National Aeronautics and
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Low-Energy Proton Testing Using Cyclotron Sources

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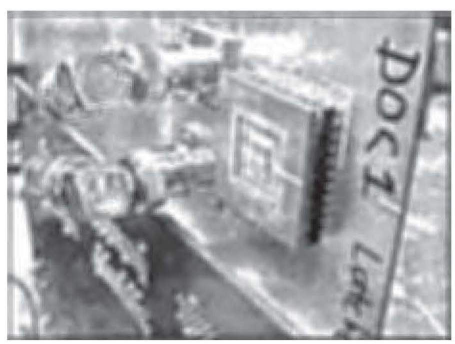
To be presented by J A Pellish at the 2011 Nuclear and Space Radiation Effects Conference (NSREC), Las Vegas, NV USA 29 July 2011 and published on http //radhome gsfc nasa gov/ and http //www nepp gov/.

Outline

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



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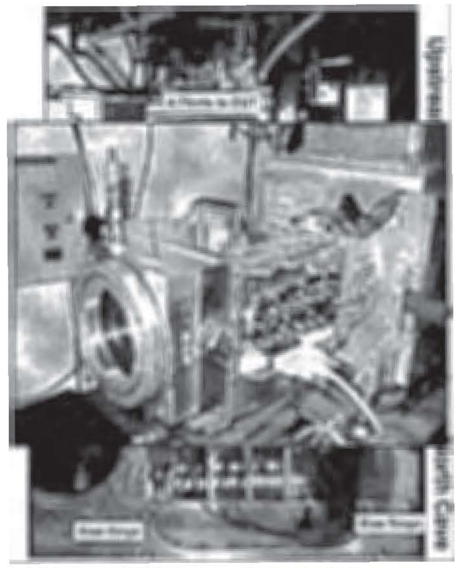
UC Davis Crocker Nuclear Laboratory

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**

Ta = tantalum

Al = aluminum



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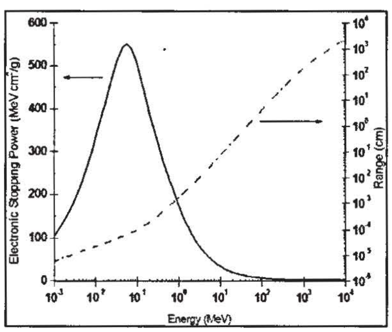
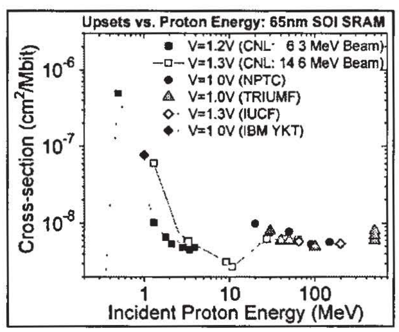
Low-Energy Proton Testing



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**
  - **Several implications/assumptions (just the mean, distribution will change by the time it reaches the sensitive volume, and no flux depletion)**
- **Greatest effect in the shortest distance; beam loss at low energy**
- **How do we know the mean energy and standard deviation?**

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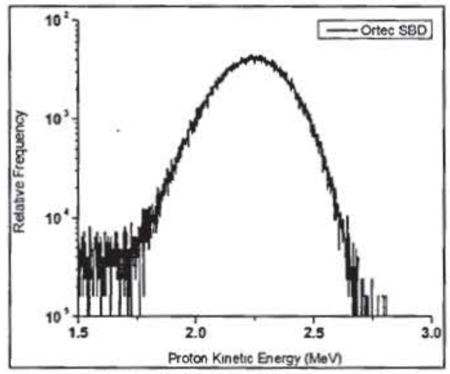
Beam Line Monitoring

- **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**

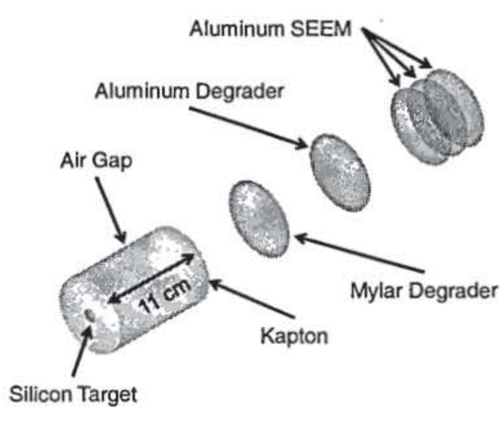


Example SSBD Proton Energy Spectrum

Am = americium

SSBD = silicon surface barrier detector

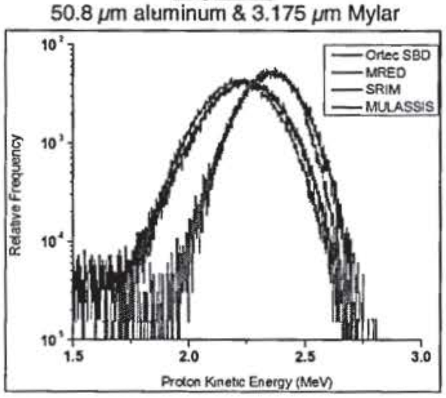
MRED 3-D Model of the CNL Beam Line



- **Realistic setup for an actual run with degraders**
  - **6.35 μm Ta scattering foil not shown (~4 m upstream)**
  - **3x 6.35 μm Al SEEM foils**
  - **Al degrader is 50.8 μm**
  - **Mylar degrader is 3.175 μm**
  - **127 μm Kapton exit window**
  - **11 cm air gap**
  - **Silicon target**

MRED, SRIM, and MULASSIS *vs.* Data

Degraders
50.8 μm aluminum & 3.175 μm Mylar



2.21 MeV	2.25 MeV	2.34 MeV	2.35 MeV
MRED	SBD	MULASSIS	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 makes 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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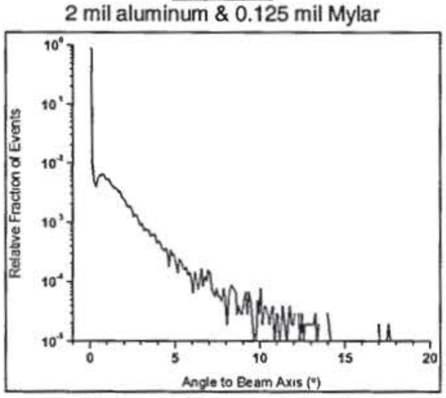
MRED-Simulated Angular Divergence

Degraders
2 mil aluminum & 0.125 mil Mylar



Representative example only

- **Assumes a perfectly parallel beam incident on the Ta foil**
  - **We know this is false**
- **Affects energy loss of proton in device under test**
- **Depends on material spacing along beam line and size of air gap**
  - **Assumed to be smaller in vacuum (advantage?)**

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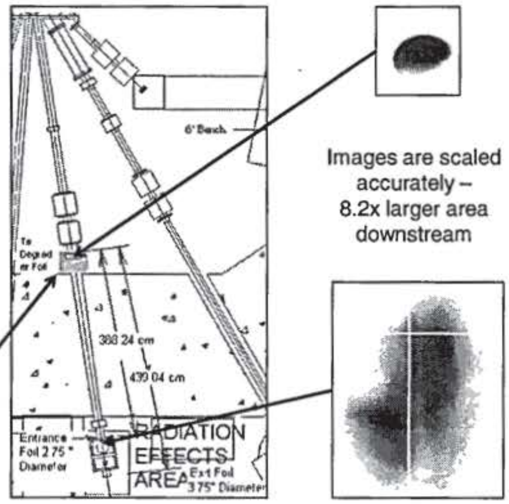
Experimental Angular Divergence

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



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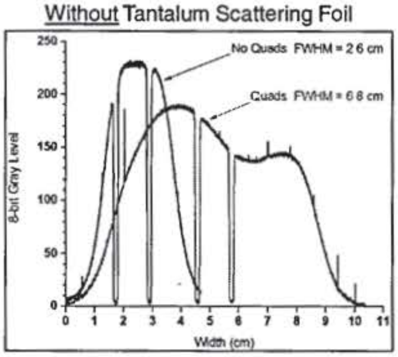
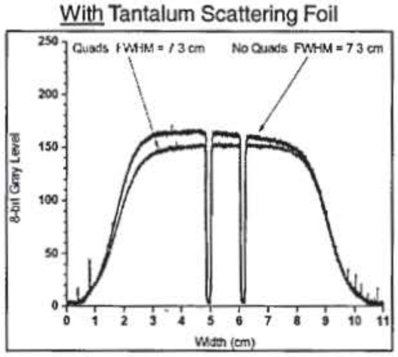
Beam Shape in North Cave

Without Tantalum Scattering Foil



With Tantalum Scattering Foil



- Ta 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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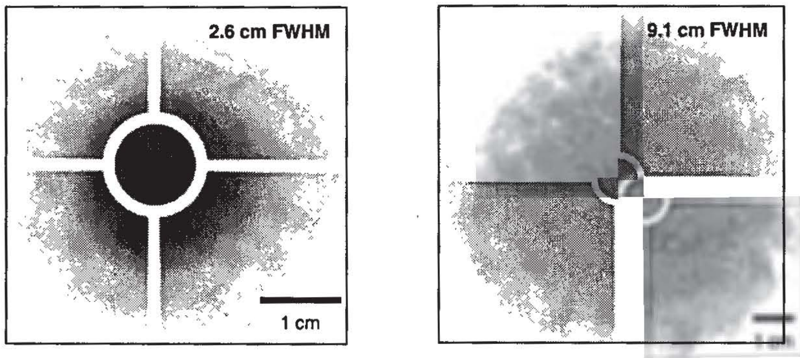
Grayscale Beam Spot in North Cave



- **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**

Conclusions

- **CNL represents ideal (though not only) choice for low-energy proton single-event testing**
  - Minimal beam line mass
  - User-controlled degrader setup in vacuum
  - Optional vacuum chamber
- **Use beam line monitoring techniques to ensure *post facto* knowledge of the beam characteristics**
  - Surface barrier detector
  - Radiochromic film
- **Employ radiation transport simulations for *a priori* investigations and Monte Carlo tools, specifically, for advanced rate calculation methodologies**
- **Need beam energy <u>and</u> momentum characteristics (*i.e.*, beam's emittance) for highest fidelity simulations**
  - Energy distribution OK for stopping and range
  - Momentum/angular distribution required for spatial effects

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Questions?