Nuclear Reaction Modeling for Actinides

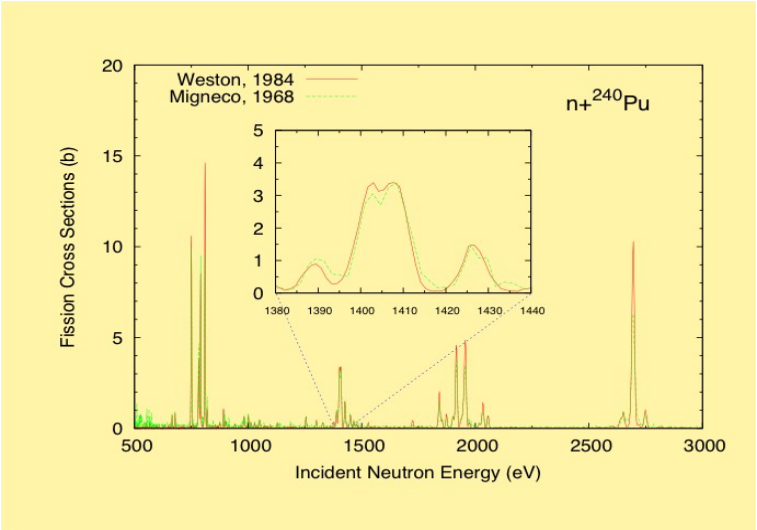
PIs: T. Kawano (LANL) and W. Younes (LLNL)

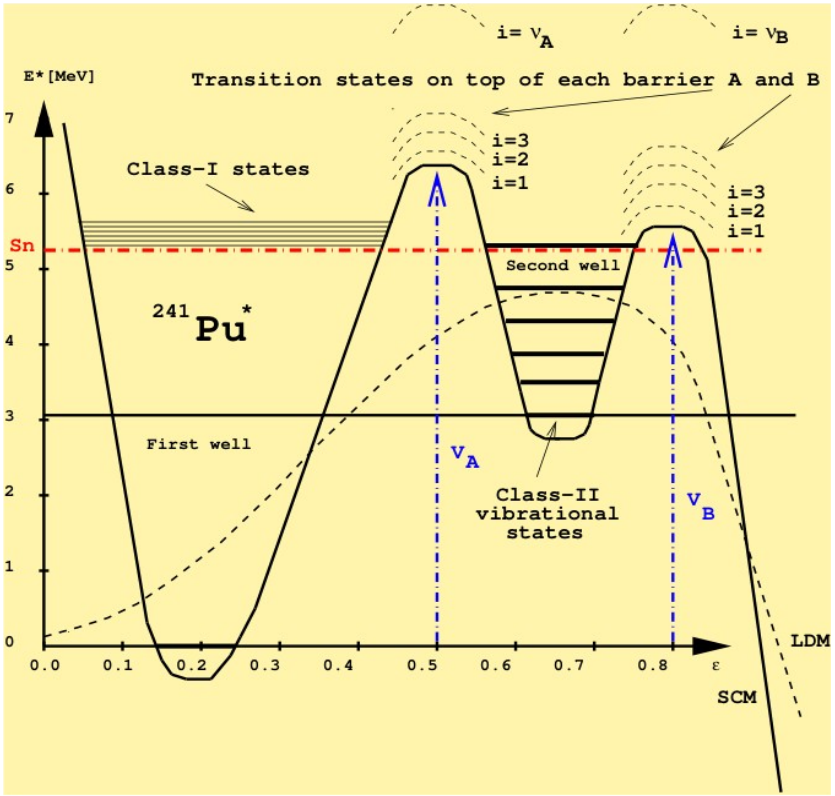
Introduction

- **Nuclear reaction modeling for actinides**
  - Nuclear reactions data, especially fission and capture, play key roles in nuclear technology
  - However, theoretical predictions are insufficient, reaction models still need to be improved
- **In This project:**
  - Microscopic description of fission (LLNL)
  - Advanced statistical Hauser-Feshbach model calculation (LANL)
    - include microscopic ingredients from nuclear structure studies
    - new Monte Carlo approach to the HF formalism
  - Prompt fission neutron spectrum modeling (LANL)
    - Monte Carlo simulation for statistical decay of fission fragments
    - include full HF calculation
  - Microscopic description of pre-equilibrium nucleon emission (LANL)

From Fission Barriers to Fission Cross Section

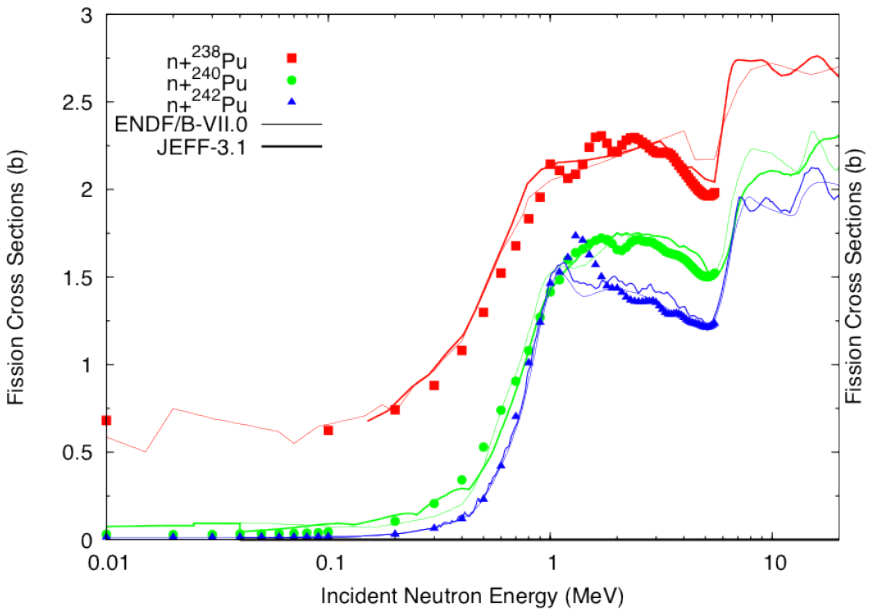
- R-matrix theory applied to fission
- Inner and outer regions connected at the outer saddle point
- Discrete transition state on top of barriers; level density above
- Double-humped barrier
  - Crass-I and Class-II states



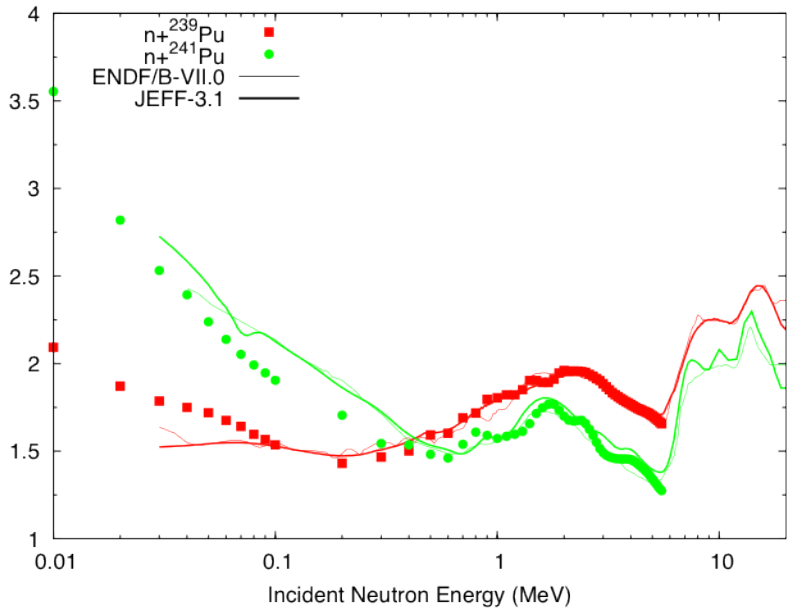


Examples of Recent Calculations: Pu Isotopes

Even Target



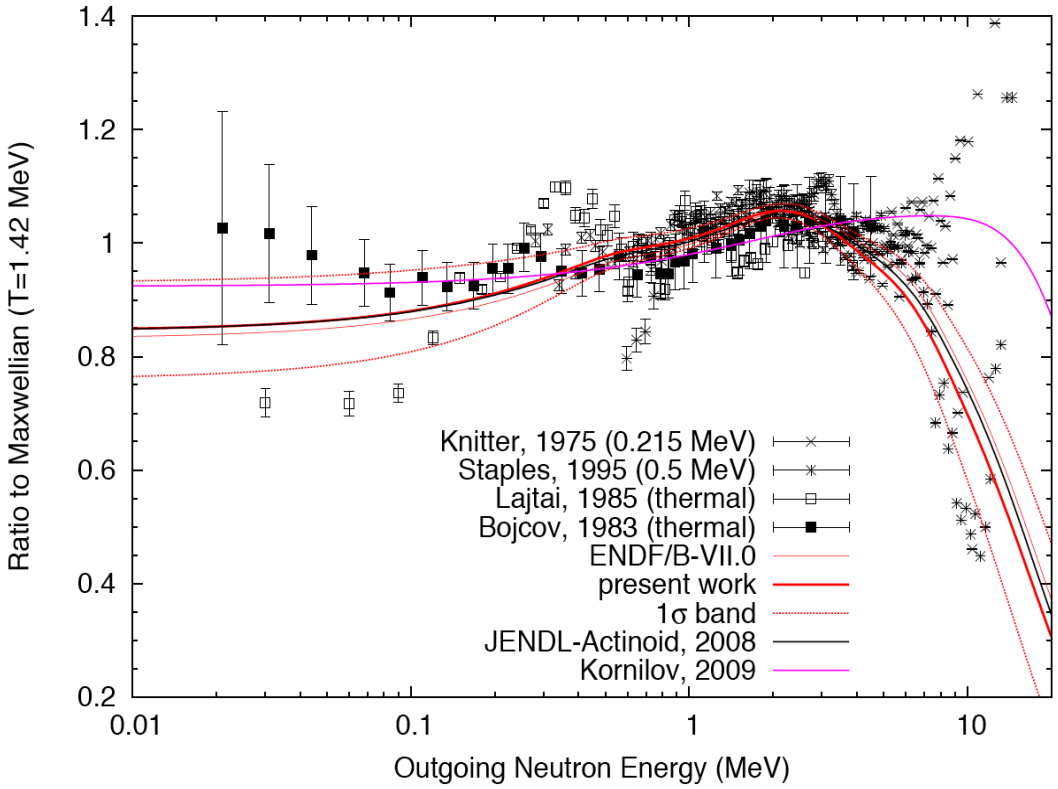
Odd Target



Searching for a better description of level densities at saddle points...

to be submitted to Phys. Rev. C

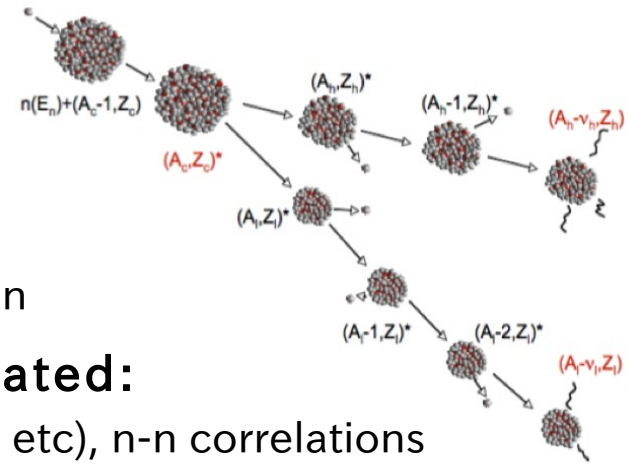
Prompt Fission Neutron Spectrum Modeling



- **Pu239 fission spectrum**
  - In the low outgoing energy region
    - data are discrepant
  - In the high energy region
    - very poort statistics
  - Theories and modeling differ widely.
    - Talou, Madland
    - Vogt, Randrup
    - Tudora, Morillon
    - Maslov
    - Kornilov
    - Ohsawa
  - Advanced modeling is essential to resolve this problem.
  - IAEA CRP on prompt fission spectrum started in 2010.

New LANL Monte Carlo Modeling of Fragment Decays

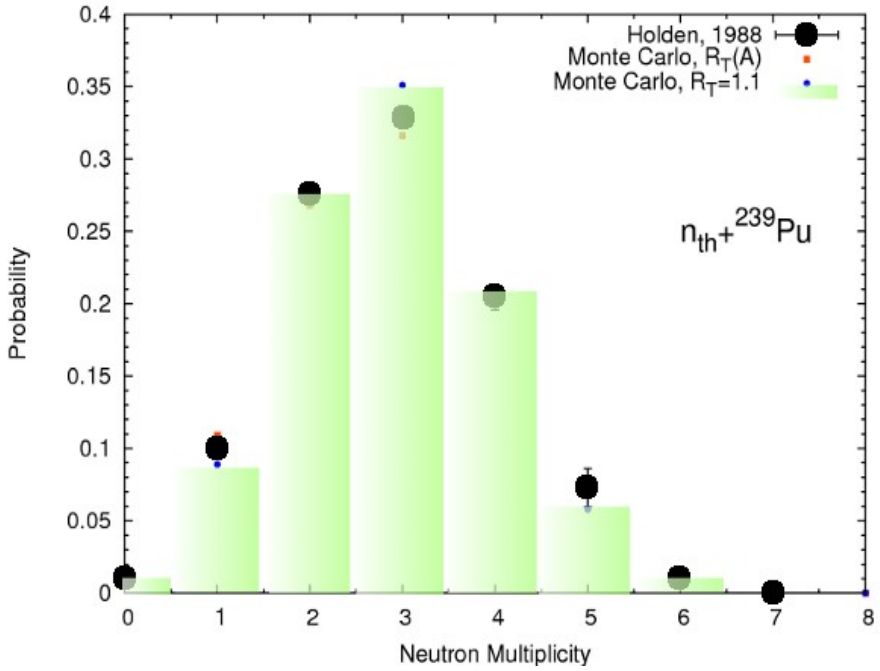
- **Should lead to increased predictive power**
- **ENDF/B-VII.0 evaluation based on Madland-Nix model**
  - model calculations adopted by other libraries - JEFF, JENDL
  - average spectrum and multiplicity only
- **Advanced modeling using Monte Carlo simulations of fission fragment decay - moving to Hauser-Feshbach decayes, not just Weisskopf-Ewing**
  - Model inputs:
    - fission fragment yields Y(A,Z,TKE)
    - masses
    - level density parameters
  - Question:
    - excitation energy sharing at scission

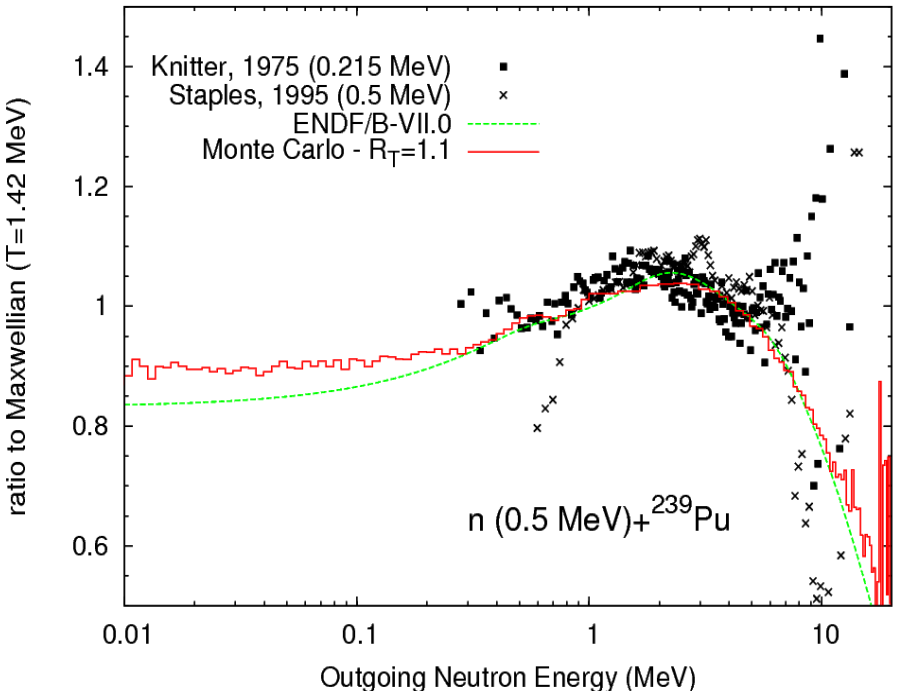


- **New physical quantities can be evaluated:**
  - P(ν), <ν>(A), exclusive spectra (for ν=1,2, etc), n-n correlations

Results: Validation Against Different Types of Data

- Builds confidence in our modeling
- Very precise prediction for <ν> and P(ν)
  - <ν>calc = 2.871, <ν>eval = 2.8725 (ENDF/B-VII.0)

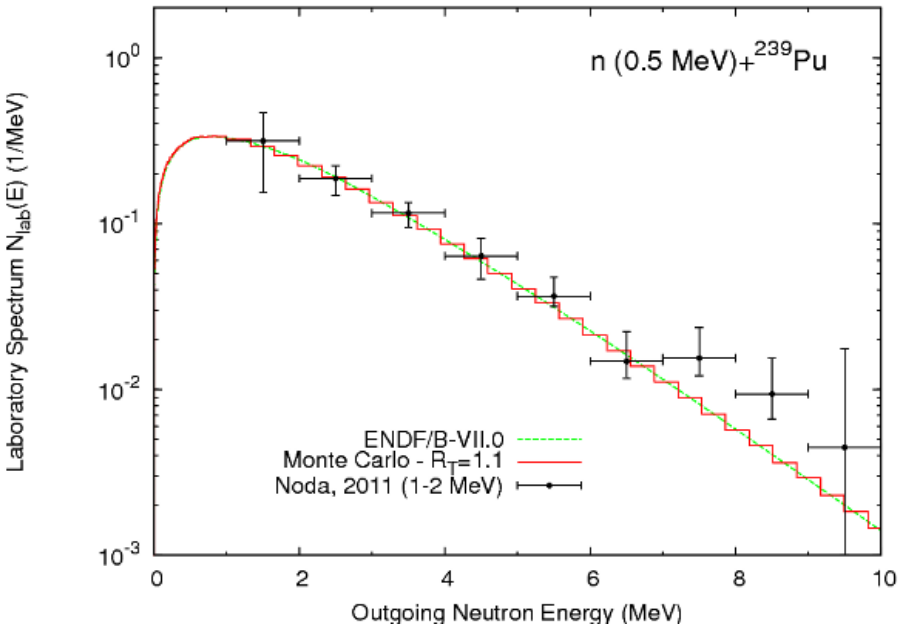


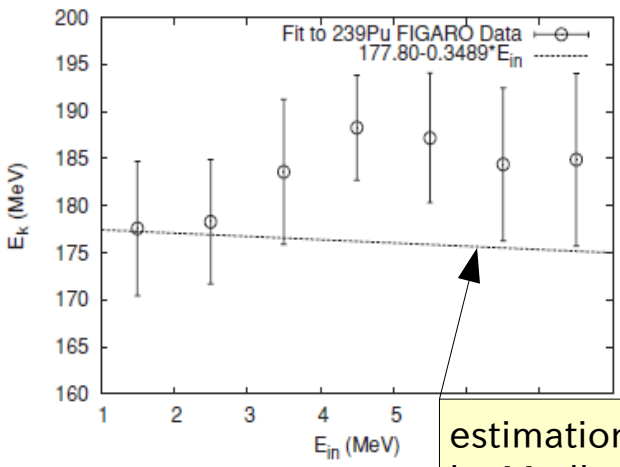


Phys. Rev. C 83, 064621 (2011)

LANL FIGARO Data, Comparison with MC

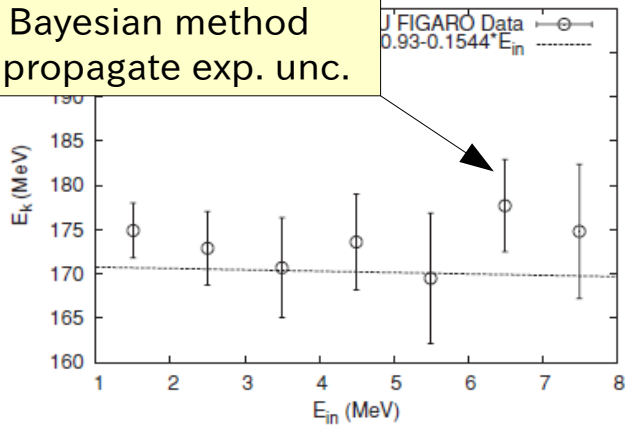
- **Measurement of prompt fission spectra and data analysis performed at CEA and LANL**
  - Madland-Nix model calculation by S. Noda (Kyushu) at T-2
    - Phys. Rev. C 83, 034604 (2011)





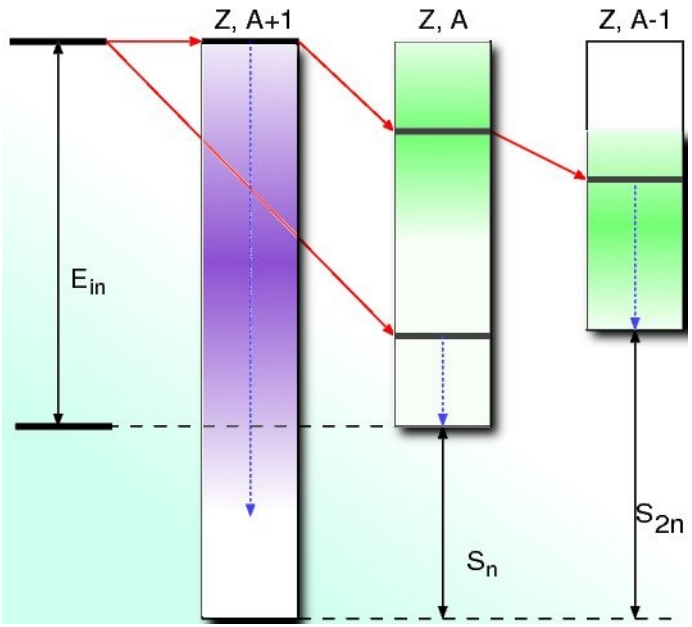
estimation by Madland

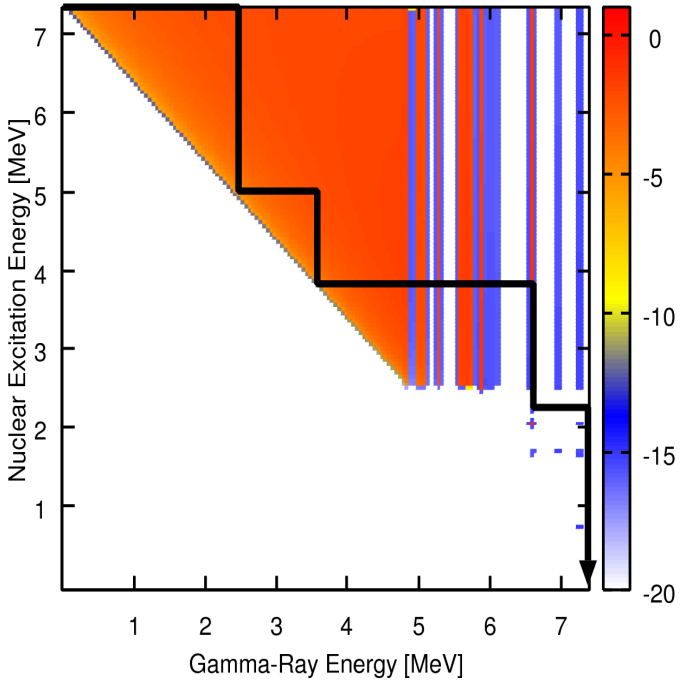
uncertainties by Bayesian method to propagate exp. unc.



HF Theory: Challenges for Future Development

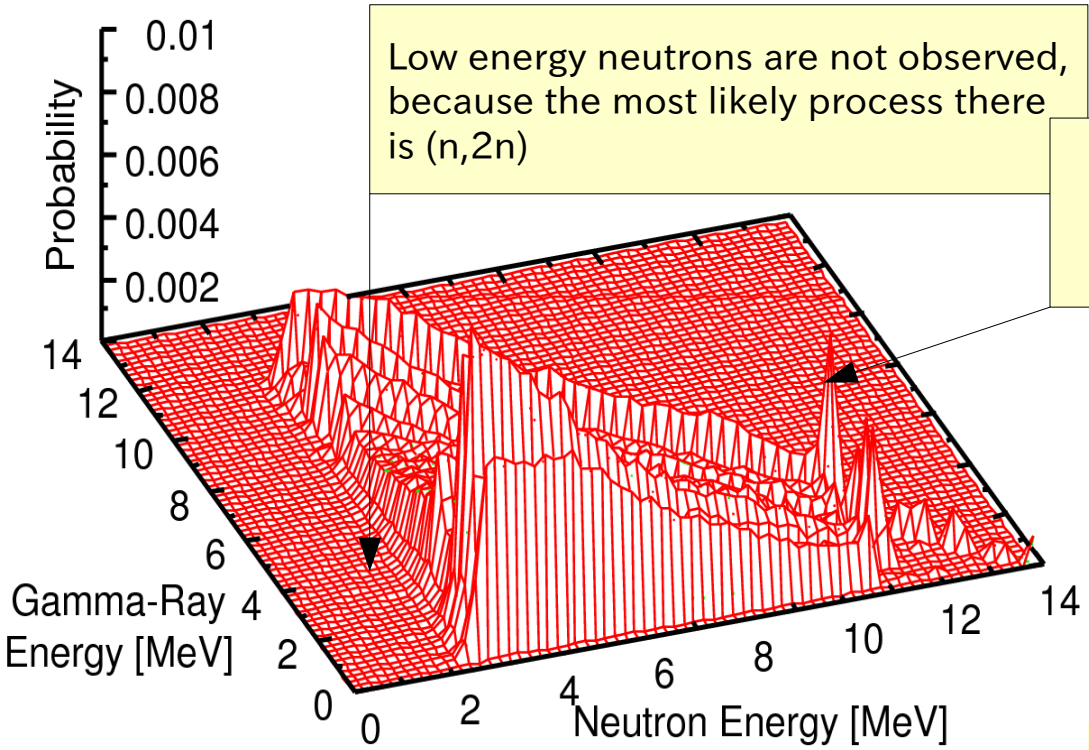
- **Beyond Cross Sections - Monte Carlo Hauser-Feshbach**
  - statistical decay process solved by a stochastic method
  - application to other nuclear process
    - exclusive spectra, coincidence, correlation
    - event generator in transport simulations





Neutron - Gamma-Ray Correlation in (n,n') Reaction

Joint probability of neutron and gamma energies for V-51+ n at 14 MeV (n,n') reaction

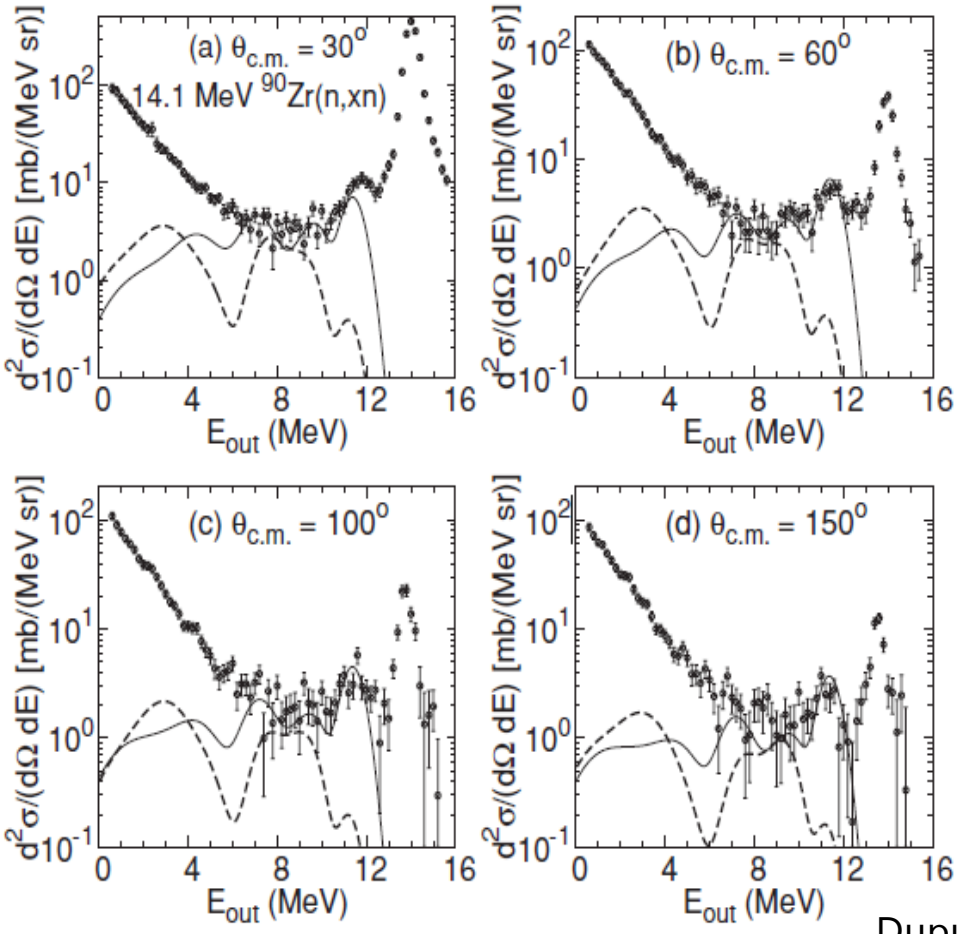


Low energy neutrons are not observed, because the most likely process there is (n,2n)

Strong gamma-ray peaks are evidence of direct inelastic scattering reaction

J. Nucl. Sci. Tech. 47, 462 (2010)

Microscopic Theories for Nuclear Reactions



(n,xn) spectra for 14-MeV neutron incuded reaction on Zn-90

RPA calculation (full curves)
p-h excitation (dashed curves).

Application to actinides underway (Hartree-Fock BCS)

Dupuis et al. in Phys. Rev. C 83, 014602 (2011)

Status Summary

- **Budget Status**
  - FY2010: 350K (allocated), 305K (actual)
  - FY2011: 330K (allocated), 196K (projected)
  - FY2012: 325K (allocated)
- **Deliverable**
  - Evaluated cross section files for minor actinides
  - Prompt fission neutron spectra for minor actinides
  - Monte Carlo Hauser-Feshbach decay simulation code
- **Publications**
  - Monte Carlo simulation for particle and gamma-ray emissions in statistical Hauser-Feshbach model, T. Kawano, et al., J. Nucl. Sci. Technol. **47**, 62 (2010) [The best paper prize 2011 by Atomic Energy Society of Japan]
  - Microscopic model approach to (n,xn) pre-equilibrium reactions for medium-energy neutrons, M .Dupuis et al., Phys. Rev. C **83** 014602 (2011).
  - Prompt fission neutron spectra from fission induced by 1 to 8 MeV neutrons on 235U and 239Pu using the double time-of-flight technique, S. Noda et al., Phys. Rev. C **83**, 034604 (2011).
  - Advanced Monte Carlo Modeling of prompt fission neutrons for thermal and fast neutron-induced fission reaction on Pu-239, P. Talou et al., Phys. Rev. C **83**, 064621 (2011)