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Title: Extending <TKE> Measurements to En=30 MeV and Beyond

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Extending <TKE> Measurements to E_n= 30 MeV and Beyond

Informal Seminar on Uncertainty Quantification of Experimental Data

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Feb. 18, 2014

ABSTRACT

The majority of energy release in the fission process is due to the kinetic energy of the fission fragments. Average Total Kinetic Energy <TKE> measurements for the major actinides over a wide range of incident neutron energies were performed at LANSCE using a Frisch-gridded ionization chamber. The experiments and results of the 238U(n,f) and 235U(n,f) will be presented, including <TKE>(En), <TKE>(A), and mass yield distributions as a function of neutron energy. A preliminary <TKE>(En) for 239Pu(n,f) will also be shown. The <TKE>(En) shows a clear structure at multichance fission thresholds for all the reactions that we studied. The fragment masses are determined using the iterative double energy (2E) method, with a resolution of A = 4 - 5 amu. The correction for the prompt fission neutrons is the main source of uncertainty, especially at high incident neutron energies, since the behavior of nubar(A,En) is largely unknown. Different correction methods will be discussed.

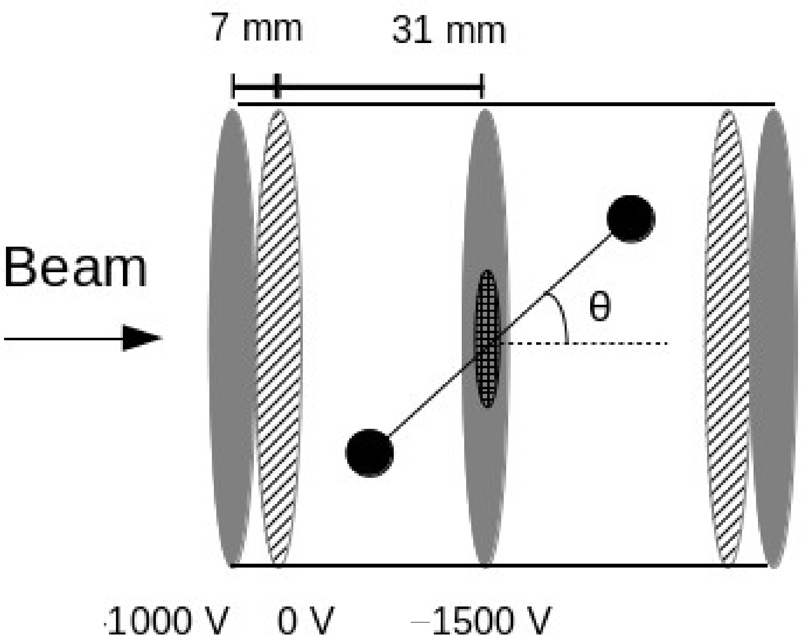
Introduction

- There is a need for more complete $<TKE>(E_n)$ data for the major actinides.
- Opportunity arose to complete the work at LANSCE using a digitizer DAQ and the white neutron source at WNR.
- Work at LANSCE has collected experimental data for neutron induced fission ^{238}U, ^{235}U, and ^{239}Pu.
  - ^{238}U is being prepared for publication
  - ^{235}U is currently being analyzed
  - ^{239}Pu data has just finished being collected and is in preliminary analysis

[**Madland, D.** *Nuclear Physics A*, 2006, 772, 113 - 137]

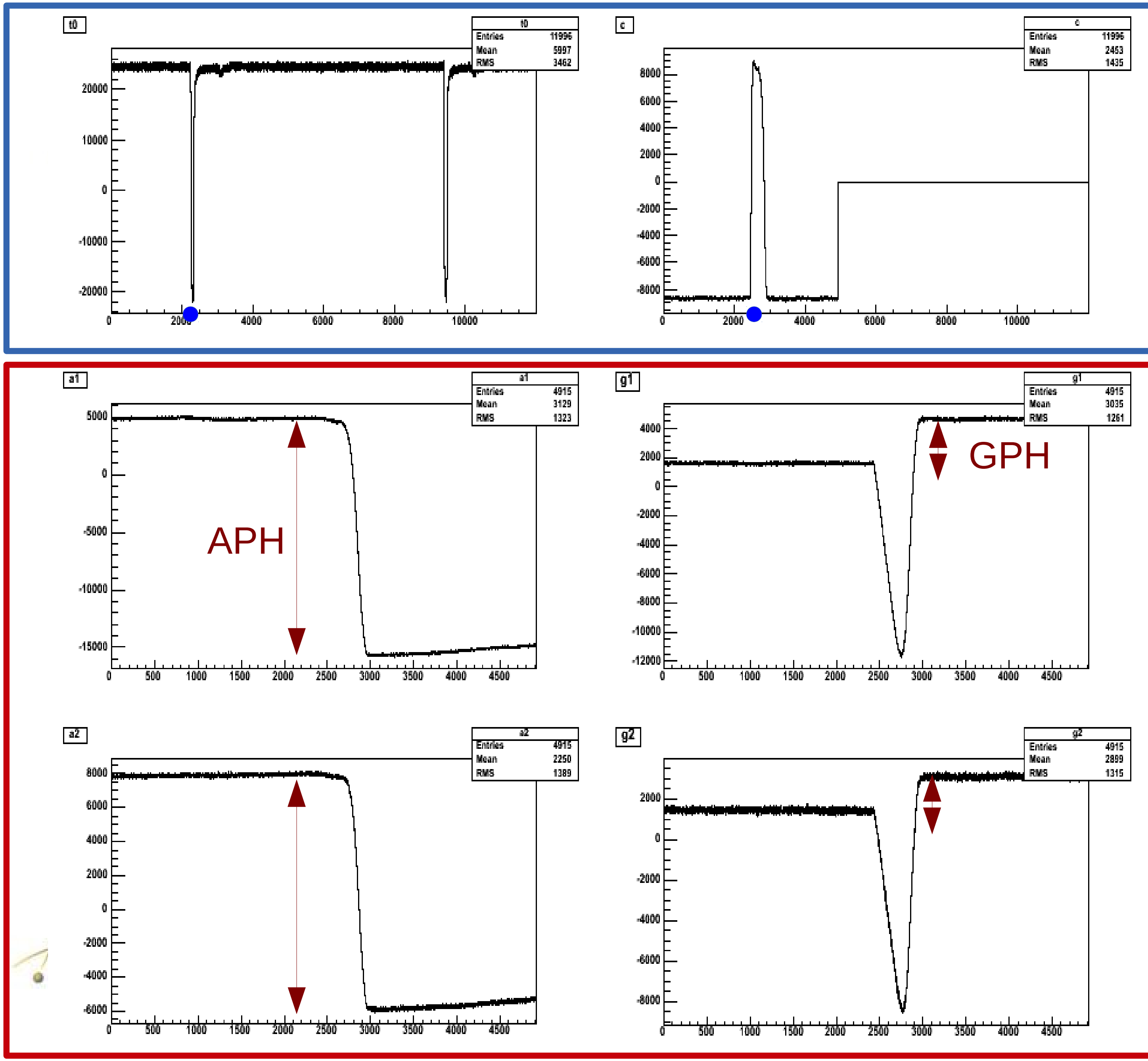
Experimental method : Ionization chamber

- The Frisch-gridded ionization chamber has been traditionally used to measure <TKE>.
- Fission products ionize the gas, producing electrical signals within the detector.
- These signals are recorded to extract energy and angle of the fission products.



Anodes, grids, and a cathode all record signals from the fission event.

[**Straede, C. et al.** *Nuclear Physics A* , 1987, 462, 85 - 108]



E_n

(E_1, θ_1)

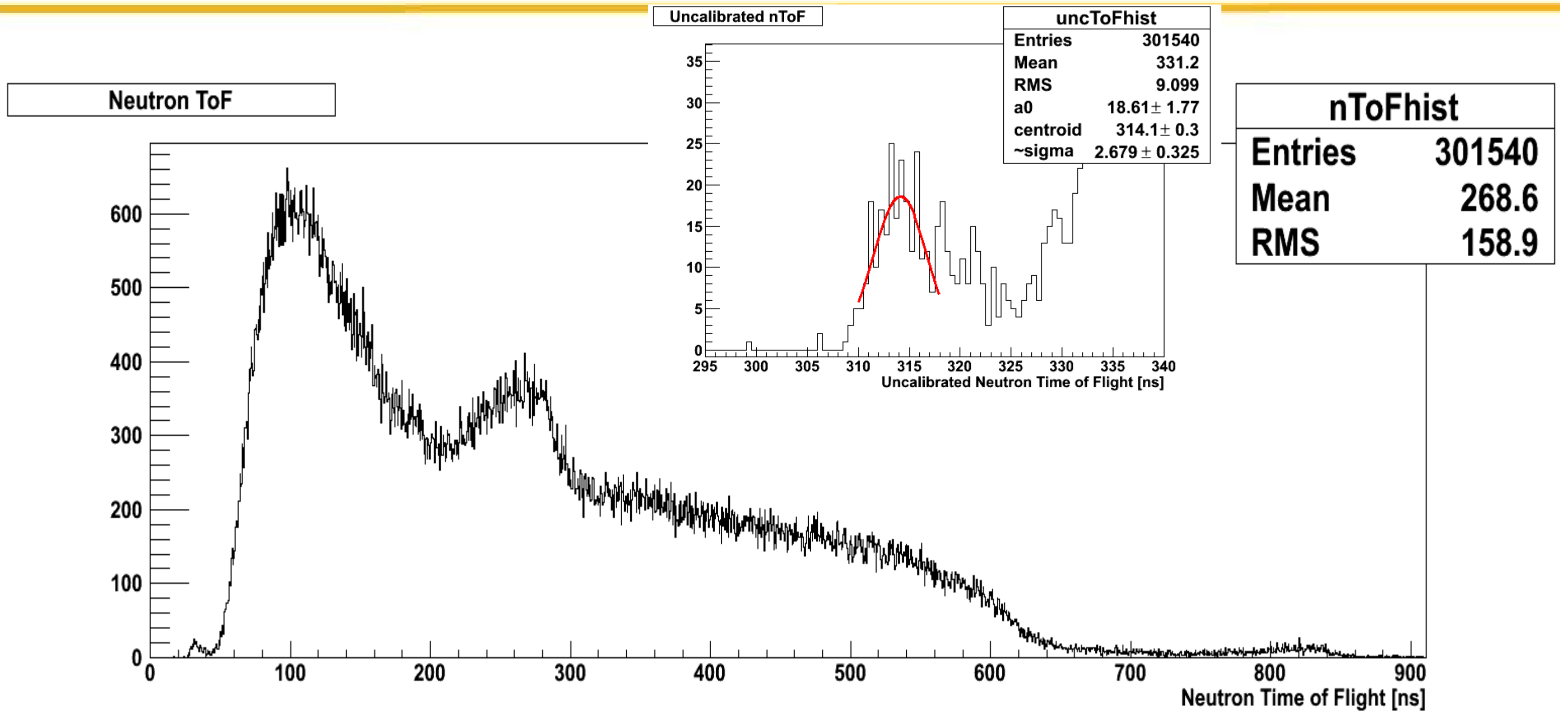
(E_2, θ_2)

Extracting the physics: E_n, angles, and energy

- Extract pulse heights and neutron time-of-flight from the wave forms.
  - Grid inefficiency and preamplifyer gain correction
  - Angular emission (calculate θ)
  - Energy loss in the target and backing material
  - Pulse height defect (detector effect)
- Calibration to previous measurement (calculate energy) *
- 2E method (calculate mass)
  - Neutron sawtooth correction *

*** Sources of systematic uncertainty**

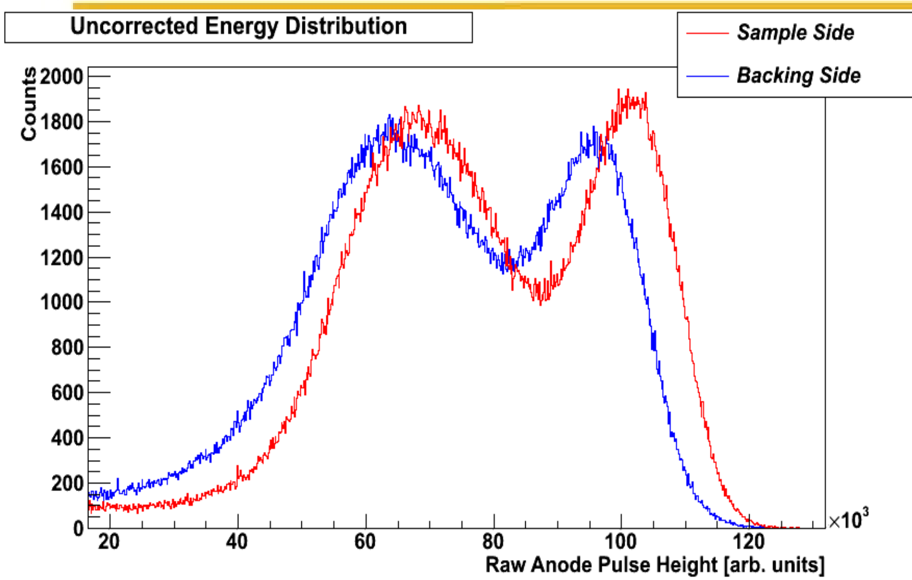
Calculate E_n – Neutron Time of Flight

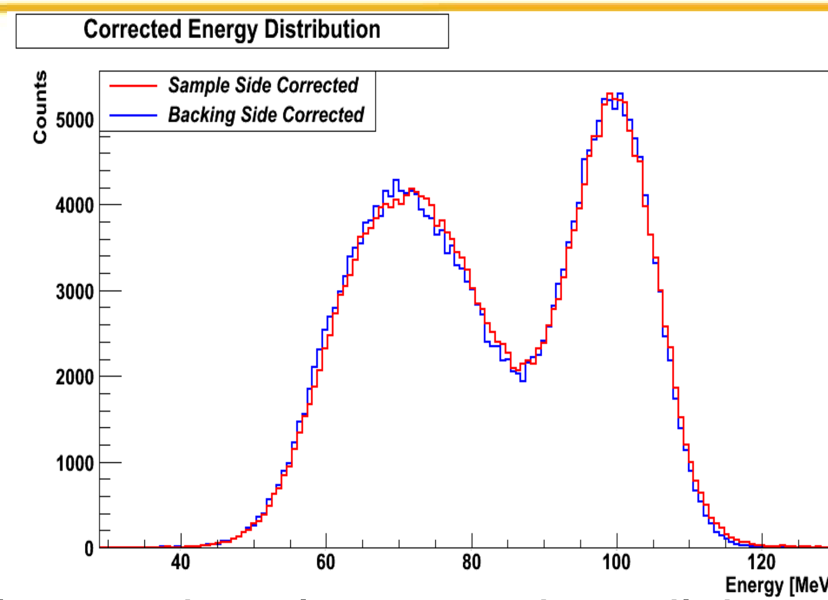


- A neutron time-of-flight method is employed to deduce the incident neutron energies. Relativistic corrections are made. Uncertainty on neutron energies is determined by the width of the photo fission peak.
- This is a common analysis technique at WNR.

[**Tovesson, F. & Hill, T. S**. Phys. Rev. C, 2007, 75, 034610]

Energy calibration





- The various correction for energy loss and angle are made until the anode pulse height (energy) overlay.
- The peaks are fit with Gaussians. Centroids of the light and heavy peak are compared with the average light and heavy product energies of a previous measurement to get a linear anode [channel] → energy [MeV] calibration equation.
- Uncertainties on the corrections goes into calibration uncertainty.

UNCLASSIFIED

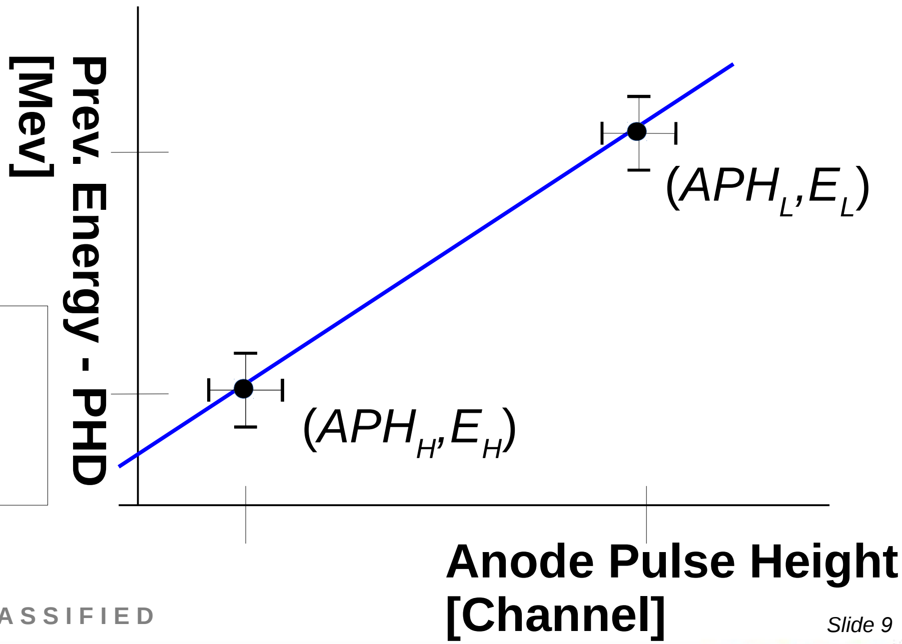
Energy calibration : notes

- Systematic uncertainty for the pulse height corrections are all part of the calibration uncertainty and includes pulse height defect (PHD).
- Uncertainty of the previous measurement is also incorporated.
- The uncertainty on the linear equation parameters is the systematic uncertainty on the fission product energies.

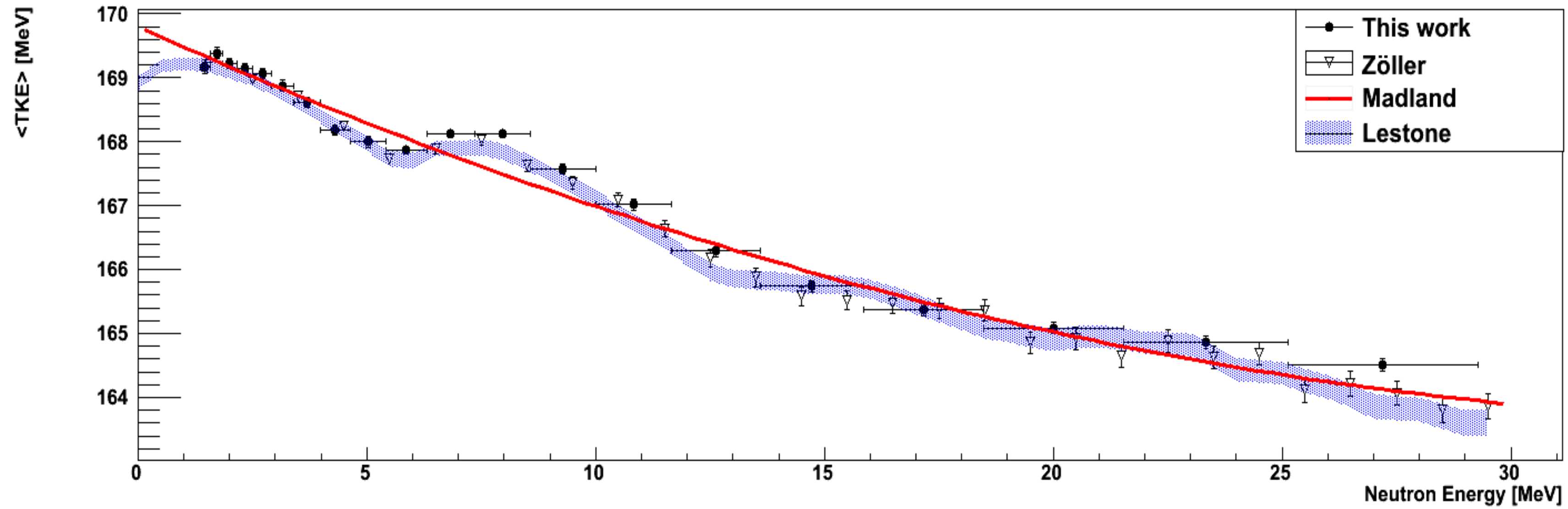
$$E = (m \pm \delta m) \cdot APH + (b \pm \delta b)$$

$$\delta E = \sqrt{(APH \cdot \delta m)^2 + (\delta b)^2}$$

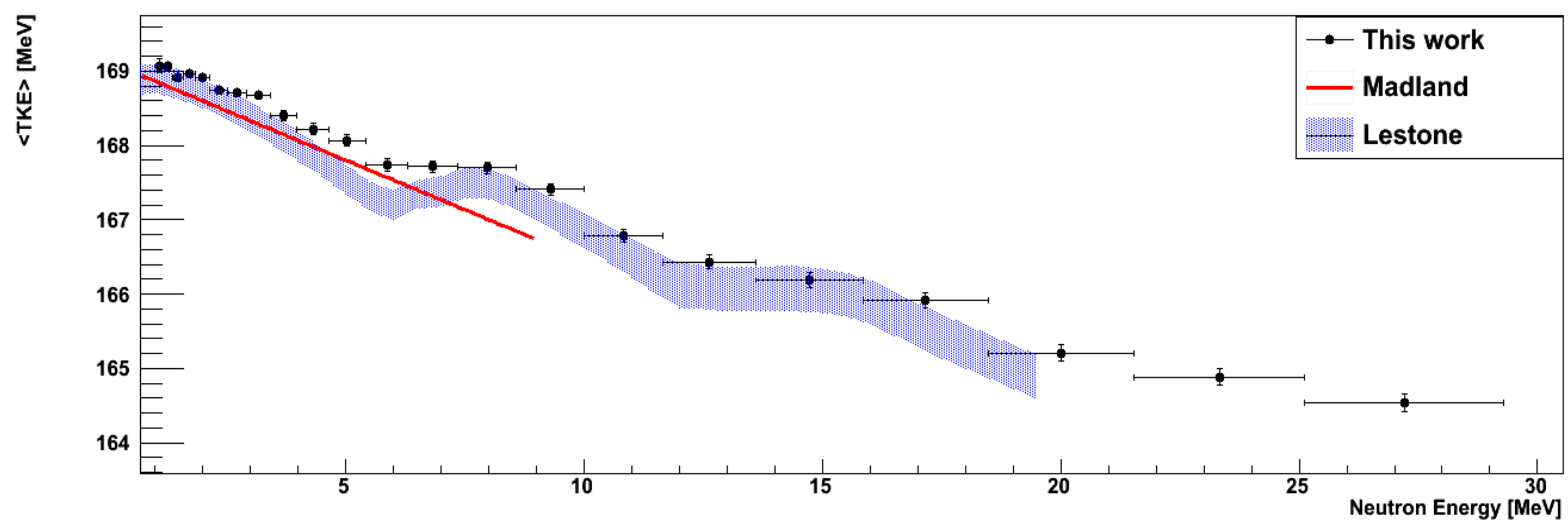
ex. m = 0.93 +- 0.004
b = 0.3 +- 0.4
If APH = 100 ch, E = (92.7 +- 0.6) MeV



238U <TKE>

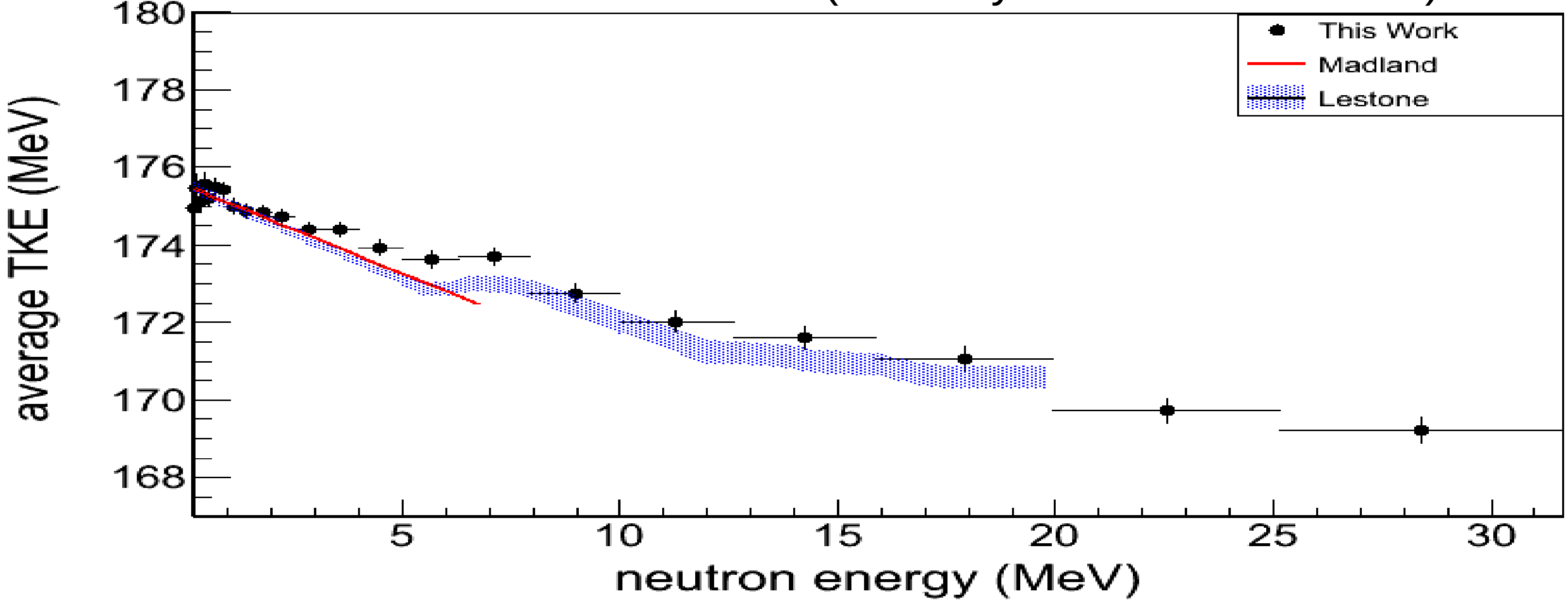


235U <TKE>

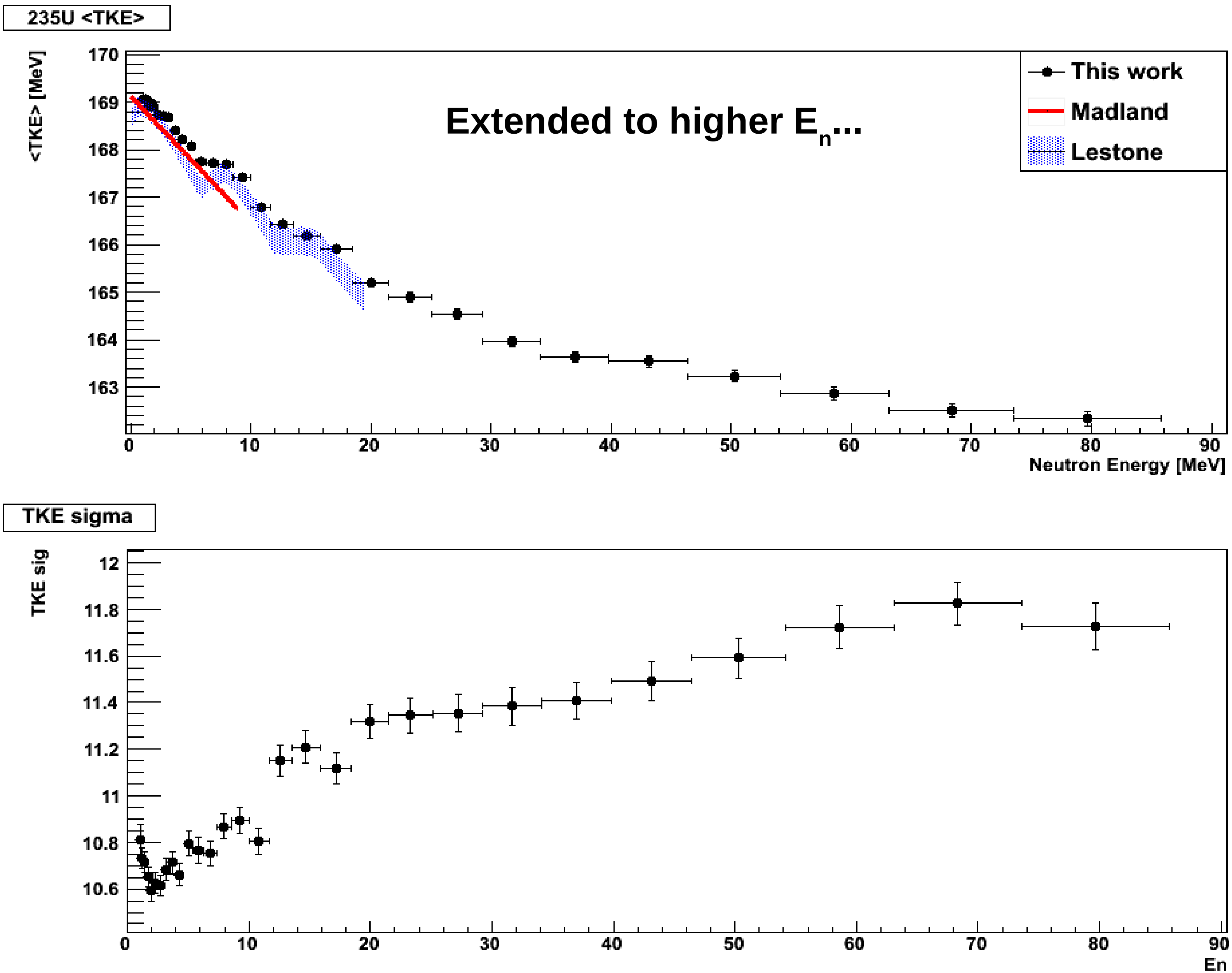


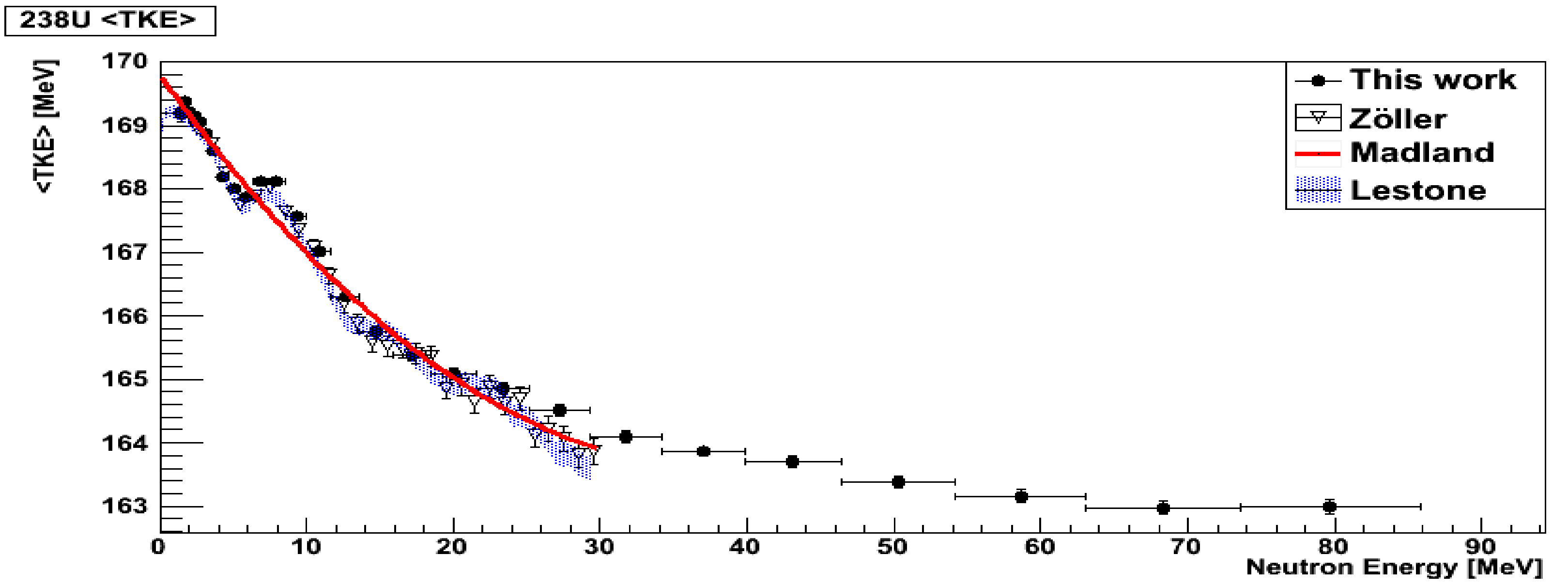
^{239}Pu Product <TKE>

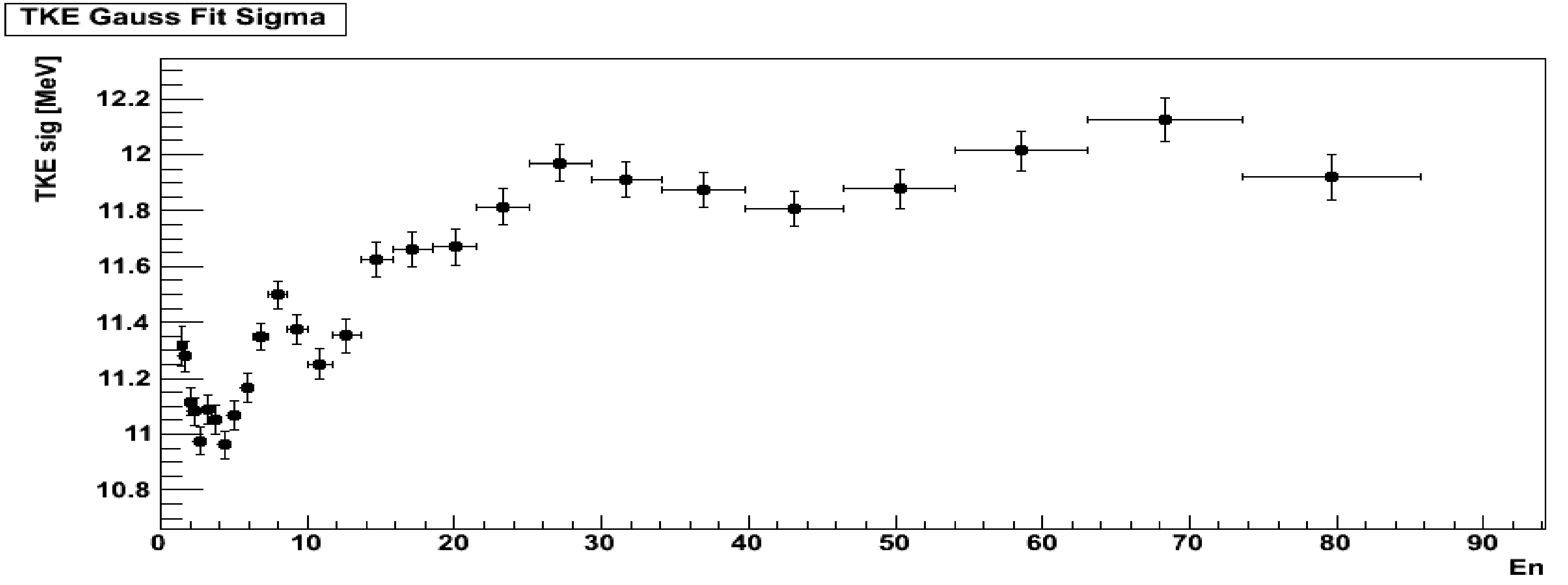
(courtesy Krista Meierbachtol)



- The models of Lestone fit the data quite well in all 3 cases.
- For uranium, the statistical error of the <TKE> is based off the uncertainty in the fit parameters of the Gaussians.
- For plutonium, the statistical error is (currently) the standard deviation of the mean.
- Systematic uncertainty in <TKE> is about 0.5 - 1% and shifts the vertical position of the data.


235U <TKE>
Extended to higher E_n...
This work
Madland
Lestone
<TKE> [MeV]
Neutron Energy [MeV]
TKE sigma
TKE sig
En


238U <TKE>
<TKE> [MeV]
170
169
168
167
166
165
164
163
This work
Zöller
Madland
Lestone
0
10
20
30
40
50
60
70
80
90
Neutron Energy [MeV]


TKE Gauss Fit Sigma
TKE sig [MeV]
12.2
12
11.8
11.6
11.4
11.2
11
10.8
0
10
20
30
40
50
60
70
80
90
En

Calculating Fission Fragment Masses with 2E

1) Assume equal mass fragments: $m_i^{pre} = (M_{tar} + m_n)/2$

2) Correct for prompt neutron emission*: $m_i^{post} = m_i^{pre} - \nu(A, E_n)$

3) Correct energy for PHD*: $E_i^{post} = E_i^{cal} + PHD(m_i^{post})$

4) Calculate fragment masses using energies:

$$m_2^{pre} = \frac{(M_{tar} + m_n)E_1^{post}}{E_2^{post}(B) + E_1^{post}} \quad m_1^{pre} = \frac{(M_{tar} + m_n)E_2^{post}}{E_1^{post}/(B) + E_2^{post}} \quad B = \frac{m_2^{pre} \cdot m_1^{post}}{m_2^{post} \cdot m_1^{pre}}$$

5) Calculate fragment energies in lab frame: $E_i^{lab} = \frac{m_i^{pre}}{m_i^{post}} E_i^{post}$

6) Test for convergence: $|m_i^{pre}(\text{end}) - m_i^{pre}(\text{begin})| \leq 0.125$

7) Start over at (2) if necessary.

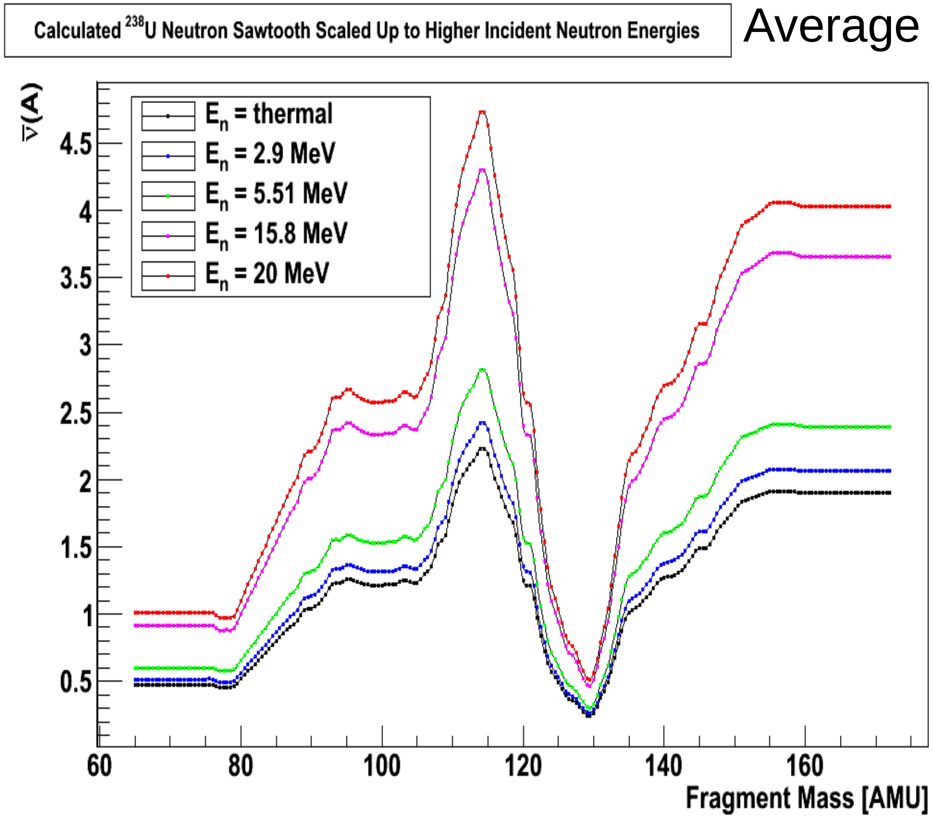
*** Sources of systematic uncertainty**

Neutron sawtooth correction, nu(A,E_n)

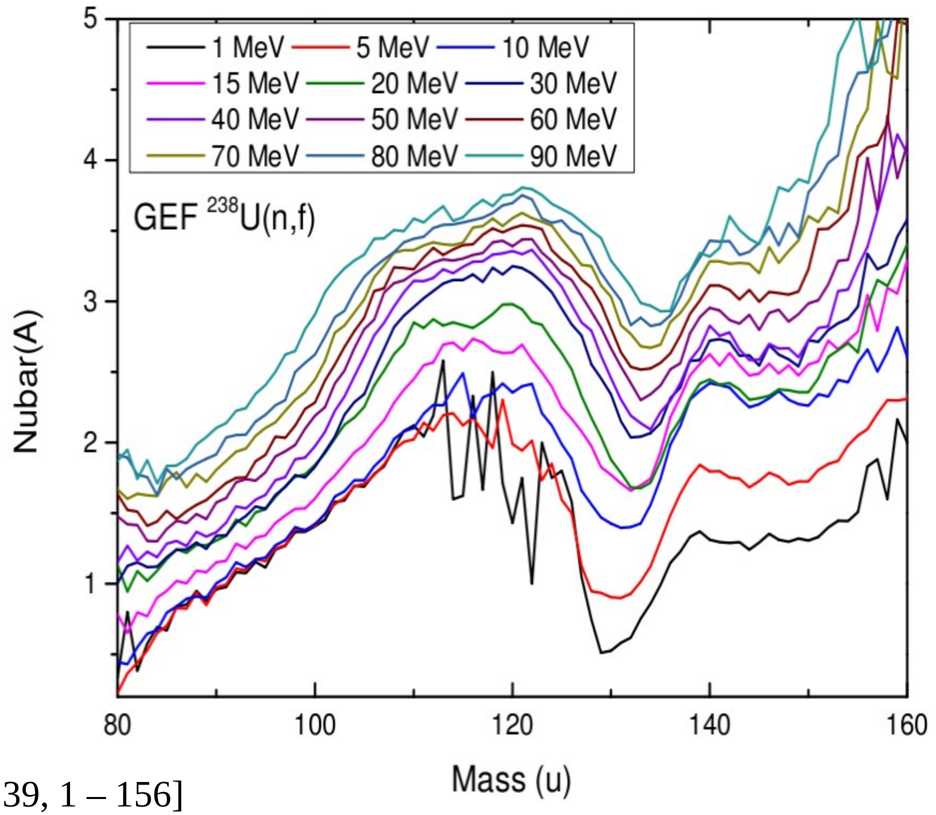
- To explore TKE(A), we calculate masses using the 2E method, which requires a correction for prompt neutron emission. $m_i^{post} = m_i^{pre} - \nu(A, E_n)$
- **Method 1: Average**
  - The sawtooth at thermal energies is “scaled” using a multiplicative factor determined by nubar. The number of emitted neutrons is shared equally between the two fragments.
- **Method 2: Heavy**
  - The sawtooth is simulated using GEF code for different incident neutron energies → Assumes the heavy fragment evaporates more neutrons.

Average vs. Heavy method

Average



Heavy



[**Wahl, A. C.** Atomic Data and Nuclear Data Tables , 1988, 39, 1 – 156]
[**J. Terrell**, Phys. Rev. 127 1962]
[**Lestone, J.** Nuclear Data Sheets , 2011, 112, 3120 – 3134]
[**Al-Adili, A**, et. al. Phys. Rev. C, 2012, 86, 54601-8]

Calculating Fission Fragment Masses with 2E

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$$m_2^{pre} = \frac{(M_{tar} + m_n)E_1^{post}}{E_2^{post}(B) + E_1^{post}} \quad m_1^{pre} = \frac{(M_{tar} + m_n)E_2^{post}}{E_1^{post}/(B) + E_2^{post}} \quad B = \frac{m_2^{pre} \cdot m_1^{post}}{m_2^{post} \cdot m_1^{pre}}$$

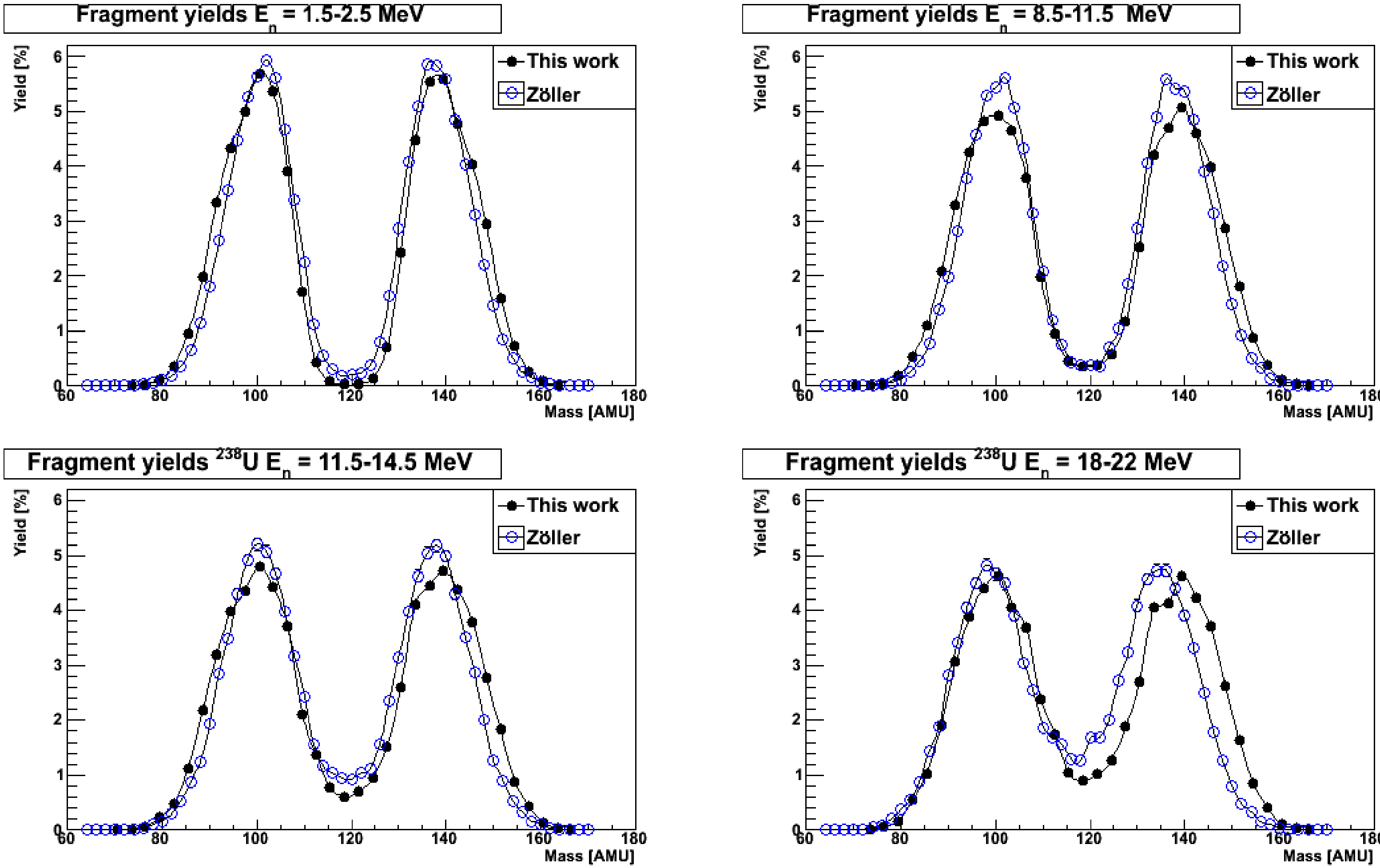
5) Calculate fragment energies in lab frame: $E_i^{lab} = \frac{m_i^{pre}}{m_i^{post}} E_i^{post}$

6) Test for convergence: $|m_i^{pre}(\text{end}) - m_i^{pre}(\text{begin})| \leq 0.125$

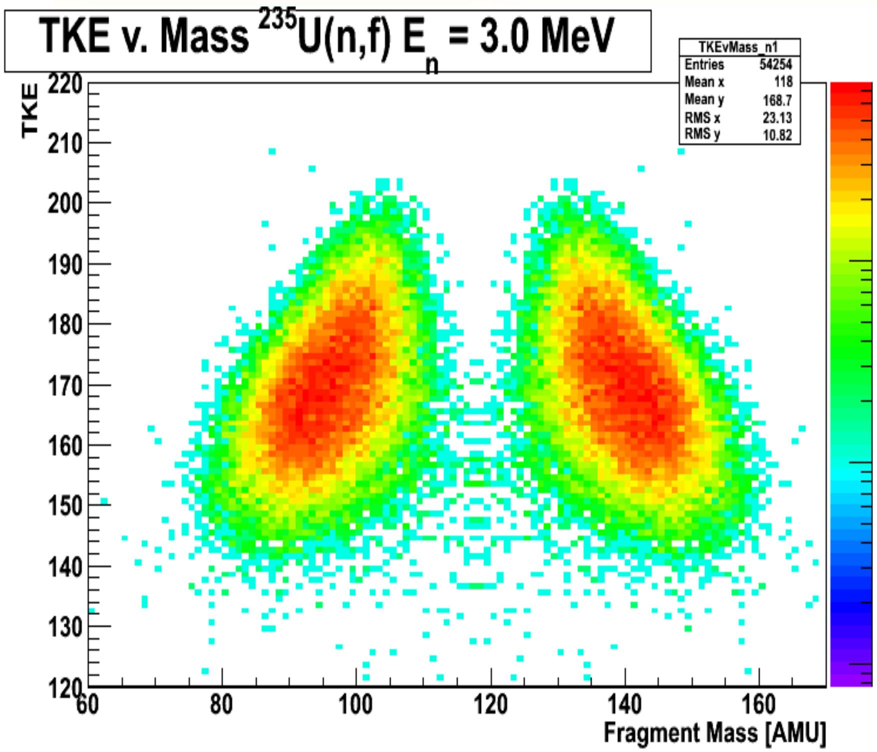
7) Start over at (2) if necessary.

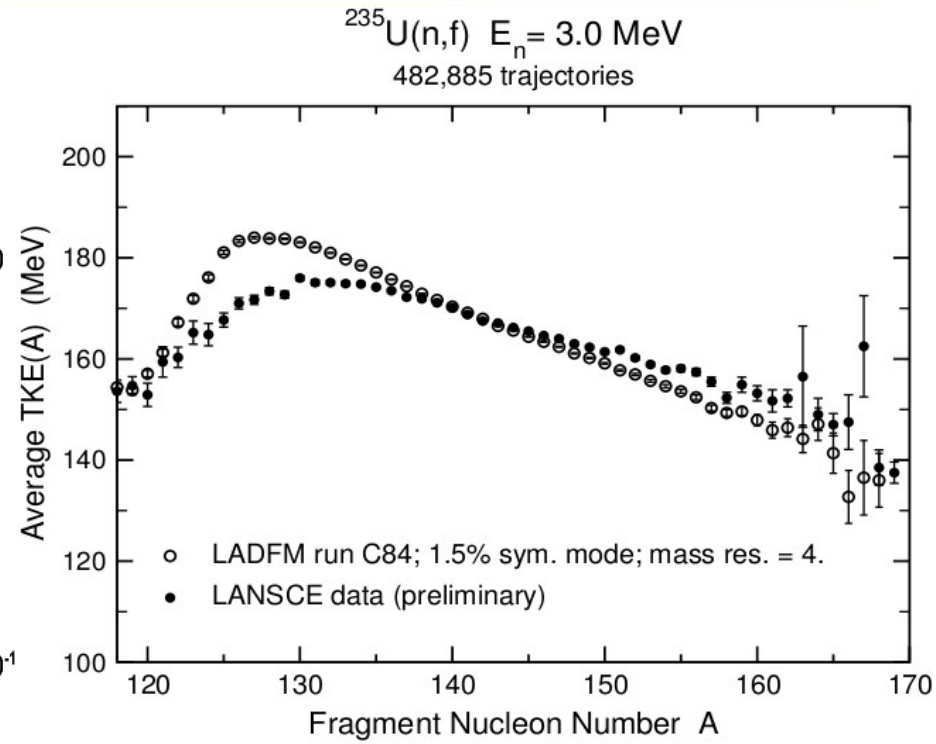
*** Sources of systematic uncertainty**

Mass yields $^{238}U(n,f)$ – Average method



Average TKE(A, E_n) for ^{235}U(n,f)





- The mass resolution of the ionization chamber is 4-5 AMU, calculated by comparing to ENDF. [**Mosby, S.** et. al., NIM *A*, 2014, 757, 75 - 81]
- Results displayed here with model for 1 AMU. (courtesy Arnie Sierk)

Conclusions

- Models of the <TKE>(E_n) fit the data quite well.
- Sources of uncertainty in the 2E method are not quantified. We can do this, but we need your input.
- The mass yields and measurement at higher energies requires a better understanding of prompt neutron evaporation and what multichance fission processes are happening.