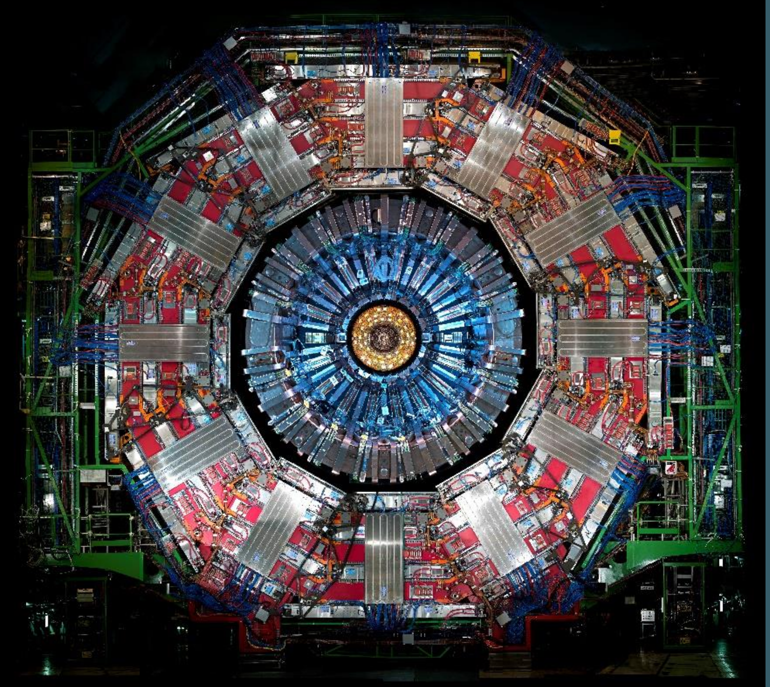

Study of the effects of radiation on the CMS Drift Tubes Muon Detector for the HL-LHC

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on behalf of the CMS Muon Group

[iWoRiD 2019 – Crete, Greece]

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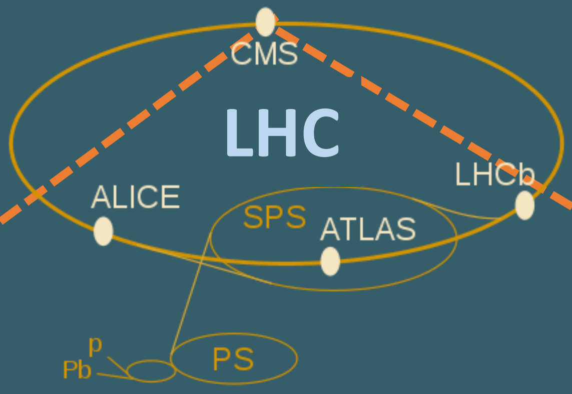
International Workshop on Radiation Imaging Detectors

21st iWoRiD

ICTEA

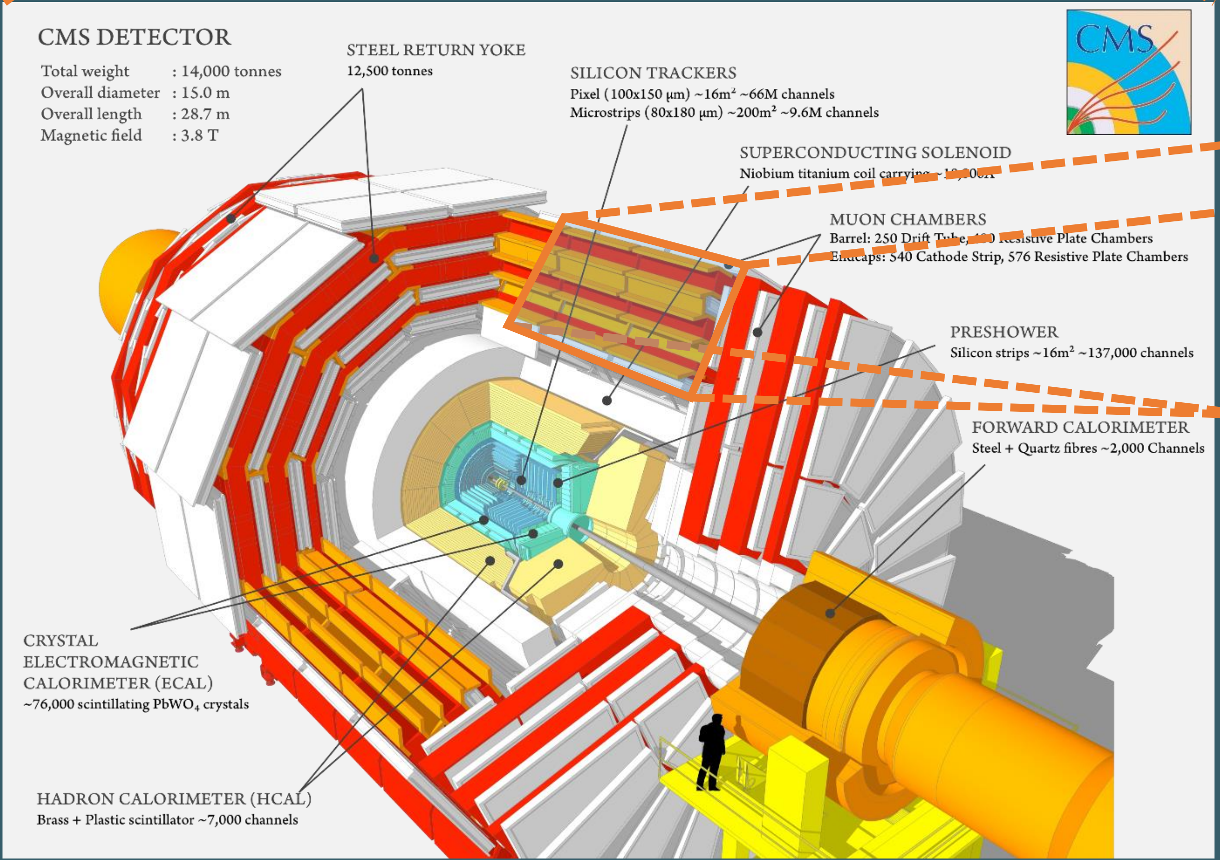
CMS

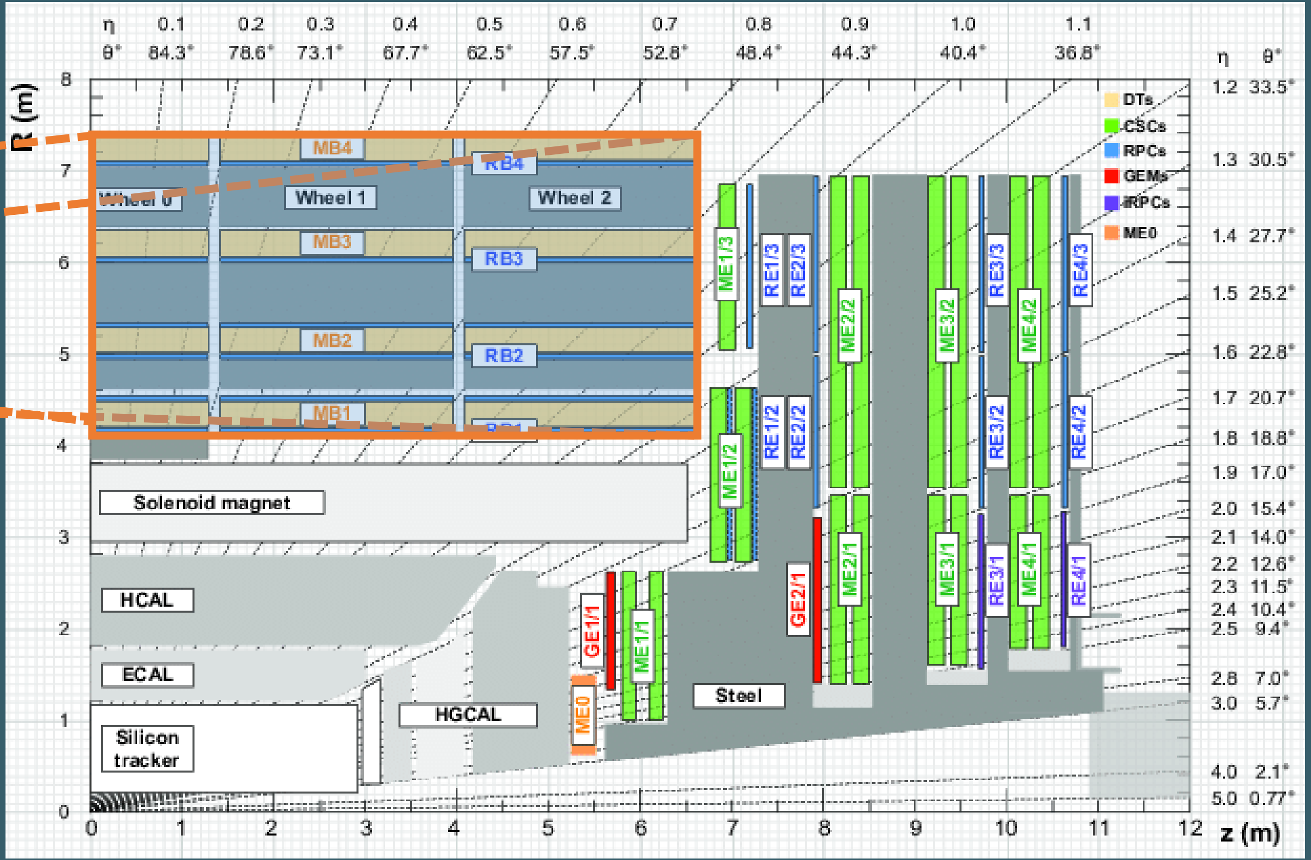
250 Muon DT Chambers @ CMS @ LHC



Located In the barrel region:

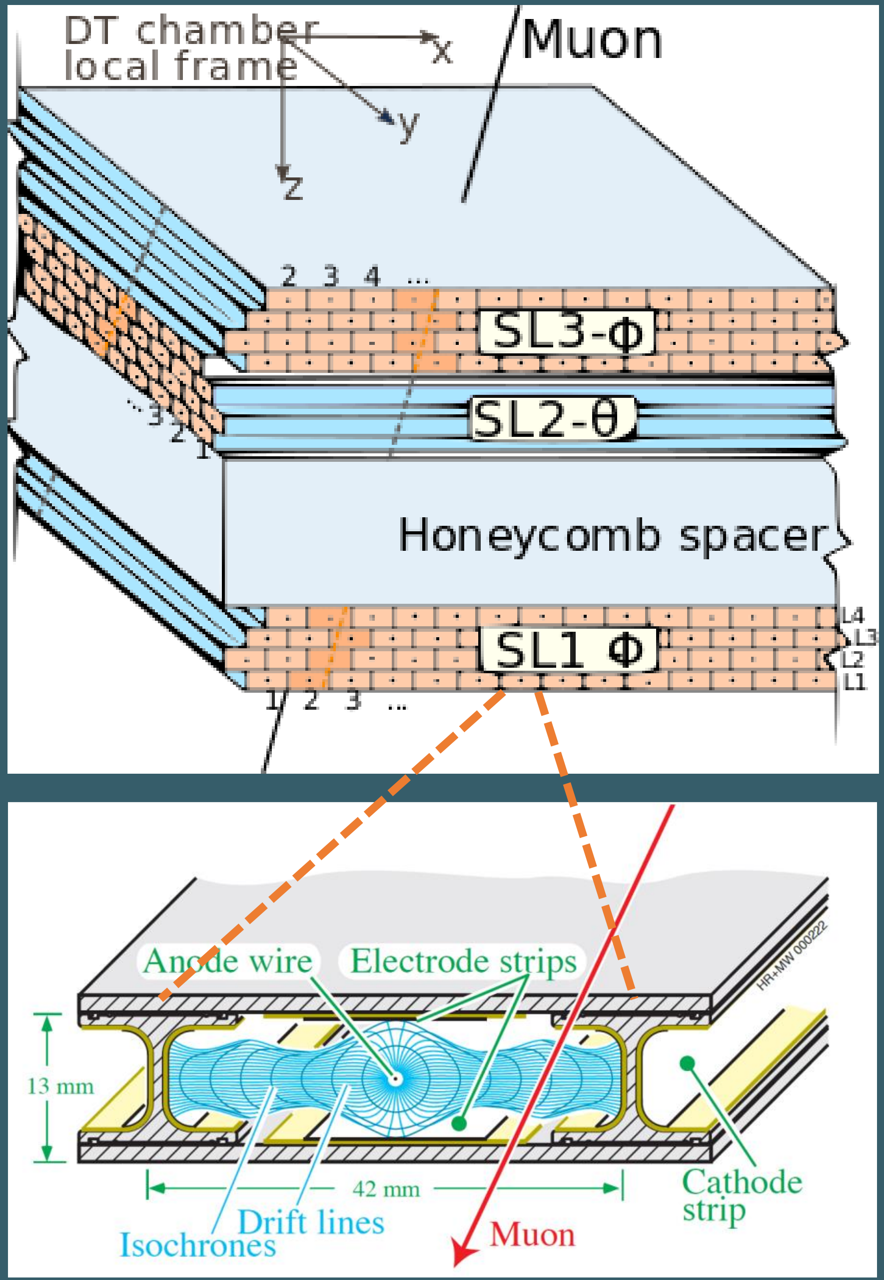
- 5 wheels: YB-2, YB-1, YB0, YB+1, YB+2
- 12 sectors: S1-S12
- 4 stations: MB1 (in), MB2, MB3, MB4 (out)





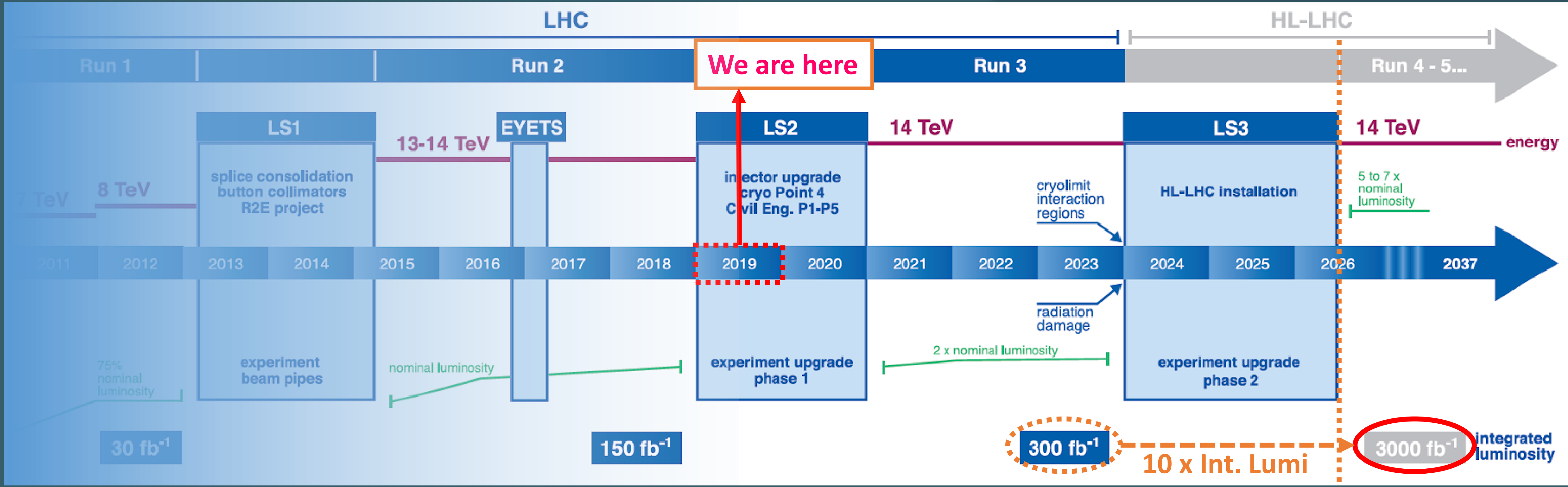
Drift Tubes @CMS

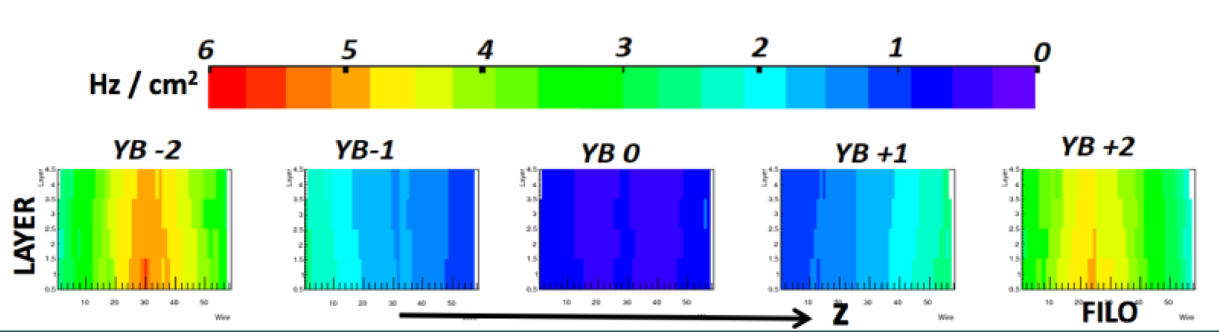
- A Drift Tube chamber (DT) is a **gas detector** designed to measure with great precision the **position of muons** from the LHC collisions
- The basic detector element is a rectangular **drift cell**, filled with an Ar/CO_2 (85/15%) gas mixture, and a gold plated steel wire (50 microns) that acts as the anode
- Particles passing through ionize the gas and the resulting electrons will drift towards the anode at approximately constant speed and generate an avalanche that results in an electric signal that can be processed by the electronics of the detector
- Timing information is related to position obtaining up to 250 µm position resolution
- Some operational parameters:
  - **Anode HV**: 3600 V (nominal) – 3500 V (now)
  - **Frontend Threshold** : 30 mV (nominal) – 20 mV (now)



Timeline towards HL-LHC

5 × increase in instantaneous luminosity
10 × increase in integrated luminosity

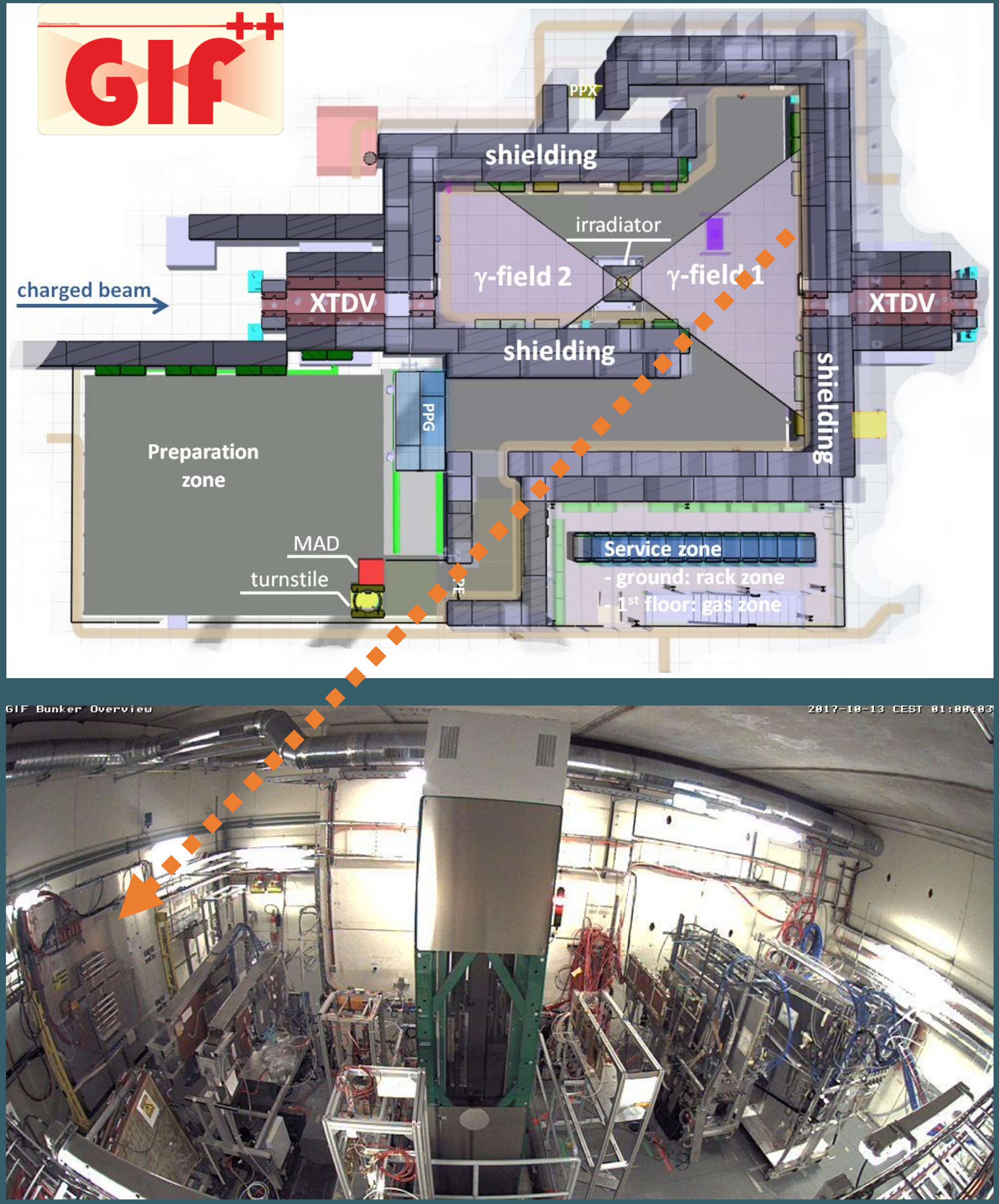




- Can we withstand the expected accumulated charge?
- Non homogeneous background rate distribution
- Most exposed DT chambers located at high pseudorapidity, in the innermost part of the muon system → MB1 YB±2

Experimental facilities

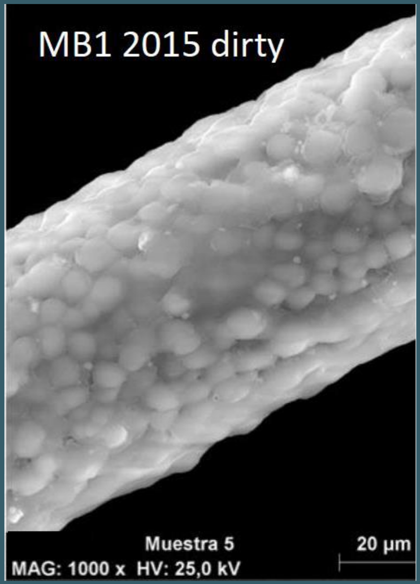
- **Irradiation & Muon test beams**: The **G**amma **I**rradiation **F**acility (**GIF++**) combines:
  - A ***high energy*** charged particle muon beam (from pions and kaons) → "Real" muon measurements
  - And a 14 TBq ^{137}***Cs source*** that produces a background gamma field ($E_{\gamma} = 662\ KeV$) → Irradiation & background studies
- Accumulate doses equivalent to HL-LHC experimental conditions in a reasonable time
  - **Instant dose** can be configured combining a set of attenuation filters
- … and, of course, the DT chambers at CMS (P5) provide additional information

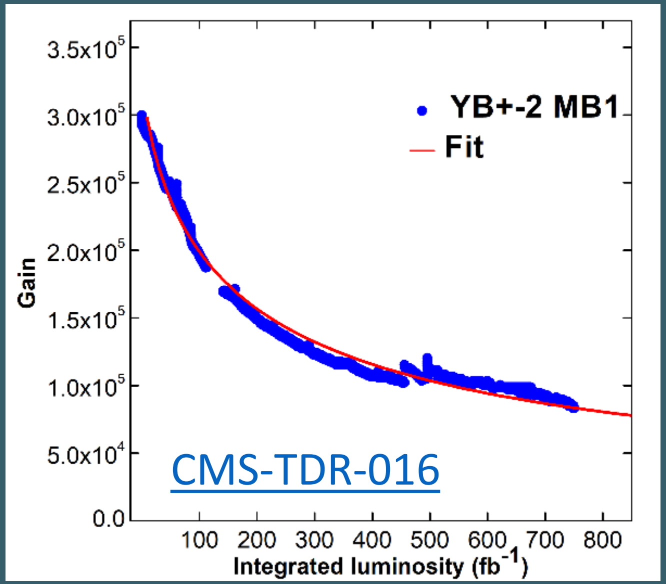


A bit of history

[2015 – 2016] Irradiation of a spare (MB1) chamber at high rate:

- Results at *CMS TDR: The Phase-2 Upgrade Muon Detectors*
- First hints that exposure to radiation change the detector performance
- Fast gain drop observed. Direct investigation of irradiated wires in Legnaro and CIEMAT showed a Si an C coating with large resistivity
- Wire aging, main contribution of the hit efficiency loss: **acceptable** due to system redundancy





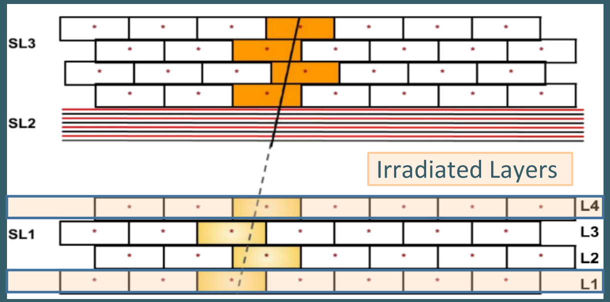
[2016 – now] Proportional counters (*simple detector mock-ups*): Bicells and Monotubes

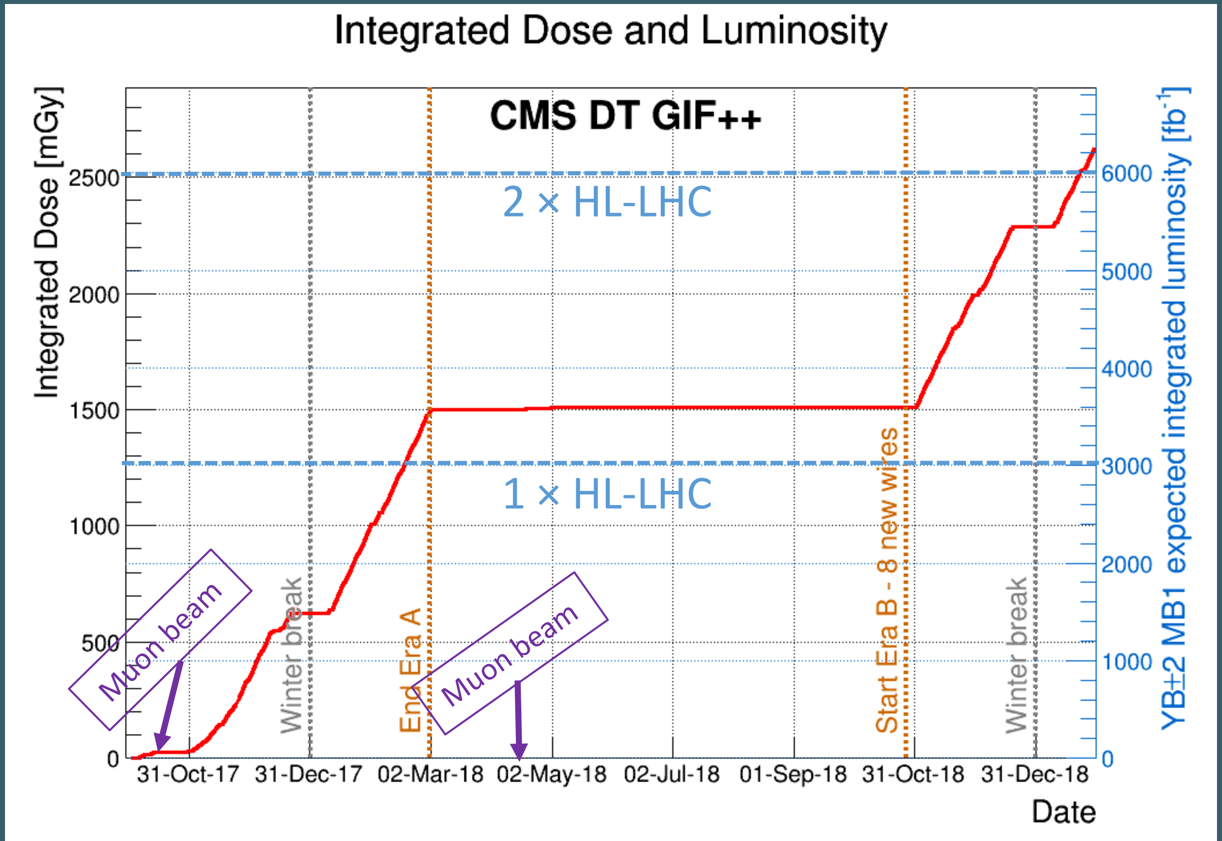
- Installed at CMS Detector and GIF++: Allows for simple comparisons
- Well suited to investigate the poisoning material

[2017 – 2019] Irradiation of new spare (MB2) at lower rate:

- Longer and more systematic data taking complemented with muon test beams
- Irradiation up to 2 × HL-LHC expected dose

MB2 irradiation and data taking



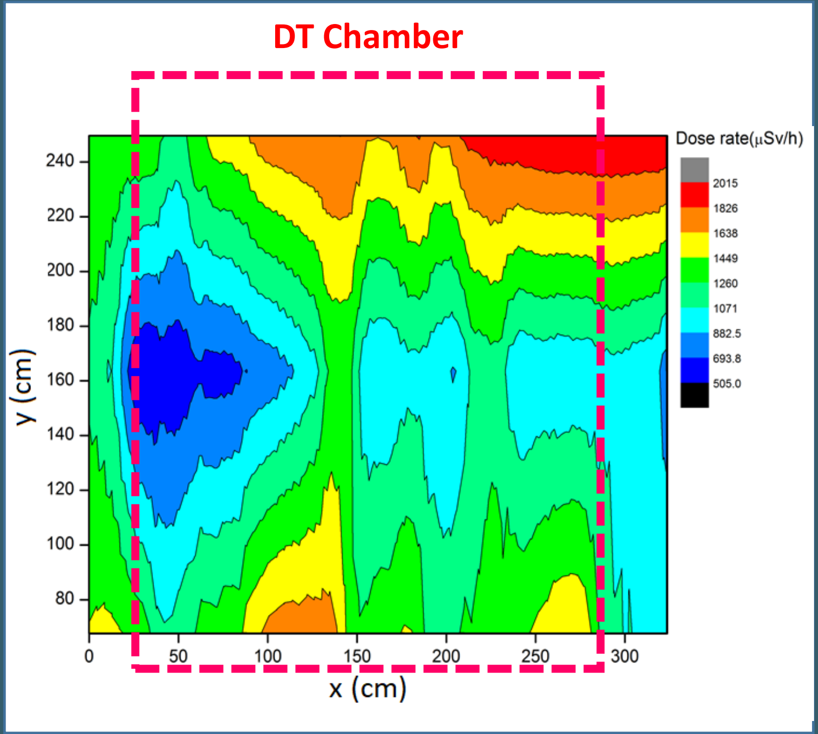


- Data taken in two campaigns (eras) during 2017-2019
  - Summer 2018: 8 wires extracted for later inspection and replaced with new non-aged wires
- The chamber was irradiated full time at ~10 times the expected dose at HL-LHC:
  - **Layers 1 and 4 from SuperLayer 1** were irradiated while HV was on at 3550 V.
  - The rest of the chamber was irradiated with HV in *standby* (1900 V) to be used as reference
- One day a week the source was off for interventions in the bunker
  - Cosmic data recorded at different operation conditions (HV, FE Thresholds, …)
  - Once a week a source scan was also performed
- Muon beam data recorded at 2 points in time

Dose and equivalent luminosity

- At GIF++ the dose rate is measured with a REMUS dosimeter inside GIF++
  - Several measurements were done with a portable dosimeter in different positions of the MB2 chamber to extrapolate the REMUS measurement to the surface of the MB2 chamber
- Conversion factors from dose to luminosity were computed comparing currents in the MB2 chamber at GIF++ and DT chambers at CMS
  - Dose rate to instantaneous luminosity conversion was calculated at HL-LHC background rate:
    1 fb^{-1}/s = 0.304 mGy/s
  - Integrated dose to integrated luminosity was calculated at GIF++ aging rate (~10 × HL-LHC):
    1 fb^{-1} = 0.42 mGy

The integrated luminosity quoted in our studies corresponds to the integrated dose expected for the most exposed chambers during the HL-LHC

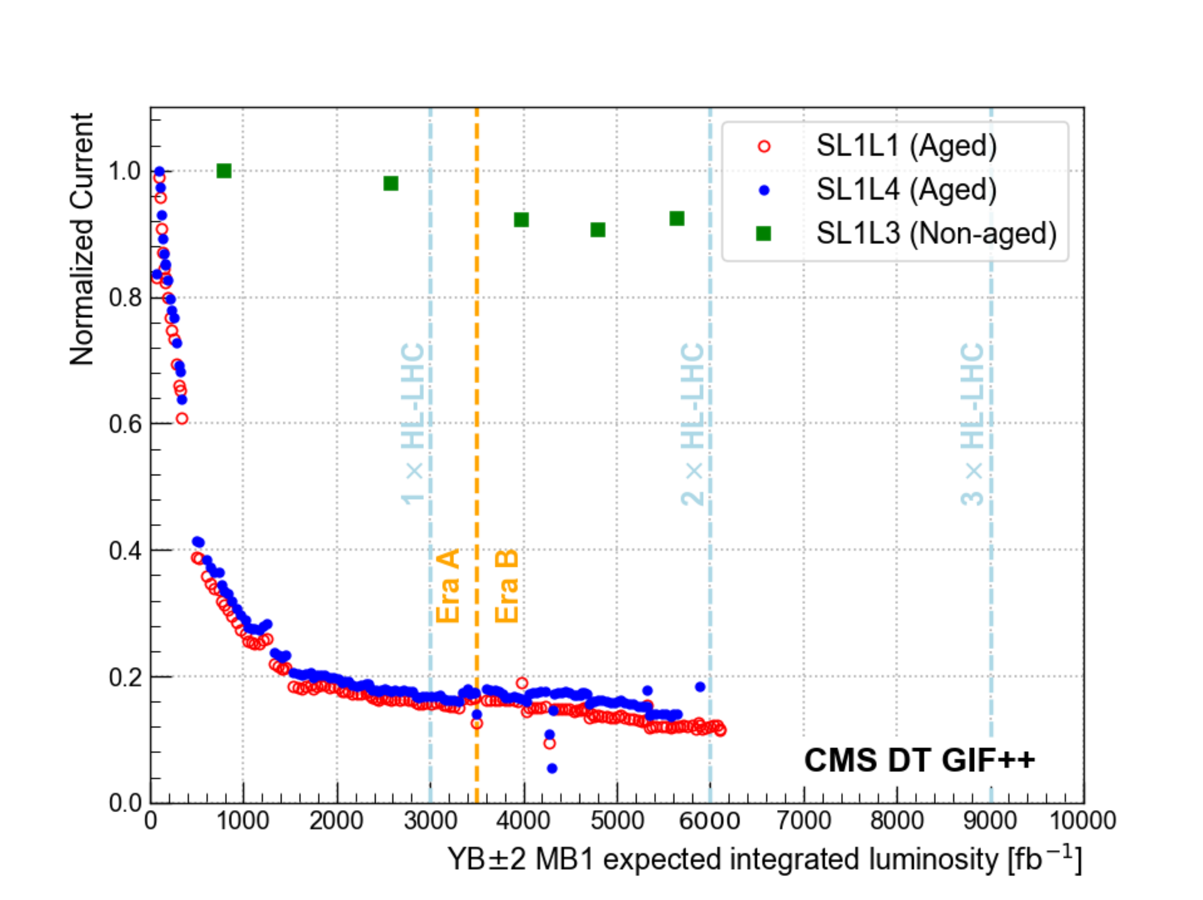


Inhomogeneous dose rate over the chamber was averaged to compute the integrated dose

Current evolution

- Normalized current: Ratio between the instantaneous current and the instantaneous dose (scaled to the initial value)
- Currents are corrected for the measured pressure in the bunker
- Gaps are caused by the loss of monitoring.
- Big drop at the beginning that seems to stabilize at high integrated dose
- This is similar to what was observed with the spare MB1 study in 2015

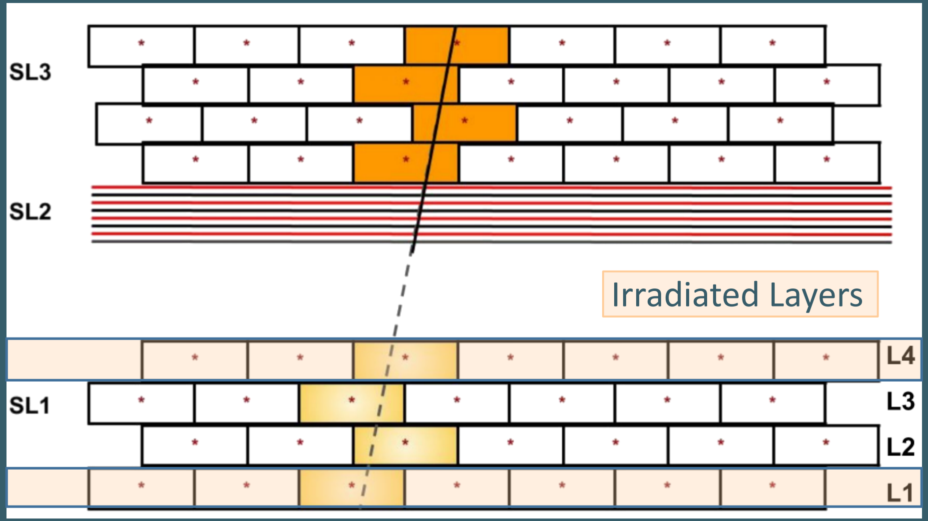
Normalized current for aged (SL1 L1, SL1 L4) and non-aged layers (SL1 L3) at HV=3550 V



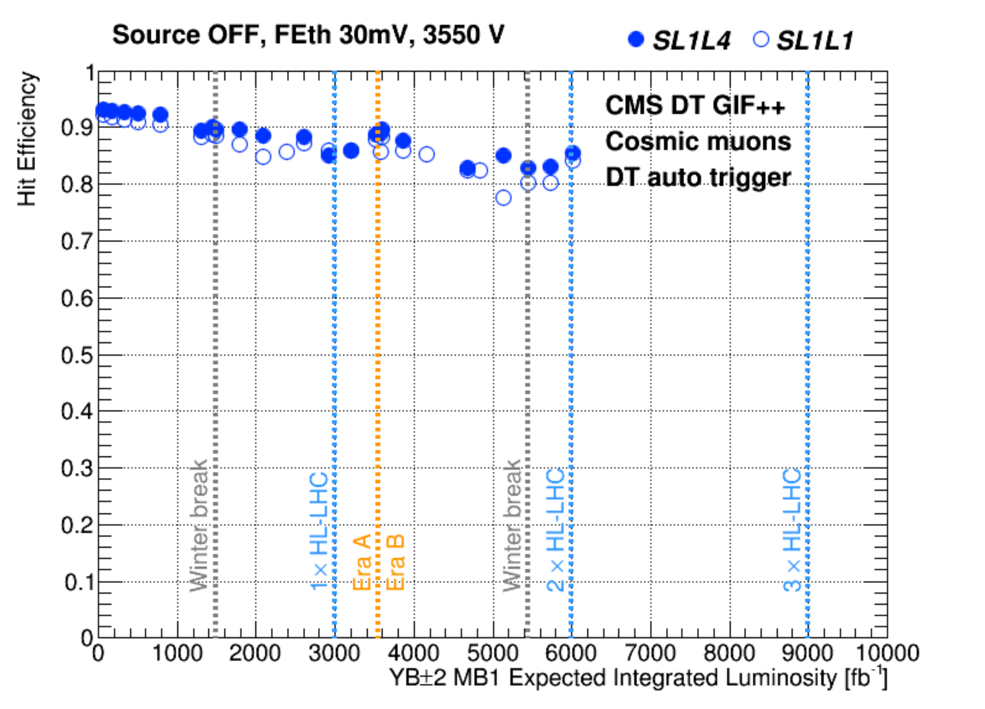
MB2 hit efficiency (Cosmics)

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

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



Hit efficiency for cosmic muons as a function of integrated luminosity for the aged layers at 3550 V

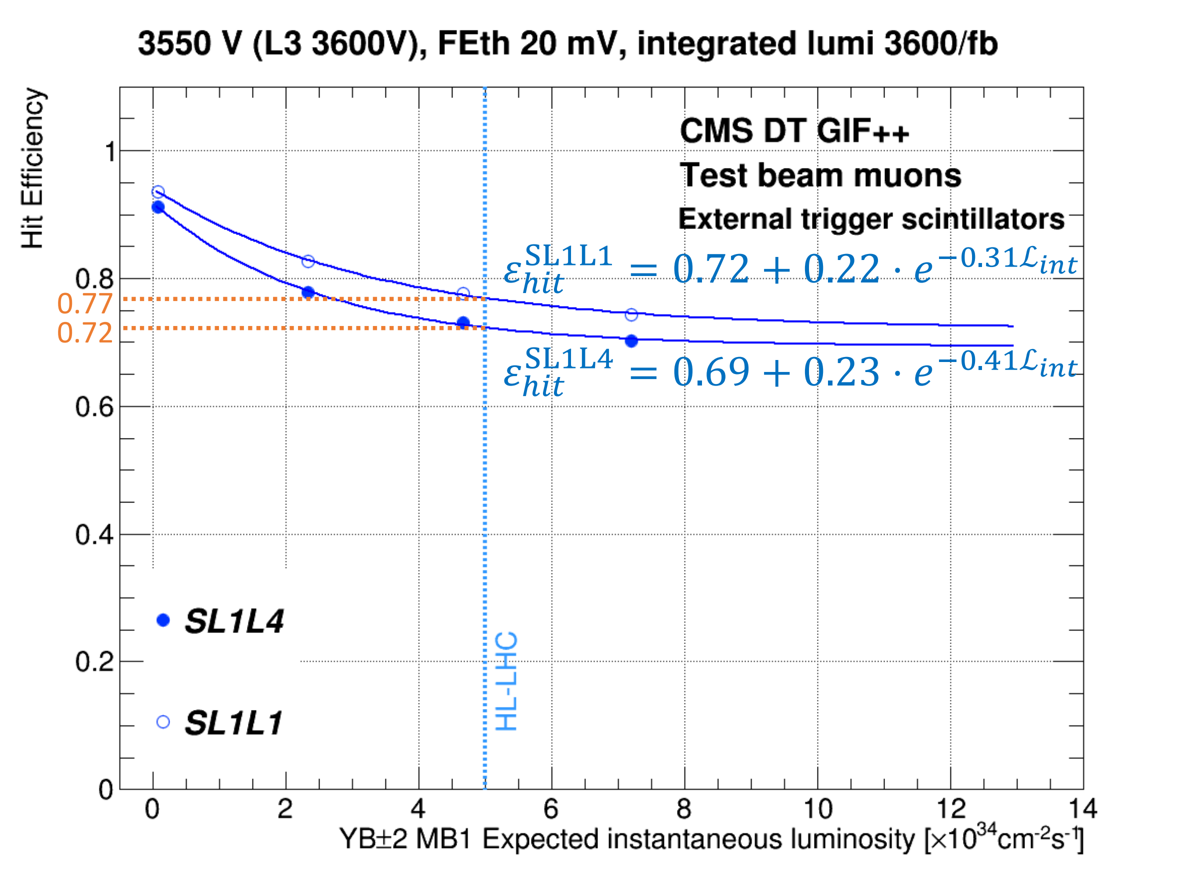


- Each point corresponds to data taking with High Voltage variation scans that were collected every week
- The DT trigger was used for cosmic muon tracks, avoiding any bias on the layers irradiated with HV ON
- The loss of efficiency without background radiation is around 10% for the expected integrated luminosity equivalent to 2 × HL-LHC

MB2 hit efficiency (Muons)

- Muon beam data taken after an integrated dose equivalent to an HL-LHC integrated luminosity of 3600 fb^{-1}
- External trigger scintillators used for muon tracks, identifying a track in both projections on SL2 and SL3 of the DT chamber in coincidence with the scintillators, avoiding any bias on the layers irradiated with HV on
- The hit efficiency degrades ~20% when in presence of background radiation equivalent to HL-LHC.
- Around **75% hit efficiency** for the most exposed chambers at **HL-LHC background rate** after HL-LHC integrated luminosity
  - Please note that test beam muons are perpendicular to the test chamber: No track length correction applied
- If we double the background rate efficiency stays around 71%

Hit efficiency for beam muons as a function of instantaneous luminosity for the aged layers at 3550V



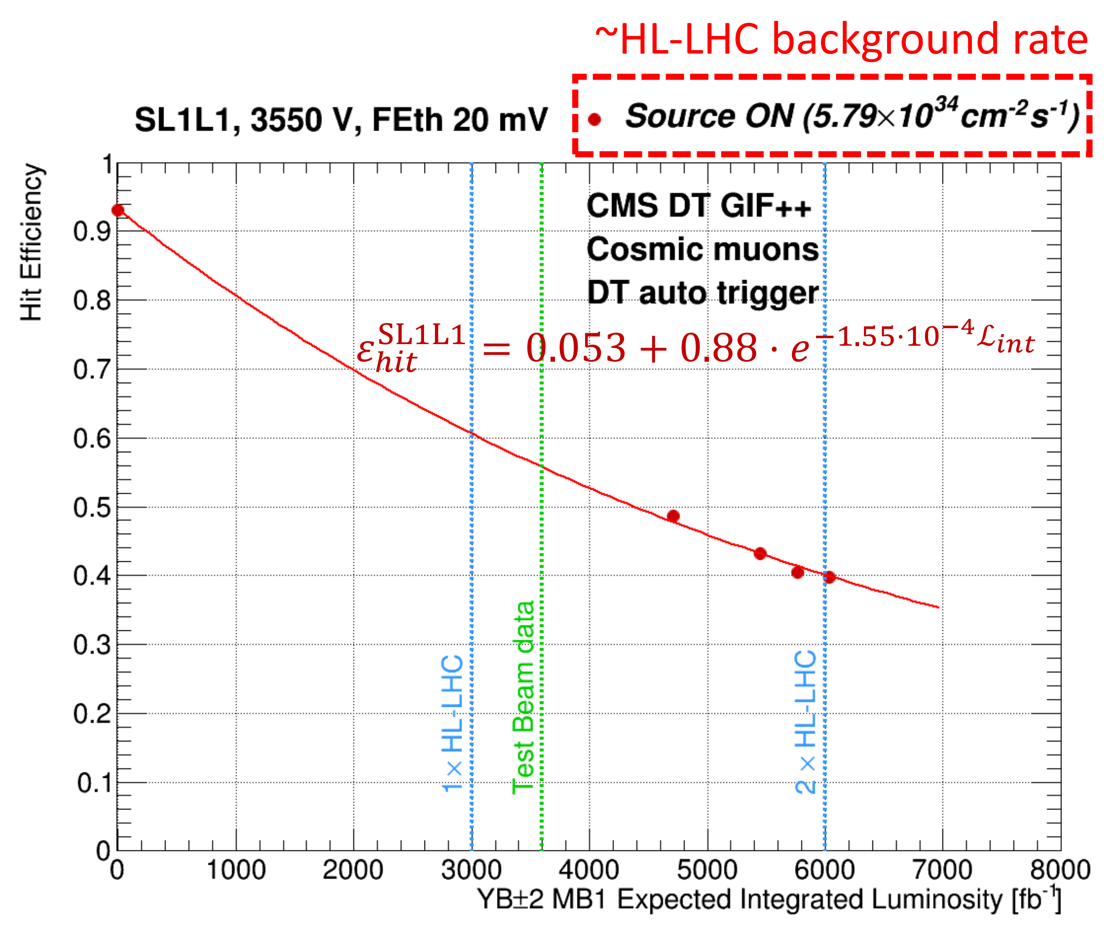
Building an ageing scenario

[Use safety factor 2 on instantaneous and integrated luminosity]

Hit efficiency for cosmic muons as a function of integrated luminosity for the aged layer SL1L1 and with a background rate ~HL-LHC

- Unfortunately we could not collect test beam data at the end of the irradiation…
- … but we have data from cosmic muons in conditions close to the HL-LHC background rate

→ We can use this data to propagate the dependency to 2 × HL-LHC (safety factor)



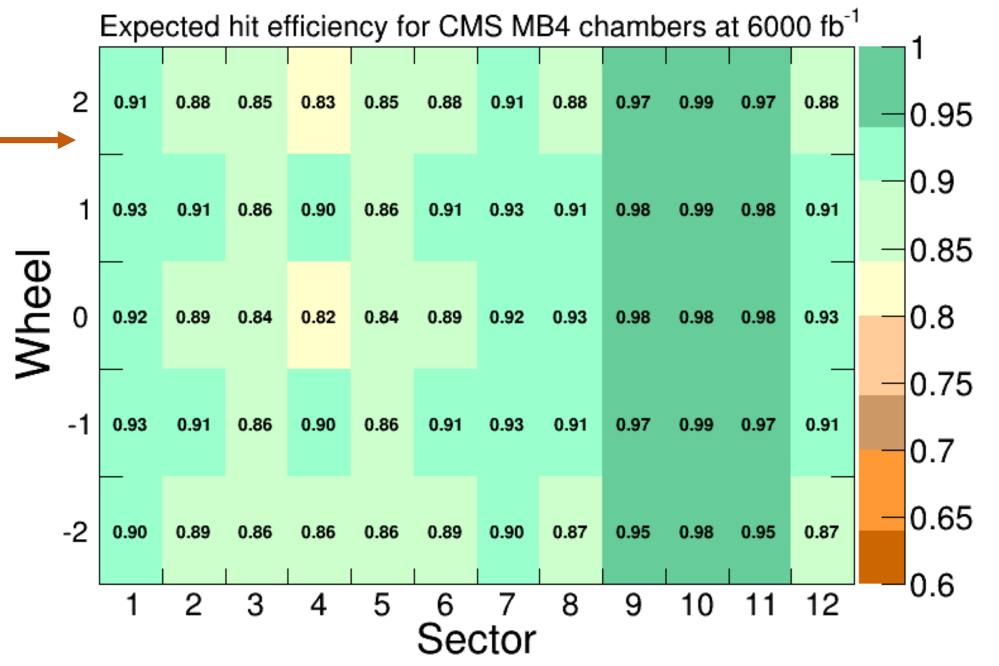
Building an ageing scenario

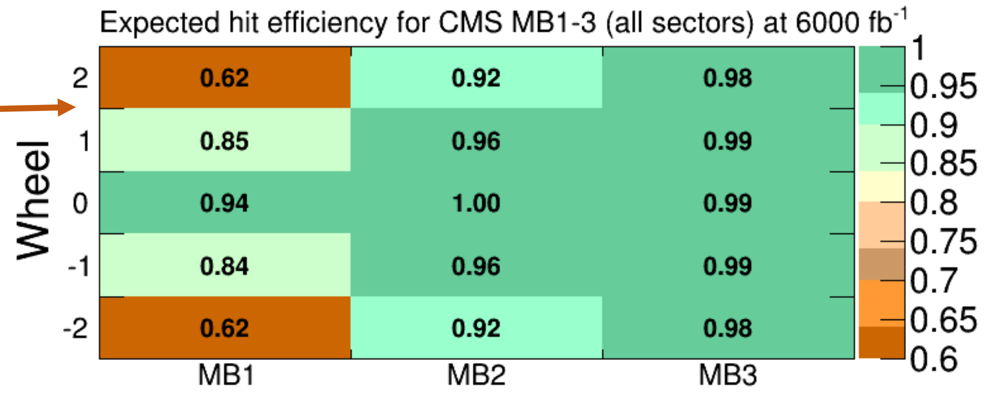
[Use safety factor 2 on instantaneous and integrated luminosity]

Expected hit efficiencies at the end of the (2 ×) HL-LHC for all the DT chambers of the CMS muon system:

- **MB4 chambers: top plot**
- **MB1, MB2 and MB3: bottom plot, all sectors together**

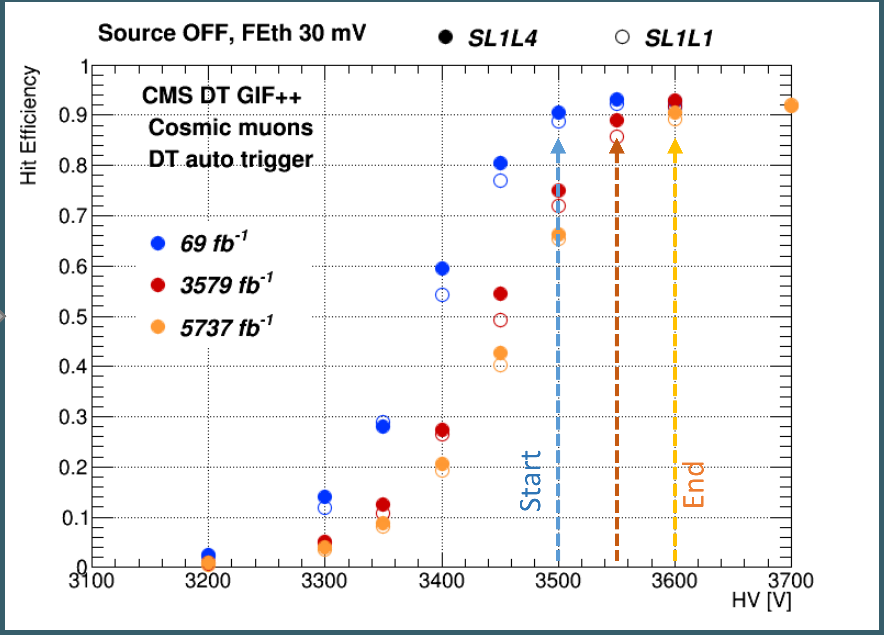
- Efficiencies estimated considering a safety factor of 2 for the expected HL-LHC background rate **($10x10^{34}$ $cm^{-2}s^{-1}$)** and a safety factor of 2 for the expected integrated luminosity (**6000 fb^{-1}**) to obtain the expected hit efficiency for the MB1 chambers in wheels ±2 and extrapolating to the rest of the CMS muon system using the expected integrated charge at the end of HL-LHC

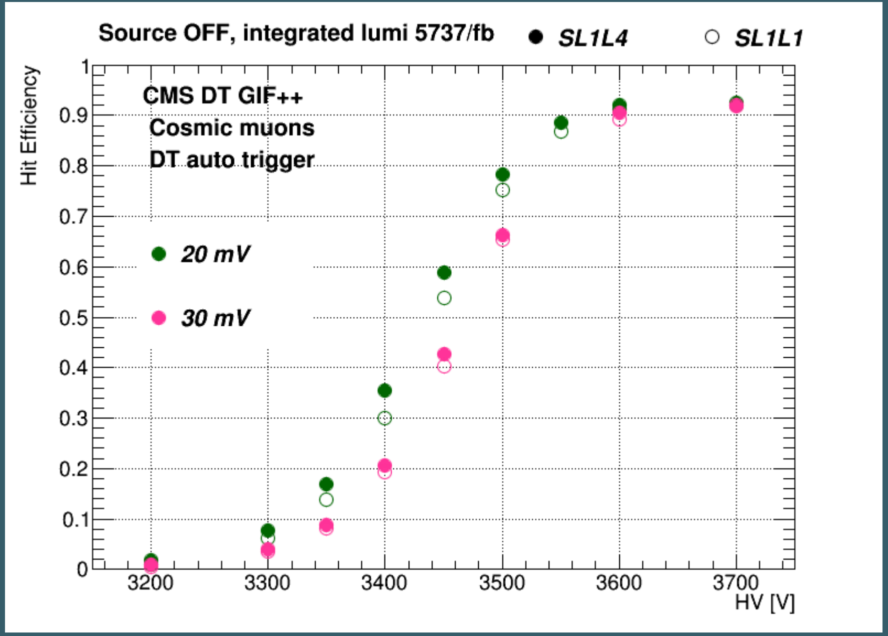




Mitigation Strategies

- Manage operational conditions (HV, FE Threshold) dynamically:
  - Lower HV (& higher FE Thr.) values at the beginning to reduce ageing
  - As signs of ageing appear, go to higher HV & lower FE Thr. to move again into the plateau
- The majority of the radiation that affects the chambers comes from the scattering on the walls and the activated materials in the CMS experimental cavern. So a 7 mm lead + 30-90 cm 5% borated polyethylene shielding is being installed on top of the most exposed DT chambers.
- For HL-LHC a new readout is foreseen (already under test in a sector this summer at P5). 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 is planned to eventually moderate the coating deposition seen at GIF++





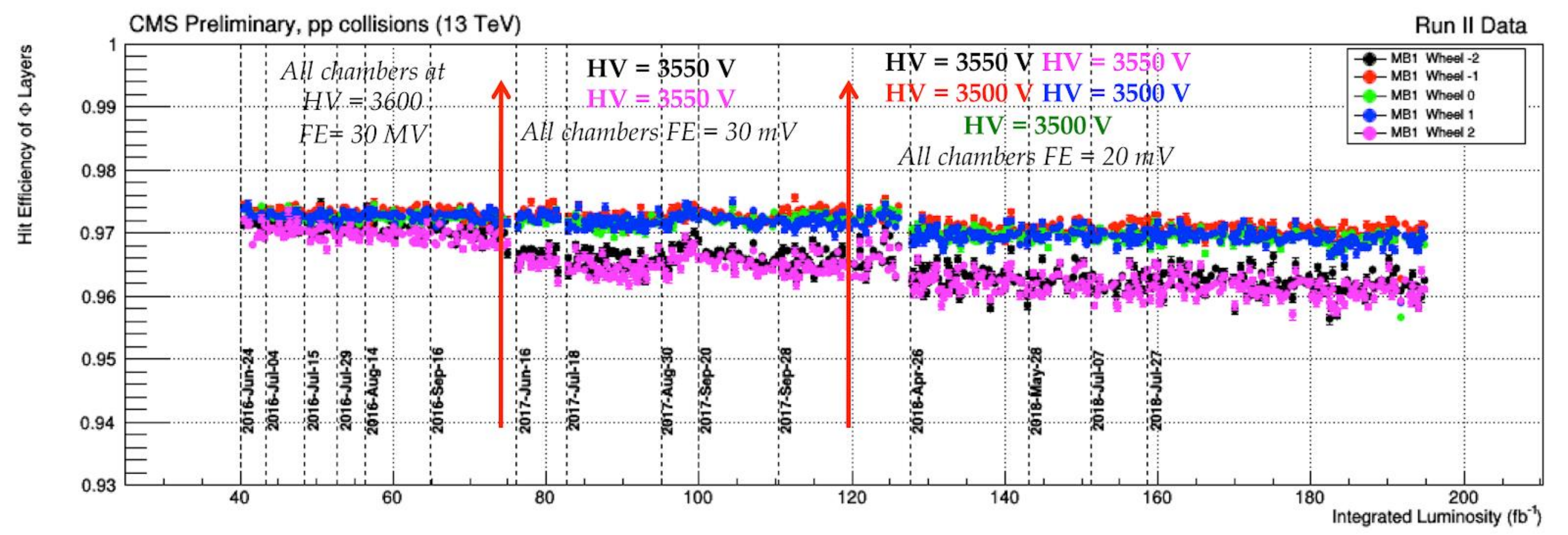
Conclusions

- HL-LHC will create a **difficult environment** for CMS subdetectors, and in particular for the Drift Tubes Muon detector that may degrade the performance on some of the chambers
- A **big effort** has been done **to characterize the radiation effects** and to develop strategies to guarantee the muon reconstruction and identification stays at an optimal level in CMS throughout the HL-LHC operation
- A pessimistic extrapolation based on the data collected at the CERN GIF++ facility shows a drop in the hit efficiency below 25% at the end of the HL-LHC for the most exposed chambers while the big majority of the system stays well above 90%. Very preliminary muon trigger and reconstruction studies show a mild localized effect in the overlap region
- We believe that with a combination of different strategies including dynamic operation and improved algorithms for muon trigger and reconstruction the Drift Tubes at CMS will have a great impact on the physics during the HL-LHC

Backup

MB1(1 ton,2.5x2.1 m)@ ~5 m from the GIF++ source

No efficiency drop seen at P5 so far. Changing the HV and FE has a very small effect on hit efficiencies, but will delay ageing.



Study of the coating on wires from MB2

- Wires studied in Legnaro and CIEMAT using SEM (Scanning Electron Microscope) and SIMS (Secondary Ion Mass Spectrometer)

→ Coating material clearly visible
→ Very resistive