Phase-2 Radiation discussion

GEM Workshop
Oct 2 2019

Piet Verwilligen – INFN Bari

Disclaimer: this is not an overview of work done but instead provides a starting point for discussion and work to be done

CERN, Oct 2 2019

https://indico.cern.ch/event/836166/

Let's roll:

Radiation WS during CMS Week

Frank Hartmann (Upgrade Coord)

Goal

- Increase common understanding at which radiation levels and why system will 'fail'!
- Get an early alarm system when levels get too high, i.e. eat too much into the margin.
  - At the same time, understand the margins better.

Today v3.7.19.1

- Define the 'neuralgic points' within each system, i.e. modules/technology representing a certain detector volume and chose the point of highest exposure within that volume
  - BRIL will check radiation levels at these defined positions for new models
    - There can be future iterations on these definitions
- Tell the 'breaking points/levels' at these locations, i.e. when does the system fails or does not delivery useful physics anymore
  - Comprehensively explain the reasons and mechanism defining these levels

Sophie Mallows (BRIL)

BRIL RS Responsibilities

BRIL

- Maintain the simulation framework; inputs, routines,
- Provide of "multi-purpose" results on RPS tool for selected runs
- Provide input code on request for experienced CMS FLUKA users of any project and check results at working group meeting
- Perform simulations for global purposes where one component modification effects other(s), example
  - Rotating shield design
  - Phase 2 upgrades
- Perform simulations on request
  - Timescales can depend on shifting priorities
- Follow limits & thresholds, specified by sub-detectors
- Follow material update requests (redesign, or update), specified by sub-detectors

Huge work, not only for us but also for the entire Muon community…

… need a common approach among the different Muon systems

Need to scrutinize each part along the detection-trigger-readout chain:

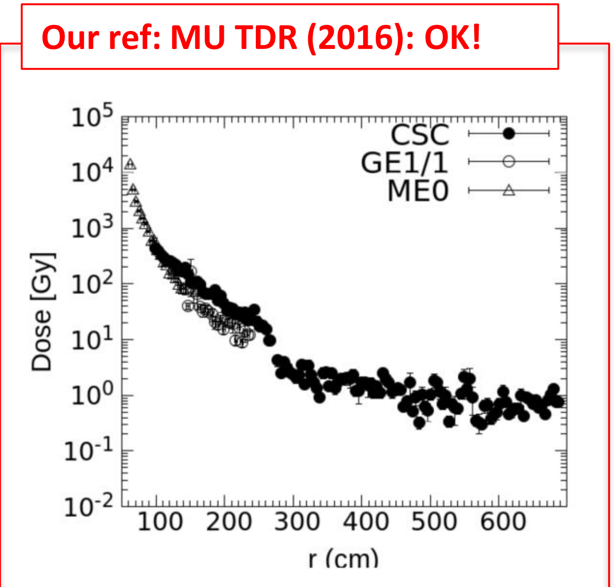
- *Rate capability of the detector*
- *Radiation hardness of detector & front-end electronics*
- *Available bandwidth to send hits to trigger*
- *Combinatorics in EMTF / Segment reconstruction*
- *…*

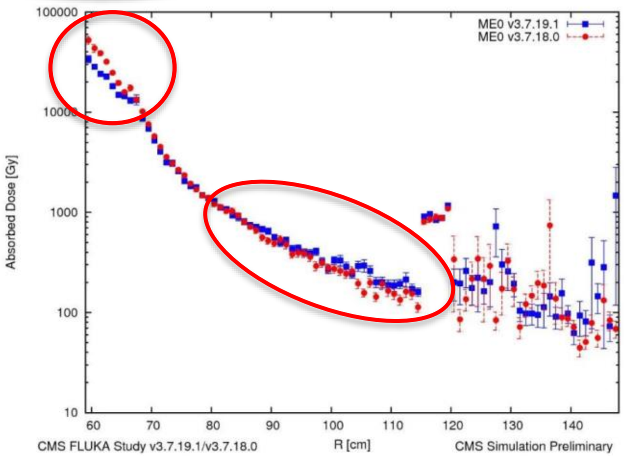
https://indico.cern.ch/event/839944/

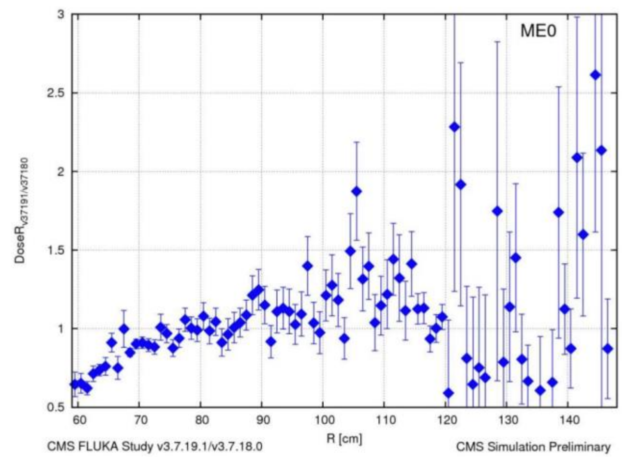
Why?

HGCAL steadily improves design

- **V.3.7.18.0** reduced material budget *(reduced absorption length* $\lambda = 9.3$ *instead of* 10.3)
- **V.3.7.19.1** new envelope & support structure
- More improvements to come ?







- Reduced dose 60 < R < 70 cm (innermost eta partition)
- Slightly higher dose for R > 90 cm
- ok for us, but they do not want to ask time and again … and want to know what limits we can stand…

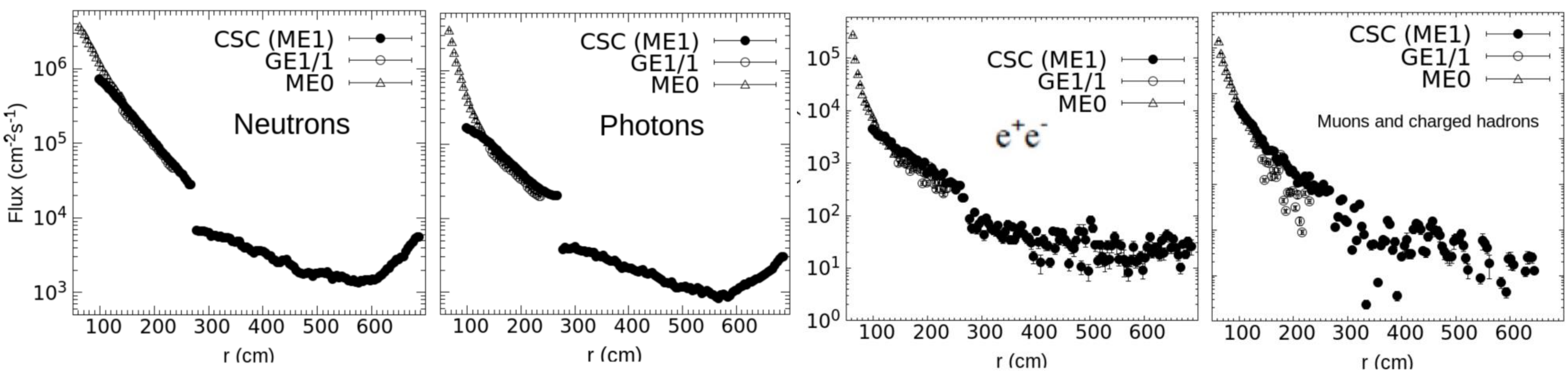
https://cds.cern.ch/record/2283189/files/CMS-TDR-016.pdf

Rate Capability

- Most recent estimates: Muon Upgrade TDR (2016);
  however Fluka simulation with old HGCAL geometru (reuse of HE absorber)
- Max hit rate (5E34 or 7.5E34 ?): 1.5kHz/cm2 (GE1/1) – 50kHz/cm2 (ME0)

Table 6.4: Expected background components and their corresponding hit rates in the GE1/1, GE2/1, and ME0 regions. The total accumulated charge is calculated from the total hit rate at a typical detector gain of 2×10^4.

GEM Station	Max. neutron flux [MHz/cm^2]	Max. neutron induced hit rate [Hz/cm^2]	Max. photon hit rate [Hz/cm^2]	Max. e^+/e^- hit rate [Hz/cm^2]	Max. total hit rate [Hz/cm^2]	Total acc. charge after 10 HL-LHC years [mC/cm^2 - no safety factor]
GE1/1	0.277	499	847	123	1469	6
GE2/1	0.191	343	273	56	672	3
ME0	3.28	5910	33900	7700	47510	283

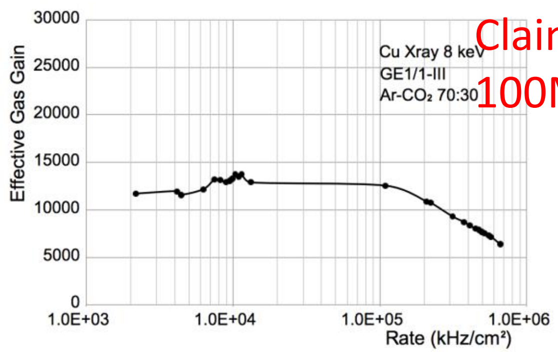


Rate Capability

https://cds.cern.ch/record/2021453/files/CMS-TDR-013.pdf

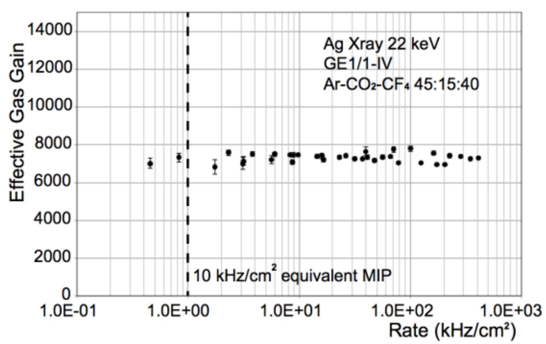
- **However we do not have margin on rate capability right now! --- tests and R&D needed!**
- Standard GEM Foils: HV filter 10k-2.2nF-100k + 10MOhm for each HV segment (40)
- Sustained operation: more efficient spark protection with 100kOhm – 1MOhm instead of 10kOhm
  but V = IR therefore higher filter resistors will result in higher voltage drop and hence lower rate-cap

GE1/1 TDR (2012): Local irradiation



Claim: 100MHz/cm^2

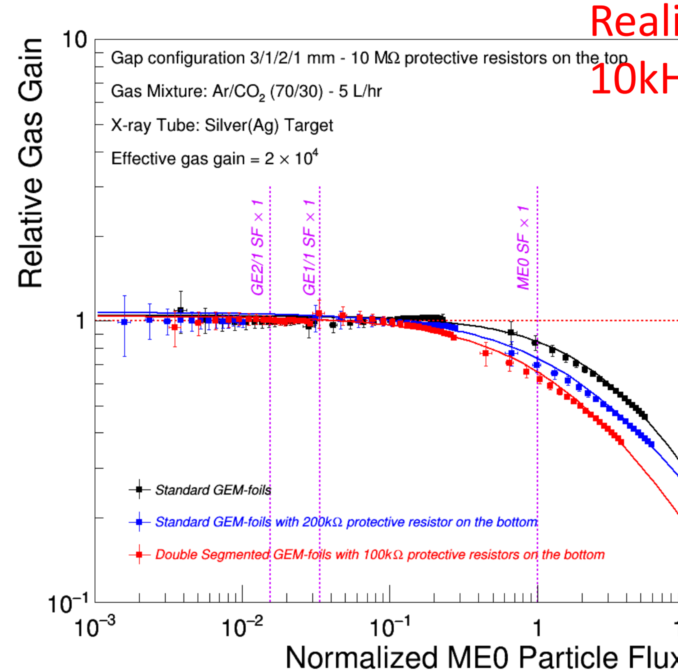
Figure 2.18: Effective gas gain as a function of the incident photon rate measured in a GE1/1-III detector operated with Ar/CO_2 70:30 and irradiated with an 8 keV X-ray source with Cu



Measured up to 400 kHz/cm^2

Figure 2.17: Effective gas gain as a function of the incident photon rate measured in a GE1/1-IV detector operated with Ar/CO_2/CF_4 45:15:40 and irradiated with a 22 keV X-ray source with Ag anode.

Irradiation of full chamber (2019)



Reality: 10kHz/cm^2

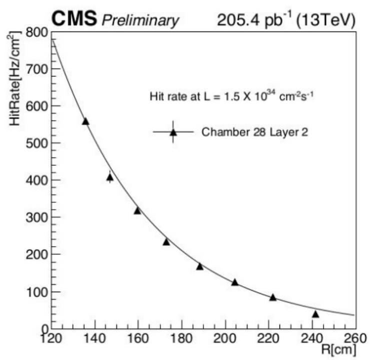
Disclaimer: result 2B scrutinized by GEM DPG: e.g. assumes for conversion of bkg-rate to bkg-induced current that all bkg particles produce MIP-like signal. Final result might be worse.

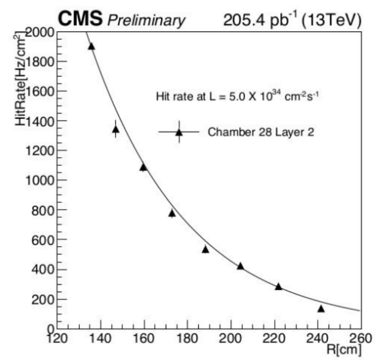
https://indico.cern.ch/event/836166/

Rate Capability

- **Furthermore let us not forget that this is simulation!**
- Background simulation is much improved in the past 5 years, but still no perfect data-mc agreement: *cfr. GEM slice-test: up to 50% difference at high eta!*

Roumyana Hadjiiska – Muon System Background

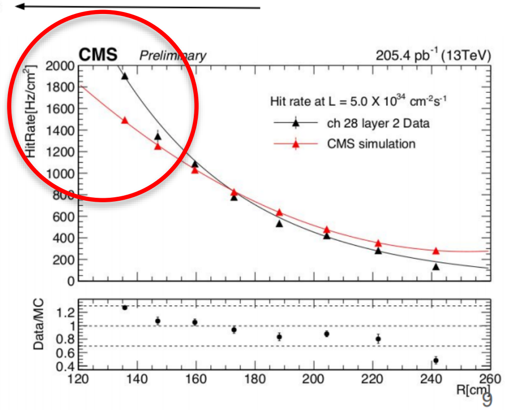




GEM Slice test Rates - Run 2

The environmental hit rate of detector chamber 28 layer 2 as a function of a distance from the beam line (left) and linearly extrapolated values to the HL-LHC (on the right).

The Fluka simulation result has implemented in the GEM digitization simulation. It has calculated with a phase 2 condition as a reference. The simulated hit rate has constructed with the digitization simulation. The hit rate of he chamber 28 layer 2 is calculated at 5.0E+34 of instantaneous luminosity with a linear fit result of the measured data. The ratio of these 2 hit rates shows about 50% difference in the worst case.



Radiation Hardness

- Requirement for all materials used for Chamber construction & FE Electronics
  - Cfr: Barrel RPC suffer leaks due to ageing of gaspipe exposed to non-negligible HF-concentration
- Materials for chamber construction tested by Jeremie (PhD thesis) – believe OK
- Electronics reviewed for GE1/1 TDR, CMS TP, MU TDR – but I would leave it to exp!
  - VFAT3 rad hard (100Mrad = 1MGy) max dose expected ME0 < 100kGy
  - I believe other components are radhard as well: FEAST, OH, …
- **What are the margins?**

Trigger BW / Trigger Combinatorics ?

- Bandwidth of hits out of ME0: need dedicated analysis to understand margins
- a.f.a.i.k. ME0 segments never added to EMTF, **so for Combinatorics we are blind!**
- More studies are needed: more manpower & experienced guidance welcome

What else?

Last word?

- I see it a little bit problematic that we should give numbers at which our technology breaks down...
- I see this once more as a push to accept higher radiation levels without good motivation.
- I believe that for the longivity of the GEM detectors we are on the safe side: our detectors are tested for several C/cm^2 expected to be accumulated over the HL-LHC period
- **limits on the particle rates come rather from the readout point of view (rate capability) and the increasing combinatorics in L1 Trigger logic**
- However accelerated radiation tests are not 100% reliable and **one should always try to keep the accumulated charge as low as possible**, for instance see the efforts in the past of the CSC to fine-tune the gain in each chamber to avoid too high gain (and charge) and the efforts of the DT colleagues to work at lower HV working point to reduce the gain in the tubes.
- *Therefore I am more in favour of giving numbers to BRIL that are for example just 20 or 30% more than what we expect from previous simulations. In the end, they just want to have an alarm.*

Fixing the margins

The main reasons of concern, related to background are:
* 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

Fixing a given "alarm" threshold - not easy and a complex task

- Effects like ageing are continuous
- Muon colleagues take measures to maximise longevity of the detectors and minimise such continuous effects
  - DT: lowering the HV WP to reduce the gain in the tubes, add shields;
  - CSC: fine-tune the gain in each chamber to avoid too high gain (and charge);
  - RPC: optimizing the HV WP balancing efficiency vs cluster size.

Some cases or studies require MC predictions before to set such alarm level

Ongoing iterations within the muon subsystems to provide optimal "alarm" levels - need some more time and careful studies, like the ones done for Muon Upgrade TDR

Roumyana Hadjiiska – Muon System Background

Study HGCAL scenarios

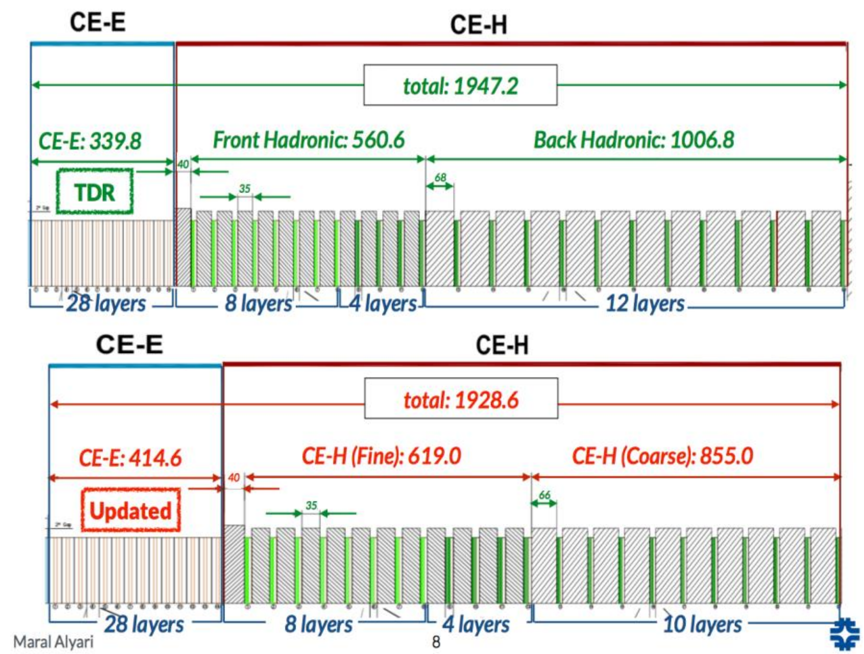
Work performed February – May 2019

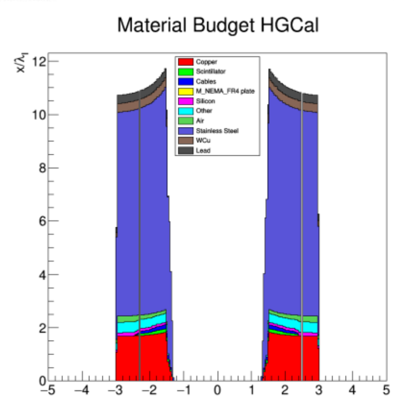
Wooijn Jang, Yechan Kang, Piet Verwilligen

CERN, Oct 2 2019

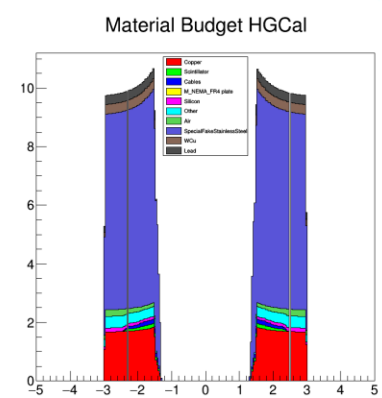
Introduction

- Changes in HGCAL to accomodate electronics has lead to a reduction of number of absorber layers in Back Hadronic from 12 to 10 layers
- resulting in an effective reduction of the total absorber thickness of 10 λ to 9 λ
- **First approach:** reduce density of HGCAL steel to have 9 λ total thickness - CMSSW_10_4_0
- **Second approach:** improved HGCAL geometry available now - CMSSW_10_6_0_pre3





Upgrade TP



Reduced λ

Studies performed on «Reduced Density HGCAL» in CMSSW_10_4

- **Expected**: *due to reduction with 1 interaction length we expect 30% less shower containment → more π, K*

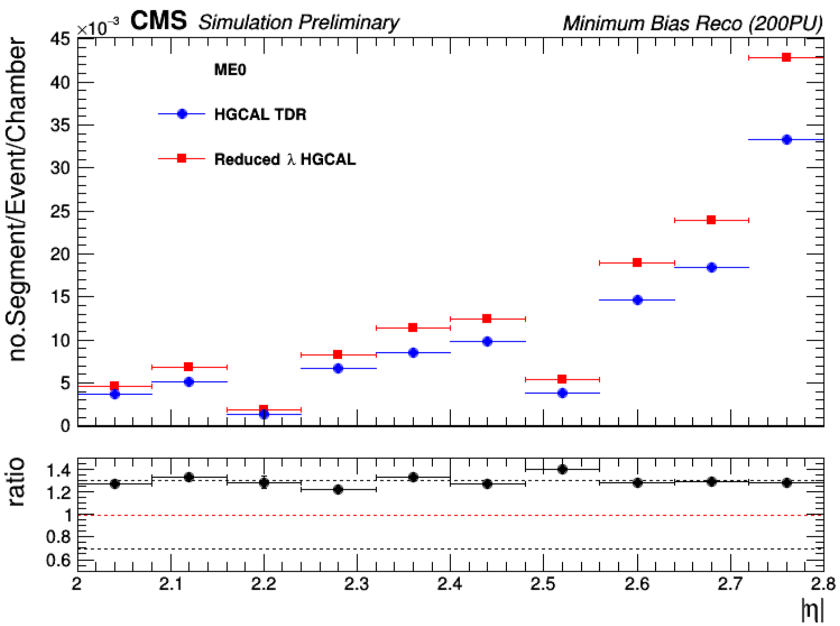
- **Expected:** *no impact on muon fake rate (dominated by $\pi, K \rightarrow \mu$ decay in flight in tracker; if decay in calorimeters, μ will arrive anyway in muon system, independently of number of λ of HCAL*

- **Observed:** *200PU Min Bias sample: 20% (avg)-30% (max) increase in simhits, digis & rechits in detectors behind HGCAL: ME0, GE1/1, ME1/1;*
  - *Increase 30-35% of segments in ME0, ME1/1*
  - *Impact on muon reco after ID and PT cuts minimal → Offline seems OK*
  - *Impact on trigger due to increased combinatorics is dangerous*

- **Observed:** *0PU Pion Gun sample: no increase of fake rate*

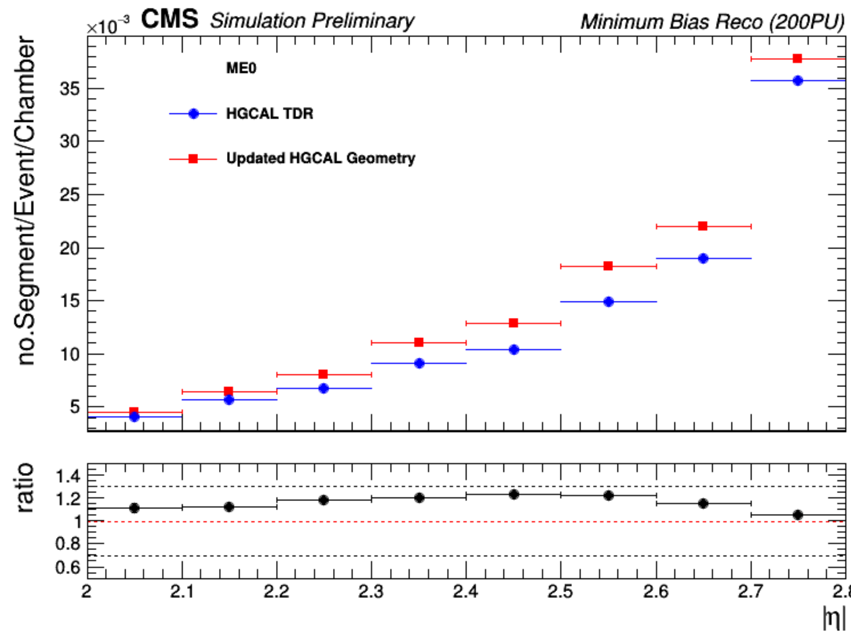
ME0 Segments

CMSSW_10_4_0



30% more segments in reduced λ HGCAL

CMSSW_10_6_0_pre3



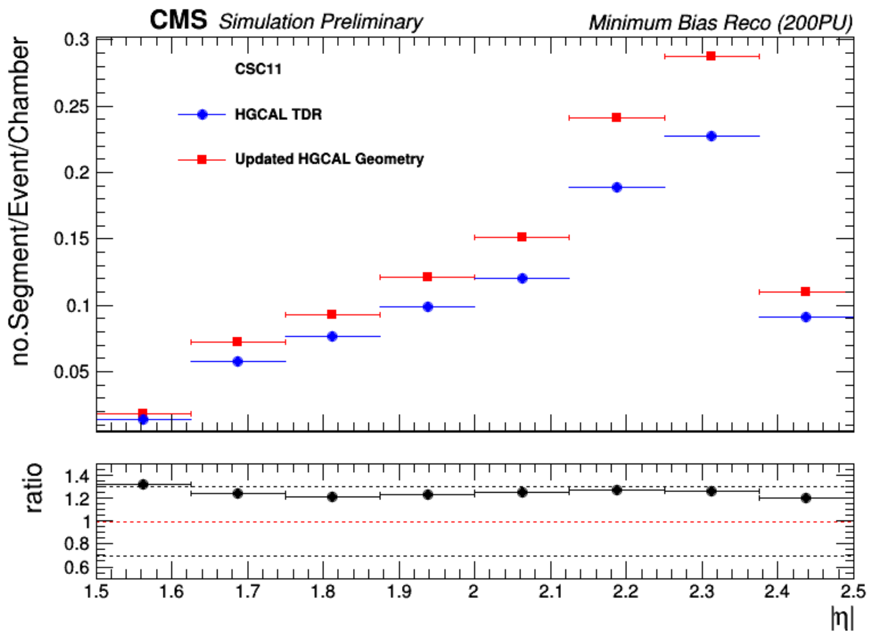
15% more segments in updated HGCAL

Strange drops at eta 2.2 & 2.5 resolved, curve is smoother and reflects better reality!
Segment increase confirmed (however only 10%) likely only due to increase in muons
However CSC keeps seeing 30% increase in segments in ME1/1! (see next slide)

CMSSW_10_6_0_pre3

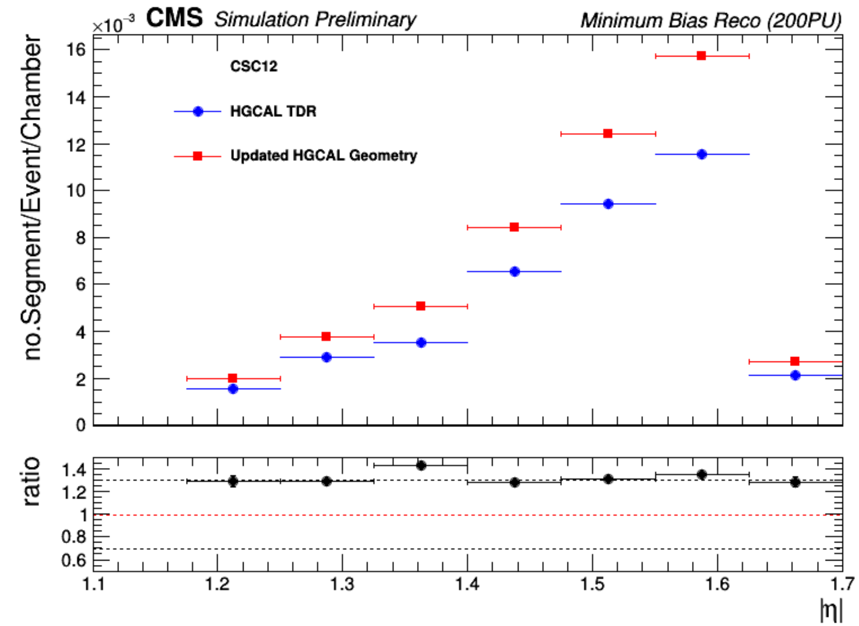
CSC Segments

ME1/1



30% more segments in reduced λ HGCAL

ME1/2

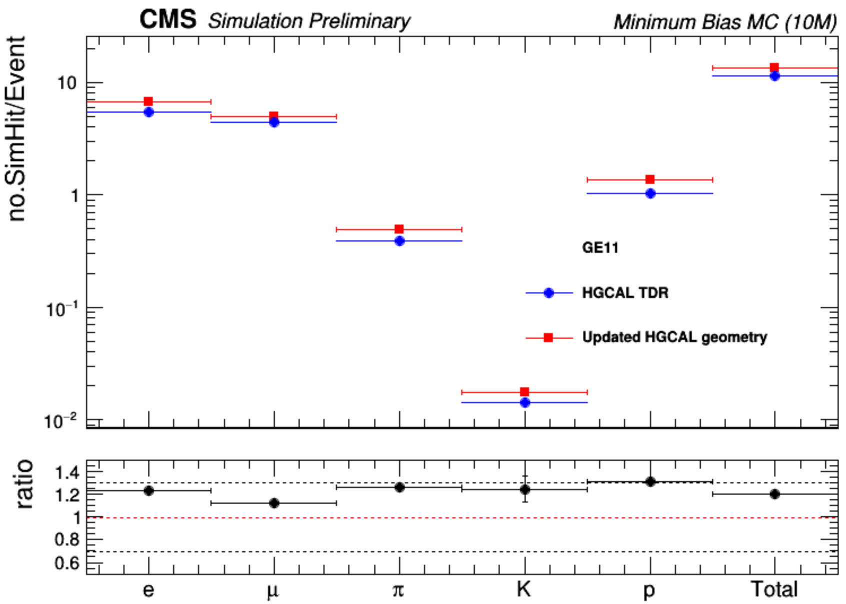


30% more segments in reduced λ HGCAL

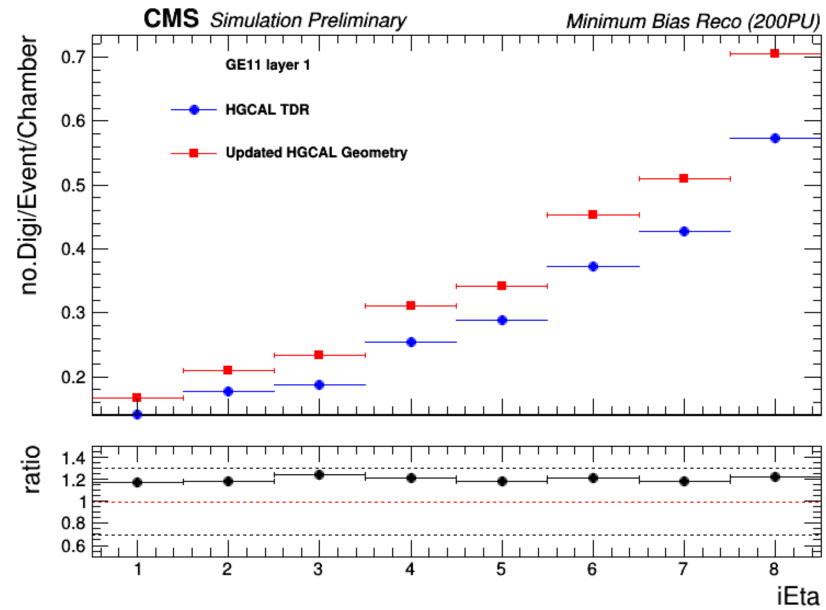
30% segment increase seen in CMSSW_10_4_0 confirmed in CMSSW_10_6_0_pre3

CMSSW_10_6_0_pre3

GEM Hits



20-30% more background hits (e,p,K,π)
15% more μ hits
Trend seen in ME0 not confirmed



20-30% more digis, increase constant over whole eta range

20-30% hit increase seen in CMSSW_10_4_0 confirmed in CMSSW_10_6_0_pre3

Summary

- 30% segment increase in ME1/1 and 20-30% hit increase in GE1/1 confirmed with more detailed HGCal geometry
- For ME0 initial 30% increase seen in CMSSW_10_4_1 was lowered to 15% increase in more detailed HGCal geometry
  - Inclusion of HGCal services in Barrel-Endcap gap
  - Due to inclusion of the back flange (vertical shield) that was missing before

Lessons learnt

- GEANT helped us to do a quick study since we had no persons working on FLUKA, neither could BRIL give us quickly an estimate of the fluxes
- However this was don in emergency mode and on best-effort basis
- Changes in GEANT geometry are implemented slowly and we cannot afford this resources intensive work for every epsilon change
- Need to get back manpower on FLUKA
- Waiting for v.3.7.19.1 to be in the webtool:
  https://cms-project-fluka-flux-map-paas.web.cern.ch/

Back Up