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High rate fast precision tracking trigger with RPCs

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ABSTRACT: Muon triggering at the super LHC luminosity imposes very strict requirements on the trigger concerning not only the rate capability but also to the tracking accuracy. This is particularly true for the very forward regions for which the LHC experiments are scheduling upgrade plans. An accurate 3D tracking allows defining a sharp threshold in the muon transverse momentum. Moreover high resolution timing is crucial to reject as much as possible fake triggers generated by correlated and uncorrelated background. We propose here a new trigger idea, exploiting the RPC sub-ns / sub-mm space-time resolution, based on a very fast multi-channel front-end circuit capable of selecting in few ns the maximum charge deposition among the input channels. The fake triggers are heavily suppressed by means of a mean-timer based local coincidence circuit gating the readout. We will present this electronics in terms of functionality and performance, supporting a detector design with a relatively low overall electronics complexity and cost with respect to other more conventional schemes.

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[1] Speaker

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1. Introduction

To realize a fast and high precision tracking trigger with RPCs at high rates the requirements are very strict: for the momentum selection is required a sub-mm space resolution in few tens nanoseconds. For this aim the proposed solution is a Maximum Selector circuit capable of a precision of the order of few hundreds μm in less than 2 ns. To suppress uncorrelated noise is required a few ns coincidence, achievable only with a very high time resolution of the detector and a very performing digital electronics.

To work at high rates a very low charge per count (less than 1pC) is needed to avoid problems of ageing and power consumption.

2. Strategies to increase the rate capability of RPCs

For what concerns RPCs the rate capability is limited by the voltage drop (V_d) in the resistive electrodes, which is determined (at high rates) by the relation

$$V_d = I \cdot R \tag{1}$$

Where the current I is proportional to the counting rate and the average charge per count while the resistance R is proportional to the resistivity and thickness of the electrodes.

The RPC's rate capability can thus be increased by reducing the resistivity, the thickness of the electrodes and the average charge per count.

The systematic ageing tests done on ATLAS RPCs [1] showed how the ageing of the detector depends strongly by the total charge integrated through the electrodes. Moreover, rising too much the current, the power consumption of the detector can reach levels capable to produce a thermic drift that can lead to a breakdown of the detector itself.

It is possible to increase the rate capability without increasing the operating current by reducing the average charge per count by means of a new front end electronics with very high performances.

The traditional approaches to realize a FE electronics – which are the charge amplifier, the transimpedance and the voltage amplifier – are not optimized to amplify the signals of the RPCs with a high signal to noise ratio. Very good results were achieved by realizing an amplifier which works in the condition showed in figure 1.

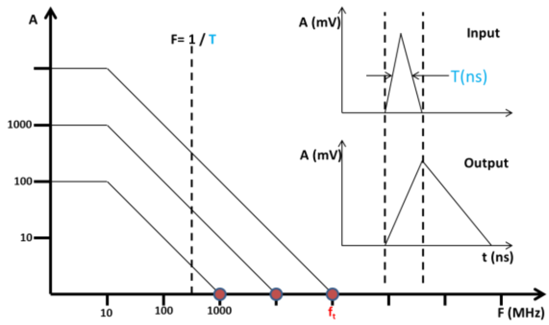


Figure 1: Strategy for the new front-end.

The bandwidth is set according to the repetition rate of the pulses, in order to avoid pile up of the signals. The rise time of the output pulse of the amplifier is equal to the duration of the pulse of the RPC. This is very useful because by reducing the gap of the RPC the duration of the pulse is consequently reduced and the time resolutions gets better. The rise time of the output signal from the amplifier is also reduced and this allows a time of flight application of the detector. In this way there is an auto-tuning of the amplifier to the time performances of the detector.

Two different versions of the amplifier have been built using BJT transistors made with different technologies: Silicon and SiGe. The performances of the amplifiers in Silicon and SiGe technology are shown respectively in tables 1 and 2.

Voltage supply	5 Volt
Sensitivity	6 mV/fC
Noise	4000 e^- RMS
Input impedance	50 Ohm
B.W.	30 MHz
Power consumption	10 mW/ch
Low cost	2 – 3 eur./ch
Rise time $\delta(t)$ input	300 – 600 ps
Radiation hardness	1 Mrad, 10^{13}ncm^{-2}

Table 1: BJT transistor using Silicon technology

Voltage supply	3 Volt
Sensitivity	6 mV/fC
Noise	500 e^- RMS
Input impedance	10 – 100 Ohm
B.W.	30 – 100 MHz
Power consumption	10 mW/ch
Low cost	2 – 3 eur./ch
Rise time $\delta(t)$ input	100 – 300 ps
Radiation hardness	50 Mrad, 10^{15}ncm^{-2}

Table 2: BJT transistor using SiGe technology

It can be seen that the SiGe technology is far better than the Silicon one and the reasons for the difference are explained in figure 2, where the working principles of the two technologies are schematized.

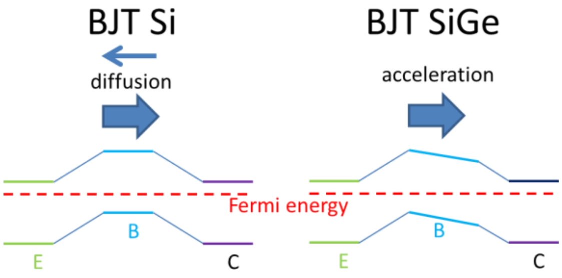


Figure 2: Working principle comparison; Silicon technology vs SiGe technology.

The main difference between the two cases is the transit time in the base of the transistor. In the silicon transistor the transit is only due to diffusion, while in the case of the SiGe technology there is an electric field into the base which accelerates the charges towards the collector (ballistic effect), reducing in this way the transit time and rising the collection efficiency of the transistor and therefor $\beta = {t_r}/{\tau_{t_b}}$, where t_r is the average recombination time into the base, while τ_{t_b} is the transit time in the base.

Another advantage of the BJT with SiGe technology in amplification of pulses is the very low corner frequency of the ${1}/{f}$ noise ($\sim 1kHz$).

If figure 3 are shown the efficiency curves for a 1mm gap RPC with and without the new front end electronics.

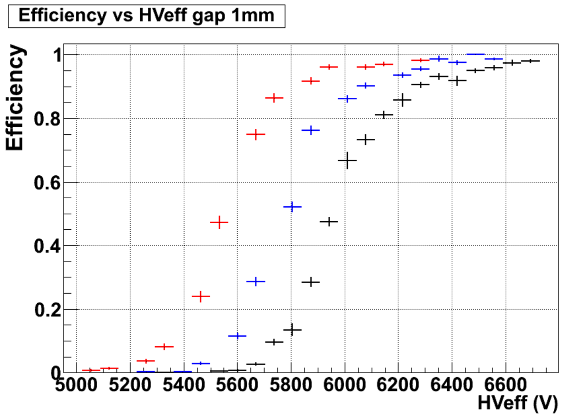


Figure 3: Efficiency curves RPC 1mm gap. In red SiGe FE; in blue Silicon FE; in black no FE.

The points in black are produced by sending directly the amplitude signal to a scope with $1GHz$ analog bandwidth and setting the threshold for efficiency to 1.5mV (which is an ATLAS like threshold). In blue are represented the efficiencies for signals amplified by the new FE amplifier with silicon technology (fixed threshold of 40mV). In red are represented the efficiencies for the SiGe technology amplified signals (fixed threshold of 8mV).

In figure 4 is shown the current as a function of the applied voltage on the gas gap. The 90% efficiency points for the three cases of the previous figure are marked.

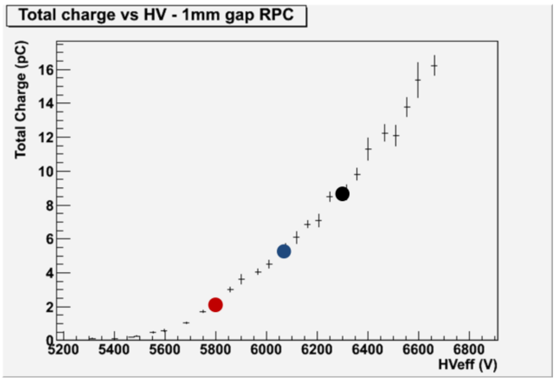


Figure 4: Total charge vs HVeff with point at 90% efficiency highlighted. In Black: No FE. In blue: Silicon FE. In Red: SiGe FE.

The detector efficiency under different rates is a pure function of the tension applied to the gas gap and can be measured at low rates, while the voltage drop on the electrodes can be computed as a function of the rate if the average charge per count is known (1). For this reason is possible to simulate the response of the detector at high rates by using the data taken in a cosmic ray test (figure 5).

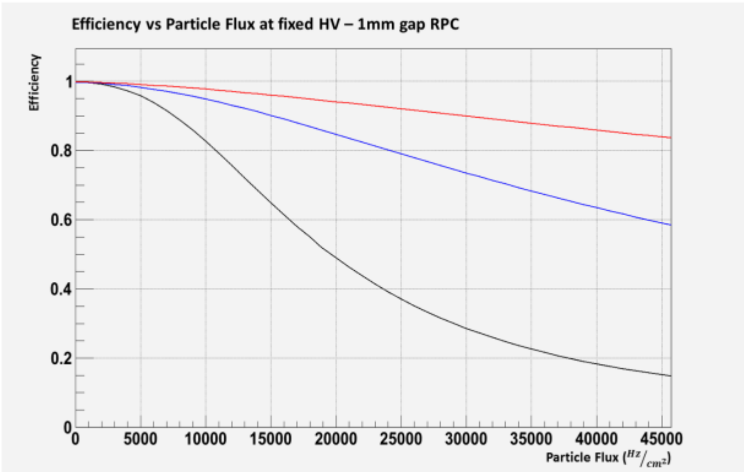
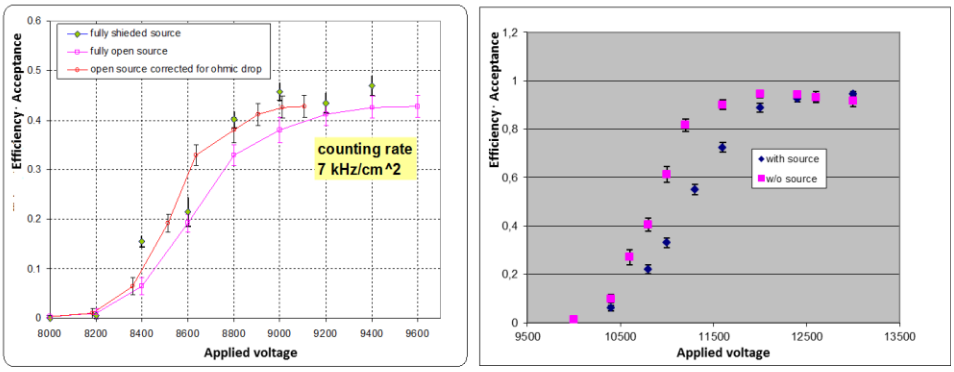


Figure 5: Efficiency at different fluxes for 1mm gap RPC operated 200V after efficiency knee (at CR rates). In black: no FE. In blue: Silicon FE. In Red: SiGe FE.

The new FE electronics with the silicon technology has been also tested at high rates at the GIF at CERN on a 2mm gap RPC and on a 1+1mm bigap RPC, both with bakelite electrodes ($2 \cdot 10^{10} \Omega cm$). In figures 6 and 7 the efficiency curves for the two RPCs both at cosmic rays rates and under heavy photons' irradiation (induced counting rate 7kHz/cm^2) are shown.



Figures 6,7: Test beam results at the GIF at CERN. Left: 2mm gap RPC. Right: 1+1mm bigap RPC.

The voltage drop on the electrodes causes the shift in high voltage of the working point but, even if with the worse performing technology of the new front end, the shift is low enough to operate the detector at full efficiency at this counting rate.

3. High space resolution in few nanoseconds for trigger applications

To improve space resolution the strip pitch can be reduced, but this strategy incurs in two problems: the first one is that the number of FE electronics channels increases and the second is that by reducing the pitch the cluster size rises due to the distribution of the induced charge on the strips (figure 8).

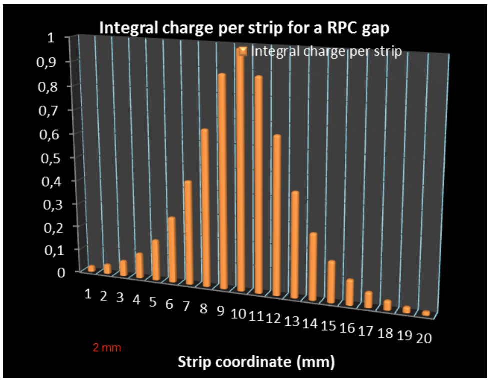


Figure 8: Induced charge distribution on a 2mm strip pitch RPC (2mm gas gap)

The first problem is only related to the cost of the trigger but it does not affect its feasibility. The second is a technical problem hard to be solved: the cluster multiplicity must be suppressed in few ns real time. A Maximum Selector circuit is proposed here: this new very simple circuit is capable to select the maximum of a charge distribution in a time of about $200ps$; the maximum cluster size can be set independently from the chosen strip pitch and the amplitude of the total charge.

In figure 9 the characteristic function of the MS and the connection scheme for contiguous circuits are reported.

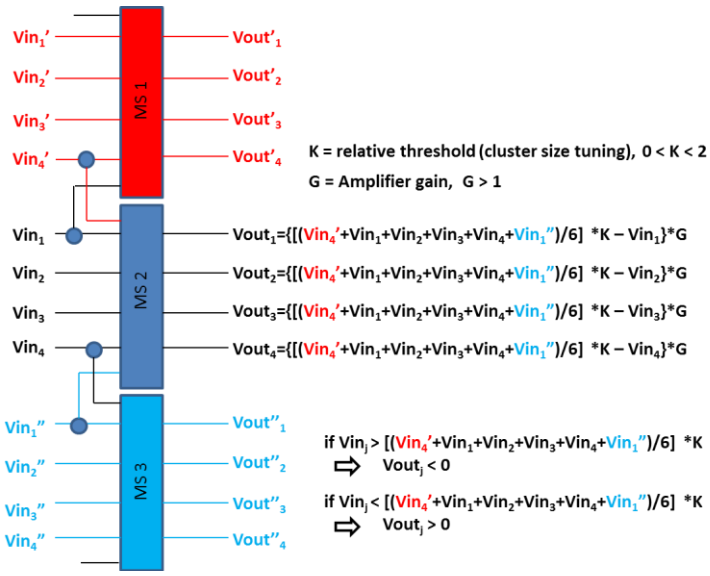


Figure 9: Connection of three contiguous Maximum Selectors (4 channels case) with the transfer function of the central one.

In the characteristic function the parameter K allows to set the maximum multiplicity required and G is the gain of the input pulse.

A 1mm gap RPC with strips of 3mm pitch equipped with this circuit has been tested successfully at the H8 test beam facility at CERN; the resolution achieved in this test is represented in figure 10.

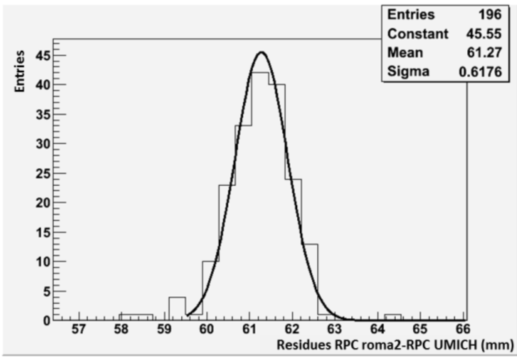


Figura 5: Residues between Roma 2 RPC and tracking apparatus using MS with cluster size information.

The expected space resolution for the output signal of the MS is

$$\sigma_s = \frac{3mm}{2\sqrt{12}} = 0.43mm$$

The obtained result of $0.62mm$ must be deconvoluted for the tracking detector resolution ($0.37mm$) and the beam divergence ($70\%\ 0.14mm, 30\%\ 0.60mm$; no tracking device was available for the test).

4. Conclusions

The RPC detector equipped with the new FE circuit presented in this article is capable to work at high efficiency at rates up to 40kHz/cm^2, with a sub-ns time resolution and a space resolution of few hundreds μm obtained in few ns.

These performances are very promising for realizing a very selective 1st level trigger for future high luminosity experiments. At the same time with the new Front-End it is possible to work at high rates with the same integral current as in the ATLAS and ARGO experiments. The experience of these experiments (total $\sim 15000m^2$ and ~half million FE circuits) show that in this working condition the detector is very robust and reliable.

References

[1] G.Aielli et al., Ageing test of ATLAS RPCs at CERN's gamma irradiation facility, Nuclear Science Symposium Conference Record, 2004 IEEE Volume 1, 16-22 Oct.2004, 226 - 230.

[2] R. Cardarelli, RPC performance vs. front-end electronics, Nuclear Instruments and Methods in in Physics Research A, doi: 10.1016/j.nima.2010.09.136 .