Exercise : Scoring II

Aim of the exercise:

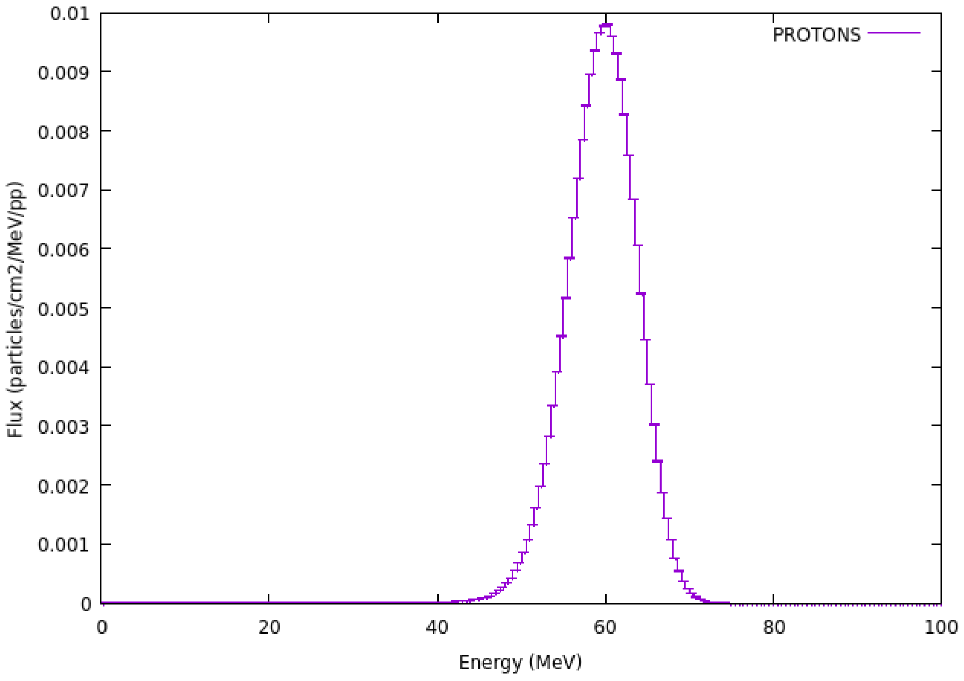
- Learn how to use **USRTRACK** and **USRYIELD** scoring cards
- Evaluate the impact of an energy degrader on a proton beam

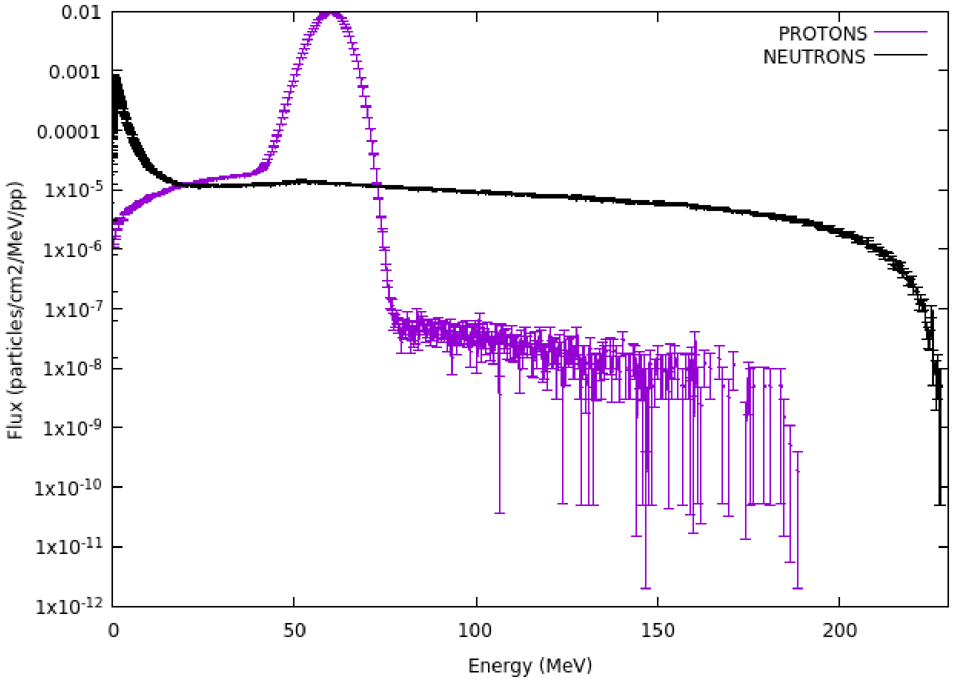
Spectra plot normalization

- Factor 4 in y-axis is simply the volume of the DETECT region (2 x 2 x 1 cm^3) in the case of USRTRACK as well as the surface between DEVICE and VOID (2 x 2 cm^2) in the case of USRYIELD
- Change from GeV to MeV (in USRTRACK) and keV/(µm×g/cm^3) to MeV×cm^2/mg (in USRYIELD), both in the x and y axes

Result – 1 : proton and neutron spectra

- What is the impact of the degraded in terms of the (i) shift of the average beam energy, (ii) introduction of beam energy spread and (iii) generation of secondaries?

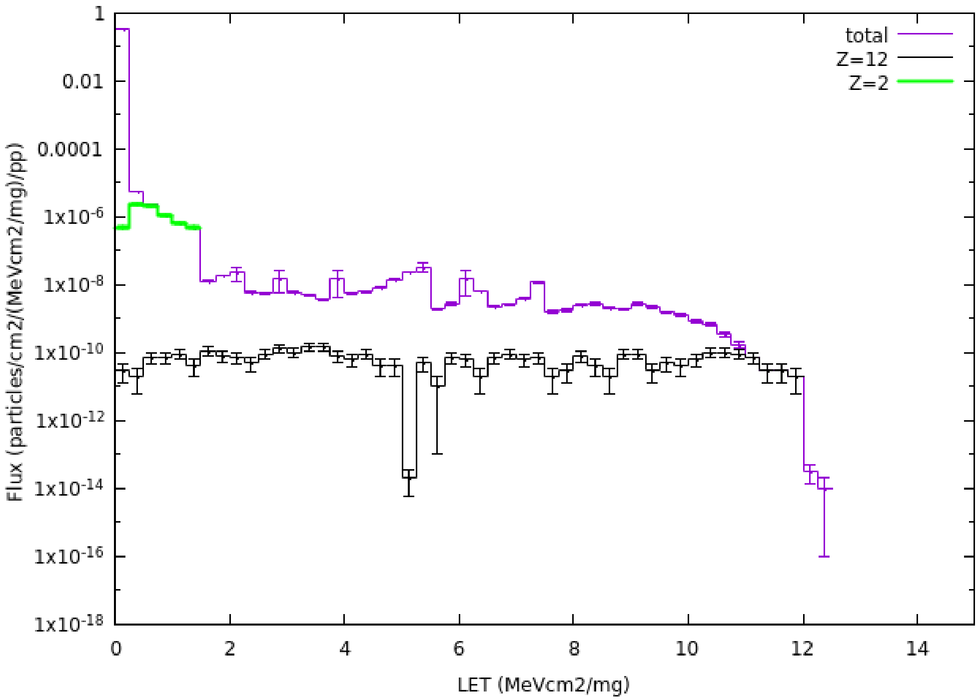




For 10^8 primaries (CPU time per primary ~0.58 ms)

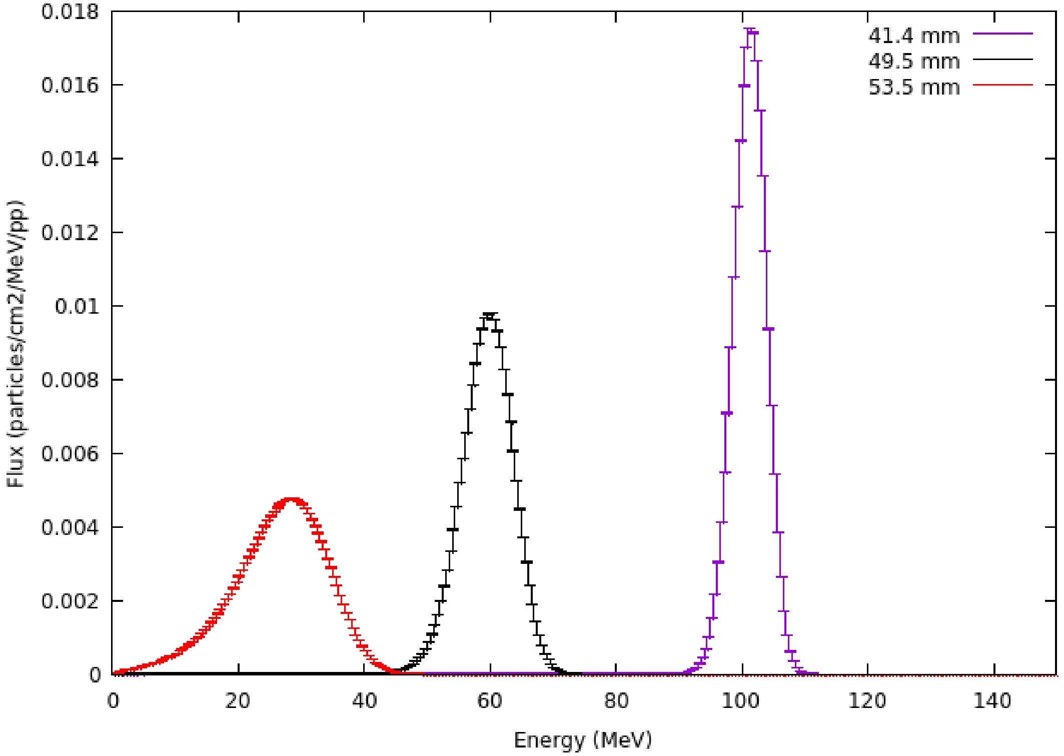
Result – 2 : LET spectra

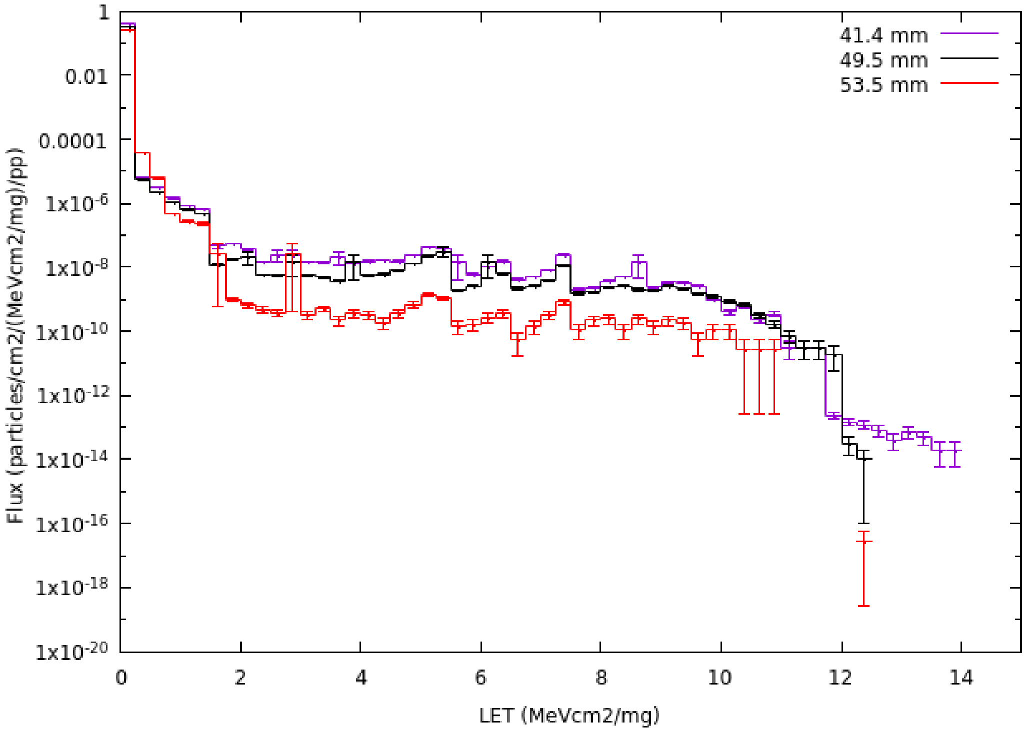
- What is the LET (in silicon) distribution of fragments leaving the DEVICE region? What is the maximum LET value produced?
- What is the contribution from Z=2 and Z=12 particles to the total distribution?



For 10^8 primaries (CPU time per primary ~0.58 ms)

Result – 3: impact of degrader thickness

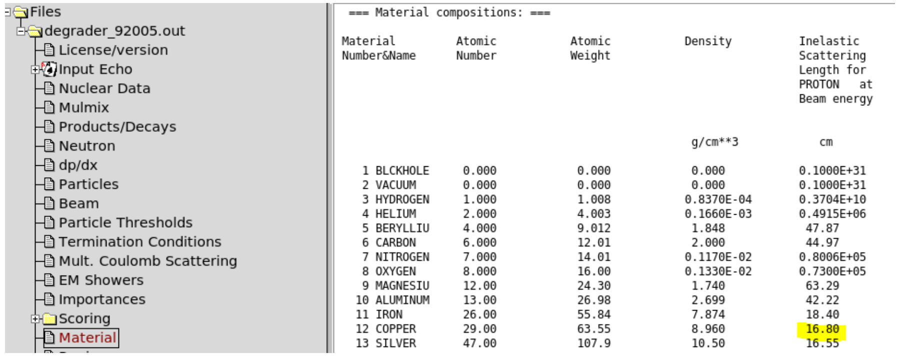




For 10^8 primaries (CPU time per primary ~0.58 ms)

Some additional results from simple post-processing

Copper degrader thickness (mm)	Average Energy (MeV)	Relative Transmitted Flux	Neutron flux (relative to protons)
41.4	100.8	0.46	2.8×10^{-2}
49.5	59.3	0.40	4.25×10^{-2}
53.5	26.4	0.34	5.6×10^{-2}



=== Material compositions: ===

Material Number&Name	Atomic Number	Atomic Weight	Density	Inelastic Scattering Length for PROTON at Beam energy
			g/cm**3	cm
1 BLCKHOLE	0.000	0.000	0.000	0.1000E+31
2 VACUUM	0.000	0.000	0.000	0.1000E+31
3 HYDROGEN	1.000	1.008	0.8370E-04	0.3704E+10
4 HELIUM	2.000	4.003	0.1660E-03	0.4915E+06
5 BERYLLIU	4.000	9.012	1.848	47.87
6 CARBON	6.000	12.01	2.000	44.97
7 NITROGEN	7.000	14.01	0.1170E-02	0.8006E+05
8 OXYGEN	8.000	16.00	0.1330E-02	0.7300E+05
9 MAGNESIU	12.00	24.30	1.740	63.29
10 ALUMINUM	13.00	26.98	2.699	42.22
11 IRON	26.00	55.84	7.874	18.40
12 COPPER	29.00	63.55	8.960	16.80
13 SILVER	47.00	107.9	10.50	16.55

Inelastic interaction length of 200 MeV protons (primary beam) in copper: 16.80 cm

$T \sim e^{-x/\lambda} = 0.78$ for x = 41.4 mm

Roughly 22% of the beam is lost due to inelastic interactions of the protons in the copper. The remaining flux reduction is due to the beam scattering in the degrader.

Some conclusions

- Degraders are useful for modifying the primary beam energy at cyclotron facilities, however:
  - They introduce a large energy spread (especially for large initial to final energy ratios)
  - They produce secondary particles (in our example, <5% with respect to primary beam flux)
  - They reduce the flux of the beam (inelastic interactions + scattering)
- Secondary particles produced are the main radiation field constituent in spallation facilities (i.e. interaction with targets as opposed to degraders)
- As expected, high-LET fragments (i.e. those most threatening for SEEs) are mainly those with high mass (i.e. target-like)

Some further applications and considerations

- Monte Carlo simulation of radiation environment and its interaction with matter (e.g. electronics) is a very useful (and powerful) tool in the domain of radiation effects
- More detailed and realistic simulations for Single Event Effect calculations require:
  - An accurate description of the component geometry (metallization and insulator regions, etc.)
  - A realistic description of the sensitive volume geometry and response function (e.g. extracted from technological information, SEE results, TCAD simulations…)
  - An event-by-event energy deposition distribution scoring, and its folding with the response function (currently, requires advanced scoring in FLUKA – related GitLab repository available for this)

FLUKA