Lawrence Livermore National Laboratory

Surrogate Reactions in the Actinide Region

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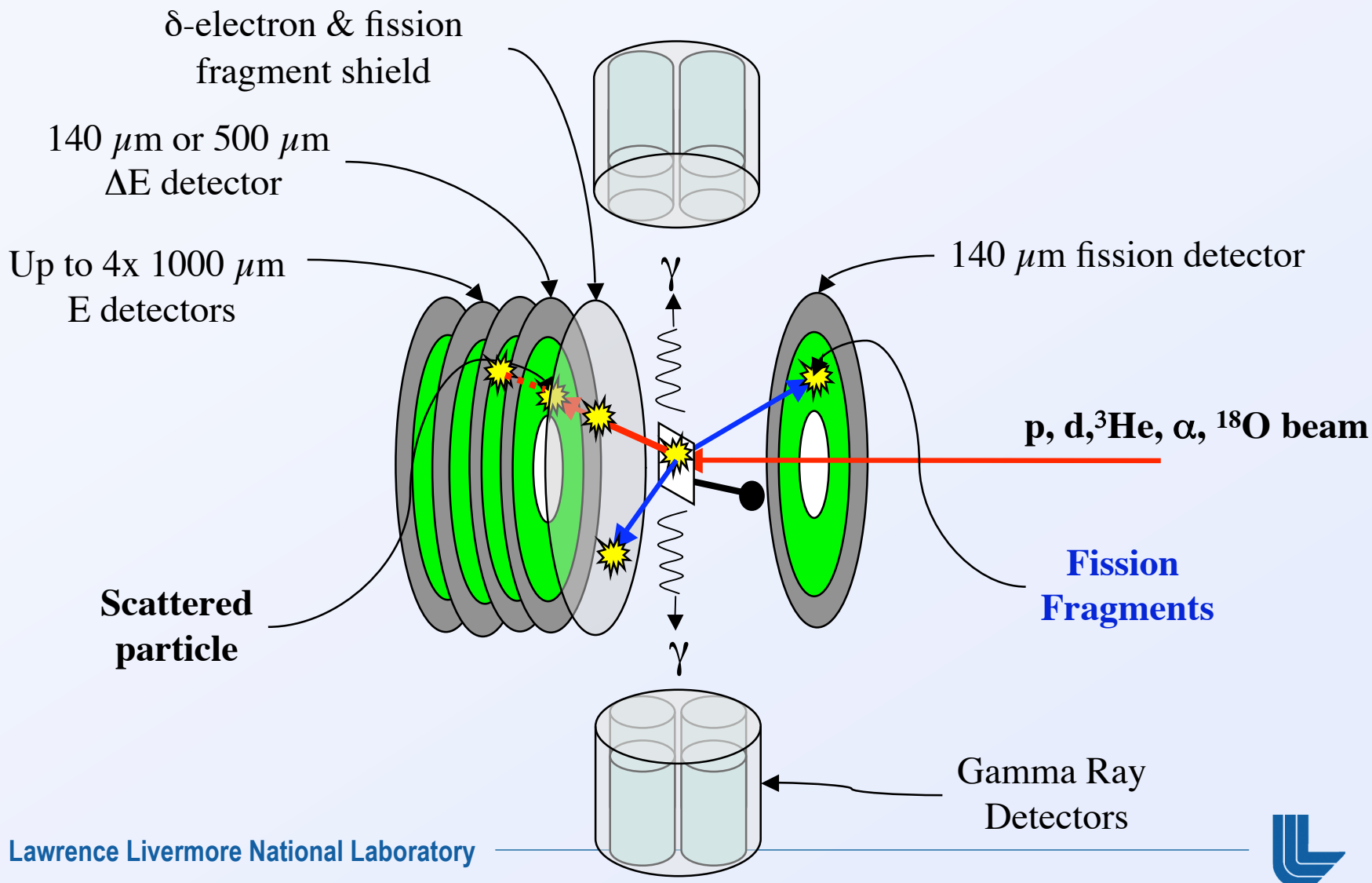
Why do we use surrogate reactions?

- Surrogate reaction technique allows us to use a more readily obtainable target. Longer half-life targets produce less activity reduces target related backgrounds.
- Allows us to expand our measurement abilities into previously inaccessible regions of the periodic chart.
- Designed correctly one experiment provides a simultaneous measurement of (n,γ), (n,2n) and (n,f). Covering a surrogate neutron energy range from about 0 to 20 MeV.
- Most cross sections for direct reactions fall in the >1mb range which allow measurements to be performed within a 5 day run time.

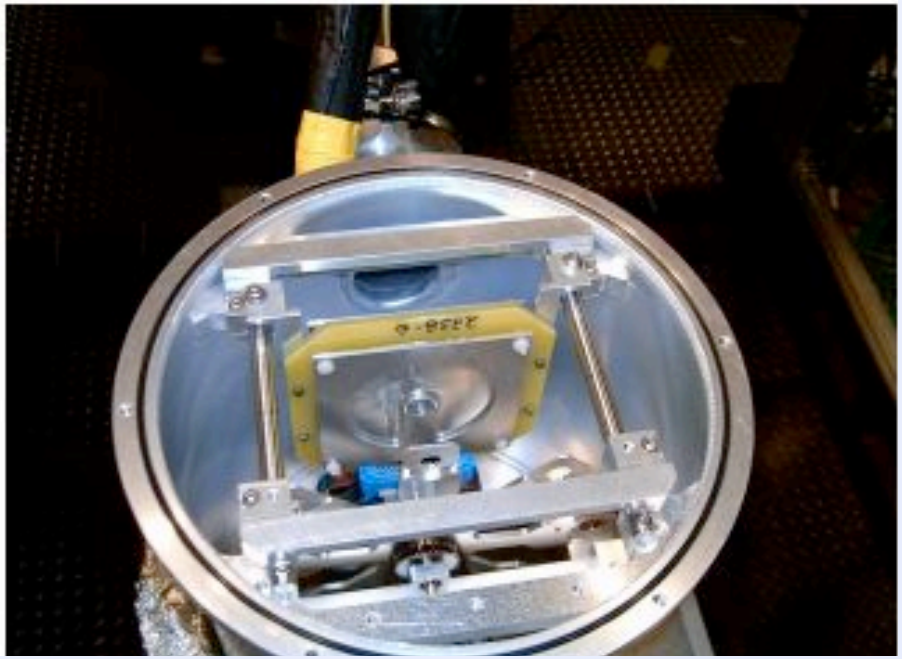
Silicon Telescope Array for Reaction Studies (STARS)
Livermore Berkeley Array for Collaborative Experiments (LIBERACE)



STARS/LIBERACE scattering chamber

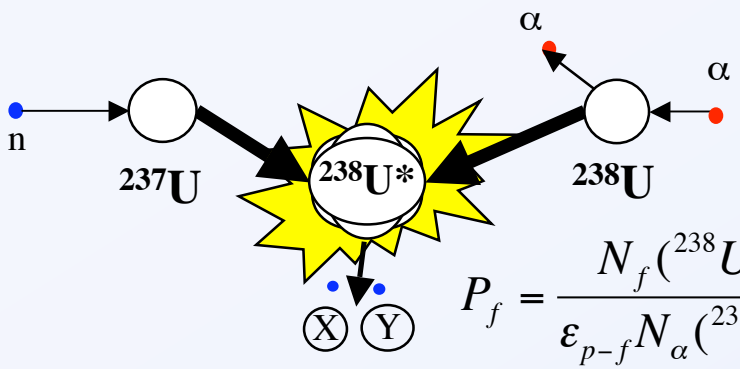
Target Chamber+Ge detectors

Interior w/Si detectors

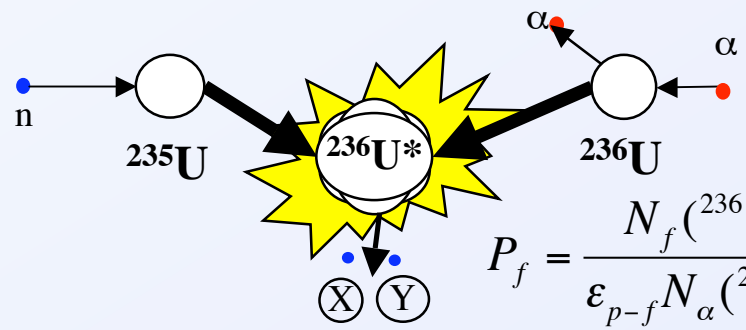


Started: July 2004
First "full-up" run: September 2004
42 Experiments >> Astrophysics, Nuclear Structure, Half-lives, Cross-sections

Surrogate Ratio Technique



$$P_f = \frac{N_f(^{238}U)}{\varepsilon_{p-f} N_\alpha(^{238}U)}$$



$$P_f = \frac{N_f(^{236}U)}{\varepsilon_{p-f} N_\alpha(^{236}U)}$$

Largest source of systematic error

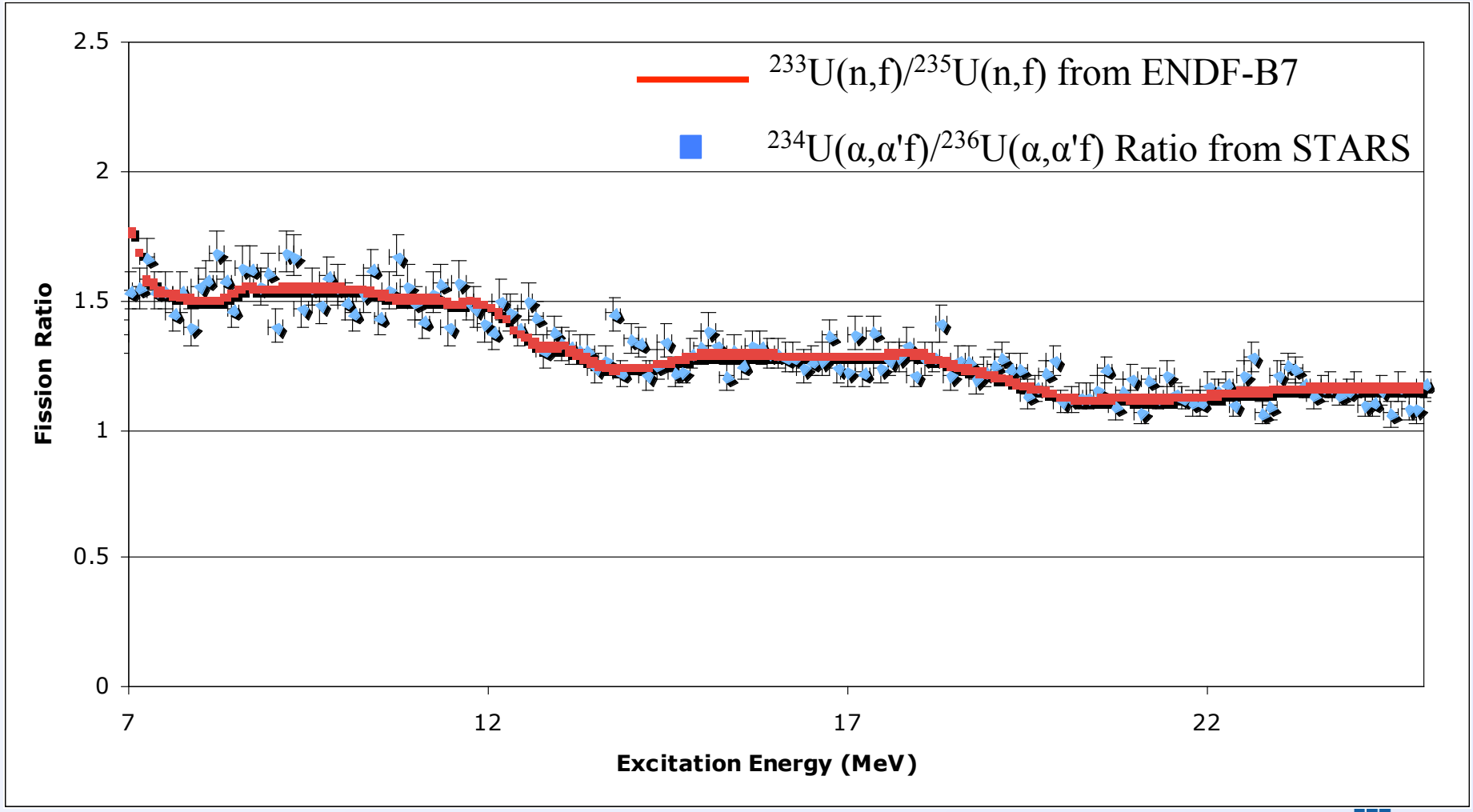
$$\frac{P_f(^{238}U(\alpha,\alpha' f))}{P_f(^{236}U(\alpha,\alpha' f))} = \frac{\cancel{\varepsilon_f} N_{\alpha-f}(^{238}U) / \cancel{N_\alpha(^{238}U)}}{\cancel{\varepsilon_f} N_{\alpha-f}(^{236}U) / \cancel{N_\alpha(^{236}U)}} = \frac{\sigma_{(n,f)}^{^{237}U}}{\sigma_{(n,f)}^{^{235}U}}$$

Assumes that direct reactions are identical on both targets

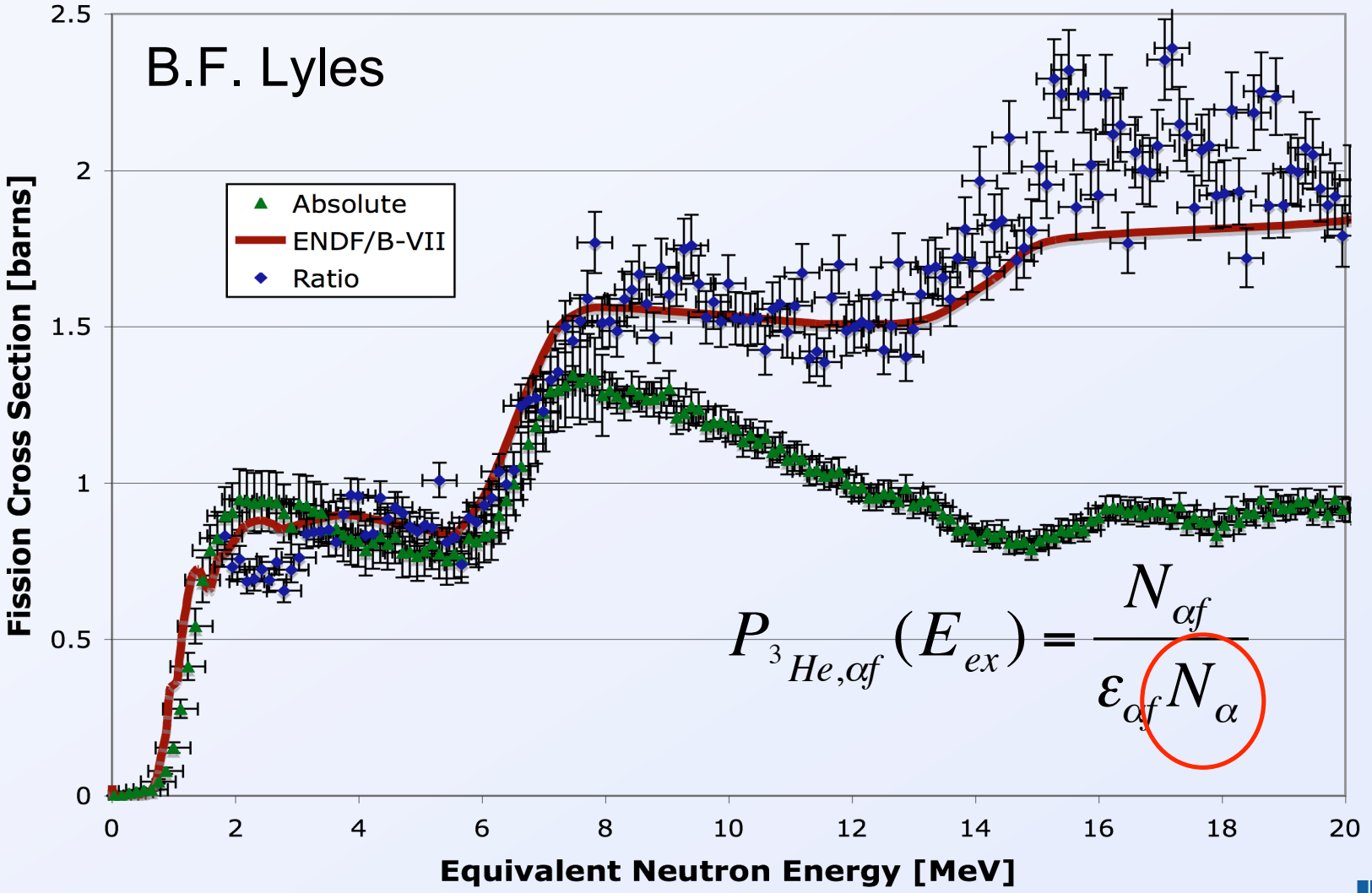
Ratio of $^{233}U(n,f)/^{235}U(n,f)$ compared to $^{234}U(\alpha,\alpha'f)/^{236}U(\alpha,\alpha'f)$

Courtesy:
Shelly Lesher

Note: Fission Ratio normalization is arbitrary and this is a preliminary result showing agreement of shape

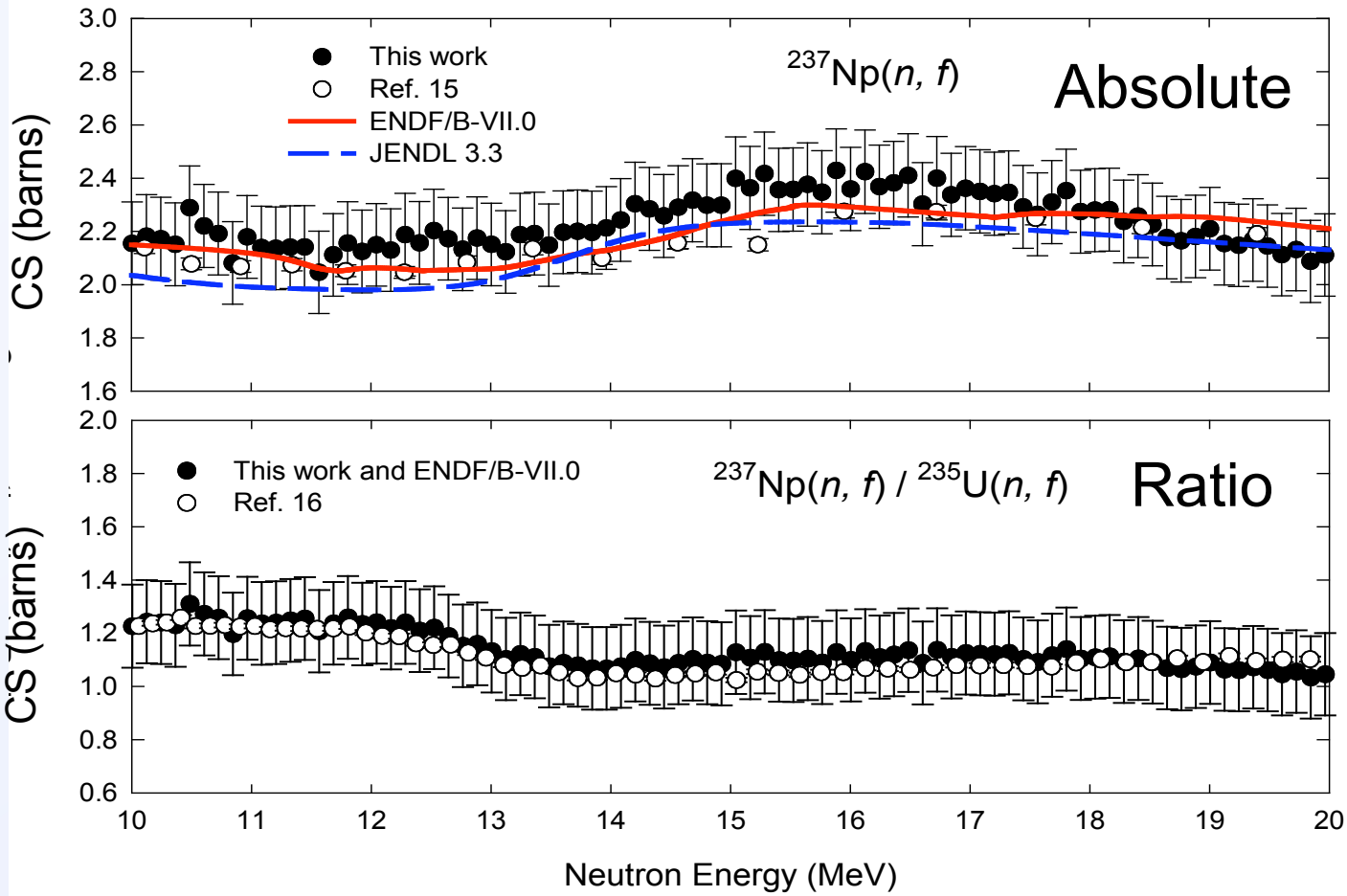


$^{236}U(n,f)$ Cross Section from ratio of ($^{238}U(^{3}He,\alpha'f)/^{235}U(^{3}He,\alpha'f))x^{233}U(n,f)$



$$P_{^3He,\alpha f}(E_{ex}) = \frac{N_{\alpha f}}{\varepsilon_{\alpha f} N_{\alpha}}$$

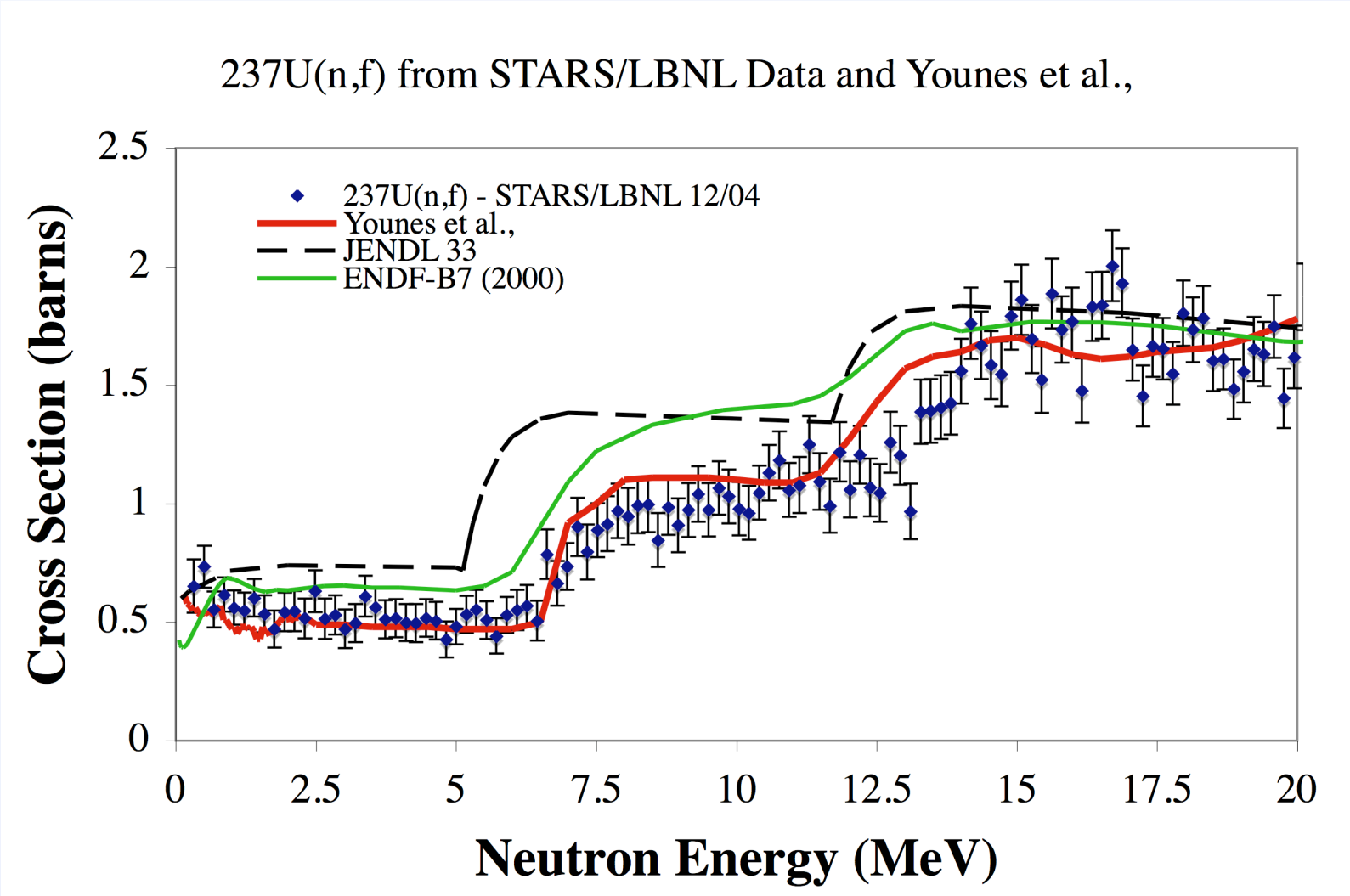
^{237}Np(n,f) cross section from ^{238}U(^{3}He,tf) Courtesy S. Basunia



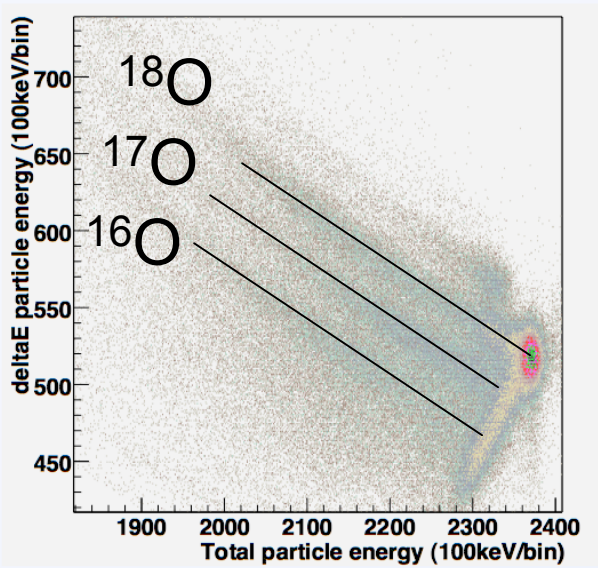
Ref. 15. O. Shcherbakov *et al.*, J. Nucl. Sci. and Tech., Supp. 2, 230, 2002

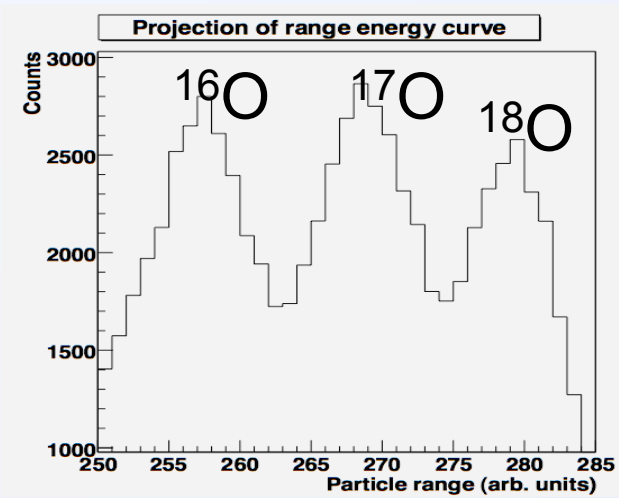
Ref. 16. F. Tovesson and T. S. Hill, Phys. Rev. C 75, 034610, 2007.

$^{237}U(n,f)$ ($\tau_{1/2}$=6.75 days) determined from $^{238}U(\alpha,\alpha f)/^{236}U(\alpha,\alpha f)$ ratio

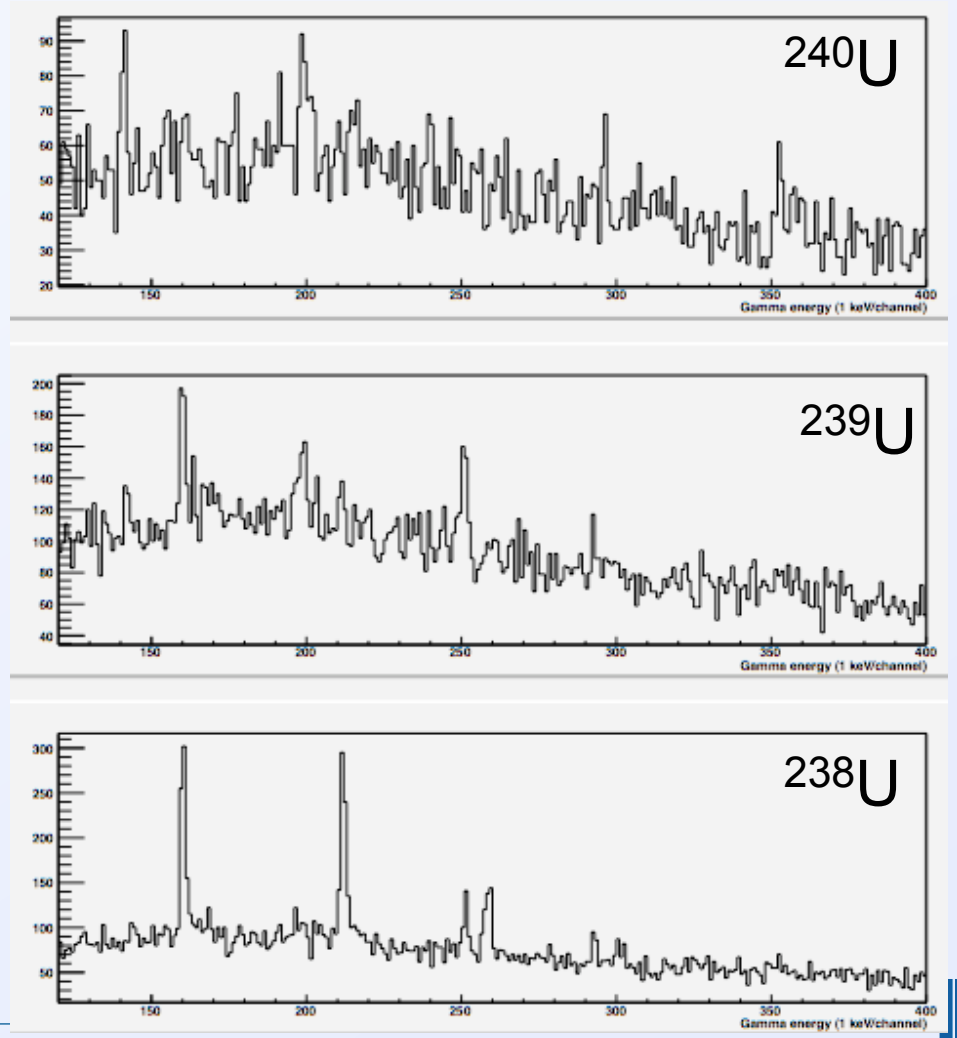


$^{239}U(n,f)(n,\gamma)$, and (n,2n) ($\tau_{1/2}$=24minutes) determined from the $^{238}U(^{18}O,^{16}O)^{240}U$ (preliminary data analysis)





Gamma ray spectrum gated on ^{16}O



Future plans

- ^{235}U(d,p) to benchmark neutron transfer reaction as a surrogate for ^{235}U(n,f), (n,γ), and (n,2n). (Nov. 2007)
- ^{239}Pu(d,p) to measure ^{235}U(n,f), (n,γ), and (n,2n) cross sections.
- Update STARS/LIBERACE electronics to full digital system and add in Strip detectors (STARS and STRIPES)
- Digital electronics: 528 channels of energy and time with waveform sampling of each channel.

Electronics Upgrade: Implementation underway Burke and Phair

- Silicon digital electronics:
  - 528 channels of energy and time with waveform sampling of each channel. 10 bit ADCs which have 12 bit enob resolution.
- Germanium digital electronics:
  - 6 GRETINA 10 channel modules which have 14 enob resolution.

Summary of actinide experiments

Desired Reaction	Surrogate Reaction	Objective	Surrogate Technique Applied	Principle Investigator
^{235}U(n,f) and ^{234}U(n,f)	^{236}U(α,α') ^{234}U(α,α')	Benchmark	External Ratio	Shelley Lesher
^{237}Np(n,f)	^{238}U(^{3}He,t)	Benchmark	Absolute	Shamsu Basunia
^{237}U(n,f) (n,γ) (n,2n)	^{238}U(α,α') ^{236}U(α,α')	CS measurement	External Ratio (n,f) Internal Ratio (n,γ) (n,2n)	Jason Burke Lee Bernstein
^{233}U(n,f) and ^{236}U(n,f)	^{235}U(^{3}He,α') ^{238}U(^{3}He,α')	Benchmark	External Ratio Absolute	Bethany Lyles
^{239}U(n,f) (n,γ) (n,2n) ^{235}U(n,f)	^{238}U(^{18}O,^{16}O) ^{234}U(^{18}O,^{16}O)	CS measurement	External Ratio (n,f) Internal Ratio (n,γ) (n,2n)	Jason Burke

STARS/LIBERACE Collaboration

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