Photoneutron Source Carachterization and Neutron Simulations

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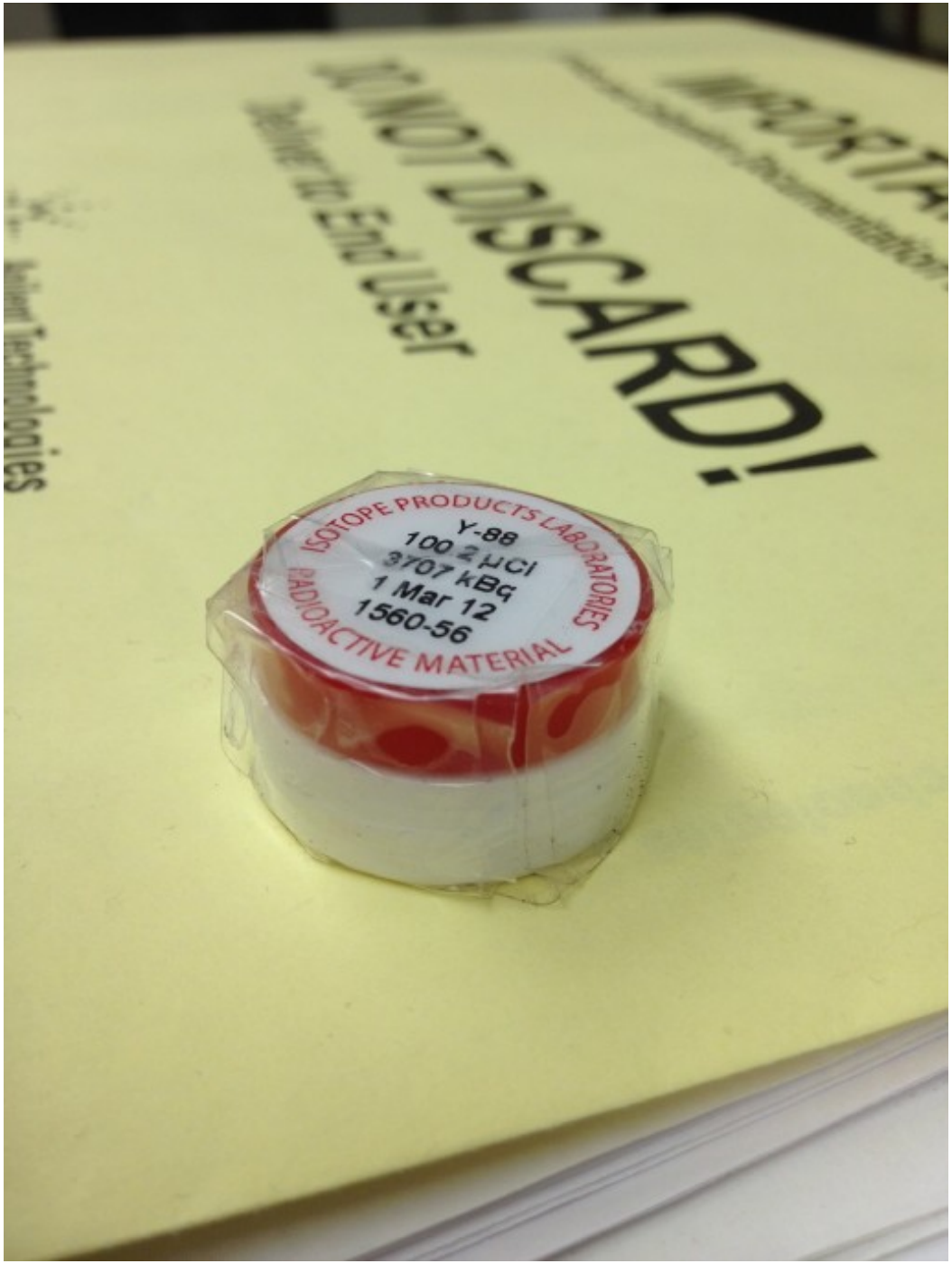
Low Energy Calibration Workshop

THE UNIVERSITY OF CHICAGO
Fermilab



Photoneutron Sources

- Portable
- Monochromatic
- Low-energy
- $10^5 – 10^6$ photons/neutron

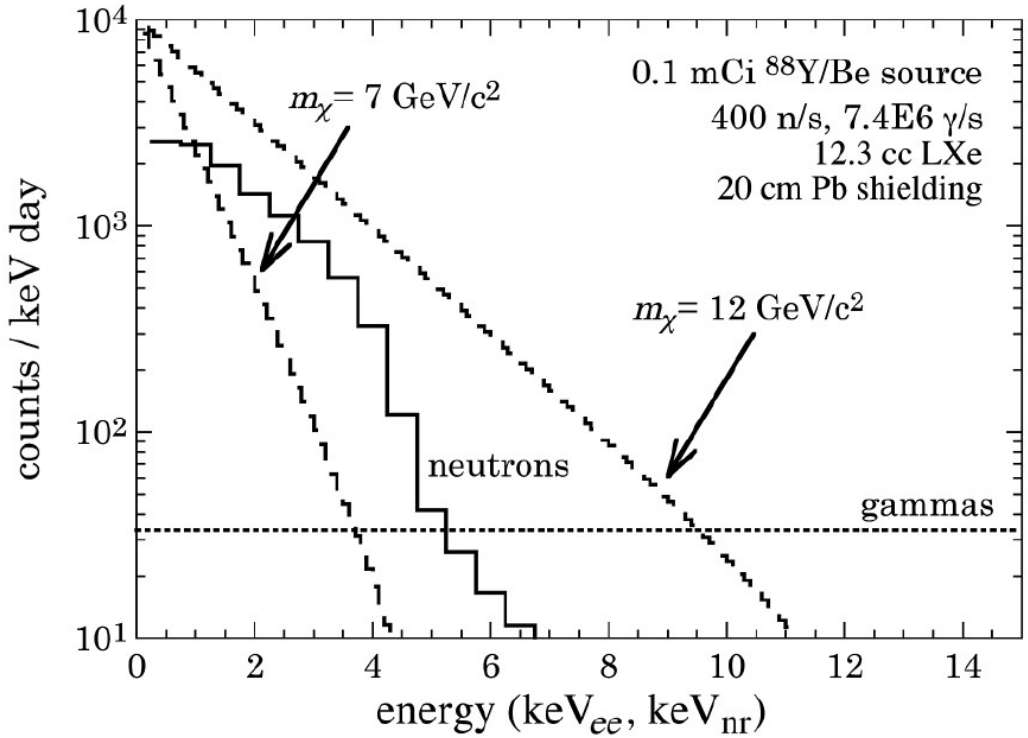


FIG. 5. Simulated response of a small LXe detector to an ^{88}Y/Be source (nuclear recoil energies in keV$_{nr}$, electron recoil energies from gamma component in keV$_{ee}$). A very similar spectral response to low-mass WIMPs like those of present interest is shown, normalized to an arbitrary cross section.

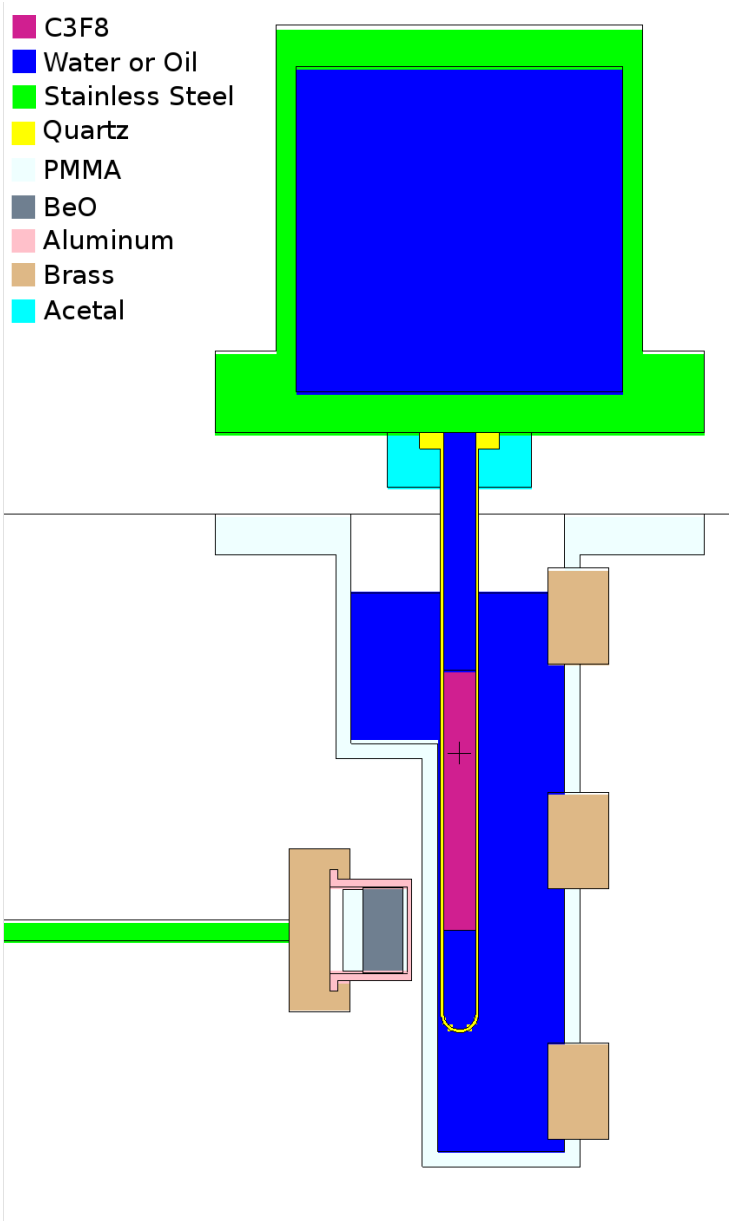
Photoneutron Sources

Radioisotope / beryllium sources

Source	Half-life	Photons	Neutron Energy
^{226}Ra	1600 y	1764 keV (15.3 %) 2204 keV (4.92 %) others (9.69 %)	89 keV 479 keV
^{124}Sb	60.2 d	1691 keV (47.6 %) 2091 keV (5.49 %) others (0.52 %)	23.5 keV 379 keV
^{88}Y	106.6 d	1836 keV (99.9 %) 2734 keV (0.71 %)	152 keV 950 keV
^{207}Bi	31.6 y	1770 keV (6.87 %)	94 keV

Photoneutron Calibrations

- Need
  - Well defined energy spectrum
  - Absolute recoil rate
- Measure source yield
- Minimize moderator
- Understand neutron recoil response.



Photoneutron History

- The NIST calibrated neutron source is a 1 Ci ^{226}Ra/Be photoneutron source.

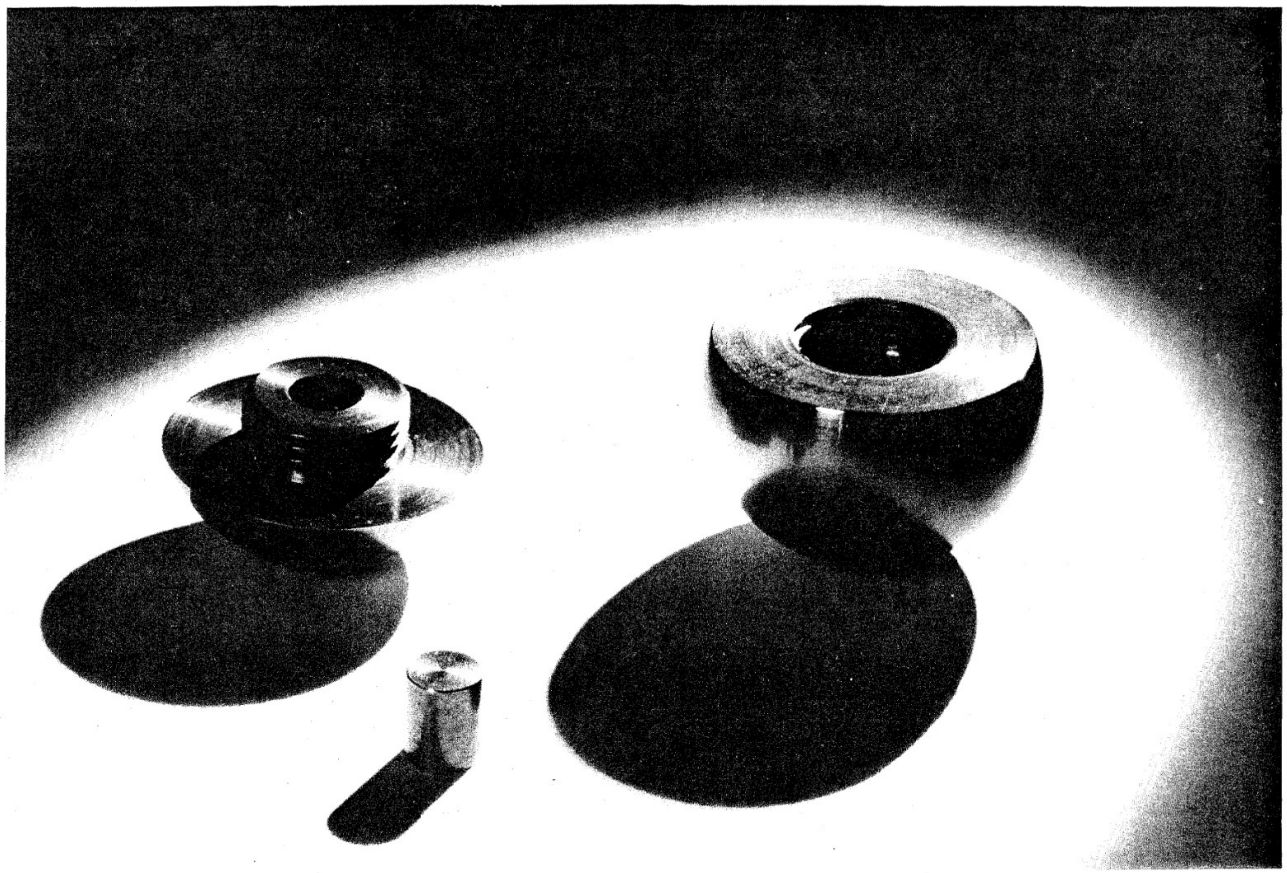


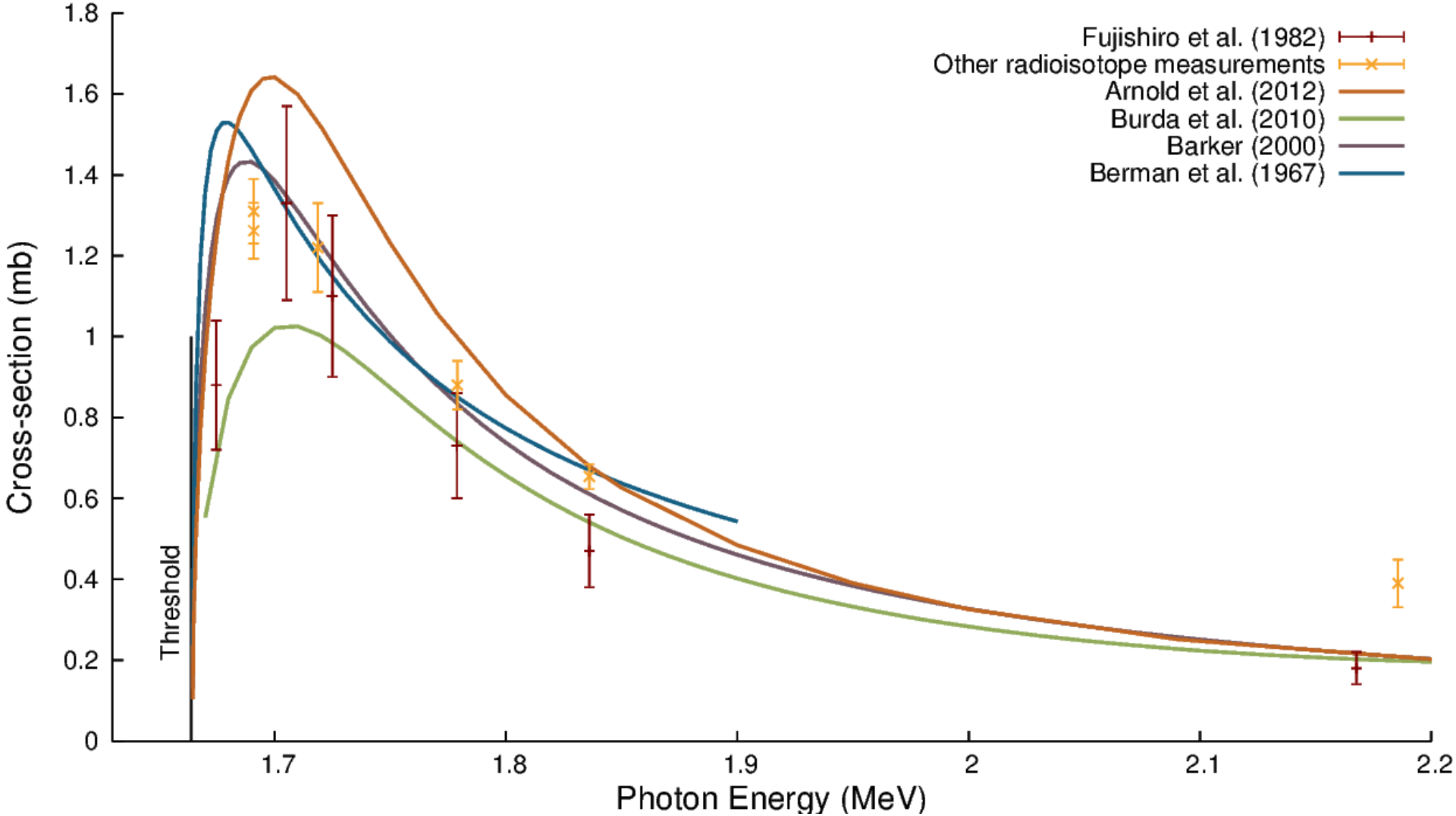
FIG. 1. Radium Beryllium Photoneutron Source NBS-I.

Photoneutron History

- Measurements of $^{9}Be(\gamma,n)$ cross-section
  - 1940-60's & 1982: Radioisotopes.
  - 1960-70's: Bremstrallung photons, charged particle scattering.
  - 2000 & 2012: Inverse compton photons.

^{9}Be(γ,n) Cross-section

A selection of existing measurements

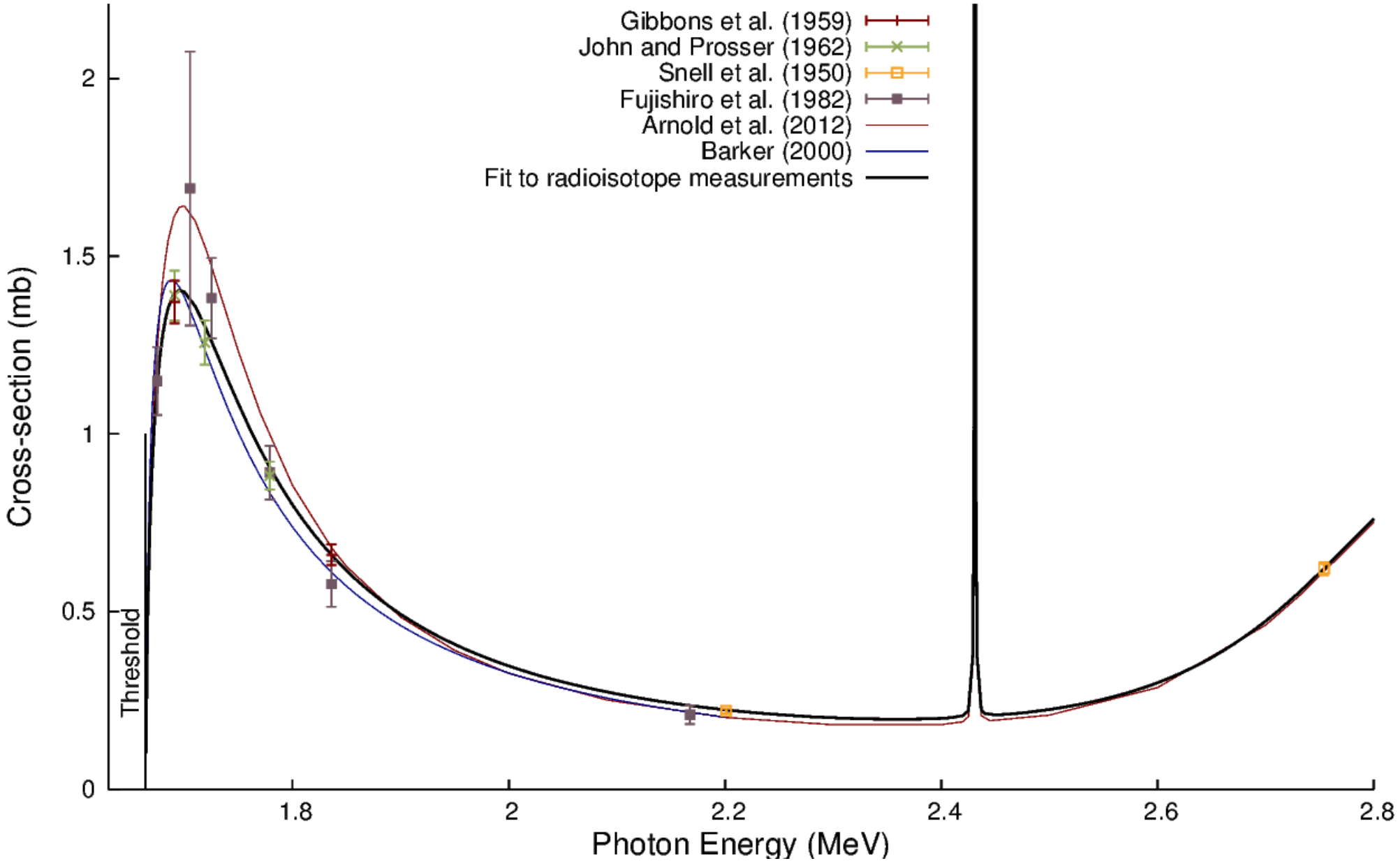


^{9}Be(γ,n) Cross-section

- Reanalyzed radioisotope measurements and corrected for
  - Branching ratios
  - Detector efficiencies (using modern MCNP simulations)
- Fitted to Breit-Wigner resonance parameters.

E_n = 1738.8 keV, Γ_n = 268.7 keV, Γ_γ = 0.7715 eV

^{9}Be(γ,n) Cross-section



Source Yield

- Calculated from known cross-sections
  - 0.659 mb at 1836 keV
  - 1.397 mb at 1691 keV
  - 955 mb at 1770 keV
- Directly measured using He-3

Source Design

- Photoneutron emission from ^{9}Be radioisotope sources is isotropic in the rest frame.
  - Energy-angle dependence in the lab frame.
    - ±6% spread in Sb/Be neutron energy.
- Photoneutron yield and energy spectrum depend on the source geometry.
  - Diminishing returns on yield of unmoderated neutrons for Be or BeO thickness >1cm.

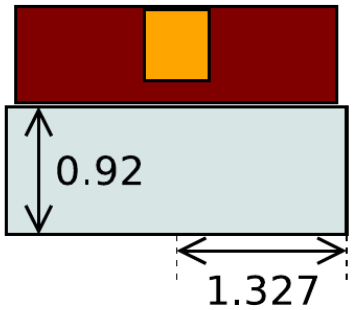
Source Design

Large yield sensitivity to BeO – ^{88}Y distance.

Low yield uncertainty
Larger spread of neutron energies

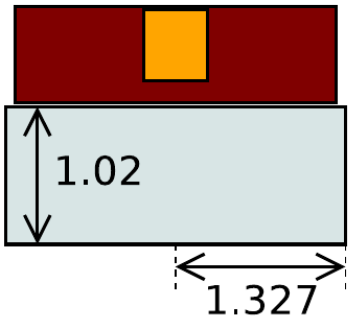
Configuration 1

14.87 g BeO



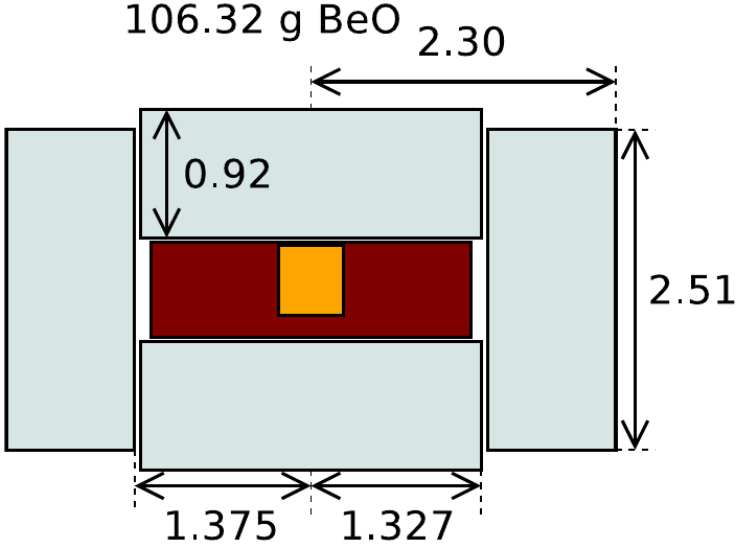
Configuration 2

16.29 g BeO

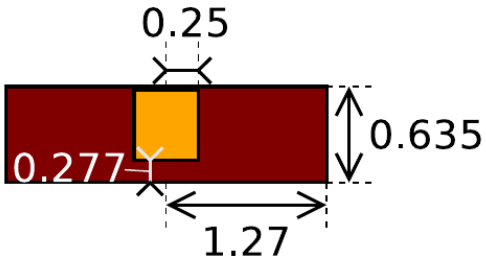


Configuration 3

106.32 g BeO

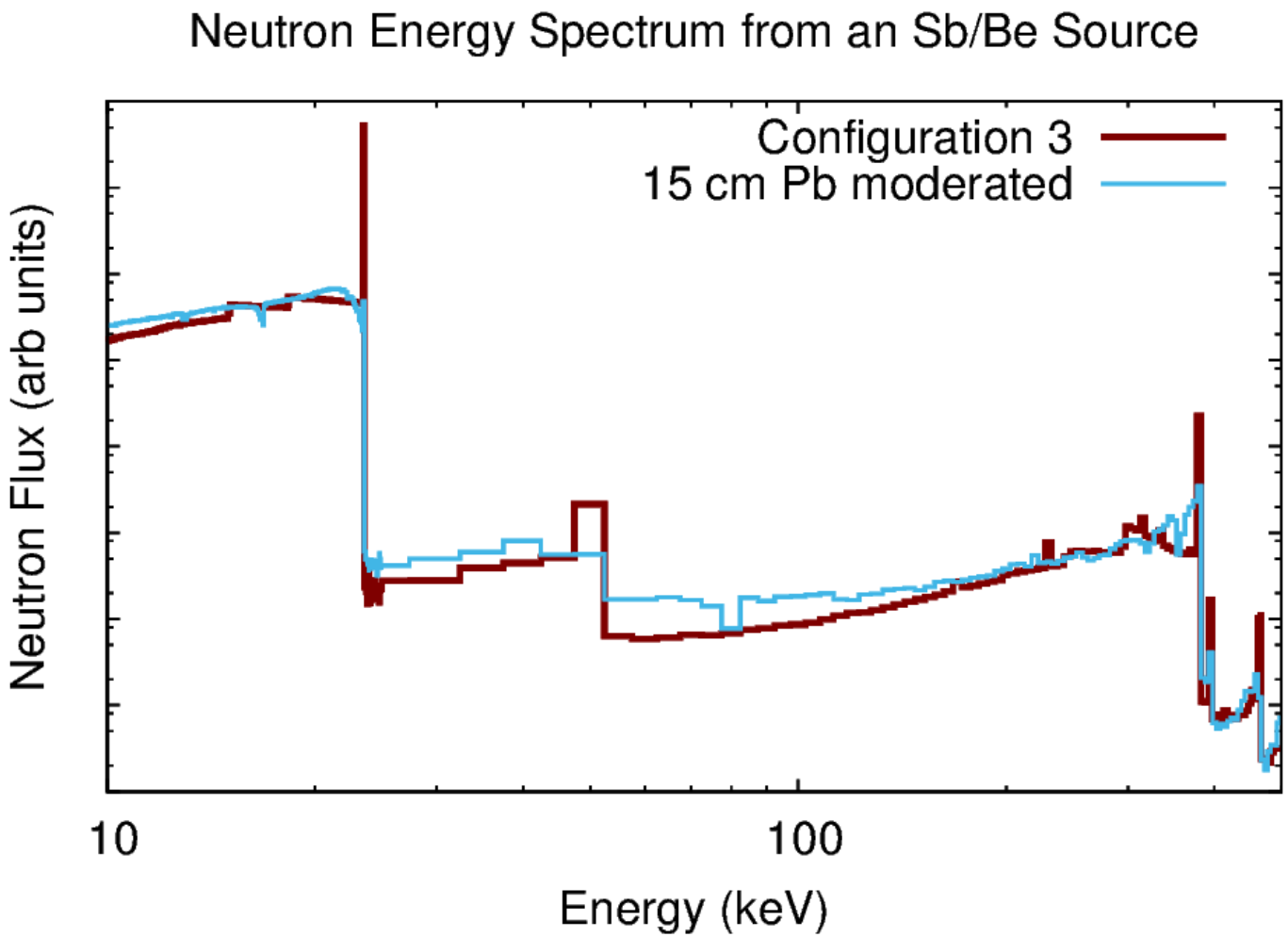


Type-D source



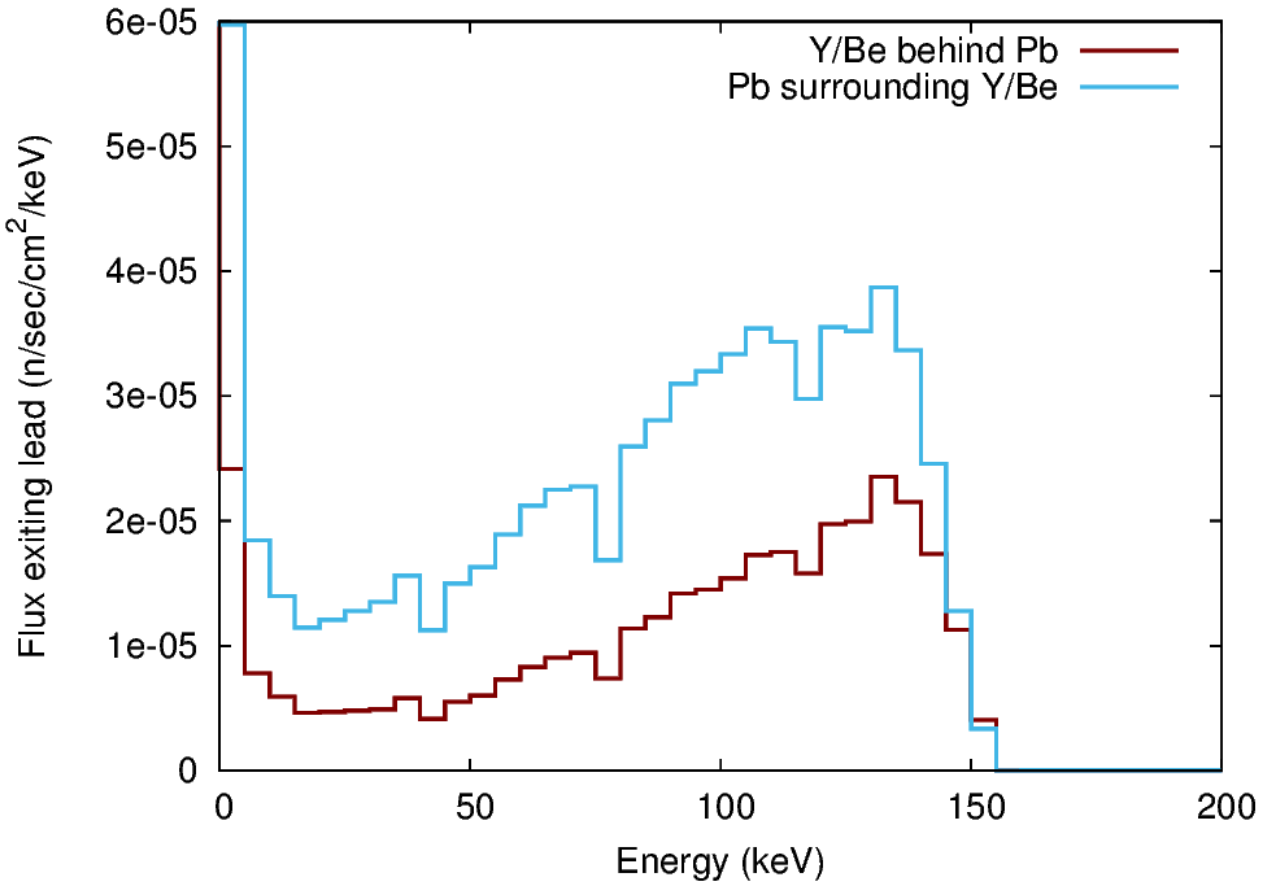
Moderation

- Energy degradation in BeO may be subdominant to other moderators.



Source Design

- If using a lead shield
  - Surround the source with lead on all sides so that lead is a diffuser instead of a reflector.



Neutron Moderation

- Libraries for both MCNP and Geant4 incorrectly describe the angular distribution from neutron scattering for most isotopes.
  - Problem not applicable to oxygen and lighter.
  - New libraries for F, Si, Ar, Cr, Fe, and Pb are available. PRC **89** 032801 (2014).

Neutron Moderation

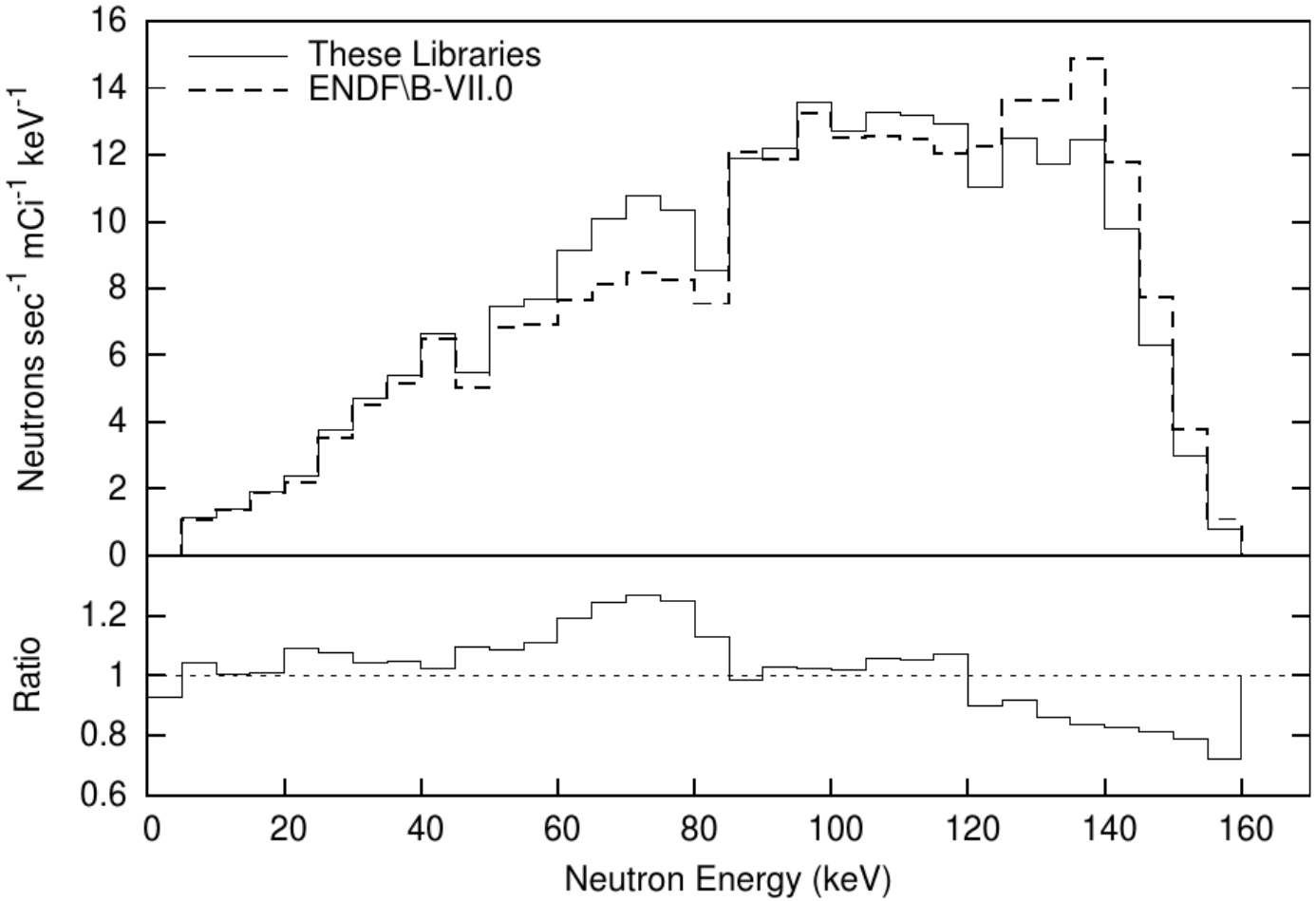
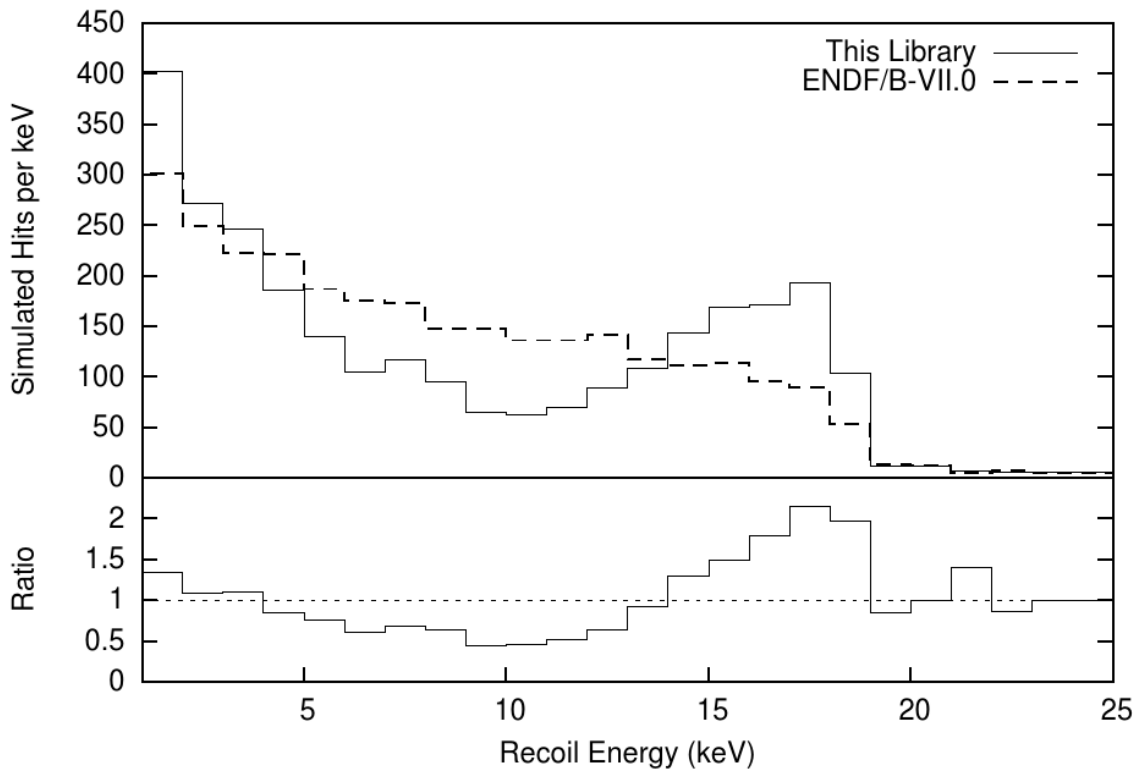


Figure 3. Simulated neutron energy spectra from an ^{88}Y/Be surrounded by 20 cm of lead as used in the ongoing XCD experiment at Fermilab (see text).

Neutron Recoils



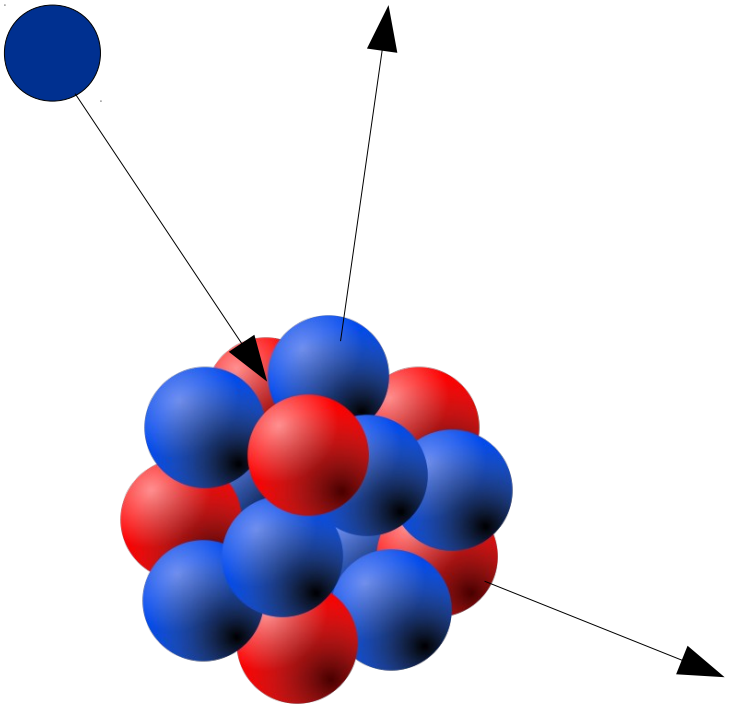


Figure 2. Simulated nuclear recoil distributions from 97 keV neutrons on C_3F_8 in the PICO-0.1 bubble chamber calibration experiment. The calibration of the detector's bubble nucleation efficiency depends critically on the number of recoils at the endpoint of the simulated nuclear recoil distribution. A factor of 2 discrepancy is found between the R-matrix calculation used in this library release and ENDF/B-VII.

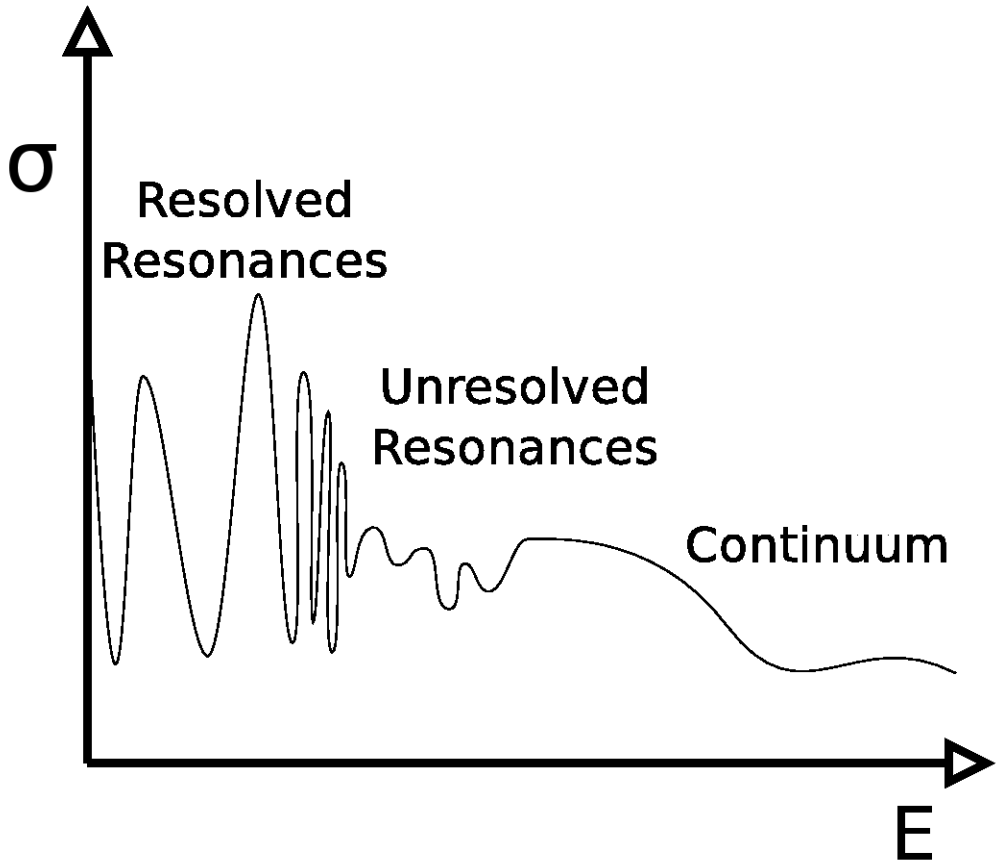
Neutron Recoils

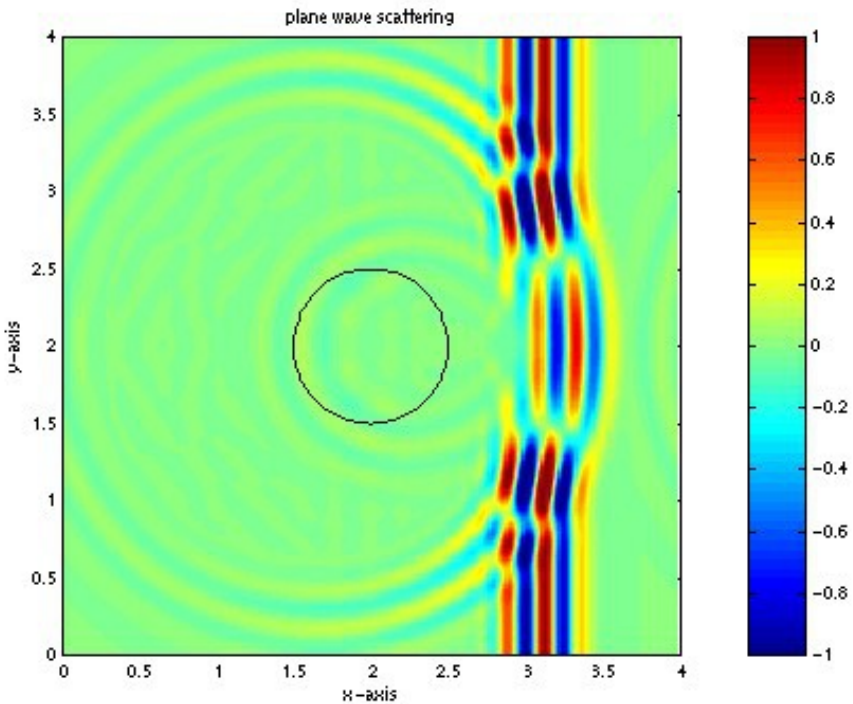
- Recoil spectrum uncertainties
  - Cross-section uncertainty
  - Resonance parameter uncertainty
  - Unresolved resonances

Extra slides

Neutron Elastic Scattering

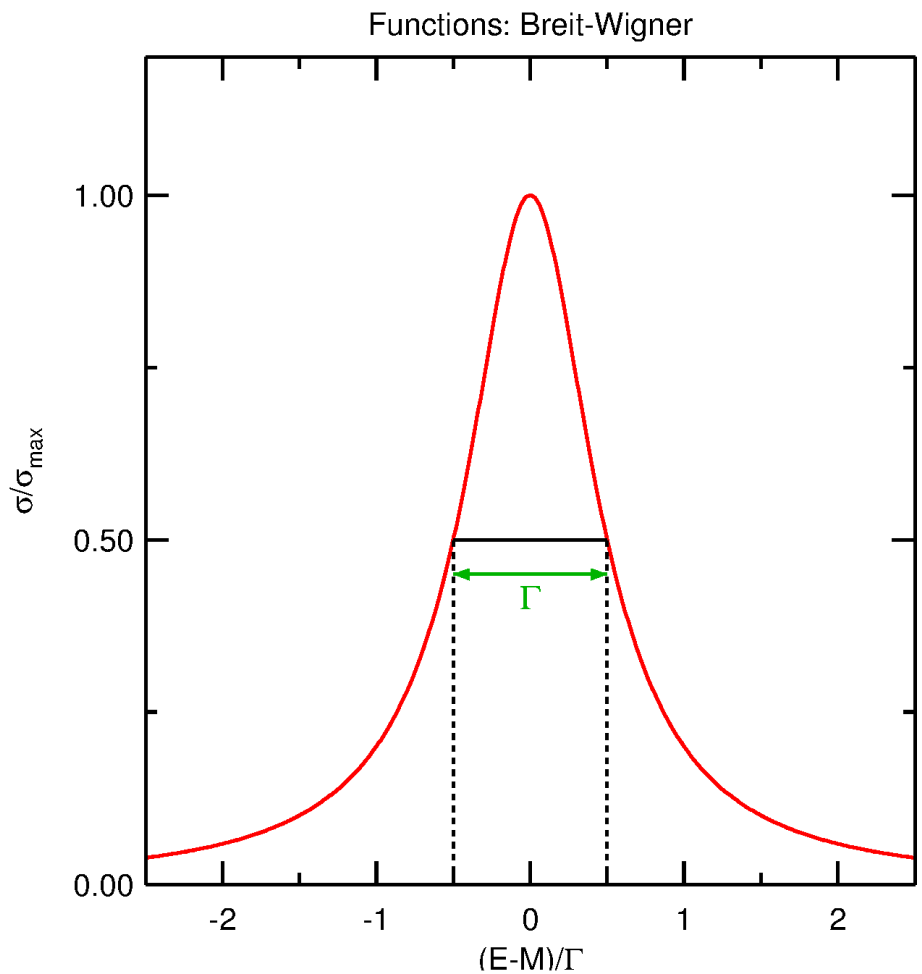
- Resonances from compound states
- Continuum from potential scattering





Breit-Wigner Resonances

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



- Interference handled by R-matrix formalism

Recalculating dσ/dΩ

- Dipole term of scattering angle distribution vs. energy