Study of Heavy Ion Fragmentation with the FLUKA Monte Carlo Code

CERN Summer Student Session 2021

Summer Student: Alexandra - Gabriela ȘERBAN

Supervisors: Giuseppe LERNER (SY-STI-BMI)
Andreas WAETS (SY-STI-BMI)

Introduction

Main Goal: - study of heavy ion fragmentation as a function of depth in a Silicon target, relevant for heavy ion tests of electronic equipment at the CHARM facility at CERN;

- investigation of the distribution of atomic number (Z) and Linear Energy Transfer (LET) of heavy ion fragments in Si with the help of Monte Carlo simulations (FLUKA).

Current Status: the results presented today for a 200 MeV **proton** beam (as a first simple check) and for 70 MeV/n ^{208}**Pb** beam

↓ serve as

preparation for the simulations with **different energies** of ^{208}**Pb** ions that are specifically relevant for the case of the CHARM facility.

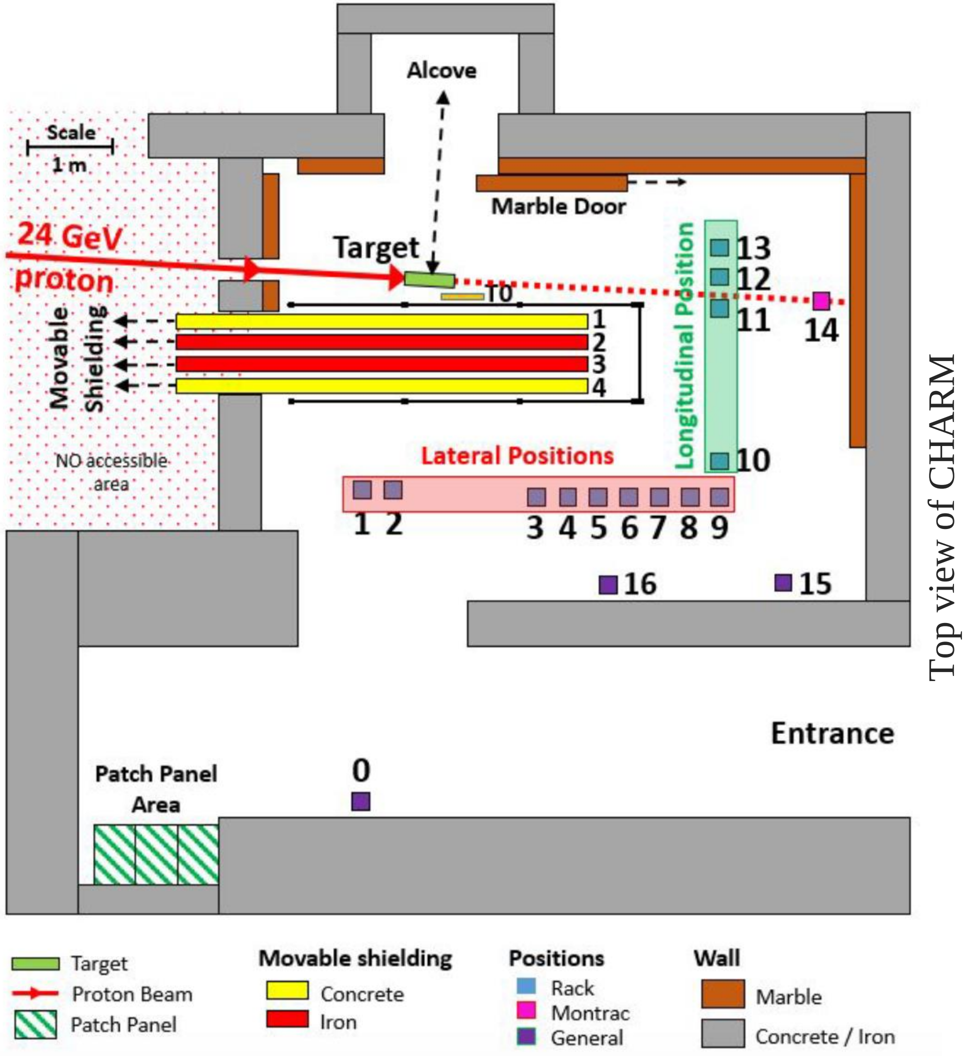
CHARM facility at CERN

CHARM = CERN High Energy Accelerator Mixed-field facility for tests of electronic components and systems in the context of the Radiation to Electronics (**R2E**) project.

Baseline: 24 **proton** GeV beam from the PS on a target, yielding a mixed and distributed radiation field that resembles the accelerator environment

Heavy ion beams: ^{208}**Pb ions** (top energy: 5.5-6 GeV/n, only available option) - target is removed & test devices are exposed directly to the beam.

CERN - ESA contract → **CHIMERA** (**C**harm **H**igh-energy **I**ons for **M**icro **E**lectronics **R**eliability **A**ssurance) project: expand the ion test capabilities at CHARM, in particular to **lower the beam energy.**

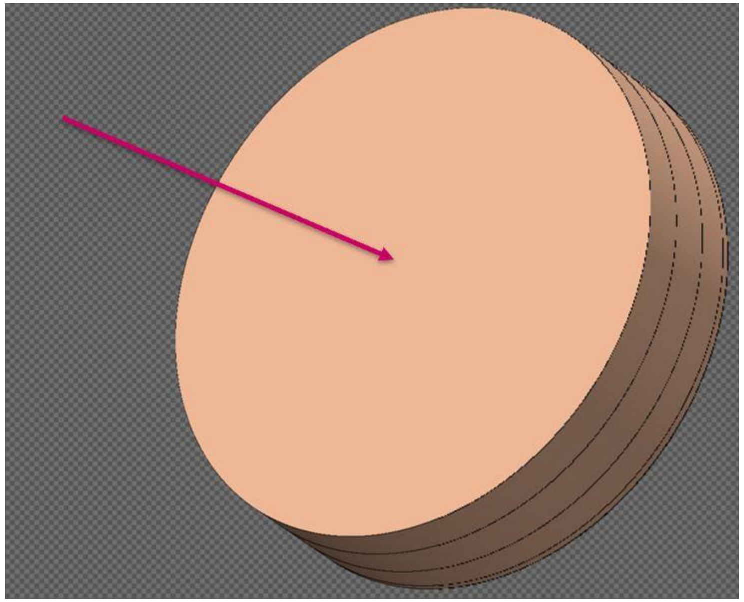


Top view of CHARM

FLUKA Monte Carlo Code

FLUKA = Monte Carlo (MC) code for radiation - matter interaction
→**simulation tool** that samples stochastically the **transport and interaction of radiation in matter** in arbitrary geometries.

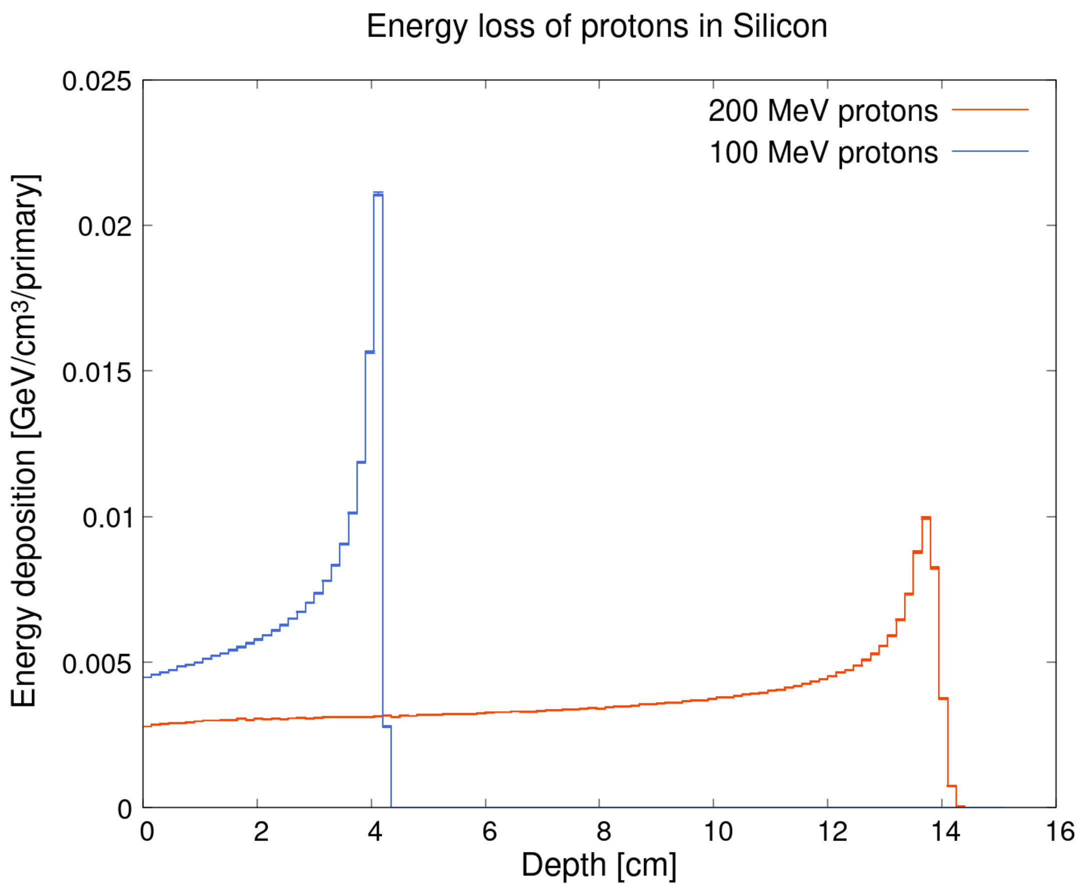
Geometry & Beam

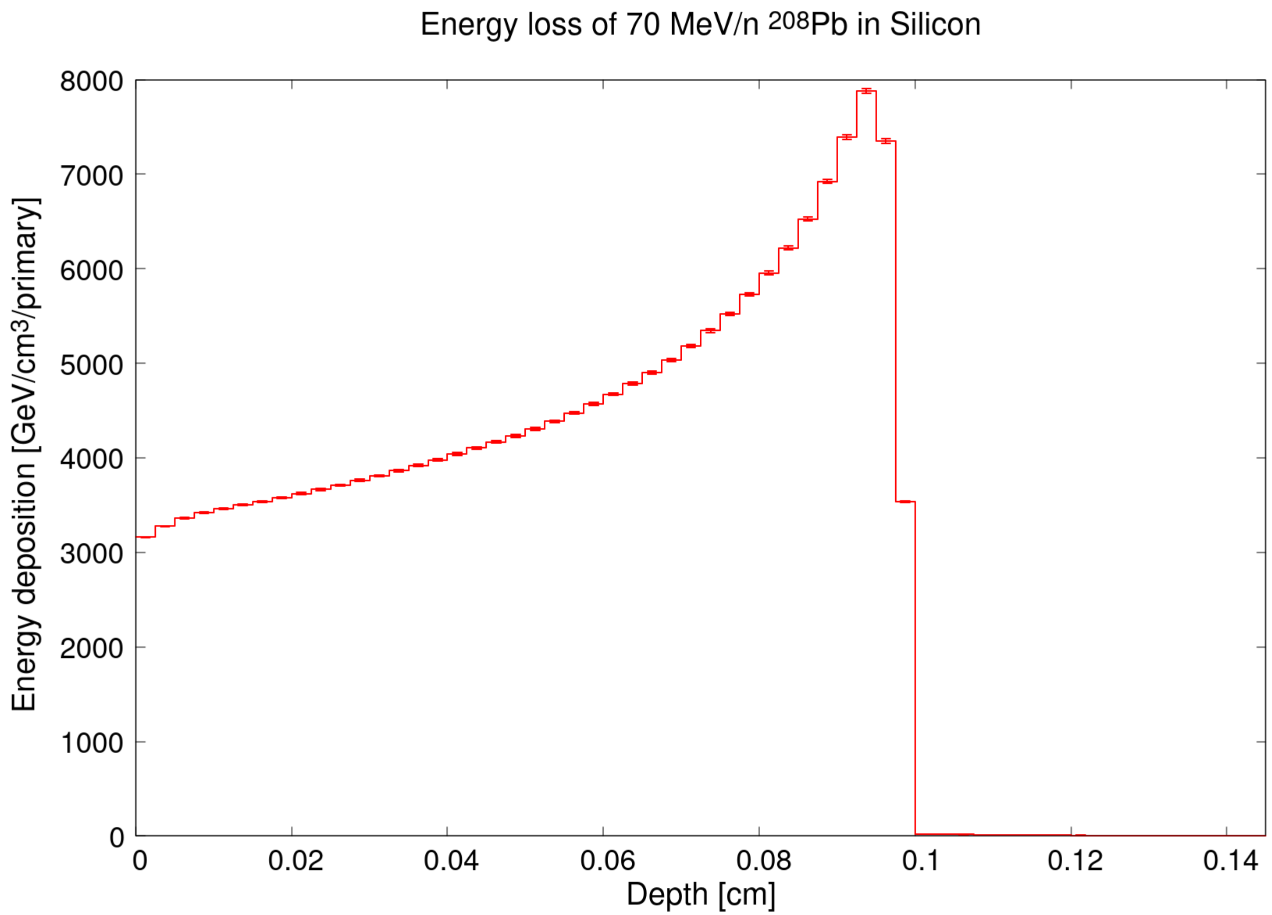


- Cylindrical Silicon target = active region of electronic devices hit by beam particles
- Total depth: 15 cm (to study fragmentation effects up to a large thickness)
- Many regions divided by planes to study the fragments at different depths
- Beams: 200 MeV and 100 MeV protons
  70 MeV/n ^{208}Pb
- Starting at the origin
- Impacting the target on the z direction

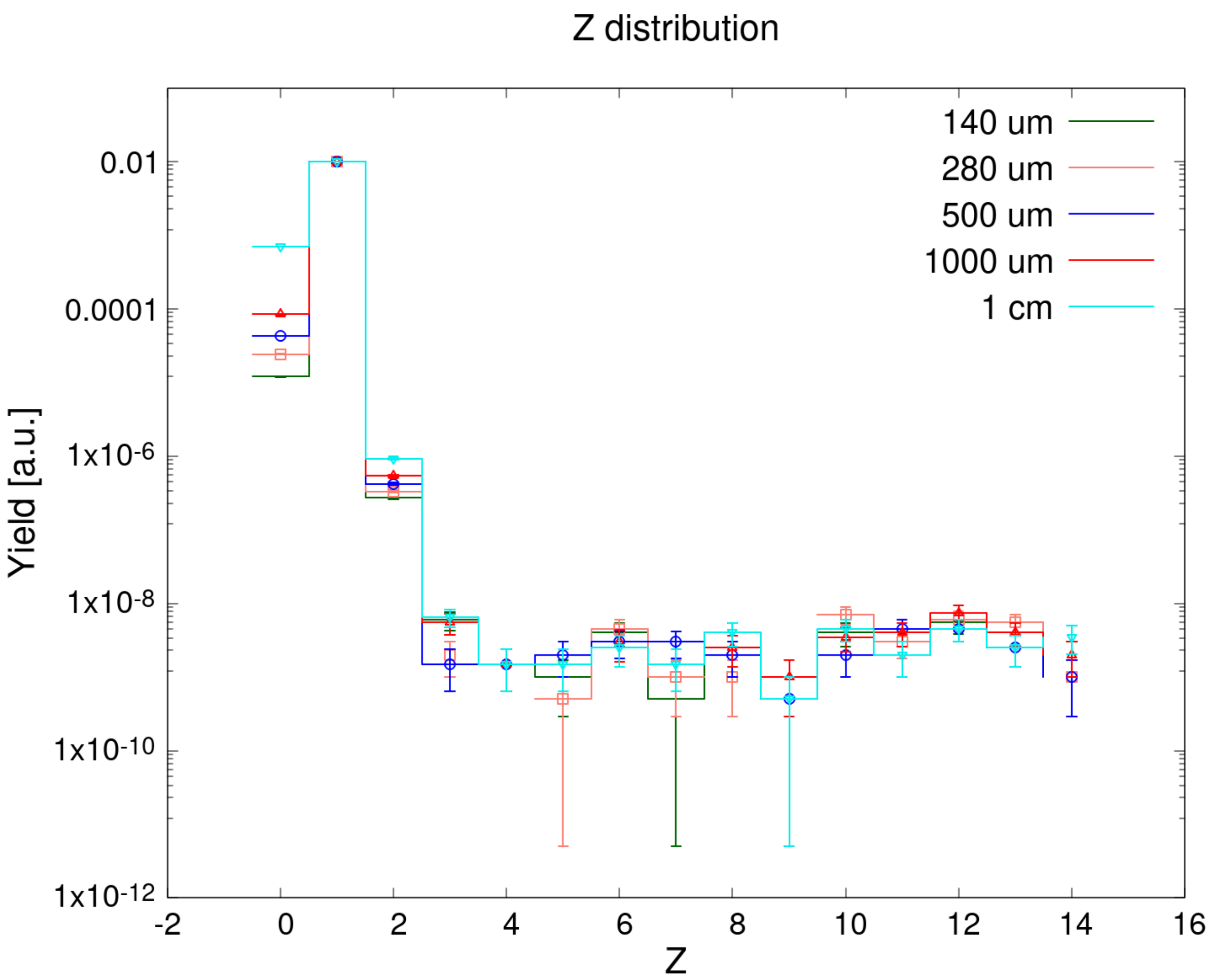
FLUKA Simulations - Bragg peak

Preliminary step: studying ionization losses in Si (**Bragg peak** at variable depth depending on energy and particle type).





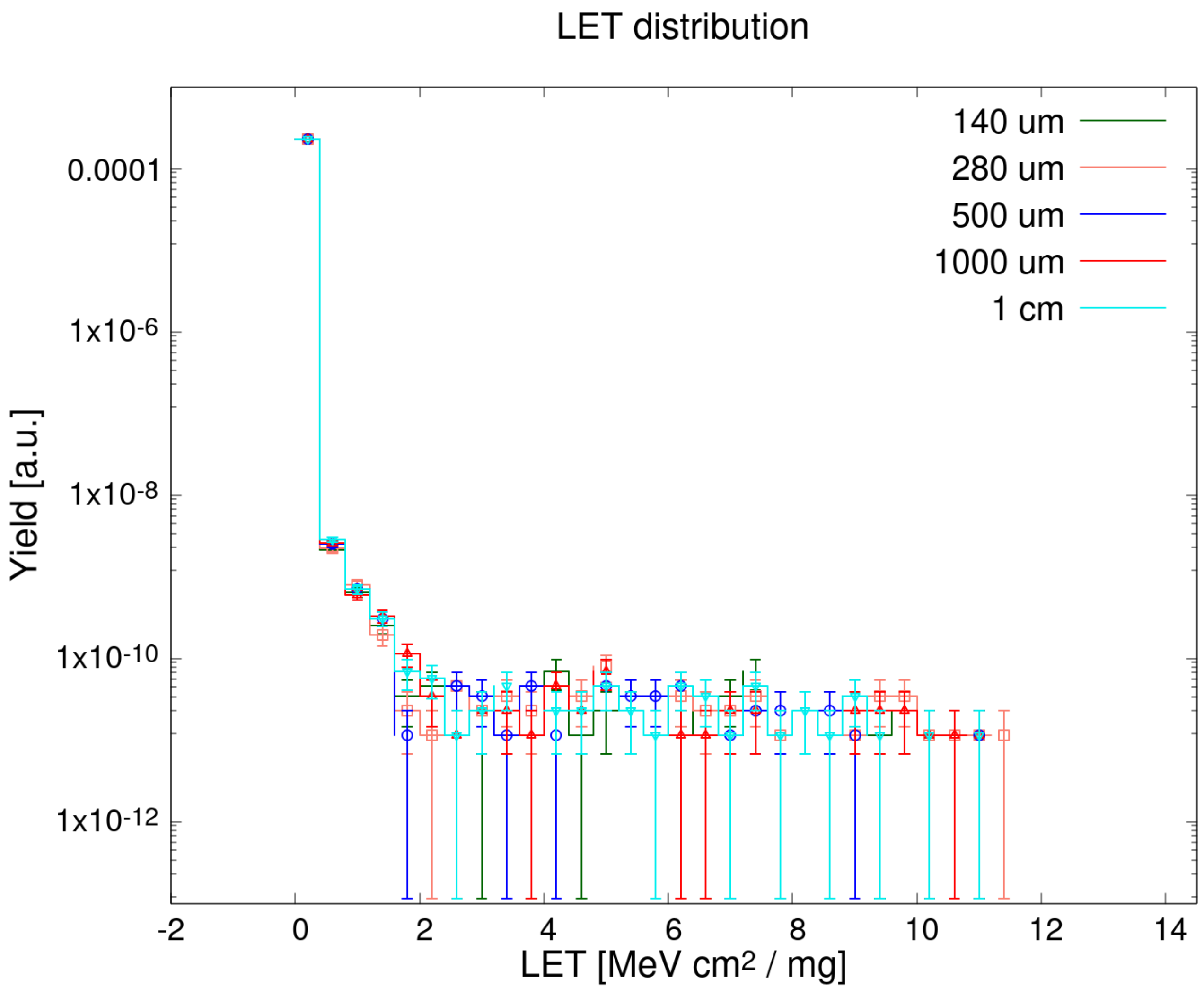
FLUKA Simulations - Z distribution vs. depth for 200 MeV protons on Si



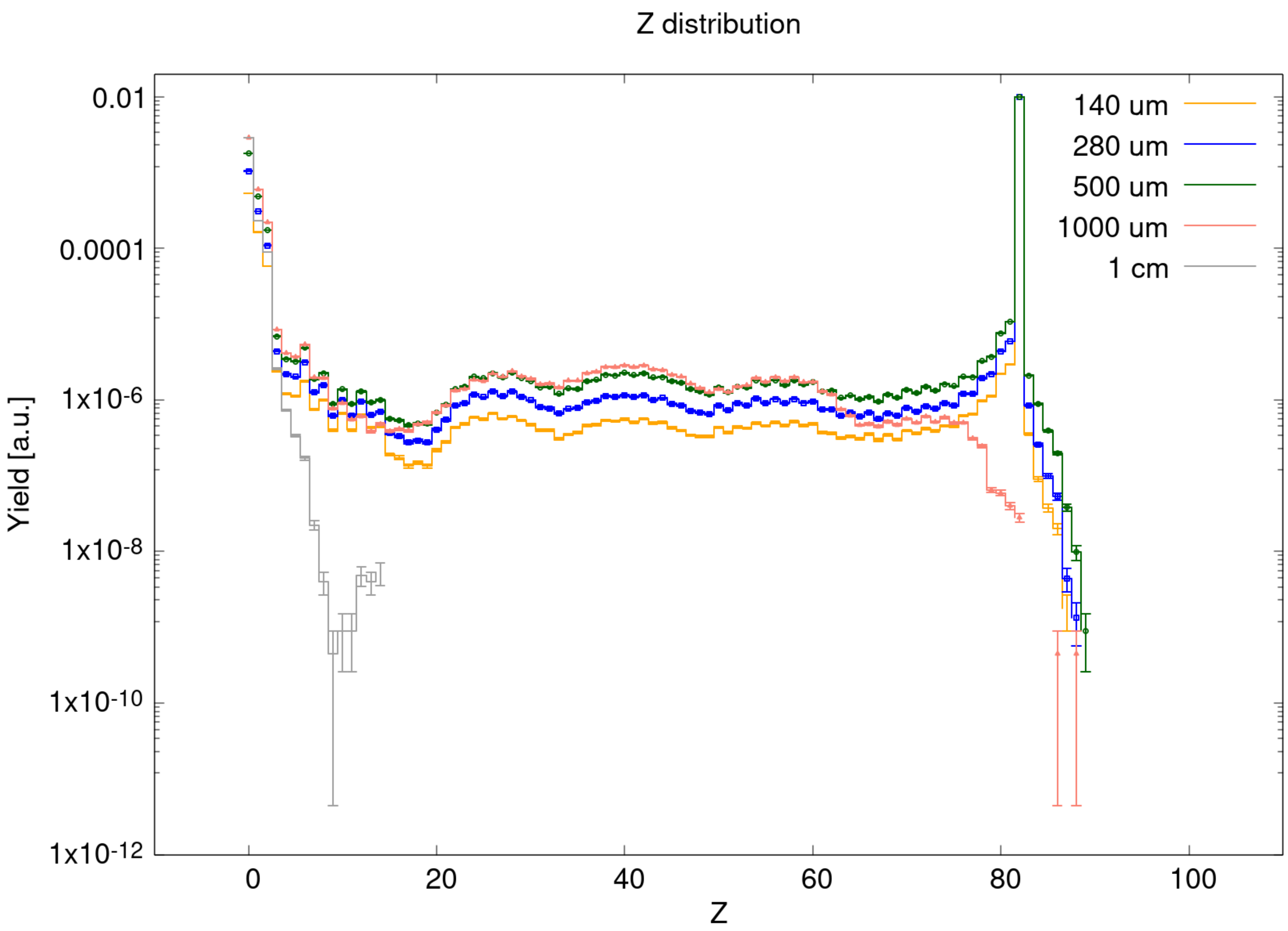
- Large peak for Z = 1 → protons are dominant regardless of the depth in the target;
- High Z fragments emerge as a result of nuclear reactions in the target;
- Similar distributions at all depths, with a visible build up effect at Z = 0 (neutrons) and a mildly build up effect for Z = 2 (alpha particles);
- The maximum value of Z is 14 → Si recoil nuclei.

FLUKA Simulations - LET distribution vs. depth for 200 MeV protons on Si

- Looking at the distribution of LET, we see the same fragments at different depths as in the case of the Z distribution;
- High-LET corresponds to High Z particles;
- The vast majority of particles have low LET;
- The distributions look very similar to each other regardless the depth in the target.



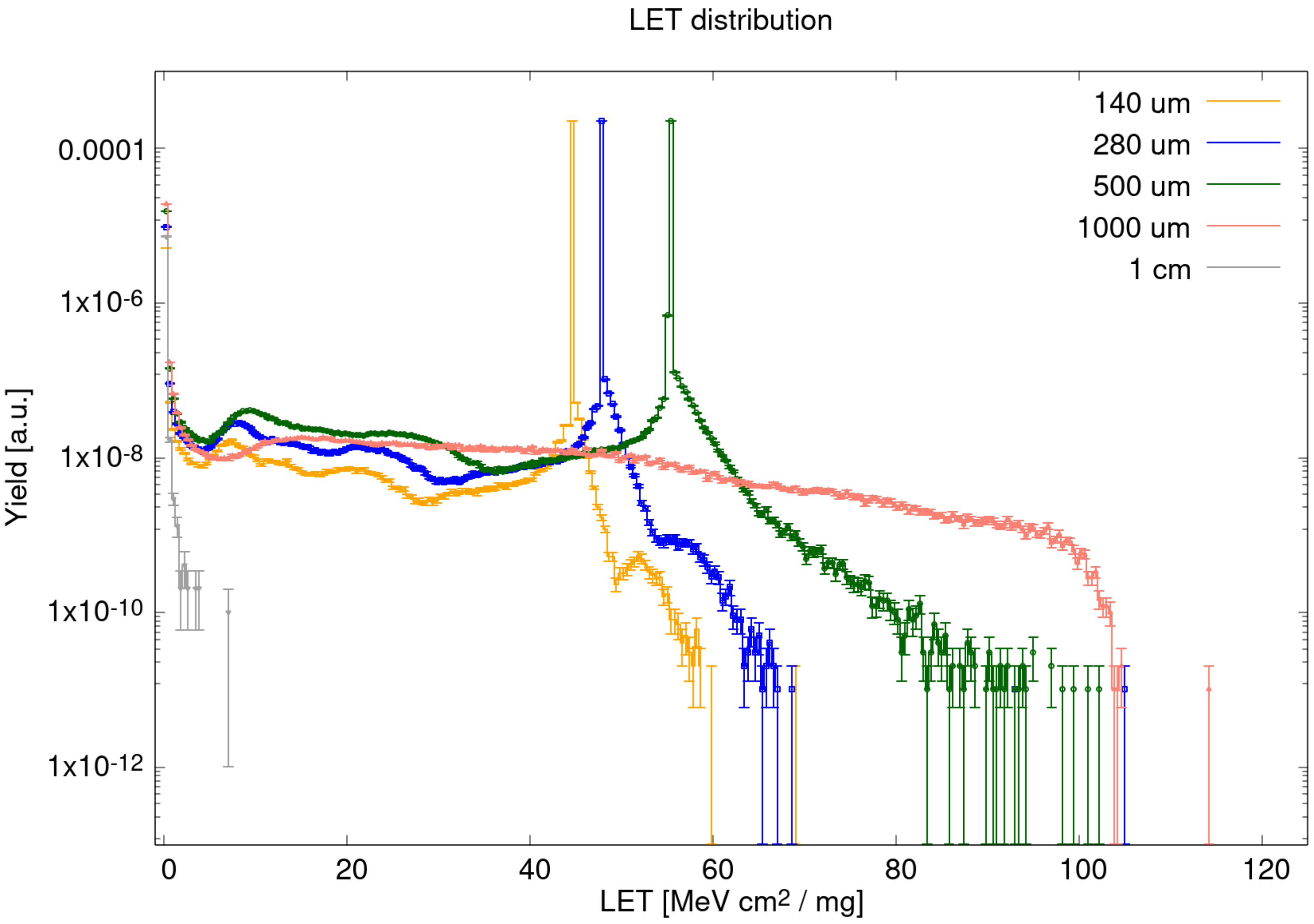
FLUKA Simulations - Z distribution vs. depth for 70 MeV/n ^{208}Pb on Si



- Planes before, as well as, after the Bragg peak;
- Similar distributions before the Bragg peak;
- High peak corresponding to Z of ^{208}Pb;
- Only low Z fragments after the Bragg peak.

FLUKA Simulations - LET distribution vs. depth for 70 MeV/n ^{208}Pb on Si

- Similar distributions before the Bragg peak with a large peak corresponding to ^{208}Pb shifted for each depth (since the energy is modified as we go deeper into the target);
- 1 mm: no ^{208}Pb peak;
- 1 cm: only low-LET fragments left.



Conclusions and Outlook

In the first part of my internship I set up FLUKA simulations to study the **fragmentation products** resulting from the interaction of **protons** (of 100 MeV and 200 MeV) and ^{208}**Pb ions** (of 70 MeV/n) with a Silicon target, focusing on the distributions of **Z** and **LET** at different depths.

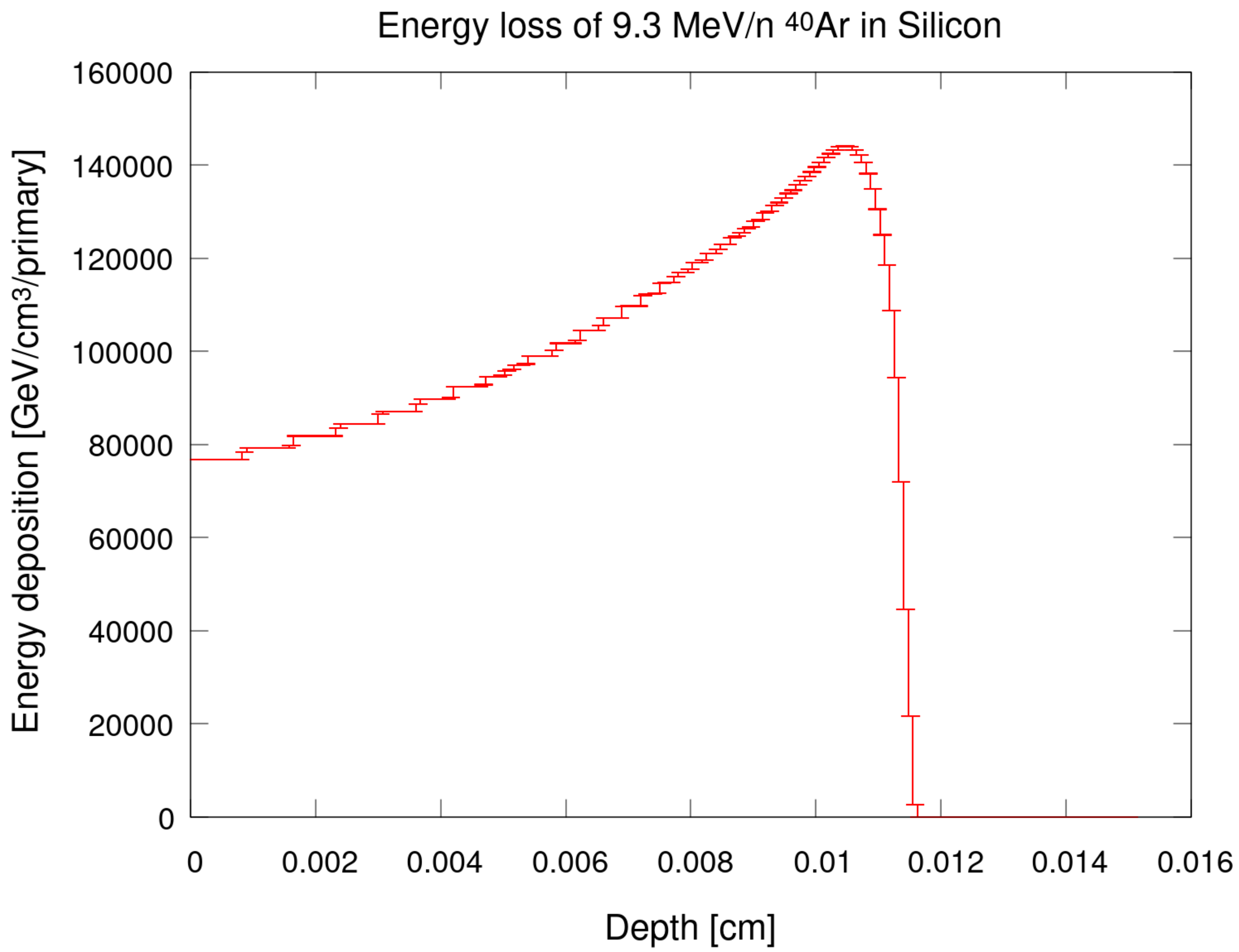
Now, I intend to repeat the study for different energies of the ^{208}**Pb** beam, relevant for Radiation to Electronics (R2E) tests at the CHARM facility, particularly in the context of the CHIMERA upgrade.

The exercise will also be done for **various target materials** in function of, for example, shielding and beam intercepting devices like collimators, useful for CHARM.

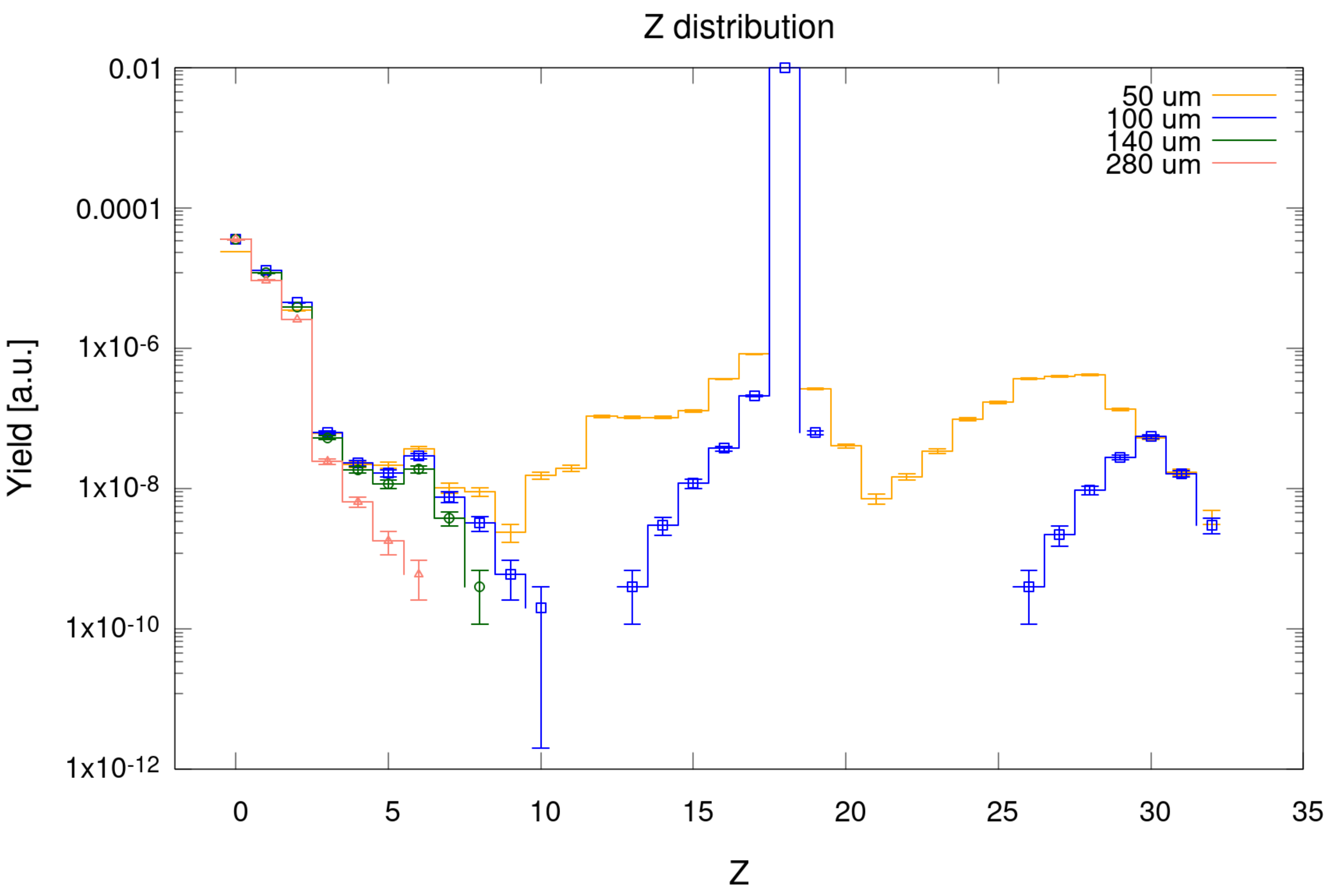
Thank you for your attention!

Back-up slides

FLUKA Simulations - Bragg peak



FLUKA Simulations - Z distribution vs. depth for 9.3 MeV/n ^{40}Ar on Si



- Some planes in the depth of the target are before and others are after the Bragg peak;
- Large number of fragments with high Z at 50 μm and a bit less at 100 μm;
- Large peak corresponding to Z of ^{40}Ar;
- Beyond the Bragg peak there are only low Z fragments;

FLUKA Simulations - LET distribution vs. depth for 9.3 MeV/n ^{40}Ar on Si

- 50 μm (before the Bragg peak): high peak for the LET of ^{40}Ar + high-LET tail that consists of ionizing high Z fragments;
- 100 μm (almost on the Bragg peak): shifted ^{40}Ar LET + much smaller high-LET tail;
- 140 μm and 280 μm (after the Bragg peak): only low-LET fragments.