Development of a new generation of Resistive Plate Chambers for high radiation environment

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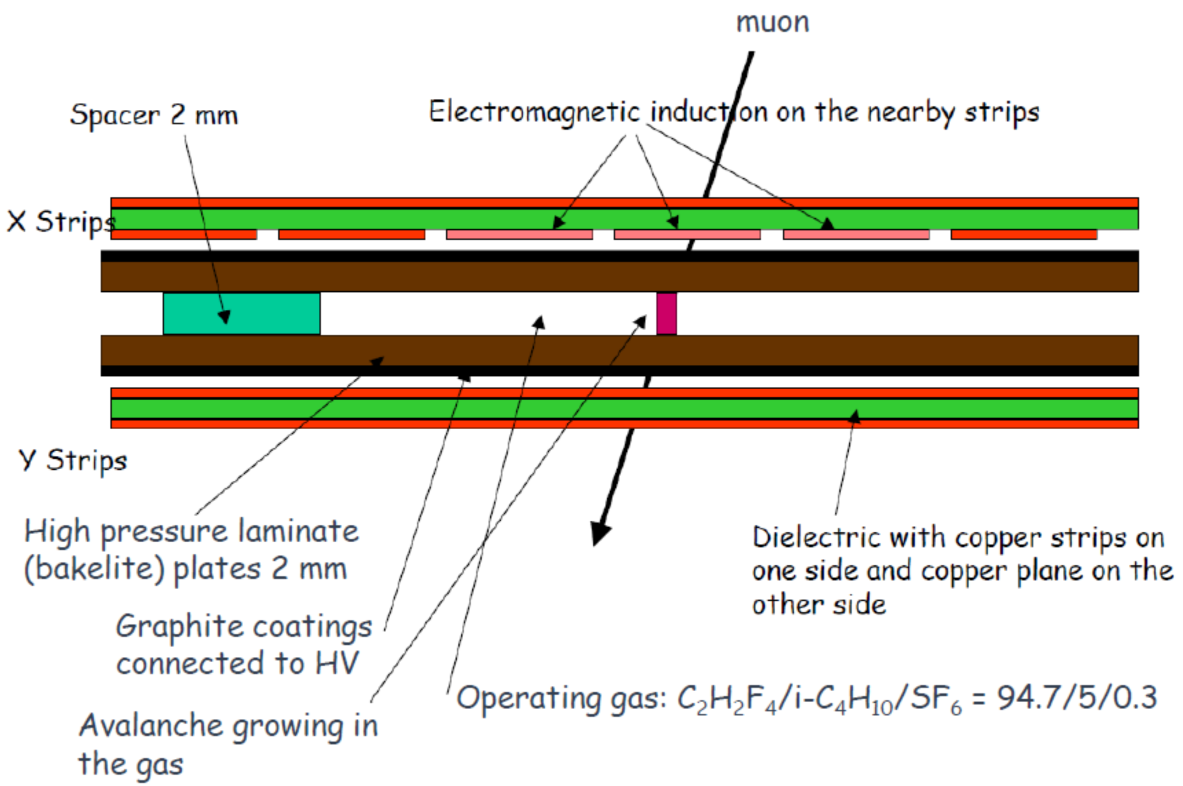
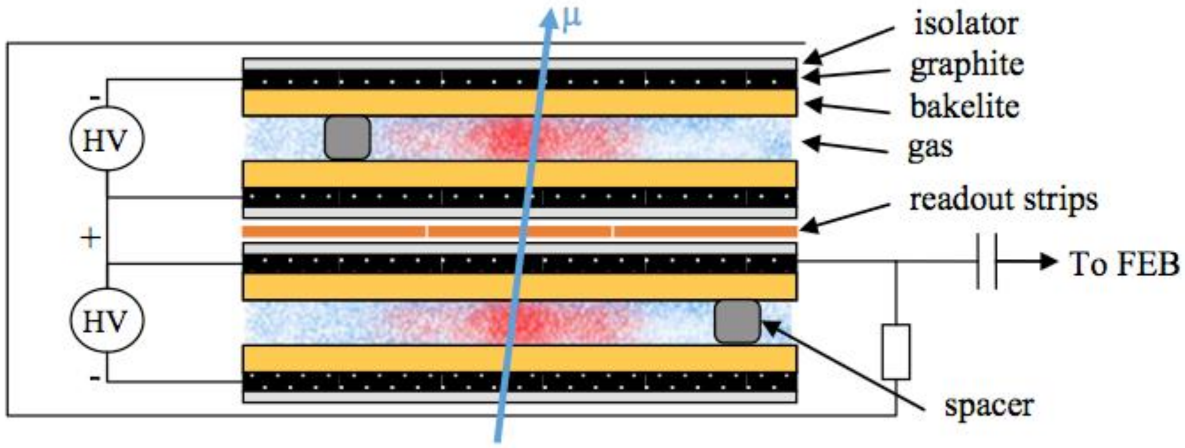
RPCs

- The RPC is a unique gaseous detector due to the **absence of any drift time**
- → The full gas volume is critical i.e. the field is strong enough to produce avalanche multiplication as soon as a free electron is created in any point of the gas
- This makes RPCs an ideal detector for fast decisions and for very high time resolutions
- Moreover their simple structure and low cost materials make them suitable for very large area applications
- This presentation intends to show how to create a new generation of RPCs to face the requirements of the HL-LHC mainly concerning rate capability and space*time resolution

Sketch of an RPC





The parameters determining the rate capability

The RPC rate capability is mainly limited by the current that can be driven by the high resistivity electrodes. It can be improved working on a number of highly interconnected parameters.

- For a working current i part of this voltage is needed to drive the current in the electrodes

$$V_{gas} = V_a - Ri = V_a - V_{el}$$

- The voltage transferred to the electrodes can be written as

$$\boldsymbol{V_{el} = \rho\, t\, r_u < Q >}$$

$\boldsymbol{\rho}$ is the bulk resistivity of the electrode material; $\boldsymbol{t}$ is the total thickness of both electrodes; $\boldsymbol{< Q >}$ is the average charge delivered in the gas for each count and $\boldsymbol{r_u}$ is the counting rate per unit surface

→ A high rate capability requires to keep V_{el} at a negligible value wrt V_{gas} even under heavy irradiation

Increasing the RPC rate capability (1)

- A natural way to reduce V_{el} is to search for **low resistivity $\boldsymbol{\rho}$** materials so that the operating current can be increased without reducing the voltage V_{gas} applied to the gas (present value $3\ 10^{10}$Ohm*cm)

- BUT: an increase of the rate capability of e.g. one order of magnitude would require to increase the operating current by the same amount.
- This would increase by one order of magnitude the concentration of the pollutants generated inside the gas
- Spontaneous detector noise could be increased as well
- → Potential ageing problems. A new robust ageing test would be required to qualify the RPCs for this high current working mode

Increasing the RPC rate capability (2)

- To reduce the **electrode thickness $\boldsymbol{t}$** has in principle a similar effect as to reduce the resistivity ρ. A few specific points however have to be stressed
- The most important effect of t is to attenuate the charge induced on the read out electrodes by a factor of

$$A = 1 + \frac{t}{\varepsilon_r g}$$

- This effect is particularly important for very thin gaps and shows that
  - the electrode thickness must be reduced according to the gap size
  - A thinner electrode produce an amplification of the induced signal and therefore improves the signal to noise ratio

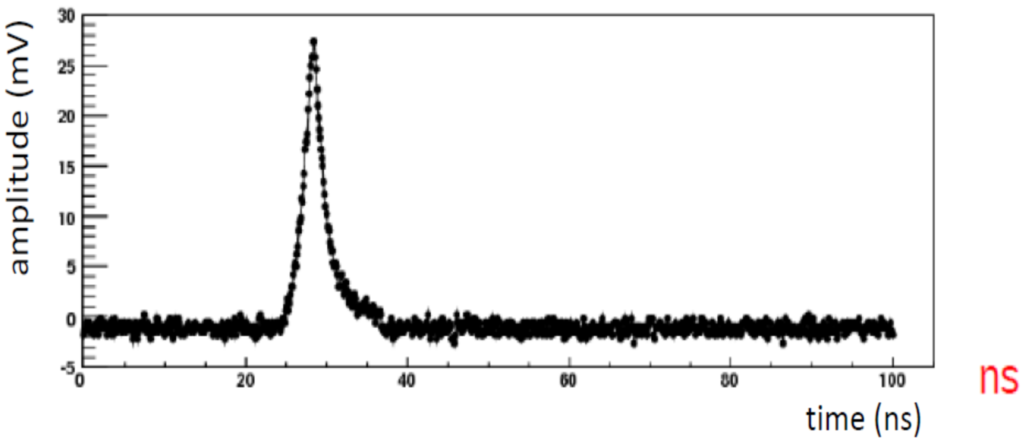
Increasing the RPC rate capability (3)

- To **reduce the average delivered charge $< \boldsymbol{Q} >$** allows, in the most ambitious approach, to increase the rate capability at constant current
- → No ageing increase due to the increased current: a crucial advantage for the future RPCs.
- The idea is to transfer from the gas to the front end electronics a relevant part of the amplification needed to detect the avalanche signal.
- It requires:
  - Very sensitive FE electronics with an excellent signal to noise ratio
  - High suppression of the noise originerated both by the detector itself and by external sources
  - Very carefull optimization of the chamber structure as a Faraday cage.
- The limit of this approach is just the possibility to discriminate from the noise a very small signal generated inside the gas

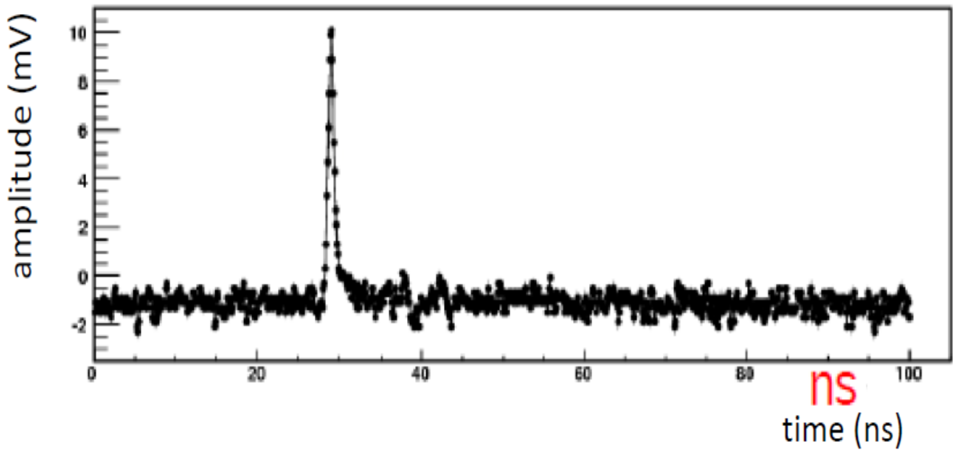
Thin gas gaps

- A thin gap
  - reduces the delivered charge $< Q >$
  - improves the timing

Prompt signal for 2 mm gap



Prompt signal for 0.5 mm gap



- The thinner gaseous target can be compensated by a multiple gap structure

Gas volume

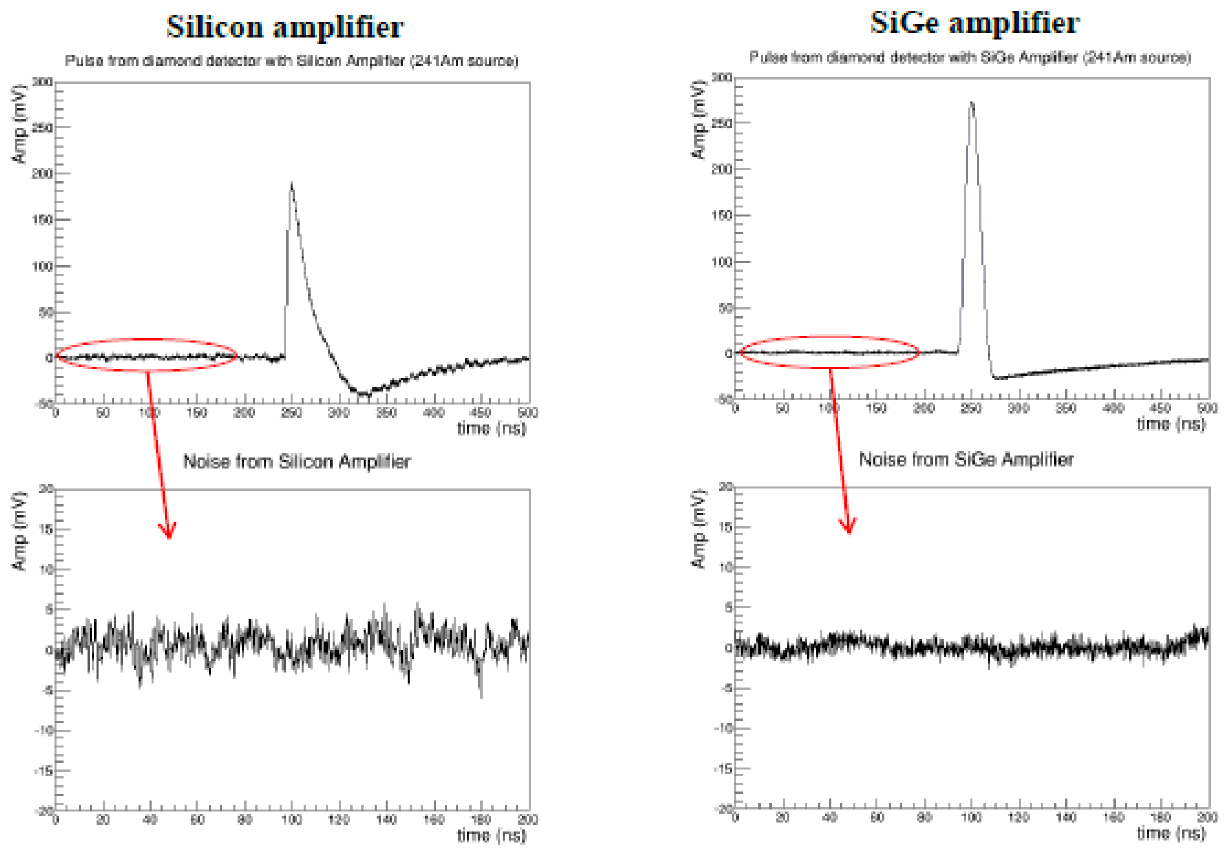
- Gas volumes of similar size and structure as the existing ones but
  - Thinner gaps
  - Thinner electrodes
  - Also possible a multigap structure implementation if required to achieve good detection efficiency
- Very thin gas volumes also required to fit modest available spaces to install new chambers
- Improved gas distribution to insure better flow uniformity at high rate

The front end electronics

- The front end electronics is a crucial detector component, like an extension of the detector itself
- Excellent “signal to noise” ratio required for the front end amplifier
- The new family of Silicon-Germanium components seems very promising

Signal and noise from SiGe Amplifier and Silicon Amplifier

Pulses recorded from a 500 micron diamond sensor irradiated by ^{241}Am source.

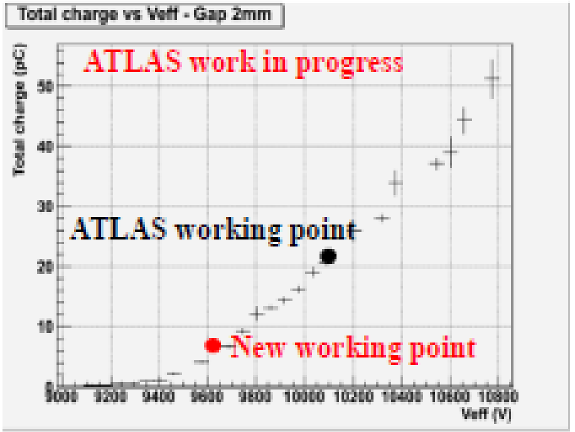


A new fast, low noise preamplifier

- The low noise permits to work at a lower gas gain and therefore at a higher rate.
- The intrinsic bandwidth of the amplifier permits to keep the time resolution of the detector itself.

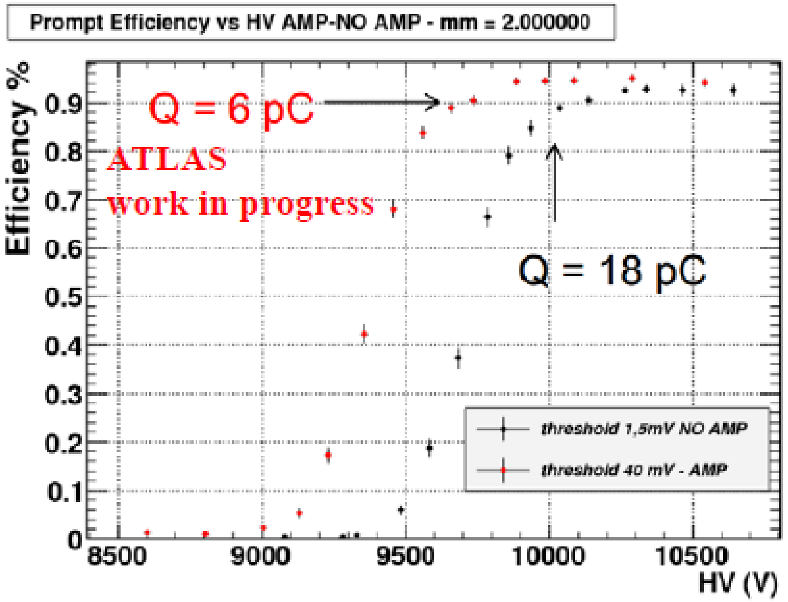
Properties of the preamplifier

Voltage supply	3-5 Volt
Sensitivity	2-4 mV/fC
Noise (up to 20 pF input capacitance)	1500 e^- RMS
Input impedance	100-50 Ohm
B.W.	10-100 MHz
Power consumption	10 mW/ch
Rise time $\delta(t)$ input	300 – 600 ps
Radiation hardness	1 Mrad, 10^{13} n cm^{-2}



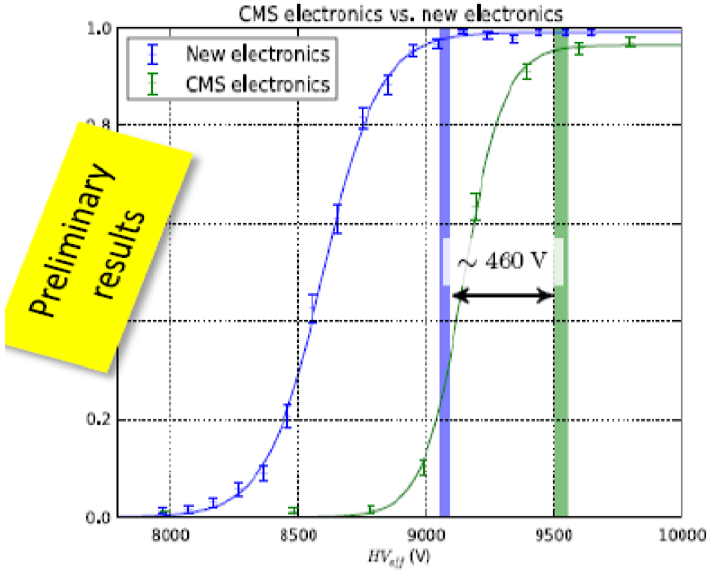
Total charge per count vs operating voltage for a 2 mm gap RPC. (Muon induced avalanche)

lower gas gain → lower working voltage



Efficiency curve for the same 2 mm gap RPC, with the new preamplifier (red) and with an "ATLAS like" threshold (black).

Test on standard CMS chamber



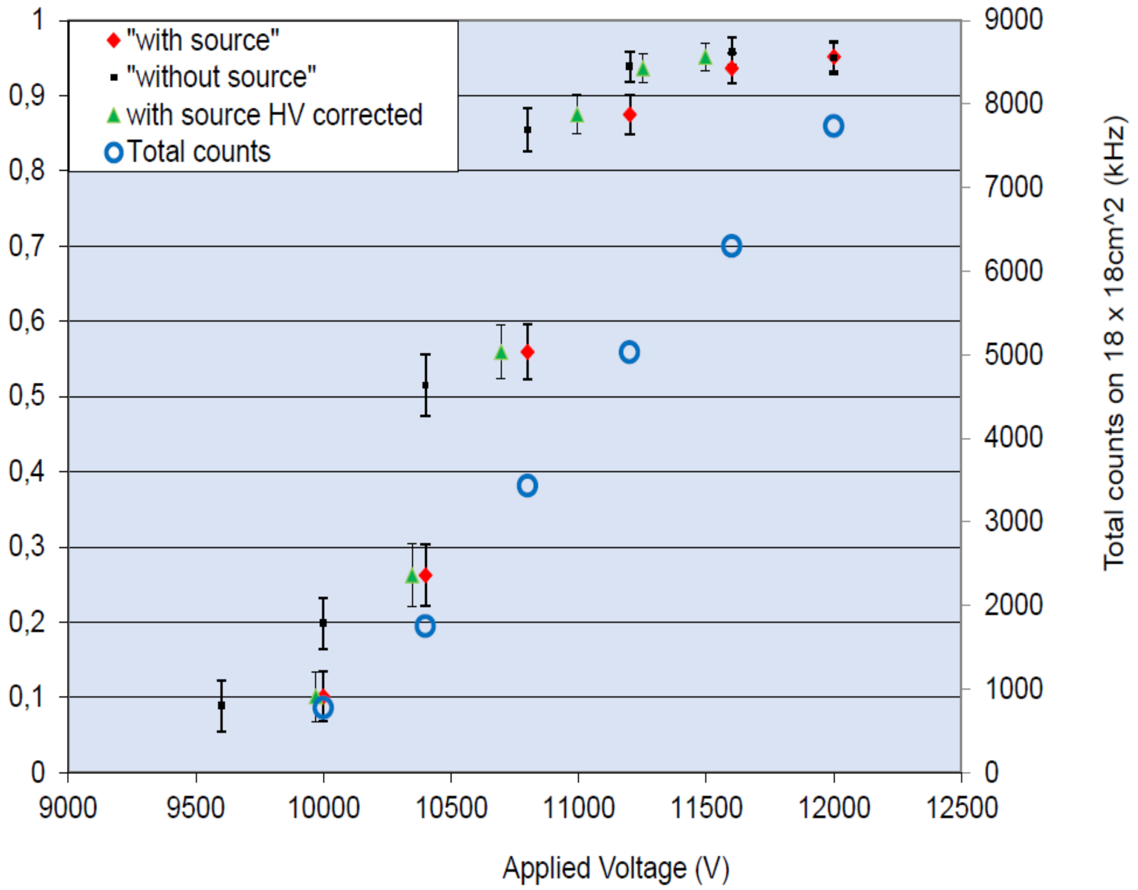
Efficiency vs voltage for a CMS RPC, with the standard (blue) and the new (green) FE electronics (same as the Atlas one)

Test of a small size 1+1mm bigap at the GIF

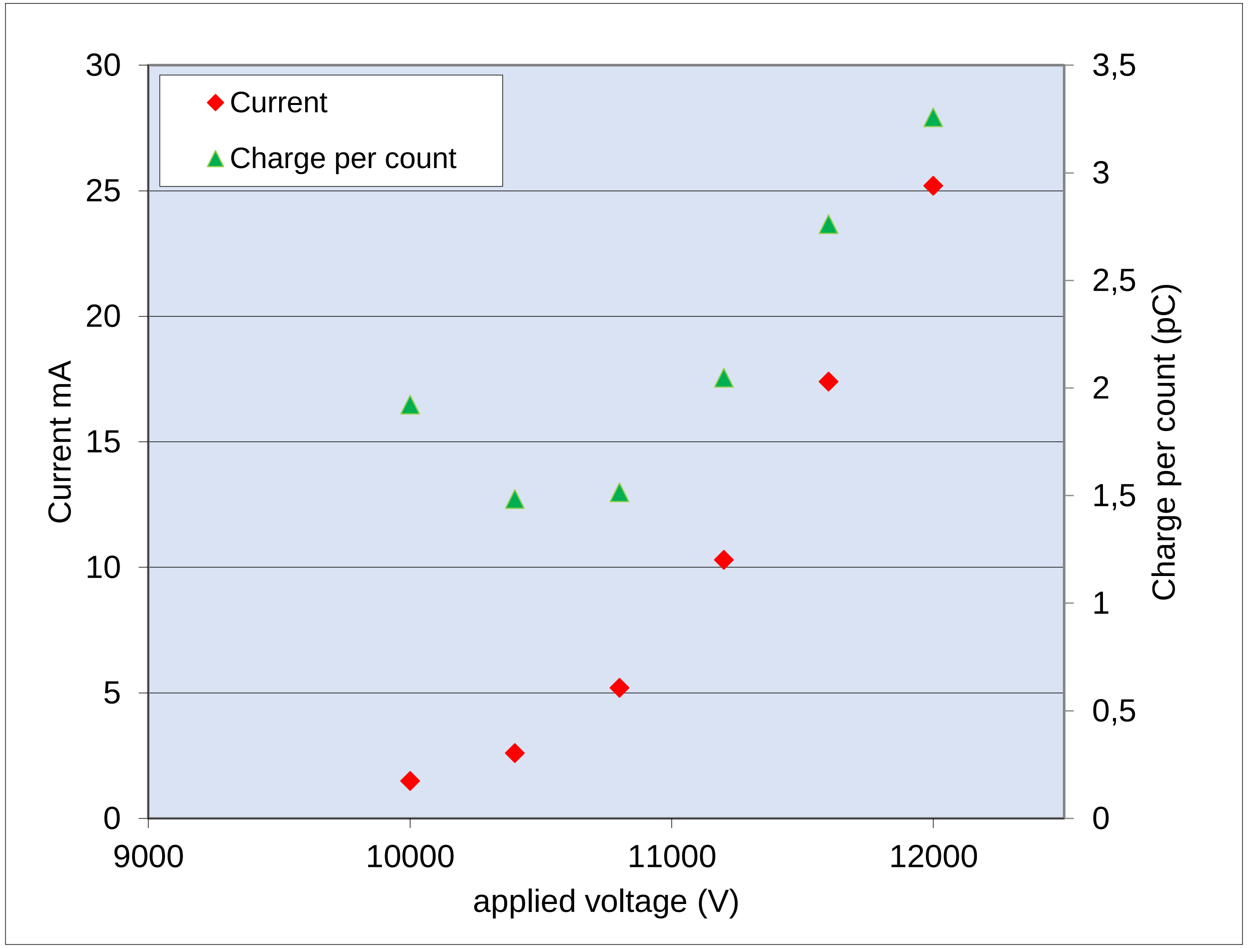
- Several weeks test carried out at GIF with a 1+1 mm bigap of sensitive area 18x18 cm^2 at 40 cm from the source
- Equipped with a new front end circuit
- HPL phenolic electrodes made with residual Atlas plates
- Measured rate at full efficiency about 20 kHz/cm^2

Test results

Efficiency x acceptance / counting rate



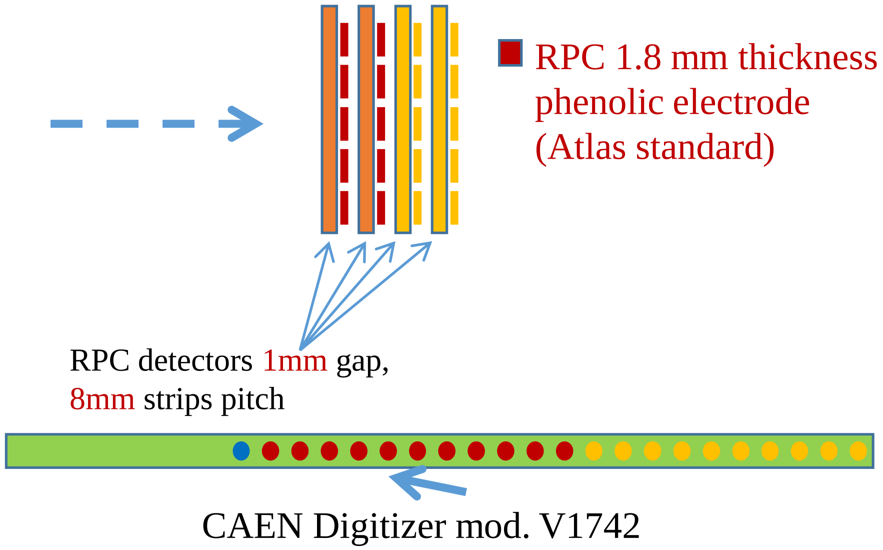
Operating current / delivered charge per count



Fine tracking with RPCs: H8 Test Beam experimental setup

The RPC quadruplet has been tested at the H8 Muon Beam facility at CERN.

- Aim of this test was to evaluate the **spatial measurement capability for perpendicular tracks.**



Scheme of the experimental setup

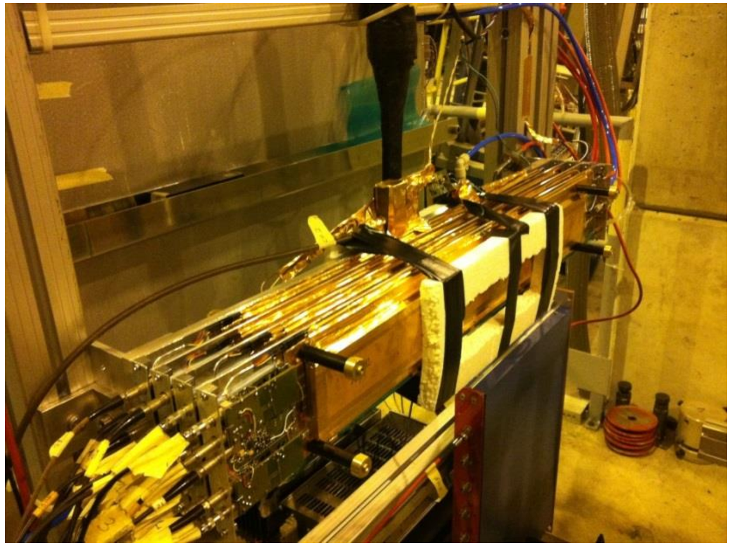
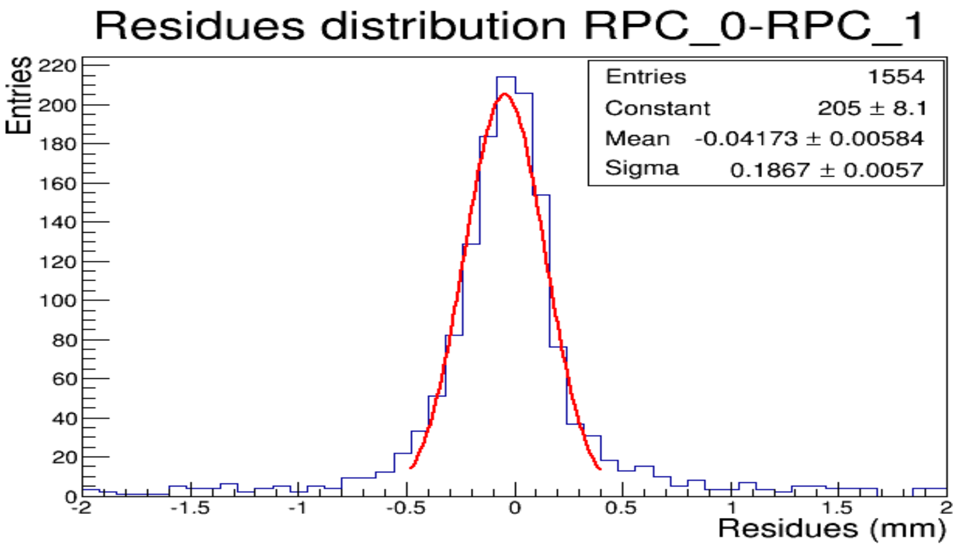


Photo of the experimental setup

Waveforms recorded by means of a 5 Gs/s, 32 channel digitizer
Trigger by a scintillator coincidence

H8 Test Beam results



- → net resolution of a single RPC with 1.8 mm electrodes and 8 mm pitch

$$\boldsymbol{\sigma_s = (132 \pm 5)\ \mu m}$$

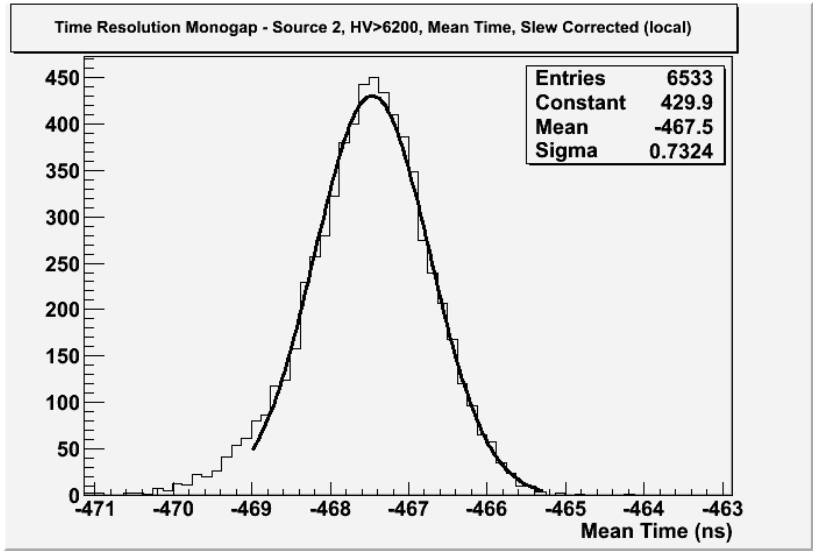
- From simulation of the FE effect

$$\sigma_{s,RPC\ FE} \cong 110\ \mu m$$

- Intrinsic resolution upper limit:

$$\sigma_{s,RPC\ intrinsic} = \sqrt{{\sigma_s}^2 - {\sigma_{s,RPC\ FE}}^2} \lesssim 70 - 80\ \mu m$$

Timing at high rates ($3\ kHz/cm^2$)



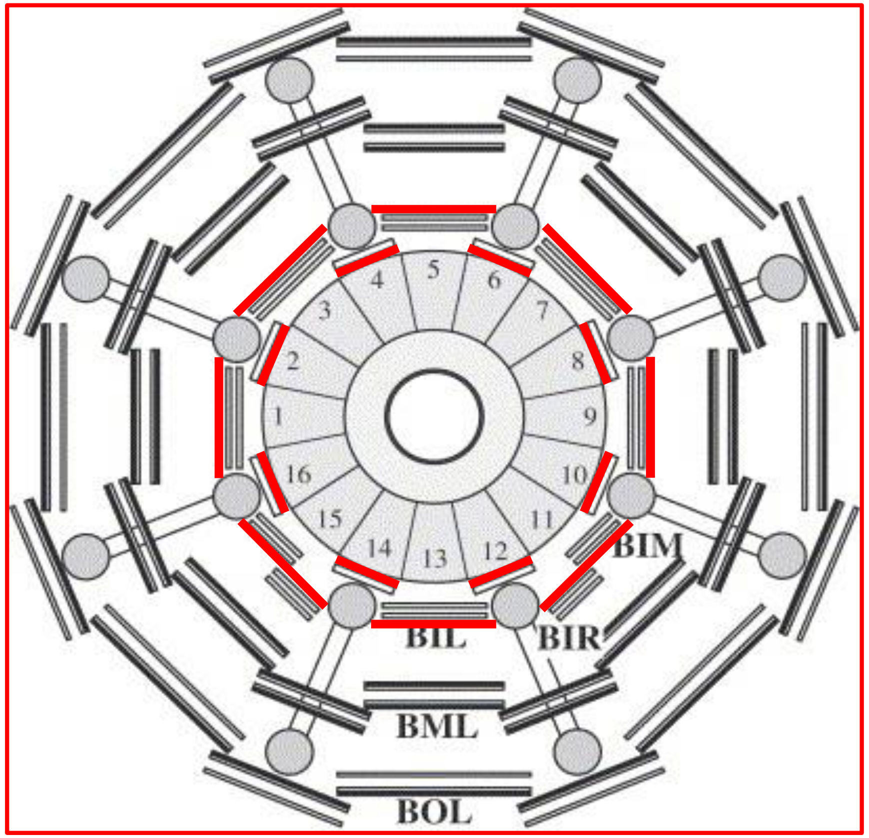
- Time resolution in high rate environment ($3\ kHz/cm^2$) after correction for scintillator trigger jitter:

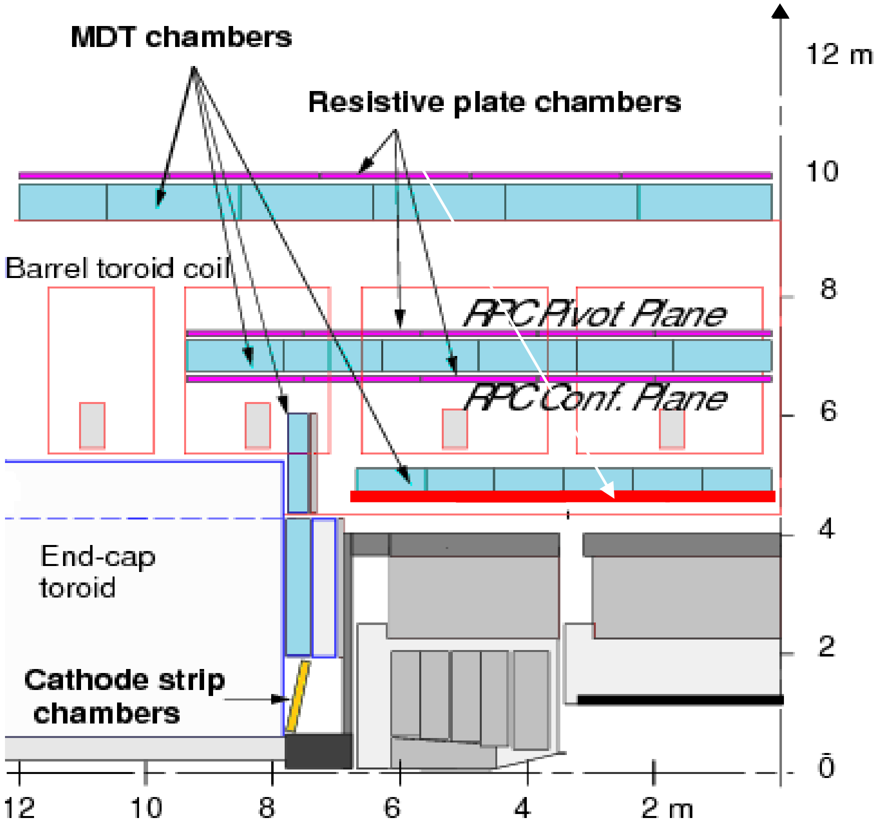
$$\boldsymbol{\sigma_t = 480 \pm 20\ ps}$$

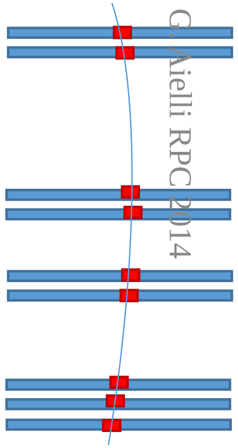
- This high rate result **is compatible with the one obtained at lower rate** with the same setup.
- Much better time resolution, **10 – 20 ps**, is achievable with very thin multigaps. To pursue this R&D line would require however a relevant **physics case**

Atlas RPC upgrade proposal

Substantial increase of redundancy by adding the RPC inner layer
Better coverage and trigger performance

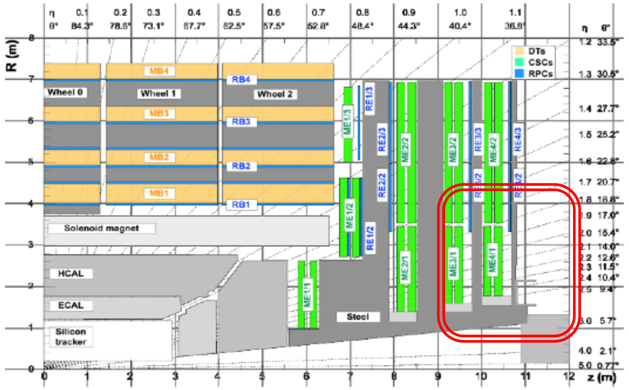


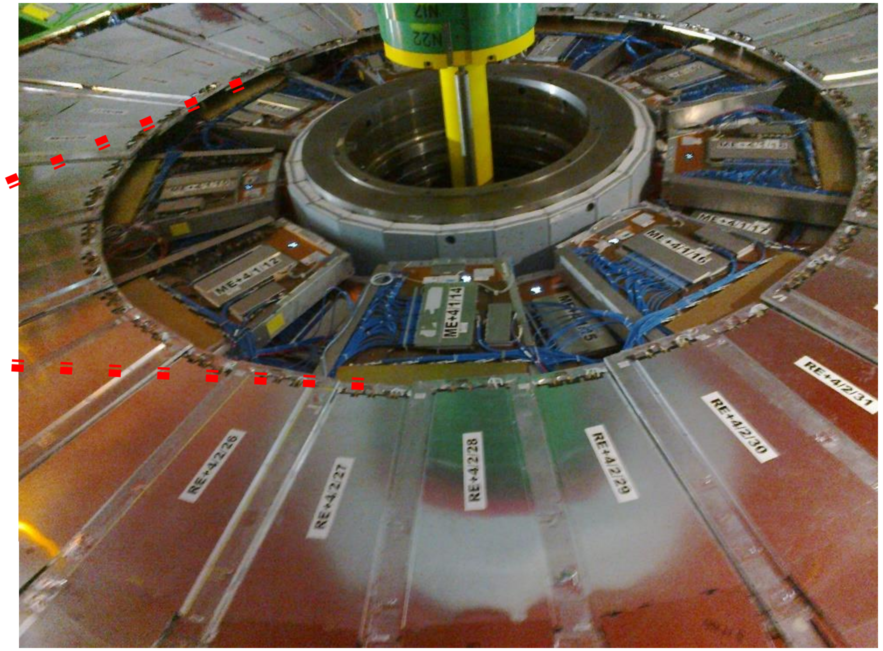


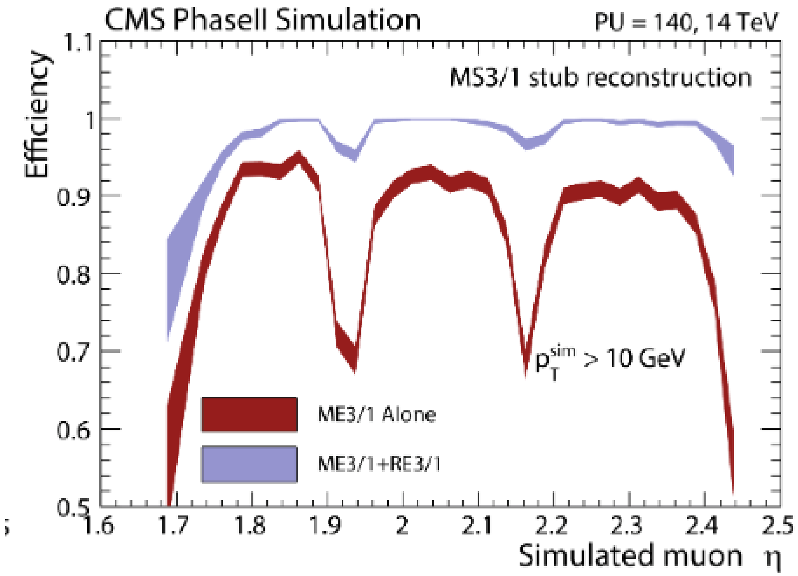


- 9 layers instead of 6
- 4 chambers instead of 3

CMS RPC for phase 2







Complete RPC coverage in the forward region (1.6< |η| <2.4) to enhance **trigger and reconstruction capability and increase the redundancy**.

R&D proposal for phase II

Two R&D documents have been submitted to CMS:

1. HPL (bakelite) RPC R&D document

- Electrode with lower resistivity → 10^{10}Ohm*cm
- Reduced gas gain
- New detector configuration: electrode thickness and multi-gap

2. Glass RPC R&D document

- single and multi-gap

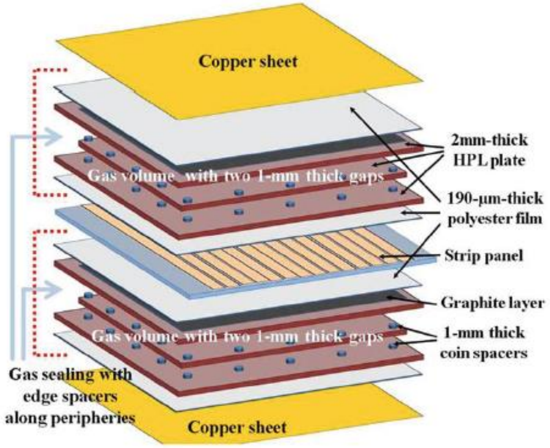
Multigap RPC (bakelite)

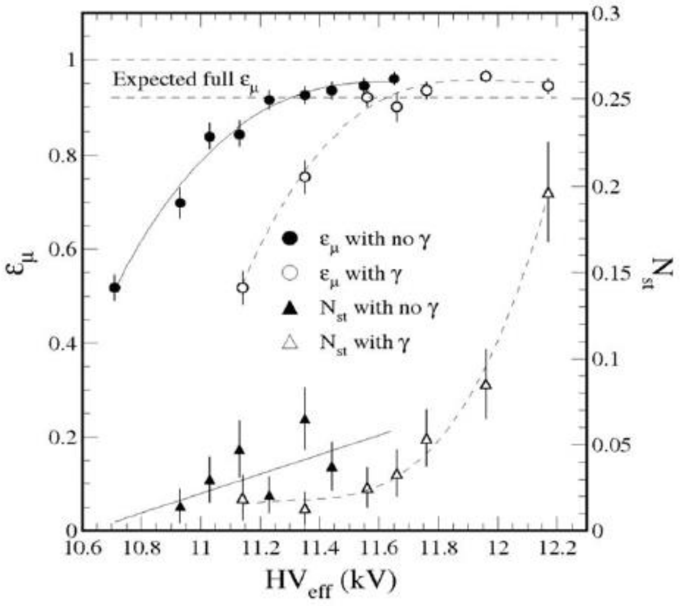
- The CMS double gap configuration has been modified with a 2-gap multigap by adding an additional thin gap (each gap thickness = 0.8 mm)
- Prototype: 45 x 45 cm^2 (active area) made with Standard HPL and front-end electronics.
- Test done with cosmic rays muon with and without irradiation. Results:

  Rate capability: 3 kHz/cm^2

  Efficiency plateau ~ 1 kV

  Low streamer probability < 2 % in the mid of efficiency plateau
- Costs, production, electronics, service to be studied in details.





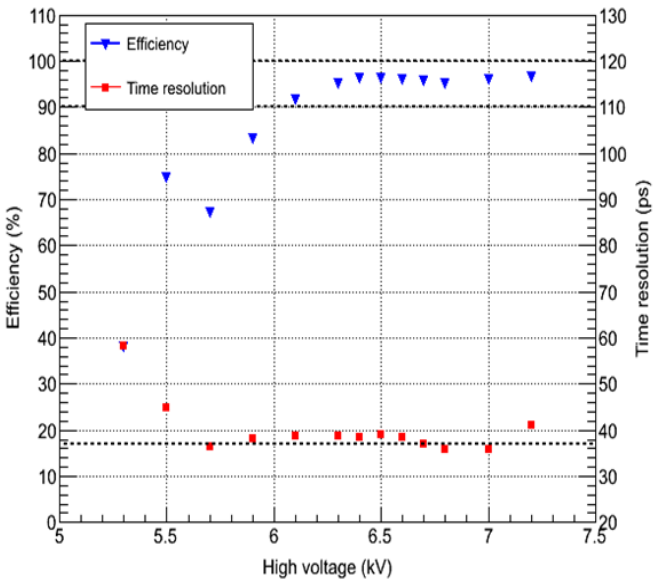
Glass RPC

Single gap RPC prototype using doped glass electrodes ($\rho \approx 10^{10} \Omega cm$) with 1.2 mm gas gap and 0.7 mm electrode thickness. Standard gas mixture

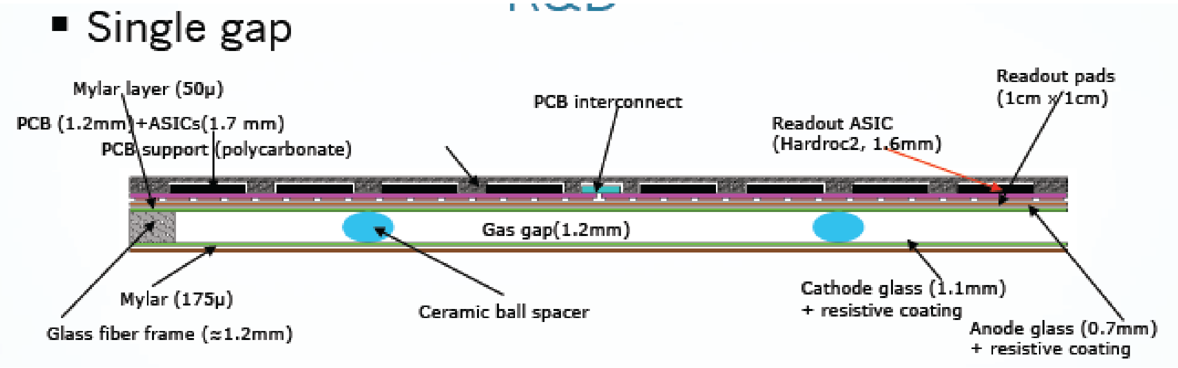
Micro strip plane of about 2-4 mm in pitch to achieve sub-millimetre spatial resolution.

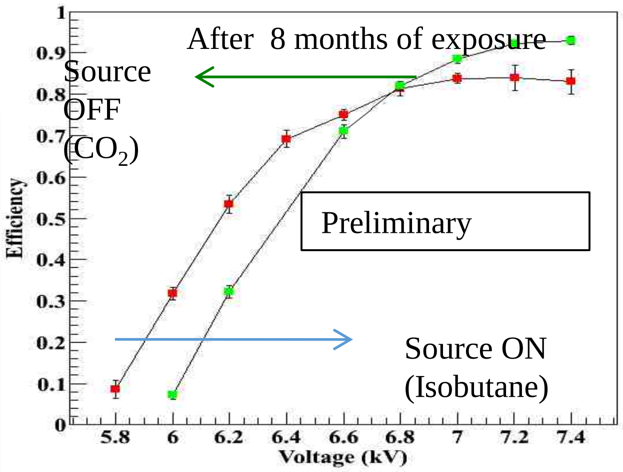
Rate capability: 10 kHz/cm^2

Constraint : Size of low-resistivity glass is limited. Largest surface is 30X30 cm^2



Multigap RPC





Conclusions

- The RPCs have a great potential of applications that has still to be expressed
- In view of LHC phase 2:
  - Their rate capability can be improved acting on all relevant parameters like the sensitivity of the front end electronics, the electrode resistivity and thickness
  - Thinner gaps and electrodes, also in a multigap structure if needed, can improve the rate capability and time resolution at the same time
  - The mechanical structure of the new chambers will be basically similar to the present one
- The spacial resolution can be improved to 100 μm in both directions of the gap => space*time resolution better than 100 μm * 100 ps is achievable on large detection areas
- The search for new working gases with high performance and low environment impact has been already started and looks very promising
- Important sinergies of the RPC groups for a joint R&D working program