# (M)RPC FOR HEP

I.Laktineh
Lyon University-IP2I

# Outline

- (M)RPC: a few words on their history
- (M)RPC why for?

Trigger& muon detectors

- RPC in L3, BABAR and learnt experiences
- RPC@OPERA
- RPC@LHC (CMS, ATLAS and ALICE): performances and issues

ToF
- MRPC@ALICE
- MRPC@CBM

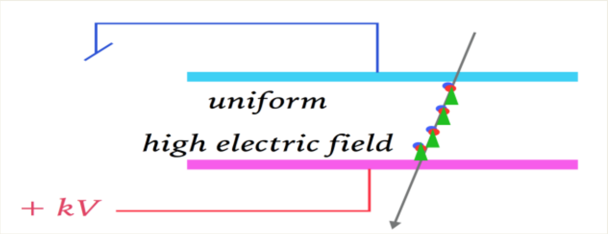
Calorimeters
- RPC@future colliders

-Parallel/Resistive Plate Chambers

**Single-gap**

One electrode in metal and one resistive(glass) **Pestov 1971**

Two resistive electrodes (HPL) **Santonico-Caldarelli 1981**

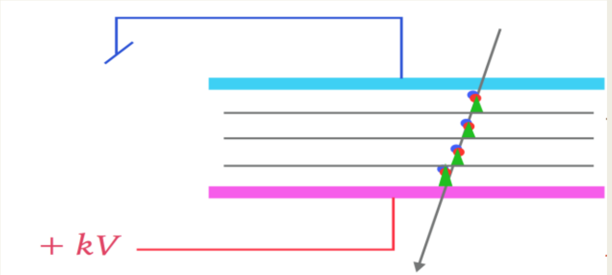



Protection against sparks due to the “high” resistivity of the electrode

This leads to reduced rate capabilities (charge evacuation time)

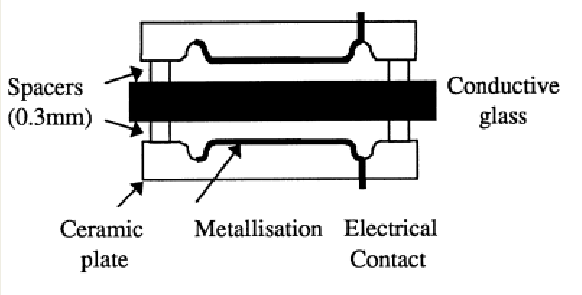
**Multigap**

Several thin gas gaps. Thin plates in glass (**Williams et al**) in **1996.**




tRPC: metal-glass RPC based on very thin gas gap proposed by

**P. Fonte** et al (1999)



## Why (M)RPC are good for HEP?

- Provide a very good detection tool in terms of spatial (a few mm down to a few hundreds of μm ) and more in time measurement precision

- Provide an **excellent** detection tool for **time measurement** (resolutions less than a few ns for RPC and down to tens of ps for MRPC (< 80 ps in Alice ToF)).

- Provide **large detection area** (6000 $m^2$ for CMS and 7000 $m^2$ for Atlas) at **low cost** ( a few hundreds of CHF/$m^2$)

- Could be **easily built** using available materials (Bakelite, glass, ceramics)

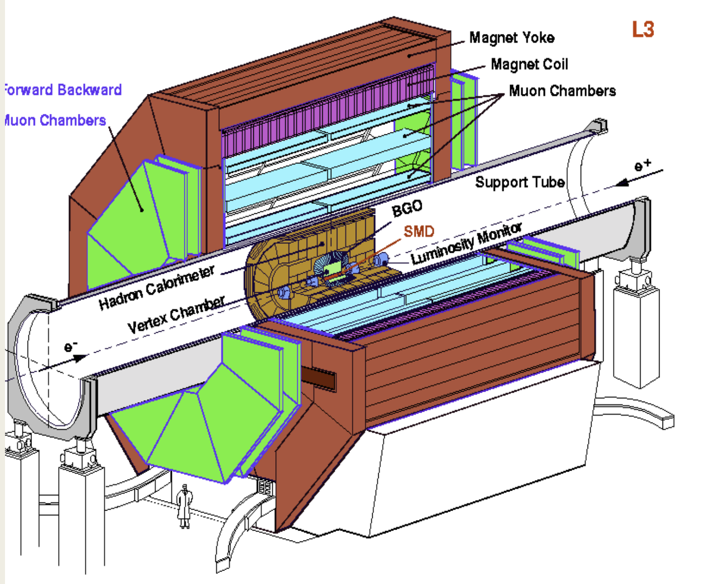
- The relatively large charge ( **> tens of fC up to 100 pc**) that (M)RPC provide, greatly simplifies the the readout electronics.

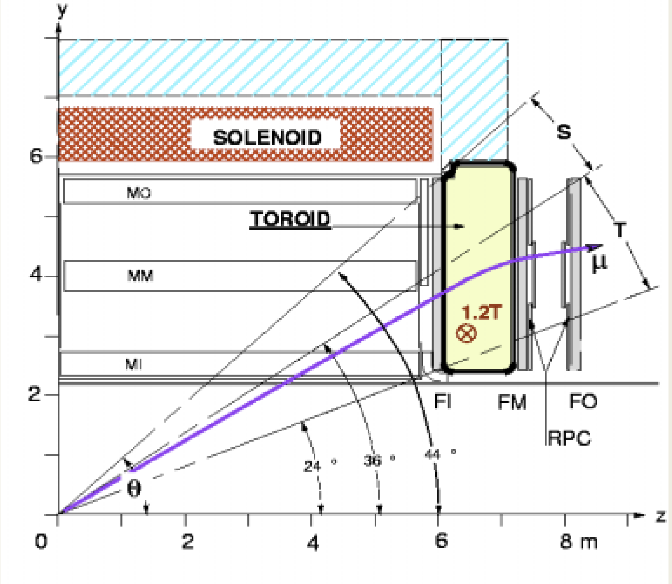
❖ Due to these excellent features, (M) RPC have played an important role in HEP experiments. More than 40 years after their invention, they are still being used but also proposed for future colliders.

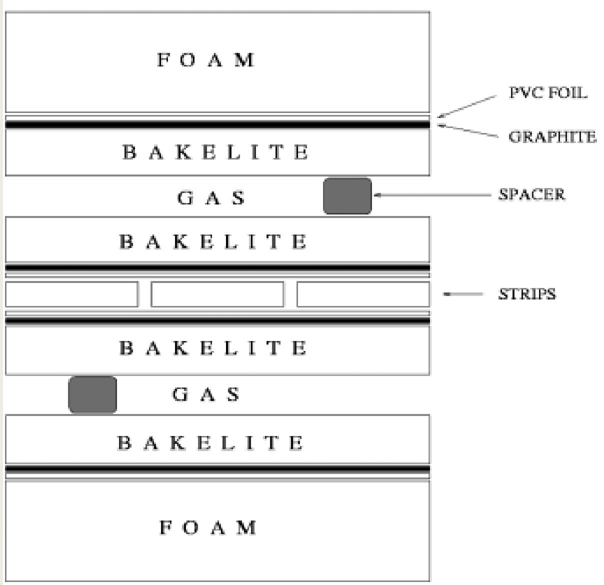
❖ (M)RPC have being improved since their invention and succeeded to succeeded to overcome many encountered problems.

# RPC@L3

The first large HEP experiment that used RPC as a muon detector and included them into its Trigger system was L3, one of the 4 LEP experiments (ALEPH, DELPHI, L3, OPAL).




Total of 192 bi-gap (300 m2) RPC, 6144 strip channels, 768 TDC channels

2mm gas gap between two electrodes of 2 mm each made of HPL ($\rho = 2.10^{11}$ $\Omega$ cm)

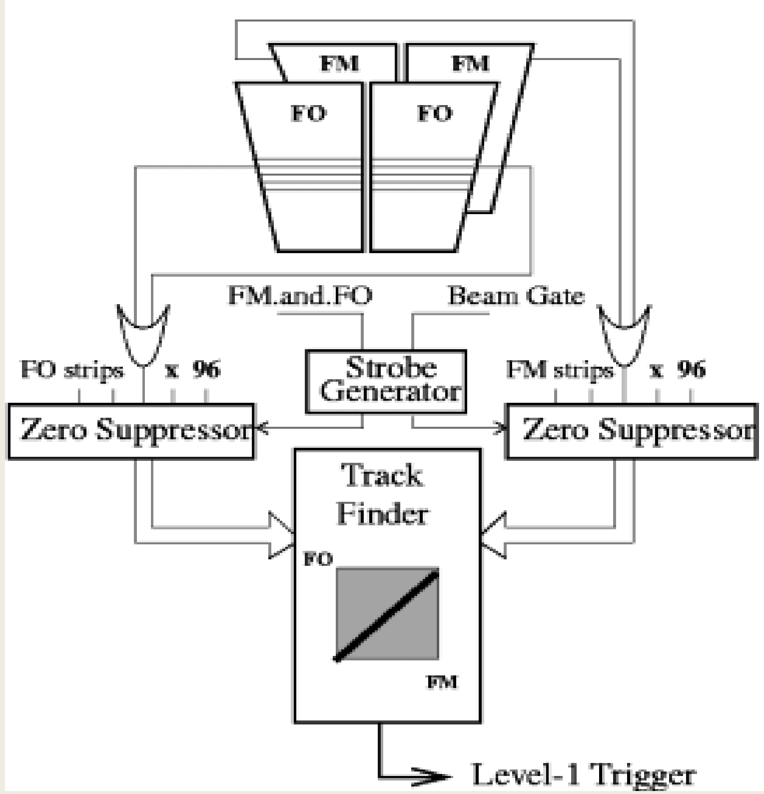
The RPC were operated in streamer mode ( high charge no need for amplifier)

(94-95): Ar (58%), Iso (38%), Freon/CF3Br (4%)

(96-00): Ar (59%), Iso (35%), Tetrafluoroethane (6%)

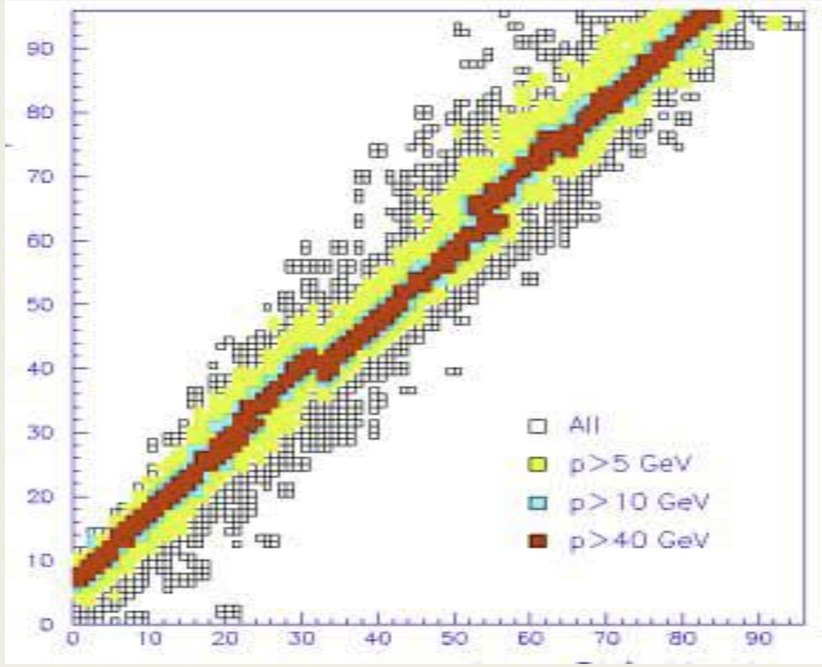
# RPC@L3

L3 RPC-trigger scheme

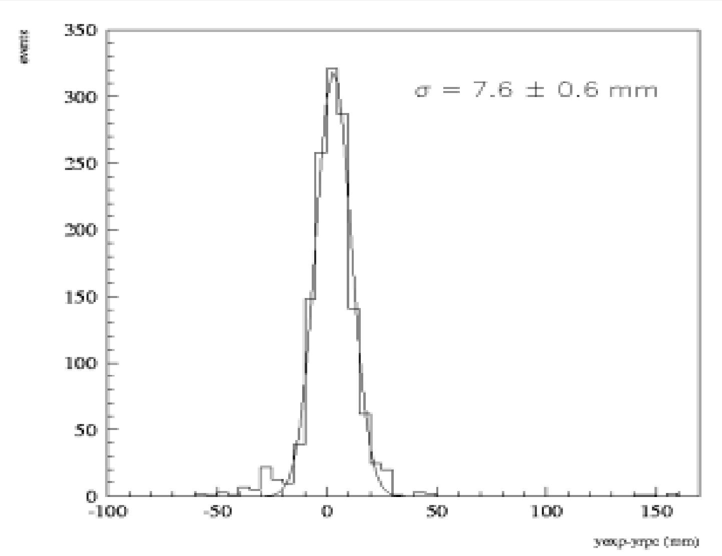



Trigger time: 1.5 μs
Trigger rate O(1) Hz

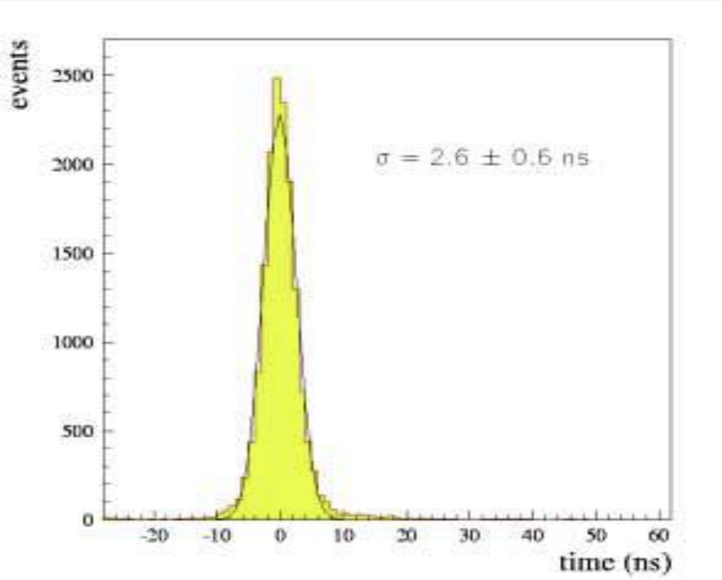
96 x 96 strips of the two RPC layers



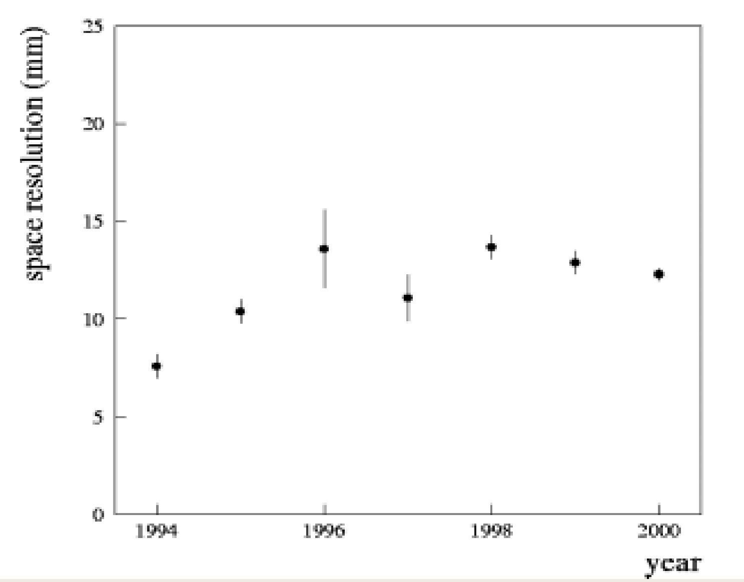

Muons from vertex fire few strips
The number of width indicate their momenta

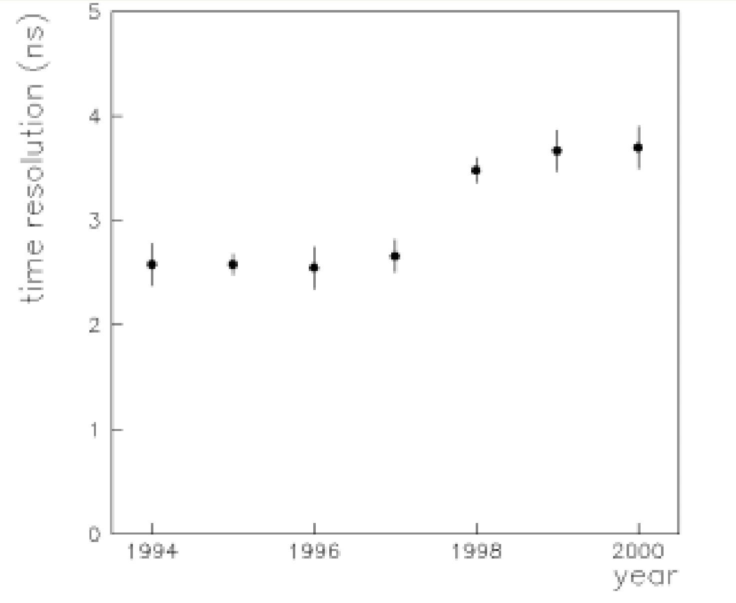



L3 RPC spatial resolution



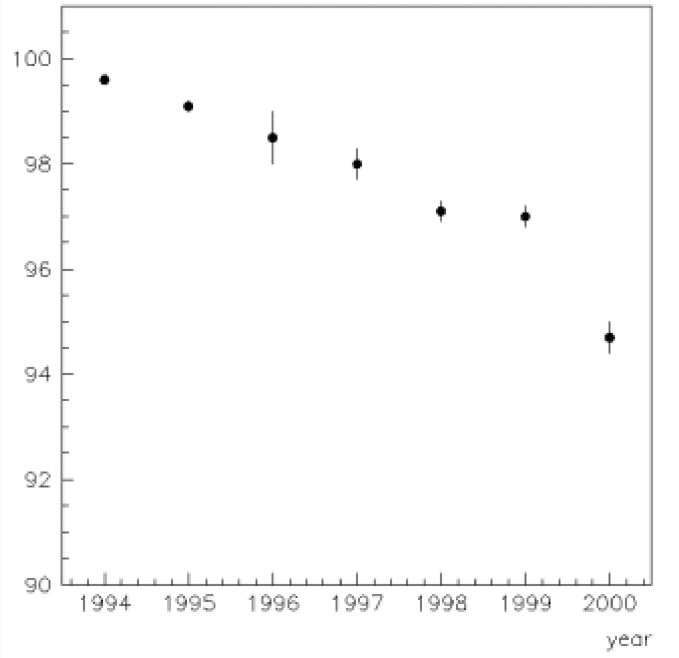

L3 RPC time resolution

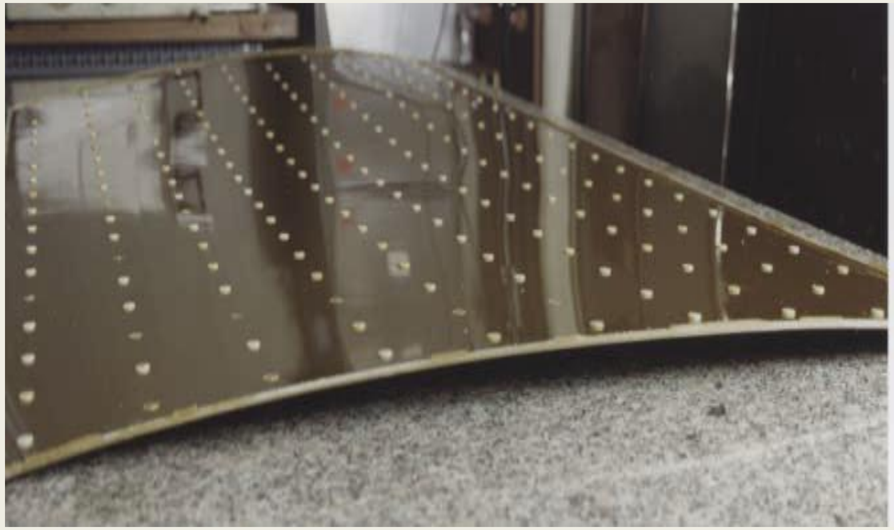


# RPC@L3

## Global efficiency



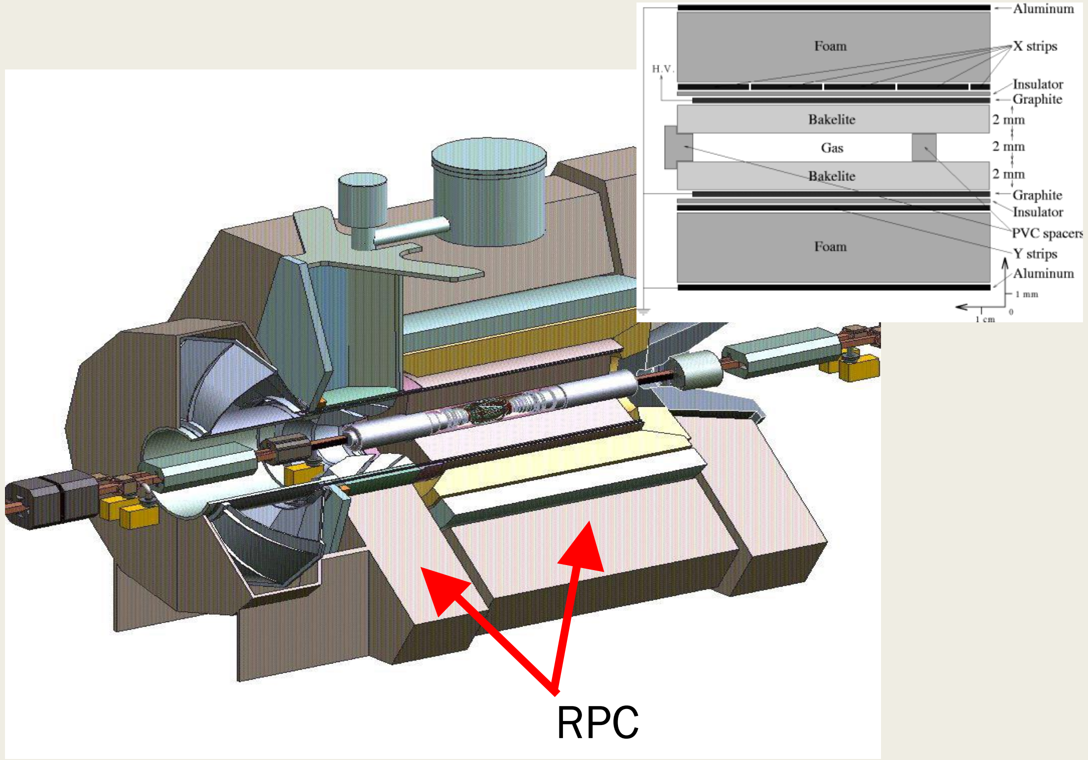
But no other big issues were found

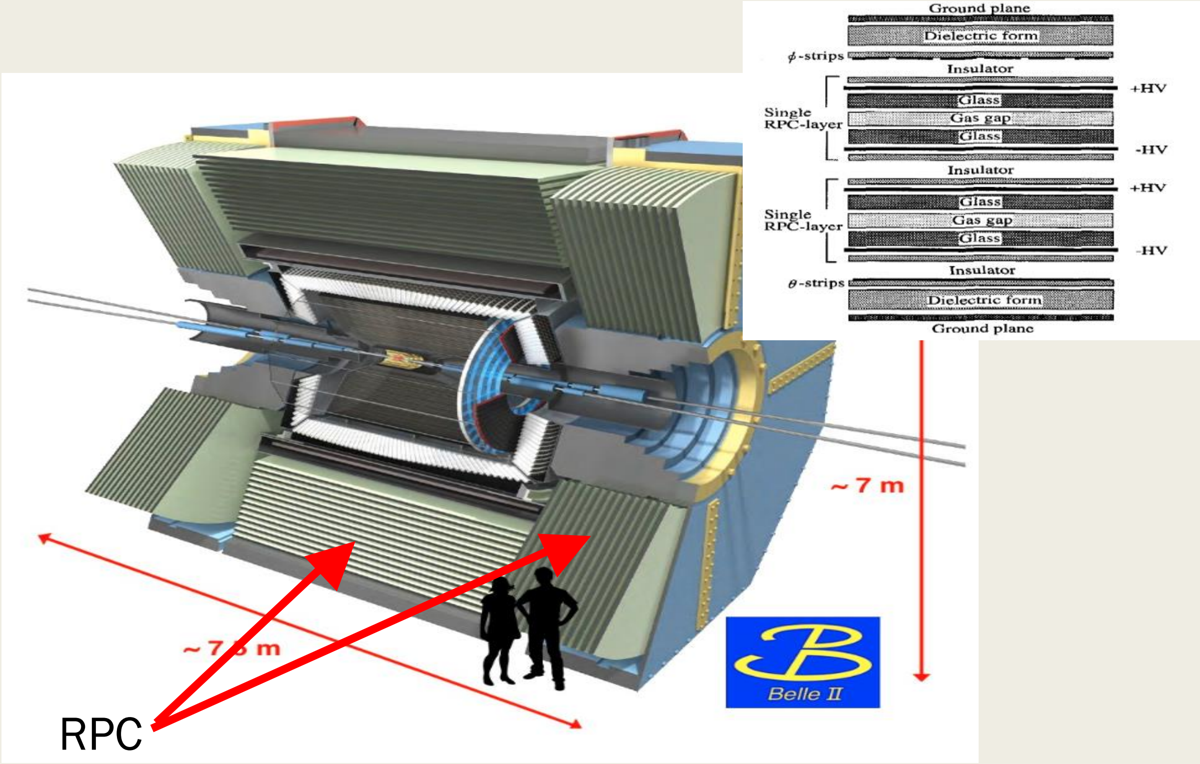
Efficiency drop explained:

- Gas leak
- Electronics failure
- Impact of gas change (HV working point)
- Some hardware related issues like mechanical stress

# RPC@BaBar&Belle

- Two b-factory experiments ($e^+ e^-$) that were built to study b physics and more generally the CKM quark matrix
- Both used RPC as muon detectors
- BaBar opted for HPL-based RPC, Belle selected glass-based ones
- Both operated RPC in the streamer mode
- Both have met some problems operating the RPC

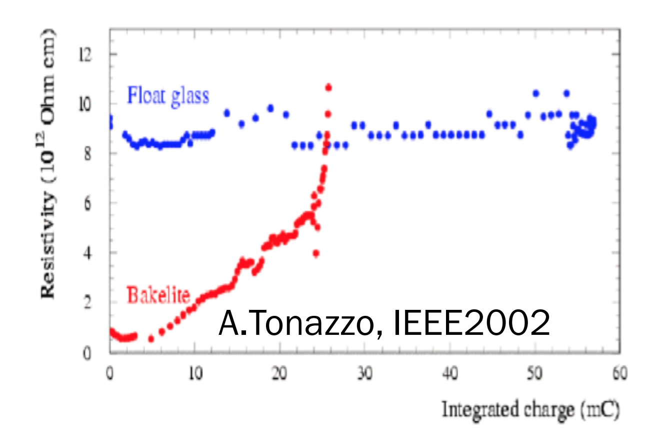


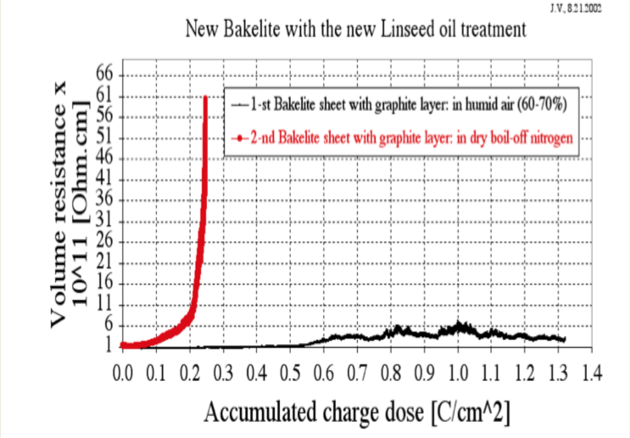



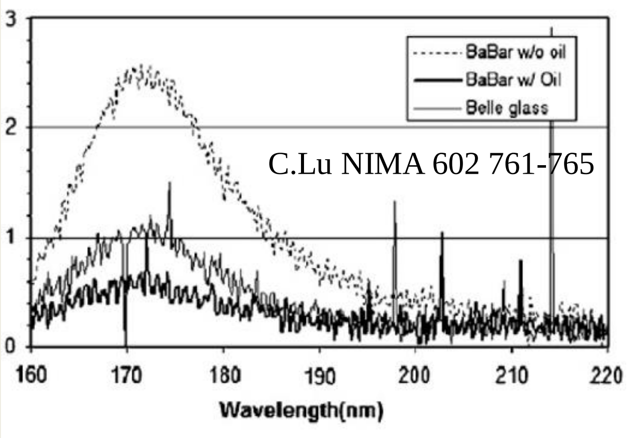

Few thousands of $m^2$ in each

# RPC@BaBar&Belle

HPL surface quality is not perfect. To avoid point-related discharges, Linseed oil was proposed to varnish the surface and render it smoother. It also better protect again UV.
HPL resistivity increases with time. Wet gas mixture (about 50% humidity) was found to maintain the initial HPL resistivity.



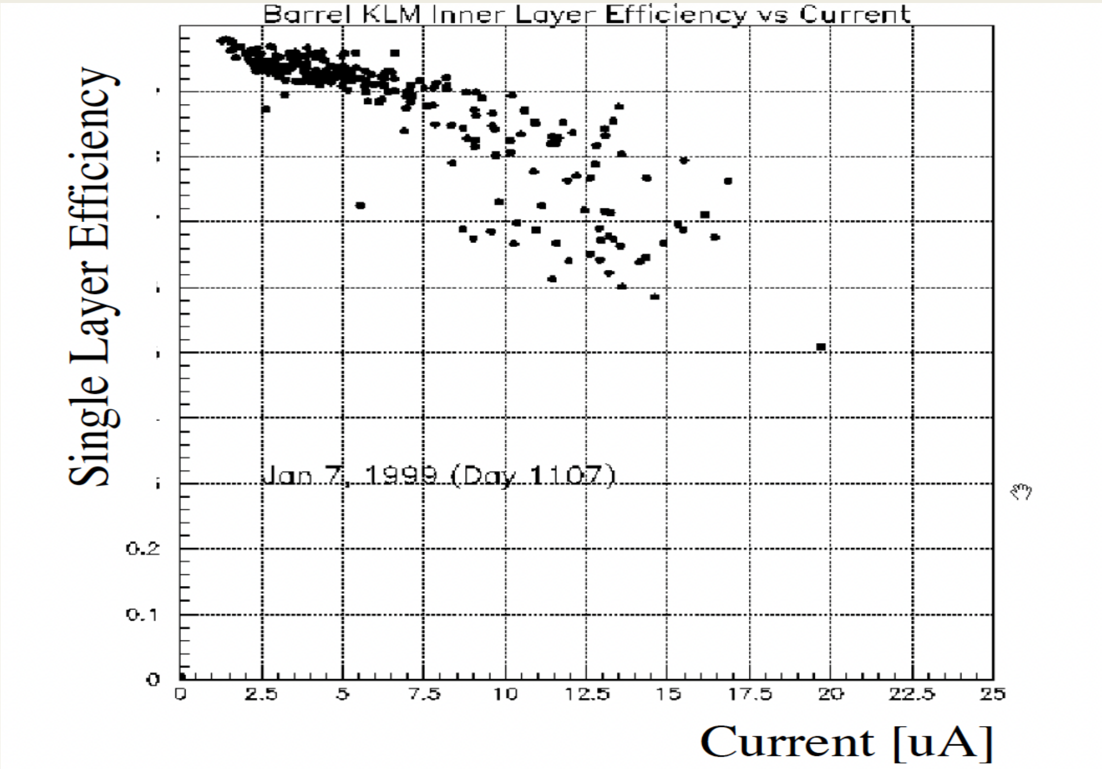




Glass has a much smoother surface but it is fragile and has 1 to 2 orders of magnitude of higher resistivity than HPL leading to lower rate capabilities.

Glass is more prone to HF attack in presence of humidity in the gas and therefore humidity is prohibited.

# Belle RPC issue

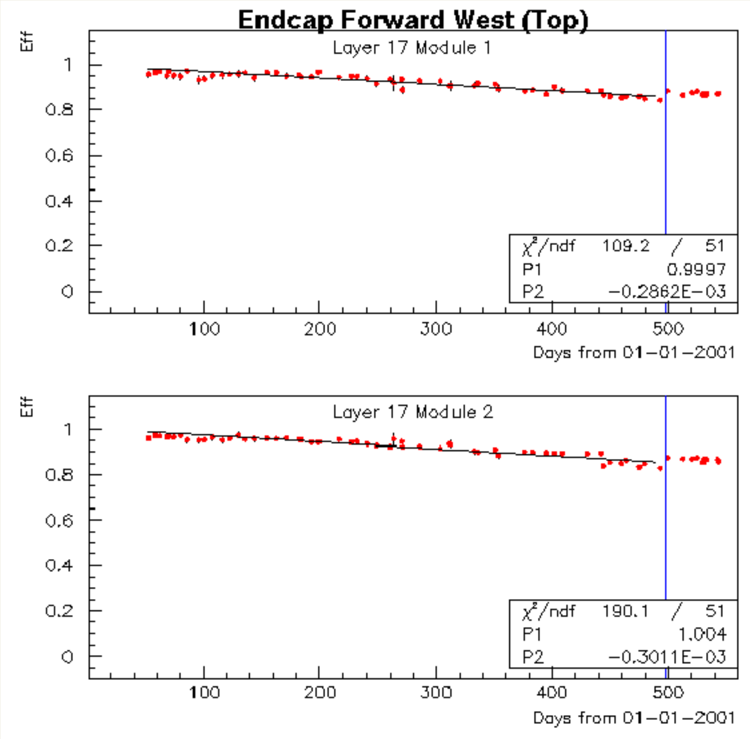
The problem of high dark current appears a few months after the installation with a drop of efficiency




The problem was traced to the presence of water vapor in the gaps. The vapor came from the gas plastic tubes
The tubes were replaced by copper one and after a purge with ammoniac the RPC retrieved their excellent behavior after

# BaBar RPC issue

Continuous loss of efficiency in RPCs placed in the higher particle rate region (a few Hz/cm$^2$)



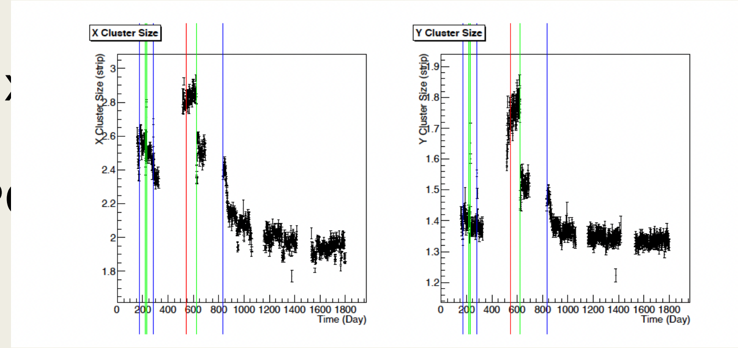

Oiling method (one layer with bad polmyrisation) was found to be the cause. Replacing the solvent used with the Linseed was shown to improve the quality.
In addition, the oil resistivity was found to decrease while this of the Bakelite increased with time leading to efficiency drop → Using water vapor fixed the problem.
BaBar RPC were operated in the streamer mode ((48:4:48) argon, isobutane and forane (C2H2F4))

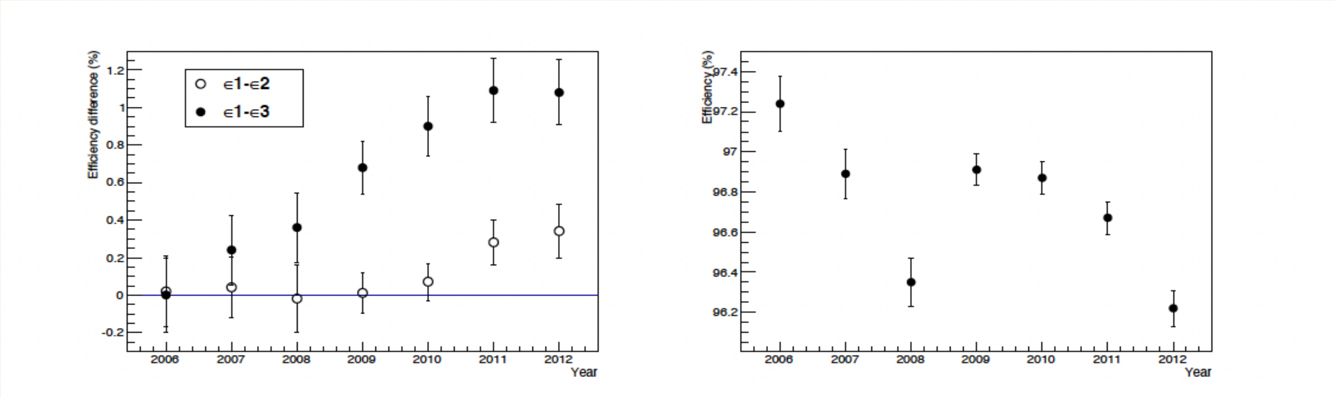
# RPC@OPERA

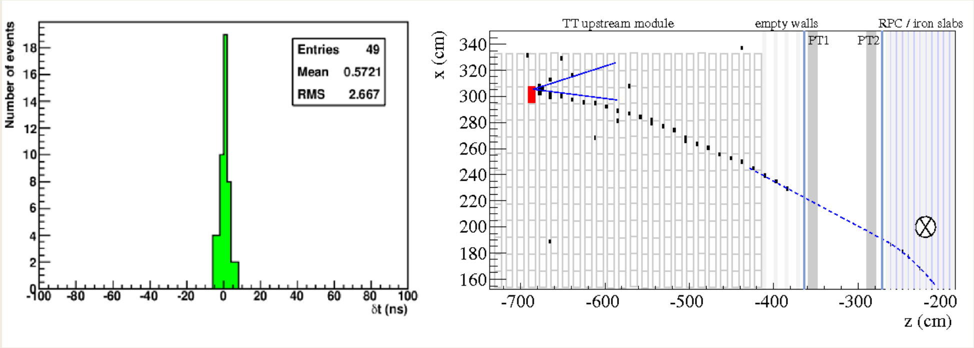
OPERA was a long baseline oscillation experiment that was conceived to demonstrate the oscillation of $\nu_m \rightarrow \nu_t$ with the appearance of a tau.

The experiment was placed in GranSasso.
The main detector was Emulsion Cloud Chambers (ECC) but RPC were used in muon spectrometer (iron dipole magnet) with the goal to construct the muons issue from neutrino interactions

3000 $m^2$ of HPL-based single gap RPC were built and read out using x y strips (except two (XPC) with U-V to eliminate ambiguities)
Time measurement using TDC performed on XCP and 7 of the 22 RPC of each module.
SF6 was added to the gas mixture for the first time
Ar/C2H2F4/i−C4H10/SF6 with volume ratios 75.4/20.0/4.0/0.6



# RPC@LHC

The problems encountered at BaBar have led to huge efforts to make the RPC that were proposed for LHC experiment to be as robust as possible.

Two important improvements were made and allowed the success of RPC in ATLAS, CMS and ALICE

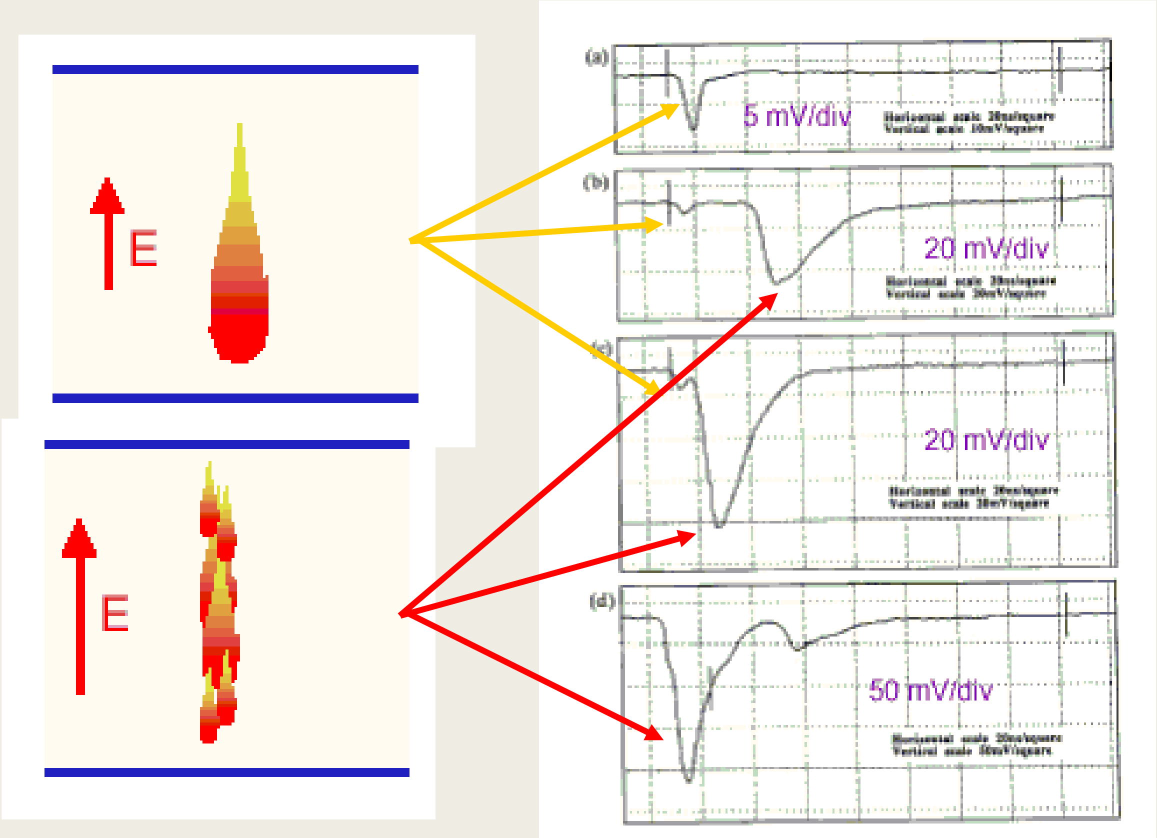
- Oiling process of HPL-based RPC modified
- Streamer→ Avalanche mode

# Streamer versus avalanche mode

ATLAS Muon TDR

Avalanche signal

Streamer signal

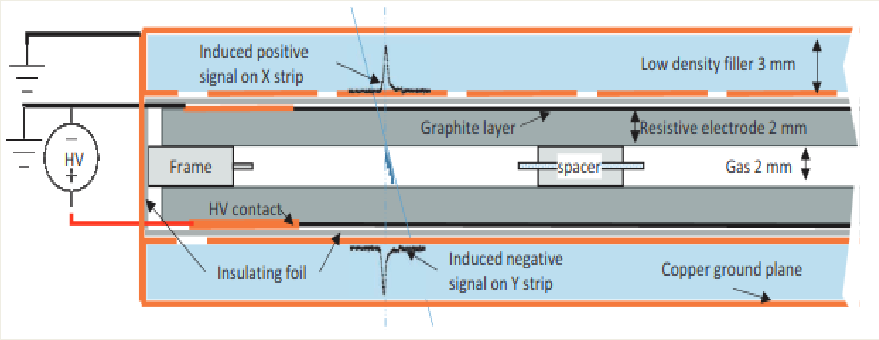


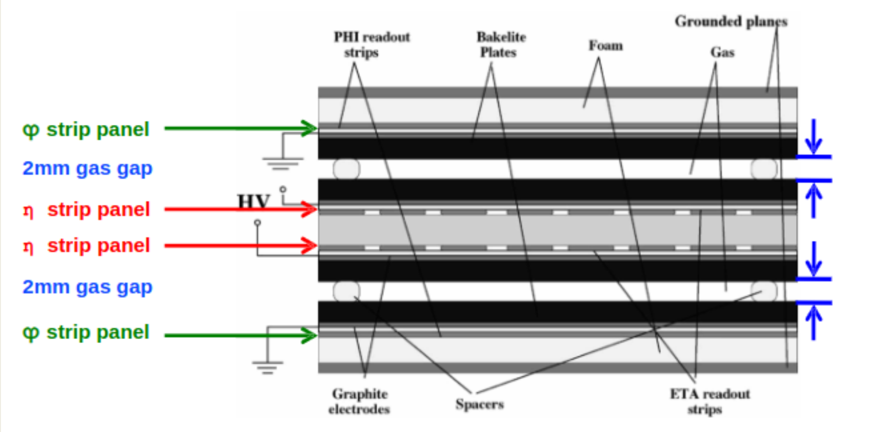

The average charge produced in Streamer mode is much higher than the one in Avalanche mode. A few hundreds pC to be compared to  few tens pC.

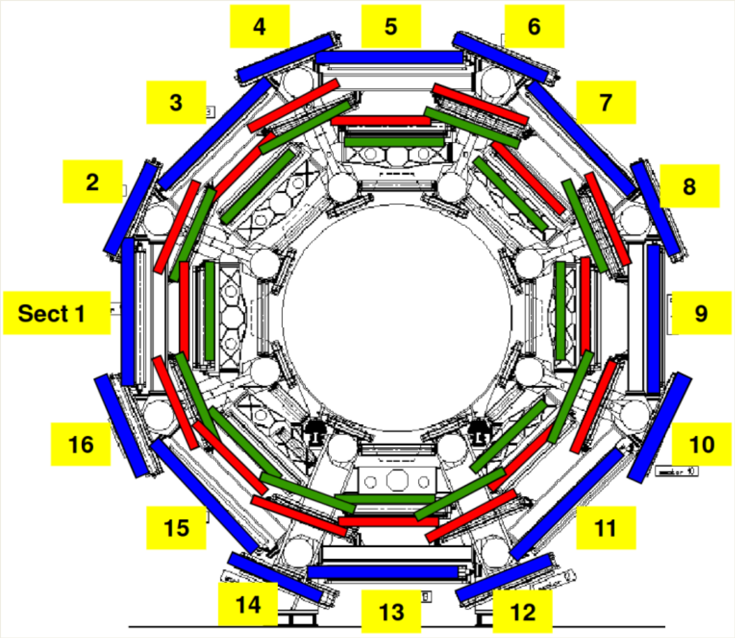
CMS&ATLAS were first to adopt the avalanche mode before to be joined by ALICE later on

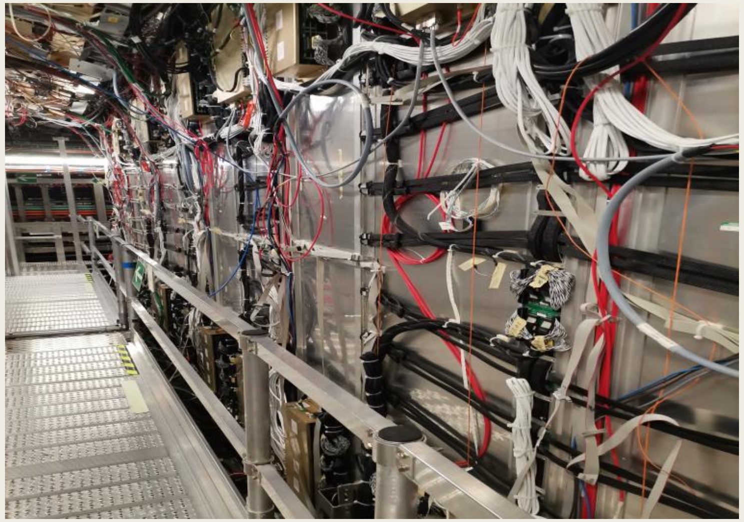
# RPC@ATLAS

Single gap with pickup strips on both sides (two orientations to determine x and y)



About 7000 $m^2$ operated in avalanche mode using the following gas mixture

**$C_2H_4F_4$ 94.7%, $C_4H_{10}$ 5%, $SF_6$ 0.3%**

which is referred to as the standard gas mixture

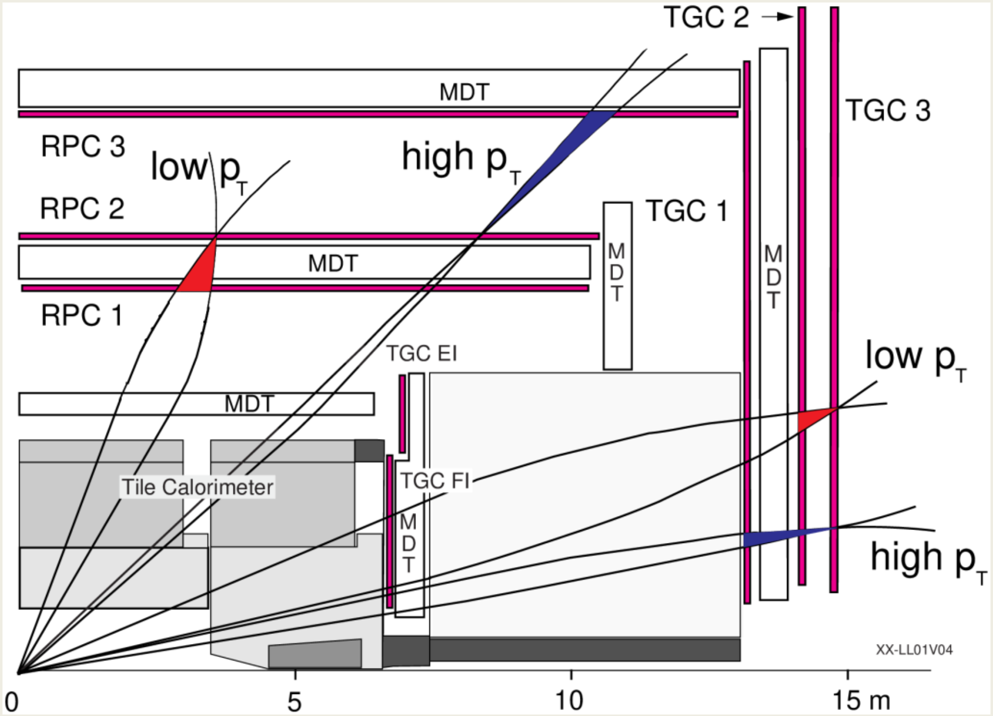
# RPC@ATLAS

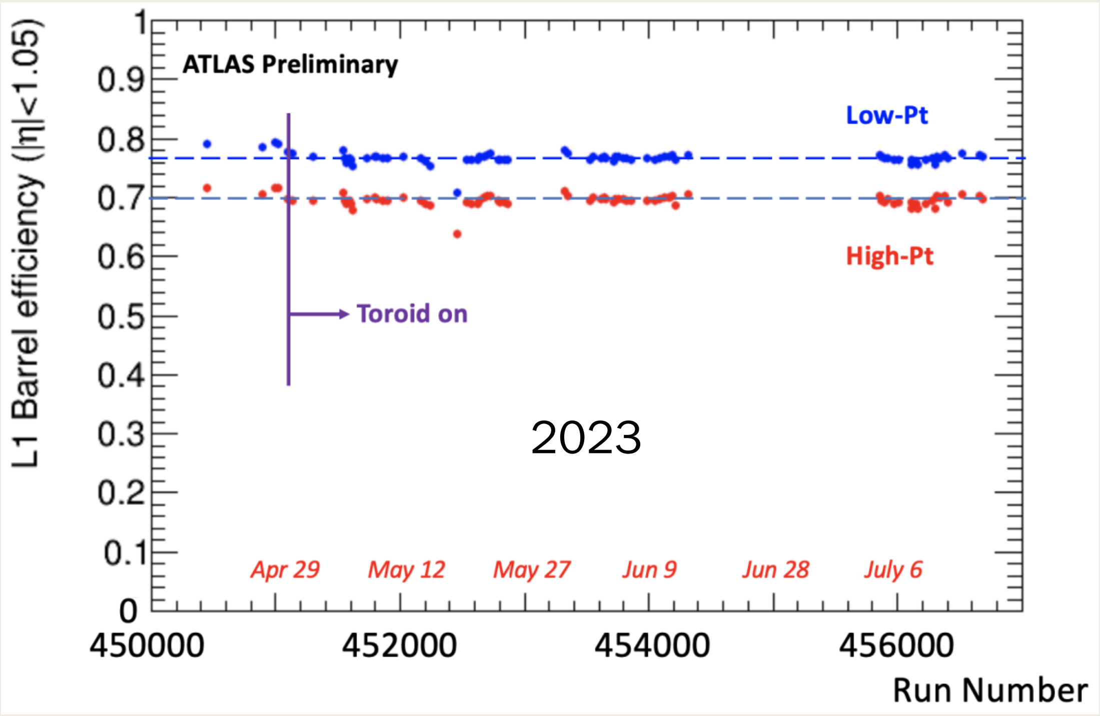
RPC is an important detector in ATLS for muon detection and for the ATLS trigger (LV1)

Low-pT trigger: RPC2 & RPC1 (3/4)

High-pT trigger: Low-pT & RPC3

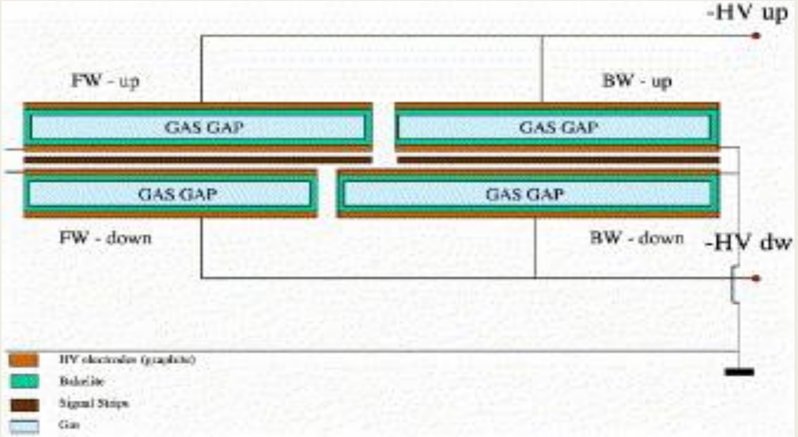
Trigger was modified in 2023 (2/4) to take into account the drop of a few RPC chambers due to HV /leak problems



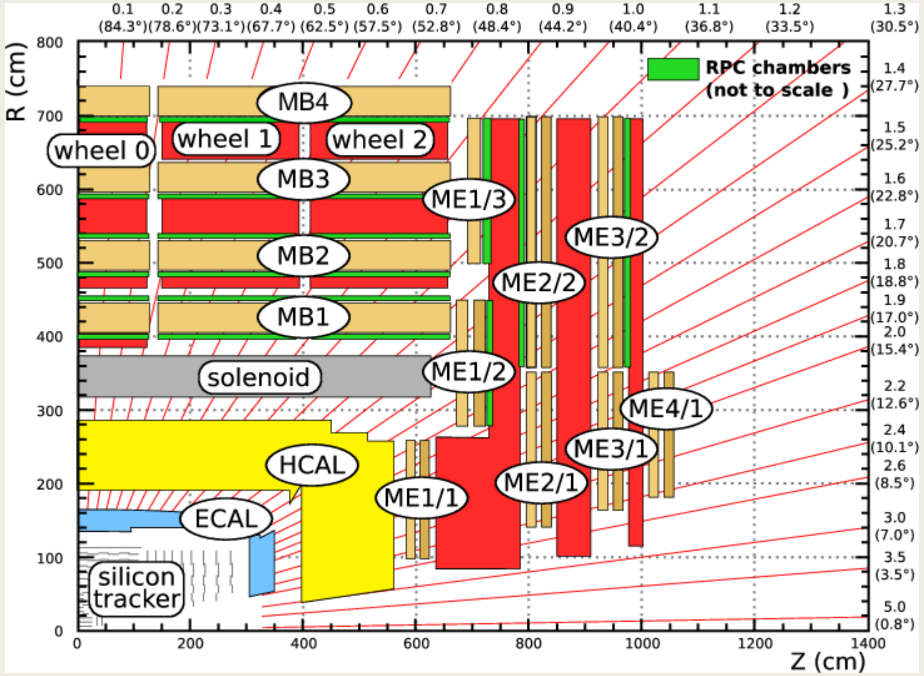
# RPC@CMS

RPC are built with two gaps separated by pickup strip panels in between in one direction; They are used in the CMS muon system in both barrel and endcaps (6000 $m^2$)

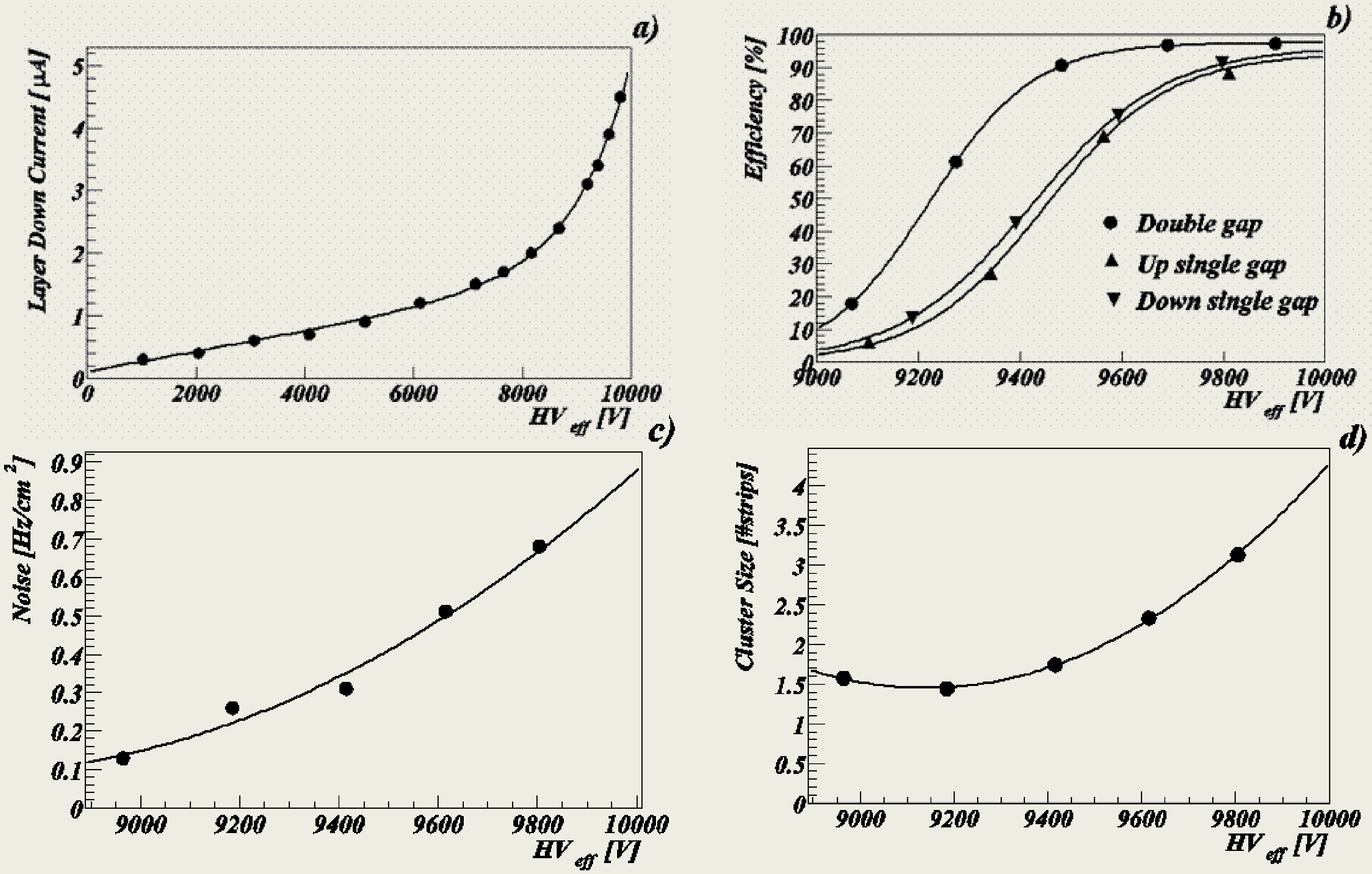



The structure of the CMS gaps is similar to those of ATLAS

- PET layer
- Graphite painting
- 2mm Bak.
- 2mm gas gap
- 2mm Bak.
- Graphite painting
- PET layer

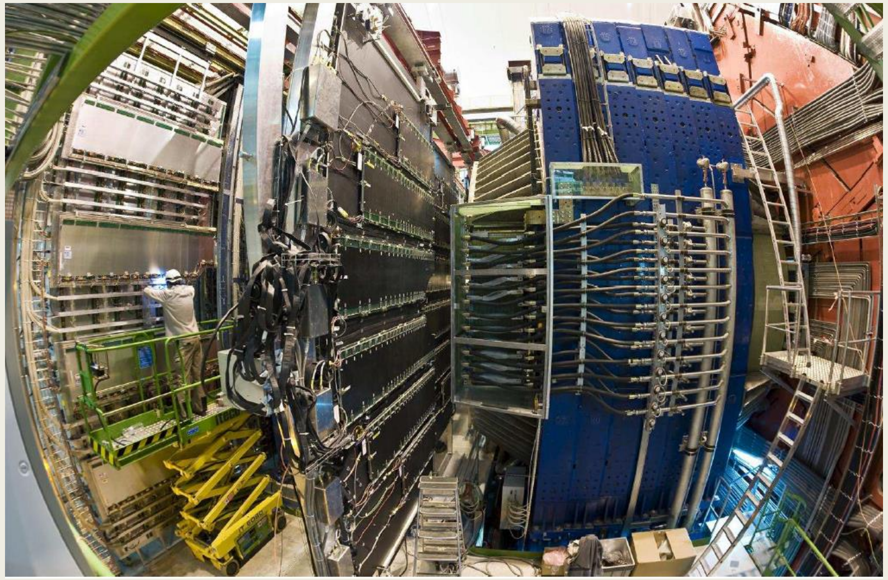



# RPC@CMS




Double-gap CMS RPC allows reaching full efficiency at HV between 9.4 and 9.8 kV

# RPC@ALICE



ALICE is one of the 4 LHC experiments that is dedicated to the study of quark-gluon plasma.
RPC are used for muon detection ($J/\psi$) decay and spectrometer trigger

The highest expected rate was of 50 $Hz/cm^2$
-> this justified why to operate RPC in streamer mode

ALICE RPC groups proposed to use SF6 (used in insulation and quenching of electric arcs) to lower the charge of the streamer > This was then adopted by the other experiments even in the avalanche mode

Table 1
Composition of the gas mixtures

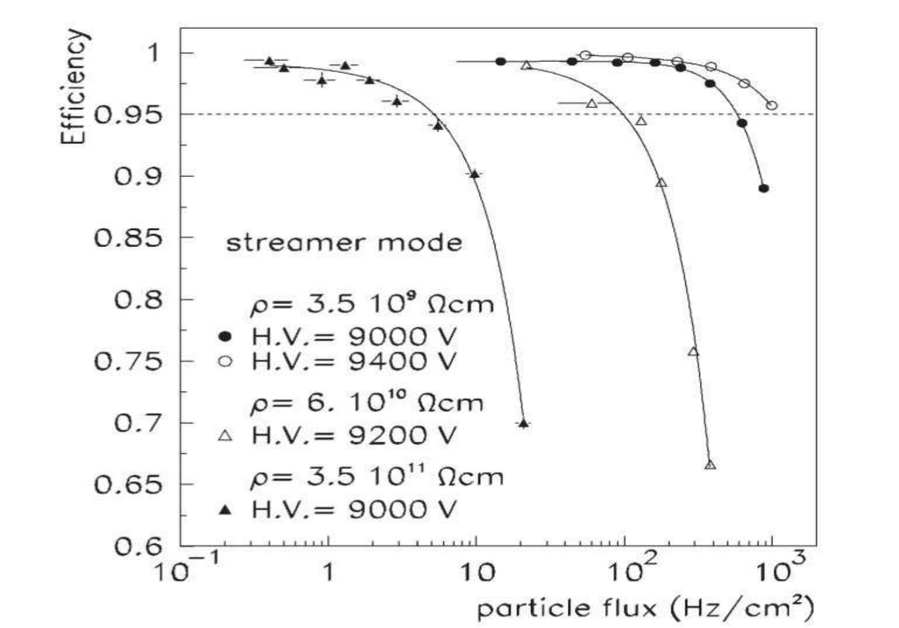
| Mixture no. | Mixture composition |
|---|---|
| 1 | $Ar/i\text{-}C_4H_{10}/C_2H_2F_4 = 70/20/10$ |
| 2 | $Ar/i\text{-}C_4H_{10}/C_2H_2F_4 = 10/7/83$ |
| 3 | $Ar/i\text{-}C_4H_{10}/C_2H_2F_4/SF_6 = 49/7/40/4$ |
| 4 | $Ar/i\text{-}C_4H_{10} = 80/20 + 4\%\ SF_6$ |

Table 2
Summary of the results for the gas mixtures

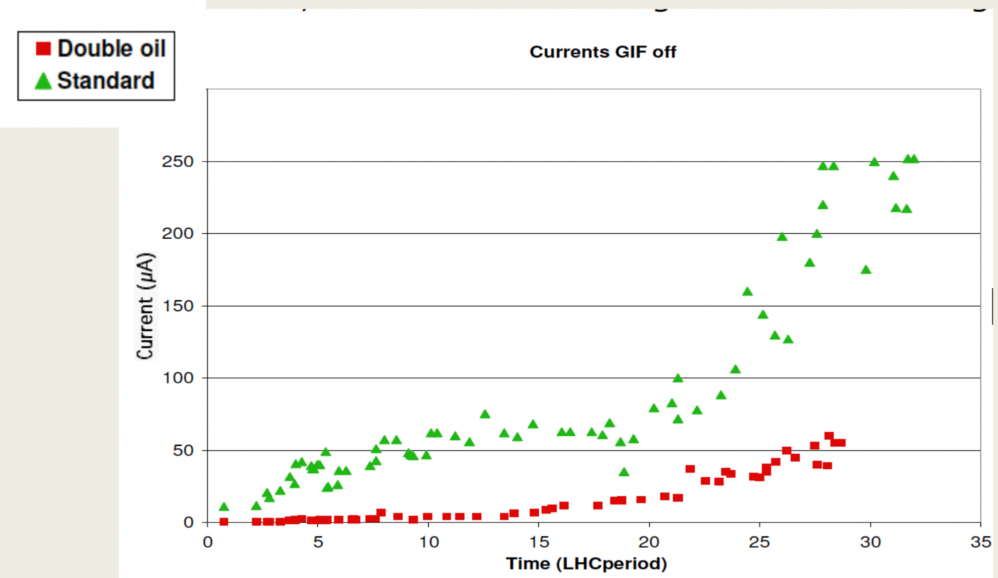
| Mixture no. | H.V. (V) | Neigh. eff (%) | Charge (pC) | Ampl. (mV) |
|---|---|---|---|---|
| 1 | 6700 | 46 | $330 \pm 160$ | $390 \pm 170$ |
| 2 | 10 000 | 15 | $106 \pm 43$ | $183 \pm 53$ |
| 3 | 9500 | 11 | $48 \pm 25$ | $113 \pm 44$ |
| 4 | 7300 | 13 | $70 \pm 40$ | $144 \pm 51$ |

# RPC@ALICE

ALICE was the first to propose **low resistivity material** such that phenolic Bakelite 3.5 $10^9\ \Omega$.cm ($10^{10}$ -$10^{12}\ \Omega$.cm for "common" Bakelite) to increase the RPC rate capability

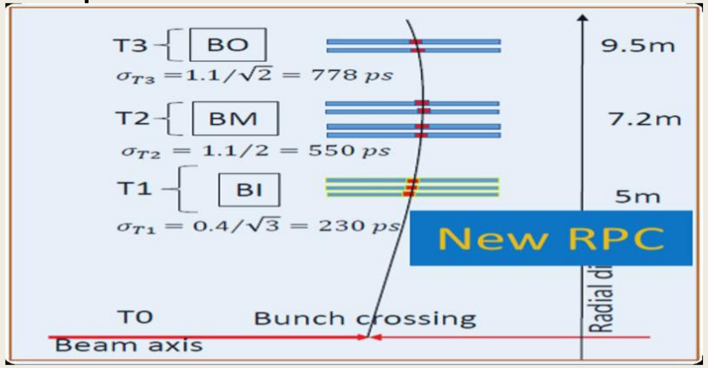



- ❖ Oiling process with two thin oil layers rather than one was found to protect RPC against damage caused by HF.
- ❖ Having a third oil layer did not bring further improvement.

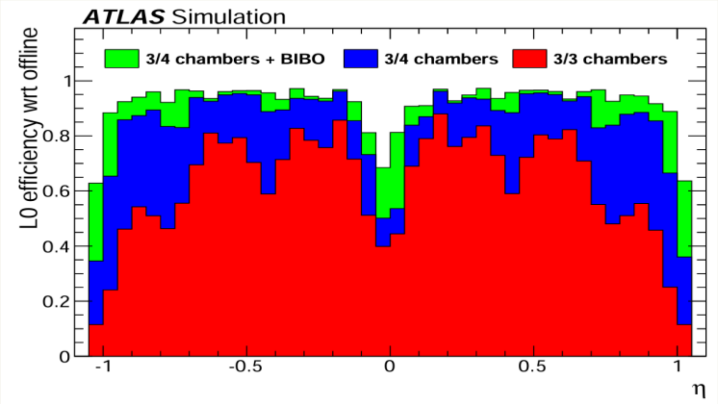


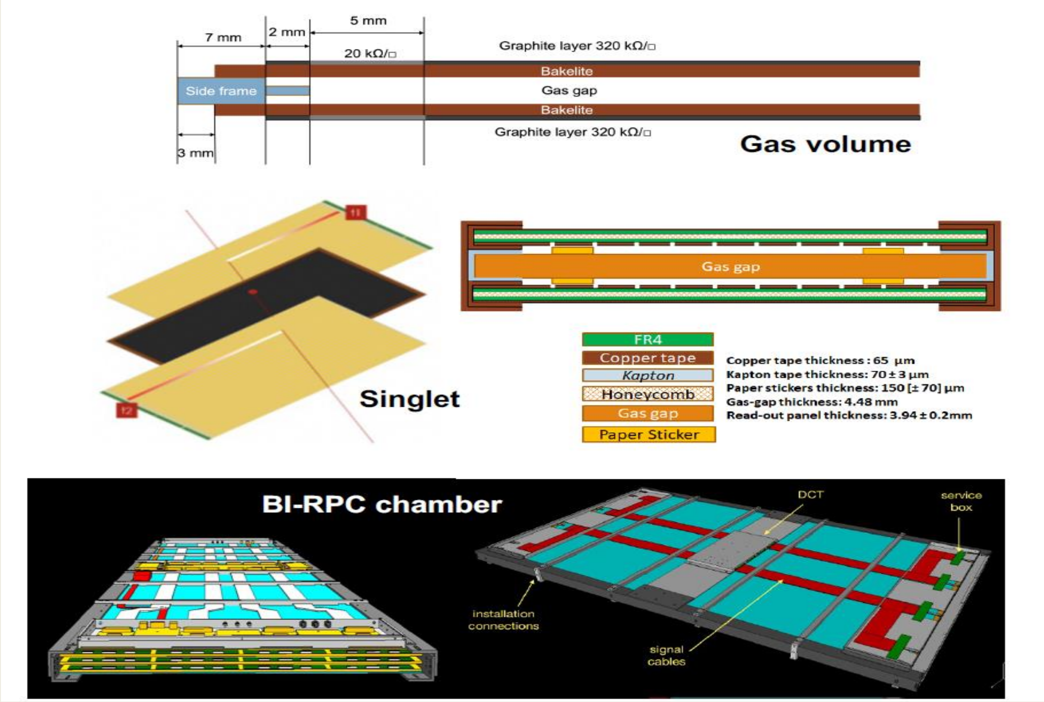
# RPC&HL-LHC

CMS & ATLAS have decided to upgrade their RPC systems to improve its performances and to cope with the high rate expected at the high η region as well as the pileup of about 200




Atlas will add 306 RPC detectors (472 $m^2$) in the BI region Increasing the trigger acceptance from 78% to 92-96% and improving on the time resolution (0.4 ns for the new RPC using new electronics)

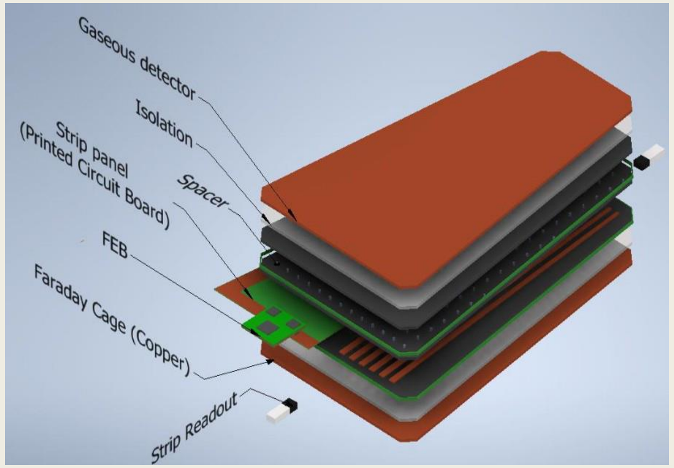


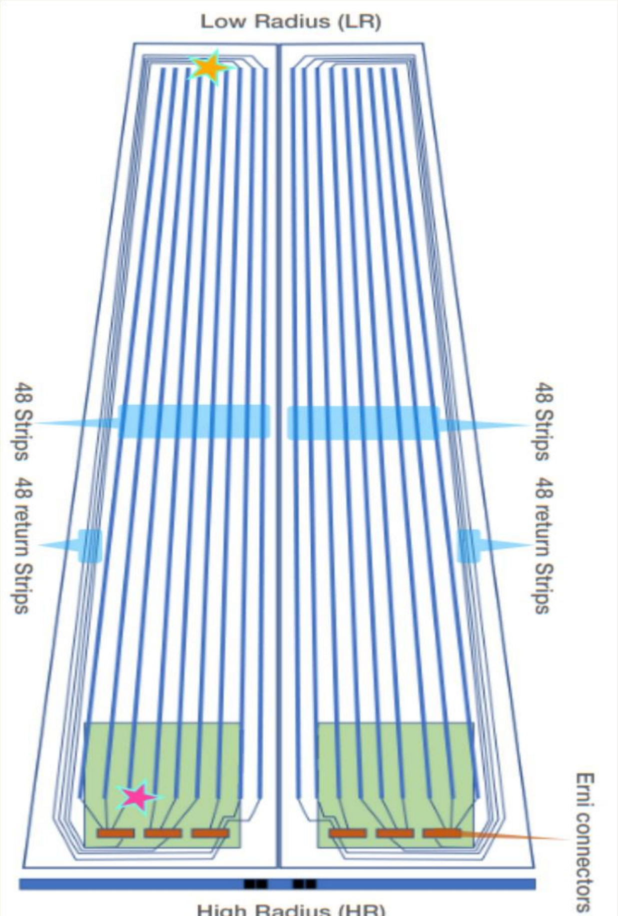

- ❖ Each RPC is made of 3 singlets
- ❖ Each singlet is 1mm gas gap
- ❖ Each singlet is readout by two strip panels in η direction
- ❖ The triplets are placed in a Faraday

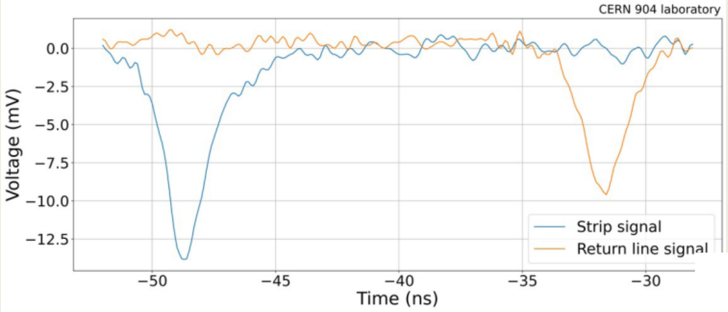
# RPC&HL-LHC

CMS will upgrade the present RPC system by replacing the BackEnd electronics to exploit the precise the time information of its RPC detectors

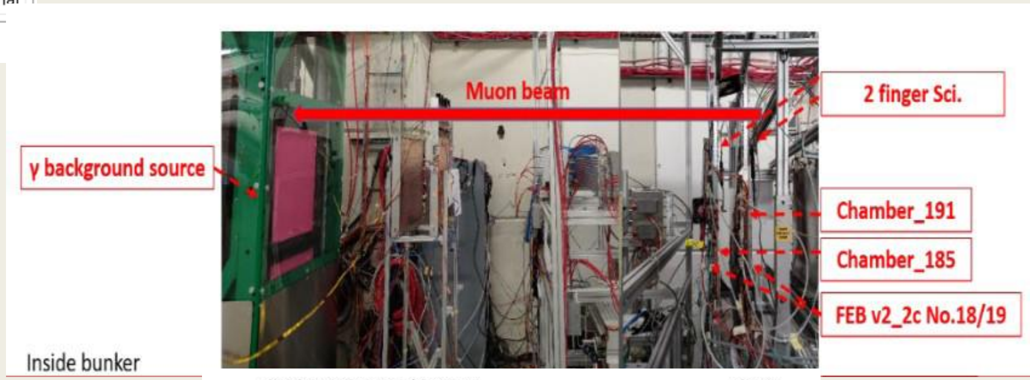


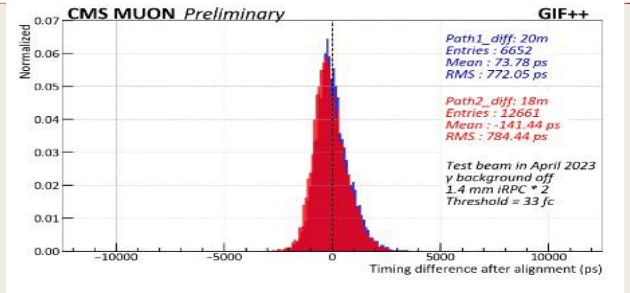

CMS will also equip two stations of the high η region of the Endcaps with a new generation RPC (2/2/2 → 1.4/1.4/1.4) with new electronics readout scheme




Delay line technique applied successfully to RPC leading to excellent spatial resolution by measuring the time difference of the signal arrival on both ends of η oriented strips

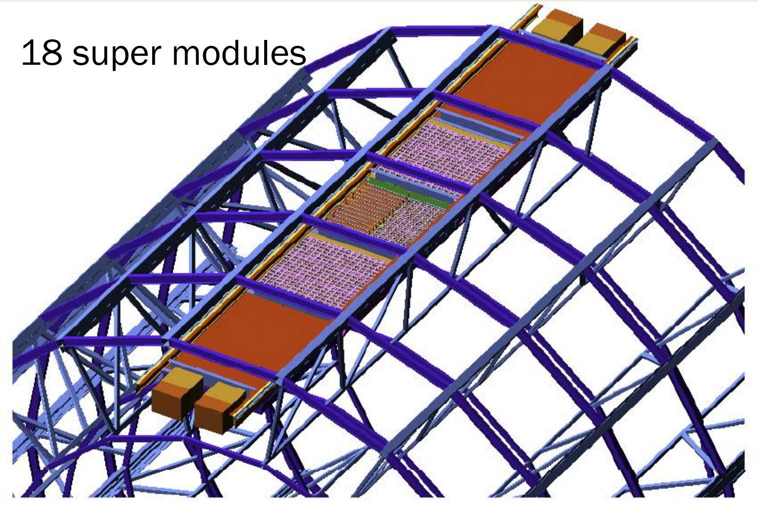


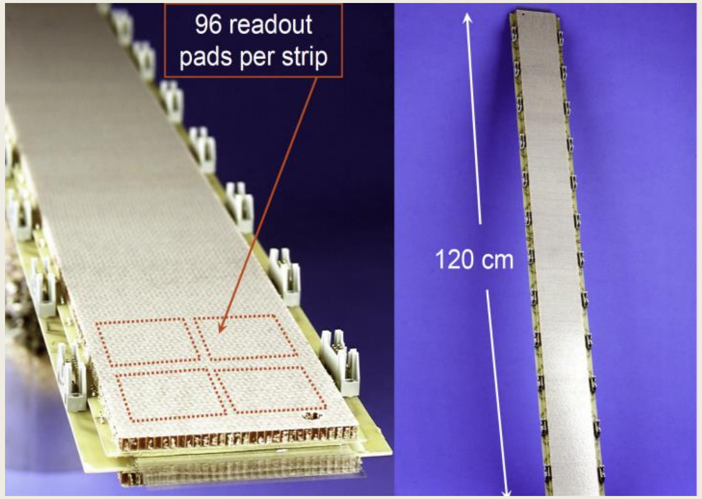



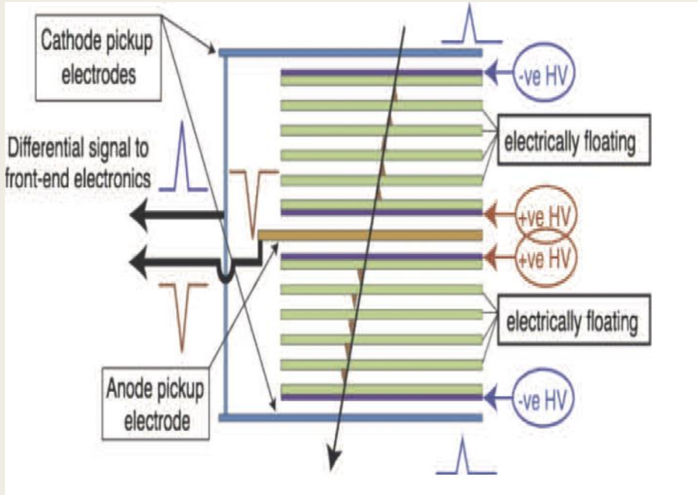

$\sigma\Delta T \sim 150$ ps → $\sigma\eta \sim 1.5$ cm

# MRPC@ALICE

ALICE collaboration has adopted the MRPC as ToF detector to identify particles based on their time of flight.
They are placed 3.7 m from the IP
The MRPC are 2x5-gap (250 μm each) with 400/550 μm internal/external glass plates
There are 1638 MRPC of 120 cm x7.5 cm each→ 150 $m^2$
The MRPC read out in a differential way to reduce the jitters and improve the timing

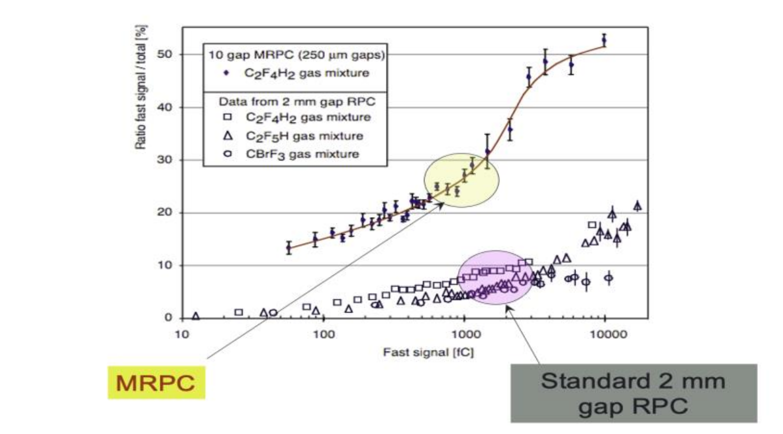


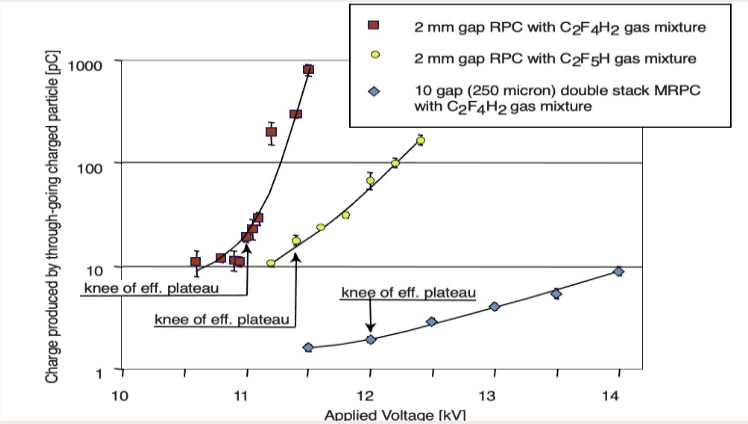



# MRPC

## Better time resolution




## Less charge and thus higher rate




## Harp (study of hadron production) at CERN was the first to use them

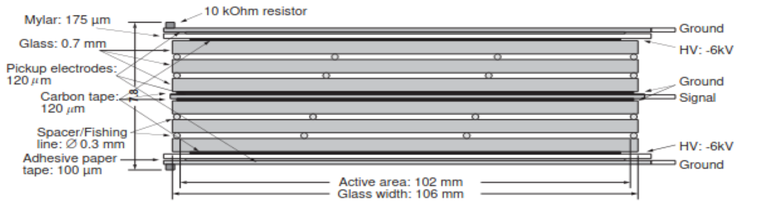



Fig. 3. Cross-section through the glass stack.

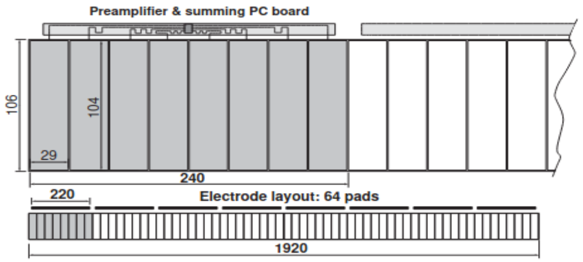
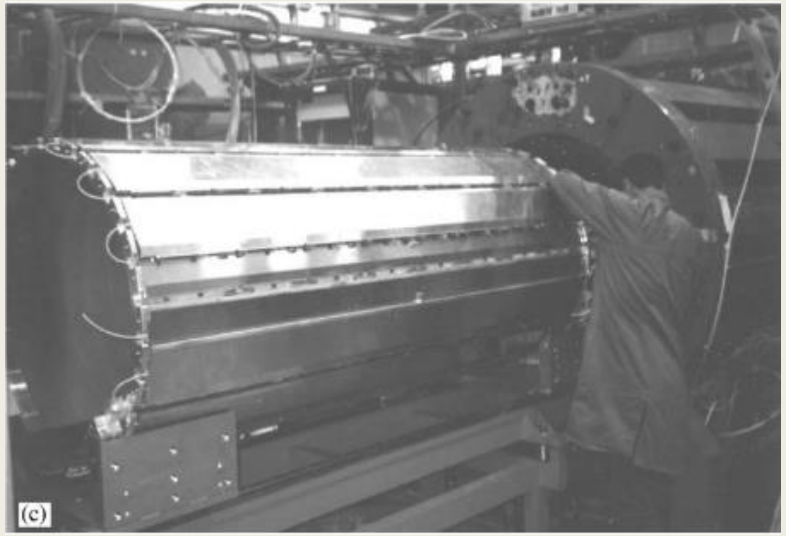
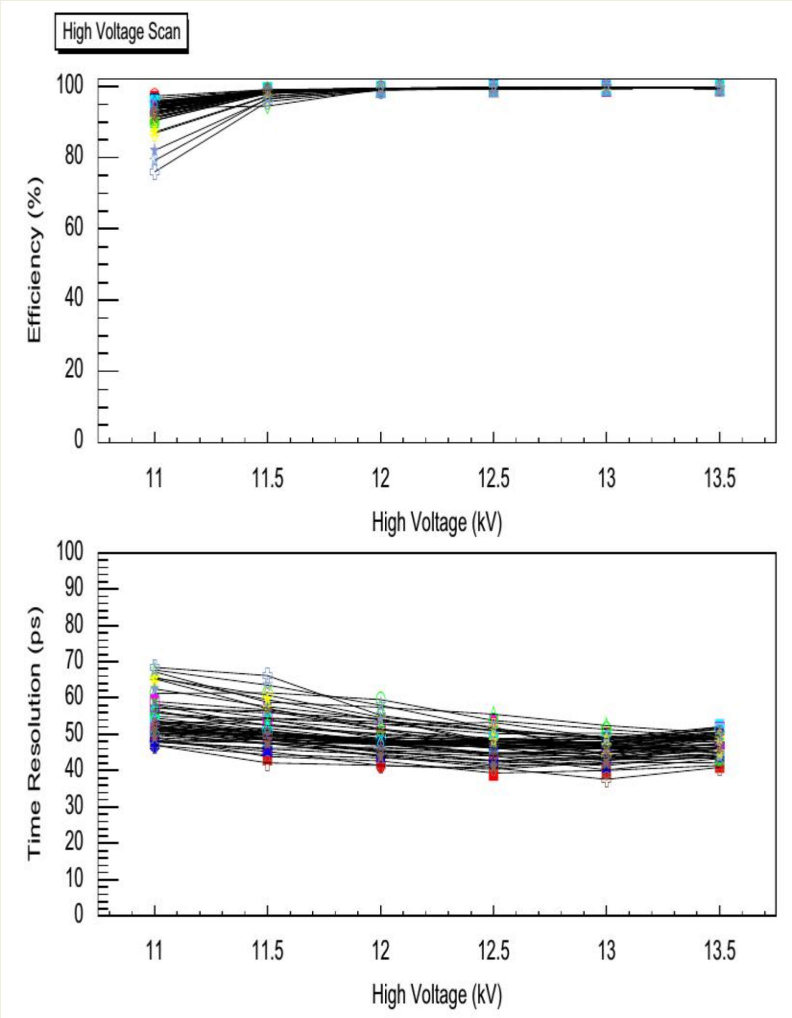



Fig. 4. Layout of the readout electrodes; eight pads are connected to the same preamplifier.

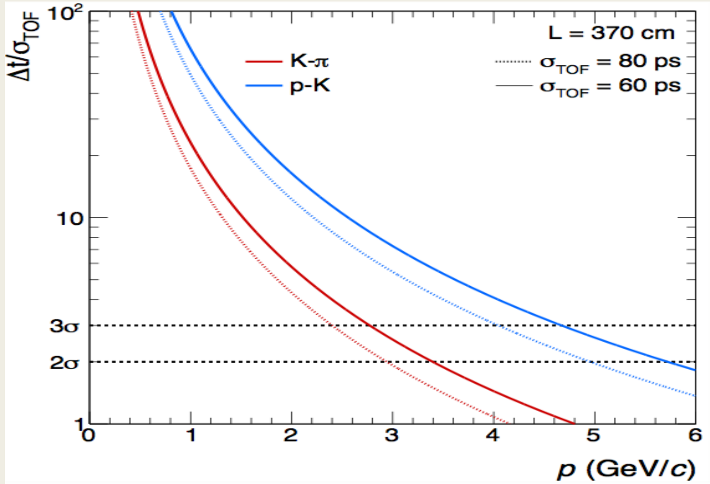


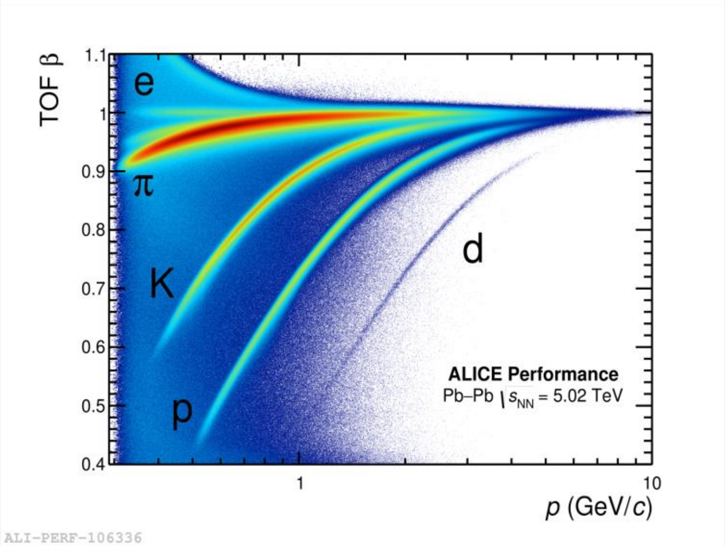
# MRPC@ALICE




$$m_{TOF} = \frac{p}{c}\sqrt{\frac{c^2 t^2}{L^2} - 1}$$

$$\Delta t_{i,j} = t_i - t_j \simeq \frac{Lc}{2p^2}\left(m_i^2 - m_j^2\right)$$



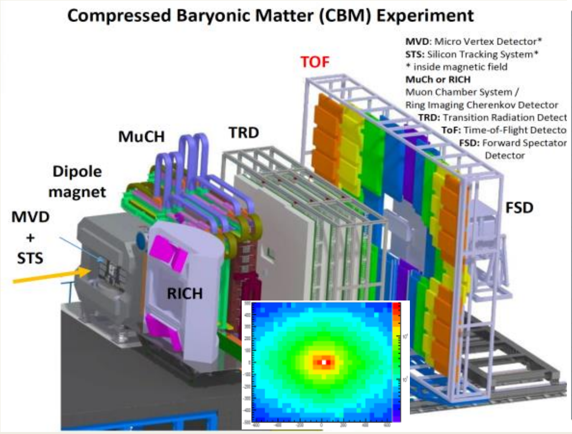



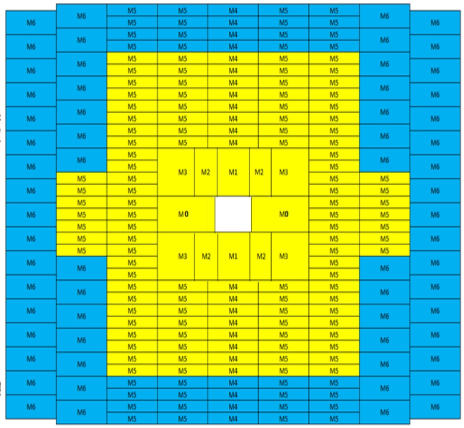

MRPC were also successfully used in nuclear physics experiments (HADES)
They will also equip the ToF wall of the CBM@Fair using new resistive glass ($10^{11}$ Ω.cm) to reach high rate capabilities (> 50 kHz/cm$^2$)

# ToF@CBM

CBM will study the nuclear matter at large density to study:

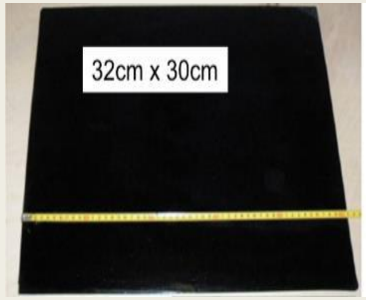
partonic phases, chiral symmetry, hyper-nuclei production, charm production and propagation in rich baryon matter
ToF detector is an essential one in the CBM.It will be made of MRPC that can reach **80 ps** (full system) time resolution while withstanding very high rate at the center.

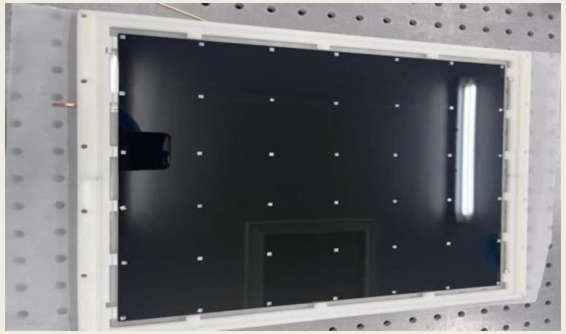


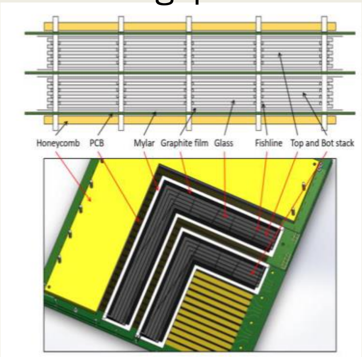
Peak Rate 10 MHz for Au+Au

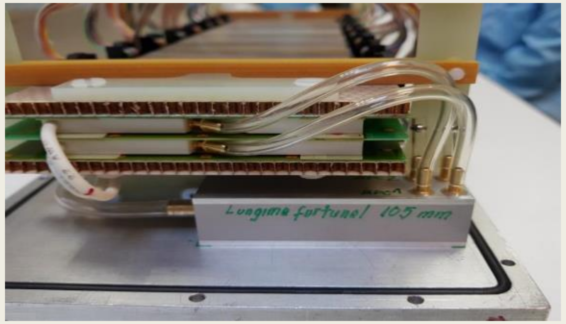
New doped glass was developed by Tsinghua University with $\rho = 10^{10}\ \Omega$.cm

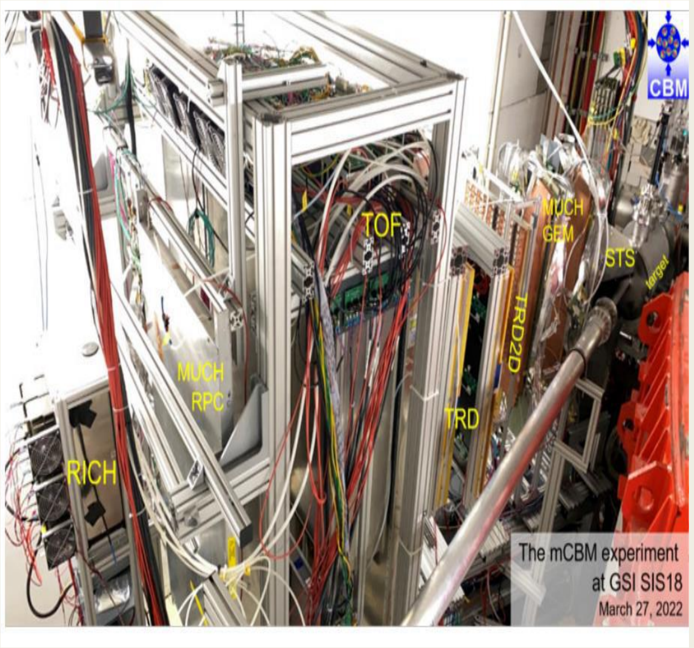


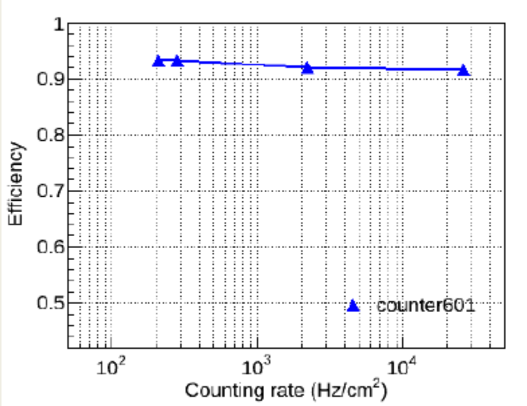



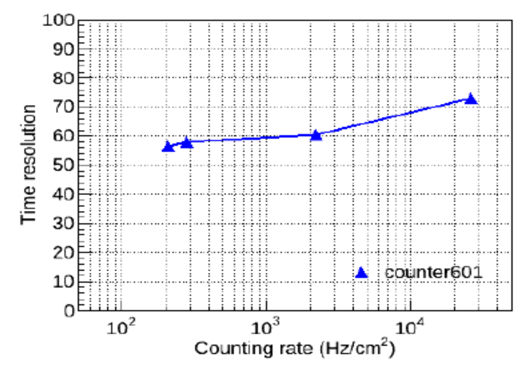
8-10 gaps





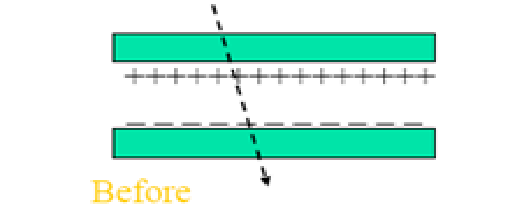



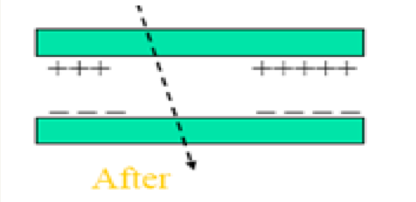
# RPC high rate detection capability

❑ Rate capability of the RPC is related to the voltage drop in the resistive plate: $\Delta V = I\ R = q\ \rho\ d\ \Phi$

**To have RPC with increased rate capability one should reduce:**




- *electrode resistivity* **ρ**: as low as the RPC principle still stands (> $10^9$ Ωcm)
  → low-resistivity HPL or doped glass (Tsinghua glass)




- *electrode thickness* **d**: depends on electrode material
  → easy for glass, possible for HPL

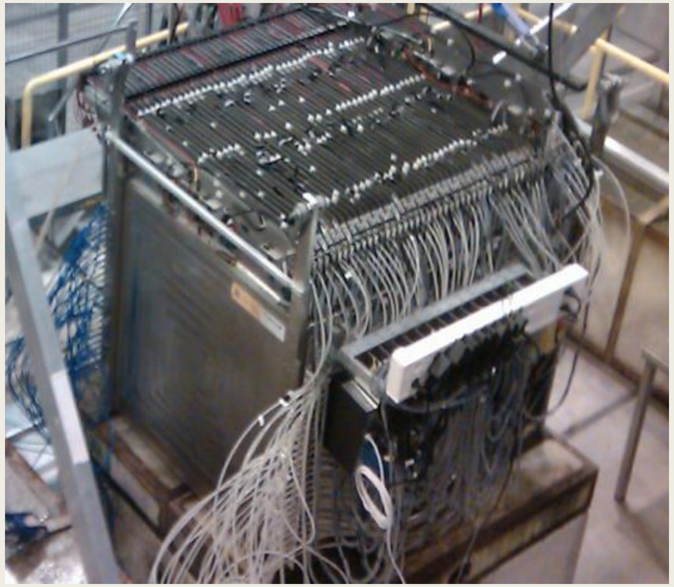
- *produced charge* **q** : depends on gas mixture and number of gaps
  The less the charge produced, faster the eviction : beneficial also for chamber aging but this necessitates to *increase FE electronics sensitivity*

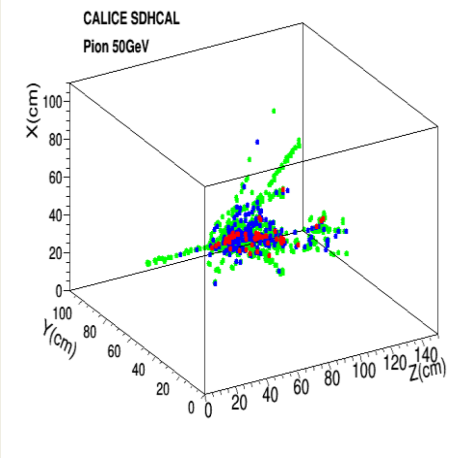
# (M)RPC for calorimetry

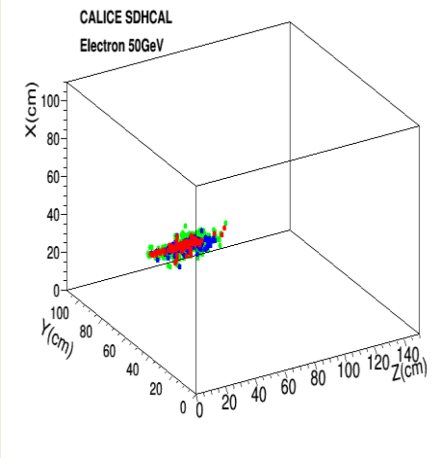
RPC were proposed to equip sampling HCAL for future collider experiments as a highly segmented active area (PFA-based calorimetry).

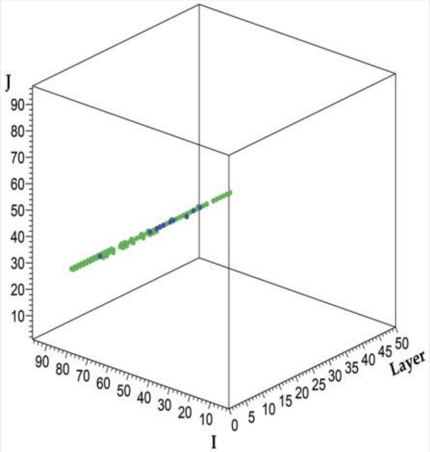
Two large prototypes (DHCAL/SDHCAL)were built and exposed to beam tests. The results show the powerful of RPC for such applications (high efficiency and high granularity with no spark issues)

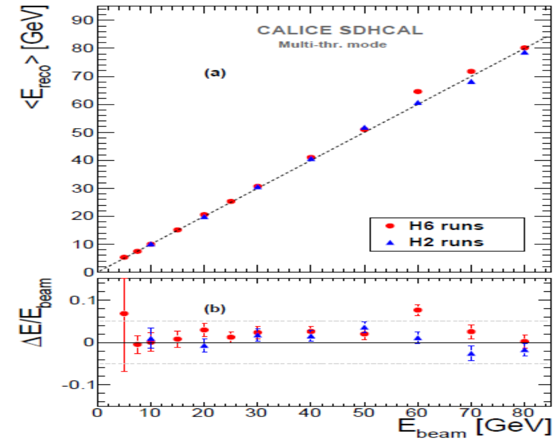
The electronics readout system in both is embedded on RPC of 1m x 1m large and 3mm thick. In the SDHCAL multi-threshold readout was adopted

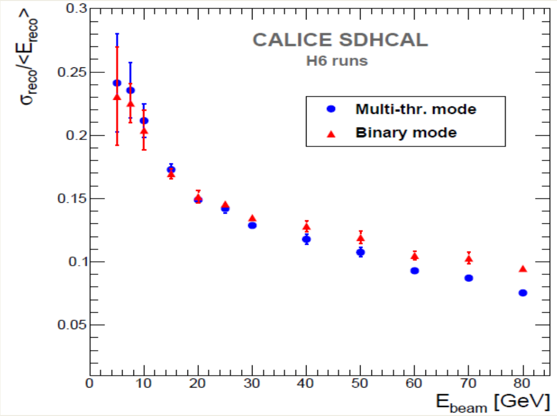




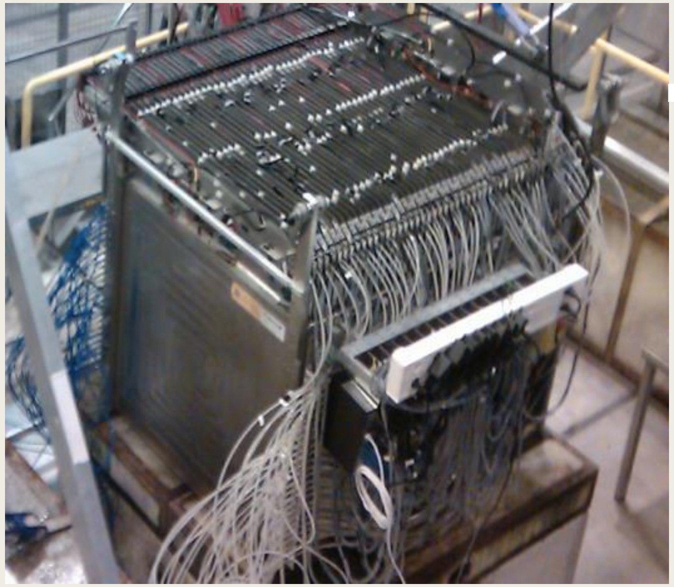



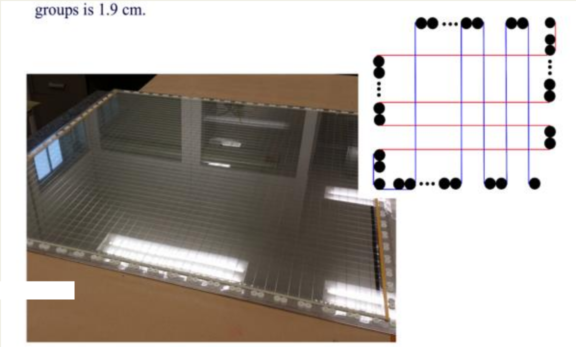



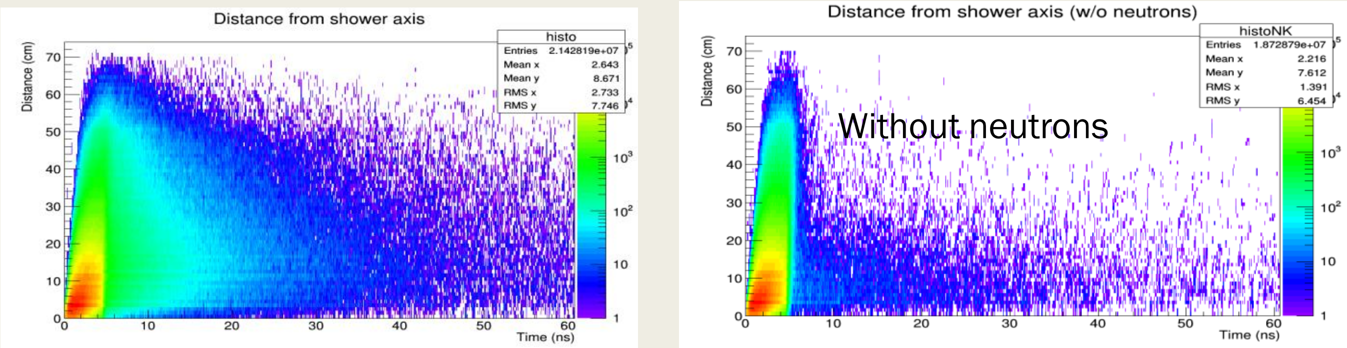



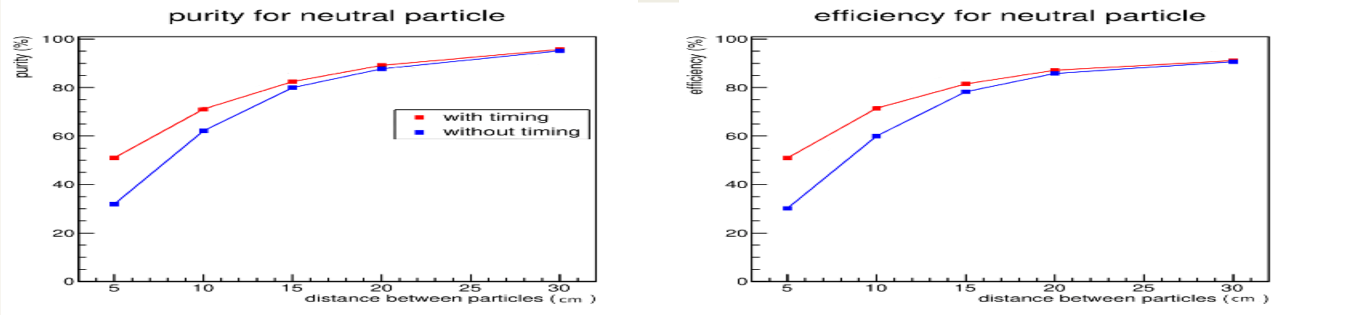
# (M)RPC for calorimetry

MRPC are being proposed to replace RPC to exploit the time resolution they provide.
4 or 5 gap RPC are expected to provide better than 150 ps time resolution so they can be exploited to better separate close-by hadronic showers and discriminate the delayed neutrons





# Development trends for HEP (M)RPC

- ❖ Replace greenhouse (TFE, SF6) gases by eco-friendly ones (HFO, NOVEC...)
- ❖ Reduce leakage by adopting new structure (sealing,..etc)
- ❖ Reduce the electrode resistivity to achieve higher rate
- ❖ Reduce avalanche charge --> higher rate and less aging → develop new generation of electronics ( as for MPGD)
- ❖ Increase uniformity → needed for better energy reconstruction in calorimeters and less uncertainties in timing

- (M)RPC were, are and will be widely used in HEP experiments

- They present excellent features and in particular their timing and cost-effectiveness

- They are muon detectors, ToF detectors and active layers for HCAL

- (M)RPC are also used in many no HEP applications such as muon tomography and medical applications but this requires another lecture in the future….