Ion Beam Energy Spectrum Calculation via Dosimetry Data Deconvolution

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ABSTRACT

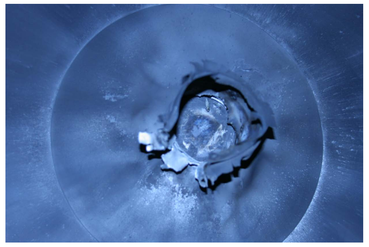
The energy spectrum of a H^+ beam generated within the HERMES III accelerator is calculated from dosimetry data to refine future experiments. Multiple layers of radiochromic film are exposed to the beam. A graphic user interface was written in MATLAB to align the film images and calculate the beam's dose depth profile. Singular value regularization is used to stabilize the unfolding and provide the H^+ beam's energy spectrum. The beam was found to have major contributions from 1MeV and 8.5MeV protons.

BACKGROUND

The HERMES III accelerator is typically used as a pulsed photon source to experimentally obtain photon impulse response of systems due to high energy photons. A series of experiments were performed to explore the use of Hermes III to generate an intense pulsed proton beam. Knowing the beam energy spectrum allows for greater precision in experiment predictions and beam model verification.

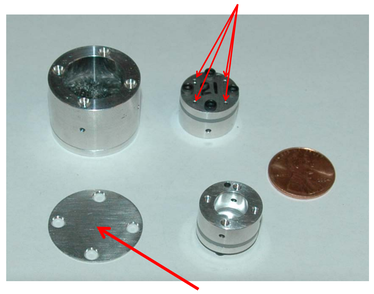
1. Pulsed power systems compress electricity into a pulse of a few ns. This pulse is on the order of 10^9 W.

2. An Al-6061 anode with a PETG covering is the source of the H^+ beam.



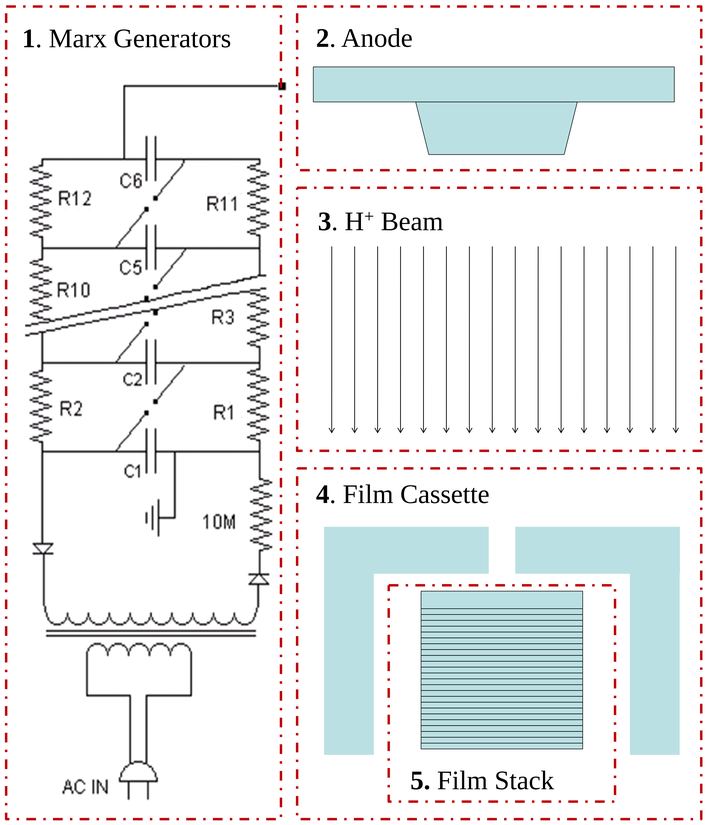
3. Spalling (above) is a typical result of high energy electrons and protons interacting with materials. A witness plate (below) is used to track beam position.

5 UV Fiducials

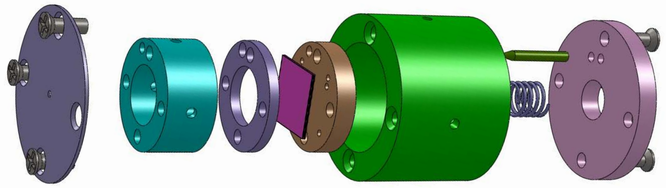


Pinhole aperture:
#80 – 0.0135in

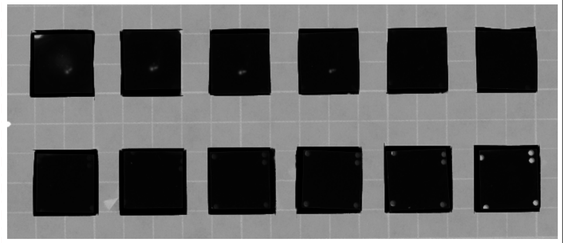
H^+ Beam Formation



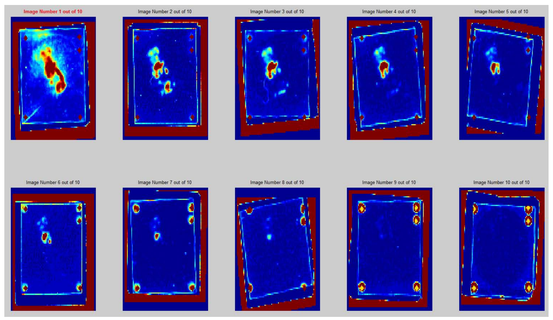
4. The film cassette is an Al-6061 cylindrical shell whose purpose is to hold the radiochromic film pieces and allow the creation of 5 UV fiducials. A cassette cover with a small aperture is used to prevent debris from depositing onto the film while still allowing the beam to pass.



5. Calibration data was taken at the Gamma Irradiation Facility (GIF). This allows for the conversion between optical density and radiation dose via a power law relationship. A graphic user interface was made in MATLAB to align the images, extract data and output the dose depth profile vector "y".

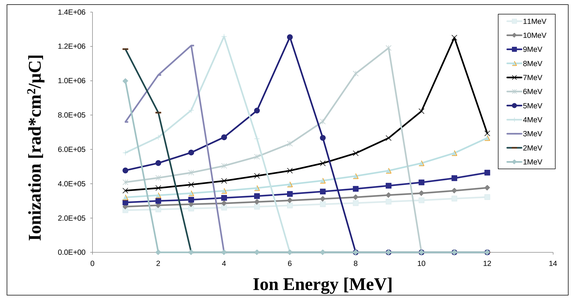


MATLAB GUI



Response Functions

Simulations in Stopping and Range of Ions in Matter (SRIM) yield impulse response of the system due to mono-energetic protons. Discretization of these response functions gives the kernel matrix "K".



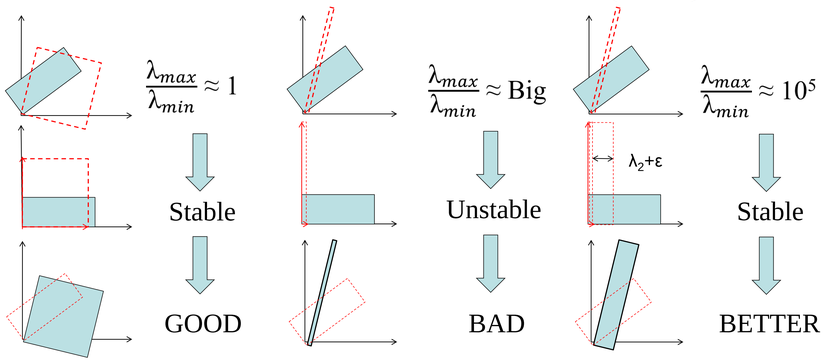
Regularization

Spectral unfolding is an unstable process. Regularization changes the problem by a small amount to stabilize the solution

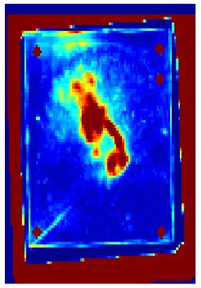
$$\boldsymbol{A}x = y \;\rightarrow\; \boldsymbol{K}x = (\boldsymbol{A}^*\boldsymbol{A})x = \boldsymbol{A}^*y = \tilde{y}$$

Every "nice" matrix can be decomposed into a rotation, a scaling, and then another rotation via Singular Value Decomposition (SVD). Add a small number to the smallest eigenvalue to lower the matrix's condition number.

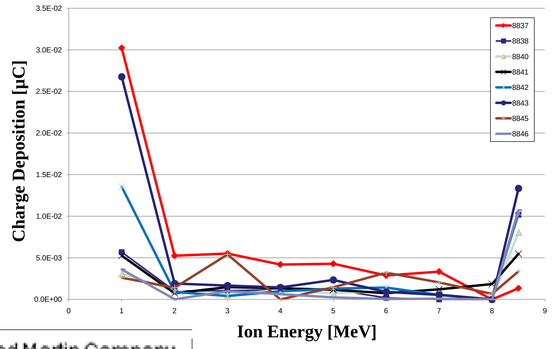
$$\boldsymbol{K} = \boldsymbol{USV}^* \;\longrightarrow\; \boldsymbol{K}^{-1} = \boldsymbol{VS}^+\boldsymbol{U}^* \;\longrightarrow\; \boldsymbol{K}^{-1} = \boldsymbol{V}(\boldsymbol{S} + \varepsilon\boldsymbol{I})^+\boldsymbol{U}^*$$



Results



SVD regularization worked to stabilize the spectral unfolding and give beam's energy spectrum (right). The unfold showed major components of 1MeV and 8.5MeV protons. Debris is suspect as the cause of the high contribution of low energy protons. The MATLAB GUI also allowed for visual inspection of beam shape (left).



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