National Aeronautics and Space Administration

Low-Energy Proton Testing Using Cyclotron Sources

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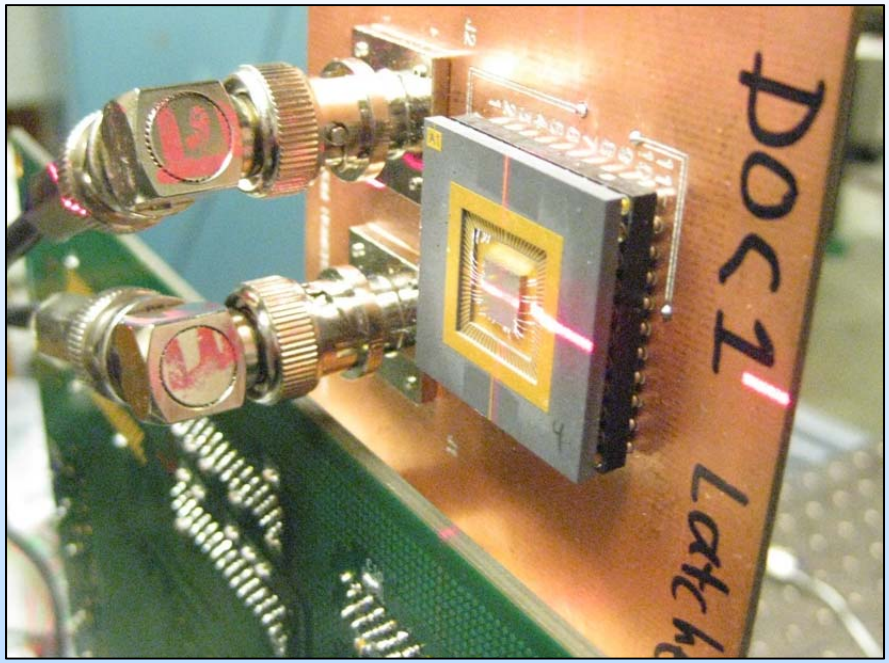
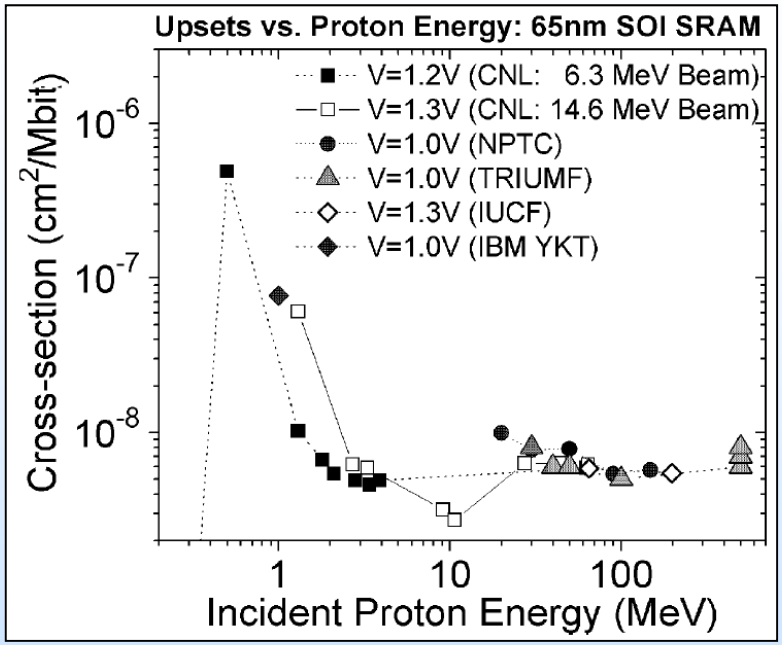
Outline

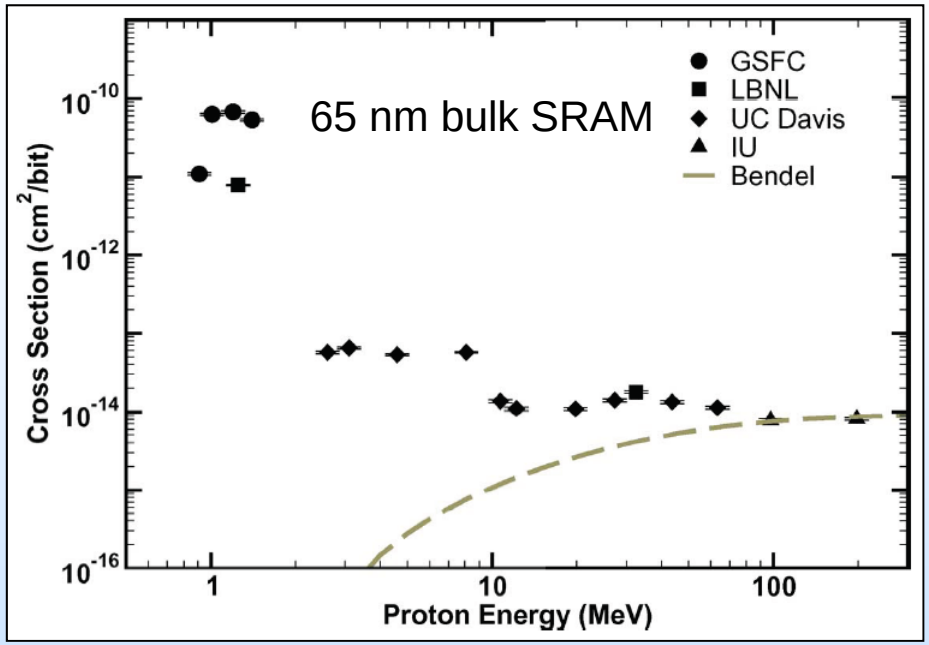
- Introduction
- Proton facility and data collection
  - UC Davis Crocker Nuclear Laboratory
  - Beam line monitoring
  - Systematic considerations
- Proton transport simulations
  - MRED, MULASSIS, SRIM
- Conclusions



Early Low-Energy Proton Data



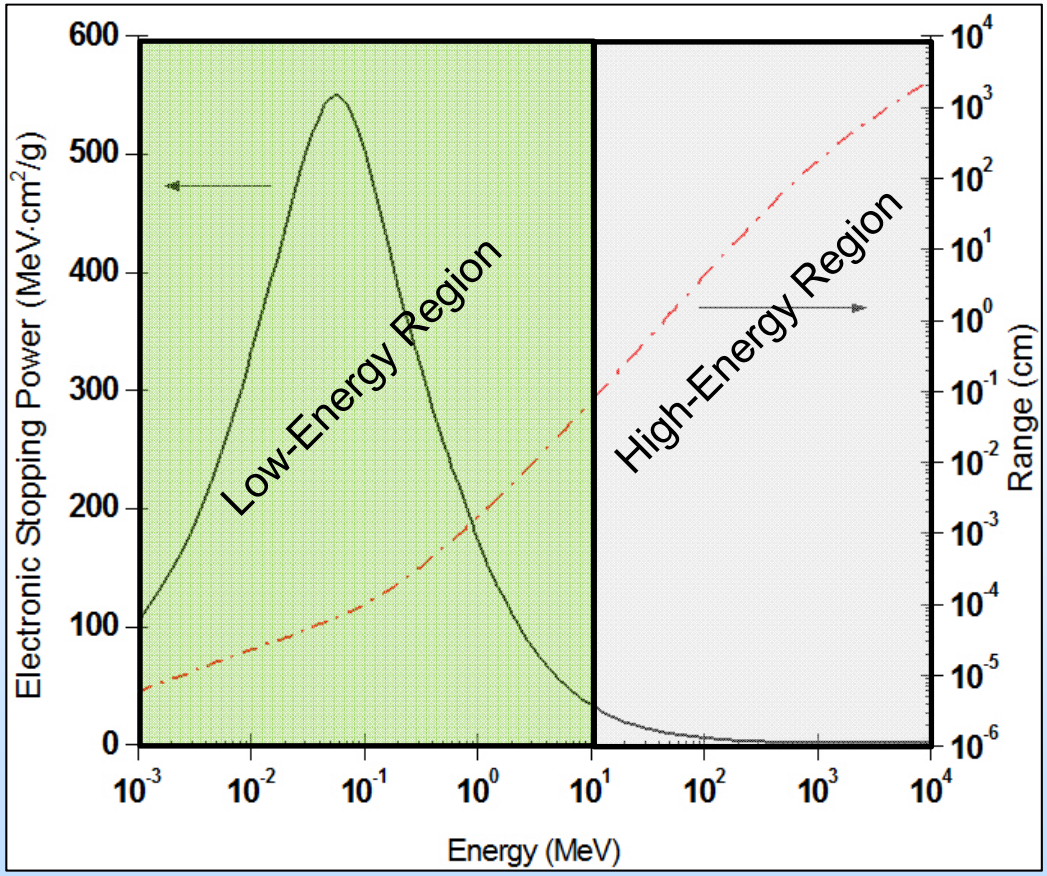
D. F. Heidel et al., TNS, vol. 6, 2008.



B. D. Sierawski et al., TNS, vol. 6, 2009.

- **Cross sections plotted as a function of <u>incident</u> proton energy – inversely proportional to degrader thickness**
  - **Several implications (just the mean, distribution will change by the time it reaches the sensitive volume, and no flux depletion)**
  - **Can also plot versus degrader thickness since that is a well-known quantity**
- **How do we know the mean energy and standard deviation?**

"The Problem" – Range & d*E*/d*x*



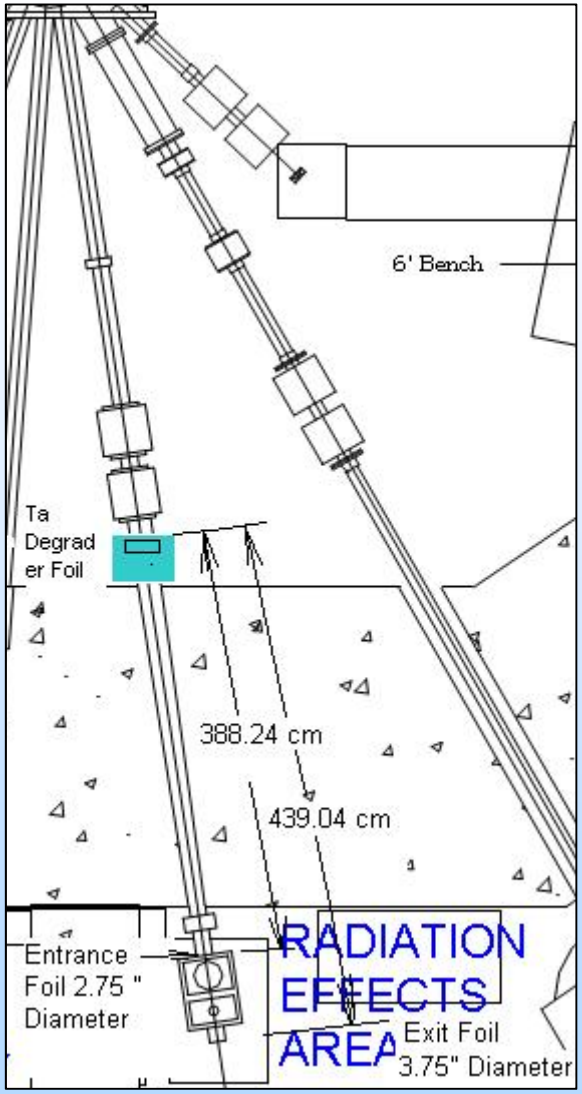
NIST PSTAR tool (ICRU Report 49, 1993)

- **Greatest effect in the shortest distance**
- **Short range at stopping implies beam loss**

UC Davis Crocker Nuclear Laboratory

Assuming Setup In-Air (can do vacuum)

- **Beam diameter on 0.25 mil Ta foil is 5/16 in**
- **Defining collimator is 2.75 in with acceptance angle of 0.018 rad**
- **Secondary electron emission monitor (SEEM) uses three 0.25 mil Al foils**
- **User-selected degraders are inserted here (Al or Mylar)**
- **Kapton exit window**
- **Air gap is user-selected within experimental parameters**



Courtesy of T. Essert and M. Van de Water (UCD/CNL)

UC Davis Crocker Nuclear Laboratory

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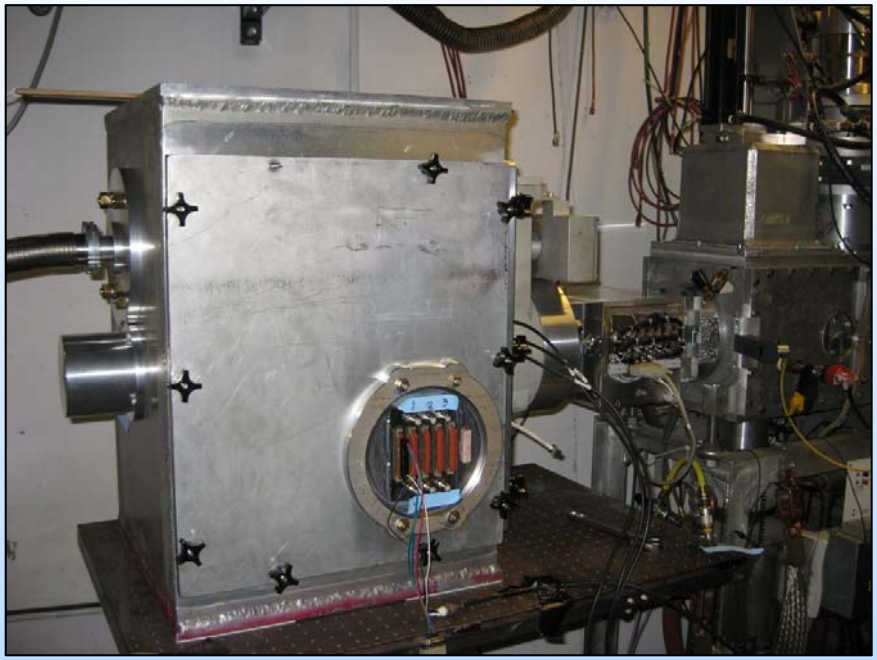
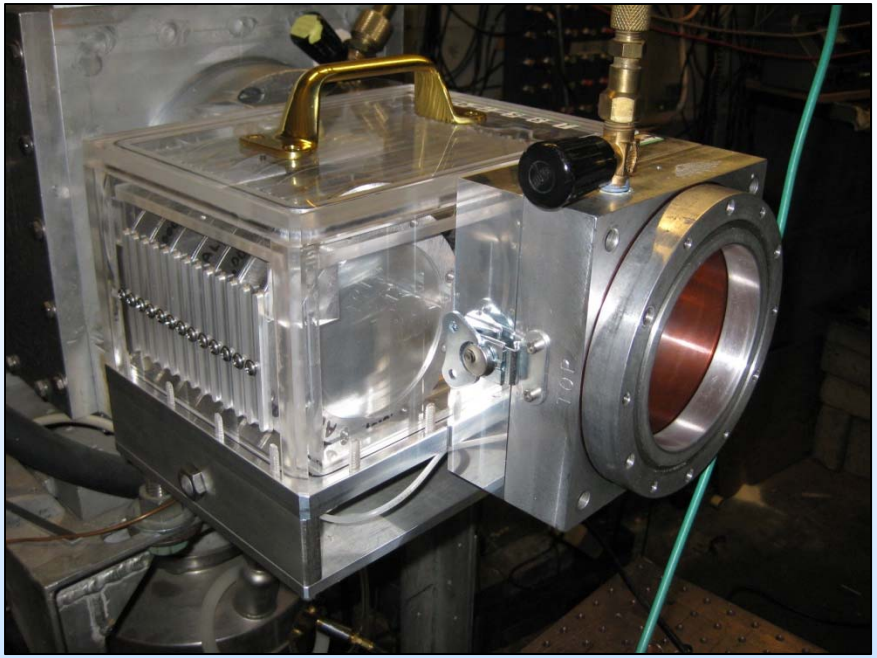
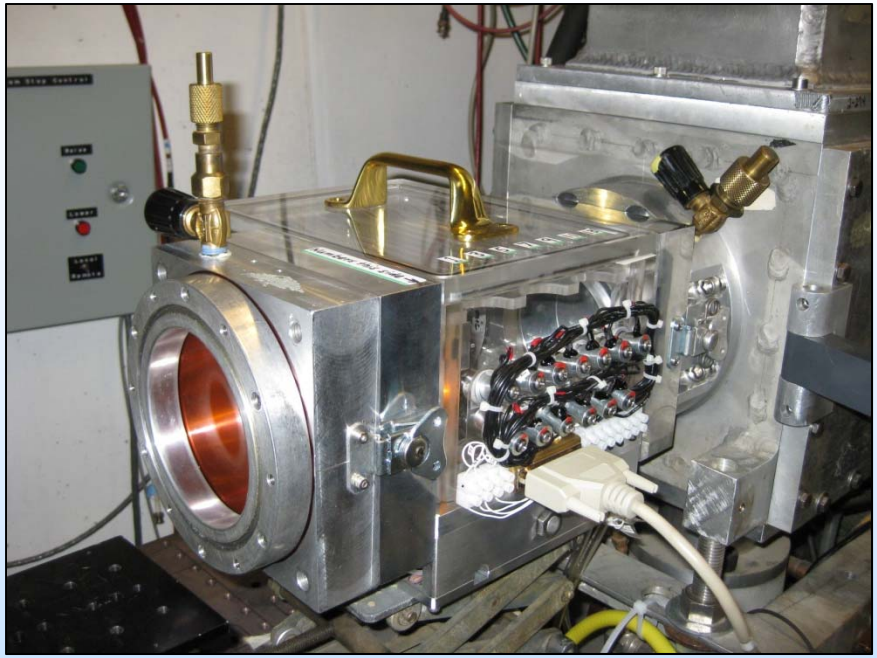


Vacuum chamber at UC Davis/CNL

UC Davis
Crocker Nuclear Laboratory (CNL)

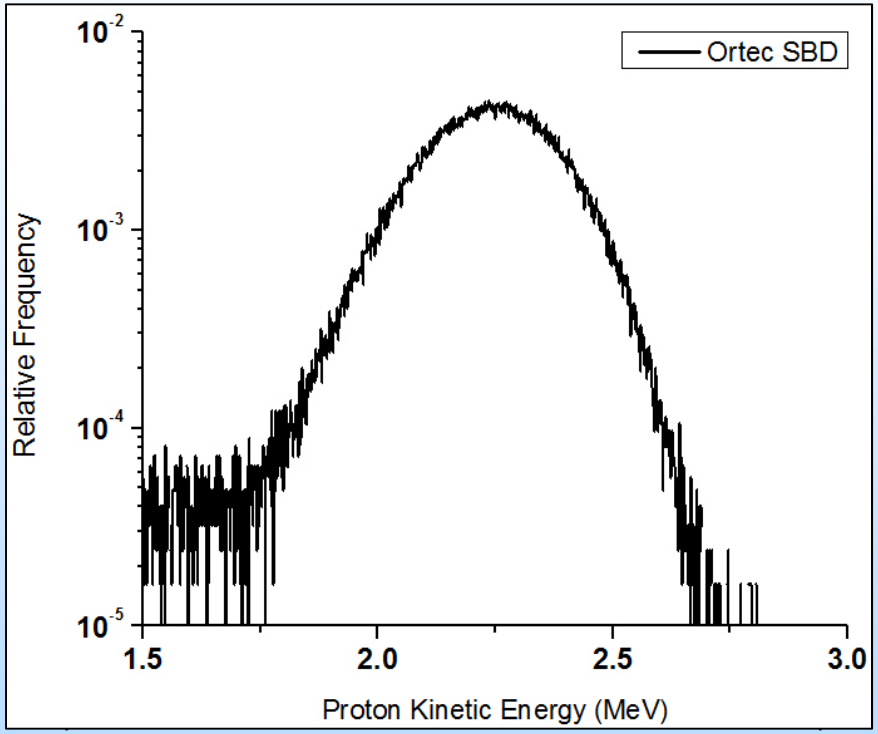




- **New degrader system with user-selectable foils (aluminum and polyethylene terepthalate)**
- **Controlled from the South Cave**

Beam Line Monitoring

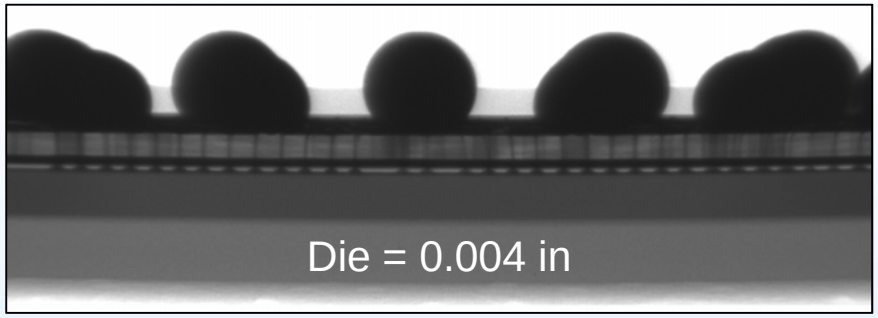
- **Use Ortec fully-depleted silicon surface barrier detectors**
  - **Calibrated with ^{241}Am source**
  - **Degraded to different energies for multiple cal points**
- **Provides in-situ information regarding mean and distribution**
  - **Not a particle counter**

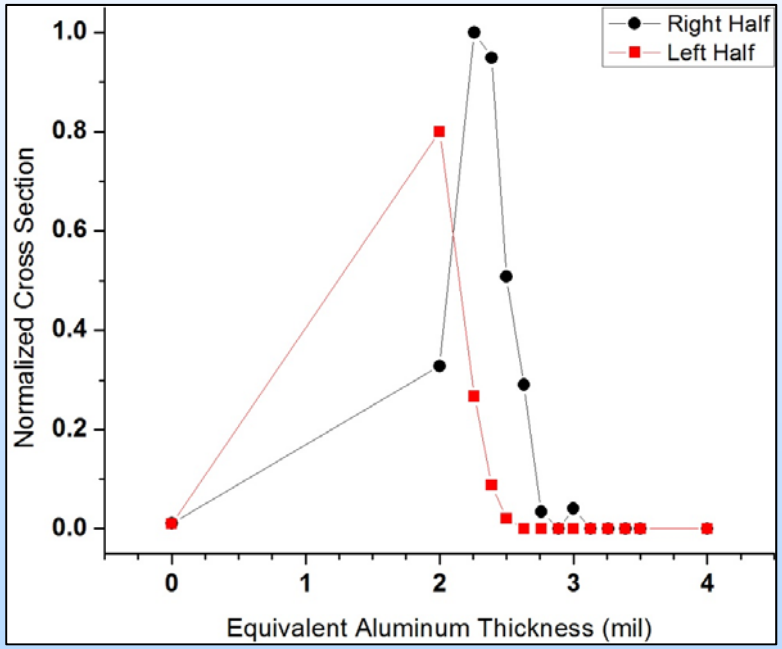


Example SSBD Proton Energy Spectrum

Systematic Effects (I) – Data

- **Flip-chip (C4) assembly thinned to ~100 um and irradiated in-air using 6.5 MeV H^+**
- **Thickness difference of < 15 μm from one side of die to other**
  - **Same scenario possible for thick back end of line**
  - **X-ray not accurate enough**
- **Distortions to device cross section**

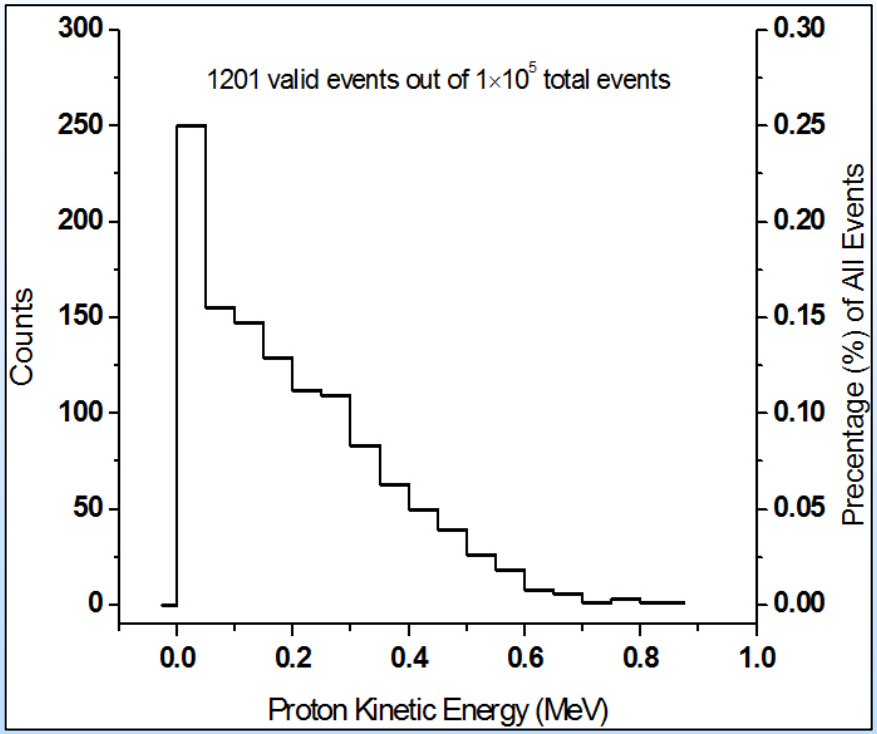




36 Mbit, 45 nm SOI SRAM
Irradiated with 6.5 MeV protons at UC Davis/CNL
Original data from D. F. Heidel, *et al.*, TNS, vol. 6, 2009.

Systematic Effects (II) – SRIM Protons Near Stopping

- **Target structure (without vacuum gaps)**
  - **0.25 mil Ta**
  - **19.05 mil Al SEEM**
  - **5.5 mil Al degrader**
  - **0.5 mil Mylar degrader**
  - **6 cm air**
- **~1% yield at die surface**
  - **Just due to stopping**
- **Mean = 0.20 ± 0.16 MeV**
  - **Which particles are dominating the response?**

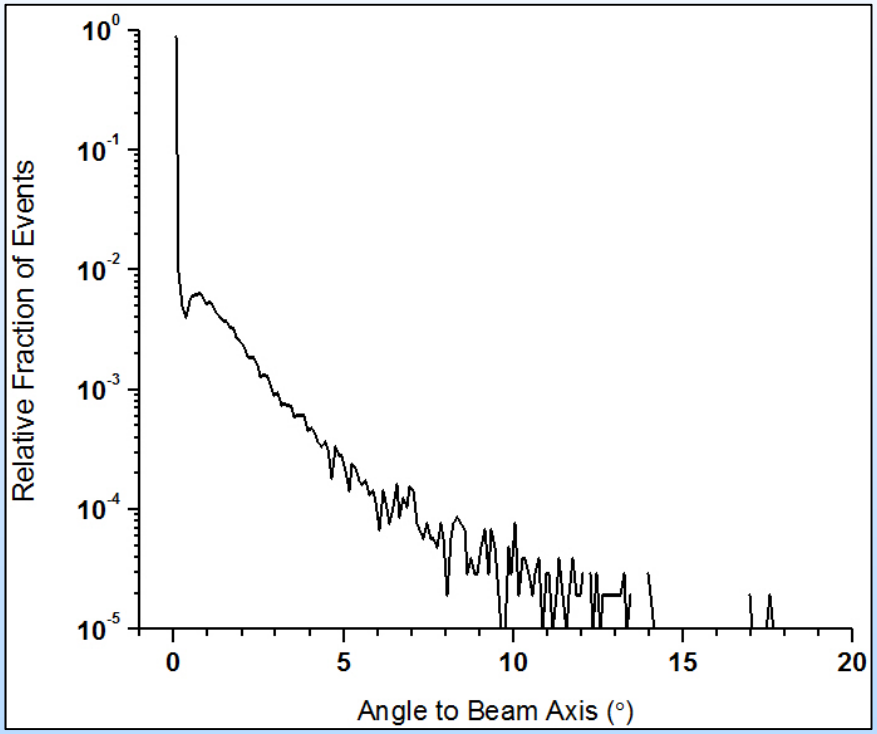


SRIM-2008.04

What about angle of incidence?

Systematic Effects (III) – MRED Angle of Incidence Distribution

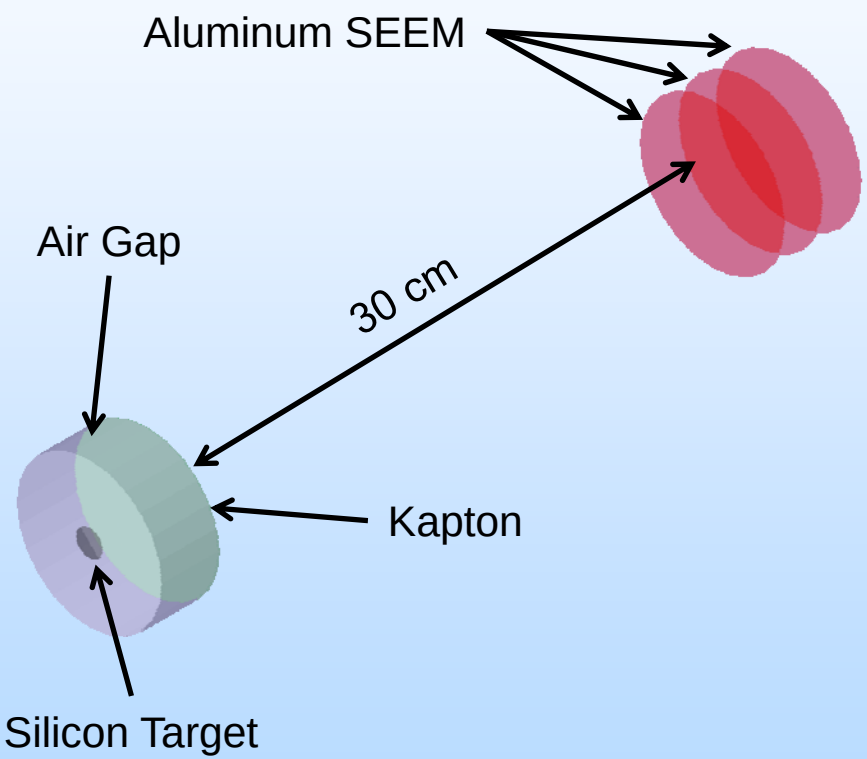
Degraders
2 mil aluminum & 0.125 mil Mylar



Representative example only

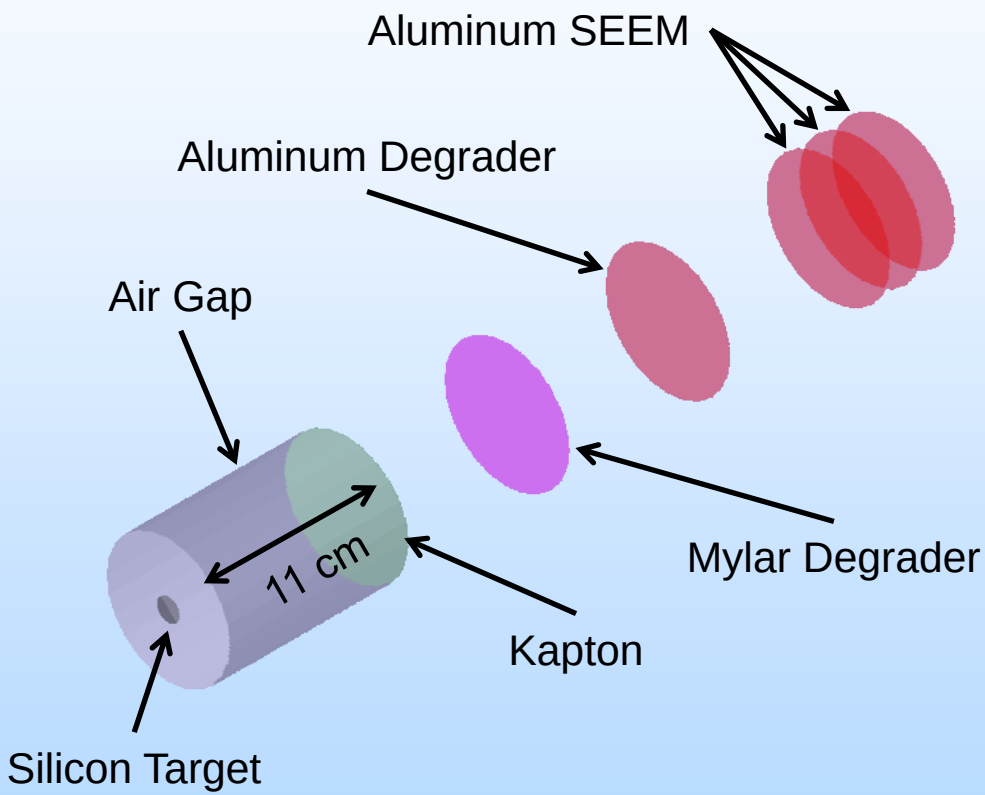
- **Affects energy loss of proton in device under test**
- **Depends on material spacing along beam line and size of air gap**
  - **Assumed to be smaller in vacuum (advantage?)**
- **Fraction of larger angles may be small, but think extremes**
  - **What are those energies?**

MRED 3-D Model of the CNL Beam Line



- **Basic starting setup of the CNL beam line**
  - **0.25 mil Ta scattering foil not shown (~4 m upstream)**
  - **3x 0.25 mil Al SEEM foils**
  - **30 cm vacuum gap is notional**
  - **5 mil Kapton exit window**
  - **3 cm air gap**
  - **Silicon target**

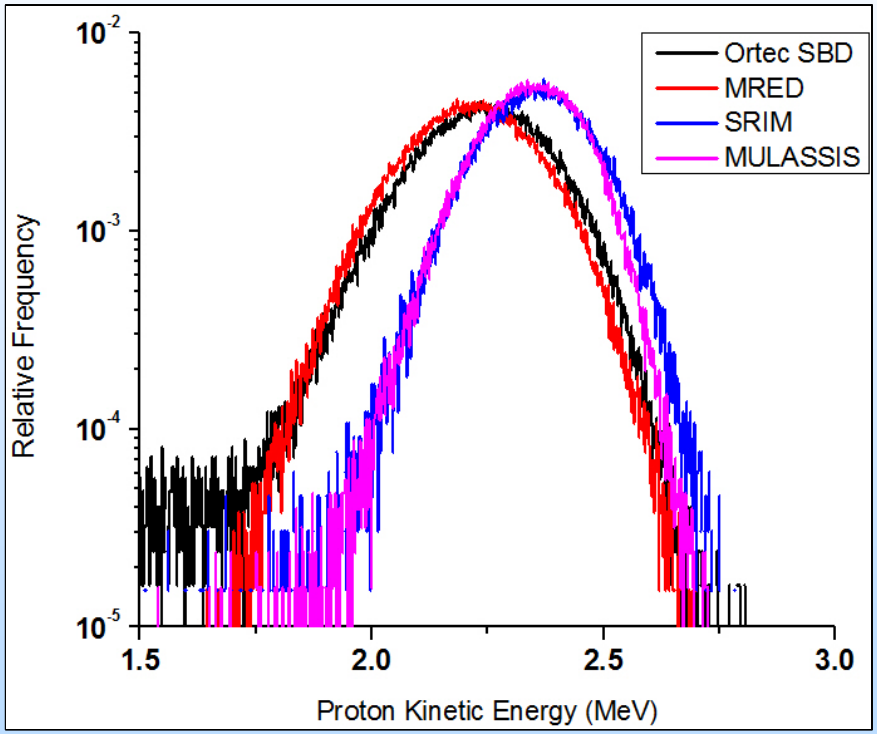
MRED 3-D Model of the CNL Beam Line



- **Realistic setup for an actual run with degraders**
  - **0.25 mil Ta scattering foil not shown (~4 m upstream)**
  - **3x 0.25 mil Al SEEM foils**
  - **Al degrader is 2 mil**
  - **Mylar degrader is 0.125 mil**
  - **5 mil Kapton exit window**
  - **11 cm air gap**
  - **Silicon target**

MRED, SRIM, and MULASSIS *vs.* Data

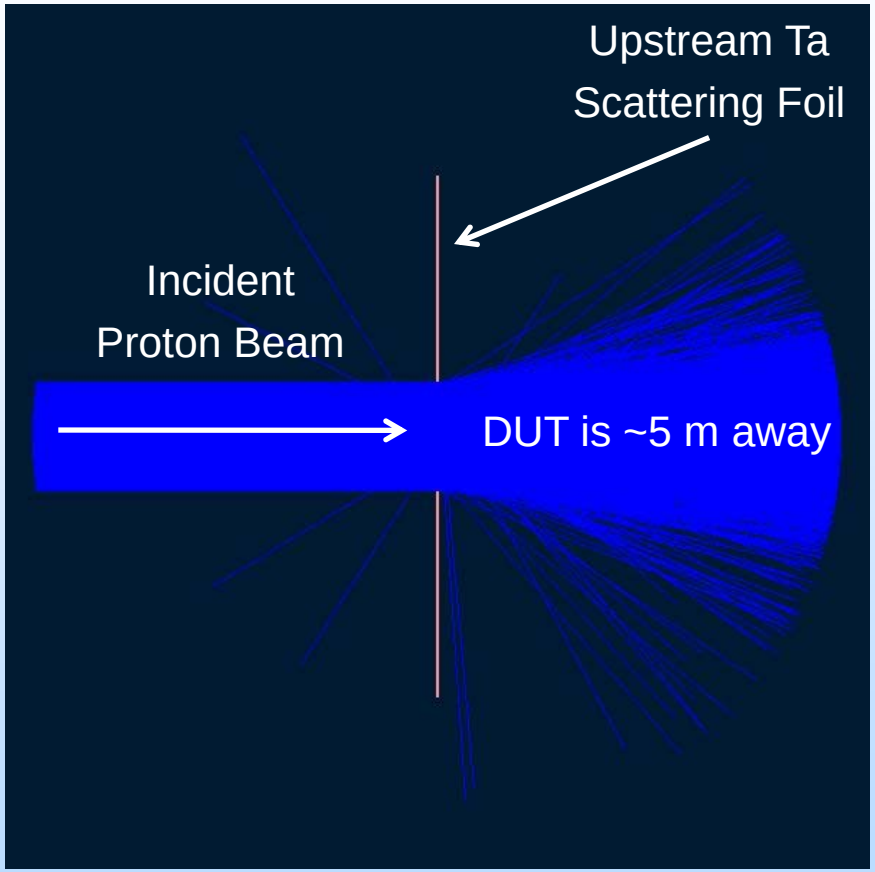
Degraders
2 mil aluminum & 0.125 mil Mylar



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**
- **Ongoing work to improve fidelity of beam line model, particularly concerning *spatial* distribution**

Conclusions



MRED calculation for 6.5 MeV protons

- **Small "window of opportunity" for maximum energy deposition**
- **Challenging to make accurate measurement AND calculation of beam energy at the device under test**
  - **Sensitivity to all elements in the beam line, not just target**
  - **Degraded to stopping, "monoenergetic" sources lose flux and produce broad distributions**
- **Key is to correlate energy and angle of incidence as a function of degrader thickness (2-D distribution)**
- **What can we do with all this information?**
  - **NEPP guideline document (FY11Q4)**
  - **Implications for rate calculations**

Many Thanks to Our Supporters

- **NASA Electronic Parts and Packaging program**
- **Defense Threat Reduction Agency**
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Questions?