Study on Cosmic Test and QC method of high-rate MRPC for CBM-TOF

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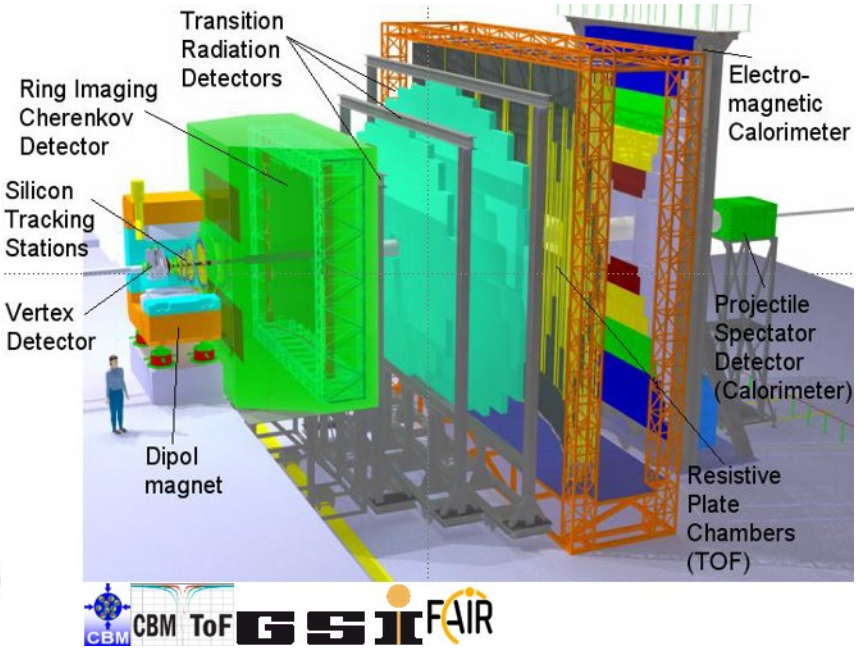
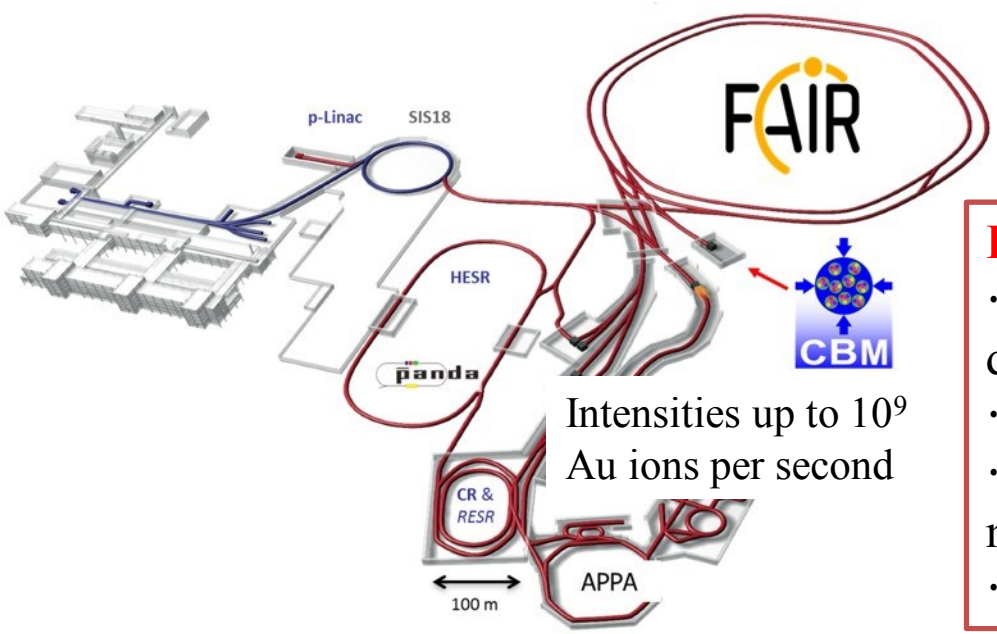
Outline

- Background Introduction
- QC method for mass production of high-rate CBM-TOF MRPC3a
- Test for the produced MRPC3a counters
  - HV test
  - Cosmic test
  - X-ray test
- The Next Working Steps
- Summary

Background Introduction: CBM TOF

In the near future, the **international Facility for Antiproton and Ion Research (FAIR)** in Darmstadt will become a unique research platform for exploring nuclear, hadron, atomic and plasma physics. The **CBM (Compressed Baryonic Matter) experiment** is one of the important experiments on FAIR.





Intensities up to 10^9 Au ions per second

Physics topics of CBM experiment:

· Equation-of-state of nuclear matter at densities close to core of neutron stars

· Properties of hadrons in a dense medium

· Phase transition from hadronic to partonic matter at high net-baryon densities

· …

Background Introduction: CBM TOF

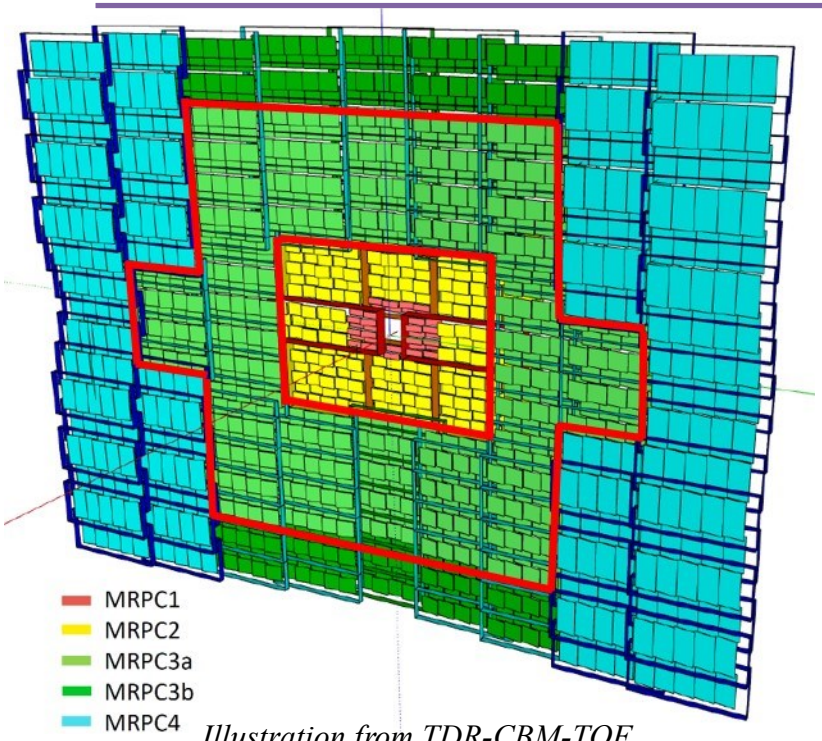


Illustration from TDR-CBM-TOF

MRPC3a (light green) is equipped with **low-resistive glass** aiming at higher rate region. It is the first time of the large scale application of these low-resistive glass MRPCs.

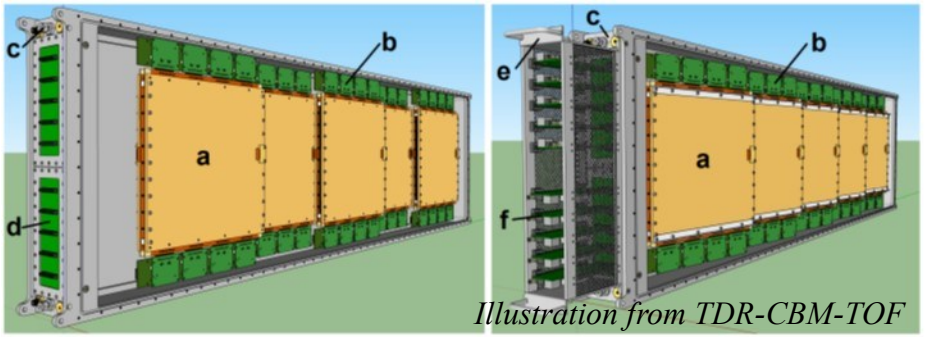
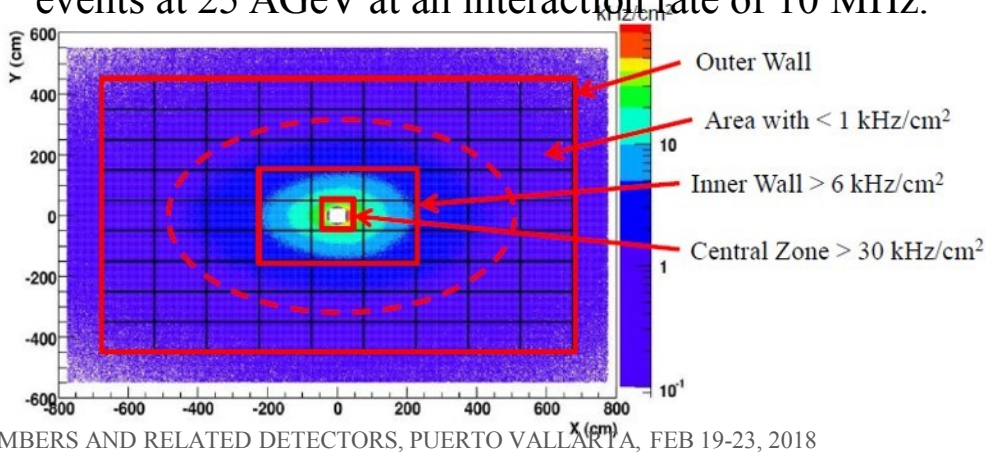


Illustration from TDR-CBM-TOF

A simulation of charged particle flux for Au+Au events at 25 AGeV at an interaction rate of 10 MHz.



CBM-TOF requirements:

Full system time resolution: < 80 ps

Efficiency: > 95%

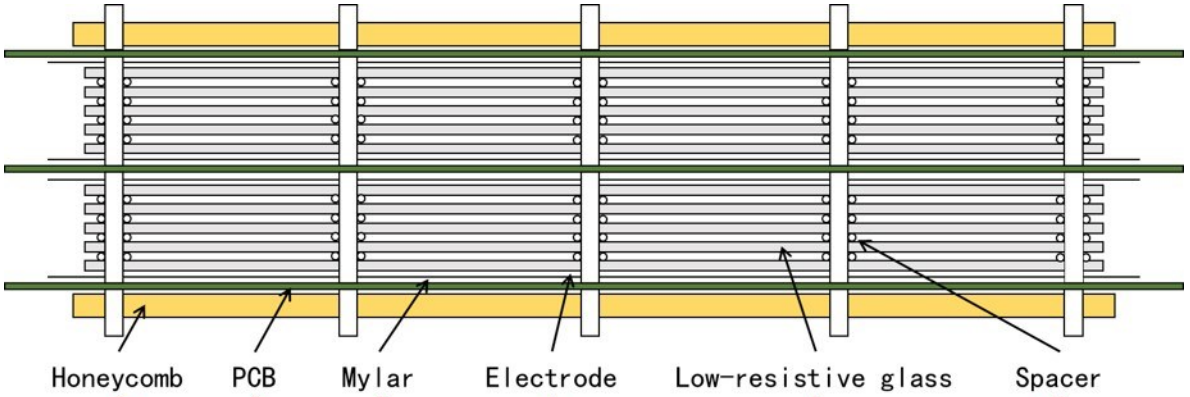
Rate capability: ~ 30 kHz/cm^2

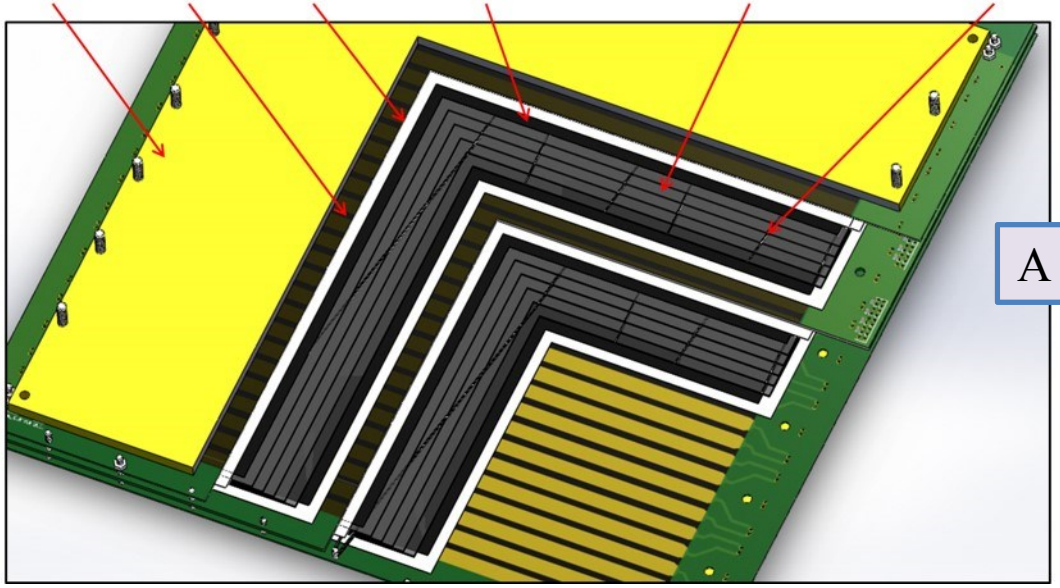
Occupancy: < 5%

Free streaming data acquisition

Background Introduction: MRPC3a

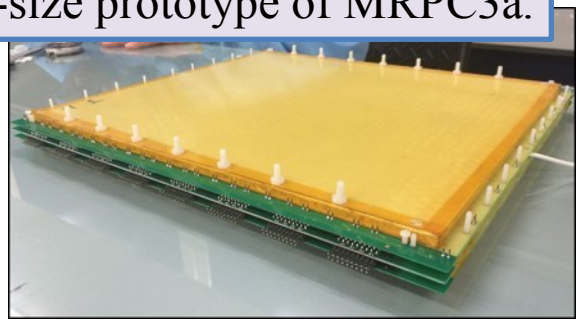
The structure and parameter of MRPC3a counter.





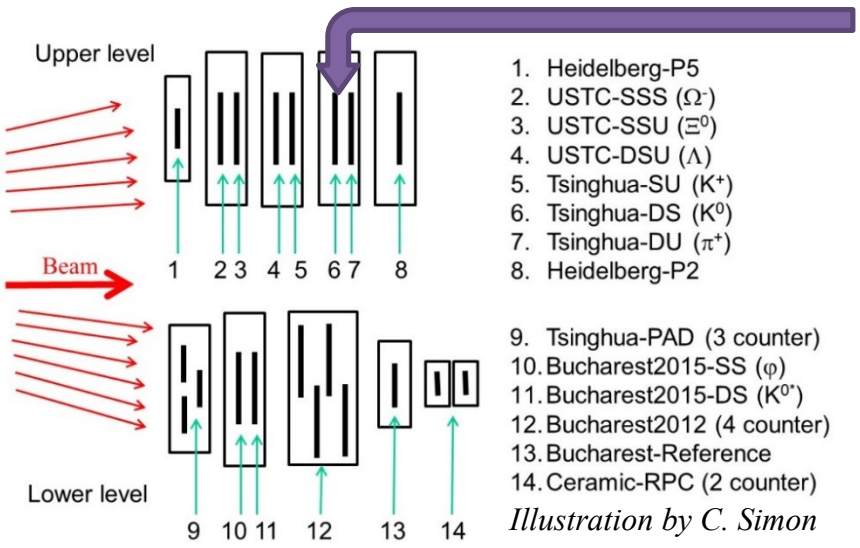
Parameter	Value
Dimension	360 × 338 mm²
Height	26 mm
Weight	3.3 kg
Glass dimension	330 × 276 mm²
Gas gap number	2 × 4
Gas gap width	0.25 mm
Strip pitch	7 + 3 mm
Strip length	270 mm
Strip number	32

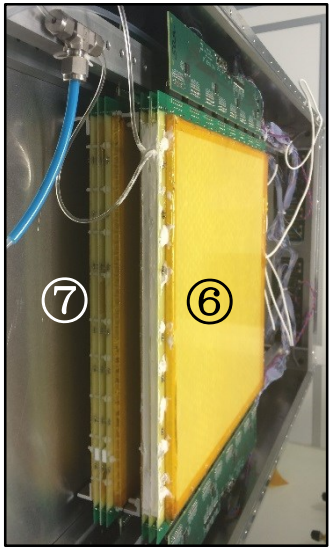
A real-size prototype of MRPC3a.



Background Introduction: MRPC3a

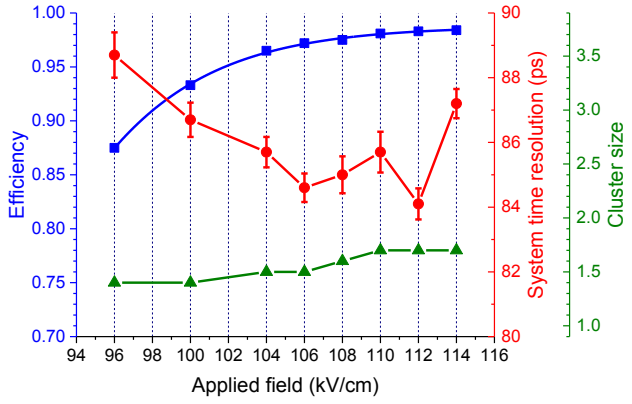
Performance of the MRPC3a prototype has been tested in SPS beamtest (Nov 2015).

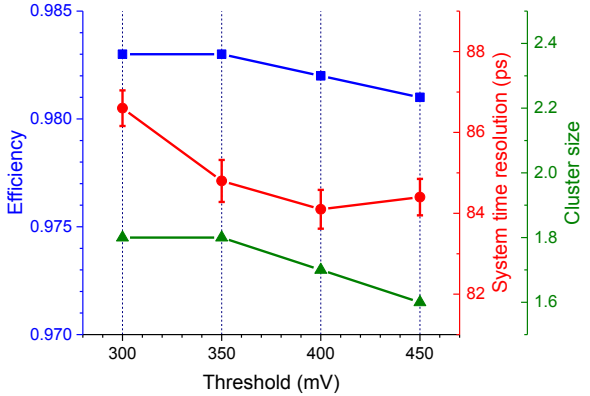




30 GeV Pb beam on 1mm/2mm/3mm Pb. Flux rate up to **10 kHz/cm²**.

A prototype of MRPC3a named THU-DU was put into STAR-box3 in upper level of the setup.



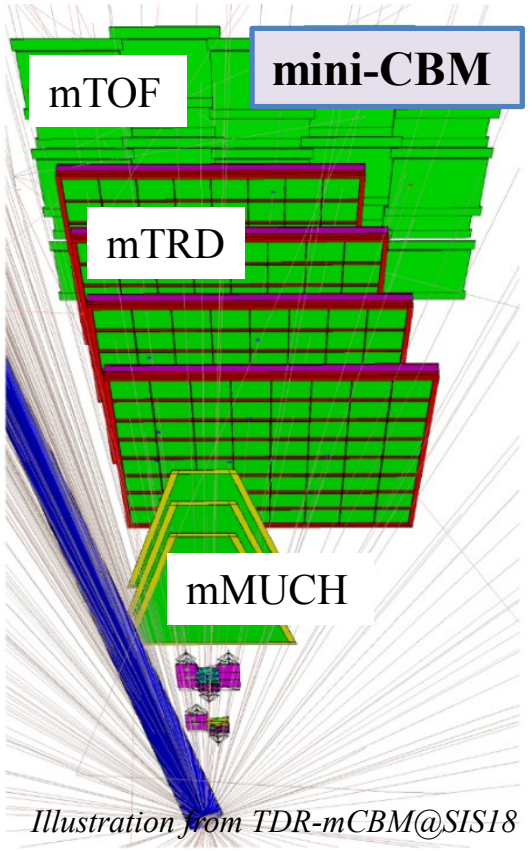


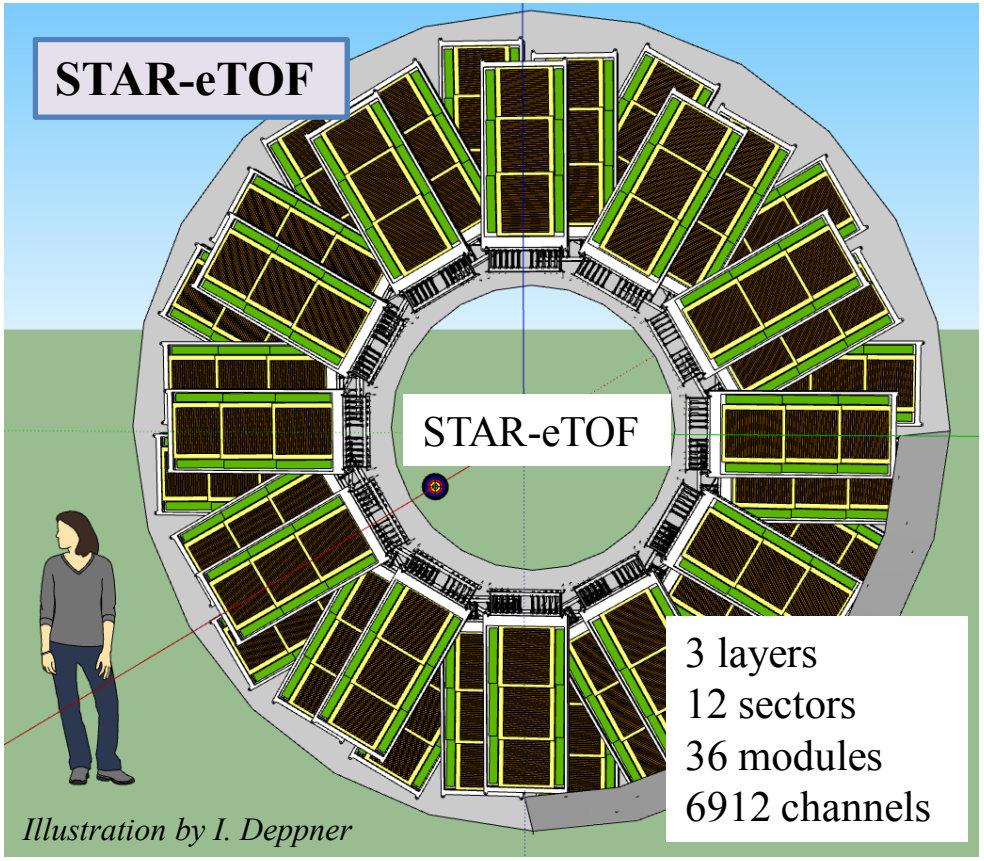
Performance in HV and threshold scan:

Time resolution: ~ 60 ps
Efficiency: > 98%
Cluster size: ~ 1.5

Background Introduction: Production

For TOF system of STAR-eTOF and mini-CBM in 2018, **73** MRPC3as are needed.





Install, commission and use 5 modules at mini-CBM.

Install, commission and use 10% of the CBM TOF modules at STAR/RHIC.

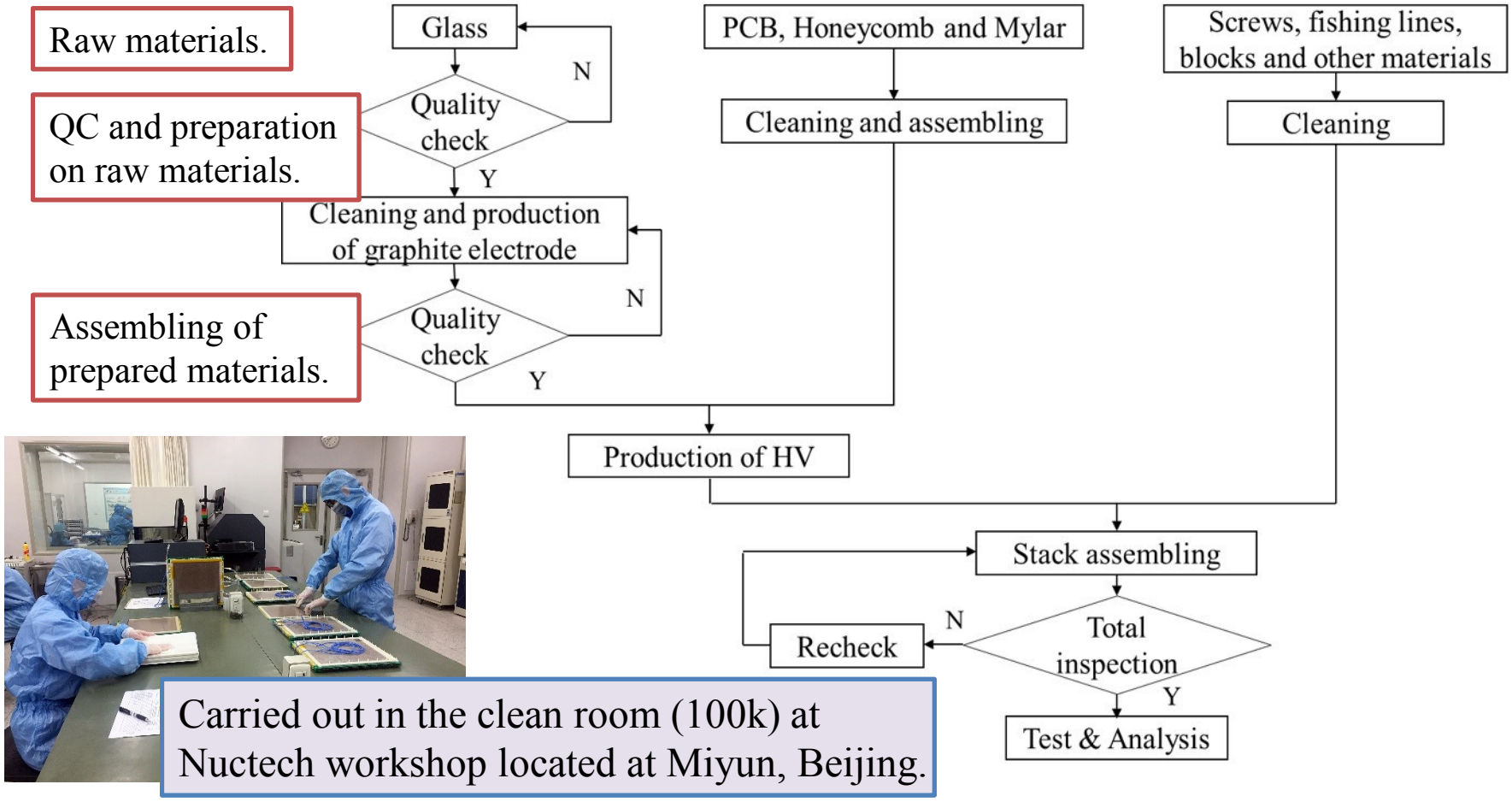
QC Method: Mass Production

A specified manufacturing procedure has been formulated to guarantee the performance of each counter.

Raw materials.

QC and preparation on raw materials.

Assembling of prepared materials.



Carried out in the clean room (100k) at Nuctech workshop located at Miyun, Beijing.

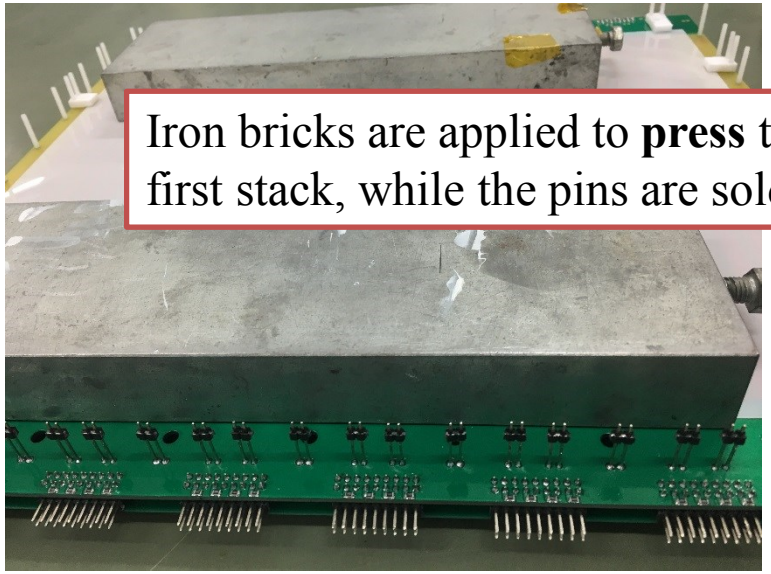
QC Method: Raw Materials

Quality check on raw materials should be done first before assembling process.

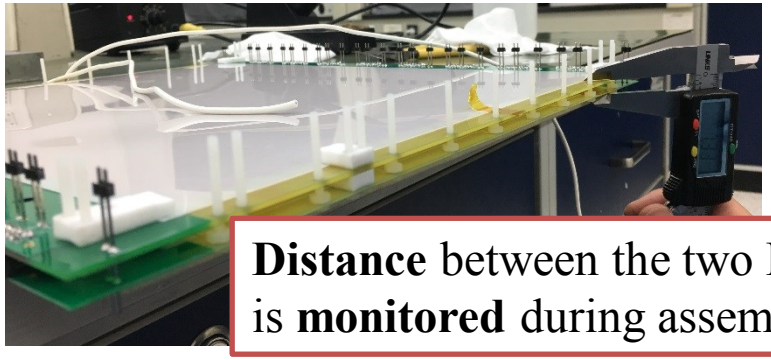
Material	Requirement	Measurement
Low-resistive glass	Dimension: 330 (± 0.2) × 276 (± 0.2) × 0.7 (± 0.02) mm^3	Micrometer screw caliper
	Defects: no visible scratch, fracture, and pinhole	Eye inspection in light
	Dark current: < 80 nA at 6000V	Test module for glass inspection
PCB board	Dimension: 360 (± 0.2) × 338 (± 0.2) × 0.8/1.6 (± 0.05) mm^3	Vernier caliper
	Defects: no visible scratch and spot	Eye inspection in light
	Quality: connection, no shortcut, 200 kΩ resistor	Voltmeter
Honeycomb board	Dimension: 333 (± 1) × 310 (± 1) × 6 (± 0.2) mm^3	Vernier caliper
	Defects: no visible scratch	Eye inspection in light
Mylar	Dimension: 340 (± 0.2) × 286 (± 0.2) × 0.25 (± 0.02) mm^3	Micrometer screw caliper
	Defects: no visible scratch and loophole	Eye inspection in light
Carbon tape	Height: 0.13 (± 0.02) mm	Micrometer screw caliper
	Surface resistance: ~ 100 kΩ/sq	Ohmmeter
Graphite electrode	Dimension: 324 (± 0.5) × 270 (± 0.5)	Vernier caliper
	Defects: no visible scratch and loophole	Eye inspection in light
	Surface resistance: < 10 MΩ/sq	Ohmmeter
Fishing line	Dimension: 330 (± 0.2) × 276 (± 0.2) × 0.7 (± 0.02) mm^3	Micrometer screw caliper

QC Method: Gas Gap Uniformity

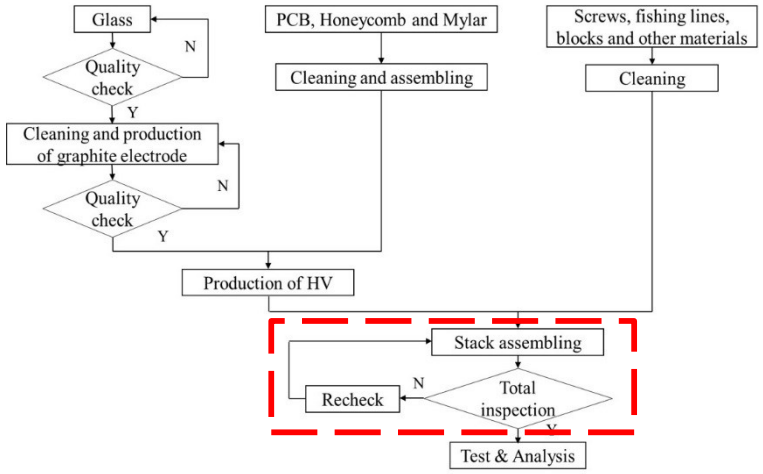
Gas gap uniformity is critical to MRPCs.



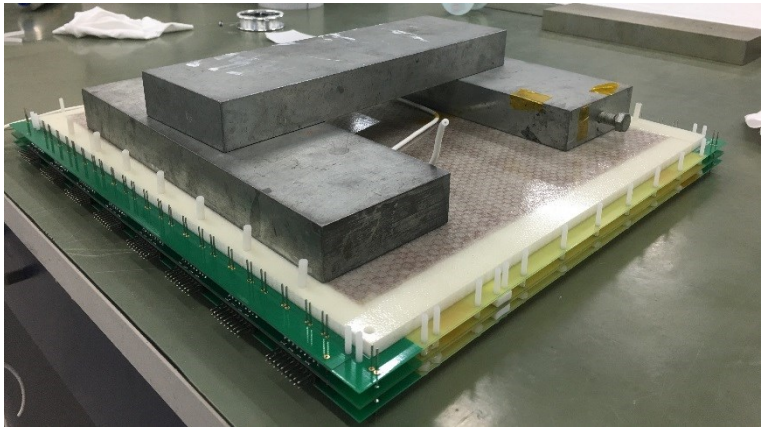
Iron bricks are applied to **press** the first stack, while the pins are soldered.



Distance between the two PCBs is **monitored** during assembling.



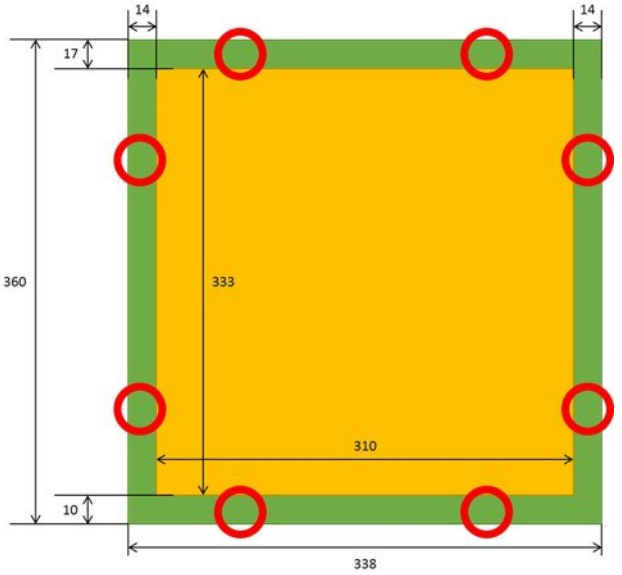
The same procedure is repeated when assembling the second stack.



QC Method: Gas Gap Uniformity

Thickness uniformity between each PCB has been measured at 8 points around the assembled counter.

The requirement is the thickness of two adjacent PCBs is within **±0.2 mm** of the nominal value.

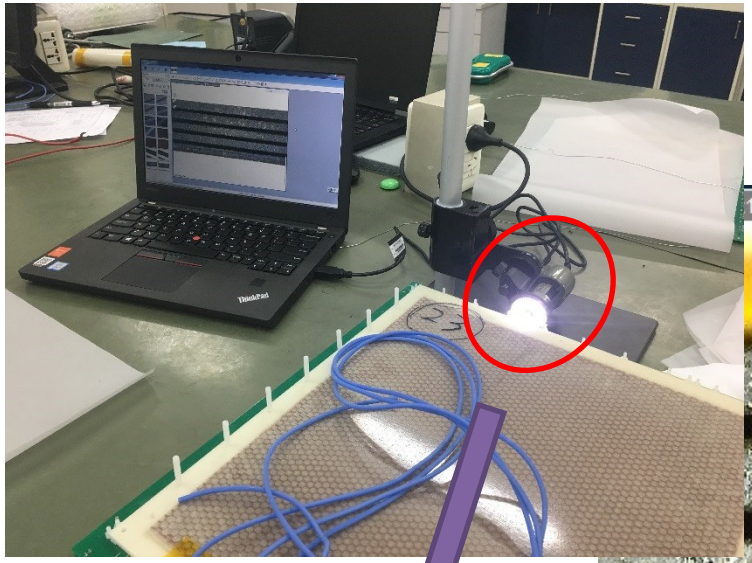


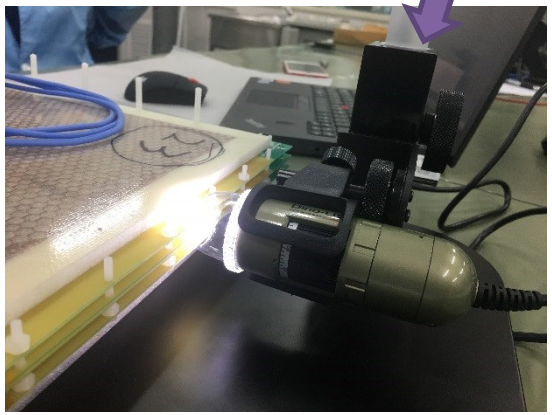
Measurement	Nominal/mm	Minimum/mm	Maximum/mm
Thickness between bottom and middle PCB (h1)	5.1	4.9	5.3
Thickness between top and middle PCB (h2)	5.1	4.9	5.3
Thickness between bottom and top PCB (h3)	11.8	11.5	12.1

MRPC3a -001	**h1**	4.89	4.94	4.74	4.79	4.65	4.81	4.87	4.95	**4.83 (mean)**
	h2	4.82	4.82	4.87	4.86	4.83	5.13	5.16	5.15	**4.96 (mean)**
	h3	11.65	11.62	11.48	11.53	11.27	11.43	11.43	11.52	**11.49 (mean)**
MRPC3a -002	**h1**	4.86	4.92	5.18	4.81	4.94	4.74	4.86	5.18	**4.94 (m**
	h3	4.9	5.03	5.03	4.64	5.23	5.08	4.73	4.86	**4.94 (m**
	h3	11.7	11.61	11.63	11.7	11.7	11.88	11.62	11.86	**11.71 (n**
MRPC3a -003	**h1**	5.05	5.06	5.25	4.96	5.12	5.03	5.09	5.04	**5.08 (m**
	h2	5.07	4.99	5.02	4.92	5.1	4.79	5.15	5.03	**5.03 (m**
	h3	11.75	11.64	11.63	11.82	11.68	11.63	11.74	11.69	**11.69 (n**

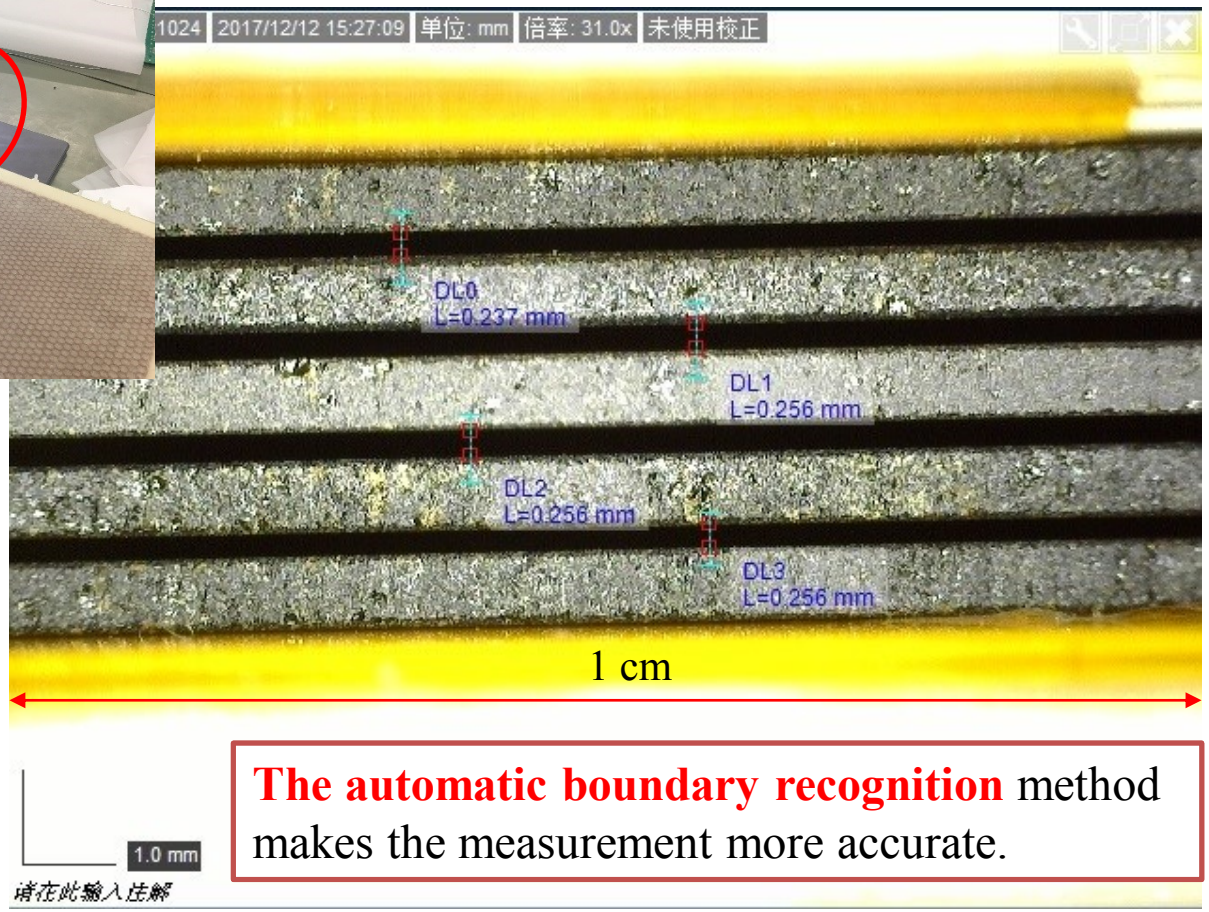
The distance measured at the edge is not absolutely equal to the thickness in glass & gap region, but it could be a reference.

QC Method: Gas Gap Uniformity





A **digital microscope** is used to observe and measure the gas gap width directly.



The automatic boundary recognition method makes the measurement more accurate.

QC Method: Statistic Results

Quality control results throughout the assembling procedure is recorded.

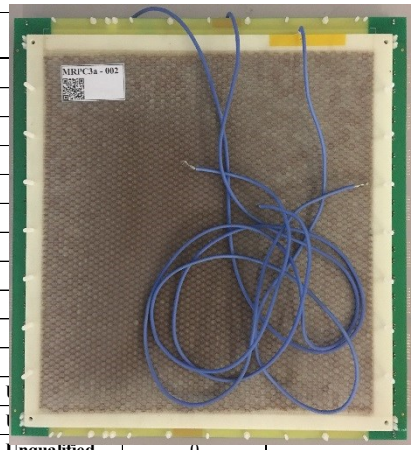
MRPC3a Quality Assurance Table								
MRPC ID	MRPC3a - 35							
Glass	**Glass Batch No.**			12# 151219	**Amount**			6
	Glass Batch No.			24# 151219	**Amount**			4 (electrode)
	Glass Batch No.				**Amount**			
Electrode	**Surface Resistance (MΩ/sq)**			**Point 1**	**Point 2**	**Point 3**	**Point 4**	**Point 5**
	Electrode 1			7	5	5	7	7
	Electrode 2			5	10	5	3	7
	Electrode 3			4	3	5	3	3
	Electrode 4			10	7	2	5	5
Honeycomb	√							
Top & Bottom PCB	√							
Middle PCB	**Protection Resistor**		**Resistance Measured on Outside Resistor**			√	**Unqualified**	0
			Resistance Measured on Inside Resistor			√	**Unqualified**	0
	Connector		**Thickness of the connectors**			√	**Unqualified**	0
Mylar	√							
Top & Bottom HV	√							
Middle HV	√							
Spacer	√							
Thickness	**Point 1**	**Point 2**	**Point 3**	**Point 4**	**Point 5**	**Point 6**	**Point 7**	**Point 8**
Between Top & Bottom PCB	11.92	11.91	12	11.88	11.98	11.78	11.04	11.06
Between Top & Middle PCB	5.05	5.2	5.03	5.06	5.2	5.03	5.04	4.95
Between Bottom & Middle PCB	5	4.91	4.88	5.07	5.08	5.08	5.04	5.03
Total Thickness	26.35	26.53	26.17	26.26	25.81	25.89	26.25	25.76
Gas Gap Thickness	**Bottom Stack**				**Top Stack**			
	Gas Gap 1	**Gas Gap 2**	**Gas Gap 3**	**Gas Gap 4**	**Gas Gap 5**	**Gas Gap 6**	**Gas Gap 7**	**Gas Gap 8**
	0.276	0.237	0.256	0.256	0.256	0.256	0.276	0.256
	0.276	0.256	0.256	0.276	0.237	0.256	0.276	0.276
	0.256	0.256	0.276	0.256	0.276	0.276	0.276	0.276
	0.256	0.256	0.237	0.256	0.276	0.276	0.276	0.256
Signature	王永亮							
Date	2017-12-1							
Note								

QC Method: Statistic Results

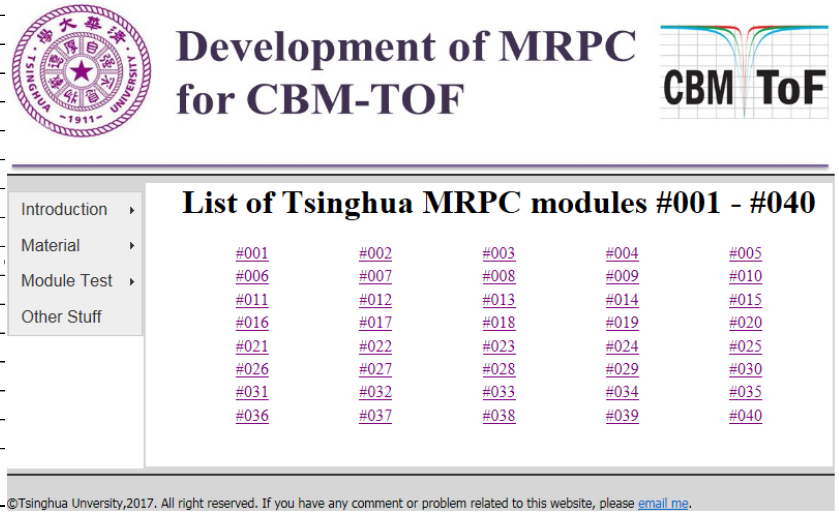
Quality control results throughout the assembling procedure is recorded.

Detailed information can be found by scanning the **QR code** on it.

Electrode	Surface Resistance (MΩ/sq)					
	Electrode 1					
	Electrode 2					
	Electrode 3					
	Electrode 4					
Honeycomb						
Top & Bottom PCB						
Middle PCB	Protection Resistor	Resistance Mea				
		Resistance Me				
	Connector	Thickness of the connectors		√	Unqualified	0
Between Bottom & Middle PCB	5	4.91	4.88			
Total Thickness	26.35	26.53	26.17			
Gas Gap Thickness	Bottom Stack					
	Gas Gap 1	Gas Gap 2	Gas Gap 3			
	0.276	0.237	0.256			
	0.276	0.256	0.256			
	0.256	0.256	0.276			
	0.256	0.256	0.237			
Signature						
Date						
Note						

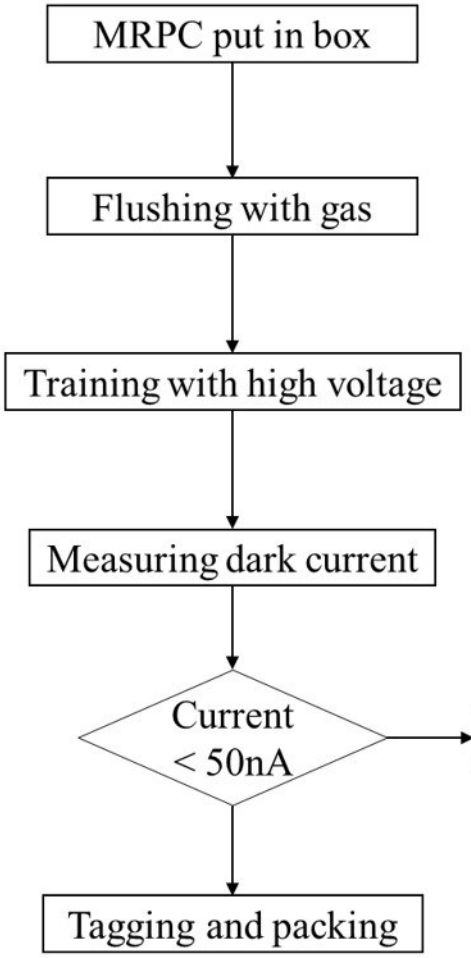


A website is developed to record all the QR information of each produced counter: http://hepd.ep.tsinghua.edu.cn/CBM_TOF/



MRPC3a Test: HV Test

All these produced MRPC3a counters should be examined with **HV** first.



The working gas is **90% $C_2H_2F_4$, 5% i-C_4H_{10} and 5% SF_6**. The flushing time is 60 hours (determined by 3 times of the gas box volume 72 L and gas flow 3.6 L/h).

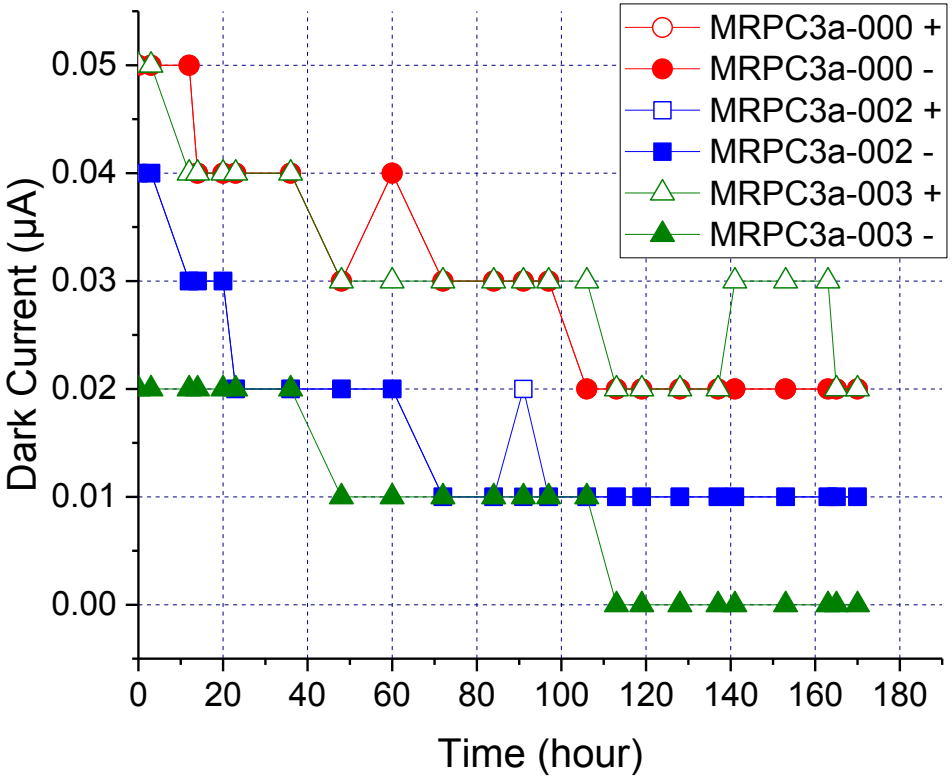
The counter should be trained **10 hours at the nominal voltage** of 5600V.

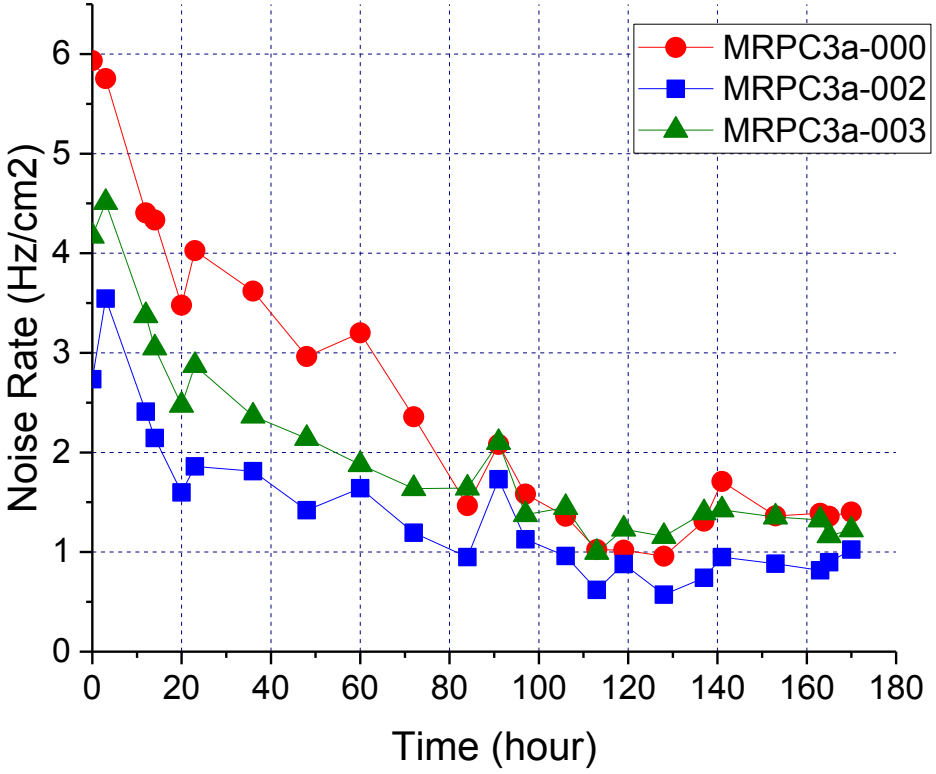
Dark current read out from HV crate should be **no more than 50 nA**, otherwise, it will be disassembled to look for the reason.

The qualified counters are ready for cosmic test.

MRPC3a Test: HV Test

The **dark current** and **noise rate** of 3 MRPC3a counters monitored in 170 hours since HV training to nominal voltage of ±5600 V.



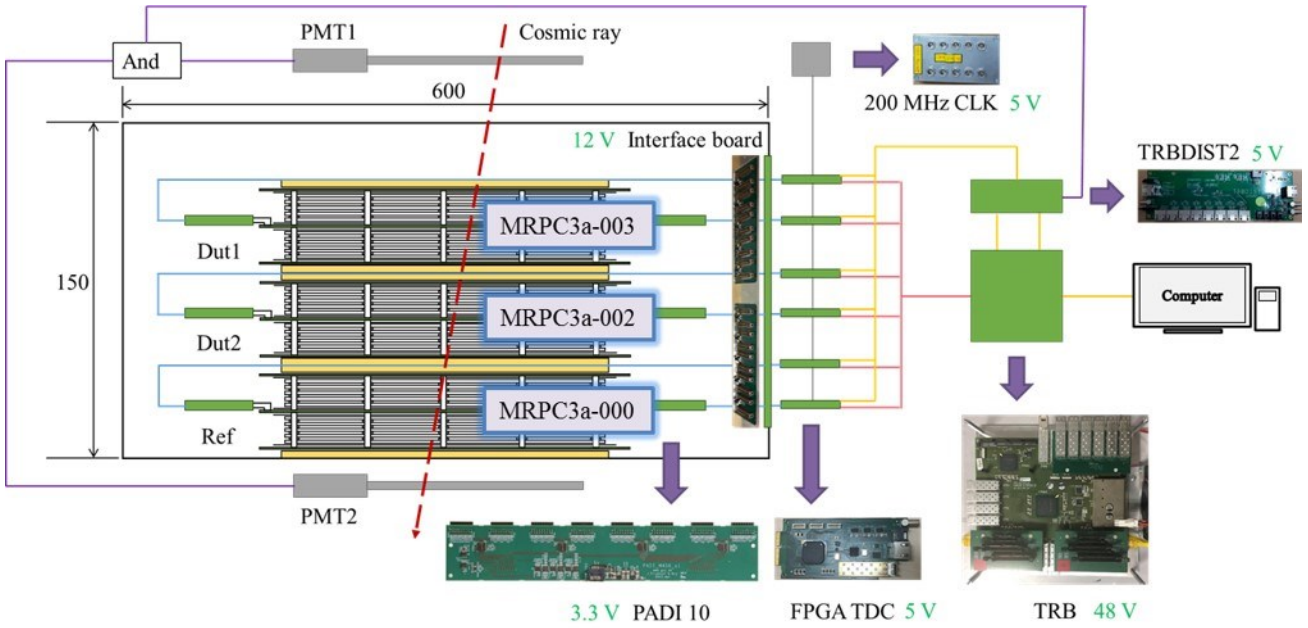


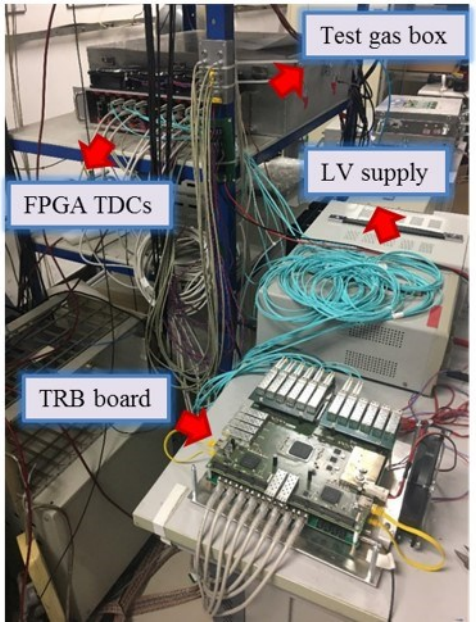
Dark current < 50 nA √

Noise rate around 1 Hz/cm²

MRPC3a Test: Cosmic Test

Part of these counters are tested with cosmic-ray based on a system composed of **TRB board**, **FPGA TDC** and **PADI10 front-end electronics**.





LEMO cable
Readout flat cable
CAT6 cable
Optical fiber

Testing conditions	Specification	Requirement
Working gas: 90% $C_2H_2F_4$, 5% i-C_4H_{10} and 5% SF_6	Dark current	< 50 nA
	Efficiency	> 95%
HV: 5500 V	System time resolution	< 125 ps
PADI threshold: 350 mV	Cluster size	< 2

Requirements of cosmic test.

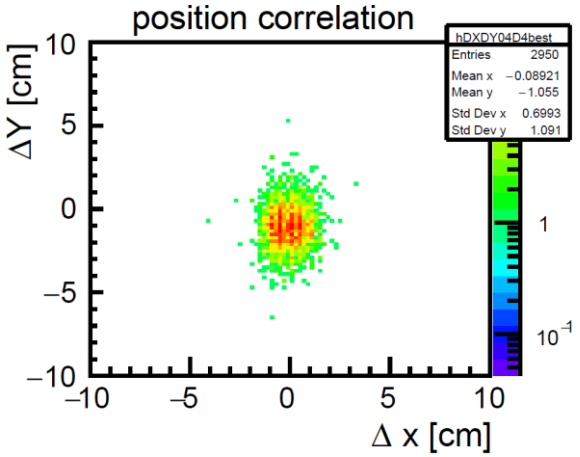
MRPC3a Test: Cosmic Test

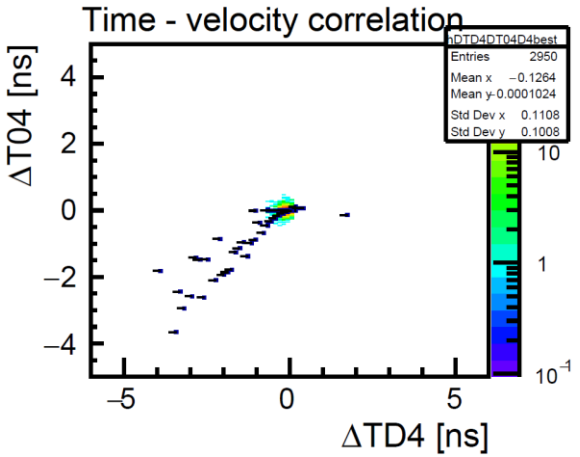
The test results are obtained through a modified CBM-Root analysis macro.

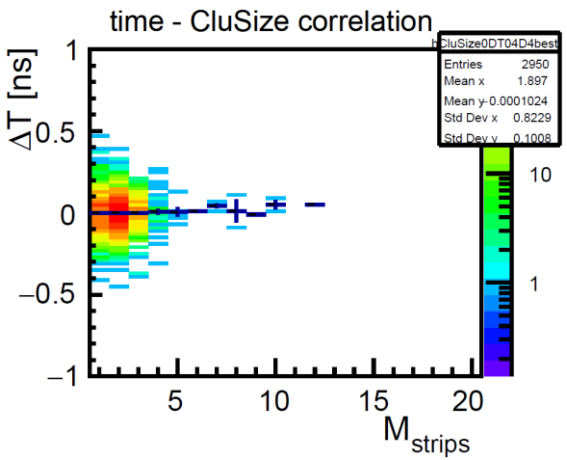
Unpacking
- create_calib.C
- apply_calib.C

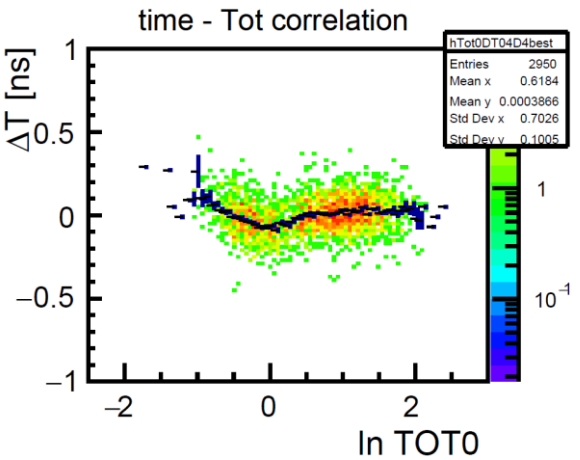
Calibration
- init_calib_digi.sh
- iter_calib_digi.sh
- gen_calib_digi.sh

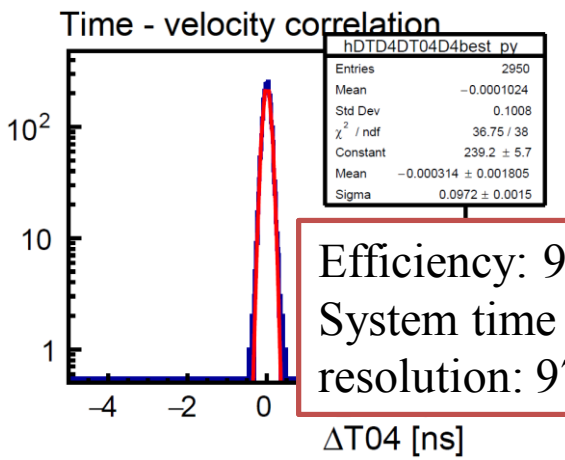
Analysis
- iter_ana_hits.sh







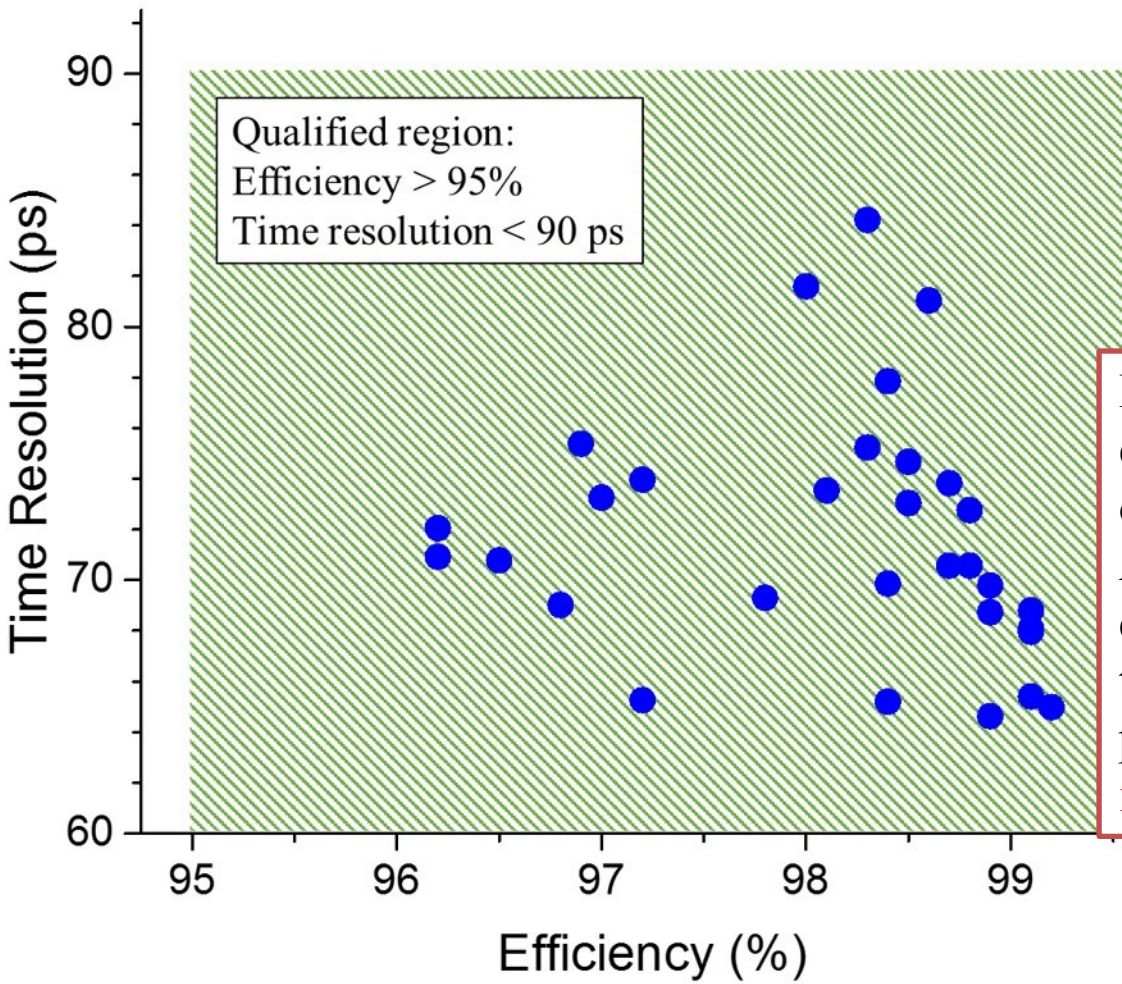




Efficiency: 98%
System time resolution: 97 ps

MRPC3a Test: Cosmic Test

The distribution of the analyzed **efficiency** and **time resolution** of 30 counters.

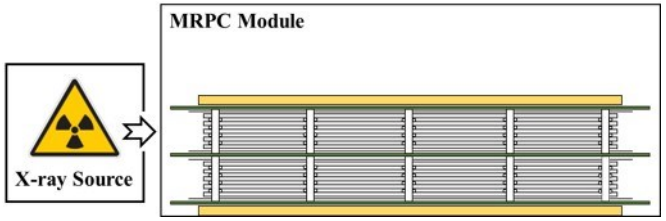


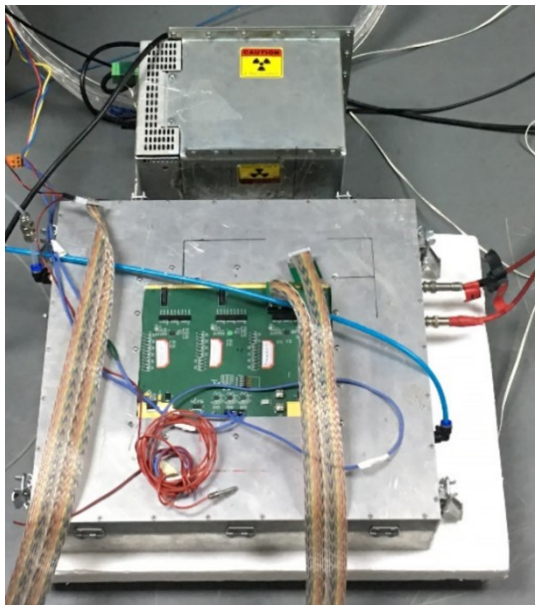
Each spot reprsents the efficiency and time resolution of one produced counter.
All the points are in the qualified region, and most of the counters show a stable performance of **70 ps time resolution** and **98% efficiency**.

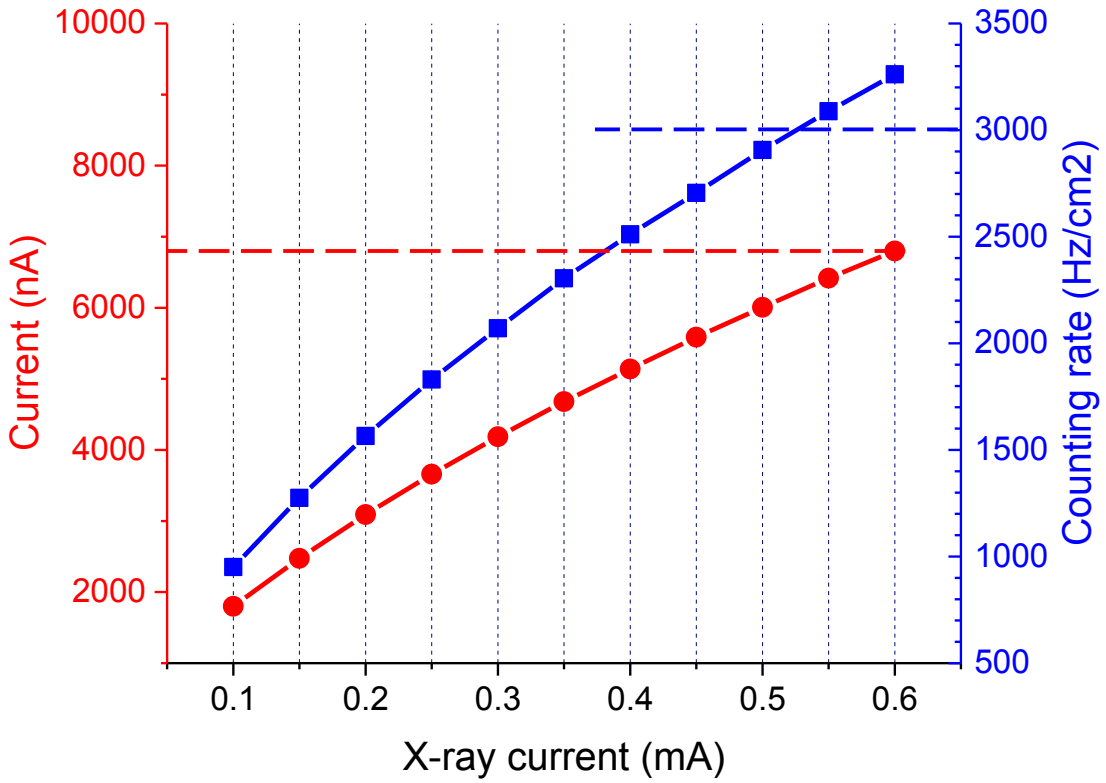
MRPC3a Test: X-ray Test

The X-ray test is conducted to confirm the counter's **rate ability**.

X-ray injects from side.



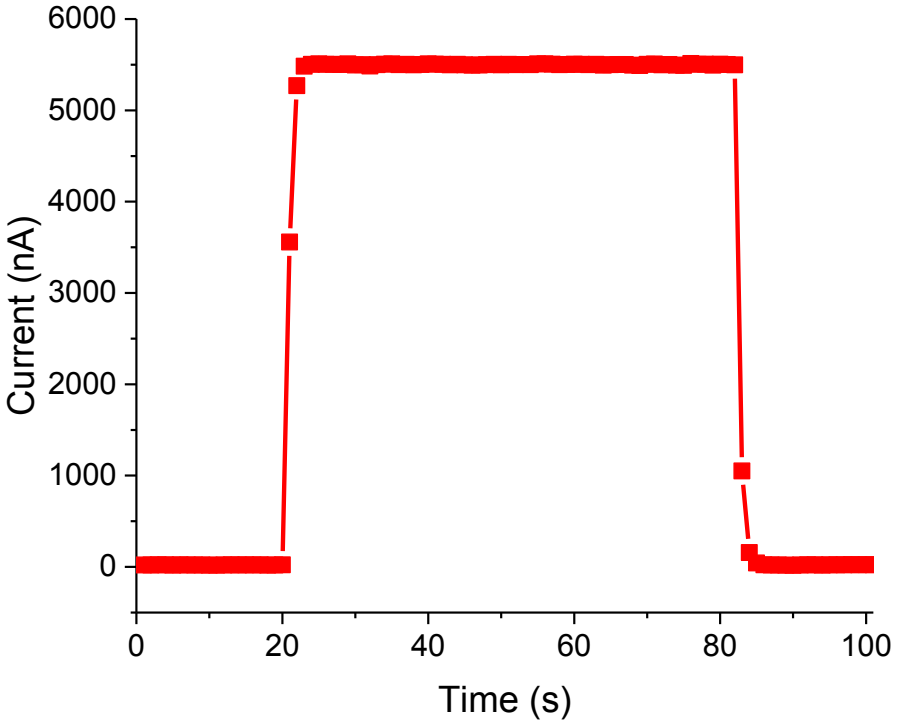


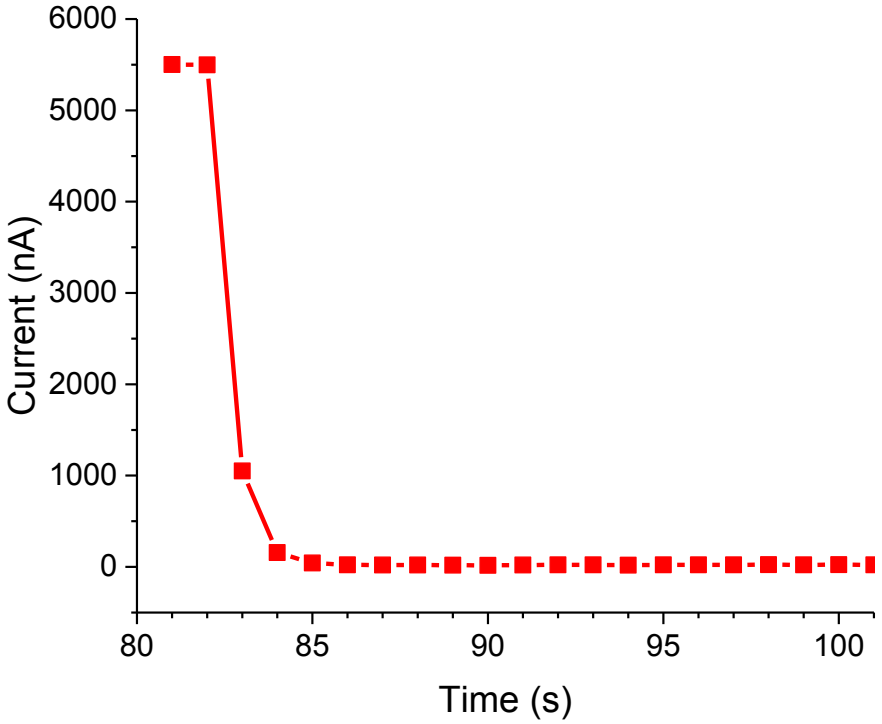


Dark current and counting rate as a function of X-ray current at the voltage of 35 kV.

MRPC3a Test: X-ray Test

The current throughout the test is recorded to study the **restoring ability**.

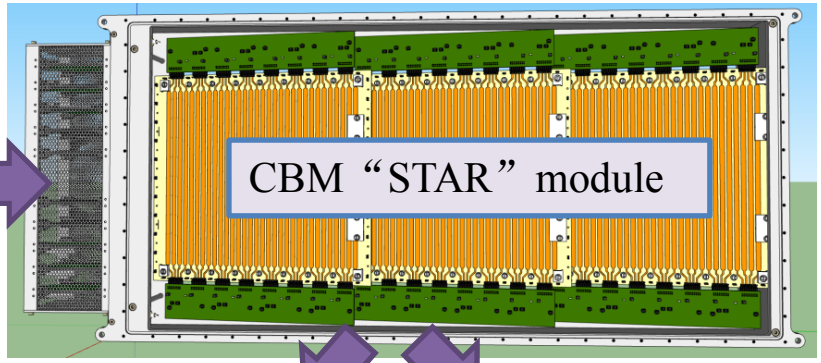




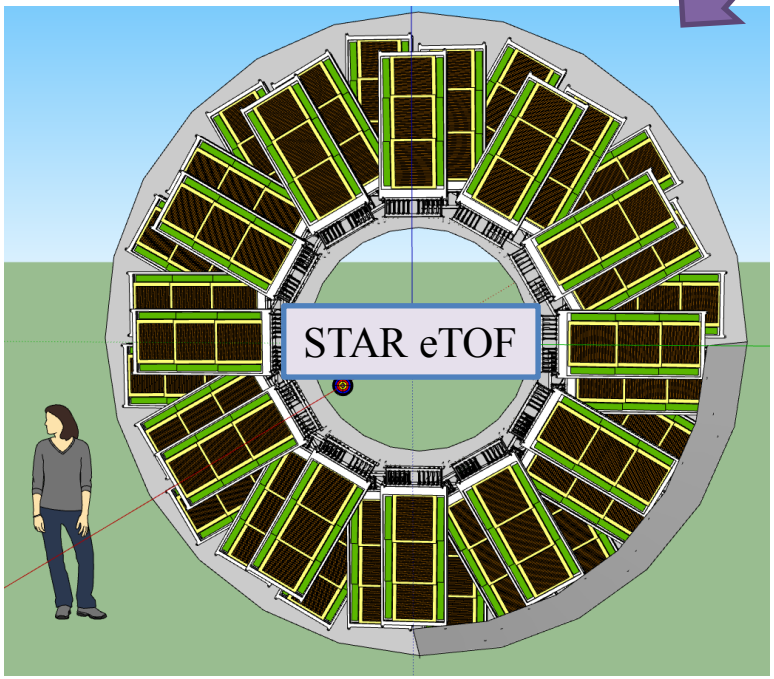
The X-ray irradiates from 20s to 80s.

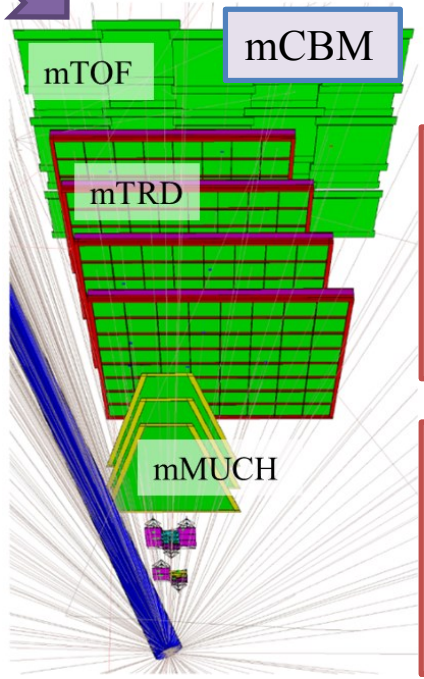
It only costs about 3s for the MRPC's current to restore to base level.

Next Working Steps



Until now, the 73 MRPC3a counters have been produced and passed the HV test. They will be shipped to Heidelberg University and installed into STAR modules there.





They will compose STAR-eToF and the ToF system at mini-CBM in the following 2018 runs.

The next step of the MRPC mass production in Tsinghua is expected to continue at the beginning of 2019.

Summary

- CBM-TOF will first time apply the low-resistive glass MRPCs in a large scale. It is important to study on the production and test procedure in mass production.
- A specified quality control method, including the scope imaging technique, has been developed.
- The HV test has been conducted to all the MRPCs.
- The cosmic test based on TRB system shows a stable performance of above 95% efficiency and below 90 ps time resolution to all the tested counters.
- 73 MRPC3a counters have been produced, and they will compose STAR-eToF and the ToF system at mini-CBM in the following 2018 runs.

Thank You!

- Lyu Pengfei
- Department of Engineering Physics,
- Tsinghua University, Beijing, China

- Feb 19~23, 2018
- 14th RPC Workshop

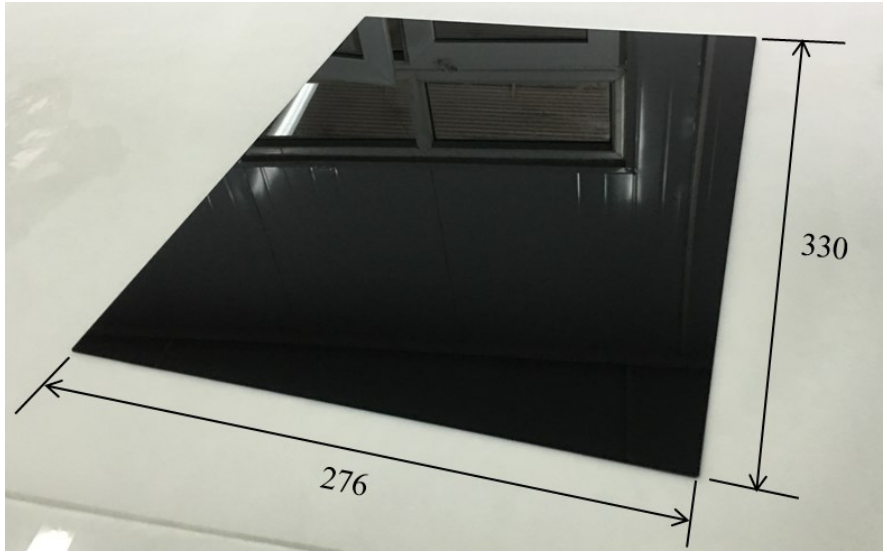
Back up

Materials for one MRPC3a counter

Material	Length/mm	Width(Diameter)/mm	Thickness(Height)/mm	Quantity	Description
Low-resistive glass	330 ± 0.2	276 ± 0.2	0.7 ± 0.02	10	~ 2×10^{10} Ωcm
HV graphite spray	324 ± 0.5	270 ± 0.5	0.005	4	< 10 MΩ/sq
Top PCB	360 ± 0.2	338 ± 0.2	0.8 ± 0.05	1	
Bottom PCB	360 ± 0.2	338 ± 0.2	0.8 ± 0.05	1	
Middle PCB	360 ± 0.2	328 ± 0.2	1.6 ± 0.05	1	
Protective resistor	/	/	/	128	200 kΩ, 0603
Honeycomb	333 ± 1	310 ± 1	6 ± 0.2	2	
Block A	23 ± 0.2	10 ± 0.2	4 ± 0.05	8	PTFE
Block B	14 ± 0.2	10 ± 0.2	4 ± 0.05	4	PTFE
Mylar	340 ± 0.2	286 ± 0.2	0.25 ± 0.02	8	
HV cable	1000	3	/	3	
Fishing line	26000	0.25 + 0.005	/	/	
M2.5 screw (nut)	40	2.5	/	32	Nylon
M4 screw (nut)	40	4	/	16	Nylon
2 × 9 connector	/	/	/	16	
Pin	19	0.6	/	100	
Carbon tape	50	50	0.13 ± 0.02	/	~ 100 kΩ/sq

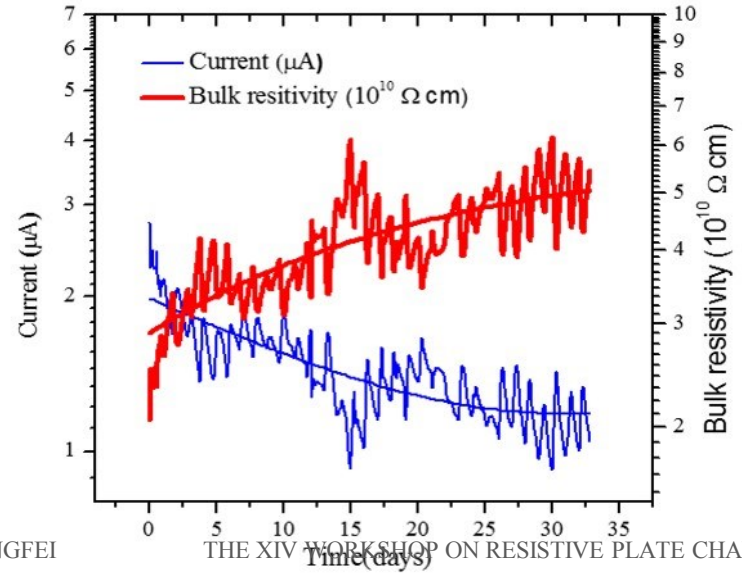
CAF4 for isolating, copper foil for HV making, absolute ethanol for cleaning are not included in this list.

Materials: Low-resistive Glass*



Specification of the **low-resistive glass** developed by Tsinghua University for CBM ToF detector.

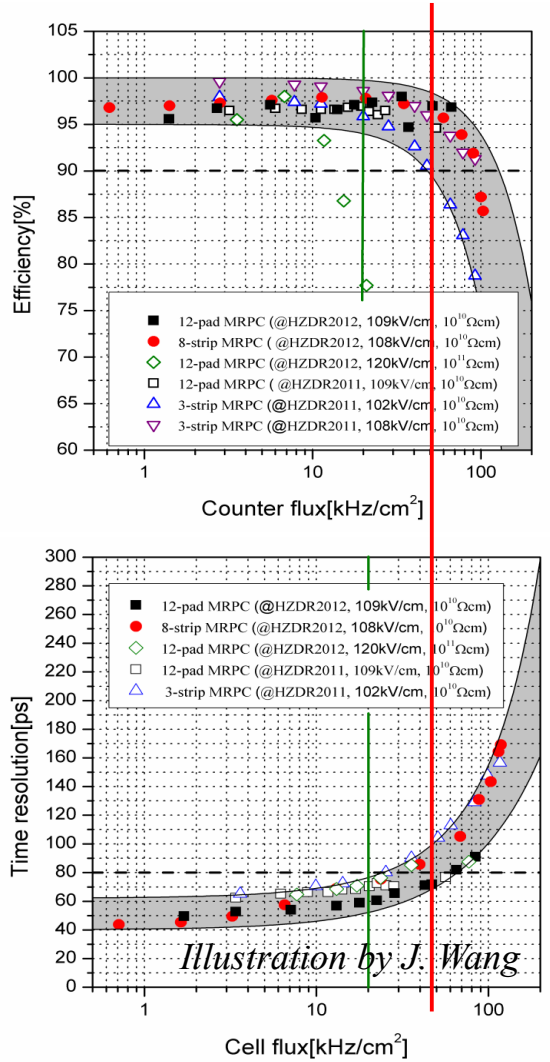
Parameter	Value
Dimension	330 × 276 mm^2
Standard thickness	0.7 mm
Thickness uniformity	< 20 μm (5 μm typical)
Bulk resistivity	10^{10} Ωcm
Surface roughness	< 10 nm
Dielectric constant	7.5 ~ 9.5
DC measurement	Ohmic behavior Stable up to 1 C/cm^2



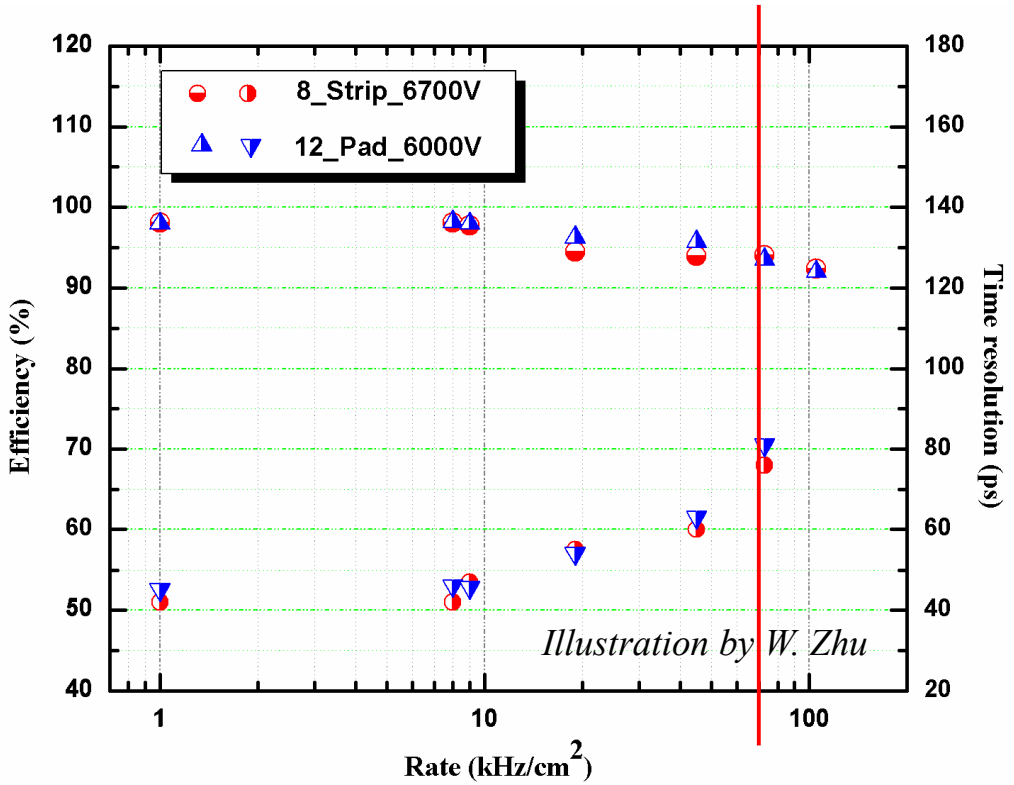
Long term stability of low-resistive glass:
The accumulated charge was **1 C/cm^2** after a 34-day test, roughly corresponding to the CBM life-time over 5 year operation at the maximum particle flux of about 20 kHz/cm^2. An increase of the bulk resistivity is **a (tolerable) factor of 2**.

Materials: Low-resistive Glass*

Rata ability

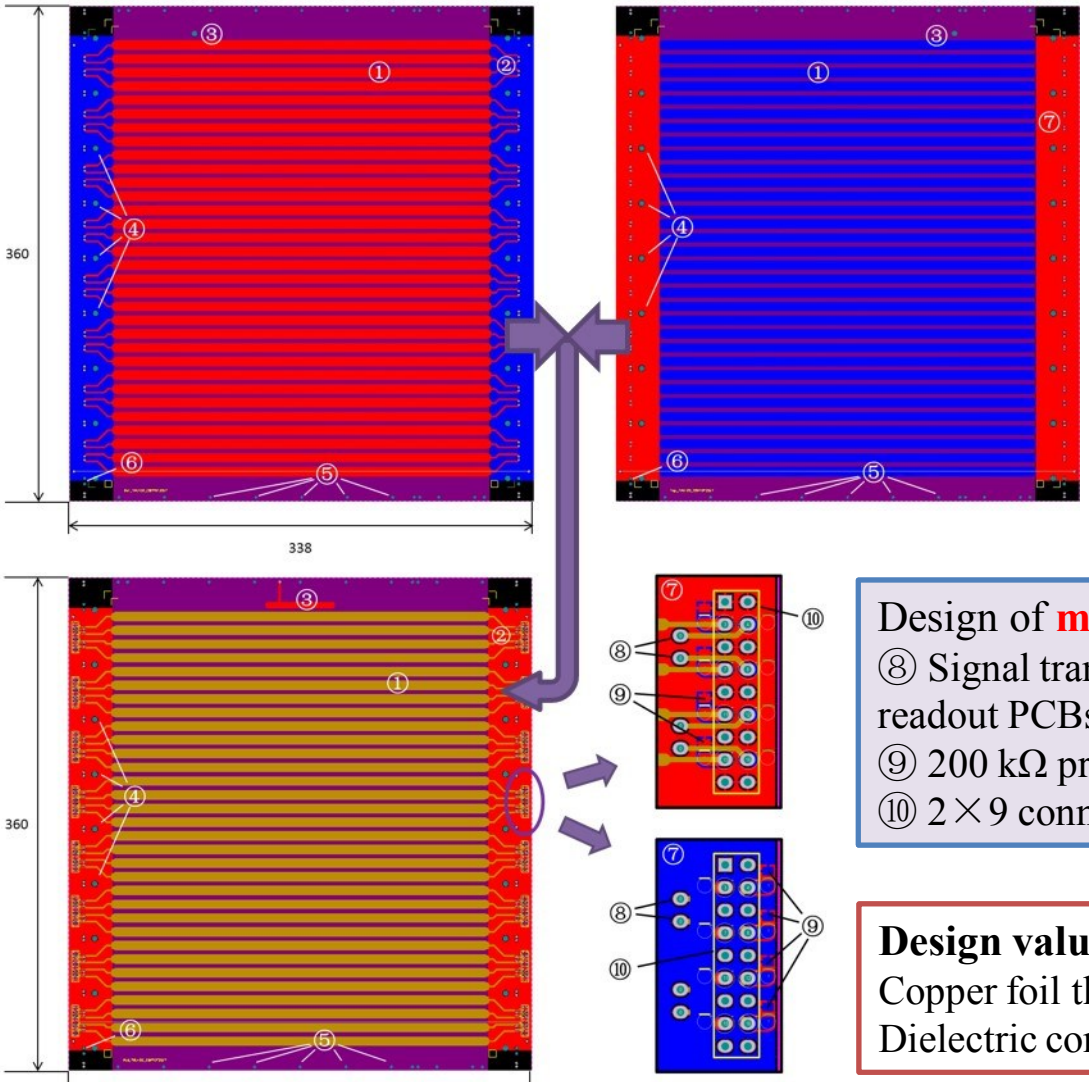


Test results in ELBE and Dubna



At a flux rate of **70 kHz/cm^2**, the efficiency is still above **90%**, the time resolution is around **80 ps**.

Materials: PCB Board



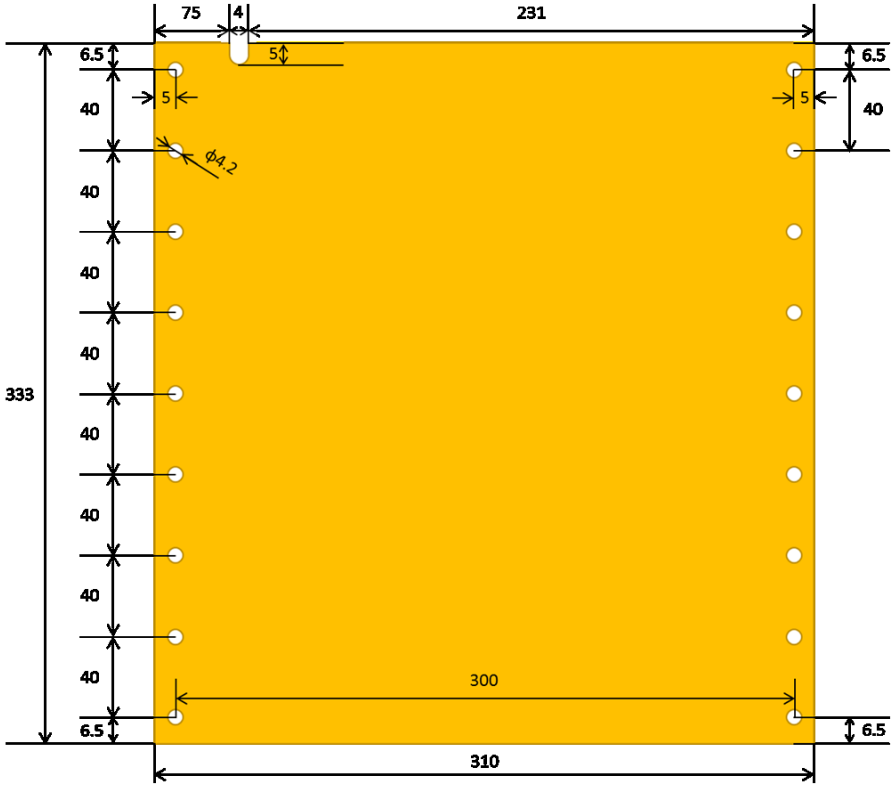
Design of **top/bottom PCB**:
① 32 readout strips on a 10 mm pitch with 3 mm interval.
② Transmission feedthrough.
③ Installing holes for HV.
④ Mounting holes.
⑤ Installing holes for fishing line columns.
⑥ Installing holes for blocks.
⑦ Copper foil.

Design of **middle PCB**:
⑧ Signal transmission pins from bottom/top readout PCBs.
⑨ 200 kΩ protective resistors.
⑩ 2×9 connectors for signal output to PADI.

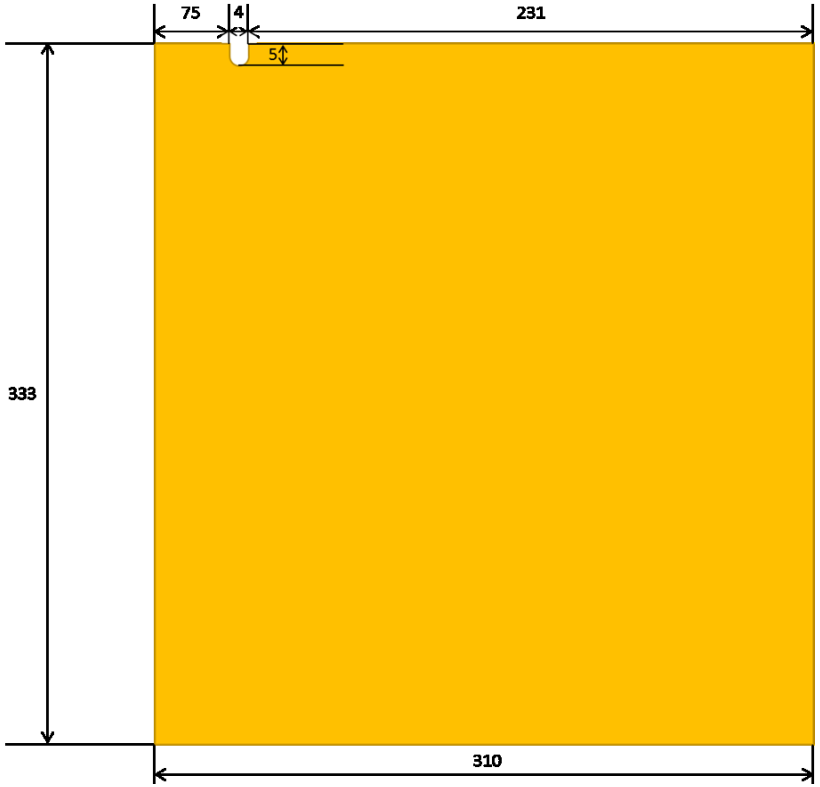
Design values of these PCBs:
Copper foil thickness: 0.035 mm.
Dielectric constant: 4.6.

Materials: Honeycomb Board

Top honeycomb design.



Bottom honeycomb design.

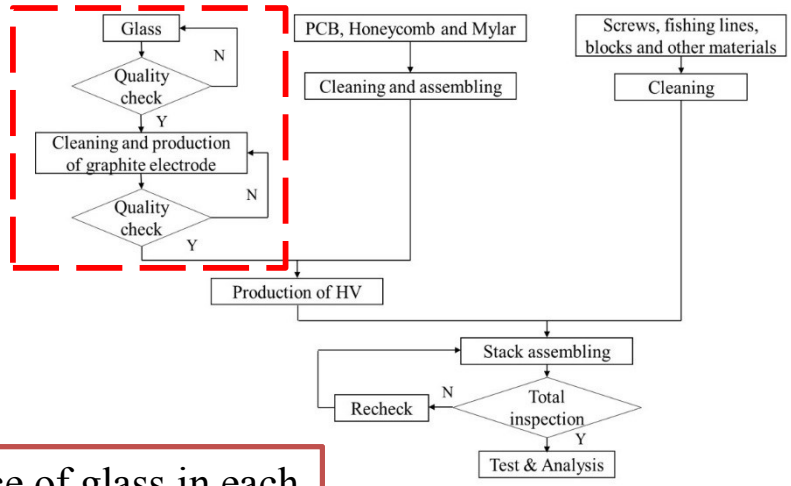


The top honeycomb design has the same fixing holes matching with that on PCBs for counter mounting.

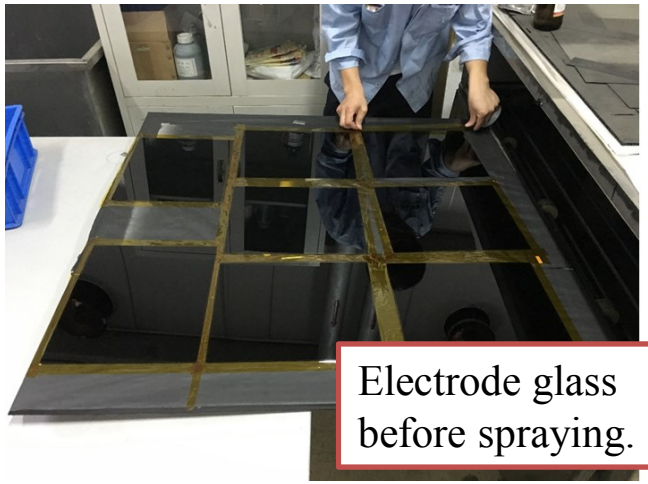
The mounting screws are only on one side of the counter, so there is only slot on top edge for HV cable installing.

QC Method: Mass Production

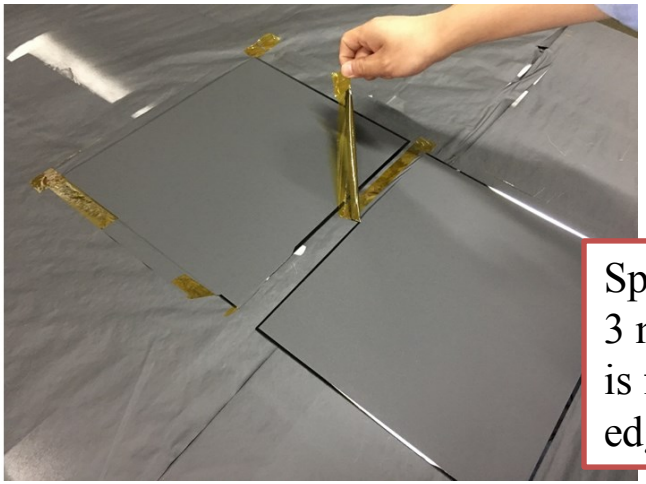
Quality check of **glass** & electrode production.



Every piece of glass in each batch has been inspected.



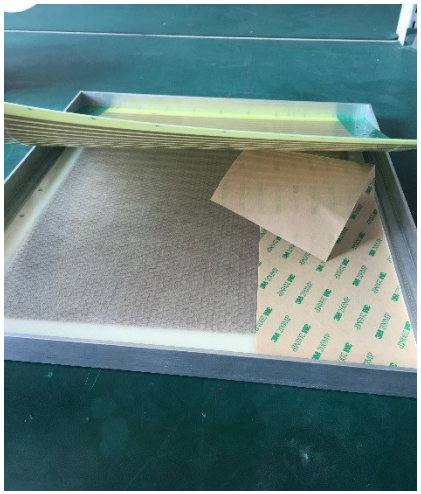
Electrode glass before spraying.

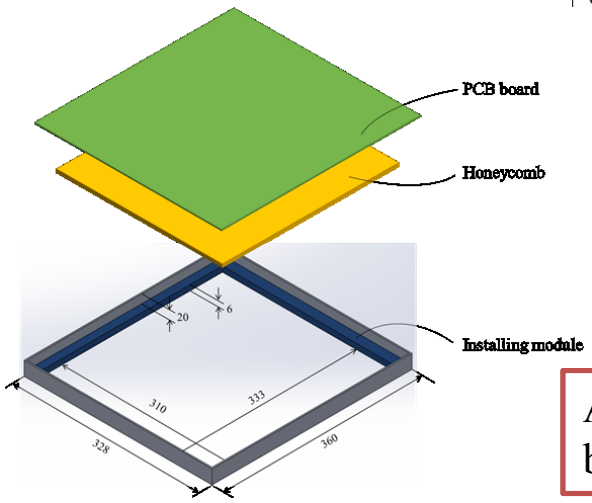


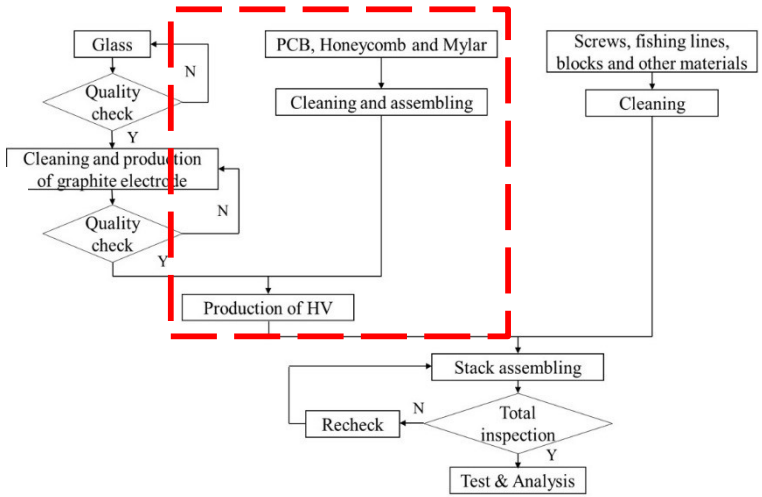
Sprayed electrode. 3 mm space on edge is for getting rid of edge effect.

QC Method: Mass Production

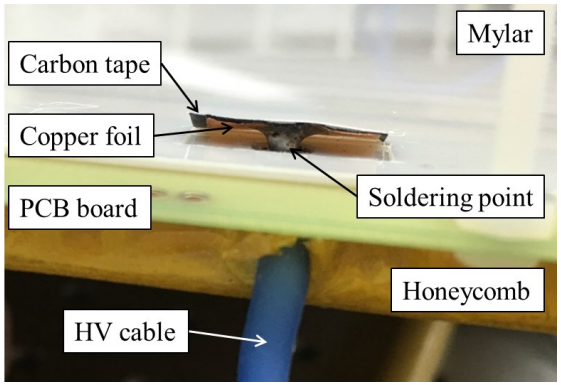
Assembling PCB board & HV production.



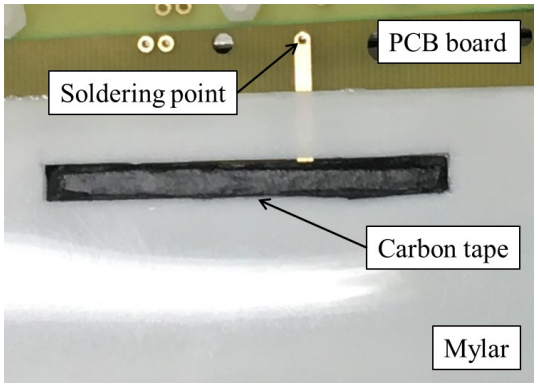




An installing module can fix the PCB board and honeycomb together exactly.



HV connection to top & bottom board. This is to avoid discharge between HV & the nearest strip.



HV connection to middle board.

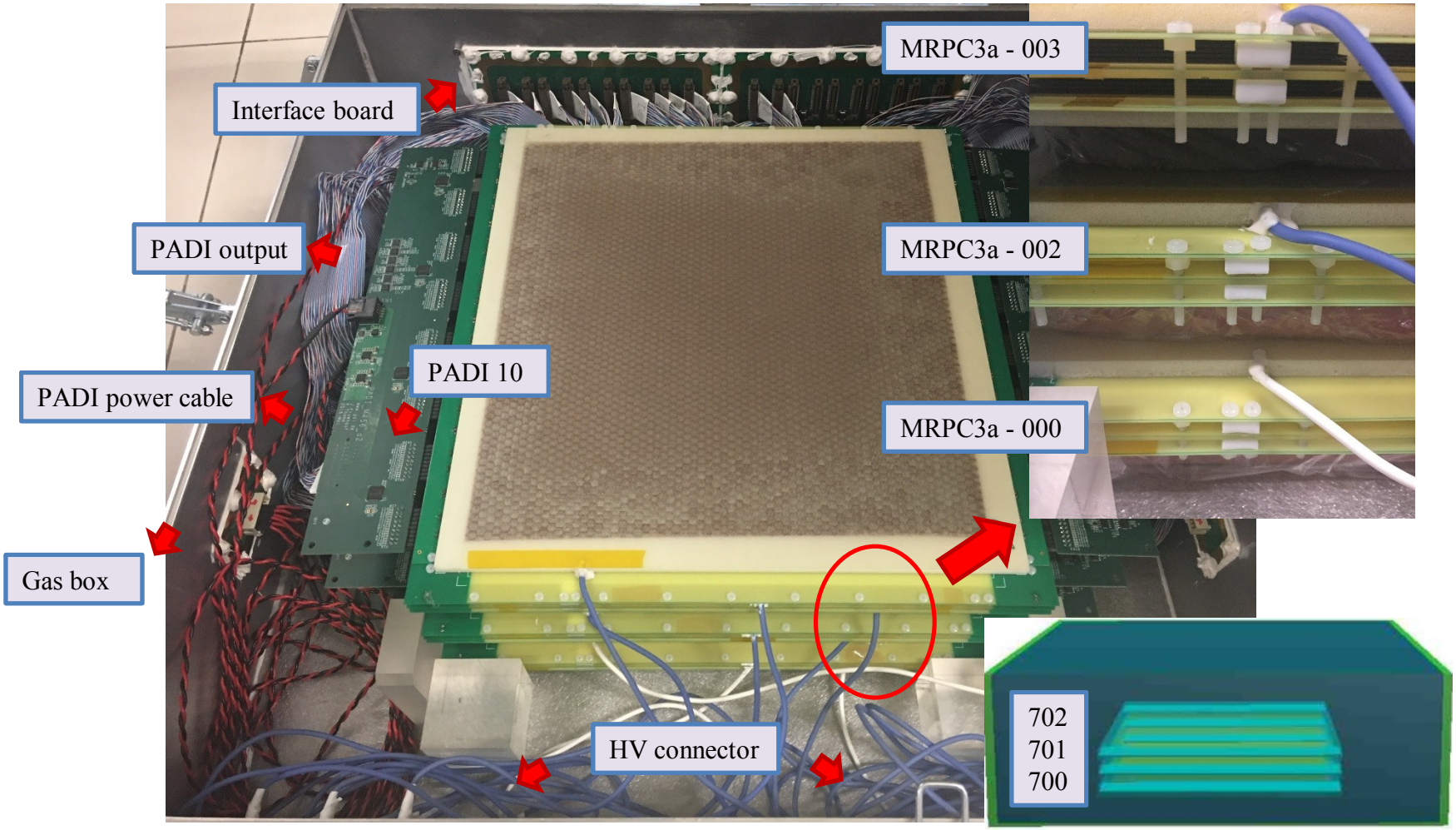
MRPC3a Test: Cosmic Test

PADI FEE parameters.

Main parameters comparison	PADI-1	PADI-2	PADI-6	PADI-8
Channels per chip	3	4	4	8
PA Bandwidth (MHz)	280	293	416	411
PA Voltage Gain	74	87	244	251
Conversion Gain (mV/fC)	6.3	7.8	35	30
Baseline DC offset σ (mV)	6.7	21.9	5.9	1
PA Noise (mV_{RMS})	3.37	2.19	5.82	5.5
Equivalent Noise Charge (e_{RMS})	3512	1753	1039	1145
Threshold type	Extern	Extern	Ext. & DAC	DAC
Threshold dynamics ($\pm$ mV)	Non.lin. 280	Non.lin. 300	Lin. 500	Lin. 750
Input Impedance Range (Ω)	30-450	37 - 370	38 - 165	30 - 160
Power consumption (mW/channel)	21.6	17.4	17.7	17

MRPC3a Test: Cosmic Test

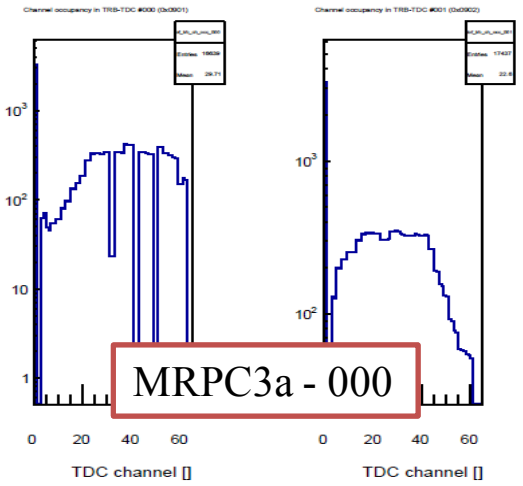
MRPC setup in the gas box.

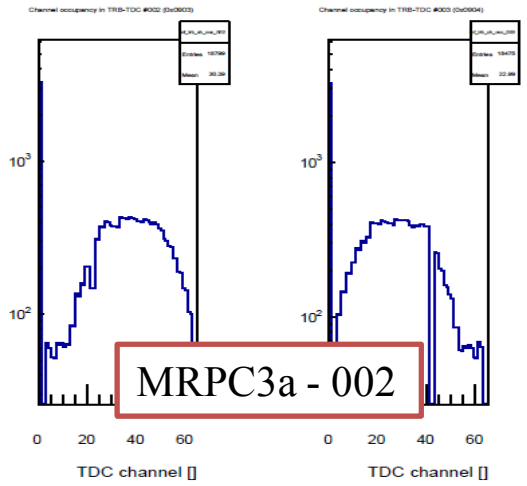


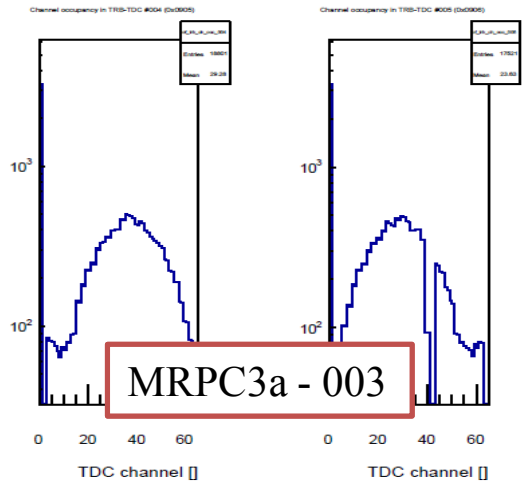
MRPC3a Test: Cosmic Test

Unpacking:

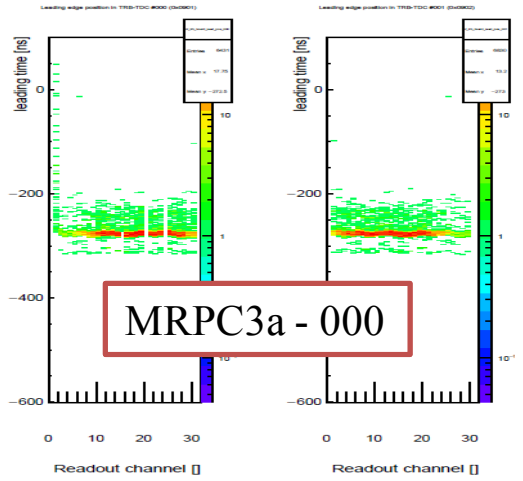
TDC channel occupancy

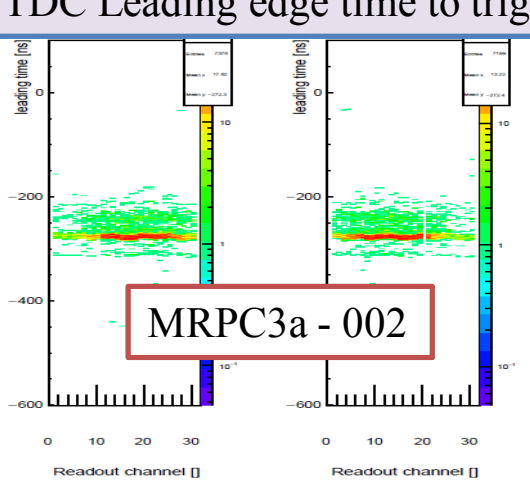


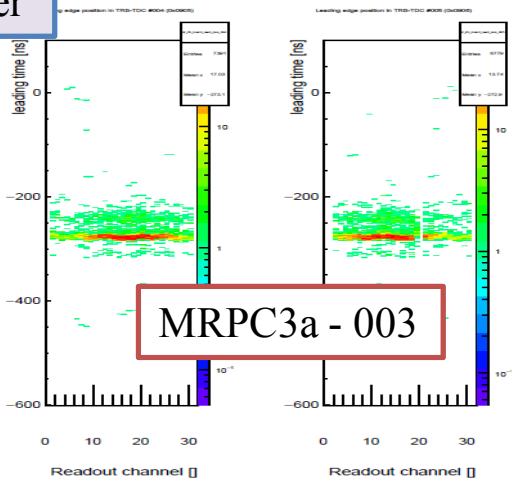




TDC Leading edge time to trigger

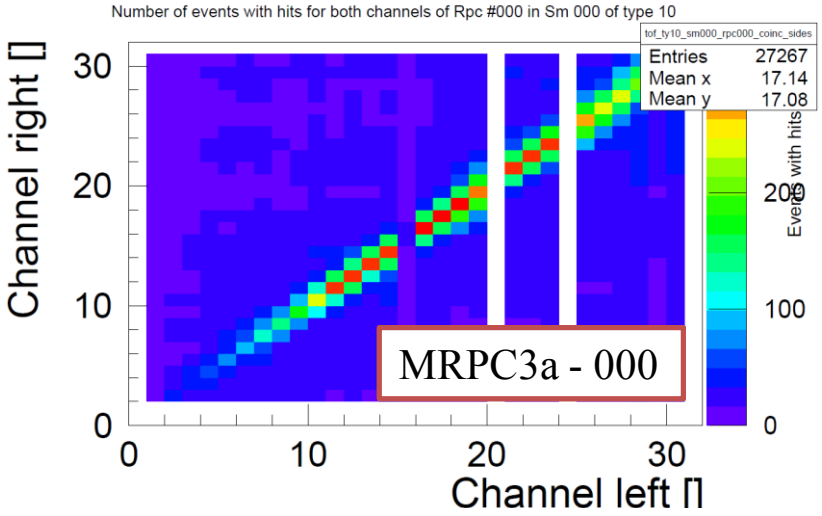


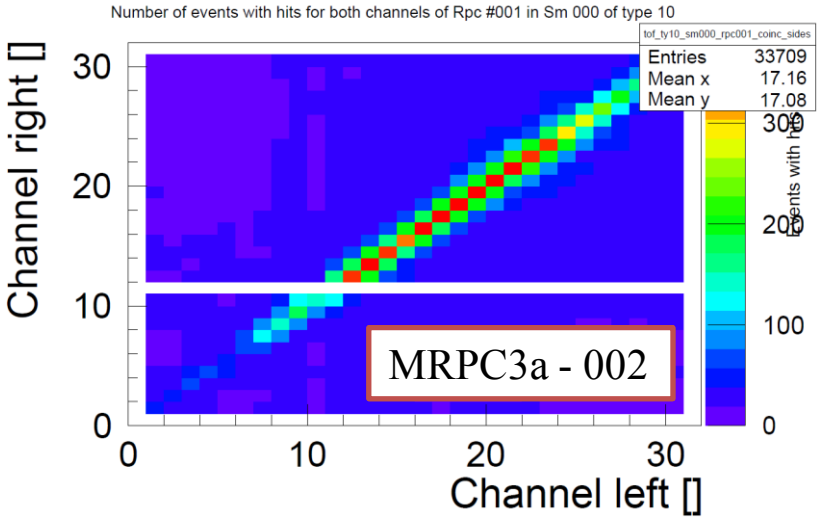


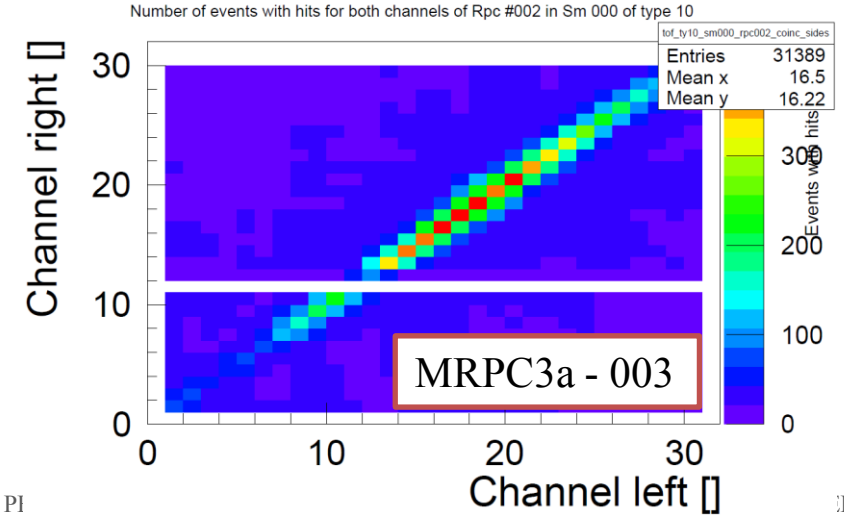


MRPC3a Test: Cosmic Test

Unpacking:







Matching of left and right side of each MRPC. It can prove the mapping file we prepare is correct.

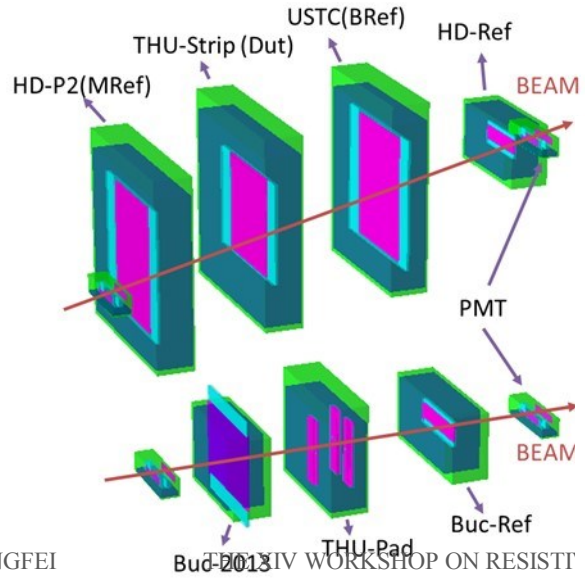
MRPC3a Test: Cosmic Test

The performance requirement of the MRPC3a counter in cosmic-ray test.

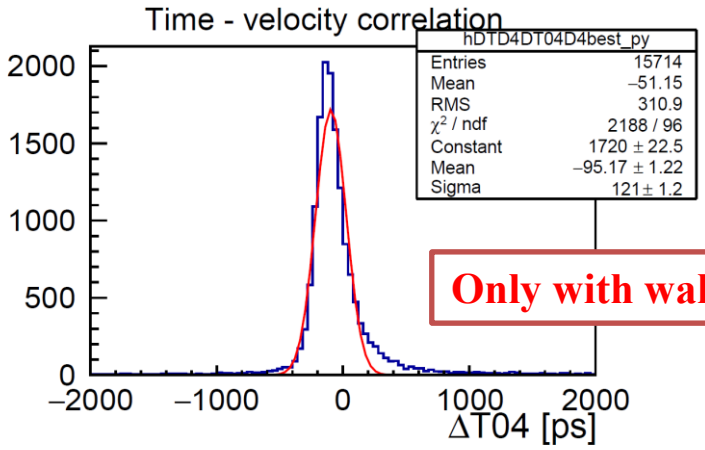
Testing conditions	Specification	Requirement
Working gas: 90% $C_2H_2F_4$, 5% i-C_4H_{10} and 5% SF_6	Dark current	< 50 nA
	Efficiency	> 95%
HV: 5500 V	System time resolution	< 125 ps
PADI threshold: 350 mV	Cluster size	< 2

Run 01Mar2217 SPS Feb 2015 (no diamond):

The time resolution in cosmic-ray can't be as good as that in beamtest (velocity correction not sufficient).



Without any cuts: 103 ps

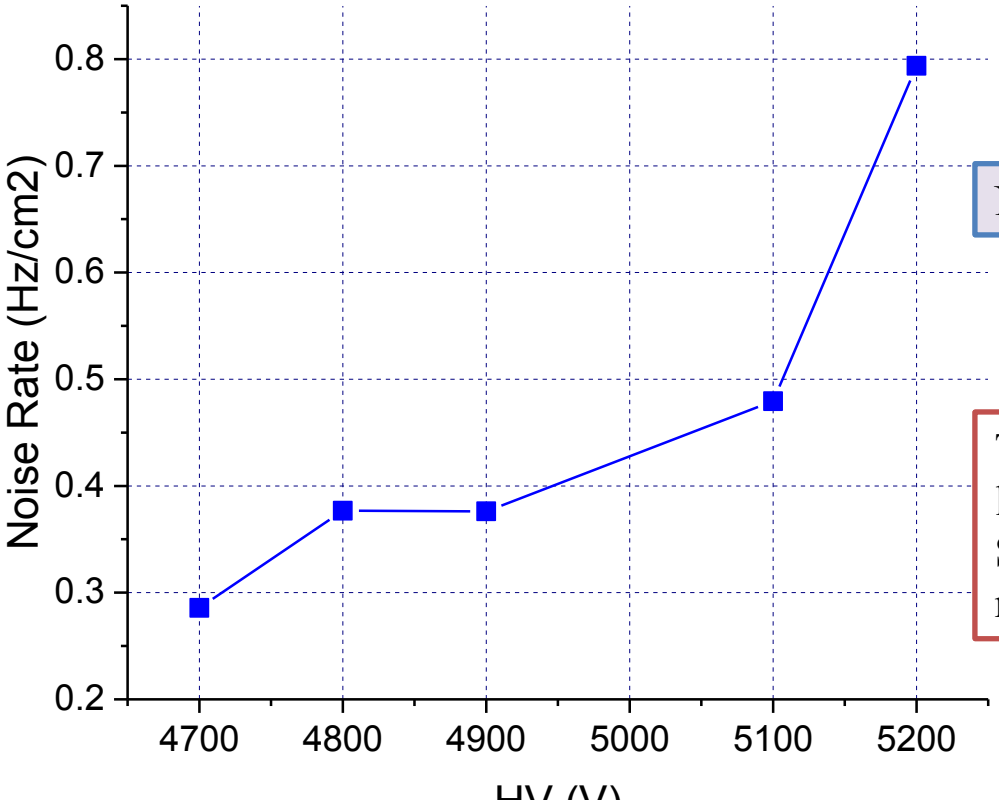


Only with walk correction: 121 ps

Cosmic Test: Non SF_6 Test

Similar non SF_6 test is repeated in Tsinghua.
Threshold: -300 mV; Gas: **95% Freon + 5% C_4H_{10}**.

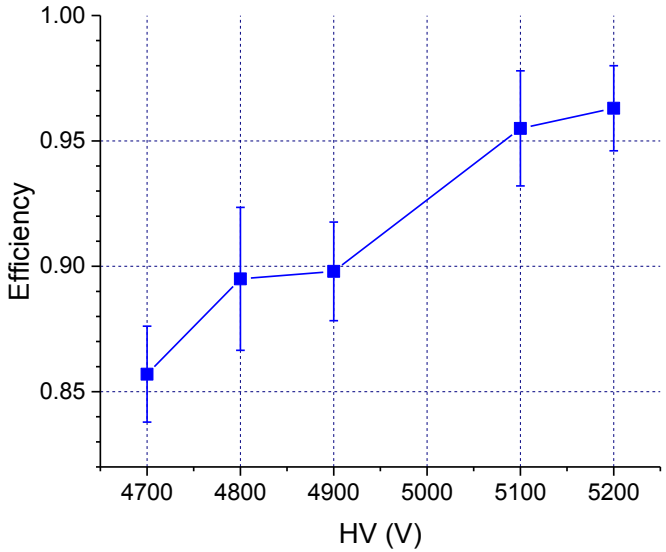
The dark current of 701 (MRPC3a - 002) always stays at **+0.01 μA / -0.01 μA** with HV increasing.

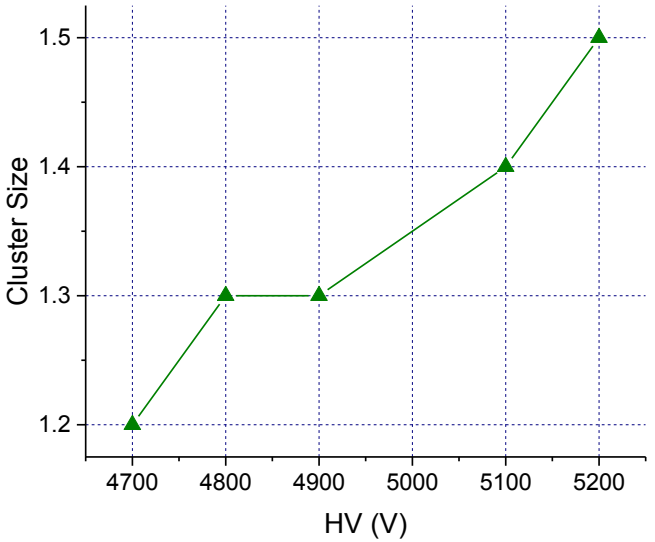


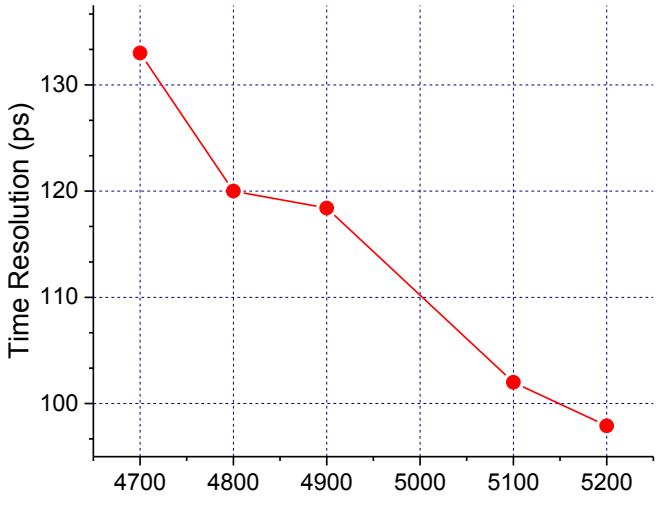
Noise rate of 701 (MRPC3a - 002)

The noise rate should be at same level to reach the same efficiency. So HV is increased to 5200 V to reach the nominal point.

Cosmic Test: Non SF_6 Test







Dut: 701; Ref: 702; Sel2/BRef: 700.
Calibration mode: 701702700.

The working point without SF_6 is 400V below that with SF_6, with an efficiency of 96%, system time resolution below 100 ps and 1.5 clustersize.