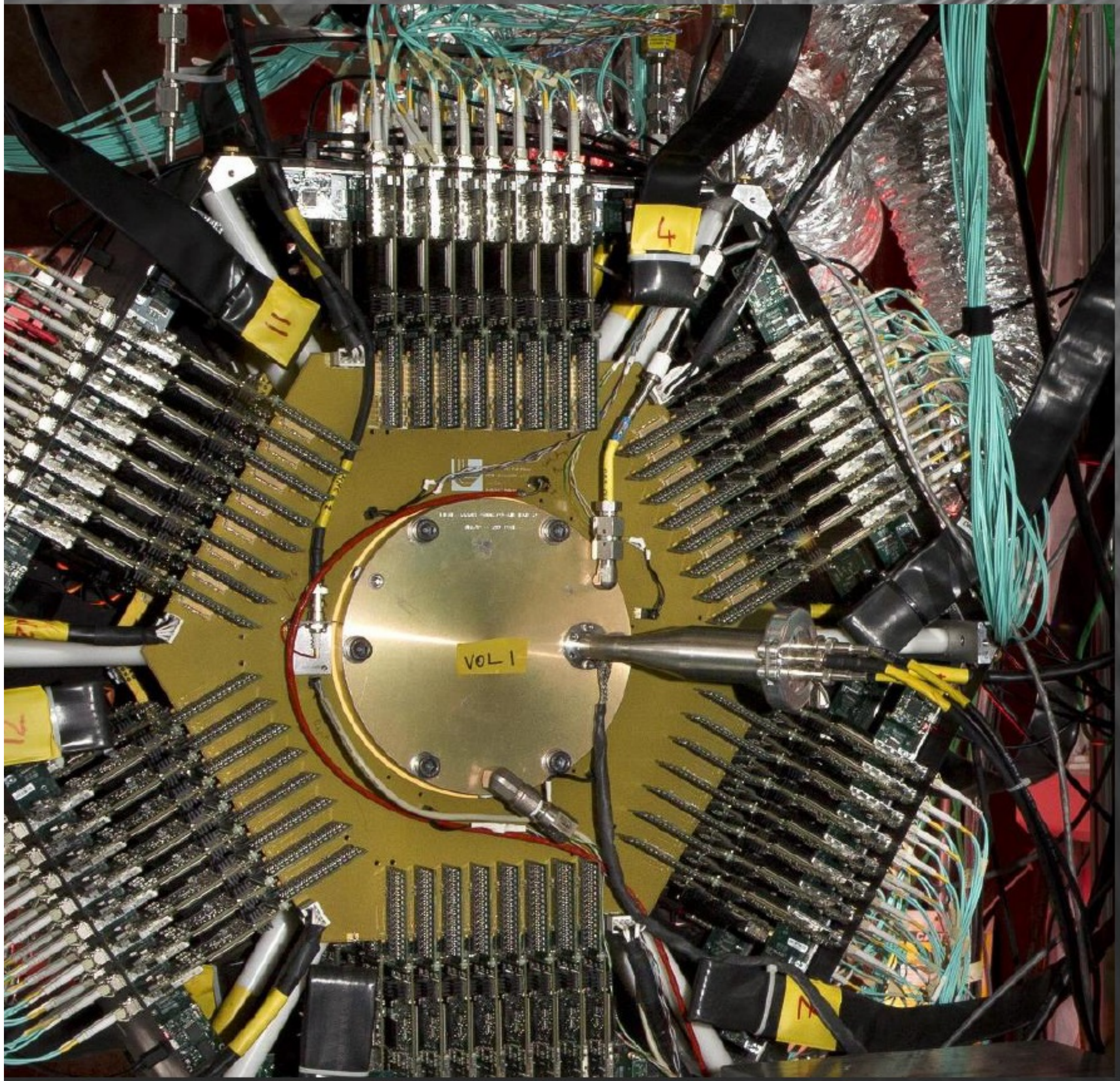
Fission fragment stopping powers in the fissionTPC

Michael E Moore (PNNL)

Workshop for Applied Nuclear Data Activities 2020

Washington DC



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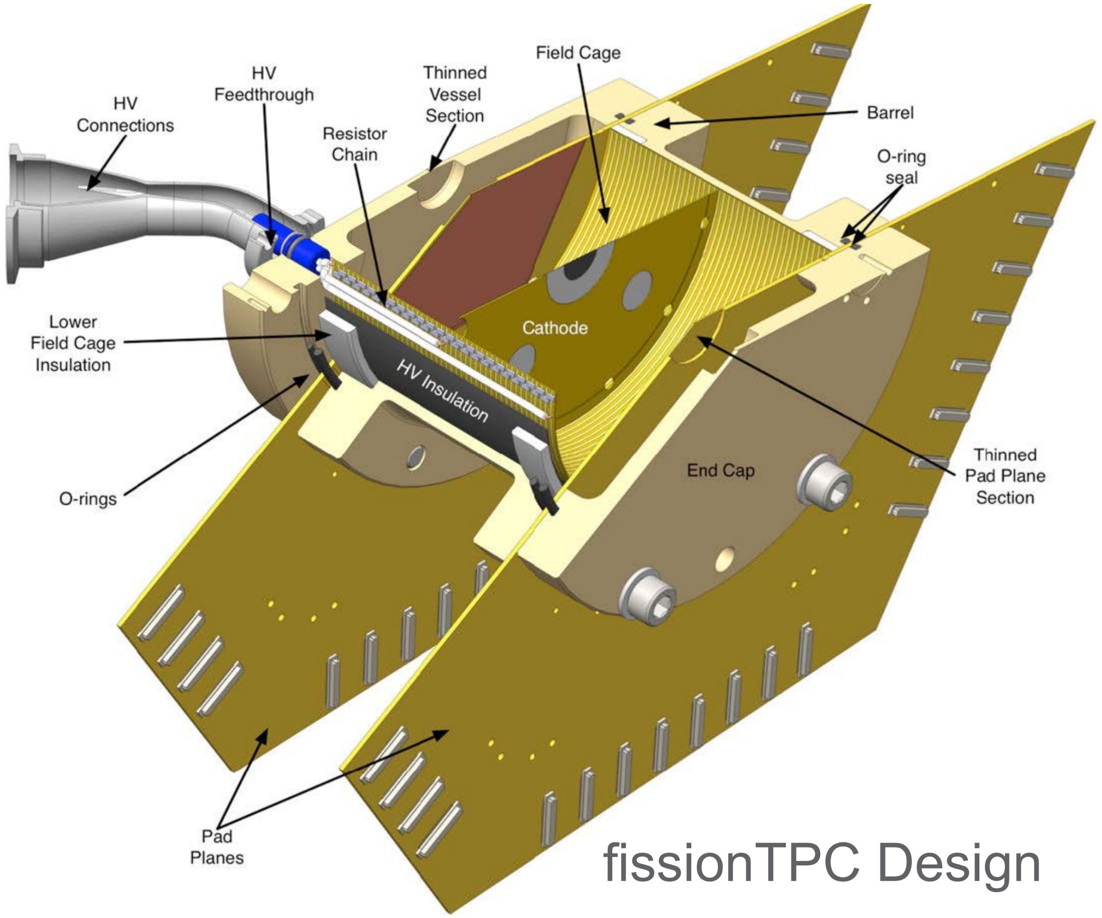
Pacific Northwest
NATIONAL LABORATORY

fissionTPC

NIFFTE Collaboration

- Constructed fissionTPC to provide precise and accurate ^{239}Pu(n,f) cross section data
- **N**eutron **I**nduced **F**ission **F**ragment **T**racking **E**xperiment
- Located at the Los Alamos Neutron Science Center (WNR 90L beamline)
- Has measured a number of cross sections and fission anisotropies by reconstructing:
  - Incident Neutron Energy (E_n) from ToF
  - Track vectors
  - Induced charge

However, reconstructed fragment ionization profiles have not yielded independent measurements yet…



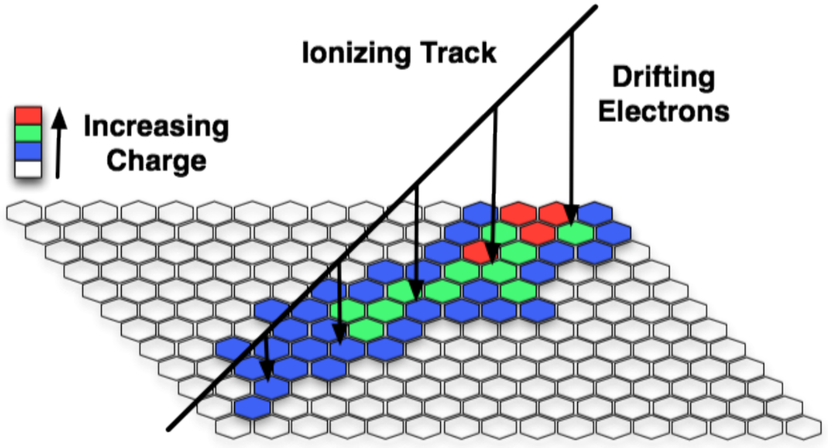
fissionTPC Design

Presentation on behalf of:
Uwe Greife, David Hensle, Joseph Latta, Kristina Montoya (CSM), Dana Duke, Verena Geppert-Kleinrath (LANL), Lucas Snyder, Nick Walsh (LLNL), Bryan Fulsom, Lynn Wood, and Stephanie Lyons (PNNL)

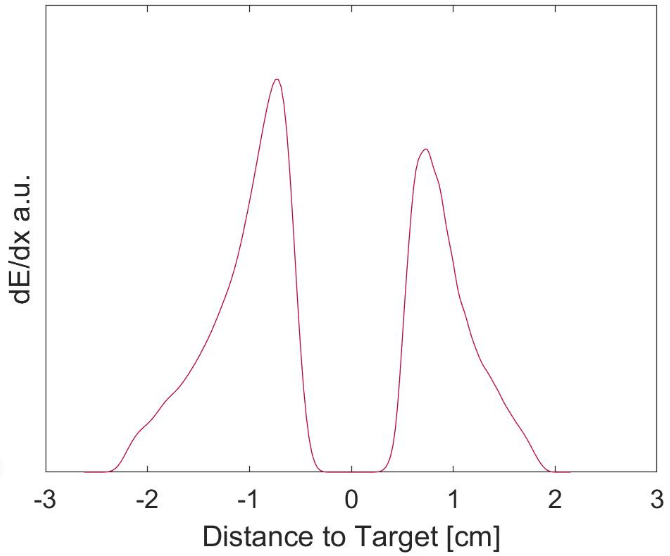
IFPY using Bragg Curve Info

Independent Fission Product Yields Measurements

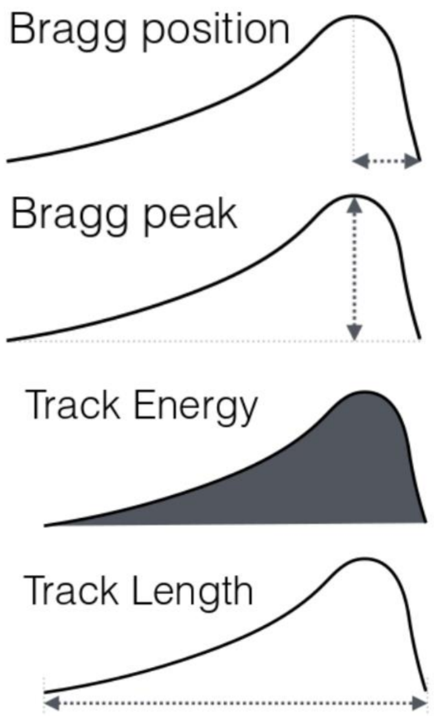
- Extend fissionTPC use to study **IFPY** of various isotopes and incident neutron energies
- Quantify the amu resolution and sources of uncertainty for yield distributions
  - 2E Method - Dana Duke (LANL) Thursday morning
- Extract Z distribution from paired fragment ionization profiles (Bragg Curves)

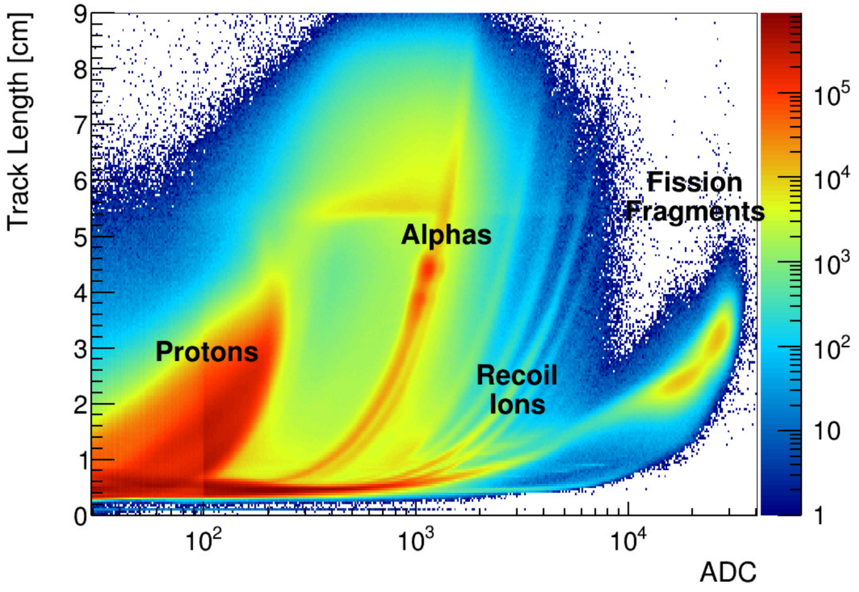


Charge Collection



Fragment Ionization Profiles





Fragment Distribution

Issues with Fragment Stopping

Bohr 1941

Müller, et al. 1984

Bethe-Bloch $$-\frac{dE}{dx} = \frac{4\pi k_0^2 z^2 e^4 n}{mc^2\beta^2}\left[ln\frac{2mc^2\beta^2}{I(1-\beta^2)} - \beta^2\right]$$

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- Bethe's formula based on assumption that ion moves much faster than atomic electrons

$$V \equiv \frac{MeV}{nucleon} \sim \ 0.9 - 1.4{\times}10^7 ms^{-1} < 0.05c$$

$$V \gg V_0 = 2.2{\times}10^6 ms^{-1} \qquad if\ V \approx V_0 \rightarrow \ln\left(\frac{2mc^2\beta^2}{I}\right) < 0$$

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- Derivation is based on Bragg's Rule, which assumes additive energy loss by an ion to a medium.

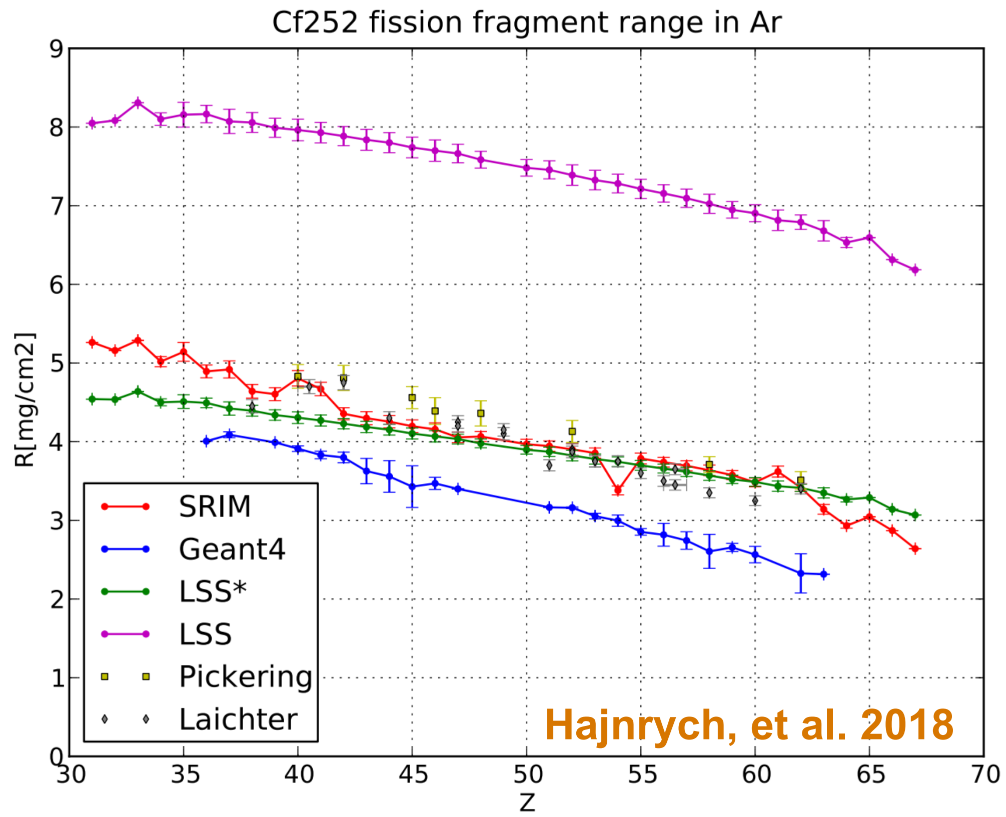
Energy loss depends on the orbital and excitation structure of the electrons in the medium. So, differences between measured bonding in elemental targets and compounds causes inaccuracy.

Models used for Nuclear Data

There are a number of codes used to model stopping powers:

BEST	GEANT4	MSTAR
BT	HISTOP	PASS
CasP	MCNP	SRIM/TRIM

Paul, et al. 2003



Hajnrych, et al. 2018

SRIM/TRIM

- By far the most popular platform in use
- Demonstrates comparably good agreement to stopping of fragments
- Uses an approximation of the Bethe formula at low velocities
- Substitutes a complex Z_{eff} that is fit to fission data (pre-1980's)
- Included a compound directory to account for molecular effects, e.g. stopping power of isobutane vs butane vs $C_4 + H_{10}$

Ziegler, et al. 2010

Experimental comparisons to SRIM show a **$7 - 30\%$ difference** in stopping power for fission fragments. Stopping and $\bar{\nu}$ uncertainties prevent accurate IFPY estimate using "Bragg Curve Spectroscopy" alone.

Knyazheva, et al. 2006

Baldez, et al. 2019

Fragment Stopping Needs

Sparse/old experimental data, a lack of code upkeep, and disagreements between stopping approximations has limited the precision of modeling fission fragment stopping with codes and stopping power parametrizations in general.

There has been a vigorous resurgence of interest in the problem of effective stopping-power ion charges recently, spurred by the needs of fusion research, space exploration, and materials development. This has stimulated large-scale compilations of literature data. They reveal striking disagreements in the experimental evidence of what "best" stopping power data might be.

Sigmund & Schinner, 2016

The Nuclear Data community must go beyond quantifying "differences" between experimental results and SRIM, GEANT, MCNP, or other models. To add precision, the community needs to:

- Revitalize a fundamental understanding of stopping theories and establish standards for fission
- Acquire and validate **modern** stopping data for high Z & amu ions and targets
- Involve other scientific communities in modeling complex molecular/gaseous stopping mediums

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-Brandt & Kitagawa, 1982

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Acknowledgments

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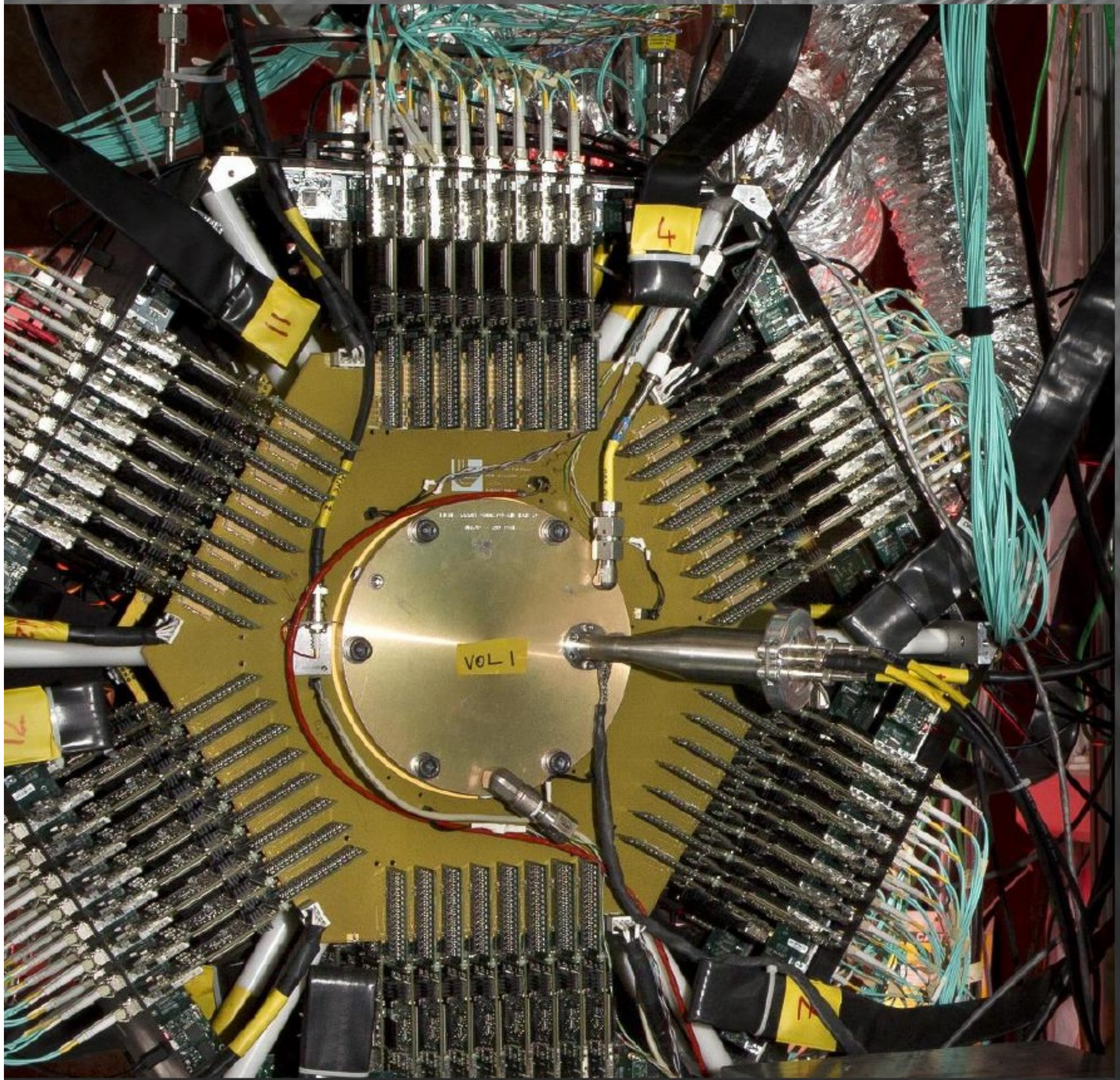
Thank you for your attention



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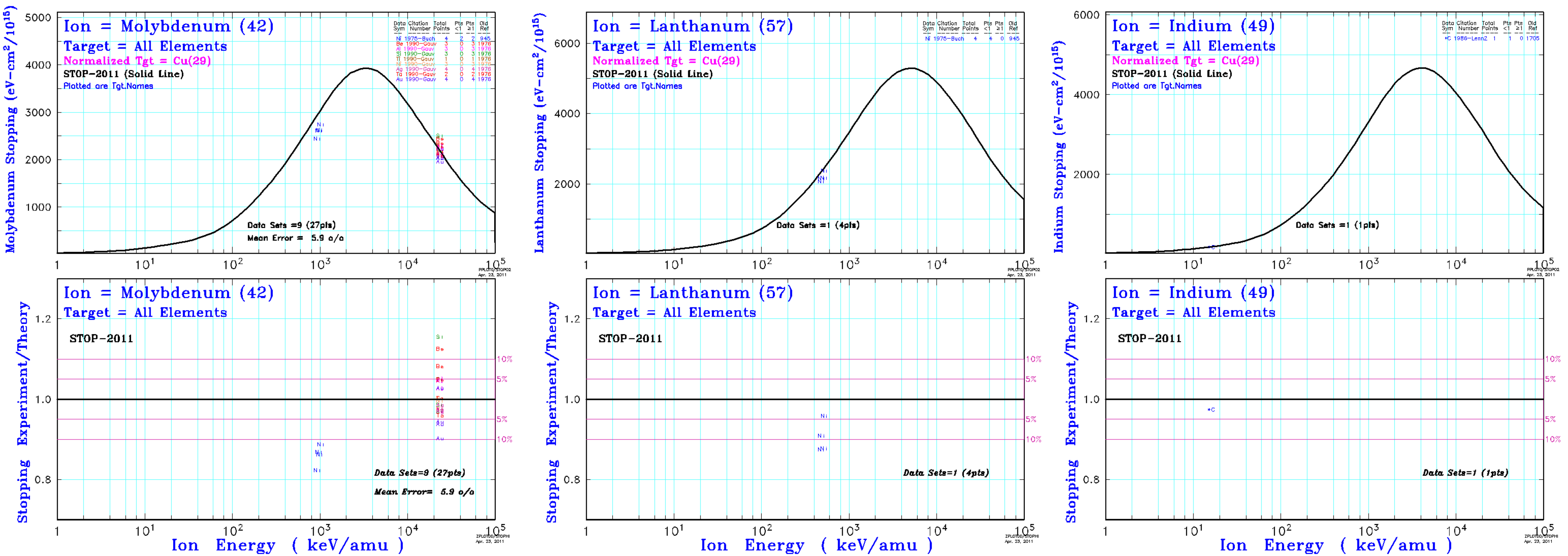
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Molybdenum Stopping (eV-cm²/10¹⁵)
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Stopping Experiment/Theory
Ion Energy (keV/amu)