IPRD2019, 14-17 Oct 2019, Siena (Italy)

Study of the Effects of Radiation at the CERN Gamma Irradiation Facility on the **CMS** Drift Tubes Muon Detector for the HL-LHC

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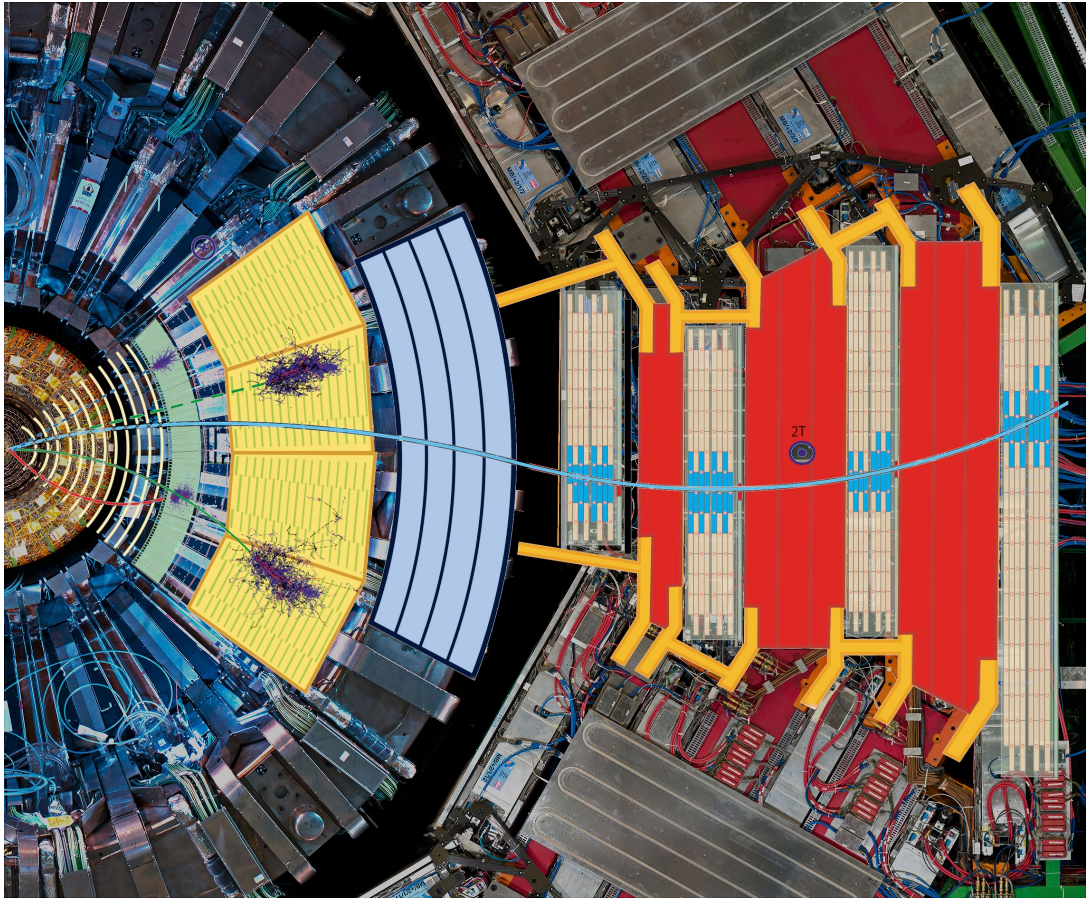
Overview

- CMS Muon System:
  - DT chambers, DT cells
- HL-LHC
- GIF++
- Hit efficiency definition
- Dose measurements
- Results
- Mitigation Actions
- Conclusions



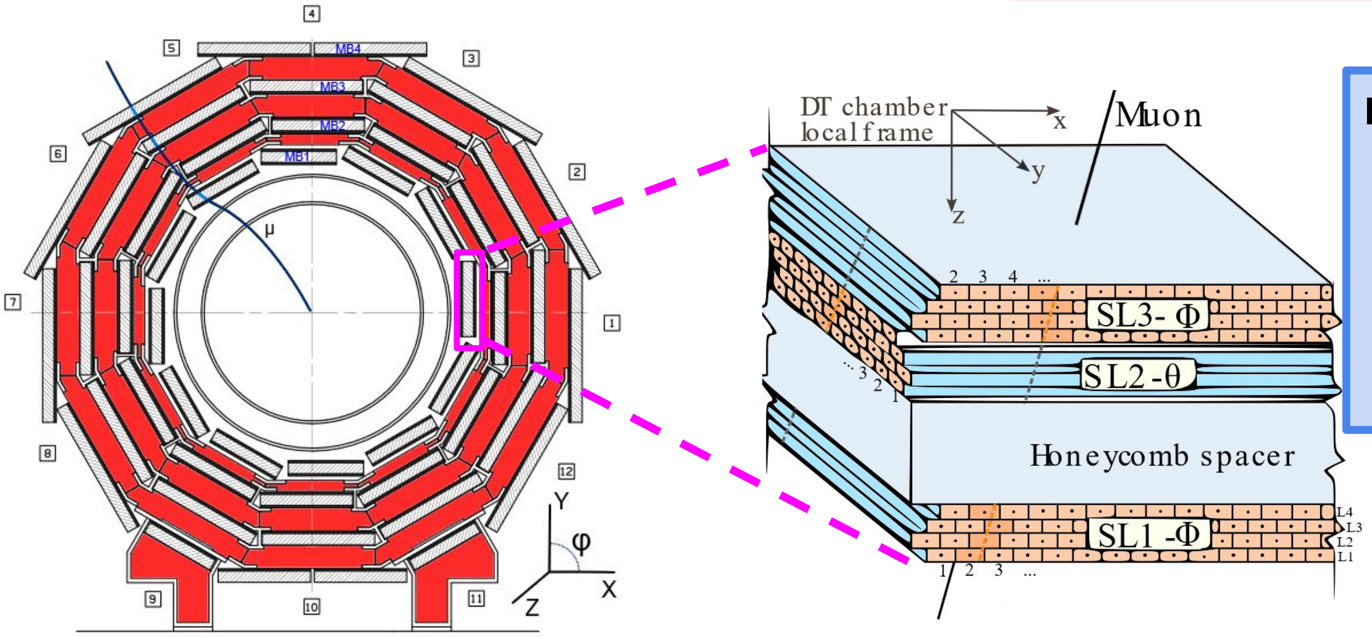
CMS Muon System: DT Chambers

Equip the barrel of the CMS muon spectrometer

A Drift Tube chamber (**DT**) is a gas detector designed to measure with great precision the position of muons from the LHC collisions

250 DT chambers in total:

- 4 concentric rings of stations **(MB1-4)**
- 12 sector slices **(S1-12)**
- 5 wheels in the whole barrel **(YB-2-+2)**



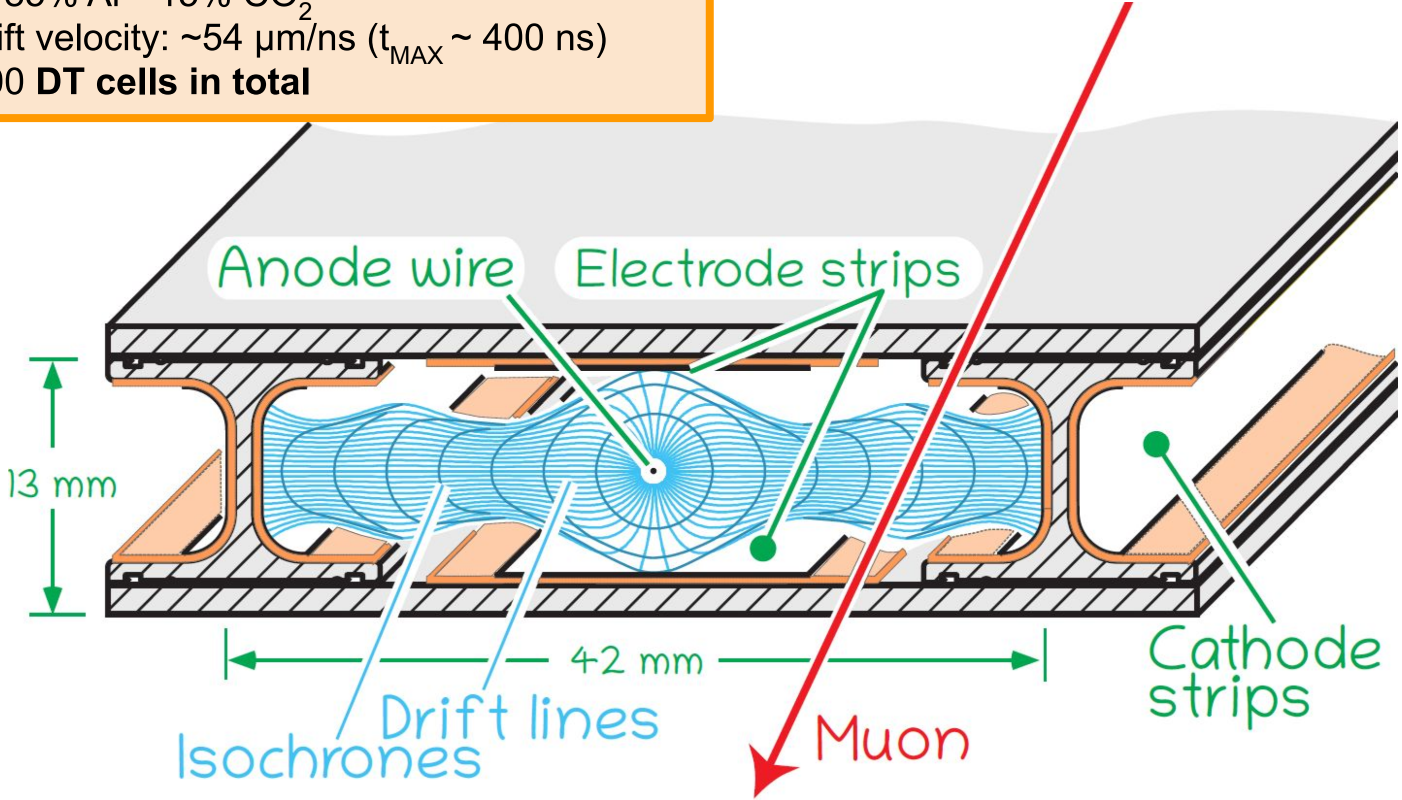
DT chamber:

- Group of 4 detection **layers** form a super-layer (SL)
- 2 SLs in r-φ + 1 SL r-z (for 3 innermost stations)

DT Cell

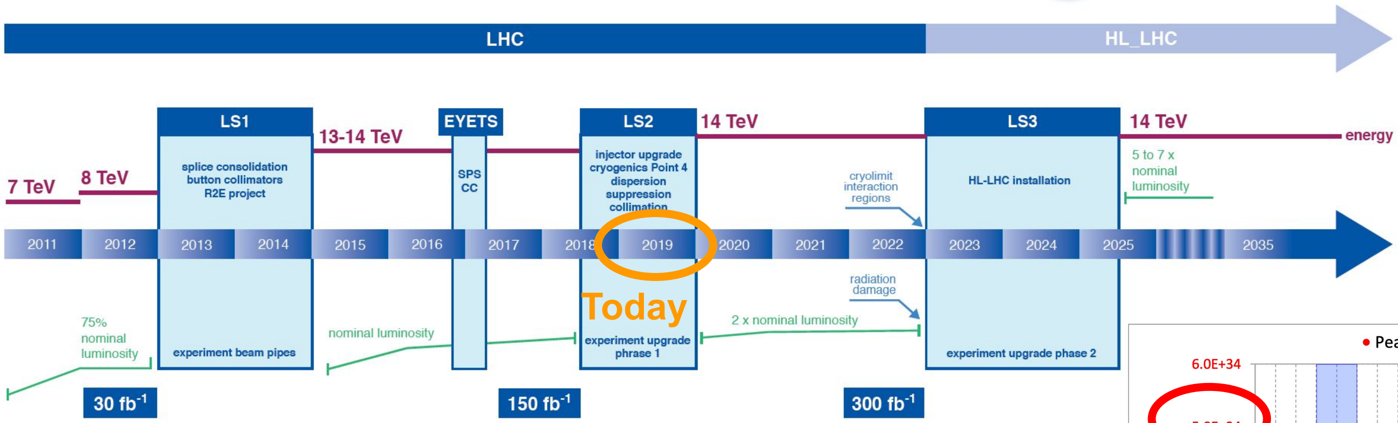
DT drift cell:

- Size: 4.2 x 1.3 mm
- Gas mixture: 85% Ar - 15% CO_2
- Constante drift velocity: ~54 µm/ns (t_{MAX} ~ 400 ns)
- About 172 000 **DT cells in total**



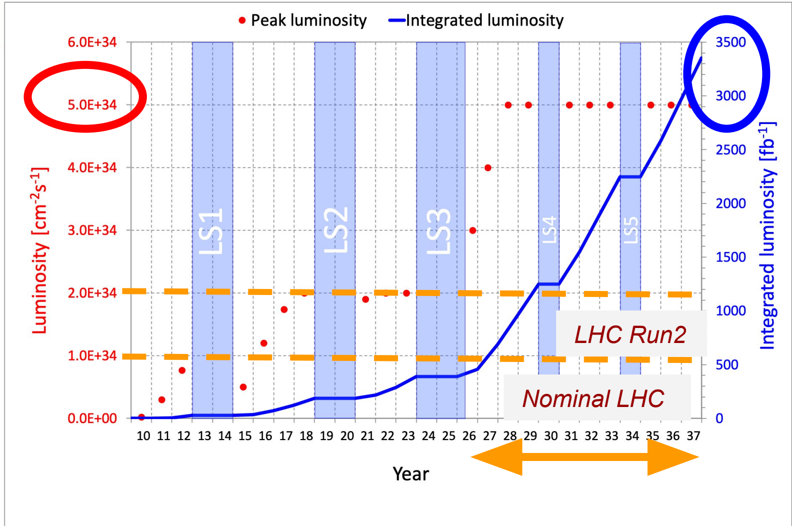
High Luminosity LHC

LHC / HL-LHC Plan



Longevity studies to test the DT chambers **performance** throughout the HL-LHC:

- Instantaneous luminosity increase: 5 to 7 x nominal luminosity ⇒ 5×10^{34} cm^{-2} s^{-1}
- Integrated luminosity increase by 10x: up to **3000 fb^{-1}** by the end of the HL-LHC

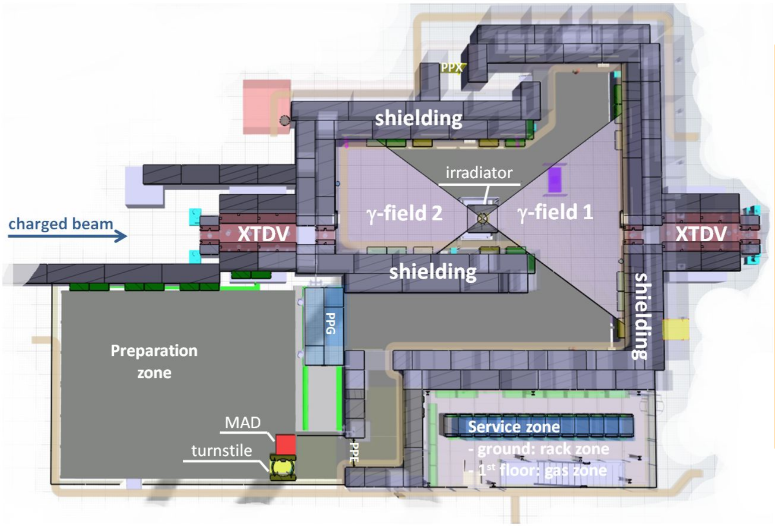


Gamma Irradiation Facility at CERN (GIF++)

Irradiation & Muon test beams: The Gamma Irradiation Facility (GIF++) combines:

- A high energy charged particle **muon beam**
- And a ~14 TBq ^{137}Cs source that produces a **background** γ field

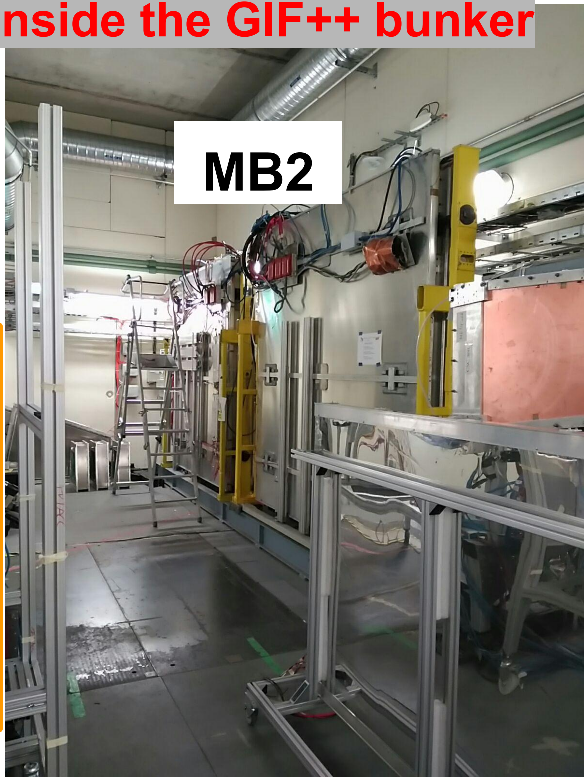
Allows to accumulate doses similar to HL-LHC in a reasonable time



Studies:

- Perform irradiation campaigns
- Generate background (dedicated filters) for studies with **muon beams** and **cosmic rays**

Picture of the DT chambers inside the GIF++ bunker



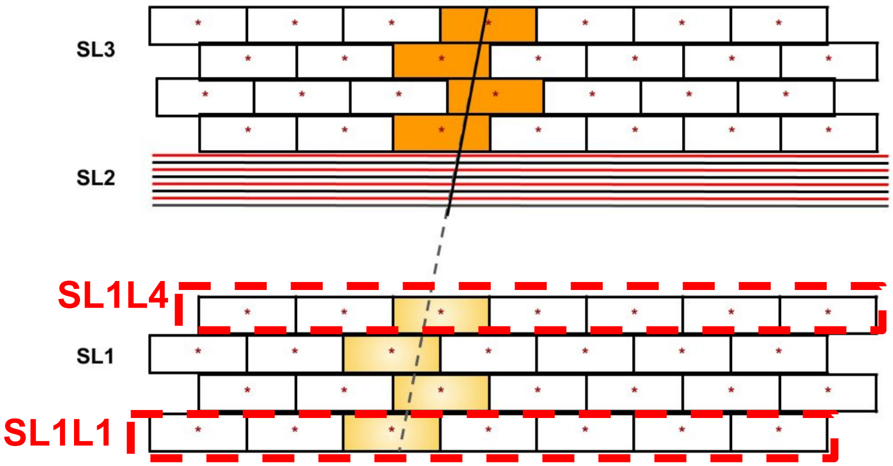
Hit Efficiency Estimation

All layers irradiated, but only 2 layers aged:

- The *layers 1* and *4* from *SL1* (**SL1L1** and **SL1L4**) irradiated with HV on at **3550 V**: *aged layers*
- The rest of chamber irradiated with HV in standby (**1900 V**): *non-aged layers and used as reference*

$$\varepsilon_{hit} = \frac{\sum hit_{detected}}{\sum hit_{expected}}$$

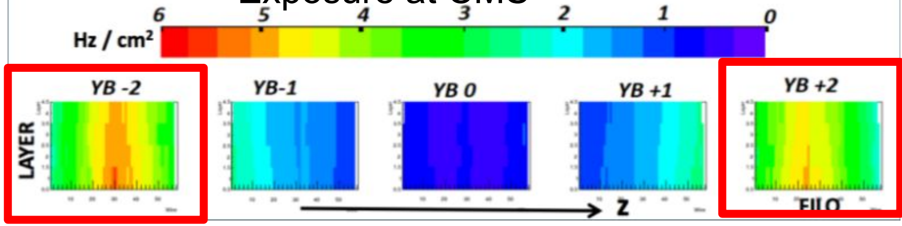
DT chamber --- Muon Track



The position of expected hits is determined using as probes sets of **well reconstructed track segments** with associated hits in at least 4 layers in **SL3** and at least 1 layer in **SL1**

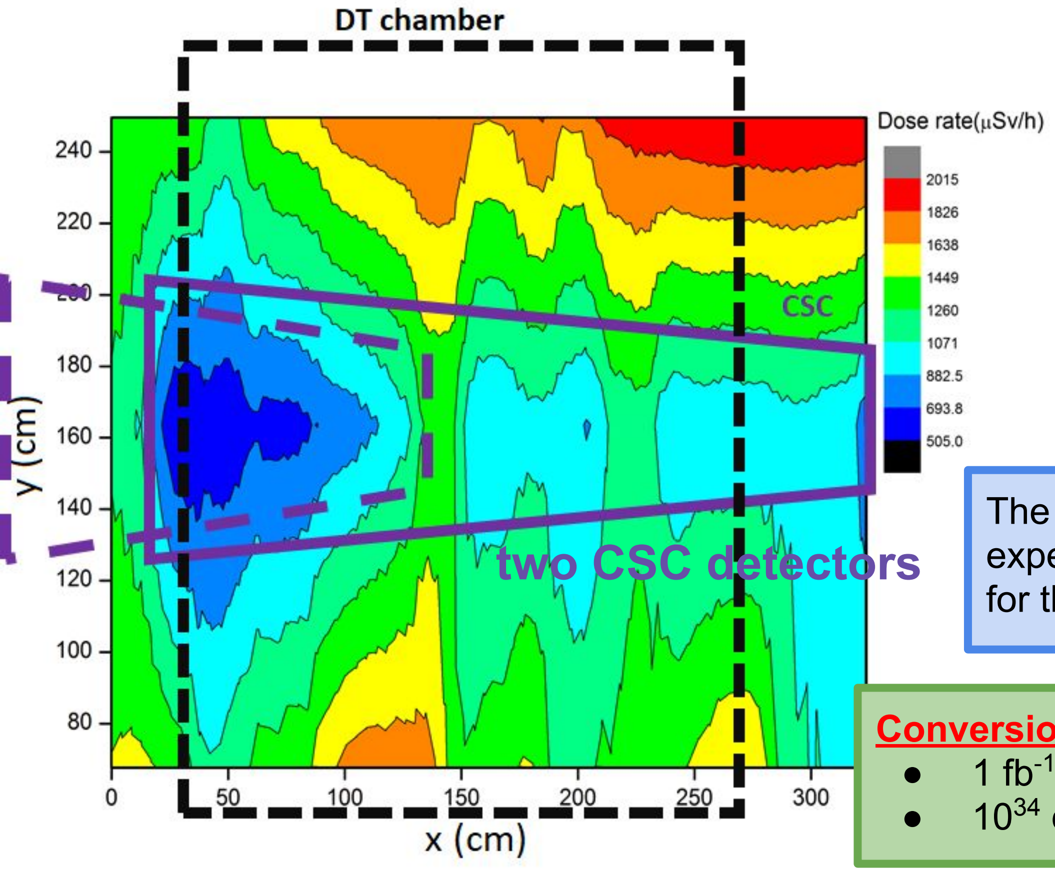
- In addition, non homogeneous background rate distribution
- Most exposed DT chambers located at high pseudorapidity, in the innermost part of the muon system **MB1 YB±2**

Exposure at CMS



Dose Map

Inhomogeneous irradiation profile on the detector



- Dose rate profile just in front of the MB2 DT chamber (facing the source) installed at GIF++
- Other detectors under irradiation placed between the source and the DT chamber (like **CSC**)
- Portable dosimeter measurements

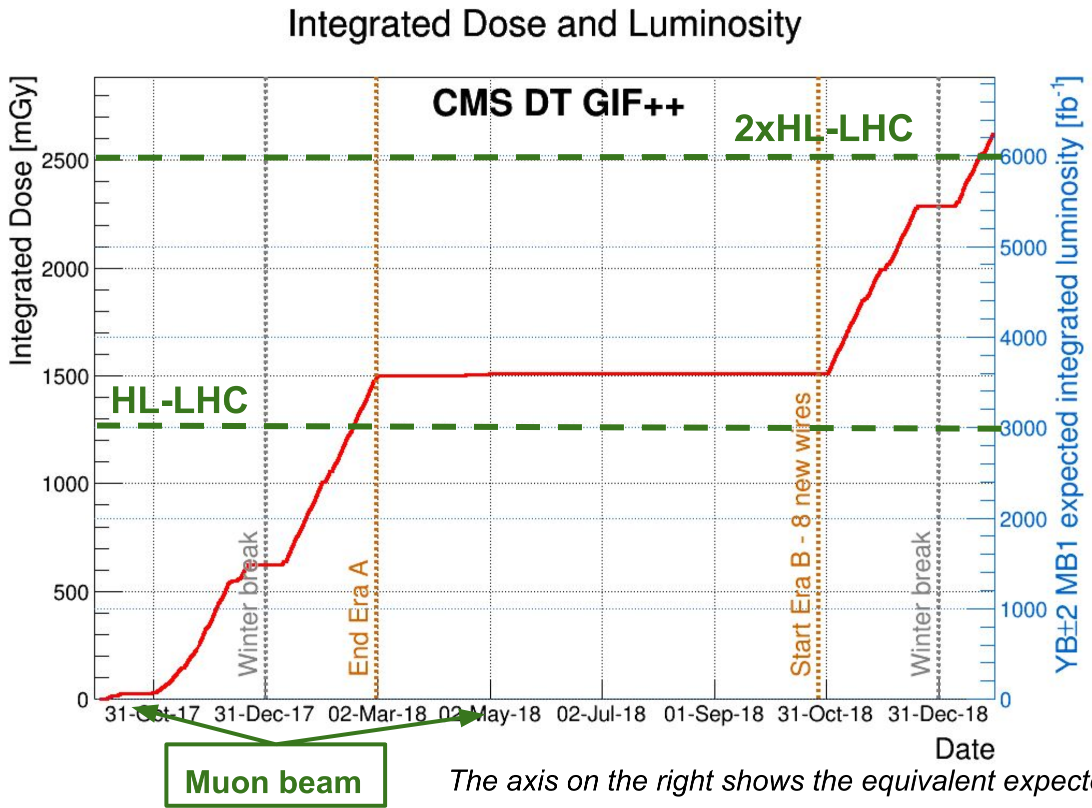
The **dose rate and integrated dose** are **converted** to expected *instantaneous* and *integrated* luminosities for the MB1 YB±2, most exposed chambers

Conversion factors:

- 1 fb^{-1} = 0.42 mGy int. dose → int. luminosity
- 10^{34} $cm^{-2}s^{-1}$=0.0109mGy/h dose rate→ inst. luminosity

Data-taking

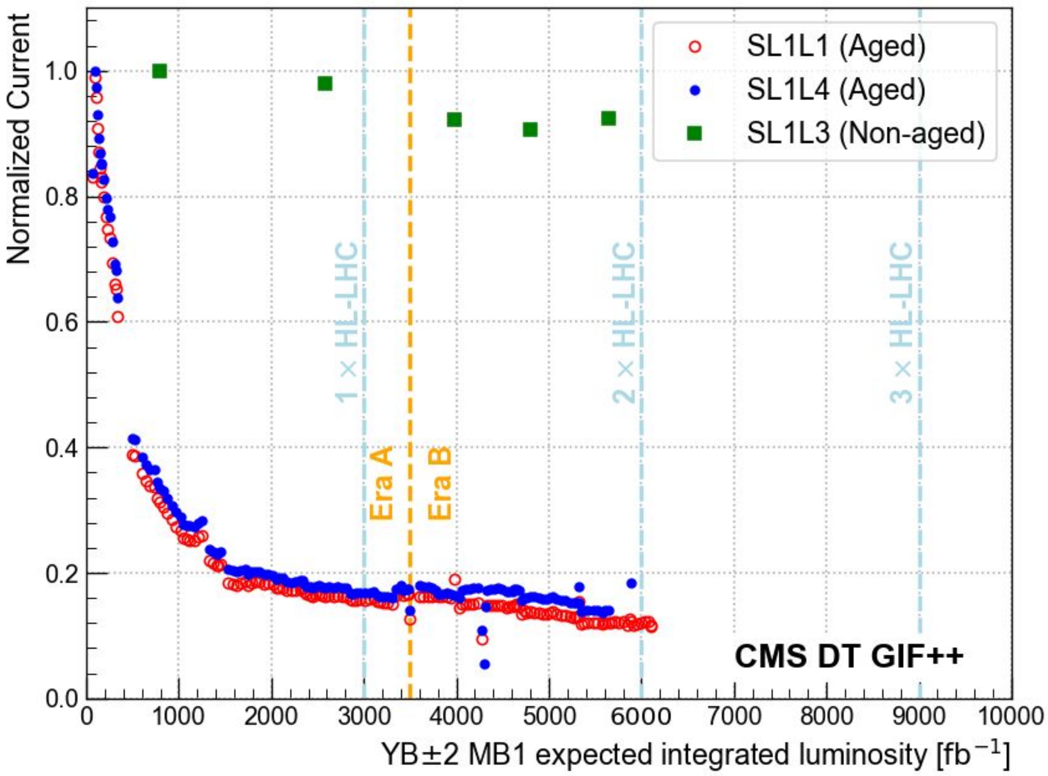
Integrated dose and luminosity as a function of time for the irradiation period of the CMS DT spare chamber 'MB2'



The axis on the right shows the equivalent expected luminosity for MB1 YB+/-2 for the HL-LHC

- Data taken in **two campaigns** (eras) during 2017-2019
- The chamber was irradiated full time at **~10 times** the expected dose at HL-LHC
- Muon test beam data recorded at 2 points in time
- One day a week the source **OFF** for interventions in the bunker:
  - HV scans
  - FEth scans
- One day a week source scans:
  - Different filter configurations
  - Same test as source **OFF**

Normalized Current as a function of Integrated Luminosity

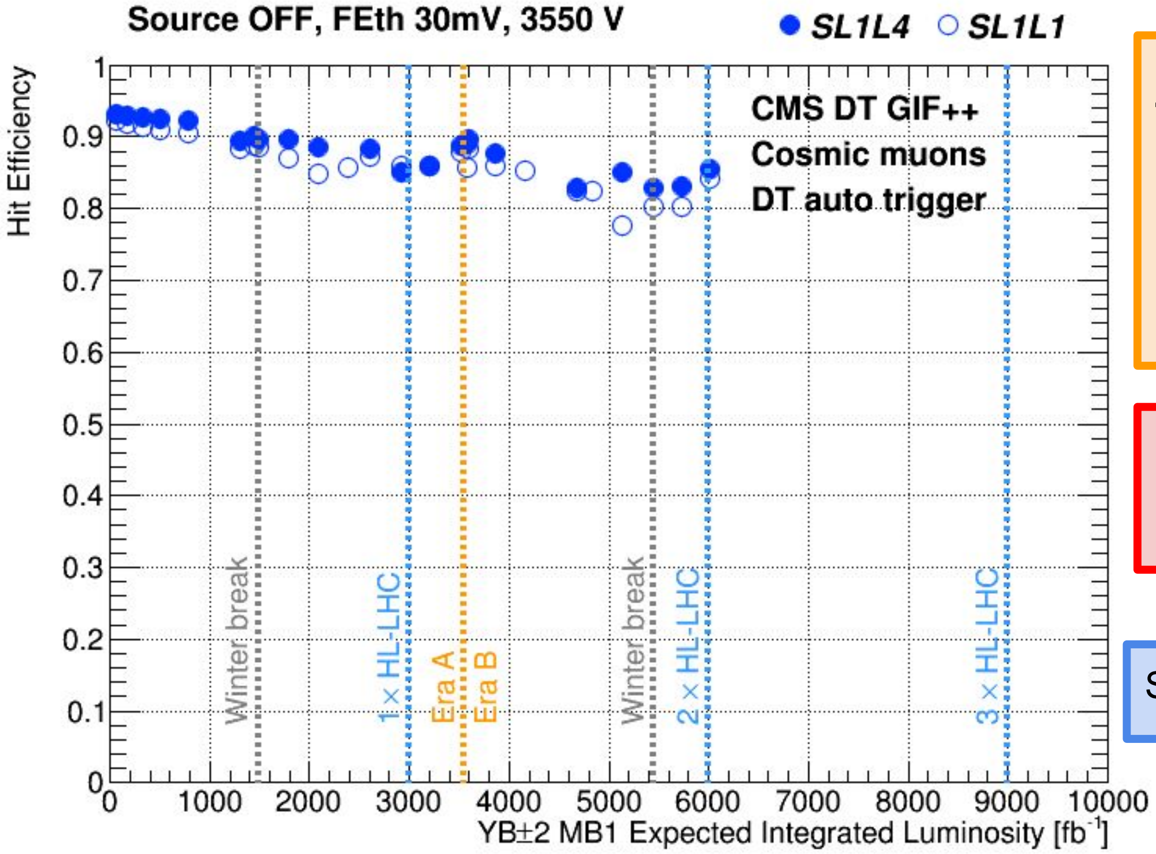


- Measurements for aged (**SL1L1** and **SL1L4**) and non-aged (**SL1L3**) @ 3550V
- Values *scaled* to the initial value measured in *SL1L3*
- **Corrections** for the measured ambient **pressure**
- Gaps are caused by the loss of monitoring

Main current drop during the first 1000 fb^{-1}

Hit Efficiency Evolution

Hit efficiency as a function of integrated luminosity



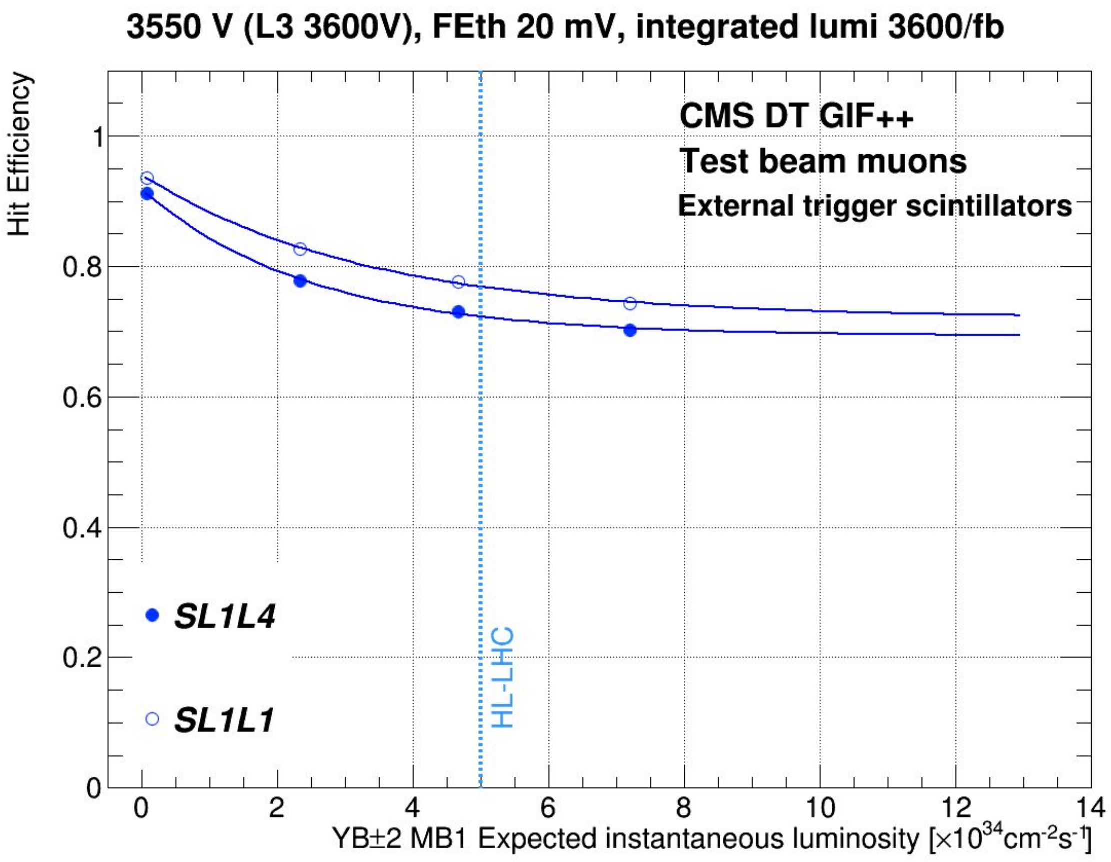
Data-taking during HV scans

- Cosmic muon data
- Aged layers (SL1L1 and SL1L4)
- At **3550** V
- FEth 30 mV
- Source off

Data collected up to **2xHL-LHC** expected integrated luminosity

Small (5%) hit efficiency decrease observed

Hit Efficiency vs Instantaneous Luminosity



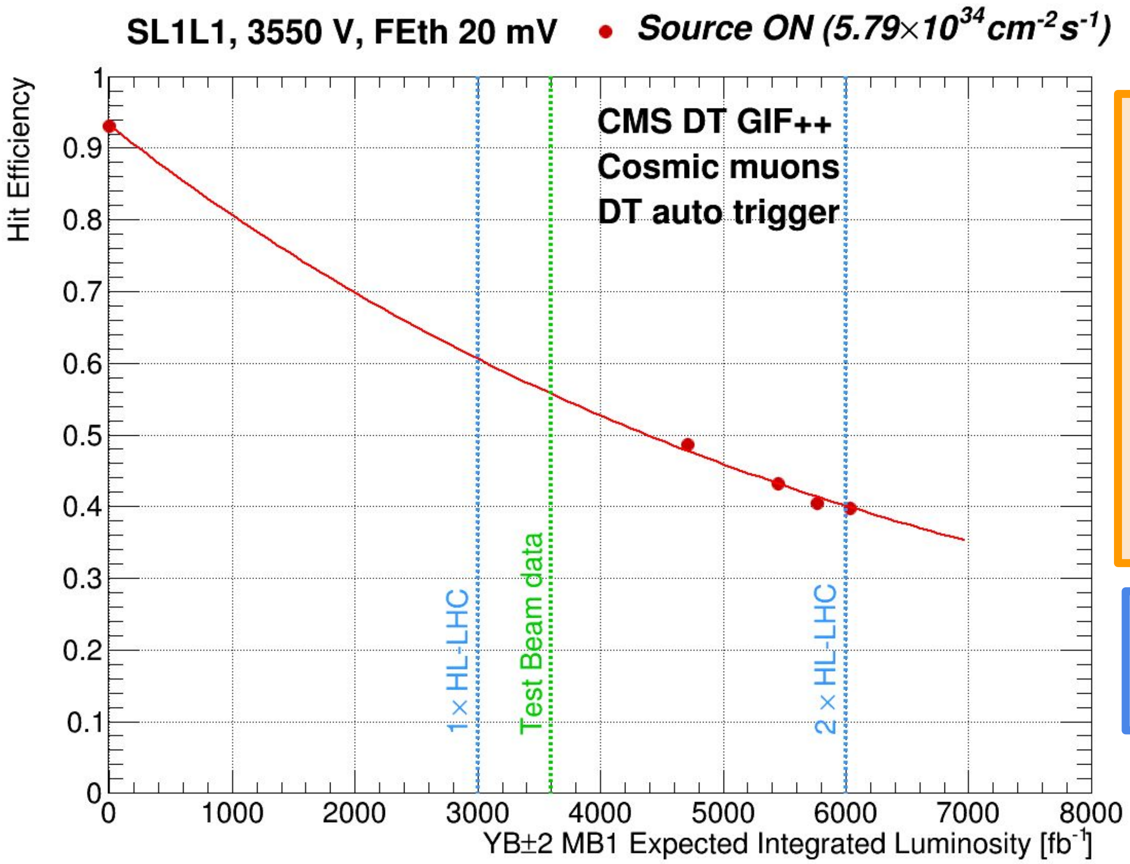
Data-taking conditions:

- Test beam muons
- Aged layers (SL1L1 and SL1L4)
- At 3550 V
- Front-end threshold of 20 mV

The test beam performed after an irradiation integrated dose equivalent to a **HL-LHC int. luminosity** of **3600 fb^{-1}**

The data are fitted using an exponential mode

Hit Efficiency vs Integrated Luminosity



Data-taking conditions:

- Cosmic muons
- Aged layer SL1L1
- At 3550 V
- FEth 20 mV
- Front-end threshold of 20 mV
- At a **background rate** slightly higher than the expected background rate at the HL-LHC (5.79×10^{34} $cm^{-2}s^{-1}$)

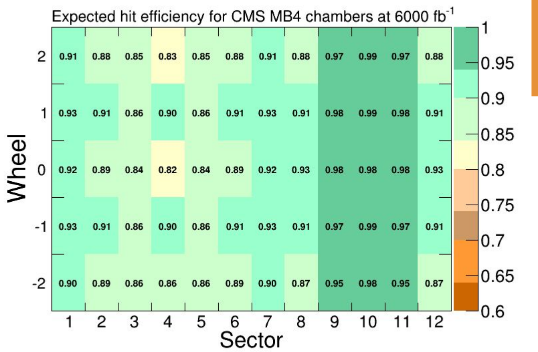
Significant **drop of efficiency** after an accumulated dose equivalent to 2xHL-LHC

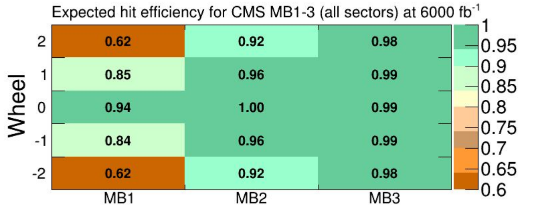
The data are fitted using an exponential mode

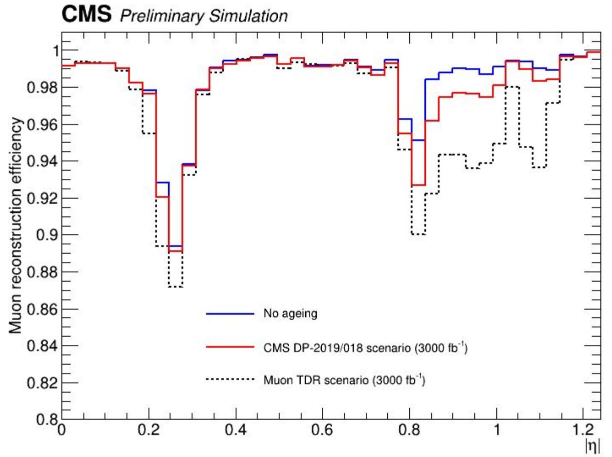
Expected Hit Efficiency: Full system

Expected hit efficiencies at the end of the HL-LHC for all the DT chambers of the CMS muon system

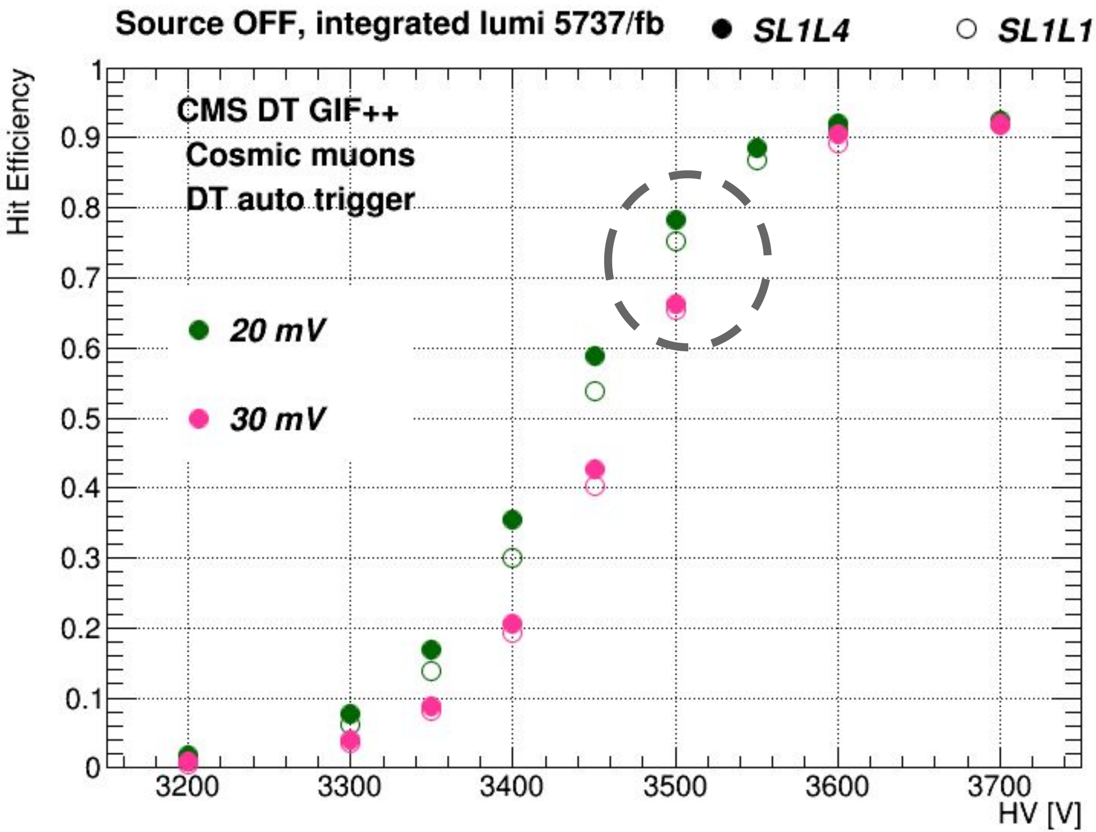
- Convolution of the test beam data (*slide 13*) and cosmic data (*slide 14*) results
- Considering a safety factor of 2 for the expected HL-LHC background rate (**10×10^{34} cm^{-2}s^{-1}**) and for the expected integrated luminosity (**6000 fb^{-1}**)
- Extrapolation from MB1 YB+/-2 most external wheel to the rest of the system, *conservative scenario*
- Small impact of the muon reconstruction due to the redundancy of the system
- L1 Trigger (Phase2) studies on-going...







Mitigation Actions



- Manage **operational conditions** (HV, FE Threshold) dynamically:
  - Reduction of **HV** ⇒ *fully implemented*
  - Reduction of **FEth** (from 30 to 20 mV) ⇒ *fully implemented*
- Upgrade of the **Gas system** to avoid recirculation ⇒ *fully implemented*
- **Shielding** of the external chambers, unprotected ⇒ being implemented in the Long Shutdown2
- New **L1 trigger algorithms** under study and development should mitigate the ageing effects
- Investigation of the effect of additional components (O_2 , H_20...) to current gas mixtures

Conclusions

HL-LHC will create a difficult environment for CMS, and in particular for the DTs, where the *performance* on some of the chambers may degrade

Hints that exposure to radiation change the *detector performance* already observed in a previous irradiation campaign

- **Results** at *CMS TDR: The Phase-2 Upgrade Muon Detectors*
- Direct investigation of irradiated wires showed some coating

An irradiation campaign of a **new spare chamber** at a lower rate has been presented:

- Longer and more systematic data-taking complemented with muon test beams
- Irradiation up to 2xHL-LHC expected dose
- Characterization of the radiation effects

Efforts on-going for the development of strategies to **guarantee** the muon reconstruction and identification stays at an optimal level in CMS throughout the HL-LHC operation

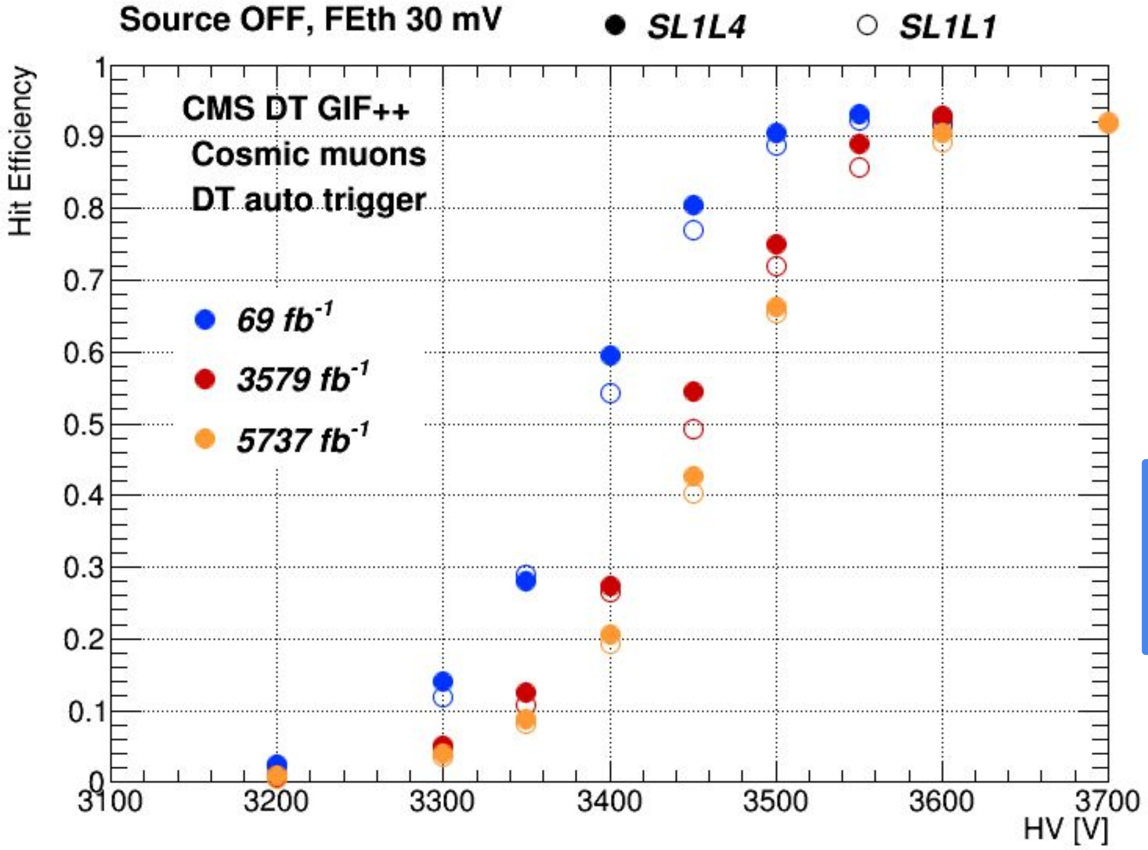
A pessimistic/conservative aging scenario, based on the data collected at GIF++ shows a drop in the hit efficiency below 25% at the end of the HL-LHC for the **most exposed chambers**

Preliminary muon trigger and reconstruction studies show a **mild localized effect** in the overlap region

EXTRA MATERIAL

High Voltage Scans

Hit efficiency vs HV, 3 datasets: **beginning**, **middle** & **end** of irradiation period of MB2



Data-taking during HV scans

- Cosmic muon data
- Aged layers (SL1L1 and SL1L4)
- FEth 30 mV
- Source off

Aging effects observed → hit eff decrease