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Response functions of Ionisation Chamber Beam Loss Monitor

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Summary

Beam Loss Monitoring system of LHC uses two main types of detectors. One of them is nitrogen-filled ionisation chamber. The properties of this ionisation chamber has been widely studied. In particular its response, in terms of generated charge as a function of impinging particle type, energy and impact angle, has been a subject of detailed analyses. This paper summarizes the results of the latest simulation of the response function, performed with Geant4 and FLUKA particle transport codes.

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Contents

1 Introduction

The properties of the ionisation chamber (IC) used in LHC Beam Loss Monitoring system (BLM, [1]) has been widely studied in [2]. A simulation of signal generation in the IC has been performed using Geant4 [3] and FLUKA [4, 5] codes and verified in numerous measurements.

The codes has been used here to perform a systematic study of the IC response function i.e. the charge generated inside the active volume of the chamber due to passage of a particle.

The chamber has a form of a cyllinder. The active medium is nitrogen. The length of the active part of the BLM is 48.3 cm and the radius is 4.245 cm. The nitrogen is enclosed in an envelope made of stainless steel. Inside the active volume there are 61 electrodes.

2 Geant4 results

The Geant4 simulations have been performed using verwion 4.9.2 in the following way:

- The flux of particles is generated in 90 bins (150 in case of neutrons).
- The bins are logarithmic.
- For neutrons the simulated kinetic energies are between 0.0002 eV and $1.0541 \cdot 10^{12}$ eV.
- For other particles the simulated kinetic energies defined between 900 eV and $1.0541 \cdot 10^{12}$ eV.
- Inside the bins a flat spectrum is simulated (i.e. spectrum has constant value over energy bin).
- The energy cut has been set to 0.01 mm [1].
- The physics list is QGSP_BERT_HP modified to include thermal neutron scattering.

The Geant4 geometry has been taken from [2]. The particles are generated using *G4GeneralParticleSource* class. The simulations are performed for impact angle between 0 and 90 degrees. It is assumed here that the chamber is symmetric and response for angles between 90 and 180 degrees will correspond to the ones between 0 and 90 degrees. Because of a presence of electronic box at one end of the IC, this assumption is not correct for particles impinging with large angle.

[1] The corresponding kinetic energy cut depends on material in which particle is travelling

2.1 Impact angle: zero degree

Figure 2 presents the response functions for particles impacting with 0 degrees with respect to BLM axis. The particles are generated uniformly from a circle with radius equal to the radius of the ionisation chamber. A case of with a few tracks generated is presented in Figure 1.

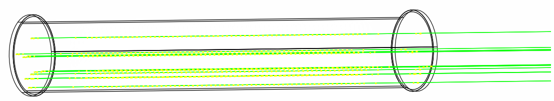

Figure 1: *Generation of events when determining 0-degree response function. Green are tracks and yellow are hits in various elements of IC. Tracks are generated on the left side of the IC.*

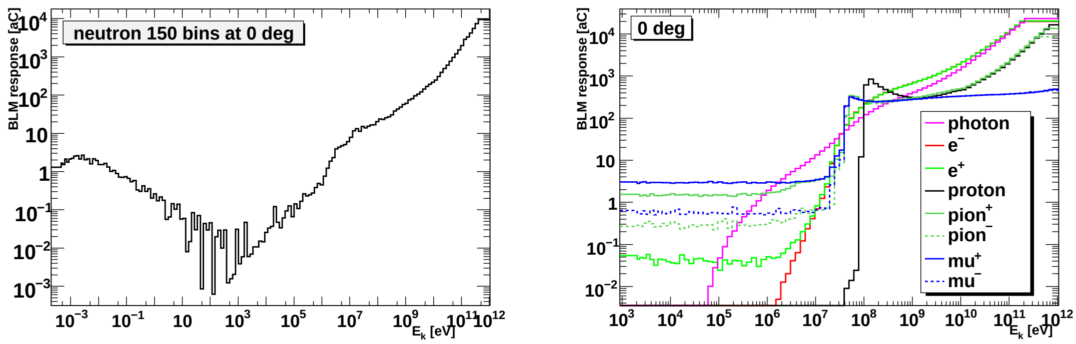

Figure 2: *Response functions for particles impacting with 0 degree with respect to BLM axis.*

2.2 Impact angle: 10 degrees

Figure 3 presents the response functions for particles impacting with 10 degrees with respect to BLM axis.

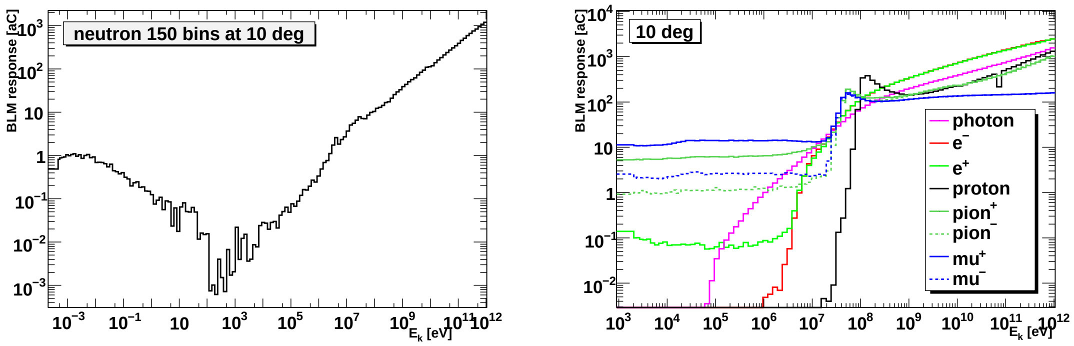

Figure 3: *Response functions for particles impacting with 10 degrees with respect to BLM axis.*

2.3 Impact angle: 30 degrees

Figure 4 presents the response functions for particles impacting with 30 degrees with respect to BLM axis.

2.4 Impact angle: 45 degrees

Figure 5 presents the response functions for particles impacting with 45 degrees with respect to BLM axis.

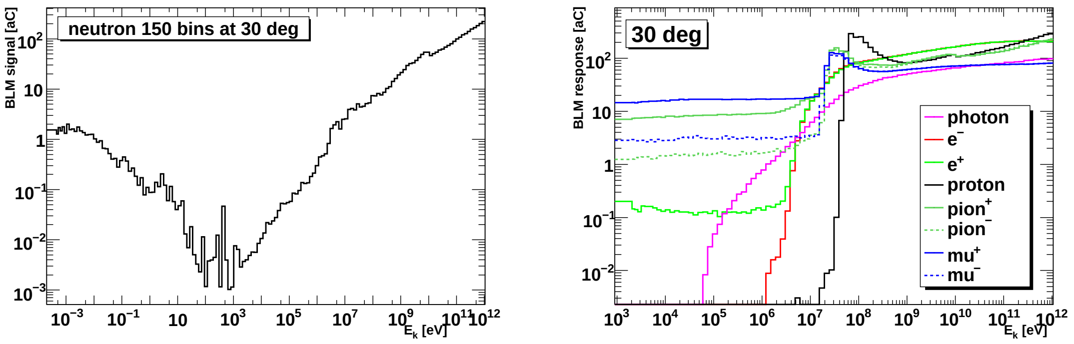

Figure 4: *Response functions for particles impacting with 30 degrees with respect to BLM axis.*

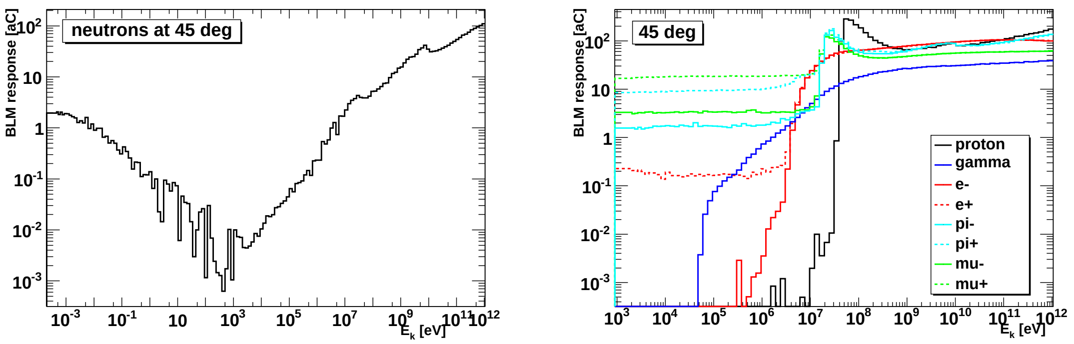

Figure 5: *Response functions for particles impacting with 45 degrees with respect to BLM axis.*

2.5 Impact angle: 60 degrees

Figure 6 presents the response functions for particles impacting with 60 degrees with respect to BLM axis.

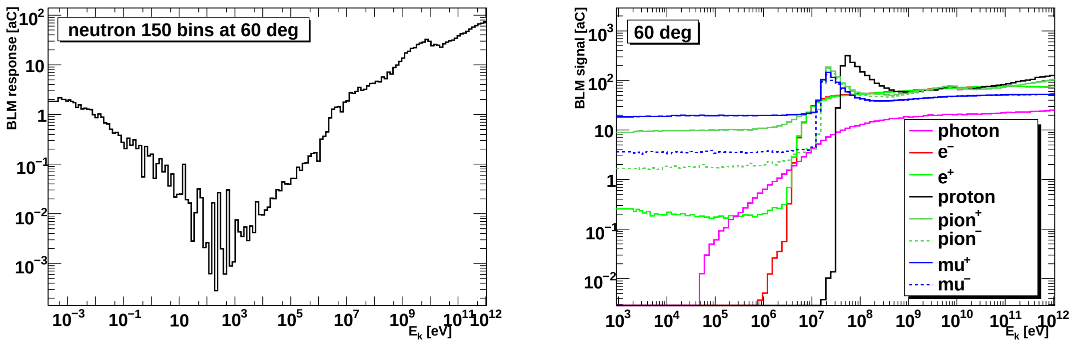

Figure 6: *Response functions for particles impacting with 60 degrees with respect to BLM axis.*

2.6 Impact angle: 90 degrees

Figure 7 presents the response functions for particles impacting perpendicular to the BLM axis.

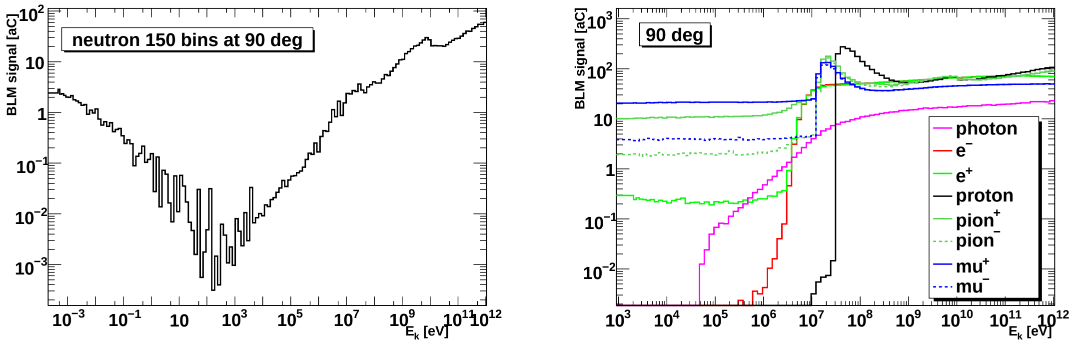

Figure 7: *Response functions for particles impacting with 90 degrees with respect to BLM axis.*

3 Comparison between Geant4 and FLUKA

In this chapter a comparison of FLUKA and Geant4 results for different particle types and various impact angles is presented.

The FLUKA simulations start at kinetic energies of 1 MeV, except of γs, which start at 100 keV and neutrons which start at $4.4 \cdot 10^{-4}$ eV.

3.1 Impact angle: 0 degrees

Figures 8-12 present comparison of FLUKA and Geant4 results for different particle types for impact angle of 0 degrees with respect to BLM axis, ie. paralell to the axis. In this particular configuration some particles must pass through metal rods being a part of mechanical construction of the chamber. These rods represent a significant amount of material and high energy showers are generated by particles passing through.

Only a small differences between FLUKA and Geant4 results are observed.

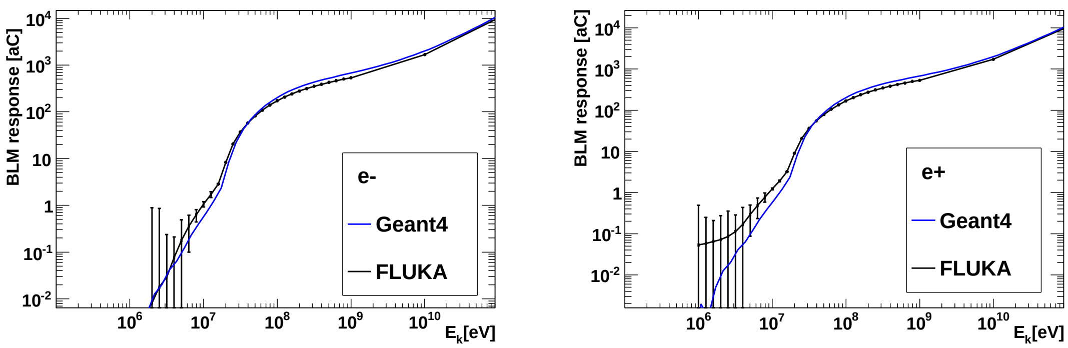

Figure 8: *Comparison of the response function calculated by Geant4 and FLUKA for electrons and positrons impacting the chamber with angle of 0 degrees.*

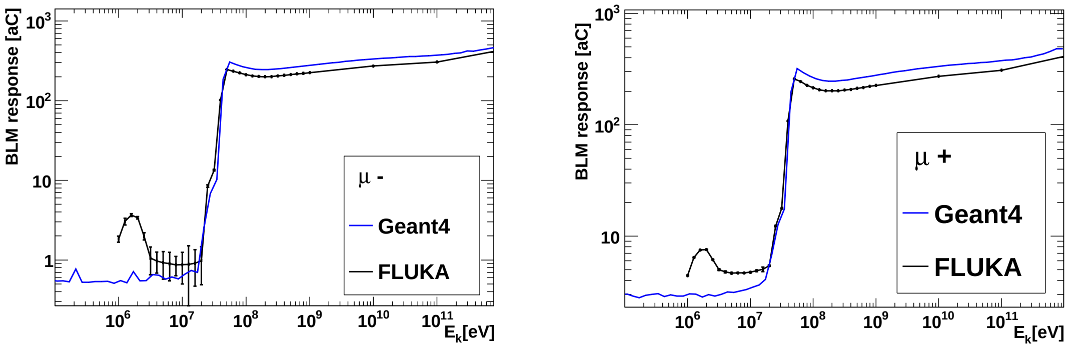

Figure 9: *Comparison of the response function calculated by Geant4 and FLUKA for muons impacting the chamber with angle of 0 degrees.*

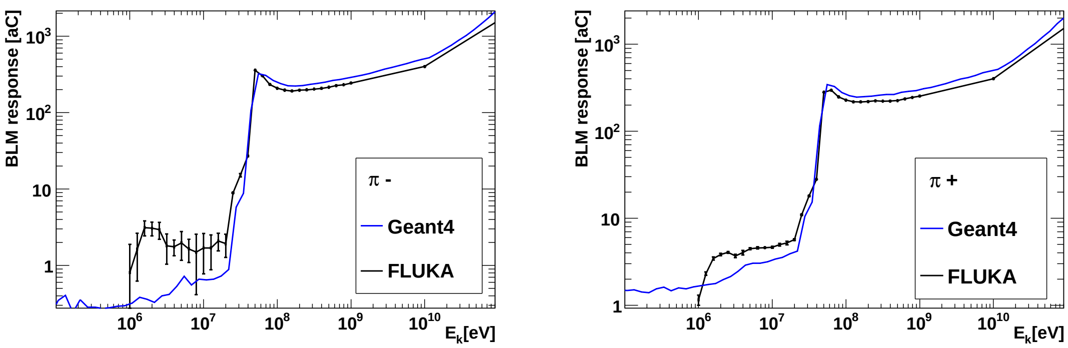

Figure 10: *Comparison of the response function calculated by Geant4 and FLUKA for pions impacting the chamber with angle of 0 degrees.*

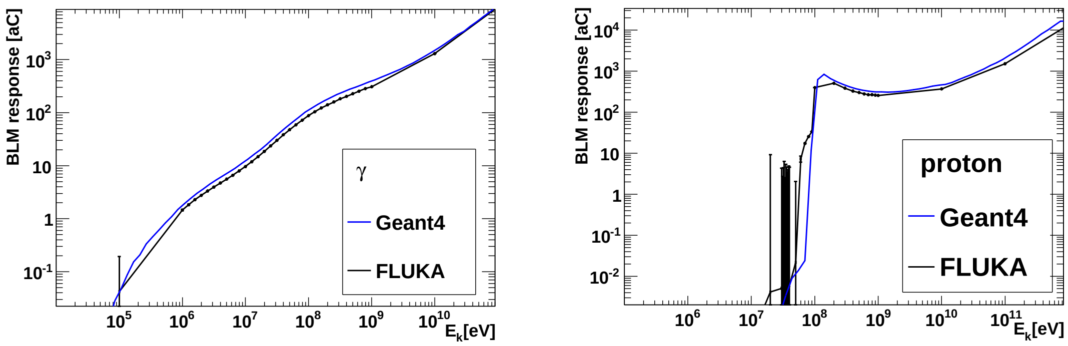

Figure 11: *Comparison of the response function calculated by Geant4 and FLUKA for gammas (left plot) and protons (right plot) impacting the chamber with angle of 0 degrees.*

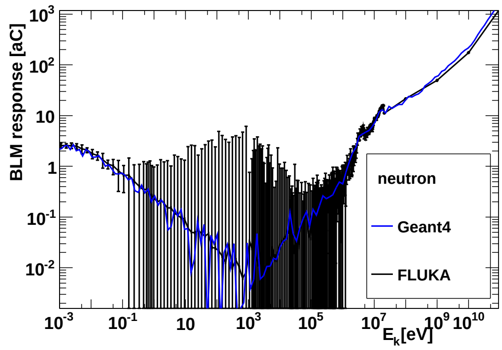

Figure 12: *Comparison of the response function calculated by Geant4 and FLUKA for neutrons impacting the chamber with angle of 0 degrees.*

3.2 Impact angle: 45 degrees

Figures 13-17 present comparison of FLUKA and Geant4 results for different particle types for impact angle of 45 degrees with respect to BLM axis.

Relatively good agreement between both simulation codes is observed. A tendency of Geant4 to give slightly higher results in most cases is seen.

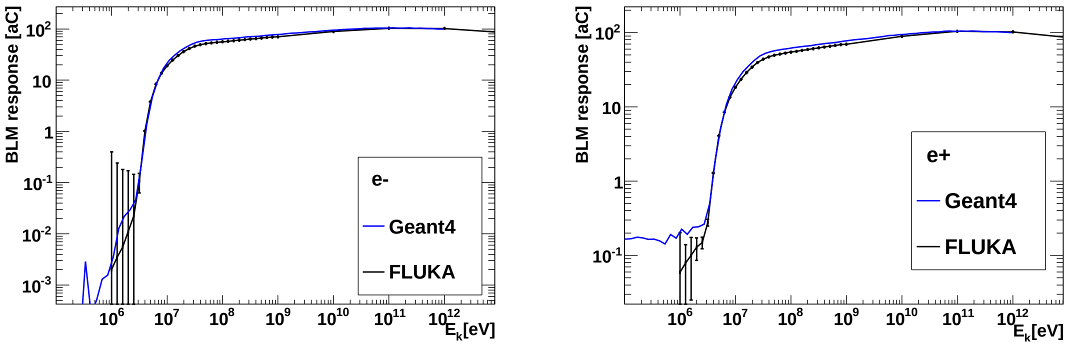

Figure 13: *Comparison of the response function calculated by Geant4 and FLUKA for electrons and positrons impacting the chamber with angle of 45 degrees.*

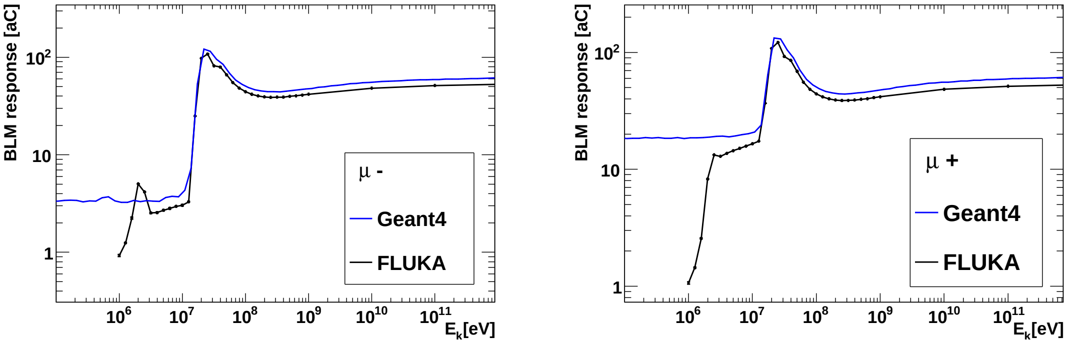

Figure 14: *Comparison of the response function calculated by Geant4 and FLUKA for muons impacting the chamber with angle of 45 degrees.*

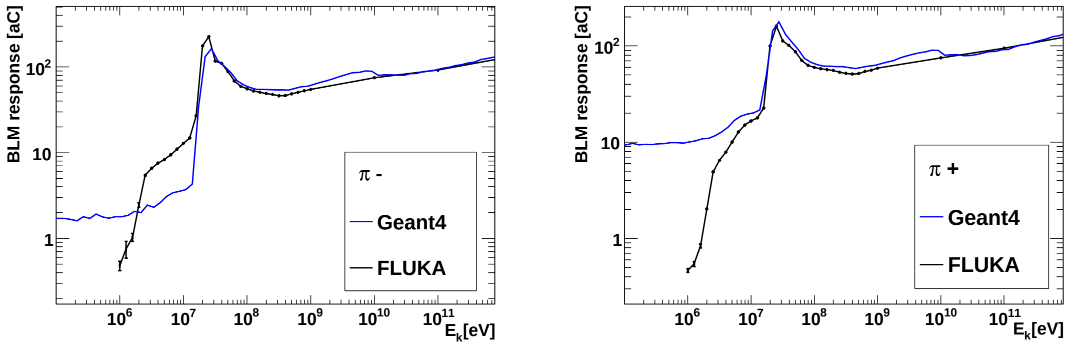

Figure 15: *Comparison of the response function calculated by Geant4 and FLUKA for pions impacting the chamber with angle of 45 degrees.*

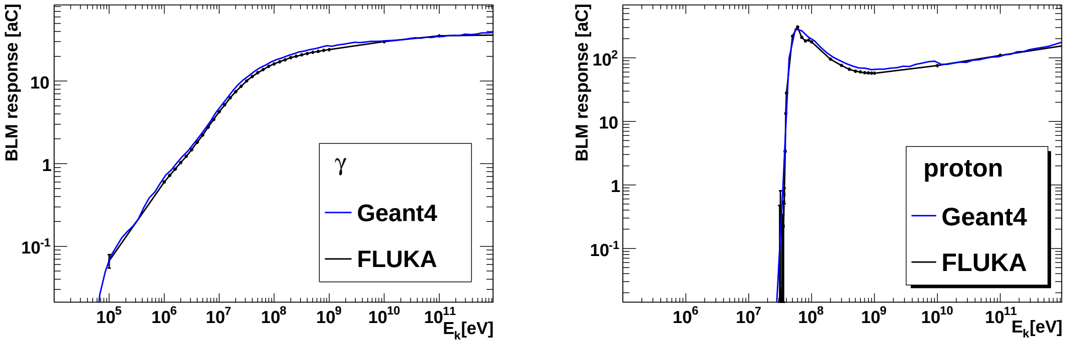

Figure 16: *Comparison of the response function calculated by Geant4 and FLUKA for gammas (left plot) and protons (right plot) impacting the chamber with angle of 45 degrees.*

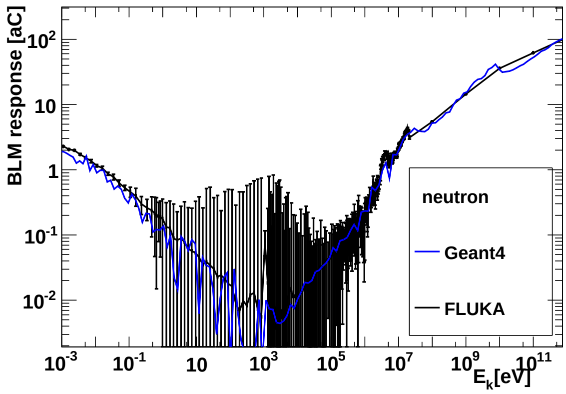

Figure 17: *Comparison of the response function calculated by Geant4 and FLUKA for neutrons impacting the chamber with angle of 45 degrees.*

3.3 Impact angle: 90 degrees

Figures 18-22 present comparison of FLUKA and Geant4 results for different particle types for impact angle of 90 degrees with respect to BLM axis.

For electrons, positrons, gammas and protons a very good agreement between the two codes is observed. Negative muons show annihilation peak at about 2 MeV, which is not observed in Geant4 results. Geant4 results are also by about 20% higher for high energies. For positive and negative muons a cutoff is observed in FLUKA at 1 MeV as this is how the simulation conditions are set.

Pion spectrum in Geant4 features a structure at about 8 GeV, which is not observed in FLUKA (although simulation points are missing there). For low energy tail the same discrepancy between Geant4 and FLUKA results as for muons is observed.

For neutrons a good agreement between Geant4 and FLUKA results is observed for low energies ($10^{-3} - 10^{-1}$ eV) and for high energies (however the same structure at a few GeV as for pions is observed (actually it is also true for protons)) - above 100 keV. In between Geant4 seems to resolve a lot of resonances while FLUKA show a significant statistical errors.

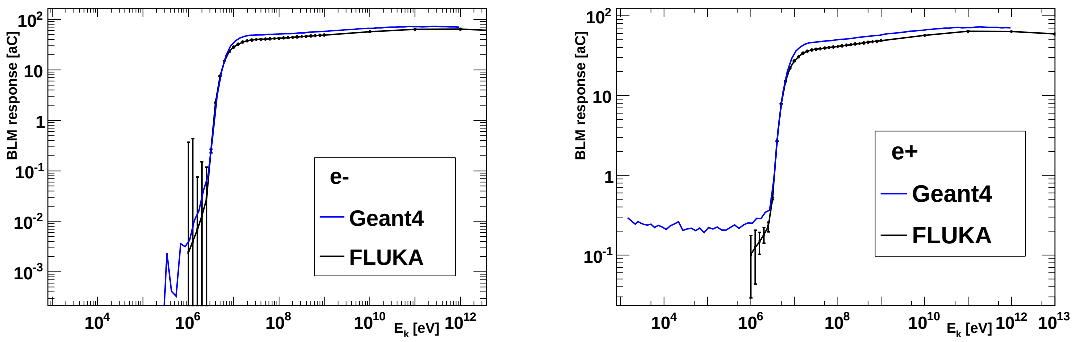

Figure 18: *Comparison of the response function calculated by Geant4 and FLUKA for electrons and positrons impacting the chamber with angle of 90 degrees.*

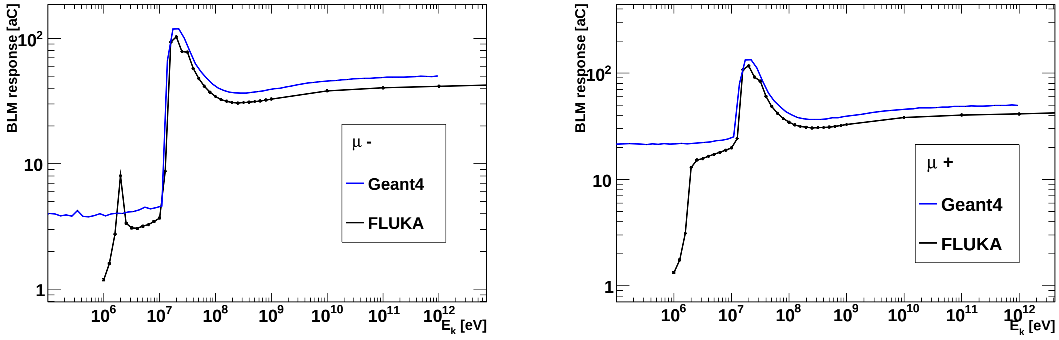

Figure 19: *Comparison of the response function calculated by Geant4 and FLUKA for negative and positive muons impacting the chamber with angle of 90 degrees.*

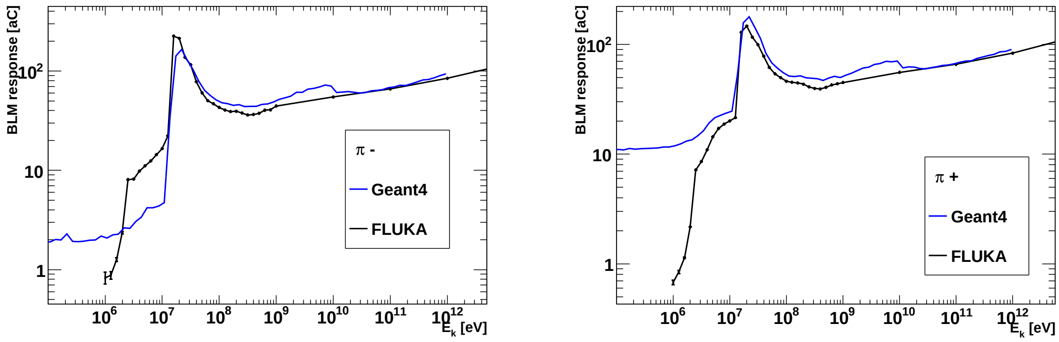

Figure 20: *Comparison of the response function calculated by Geant4 and FLUKA for negative and positive pions impacting the chamber with angle of 90 degrees.*

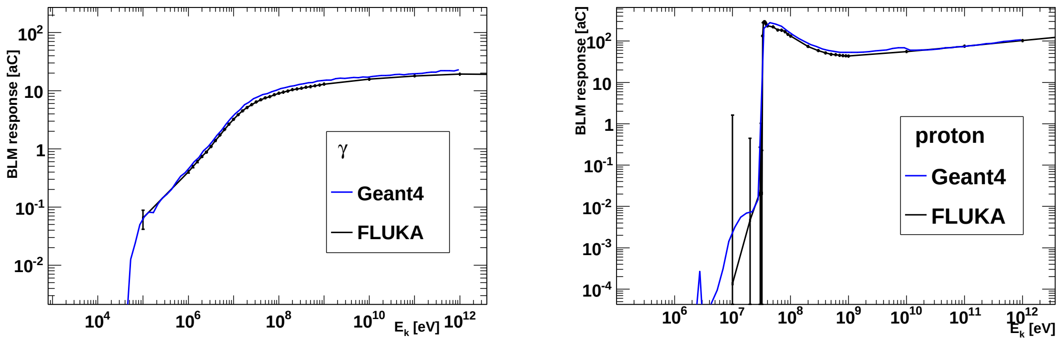

Figure 21: *Comparison of the response function calculated by Geant4 and FLUKA for gammas and protons impacting the chamber with angle of 90 degrees.*

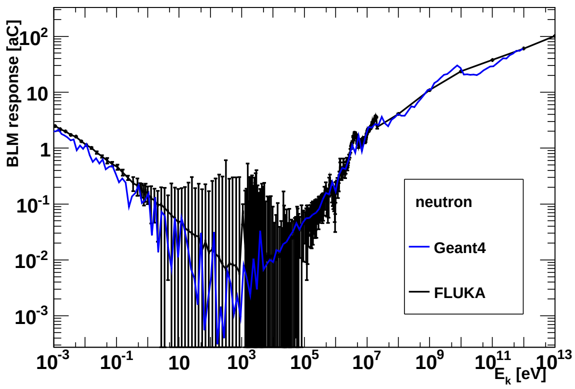

Figure 22: *Comparison of the response function calculated by Geant4 and FLUKA for neutrons impacting the chamber with angle of 90 degrees.*

4 Very low energies

Additional Geant4 simulations have been done in order to understand low energy tails of the response functions in case of e^+, μ^+, μ^-, μ^+, π^+ and π^-. The simulation has been made to investigate the signal from very low energy particles. Results are shown in Figure 23.

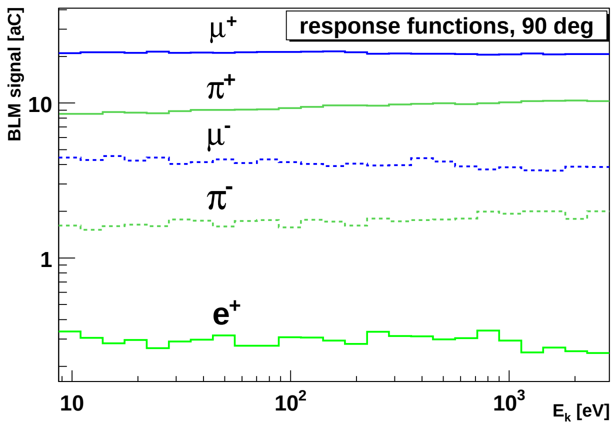

Figure 23: *Response functions for particles impacting with 90 degrees with respect to the BLM axis. Presented for very low kinetic energy.*

Positron annihilates in the 1 mm of stainless steel which encloses the active volume. They produce two photons with energy 511 keV each. There is a small probability that one of these photons gets through to the gas. This is where the signal of 0.3 aC per positron comes from.

The slow negative muons leave a signal of about 4 aC per particle. Only few of muons stopping in the stainless steel wall of the chamber decay. The rest are absorbed by the iron nucleai and deliver low-energy gamma and e- (a few MeV in total), main energy will go to neutron emission, less probable are protons and light ions.

The slow positive muons leave a large signal of about 20 aC per particle.

It must be stressed that these low energy parts of the response functions do not contribute to the total signal in the IC, therefore this investigations have purely academic sense.

5 Summary

The response functions for Ionisation Chamber used in LHC Beam Loss Monitoring system have been presented for particle impact angles of 0, 10, 30, 45, 60 and 90 degrees. The responses are the highest for 0 degree impact angle as particles has to pass a maximum of active material in such configuration.

The two simulation codes used for the simulation agree very well. The largest discrepancies are observed for muons and pions which give relatively small contributions to the total signal. The response to neutrons in energy range between 1 eV and 100 keV should be further investigated, but in this energy range neutrons also do not contribute significantly to the total signal.

References

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