R&D and performance studies of improved RPC detectors for the CMS muon system upgrade at HL-LHC

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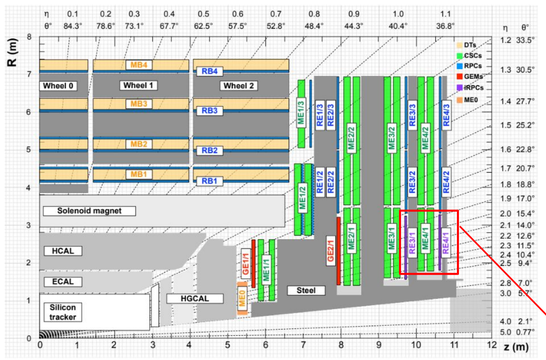
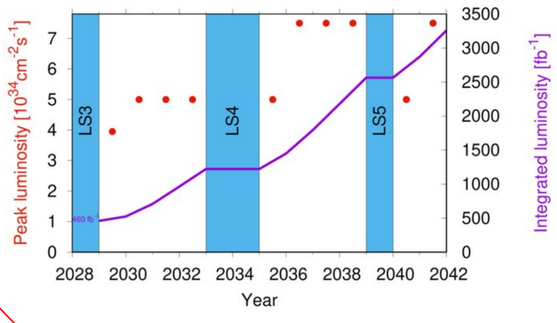
1. INTRODUCTION

RPCs are gaseous detectors widely used in High Energy Physics and the CMS Muon System, valued for their time resolution, robustness, and cost-effectiveness. For the HL-LHC phase, improved iRPCs have been developed to cope with higher particle rates and radiation levels in the forward region.

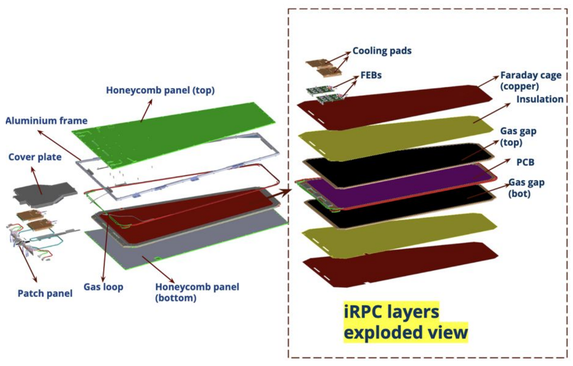




maximum background rate ~700 Hz/cm^2

The iRPCs for RE3/1 and RE4/1 stations provide redundancy to the CSC trigger, improving L1 trigger efficiency and rate capability in the high-η region .

2. iRPC CONFIGURATION



iRPCs are characterised by a **reduced gap** width and **electrode** thickness.
Signals are read out from both ends of each strip.

	RPC	iRPC
HPL thickness (mm)	2	1.4
Number of gaps	2	2
Gas gap thickness (mm)	2	1.4
Resistivity (Ωcm)	1 - 6 x 10^{10}	0.9 - 3 x 10^{10}
Charge threshold (fC)	150	30 - 40
Space resolution in η (cm)	20 - 28	1.5
Space resolution in φ (cm)	0.8 - 1.9	0.3 - 0.6
Intrinsic timing resolution (ns)	1.5	0.5

iRPC FEB is equipped with low noise front-end electronics that can detect signals with a charge as low as 30 fC

3. iRPC PERFORMANCE WITH COSMIC TEST

DEFINITIONS

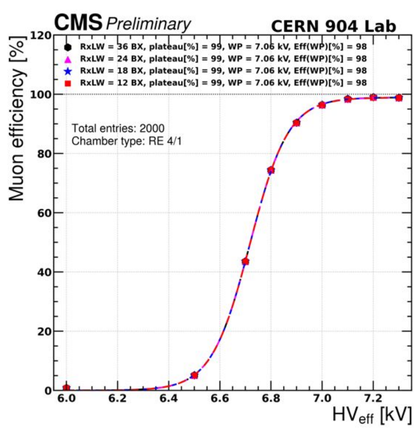
Efficiency

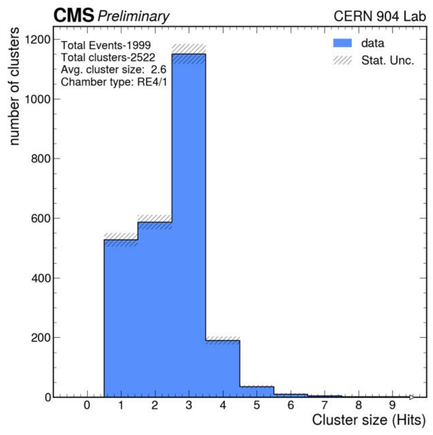
$$\epsilon(HV) = \frac{\epsilon_{max}}{1 + e^{-\beta(HV - HV_{50})}}$$

Working Point

$$WP = \frac{ln19}{\beta} + HV_{50} + 150V$$

Detector performance was assessed at the CERN 904 Laboratory using cosmic muons: 11 HV points were sampled, collecting 2K events/point for efficiency and 15K events/point for noise measurements.





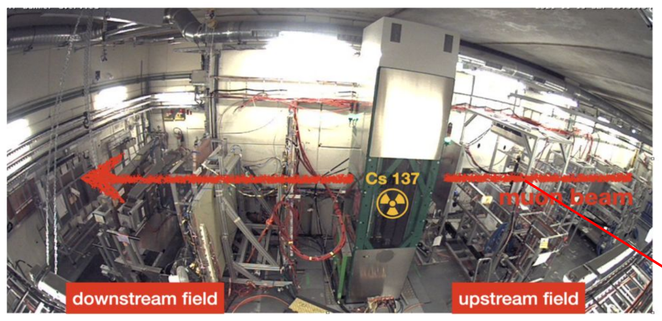
HV_eff: effective high voltage with environmental (T, P) correction

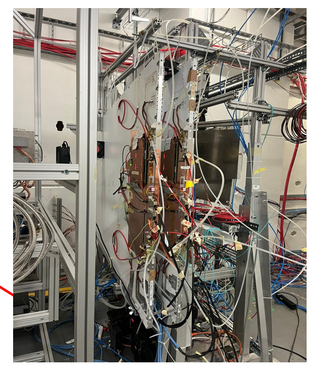
An efficiency of 98% and a mean cluster size of 2.6 strips were measured.

4. iRPC PERFORMANCE AT GIF++

iRPC performance studies under gamma irradiation were carried out at the Gamma Irradiation Facility (GIF++) at CERN, which provides a 12 TBq ^{137}Cs gamma source at 662 keV and a muon beam of ~150 GeV/c.

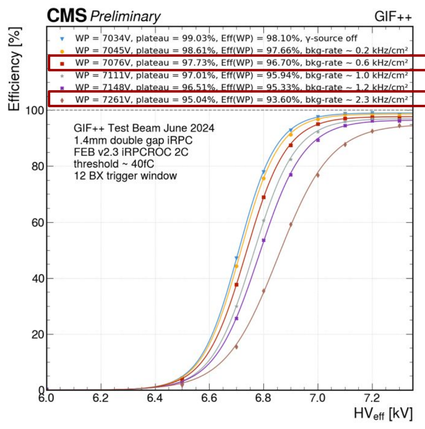
4.1 SETUP





Two iRPCs have been tested in HL-LHC background conditions at GIF++ facility

4.2 RESULTS



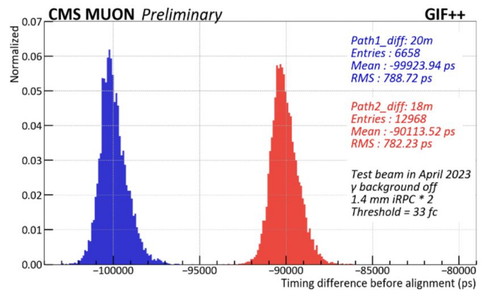
Expected background rate for HL-LHC
→ efficiency: 96.70%
→ WP: 7076V

Safety factor 3 of HL-LHC background
→ efficiency: 93.60%
→ WP: 7261V

High efficiency up to **~1 kHz/cm^2**

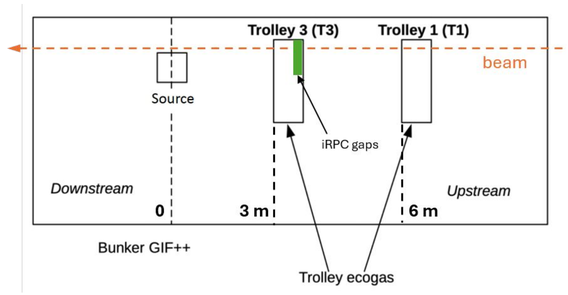
Time resolution measurement at GIF++ has been performed by time of flight measurements with 2 identical chambers.
The absolute timing resolution after alignment by back-end:

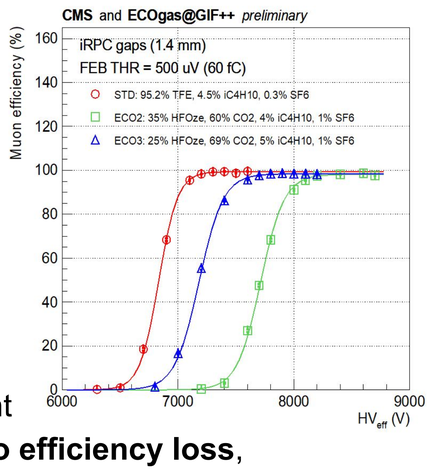
$$\frac{780}{\sqrt{2}} \approx 550 \text{ ps}$$



5. iRPCs PERFORMANCE WITH ALTERNATIVE MIXTURE

The standard RPC gas mixture contains R134a and SF_6, potent greenhouse gases regulated by EU F-gas Regulation 2024/573.
An iRPC prototype was tested at CERN's GIF++ facility using HFO-based eco-friendly alternative mixtures.





After ~45 mC/cm² density charge accumulation (≈1 year at GIF++), only a slight increase in WP values was observed, with **no efficiency loss**, confirming the long-term stability of HFO-based mixtures.

6. CONCLUSION

- **iRPCs** show **96.7% efficiency** and a Working Point of **7076 V** at expected HL-LHC background; 93.6% efficiency at 3× safety factor.
- Timing resolution of **~550 ps** meeting HL-LHC L1 trigger requirements.
- These results demonstrate that iRPC technology satisfies the efficiency, timing, and rate-capability requirements for CMS operation during the HL-LHC era.

REFERENCES

[1] Joao Pedro Gomes Pinheiro et al., “Improved Resistive Plate Chambers for Phase-II upgrade of the CMS detector in LHC” (2024), https://doi.org/10.1016/j.nima.2024.169923.
[2] CMS Collaboration “The phase-2 upgrade of the CMS muon detectors “ (2017), CERN-LHCC-2017-012
[3] R. Guida, GIF++: The new CERN Irradiation Facility to test large-area detectors for HL-LHC, in: IEEE Nuclear Science Symposium and Medical Imaging Conference, 2015.