Photodisintegration of Lithium Isotopes

*R.E. Pywell, **W.A. Wurtz***
University of Saskatchewan
B. Norum, S. Kucucker
University of Virginia
H.R. Weller, M.W. Ahmed, S.Stave
Duke University

UNIVERSITY OF SASKATCHEWAN

Few-Body Photodisintegration

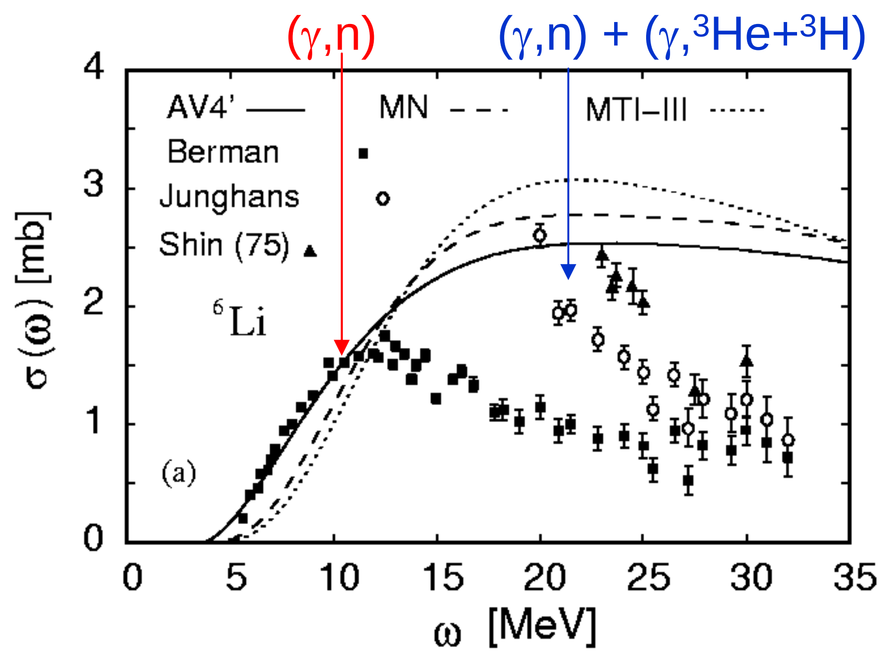
Accurate theoretical calculations are now possible

- 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 quality to differentiate between potential models.
- 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

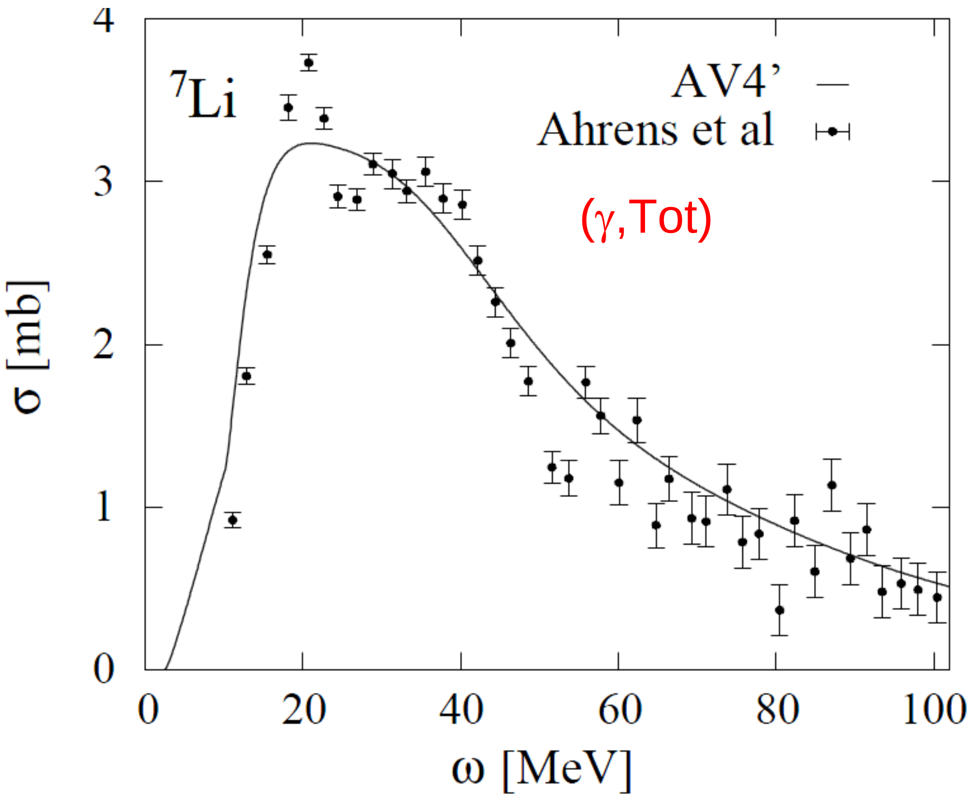
Bacca, *et al*., Phys. Rev. C **69**, 057001



Lithium-7

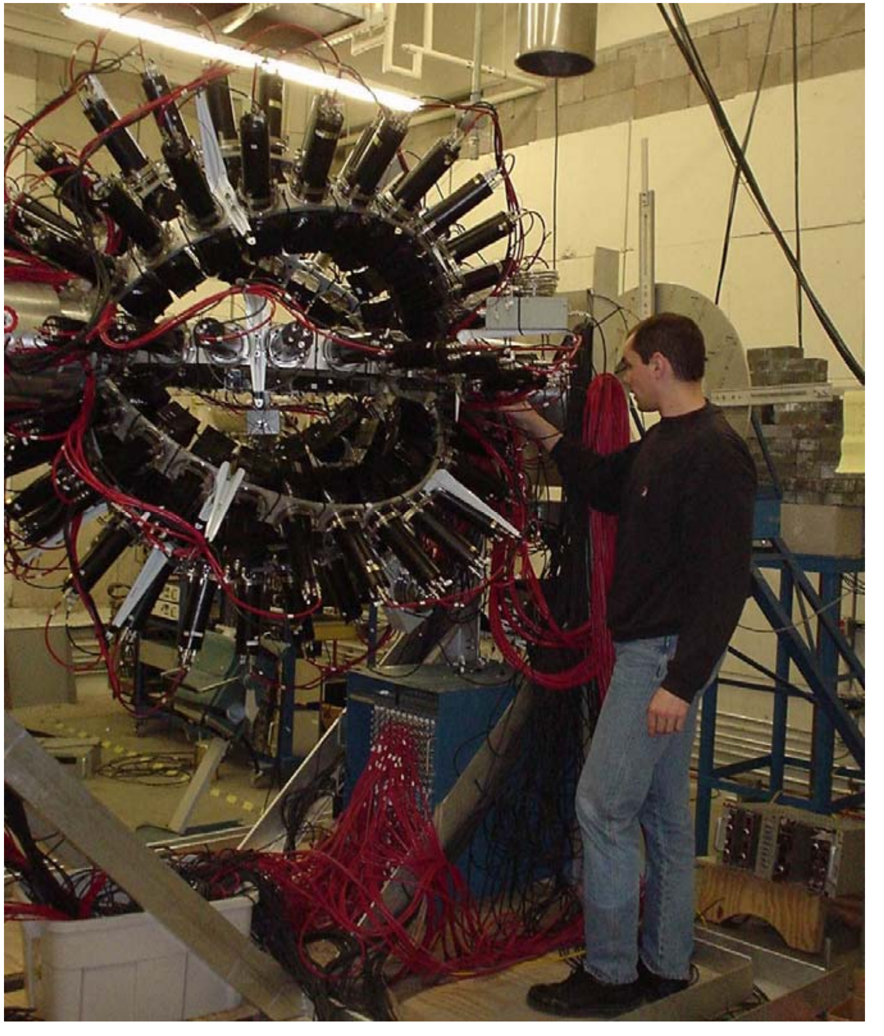
- Theoretical situation looks better.
- ^{7}Li needs to be measured anyway due to its presence in the ^{6}Li sample.

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



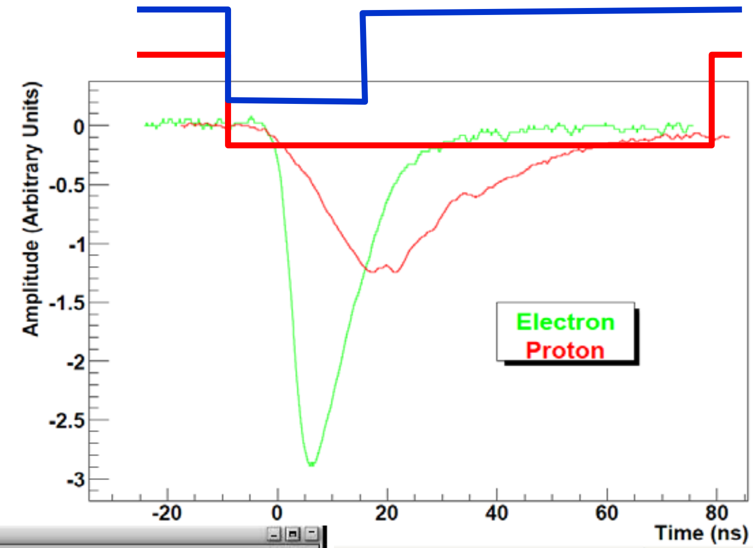
Blowfish

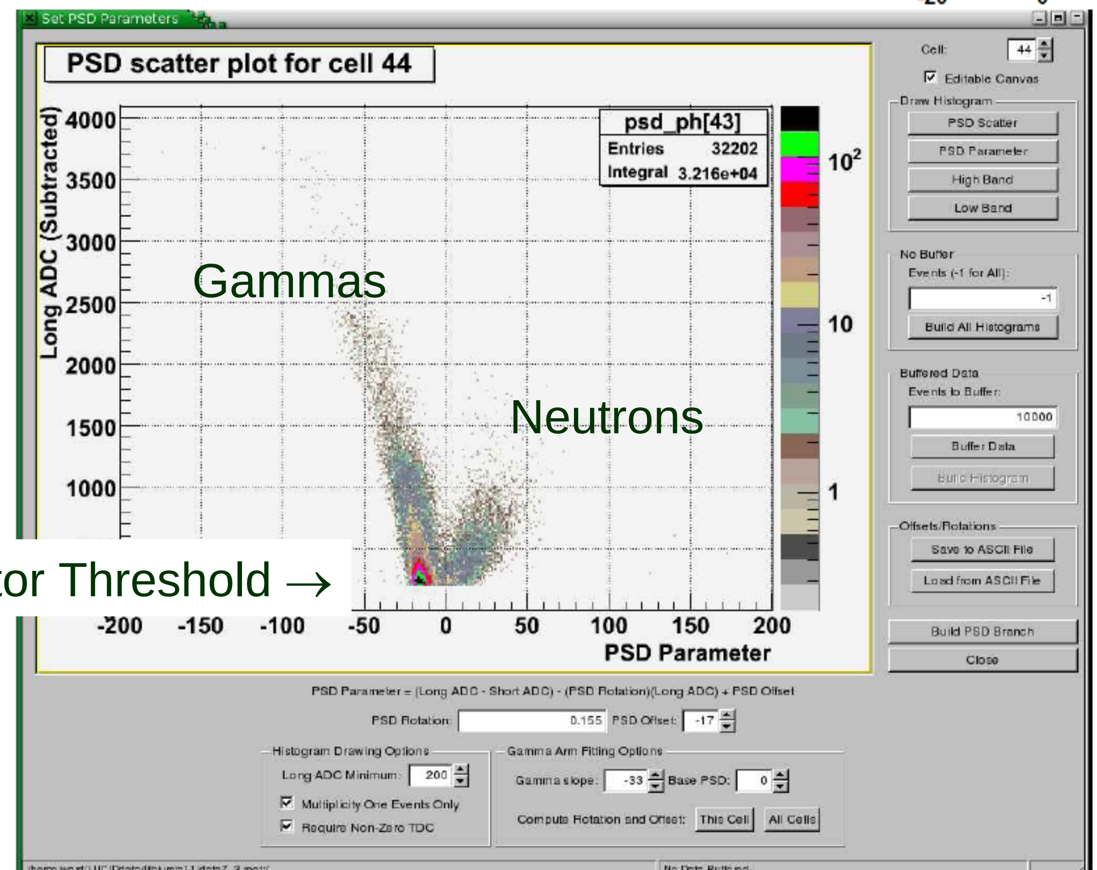
- Large solid angle neutron detector
- 88 BC-505 liquid scintillator cells
  - Spherically arranged on a 16 inch radius.
  - Covers ¼ of 4 π sr.
  - Particle identification using
    - Pulse shape discrimination.
    - Time-of-flight



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

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

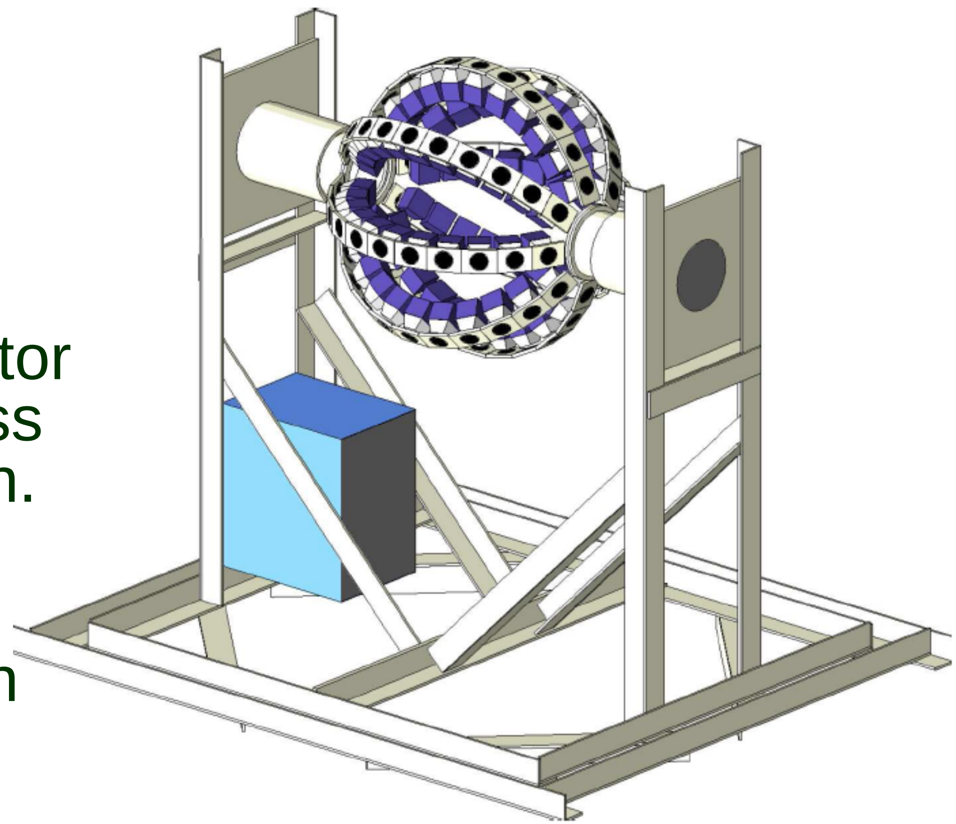
- In general there are many reaction channels to consider.
- Each channel is characterized by a different neutron energy spectrum.
- This must be included in the detector response function.

Reaction Channels with neutrons in the final state for ^{7}Li with photon energies below 16 MeV.

Label	Reaction		Threshold (MeV)
7n0	$^7\mathrm{Li} + \gamma \rightarrow n + {}^6\mathrm{Li(g.s.)}$		7.3
7nd	$^7\mathrm{Li} + \gamma \rightarrow n + d + {}^4\mathrm{He(g.s.)}$		8.7
7n1	$^7\mathrm{Li} + \gamma \rightarrow n + {}^6\mathrm{Li}(2.19)$		9.5
7d0	$^7\mathrm{Li} + \gamma \rightarrow d + {}^5\mathrm{He(g.s.)}$	$\rightarrow n + d + {}^4\mathrm{He(g.s.)}$	9.6
7n2	$^7\mathrm{Li} + \gamma \rightarrow n + {}^6\mathrm{Li}(3.56)$		10.9
7d1	$^7\mathrm{Li} + \gamma \rightarrow d + {}^5\mathrm{He}(1.27)$	$\rightarrow n + d + {}^4\mathrm{He(g.s.)}$	10.9
7n3	$^7\mathrm{Li} + \gamma \rightarrow n + {}^6\mathrm{Li}(4.31)$		11.6
7p1	$^7\mathrm{Li} + \gamma \rightarrow p + {}^6\mathrm{He}(1.78)$	$\rightarrow p + 2n + {}^4\mathrm{He(g.s.)}$	11.8
7np0	$^7\mathrm{Li} + \gamma \rightarrow n + p + {}^5\mathrm{He(g.s.)}$	$\rightarrow 2n + p + {}^4\mathrm{He(g.s.)}$	11.8
7n4	$^7\mathrm{Li} + \gamma \rightarrow n + {}^6\mathrm{Li}(5.37)$		12.7
7n5	$^7\mathrm{Li} + \gamma \rightarrow n + {}^6\mathrm{Li}(5.65)$		12.9
7nn0	$^7\mathrm{Li} + \gamma \rightarrow 2n + {}^5\mathrm{Li(g.s.)}$	$\rightarrow 2n + p + {}^4\mathrm{He(g.s.)}$	12.9
7np1	$^7\mathrm{Li} + \gamma \rightarrow n + p + {}^5\mathrm{He}(1.27)$	$\rightarrow 2n + p + {}^4\mathrm{He(g.s.)}$	13.1
7nn1	$^7\mathrm{Li} + \gamma \rightarrow 2n + {}^5\mathrm{Li}(1.49)$	$\rightarrow 2n + p + {}^4\mathrm{He(g.s.)}$	14.4

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.

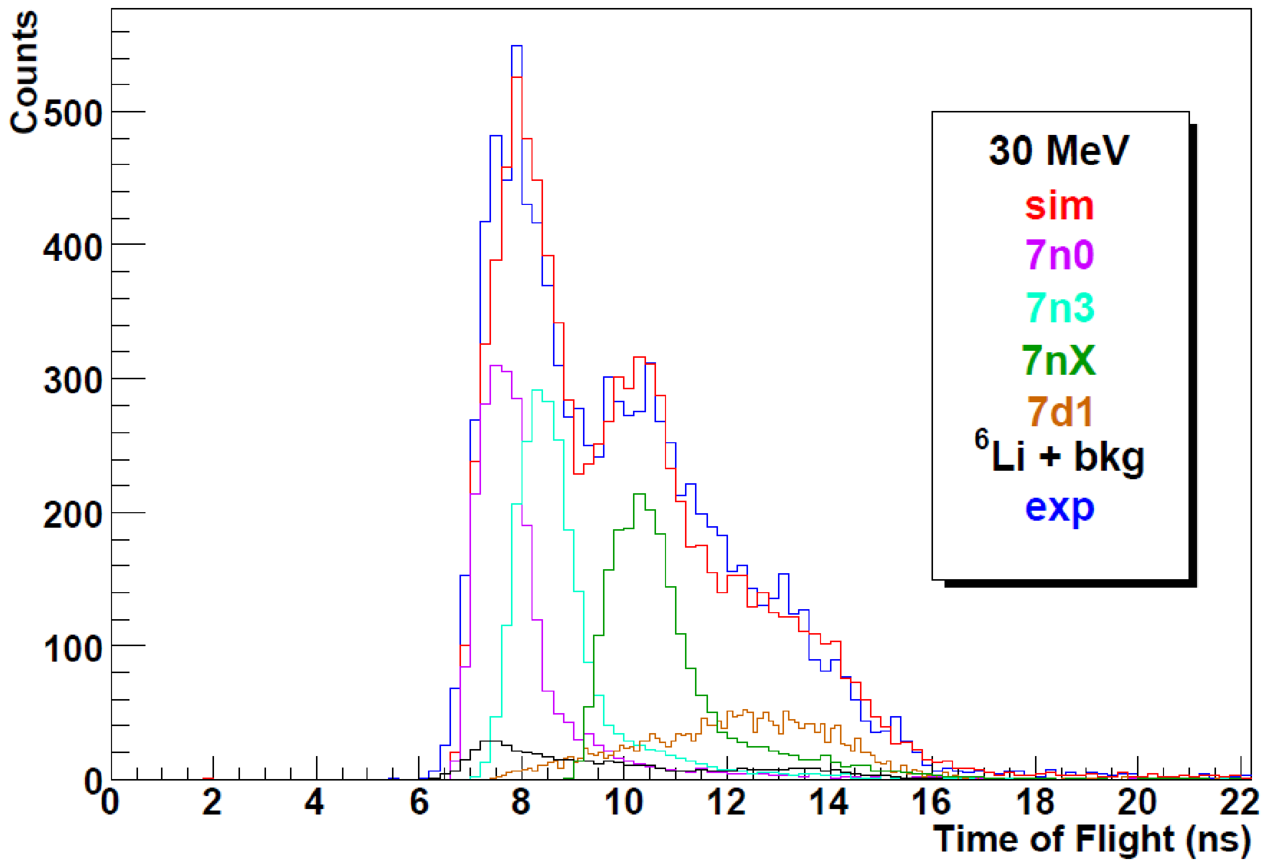


Blowfish and support structure as rendered by GEANT4

Fitting

- Fit to each neutron detector time-of-flight spectrum after PSD cuts.

Example:
^{7}Li at
E_γ = 30 MeV



Results

A sample: ^{6}Li below 16 MeV.

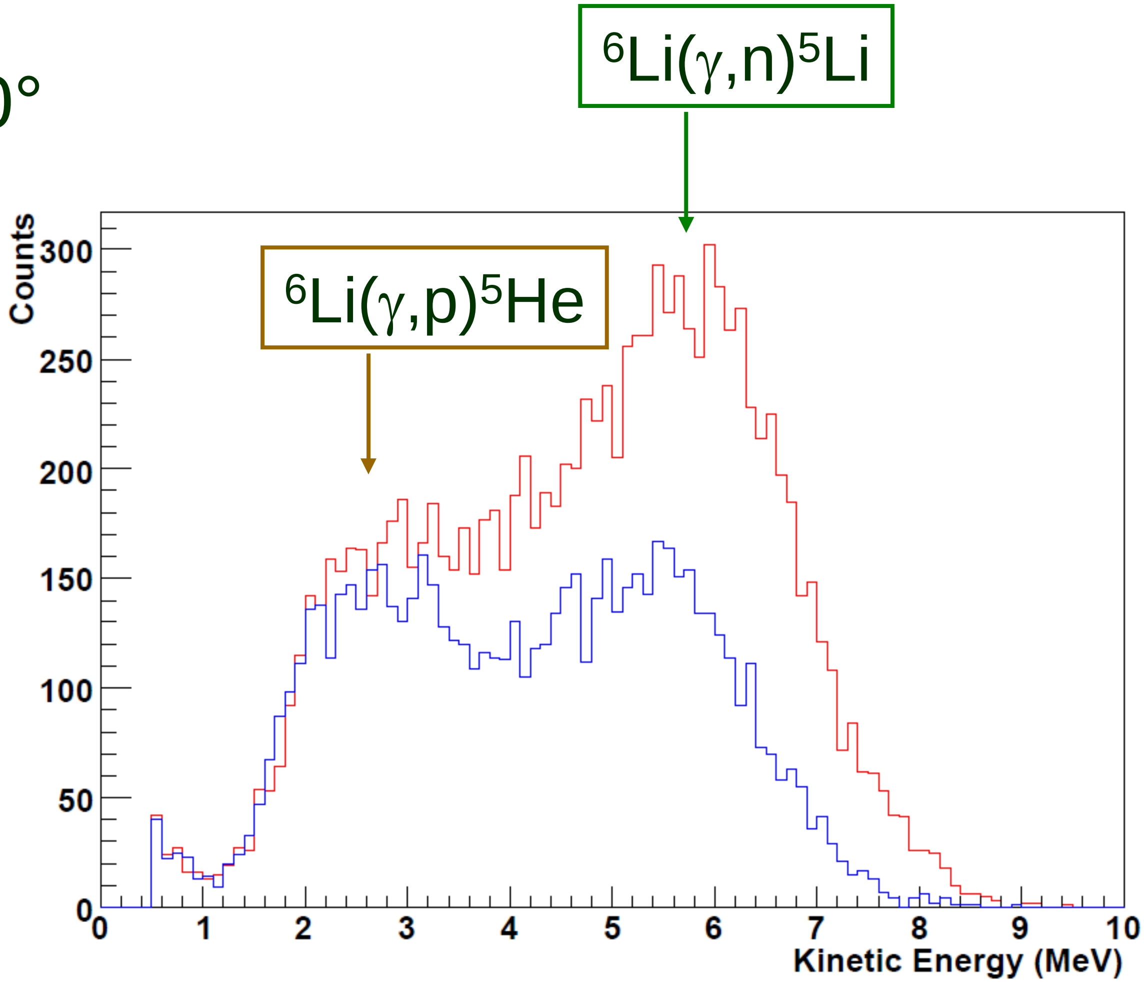
Label	Reaction		Threshold (MeV)
6np	$^6\mathrm{Li} + \gamma \to n + p + {}^4\mathrm{He(g.s.)}$		3.7
6p0	$^6\mathrm{Li} + \gamma \to p + {}^5\mathrm{He(g.s.)}$	$\to n + p + {}^4\mathrm{He(g.s.)}$	4.6
6n0	$^6\mathrm{Li} + \gamma \to n + {}^5\mathrm{Li(g.s.)}$		5.7
6p1	$^6\mathrm{Li} + \gamma \to p + {}^5\mathrm{He}(1.27)$	$\to n + p + {}^4\mathrm{He(g.s.)}$	5.9
6n1	$^6\mathrm{Li} + \gamma \to n + {}^5\mathrm{Li}(1.49)$		7.0

The 6np channel (with even weakly correlated n and p) is found to be negligible.

^{6}Li

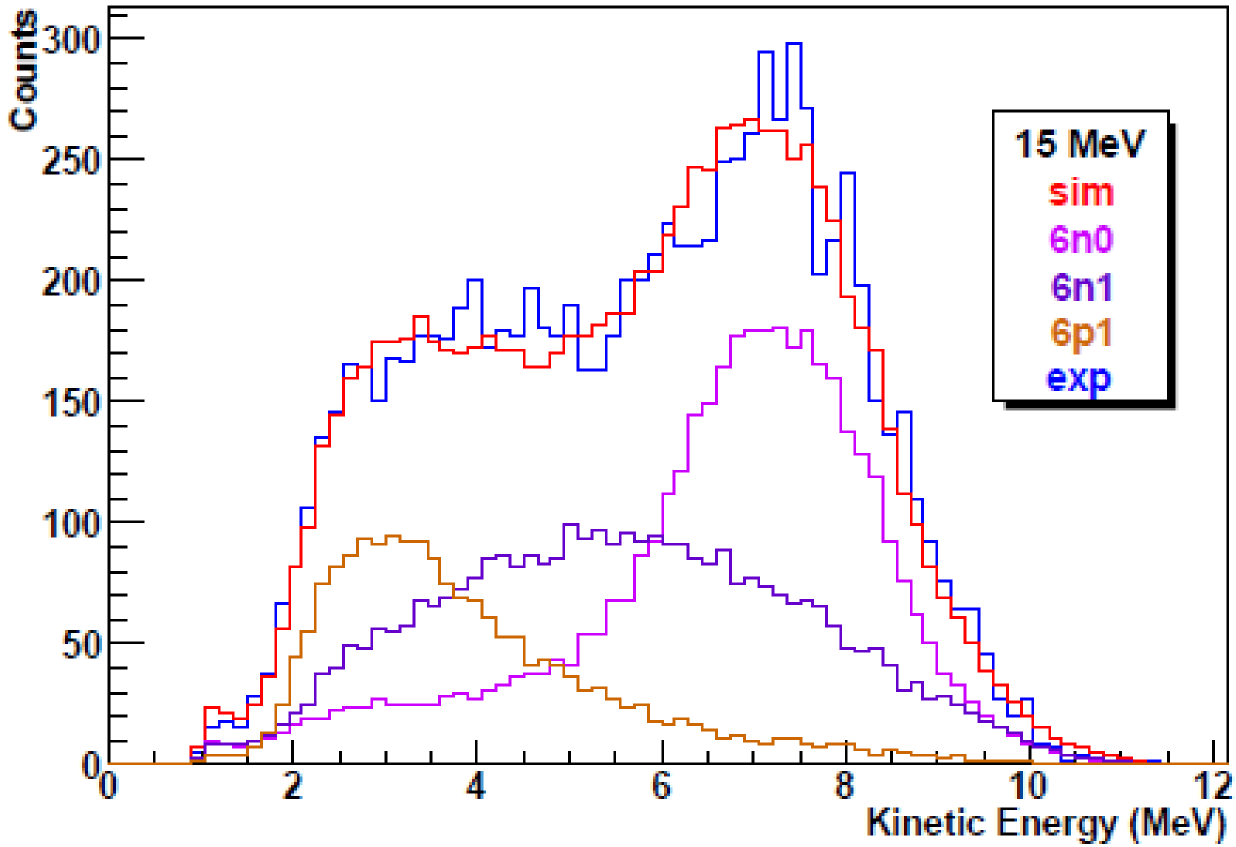
- One detector cell, $\theta = 90°$, $E_\gamma = 13$ MeV
- Red – $\varphi = 0°$
- Blue – $\varphi = 90°$

$^{5}He \rightarrow {}^{4}He + n$
neutrons are isotropic



^{6}Li

- 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
  - Some checks still to do

Conclusions

- Data analysis very advanced.

Results will be

- For specific reaction channels
  - absolute differential cross sections
  - asymmetries
- Total absorption cross sections where possible
- Provide incentive for theorists to complete calculations using realistic potentials.
- Will then provided a sensitive test for the dynamics included in the models.