Measurement of neutron-capture cross sections and gamma-emission spectra from 1 eV to 100 keV using the DANCE detector at LANSCE

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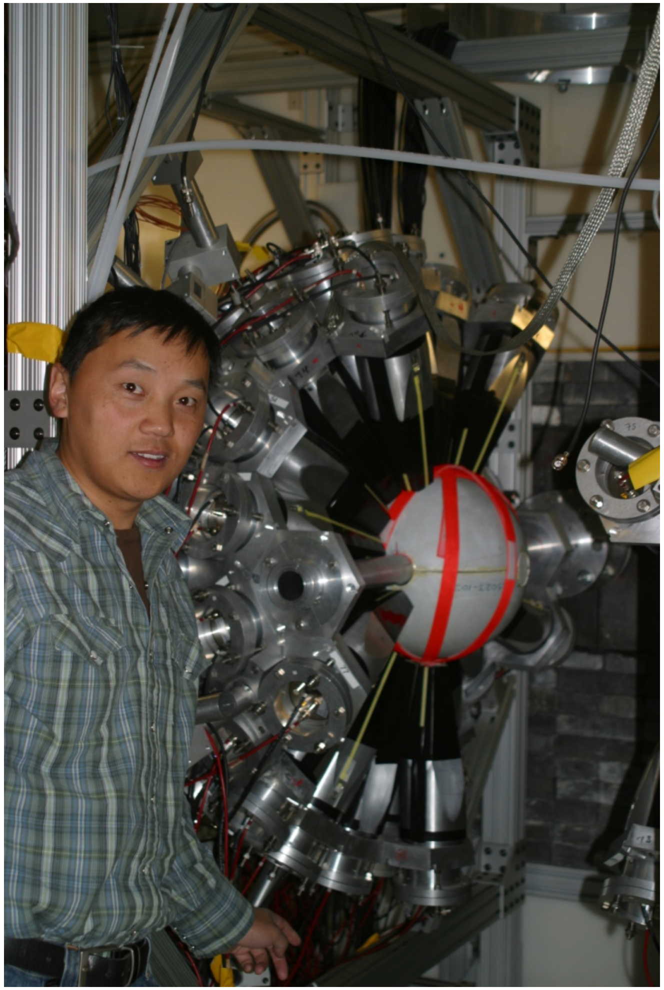
Outline

- DANCE
- Cross section measurements
  - $^{238}U(n,\gamma)$
- Comparison of capture data to estimates made with various radiative strength functions
  - $^{95}Mo(n,\gamma)$
  - Gd(n,γ)
  - $^{241}Am(n,\gamma)$
  - $^{234,236,238}U(n,\gamma)$

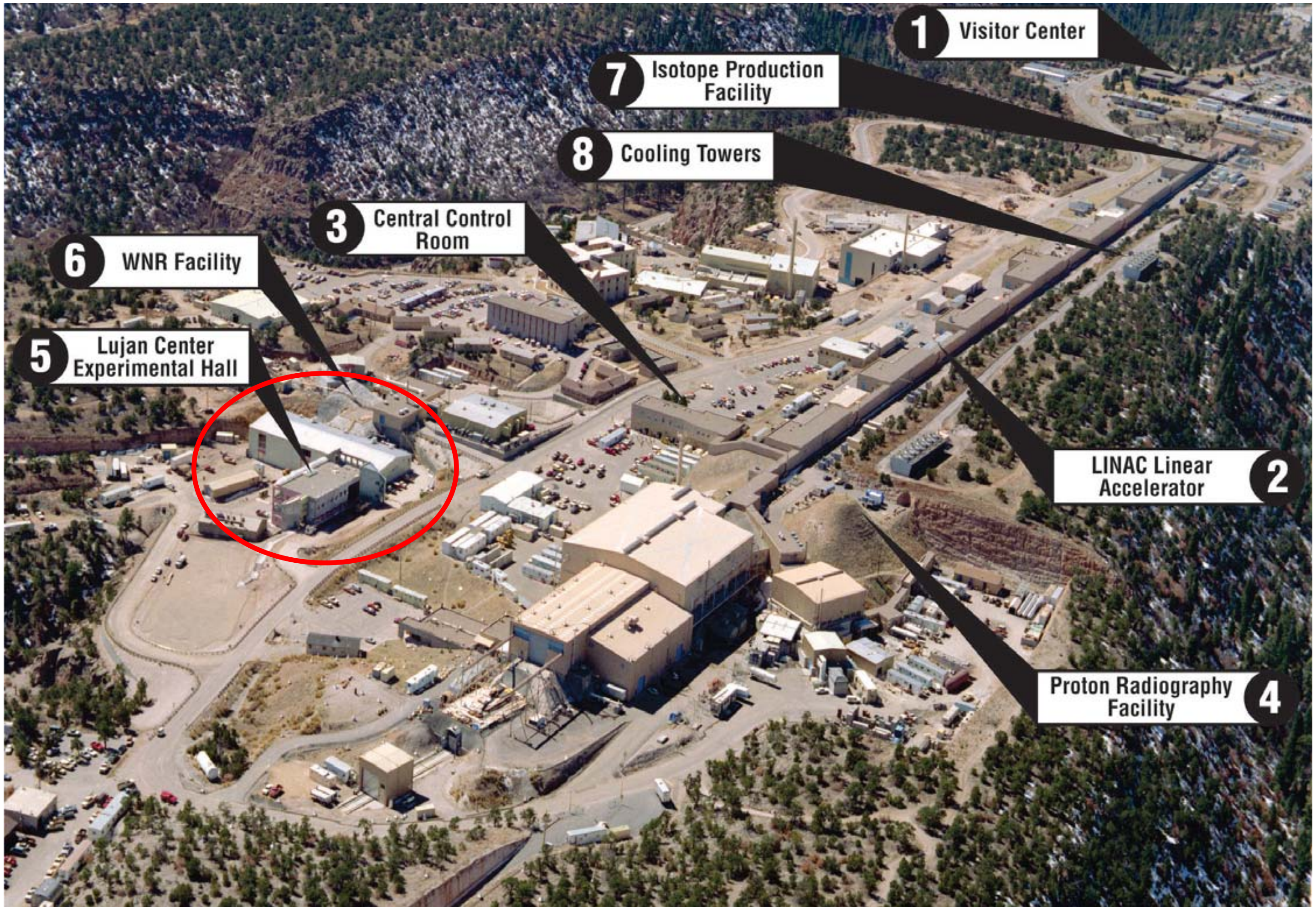
Detector for Advanced Neutron Capture Experiments (DANCE)



- 160 BaF_2 crystals with 4 different shapes (162 segments total)
- High efficiency and high neutron flux allows measurements on milligram samples
- Highly segmented to allow detection of radioactive targets
- Multiplicity analysis and reaction calorimetry to minimize backgrounds
- Inner radius = 17 cm
- Crystal depth = 15 cm
- State-of-the-art fast transient digitizers for data acquisition – 324 channels with 15 distributed front-end computers
- ^{6}LiH inner sphere to absorb scattered neutrons

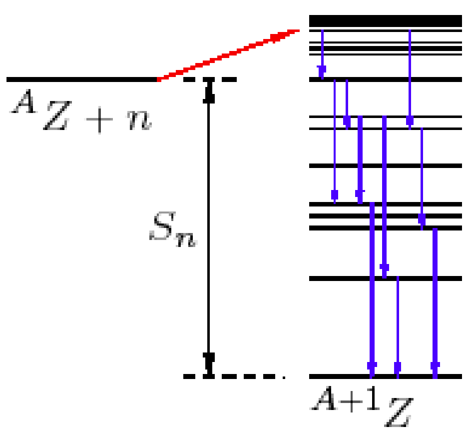
Los Alamos Neutron Science Center *(LANSCE)*

800 MeV H^-
100 μA
20/sec

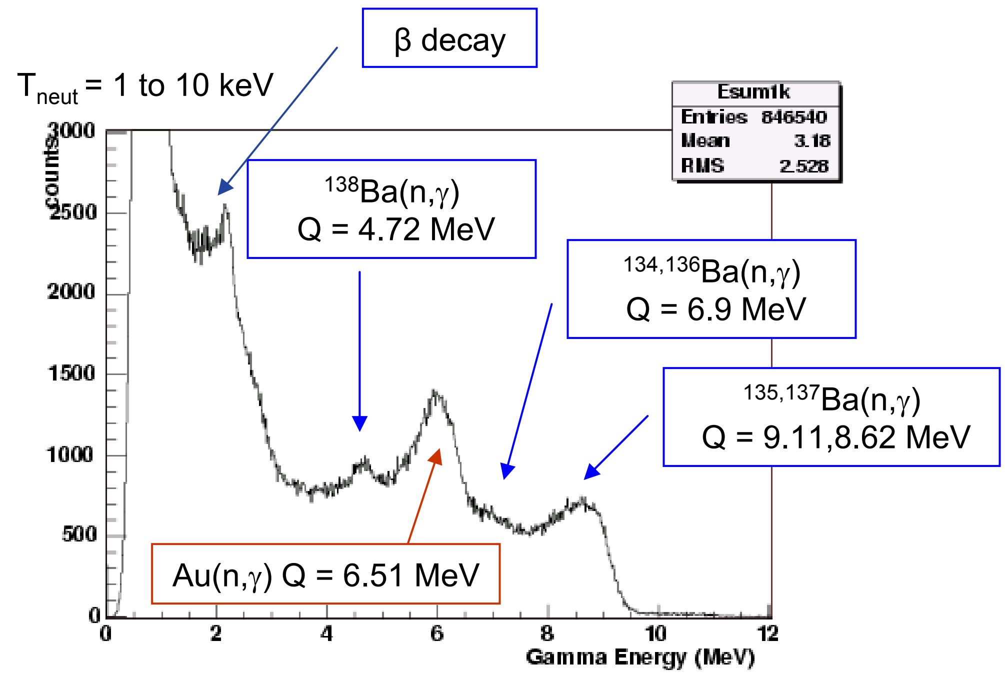


DANCE designed for neutron capture experiments

- 160 Crystals, 3.5π
- Calorimetric, Summed Gamma Energy ≈ Q value
- Permits ID of target!
- $E_x = T_n(1+M_n/M_A)+Q$

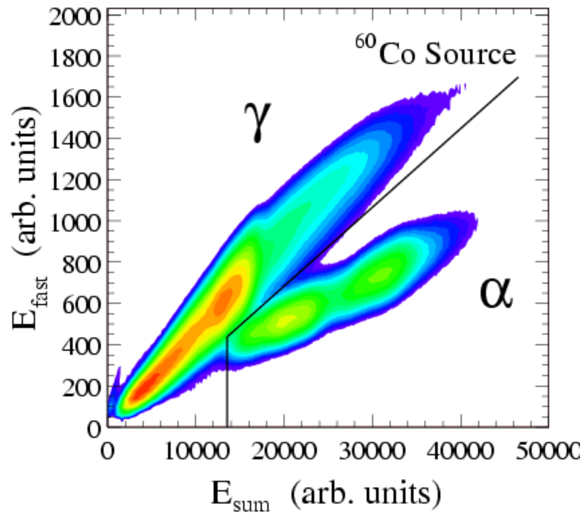


➢ High detection efficiency and neutron flux permits measurements on 1 mg (or less) samples

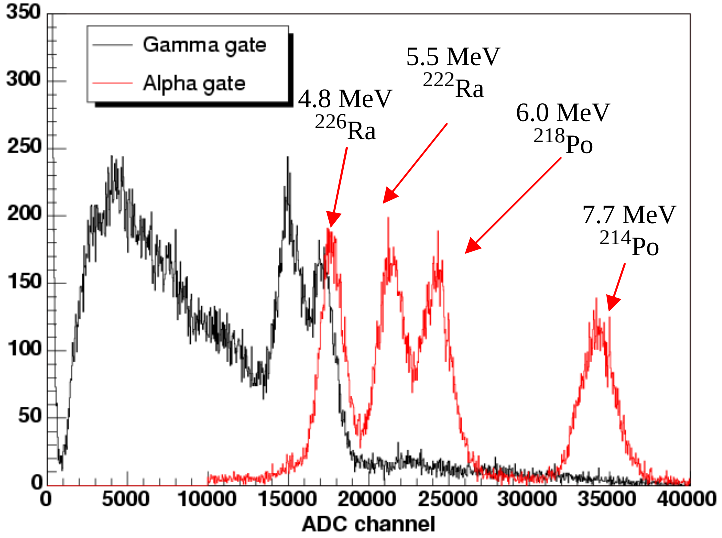


Gamma energy calibration uses α decay peaks

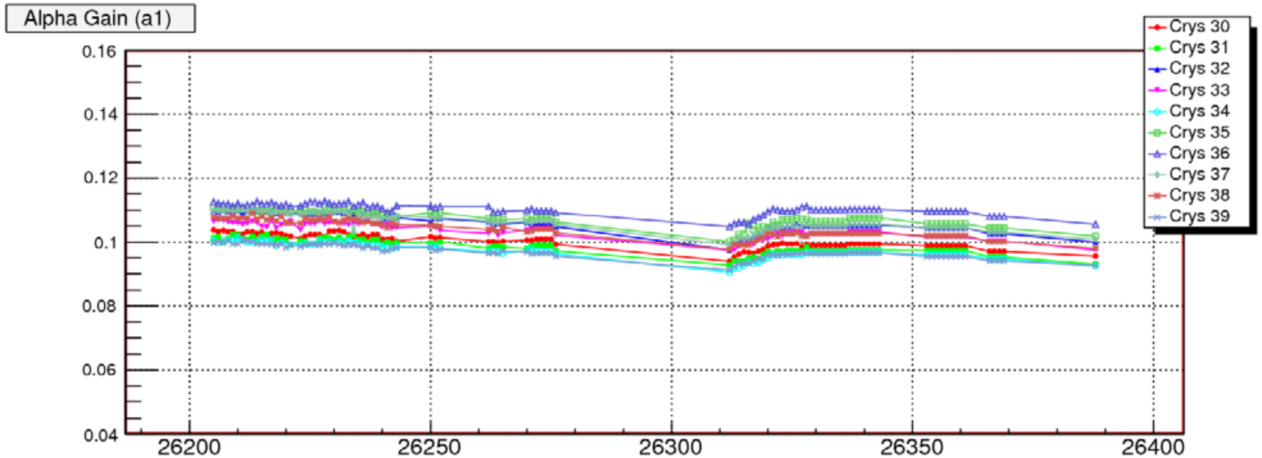
Fast vs Fast+Slow in BaF_2



Spectra in BaF_2 from ^{60}Co



Time variation of gain parameter



5-July-10

29-July-10

Neutron Flux Measurement

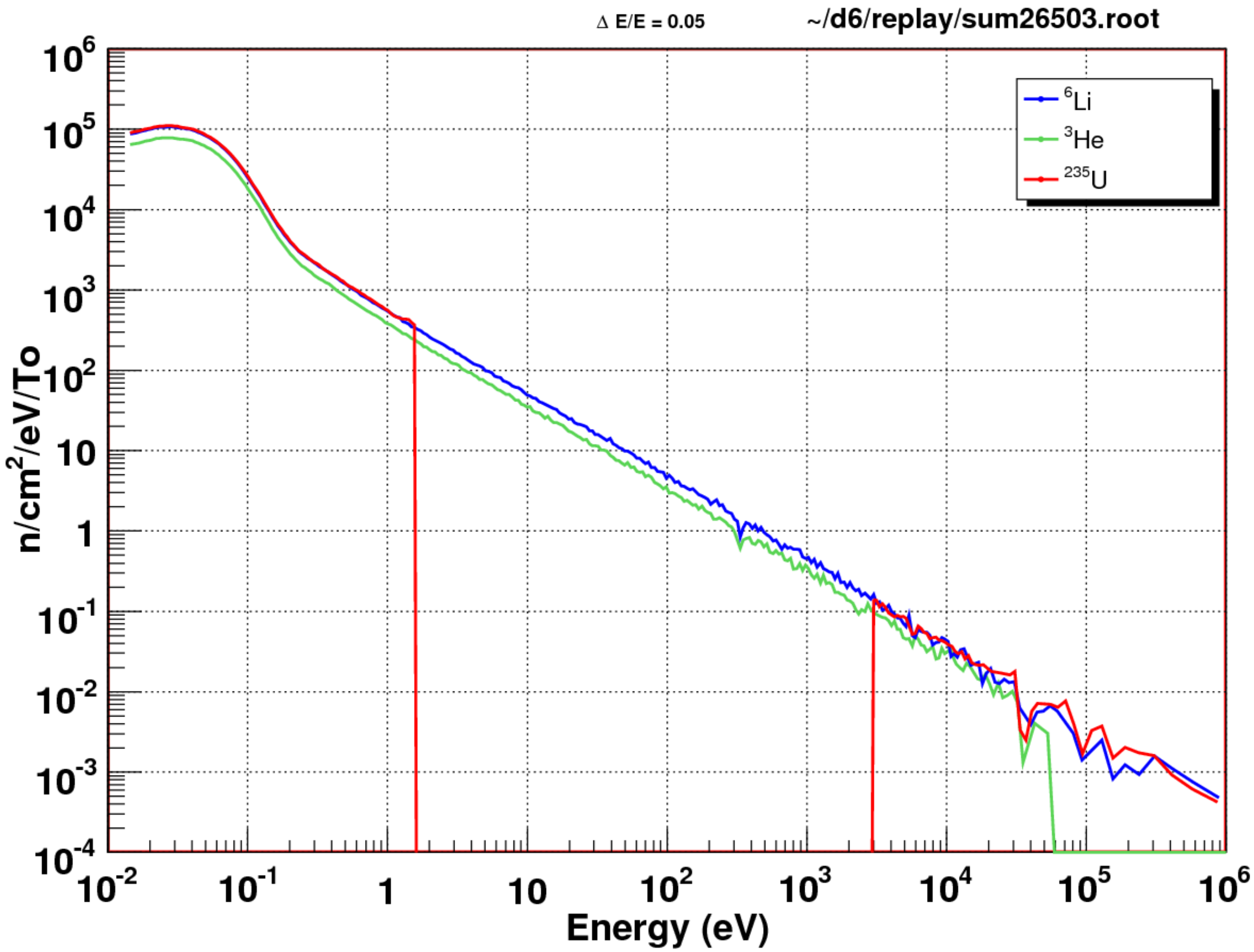
3 Neutron Monitors

$^{6}Li(n,\alpha t)$ 22.60 m

$^{10}B(n,\alpha)$ 22.76 m

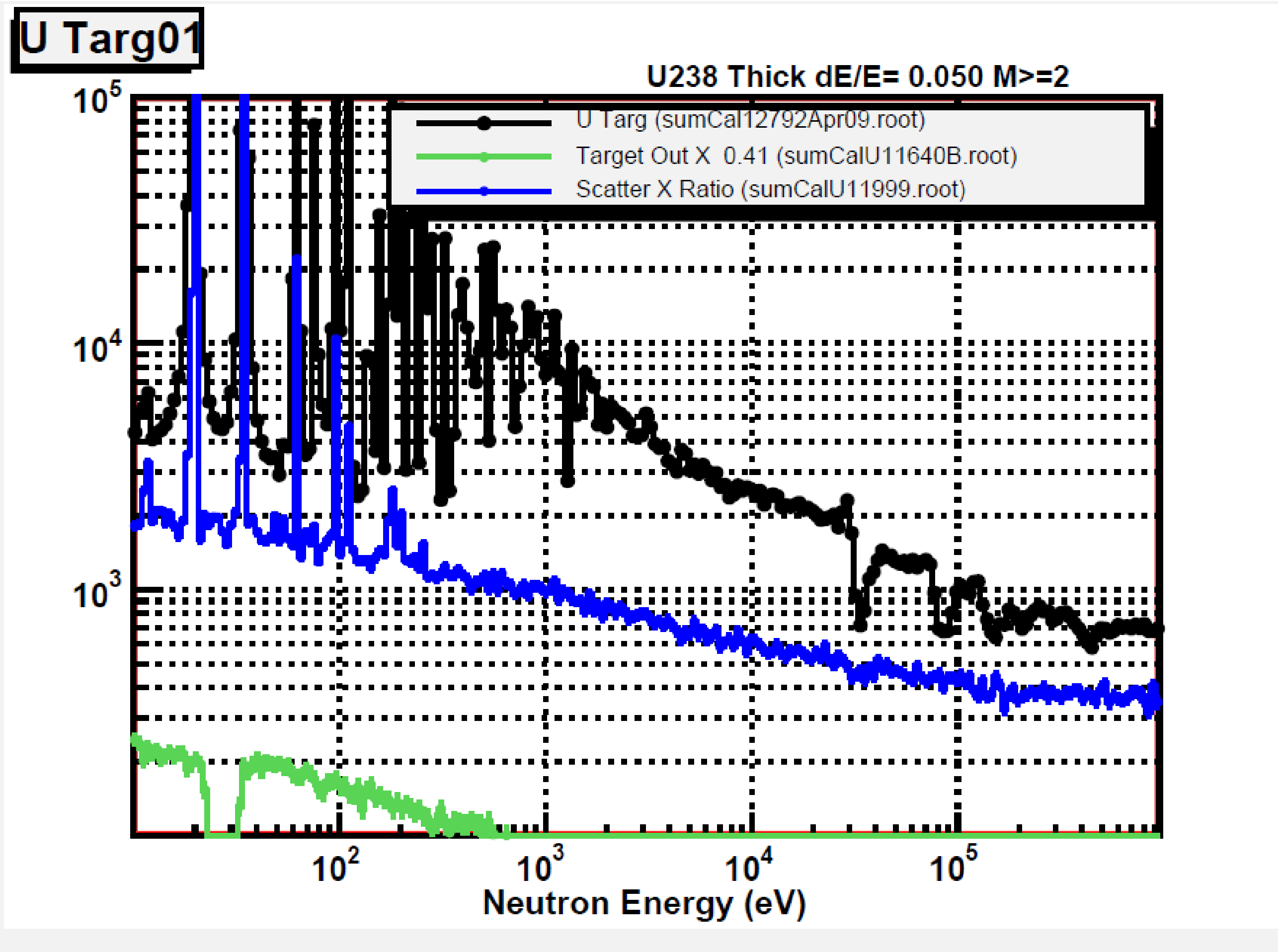
$^{235}U(n,f)$ 22.82 m

Flux from ^{6}Li:
~547 $E^{-1.04}$
n/cm^2/eV/To
(nominal, at monitor)
I = 100 μA
(5-Aug-10)

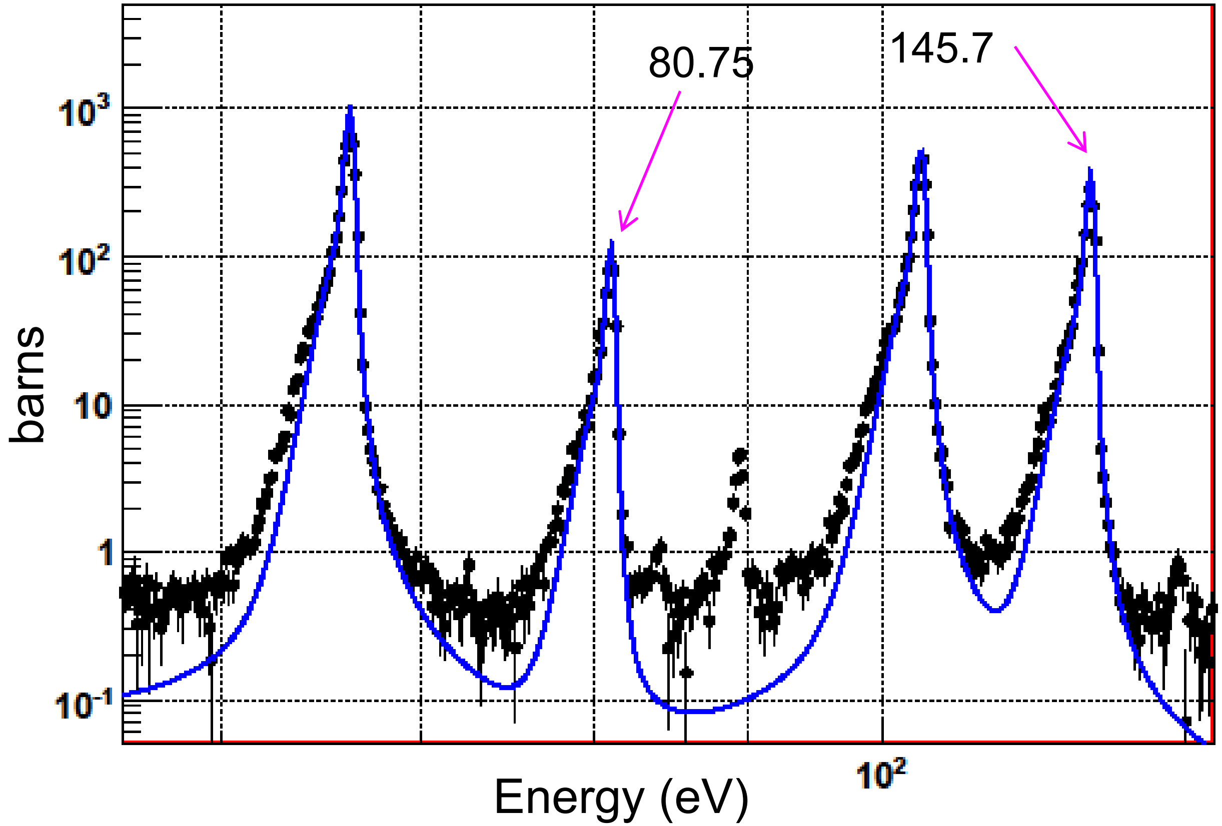


Background subtraction

$^{238}U(n,\gamma)$ 48 mg/cm^2

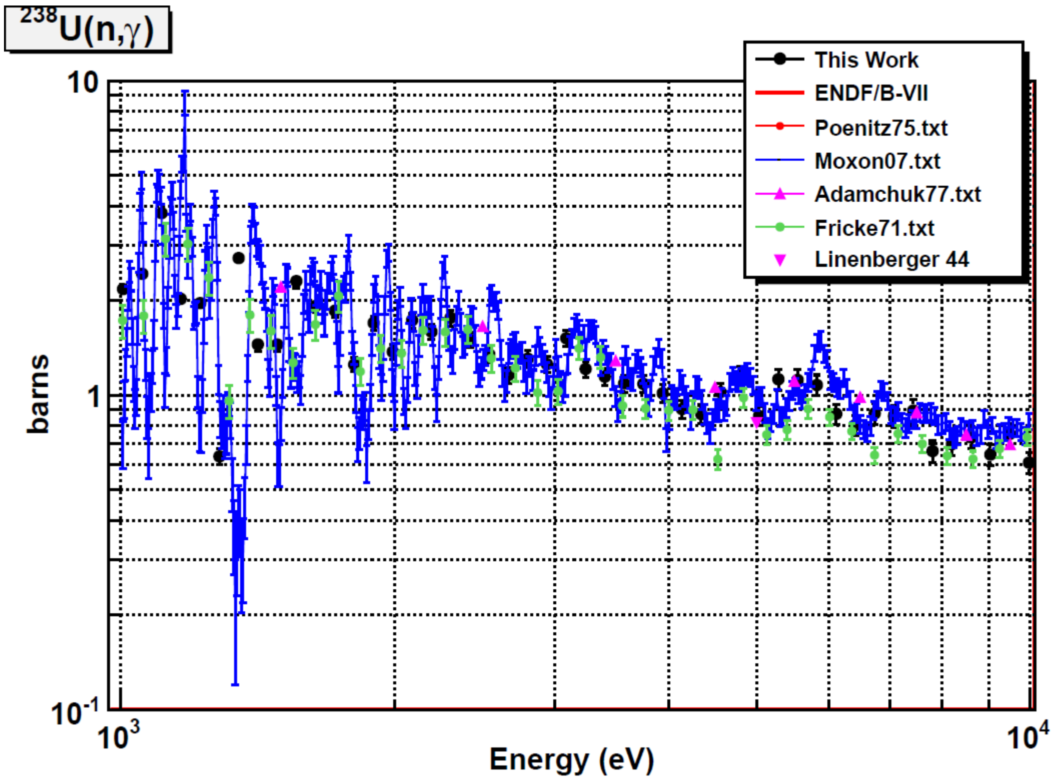


Normalize to resonance area



- Normalize resonance area at 80.75 and 145.67 eV to area calculated with ENDF/B-VII parameters and resolution broadening
- Minimize self-attenuation and multiple scatter corrections
- Ratios ± 2% -> Normalization uncertainty

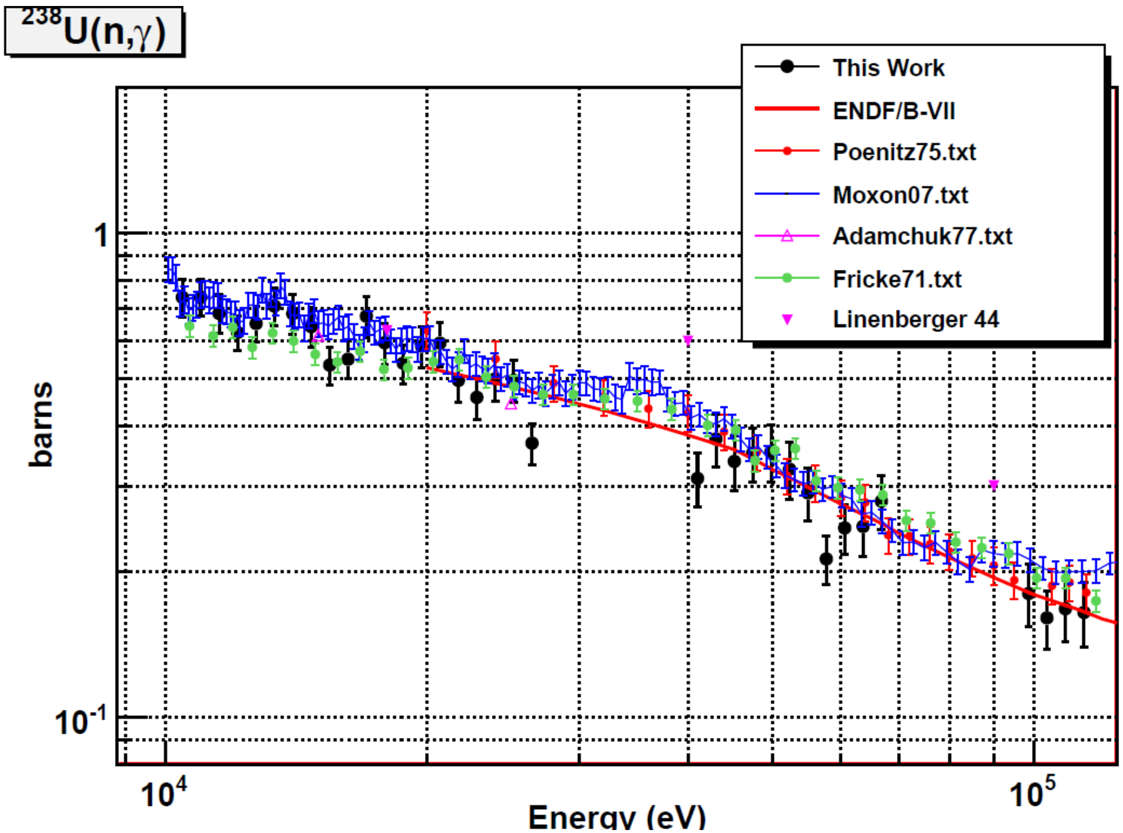
$^{238}U(n,\gamma)$ From 1 keV to 10 keV



This Work
dE/E = 0.05
~48 mg/cm^2

- Moxon 07: Reanalysis of 1968 data w/ Moxon-Rae detector (629 mg/cm^2 target)
- Poenitz, 75: Ge(Li) detector,
- Adamchuk 77: 4π NaI (12 detectors, sum=26 liters (500 mg/cm^2 target)
- Fricke 71: Liquid scintillator tank
- Linenberger 44: LANL- proportional counter (740 mg/cm^2 target)

$^{238}U(n,\gamma)$ from 10 keV to 200 keV



This Work
dE/E = 0.05

ENDF Calculation
P. Young et al.,
Nucl. Dat. Sheets, 108 (2007)

- Program CoH (T. Kawano)
- Optical Model: Soukhovitskij (J. Nucl. Sci. Tech. 37, 120 (2000)
- Level Density: T. Kawano, J. Nucl. Sci. Tech 43, 1 (2006)
- Strength Function: " Generalized Lorentzian" Kopecki and Uhl, Phys. Rev C42, 1941 (1990)
- $<\Gamma_\gamma>$ = 17 meV ($<\Gamma_\gamma>$ = 23.6 meV from RIPL)

Calculate gamma spectra with various RSF's

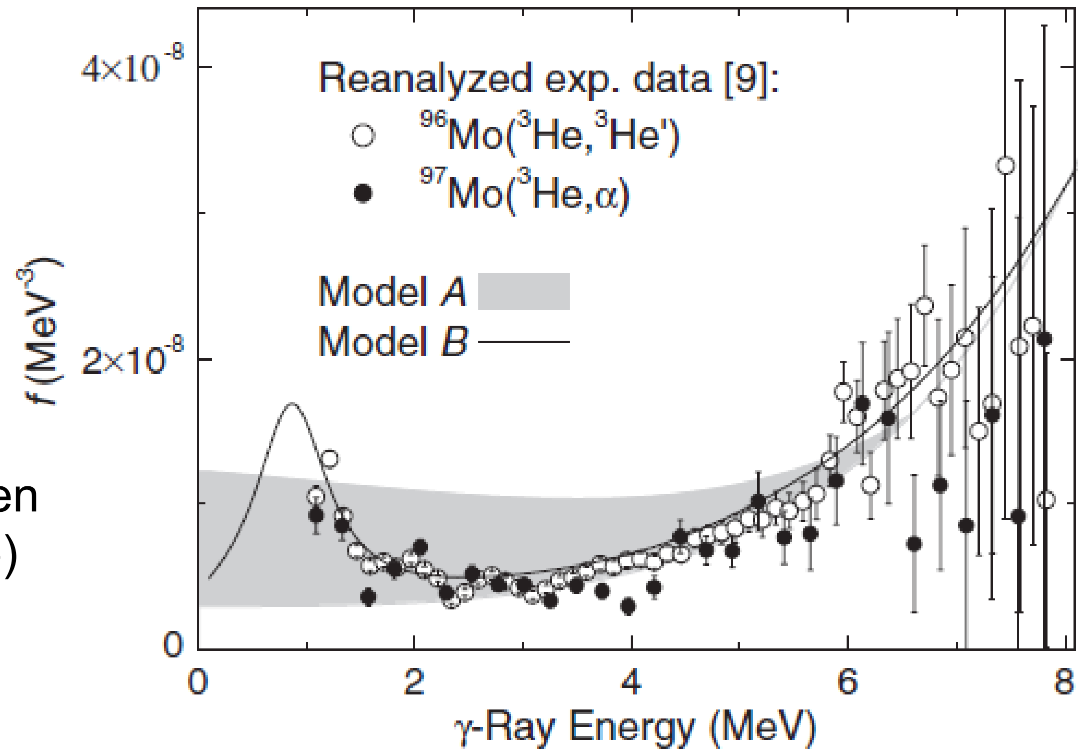
Procedure:

- "Spectrum fitting method"
- Assume form of Radiative Strength Function
- Generate gamma casades
  - DICEBOX (F. Bečvář, NIM A **417, 434** (1998).)
- Process cascades through GEANT4 model of DANCE
  - Use formulation of Jandel
  (M. Jandel, et al., NIM B **261,** 1117 (2007).)
  - Based on original model by Reifarth and Heil
  (M. Heil, R. Reifarth, et al., NIM A **459, 229**(2001).)
- Compare to measured gamma-ray spectra – (qualitative !)
  - Gamma spectra gated on Q–value and resonance energy
  - Spectra from particular resonance => known J^{π}
  - Compare shapes – arbitrary normalization

$^{95}Mo(n,\gamma)^{96}Mo$

S.A. Sheets – PhD Dissertation, North Carolina State Univ 2005

- Studied all s- + p- wave resonances for ^{95}Mo(n,γ) (GS=5/2^{+})
- Extensive study of different parameters for RSF
- Study of 2 parameter sets – Phys. Rev. C **79**, 024301 (2009)



A: suggested by M. Krticka
B: Suggested by M. Guttormsen
(Phys Rev C**71**, 044307 (2005)
And "private communication")

$^{95}Mo(n,\gamma)^{96}Mo$ RSF Parameters

Radiative Strength Function Parameters

(S.A. Sheets, et al., Phys Rev. C **79**, 024301 (2009)

Model	**A**	**B**
E1	Temp Dependent GLO	KMF
M1	Single Particle	Spin-flip Lorentzian
	$f_{M1}=1x10^{-9}$ MeV^{-3}	$\Gamma_R=8.95$ MeV $\Gamma_R=4.0$ MeV $\sigma_R=1.5$ mb
	Spin-Flip Lorentzian	2nd Lorentzian
	$\Gamma_R=8.95$ MeV $\Gamma_R=4.0$ MeV $\sigma_R=1.5$ mb	$\Gamma_R=0.95$ MeV $\Gamma_R=0.77$ MeV $\sigma_R=0.14$ mb MeV
E2	Single-Particle	GQR Lorentzian
	$f_{E2}=1.2x10^{-12}$ MeV^{-5}	$\Gamma_R=13.76$ MeV $\Gamma_R=4.96$ MeV $\sigma_R=2.21$ mb

Level Density: Back-shifted Fermi gas

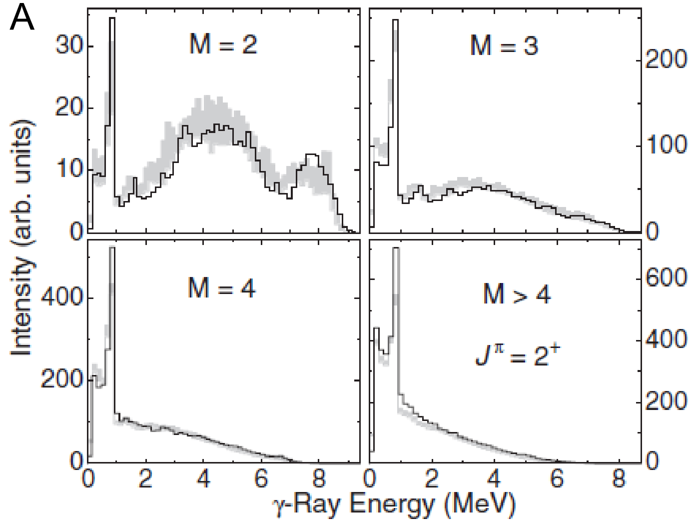
T. Von Egidy et al., Nucl. Phys. A481, 189 (1988)

Correction for parity asymmetry

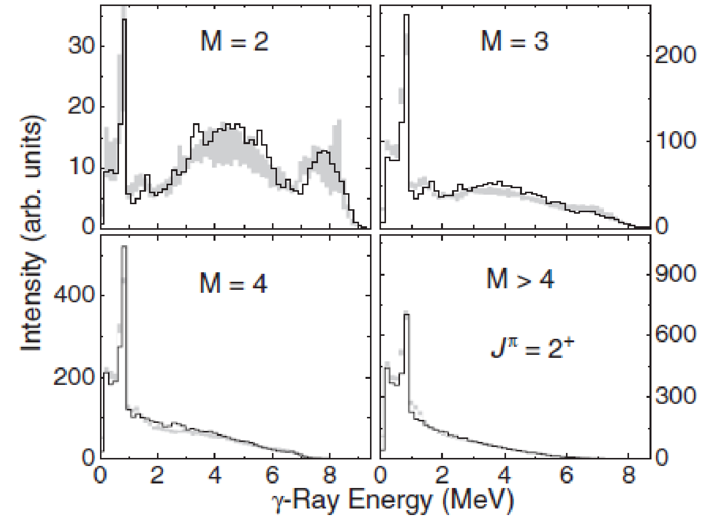
S.I. Al-Quraisi et al., Phys. Rev. C **67**, 015803 (2003)

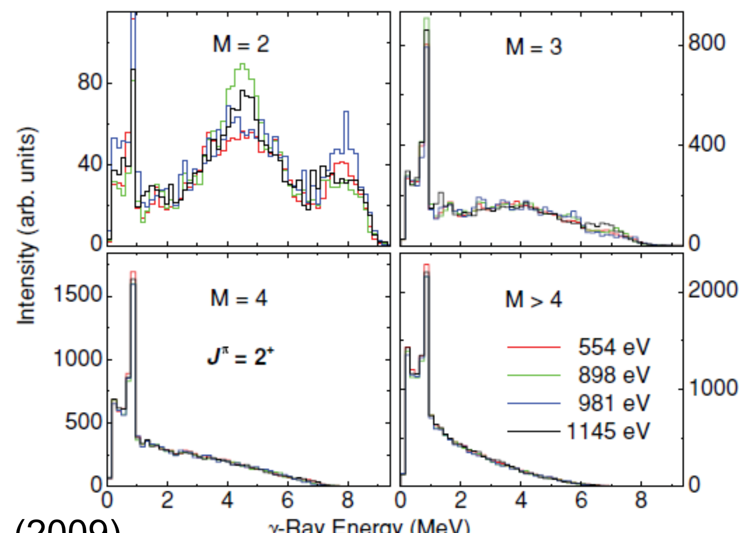
$^{95}Mo(n,\gamma)^{96}Mo$ results for 2^+ resonance at 554 eV

Model A



Model B





Compare measured spectra to calc's
(Spectra gated on Q=7.6 – 9.2 MeV)

- Predicted spectra for A,B different
- Neither is preferred for 554 eV res.
- Wide variation of shapes for 2+ res.

S.A. Sheets, et al., Phys. Rev. C **79**, 024301 (2009).

^{155,156,158}Gd(n,γ)

Study of gamma emission spectra-
B. Baramsai, Dissertation, North Carolina State University, 2010

Level Density

Back-shifted Fermi Gas
(T. von Egidy, Phys. Rev C 72,044311 (2005))

E1 Strength

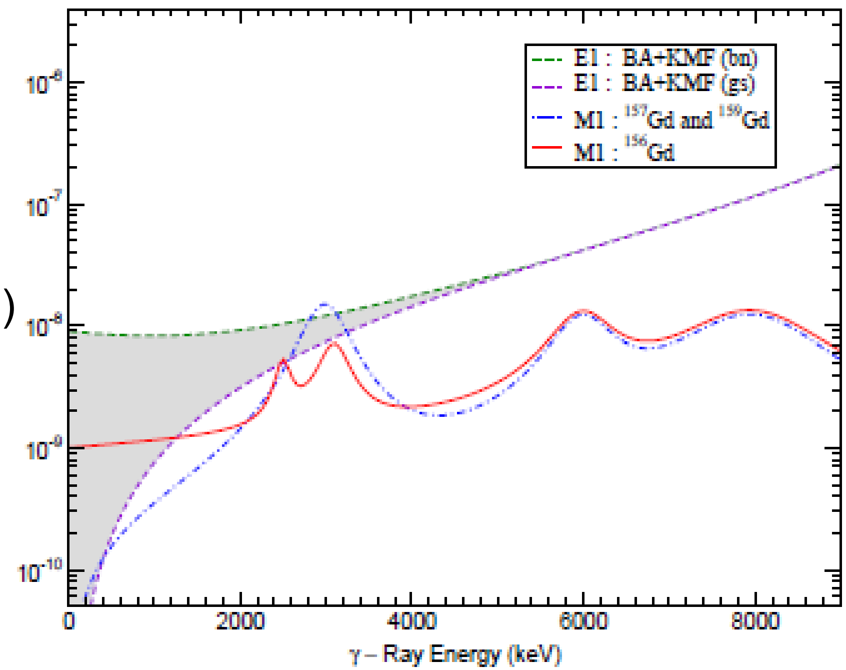
Hybrid Model
KMF E_γ < ~ 7 MeV
BA (GDR Lorentzian) E_γ > ~ 7 MeV

M1 Strength

Single Particle
2 GT components (Lorentzian)
2 "Scissors" components (Lorentzian)

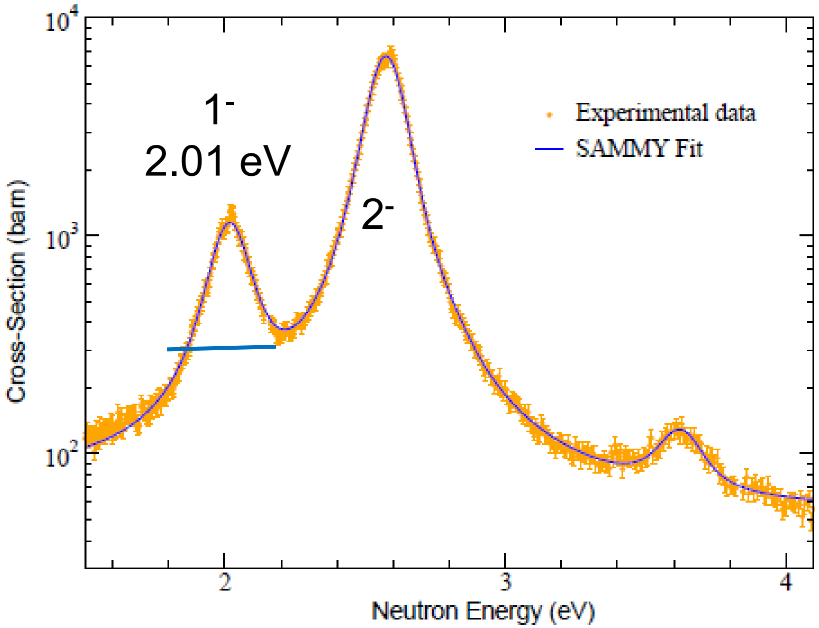
E2

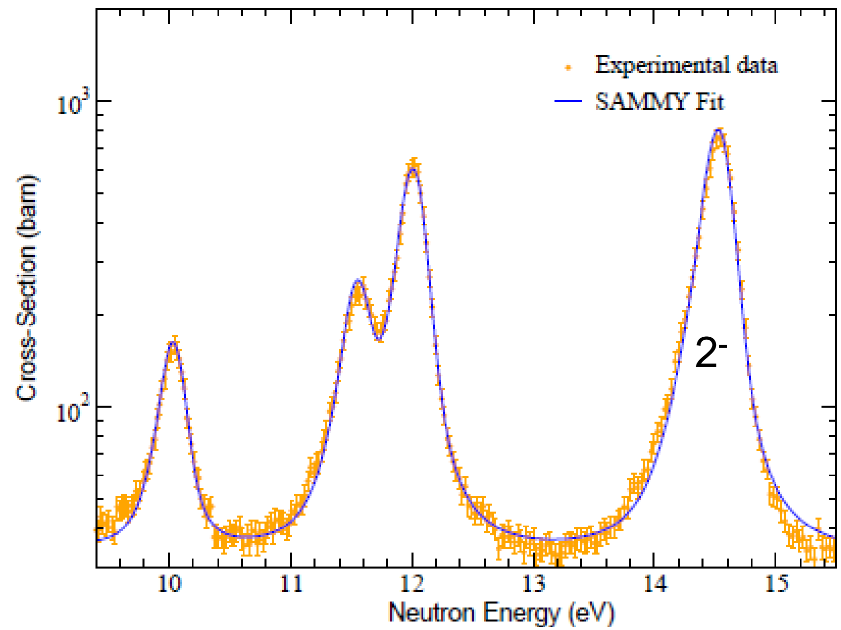
Single Particle 5 x 10^{-9} MeV^{-3}



M1 modes	E_0 (MeV)	σ_0 (mb)	Γ (MeV)
SC for ^{156}Gd	2.6	0.1	0.2
	3.1	0.2	0.4
SC for ^{157}Gd and ^{159}Gd	3.0	0.5	0.6
SF for ^{156}Gd	6.0	0.8	0.8
	8.0	1.2	1.8
SF for ^{157}Gd and ^{159}Gd	6.0	0.7	0.8
	8.0	1.1	1.8

Resonance studied in $^{155}Gd(n,\gamma)$





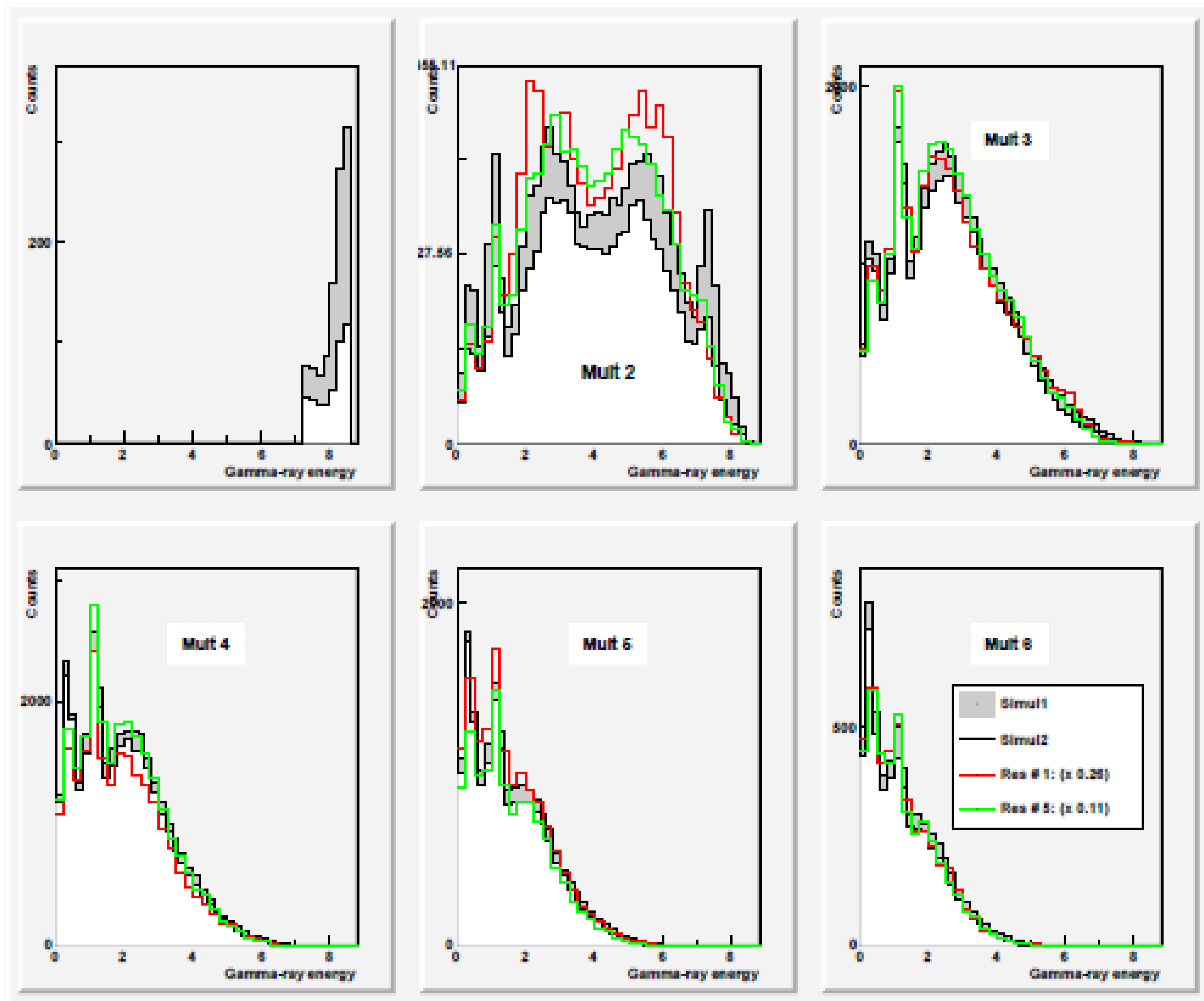
B. Baramsai, North Carolina State Univ. 2010

Gamma Spectra from $^{155}Gd(n,\gamma)^{156}Gd$ 1^- Res.

1^- Resonances

2.01 eV

21.03 eV



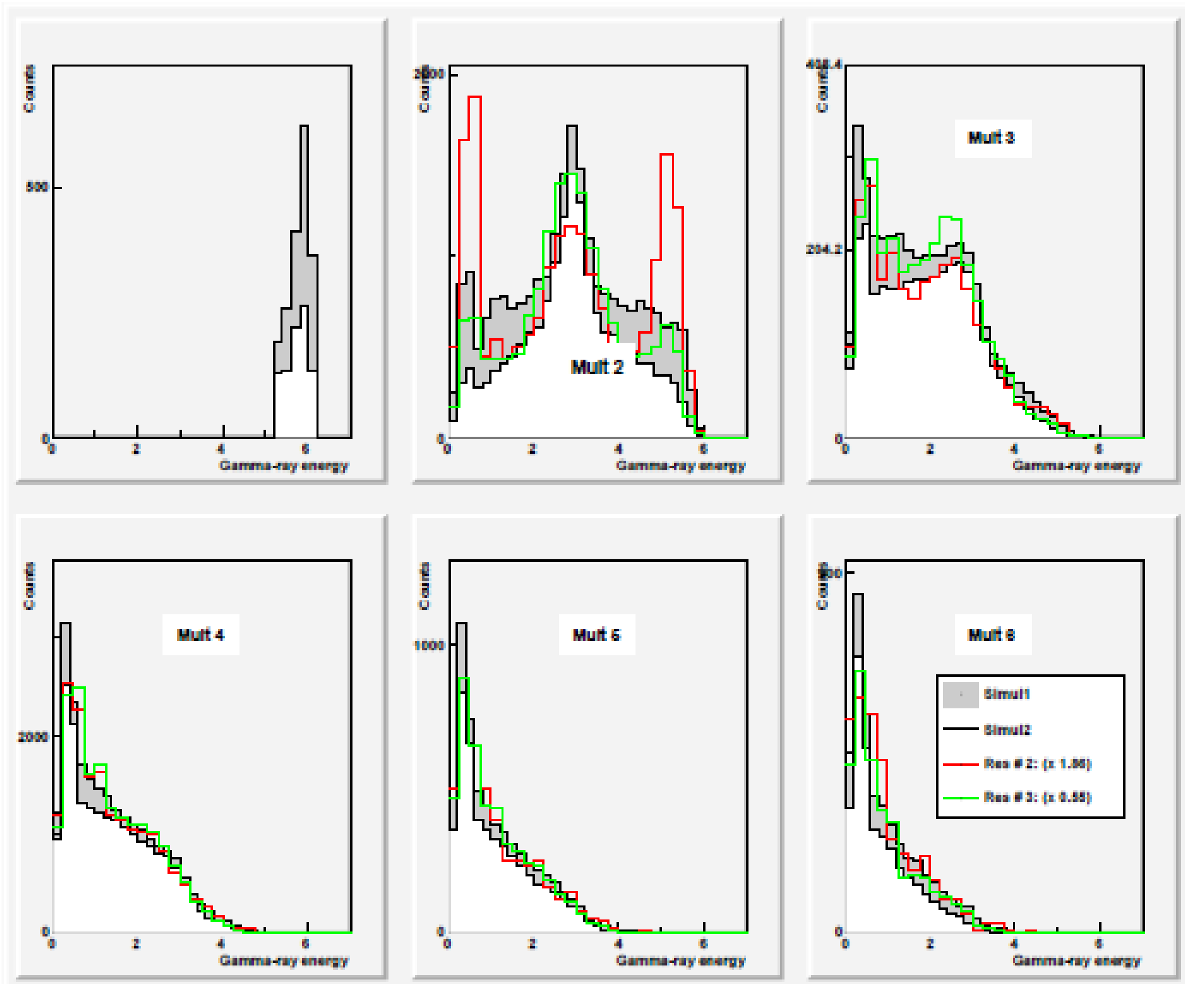
B. Baramsai, North Carolina State Univ. 2010

$^{158}Gd(n,\gamma)^{159}Gd$ 1/2$^+$ Resonances

1/2$^+$ Resonances

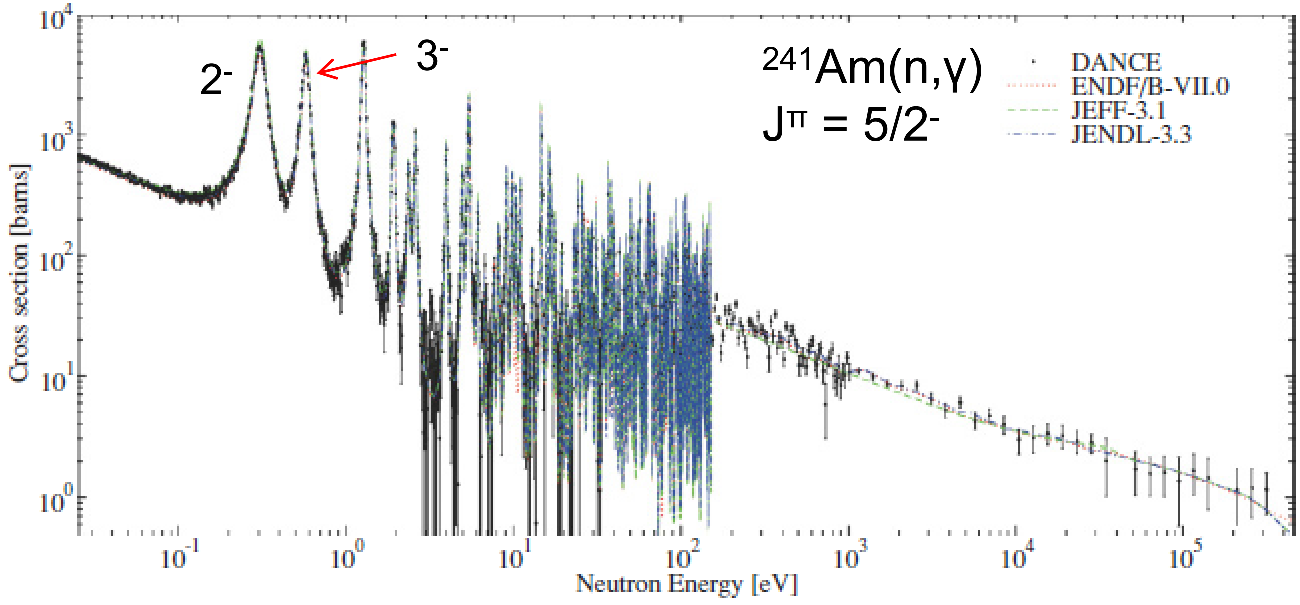
- red line: 22.3 eV
- green line: 101.1 eV

(Simulations- gray)



B. Baramsai, North Carolina State Univ. 2010

^{241}Am



Target: 219 μg
(0.69 mg/cm^2)

Q Gate: 4.5 – 5.5 MeV

Segment mode

Level Density
BSFG
(T. von Egidy,
Nucl. Phys A481 (189, (1988))

E1 Parameters
(Deformed GDR)

E_R	Γ_R	σ_R
6.58 MeV	4.0 MeV	4.0 mb
2.50	0.6	0.8

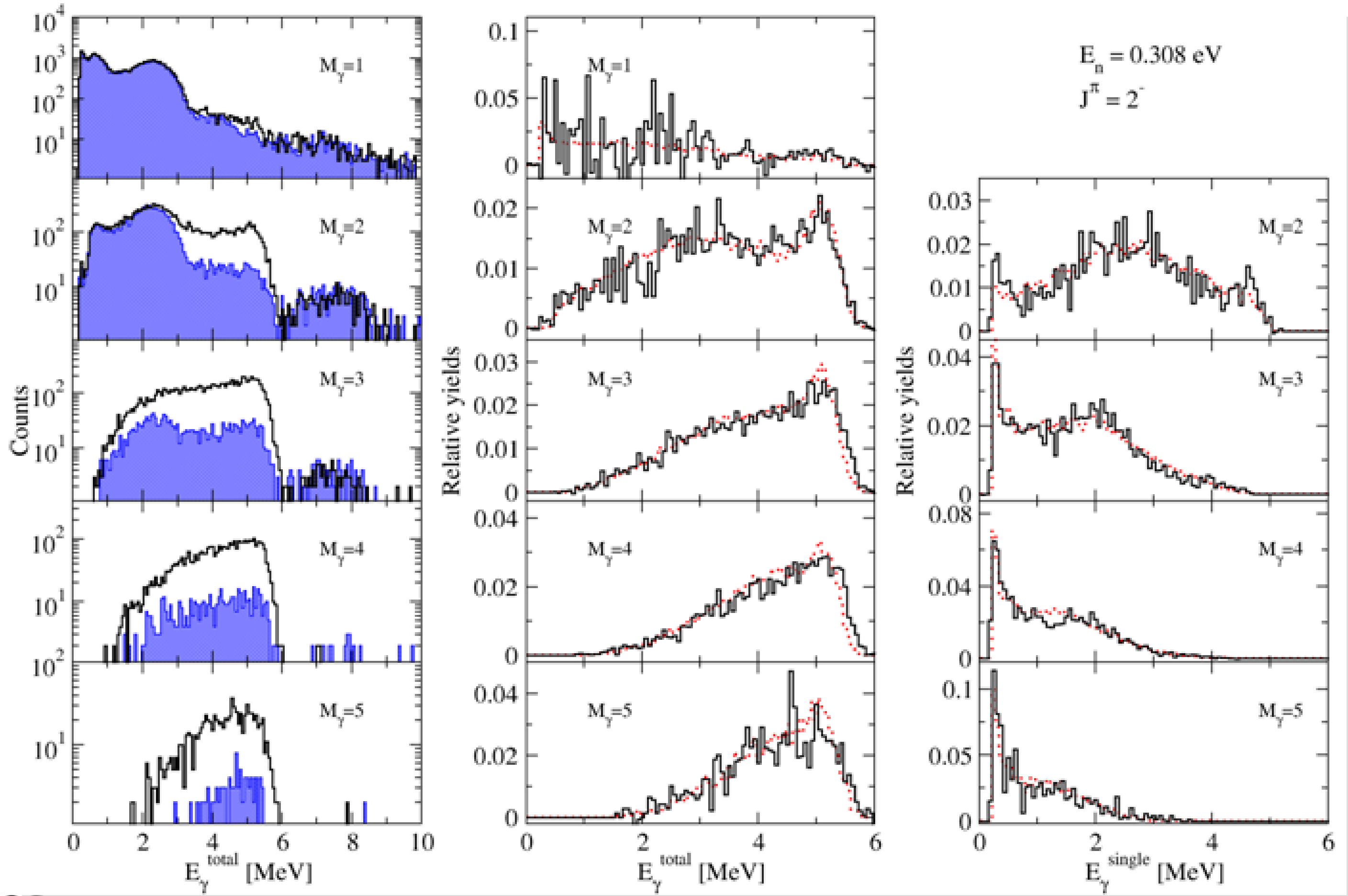
M1 Parameters
(Lorentzian)

E_R	Γ_R	σ_R
SF6.58 MeV	4.0 MeV	4.0 mb
SC2.50	0.6	0.8

M. Jandel, et al., Phys. Rev. C **78**, 034609 (2008)

^{241}Am: 0.308 eV 2^- Resonance, data + calc's

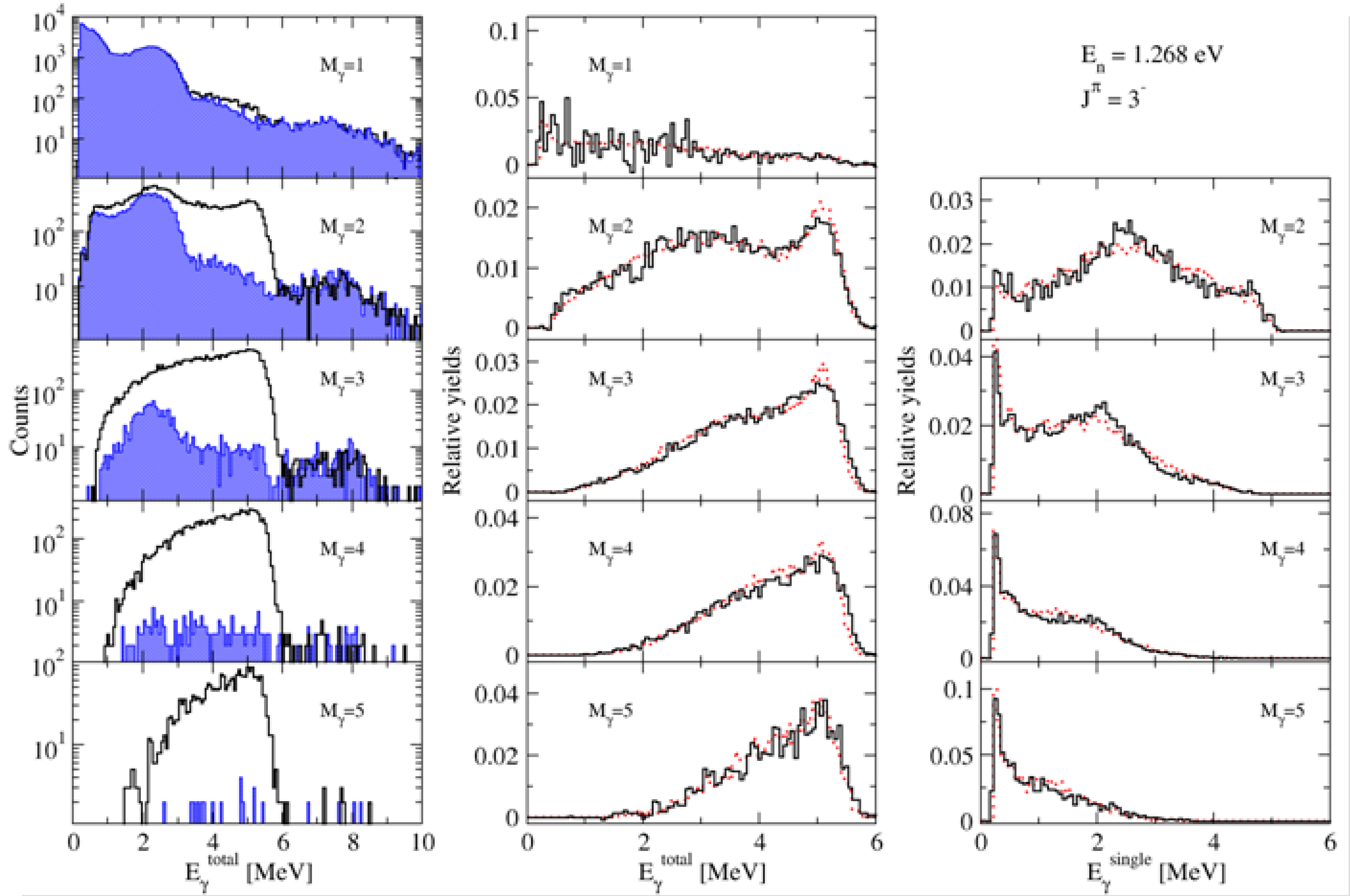
- First column: total γ-ray spectra, **black – ^{241}Am**, blue – Background – between resonances
- Red lines is DICEBOX-Geant4 calculation



M. Jandel, et al., Phys. Rev. C **78**, 034609 (2008)

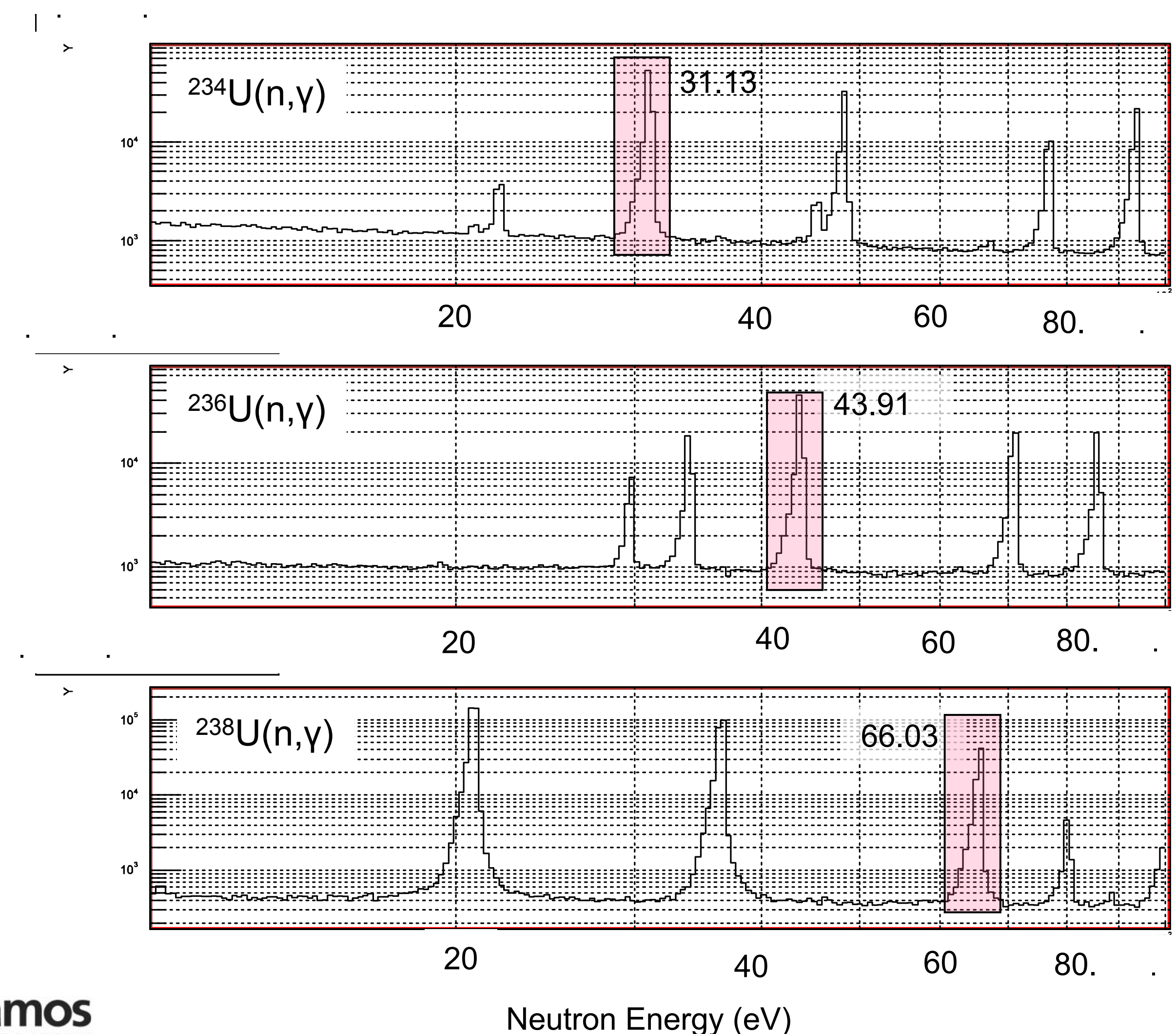
^{241}Am: 1.268 eV 3$^-$ resonance, data+ calc's

- First column: total γ-ray spectra, **black – ^{241}Am**, blue - Background
- Red lines is DICEBOX-Geant4 calculation



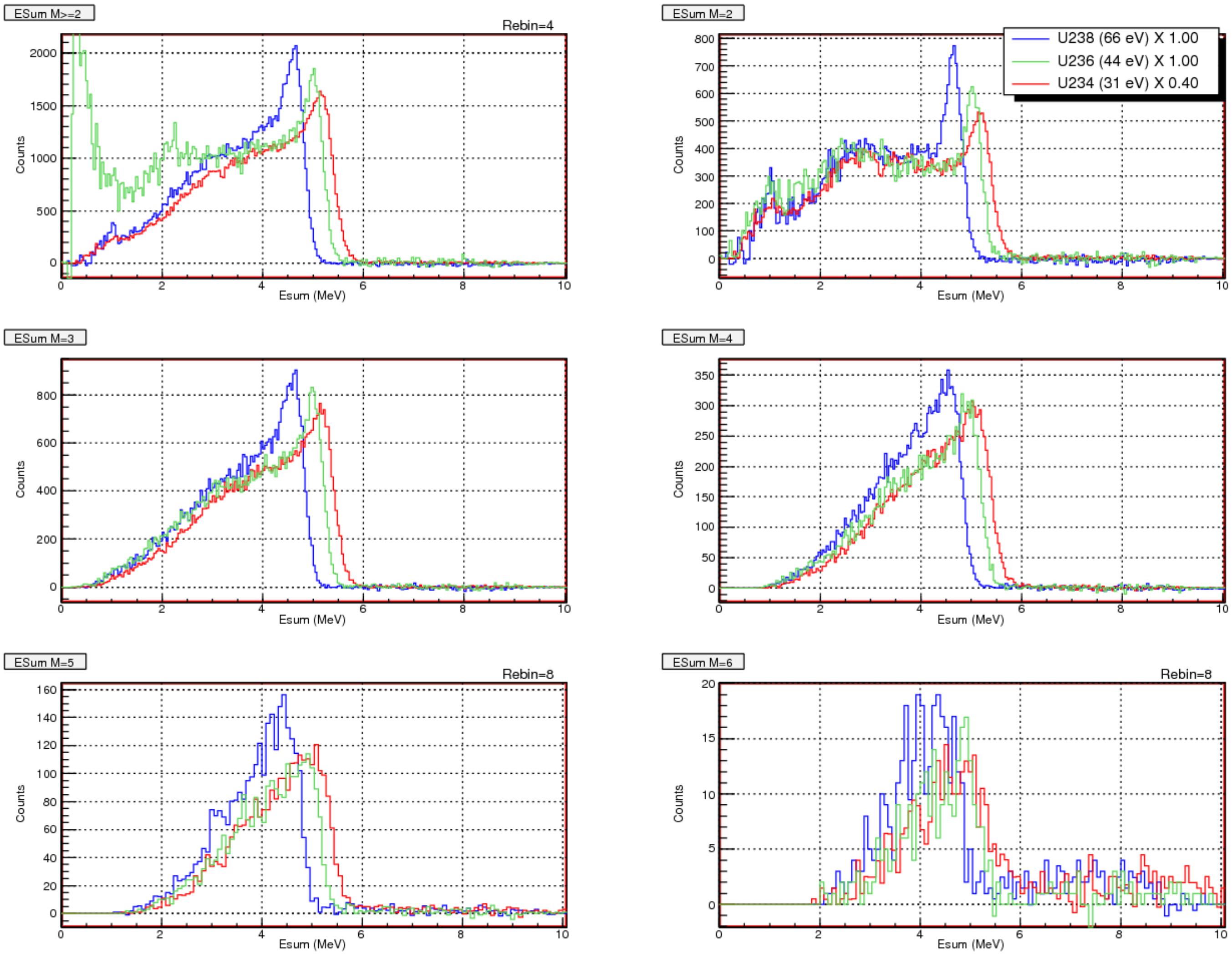
M. Jandel, et al., Phys. Rev. C **78**, 034609 (2008)

Uranium resonances



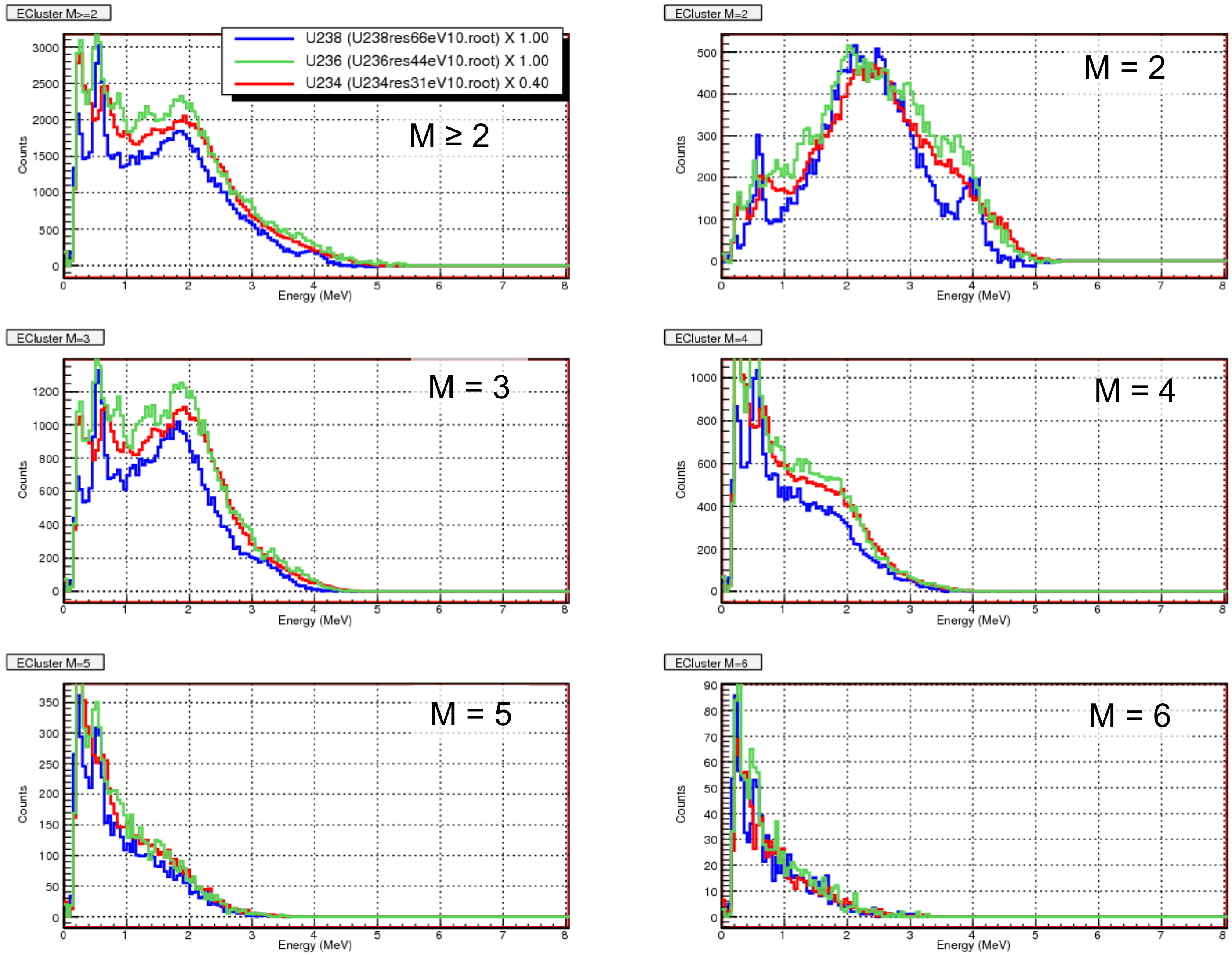
Uranium resonances – “sum” energy spectra

- ^{238}U, 66 eV
- ^{236}U, 44 eV
- ^{234}U, 31 eV



Uranium resonances – Gamma ray spectra

^{238}U, 66 eV
^{236}U, 44 eV
^{234}U, 31 eV



^{238}U(n,γ) Simulations

➢Preliminary Calculations (!!) by Krticka

Level Density

Back-shifted Fermi gas
((T. von Egidy, Phys. Rev C 72,044311 (2005))

E1 Strength

Deformed GDR

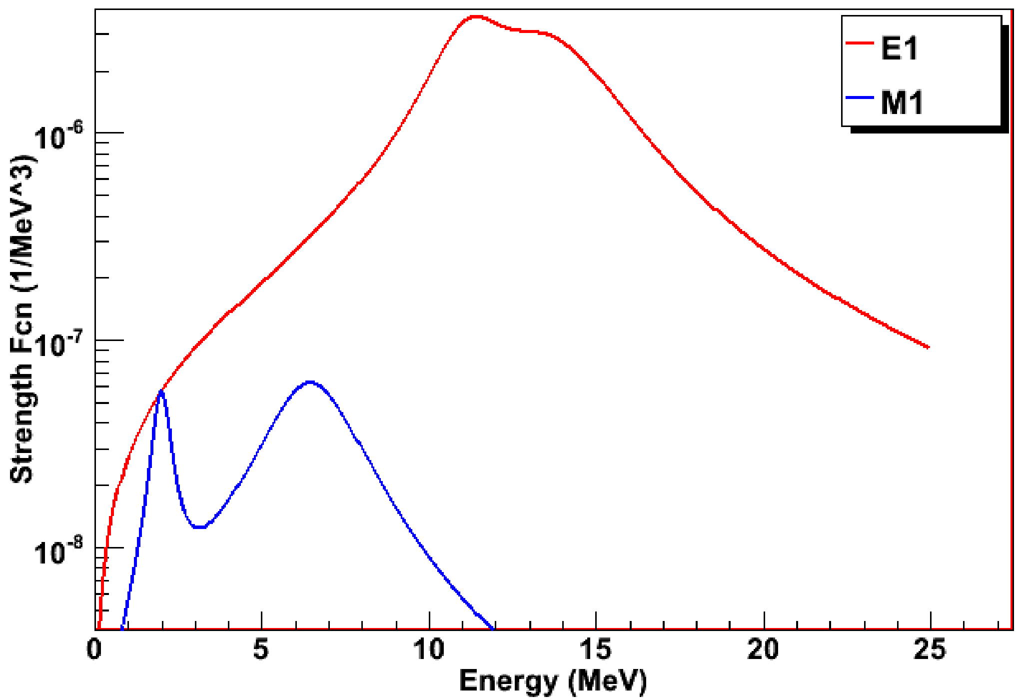
M1 Strength

Single Particle

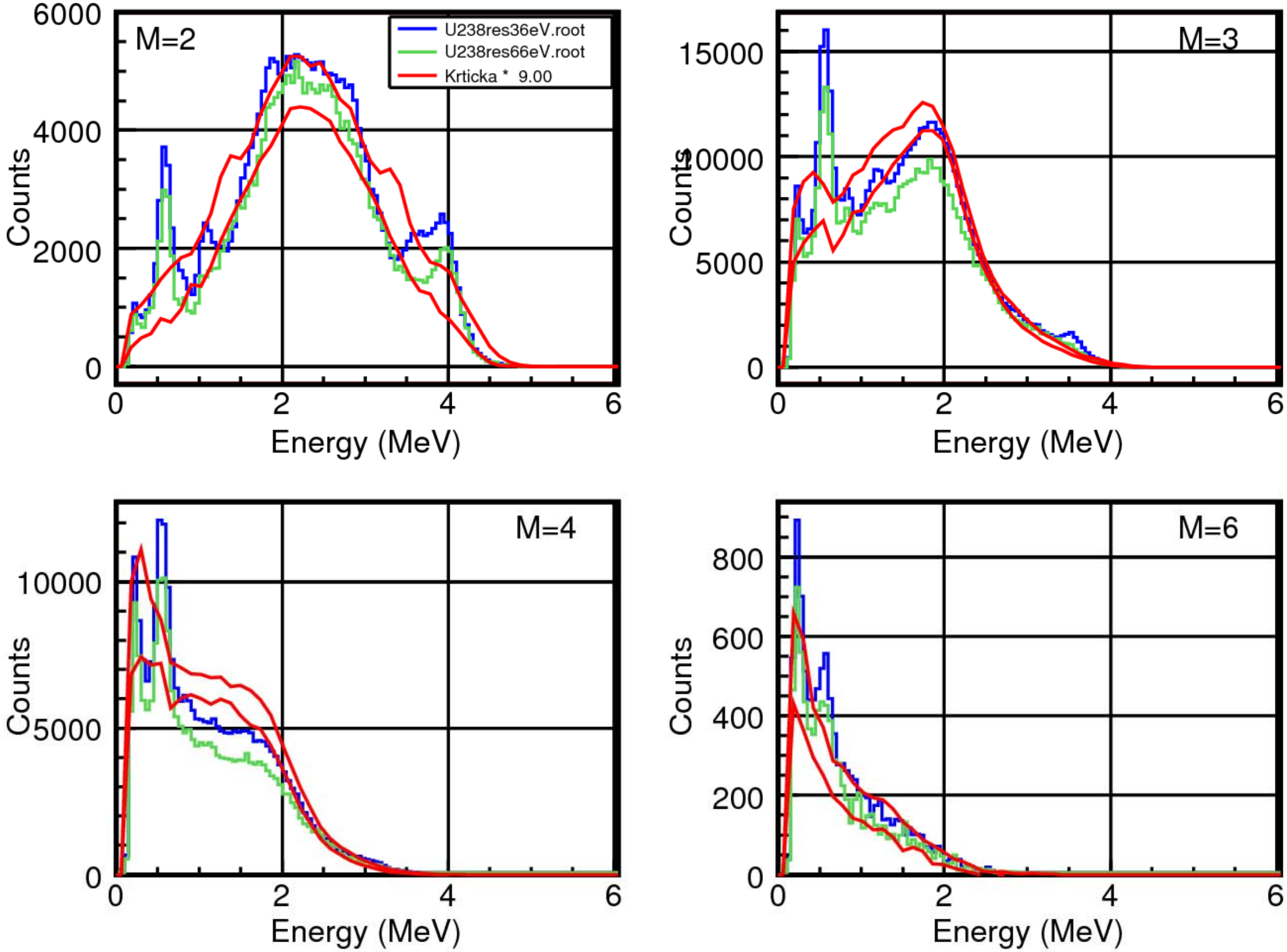
	E_R	Γ_R	σ_R
SF	7.0 MeV		
SC	2.0 MeV	0.6 MeV	1.2 mb

E2 Strength

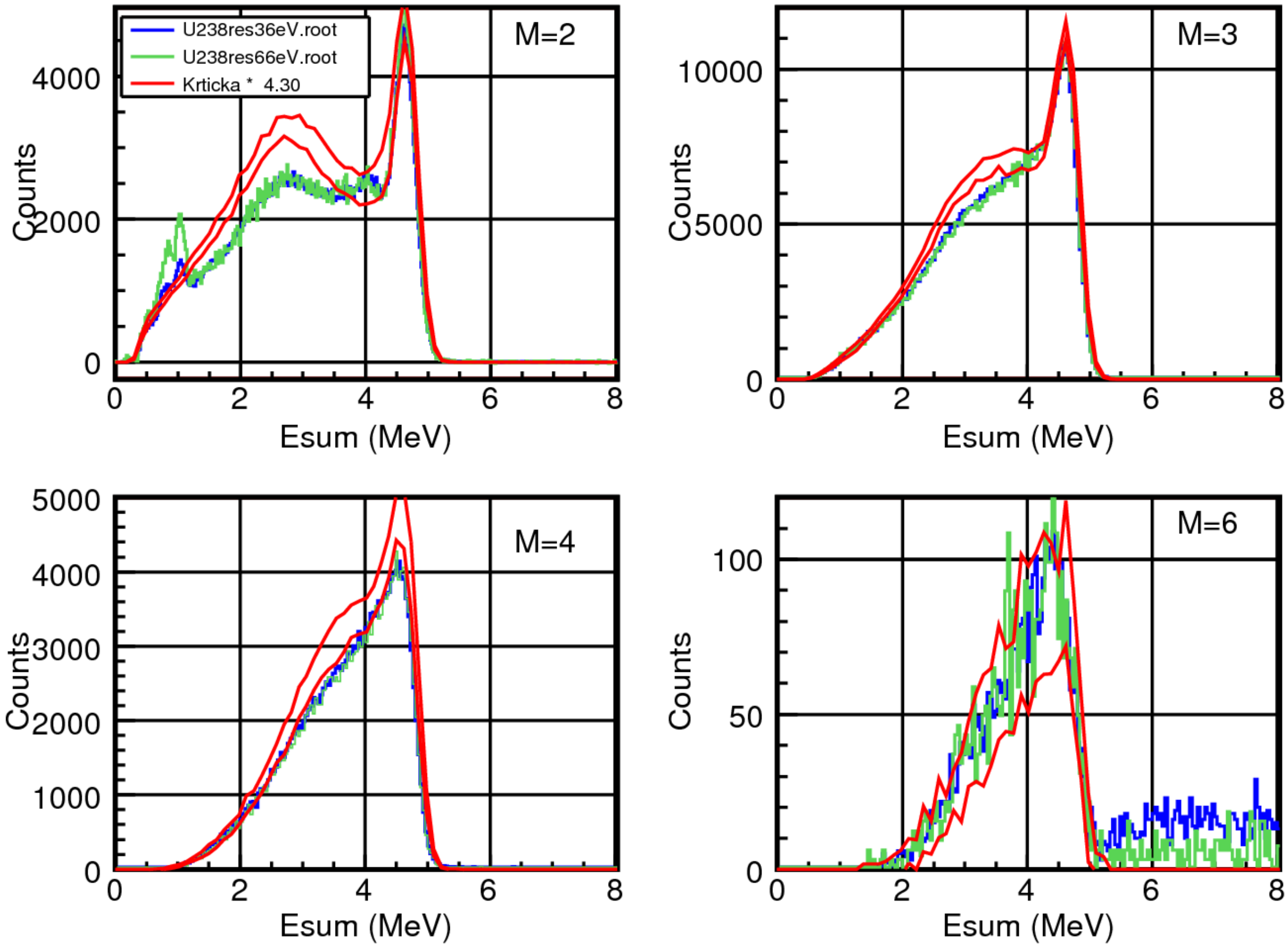
Single particle



^{238}U γ-ray spectra for resonances at 36, 66 eV



^{238}U Summed energy (Esum) spectra



Conclusions

- This (normalized) measurement of $^{238}U(n,\gamma)$ cross section is in good agreement with previous work, but favors lower values in the keV region
- DANCE can make measurements on thin targets, minimizing the effects of multiple scatter and self-absorption.
- Resonance-gated summed-energy and gamma-energy spectra can be measured as a function of gamma multiplicity.
- Spectral shapes can be calculated using reasonable RSF's and level densities