Basic R & D for HPLs Consisting of Melamine + Phenol: $\rho < 10^{11}$

M. S. Jeong (Korea Univ.)

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2. Why R & D of Multi-gap RPC?
3. Basic R & D for HPLs
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1. Introductions

RPCs : Gaseous detectors for trigger of high-energy particles

Designed by R. Santonico in 1981 {NIMA187(1981)377}.

Consists of thin layers of uniform gas gaps which form electrodes.

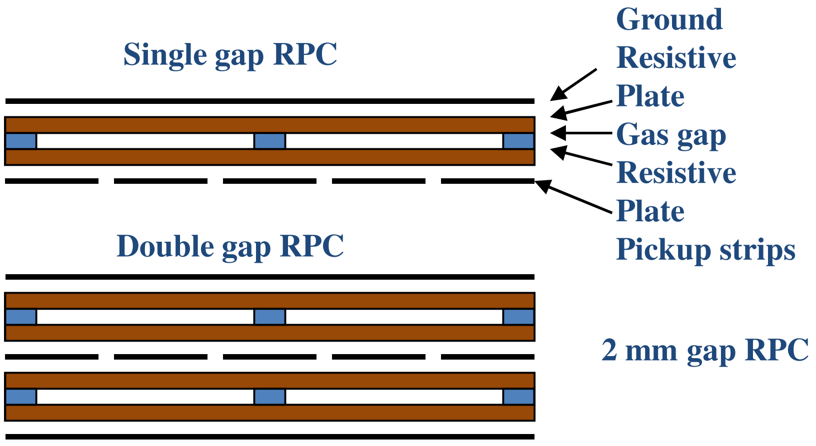
Materials for the RPC electrodes : high resistive plates to reduce spark noises

⇒ Bakelite, melamine, or glass plate

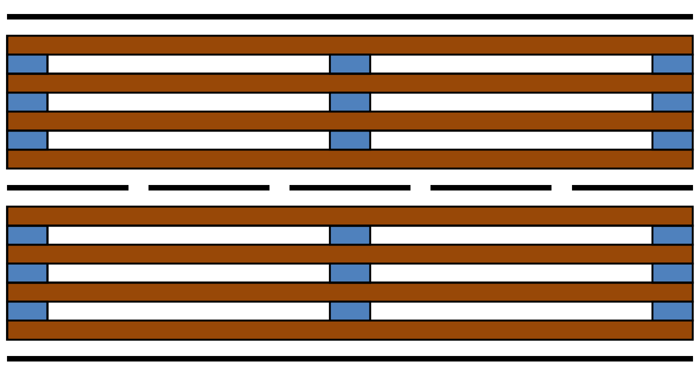
RPCs for LHC : 2 mm thick double gap RPCs

Timing RPCs for high time resolution

⇒ Multi-gap RPCs : gap thickness : 0.2 ~ 0.5 mm



Milti-gap RPC



0.3 ~ 0.7 mm gap RPC

Operation mode :

- Spark mode (original)

  BELLE (glass), Argo YBJ (HPL)

- Avalanche mode for high rate capability

  LHC (HPL), PHENIX (HPL), All timing RPCs (glass)

2. Why R&D of multi-gap RPCs for CMS ?

- Higher rate capability > 5 kHz/cm^2
- Aiming for future muon triggers at RE1/1 for CMS
- SLHC requires faster trigger with higher background

$$q_e = \sum_{i=1}^{m}\sum_{j=1} \frac{q_{el}}{\eta d} n_{0ij} M_{ij} k [e^{\eta(d-x_{ij})} - 1]$$

$$< q_e > = m \sum_{j=1} \frac{q_{el}}{\eta d} \mu k e^{\eta d} \left(\frac{\lambda}{\lambda+\eta}\right)^j$$

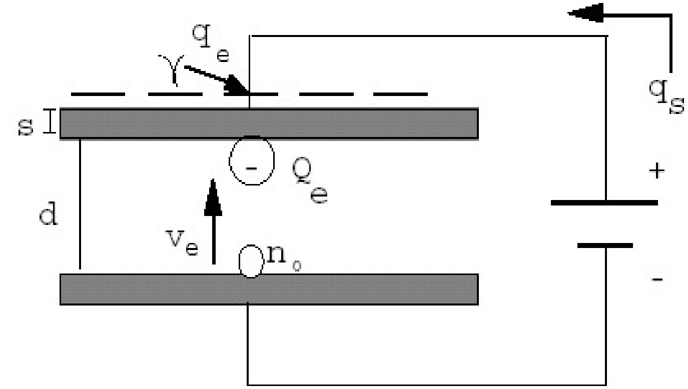
Higher rate with smaller avalanche charge

- Rate capability ~ 1 /<q_e> (actually depends on <Q_e>)
- Rate capability ~ 1/ ρ (ρ : resistivity of electrode material)

$$< Q_e > = \frac{\eta d}{k} < q_e > \qquad k = \frac{\epsilon_r d/s}{\epsilon_r d/s + 2}$$

Typical Timing RPCs consisting of multi-gap glass RPCs

- <Q_e> more than 10 times smaller compared to CMS RPCs
- ρ ~ a few 100 times larger compared to CMS RPCs
  10^{10} ~ 10^{11} for CMS/ATLAS RPCs, ~ 10^{13} for timing RPCs
- Rate capability < 1 kHz/cm^2 for timing RPCs



Then, what if multi-gap RPCs with HPLs ?

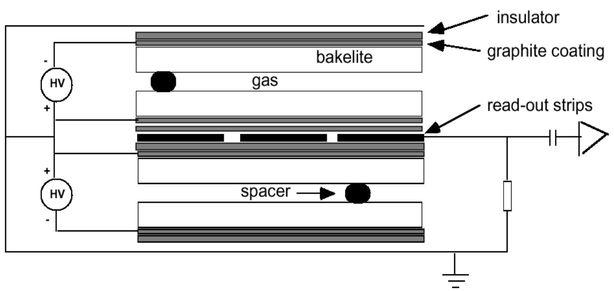
- <Q_e> ~ 10 times smaller compared to the current CMS RPCs
- New HPL : Melamine-Phenol-Melamine → ρ < 10^{11}
- Oiling required to reduce noises (nobody tried)
- Expected rate capability > 5 kHz/cm^2

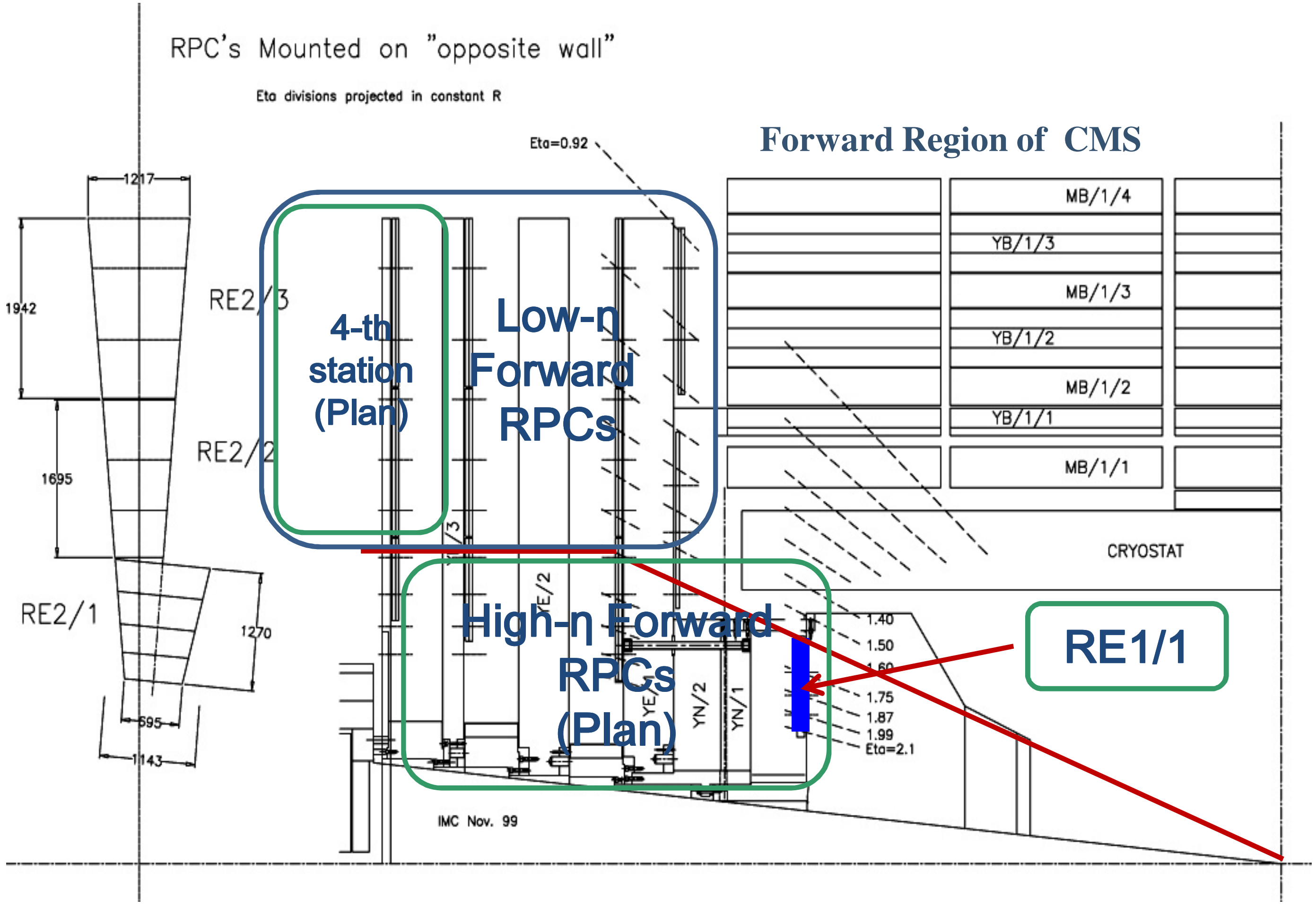
Advantage : we can keep the current RPC technology for the CMS trigger.

Disadvantage : more difficult in the detector construction compared to the current double-gap RPCs

Forward Region CMS RPCs System

Function : L1 muon triggers
2 wings (RE+, RE-)
4 stations (RE1, RE2, RE3, RE4)
Pseudo rapidity covering 0.9 < η <2.1 (1.6)
η segmentations : 10 (6)

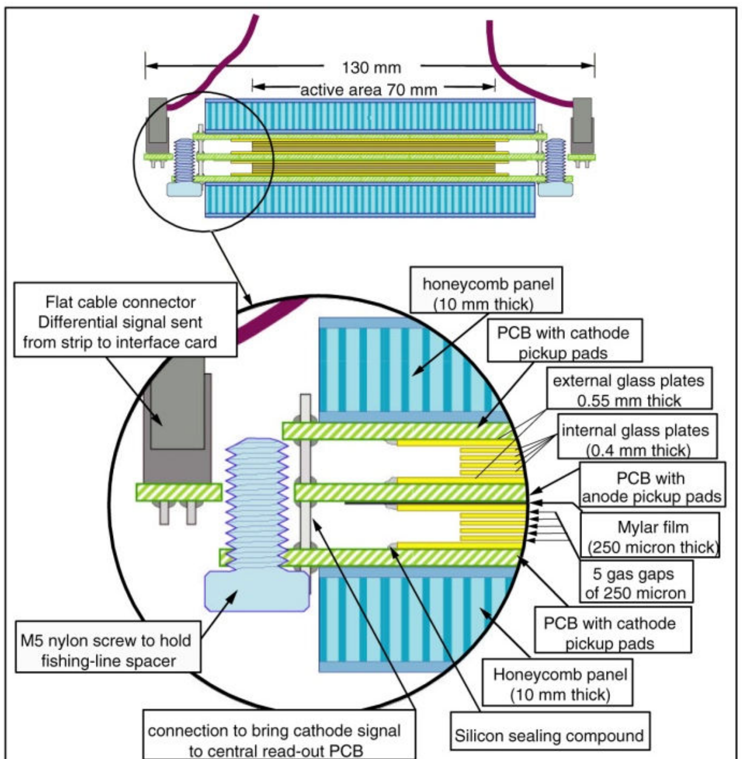




Benchmark

Multi-gap timing RPCs for ALICE (glass, C. Williams)

Cross section of double-stack MRPC - ALICE TOF



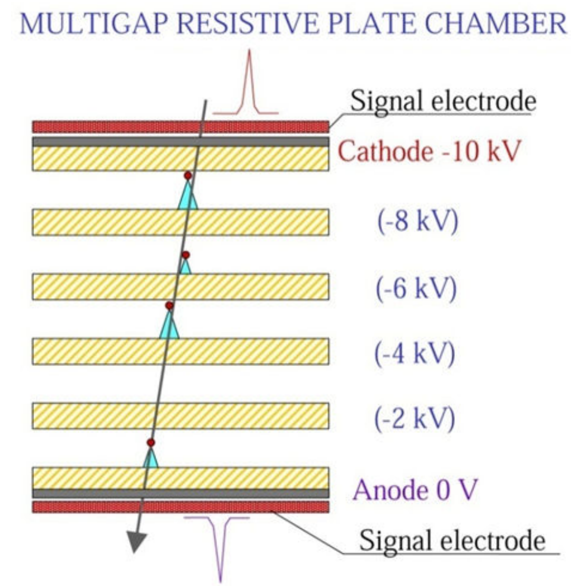
Double stack
- each stack has 5 gaps
(i.e. 10 gaps in total)

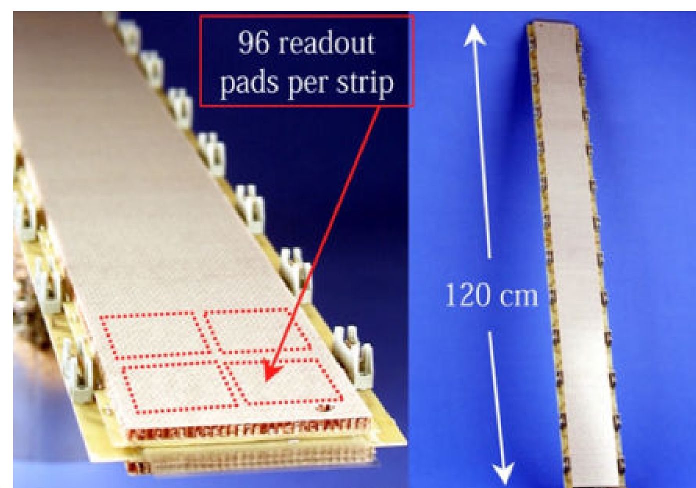
250 micron gaps with spacers made from fishing line

Resistive plates 'off-the-shelf' soda lime glass

400 micron internal glass
550 micron external glass

Resistive coating
5 MΩ/square





ALICE timing RPCs

N. Akindinov, et al., NIMA 533 74 (2004)

Time resolution σ ~ 50 ps

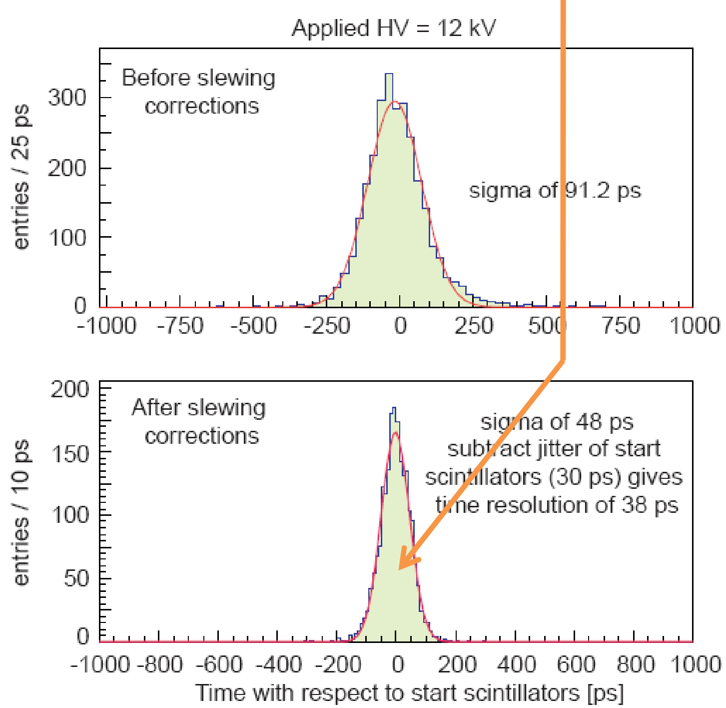


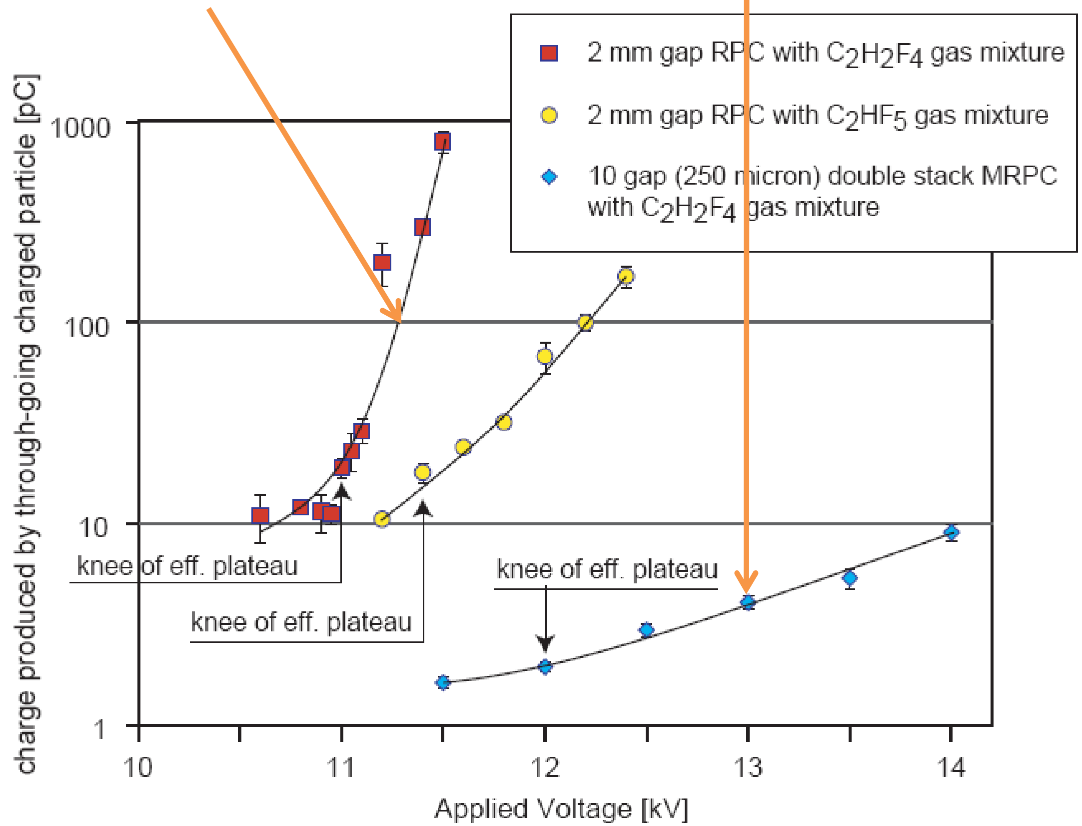
Fig. 3. Time distribution of MRPC before and after slewing corrections.

Mean avalanche charge induced in the gas volume

$$< Q_e > = \frac{\eta d}{k} < q_e > \qquad k = \frac{\epsilon_r d/s}{\epsilon_r d/s + 2}$$

Typical $<Q_e>$ for 2-mm double-gap RPCs (CMS) ~ 100 pC

Typical $<Q_e>$ for multi-gap RPCs ~ 4 pC



Choice of R&D for future CMS RPCs ?

- Higher rate capability > 5 kHz/cm^2
- Aiming for future muon triggers at RE1/1 for CMS
- SLHC requires faster trigger with higher background

→ Proposing 6-gap RPCs with melamine-phenol HPLs → $\rho < 10^{11}$

- First oiled multi-gap RPCs (for curing noises)

Multi-gap RPCs working in the current environment of the CMS forward RPC ?

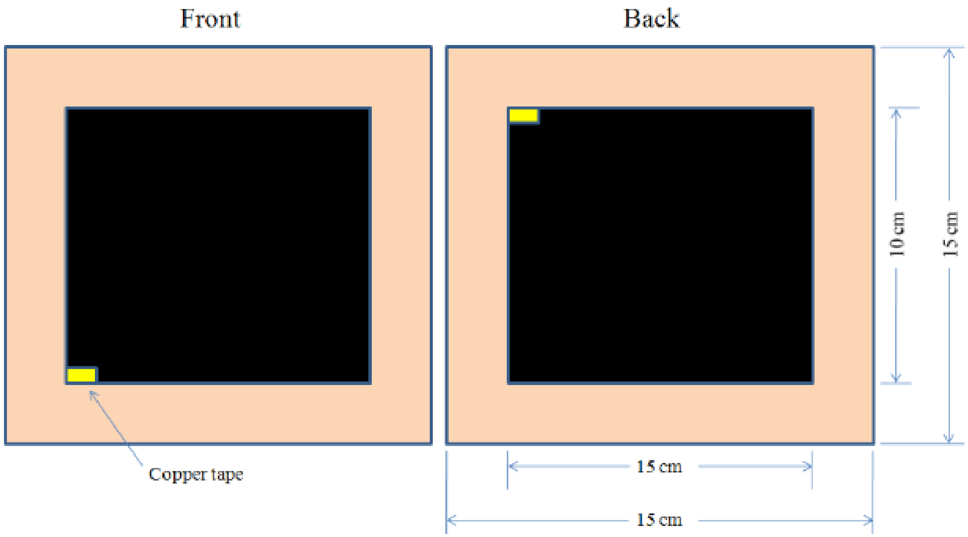
- Same gas system → same gas mixture
- Same electronics → same FEE

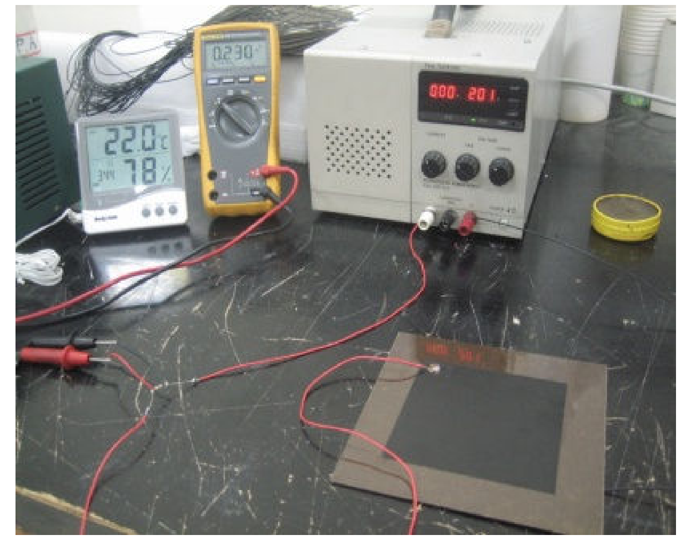
→ The detector characteristics should lie between the standard double-gap and the timing RPCs.

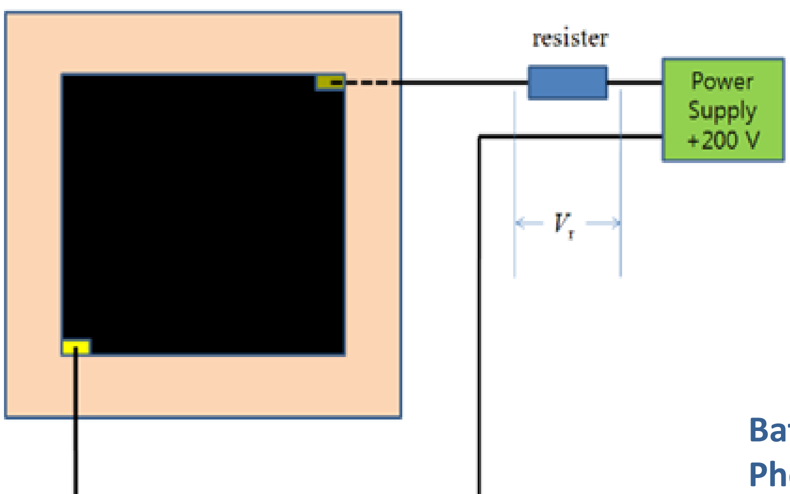
	CMS Double gap RPC	6-gap RPC
Gap width	2 mm	0.65 mm
Total gas volume	4 mm	3.9 mm
$< q_e >$	2 ~ 5 pC	~ 0.7 pC
$< Q_e >$	60 ~ 150 pC	~ 10 pC
Threshold	~ 200 fC	~ 70 fC
Type of HPLs	phenol	melamine+phenol
Thickness of resistive plate	2 mm	1.0 mm
Number of resistive plate	4	8
Resistivity of HPL	1 ~ 5 x 10^{10} Ohm-cm	< 10^{11} Ohm-cm
Rate capability	2 ~ 3 kHz/cm^2	~ 10 kHz/cm^2

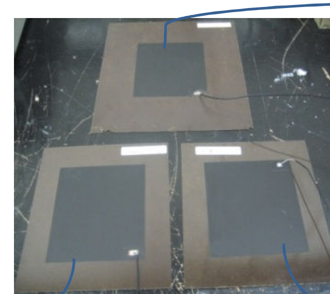
3. Basic R&D of HPLs

Resistivity tests for HPLs consisting of Melamine + Phenol sheets









Batch 1 (0.5mm Melamine)

Batch 2 (0.5mm HPLs Melamine-Phenol)

Batch 3 (1mm HPLs Melamine-Phenol)

Using simple math, we can calculate the resistivity.

$$\rho_b = R_r \frac{A}{d}\left(\frac{V_0 - V_r}{V_r}\right)$$

- Power supply voltage= V_0
- Voltage difference from R_r= V_r
- Area of electrode= A
- Thickness of HPL = d
- Resistance=R_r

Normalization to the expected values at T=20°

$$\rho_b^{20} = \rho_T e^{\alpha(T - T_0)}$$

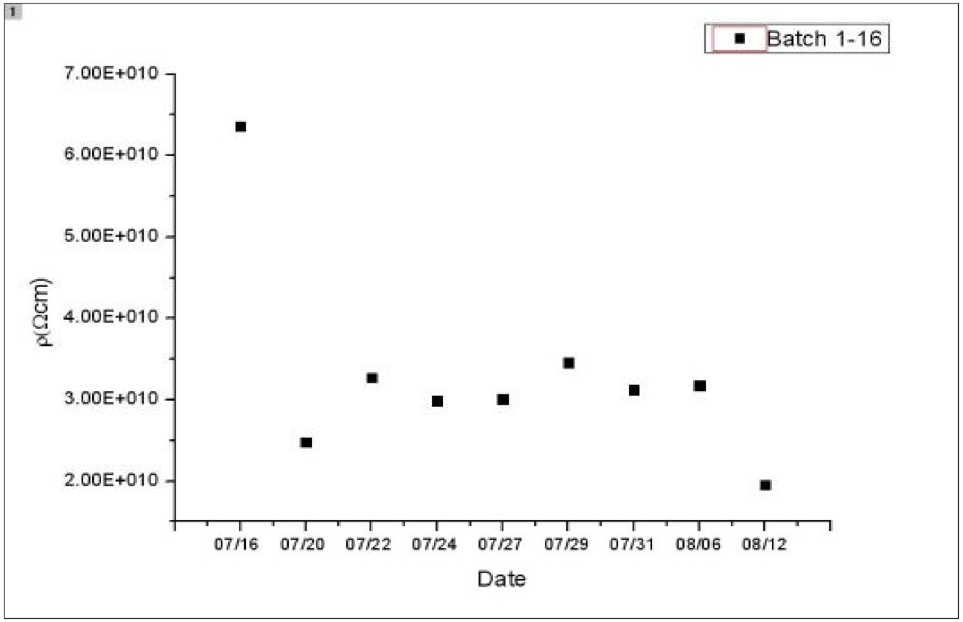
Coefficient for temperature-dependence (0.12/°C)

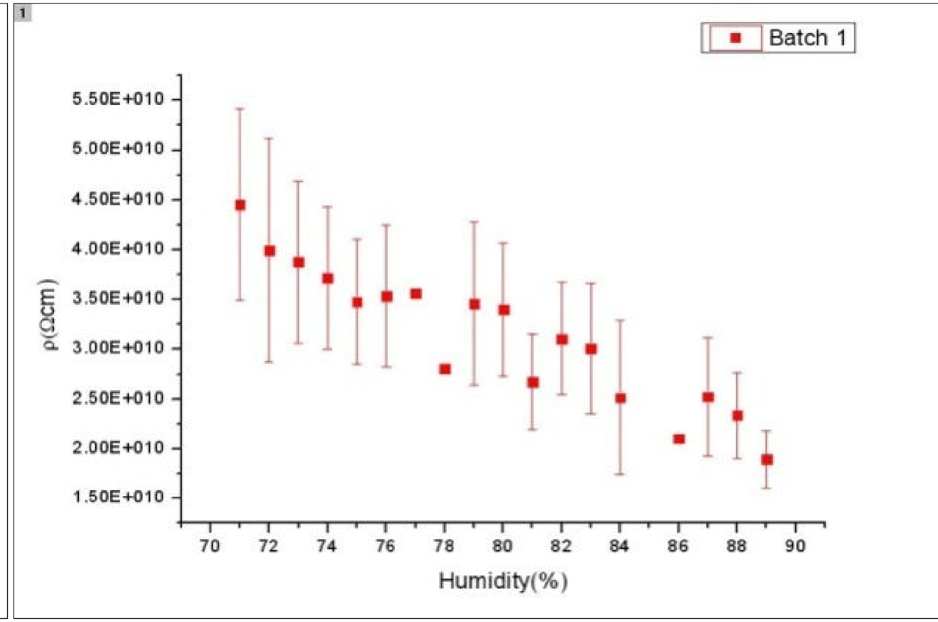
- Resistivity ~ strongly depends both on temperature and humidity

4. Results

Initial Condition	
V_0(V)	200
A(cm^2)	100
$R_\gamma(k\Omega)$	47.46

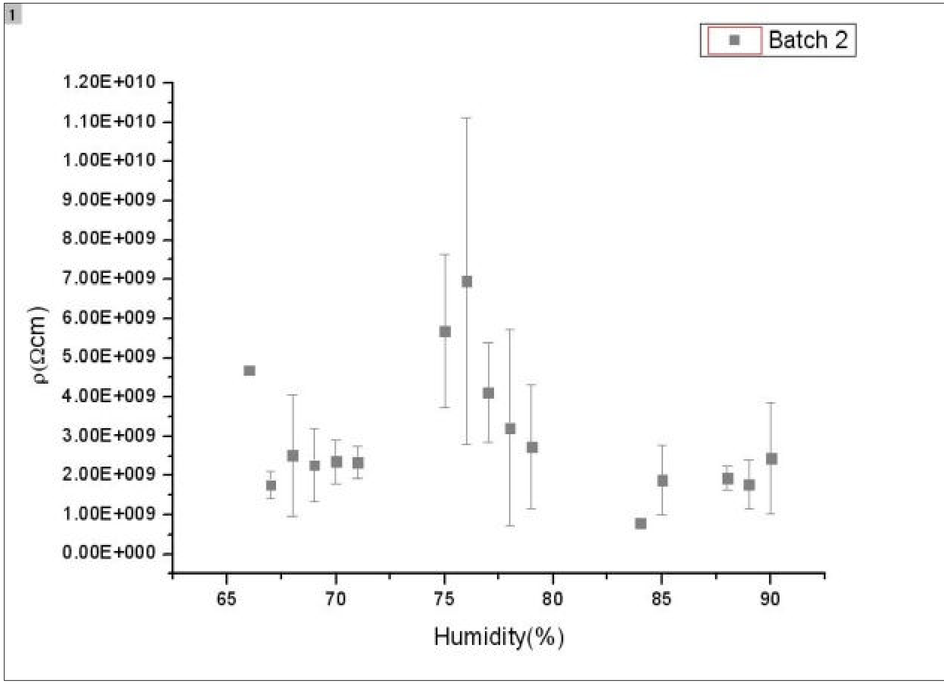
	Batch 1 (M-P 0.5mm)	Batch 2 (HPLs M-P 0.5mm)	Batch 3 (HPL M-P 1mm)
Average Voltage Difference V_γ(V)	0.697	8.21	0.205
Thickness d(cm)	0.05	0.05	0.1
Average $\rho_{20}(\Omega cm)$	3.91×10^{10}	5.13×10^{9}	6.94×10^{10}
└Max.(Ωcm)	1.28×10^{11}	2.21×10^{10}	1.95×10^{11}
└Min.(Ωcm)	1.59×10^{10}	8.00×10^{8}	5.94×10^{10}
└Standard Deviation	1.77×10^{10}	4.39×10^{9}	3.47×10^{10}

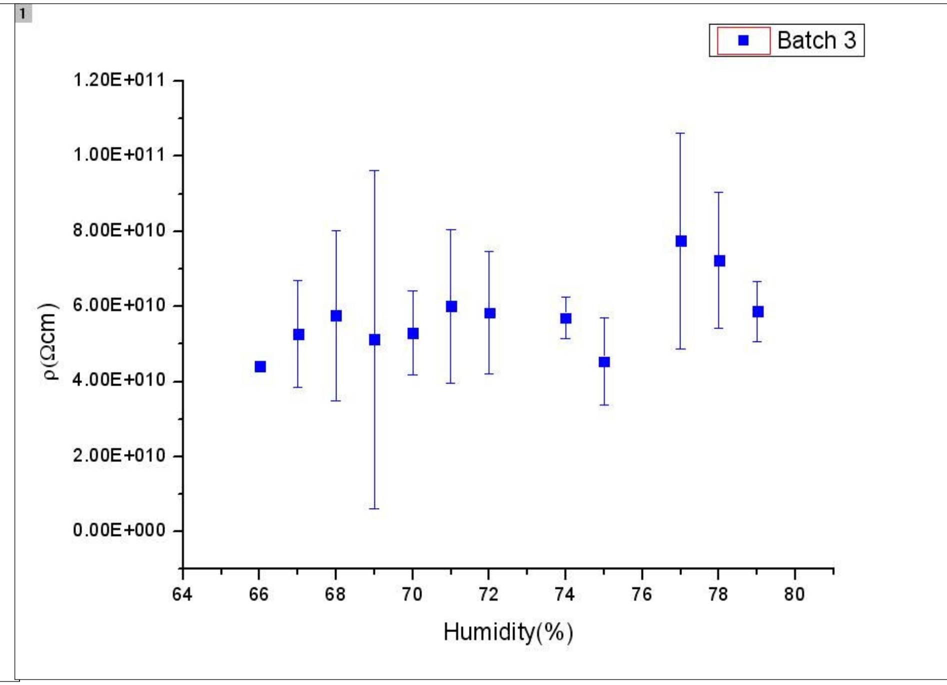


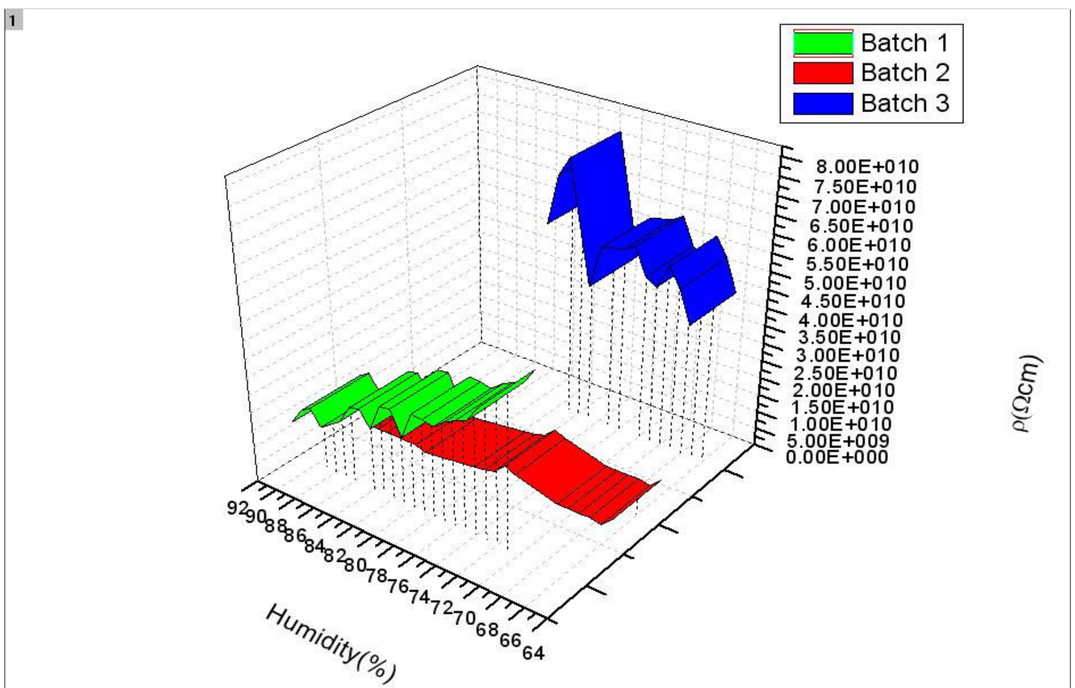


Date	**July 19th**	**July 20th**	**July 22nd**	**July 24th**	**July 27th**	**July 29th**
ρ_{20}	6.4×10^{10}	2.5×10^{10}	3.3×10^{10}	3.0×10^{10}	3.0×10^{10}	3.5×10^{10}
Humidity(%)	76	**84**	75	75	79	74
Date	**July 31st**	**August 6th**	**August 12th**	**Standard Deviation**	1.25×10^{10}	
ρ_{20}	3.1×10^{10}	3.2×10^{10}	1.9×10^{10}			
Humidity(%)	75	74	**88**			

Data for batch 1-16


1
Batch 2
ρ(Ωcm)
1.20E+010
1.10E+010
1.00E+010
9.00E+009
8.00E+009
7.00E+009
6.00E+009
5.00E+009
4.00E+009
3.00E+009
2.00E+009
1.00E+009
0.00E+000
65
70
75
80
85
90
Humidity(%)


1
Batch 3
ρ(Ωcm)
1.20E+011
1.00E+011
8.00E+010
6.00E+010
4.00E+010
2.00E+010
0.00E+000
64
66
68
70
72
74
76
78
80
Humidity(%)


1
Batch 1
Batch 2
Batch 3
8.00E+010
7.50E+010
7.00E+010
6.50E+010
6.00E+010
5.50E+010
5.00E+010
4.50E+010
4.00E+010
3.50E+010
3.00E+010
2.50E+010
2.00E+010
1.50E+010
1.00E+010
5.00E+009
0.00E+000
ρ(Ωcm)
92 90 88 86 84 82 80 78 76 74 72 70 68 66 64
Humidity(%)

5. Conclusions

- Resistivity ~ strongly depends both on temperature and humidity

- HPL samples : successful to build low-resistive multi-gap RPCs

  Resistivity :

  Batch 1 : $\rho = 3.91 \times 10^{10}\ \Omega$ cm ($\sigma = 1.77 \times 10^{10}\ \Omega$ cm)

  Batch 2 : $\rho = 5.13 \times 10^{9}\ \Omega$ cm ($\sigma = 4.39 \times 10^{9}\ \Omega$ cm)

  Batch 3 : $\rho = 6.94 \times 10^{10}\ \Omega$ cm ($\sigma = 3.47 \times 10^{10}\ \Omega$ cm)

  ⇒ Able to select HPLs with resistivity in a range $10^{10} < \rho < 10^{11}$ at $T=20^{o}$ and $H=50\%$

- We recently manufactured

  1 oiled and 1 non-oiled 6-gap RPCs with Batch 3 HPLs (1 mm)

  to address the feasibility for the future CMS muon triggers.