Wire scanner and harp signal levels in the SNS

When an H^- beam strikes a wire the signal induced on the wire can be modeled by considering the H^- particle as a single particle entering the wire, whereupon it fragments into two electrons and a proton. Any electrons or protons that stop in the wire or exit the wire should be considered separately. The signal will thus comprise several sources: 1) the secondary electron emission (SEM) caused by the H^- particle entering the wire, 2) any electrons or protons that stop in the wire, and 3) SEM caused by any electrons or protons exiting the wire.

A well-known theory from Sternglass[1] describes the secondary emission yield as

$$Y = \frac{P\, d_s}{E_*} \frac{dE}{dx} ,$$

where Y is the secondary yield, P is the probability of an electron escaping, d_s is the average depth from which secondaries arise, E_* is the average amount of kinetic energy lost by the incoming particle per ionization produced in the target, and dE/dx is the stopping power of the target. Values for P, d_s, and E_* suggested by Sternglass are P § 0.5, d_s § 1 nm, and E_* § 25 eV. For a round wire the number of particles intercepted by the wire is calculated from the wire diameter, but the SEM signal is calculated from the wire circumference. The 1 nm thick layer of material just below the surface of the wire acts like an ion chamber that creates an electron for every 25 eV of energy loss within that layer.

The wire scanner signal computation therefore reduces to calculating stopping powers and ranges for H^- particles, protons and electrons. The H^- stopping power is the same as the proton stopping power for the very thin layer within the entering surface. It can be estimated from the Bethe-Bloch equation[2], and the proton range can be estimated by numerically integrating this equation. The electron range can be estimated with Feather's rule[3] suitably modified[4] for materials other than aluminum:

$$R(E) = 412\left(\frac{13}{27}\right)\left(\frac{A}{Z}\right)E^n \quad \left[\frac{\text{mg}}{\text{cm}^2}\right] ,$$

where $n = 1.265 - 0.0954\ln(E)$, A and Z are the atomic mass and number, and E is in MeV. The energy lost by the electron in the thin layer within the exiting surface of the wire can be estimated from the range equation. The above equations predict precise ranges for the electron and proton, but in reality there is straggling and scattering that leads to imprecision.

To further simplify our task we assume the wire has a uniform thickness given by the average thickness. For a wire diameter of D, the average thickness is $t = D^*\pi/4$. This assumption leads to further imprecision in the particle range and stopping power calculations. Sharp peaks that appear in the plots of signal vs. incident energy are in reality more rounded. I've written a Java program to calculate and plot the wire scanner signals as a function of H^- beam energy. Some results are shown in Figs. 1–10.

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[1] E.J. Sternglass, Phys Rev **108**, 1 (1957). J.E. Borovsky and D.M. Suszeynsky, Phys. Rev. **A43**, 1416 (1991).
[2] See, e.g., Review of Particle Physics.
[3] Evans, "The Atomic Nucleus", McGraw-Hill, 1965.
[4] R.E. Shafer, "Comparison of H-minus and Proton Beam Heating in Thin Foils", 6/16/2000, SNS Tech Note SNS-104050000-TD0001 - R00.

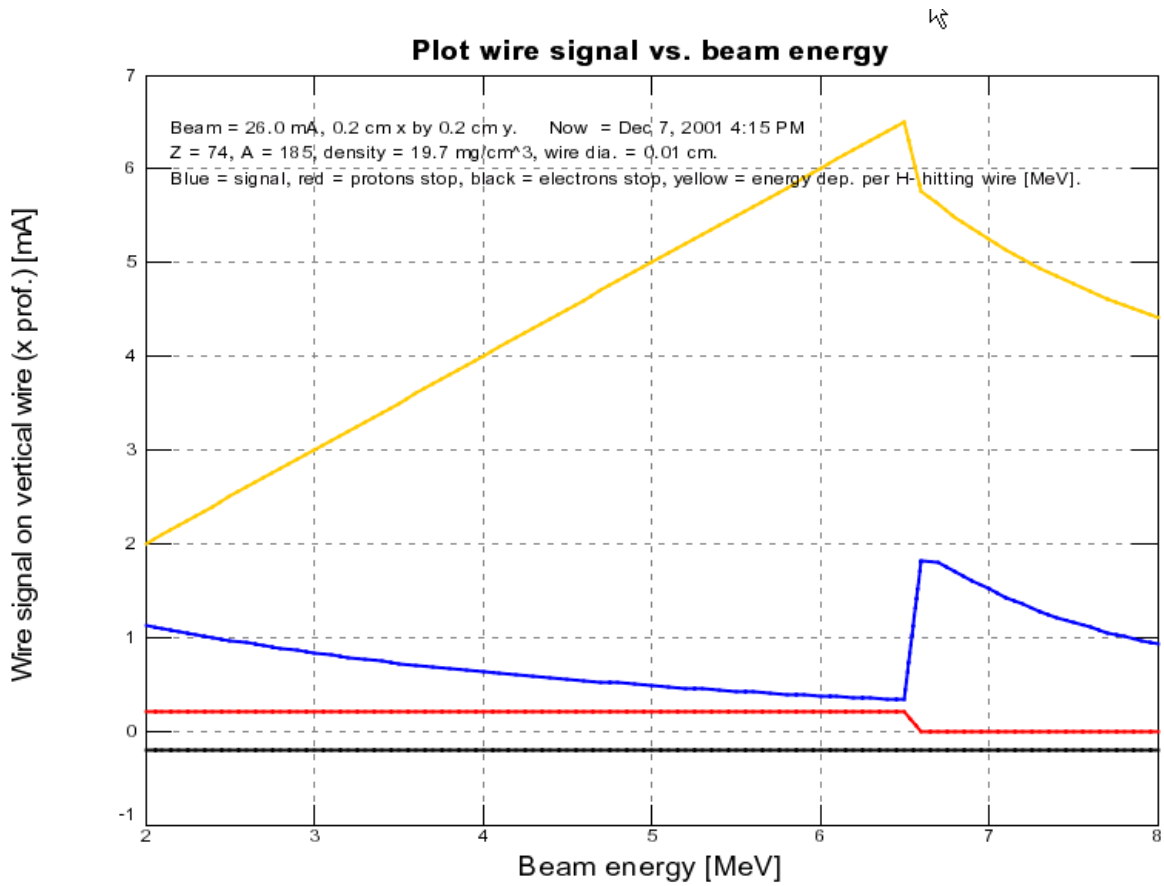

Figure 7. Tungsten-rhenium wire, detailed view of the 2 to 8 MeV region.

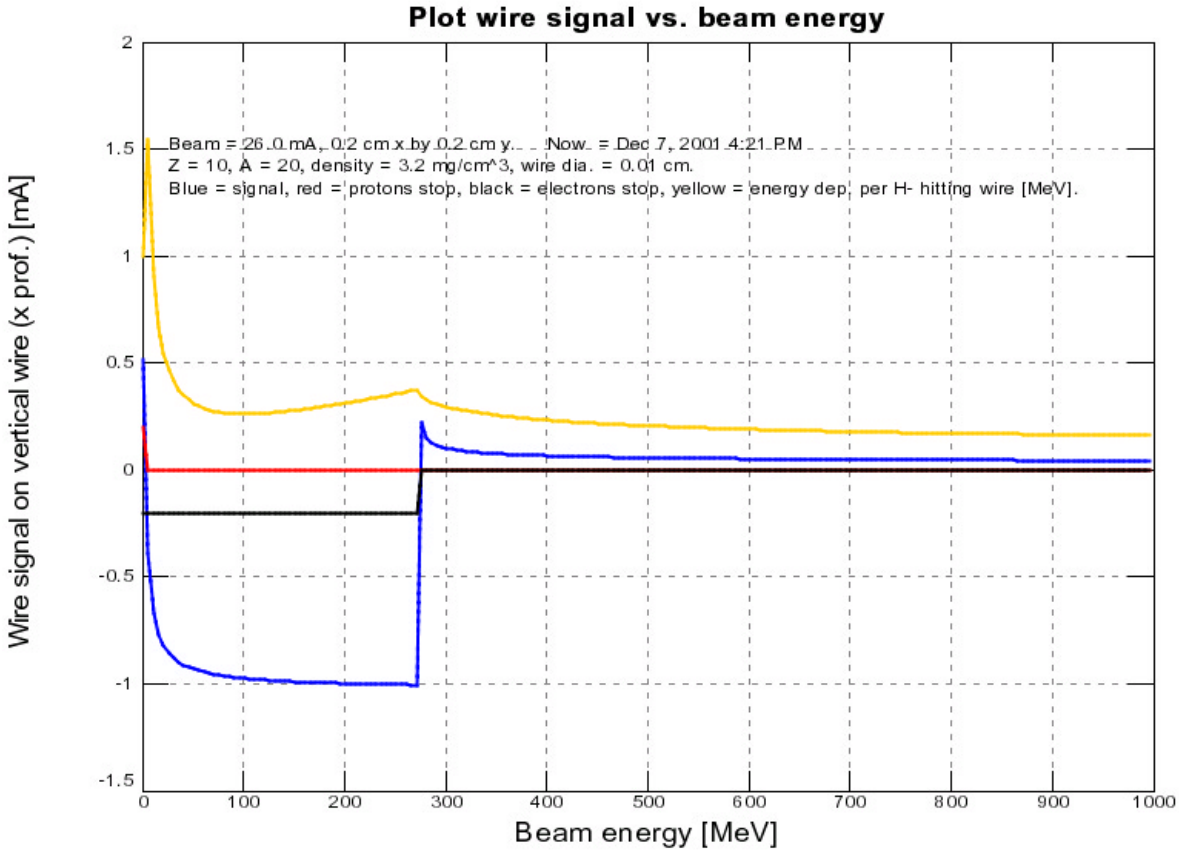

Figure 8. SiC wire, 0.1 mm dia. (A = 20, Z = 10, I = 138 eV, ρ = 3.2 g/cm^3). Detailed view of the 2 to 8 MeV region. The blue line is the wire scanner signal in units of mA. The red line, when non-zero, indicates that protons are stopping in the wire. The black line, when non-zero, indicates that electrons are stopping in the wire. The yellow line indicates energy deposited in the wire per H^- particle, in units of MeV. Note that above about 25 MeV, the most wire heating occurs at about 270 MeV.

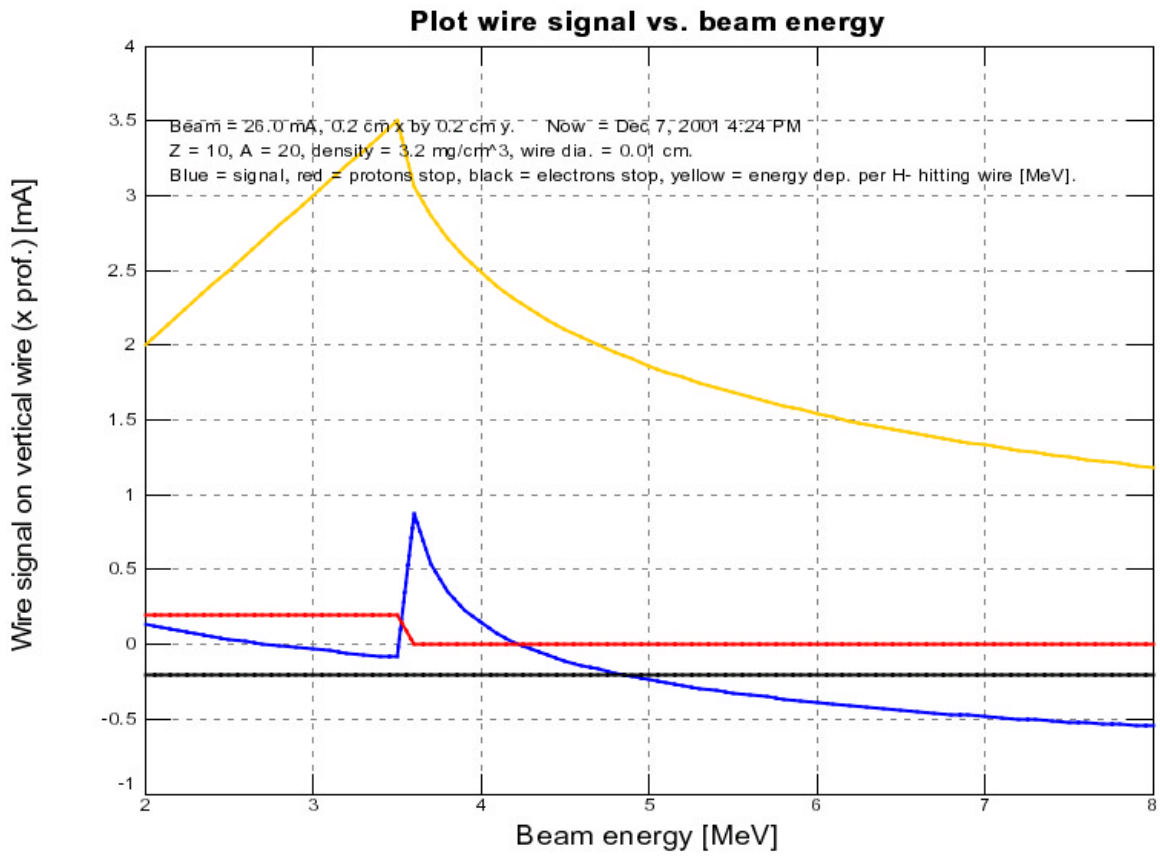

Figure 9. SiC wire, 0.1 mm dia., detailed view of the 2 to 8 MeV region.

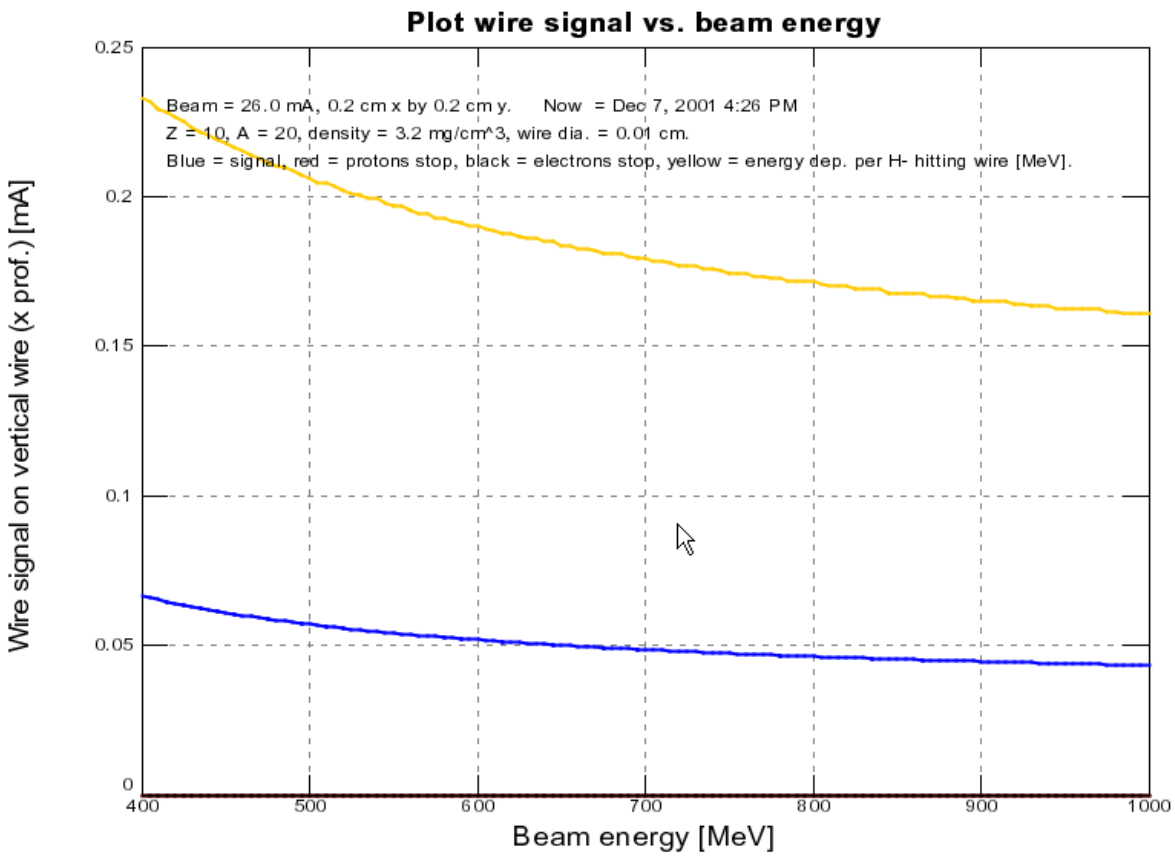

Figure 10. SiC wire, 0.1 mm dia., detailed view of the 400 to 1000 MeV region.