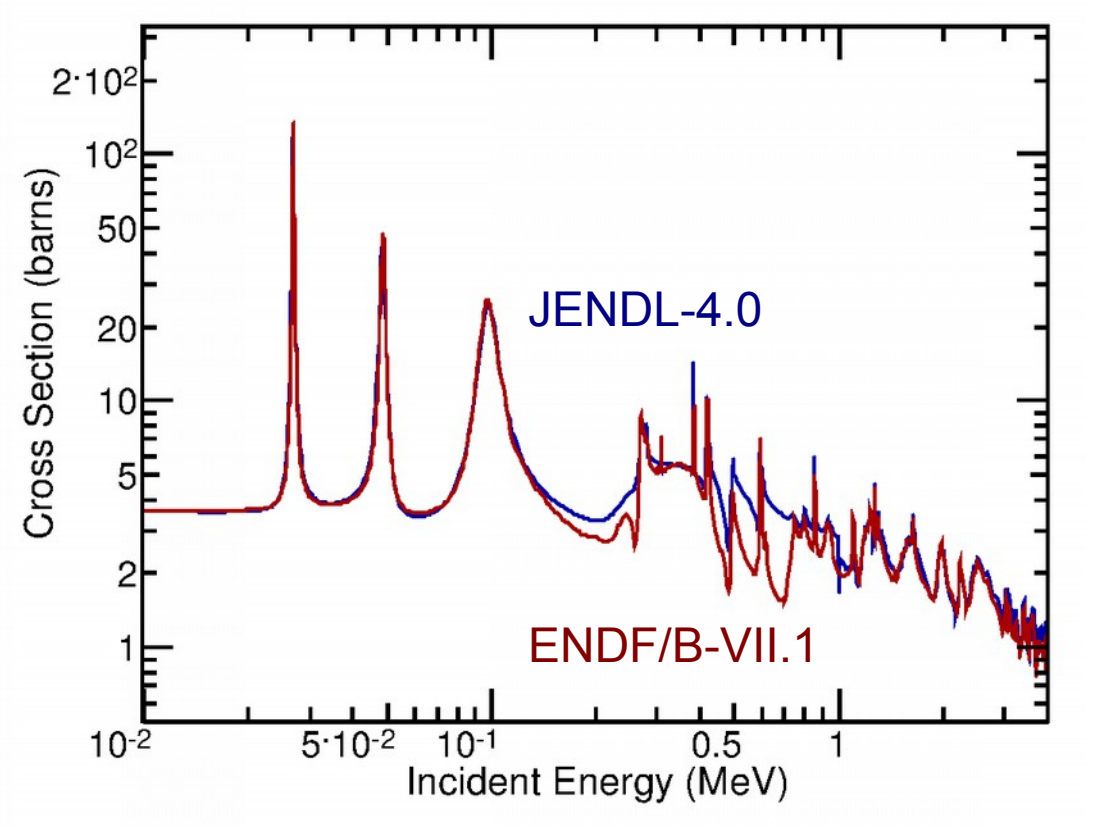
Neutron Elastic Scattering Libraries for MCNP and Geant4



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Overview

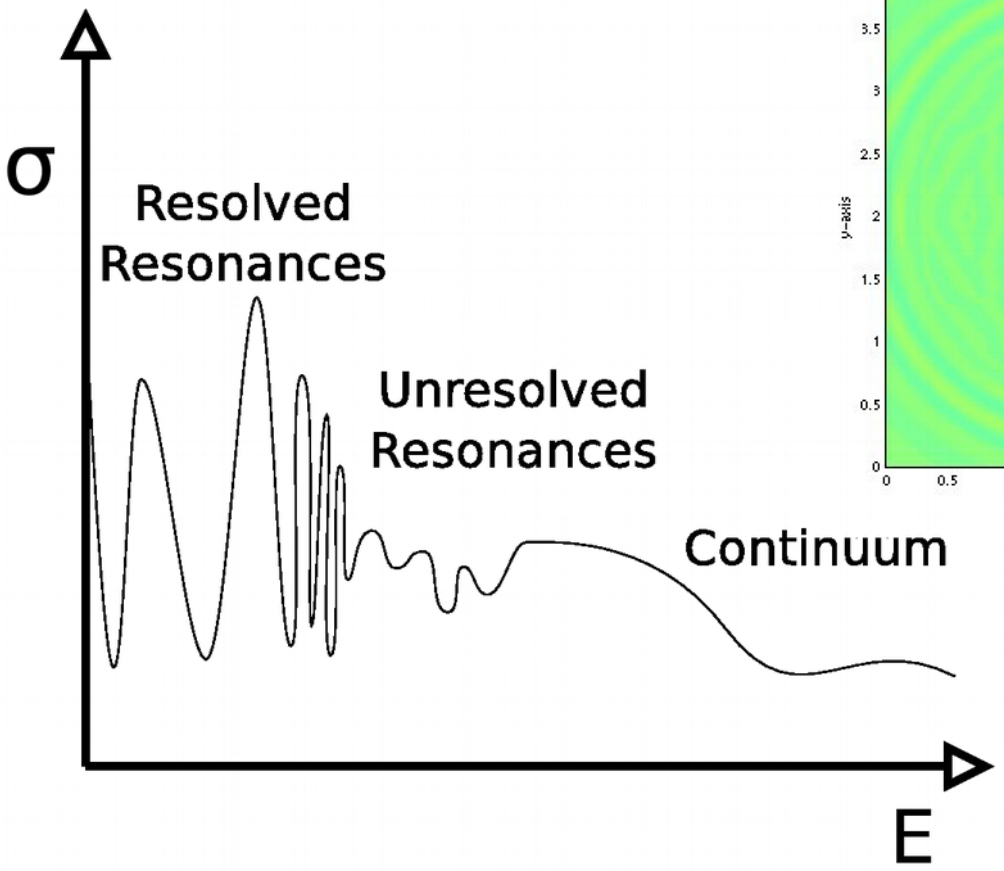
- How neutron data libraries are made
- A problem with differential cross-sections
- Effects on simulations of neutron calibrations
- Published in PRC **89** 032801

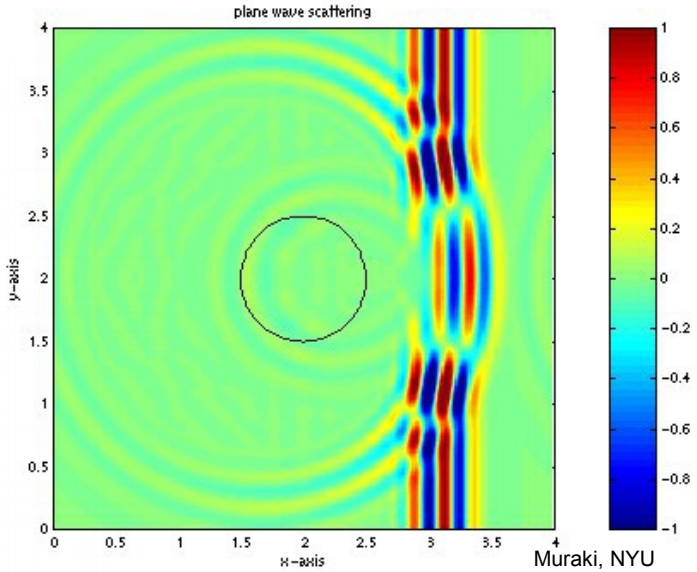
Making a Library

- Measure neutron cross-sections
- Identify levels and resonances, and fit data to a model.
- Create an Evaluated Nuclear Data Format file.
- Process the file into MCNP or Geant formats

Neutron Elastic Scattering

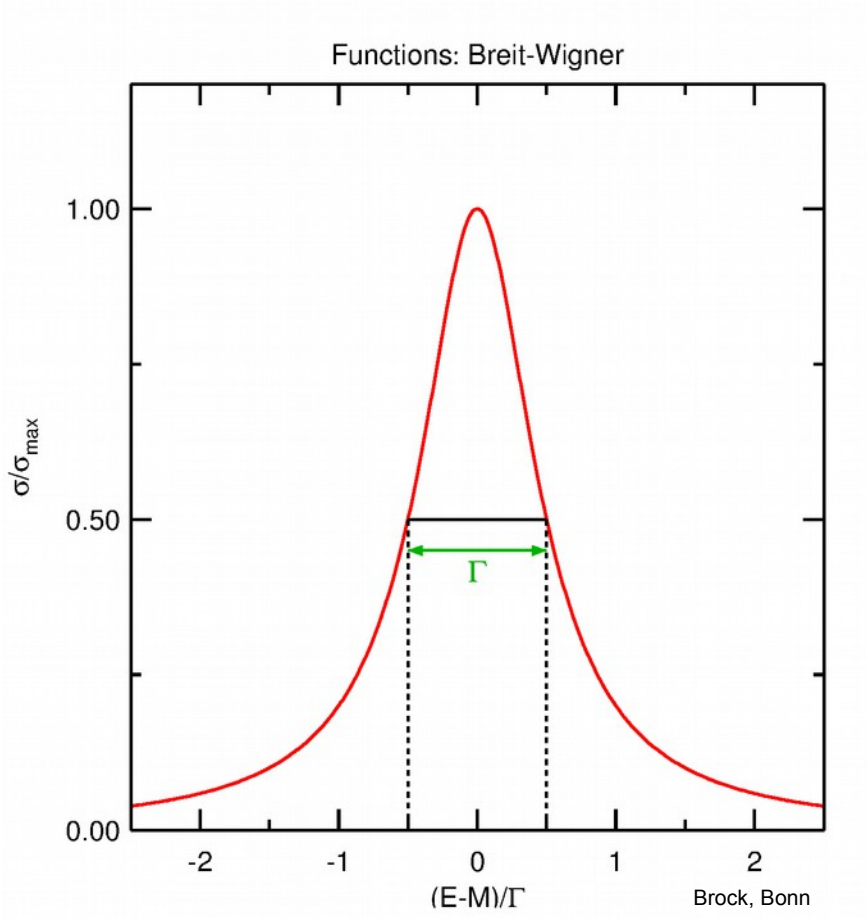
- Resonances from compound states
- Continuum from potential scattering





Breit-Wigner Resonances

- Parameterized by
  - Resonance widths
  - Neutron Energy
  - Spins
  - Parity



- Interference handled by R-matrix formalism

ENDF Format


```
 5.413600+4 1.347400+2          0          0          1          05461 2151     1
 5.413600+4 1.000000+0          0          0          1          05461 2151     2
 1.000000-5 4.900000+5          1          2          0          05461 2151     3
 0.000000+0 7.122766-1          0          0          2          05461 2151     4
 1.347400+2 0.000000+0          0          0         12          25461 2151     5
-8.220000+2 5.000000-1 1.002250+1 9.900000+0 1.224910-1 0.000000+05461 2151     6
 7.930100+4 5.000000-1 8.030000+0 8.000000+0 3.000000-2 0.000000+05461 2151     7
 1.347400+2 0.000000+0          1          0        210         355461 2151     8
 2.154000+3 1.500000+0 4.500000-2 1.500000-2 3.000000-2 0.000000+05461 2151     9
 1.839300+4 5.000000-1 2.503200+1 2.500000+1 3.200000-2 0.000000+05461 2151    10
 3.562900+4 1.500000+0 1.203200+1 1.200000+1 3.200000-2 0.000000+05461 2151    11
 4.641000+4 5.000000-1 5.730320+2 5.730000+2 3.200000-2 0.000000+05461 2151    12
 5.917900+4 1.500000+0 1.203200+1 1.200000+1 3.200000-2 0.000000+05461 2151    13
 6.764400+4 1.500000+0 3.253000+1 3.250000+1 3.000000-2 0.000000+05461 2151    14
 7.615000+4 1.500000+0 4.453000+1 4.450000+1 3.000000-2 0.000000+05461 2151    15
 1.353900+5 5.000000-1 1.630300+2 1.630000+2 3.000000-2 0.000000+05461 2151    16
 1.630400+5 5.000000-1 1.950300+2 1.950000+2 3.000000-2 0.000000+05461 2151    17
```

- File 2 – Resonance parameters
- File 3 – Explicit Cross-sections
- File 4 – Differential Cross-sections

- Recommended reading: http://t2.lanl.gov/nis/endf

Evaluations

- Generated by National Labs in
  - USA – ENDF/B
  - Japan – JENDL

  Best at low energy
  - Europe – JEFF
  - Russia – ROSFOND / BROND
  - China – CENDL
- Updated on a regular basis and incomplete for many nuclei.
- Libs available at www-nds.iaea.org

Example

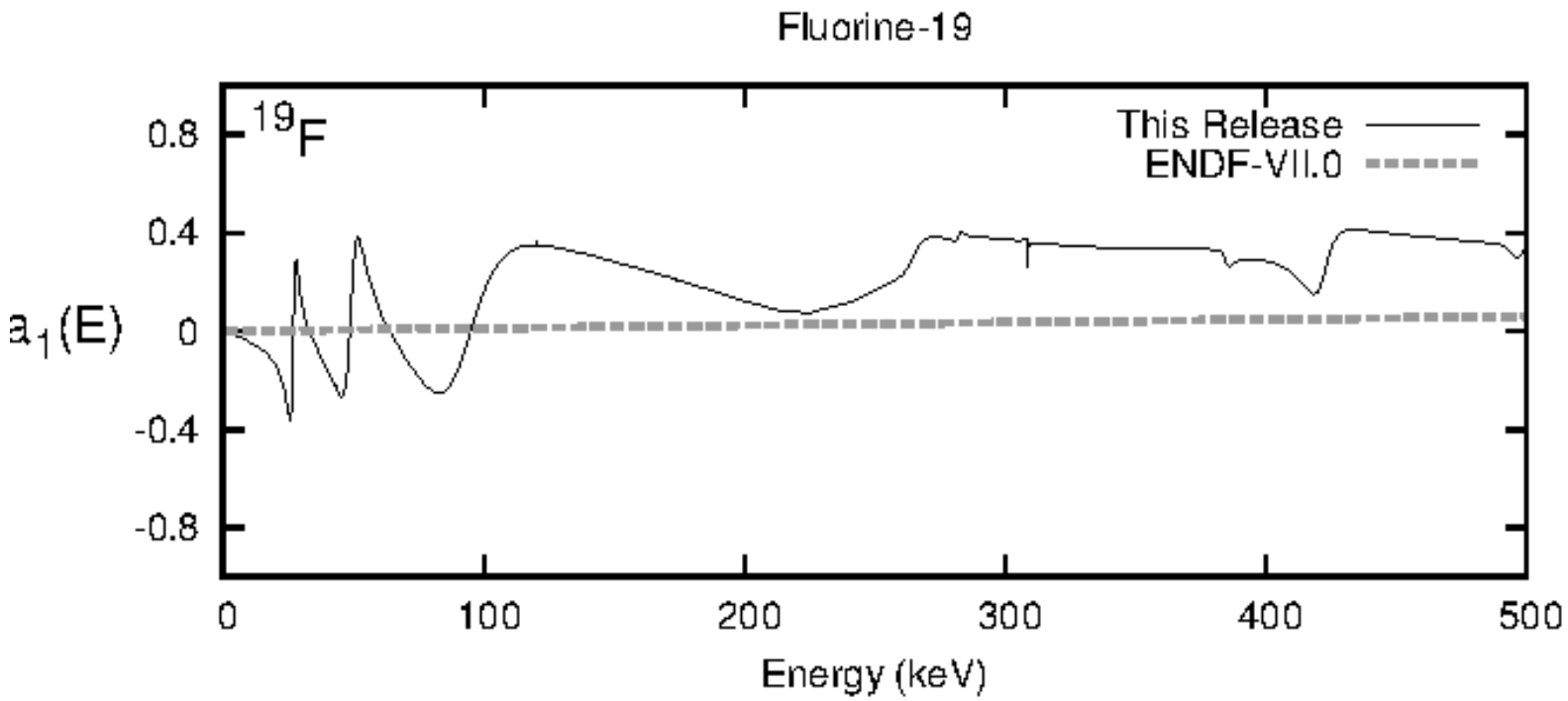
- F-19 ENDF-VII.0 as example:
  - File 2, < 1MeV. evaluated in 2004, global R-matrix fit to 6 sets of experimental data w/ uncertainties.
  - File 3, 1-2 MeV. eval in 1990, global R-matrix fit. > 2MeV, borrowed from evaluation before 1990.
  - File 4, based on optical model calculation.

Processing into libraries

- NJOY or PREPRO
  - Calculate cross-sections from resonance parameters in File 2 at low energy.
  - Convert File 3 and File 4 data.
  - Used to produce both Geant4 and MCNP libraries

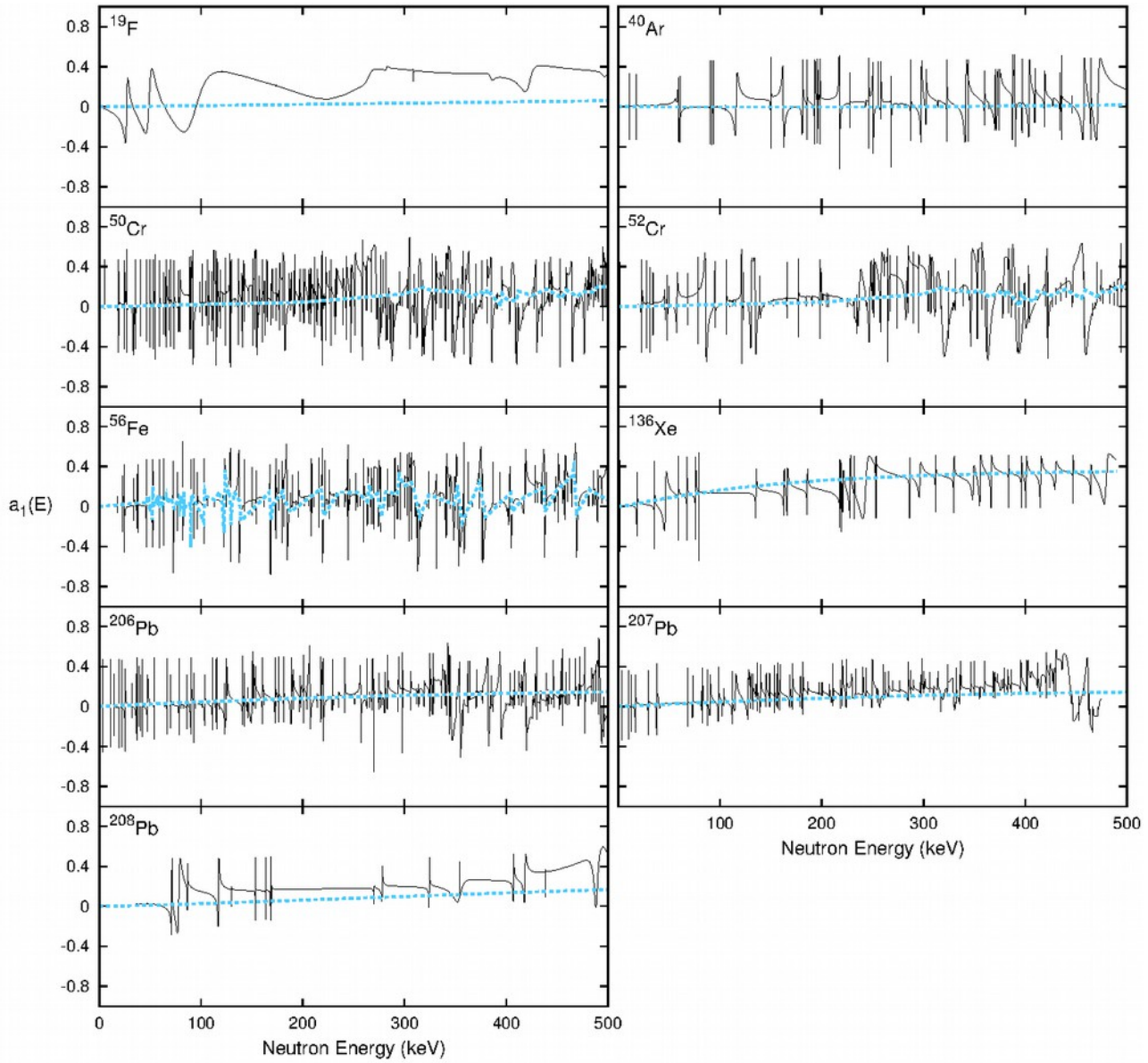
- Recompiling NJOY2012 give the option to calculate differential cross-sections from resonances.

Recalculating dσ/dΩ



Recalculating dσ/dΩ

- Overview
- Making a library
- dσ/dΩ
- Effects on simulations



Extent of the Problem

- Does not affect isotopes O-16 and lighter
- Some isotopes have no resolved resonances important to DM calibrations (most Xe isotopes, I-127, Cs-133).
- Some isotopes have File 4 evaluations based on smoothed experimental data (Fe-56, Cr, Si)

New Libraries Available

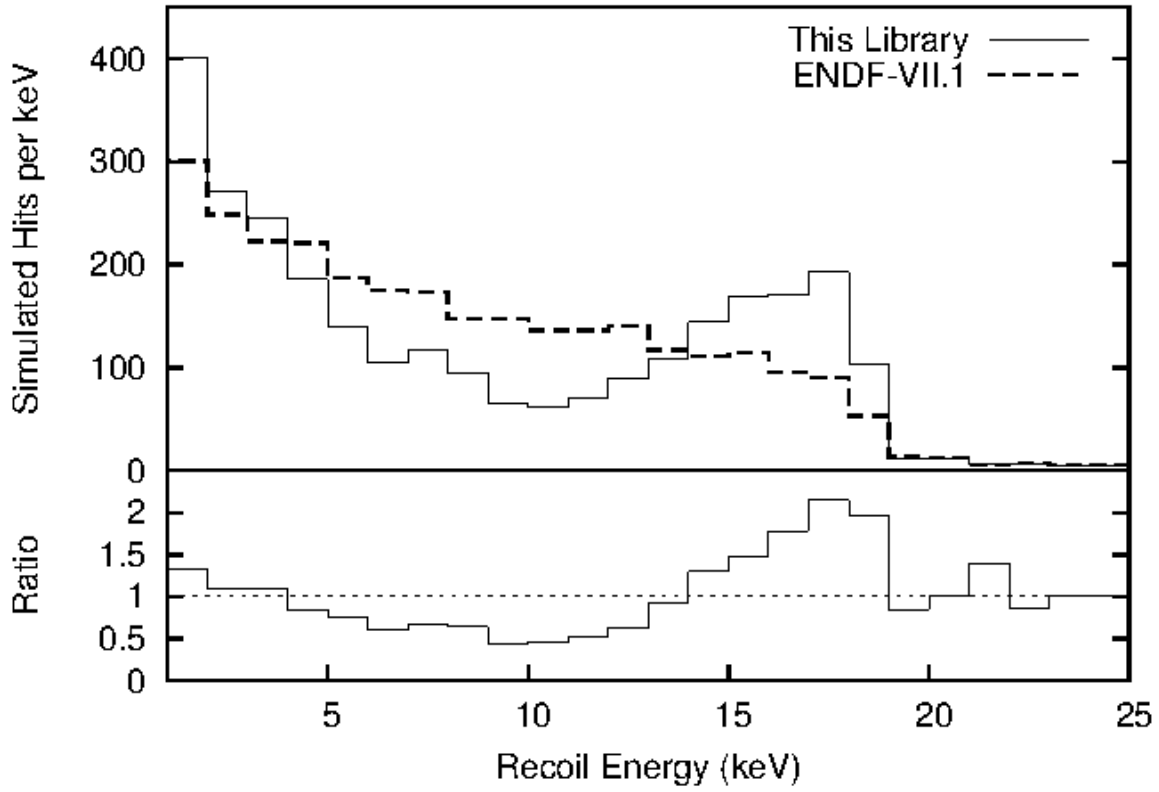
- For MCNP & Geant4
  - Based on resonance parameters in ENDF/B-VII.0 (.70c libs)
  - Only covers the resolved resonance range defined in the libraries, up to 1.5 MeV.
  - Available for Si, Ar, Cr-50,52, Fe-56, Xe-136, Pb-206,207,208

Effect on DM detectors

- $E_r \propto \cos\theta$
  - Neutron generated recoil distributions are directly affected.
- Neutrons can propagate further
- Multiple scattering can change

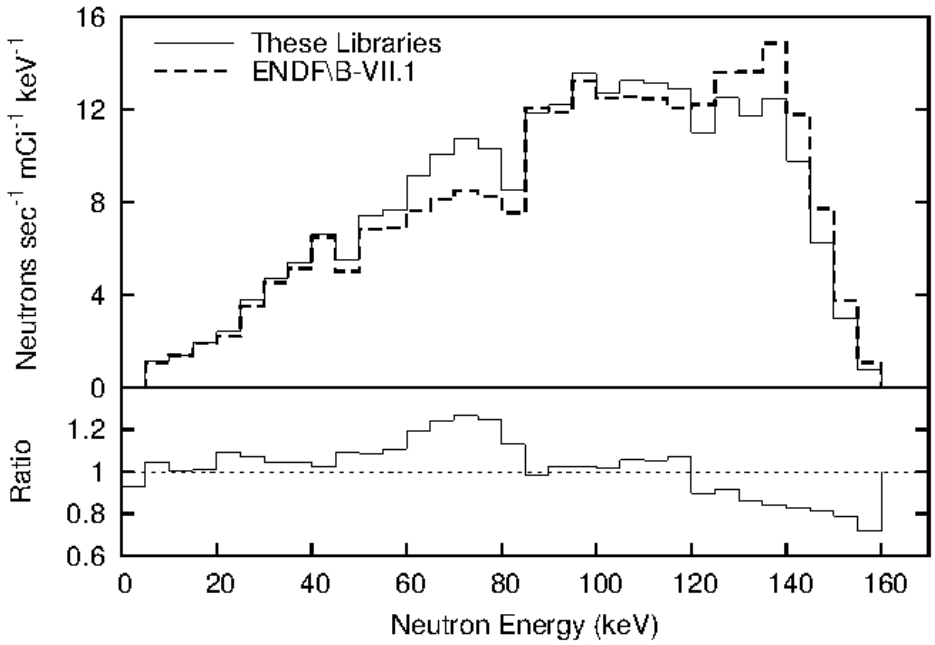
PICO calibration

- Slightly moderated 97 keV neutron field. No coincidence triggers.
- Measurement of efficiency at endpoint.



Forward scattering

- Dipole terms tend to increase forward scattering.
  - Multiple scattering
    - More low energy scatters
    - Scatters deeper in your detector
  - Shielding



Know your simulations

- Nuclear data is missing from simulation libraries
- Not all simulations have “15%” accuracy
- Know where to look to find nuclear data