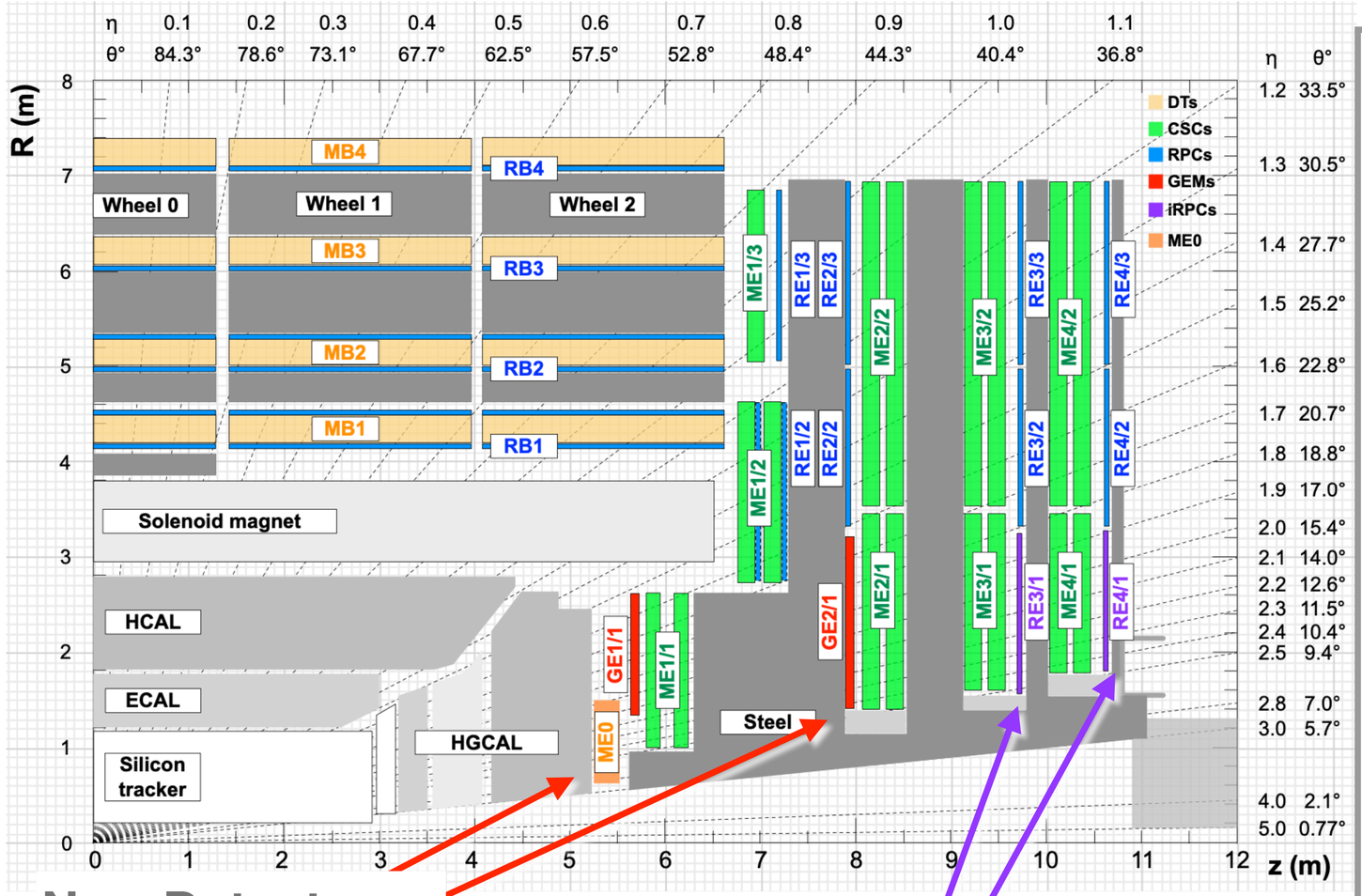
Background in the CMS muon detectors: simulation and measure with pp collision data

Daniele Fasanella (CERN)
on behalf of the CMS Muon Group

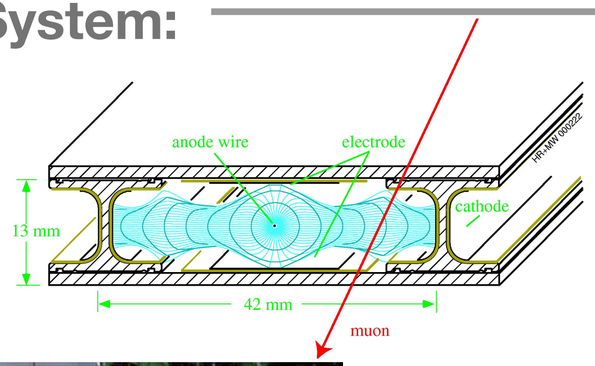
IPRD2019:
15th Topical Seminar on
Innovative Particle and Radiation Detectors
14-17 Oct 2019, Siena (Italy)

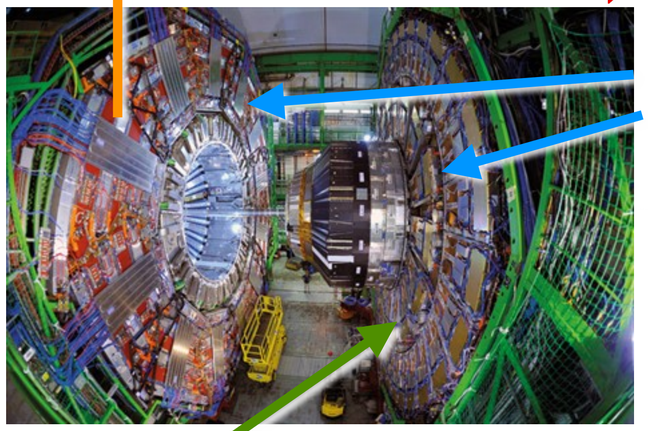
The CMS Muon Spectrometer



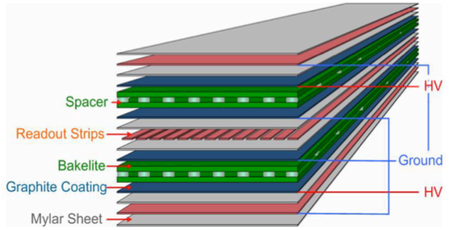
Actual System:

DT:
250 Chambers
|η|<1.2

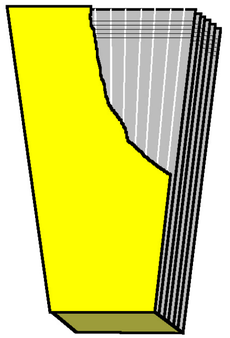


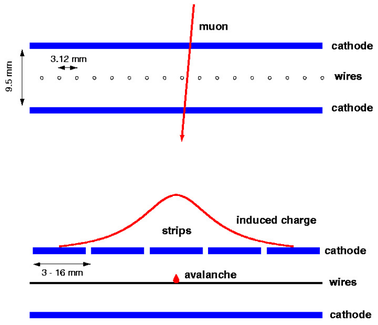


RPC:
480 Chambers Barrel
576 Chambers EndCap
|η|<1.9



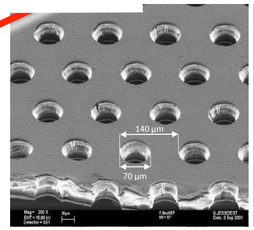
CSC:
540 Chambers
0.9<|η|<2.4

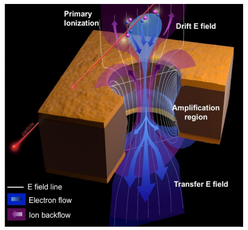




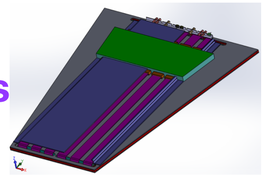
New Detectors:

GEM:
72 Chambers
1.6≲|η|≲2.8



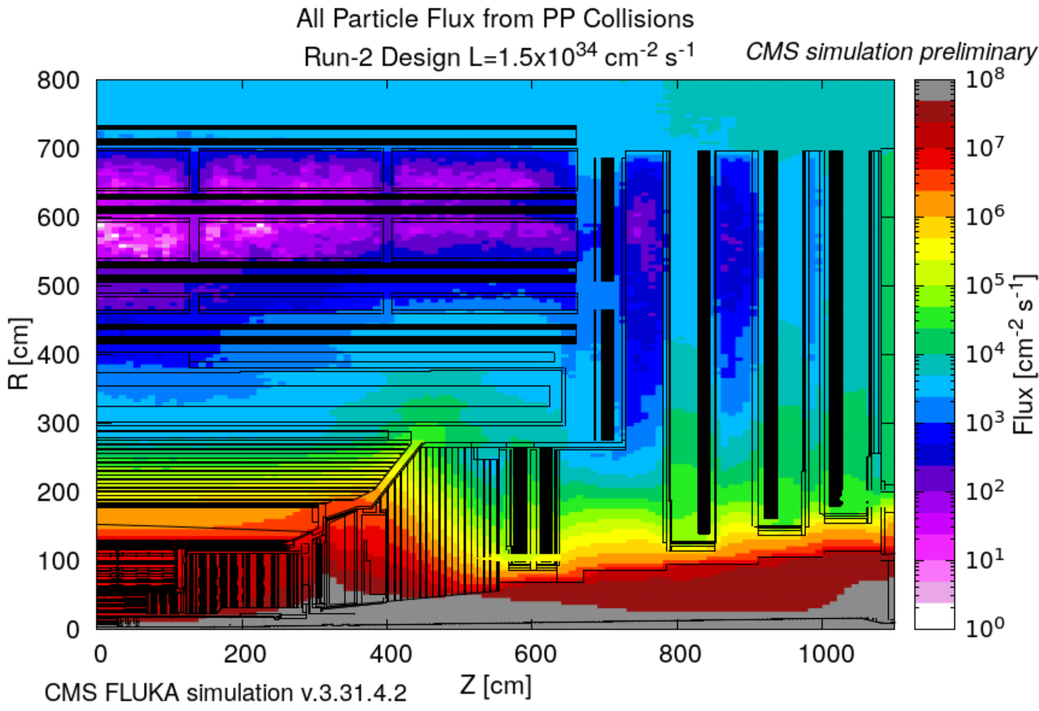


iRPC:
18 Chambers
1.8<|η|<2.4



Background in the Muon Detectors

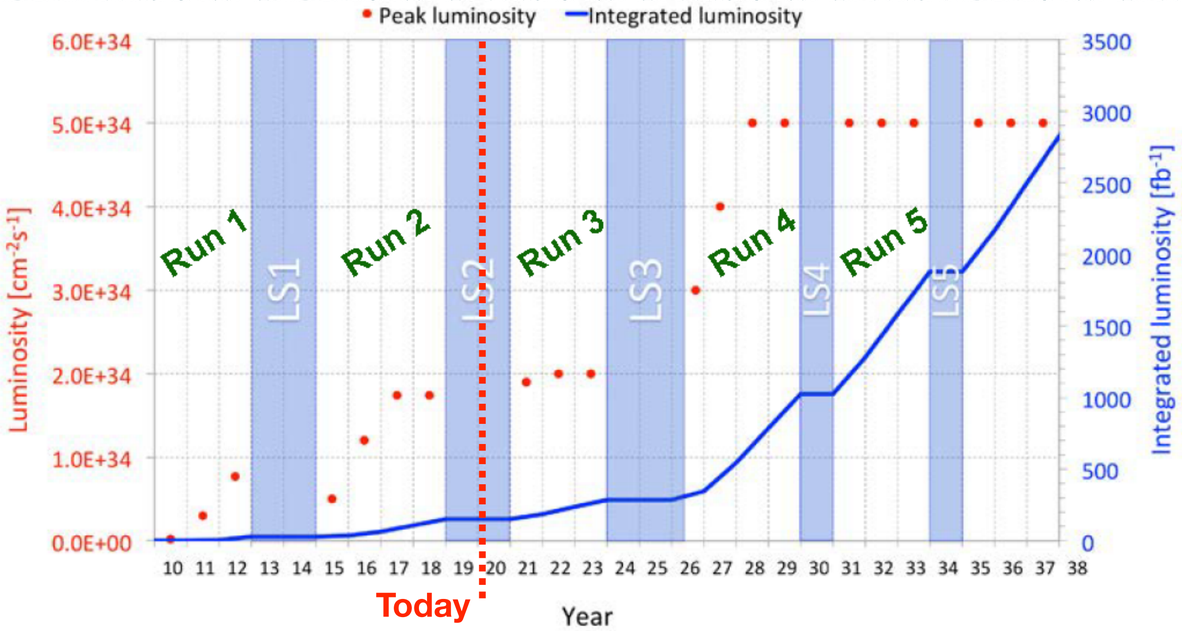
- The different types of detectors have been chosen to withstand different particle fluxes
- **Main sources of background**:
  - **Punch through hadrons** from the inner detectors and muons from machine background
    - low rate but main concern in segment reconstruction
  - **Neutrons** from showers or from the leaks in the forward shielding
    - large effect on the detector longevity
  - **Photons** produced in de-excitation of nuclei
    - nuclei excitation via capture of low energy neutrons
    - main source of background hits



Background Study

The high rates expected at the HL-LHC are a **challenge** for muon detectors

	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

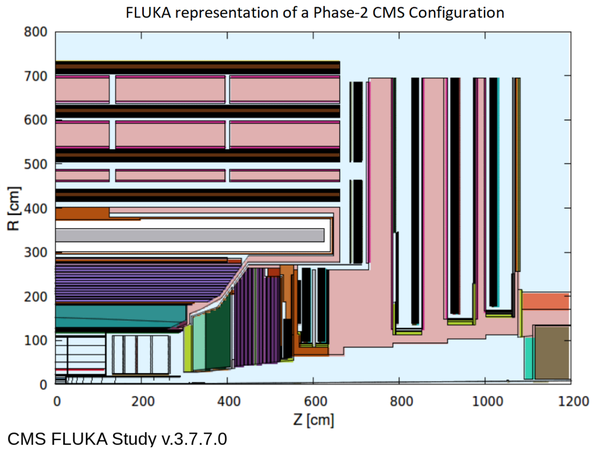


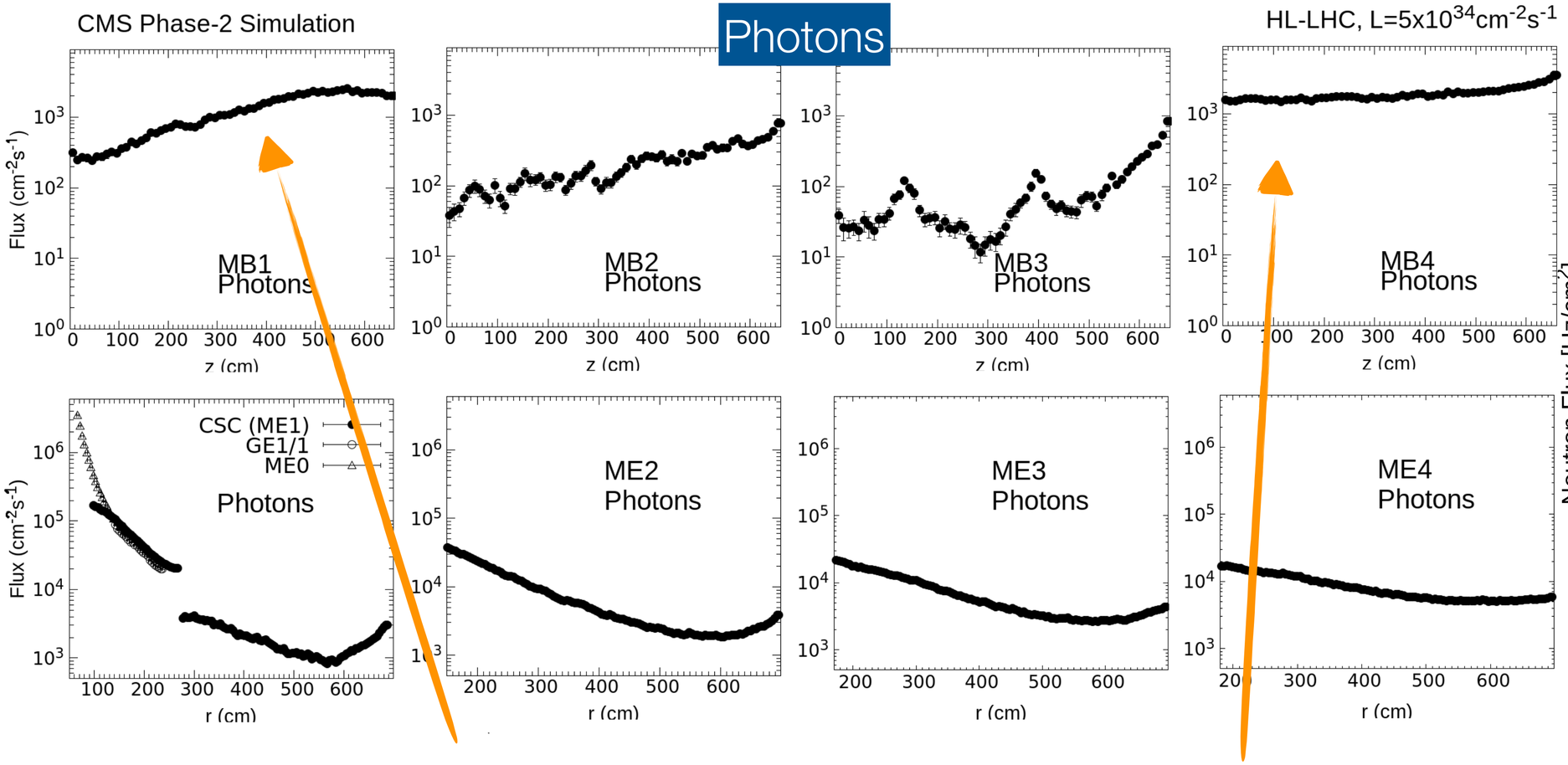
- **Main source of concern:**
  - background hits may spoil efficiency of trigger, hit detection and segment reconstruction
  - background hits may spoil the space and time resolutions
  - background segments may affect the muon reconstruction
  - charge accumulation may cause early detector ageing

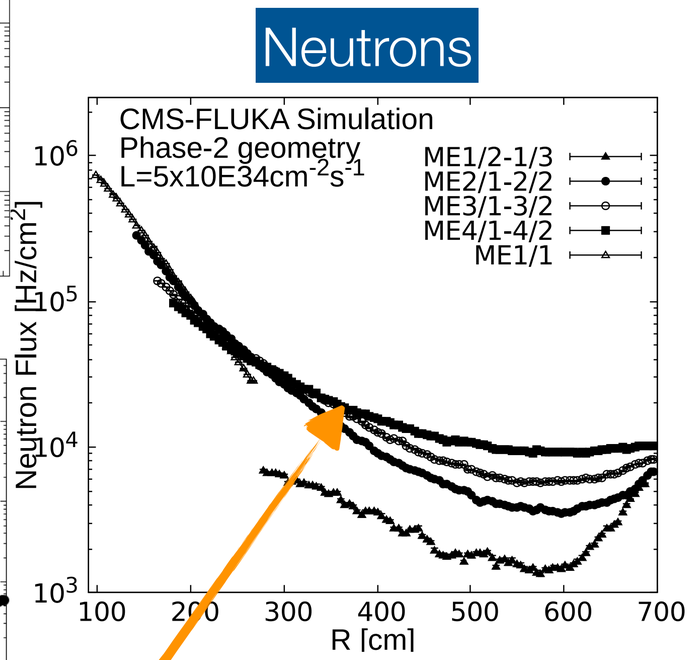
- **Main study tools:**
  - Measured **hit rates** and **currents** dependence on instantaneous luminosity.
    - Hit rates determined at the lower level in each detector
    - Currents measured by the used HV modules
  - Simulation studies
  - Studies at test facilities (CHARM, GIF++)

Simulation of Background

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



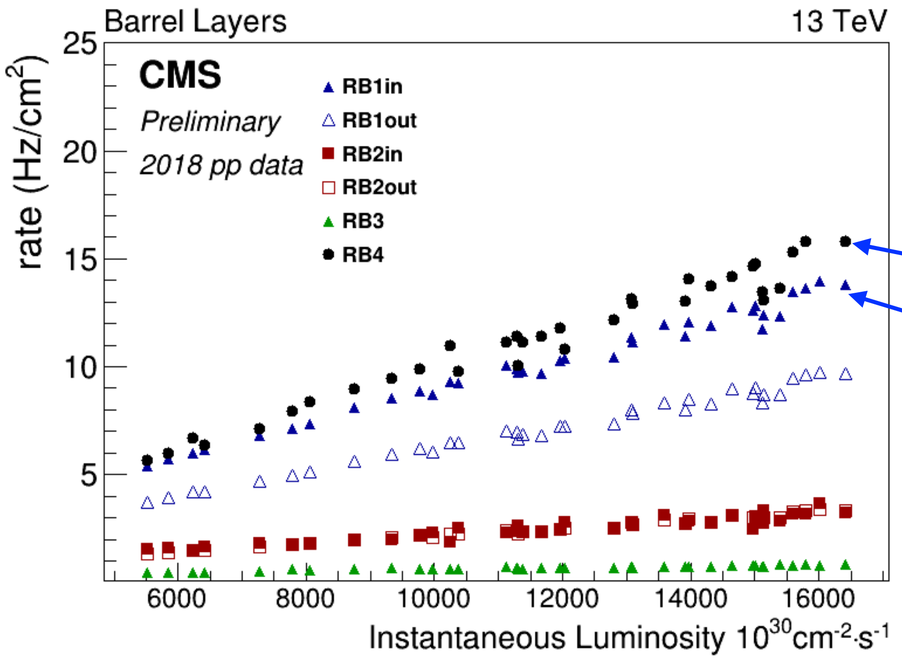




Large background levels in the external station due to "**neutron cloud**"in the experimental cavern

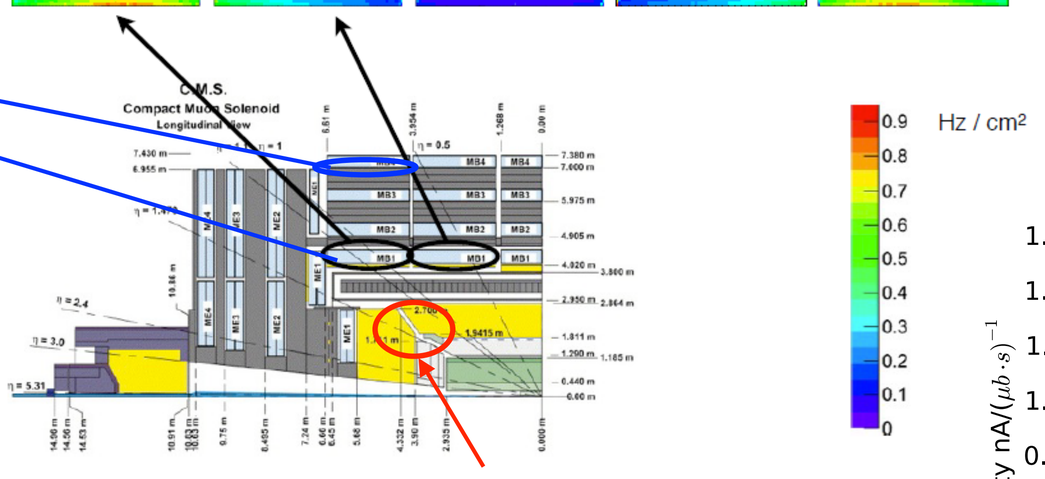
RPC and DT Barrel Measurements

RPC Station Rates vs Luminosity

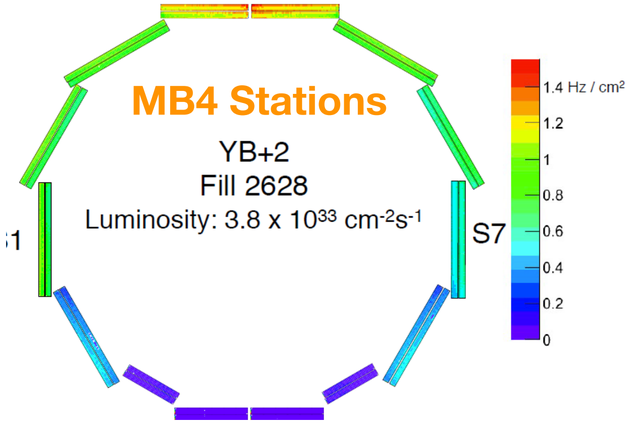


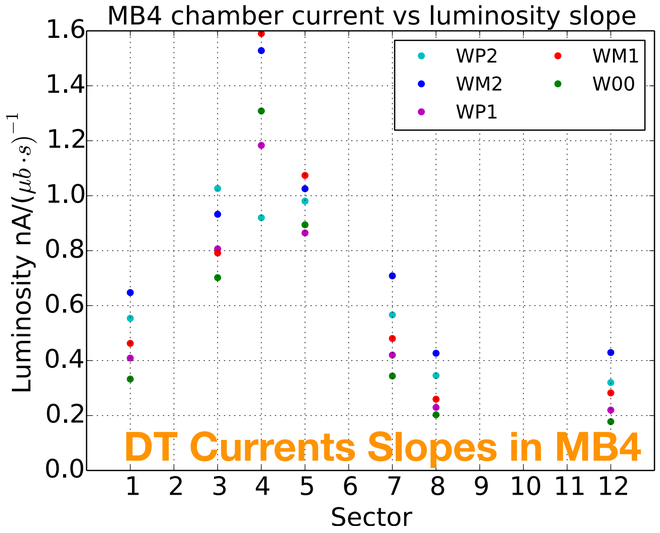
DT Rates at 3.8 x 10^{33} $cm^{-2}s^{-1}$

MB1 Stations



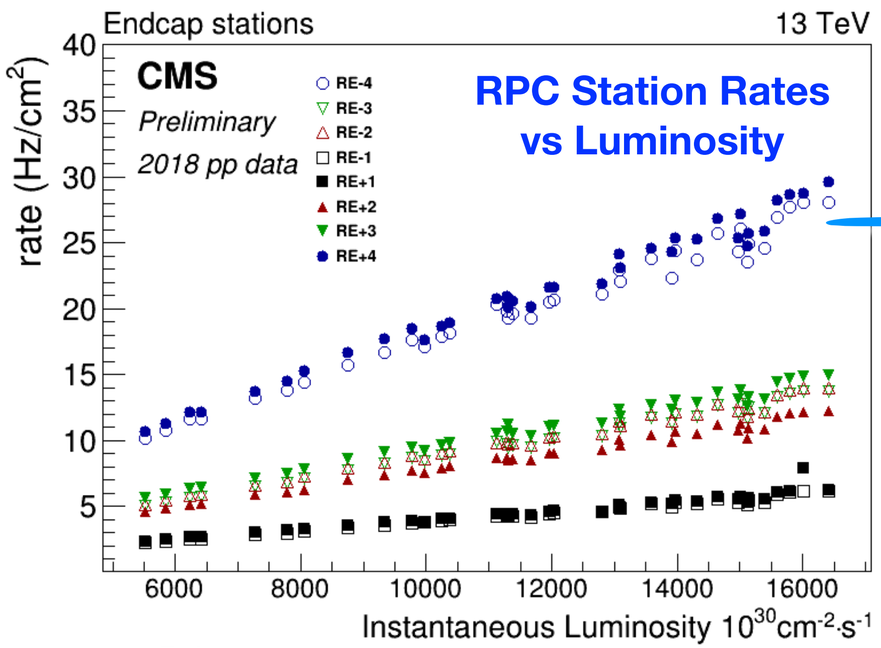
Gap in the calorimeters

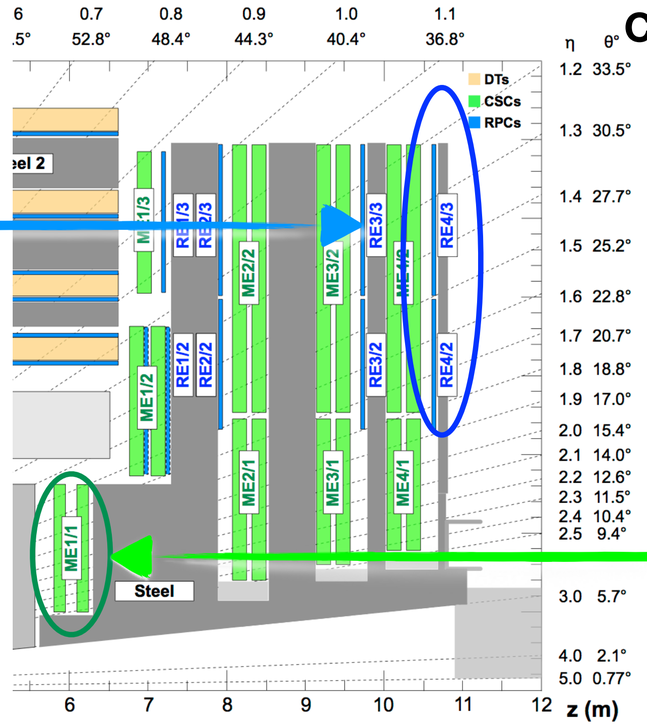




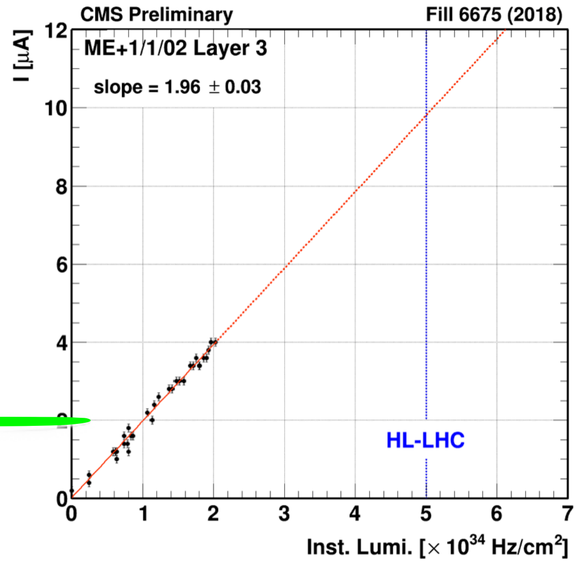
- Linear dependence of Hit Rates vs Instantaneous Luminosity
- Similar rate between the more internal and external station external stations
- Hot points in the **DT MB1** chambers in the external wheels linked to the gap in the calorimeters
- Background in MB4 is not φ-symmetric ⇒ **it affects more the top of the detector.**

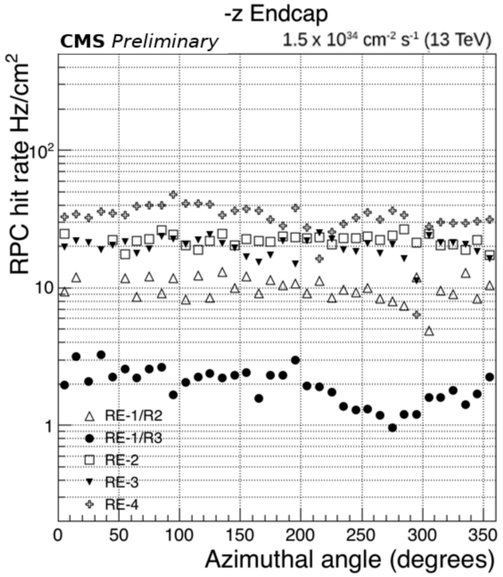
RPC and CSC EndCap Measurements





CSC ME+1/1 Currents vs Luminosity

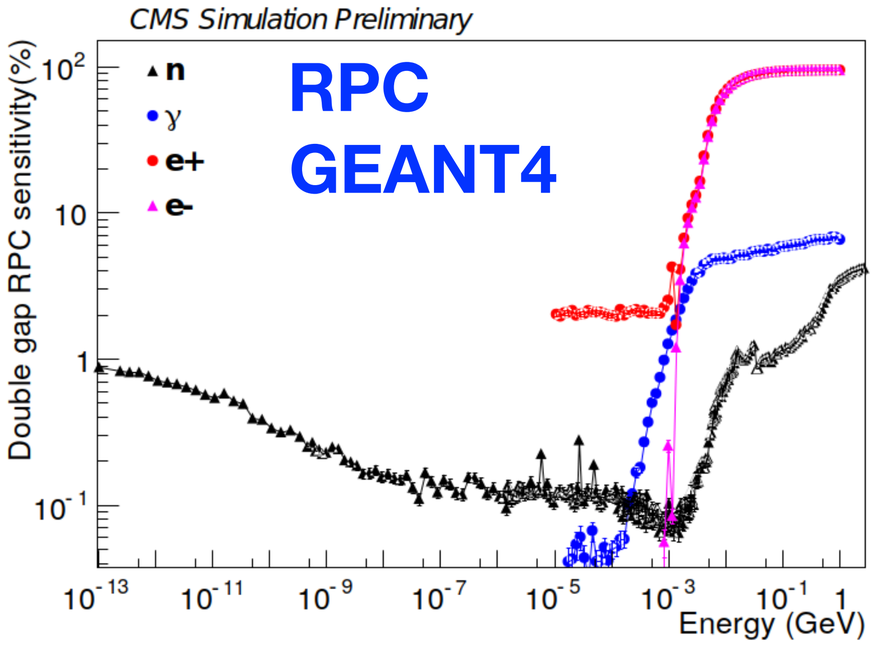




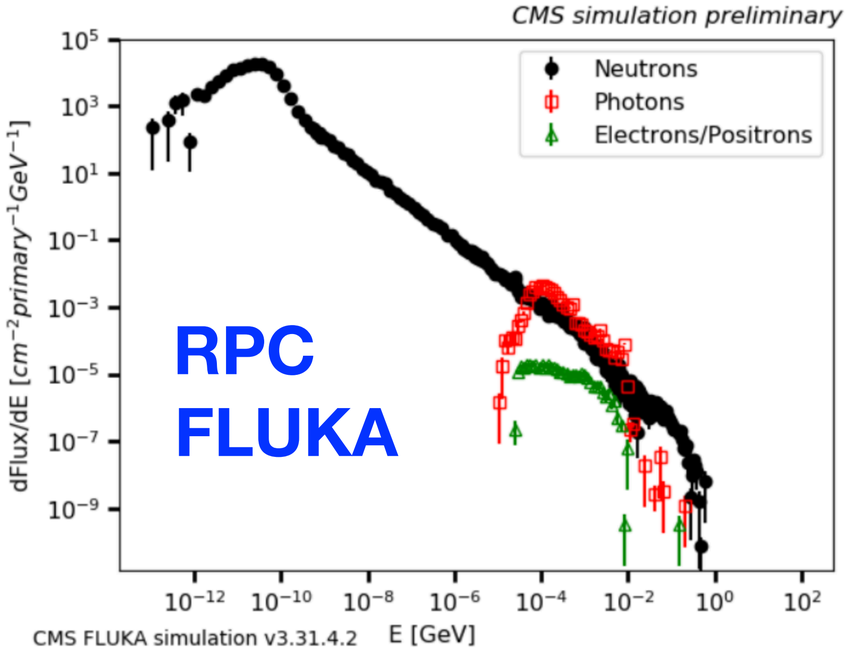
- The most exposed chambers are the one more far from the interaction point
  - In the Endcap small Φ-**asymmetry**
- Linear dependence of hit rates and currents on the instantaneous luminosity for every detector in all the range in Run2

Detector Sensitivities

- The Sensitivity of the detector is **needed to convert simulated fluxes to Hit Rates**
  - defined as the probability for a background particle to create a signal: $S = \frac{N_{signals}}{N_{incident\ particles}}$
  - computed as a function of the energy of the incident particle for different kinds of particles using GEANT4



+

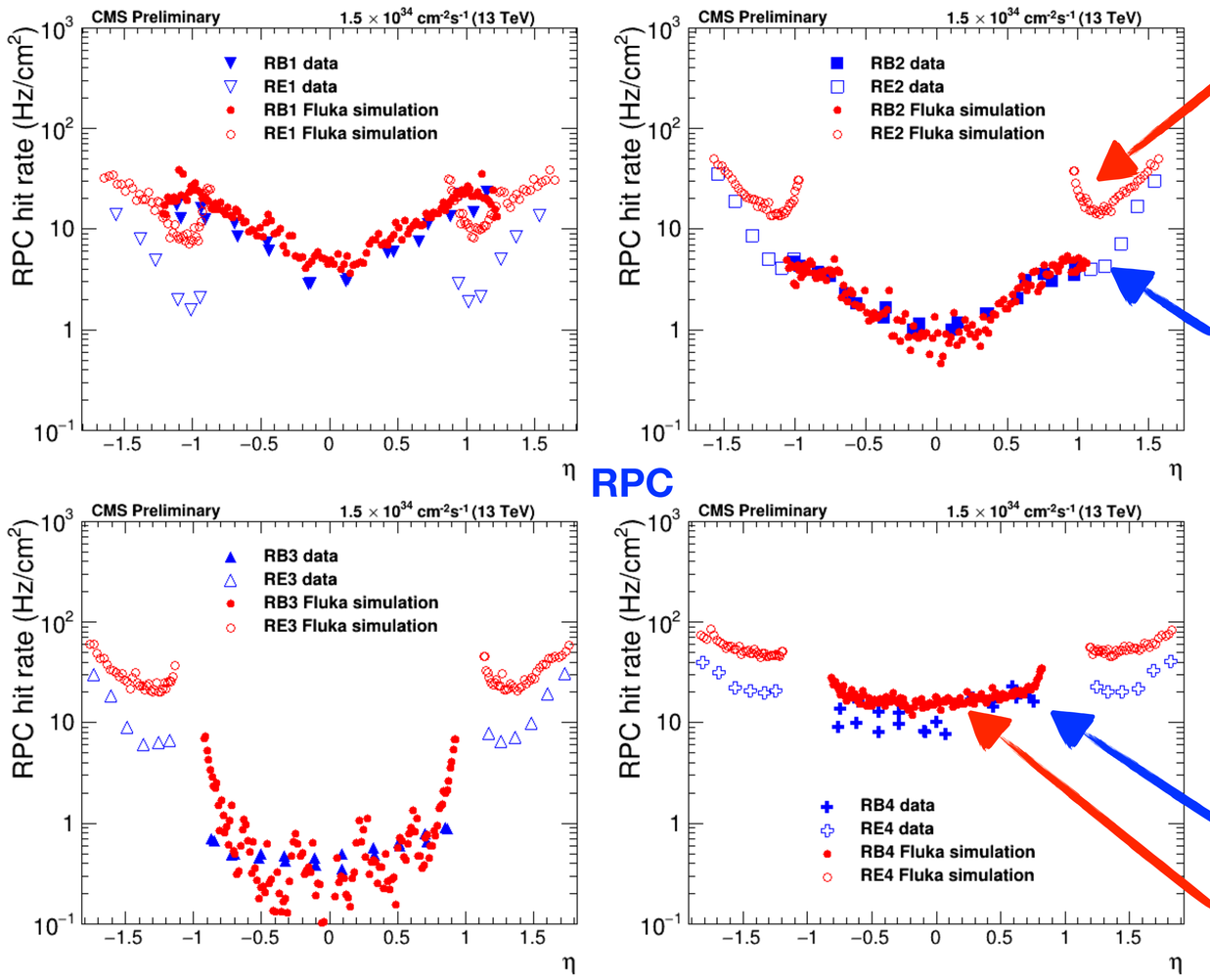


Predicted Hit Rates

Energy Spectra normalised to the Luminosity:

$$\sum \Delta(df/dE) * norm(R) = flux * norm(R) \quad flux\ @\ 1.5 \times 10^{34} cm^{-2} s{-}1$$

Data/Simulation Comparison



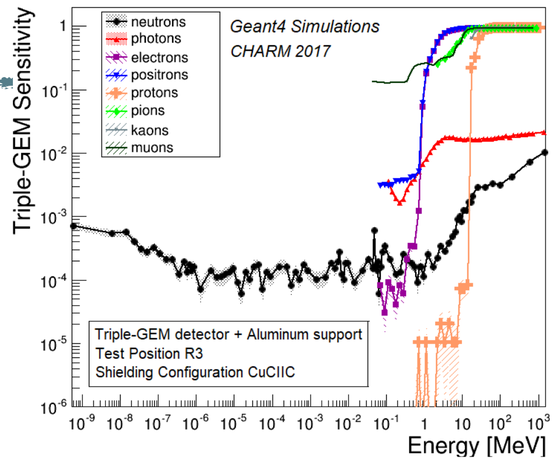
RPC

SIMULATION ENDCAP

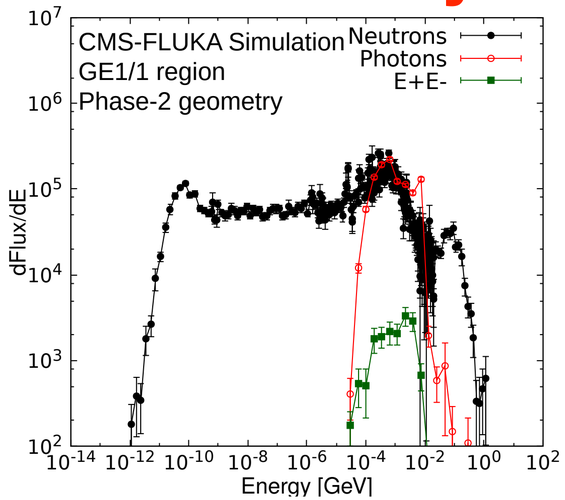
DATA ENDCAP

DATA BARREL

SIMULATION BARREL



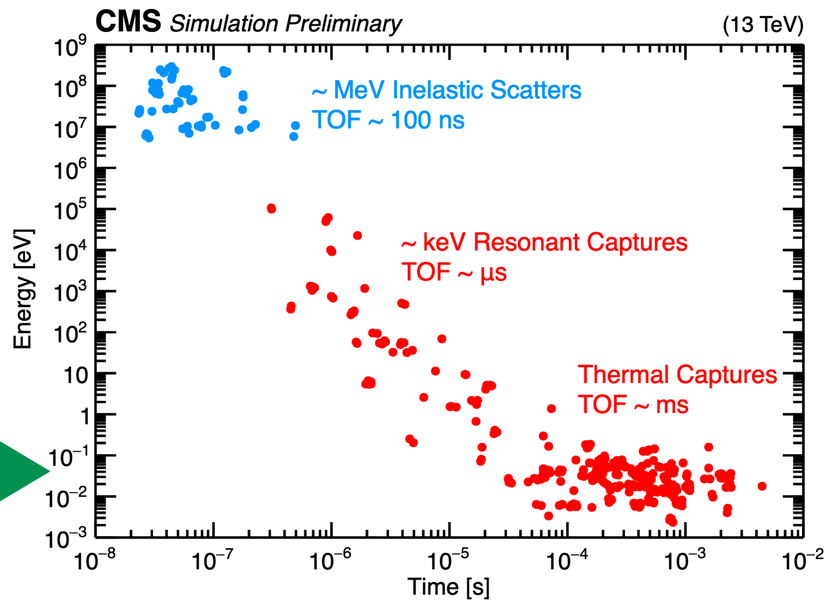
GEM Sensitivity

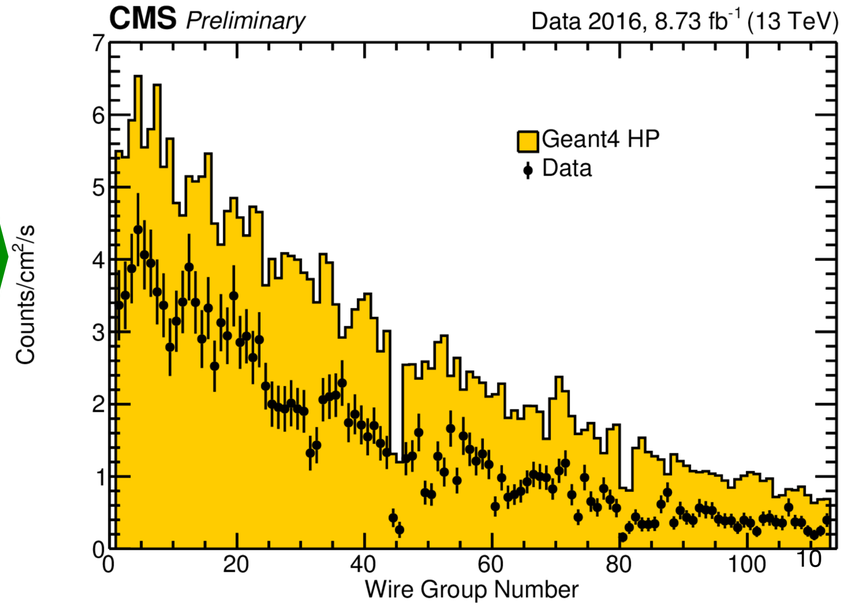


- Good agreement between the experimentally obtained results and MC predicted ones!
- Validation on data give confidence on the use of simulation for new detectors

Neutron-induced background in CSC

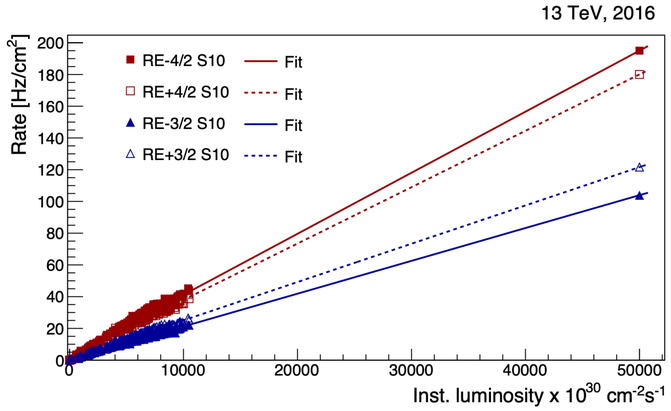
- Study on the impact of increased hit rates at HL-LHC due to **fast (~MeV) and thermal neutrons**
  - cause of **delayed hits** due to γ emitted by neutron capture
  - expected hit regime evaluated in simulation
  - delayed hits **measured in data** using the structure of the LHC bunches
  - results compared to specially modified GEANT4 simulation
  - For all CSCs at various rand z positions, **simulation reproduces data to within a factor of 2**

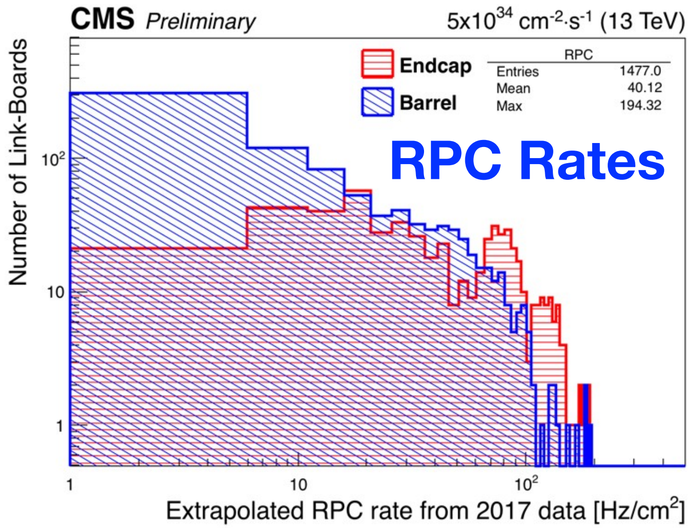


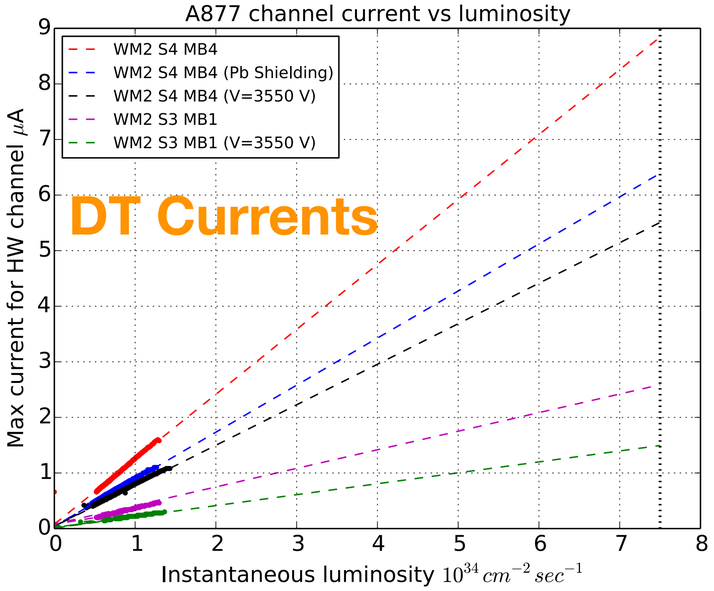


HL-LHC Extrapolation

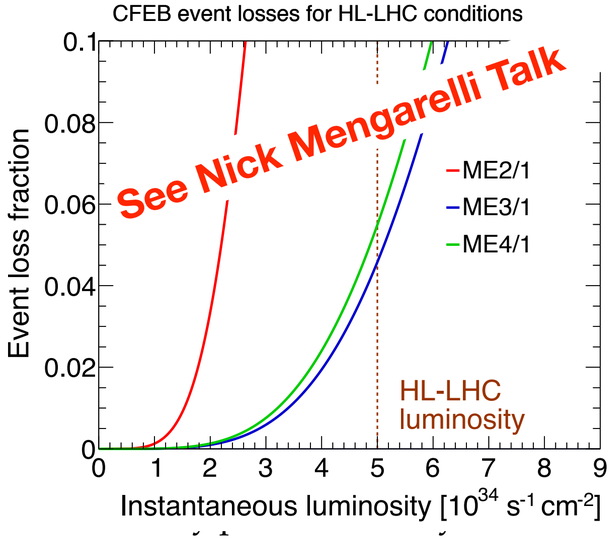
- **Linearity of Currents and Hit Rates ➜ extrapolation to HL-LHC conditions from measured data**
- Together with simulation clear picture of HL-LHC conditions
  - important for new detector developments
  - evaluation of the intervention on existing detectors







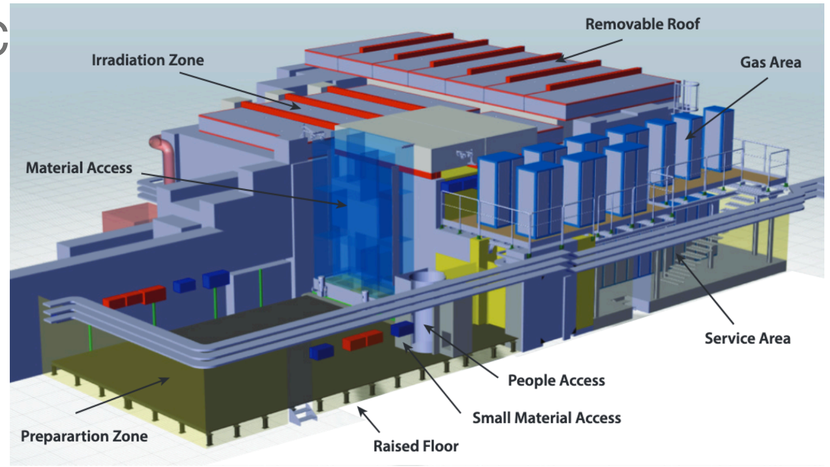
CSC FEB Data Loss



$\lvert\eta\rvert$ 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

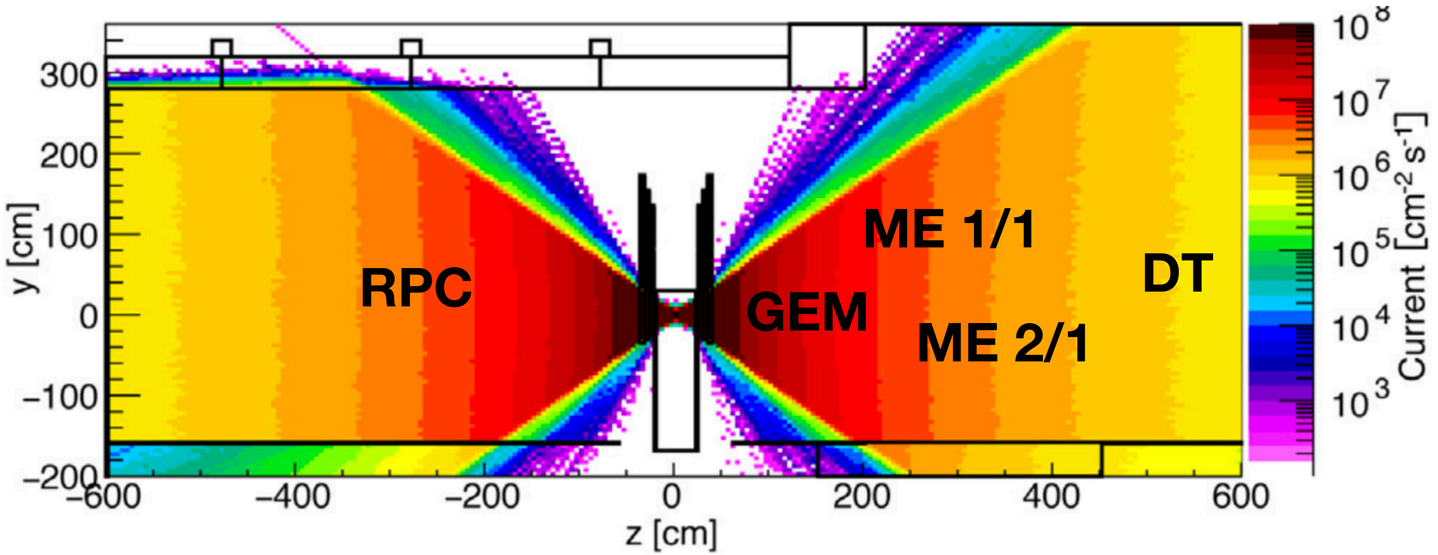
Background and Ageing

- GIF++ used to certify existing and new detectors at the extrapolated HL-LHC conditions
- ^{137}Cs source, intensity 14 TBq, emitting 662 keV photons, plus a high momentum muon beam (100 GeV)
  - **realistic environment:** neutron-induced photons have an energy in the range 0.1–10 MeV.
  - long period of irradiation to study ageing
  - allows detector performance studies with a high momentum muon beam (100 GeV) in the presence of high radiation

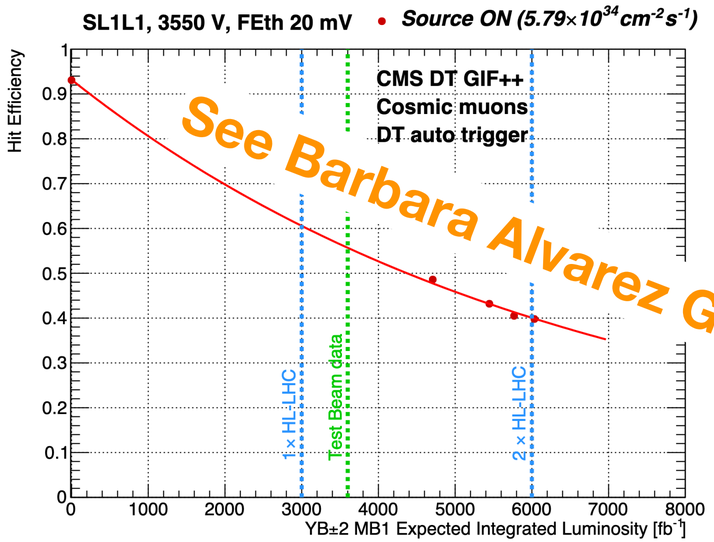


Chambers under test:

- 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

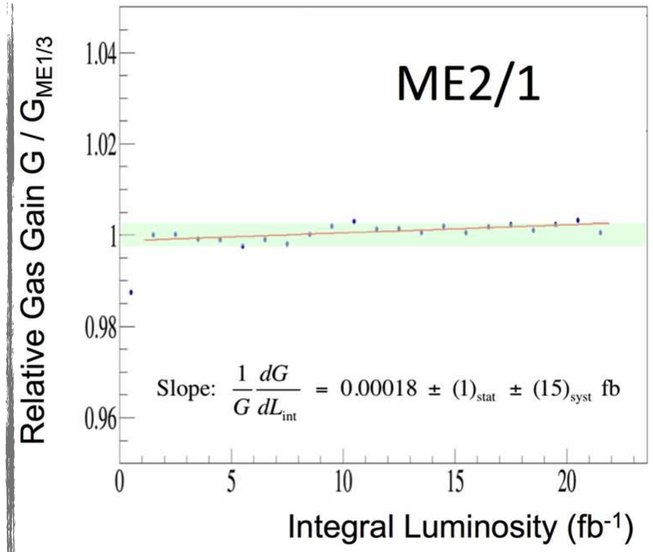


GIF++ results



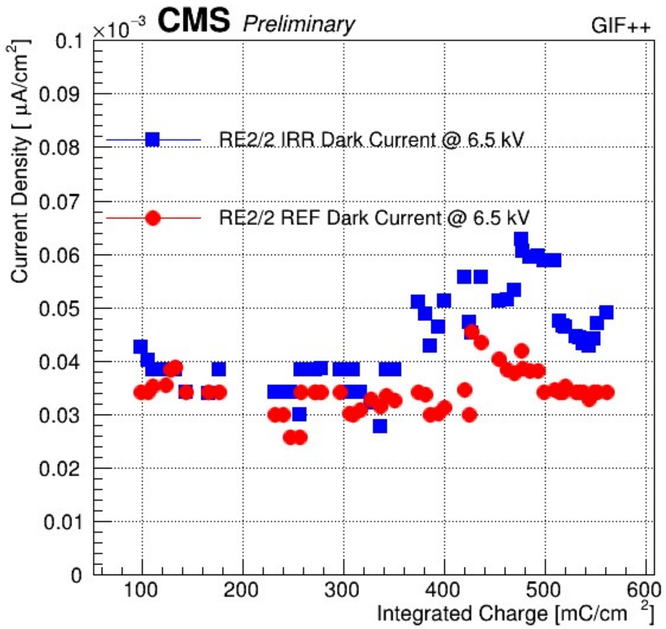
See Barbara Alvarez Gonzalez Talk

DT:
Strong evidence of ageing!



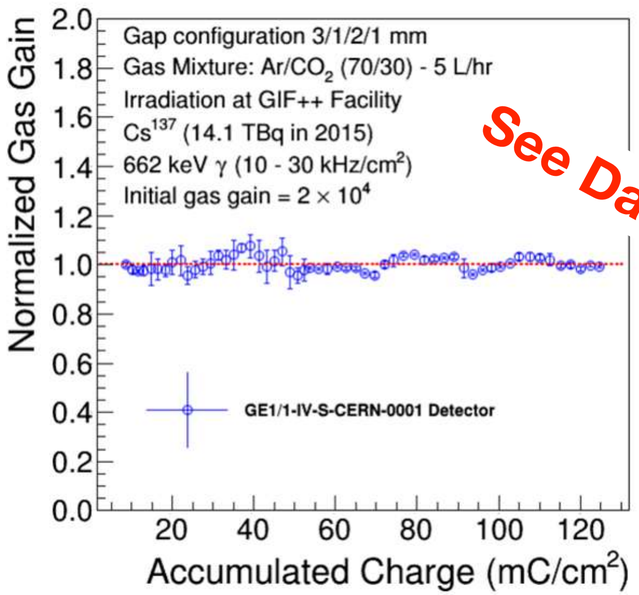
CSC

- Total integrated charge of 330 (ME1/1) and 340 (ME2/1) mC/cm
- **No noticeable gas gain loss** up to 3 × HL-LHC



RPC:

- **No noticeable effects** of detector degradation up to ~600 mC/cm²
- Longevity tests also on large size prototype of **iRPC**
  - **main parameters are stable so far**
- Tests are ongoing



See Davide Fiorina Talk

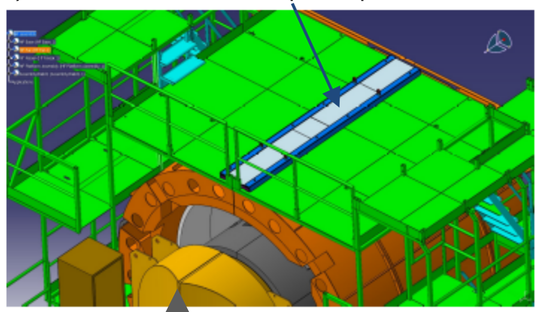
GEM:

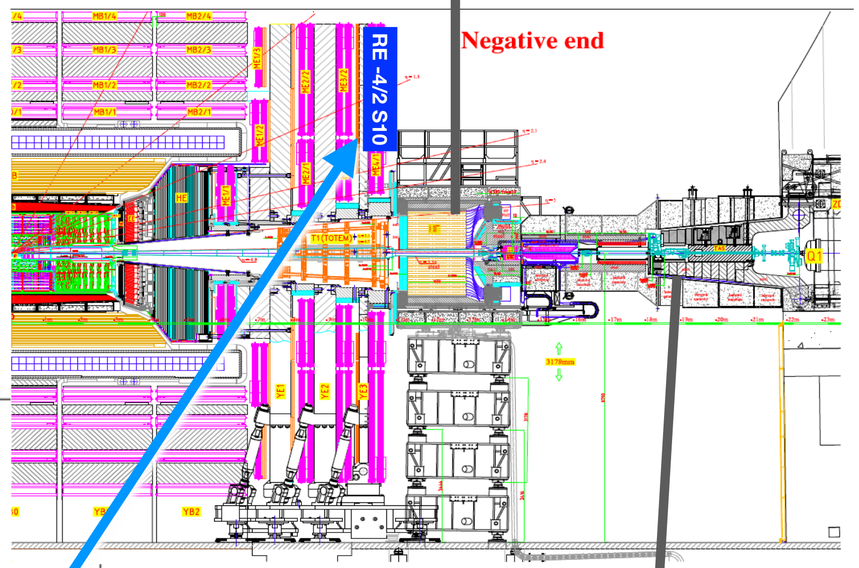
- **No ageing observed**

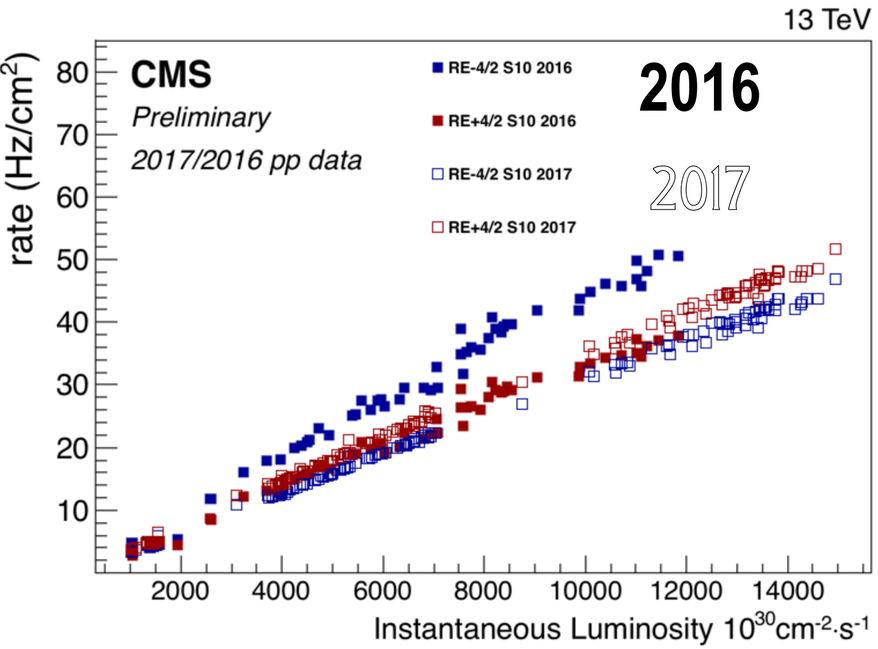
Background Mitigation: Forward Shielding

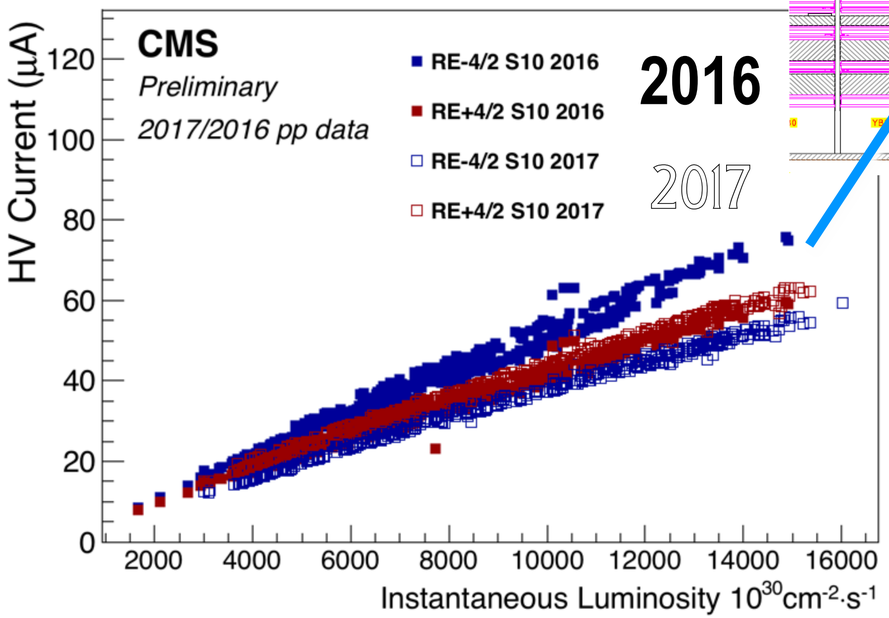
- **Leakage in the forward shielding** is one of the main source of background in the experimental cavern
- Additional shielding have been installed in the Christmas break between 2016 and 2017
  - Obtained a reduction in the currents and hit rates of the most exposed chambers
- Improvements in the forward shielding are planned during **LS2**

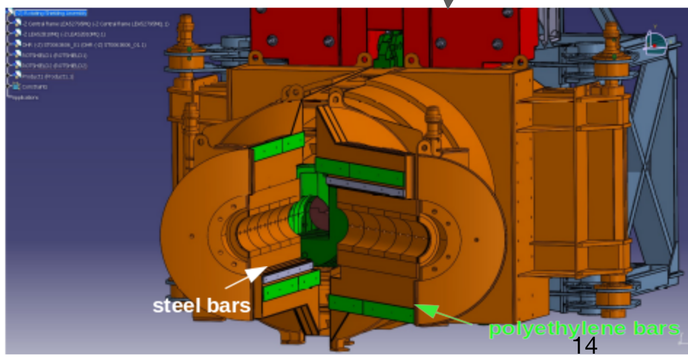
(45mm) of BOROTRON UH 050 plates plus 20mm of lead





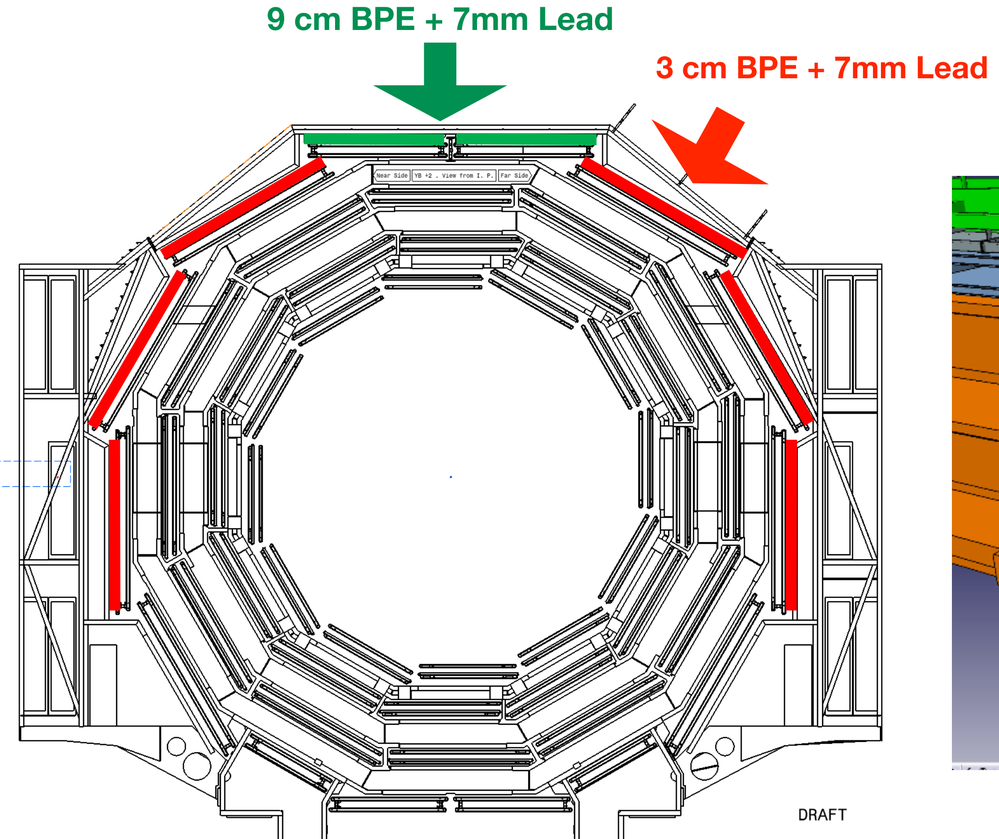


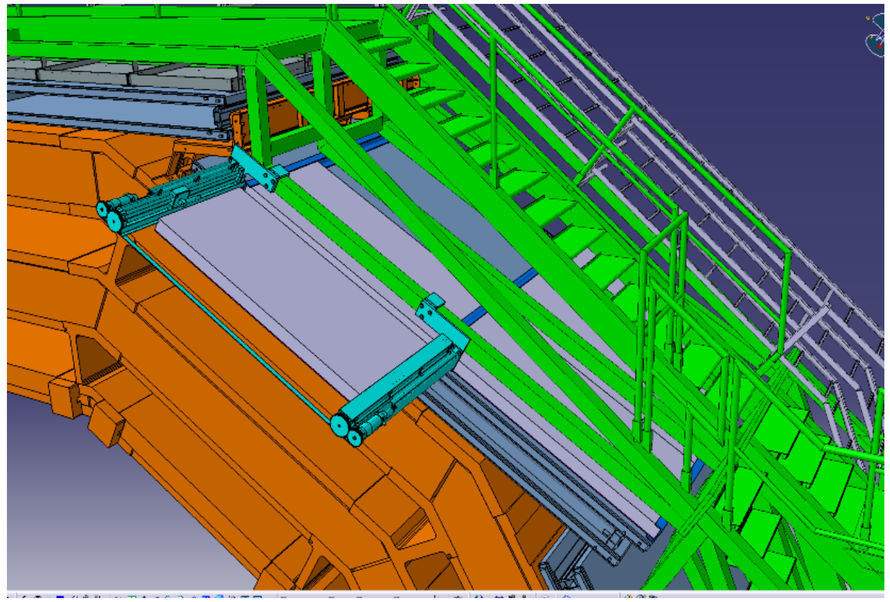


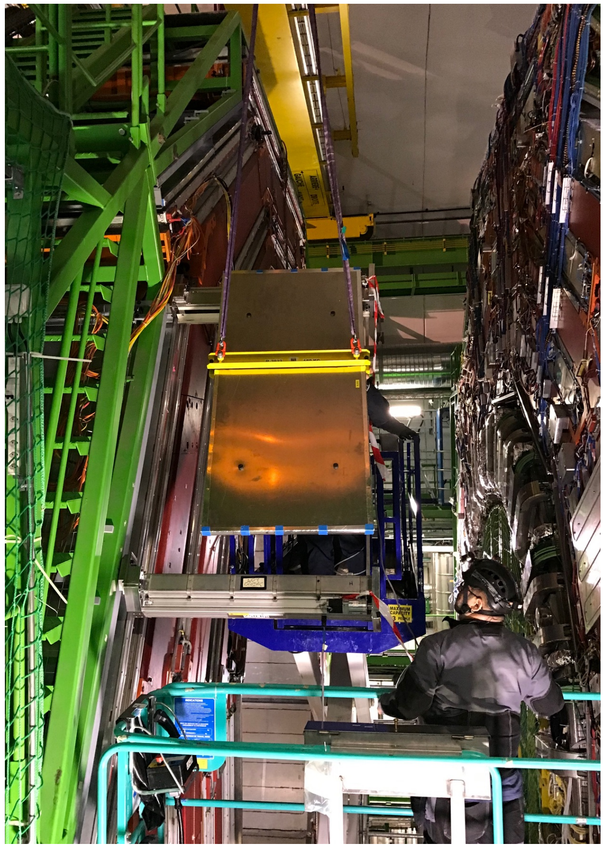


Background Mitigation: Barrel Shielding

- Results at GIF++ have shown the risk of **fast ageing** for DT due to depositions on the wires
- A shielding is being installed in LS2 on the top of the detector to reduce neutron induced charge production
- **Different prototypes tested in Run2**
  - final design uses Borated Polyethylene (**BPE**) to attenuate and absorb neutron radiation plus lead for photons
  - HV currents halved with **3cm BPE +7mm of lead** on a single chamber







Conclusions

- Extensive program of **measurements on the radiation background** in the CMS Muon system during LHC operations.
- **Simulation**, using FLUKA for flux and dose estimation, and GEANT4 for sensitivity studies, **well describes the data.**

- Detailed description of **expected radiation background.**
- **Essential an input for**
  - **future operations**
  - **new detector design**

- Longevity tests being performed at the CERN **GIF++** facility show **no evidence of ageing effects** for most of the Muon detectors, **except for the DT**
- **Improvements on the shielding** are ongoing during LS2 in order to reduce the large background coming from neutrons in the CMS experimental cavern

- **Public results at: https://twiki.cern.ch/twiki/bin/view/CMSPublic/MuonDPGResults**
- **Muon Upgrade TDR: https://cds.cern.ch/record/2283189**