Background in the CMS muon detectors: simulation and measurements with pp collision data

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On behalf of the CMS Collaboration

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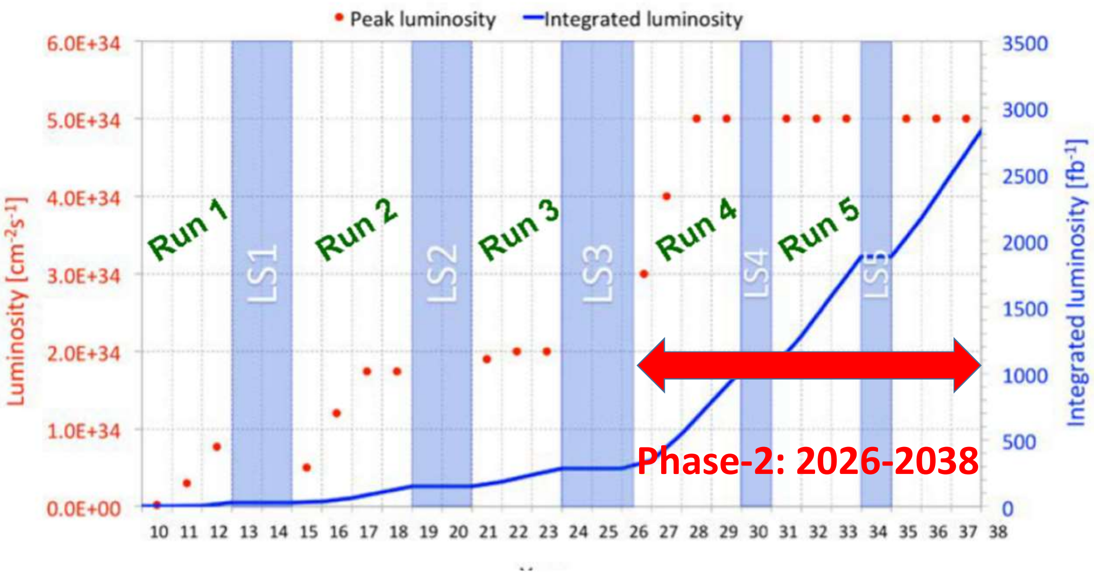
HL-LHC

Increase the sensitivity to new physics by increasing

- √s to 14 TeV
- Inst. luminosity to 5 $\cdot 10^{34}$ $cm^{-2}s^{-1}$
- Expected to reach 3000 fb^{-1}
- Average number of additional pp interactions (pileup) to reach 140

	LHC design	HL-LHC design	HL-LHC ultimate
peak luminosity (10^{34} $cm^{-2}s^{-1}$)	1.0	5.0	7.5
integrated luminosity (fb^{-1})	300	3000	4000
number of pileup events	~30	~140	~200



High rates expected at the HL-LHC challenge for muon detectors

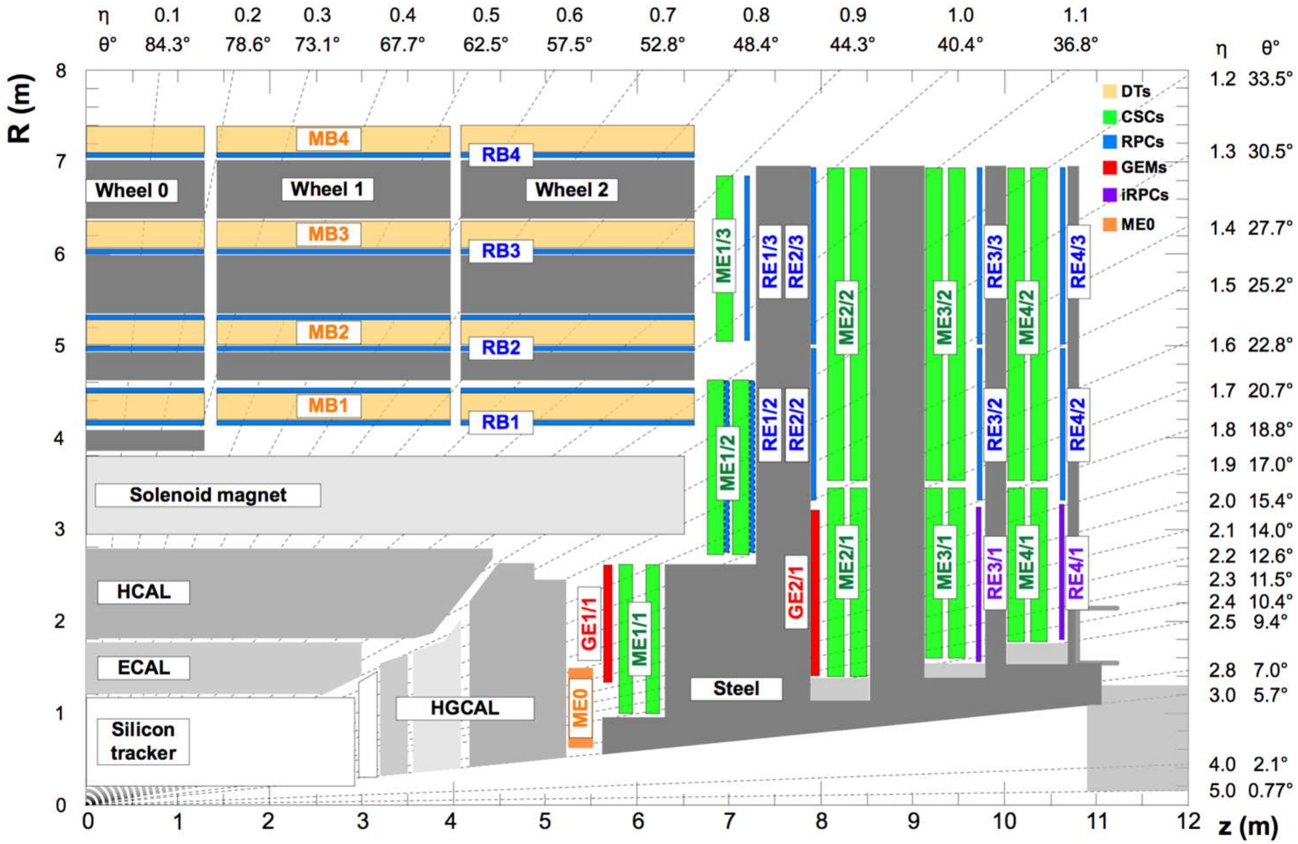
Could affect the muon reconstruction and in general the longevity of the detectors

Radiation damage could lead to noise or even failures of the electronics

Could decrease the gas gain and cause efficiency loss

Therefore studies and simulation of the radiation background in the muon system are fundamental for future operation

CMS Muon system and upgrade



Present system: multi-layer gas ionization detectors outside the CMS solenoid, three technologies:

DTs : |η| < 1.2

CSCs : 0.9 < |η| < 2.4

RPCs : |η| < 1.9

Upgrade:

- Replace detector electronics
- Increase the acceptance, increase the trigger and reconstruction capabilities in the forward region at high |η| up to 2.8:

ME0: 2.0 < |η| < 2.8

GE1/1: 1.6 < |η| < 2.2

GE2/1: 1.5 < |η| < 2.5

RE3/1, RE4/1: 1.8 < |η| < 2.4

ME0 : •18 chamber spanning 20° •6 layers of GEM technology •multi-layer design for background and pileup rejection

GE1/1: •36 super-chambers (SC) per endcap, spanning 10° each • Each SC is made of 2 back-to-back triple-GEM detectors •**Installation: LS2 (2019-20)**

GE2/1: •18 SC per endcap, each SC covers 20°•2 layers of GEM technology

RE3/1, RE4/1: •18 chambers per endcap, each covering 20° • one layer per station of iRPC technology • high time resolution for background and pileup rejection

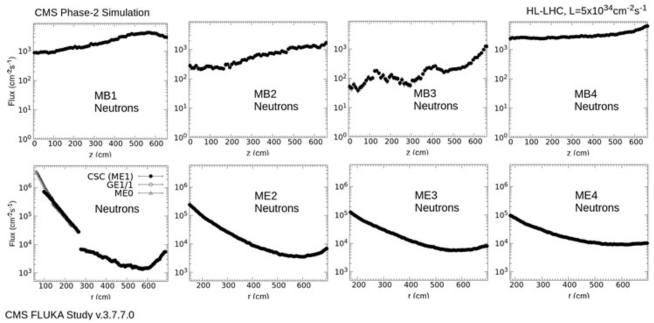
Expected background in the CMS muon system

Rate estimation from radiation background essential to choose detector technologies and design detectors and electronics

FLUKA used to simulate pp primary interactions and particle transport and to estimate the expected fluxes

Rates estimated normalizing the fluxes by the detector sensitivities determined with GEANT4

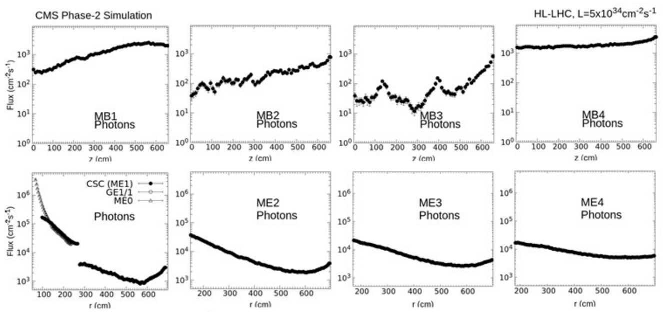
Very accurate description of the CMS detector and the CMS cavern are implemented in the simulation, well reproducing the Run1 and Run2 measurements (next slides)



Neutrons
Barrel

Endcap

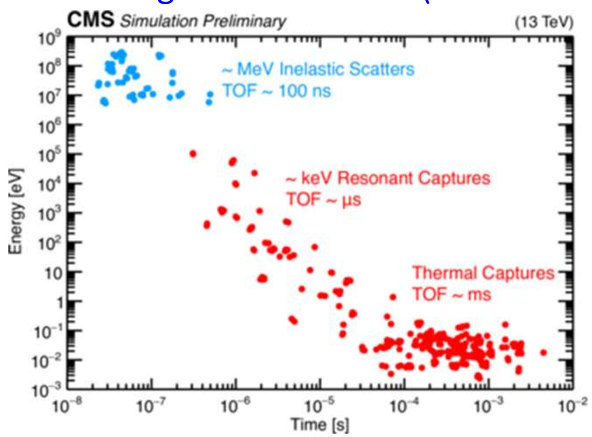
FLUKA



Photons
Barrel

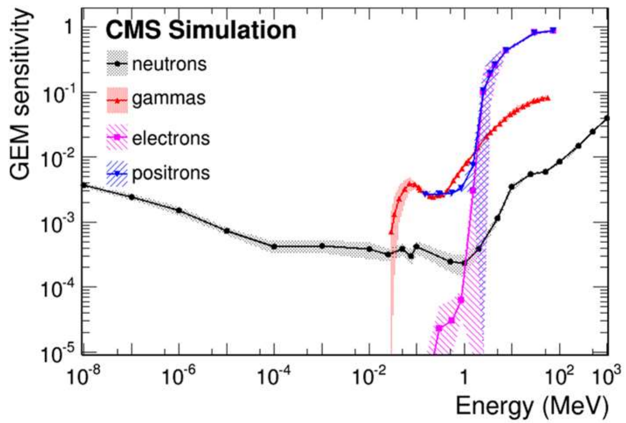
Endcap

Main background source: neutrons and neutron induced background via nuclear interactions and capture, followed by gamma emission (E ~1-10 MeV) and Compton (E~MeV)

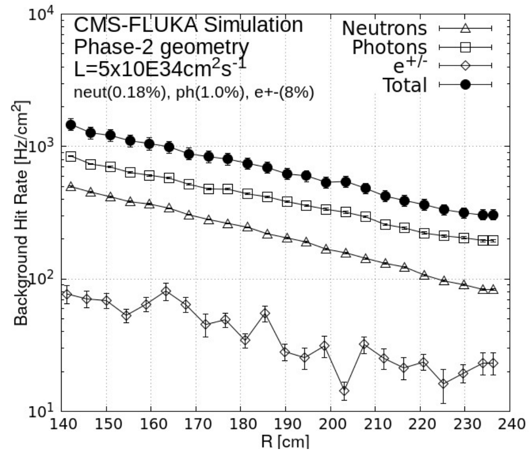


Energy of simulated neutron vs. time since pp collision for hits in the CSCs, with GEANT4 simulated minimum-bias pp collisions at 13 TeV
Hits induced by electrons, produced from photons, which are produced from thermal or resonant neutron capture or from neutron inelastic scattering.

GEM sensitivities with GEANT4



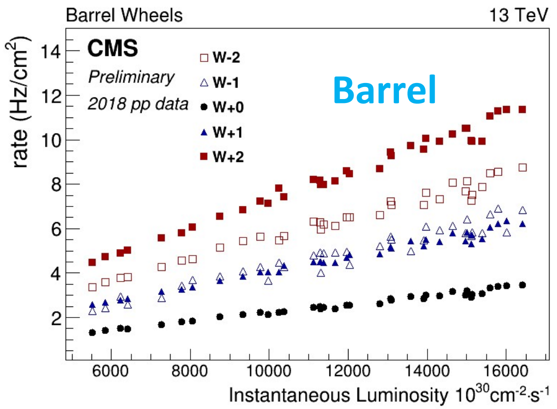
Expected rate in GE1/1

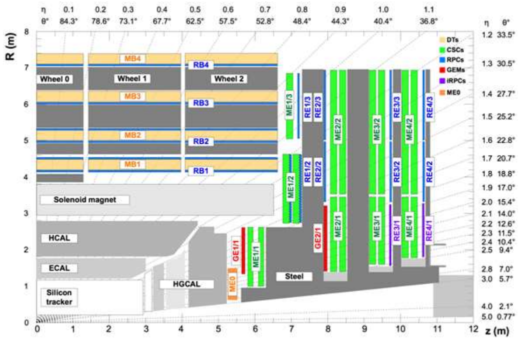


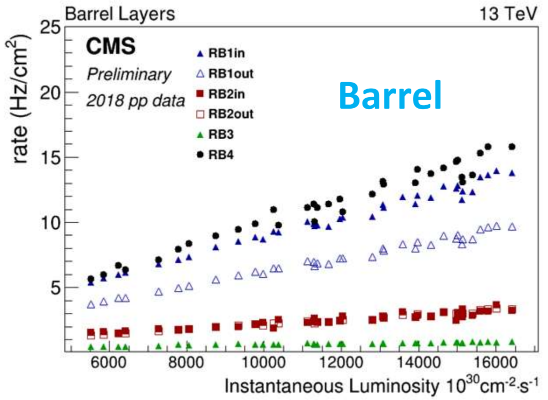
RPC background measurements

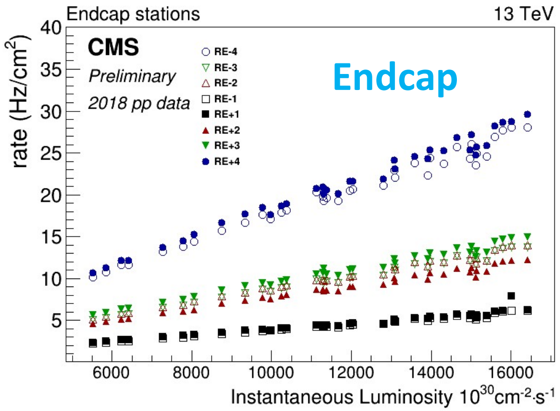
- Hit rate vs. instantaneous luminosity in the barrel and endcap
- Linear dependence over several order of magnitudes: can be used to extrapolate to higher values of the instantaneous luminosity in the present detectors

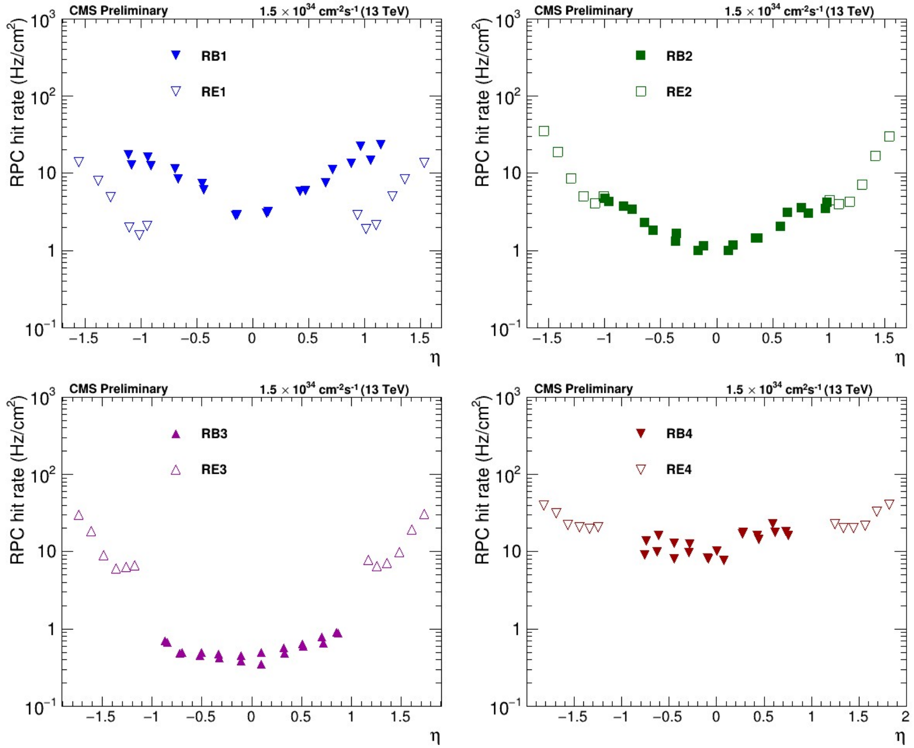
At $1.5 \cdot 10^{34}\ cm^{-2}s^{-1}$





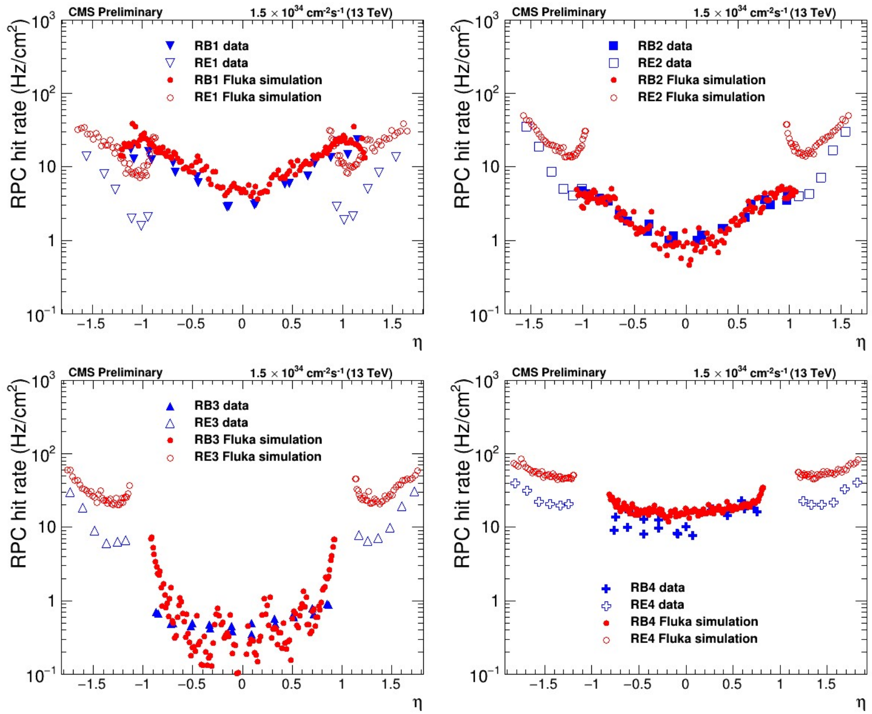






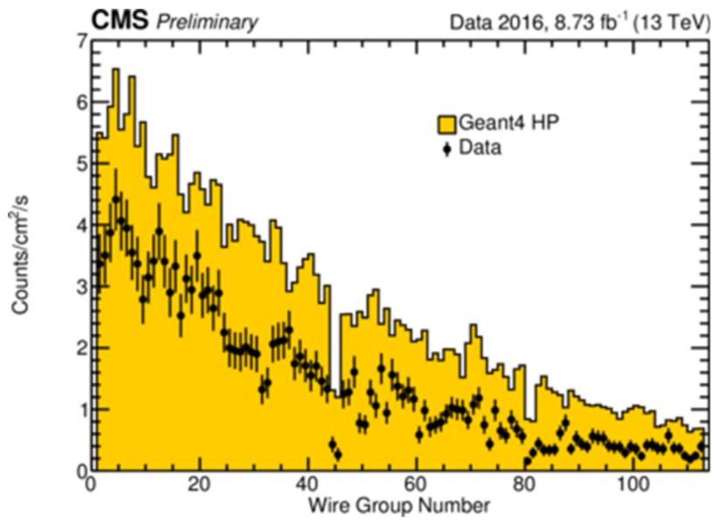
RPCs and CSCs: comparison with simulation

RPC



- Particle fluxes obtained with FLUKA and RPC average sensitivities determined with GEANT4: neutrons: (0.26±0.03)%; gammas: (1.6±0.2)%; e+e-: (35±16)%.
- Agreement: good in the barrel, within a factor 2 in the endcap, with coherent trends.

CSC

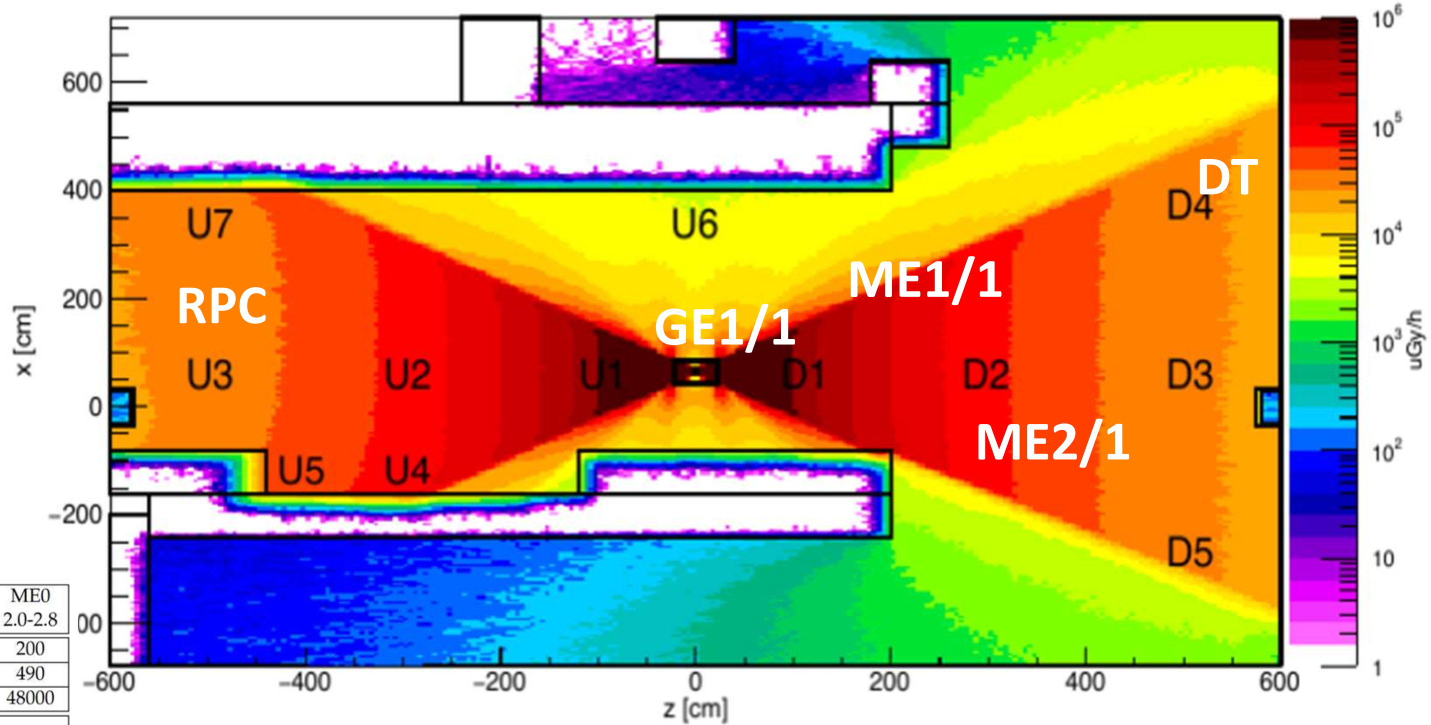


- Agreement within a factor 2
- anode wire hits induced in ME2/1 by candidate thermal-neutrons using CMS data
- CMS data are compared to the GEANT4

Irradiation tests at the CERN GIF++ facility

- Existing and new detectors have to be certified for HL-LHC conditions (below), ~5 times the LHC doses and rates
- GIF++ provides a fairly realistic simulation of the HL-LHC conditions and allows detector performance studies with muon beam in the presence of high radiation
- ^{137}Cs source, intensity 14 TBq, emitting 662 keV photons, plus a high momentum muon beam (100 GeV)
- Neutron-induced photons have an energy in the range 0.1–10 MeV.

Chambers under test:
- •CSCs: 1 ME1/1 and 1 ME2/1
- •DTs: 1 MB1, 1 MB2
- •GEMs: 1 GE1/1, 1 GE2/1
- •RPCs: 1 RE2, 1 RE4, 1 iRPC large prototype



Highest rates shown
Safety factor of 3 not included

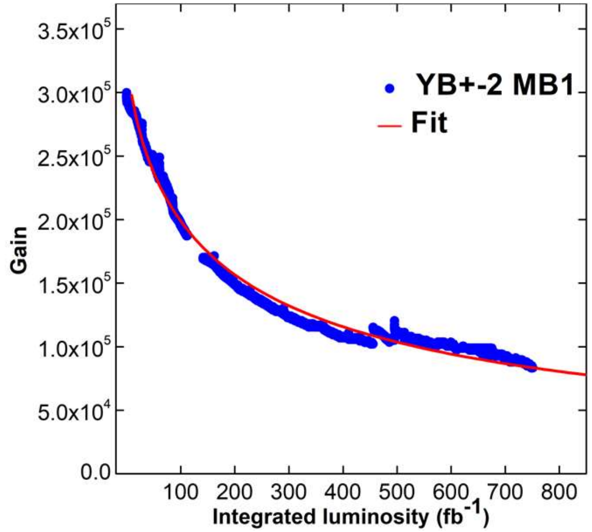
$\|\eta\|$ range	DT 0-1.2	CSC 0.9-2.4	RPC 0-1.9	iRPC 1.8-2.4	GE1/1 1.6-2.15	GE2/1 1.6-2.4	ME0 2.0-2.8
neutron fluence (10^{12} n/cm^2)	0.4	40	1	7	20	12	200
total ionization dose (kRad)	0.12	10	2	3	3	7	490
hit rate (Hz/cm^2)	50	4500	200	700	1500	700	48000
charge per wire (mC/cm)	20	110	-	-	-	-	-
charge per area (mC/cm^2)	-	-	280	330	6	3	280

DTs and CSCs

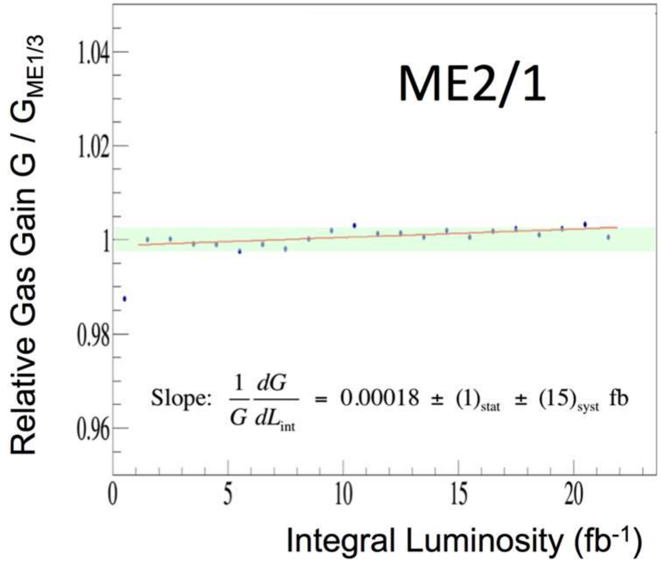
Effects of prolonged exposition to radiation: •loss of gas gain •rise in spurious signal rates ("dark rate") •increase in leakage currents ("dark current") •development of self-sustained discharges set off at high radiation rates (Malter effect)

DTs:

See talk by Isidro Gonzalez



CSCs: •Total integrated charge of 330 (ME1/1) and 340 (ME2/1) mC/cm•No noticeable gas gain loss up to 3 × HL-LHC•Tests going on



RPCs and GEMs

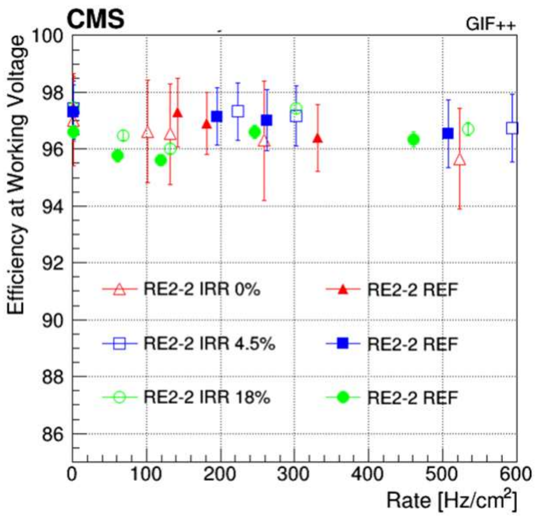
RPCs:

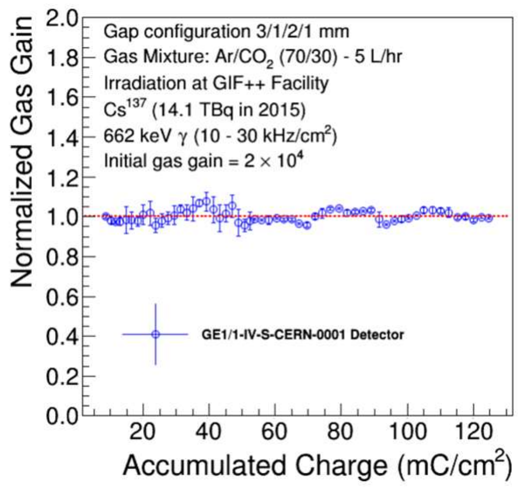
•No noticeable effects of detector degradation up to values of the integrated charge of up to ~600 mC/cm^2 (~70% of the ones expected at the HL-LHC) •Longevity tests also on large size prototype of iRPC main parameters are stable so far •Tests are ongoing

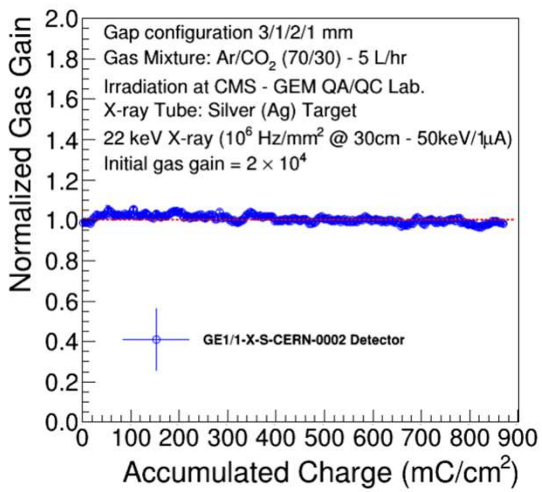
GEMs:

•Total accumulated charge of 125 mC/cm^2, i.e. 10 years of GE1/1 (GE2/1) operation at the HL-LHC with a safety factor 21 (42), and 44% of the total ME0 operation •No aging observed

•Aging study is in course also with an X-ray source. The accumulated total charge is 875 mC/cm^2, i.e. 10 years of operation in ME0 region with a safety factor 3.1•No aging observed







Conclusions and outlook

- Extensive measurements have been performed leading to an accurate understanding of the radiation background in the CMS Muon system

- Background simulation studies also carried out by the CMS Muon community. The simulation, with FLUKA being mainly used for flux and dose estimation, and GEANT4 for sensitivity studies, well describes the data, within a factor 2 in the endcap

- The agreement with present measurements, in the regions covered by the existing detectors, allows to estimate the expected radiation background where new detectors are going to be installed at the HL-LHC, and it is essential for detector design ad future operation

- Longevity tests being performed at the CERN GIF++ facility show no evidence of aging effects at the total integrated charge collected so far, for most of the Muon detectors, except the DTs. See I.Gonzalez' talk for details

Public results at: https://twiki.cern.ch/twiki/bin/view/CMSPublic/MuonDPGResults