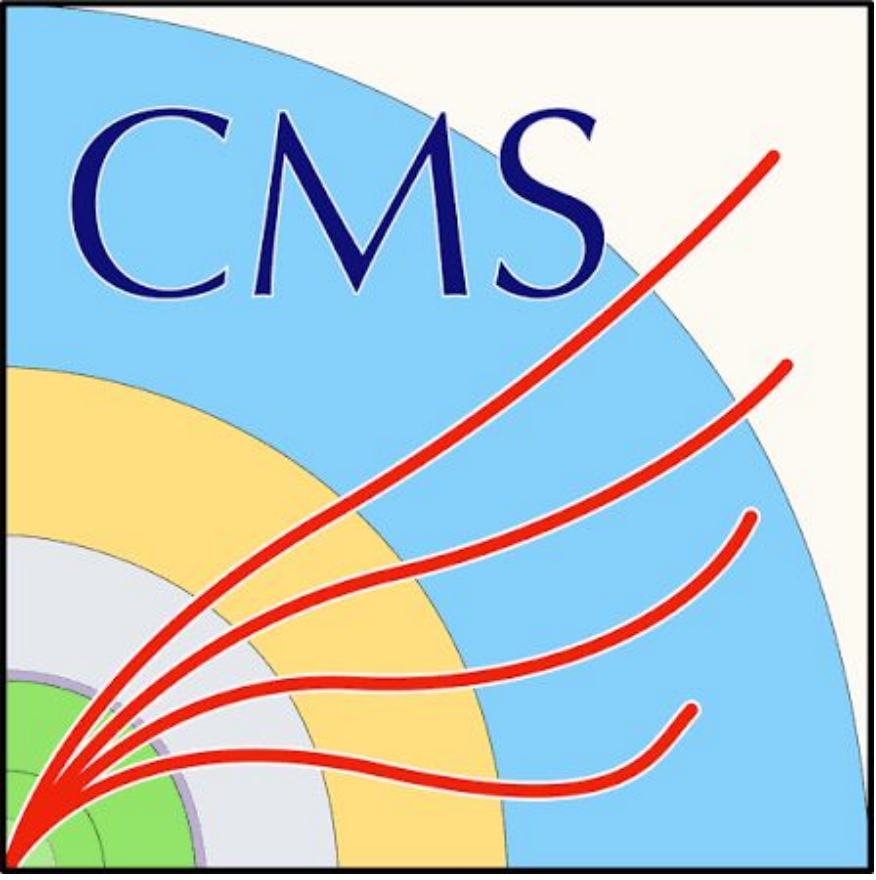




CMS-RPC Timing Resolution Evolution Under the Longevity Campaign

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The aging process is one of the main concerns when operating Resistive Plate Chambers (RPCs) in high-luminosity, as in long-term detector experiments such as the Compact Muon Solenoid (CMS). Since 2010, the CMS experiment has collected about 500 fb⁻¹ of pp collision data, while the expectation for the HL-LHC is to collect more than 3000 fb⁻¹. To ensure reliable operation throughout this period, the CMS-RPC system has undergone an extensive longevity campaign at the Gamma Irradiation Facility (GIF++). The irradiation campaign has delivered an integrated charge equivalent to the full HL-LHC expectation for the RE2 chambers, with a safety factor of three included in the estimate. RPCs are known for their excellent timing resolution, which is an important component of the CMS muon trigger system. This work investigates the evolution of the RPC time resolution throughout the longevity campaign for the RE2 chambers.

The CMS-RPC Longevity Campaign

A dedicated longevity test has been carried out at the CERN Gamma Irradiation Facility (GIF++) [1] since July 2016 using spare CMS RPC chambers. For this study, an RE2/2 chamber, corresponding to the second station and second ring of the endcap RPC system, was continuously irradiated, while a second RE2/2 chamber was kept as a reference [2]. The chambers are operated with the standard CMS RPC gas mixture of 95.2% C₂H₂F₄, 4.5% i-C₄H₁₀ and 0.3% SF₆. The RE2/2 is a double-gap RPC with 2 mm gas gaps and 2 mm electrodes, equipped with one-dimensional radial copper-strip readout, divided into three η partitions (Rolls A, B and C) with 32 strips per roll [3]. The legacy front-end electronics operate in avalanche mode with a nominal threshold of approximately 150 fC, while the signal timing is measured using a CAEN V1190A TDC with 100 ps/bin resolution.

The longevity study provides an opportunity to investigate the dependence of the detector performance, in particular the time resolution, on the accumulated integrated charge. The irradiated RE2/2 chamber reached an integrated charge of 863 mC/cm² in October 2024, corresponding to more than three times than the expected HL-LHC operation. Throughout the irradiation campaign, the detector efficiency remained stable for integrated charge values up to the full HL-LHC expectation and for background rates reaching the expected HL-LHC level of approximately 600 Hz/cm². In this work, the results obtained for the RE2/2 chambers are presented, with particular emphasis on the evolution of the time resolution as a function of the accumulated charge.

Method

For this study we considered both chambers (irradiated and reference) with very similar time resolution before the longevity campaign started,

$$\sigma_{t_{REF}} \cong \sigma_{t_{IRR}} = \sigma_t \quad (1)$$

The time resolution is extracted from the standard deviation of a gaussian fit of the time difference of the two chambers,

$$\Delta t = t_{REF} - t_{IRR} \quad (2)$$

$$\sigma_{\Delta t} = \sqrt{\sigma_{t_{REF}}^2 + \sigma_{t_{IRR}}^2} = \sigma_t \sqrt{2} \quad (3)$$

where:

- t_{REF} : measured time in the reference RE2/2 chamber;
- t_{IRR} : measured time in the irradiated RE2/2 chamber;
- Δt : time difference between the two chambers;
- $\sigma_{\Delta t}$: standard deviation (time resolution) of the Δt distribution, from a gaussian fit;
- $\sigma_{t_{REF}}$: intrinsic time resolution of the reference chamber;
- $\sigma_{t_{IRR}}$: intrinsic time resolution of the irradiated chamber;
- σ_t : common intrinsic time resolution of the two chambers before irradiation.

After the longevity campaign begins, we consider the time resolution of the reference chamber as unchanged. Equation (3) can therefore be rewritten in terms of the time resolution of the irradiated chamber:

$$\sigma_{t_{REF}} = \sigma_t \quad (4)$$

$$\sigma_{t_{IRR}} = \sqrt{\sigma_{\Delta t}^2 - \sigma_{t_{REF}}^2} = \sqrt{\sigma_{\Delta t}^2 - \sigma_t^2} \quad (5)$$

So for different scans we evaluate the time resolution of the irradiated chamber in terms of the gaussian fit of the time difference and the time resolution of the reference chamber, evaluated in the beginning of the campaign.

References

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- [4] ABBRESCIA, Marcello. Time resolution in Resistive Plate Chambers from statistical considerations. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, v. 1079, 2025, 170589. DOI: <https://doi.org/10.1016/j.nima.2025.170589>.

Signal Selection Methods

Different Methods have been used to evaluate the time difference between two chambers of the same type:

- Using the most (1st, 2nd, 3rd, 4th) activated strip from reference chamber; find the most activated strip for irradiated chamber (for the events that the most activated strip from reference chamber is fired).
- Hits are first grouped into space-time clusters using strip adjacency (± 2 strips) and a 15 ns clustering window, after which the pair of clusters with the smallest time difference satisfying the spatial matching criterion is selected.

Results

The time resolution was evaluated at the high-voltage (HV) point closest to the working point (WP). To assess the impact of small HV variations around the WP, the standard deviation of the time-difference distribution, obtained from a Gaussian fit, was evaluated as a function of HV for scans with different accumulated charges. The results for both methods are shown in Fig. 1.

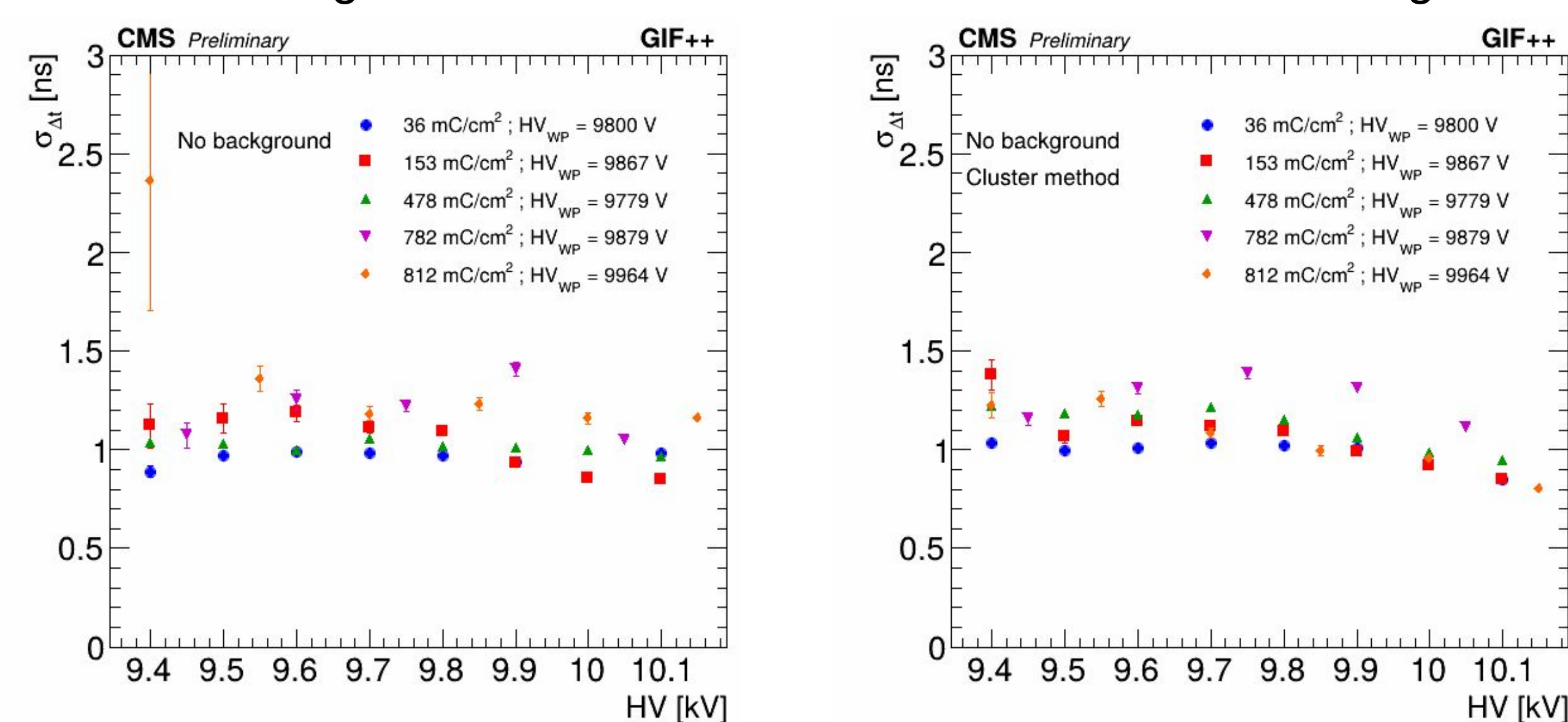


Figure 1: Standard deviation of the Gaussian fit to the time difference between the irradiated and reference RE2/2 chambers as a function of HV, using the most active channel and its correlated partner (left) and clustered signals (right). Different markers and colors indicate different integrated charges. The values remain stable around the working point. Error bars are statistical only.

The time resolution of the irradiated RE2/2 chamber was then evaluated as a function of the accumulated integrated charge. The results obtained with the two methods are shown in Fig. 2. The time resolution remains typically below 1 ns throughout the longevity campaign.

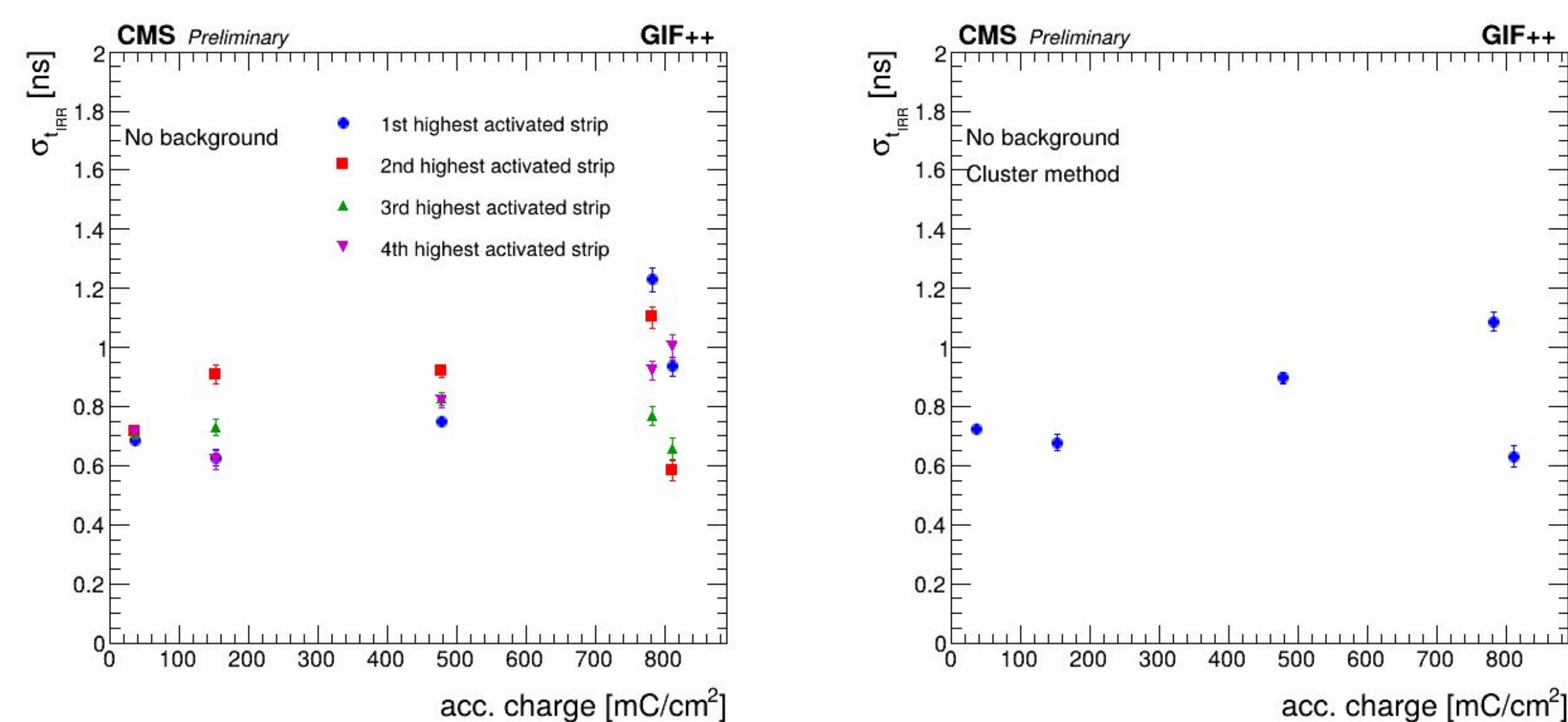
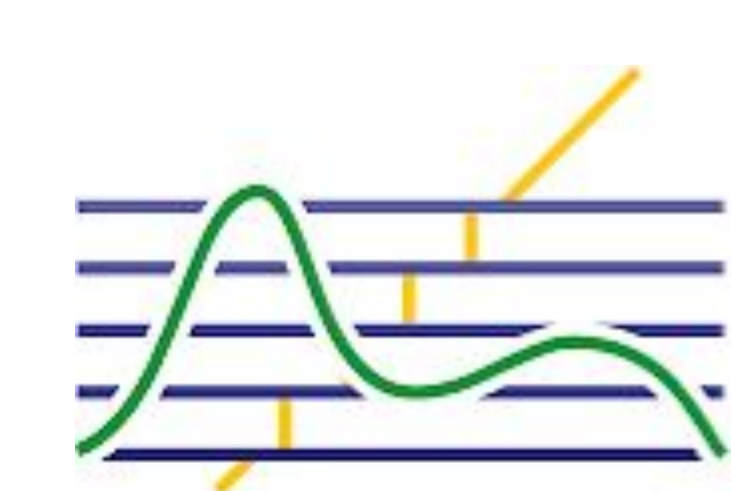


Figure 2: Time resolution of the irradiated RE2/2 chamber as a function of integrated charge, measured at the HV point closest to the calculated working point, using the most active channels and their correlated partners (left) and clustered signals (right). Different markers and colors indicate different channel pairs. Error bars are statistical only.

Conclusions

A time resolution study of the CMS RPC RE2/2 chamber was performed using the large amount of data collected during the longevity campaign. The RE2/2 chambers are representative of the Barrel and Endcap (RE1, RE2, and RE3) production, covering approximately 86% of the CMS RPC chambers. **No strong correlation was observed between the time resolution and the accumulated charge.** The different analysis methods provide consistent results, with the **time resolution typically remaining below 1 ns**, in agreement with statistical considerations study [4], even at an accumulated charge approximately three times higher than the expected HL-LHC value.



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