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Photodisintegration of Lithium Isotopes

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Few-Body Photodisintegration

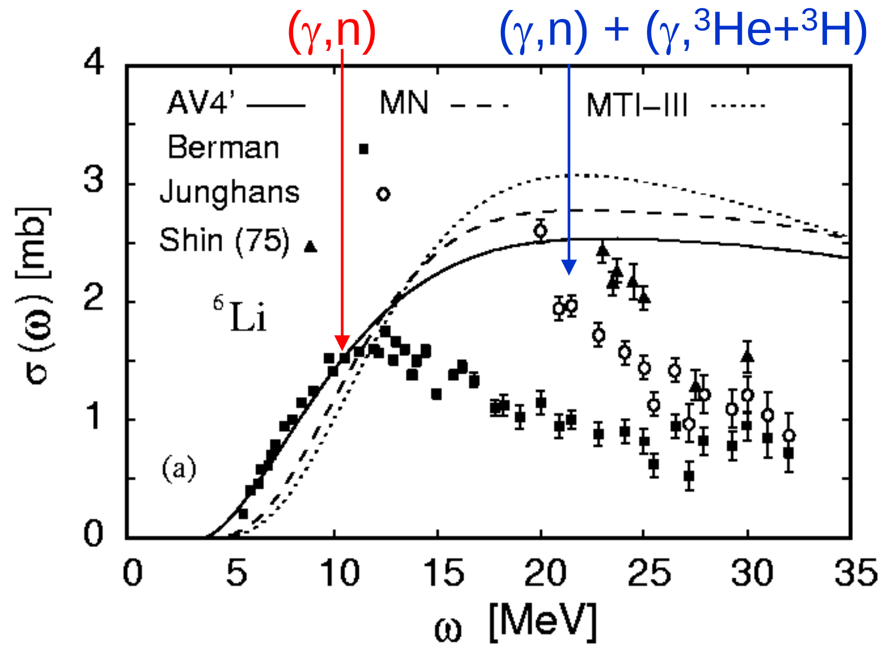
Accurate theoretical calculations are now possible

- e.g. Lorentz Integral Transform technique (e.g. Bacca, PRC 75, 044001 (2007))
- Now possible to see significant differences between the predictions of different nucleon-nucleon potential models in the giant dipole resonance region.
- Current measurements do not have the precision needed to differentiate between potential models.
- High Intensity Gamma Source (HIGS) has the potential to address this.
- Aiming for measurements with uncertainties less than a few percent – driven by systematics.

Lithium-6

- Predictions, using semi-realistic potentials, have been made for the ^{6}Li total cross section.
  - Argonne V4' (AV4'), Maliet-Tjon I-III (MTI-III) and Minnesota (MN)
- Agreement with measurements poor.
- However, the existence of multiple reaction channels makes interpretation difficult.
- Our aim is to provide detailed reaction channel information.
- To prompt calculations using realistic potentials and for specific reaction channels.
  - Such as has been done for ^{4}He

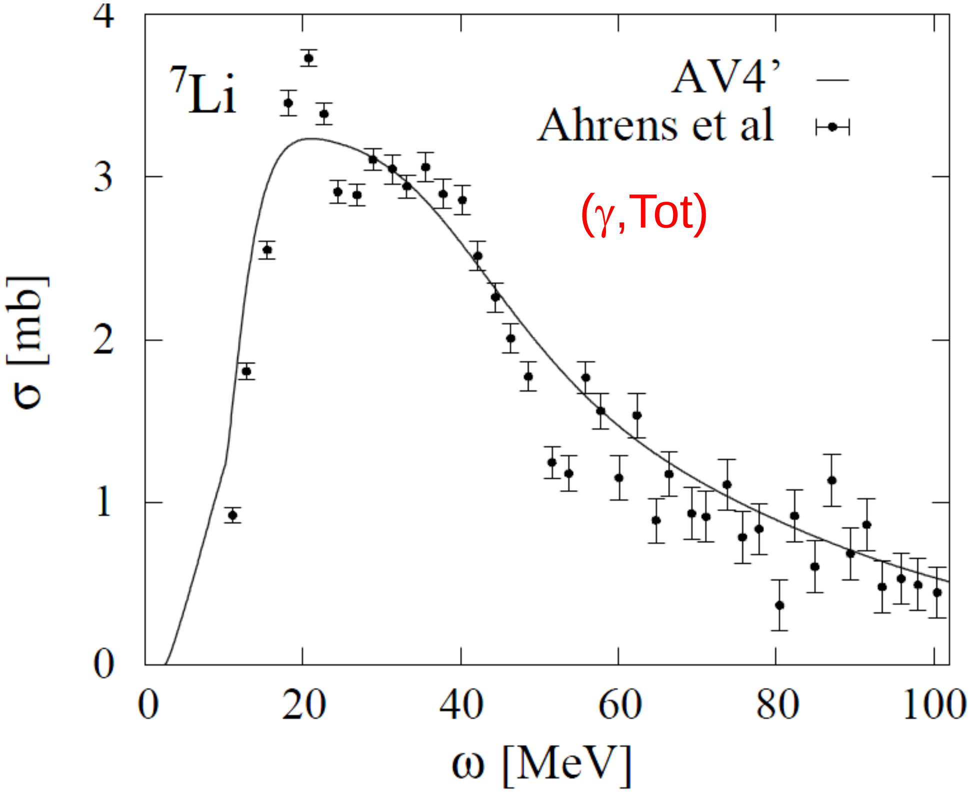
Bacca, *et al*., Phys. Rev. C **69**, 057001



Lithium-7

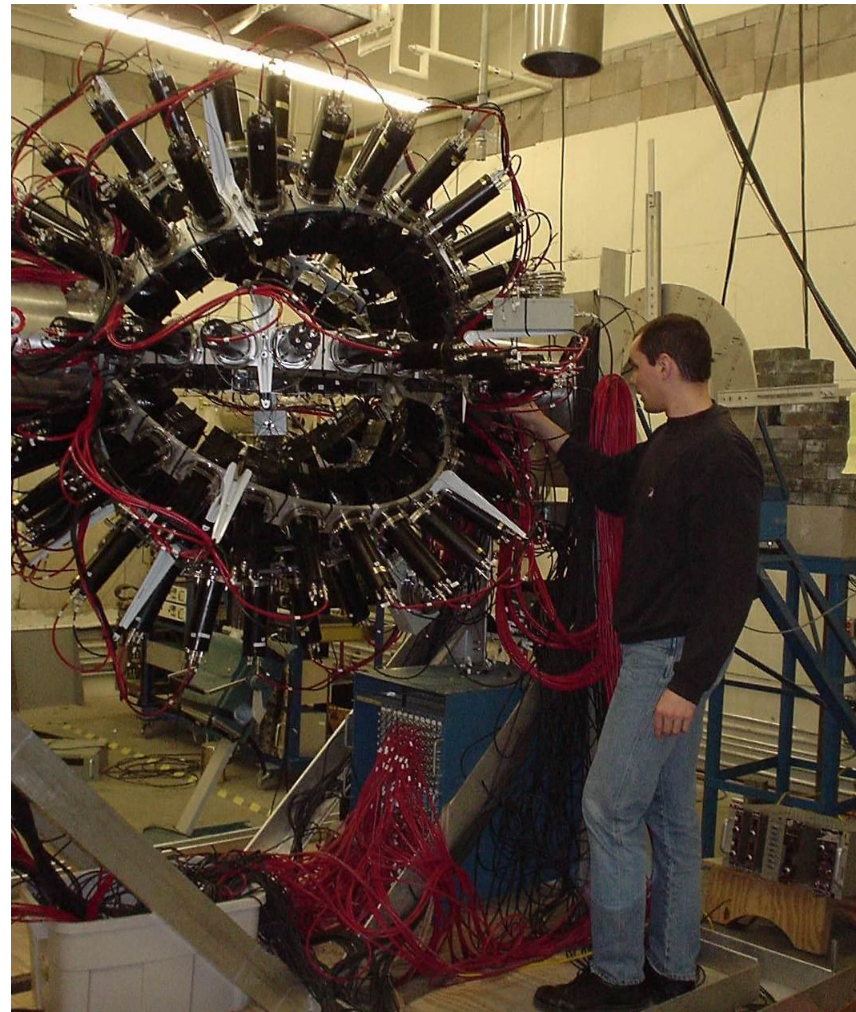
- Theoretical situation looks better.
- ^{7}Li was measured using a natural Lithium sample and subtracting the ^{6}Li contribution.
- Today I will only talk about our ^{6}Li results.

Bacca *et. al.* Phys. Lett. B 603,159 (2004).



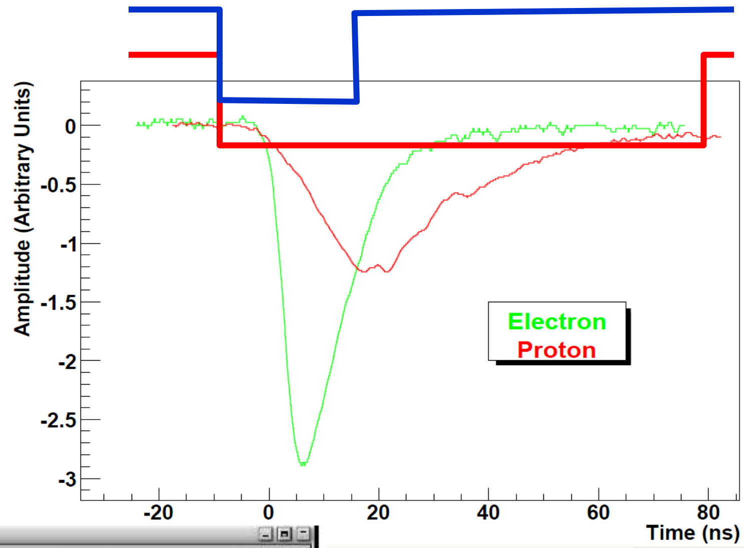
Blowfish

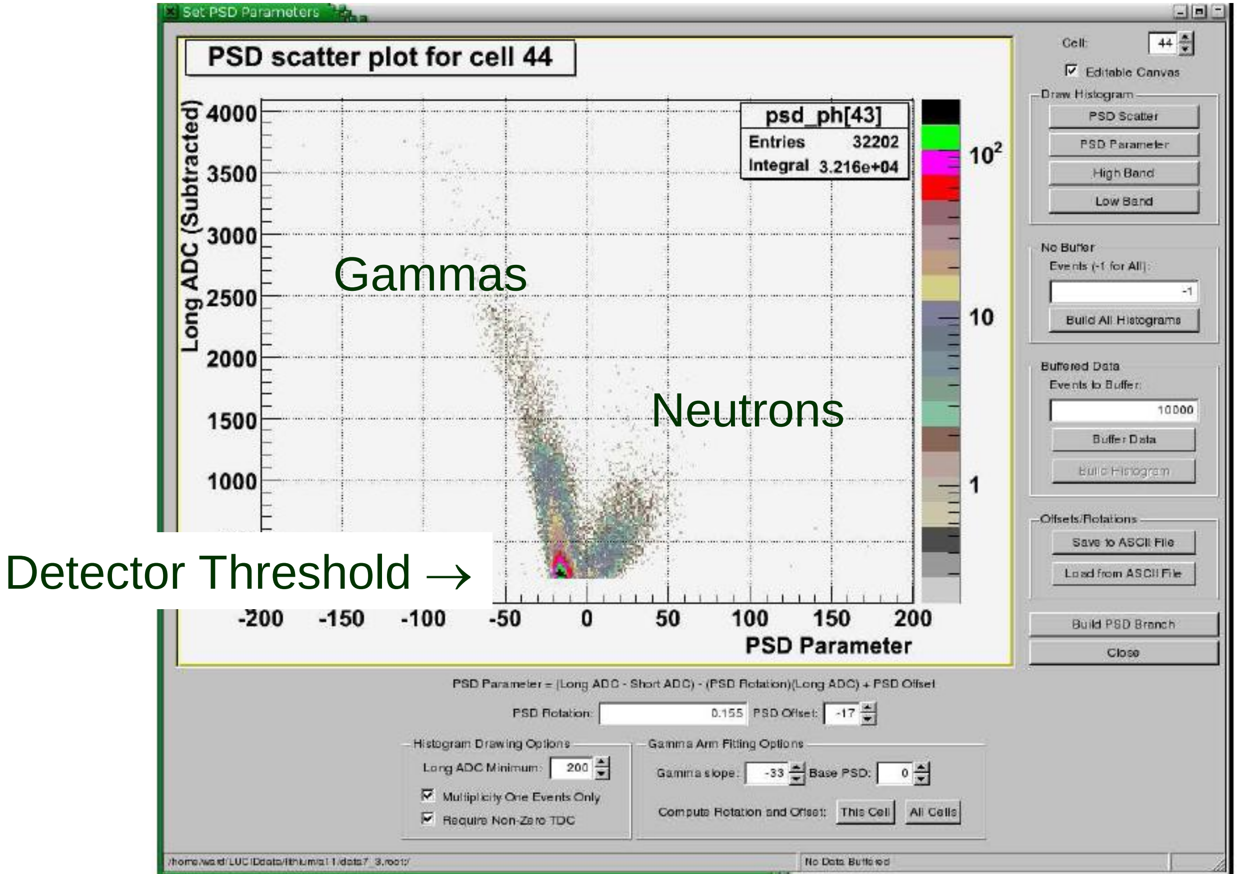
- We measure photoneutron cross sections using “Blowfish”.
- Large solid angle neutron detector
- 88 BC-505 liquid scintillator cells
  - Spherically arranged on a 16 inch radius.
  - Covers ¼ of 4 π sr.
  - Particle identification using
    - Pulse shape discrimination.
    - Time-of-flight



Blowfish

- Pulse shape discrimination
  - Short/Long gate QDC





Graphical user interface in Root

Measurements

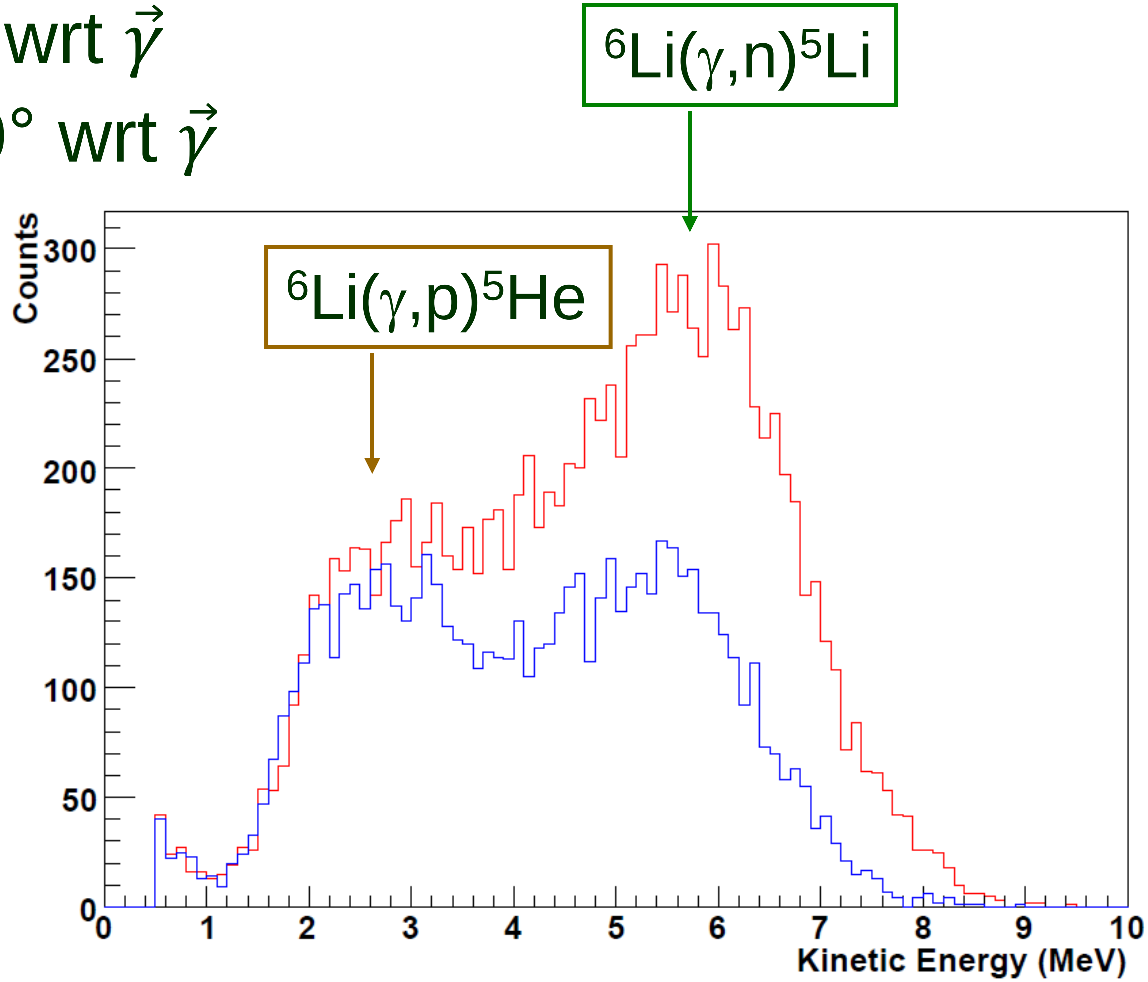
- Measurements were made using ^{6}Li, ^{7}Li(nat), and Blank targets.
- Linear polarized photons at 8, 9, 10, 11, 12, 13, 15 and 15.6 MeV.
- Circularly polarized photons at 20, 25, 30 and 35 MeV.
- Two blowfish array orientations were used at most energies to quantify systematics.

Teflon target container

^{6}Li

- One detector cell, $\theta = 90°$, $E_\gamma = 13$ MeV
- Neutron energy distribution obtained from time-of-flight
- Red – $\varphi = 0°$ wrt $\vec{\gamma}$
- Blue – $\varphi = 90°$ wrt $\vec{\gamma}$

^{5}He → ^{4}He + n
neutrons are isotropic



Cross Section

- We parameterize the cross section for each reaction channel in term of associated Legendre functions
  - For linearly polarized photons

$$\frac{d\sigma}{d\Omega}(\theta,\varphi)=\frac{\sigma}{4\pi}\left[1+\sum_{k=1}^{\infty}a_k P_k^0(\cos\theta)+\sum_{k=2}^{\infty}e_k P_k^2(\cos\theta)\cos 2\varphi\right]$$

θ = centre-of-mass polar angle w.r.t. beam

φ = azimuthal angle w.r.t. beam polarization

  - For circularly polarized photons

$$\frac{d\sigma}{d\Omega}(\theta)=\frac{\sigma}{4\pi}\left[1+\sum_{k=1}^{\infty}a_k P_k^0(\cos\theta)\right]$$

  - We find $k \le 4$ sufficient.

Detector Simulation

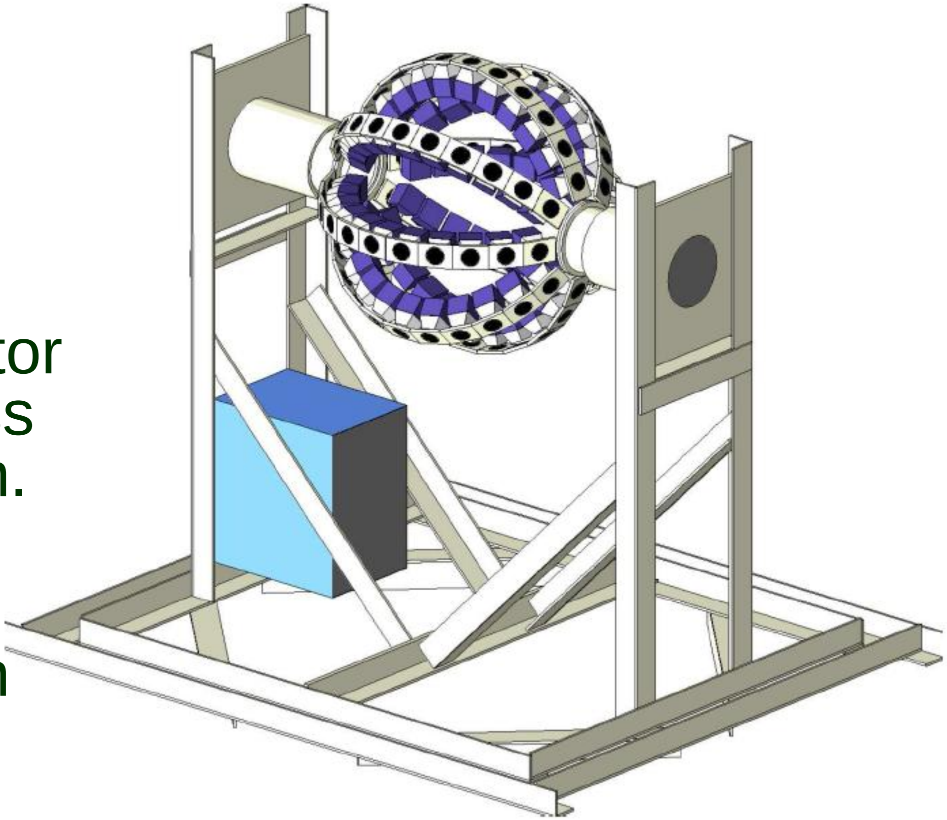
- In general there are many reaction channels producing neutrons to consider.
- Each channel is characterized by a different neutron energy spectrum.
- This must be included in the detector response function.

Reaction Channels with neutrons in the final state for ^{6}Li.

Label	Reaction	Threshold (MeV)
(γ, p_0)	$^6\mathrm{Li} + \gamma \rightarrow p + {}^5\mathrm{He(g.s.)} \rightarrow n + p + {}^4\mathrm{He}$	4.6
(γ, n_0)	$^6\mathrm{Li} + \gamma \rightarrow n + {}^5\mathrm{Li(g.s.)}$	5.7
(γ, p_1)	$^6\mathrm{Li} + \gamma \rightarrow p + {}^5\mathrm{He}(1.27) \rightarrow n + p + {}^4\mathrm{He}$	5.9
(γ, n_1)	$^6\mathrm{Li} + \gamma \rightarrow n + {}^5\mathrm{Li}(1.49)$	7.0
(γ, p_2)	$^6\mathrm{Li} + \gamma \rightarrow p + {}^5\mathrm{He}(16.8) \rightarrow n + p + {}^4\mathrm{He}$	21.4
(γ, n_2)	$^6\mathrm{Li} + \gamma \rightarrow n + {}^5\mathrm{Li}(16.9)$	22.6
(γ, p_3)	$^6\mathrm{Li} + \gamma \rightarrow p + {}^5\mathrm{He}(19.1) \rightarrow n + p + {}^4\mathrm{He}$	23.7
(γ, n_3)	$^6\mathrm{Li} + \gamma \rightarrow n + {}^5\mathrm{Li}(19.3)$	25.0

Detector Simulation

- Simulation uses the GEANT4 toolkit.
- Light output for BC-505 well understood
  - NIMA 565, 725 (2006).
- Used to determine the **detector response function** for each detector for each term in the cross section parameterization.
- Fit to data to determine reaction channel cross section parameterization coefficients.



Blowfish and support structure as rendered by GEANT4

Fitting

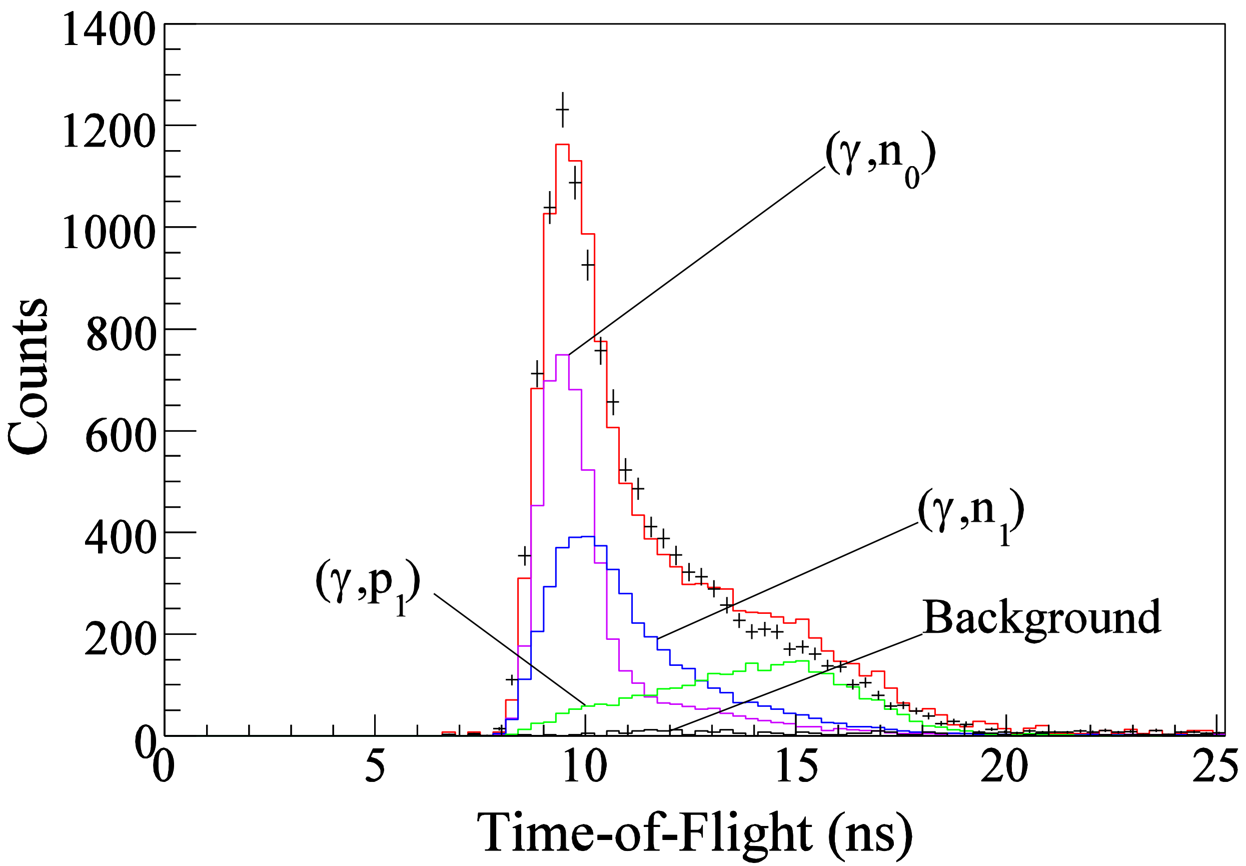
- Fit to each neutron detector time-of-flight spectrum after PSD cuts based on the expected neutron energy spectrum for each reaction channel.

Example:

^{6}Li at

E_γ = 20 MeV

Background from atmospheric nitrogen.



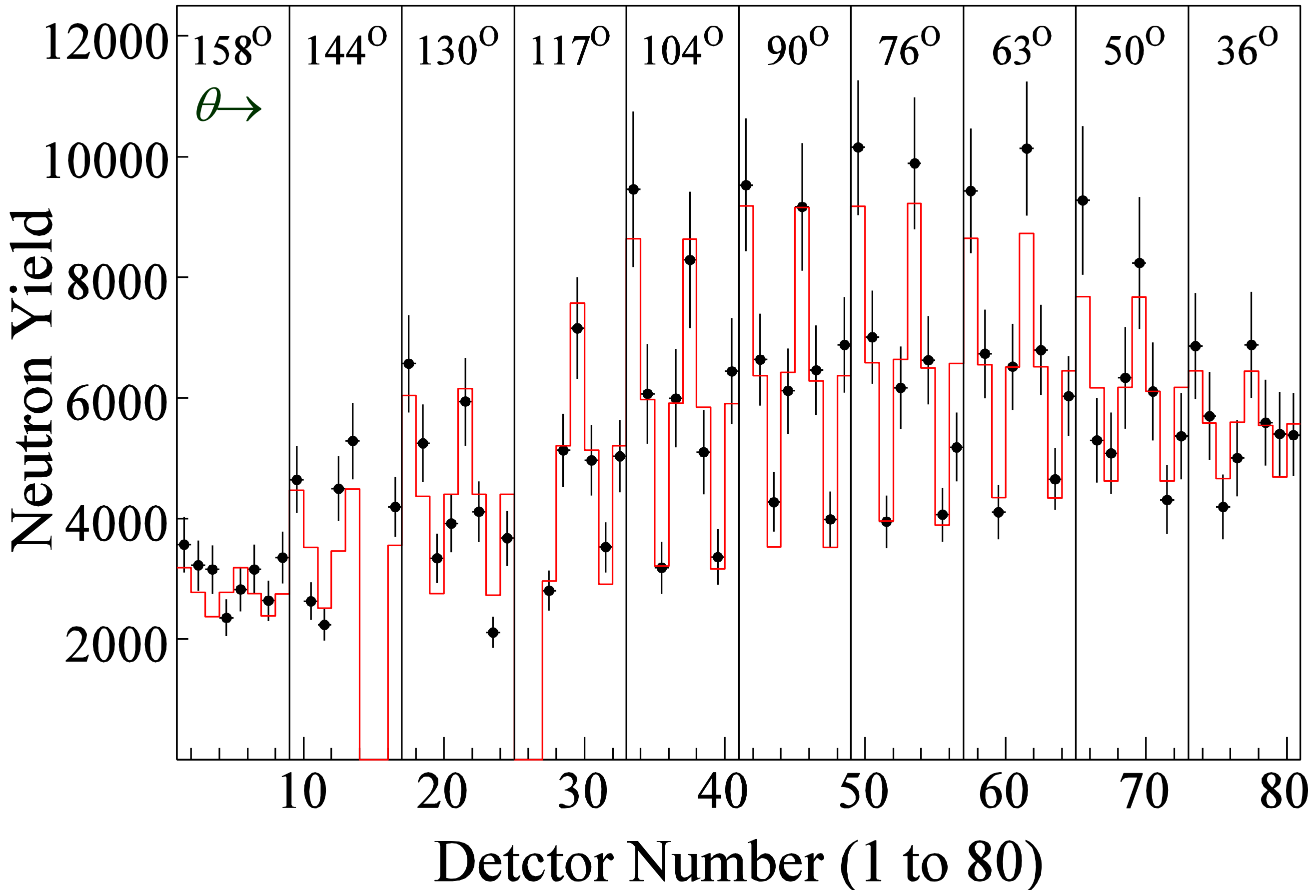
Fitting

- Then, knowing the contribution from each reaction channel in each detector cell we can fit the yields in each cell to determine the differential cross section coefficients.

Example:

^{6}Li at

E_γ = 13 MeV



Fitting

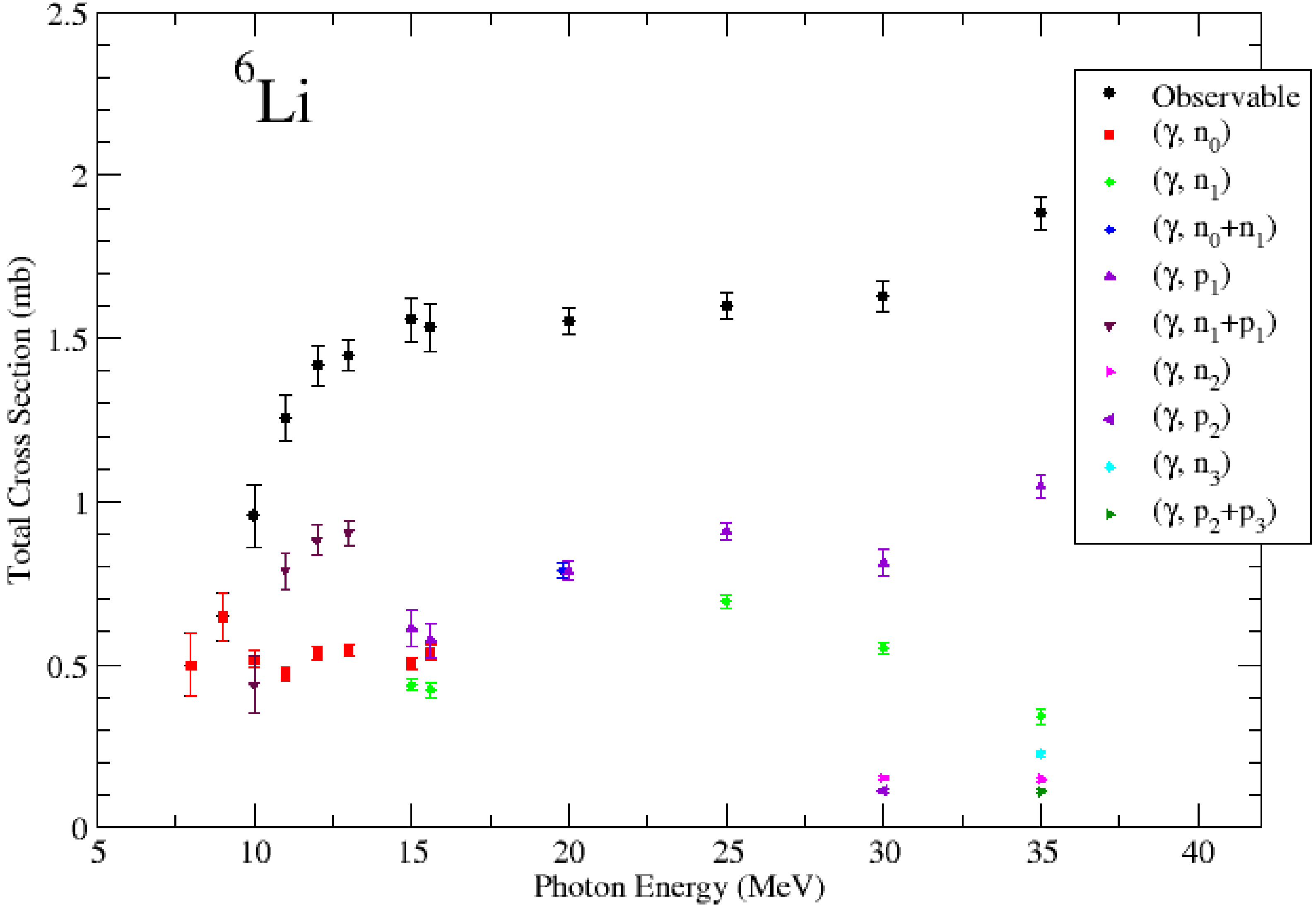
- Not all reaction channels contribute significantly at all energies.
- Some reaction channels at some energies have neutron energy distributions that cannot be separated with statistical significance – so they are combined in the fit.
  - e.g. At 20 MeV we can only extract the cross section for ^{6}Li(γ,n_0+n_1)
- Only those coefficients that are needed to accurately describe the cross section, with statistical significance, are reported.
  - e.g. Coefficients a_1, a_2, e_2, e_3 are extracted for the ^{6}Li(γ,n_0) channel.
  - e.g. Only a_1 Coefficient is statistically significant for the ^{6}Li(γ,p_1) channel.

Absolute Cross Sections

- We have two methods of determining the Photon Flux.
- Photon Flux Monitor
  - Accurately calibrated against a NaI detector
  - ~2% accuracy
- Compton scattering from target into Blowfish cells
  - Calibrates product of target thickness and photon flux.
- Methods give cross sections that agree within errors.

^{6}Li Cross Sections

Errors are dominated by the systematic uncertainties associated with the fitting process.

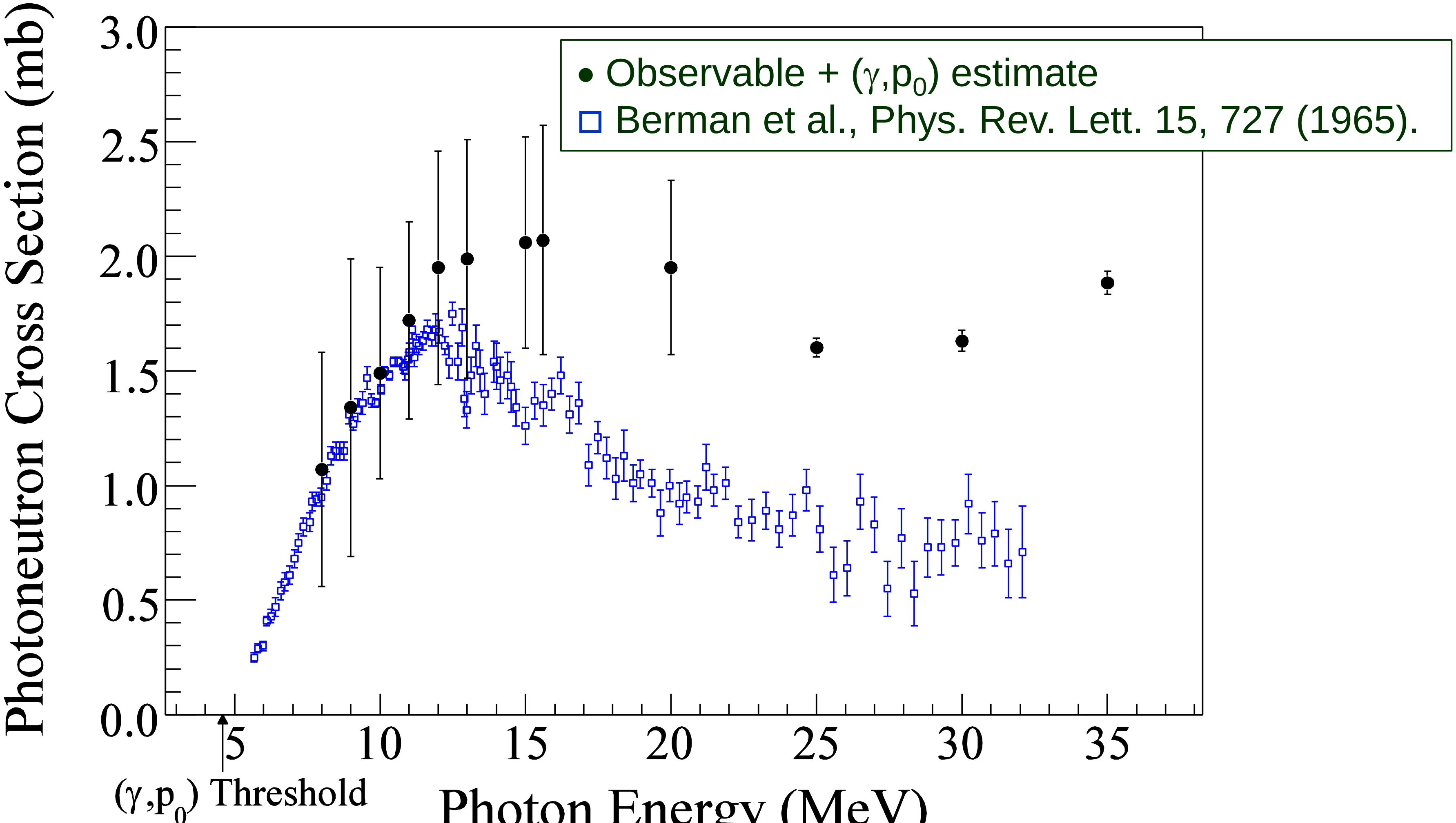


Comparison to Earlier Photoneutron Measurements

- Although the ^{6}Li(γ,p_0) channel produces neutrons, they are of low energy and are below our detector thresholds.
- Measurements, such as the quasi-monoenergetic photon measurements of the Livermore group, are sensitive to neutrons of all energies.
- Direct measurements of (γ,p_0) are poor.
- Therefore, to make a comparison, the best we can do is make the assumption that

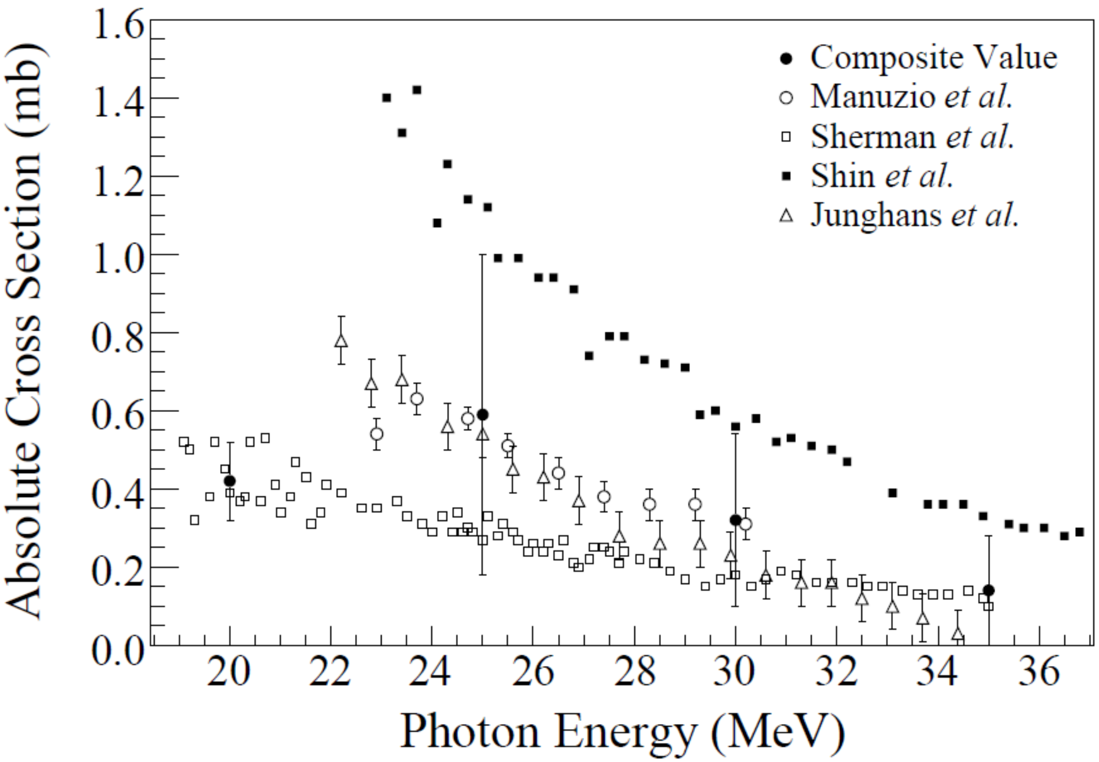
$$\sigma(\gamma,p_0) = \sigma(\gamma,n_0) \pm 100\%$$

Comparison to Earlier Photoneutron Measurements



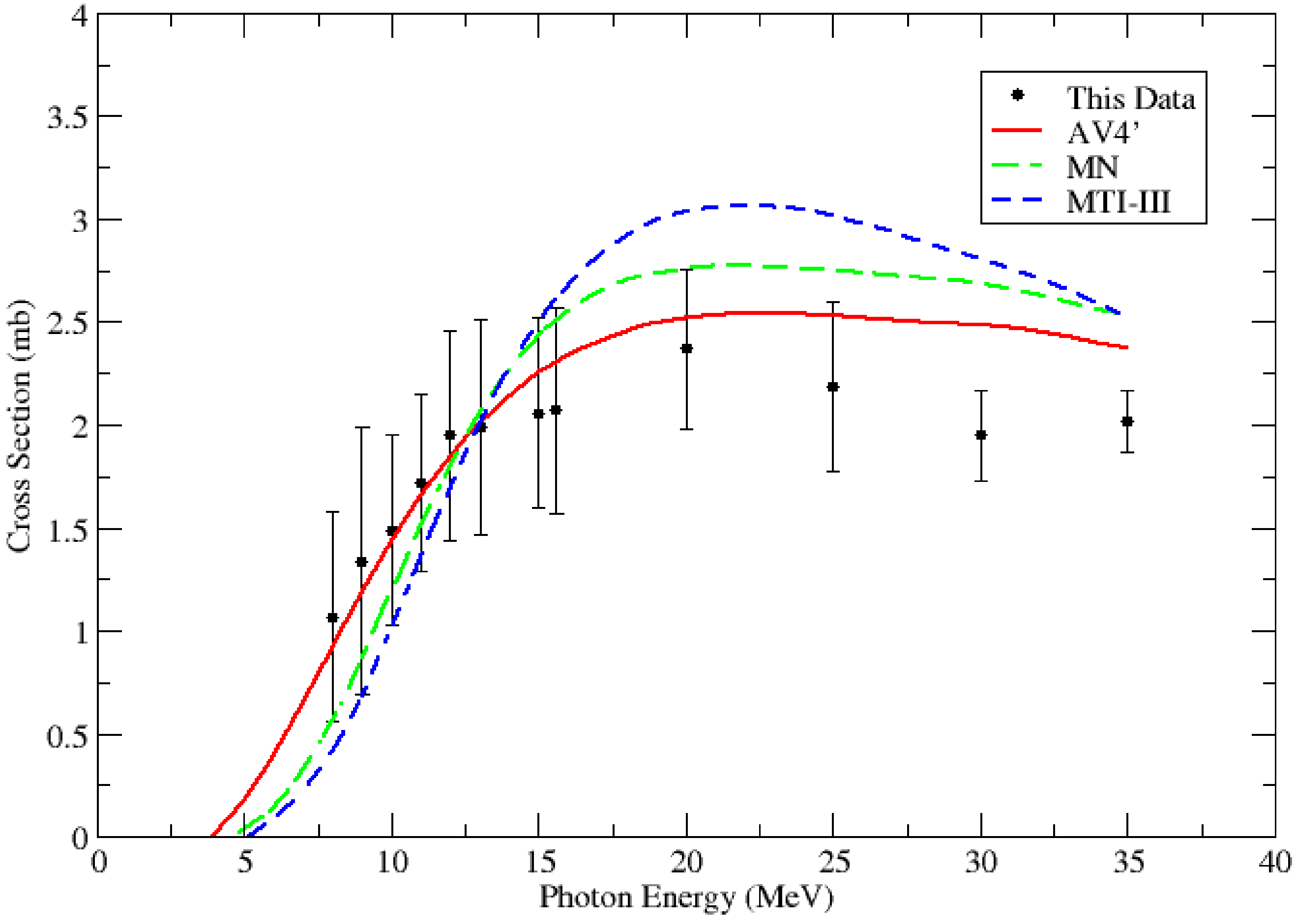
Comparison to Theory

- To compare to the theoretical prediction for the total photoabsorption cross section we need to add an estimate for the (γ,^{3}He,^{3}H) reaction channel.
- This is the most important reaction channel that does not produce neutrons.
- Significant disagreement between measurements.
- We make an estimate by averaging existing data.



Comparison to Theory

- Seems to favor AV4’
- Large error bars are because of unmeasured reaction channels.



Conclusions

- Individual reaction channels can be measured with high precision.
- Comparison to Theory is compromised by the need to estimate unmeasured reaction channels.
  - (γ,p_0) and (γ,^{3}He,^{3}H)
- Motivation for theorists to make predictions for specific reaction channels that are measurable with high precision.
- Long base-line neutron time-of-flight measurement may be able to unravel (γ,p_0) for other reaction channels.