Los Alamos
NATIONAL LABORATORY
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First Results of Fission Mass Yield Measurements with SPIDER at LANSCE

SPIDER

FIESTA Workshop

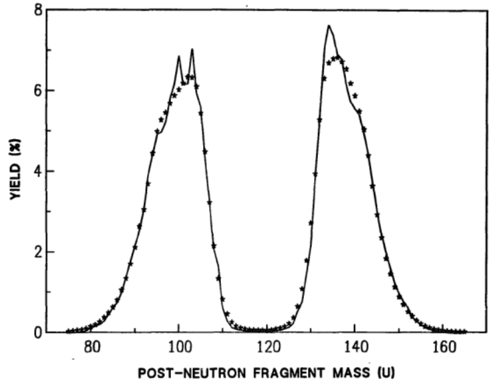
Santa Fe, NM

September 12, 2014

NNSA
National Nuclear Security Administration

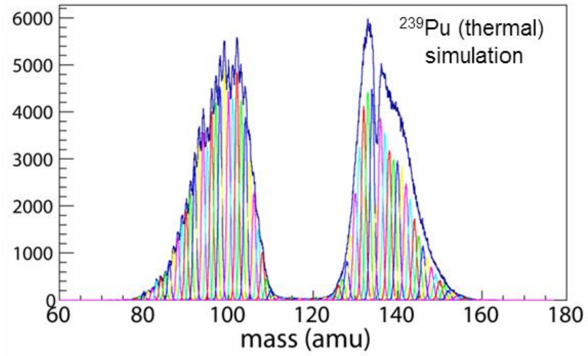
Anticipated Benefits - Applications

- Improved input for calculations and simulations



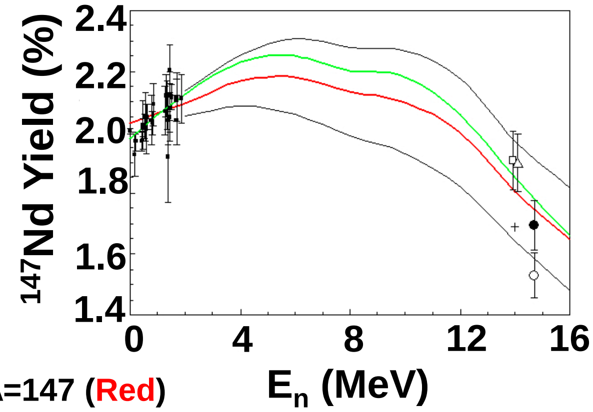
^{239}Pu
Schillebeeckx
Phys. Rev. A545

Example of current mass yield distribution



Simulation of mass yield distribution using expected SPIDER measurements

- Interpretation of data collected from device tests

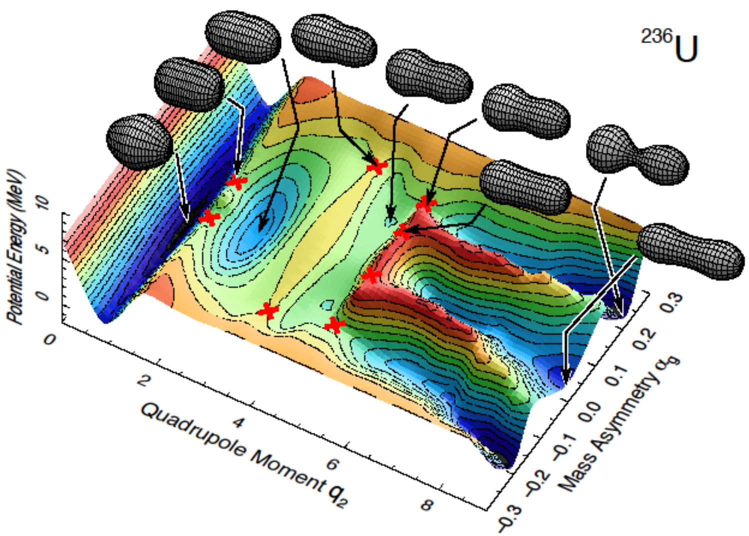


^{147}Nd fission yield vs incident E_n

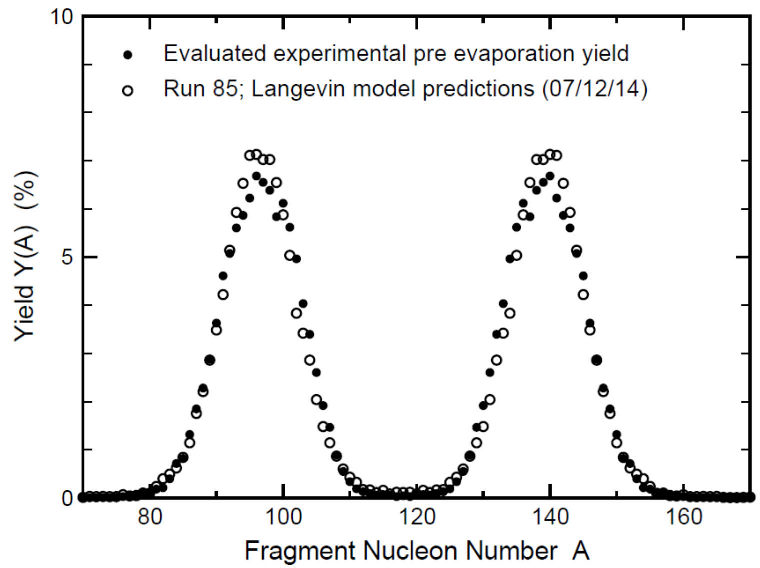
<u>Predictions for</u>
A=148 (Green) A=147 (Red)
A=147 Uncertainty (Black)

Anticipated Benefits – Fundamental Studies

- Comparison to sophisticated fission models
  - LANL nuclear potential-energy model (P. Moller)
  - Model dynamic evolution of fission across the potential-energy surface (A. Sierk)
  - Probe initial conditions (J. Lestone)



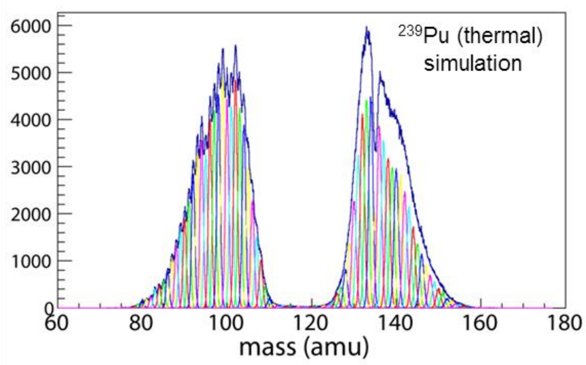
Two dimensional energy surface of fissioning ^{236}U



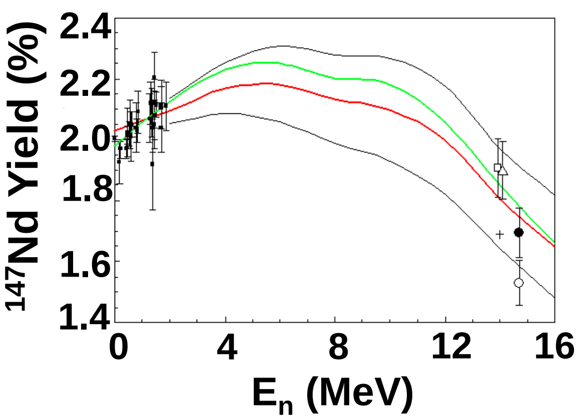
^{236}U fission, En ~0.005 MeV

SPIDER Project Goals

- Measure fission-fragment yields as a function of (E_n, Z, A, TKE)
  - Our measurements will reach 2-5% accuracy from 0.01 eV to 20 MeV

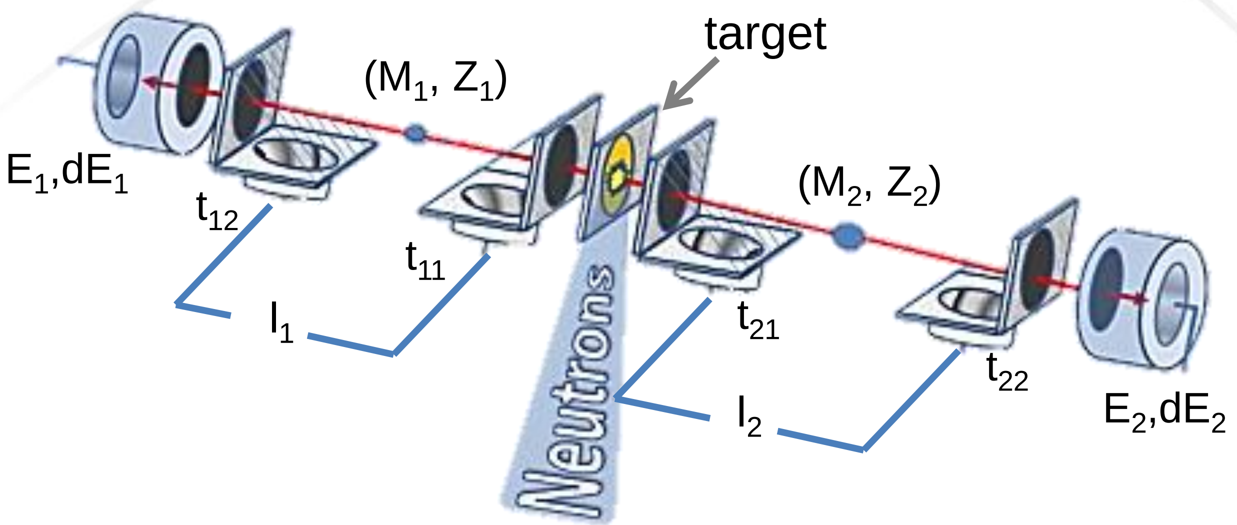


- Develop theory in order to evaluate fission yield data
  - Model dynamic evolution of fission across the potential-energy surface (A. Sierk)
- Provide an evaluation of the Pu-239 fission yields
  - Blend the best of experiment and theory (J. Lestone)



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

The 2E-2v method with SPIDER

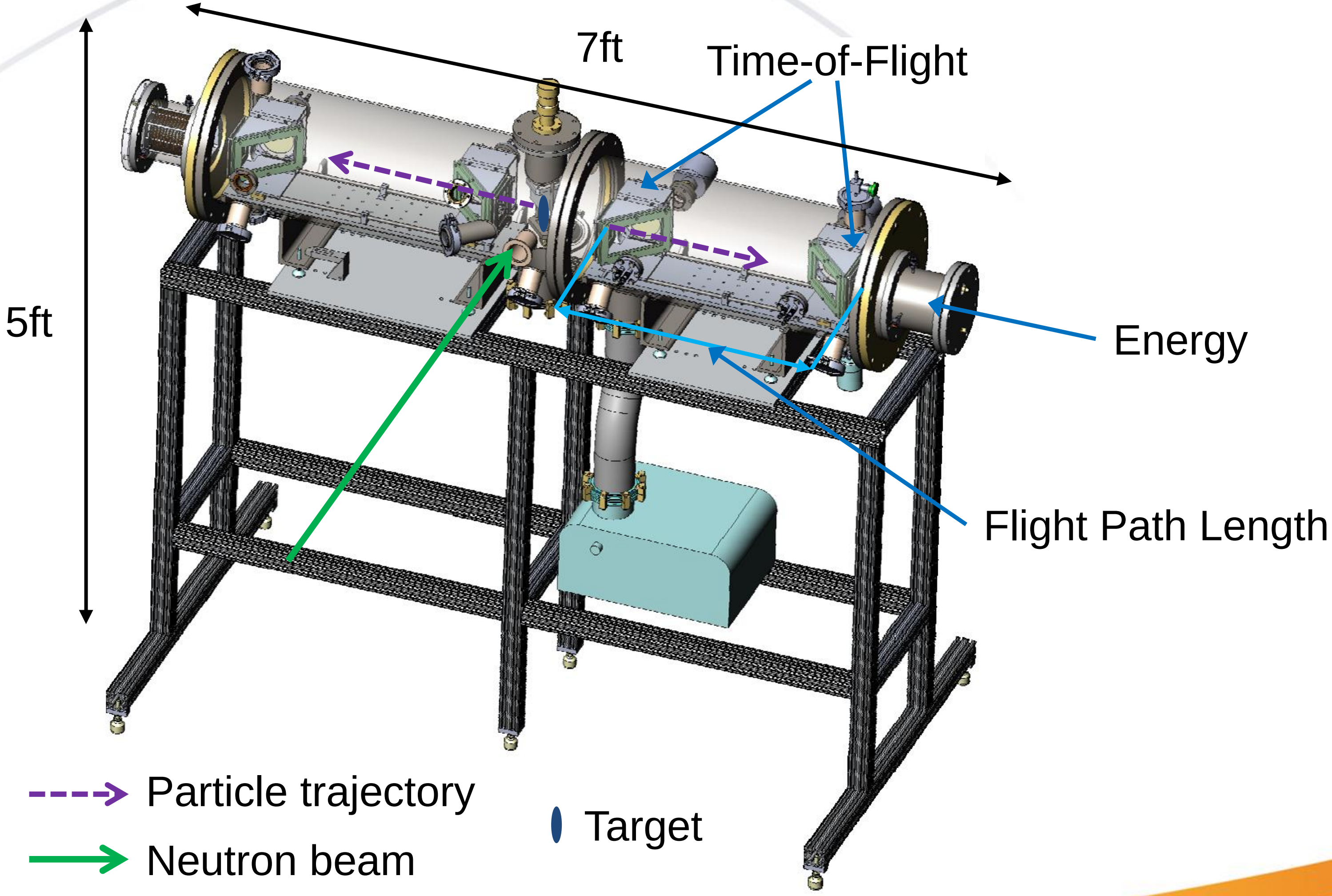


$$M = \frac{2Et^2}{l^2}$$

M = mass
E = energy
t = time
l = length

- **Neutron beam hits actinide target, inducing fission into two main fragments**
- **Mass (M) of both outgoing fission products are determined by measuring each fragments time of flight (t), energy (E), and path length (l)**

SPIDER arm pair prototype



High Resolution Measurement

- Using the 2E-2v method the mass of each product can be measured with improved resolution

Equation to determine mass resolution

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

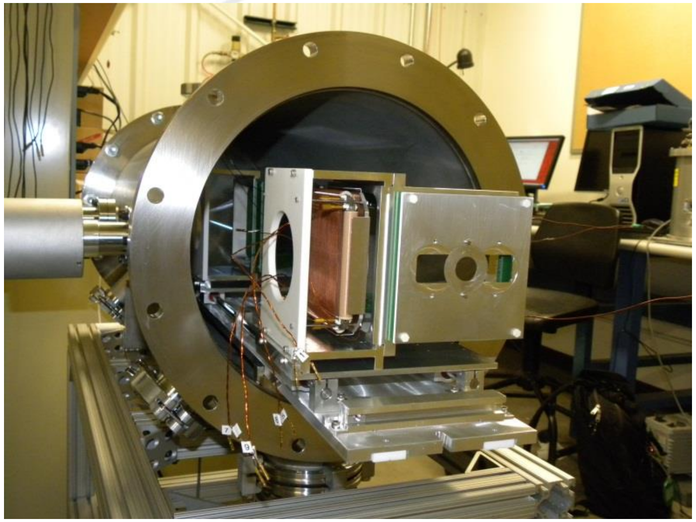
M = mass, *E* = energy, *t* = time, *l* = path length

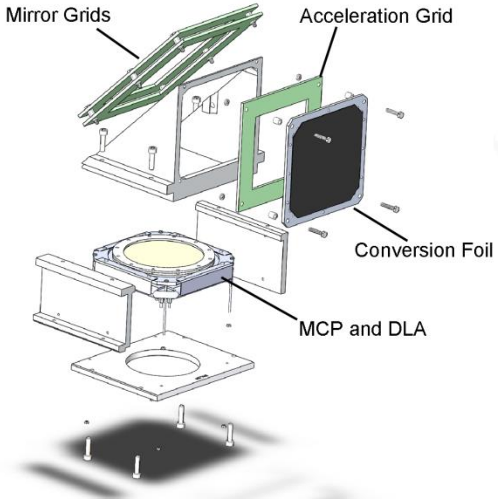
Mass Measurement Goal:

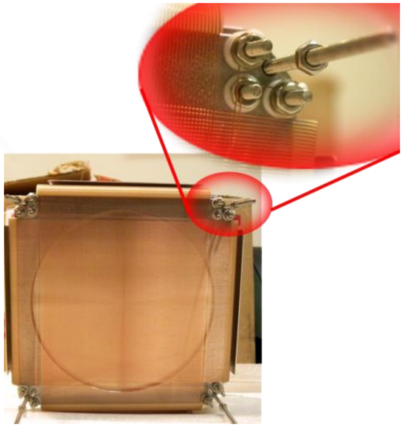
$$\frac{\delta M}{M} = 1\text{AMU or A = 85} \rightarrow \text{155 : 1.2\% to 0.65\%}$$

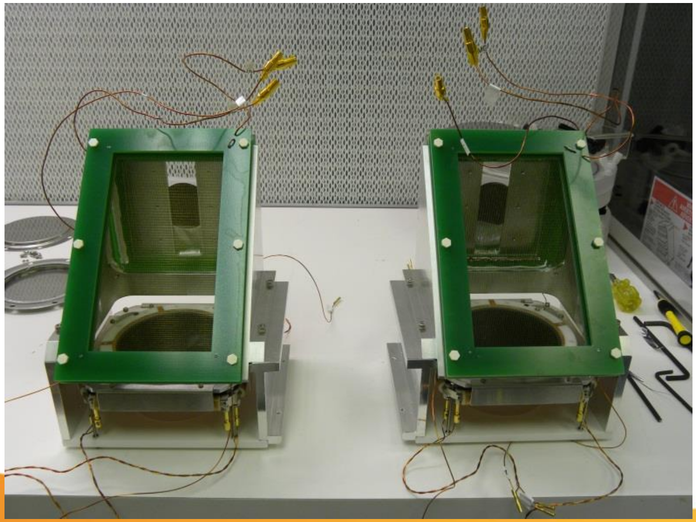
This translates into individual measurements resolution as:
dE/E → ≤ 0.5%,
dl/l → ≤ 0.02%,
dt/t → ≤ 0.7% to 0.3 %
or A 85 → 155 : 1.32% to 0.72%

Time-of-flight and Position Measurements







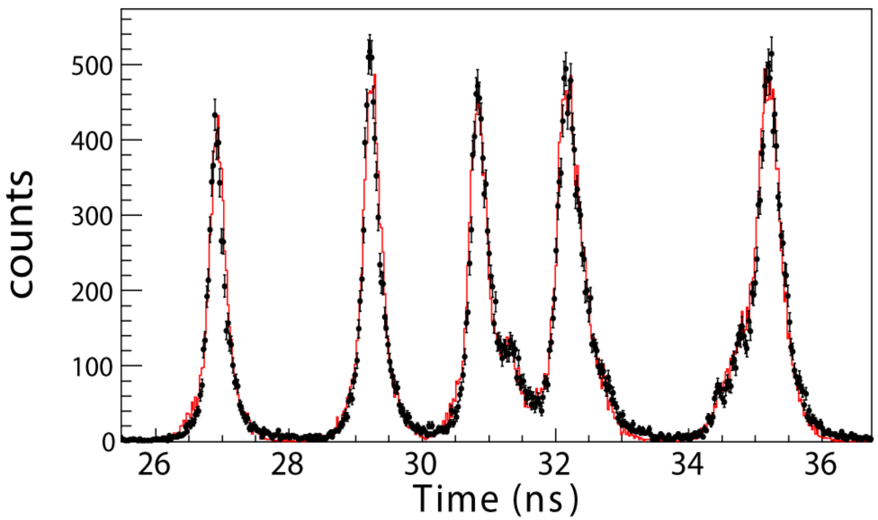


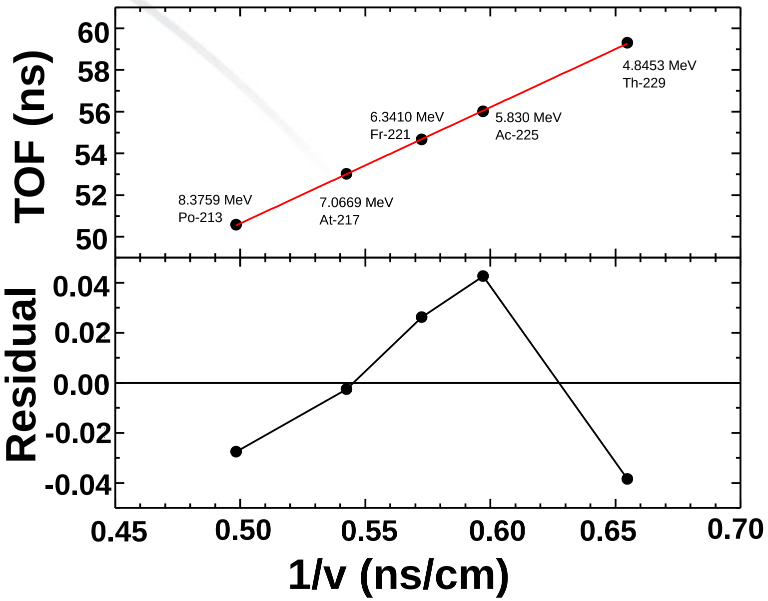
- 70 cm flight path
  - Distance between conversion foils
- Micro channel plates (MCP)
  - Chevron configuration
  - 12 µm channel diameter = fast timing
- RoentDek Delay-line anode
  - (x,y) position readout
  - 1-2 mm resolution achieved with similar size and arrangement

Time-of-flight Resolution

- Characterized with Th-229 α-source
- Five main α-lines with energies between 4.8 and 8.4 MeV

TOF Data (black) and Simulation

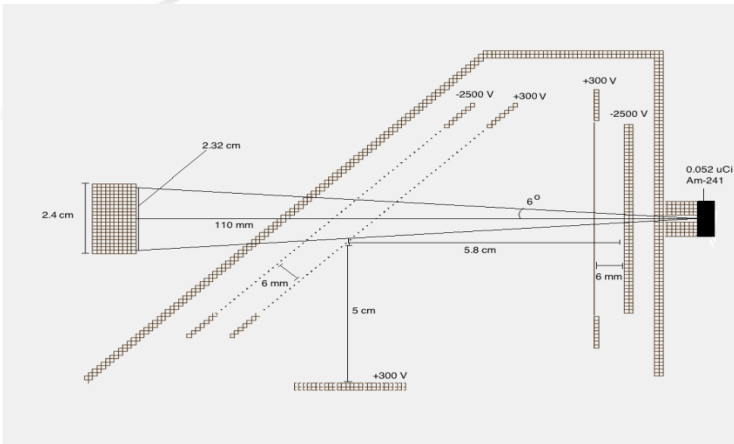


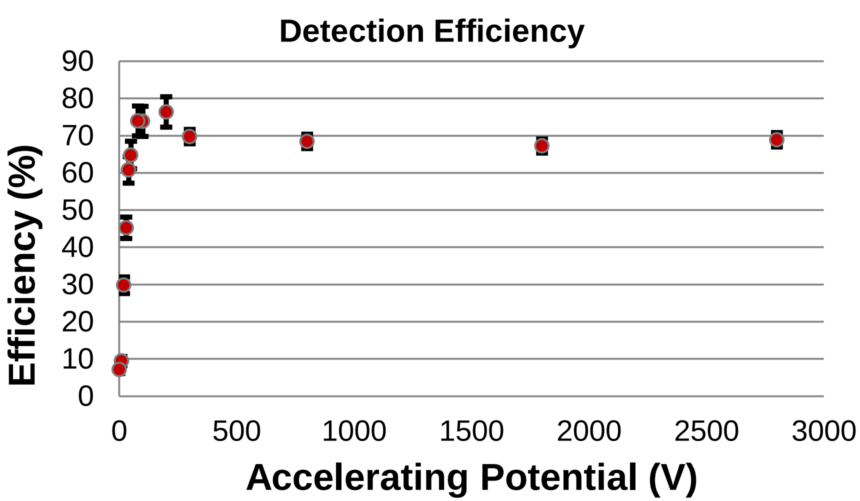


Temporal resolution

Δt=250ps (FWHM)

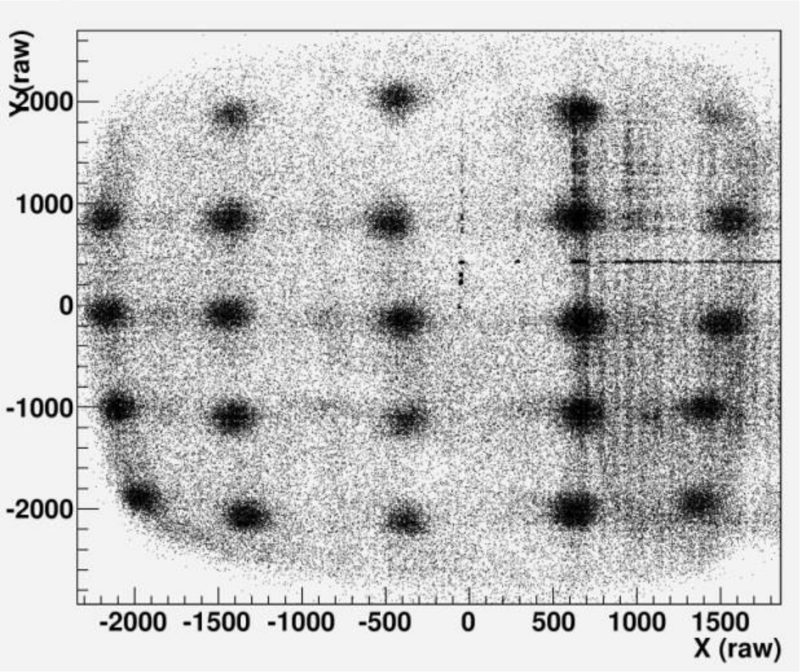
Time-of-flight Detector Efficiency





- The efficiency of the TOF detectors is about 70% for α-particles
- Based on previous work we expect the efficiency for fission fragments to be significantly higher
- Efficiency is not very sensitive to accelerating potential or temporal resolution

Spatial Resolution



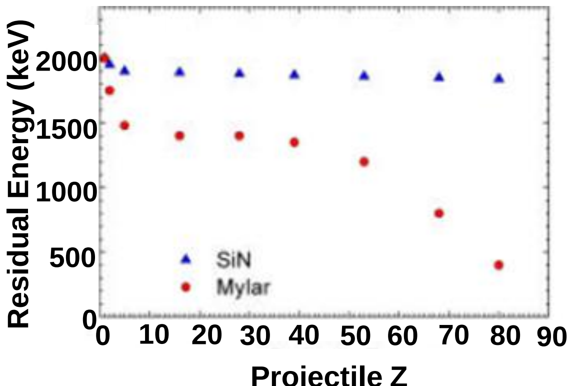
- Applied a mask in front of carbon conversion foil

<u>Position resolution</u>
2 mm

- Overall path length uncertainty: <0.1 %.
- Will ultimately use position information to correct for flight path length
  - Need 8 signals per path length – requires high statistics based on relative high percentage for all signals

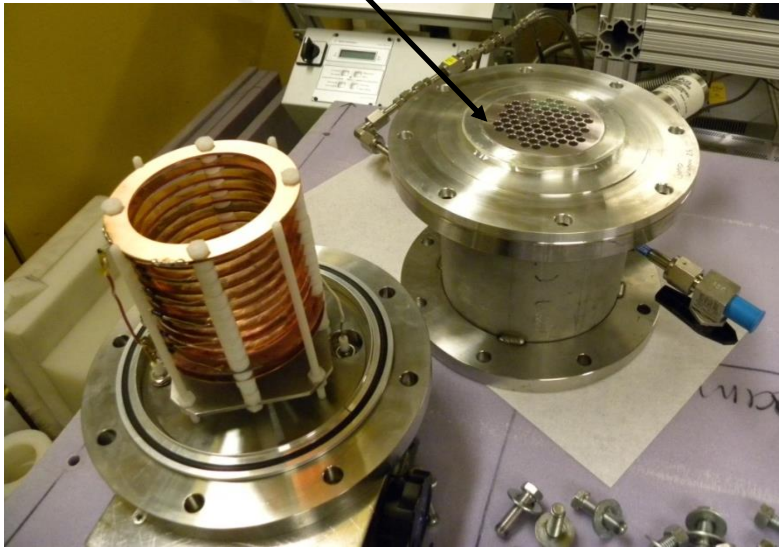
Energy Measurement

- Axial ionization chamber
  - Isobutane fill gas
  - ~28 sccm flow rate
  - 8 cm path length
  - ~ 5.5 cm/s electron drift
- Entrance window
  - Started with 2.5 µm Mylar
  - Testing 200 nm silicon nitride membranes, which has been shown to greatly reduce energy losses and straggling

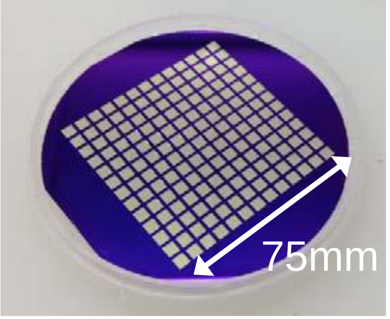


Kottler *et al*, Paul Scherrer Institute and ETH Zurich, Switzerland

Mylar window with support structure

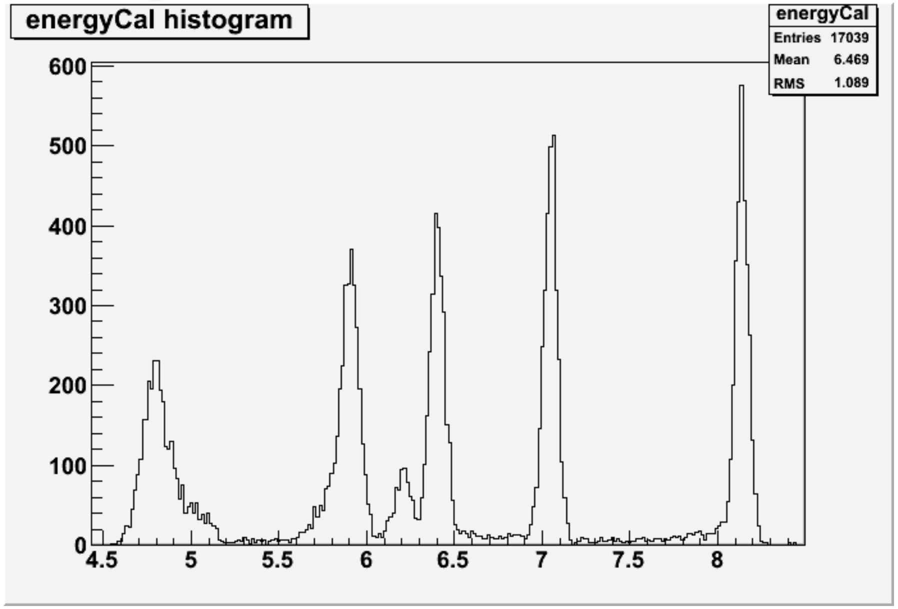


Silicon nitride window

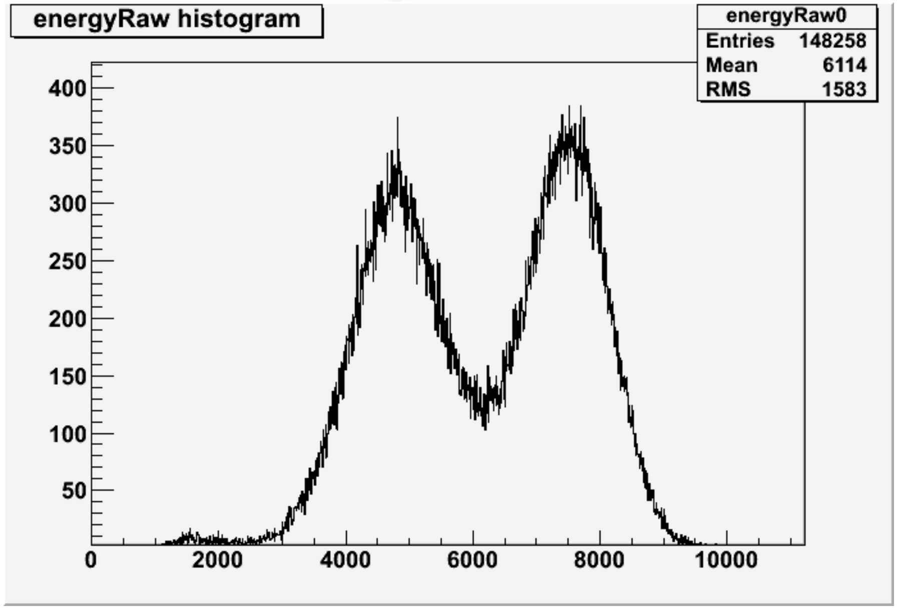


Energy Resolution

Alphas



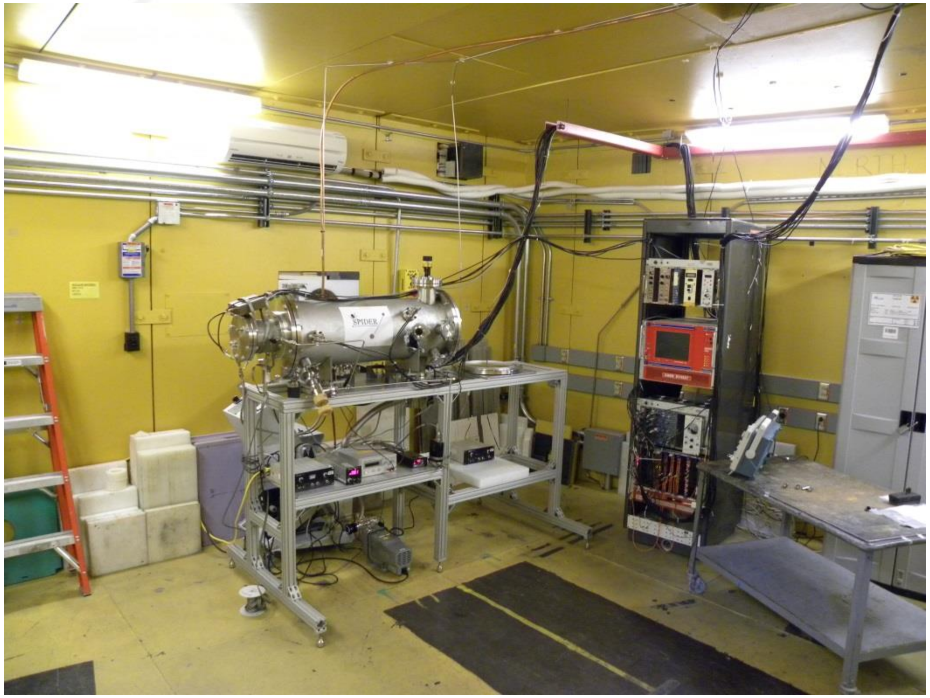
^{252}Cf

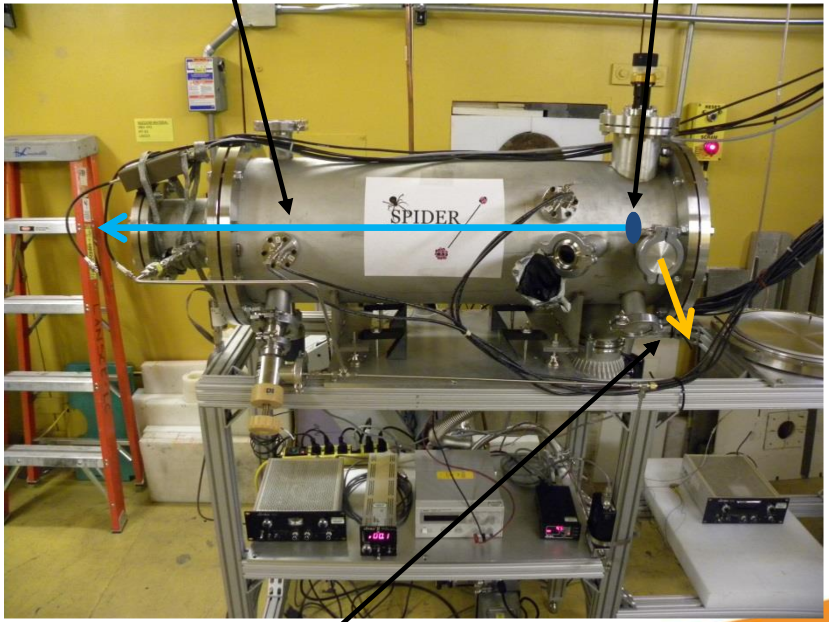


Energy Resolution
1% for alpha-particles

SPIDER Installation

- Fall 2013 - first experiments with spontaneous fission of ^{252}Cf and thermal neutron spectrum on ^{235}U, using half an arm pair (1E-1v measurement)

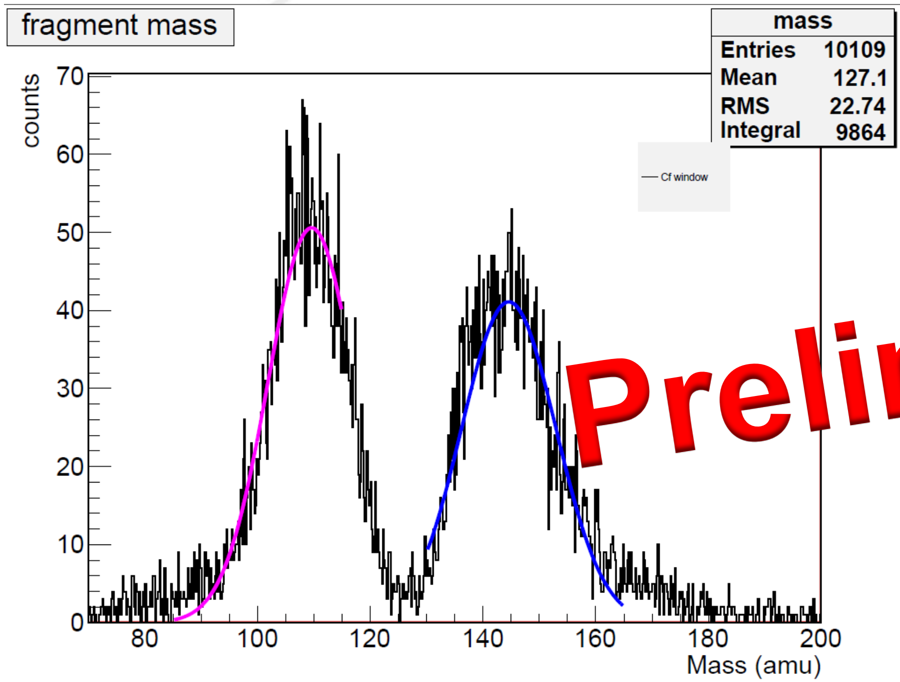




Details

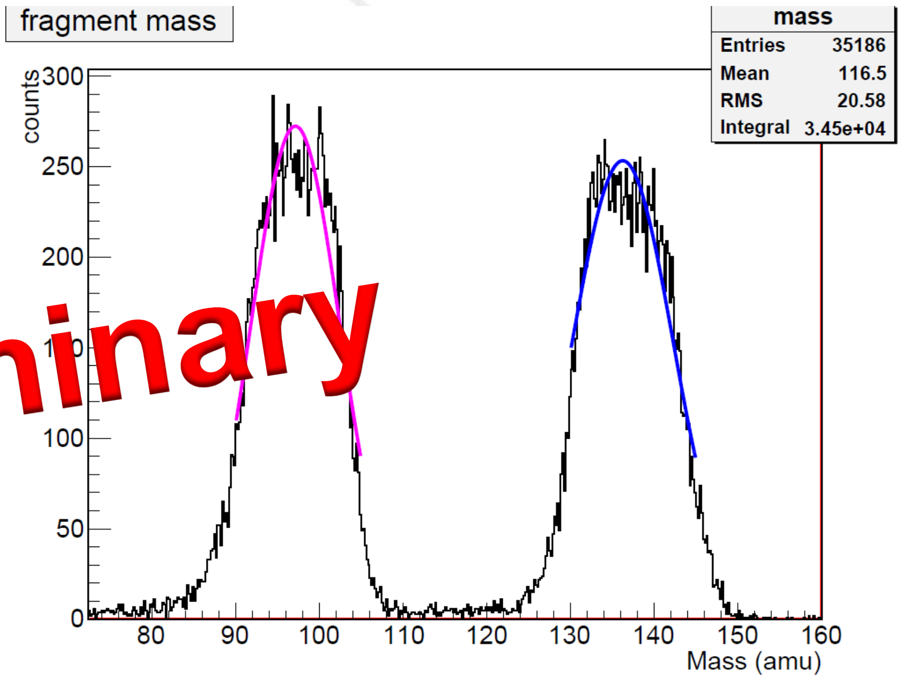
- 100 ug/cm^2 UF_4 on 100 ug/cm^2 C
- "Thick" Mylar window: 2500 ug/cm^2
- Neutron time-of-flight was recorded

First Results –
One-arm operation, Mylar entrance window



Spontaneous fission ^{252}Cf

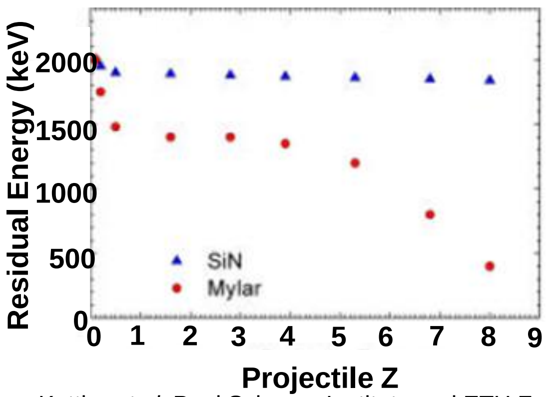
Preliminary



Preliminary thermal ^{235}U mass yield

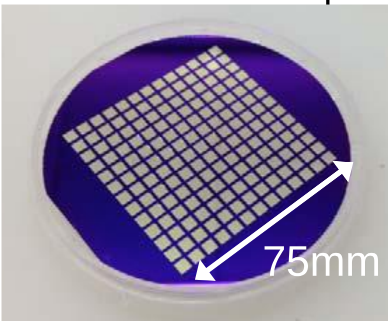
New Entrance Window

- Recently moved to using 200 nm silicon nitride membranes, which has been shown to greatly reduce energy losses and straggling



Kottler *et al*, Paul Scherrer Institute and ETH Zurich, Switzerland

Silicon nitride window prototype



<u>Window energy loss and straggling TRIM calculations</u>

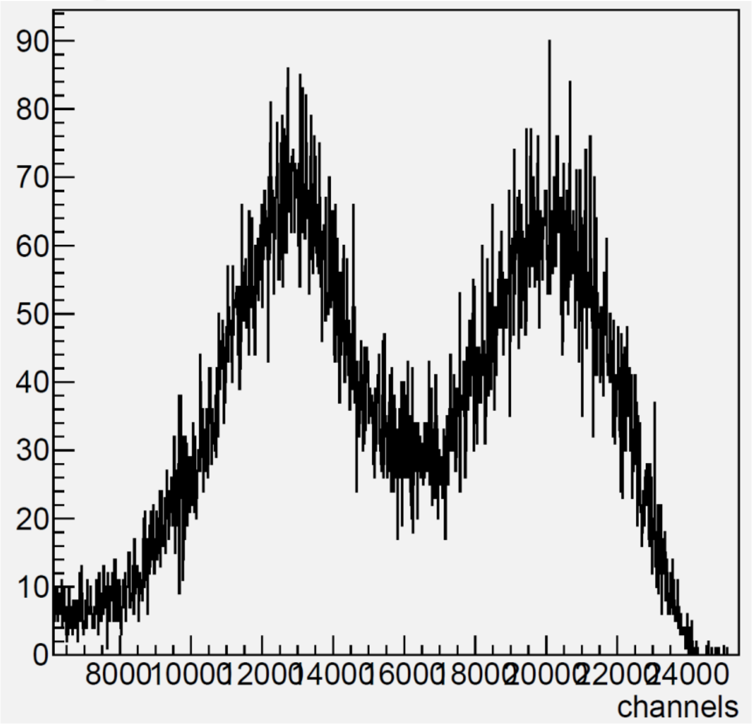
Energy loss and straggling of 100 MeV light fragment (Tc-97) in different windows

2500 nm Mylar: dE = 21 MeV, straggling = 1.8 MeV (1.8%)

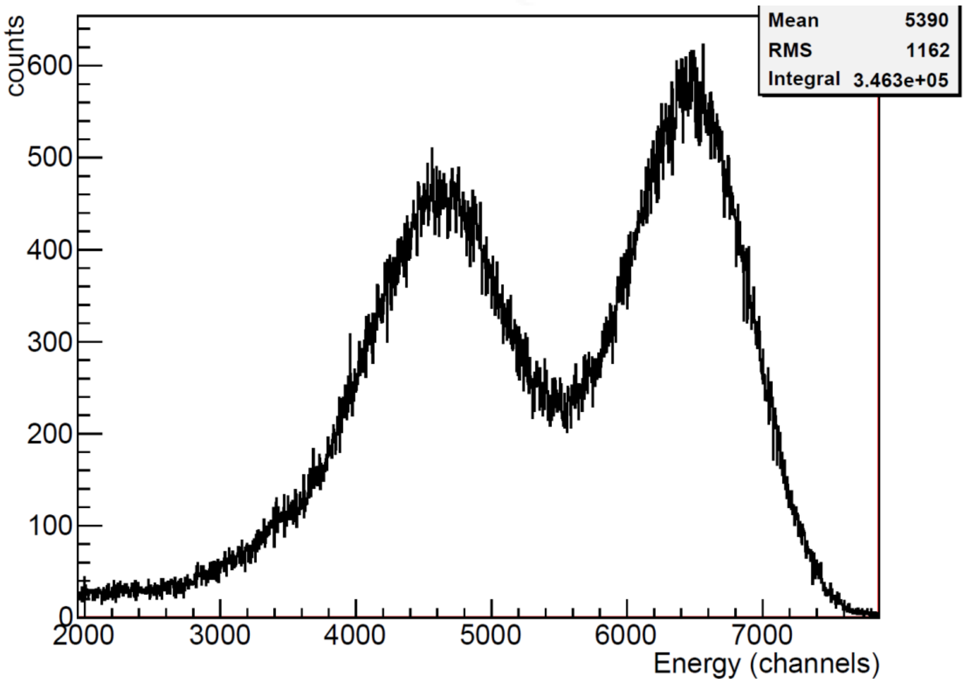
200 nm Si_3N_4: dE = 3.25 MeV, straggling = 320 keV (0.3%)

New Entrance Window

Raw Cf Energy Histograms

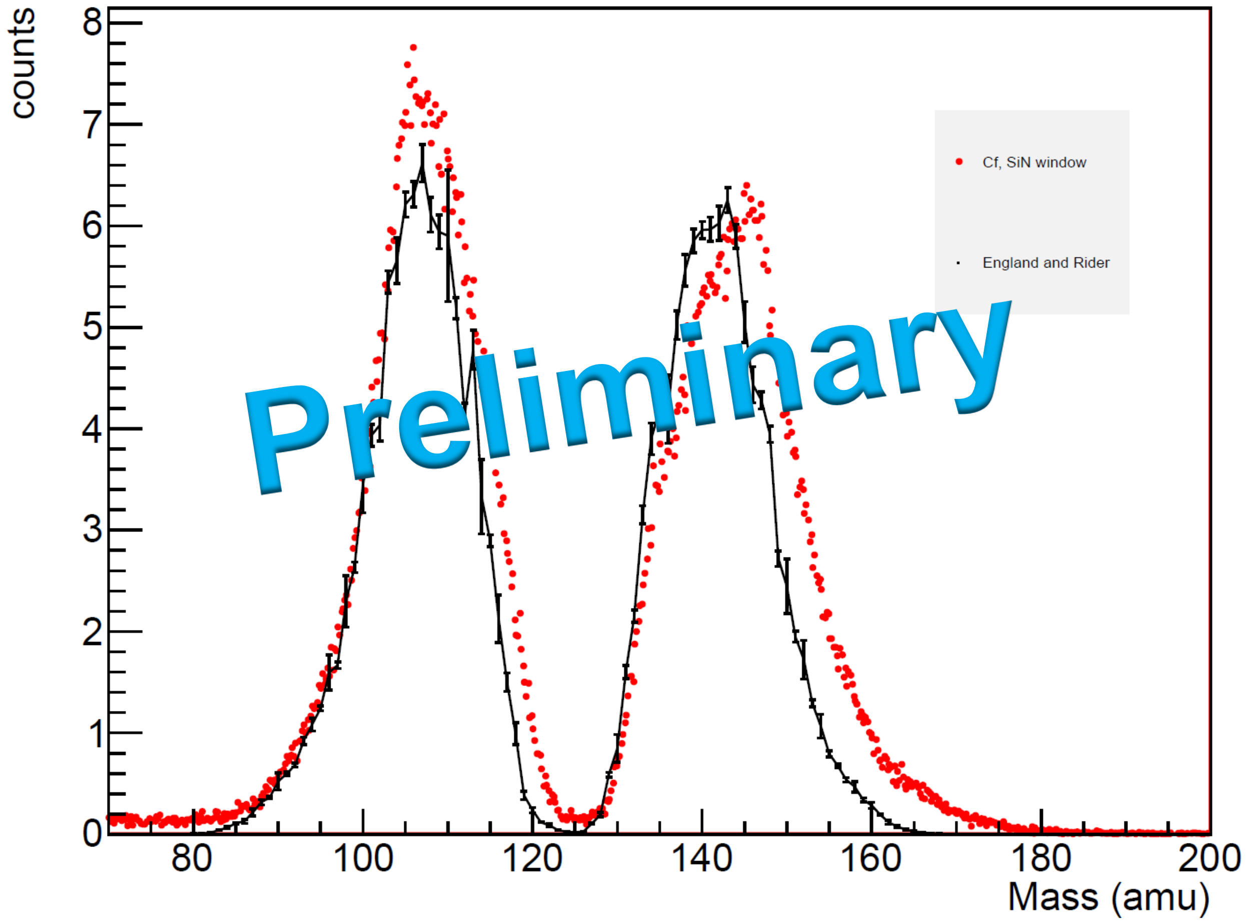


Mylar Window

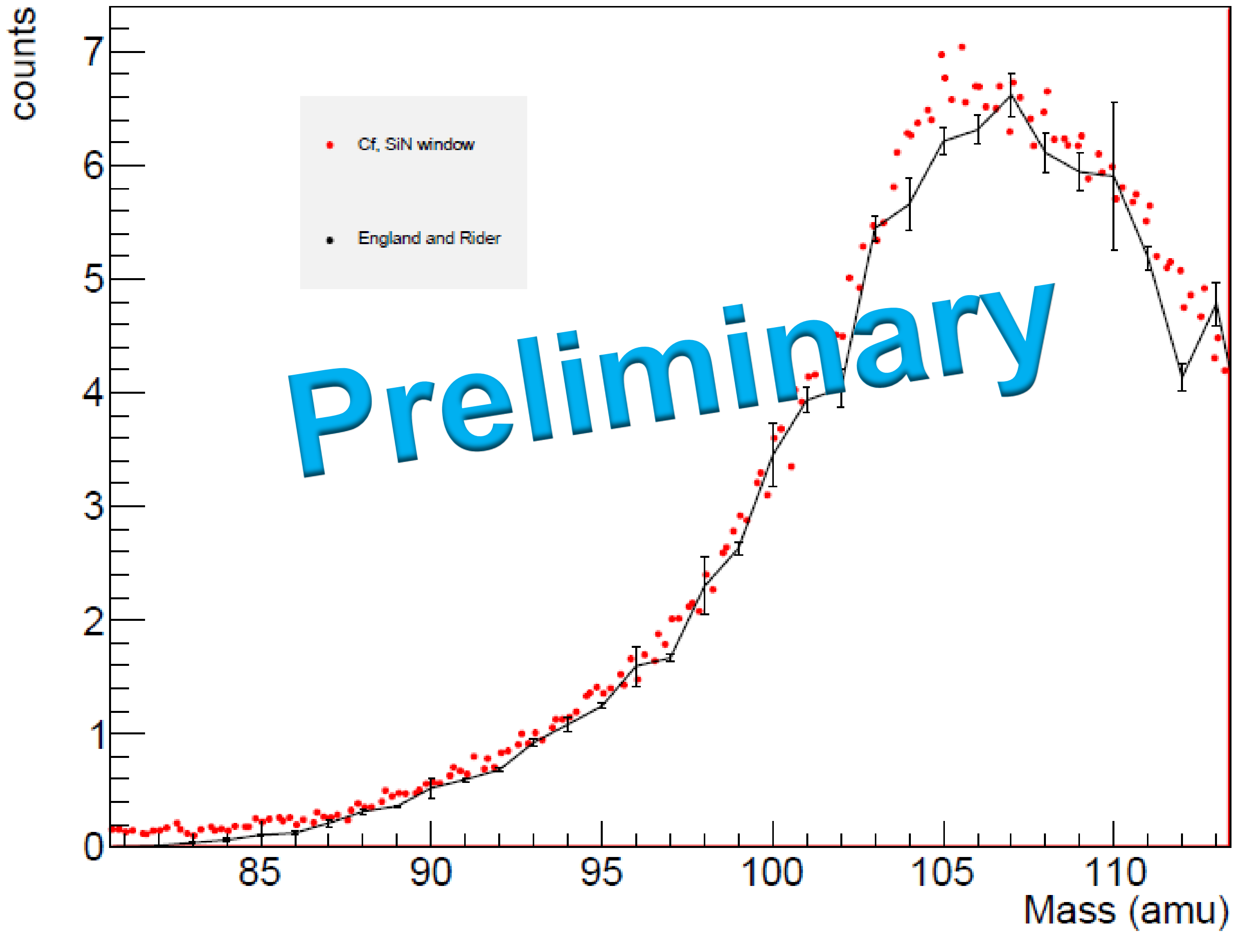


Silicon nitride Window

First Results –
One-arm operation, silicon nitride entrance window

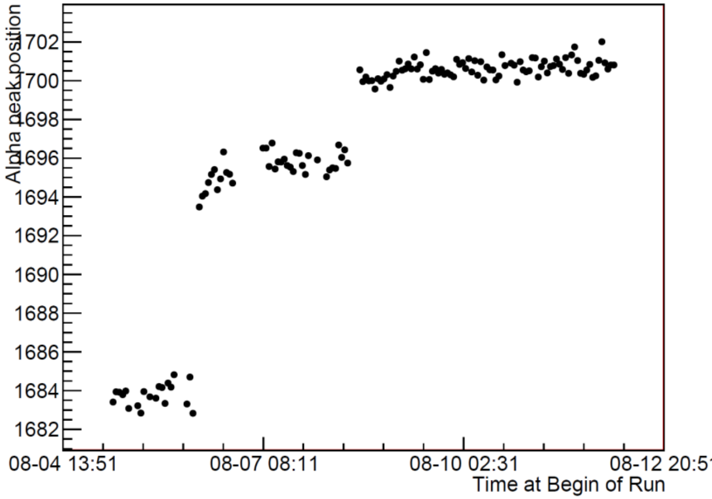


First Results –
One-arm operation, silicon nitride entrance window



Further Analysis

- Verify calibration constants
- Known dependencies in TOF measurement
  - Time
  - Position
- Verify energy correction through silicon nitride window
- Add path length calculation from position signals
  - If statistics allow



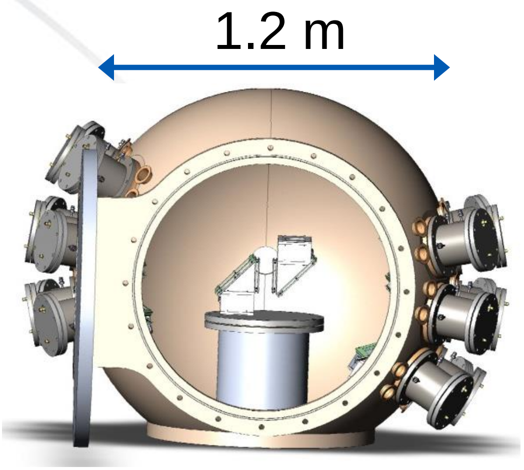
Shift in Cf alpha peak position over time

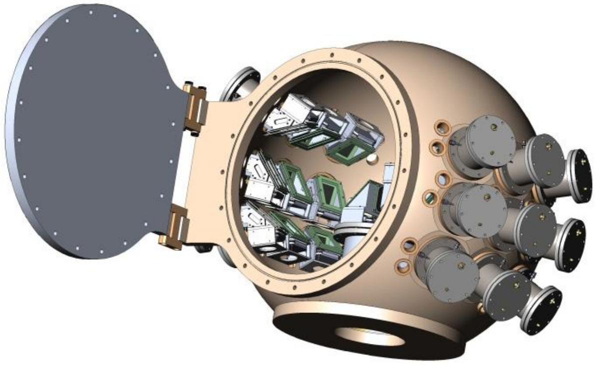
Arm pair prototype operation

- **2014-2015 Run Cycle**
  - Thin backing U235 at Lujan (thermal)
  - Thick backing Pu239 at Lujan (thermal)
  - U235 at WNR (no energy binning due to expected low statistics)

Full SPIDER Detector

- **Multiple detectors increases efficiency**
- Current design calls for 9 arm pairs
  - 36 timing detectors
  - 18 ionization chambers
- System Challenges
  - large high vacuum (10^{-7} torr) volume
  - 18 vacuum - gas detector interfaces
  - flowing gas system to 18 separate chambers
- More measurements to be done
  - Lots of interesting actinides have low resolution yields measurements





Summary

- SPIDER is providing improved yield measurements and correlated details about fragment masses, charges, and energies over a wide range of incident neutron energies
- New SPIDER detector will measure high resolution fission yields as a function of:
  - Incident neutron energy
  - Fragment mass
  - Fragment charge
  - Fragment energy
- Reached individual goal resolution capabilities

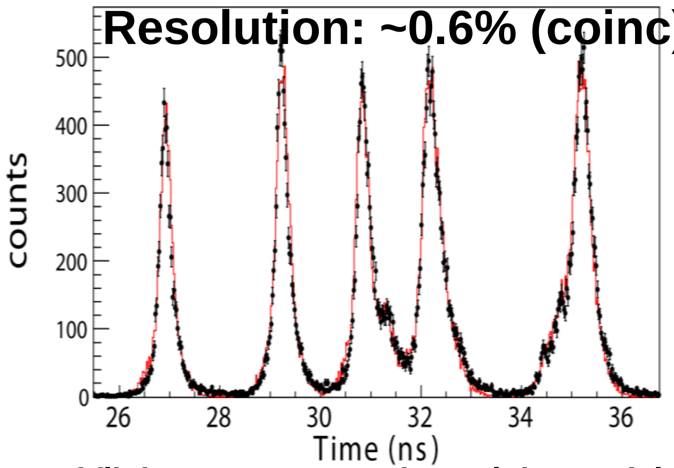
$$dE/E \rightarrow \leq 0.5\% \quad \surd$$
$$dl/l \rightarrow \leq 0.02\% \quad \surd$$
$$dt/t \rightarrow \leq 0.7\% \text{ to } 0.3\ \% \quad \surd$$

- First 1E-1v measurements of ^{252}Cf(sf) with silicon nitride window
- Will take first 2E-2v measurements fall 2014
  - Both at Lujan (thermal) and WNR

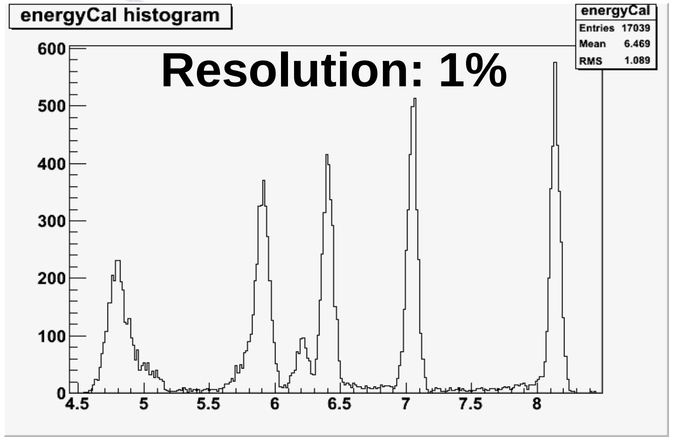
The SPIDER Collaboration

- Los Alamos National Laboratory (LANL)
  Charles Arnold, Todd Bredeweg, Tom Burr, Matt Devlin, Mac Fowler, Marian Jandel, Justin Jorgenson, Alexander Laptev, John Lestone, Paul Lisowski, Rhiannon Meharchand, Krista Meierbachtol, Peter Moller, Ron Nelson, John O'Donnell, Arnie Sierk, Fredrik Tovesson, Morgan White
- University of New Mexico (UNM)
  Adam Hecht, Rick Blakeley, Drew Mader, Lena Heffern
- Colorado School of Mines (CSM)
  Uwe Greife, Bill Moore, Dan Shields, Sergey Ilyushkin
- Lawrence Livermore National Laboratory (LLNL)
  Lucas Snyder
- Lawrence Berkeley Laboratory (LBL)
  Jorgen Randrup

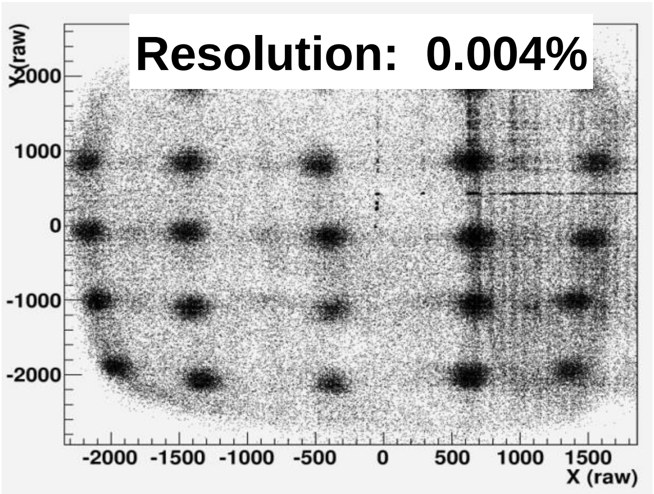
Individual Measurement Resolutions



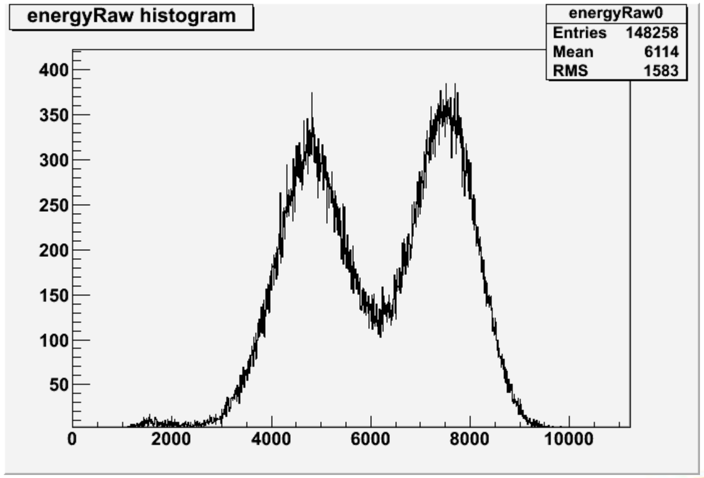
Time of flight measurement for 5 alpha particles



Energy measurement for 5 alpha energies



Position measurement with a 1 cm mask



Energy measurement for 252Cf fission products