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NSRL Energy Loss Calculator

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A means of calculating the energy lost down the NSRL beam line was needed. The program takes the geometry of the NSRL beam line, starting at the D6 foil drive, to the first Ion chamber that A. Rusek uses for the Bragg Curve measurements. Below is a description of how the NSRL Energy Loss Calculator works. The variable definitions are similar to those variable names used in the program. Note that the beam energy quoted in the NSRL Target Room is just before entering the first ion chamber that makes up the Bragg Curve Equipment (see appendix C).

Access to program through a Linux terminal window:

1.) At prompt>cd /home/cfsb/kuik/Programs/Tcl_Tk/NSRL

2.) At prompt>xemacs NsrlEnergyLossInteractive.tcl &
(to view the source code)

3.) At prompt>NsrlEnergyLossInteractive.tcl &
(to run the program)

Variable definitions:

TMZ = Target Material Atomic Number
TMA = Target Material Atomic Mass
TMT = Target Material Thickness (in cm converted from inches)
TMD = Target Material Density (g/cm^3)
TMI = Target Material Mean Excitation Energy (eV)
BeamZ = Charge of the Beam
Beam_n = Number of Nucleons per ion for the Beam
rme = Rest Mass Energy of the beam (GeV)

I. Set the Beam type (Protons, Iron, Copper, Titanium, Carbon, etc...)

1.) Set the beam's Charge, Atomic Weight, Rest Mass Energy, & Nucleon Count (z, beam_a, rme, beam_n)

II. Set Starting Kinetic Energy as measured at Booster Extraction

1.) Measure the RF Frequency (*freqRF*) at Booster Extraction (MHz)

2.) Using nominal Booster radius

$$boosterR = 32.11428 \text{ meters}$$

3.) Convert frequency from MHz to Hz

$$freqRF = freqRF * 10^6$$

4.) Convert Rest Mass Energy of the Beam (rme) from GeV to MeV

$$rme = rme * 10^3$$

5.) Measure the radial shift dr at Booster Extraction in millimeters.

6.) Convert radial shift from millimeters to meters

$$dr = \frac{dr}{10^3}$$

7.) Adjust the booster extraction radius

$$boosterR = boosterR + dr$$

8.) Calculate Beta, where h is the harmonic number and c is the speed of light:

$$b = \frac{2 * p * boosterR * freqRF}{h * c}$$

9.) Calculate Gamma

$$g = \frac{1}{\sqrt{1 - b^2}}$$

10.) Calculate total energy (MeV/ion)

$$energyTot = g * rme$$

11.) Calculate kinetic energy per ion (MeV/ion)

$$boosterExtKE = energyTot - rme$$

12.) Convert kinetic energy per ion to energy per nucleon (MeV/n)

$$boosterExtKE = \frac{boosterExtKE}{Beam\_n}$$

III. Intercepting the various materials.

Starting with the Booster Extracted Kinetic Energy this value gets put into two variables *previousKE* & *newKE*. The first variable, *previousKE*, is used to calculate the overall energy loss if the intercepting material is composed of several types of material. The second variable, *newKE*, is the energy of the beam intercepting the material. The energy of the beam always becomes the *newKE* being indifferent to either a slice of material or a new material intercepting the beam.

The next several steps are basic to every material the beam intercepts in the NSRL beam line.

1.) Get the specific values for the material the beam is intercepting
   a.) set the target material
   b.) set the target thickness (convert to centimeter from inches)
   c.) set the *Z* (atomic number), *A* (atomic mass), *Z/A* (ratio of the atomic number over the atomic weight), *TMI* (mean excitation energy), & *density* for the target material
      i.) Calculate $\frac{Z}{A}$ if it has not been provide for in the tables.
      ii.) Calculate the Mean Excitation Energy $TMI = 16 * Z^{0.9}$ of the material if the experimental number is not available.

2.) Convert TMI from eV to MeV:

$$TMI = TMI * \left(\frac{1}{10^6}\right)$$

3.) Calculate gamma from Kinetic Energy:

$$g = \frac{newKE + rme}{rme}$$

4.) Calculate Beta from Gamma:

$$b = \sqrt{1 - \frac{1}{g^2}}$$

5.) Calculate Bethe-Bloch[1] [2] dE/dx

$$-\frac{dE}{dx} = K * BeamZ^2 * \frac{TMZ}{TMA} * \frac{1}{b^2} * \left[0.5 * \ln\left(\frac{2.0 * m_e c^2 * b^2 * g^2 * newKE}{TMI^2}\right) - b^2\right]$$

$$K = 0.3071 \text{ MeV}$$
$$m_e c^2 = 0.5109906 \text{ MeV}$$

6.) Calculate dE, in units of MeV, by multiplying the Target Material's thickness and density to the Bethe-Bloch result.

$$dE = \frac{dE}{dx} * TMT * TMD$$

7.) Calculate new Kinetic Energy (newKE) in units of MeV per nucleon:

$$newKE = \frac{newKE * Beam\_n - dE}{Beam\_n}$$

8.) Move on to the next material and repeat up to the point that the air gap just before the plastic used for Bragg curve measurements.

The D6 flag drive is the first object the beam sees after leaving the Booster. There are 8 possible positions for the drive with one being a blank target. Afterward there are 4 insertable instrumentation packages in the NSRL beam line, an aluminum window, and a permanently inserted instrumentation package in the target room (see Appendix C). Each instrumentation package contains an ion chamber (made up of 5 aluminum planes), a SWIC (both horizontal and vertical measuring planes), and a scintillator detectors (see appendix D). When the insertable instrumentation packages are retracted, the beam only sees vacuum. The permanently inserted instrumentation package is flanked by air gaps on both sides. All of the instrumentation packages are filled with nitrogen gas.

Each material that the beam intercepts is sliced up into 40 parts to ensure that energy loss is close to as fully accounted for by the material. In some cases the material is thin enough where this is most likely overkill. Even though this is probably overkill, there is a mix of materials within the instrumentation packages with thicknesses varying from 0.001” to 0.780” thick. Also of note, for the D6 foil, those beam species whose charge is stripped full after the D6 foil, the ion is considered fully stripped after the first slice of the material layer.

Available:

NSRL beam line Instrumentation layout http://www.c-ad.bnl.gov/esfd/nsrl/operations/InstruLayoutNSRL.pdf
Atomic Information used (see Appendix A)
Program Interface (see Appendix B)
NSRL target room layout (see Appendix C)
Instrument Package Cross Section (see Appendix D)
Send request for program code to B. van Kuik at vankuik@bnl.gov

Acknowledgements:

S. Bellavia & A. Rusek for providing technical data on the NSRL beam line.
K. Brown, K. Gardner, & A. Rusek for providing consultation.

Appendix A: Atomic Information

Table of Element values used within the calculator. These data came from references [3], [4], and [5].

Element	Atomic Symbol	Z	A	<Z/A>	Mean Excitation Energy eV I=16*Z^0.9	Experimental Mean Excitation Energy eV	Density g/cm^3	Rest Mass GeV
Hydrogen	H	1	1.007825032	0.99212	16	19.2		0.938272
Helium	He	2	4.00260325	0.49968	29.85705573	41.8	1.66322E-04	
Lithium	Li	3	6.941	0.43221	43.00600607			
Beryllium	Be	4	9.012182	0.44384	55.71523605	63.7	1.848	11.1754
Carbon	C	6	12.00000	0.49954	80.252045	81.0	2.0	
Nitrogen	N	7	14.00674	0.49976	92.19518045	82.0	1.16528E-03	
Oxygen	O	8	15.99491462	0.50002	103.9683067	95.0	1.33151E-03	14.8956
Flourine	F	9	18.9984032	0.47372	115.5947849			
Aluminum	Al	13	26.981539	0.48181	160.9418539	166.0	2.6989	
Sillicon	Si	14	27.97692653	0.49848	172.04229	173.0	2.33	26.0536
Chlorine	Cl	17	35.453	0.49848	204.891533			32.5661
Argon	Ar	18	39.948	0.45059	215.7074959	188.0	1.66201E-03	
Titanium	Ti	22	47.9479471	0.45948	258.4046922	233.0	4.54	44.65
Iron	Fe	26	55.9349421	0.46556	300.3281188	286.0	7.874	52.09
Copper	Cu	29	62.9296011	0.45636	331.3432905	322.0	8.96	
Tungsten	W	74	183.84	0.40250	769.8897372	727.0	19.3	
Gold	Au	79	196.966552	0.40108	816.5529738	790.0	19.32	183.457
Kapton	nm	6.35993	12.70055	0.50076	84.57209418	79.6	1.42	0
Carbon Dioxide	CO2	7.454168	14.90698	0.50005	97.56167356	85.0	1.84E-03	
Silicon Dioxide	SiO2	10.80461	21.64599	0.49915	136.2599322	139.2	2.32	
Air	C,N,O,Ar	7.372747	14.80005	0.49816	96.60205844	85.7	1.20E-03	

Below are the computed values for Kapton, Carbon Dioxide, Silicon Dioxide, and Air. Each atomic numbers and atomic mass is multiplied by the weighting value for the material, then summed together to give the effective atomic numbers and atomic mass. Compositional data provided by NIST Physics Laboratory website (http://physics.nist.gov/cgi-bin/Star/compos.pl?ap).

Kapton Composition		Weighting	Weighted	Weighted
Z	A	Value	Z	A
1	1.00794	0.026362	0.026362	0.026571314
6	12.00000	0.691133	4.146798	8.293596
7	14.00674	0.07327	0.51289	1.02627384
8	15.994	0.209235	1.67388	3.34650459
		effective	6.35993	12.69294574

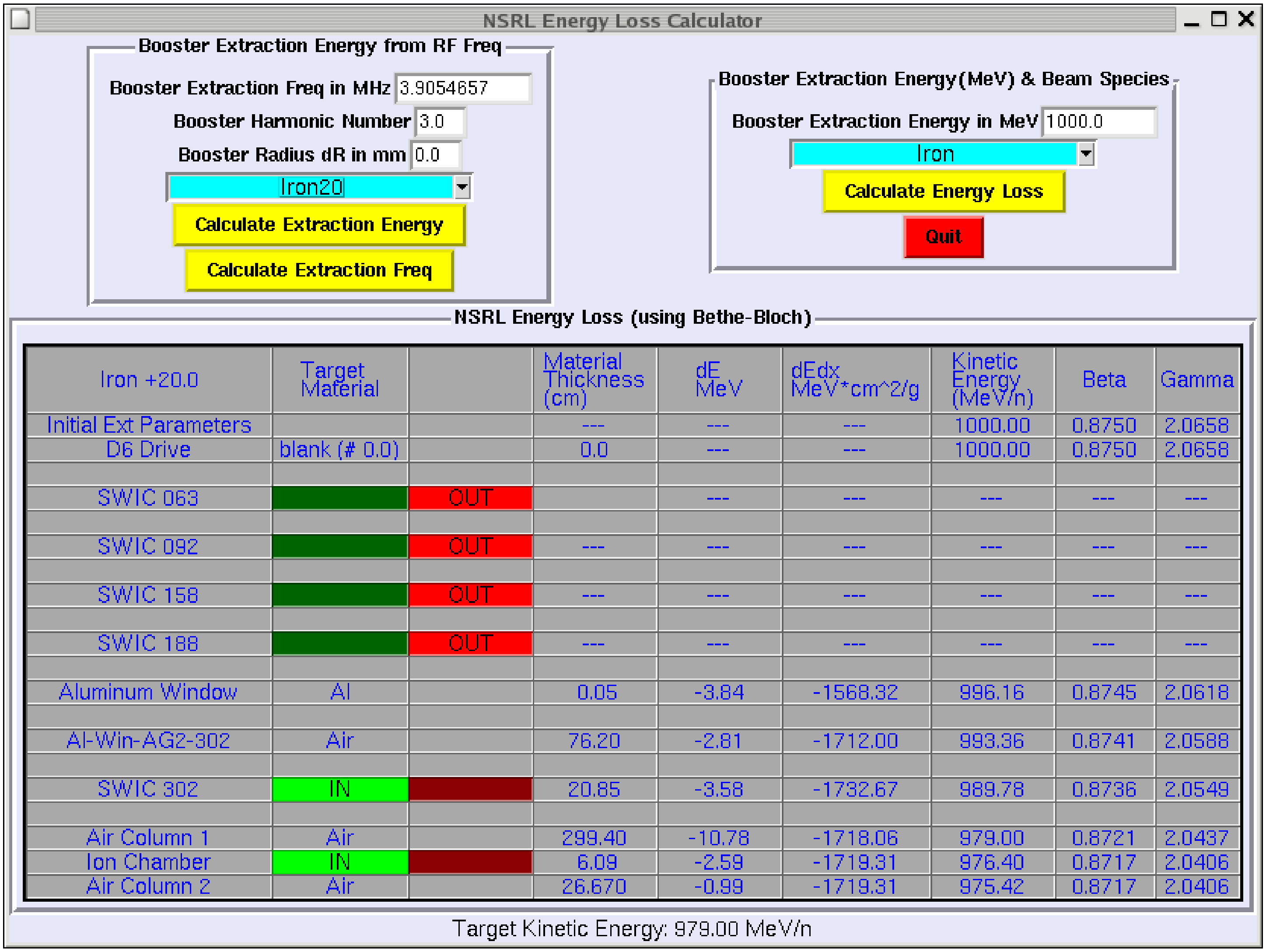
CO2		Weighting	Weighted	Weighted
Z	A	Value	Z	A
6	12.00000	0.272916	1.637496	3.274992
8	15.994	0.727084	5.816672	11.6289815
		effective	7.454168	14.9039735

SiO2		Weighting	Weighted	Weighted
Z	A	Value	Z	A
8	15.994	0.532565	4.26052	8.51784461
14	28.0855	0.467435	6.54409	13.12814569
		effective	10.80461	21.6459903

Air		Weighting	Weighted	Weighted
Z	A	Value	Z	A
6	12.00000	0.000124	0.000744	0.001488
7	14.00674	0.755267	5.286869	10.5788285
8	15.99491462	0.231781	1.854248	3.707317306
18	39.948	0.012827	0.230886	0.512412996
		effective	7.372747	14.800046802

Appendix B: NSRL Energy Loss Calculator

Below is the interface for the NSRL Energy Loss Calculator. To use the main function of calculating the energy loss down the NSRL beam line, enter a Beam Energy value in units of MeV into the *Booster Extraction Energy* field, select the beam species, and click the *Calculate Energy Loss* button. The program will then calculate the energy loss, retrieving any elements that are intercepting the beam in the live machine.

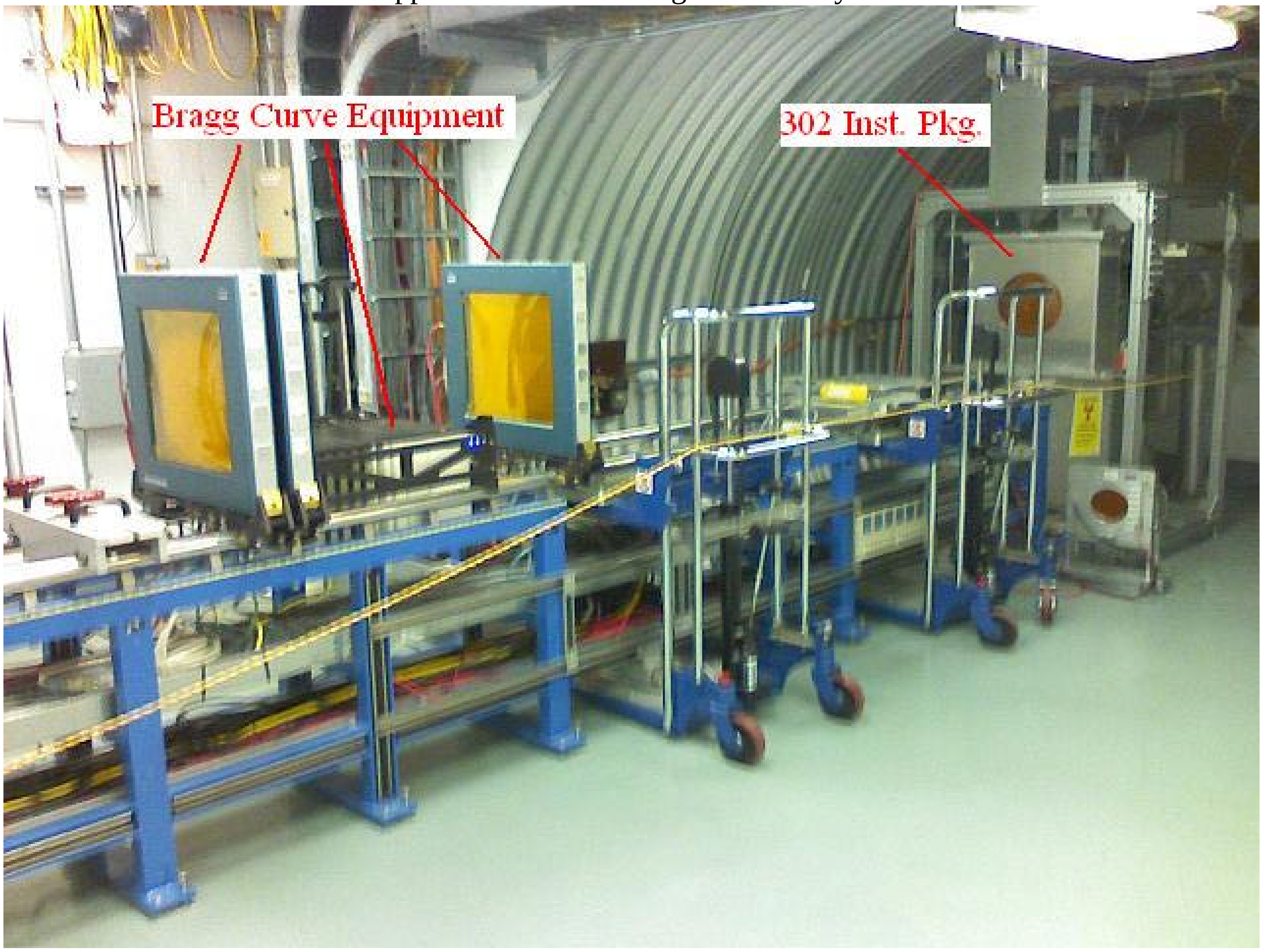


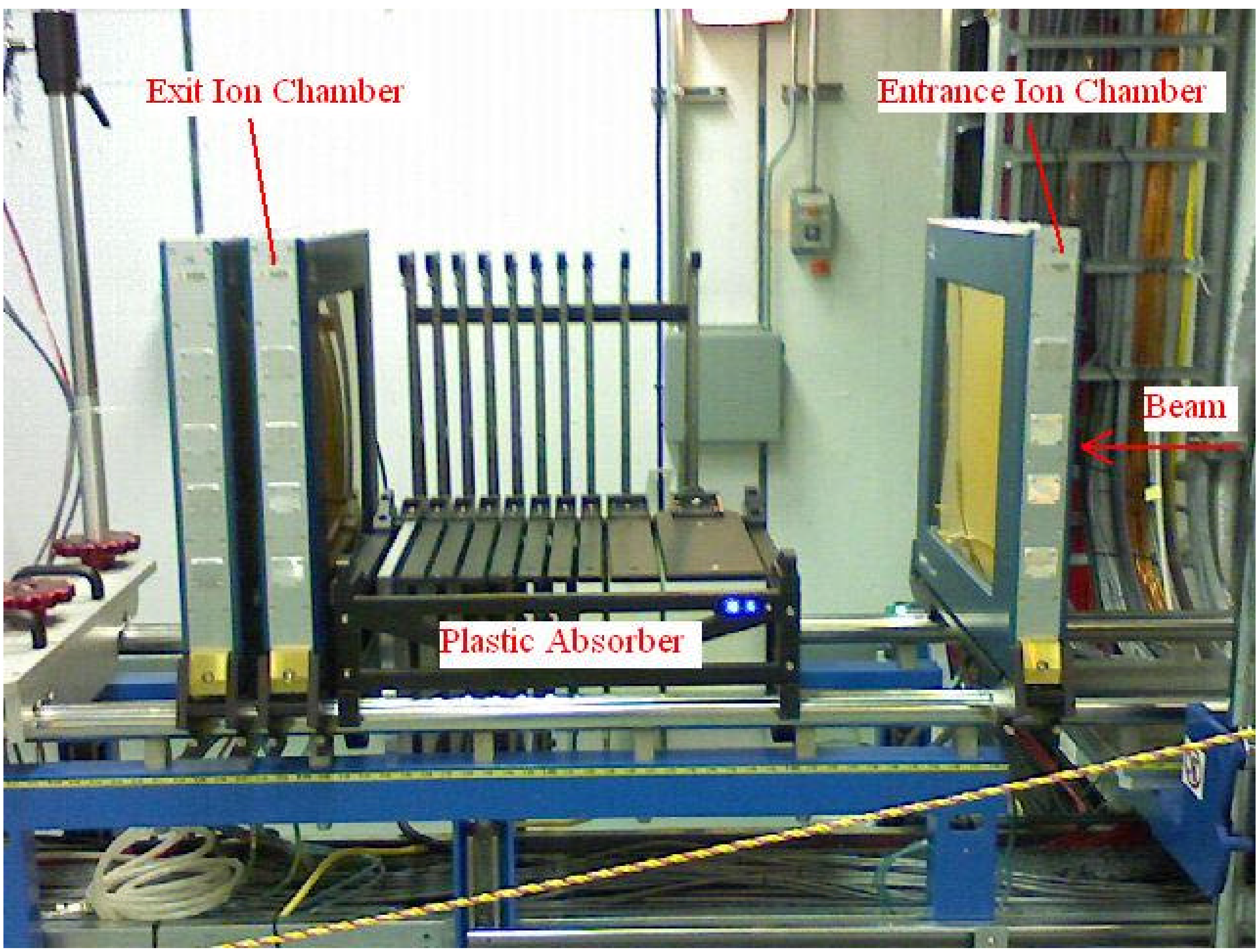
Iron +20.0	Target Material		Material Thickness (cm)	dE MeV	dEdx MeV*cm^2/g	Kinetic Energy (MeV/n)	Beta	Gamma
Initial Ext Parameters			---	---	---	1000.00	0.8750	2.0658
D6 Drive	blank (# 0.0)		0.0	---	---	1000.00	0.8750	2.0658
SWIC 063		OUT		---	---	---	---	---
SWIC 092		OUT	---	---	---	---	---	---
SWIC 158		OUT	---	---	---	---	---	---
SWIC 188		OUT	---	---	---	---	---	---
Aluminum Window	Al		0.05	-3.84	-1568.32	996.16	0.8745	2.0618
Al-Win-AG2-302	Air		76.20	-2.81	-1712.00	993.36	0.8741	2.0588
SWIC 302	IN		20.85	-3.58	-1732.67	989.78	0.8736	2.0549
Air Column 1	Air		299.40	-10.78	-1718.06	979.00	0.8721	2.0437
Ion Chamber	IN		6.09	-2.59	-1719.31	976.40	0.8717	2.0406
Air Column 2	Air		26.670	-0.99	-1719.31	975.42	0.8717	2.0406

There are two other functions contained in the NSRL Energy Loss Calculator the ability to calculate the *Booster Extraction Energy* from a measured extraction frequency and the ability to calculate the expected *Booster Extraction Frequency* for a given extraction energy. To calculate the Booster Extraction energy, enter the Booster Extraction frequency in MHz and the appropriate Booster harmonic number for the beam species. To calculate the *Booster Extraction Frequency* enter an extraction energy value in the Booster Extraction Energy field and enter the appropriate Booster harmonic number. Generally the harmonic numbers for protons and ions are h=2 and h=3 respectively. Click the relevant calculation button. The *Booster Radius dR* field is for the radial change in the Booster at extraction if known, otherwise the default is zero. The calculated extraction energy can then be used to calculate the NSRL energy loss.

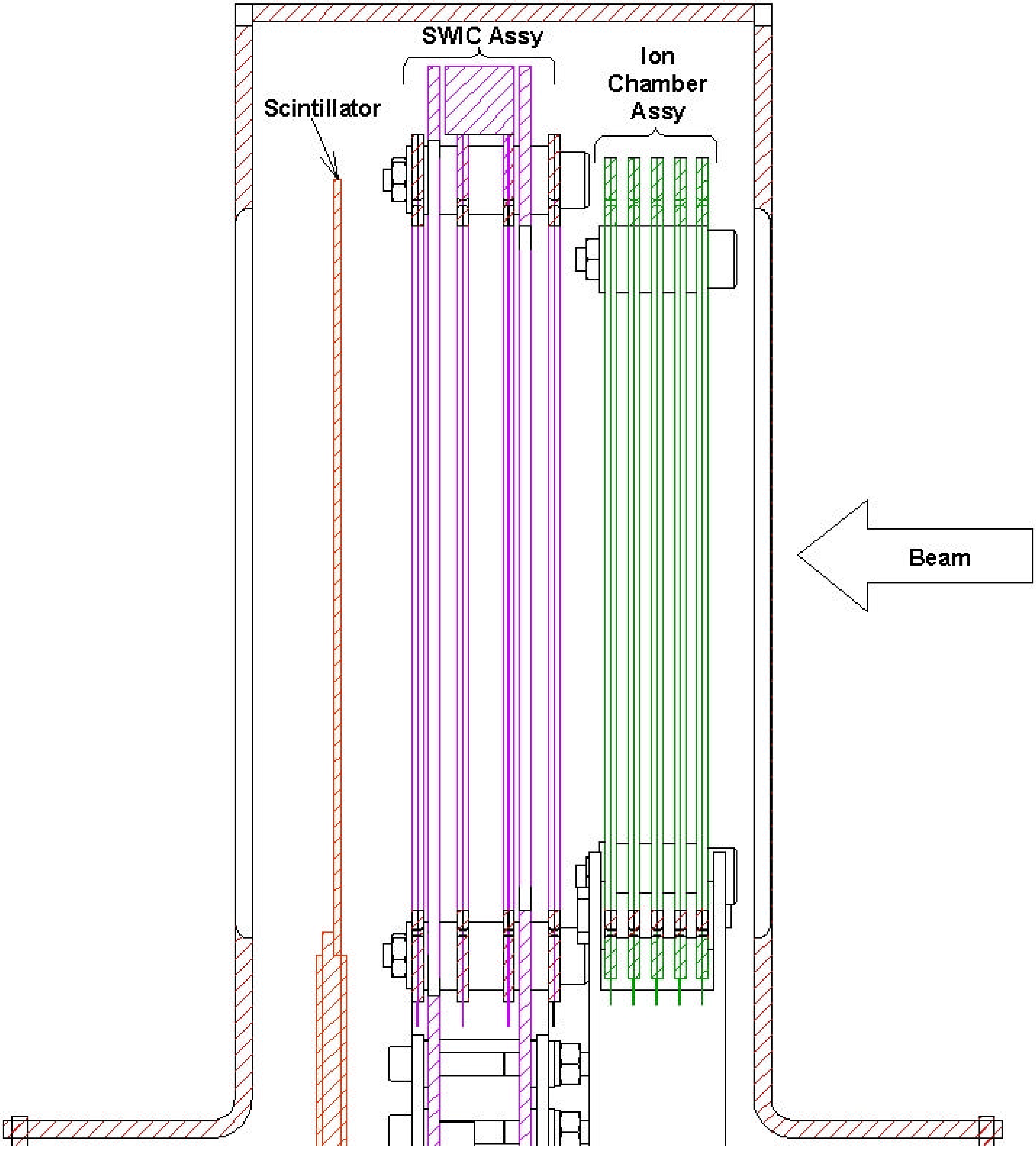
Note that the dEdx, MeV/n, Beta, and Gamma are the parameters for the beam upon exit of the material.

Appendix C: NSRL Target Room Layout





Appendix D: Instrument Package Cross Section



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[1] Nuclear and Particle Physics, W.S.C. Williams, pg 234-239
[2] An Empirical Model for the Response of BtA Multiwires to Different Ions, C-A/AP#221, K. Zeno, October 2005
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[4] Nsrl# Schedule and Parameters, C. J. Gardner, located at
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[5] NIST Physics Laboratory, located at
http://physics.nist.gov/cgi-bin/Star/compos.pl?ap