LA-UR-20-21975

Measurements of Independent Fission Product Yields

Workshop on Applied Nuclear Data Activities (WANDA)

March 5, 2020

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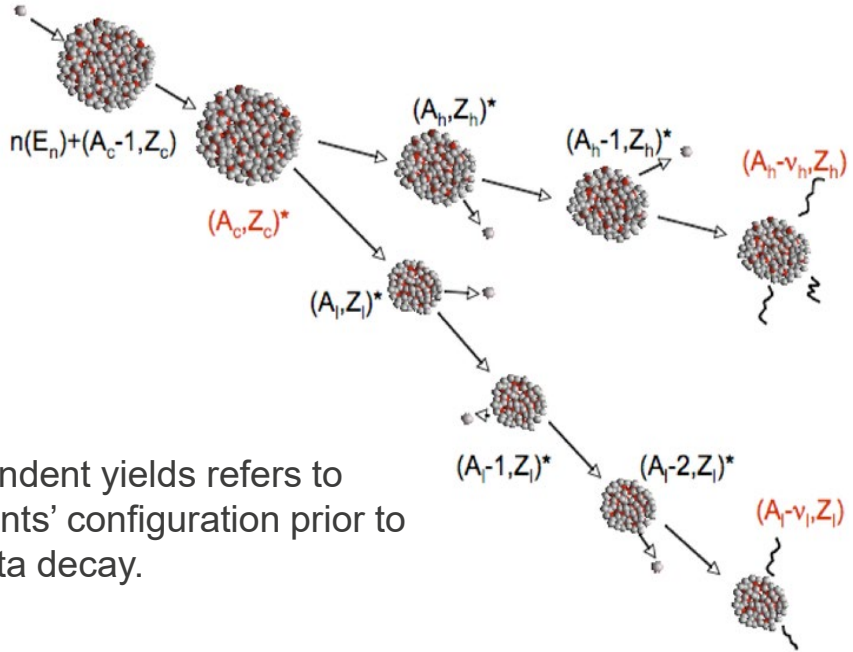
The goal of this experiment is to improve IFPY nuclear data by minimizing and understanding uncertainty in new measurements.

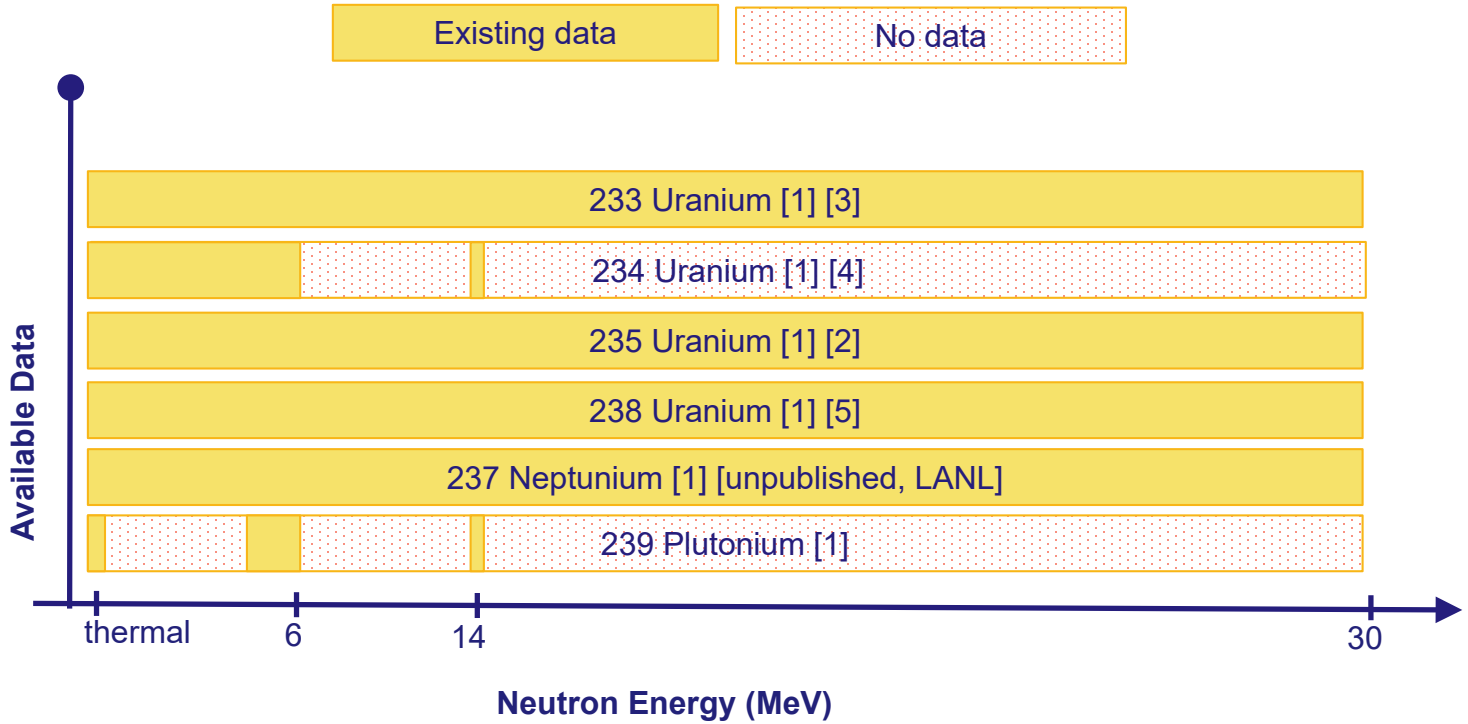
We will accomplish this by leveraging existing and newly applied technologies: 2E Frisch Gridded Ionization Chamber (FGIC) and the fission Time Projection Chamber (fissionTPC)



Independent yields refers to fragments' configuration prior to any beta decay.

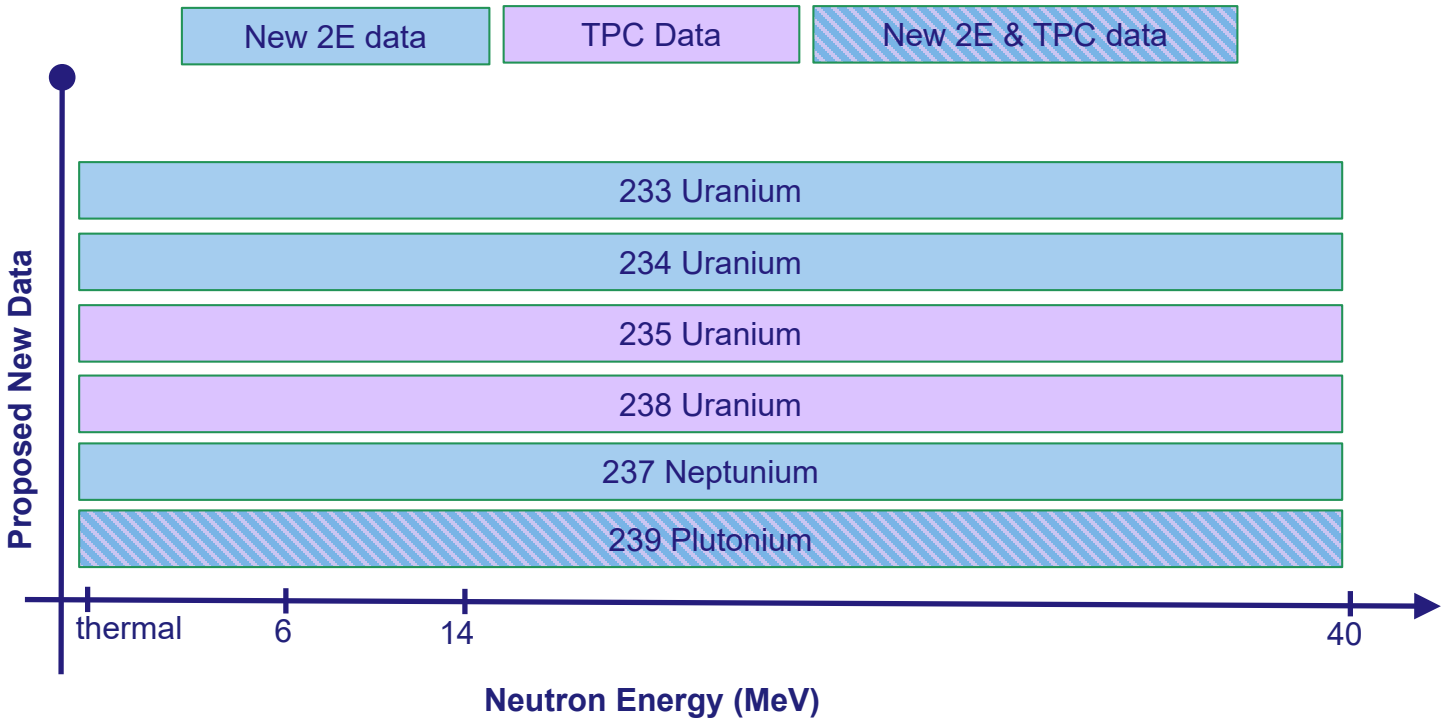
As models of nuclear fission evolve, more independent fission product yield data (IFPY) are needed to support applications.

- The available data have gaps, especially at higher neutron energies, and needs improved uncertainty quantification.



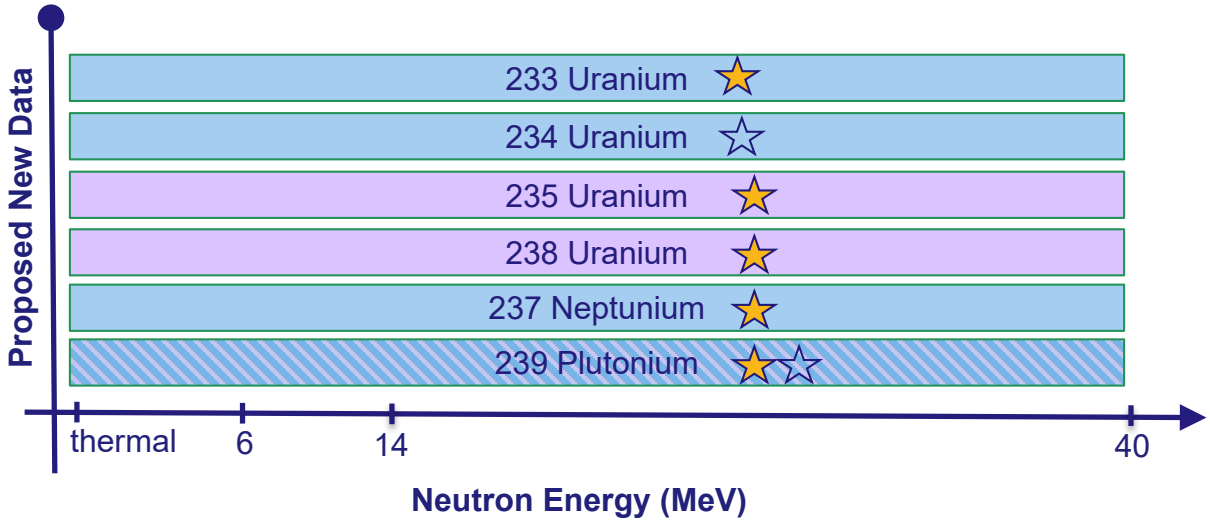
As models of nuclear fission evolve, more independent fission product yield data (IFPY) are needed to support applications.

- New data 2E will be added during this experimental program; the TPC data already exists and is awaiting analysis.



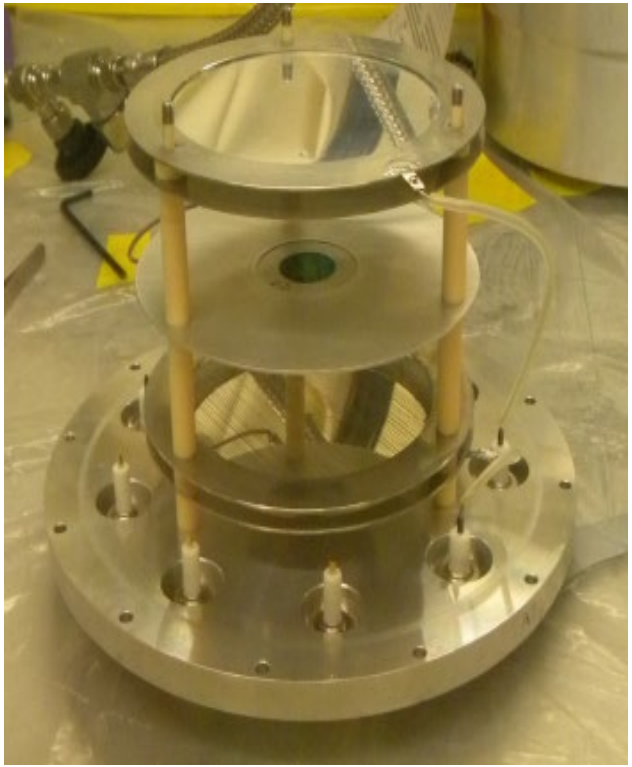
Three experimental methods are providing new data and are already delivering preliminary results.

1) Perform 2E measurements of 233-U, 234-U, 237-Np, and 239-Pu using the proven technology of the FGIC with a full uncertainty analysis.
2) Analyze existing TPC 235-U, 238-U, and 239-Pu data to produce FPY measurements and probe uncertainties related to energy loss, pulse height defect, and pile-up.
3) Develop a new Bragg curve-based TPC analysis. This method has potential to provide fission product mass and charge distributions. This independent method provides another way to study fission product yields.



1) FGIC's are a proven technology used to measure fission observables such as IFPY's, total kinetic energy release, and cross sections.

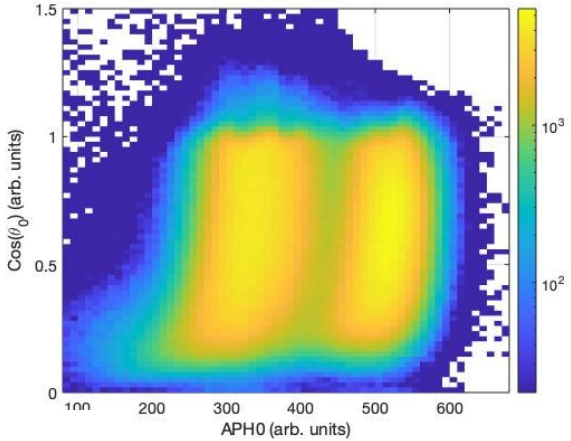
- The FGIC measures energies and emission angles of fission fragments, which are used to calculate masses and TKE in the 2E method.
- This detector type was used in most of the existing IFPY measurements, which provide about 4-5 amu mass resolution and have some systematic uncertainties.



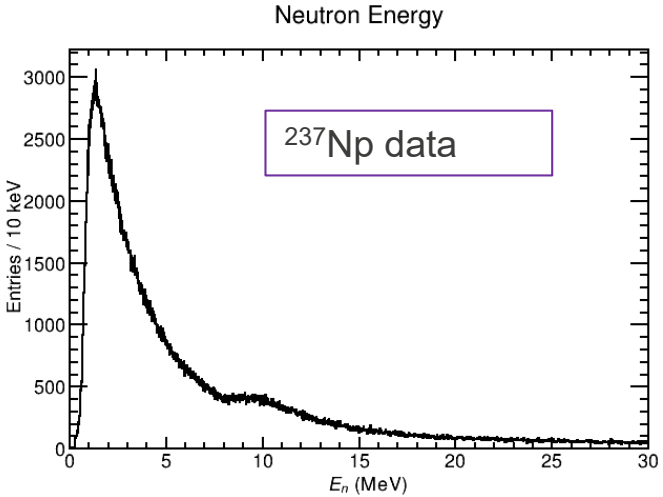
[2,6]

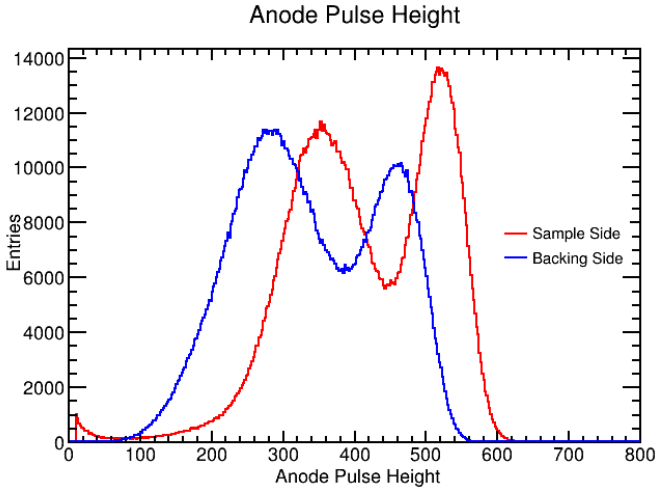
We collected high statistics data sets on ^{237}Np and ^{233}U in LANSCE run cycle 2019 and preliminary data analysis is promising.

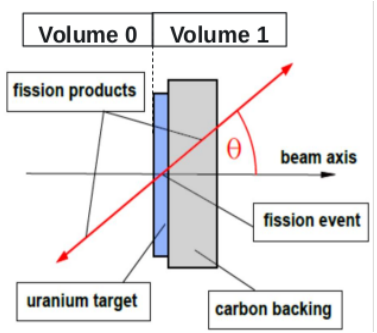
- New target fabrication techniques by Walt Loveland (OSU) have improved data quality.
- Collected high statistics data sets on ^{237}Np and ^{233}U in 2019
- Data analysis by PhD student Kristina Montoya and postdoc Devin Connolly.



^{233}U data

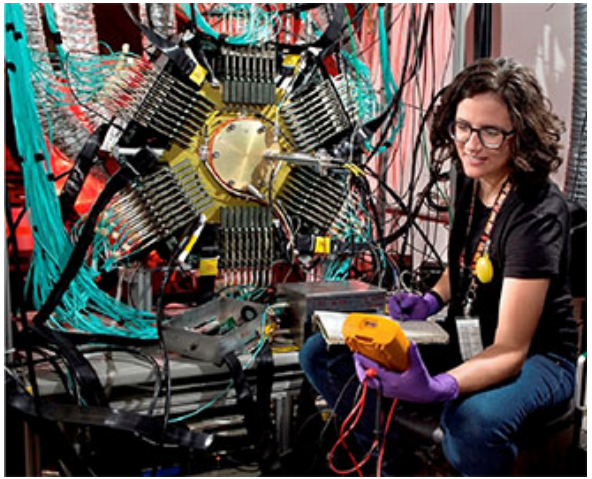


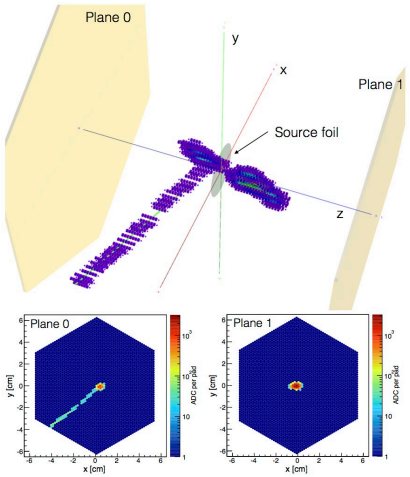


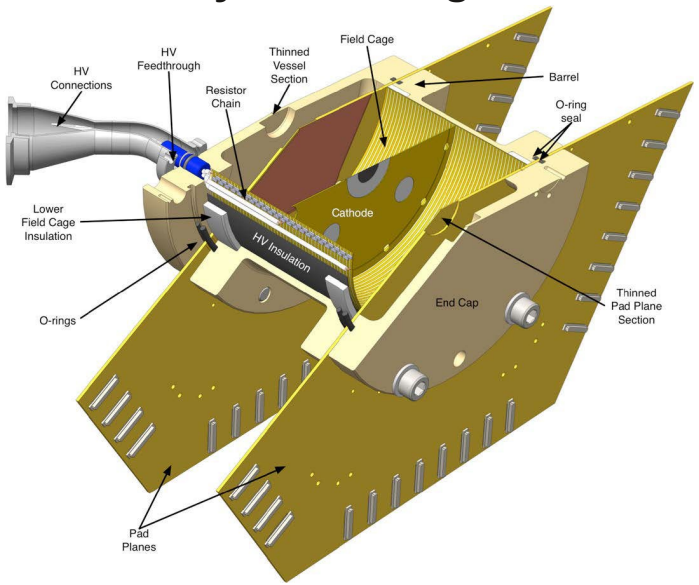


2) The TPC will use a 2E analysis technique on existing data to probe the uncertainties inherent in the method.

- The fissionTPC has added valuable precision cross section data to nuclear data libraries.
- A three dimensional reconstruction of the fission fragment track provides additional information that can be used to assess uncertainties in previous 2E measurements.
- TPC data for ^{235,238}U and ^{239}Pu was already available and analysis has begun.

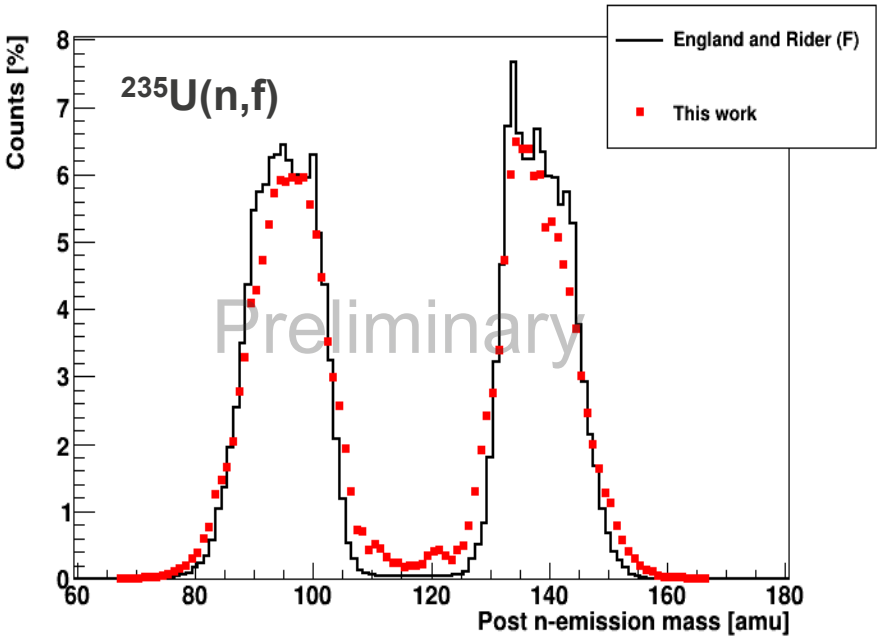


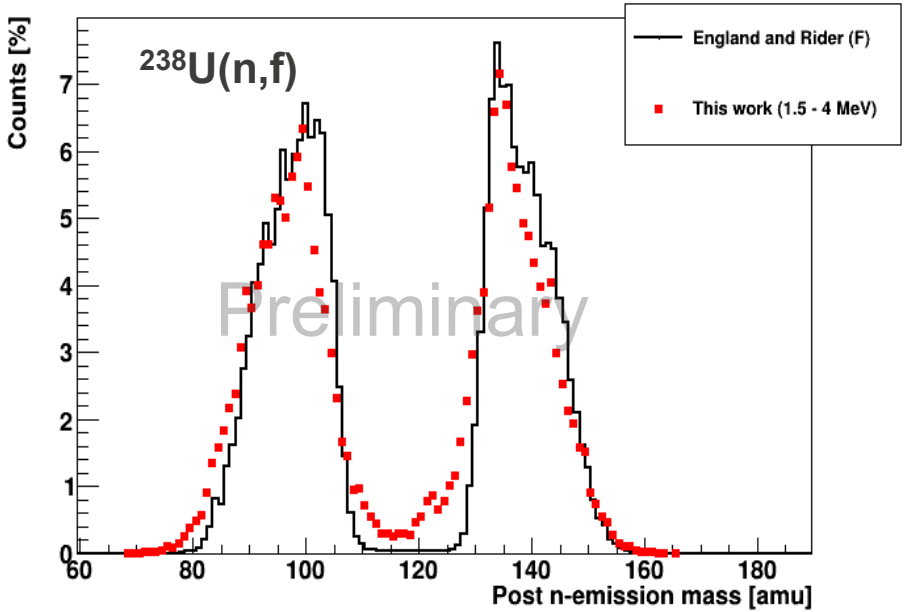




[7]

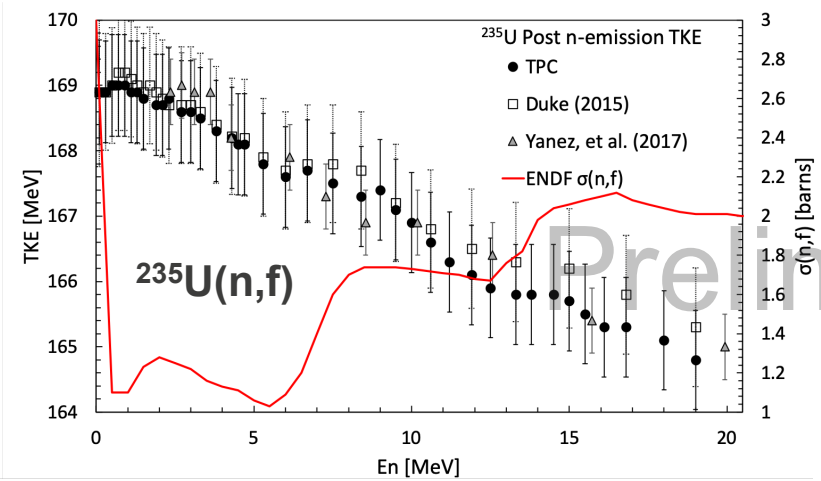
Preliminary TPC mass yields have a shape/structure of the post n-emission distribution is very dependent on nu(A) due to application of 2E method.

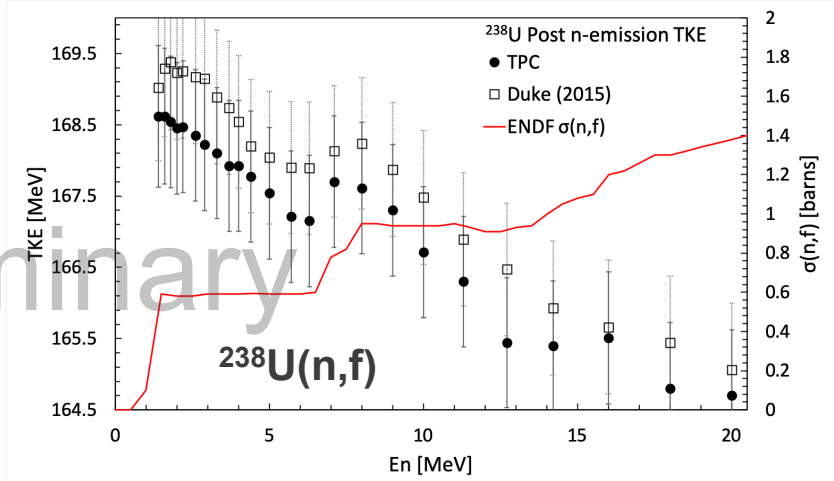


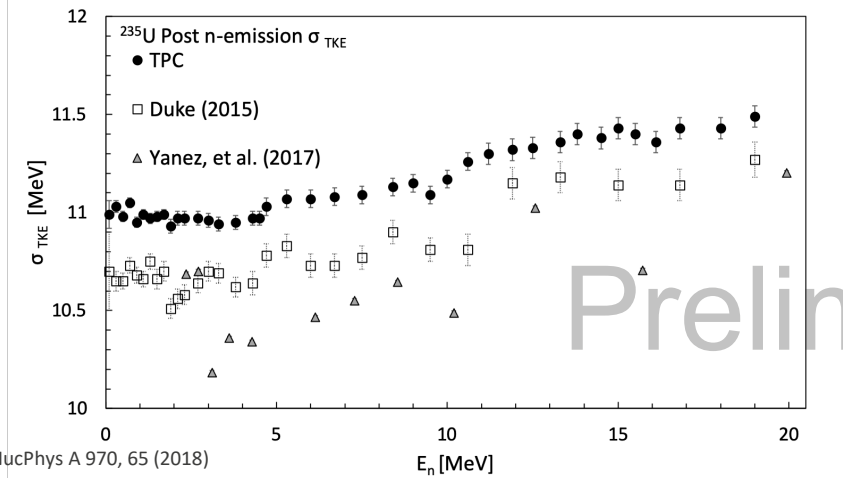


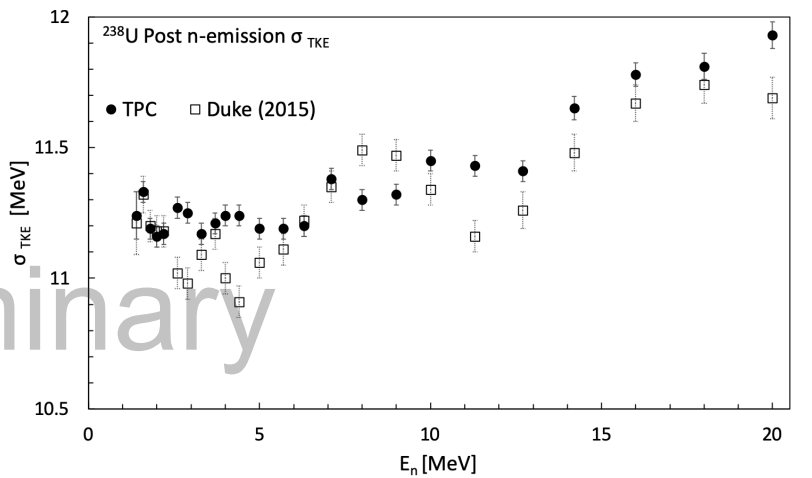
Analysis by Ph.D. student Joseph Latta.

The TPC can also measure Total Kinetic Energy of the fission fragments without the 2E method.



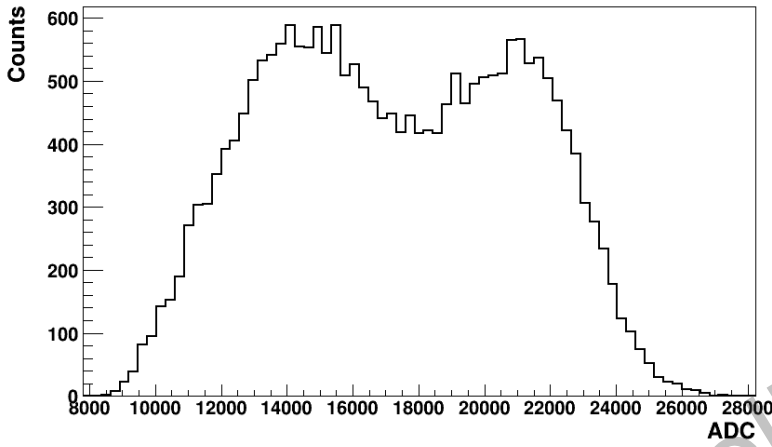


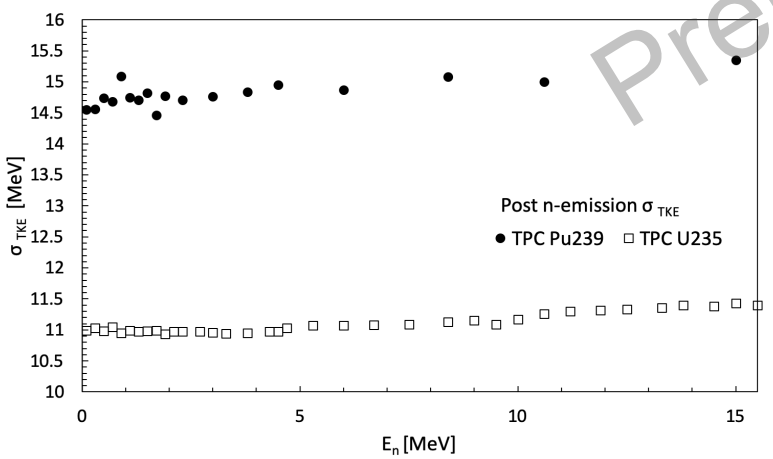


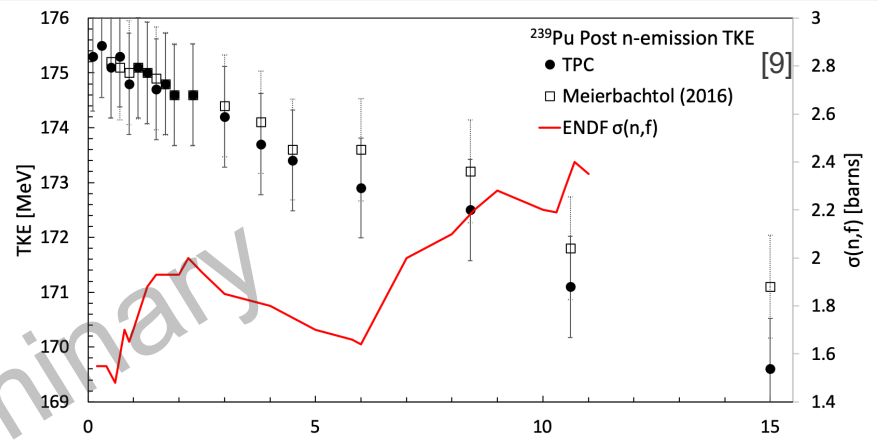


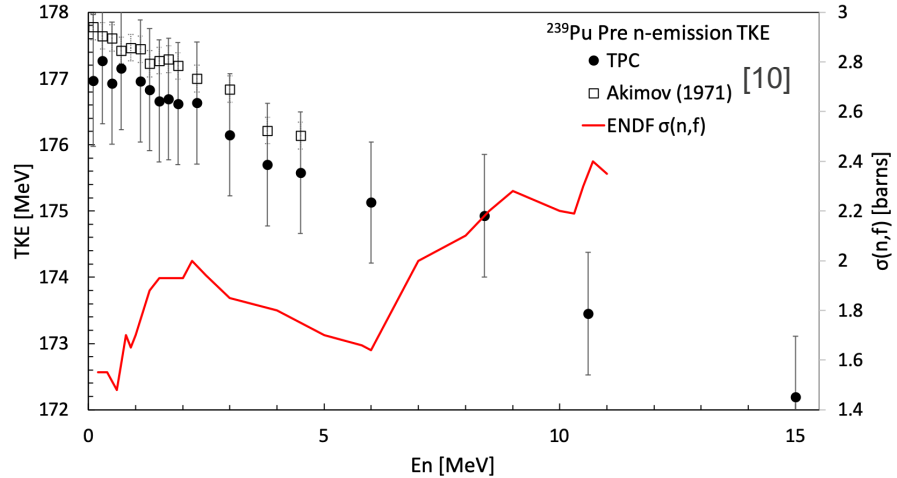
Yanez. NucPhys A 970, 65 (2018)

Preliminary ^{239}Pu TKE data is comparable to previous work, despite poor energy resolution due to similar target manufacturing.



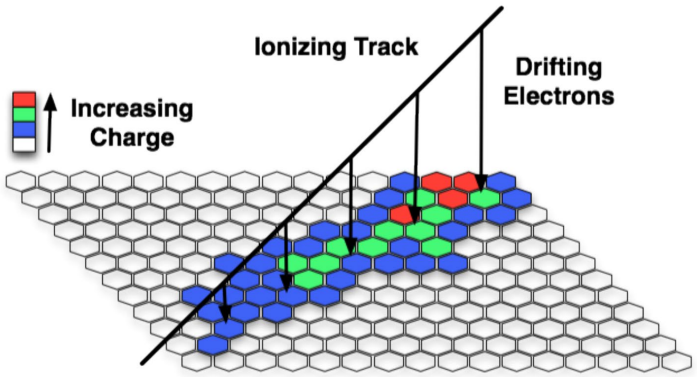


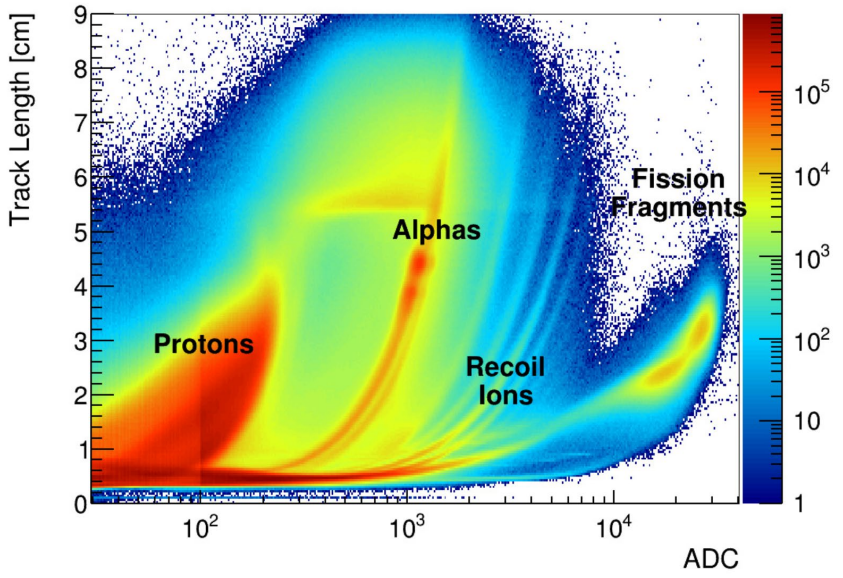




3) We are developing a Bragg curve analysis and exploring uncertainty reduction to IFPY's using the fissionTPC.

- **Bragg curve spectroscopy can provide not only the mass (A) of the particle, but its charge (Z) and recent analysis suggest this may be possible using the fissionTPC.**
- **If A and Z of a fragment can be measured, it would have a lasting effect on the way that 2E analysis is performed because uncertainty from prompt-neutron emission could be significantly reduced.**

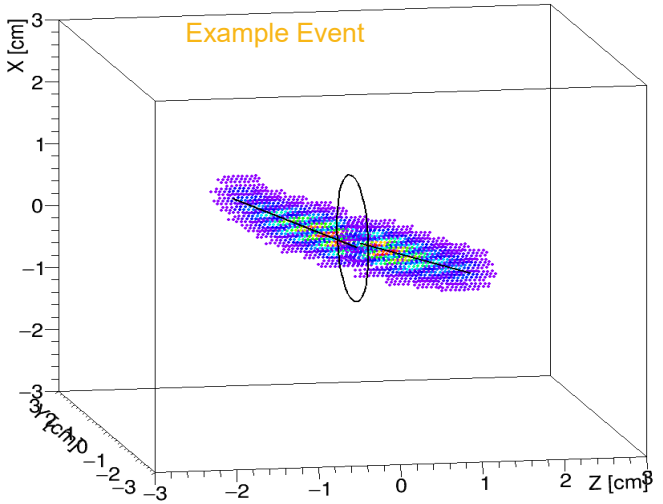


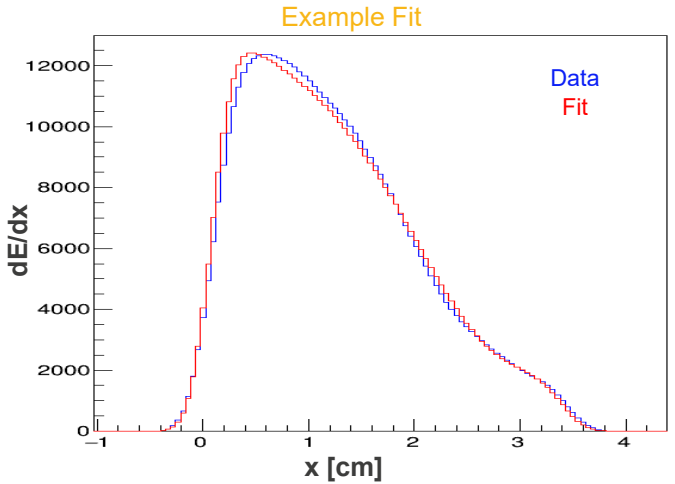


[8]

Bragg Curve fitting currently employs a track-by-track ionization profile.

- Issues
  - Accuracy of SRIM energy loss model
  - Pulse height defect / energy measurement
  - Uniformity of energy deposition along track
- Result in poor A,Z resolution
- Next steps
  - Data-based corrections to line shape model
  - Integrate with 2E method for combined event-by-event result

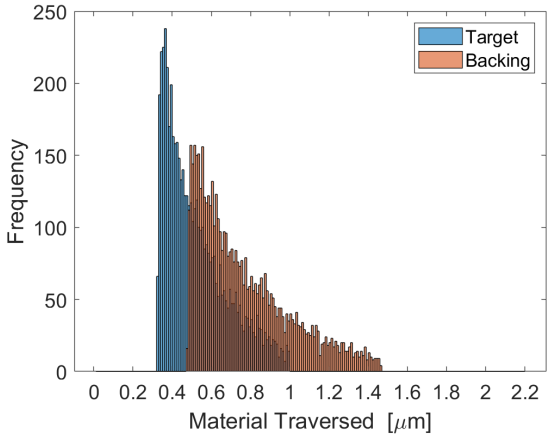




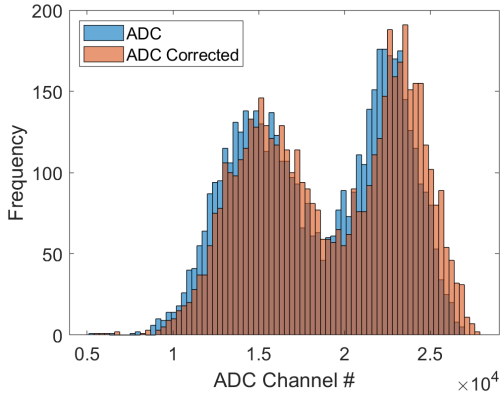
Bragg curve derived Z distributions still require empirical conversion of ADC to dE/dx independent of 2E method and standard PHD corrections.

Extract independent Z distribution from reconstructed fragment ionization profiles

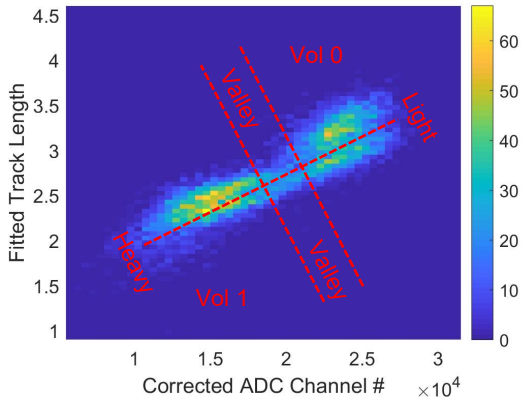
- Reconstruction fragment pair vectors through target/backing
- Apply angular stopping power loss correction for light/heavy ADC windows
- Create ADC dependent Bragg parameter distribution



Fragment travel distance through target/backing



ADC correction for stopping loss to target in volume 0



Light/heavy fragment distributions for both volumes

Conclusion: We are leveraging the strengths of both detectors to provide multiple IFPY's data sets with reduced uncertainty.

- The FGIC will collect new data and IFPY's will be analyzed with input from TPC on uncertainty analysis.
- Existing TPC data analysis will be refined and uncertainties developed.
- By applying the TPC to measuring fission product yields, we will be able to better understand the uncertainties inherent in existing ionization chamber measurements, thereby improving the nuclear data libraries.

Progress (as of 02/27/19)

- Acquired 239Pu target for upcoming 2020 LANSCE run cycle
- Preliminary fissionTPC data U235, U238 & Pu239 analysis
- Preliminary FGIC data for Np237 and U233 analysis
- Planned work to addressed uncertainties in stopping power, energy loss, and pulse height defect

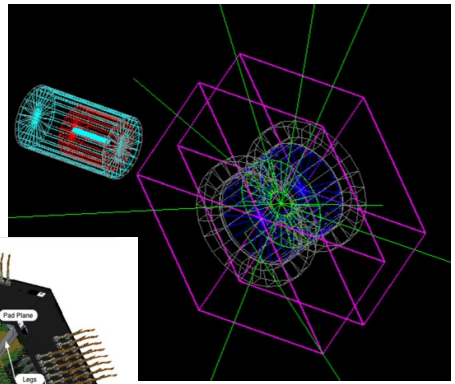
Thanks for your attention!

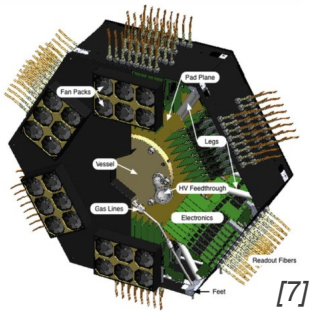
1) T. R. England and B. F. Rider. ENDF-349. 1993.
2) D. L. Duke. PhD Dissertation. Colorado School of Mines. 2015.
3) D. Higgins. PhD Dissertation. Colorado School of Mines. 2018.
4) A. Al-Adili et al. *Phys. Procedia.* 31:158-164. 2012.
5) D.L. Duke et al. *Phys. Rev. C.* 94:54-60 Nov. 2016.
6) S. Mosby et al. *Nuc. Inst. & Meth. A.* 757:75-81. Aug. 2014.
7) M. Heffner et al. *Nuc. Inst. & Meth. A.* 759:50-64. Sept. 2014.
8) D. Duke, L. Snyder, L. Wood. Measurements of IFPY's. LAB 18-1903.
9) K. Meierbachtol et al. *Phys. Rev. C* 94, 034611 (2016)
10) A. Akimov et al. *Sov. J. Nuc. Phys.* 13, 272 (1971)

Efforts to determine the possible improvements to understanding data from the fTPC through coincidence measurements of the prompt γ signatures from fission fragments.

Prompt γ-emission from fission is also an area lacking in present fission data, but can provide insight into:

- Partition of energy
- Angular momentum
- Neutron-γ competition during fragment de-excitation

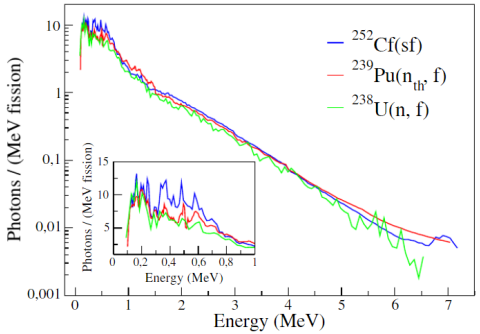




[7]

Figure from S. Lyons (PNNL)

Recent work from a Romanian group used $LaBr_3(Ce)$ detectors to observe prompt γ emission from $^{238}U(n,f)$, $^{239}Pu(n_{th},f)$, and $^{252}Cf(sf)$ over a wide energy range.

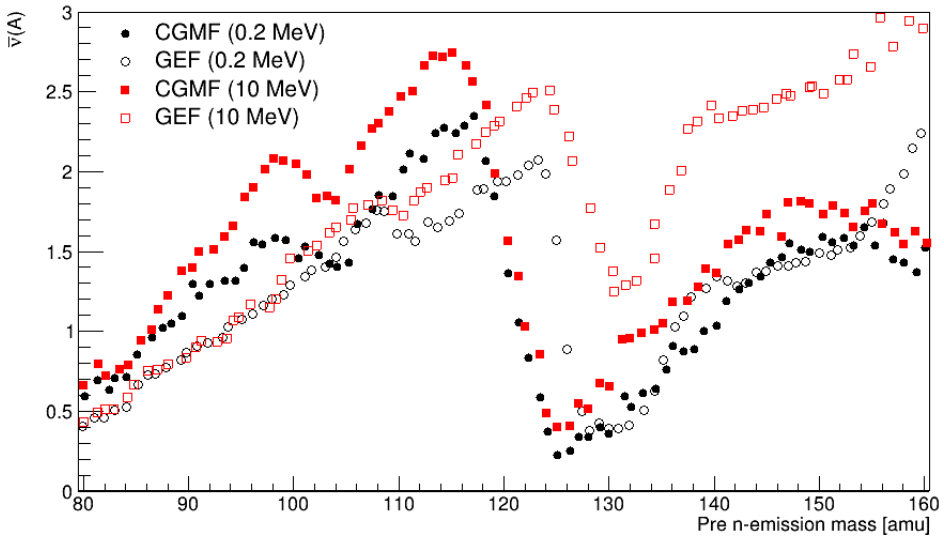


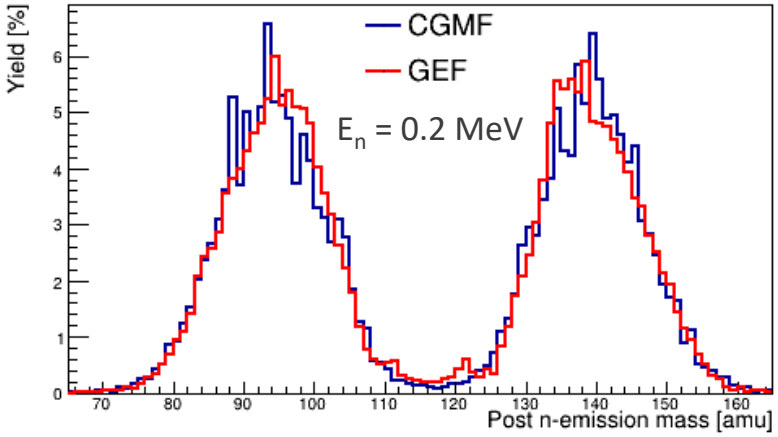
D. Choudhury et al. AIP Conf. Proc. 2076, 060002 (2019)

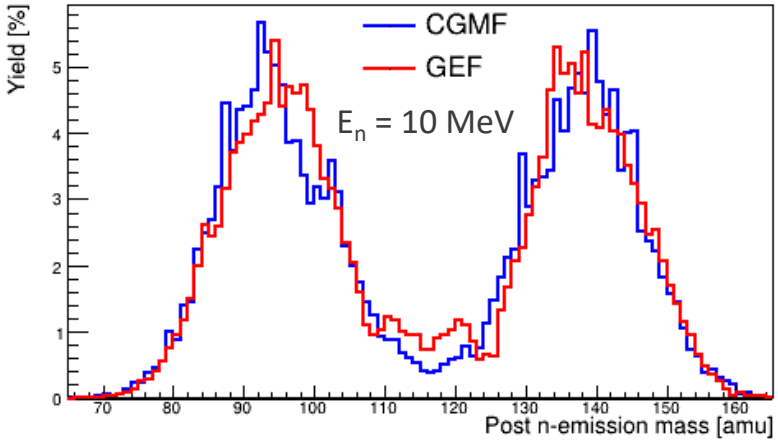
Begun simulations to estimate the feasibility of incorporating γ-detectors to measure the deexcitation of fragment yields, to facilitate further analysis goals.

Effect of model inputs on 2E analysis

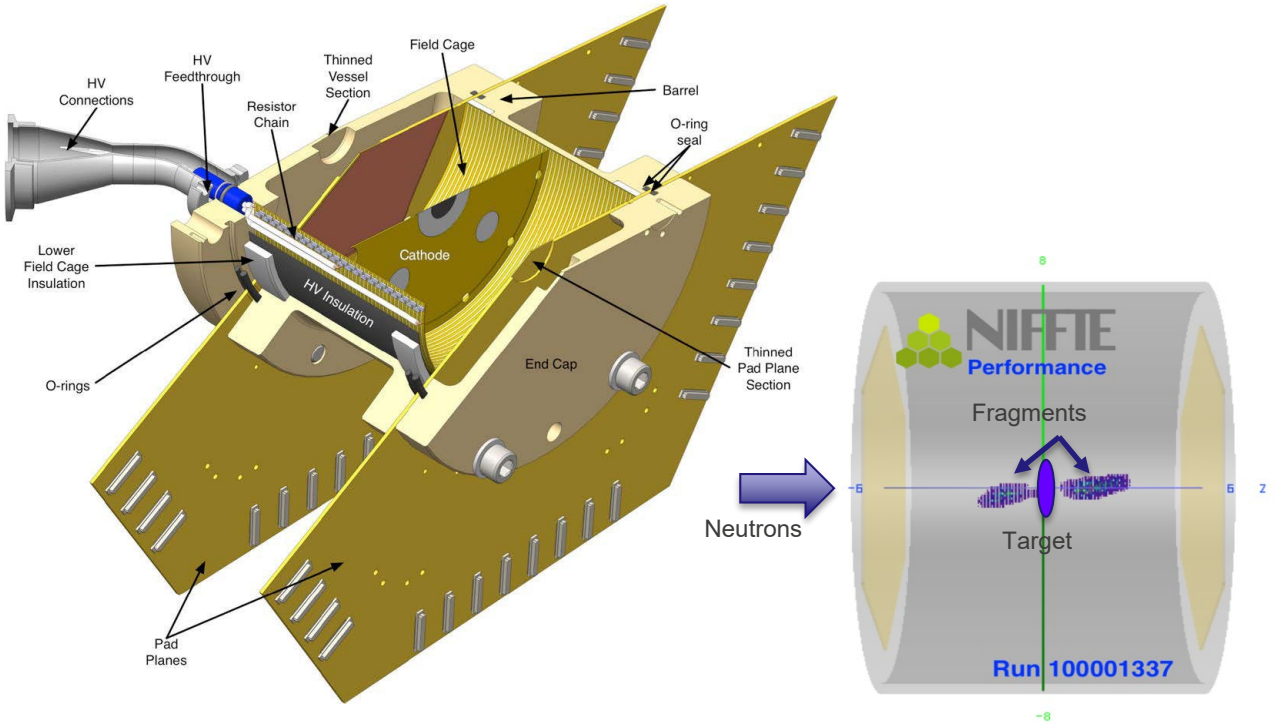
U235 Neutron multiplicity models



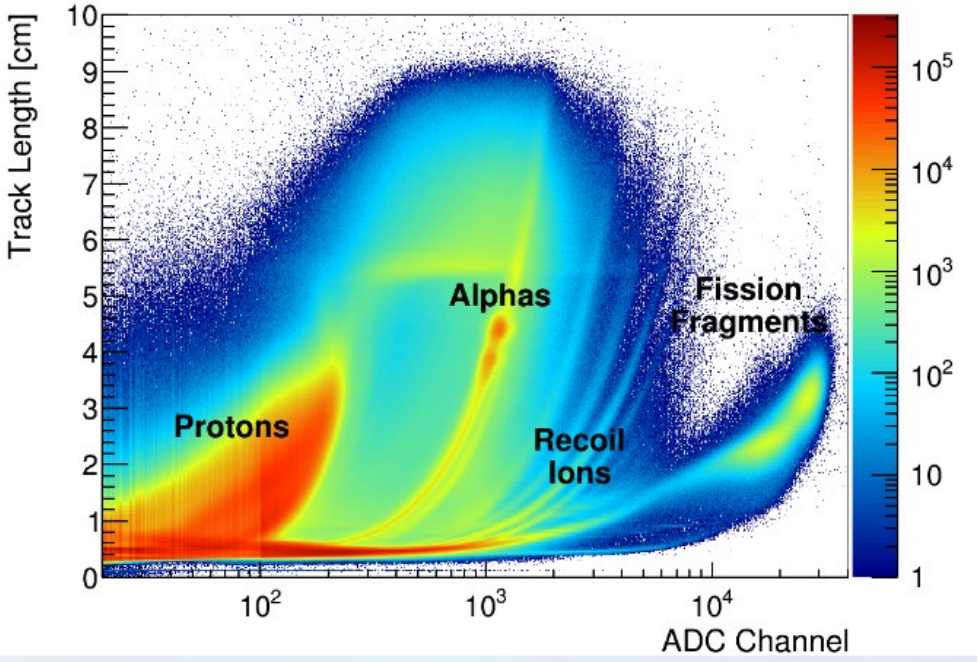




How does the fissionTPC work?



fissionTPC Data



- Utilize advantages of fissionTPC such as measured track angle, 3D track reconstruction, track length and particle identification capability (address alpha pile-up in 239Pu data).
- Probe uncertainties related to energy loss in target/backing, v(A), and pulse height defect .
- Inform Bragg Curve Analysis

Effect of model inputs on 2E analysis

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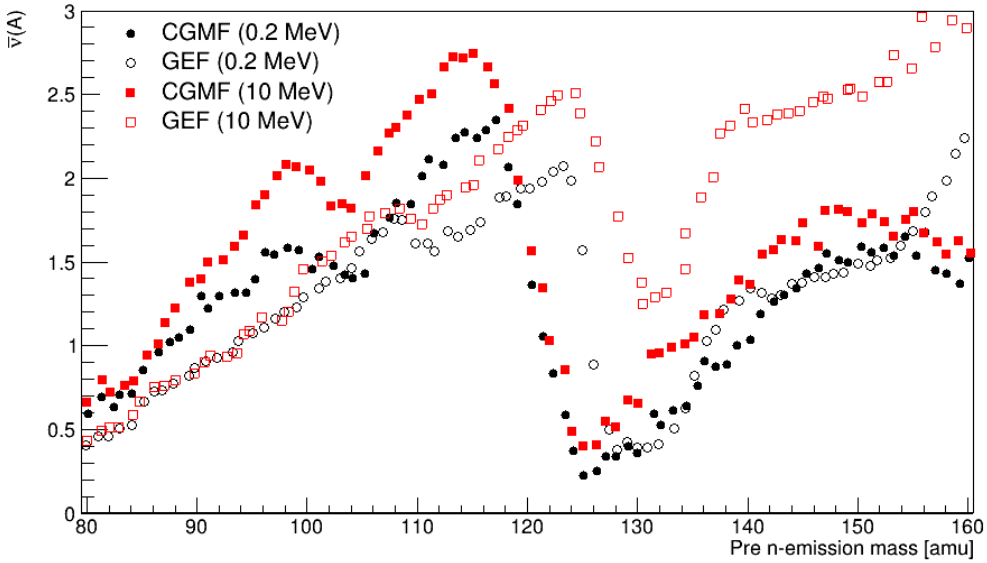
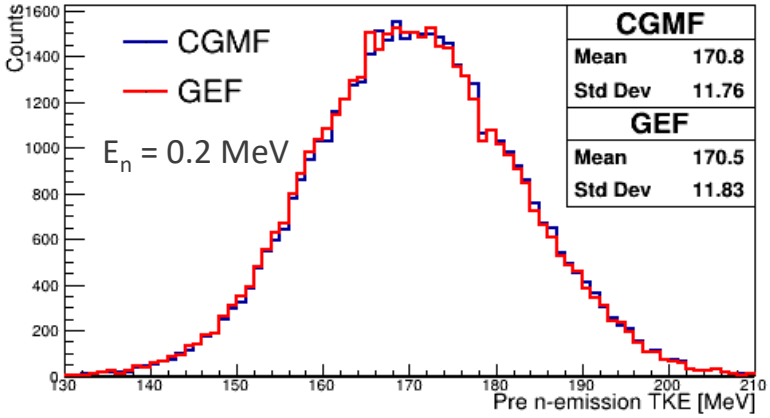
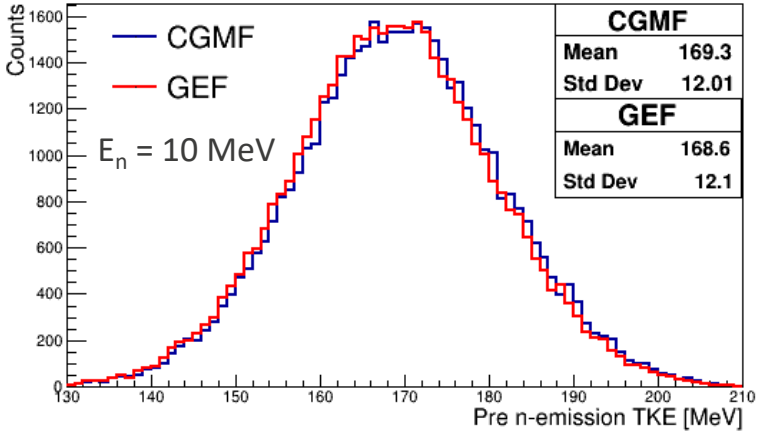
U235 Neutron multiplicity models







Anode Corrections

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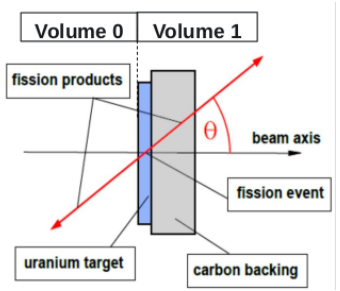
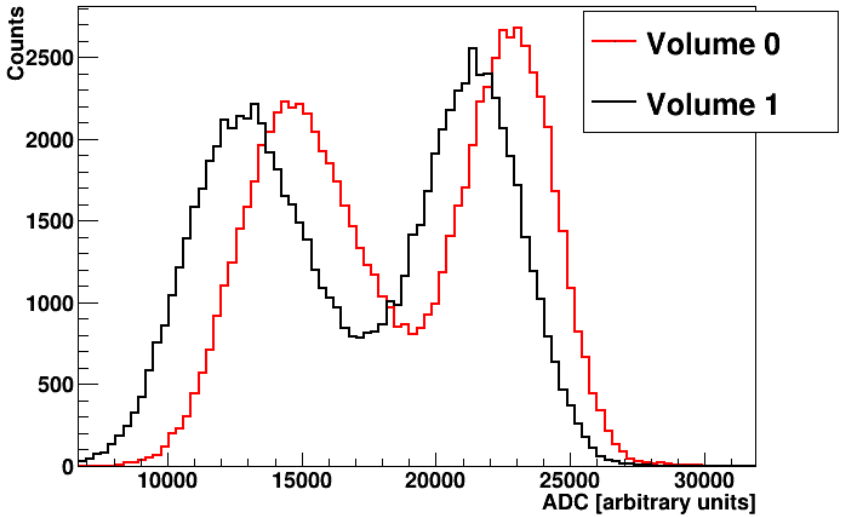
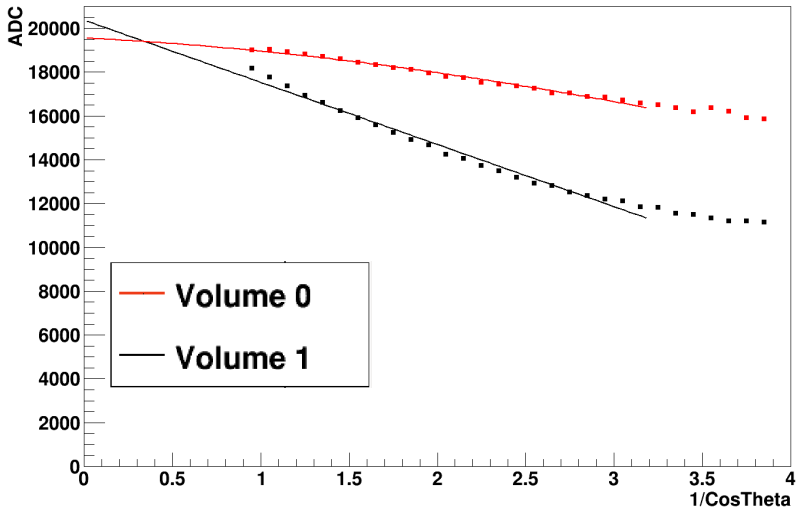
Correction for fragment interactions in target and backing material



ADC prior to corrections



Energy Loss Correction

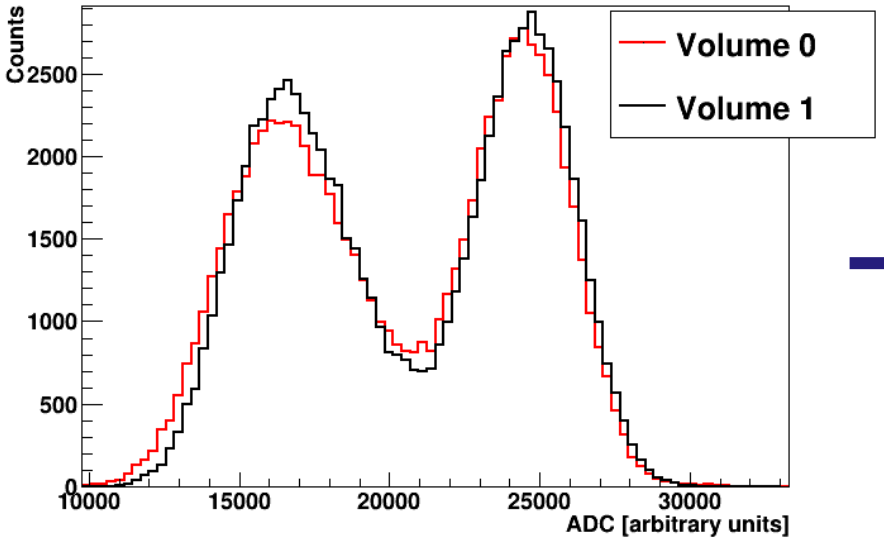


Energy Calibration

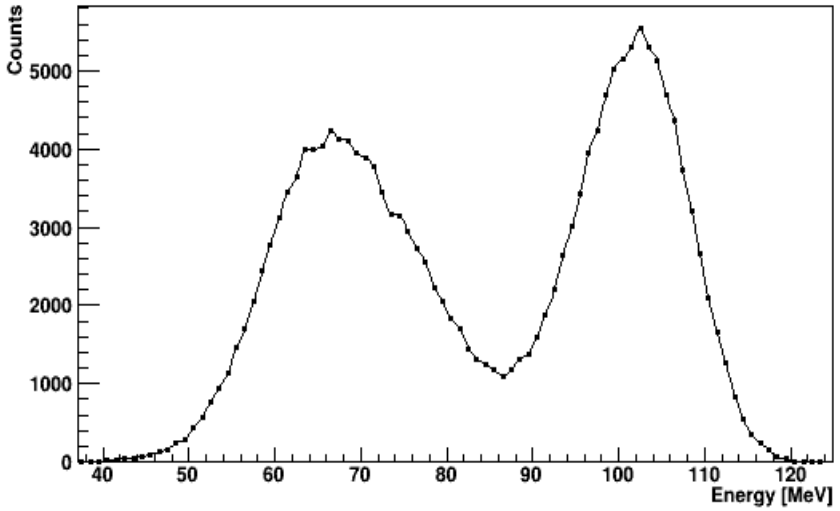
^{235}U Target
Convert ADC to energy in MeV
Scale TKE to average of literature values
MeV = 0.004115*ADC

CJP 40, 1626 (1962)
PhysRev 141, 1146 (1966)
PhysRev 156, 1277 (1967)
LA-UR-15-28829 (2015)

ADC after corrections



Fission Fragment Kinetic Energy Distribution



Effect of model inputs on 2E analysis

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- Continuing work
  - Utilize 2E analysis to inform bragg curve analysis for nuclear charge determination
  - Explore more model based effects on 2E analysis
    - Other v(A) models
    - Multi-chance fission probabilities
    - Model based energy loss
  - Quantify error induced by model inputs
  - Potential to utilize length to compensate for poor TPC energy resolution