Spectral Unfolding of HERMES III H^+ Beam

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Andrew Sharp
Dept. 1344 – Radiation Effects Research

Sandia National Laboratories

Objective

- **Deconvolve radiochromic film data into ion energy spectrum**
  - Automated
  - Robust
  - Use “Modern” techniques

Purpose

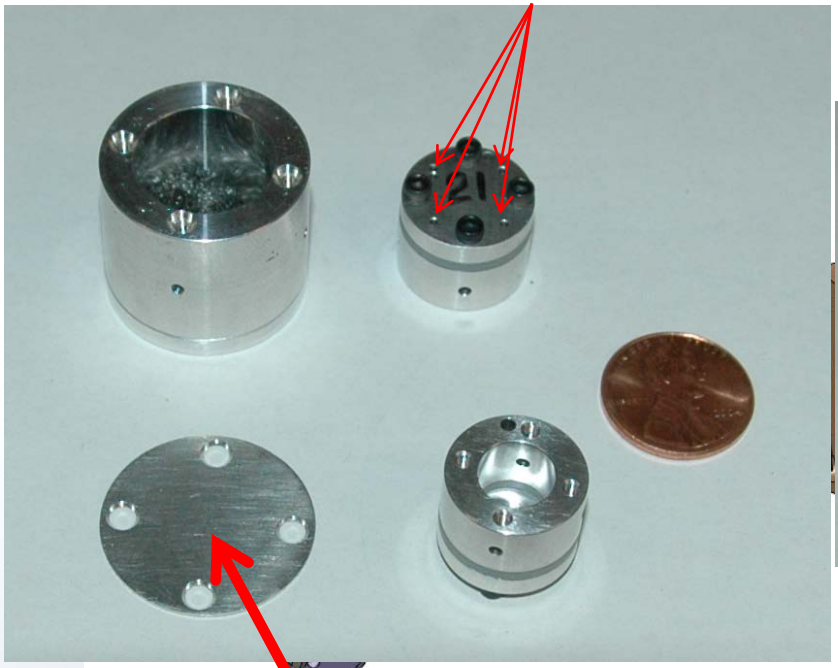
- **Experiment:**
  - Utilize HERMES III as a pulsed neutron source
- **Unfolding:**
  - Ion energy spectrum gives insight into when the H^+ ions form
  - Spectrum is needed to predict neutron production

Background

- H^+ ions are emitted from the anode
- Ions deposit in layers of radiochromic film
- Film allows conversion of optical density to dose
- Deconvolve ion depth-dose profile into ion energy spectrum

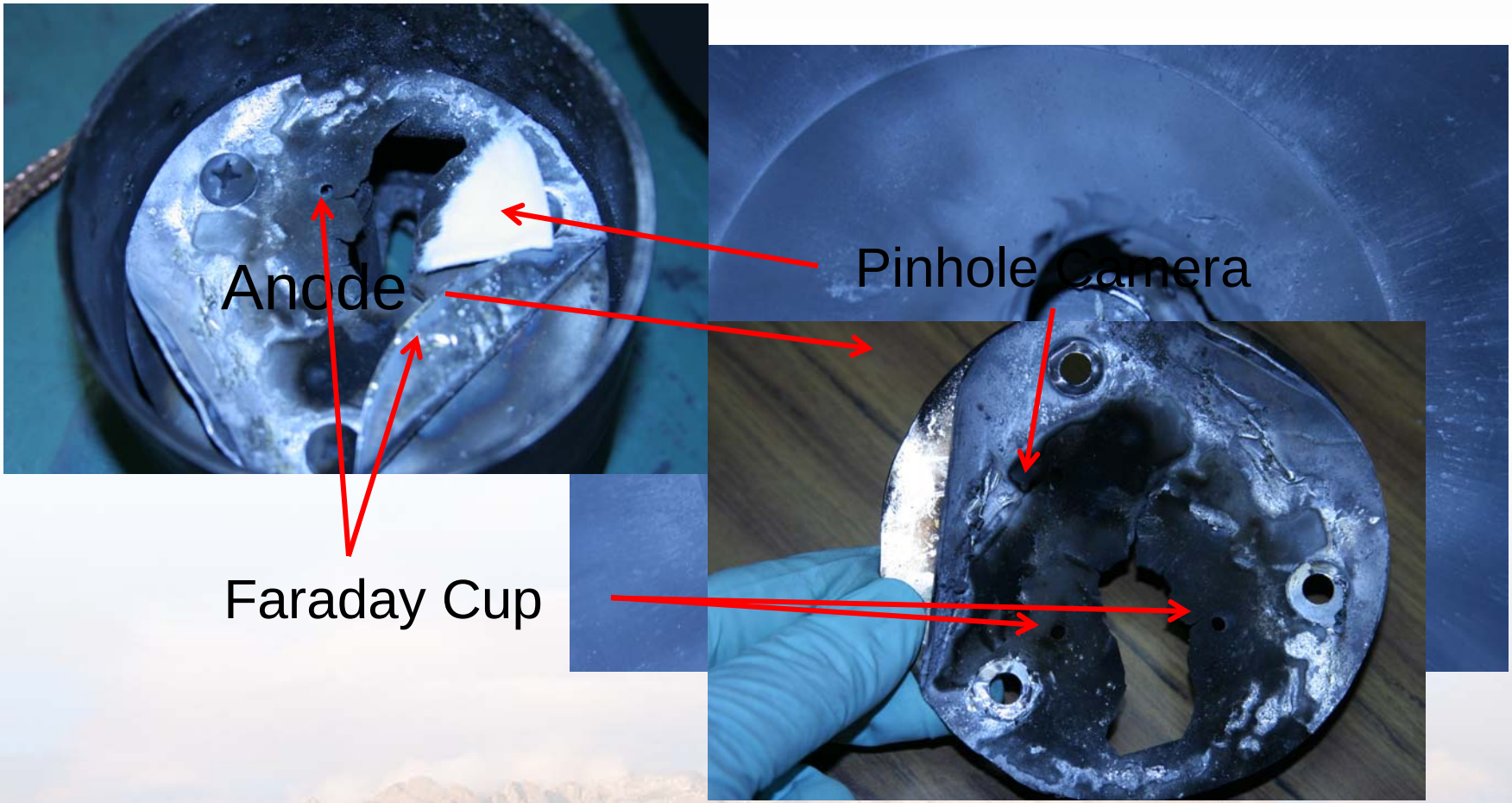
Apparatus

5 UV Fiducials



#80 – 0.0135in

Testing

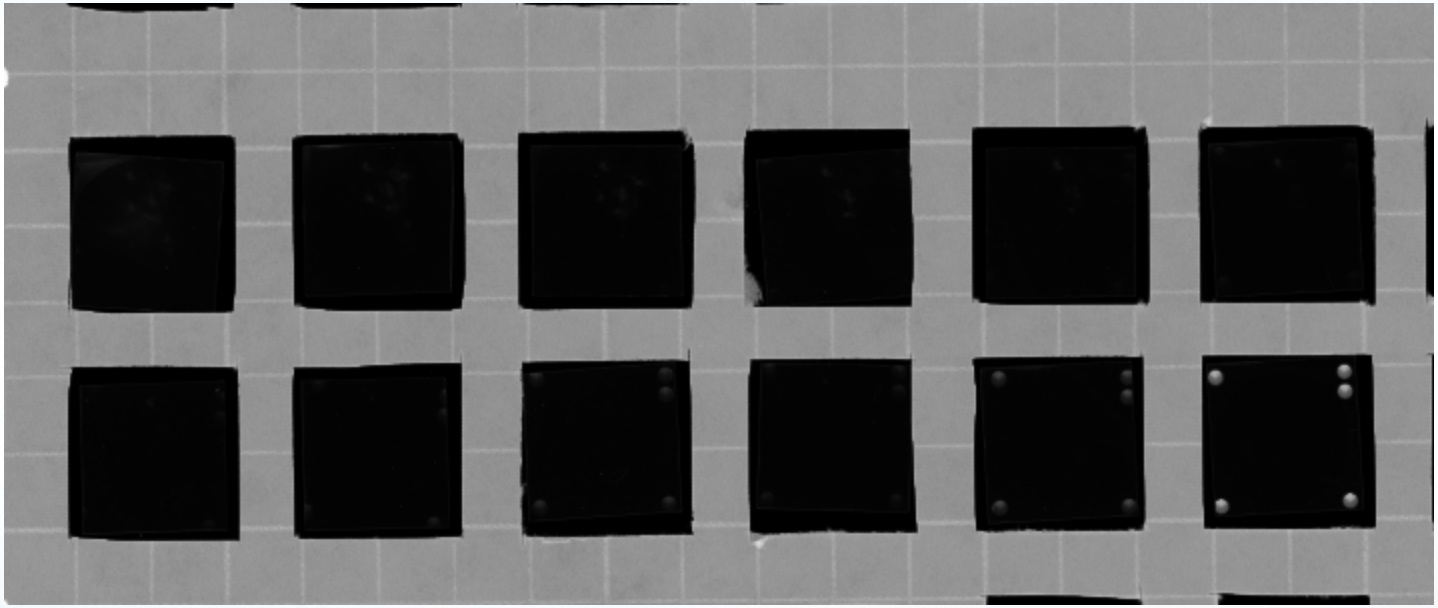


20mil SS and 4mil Ta

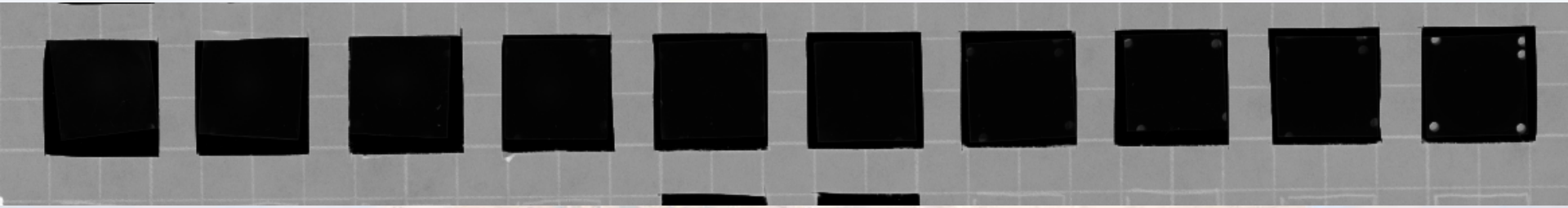
Methodology – Image Processing

- **Image Processing**
  - Film Parsing – separating individual images from film strip
  - Alignment – aligning five fiducials
  - Calibration
    1. Subtract background noise
    2. converting from optical density to [rad*cm^2]

Methodology – Image Processing

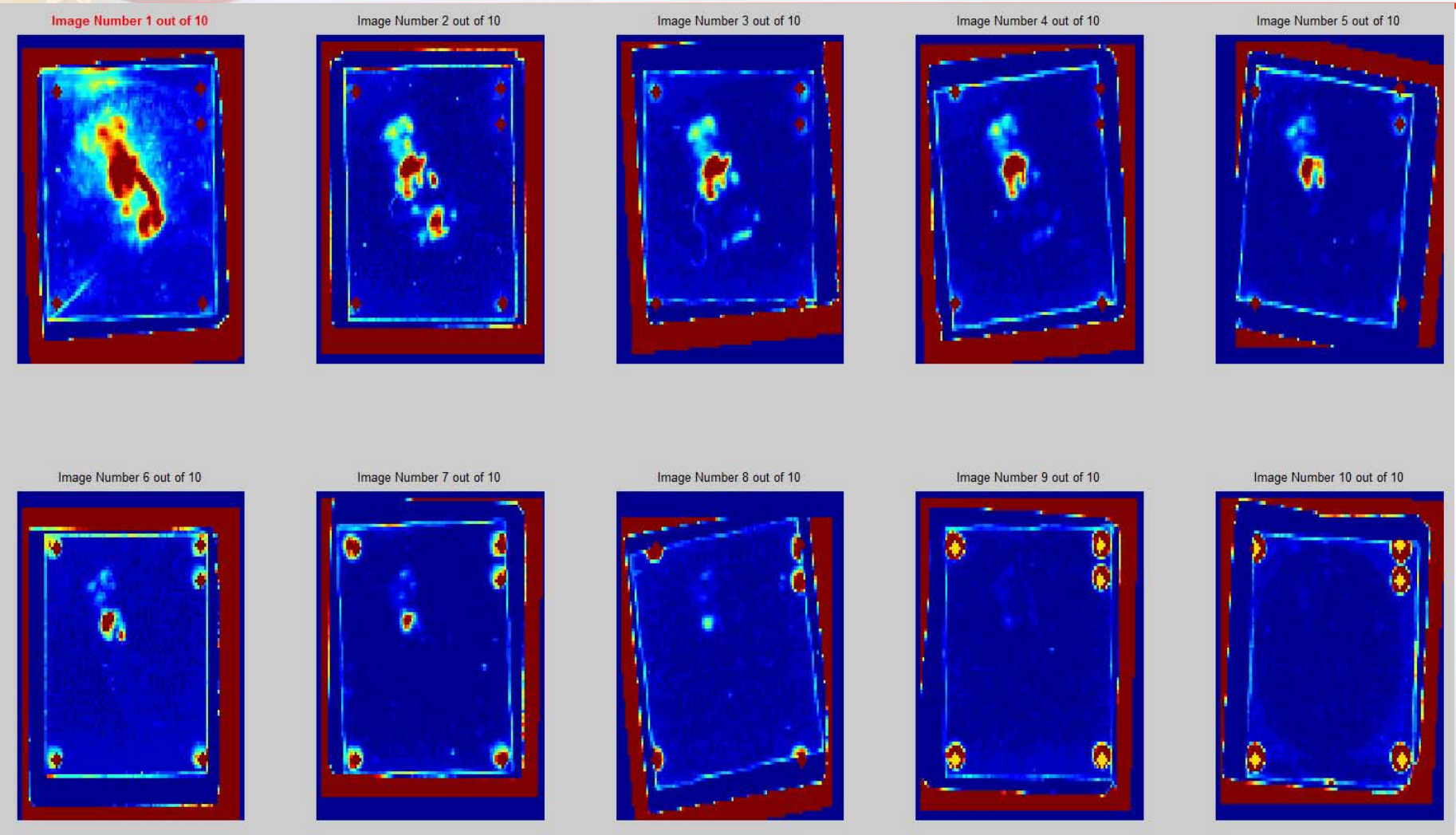


Shot 8840



Shot 8846

Methodology – Image Processing



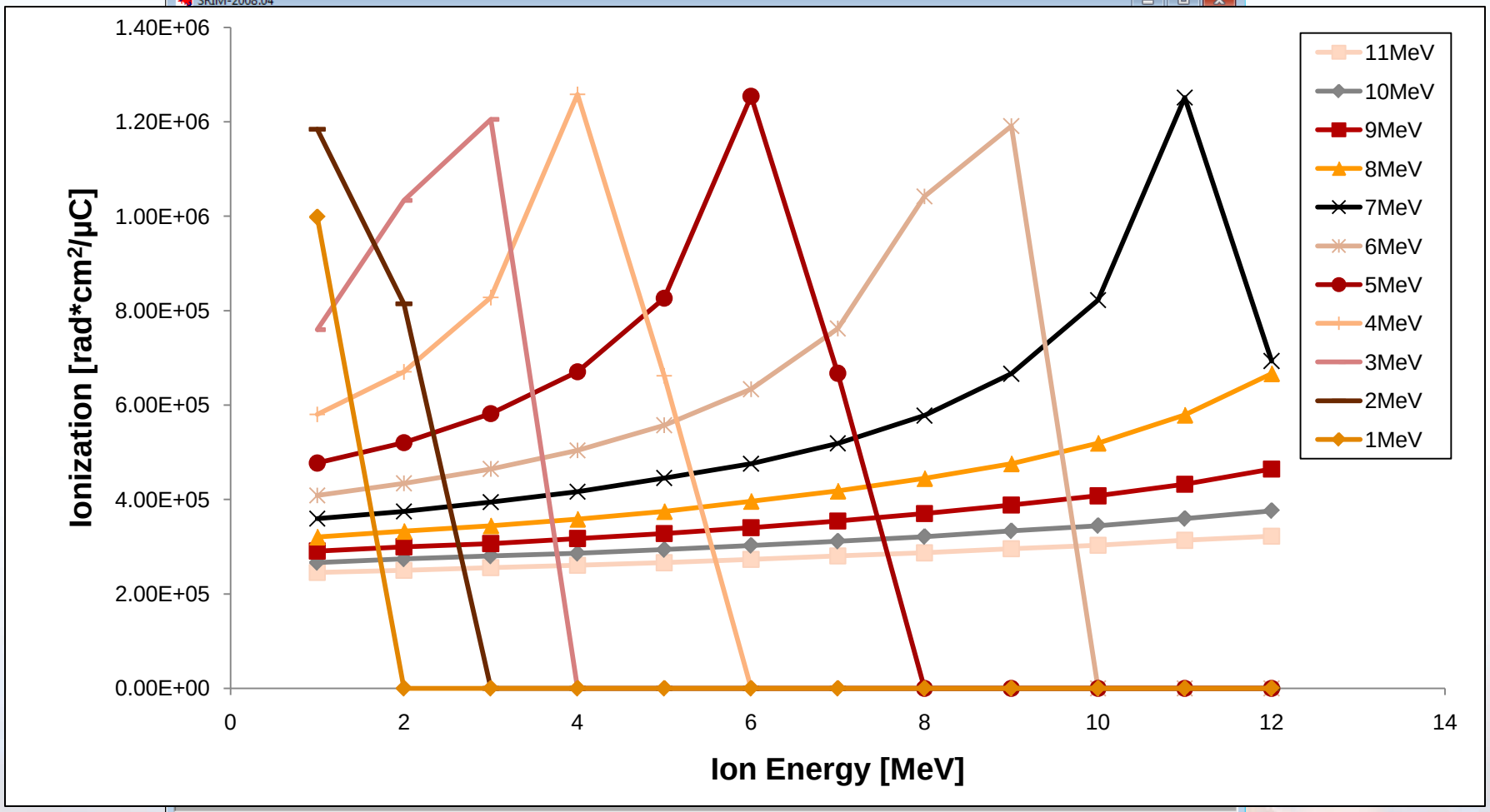
Processed 8838

Methodology – Kernels

- **The kernel matrix is equal to the discretized Green's function**
  - Usually is poor conditioned in the sense that cond(**A**) = $||\mathbf{A}||_2 * ||\mathbf{A}^{-1}||_2$ is large
  - Each row is the depth-dose profile of an ion at a specific energy

- **Generate kernels via Stopping and Range of Ions in Matter (SRIM)**
  - Units are rad*cm^2/μC

Methodology – Kernels



Methodology - Unfolding

- **Singular Value Regularization**
  - Helps to invert poorly conditioned matrices
  - Cannot use Tikhonov since no information about output is known

- **Simplex Optimization**
  - Used to minimize sets of linear inequalities

Methodology - Unfolding

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

Normal Equations

$$\boldsymbol{K} = \boldsymbol{U}\boldsymbol{S}\boldsymbol{V}^*$$

U and **V** are unitary

$$\boldsymbol{K}^{-1} = \boldsymbol{V}\boldsymbol{S}^+\boldsymbol{U}^*$$

Moore-Penrose Inverse

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

Singular Value Regularization

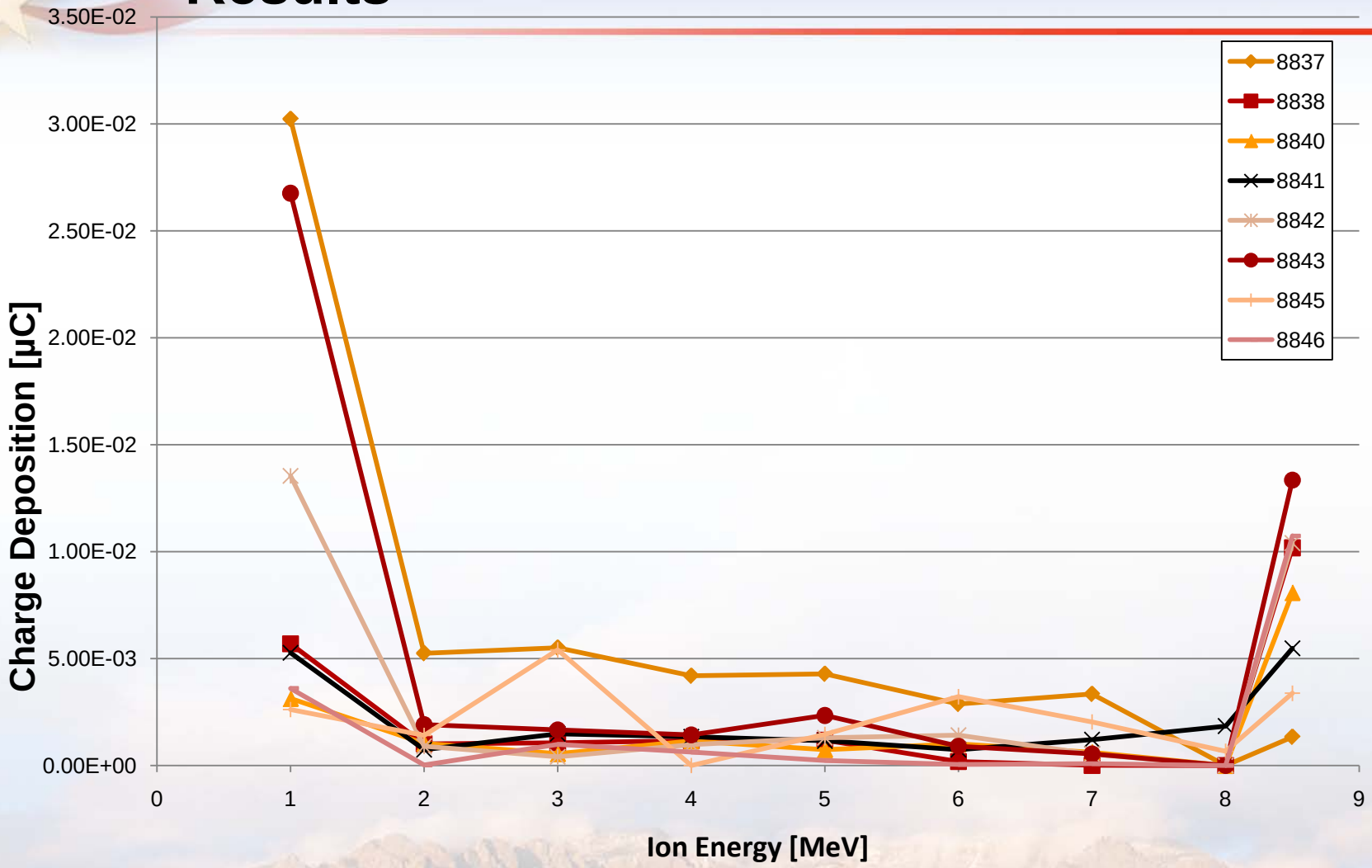
S$^+$ is real, diagonal, positive definite

$$x_0 = \boldsymbol{V}(\boldsymbol{S} + \varepsilon\boldsymbol{I})^+\boldsymbol{U}^*\tilde{y}$$

Initial guess for Simplex Optimization

$$\left\{ \boldsymbol{A}x = y \right\}$$

Results



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Conclusion

- Majority of ions are high energy, therefore they form during the main beam pulse
- Image processing worked
- Unfolding proved to be relatively stable

Acknowledgments

- Victor Harper-Slaboszewicz
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- HERMES Folks

And of course, Patricia St. John