# Simulation of energy deposition of Lightly Ionizing Particles in GEANT4

Samir Banik (for SuperCDMS collaboration)*
*National Institute of Science Education and Research, HBNI, Jatni, 752050, INDIA*

## Introduction

Super Cryogenic Dark Matter Search (SuperCDMS) [1] is a direct dark matter search experiment whose primary aim is to detect Weakly Interacting Massive Particles (WIMPs) that are dark matter candidates. WIMPs are expected to interact with atomic nuclei via elastic scattering resulting in a nuclear recoil. The experiment is designed to measure nuclear recoil energy that would come from WIMPs interaction. During its operation at Soudan underground laboratory, Germanium detectors were run with a high bias voltage mode or CDMSlite (Cryogenic Dark Matter Search low ionization threshold experiment) mode to search for low mass (mass approximately less than 10 GeV/$c^2$) WIMPs. The high bias voltage enables the use of lower threshold in the detector.

Using a low threshold, the detector also allows to search for Lightly Ionizing Particles (LIPs) with very small fractional charges. There is no strong theoretical motivation for the quantization of particle charges. One of Dirac's works [2], suggests that existence of magnetic monopoles in nature is the reason for quantization of charge. Till now, no evidence for the existence of a magnetic monopole has been found. On the other hand, there exist numerous theoretical models that naturally allow existence of particles with fractional electromagnetic charge. If particles with fractional charge are considered to follow the Bethe-Bloch theory [3], they should lose energy much more slowly than minimum ionizing particles such as muons. In a previous study, CDMS II [4] (SuperCDMS Soudan is successor to CDMS II) excluded parameter space for LIPs with charges between e/6 and e/200. SuperCDMS with CDMSlite mode detectors can look for particles with even smaller fractional charges.

*Electronic address: `samir.banik@niser.ac.in`

To search for LIPs in experimentally acquired data, an expected probability distribution function (PDF) for its energy deposition in the detector is required. We have made an attempt to obtain energy deposition PDF using GEANT4 [6] simulations. Although GEANT4 provides several particles for use in simulation, there is no LIP or fractionally charged particle already defined in GEANT4. We present some results obtained after the implementation of LIPs in GEANT4.

## Simulation using GEANT4

The detector geometry and material used for simulation is based on the SuperCDMS Soudan experiment. It is a circular disk with diameter 7.6 cm and thickness 2.5 cm, made of Germanium.

GEANT4 physics processes and models that are used for LIPs are listed in Table I. Some of the models and processes for muons (`G4MuBetheBloch` and `G4MuBremsstrahlung`) did not respect particle charge. They have been modified to incorporate fractional charge dependence. A particle class has been written to provide the description for LIPs in GEANT4.

TABLE I: Processes and Models used in GEANT4

| Process (EM) | Model | Energy range |
|---|---|---|
| Ionization | `G4Bragg` | 0 - 0.2 MeV |
| | `G4BetheBloch` | 0.2 MeV - 1 GeV |
| | `G4MuBetheBloch` | 1 GeV - 10 TeV |
| Bremsstrahlung | `G4MuBremsstrahlung` | 0 - 10 TeV |
| Coulomb Scattering | `G4eCoulombScattering` | 0 - 10 TeV |
| Multiple Scattering | `G4WentzelVIUni` | 0 - 10 TeV |

## Results and discussion

Figure 1 shows energy loss of the particle for its different masses. The charge of the particle is fixed to $+e$. The results from the simulation is compared with the Bethe-Bloch curve. Since most of the properties of the LIP (except decay) are similar to muons when charge is $+e$ and mass is 100 MeV, the results are also compared with the Particle Data Group (PDG) data [7] for muons. It can be seen that the energy loss from

GEANT4 simulation follows Bethe-Bloch curve (plotted upto $10^5$ MeV). For LIPs of mass 100 MeV and charge $+e$, the simulation is in agreement with the PDG. Figure 2 shows how energy

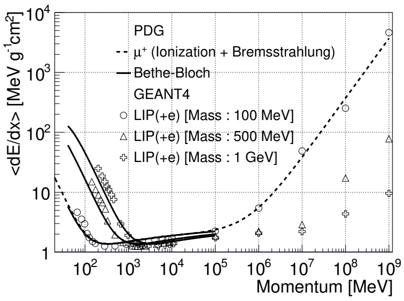


FIG. 1: $\langle dE/dx \rangle$ as a function of momentum as LIP mass is varied with LIP charge held at $+e$. The solid curve represents the Bethe-Bloch curve, dotted line is the PDG data and the markers represent GEANT4 simulation results. In the PDG data shown, only contributions from ionization and bremsstrahlung processes have been considered. This is because, only these processes have been used in the simulation for calculating energy loss.

loss varies with LIP charge. It can be seen that $\langle dE/dx \rangle$ follows a charge squared dependence as expected from Bethe-Bloch formula [3]. We ob-

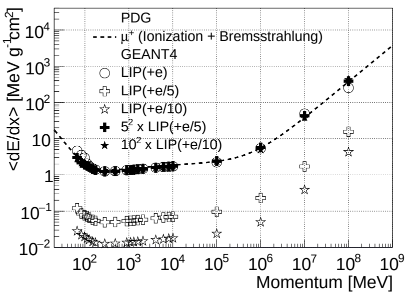


FIG. 2: $\langle dE/dx \rangle$ plotted as a function of momentum for LIPs with different charges. Mass is fixed to 100 MeV. The dotted line represents the PDG data for muons. Open circle, plus and star markers represent simulation results for LIP with charge $+e$, $+e/5$ and $+e/10$ respectively. $\langle dE/dx \rangle$ for fractioanl charges are multiplied by the inverse of charge square and are shown as solid markers.

tained an energy deposition probability distribution for LIPs in Germanium. The GEANT4 results for two values of fractional charges are compared with the energy deposition PDF used for CDMS-II LIPs analysis in figure 3. In the CDMS-II analysis, the Photo Absorption Ionization (PAI) model [4] was used for generating the PDF. The GEANT4 PDFs agree with CDMS II PDFs at higher energies and the peak positions are nearly the same. The difference at lower energy may be due to the model differences.

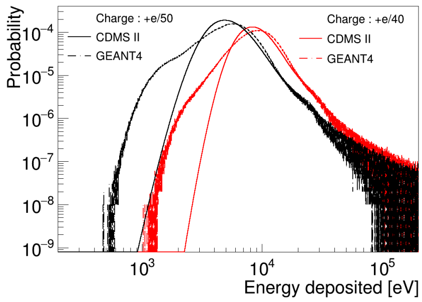


FIG. 3: Energy deposition PDF obtained from GEANT4 compared with that used in CDMS-II [4].

## Conclusions and Outlook

An attempt has been made to simulate energy deposition of LIPs in GEANT4. The particle definition implemented for LIPs could be useful to simulate energy deposition for different detector geometries at different LIPs search experiments. We are in the process of incorporating more processes/models in the simulation.

## Acknowledgments

DAE and DST are acknowledged for financial support.

## References

[1] Z. Ahmed et al, J Low Temp. Phys. (2008) 151: 800-805; D.S. Akerib et al, *ibid.*, 818-823.
[2] P. A. M. Dirac, Proc. of Royal Society London A133, 60 (1931).
[3] C. Patrignani et al. (Particle Data Group), Chin. Phys. C, 40, 100001 (2016).
[4] R. Agnese et al, PRL 114, 111302 (2015).
[5] M. Ambrosio et al, PRD 62, 052003 (2000).
[6] S.Agostinelli et al, NIM A 506, 250 (2003); J.Allison et al, NIM A 835, 186 (2016).
[7] `http://pdg.lbl.gov/2017/`