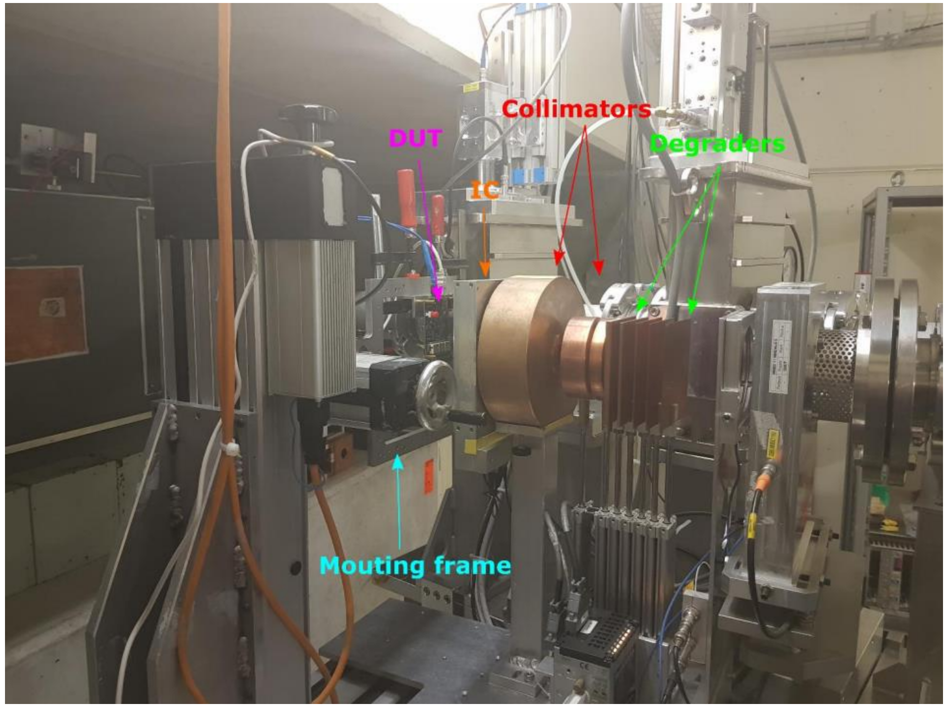
Exercise : Scoring II

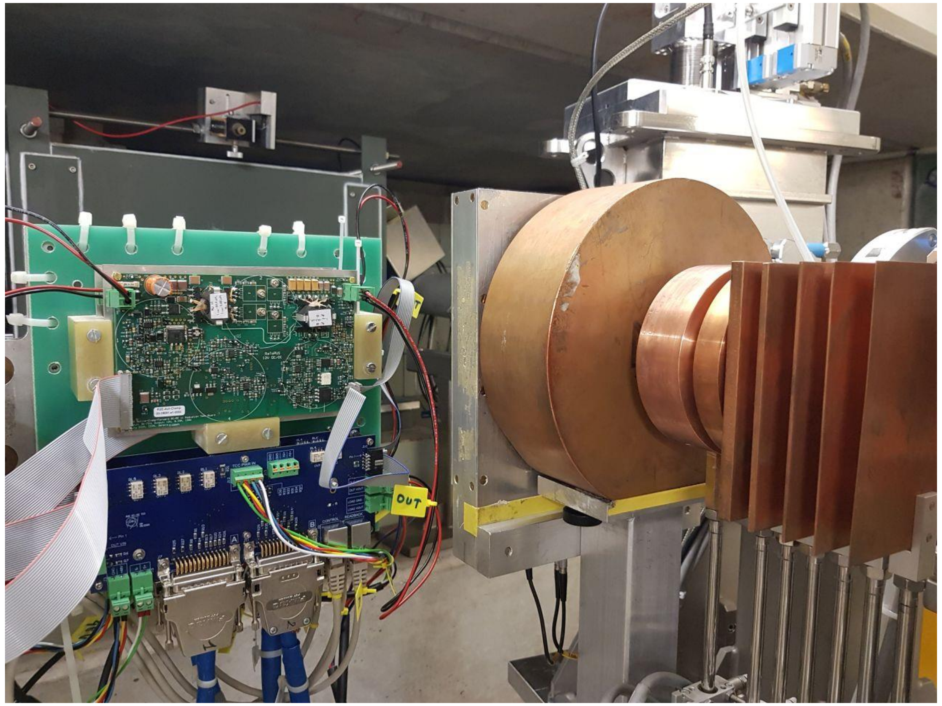
Aim of the exercise:

- 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 testing radiation effects 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 trapped proton energy spectra 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 nuclear event statistics.
- Evaporation of heavy particles 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 **$d2N/dx_1dx_2$**, 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 the value is 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 the impact on the 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?
  (iii) the generation of secondary 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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