NIFFTE fissionTPC status update on ^{239}Pu(n,f)/^{235}U(n,f) and ^{235}U(n,f)/^{6}Li(n,t) cross section ratio measurements

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NDS Meeting Oct 9-13, 2023

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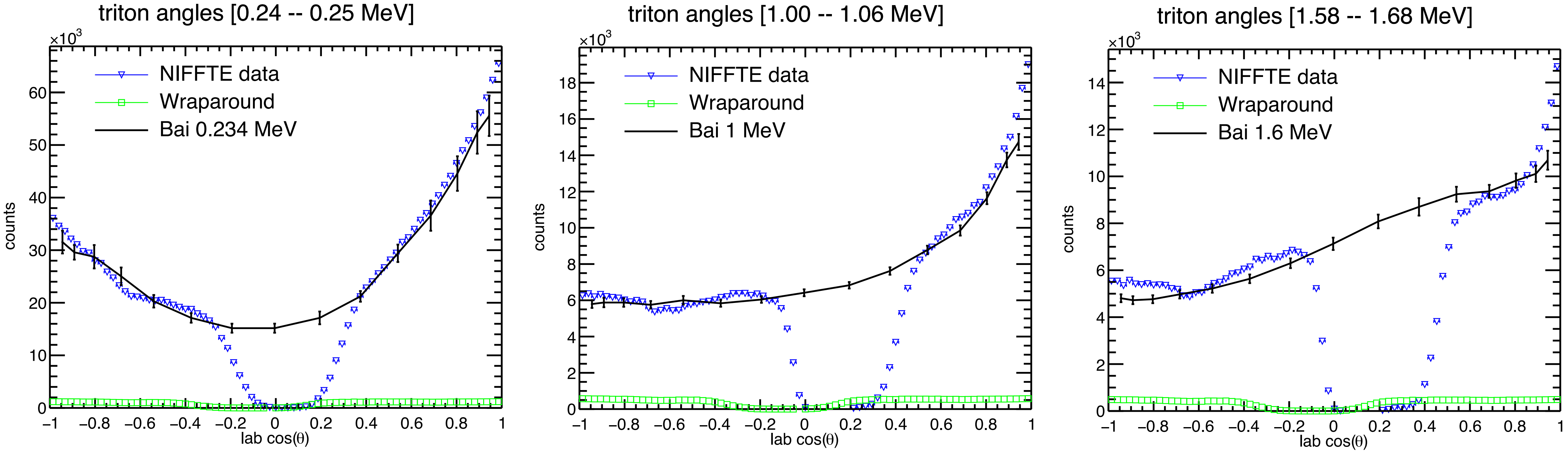
$^{235}U(n,f)/^{6}Li(n,t)$ cross section ratio - Status Update

- Finalize $^{235}U(n,f)$ selection efficiency and wraparound corrections
- $^{6}Li(n,t)$ selection efficiency + corrections (wraparound, scattered neutrons, etc) in progress
- $^{6}Li(n,t)$ Angular distributions in progress:
  - This analysis is part of our efficiency correction procedure
  - Extracted from our data
  - Preliminary data compared to Bai data *(Chinese Physics C Vol. 44, No. 1 (2020) 014003)*
- Last step: Selection cuts variation analysis.

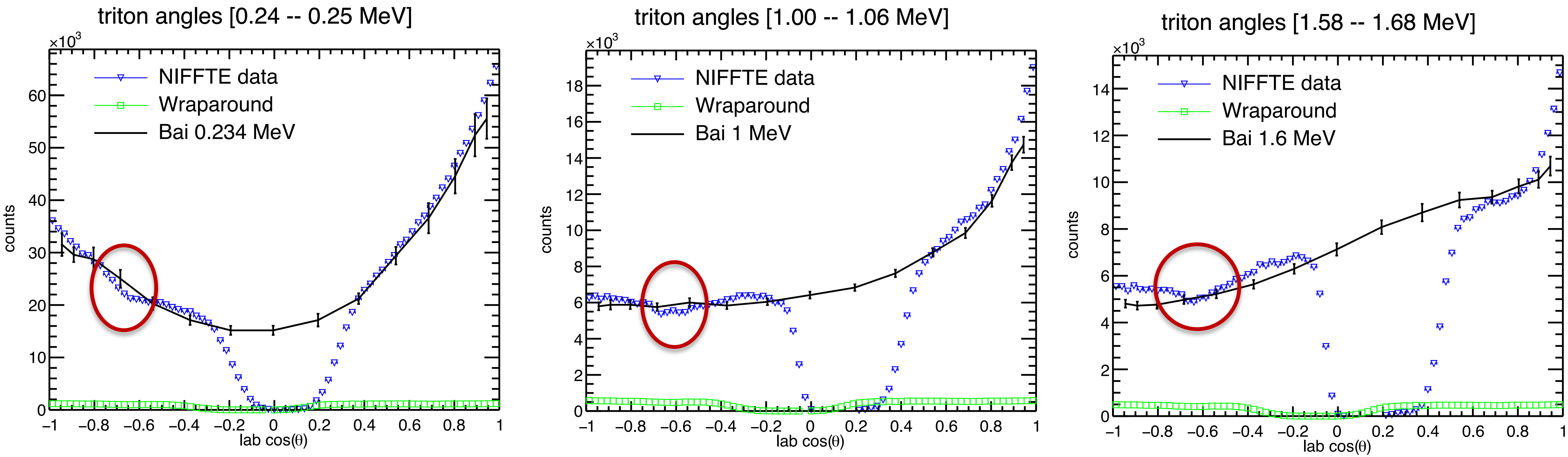
^{6}Li(n,t) reaction: triton angles distributions #1



Plots by M. Mendenhall

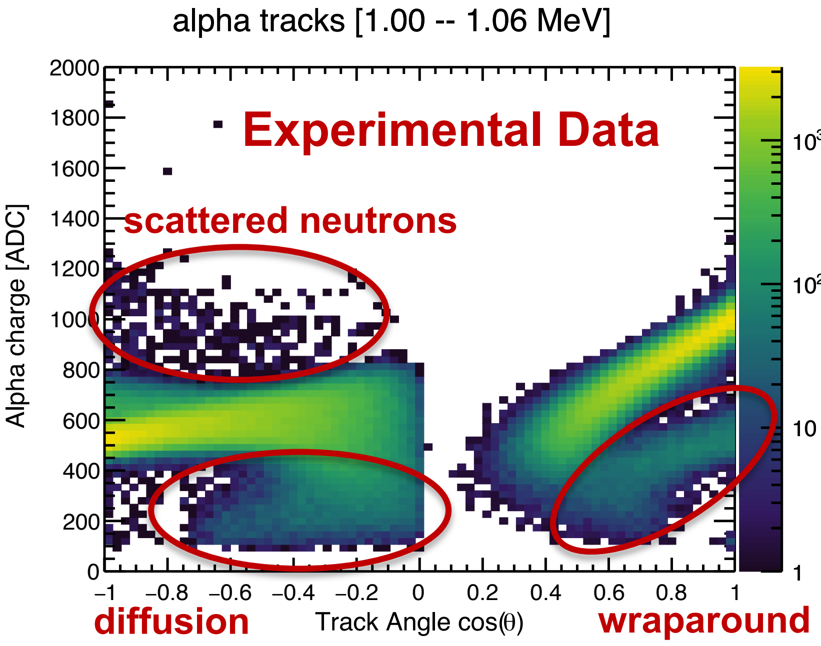
- Examples of 3 neutron energy bins.
- Our major selection efficiency correction is at cosθ(-0.3,0.3). We observe the effect of energy loss in the target for particles with high polar angles.
- Preliminary comparison to the recent Bai data shows that we are in good agreement.
- ***With the fissionTPC's large angular coverage an "almost"-continuous distribution could be provided in comparison to experiments where detectors were placed in fixed angles.***

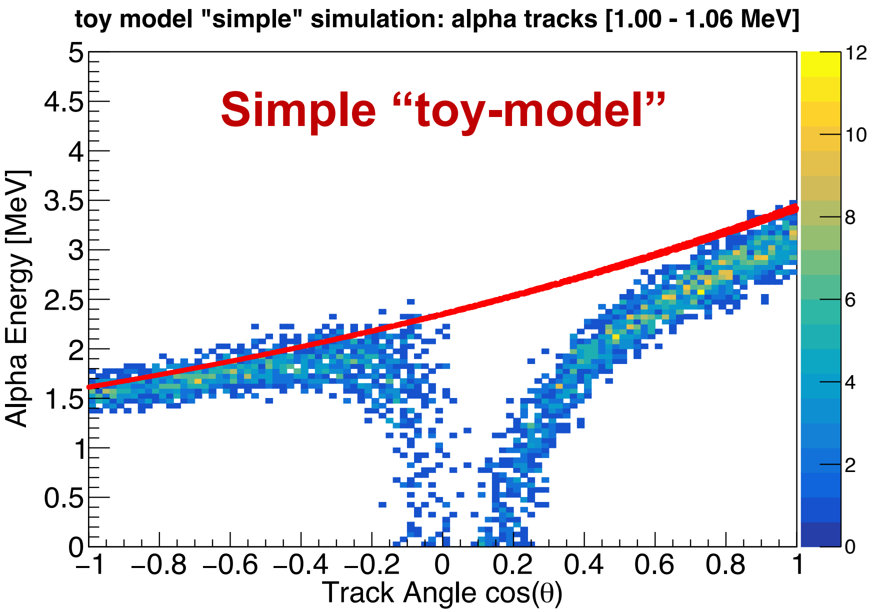
$^6Li(n,t)$ reaction: triton angles distributions #2

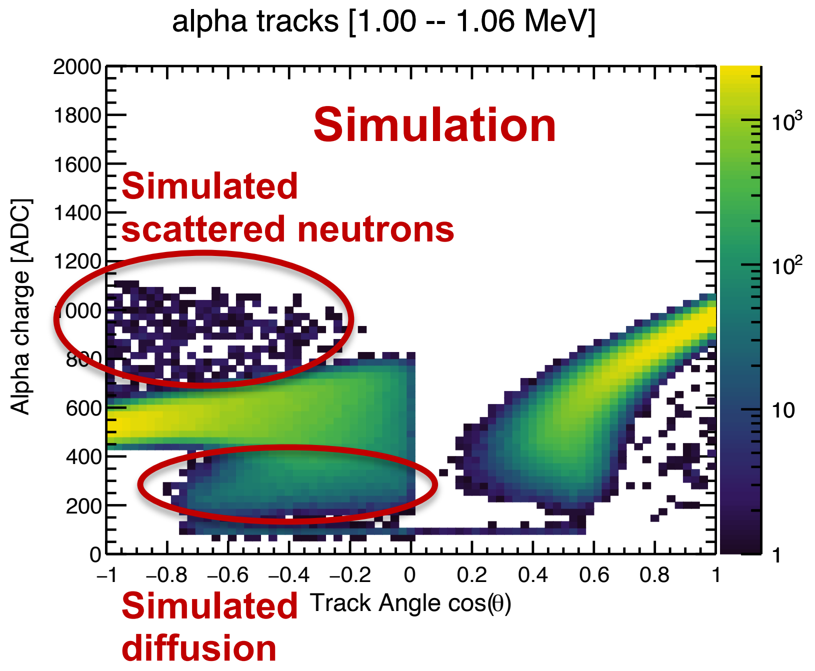


- The data shown are corrected for the wraparound contribution that is also plotted (green points). The "wraparound angular shape" as it can be seen is rather flat.
- Additional corrections are currently in progress:
  - Diffusion (due to fissionTPC angular tracking detector effects)
  - Scattered neutrons
- ***We need to know how much these events contribute to each neutron energy bin and to each cosϑ bin, so that we properly account for them.***
- Detector response model (data-driven simulation) will provide a handle on those effects.

Comparison of Exp. Data vs Simulation

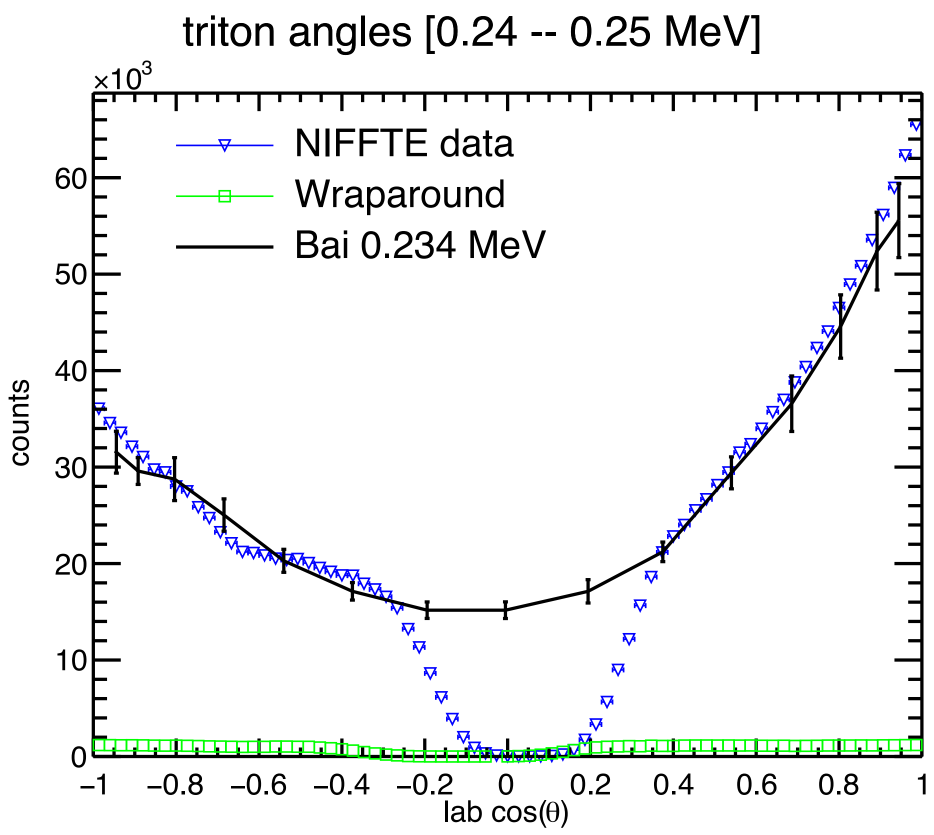






- Alpha-particle energy vs cosθ. Example at a single neutron energy bin
- We capture the kinematics curves and we observe the energy loss in the target for the particles at high angles.
- Wraparound distributions can be separated from the main alpha distributions, especially at higher neutron energy bins due to differences in kinematics.
- Diffusion and scattered neutron effects will be simulated

Takeaway



- Selection efficiency and additional corrections for the ^{6}Li(n,t) reaction events are in progress for the ^{235}U(n,f)/^{6}Li(n,t) cross section ratio.
- Angular distributions for the ^{6}Li(n,t) reaction will also be provided from this measurement.
- Angular distribution data points provided by the fissionTPC will be more dense due to our large angular coverage and large counting statistics .
- The preliminary comparison to the recent Bai-data is in good agreement.

Update on FissionTPC Cross-Section Ratio Measurement of $^{239}Pu(n,f)/^{235}U(n,f)$

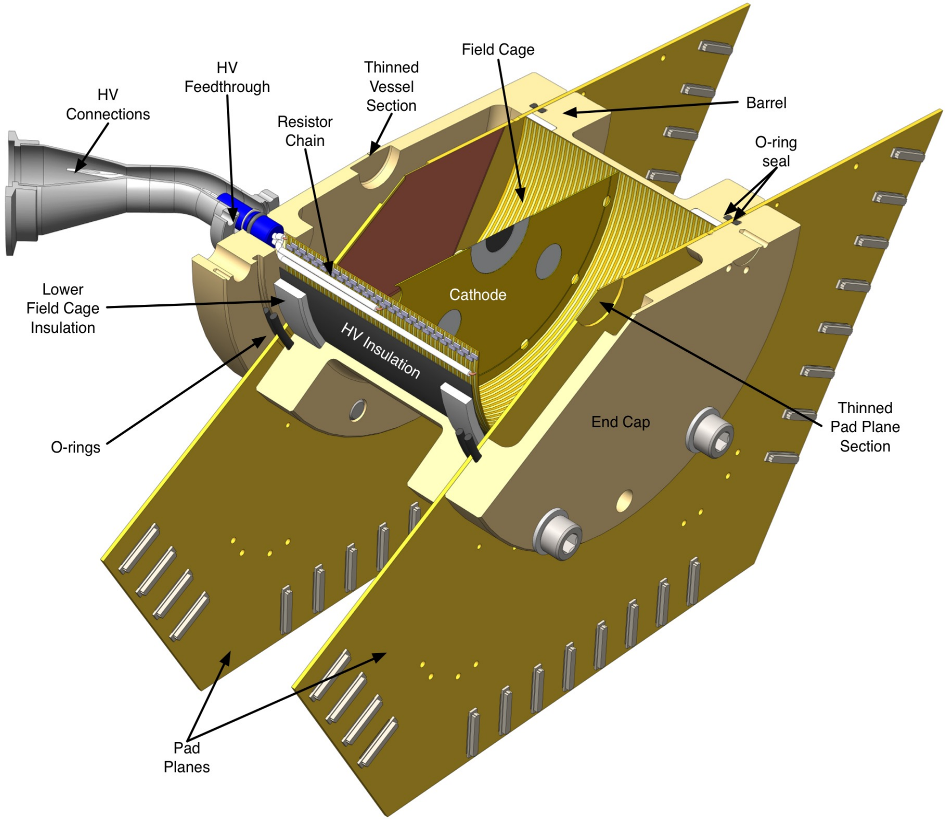
IAEA, Technical Meeting on Neutron Data Standards

October 2023

Lucas Snyder
For the NIFFTE Collaboration

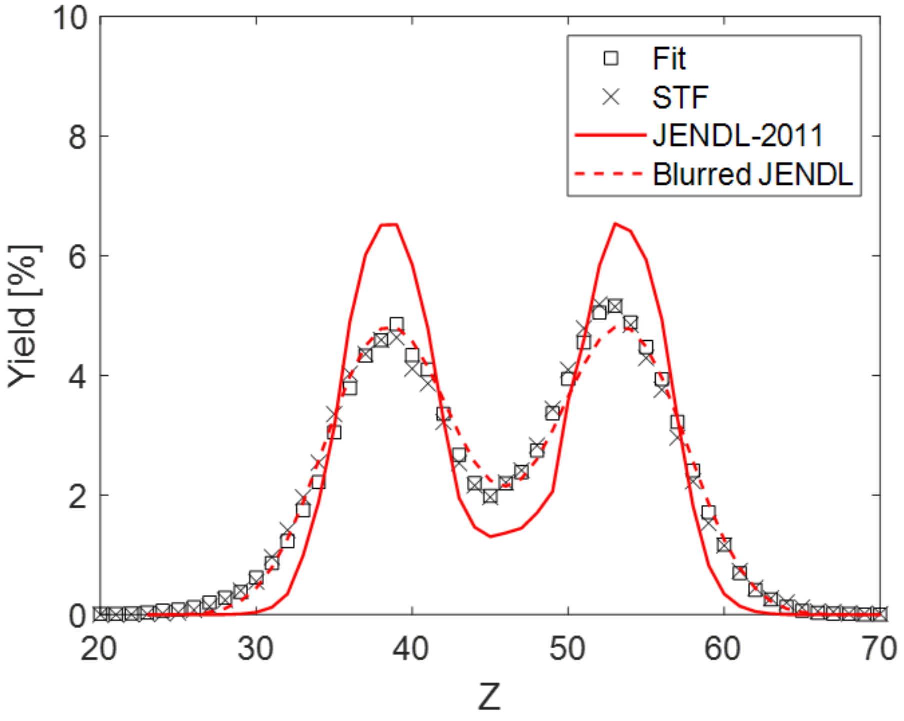
Outline

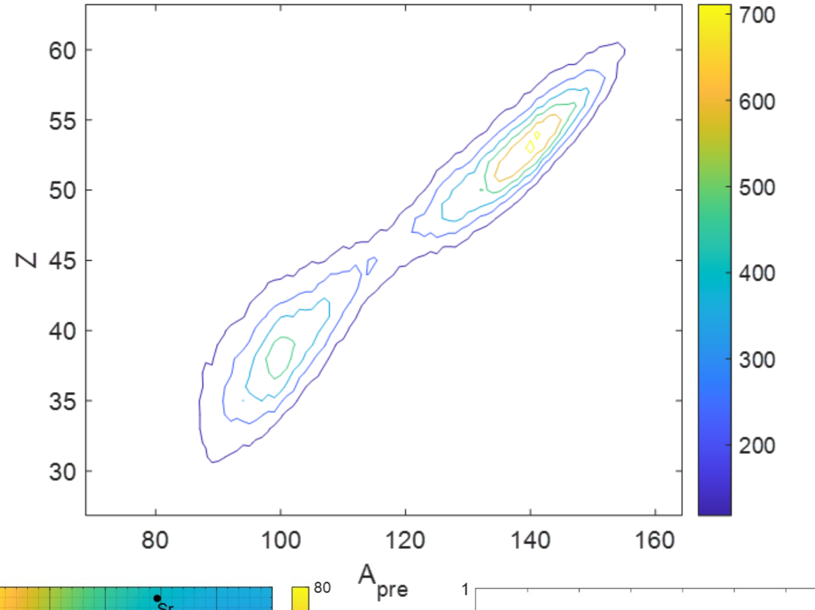
- Review Previous Results
- Target Uniformity
- Shape comparison of current and previous results
- Normalization Status

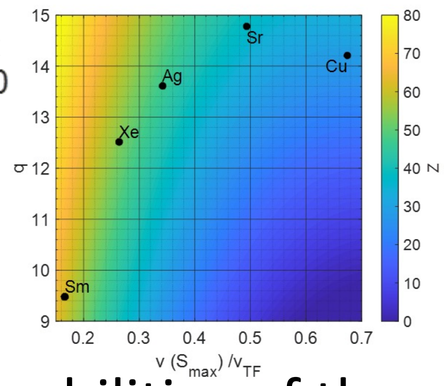


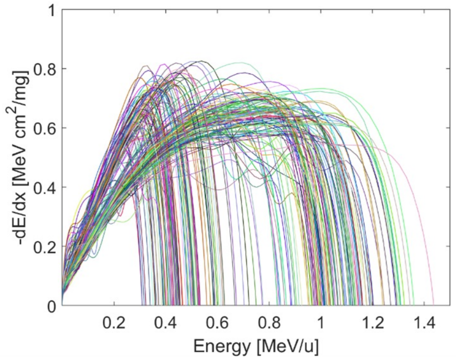
Bragg Curve Analysis for Isotopic (Z) FPY

M.E. Moore, et al. Nuclear Data Sheets 184 (2022) 1—28



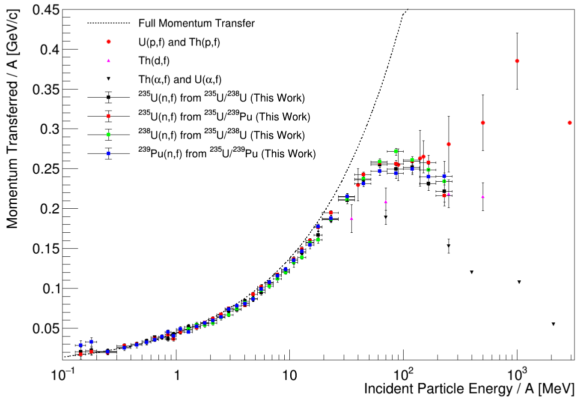




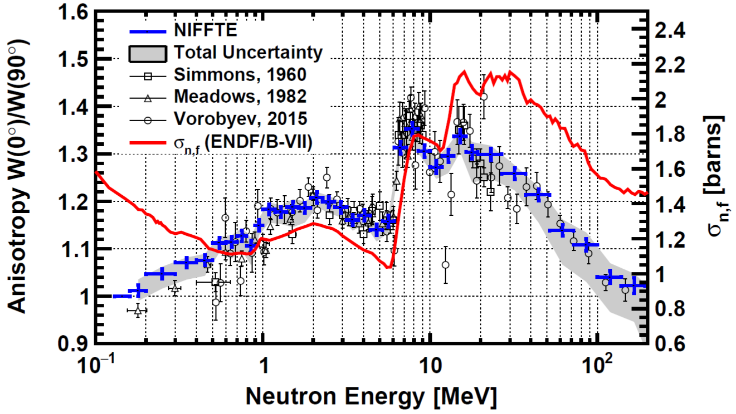


- 3 Z resolution
- Well researched
- Good assessment of ultimate capabilities of the method

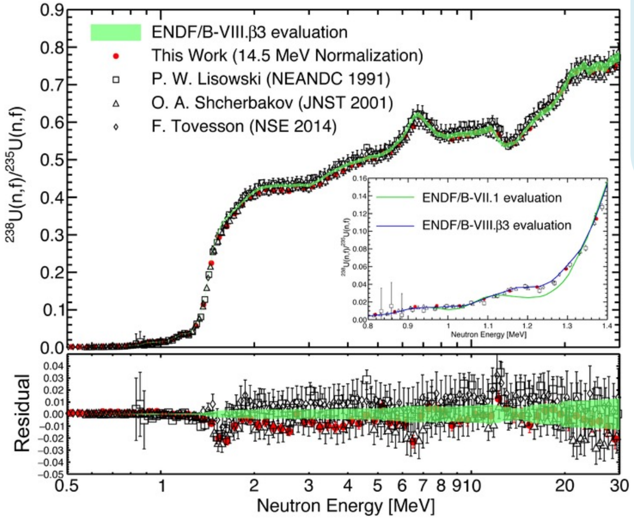
Other Publications



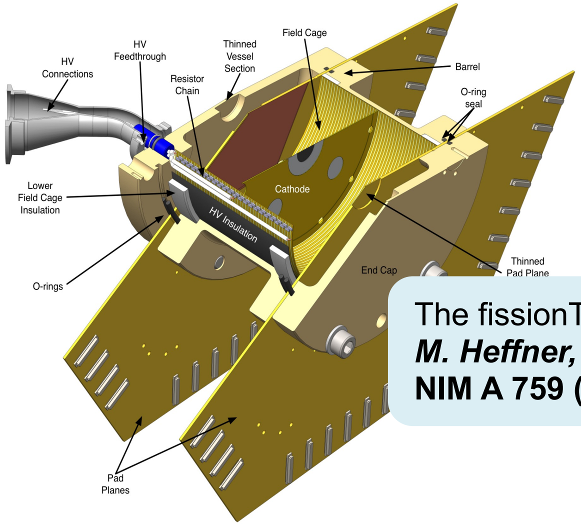
Measurement of ^{235}U Anisotropy and Linear Momentum Transfer.
D. Hensle, et al.
PRC 102, 014605 (2020)



Fission Fragment Angular Anisotropy in Neutron-Induced Fission of ^{235}U …
V. Geppert-Kleinrath, et al.
PRC 99, 064619 (2019)

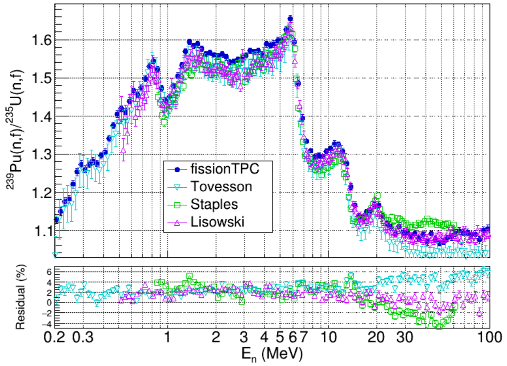


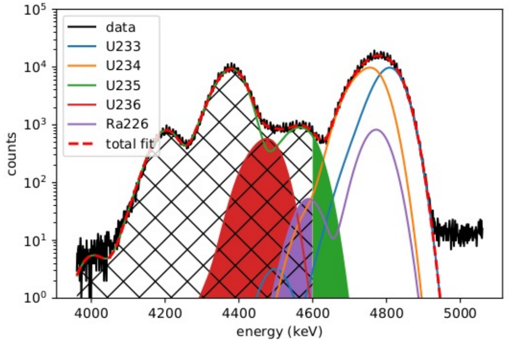
Measurements of the normalized ^{238}U(n,f)/^{235}U(n,f) cross section ratio form threshold to 30 MeV …
R. Casperson, et al.
PRC 97, 034618 (2018)

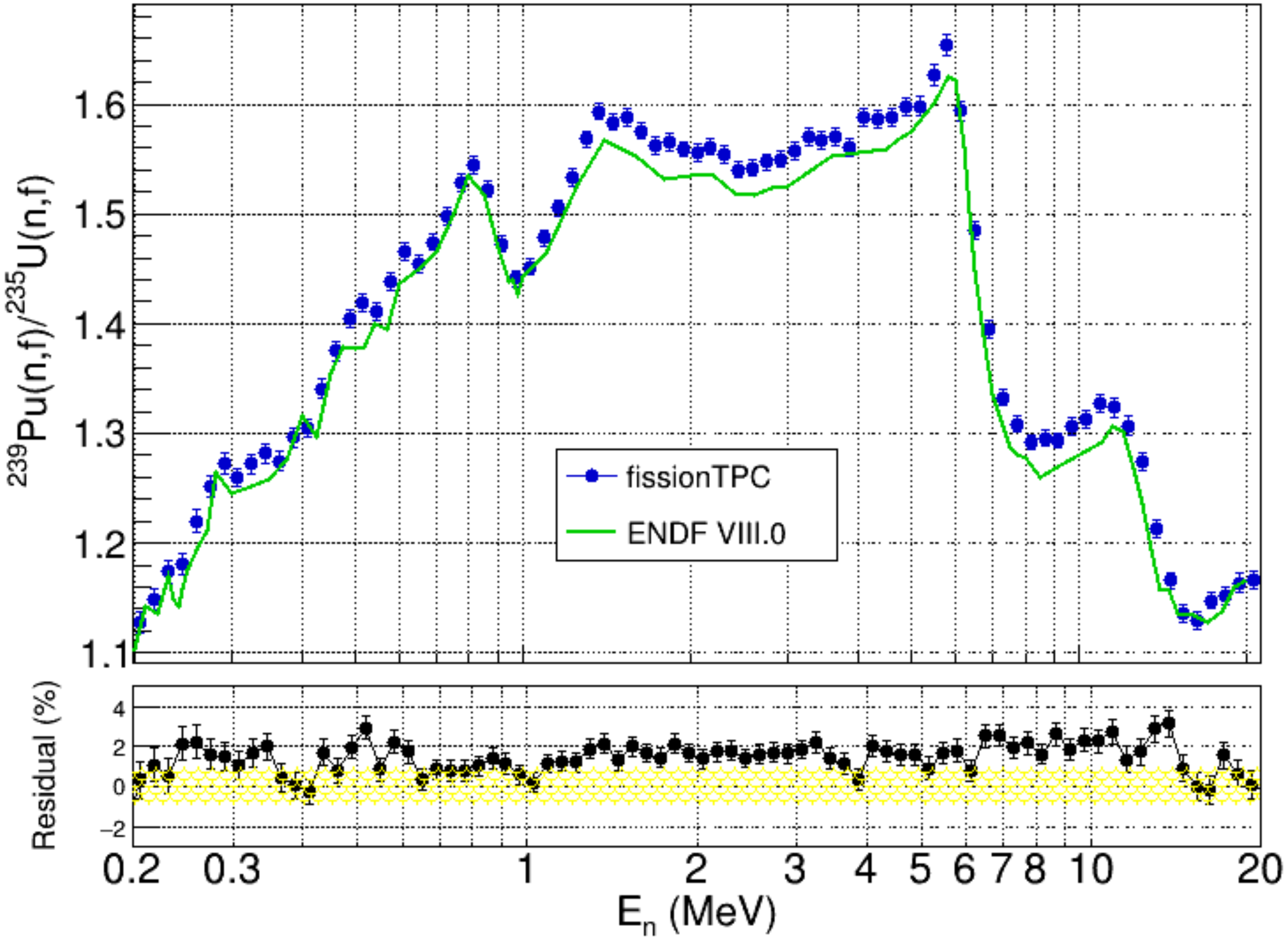


The fissionTPC…
M. Heffner, et al.
NIM A 759 (2014) 50-64

Previous Results







- Systematic deviation from ENDF
- We recommended it as Shape only
- Target counting done only after beam data. Target damaged?

- L. Snyder, et al. NDS 178 (2021) 1–40
- M. Monterial, et al. NIM, A 1021 (2022) 165864

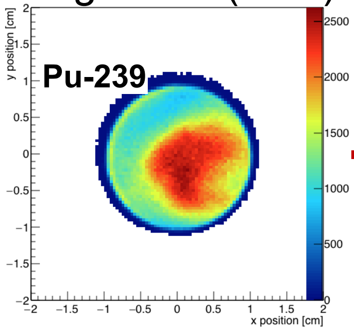
Neutron Flux Profile & Target Overlap

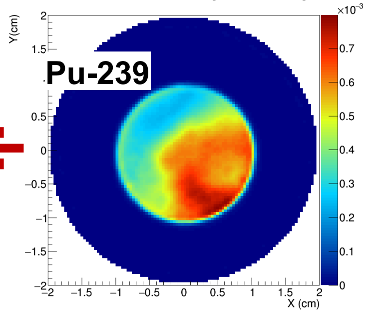
$$\frac{\sigma_x}{\sigma_s} = \frac{\epsilon^s_{ff}}{\epsilon^x_{ff}} \cdot \frac{\Phi_s}{\Phi_x} \cdot \frac{N_s}{N_x} \cdot \frac{\sum_{XY}(\phi_{s,i}\cdot n_{s,i})}{\sum_{XY}(\phi_{x,i}\cdot n_{x,i})} \cdot \frac{w_x^{-1}}{w_s^{-1}} \cdot \frac{(C^x_{ff}-C^x_r-C^x_\alpha)-C^x_{bb}}{(C^s_{ff}-C^s_r-C^s_\alpha)-C^s_{bb}}$$

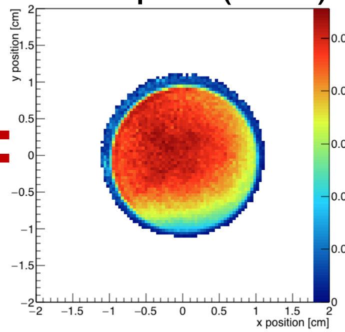
Correction required if beam *and* actinide target have spatial non-uniformity

$$\frac{\sum_{XY}\phi_{s,i}\cdot\sum_{XY}n_{s,i}}{\sum_{XY}\phi_{x,i}\cdot\sum_{XY}n_{x,i}} = 1 \neq \frac{\sum_{XY}(\phi_{s,i}\cdot n_{s,i})}{\sum_{XY}(\phi_{x,i}\cdot n_{x,i})}$$

Fragments (data) ÷ Alphas (data) = FF/alpha (data)



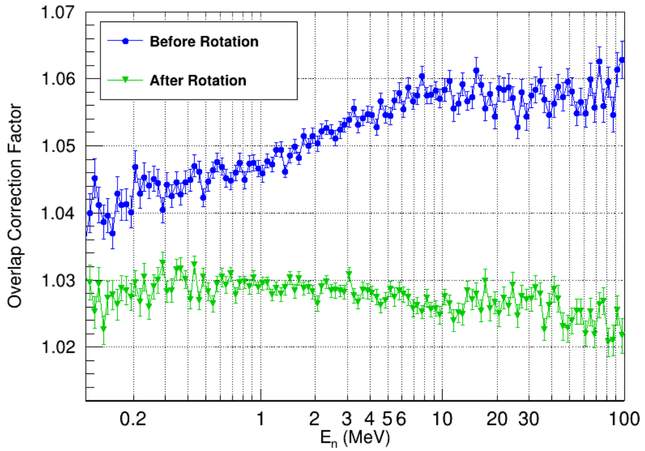




$$\mathrm{OT} = \text{Overlap Term}$$
$$= B\sum_i \frac{n_i}{\sum_j n_j}\frac{T_t}{\sum_k T_k}$$
$$= B\frac{1}{\sum_j n_j}\frac{1}{\sum_k T_k}\sum_i n_i T_i$$

$$\frac{\mathrm{OT}^{Pu}}{\mathrm{OT}^{U}} = \frac{\frac{1}{\sum_k \alpha_k^{Pu}}\sum_j \frac{f_j^u}{\alpha_j^U}\alpha_j^{Pu}}{\frac{1}{\sum_i \alpha_i^U}\sum_l f_l^U}$$

Data driven correction
"U-corrected Pu-overlap term"



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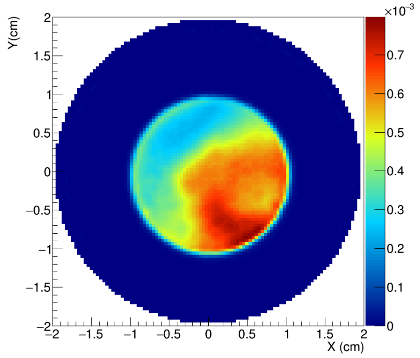
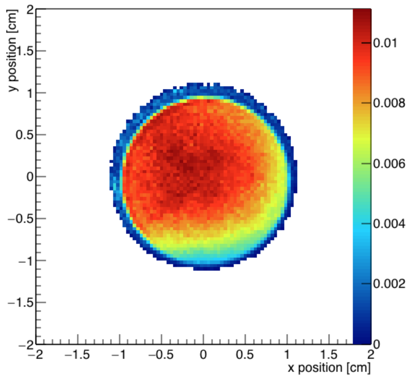
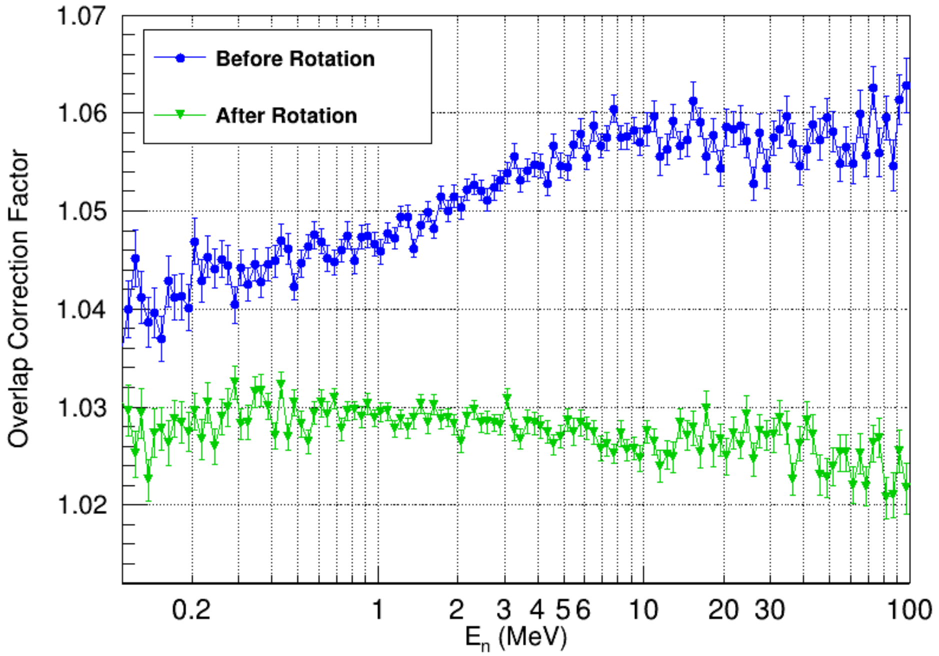
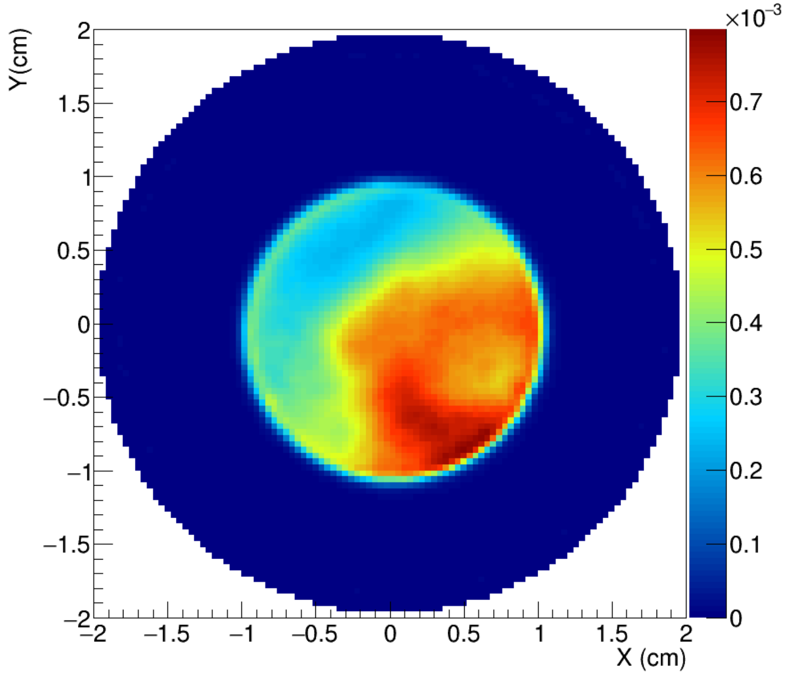


Dot product



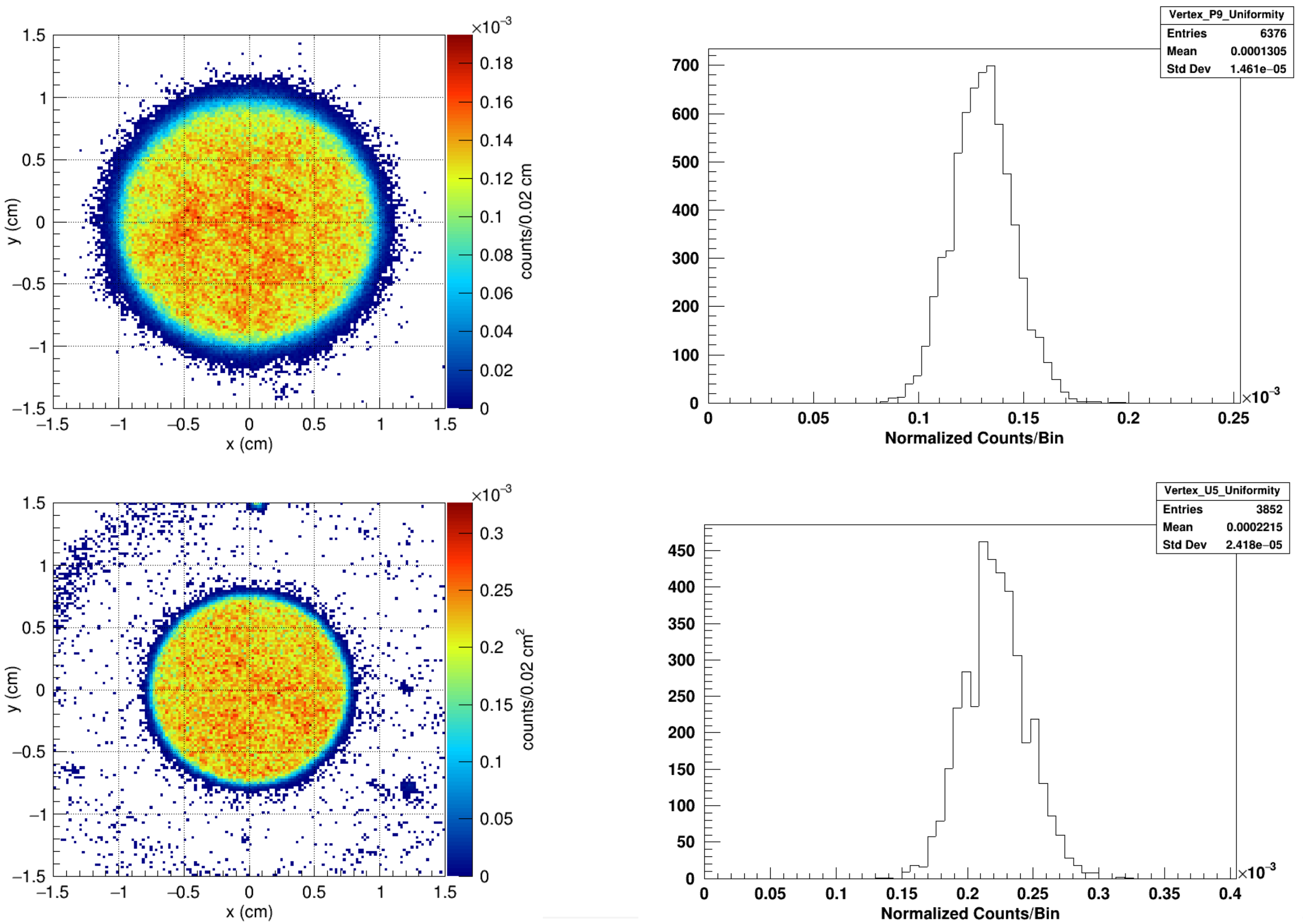
Neutron Flux Profile & Target Overlap



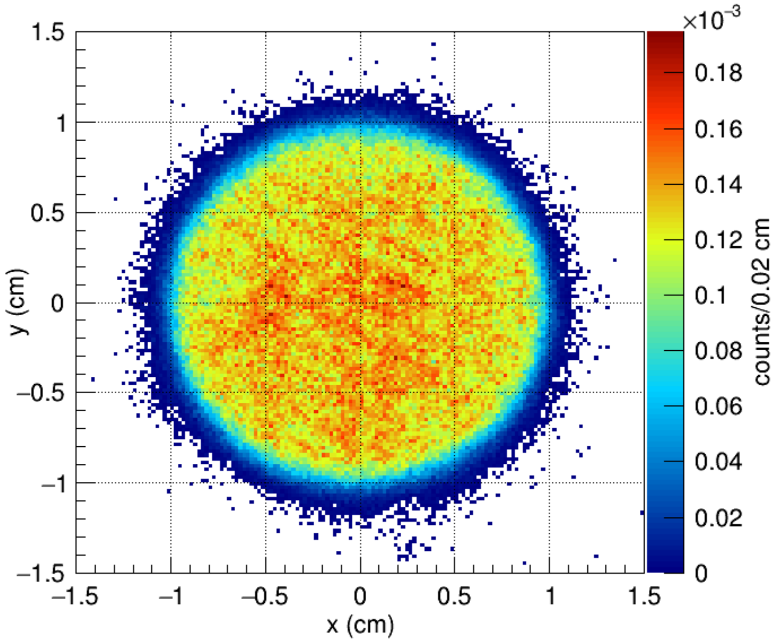


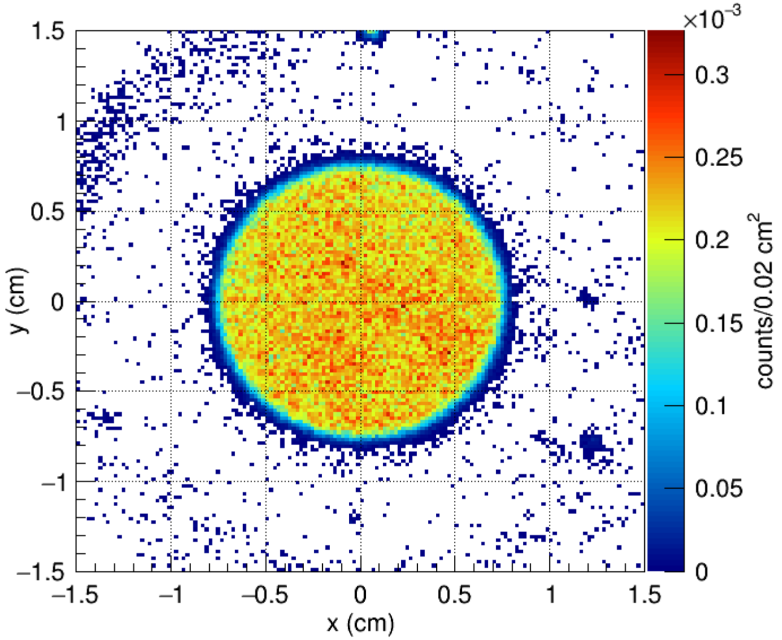
- *Shape* of the correction was thoroughly validated
- There remains some potential for a systematic offset resulting from “space-charge”
- We attempted to correct and estimate it at 0.5%

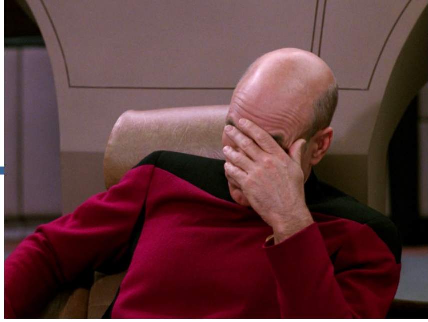
New Targets: Uniform at 10% level per Std. Dev.



New Targets: Different Sizes

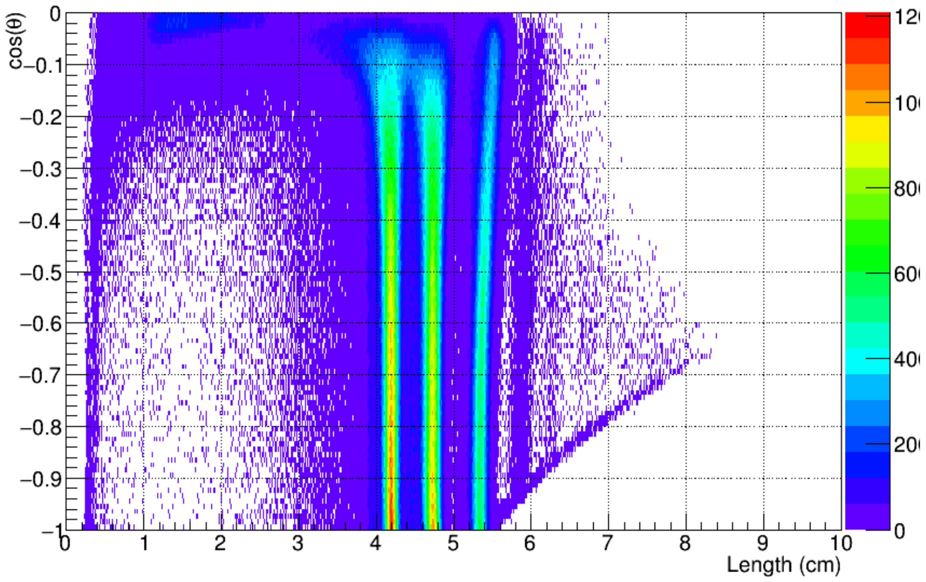


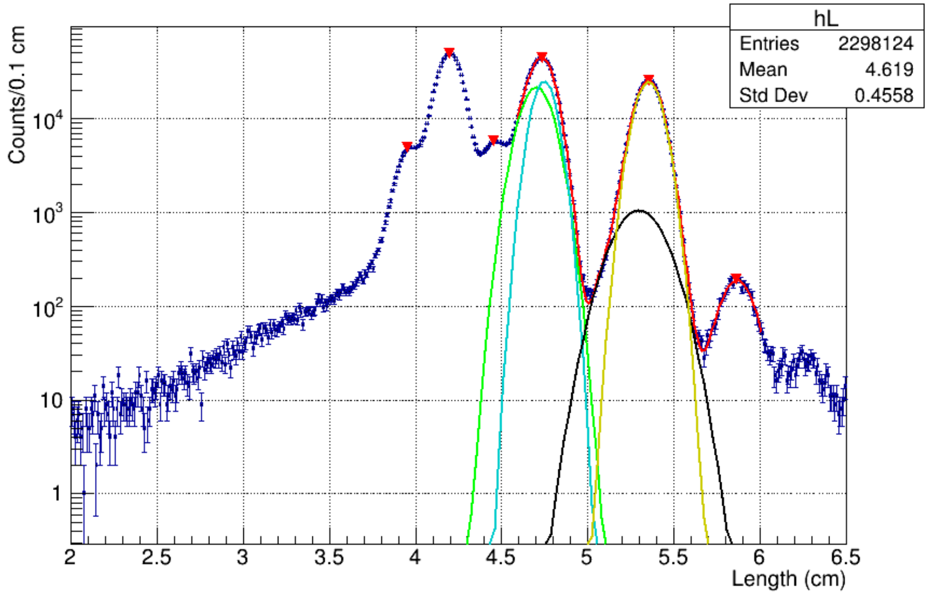




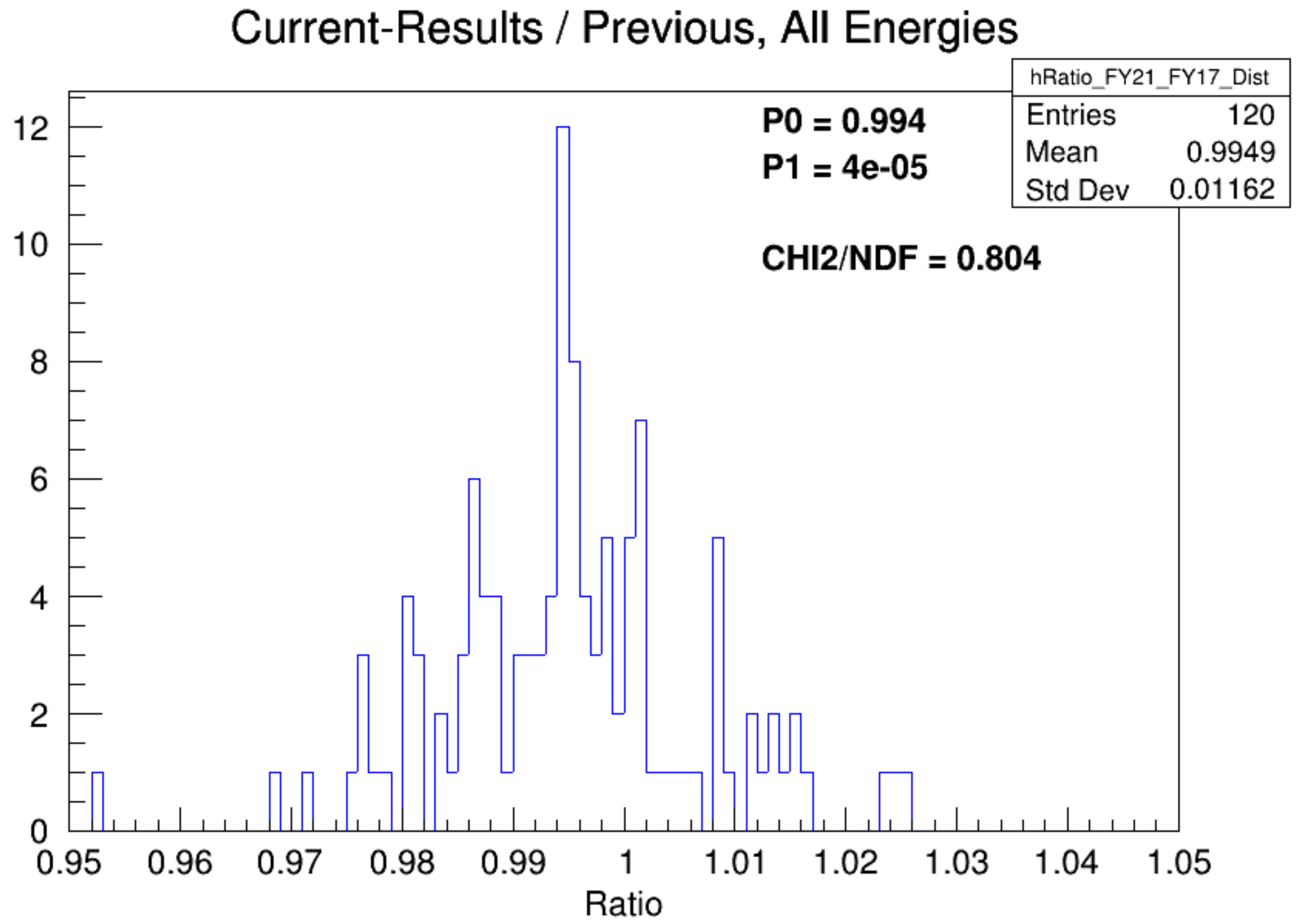
- Somewhat a blessing in disguise
- Targets were never going to be the exact same size or perfectly aligned
- Forces us to make a careful check and avoid assumptions
- It essentially becomes a normalization correction which can be validated with radial cuts
- Space-charge remains a challenge at the 0.5% level

Preliminary Normalization w/ fissionTPC Radiograph

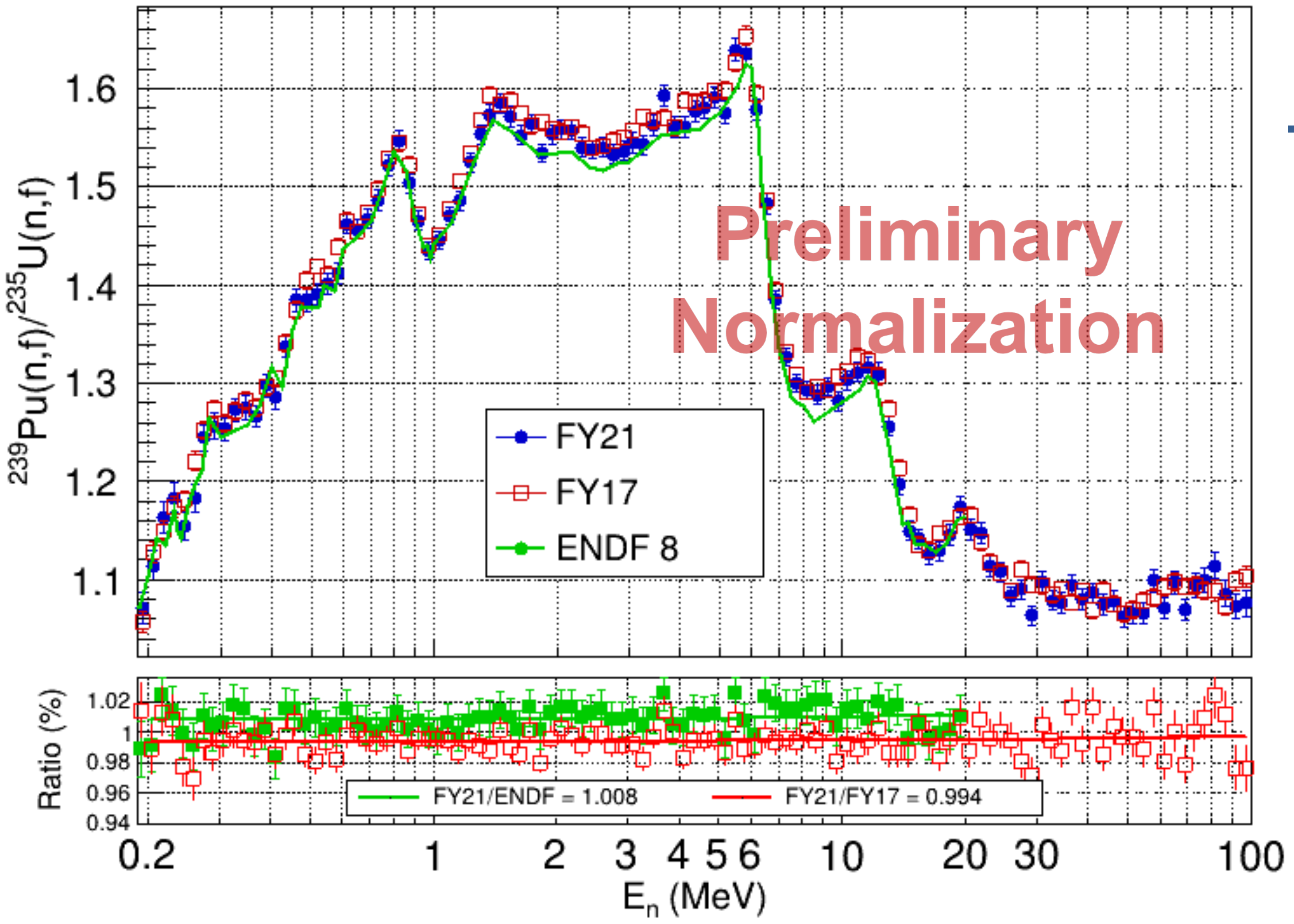




- We do have, and are analyzing, data collected with silicon detector
- Tracking improved over the years, so it was worth revisiting the fissionTPC capabilities
- Distortions to track angle are well understood. i.e., we can make angular cuts and correct for efficiency
- Track length resolution is much better than energy resolution



- **TAKEAWAY: Shape is in good agreement**
- 1% standard deviation of the ratio of ratios
- Reduced $X^2 = 0.8$
  - Probably not the right test for this, I am open to suggestions



- Uncertainty on normalization is not well understood at this point
- **TAKEAWAY: Too early to draw conclusions!**
  re: agreement with previous result or ENDF

Next Steps

- Complete normalization analysis of silicon det. data
- Space-charge effect quantification: Simulation and collection of more radiograph data
- Radial cut variational analysis
- Lessons learned: Revisit previous measurement radiograph data and overlap correction