Title: High-Resolution Correlated Fission Product Studies of 235U(n,f), 239Pu(n,f), and 252Cf(sf) with SPIDER at LANSCE

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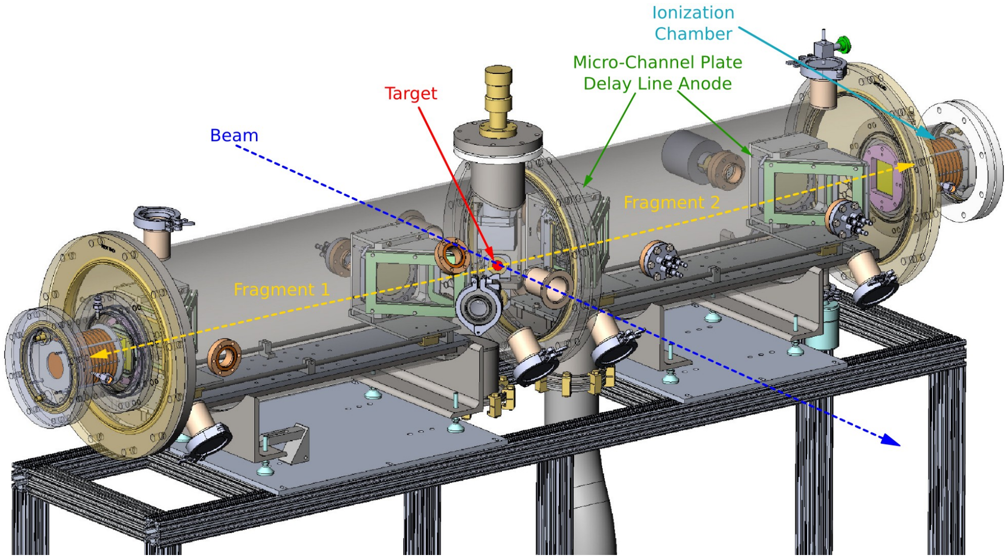
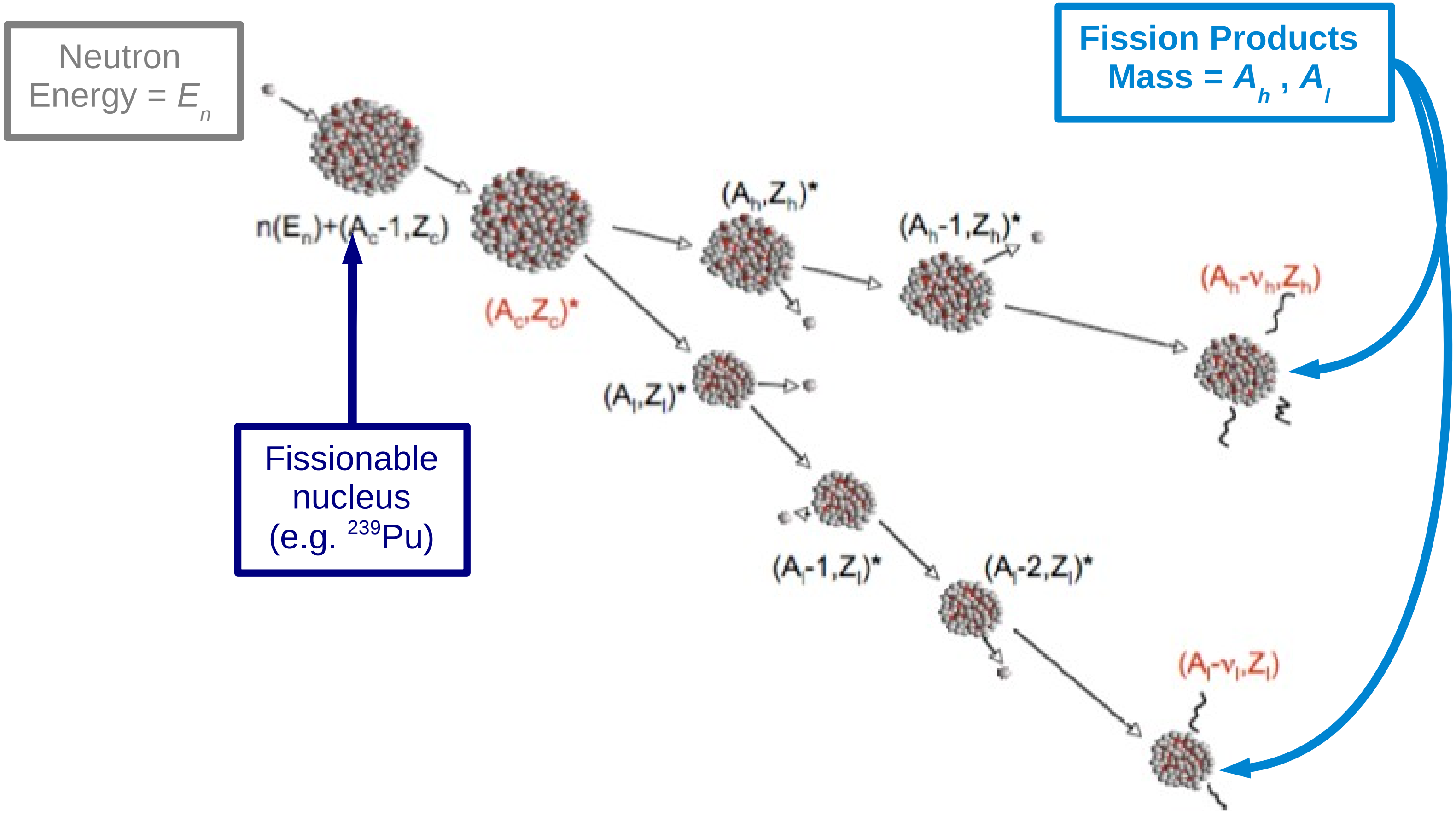
High-Resolution Correlated Fission Product Studies of ^{235}U(*n*,*f*), ^{239}Pu(*n*,*f*), and ^{252}Cf(*sf*) with SPIDER at LANSCE



Dan Shields for the SPIDER Collaboration

Nuclear Fission


Neutron Energy = E_n

Fissionable nucleus (e.g. ^{239}Pu)

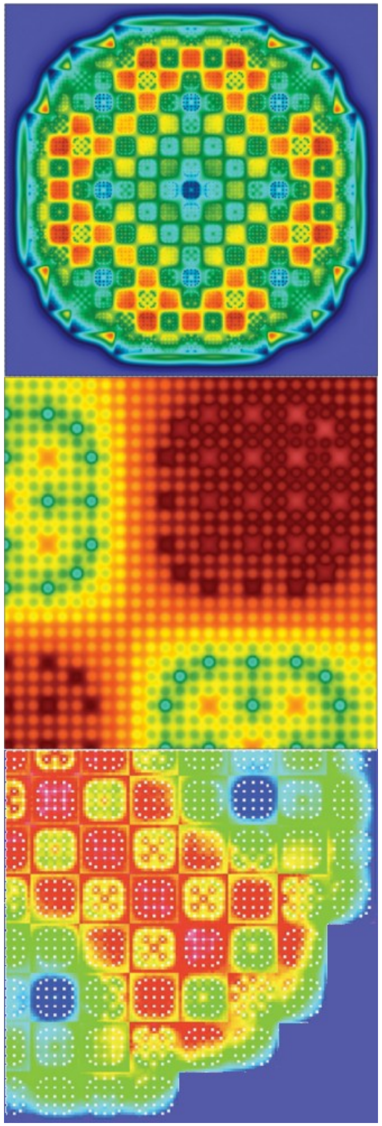
Fission Products Mass = A_h , A_l

- SPIDER is commissioned to measure fission product mass (*A*) with 1 AMU resolution
  - Mass Spectrum of Products = Fission Product Yields (FPY(E_n))

Fission Data Motivation: Nuclear Applications

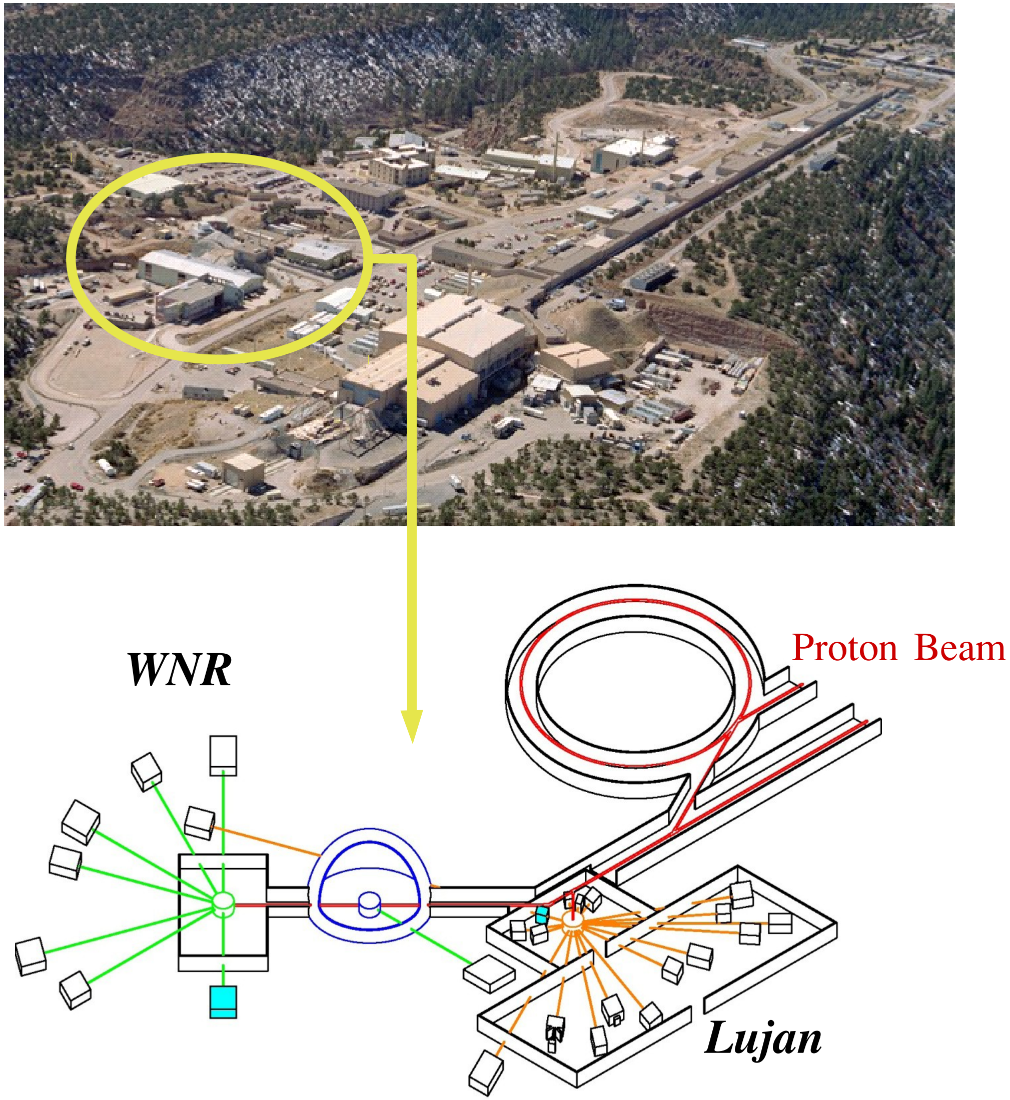
- Experimental data over full fission observable space with highly constrained uncertainty is vital to:
  - Energy
    - Predictive modeling and reliable design ⇒
  - Stockpile Stewardship
    - Understanding the health of aging devices
  - Nuclear Forensics
    - Confidence in conclusions and may lead to new methods
  - Theory
    - Constraining present and developing new models
  - Standards
    - Trust in relative measurement against well known fission
- ^{235}U(*n*,*f*) *and* ^{239}Pu(*n*,*f*) *are some of the most important to all customers*
- Especially for E_n dependence, there are a lot of gaps in existing data!

CASL Reactor Sim.

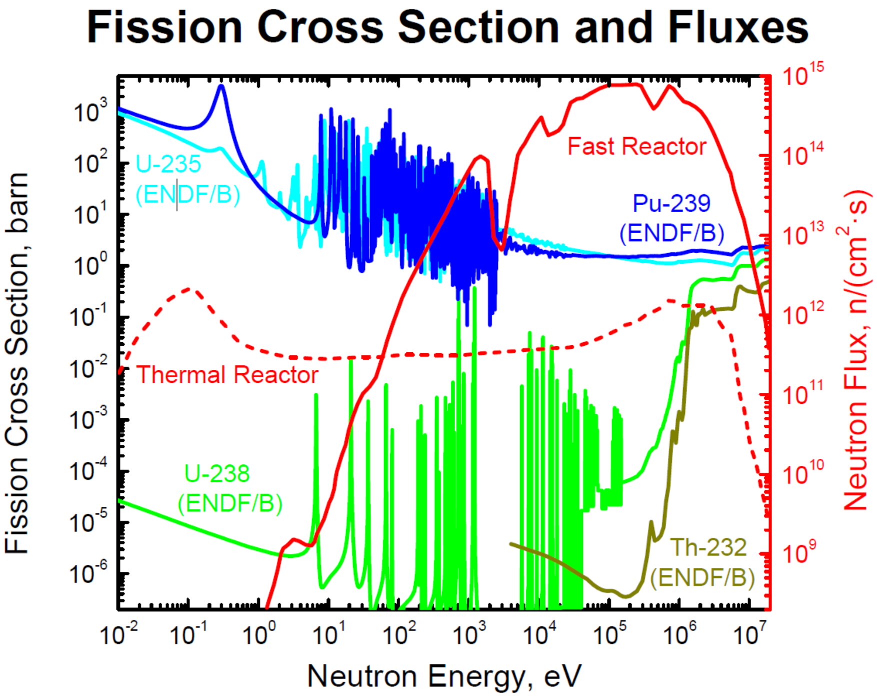


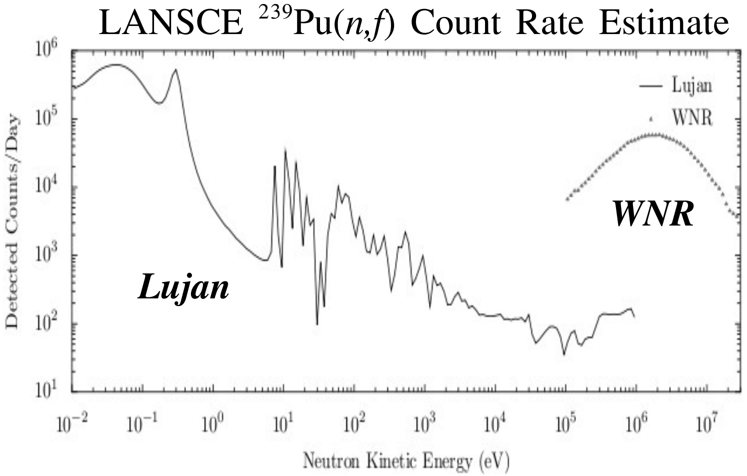
LASNCE: E_n Dependent X(*n*,*f*) Studies

- **LANSCE**
  - Pulsed 800 MeV proton linac
  - Neutrons from spallation targets
    - E_n recoverable via neutron ToF
- **Lujan Center**
  - Sub-thermal neutron flux
    - micro-eV to ~100 keV
- **Weapons Neutron Research (WNR)**
  - Fast neutron flux
    - ~100 keV to ~100 MeV



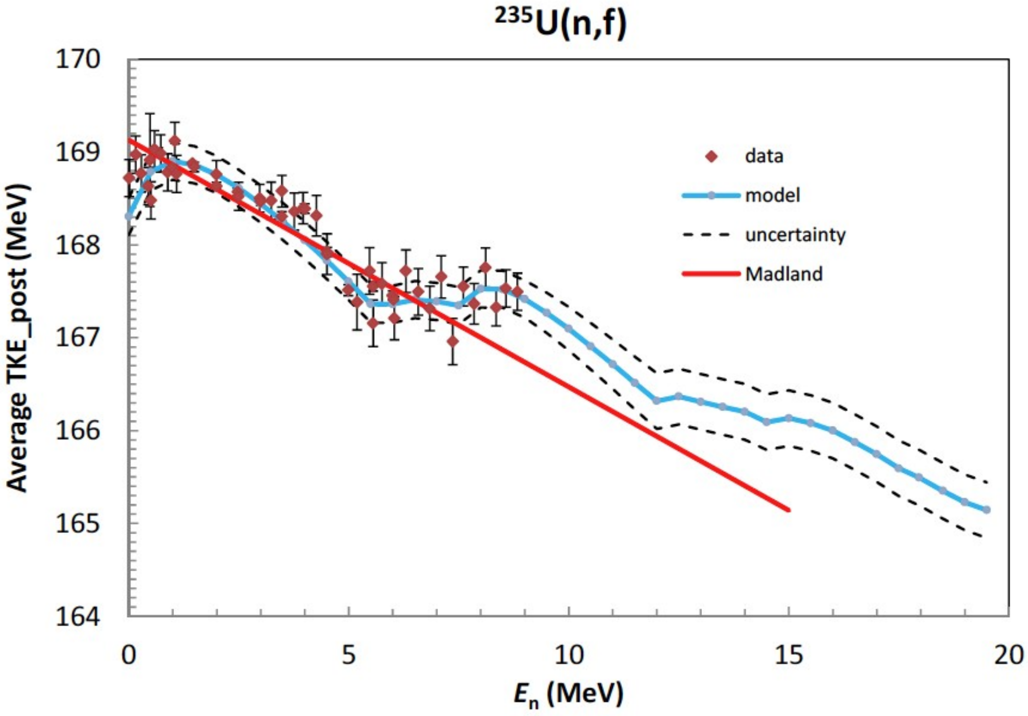
LASNCE: E_n Dependent X(n,f) Studies


Fission Cross Section and Fluxes


LANSCE ^{239}Pu(n,f) Count Rate Estimate

Goal: *Correlated* Fission Product Measurements

- ***Correlated* Fission Product Data with SPIDER:**
  - Energy (E) (0.5% resolution)
    - Total Kinetic Energy (TKE)
      - TKE(E_n)
  - Mass (A) (1 amu resolution)
    - Fission Product Yields (FPY)
      - FPY(E_n)
    - Prompt neutron emission
    - Neutron sawtooth
  - Charge (Z) (~1 charge resolution)
    - Isotope identification
      - FPY(E_n, Z)



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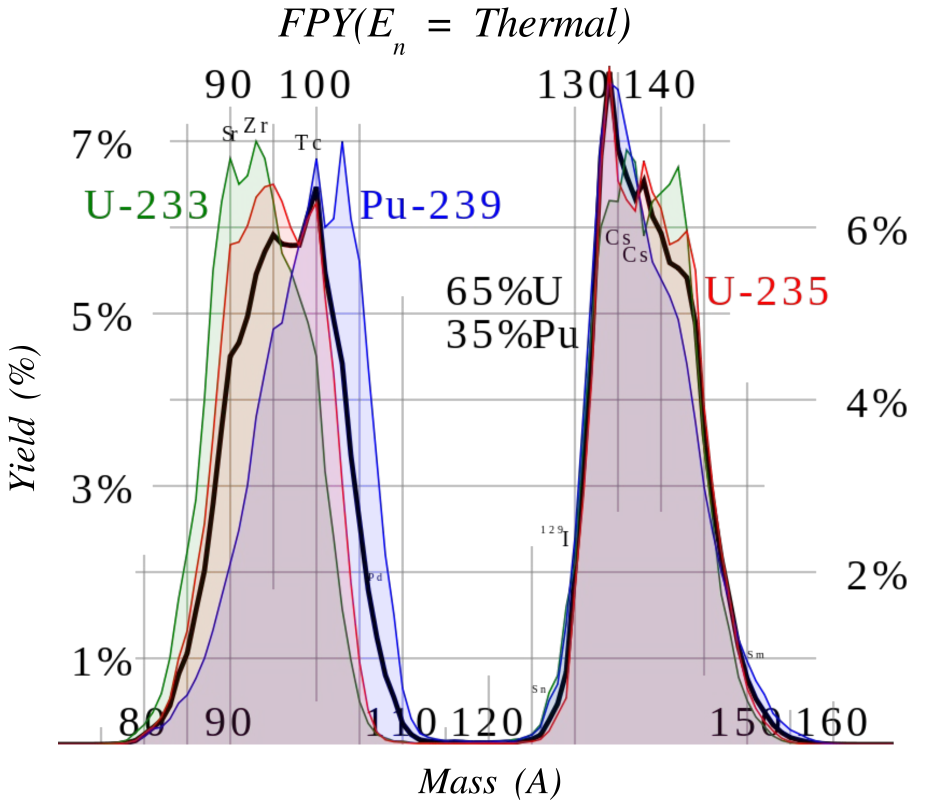
  - **Charge (*Z*)** (~1 charge resolution)
    - Isotope identification
      - FPY(E_n, Z)

WHY SPIDER IS COMMISHIONED:
Independent FPY(E_n)

Taken a few micro-seconds after fission



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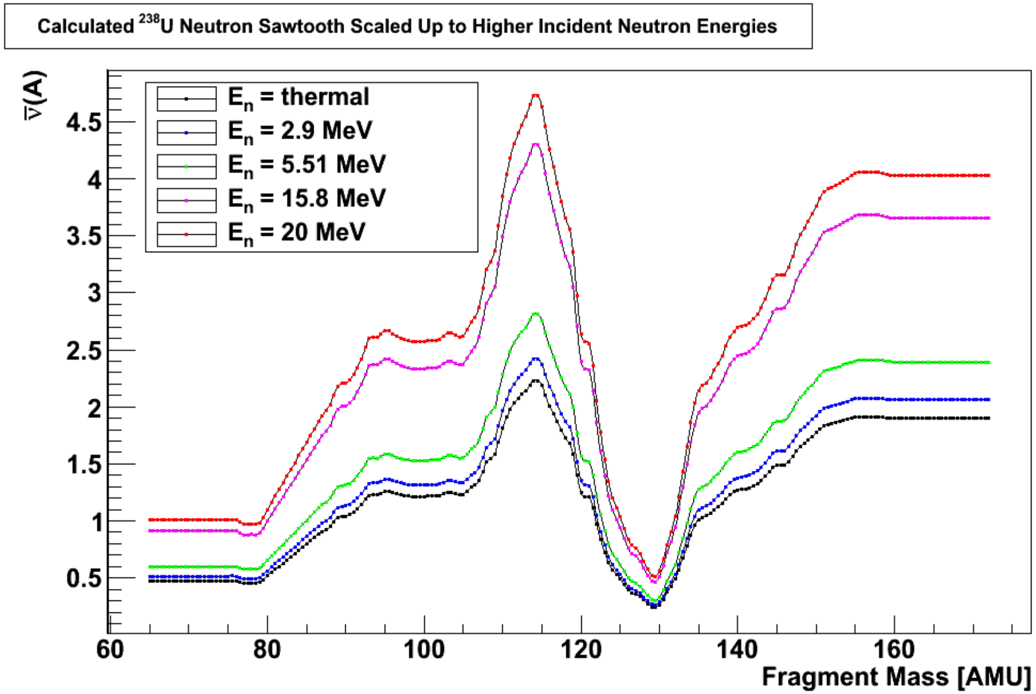

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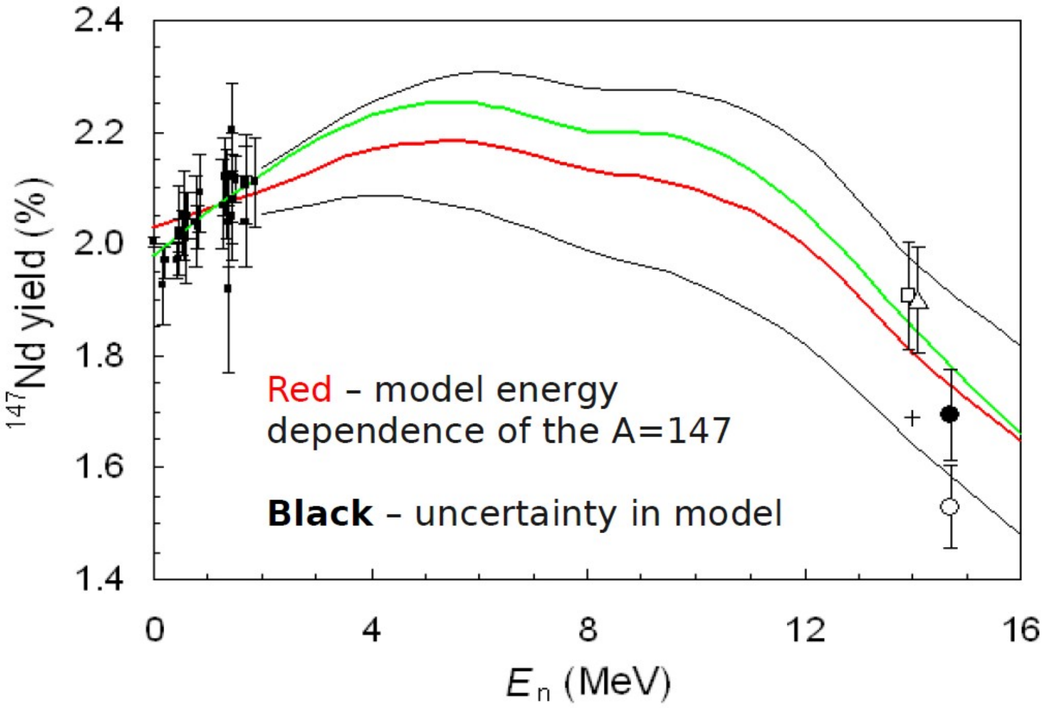


SPIDER Mass Method: ‘E-V’

- ***Mass found by measuring Energy and Velocity:***

$$E = \frac{1}{2}m|\vec{v}|^2 \quad \Rightarrow \quad m = \frac{2E}{|\vec{v}|^2}$$

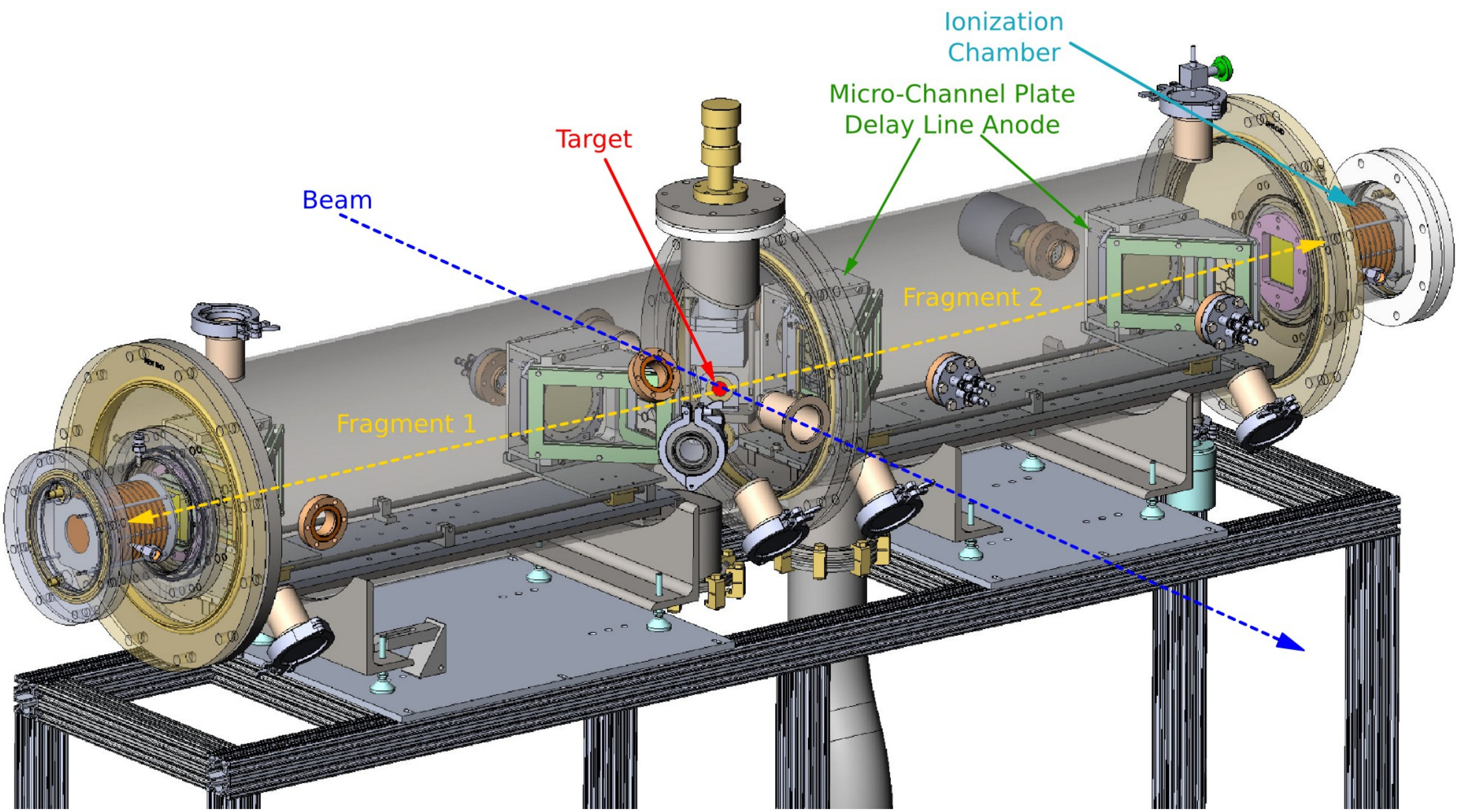
- **Trajectory *l***
  - Particle travels distance *D* between planar detectors
  - *x*, *y* positions for start (1) and stop (2) detectors
- **ToF *T***
  - Particle transits in time *T* between planar detectors
  - Time *t* for start (1) and stop (2)

$$\vec{v} = \frac{\vec{l}}{T} = \frac{(x_2 - x_1)\hat{x} + (y_2 - y_1)\hat{y} + D\hat{z}}{t_2 - t_1}$$

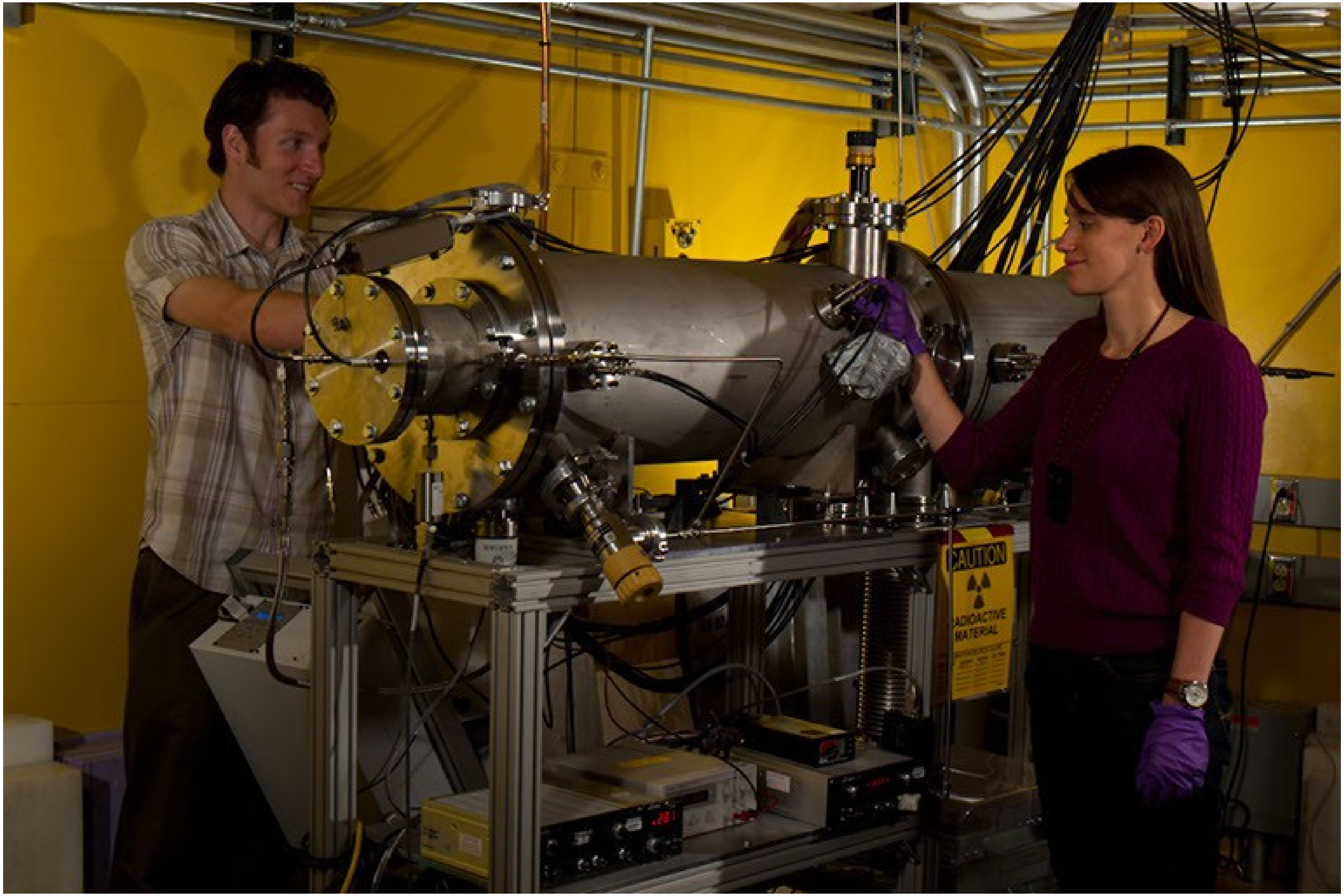
- **Kinetic Energy *E***
  - Particle stops in energy sensitive detector material
- **Mass Error Estimate**
  - Goal: 1 AMU for light FPs

$$\underbrace{\frac{\delta m}{m}}_{1/115\ =\ 0.85\%} = \sqrt{\underbrace{\left(\frac{\delta E}{E}\right)^2}_{\sim 0.5/100\ =\ 0.5\%} + \overbrace{\left(2\frac{\delta t}{t}\right)^2}^{\sim 0.25/45\ =\ 0.55\%} + \underbrace{\left(2\frac{\delta l}{l}\right)^2}_{\sim 0.3/70\ =\ 0.43\%}}$$

Dual Arm SPIDER Prototype Design

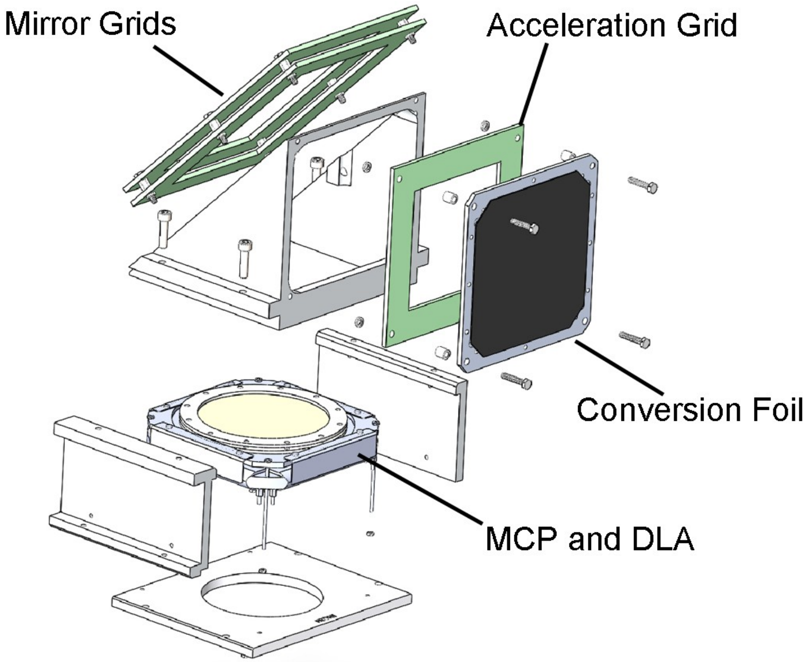


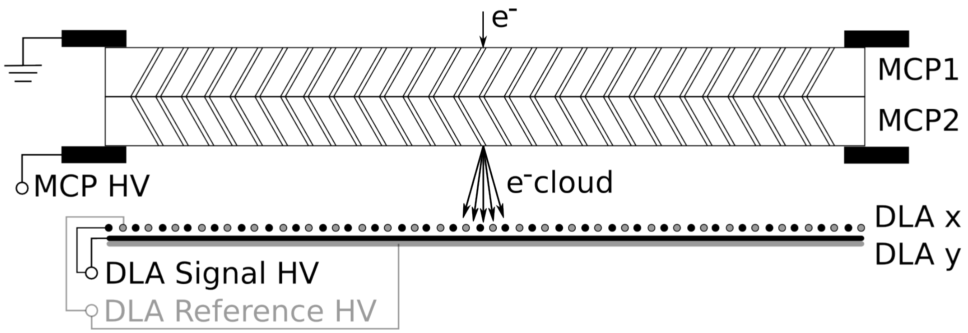
Dual Arm SPIDER Prototype Instrumented



SPIDER: Time of Flight and Position

- Conversion Foil
  - Minimal ion energy losses
  - High precision timing/position
- Microchannel Plates (MCPs)
  - Response time ~1 *ns*
    - Minimal deadtime
    - Time resolution ~100 *ps*
- Delay Line Anodes (DLAs)
  - 2D position resolution ~1x1 *mm*
- Velocity measurement
  - With two MCP-DLAs, one obtains:
    - Ion trajectory
    - Ion Time of Flight (ToF)

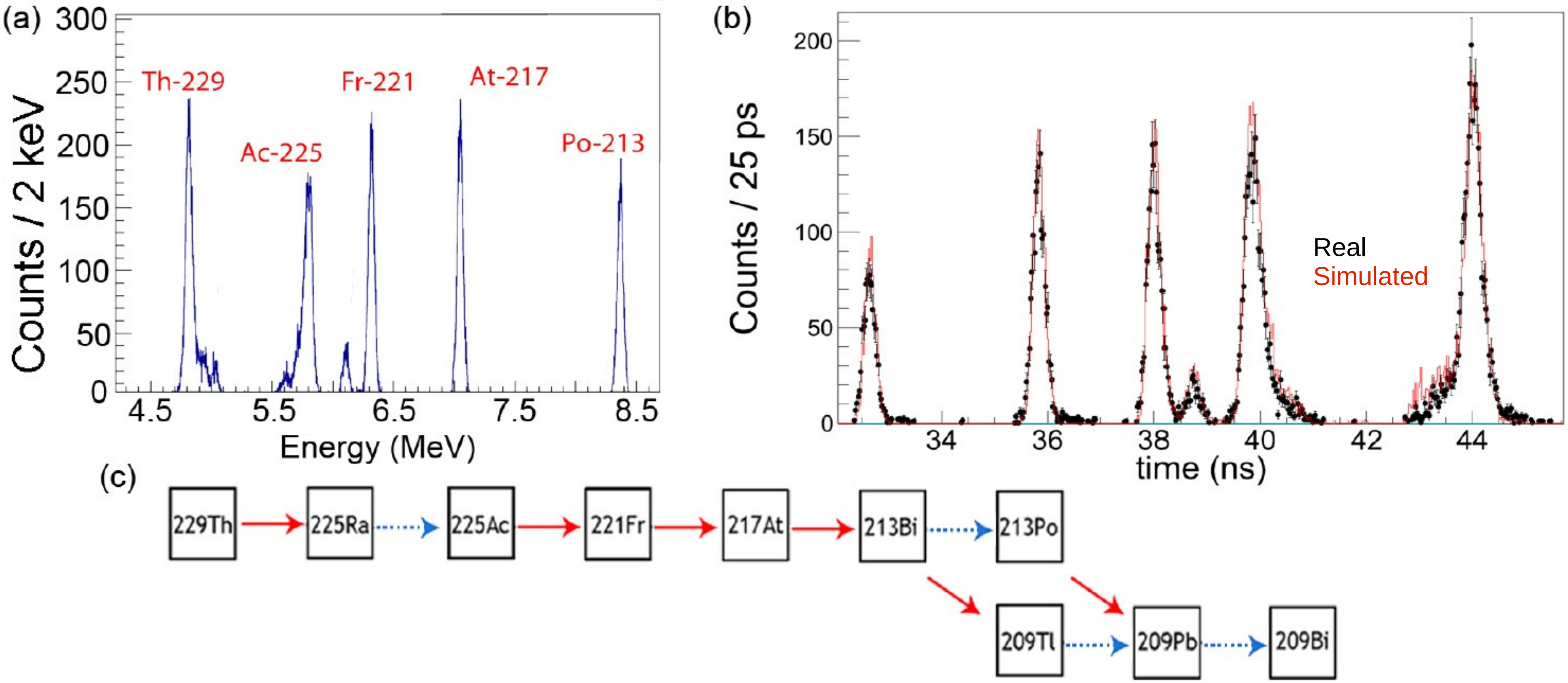




Preliminary Work: MCP ToF Tests

^{229}Th decay chain alpha lines

Real and Sim. ToF Data



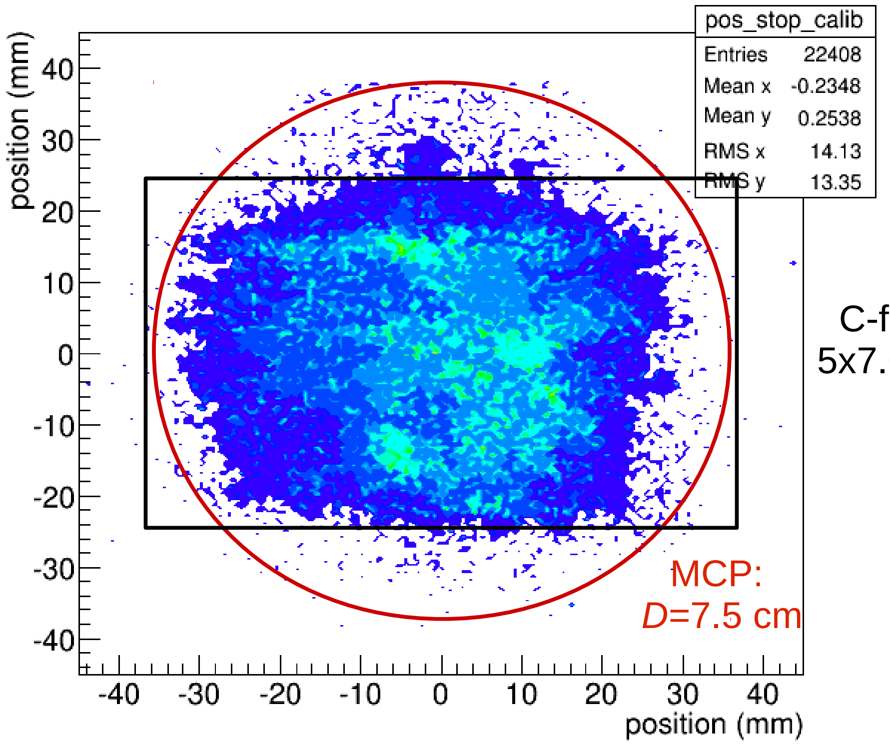
250 ps FWHM ToF timing resolution (~0.5%)

Arnold, C. W., et al. "Development of position-sensitive time-of-flight spectrometer for fission fragment research."

DOI: 10.1016/j.nima.2014.07.001

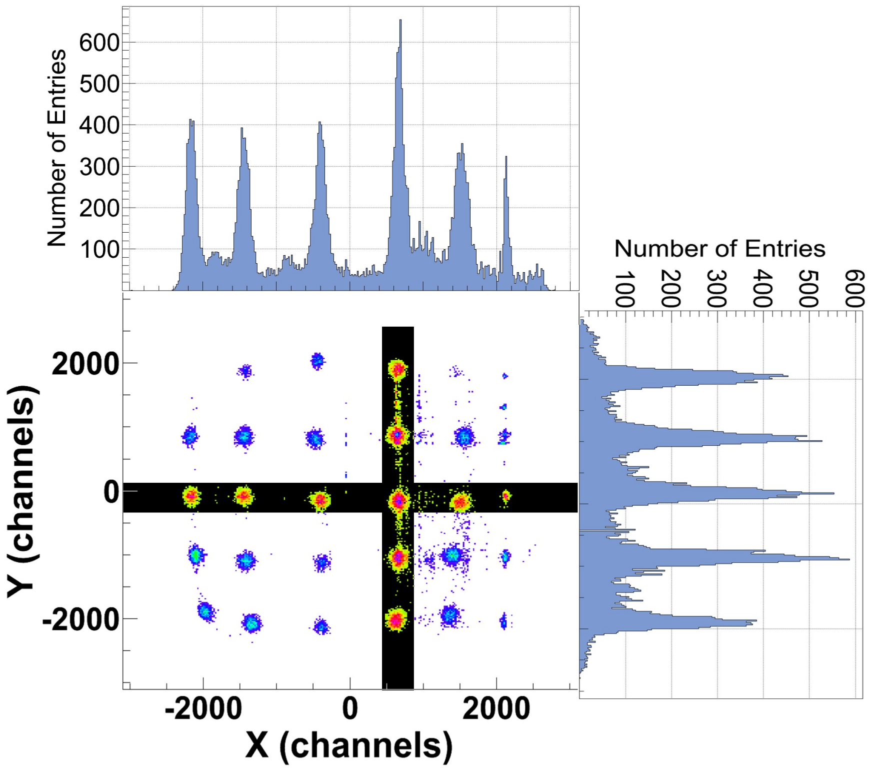
Preliminary Work: DLA Position Tests

Carbon Foil Image on MCP



C-foil:
5x7.6 cm

5x5, 1 cm grid, 1 mm openings



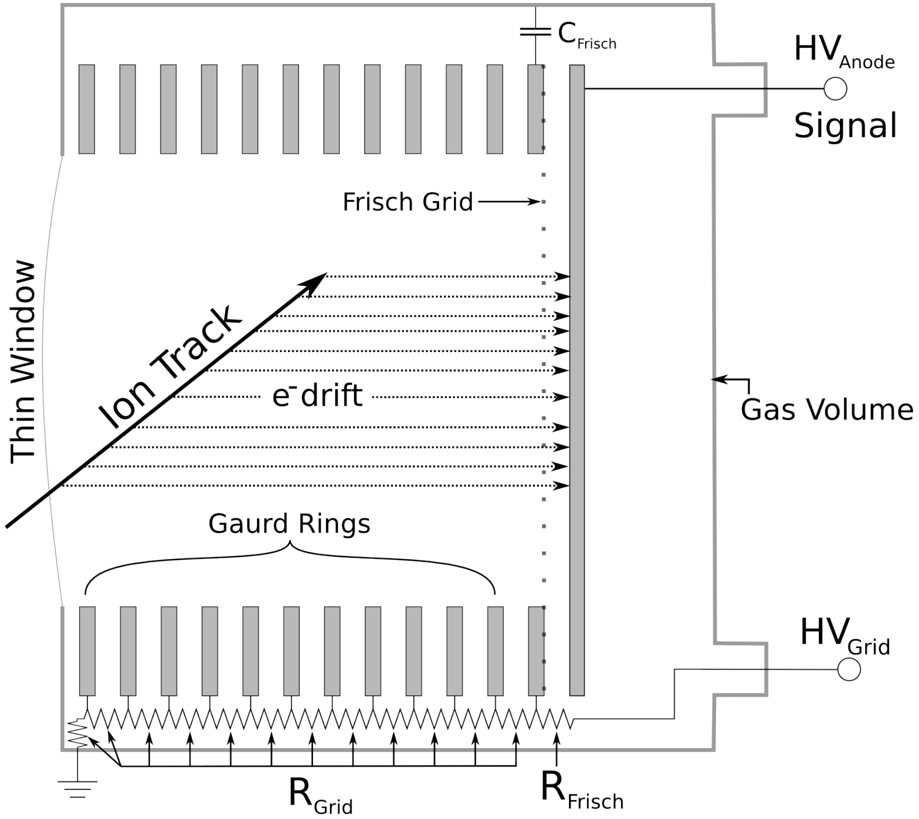
2 mm FWHM position resolution (~0.3%)

Arnold, C. W., et al. "Development of position-sensitive time-of-flight spectrometer for fission fragment research."

DOI: 10.1016/j.nima.2014.07.001

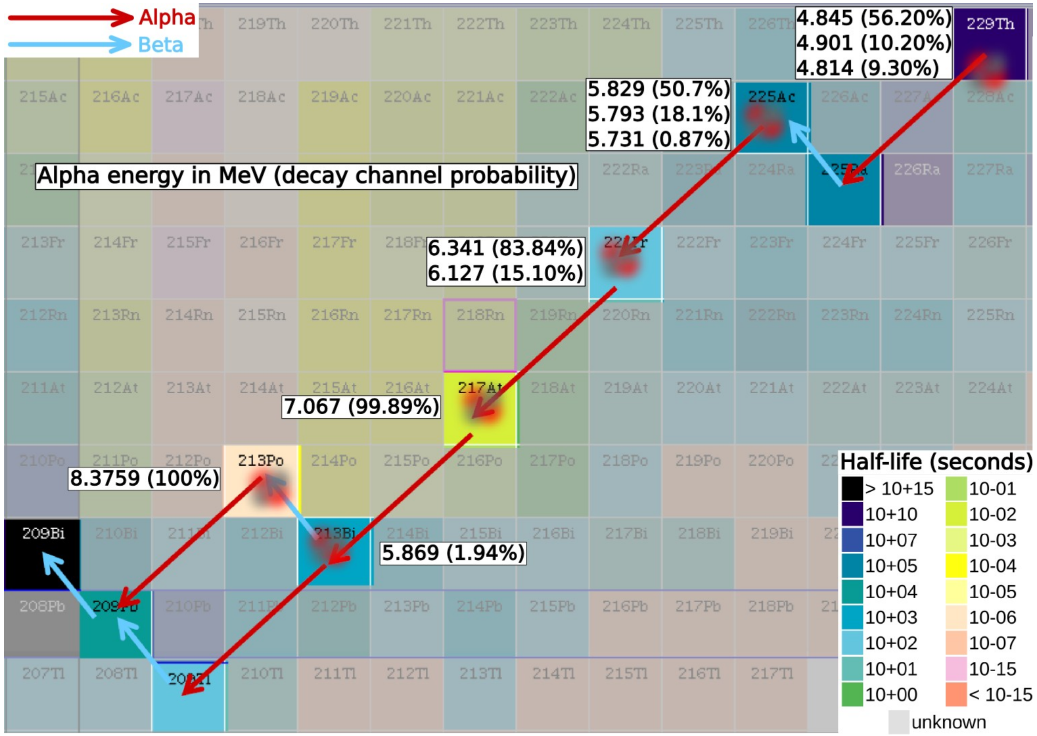
SPIDER: Energy

- **Ionization Chamber (IC)**
  - Radiation hard with gas flow
  - Excellent energy resolution for ions
    - ~1% for alpha, ~0.5% for heavy ions
  - Window between high vacuum and fill gas required
    - Energy straggling = resolution loss
    - Minimal areal density of window required

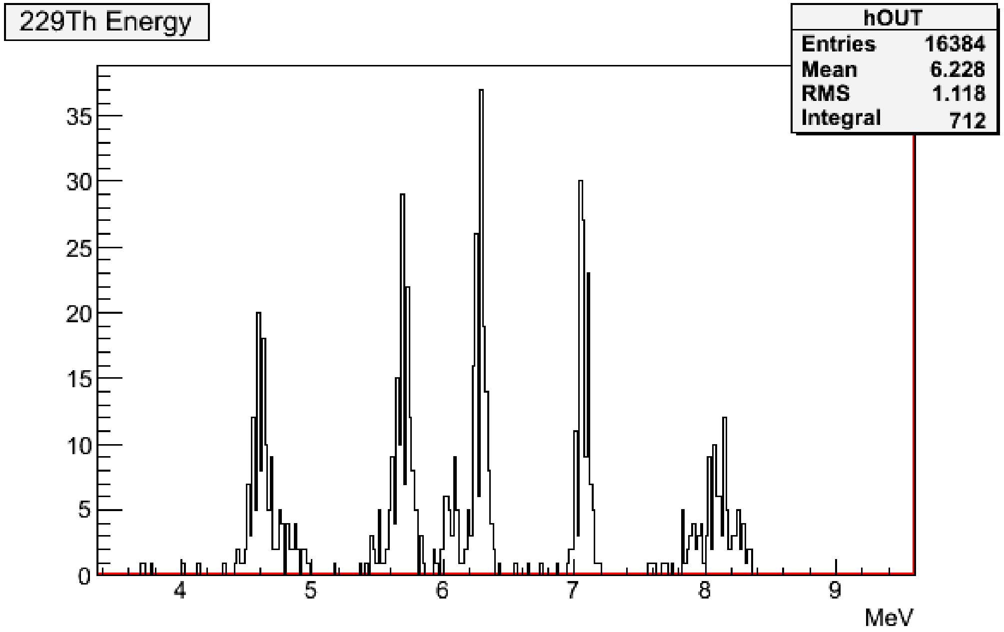


Preliminary Work: Alpha Energy Tests

^{229}Th alpha lines



Full Arm Energy Data***

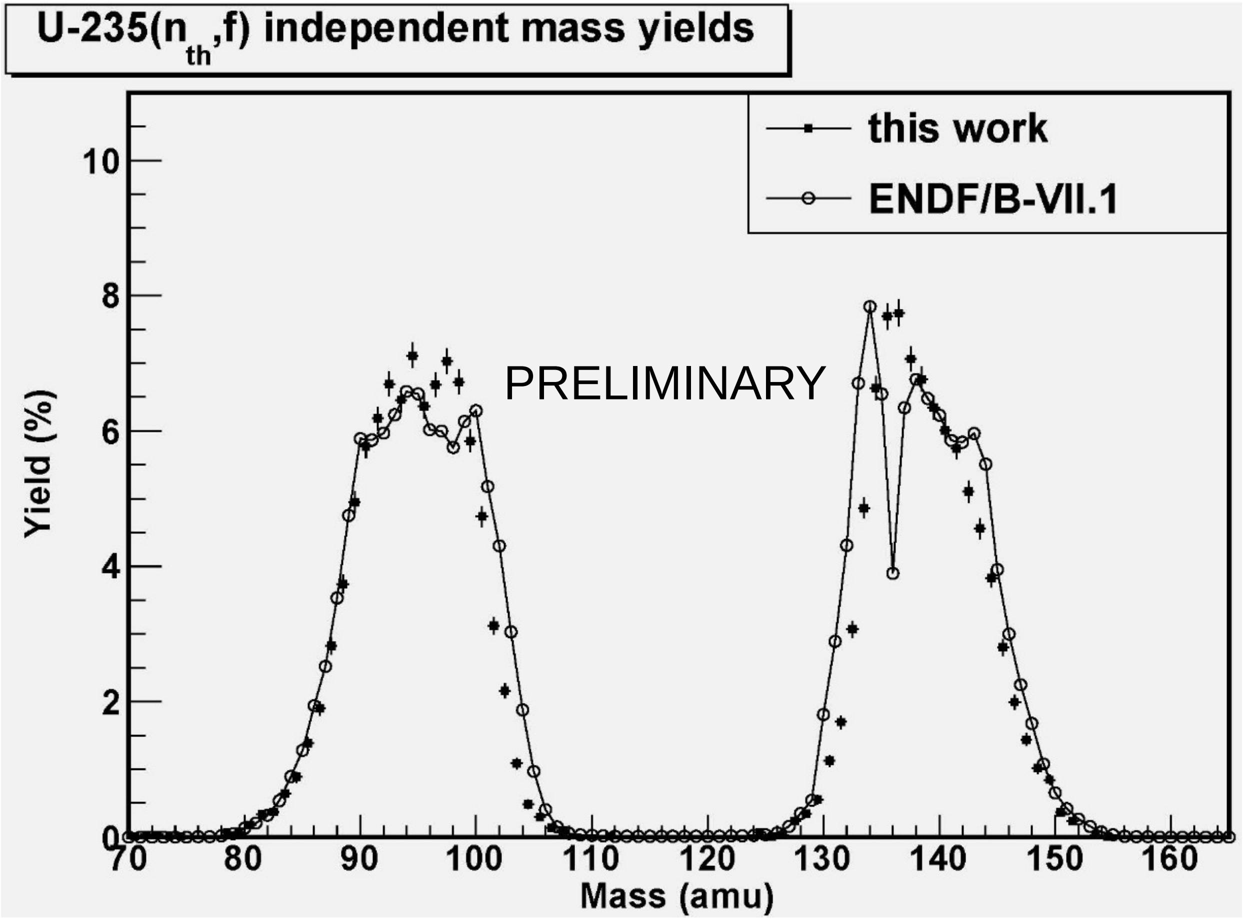


100 keV FWHM energy resolution (alpha – ~1.5%, FP - ~0.75%)

***with 2.5 um Mylar windows

Best to Date Mass Results

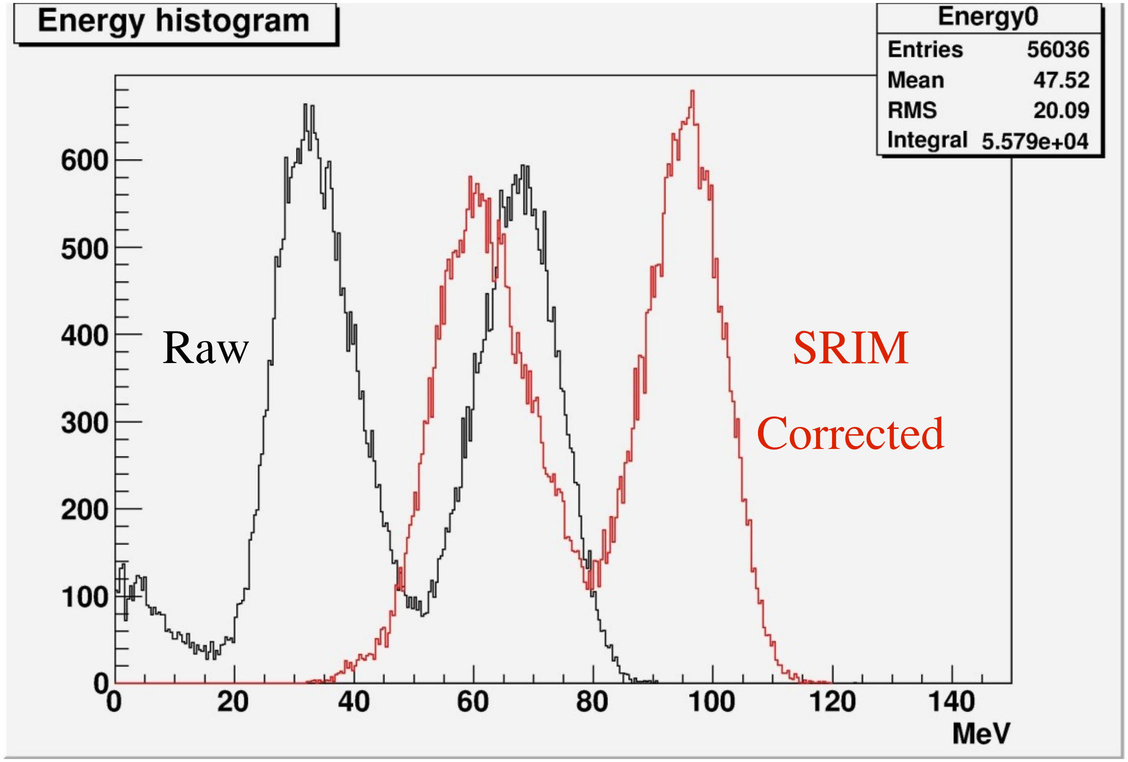
- ^{235}U(n_{th}, f) data
  - Roughly 3 amu resolution
    - With Mylar windows and conversion foils



Planned Work: Improved Hardware

- Silicon Nitride (SiN) to replace Mylar windows
  - Spontaneous fission data: *as we speak*
  - ~30% loss through 2.5 um Mylar; ~3% with 200 nm SiN — energy straggling is directly proportional to loss

^{235}U(*n*,*f*) FP Energy *w/ Mylar*



Conclusion

- What we have now:
  - Fully constructed Dual Arm
    - ~3 AMU mass resolution
    - In place to take E_n dependent correlated FPY data
- What we aim to accomplish:
  - 1 AMU mass resolution with SiN windows.
  - Correlated ^{252}Cf(*sf*) data by September
    - PRC paper by early 2015
  - Correlated ^{235}U(*n*,*f*) and ^{239}Pu(*n*,*f*) data by early 2015
    - PRC papers
  - Dan getting a PhD
    - ^{235}U(*n*,*f*) , ^{239}Pu(*n*,*f*) and ^{252}Cf(*sf*) data for a defense in late 2015

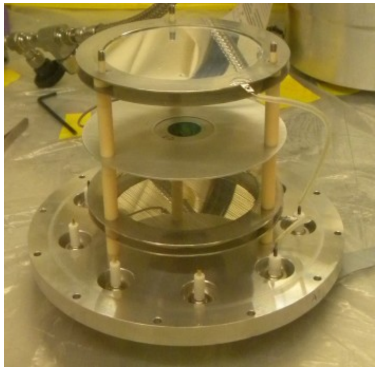
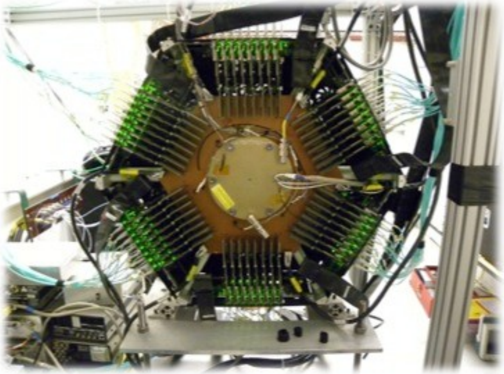
The SPIDER Collaboration

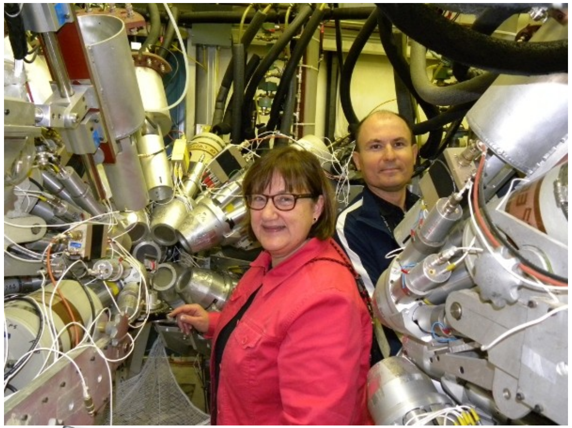
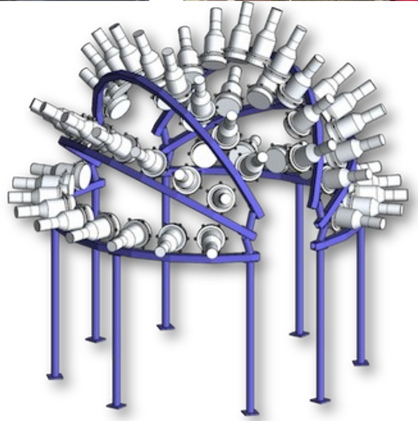
- **Los Alamos National Laboratory (LANL)**
  Charles Arnold, Todd Bredeweg, Tom Burr, Matt Devlin, Mac Fowler, Marian Jandel, ***Justin Jorgenson***, Alexander Laptev, John Lestone, Paul Lisowski, Rhiannon Meharchand, ***Krista Meierbachtol***, Peter Moller, Ron Nelson, John O’Donnell, Brent Perdue,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

Supplemental Slides

LANSCE Fission Experiments

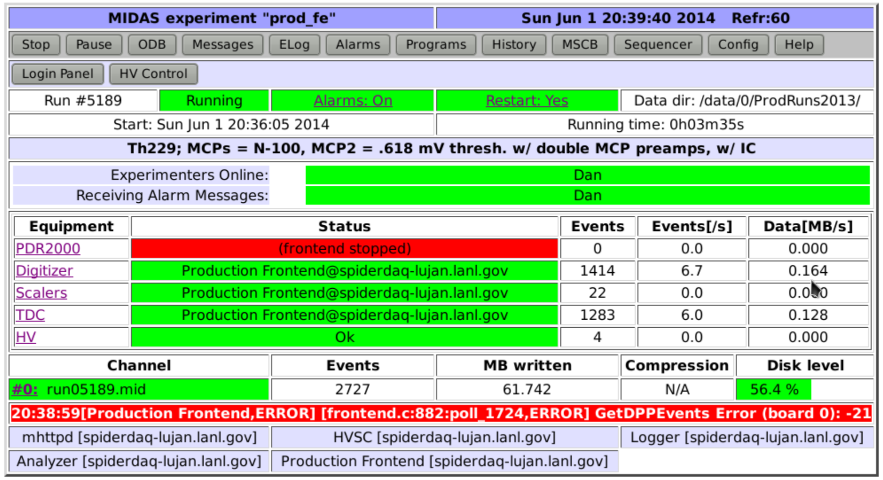
- **Fission Fragment Observables**
  - Fission Product Yields
    - SPIDER, TKE
  - Total Kinetic Energy
    - SPIDER, TKE
- **Fragment Emission Observables**
  - ***Gamma*** Multiplicity and Energy Spec.
    - DANSCE, GEANIE, Chi Nu
  - ***Neutron*** Multiplicity and Energy Spec.
    - Chi-Nu (SPIDER)
- **Fission Cross Section**
  - DANSCE, GEANIE, TPC

SPIDER: DAQ

- **NIM**
  - MCP-DLA signals fed into Constant Fraction Discriminators (CFDs)
    - 10 ps intrinsic time resolution
  - Trigger logic for X(*n*,*f*)
- **VME**
  - Time to Digital Converter (TDC)
    - CFD used as input
    - 25 ps sampling
  - Digitizer
    - 14 bit, 100 MS/s
    - 2.25 Vpp range
- **Software**
  - MIDAS interfaced fronted and slow controls, ROOT analyser.



MIDAS experiment "prod_fe"	**Sun Jun 1 20:39:40 2014 Refr:60**

Run #5189	Running	Alarms: On	Restart: Yes	Data dir: /data/0/ProdRuns2013/

Start: Sun Jun 1 20:36:05 2014

Running time: 0h03m35s

Th229; MCPs = N-100, MCP2 = .618 mV thresh. w/ double MCP preamps, w/ IC

Experimenters Online: Dan

Receiving Alarm Messages: Dan

Equipment	Status	Events	Events[/s]	Data[MB/s]
PDR2000	(frontend stopped)	0	0.0	0.000
Digitizer	Production Frontend@spiderdaq-lujan.lanl.gov	1414	6.7	0.164
Scalers	Production Frontend@spiderdaq-lujan.lanl.gov	22	0.0	0.0[illegible]0
TDC	Production Frontend@spiderdaq-lujan.lanl.gov	1283	6.0	0.128
HV	Ok	4	0.0	0.000

Channel	Events	MB written	Compression	Disk level
#0: run05189.mid	2727	61.742	N/A	56.4 %

```
20:38:59[Production Frontend,ERROR] [frontend.c:882:poll_1724,ERROR] GetDPPEvents Error (board 0): -21
```

mhttpd [spiderdaq-lujan.lanl.gov]

HVSC [spiderdaq-lujan.lanl.gov]

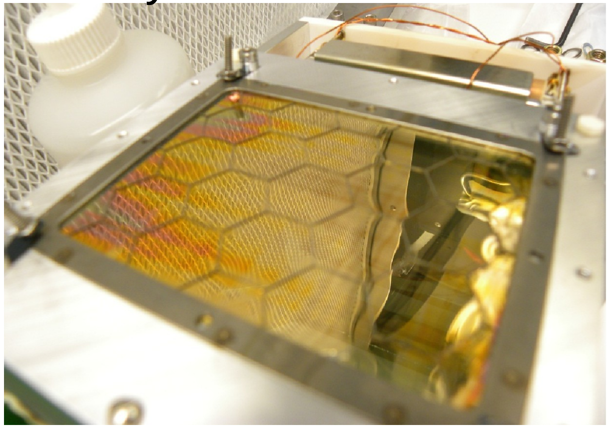
Logger [spiderdaq-lujan.lanl.gov]

Analyzer [spiderdaq-lujan.lanl.gov]

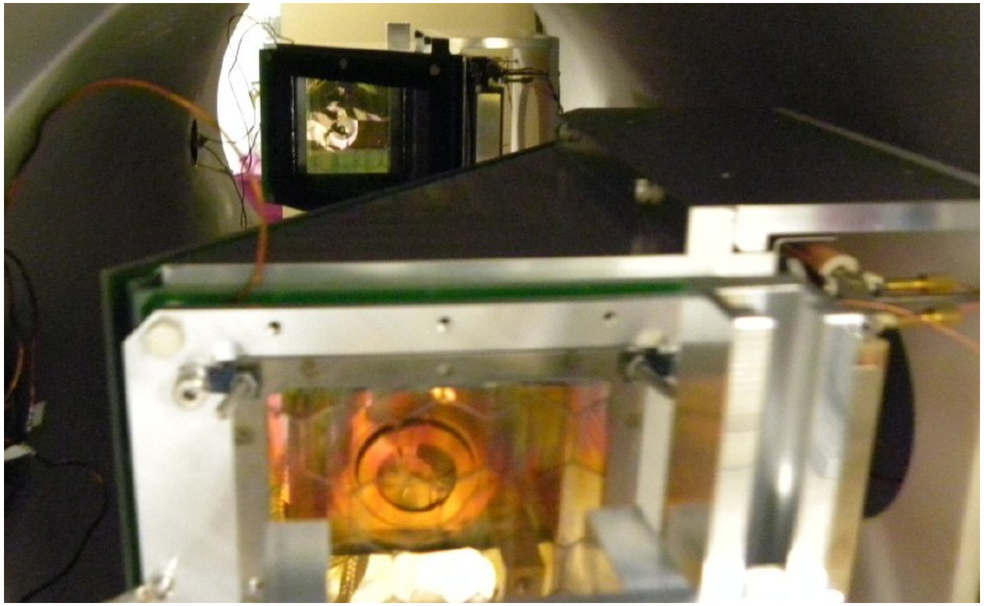
Production Frontend [spiderdaq-lujan.lanl.gov]

Preliminary Work: MCP-DLA Hardware

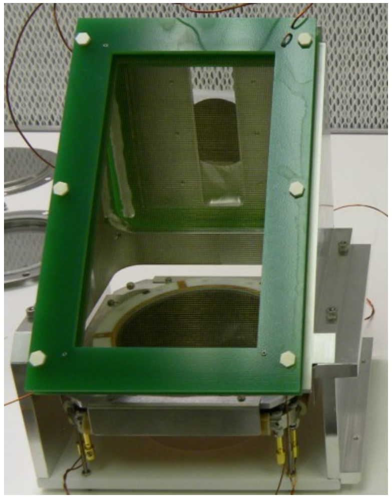
Au+Mylar Conversion Foil



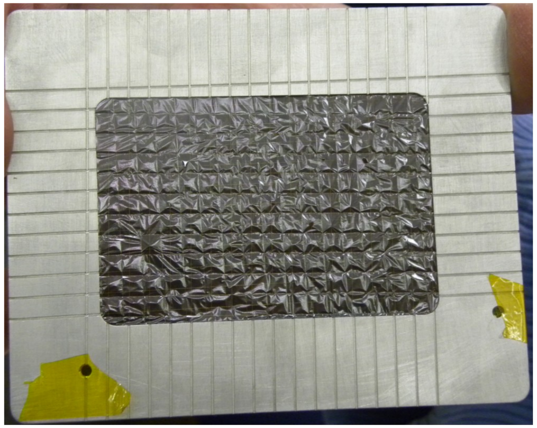
ToF Arm in Chamber



MCP-DLA

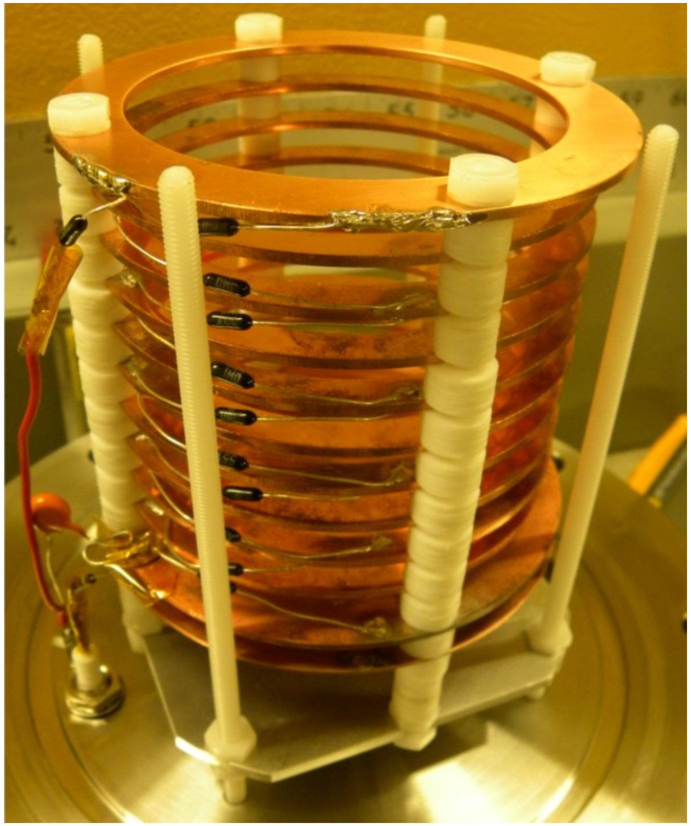


Carbon Conversion Foil

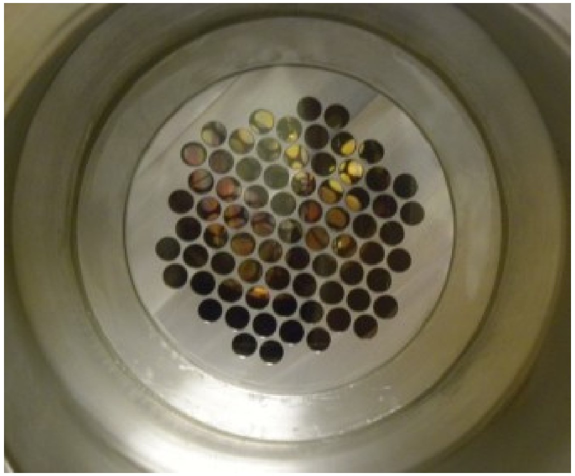


Preliminary Work: IC Hardware

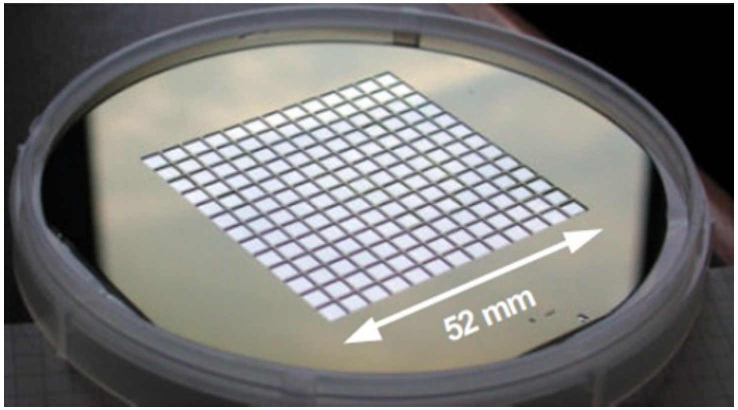
Electrical Detail



Mylar Window Detail



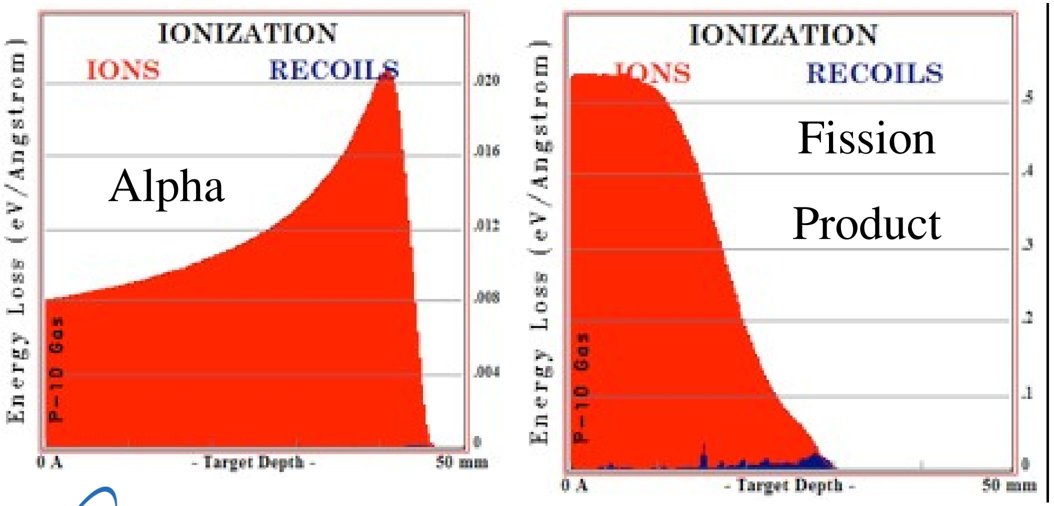
SiN Window Detail



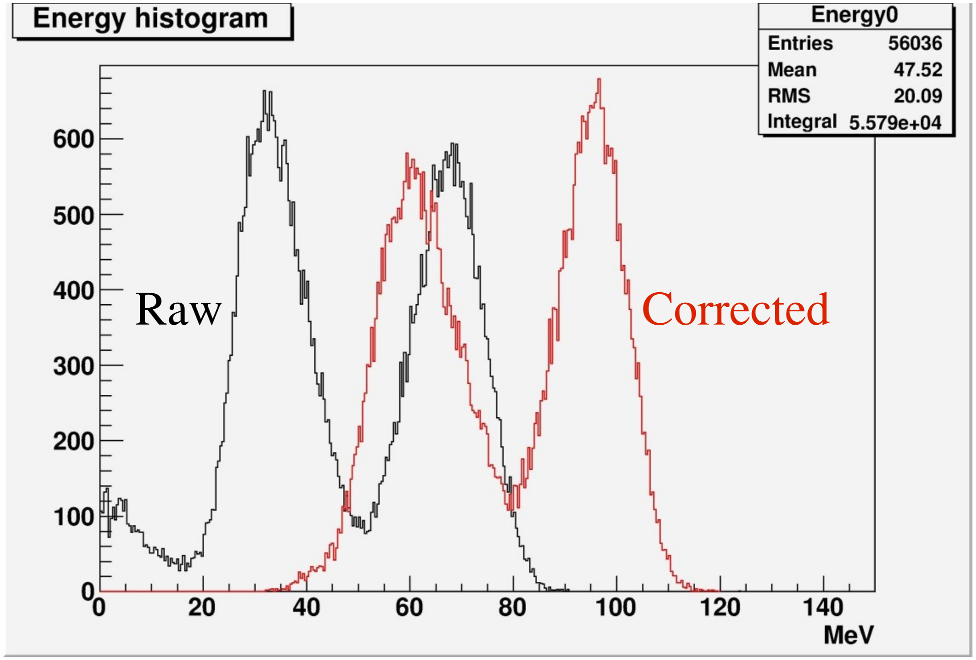
SPIDER: Basic Energy Simulation

- **TRIM Simulation of Energy Loss and Straggling**
  - Add back losses in conversion foils and IC window
    - Based on fission product *m, Z, E*
    - TRIM stopping power within media accurate within ~15% for fission products
  - Account for nuclear stopping losses in IC
    - Pulse height defect estimation

TRIM Brag Peaking



Fission Product Energy



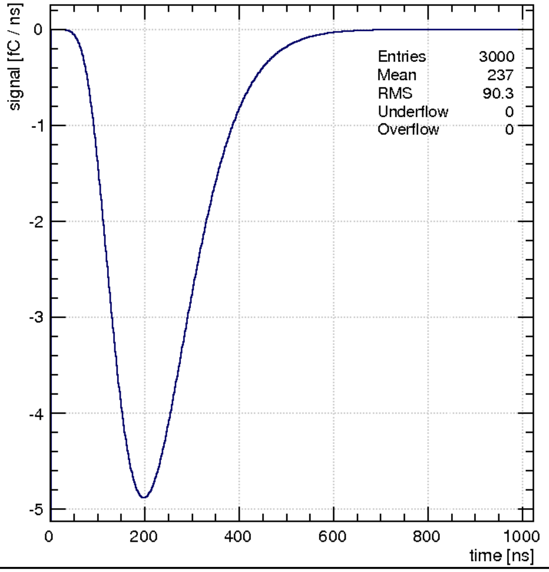
SPIDER: Advanced Energy Simulation

- *Under Development!*
- **TRIM&Garfield Simulation**
  - Most realistic gas ionization pattern via ***TRIM***
  - Drift electrons in gas via ***Garfield*** to:
    - Non-uniform IC e-field losses
    - Ionized gas recombination losses
    - Frisch grid inefficiency
    - Generate realistic IC signals and energy spectra
  - ***Deconvolution*** of real signal to obtain fission product energy
    - Use simulated signals for various *E, Z, m* and trajectory of fission products.


TRIM Track

Garfield Drift

Garfield Preamp Anode Signal



SPIDER: Basic Mass Analysis

- Assume *m (and Z)* from measured velocity
  - From available ENDF/JEFF FPY data
  - Measured velocity has negligible *Z* dependence
  - Less fission product *E* straggling in ToF detector
  - Better resolution than measured *E*
- Correct and calibrate measured *E* based on TRIM losses
- Correct and calibrate ToF based on TRIM losses
- Calibrate position based on position mapping
- Calculate *m*
  - $E = \frac{1}{2}m|\vec{v}|^2 \quad \Rightarrow \quad m = \frac{2E}{|\vec{v}|^2}$

SPIDER: Advanced Mass Analysis

- ***Under Development!***
- Assume A and Z from measured velocity
- Iterative Method:
  1) Correct velocity from target and first foil losses
  2) Correct E from target, foils, and window losses
  3) Calculate m *(and* Z*)*
  4) Repeat until convergent on 1 unit m *(and* Z*)*