Heavy ion stopping power data needs for fission product mass yield measurements

Adam Hecht
University of New Mexico

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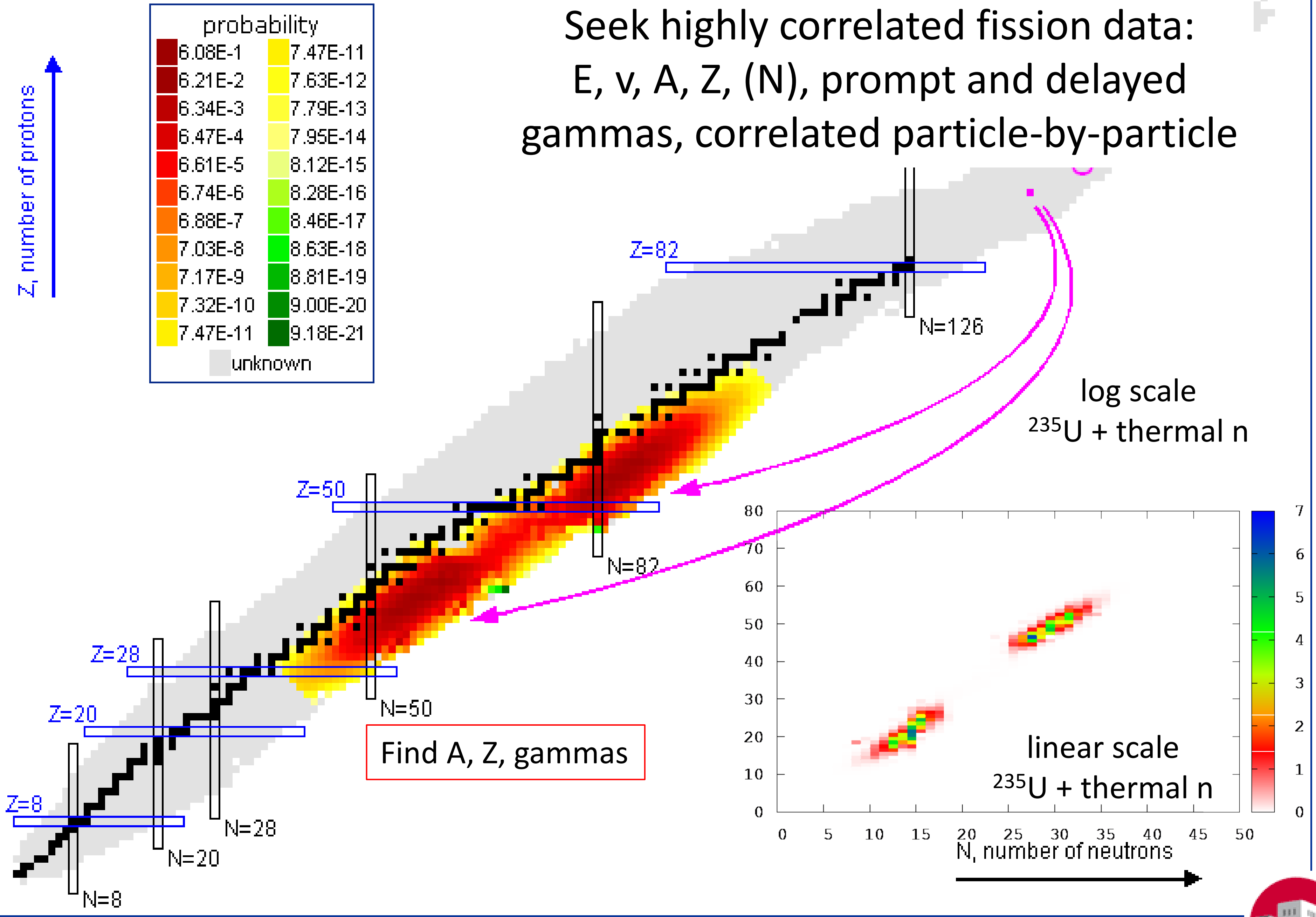
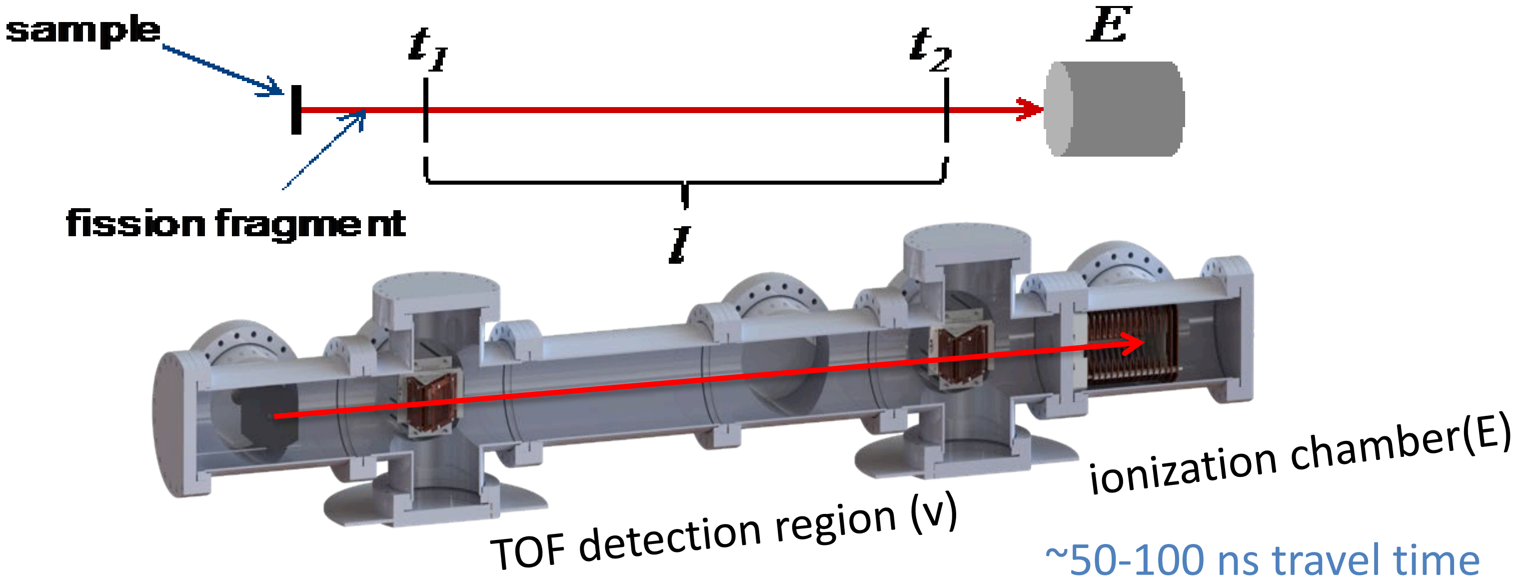
Seek highly correlated fission data: E, ν, A, Z, (N), prompt and delayed gammas, correlated particle-by-particle



UNM E-v Fission Spectrometer



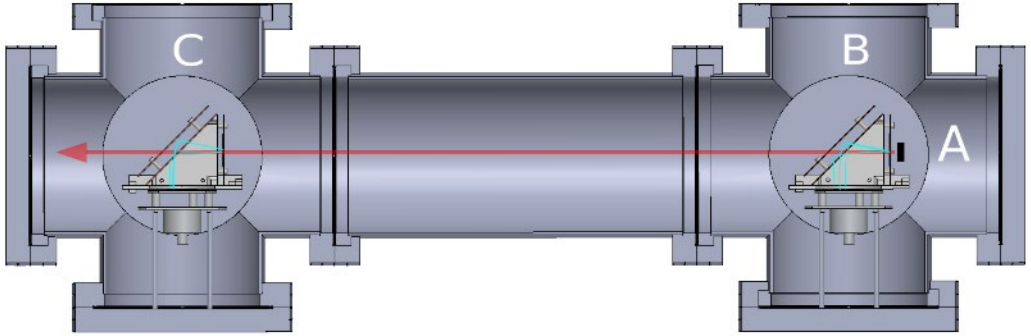
Correlated E,A,Z,N
Measure TOF: v = L/TOF
Measure **E** directly – ionization chamber

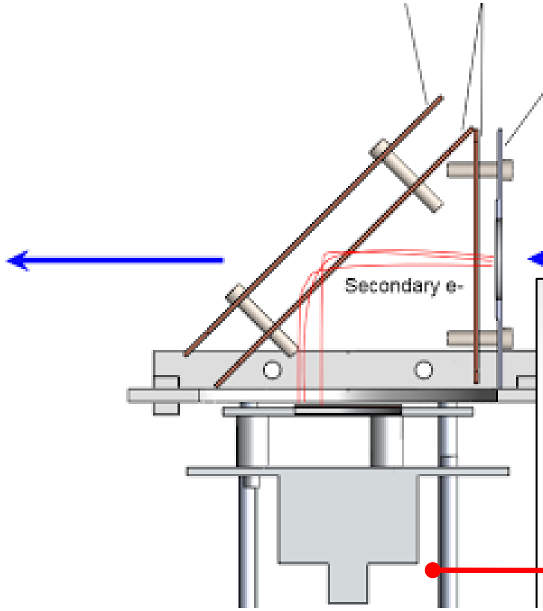
Extract ***A:*** $$m = \frac{2E}{v^2} = \frac{2Et^2}{l^2} \qquad \frac{\delta m}{m} = \sqrt{\left(\frac{\delta E}{E}\right)^2 + \left(2\frac{\delta t}{t}\right)^2 + \left(2\frac{\delta l}{l}\right)^2}$$

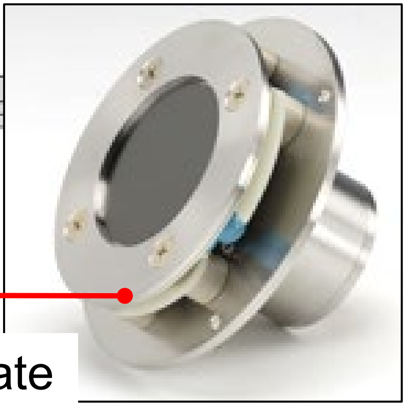
Extract ***Z:*** *Ionization chamber as TPC, active cathode and anode*

Extract ***N:*** A and Z → N

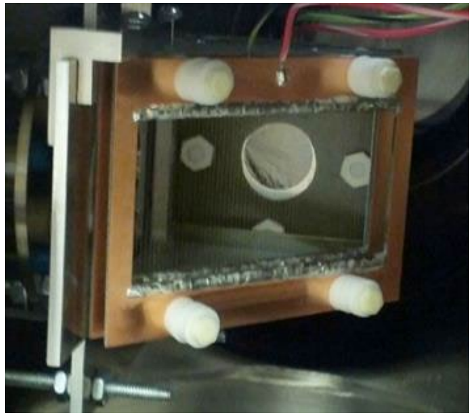
Transmission Time of Flight

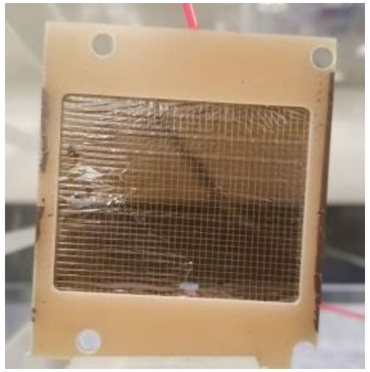




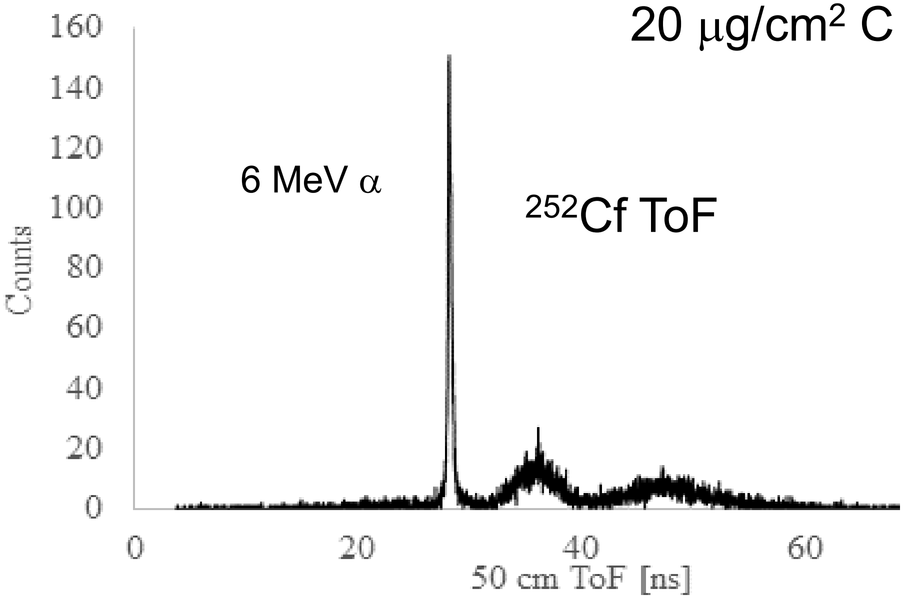


Microchannel plate Detector (MCP)





20 μg/cm^2 C



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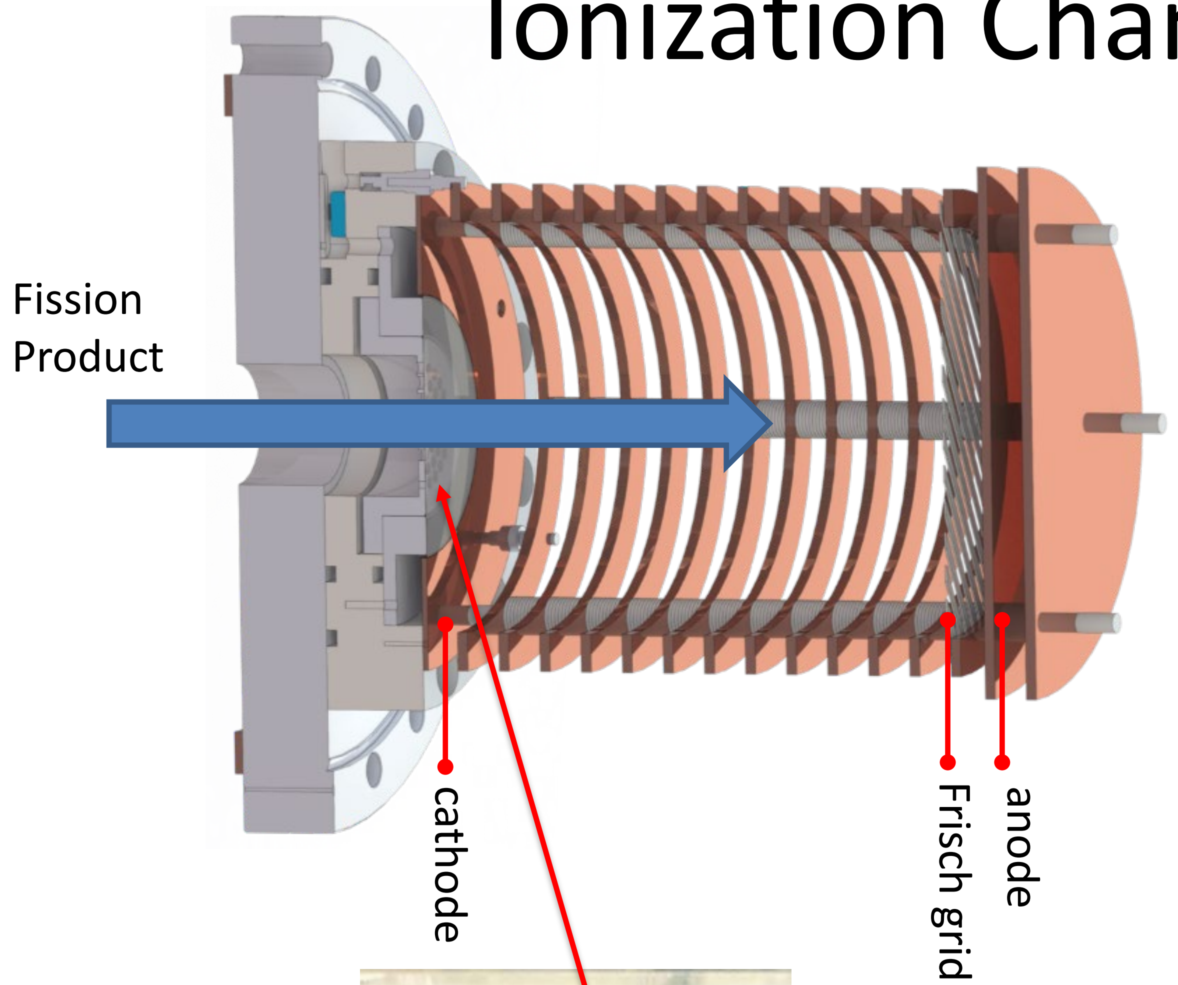
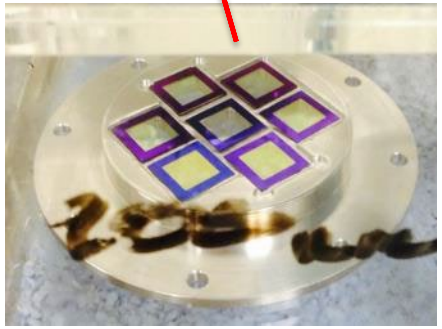
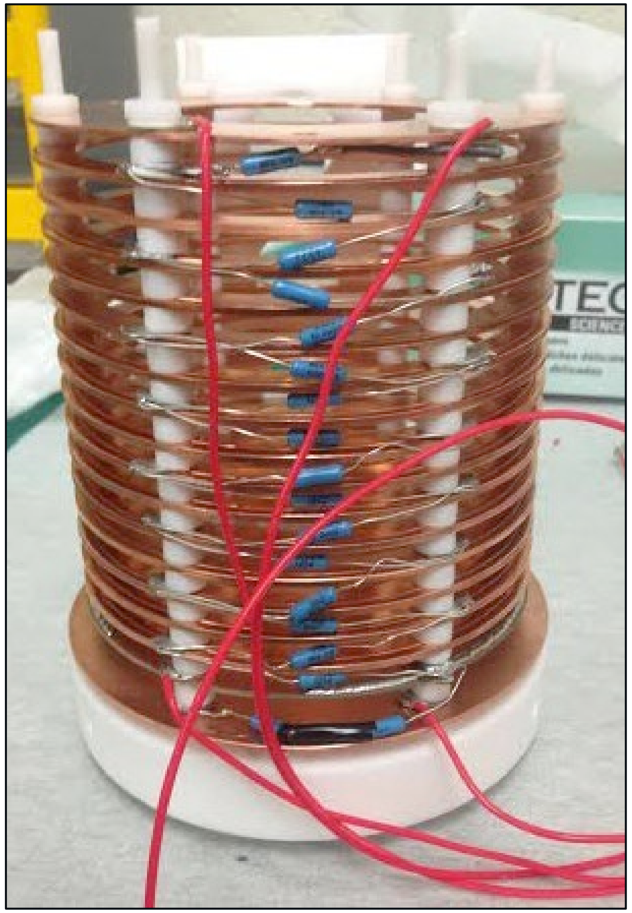
Ionization Chamber





~70 torr isobutane

200 nm SiN windows



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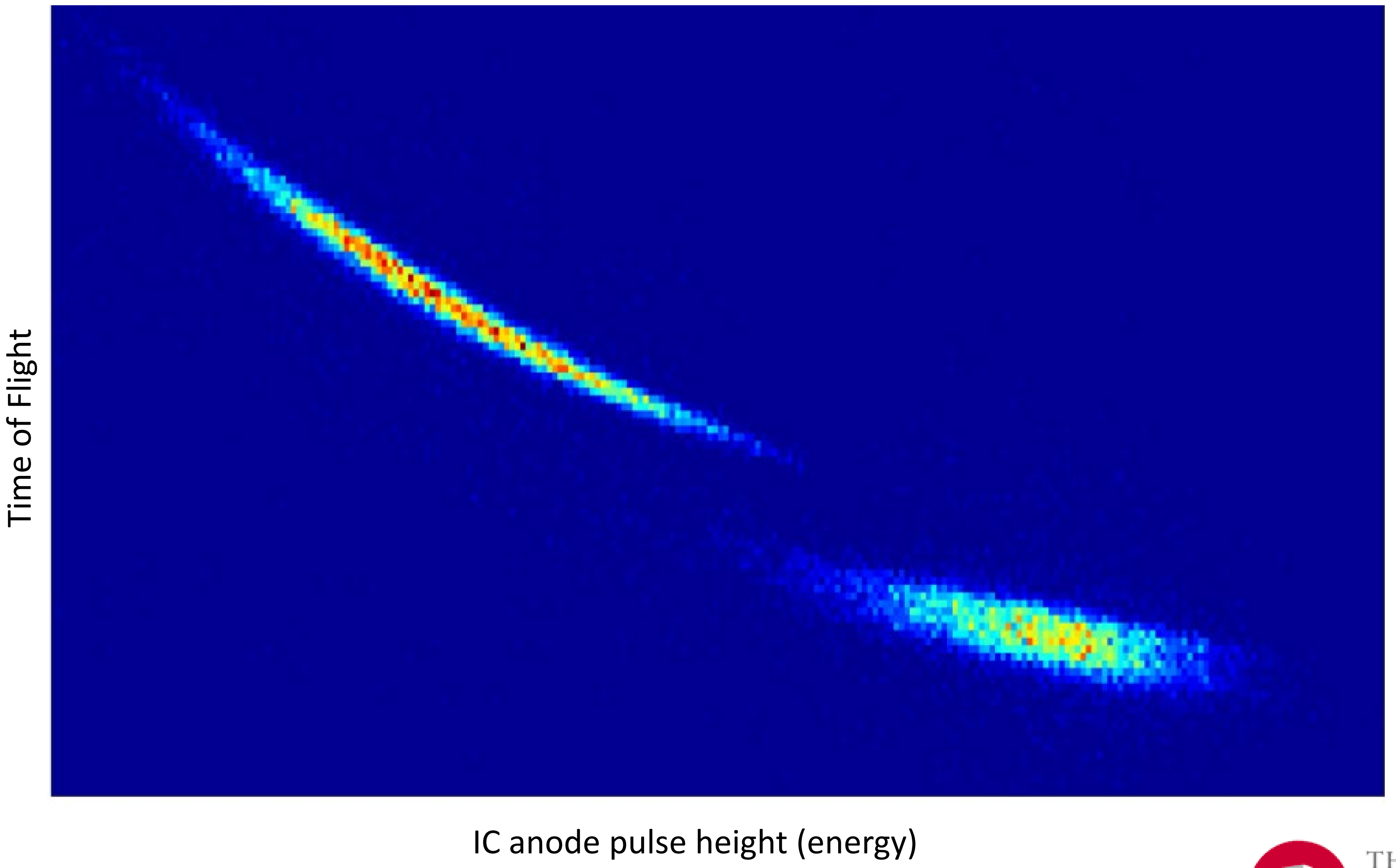
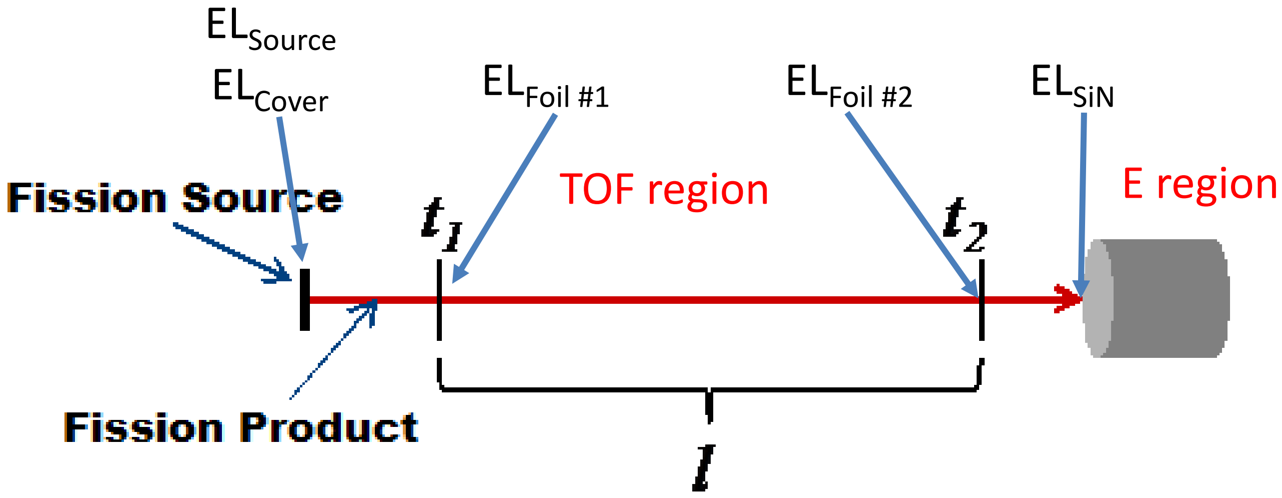
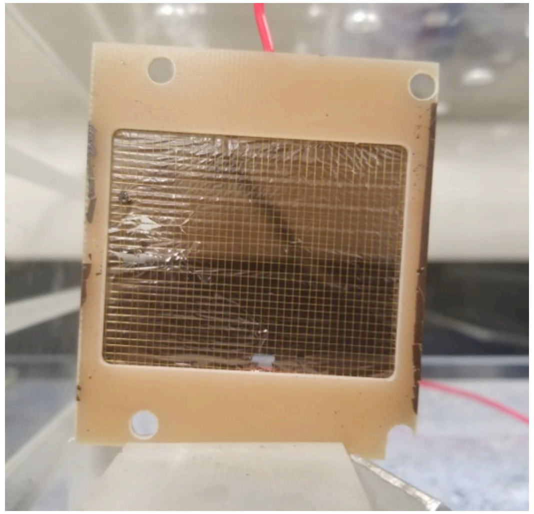
Raw IC-TOF Data: ^{235}U



To use $E = {}^{1}/_{2}\, mv^2$ for mass, correct for energy loss, v loss

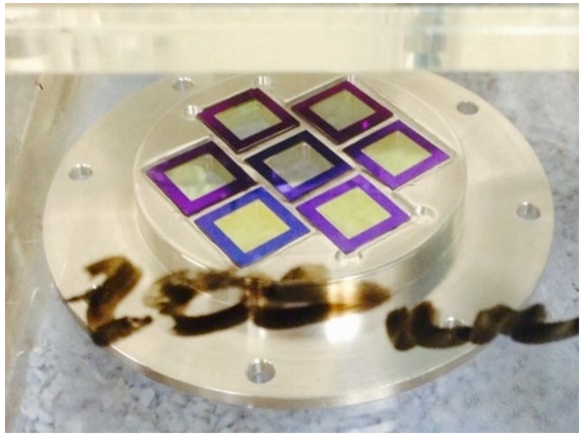


Combine v in TOF and E in IC to find A, but E different in TOF and IC



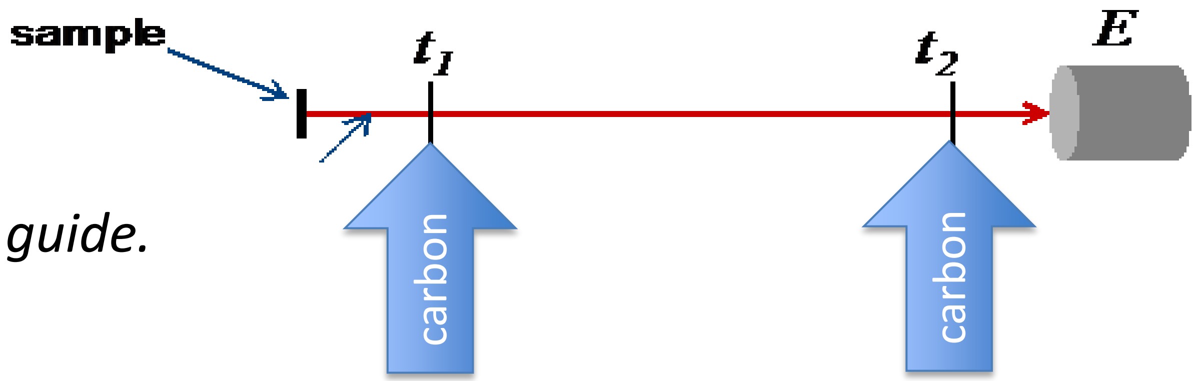
electron conversion carbon foil
(thin foils very hard to handle)

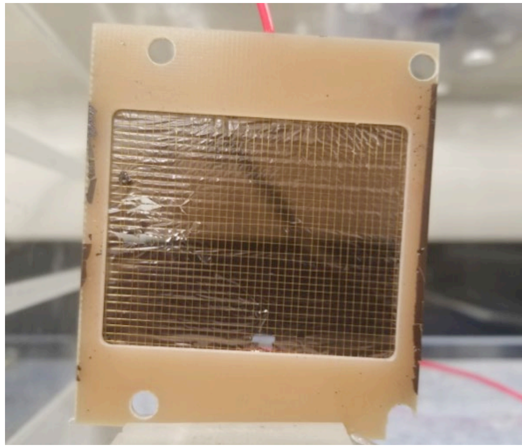
Thin windows/foils
reduce
E loss correction
(and broadening)



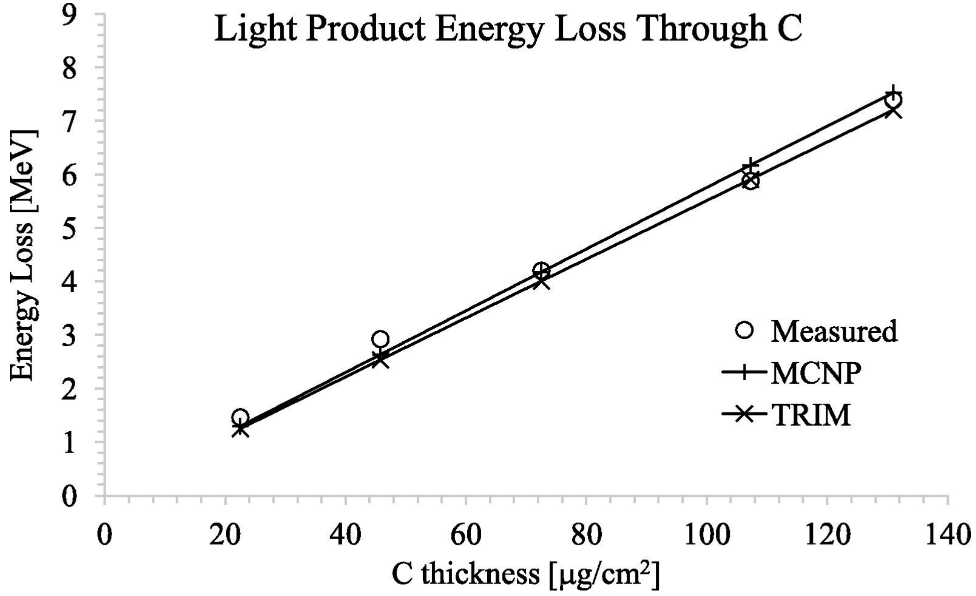
200 nm SiN window to IC

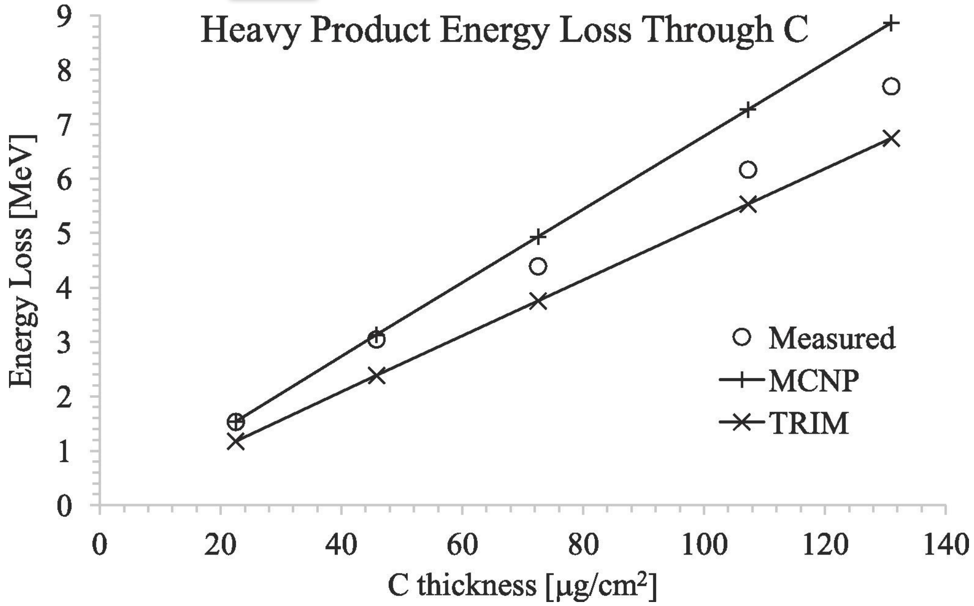
To use $E = {}^{1}/_{2}\, mv^2$ for mass, correct for energy loss, v loss





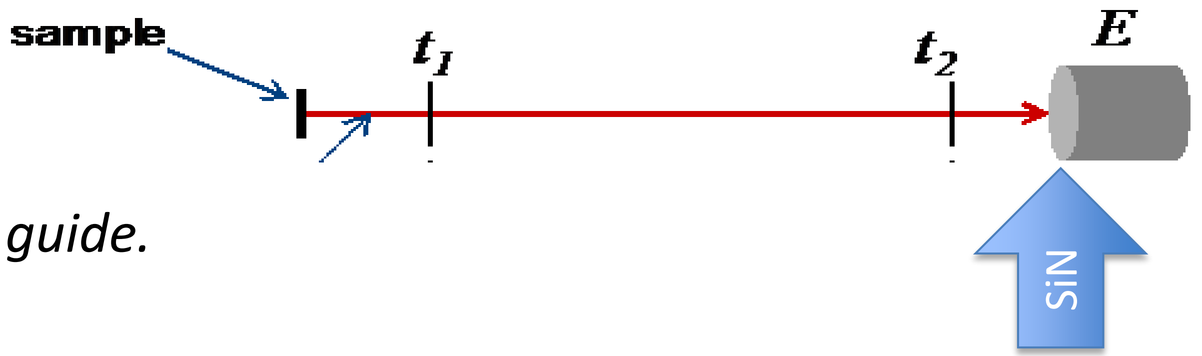
Using simulations to guide.

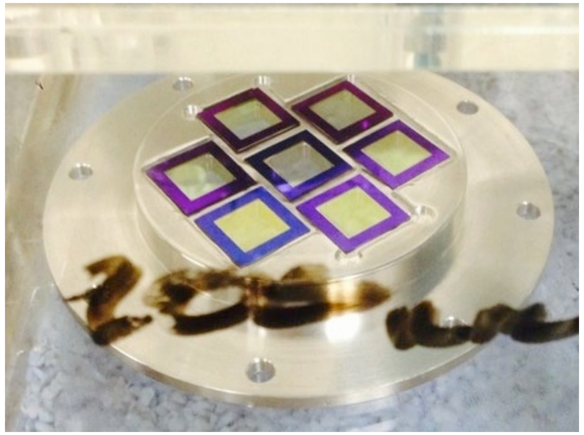




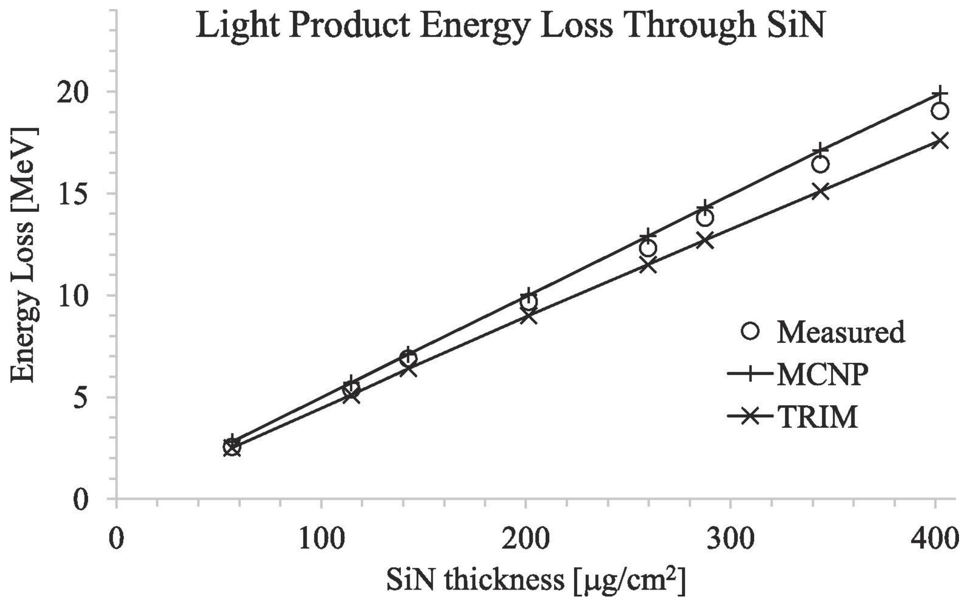
Measurements of ^{252}Cf fission product energy loss through thin silicon nitride and carbon foils, and comparison with SRIM-2013 and MCNP 6.2 simulations, P. Baldez et al, Nuclear Instruments and Methods B 456, 142-147 (2019); https://doi.org/10.1016/j.nimb.2019.06.027

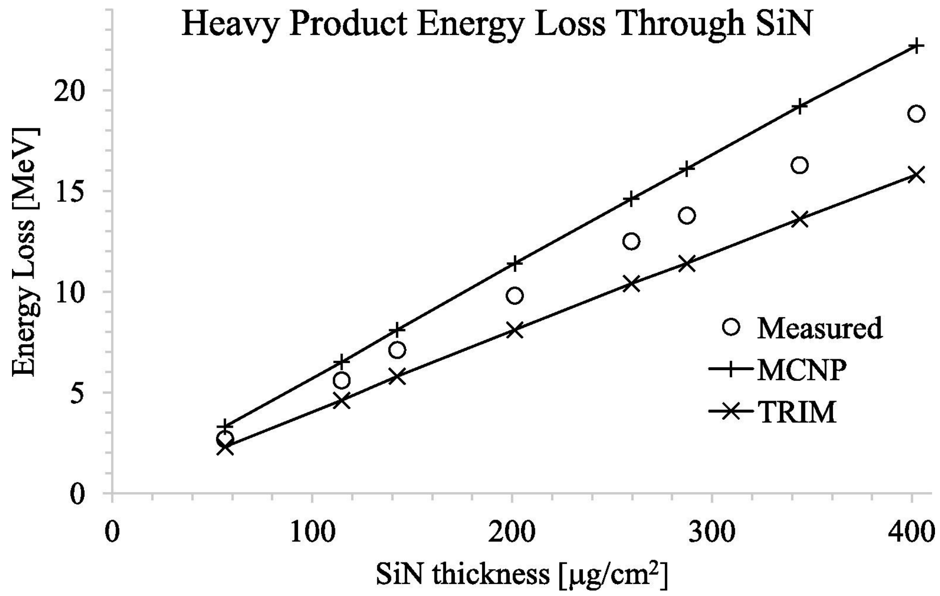
To use $E = {}^{1}/_{2}\, mv^2$ for mass, correct for energy loss, v loss





Using simulations to guide.





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Why different? Dealing with charge states
FF emitted with Q_{av} ~ in the 20s

Charge state distributions of single species, single E_{in}

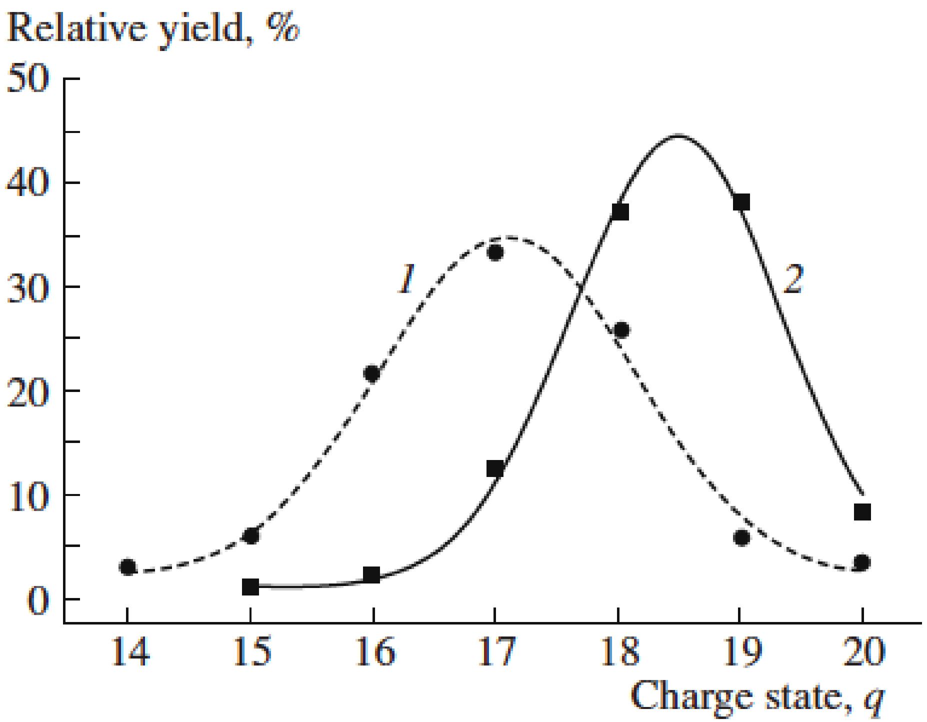

Fig. 3. Charge-state distributions of ^{48}Ca ions with an energy of 264.5 MeV, measured after their passing through (*1*) the Au and (2) C foils.

Fig: N.K. Skobelev, Instruments and Experimental Techniques, 51, pp 351-357, 2008.
Qav: R.D. Evans, The Atomic Nucleus, 1955.

MCNP and SRIM both use Bethe Bloch

$$-\frac{dE}{d\rho x} = \frac{4\pi (ke^2)^2 N_A}{mc^2} \frac{Z_p^2}{\beta^2} \frac{Z_t}{A_t} \left[ln \frac{2mc^2\beta^2}{(1-\beta^2)} - \beta^2 - lnI \right]$$

(with shell and target density effects)

<u>But different charge state Z* calculations:</u>

MCNP6.2 follows method of Bichsel for effective Z*
$Z^* = Z\,[\,1 - \exp(-1.316x + 0.1112\,x^2 - 0.0650\,x^3)]$
Where $x = 100\,\beta\,Z^{-2/3}$

Low E, MCNP6 similar to SPAR code
$Z^* = Z\,[\,1 - \exp(-125\,\beta\,Z^{-2/3})]$

SRIM Z* modeled by the **Brandt-Kitagawa** method

See: P. Baldez et al, NIM B 456, 142-147 (2019); https://doi.org/10.1016/j.nimb.2019.06.027

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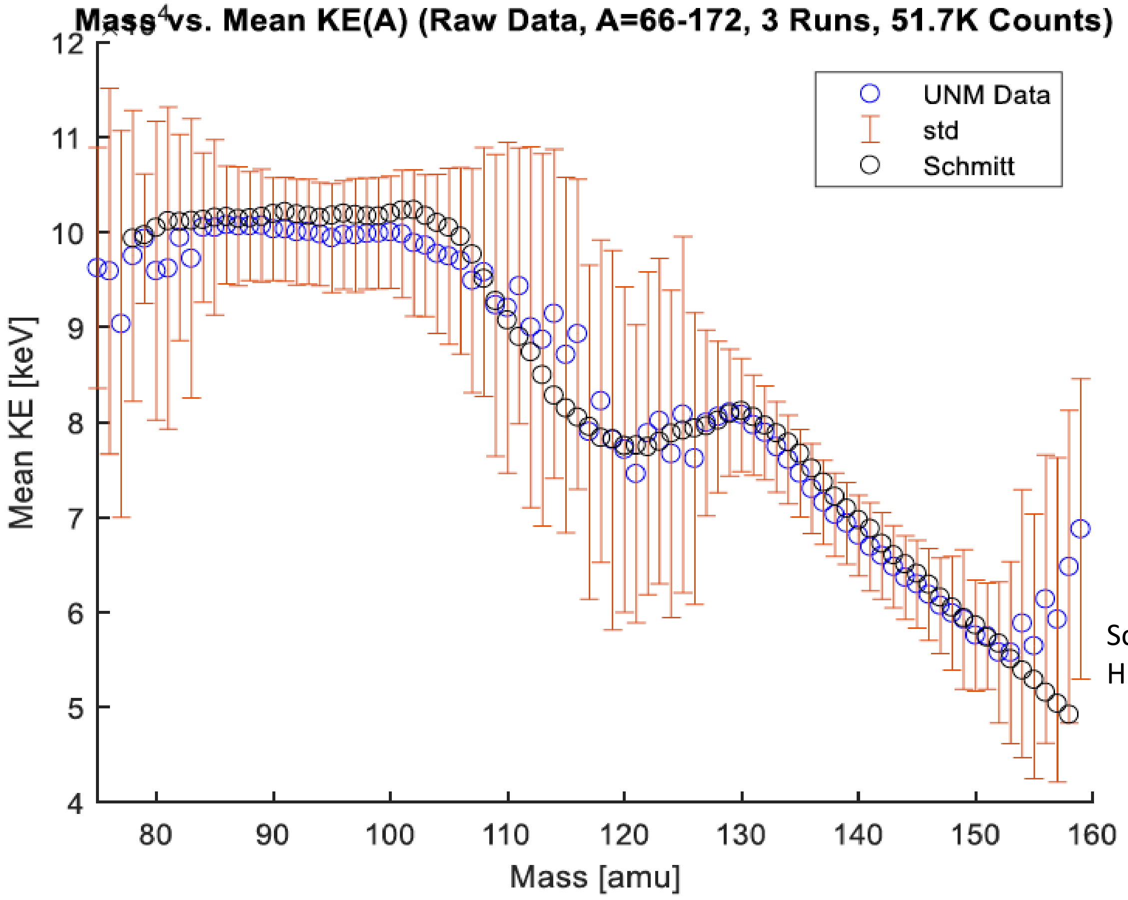
To use E = $^1/_2$ mv^2 for mass, must correct for energy loss, v loss

Matched E at source backed out from both TOF and IC data at same time:

E loss is mass dependent,

v related to m,

iterative v dependent E reconstruction



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

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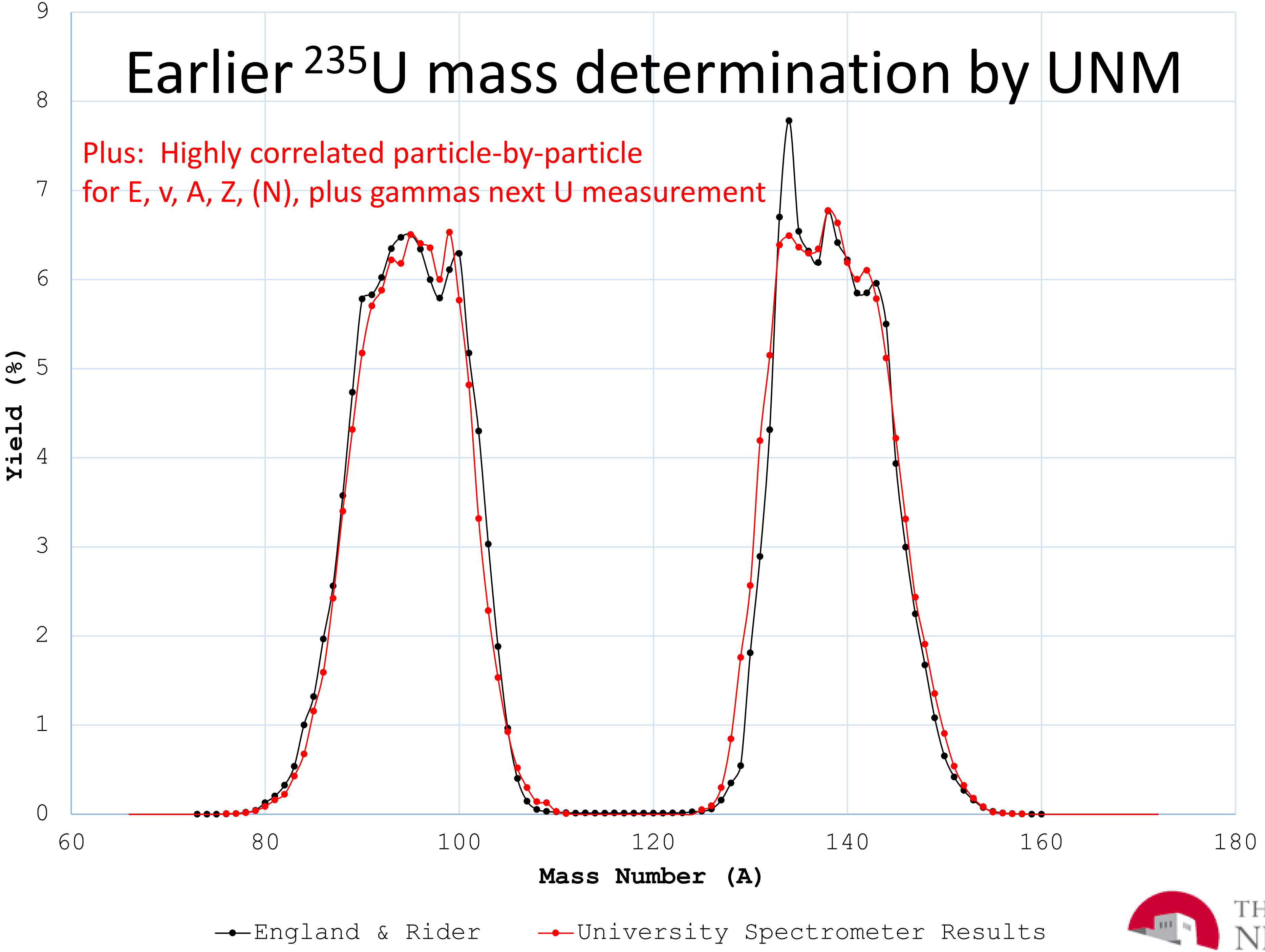
Earlier ^{235}U mass determination by UNM

Plus: Highly correlated particle-by-particle
for E, v, A, Z, (N), plus gammas next U measurement



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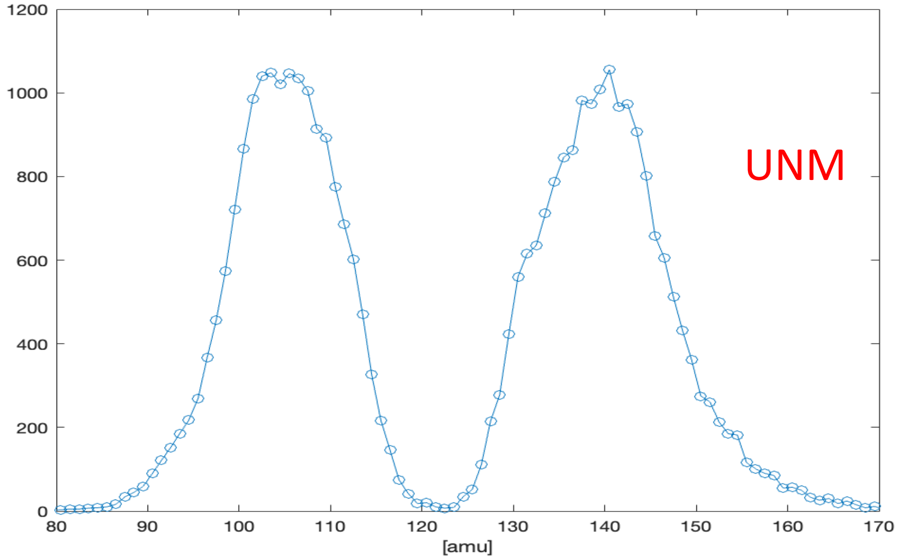
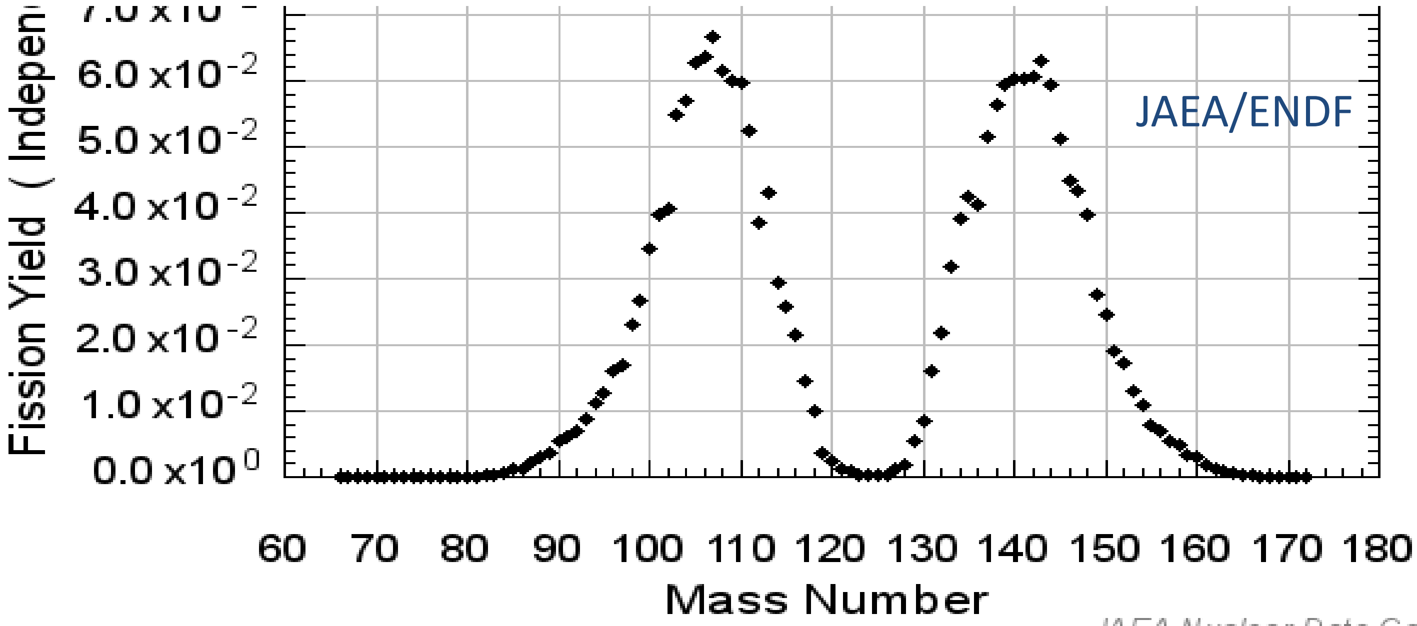
Recent (2022) ^{252}Cf s.f. mass yield measurements at UNM





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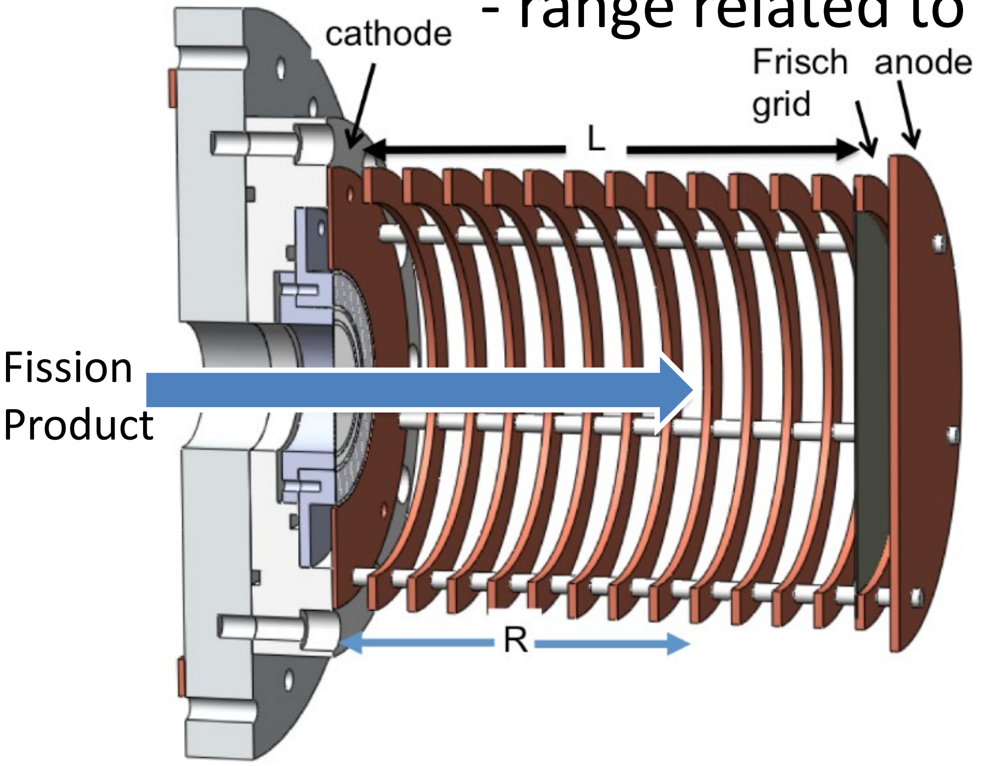
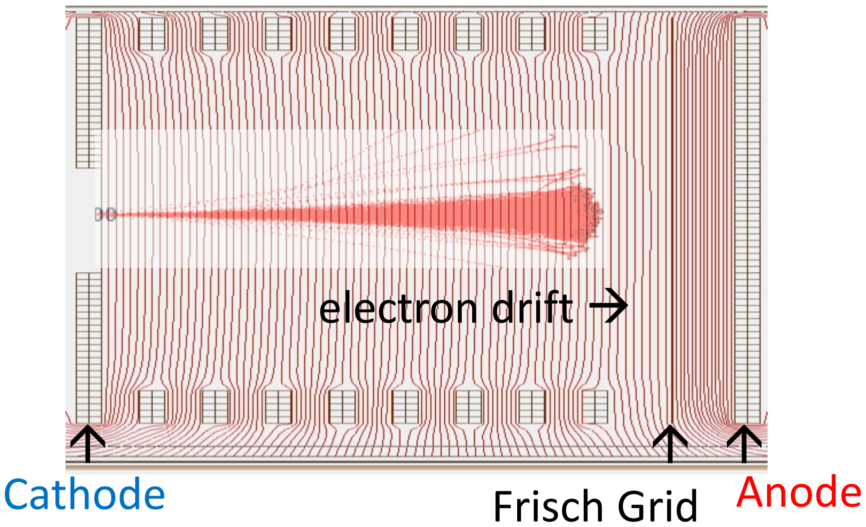
Ionization Chamber and Z determination

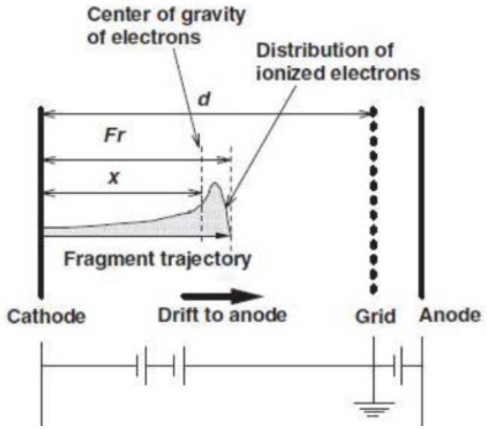
- time projection chamber
- range related to stopping power: Z*, A, E

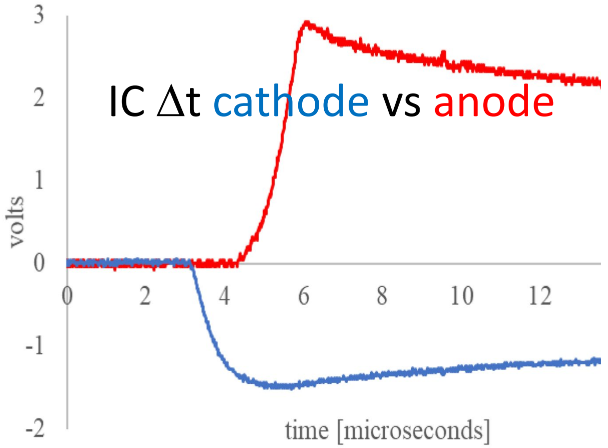




Stopping power is charge dependent

"Active cathode" isolated by Teflon standoff
Timing from cathode, anode
Electron drift time to FG to extract range
Fit to simulation to extract Z

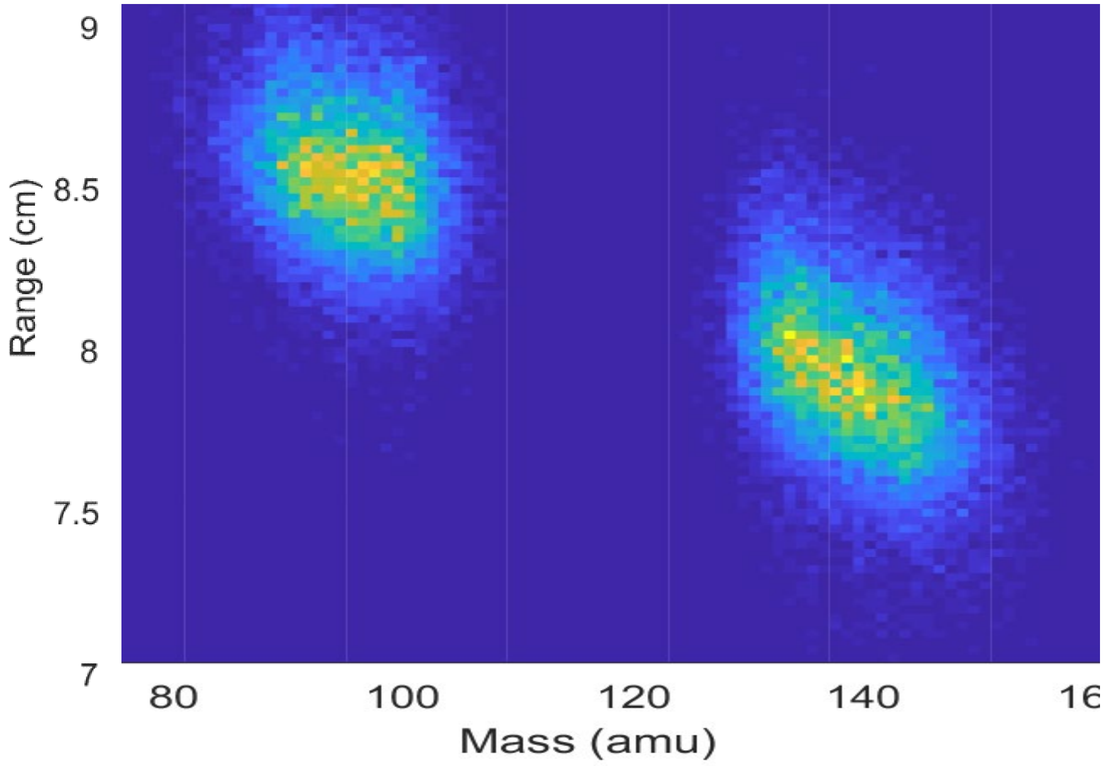


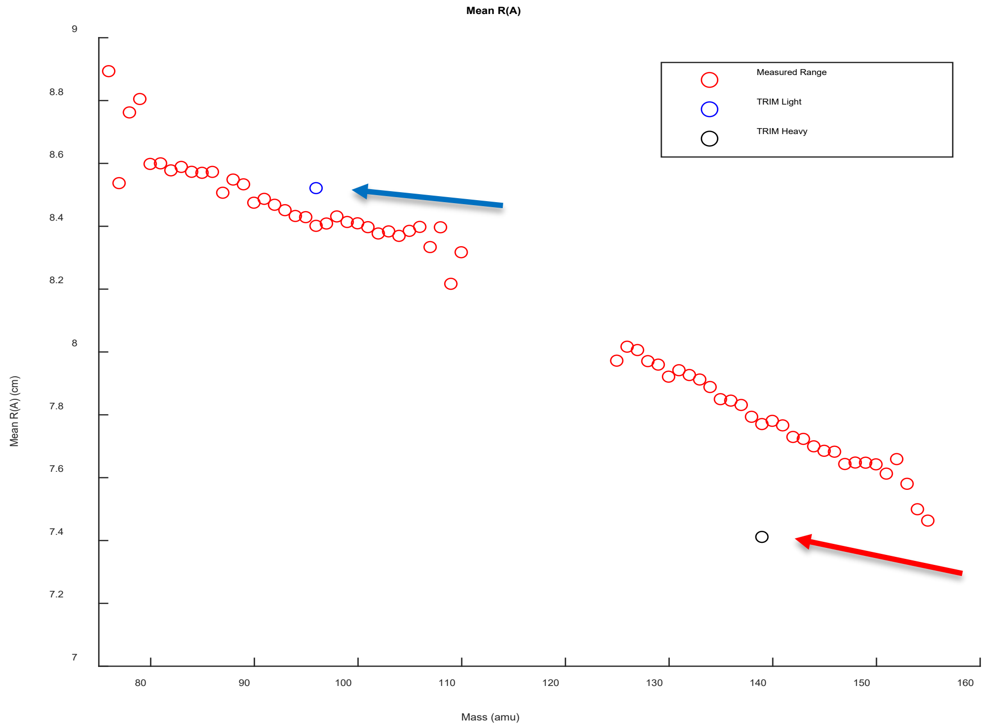


Range

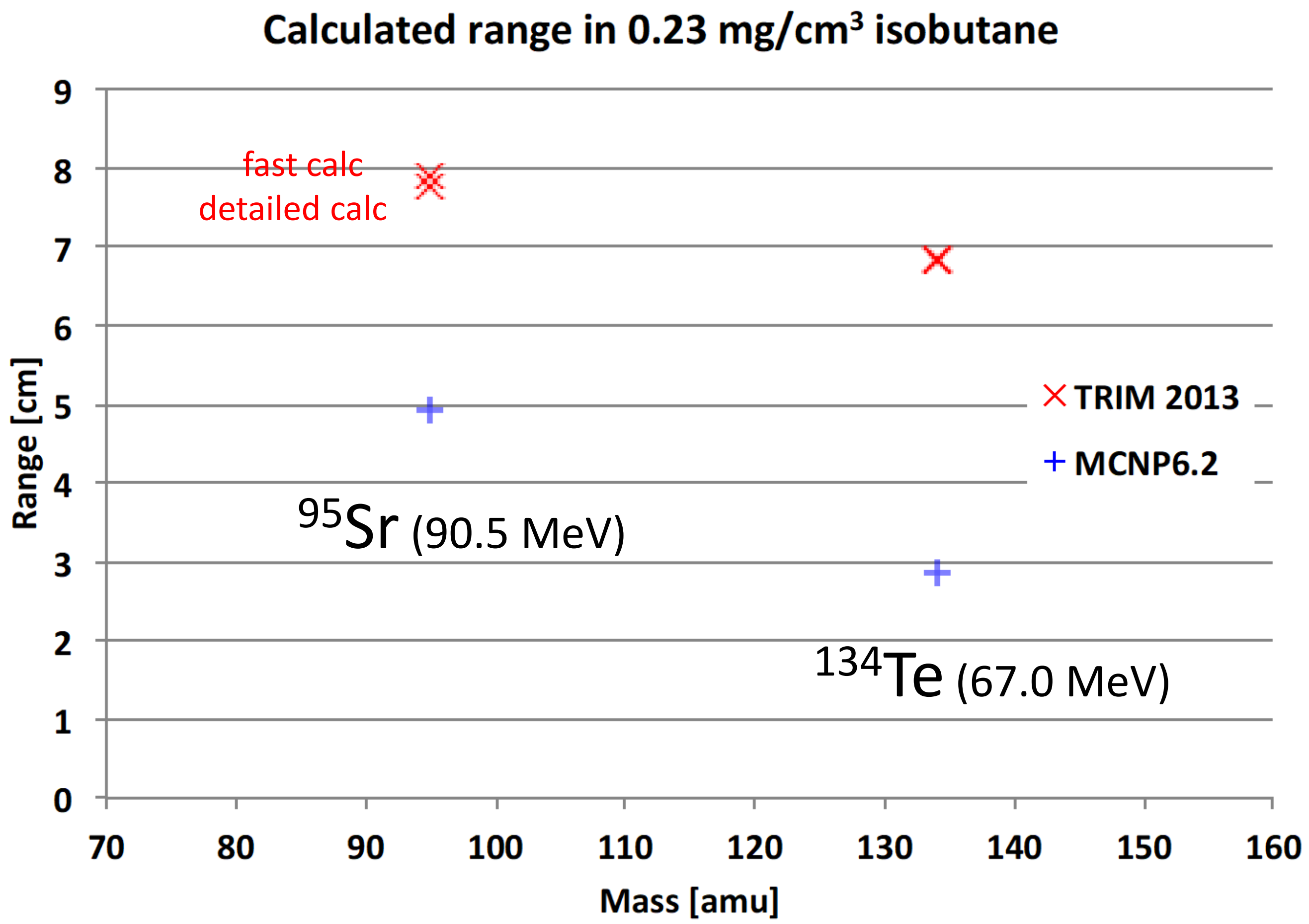
Active cathode design enables timing measurements
Determination of penetration depth/range

^{235}U





Comparing codes, expected ranges for different nuclides



Codes are not directly useful for range.

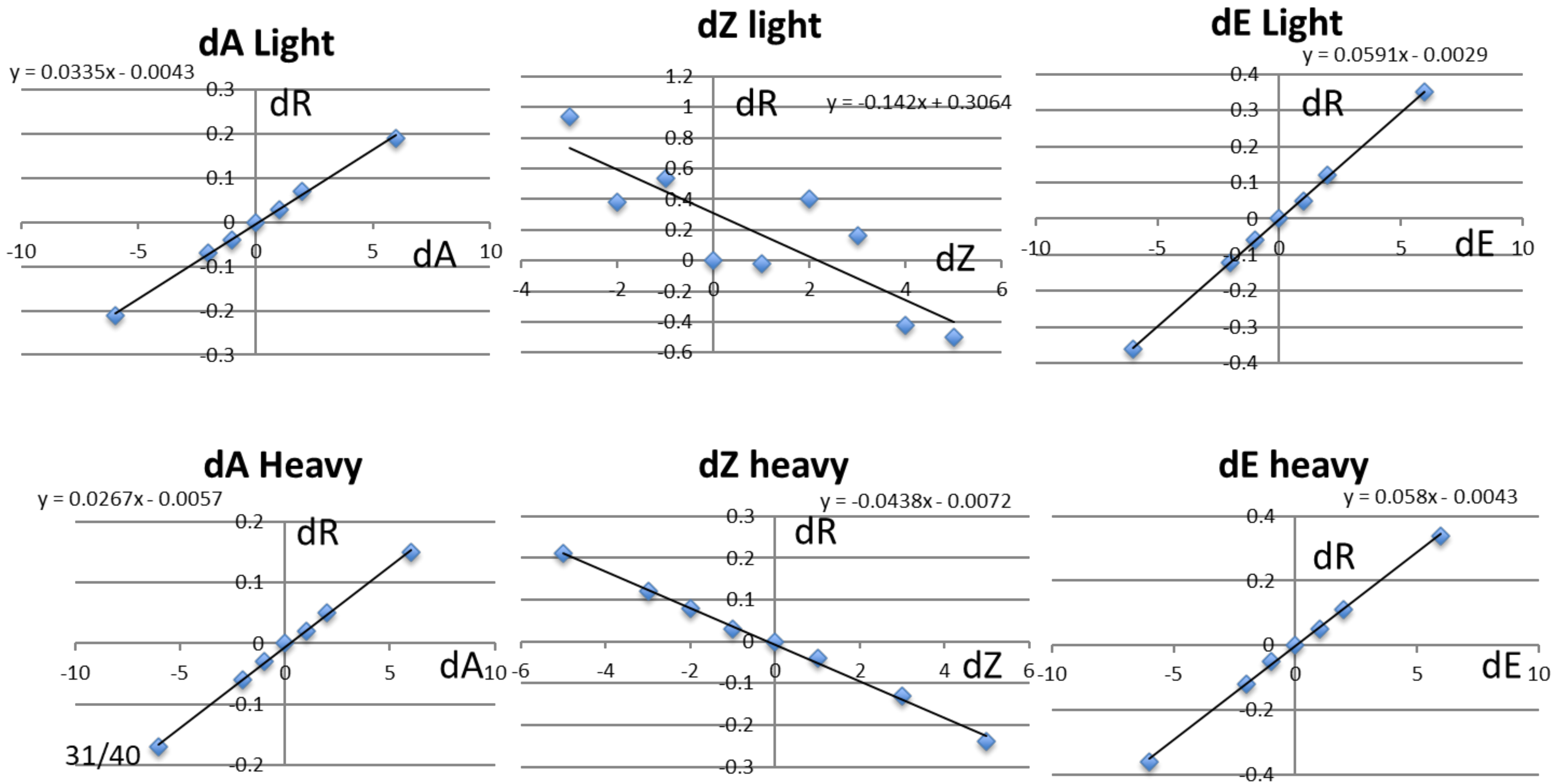
Perturbation functional dependence R(Z,A,E) to get Z(R,A,E)

SRIM calculated range R dependence on perturbations of Z, A, E of average Heavy & Light FF
- Mean light: A= 96, Z=38, E=90 MeV (at entrance to IC)
- Mean heavy: A=139, Z=53, E=57 MeV (at entrance to IC)

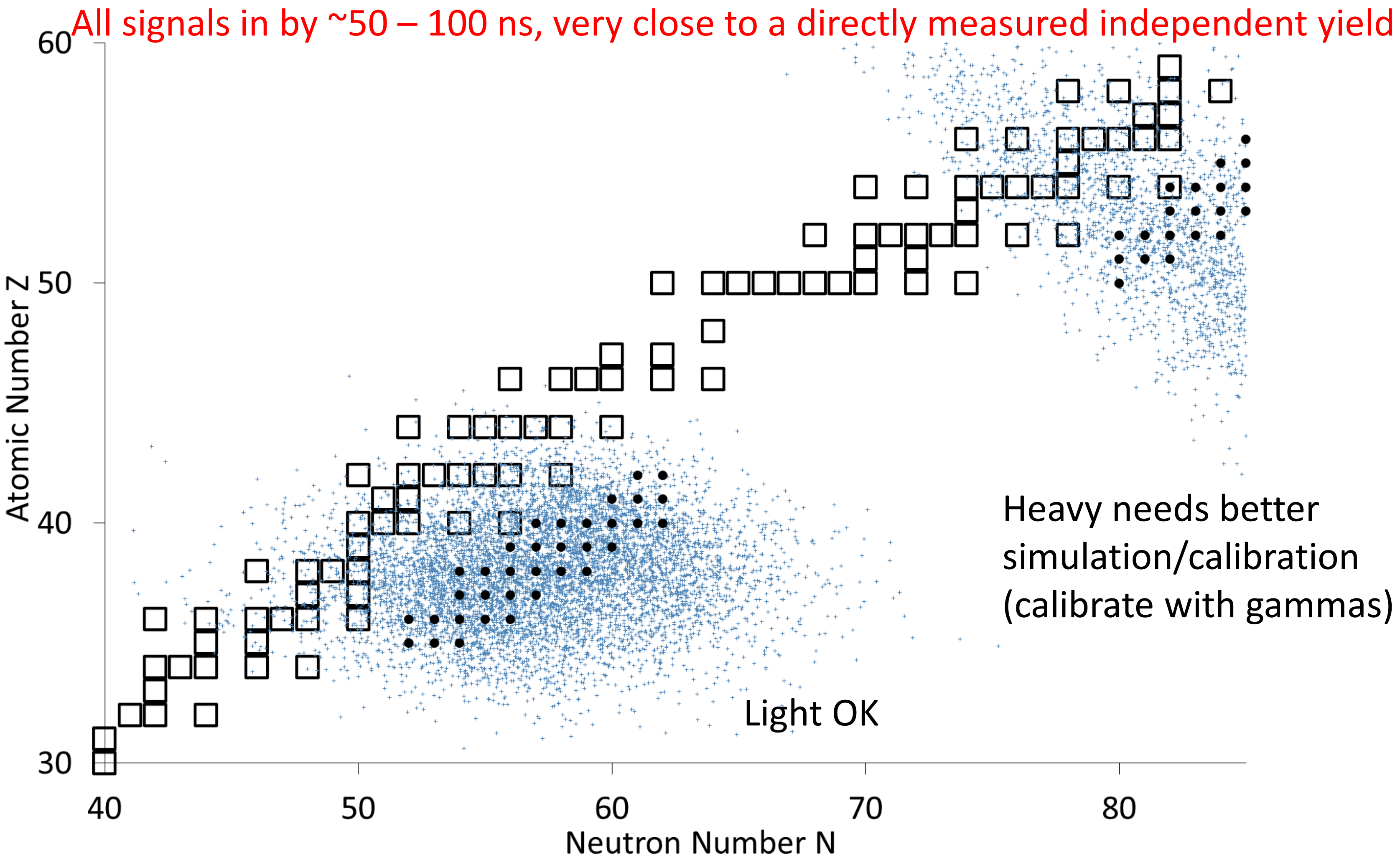
$$Zi(R,A,E)_{Light} = -7.04225*(Ri-8.52)+0.23592*(Ai-96)+0.416197*(Ei-90.563)+0.16507$$

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

R as a fcn of A, Z, E (near a central point)



A and Z data → N,Z distribution for $^{235}U(n,f)$



Square = stable, blue dots = data, black dots >1% independent yield JAEA

Signal Processing and Data Acquisition for the UNM Fission Spectrometer to Measure Binary Fission Product Mass, Energy, Velocity, Atomic Number, and Gamma Rays, Correlated Particle-By-Particle, P. Baldez, M.L. Wetzel, R.E. Blakeley, A. Ragsdale, A.A. Hecht, Journal of Signal Processing Systems (2021); https://doi.org/10.1017/s11265-021-01703-w

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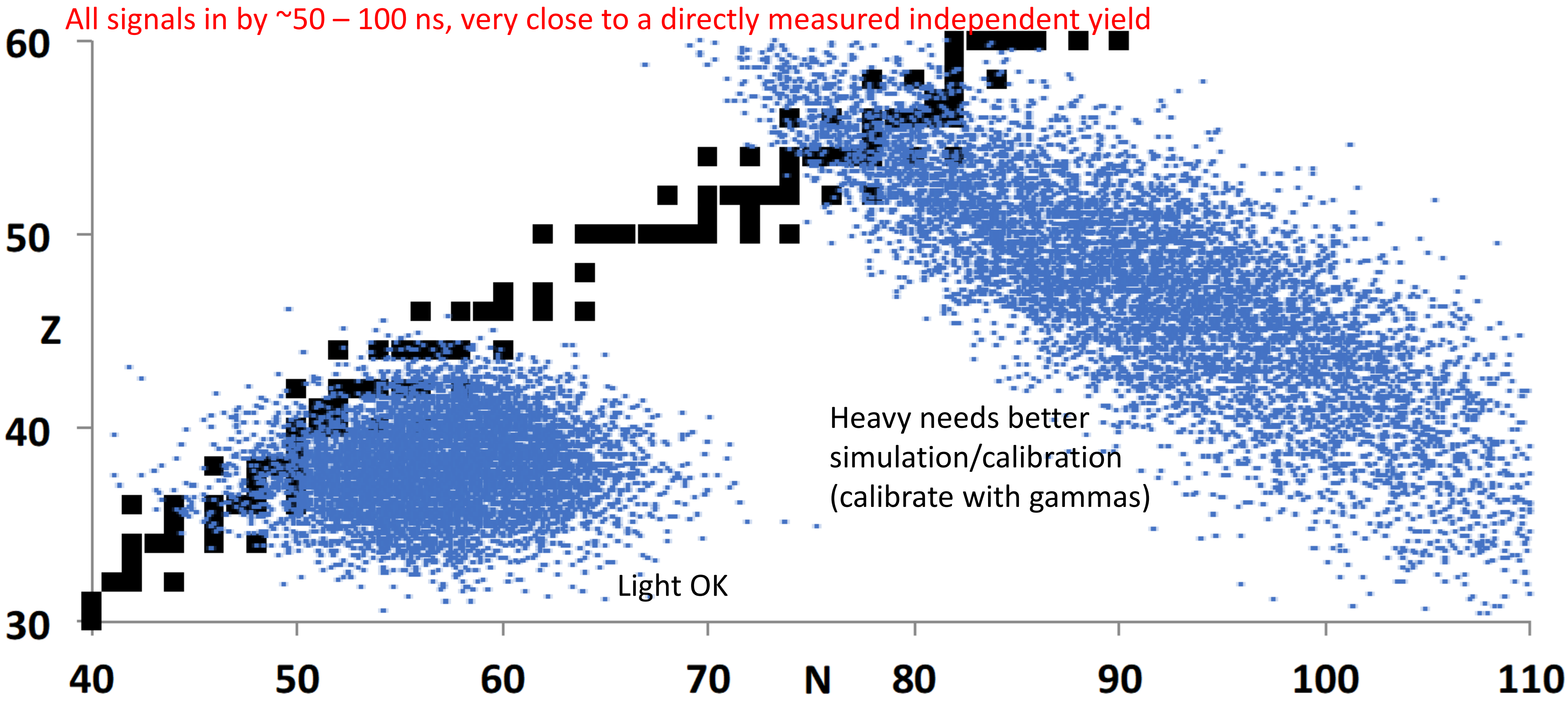


Square = stable, blue dots = data, black dots >1% independent yield JAEA

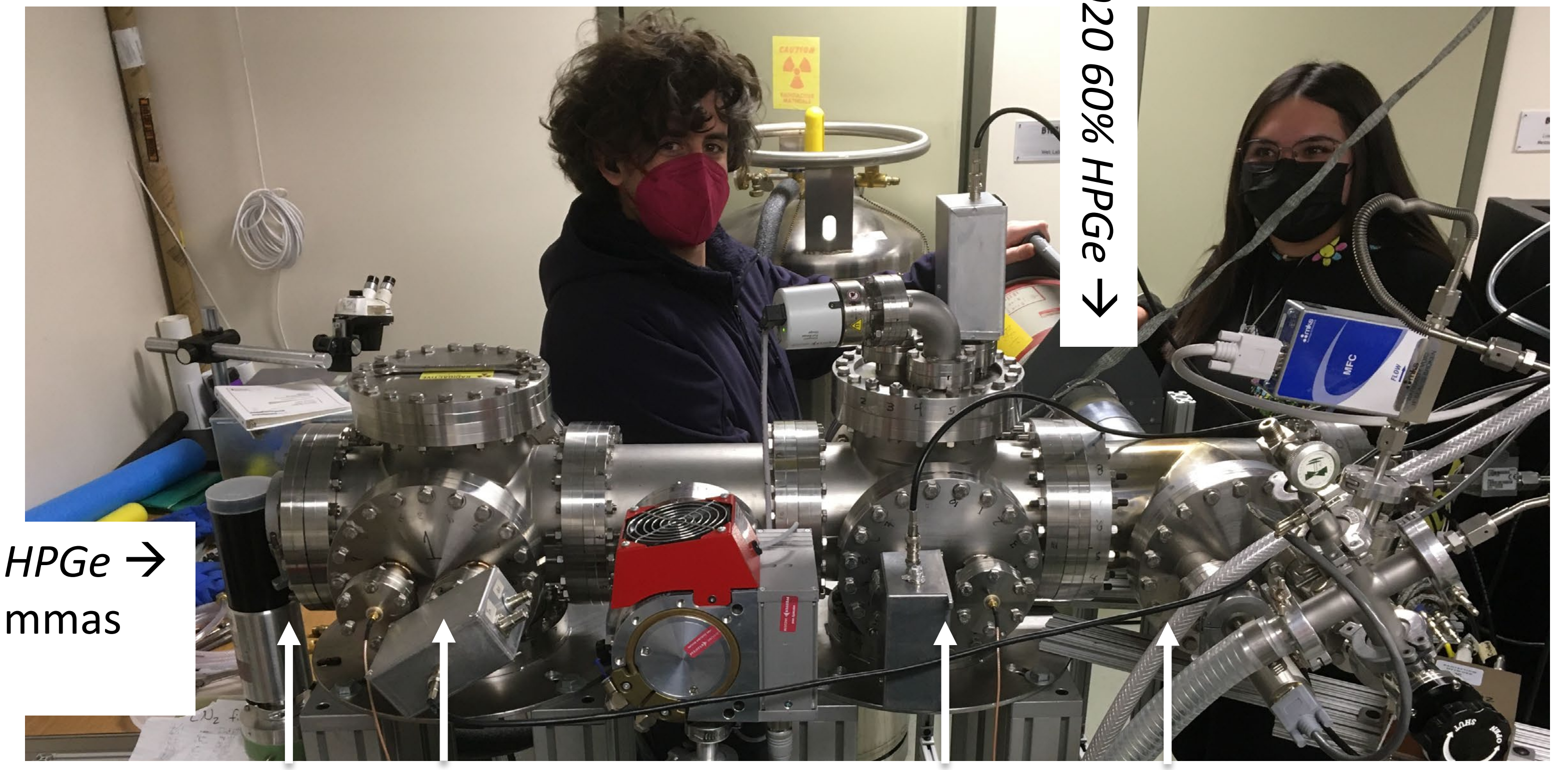
Fission-gamma coincidences

Delayed gammas (at IC)
>50-100 ns post fission

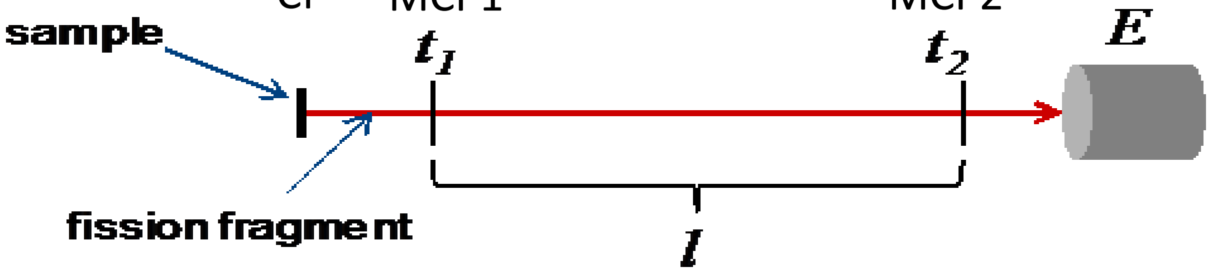
GX6020 60% HPGe →

1.2 uCi Cf

GMX 25% HPGe →
Prompt gammas
(at Cf)

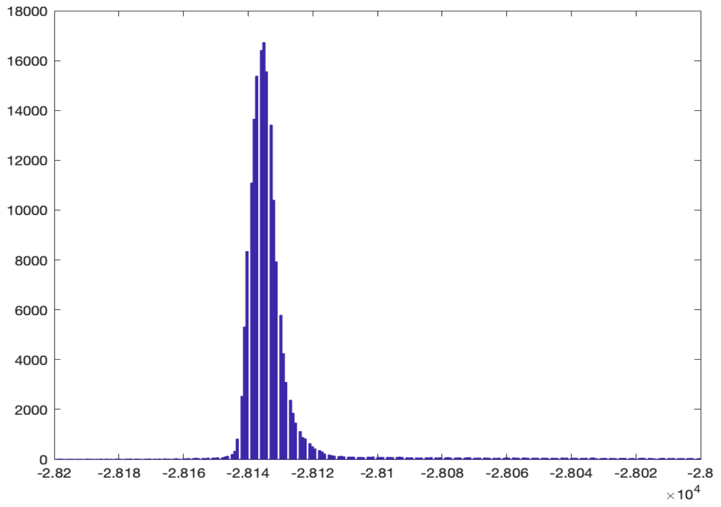


Cf
MCP1
MCP2
Ionization Chamber



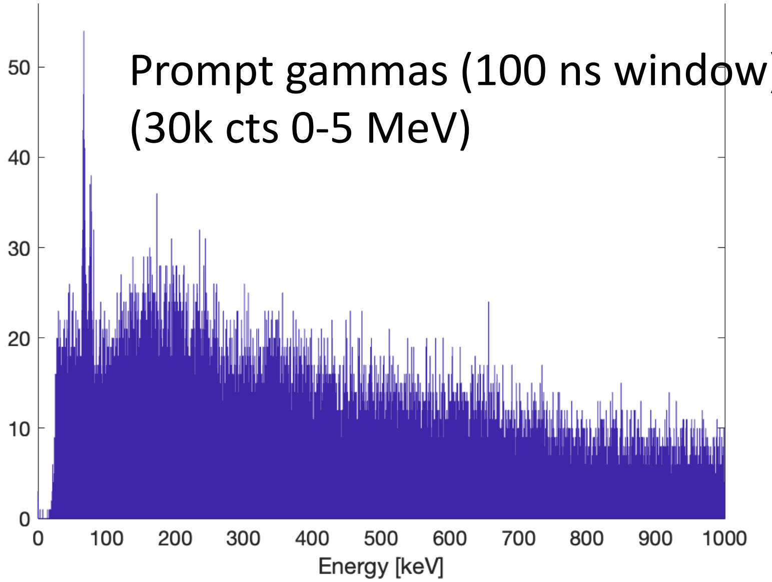
Fission-gamma coincidences

Prompt

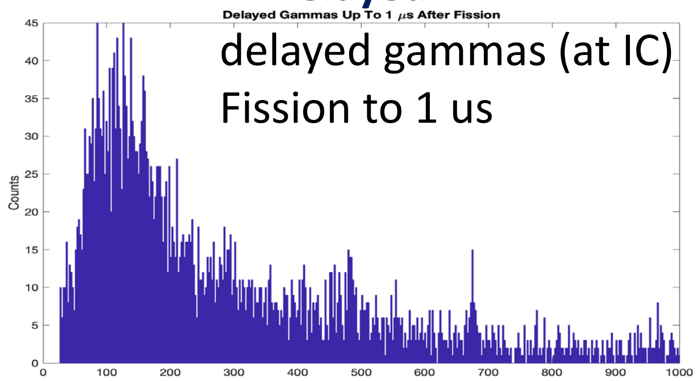


Prompt gamma time minus MCP1 time: 100 ns width.
Low noise outside of prompt gamma pulse.

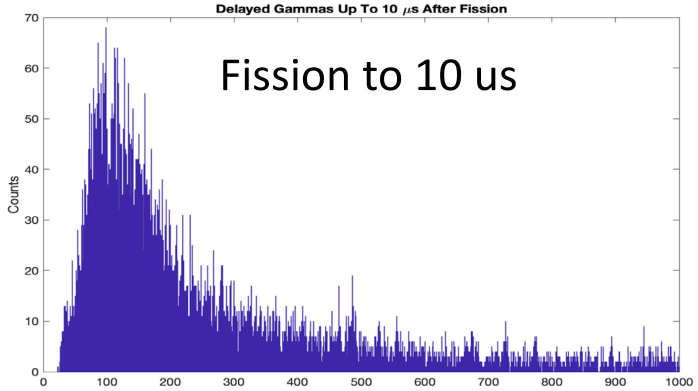
Prompt gammas (100 ns window) at Cf
(30k cts 0-5 MeV)



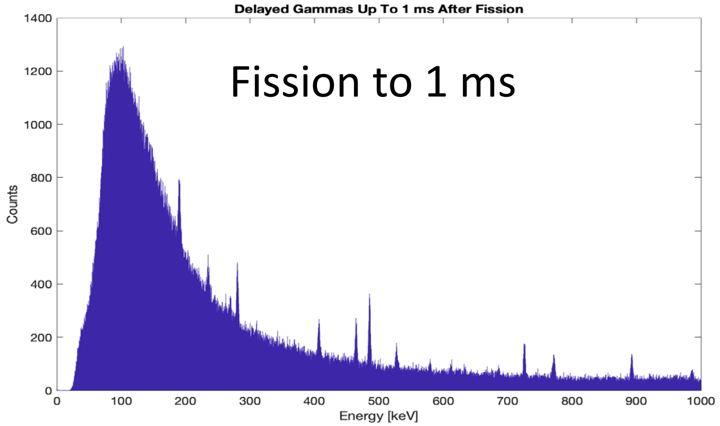
Delayed



delayed gammas (at IC)
Fission to 1 us

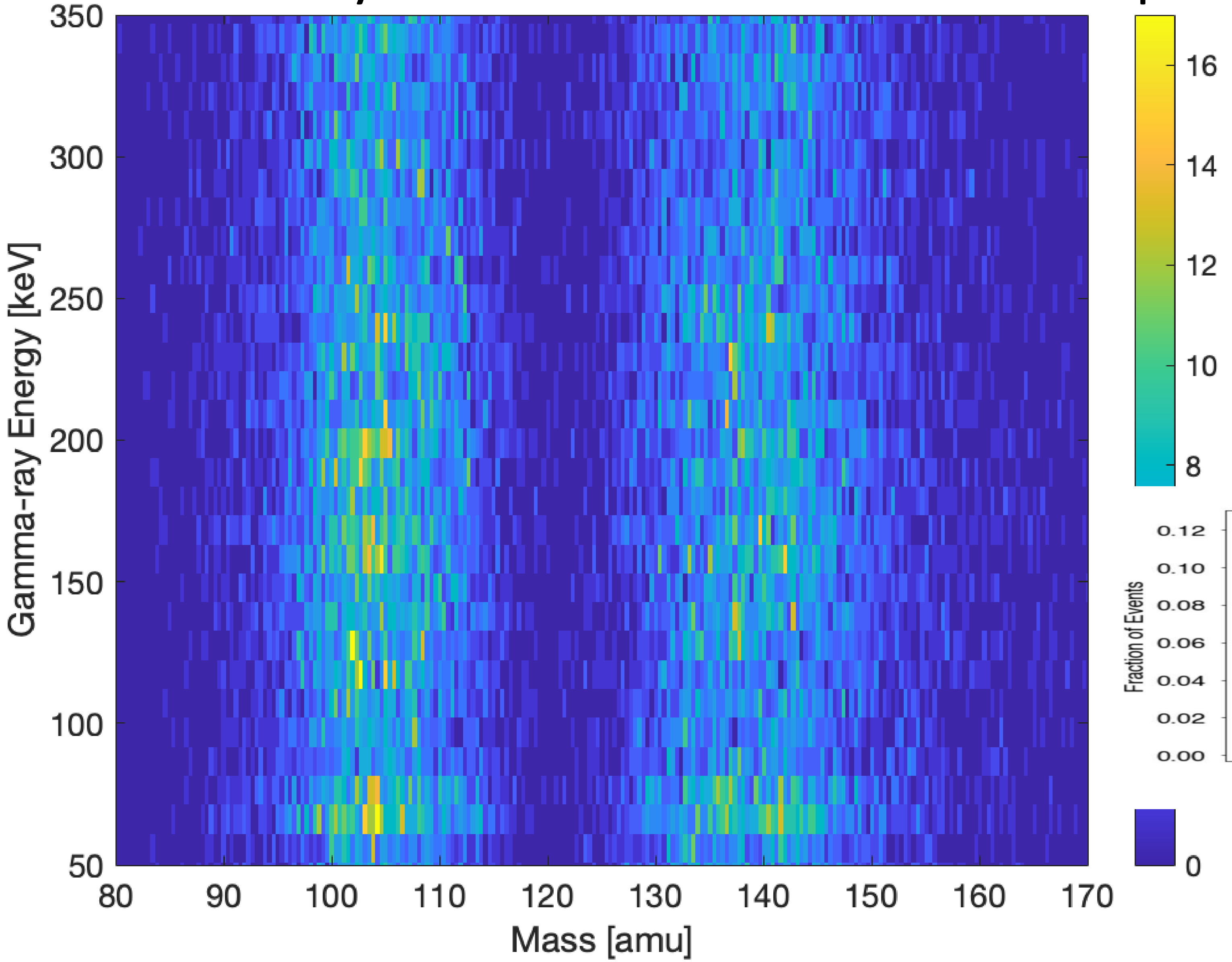


Fission to 10 us

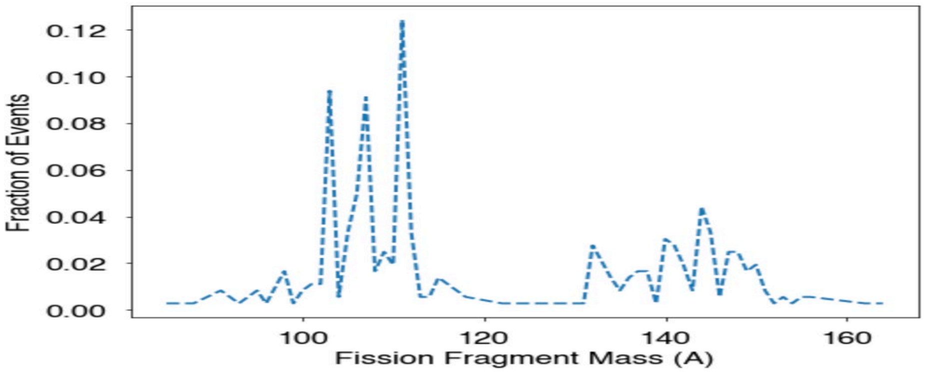


Fission to 1 ms

Fission product mass vs. coincident prompt gamma energy
Will try to calibrate A and Z based on prompt gammas



CGMF simulation example for 105 keV



Thank You!

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