Measurements of Independent Fission Product Yields

Workshop on Applied Nuclear Data Activities (WANDA)

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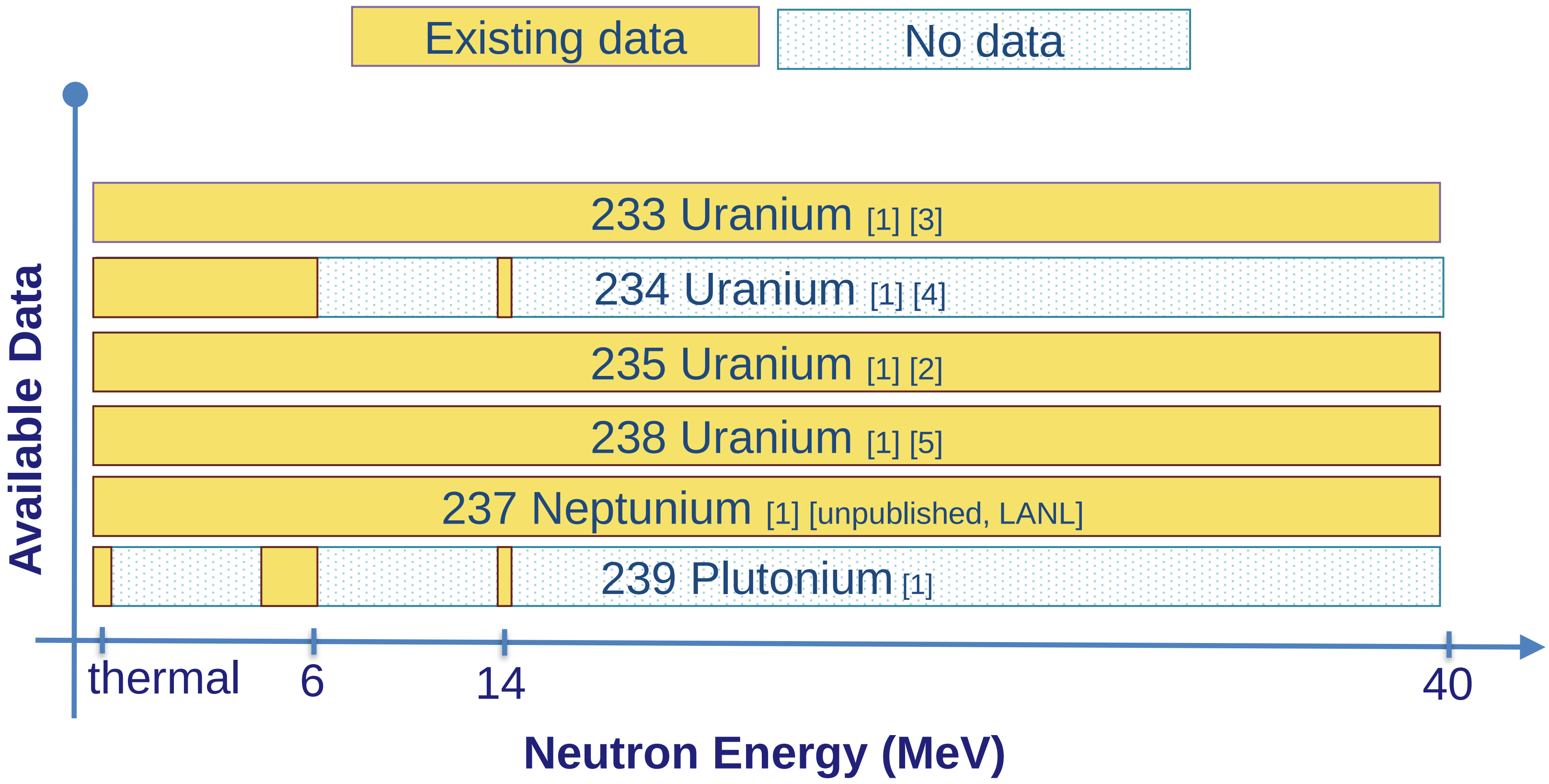
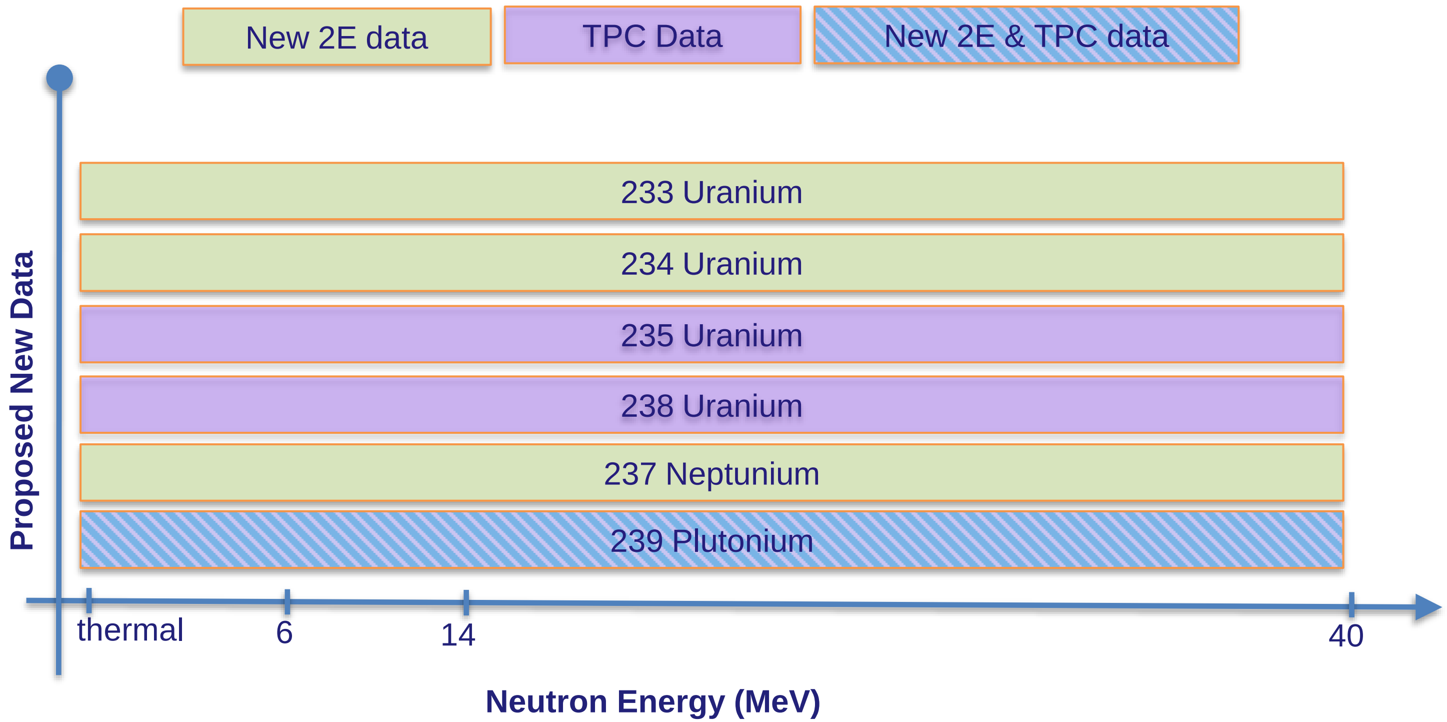
Objective: Fill in gaps in IFPY nuclear data and improve quantification of uncertainty in new measurements



Leverage Existing and New Technologies

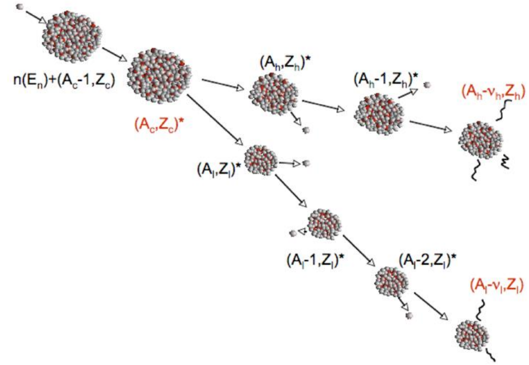
- Frisch Gridded Ionization Chamber (FGIC) and the fission Time Projection Chamber (fissionTPC)



The 2E Method

D.L. Duke, et al.
PRC 94, 054604 (2016)

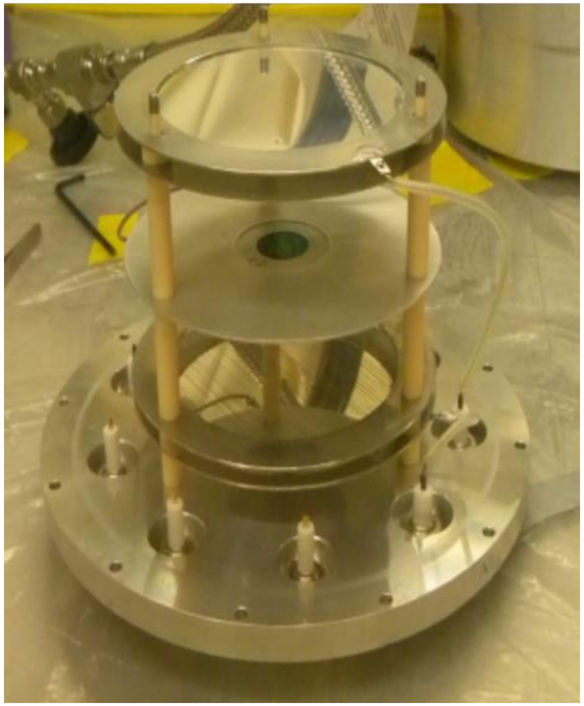
- Iterative analysis relying on conservation of momentum
- Advantage: Independent FPY, Pre- & Post-Neutron Emission
  - Measured at earliest possible time, before beta-decay
- Disadvantage: Mass only, Limited resolution
  - 3-5 AMU, Typical

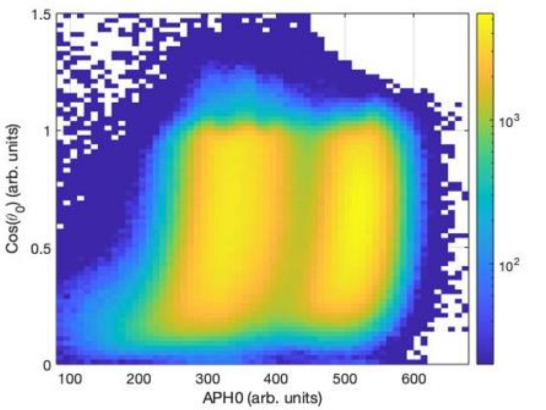


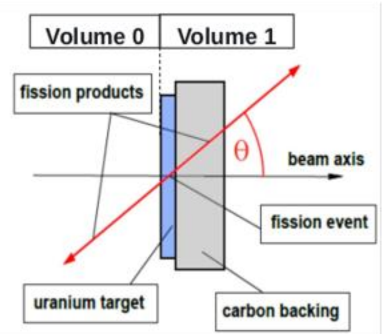
- 2E Analysis
  - Assume symmetric fission
    - $m_1^{pre} + m_2^{pre} = \frac{M_{cn}}{2}$
  - Determine m^{post} based on ν(A) curve
  - Recalculate m^{pre}
    - $m_1^{preNew} = M_{cn} \times \frac{E_2}{E_1/_b + E_2}$
    - $b = \frac{m_2^{pre} \times m_1^{post}}{m_2^{post} \times m_1^{pre}}$
  - Iterate to convergence criteria
    - $m^{pre} - m^{preNew} < 0.125$

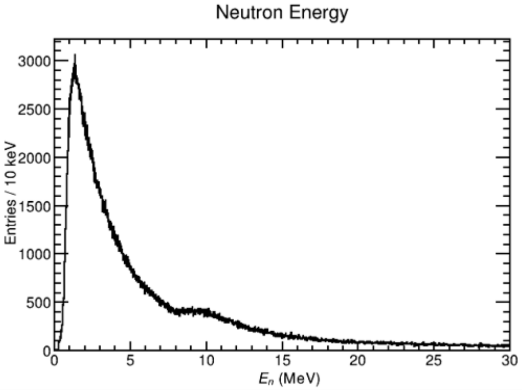
FGIC are a proven technology used to measure fission observables such as TKE, Cross Sections, and IFPY

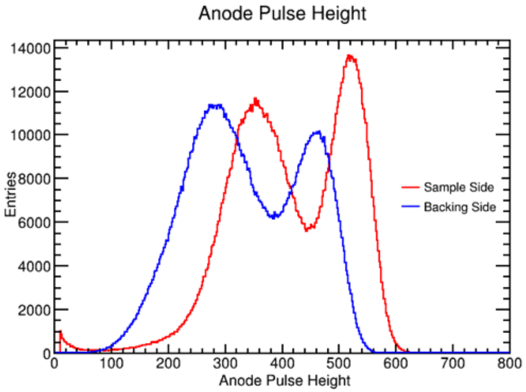
- This detector type was used in most of the existing IFPY measurements, which provide about 3-5 amu mass resolution
- Data analysis by CSM Ph.D. student Kristina Montoya







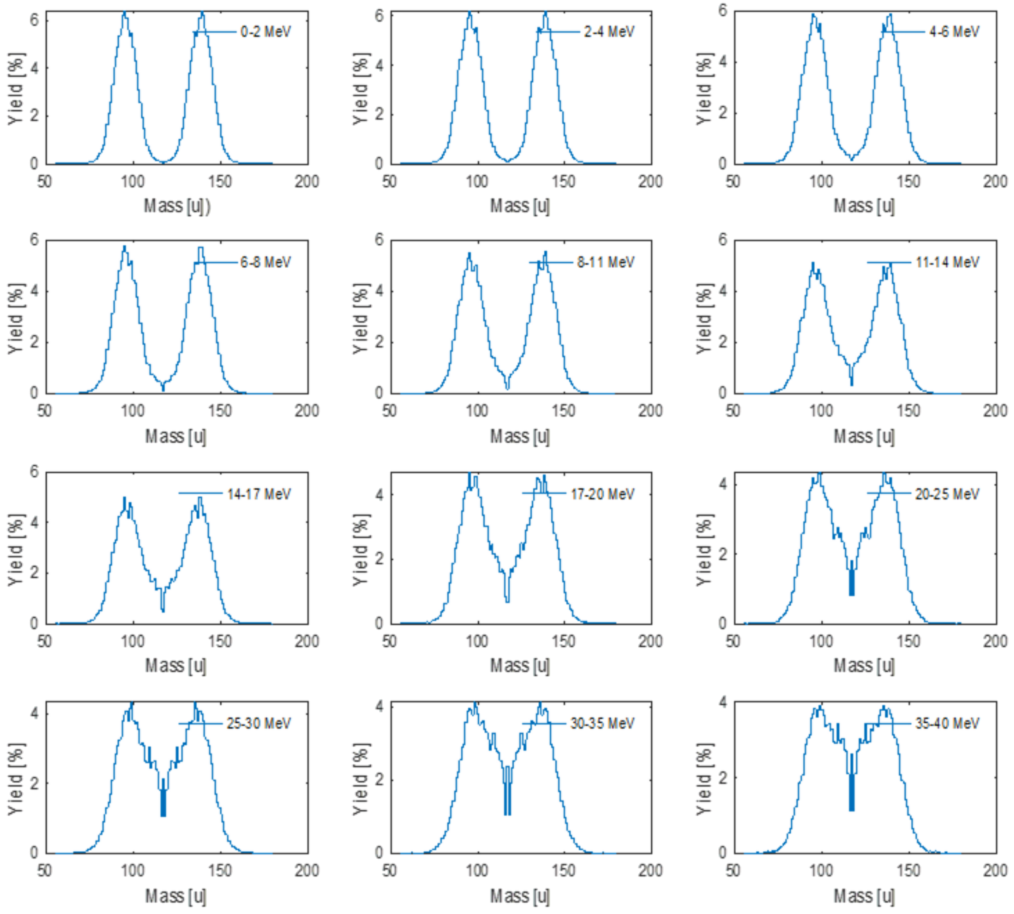




FGIC Analysis Status

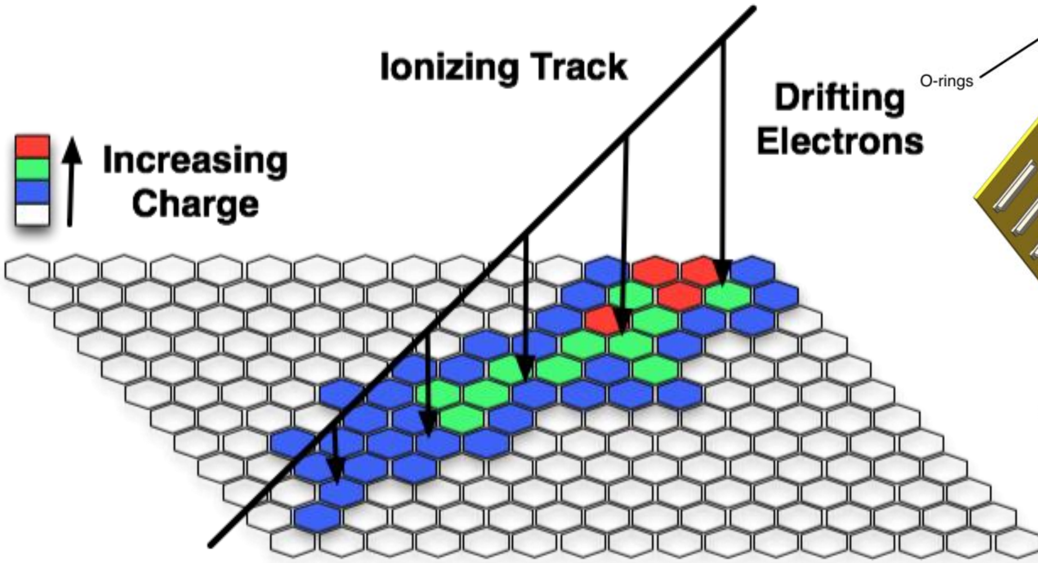
K. Montoya, D.L. Duke

- ^{237}Np data submitted for publication in Journal of Physics G
- ^{233}U data analysis under final review
- ^{234}U data was not collected
- ^{239}Pu initial analysis stage. Early indications that alpha background correction will be successful
- Expected completion of ^{233}U,^{239}Pu by Q1 FY23

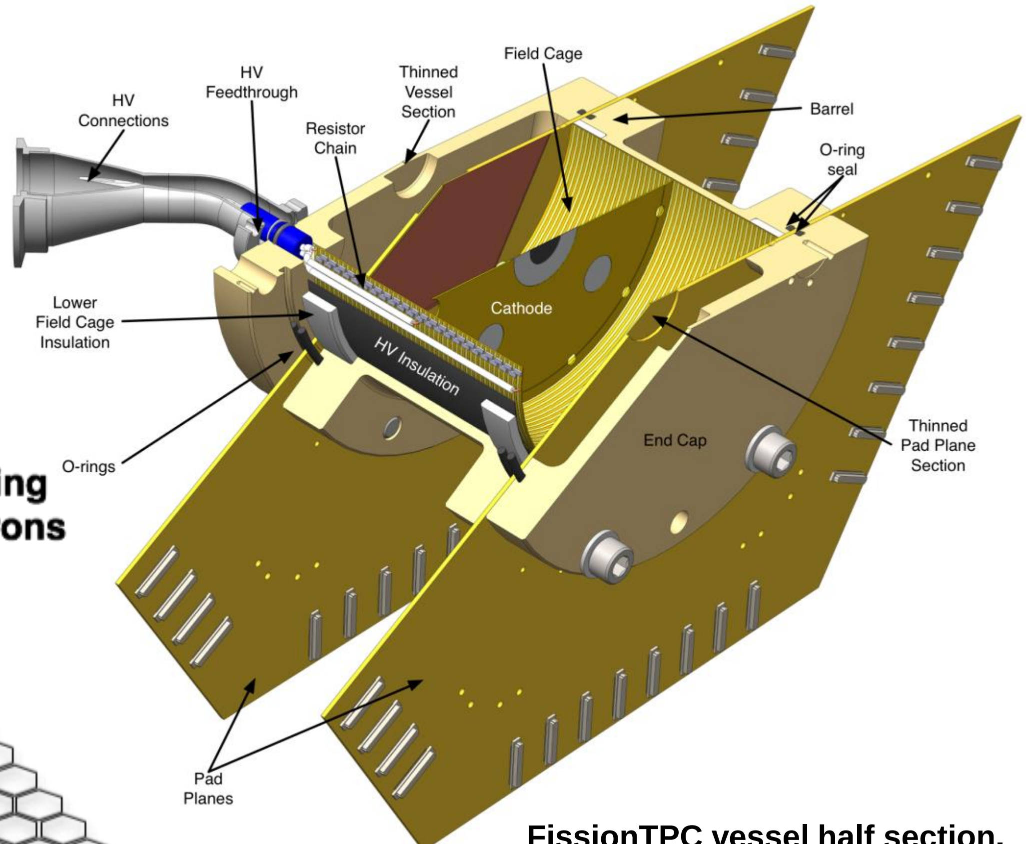


The fissionTPC IFPY Analysis

IFPY analysis can be found in:
J. Latta, Colorado School of Mines Dissertation, 2021
"Fission Fragment Mass and Energy Distributions for Neutron Induced Fission of ^{235}U, ^{238}U and ^{239}Pu Measured with the NIFFTE Time Projection Chamber"



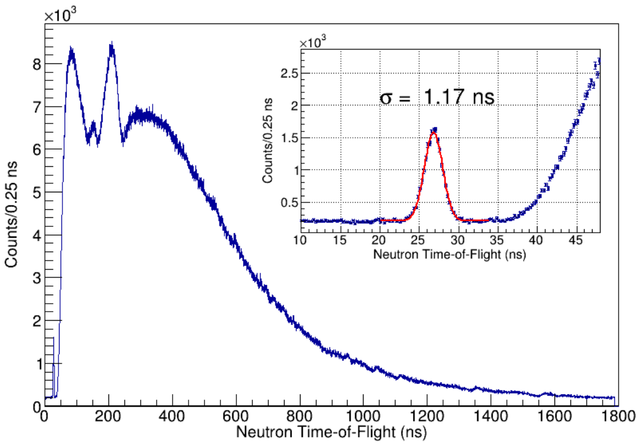
The constant drift velocity of electrons in a gas allows for 3D reconstruction of the ionization left by fission fragments and other charged particles.

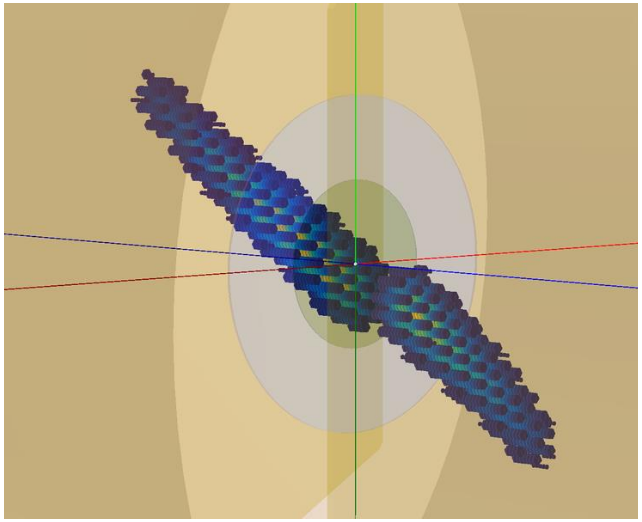


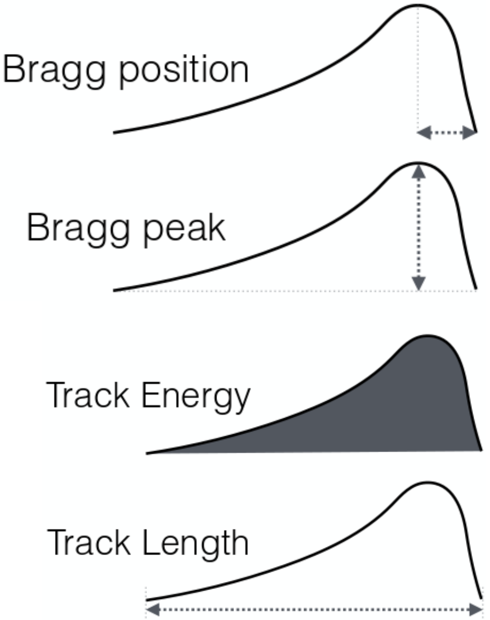
FissionTPC vessel half section.

fissionTPC Details can be found in:
M. Heffner, et al.
NIM A 759 (2014) 50-64

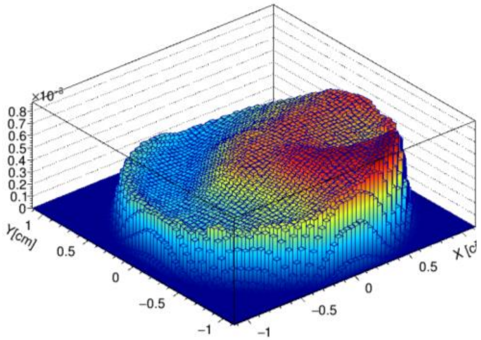
Quantities measured by the fissionTPC

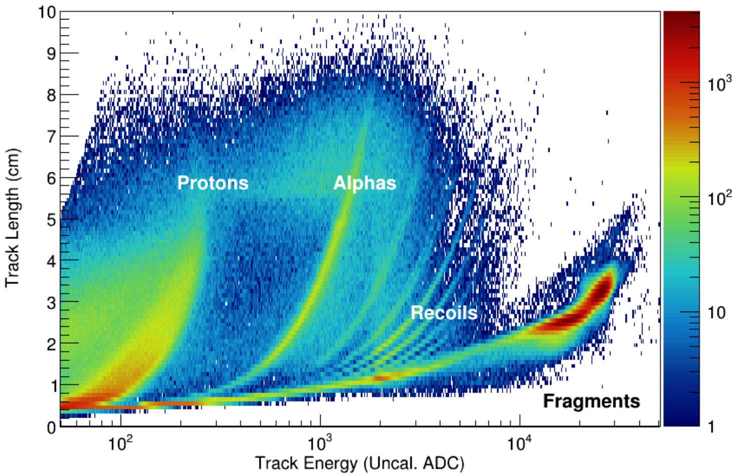






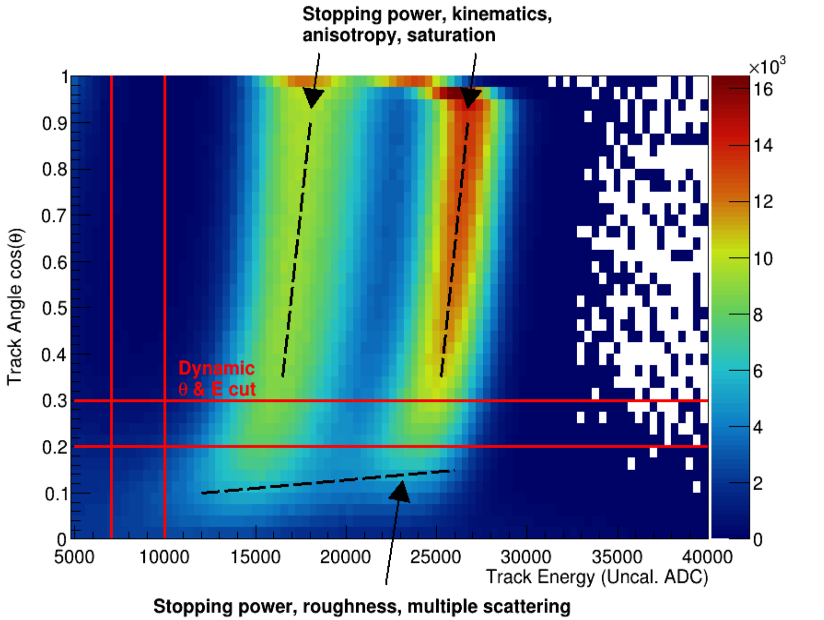
- 3D ionization profile for individual tracks provides:
  - Track length
  - Total energy
  - Location & value of max ionization
  - Interaction vertex
  - Track direction
  - Ionization profile (Bragg curve)

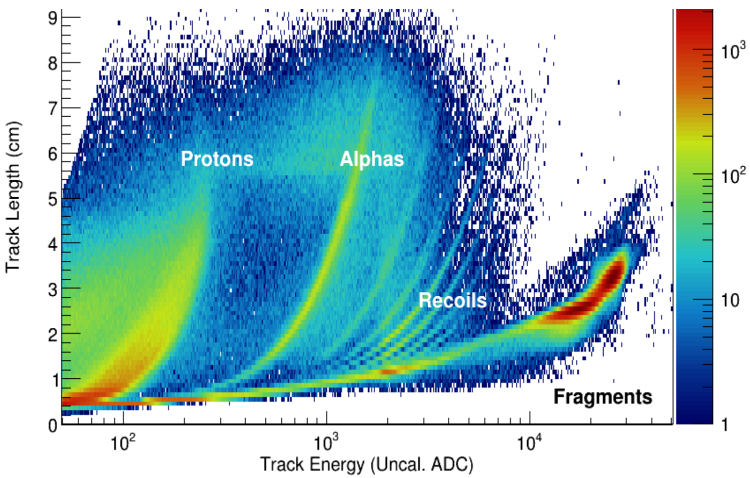




The 2E Method with the fissionTPC

- Advantage: Wealth of information
  - Direct measurement of angle: energy loss correction
  - High dynamic range: Energy resolution determination independent of fission fragments
- Disadvantage: Reduced energy resolution
  - 3k channel/anode
  - Not optimized for energy



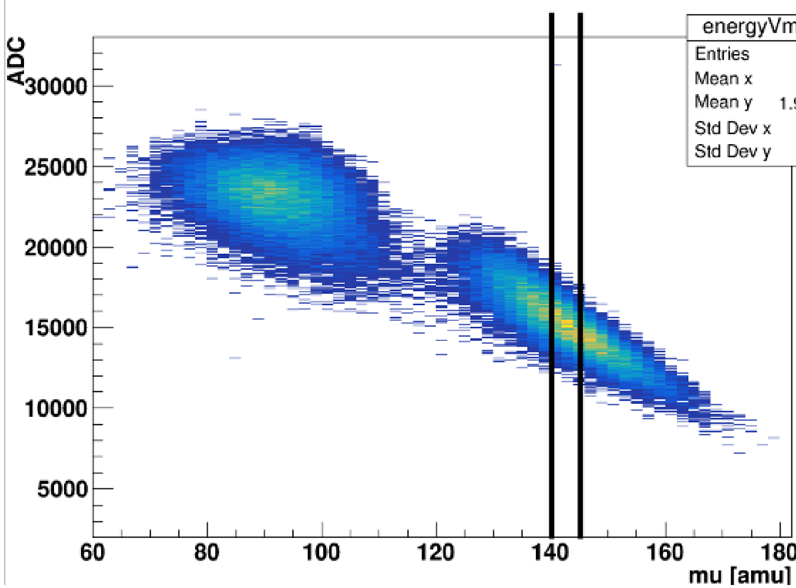


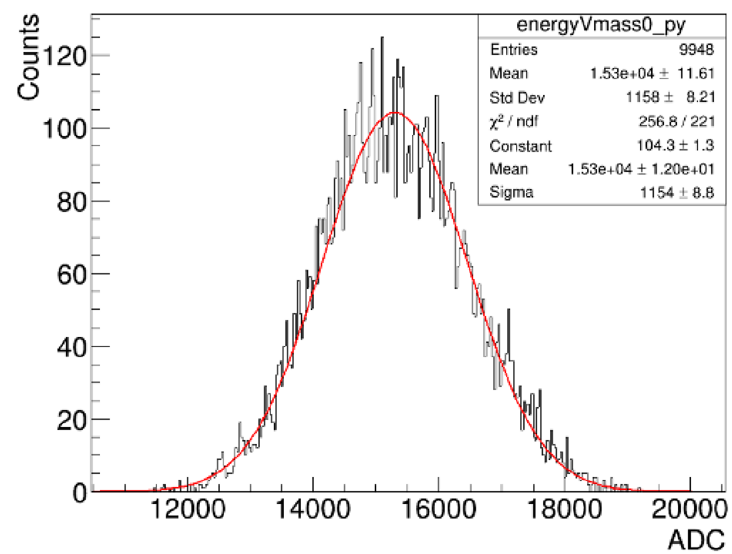
Refined Energy Loss Correction

- Energy loss typically corrected with an average 1/cos(theta) over all fragments

- Gate on angle and initial mass determination to produce a mass dependent correction *with uncertainties*

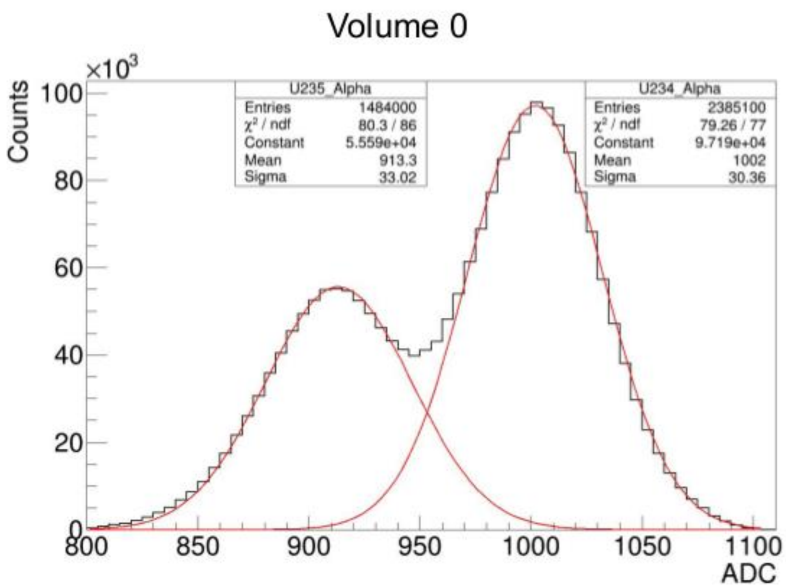
  - For a given Cos(θ) range, Slice X-axis to get each mass range
  - Project to Y-axis
  - Get mean and error in mean from Gaussian statistics
  - Example: Average heavy fragment region (En = 0.2 – 2 MeV)





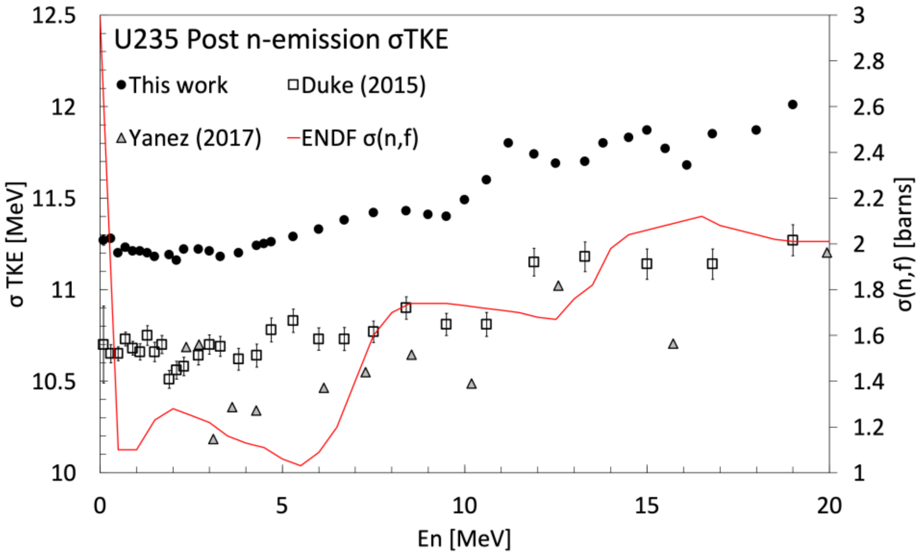
FissionTPC Energy Resolution

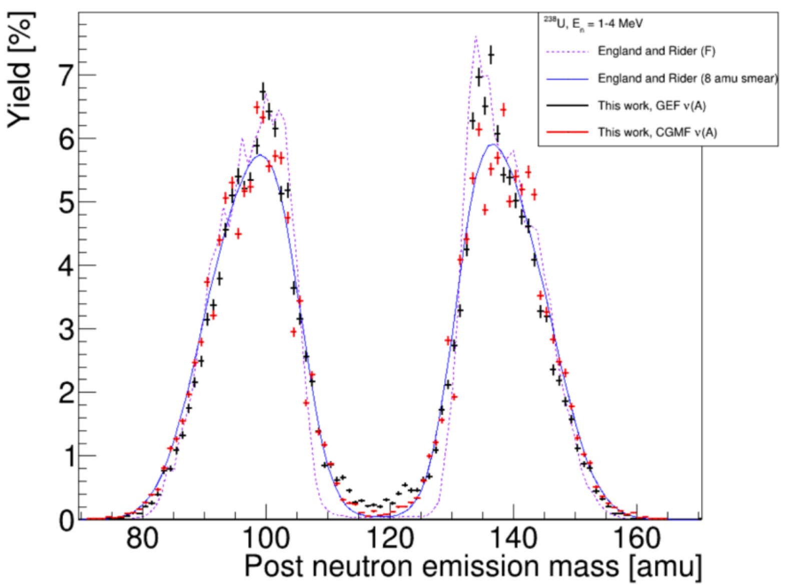
- FissionTPC can identify spontaneous alpha decay
- Generally, no equivalent measurement of energy resolution for FGIC
- E_{res} = ~8% for alphas
- Assume it is similar for fission fragments, translates into ~7 AMU mass resolution
- Assign a partial uncertainty E_{res}

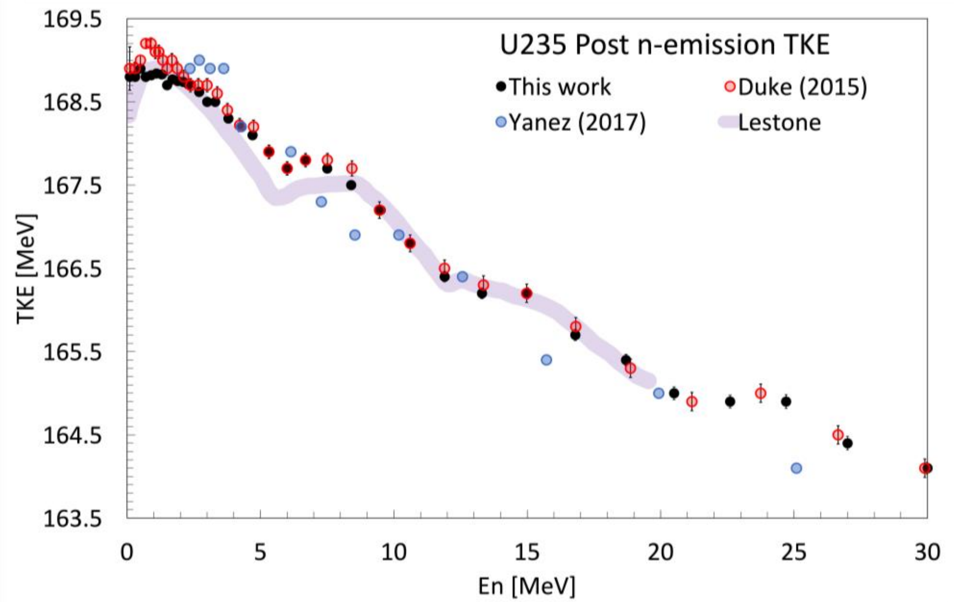


FissionTPC 2E Results

- Comparison ^{235}U to England & Rider indicates an 7-8 AMU resolution
- This is in agreement with the estimate based on fissionTPC energy resolution

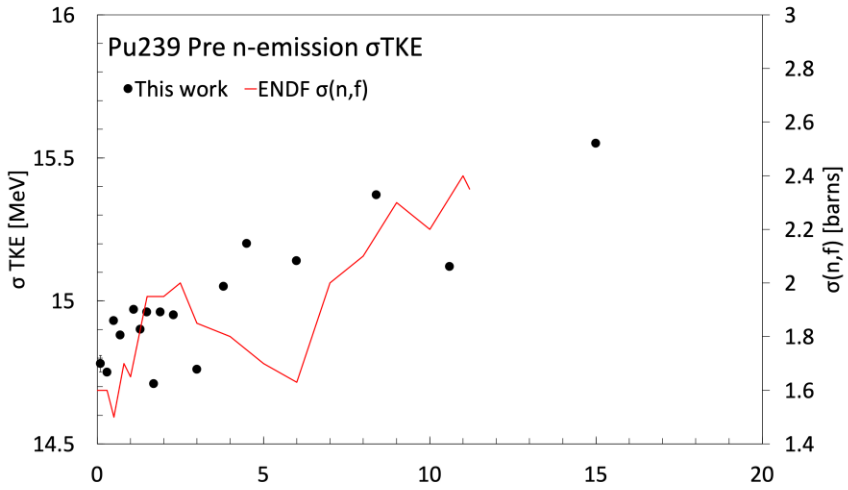


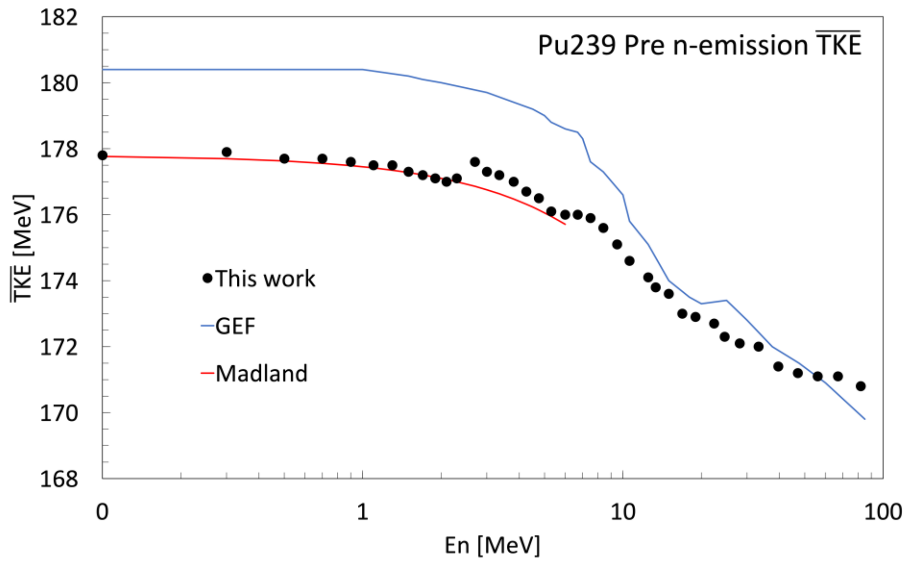


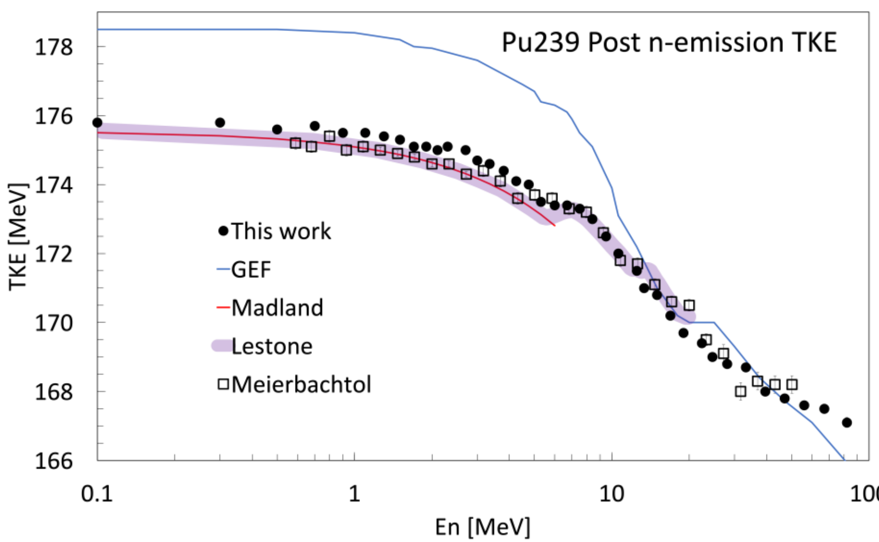


FissionTPC 2E Results

- First measurement of $^{239}Pu(n,f)$ Pre-neutron TKE above 5 MeV
- IFPY for ^{239}Pu not completed







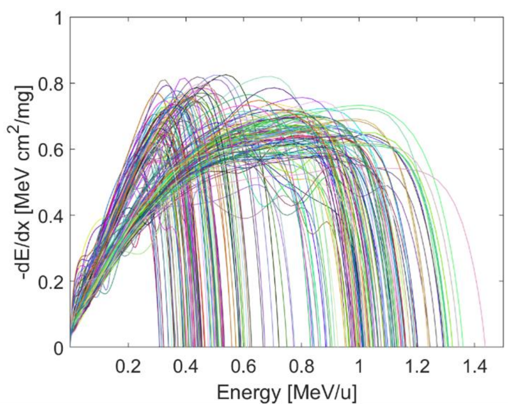
Bragg Curve Analysis with the fissionTPC for ^{235}U Elemental (Z) IFPY

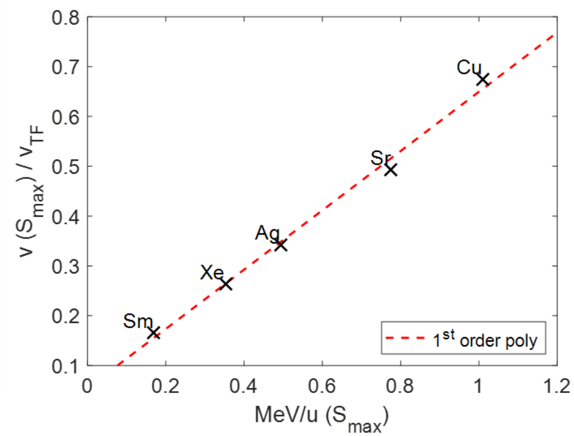
Stopping Force Analysis of ^{235}U for Elemental IFPY with the fissionTPC, M.E. Moore et al., submitted to NDS

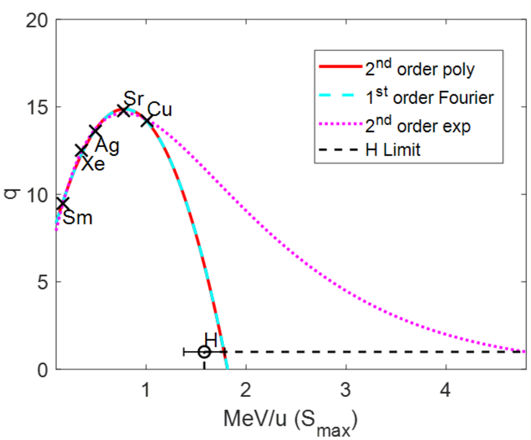
- Using input mass value and velocity produced by 2E analysis and Bragg curves
- Using Standard Thomas-Fermi charge for *effective* charge
- Empirically fit parameters of atomic number at the instant of maximum stopping power
- 3 Z resolution

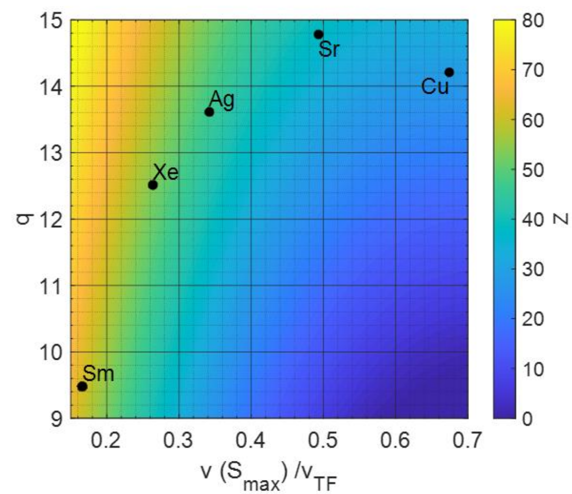
$$S = \frac{4\pi Z_1^2 Z_2 e^4}{mv^2} L; \quad L = \begin{cases} \ln\left(\frac{Cmv^3}{Z_1 e^2 \omega}\right) & \text{Bohr} \\ \ln\left(\frac{2mv^2}{h\omega}\right) & \text{Bethe} \end{cases}$$

$$q = Z_1 \left[1 - e^{-\frac{v}{v_{TF}}}\right]; \quad v_{TF} = Z_1^{2/3} v_0$$









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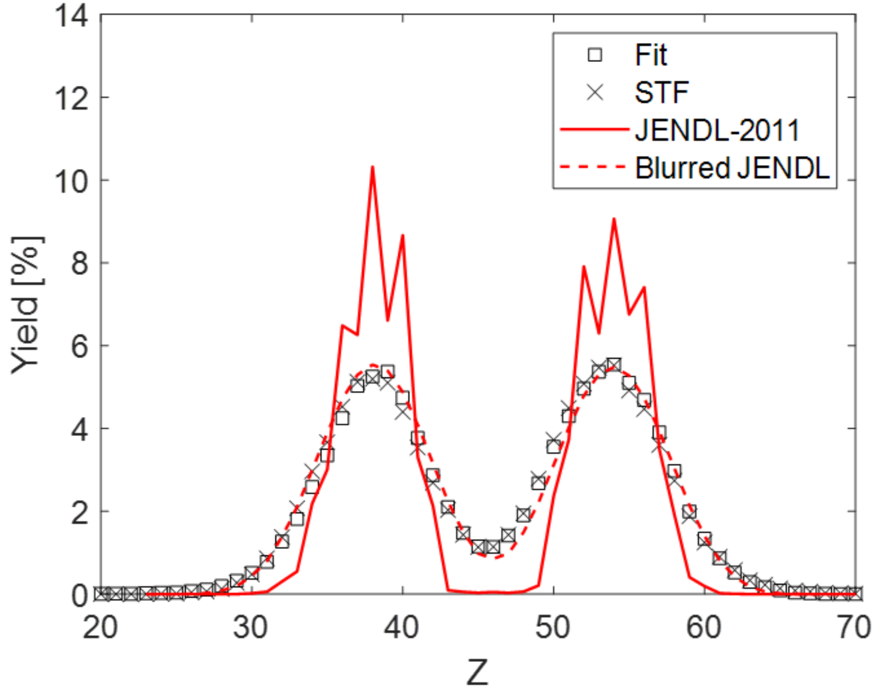
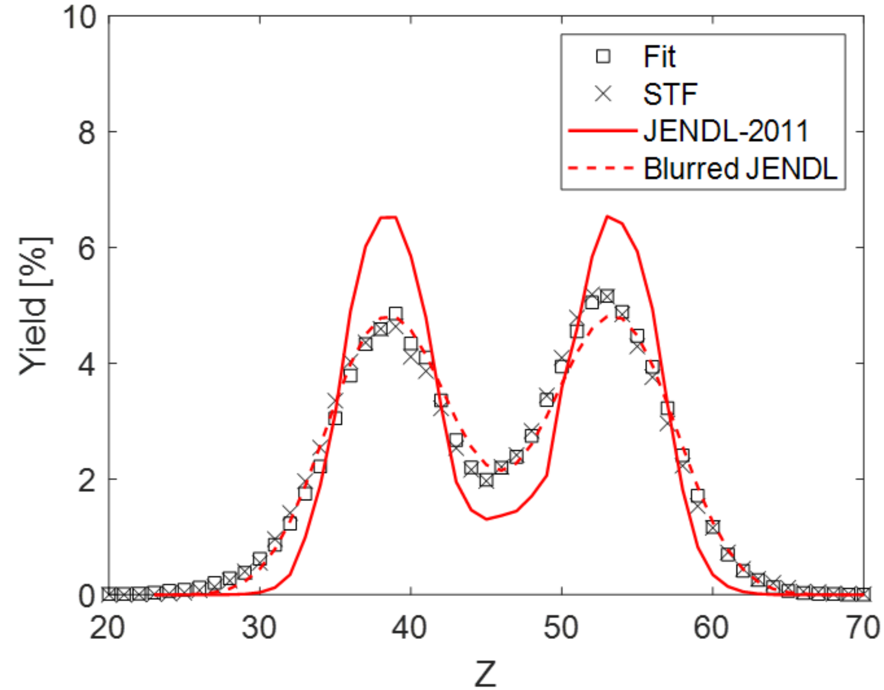
Stopping Force Analysis of ^{235}U for Elemental IFPY with the fissionTPC,
M.E. Moore et al., submitted to NDS

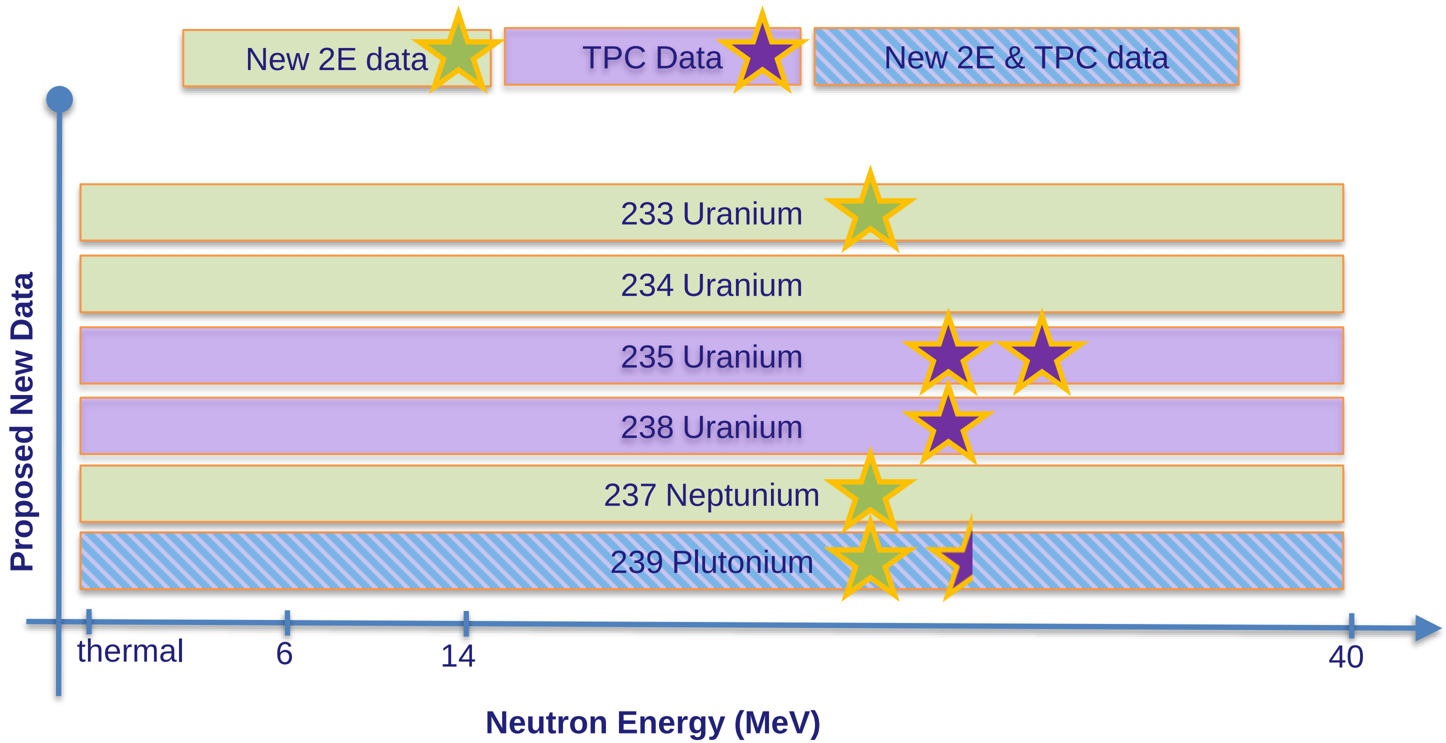
- First of its kind measurement, explores the method; Limitations and possible improvements
- A good review of references for fission fragment (heavy ion) stopping
- Paper does include data tables



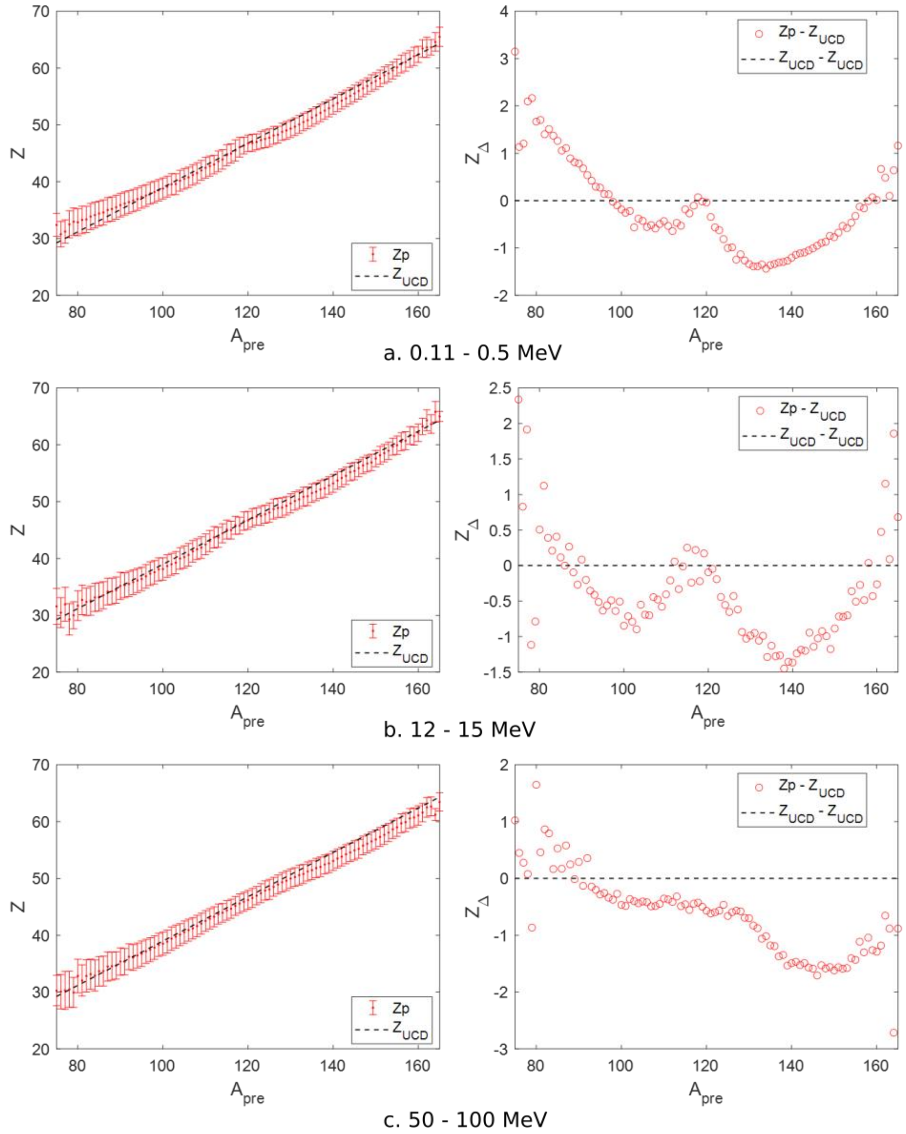


Conclusion

- New data collected, objectives largely met
- FissionTPC analysis explored partial uncertainties. 2E uncertainty dominated by energy resolution followed by systematic effects of prompt neutron estimates
- Stopping force analysis for Z yield was completed. Improvements in energy resolution and calibration could make such an analysis very useful



Backup



Z
Apre
Zp
ZUCD
ZΔ
Zp - ZUCD
ZUCD - ZUCD
a. 0.11 - 0.5 MeV
b. 12 - 15 MeV
c. 50 - 100 MeV