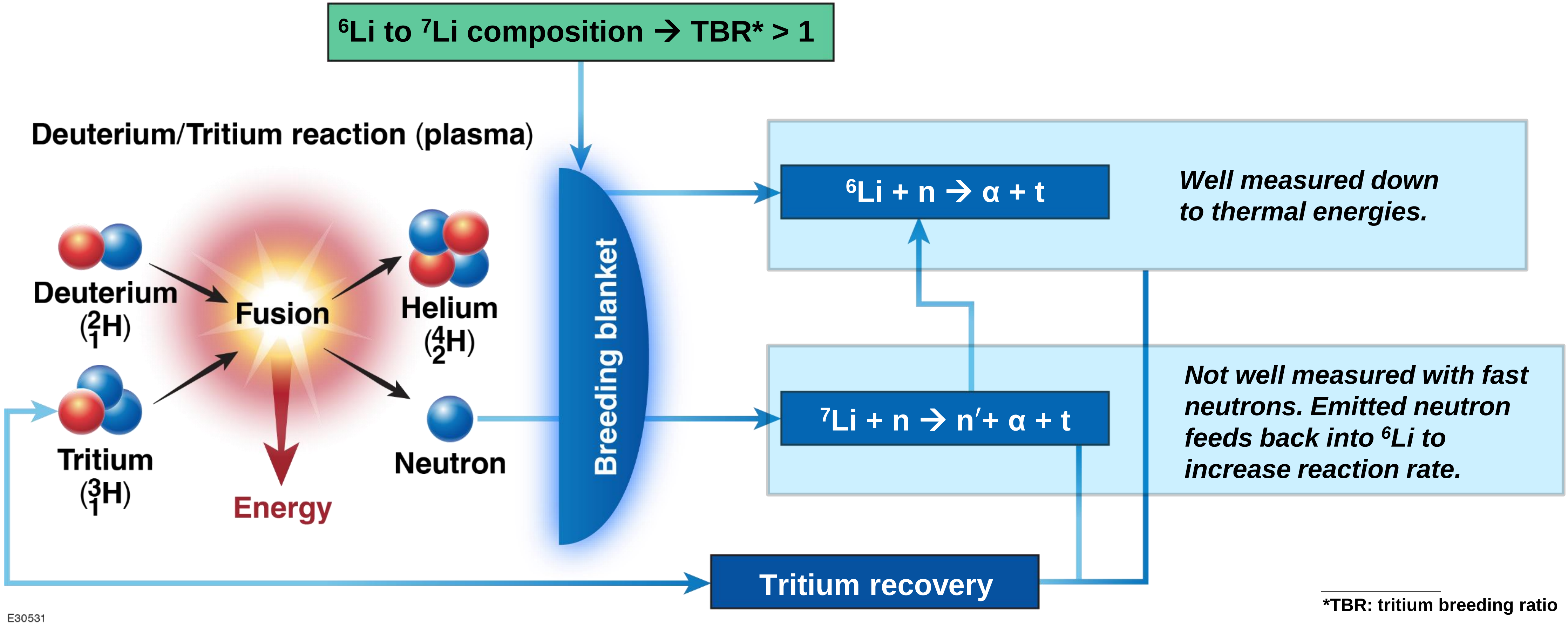
Measurements of Neutron-Induced Breakup Reactions from Lithium Isotopes with Fast Neutrons Using an Inertial Confinement Fusion Platform



*TBR: tritium breeding ratio

C. J. Forrest
University of Rochester
Laboratory for Laser Energetics

WANDA
Arlington, VA February 26–29 2024

Summary

Discrepancies between measured spectra from the neutron-induced scattering reactions and theoretical calculations still exist for lithium isotopes

- Lithium isotopes are one of the primary components being proposed for DT fusion reactor liners for the breeding of tritium from ^{6}Li(n,<u>t</u>)α and ^{7}Li(n,n′)<u>t</u>α reaction channels*
  - the amount tritium required for commercial applications of fusion reactors for energy generation does not occur in nature
- Knowledge of the particle production cross sections from interactions of 14-MeV neutrons in thick targets is required for simulations of neutronics and the tritium breeding rates
- The bright neutron source available at the OMEGA laser facility makes this an important instrument to measure neutron-induced breakup reactions and tritium breeding rates from lithium isotopes.

*M. Rubel *et al.*, Fusion Eng. Des. 136, 579 (2018).

Discrepancies between measured spectra from the neutron-induced scattering reactions and theoretical calculations still exist for lithium isotopes

- Lithium isotopes are one of the primary components being proposed for DT fusion reactor liners for the breeding of tritium from ^{6}Li(n,t)α and ^{7}Li(n,n′)tα reaction channels*
  - the amount tritium required for commercial applications of fusion reactors for energy generation does not occur in nature
- Knowledge of the particle production cross sections from interactions of 14-MeV neutrons in thick targets is required for simulations of neutronics and the tritium breeding rates
- The bright neutron source available at the OMEGA laser facility makes this an important instrument to measure neutron-induced breakup reactions and tritium breeding rates from lithium isotopes.

^{7}Li(n,n′)tα

→ (α) – Not discussed here

→ (t) – A recent proposal to measure tritium production will be presented

→ (n’) – Recent experiments show an enhancement in the lower energy region. More experiments are needed.

*M. Rubel *et al.*, Fusion Eng. Des. 136, 579 (2018).

Collaborators

J. P. Knauer[1], W. U. Schroeder[2], V. Yu. Glebov[1], K.L. Marshall[1],
P. B. Radha[1], A. Schwemmlein[1], and C. Stoeckl[1]

[1]University of Rochester Laboratory for Laser Energetics
[2]University of Rochester Departments of Chemistry and Physics

G. Hale and M. Paris

Los Alamos National Laboratory

B. Appelbe and A. Crilly

Imperial College

Natural lithium as breeder material will not lead to a tritium breeding rate large enough for a reactor to sustain self-sufficiency

A solution is to increase the content of ^{6}Li(%) to a level required to achieve a tritium-breeding ration (TBR > 1).

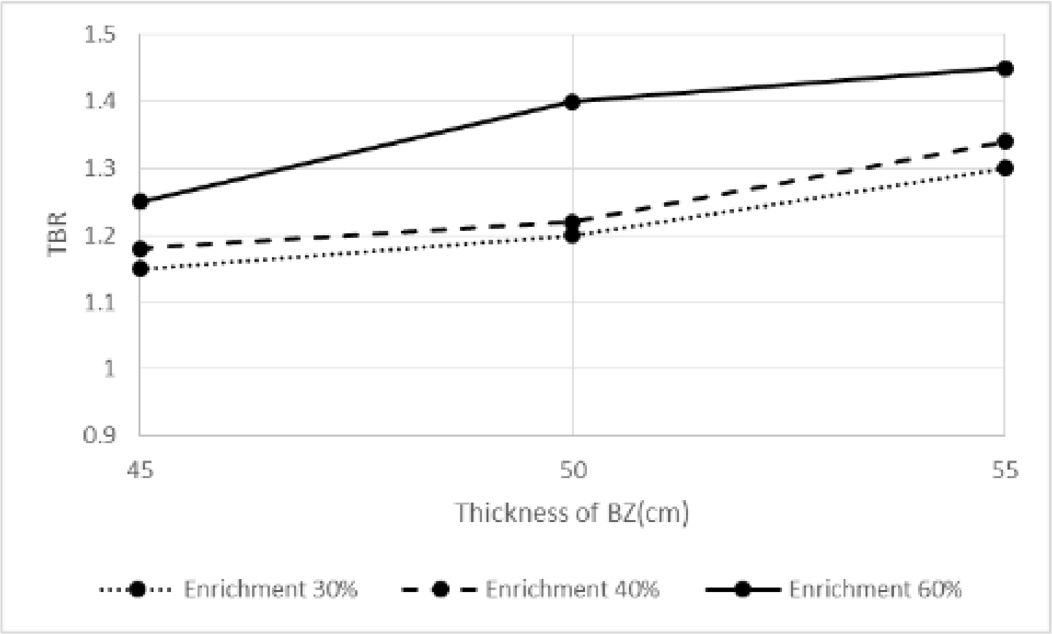
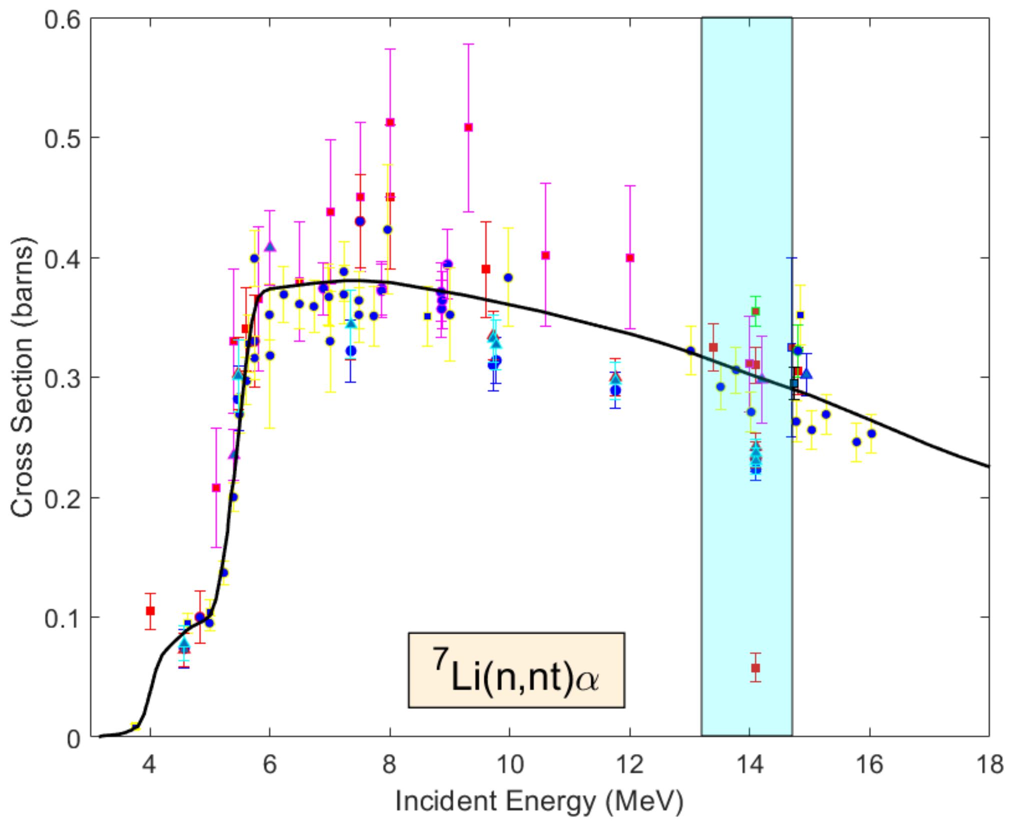


Figure 3. TBR value in different ^{6}Li enrichment

The measured cross sections for the ^{7}Li(n,n′t)α reaction channel available in the literature vary significantly.

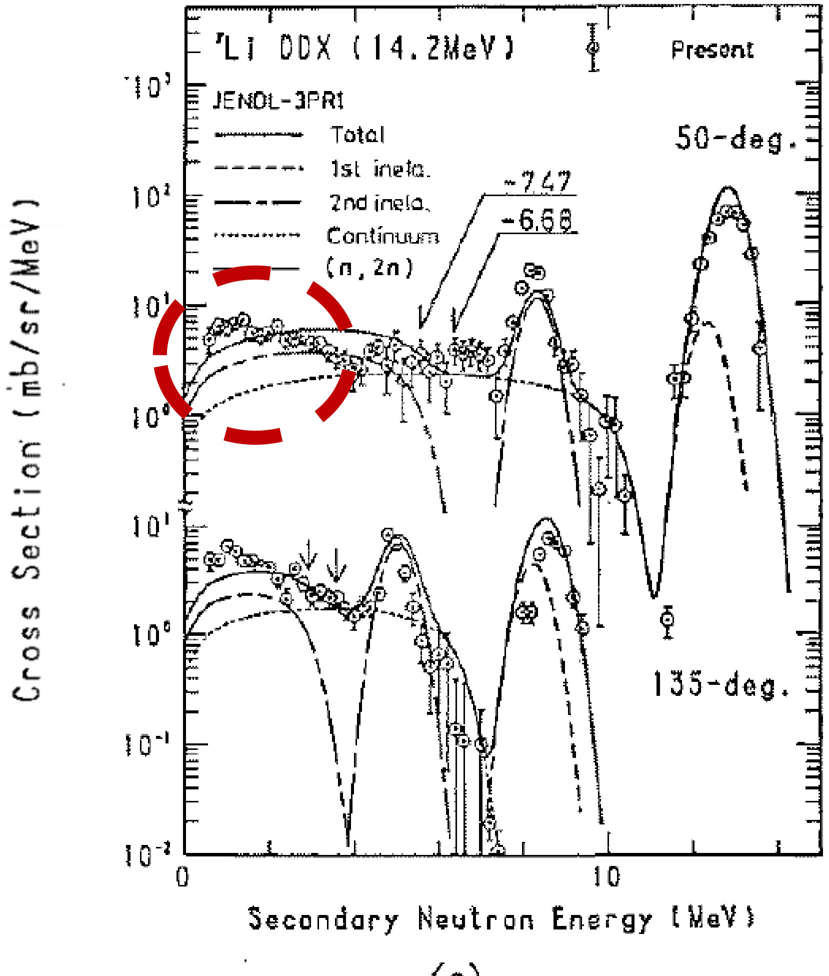


- **The final blanket material will likely be a variant of lithium isotopes, beryllium, fluorine, lead, …..**
- **Accurate measurements of this cross section is required for simulations of neutronics and the tritium breeding rates.**

* I. Rosidah *et al.*, Journal of Physics. 493 (2020) 012003).

Experiments to study neutron-induced breakup reactions are required since past measurements show significant differences

Lithium-7



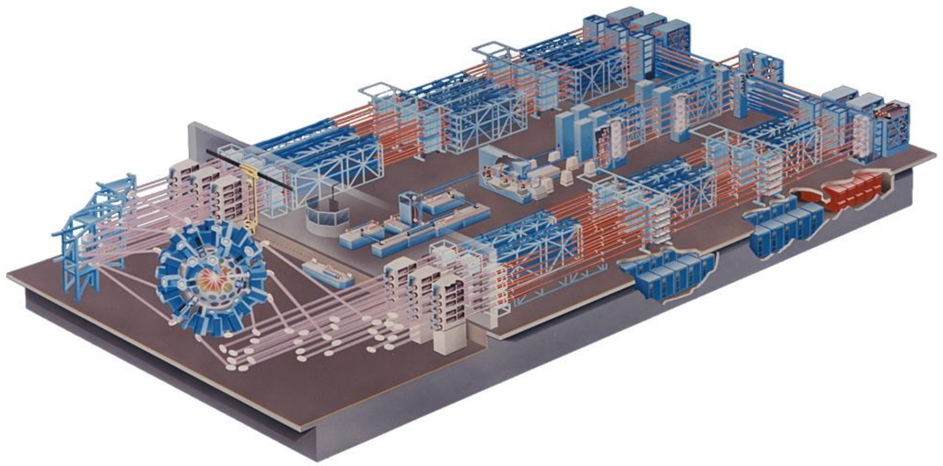
(c)

- Earlier experimental data as compared to the available evaluated nuclear data (JENDL) show a large disagreement below the second inelastic excited state.
- Enhancement in the lower-energy region is believed to be caused by the excitation of higher energy states that have not been fully resolved.
- There is no available experimental data that measured the cross section below 30° with 14-MeV neutrons.
  - the experimental platform on OMEGA has been shown to make successful measurements near 0°. **
  - recent experiments have looked at ^{6}LI, ^{7}Li, and ^{9}Be.

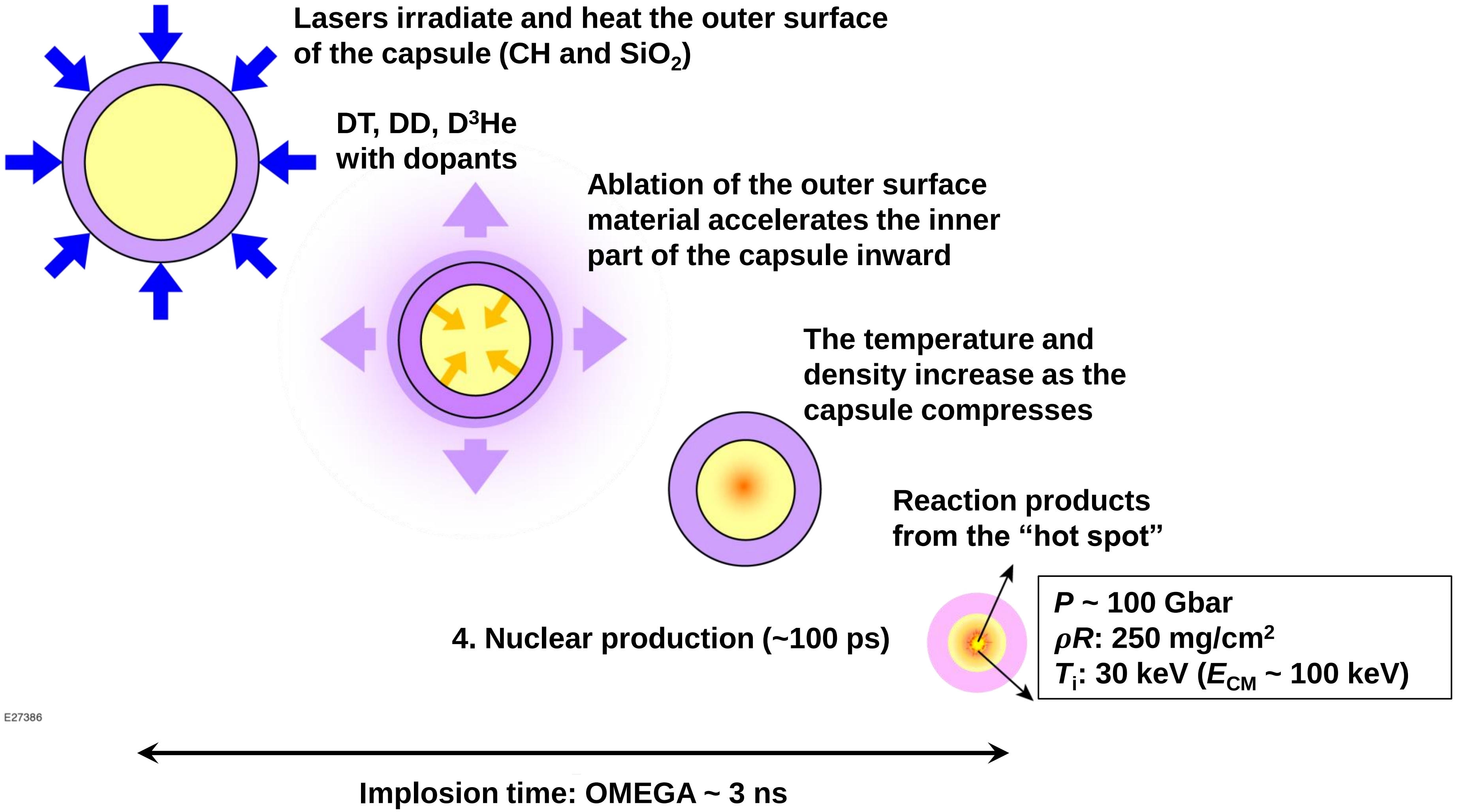
* S. Chiba *et al.*, J. Nucl. Sci. Technol. 22, 771 (1985).
** C. J. Forrest *et al.*, Phys. Rev. C. 100, 034001 (2019).

A high-yield neutron source is achieved with ICF lasers that create pressures of ~100 Gbar and plasma temperatures up to 100 keV

The OMEGA Laser System

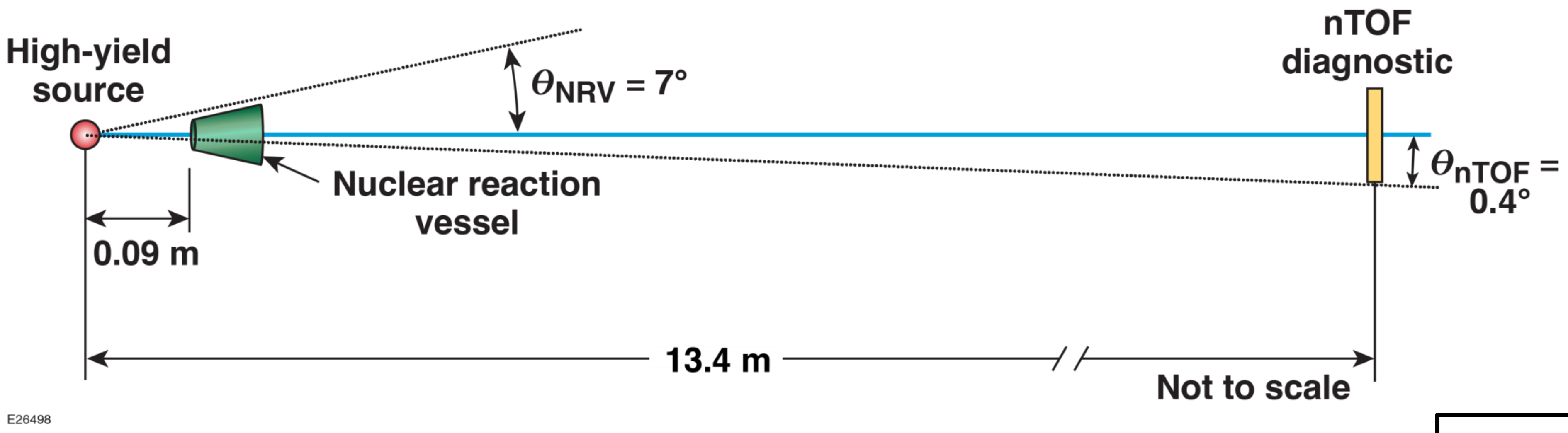


- 60 beams
- Symmetric configuration
- Maximum 30 kJ_{UV} on target
- Up to 16 shots/day (1600/yr)
- 3.2-m target chamber
- DT fusion Y_n up to 2×10^{14}
- <40-μm-diam hot spot
- <100-ps burn

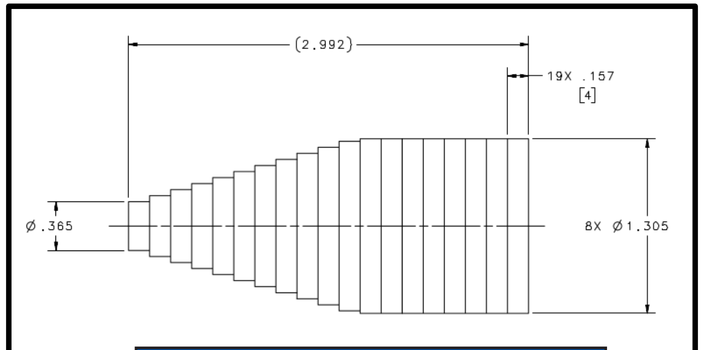


E27386

A novel approach to measure the neutron-induced scattering reactions between light-*Z* nuclei has been developed at the OMEGA Laser Facility.



- The vessel is located as close as possible to the implosion, maximizing the solid angle without interfering with the laser pulses required for illuminating the DT implosion target.



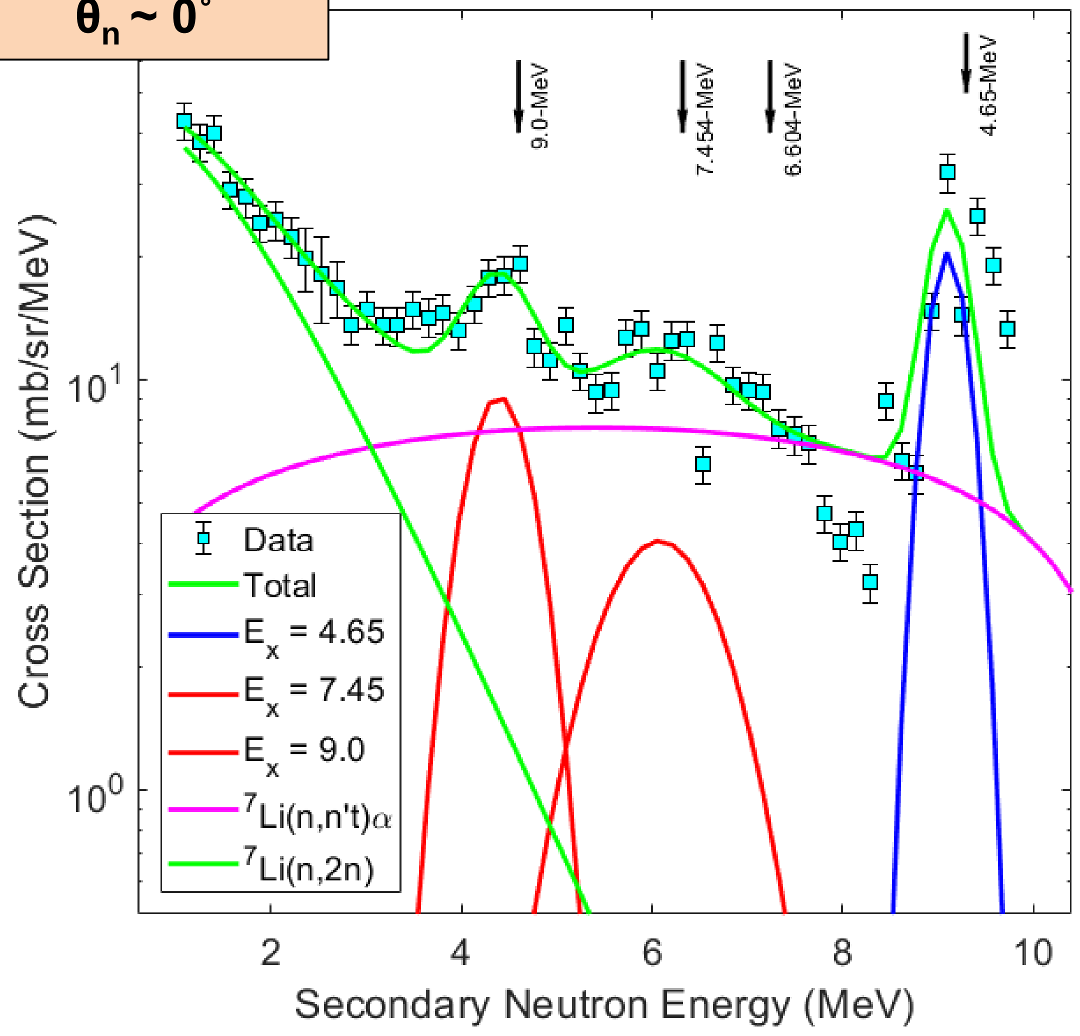
Stacked washers

The experimental time-of-flight data are post-processed to achieve a "model-independent" energy spectrum of the inelastic scattering contributions.*

* C. J. Forrest *et al.*, Rev Sci. Instrum. 93 .(2022).

A trial function was used to evaluate the scattering cross sections from the different reaction channels*

Forrest (2021)
$\theta_n \sim 0^\circ$



1st | **2nd** | **3rd**

$$\frac{d^2\sigma}{d\Omega dE'}(E_{in},\theta,E') = \sum_{i=1}^{n} A_i \exp(-\frac{(E'-E_i)^2}{\sigma_i^2}) + A_{n+1}C_0^2\rho(E_{in},\theta,E') + A_{n+2}E'(-\frac{E'}{T})$$

1st Term: The discrete energy levels from the scattered neutrons.

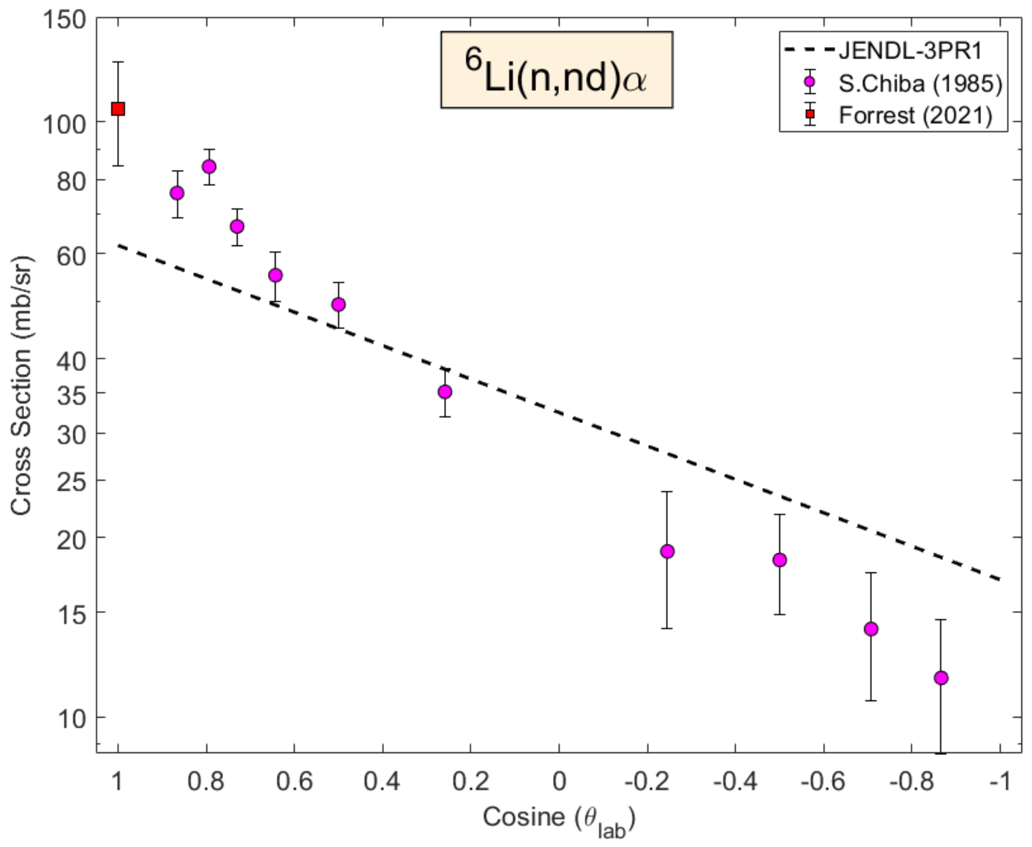
2nd Term: The three-body phase space distribution for ^{6}Li(n,n′)dα and ^{7}Li(n,n′)tα reaction channels.

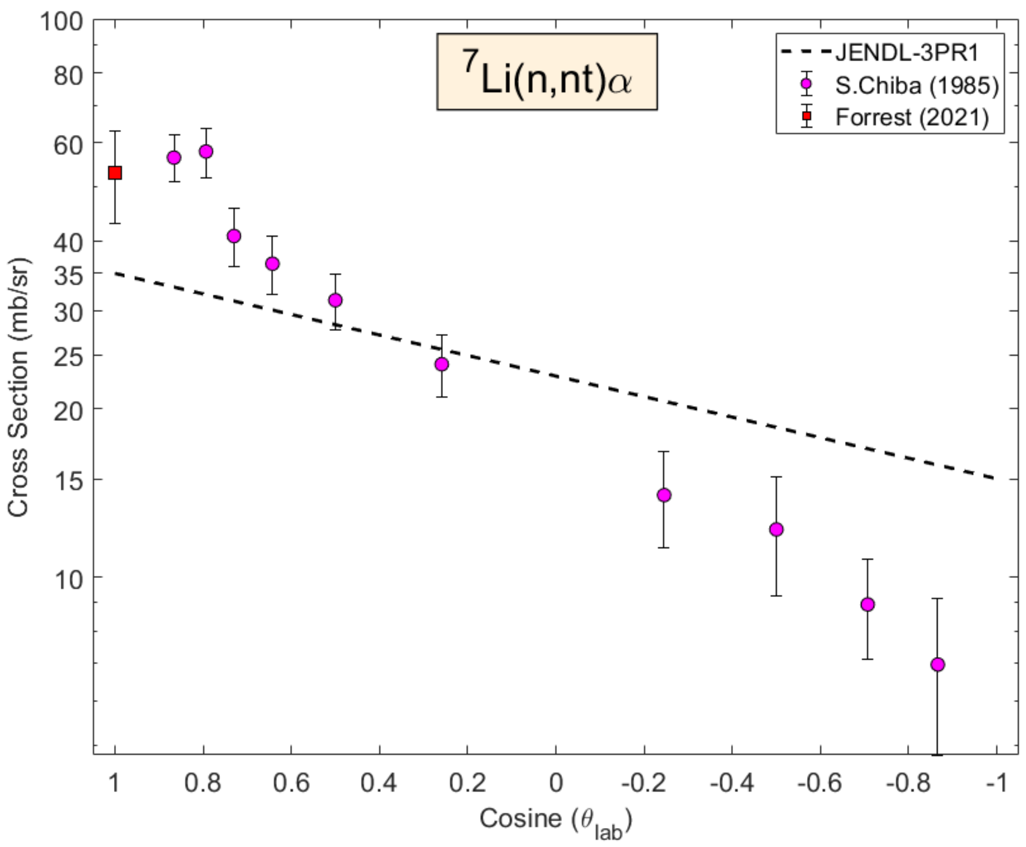
3rd Term: The evaporation term for the n,2n reactions.

The 2nd term of this trial function does not capture the decrease in the signal around 8 MeV.

* S. Chiba *et al.*, J. Nucl. Sci. Technol. 22, 771 (1985).

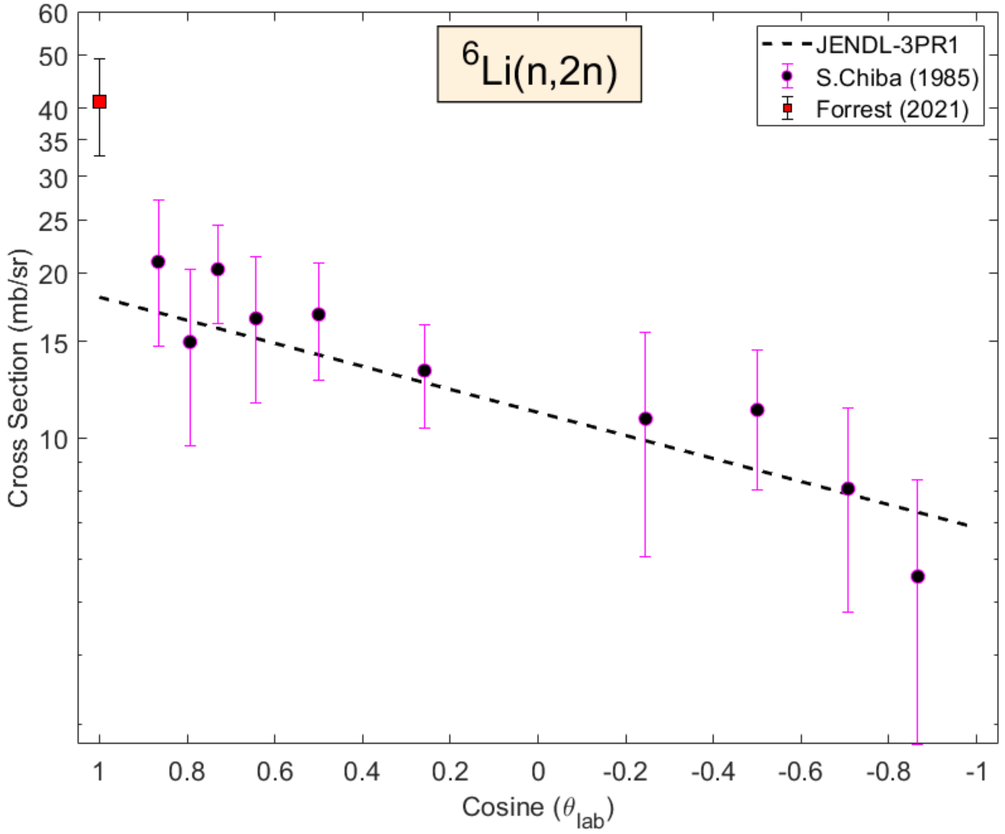
The three-body breakup from ^{6}Li(n,n′)dα and ^{7}Li(n,n′)tα show good agreement with earlier measurements

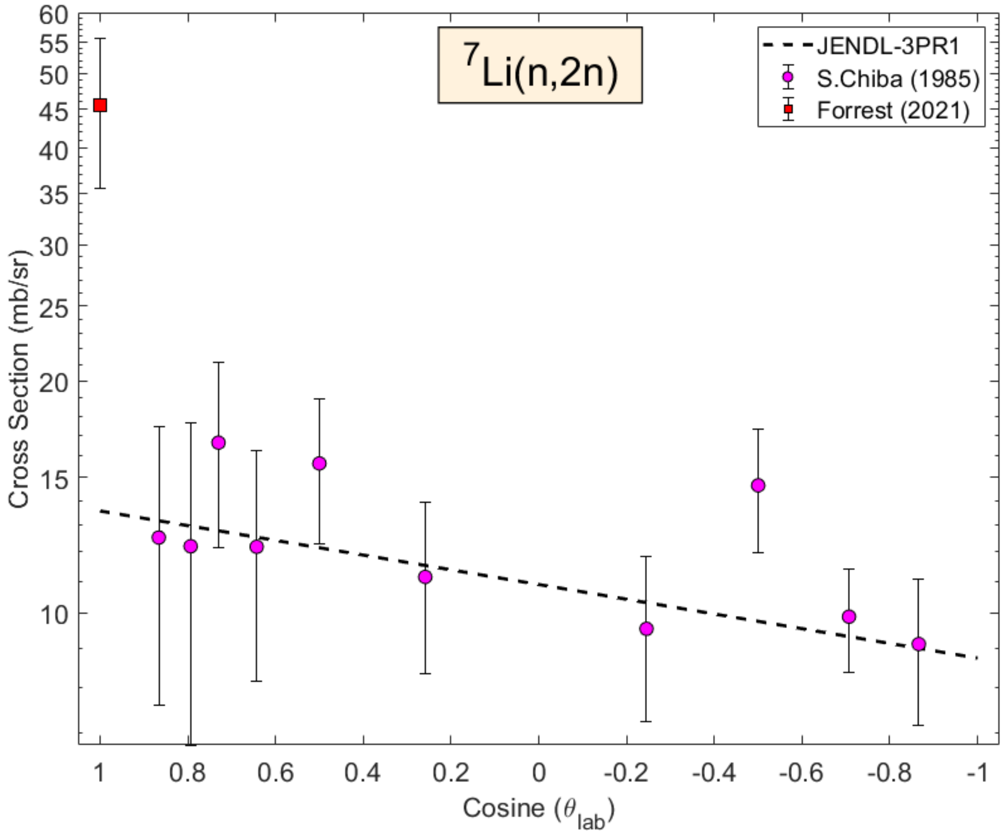




- **The evaluated data (JENDL-3PR1) show a smaller cross-section at lower neutron emission angles for both ^{6}Li and ^{7}Li**
- **First measurements with a neutron emission angle at θ_{lab} ~ 0˚**

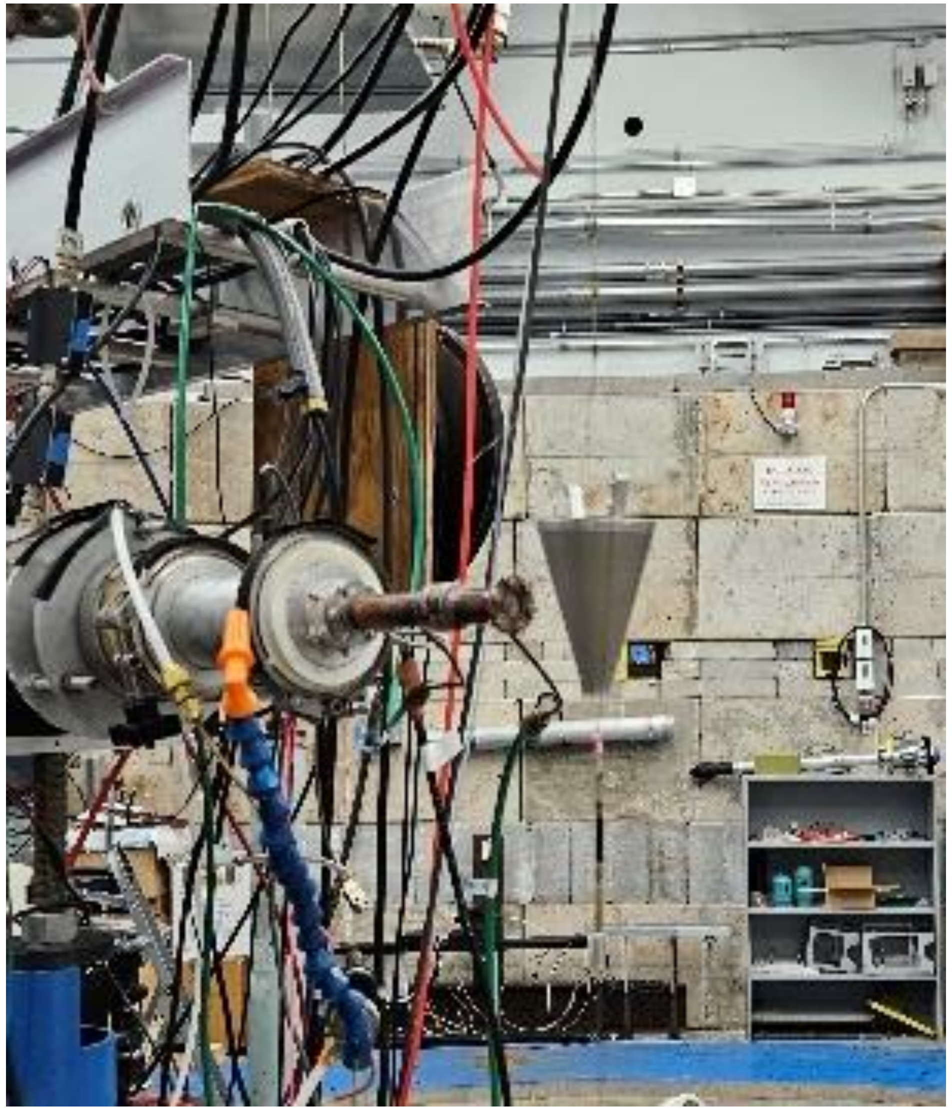
A significant deviation in the cross section at the near-zero neutron emission angle is observed for both ^{6}Li and ^{7}Li.





- **Only a single data set for (n,2n) cross sections with 14 MeV incident neutrons are available in the literature**
- **Again, first measurements with a neutron emission angle at θ_{lab} ~ 0˚**

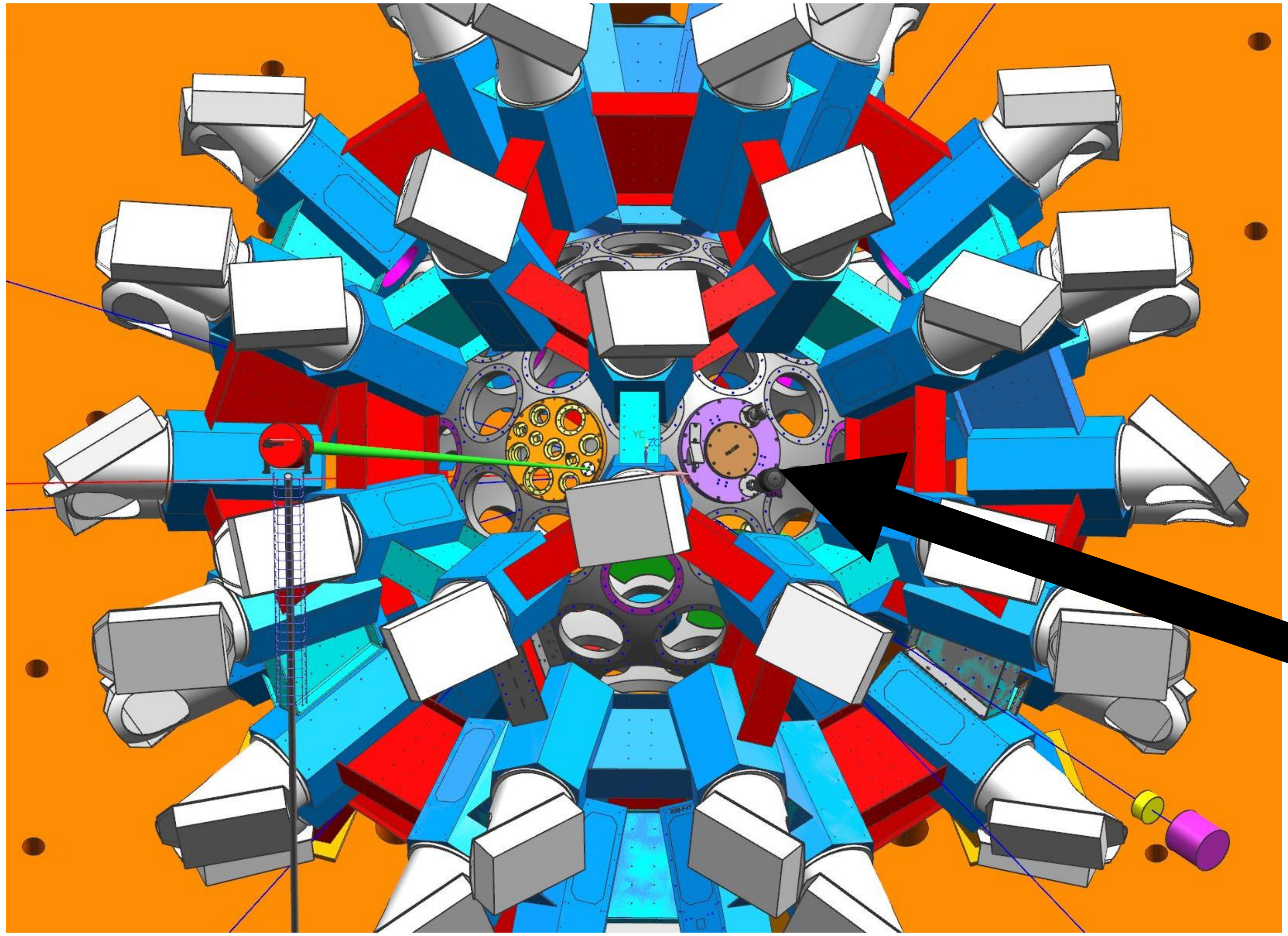
An effort is underway to measure of the cross sections from lithium isotopes with fast neutrons at the TUNL facility



- **Interactions vessels used on OMEGA where brought to the TUNL facility for cross section measurements.**
  - **preliminary measurements were performed and the data is still being analyzed.**
  - **remaining lithium will be melted into cylindrical samples at the University of Rochester and will be sent to TUNL.**
  - **More experiments are being planned for this upcoming summer.**

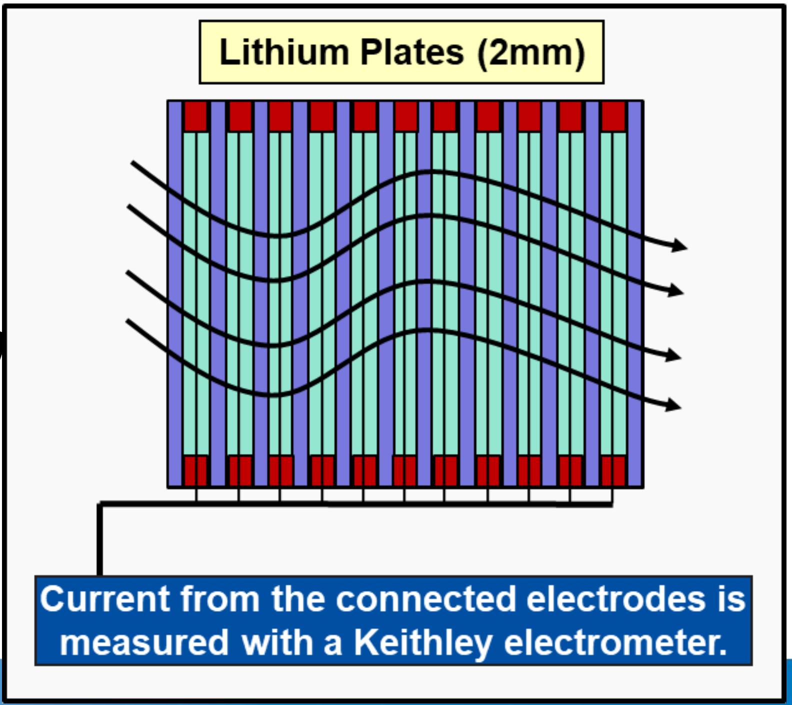
A major goal of doing these measurements is to investigate the lower energy region at the lowest neutron emission angle that can be achieved.

An experimental platform to position a mini-blanket on the exterior wall of the OMEGA target chamber is being proposed



An open port on the OMEGA chamber is available to build ionization chamber using test materials.

- On average the OMEGA Laser Facility performs up 100 high-yield DT implosions per year each generating up 2x10^{24} neutrons/second in 4π.
- The mini-blanket will measure the tritium production with one of the highest neutron fluxes used to test blanket materials currently available.



This proposal is apart of the recent Basic Research Need (BRN) workshop that was held in January 2024

- **These measurements would also be beneficial (cross cutting) for both IFE and MFE when designing inner facing components (i.e. liquid lithium walls).**

- **Part of the proposal is to quantify how much of the tritium may be trapped in the chamber material itself which could potentially be difficult to extract back out.**
  - **vanadium is a candidate material for blankets but vanadium alloys have a high hydrogen solubility and require permeation barriers to prevent significant tritium permeation into the vanadium structural material.**

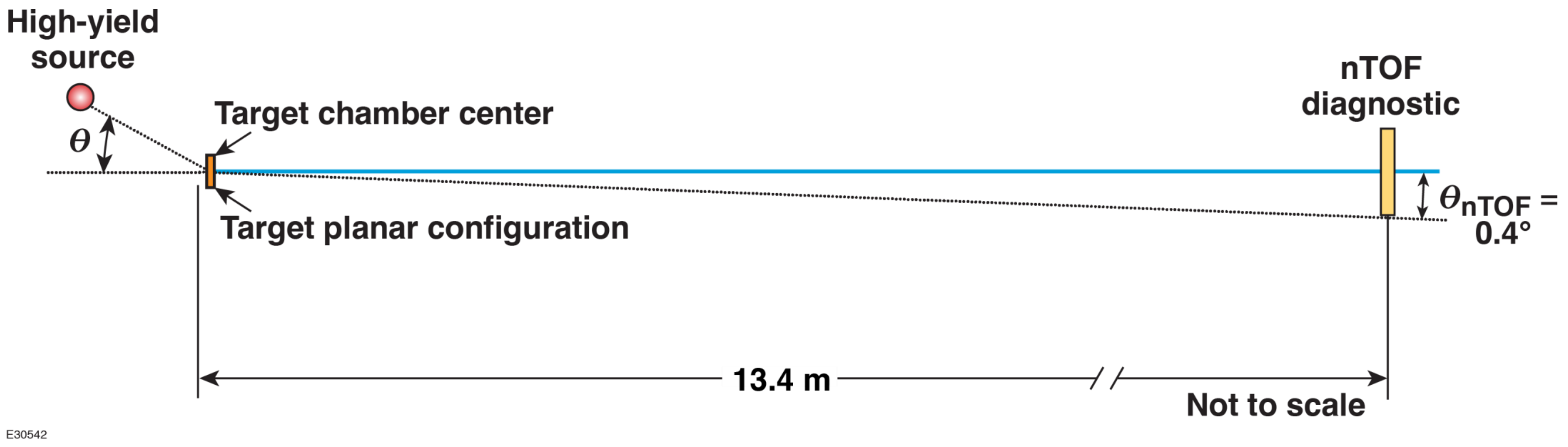
- **Designs of what a ionization chamber (wall and blanket materials) is only in the conceptual design phases.**
  - **requires ~500 grams of lithium and configuration is critical (possibly 3D print lattice).**
  - **residual scattering into test chamber will compromise measurements (need to model).**
  - **the community requires 1% accuracy for tritium accountancy (FOA reviewed and challenging).**

Discrepancies between measured spectra from the neutron-induced scattering reactions and theoretical calculations still exist for lithium isotopes

- Lithium isotopes are one of the primary components being proposed for DT fusion reactor liners for the breeding of tritium from ^{6}Li(n,t)α and ^{7}Li(n,n′)tα reaction channels*
  - the amount tritium required for commercial applications of fusion reactors for energy generation does not occur in nature
- Knowledge of the particle production cross sections from interactions of 14-MeV neutrons in thick targets is required for simulations of neutronics and the tritium breeding rates
- The bright neutron source available at the OMEGA laser facility makes this an important instrument to measure neutron-induced breakup reactions and tritium breeding rates from lithium isotopes.

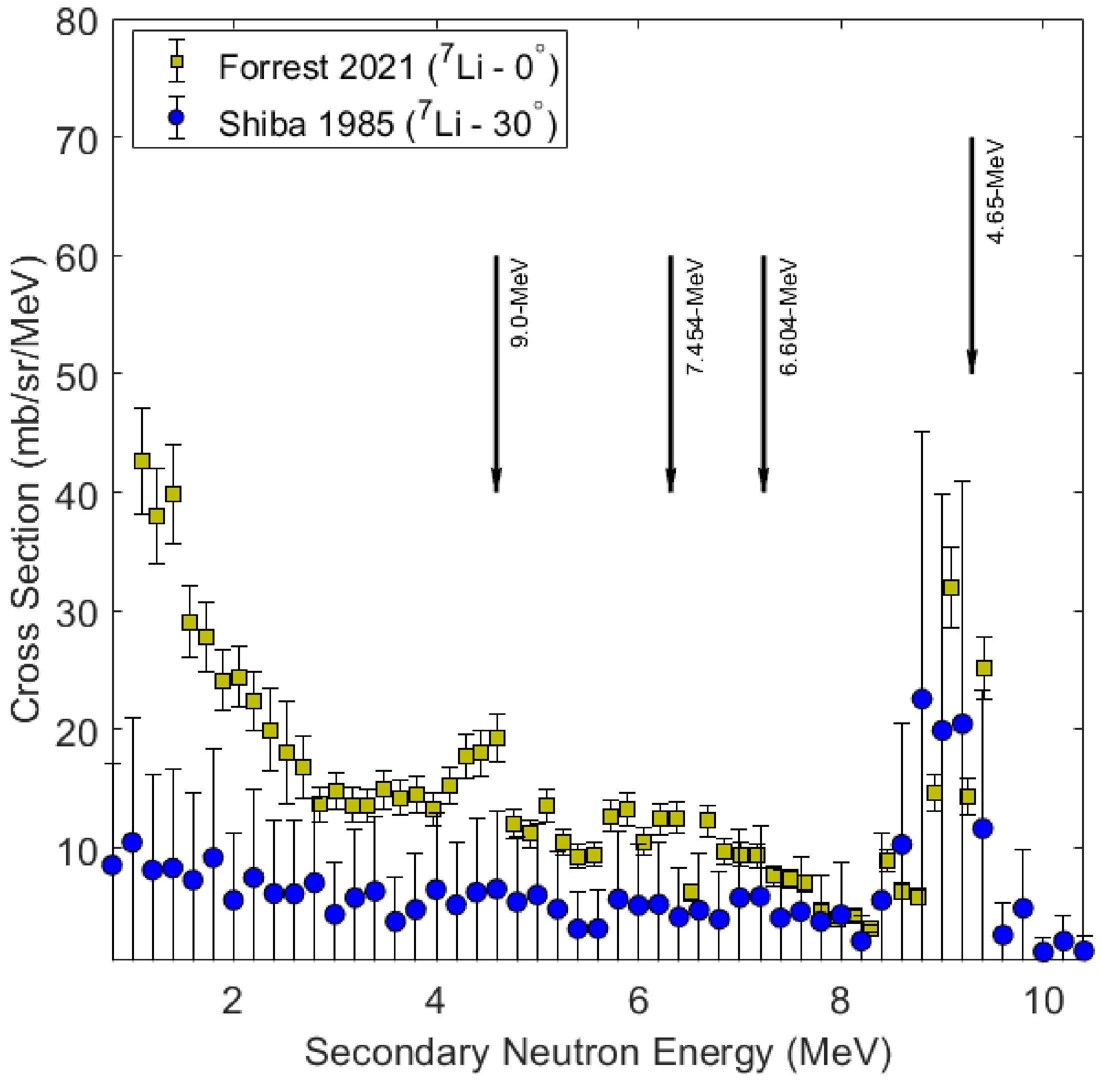
An experimental platform to measure the emitted neutron with increasing angles is under development at the Omega Laser Facility

- **Experimental data in the lower energy region <4 MeV with increasing neutron emission angles (0˚ to 90˚) is required to reduce the uncertainty**

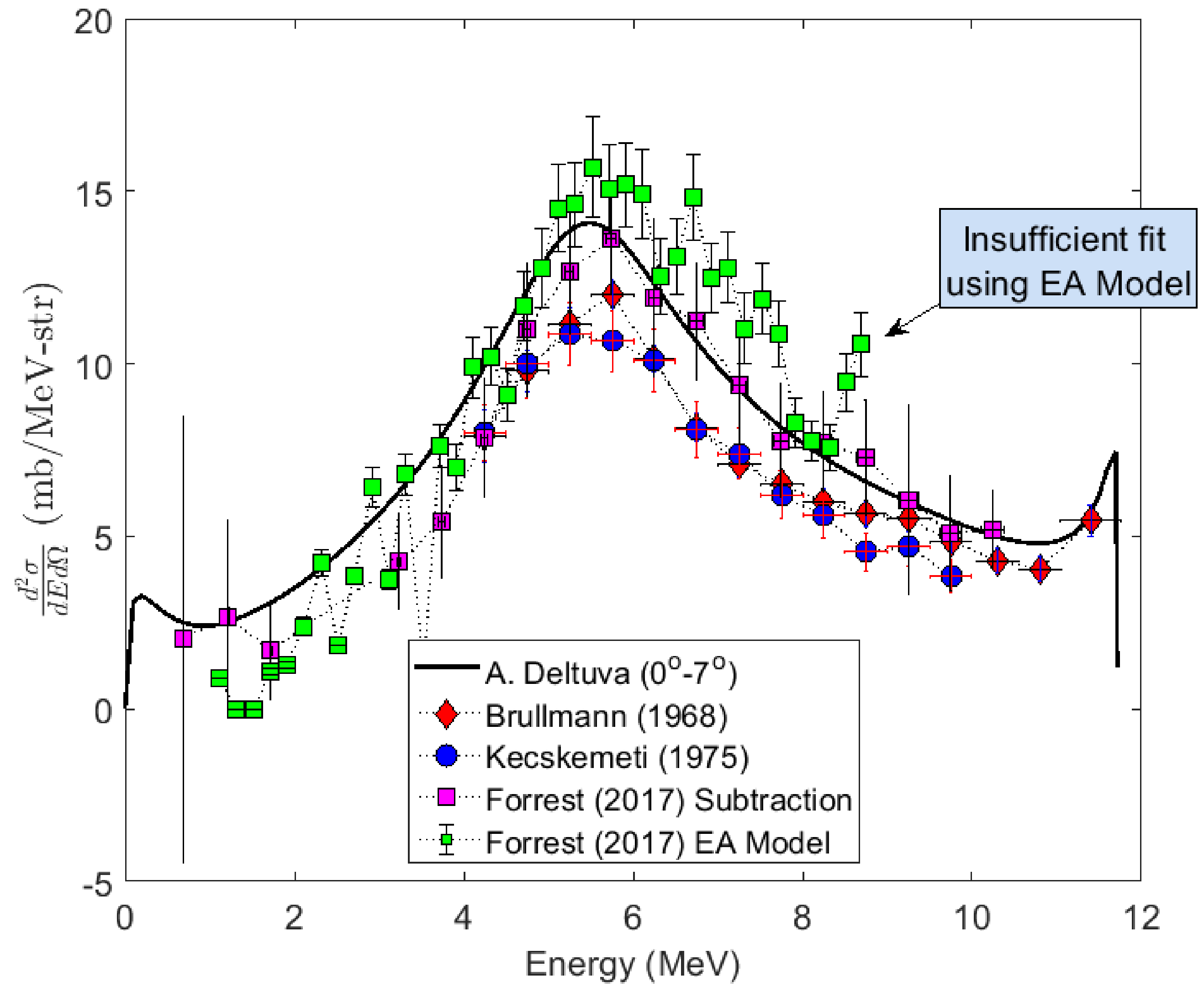


This configuration will allow for less lithium since the neutron source will be much closer to the target sample.

A proof of principle with deuteron breakup



A comparison between the earlier method to extract the cross section shows good agreement with the evolutionary algorithm



- These results are a good indication that the subtraction approach is sufficient to extract the cross section.
  - One campaigns used H_2O/D_2O.
  - Three campaigns used C_6H_6/C_6D_6.
- The three campaigns have been averaged together.