Creation of didactic content for basic FLUKA learners/trainees

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Abstract
The aim of this project was to provide didactical content for FLUKA to high school students and beginners. As a result, a program with a theoretical introduction and three practical exercises also combined with theoretical introductions was compiled. As the most concise overview of the created content, selections of both theoretical and practical parts will be given.

Keywords
FLUKA; FLAIR; didactical content.

1 Introduction

Welcome to this short course on the FLUKA particle simulation programme and particle physics in general. First, we will have an overview of particle beams, the dynamics and software. Afterwards, we will have three exercises. There will be, at first, a small introduction to the subject dealt with by the exercise and then the computational part. This document will be the leading guide, designed to be thorough enough to enable us to perform everything as necessary.

1.1 FLUKA

FLUKA is a Monte Carlo simulation programme. What this means is that results rely on the inherent randomness. Let's say a high-energy proton enters a material; it has a 0.1 percent chance to change trajectory (scatter) in a distance x. Therefore, one proton out of 1000 will scatter at this distance in a simulation. It can also simulate a multitude of different events in the simulation, but the key is that the interaction probabilities are known. The program picks randomly, but according to the statistics, the behaviour of the particle.

In FLUKA, the initial beam particle is called primary. If one simulation has many primaries, the system starts generalising itself according to the statistical distribution. That is, if you have 100 particles, for the 0.1 percent chance, you might not get any direction change. However, for 100,000 particles, it is almost certain that close to 100 protons out of that amount will scatter and form an approximative model of the real process. One picture with 40 000 000 primaries follows afterwards. The previous computational framework also applies to other processes, such as ionisation of electrons, nuclear reactions and energy deposition rates. All may depend on the simulated particle, matter type it is traversing and the momentum it possesses.

All the probabilities (or reaction cross sections - likelihood of a "collision" producing a certain effect) are characterised for the necessary ranges. Therefore, FLUKA relies on a large number of particles to form a picture of the behaviour that is otherwise hard to compute. The same happens with proton energy distribution. The loss of energy is beforehand statistically calculated for one particle, and so with many single particles, the same rules are applied. FLUKA only provides the average value of what you want to know per primary. Therefore, it is the task of the user to calculate the realistic intensity of the value per the actual amount of particles.

1.2 Exercices

Three exercises will follow after the introduction. First, we will deal with energy deposition; second, with effects involving photons; and third, with magnetic fields. As said before, there will be further

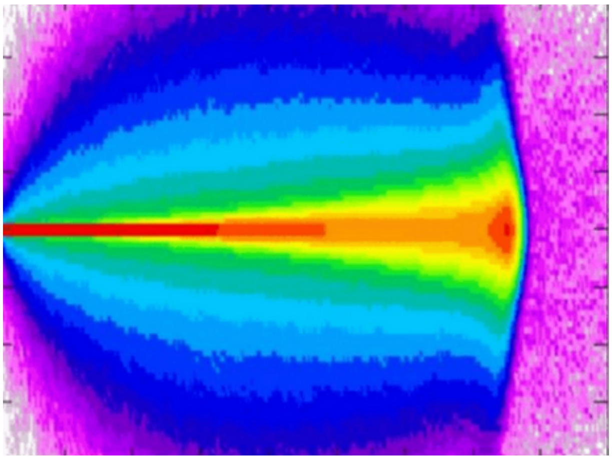

Figure 1: Proton energy deposition with 400 000 primaries

material and guides with every exercise, which will give the necessary background and information. Good luck and have fun!

2 Exercise 1: energy deposition and Bragg peak

2.1 Introduction

One effect of the theory and simulation results is that the energy loss of charged particles along the movement track is inversely proportional to their speed. Think of this as a bullet going straight through when it has a lot of energy but tumbling, rolling and causing a lot of damage when getting stuck in ballistic gel. This means the energy loss graphs for protons (and other charged ions) form a Bragg peak.

That shows the amount of energy deposited to material is the largest before stopping. Several things affect the position of the peak. As expected, the higher the particle energy, the further it goes. The higher the density of the material, the faster the energy loss and more pronounced the maximum. Also note the sharper peaks, which means the energy loss is more pronounced for lower energy and particles stop at a relatively similar distance.

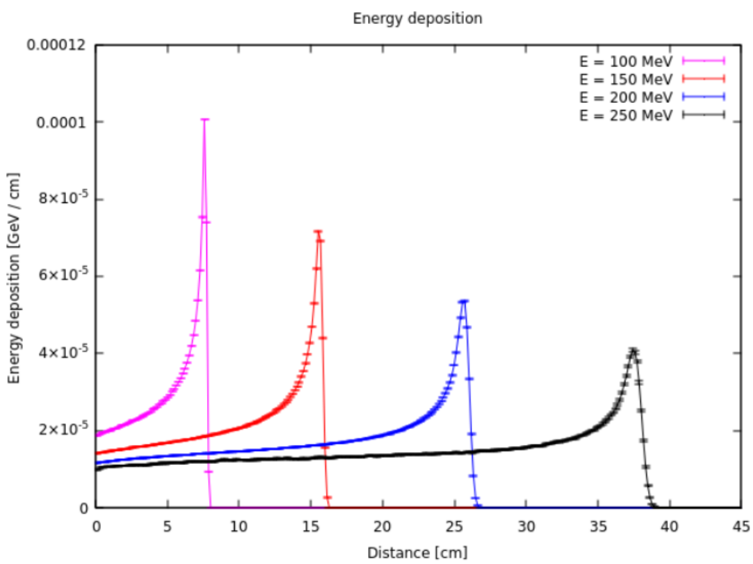

Figure 2: Bragg peak dependence on particle energy

The dependence graph for differing energy is shown on the left with energies from 100 to 250 MeV. The characteristics of the graph also change at higher energies. At one point nuclear reactions can occur which results in a different energy deposition. But more on that subject in a later exercise. This effect can also have broader applications, such as cancer irradiation, where the beam energy can be adjusted to deliver the maximum energy straight to the necessary region. Or with the usage of a range of energies, a larger region.

Now, after the initial introduction, it is time to practise.

2.2 Results of Exercise 1

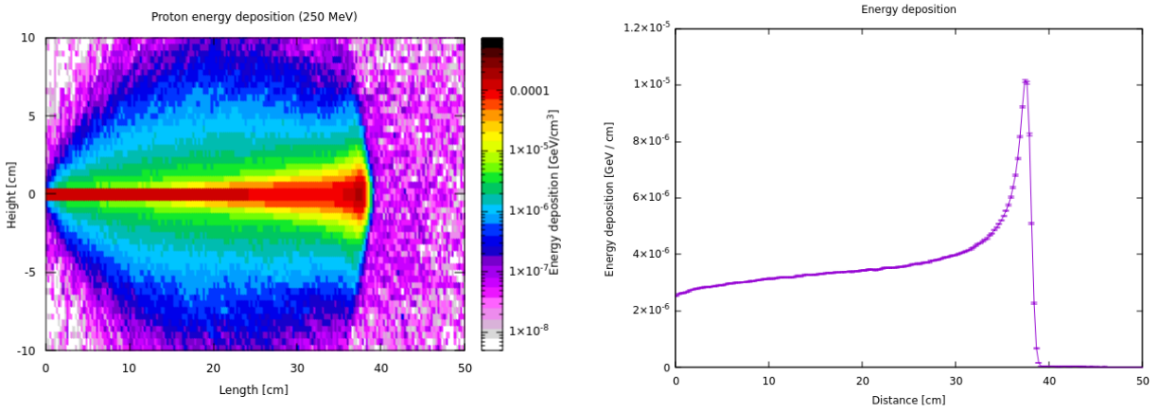

Figure 3: Student created 2D and 1D deposition graphs

3 Exercise 2: Photonic quantum effects

3.1 Introduction

The photoelectric effect is one of the most important discoveries in connection to quantum physics. An incoming photon can ionise an orbital electron, which is emitted from the material. You may have heard of this already in your school programme. But there are two additional processes. The Compton effect applies to even more energetic photons. During the collision between the photon and an atom, a single electron is ejected, but the photon is not absorbed; it loses energy and changes direction, but continues to propagate.

When the energy of a photon is even greater, a process called pair production can occur near the atomic nucleus. The presence of a nucleus is necessary to satisfy the conservation of momentum and energy. The photon creates an electron-positron pair. These fly off into matter with the positron eventually annihilating with another electron and creating two photons.

These effects can compound to create an electromagnetic cascade, which is the main energy loss pathway for lower energy charged particle beams. Electrons or protons start losing energy by ionisation processes, photons and electrons start multiplying and can create a wave of electrons and photons. This dissipates only when enough energy is deposited and further excitation is not possible.

3.2 Exercise

If you remember from the slides, all the previous effects had different energies, where they dominated. They are shown again here.

Now it is your task to choose energies in the correct area and enter them in FLAIR to the correct Energy value card as shown before.

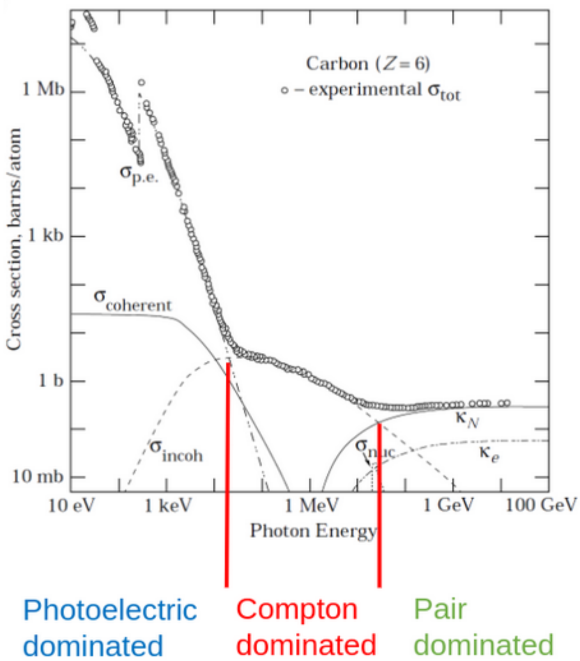

Figure 4: Energy dependence graph

3.3 Results of Exercise 2

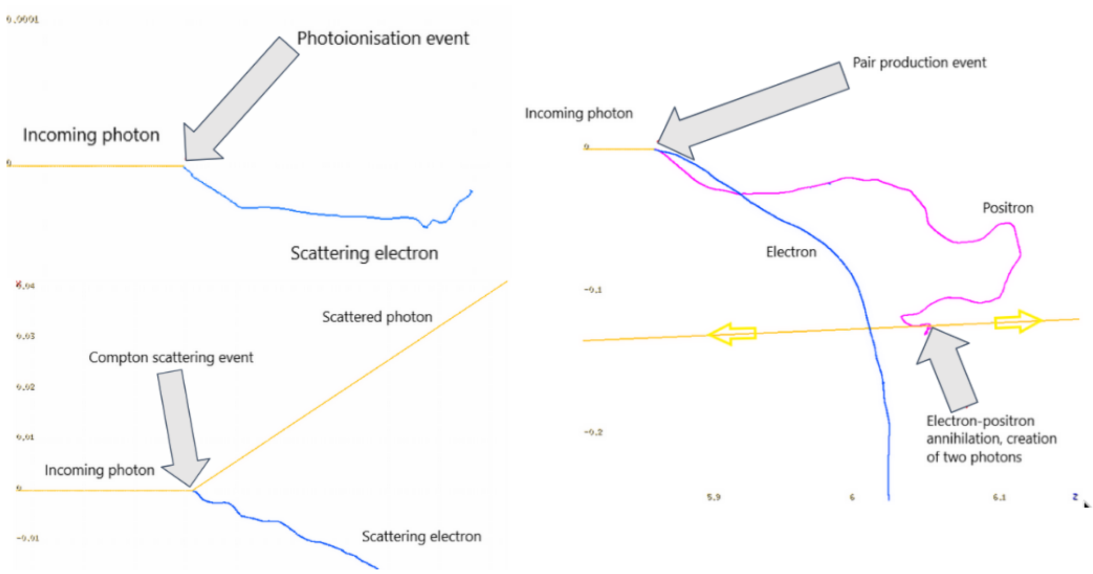

Figure 5: Visualisation of the effects seen by students

4 Exercise 3: Magnetic field dynamics

4.1 Introduction

A beam of protons is moving parallel to the z-axis. A target is situated above the trajectory of the beam. The task is to apply a magnetic field with enough strength to bend the beam towards the target. The protons have an impulse p of 600 MeV/c. The magnet is 50 cm long (Lz). Needed deflection is 27.5

degrees. And the charge of a proton is one elementary charge or 1.6×10^{-19}C.

4.2 Second test

Now that the beam is calibrated, the momentum of the particles will be increased from 0.6 GeV to 1.2 GeV as the current beam line was upgraded.Unfortunately, the magnetic field can not be strengthened anymore due to field strength limitation of the resistive magnet - a real limit in accelerator operation. But it is possible to lengthen the field with an addition of a section. Take a guess at the new required length based on the previous equation and try again.

4.3 Results of Exercise 3

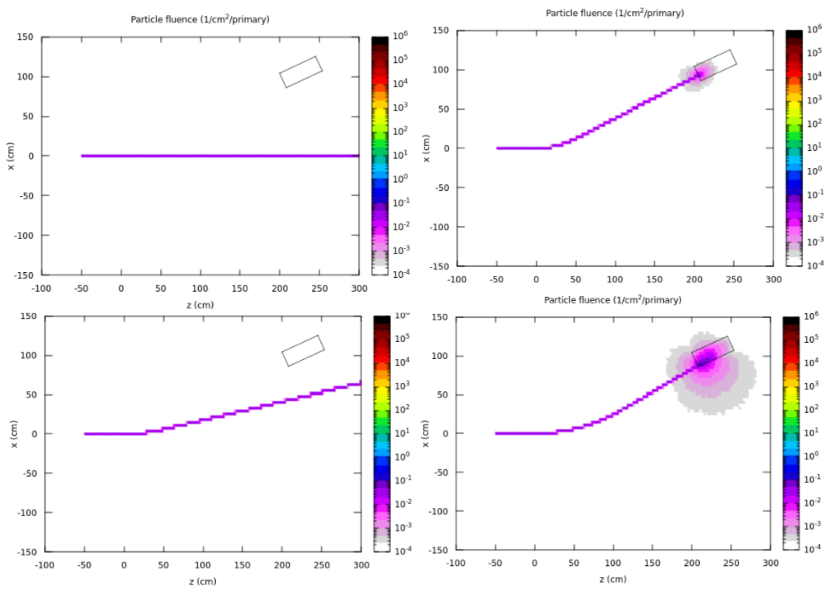

Figure 6: Progression of the exercise

5 Availablity of materials

All materials including introduction, theory slides, guiding PDFs and FLAIR inputs are uploaded to a Gitlab repository.

https://gitlab.cern.ch/bmi/didactic/didactical-fluka