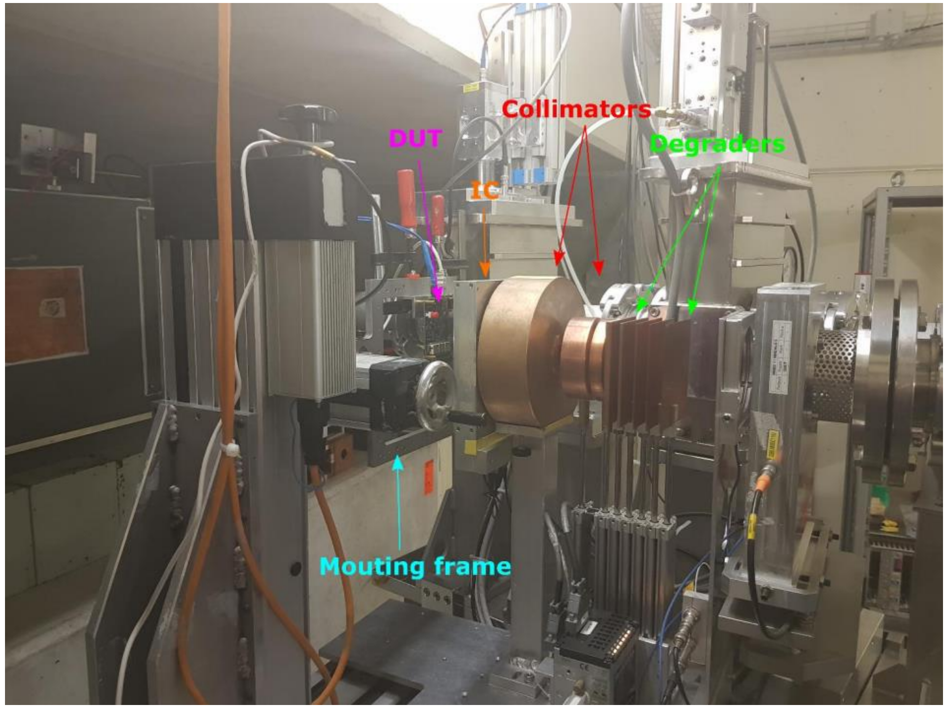
Exercise : Scoring II

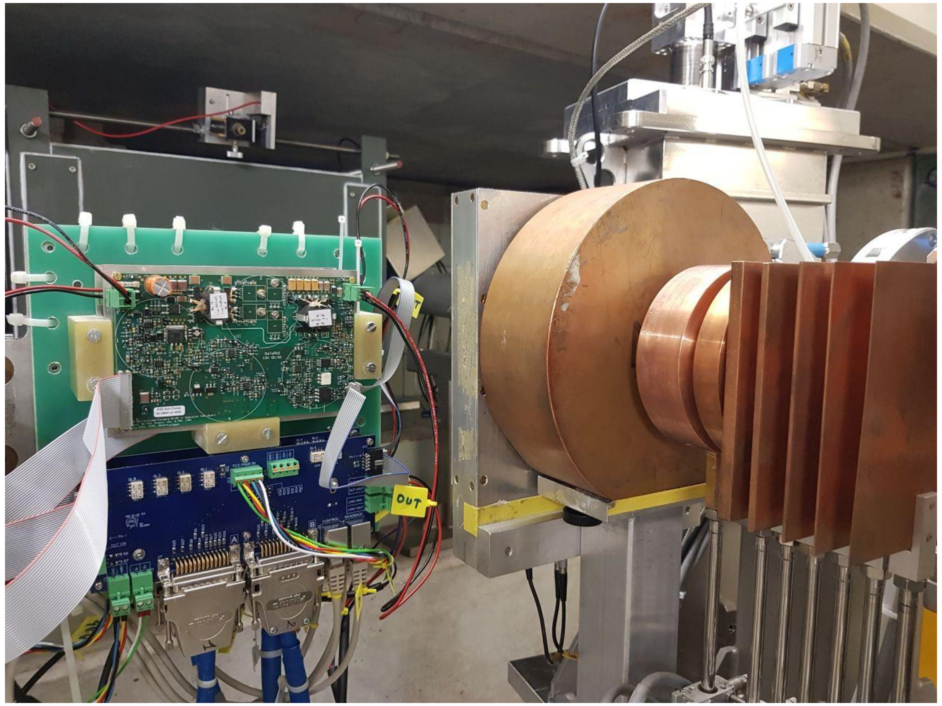
Aim of the exercise:

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

Exercise inspiration



Credit: Daniel Söderström



Credit: Grzegorz Daniluk

Paul Scherrer Institute (PSI) Proton Irradiation Facility (PIF) degrader system (more info at http://pif.web.psi.ch/pif.htm)

Short intro

- Protons up to 200 MeV are very popular for radiation effects testing on electronics, mainly due to:
  - The (relatively) high availability of ~200 MeV proton cyclotron facilities, linked primarily to proton therapy
  - Their capability of inducing all three type of effects on electronics (total ionizing dose, displacement damage and Single Event Effects - SEEs)
  - Their coverage of the particle energy spectra for trapped protons in space
- Space standards require testing for SEEs in the 20-200 MeV proton energy range. Therefore, degraders are often used to modify the primary beam energy at cyclotron facilities.
- The figure-of-merit for SEE induction is the linear energy transfer (LET) in silicon. Protons in general do not induce SEEs via direct ionization (LET < 0.54 MeVcm^2/mg) but rather indirect ionization (i.e. reaction products with LET > 1 MeVcm^2/mg)

The input file

- Simplified example of the two main parts of a radiation effects on electronics simulations:
  - Simulation of radiation environment (in this case, proton beam interacting with degrader – as performed in irradiation facilities)
  - Interaction with a micro-electronic component (in this case, a thin silicon layer)
- The input file contains a 230 MeV proton beam interacting with a **49.5 mm** copper degrader, and a thin silicon region representing a micro-electronic component under irradiation
- Biasing of inelastic reactions is included in the silicon region to enhance the event statistics
- Neutron evaporation is also enabled

Add these scorings and run

1. Proton and neutron fluence:
   - Add a **USRTRACK** to score the energy spectrum of protons and neutrons in the DETECT region (e.g. linear, up to 250 MeV, with 500 bins)
2. LET distribution in silicon
   - Add a **USRYIELD** to score LET of particles travelling from DEVICE to VOID (e.g. up to 5000 keV/(μm×g/cm^3), which corresponds to 50 MeVcm^2/mg)
     - Scoring kind needs to be set to **d2N/dx1dx2**, and material to **silicon**
   - Use the range of the 2nd variable to score (i) the total LET distribution (i.e. all particles), and (ii) the LET for a charge (i.e. Z) of 2, and 12 (use half-integers as limits!)
3. Run 10 cycles of 10^4 primaries each
4. Plot the **USRTRACK** results for protons in linear y-axis scale, and protons and neutrons in logarithmic y-axis scale, in units of differential flux (reminder: divide by detector volume if not explicitly included in scoring card!)
5. Plot the **USRYIELD** results in logarithmic y-axis, including the total, Z=2 and Z=12 distributions (reminder: multiply by the bin width of the second variable of USRYIELD)
6. Bonus: run same simulation but with different degrader thickness (e.g. **41.4 mm, 53.5 mm**) and check impact on results

Questions that can be answered from looking at generated plots

- What is the impact of the degrader in terms of (i) the shift of the average beam energy, (ii) the introduction of beam energy spread and (iii) the generation of secondary particles (i.e. neutrons)?
- 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?

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