Experimental nuclear data program at LLNL

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This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

CSEWG at BNL, Nov 16, 2011

LLNL-PRES-513456

Outline

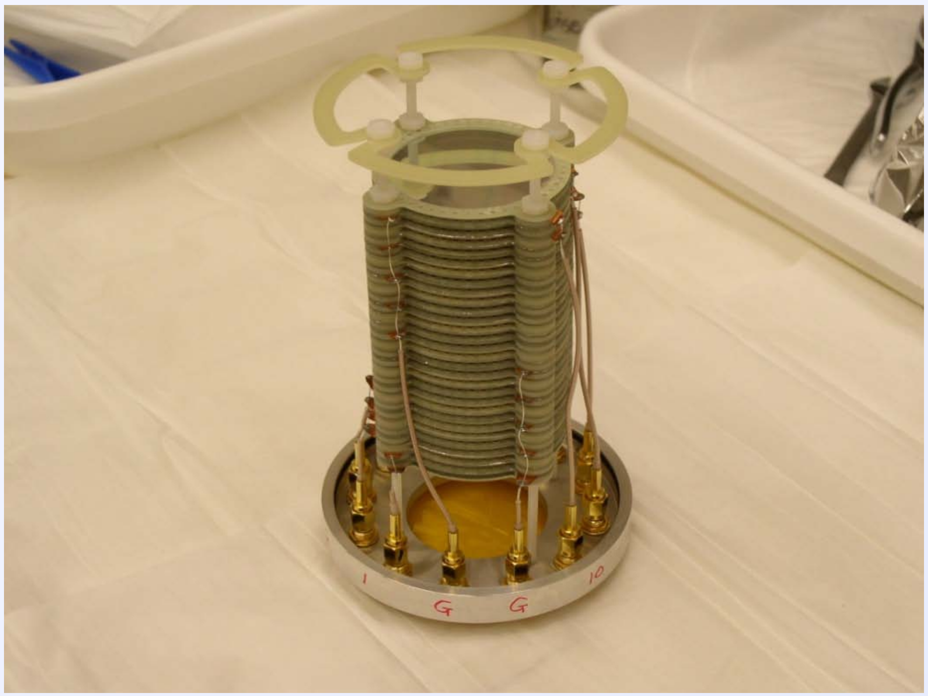
- Direct measurements for the neutron-induced reactions on actinides
- Surrogate cross section measurements
- β-delayed neutron emission measurements for fission fragments
- Summary

Direct measurements for the neutron-induced reactions on actinides

- Measurement of the prompt neutron and gamma emission in neutron-induced fission using the $\chi\nu$ array
- Neutron capture and the fission prompt gamma measurement using the DANCE array

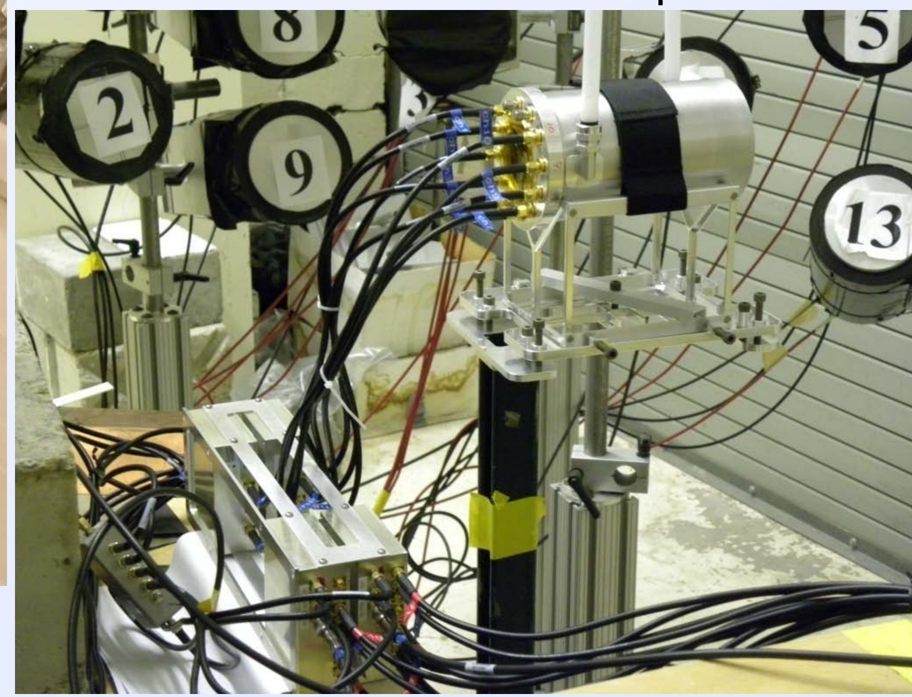
Prompt γ emission in fission – Experiments

- The prompt γ emission in fission was measured using an array consisting of ~ 20 large volume scintillators in coincidence with the detection of fission fragments
- The latter was accomplished using a parallel-plate avalanche counter



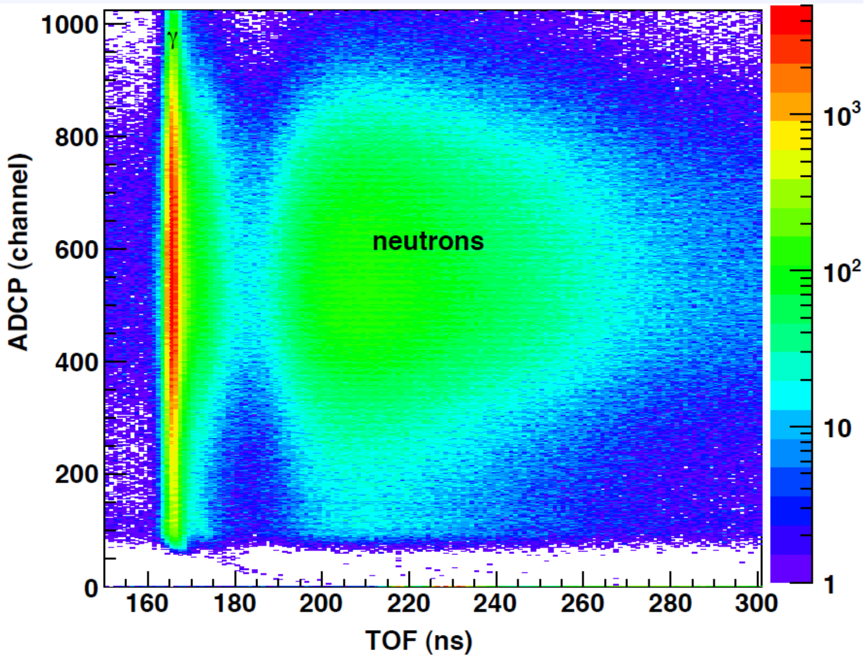
Fully assembled ^{235}U counter with a total mass of 113 mg

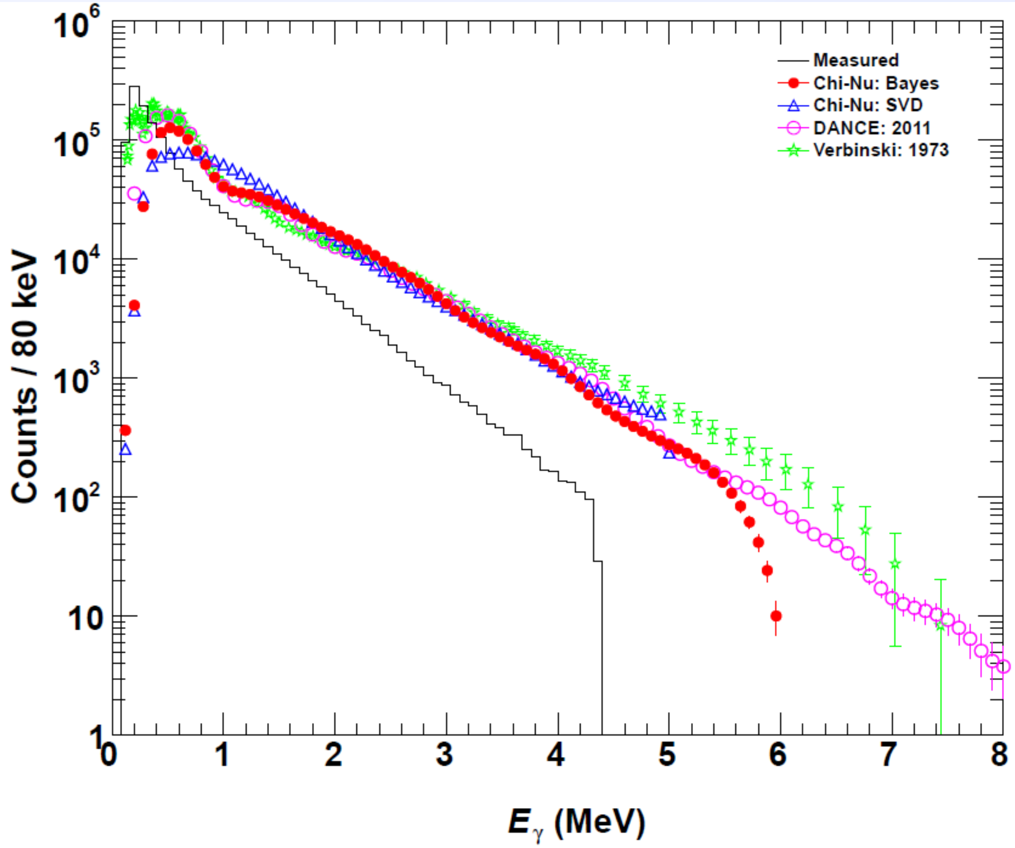
Fission counter setup



Prompt γ emission in fission – Results for the SF in ^{252}Cf

- The measured γ energy spectra were unfolded using both Bayesian and SVD methods according to the detector response, simulated numerically using a model validated by the γ-ray calibration sources, ^{22}Na, ^{60}Co, and ^{88}Y.

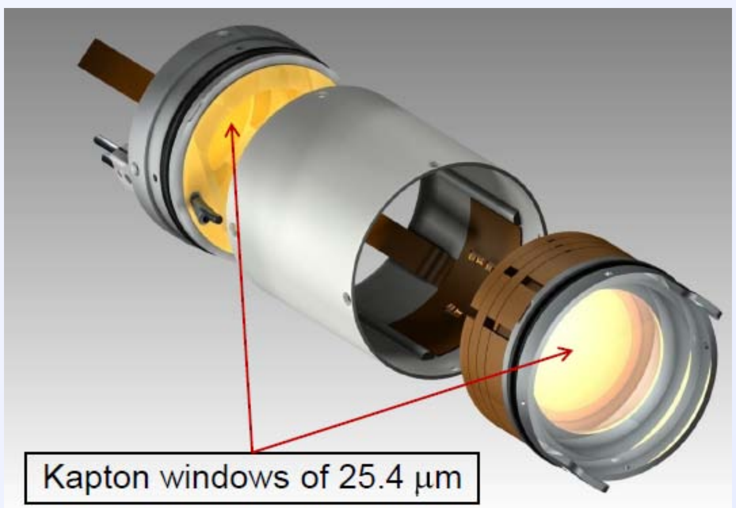


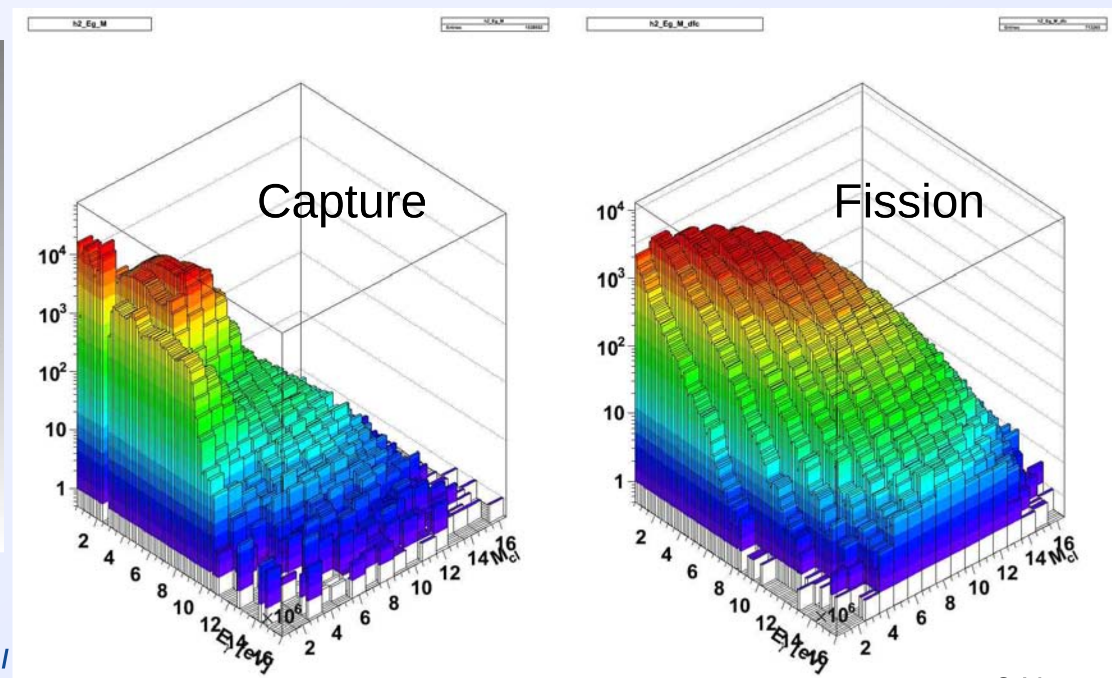


Elaine Kwan

Neutron capture cross section measurement

- Experiments fielded using the DANCE array together with a newly designed fission counter between Sep 2010 and Oct 2011
  - ^{239}Pu (0.937 mg), ^{241}Pu (0.147 mg), ^{235}U (0.923 mg), ^{238}Pu (0.374 mg)
- Events recognized by the total γ energy with the summed photopeak equivalent to the reaction Q value
- Cross sections derived for E_n from thermal to ~ 100 keV

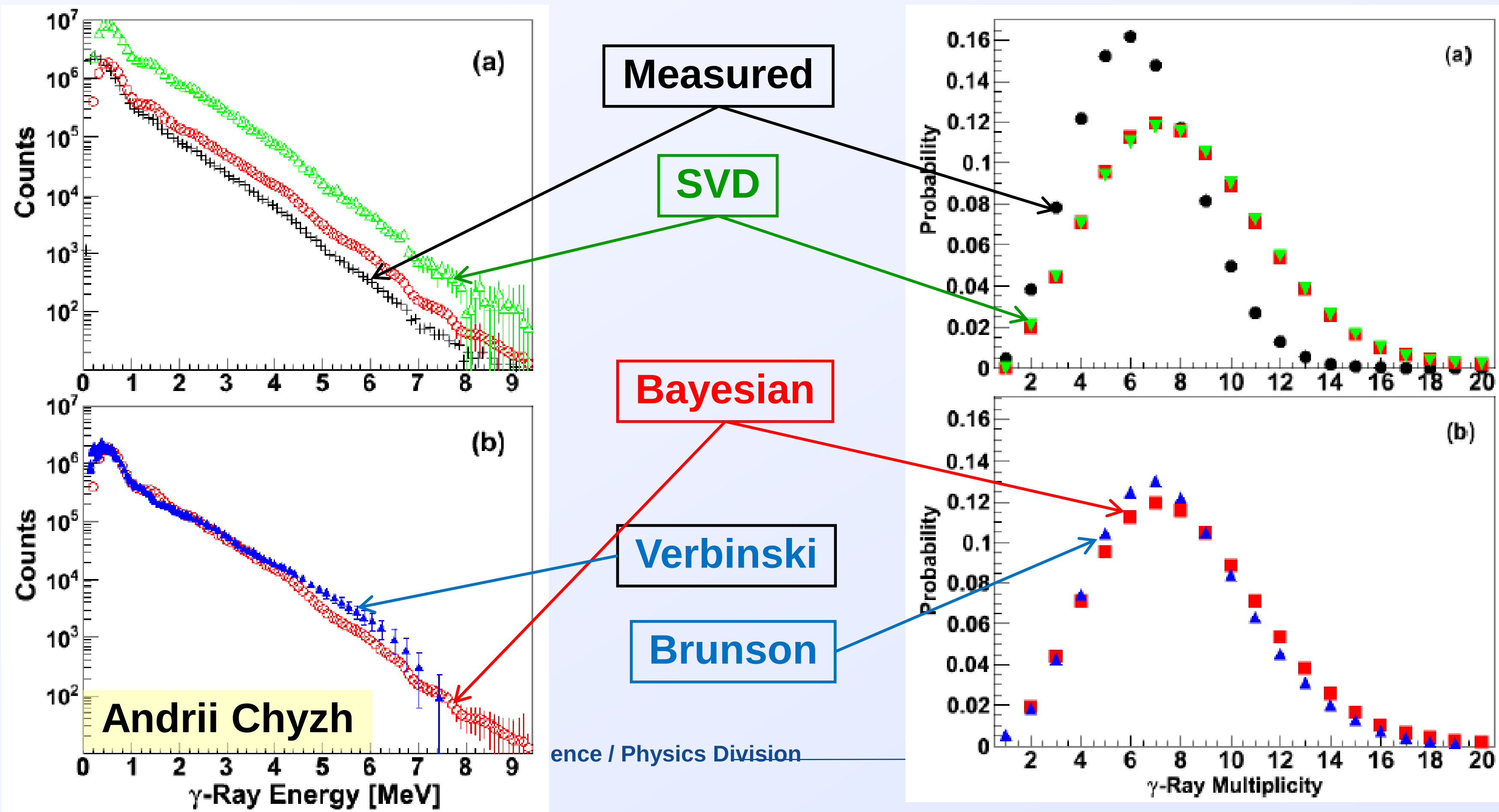




Total γ energy-multiplicity distribution for ^{241}Pu

Prompt γ energy and multiplicity in the SF of ^{252}Cf

- Both γ energy and multiplicity distributions were unfolded using both Bayesian and SVD methods
  - The actual γ multiplicity distribution derived experimentally for the first time



Future plan

- Manuscript ready to submit to PRL, addressing the stochastic aspect of the prompt gamma emission in fission
- Prompt γ energy distribution in fission for ^{235}U and ^{239}Pu for E_n above 1 MeV
- Prompt γ energy and multiplicity distribution in fission for ^{235}U, ^{238}Pu, and ^{241}Pu for E_n below 100 keV
- Neutron capture cross sections for ^{238}Pu and ^{241}Pu for E_n below 100 keV

Physical Sciences

Collaborators

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Surrogate cross section measurements

Contributed by Jason Burke

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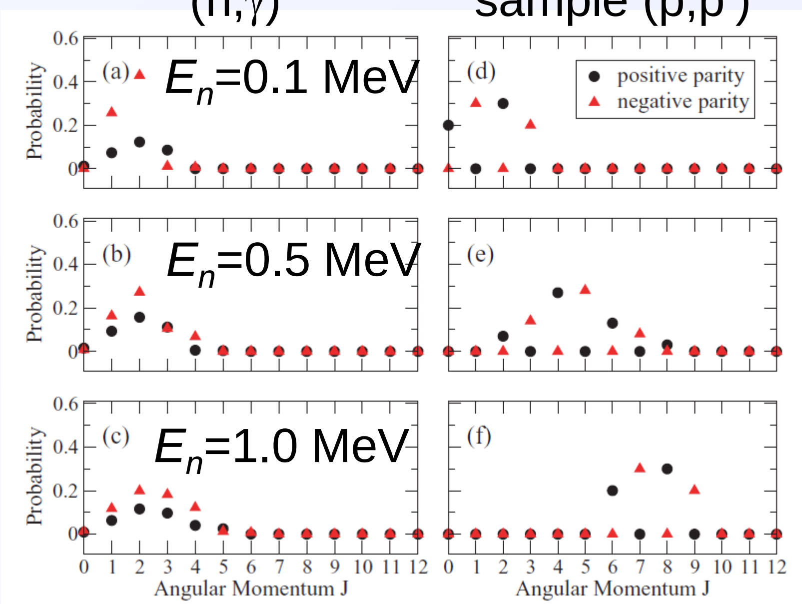
Extracting the Surrogate (p,p') spin distribution: result for ^{156}Gd

Results are being used to determine (n,γ) cross section for ^{153}Gd ($t_{1/2}$=242 day)

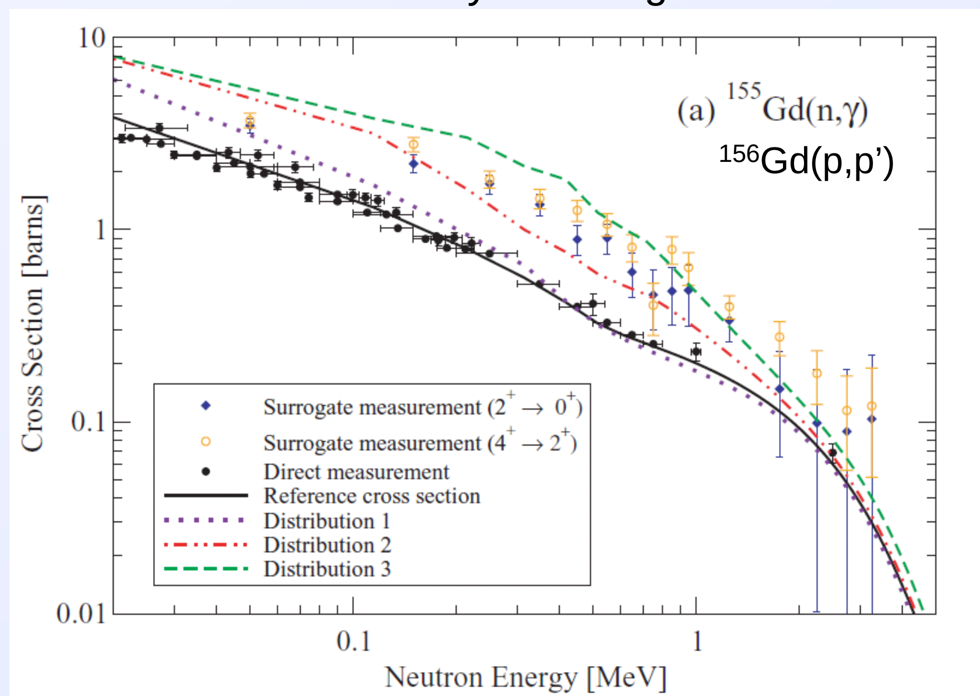
J^{π} distribution of

surrogate reaction $\neq$ desired reaction

(n,γ) sample (p,p')



Experiment performed to determine ^{155}Gd(n,γ) cross section sensitivity to surrogate reaction J^{π}

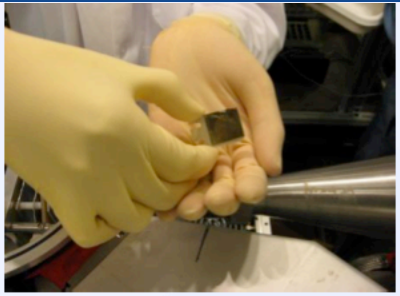


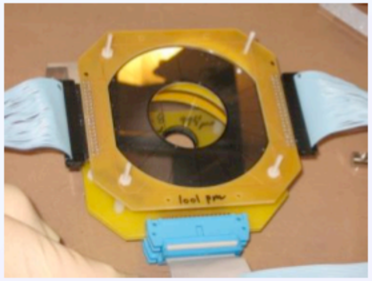
N.D. Scielzo *et al*., Phys. Rev. C 81, 034608 (2010)

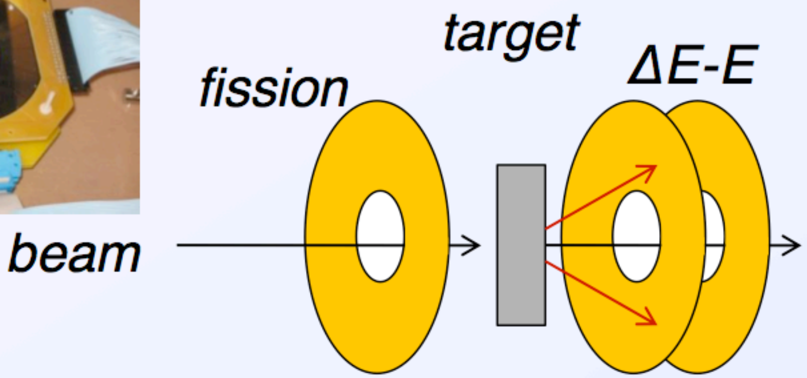
J.E. Escher and F.S. Dietrich, Phys. Rev. C 81, 024612 (2010)

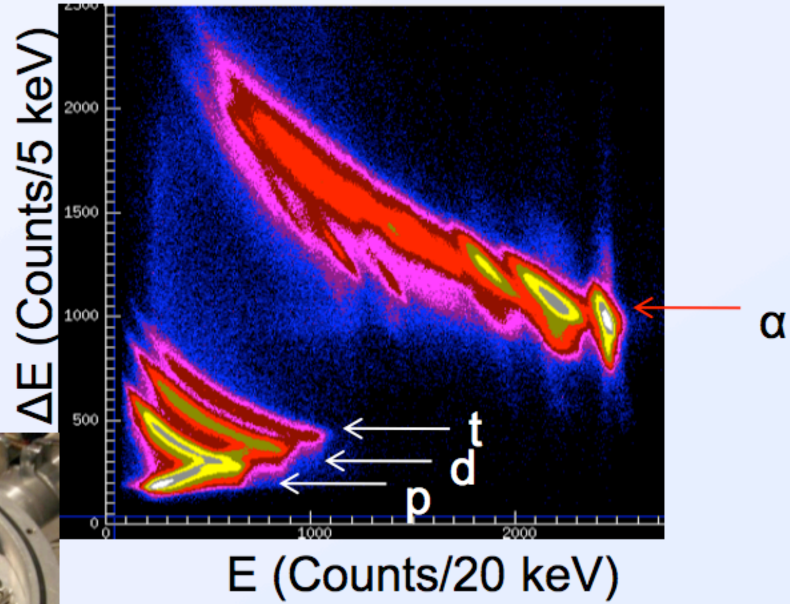
^{238}Pu(n,f) surrogate experiment

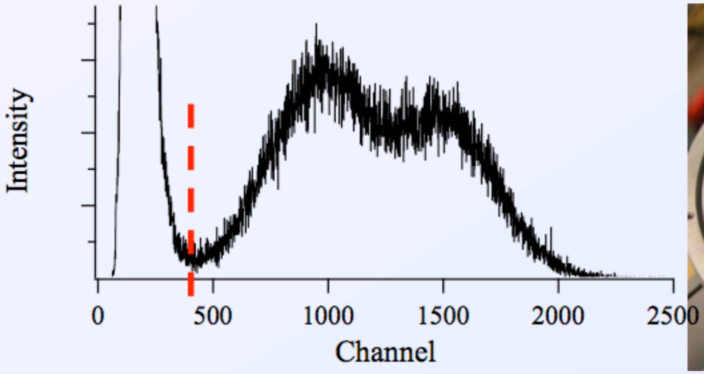
- 55 MeV alpha beam from 88” cyclotron at LBNL
  - 5 day measurement period
- 140 μg/cm² ^{239}Pu, 416 μg/cm² ^{235}U, 322 μg/cm² ^{236}U
- 1 – 20 MeV equivalent neutron energy range

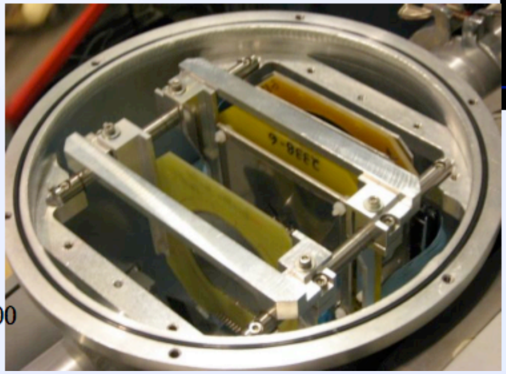






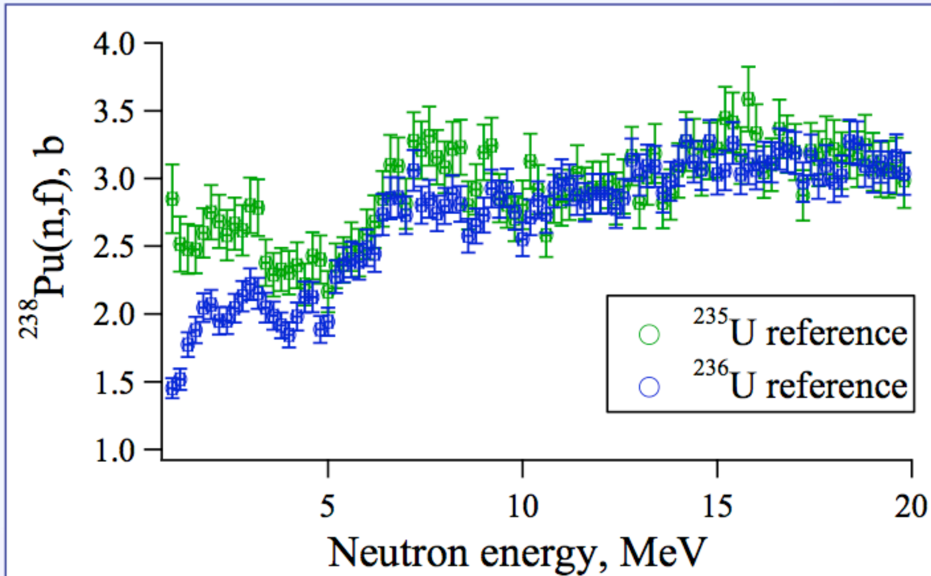






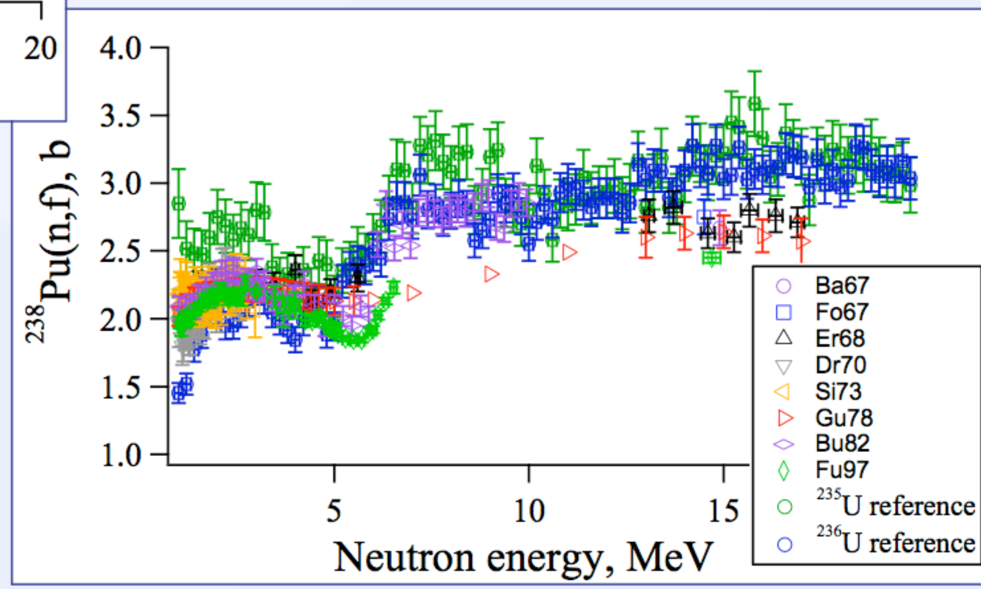
STARS

^{238}Pu(n,f) surrogate results (Courtesy J.J. Ressler)



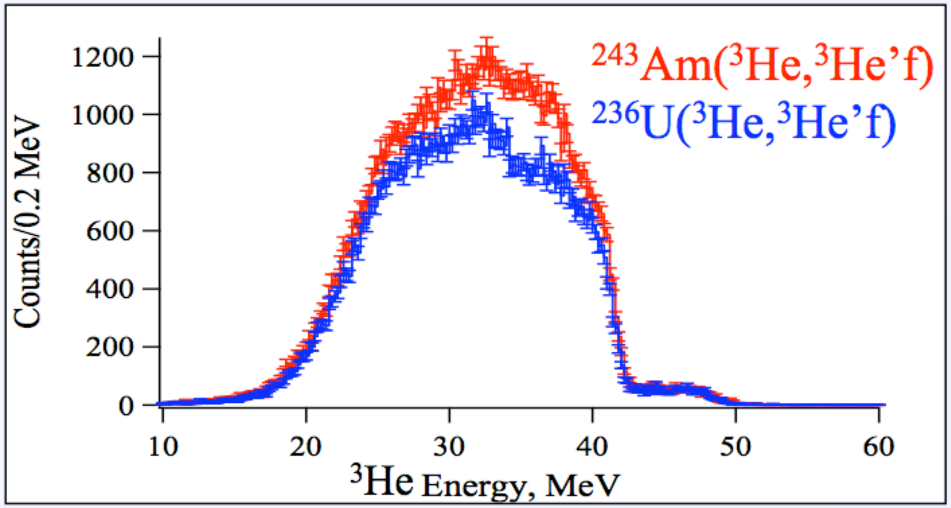
- Good agreement between both surrogate reactions above 5 MeV
- Spin effects below 5 MeV

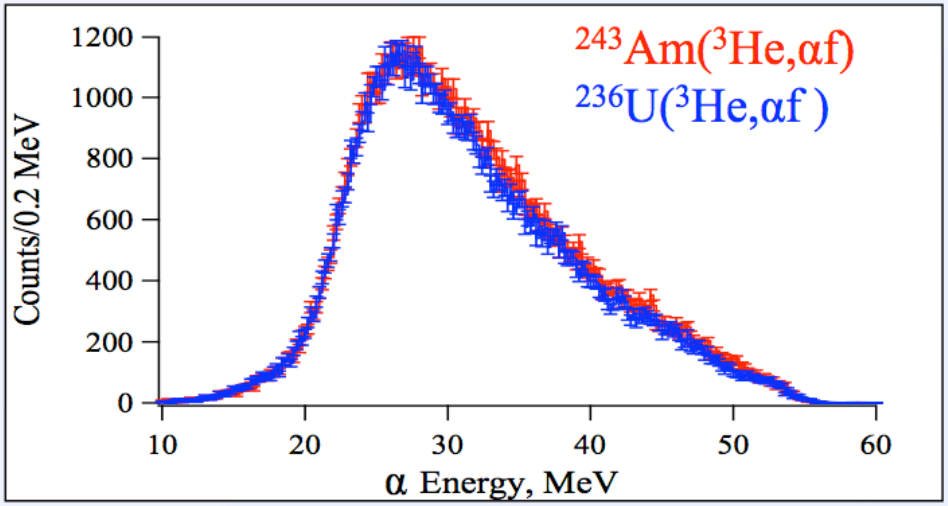
- Surrogate ratio with ^{235}U reference reaction suggests higher cross-section at second-chance fission
  - Spin effects?
- Both surrogates have higher cross-section near 14 MeV



Ressler et al. Phys. Rev. C ***83****, 054610, 2011.*

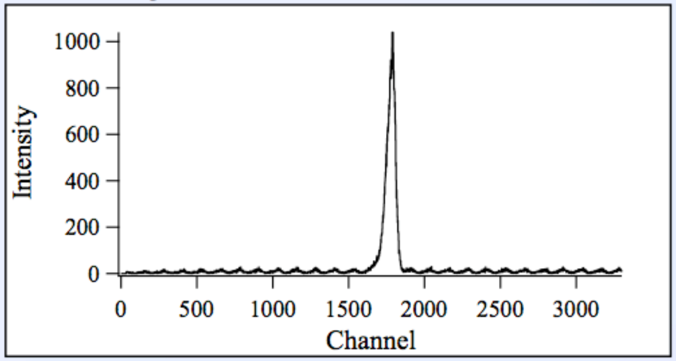
^{241}Am(n,f) and ^{242}Am(n,f) cross sections – CS being determined





- ~71 hours ^{243}Am, 28 hours ^{236}U targets
- Refine experimental analysis
  - Gain corrections
  - Fission tagging
  - Examine particle-gamma coincidences
- Perform theoretical analysis
- Determine ^{242,241}Am(n,f) cross sections
- Publish results (September 2011)

Particle-fission TAC



Physical Sciences

Collaborators (students in red post-docs in green)

J.T. Burke, N.D. Scielzo, J.E. Escher, J.J. Ressler**,** I.J. Thompson, R.J. Casperson, F.S. Dietrich, R. Henderson, J. Gostic**,** R.D. Hoffman
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B. Jurado, M. Aiche, G. Boutoux **– *CENBG, Bordeaux, France***

J. Benstead – AWE, England

L.W. Phair, M.S. Basunia, A. Hurst, P.Fallon, I.Y. Lee, and A.O. Macchiavelli - *Lawrence Berkeley National Laboratory*

C.W. Beausang **and** R.A. Hughes - *University of Richmond*

V. Werner – *Yale University*

J. Tostevin, T. Ross - *University of Surrey, England*

J.A. Cizewski, N. Koller **and A. Ratkiewicz** - *Rutgers University*

E.B. Norman, J. Munson, P. Chodash, E. Swanberg **-** *U.C. Berkeley*

R. Austin - *St. Mary's University, Canada*

S. Chiba, K. Nishio, H. Koura, I. Nishinaka – *JAEA, Japan*

STARS - Collaboration past and future planned measurements (more to be added as year develops)

FY2011 Experiments

Item	Experiment	PI	Institution
1	Y/Zr(3He,x) surr Y(n,2n)	Scielzo/Burke	LLNL
2	Y/Zr(p,p') surr Y(n,g)	Scielzo/Burke	LLNL
3	243Am(3He,x) surr 241Am(n,f) 242Am(n,f)	Ressler/Burke	LLNL
4	243Am(p,t) surr 240Am(n,f)	Ressler/Burke	LLNL
5	239Pu(d,p) surr 239Pu(n,f)	Casperson/Burke	LLNL
6	238U(3He,p) surr 239Np(n,f)	Norman/Angell	U.C. Berkeley
7	238U(p,d) surr 236U(n,g)	Beausang/Hughes	University of Richmond
8	Mo(d,p) and Ge(d,p)	Wiedeking	Ithemba
9	106,108,110Pd(p,p')	Hurst	LBNL
10	24Mg(4He,4He) astro	Munson/Norman	U.C. Berkeley
11	168Er(d,p) nuclear structure	Basunia/Firestone	LBNL

FY2012 Experiments

Item	Experiment	PI	Institution
1	actinide cross section - TBD	Burke/Scielzo	LLNL
2	nuclear structure - TBD	Burke/Scielzo	LLNL
3	95Mo(d,p) surr > (n,g)	Cizewski + PD	Rutgers University
4	174Yb(p,d) surr 172Yb(n,g)	Meot + PD	BIII
5	175Lu(p,d) surr > 173(n,g)	Roig	BIII
6	actinide cross section - TBD	Norman + PDs + GSs	U.C. Berkeley - NSSC
7	(p,d) benchmark - TBD	Beausang + PD + GS	University of Richmond
8	Nd nuclear structure	Beausang + PD + GS	University of Richmond
9	Nuclear structure TBD	Volker Werner	Yale University
10	G factor measurement and nuclear structure	Noemie Koller + PDs + GSs	Rutgers University

β-delayed neutron decay measurements for fission fragments

Contributed by Nicholas Scielzo
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Delayed Neutrons play a fundamental role in many basic and applied sciences

Need better (or any) data for:

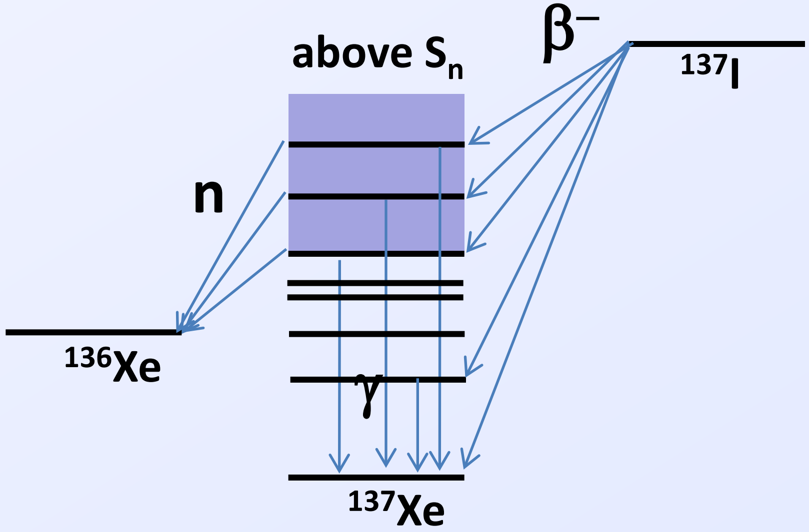
Astrophysics: nucleosynthesis of elements heavier than Fe

Nuclear Structure: predicting properties of neutron-rich nuclei

Nuclear Energy: reactor design, performance, and safety studies

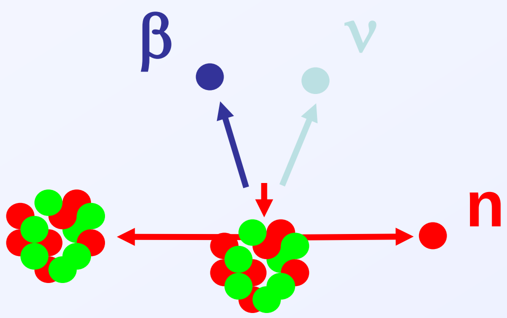
Stockpile Stewardship: interpreting results involving production of fission fragments

β-delayed neutron emission



Apply precision ion trap approaches to β-delayed neutron spectroscopy

Perform delayed-neutron spectroscopy by detecting recoiling daughter ions emerging from an ion trap to reconstruct neutron momentum/energy



Neutron emission

β (1 MeV): ~0.01 keV recoil

n (1 MeV): ~10 keV recoil

Identify neutron emission from large nuclear recoil!

AVOID NEUTRON DETECTION!

Traps have favorable properties:

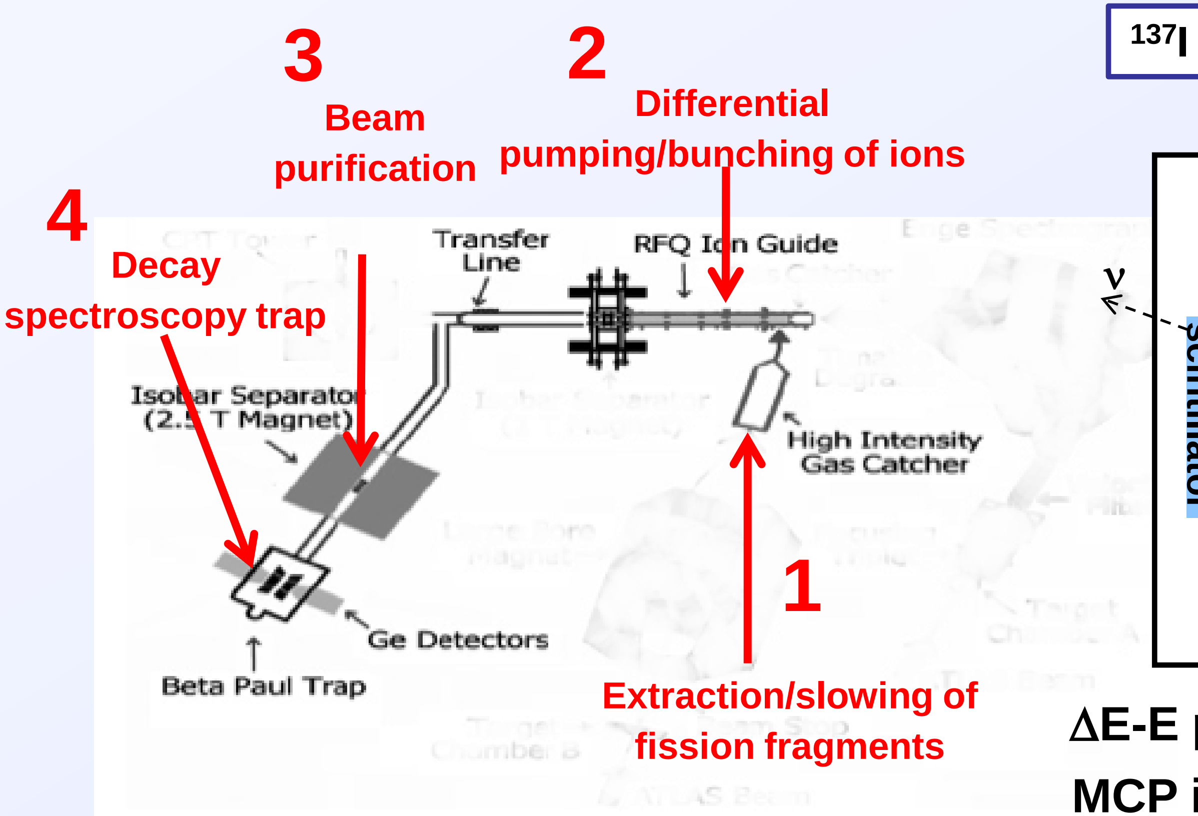
- nuclei suspended in vacuum → no scattering
- activity localized (~1mm^3)
- nuclei nearly at rest
- accessible decay times of 10 ms to >1000 s
- works for any isotope

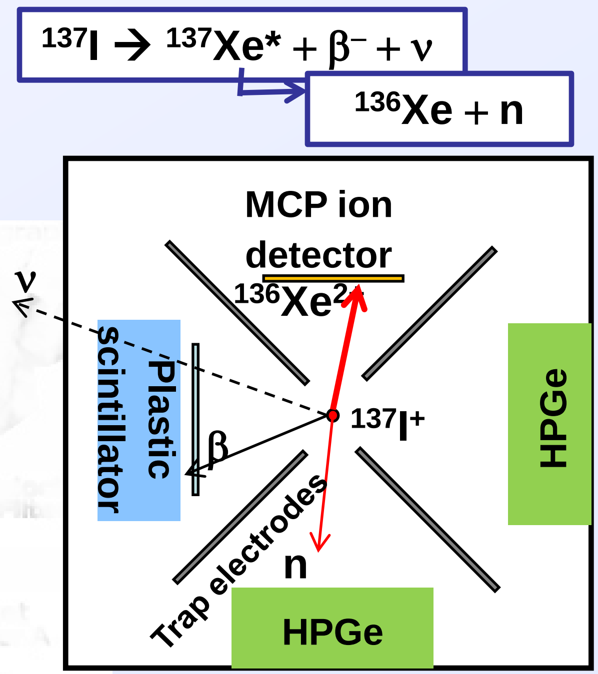
Many anticipated advantages to recoil-ion detection: excellent energy resolution, reduced systematic effects, negligible backgrounds, high efficiency,…

Demonstrate technique offline by studying well-characterized ^{137}I decay

Demonstrate technique with smaller fission-fragment set-up (1 mCi ^{252}Cf offline source at ANL) and simpler/smaller detector array

Surround open-geometry ion trap with plastic scintillator and MCP detectors and reconstruct neutron from ion time-of-flight



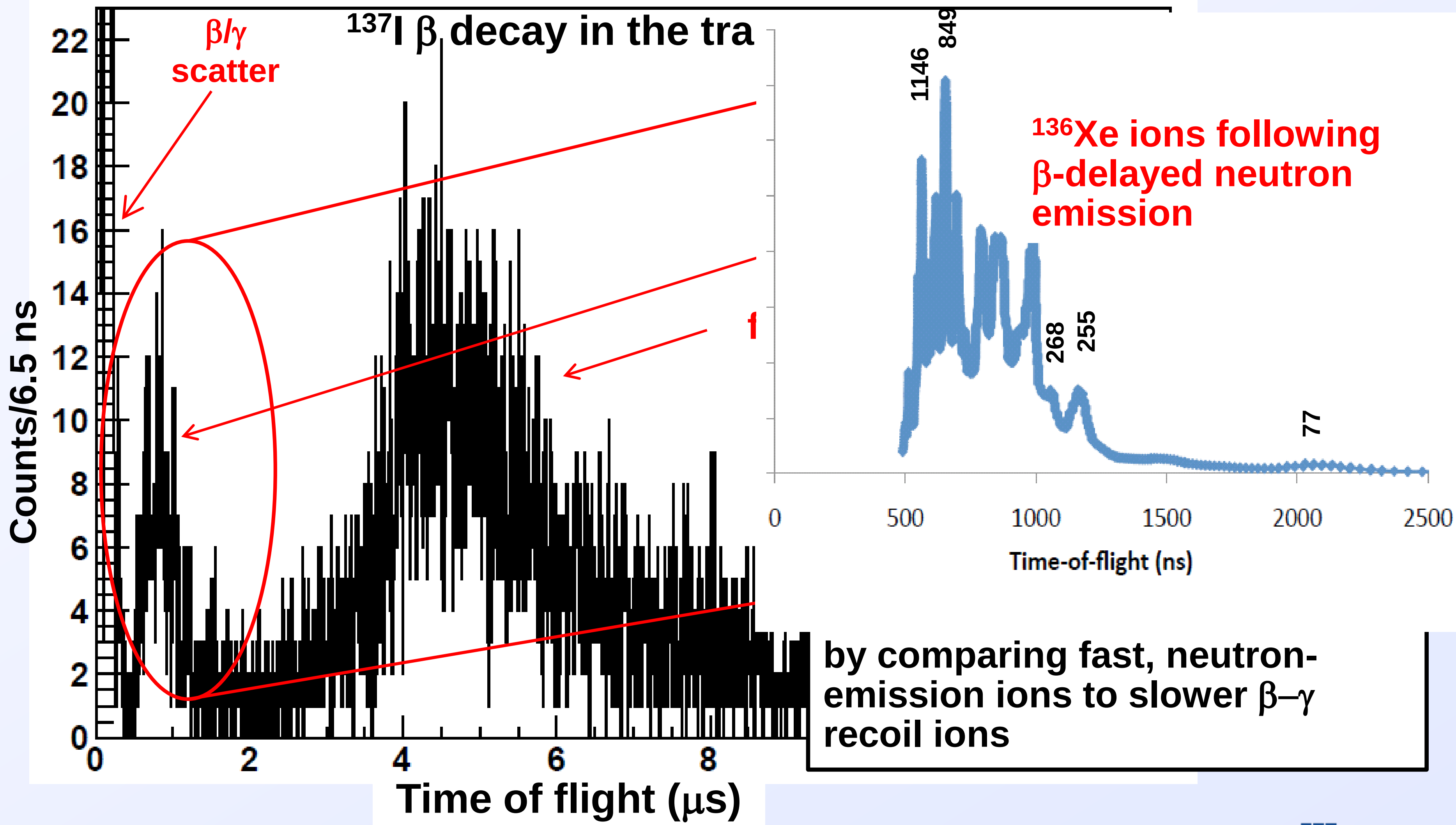


ΔE-E plastic scintillator: Ω_{β} = 3%

MCP ion detector: Ω_{ion} = 3%

Data collected with $^{137}I^{+}$ beam of 30 ions/sec

Ryan Yee
UC Berkeley GS



by comparing fast, neutron-emission ions to slower β–γ recoil ions

From Demonstration to CARIBU

Proof-of-principle…

…at CARIBU

Detector array Ω_β, Ω_{ion} each 3% → **Increase both Ω_β, Ω_{ion} to 10-20% with optimized detector array (FY12)**

→ coinc. efficiency: ×10-40

High-quality data with ion beams of 0.1-1 ion/sec

→ reach very exotic nuclei: r-process, nuclear structure, etc.

Ion beam 30 ions/sec (for ^{137}I, near mass peak) → **CARIBU 1-Ci source: 4×10^6 ions/sec (for ^{137}I at low-energy beamline) (FY13)**

High statistics for precision and systematic checks

→ nuclear energy, stockpile stewardship, etc.

Future plan

- Measurements will be made for $^{144,145}Cs$, $^{105,106}Nb$ in addition to ^{137}I
- Waiting for CARIBU online …

Collaborators

N.D. Scielzo, R. Yee, M. Pedretti, E.B. Norman

M. Alcorta, J.A. Clark, C.M. Deibel, A.F. Levand, P. Bertone, G. Savard

S. Caldwell, M.G. Sternberg, J. Van Schelt

F. Buchinger, J.E. Crawford, S. Gulick, G. Li

R. Segel, D. Lascar

A. Chaudhuri, K.S. Sharma, G. Gwinner

Summary

- A suite of hardware has been developed for the nuclear data program at LLNL
- Relevant to Stockpile Stewardship, nuclear forensics, nuclear energy, …
- Continue to look for research opportunities in both basic and applied nuclear physics important to national security