Latest results from Longevity Studies of CMS RPC Chambers towards HL-LHC Operation

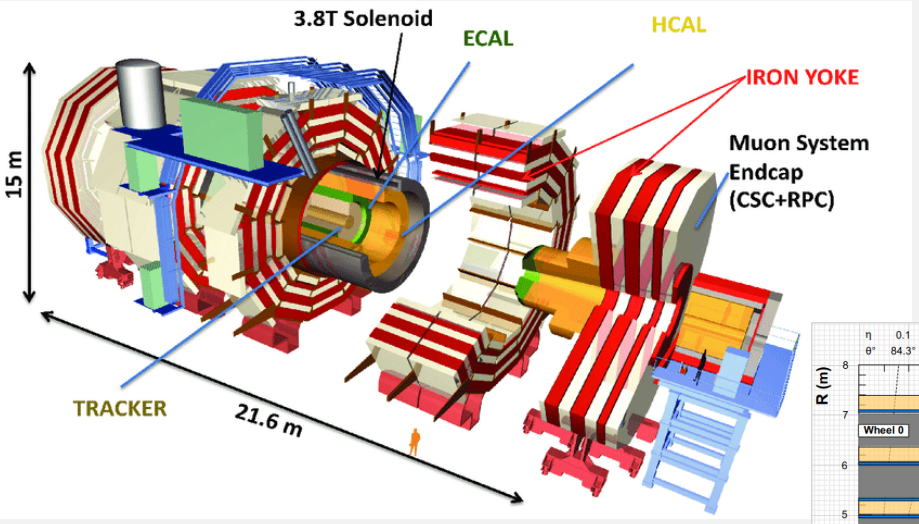
Reham Aly
INFN, Bari - Italy
On behalf of the CMS Collaboration

RPC2026: XVIII Conference on Resistive Plate Chambers
14–18 September 2026 · Rio de Janeiro, Brazil

RPC 2026
RIO DE JANEIRO

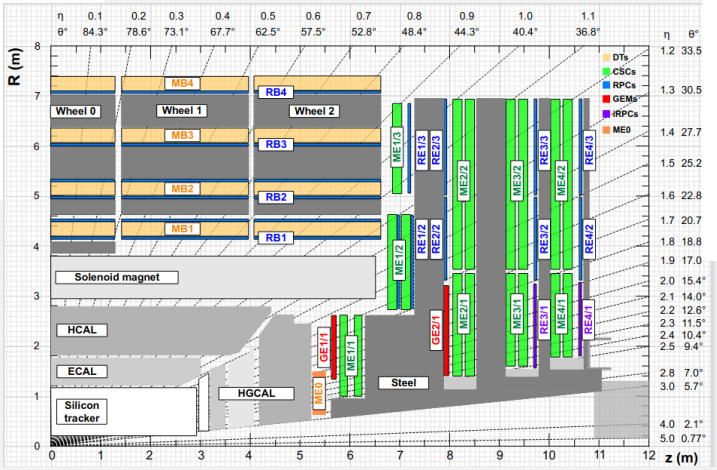
The CMS RPC System @ HL-LHC

Aim: Validation of the present CMS RPC system in view of the HL-LHC phase



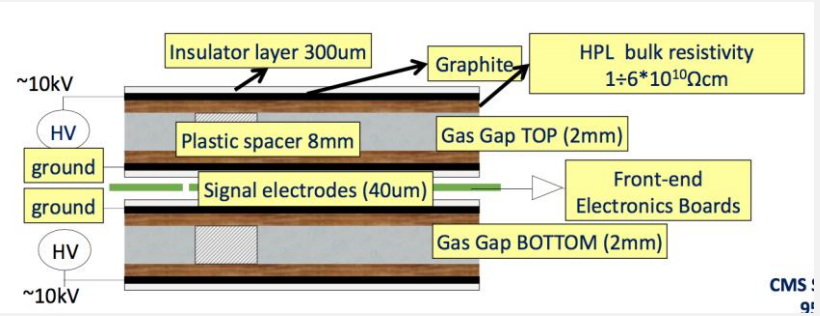
CMS Standard gas Mixture:
- 95.2% C2H2F4 (Freon)
- 4.5% iC4H10 (isobutane)
- 0.3% SF6 (Sulphur Hexafluoride)

Gas relative Humidity 40 %



- *RPC system covers $0 < |\eta| < 1.9$*
- *1056 chambers:*
  480 in Barrel & 576 in Endcap

- *Working in avalanche mode*
- *Double gas-gaps RPC*
- *2 mm gas gap and electrodes thickness*
- *HPL bulk resistivity: $\rho = 1 - 6 \cdot 10^{10}\ \Omega cm$*



- ❑ ***Excellent timing and triggering redundancy in the barrel + endcap***
- ❑ ***15 Years of High and stable performance during LHC operation (Run 1 – Run 3)***

Andreas Talk: **Operation and performance of the CMS RPC system during LHC Run 3 data taking**

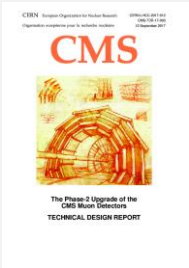
Longevity Procedure & Setup I

- **Longevity studies are necessary to check the behavior of the RPC system at HL-LHC (5 x10^{34} $cm^{-2}s^{-1}$)**

Expected Rate :

- Max. Rate : ~ 200 Hz/cm^2

  ~ 600 Hz/cm^2 (including safety factor of 3)



Expected Integrated Charge :

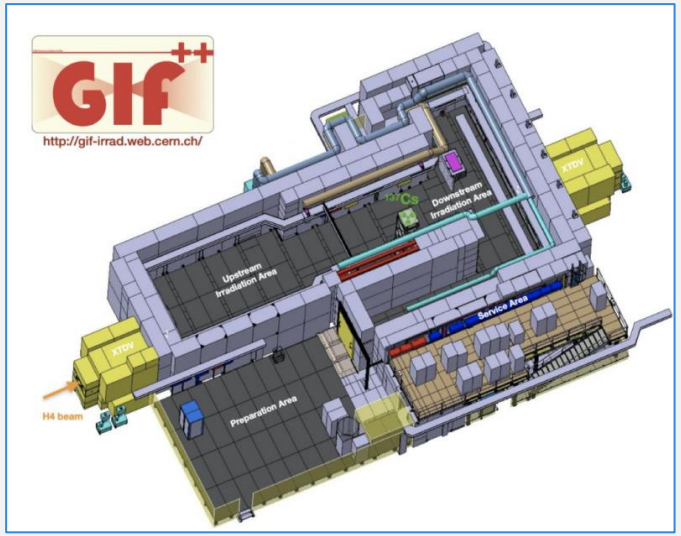
- Max. integrated charge : 280 mC/cm^2

  ~ 840 mC/cm^2 (including safety factor of 3)

2017: The Phase-2 Upgrade of the CMS Muon Detector TDR

- A dedicated longevity test is set up at the CERN Gamma Irradiation Facility (GIF++) since July 2016 with few spare RPCs :
  - **Two RE2/2 chambers**
  - **Two RE4/2 chambers**

- Two types of chambers from different production campaigns were used.
- The RE2 chambers belong to initial production (2002 - 2008) while RE4 chambers belong to most recent production (2011–2014).
- Initial production represent **86 %** of the CMS RPC chambres.
- **Two chambers are continuously irradiated & two used as reference.**



Longevity Procedure & Setup II

- **During the longevity test the main detector parameters are monitored as a function of the collected integrated charge:**

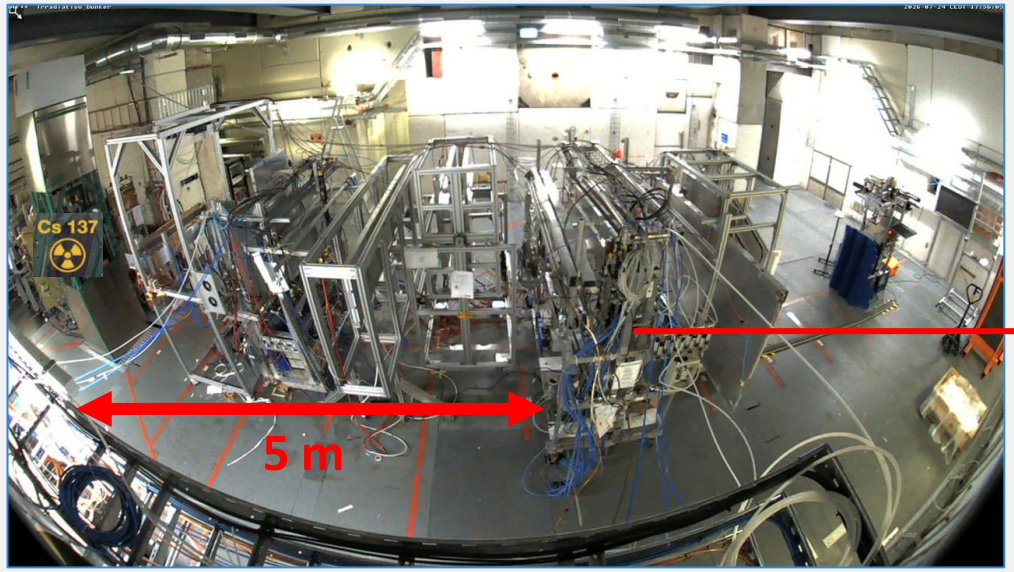
❑ Daily monitoring:
Current with irradiation

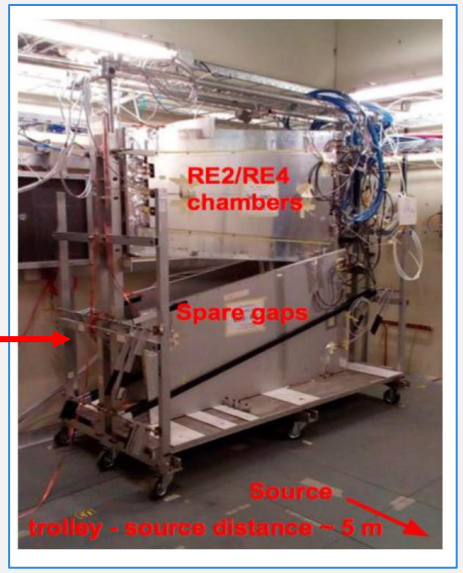
❑ Weekly measurements:
Current and rate without irradiation

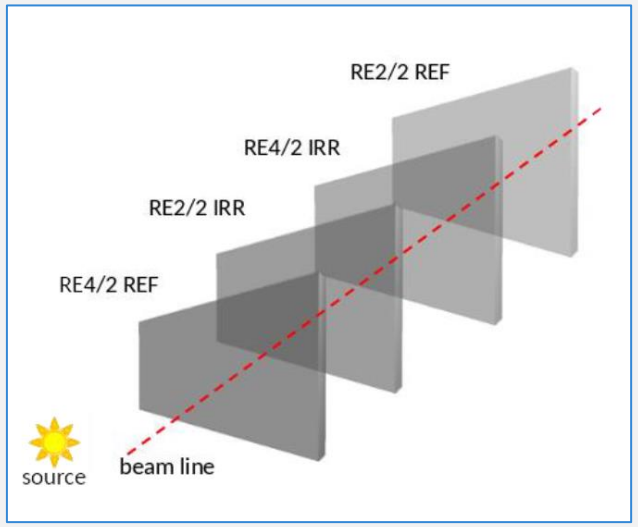
❑ Bi-Weekly measurements:
Long HV scan without irradiation

❑ 2 - 3 times per year:
Argon Resistivity measurements

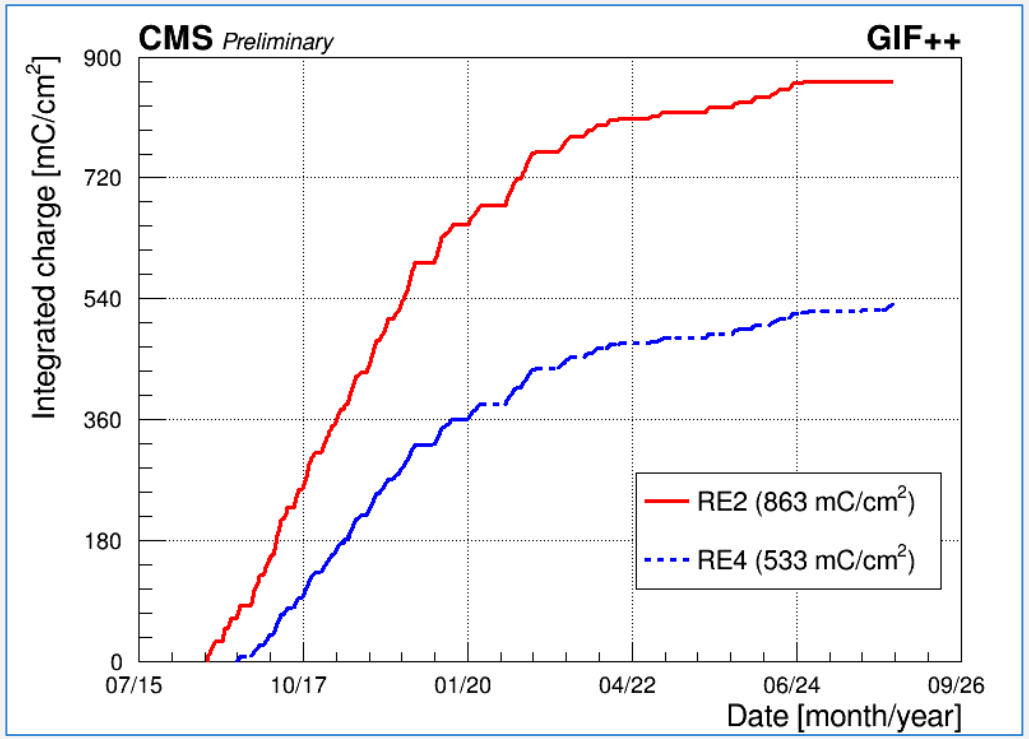
❑ 2 - 3 times per year Test beam:
Detector performance measurements with muon beam at several irradiation conditions







Longevity Status



RE2 Chamber

Irradiation start: 3 July 2016

Q_{int} : 863 mC/cm²

100% of HL-LHC target

RE4 Chamber

Irradiation start: 25 Nov. 2016

Q_{int} : 533 mC/cm²

63% of HL-LHC target

✓ Expected Integrated charge (Q_{int}) @HL-LHC 840 mC /cm²

With safety factor 3

✓ Average Integrated charge:

$$J_{mon} = \frac{I_{mon}^{TW} + I_{mon}^{TN} + I_{mon}^{BOT}}{A_{TW} + A_{TN} + A_{BOT}}$$

$$Q_{int} = \int_{t_i}^{t_f} J_{mon} dt$$

J_{mon} : current density

I_{mon}^{TW}, I_{mon}^{TN}, I_{mon}^{BOT} : currents through the three gaps

A_{TW}, A_{TN}, A_{BOT} : areas of the three gaps

RE2 Certification @ HL-LHC

Excellent detector performance confirmed at 100% of expected HL-LHC integrated charge with safety factor 3

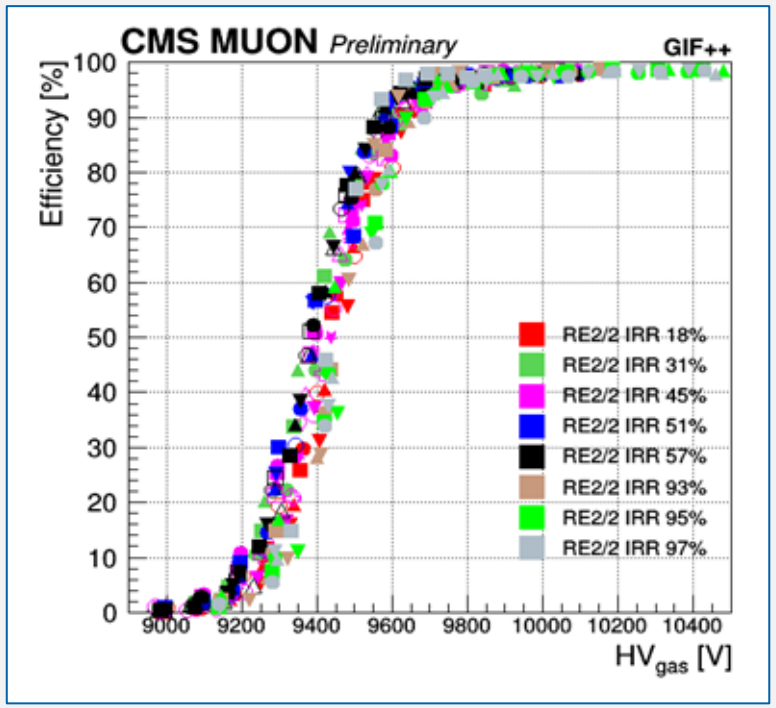
Efficiency Stability:

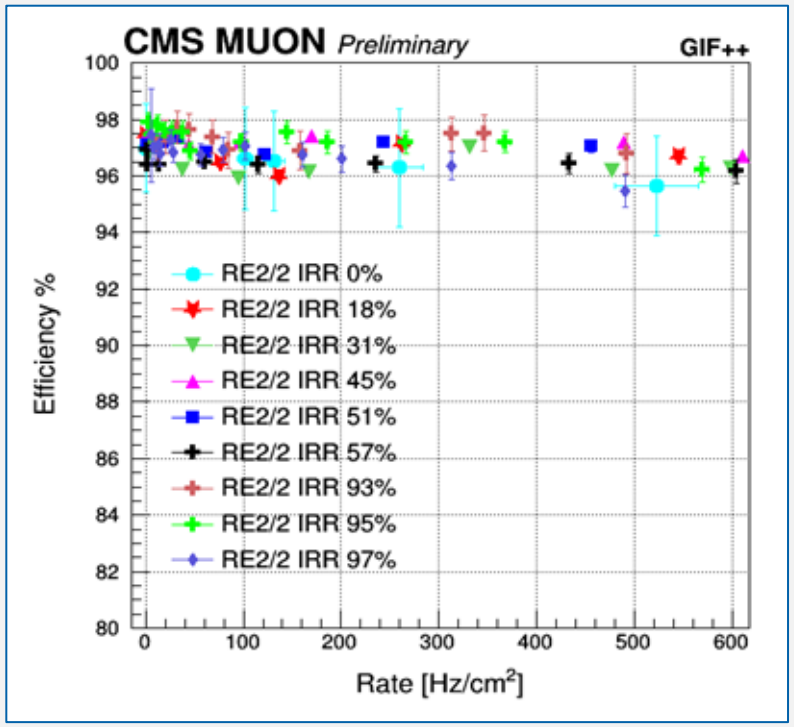
- The detector efficiency remains stable at :
  - different values of IC up to 100 % of expected IC @ HL-LHC
  - different values of background rate up to background rate expected at HL-LHC (600 Hz/cm^2)

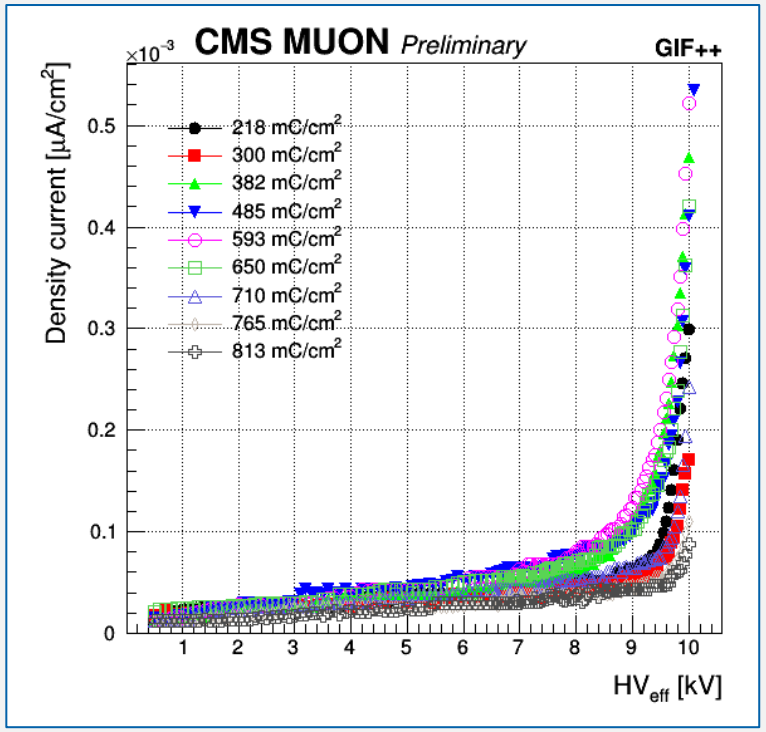
Detector Parameters

Stable detector parameter (Dark Current & Noise rate)

Poster: CMS-RPC Timing Resolution Evolution Under the Longevity Campaign
Mauricio & Reham







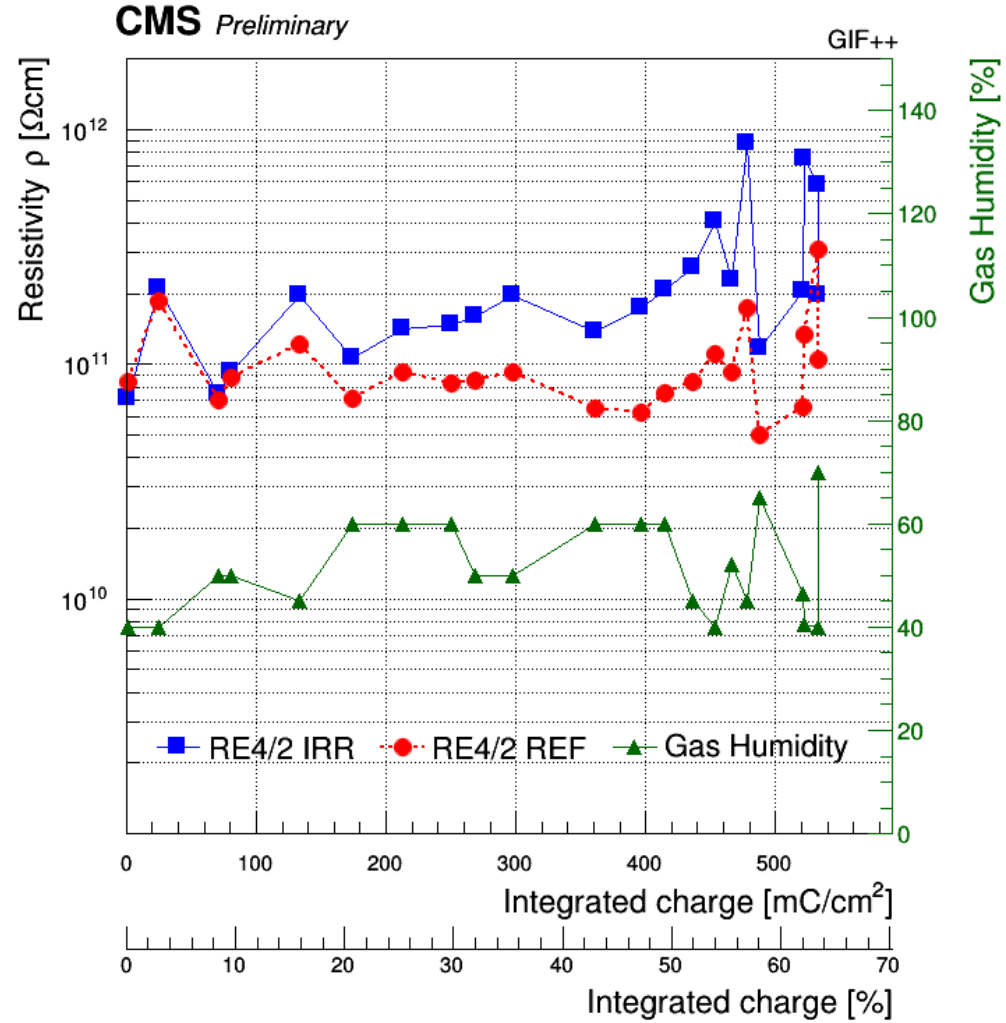


RE4 Detector Parameters

Resistivity measurement

- The resistivity is periodically measured at GIF++ with Argon.
- By measuring the current as a function of the applied high voltage we can measure the resistance of the HPL plates, and hence their resistivity
- The measured resistivity values are normalized at 20°C
- **The measured resistivity tends to increase during periods of lower gas humidity, indicating that gas humidity significantly influences the measured resistivity**

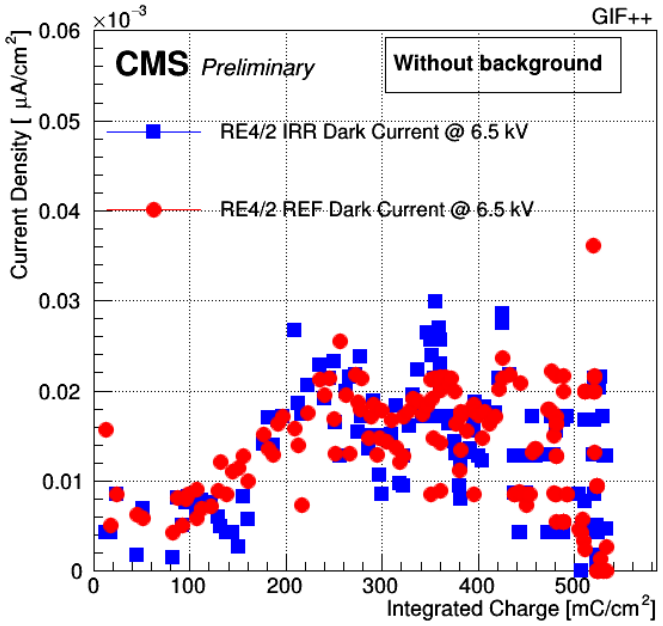
All resistivity values normalized to 20°C for cross-comparison across measurement campaigns



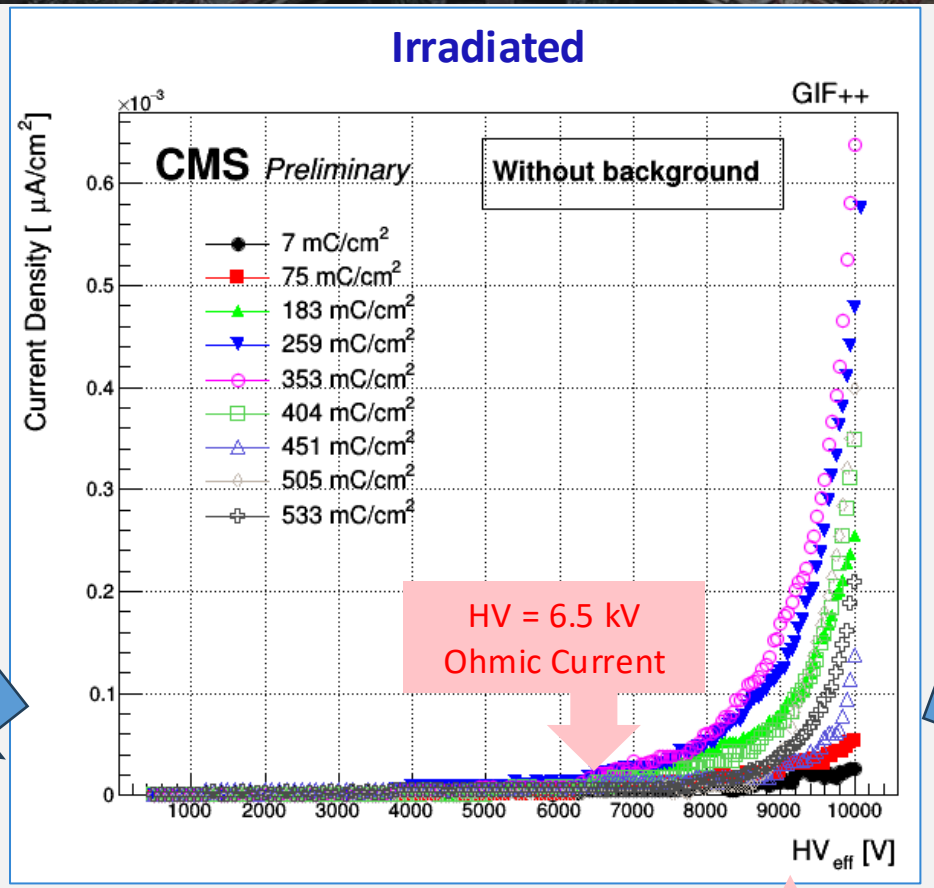
Dark Current

- **Ohmic current** is stable with time and after collecting 533 mC/cm^2 of IC & in agreement with values before the irradiation for IRR. & REF. chambers.

RE4/2 IRR. & REF **ohmic** current



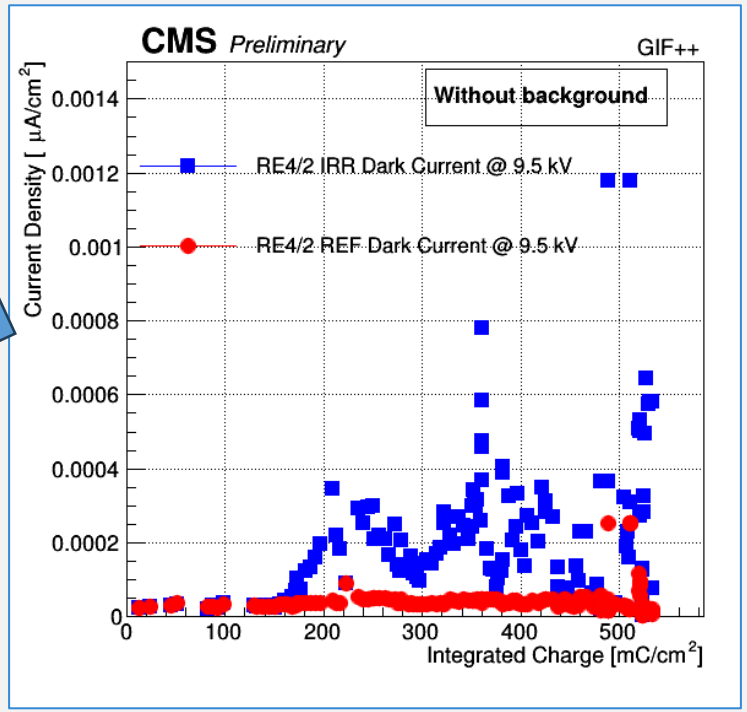
Irradiated



$$HV_{app} = HV_{eff}\left[(1-\alpha) + \alpha \frac{P}{P_0}\frac{T_0}{T}\right]$$

- **Total current:** An increase in the physics contribution of the total current is observed in the irradiated chamber.

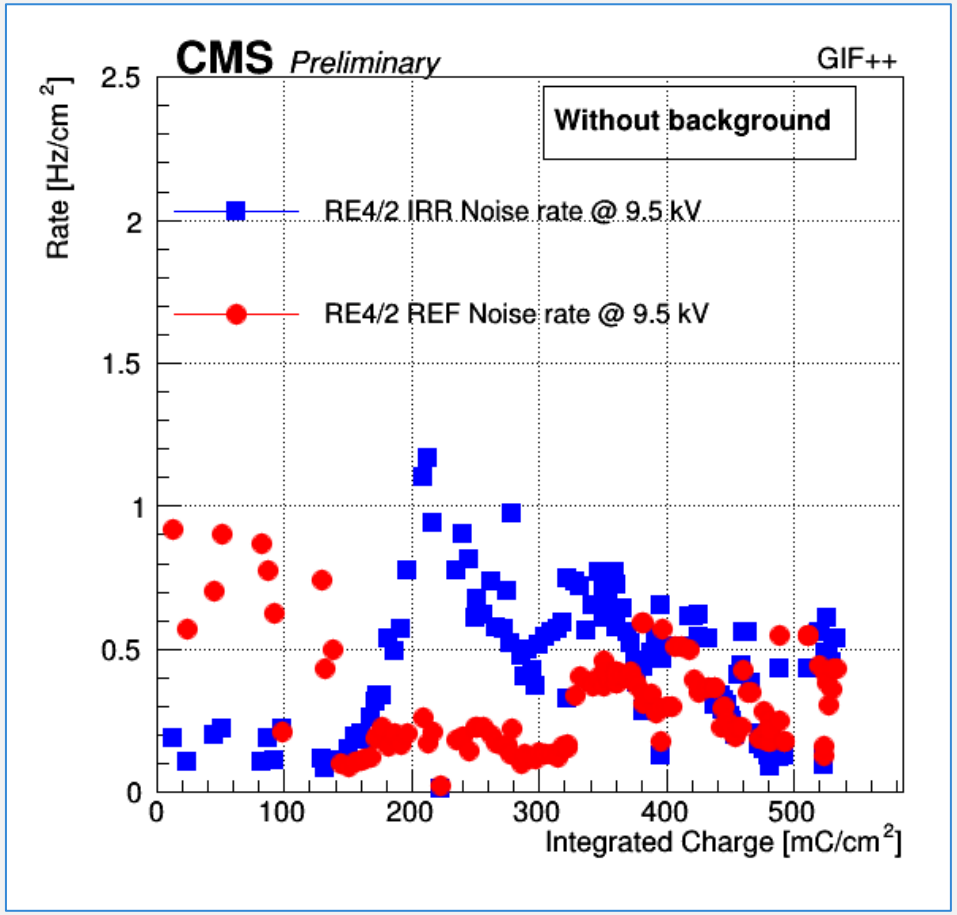
RE4/2 IRR. & REF **total** current



1.S. Colafranceschi et al., *Resistive plate chambers for 2013-2014 muon upgrade in CMS at LHC*, JINST 9 (2014) C10033. doi:10.1088/1748-0221/9/10/c10033

Noise Rate

RE4/2 IRR. & REF Noise rate



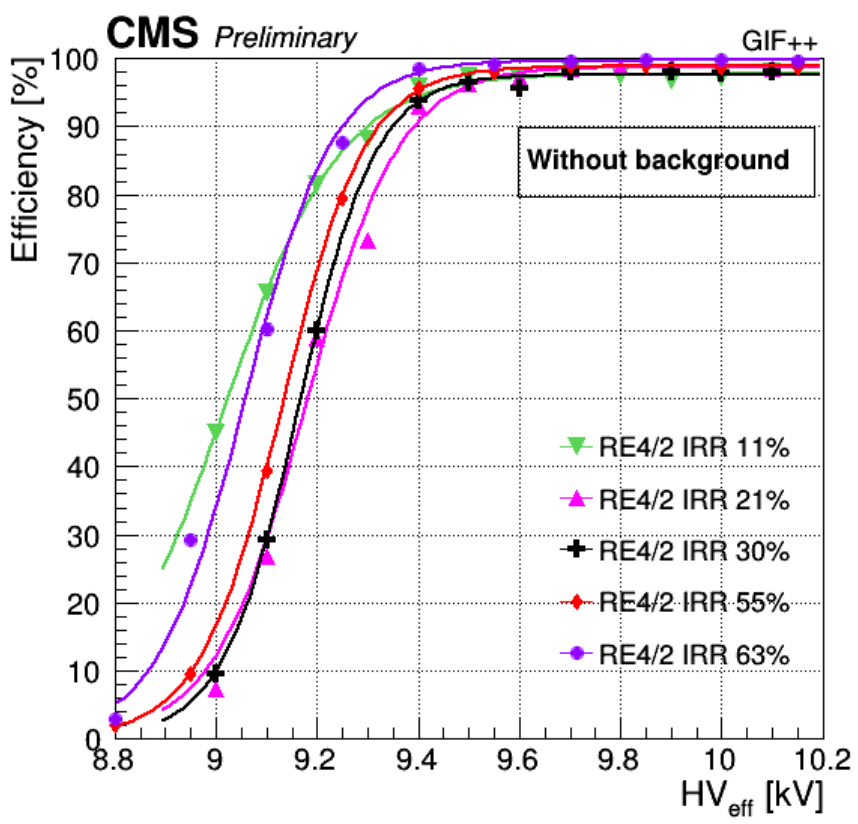
- Noise rate is almost stable with time.
- **Average noise rate** is less than 1 Hz/cm^2



RE4 Detector performance Monitoring

Efficiency

Without Background radiation & with muon beam

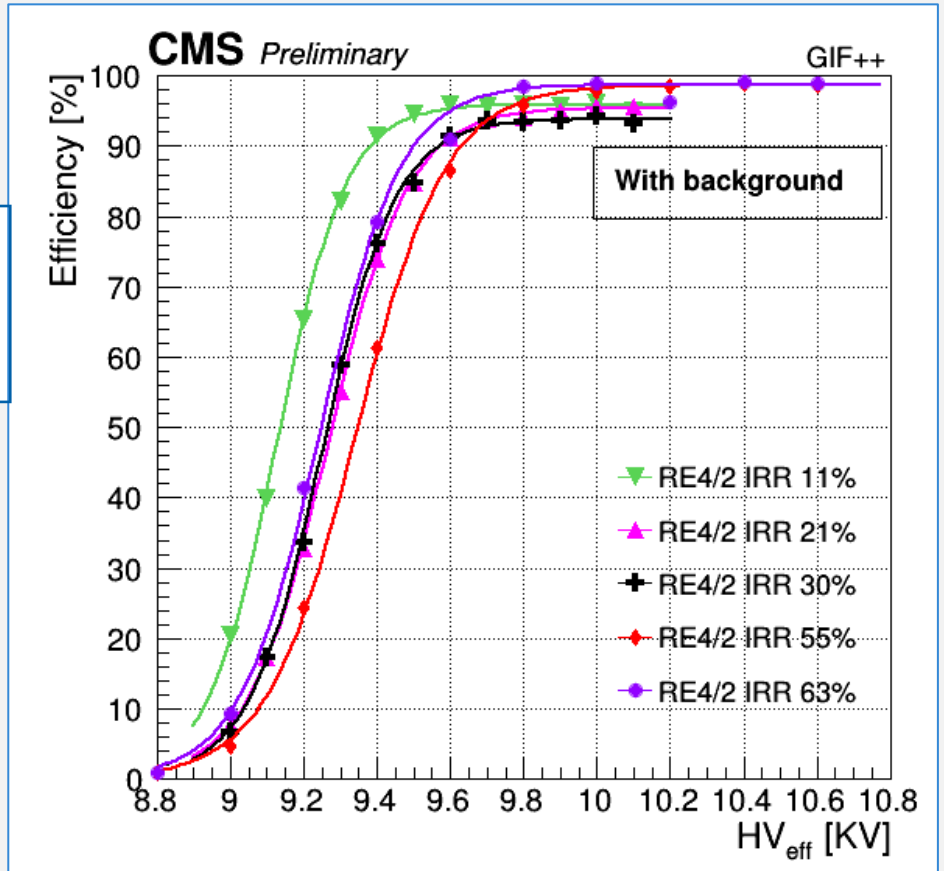


Irradiated

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

$WP = HV_{knee} + 150$

With Background radiation (200 Hz/cm²) & with muon beam



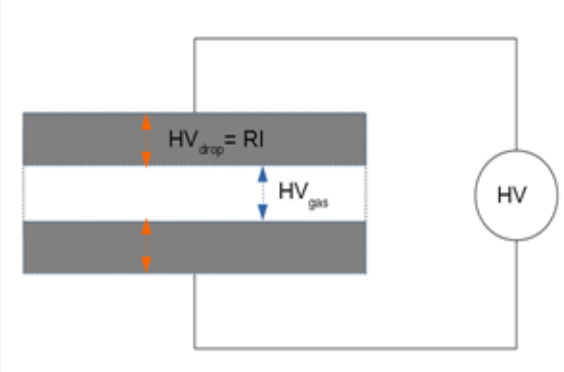
Stable Efficiency & detector Working point

J. H. Lim (CMS), CMS CR-2018/133 (2018).

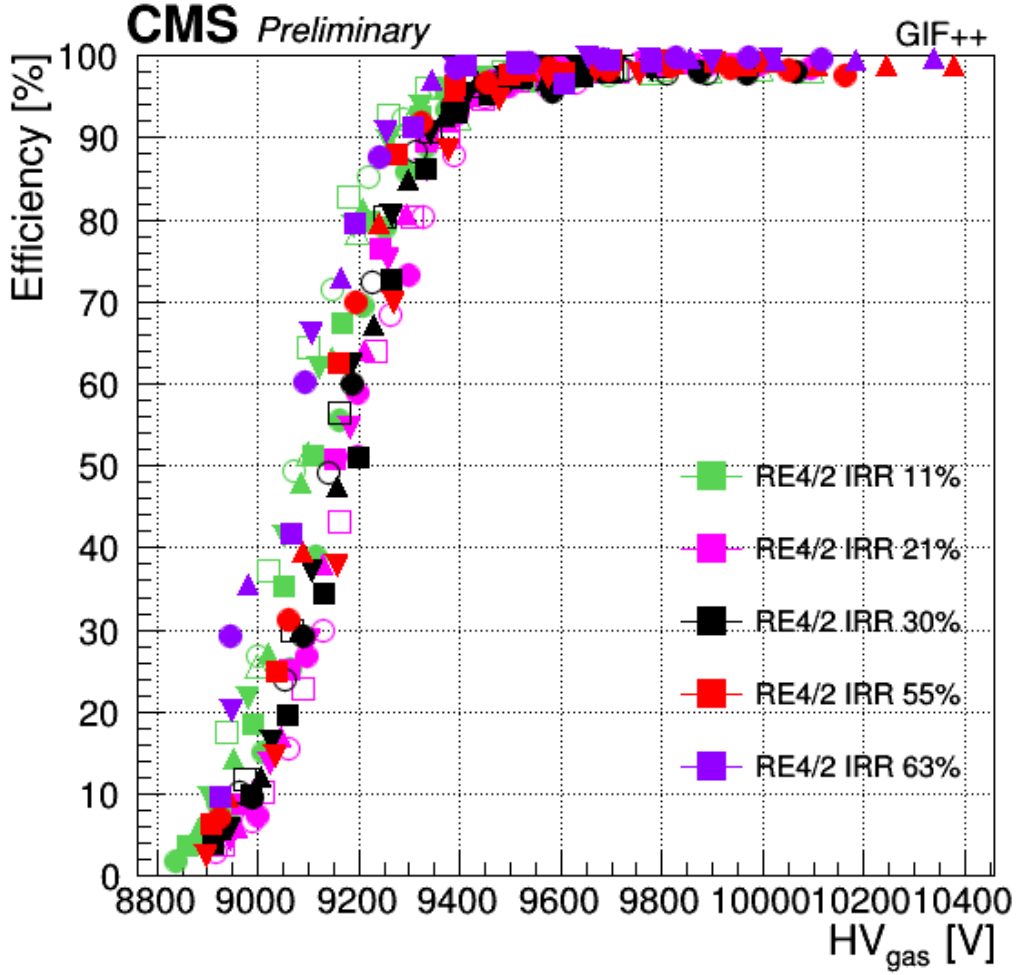
Efficiency with HV correction

- The voltage applied to the electrodes (**HV**) is reduced by the voltage drop (**RI**). The effective voltage applied to the gas (HV_{gas}) is defined as:

$$HV_{gas} = HV - RI$$



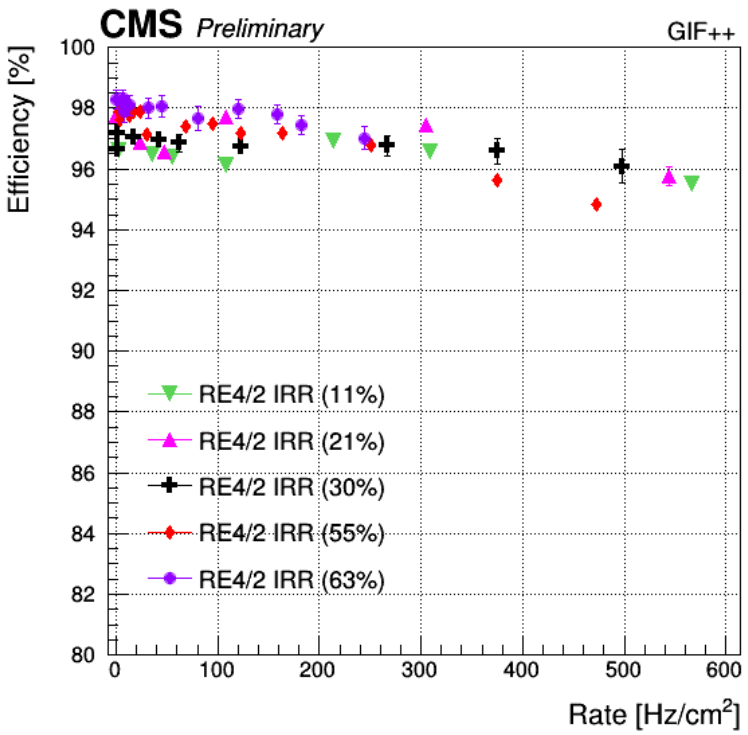
- The efficiency plotted as a function of HV_{gas} does not depend on the background conditions and on the electrodes resistance.
- **The operation regime of the detector is invariant with respect to HV_{gas}**



- ✓ Stable Efficiency at different Integrated charge & different background conditions
- ✓ No shift observed vs in the detector working point

Performance at Working Point

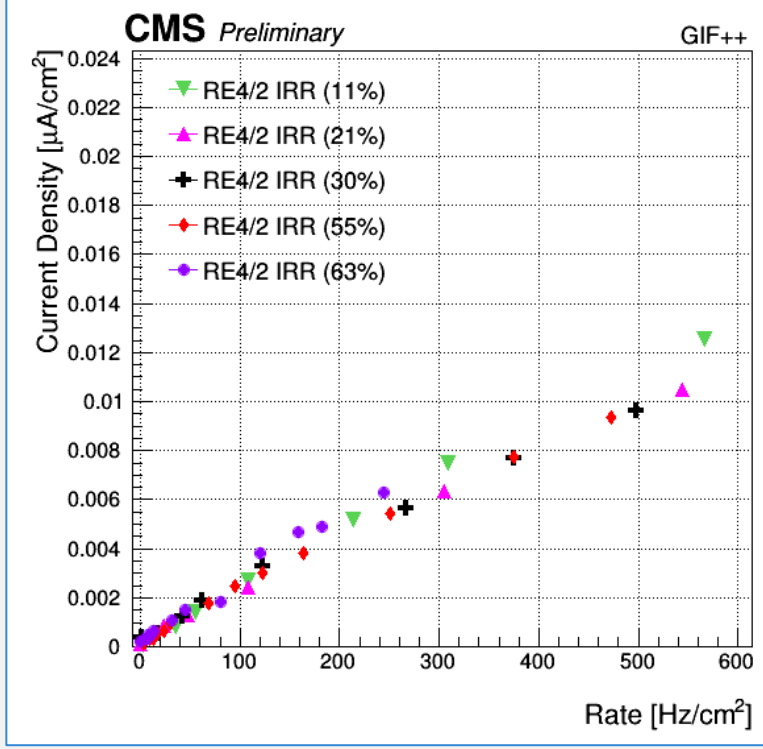
Efficiency vs. Rate @ different Test Beams



Efficiency remains stable as a function of:

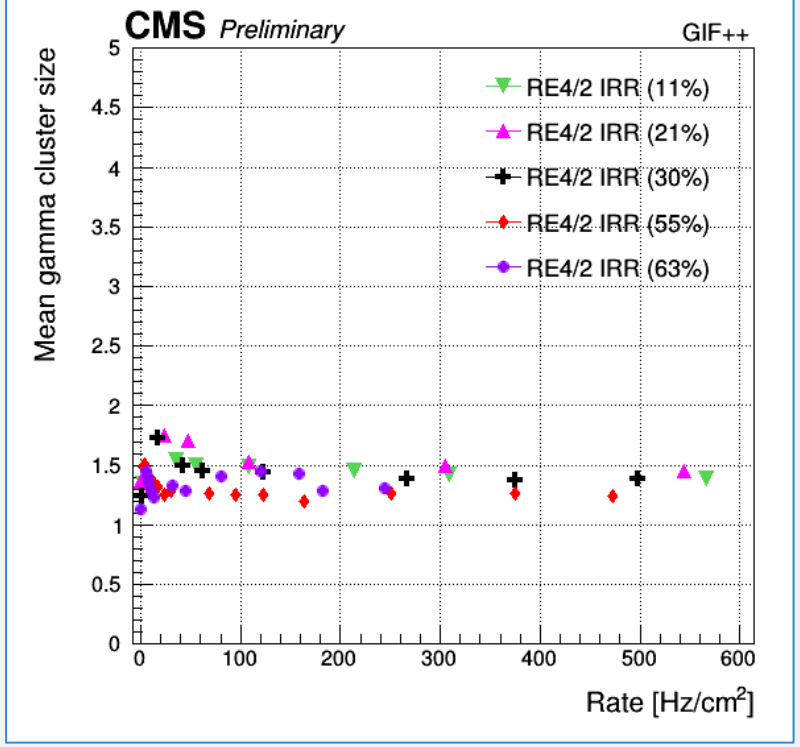
- accumulated integrated charge
- background rate

Current Density vs. Rate @ different Test Beams



- The detector gain remains stable
- no degradation observed throughout the longevity test

Gamma cluster size vs. Rate @ different Test Beams



- Gamma cluster size measured with gamma background remains stable

Conclusions

- **CMS RPC system: stable performance over Run 1–3**
  - After **15 years of operation**, the CMS RPC system continues to perform **within specifications**, despite increasing luminosity and radiation levels.
  - The longevity studies are essential to **certify the RPC system for operation during the HL-LHC phase**.
- **RE2 chambers certified for HL-LHC operation**
  - RE2 chambers represent approximately **86% of the CMS RPC system**.
  - The chambers have accumulated **100% of the expected integrated charge (IC) at HL-LHC**, including a **safety factor of 3**.
  - Detector performance and operating parameters remain **stable up to the expected HL-LHC background rate and integrated charge**.
  - **No evidence of aging effects** has been observed, demonstrating excellent long-term detector stability
- **RE4 irradiation study ongoing**
  - The irradiation campaign has reached **63% of the expected HL-LHC integrated charge with a safety factor of 3** (**currently corresponding to a safety factor of 2**).
  - **Noise rate and ohmic current remain stable** throughout the irradiation campaign.
  - An increase in **the physics contribution to the dark current** has been observed.
  - An increase in electrode resistivity was observed during periods of **low gas humidity**; this effect was mitigated by maintaining the gas humidity at approximately **60%**.
  - **Detector performance remains stable** across different test-beam campaigns, Efficiency remains stable as a function of Integrated charge and background Rate.

Backup

Gamma Irradiation Facility (GIF++)

GIF++ is a facility that allows to test real size detectors in different irradiation condition.

- 14 TBq ^{137}Cs source (662 keV gammas)
- Gamma Filters:
  System of movable attenuators allow to test the detector in different irradiation conditions.
- Muon Beam (2 - 3 times per year)
  Energy up to 100 GeV
- Control and monitor of the environmental parameters:
  - Temperature
  - Humidity
  - Pressure
- Gas parameters monitoring:
  - gas composition
  - gas flow
  - gas temperature
  - gas humidity
  - gas pressure

