Performance of a new generation RPCs for particle physics at colliders of the next generation

Lorenzo Paolozzi, University and INFN of Roma Tor Vergata

On behalf of ATLAS Muon Collaboration

Requirements for the muon trigger system of experiments at high luminosity colliders

Future experiments at high luminosity colliders will be characterized by:

- Very high background of both neutral and charged particles.
- Better momentum resolution required for the 1st level trigger

Optimal features for the trigger detector in the muon spectrometer:

Rate Capability $\sim 10\ ^{kHz}/_{cm^2}$

Time Resolution $\lesssim 1\ ns$

Space Resolution few hundreds microns

A new generation of RPCs

The Resistive Plate Chamber (RPC) [1] is a very fast and reliable gaseous detector, widely used in high energy physics experiments.

This detector is presently operating in three of the four main experiments at the Large Hadron Collider (LHC) at CERN. This poster is focused on the development of a new generation of RPCs using a new gas gap layout and front-end electronics. The material is a plastic phenolic laminate with a bulk resistivity $\rho \cong 3 \cdot 10^{10}\Omega\ cm$, like in the present generation of RPCs.

The intrinsic time resolution ($\sim 1\ ns$ for the 2 mm gap) of this detector is the key feature for the bunch cross identification and grants at the same time an effective background rejection in a high rate environment.

The aim of this R&D[2] was to increase the rate capability by a factor about 10 with respect to present RPCs and at the same time to substantially improve the time and space resolution of the detector.

At very high rates the voltage drop on the resistive electrodes reduces the actual Electric Field applied to the gas gap.

$$V_{gas} = V_A - \rho \cdot d \cdot \Phi \cdot Q(V_{gas})$$

The direction followed in the recent development was to **reduce the average charge per count** of the detector, in order to increase the rate capability without incurring in ageing effects [3]. This was achieved by introducing **a new fast and low noise front end amplifier** and by exploiting new geometries for the detector.

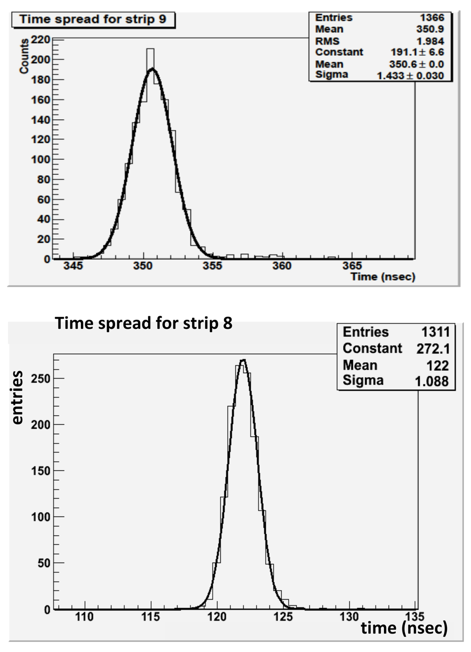
Recent developments for the RPC detector and front-end electronics

Studies on gap width and multigap structure

Given the ATLAS 2 mm gap RPC layout as a starting point, the idea is to improve time resolution and lower the charge per count by reducing the gas gap size [4].

The RPC timing performance for different gap sizes is shown below. The 1 mm gap has been chosen for having a good timing performance without compromising the maximum efficiency.

Time resolution studied at the H8 muon test beam facility at CERN.
Combined jitter of Scintillator trigger and RPCs.

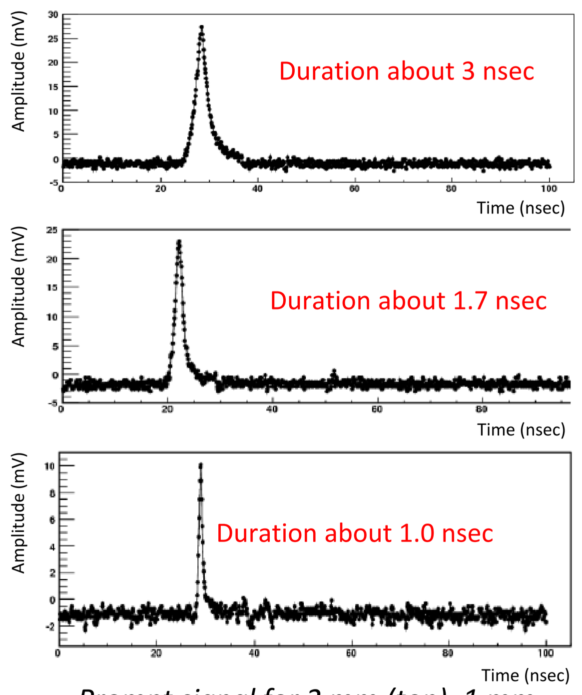


Arrival time distribution for 2 mm gap RPC (above) and 1 mm gap RPC (below)

- 2009 data, 2mm gas gap
- Raw time resolution 1.43 nsec, which is consistent with a net time resolution σ_t=1.14 nsec after subtracting the scintillator jitter.

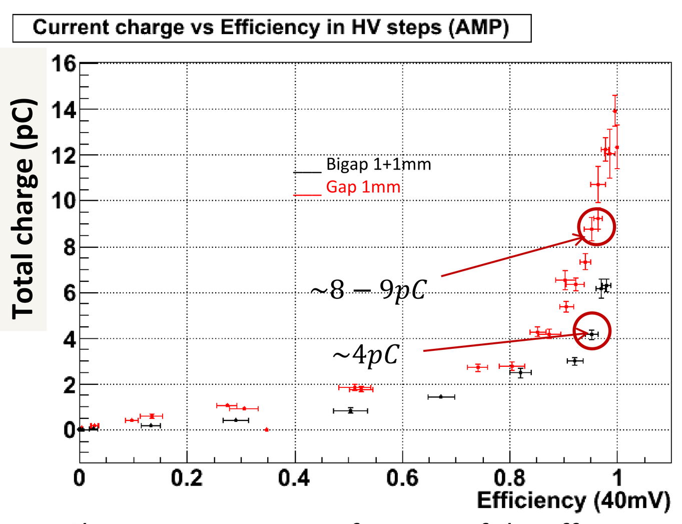
- 2011 data with 1mm gas gap
- raw time resolution 1.09 nsec, which is consistent with a net time resolution σ_t=0.63 nsec after subtracting the scintillator jitter.

Gap reduction leads to better timing performances as expected.



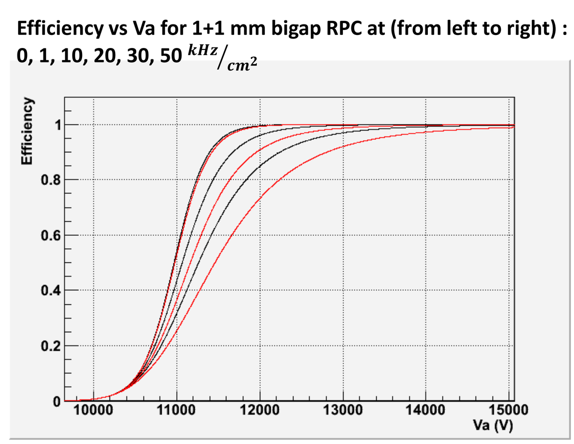
Prompt signal for 2 mm (top), 1 mm (middle) and 0.5 mm gap RPC (bottom).

A better performance in terms of charge per count was also achieved by building a 1+1 mm bigap structure.



Charge per count as a function of the efficiency. RPCs equipped with the new preamplifier.

The measurements done in a dedicated cosmic ray test allowed to collect data and to make predictions on the expected maximum rate capability for an RPC with 2 mm thick electrodes and $\rho = 3 \cdot 10^{10}\ \Omega\ cm$.



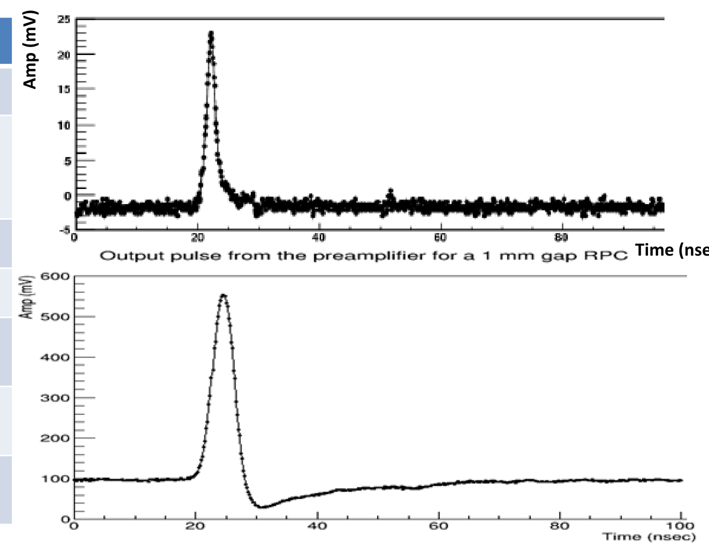
Simulated efficiency curve at different rates for a 1+1 mm bigap RPC with the new preamplifier.

The new fast, low noise preamplifier

The low noise of this new preamplifier with high detector capacitance 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.

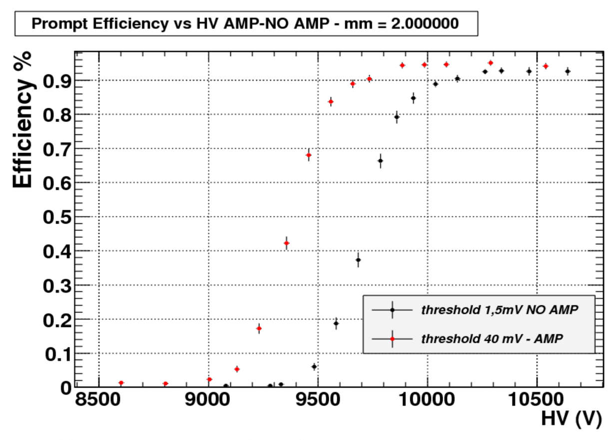
Voltage supply	3-5 Volt
Sensitivity	2-4 mV/fC
Noise (independent from detector)	4000 e- RMS
Input impedance	100-50 Ohm
B.W.	10-100 MHz
Power consumption	10 mW/ch
Rise time $\delta(t)$ input	300 – 600 ps
Radiation hardness	1 Mrad, 10^{13} n cm^{-2}

Properties of the new preamplifier for fast signals [5]



Timing structure of a prompt signal from a 1 mm gap RPC (above) and the amplified signal (below).

The introduction of this new preamplifier allowed to lower significantly the working point of the detector and thus the charge per count [6].



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

The effect of the new preamplifier allowed to reduce the charge per count, with the optimization of the new geometry, **from the 30 pC/count [7] of the ATLAS RPCs to about 2 pC/count**.

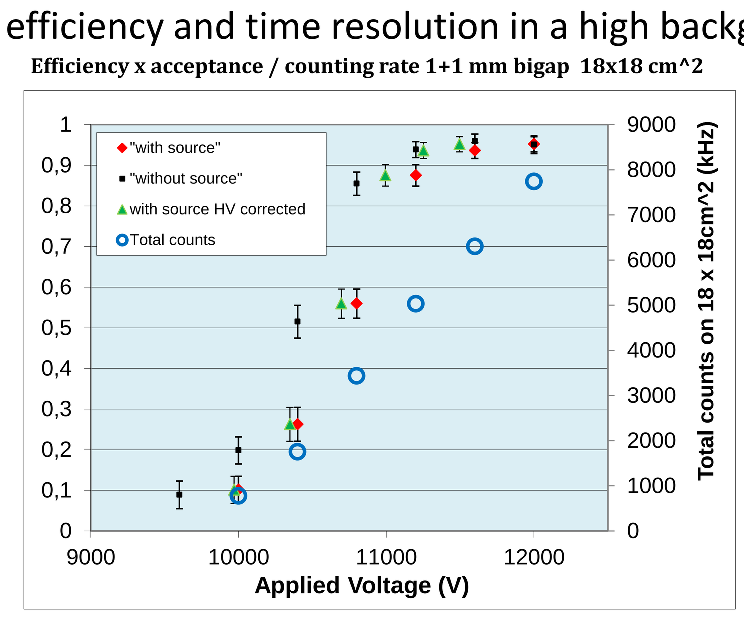
Most important, thanks to its intrinsic low noise this circuit allows to work with a very large dynamic range. This is fundamental for position measurements based on the charge centroid method.

It must be pointed out that the development of this front end preamplifier is still in progress and a new version in SiGe technology with better performance has been already tested on diamond detectors [5].

Experimental results for the RPCs with the new preamplifier

Detector performance at high rates

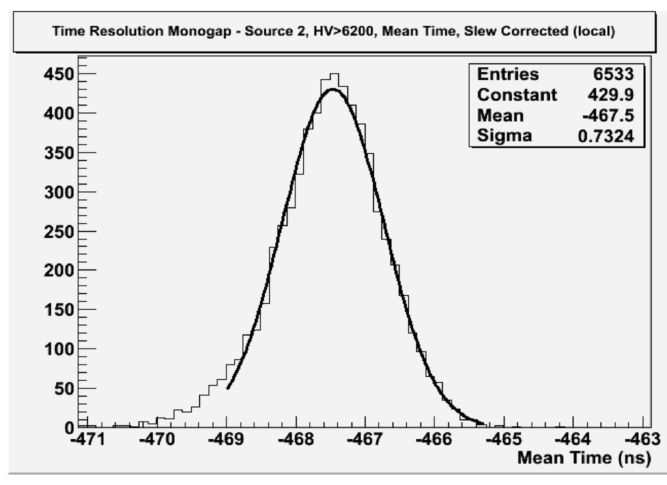
The first test, carried out at the Gamma Irradiation Facility at CERN, allowed to measure both the efficiency and time resolution in a high background environment.



Efficiency curve at a rate of about 12 kHz/cm^2 for a 1+1 mm bigap RPC equipped with the new preamplifier. The rate was induced by a ^{137}Cs source.

The efficiency is compatible with the expectations from the cosmic ray test.

Furthermore, the correction for the voltage drop on the electrodes is coherent with the proposed model.



Time distribution for a 1 mm gap RPC at a counting rate of 3 kHz/cm^2. Raw resolution 730±9 ps including the trigger scintillator jitter of 550±5 ps.

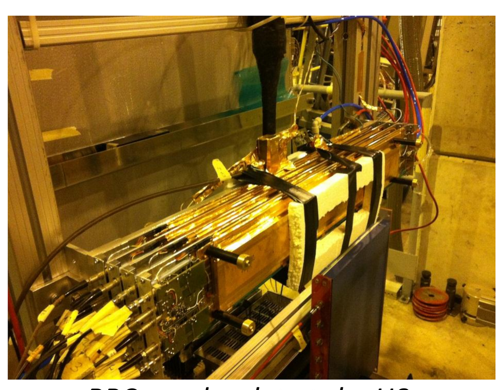
Time resolution in high rate environment after correction for trigger jitter:

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

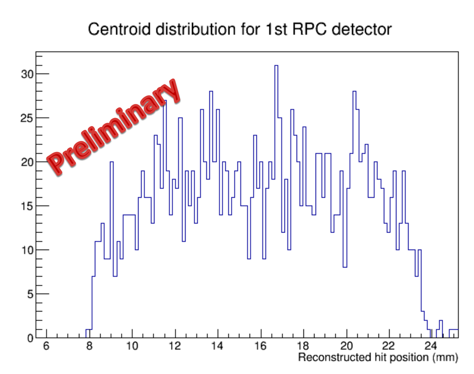
The result obtained at high rate **is compatible with the one obtained at lower rate** with the same setup (see the poster *Studies on fast timing and high precision tracking performance of Resistive Plate Chamber*).

Space resolution measurements

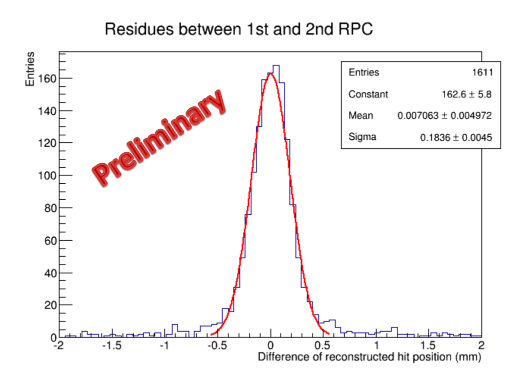
A second test at the H8 muon test beam facility was done in order to measure the space resolution for perpendicular tracks of the detector. For this test a quadruplet of 1 mm gap RPCs with **8 mm pitch readout strips** was used. The RPCs were equipped with the new preamplifier. We show here preliminary results while the analysis is still in progress.



RPC quadruplet at the H8 beam line (CERN)



Muon hit position distribution reconstructed by the first RPC using the charge centroid method.



Residues between 1st and 2nd RPC hit position reconstructed with the charge centroid method.

If we consider both RPCs to have the same resolution this would give a **preliminary space resolution of $(130 \pm 5)\mu m$** for the single RPC. A new test for inclined tracks in high background is in progress.

Conclusions

The studies and measurements done so far allowed to improve the performance of the detector in all the key features required for high luminosity colliders. Moreover, all the properties of the new front-end amplifier – from the low noise to the large dynamics and the fast response – have been exploited to produce **a fast tracker capable to work in a very high background environment** [8][9].

It must be pointed out that these features are obtained without affecting the traditional characteristics of **reliability, simplicity and low cost production** typical of the RPC detector.

References:

[1] R. Santonico and R. Cardarelli, Nucl. Instr. and Meth. A 187, 377 (1981)
[2] R. Santonico , Nucl. Instr. and Meth. A 623, 117-119 (2010)
[3] L. Paolozzi, Test for upgrading the RPCs at very high counting rate, XI workshop on Resistive Plate Chambers and Related Detectors, (2012)
[4] R. Santonico, A new generation of RPCs to be used as muon trigger detectors at the super- LHC, TIPP 2011
[5] R. Cardarelli et al., 2013 *JINST* **8** P01003 doi:10.1088/1748-0221/8/01/P01003
[6] R. Cardarelli, RPC Performances versus Front-End Electronics, X workshop on Resistive Plate Chambers and Related Detectors, (2010)
[7] G. Aielli, ATLAS Cavern Background with RPCs, XI workshop on Resistive Plate Chambers and Related Detectors, (2012)
[8] R. Cardarelli, High rate fast precision tracking trigger with RPCs, XI workshop on Resistive Plate Chambers and Related Detectors, (2012)
[9] R. Cardarelli, A fast precision tracking trigger with RPCs for high luminosity LHC upgrade, TIPP 2011

13TH VIENNA CONFERENCE ON INSTRUMENTATION