Ion Stripping at the Irradiation Physics Area

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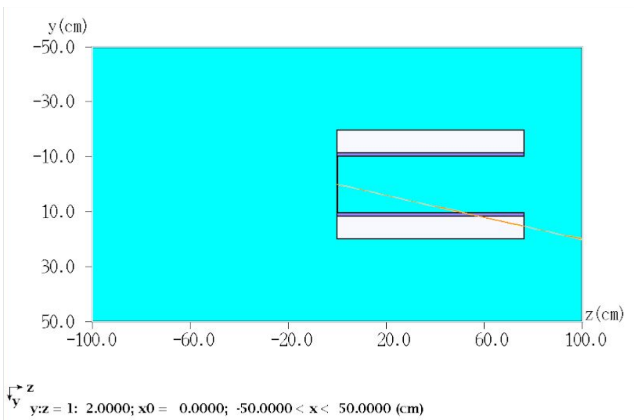
Fermilab
Jason St. John

The Linac provides a 400 MeV H^- ion beam to the Fermilab Irradiation Physics Area. In order to disassociate the two electrons of each ion, the beam is made to pass through a thin carbon foil of adjustable thickness (typically 300 μg/cm^2) and then a bending dipole (IDV) which redirects the bare protons from their ~28 milliradian climb to a level path. This Technical Note addresses the fate and consequences of the electrons and neutral hydrogen atoms which emerge from the foil.

Foil thickness:
(300 μg/cm^2) / (2.266 g/cm3) = 1.32 microns = 0.00132 millimeters



<u>Activation due to disassociated electrons</u>

A simple MARS model was constructed consisting of a thin carbon disk at the end of a 4" ID (4.5" OD) stainless steel tube and encasing iron. This is designed to represent an ion stripping station immediately adjacent to the vertical dipole magnet which will select out the H^+, mis-steering the electrons.

The simulated beam was an electron beam of 1.0E+13 e^-/second, consistent with the 5.0E+12 H^-/second intensities studied elsewhere in connection with the Irradiation Physics Area (see BeamDocs #6339). Extrapolating from 1E+06 simulated electrons, MARS estimates the residual dose rates of the stainless steel from twelve hours of continuous operation to be 9.41E-03 mrem/hour after only one second of cooldown. This scenario makes the following simplifying, conservative assumptions:

- Every electron will be stripped from the H^- ions.
- Every electron escapes the stripping foil.
- All electrons will impact the beam pipe in a tightly focused area, spread only by scattering effects of the carbon foil.

The conclusion is that electrons from the stripping station do not present nor do they activate a significant radiation hazard.

Calculations at Final Vertical Bend

UVB12, and IDV Main Injector trim dipole of 30 cm length, makes the vertical kick of the beam from rising at 29 milliradians to the level path it follows through the irradiation cave and into the final absorber.

1. Magnetic rigidity of the MTA beam:

$$B\rho = \frac{10}{2.998}\beta E$$

Where B is in Tesla, ρ is in meters, β is the fractional velocity with respect to c, and the kinetic energy E is in GeV. For H^- ions (938 GeV/c^2) with 0.4 GeV kinetic energy, β = 0.713, and so

$$B\rho = 0.951 \text{ T*m} \quad [1]$$

2. Integrated B-field

$$B * dl \approx \theta * B\rho = 29\text{E-3} * 0.951 = 0.0276 \text{ T*m}$$

3. Approximate B-field in operation

$$0.0276 \text{ T*m} / 0.03 \text{ m} = 0.92 \text{ T}$$

where we take the effective field length of the IDV as 0.03 m.

4. Electron path through the magnetic field

Electrons emerge from the stripping foil have at most their initial velocity of 0.713c. Taking the magnetic field of the final bend (IDV trim from the Main Injector) at 0.92 tesla, we calculate the relativistic gyroradius of these electrons:

$$r_g[m] = 3.3\frac{\gamma mc^2\ [GeV] * v_{\perp}/c}{B\ [T]} = 3.3\frac{(0.511e{-}3)(0.713)}{(0.92)} = 1.3\text{e-3 m}$$

Because r_g =1.3 mm is much smaller than the beam pipe diameter of 3” = 76.2 mm, we conclude that dis-associated electrons entering the field of the final bend will be swept to the upper beam pipe wall well before they have traverse the magnet’s ~300 mm length.

Activation Due to Neutral Flux and its Mitigation

Partially stripped ions emerging from the foil as neutral hydrogen atoms retain at most the original kinetic energy of the incident ion beam. The fraction of incident beam going into this neutral beam flux is expected to be on the order of 1E-2 or less, dropping as the thickness of the stripping foil is increased. See Eqn. 1

References

[1] “Stripping Efficiency and Lifetime of Carbon Foils”, W. Chou, M. Kostin, and Z. Tang. NIM-A 2006 Proceedings of the 23rd World Conference of the International Nuclear Target Development Society (INTDS 2006). Tsukuba, Ibaraki-ken, Japan.