Impact of the Radiation Background on the CMS Muon High-η Upgrade for the LHC High Luminosity Scenario

TIPP2014 Conference

A. Castaneda
on behalf of the CMS collaboration

Texas A&M University at Qatar

castaned@cern.ch

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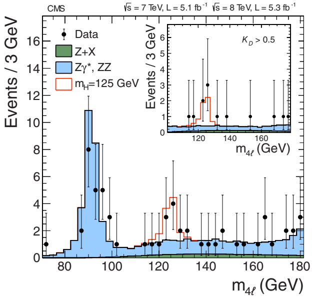
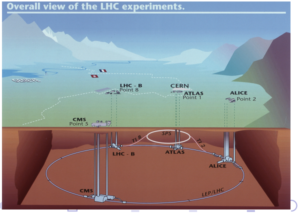
Intro

- The Large Hadron Collider (LHC) performed great during the Run-I data taking period.
- Run-I culminated with the discovery of a Higgs boson-like particle ($m_H = 125$ GeV) (announced in July 2012).
- Following the discovery the LHC has started a series of detector upgrades and maintenance to resume activities with a substantial increase on luminosity (collision rate) and collision energy needed for precision measurements of the new particle properties and possible discovery of new phenomena (SUSY, Exotics,...)
- As a result of the increase on luminosity an unprecedented radiation environment will be created.
- A reliable estimation of the radiation environment is fundamental for the detector design and expected performance

"Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC"
http://arxiv.org/abs/1207.7235

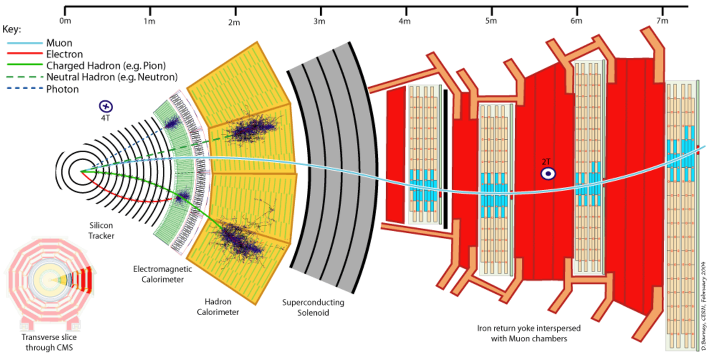


Schematic view of the LHC tunnel and experiments



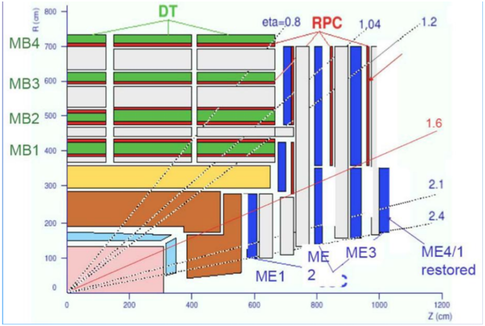
Overview of The CMS detector

- One of the largest experiments at the LHC
- Multipurpose particle detector (Higgs, SUSY, SM, Exotics)
- It consist of the following important subsystems:
  - **Tracker**: Silicon detectors to reconstruct trajectory of charged particles: $e^{\pm}$,$\mu^{\pm}$,hadrons
  - **Calorimeter**: Divided in Electromagnetic (ECAL) and Hadronic (HCAL), designed to measure with high accuracy the energy of electrons, photons and hadrons.
  - **Magnet**: Solenoid magnet providing 4 Tesla magnetic field.
  - **Muon detectors**: Three different types of Muon detectors: Drift Tube (DT), Cathode Strip Chambers (CSCs), Resistive Plate Chambers (RPCs), designed for a precise trajectory measurement and fast signal detection.



CMS Muon System Layout

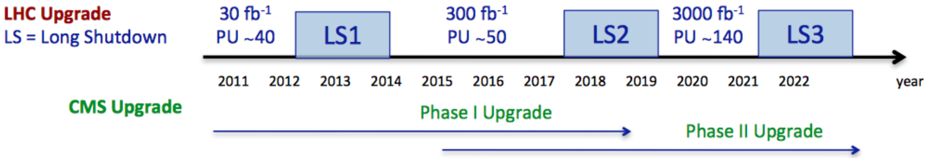
R-z view of CMS quadrant (Run-I)



- Central and Forward detector differences due to:
  - Background rates
  - Magnetic Field Intensity (see backup slides)
- **Central**: DTsand RPCs
- **Forward**: CSCsand RPCs
- DTs and CSCs with excellent spatial resolution and RPCs for timing triggering.

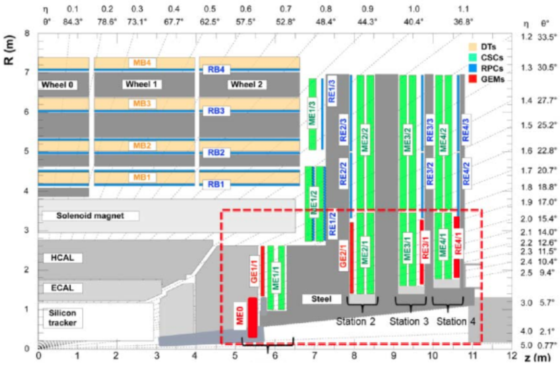
- In the very forward region ($|\eta| > 1.6$) CMS currently relies only on CSCs for muon identification
- For the HL-LHC scenario important upgrades to mantain a good muon reconstruction and triggering

CMS upgrade timeline



- 14 TeV C.M.E
- Optimal luminosity of $5 \times 10^{34} Hz/cm^{-2}$
- Major upgrades for the HL-LHC era on Tracker, Calorimetry and Muon detection
- Recording $3000 fb^{-1}$ in $\sim$10 years operations
- CMS is working to document the overall scope for Phase 2 in a Technical Proposal (2014)

Overview of CMS Muon upgrades for Phase-2

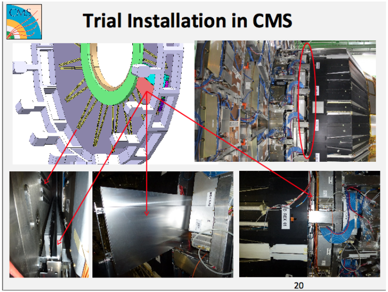


- Extended muon detection capabilities (triggering, reconstruction) in forward region
- New muon stations based on Gas Electron Multipliers (GEM) technology
- New RPC stations (last two stations)
- Increased muon coverage ($2.2 < |\eta| < 3.0/4.0$) with a GEM tagging station

- Currently focused on the radiation environment for the GEM stations. ME0, GE1/1 and GE2/1
- Closer to the interaction point and suffering of intense flux of particles

GEM detectors

- Spatial/Time resolution: 100-200μm/4-5n
- Efficiency>98%
- rate capability$\sim 10^5 Hz/cm^2$



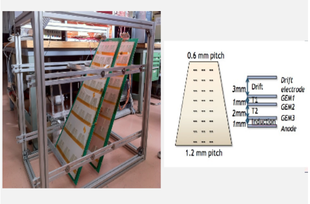


Figure : Large Triple-GEM chambers with trapezoidal shape

- dummy chambers already produced
- Optimize the design and perform trial insertion into CMS
- A complete status of the project already presented by Michael TYTGAT (Tuesday) `http://indico.cern.ch/event/192695/session/3/contribution/223`

Radiation Environment in CMS

- Compared to lepton-lepton collisions hadron-hadron interactions are "dirty" processes
- High energy particles from interaction point initiate hadronic and electromagnetic showers.
- If material is tick these cascades will continue until most of the charged particles are absorbed
- The remaining neutrals are mostly neutrons, which can travel long distances, losing energy gradually

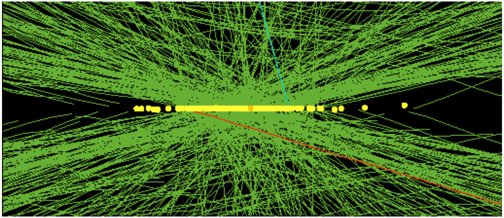
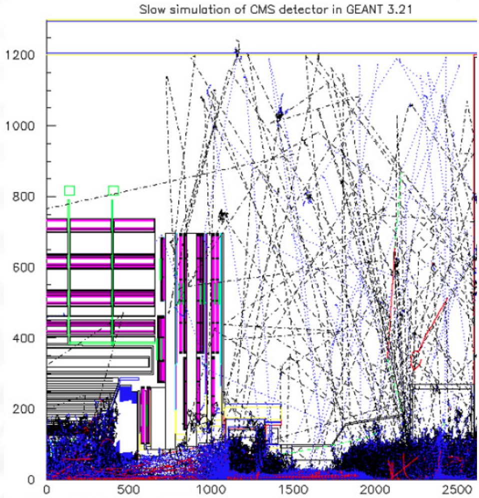


Figure : Event with high pileup

Neutron simulation



plot created by Tim Cox in 2001

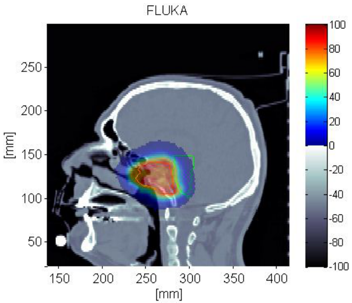
- Long lived neutrons created, diffuse around collision hall
- They get captured by nuclei, emitting a photon
- Compton scattering or photoelectric effects makes MeV electrons, which could potentially cause hit in the muon chambers

$$neutron \rightarrow \gamma \rightarrow e^{\pm} \quad (1)$$

- Current GEANT4 CMS simulation not suitable for neutrons (max simulation time 500ns). Neutron TOF O(seconds)

FLUKA simulation

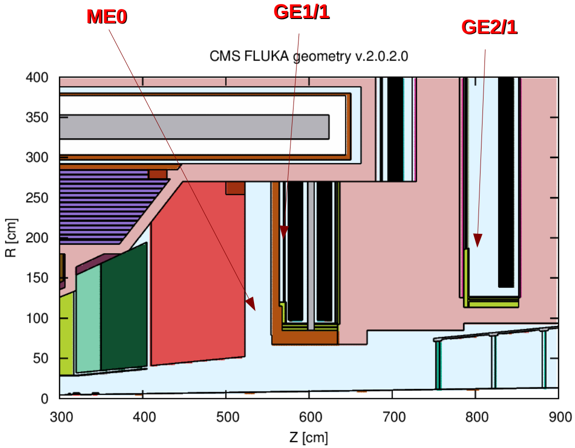
- FLUKA (`http://www.fluka.org/fluka.php?id=about`) is a general purpose tool for calculation of particle transport and interaction with matter.
- Cover an extended range of applications in HEP and medical physics such as shielding design, Calorimetry, activation, neutrino physics, radiotherapy, etc..
- It can handle complex geometries such as the LHC experiment
- Simulations results have been compared in the past with experimental data showing good agreement



FLUKA calculates the dose distribution for a patient treated at Centro Nazionale di Adroterapia Oncologica per il trattamento deitumori(National Hadrontherapy Center for Cancer Treatment), in Italy, with proton beams. The color-bar displays the normalized dose values. Image courtesy A. Mairani (CNAO).

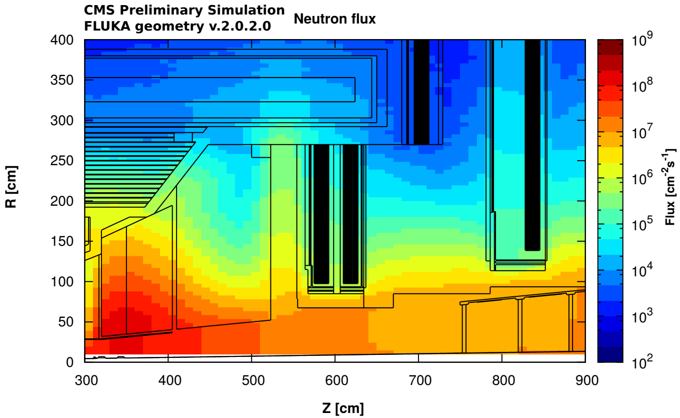
CMS geometry for FLUKA

- Trying to represent the most realistic picture of the detector
- CMS geometry for FLUKA has evolved during the years (improving sub-detector description, shielding, beam-pipe, etc..)
- A preliminary geometry for Phase-2 has been built with the following specifications:



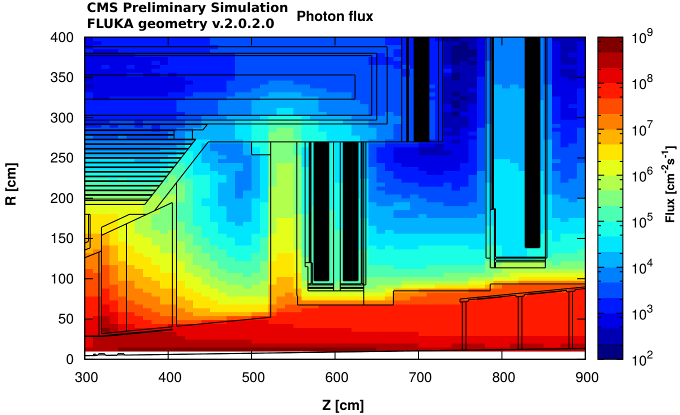
- One of the proposed scenarios for Phase-2 upgrade
  - Current calorimeters replaced with a preliminary model of the High Granularity Calorimeter (HGC) and the HE rebuild
  - Calorimeter maximum coverage up to $|\eta| = 3$
- The image shows the calorimeter end-cap the first two muon stations (CSCs ME1/1 and ME2/1)
- ME0,GE1/1 and GE2/1 volumes currently filled with air

- FLUKA simulation returns the particle flux 2D map
- Flux in Hz/cm^2 assuming a inst. luminosity of $5 \times 10^{34} cm^{-2} s^{-1}$ and c.m.e 14 TeV
- Plots produced running 45k events



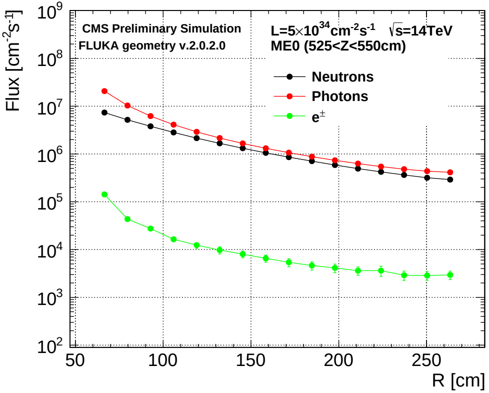
Photon flux

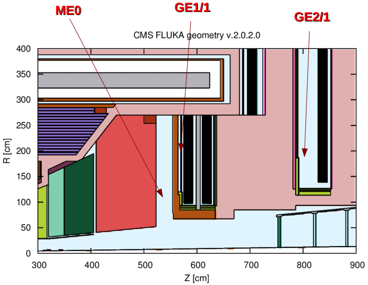
- FLUKA simulation returns the particle flux 2D map
- Flux in Hz/cm^2 assuming a inst. luminosity of $5 \times 10^{34} cm^{-2} s^{-1}$ and c.m.e 14 TeV
- Plots produced running 45k events



A closer look: ME0

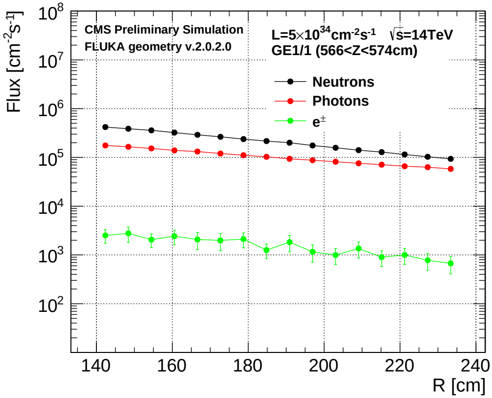
- ME0 will be the detector most affected by intenser flux of particles
- The coverage is up to $|\eta| = 3$ (or R$\sim$60cm)
- Additional shielding will be needed to reduce the particle flux to desirable levels

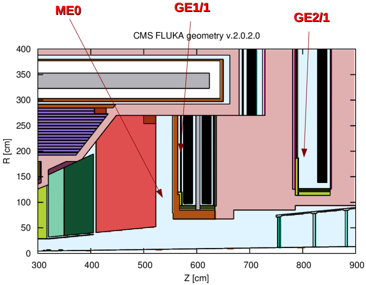




A closer look: GE1/1

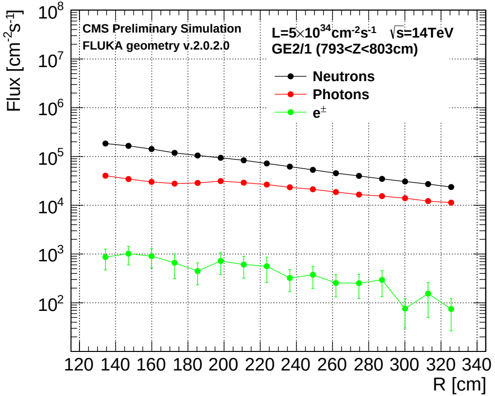
- GE1/1 close to ME1/1 CSC station to increase the capabilities on trigger and reconstruction
- Much lower particle flux compared with ME0

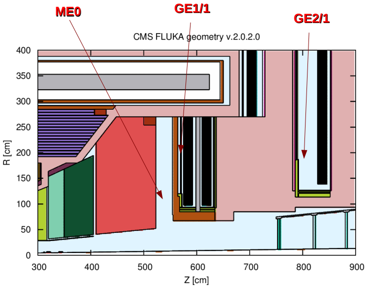




A closer look: GE2/1

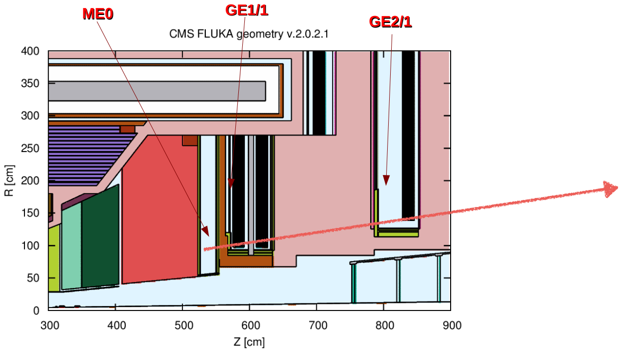
- GE2/1 is the GEM station located further from the IP



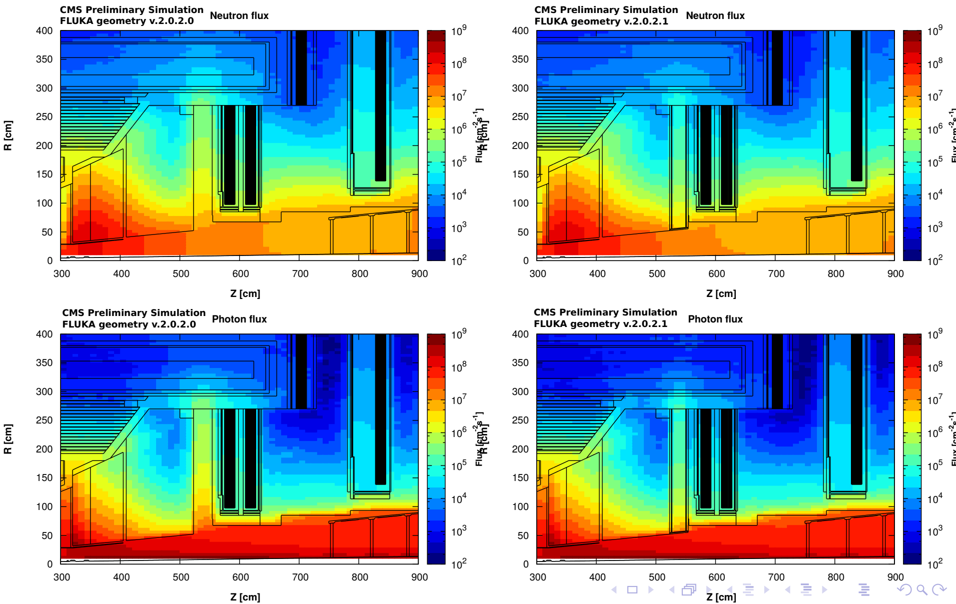


Baseline shielding for ME0

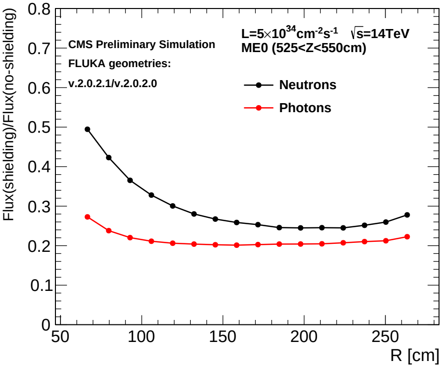
- Intense particle flux in ME0
- A baseline shielding scenario was built
- It consist of layers of B-Polyethylene and Lead-Antimony to further reduce the flux of neutrons and photons



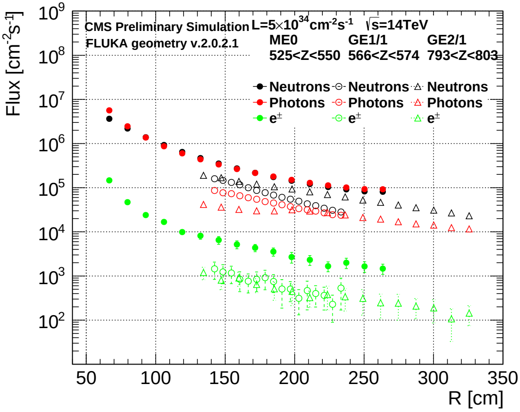
Flux comparison: ME0 vs ME0 (baseline shielding)



Flux reduction: ME0 vs ME0 (baseline shielding)



- Substantial flux reduction on neutrons and photons
- Shielding designed to reduce Bkg contribution with little effect on signal reduction (muons)



- Not all particles will cause a "fake" signal in the detector
- The quantified impact is considering the HitRate

$$HitRate = Flux \times Sensitivity \quad (2)$$

- Dedicated GEM GEANT4 sensitivity studies are undergoing
- Preliminary results shown the following expectations:
- Max HitRate $\sim 10^5 cm^{-2}s^{-1}$ (ME0,R$\sim$60cm)
- Min HitRated $\sim 10^2 cm^{-2}s^{-1}$ (GE2/1,R$\sim$330cm)
- HitRate numbers withing the GEM affordable values

Summary

- The radiation environment was estimated for the CMS forward region during Phase-2 upgrade using FLUKA simulation
- New detector technology (GEMs) will be installed in the forward region to increase capabilities on muon triggering and reconstruction
- Intense particle flux expected for the HL-LHC era
- The most affected detector will be the ME0 tagging station, a baseline shielding was proposed with promising results on neutron and photon flux reduction
- Considering particle fluxes and GEM detector sensitivities the expected HitRate still within the detector capabilities

Acknowledgements

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Backup

Flux definition and normalization

- Track length definition, USRBIN scoring option in FLUKA
- Flux normalization: The number given by FLUKA is normalized to particles/cm^2 per primary, additional normalization factor for number of collisions expected for example for an inst. luminosity of $10^{34} cm^{-2} s^{-1}$

$$Flux\left[\frac{particles}{cm^2 * s}\right] = Flux(fluka)\left[\frac{particles}{cm^2 * primaries}\right] * norm\left[\frac{primaries}{s}\right] \quad (3)$$

$$norm\left[\frac{primaries}{s}\right] = Luminosity * \sigma_{inelastic} \quad (4)$$

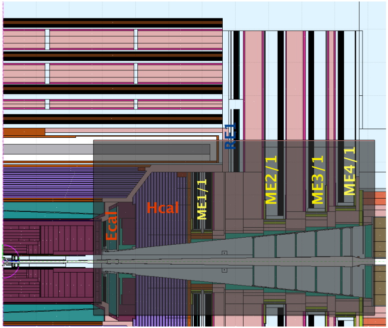
$$norm\left[\frac{primaries}{s}\right] = 10E34\left[\frac{primaries}{cm^2 s}\right] * 80[mb] \quad (5)$$

$$norm\left[\frac{primaries}{s}\right] = 10E7\left[\frac{primaries}{mb * s}\right] * 80[mb] \quad (6)$$

$$norm\left[\frac{primaries}{s}\right] = 80 \times 10^7\left[\frac{primaries}{s}\right] \quad (7)$$

$$(8)$$

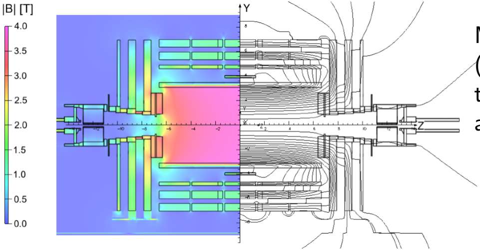
- Years of work and validation to build this geometry
- Baseline geometry for Phase-2 scenarios



- HCAL and ECAL
- CSC stations
- RPC station

CMS magnetic field

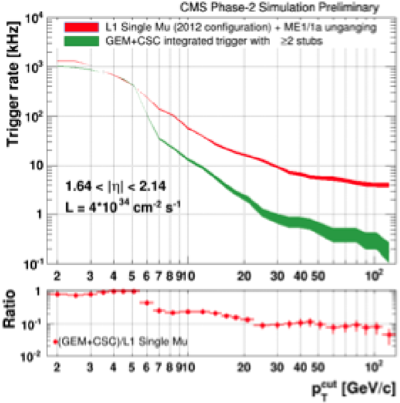
The performance of the CMS muon detector in proton-proton collisions at $s = 7$ TeV at the LHC - Chatrchyan, Serguei et al - `arXiv:1306.6905`



Map of the —B— field (left) and field lines (right) predicted for a longitudinal section of the CMS detector by a magnetic field model at a central magnetic flux density of 3.8T.

Trigger rate reduction using GE1/1

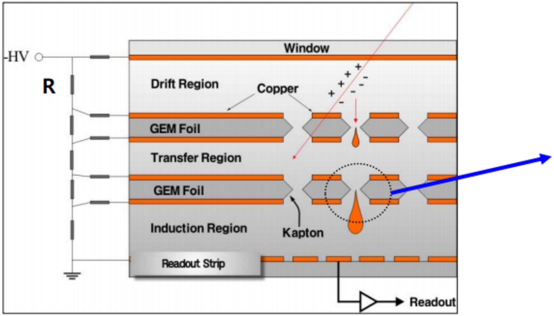
Example of single μ trigger rate reduction with GEM1/1 station

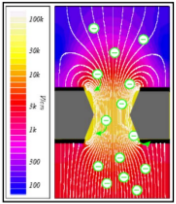


- GEM detector working together with CSCs may improve the muon trigger resolution helping to reduce the rate
- Lowering of muon pT threshold possible

Principles of a GEM detector

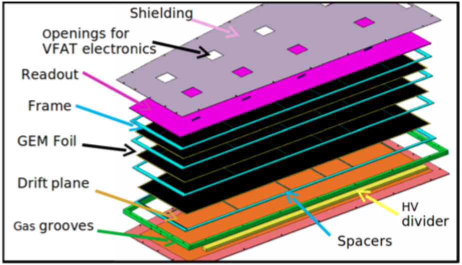
- Gas Electron Multiplier (GEMs) has been successfully applied not only in particle physics experiments but also in medicine with the improvement of imaging techniques in the detection of cancer for instance.
- GEMs are gaseous detectors that consists of foils (kapton), chemical perfored with a high density of holes (multiplication region)
- Charged particles interact with the gas ($ArC0_2CF_4$), as a product of the ionization free electrons are produced and then multiplied (avalanche) until they reach the readout system

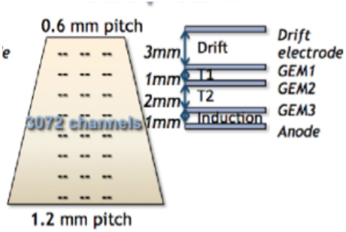




Electron Avalanche
→ Amplification

- Triple-layer GEM detector was chosen as the optimal configuration
- GE1/1 is composed of two triple-layer GEM mounted face-to-face
- Full size trapezoidal prototypes were already tested using beams of muons and pions
- Dummy chambers already installed in the CMS experiment





Shielding material

Material	ρ (g/cm^3)	Λ_0 (cm)	X_0 (cm)	Comment
Pure Cu	8.9	17.5	1.45	(expensive)
Cu Alloy	8.6-8.8	18.0-18.4	1.40-1.35	(machinable)
Pure Fe	7.9	19.1	1.8	(n resonances)
Steel	7.8	19.2	1.8	(low carbon)
Cast Fe	7.2	20.4	2.0	(3% carbon)
Pb	11.4	18.9	.56	(γ filter)
Pure W	19.3	10.3	.35	(elemental)
W Alloy	18.2	11.2	.38	(expensive)
Concrete	2.4	46.9	10.9	(walls)
C	2.3	50.0	18.8	(moderator)
Al	2.7	37.2	8.9	(structural)
Polyethylene	.94	92.4	47.0	(moderator)

Table 2.1 Radiation lengths and interaction lengths for the materials more commonly used in the shielding