National Aeronautics and
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Low-Energy Proton Testing Using Cyclotron Sources

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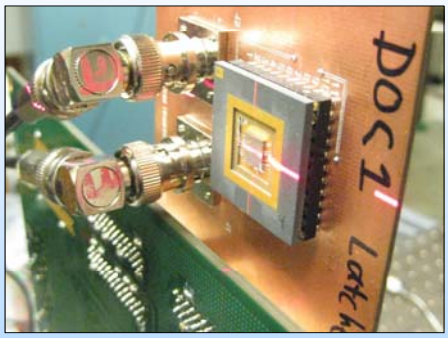
To be presented by J. A. Pellish at the 2011 Nuclear and Space Radiation Effects Conference (NSREC), Las Vegas, NV USA 29 July 2011 and published on http://radhome.gsfc.nasa.gov/ and http://www.nepp.gov/.

Outline

- Introduction
- Proton facility
  - UC Davis Crocker Nuclear Laboratory (CNL), BL2
  - Beam line monitoring
    - Surface barrier detector
    - Radiochromic film
- Transport simulations
- Missing pieces
  - Angular divergence
  - Beam spot shape
- Conclusions



Conflict between the ideal beam that we would like versus realities we have to accept

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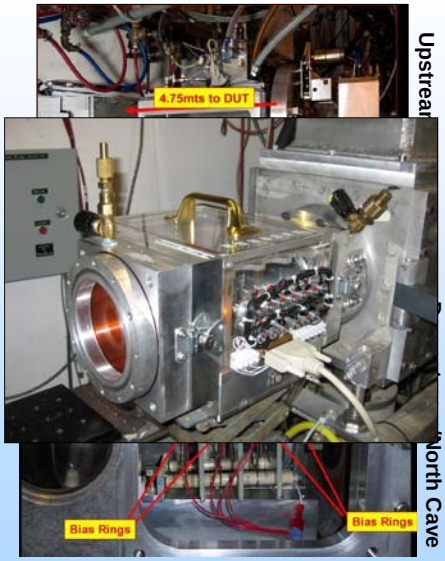
UC Davis Crocker Nuclear Laboratory

Assuming Setup In-Air (can do vacuum)

- **Upstream-to-downstream progression:**
  - **Beam diameter on 6.35 μm Ta foil is 0.79 cm**
  - **Defining collimator is 0.95 cm**
  - **Secondary electron emission monitor (SEEM) uses three 6.35 μm Al foils**
  - **User-selected degraders are inserted here (Al or Mylar)**
  - **Kapton exit window and defining collimator**
  - **Air gap is user-selected within experimental parameters**
  - **Can put vacuum chamber here**

C. M. Castaneda, *IEEE REDW,* Vancouver, BC Canada, 2001, pp. 77-81.



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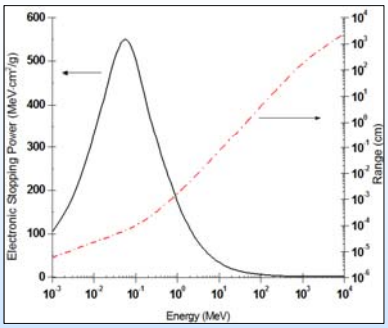
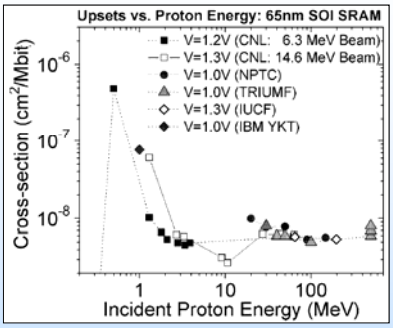
Low-Energy Proton Testing



NIST PSTAR tool (ICRU Report 49, 1993)



D. F. Heidel et al., TNS, vol. 6, 2008.

- **Cross sections plotted as a function of <u>incident</u> proton energy – inversely proportional to degrader thickness**
- **Greatest effect in the shortest distance; beam loss at low energy**

Early analysis efforts were bound by existing beam analysis techniques; dependent on knowledge of flux, energy, and angular divergence

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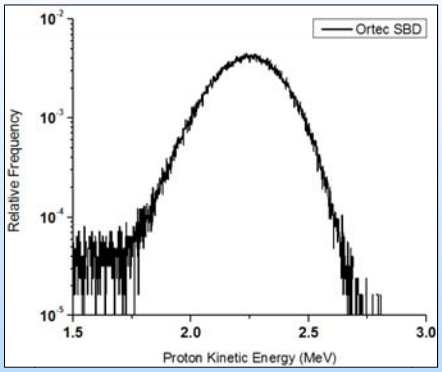
Beam Line Monitoring

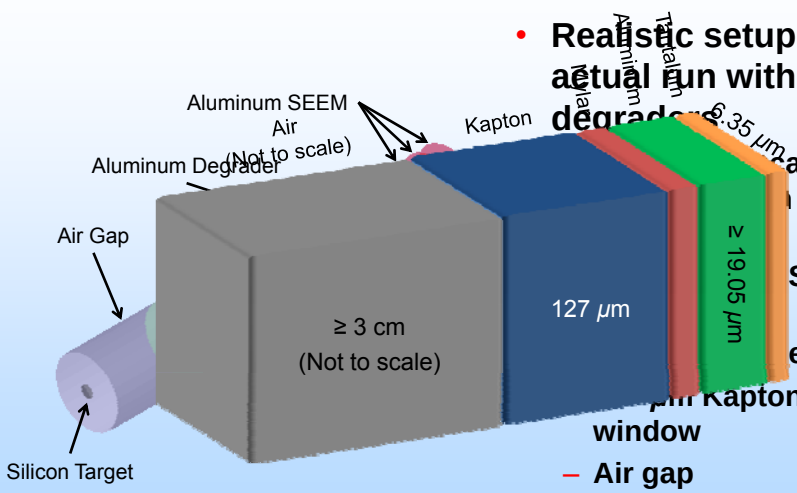
- **Use Ortec fully-depleted silicon surface barrier detectors**
  - **Calibrated with ^{241}Am source**
  - **Degraded to different energies for multiple cal points**
- **Provides in-situ information regarding mean and distribution**
  - **Not a particle counter**
- **Not possible to make measurements for all beam scenarios**



Example SSBD Proton Energy Spectrum
SSBD = silicon surface barrier detector

Modeling the CNL Beam Line

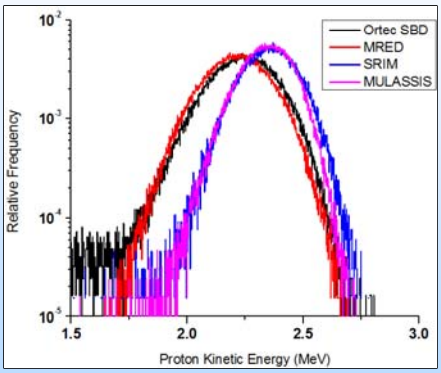
- **Realistic setup for an actual run with degrad**
  attering
  (~4 m
  SEEM
  ers
  μm Kapton exit window
  - **Air gap**
  - **Silicon target**



Typical planar stacked target (*e.g.*, SRIM)

MRED, SRIM, and MULASSIS *vs.* Data

Degraders
50.8 μm aluminum & 3.175 μm Mylar



2.21 MeV MRED | 2.25 MeV SBD | 2.34 MeV MULASSIS | 2.35 MeV SRIM

- **Beam data comes from a calibrated Ortec B-18-150-300 fully depleted silicon surface barrier detector**
- **~120k events for each dataset**
- **Spacing between beam line elements and target size make a difference**
  - **SRIM and MULASSIS are planar stacks**
  - **Could be additional factors**
- **Energy distribution appears to be well-described, but what about the *spatial* distribution?**

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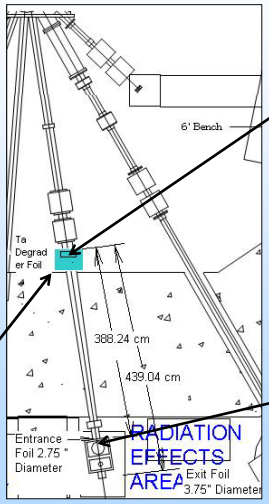
Experimental Angular Divergence

- **Raw beam with no Ta foil and no quadrupole doublet**
- **Radiochromic film images are not correlated due to retuning after entering vault; may change shape with next tune**
- **Angular divergence of beam due to beam tune only**
- **Measured divergence is approximately 0.7°**
  - **Via phosphorus screen (not shown)**



Images are scaled accurately – 8.2x larger area downstream

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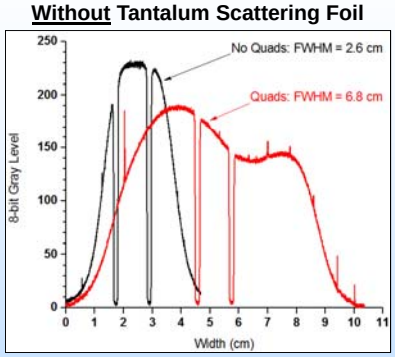
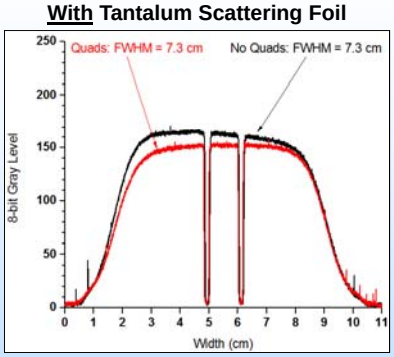
Beam Shape in North Cave

Without Tantalum Scattering Foil



With Tantalum Scattering Foil



- **Tantalum foil and quadrupole doublet each have critical role to play**
- **Effect of magnets cannot be described analytically**
  - **Information about the quadrupoles lost to history, but…**

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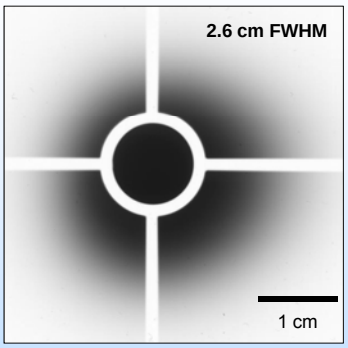
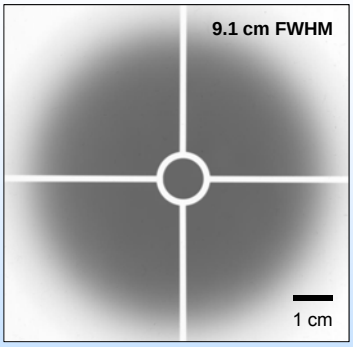
Grayscale Beam Spot in North Cave

No Ta foil + No Quads



Ta foil + Quads



- **Pictorial description of quadrupole doublet and Ta foil interactions**
- **Upshot is that the arrangement works and we can prove it even if we cannot write it down**

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Conclusions

- CNL represents ideal (though not only) choice for cyclotron low-energy proton single-event testing – outside of normal use
  - Minimal beam line mass
  - User-controlled degrader setup in vacuum
  - Optional vacuum chamber
- Use beam line monitoring techniques to ensure knowledge of the beam characteristics
  - Surface barrier detector (calorimetry and scattering meas.)
  - Radiochromic film
- Employ radiation transport simulations for pre-experiment investigations and extrapolation of observed conditions (energy deposition, cross section, and rates)
- Need beam energy and momentum characteristics for highest fidelity simulations
  - Energy distribution OK for stopping and range
  - Divergence remains an important unquantified variable

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Questions?