UNIVERSITÀ DEGLI STUDI DI BARI ALDO MORO

PhD School in Physics XXXII Cycle

Activity report on the II year

CMS-RPC system upgrade project for the phase II of LHC

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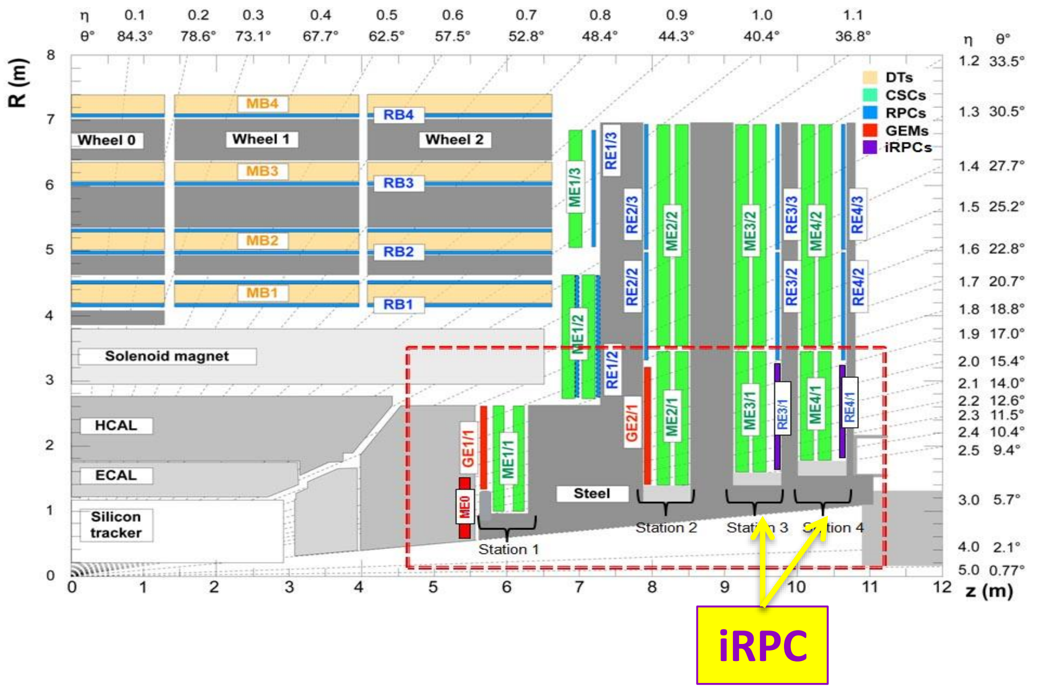
Bari, 16 Oct 2018

Overview

- **II year research activities:**
  1. **Longevity study of the CMS-RPC present system**
  2. **R&D RPC system extension and study of the expected background at HL-LHC in the RE3-4/1 stations**

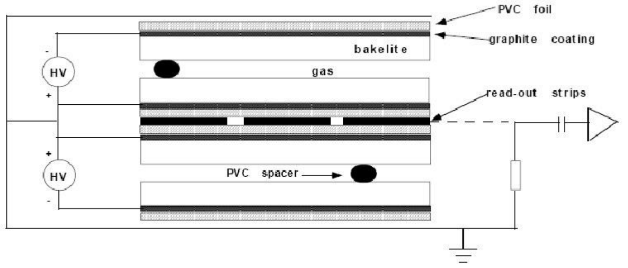
- **Schools, conferences and publications**
- **Future plans**

The CMS-RPC system

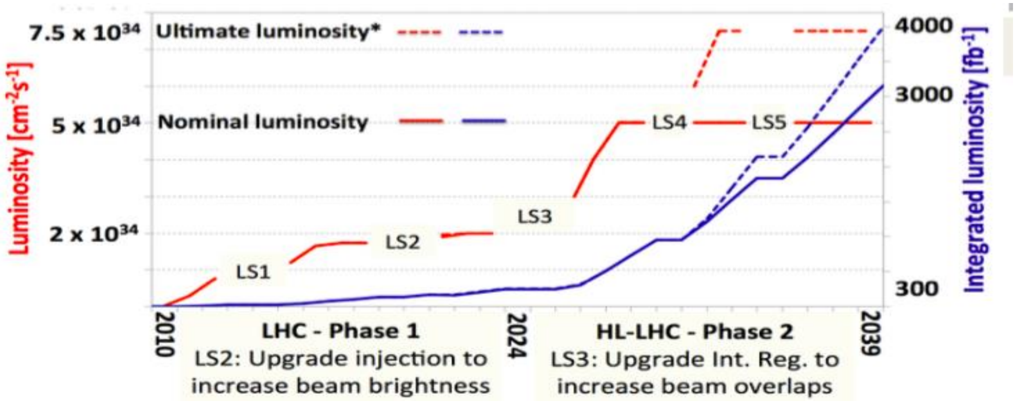


- RPC system covers $0 < |\eta| < 1.9$
- 1056 chambers: 480 in Barrel & 576 in Endcap

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



- RPC information for muon trigger, reconstruction and identification
- **High and stable RPC performance during LHC operation**

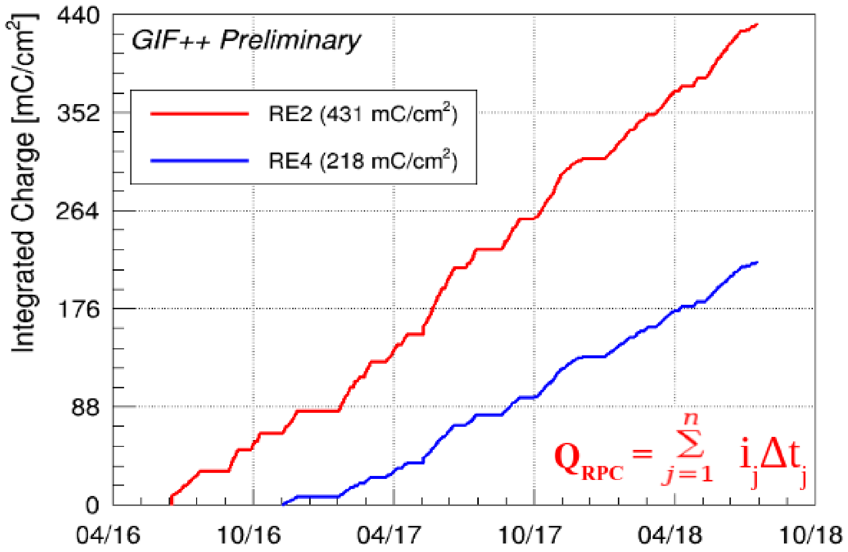


RPC Upgrade program in view of HL-LHC:

1. CONSOLIDATION of present RPC system
2. RPC system EXTENSION at high eta region

1. Consolidation of the present RPC system

Expected conditions @ HL-LHC:
Max rate ~ 600 Hz/cm^2
Max integrated charge ~ 840 mC/cm^2



$$Q_{RPC} = \sum_{j=1}^{n} i_j \Delta t_j$$

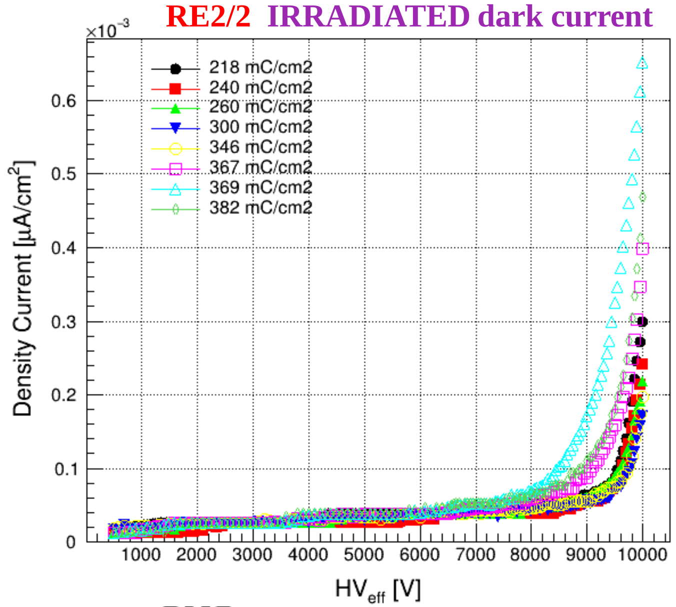
- **Setup @ GIF++:**
  - ↦ 2 **RE2** chambers (Irr & Ref)
  - ↦ 2 **RE4** chambers (Irr & Ref)

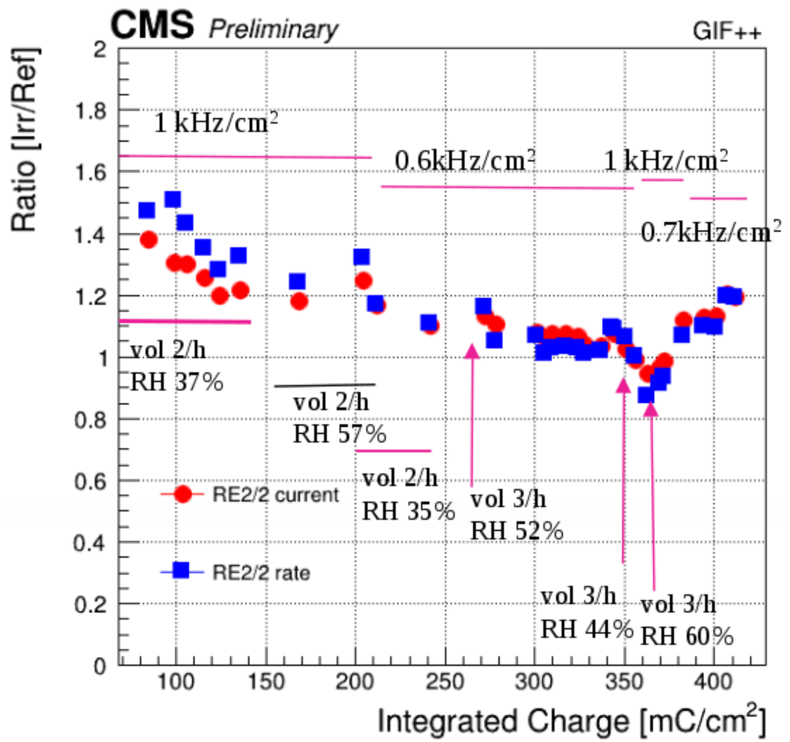
- Daily measurements: Current & rate with background.
- Weekly measurements: Current and rate at different background conditions and without background.
- 3-4 time per year: Argon resistivity measurements.
- 3-4 times per year Test beam: Performance measured with muon beam @ several background conditions.

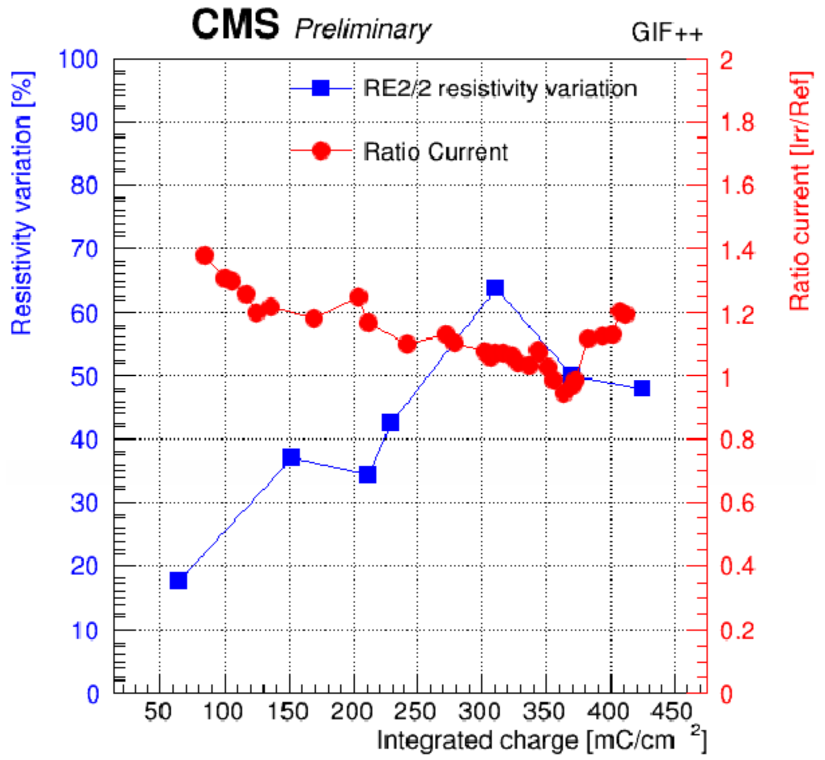
Accumulated charge:

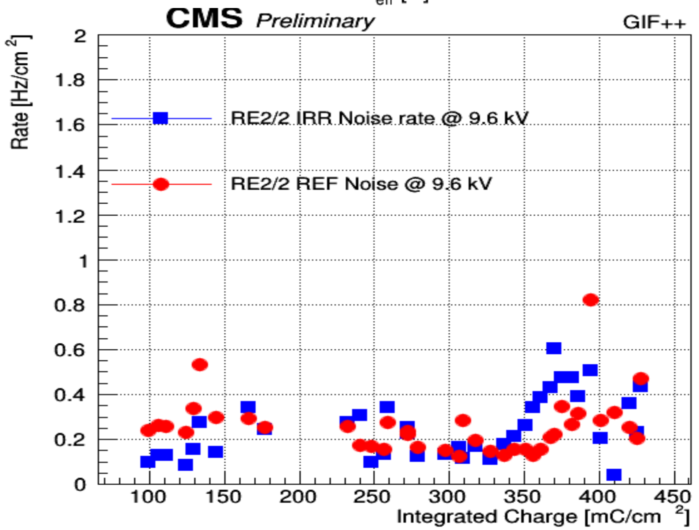
RE2 IRR	RE4 IRR :
↦ Q_{Int} = 431 mC.cm^2	↦ Q_{Int} = 218 mC.cm^2
51 %	**26 %**

Detector parameters monitoring



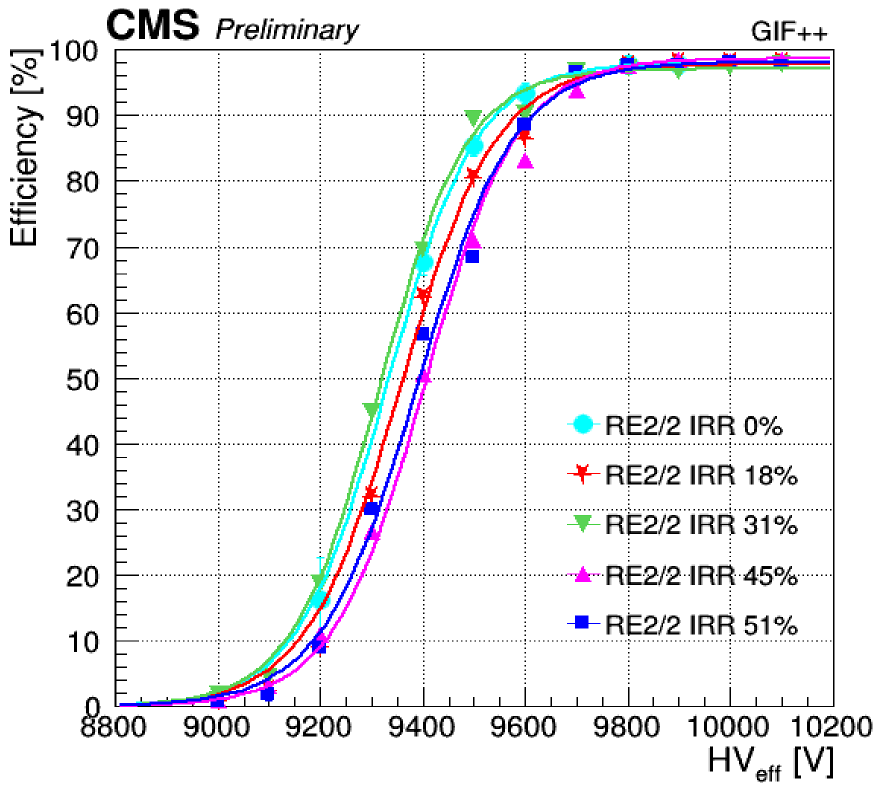


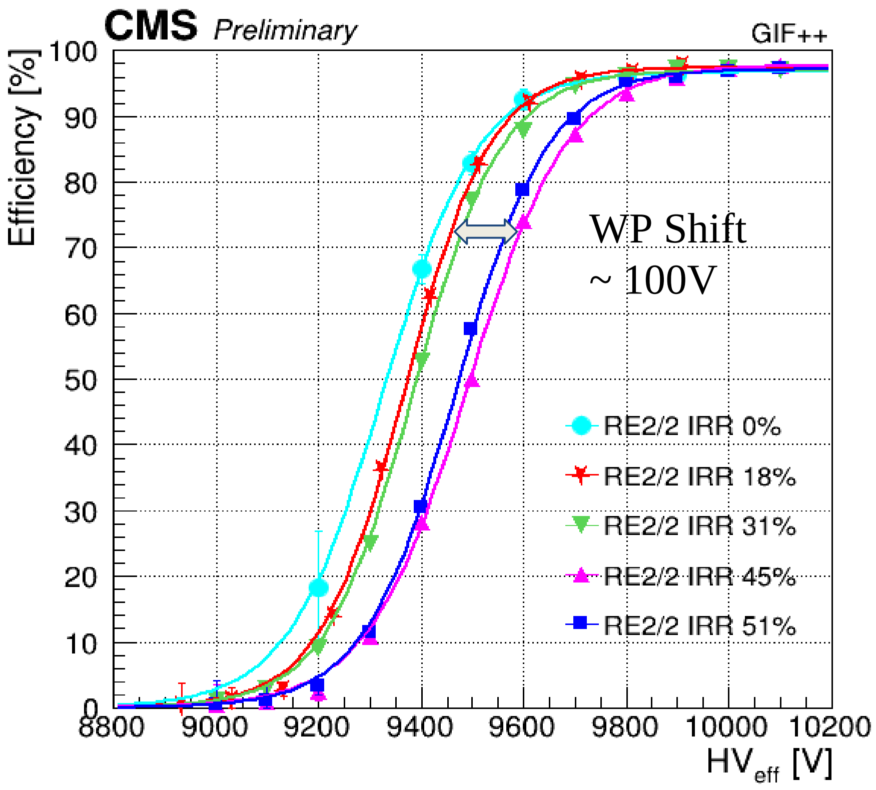




- **Dark currents** & **noise rate almost stable**
- **Electrodes resistivity increase** due to the too low humidity and gas flow rate with respect to the high background rate → **Currents and rate decrease**
- **Recoverable effect** mitigated with the gas **RH increase at 60 %**

RPC performance monitoring





Efficiency vs HV$_{eff}$ measured without background

- ★ Stable performance: stable WP and efficiency

Efficiency vs HV$_{eff}$ measured with background (600 Hz/cm^2)

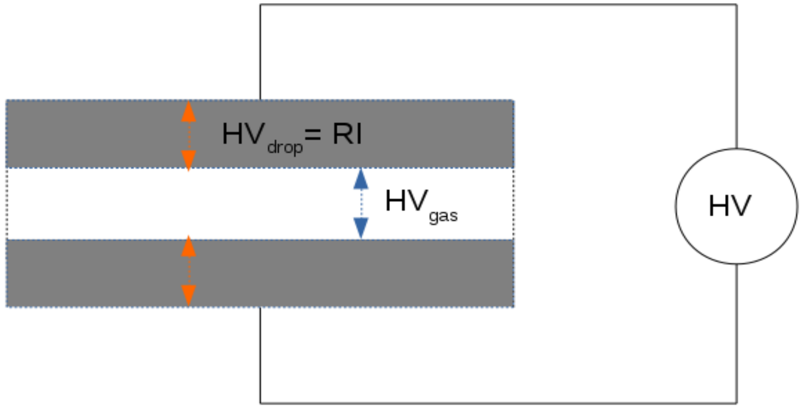
- ★ Stable performance
- ★ WP shift of ~ 100 V during MAY and AUG 2018 TB (45% and 51% integrated charge)

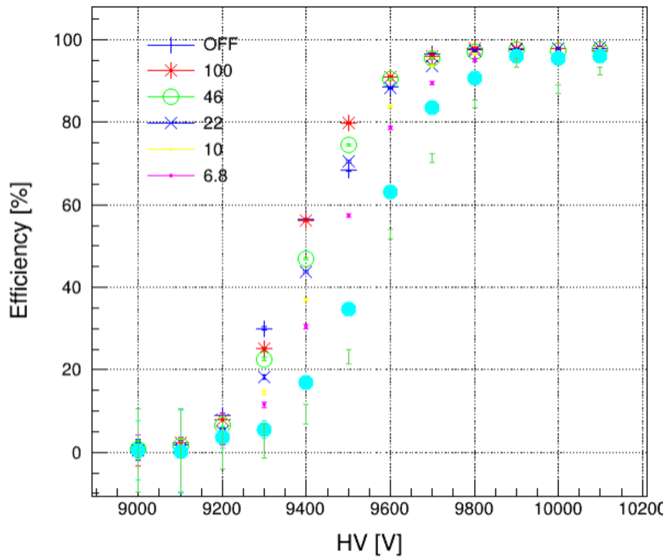
HV correction

- The effective voltage applied to the gas volume (**HV_{gas}**) is reduced by the voltage drop (**HV_{drop}**) across the electrodes:

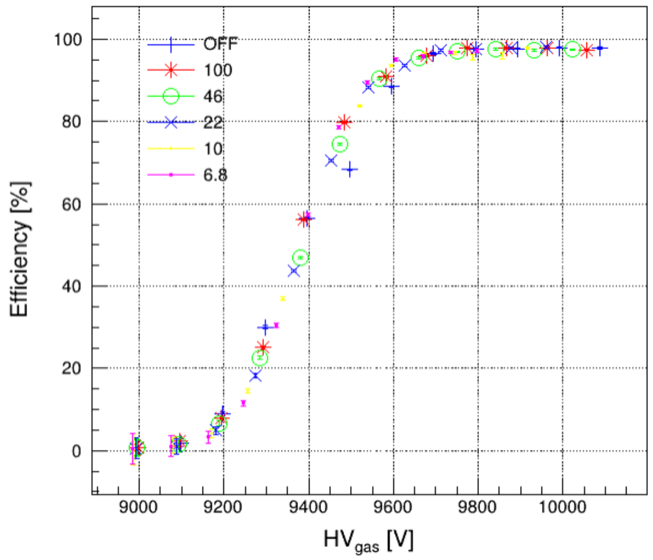
$$HV_{gas} = HV - RI$$

Where **R** the bakelite resistance and **I** is the current produced by the ionizing particles.



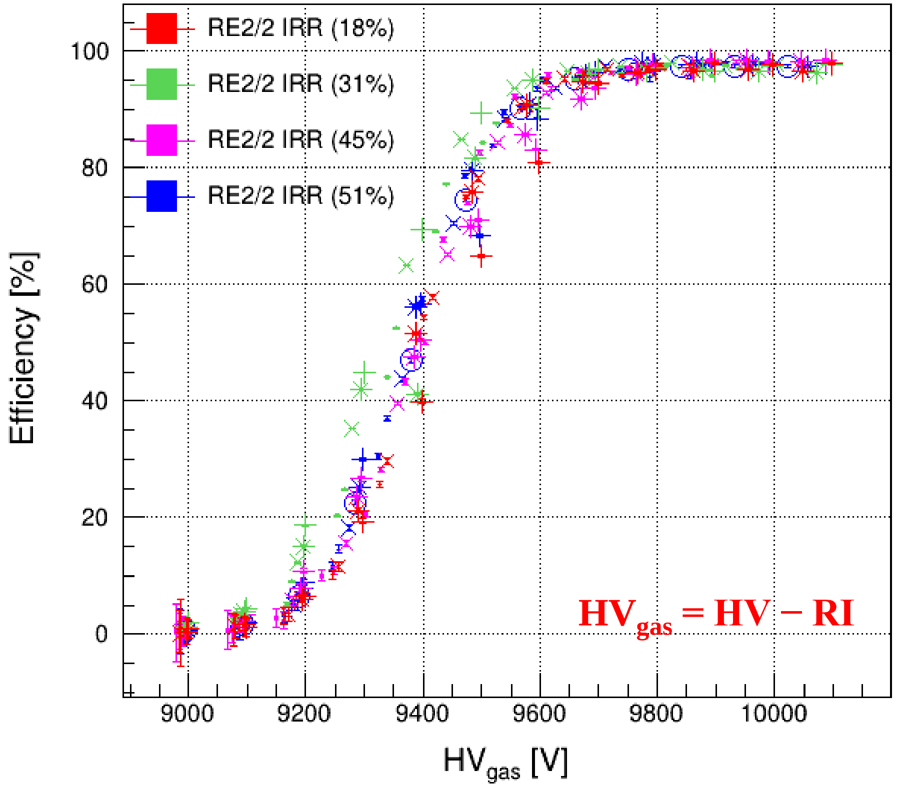


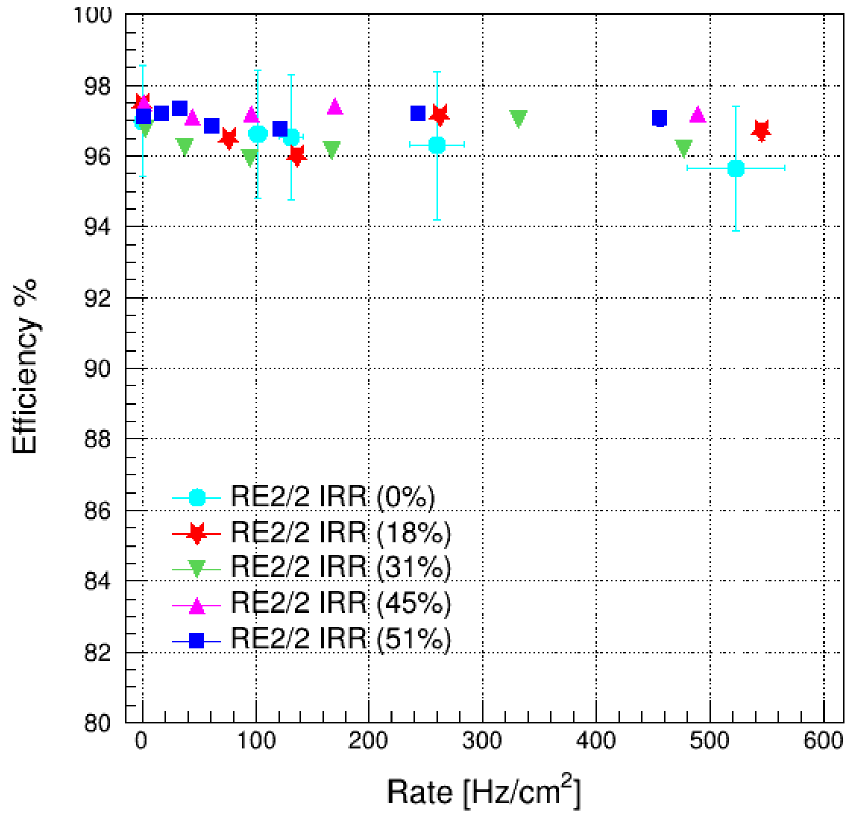
- The efficiency plotted as a function of HV_{gas} does not depends on the background conditions.

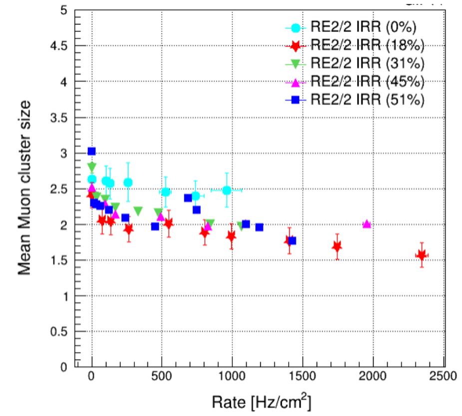


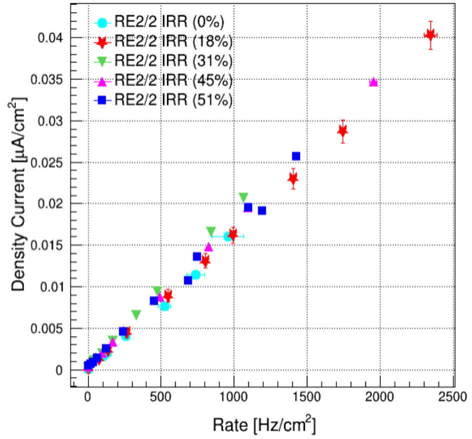
G. Pugliese, *"Aging study for resistive plate chambers of the CMS muon trigger detector"*
G. Aielli, *"Further advances in aging studies for RPCs"*

RPC performance monitoring









- Efficiency at different ABS and at different Integrated charge (different TB) overlap.
- NO any shift observed vs time and up to background rate of 600 Hz/cm^2.
- Efficiency @ **WP remains stable in time** up to the maximum expected rate (600 Hz/cm^2).

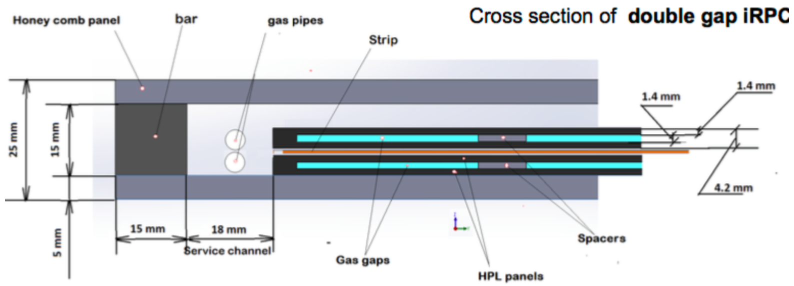
No evidence of any aging effects has been observed

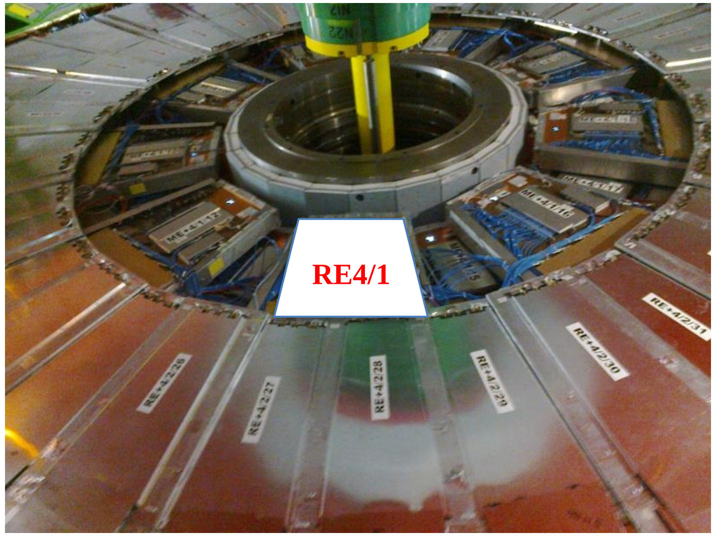
2. RPC system extension & background rate study

RPC system extension to complement existing ME3-4/1 (1.8<|η|<2.4) and increase the muon system redundancy extending the contribution of RPCs for both muon tracking and triggering in the forward region

Improved RPC will complete the coverage in the RE3-4/1 Endcap stations.

iRPC baseline:
- ***gas gaps 1.4mm***
- ***electrodes 1.4mm***





Study to accurately **estimate the expected background hit rate $R_{iRPC}(E)$** at HL-LHC in the forward region RE3-4/1.

Incident fluxes $\phi^{CMS}_{bkg}(E)$
FLUKA simulation

Detector sensitivity $S(E) = \frac{N_{HIT}}{N_{bkg}}(E)$
GEANT simulation

Hit rate
$$R_{iRPC}(E) = \phi^{CMS}_{bkg}(E) \times S(E)$$

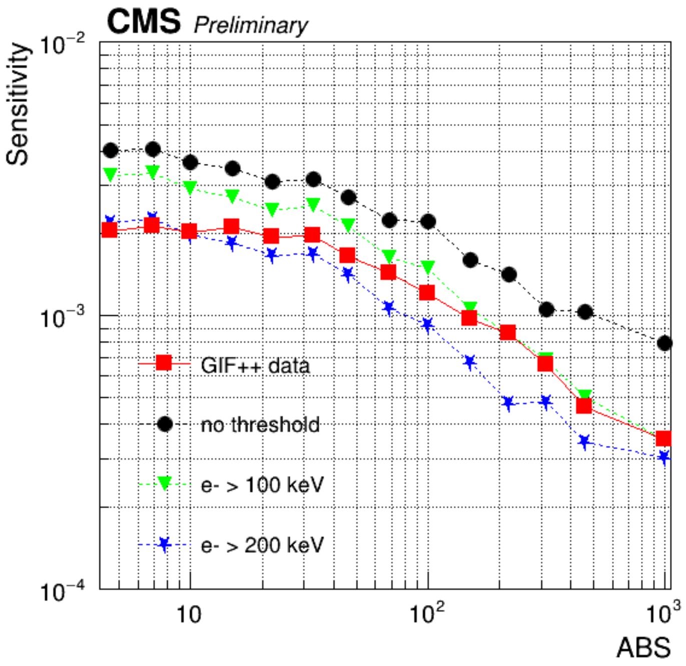
iRPC sensitivity

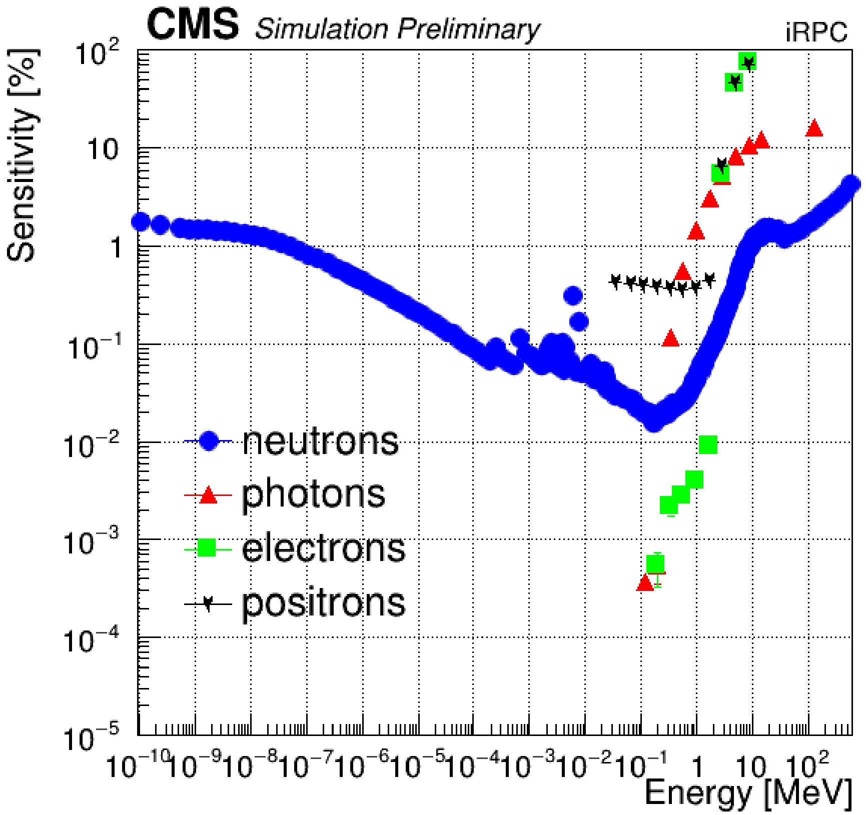
Detector geometry validated @ GIF++ ✔

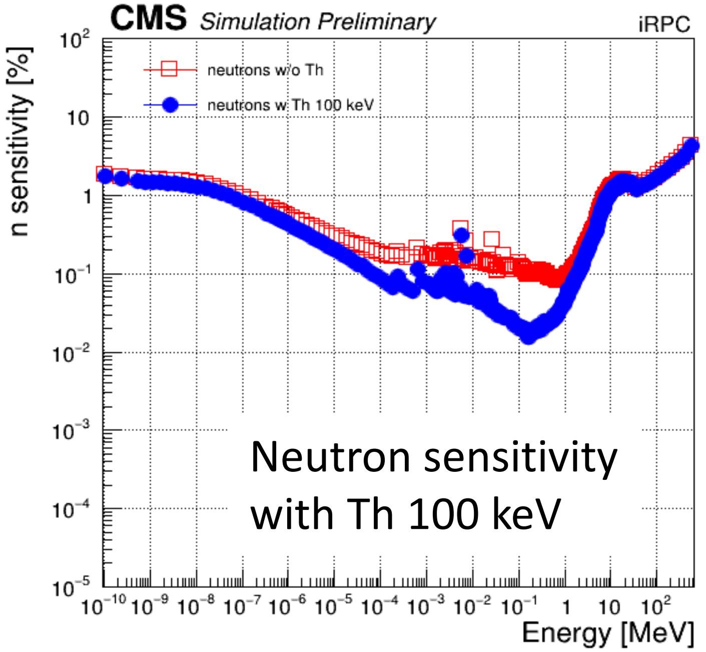
Optimal threshold > 100 keV ✔

iRPC sensitivity applying the threshold of **100 keV** on the charged particles which reach the gas gap.

Threshold effect:
10% less sensitivity.
More evident difference in the neutron sensitivity $10^{-4} < E_n < 1$ MeV.





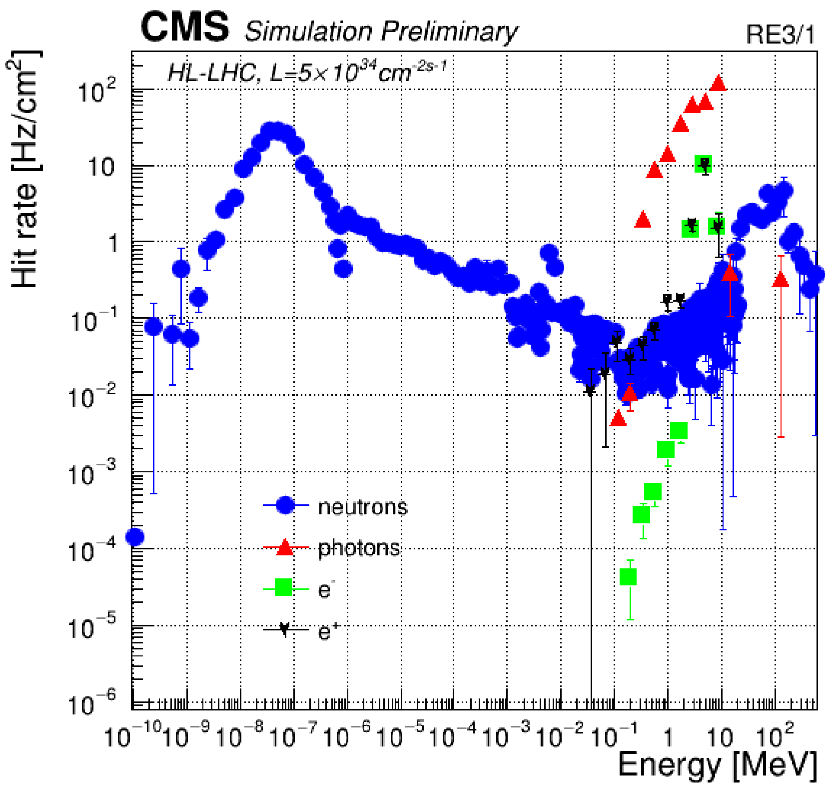


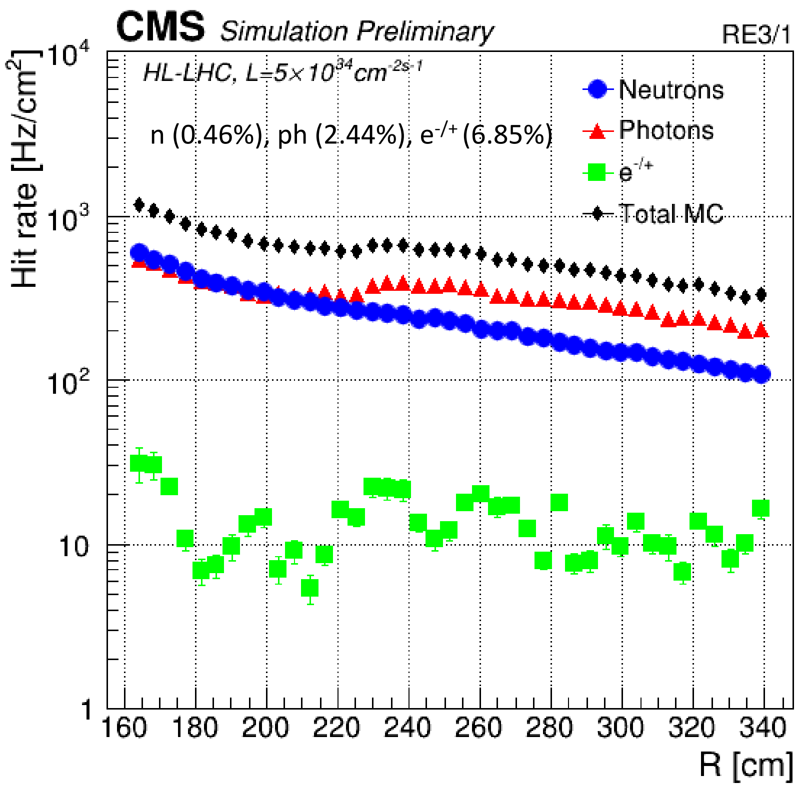
Neutron sensitivity with Th 100 keV

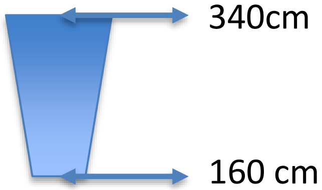
iRPC background

$$R_{iRPC}(E) = \phi_{bkg}^{CMS}(E) \times S(E)$$

<u>**Expected background hit rate vs R**</u> calculated scaling the incident background flux with the **AVERAGE** iRPC sensitivity.







Particles	RE3/1 HIT RATE Hz/cm^2	RE4/1 HIT RATE Hz/cm^2
Neutrons	251 ± 33	211 ± 20
Gammas	304 ± 23	243 ± 18
Electrons/ Positrons	13 ± 3	19 ± 9
TOT HIT-RATE	$\mathbf{568 \pm 27}$	$\mathbf{473 \pm 19}$

Average background rate of ≈ 600 Hz/cm^2 indicates the requirement of a minimum rate capability of **≈ 2 kHz/cm^2** for the iRPCs when considering a safety factor of 3.

Schools and conferences

Schools:

- *RD51 Gaseous detectors lectures, 11-15 December 2017, CERN, Switzerland*
- *First International RPC detector school, 14-17 February 2018, Mexico City, Mexico*
- *XXX National seminar of nuclear and subnuclear physics, 5-12 June 2018, Otranto, Italy*
- *CMS Machine Learning workshop, 2-4 July 2018, CERN, Switzerland*

International conferences:

- ***XIV Workshop on Resistive Plate Chambers and Related Detectors (RPC 2018),*** *19-23 February 2018, Puerto Vallarta, Mexico*
  Oral presentation: "Longevity studies for the CMS-RPC system"

- ***14th Pisa Meeting on Advanced Detectors PM2018,*** *27 May - 2 June 2018, La Biodola, Isola d'Elba, Italy*
  Poster: "Background rate study for the CMS improved-RPC at HL-LHC using GEANT4"

- ***Incontri di Fisica dele Alte Energie IFAE 2018,*** *4-6 April 2018, Milano, Italy.*
  National conference, oral presentation: "RPC upgrade project for CMS Phase II"

Publications

First author publications:

- ***"Longevity studies for the CMS-RPC system",*** A. Gelmi et al., JINST, JINST-017P-0818, Proceeding of: "XIV Workshop on Resistive Plate Chambers and Related Detectors". Under review.

- ***"Background rate study for the CMS improved-RPC at HL-LHC using GEANT4",*** A. Gelmi et al. (on behalf of the CMS collaboration), Nucl. Instrum. Meth., NIMA-D-18-00307R1, Proceeding of: "XIV Workshop on Resistive Plate Chambers and Related Detectors". Already reviewed, going to print.

CMS Publications:

CMS Collaboration Author since 11th November 2017 (85 papers)

- ***"The Phase-2 Upgrade of the CMS Muon Detectors",*** CMS Collaboration, CERN-LHCC-2017-012. CMS-TDR-016

Publications

RPC group publications:

- "RPC upgrade project for CMS Phase II", M.I. Pedraza et al. (on behalf of the CMS collaboration), JINST, Proceeding of: "XIV Workshop on Resistive Plate Chambers and Related Detectors".
- "R&D results of iRPC tested at GIF++ for CMS Phase II upgrade", J. H. Lim et al. (on behalf of the CMS collaboration), JINST, Proceeding of: "XIV Workshop on Resistive Plate Chambers and Related Detectors".
- "Fast timing measurement for CMS RPC Phase II upgrade", C. Combaret et al. (on behalf of the CMS collaboration), JINST, Proceeding of: "XIV Workshop on Resistive Plate Chambers and Related Detectors".
- "RPC Radiation Background Simulations for the High Luminosity Phase in the CMS Experiment", B. Carpinteyro et al. (on behalf of the CMS collaboration), JINST, Proceeding of: "XIV Workshop on Resistive Plate Chambers and Related Detectors".
- "CMS RPC background studies during LHC run II", R. Trejo et al. (on behalf of the CMS collaboration), JINST, Proceeding of: "XIV Workshop on Resistive Plate Chambers and Related Detectors".

Publications

RPC group publications:

- “High rate, high time precision RPC detector for LHC”, F. Lagarde et al. (on behalf of the CMS collaboration), JINST, Proceeding of: ”XIV Workshop on Resistive Plate Chambers and Related Detectors”.

- “The CMS RPC Detector Status and Operation at LHC”, M.Shah et al. (on behalf of the CMS collaboration), JINST, Proceeding of: ”XIV Workshop on Resistive Plate Chambers and Related Detectors”.

- “Test of a real-size Mosaic MRPC developed for CMS muon upgrade”, Y. Yu et al. (on behalf of the CMS collaboration), JINST, Proceeding of: ”XIV Workshop on Resistive Plate Chambers and Related Detectors”.

- “CMS RPC efficiency measurement using the Tag and Probe method”, J. Goh et al. (on behalf of the CMS collaboration), JINST, Proceeding of: ”XIV Workshop on Resistive Plate Chambers and Related Detectors”.

- “CMS RPC Integrated Charge”, M. Cecilia et al. (on behalf of the CMS collaboration), JINST, Proceeding of: ”XIV Workshop on Resistive Plate Chambers and Related Detectors”.

Publications

RPC group publications:

- "The CMS RPC system calibration", R. Reyes et al. (on behalf of the CMS collaboration), JINST, Proceeding of: "XIV Workshop on Resistive Plate Chambers and Related Detectors".

- "RE3/1 and RE4/1 chambers integration with Forward region of CMS Muon spectrometer", E. Voevodina et al. (on behalf of the CMS collaboration), JINST, Proceeding of: "XIV Workshop on Resistive Plate Chambers and Related Detectors".

- "CMS RPC Condition Data Automation", O. M. Colin et al. (on behalf of the CMS collaboration), JINST, Proceeding of: "XIV Workshop on Resistive Plate Chambers and Related Detectors".

- "Search for Heavy Stable Charged Particles in the CMS Experiment using the RPC phase II upgraded detectors", G. Sanchez et al. (on behalf of the CMS collaboration), JINST, Proceeding of: "XIV Workshop on Resistive Plate Chambers and Related Detectors".

Future plan

SimilFellow at CERN, starting from July 2018 for one year (July 2019)

- **RPC longevity studies**

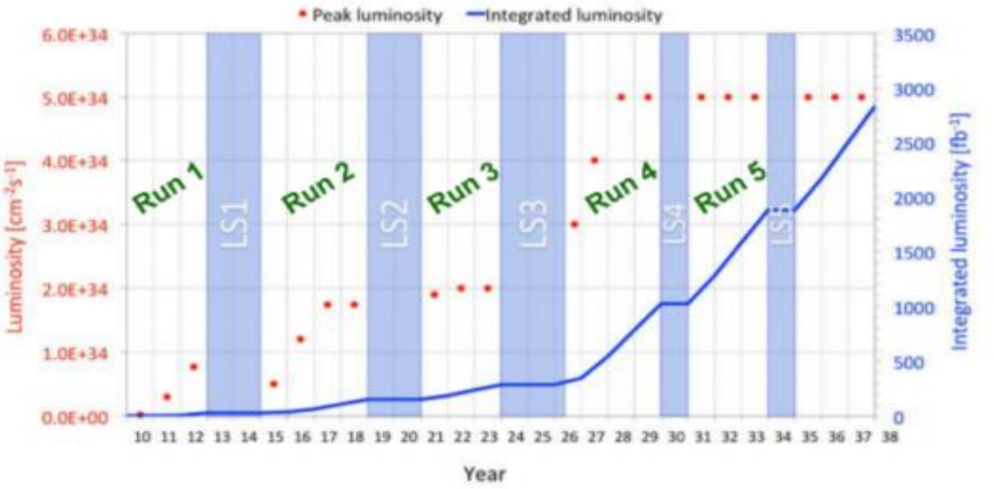
- **CMS Endcap trigger performance during HL-LHC:** study the impact on the muon L1 trigger of the upgraded RPC system with improved time resolution (new link system) and with extended acceptance with the installation of the RE3-4/1 stations

Thanks

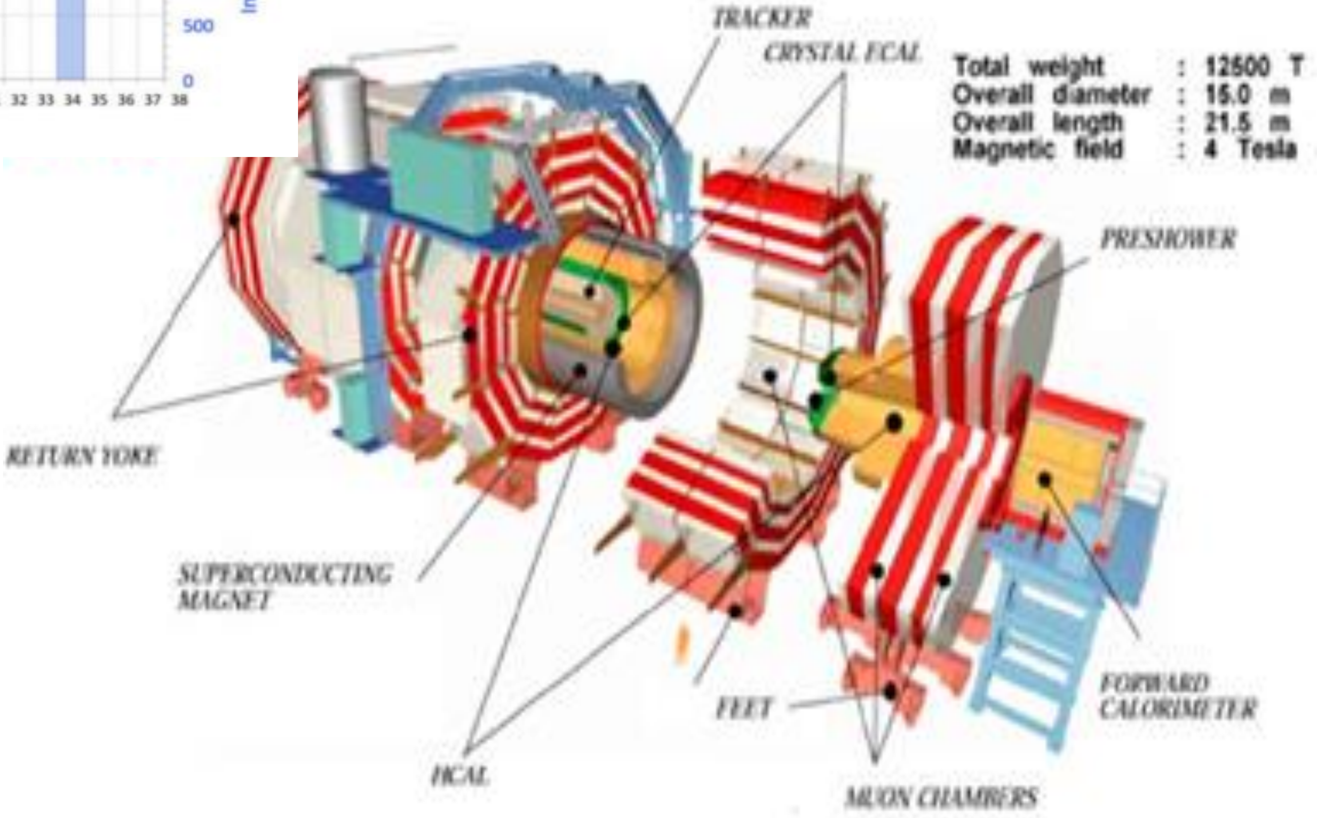
for your attention

Back up

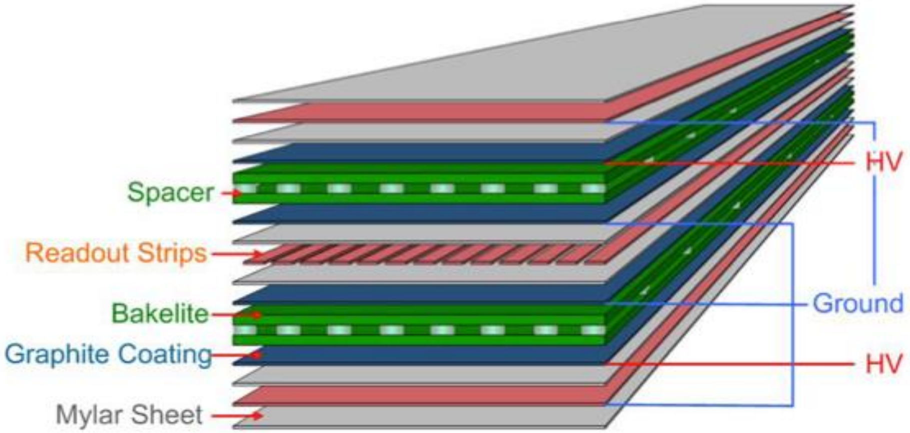
HL-LHC



$$L = \frac{R_{inel}}{\sigma_{inel}}$$

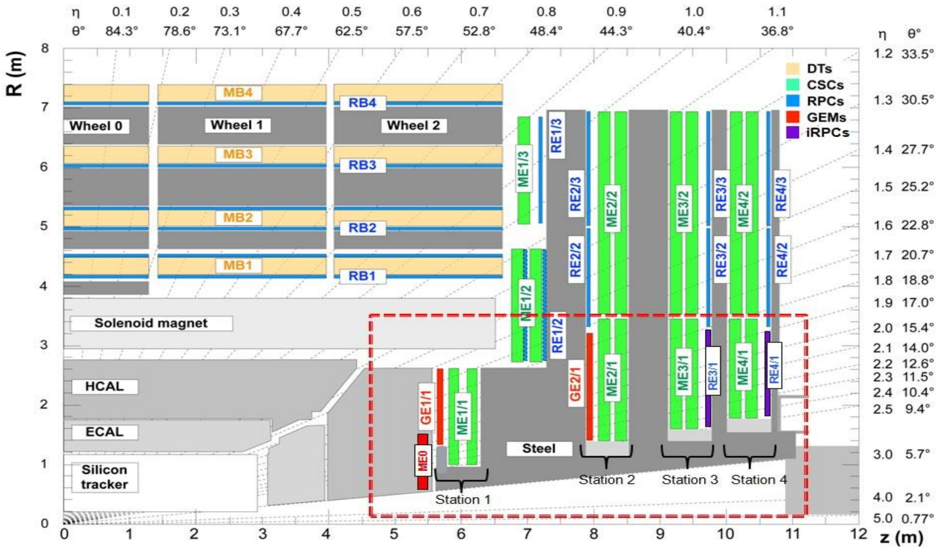


CMS RPC System



- **Covers $0 < |\eta| < 1.8$**
- **1056 chambers** (480 in Barrel and 576 in Endcap)
- 120000 **electronic channels** and 400 m^2 **of active area**
- **Double gaps gas chamber:** 2 mm gas width
- **Electrodes:** High Pressure Laminate
- **HPL** bulk resistivity: $\rho = 1 - 6 \times 10^{10}\ \Omega cm$
- **Humidified Gas mixture:** $C_2H_2F_4$ + isoC_4H_{10} + SF_6 (40% of H)
  95.2% 4.5% 0.3%
- Close loop with 10% -15% of fresh gas
- Operated in **avalanche mode**

1. Consolidation present RPC system



RPC @ LHC

- ***Covers 0 < | η | < 1.8 with 1056 chambers***
- ***Double gap RPC***
- *RPC information used in the Muon Trigger, reconstruction and identification*
- *High and stable RPC performance (efficiency 95 %) with the increasing of luminosity*

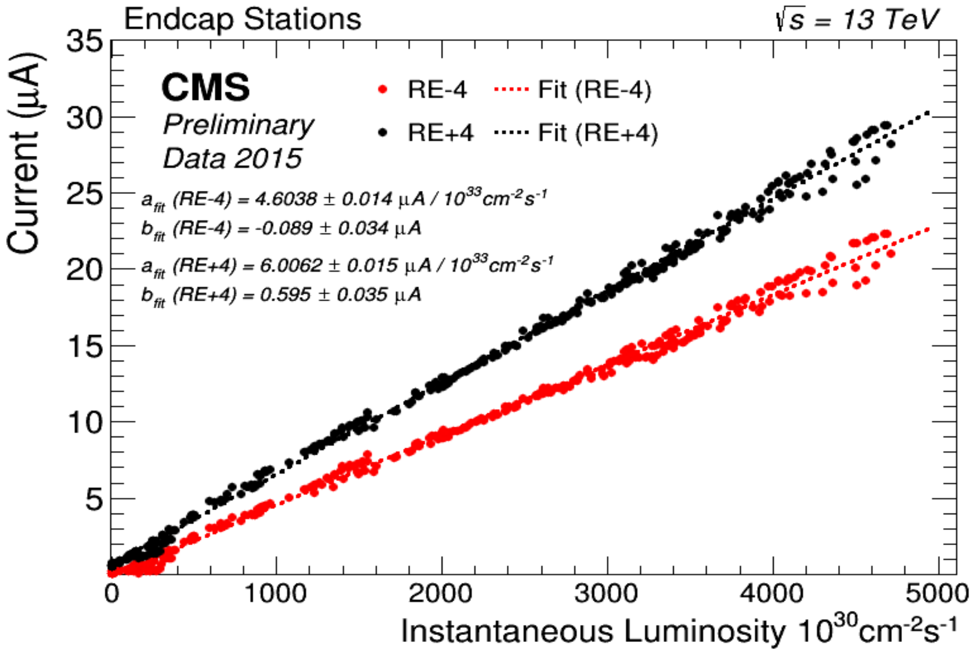
The RPC system has been certified for 10 years of LHC (at nominal luminosity of 10^{34} cm^2s) to maximum rate of ***300 Hz/cm²*** *and 0.05 C/cm²*

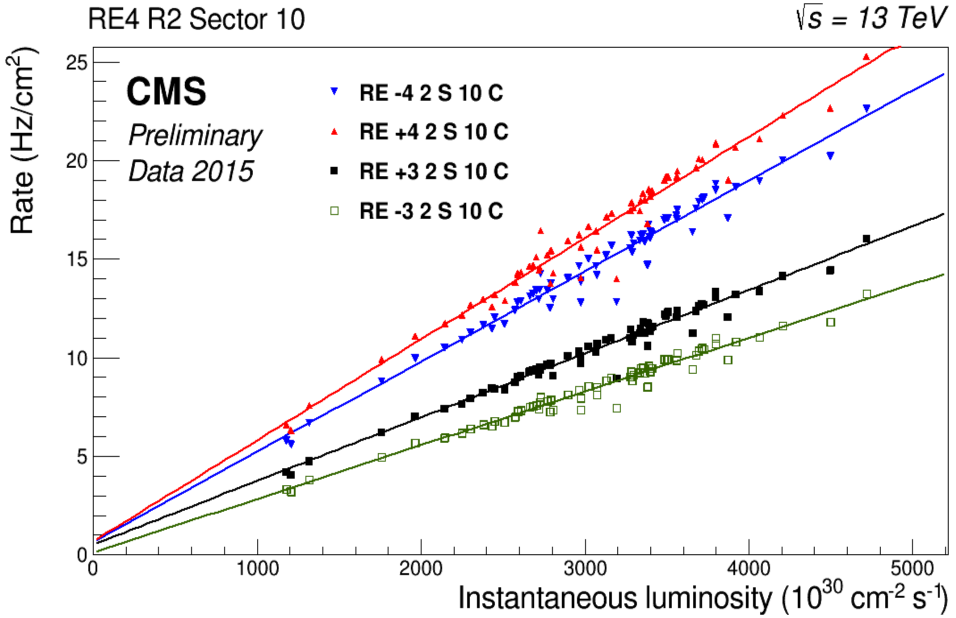
By the end of LS3 the RPCs will be 20 years old and be required to operate beyond the design specification

To maintain high and stable muon performance through ***HL-LHC:***

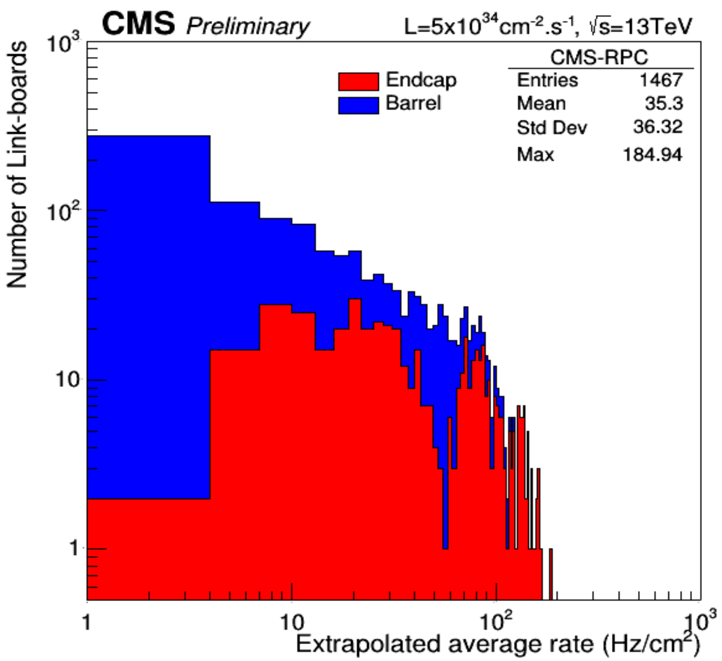
- *LONGEVITY STUDIES: The detector is expected to maintain excellent performance up to 3 times the expected HL-LHC conditions (integrated charge and rates).*

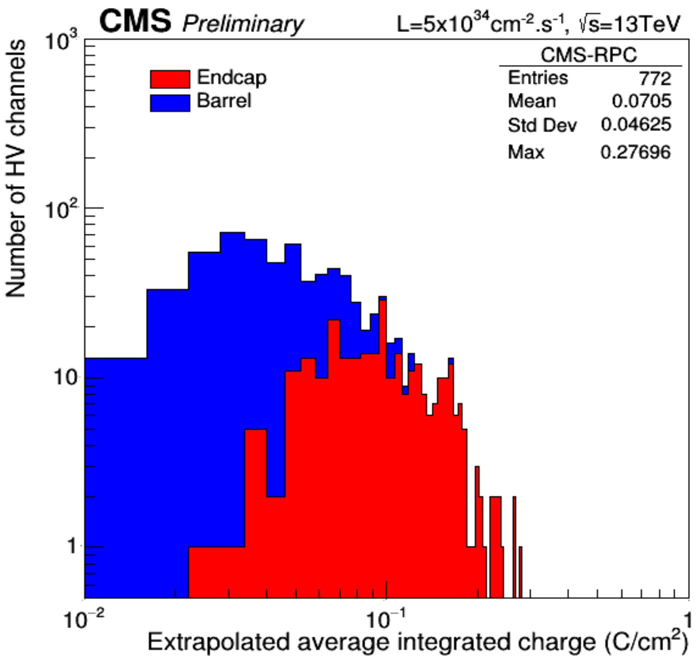
Current and rate vs Luminosity

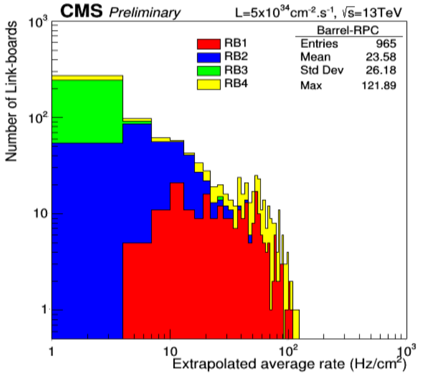


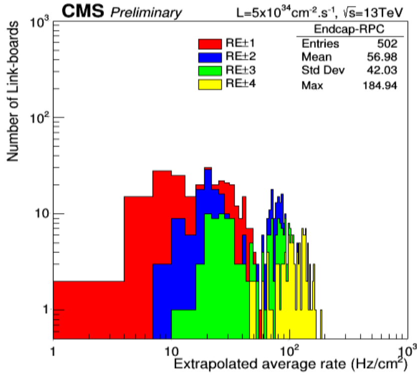


Expected conditions at HL LHC
Background rates and Integrated charge









iRPC design

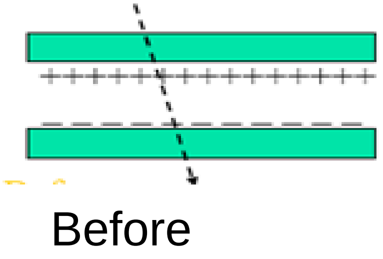
- ***Present CMS RPC chambers certified up to 300Hz/cm²***, *irradiated with photons up to an integrated charge of 0.05 C/cm² : not suitable for the high forward region.*

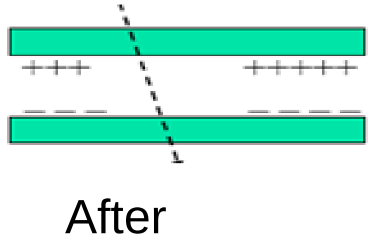
↓

- ***Rate capability of the RPC is related to the voltage drop in the resistive plate:*** $\Delta V = I\,R = \rho\, d\, q\, \Phi$

➢ ***Increase rate capability by reducing***

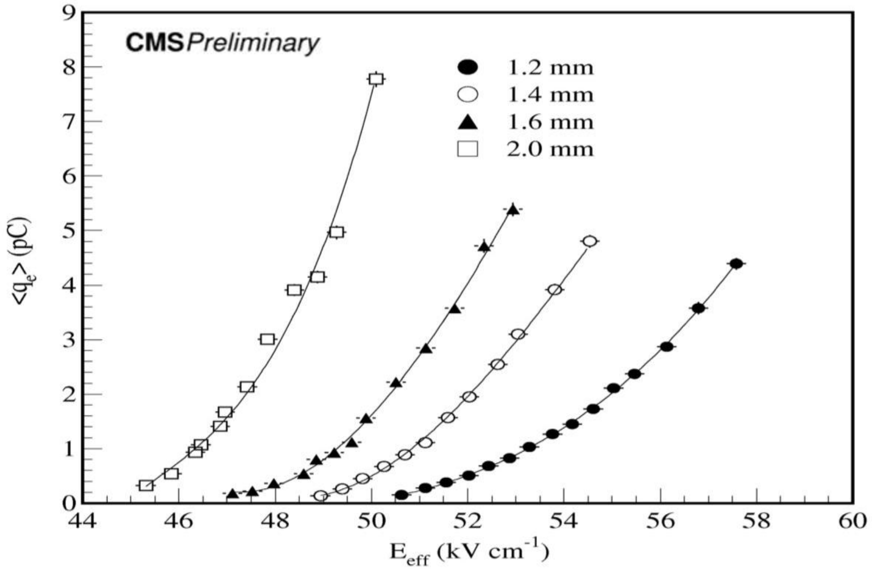
- *electrode resistivity* ρ*: as low as the RPC principle still stands (> ~*10^8*-*10^9 *Ωcm)*
- *electrode thickness* **d***: depends on electrode material → possible with both glass and HPL*
- *produced charge* **q** *(+ increasing FE electronics sensitivity): depends on gas mixture, number of gaps, and thickness of gaps → beneficial also for chamber aging*





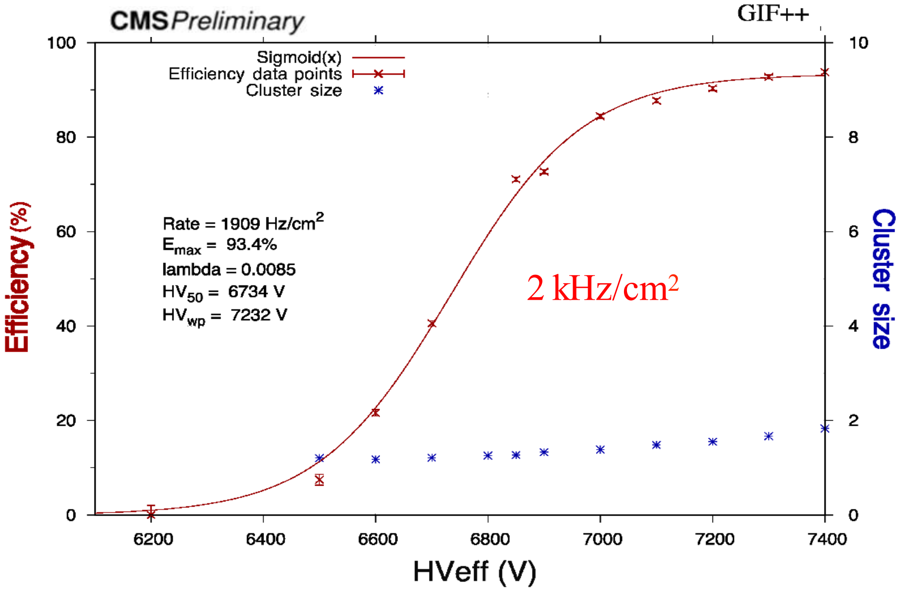
iRPC design

	RPC	iRPC
Gas Gap	2 mm	**1.4 mm**
High Pressure Laminate	2 mm	**1.4 mm**
Resistivity (Ωcm)	1 - 6 x 10^{10}	**0.9 - 3 x 10^{10}**
Strip pitch	2-4 cm	**0.7-1.2 cm**
Electronics Threshold	150 fC	**10 fC**
Chamber dimension	10 degrees	**20 degrees**



*The **thinner gap thicknesses**:*

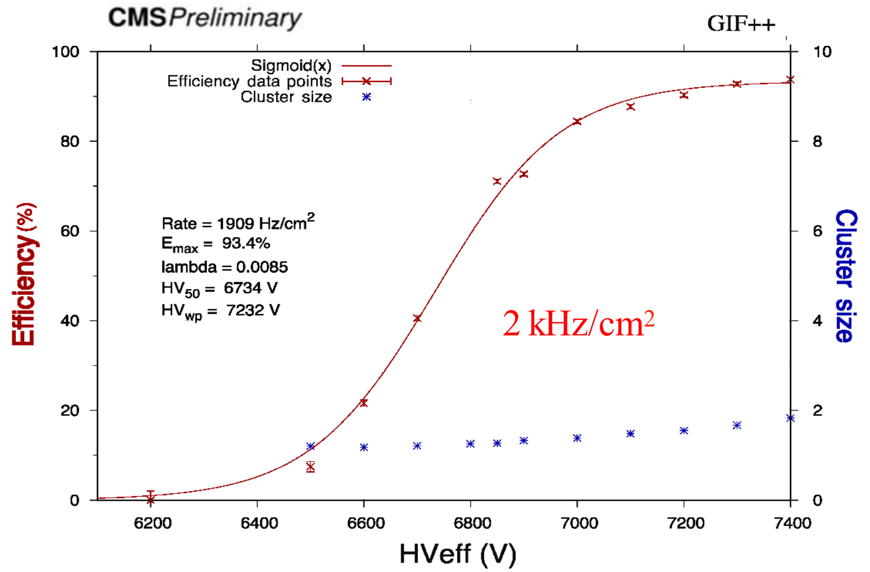
- *retard the fast growth of the pickup charges*
- *reduce aging effects*
- *reduction of the high improving the robustness of the system*

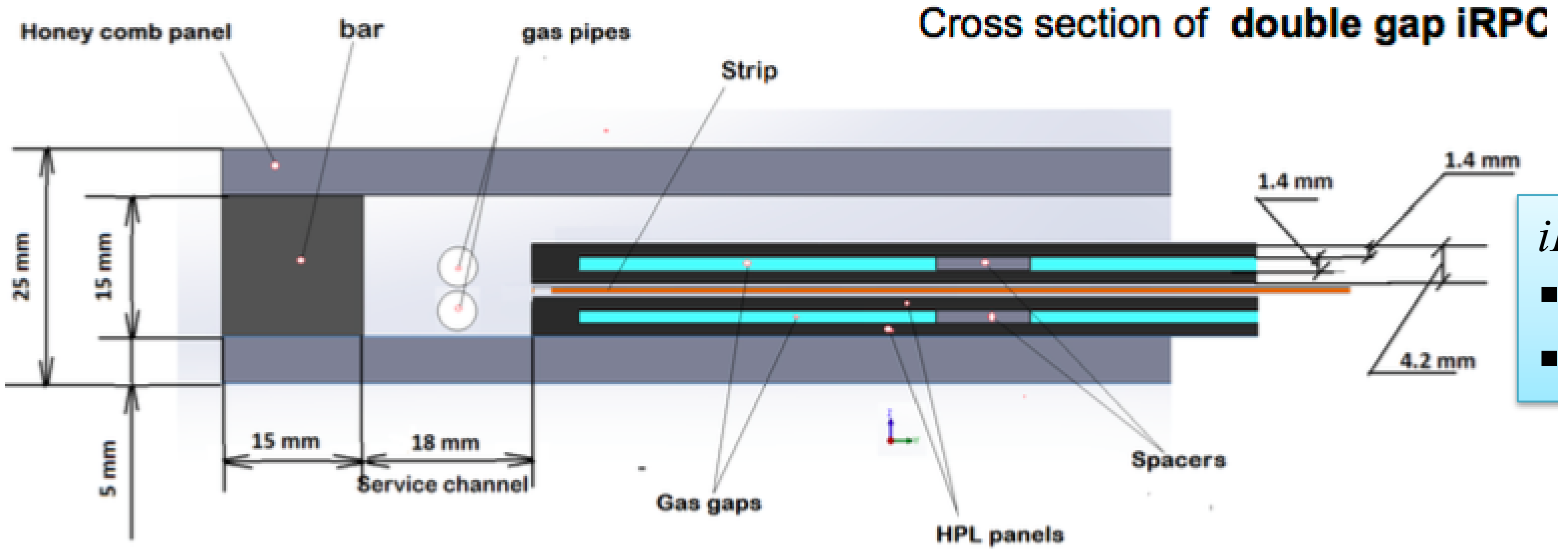


Large-size chamber iRPC 1.4 mm has been tested at Gamma irradiation Facility (GIF++) *at several gamma rate values. Achieved rate capability with more than 94% of efficiency at **2 kHz/cm²***

iRPC design

During last years, an intense R&D program has been done, and several RPC prototypes have been built using similar technology of the present RPC but having different geometry configurations in order to satisfy the CMS requirements.





iRPC baseline:

- ***gas gaps 1.4mm***
- ***electrodes 1.4mm***

RPC gas mixture

In view of a reduction of the Green-House gases emission ***an extended R&D program*** *has been started.*

The CMS RPC gas mixture has a high Global Warming Potential (GWP ~ 1433)

- *95.2% $C_2H_2F_4$ (tetrafluoroethane): GWP =* ***1430*** → ***active gas***
- *0.3% SF_6 (sulphur hexafluoride): GWP =* ***23900*** → ***electronegative gas***
- *4.5% C_4H_{10} (isobutane): GWP =* ***3.3*** → ***quencher gas***

This gas mixture has been optimized to ensure a stable and long term operation of the system at LHC .

Strategy to find a suitable ecogas:

- ✓ *Search for candidates with a low GWP to replace the $C_2H_2F_4$ within the gas used as Freon replacement in the industry.*
- ➢ *Study the detector performance with these new gases (efficiency, time resolution, streamer probability) also in combination to other gases (like the CO_2).*
- ➢ *Study the detector longevity performance in presence of gamma background on few candidate gas mixtures at GIF++.*

iRPC Background rate study @ HL-LHC

The goal of the study is to accurately estimate the expected **background hit rate** $R_{iRPC}(E)$ at HL-LHC in the forward region RE3-4/1 where will be installed the new improved RPC (iRPC).

The estimation of the background hit rate is done scaling the incident background fluxes $\phi_{bkg}^{CMS}(E)$ obtained by FLUKA with the iRPC sensitivity $S(E)$.

$$R_{iRPC}(E) = \phi_{bkg}^{CMS}(E) \times S(E)$$

from FLUKA simulation simulation

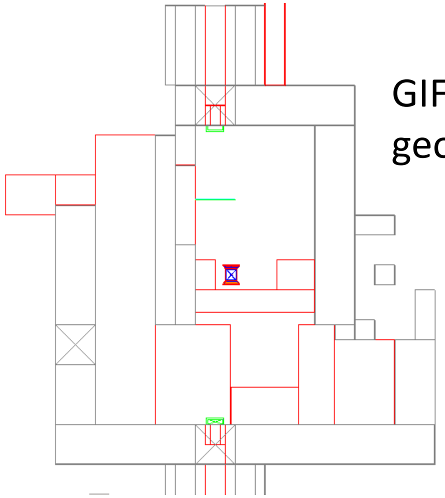
from GEANT

The GEANT Monte Carlo simulation allows to study the **sensitivity S(E)** of the iRPC at HL-LHC background conditions. The detector sensitivity is defined as the probability for a background particle N_{bkg} (neutrons, gammas, electrons, positrons) at a given energy reaching the surface of the iRPC, to producing a signal in the detector N_{HIT}.

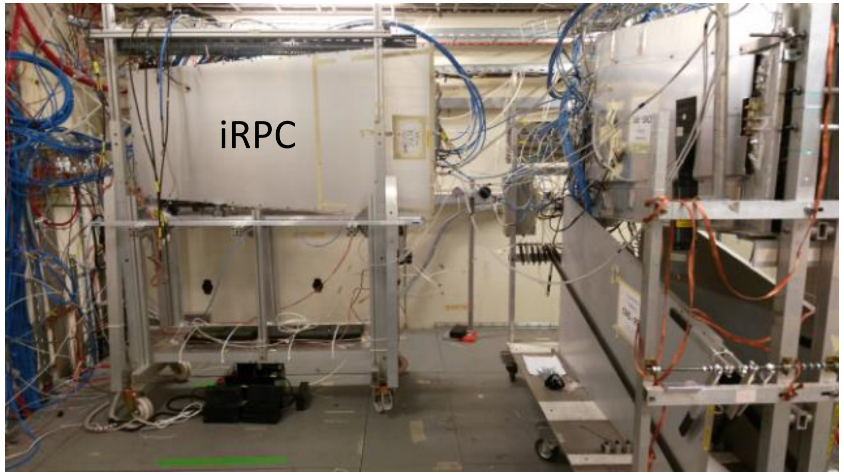
$$S(E) = \frac{N_{HIT}}{N_{bkg}}(E)$$

iRPC geometry simulation

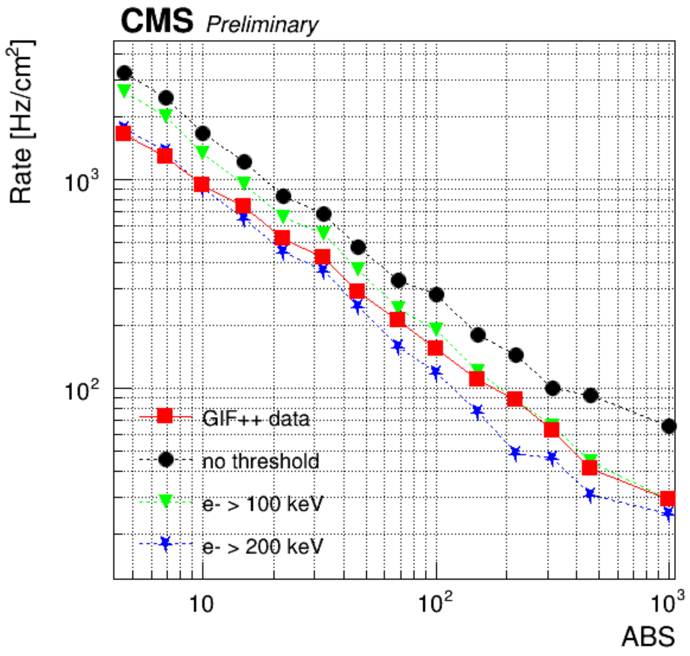
The comparison between experimental results (GIF++) and simulation results (iRPC geometry implemented in the GIF++ geometry) suggest to apply an energy threshold for the primary and secondary charged particles that produce a signals in the gas gaps.

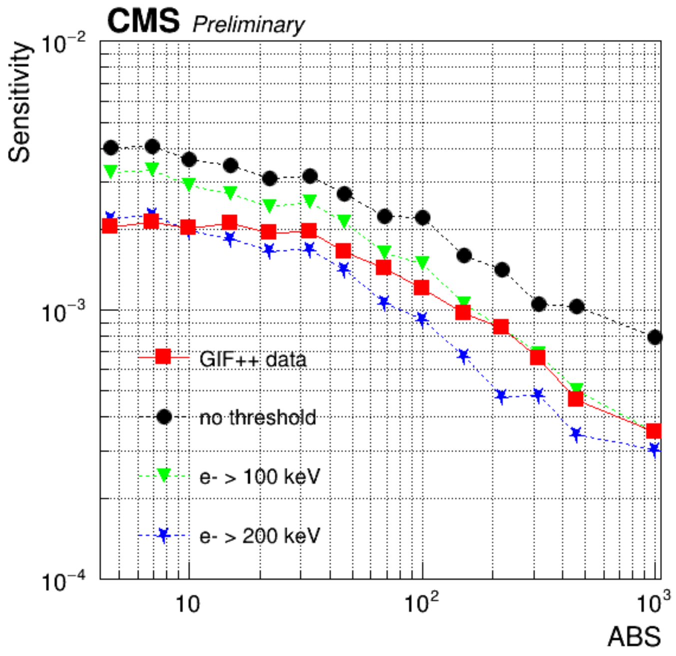


GIF++ geometry



GIF++ experiments results vs simulation results





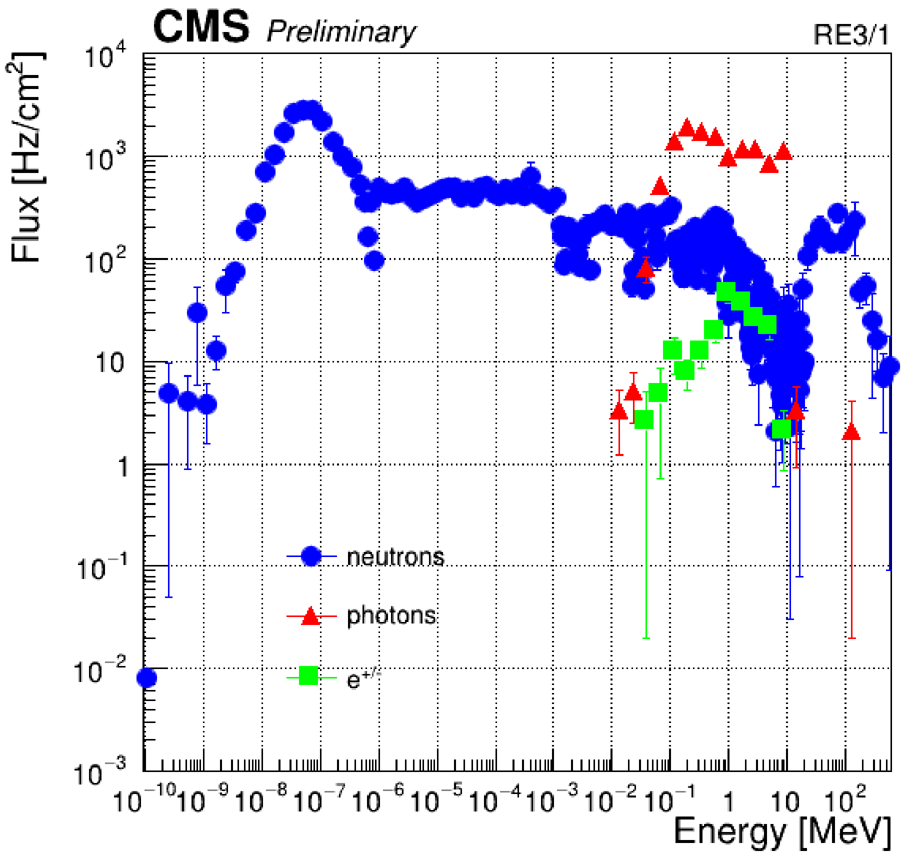
Detector geometry validated ✓
Optimal charged particles threshold > 100 keV ✓

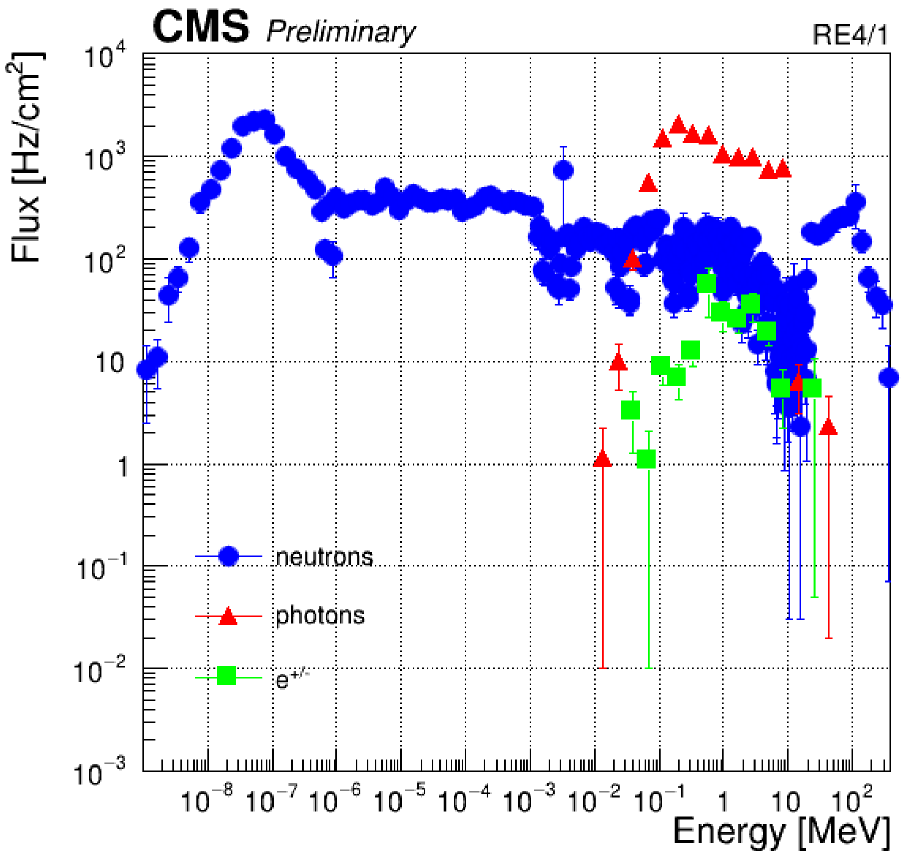
CMS BACKGROUND

<u>Background particles</u> $\phi_{bkg}^{CMS}(E)$ **:**

<u>neutrons, gammas, electrons and positrons</u>

Average flux of incident particles over the total detector surface (along R)



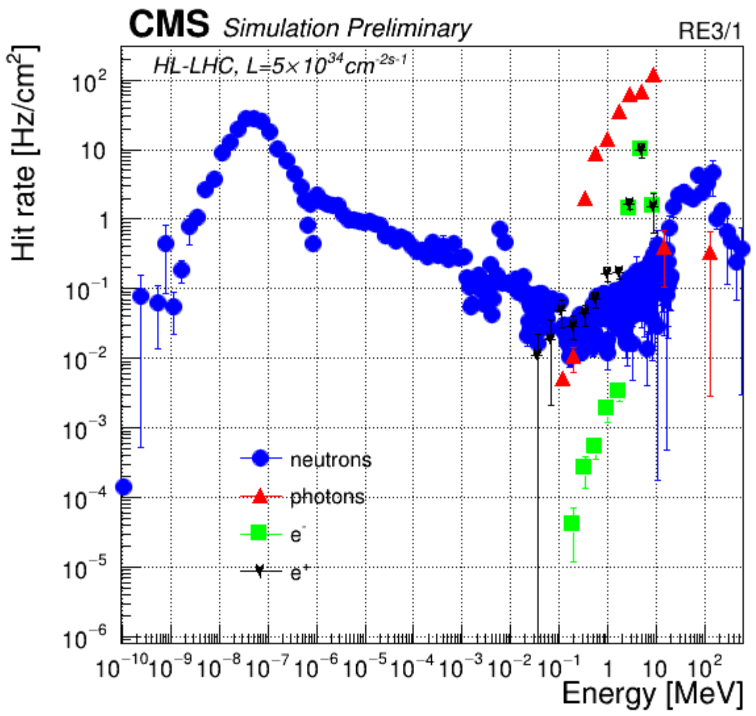


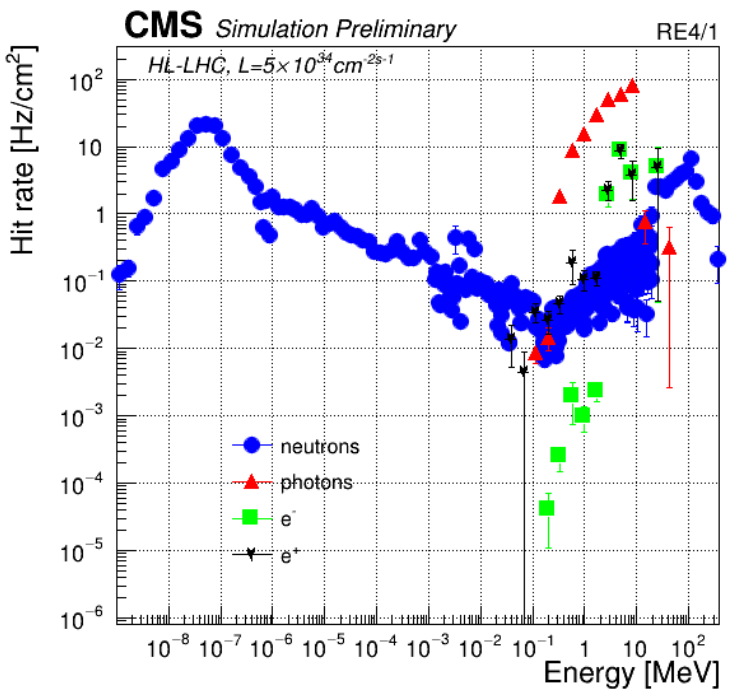
Error bars due to the low statistics

iRPC Background

$$R_{iRPC}(E) = \phi_{bkg}^{CMS}(E) \times S(E)$$

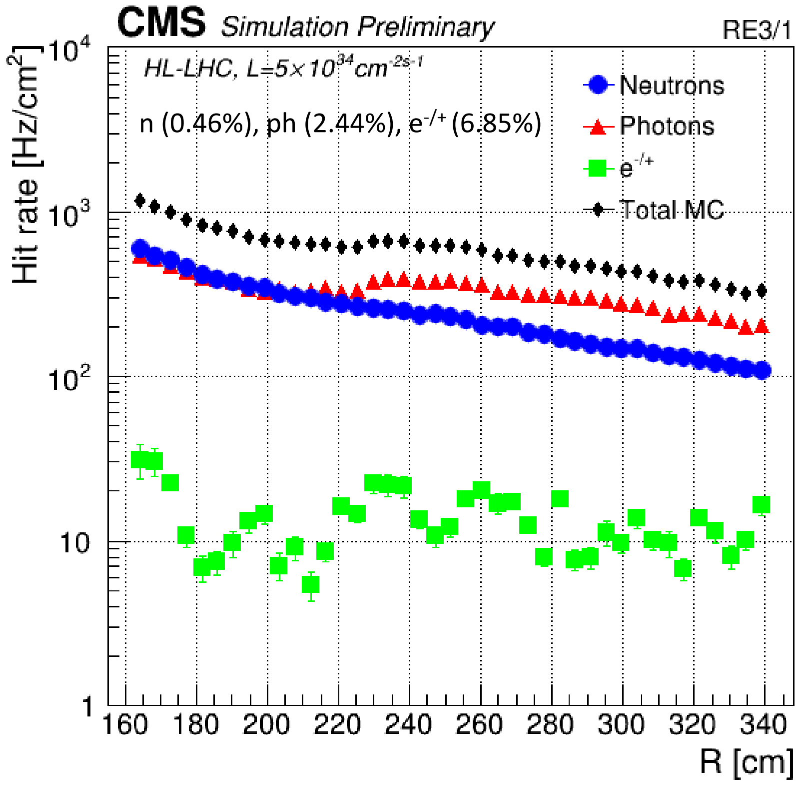
convolution between the incident background fluxes $\phi_{bkg}^{CMS}(E)$ and the sensitivity $S(E)$.

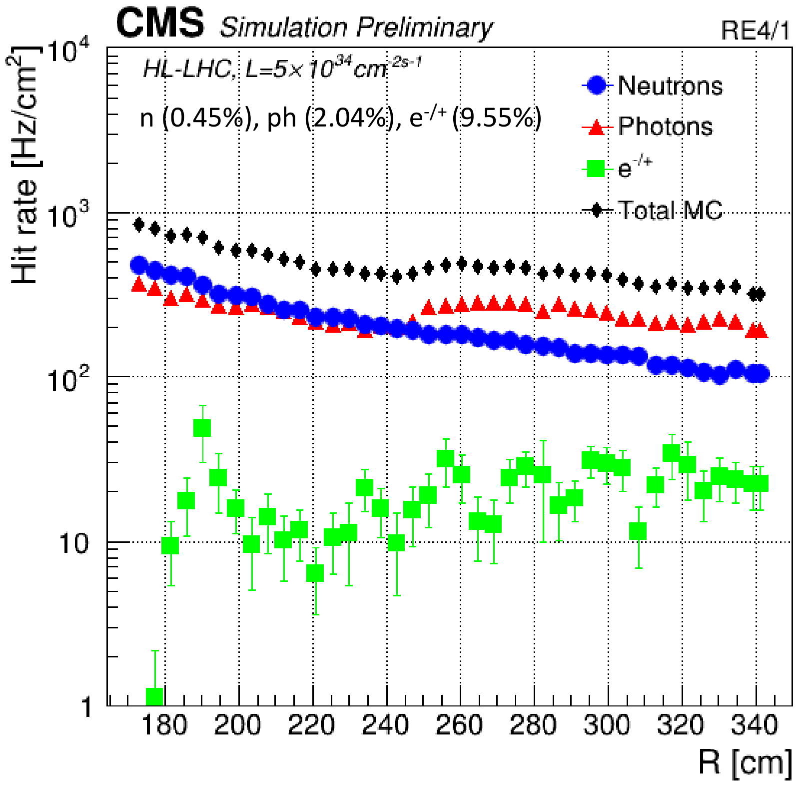




iRPC Background

<u>**Expected background hit rate vs R**</u> calculated scaling the incident background flux with the **AVERAGE** iRPC sensitivity applying the threshold.





Particles	RE3/1 HIT RATE Hz/cm^2	RE4/1 HIT RATE Hz/cm^2
Neutrons	251 ± 33	211 ± 20
Gammas	304 ± 23	243 ± 18
Electrons/ Positrons	13 ± 3	19 ± 9
TOT HIT-RATE	568 ± 27	473 ± 19

iRPC vs RPC sensitivity

Average iRPC sensitivity from the convolution between the incident background fluxes $\phi_{bkg}^{CMS}(E)$ and the sensitivity $S(E)$.

Particles	iRPC sensitivity	RPC sensitivity	**Δ iRPC - RPC**
Neutrons	0.468 % $\pm$ 0.004 %	0.26 % $\pm$ 0.03 %	0.21 %
Gammas	2.446 % $\pm$ 0.006 %	1.6 % $\pm$ 0.2 %	0.85 %
Electrons	6.619 % $\pm$ 0.003 %	35 % $\pm$ 16 %	-28,39 %
Positrons	7.102 % $\pm$ 0.012 %	35 % $\pm$ 16 %	-27.90 %

Possible reasons of the differences:
- Different energy spectrum
- Different detector geometry

Aluminium honeycomb panel influence