

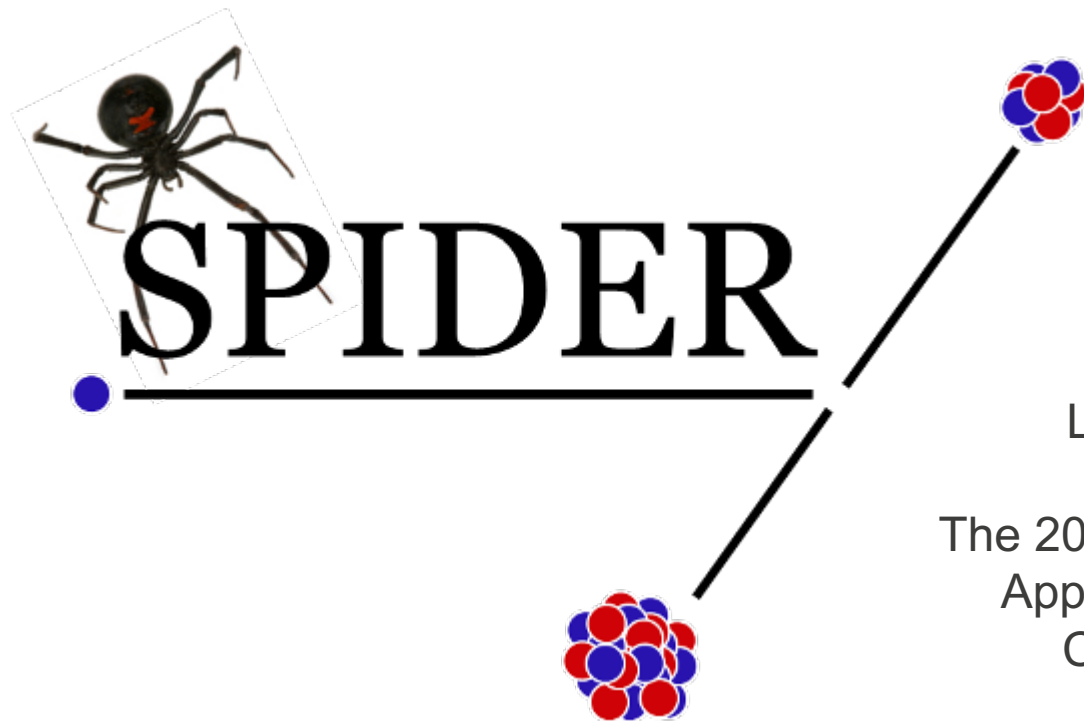


  
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NATIONAL LABORATORY  
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Delivering science and technology  
to protect our nation  
and promote world stability



# The MegaSPIDER Detector System for Fission Product Yield Measurements



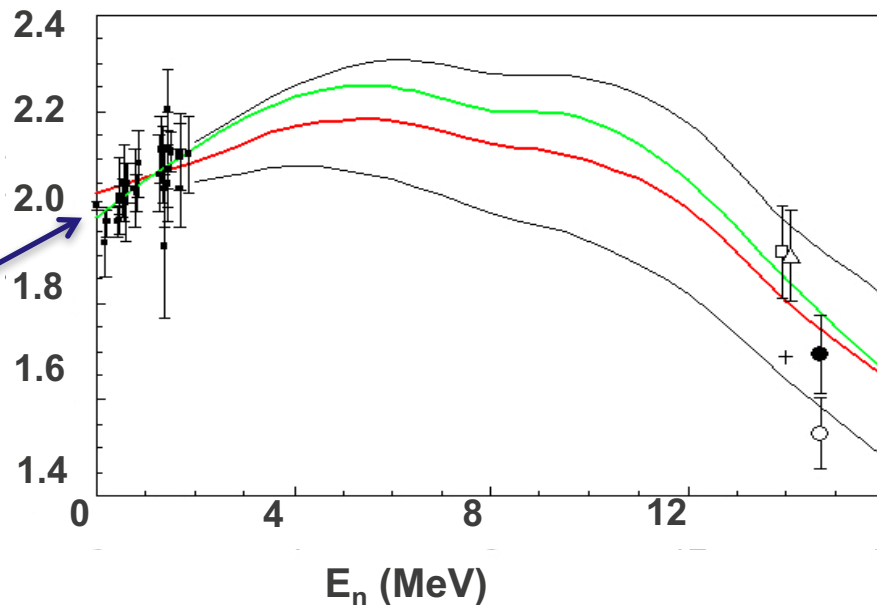
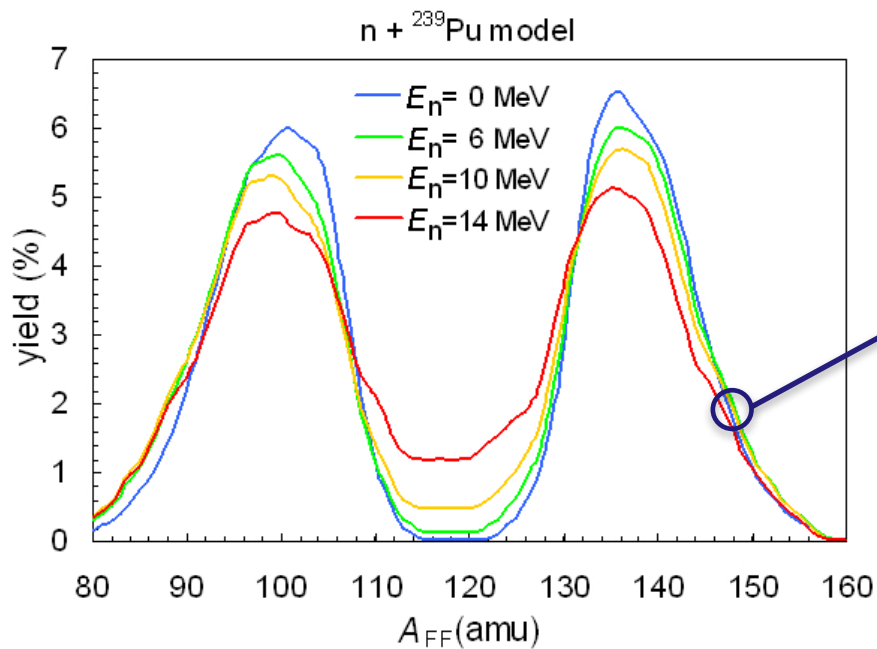
**Fredrik Tovesson**  
Los Alamos National Laboratory

The 2017 International Conference on  
Applications of Nuclear Techniques  
Crete, Greece June 11-17, 2017

# Introduction

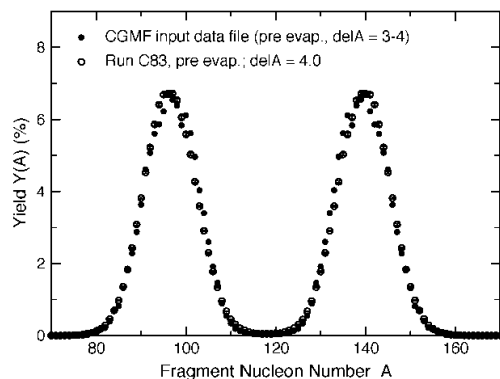
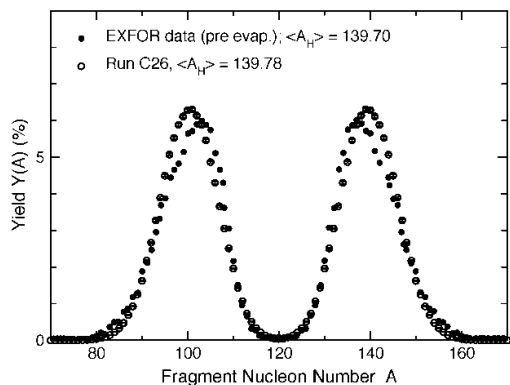
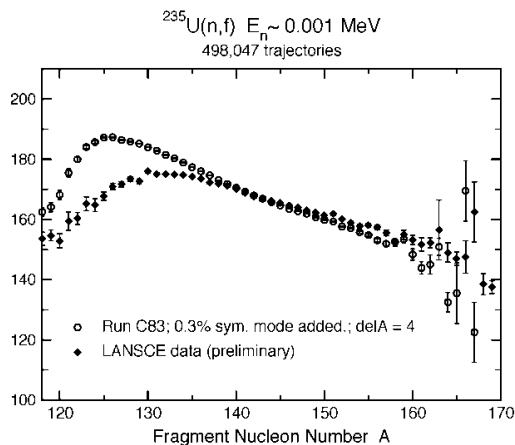
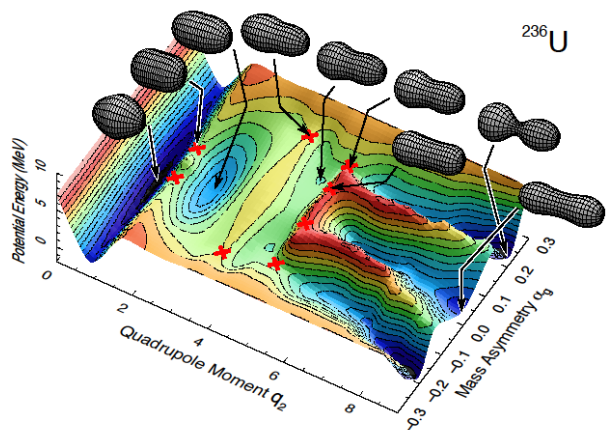
- **Discrepancies between the LANL and LLNL fission basis led to a closer look at experimental data**
  - For some of the important fission products there were ~5% yield discrepancies
- **The discrepancies seemed to be connected to the energy dependence of fission product yields (FPY)**
  - By taking into account small variations in the average neutron energy in different experiments the energy dependence of FPY in the fission neutron energy region was fitted based on existing data
  - This allow for the FPY uncertainties to be reduced
- **LANL is involved in two experimental programs to confirm the FPY energy dependence (TUNL and LANSCE)**
- **Models are being developed to support new evaluations**

# The neutron energy dependence of individual yields can be modelled from global trends in the mass yields



Predictions for  
 A=148 (Green)  
 A=147 (Red)  
 A=147 Uncertainty (Black)

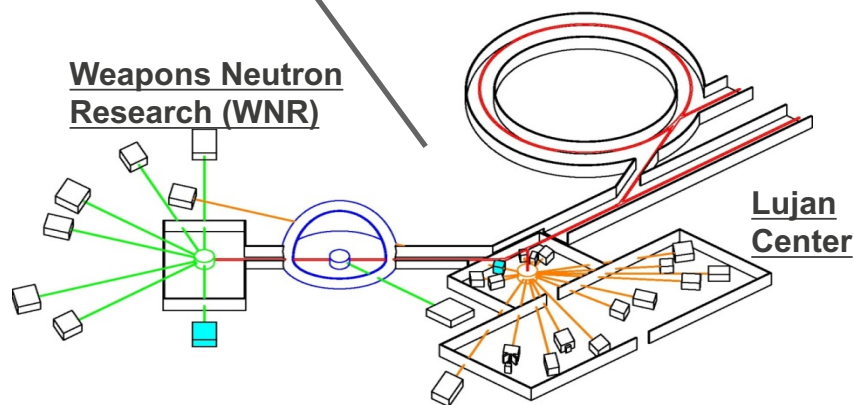
# Theoretical calculations of fission fragment properties



- Macroscopic-microscopic description of fission successfully models potential energy of nuclei
- New advanced calculations of nuclei advancing through the potential predicts mass, charge and kinetic energy of fission fragments
- Theory will provide nuclear data for isotopes that are challenging to measure
- Measurements of fission correlation helps constrain theoretical models
- SPIDER is a great tool for providing data to refine fission models (several outputs)

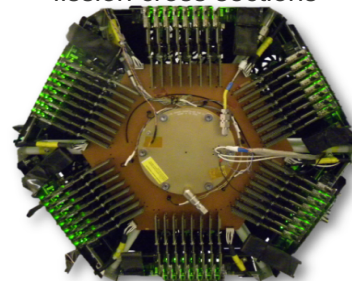
From A. Sierk, LANL

# The Los Alamos Neutron Science Center (LANSCE)



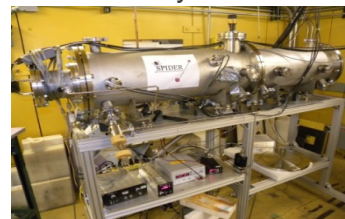
## TPC

fission cross sections



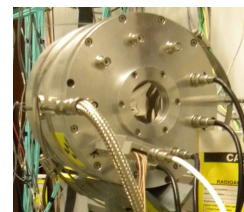
## SPIDER

fission yields



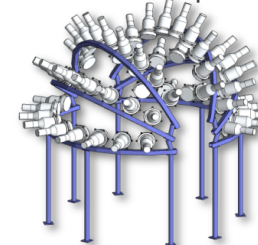
## Fission chambers

TKE, fission yields



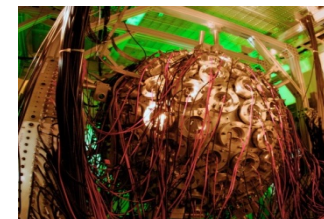
## Chi-Nu

neutron output



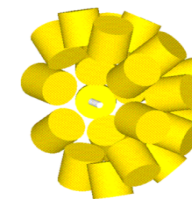
## DANCE

neutron capture, fission  $\gamma$ -rays

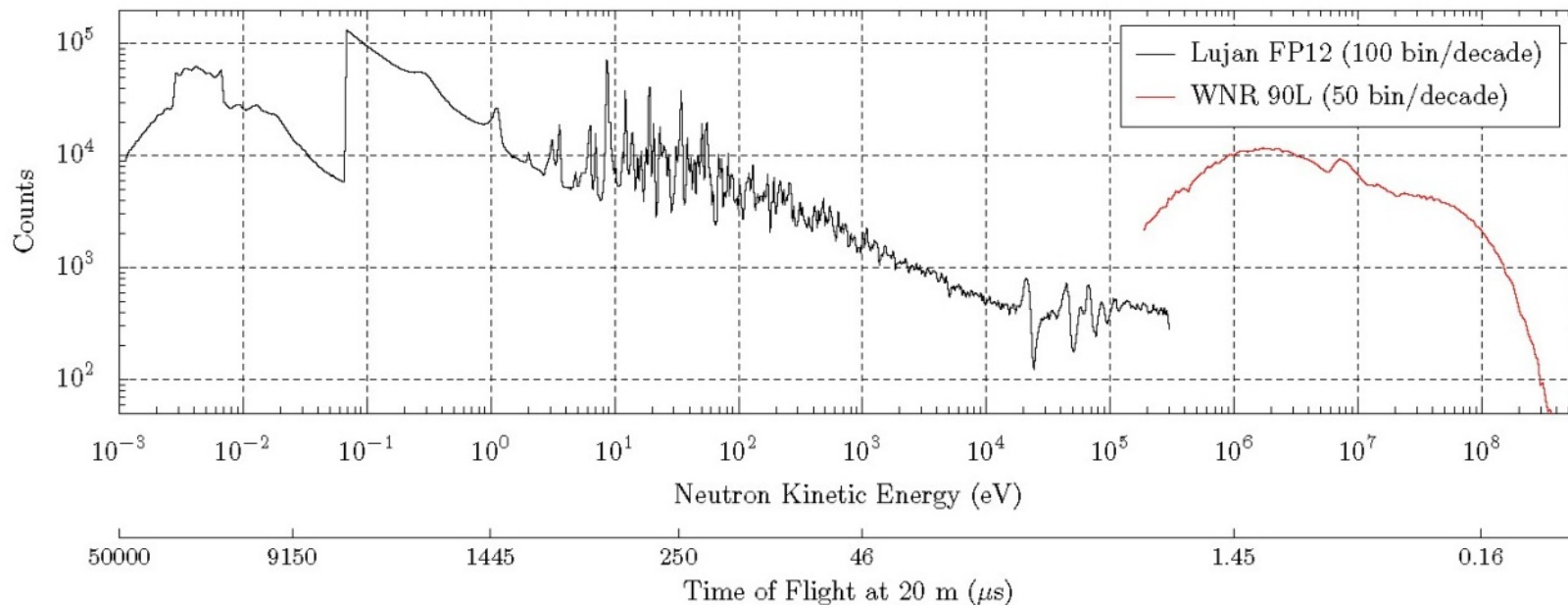


## APOLLO

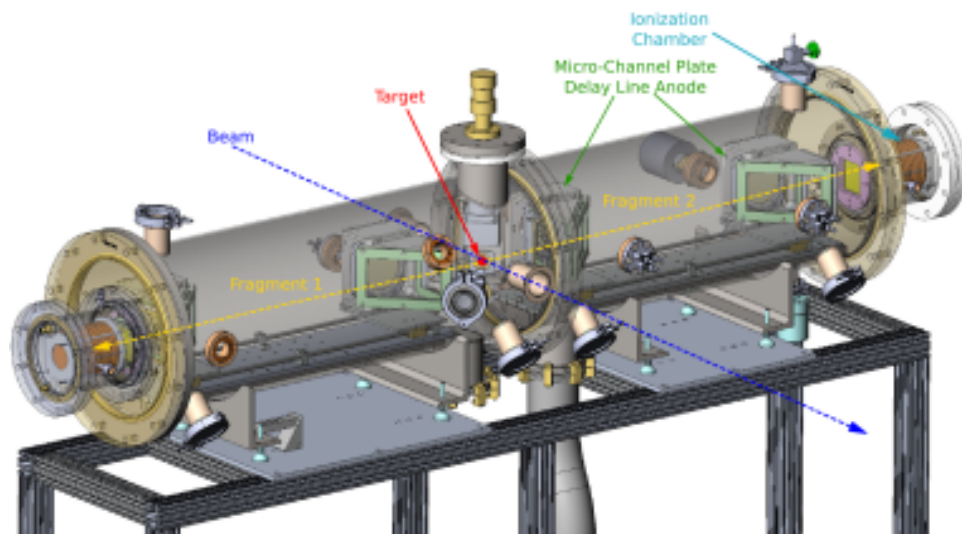
$\gamma$ -rays for ion beam experiments



# LANSCCE provide neutrons from thermal energies to hundreds of MeV



# The SPIDER instrument

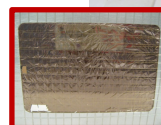
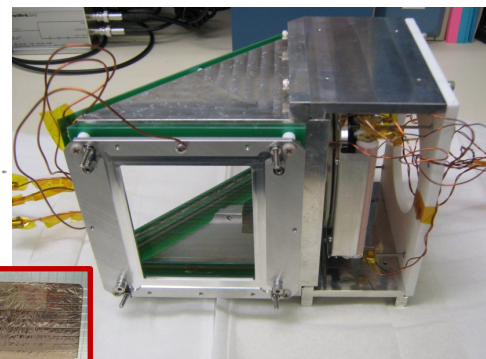
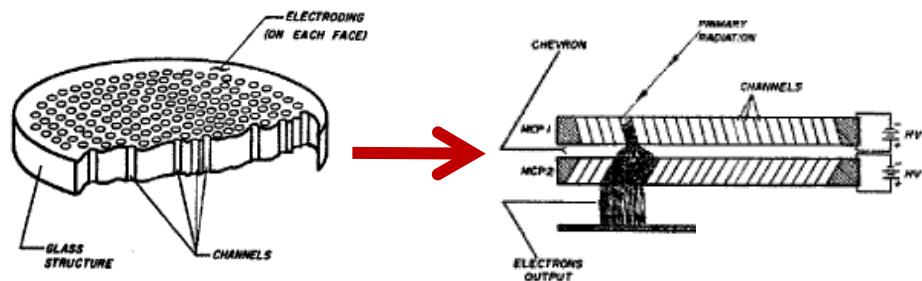
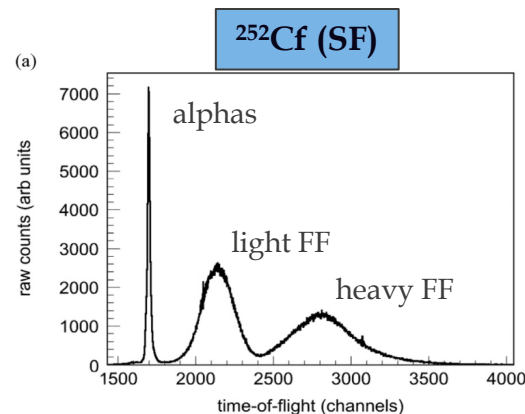
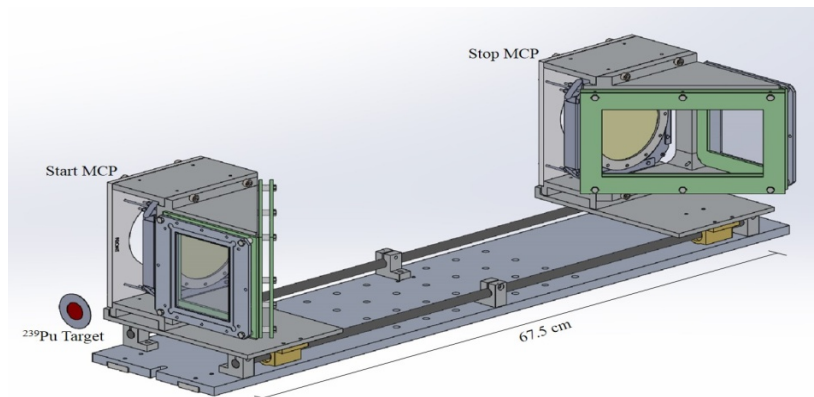


$$M = \frac{2Et^2}{l^2}$$

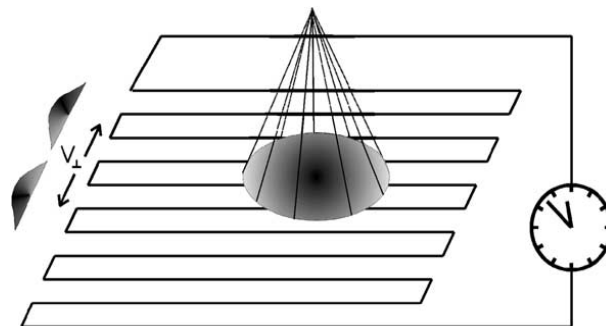
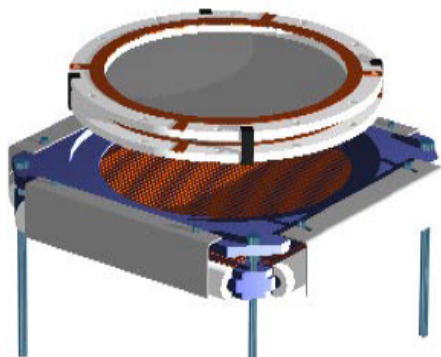
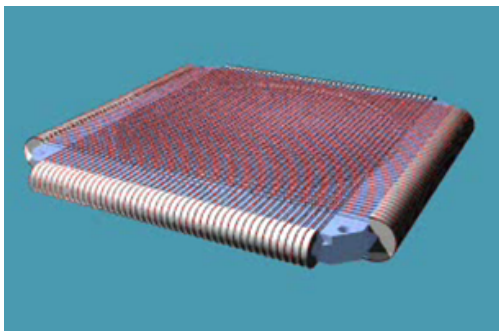
$$\frac{\delta M}{M} = \sqrt{\left(\frac{\delta E}{E}\right)^2 + \left(2\frac{\delta t}{t}\right)^2 + \left(2\frac{\delta l}{l}\right)^2}$$

- **The 2E-2v method can provide 1 amu resolution for light fragments**
  - Demonstrated with Cosi-fan-Tutti at ILL
- **Measures independent yields**
  - Currently mass
  - Plans for charge identification

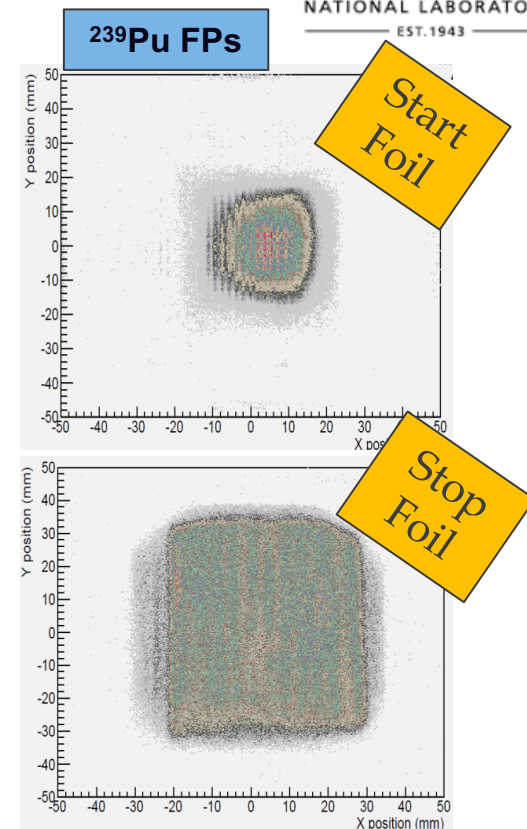
# Fission fragment Time-of-Flight Measurement



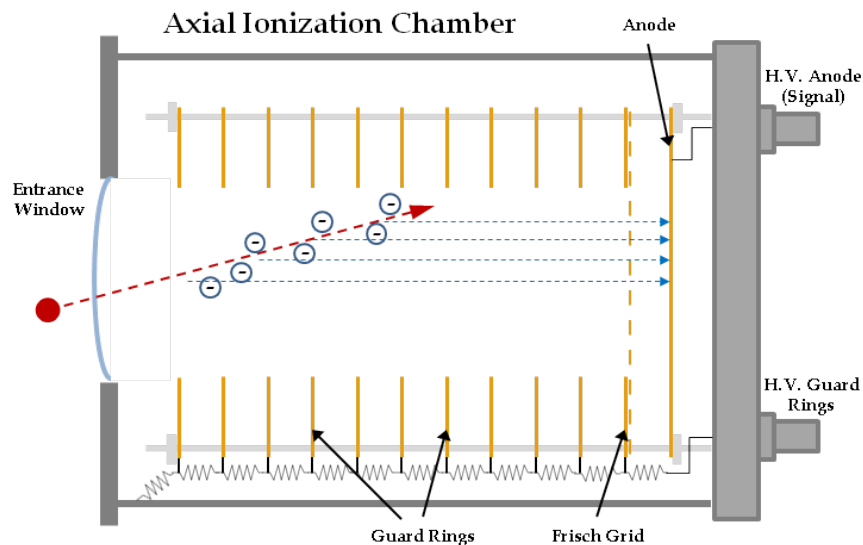
# Flight Path Measurement



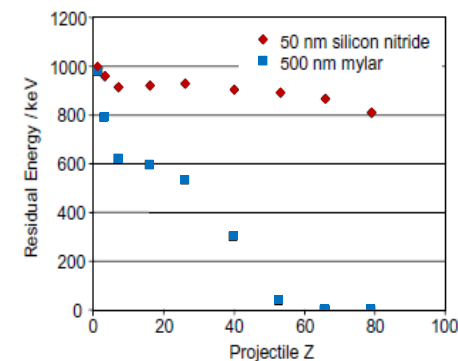
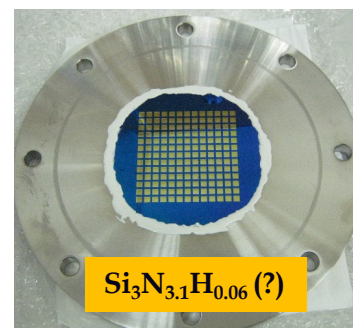
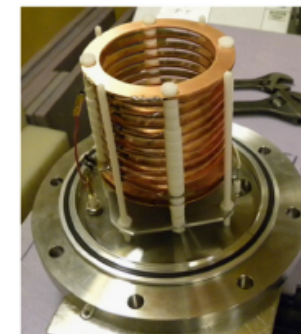
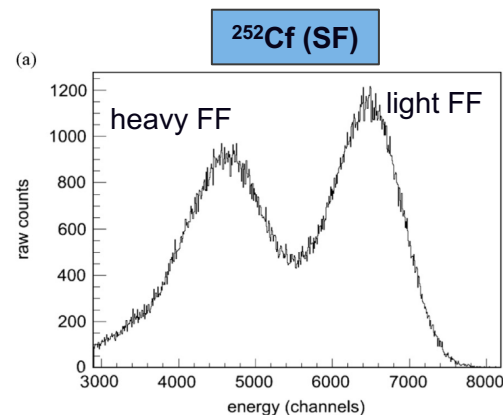
- Orthogonal grids, 1 wire/mm
  - “X” and “Y” coordinates
  - Parallel signal and reference
- Position measured as  $\Delta t$  (ns)
- Built in-house, design by RoentDek
- $\leq 2$  mm (FWHM) resolution



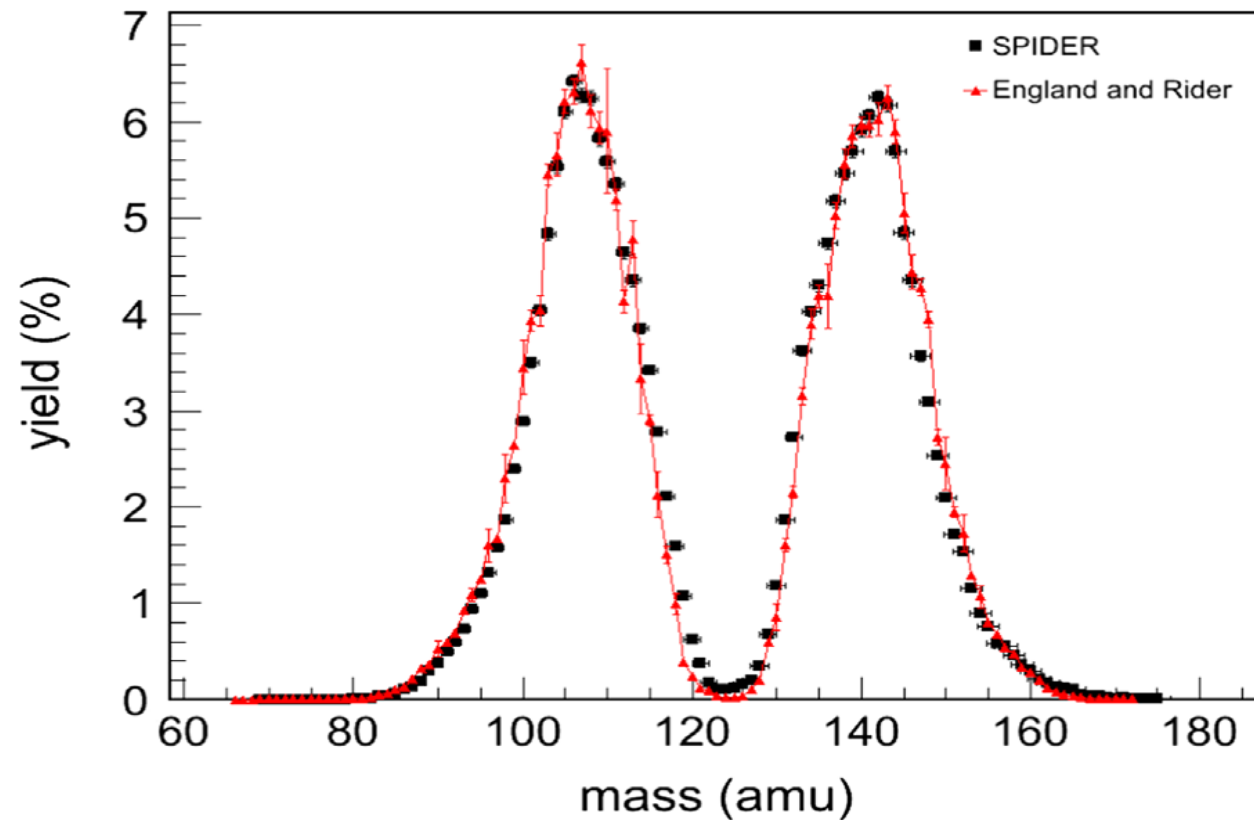
# Energy Measurement



- $\delta E \approx 410$  keV demonstrated for  $A = 90$ ,  $E = 98.2$  MeV ions
- $\delta E \geq 1$  MeV typical for Si detector\*

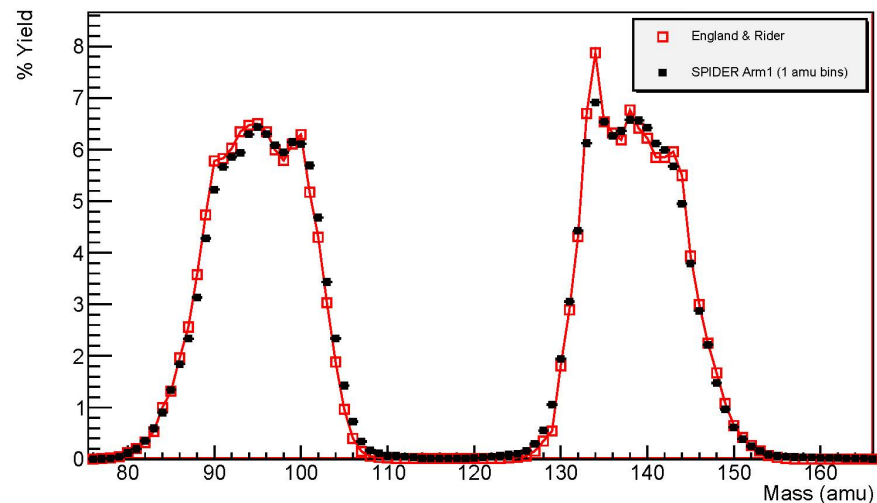


# Spontaneous fission of Cf-252

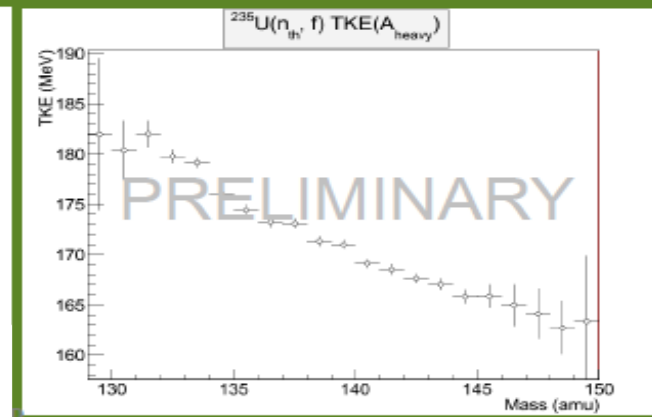
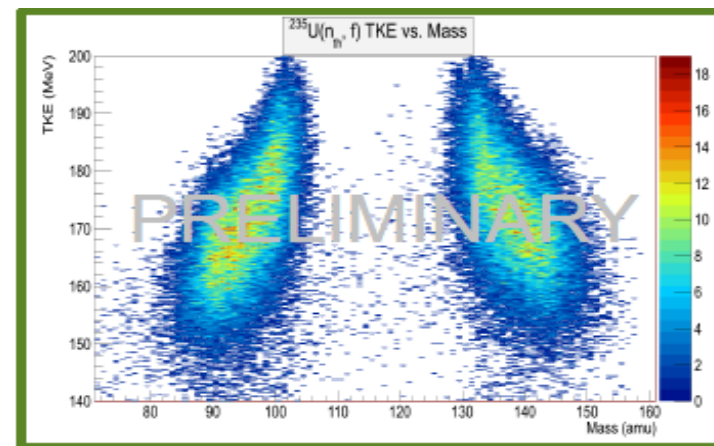


Meierbachtol et al., NIM A788, 59 (2015)

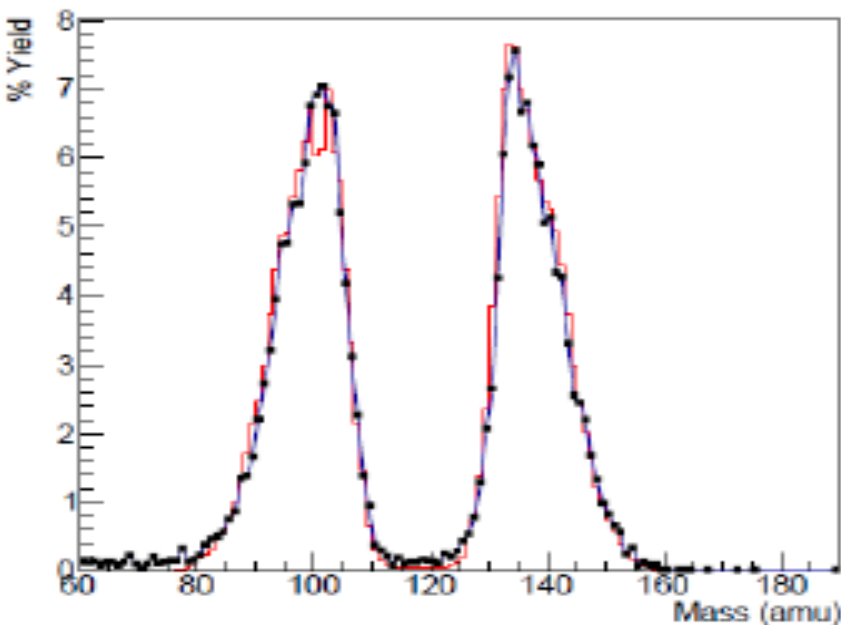
# Thermal neutron-induced fission of $^{235}\text{U}$



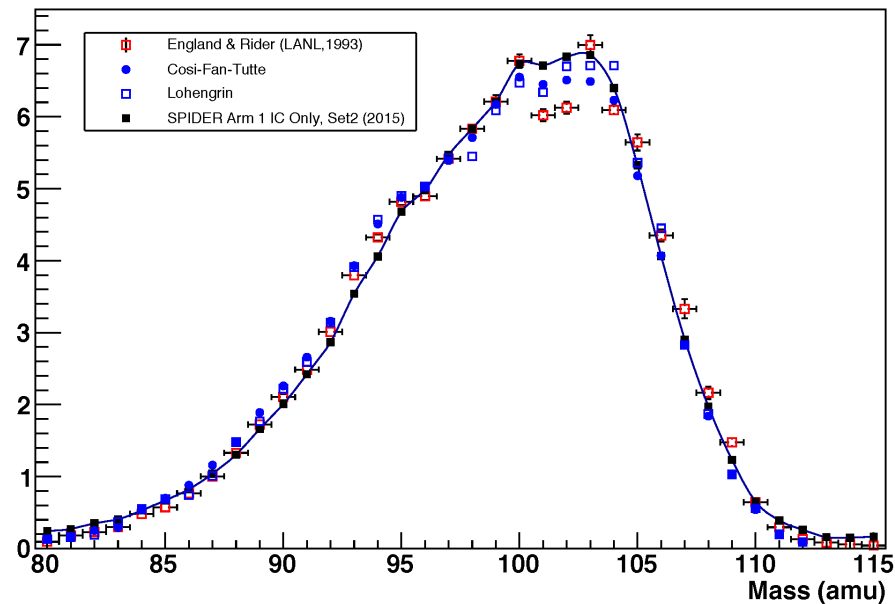
- **$\text{U-235 } (n_{\text{th}}, f)$  was measured using both spectrometer arms**
  - M vs TKE supports models describing deexcitation of fission fragments
  - Can also be used to study prompt neutron emission
- **This data, together with  $^{252}\text{Cf}(sf)$  is an important benchmark**



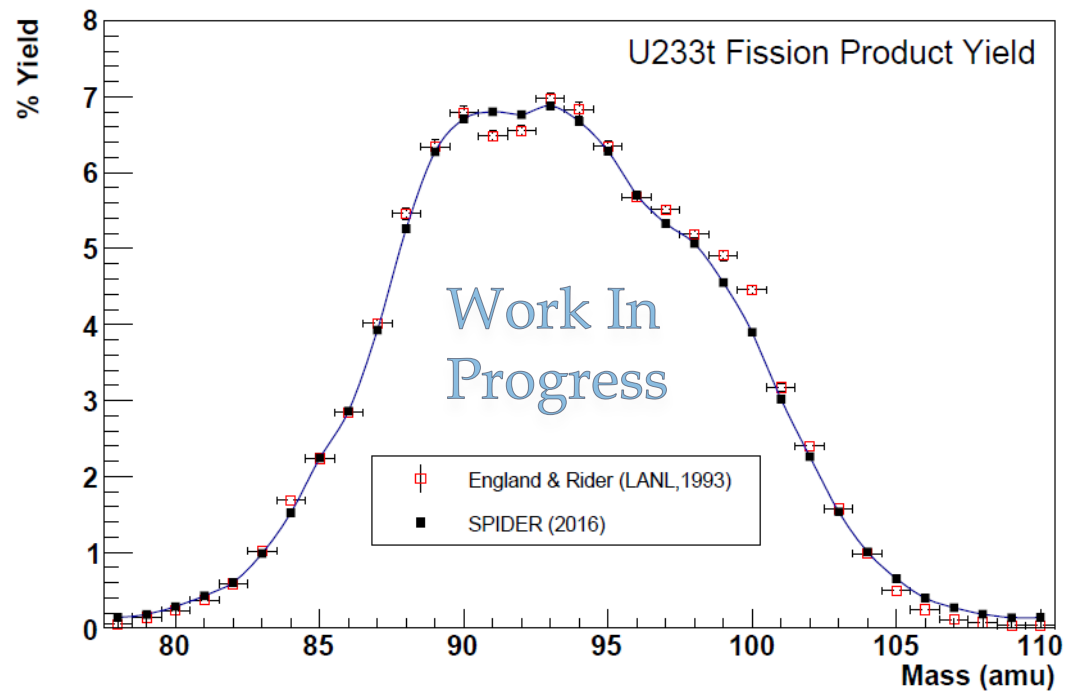
# Thermal neutron-induced fission of $^{239}\text{Pu}$



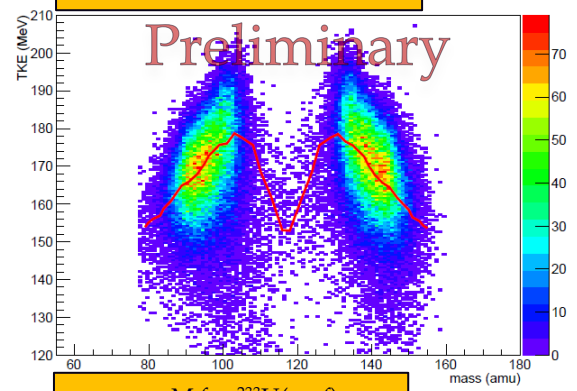
Pu239t Fission Product Yield



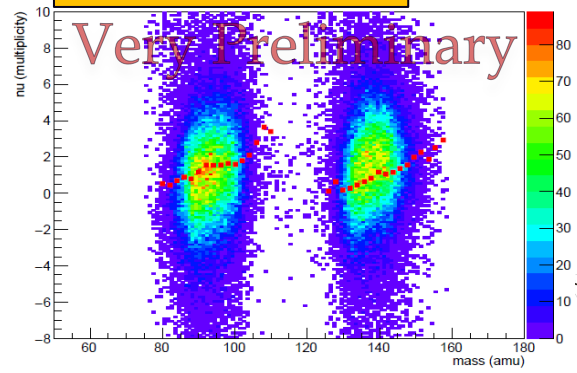
# $^{233}\text{U}$ Thermal Fission



TKE vs M for  $^{233}\text{U}(n_{th},f)$   
Red Curve = Lit. Data for TKE

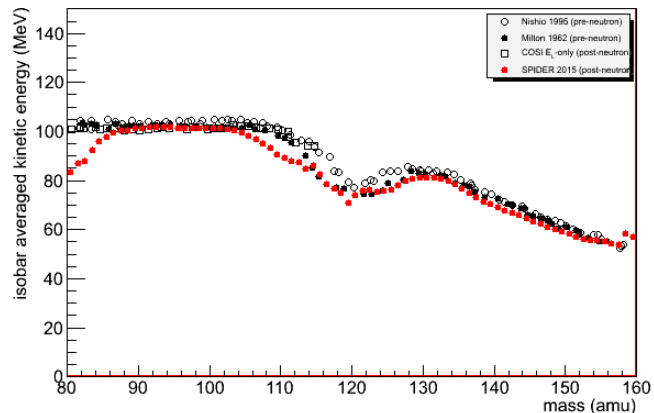


$\nu$  vs M for  $^{233}\text{U}(n_{th},f)$   
Red Points = Lit. Data for  $\nu$

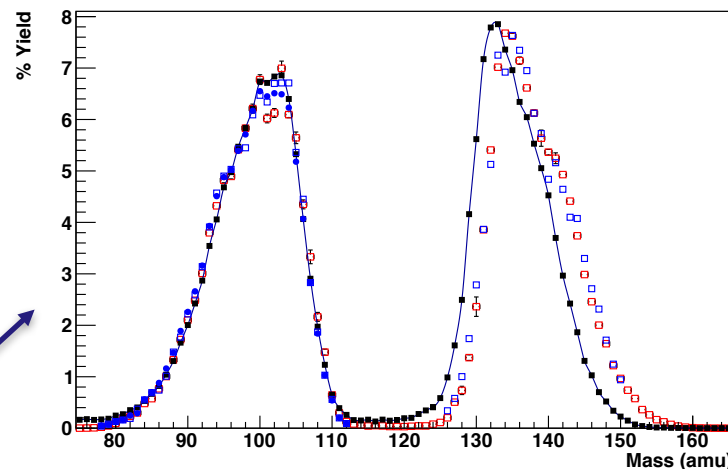


# The main challenge in 2E-2v measurements is in the energy loss correction

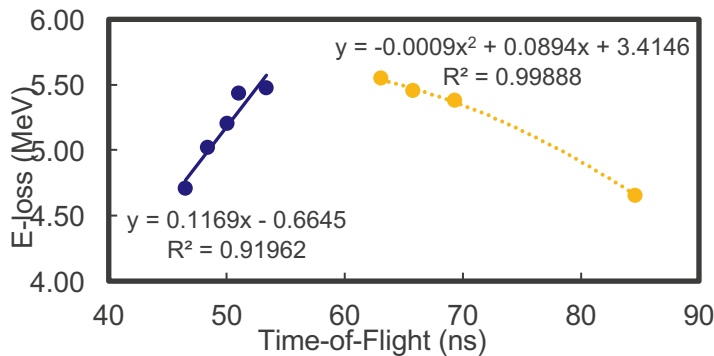
Averaged E vs Fragment Mass



Pu239t Fission Product Yield



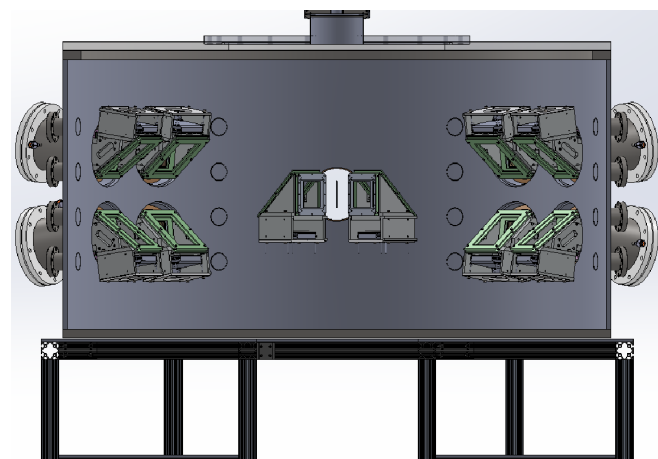
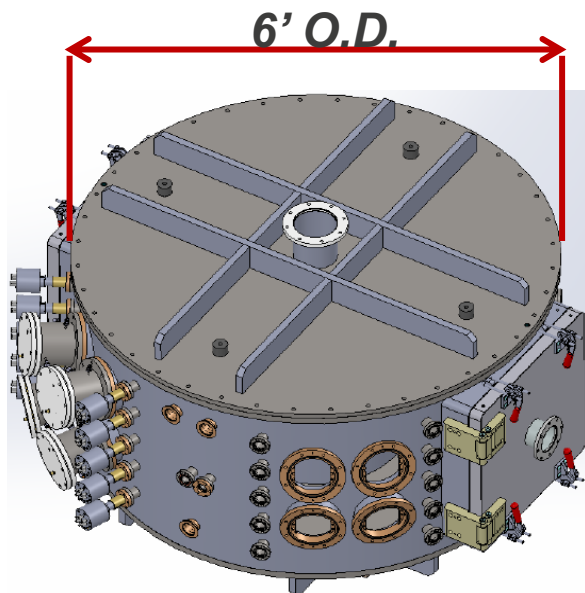
Energy Loss Correction (based on Ziegler et al.)



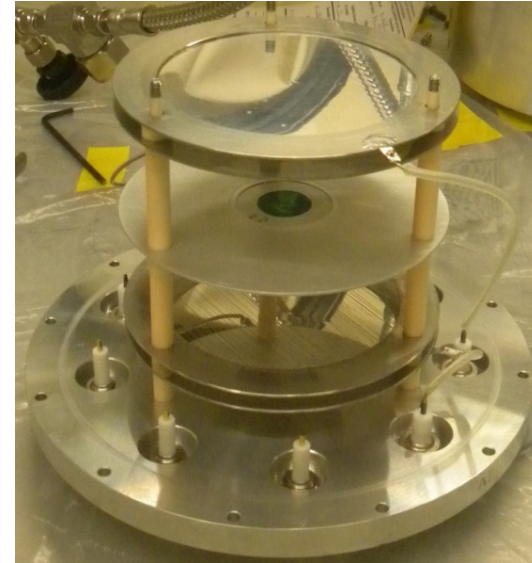
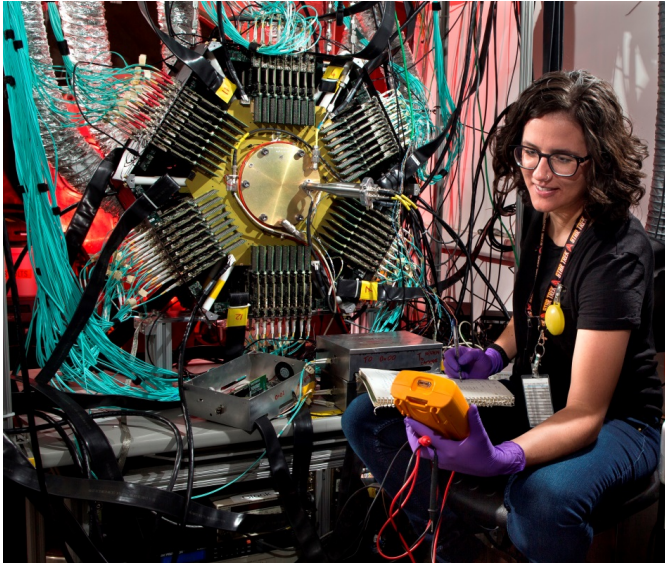
The average energy loss of heavy fission fragments appear to be underestimated by approximately 30% in TRIM

# MegaSPIDER

- In order to study product yields, especially specific isotope yields over a large range of neutron energies, a higher efficiency detector is needed
- Increasing SPIDER from 1 arm pair to 8 arm pairs = 1-2% efficiency
- One 'start' detector for 4 'stop' detectors and 4 corresponding ionization chambers
- Logistical challenges include large volume of high vacuum, 16 ionization chambers flowing isobutane gas, lots of thin films



# Complementary work with the Time Projection Chamber (TPC) and Frisch-gridded ionization chamber



- **Cross sections**
- **Anisotropy**
- **Ternary fission**

- **Total kinetic energy (TKE)**
- **Mass yields with 4-5 amu resolution**
- **Anisotropy**

# Conclusions

- **The ability to measure independent fission product yields with the SPIDER instrument was demonstrated**
  - $^{252}\text{Cf}(\text{sf})$  and  $^{235}\text{U}(n_{\text{th}},\text{f})$  serve as benchmarks
  - The  $^{239}\text{Pu}(n_{\text{th}},\text{f})$  measurement generally agree with previous measurements in the light fission product peak
- **Higher detection efficiency with a larger detector array is necessary to study fast neutron-induced fission**
  - MegaSPIDER will be commissioned in 2017
- **The energy dependence of fission products should be address using several experimental techniques**
  - Independent and cumulative yields
  - Mono energetic neutron sources and white spectrum sources
  - Normal and inverse kinematics

# Acknowledgements



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- Arnie Sierk (T-2)
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- Richard van de Water (P-25)
- Morgan White (XCP-5)

- Rick Blakeley
- **Adam Hecht (PI)**

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- Bill Moore
- Dan Shields

- Walt Loveland

