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Title: SPIDER: A new tool for measuring fission yields

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SPIDER: A new tool for measuring fission yields

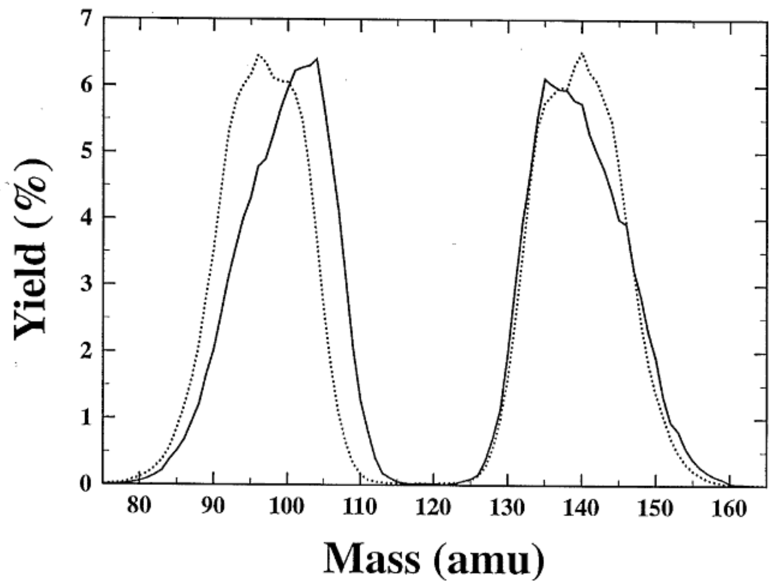
SPIDER

SSAA Workshop

March 19, 2014

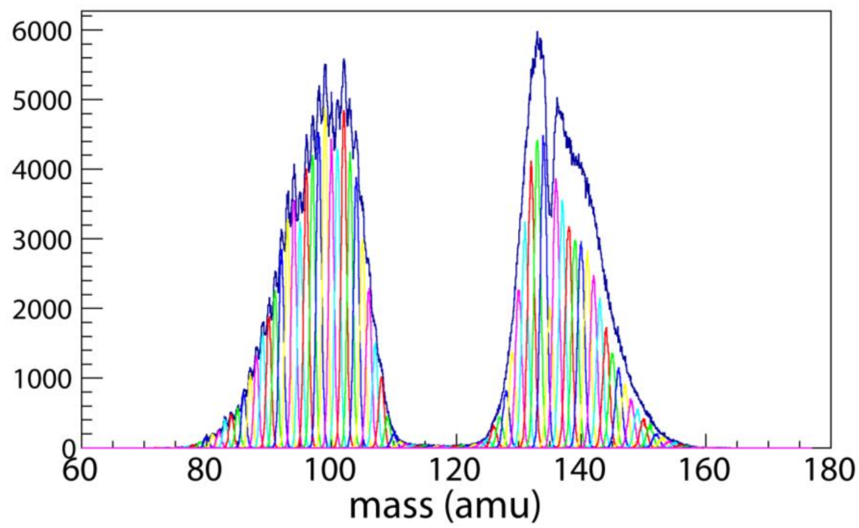
Fission mass yields
– Better measurements are needed!

Current Yield Measurements



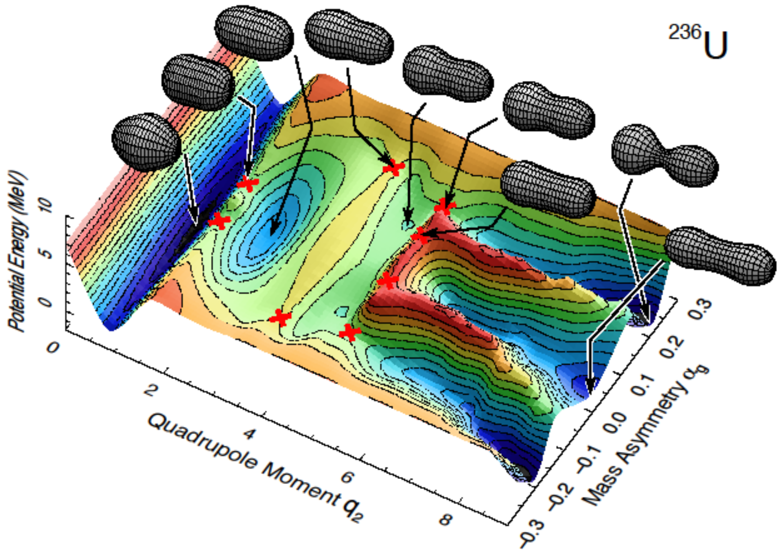
solid: ^{238}U(1.7 MeV)
dashed: ^{235}U (thermal)

Expected Yield Measurements
with SPIDER



^{239}Pu (thermal) simulation

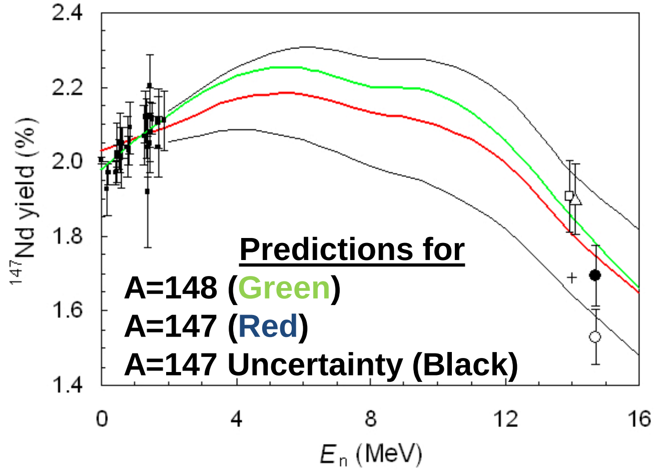
Simulation Efforts



- Yield Predictions
  - Predictions of yields is an important test for different theoretical models describing the fission process under active development
- Distributions
  - New model describing fragment de-excitation using a Monte Carlo approach need (A,TKE) fragment distributions as input.
- Correlations
  - Correlation between A, Z and TKE of fission fragments vs yields are important to improve modeling. Very limited experimental information on such correlations.

Application Needs

- Data Evaluations - Combine the best of theory with the relevant experimental data using expert judgment to produce complete data



Compilation data of Nd147 yield from Pu239 - no data from 2-14 MeV

- Independent versus Cumulative Yields
  - Computing cumulative from high-precision independent yields is straight-forward, cumulative to independent is extremely challenging

Fission mass yields – previous approaches

- **Radiochemical methods**
  - Pros
    - Direct measurement of cumulative fission product yields
    - Relatively high accuracy
  - Cons
    - Limited information about the fission process
    - Access to 70-80% of all fission products
- **Mass separators** (Kozulin et al, Nucl Exp. Tech, No. 1., pp. 44-58, 2008)
  - Pros:
    - High mass resolution (<1%)
    - Covers >90% of fission fragment
  - Cons:
    - Very low detection efficiency
- **Double energy (2E) method: Kinetic energy of both fragments are measured, and the fragment masses are deduced using momentum conservation**
  - Pros
    - Small-scale experimental arrangement
    - High detection efficiency (~95%)
  - Cons
    - Low mass resolution (4-5 amu FWHM)
    - Dependent on assumptions about neutron emission

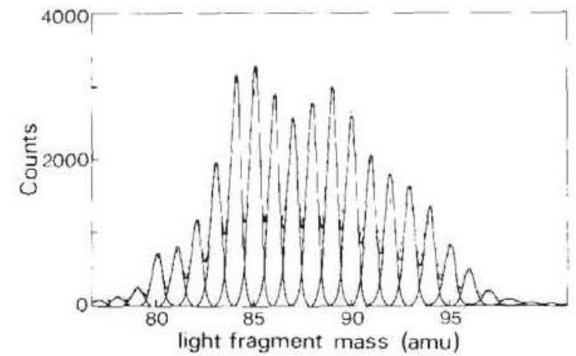
Project Goals

- 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
  - LANL nuclear potential-energy model (P. Moller)
  - Model dynamic evolution of fission across the potential-energy surface (A. Sierk)
  - Probe the initial conditions
- Provide an evaluation of the Pu-239 fission yields
  - Blend the best of experiment and theory (J. Lestone)

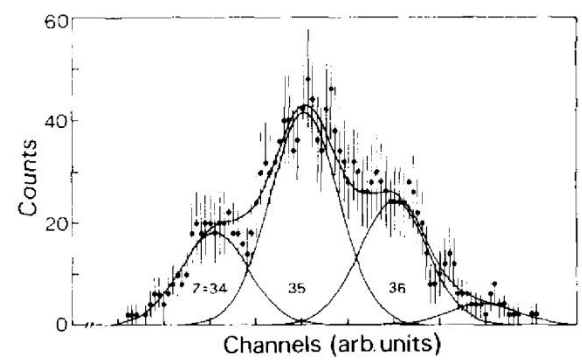
The 2E-2v method

- Time-of-flight approach to fission fragment spectroscopy
  - the mass is obtained by measuring energy and velocity
- First demonstrated in the 1980s at ILL
  - Boucheneb et al, Nuc. Phys. A502 (1989) 261c-270c
- <1 amu mass resolution of light products
- ~1 unit charge resolution for light products
- (A,Z,TKE) yields for both products
  - Significant information about the fission process

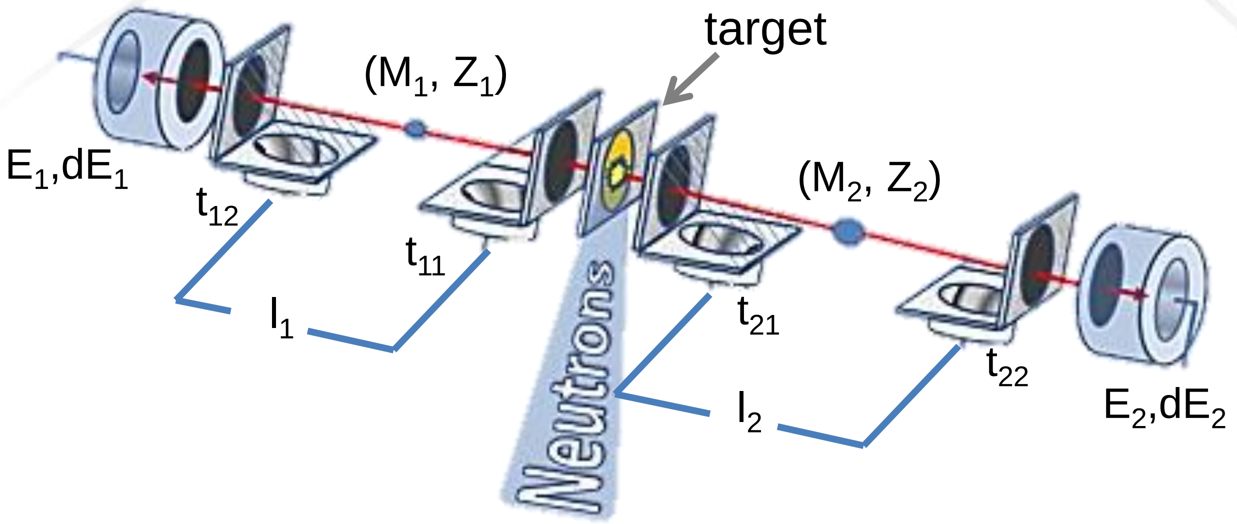
FPY measured with COSI-FAN-TUTTE



Nuclear charge distribution for A=87



The 2E-2v method with SPIDER

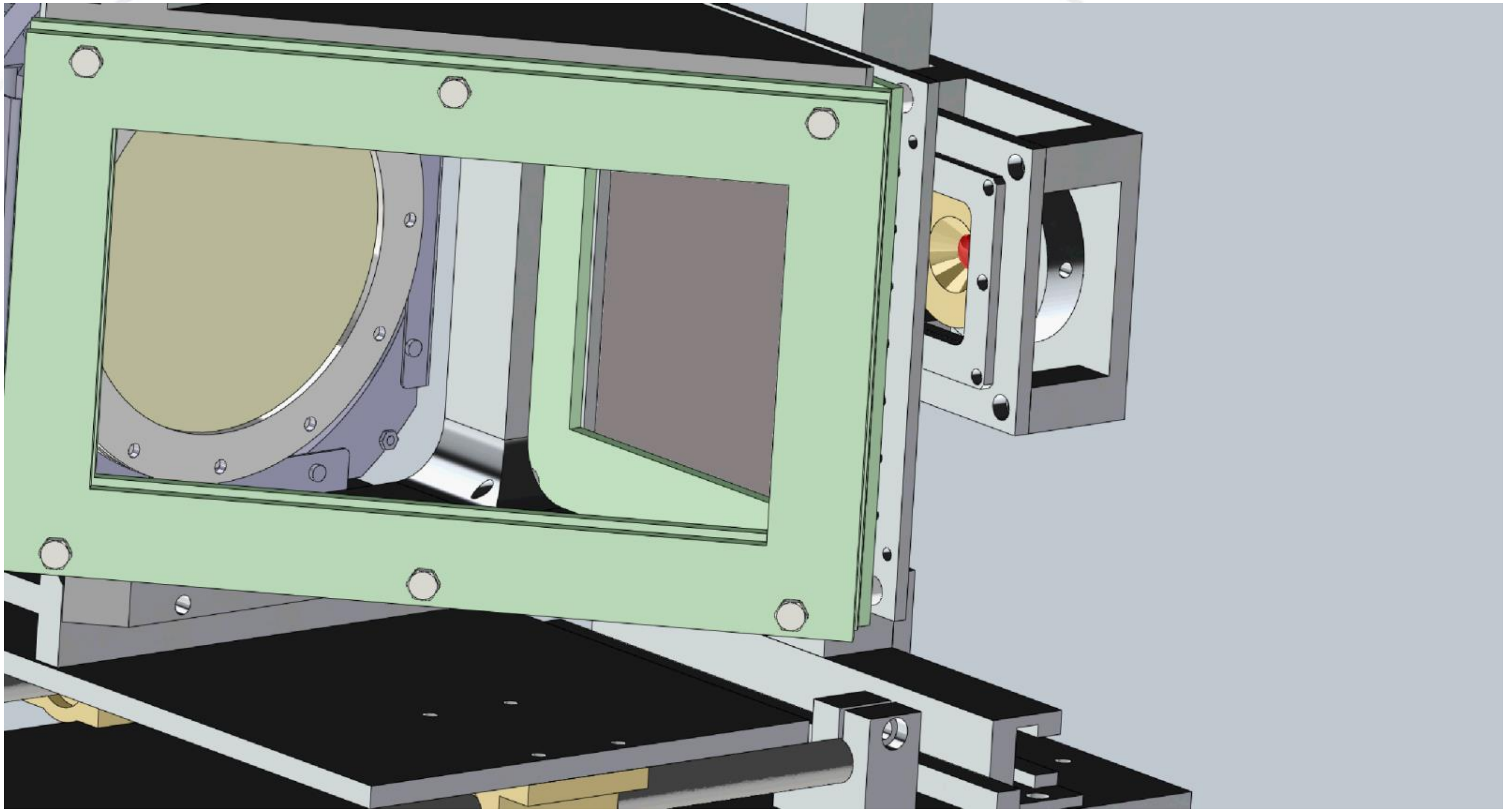


$$M = \frac{2Et^2}{l^2}$$

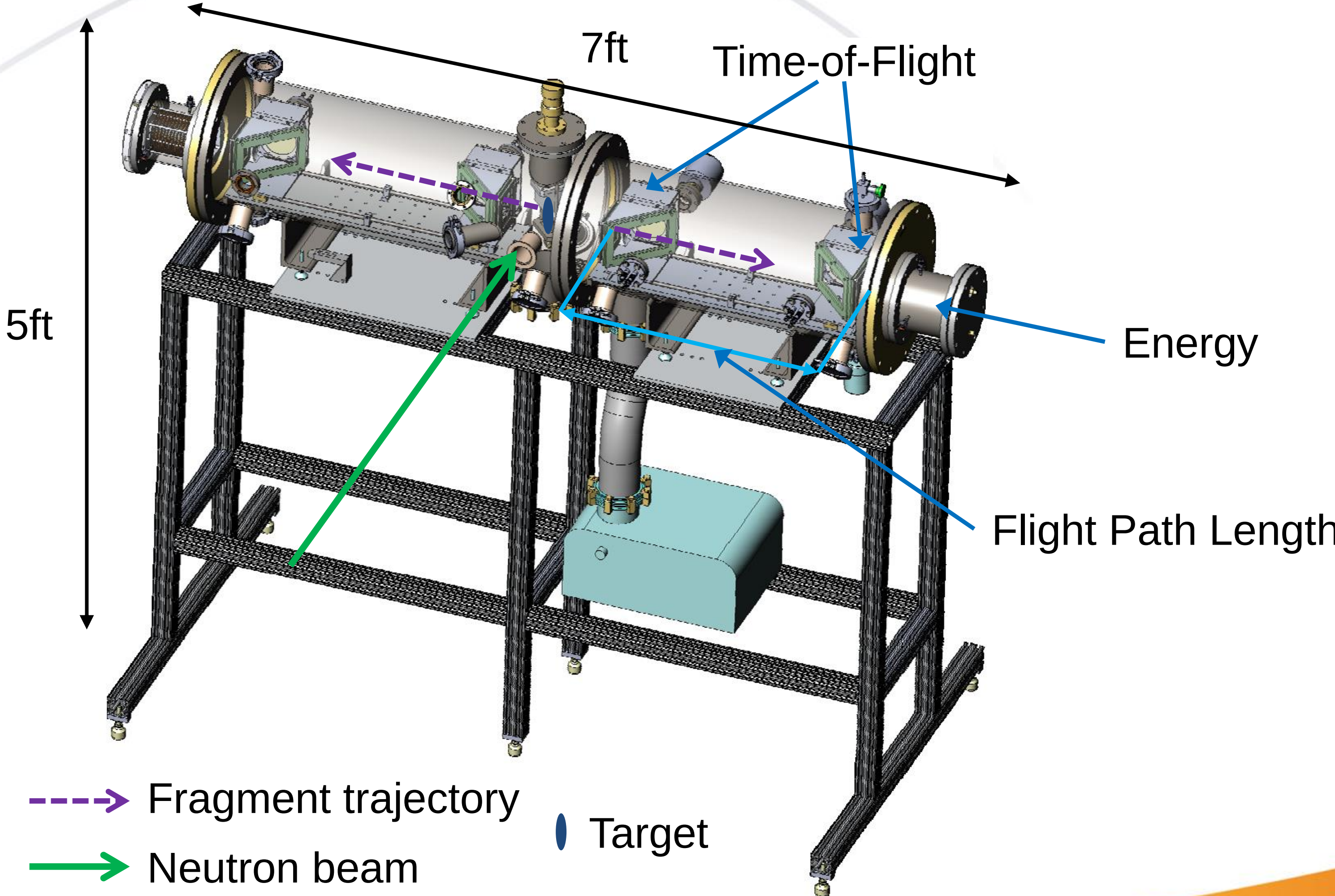
M = mass
E = energy
t = time
l = length
Z = charge

- **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)**

The 2E-2v method with SPIDER – A Movie!



SPIDER arm pair prototype – the ‘2’ in 2E-2v



The 2E-2v method with SPIDER

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

Equation to determine mass resolution

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

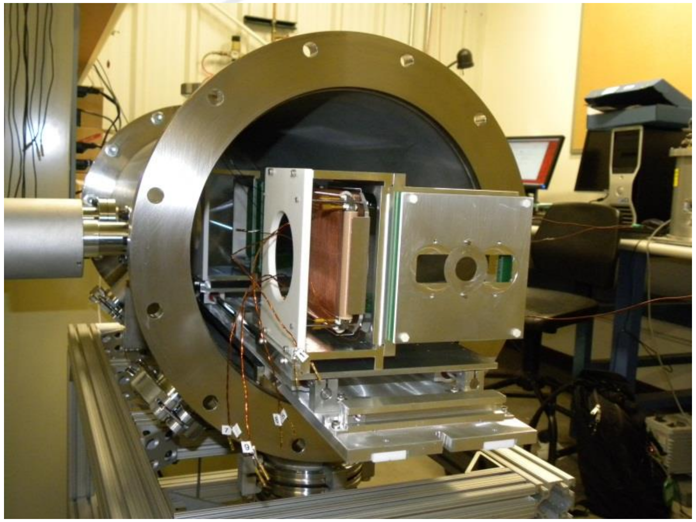
M = mass, *E* = energy, *t* = time, *l* = path length

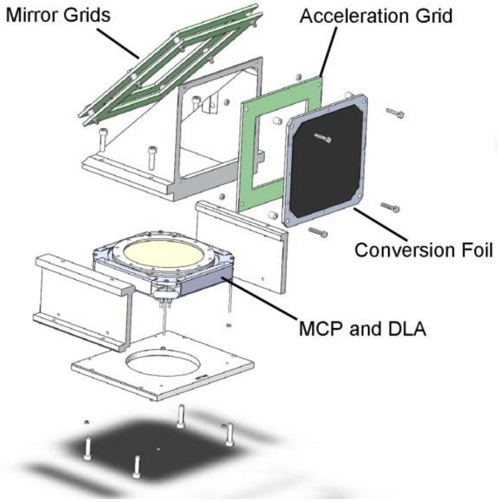
MEASUREMENT GOAL:

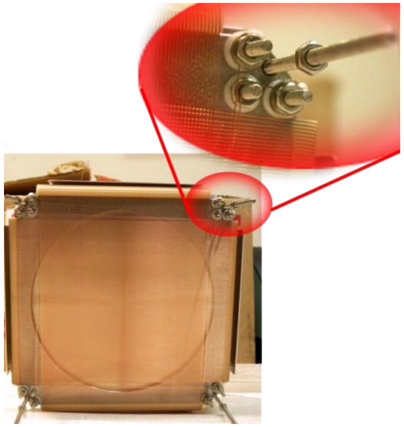
$$\frac{\delta M}{M} = 1\text{AMU or A} = 85 \rightarrow 155 : 1.2\% \text{ to } 0.65\%$$

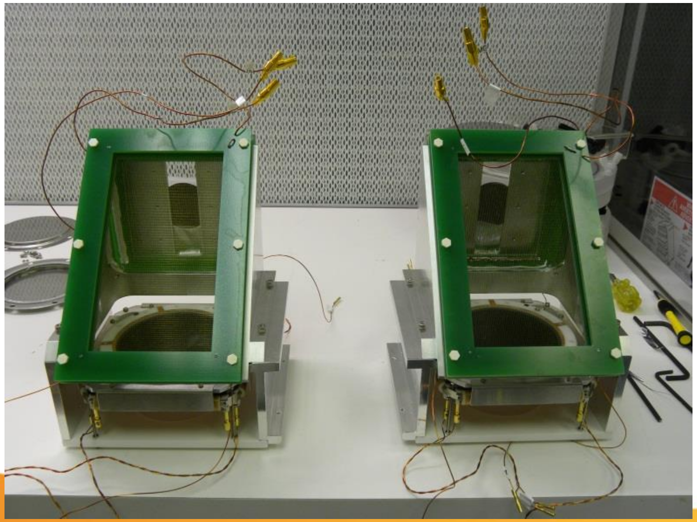
This translates into individual resolution measurements as:
dE/E → ≤ 0.5%,
dl/l → ≤ 0.02%,
dt/t → ≤ 0.7% to 0.3 %
or A 85 → 155 : 1.32% to 0.72%

Time-of-flight Detectors







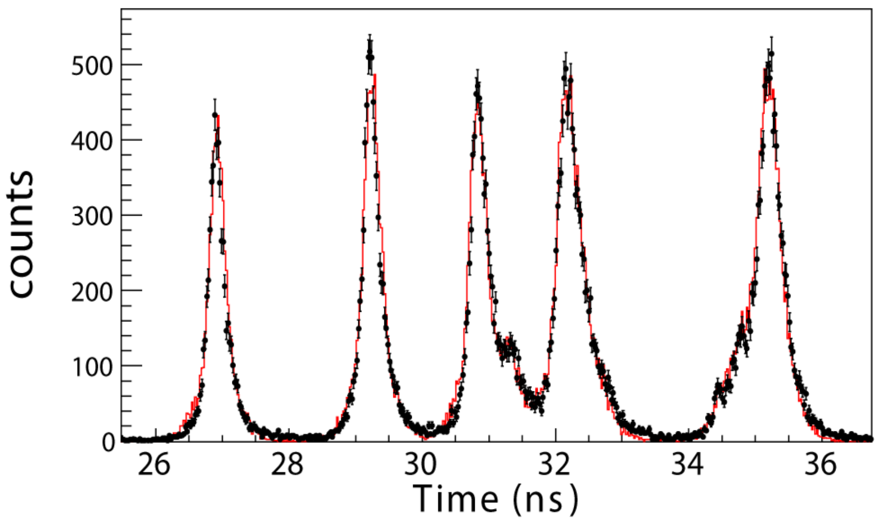


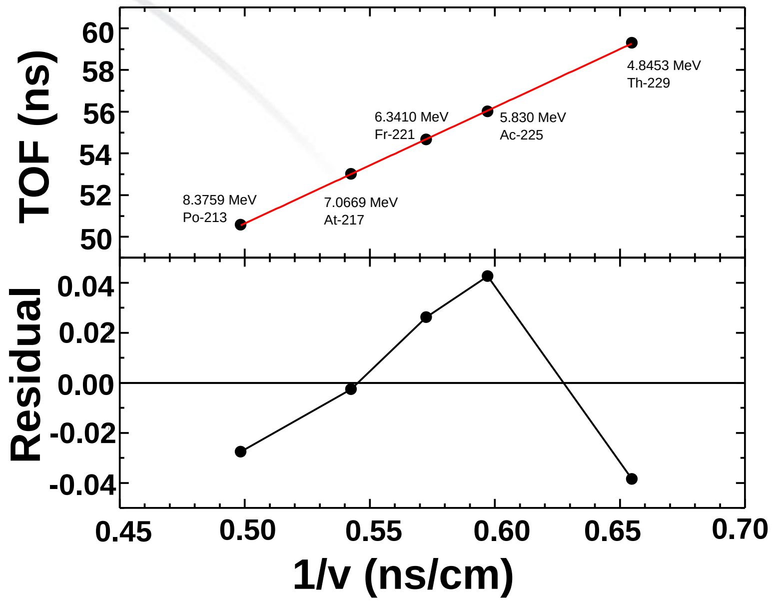
- 52 cm flight path
  - Distance between conversion foils
- Micro channel plates (MCP)
  - Chevron configuration
  - 12 µm channel diameter = fast timing
- RoentDek Delay-line anode
  - (x,y) position readout
  - 1-2 mm resolution achieved with similar arrangement

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

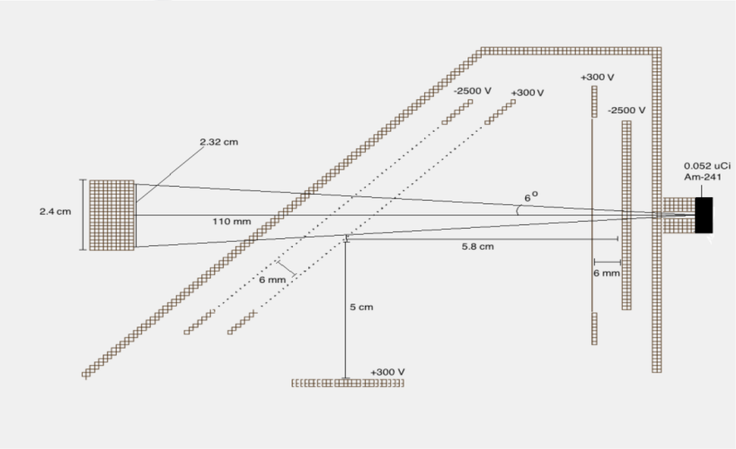


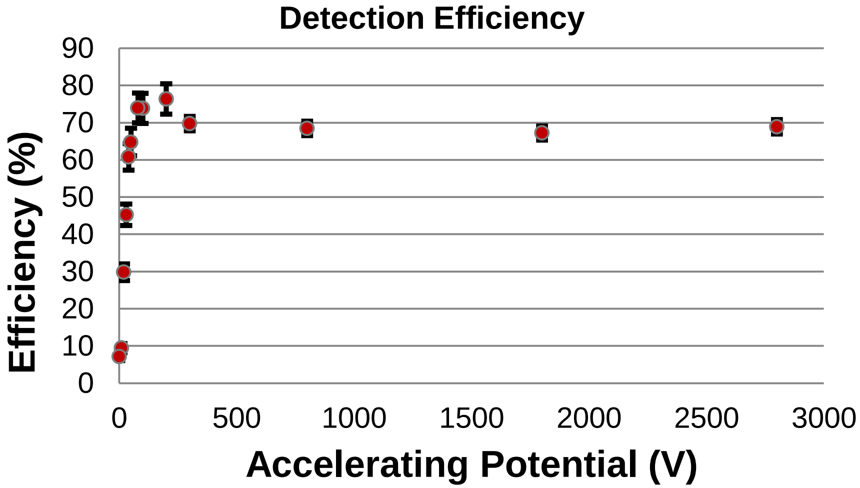


Temporal resolution

Δt=190ps (FWHM)

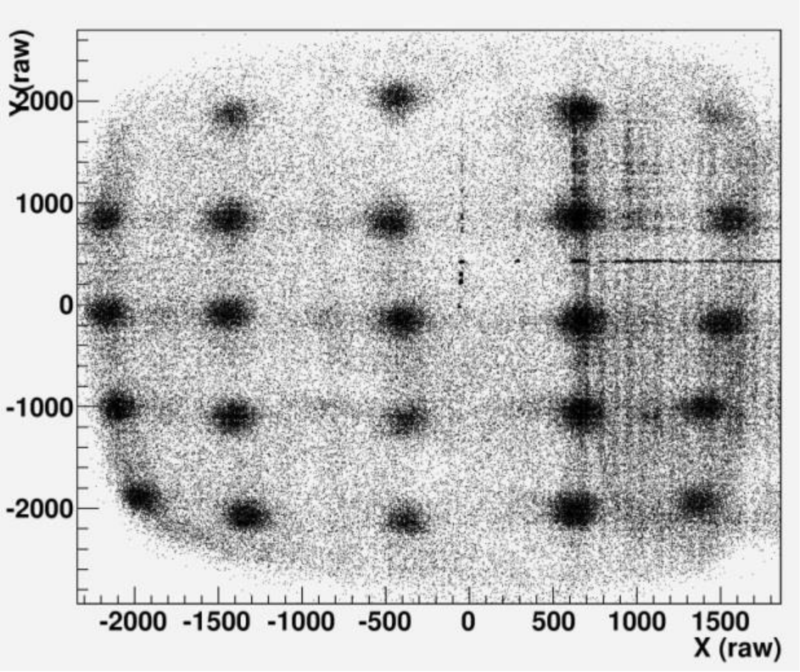
Time-of-flight Detector Efficiency





- 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:
  1. Accelerating potential
  2. Temporal resolution
  3. Spatial resolution-needs to be investigated

Spatial Resolution

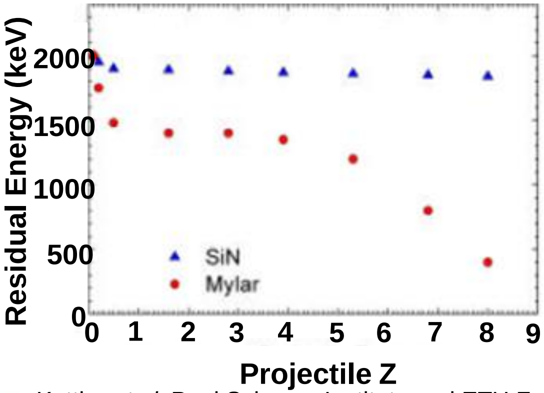


- The delay line anodes can theoretically provide µm-level of resolution
- With delay lines and electrostatic mirrors 1-2 mm resolution has been demonstrated in literature
- Applied a mask to conversion foil

Position resolution
2 mm

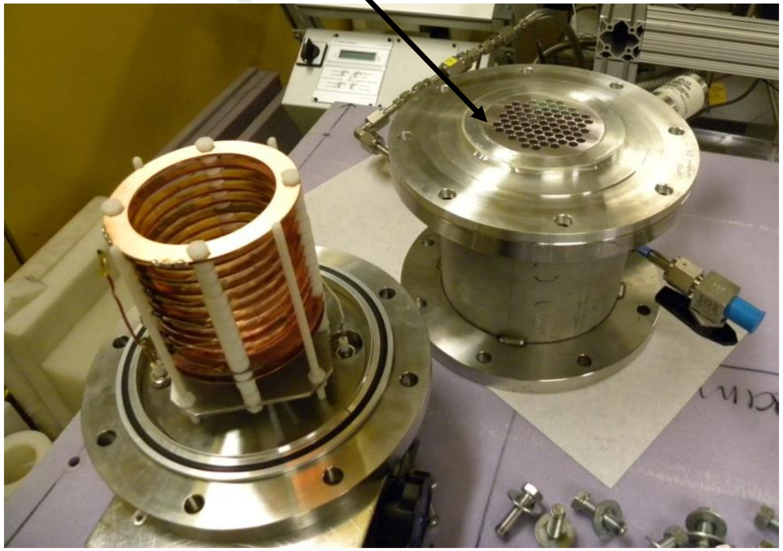
Energy Detector

- Ionization chamber
  - Isobutane fill gas
  - ~12 sccm flow rate
  - 8 cm path length
  - ~ 5.5 cm/s electron drift
- Entrance window
  - Currently using 2.5 µm Mylar
  - Testing 200 – 1000 nm silicon nitride membranes, which has been shown to greatly reduce energy losses

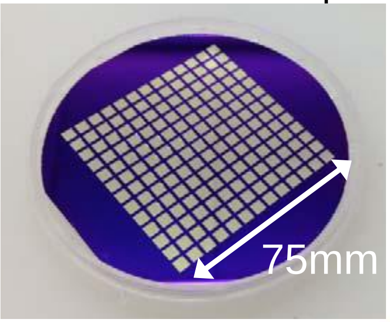


Kottler *et al*, Paul Scherrer Institute and ETH Zurich, Switzerland

Mylar window with support structure



Silicon nitride window prototype



Energy Resolution

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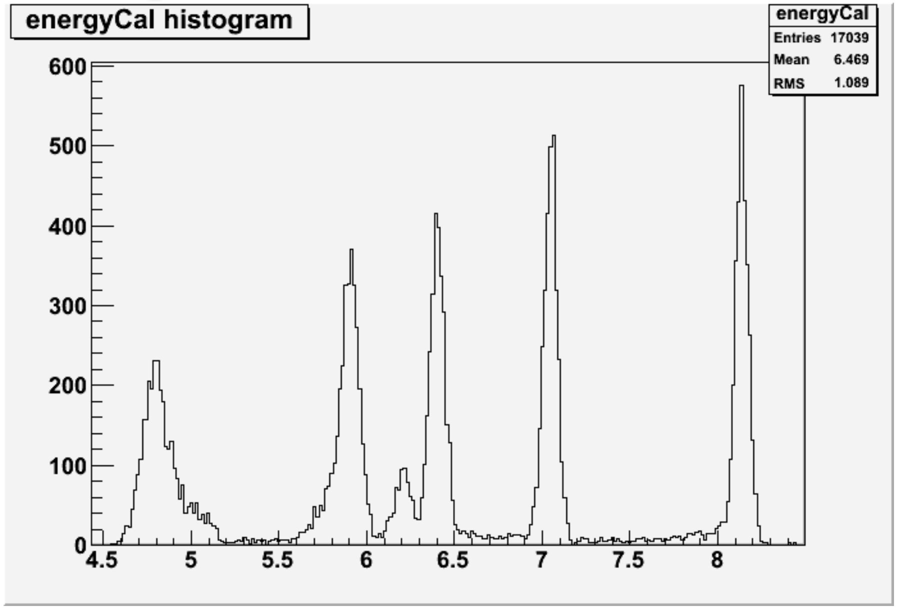
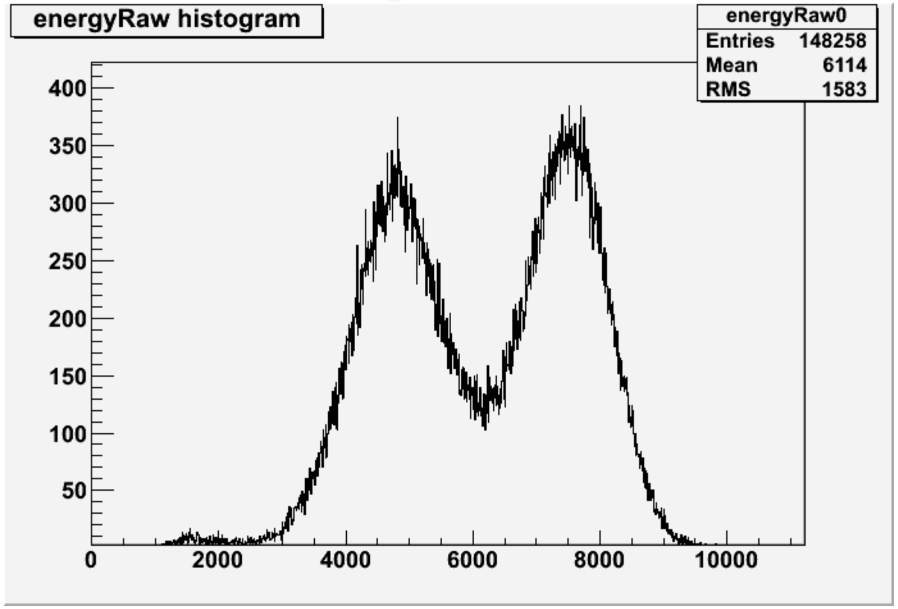
Alphas



^{252}Cf

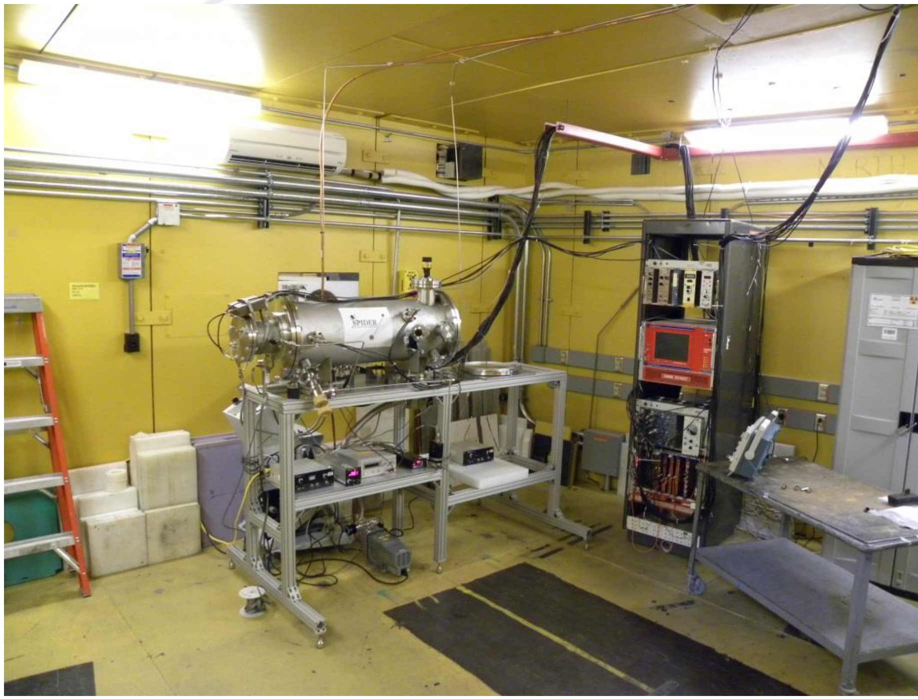


<u>Energy Resolution</u>

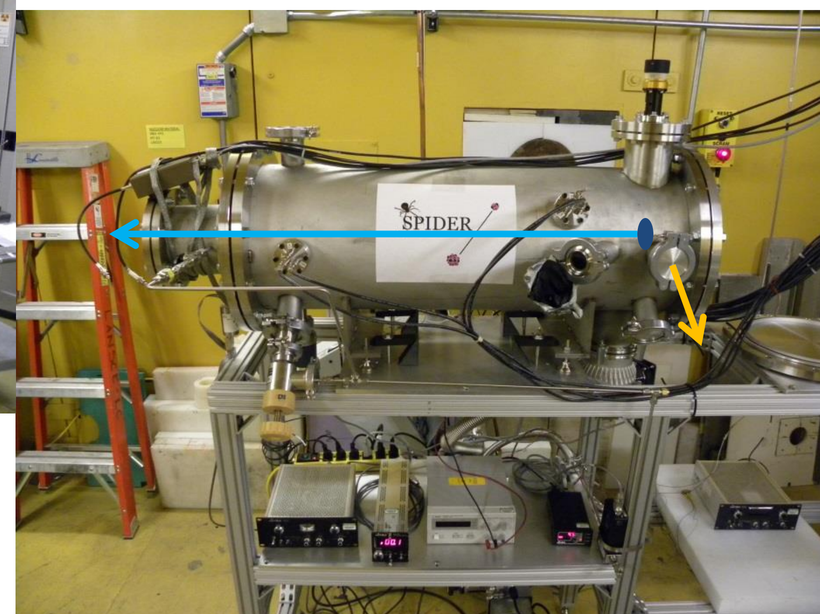
1% for alpha-particles

SPIDER Installation

- Installed at FP12 at Lujan Center, looking at thermal neutron spectrum on ^{235}U



Target position

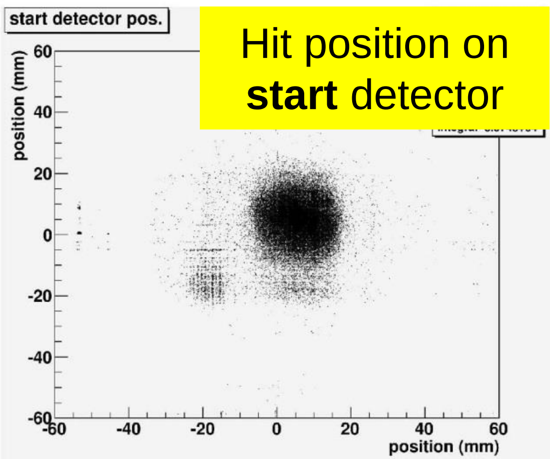


Fragment trajectory through detectors

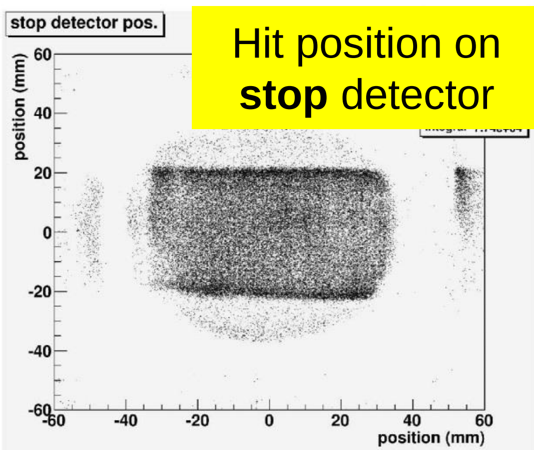
Beam direction

Mass yields in $^{235}U(n_{th},f)$ was measured with one arm instrumented

Hit position on **start** detector

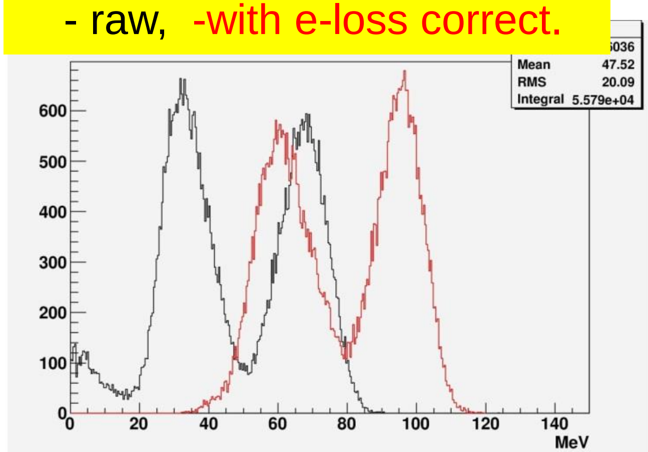


Hit position on **stop** detector

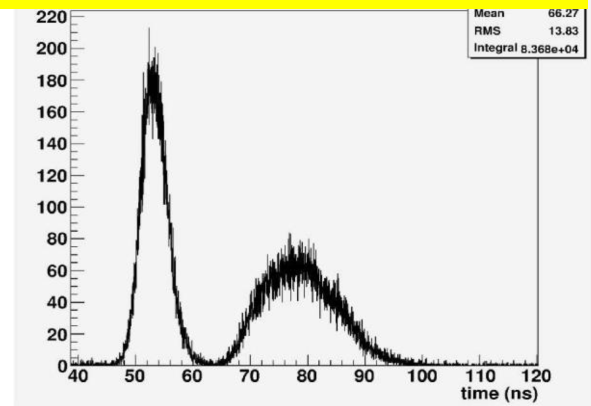


- 1E-1v
- 100 ug/cm^2 UF_4 on 100 ug/cm^2 C
- “Thick” Mylar window: 2500 ug/cm^2
- Neutron time-o-flight was recorded

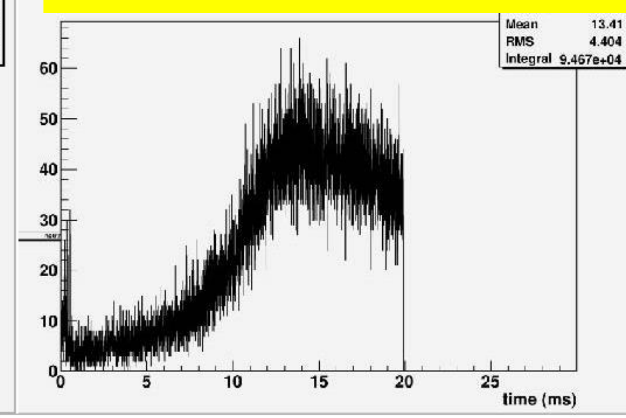
Fragment energy
- raw, -with e-loss correct.



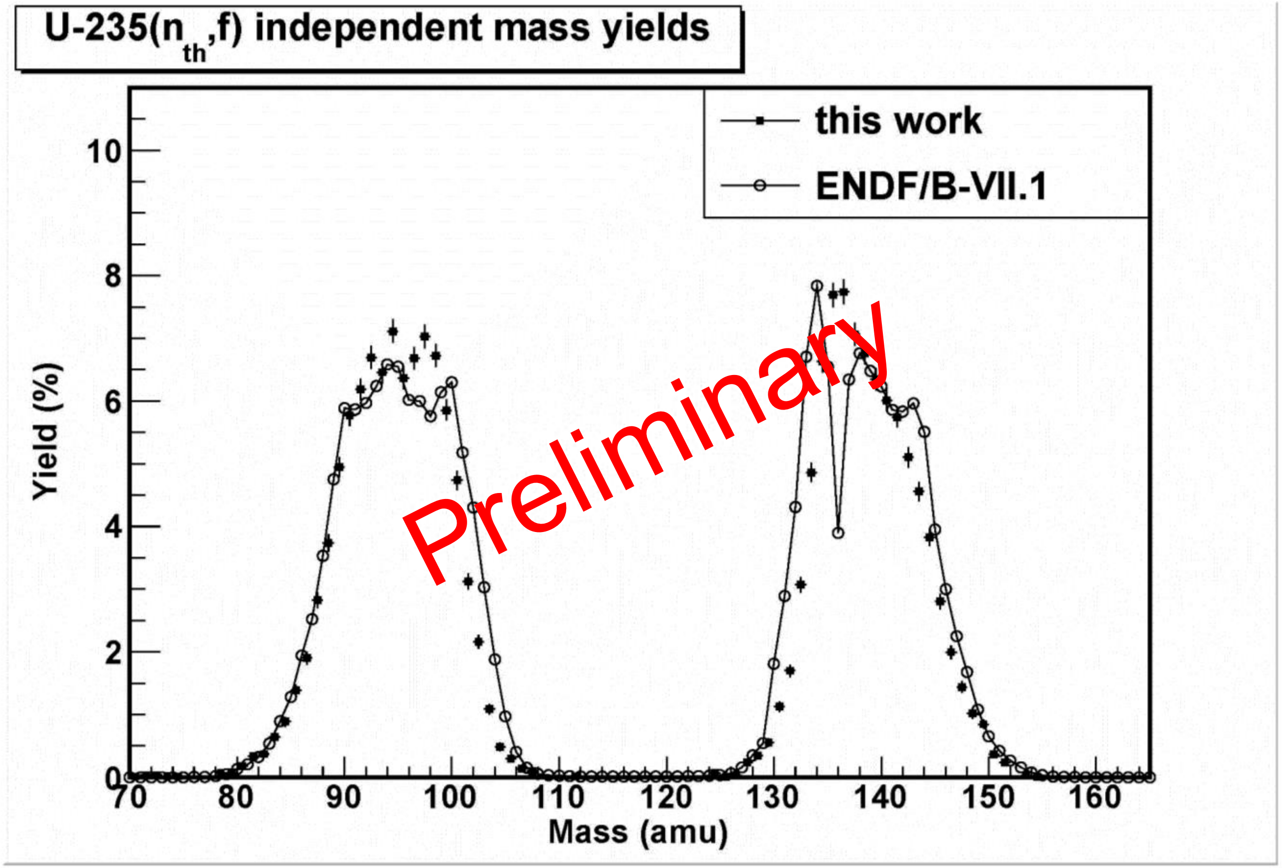
Fission fragment TOF



Neutron TOF

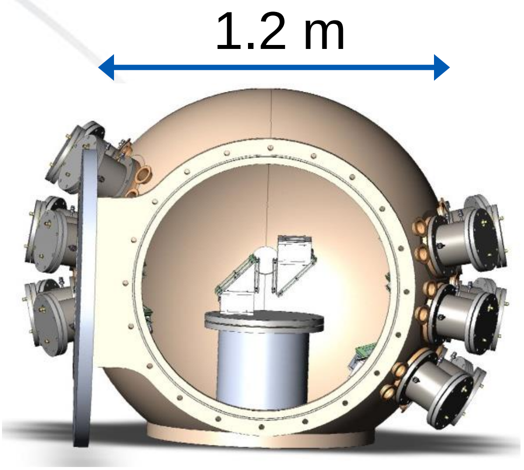


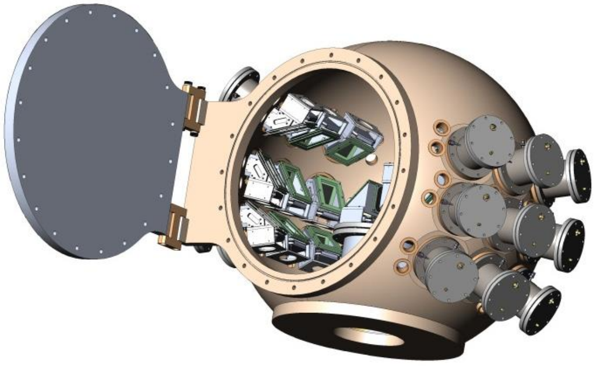
Preliminary mass yield agrees well with literature



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



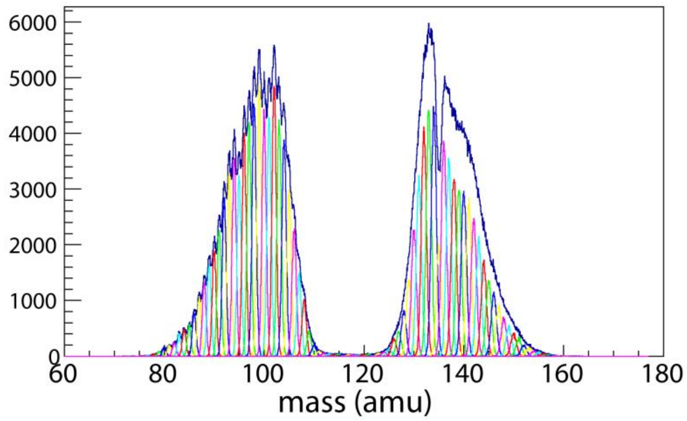


Conclusions

- Improved yield measurements and correlated details about fragment masses, charges, and energies over a wide range of incident neutron energies will go a long way!
- New SPIDER detector will measure fission yields as a function of:
  - Incident neutron energy
  - Fragment mass
  - Fragment charge
  - Fragment energy
- Current resolution capabilities

dE/E → ≤ 0.5% √
dl/l → ≤ 0.02% √
dt/t → ≤ 0.7% to 0.3 % √

MEASUREMENT GOAL: $\frac{\delta M}{M} = 1$ AMU



The SPIDER Collaboration

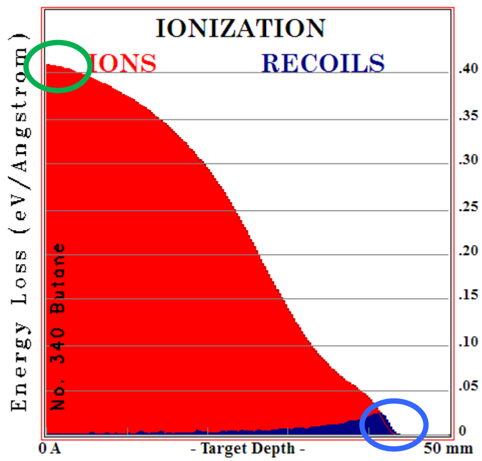
- Los Alamos National Laboratory (LANL)
  Charles Arnold, Todd Bredeweg, Tom Burr, Matt Devlin, Mac Fowler, Marian Jandel, Justin Jorgenson, Alexander Laptev, John Lestone, Paul Lisowski, Rhiannon Meharchand, Krista Meierbachtol, Peter Moller, Ron Nelson, John O'Donnell, Brent Perdue, Arnie Sierk, Fredrik Tovesson, Dave Vieira, Morgan White
- University of New Mexico (UNM)
  Adam Hecht, Rick Blakeley, Drew Mader
- 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

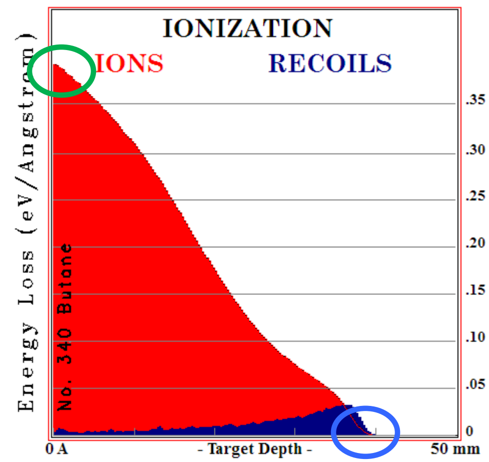
Extra Slides

Bragg Curve Spectroscopy with ionization chamber

- Fission fragments lose energy continuously along their track
- Peak height and path length differentiation are options for uniquely identifying particle charges
- Energy losses of light fragments will be easier to measure due to kinetic energy distributions
  - Charge conservation will allow identification of the heavy fragment: $Z_{fission}=Z_{light}+Z_{heavy}$

light fragment





heavy fragment

Example energy loss curves as a function of track length for light and heavy fragments from ^{252}Cf fission (through 0.2 atm isobutane)

Proposed advancements to measuring fission yields with this project

- **Measure fission-fragment yields as a function of (E_n, Z, A, TKE)**
  - Good thermal data exist but the incident energy (E_n) dependence remains unknown
  - Our measurements will reach from 0.01 eV to 20 MeV
- **Develop theory in order to evaluate fission yield data**
  - Based on the LANL nuclear potential-energy model (P. Moller)
  - Langevin equations for inertial and dissipation effects will be used to model the dynamic evolution of fission across the potential-energy surface (A. Sierk)
  - Experimental data will be used to probe the initial conditions
- **Provide an evaluation of the Pu-239 fission yields**
  - Evaluation blends the best of experiment and theory to provide complete data (J. Lestone)
  - Provide a definitive answer regarding the energy-dependence of Nd-147 yield