Development of large area mosaic high rate MRPC for CMS muon upgrade

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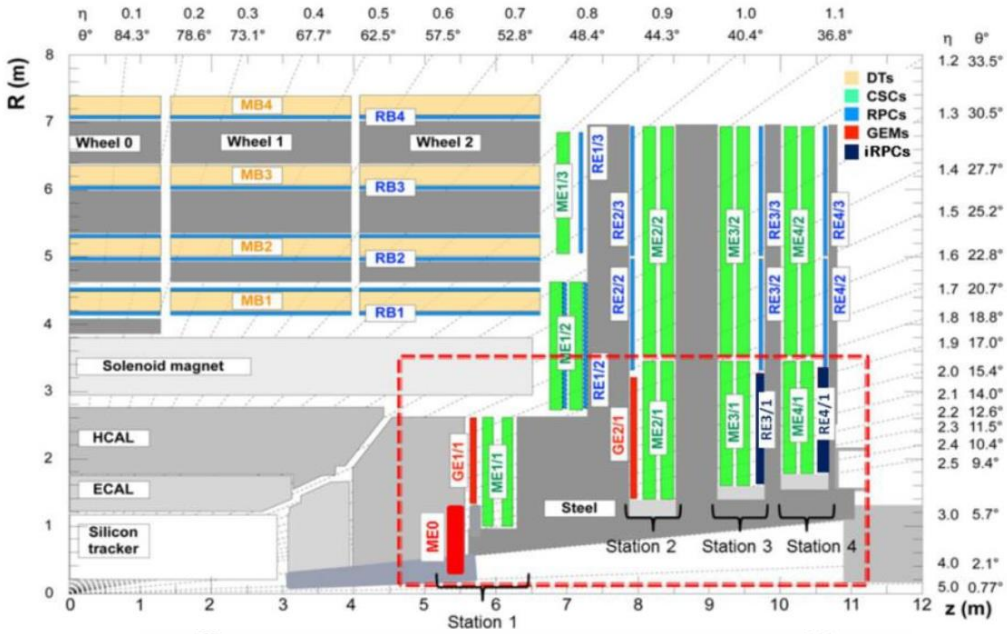
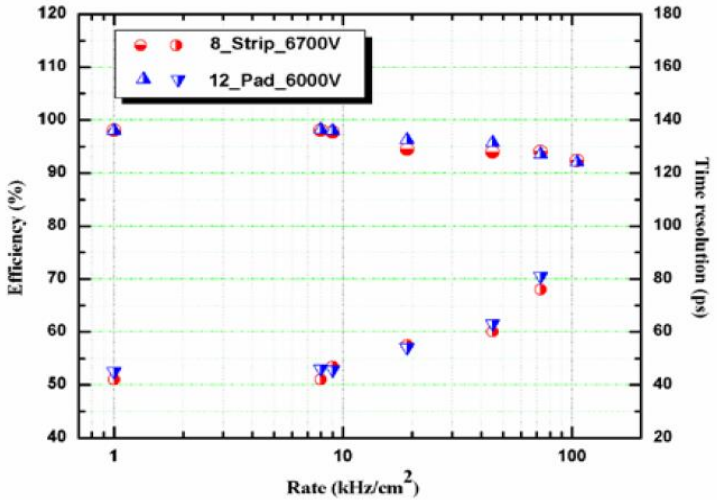
Outline

- Introduction of real-size mosaic MRPC
- 904 cosmic test
- HZDR beamtest
  - Beamtest preparation and setup
  - Preliminary result
- GIF++ beamtest
- Impedance of transmission lines in MRPC Detector
- Summary

Introduction of the mosaic MRPC





The planned HL operation during the LHC phase- Ⅱ :

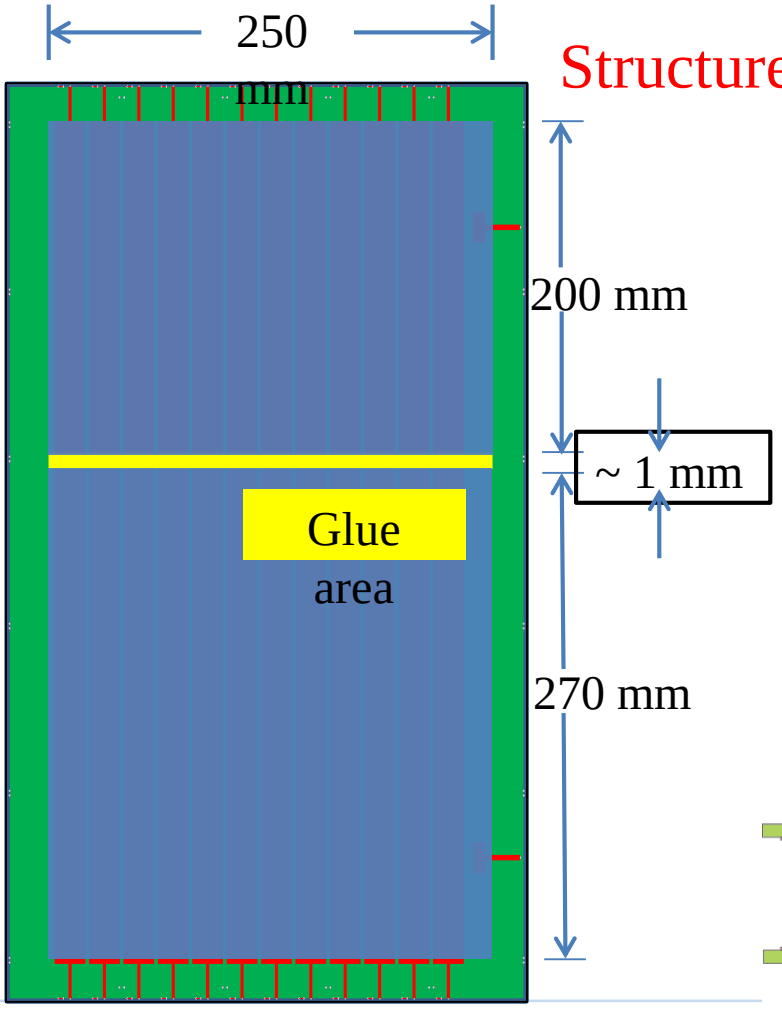
- Larger instantaneous luminosity up to $5 \times 10^{34} cm^{-2} s^{-1}$
- Integrated luminosity up to 3000 fb-1
- Rate requirement :2 kHz/cm2

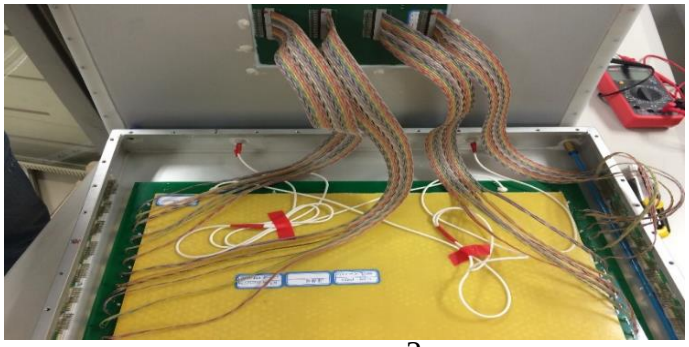
High rate MRPC based on low resistive glass is best candidate for the upgrade of endcap muon system.

- **High rate capability >70kHz/cm2**
- **Time resolution<100ps, eliminate most of background**
- **Limitation: glass size** $33\ cm \times 28\ cm$
- **Solution: glass mosaic**

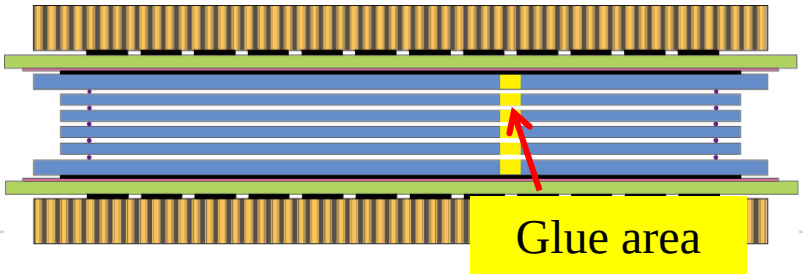
Introduction of the mosaic MRPC

Mosaic design 1 : glue glass





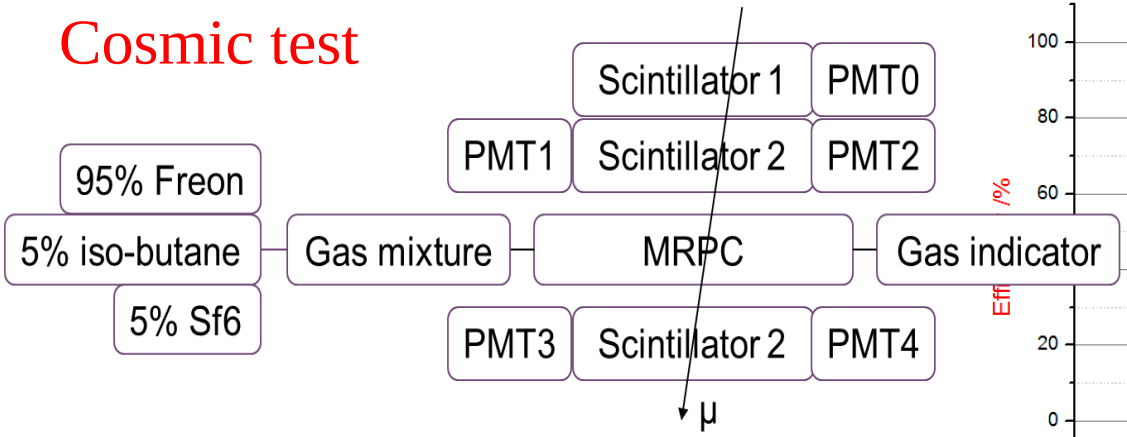
PCB: 320 × 540 mm^2
Strip length: 498 mm
Strip pitch: (17 + 2) mm
Strip number: 12
Glass: (200 + 270) × 250 mm^2, 0.7 mm,10^{10} Ω ·cm
Gas gap width: 250 um
Gas gap number: 5

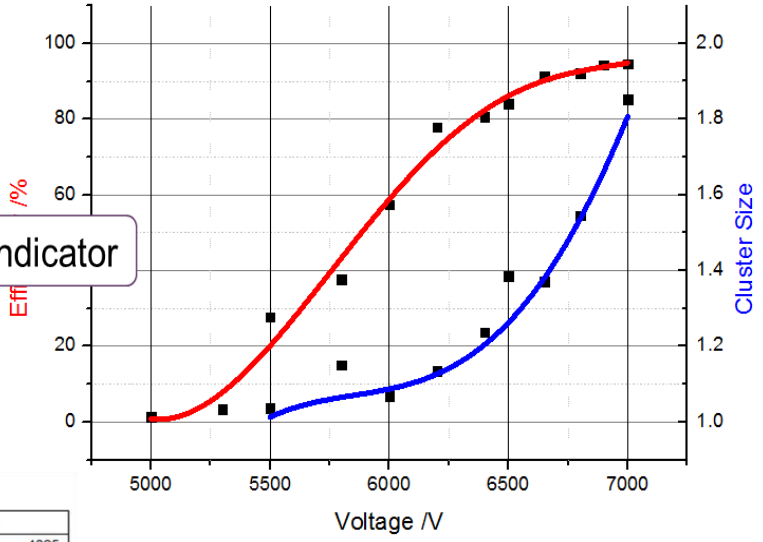


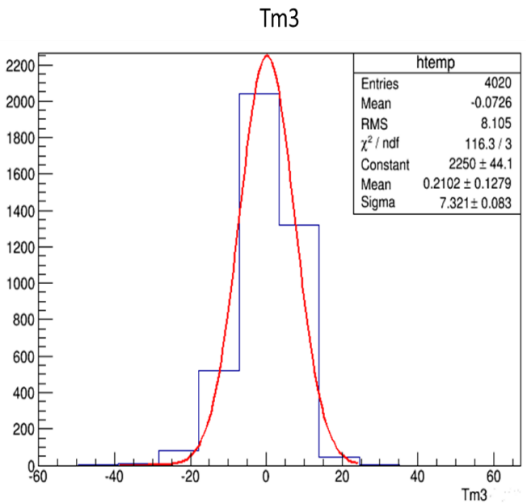
Introduction of the mosaic MRPC

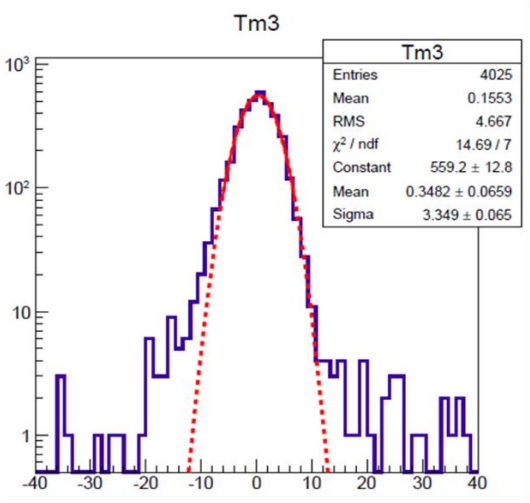
Mosaic design 1 : glue glass

Cosmic test









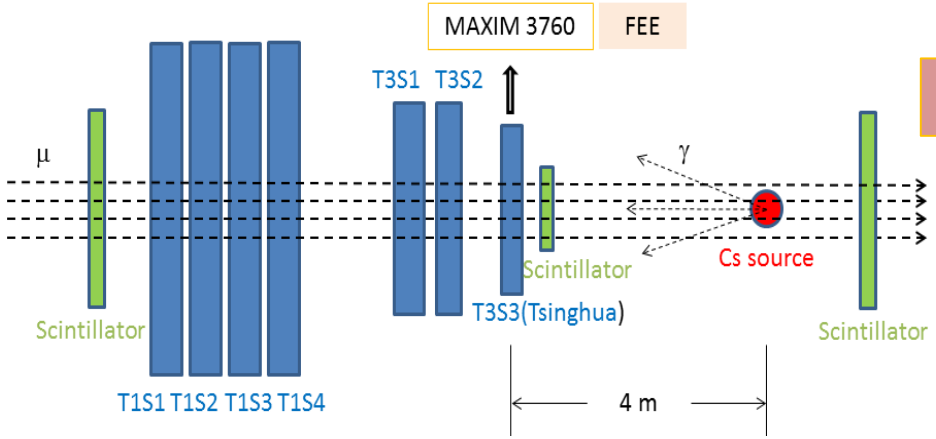
- ✓ Efficiency： 94%
- ✓ Time Resolution： 71ps

$$\delta = \sqrt{3.349^2 - 1.766^2} \times 25 = 71.1ps$$

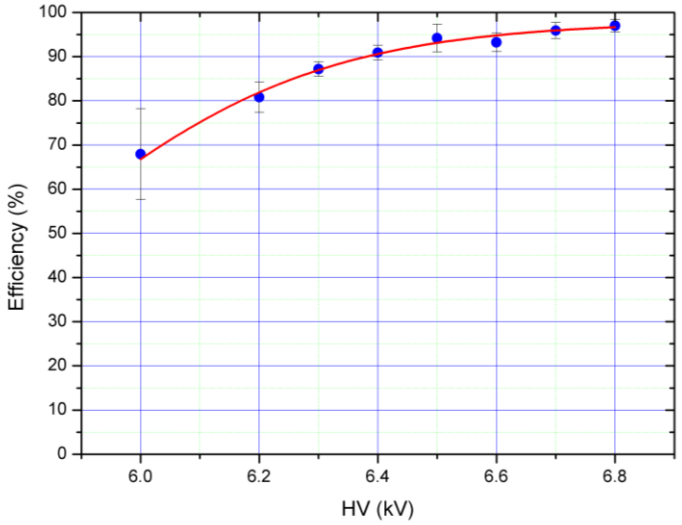
Introduction of the mosaic MRPC

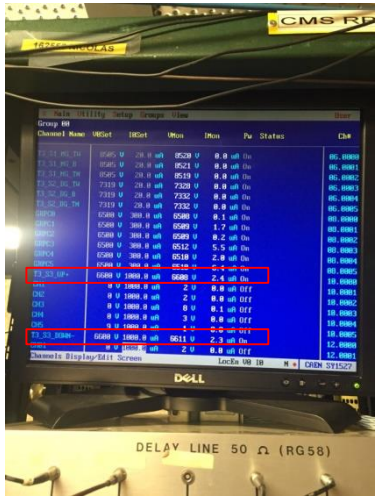
Mosaic design 1 : glue glass

Beam test @ GIF++, Aug, 2015



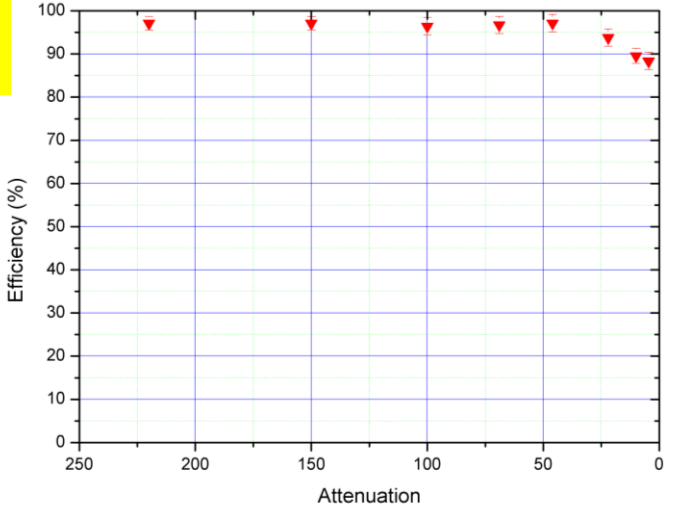
HV scan





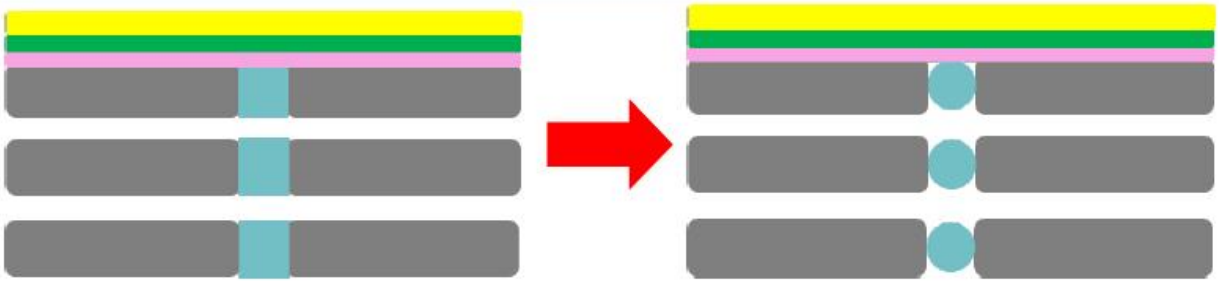
Problem: big current!

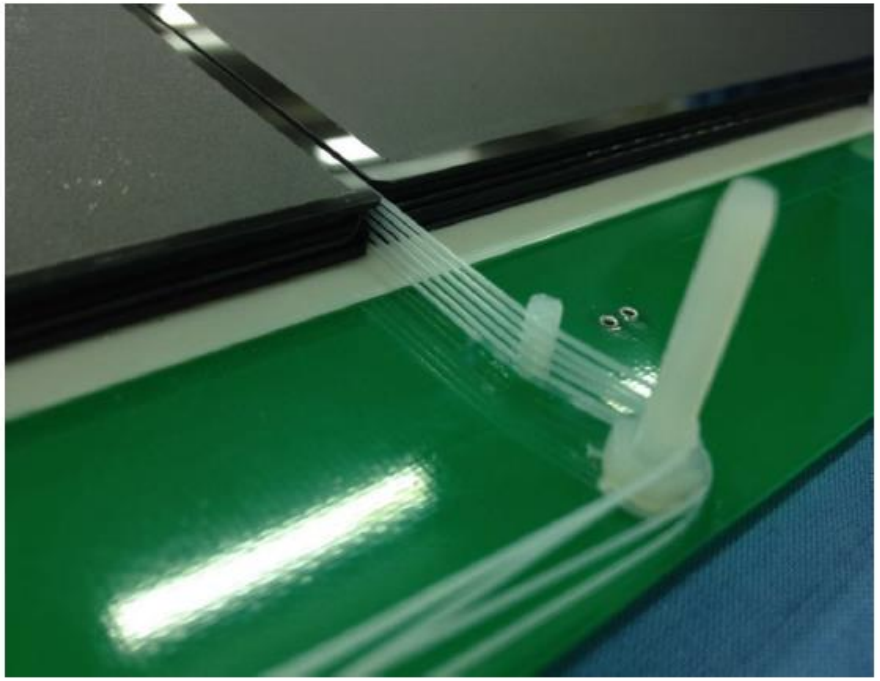
rate scan



Introduction of the mosaic MRPC

Mosaic design 2 : block by fishing line

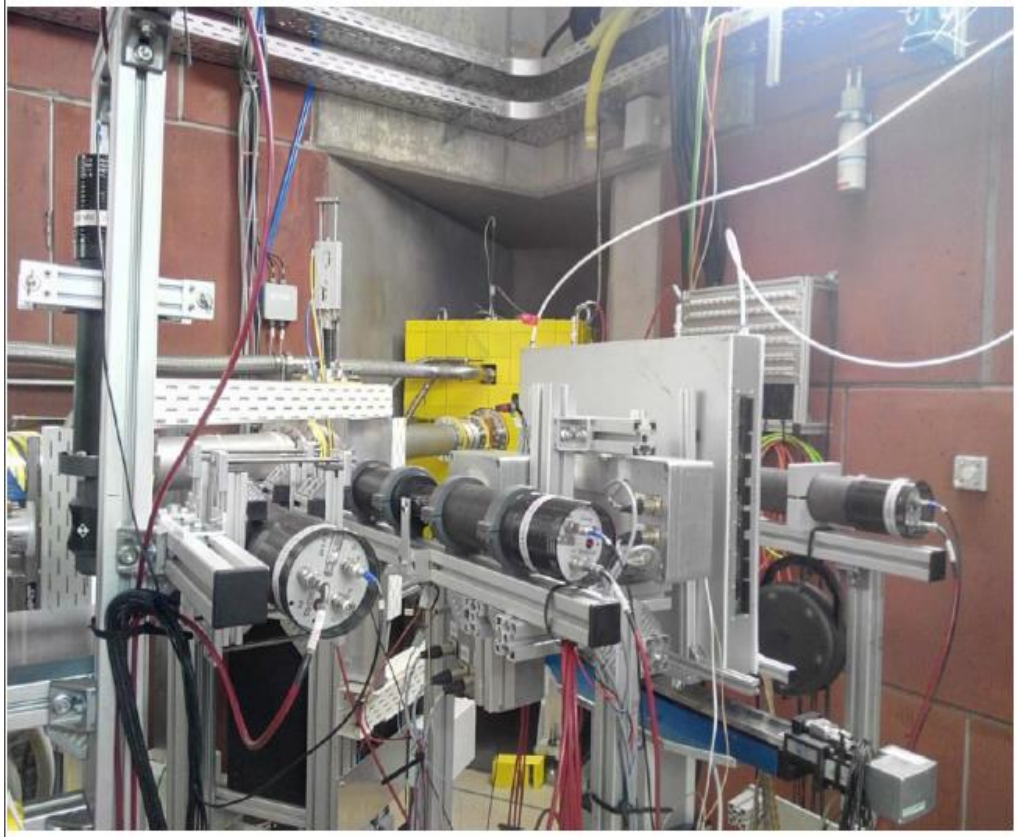




Introduction of the mosaic MRPC

Mosaic design 2 : block by fishing line

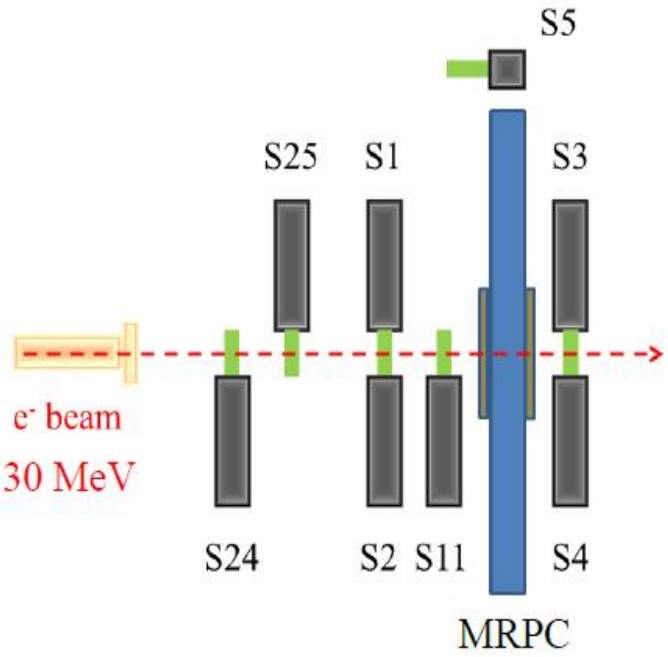
Beam test @ ELBE, HZDR, Sep, 2015



S24, S25 : 4 × 4 cm^2

S11 : 5 × 5 mm^2

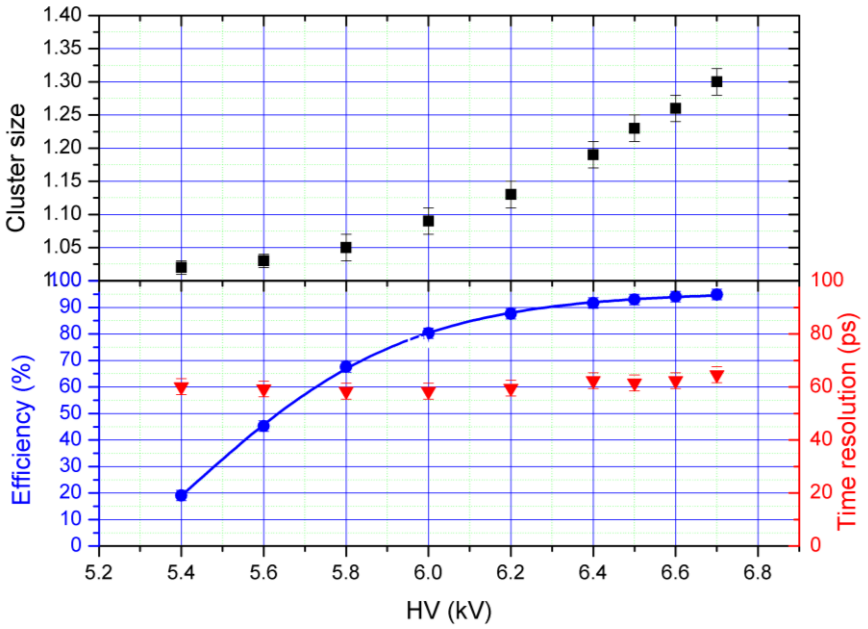
S1, S2, S3, S4 : 2 × 2 cm^2



Gas supply: 90% Freon, 5% iso-butane, 5% SF6, 50ml/min

Introduction of the mosaic MRPC

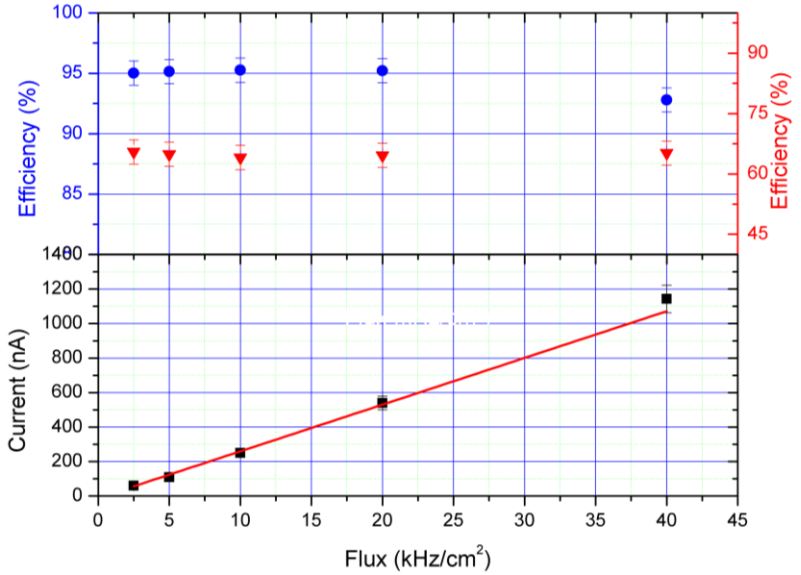
Mosaic design 2 : block by fishing line



Cluster size<1.3

Efficiency→ 95%

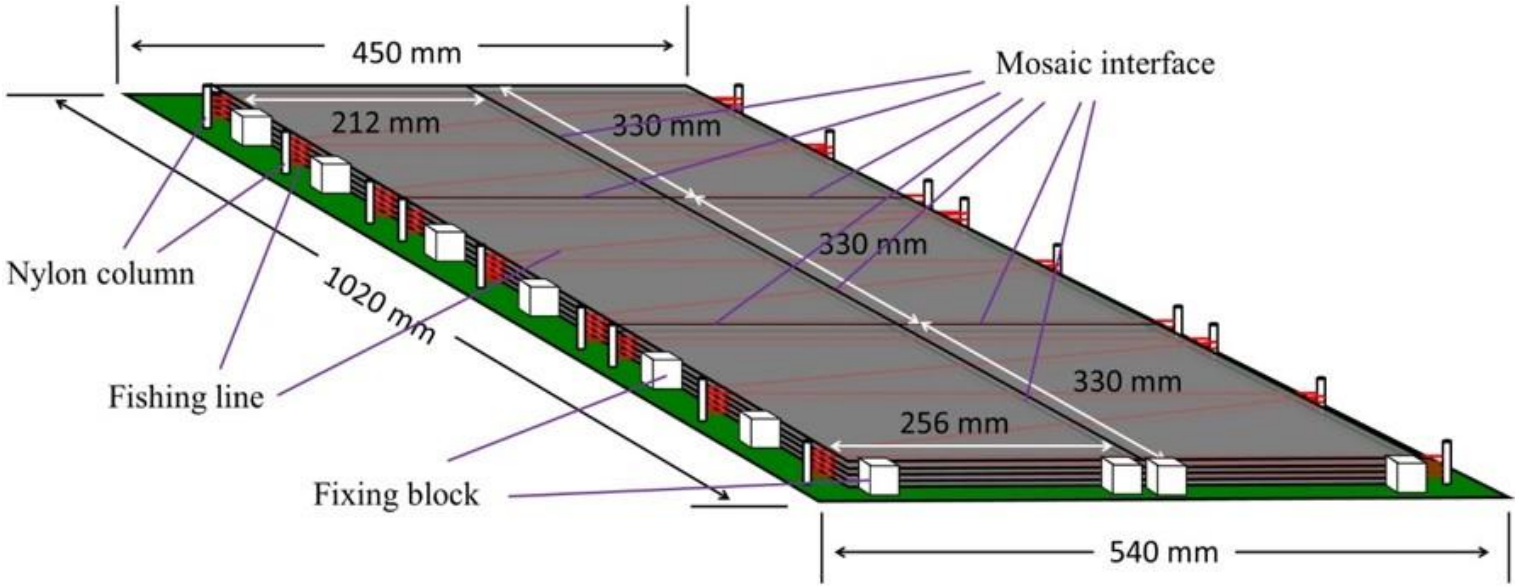
Time resolution ~60ps



计数率>40kHz/cm²

Introduction of the mosaic MRPC

Real size mosaic MRPC.



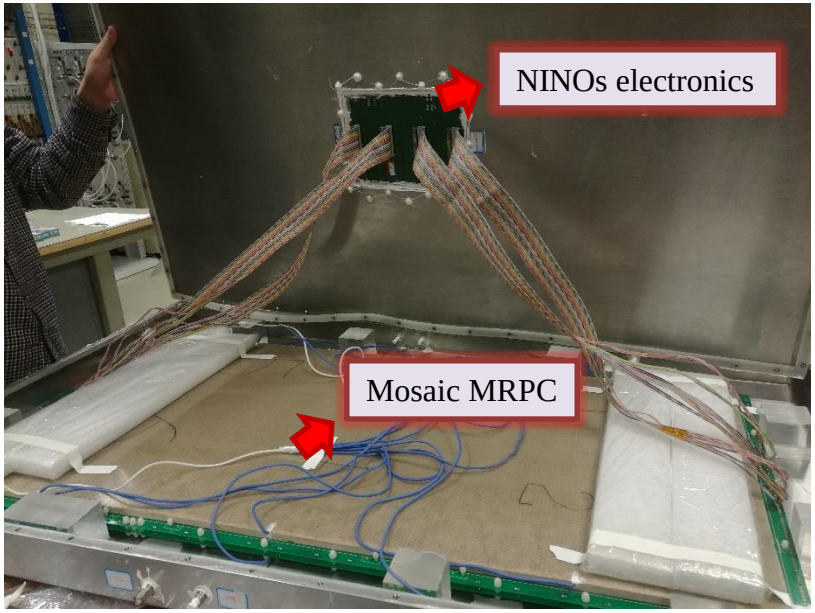
Gas gap number:	5
Gas gap width:	250 μm
Glass thickness:	0.7 mm
Glass bulk resistivity:	~ 10^{10} Ωcm
Mosaic interface:	glass directly mosaic together

Strip number:	44
Strip shape:	trapezoidal (6 mm/8 mm)
Strip interval:	3 mm
Strip length:	1 m

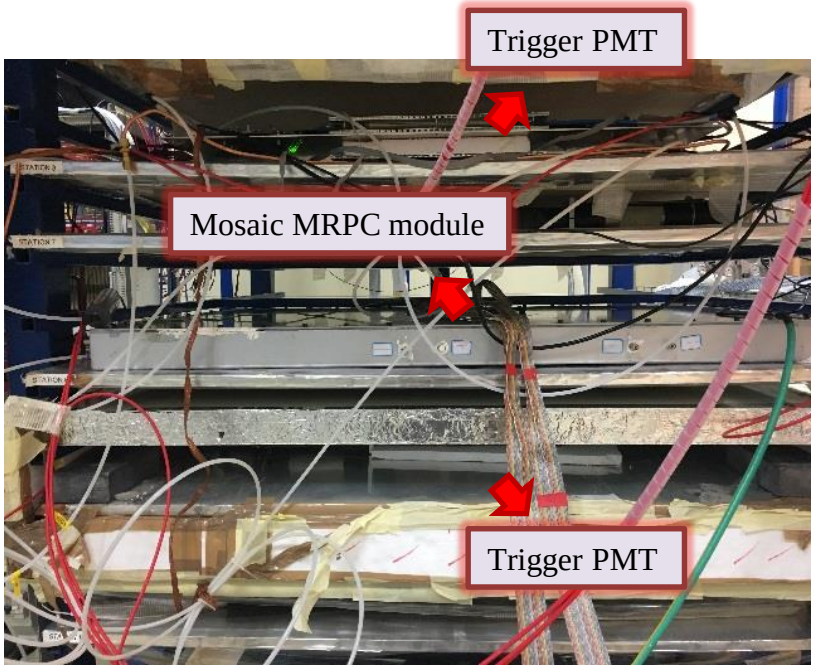
Cosmic test at CERN 904

Cosmic ray test at CERN in Feb, 2017:
Gas component: **90% $C_2H_2F_4$ + 5% i-C_4H_{10} + 5% SF_6.**

Mosaic MRPC in gas box.



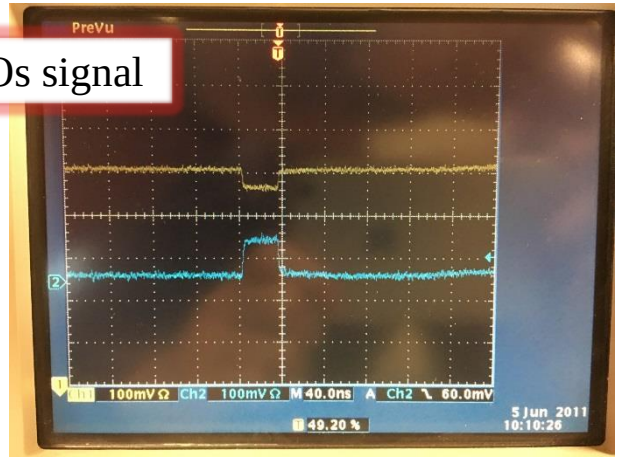
Test module in cosmic setup.

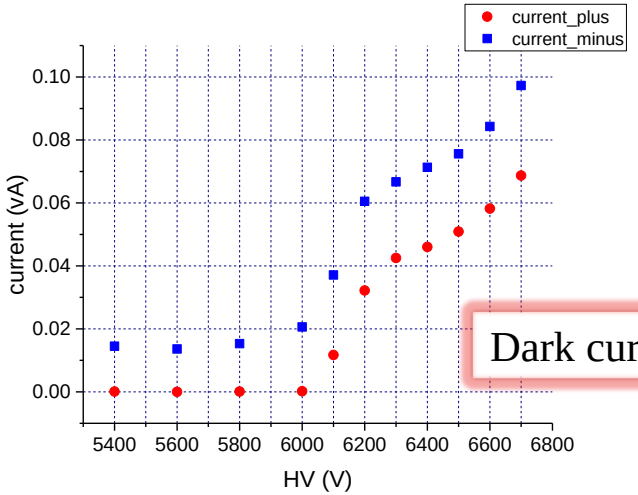


Cosmic test at CERN 904

Cosmic ray test at CERN in Feb, 2017:
Scan000086: 5000 trigger events.

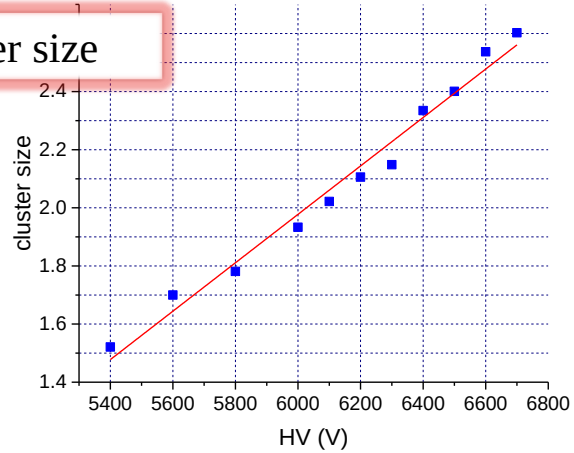
NINOs signal

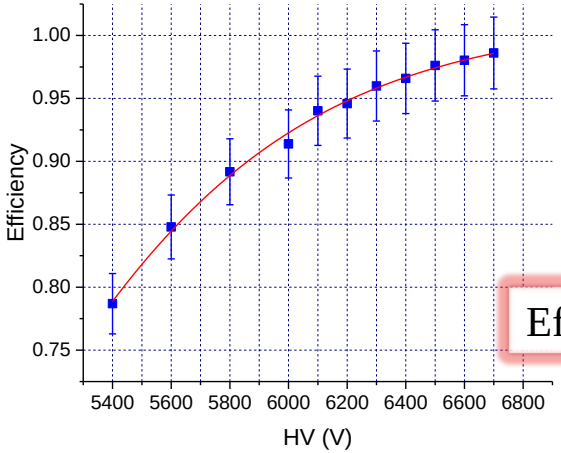




Dark current

Cluster size

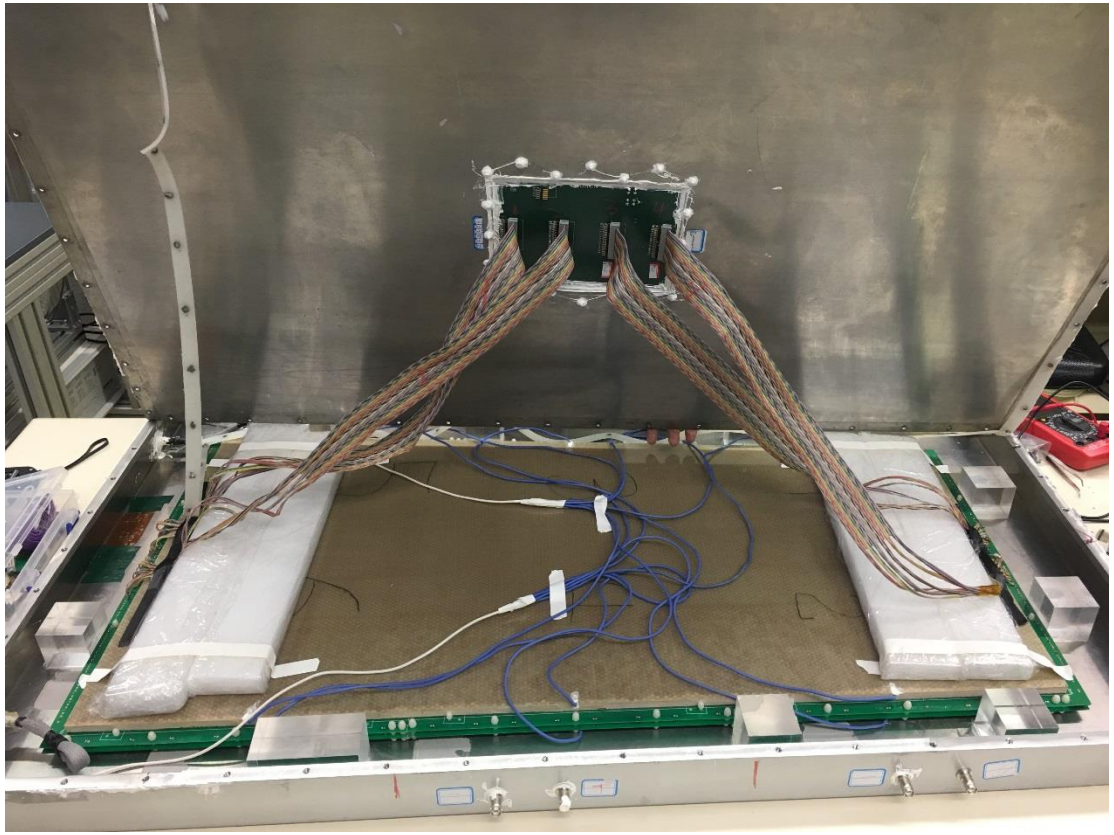




Efficiency

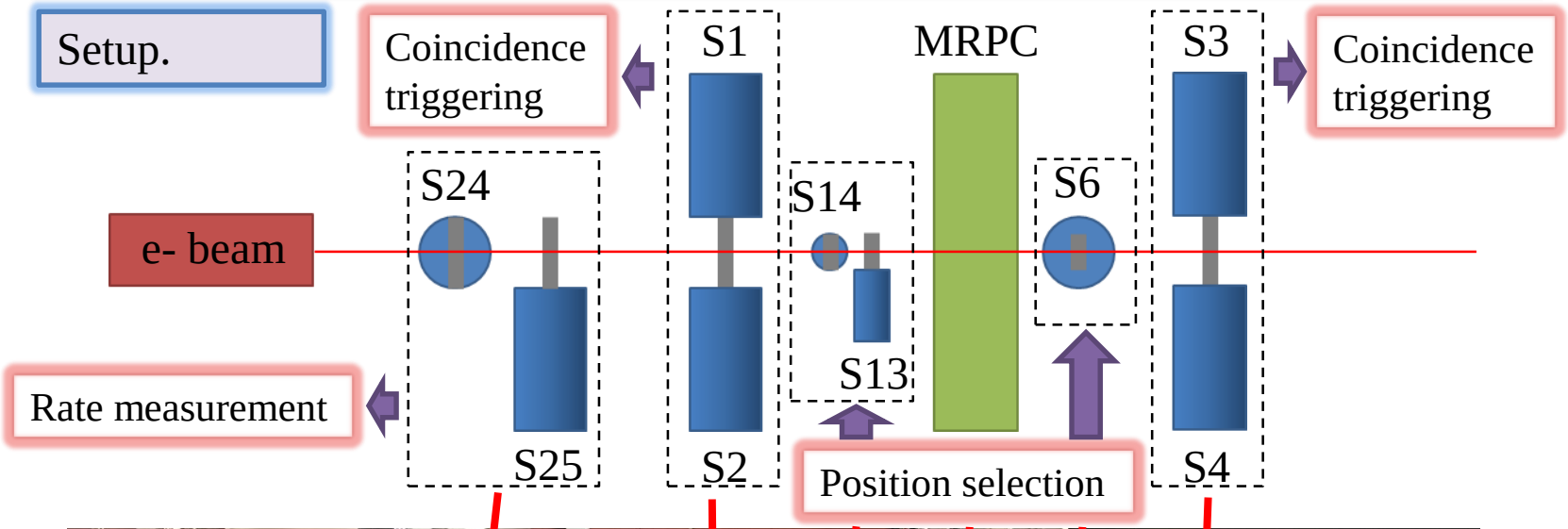
HZDR beamtest: Preparation

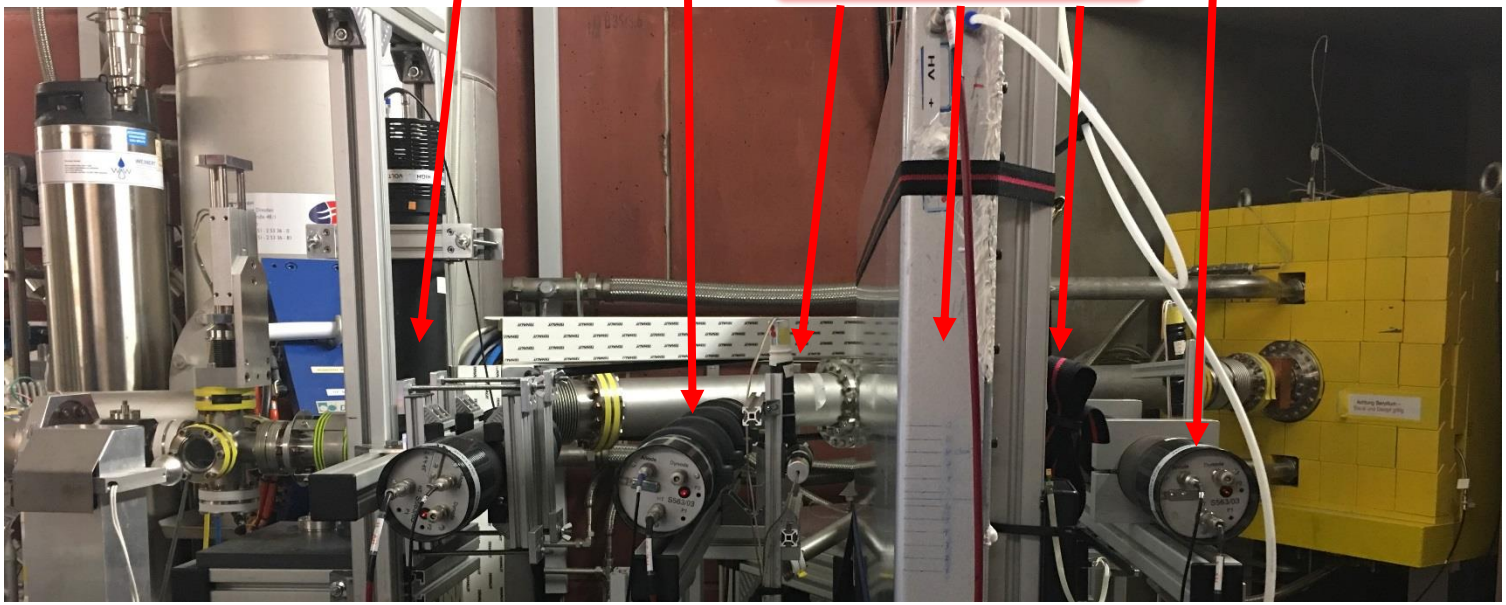
Maxime and xiaolong brought the **Mosaic MRPC to HZDR** by car on March 24th.



Gas box was again opened to switch the Jupiter HV connector to SHV connector.
Gas was flushed with a component: **90% $C_2H_2F_4$ + 5% i-C_4H_{10} + 5% SF_6**.

HZDR beamtest: Setup

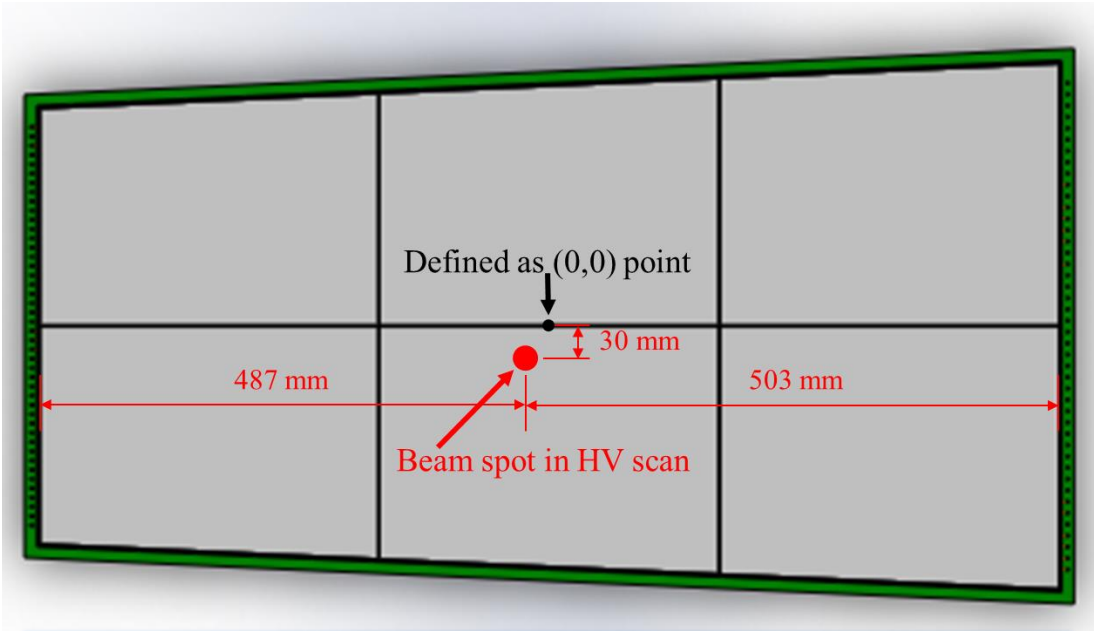


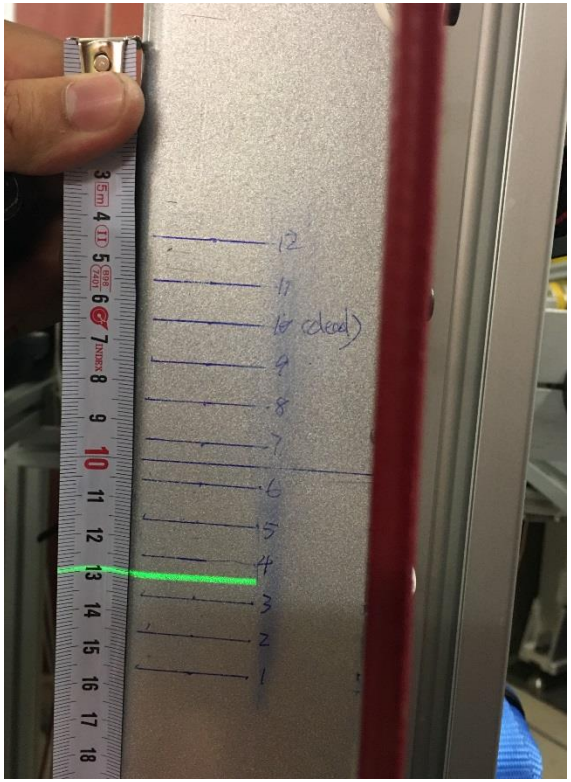


HZDR HV Scan: Setup

Run005 ~ Run021: HV: ±5400 V ~ ±6800 V; Rate: 11 kHz/cm^2.
Beam spot position: Horizontal – center; Vertical: between 3rd and 4th strip.

Define the horizontal center on the mosaic interface as zero point, beam spot at (-8, -30).

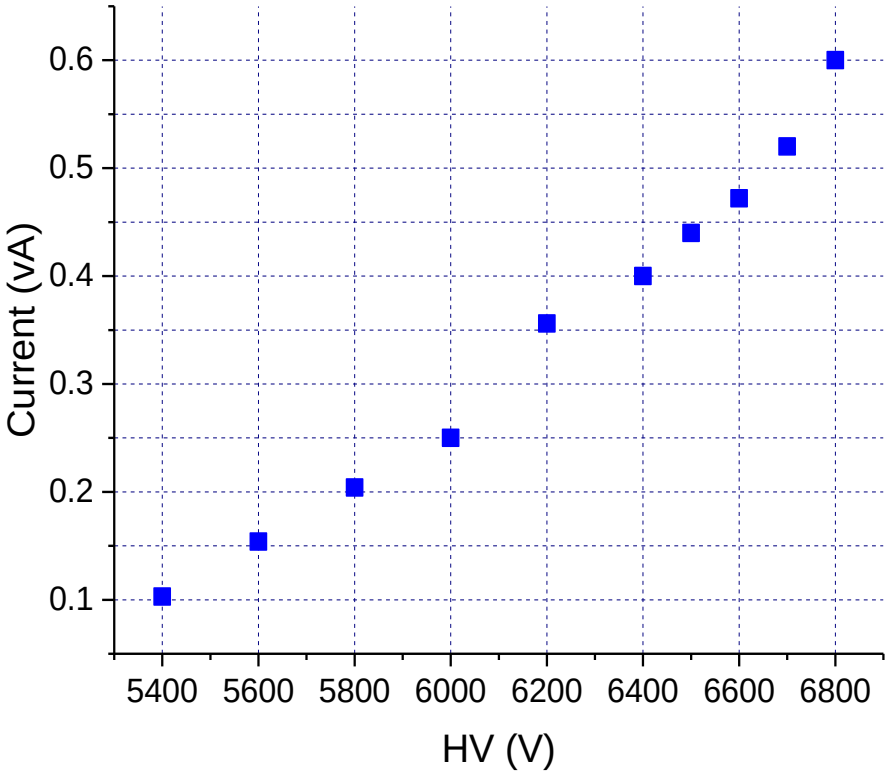


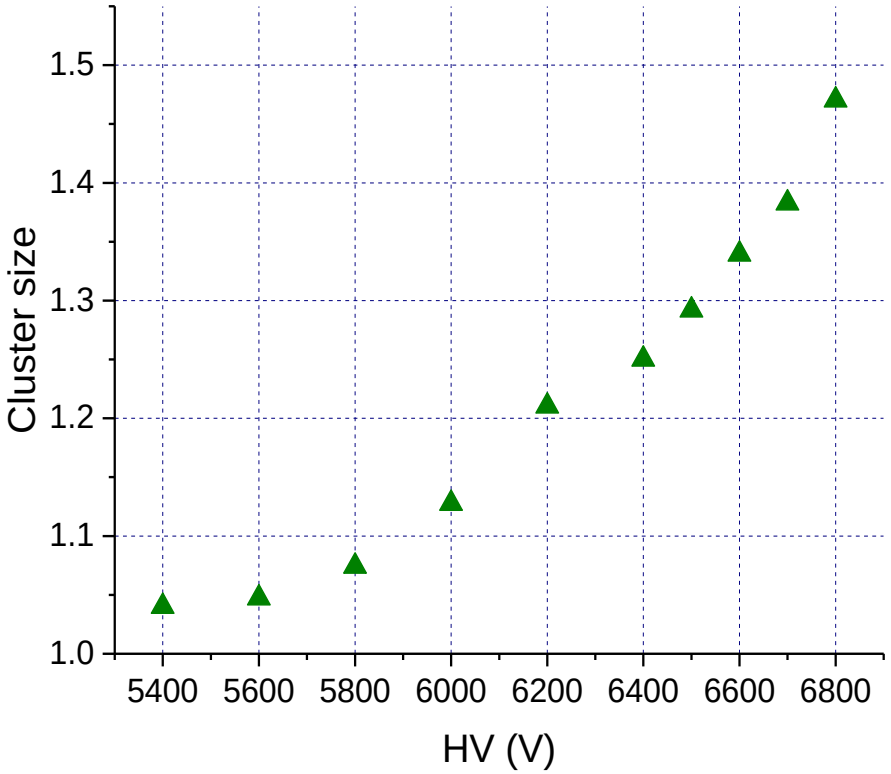


PMT Trigger (S1&S2&S3&S4) dimension: 20 × 20 mm^2.
Beam spot dimension: 100 mm in diameter.

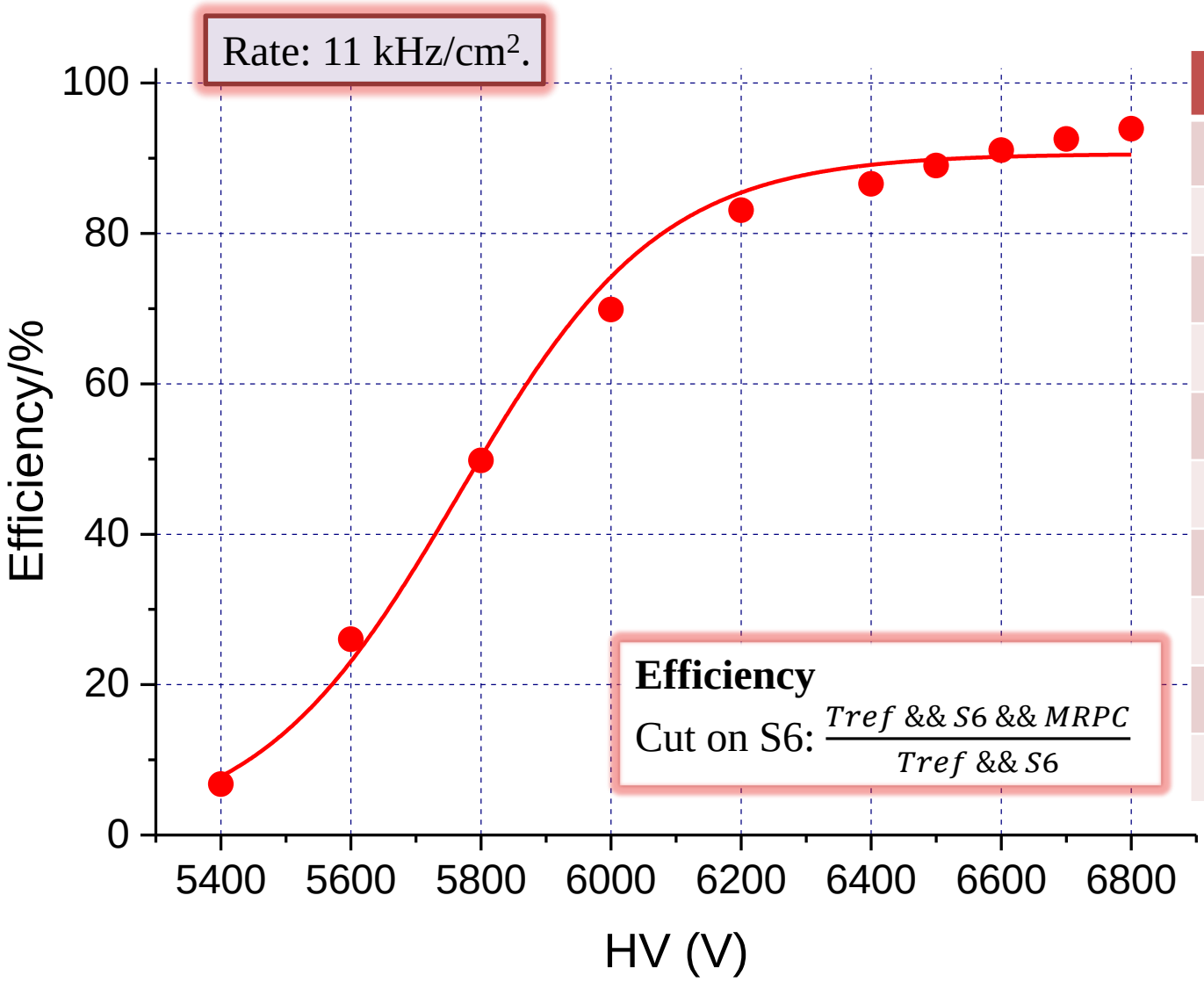
HZDR HV Scan: Current and Cluster Size

Rate: 11 kHz/cm^2



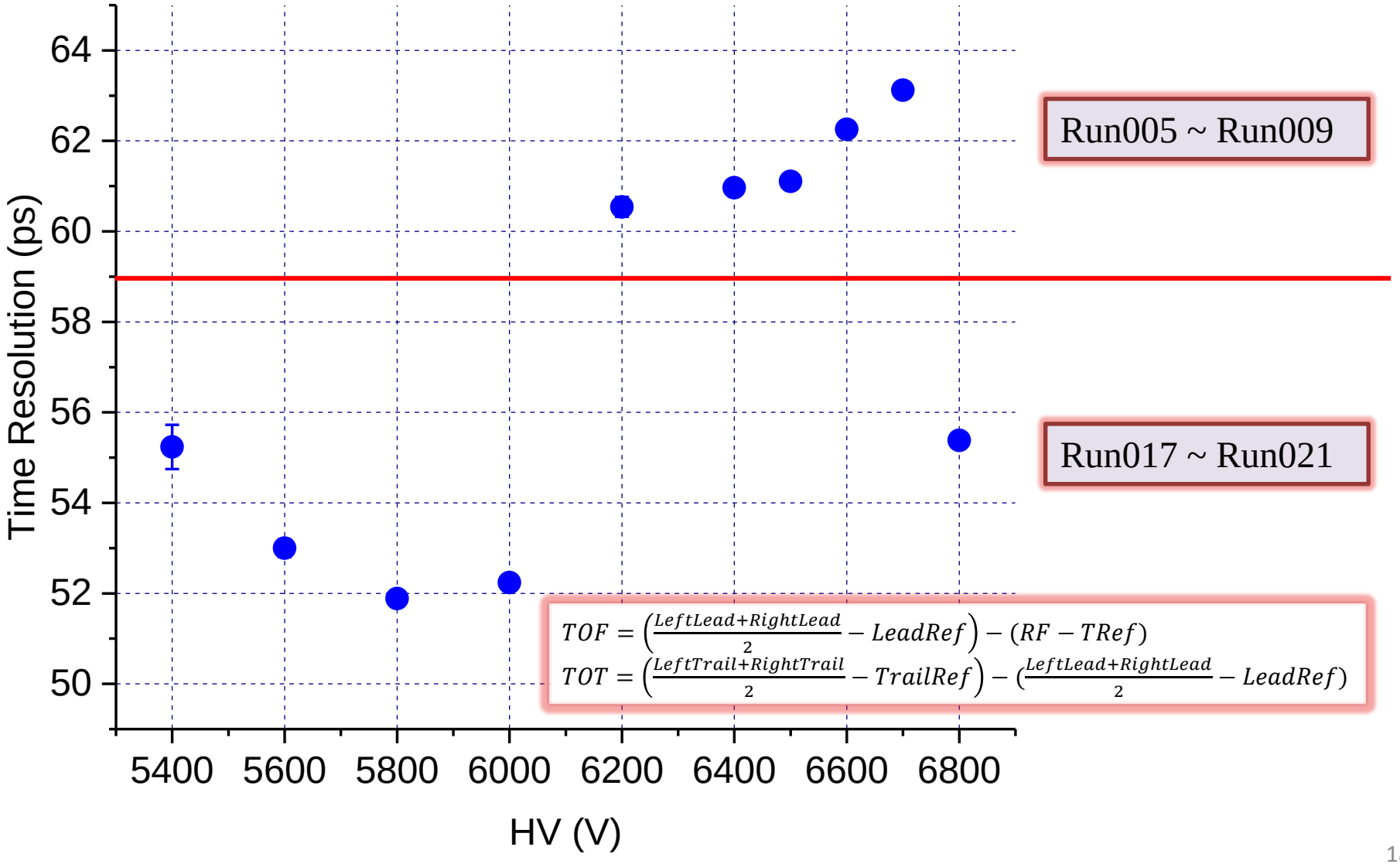


HZDR HV Scan: Efficiency



HV/V	Efficiency
±5400	6.7%
±5600	26.0%
±5800	49.8%
±6000	69.9%
±6200	83.1%
±6400	86.6%
±6500	89.0%
±6600	91.1%
±6700	92.6%
±6800	93.9%

HZDR HV Scan: Time Resolution



HZDR Rate Scan

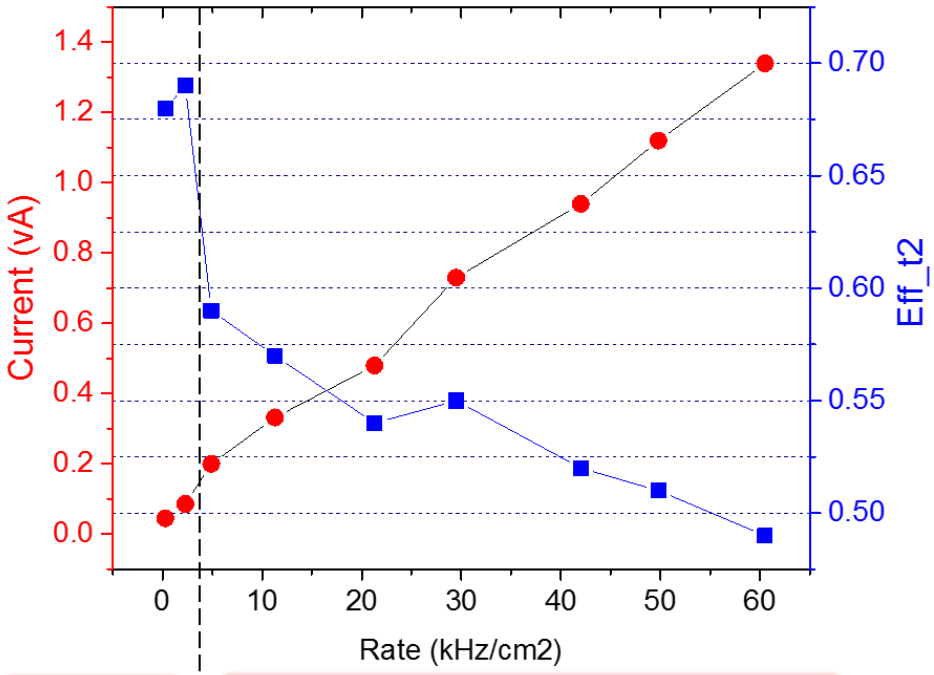
Rate scan plan: at ±7000V

Rate/ kHz/cm²	Eff_t2
0.35	96%
2.3	96%
5	×
10	×
20	×
30	×
40	×
50	×
60	×

Actual rate scan: at ±6000V

Rate/ kHz/cm²	Eff_t2
0.35	68%
2.3	69%
4.9	59%
11.3	57%
21.3	54%
29.5	55%
42	52%
49.8	51%
60.5	49%

Current and efficiency in the rate scan:



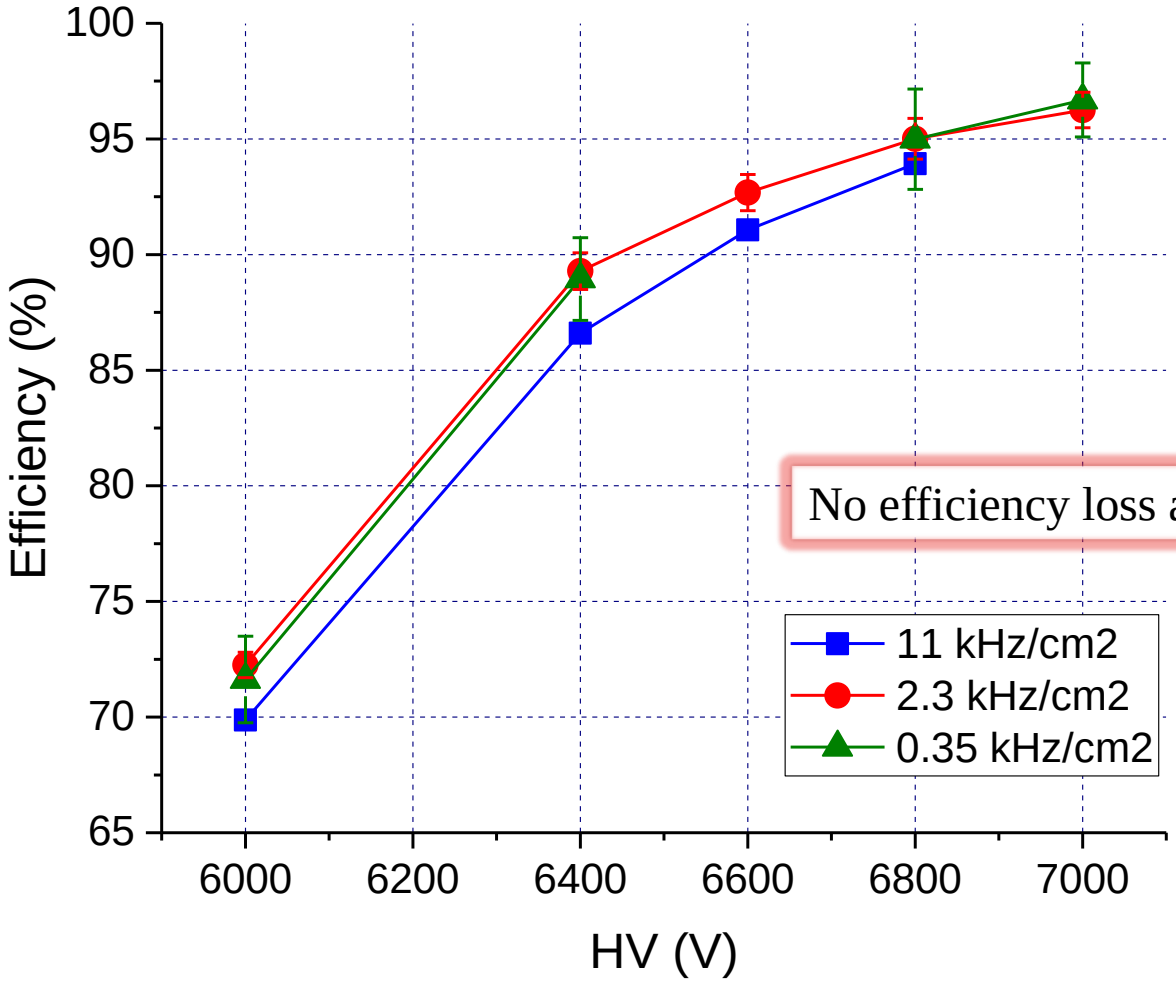
Before

After the MRPC was damaged.

When increasing from 2 kHz/cm² to 5 kHz/cm², rate went directly to 120 kHz/cm². Current went up to 8 μA. After 10 s, rate dropped back to 5 kHz/cm², but **MRPC can't work** anymore.

HZDR Rate Scan: Efficiency

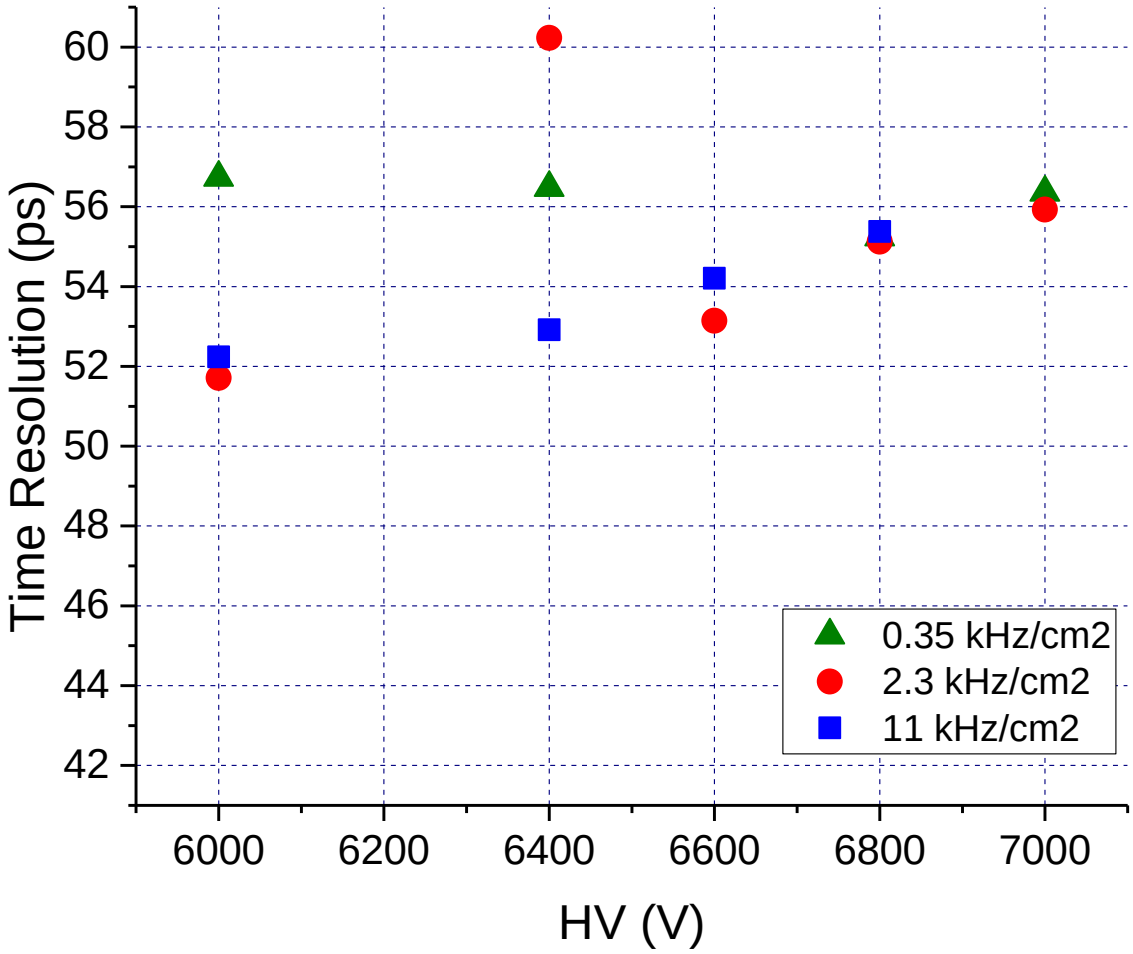
HV scan at different rate of 0.35 kHz/cm^2, 2.3 kHz/cm^2 and 11 kHz/cm^2 before the MRPC was damaged.



No efficiency loss at 2.3 kHz/cm^2.

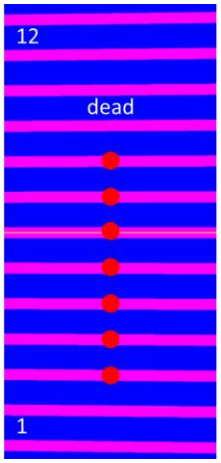
HZDR Rate Scan: Time Resolution

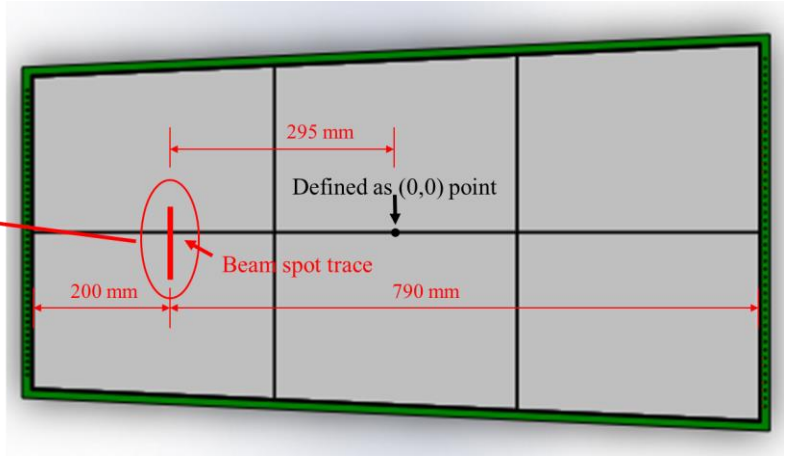
HV scan at different rate of 0.35 kHz/cm^2, 2.3 kHz/cm^2 and 11 kHz/cm^2 before the MRPC was damaged.



HZDR Position Scan

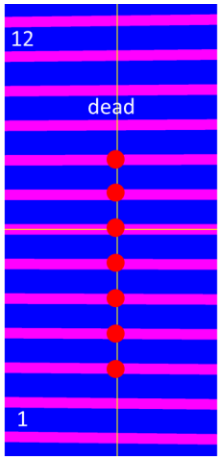
Two position scan at 295 mm and 165 mm from zero point.

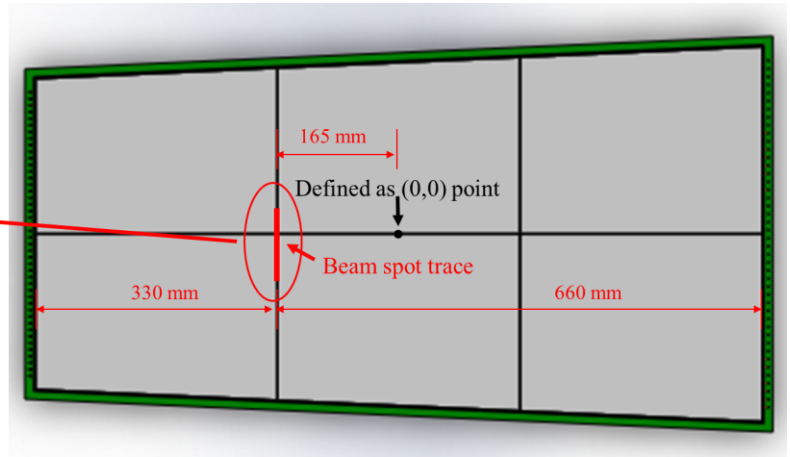




Position scan at horizontal position – 295 mm.

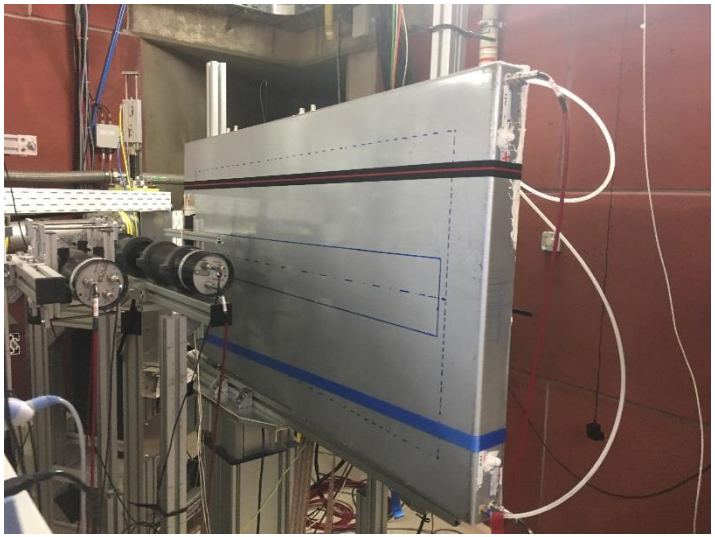
PMT Trigger (S1&S2&S3&S4) dimension: 20 × 20 mm^2. Beam spot dimension: 100 mm in diameter.

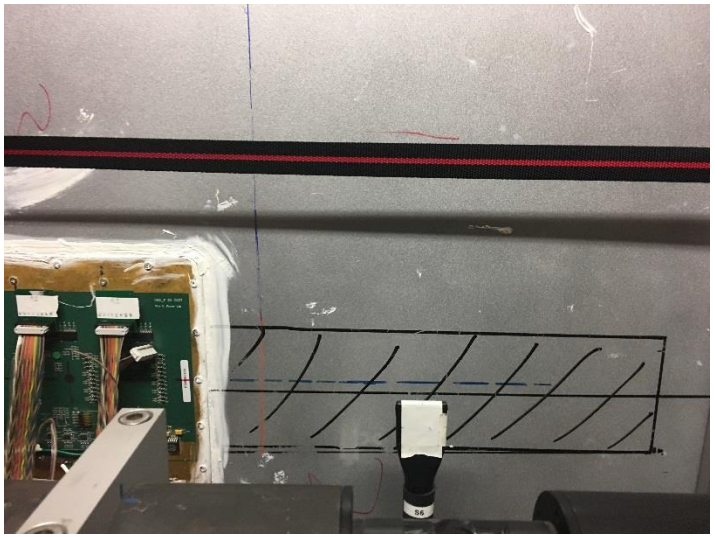




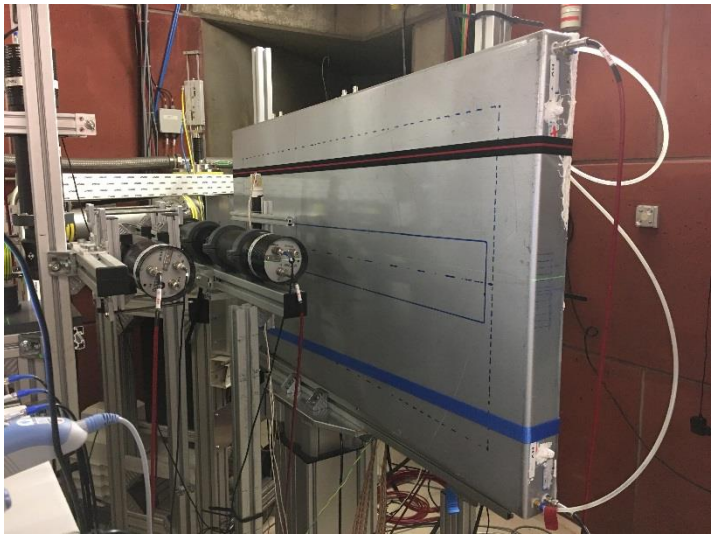
Position scan at horizontal position – 165 mm (mosaic interface).

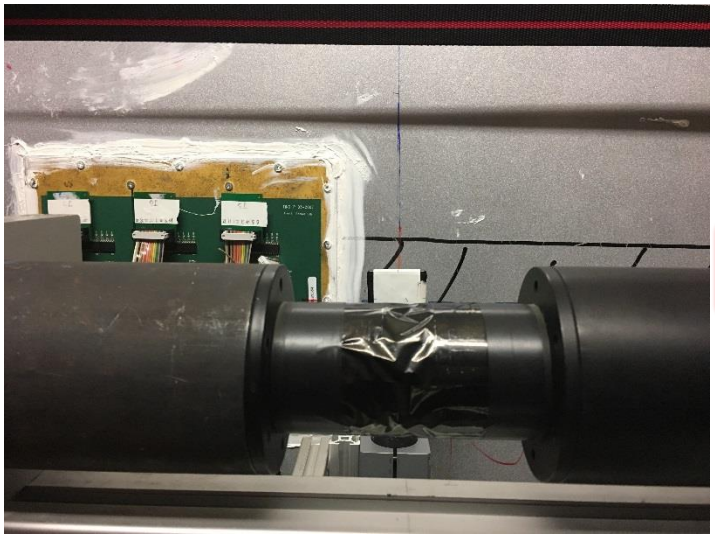
HZDR Position Scan





At – 295 mm.



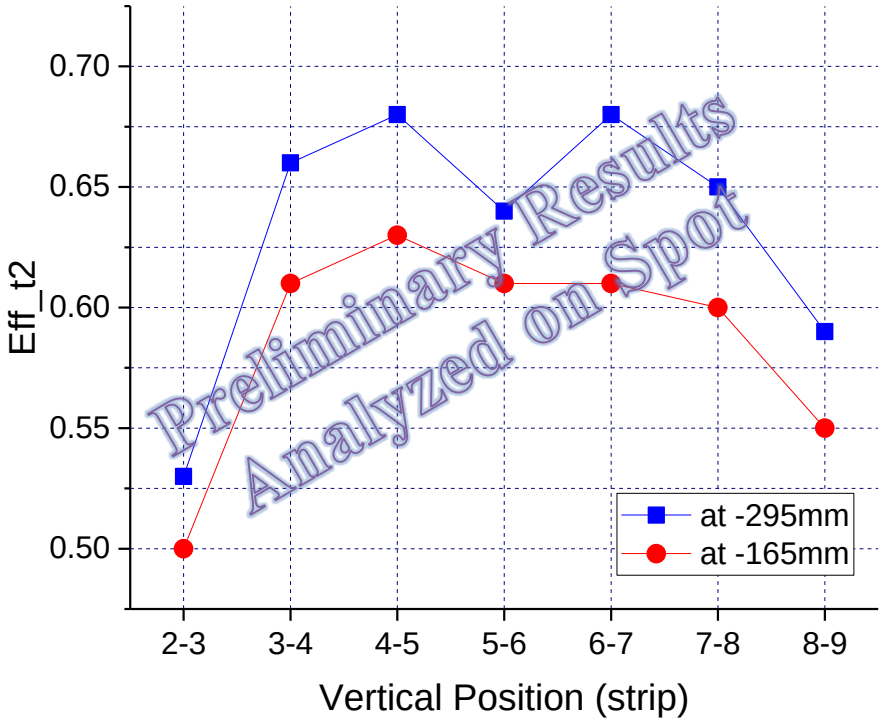


At – 165 mm.

HZDR Position Scan

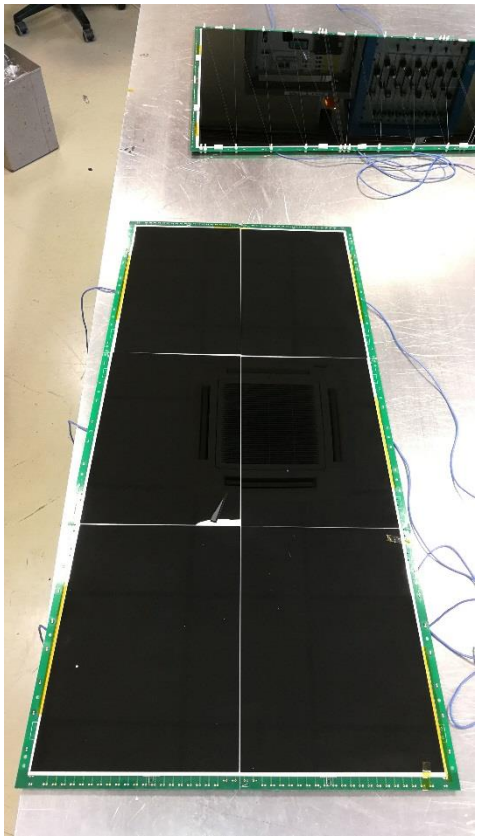
Position scan at rate 10 kHz/cm^2, HV ±6000V.

Position	-295 mm	-165 mm
2-3	53%	50%
3-4	66%	61%
4-5	68%	63%
5-6	64%	61%
6-7	68%	61%
7-8	65%	60%
8-9	59%	55%

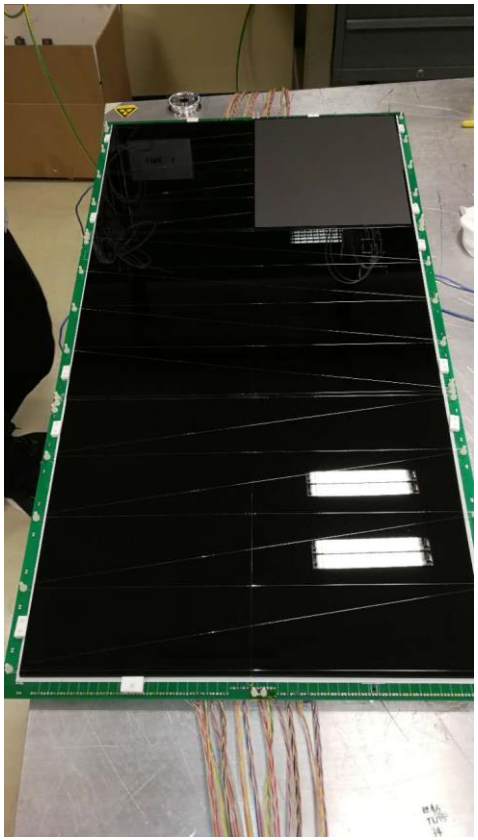


Vertical mosaic interface's influence on efficiency is more obvious, around 5% lower.

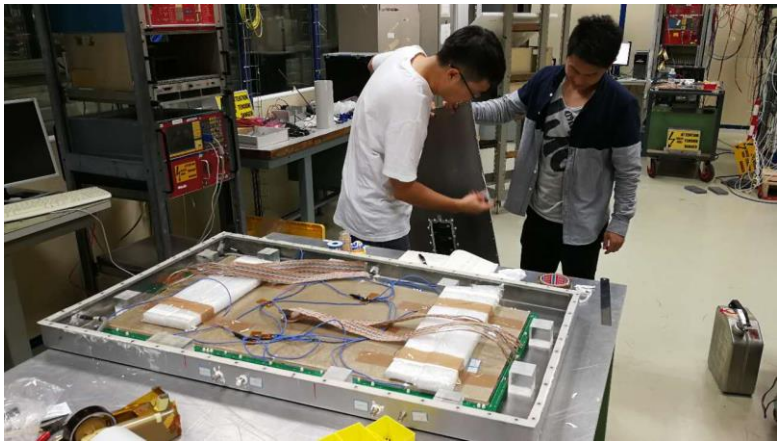
GIF++ beamtest: Preparation



Before repair

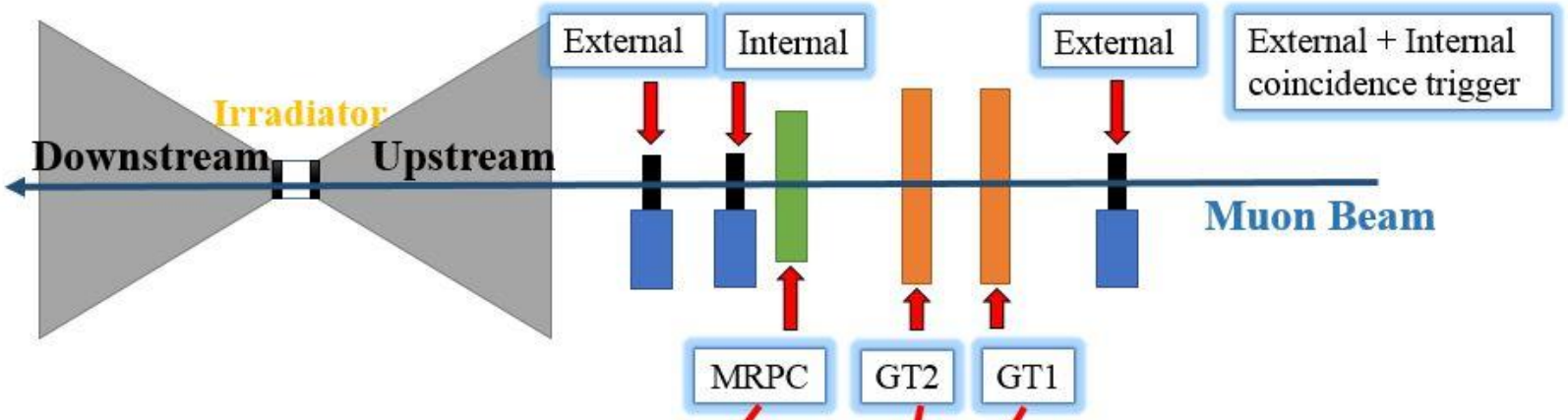


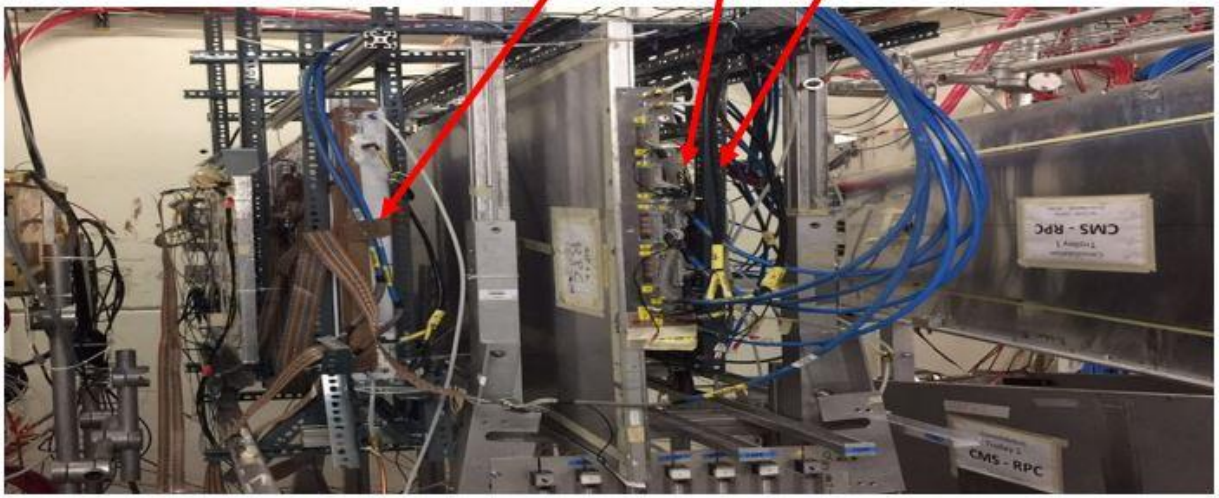
After repair



- Chamber has been repaired at CERN in Sep, 2017
- It was flushed with CMS gas: **95.2% $C_2H_2F_4$ + 4.5% i-C_4H_{10} + 0.3% SF_6.**
- Dark current was **0.02 μA** at ±5000 V

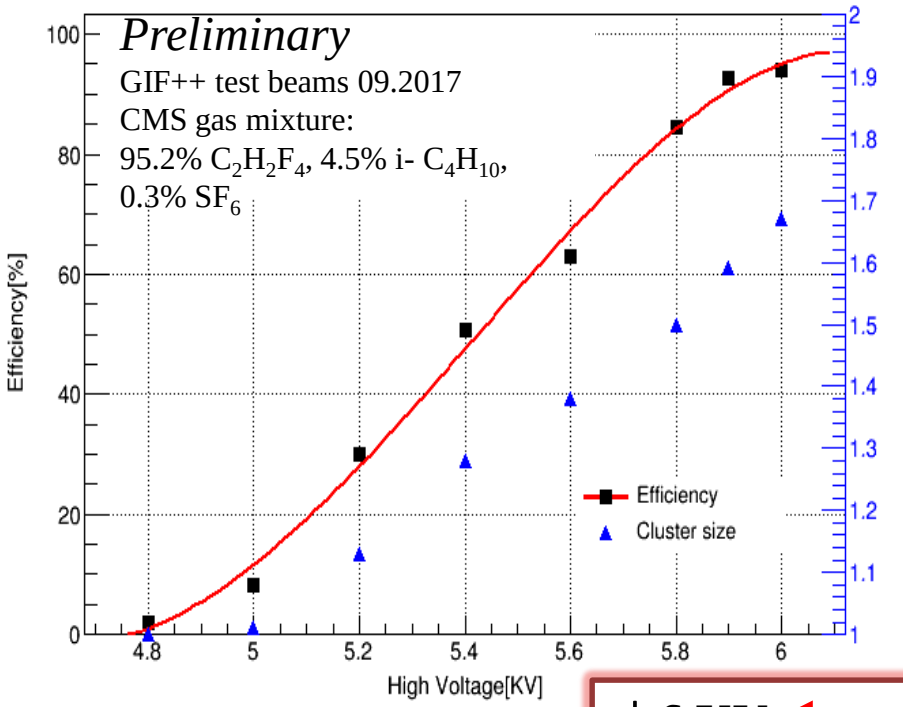
GIF++ beamtest: Setup



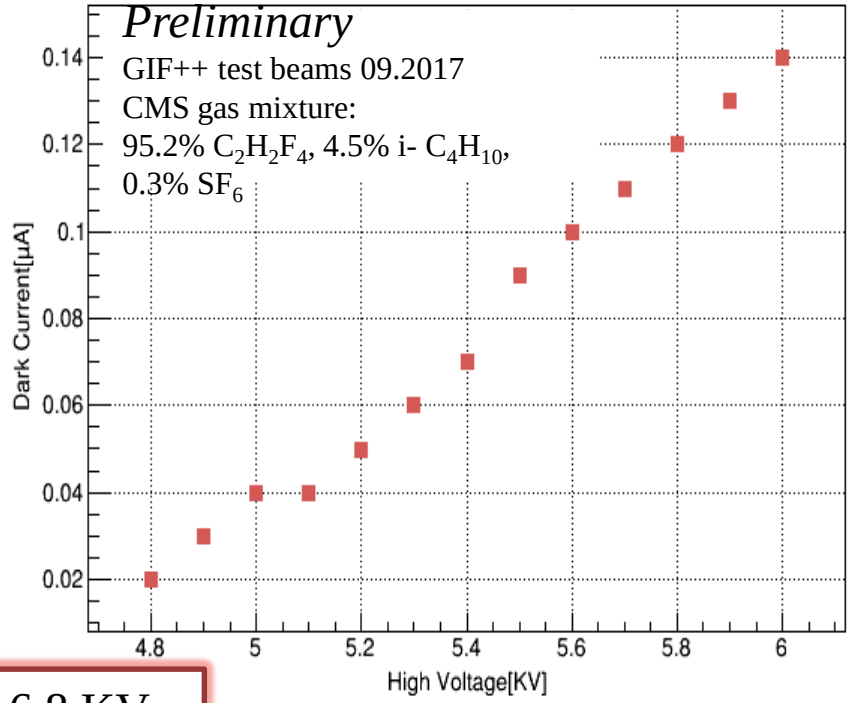


GIF++ beamtest:HV Scan

Source off



(a)

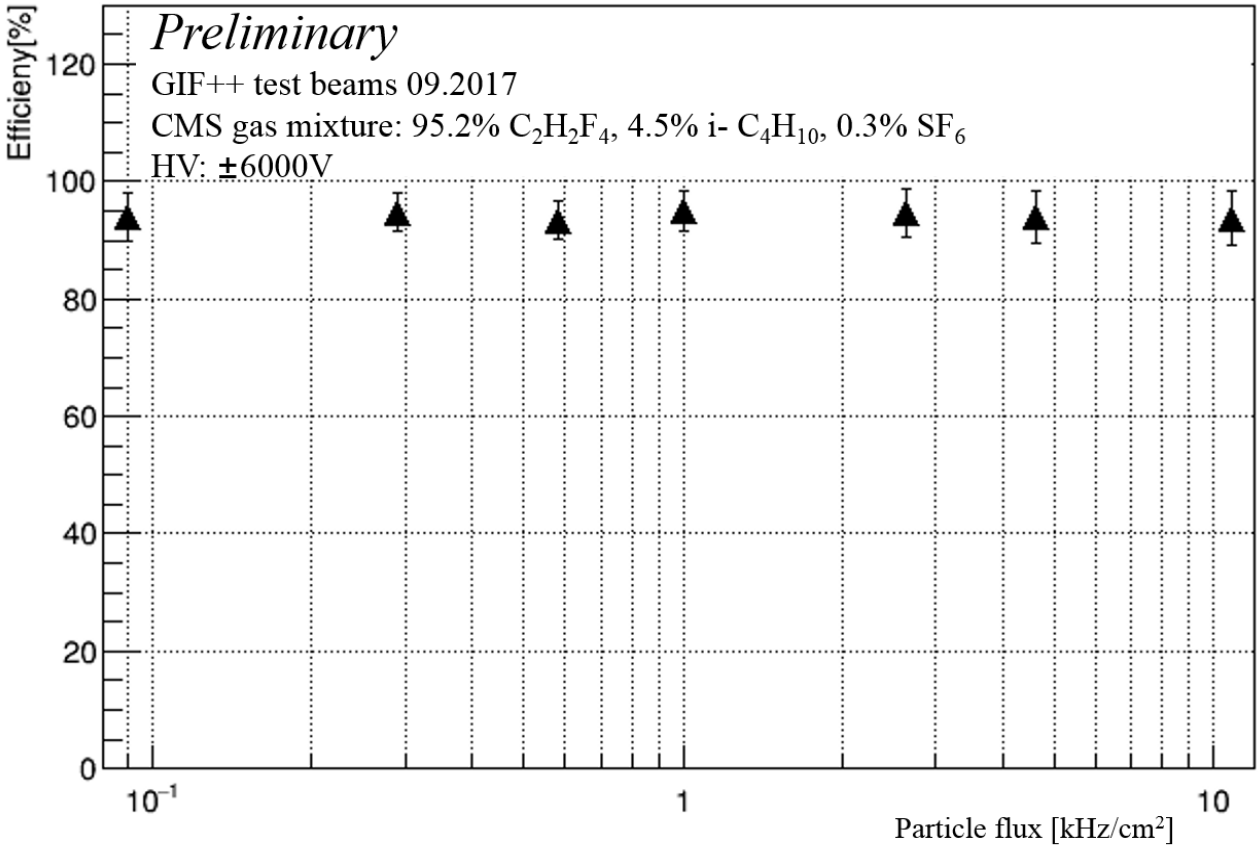


(b)

±6 KV ← ±6.8 KV

There is a big **working point shift** at different gas mixture!

GIF++ beamtest:Rate Scan



Rate[kHz/cm^2]	Efficieny[%]
0	94.12
0.29	94.81
0.58	93.41
1.007	95
2.64	94.68
4.64	93.93
10.83	93.75

- There is no efficiency loss along with high rate. Efficiency always reaches about 94% at ± 6000V.

Study of impedance

- **Impedance matching** of the signal transmission line to the input impedance of the front-end electronics is very critical.
- The impedance test platform based on Digital Sampling Oscilloscope (DSA8300) has been set up.
- It allows for differential or common mode **TDR or S-parameter** testing of two coupled lines.

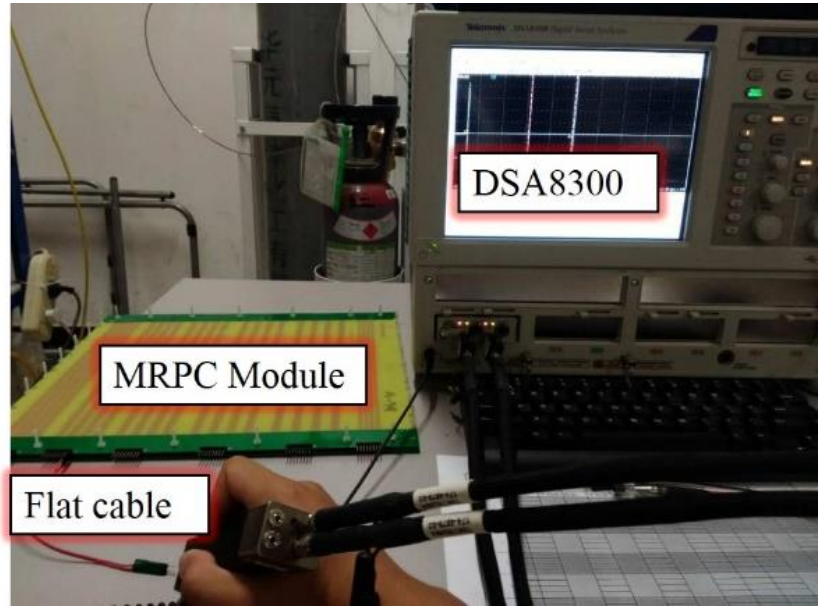
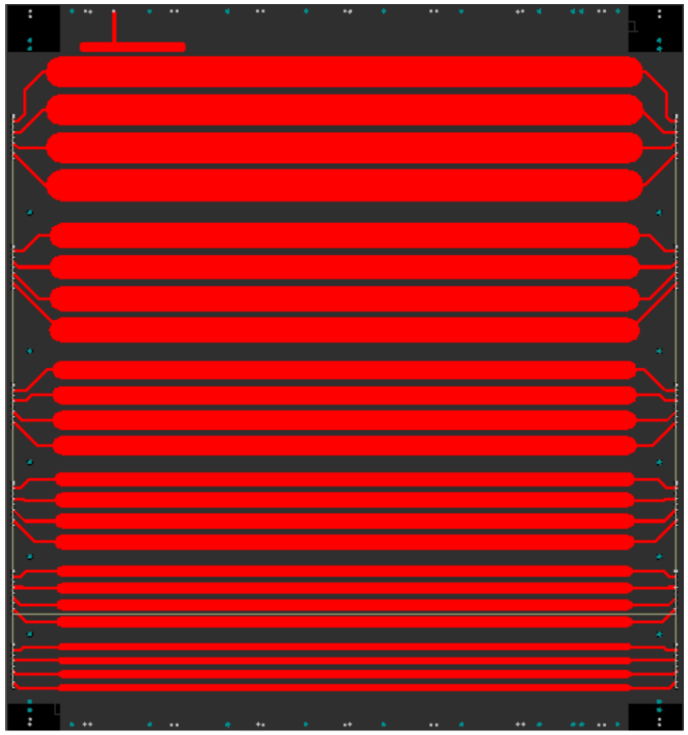


Figure 1 Impedance Test Platform

Figure 2 Differential TDR Waveforms

Study of impedance



PCB Design with different width of strips

MRPC parameters:

- Strips width : 3.5, 5, 7, 9, 12, 15(mm)
- The number of gas gaps: 4, 6, 8
- The number of stacks: 1, 2, 3, 4
- The thickness of gaps: 0.12, 0.20, 0.28(mm)

  ----Determined by fishing line
- The thickness of **float glass**: 0.23, 0.7 (mm)

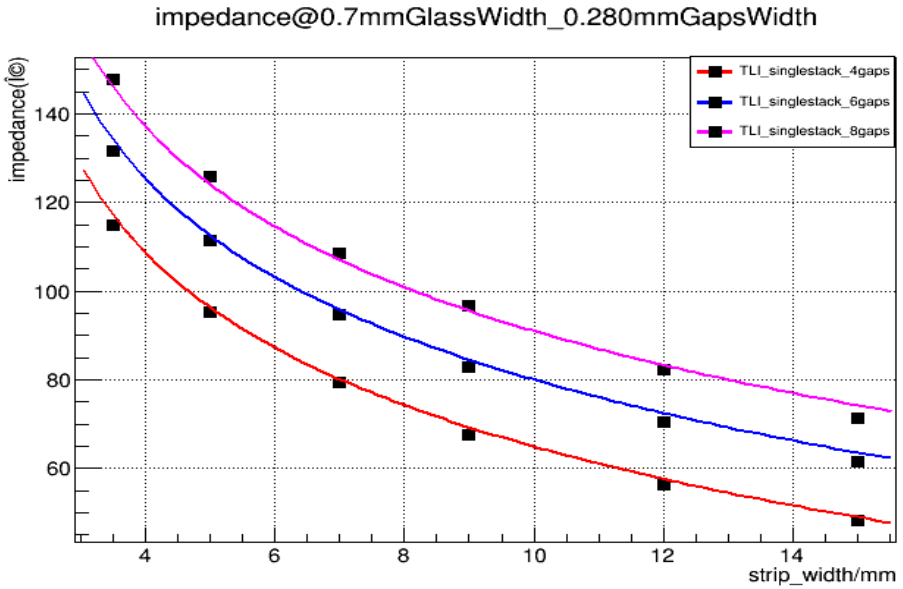
➢ **72** kinds of different structures of the detectors have been finished and tested

➢ **432** sets of impedance data

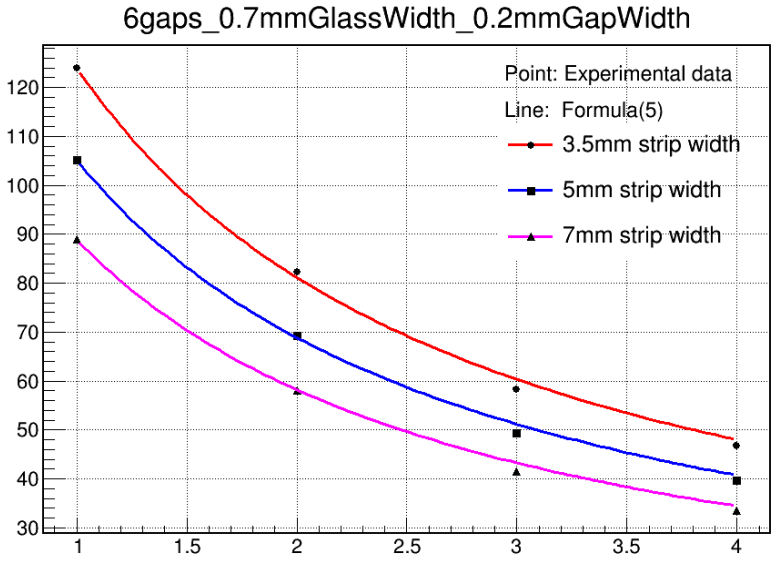
Study of impedance

Goal:

- Study on the relationship between the impedance and the width of strip, the thickness of gaps……
- Develop an approximate formula for impedance estimation



Impedance Results of three single-stack MRPCs

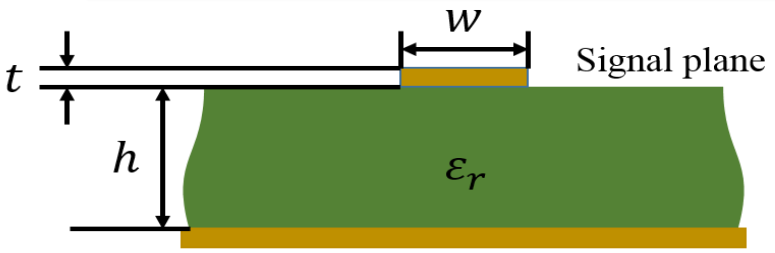


Impedance Results of MRPC with different stacks

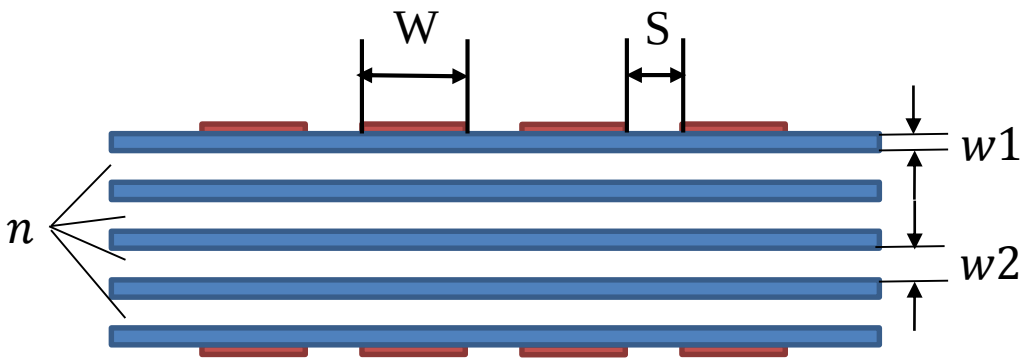
$$Z \propto \log \frac{a}{widthofstrip + b}$$

$$Z_{0,ns} = \frac{(1 + 0.895) \times Z_{0,single-stack}}{ns + 0.895}$$

Study of impedance



$$Z_0 = \frac{87}{\sqrt{\varepsilon_r + 1.41}} \ln \frac{5.98h}{0.8w + t}$$



Coefficients: $a(1) - a(8)$
Number of gas gaps: n
Number of stacks: ns
Width of glass: w1
Width of gaps: w2
Width of strips: w
Equivalent dielectric constant: ε

Approximate formula for different-stack MRPC based on float glass:

$$Imp = \frac{\frac{a(1)}{\sqrt{\varepsilon + a(2)}} \times \log \frac{a(3) \times n \times w2 + a(4) \times (n+1) \times w1}{w - a(5)} + a(6) \times \sqrt{\frac{w}{n \times w2 + (n+1) \times w1}} + a(7) \times \log \frac{w1}{w2}}{ns + a(8)}$$

$$\varepsilon_{eq} = \left(\frac{n \times w2 \times \sqrt{\varepsilon_{air}} + (n+1) \times w1 \times \sqrt{\varepsilon_g}}{n \times w2 + (n+1) \times w1} \right)^2$$

Study of impedance

The coefficients have been determined by analysing experimental data by **nonlinear least squares** (NLS) algorithm with MATLAB.

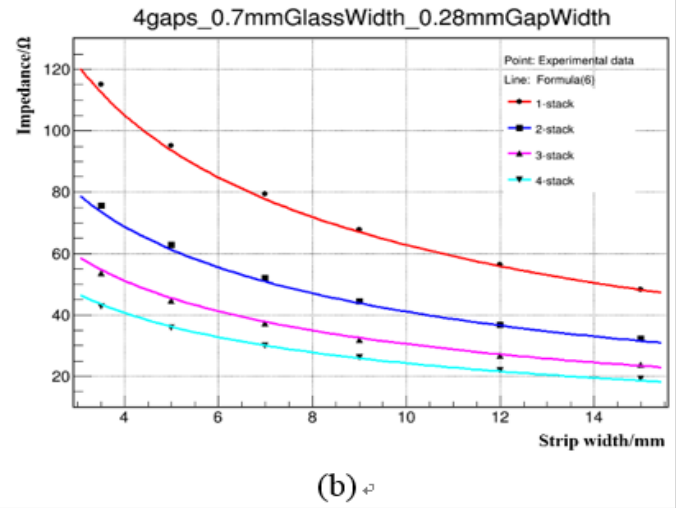
Coefficients: $a(1) - a(8)$

406.3467 ± 15.0495
8.6294 ± 1.0010
6.1138 ± 0.1998
0.6871 ± 0.0606
0.5577 ± 0.0289
59.0823 ± 1.8964
37.5319 ± 1.8673
0.895 ± 0.0089

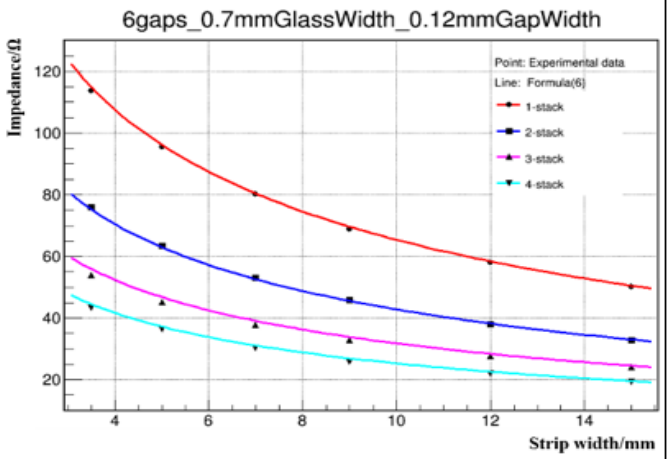
RMSE= 1.2043

R-square= 0.9977

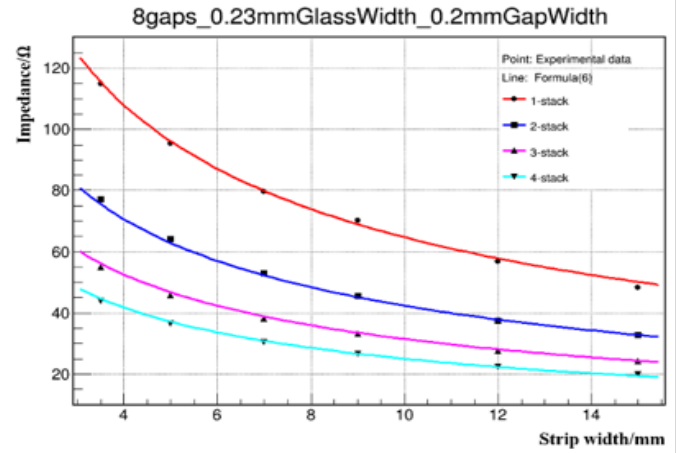
(a)



(b)



(c)



(d)

Summary

- A good solution to develop **large area high rate MRPC**
  - Cosmic ray test at CERN
  - ✓ Efficiency above 95% at ±6800V.
  - 30 MeV electron beam at HZDR at rate of 10kHz/cm^2
  - ✓ Efficiency 95% , time resolution around 55ps at ±6800V
  - ✓ Efficiency loss at mosaic interface is very low.
  - GIF++ beamtest with CMS dry gas
  - ✓ Efficiency can reaches about 94% at ±6000V at rate of 10kHz/cm^2.
- **New material--Low resistive glass**
  - Working voltage shift at different gas mixture.
- **An approximate formula** for the impedance of MRPC based on float glass has been proposed.

Thank You!

- Yu Yancheng
- Department of Engineering Physics,
- Tsinghua University, Beijing, China

- June 29th, 2018

Backup

Structure and performance of small mosaic MRPC

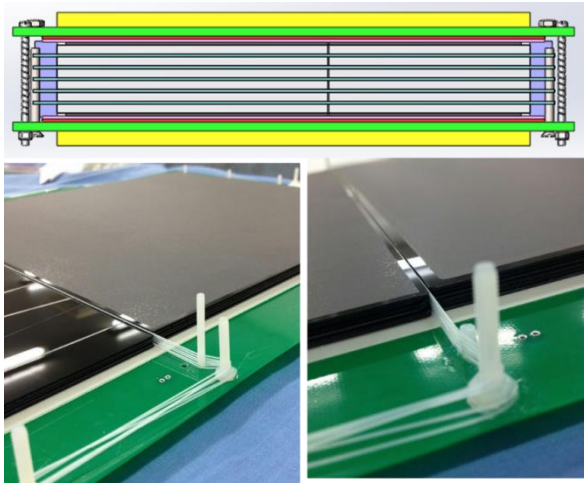


Fig.1 structure of mosaic MRPC

Table 1 Component of mosaic MRPC

MRPC Component	Size (mm)
Honey Comb	255×472×6
PCB	320×540×0.7
Mylar	260×480×0.18
Mosaic Glass	250×470×0.7 & 250×200×0.7
Spacer	0.5
Gap	0.25×5

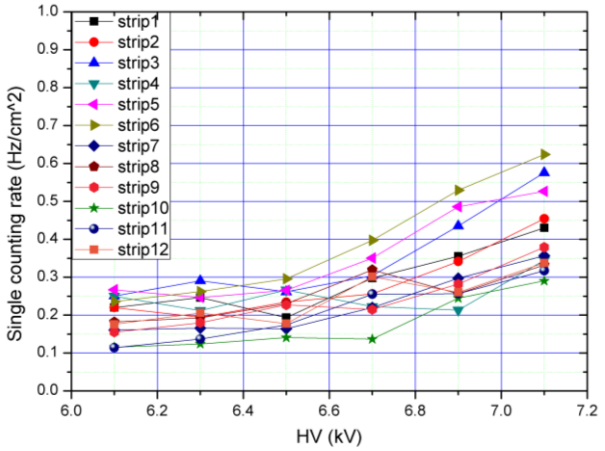


Fig.2 Noise rate

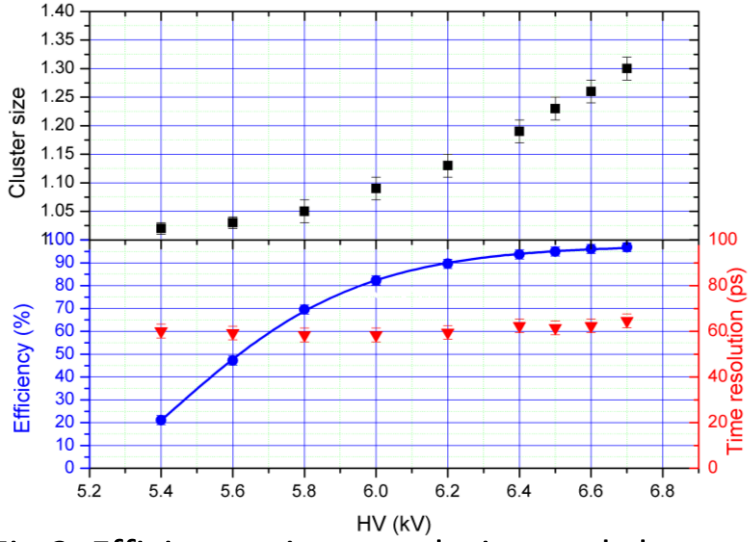


Fig.3 Efficiency, time resolution and cluster size

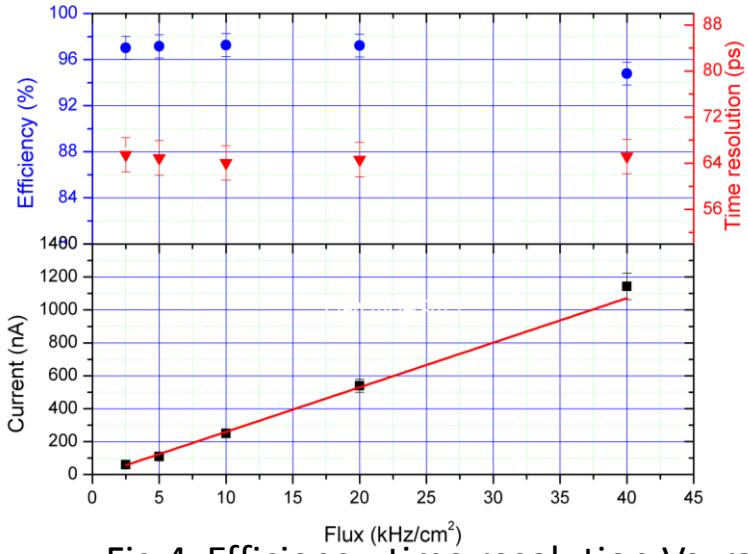
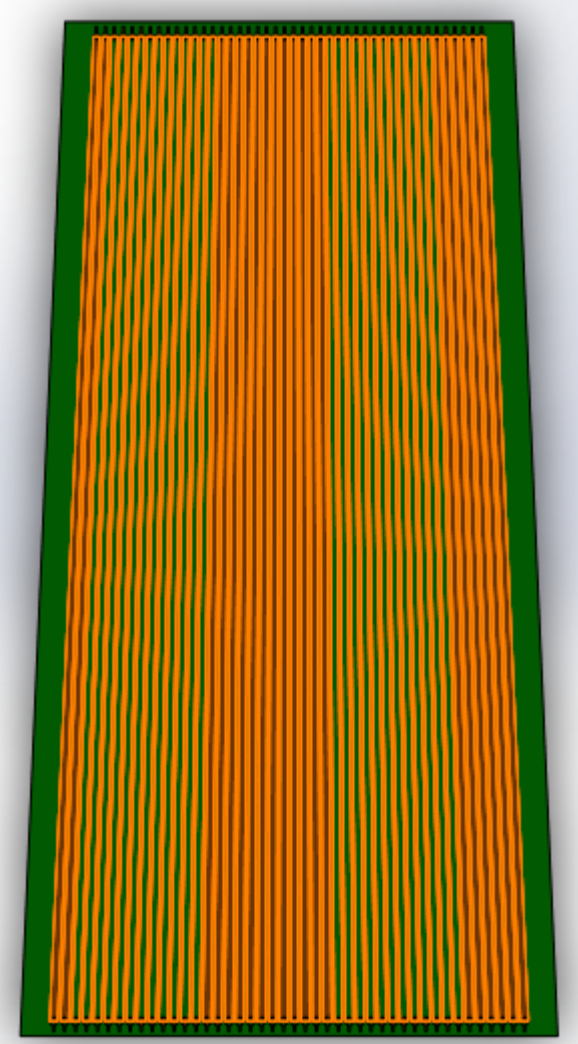


Fig.4 Efficiency, time resolution Vs. rate

Introduction of the mosaic MRPC



Gap number: 5

Gap width: 250 μm

Glass thickness: 0.7 mm

Bulk resistivity: ~ 10^{10} Ωcm

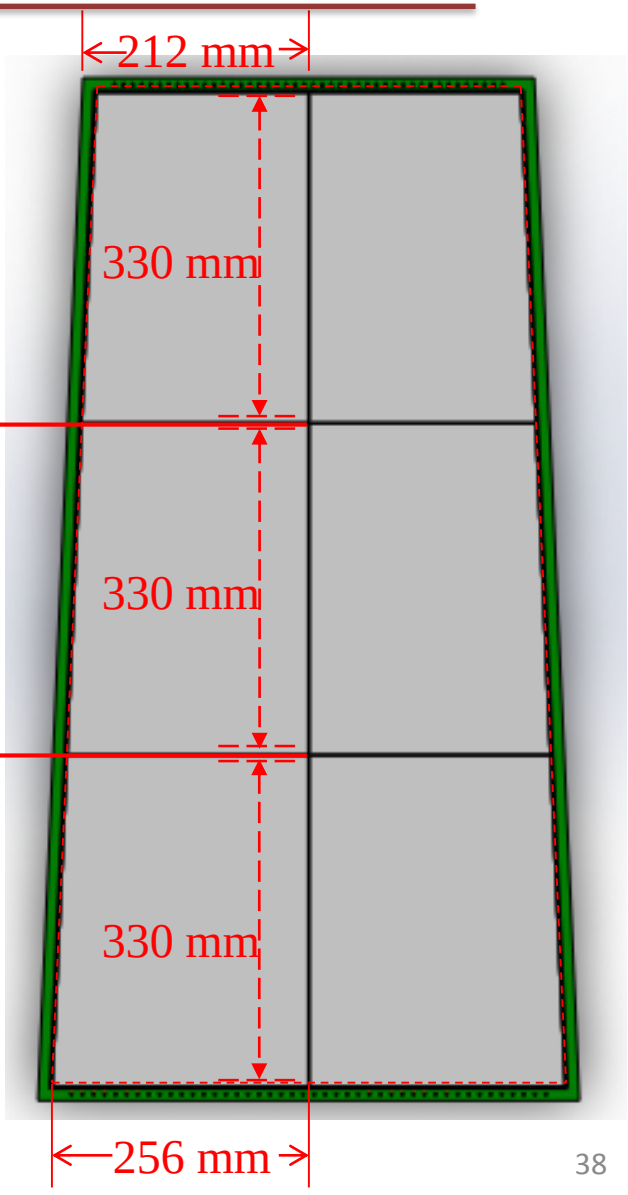
0.5 mm-wide fishing line block

Strip number: 44

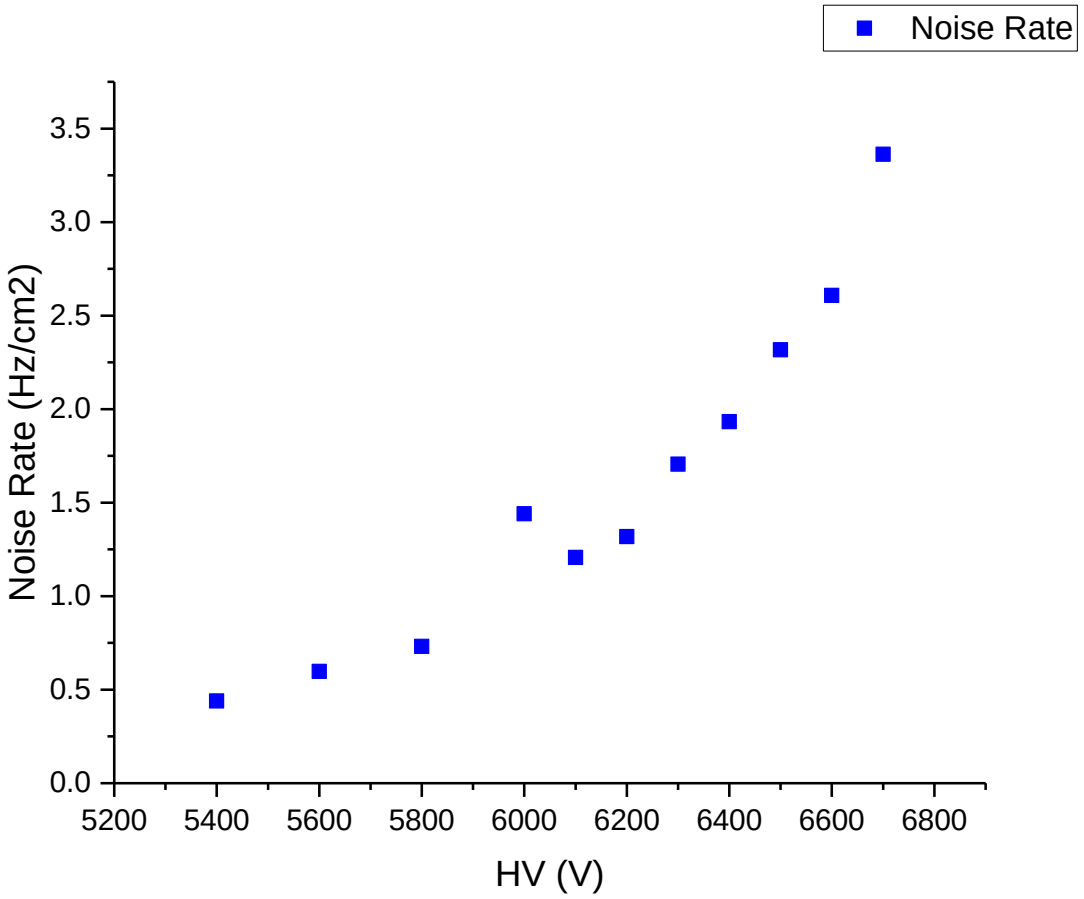
Strip shape: trapezoidal (Narrow side 6 mm, Wide side 8mm)

Internal width between strips: 3mm

Strip length: 1 m



Cosmic Test: Noise Rate



Geometry of HZDR beamtest setup

The geometry of the setup is as follows:

element	material	thickness mm	width mm	height mm	diameter mm
window	Be	0.2			40
drift	air	140			
S24	BC408	2			40
drift	air	133			
S25	BC408	2			40
drift	air	225			
S1S2	BC418	5	20	20	
drift	air	115			
S14	BC408	2.5	5	15	
drift	air	105			
S13	BC408	2.5	15	5	
drift	air	25.00			
box	aluminum	3			
MRPC	glass	215			
drift	working gas	435			
box	aluminum	3			
drift	air	650			
S6	BC408	5	35	35	
drift	air	155			
S3S4	BC418	5	20	20	

HZDR beamtest: Setup

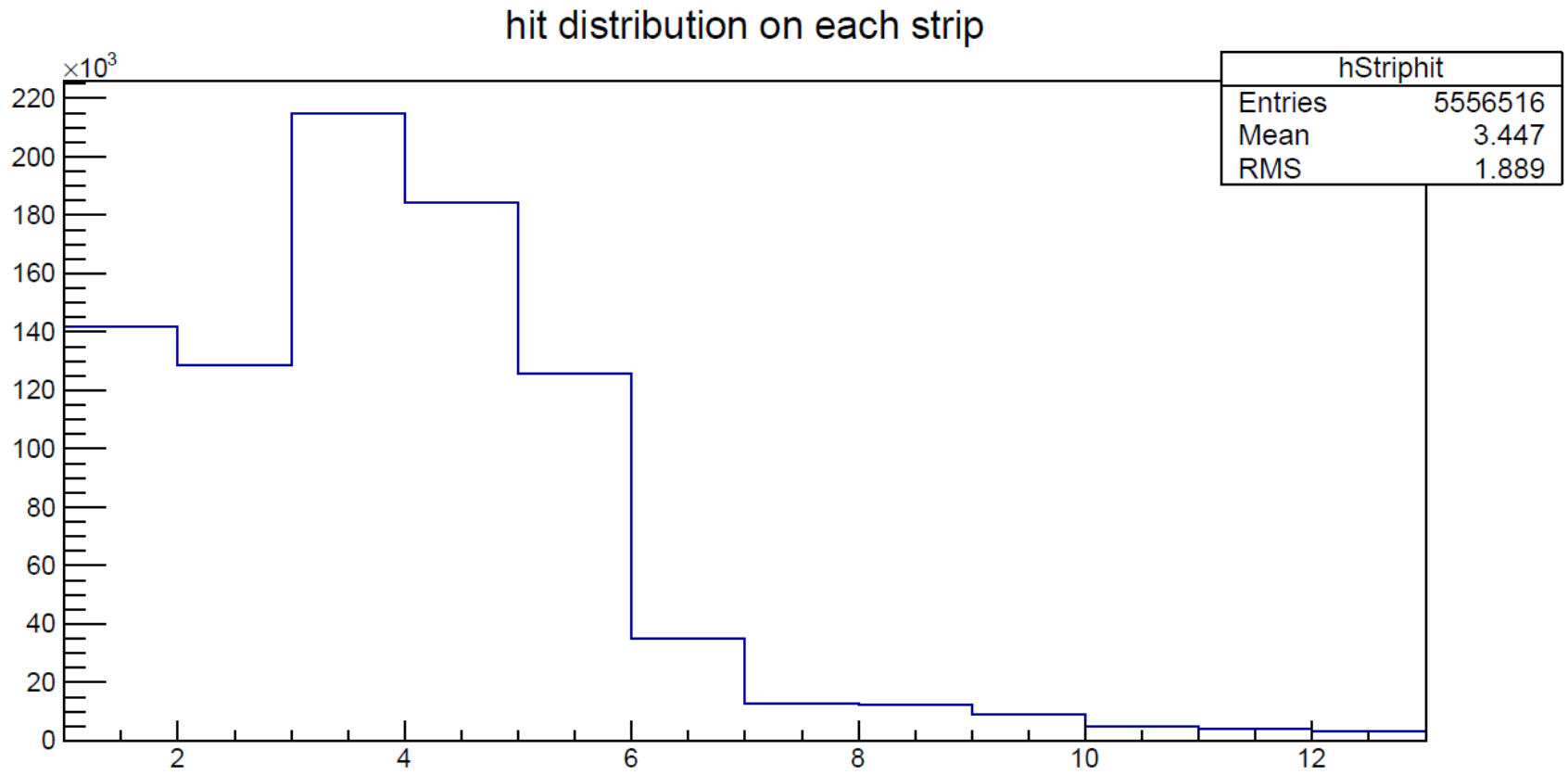
Timing of trigger.

Coincidence of scintillators: S1&S2&S3&S4.

R_F: Accelerator clock.

TDC trigger: S1&S2&S3&S4 & R_F.

Run005: Efficiency

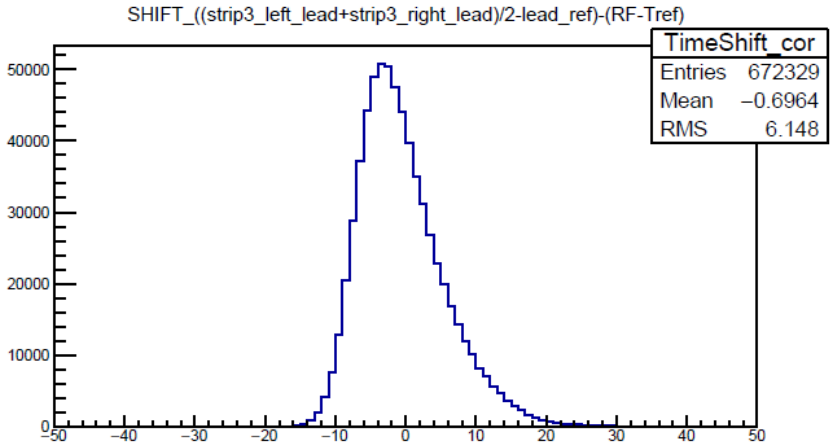


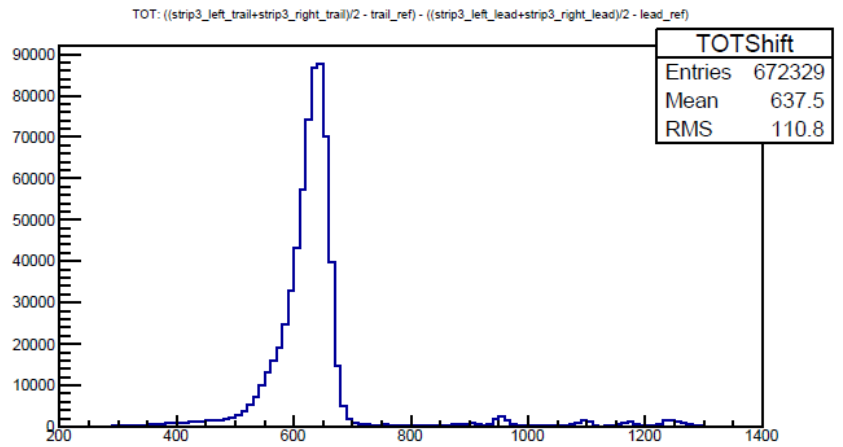
Efficiency

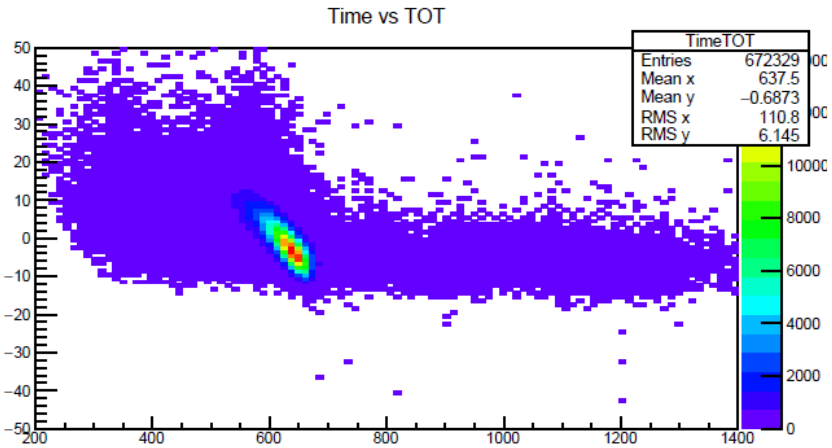
No cut: $\frac{Tref \;\&\&\; MRPC}{Tref}$ 93.62%

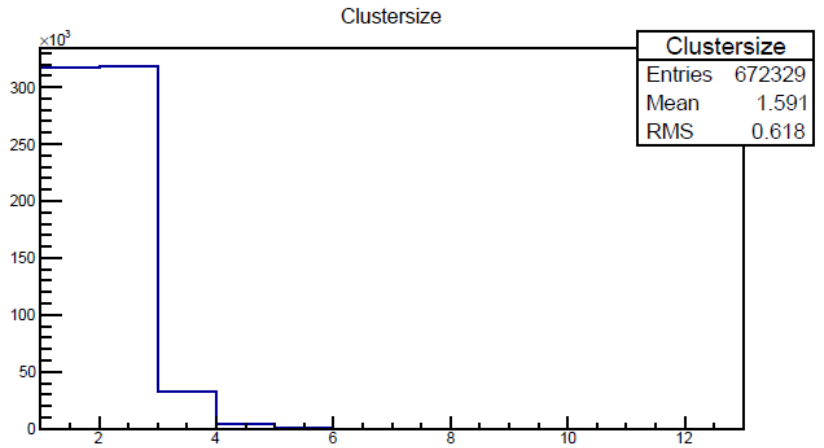
Cut on S6: $\frac{Tref \;\&\&\; S6 \;\&\&\; MRPC}{Tref \;\&\&\; S6}$ 93.93%

Run005: Time Resolution





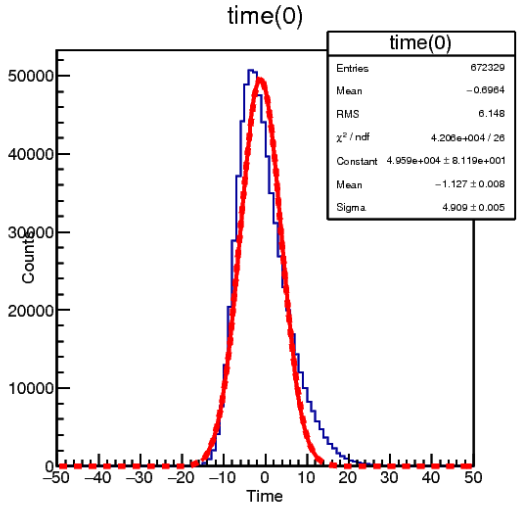


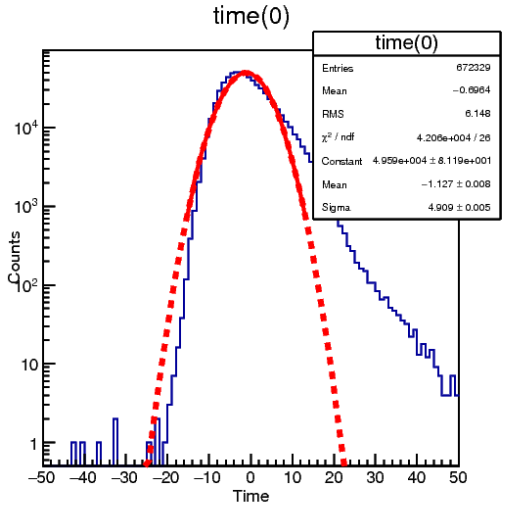


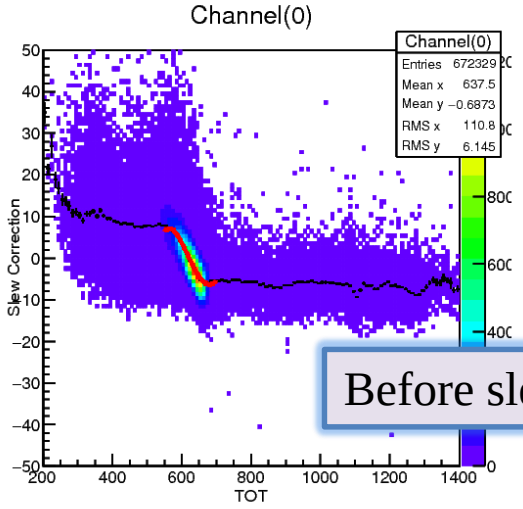
$$TOF = \left(\frac{LeftLead+RightLead}{2} - LeadRef\right) - (RF - TRef)$$

$$TOT = \left(\frac{LeftTrail+RightTrail}{2} - TrailRef\right) - \left(\frac{LeftLead+RightLead}{2} - LeadRef\right)$$

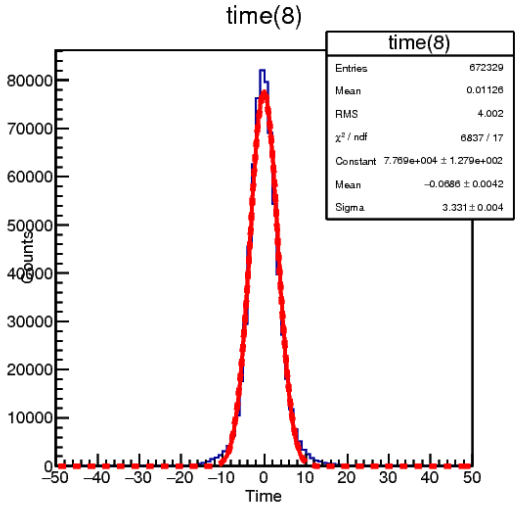
Run005: Time Resolution

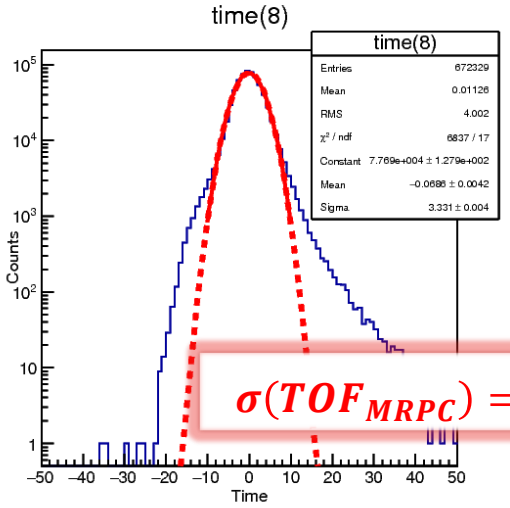


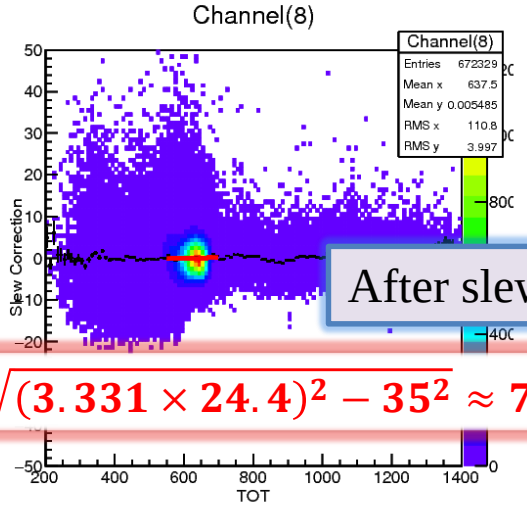




Before slewing







After slewing

$$\sigma(TOF_{MRPC}) = \sqrt{(3.331 \times 24.4)^2 - 35^2} \approx 73.4\ ps$$

HZDR Rate Scan: Efficiency

HV: ±6000 V