A Simulation of Primary Ionization for Different Gas Mixtures

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Outline

- Motivation
- Simulation Framework
- Alpha Simulation
- Muon Simulation
- Fe-55 Simulation
- Summary

Motivation

- To study primary ionization using different gas mixtures

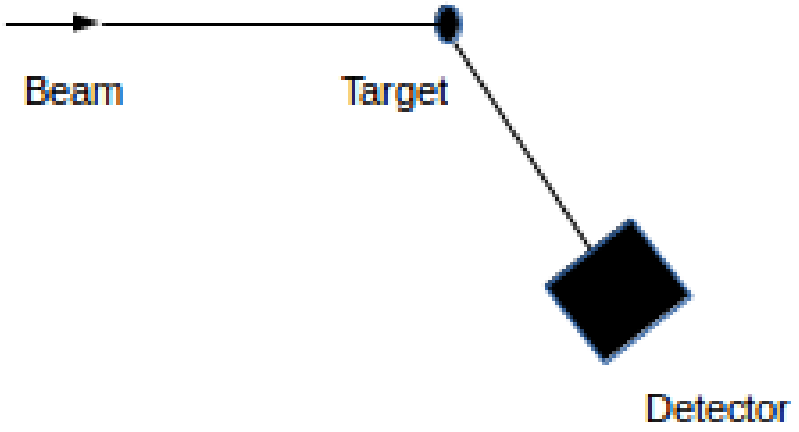
Why ?

- The primary ionization is utilized in understanding the charge density and discharge formation studies
- In the high rate experiments, radiation hardness, ageing resistance and stability against discharges are the main criteria for the long-term operation of the detectors
- A discharge may cause irreversible damages such as enhanced leakage currents, a permanent short between the electrodes of the detector that may lead to the detector non-operational
- Also, it has been proposed that charge density in the amplification region could be one of the limiting factors of detector stability against discharges
- * The primary ionization has been determined from the simulation of alpha source to obtain discharge probability utilizing the single and triple GEM configuration in argon gas mixture
- We present here the simulation of primary ionization in argon based gas mixtures to get the number of primaries, energy and spatial information

*P. K. Rout, R. Kanishka et al, Numerical estimation of discharge probability in GEM-based detectors, JINST 16 P09001 (2021)

Simulation Framework

- **Geant4** is a toolkit for the simulation of the passage of particles through matter
- Applications: Particle physics, nuclear, accelerator physics, medical and space sciences
- In any experiment, we need beam, target and detector
- We simulate it in Geant4



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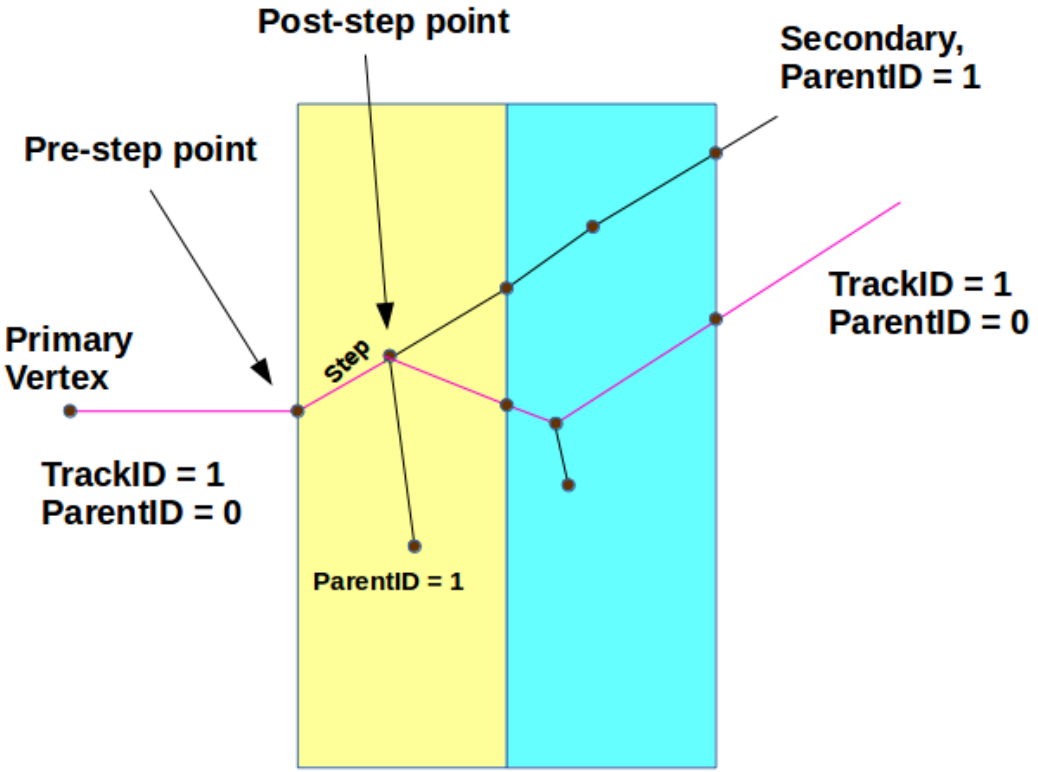
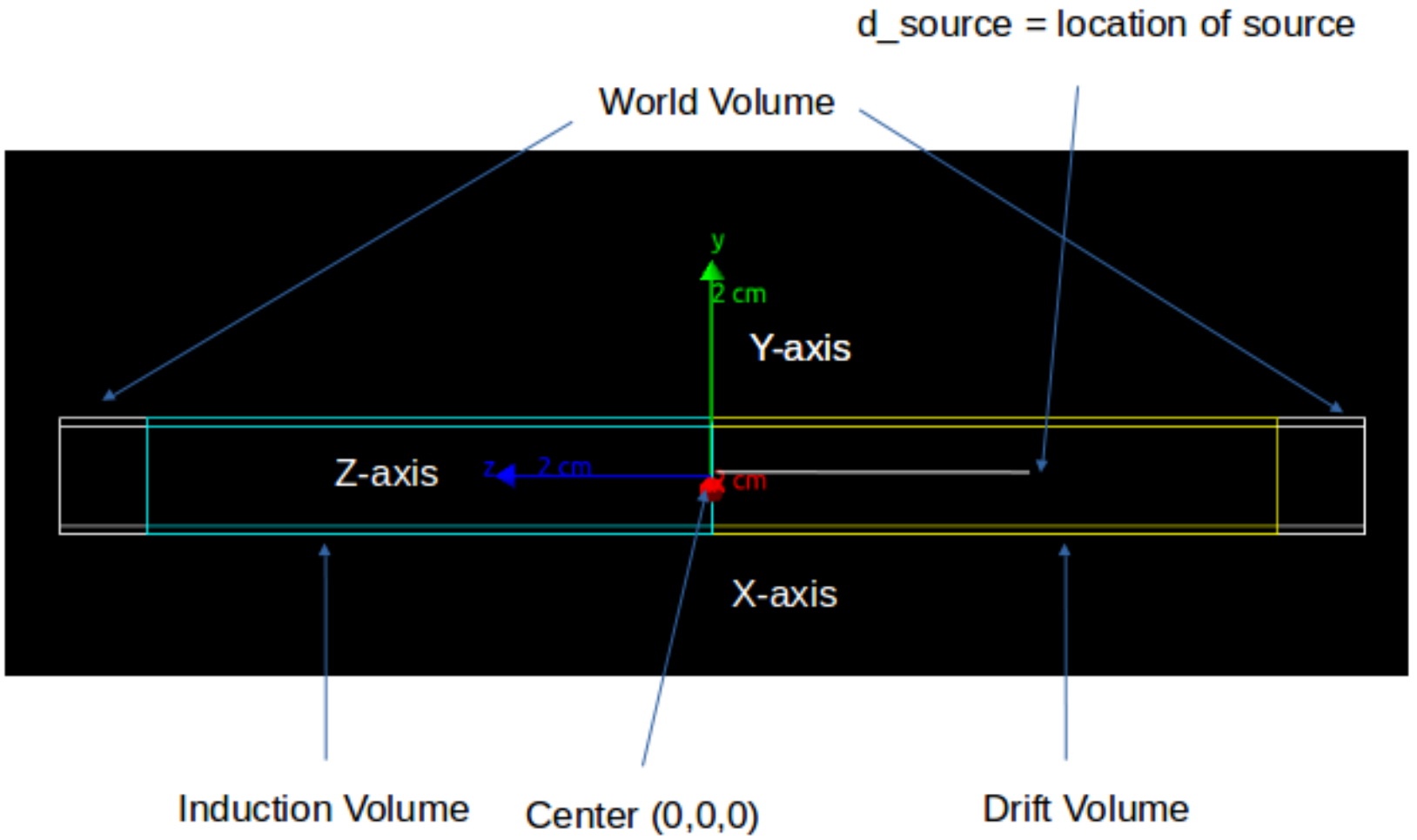
- **Define :**
  - Detector geometry: G4VSolid, G4LogicalVolume, G4VPhysicalVolume
  - Physics process
  - Specify initial position, direction, type of particles, energy
- Introduce field
- Step Action defined
- Poststep : particle interacts, decays etc
- Analyse the data



- **Garfield++** : An object-oriented toolkit for the detailed simulation of particle detectors based on measurement of ionization in gases or semiconductors
- The ionization pattern produced along the track of relativistic charged particles can be simulated using the program "**Heed**"

Geant4 Display



Work Done

Geant4 Simulation Input

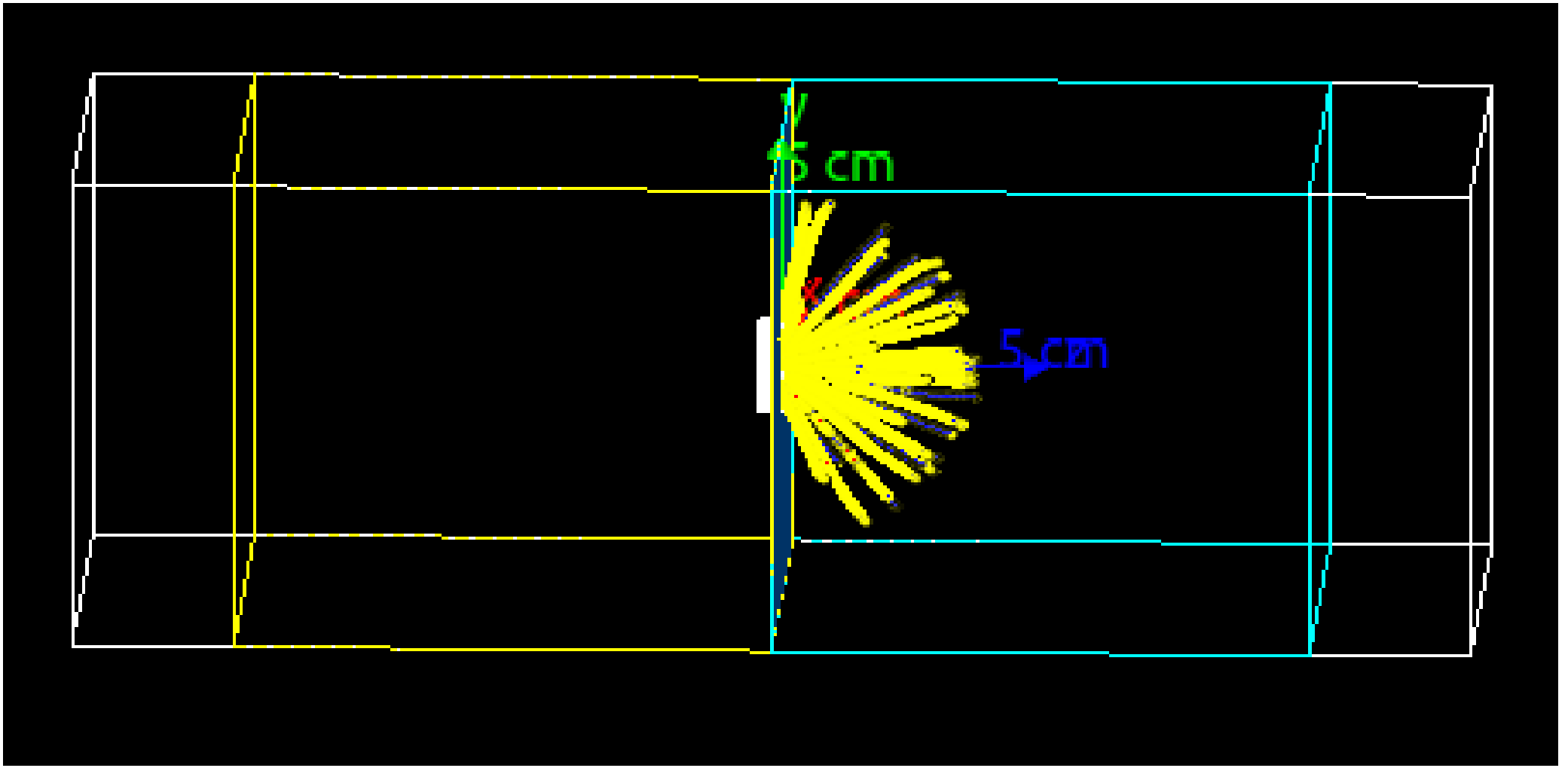
- Gas mixtures used: Ar:CO2::90:10, Ar:CO2::80:20, Ar:CO2::70:30, Ar:CO2:CF4::45:15:40
- Source: An alpha beam (Am-241) with energy 5.6 MeV at (0,0,0*μm) as per the experiment (next slide)*

- Gas volume*: x = 5 cm, y = 5 cm, z = 20 cm
- Physics List*: EMLivermore, EMPenelope, PAI, PAI-Photon
- 10000 events*
- Source: Muon with energy 1 GeV at (0,0,-10*cm) in Ar:CO2::70:30 gas volume***

*P. K. Rout, R. Kanishka et al, Numerical estimation of discharge probability in GEM-based detectors, JINST 16 P09001 (2021)

*S. Bachmann et al., Discharge studies and prevention in the gas electron multiplier (GEM), Nucl. Instrum. Meth. A 479 (2002) 294

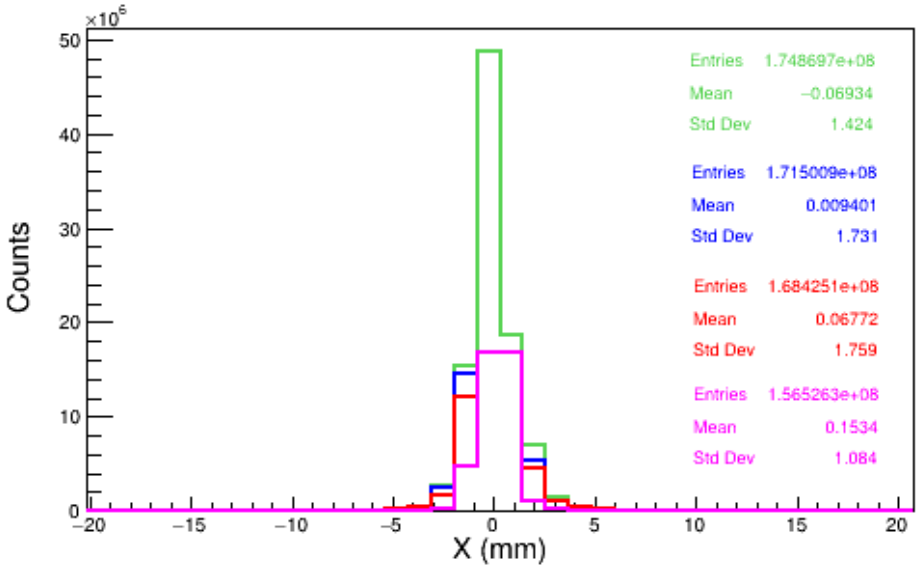
Geant4 Display of Alpha Simulation

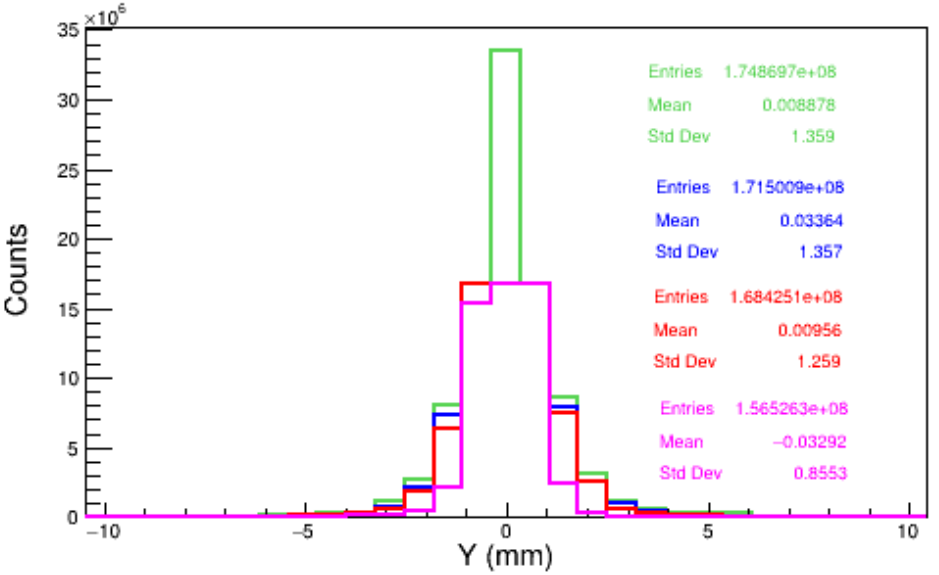


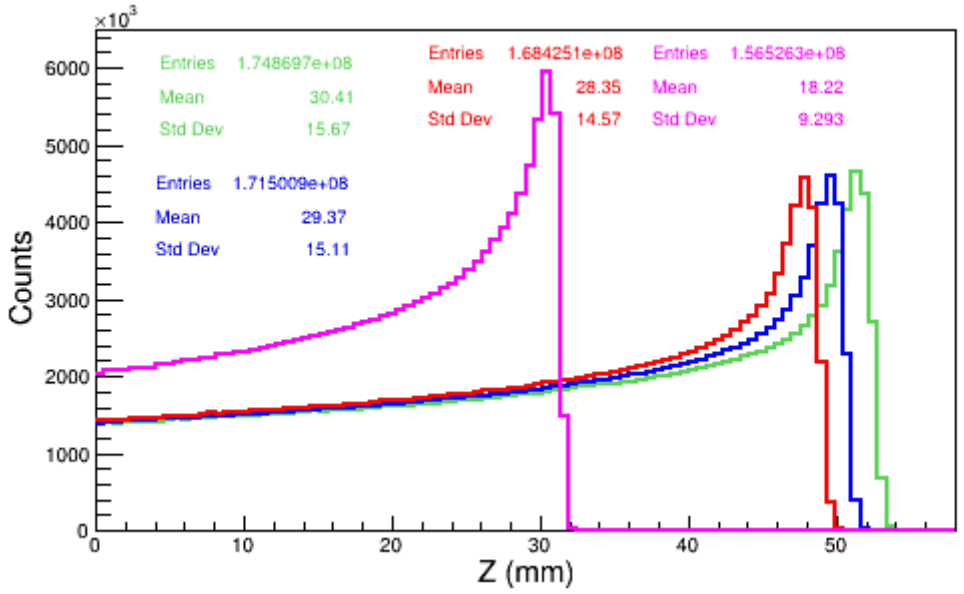
- Collimated beam of alpha particles through mylar sheet at (0,0,-2003.5*µm)
- - Collimator height = 2000 µm at (0,0,-2003.5*µm)
  - Mylar width = 3.5 µm, at (0,0,0.001*µm)
  - Opening angle (theta): -30 to 30, Phi: 0 to 360
- For 50 alpha events. Blue: Alpha, Yellow: electron hits
- Gas: Ar:CO2::70:30, Volume: x = 5 cm, y = 5 cm, z = 20 cm

Contd...

Position Co-ordinates Using Geant4





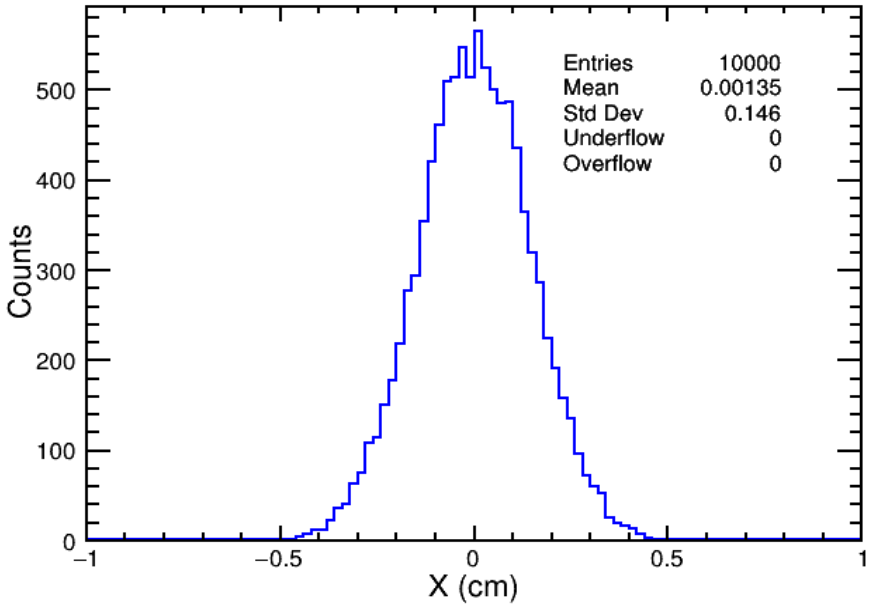


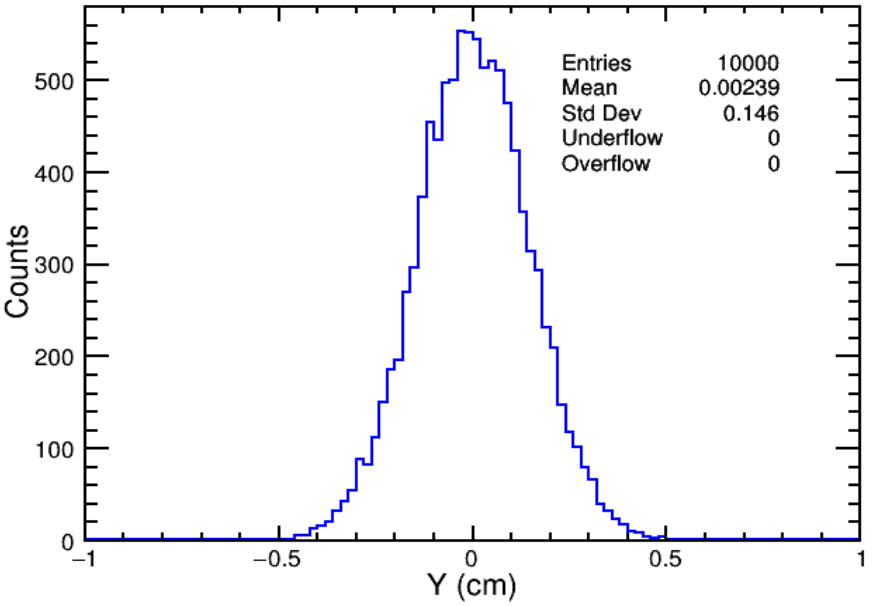
- For Am-241 (alpha) of 5.6 MeV at (0,0,0*μm)
- No mylar, no opening angle

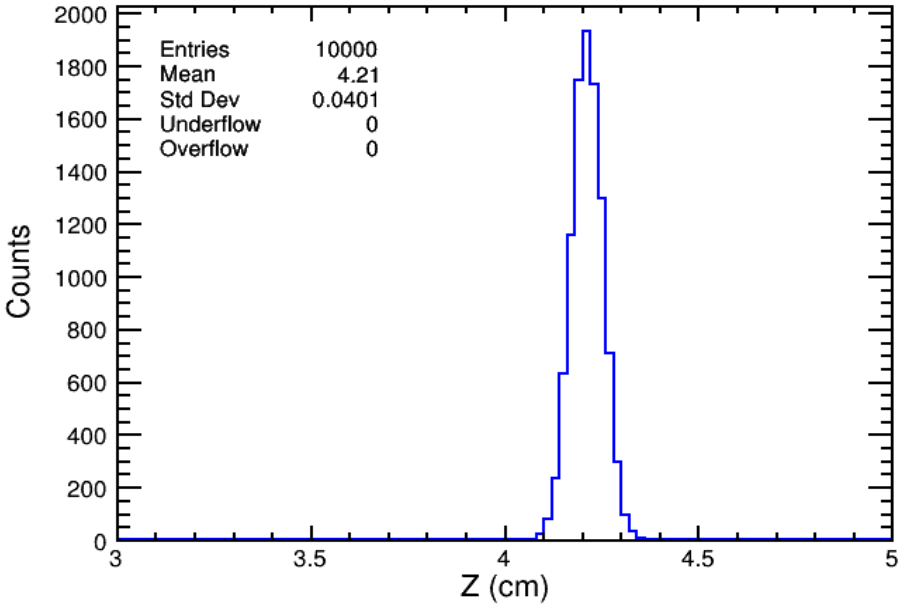
Ar:CO2::90:10
Ar:CO2::80:20
Ar:CO2::70:30
Ar:CO2:CF4::45:15:40

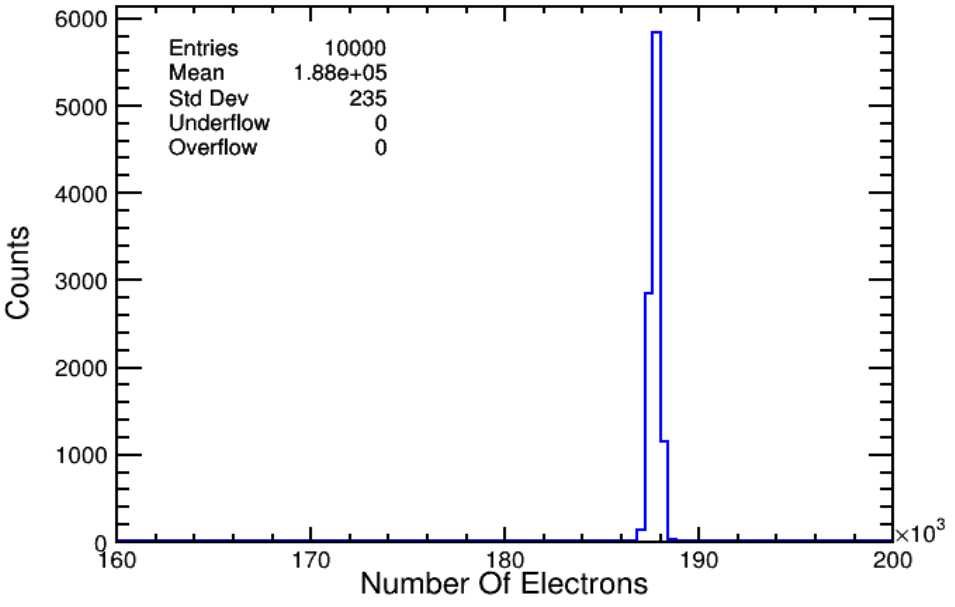
Heed Simulation For Alpha Particles

- 10000 events for alpha particles
- Gas: Ar:CO2::70:30
- Volume: x = 5 cm, y = 5 cm, z = 20 cm

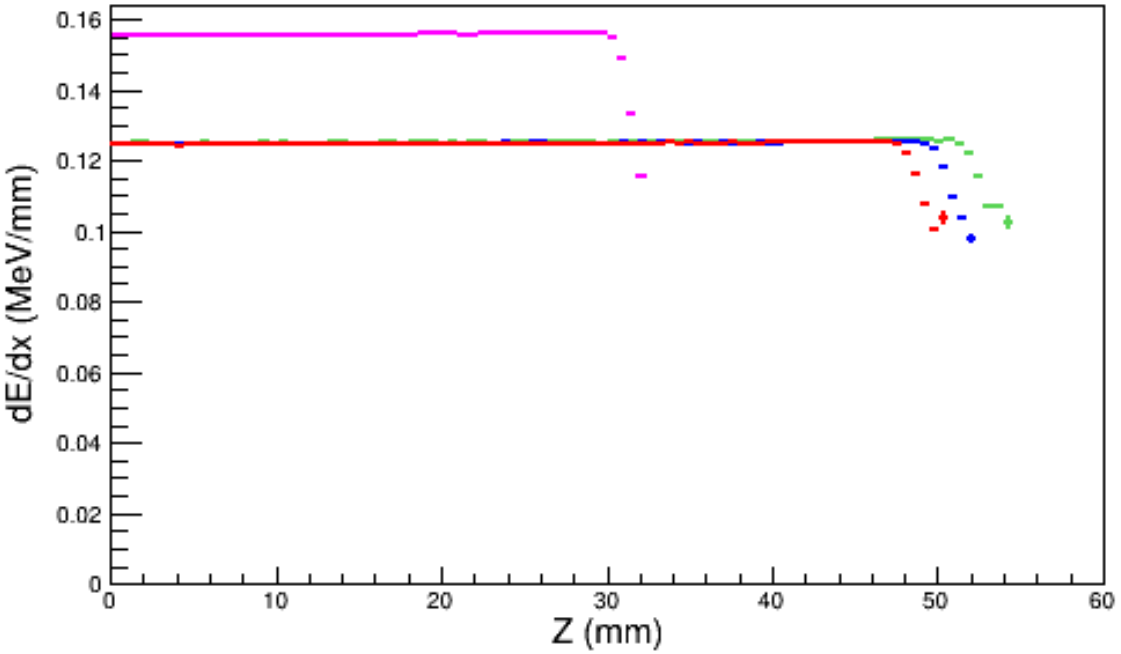






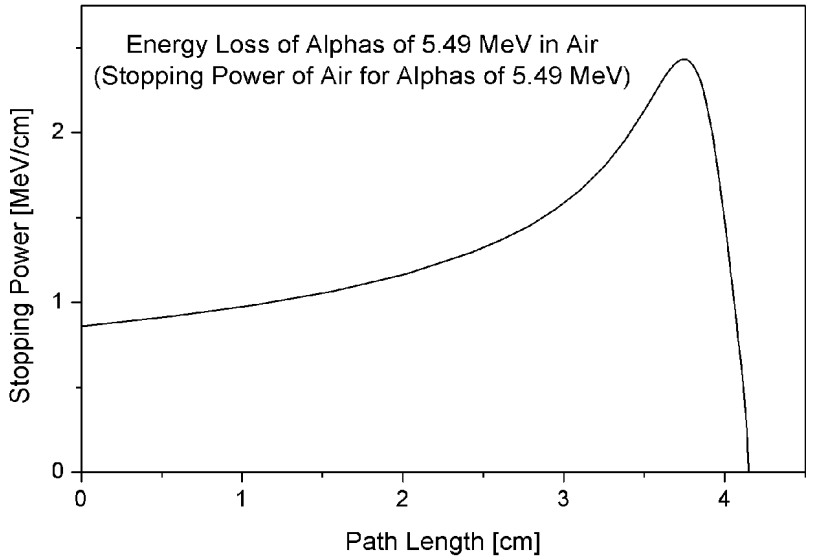


Bragg Peak for Alpha Particles (Geant4)



Ar:CO2::90:10
Ar:CO2::80:20
Ar:CO2::70:30
Ar:CO2:CF4::45:15:40

- For Am-241 (Alpha) at 5.6 MeV*
- No. of electrons from Geant4 = 1.68 * 10^5
- No. of electrons from Heed = 1.88 * 10^5



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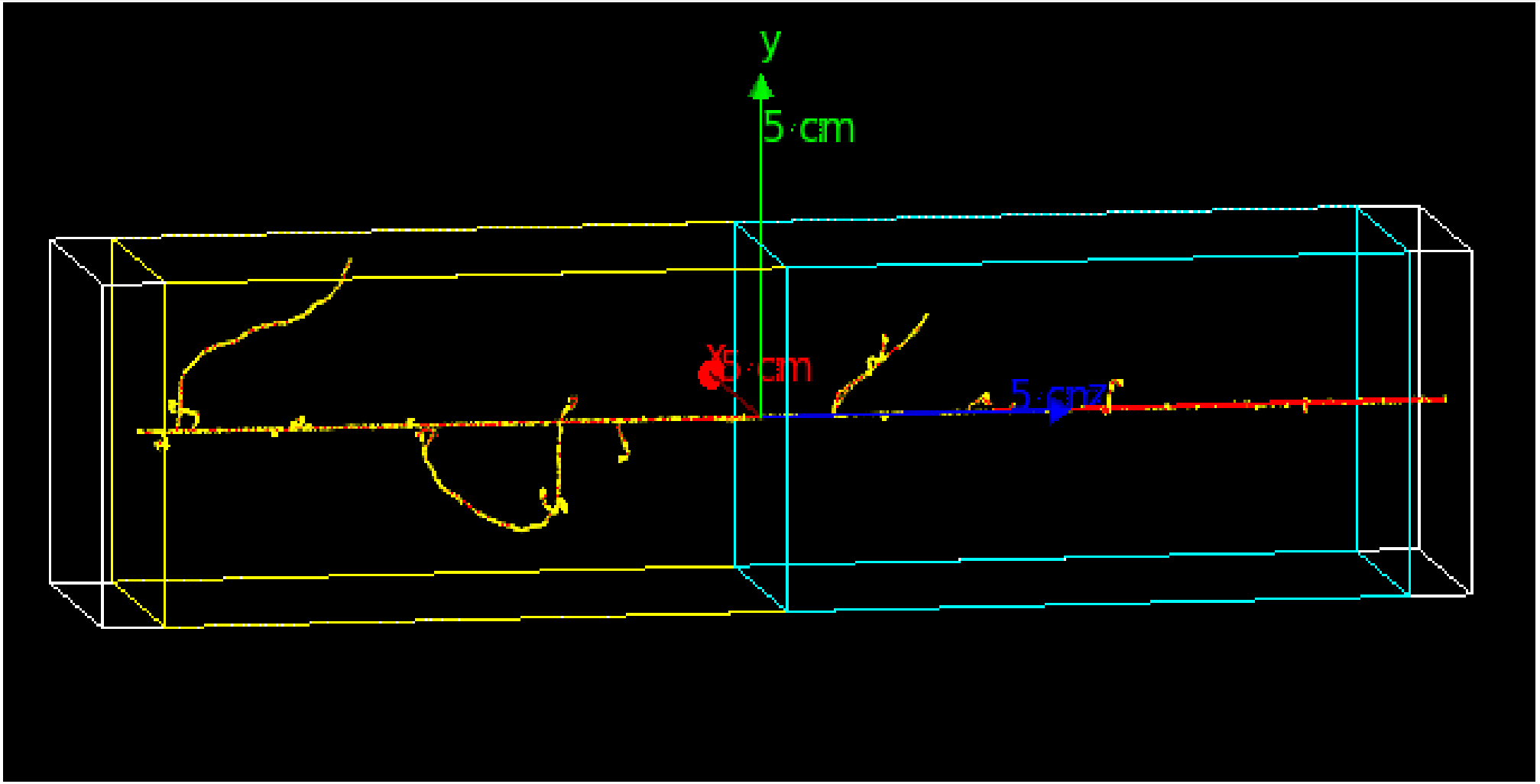
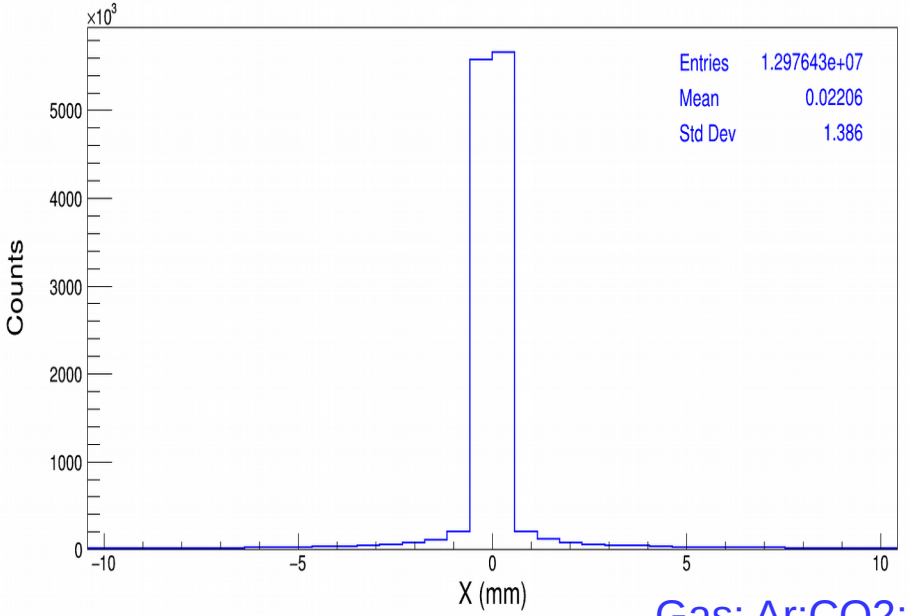
Geant4 Display of Muon Simulation

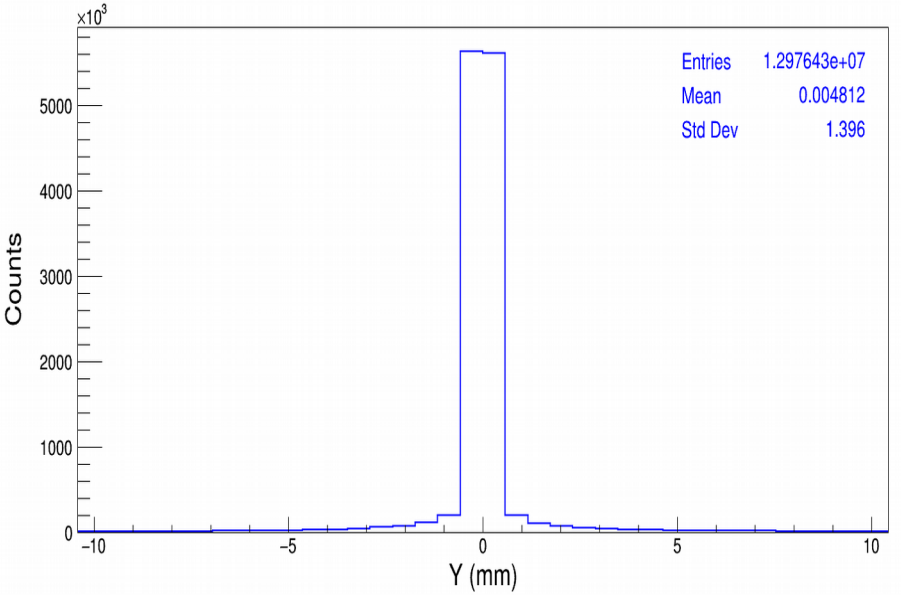


- For 50 Muons. Red μ^- , yellow e-
- Energy 1 GeV at (0,0,-10*cm)
- Gas: Ar:CO2::70:30, Volume: x = 5 cm, y = 5 cm, z = 20 cm

Contd...

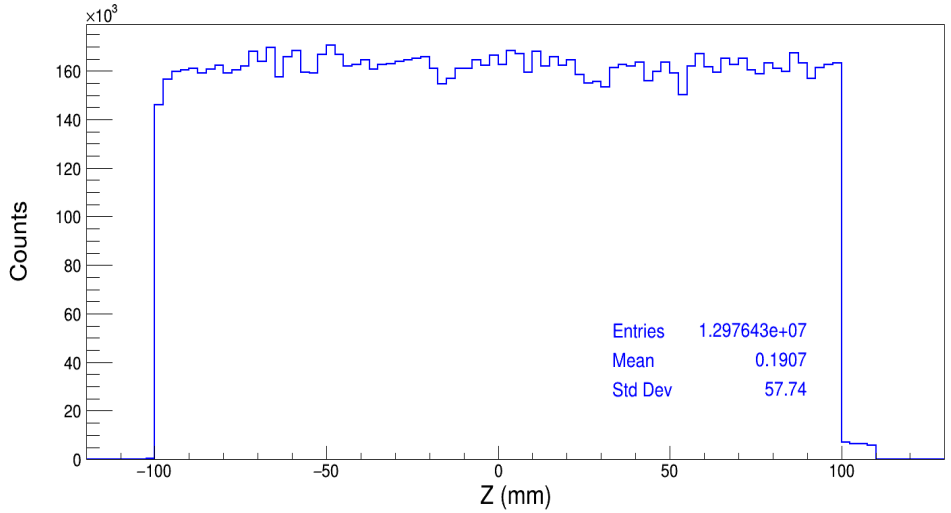
Muon Simulation With Geant4 & Heed

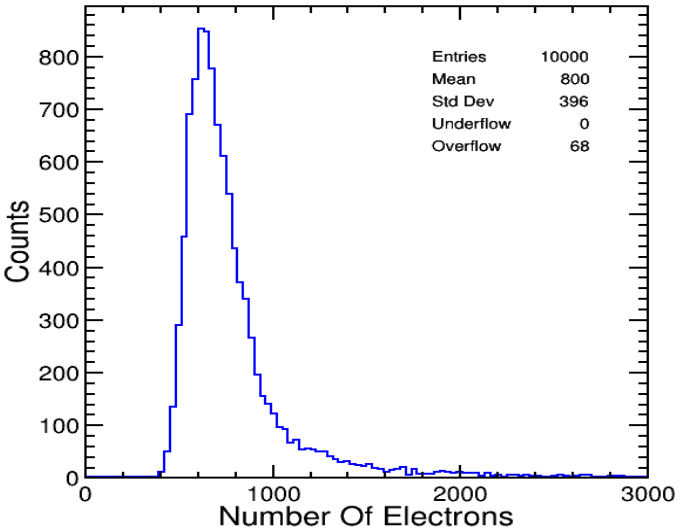




Gas: Ar:CO2::70:30

Volume : x = 5 cm, y = 5 cm, z = 20 cm

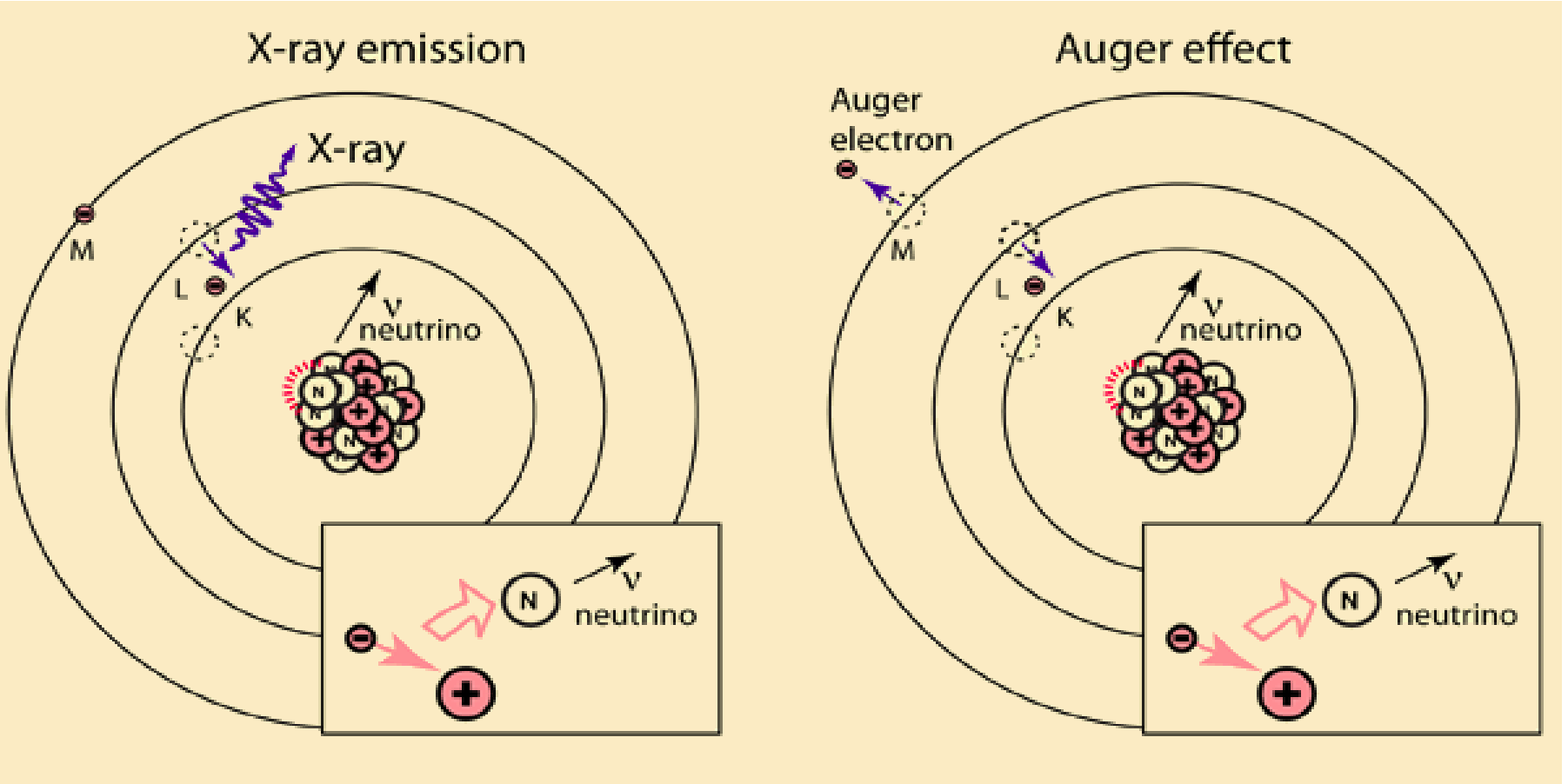




10000 events for μ- with Geant4, No. of e- = 1297

10000 events for μ- with Heed, No. of e- = 800

Electron Capture in Fe-55



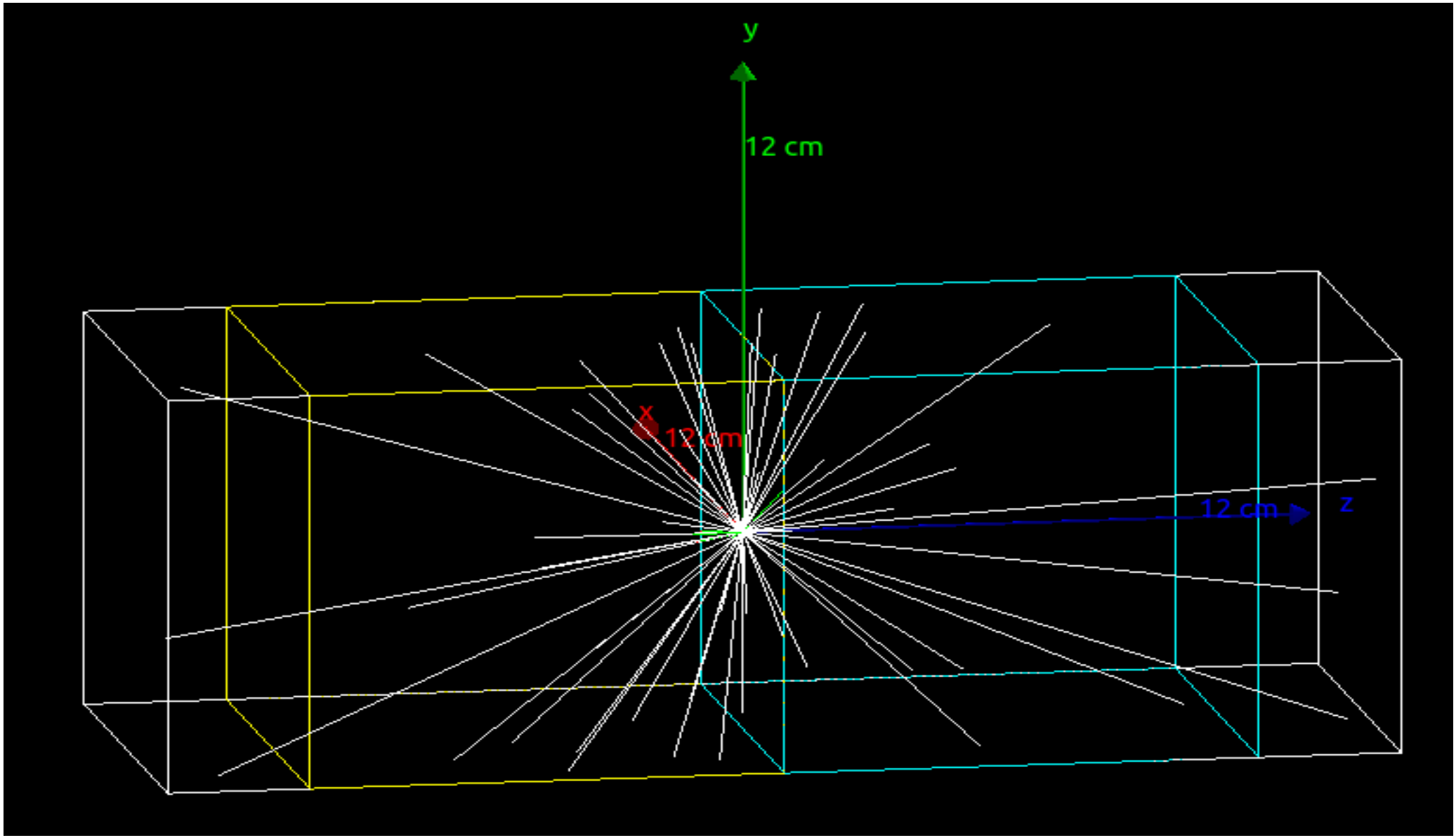
e- capture

$$\text{Fe-55} \xrightarrow{\text{----------}} \text{Mn-55} + \text{e- (Auger)} + \text{Anti } \nu_e + \gamma$$

- X-ray emission by Fe-55
  L ---> K ($K_{\alpha 1}$)
  M ---> K ($K_{\beta 1}$)

Contd...

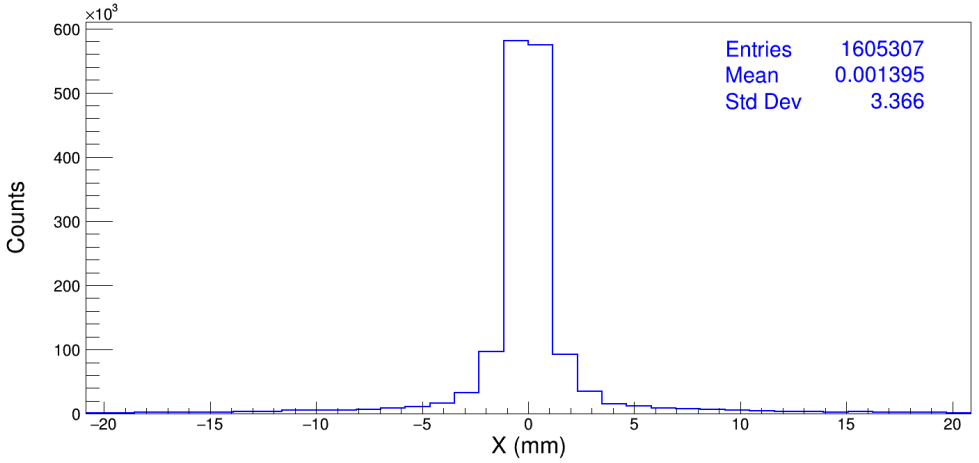
Geant4 Display of Fe-55 Simulation

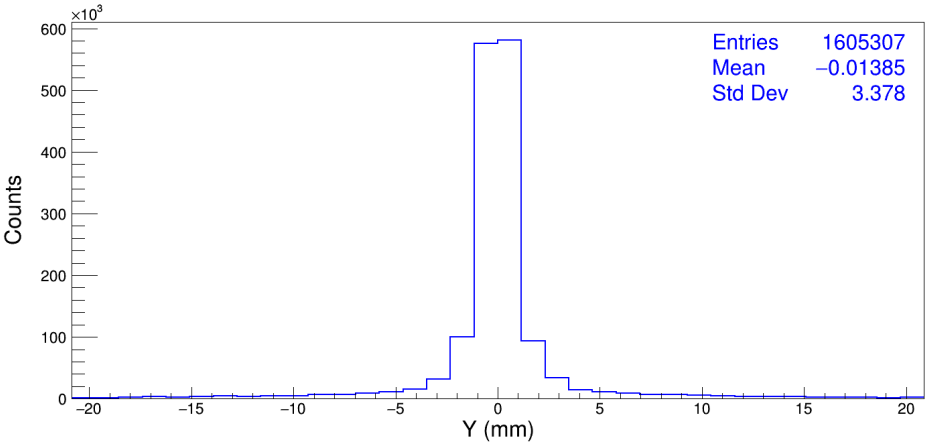


Simulation of Fe-55 (50 events) in Ar:CO2 :: 70:30, White: Mn55, Green: gamma, Red: Auger cascade

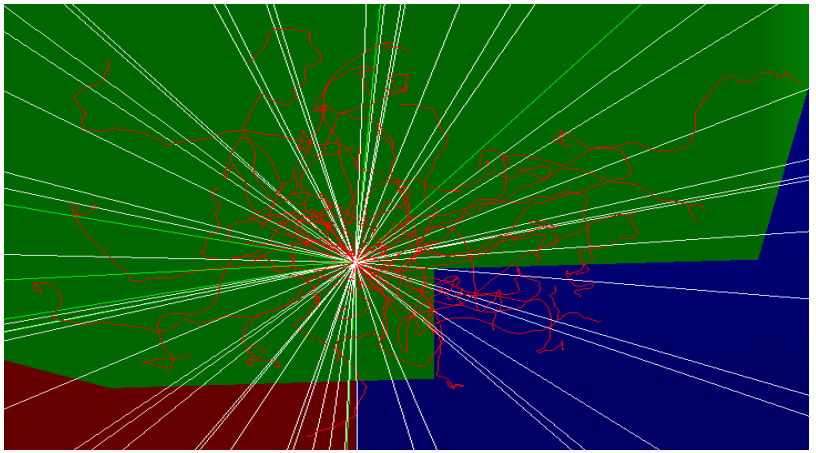
Contd...

Position Co-ordinates Using Geant4

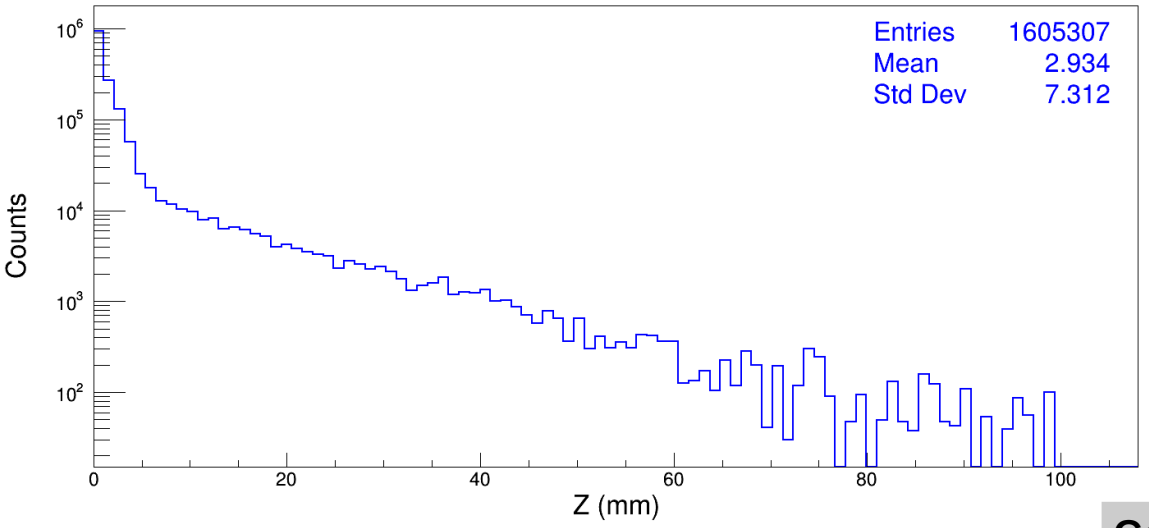




- 10000 events of Fe-55 in Ar:CO2 :: 70:30
- Volume: x = 5 cm, y = 5 cm, z = 20 cm
- Energy of Fe-55 = 5.89 keV at (0,0,0)
- Number of primaries = 160



Zoomed view of Auger Cascade



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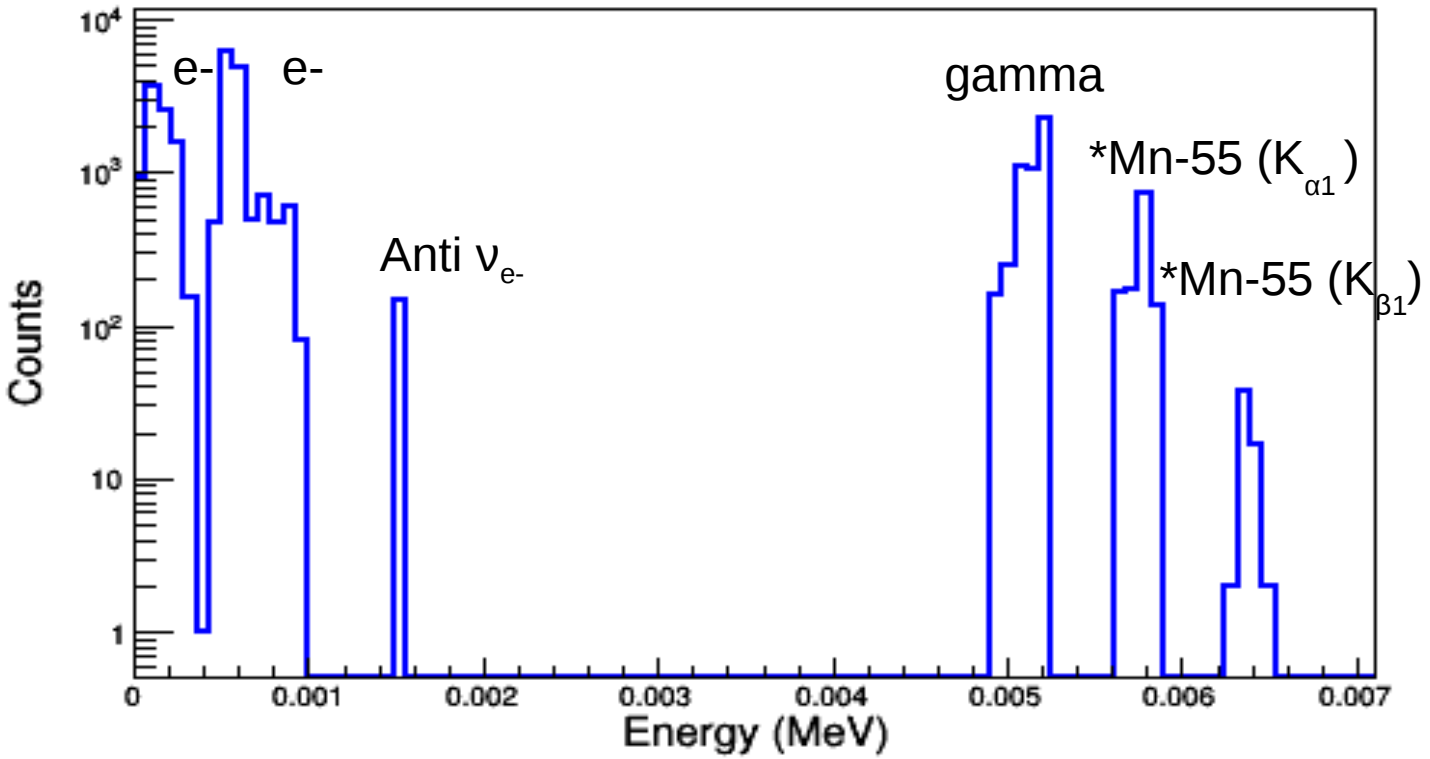
Fe-55 Geant4 Simulation



Standard Results:

Mn-55 ($K_{\alpha 1}$) = 5.89 keV

Mn-55 ($K_{\beta 1}$) = 6.49 keV

Auger e- = 0.5-0.8 keV

Mn: *http://nucleardata.nuclear.lu.se/toi/nuclide.asp?iza=260055

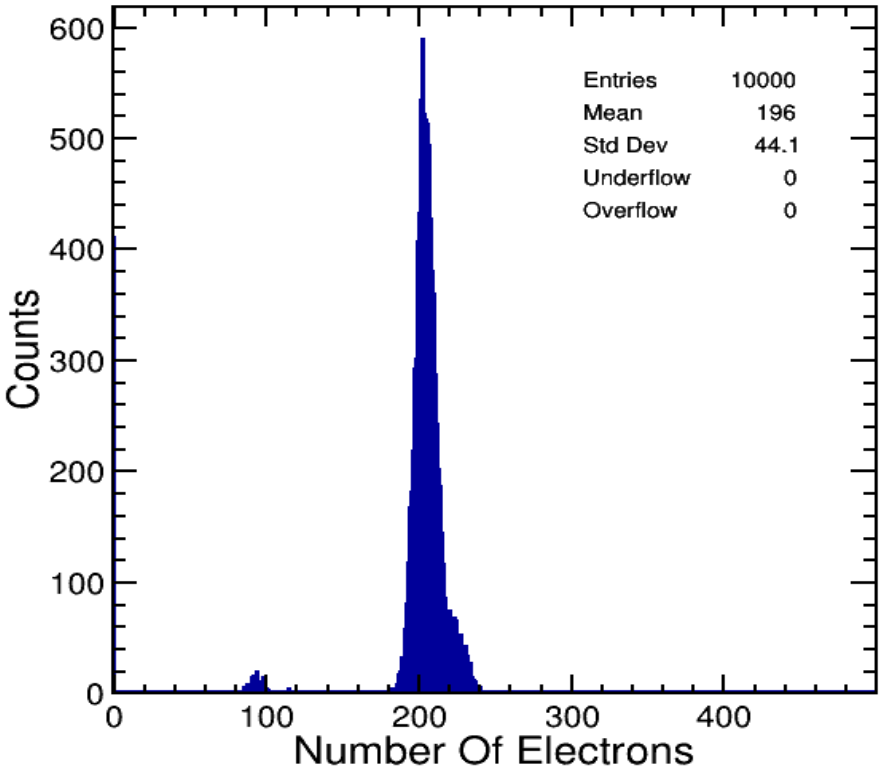
Auger e- : http://www.nucleide.org/DDEP_WG/Nuclides/Fe-55_tables.pdf

Auger e- : LMRI. Table de radionuclides. 1982 ff

- 10000 events of Fe-55 in Ar:CO2 :: 70:30
- Energy = 5.89 keV at (0,0,0)
- Auger e- Probability = 67.97 %, Published results = 65.8% *

*X-RAY LINES CLOSE TO KLL AUGER ELECTRON ENERGIESFR OM Fe, Co, Ni, AND Cu MONOCRYSTALS by YEON DEOG KOO

Fe-55 Heed Simulation

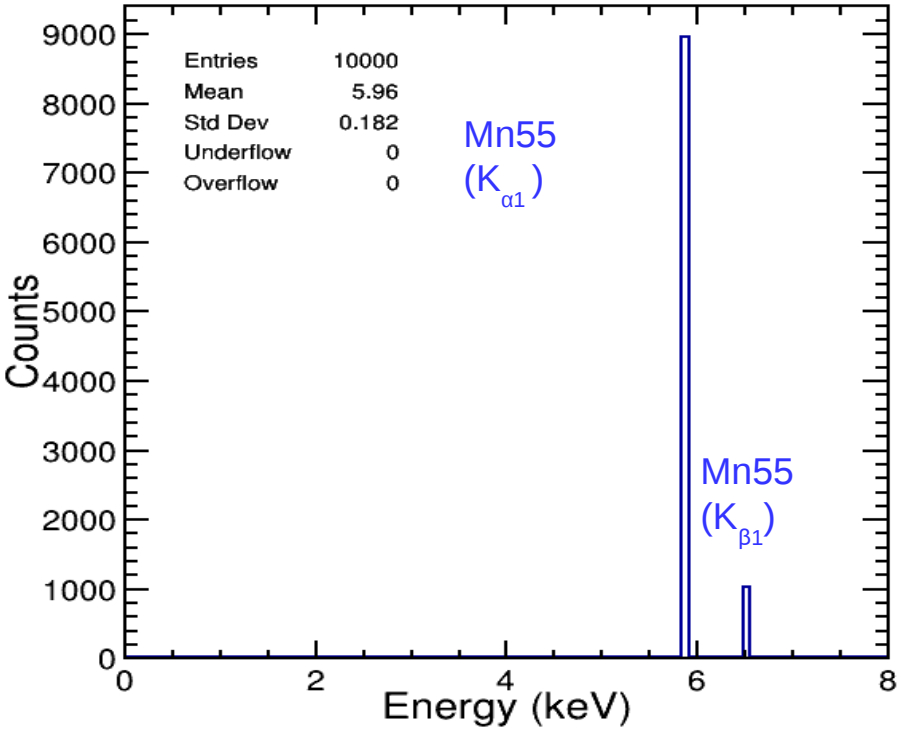


No. of e- = 196

- Gamma source in Ar:CO2 :: 70:30
- Volume: x = 5 cm, y = 5 cm, z = 20 cm
- Number of events: 10000

Mn55 ($K_{\alpha 1}$) : 5.89 keV

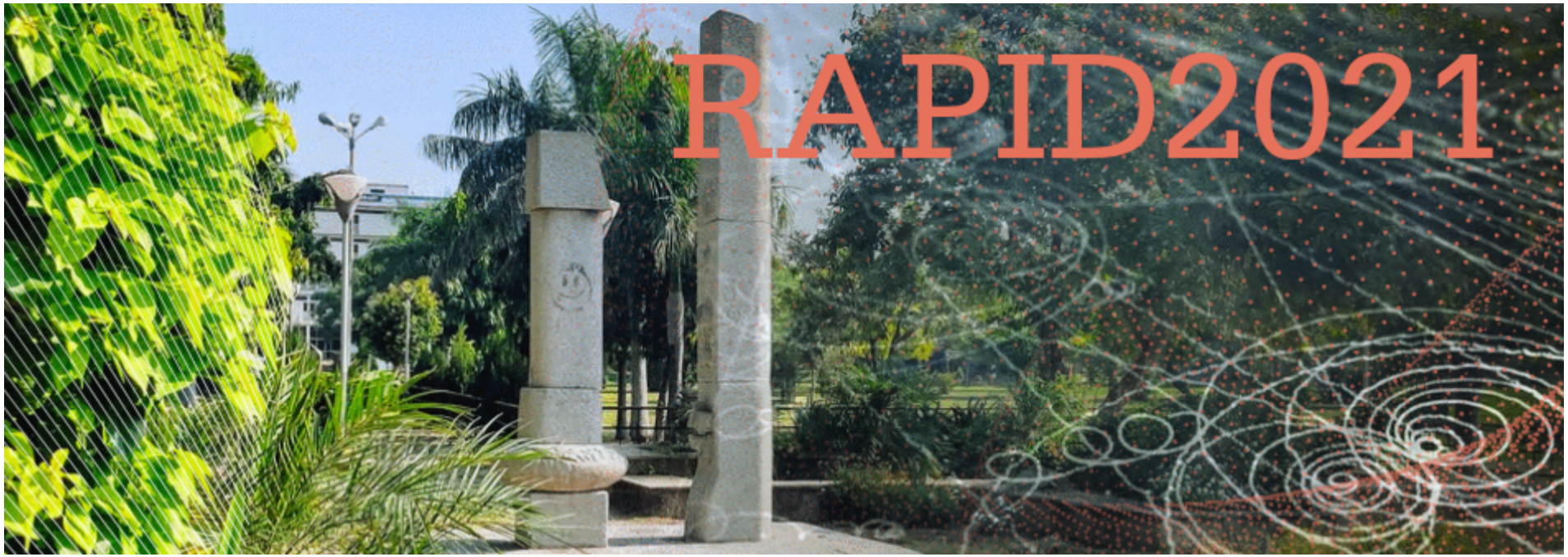
Mn55 ($K_{\beta 1}$) : 6.49 keV



Summary

- Primary ionization is necessary in nuclear and particle physics experiments
- Primary ionization is utilized in charge density and discharge formation studies
- Geant4 and Heed toolkit were utilized for the studies
- Obtained spatial information for alpha particles, shot in argon based gas mixtures
- Obtained Bragg peak which was comparable with the standard results
- The number of primaries for alpha simulation using Geant4 and Heed were comparable
- A similar analysis was done with muon source, shot in Ar:CO2 gas mixture and a comparison of the number of primaries was done with Heed
- Fe-55 simulation was done in Geant4 and Heed
- Auger electron probability was found and compared with published results

- Alpha particle simulation has been used in discharge probability studies
- Fe-55 simulation studies will be used in the GEM detector studies that are our ongoing studies.



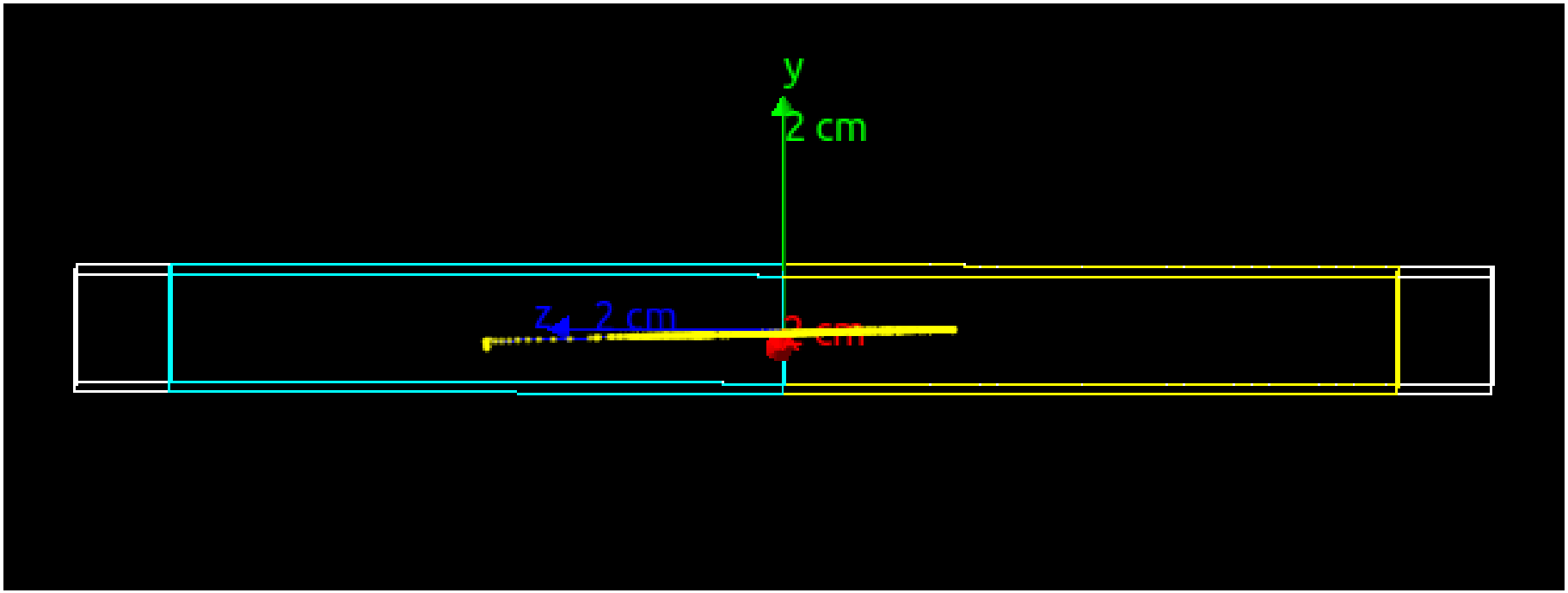
- **Thank You !!!**

- **Acknowledgements**

- Collaborators: Prasant Kumar Rout, Supratik Mukhopadhyay, Nayana Majumdar, Sandip Sarkar.

- Labmates: Jaydeep Datta and Sridhar Tripathy, Promita, Vishal Kumar, Pralay Das, Subhendu Das.
- SINP Computing Service.

Back-up Slides


y
2 cm
z
2 cm

X-rays from ^{55}Fe (2.73 y *3*)

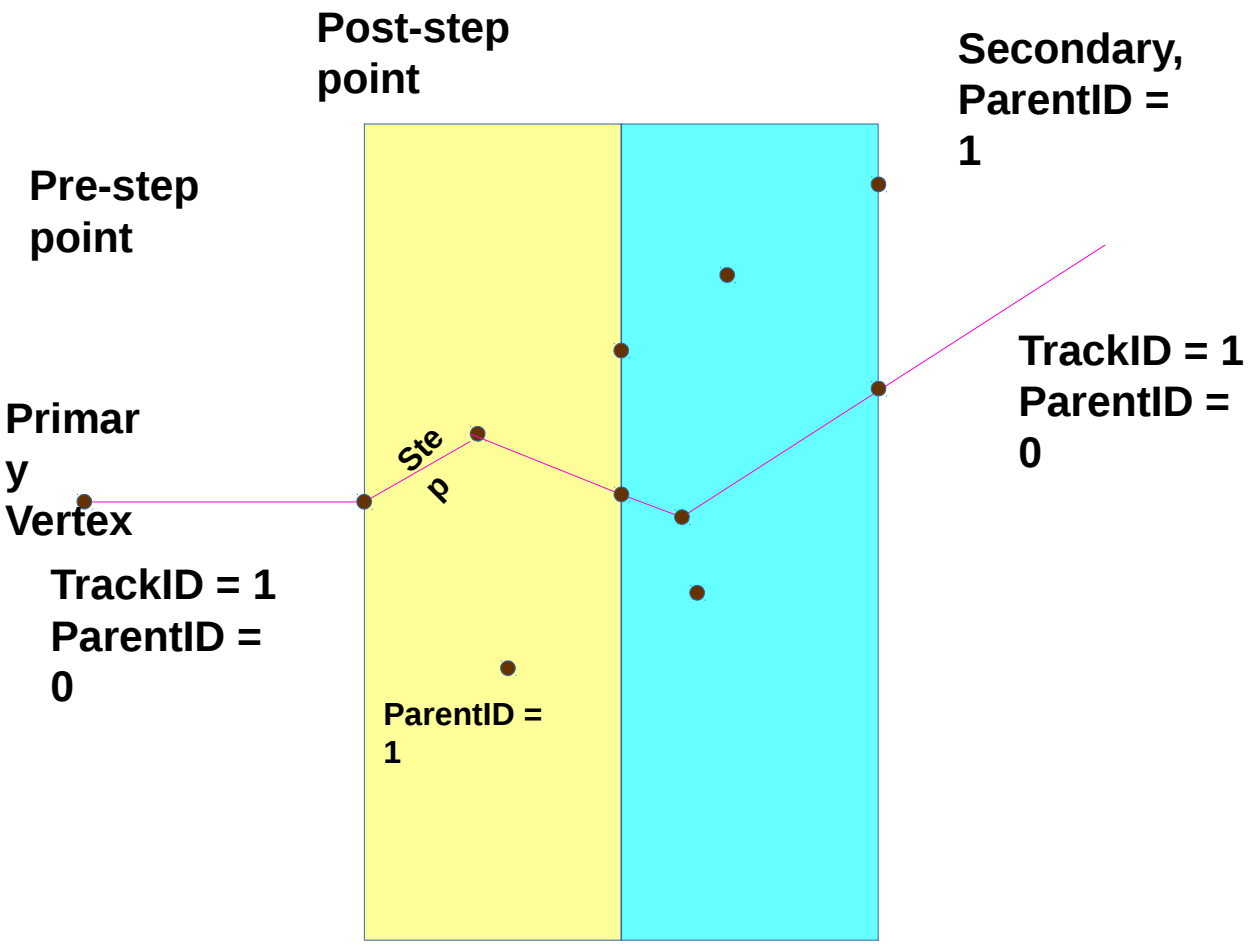
E (keV)	I (%)	Assignment
0,556	0.037 *10*	Mn L_l
0,568	0.025 *6*	Mn L_h
0,637	0.028 *7*	Mn L_{a2}
0,637	0.25 *6*	Mn L_{a1}
0,640	0.0022 *6*	Mn L_{b6}
0,648	0.19 *5*	Mn L_{b1}
0,720	0.011 *3*	Mn L_{b4}
0,720	0.017 *5*	Mn L_{b3}
5,770	6.9E-06 *4*	Mn K_{a3}
5,888	8.5 *4*	Mn K_{a2}
5,899	16.9 *8*	Mn K_{a1}
6,490	1.01 *5*	Mn K_{b3}
6,490	1.98 *10*	Mn K_{b1}
6,536	0.00089 *5*	Mn K_{b5}
6,539	8.5E-08 *5*	Mn K_{b4}

		Energy keV	Electrons per 100 disint.
e_{AL}	(Mn)	0,47 - 0,67	140,2 (8)
e_{AK}	(Mn)		60,1 (5)
	KLL	4,953 - 5,210	}
	KLX	5,671 - 5,895	}
	KXY	6,370 - 6,532	}

Recommended Nuclear Decay Data

Fe-55

Decay Mode: EC	Half-Life: (1001.0 ± 2.3) d					[2]
Radiation Type	Energy (keV)			Intensity (%)		Ref.
Auger-L	0.5	-	0.8	144	8	[3]
Auger-K	4.95	-	6.49	60.0	10	[3]
X-ray L	0.64			0.56	9	[2]
X-ray Kα	5.89			24.9	9	[2]
X-ray Kβ	6.49			3.4	1	[2]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Pre-step point
TrackID = 1 ParentID = 0
Primary Vertex
Step
TrackID = 1 ParentID = 0
ParentID = 1