Simulation of Neutron Background in CMS GE11 Triple-GEM chambers

O. Bouhali[1], A. Castaneda[2], S. S. Chauhan[3], T. Kamon[4], Y. Kang[5],
S. Kumar[3], A. K. Virdi[3]
[1] *Texas A&M University, Qatar*
[2] *Universidad de Sonora, Mexico*
[3] *Panjab University, Chandigarh*
[4] *Texas A&M University, USA*
[5] *University of Seoul, South Korea*

RD51 Collaboration Meeting
June 2021

Overview

- **Main Background sources in GE1/1 region.**
- **Estimation of background particles**
  - **FLUKA Simulation of the CMS Geometry.**
- **Response of GE1/1 detector**
  - **GEANT4 simulation of Superchamber**
  - **Different parameters can affect the response.**
- **Comparison of Simulation with Run-2 Slice Test background data.**

*** Detailded study is in the DN-20-035**
**** TWiki:** ***https://twiki.cern.ch/twiki/bin/view/CMS/RadiationBackgroundForGE11JINST***

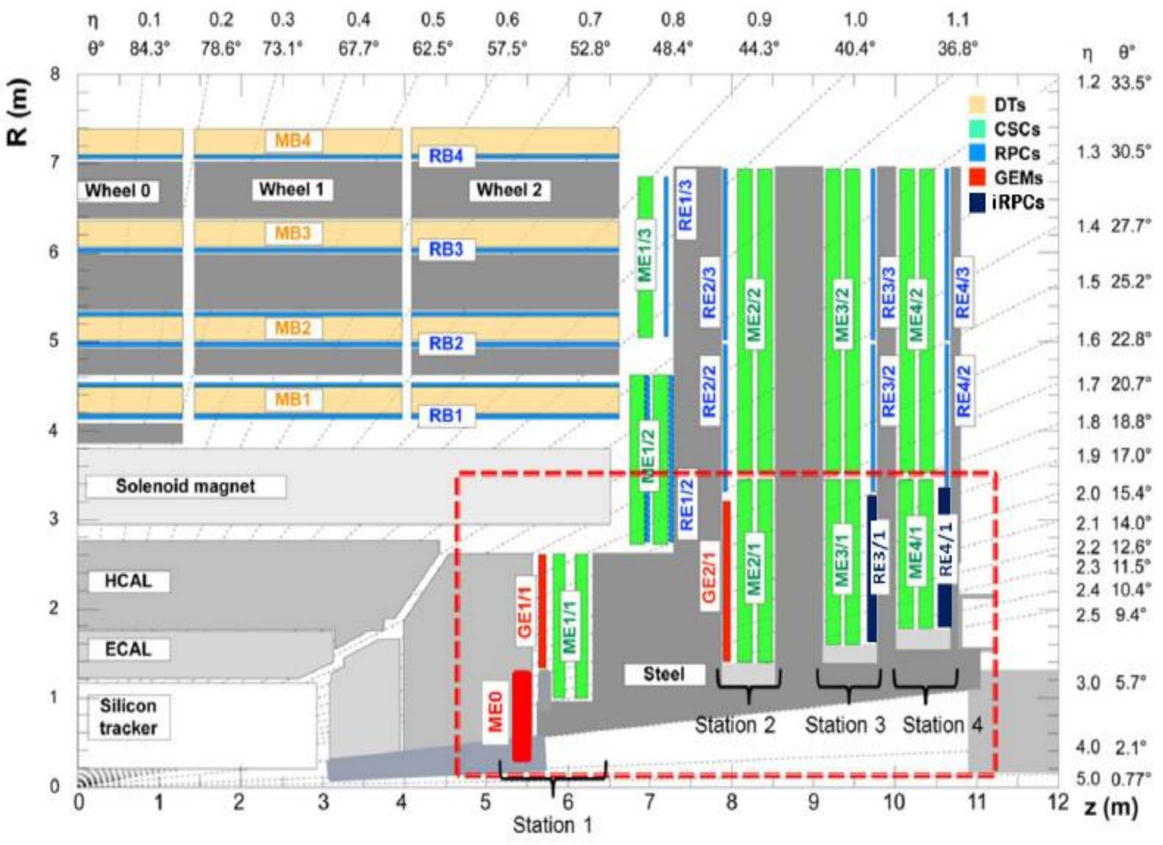
Background Sources

Main sources of background radiations identified in the Muon System:

- From collisions and radiation leak from HCAL gap
  - mainly charged hadrons i.e. kaons($K^{\pm}$), pions ($\pi^{\pm}$) and protons (p^{+})
- From Cavern
  - neutrons from the hadrons interactions with the material I.e. beam pipe
  - Secondaries (e+, e-) from these neutrons interactions.

Role of background:

- Can damage the detector system if the rates are too high.
- Complicates the signal identification.



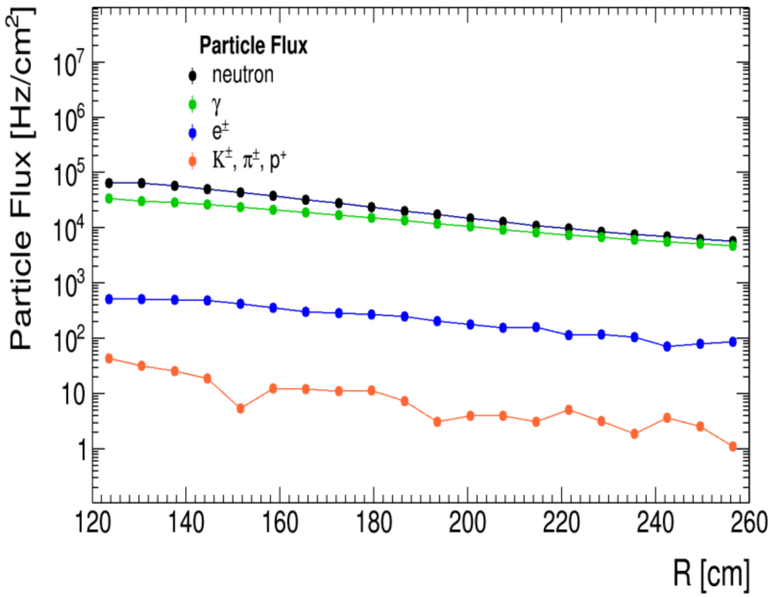
A quadrant plot of the CMS detector is shown. The Triple GEM station is labeled with GE (in red). The currently installed GEM station is given in Red GE1/1.

Method for background rate calculation

$$\text{Hit Rate} = \sum_{\text{type}} \text{Flux}(type, E, \theta, R) \otimes \text{Sensitivity}(type, E, \theta)$$

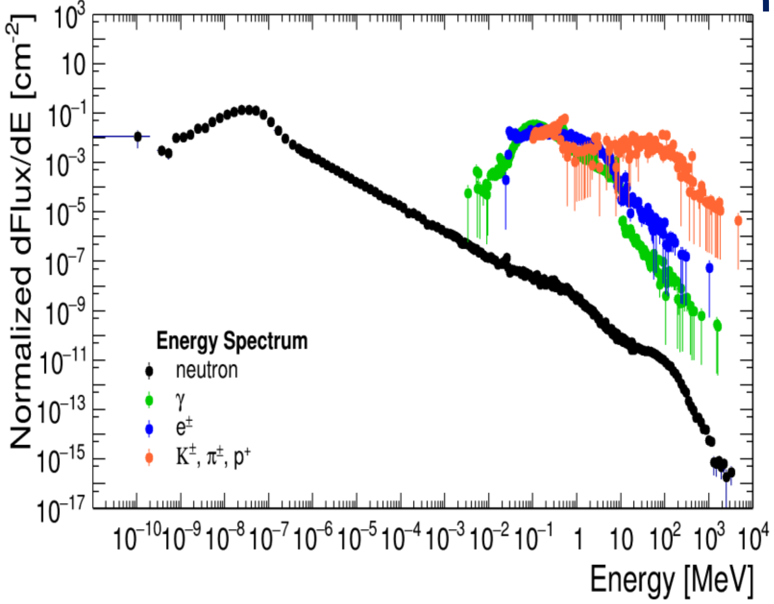
CMS simulation using *FLUKA v2011-3.0* Framework

Super-Chamber simulation using *GEANT4 v10.6* Framework



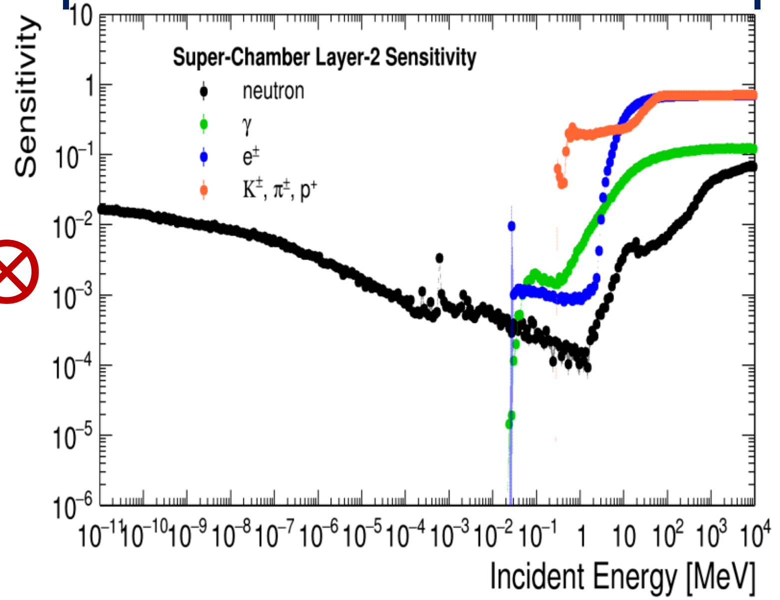
Particle-Flux φ

×



Normalized Energy Spectrum (1/φ) (dφ/dE)

⊗



Sensitivity-Energy Spectrum dS/dE

Flux* multiplied by the *Average Sensitivity* is called as *Hit Rate

Integration of the product will give a number as *Average Sensitivity*

FLUKA Simulation

CMS FLUKA Simulation

FLUKA simulation of **CMS (Compact Muon Solenoid)** is performed for **proton-proton** collision and particle fluxes, differential energy spectrum (**dN/dE**) and direction cosines spectrum (**dN/dcosθ_i, i = x, y, z**) for the

- **Luminosity 1.5 x 10^{34} cm^{-2}s^{-1}**
- **120 < R < 260**
- **565 < Z < 574**

are obtained for

- **charged hadrons ($K^{\pm}$, $\pi^{\pm}$, p^{+})**
- **neutrons (n)**
- **photons (γ)**
- **electrons and positrons ($e^{\pm}$)**

***FLUKA:* a fully integrated particle physics Monte Carlo simulation package. Suitable for calculating flux maps, particle spectra, energy depositions, dose distributions & ambient dose...**
BRIL uses FLUKA for the radiation doses and background calculations.

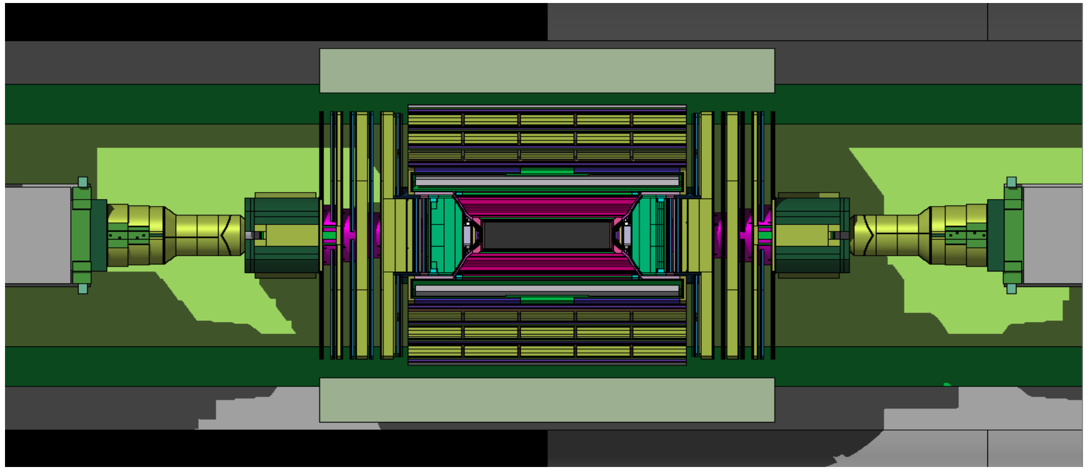
Flux Calculation at Luminosity 1.5 x 10^{34} cm^{-2}s^{-1}

Desired result — **FLUKA result** — **Normalization factor**

$$\text{FLUX}\left[\frac{1}{\text{cm}^2\text{s}}\right] = \text{FLUX}\left[\frac{1}{\text{cm}^2\,\text{primary}}\right]\cdot \#\text{collisions}\left[\frac{\text{primaries}}{\text{s}}\right]$$

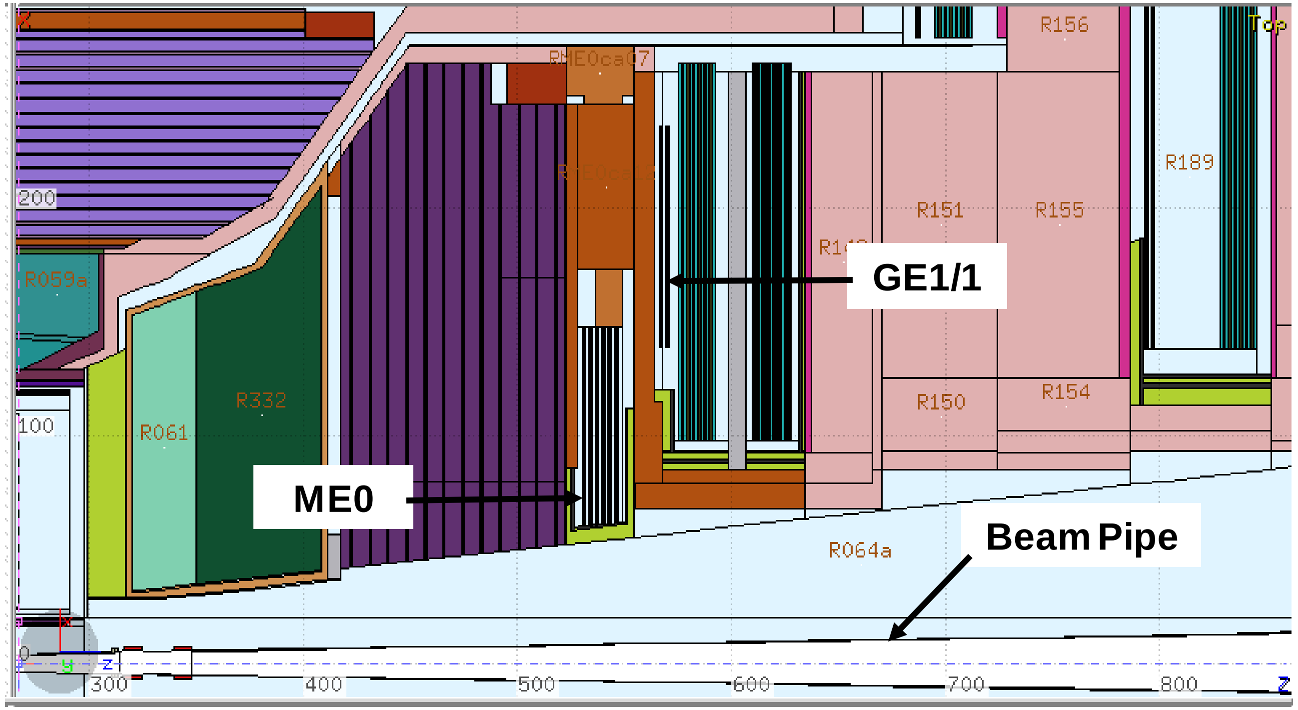
$$\#\text{collisions}\left[\frac{\text{primaries}}{\text{s}}\right] = \text{Lumi}\left[\frac{1}{\text{mb}\cdot\text{s}}\right]\cdot\sigma_{\text{inel}}[\text{mb}]$$

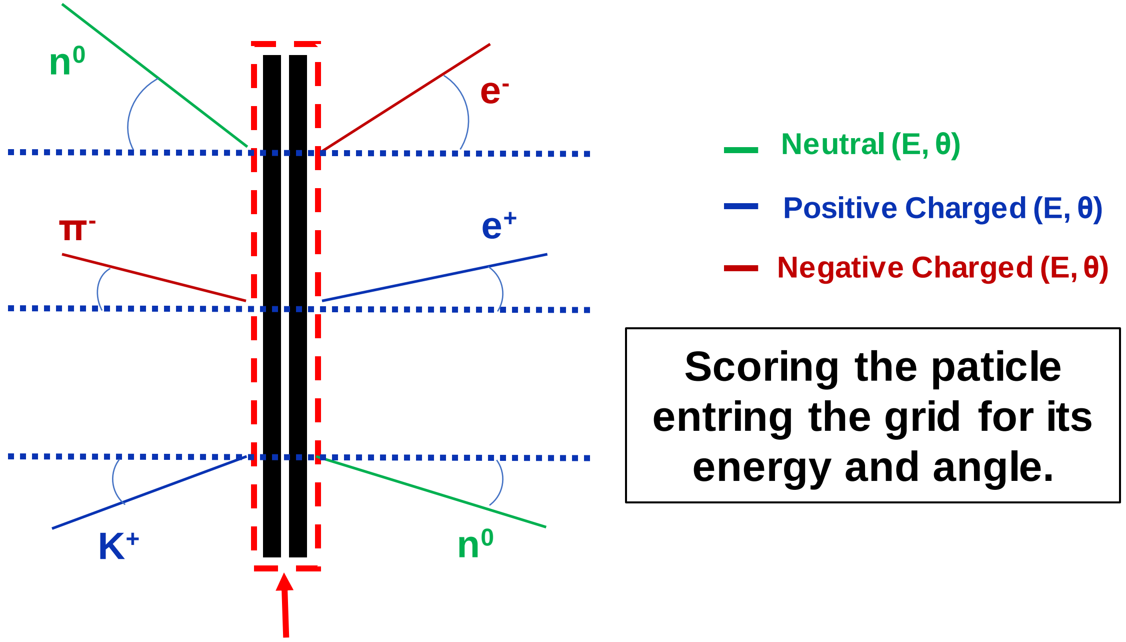
User configured — **Energy depended**



CMS FLUKA simulation run 3.41.4.3

FLUKA Simulation

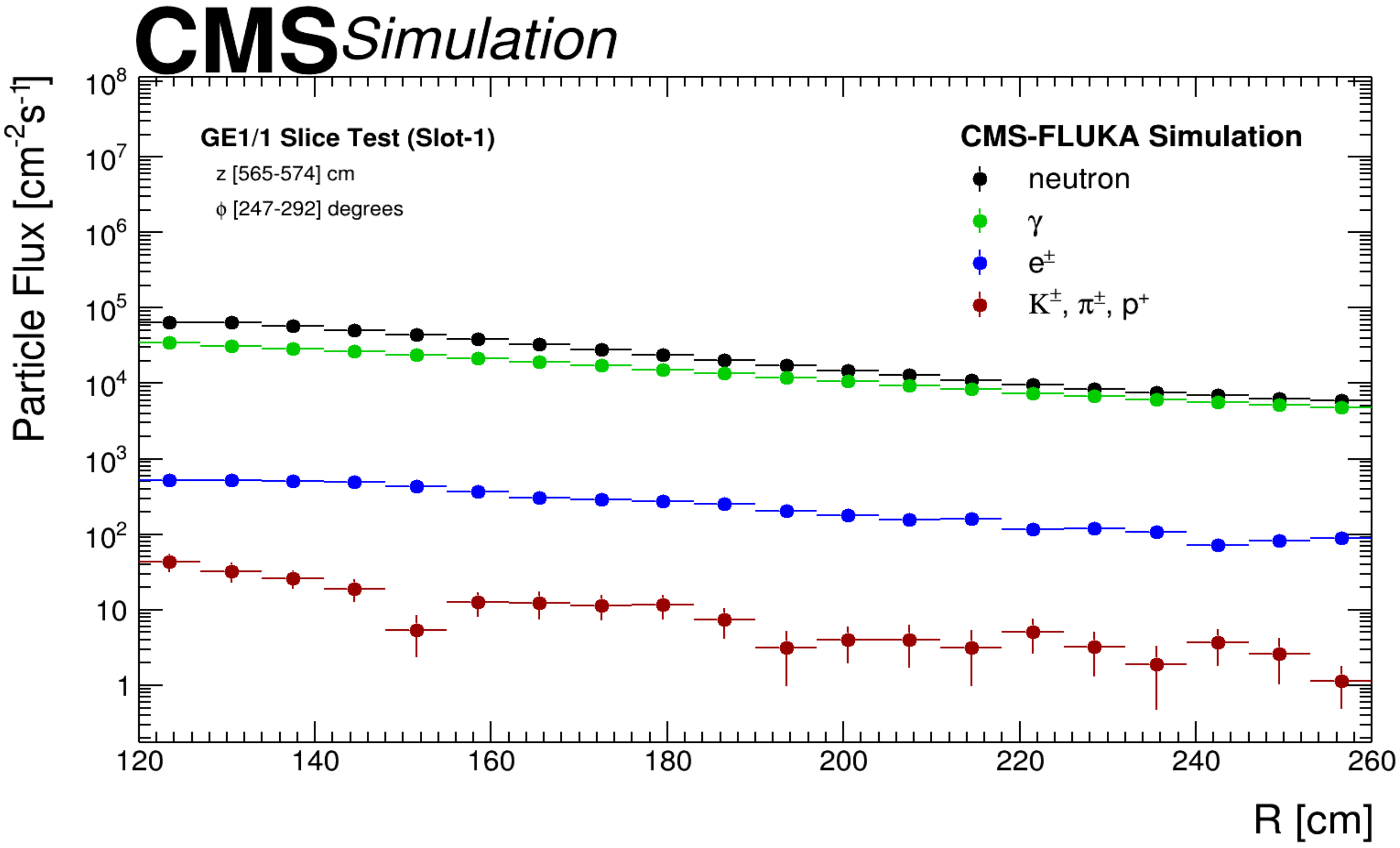




Three primary distributions are obtained by FLUKA simulation with Run-2 Geometry v3.31.4.3.

I. Flux vs R, dN/dR , used to normalize with sensitivity factor
II. Energy spectra, dN/dE , defined in the whole GEM detector volume.
III. Angular distribution, $dN/d\cos\theta_z$, defined in the whole GEM detector volume.

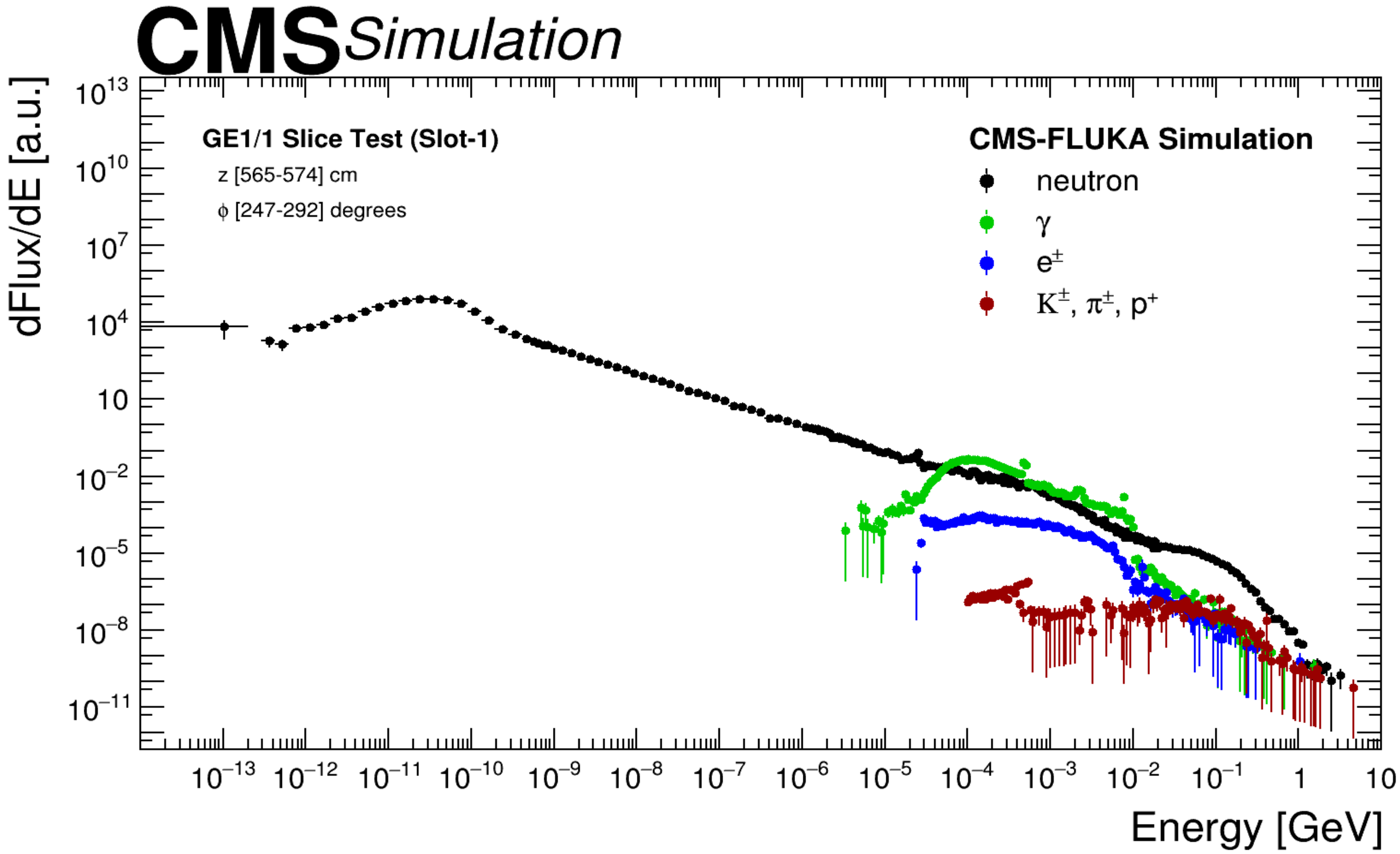
Particle Flux



Inelastic cross section used for normalization is 80 mb to normalize for an instantaneous luminosity of 1.5×10^{34} $cm^{-2}s^{-1}$.

https://twiki.cern.ch/twiki/bin/view/CMSPublic/GEMDPGPublic#GE1_1_background_simulation_and

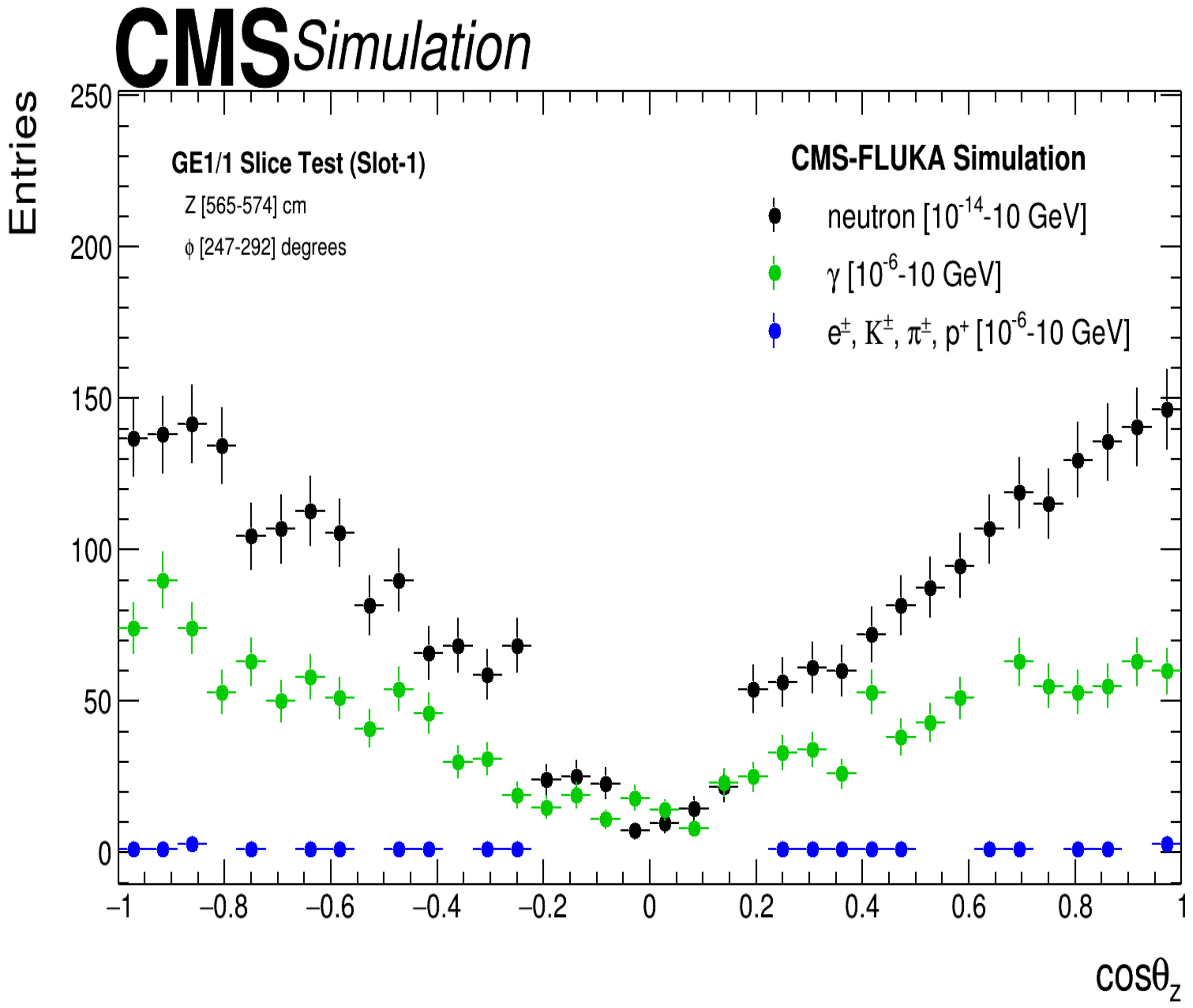
Energy Spectrum



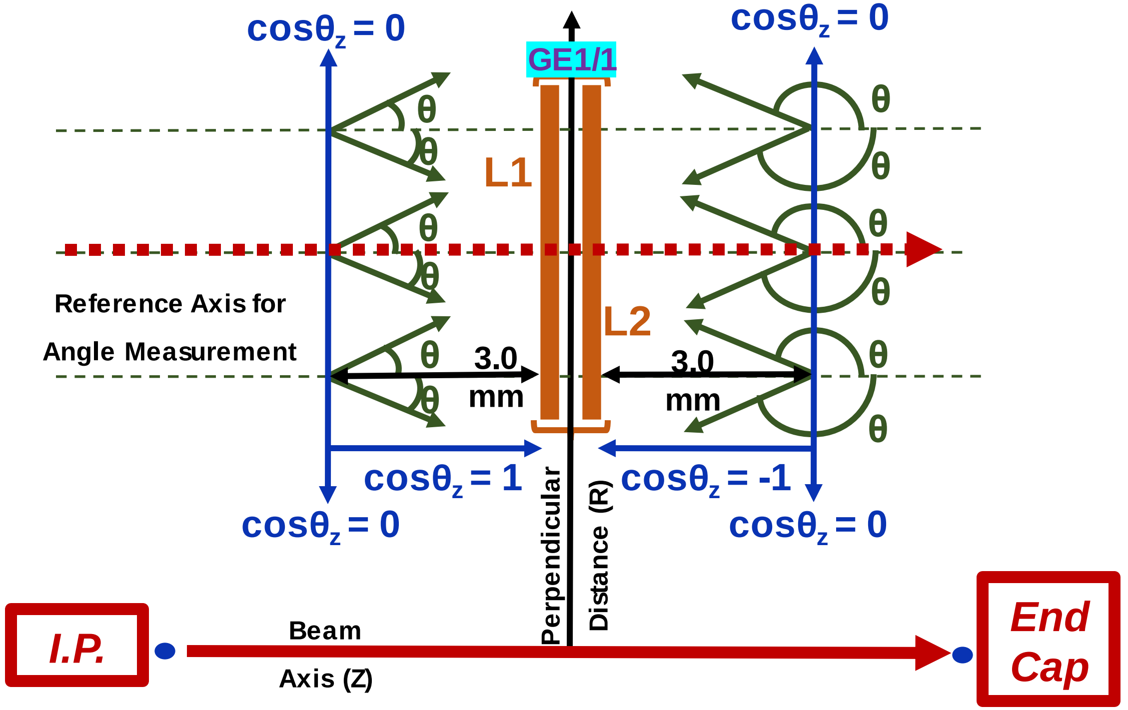
Cut-offs of 100 keV for charged hadrons ($K^{\pm}$, $\pi^{\pm}$, p^{+}), 0.01 meV for neutrons (n^0), 3 keV for photons (γ), 30 keV for electrons/positrons ($e^{\pm}$) is applied.

https://twiki.cern.ch/twiki/bin/view/CMSPublic/GEMDPGPublic#GE1_1_background_simulation_and

Direction cosine-z



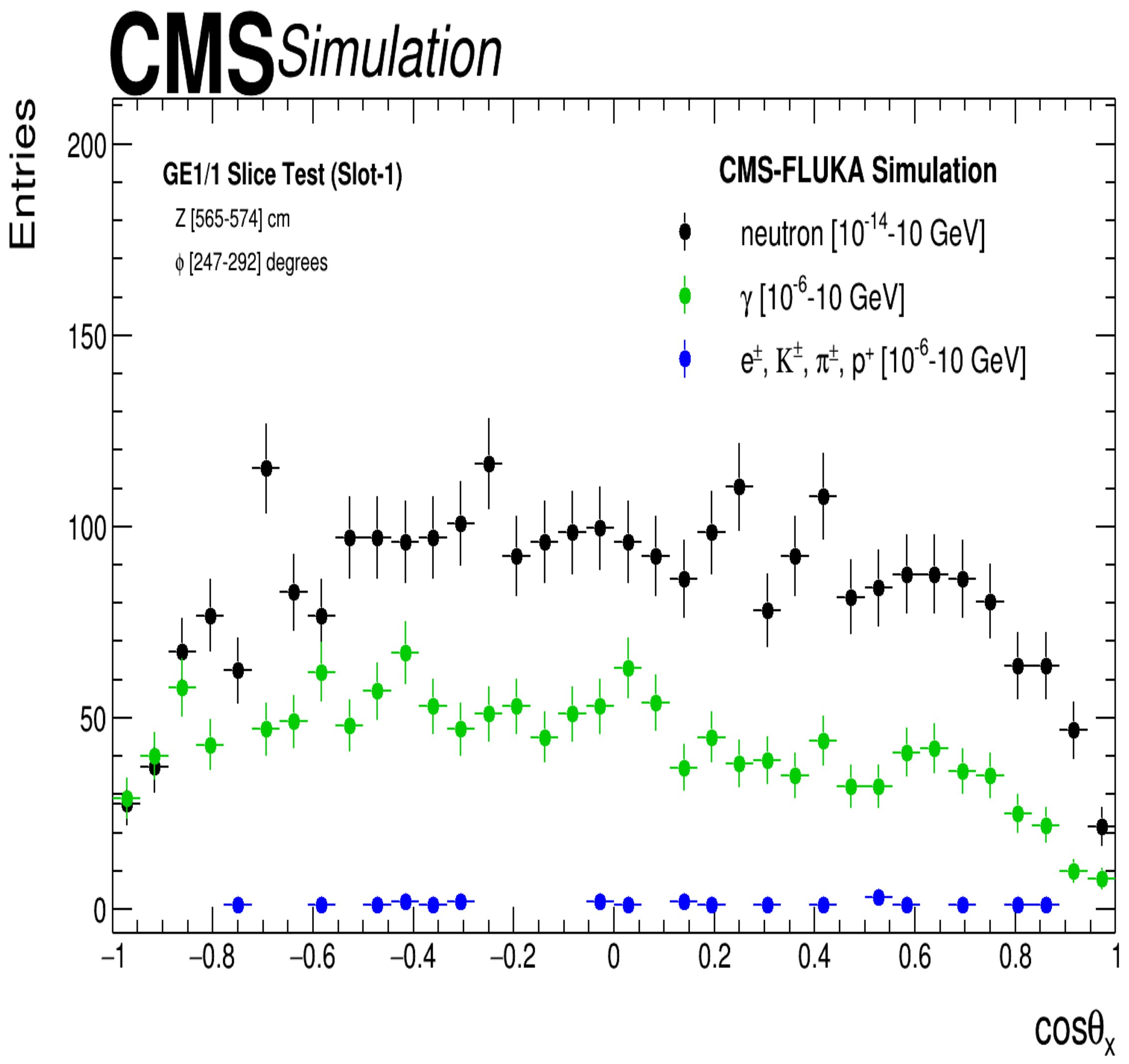
Beam axis directing from Interaction Point (I.P.) to endcap is taken as reference direction for the measurement of angle

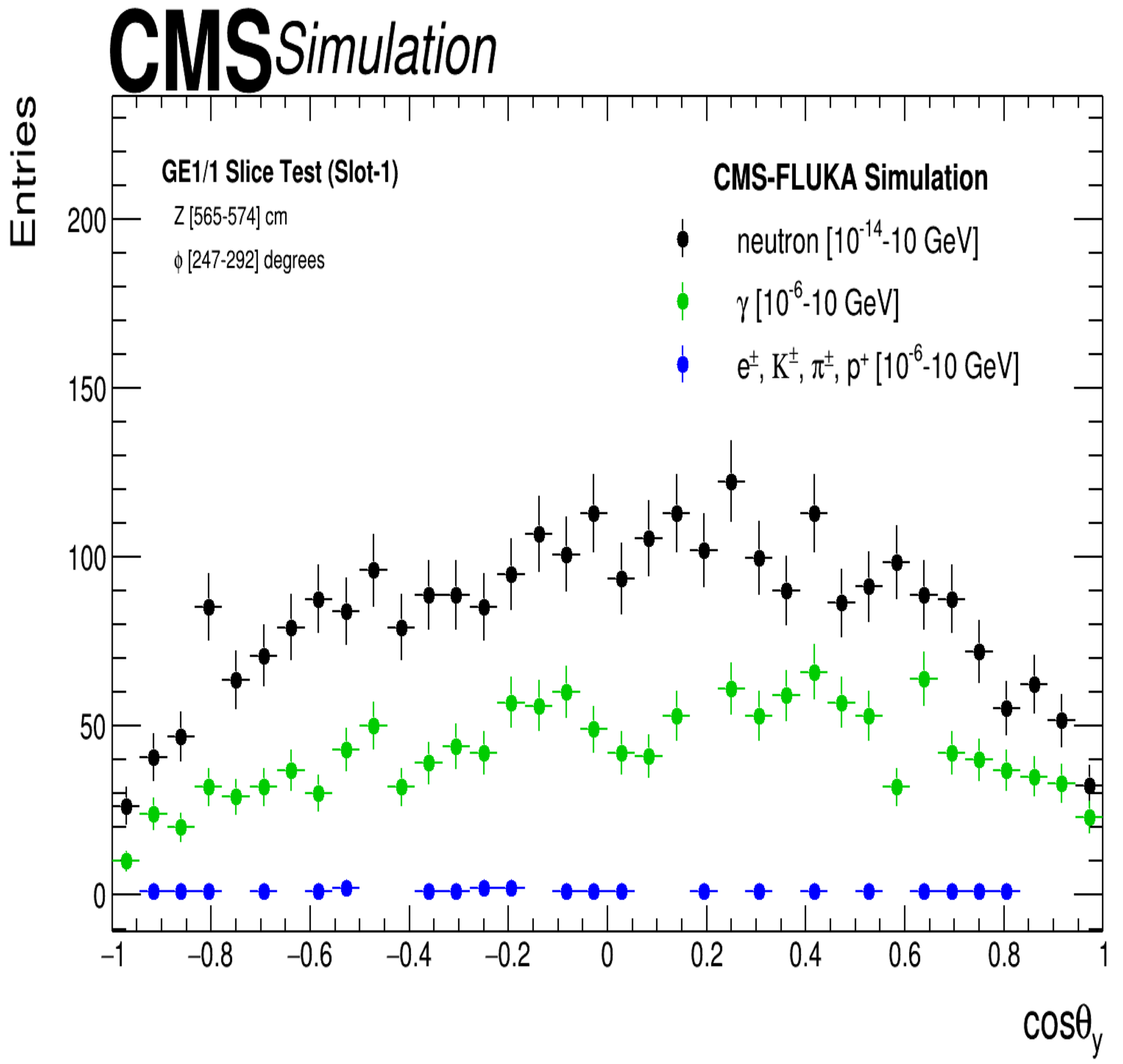


GEANT4 use direction cosine as an input, so we used direction cosine for particle generation.

https://twiki.cern.ch/twiki/bin/view/CMSPublic/GEMDPGPublic#GE1_1_background_simulation_and

Direction cosine-x & cosine-y





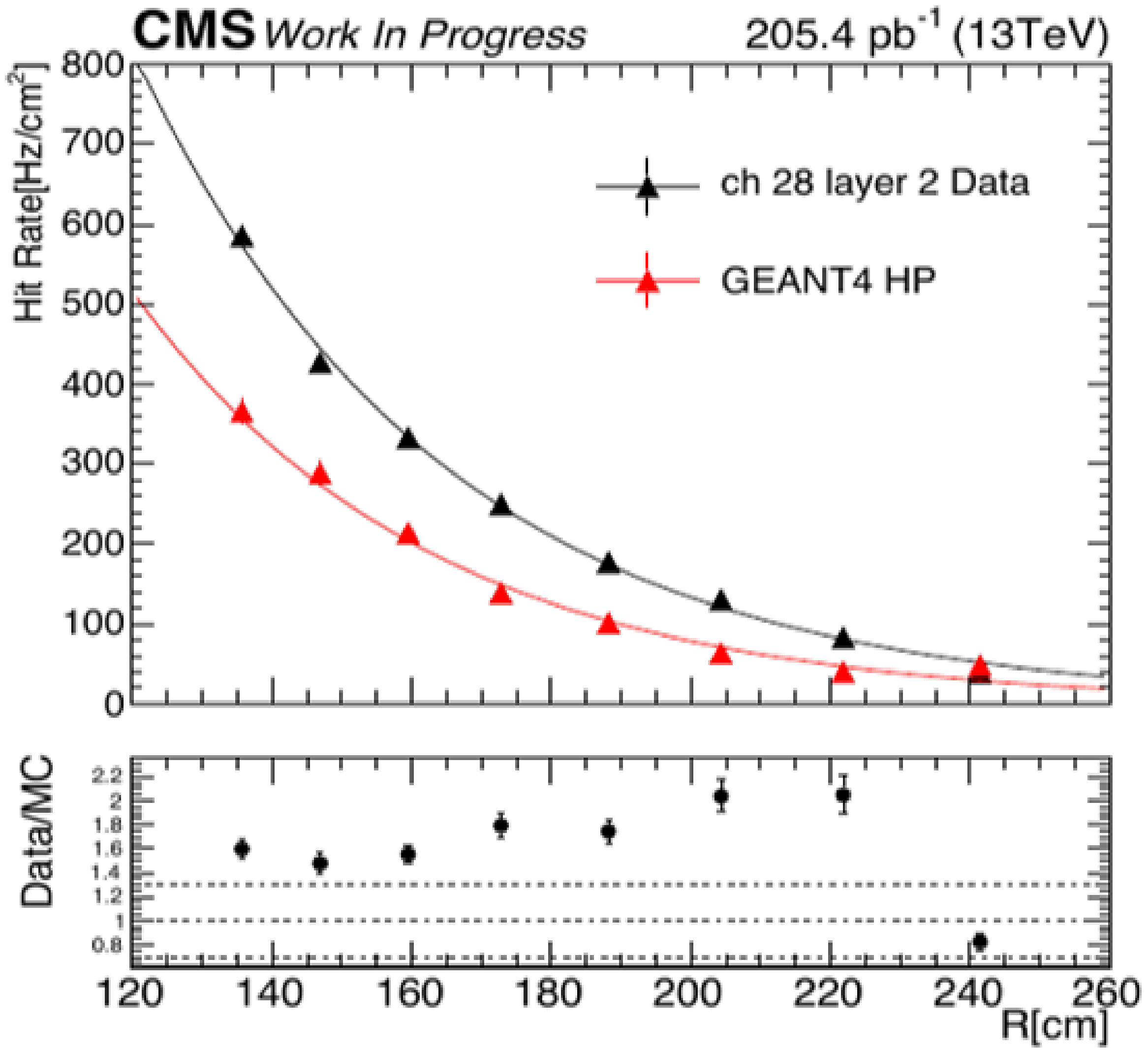
GEANT4 Simulation

Discrepancy with Data vs MC (Earlier Work)

Initially, we simulated for the a simplified single triple-GEM geometry – with the assumption of same behavior for layer-1 and layer-2.

TDR	
Incident Particle	**Average Sensitivity**
neutron	0.18 ± 0.05
photon	0.97 ± 0.04
e^{+-}	8 ± 3

Prediction was inconsistent with the data ~ 40%



**link to plot*
https://indico.cern.ch/event/866479/contributions/3651201/attachments/1951456/3239739/26.Nov.BackgroundSim.SliceTest.pdf

Sensitivity and Thresholds used in GEANT4

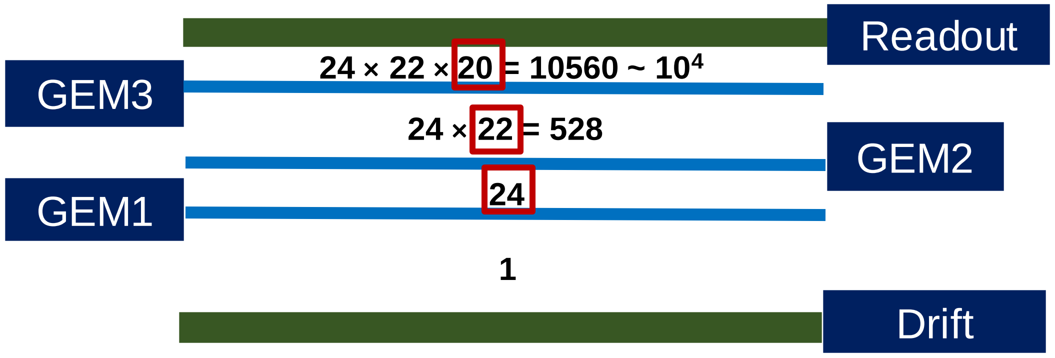
Sensitivity ➡ **probability for a particle to interact inside the sensitive material and produce a signal event**
Signal ➡ **when energy deposit of the charged particles produced as a consequence of the interaction of the primary particle in the sensitive volume of the detector exceeds a particular threshold.**

(Drift & Transfer-1 Gap are used as sensitive volume)

$$\textit{Sensitivity} = \frac{\textit{Numbers of Detected Events}}{\textit{Number of Events fall on the Detector Surface}}$$

(For Super-chamber denominator is sum events of from both side i.e. drift and readout side)

Approximate Gain per foil in Triple-GEM (3,1,2,1)



Threshold used for Super-Chamber @ Gain ~ 10^4

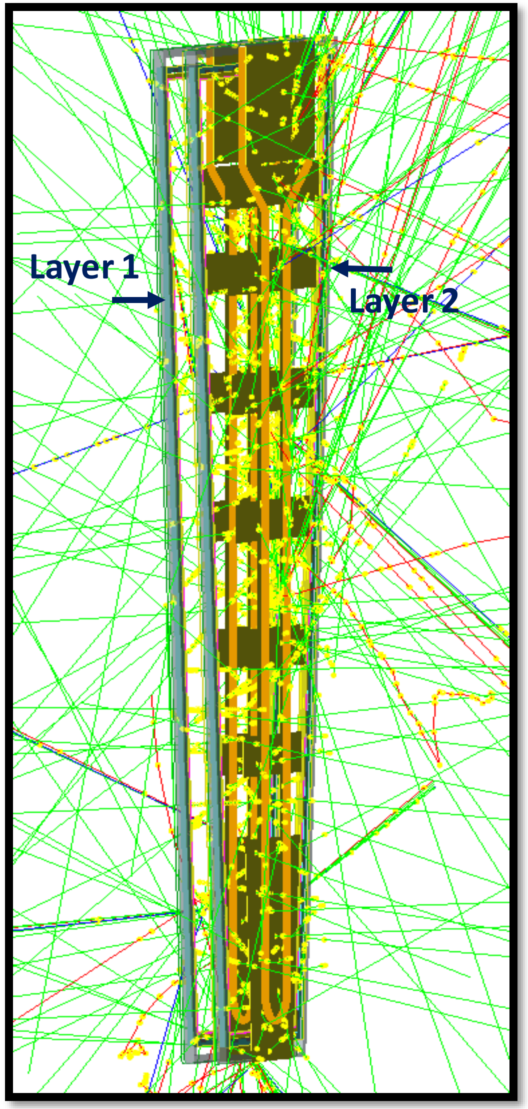
Parameters	**Drift Gap**	**Transfer-1 Gap**
Minimum no. of electrons in gap Energy Thresholds	1 28.1 eV	24 674.4 eV

The number of secondary electrons produced by an incident particle is calculated by dividing the energy deposited by an incident particle to the energy required **(28.1 eV)** for one **simhit** in a gas gap.
Method of counting of electron tracks is not used because GEANT4 only reports them if they pass the production cut threshold of 0.7 mm on track length.

Super-Chamber in The CMS Experiment

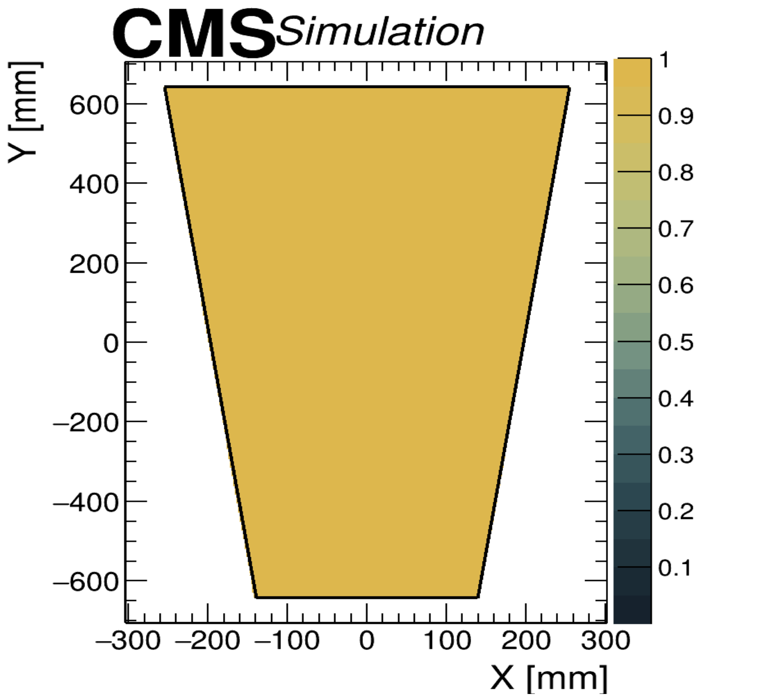
Layer	Z-Dimensions	Material
Drift Board	35 µm / 3.2 mm / 35 µm	Copper / FR4 / Copper
Drift Gap	3 mm	ArCO2
GEM 1	5 µm / 50 µm / 5 µm	Copper / Kapton / Copper
Transfer 1 Gap	1 mm	ArCO2
GEM 2	5 µm / 50 µm / 5 µm	Copper / Kapton / Copper
Transfer 1 Gap	2 mm	ArCO2
GEM 3	5 µm / 50 µm / 5 µm	Copper / Kapton / Copper
Induction Gap	1 mm	ArCO2
Readout Board	35 µm / 3.2 mm / 35 µm	Copper / FR4 / Copper
GEB	0.1 mm / 0.9 mm	Copper / FR4
V-Fat & Opto-hybrid	1.00 mm / 1.6 mm	FR4/Copper
Cooling Pads	1.00 mm	Copper
Cooling Pipes	8.0 mm external, 6.0 mm internal	Copper(Filled with H_2O)
Spacers	3 mm/1 mm/2 mm/1 mm	FR4
External Frame	7.2 mm	FR4
ZIG	11.5 mm	Aluminium
Cover	1.00 mm	Aluminium

Pull-outs, Spacers, External Frame, Aluminum Zig is used in the Detector Geometry.

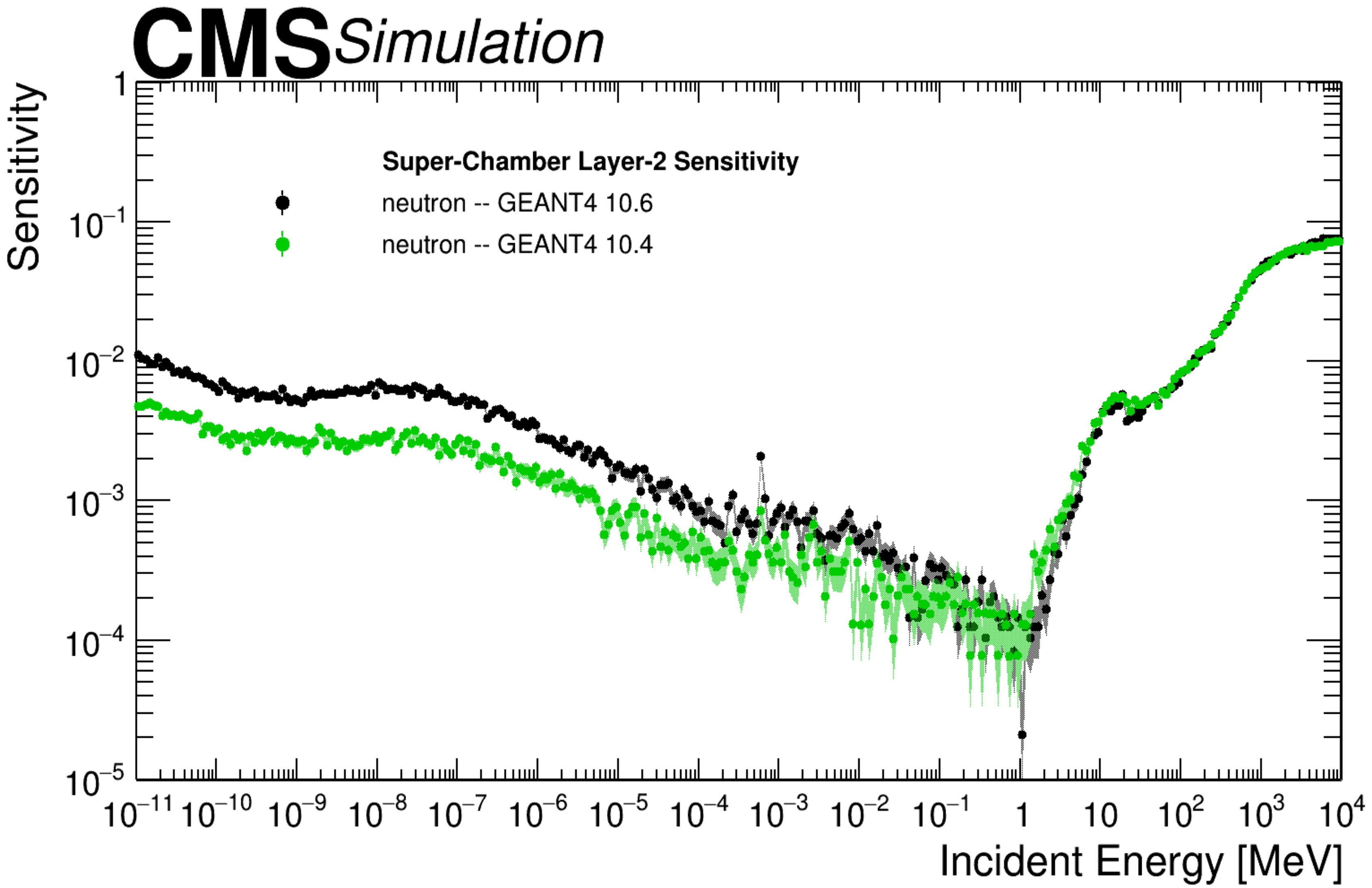


Position of Primary Incident Particle = (trapezoidal shape uniform distribution at 3 mm above on either sides of detector) & Angle Coverage = 90° (with respect to normal to the detector surface)

Primary Particle Distribution

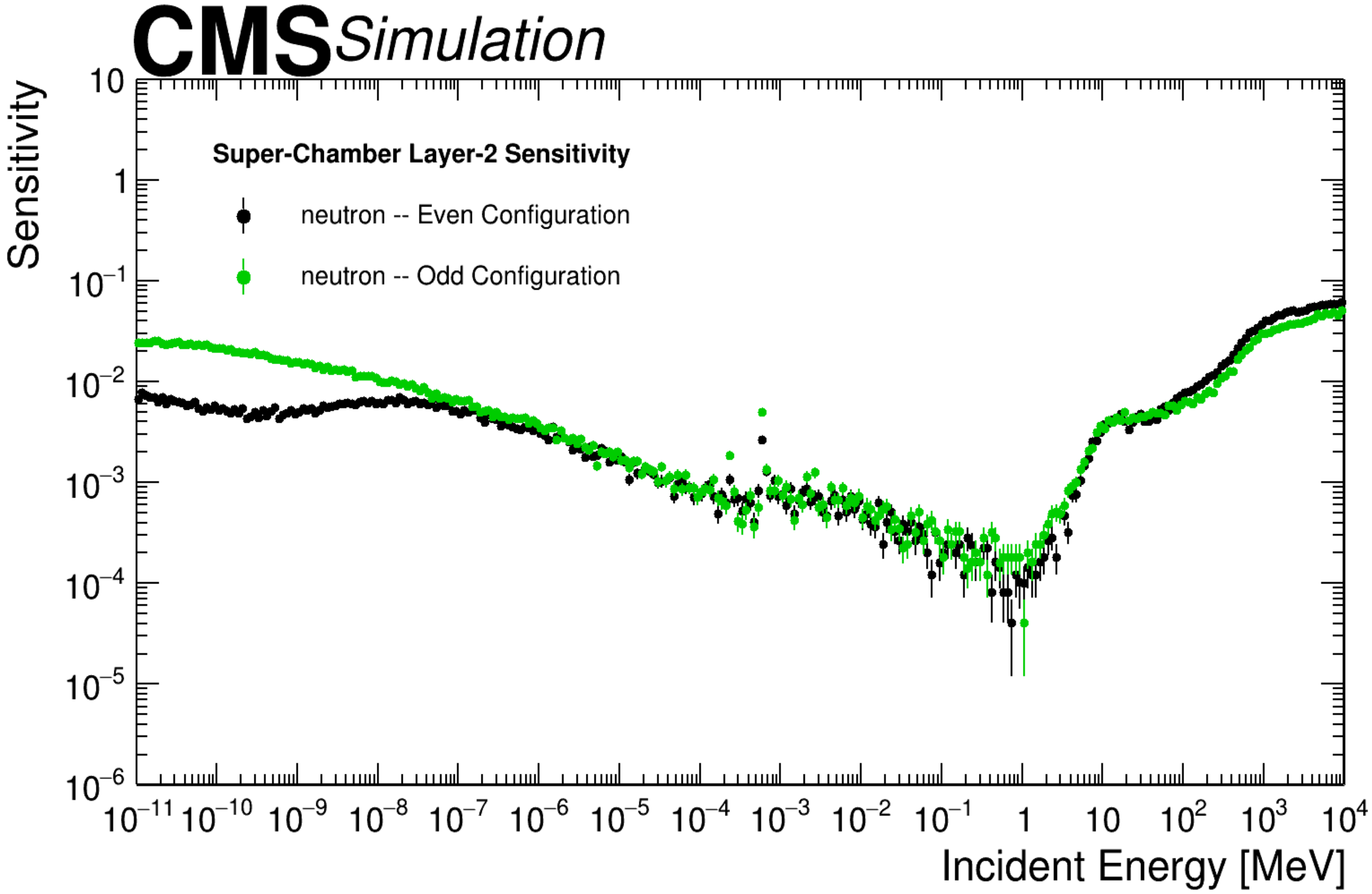


Neutron Sensitivity – GEANT4 Version Comparison



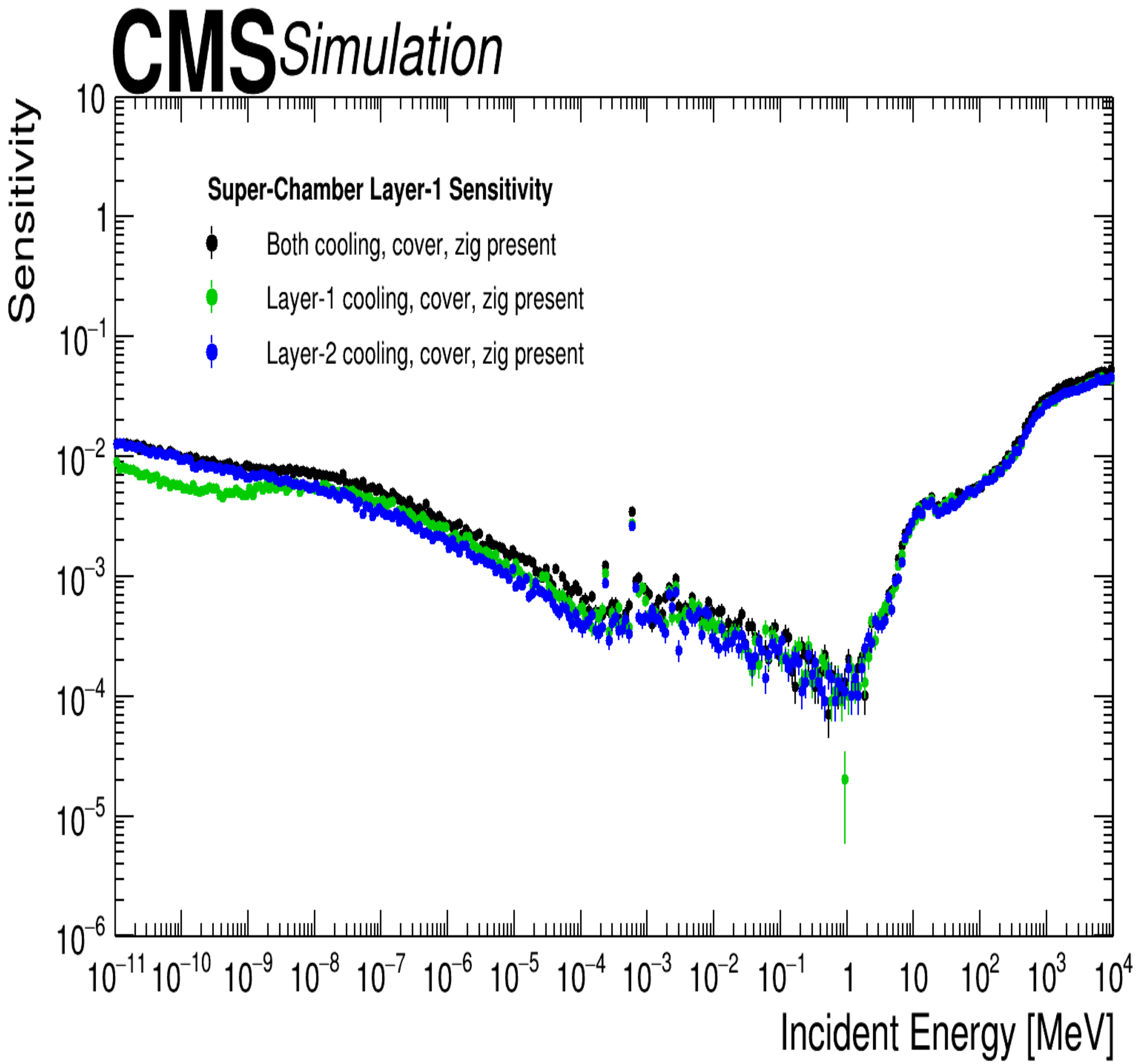
Updated thermal neutron modelling in the newer GEANT4 version.

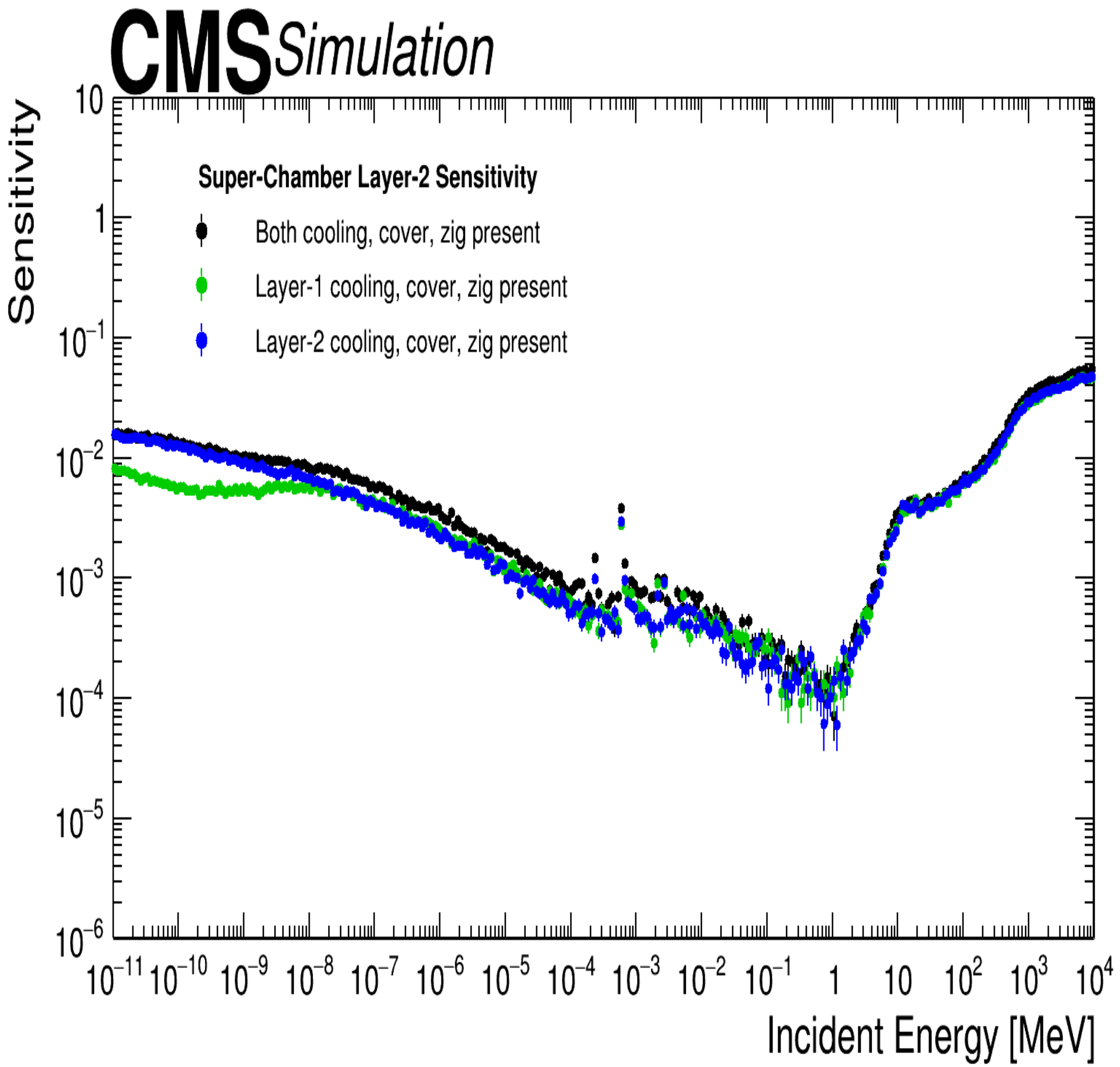
Neutron Sensitivity – Even & Odd Configuration



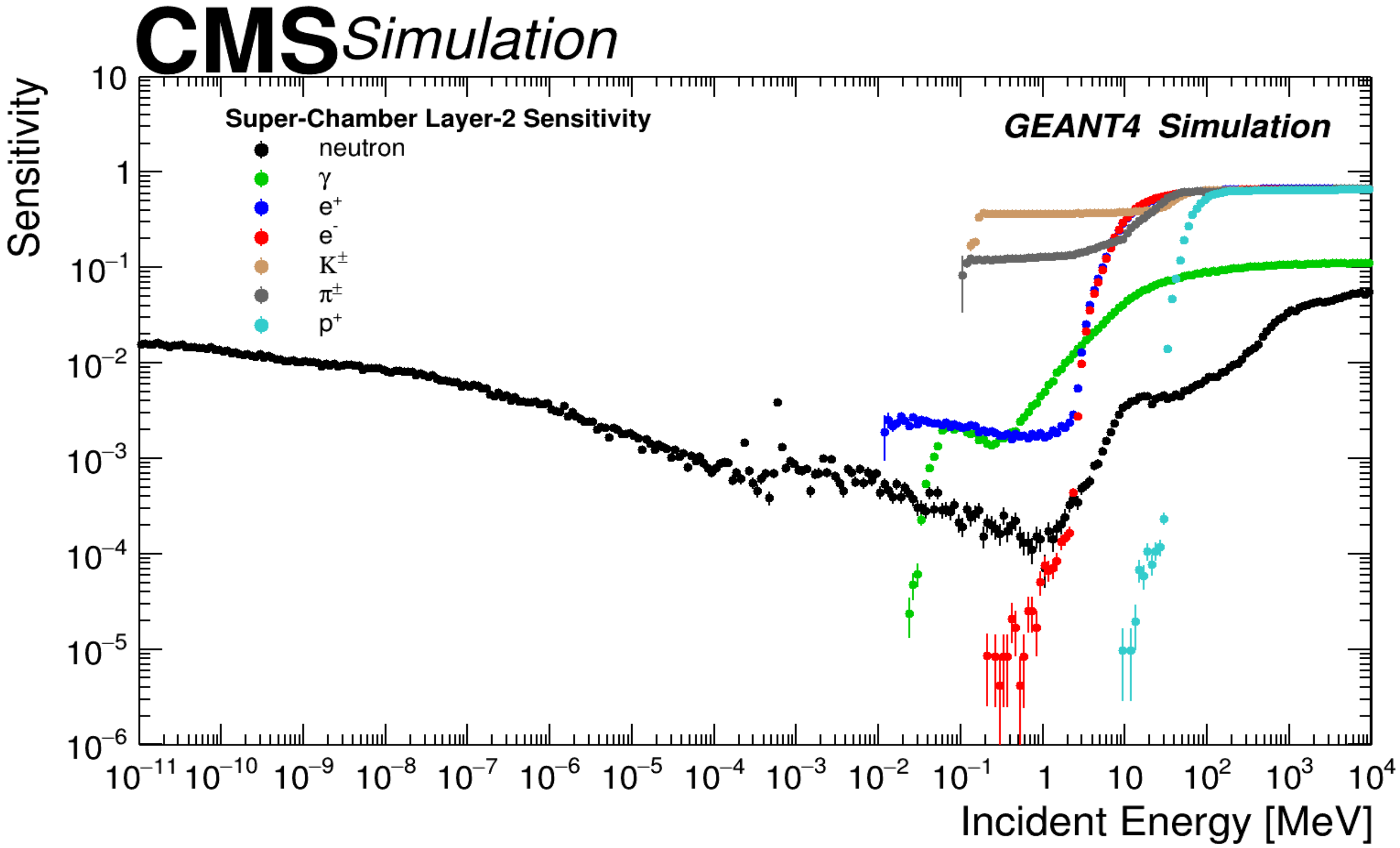
Difference in the path traversed in the copper material.

Neutron Sensitivity – Cooling Material Effects





Sensitivity vs Energy



Sensitivity vs. energy for charged particles shows a linear response beyond 1 MeV, whereas the neutral particles show an energy dependent behavior.

https://twiki.cern.ch/twiki/bin/view/CMSPublic/GEMDPGPublic#GE1_1_background_simulation_and

Average Sensitivity (Table 3 in DN)

	Configurations					
	From Drift side	From Read-out side	Combined	From Drift side	From Read-out side	Combined
Incident Particle	Layer - 1			Layer – 2		
neutron	0.63 ± 0.01	0.65 ± 0.01	**0.64 ± 0.01**	0.59 ± 0.01	0.93 ± 0.02	**0.76 ± 0.01**
photon	0.43 ± 0.01	0.14 ± 0.01	**0.28 ± 0.01**	0.18 ± 0.01	0.25 ± 0.01	**0.22 ± 0.01**
$e^{\pm}$	2.38 ± 0.07	0.10 ± 0.01	**1.24 ± 0.02**	0.15 ± 0.01	0.48 ± 0.02	**0.31 ± 0.01**
charged hadrons	34.47 ± 1.66	18.12 ± 0.87	**26.29 ± 1.240**	22.01 ± 1.07	26.57 ± 1.25	**24.29 ± 1.14**
	Average Sensitivity (%)					

- **Sensitivity of Layer-1 for neutrons is less as compared to Sensitivity of Layer-2 because the cooling material (*Cu*) helps in slow down and interaction of neutron in the material to produce secondary particle/particles to produce signal in Layer-2 .**
- **For $e^{\pm}$, Layer-1 is more sensitive than Layer-2 as mostly interacts and gets absorbed in Layer-1 before reaching to Layer-2 if it hits from drift side. If it hits from the other side, mostly interacts with cooling first and get absorbed.**
- **For photons, cooling act as an attenuator. The overall calculation for both the cases (hitting from drift side and from readout side) resulted layer-1 to be more sensitive than layer-2.**

Systematics on Average Sensitivity & Flux

Systematics of GEANT4

DGW = Drift Gap Width (Nominal 3.0 mm)
GMP = Gas Mixture proportion (Nominal ArCO2 [70:30])
SGP = Source Generation Point of Primary from the Detector surface (Nominal 3 mm)
SAR = Surface Area of Primary over the Detector surface (Nominal 100 % area of Drift Board)

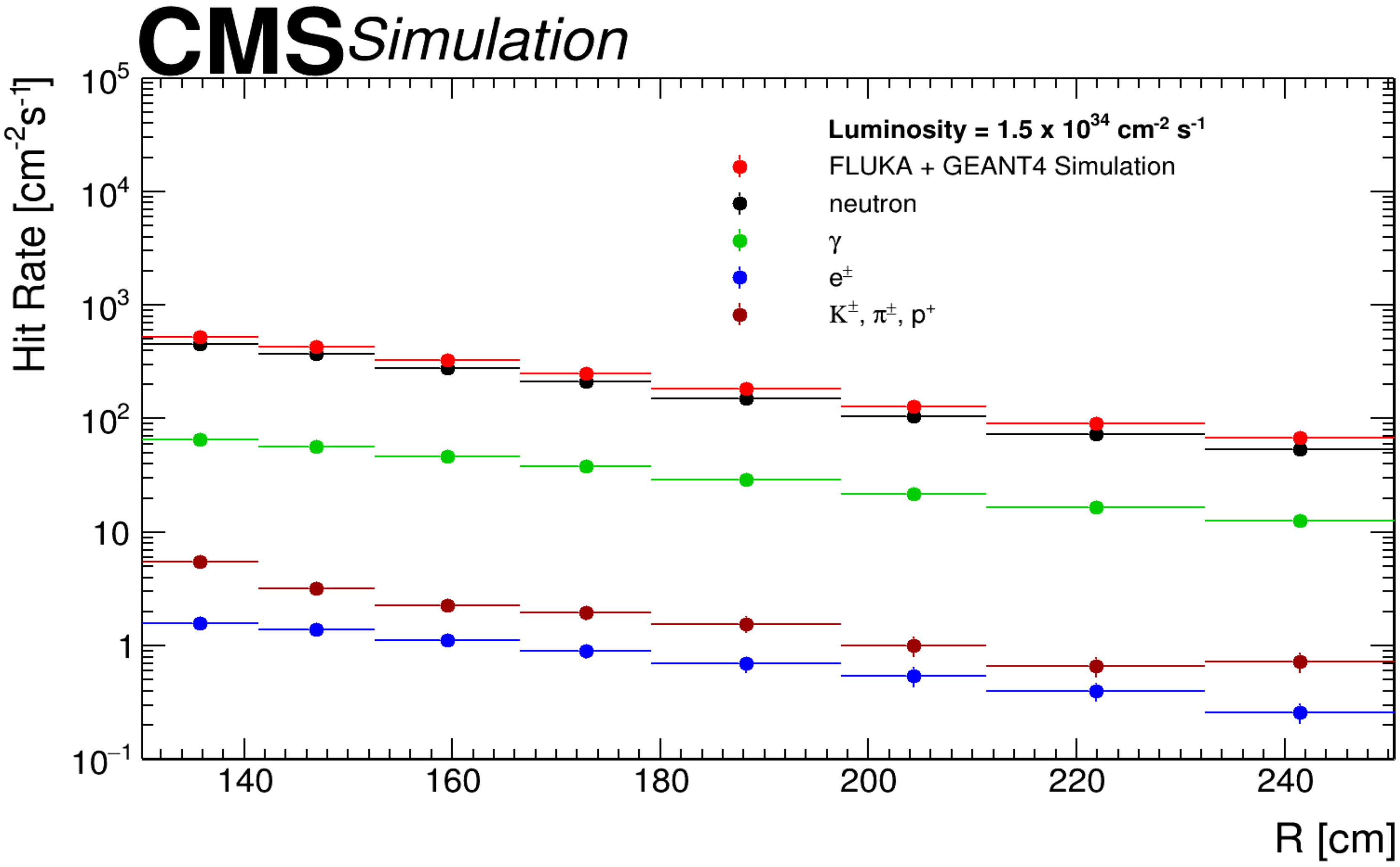
Parameters	Values for Variations	Impact on Average Sensitivity of Layer-2 (in %)			
		neutron	γ	$e^{\pm}$	Charged hadrons ($K^{\pm}$, $\pi^{\pm}$, p^{+})
DGW	2.7 mm 3.3 mm	0.6 0.3	1.4 0.4	1.0 0.0	0.5 0.6
GMP	Ar/CO_2 (60/40) Ar/CO_2 (80/20)	1.0 0.1	0.4 0.9	0.3 0.9	0.5 0.2
SGP	1 mm 5 mm	0.6 1.0	0.4 1.4	0.9 0.9	4.0 9.9
SAR	-10 % +10 %	6.7 1.0	6.4 0.9	5.4 0.9	4.8 1.3

Systematics of FLUKA

Variation in Geometry	FLUX	15.0	15.0	15.0	15.0

***% Variation = ((Avg. Sensitivity at particular configuration – nominal Avg. Sensitivity) / nominal Avg. Sensitivity) x 100**

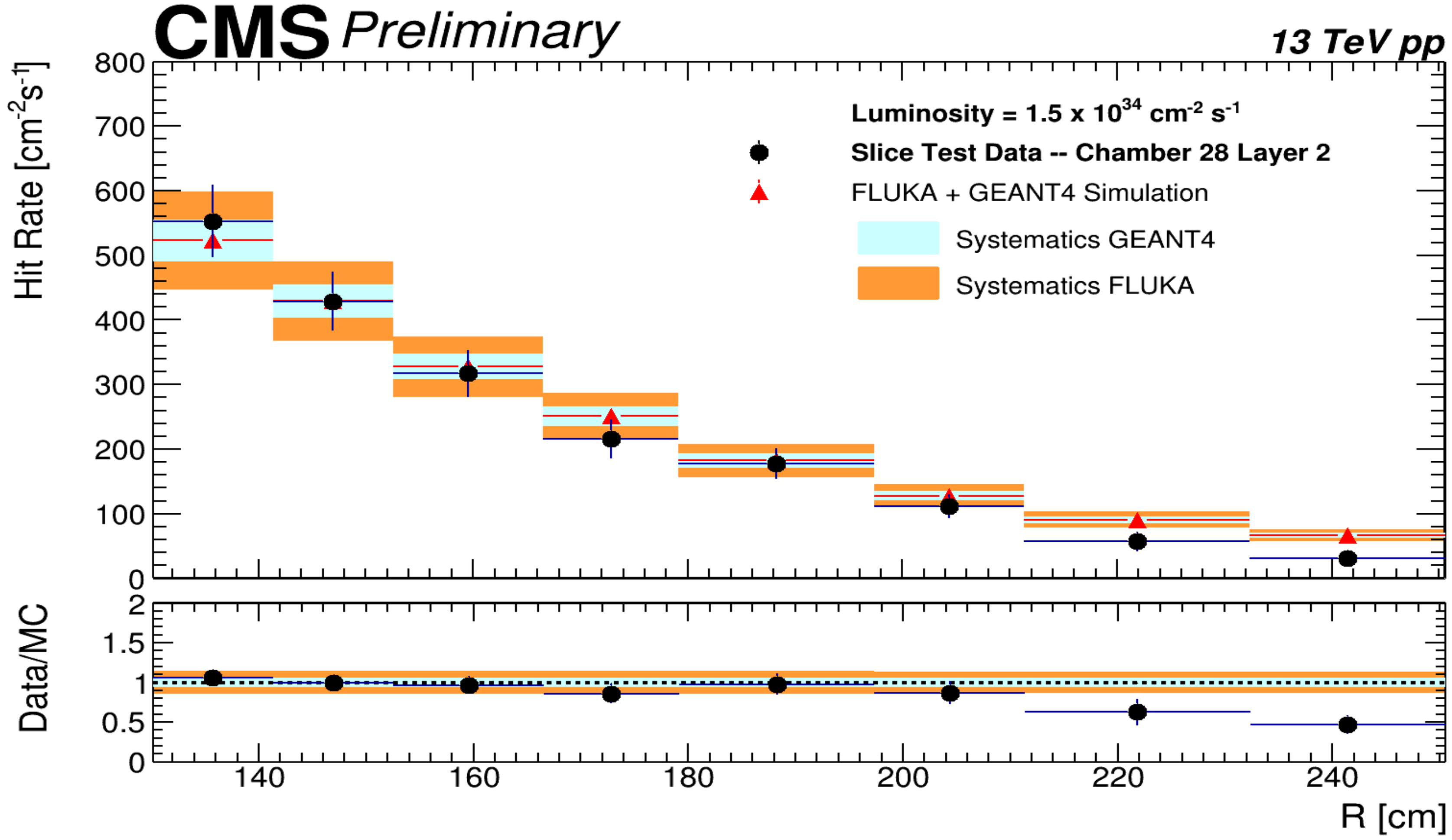
Sensitivity vs Energy



The largest contribution comes from neutrons while photons contributes about ~ 15 %, charged hadrons and e± contributes about 1% only.

https://twiki.cern.ch/twiki/bin/view/CMSPublic/GEMDPGPublic#GE1_1_background_simulation_and

Sensitivity vs Energy



Data→CMS Detector Performance Summary DP-2020/053

Systematics are added in quadrature

Total Systematics ~14.5 %

Data & Simulation are in good agreement within uncertainty for η=3 to η=8, but for η=1 and η=2 prediction is 54% and 38% off from data due to higher threshold applied at η=1 and η=2 (as shown in previous slide)

https://twiki.cern.ch/twiki/bin/view/CMSPublic/GEMDPGPublic#GE1_1_background_simulation_and

Sensitivity Comparison

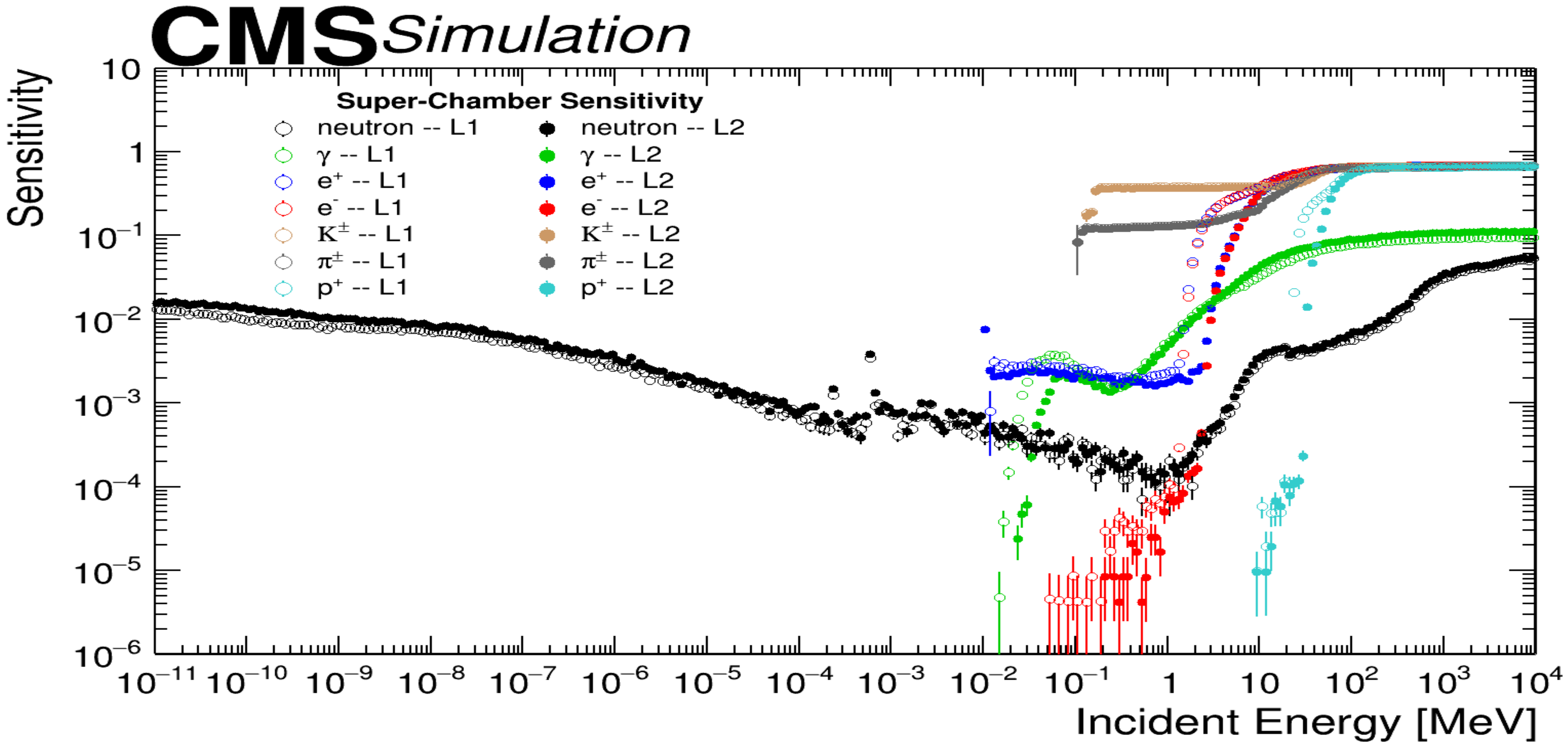
	TDR	This Study (Chamber28L2)	Comments
Triple-GEM Geometry	Simplified, Single Triple-GEM	Revised/precise to GE1/1 Slice Test, two triple-GEM in super chamber configuration Pullouts, Alluminium zig and cover, Spacers, VFATs & cooling system is precisely designed in GEANT4	
GEANT4 Version	v10.04	v10.06 (improved thermal neutrons modelling)	
neutrons	0.18 ± 0.05%	0.76 ± 0.01 %	The increase comes from GEANT4 v10.06 and due to cooling (Cu), both side irradiation and precise geometry. This is for Layer-2.
photons	0.97 ± 0.04%	0.22 ± 0.01 %	
$e^{\pm}$	8 ± 3%	0.31 ± 0.01 %	
charged hadrons ($K^{\pm}$, $\pi^{\pm}$, p^{+})	---	24.3 ± 1.1 %	Were not included in TDR

[1] Average sensitivities in TDR and Florian's thesis (2014) are based on a simplified single triple-GEM geometry using G4 (v10.04). PU team reproduced the sensitivities (n's, γ's, e's) in TDR

[2] In this study, we updated geometry using (i) correct drift board thickness (3.2 mm), (ii) cooling pipe filled with water, (iii) adjusted GEB copper and GEMFR4 thicknesses but maintaining the total thickness of 1 mm, and (iv) additional OH (on iEta = 1) and VFATs.

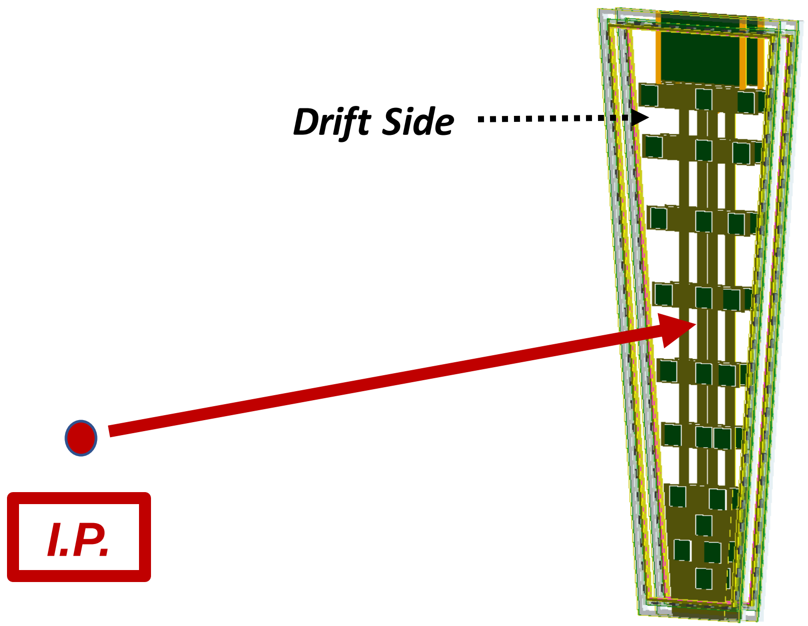
Back-up

Layer-1 & Layer-2 Sensitivity Comparison

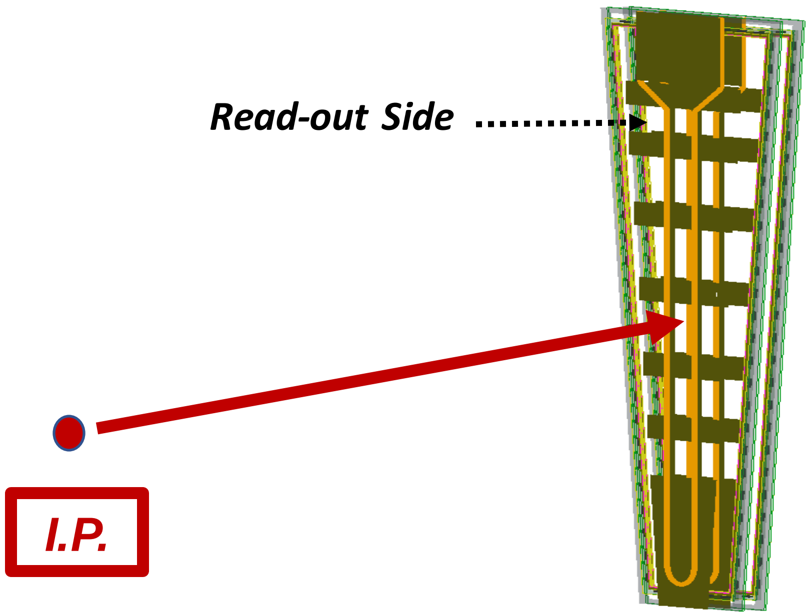


Even & Odd Configuration

Even Configuration	Odd Configuration



Long Chamber in context to CMS



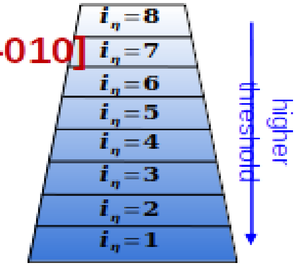
Short Chamber in context to CMS

VFAT Thresholds

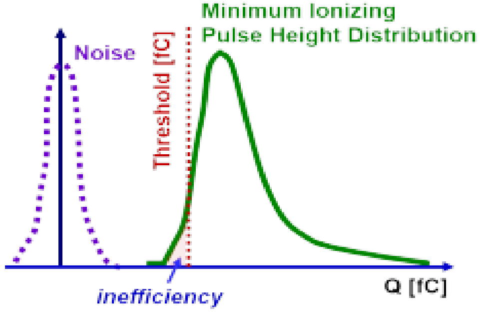
Ref. 3.1: GE1/1 VFAT Threshold and Landau Peak

[DP-2019-010]

PUBLIC. May



8	2.8	0.3
7	3.1	0.5
6	2.5	0.3
5	3.0	0.6
4	3.2	0.6
3	3.5	0.3
2	4.0	0.9
1	8.8	2.6

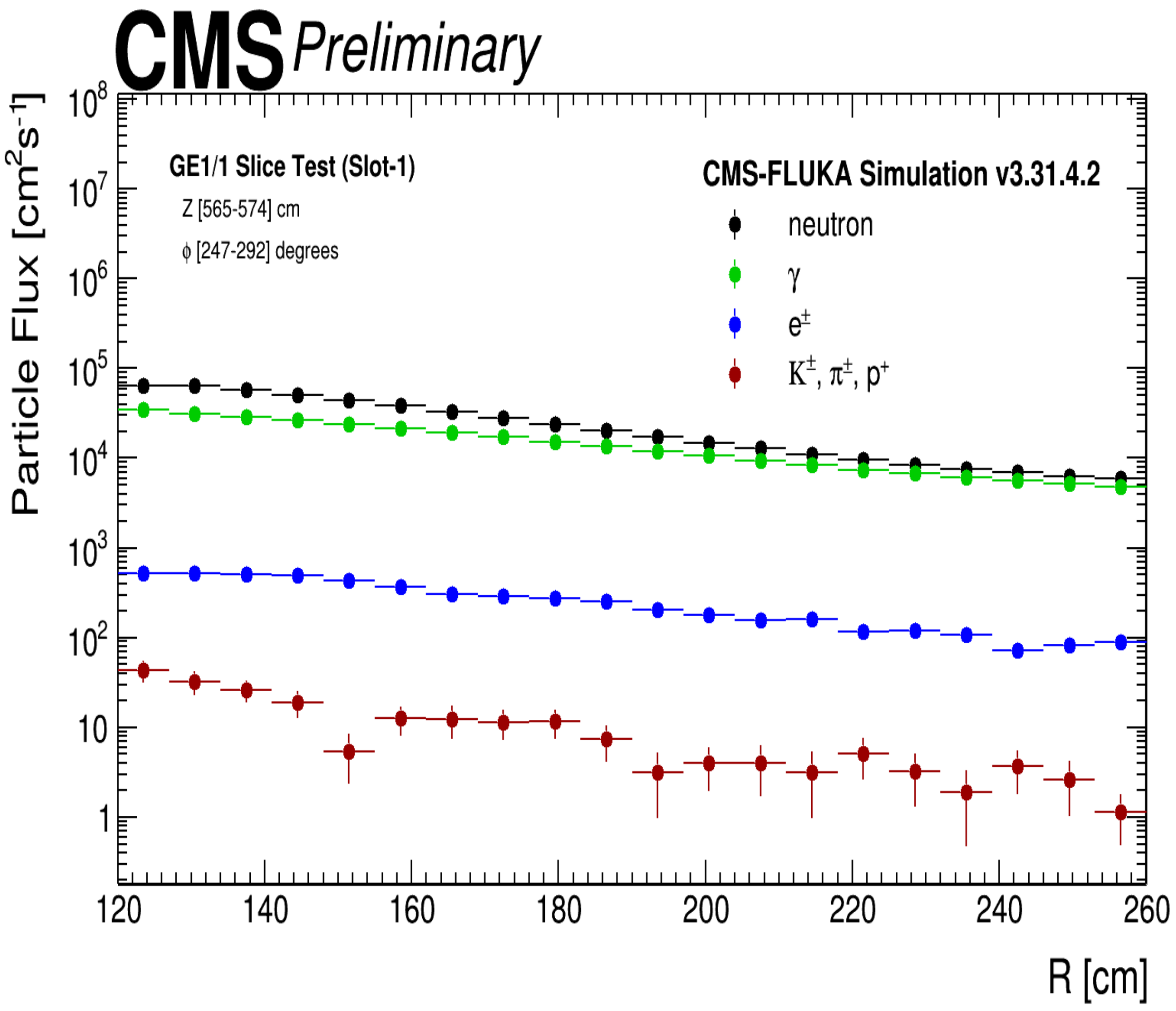


- Each GE1/1 detector is segmented with 8 partitions, referred to () as a discrete variable associated with each row of the electronics readout on the detector.
- The table shows the threshold applied to the VFATs on each partition ().
- A sketch of the muon Landau distribution on strip. Based on the measurement by Vallary Bhopatkar [1], the MPV is 11.5 0.1 fC at an effective gain of . The GE1/1 slice test detectors were operated at , resulted in the MPV of 14.5 0.1 fC. The detection efficiency for = 1 is most affected by the higher threshold at the strip level. This applied threshold was cutting the signal charge on each strip, causing the real strip multiplicity distributions to be biased on lower partitions (especially at = 1).

[1] https://cds.cern.ch/record/2298721/files/CERN-THESIS-2017-267.pdf

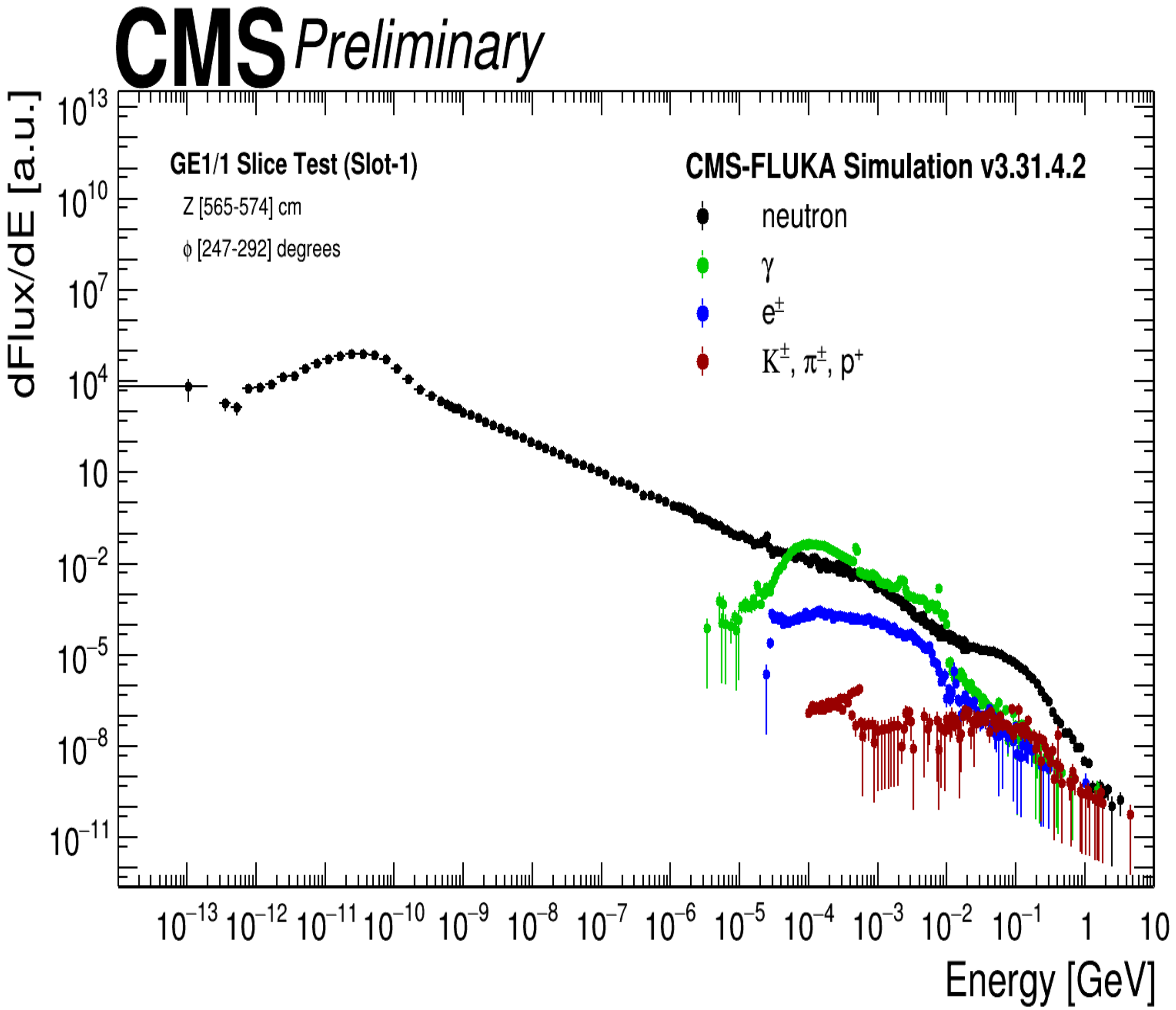
Flux Plot - FLUKA

Monte Carlo estimation of particle flux at CMS using FLUKA. Primary proton-proton collisions with an energy of 6.5 TeV per beam. Inelastic cross section used for normalization is 80mb. Cut-offs are: Hadrons 100keV, Neutrons 0.01 meV, Photons 3keV, Electrons 30 keV. Photons and Electrons have significantly higher cut-offs in some other regions (heavy parts, but not inside tracker). The geometry model reflects a Run 2 configuration with updates since v3.13.0.0 http://cds.cern.ch/record/2039908/files/DP2015_022.pdf that include an implementation of the phase 0 pixel and shift of the RPC detectors to the inner radius of Muon Barrel 4 , and update of the material budget in ECAL Barrel and ECAL endcap. The plot shows the particle flux in a region where the GEM detectors were installed during 2017-2018, the estimations are normalized for an instantaneous luminosity of 1.5x10^{34}cm^{-2}s^{-1}.



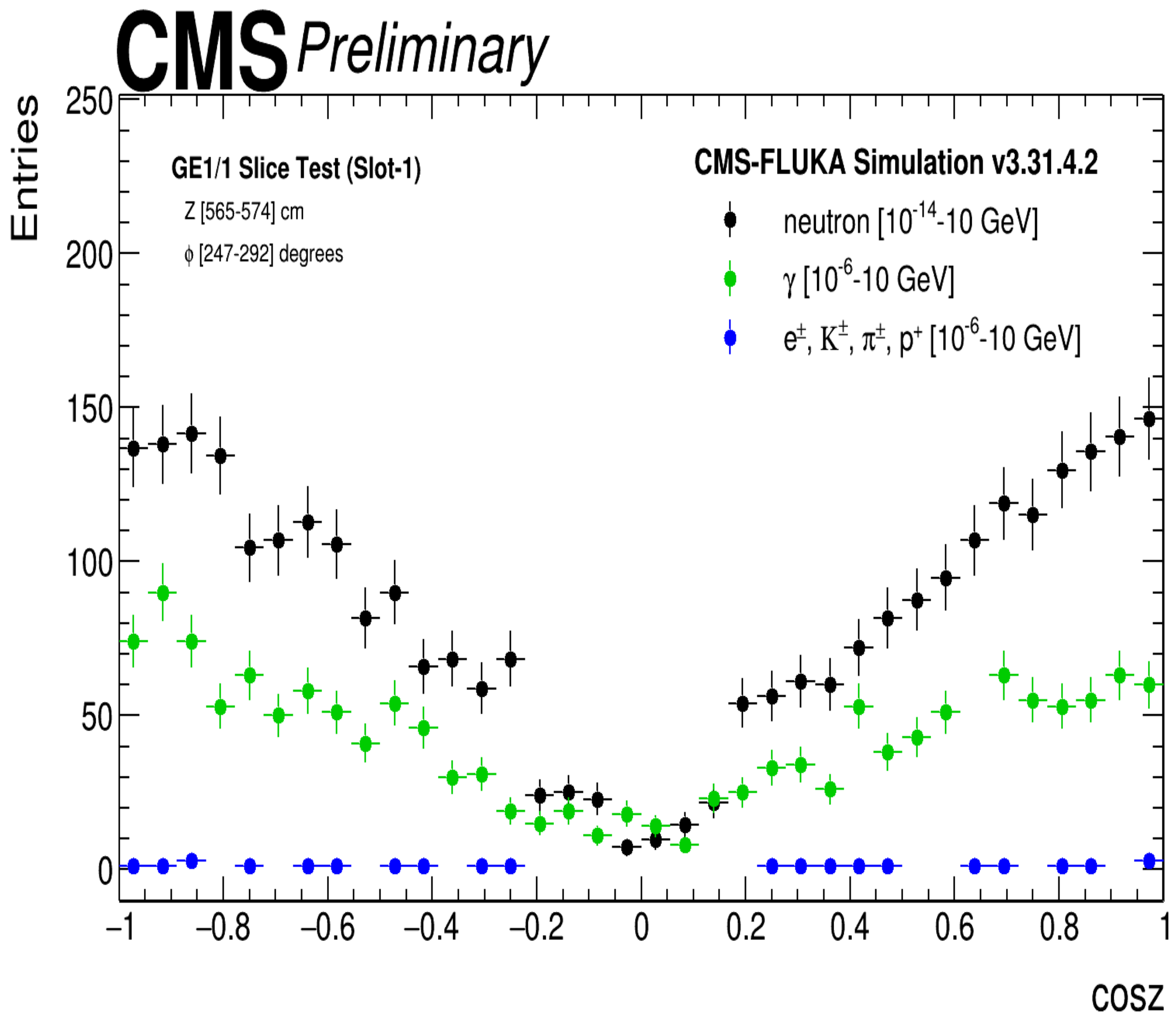
Energy Plot - FLUKA

Monte Carlo estimation of fluence as a function of energy at CMS using FLUKA. Primary proton-proton collisions with an energy of 6.5 TeV per beam. Inelastic cross section used for normalization is 80mb. Cut-offs are: Hadrons 100keV, Neutrons 0.01 MeV, Photons 3keV, Electrons 30 keV. Photons and Electrons have significantly higher cut-offs in some other regions (heavy parts, but not inside tracker). The geometry model reflects a Run 2 configuration with updates since v3.13.0.0 http://cds.cern.ch/record/2039908/files/DP2015_022.pdf that include an implementation of the phase 0 pixel and shift of the RPC detectors to the inner radius of Muon Barrel 4 , and update of the material budget in ECAL Barrel and ECAL endcap. The plot shows the fluence as a function of energy in a region where the GEM detectors were installed during 2017-2018, the estimations are normalized for an instantaneous luminosity of $1.5 \times 10^{34} cm^{-2} s^{-1}$.



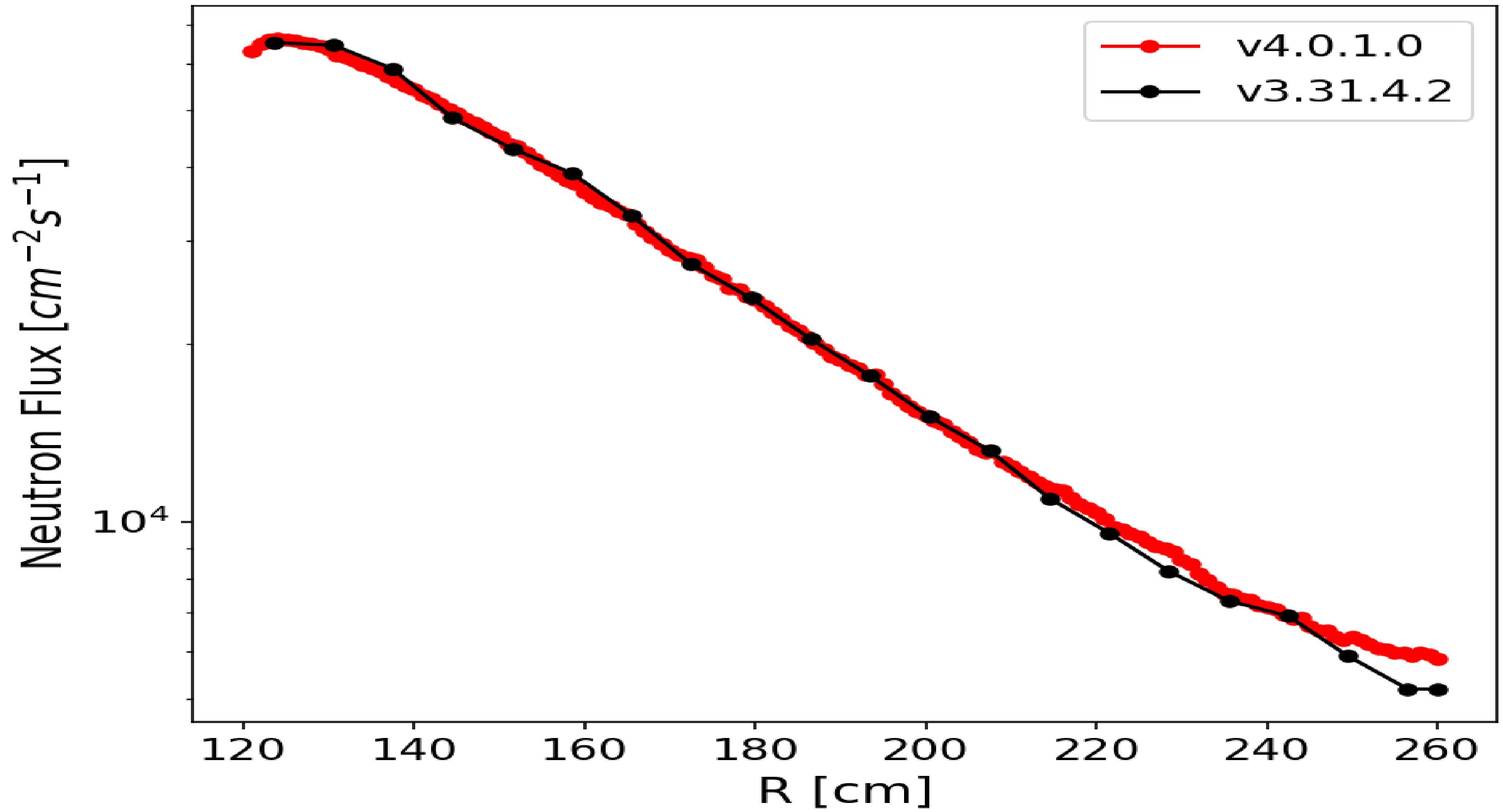
Angle Plot - FLUKA

Monte Carlo estimation direction for incoming neutrons (cosine direction) entering GE1/1 region at CMS using FLUKA. Primary proton-proton collisions with an energy of 6.5 TeV per beam. The geometry model used reflects Run 2 configuration with updates since v3.13.0.0 http://cds.cern.ch/record/2039908/files/DP2015_022.pdf that include an implementation of the phase 0 pixel and shift of the RPC detectors to the inner radius of Muon Barrel 4 , and update of the material budget in ECAL Barrel and ECAL endcap. Cut-offs are: Hadrons 100 keV, Neutrons 0.01 MeV, Photons 3 keV, Electrons 30 keV. Photons and Electrons have significantly higher cut-offs in some other regions (heavy parts, but not inside tracker). The plot shows the cosine direction at z-axis for neutrons crossing the volume used for the installation of GEM test chambers (slot-1) during 2017-2018 slice test exercise.

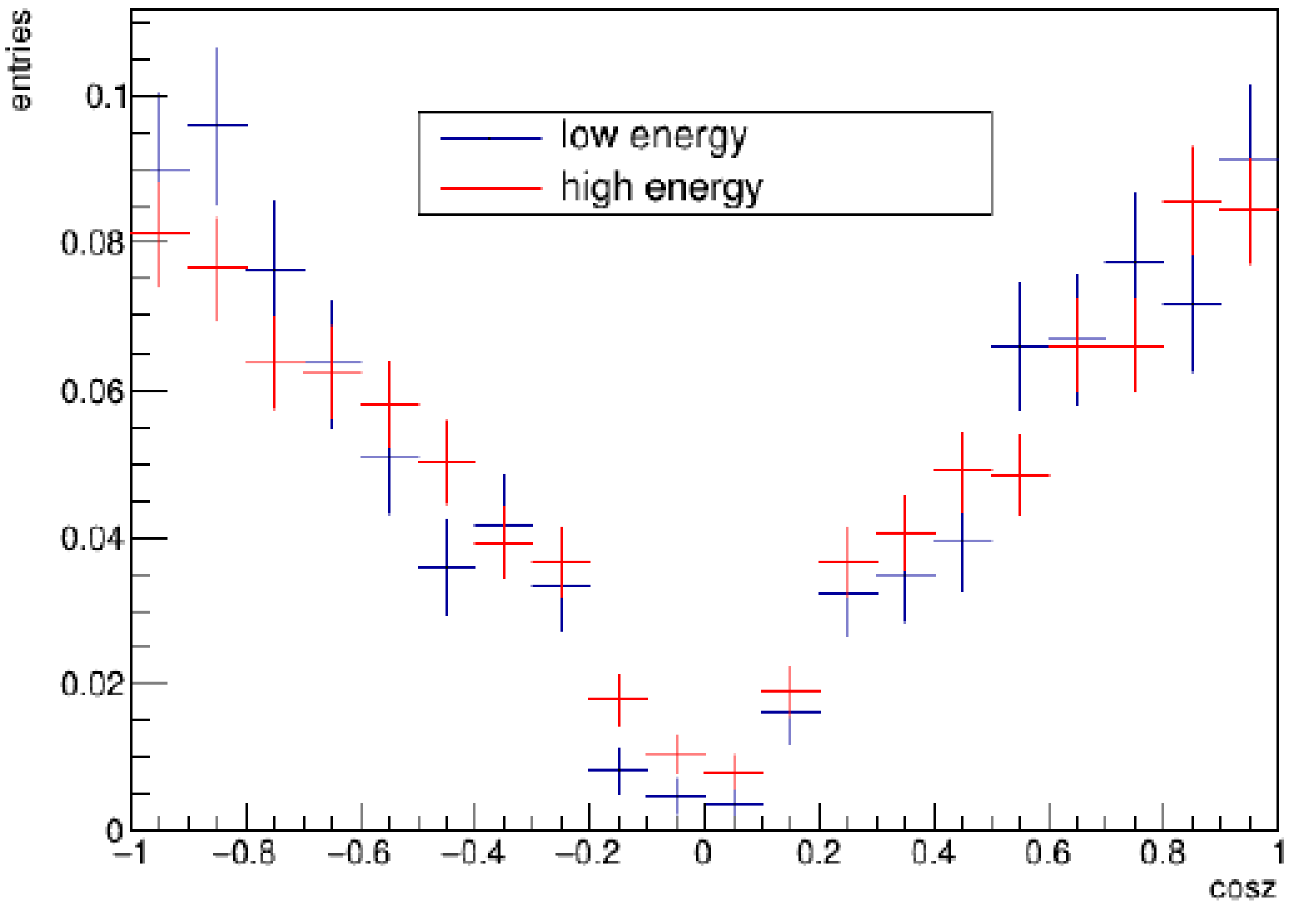


Comparison v4.0.1.0 vs v3.31.4.2 (Neutron flux)

- Compatible estimation between v3.31.4.2 and most recent v.4.0.1.0



Correlation between Energy and Angle? (From FLUKA)



No Correlation

Low energy range: 10^{-11}-10^{-3} MeV

High Energy Range: >10^{-3} MeV

Updated Distribution for Particle Direction

One of the distributions used as input in Geant4 simulation is the direction of incoming particles, since this variable is not frequently requested by users the instructions to get those varies depending of the situation. below is the description of the variable used in the past and the updated ones.

- **Previous distribution was extracted using USRYIELD scoring in fluka which get a double differential distribution in which one of those variables is related to the angular distribution however the axis in which that was calculated did not correspond to the detector frame so interpretation is different to the direction of incoming particles.**

- **The new distributions uses the USERDUMP configuration in FLUKA which dumps information about incoming particles in a region of interest, among other variables the ones related to angular distributions are the cosine directions (cosx, cosy, cosz) which clearly reflect the direction of incoming particles in GE1/1 region.**

$$\alpha = \cos x = \frac{\mathbf{v}\cdot\mathbf{e}_x}{|\mathbf{v}|} = \frac{v_x}{\sqrt{v_x^2+v_y^2+v_z^2}} \qquad \beta = \cos y = \frac{\mathbf{v}\cdot\mathbf{e}_y}{|\mathbf{v}|} = \frac{v_y}{\sqrt{v_x^2+v_y^2+v_z^2}} \qquad \gamma = \cos z = \frac{\mathbf{v}\cdot\mathbf{e}_z}{|\mathbf{v}|} = \frac{v_z}{\sqrt{v_x^2+v_y^2+v_z^2}}.$$

Here *cosx, cosy, cosz* is the direction cosine with *X-axis, Y- axis, Z-axis*, *v* is a Euclidian vector and e_x, e_y, e_z *is* the basis in cartesian notation.

FLUKA Comments Answered

Granularity

The flux is extracted considering the estimated volume where the GE1/1 chamber is positioned (exact binning in the next question). The simulation granularity is not as fine to consider the positions you are suggesting and moreover from the point of view of FLUKA the variations in flux in such small regions will be negligible for our study. It is important to mention that in FLUKA only big elements such as calorimeters, shielding, etc… strongly impact the variations in particle flux.

FLUKA scoring grid dimension

The scoring dimension was defined according to the dimension of the GE1/1 chamber, this is 1 bin in Z (this is desired because if we define more binning's there is a wrong interpretation in Flair when plotting statistical error). 20 bins in R and 1 in bin in phi as follows:

R [120-260cm] 20 bins
Z [565-574cm] 1 bin
Phi [-1.96 - 1.17rad] 1 bin

This covers well the volume for slot1 test chambers and there is no overlap with other big materials (calorimeters, muon shielding, etc.….)

Effect of Cooling on Neutron Sensitivity

	Configurations					
	From Drift side	From Read-out side	Combined	From Drift side	From Read-out side	Combined
	Layer - 1			Layer – 2		
With normal setup	0.634 ± 0.011	0.650 ± 0.014	**0.642 ± 0.012**	0.594 ± 0.009	0.927 ± 0.022	**0.760 ± 0.014**
Removing cooling, cover, zig of layer-2 only	0.573 ± 0.010	0.427 ± 0.007	**0.500 ± 0.008**	0.494 ± 0.009	0.535 ± 0.010	**0.515 ± 0.008**
Removing cooling, cover, zig of layer-1 only	0.448 ± 0.009	0.508 ± 0.013	**0.478 ± 0.010**	0.394 ± 0.007	0.772 ± 0.021	**0.583 ± 0.013**
	Average Sensitivity (%)					

Calculation for 3 fC

N_{Min} = Number of minimum electrons should be collected at the readout
N_{Drift} = Number of electrons should be produced in Drift
$N_{Transfer1}$ = Number of electrons should be produced in Transfer1
ED_{Drift} = Energy deposit required in Drift
$ED_{Transfer1}$ = Energy deposit required in Transfer1

W_{Ar} = 26 eV
W_{CO2} = 33 eV
$W_{ArCO2(70:30)}$ = 26 x 0.7 + 33 x 0.3
= 28.1 eV

G = Gain = 10560 (For Slice Test)
Q_e = 1.602176634 x 10^{-19} C
Threshold = 3 fC = 3 x 10^{-15} C

N_{Min} = Threshold / Q_e = 3 x 10^{-15} / 1.602176634 x 10^{-19} = 1.87245272234 x 10^4
~ 18725

N_{Drift} = N_{Min} / G = 18725 / 10560 = 1.77320075758 ~ 2
ED_{Drift} = N_{Drift} x $W_{ArCO2(70:30)}$ = 2 x 28.1 = 56.2 eV

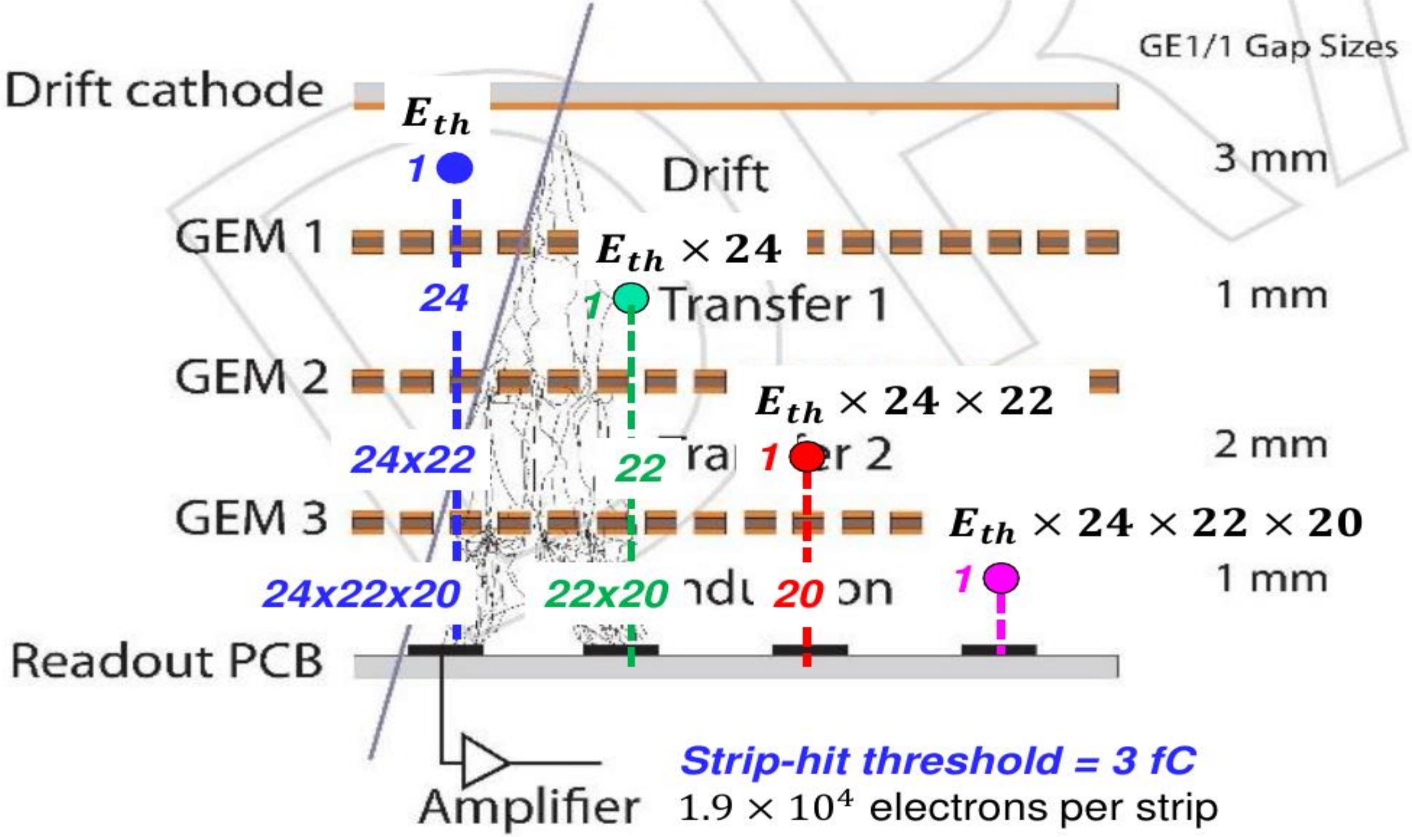
$N_{Transfer1}$ = N_{Min} / $(G^{1/3})^2$ = 18725 / $(10^4)^{2/3}$
= 18725 / 440 = 42.5568181818 ~ 43
$ED_{Transfer1}$ = $N_{Transfer1}$ x $W_{ArCO2(70:30)}$ = 43 x 28.1 = 1208.3 eV
= 1.2083 keV

Threshold is applied on single strip
So it is assumed that Cluster Size ~ 1 strip

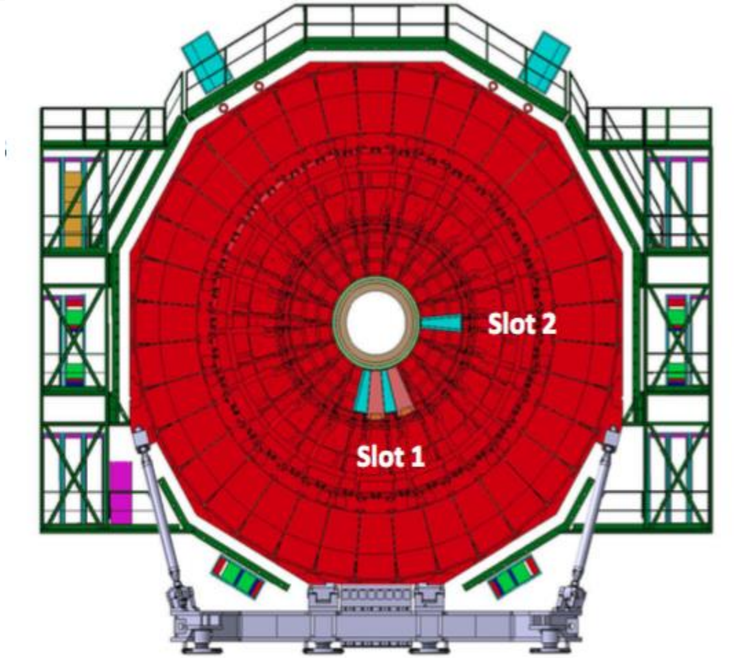
Gain Per Foil

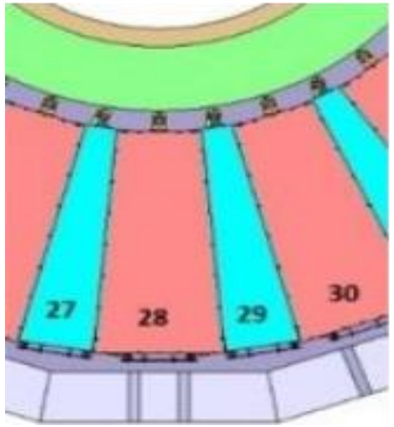
Ref. 3.5(b): Gain at Each Gap for Counting BKG

Approximate multiplication factors for an ionization in for drift, transfer1, transfer2, and transfer3 gaps will be 24, 22, 20, and 1, respectively, when it reaches the readout PCB.



Slice Test





27 – Short Chamber
28 – Long Chamber
29 – Short Chamber
30 – Long Chamber