# New resistive materials for High-Rate RPC

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# Outline

Motivation

R&D on High Rate GRPC

R&D on Large HR GRPC

R&D on new resistive materials

Conclusion

# Motivation

With the increase of CM energy and luminosity, LHC detectors, namely the muon detectors, in the high η region should be able to withstand **high rate**

**Rates at Muon Trigger Upgrade**

| Parameter | LHC | HL-LHC |
|---|---|---|
| s | 14TeV | 14TeV |
| L | $10^{34}/cm^2s$ | $10^{35}/cm^2s$ |
| bunch spacing | 25ns | 12.5ns |
| interactions/crossing | $\approx 12$ | $\approx 62$ |
| $dN/d\eta$ crossing | 75 | 375 |
| CMS particle flux $1^{st}$ muon layer $\eta \approx 2.4$ | $\approx 1kHz/cm^2$ | $\approx 10kHz/cm^2$ |
| CMS particle flux $1^{st}$ muon layer $\eta \approx 2.4$ | $\approx 1kHz/cm^2$ | $\approx 10kHz/cm^2$ |
| ATLAS particle flux $1^{st}$ muon layer $\eta \approx 2.4$ | $\approx 1 - 10kHz/cm^2$ | $\approx 1 - 15kHz/cm^2$ |
| ATLAS particle flux $1^{st}$ muon layer $\eta \approx 2.4$ | $\approx 1 - 10kHz/cm^2$ | $\approx 1 - 15kHz/cm^2$ |

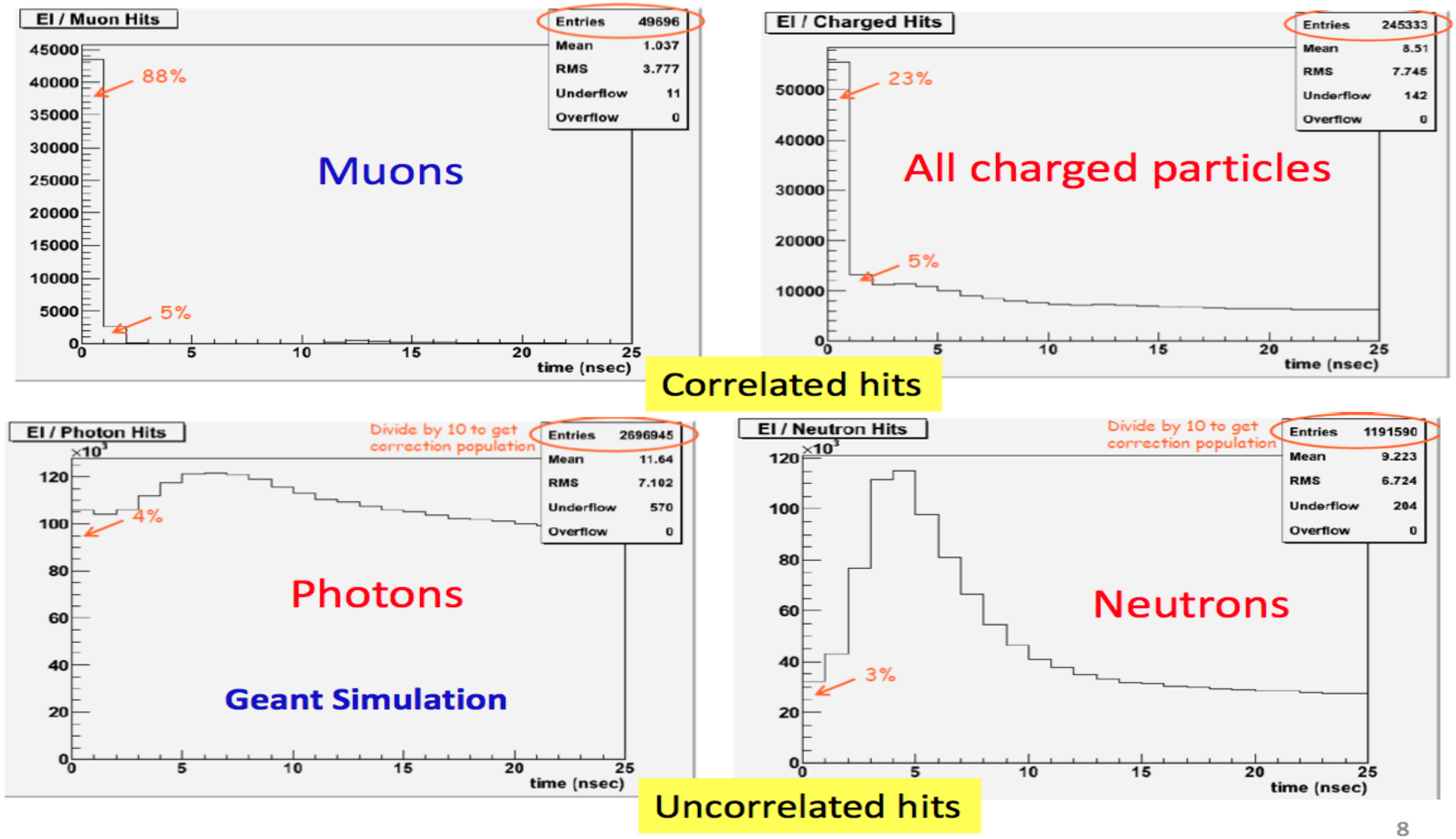
A. Sharma, Frascati, RPC2012

MPGDs are the best solution among the present gaseous detectors but….

# Motivation

Excellent timing resolution **could be of big importance for the future HL-LHC**. RPC and MRPC are the best to achieve this.

**Excellent timing capability is crucial**

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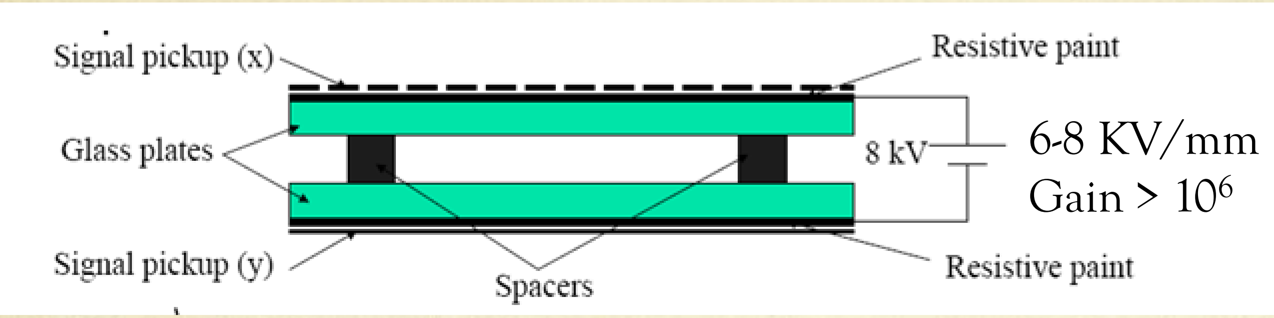
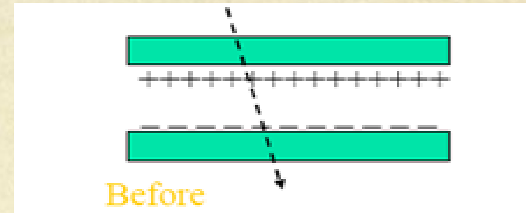
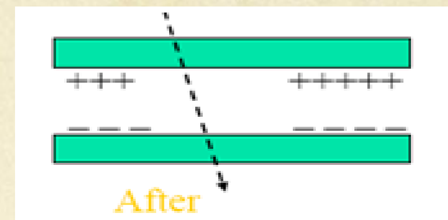
Number of hits as a function of the arrival time within one LHC BX (25 ns) with TOF subtracted

J.Zhu, ATLAS collaboration, RPC2012

# RPC: Resistive Plate Chamber




The needed time to restore the electric field within the chamber depends on the voltage drop in the resistive plate:

$\Delta V = I\,R = q\,\rho\,d\,\Phi$

At high flux $\Phi$ one could try to reduce one of the three parameters:

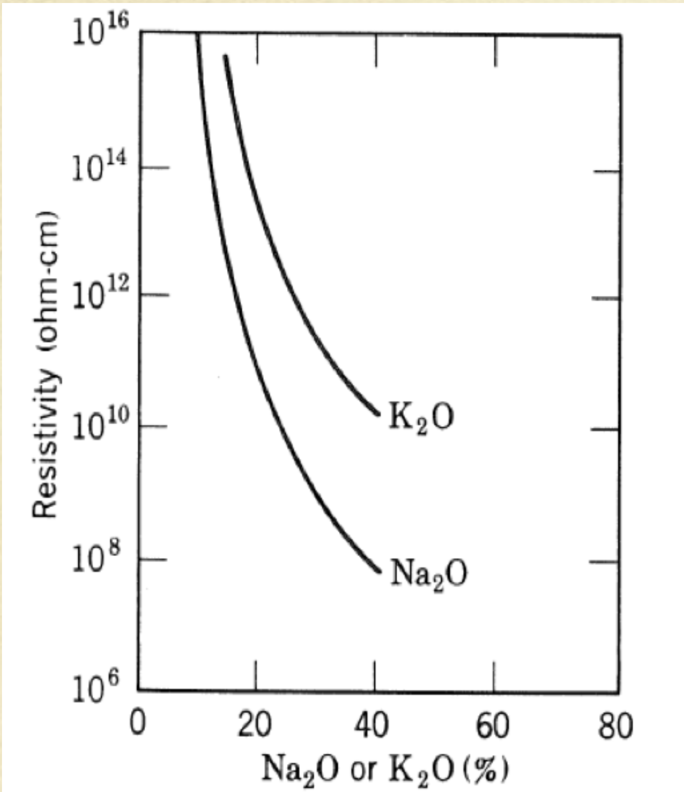
**q:** streamer/avalanche charge : this depends on the gas mixture, gas gap width and number of gas gaps;

**d**: plate thickness : this depends on the plate nature (Bakelite, glass, ceramics…);

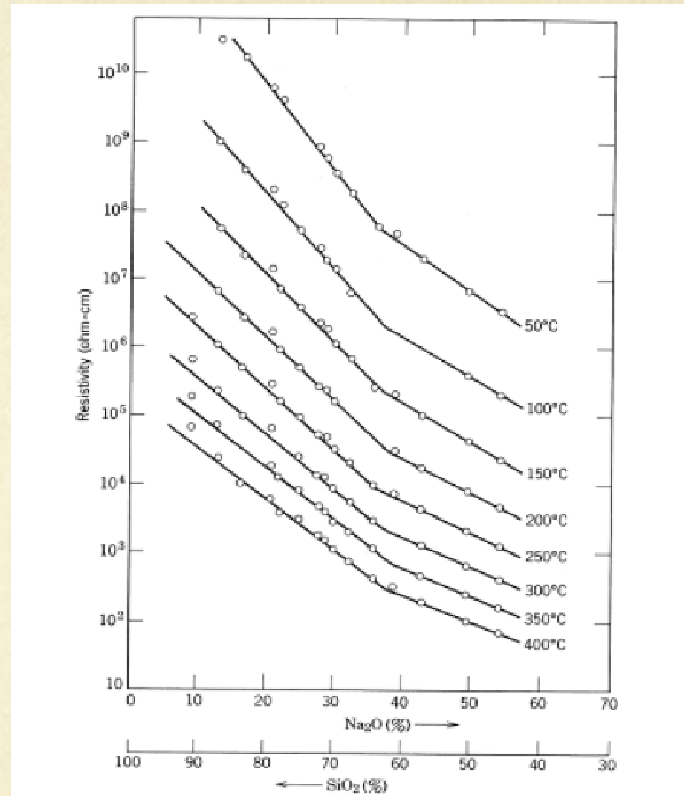
**ρ**: electric resistivity : the problem is the absence of natural resistive material between $10^4$-$10^9$ $\Omega$.cm

# Low-Resistivity glass

Glass is one of the resistive materials used to build RPC. Its resistivity could be modified.




Fulda M. (1927), sprechsaal, 60, 810

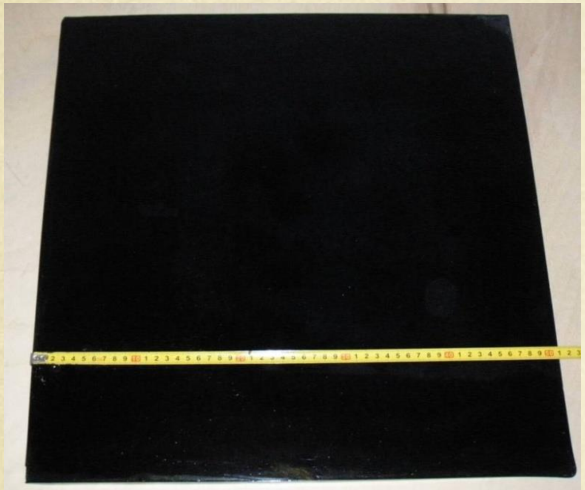



Seddon E., Tippett E. J., Turner W. E. S. (1932). The Electrical Conductivity of Sodium Meta-silicate-Silica Glasses. *J. Soc. Glass Technol.*, ***16, 450.***

The problem is the alkali ions migration which may result in glass with heterogenic resistivity

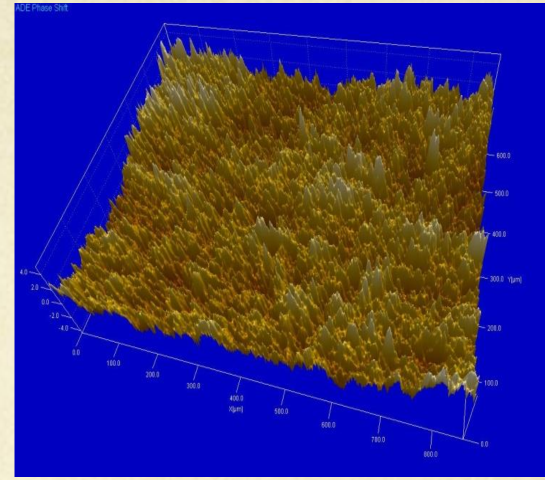
# Low-Resistivity glass

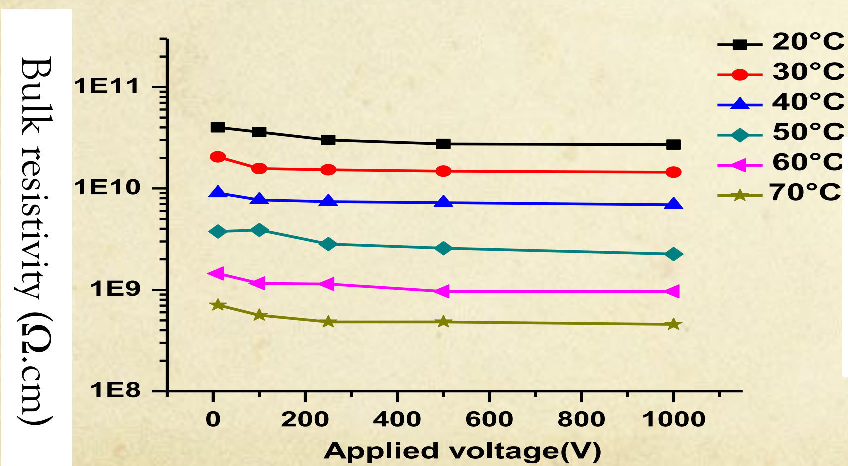
## A new kind of glass developed by **Tsinghua** University

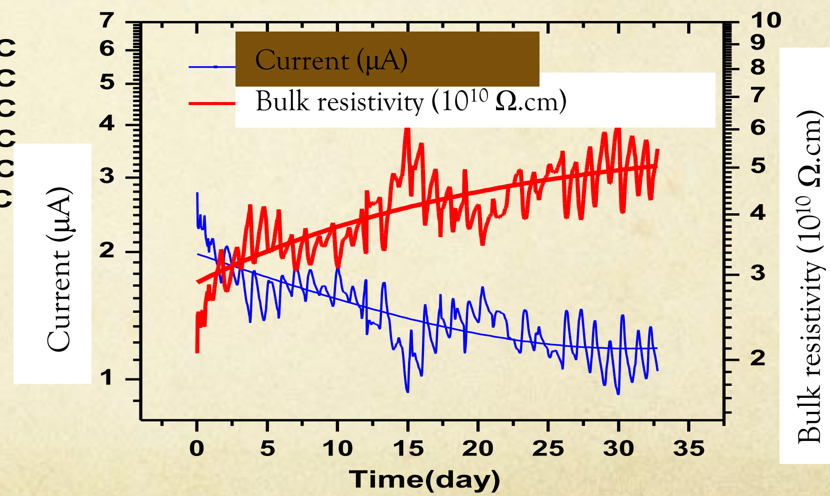


**Glass Specifications:**

Present max. dimension: 32cm×30cm
Bulk resistivity: ≈$10^{10}\Omega$.cm
Standard thickness: 0.5mm--2mm
Thickness uniformity: ±0.02mm
Dielectric constant: ≈7.5-9.5
Surface roughness: < 10 nm
DC measurement: Ohmic behavior, stable up to 1 C/$cm^2$



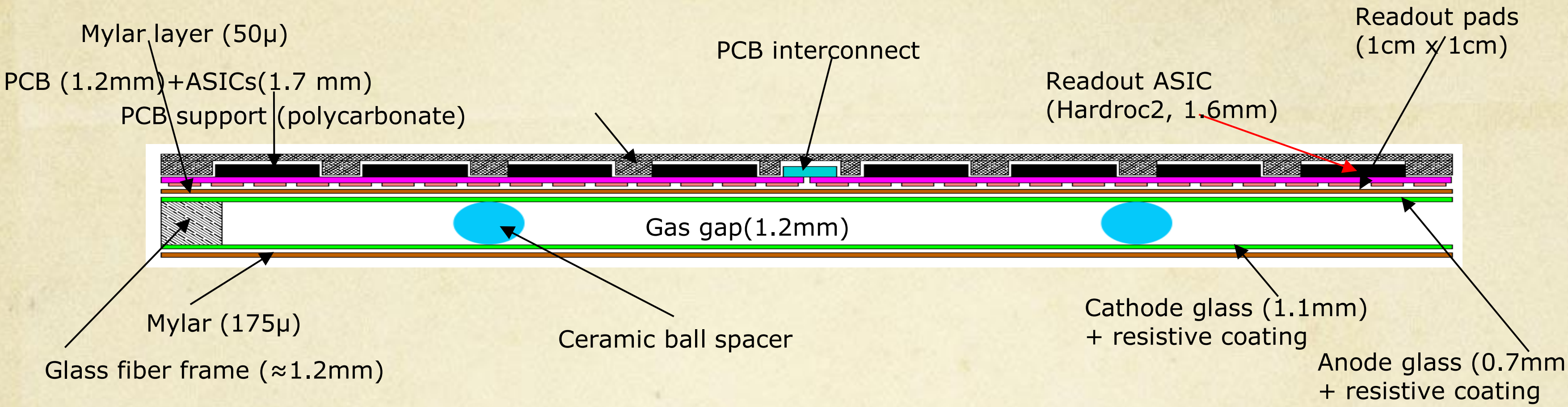


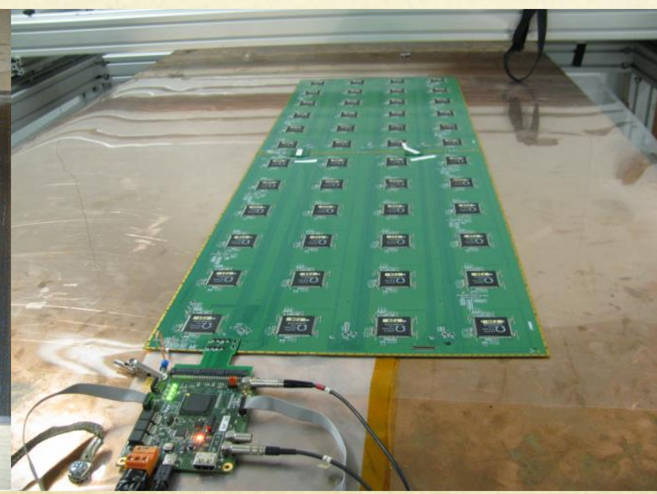

- Resistivity decreases with temperature
- Resistivity is very stable in DC measurement

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

- **Single gap**

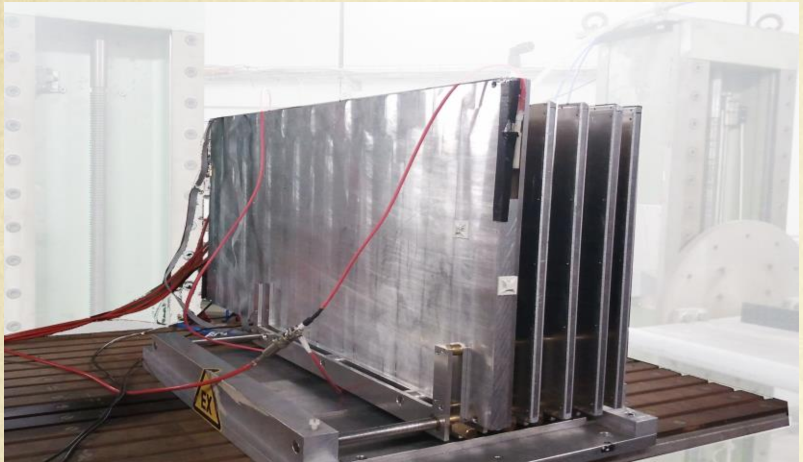


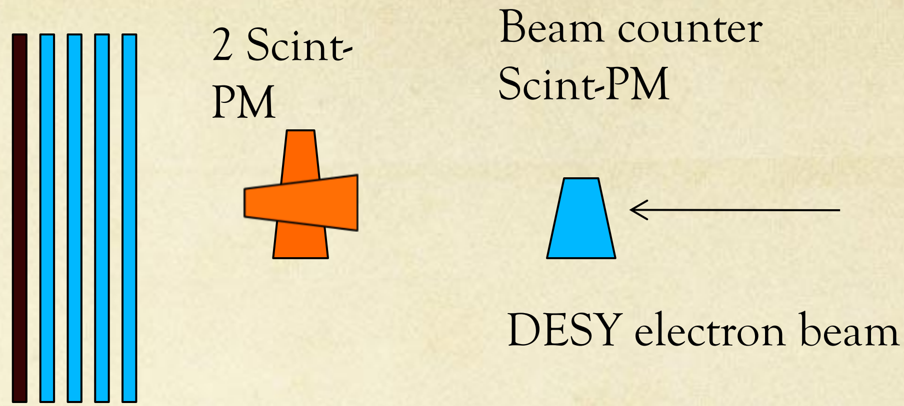

Total thickness (detector 3 mm+ readout electronics 3 mm): 6.0mm

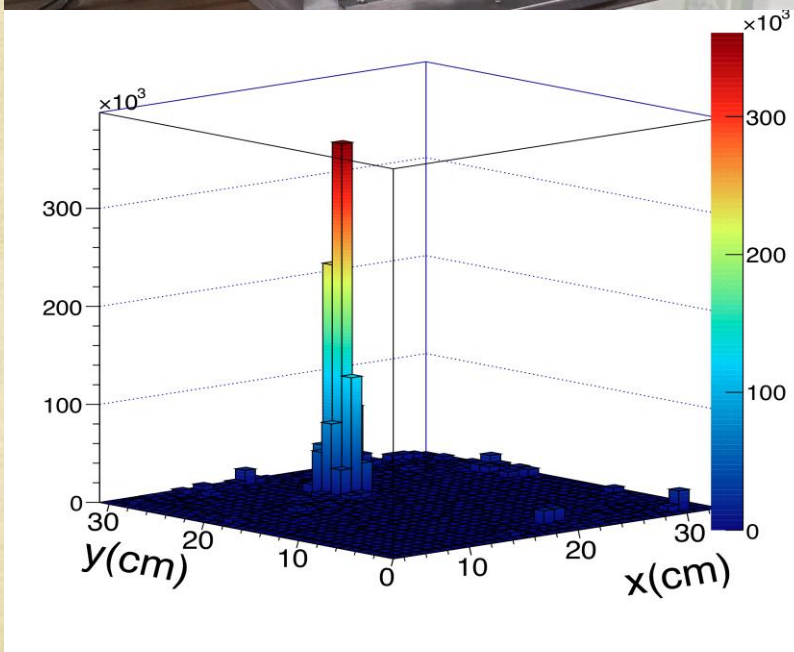
Tsinghua glass ($10^{10}$ Ω.cm)

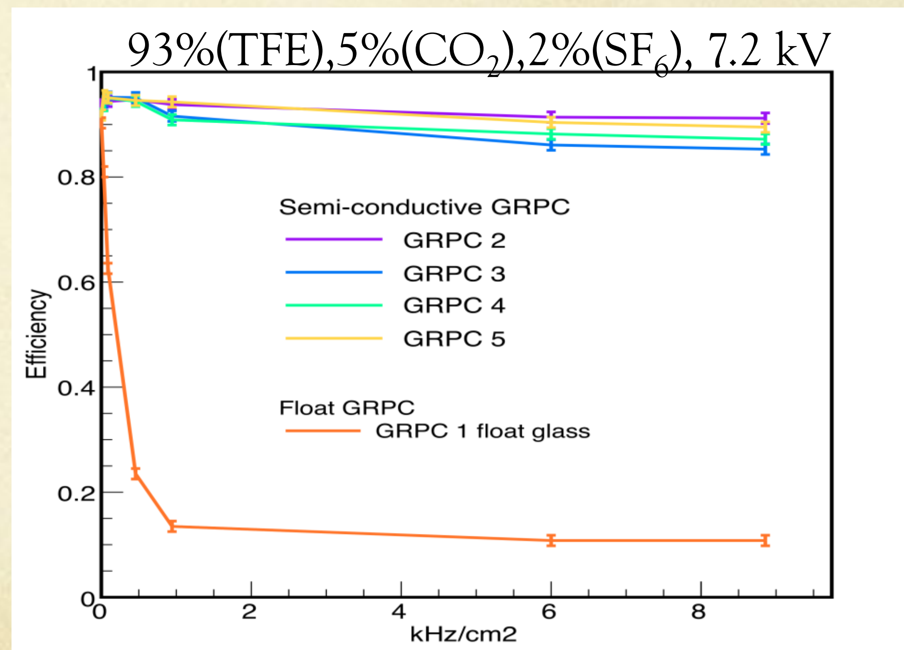
Same multi-threshold electronics readout (64ch-HR2) used in the SDHCAL






1 standard GRPC+ 4 low-resistivity GRPC

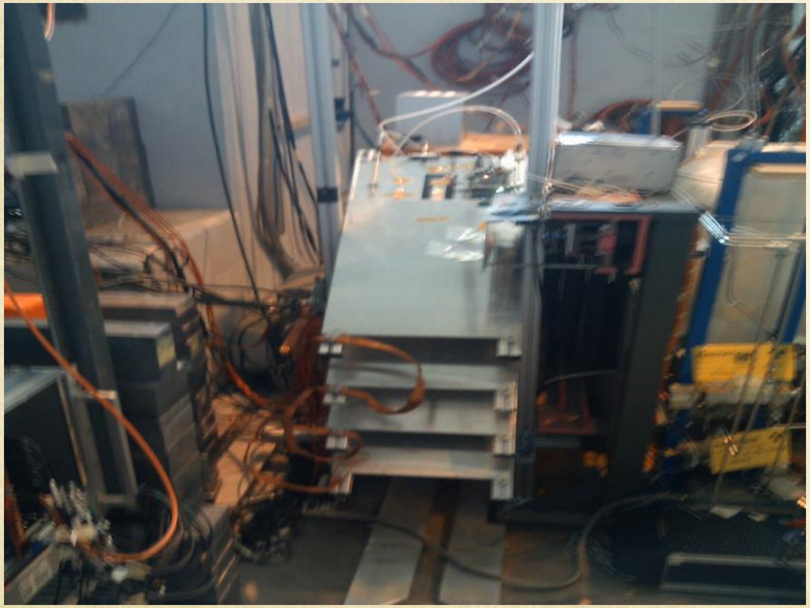


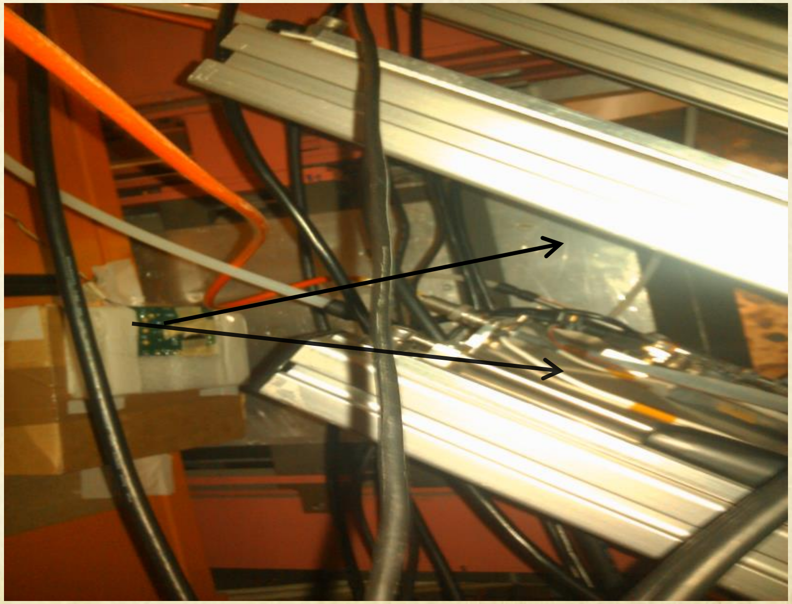




9 kHz/cm$^2$ is highest rate one can get at DESY

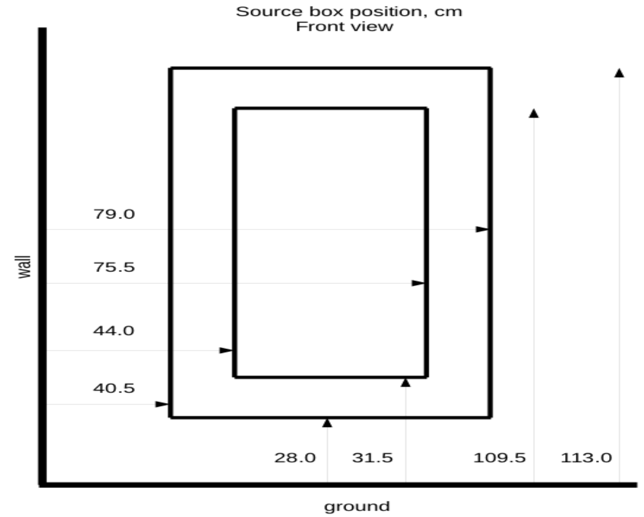
Threshold =100 fc

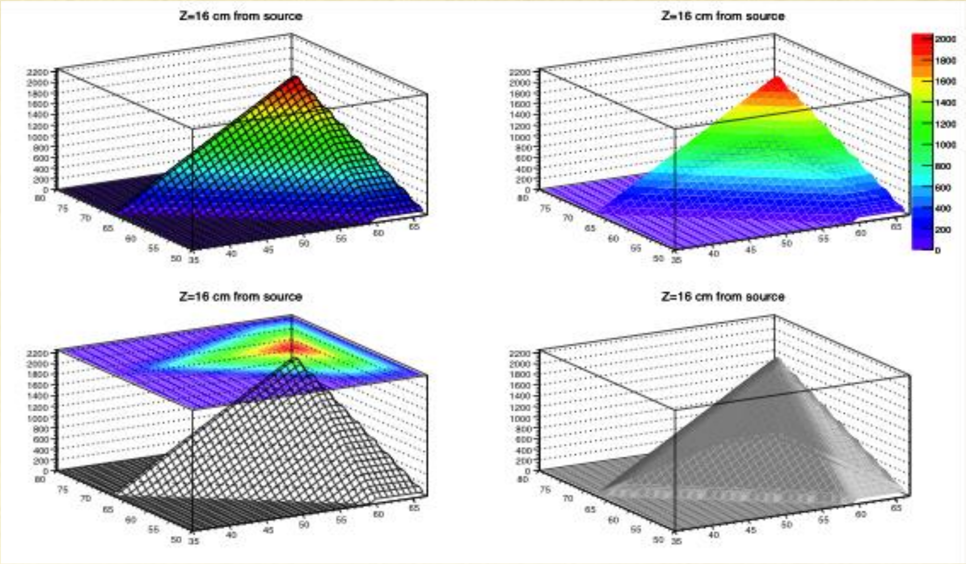
The same chambers 1 standard + 4 small (32x30 $cm^2$) low resistivity GRPC are brought to GIF in June 2013 and exposed to the GIF source at small distance with the aim to check the effect of long time exposure to high rate on the whole surface and to check their efficiency in these conditions using the cosmics.
With the lateral aperture of the source essentially two RPCs are exposed to the gamma irradiation.



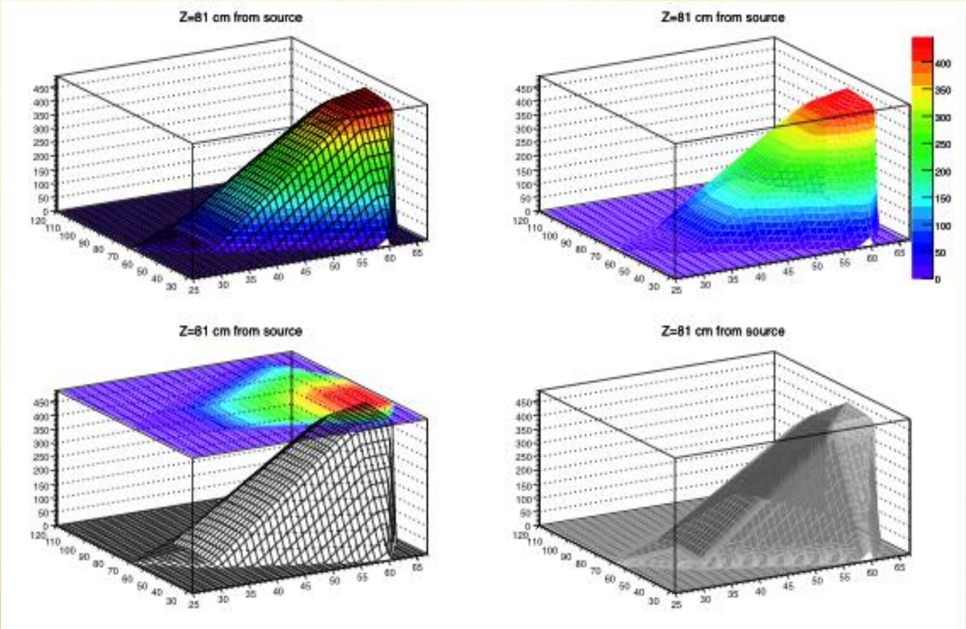


Gamma rate: 7.1 $10^6$ gamma/(cm2 s) as given by GIF staff.



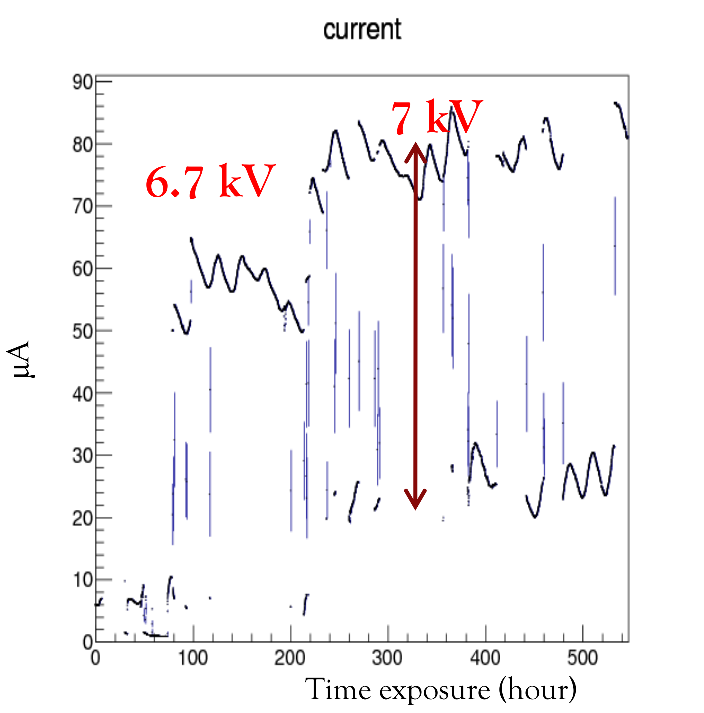




| # | x | y | z | T | P | mGy | Bq/cm$^2$/s |
|---|---|---|---|---|---|---|---|
| 1 | 60 | 68 | 81 | 19.2 | 951.3 | 420.5 | 2.33686e+06 |
| 2 | 60 | 27 | 81 | 19.2 | 951.5 | 7.695 | 42763.6 |
| 3 | 60 | 120 | 81 | 20.3 | 951.3 | 2.034 | 11303.6 |
| 4 | 60 | 50 | 81 | 20.3 | 951.3 | 425.3 | 2.36353e+06 |
| 5 | 60 | 80 | 81 | 20.5 | 951.5 | 351 | 1.95062e+06 |
| 6 | 67 | 50 | 81 | 20.2 | 951.5 | 432.3 | 2.40243e+06 |
| 7 | 67 | 68 | 81 | 20.2 | 951.5 | 447.4 | 2.48635e+06 |
| 8 | 67 | 80 | 81 | 20.5 | 952.7 | 331.5 | 1.84225e+06 |
| 9 | 35 | 80 | 81 | 20.5 | 952.7 | 6.96 | 38679 |
| 10 | 35 | 68 | 81 | 20.5 | 952.7 | 17.96 | 99809.6 |
| 11 | 35 | 50 | 81 | 20.5 | 952.7 | 9.144 | 50816.2 |
| 12 | 25 | 68 | 81 | 20.2 | 951.9 | 4.554 | 25308.1 |
| **13** | **60** | **80** | **40** | **19.7** | **952.7** | **19.71** | **109535** |
| **14** | **60** | **68** | **40** | **19.7** | **952.7** | **1119** | **6.21865e+06** |
| **15** | **60** | **50** | **40** | **19.7** | **952.7** | **949.6** | **5.27724e+06** |
| **16** | **67** | **50** | **40** | **20** | **952.4** | **971.2** | **5.39727e+06** |
| **17** | **67** | **68** | **40** | **20** | **952.4** | **1122** | **6.23532e+06** |
| **18** | **67** | **80** | **40** | **20** | **952.4** | **38.07** | **21156** |
| 19 | 35 | 68 | 16 | 20 | 952.4 | 3.285 | 18255.8 |
| 20 | 60 | 80 | 16 | 20 | 952.4 | 8.676 | 48215.4 |
| 21 | 60 | 68 | 16 | 20 | 952.4 | 2107 | 1.17093e+07 |
| 22 | 60 | 50 | 16 | 20 | 952.4 | 30.29 | 168331 |
| 23 | 67 | 80 | 16 | 19.7 | 952.7 | 10.54 | 58574.2 |
| 24 | 67 | 68 | 16 | 19.7 | 952.7 | 10.74 | 59685.7 |
| 25 | 67 | 50 | 16 | 19.7 | 952.7 | 25.83 | 143546 |

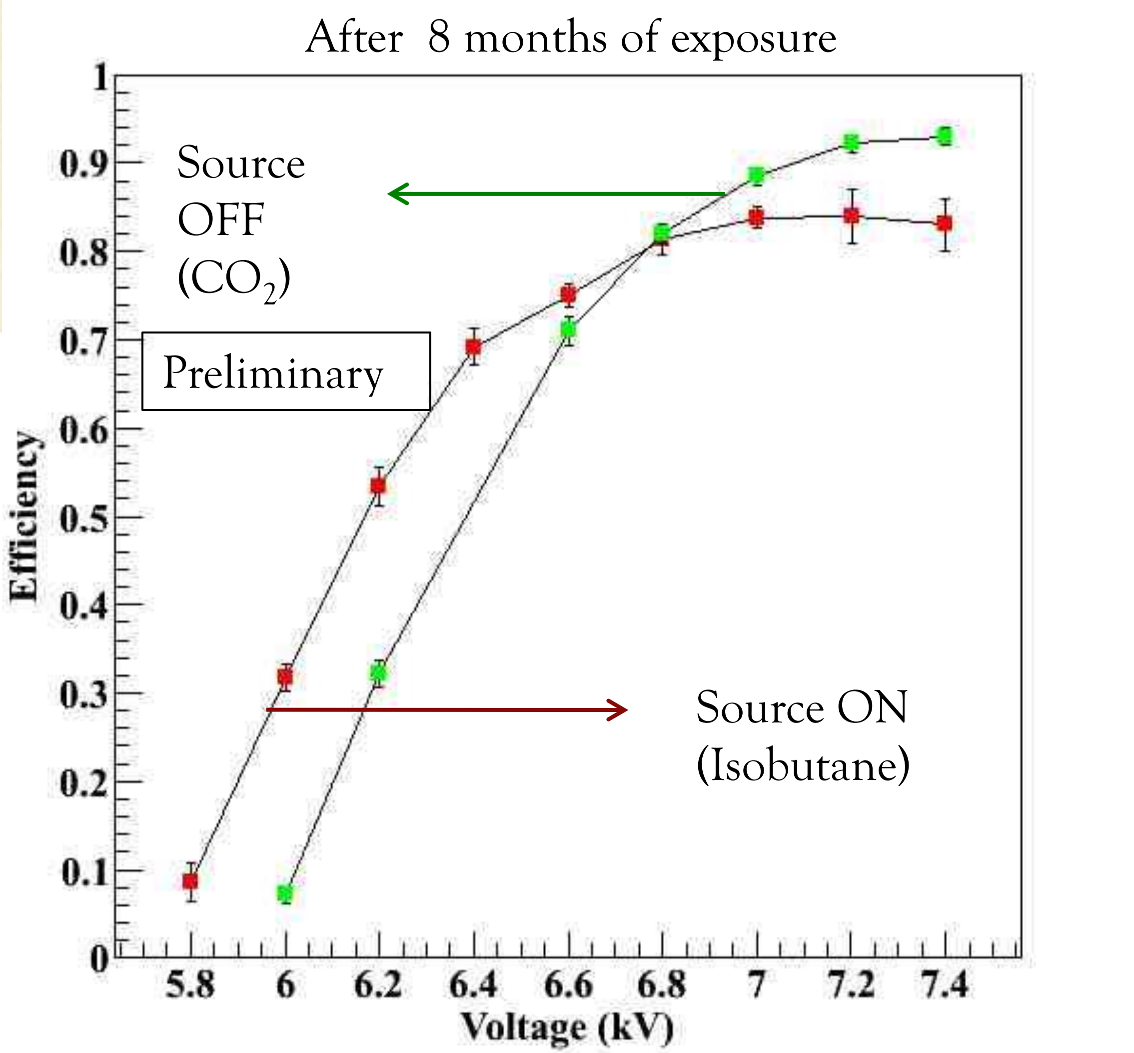


# R&D on high rate RPC

Measuring the current with and without source one can deduce that the effective average gamma rate penetrating in the RPC is higher than 10 kHz/cm$^2$



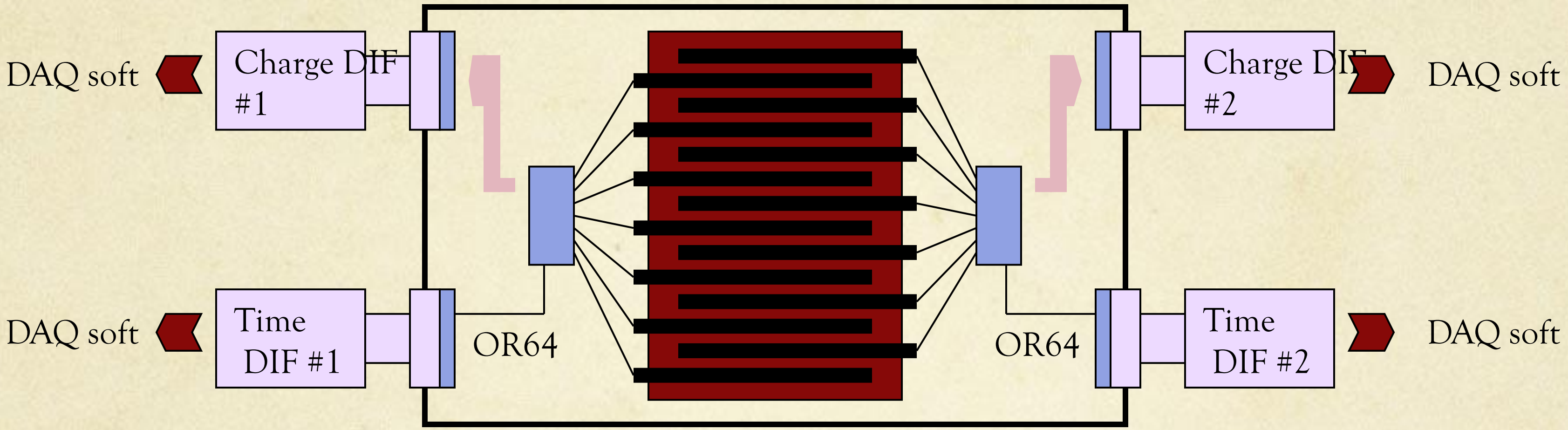

93.7%(TFE),4.5%($CO_2$),0.3%($SF_6$)




N.B : F-product including HF were measured and found to be negligible

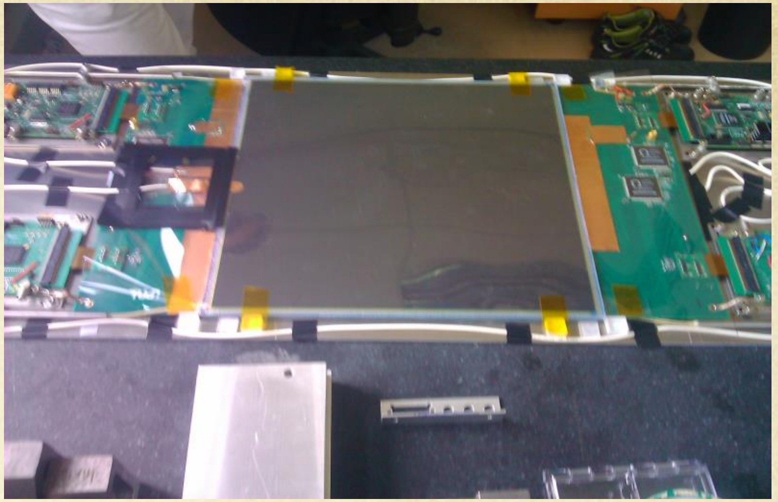
# R&D on High-Rate RPC

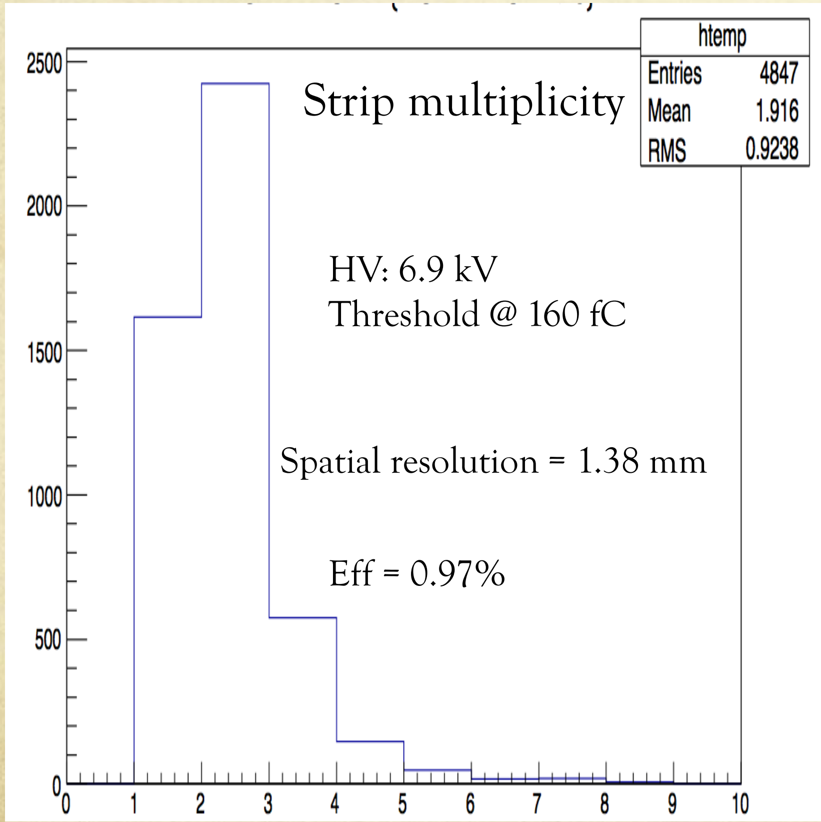
A adouble-face PCB with pick-up strips (pitch of 2.5 mm) on the two faces with 1 mm staggering between the two faces was conceived and produced. The PCB is to be inserted between two single-gap RPC.

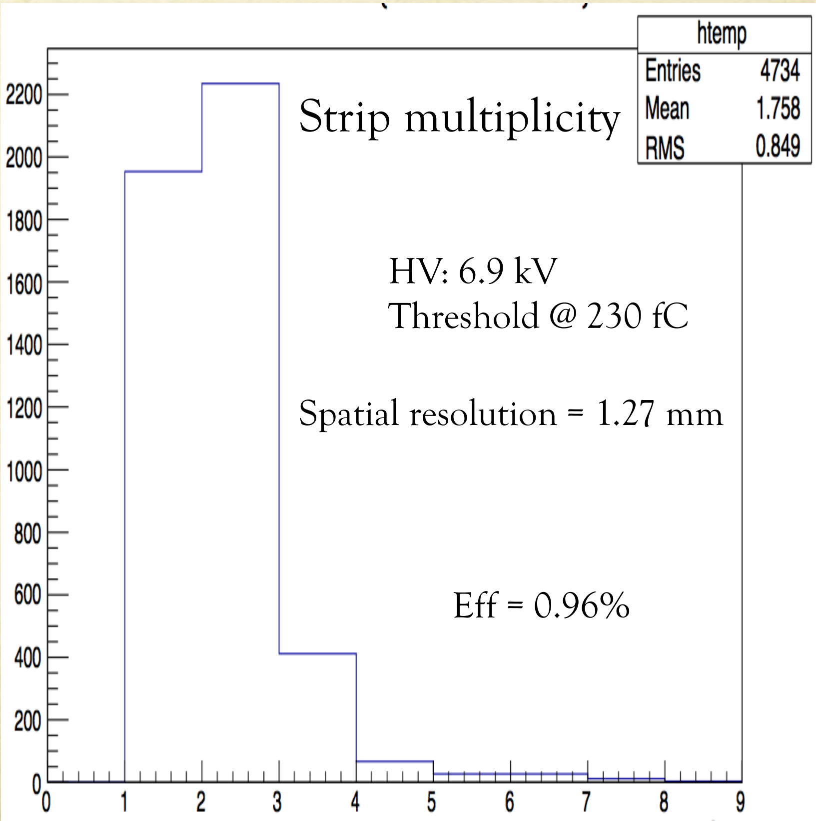



# Space resolution:

Using the coincidence of three Scint-PM signals as a trigger. The efficiency and the multiplicity are studied in combining **digital** information of both plans of strips:





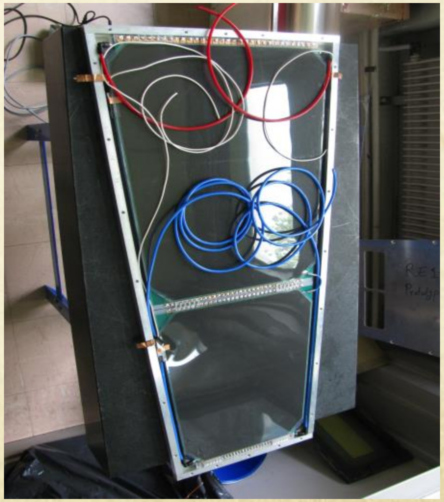



# R&D on large High-Rate RPC

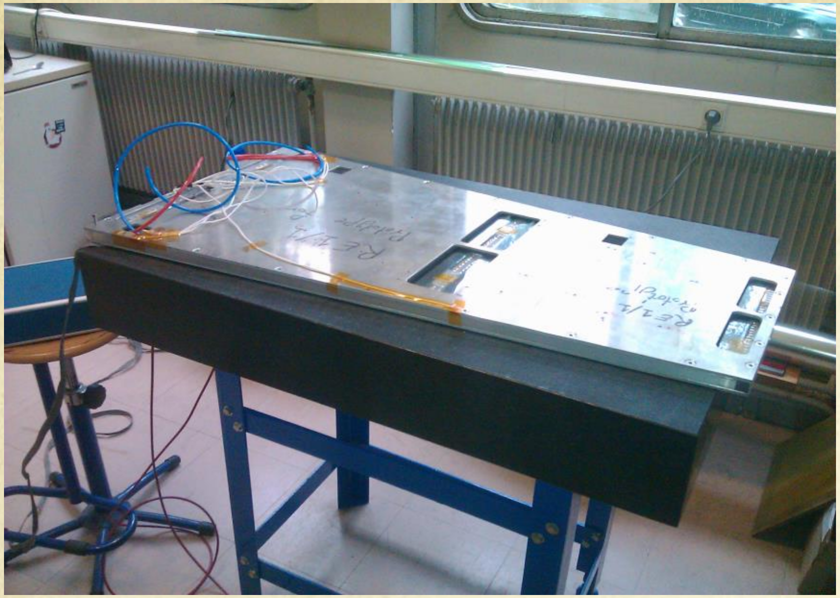
The small size of the low-resistivity Tsinghua glass is a limitation to build large RPC a la CMS for instance. However solutions do exist: gluing is one of them (HARP)

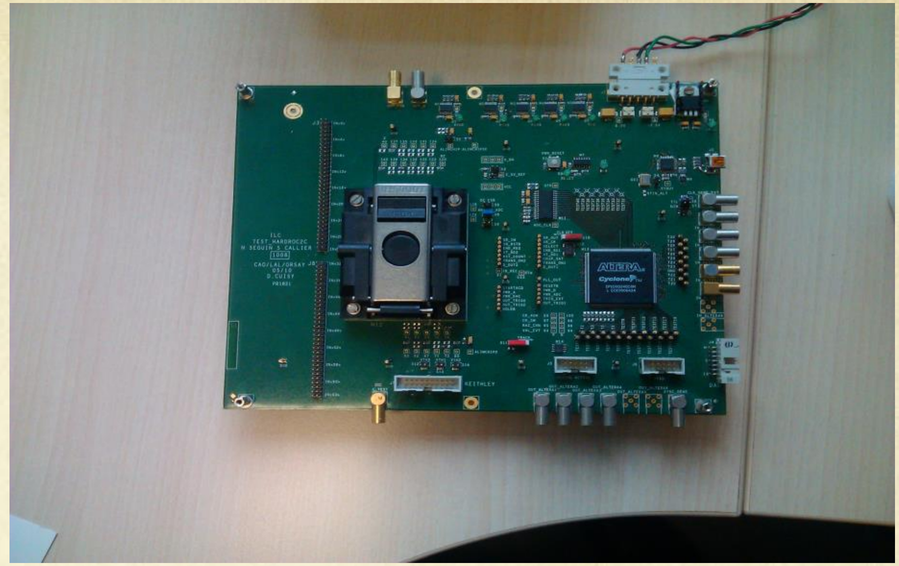




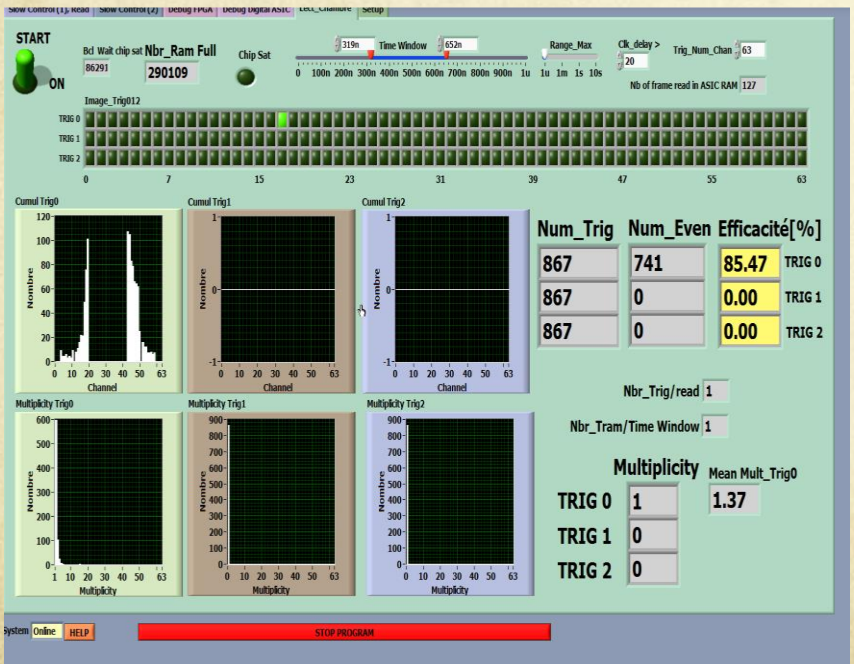



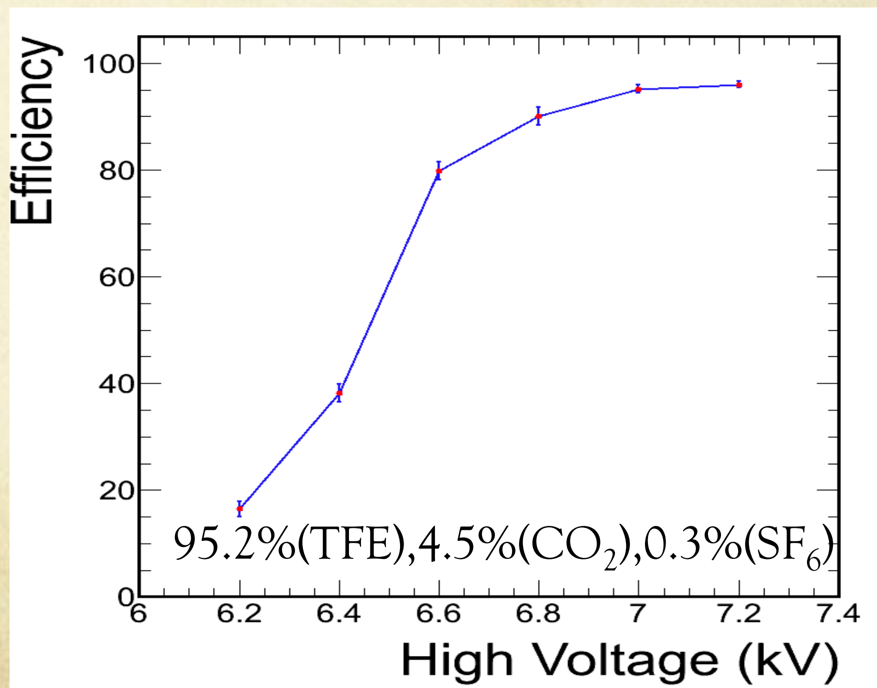
2-gap large chamber is built by gluing small pieces of glass





Strip (32 of #1 cm pitch) read out by HARDROC ASIC

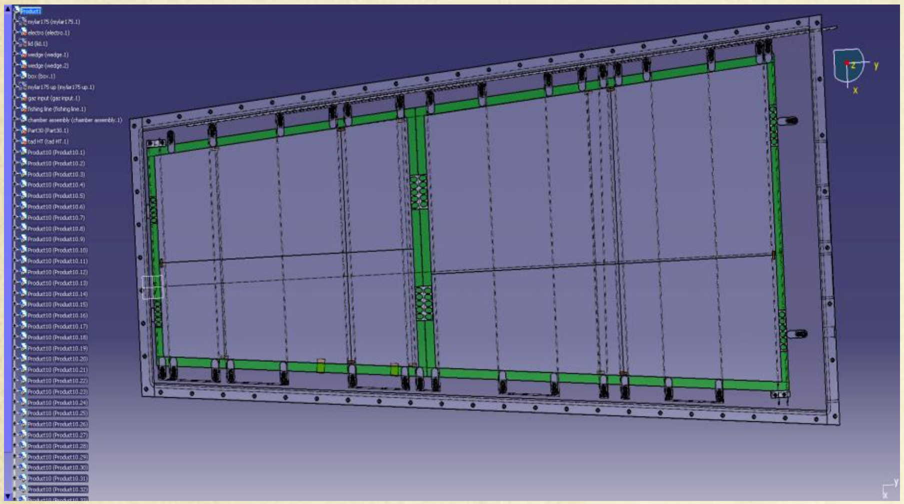


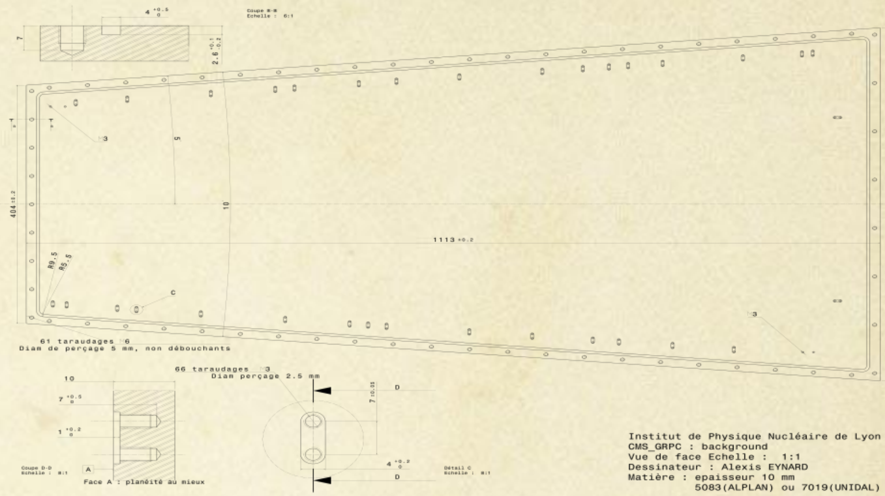



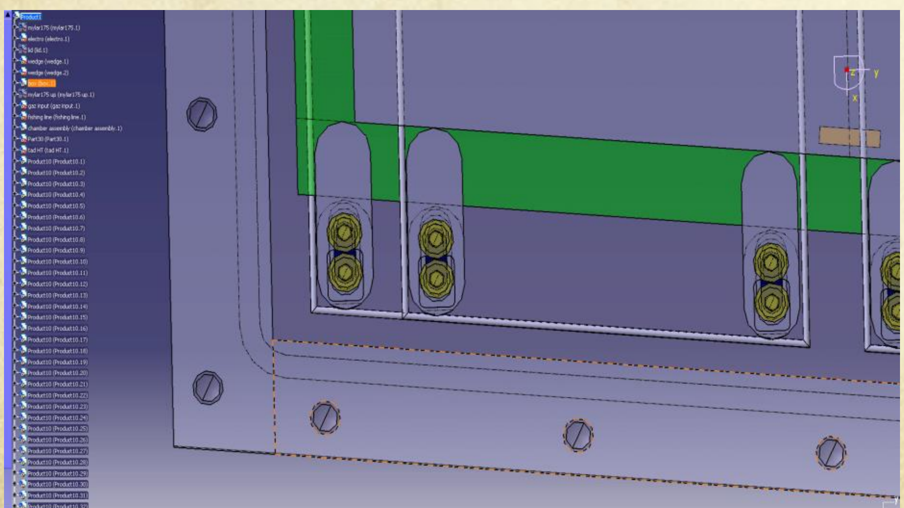
# New scheme

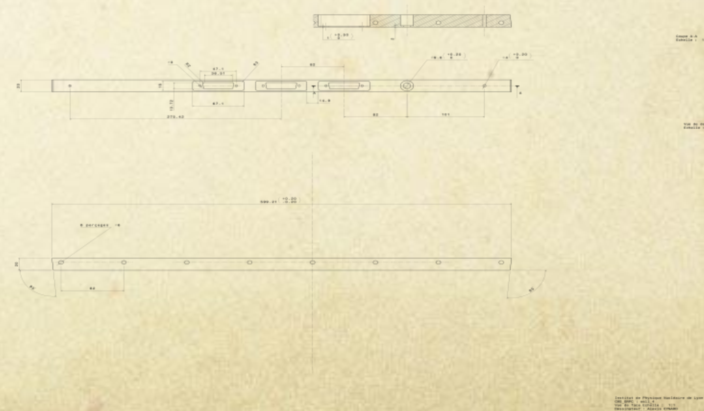
Gluing may be avoided by assembling together small chambers fixed mechanically.

Gas tightness is obtained within the cassette.







# R&D on new resistive materials

To increase the RPC rate capability the electrode resistivity should be reduced
Increasing the metallic ions component in glass is not a good option:

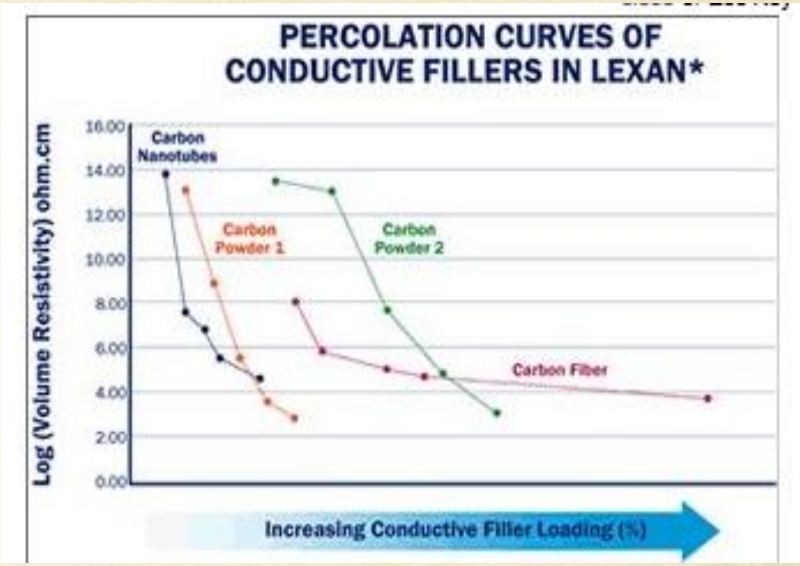
→ It will change the glass proprieties
→ It could suffer the ion migration

We propose a new solution based doping different materials with carbon nanotubes (CNT).
Some materials (plastics) could be easily produced but their mechanical proprieties do not entitle them to be used as RPC electrodes

We are following two promising R&D :

→ CNT doped glass

→ CNT Poly Ether Ether Ketone (PEEK)




Courtesy of LNP engineering plastic

# CNT doped glass

High temperatures (1050-1200 C° ) are needed for glass manufacturing.
At these temperature CNT could not survive (destruction temperature around 800 C°). To get glass doped with CNT there is another technique known by chemists

**Sol-Gel** : A precursor sol-gel solution (sol) is either poured into a mold and allowed to gel or is diluted and applied to a substrate by spinning, dipping, spraying, electrophoresis, inkjet printing or roll coating. Controlled drying of the wet gel results in either a ceramic or glass bulk part or a thin film on a glass, plastic, ceramic or metal substrate.

The Sol-Gel glass is obtained at room temperature ( reaction temperature < 200 C°). In collaboration with Chemistry department of Lyon University we used Single-Walled CNT to produce small pieces of glass ($< 15\ cm^2$) of less than 1 mm thickness and low resistivity of $10^{9-11}\ \Omega.cm$ but this could be reduced further.

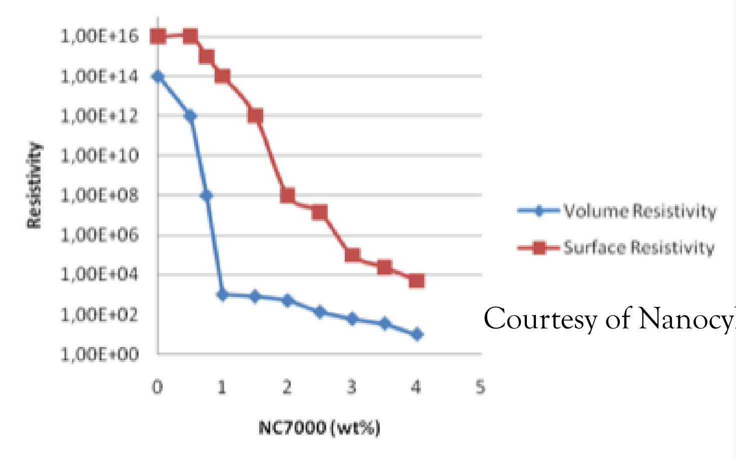
The challenge is to be able to produce large plates without breaking the glass…

# CNT doped PEEK

PEEK is one of the most robust plastic. It features excellent chemical and mechanical proprieties. It is produced either by extrusion or injection processes

The electric resistivity of PEEK is about $10^{16}$ Ω.cm. To reach the resistivity range $10^{4}$-$10^{9}$ Ω.cm the choice of the CNT dose is very important.

Another issue is to produce plates of small thickness (< 1 mm).




Courtesy of Nanocy

With the help of European companies we succeeded to produce several batches with resistivity ranging from $10^{4}$ to $10^{12}$ Ω.cm.

## CNT doped PEEK

The problem we faced is a well known problem by material physicist. It is related to CNT bundling leading to a conductive connection through the thickness of the film/plate.
Solutions do exist. Either to wrap CNT with surfactants or to add a small amount of fullerene-like particles. Collaboration with groups from Toulouse, Pau and Madrid but also with a big company is ongoing. First results are very promising.

# Conclusion

-R&D on high rate and fast timing of large RPC is very active.

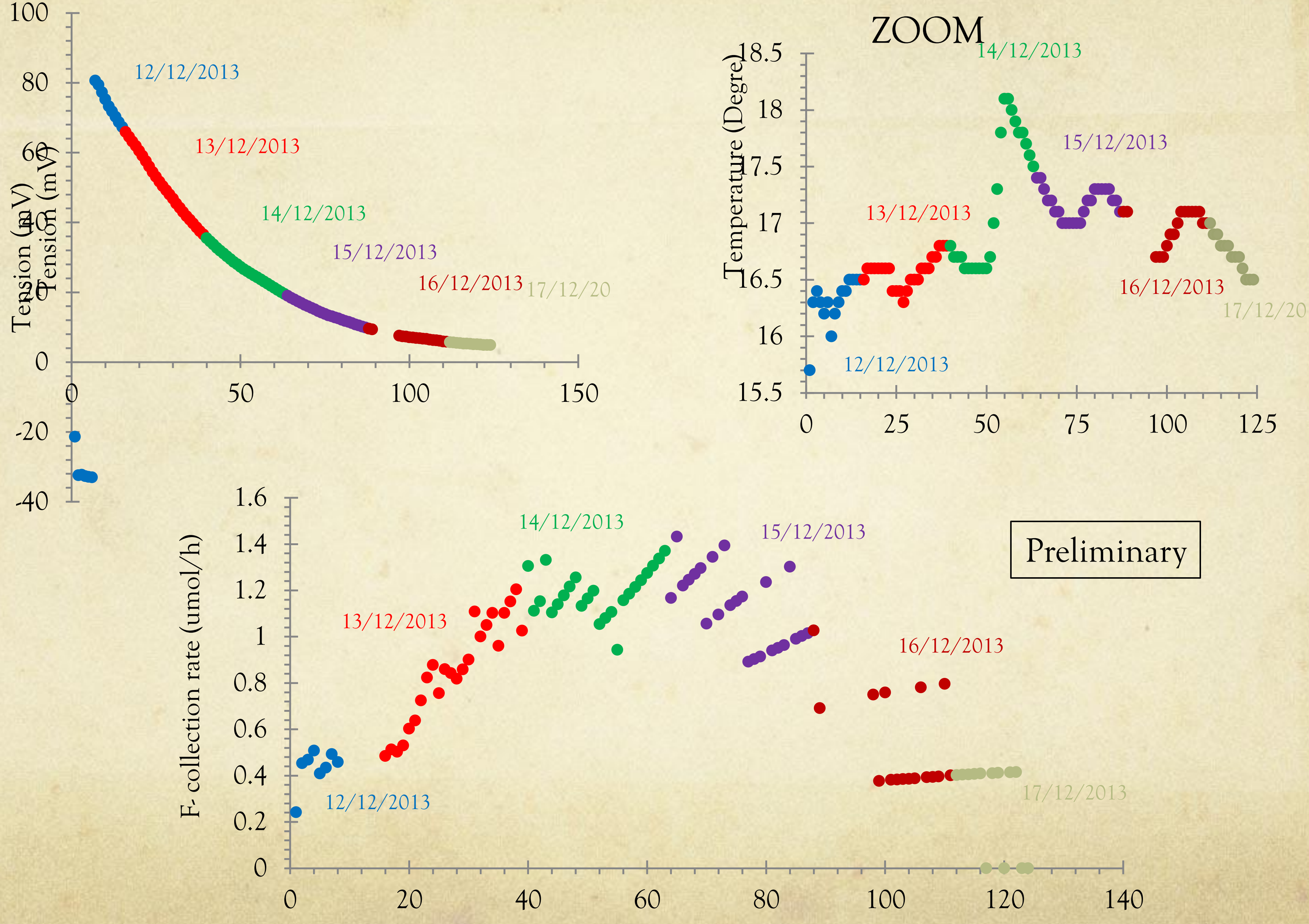
-High rate capability is demonstrated. Single–gap detectors using Tsinghua low-resistivity glass are still efficient with few kHz/cm2 rate.

-New resistive materials using CNT are ongoing and the first results are very promising.

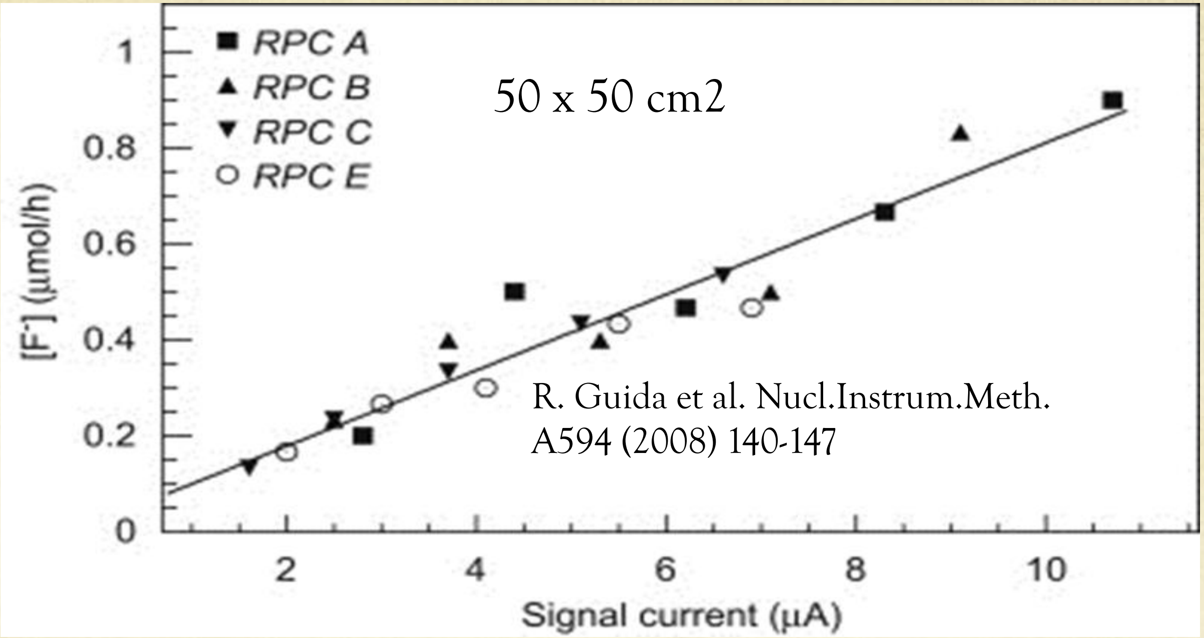
- The MPGD should get benefit of the R&D on new resistive material in the very near future.

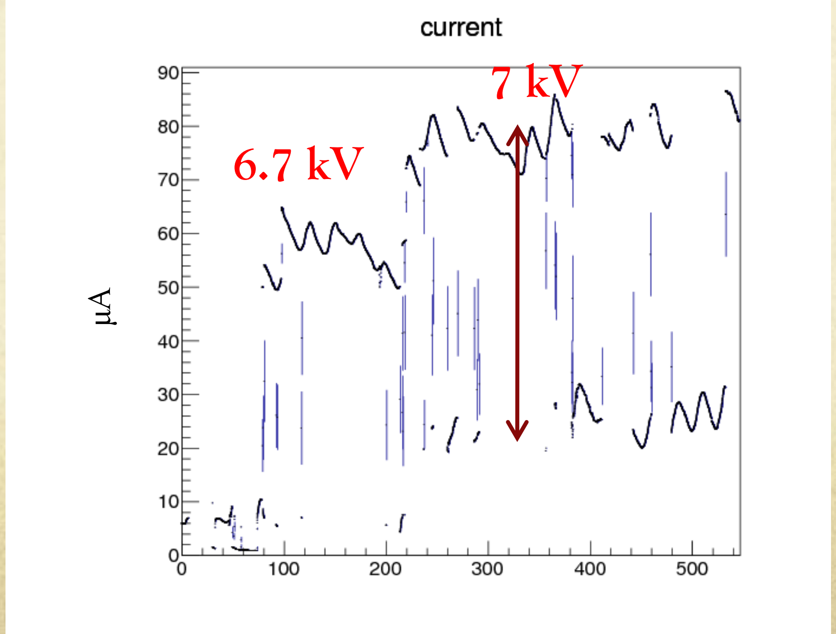
HF measurement based on method used for the CMS Bakelite RPC

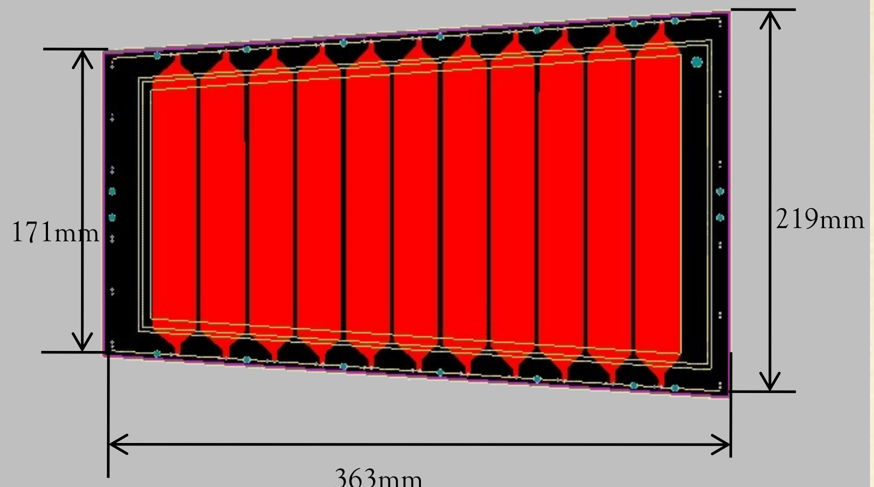
R. Guida et al. Nucl.Phys.Proc.Suppl. 158 (2006) 30-34

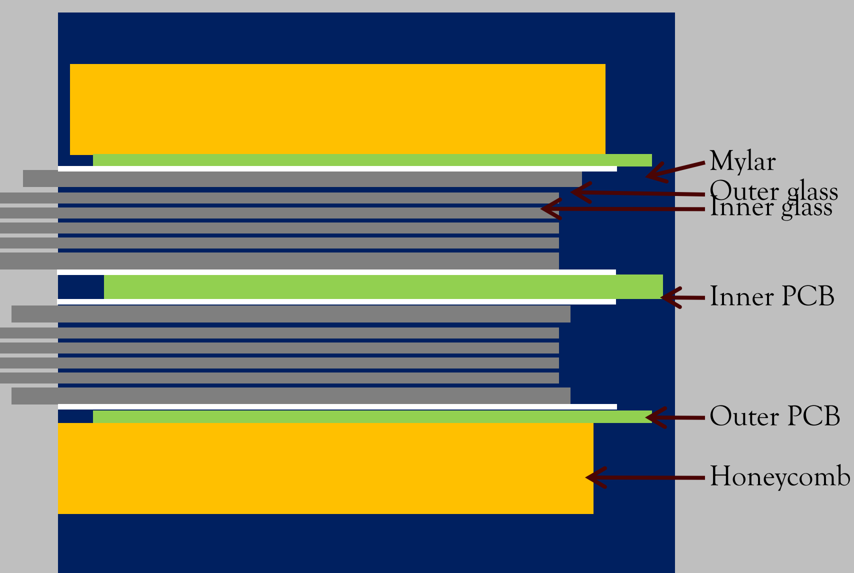


CMS Bakelite RPC measurement (2.5 m from the source): Strong dependence on the current






| | |
|---|---|
| Gas Mixture(Pre-mixed) | Freon 90%<br>iso-butane 5%<br>SF6 5% |
| Working Voltage | ±6800V |
| Electrical field | ~108.8kV/cm |

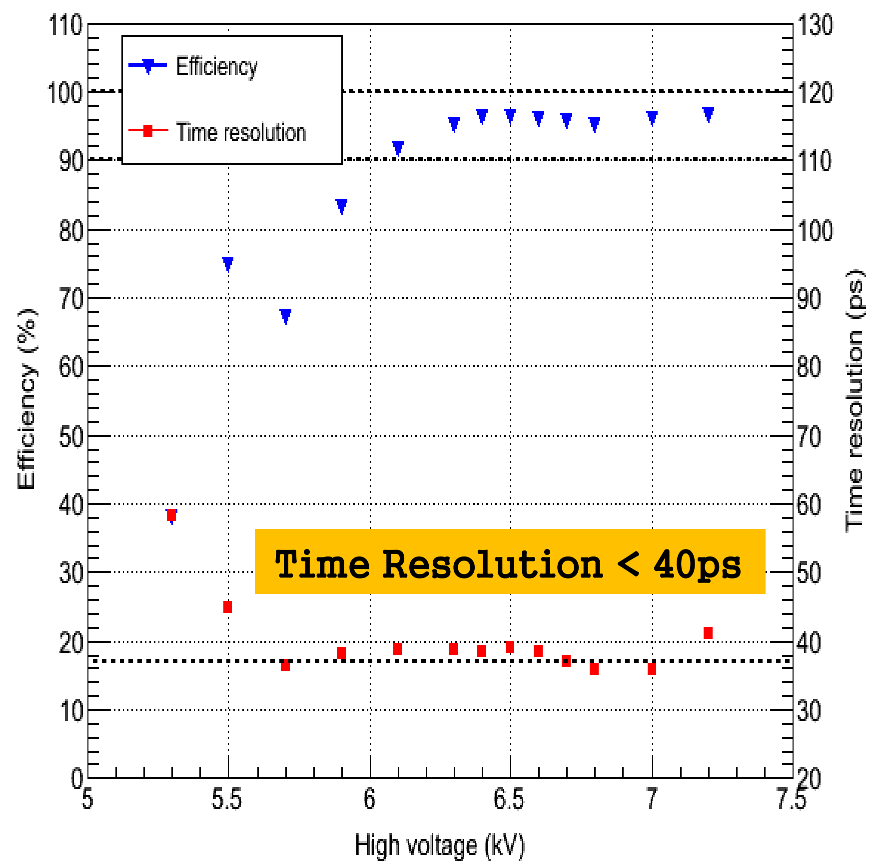
## The design of MRPC readout

| | |
|---|---|
| Interval | 3mm |
| Strip width | 25mm |
| Readout mode | Differential |

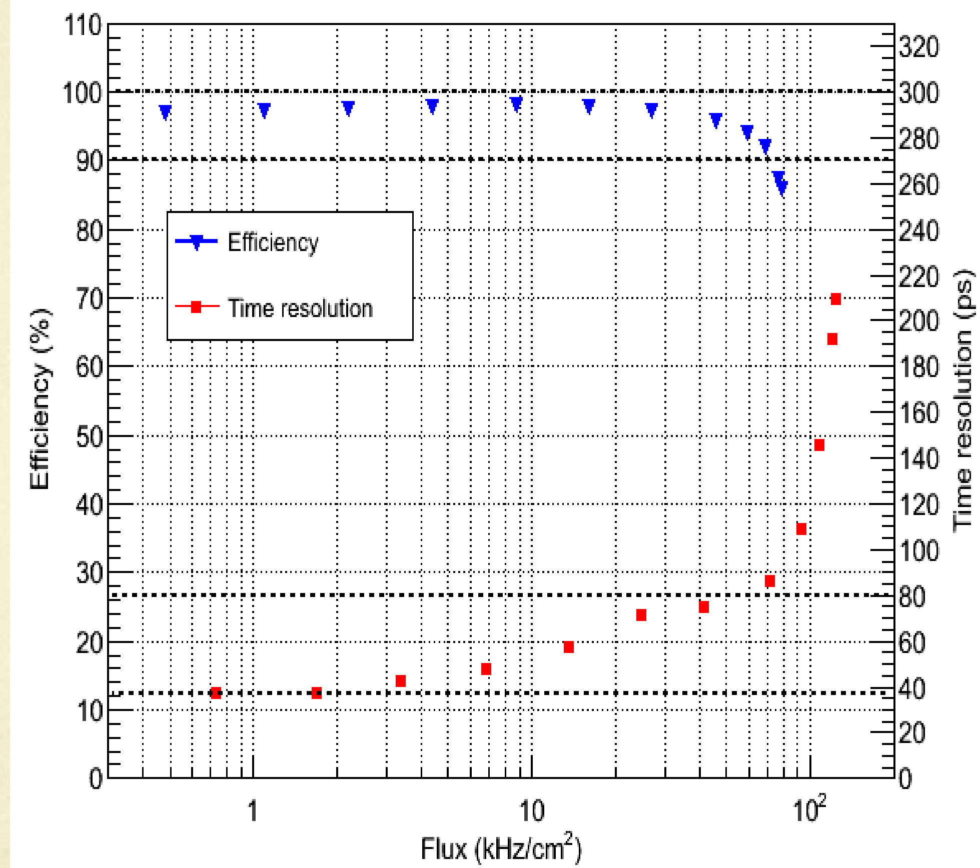
## Dimensions

| | Length/mm | Width/mm | Thickness/mm |
|---|---|---|---|
| Gas gap | - | - | 0.25×10 |
| Inner glass | 320 | 130-171 | 0.7 |
| Outer glass | 330 | 138-182 | 1.1 |
| Mylar | 335 | 153-198 | 0.18 |
| Inner PCB | 350 | 182-228 | 1.6 |
| Outer PCB | 350 | 172-218 | 0.8 |
| Honeycomb | 330 | 153-198 | 6 |

**Beam Test@HZDR June, 2012**

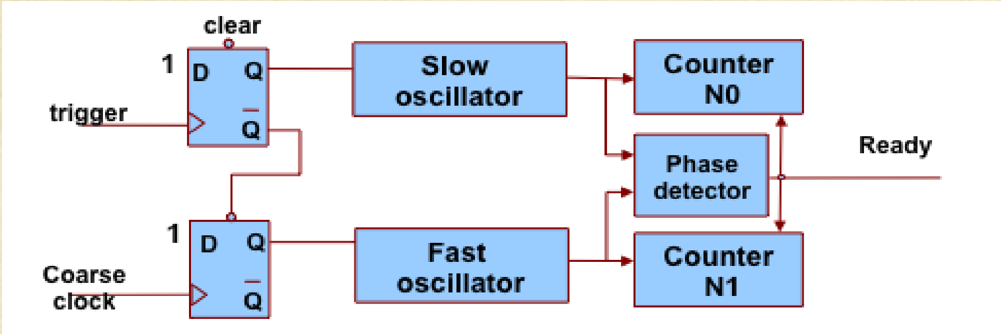


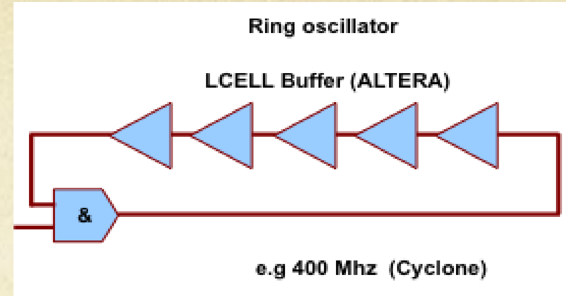

HV scan

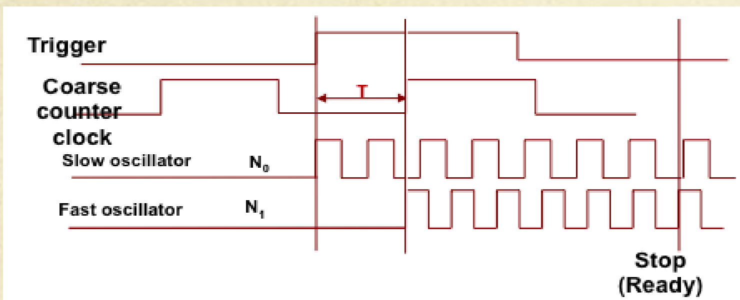



Rate scan

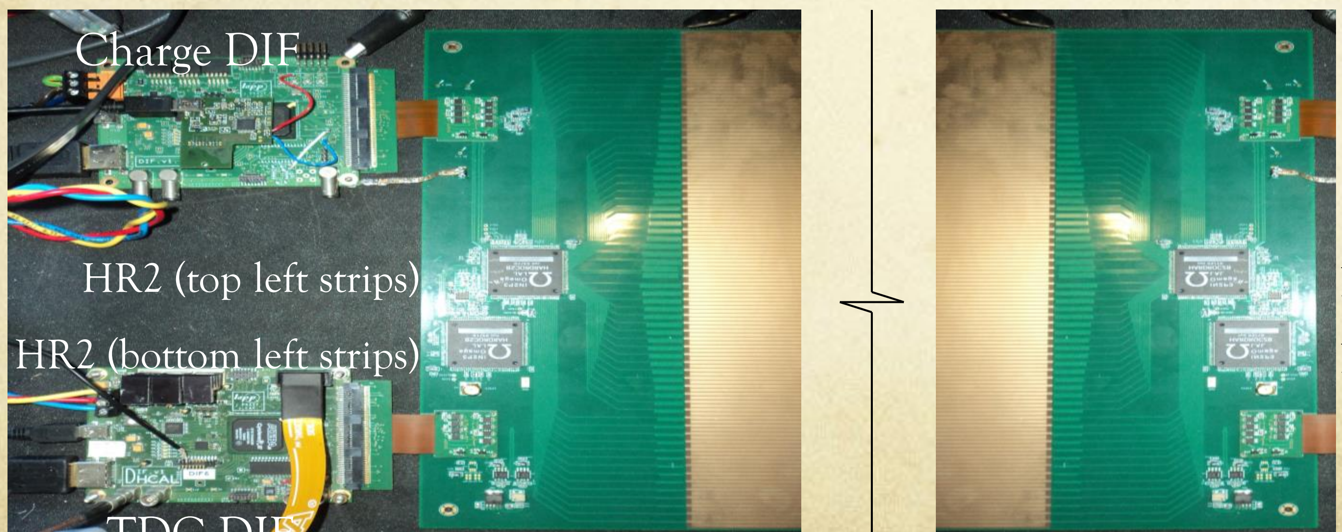
# TDC principle



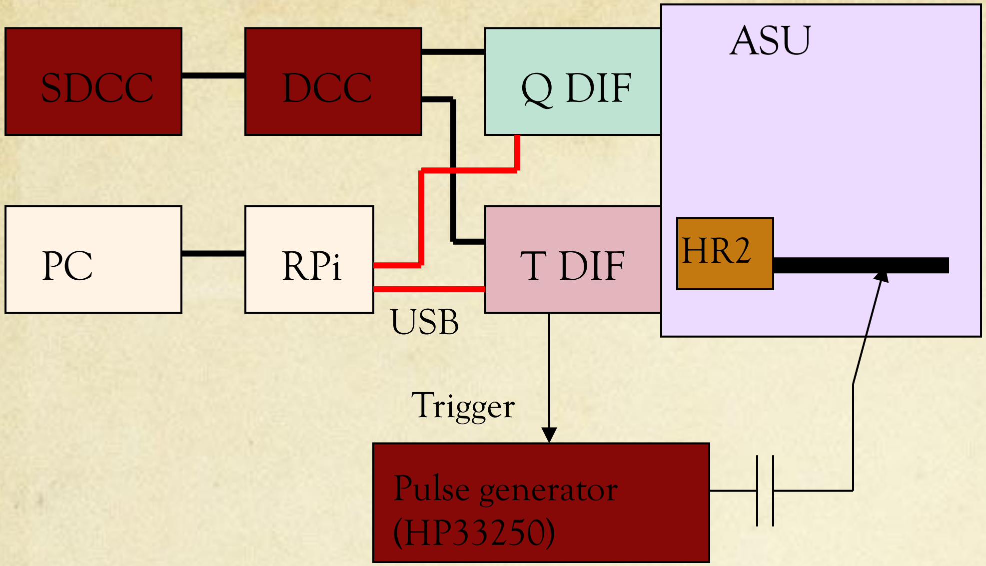

$$T = N_0 T_{slow} - N_1 T_{fast}$$

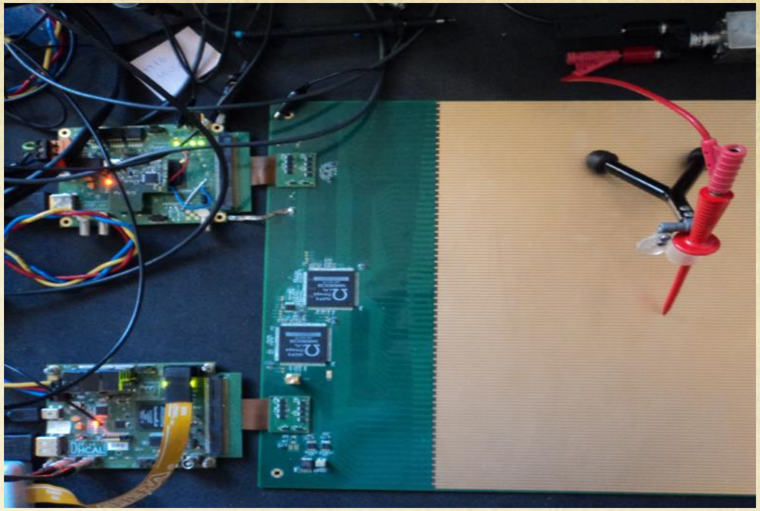



HR2 (top right strips)

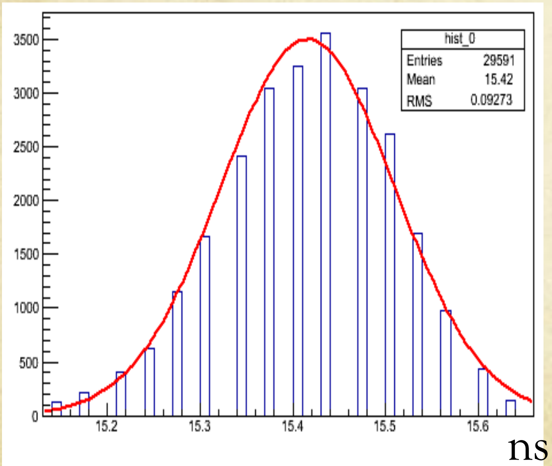
HR2 (bottom right strips)

2.5 mm pitch

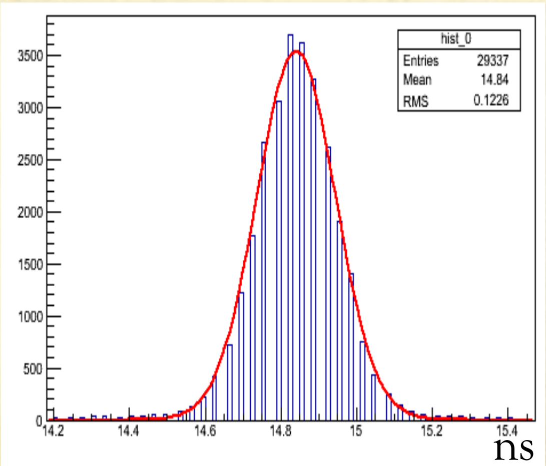


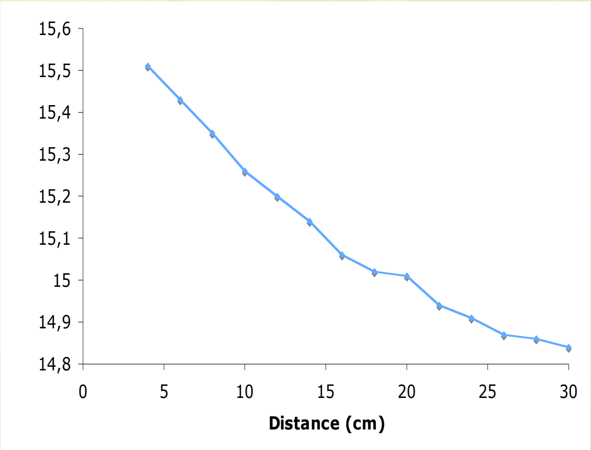
- Injection is made with a pulse generator on one strip (other channels are disabled)
- Pulse generator is triggered by the DIF (synchronous with the DIF clock)
- Delay between pulse and trigger is adjusted inside the generator




6mm from start of strip




30 mm from start of strip



# -To achieve sub-nanosecond

-Multi-gap GRPC is needed. The more gaps the more precise the time measurement.

-OPTIROC ASIC : 16/32-channel, high bandwidth preamp (GBWP> 10 GHz), <3 mW/ch, dual time and charge measurement (160 fC-400 pC), **jitter < 20 ps rms**

-TDC chip using the vernier principle with 10 ps time resolution is produced and being tested. Another TDC using the white rabbit technology could also be used

-.New PCB with pick-up strips read from both sides is being designed information with the aim to achieve Y-position determination $Y= L/2-v*(t_2-t_1)/2$.
Time resolution can be measured: $(t_1+t_2)- L/v$