



Performance of the CMS RPC upgrade using 2D fast timing readout system

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Introduction

During Phase II of the LHC program (HL-LHC) the instantaneous luminosity in CMS experience is expected to increase by a factor 5-7 [1].

In this case, a new generation of RPC capable to sustain high particle fluxes and instrumented with a precise timing readout electronics is proposed to equip the high η muon stations (Fig. 1):

$$1.8 < |\eta| < 2.4$$

Improved RPC (iRPC) detectors should be able to withstand particle rates as high as:

$$\text{up to } 2 \text{ kHz} \cdot \text{cm}^{-2}$$

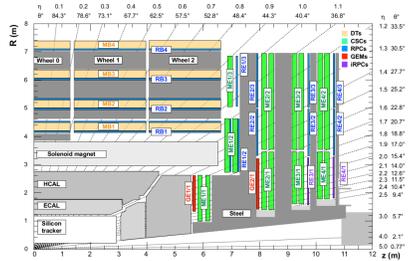


Figure 1: Layout of one quadrant of CMS. The slots RE3/1 and RE4/1 are to be instrumented by RPC chambers for HL-LHC upgrade.

Prototype Design

Thinner gap ($2 \text{ mm} \rightarrow 1.4 \text{ mm}$) in the double gap RPC detector [2] reduces the amount of avalanche charge.

This improves rate capability by reducing the needed time to absorb this charge. To keep the iRPC efficiency high a sensitive, low-noise and high time resolution electronics readout is needed (Fig. 2).

lower charge \rightarrow less aging \rightarrow needs more sensitive electronics.

higher rate \rightarrow more combinatory \rightarrow needs better space resolution.

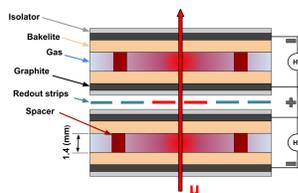


Figure 2: Double gas gap.

A strip signal is read out from both strip's ends. PETIROC2A chip [3] with a low-jitters preamplifier is used for the readout (Fig. 3,4).

Thin (0.6 mm) Printed Circuit Board (PCB), 165 cm long, equipped with impedance-matched pickup strips of 0.75 cm pitch, is inserted between the two RPC gaps (Fig. 4).

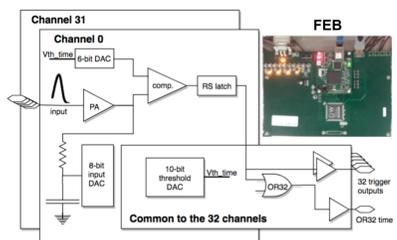


Figure 3: Front-end electronic.

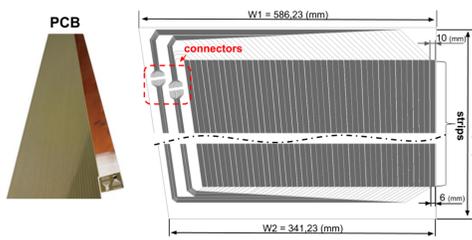


Figure 4: PCB Layout.

Performance

To emulate HL-LHC conditions in GIF++ [4]: Muon beam from SPS (Fig. 5) and Source ($14 \text{ TBq } ^{137}\text{Cesium}$) with different Attenuation factors (ATT) allow reaching a rate of gamma cluster seen by the RPC chamber up to $3 \text{ kHz} \cdot \text{cm}^{-2}$ (Fig. 6).

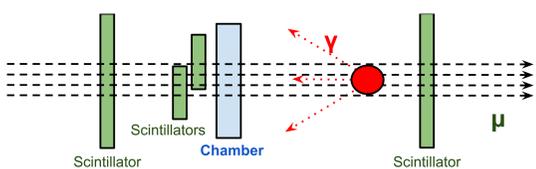


Figure 5: Setup in Gamma irradiation facility (GIF++).

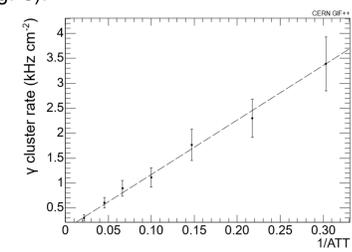


Figure 6: Background rate.

Using reference signals from a scintillators-based coincidence unit (Fig. 5) allows calculating efficiency (Fig. 8) as follows:

$$\epsilon = \frac{\frac{N}{N_{trig}} - \frac{N_{bkg}}{N_{trig}}}{1 - \frac{N_{bkg}}{N_{trig}}} \quad (1)$$

ϵ : Muon Efficiency;
 N_{trig} : Number of triggers;
 N : Number of events for which at least a strip is fired (both ends);
 N_{bkg} : Estimated by counting events for which at least a strip is fired (both ends) in a time interval outside that associated to the signal.

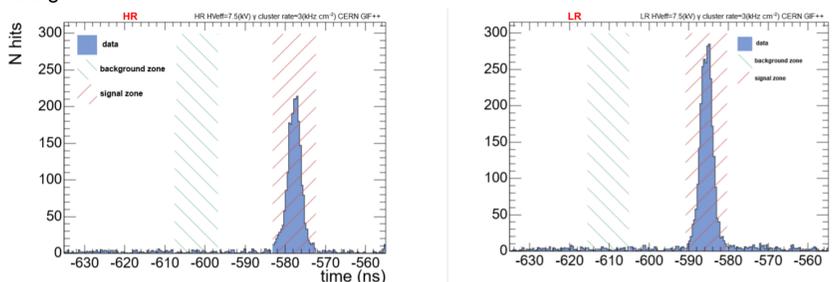
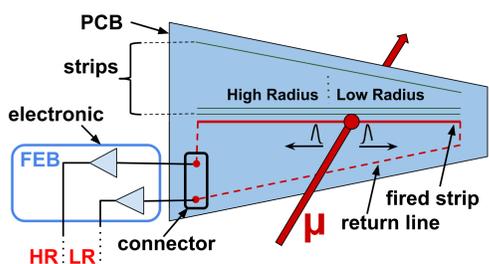


Figure 7: HR and LR time profiles of strips signals associated to the beam.

Windows size for events counting are determined by mean ± 3 sigma of Gaussian fit for the signal zone and 6 sigmas in the zone outside the signal region for background zone.

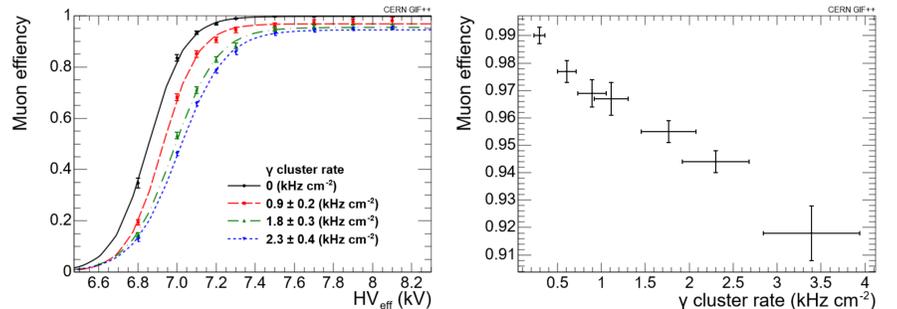


Figure 8: Efficiency of the chamber with various background levels.

Note: Effective HV takes into account the change in pressure and temperature with respect to an HV reference value V_0 at given pressure P_0 and temperature T_0 .

Linearity and Along-Strip Resolution

A position scan of the chamber was performed in SPS H2 beamline using a muon beam.

The chamber was mounted on 0.1 mm precision movable table (Fig. 9). For each position of the table the time difference is estimated:

$$T = T_{HR} - T_{LR}$$

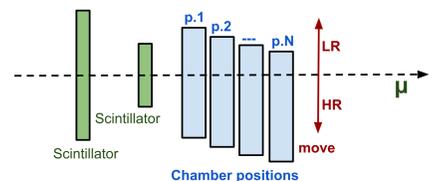


Figure 9: Setup with the movable table.

Very good linearity is observed. Maximum deviation is less than 2 cm with respect to the exact value.

With a time resolution of 177 ps and a signal propagation speed in a strip of approximately 5.25 ns , the along-strip position resolution is $\approx 1.7 \text{ cm}$ (Fig. 10).

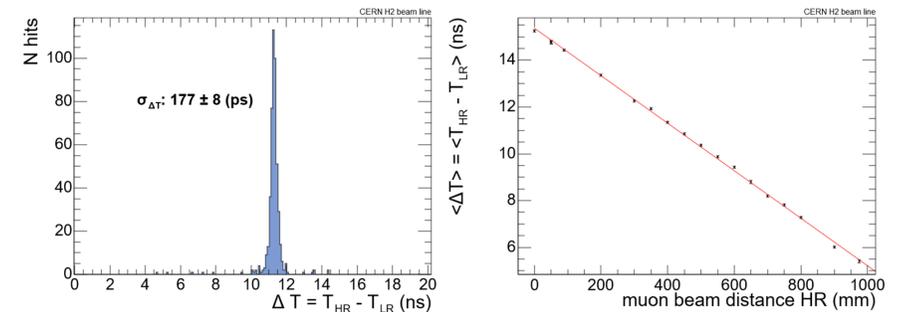


Figure 10: Strip time resolution and time measurement linearity.

Absolute Time Resolution

Measured as the resolution of arrival time difference of the signals of two chambers crossed by the same particle divided by $\sqrt{2}$. The assumption is that both electronics are identical and uncorrelated (Fig. 11).

$$\Delta t = ((T_{prot.1}^{HR} - T_{prot.2}^{HR}) + (T_{prot.1}^{LR} - T_{prot.2}^{LR}))/2$$

$$\Delta t = t_1 - t_2 \rightarrow \sigma_{\Delta t}^2 = \sigma_{t_1}^2 + \sigma_{t_2}^2 - 2 * \sigma_{t_1} * \sigma_{t_2}$$

$$\langle \sigma_{\Delta t}^2 \rangle = \langle \sigma_t^2 \rangle + \langle \sigma_t^2 \rangle \text{ if detect. are independ.}$$

$$\langle \sigma_t \rangle = \frac{\langle \sigma_{\Delta t} \rangle}{\sqrt{2}}$$

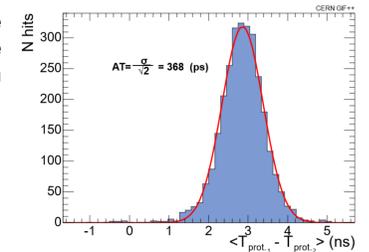


Figure 11: Absolute time resolution.

Conclusion

A new RPC technology to equip two stations of the high η region of the CMS muon spectrometer is proposed and validated on real size prototypes. The resulting detector fulfills all the requirements: space resolution better than 1.7 cm , absolute time resolution of $\approx 370 \text{ ps}$ and an efficiency of 95% for the maximum expected background rate of $2 \text{ kHz} \cdot \text{cm}^{-2}$. The detector is found to be uniform over 1 m length.

References

- [1] CMS Collaboration, The Phase-2 Upgrade of the CMS Muon Detectors, Tech. Rep. CERN-LHCC-2017-012. CMS-TDR-016, CERN, 2017.
- [2] K. S. Lee, et al. Study of Thin Double-Gap RPCs for the CMS Muon System. Journal of the Korean Physical Society. 73. 1080-1087. 10.3938/jkps.73.1080. 2018
- [3] J. Fleury et al., Petiroc, a new front-end asic for time of flight application, in 2013 IEEE Nuclear Science Symposium and Medical Imaging Conference (2013 NSS/MIC), pp. 1-5, Oct, 2013.
- [4] M. R. Jakel et al., CERN-GIF++: a new irradiation facility to test large-area particle detectors for the high-luminosity LHC program, PoS TIPP2014, 2014.