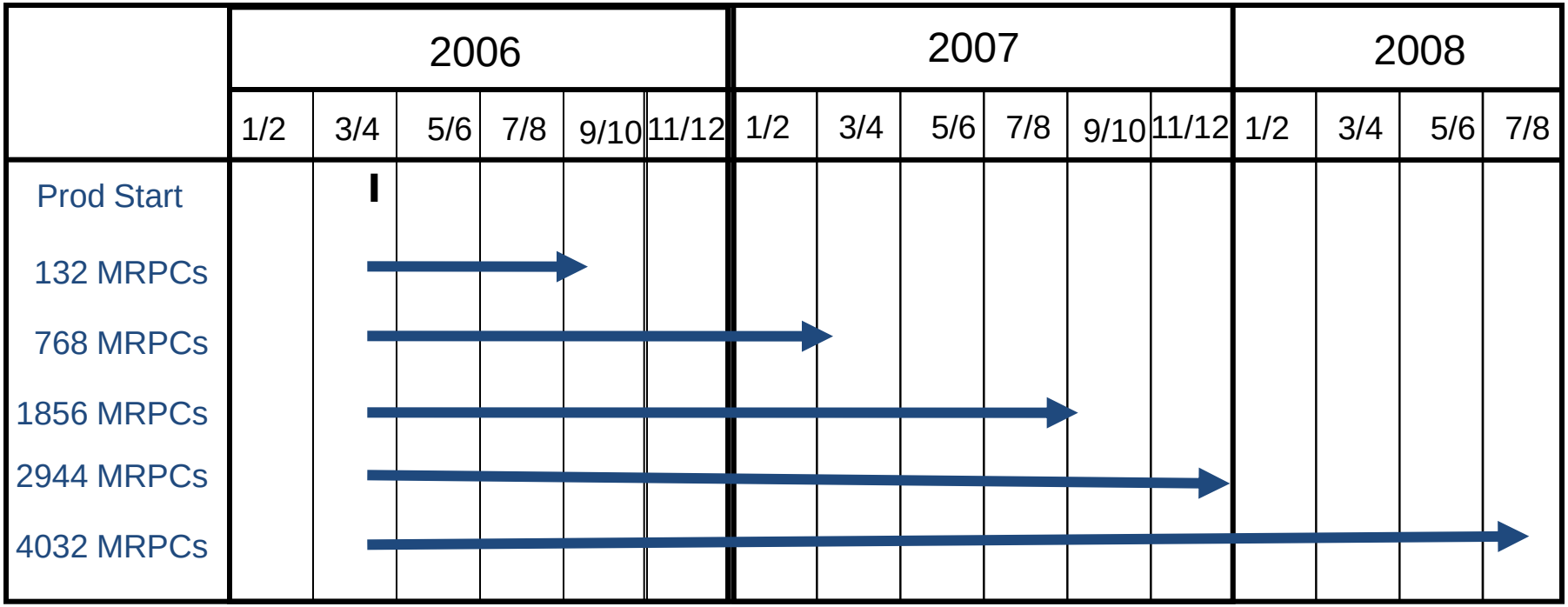
STAR-MTD running results





The peak shows an enhancement of particle yield at the angle where the MTD is positioned. The ratio is about 2:1.

MRPC Production Milestones (STAR MRPC)



MRPC production was finished in September of 2008.

In Tsinghua:

3100 MRPC have been produced;

2951 Modules passed QA, yield >95% ;

2840 modules shipped to UT Austin .

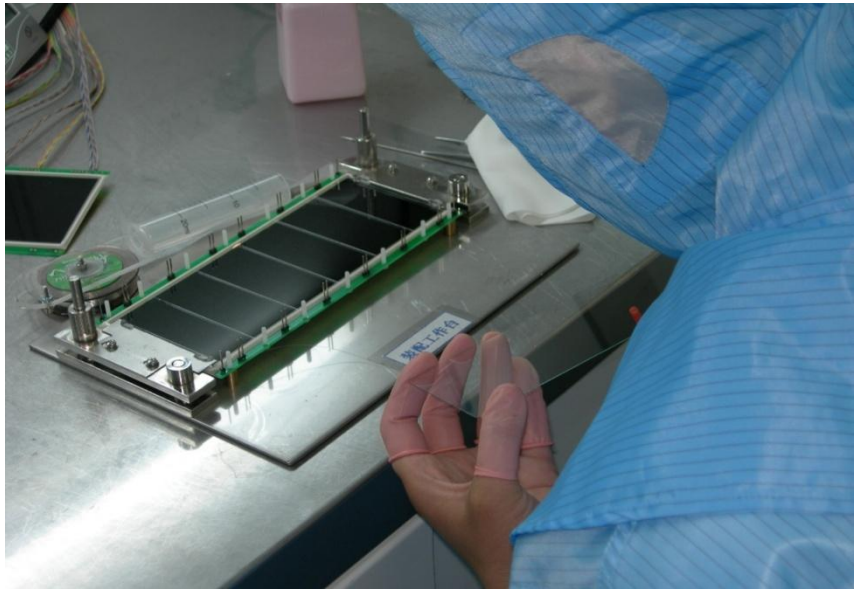
MRPC mechanical specifications

	Nominal	Minimum	Maximum
Length	212mm	211.5mm	212.5mm
Width	94mm	93.5mm	94.5mm
Thickness between two PCBs	9.7mm	9.4mm	10mm
HV lead length	18cm	17.7cm	18.5cm
Signal lead length	22.5cm	22cm	23cm

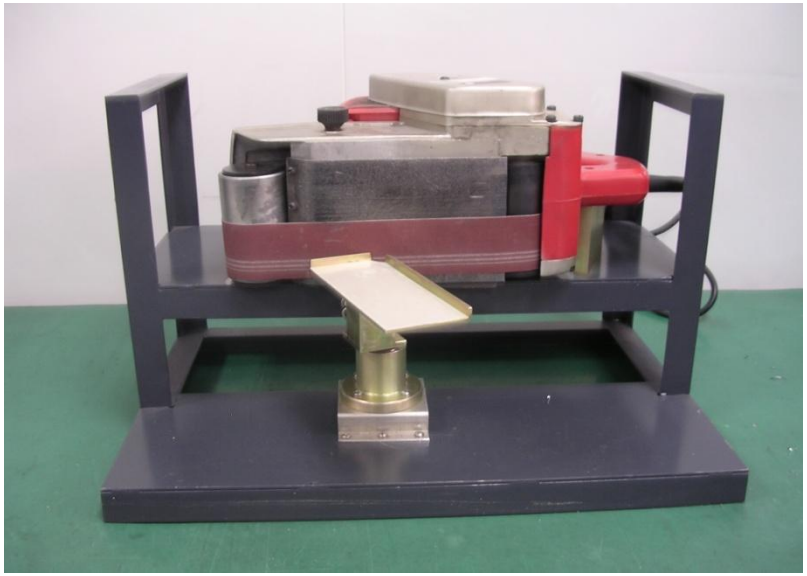
MRPC performance requirement

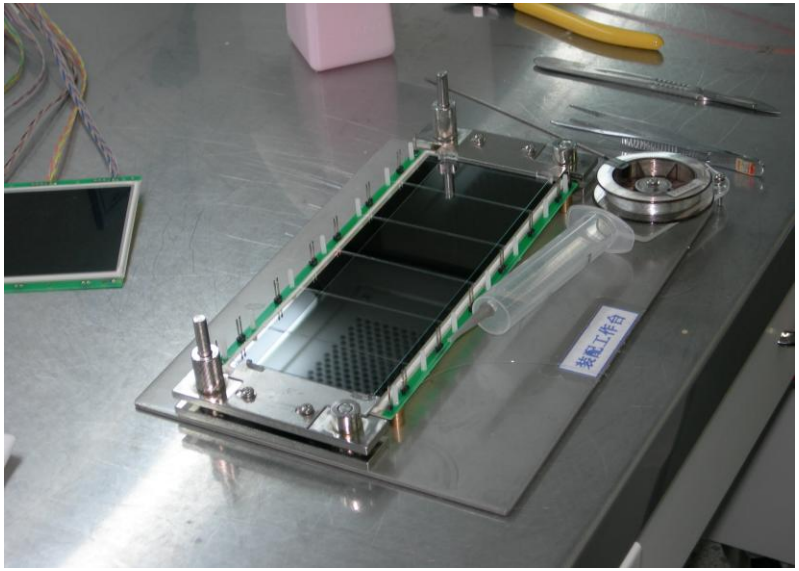
Testing conditions	Specifications
Working gas: 95% F134A+5% iso-butane	**Leakage current:** < 2 nA
HV: 14kV	**Noise rate:** <50 Hz for each channel
FEE threshold: 80mV	**Avalanche ratio:** > 80% of ADC spectrum
	Efficiency : > 90%
	Timing resolution of 90% channels < 120 ps
	Crosstalk of two pads: <0.4

MRPC workshop @ Tsinghua

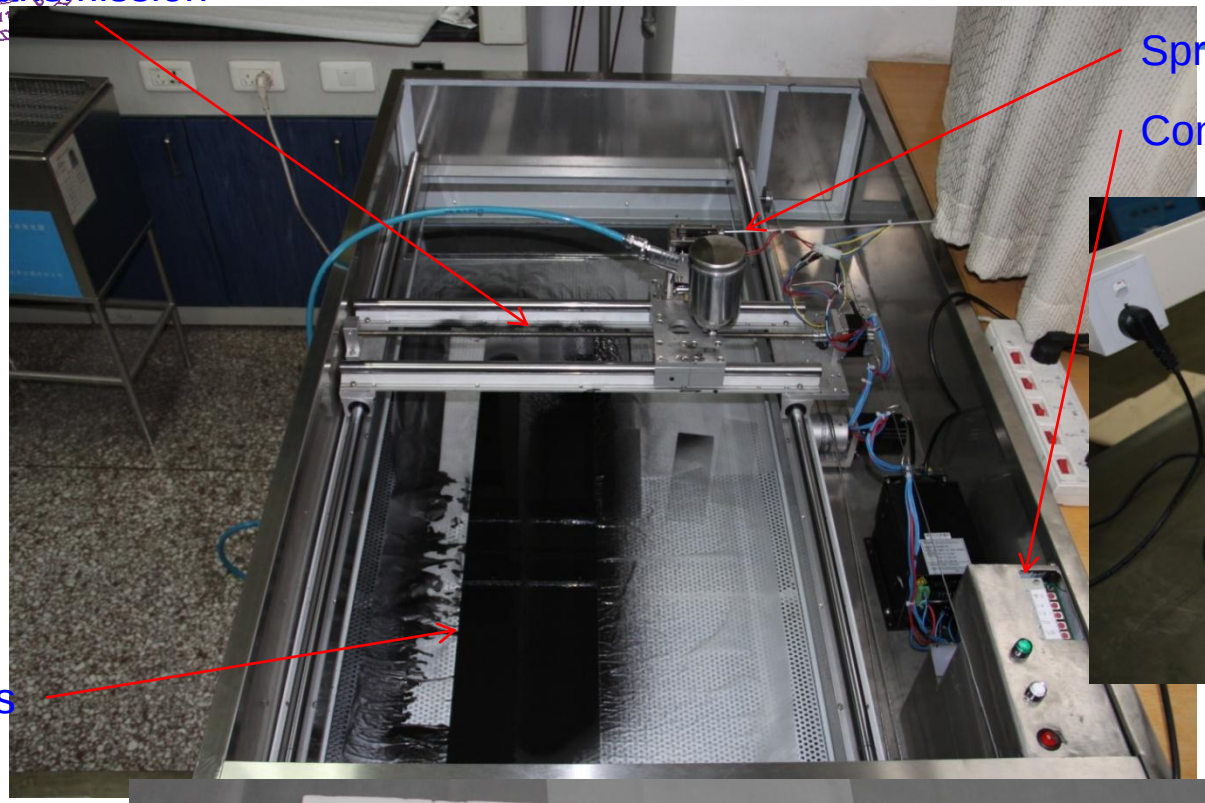


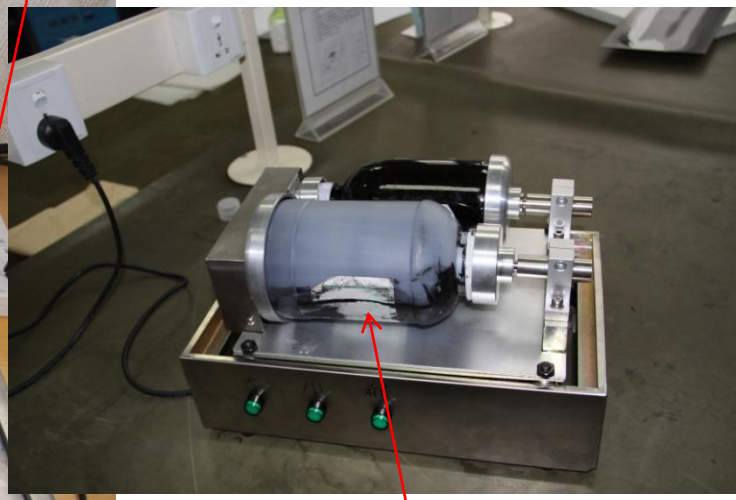
Production tools



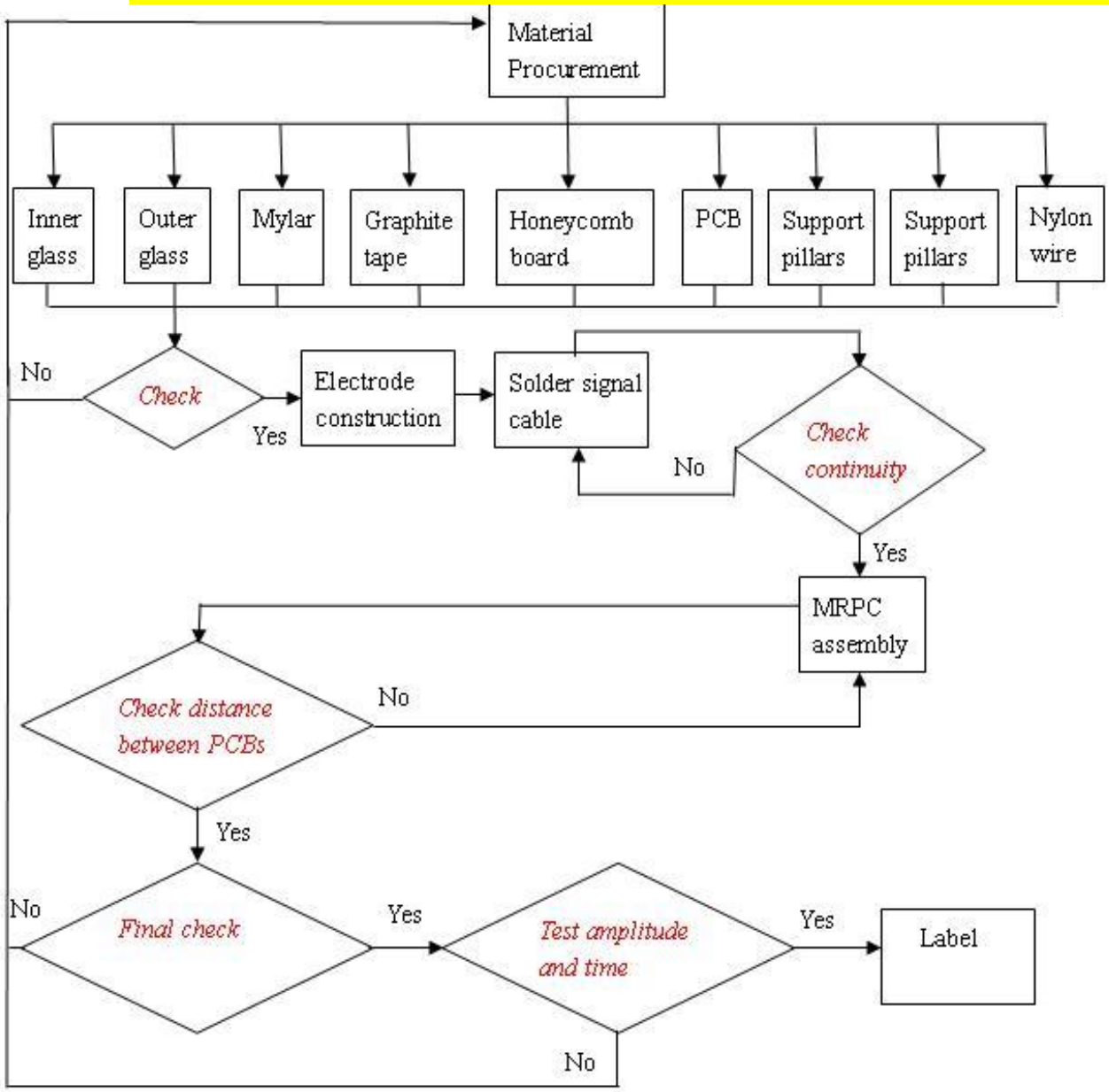


Production of graphite electrodes



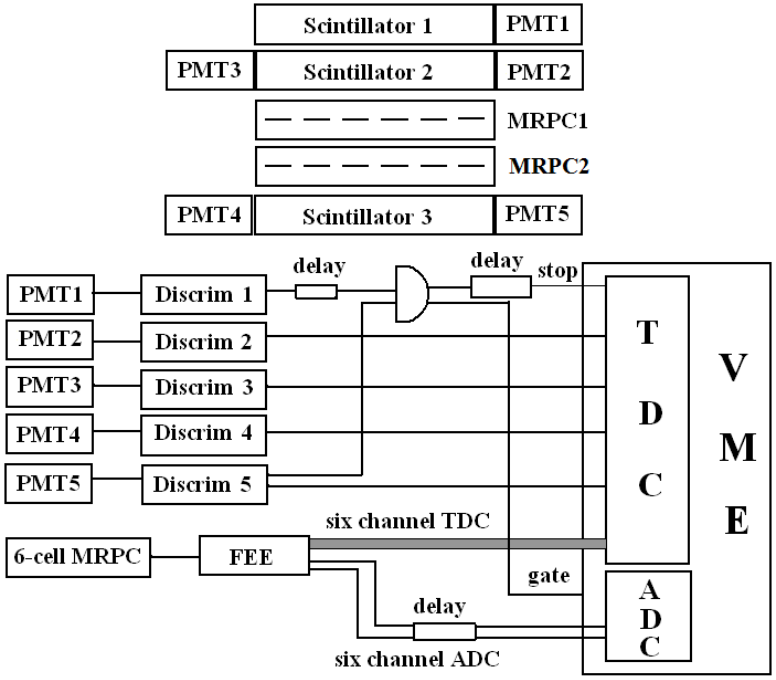


Procedures of construction and QC



6S criterion, ISO 9000 and 14000 standards are also carried out in MRPC production.

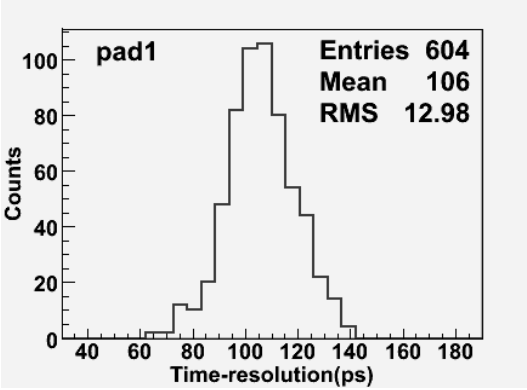
QC setup- cosmic ray testing system

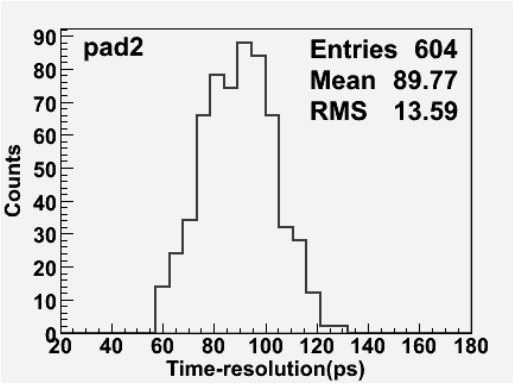


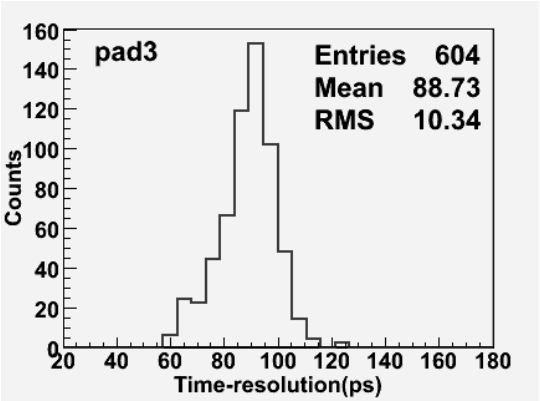
Time resolution testing system

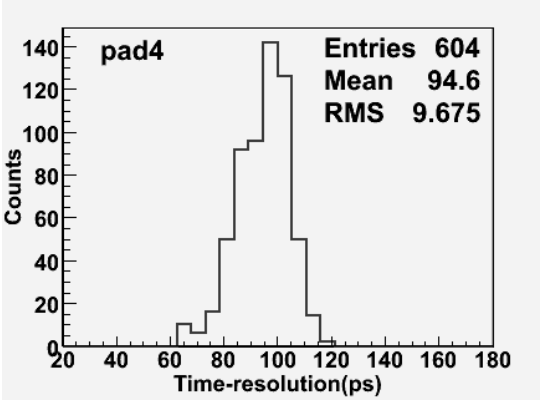
QC capability: 10 modules/day

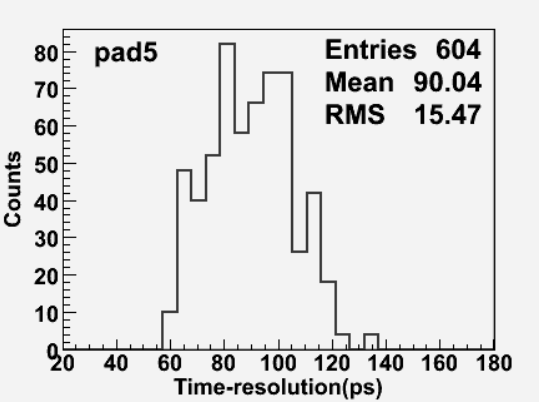
QC - Performance statistics
Time resolution of each pad

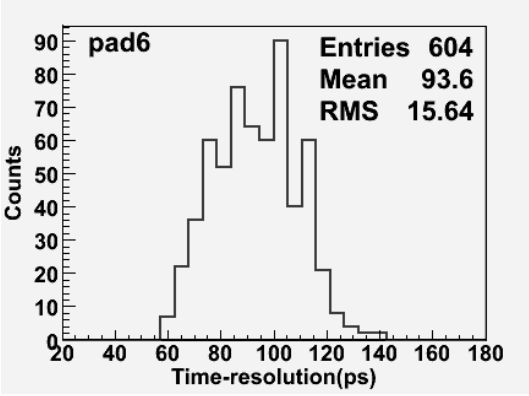


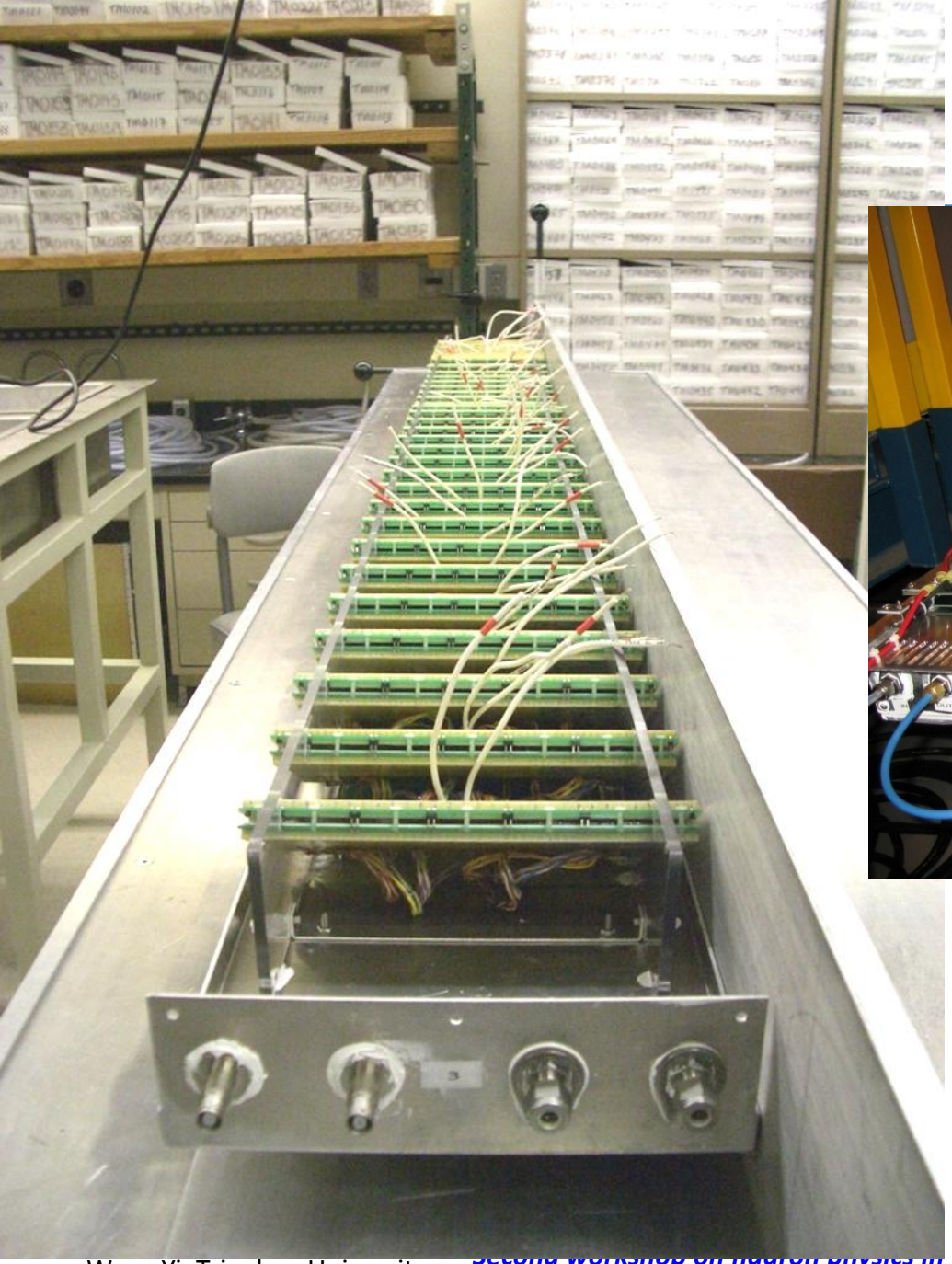


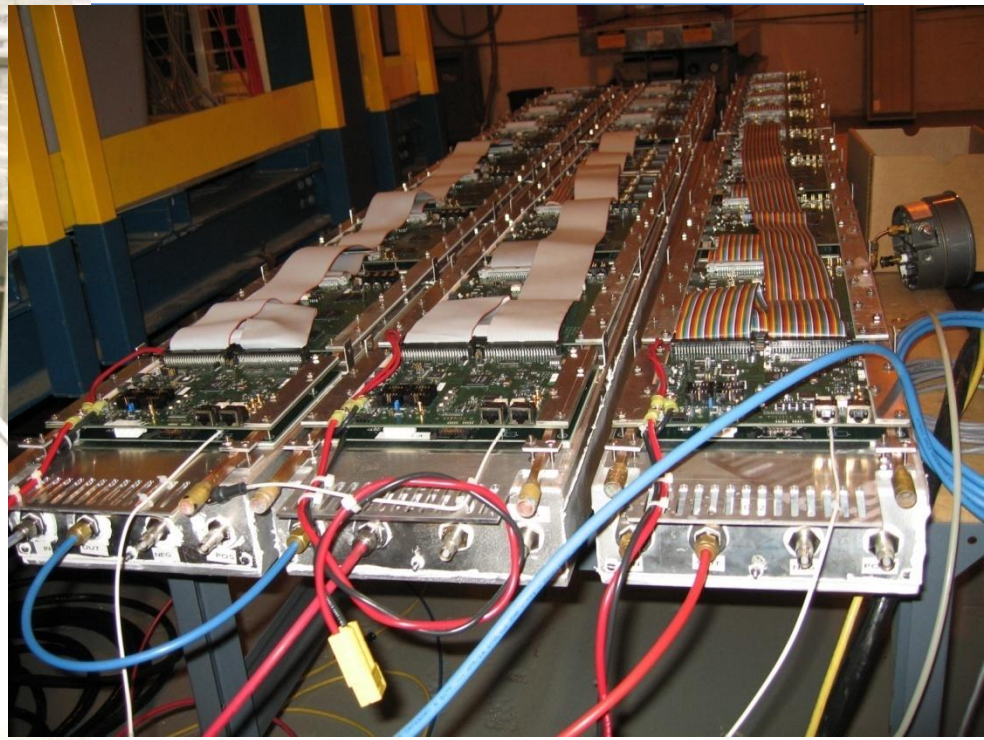




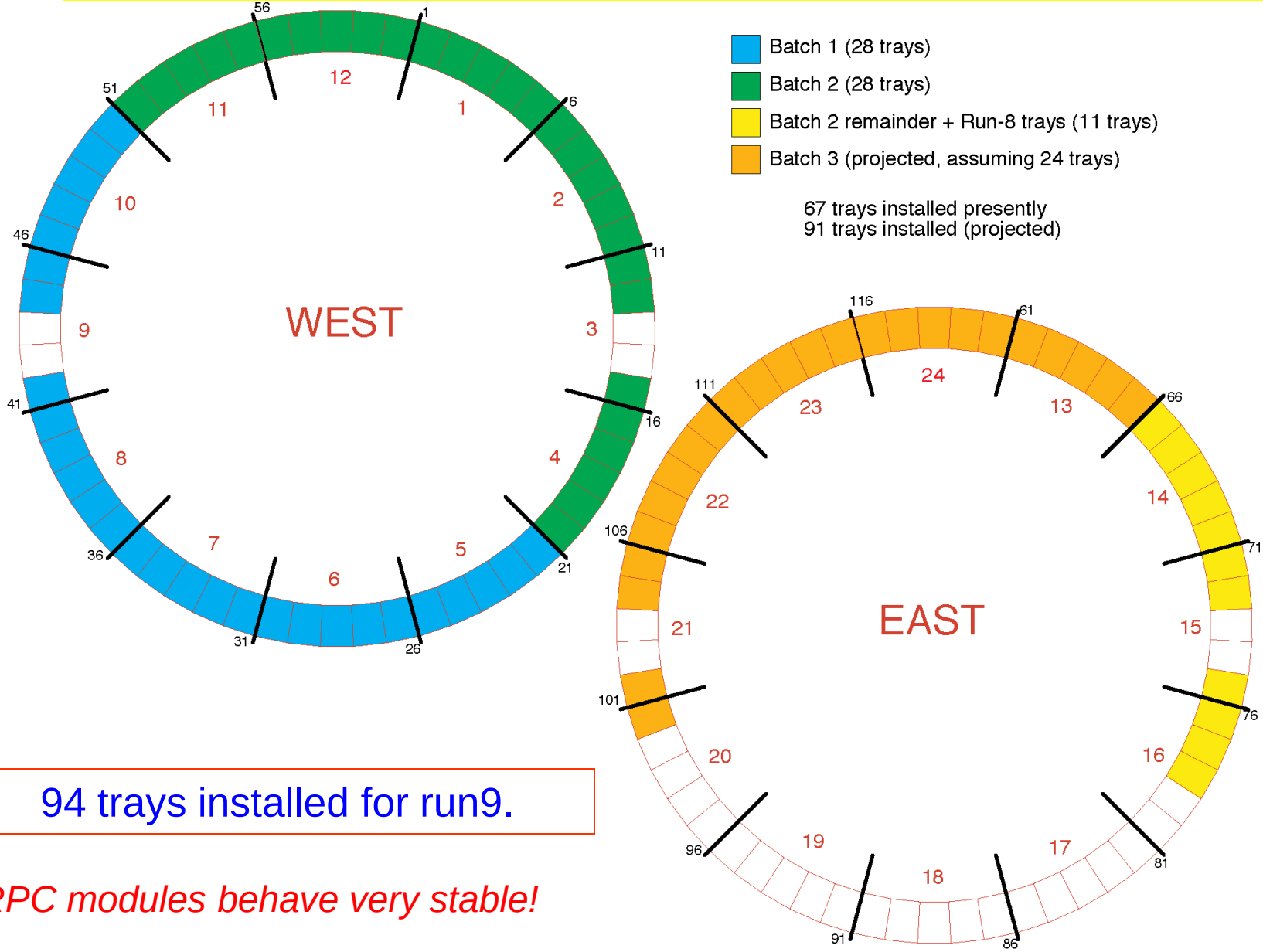








The Time of Flight System in Year 2009



- 94 trays installed for run9.

MRPC modules behave very stable!

Conclusions

- Development of 6-gap MRPC for STAR-TOF, time resolution<70ps, efficiency>95%
- 3100 MRPCs were assembled for STAR-TOF, yield>95%
- Development of low resistive glass with resistivity ~ $10^{10}\Omega$cm
- Development of pad- and strip- readout high rate MRPCs, rate capability>20kHz/cm^2, time resolution<80ps
- Application in Jefferson lab 12GeV project and NICA-MPD,…

Thank You!