MEMORANDUM

To: Bobby Johnston, Charles Epstein

From: Peter Fisher

Subject: Beam current and NaI data

Date: October 30, 2017

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1. Data from HRVL with Faraday cup.

   Calibration:
   $$E\,(\mathrm{keV}) = 7.7\frac{\mathrm{keV}}{\mathrm{ch}} \times \mathrm{ch} - 5.6\mathrm{keV}$$

   Electron stopping power[**?**]:
   Collision: 3.924 cm^2/g
   Radiation: 0.01931 cm^2/g
   Density of graphite: 2.266 g/cm^3
   Range: 0.11 cm

   Fit over range 500-2500 keV:
   $$\frac{d^2N}{dtdE} = \frac{8.6 \text{ counts}}{\mathrm{keV} - \mathrm{s}} 10^{-E/848\mathrm{keV}}$$

2. The Method of Virtual Quanta ([**?**], Section15.4) gives an expression for bremstrahlung in the scattering between two particles:
   $$\frac{d^2\chi}{d\omega d\Omega} \sim \frac{16}{3}\frac{Z^2e^2}{c}\left(\frac{z^2e^2}{Mc^2}\right)\ln\frac{2\lambda\gamma^2Mc^2}{\hbar\omega\left(1+\gamma^2\theta^2\right)}\left[\frac{3\gamma^2\left(1+\gamma^4\theta^4\right)}{2\pi\left(1+\gamma^2\theta^2\right)^4}\right]$$
   this expression is the differential radiation cross section. The differential cross section is
   $$\frac{d^2\sigma}{dEd\Omega} = \frac{1}{\hbar^2c}\frac{d^2\chi}{d\omega d\Omega}$$
   These expression work for photon energies much smaller than the electron energy. Fig. 2 shows the photon spectrum at various angles.

3. For a 1 μA, 3 MeV electron beam incident on a graphite target, the areal number density is $4{\times}10^{21}$/cm^2 and incident particle rate is $6{\times}10^{12}$/s. From the NIST tables, the stopping distance is $d = 0.11$ cm, which seems very low. Assume the electrons lose energy linearly, compute the cross section for 1, 2, and 3 MeV for a thickness of $d/3$, sum, multiply by solid angle of NaI at 3 m, $d\Omega = 22\mu$str. Fig. 4 shows the resulting spectrum for a 300 s run at 1 μ A.

4. Not all the photons that hit the detector are absorbed and note all the photons are are absorbed leave their full energy. Fig. 5 shows the photon absorption probability as a function of energy. Fig. 5 show the probability that a photon of some energy leaves *some* energy in the NaI detector, so it cannot predict the spectrum shown in Fig. 1, but we can use it to give an integral rate estimate. Integrating the spectrum in Fig. **??** with the absorption from $E_\gamma = 1 - -500$keV gives an expectation of 3 counts in a 300 s run (!).

5. Integrating the fit to the data spectrum over the same range gives 680,000 counts in 300 s.

6. This agreement should be within a factor of two.

References

[1] https://physics.nist.gov/PhysRefData/Star/Text/method.html

[2] Jackson, JD, “Classical Electrodynamics”, Wiley, 1975.

[3] “Efficiency Calculations for Selected Scintillators”, Saint-Gobain Crystals, http://www.crystals.saint-gobain.com/sites/imdf.crystals.com/files/documents/efficiency_calculations_b

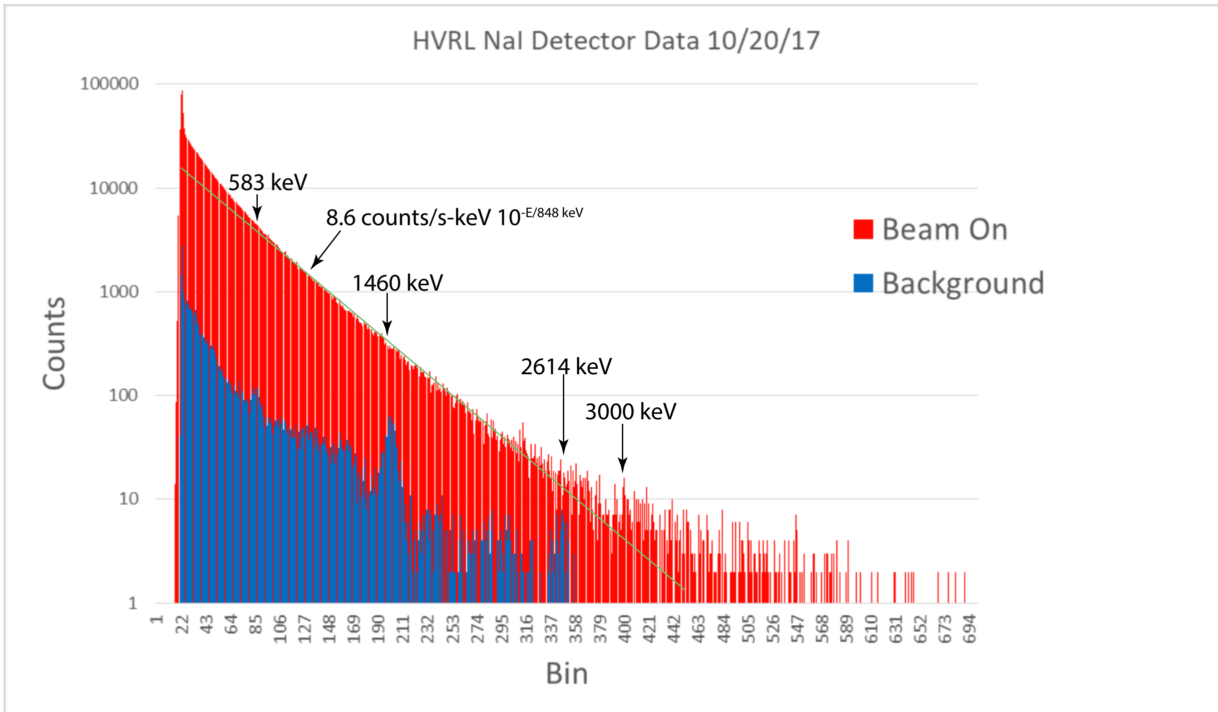

Figure 1: Red shows 300 s run during 3 MeV beam. Blue shows 300 s spectrum with no beam.

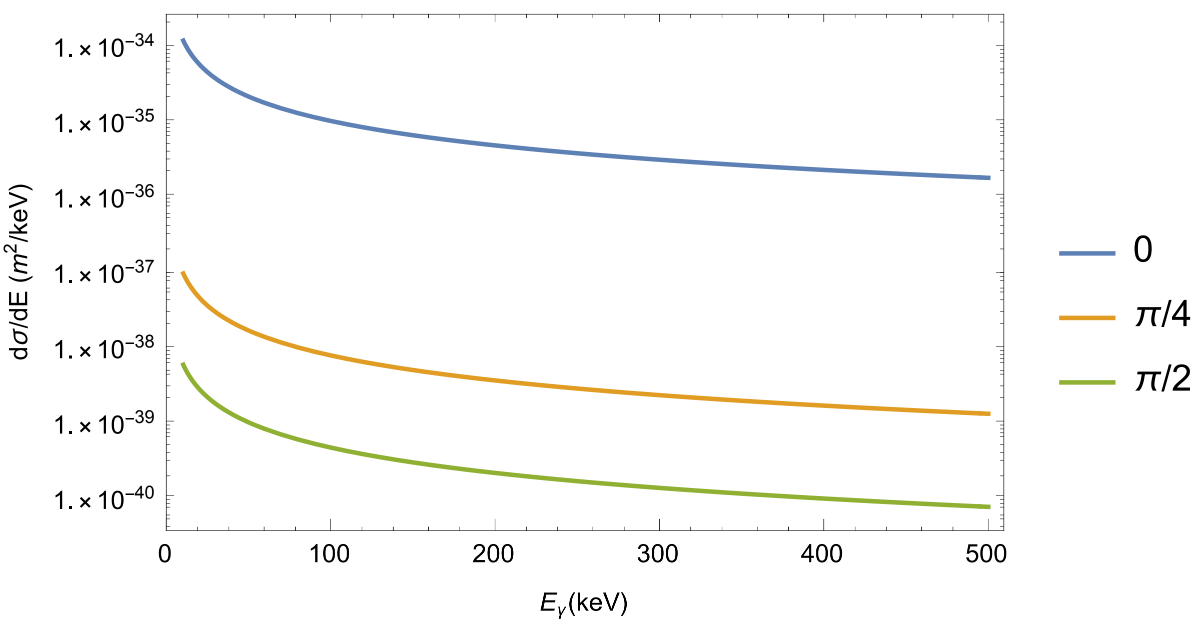

Figure 2: Bremstrahlung spectrum for 3 MeV electron beam.

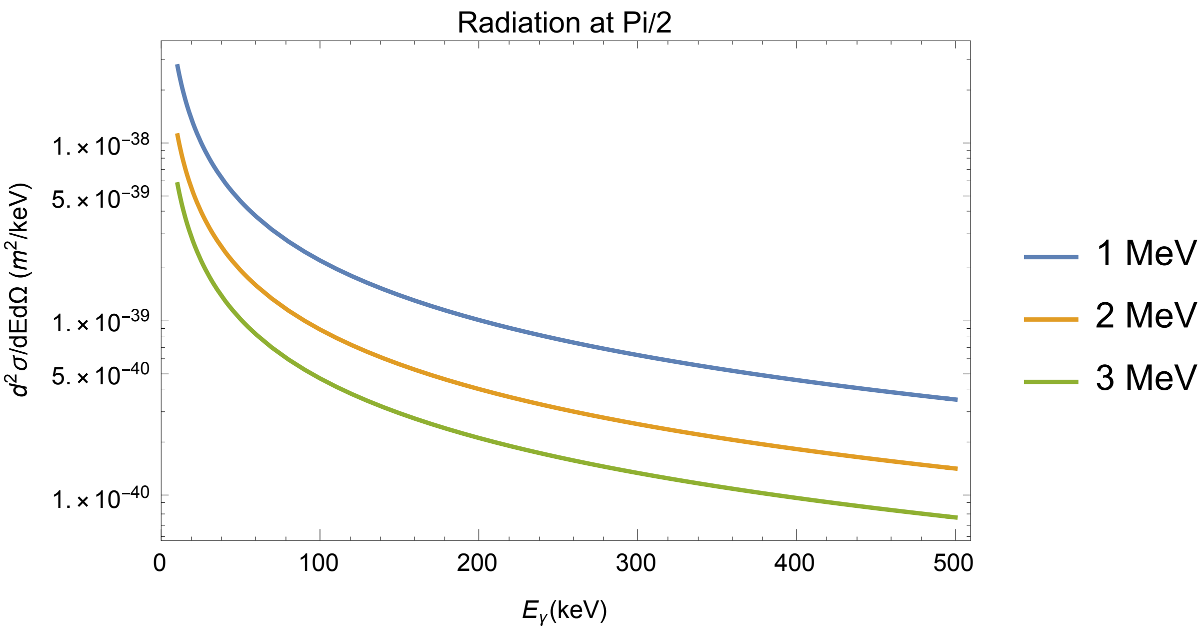

Figure 3: Bremstrahlung spectrum at $\theta = \pi/2$ for different beam energies.

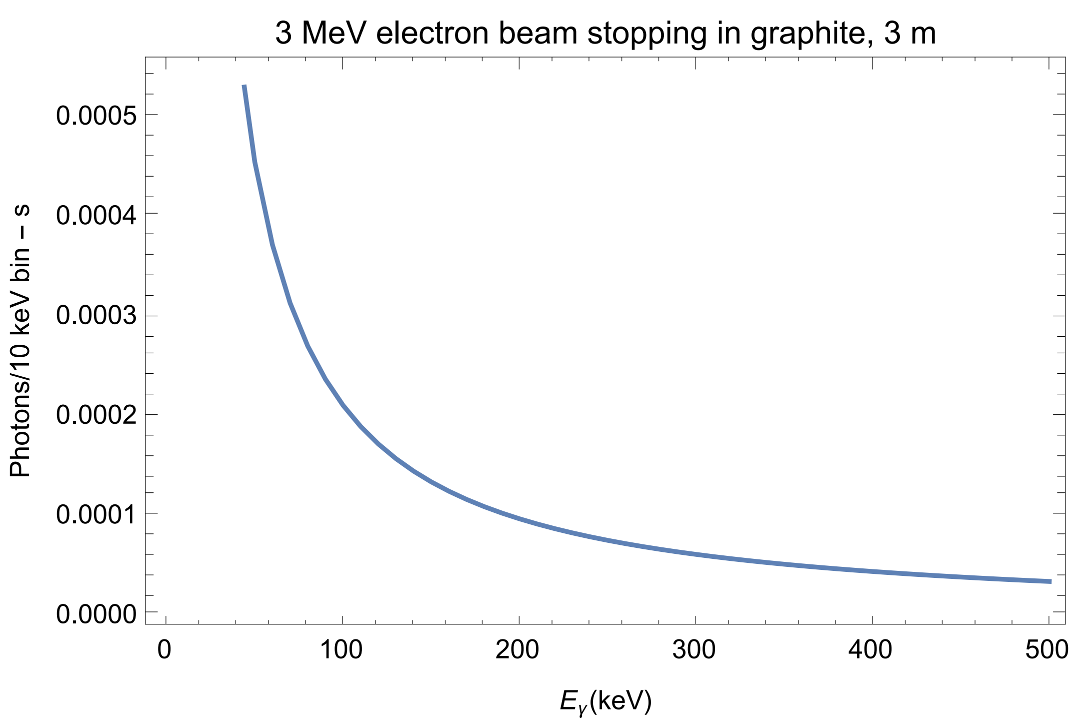

Figure 4: Bremstrahlung spectrum at $\theta = \pi/2$ sum over energy loss and adjusted for running time of 300 s.

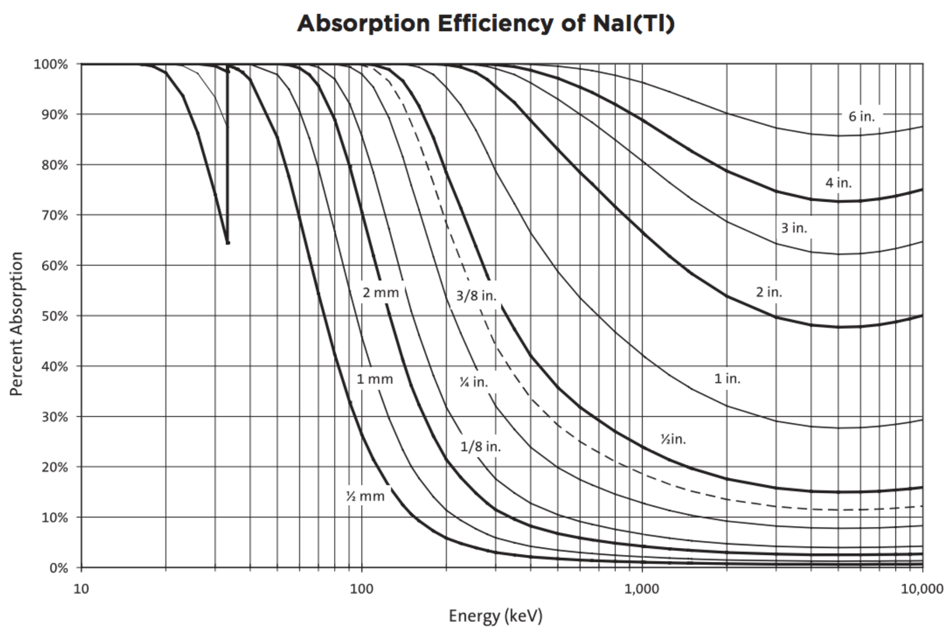

Figure 4.

Figure 5: Photon absorption probability as a function of photon energy. From [1].