BDSIM Simulations of the Input Beam and End Station

Laura Murgatroyd

Aims

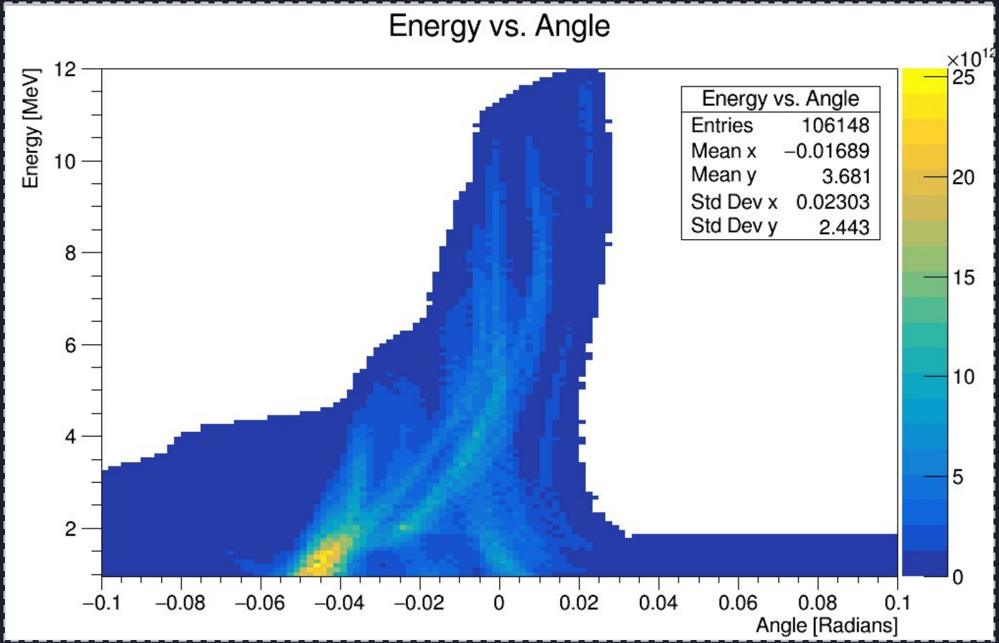
1. Simulate the input proton beam.

2. Simulate the interactions of the beam in the end station.

Simulating the Input Beam

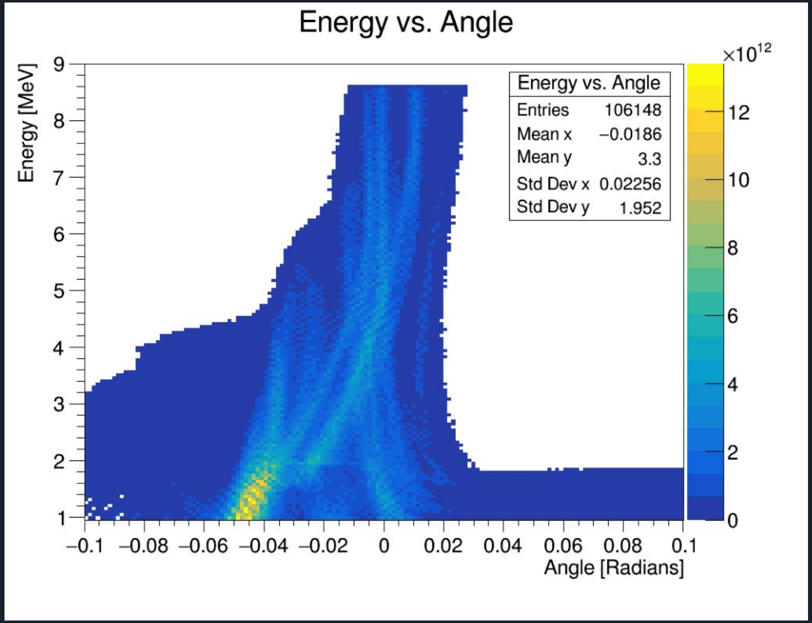
- Information from laser simulation:
  - Momentum along the beam axis.
  - Momentum in the r direction (polar coordinates).
  - Number of particles with these momenta.
- BDSIM does not work in polar coordinates, so the data had to be converted to cartesian momenta coordinates.
- The laser simulation assumed all protons come from a point source at the back of the target.
- For BDSIM input: Gaussian beam with 1.7um width at target position was generated.

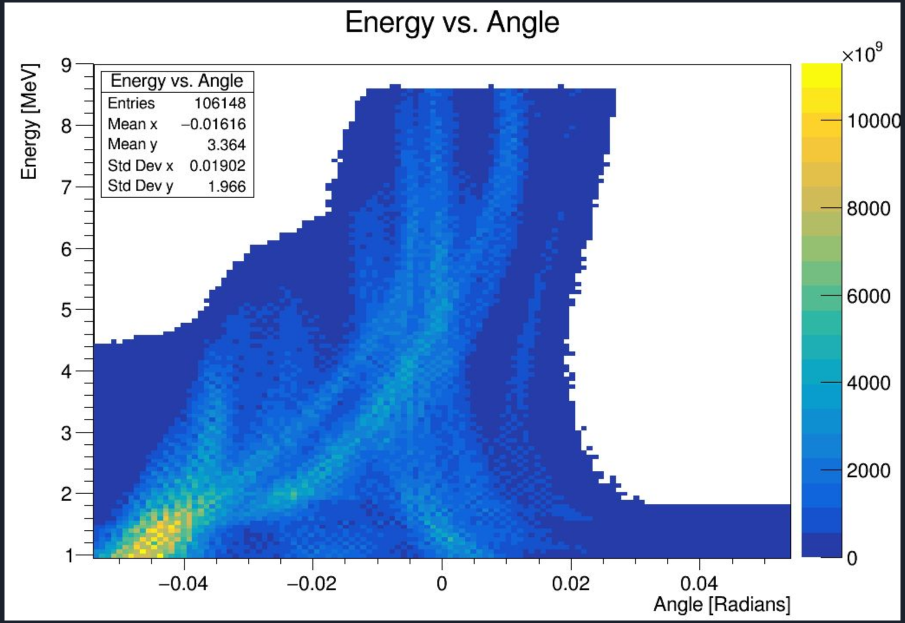
Angular Beam Selection



- Angular selection required to simulate beam in BDSIM.
- Acceptance angles considered: 100mrad, 54mrad, 48mrad.
- Centred on highest proton number.
- Max Energy: 11.9MeV

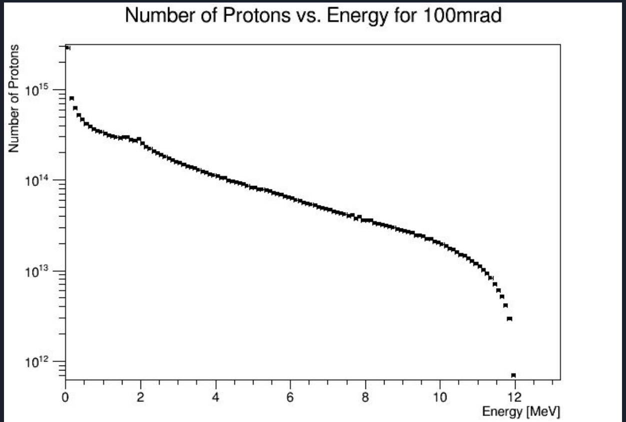
100mrad and 54mrad Energy-Angle Graphs for 0.9MeV-8.6MeV Beam

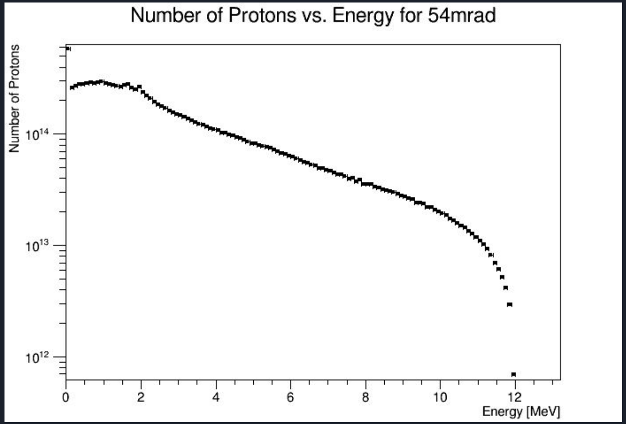


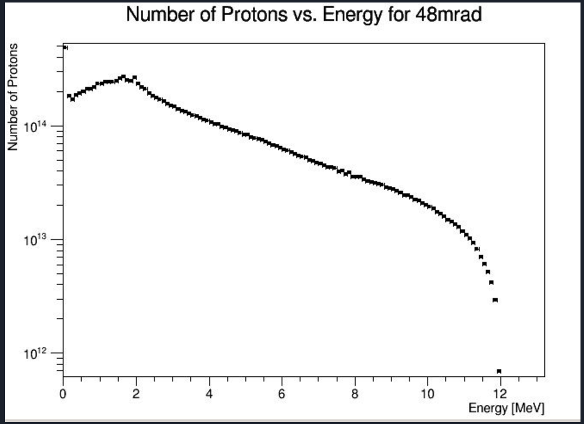


Input Beam Proton Numbers Comparison

Angular Cut / mrad	Percentage of Total Particles
48	48.49%
54	52.95%
100	71.70%







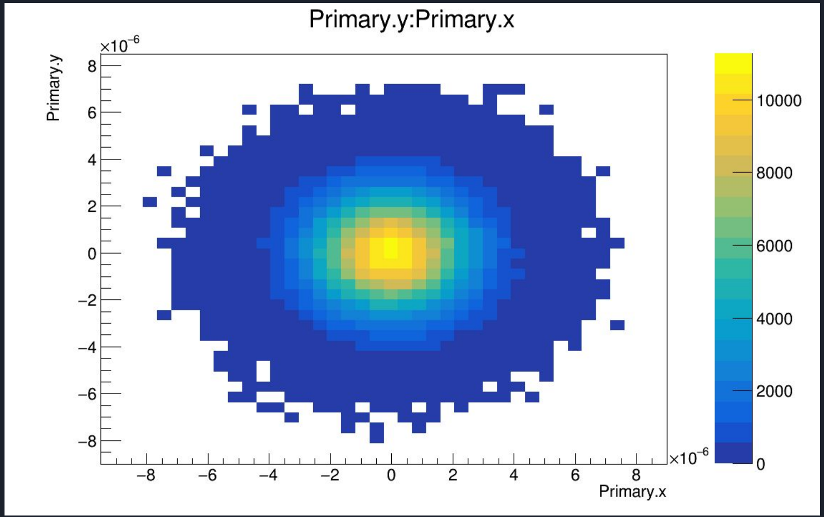
This stepped through the energies and found the number of protons in each 0.1MeV step.

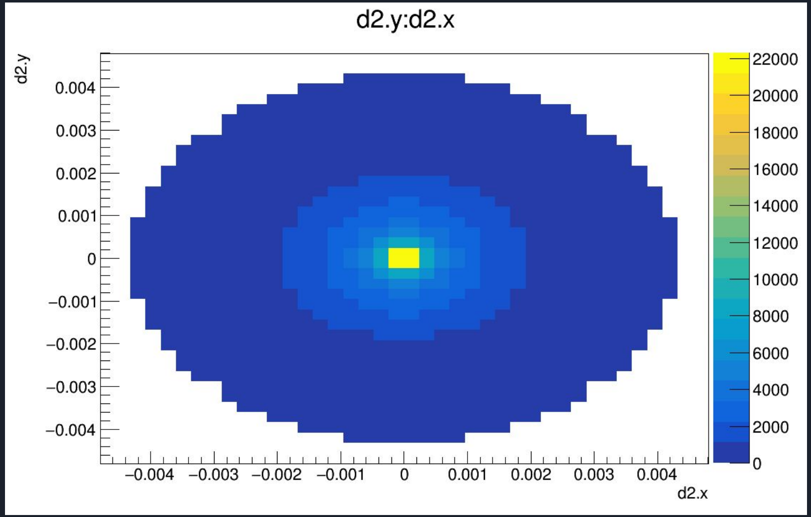
Beam in BDSim

Energy: 8.6MeV±10%

Assumed Gaussian distribution with σ=1.7um.

Run with 1 million particles.





Outcomes of Work on Input Beam Simulation

- Scripts which convert the data from the laser simulation into a BDSIM input file for simulating the proton beam have been developed
  - This could be used to make beams of different energy cuts, angle cuts or from new simulation data.
  - Could be used to simulate a carbon beam if the file from the laser simulation is in the same format.
- 8.6MeV+-10% beam simulation in BDSIM.
- Scripts to plot the graphs shown and calculate the number ratios of different energy cuts.

Simulating the End Station - Aims:

- Investigate which physics models are required to simulate proton interactions in the end station in BDSIM.
- Compare results in BDSIM to results previously obtained in TRIM for proton, ion and carbon beams in water and an example end station.
- Simulate the CCAP end station in BDSIM and find the beam energy required for the bragg peak to be in the cell layer.

Investigation of Physics Models in Geant-4 and BDSIM

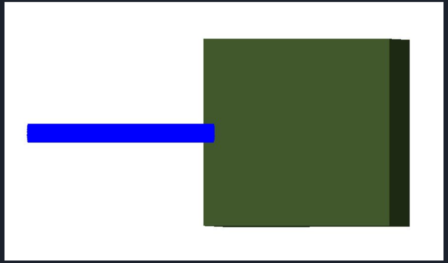
- BDSIM allows the inclusion of most of the physics packages included in Geant4. These have to be turned on individually.
- Modelled cylindrical proton and helium ion beams going into water and calculated their mean stopping distances and the mean dose delivered to the total volume swept out by the beam.
- Tested with different electromagnetic physics packages.

Modelling Stopping Distance & Dose in Water in BDSIM

Particle	Kinetic Energy /MeV	Physics	Measured Stopping Distance /m	Standard Deviation / m	Known Stopping Distance / m	Measured Dose /Grays	Mean Dose /Grays
Proton	11	em decay ion	1.50E-03	3.78E-05	1.46E-03	1.55E-02	1.54E-02
		em_extra decay ion		8.42E-05		1.53E-02	
		Em_4 decay ion		2.42E-05		1.50E-02	
		em_livermore decay ion		1.92E-05		1.53E-02	
		em_low_ep decay ion		2.29E-05		1.56E-02	
		em_low_ep decay		1.94E-05		1.56E-02	
Helium-4 Ion	12.02	em decay ion	2.00E-04	4.35E-06	1.53E-04	1.74E-01	1.67E-01
		em_low_ep decay ion		3.13E-06		1.58E-01	
		em em_extra decay ion		4.28E-06		1.65E-01	
		Em_4 decay ion		2.61E-06		1.77E-01	
		em_low_ep decay		1.95E-06		1.59E-01	

- No variation in mean stopping distances.
- Variation in standard deviation and thus spread of bragg peak.

- Em_low_ep (G4EmLowEnergy) includes the lowest energy models so this was chosen for the subsequent simulations.



Modelling Stopping Distance in Water in Geant4 with DNA Physics Models

- Geant4-DNA models allow physics processes for the interactions of protons, electrons and ions in water to be modelled down to the order of 1eV.
- Will be included in the next release of BDSIM.

Geant4 DNA Results

Particle	Physics List	Number of Particles	Kinetic Energy / MeV	Measured stopping distance /m	Error	Known stopping distance /m
proton	G4EmDNAPhysics	100	1.00E+06	2.4E-05	5.1E-07	2.4E-05
	G4EmDNAPhysics_option2	100		2.5E-05	4.4E-07	2.4E-05
	G4EmDNAPhysics_option5	100		2.4E-05	5.7E-07	2.4E-05
	G4EmDNAPhysics_option6	100		2.4E-05	5.0E-07	2.4E-05
	G4EmLowEPPhysics	100		2.6E-05	1.4E-06	2.4E-05
	G4EmDNAPhysics_option2	100	1.10E+07	1.46E-03	1.3E-05	1.455E-03
	G4EmLowEPPhysics			1.46E-03	2.0E-05	1.455E-03
Helium	G4EmDNAPhysics_option2	100	1.00E+06	5.6E-06	2.3E-07	5.7E-06
	G4EmLowEPPhysics	100	1.00E+06	6.45E-06	1.13E-06	5.70E-06
Carbon	G4EmDNAPhysics_option2	100	1.00E+06	7.18E-06	5.02E-08	-
	G4EmLowEPPhysics	100		1.49E-05	3.19E-07	

- Variation in ‘error’ = standard deviation between the models.
- For Helium, only with DNA physics turned on is stopping distance within standard deviation of known value.

Note: Known stopping distance values taken from NIST’s PSTAR and ASTAR databases.

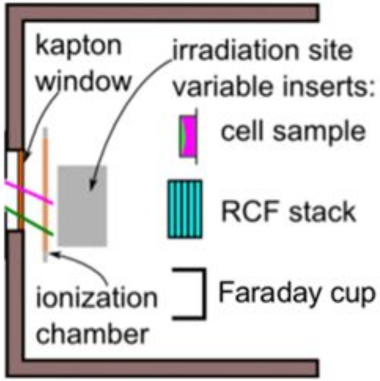
Comparison of Results in BDSIM and TRIM -Water

						BDSIM Results		TRIM Results	
Ion		# of Particles	Kinetic Energy (MeV) / ion	Energy (MeV) / u	Total Energy (MeV)	Mean Range (cm)	Standard Deviation	Mean Range	Straggling
1	H	1000	79	79	1017.3	5.09	0.05	5.000	0.070
1	H	9999	79	79	1017.3	5.09	0.06	5.000	0.070
3	He	1000	273	91	3081.39	4.93	0.03	5.000	0.040
3	He	9999	108.3	36.1	2916.69	0.94	0.01	0.942	0.008
4	He	1000	310	77.5	4037.38	4.95	0.03	5.000	0.070
4	He	9999	82	20.5	3809.38	0.45	0.00	0.444	0.003
12	C	1000	1740	145	12914.9	5.01	0.02	5.000	0.020
12	C	9999	246	20.5	11420.9	0.15	0.01	0.15	0.00

Note: Beam distribution in TRIM simulation unknown. Discrepancies in stopping distance when different shaped beams are used. A gaussian beam was chosen for the BDSIM simulation as this is closest to the real beam distribution.

Comparison of Results in BDSIM and TRIM - Kraft End Station

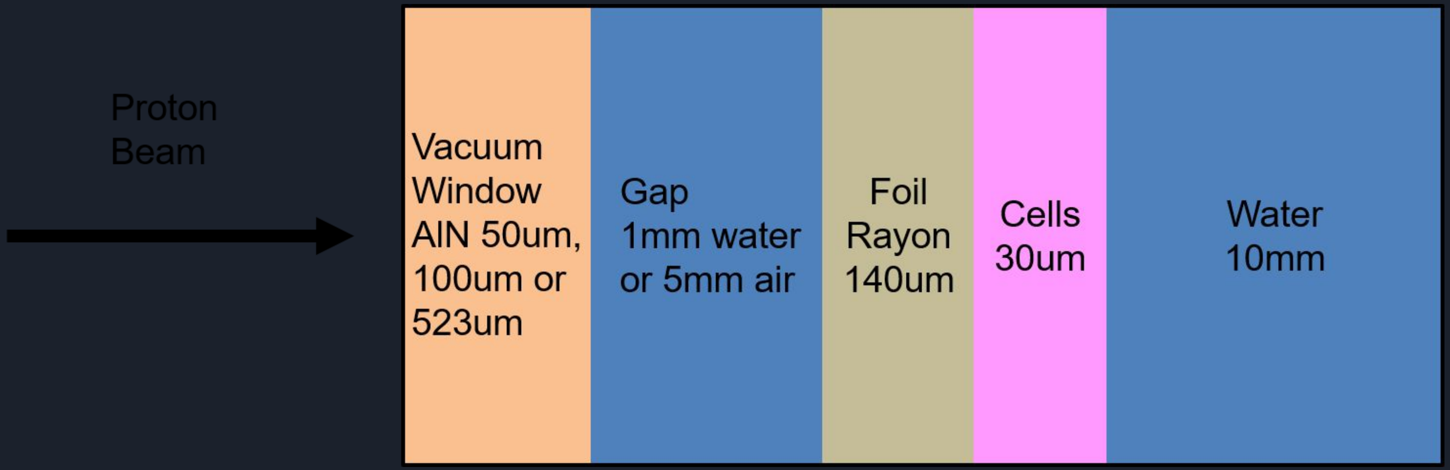
Article: S D Kraft et al 2010 New J Phys. 12 085003



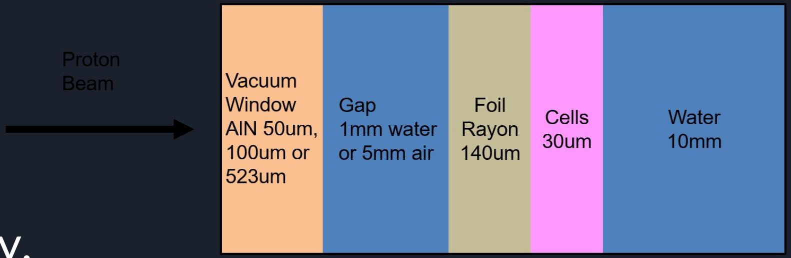
Protons have to pass through
1) Vacuum window (7.5um of kapton)
2) Ionization chamber (~ 22.5um of kapton)
3) Bottom of petri dish (50um of lumox/pca; Polyethylene in the simulations)
4) Air on left and right side of IC (~ 500um of dry air)
5) Monolayer of cells (30um for skin cells type1)
6) Parafilm (I used Plexiglas instead) used to close well (100um)

- In both TRIM and BDSIM a 3MeV proton beam was found to have an average stopping point in the parafilm.

End Station Design - First Estimate

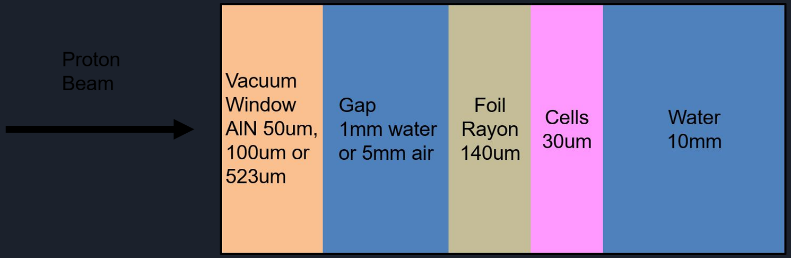


End Station Design - Vacuum Window



- Same material used as at Surrey.
- 523um comes from online calculator. Required input of:
  - Modulus of rupture: 53228.8 psi (max. value).
  - Diameter of window: 30mm.
  - Pressure: atmospheric

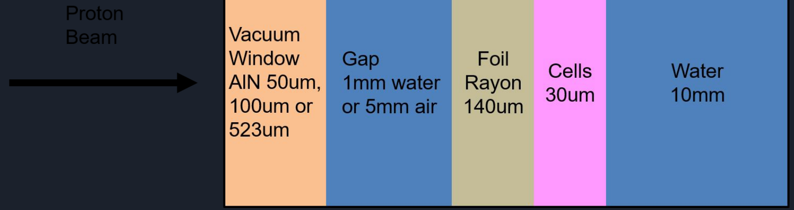
End Station Design - Foil



- Foil: 140um foil tested already. 100-200um possible.
- Cells would be placed in a flask whose plastic bottom would be removed and replaced with the foil.
- Therefore no plastic/water in front of cells.

End Station Design - Gap

- Foil placed as close to end station as possible.
- Ideally gap should be filled with water as it has a closer density to that of cells so there would be less inhomogeneities in the energy deposition at the edges of the cell layer.
- Modelled as air or water.

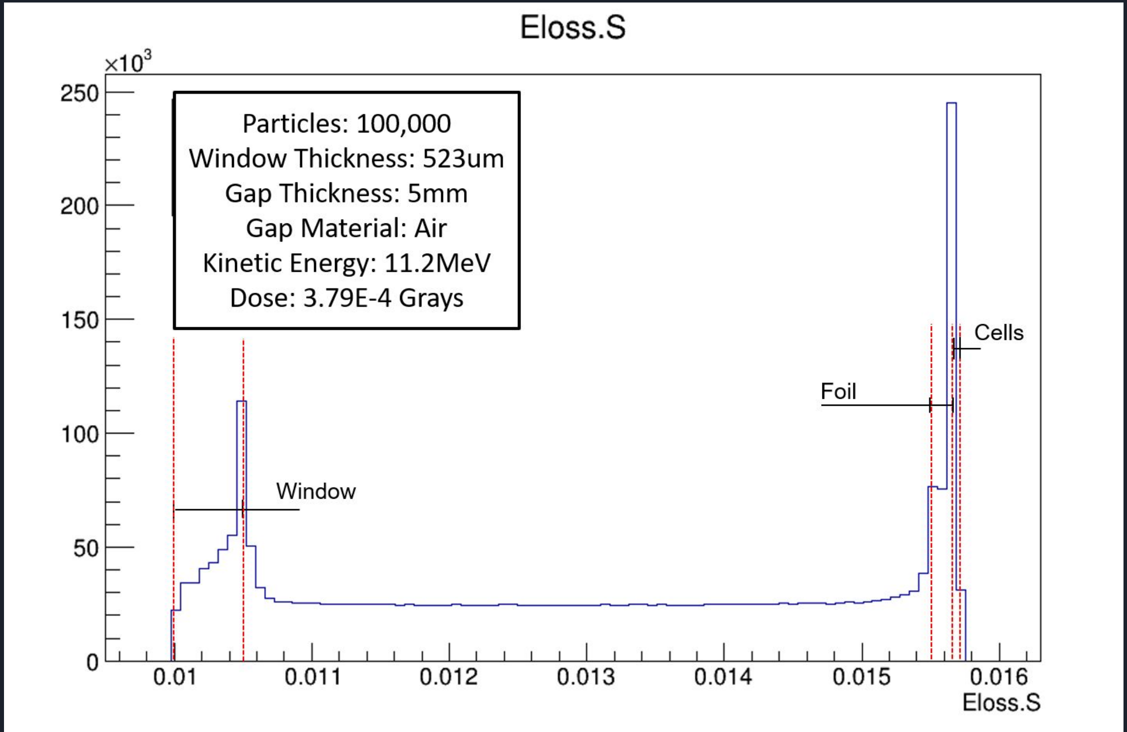


Energies Required for Bragg Peak in Cell Layer

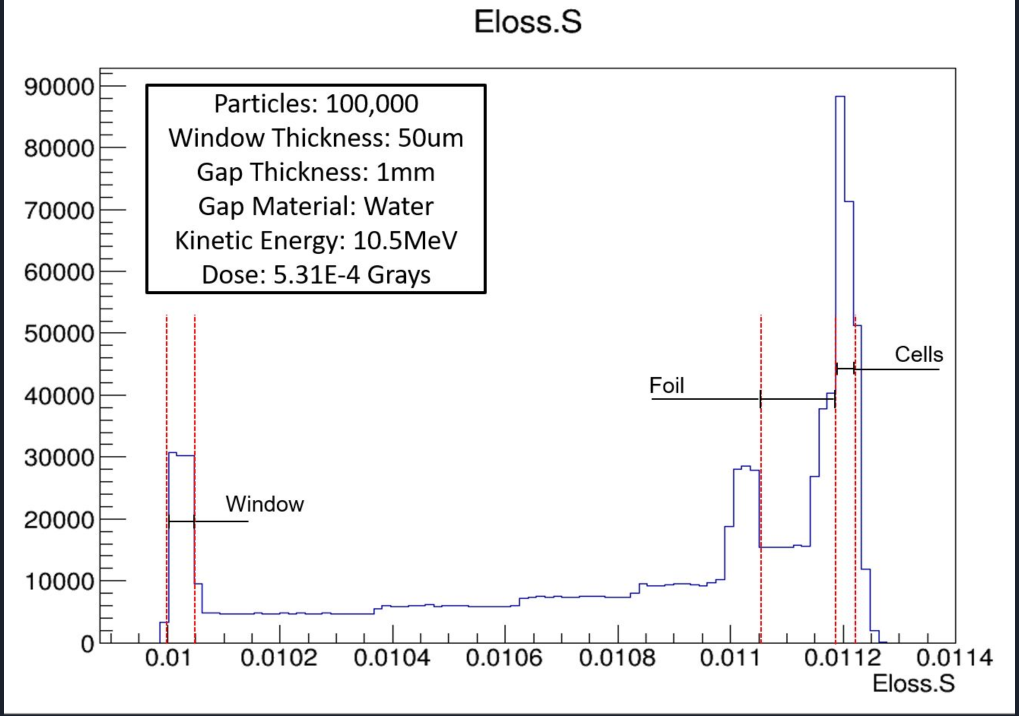
Kinetic energy /MeV	Vacuum Window Thickness /m	Gap Thickness /m	Gap Material	Mean Stopping Distance into Cell Layer / um	Standard Deviation	Mean Dose Delivered to Cells /Grays
4.7	5.00E-05	5.00E-03	Air	0.0	6.48E-05	7.27E-05
5.8	1.00E-04	5.00E-03	Air	10.0	2.41E-05	5.12E-04
11.4	5.23E-04	5.00E-03	Air	7.0	1.04E-03	3.79E-04
11	1.00E-04	1.00E-03	Water	10.0	1.92E-05	3.57E-04
10.5	5.00E-05	1.00E-03	Water	20.0	1.93E-05	5.31E-04

- 11.4MeV beam required to reach cell layer.
- Much larger standard deviation with thickest window - broader bragg peak.

Graph of Energy Deposition Locations with 5mm Air, 523um Window



Graph of Energy Deposition Locations with 1mm Water, 50um Window



Is 11.4MeV possible with the current laser?

- Yes! We get protons up to 11.9MeV from the Laser.

Energy (±2%) / MeV	Percentage of total number in 54mrad Beam of all energies	Percentage of total number of protons leaving target
8.0	0.93%	0.49%
8.6	0.86%	0.46%
9.0	0.80%	0.42%
10.0	0.64%	0.34%
11.0	0.41%	0.21%
11.4	0.28%	0.15%

- The proton numbers output by the laser simulation are unreliable the relative numbers are reliable, so can be used to find the ratios of particles contained in different energy selections.
- A 54mrad angular selection is assumed in these calculations.

Conclusions & Limitations

- With the current model for the end station, the current laser can be used to achieve the proton energies required for the bragg peak to be inside the cell layer in the end station.
- Limitations to end station model:
    - Vacuum window thickness estimated from online calculator. More exact calculations need to be performed.
    - Thickness of gap between window and foil unknown.
    - Foil thickness could range from 100-200um.

Future Investigations

- Edit the end station model when more information is known.
- Run with a beam which has an energy spread and investigate how this affects the energy deposition.
- Run with ions.
- Run with the real beam after the capture and transport sections.
- Run with Geant4-DNA turned on once it's implemented in BDSIM.

Thank you!

Graph of Energy Deposition in Cell Layer with 5mm Air, 523um Window