*Re*measurement of ^{239}Pu(n,f)/^{235}U(n,f) with the fissionTPC

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Submitted to NDS

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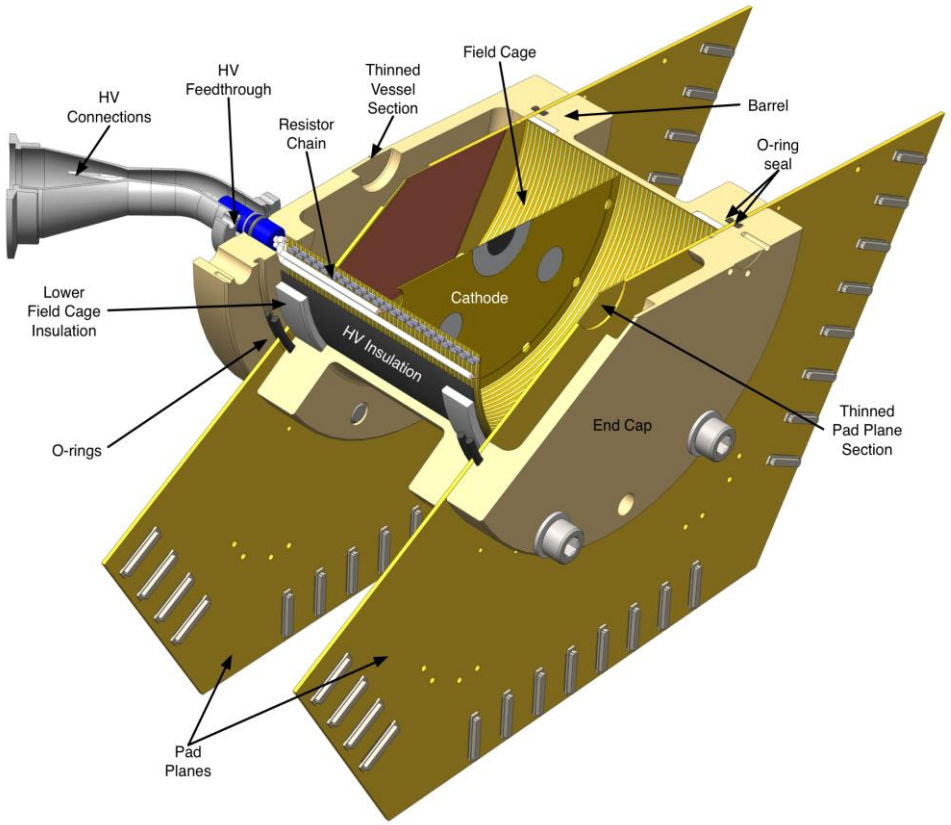
Outline

- **Review Previous Results**
- **Overlap Correction**
  - **Target Uniformity/Size**
  - **Space-charge**
- **Normalization**
- **Comparison of current and previous results**

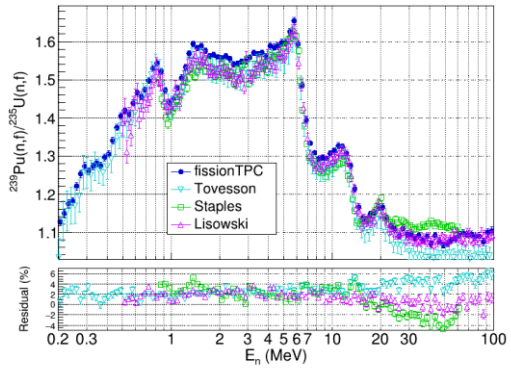


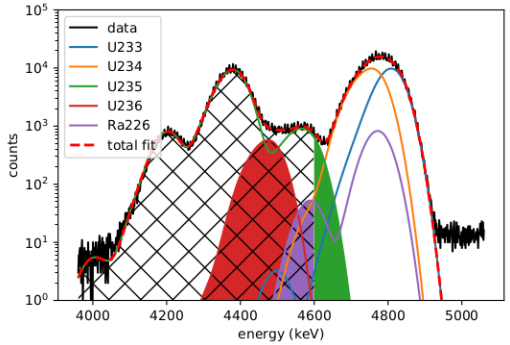
SUMMARY:

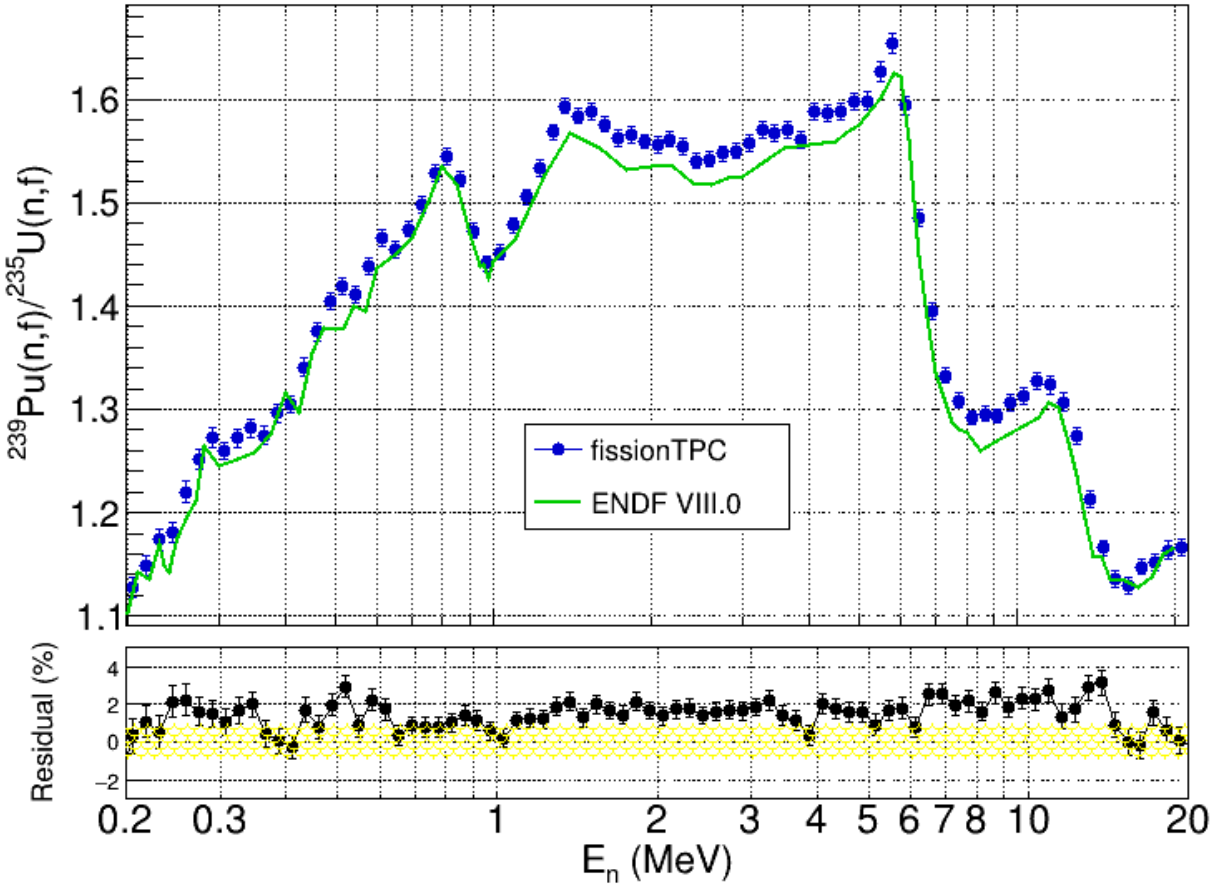
New result agrees with previous result within uncertainties

~2% high relative to ENDF VIII.0

Previous Results







- Systematic deviation from ENDF
- We recommended it as Shape only
  (confirmation bias & circumstantial evidence)
- Large target/beam nonuniformity
- 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

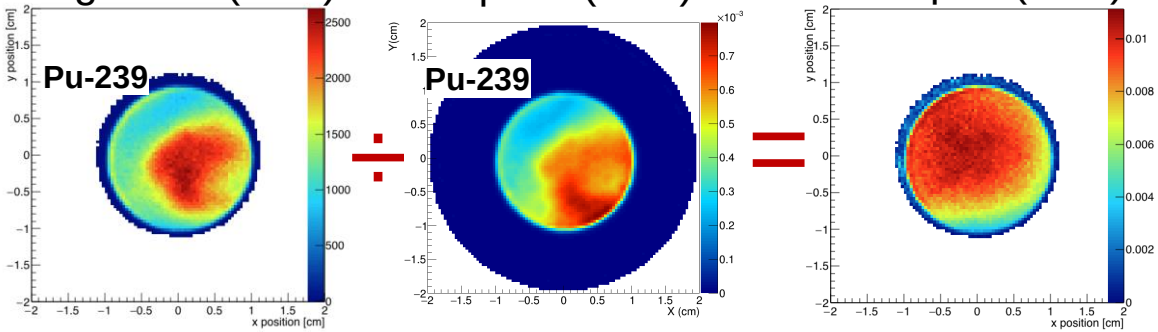
Neutron Flux Profile & Target Overlap

$$\frac{\sigma_x}{\sigma_s} = \frac{\epsilon_{ff}^s}{\epsilon_{ff}^x} \cdot \frac{\Phi_s}{\Phi_x} \cdot \frac{N_s}{N_x} \cdot \frac{\sum_{XY}(\phi_{s,i}\cdot n_{s,i})}{\sum_{XY}(\phi_{x,i}\cdot n_{x,i})} \cdot \frac{w_x^{-1}}{w_s^{-1}} \cdot \frac{(C_{ff}^x - C_r^x - C_\alpha^x) - C_{bb}^x}{(C_{ff}^s - C_r^s - C_\alpha^s) - C_{bb}^s}$$

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

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

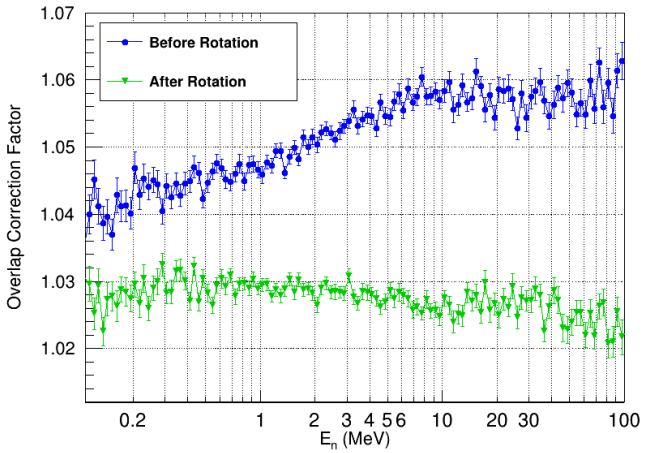
Fragments (data) ÷ Alphas (data) = FF/alpha (data)



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

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

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



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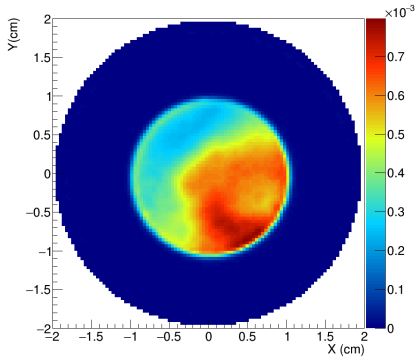
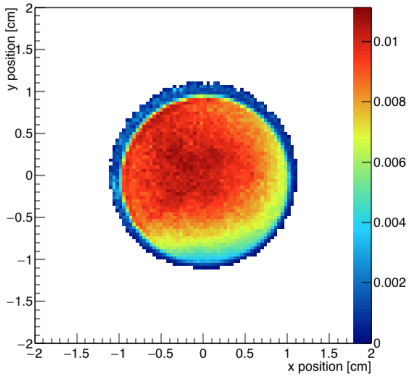
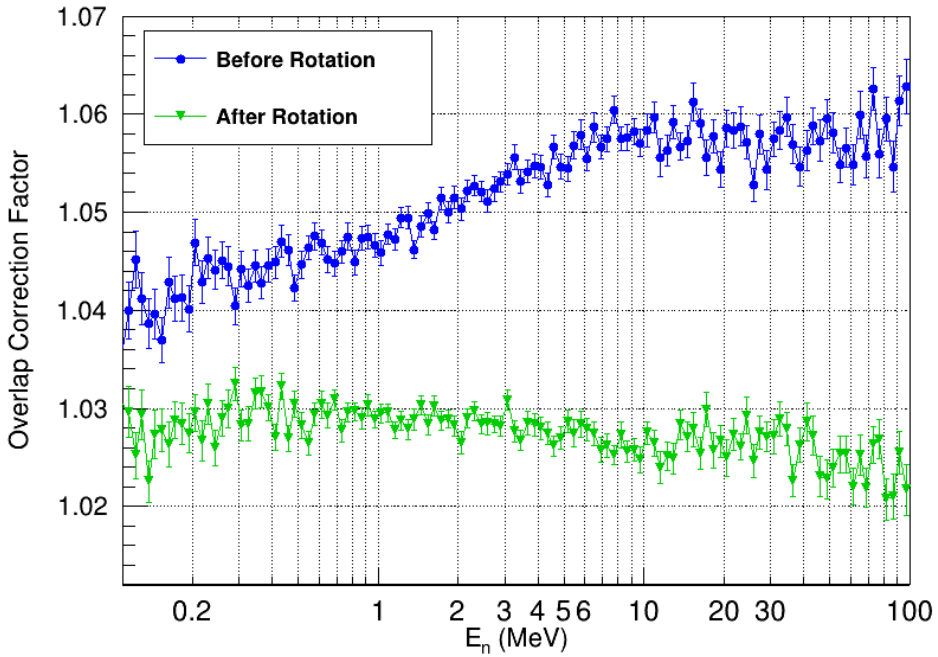
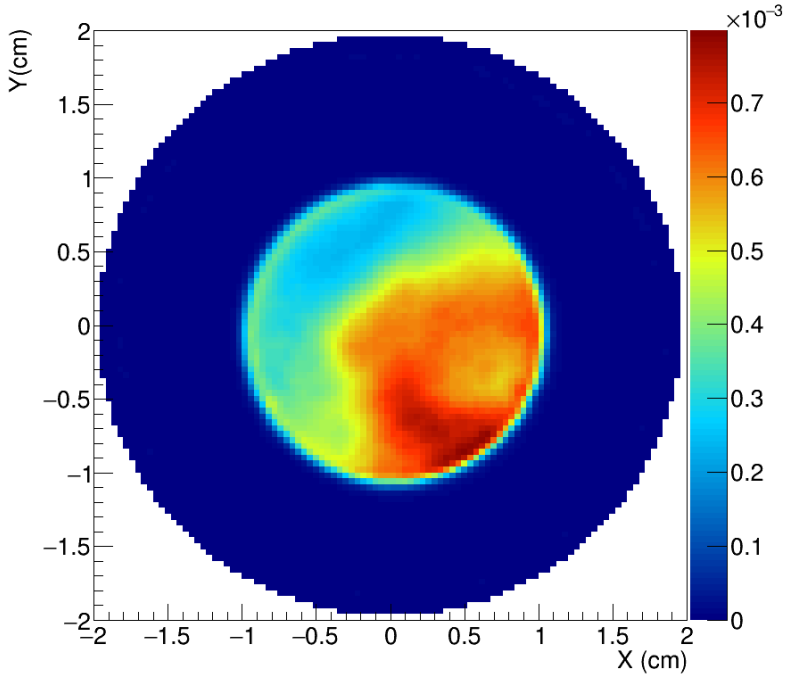


Dot product



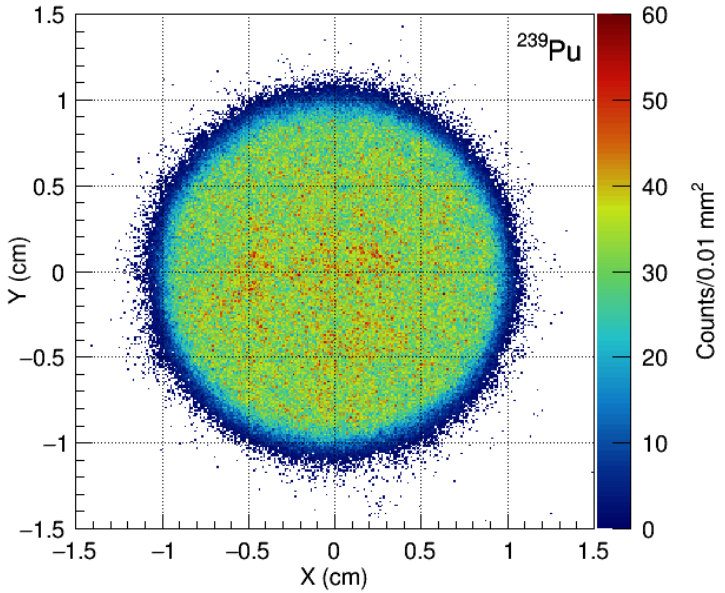
Neutron Flux Profile & Target Overlap

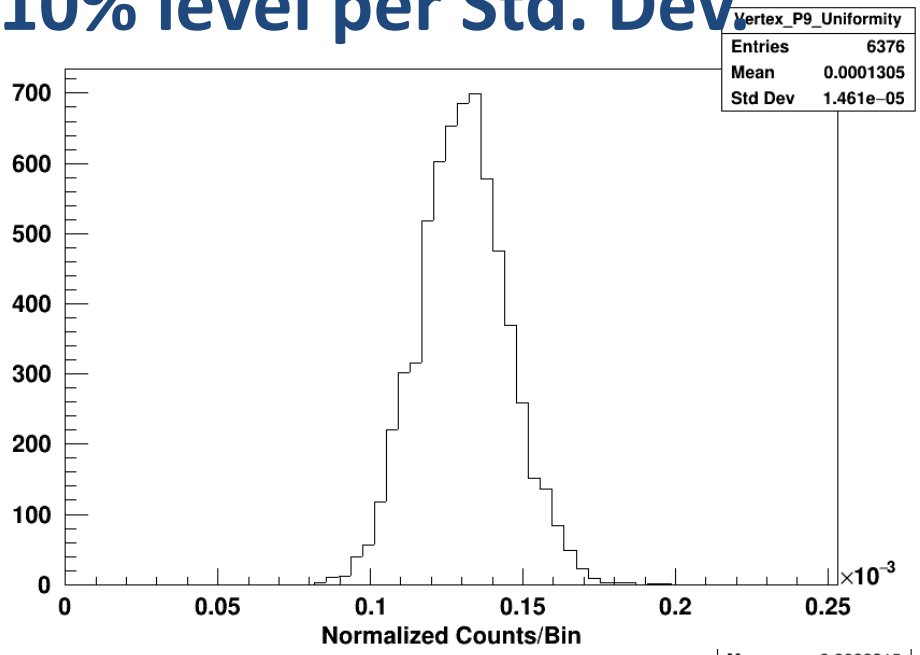


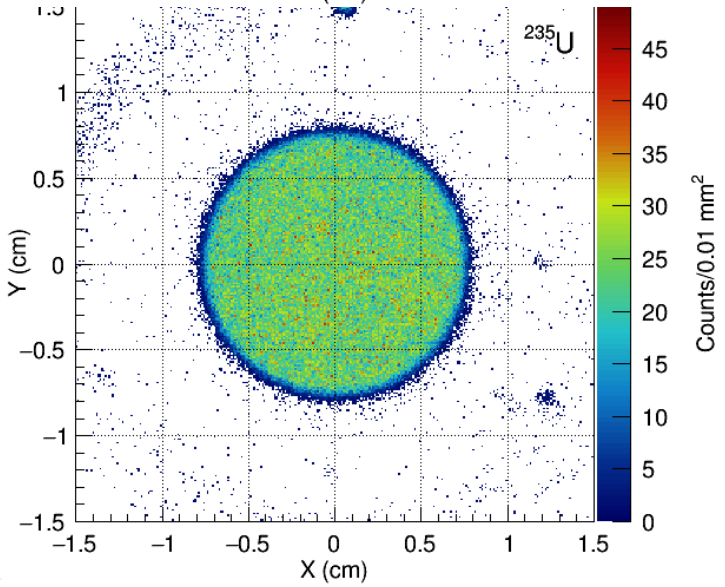


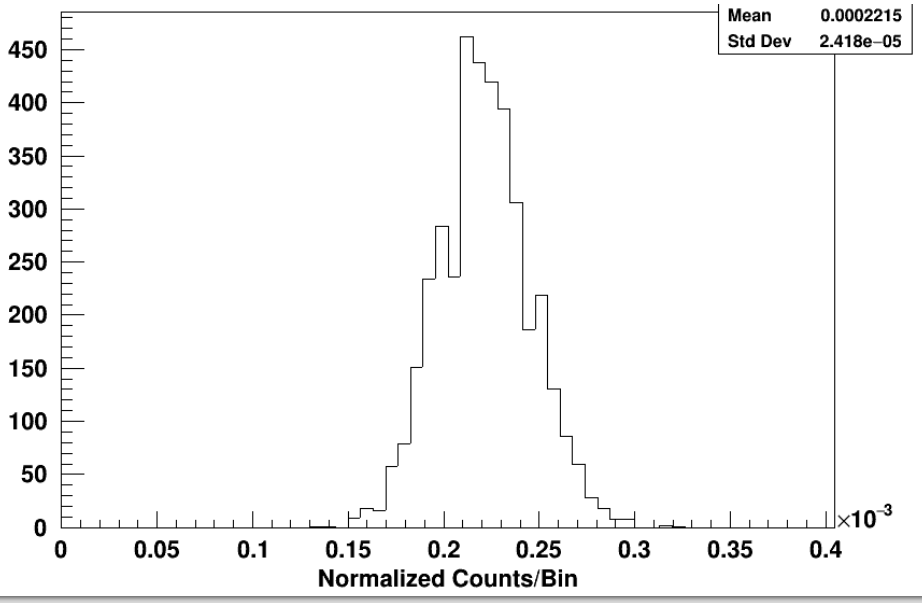
- *Shape* of the correction was validated
- There is a systematic (with energy) component of the correction resulting from “space-charge”
- 0.5% correction, not validated by rotation

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

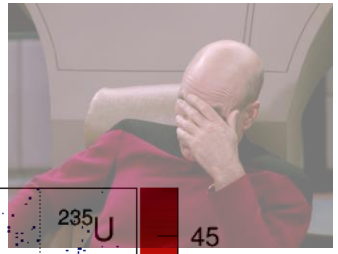


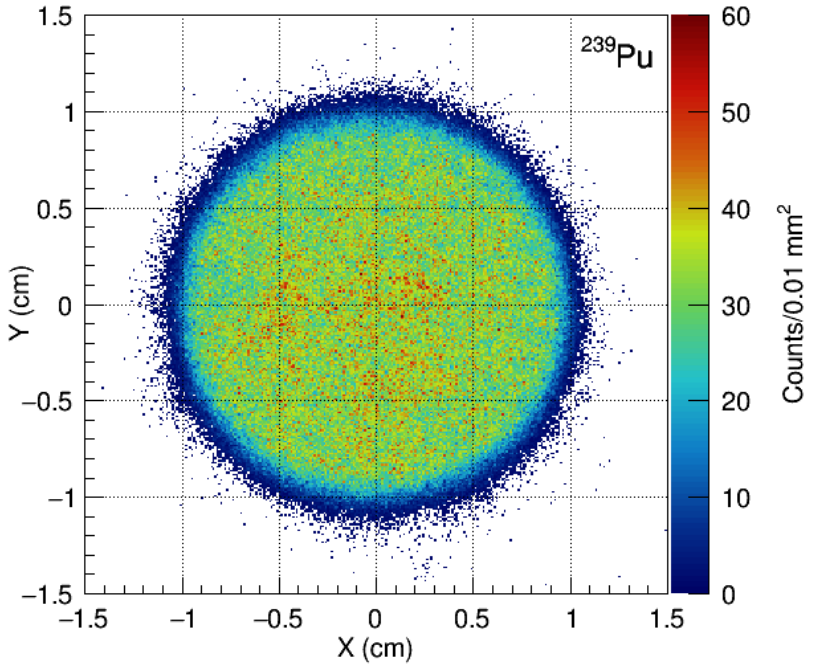


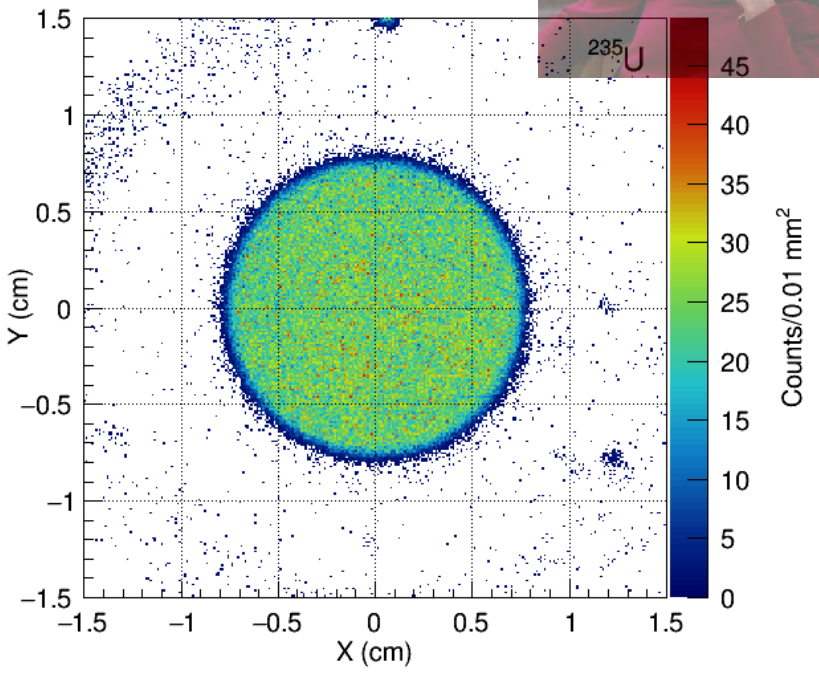




New Targets: Different Sizes



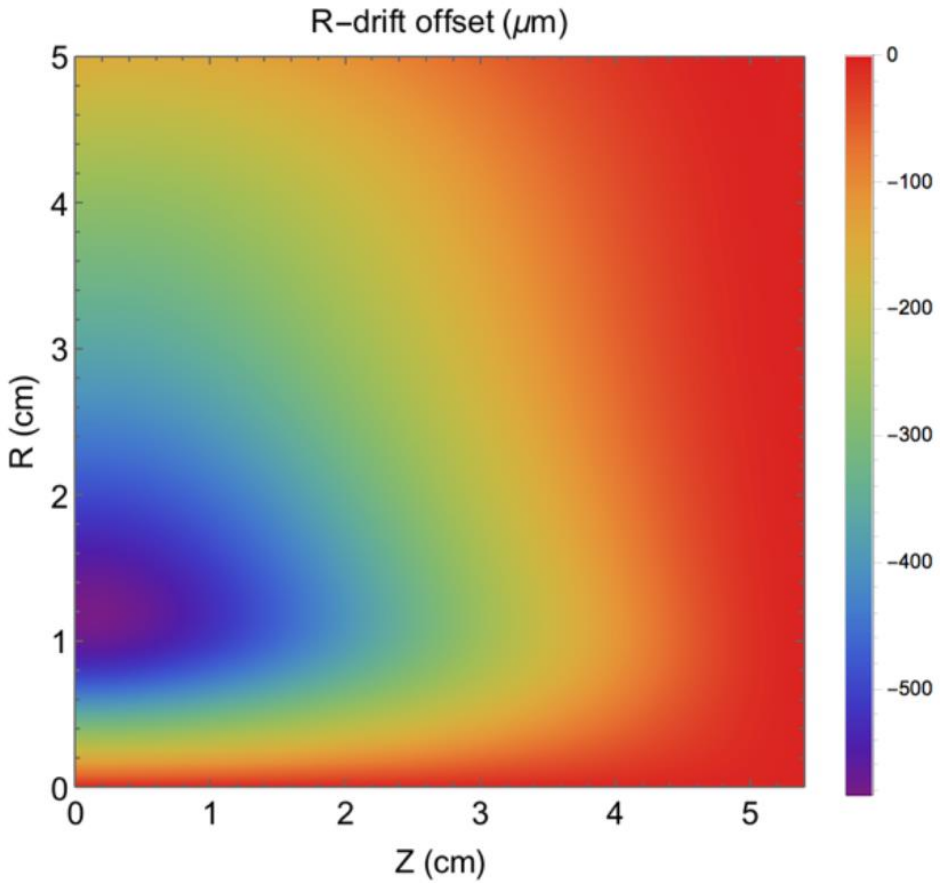




- Somewhat a blessing in disguise
- Targets were never going to be the exact same size or perfectly aligned
- Forced us to make a careful check and avoid assumptions
- Further data was collected to determine space-charge correction

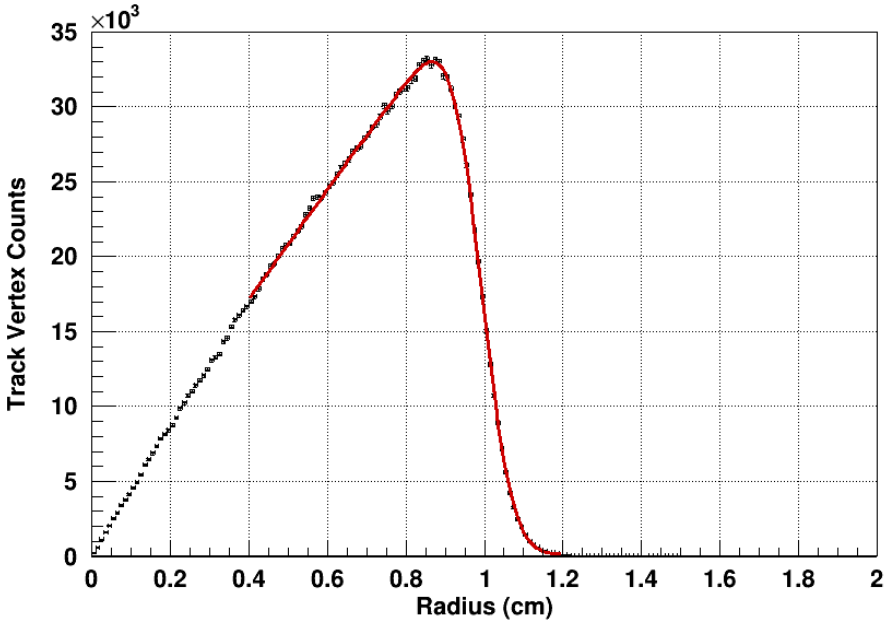
Space-charge

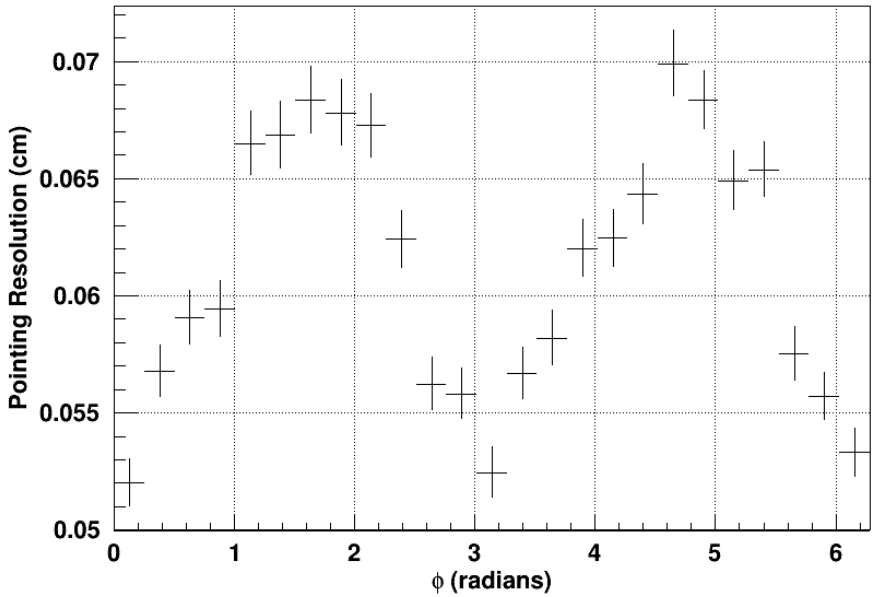
- There is always some positive ion backflow from the MICROMEGAS gain stage
- The high α-decay rate of ^{239}Pu results in sustained ion backflow substantial enough to distort the drift field
- Radially symmetric, having the net effect of making the reconstructed target radius appear smaller than in actuality



Space-charge

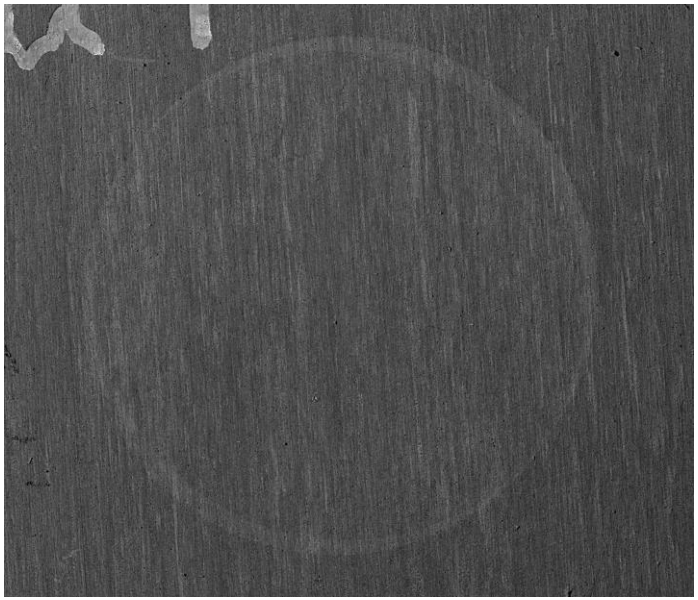
- Simple correction in previous work using a photo of the target
- Complication in current effort due to target deposit layer offset

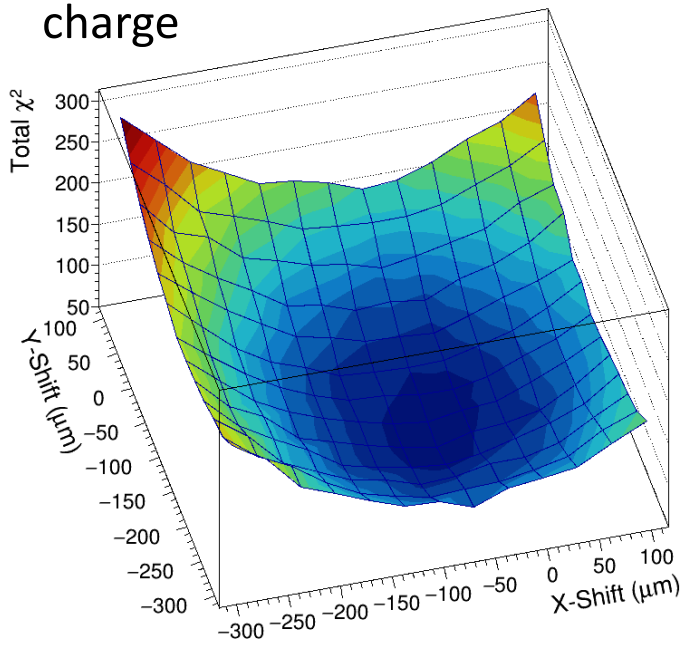


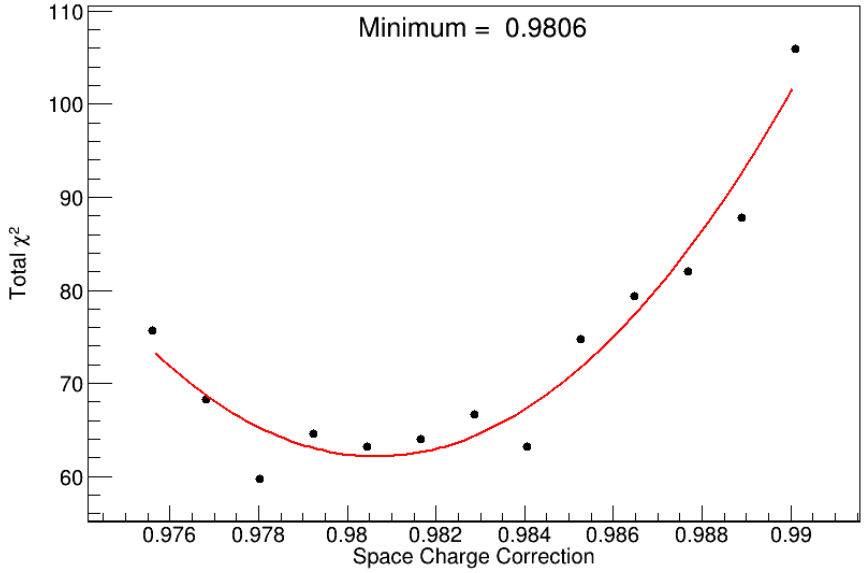


Space-charge

- Target deposit radius and layer offset determined from analysis of photograph
- Simple tracking simulation parameters minimized to match data
  - Offset, rotational orientation, Space-charge

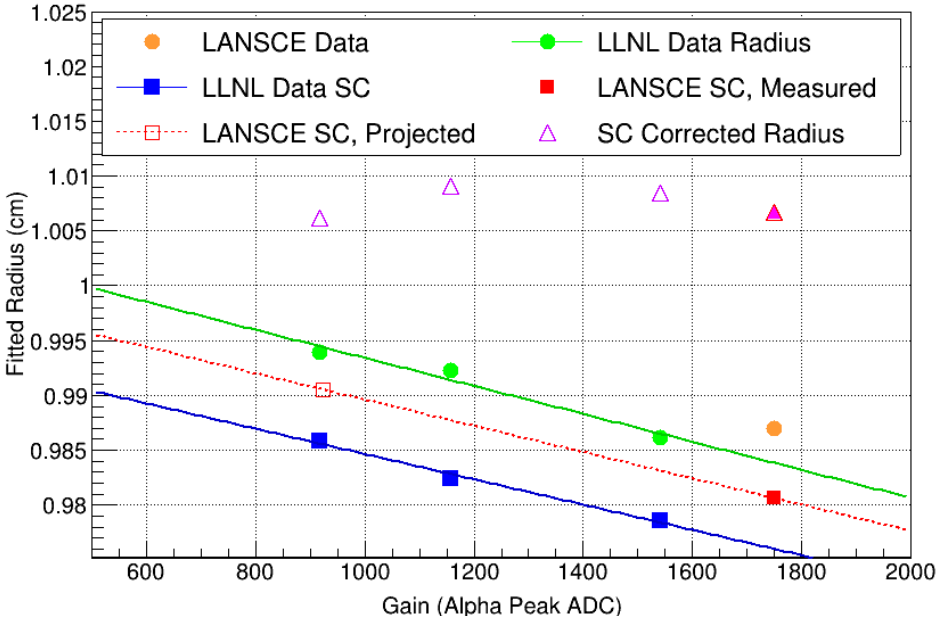


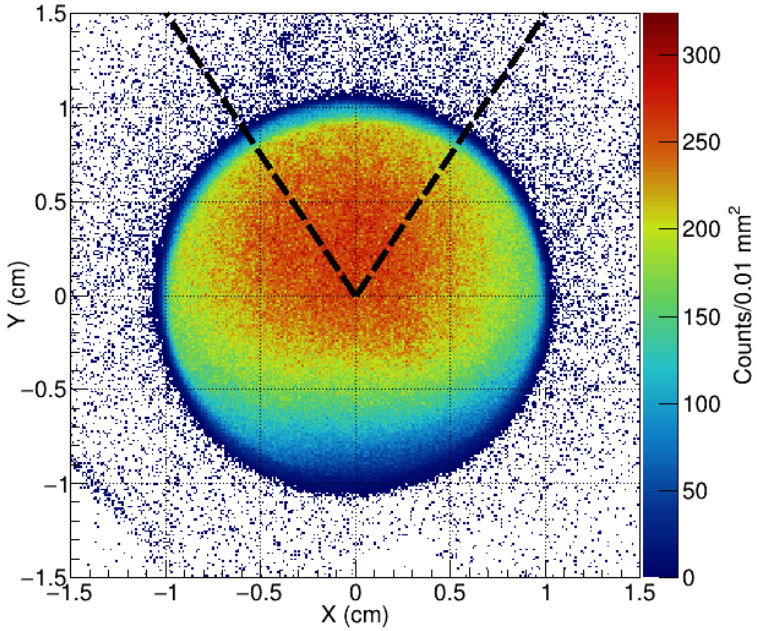


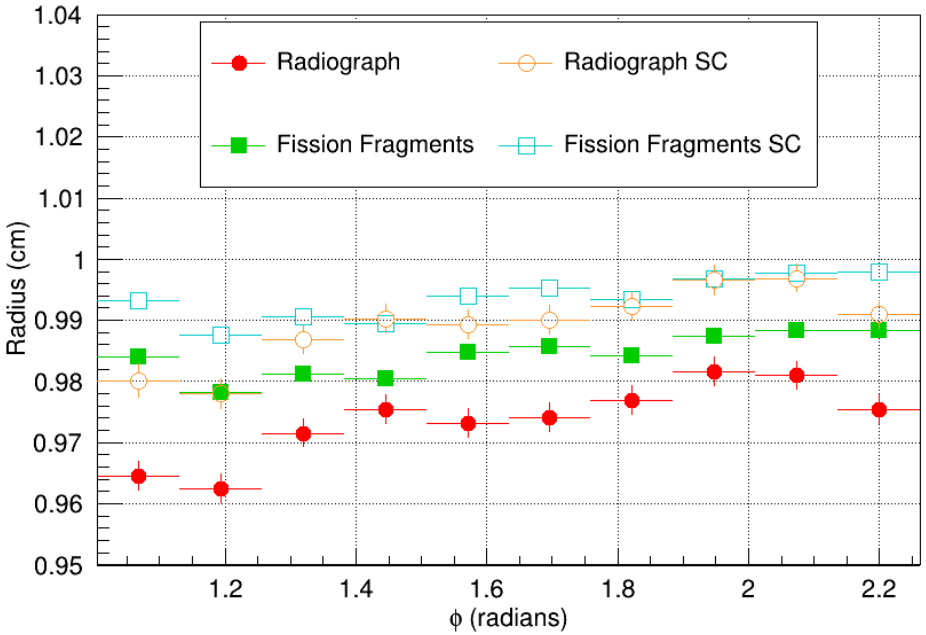


Space-charge

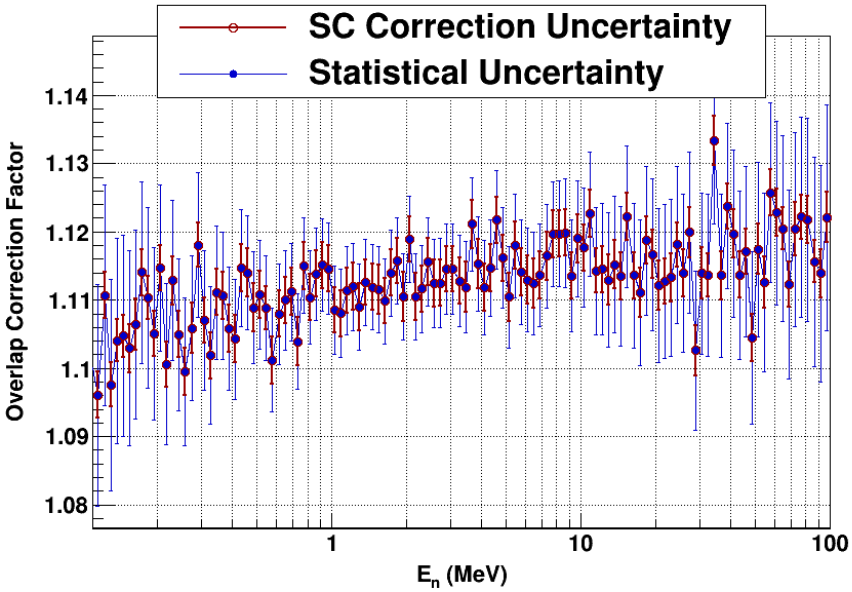
- Further complicated by fission data being collected at lower gain
- Additional data collected to validate Space-charge effect vs. gain

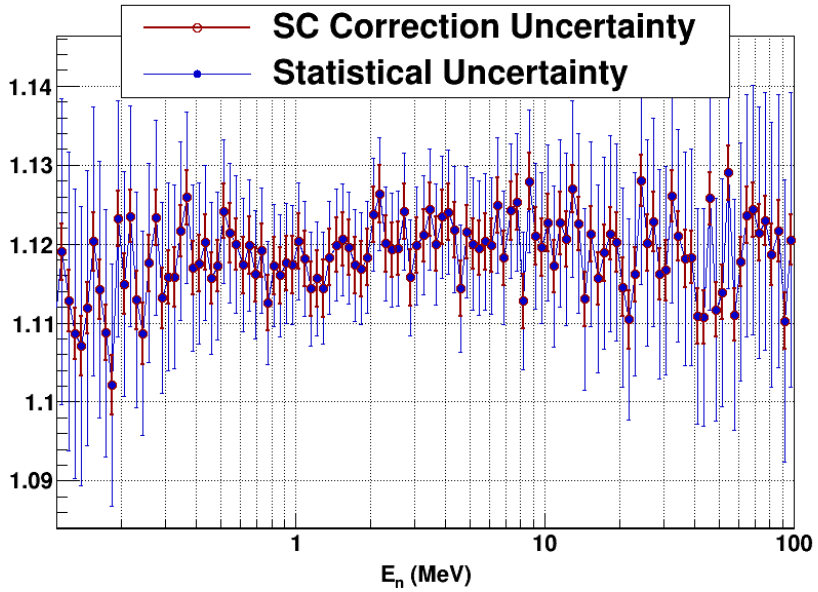






Overlap Correction

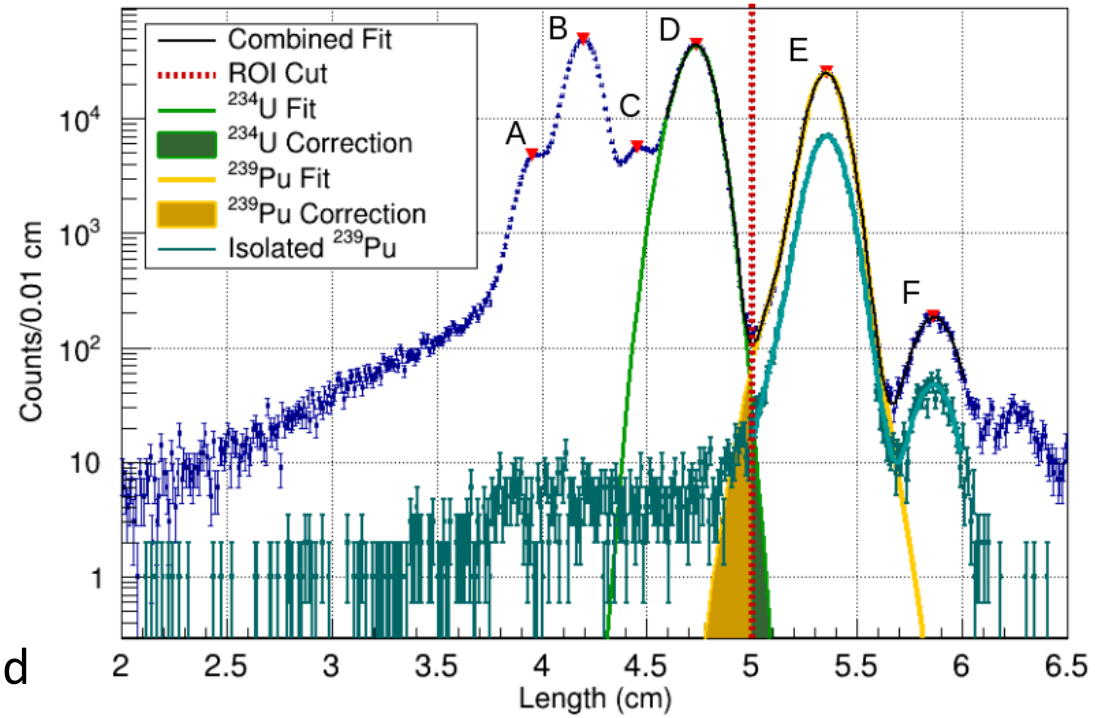




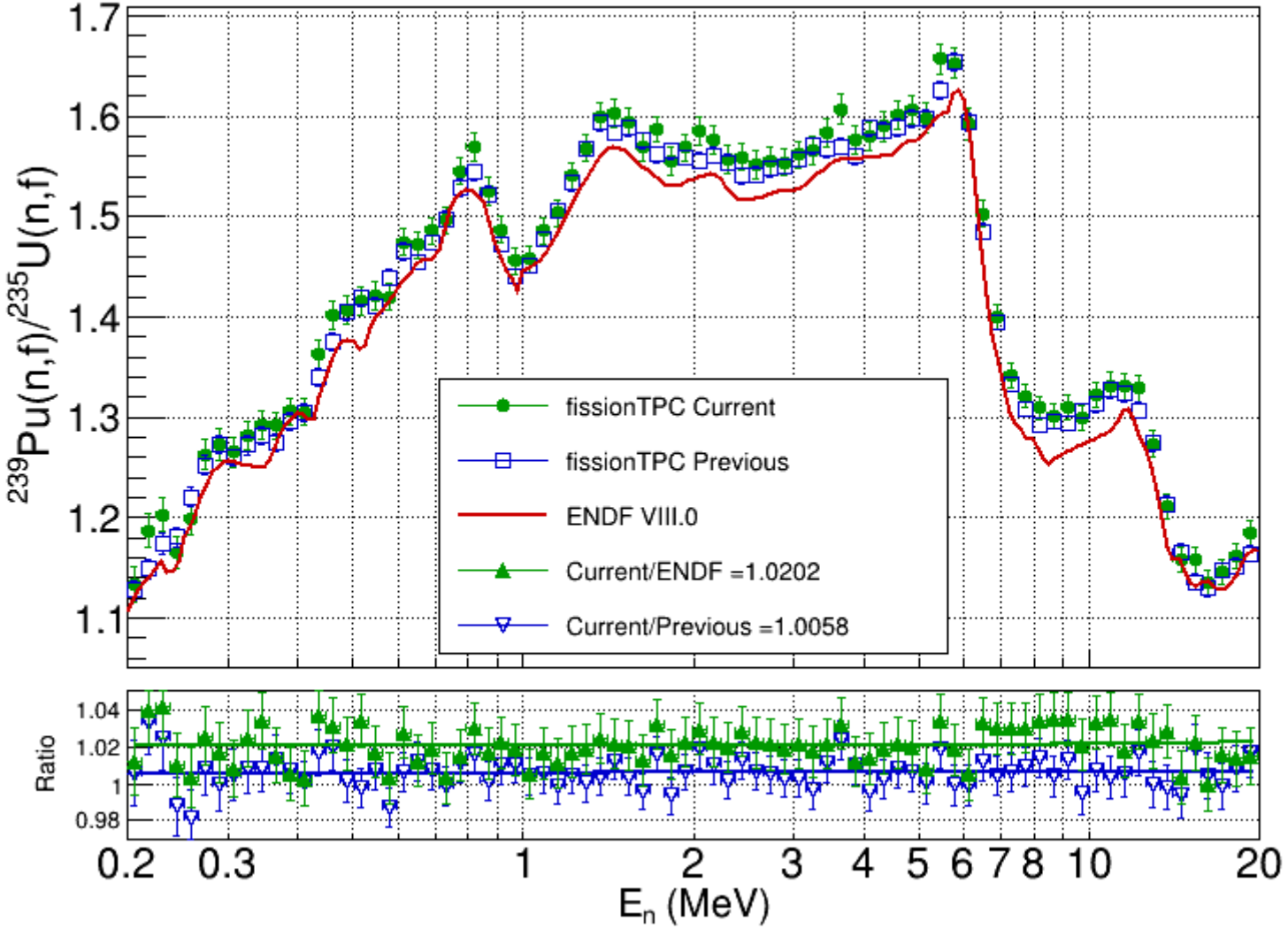
- Correction shape is validated by fissionTPC rotation
- *Space-charge* component of the correction is flat with energy, essentially a normalization correction

Normalization with fissionTPC Radiograph

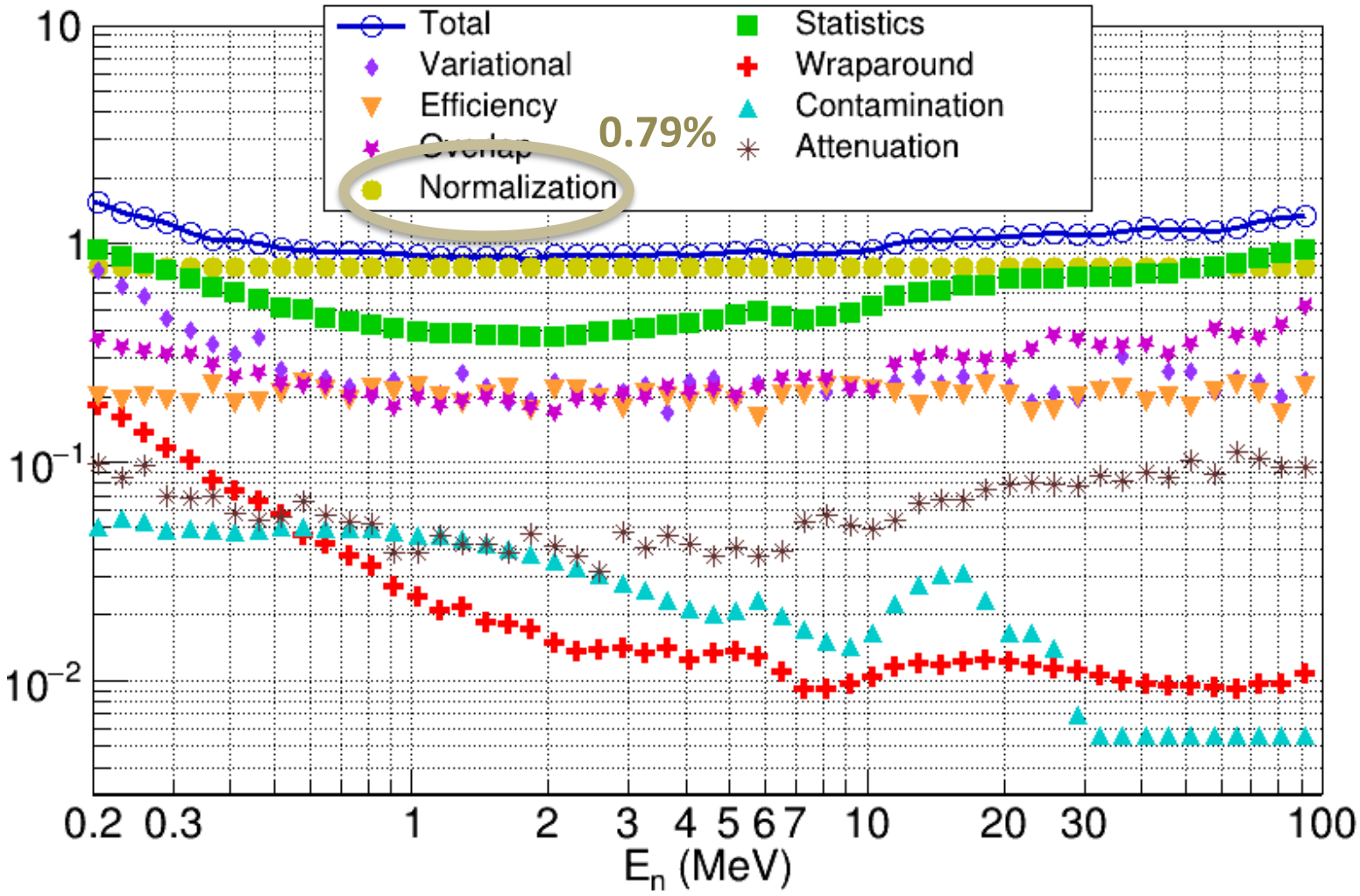
- Tracking improvements since start of project
  - Length resolution is better than energy
- Disadvantage
  - Reduced resolution impacting fit quality
- Advantages
  - Beam and radiograph data collected in same setup/run
  - System better equipped to handle 5 orders of mag. difference in activity
  - Can quantify and make efficiency cuts
  - Pileup effects are reduced and accurately quantified
  - No dead time



Results


^{239}Pu(n,f)/^{235}U(n,f)
1.7
1.6
1.5
1.4
1.3
1.2
1.1
fissionTPC Current
fissionTPC Previous
ENDF VIII.0
Current/ENDF =1.0202
Current/Previous =1.0058
Ratio
1.04
1.02
1
0.98
0.2
0.3
1
2
3
4
5
6
7
8
10
20
E_n (MeV)

Results

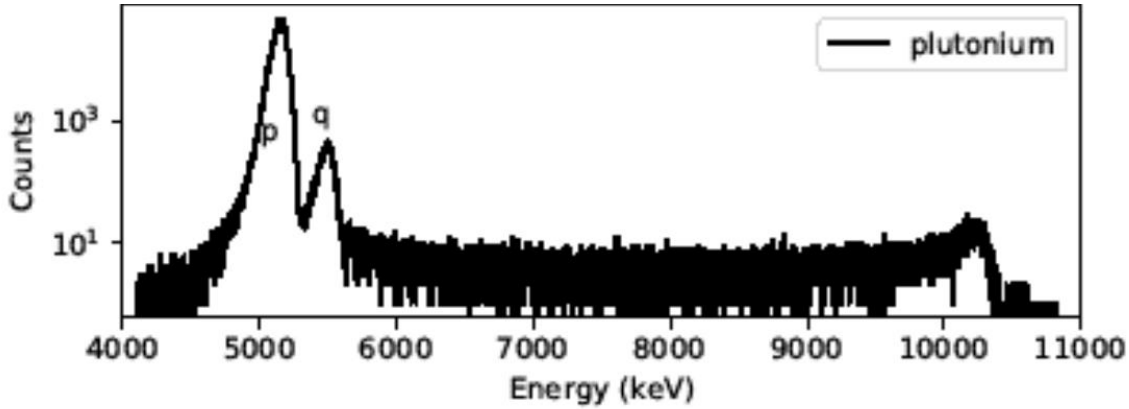

Total
Variational
Efficiency
Overlap
Normalization
Statistics
Wraparound
Contamination
Attenuation
0.79%
10
1
10^{-1}
10^{-2}
0.2 0.3 1 2 3 4 5 6 7 10 20 30 100
E_n (MeV)

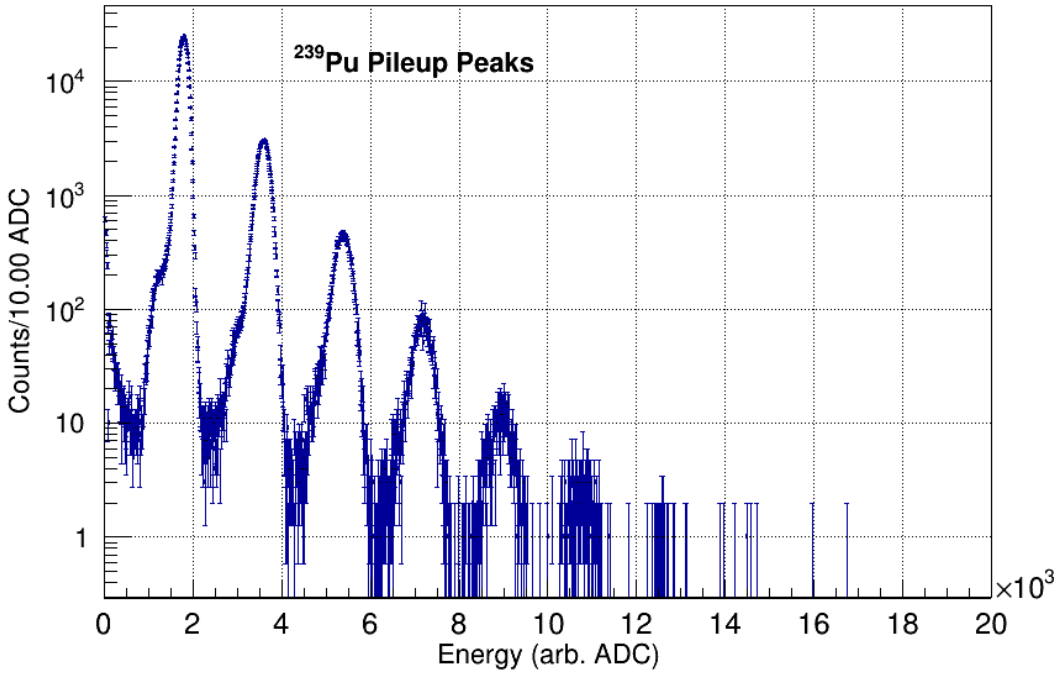
Conclusion

- Confident in the overlap correction
  - We didn't eliminate the need for it, but it was substantially different
  - Additional data gathered to support correction
- Different approach to normalization measurement
  - Greater measurement uncertainty
  - Avoided the concern of previous measurement
- Previous measurement should be treated on equal footing, i.e. normalized
- At the very least, this work supports the inclusion of USU

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Pileup


plutonium
Counts
10^3
10^1
p
q
4000
5000
6000
7000
8000
9000
10000
11000
Energy (keV)


^{239}Pu Pileup Peaks
Counts/10.00 ADC
10^4
10^3
10^2
10
1
0
2
4
6
8
10
12
14
16
18
20
$\times 10^3$
Energy (arb. ADC)