Lawrence Livermore National Laboratory

Update of Experimental Activities in Low-Energy Nuclear Physics at LLNL

N.D. Scielzo

Cross Section Evaluation Working Group Annual Meeting

November 8, 2012

Lawrence Livermore National Laboratory, P. O. Box 808, Livermore, CA 94551

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

Direct measurements of neutron-induced rea on actinides

slide from
C.Y. Wu

- Measurements of the prompt neutron and γ-ray emission in the neutron-induced fission using the $\chi\nu$ array
- Measurements of neutron capture and fission prompt γ-ray emission using the DANCE array

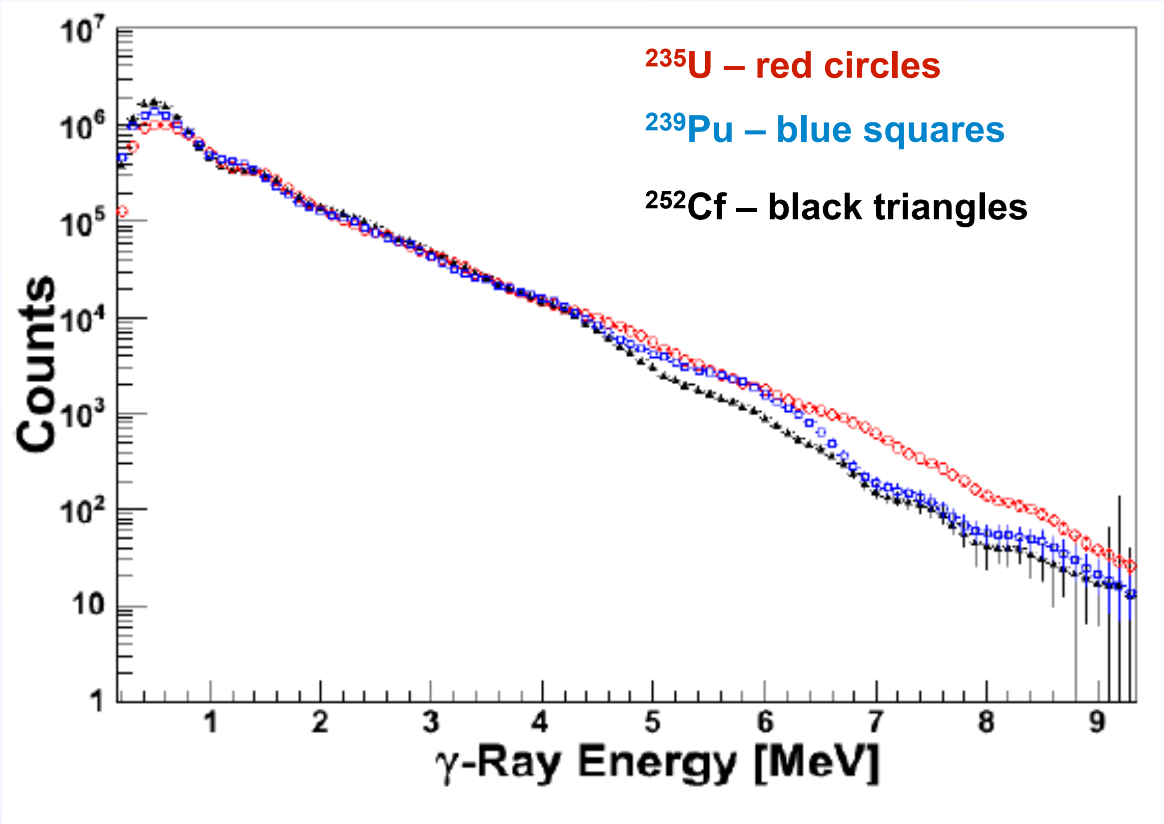
slide from
C.Y. Wu

Published results

- "*Evidence for the stochastic aspect of prompt gamma emission in spontaneous fission*" A. Chyzh *et al*., PRC 85, 021601(R) (2012)
- "*Prompt energy distribution of ^{235}U(n,f)γ at bombarding energies of 1 – 20 MeV*" E. Kwan et al., NIMA 688, 55 (2012)
- "*Systematics of the prompt gamma-ray emission in fission*", A Chyzh *et al*., submitted to PRC for publication Oct, 2012

Systematics of the prompt γ-ray energy distribution in fission

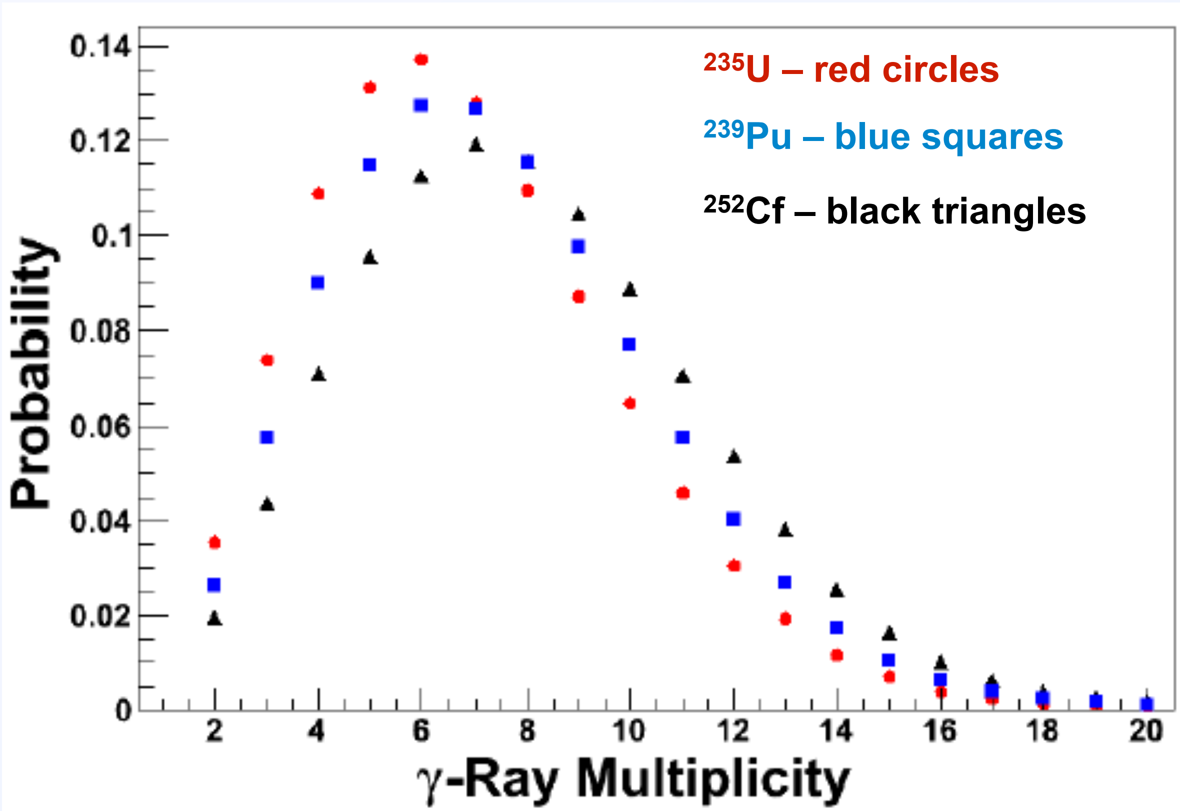
slide from
C.Y. Wu



- Data normalized according to the yields of γ-ray energy between 1 – 4 MeV
- The spectrum above 5 MeV shows a strong dependence on the species of fissile nuclei

Systematics of the prompt γ-ray multiplicity distribution in fission

slide from C.Y. Wu

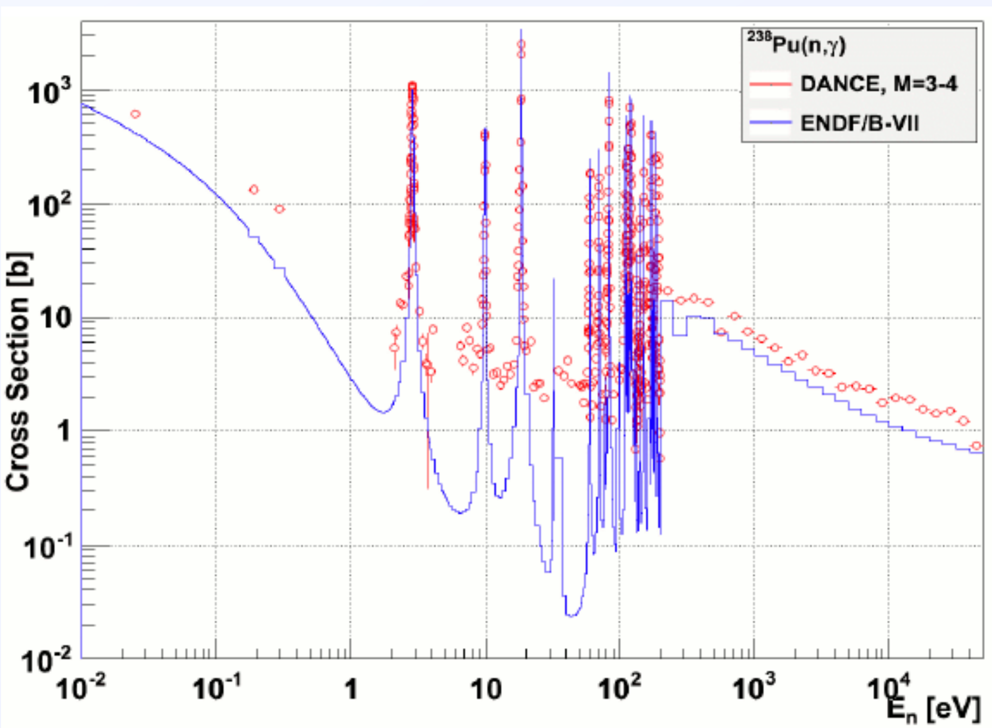


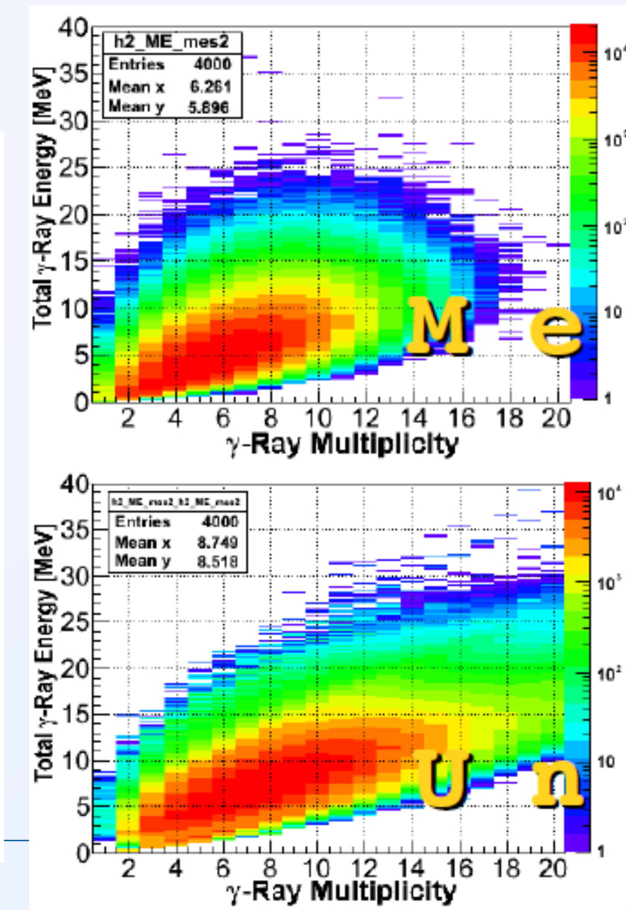
- Distributions have a similar Gaussian-like shape with the tail extending to the higher M_γ
- The mean M_γ is increasing with increasing mass of fissile nuclei, while the width shows the same trend and is nearly the same as the mean value

Coming soon…

slide from
C.Y. Wu

- Precision measurement of the neutron-capture cross section on ^{238}Pu
  - *The first ever measured at laboratory environment*
- The total γ-ray energy vs. multiplicity for the fission prompt γ-ray emission
  - *The unfolding story continues*





Measured

Unfolded

slide from C.Y. Wu

Participants

C.Y. Wu, A. Chyzh, E. Kwan, R.A. Henderson, J.M. Gostic

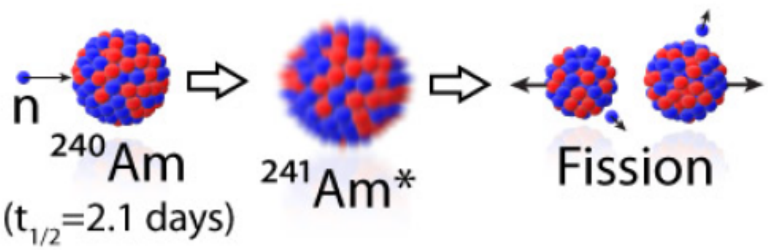
Los Alamos NATIONAL LABORATORY

R.C. Haight, H.Y. Lee, T. Taddeucci, J. O'Donnell, B. Perdue, N. Fontiades, M. Devlin, J.L. Ullmann, A. Laptev, T. A. Bredeweg, M. Jandel, A. Couture, A.C. Hayes-Sterbenz, S. Mosby

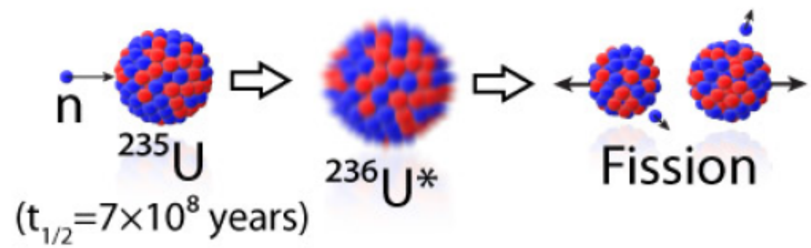
The Surrogate Reaction

slide from
R. Casperson

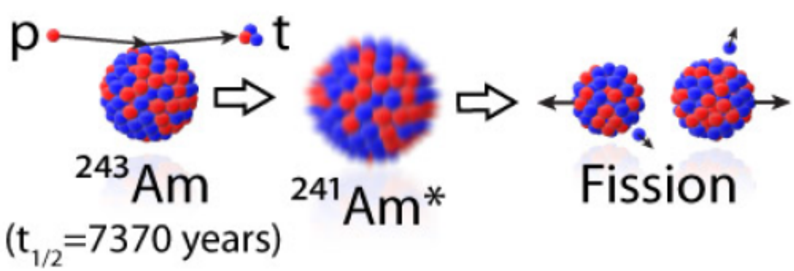
Desired Reaction: ^{240}Am(n,f)



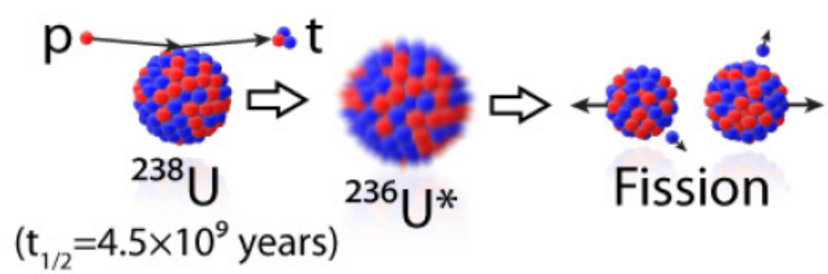
Reference Reaction: ^{235}U(n,f)



Surrogate Reaction: ^{243}Am(p,tf)



Ratio Reaction: ^{238}U(p,tf)



$$\sigma(^{240}\mathrm{Am}(n,f),E) = \frac{N(^{243}\mathrm{Am}(p,tf),E)}{N(^{238}\mathrm{U}(p,tf),E)} \times \frac{\sigma_{CN}(^{240}\mathrm{Am}(n,tot)^{241}\mathrm{Am}^*,E)}{\sigma_{CN}(^{235}\mathrm{U}(n,tot)^{236}\mathrm{U}^*,E)} \times \sigma(^{235}\mathrm{U}(n,f),E)$$

Status of Surrogate Cross Section Measurements

Cross section measurements of $^{240,241,242}Am(n,f)$ have been completed. Evaluations are underway and expect to be complete by December 2012.

Cross section measurement of $^{88}Y(n,2n)$ is complete and final evaluation is underway. Evaluation to be complete December 2012.

Data for $^{87,88}Y(n,\gamma)$ has been taken and data analysis and reduction is underway. Evaluation to be completed September 2013.

Final analysis being completed on $^{239}Np(n,f)$ cross section. Results to be submitted December 2012 to peer-reviewed journal.

^{237}U nuclear structure investigated: 2 new states and 10 new γ rays discovered

^{235}U nuclear structure investigated: 1 new state and 6-8 new γ rays discovered

Data taken and analysis underway for $^{236,237}Pu(n,f)$ cross sections over neutron energy range 0-6 MeV.

Data taken and analysis underway for $^{232,233}U(n,f)$ cross sections over neutron energy range 0-6 MeV.

Data taken on Yb isotopes to validate (p,d) reaction channel in preparation for Lu measurements in FY13.

Data taken on $^{95}Mo(d,p)$ to benchmark surrogate technique in spherical region for (n,γ) reactions.

Surrogate Reactions Publications in FY12

Review of Modern Physics article on surrogate nuclear reactions method

REVIEWS OF MODERN PHYSICS, VOLUME 84, JANUARY–MARCH 2012

Compound-nuclear reaction cross sections from surrogate measurements

Jutta E. Escher, Jason T. Burke, Frank S. Dietrich, Nicholas D. Scielzo,
Ian J. Thompson, and Walid Younes

Lawrence Livermore National Laboratory, Livermore, California 94550, USA

(published 13 March 2012)

Nuclear reaction cross sections are important for a variety of applications in the areas of astrophysics, nuclear energy, and national security. When these cross sections cannot be measured directly or predicted reliably, it becomes necessary to develop indirect methods for determining the relevant reaction rates. The *surrogate nuclear reactions* approach is such an indirect method. First used in the 1970s for estimating (n, f) cross sections, the method has recently been recognized as a potentially powerful tool for a wide range of applications that involve compound-nuclear reactions. The method is expected to become an important focus of inverse-kinematics experiments at rare-isotope facilities. The present paper reviews the current status of the surrogate approach. Experimental techniques employed and theoretical descriptions of the reaction mechanisms involved are presented and representative cross section measurements are discussed.

DOI: 10.1103/RevModPhys.84.353 PACS numbers: 24.87.+y, 24.60.Dr, 25.85.Ec, 24.50.+g

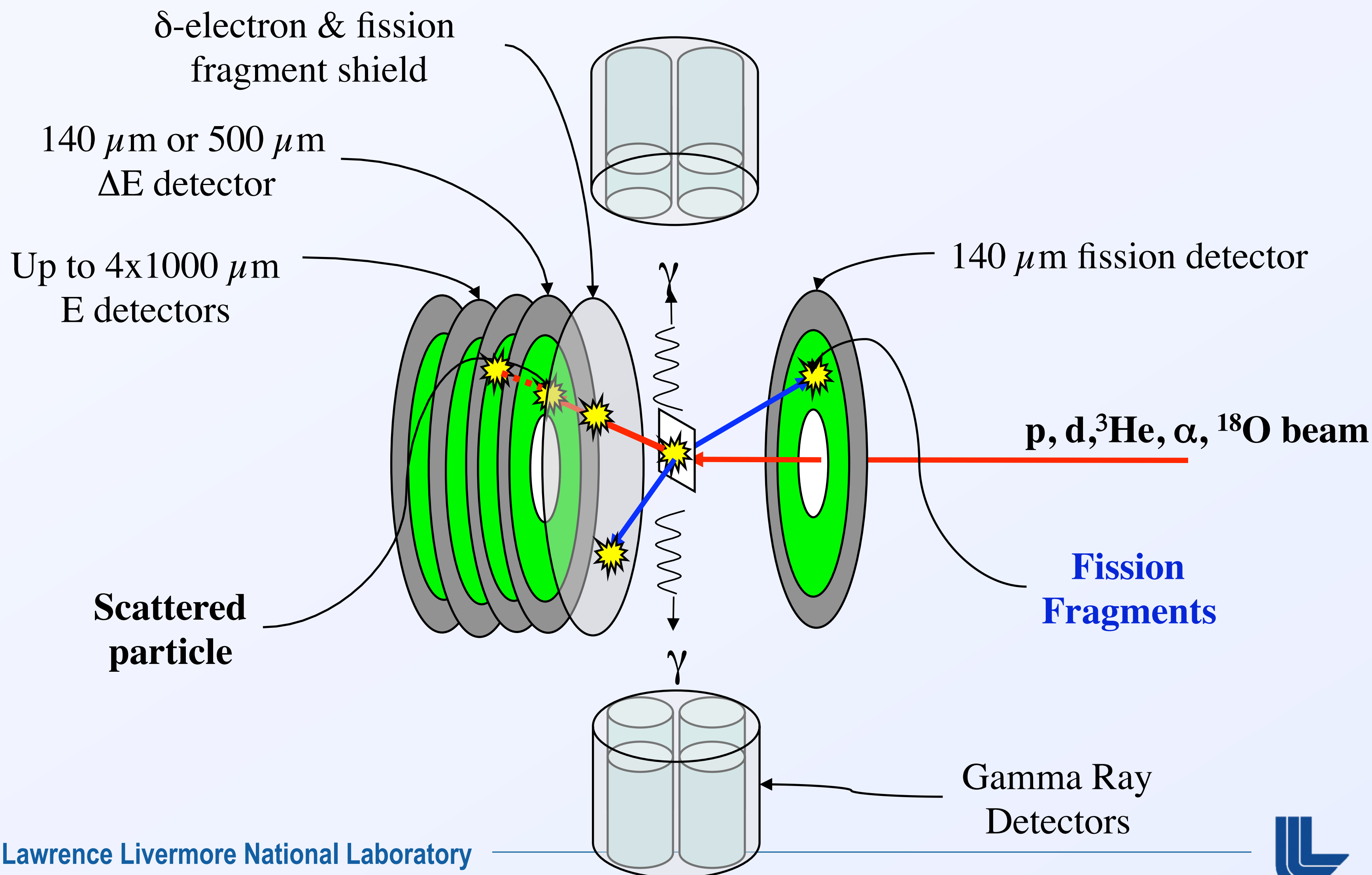
R.O. Hughes *et al*., “Utilizing (p,d) and (p,t) reactions to obtain (n,f) cross sections in uranium nuclei via the surrogate-ratio method,” Physical Review C **85**, 024613 (2012)

N.D. Scielzo *et al*., “Statistical gamma rays in the analysis of surrogate nuclear reactions”, Physical Review C **85**, 054619 (2012)

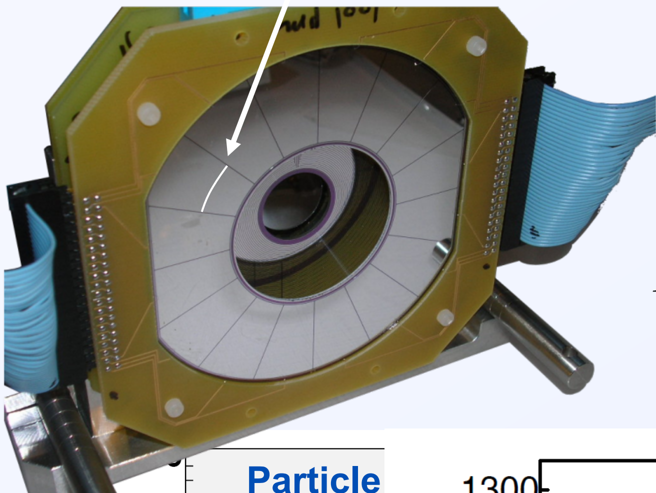
B.L. Goldblum *et al*., “Indirect determination of neutron capture cross sections on spherical and near-spherical nuclei using the surrogate method”, Physical Review C **85**, 054616 (2012)

G. Boutoux *et al*., “Study of the surrogate-reaction method applied to neutron-induced capture cross sections,” Physics Letters B **712**, 319 (2012)

Silicon Telescope Array for Reaction Studies (STARS)
Livermore Berkeley Array for Collaborative Experiments (LIBERACE)



Particle detection determines compound nucleus and neutron energy

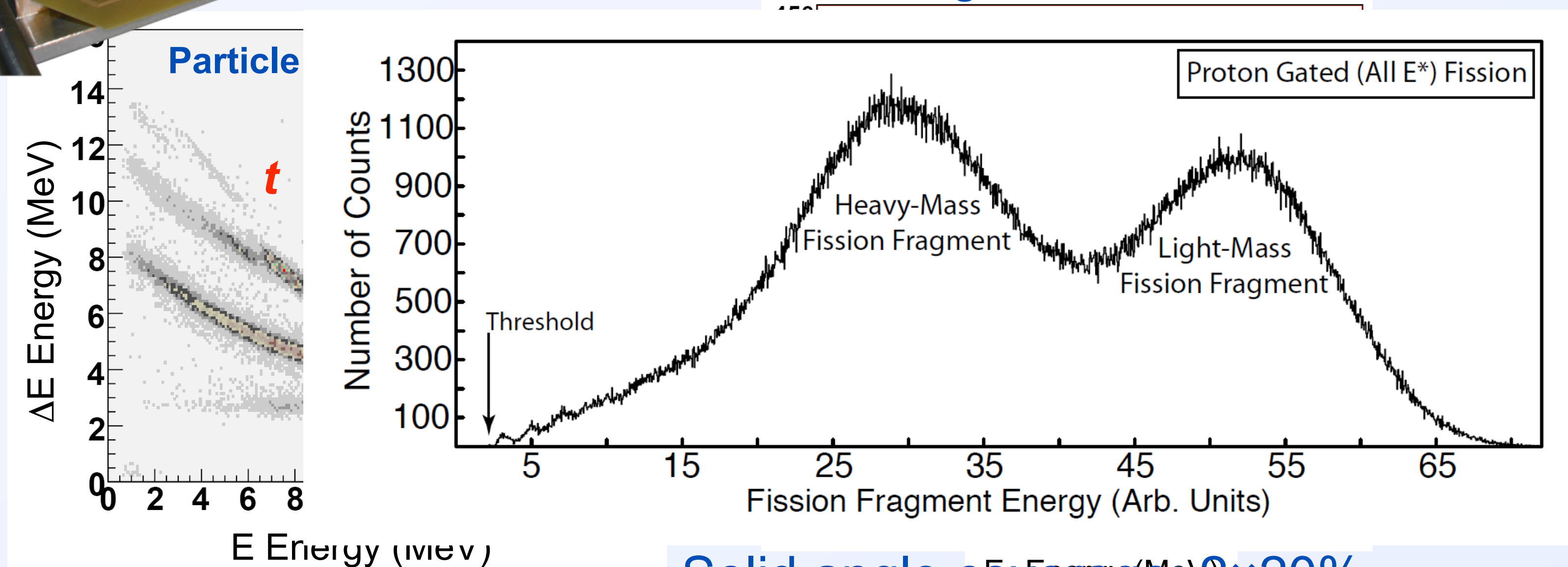


Highly segmented silicon array for particle identification and precise energy determination

with E_n determined from particle energy:

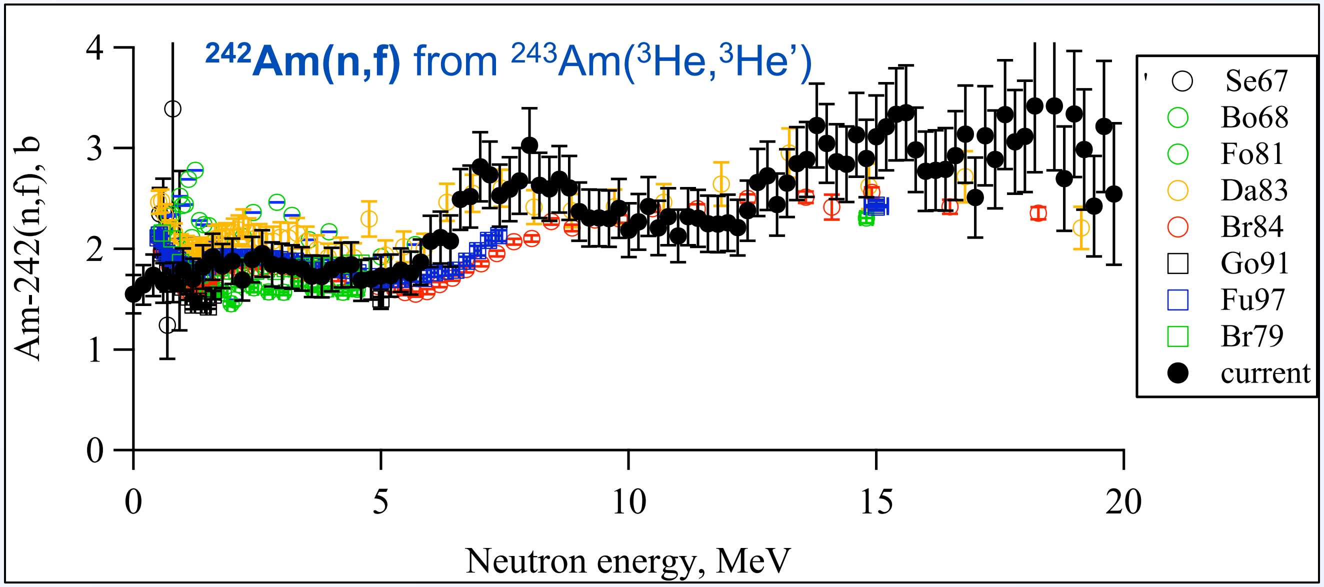
$$E_n = E_{ex} - S_n = E_{beam} - \left(E_p^{obs} + E_{deadlayer} + E_{recoil}\right) - S_n$$

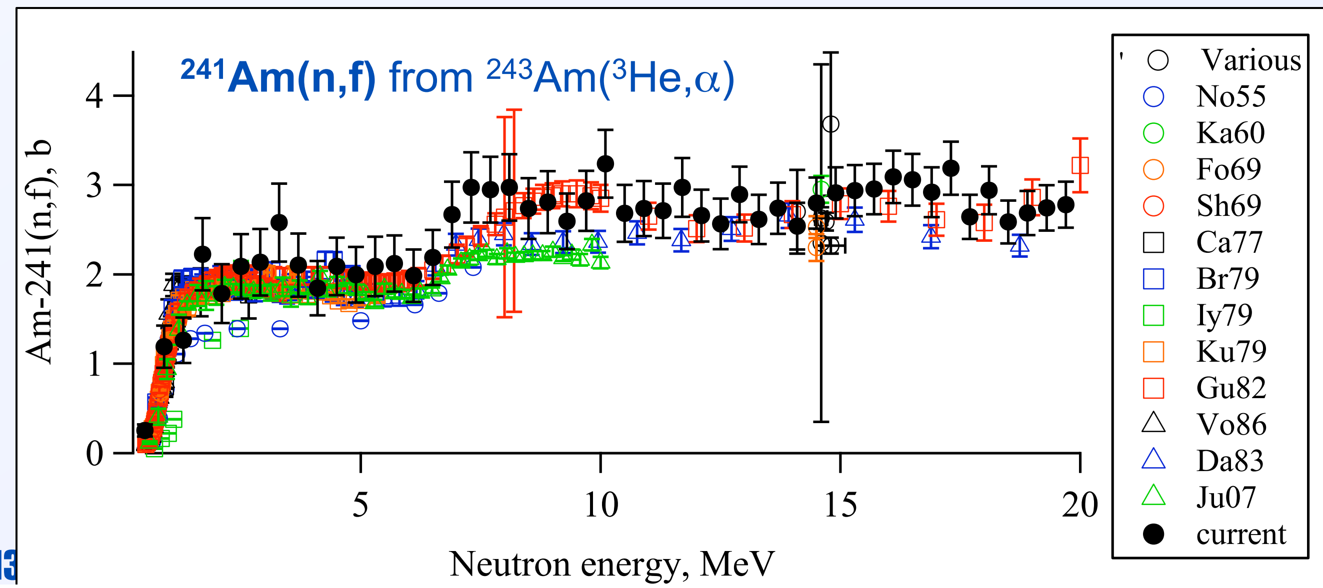
Fission-fragment detection



Solid angle coverage: 2×20%

^{241,242}Am(n,f) cross sections

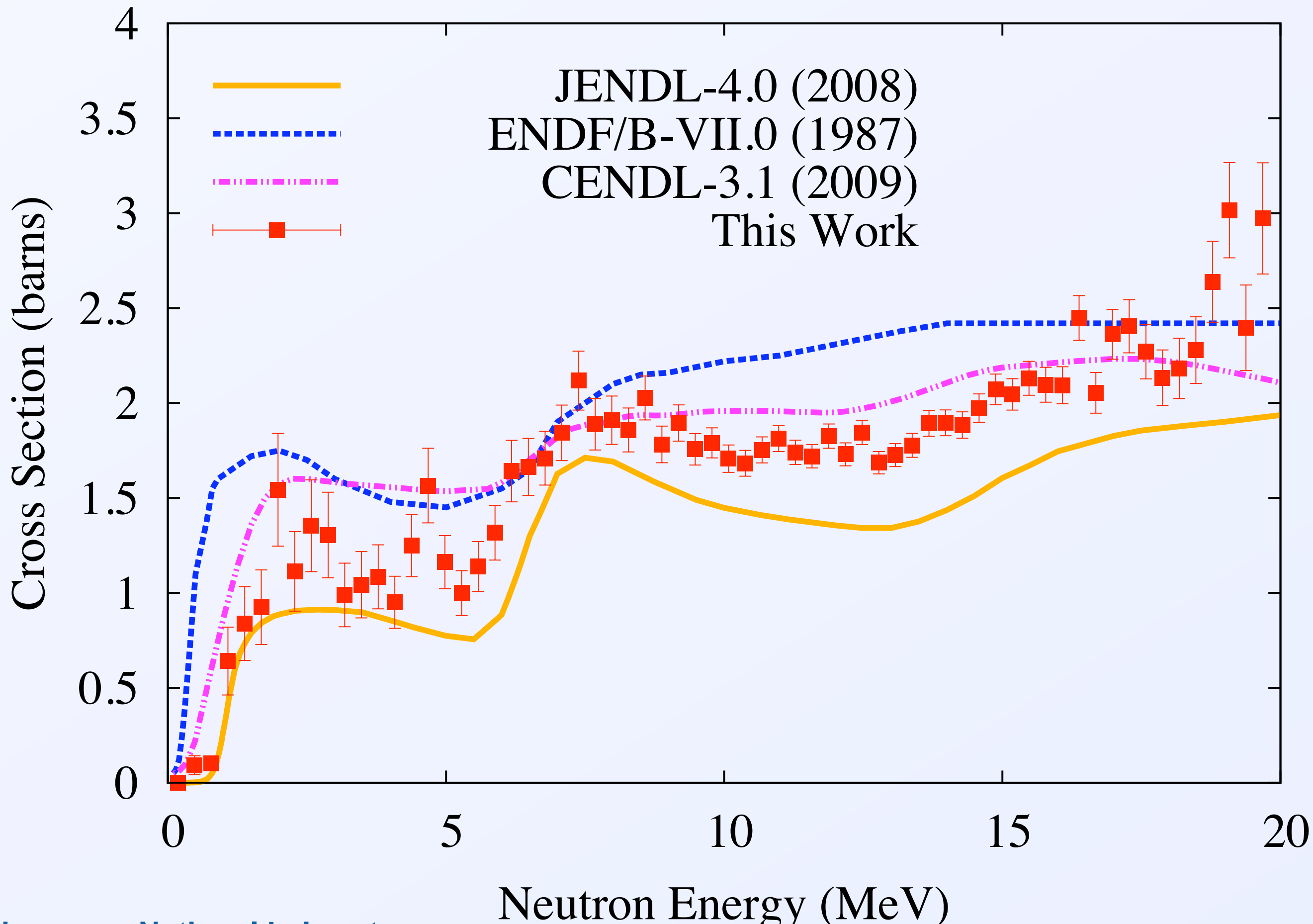




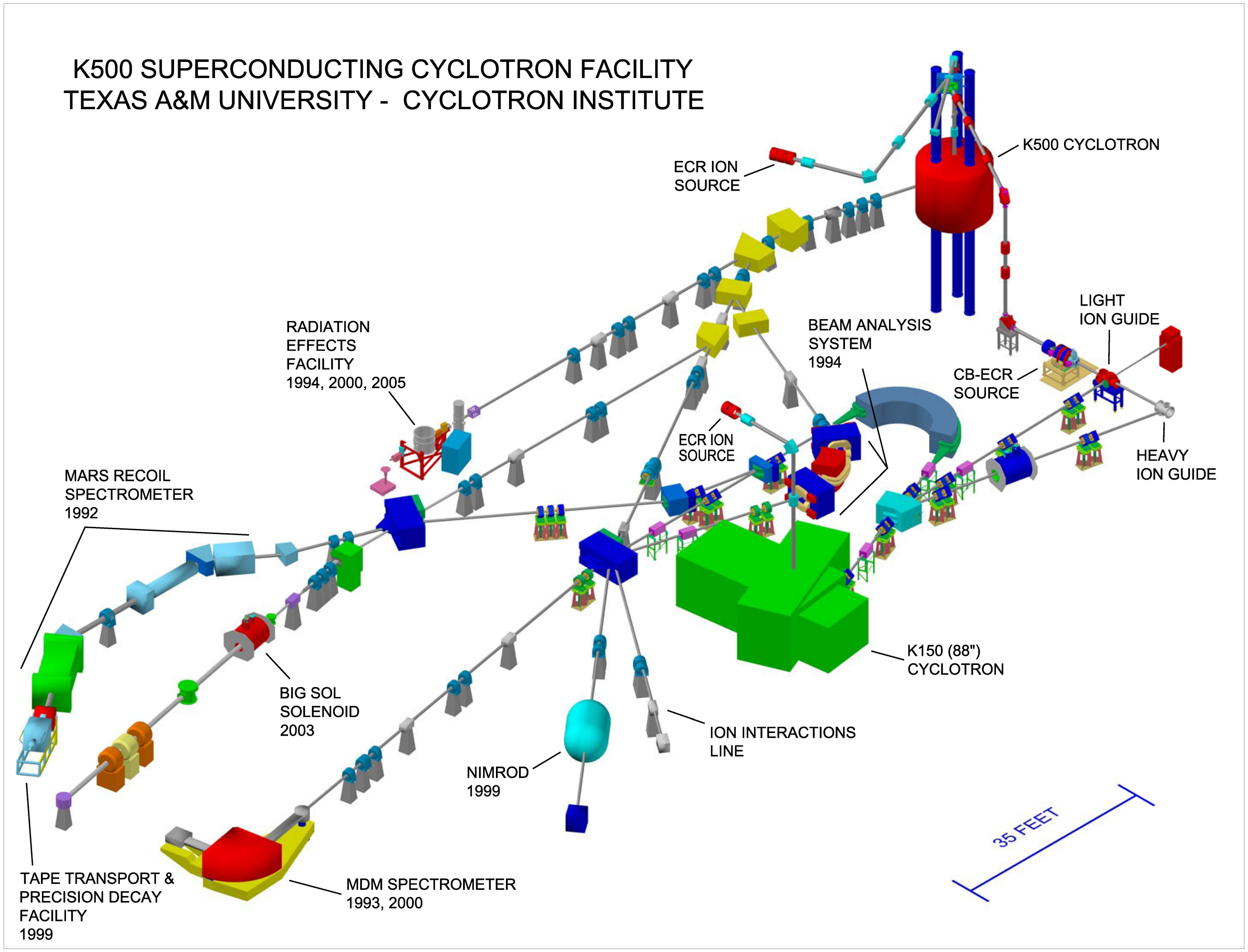
- ^{242}Am(n,f) and ^{241}Am(n,f) agree well with previous data
- Some differences at first-chance fission – may be due to spin effects
- New measurement provides consistent cross section value
- Measurements performed relative to ^{234,235}U(n,f) cross sections

^{239}Np(n,f) SRM Cross Section Measurement

Using reactions ^{238}U(^{3}He,p)^{240}Np and ^{236}U(^{3}He,p)^{238}Np, normalized to well-known ^{237}Np(n,f)



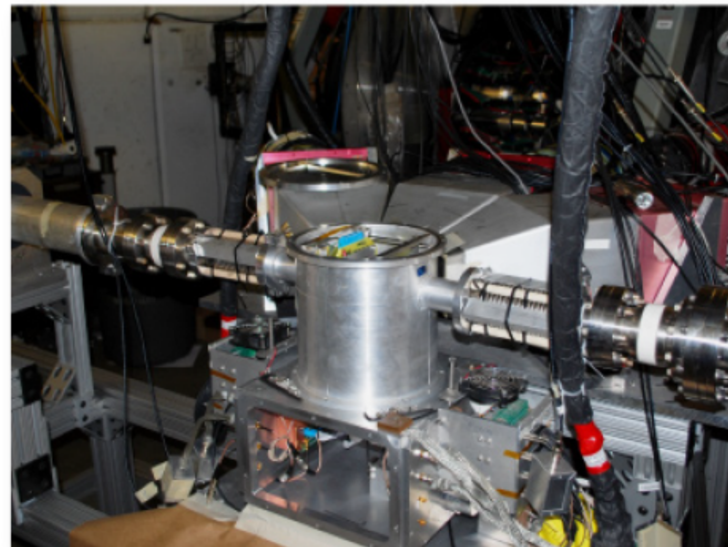
STARS-LiBerACE moves to Texas A&M Cyclotron Institute and renamed the STAR-LiTe (Livermore-Texas) collaboration



The STARLiTe detector system

slide from
R. Casperson

Texas A&M Cyclotron Institute



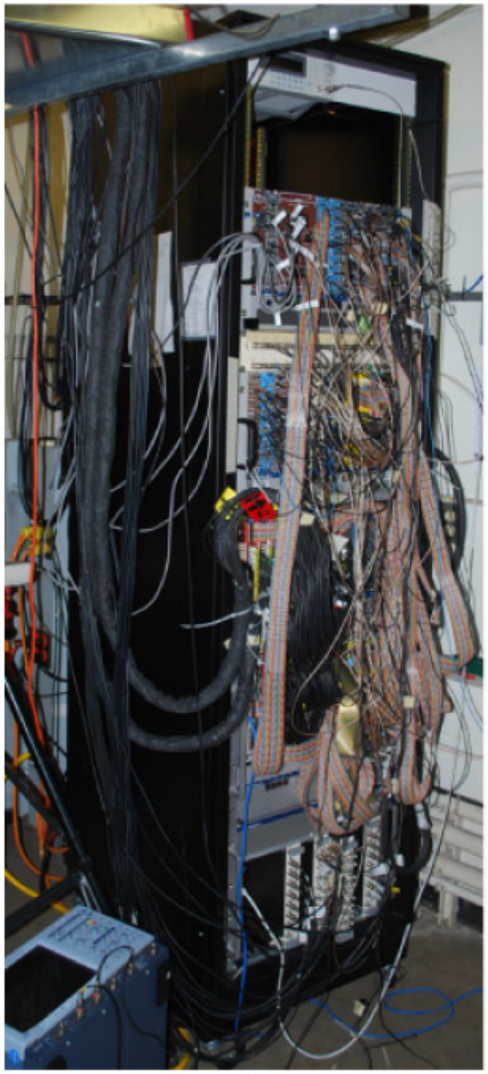
STARLiTe

The silicon telescope and high purity germanium array have moved to the Texas A&M Cyclotron Institute on the K150 cyclotron beam line.

This was the first experiment fielded on the new setup.

The new STARLiTe DAQ

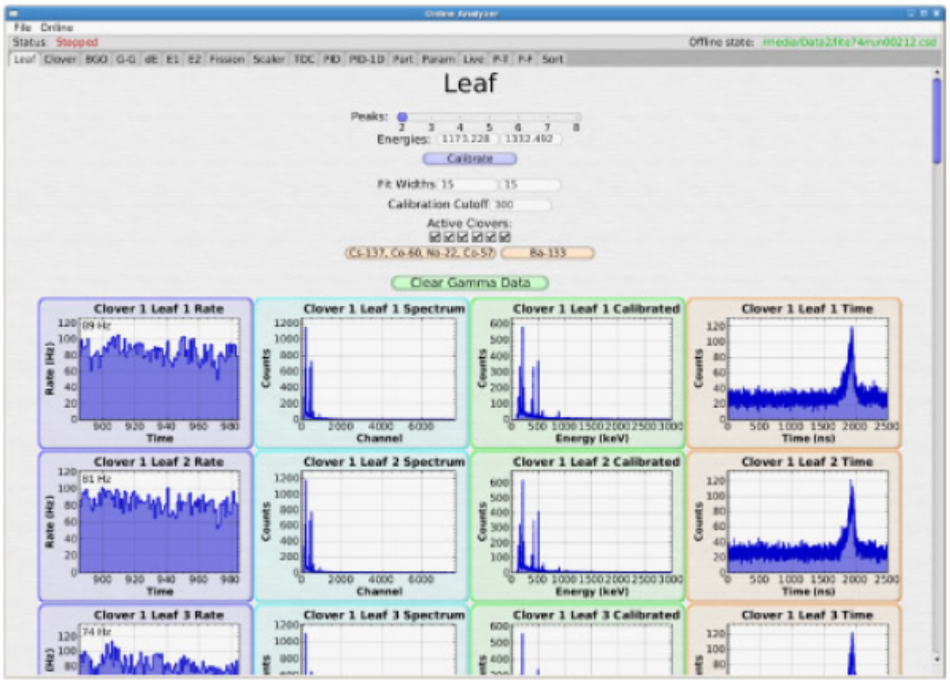
slide from
R. Casperson



- 3 NIM crates, 1 VME crate and 1 MPOD crate.
- 192 peak-sensing ADC channels with 13-bit resolution.
- 128 TDC channels with 100 ps timing and multiple pulse per channel capabilities.
- 32 independent scalers.
- With a reasonable number of channels firing, can operate with up to a 40 kHz trigger rate.

The Online Analyzer

slide from
R. Casperson



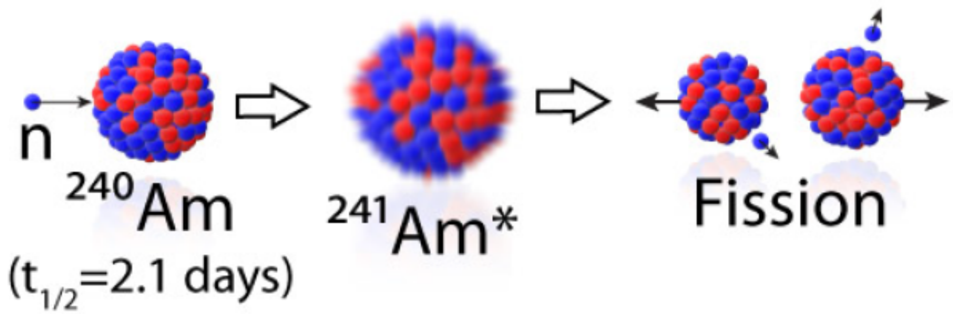
- Realtime updates that can keep up with the DAQ data rate, and redisplay rapidly.
- Processing older data works the same way as online data.
- Built with the library WiGL, which was also written for this project, so it is hardware accelerated.

Data can be replayed using the online analyzer

slide from
R. Casperson

The desired reaction: ^{240}Am(n,f)

This reaction has never been measured. ^{240}Am has a half-life of 2.1 days, which makes it unreasonable to use as a target.



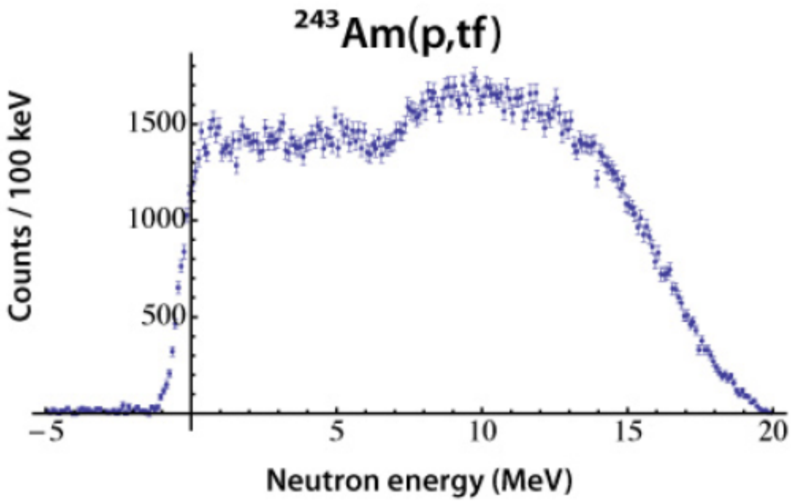
^{239}Am	^{240}Am	^{241}Am	^{242}Am	^{243}Am	^{244}Am
12 hours	2.1 days	433 years	16 hours	7370 years	10 hours

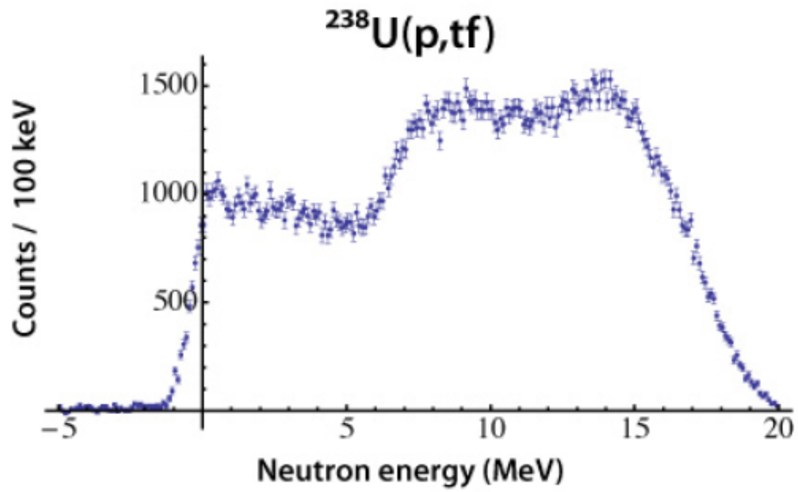
Desired → ← Surrogate

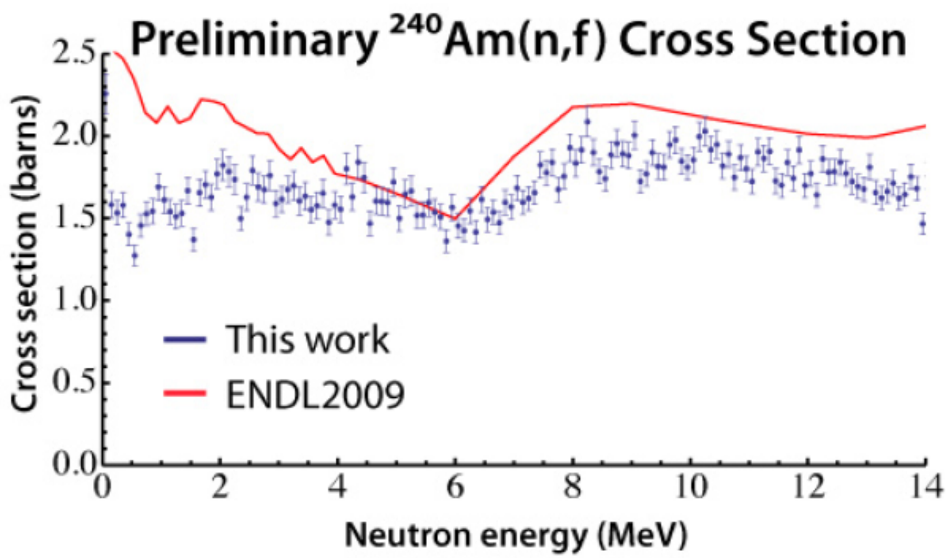
The surrogate ratio technique can be used, by populating the same compound nucleus using a longer-lived target.

Particle spectra and ^{240}Am(n,f)

slide from
R. Casperson

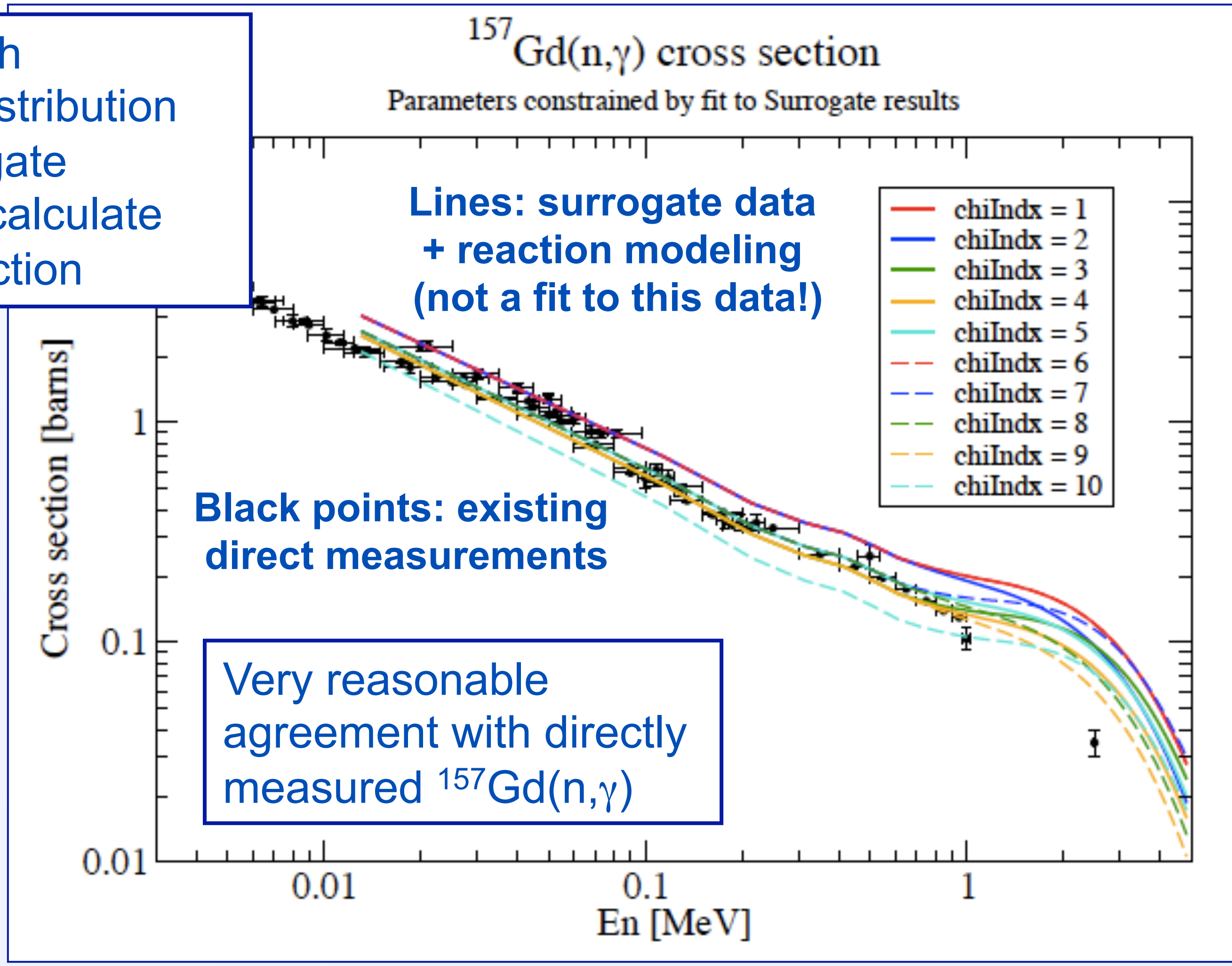






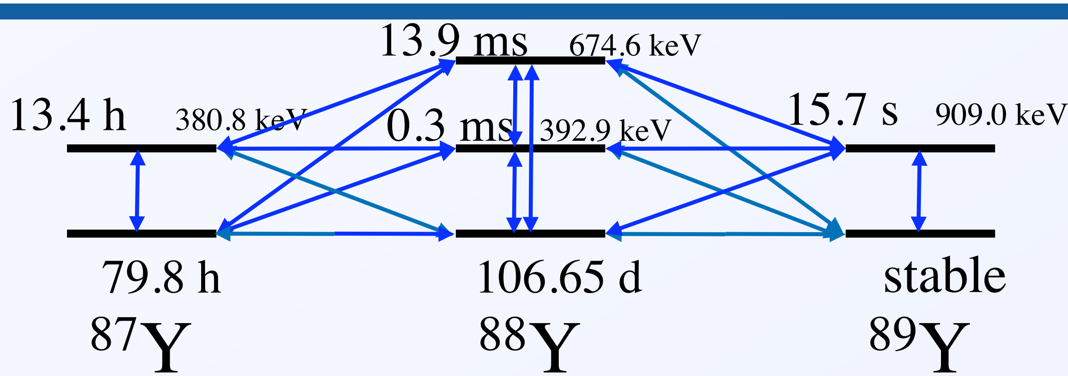
Obtaining an (n,γ) cross section using surrogate reactions

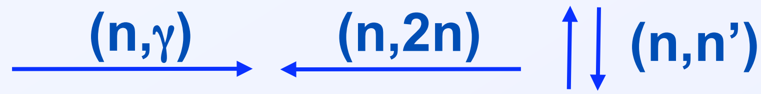
Using Hauser-Feshbach parameters and spin distribution determined from surrogate ^{158}Gd(p,p') reaction to calculate the ^{157}Gd(n,γ) cross section



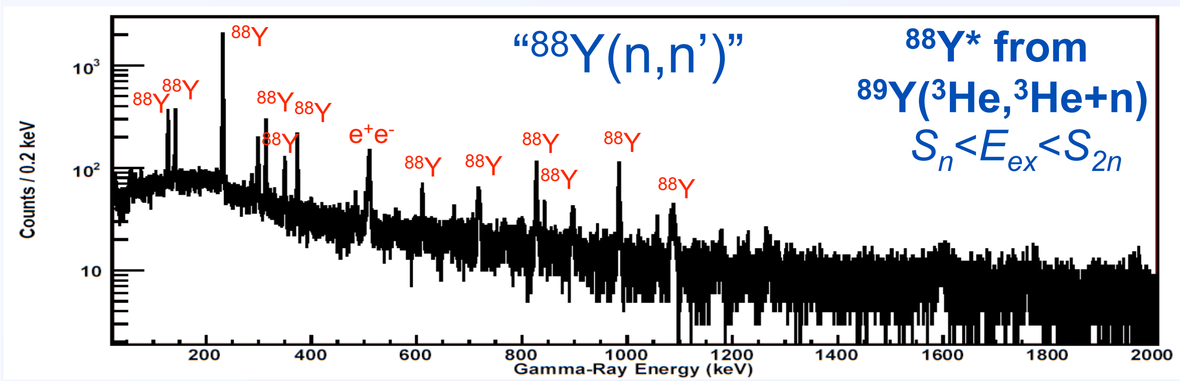
Next step: Improve precision and apply technique to determine unknown ^{153}Gd(n,γ), ^{87,88}Y(n,γ) and ^{87,88}Y(n,2n) cross sections

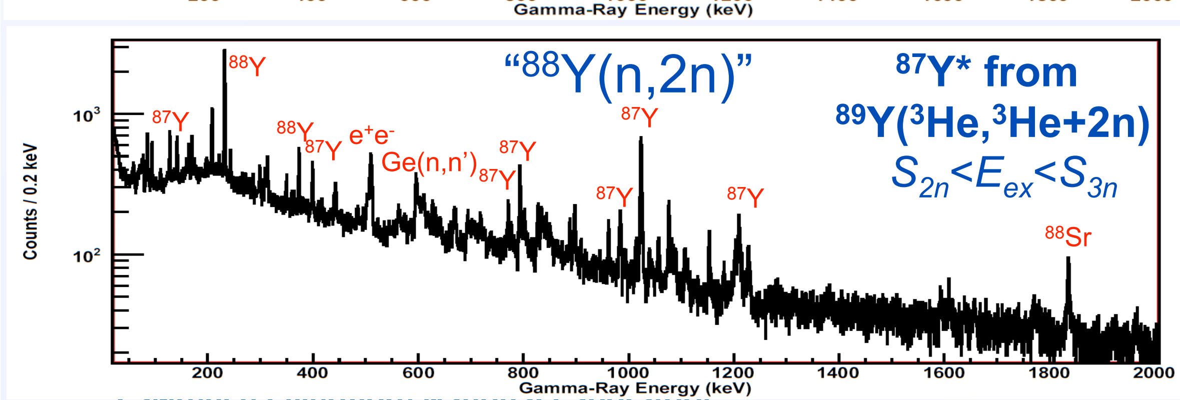
Surrogate data to determine ^{87}Y(n,γ) and ^{88}Y(n,2n) cross sections → bombard ^{89}Y, $^{90-92}$Zr with 50-MeV ^{3}He

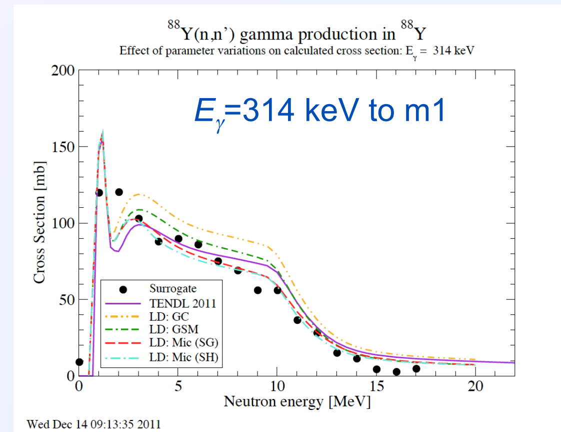


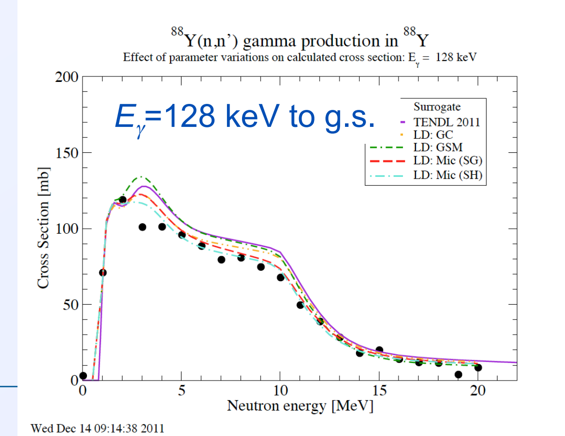


measured Y/Zr decay probabilities used to calculate J^{π} distribution and nuclear-structure parameters needed for Hauser-Feshbach cross section calculations









STARS-LiBerACE and STAR-LiTe Collaborations

L.A. Bernstein, D. Bleuel, R. Casperson, J.T. Burke, F.S. Dietrich, J.E. Escher, J.J. Ressler, N.D. Scielzo, M. Stoyer, and I. Thompson
Lawrence Livermore National Laboratory

M. McCleskey, A. Saastamoinen, E. Simmons, and A. Spiridon
Cyclotron Institute, Texas A&M University

A. Blanc
CEA, Service de Physique Nucleaire

M. Kurokawa
RIKEN Nishina Center

R. G. Pizzone
Laboratori Nazionali del Sud-INFN

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

C.W. Beausang
University of Richmond

R. Hughes and T. Ross
University of Surrey

J.A. Cizewski, P.D. O'Malley A. Ratkeiwicz, and T. Swan
Rutgers University

E.B. Norman, C. Angell, B.L. Goldblum, and J. Munson
University of California Berkeley