

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

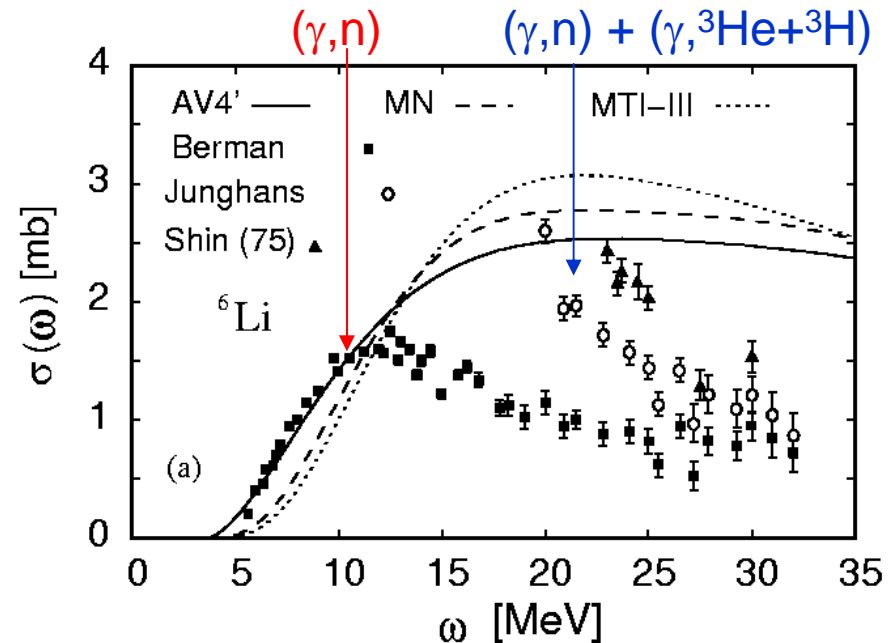
Accurate theoretical calculations are now possible

- 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 ${}^6\text{Li}$ 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 ${}^4\text{He}$

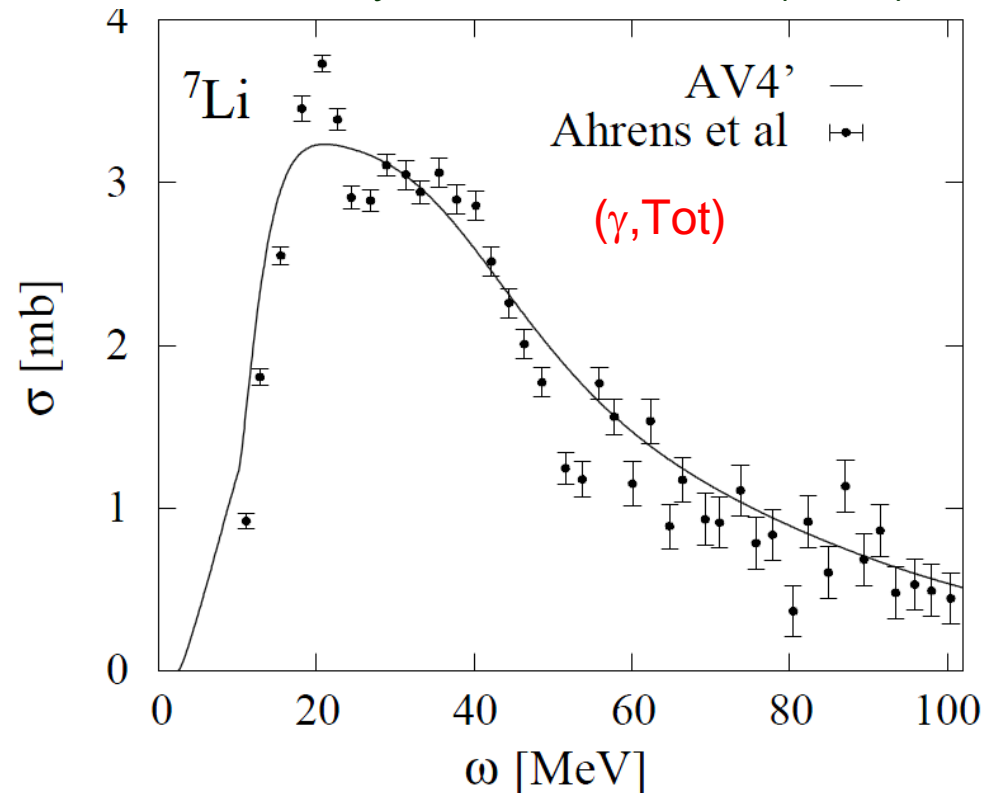
Bacca, *et al.*, Phys. Rev. C **69**, 057001



Lithium-7

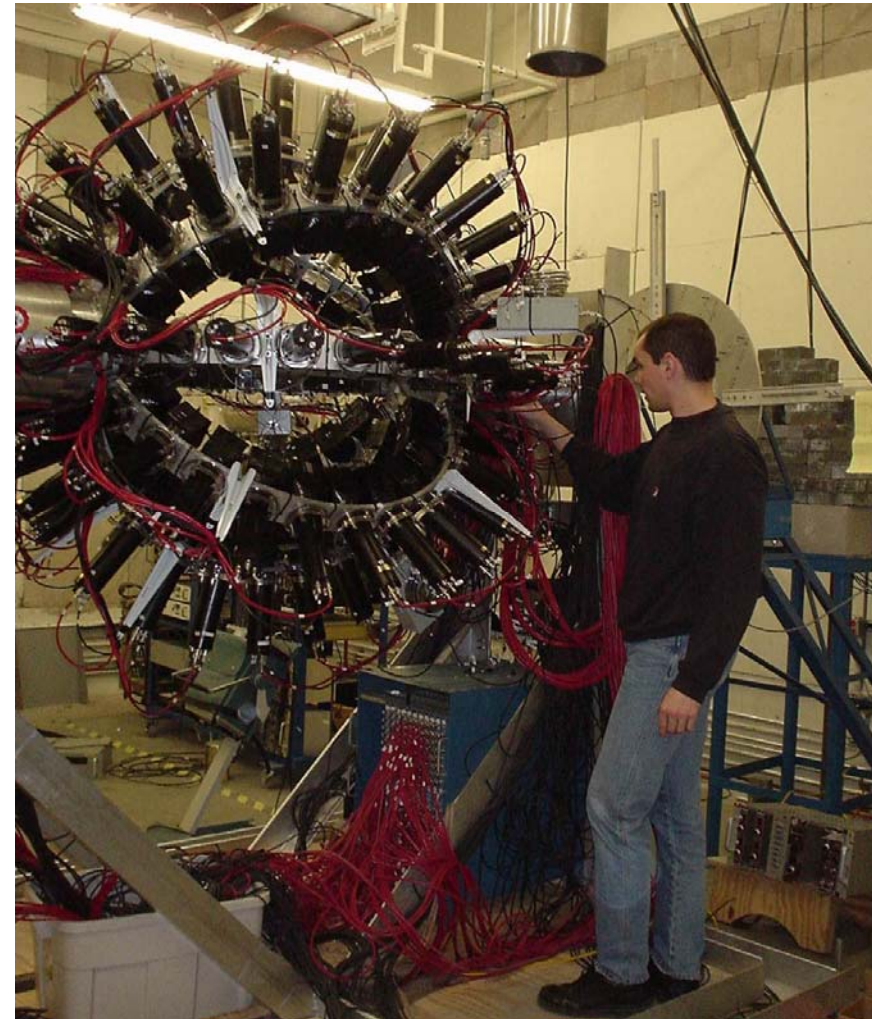
- Theoretical situation looks better.
- ${}^7\text{Li}$ needs to be measured anyway due to its presence in the ${}^6\text{Li}$ sample.

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



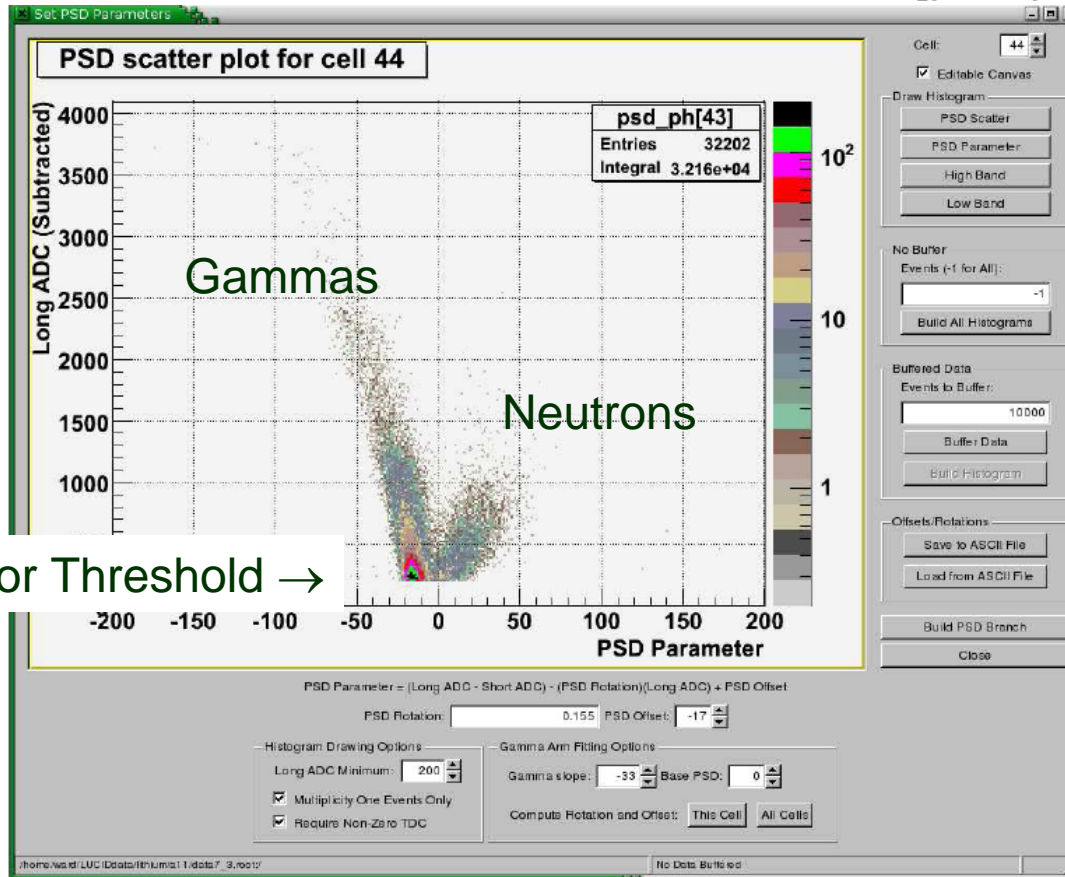
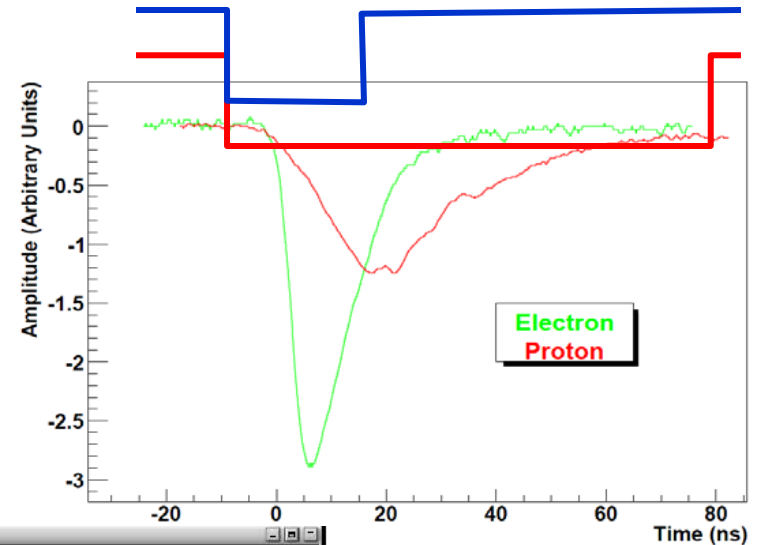
Blowfish

- Large solid angle neutron detector
- 88 BC-505 liquid scintillator cells
 - Spherically arranged on a 16 inch radius.
 - Covers $\frac{1}{4}$ of 4π sr.
 - Particle identification using
 - Pulse shape discrimination.
 - Time-of-flight



Blowfish

- Pulse shape discrimination
- Short/Long gate QDC



Detector Threshold →

Graphical user interface in Root

Measurements

- Measurements were made using ${}^6\text{Li}$, ${}^7\text{Li}(\text{nat})$, 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 $k \leq 4$ sufficient.

Detector Simulation

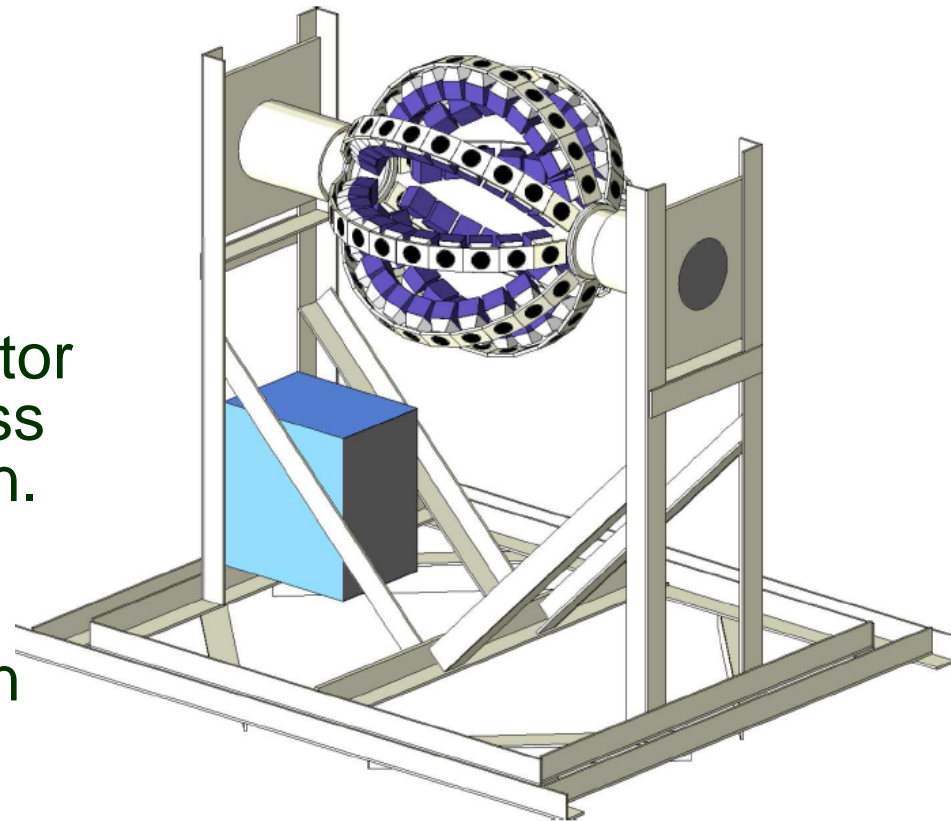
- In general there are many reaction channels to consider.
- Each channel is characterized by a different neutron energy spectrum.
- This must be included in the detector response function.

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

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

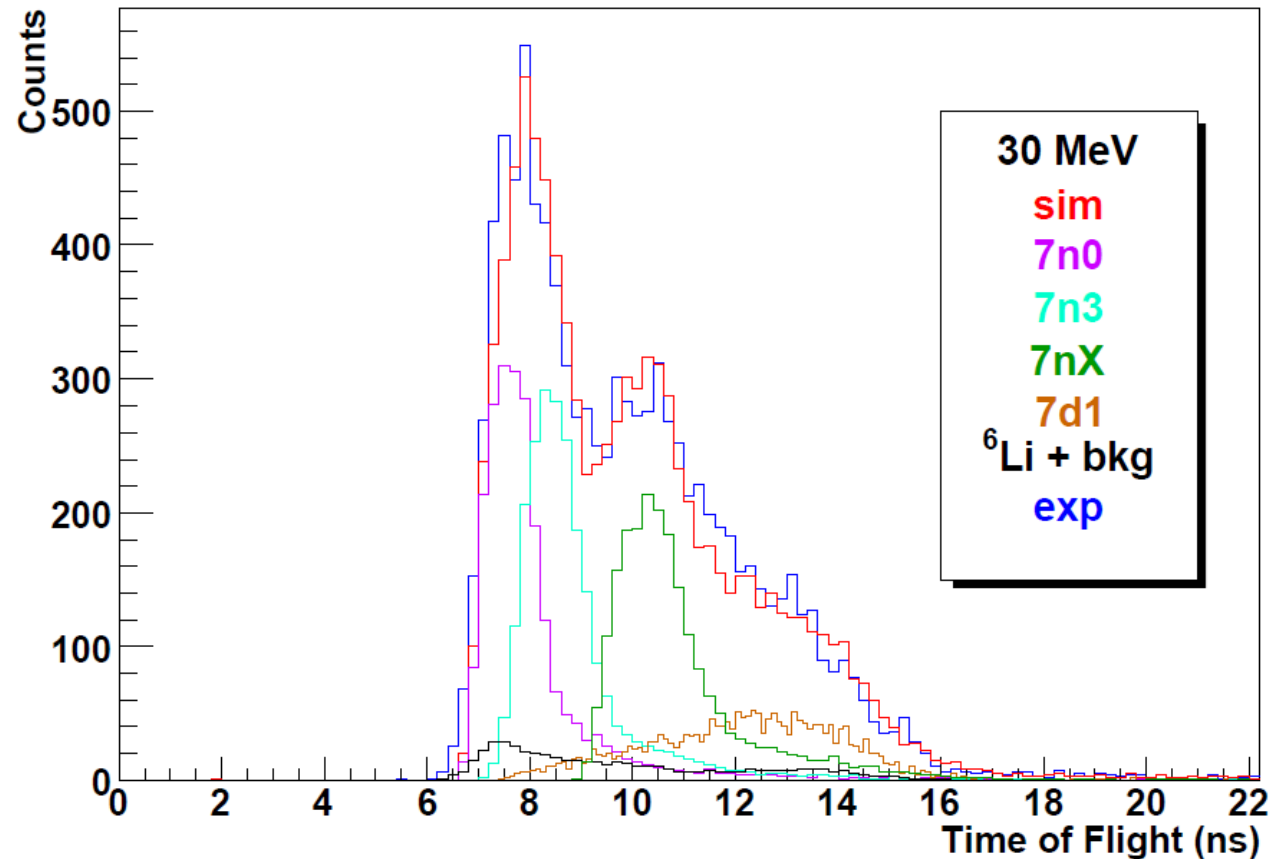
Fitting

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

Example:

${}^7\text{Li}$ at

$E_\gamma = 30 \text{ MeV}$



Results

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

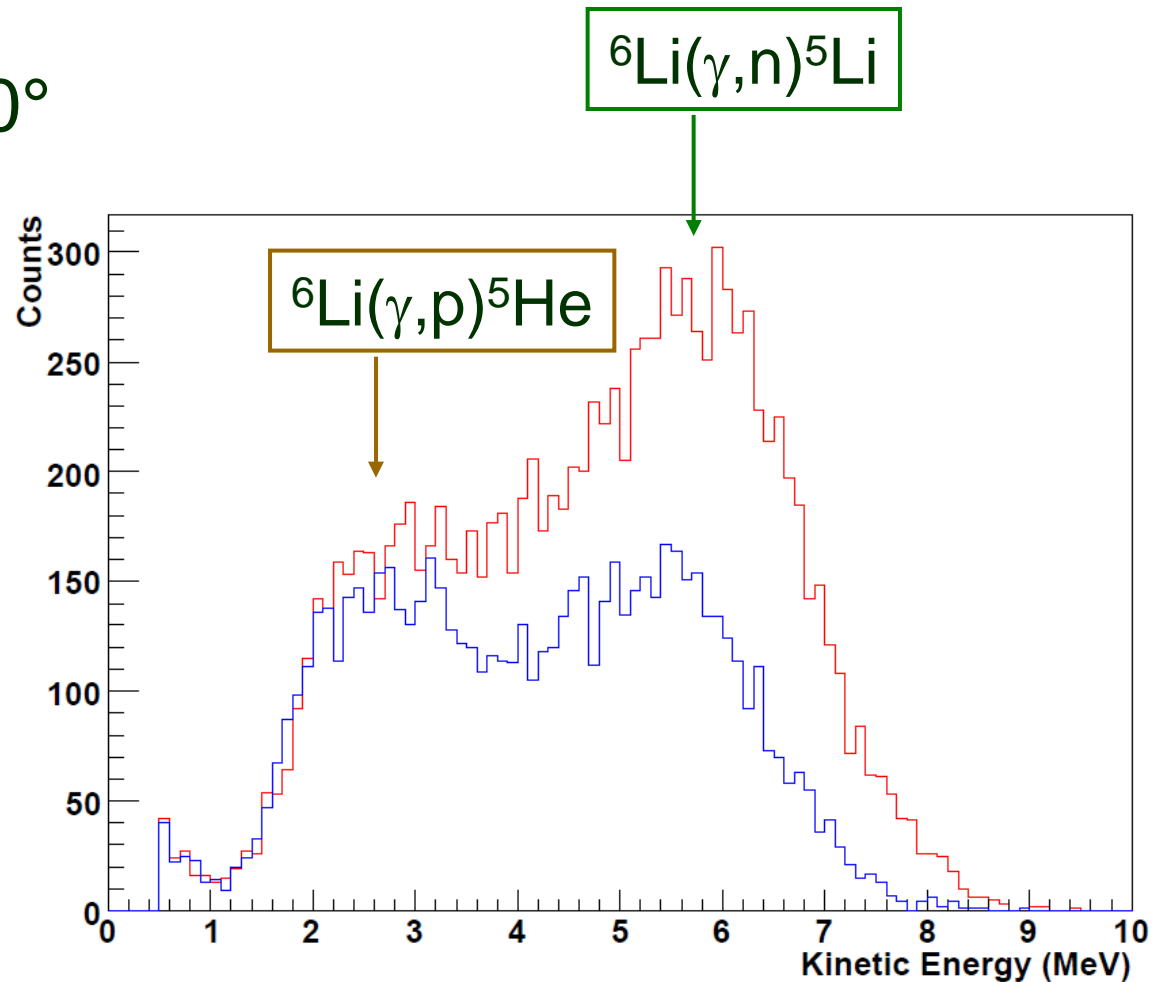
Label	Reaction	Threshold (MeV)
6np	${}^6\text{Li} + \gamma \rightarrow n + p + {}^4\text{He}(\text{g.s.})$	3.7
6p0	${}^6\text{Li} + \gamma \rightarrow p + {}^5\text{He}(\text{g.s.}) \rightarrow n + p + {}^4\text{He}(\text{g.s.})$	4.6
6n0	${}^6\text{Li} + \gamma \rightarrow n + {}^5\text{Li}(\text{g.s.})$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

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

${}^6\text{Li}$

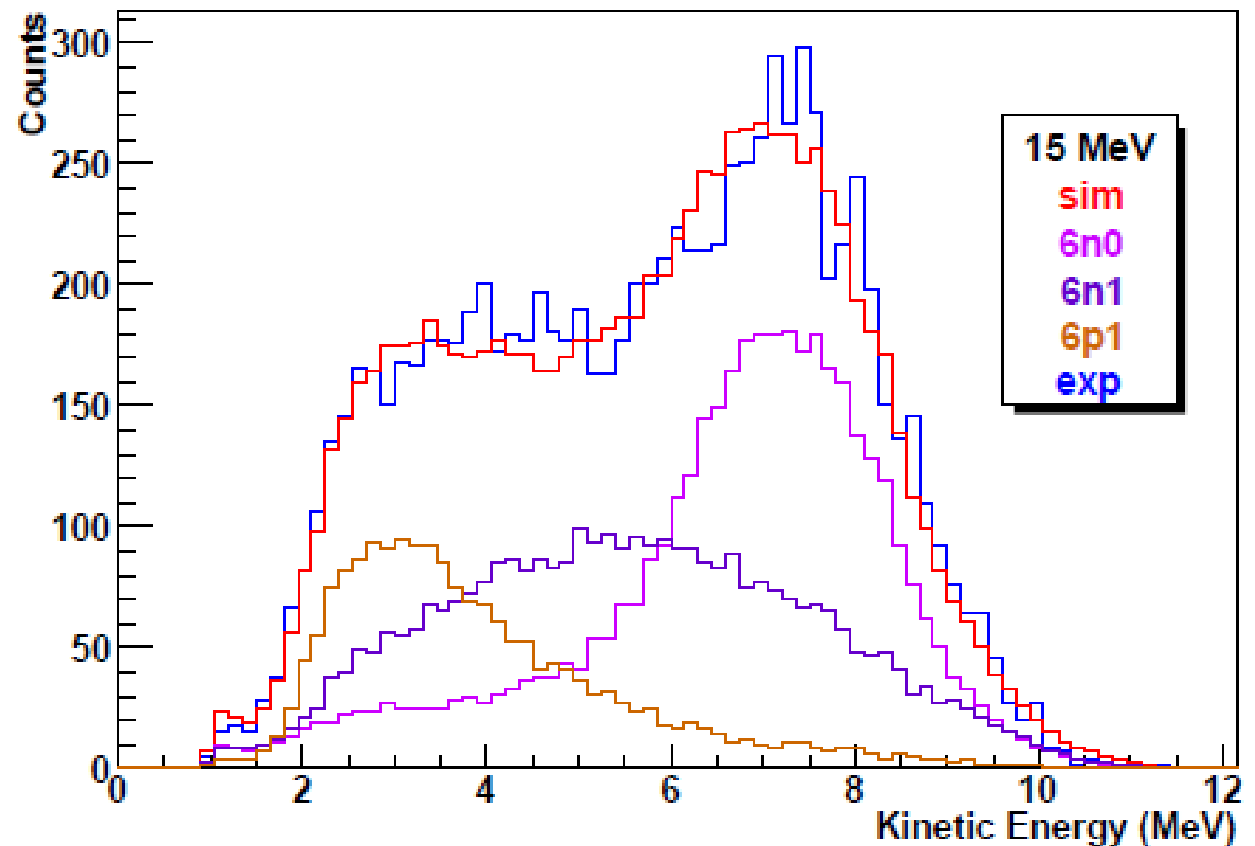
- One detector cell, $\theta = 90^\circ$, $E_\gamma = 13 \text{ MeV}$
- Red – $\varphi = 0^\circ$
- Blue – $\varphi = 90^\circ$

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



${}^6\text{Li}$

- e.g. Coefficients a_1, a_2, e_2, e_3 are extracted for the ${}^6\text{Li}(\gamma, n_0)$ channel
- e.g. Only a_1 Coefficient is statistically significant for the ${}^6\text{Li}(\gamma, p_1)$ 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.