

Update on Reaction Theory Development at LANL

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Nuclear Reaction Theory at LANL Highlights

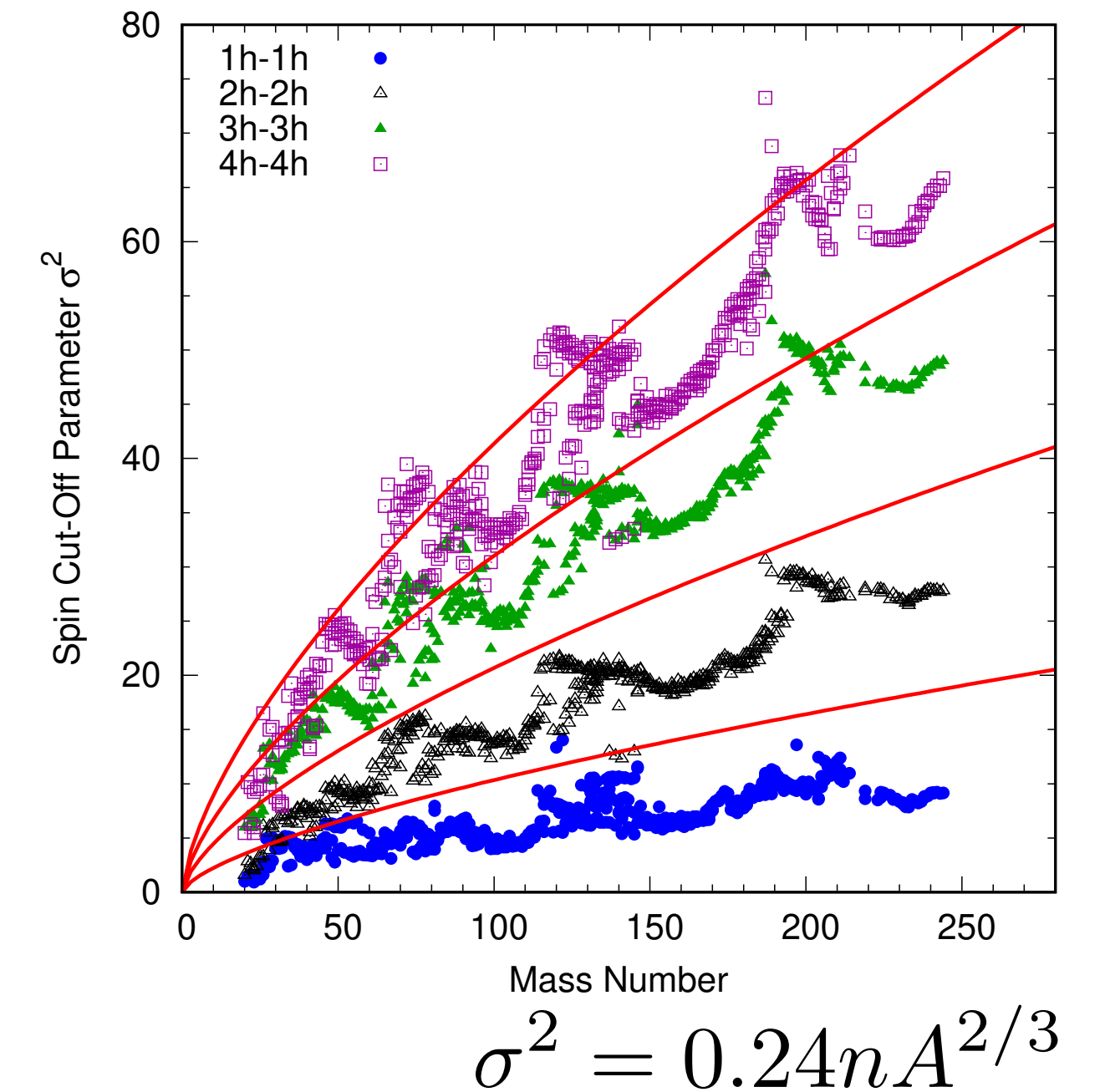
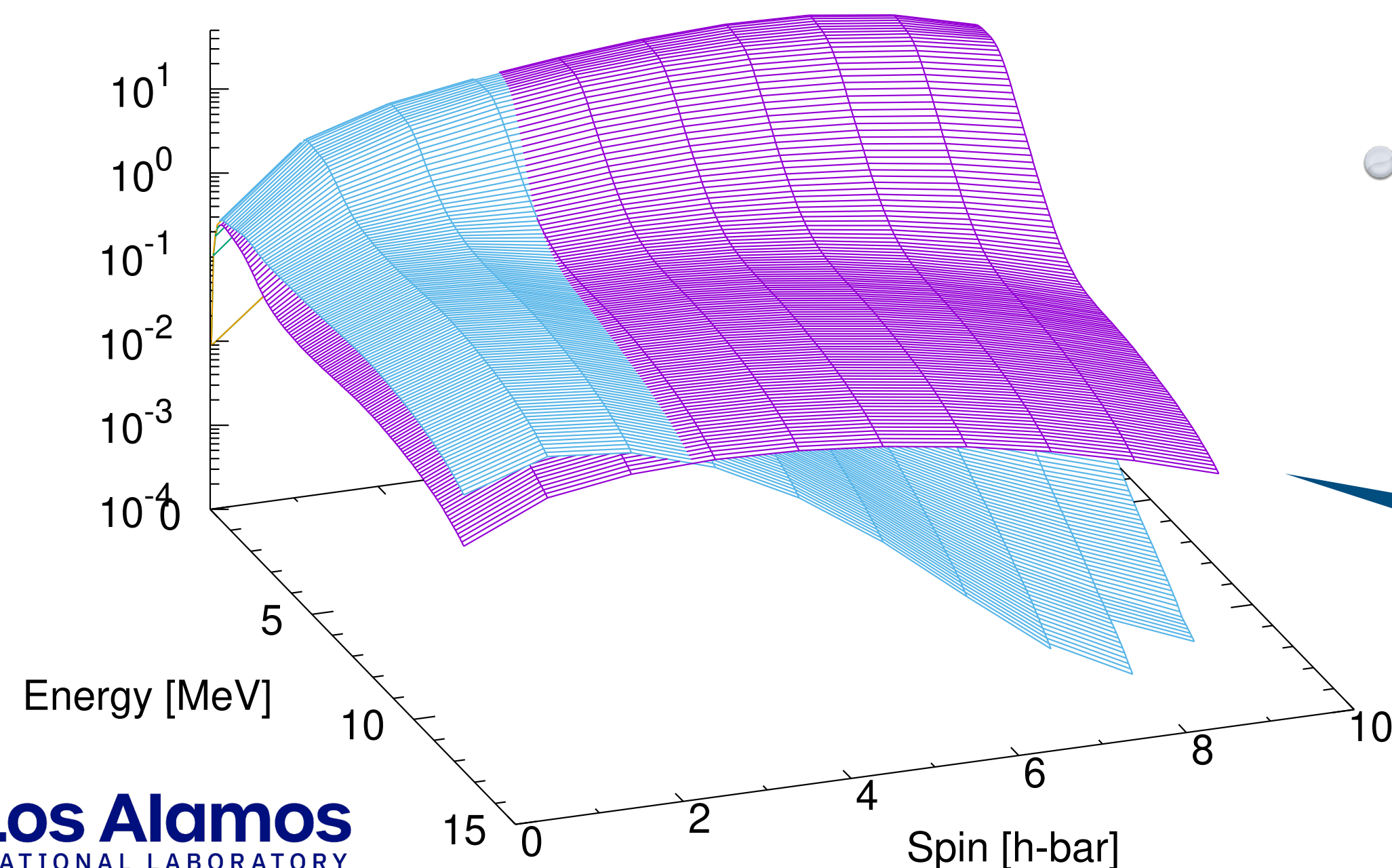
- **Finite Amplitude Method (FAM) for neutron inelastic scattering**
 - Microscopic calculation of (n,n') for both discrete and continuum final states
 - Paper by H. Sasaki, T. Kawano, and M. Dupuis accepted by PRC
- **Random matrix approaches to statistical properties of nuclear reaction**
 - New method to calculate average and distribution of cross section in unresolved resonance range
 - Manuscript by K. Fujio, T. Kawano, A.E. Lovell, and D. Neudecker submitted to PRC
- **Fission-related nuclear data production**
 - Prototype of LACE (Los Alamos CoH-based Evaluation) framework
- **Correction to GEANIE experimental data**
 - Discrimination of gamma rays produced by (n,xn) reactions and fission
 - Manuscript prepared by T. Kawano, A.E. Lovell, P. Talou
- Pre-equilibrium neutron emission of photo-nuclear reaction (not in this talk)
- Open source codes (CoH and DeCE) updates (not in this talk)
- ...

Number of Configurations in Pre-Equilibrium — Partial Level Density

- **1-Step MSD double differential cross section**

$$\left(\frac{d^2\sigma}{d\Omega dE} \right)_m = \sum_{\mu} |\langle \chi^{(-)} u_{m\mu} | \mathcal{V} | \chi^{(+)} u_0 \rangle|^2 \rho_{m\mu}(E_x)$$

- microscopic approach (FAM) developed
- **Combinatorial calculation for intrinsic level density**
 - single-particle spectra generated in folding Yukawa potential
 - J-dependence is almost pure Fermi gas spin distribution



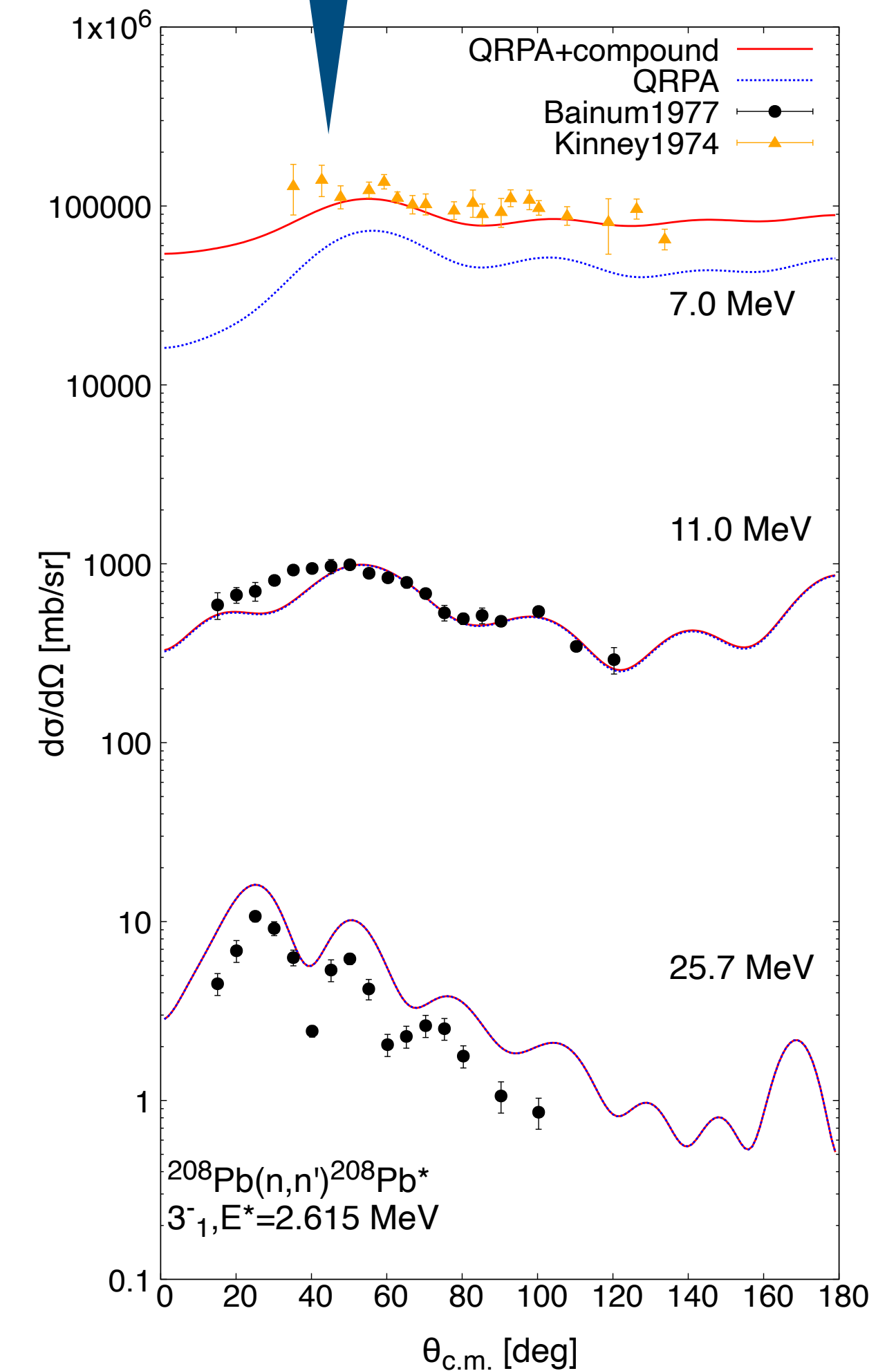
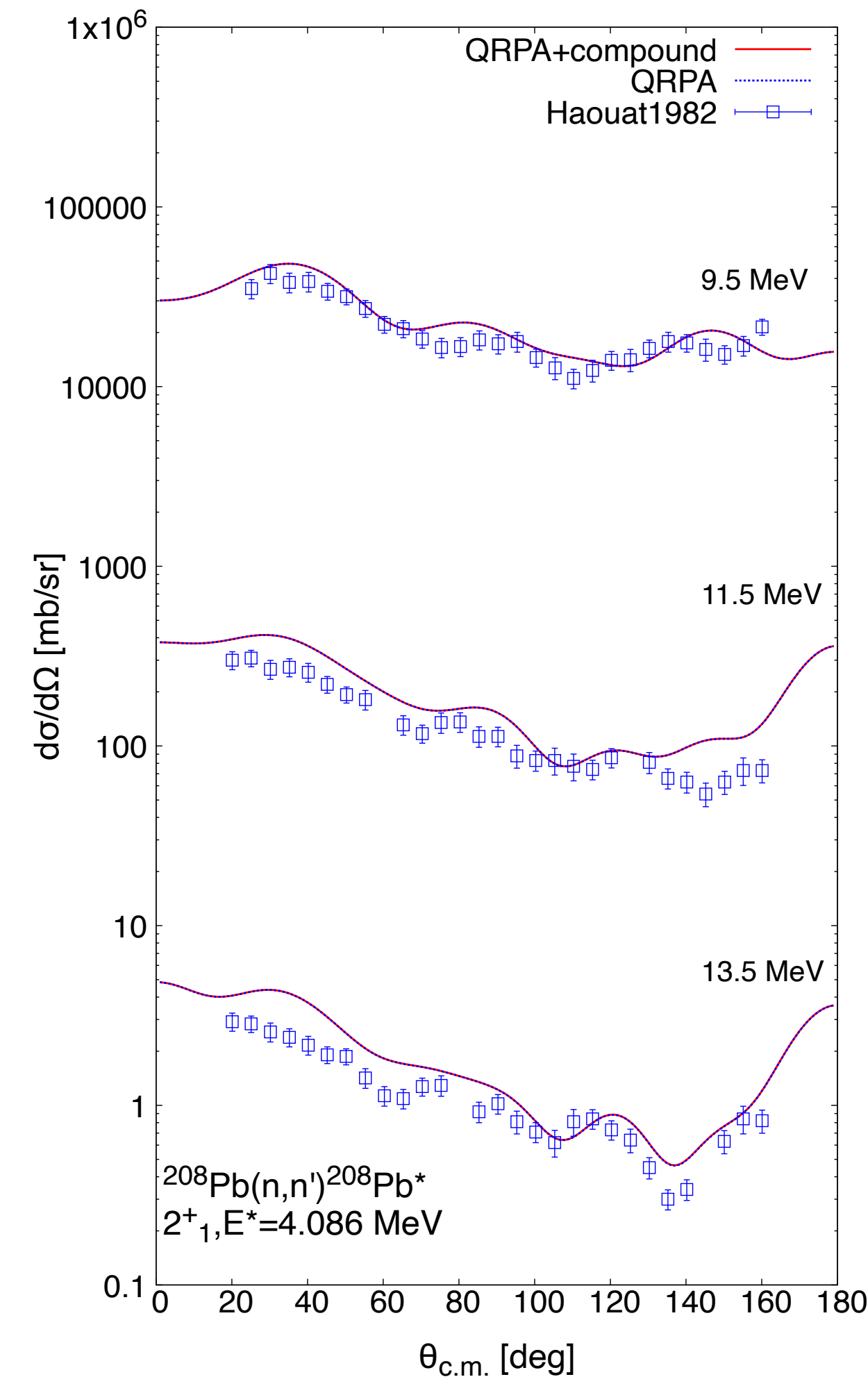
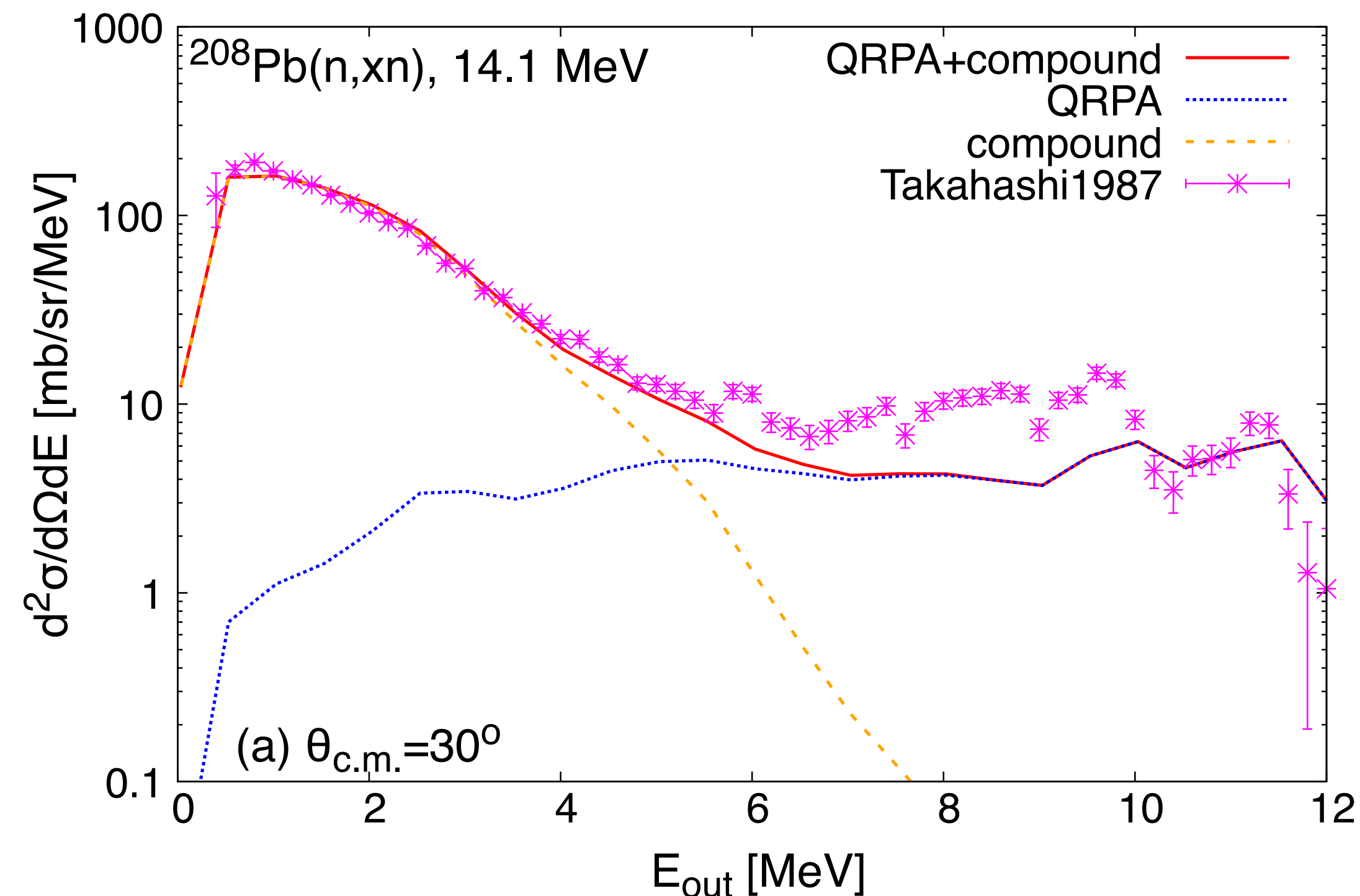
- **Recent experiments**

- gamma-ray production data suggest that states are strongly suppressed by the PE degree-of-freedom

High spin states should not be produced

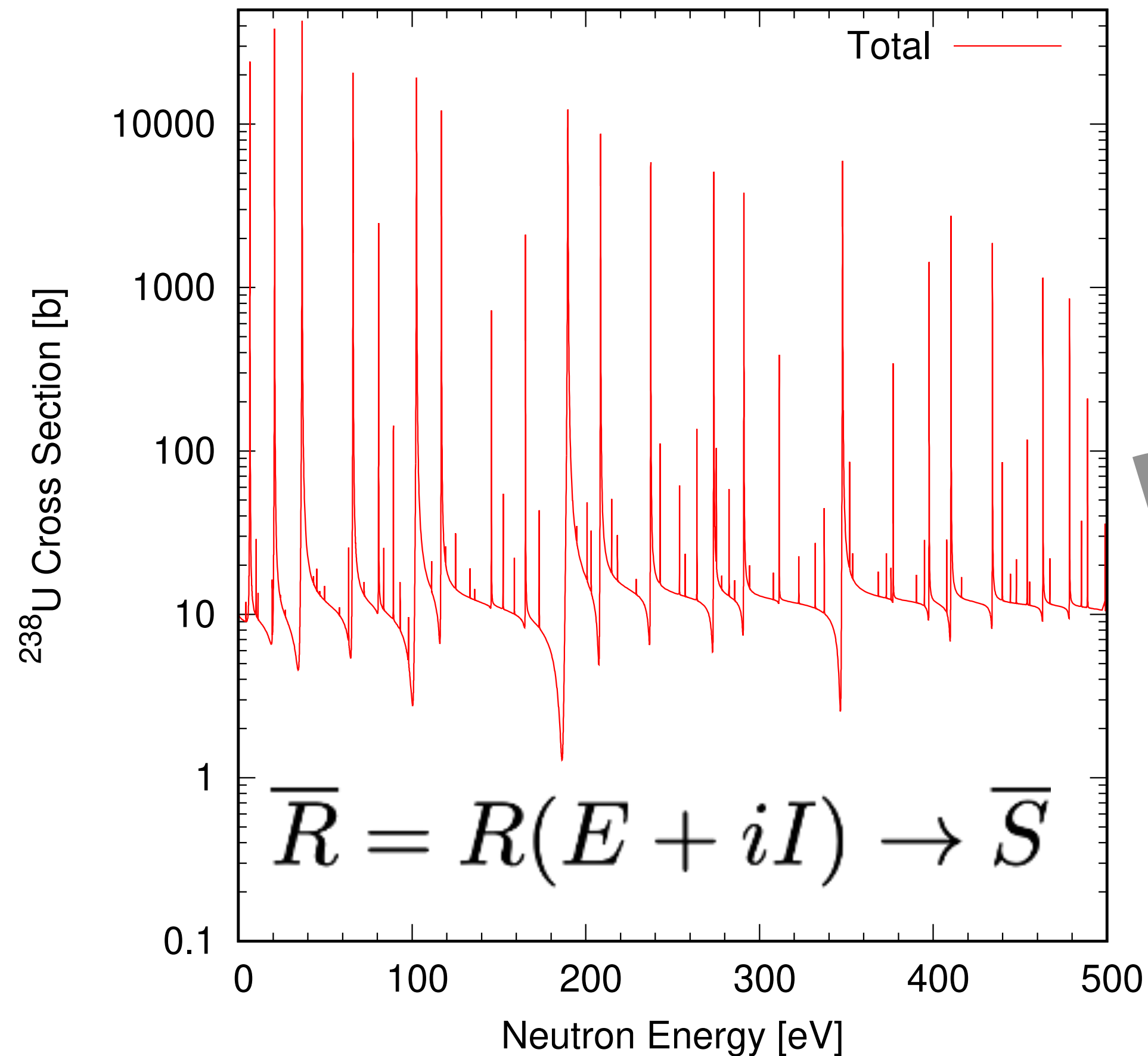
Inelastic Scattering off ^{208}Pb , No Adjustable Parameter

- Microscopic approach to calculate (n,n') c.s. for both discrete and continuum final states
 - Hartree-Fock BCS and Skyrme interaction
 - Non-Iterative Finite Amplitude Method to solve Quasi-particle Random Phase Approximation



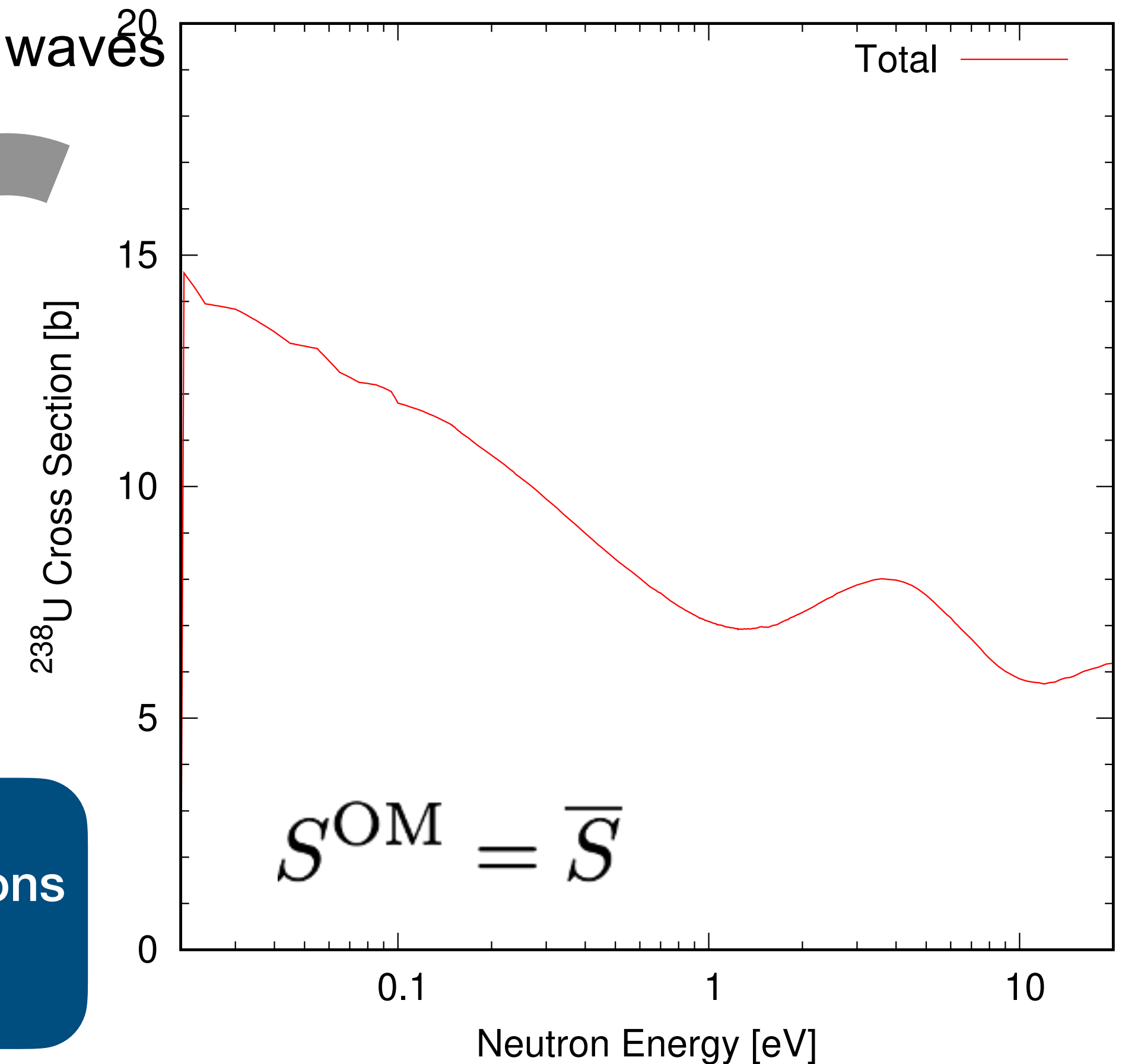
No deformation parameters used

Random Matrix Approach to Smoothly Connect 2 Regions



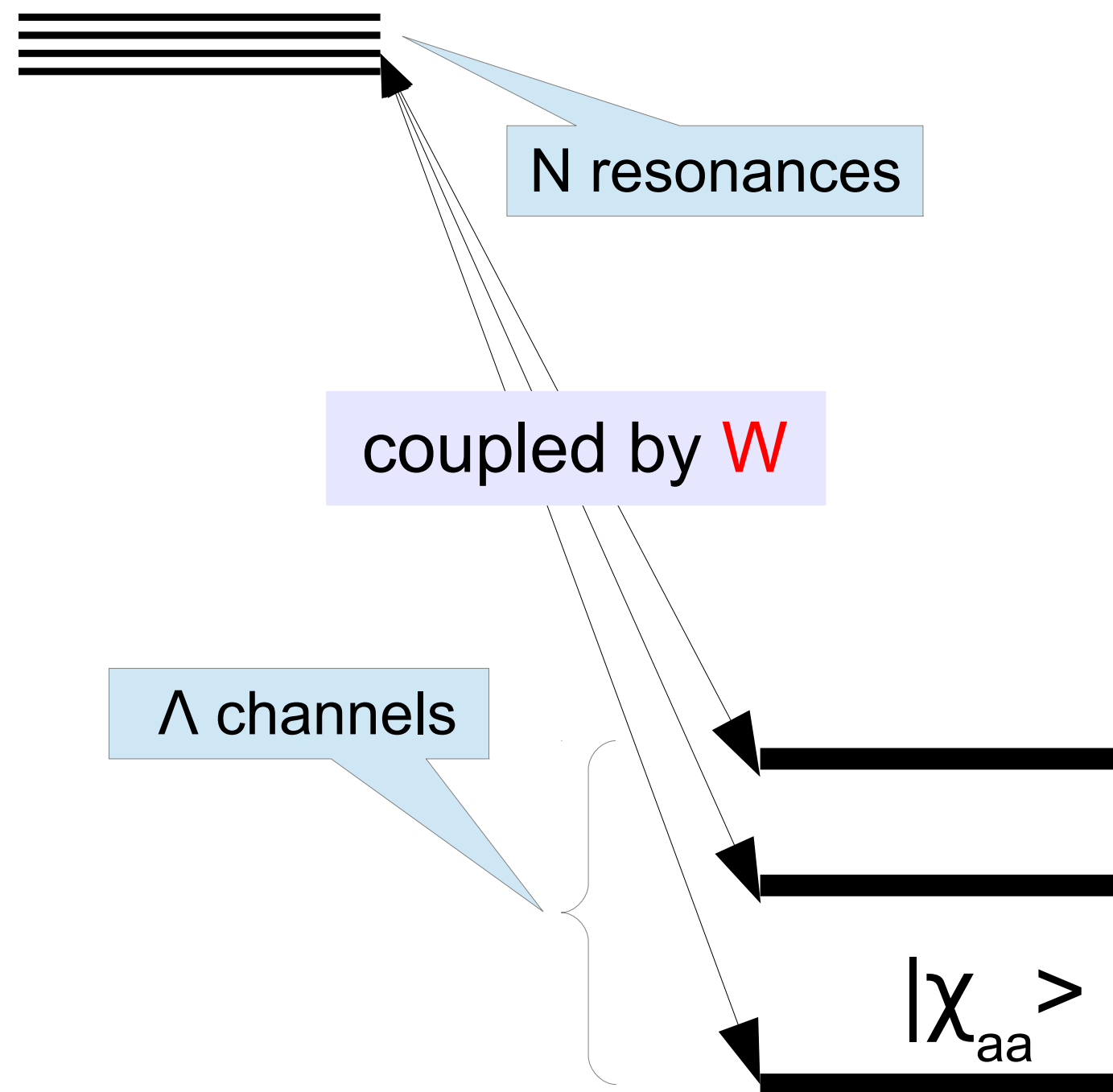
- **Transmission coefficients in both regions**
 - it guarantees smoothly connected cross sections
 - but limited to s-wave (and p-wave) only
- **Optical model**
 - for higher partial waves

$$T = 1 - |\bar{S}|^2$$



GOE model provides average cross sections as well as their realistic distribution

Stochastic S-matrix (K-matrix) based on GOE



GOE S-Matrix

$$S_{ab}^{(\text{GOE})} = \delta_{ab} - 2i\pi \sum_{\mu\nu} W_{a\mu} (D^{-1})_{\mu\nu} W_{\nu b}$$

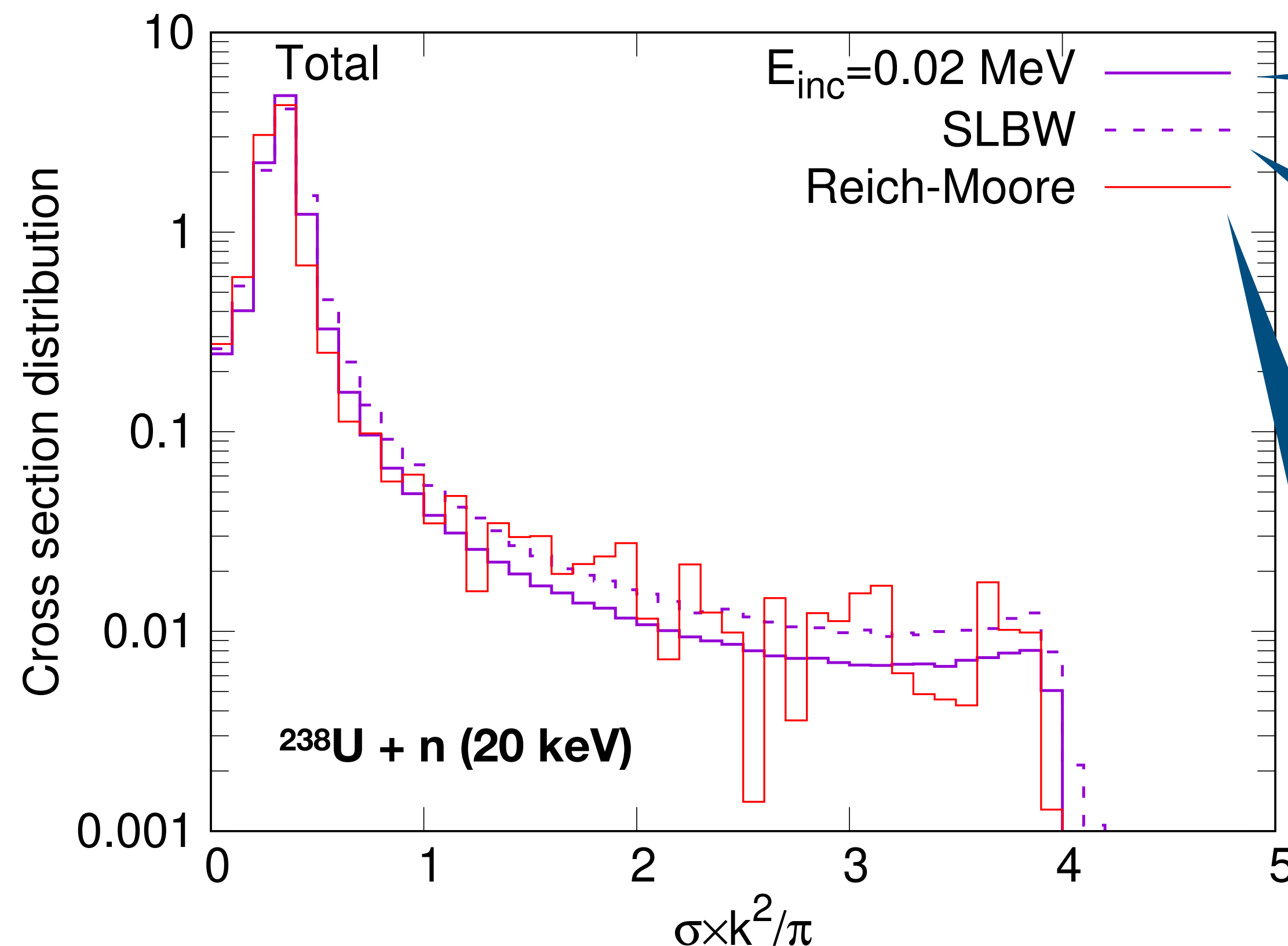
$$D_{\mu\nu} = E\delta_{\mu\nu} - H_{\mu\nu}^{(\text{GOE})} + i\pi \sum_c W_{\mu c} W_{c\nu}$$

$$\overline{H_{\mu\nu}^{(\text{GOE})} H_{\rho\sigma}^{(\text{GOE})}} = \frac{1}{N} (\delta_{\mu\rho} \delta_{\nu\sigma} + \delta_{\mu\sigma} \delta_{\nu\rho})$$

- Perform ensemble average $\overline{|S_{aa}|^2}$ by realization of $H^{(\text{GOE})}$
- T_a given by eigenvalues of WW^T
- Model parameters are T_a (transmission), N (number of resonance), and Λ (channel)

GOE S-Matrix Model in Cross Section Space

- Transform GOE S-matrix into actual energy/cross section space
 - Provides smooth connection between resolved resonance and Hauser-Feshbach regions - URR
 - New method to produce probability table in URR can be proposed



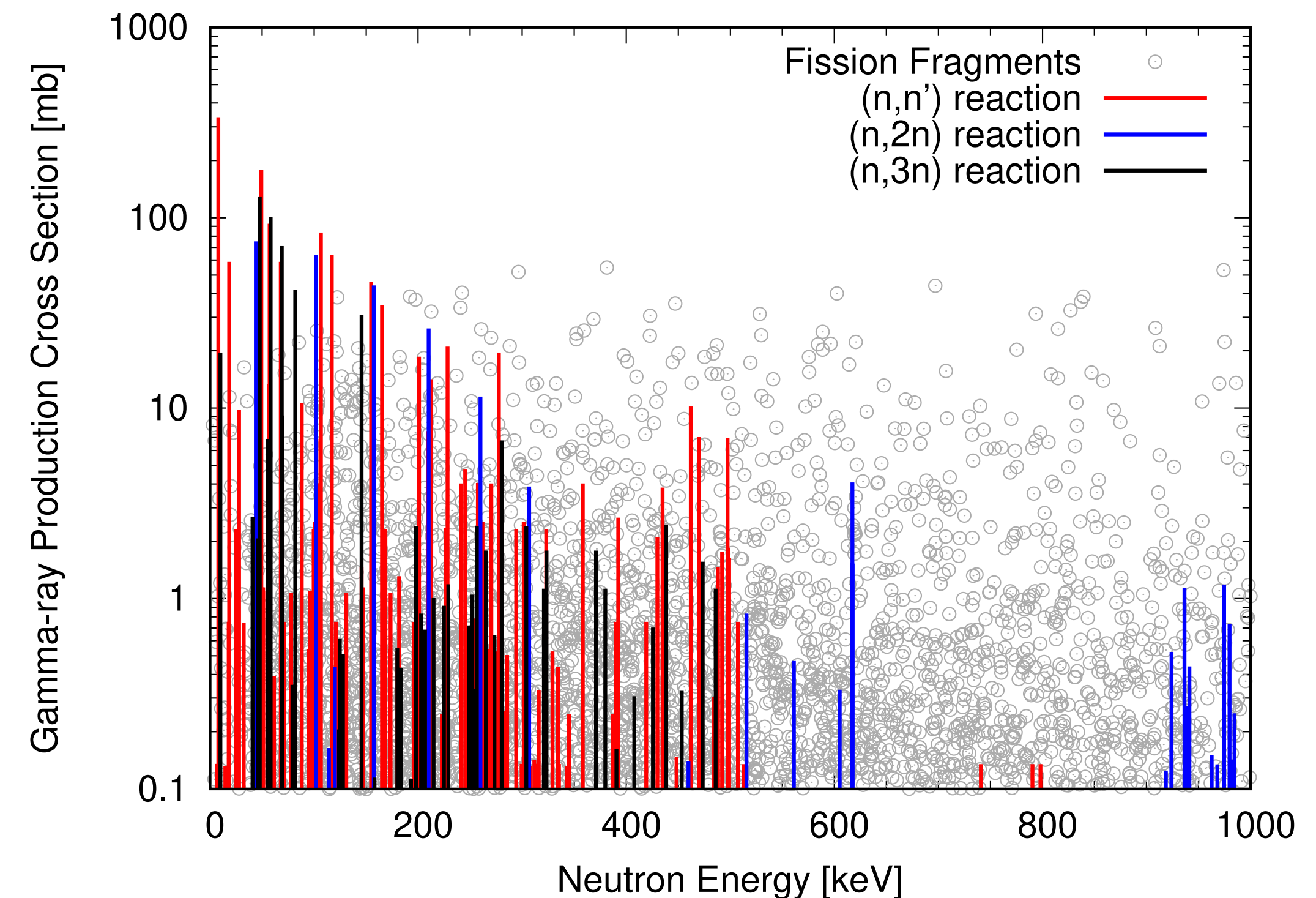
GOE-Smatrix uses optical model transmission coefficients, but no $\langle \Gamma \rangle$ nor D

URR: assuming distributions of $\langle \Gamma \rangle$ and D , cross section distribution is calculated by Monte Carlo sampling

RRR: Reich-Moore R-matrix represents experimentally observed cross sections

Test of Evaluated FPY Data at Higher Energies

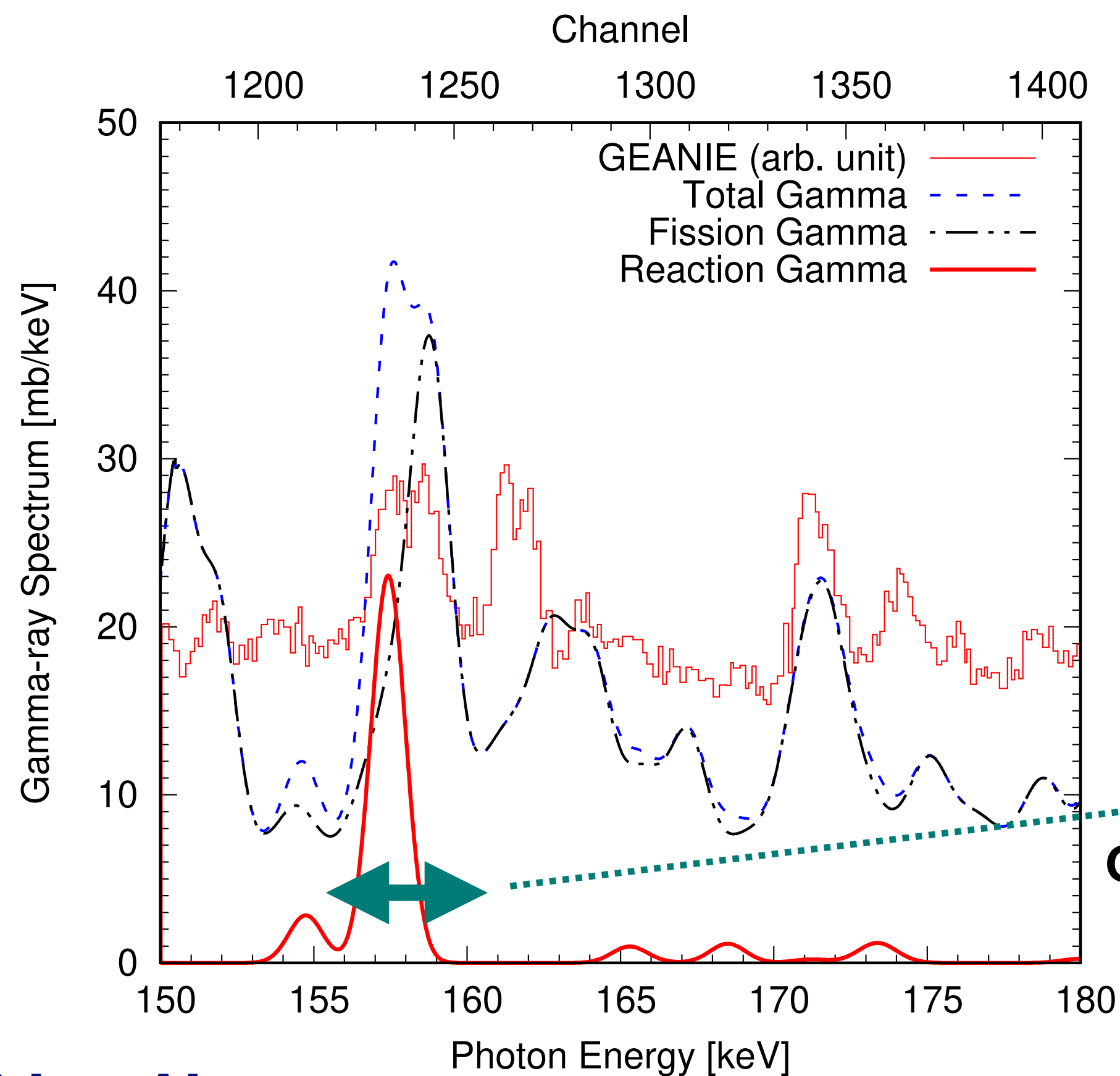
- **Recent measurements of neutron inelastic scattering at Geel**
 - (n,n') gamma-ray production for actinide measured, but didn't agree with model calculations
 - Probably prompt fission gamma rays were measured instead
- **Recent progress on fission modeling at LANL**
 - BeoH produces more than 10,000 gamma lines per fission
- **Revisiting GEANIE $^{239}\text{Pu}(n,xn)$ data reported in 2002**
 - Calculate gammas by (n,xn) and fission separately
 - GEANIE data could have high fission background



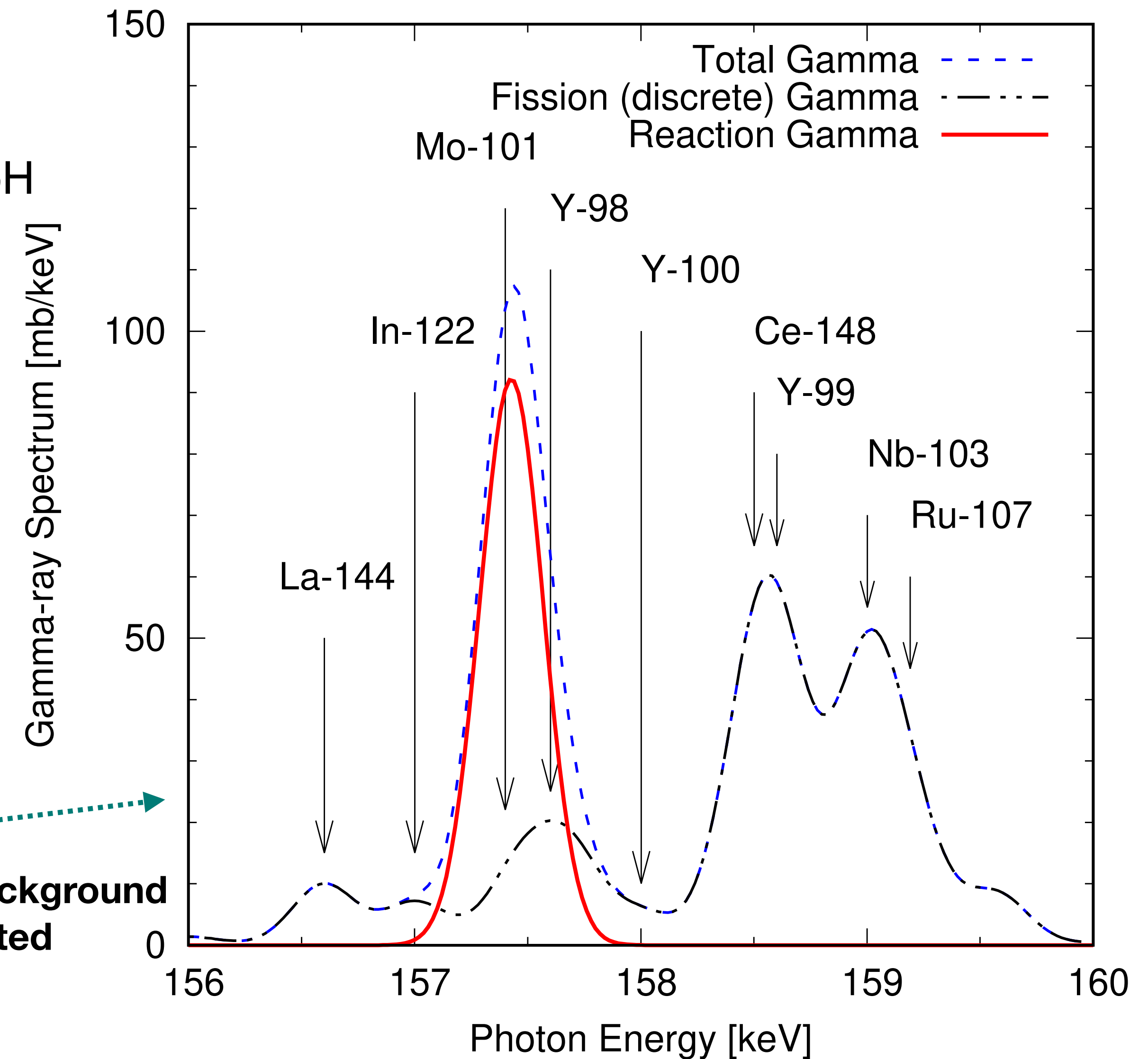
Fission Gamma Ray Background

- **Gamma production calculation**

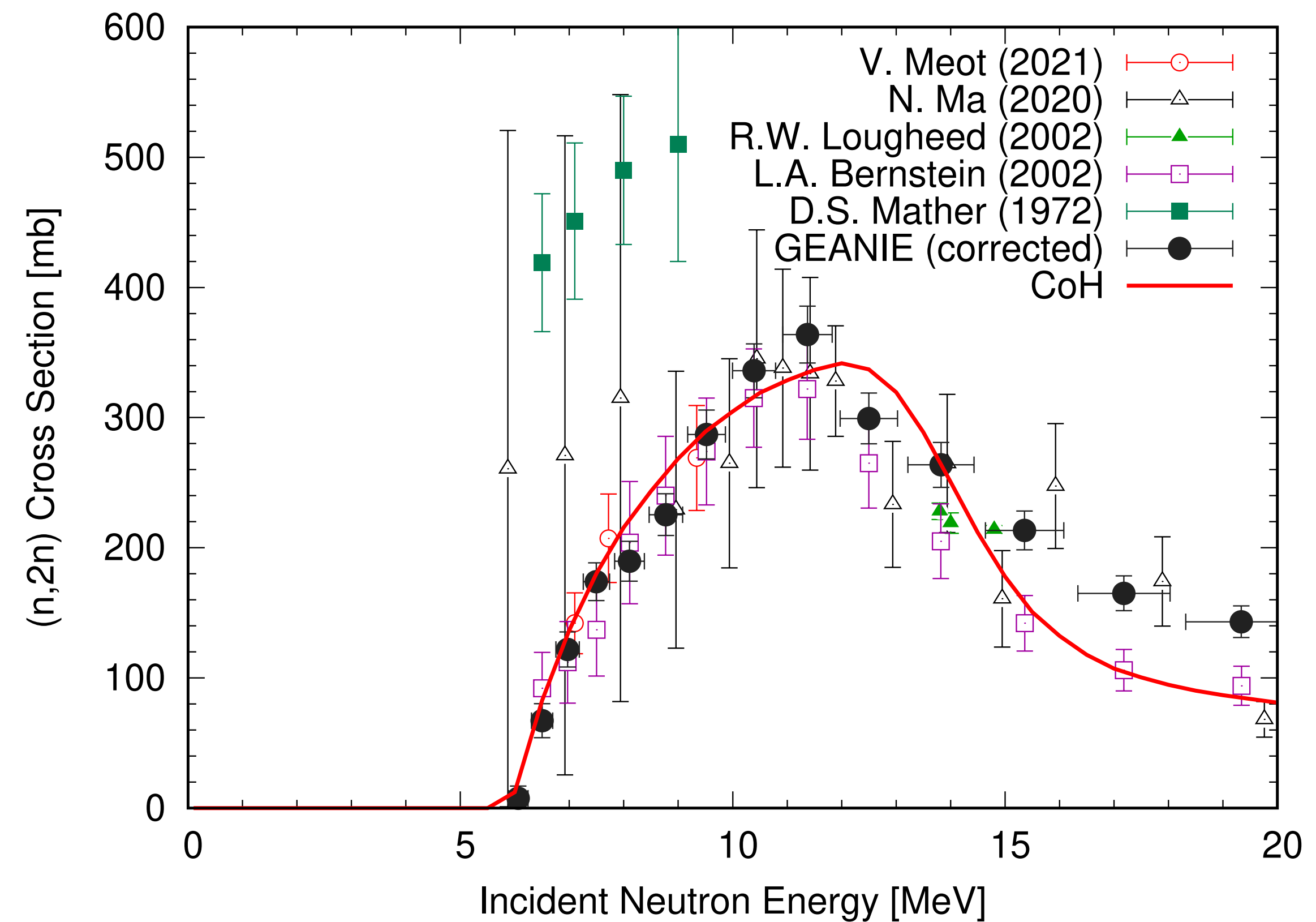
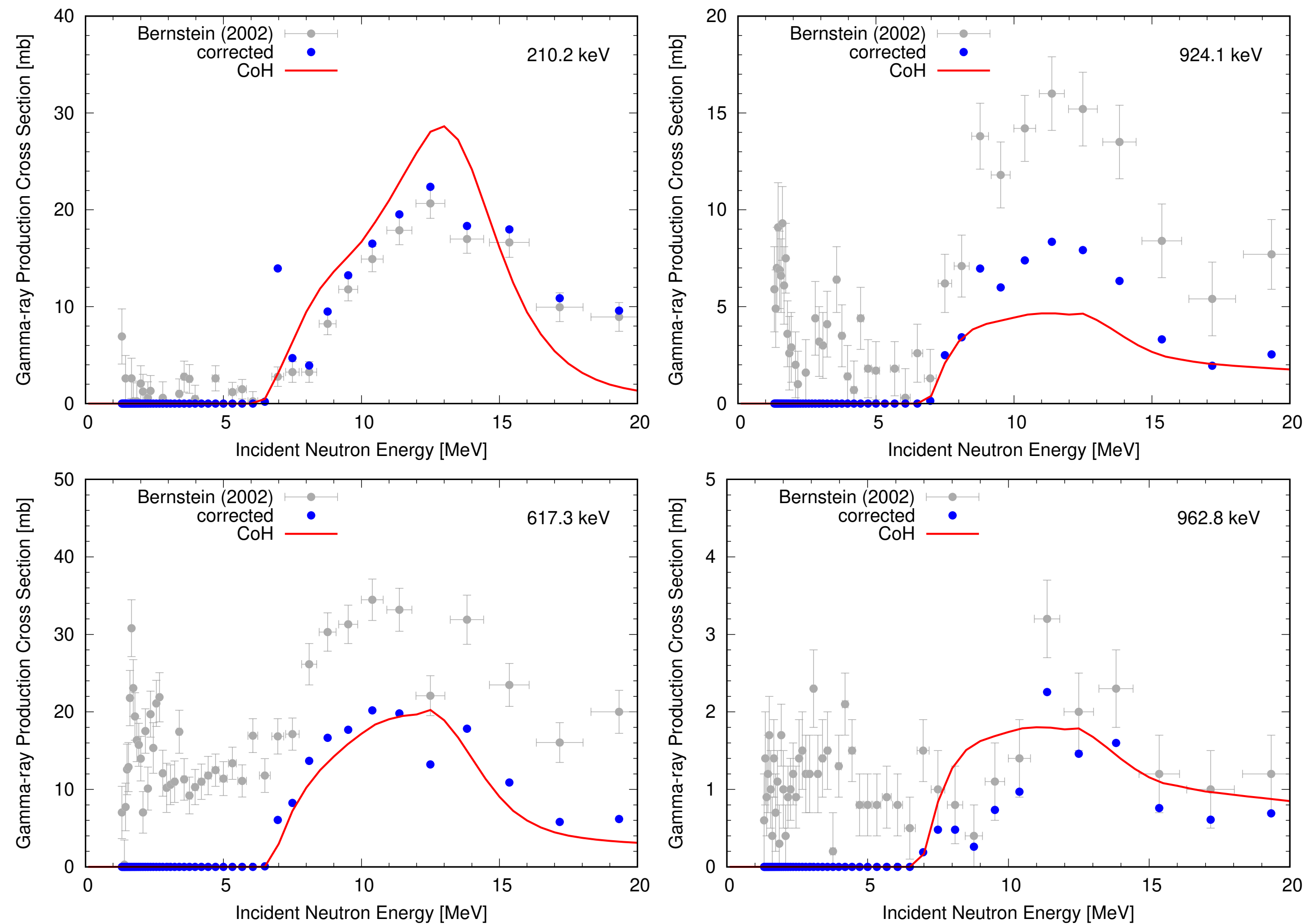
- (n,xn) reactions by CoH₃
- gamma-rays produce by fission fragments by BeoH



Continuum background
subtracted

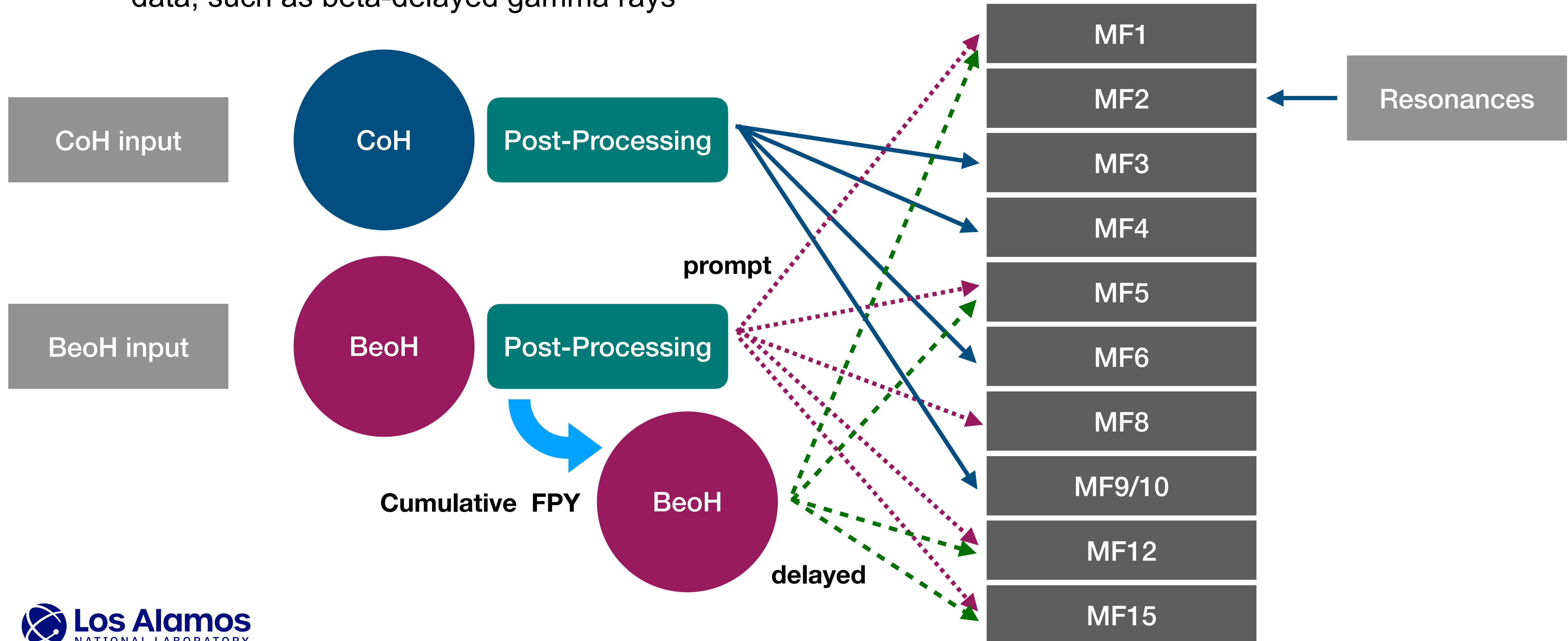


$^{239}\text{Pu}(n,2n)$ Cross Section Inferred by GEANIE/CoH



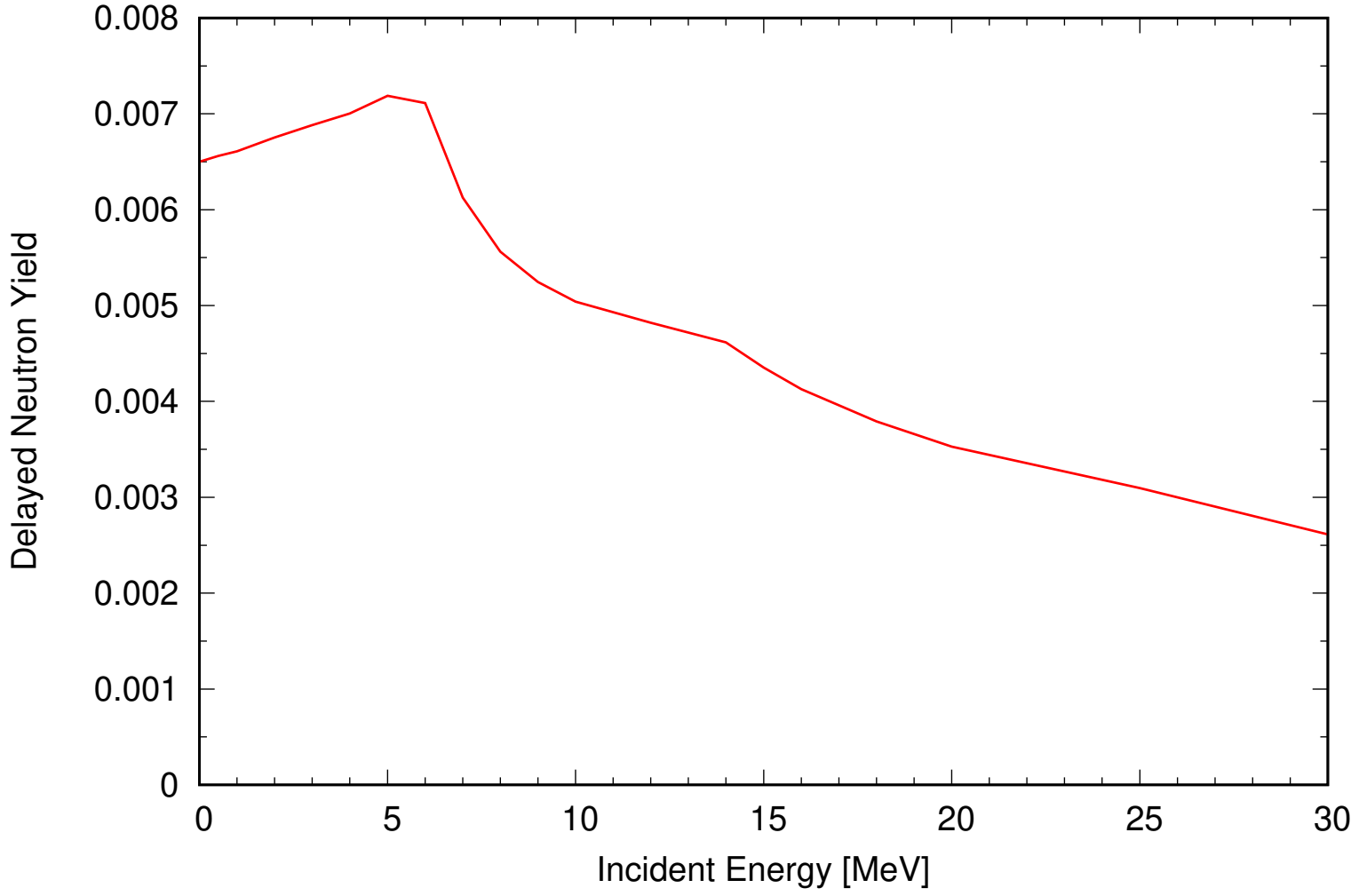
Los Alamos CoH₃-based Evaluation: LACE

- **Production of all nuclear data using the CoH₃ and BeoH codes (with external resonance files)**
 - Facilitate to produce evaluated nuclear data files automatically, and provide not-so-commonly used data, such as beta-delayed gamma rays

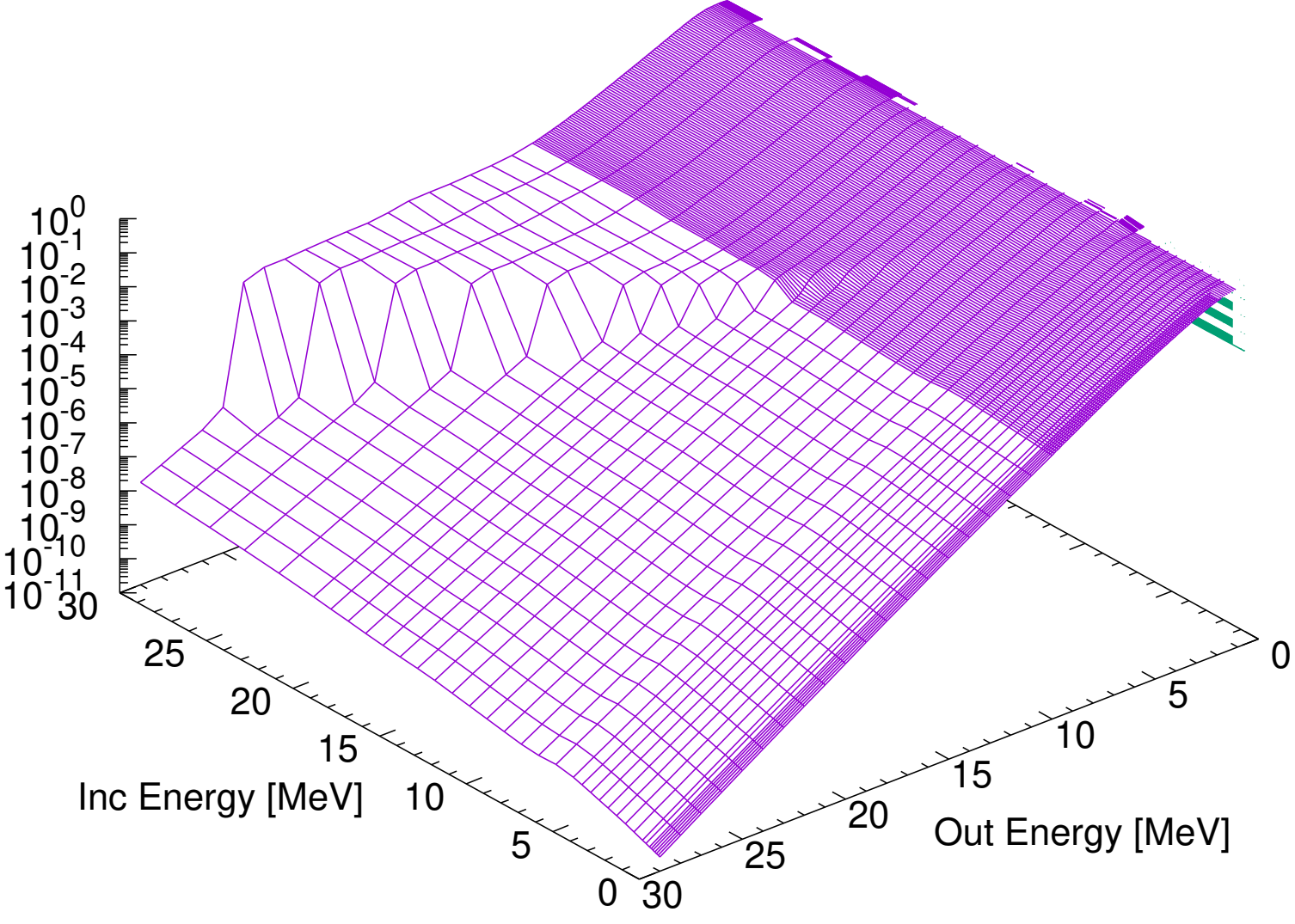
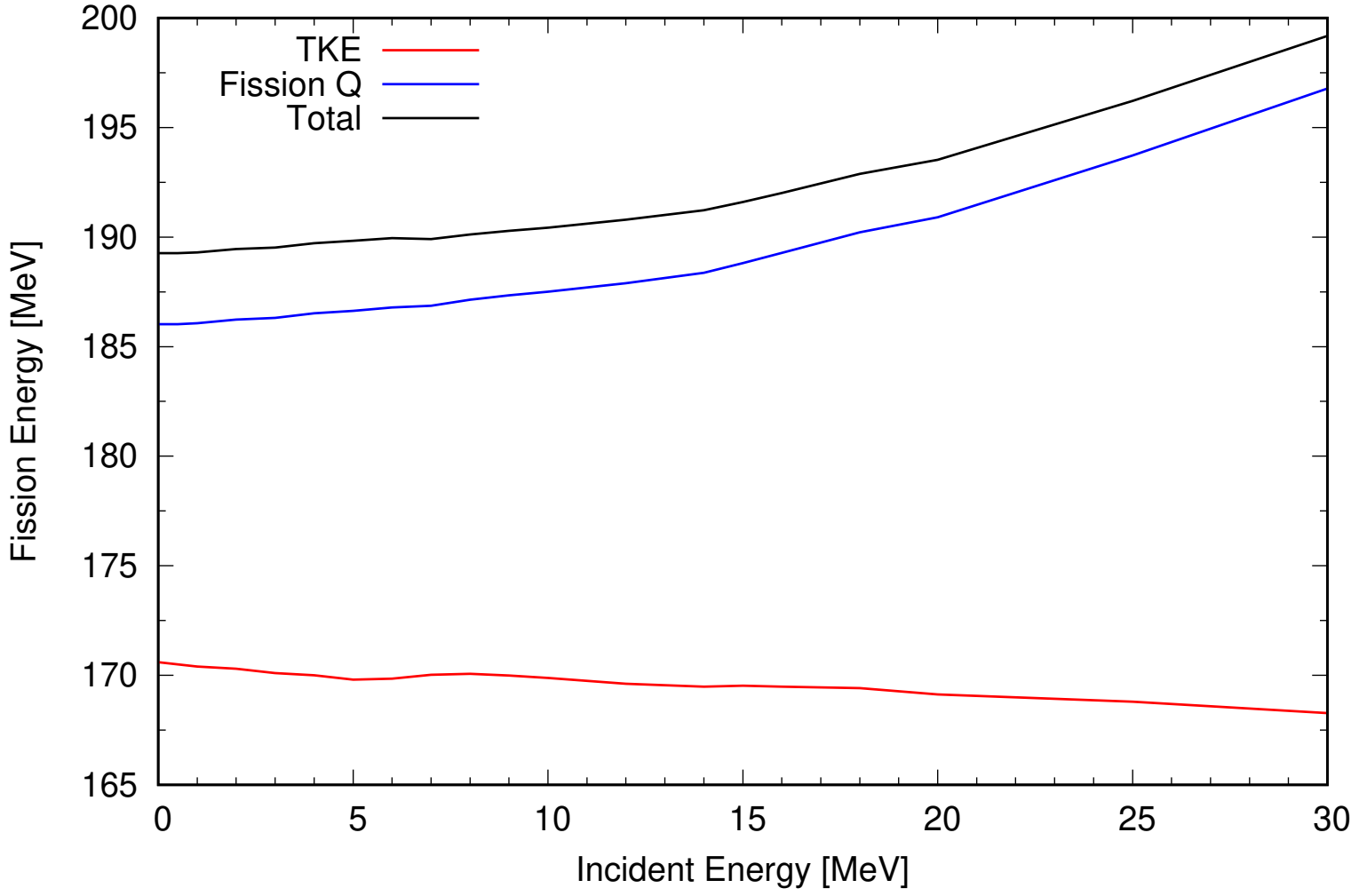


LACE Example ^{233}U Data, Fission Energy, Spectrum and Multiplicity

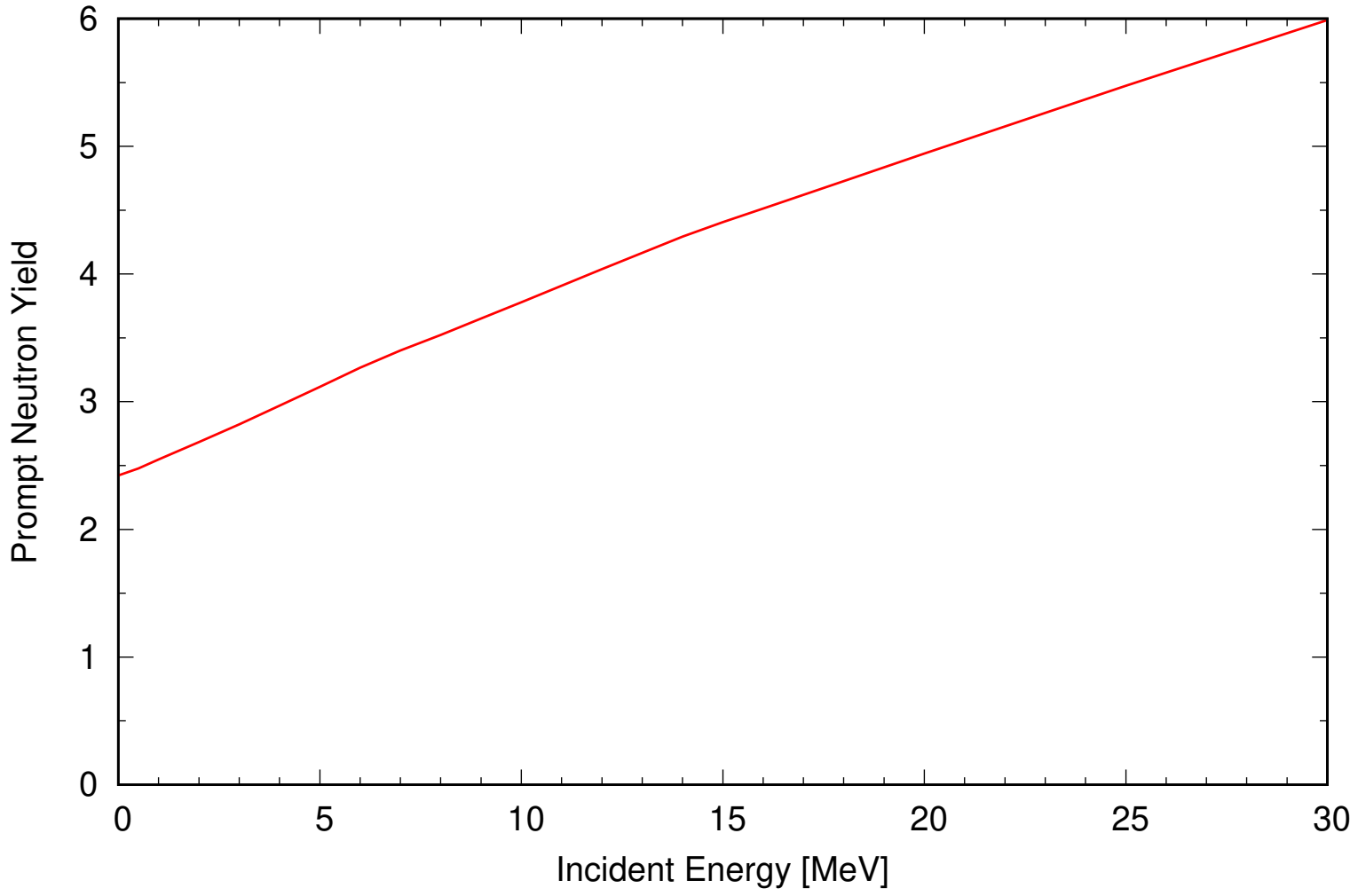
MF1 MT455



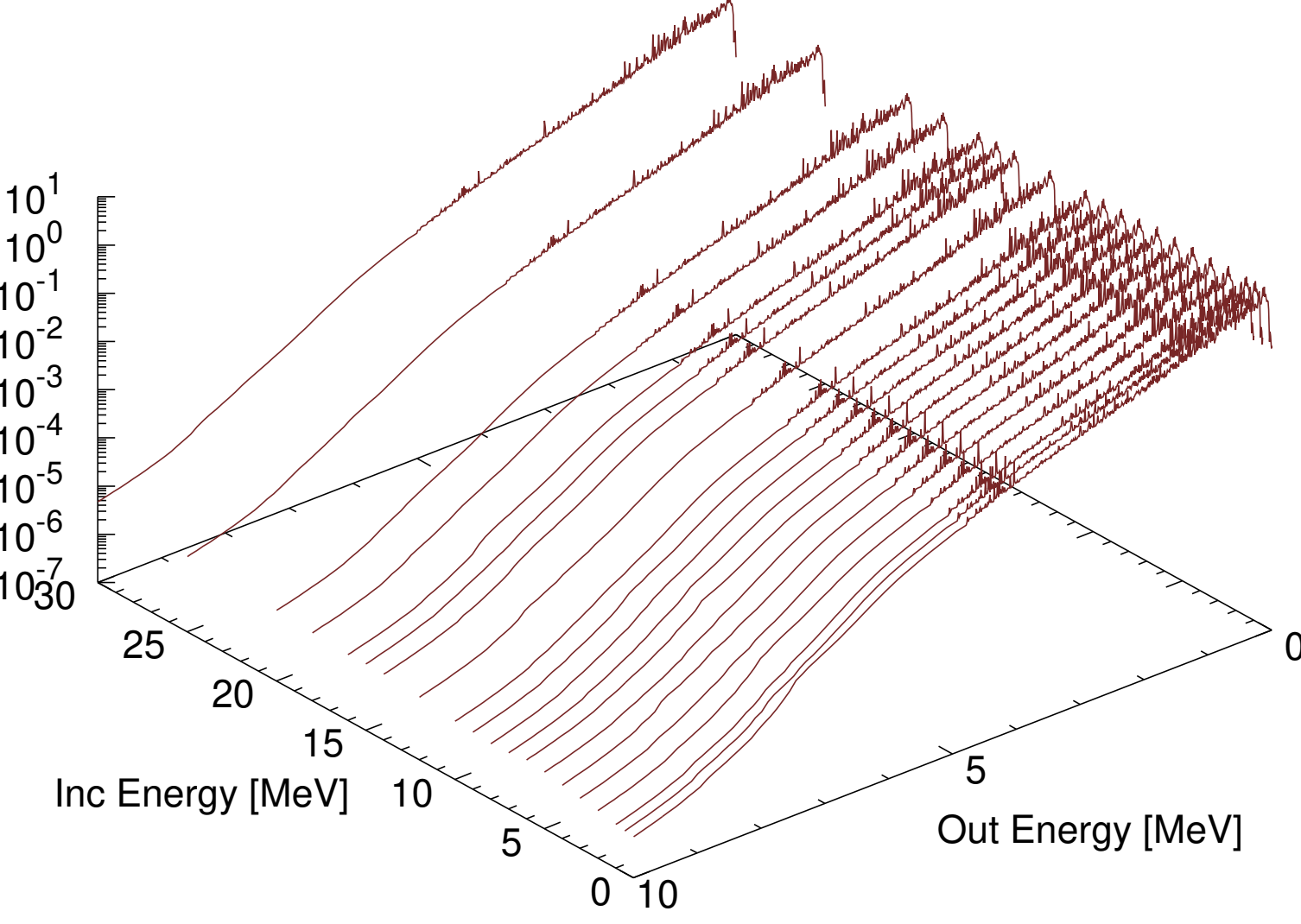
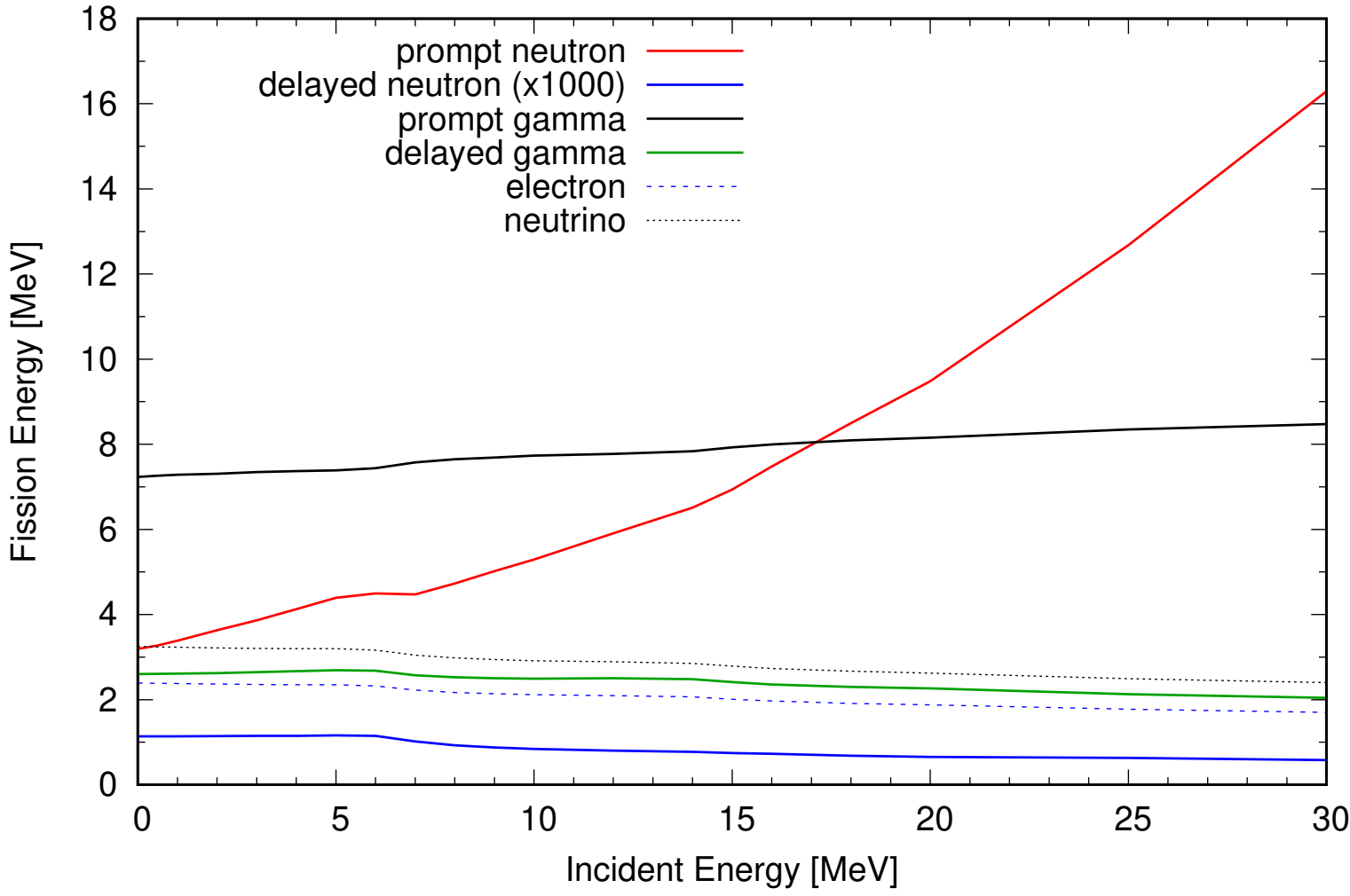
MF1 MT458



MF1 MT456

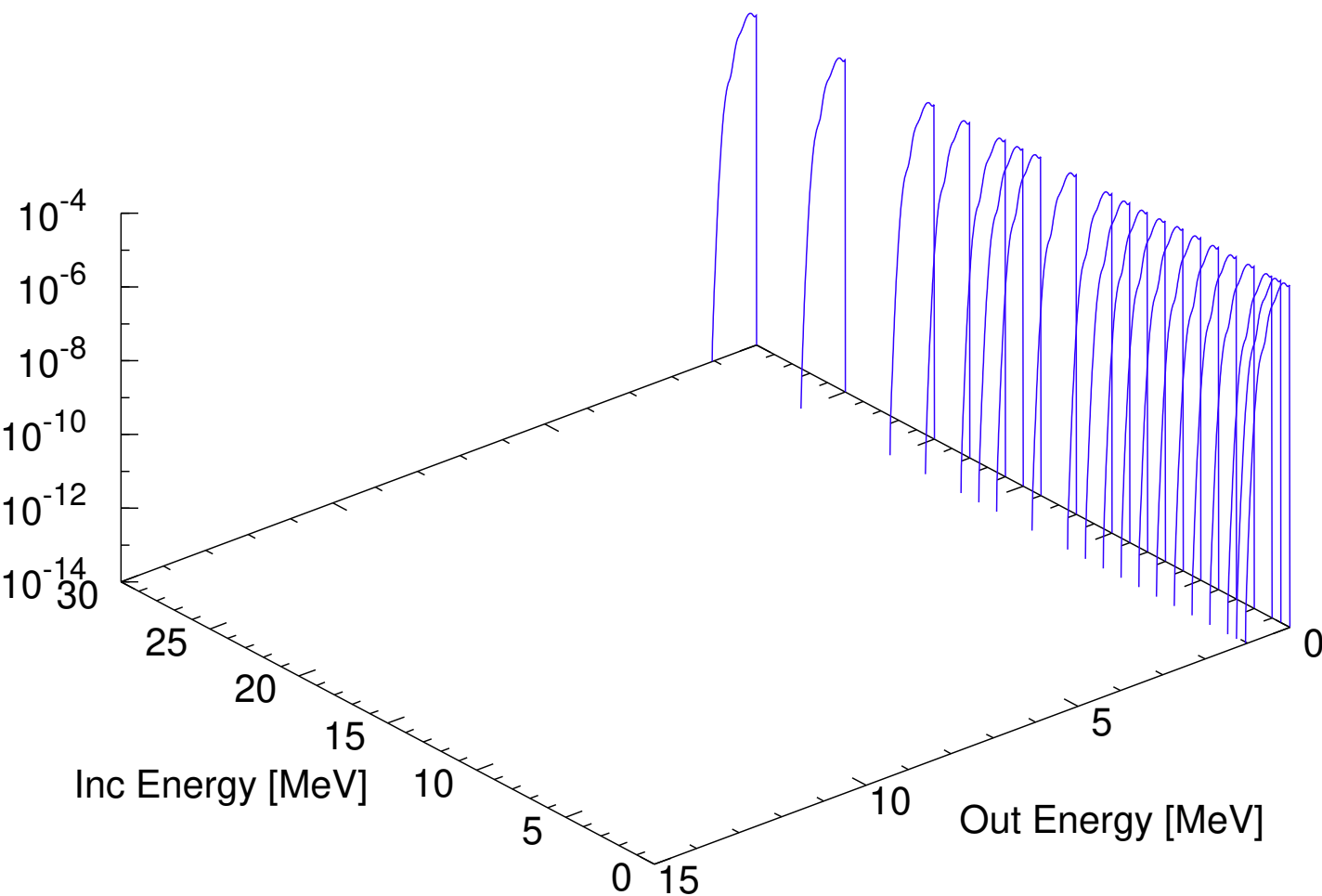


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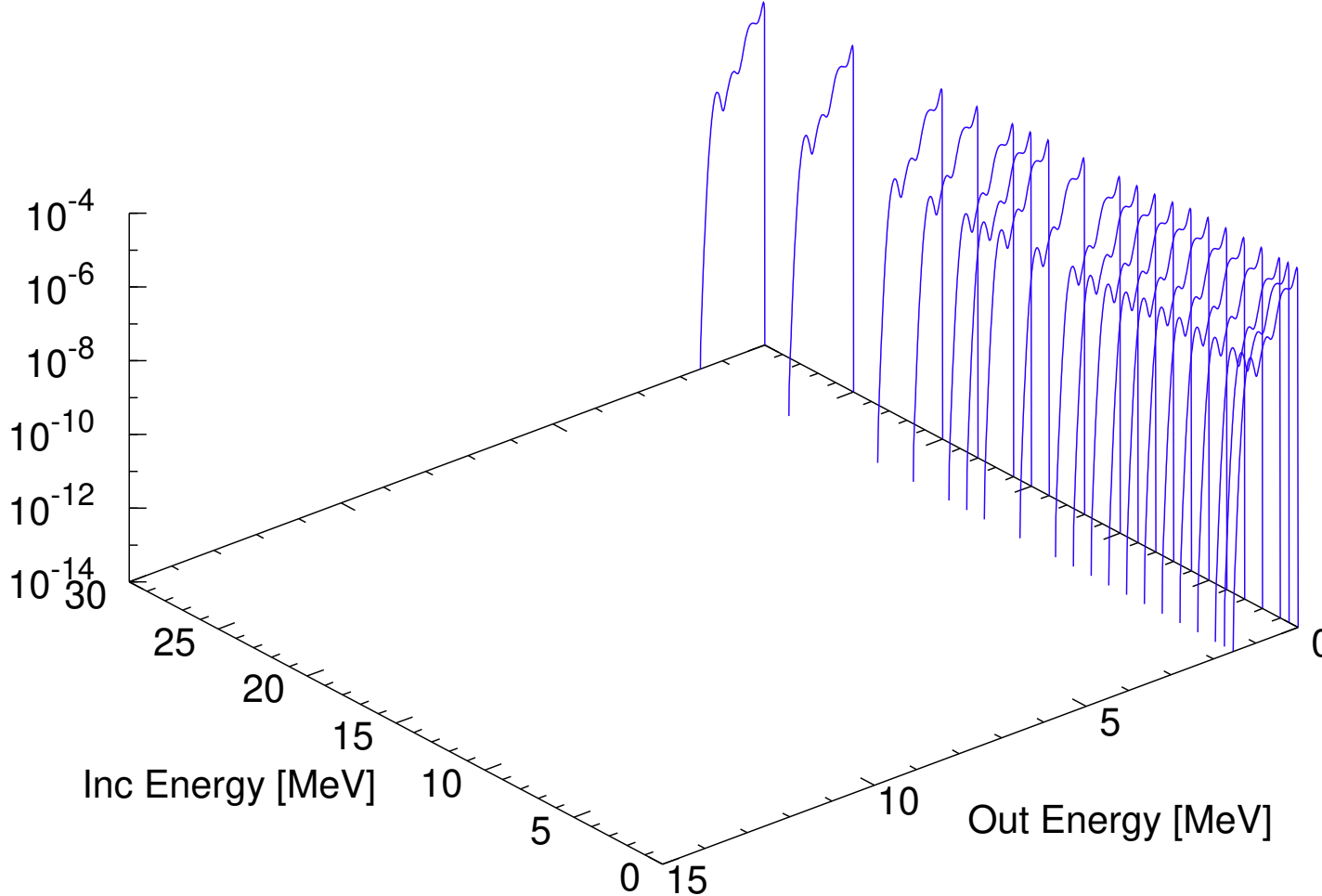


LACE Example ^{233}U Data, Delayed Neutron Energy Spectra

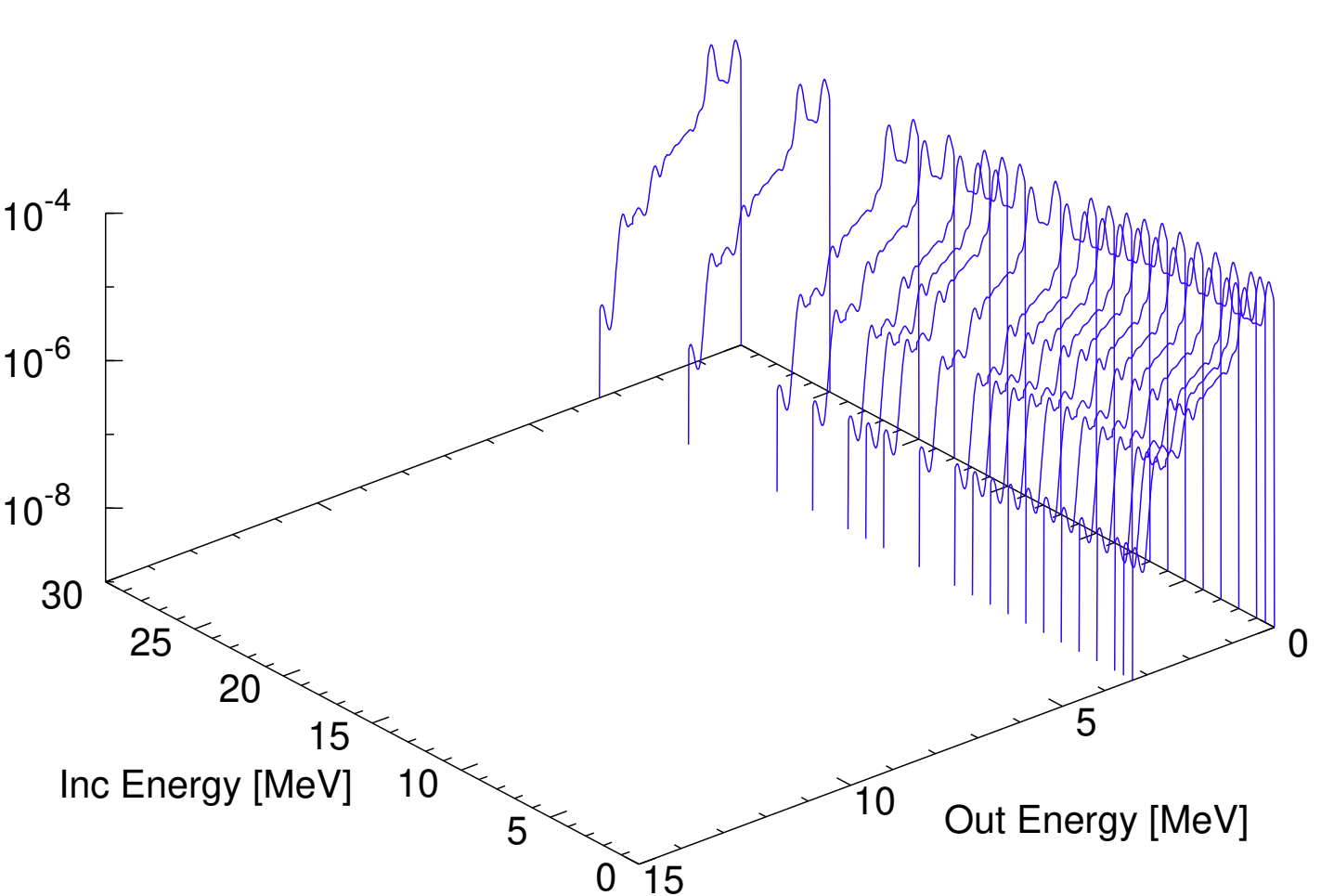
MF5 MT455 Group 1



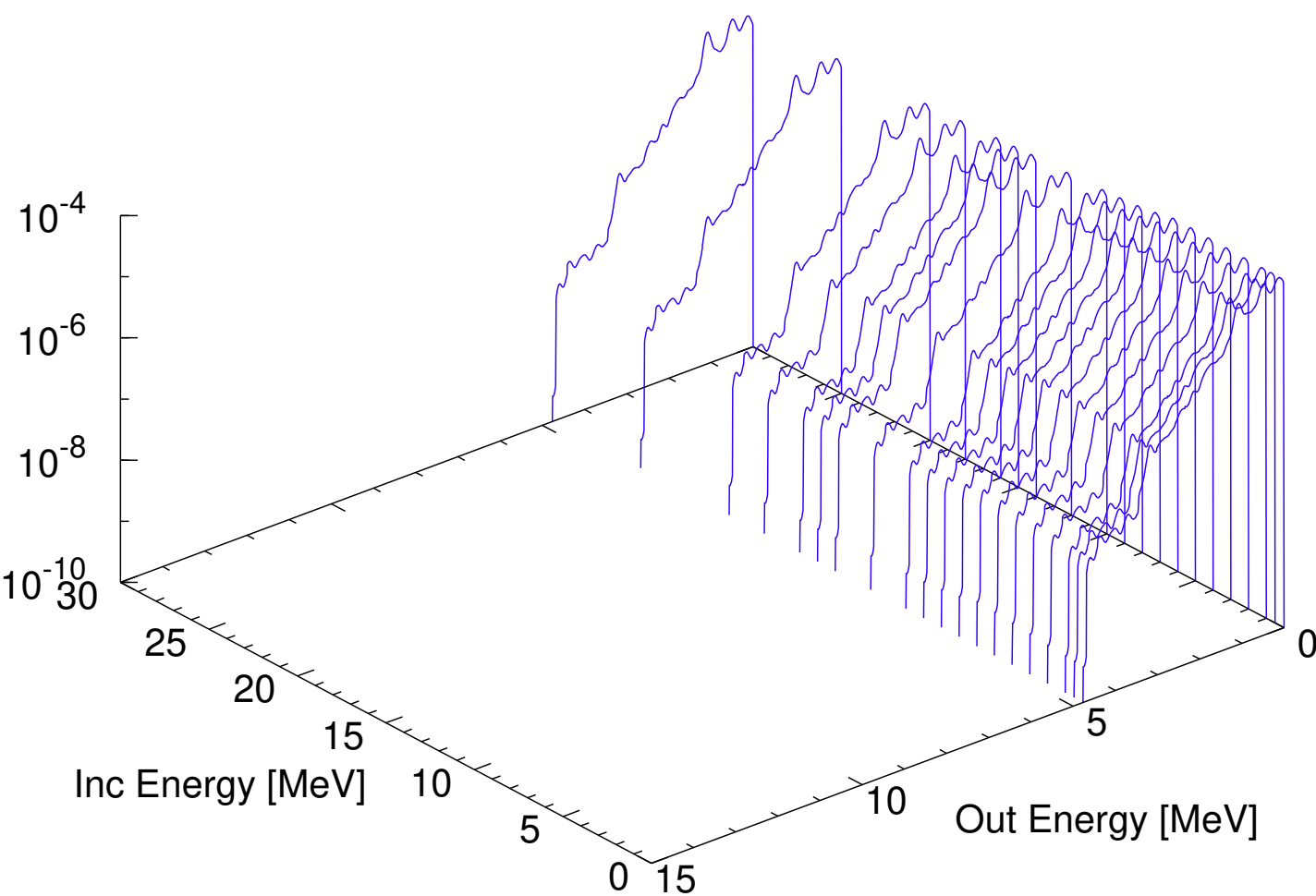
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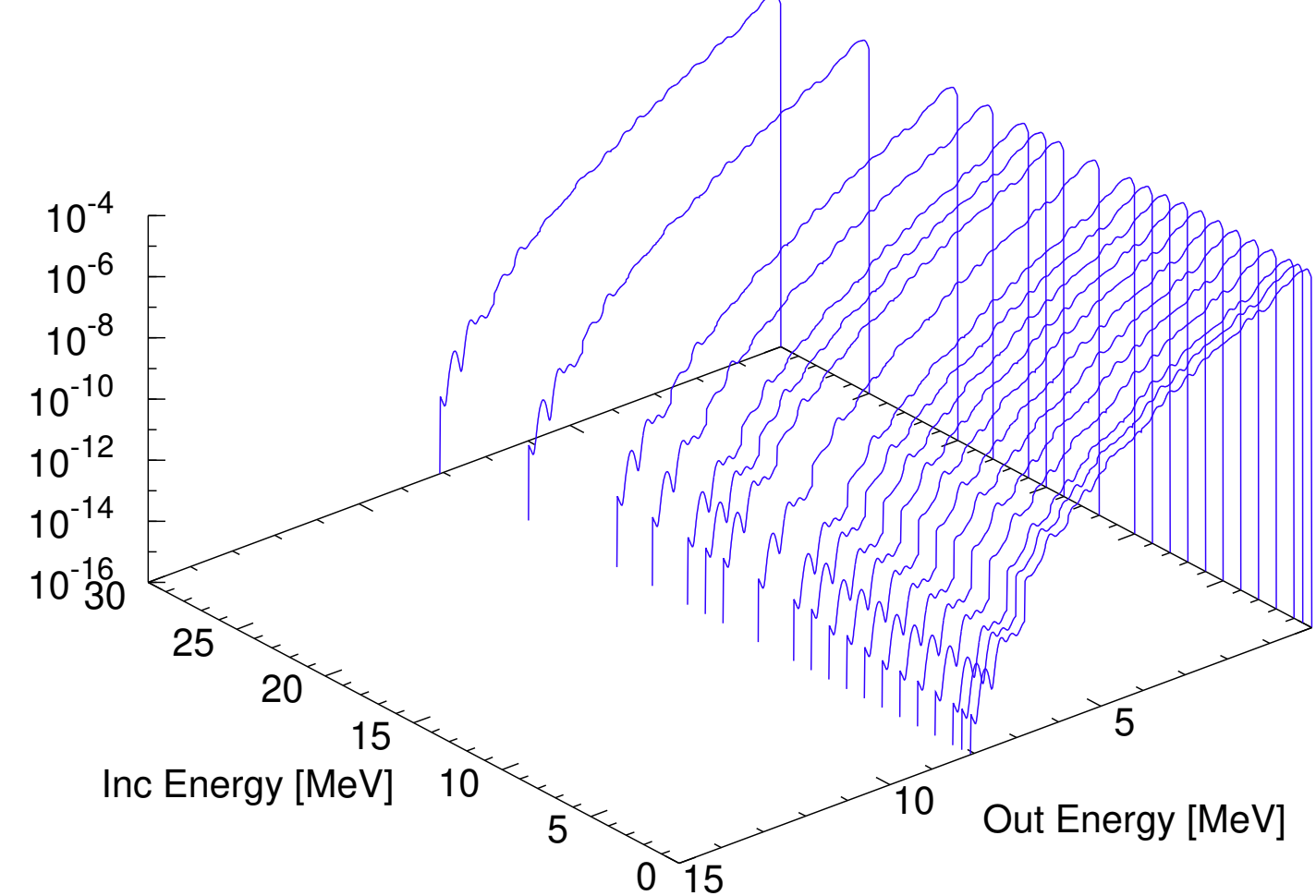
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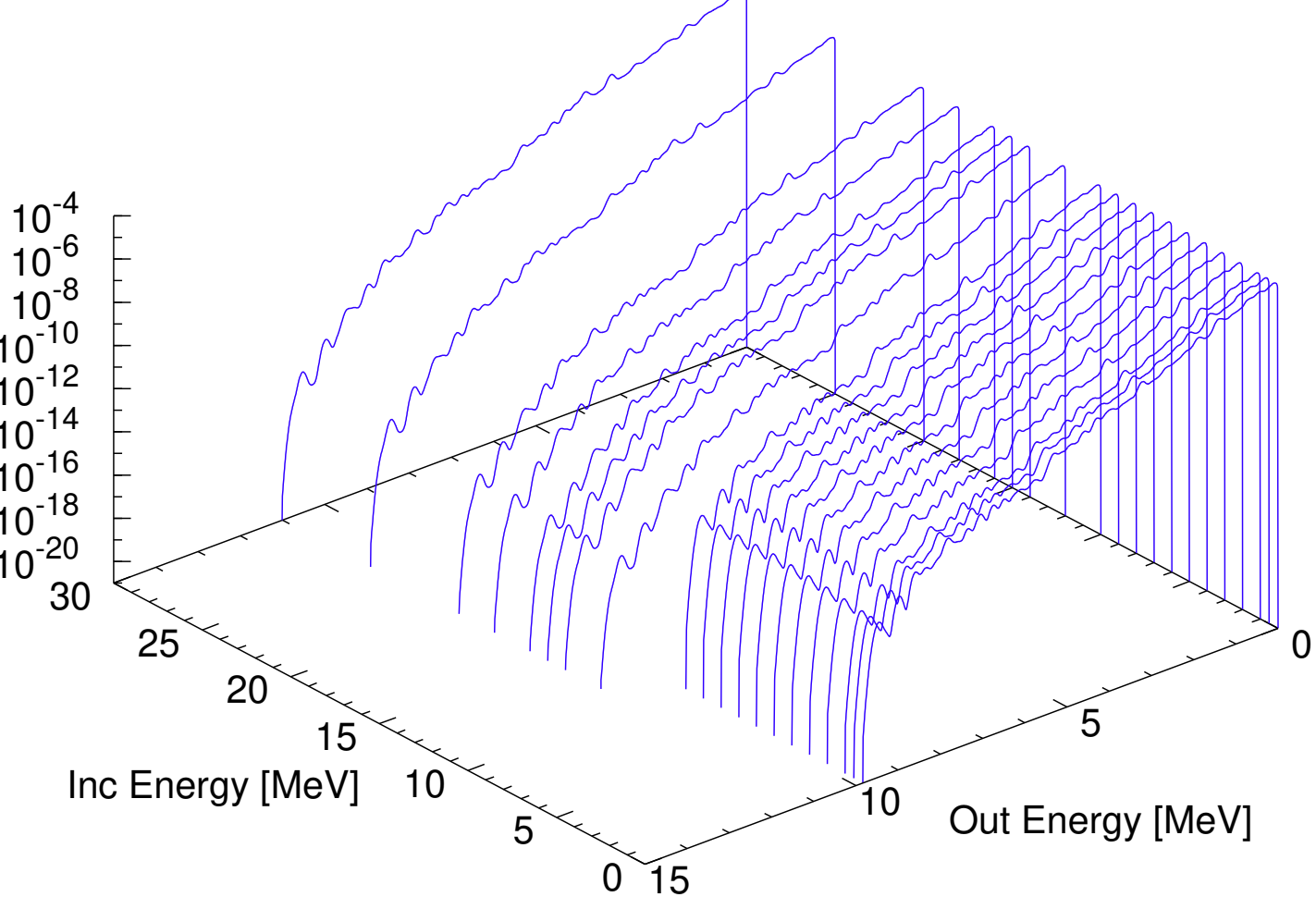
MF5 MT455 Group 4



MF5 MT455 Group 5

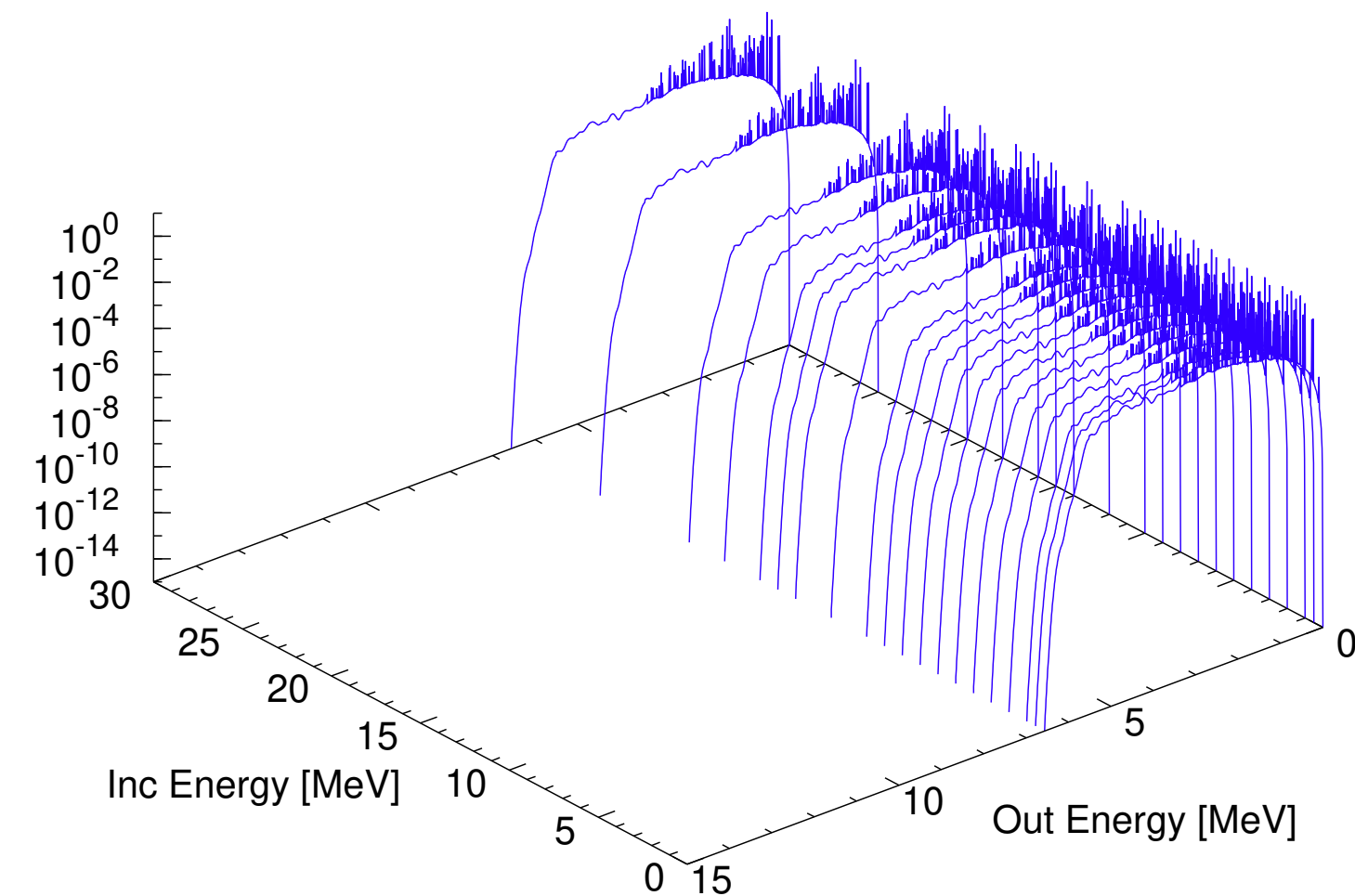


MF5 MT455 Group 6

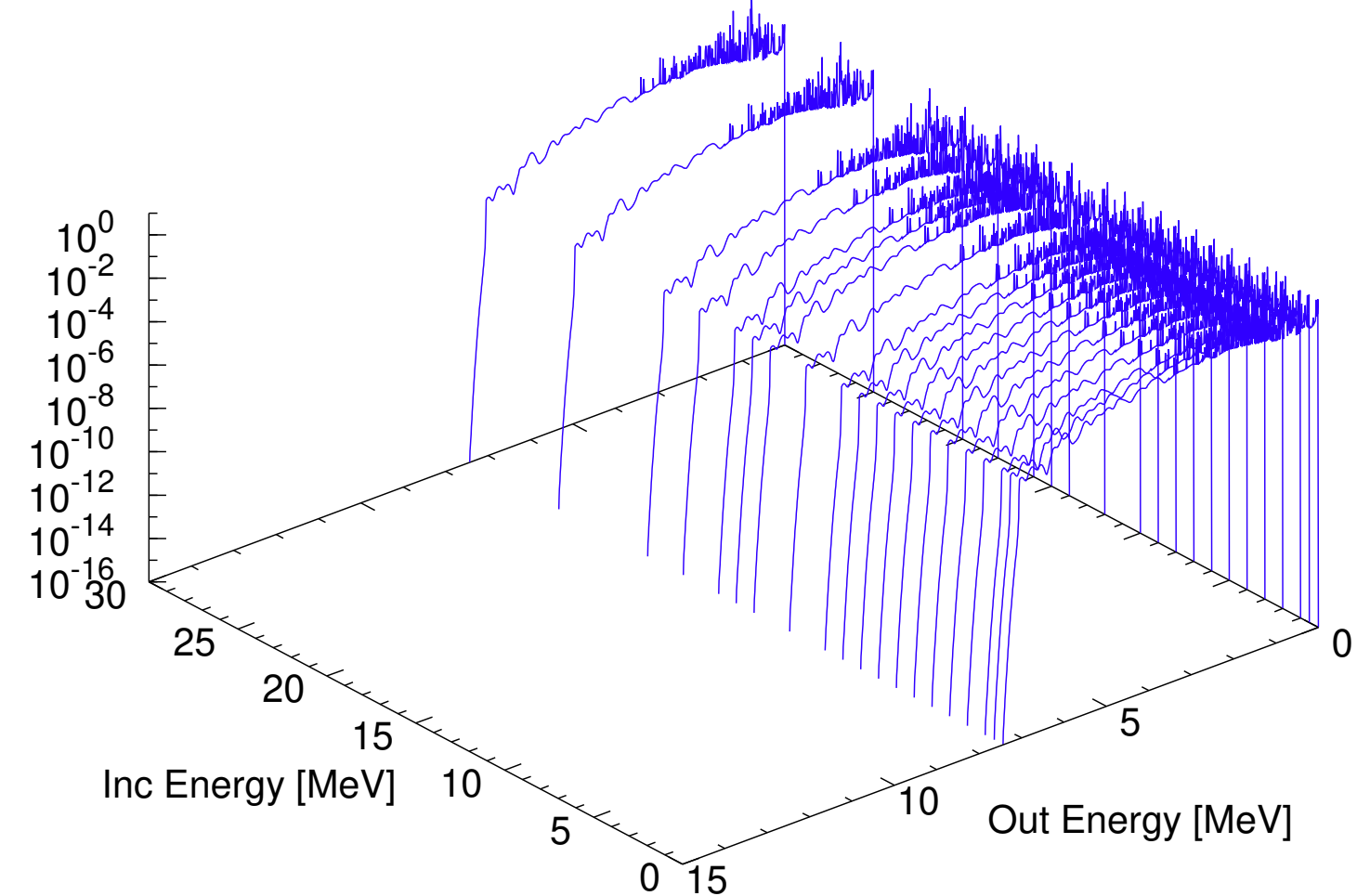


LACE Example ^{233}U Data, Delayed Photon Energy Spectra

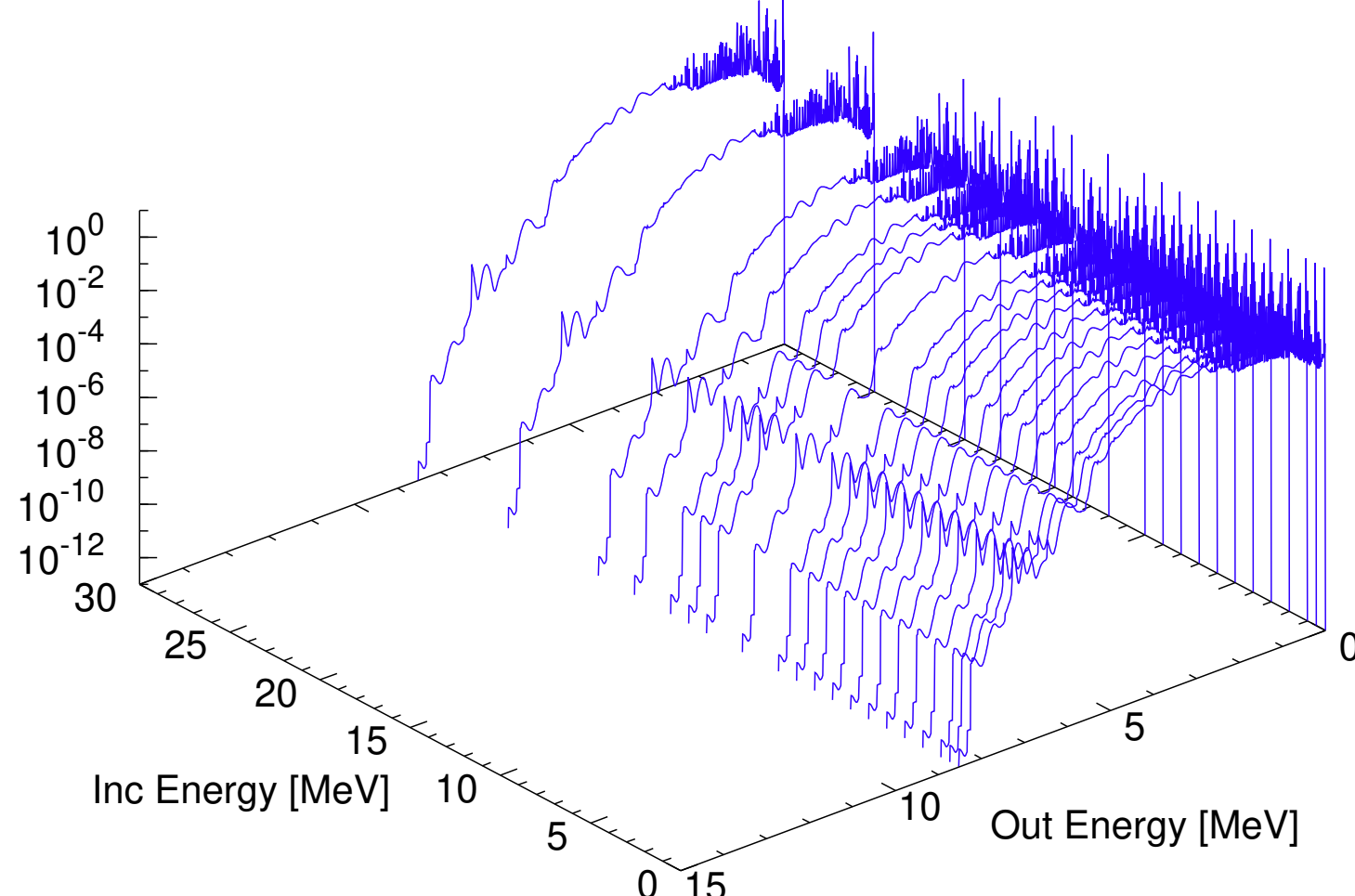
MF15 MT460 Group 1



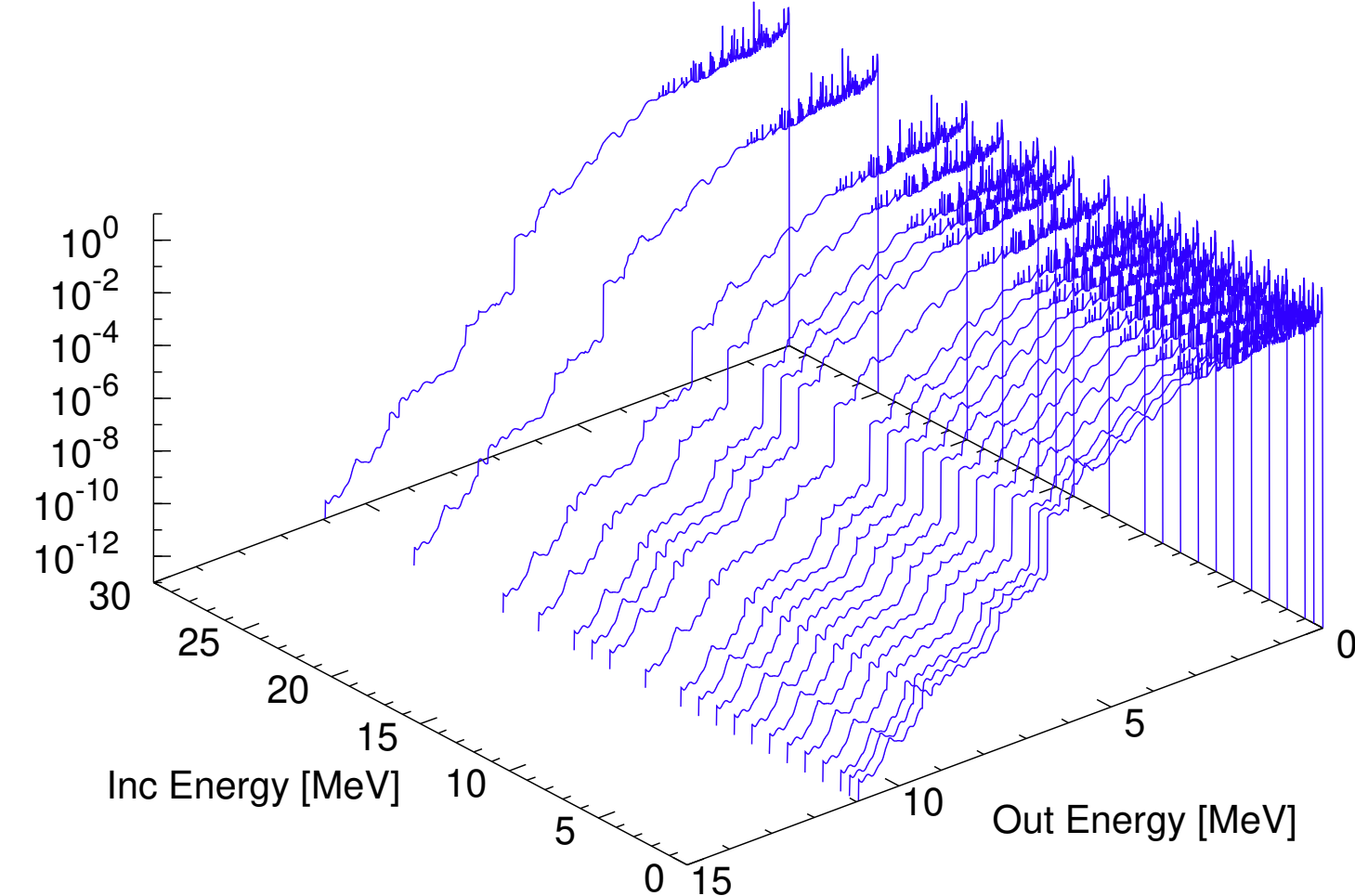
MF15 MT460 Group 2



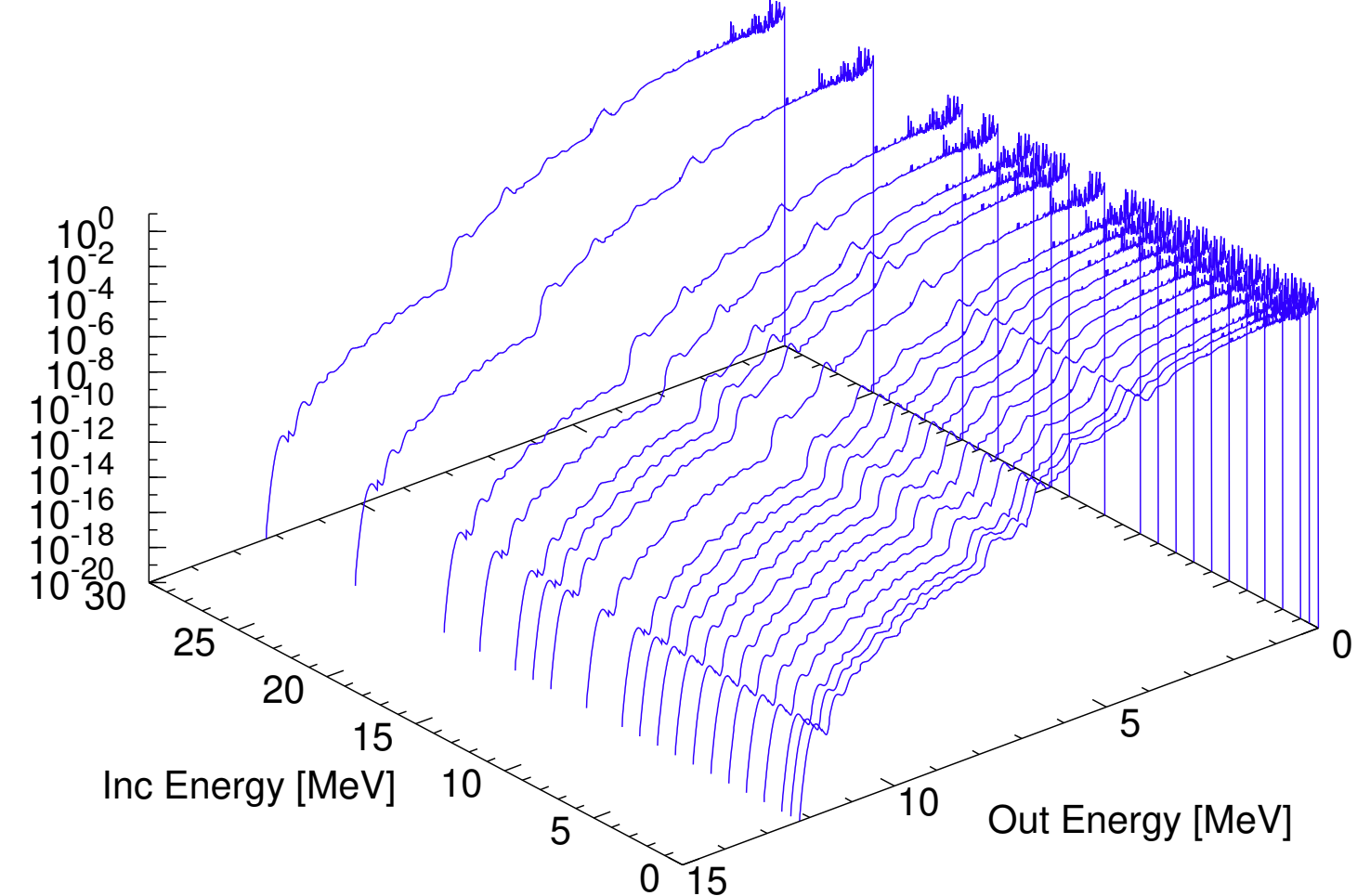
MF15 MT460 Group 3



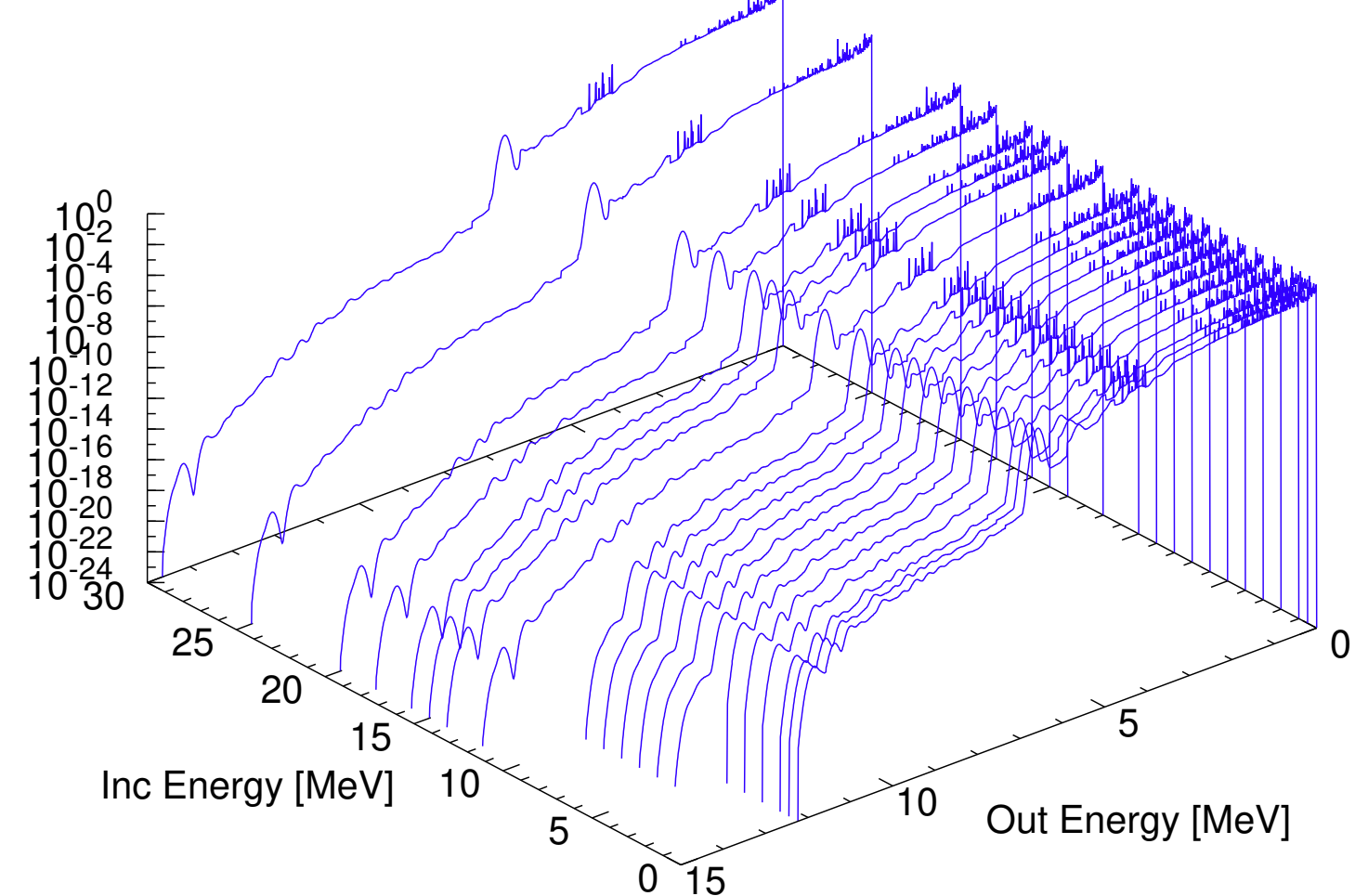
MF15 MT460 Group 4



MF15 MT460 Group 5



MF15 MT460 Group 6



Summary

- **LANL nuclear reaction theory efforts in this FY includes:**
 - Microscopic calculations of neutron inelastic scattering for both direct and pre-equilibrium
 - GOE S-matrix model in realistic energy/cross section space to study URR
 - LACE (Los Alamos CoH-based Evaluation) Library (or framework)
 - Re-visited GEANIE $^{239}\text{Pu}(n,xn)$ data, and subtracted gamma rays produced by fission fragments
- **Perspective**
 - New pre-equilibrium model can be proposed
 - impact on 14 MeV neutron induced reaction for fusion reactor applications
 - pre-equilibrium process for photo-nuclear reaction in progress
 - More accurate treatment of URR in Monte Carlo transport simulations
 - new method to produce probability table
 - Extension of LACE to model calculation based evaluation for non-fissioning targets
 - ideal for production of activation library
 - LACE produces isotope production cross sections too