The UNM Fission Spectrometer for individual fission fragment identification and correlated gamma-rays

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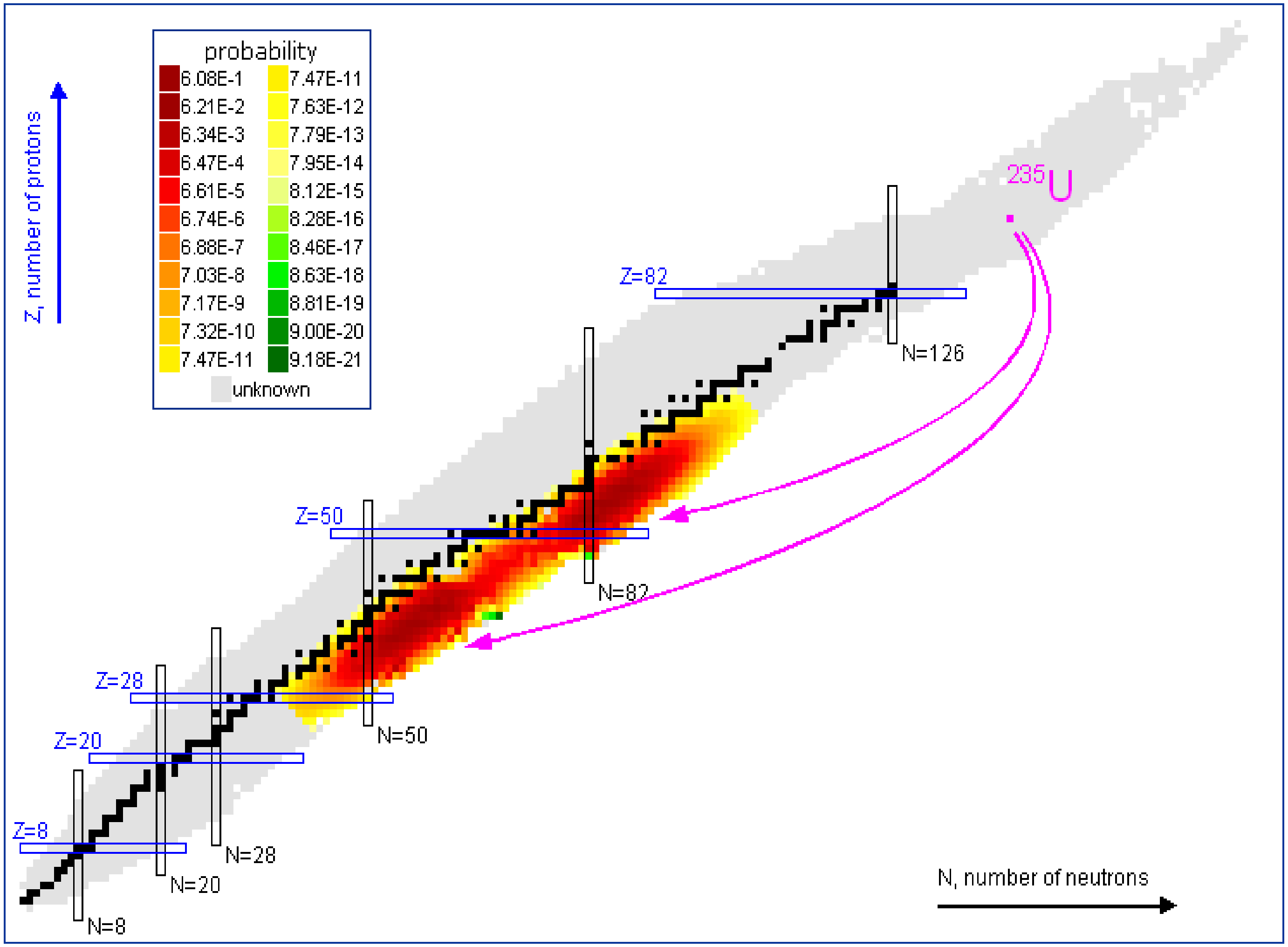
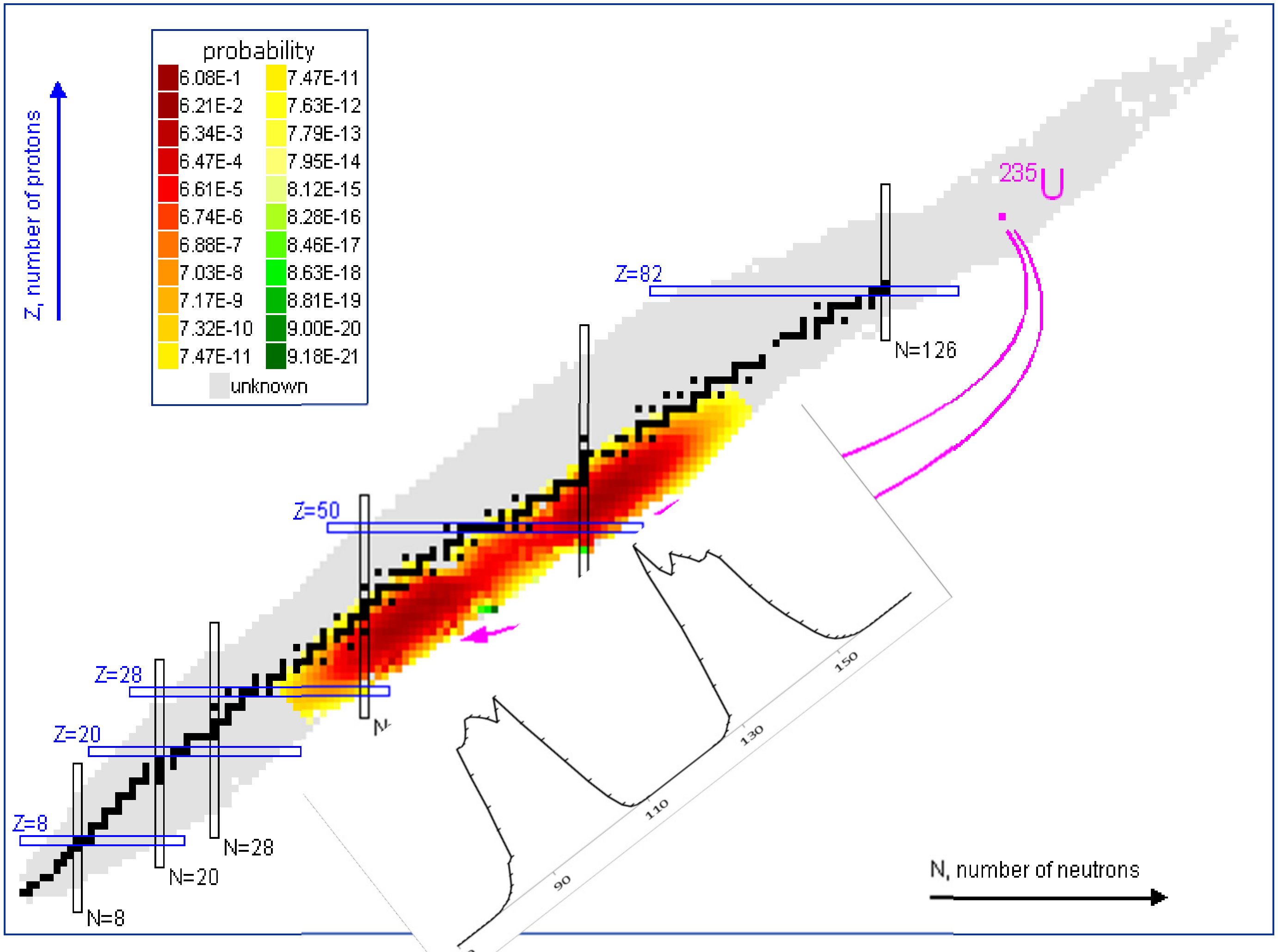
March 23, 2021

ANS Trinity Lightning Talk

Motivation


probability
6.08E-1
6.21E-2
6.34E-3
6.47E-4
6.61E-5
6.74E-6
6.88E-7
7.03E-8
7.17E-9
7.32E-10
7.47E-11
7.47E-11
7.63E-12
7.79E-13
7.95E-14
8.12E-15
8.28E-16
8.46E-17
8.63E-18
8.81E-19
9.00E-20
9.18E-21
unknown
Z, number of protons
N, number of neutrons
235U
Z=82
Z=50
Z=28
Z=20
Z=8
N=126
N=82
N=50
N=28
N=20
N=8

Motivation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Z, number of protons
Z=8
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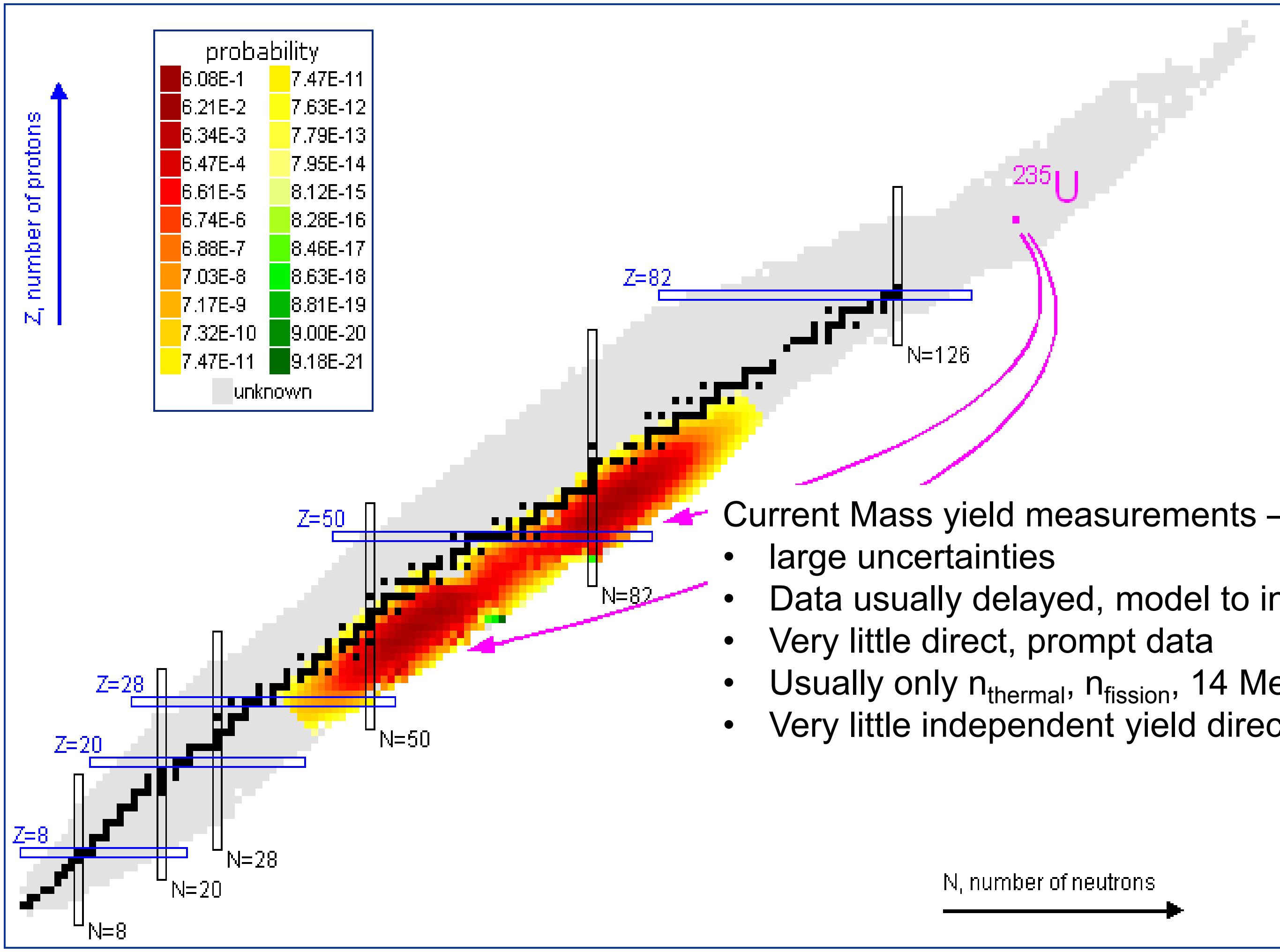
N=8
N=20
N=28
N=126
235U
90
110
130
150
N, number of neutrons

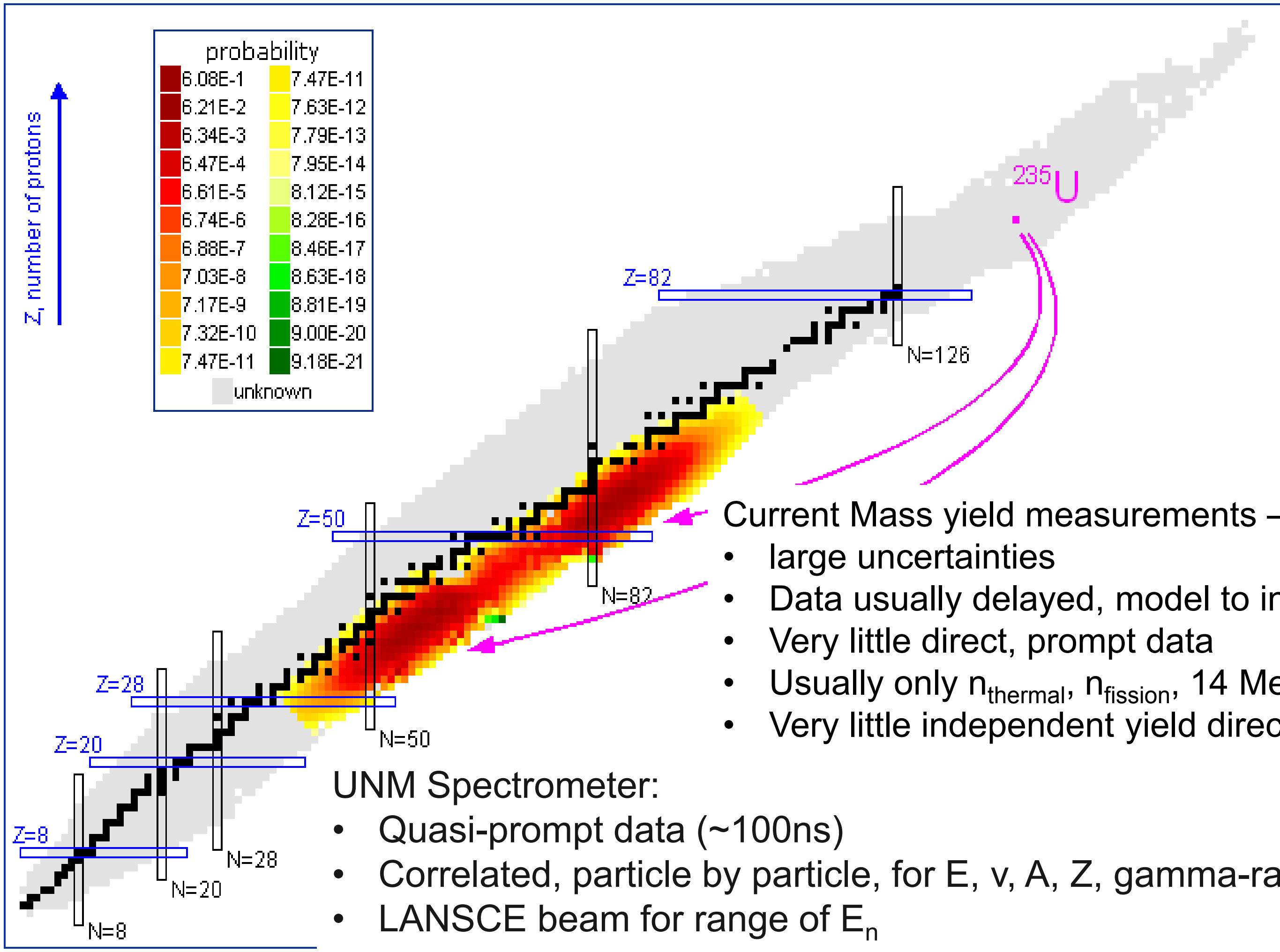
Motivation



Current Mass yield measurements –

- large uncertainties
- Data usually delayed, model to independent
- Very little direct, prompt data
- Usually only $n_{thermal}$, $n_{fission}$, 14 MeV
- Very little independent yield direct data

Motivation



Current Mass yield measurements –

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- Usually only $n_{thermal}$, $n_{fission}$, 14 MeV
- Very little independent yield direct data

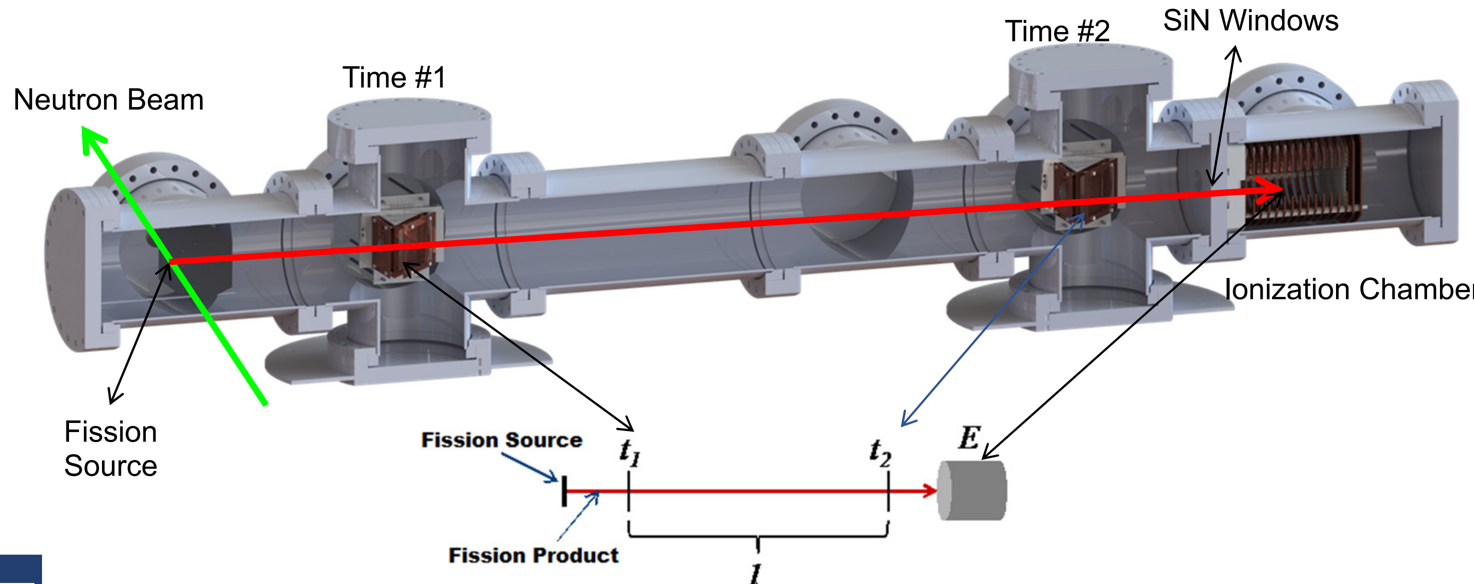
UNM Spectrometer:

- Quasi-prompt data (~100ns)
- Correlated, particle by particle, for E, v, A, Z, gamma-rays
- LANSCE beam for range of E_n

UNM SPIDER Detector: E-v

SPectrometer for
Ion
DEtermination in fission
Research
(SPIDER)

Correlated E, v, A, Z, N for each particle



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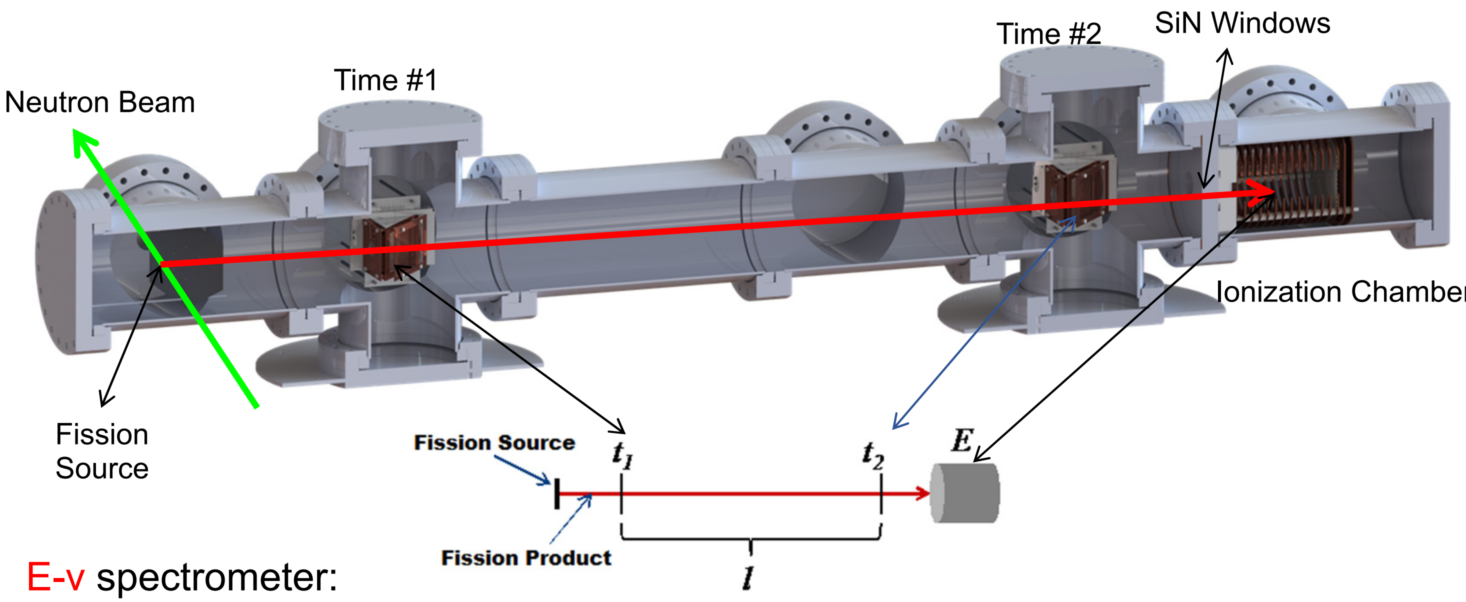
UNM SPIDER Detector: Measuring Particles on the Fly

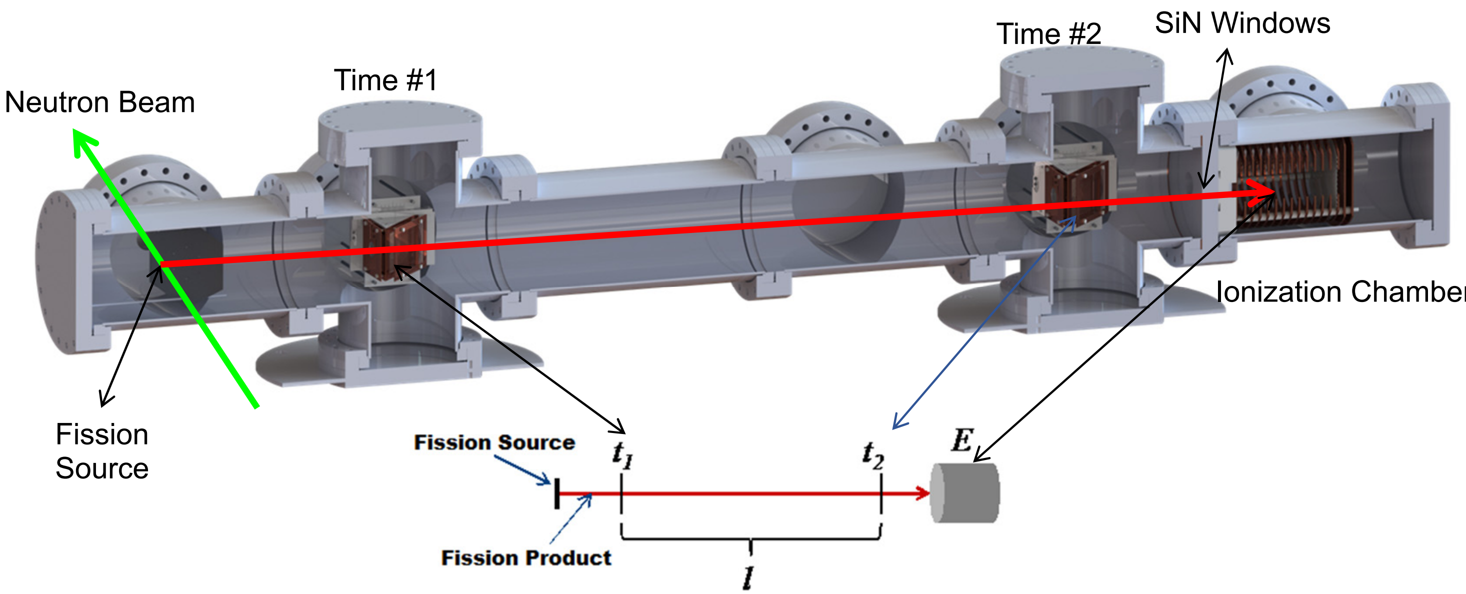


E-v spectrometer:

Measure particle Time of Flight (ToF) → ToF = t_2- t_1 → v = l/ToF

Measure particle energy directly → Ionization chamber gives E

UNM SPIDER Detector: Extracting Mass (A)



Extract A:

$$m = \frac{2E}{v^2} = \frac{2Et^2}{l^2}$$

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

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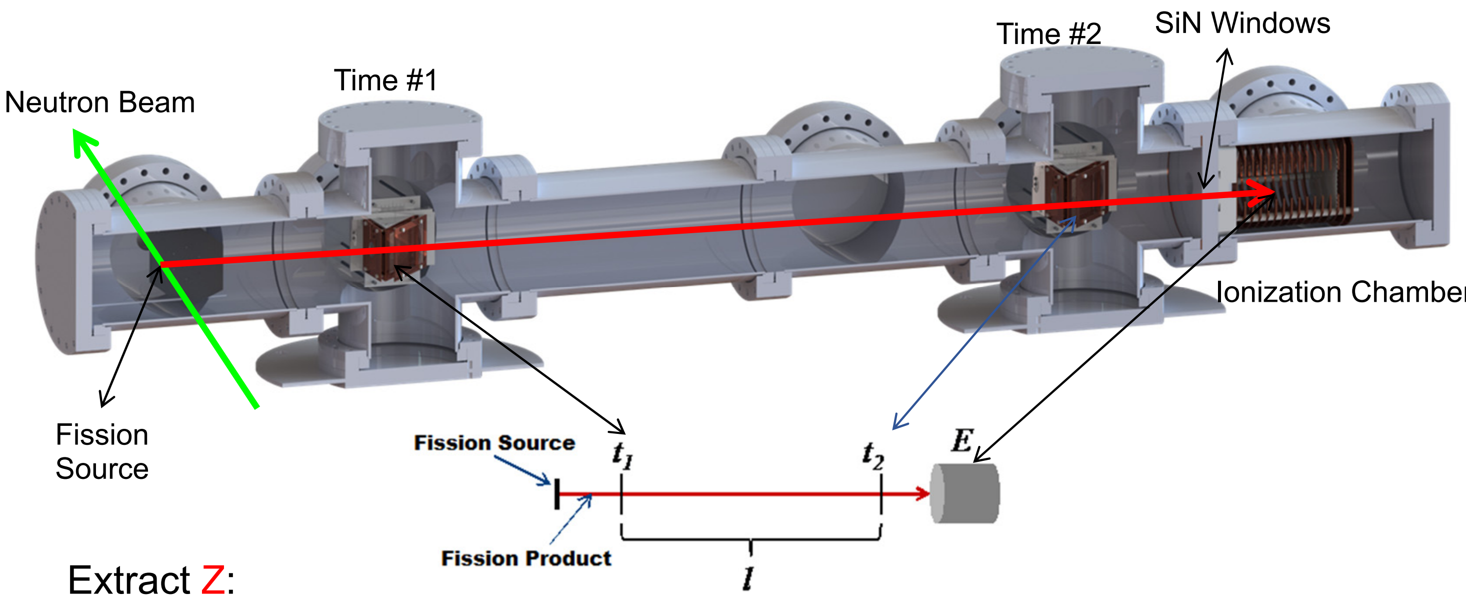
UNM SPIDER Detector: Extracting Charge (Z)



Extract Z:

- Ionization chamber used as time projection chamber
- Active cathode and anode
- Time differences used to determine range
- Range related to Z

Extract N: Knowing A and Z → N

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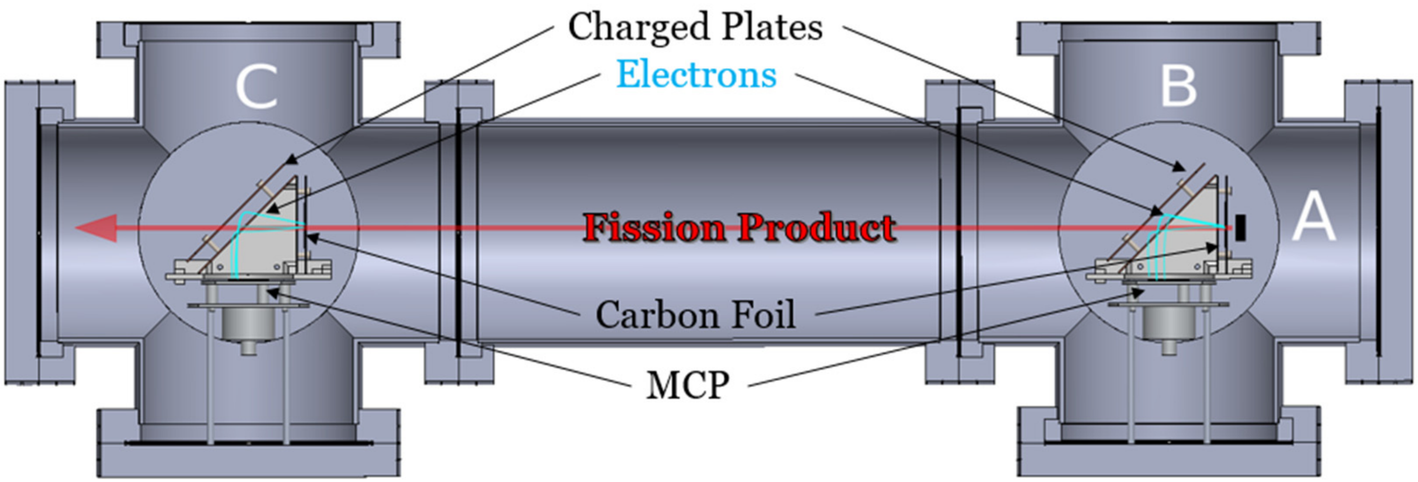
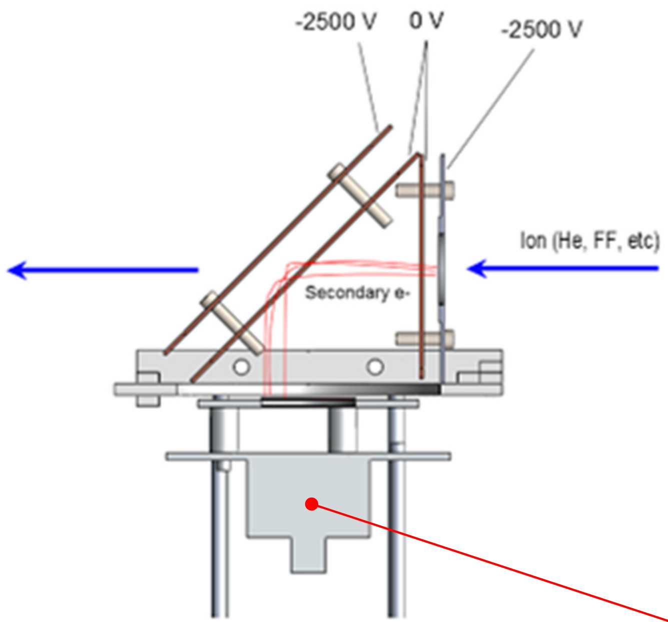
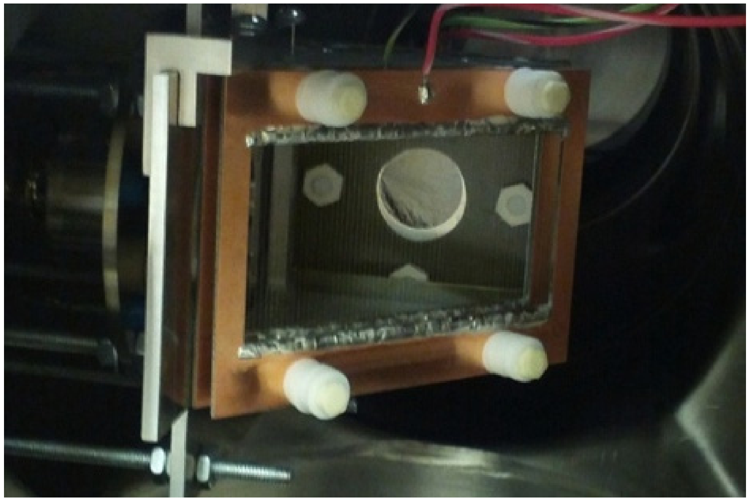
Time of Flight



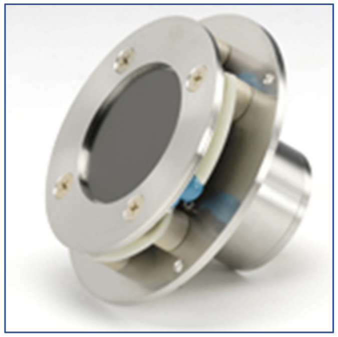
A: Source
B: Timing signal #1
C: Timing signal #2

Time of Flight

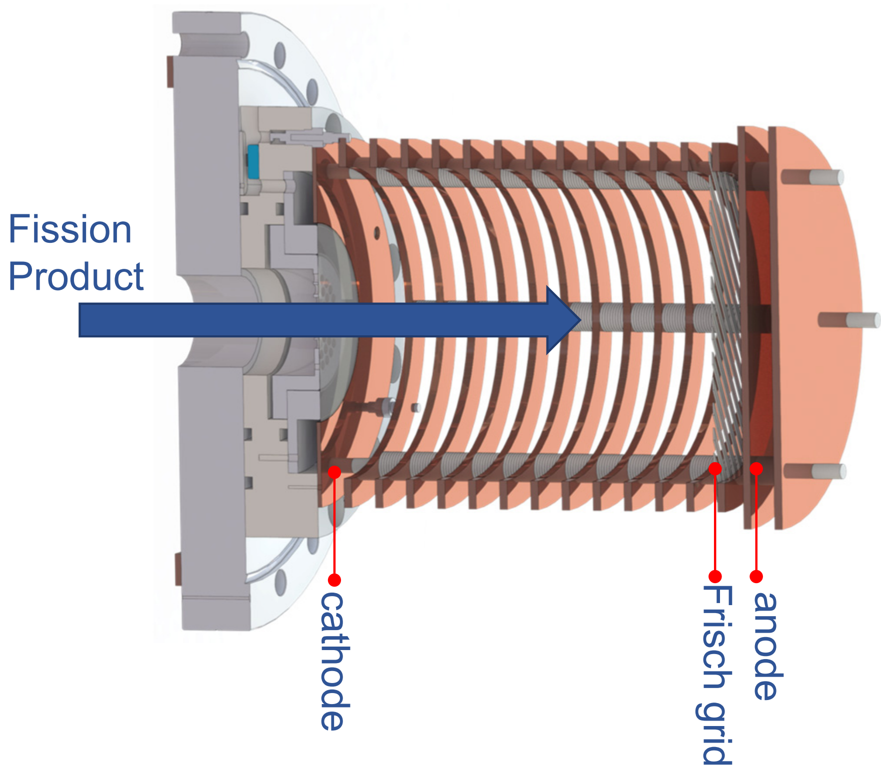


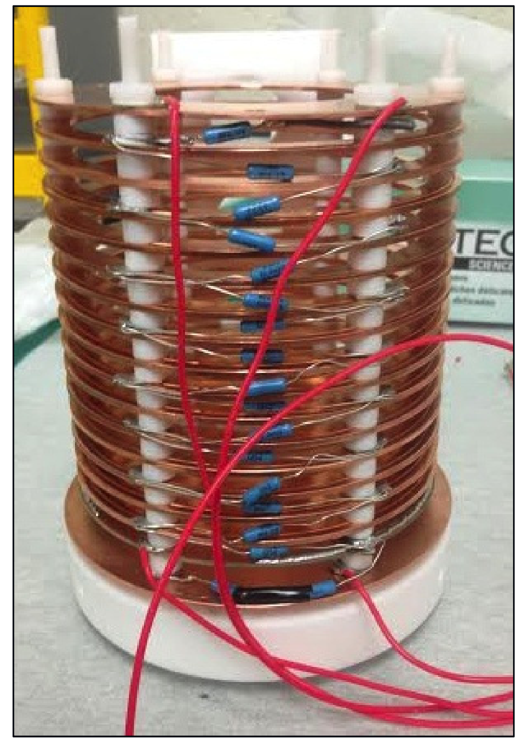


Microchannel plate detector

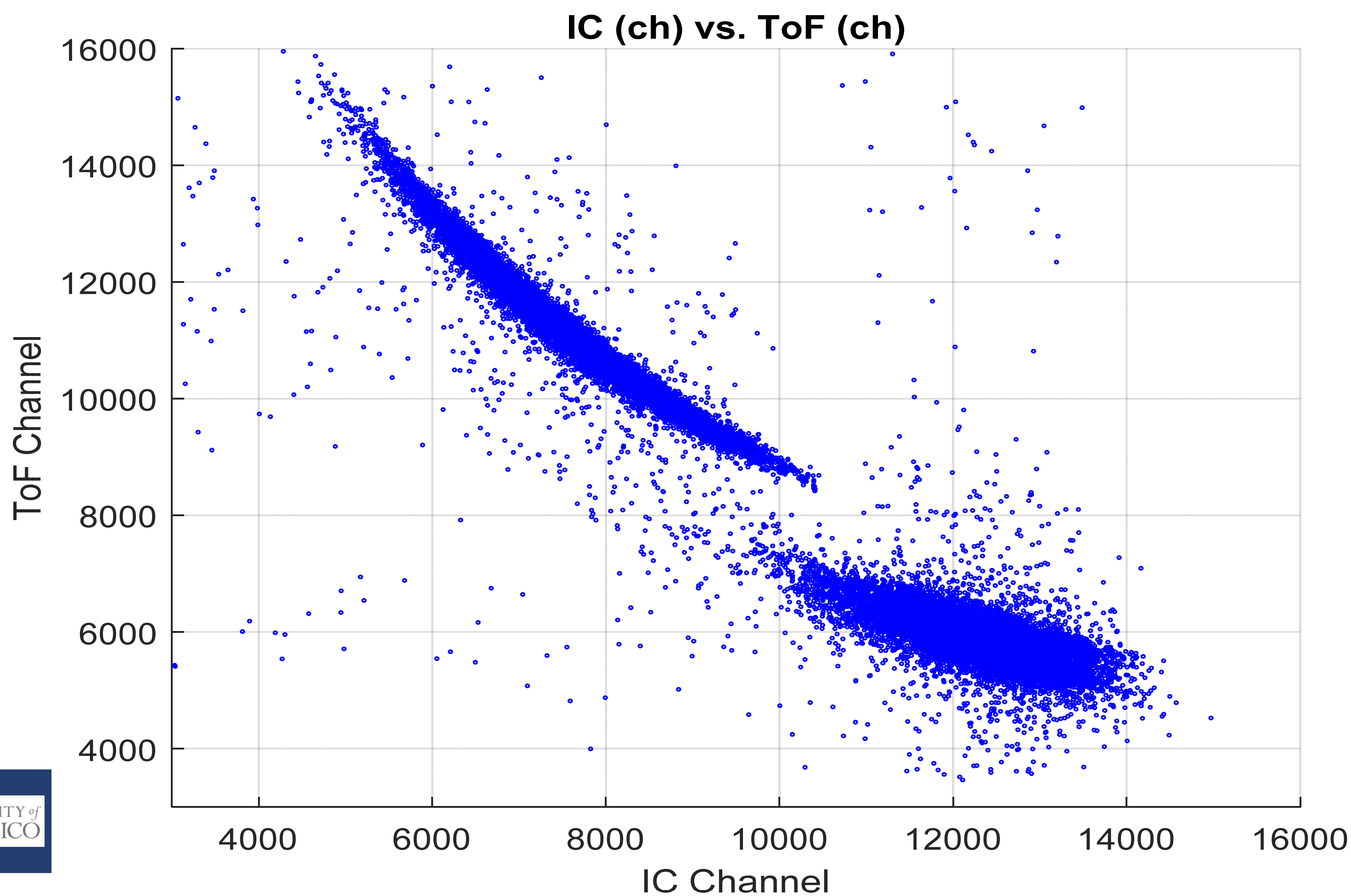


Ionization Chamber

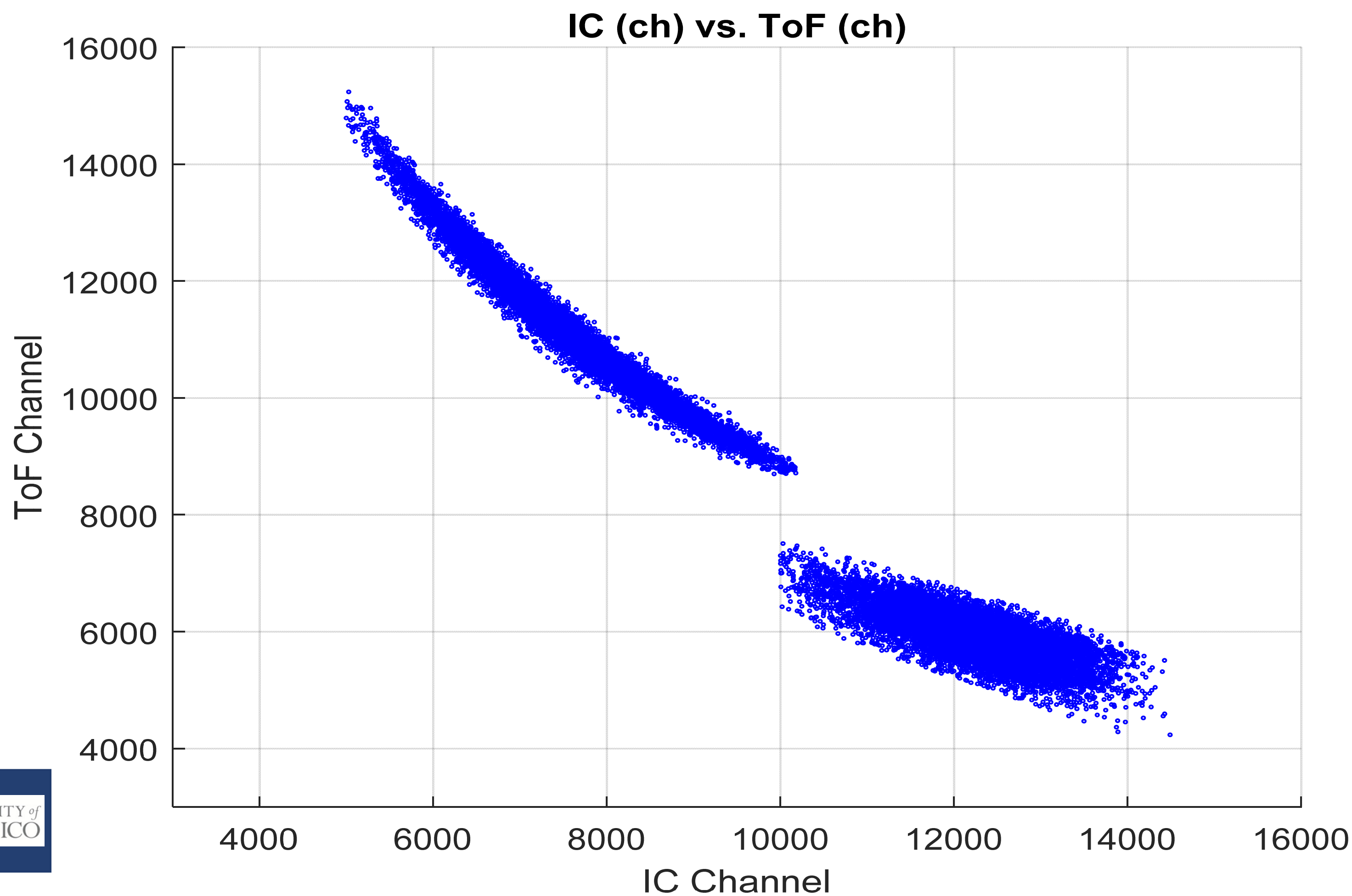




Raw Data


IC (ch) vs. ToF (ch)
ToF Channel
IC Channel
16000
14000
12000
10000
8000
6000
4000
4000
6000
8000
10000
12000
14000
16000

Raw Data with Scatter Removed: ^{235}U



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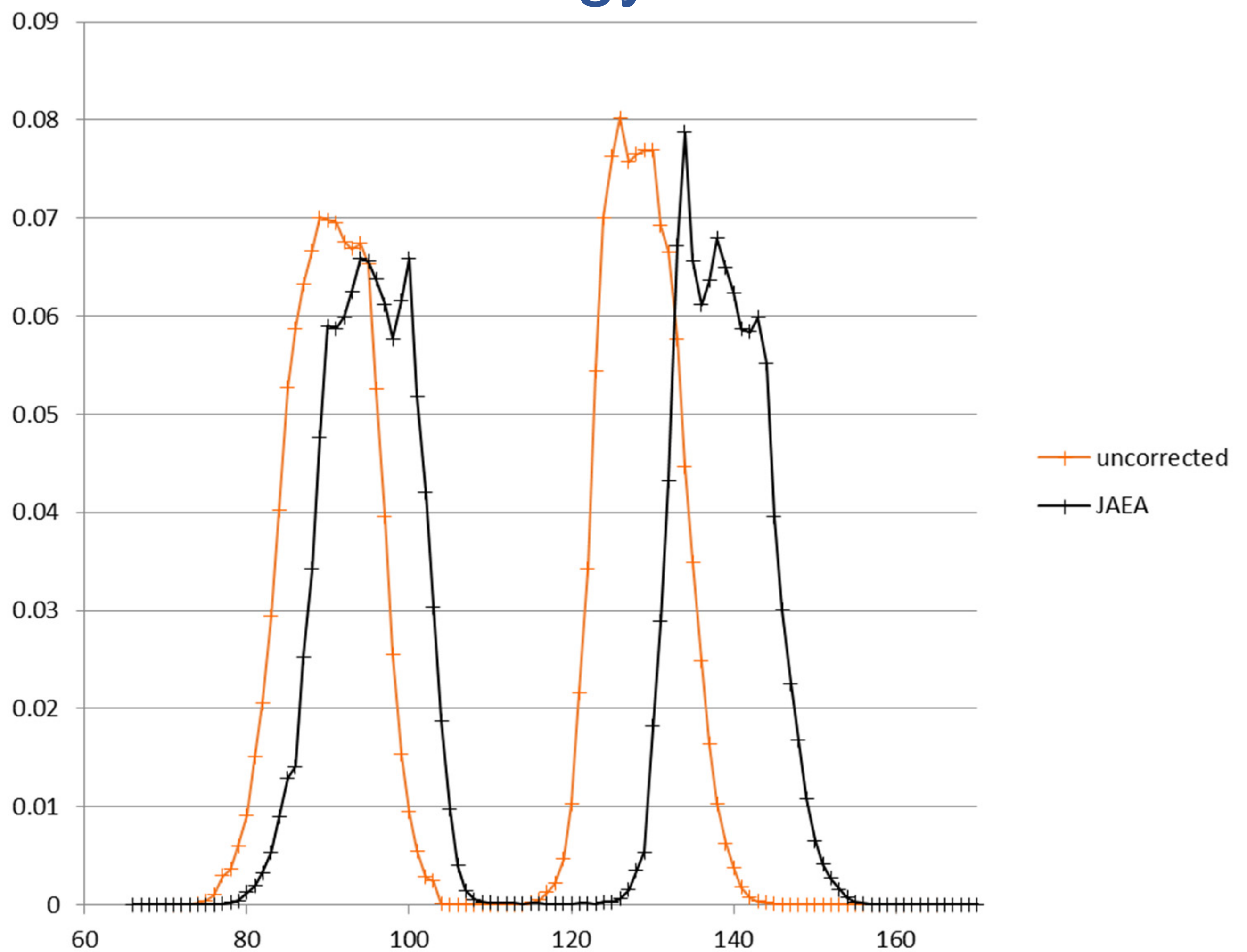
Mass Yields Without Energy Addback



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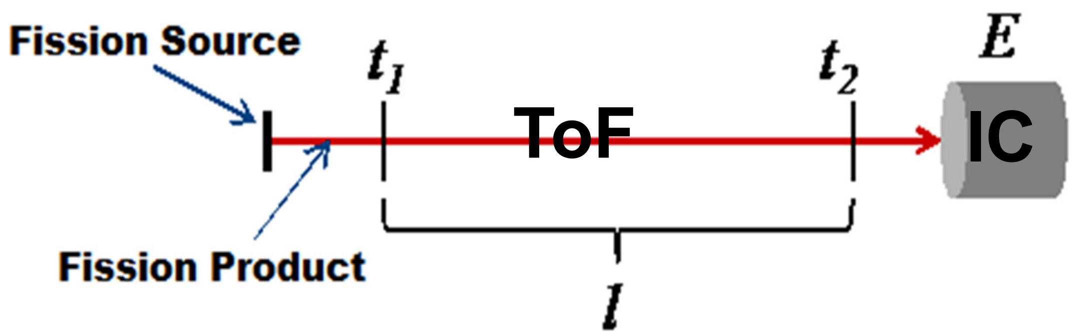
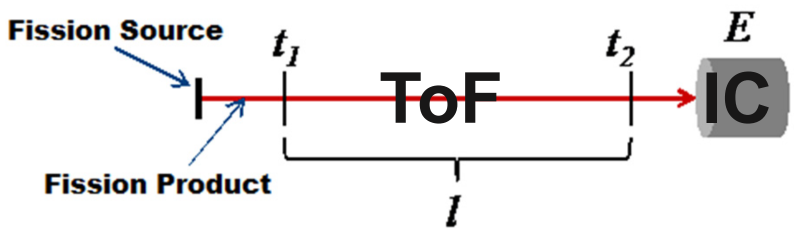
Correcting for Energy Loss

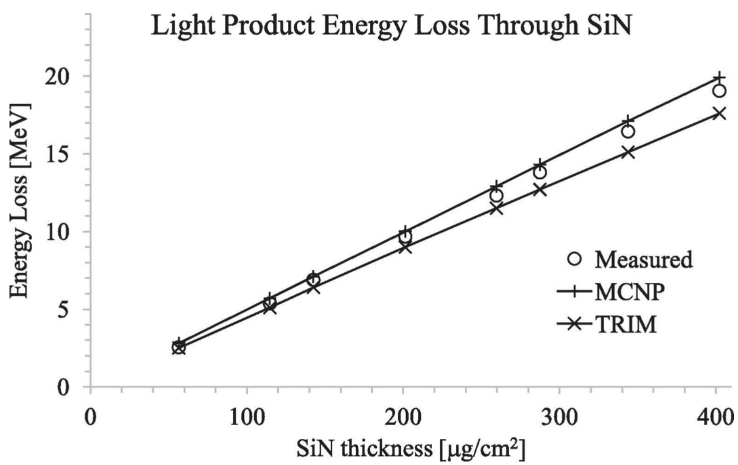


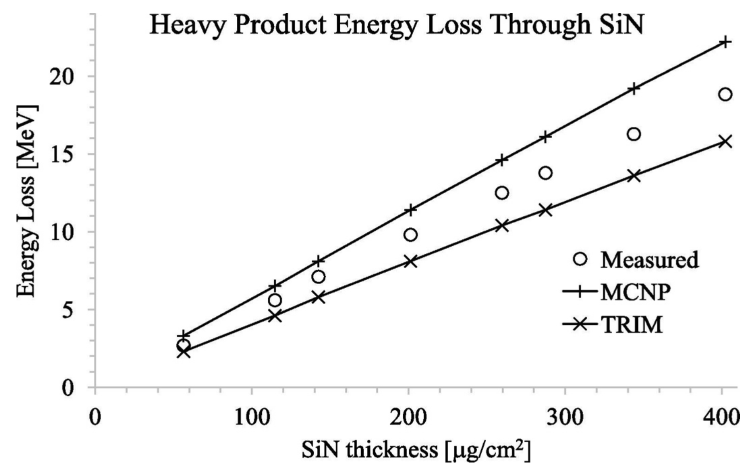
Energy in ToF and IC regions are different, cannot be correlated directly

- 159.4 ug/cm^2 UF_4 Target
- 50 ug/cm^2 Carbon ToF Foils
- 58 ug/cm^2 SiN IC Window

Energy Loss Corrections: Simulations







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P. Baldez, S. Fellows, R.E. Blakeley, M. Tanguay, M.L. Wetzel, A.A. Hecht, D. Mayorov, F. Tovesson, J. Winkelbauer, *Measurements of ^{252}Cf fission product energy loss through thin silicon nitride and carbon foils, and comparison with SRIM-2013 and MCNP6.2 simulations*, NIM B 456, 2019.

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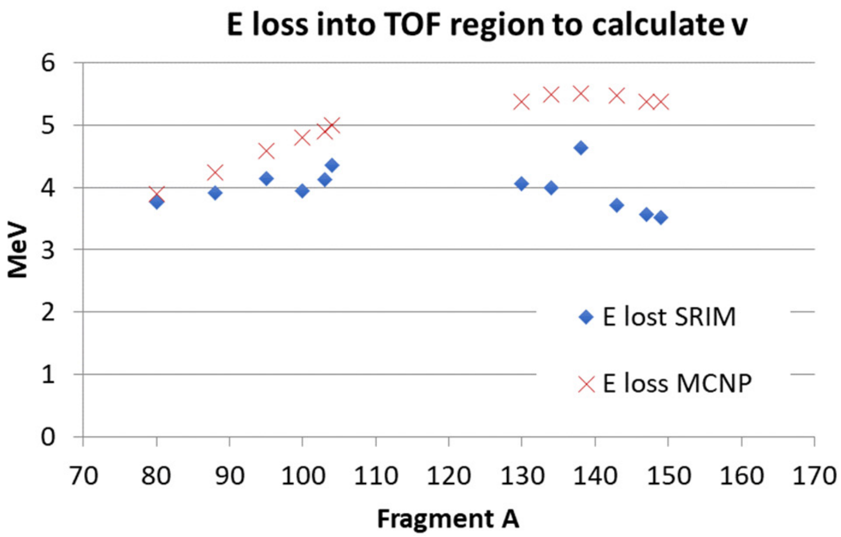
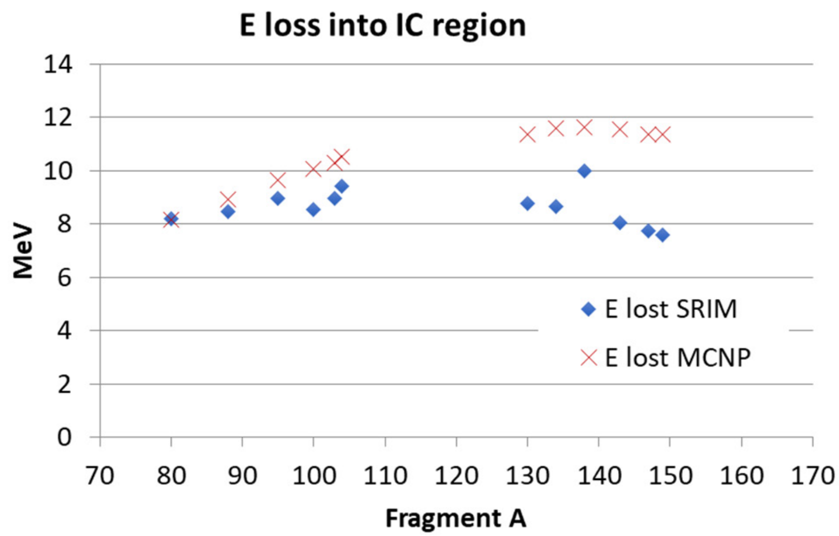
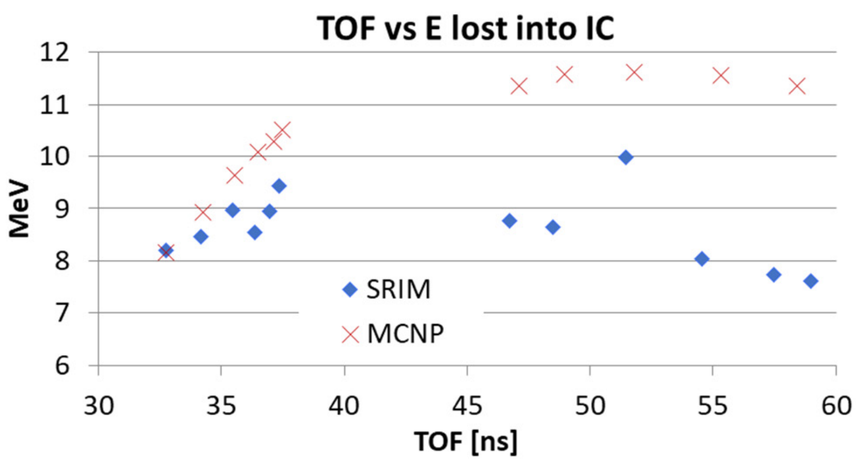
Simulations: SRIM vs. MCNP







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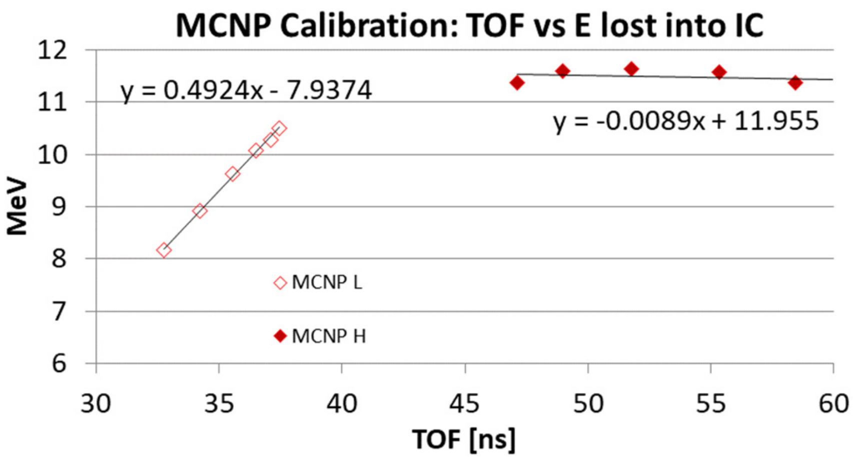
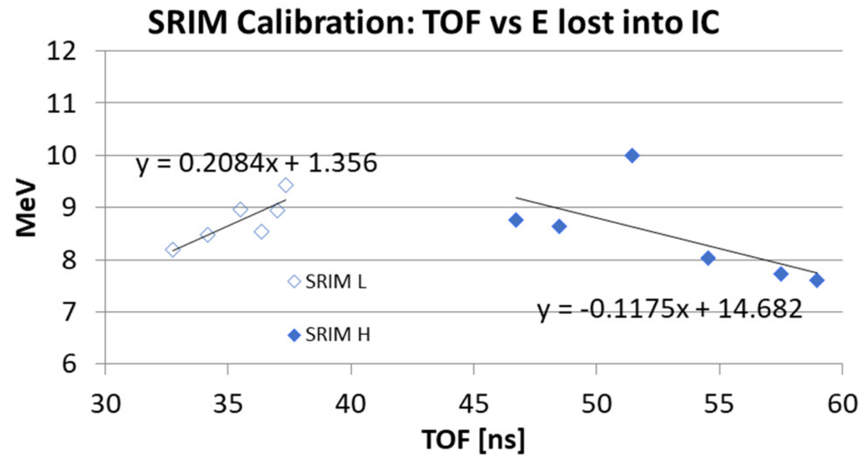
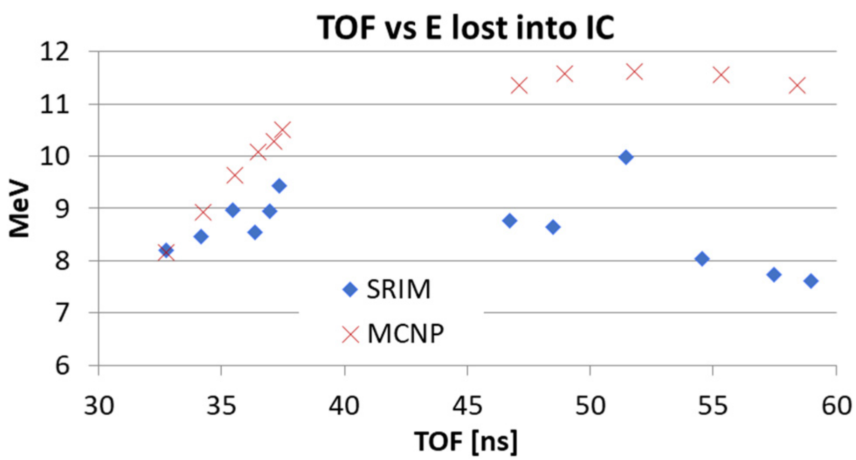
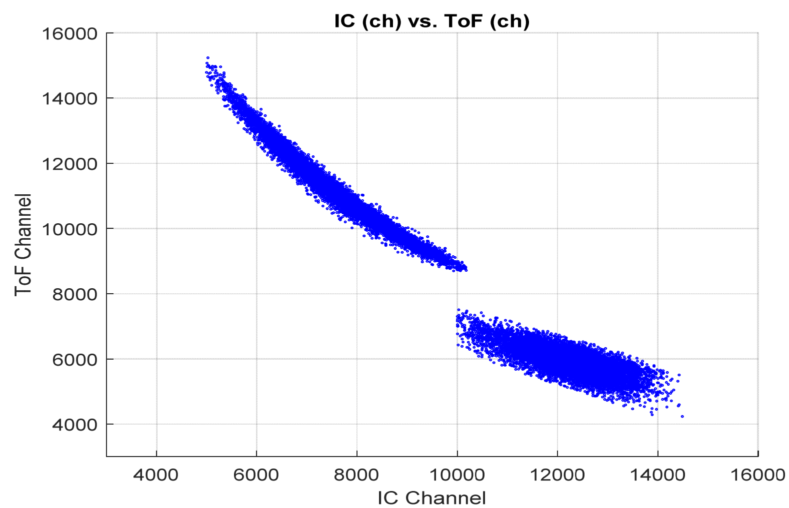


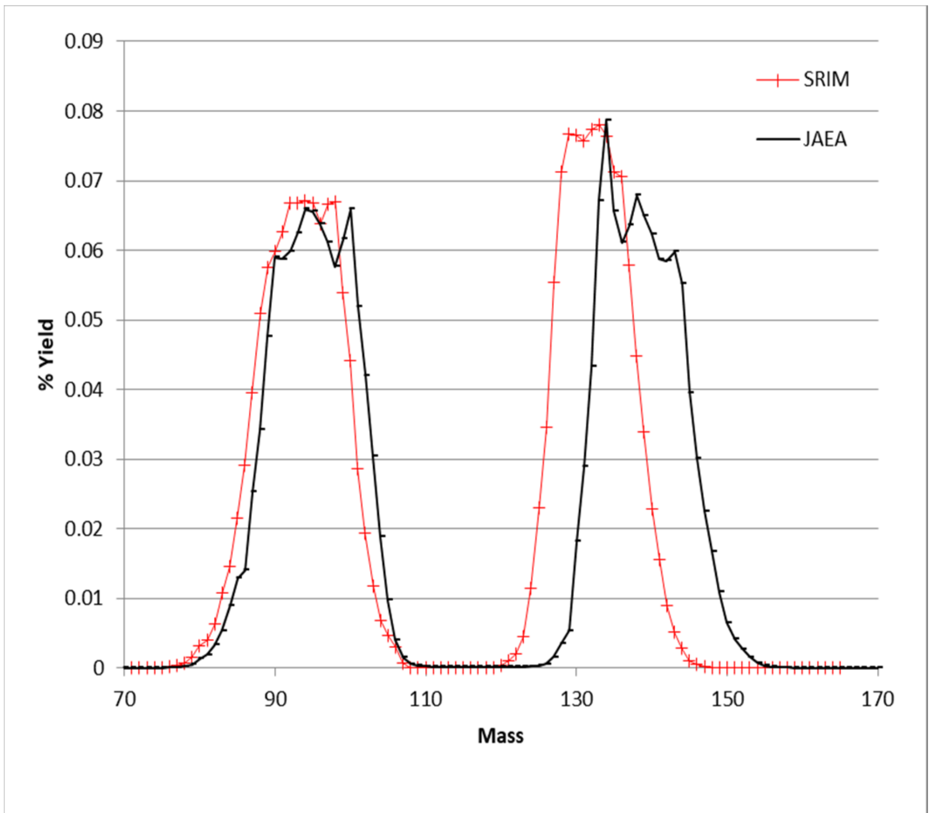


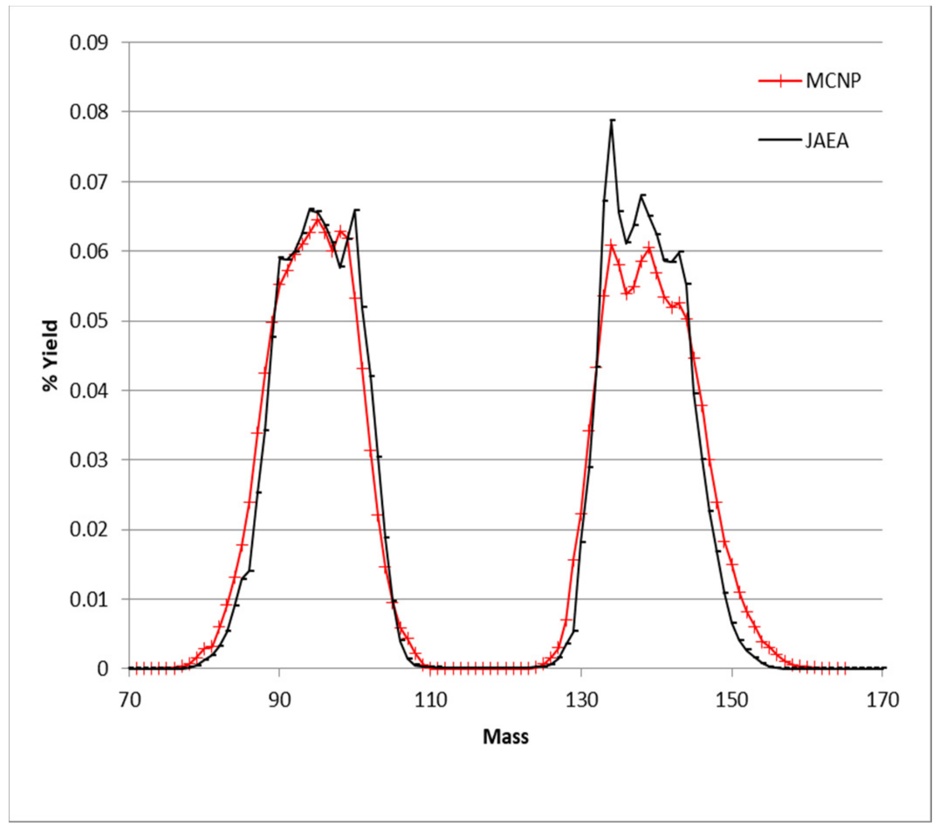




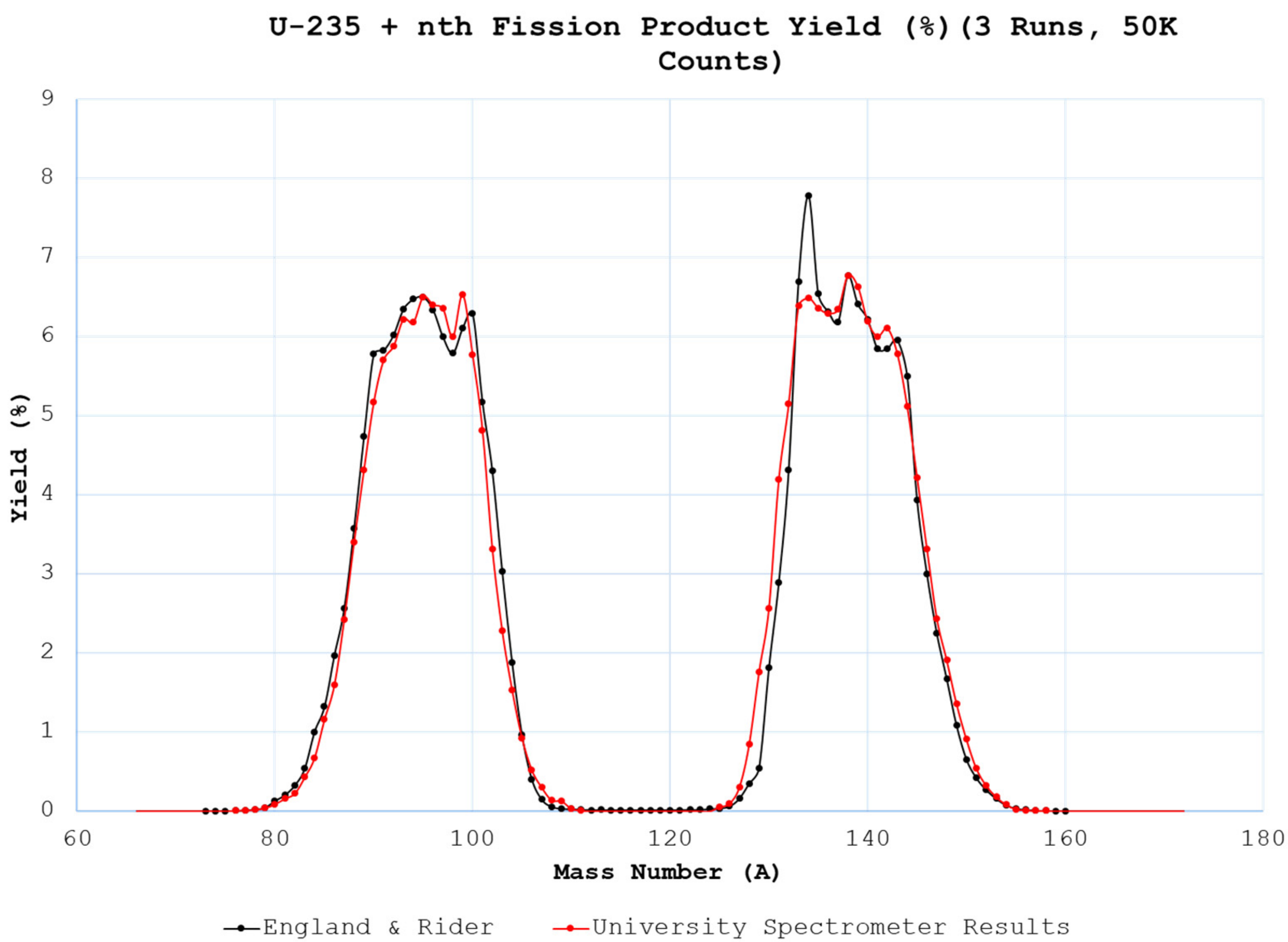
Simulations: Mass Yield Comparison

Light 1 AMU = 1/90 = 1.1% FWHM
Heavy 1 AMU = 1/140 = 0.7% FWHM





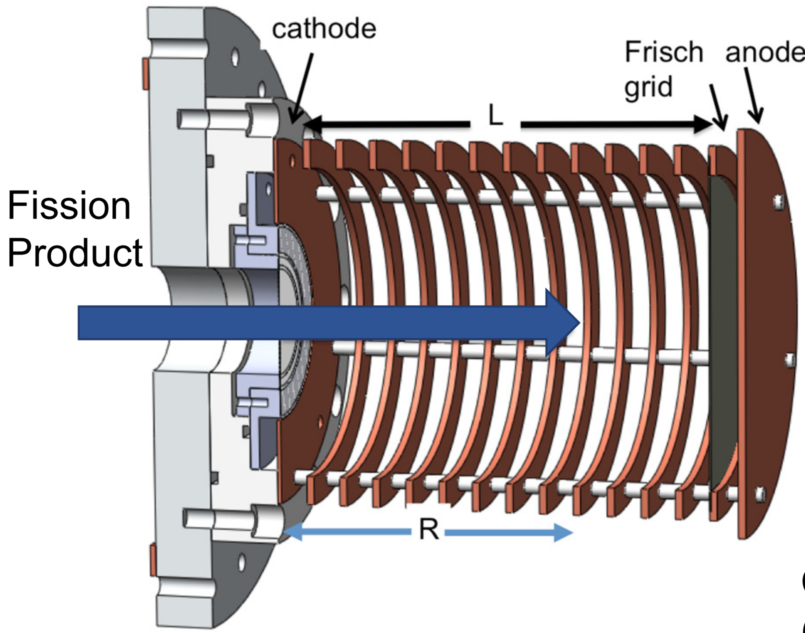
Mass Yield Comparison

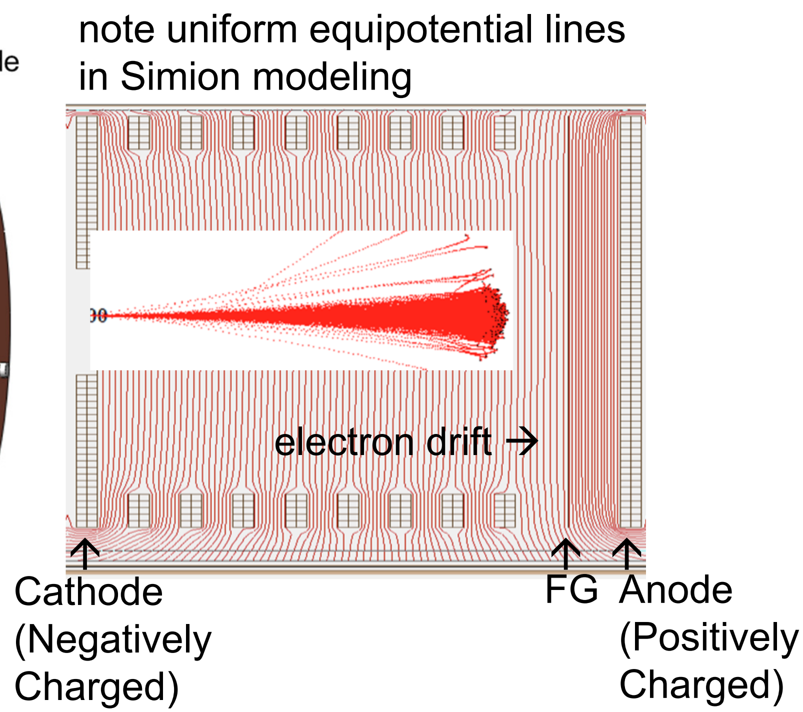


For Better Mass Yields

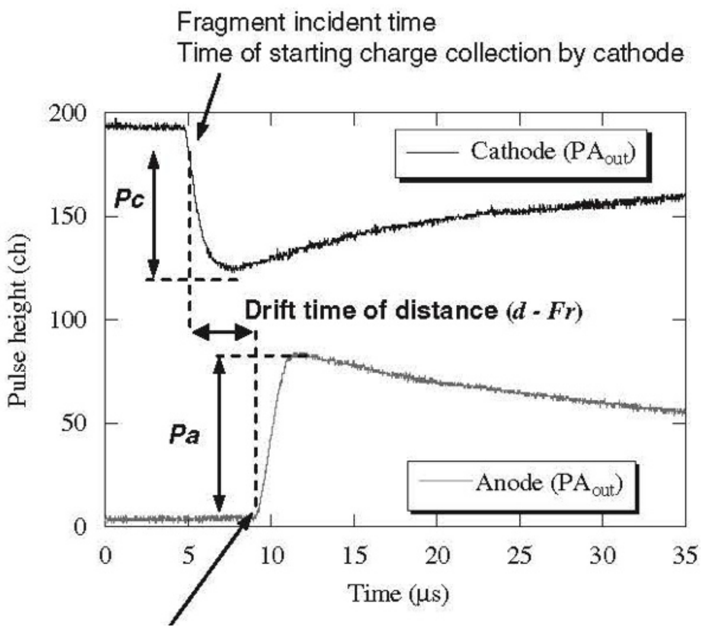
- Need beam calibration
- Suggestions for better simulation for fission product energy loss???

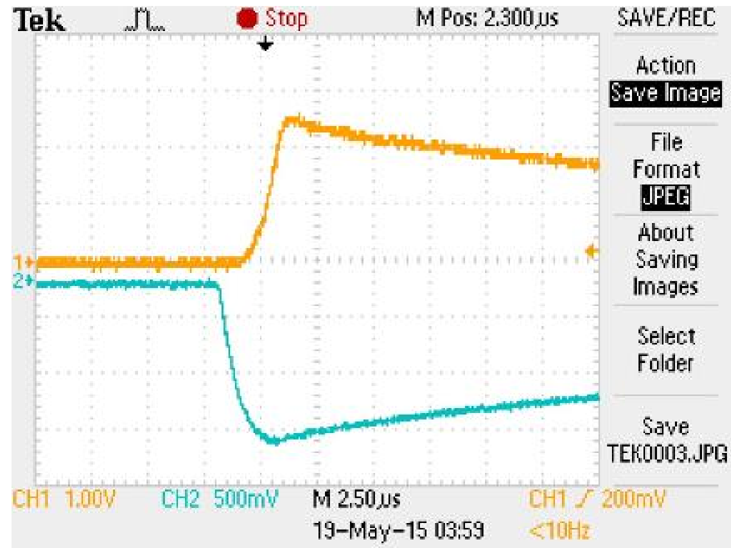
Ionization Chamber and Z determination





Z determination - Active Cathode (> 0.5 MeV/amu)





Range Z dependent

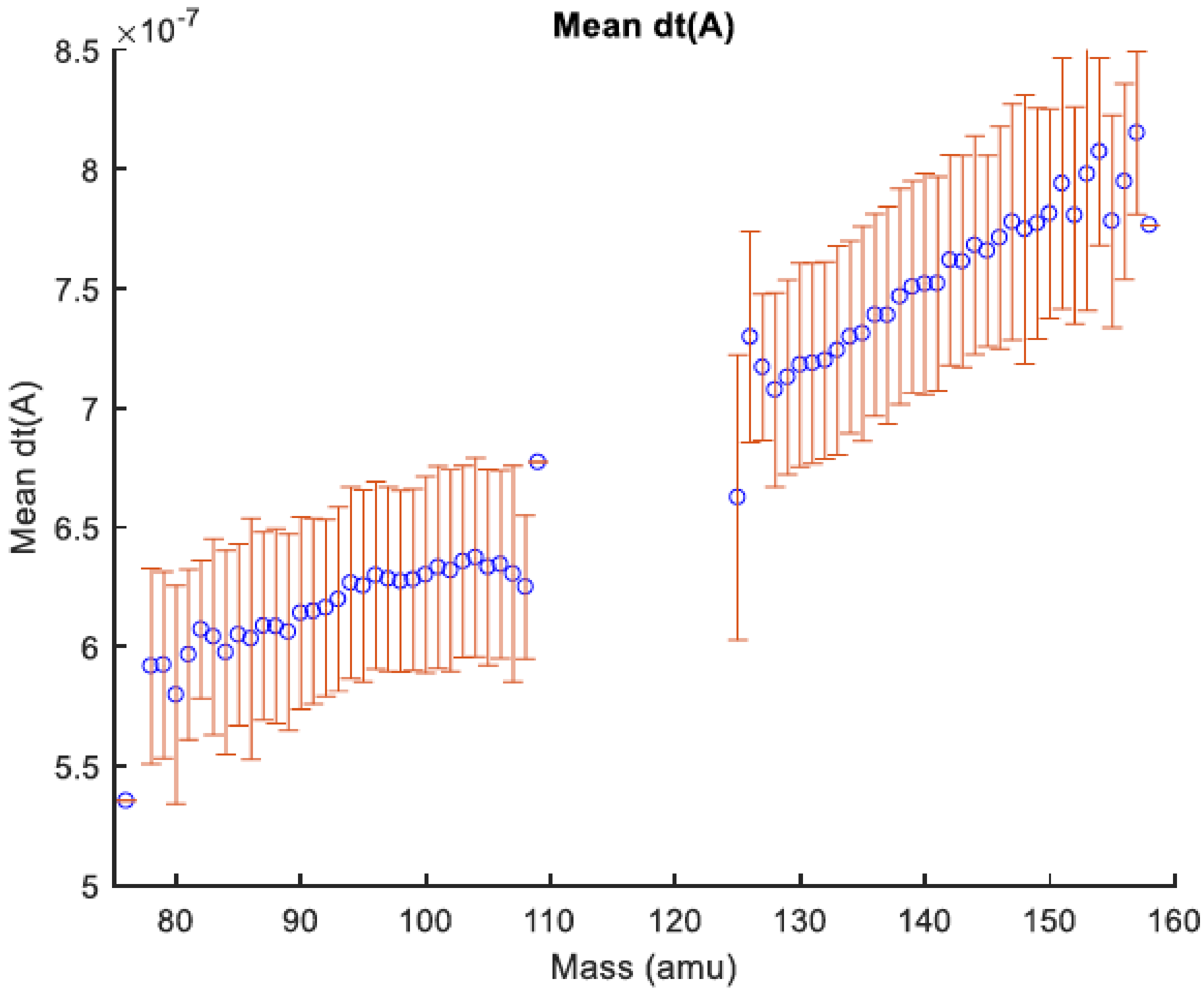
Measure range from Cathode vs. anode time

= IC Δt

using e$^-$ drift velocity

T. Sanami, M. Hagiwara, T. Oishi, M. Baba, M. Takada, NIM A 589, 2008.

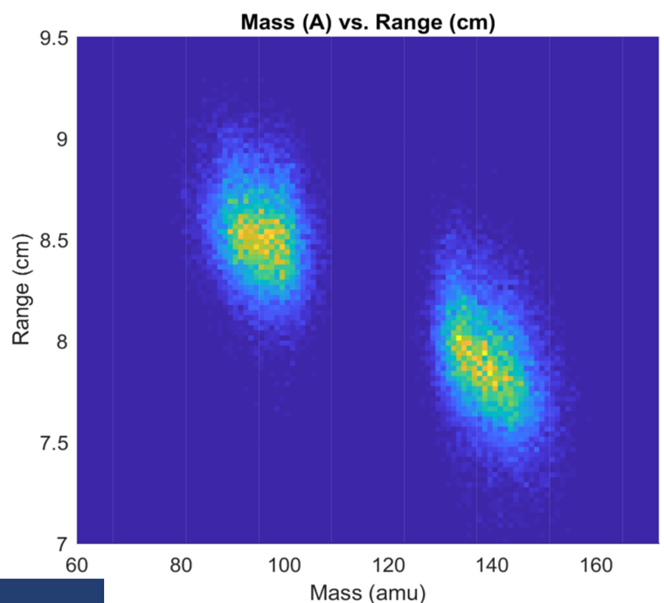
IC Δt cathode vs anode

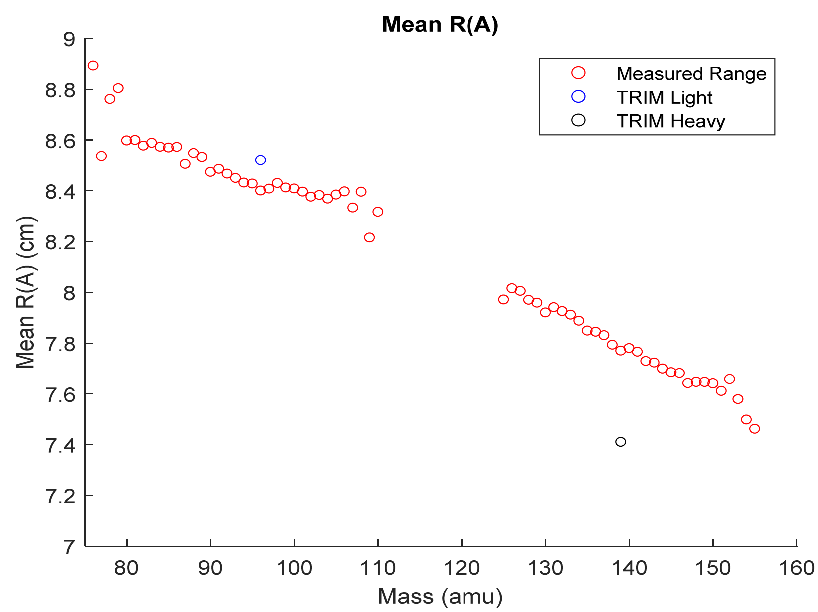


Range & Z

- Active cathode design enables timing measurements
- Determination of penetration depth/range

- *L* is the IC length from C-FG, measured time difference of Cathode-Anode signals,
- v_{dr} =electron drift velocity as a function of E/P conditions





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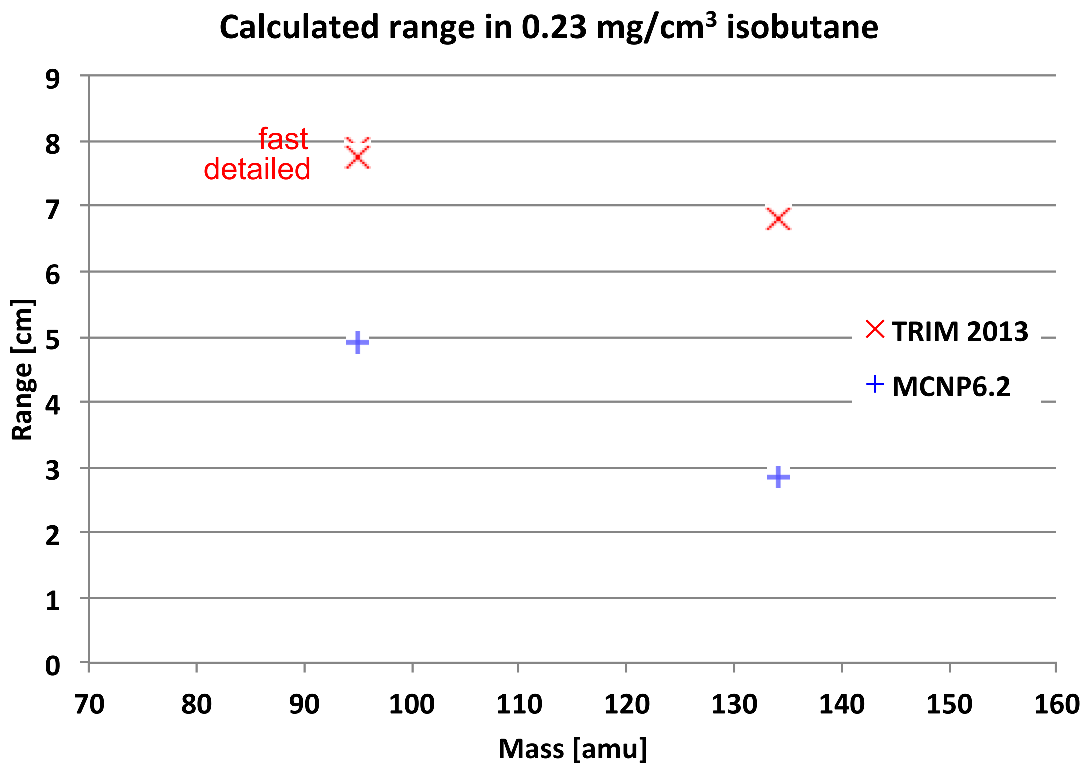
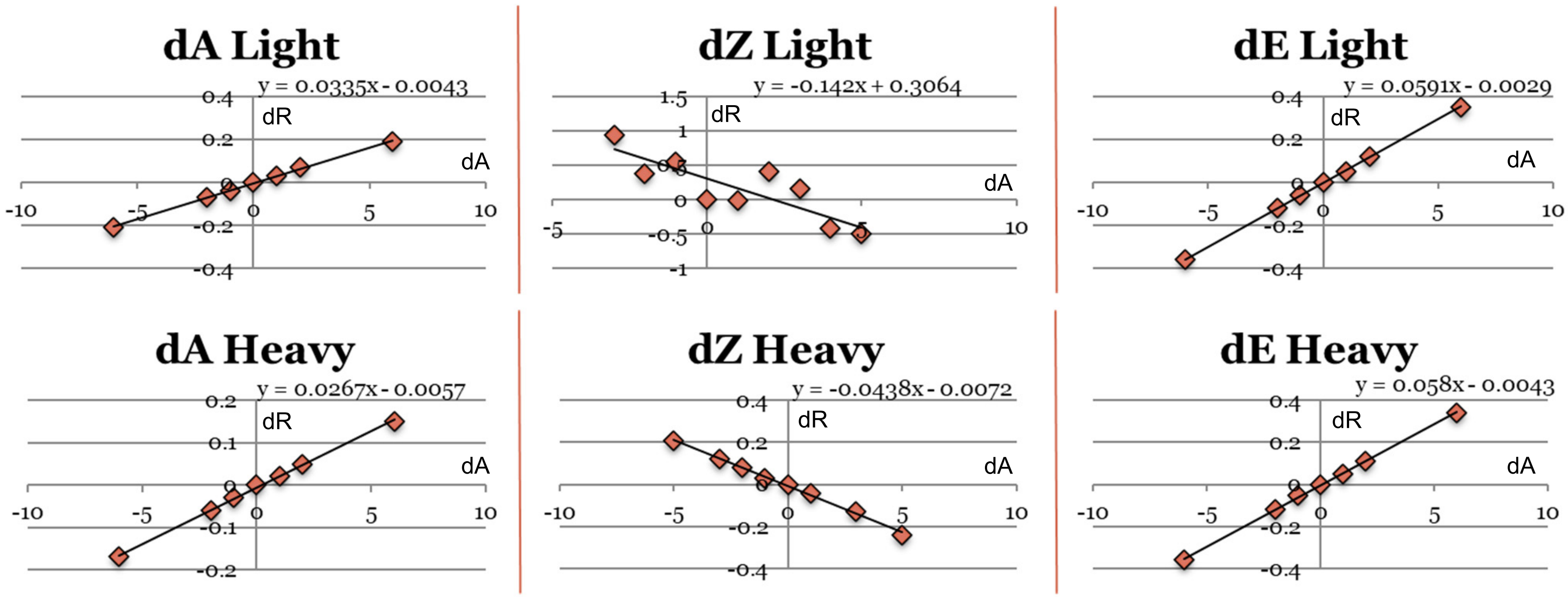
Expected ranges for different nuclides



Test calculations with ^{95}Sr (90.5 MeV) and ^{134}Te (67.0 MeV) in gas to show code differences. Codes not directly useful.

Functional dependence R(Z,A,E) to get Z(R,A,E)

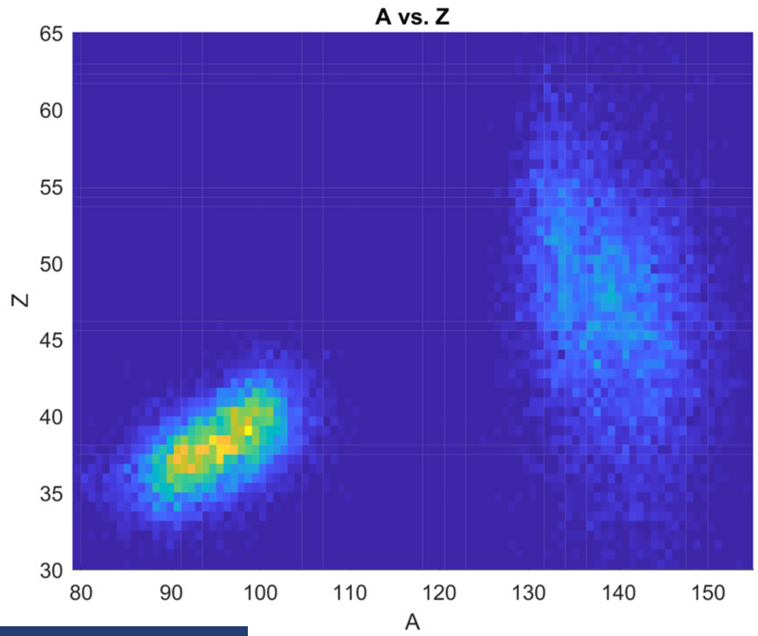
- Perturbations of Z , A, E with respect to the range (R) for average A & Z values for heavy/light peaks.
  - Selected Mean A/Z/E For U-235:
    - light: A= 96, Z=38, E=90 MeV (at entrance to IC)
    - heavy: A=139, Z=53, E=57 MeV
- Relate changes in A, E, and Z to R R_o+dR = a(A_o+dA) + b(Z_o+dZ) +c(E_o+dE) +d

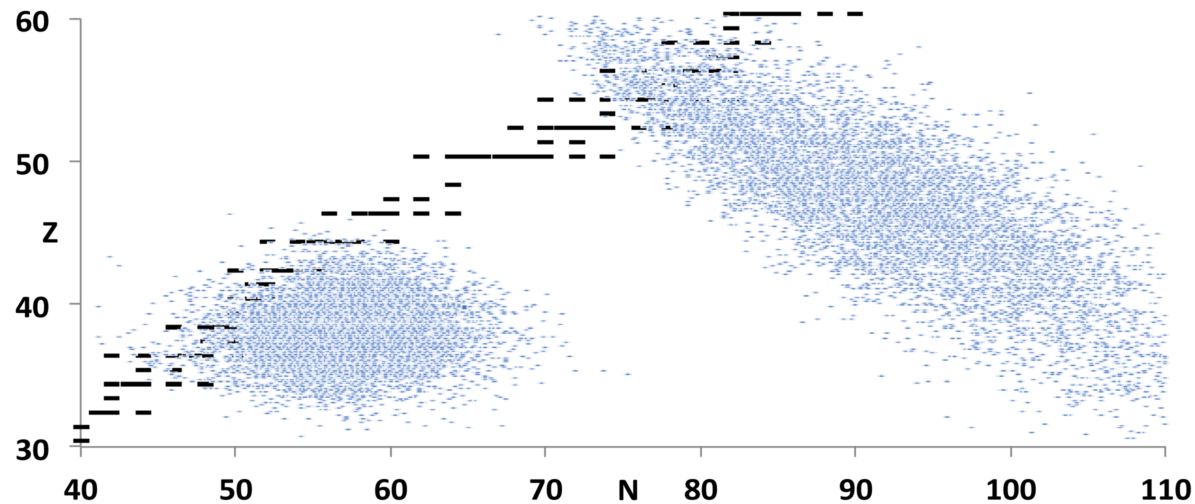


Z Yield from Range

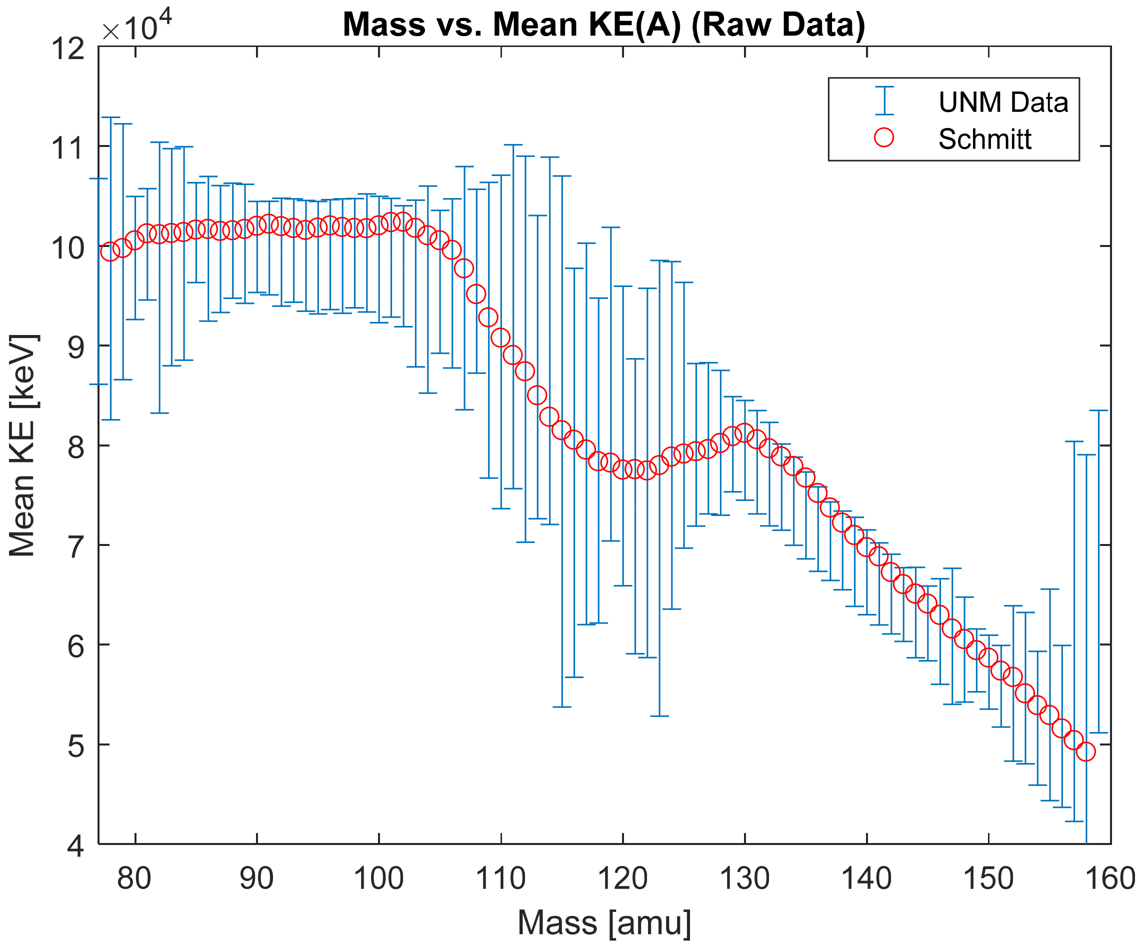
$$Zi(R,A,E)_{Light} = -7.04225*(Ri-8.52)+0.23592*(Ai-96)+0.416197*(Ei-90.563)+0.16507$$

$$Zi(R,A,E)_{Heavy} = -22.8311*(Ri-7.41)+.609589*(Ai-139)+ 1.324201*(Ei-57.036)-.39269$$





Kinetic Energy Dependence



Heavy fragment Z reconstruction too sensitive to small changes in E?

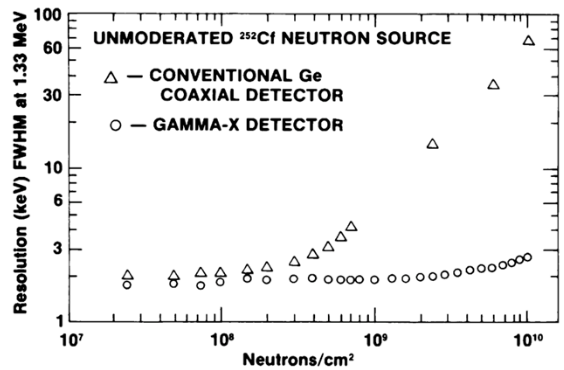
Schmitt data from: H.W. Schmitt, J.H. Neiler, F.J. Walter, Phys. Rev. 141, 1966

Need Calibration

- Have been calibrating using fission E and A curves
- Need good energy calibration of IC
- Calibrate Z with x-ray detector near Cf source
- Hope to calibrate IC energy with beam…

Gamma coincidences

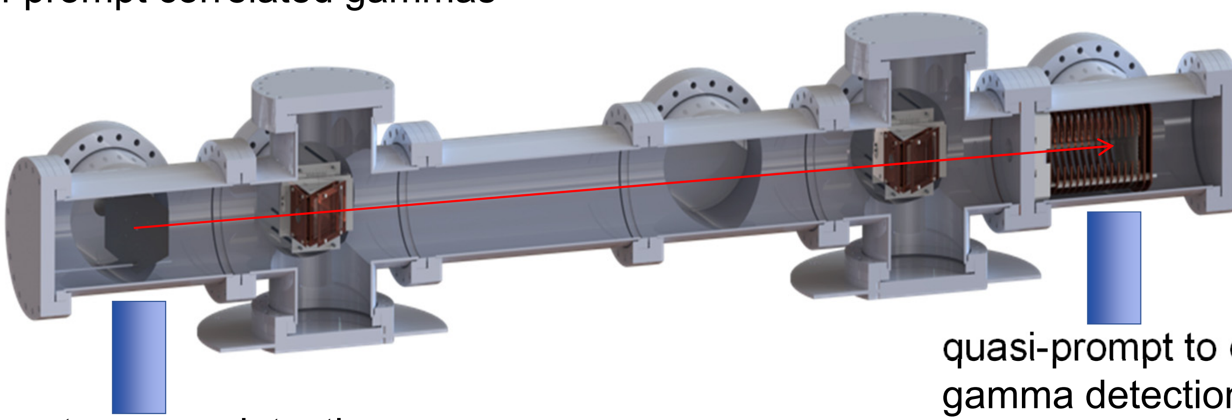
- Have E, v, A, Z, N coincidences. Include gammas
- Recent (July start) NNSA-SSAA grant DE-NA0003901
- New measurements of independent fission fragment yields and energies, and prompt and delayed gammas, for stockpile stewardship data needs



Have 3 Ortec GMX 25% HPGe (good around neutrons) and other gamma detectors

Gammas in Coincidence with Well Characterized Individual Particles

Have gammas correlated with individual particles with A, E, v, Z, N data
Prompt and quasi-prompt correlated gammas



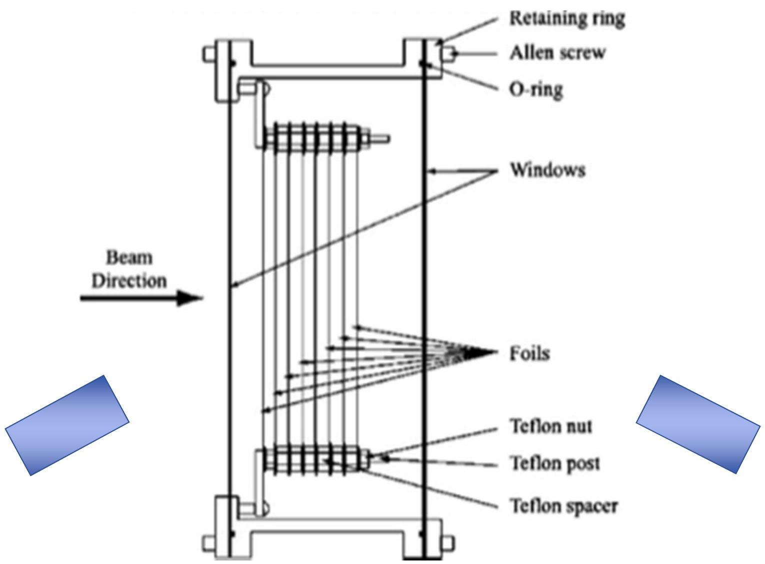
Prompt gamma detection

quasi-prompt to delayed gamma detection
Arrive at 50 – 100 ns
(~ 1us for IC readout)

Fission spectrometer geometric efficiency currently ~10^{-4}

Other methods for much higher fission tagging efficiency…

Standalone Ionization Chamber for Fission Tagged Gamma Rays



- Fission tagged gammas
- Will have energy information
- Geometric efficiency for fission fragment detection near 1 (some emitted along foil)
- Fission tagged gamma detection limited by gamma detectors
- Build while interacting with LANL, will use LANL sources

Build IC based on Parallel Plate Ionization Chamber (PPIC) for fission tagging, good FF/α discrimination

F. Tovesson, T. S. Hill, Phys. Rev. C 75, 034610 (2007).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Shelby Fellows
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Lena Heffern
Drew Mader
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Phoenix Baldez
Mark Wetzel
Adam Hecht
Alexandria Ragsdale
Delaney Heileman

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