Measuring Cross Section Enhancement of the ^{7}Li(^{1}H,α)α Reaction in Lithium Bearing Materials

Preliminary Results

Aaron English

February 13, 2025

Carleton Univeristy
Department of Electronics

Outline

Project Background

Motivation

Project goal: Extend measurement of cross section enhancement

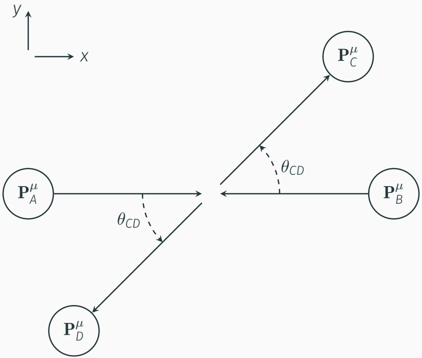
- outstanding question about source of enhancement
- few measurements for ^{7}Li(^{1}H,α)α
- more for ^{2}H + ^{2}H
- exploratory

Potential benefit to power generating fusion technology

- directly
- wall materials
- fuel breeding
- other?

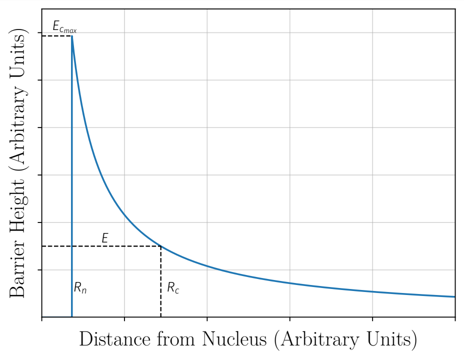
Theory

Inelastic scattering of nuclei



Inelastic scattering of nuclei

Must overcome, or tunnel through, coulombic barrier



Nuclear Fusion

Inelastic scattering of nuclei

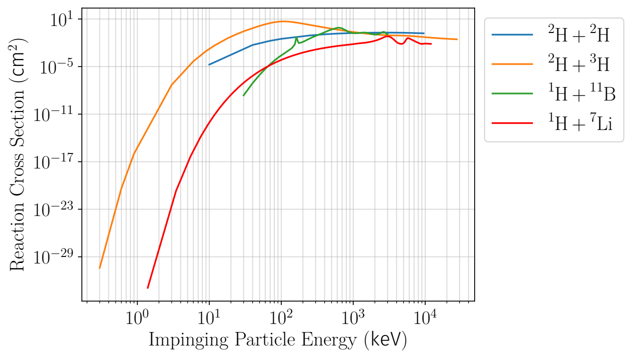
Must overcome, or tunnel through, coulombic barrier

Reaction is probabilistic

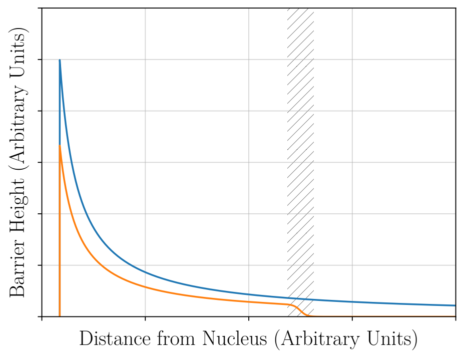
$$\sigma(E) = \frac{S(E)}{E} \exp\left(-\sqrt{\frac{E_G}{E}}\right) \tag{1}$$

- $S(E)$ Astrophysical S-factor
- E is the CM energy
- E_G is the Gamow Energy— $E_G \equiv (\pi \alpha Z_a Z_b)^2 m_a m_b c^2 / (m_a + m_b)$

Measured values of cross section for selection of reactions of interest



Electrostatic Screening

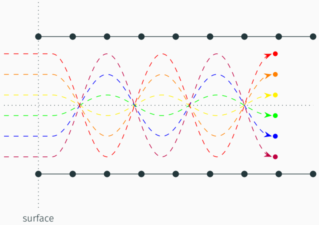


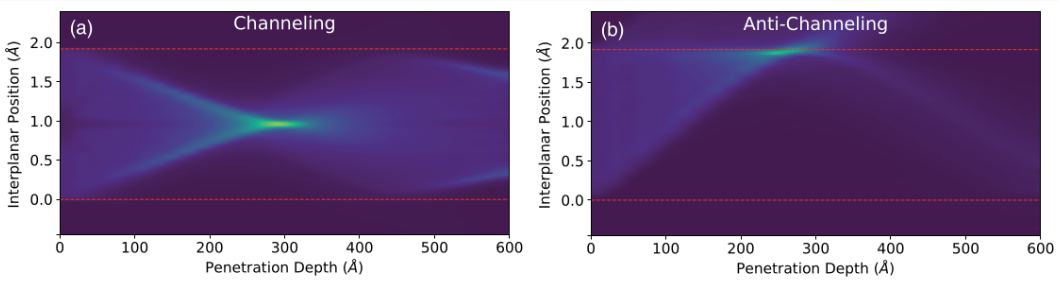
Cross Section Enhancement

Electrostatic Screening

Channeling and Anti-channeling

- Figure by Bagli et al [1]





Electrostatic Screening

Channeling and Anti-channeling

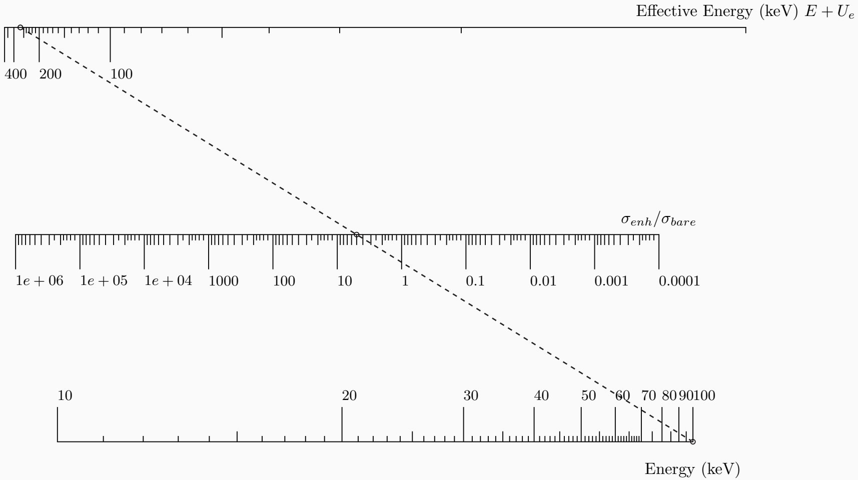
Equation

$$\sigma_{enh} = \frac{S(E)}{\sqrt{E(E+U_e)}} \exp\left(-\sqrt{\frac{E_G}{E+U_e}}\right) \tag{2}$$

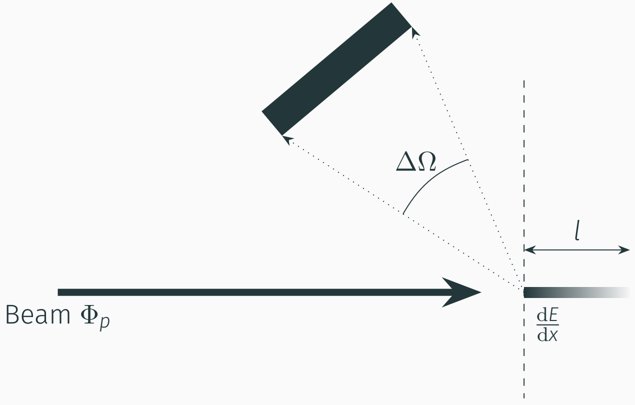
Where U_e is enhancement energy

$$F = \frac{\sigma_{enh}}{\sigma_{bare}} \tag{3}$$

Energy Enhancement Nomograph



Beam-Target Experiments



Reaction rate

$$\frac{\mathrm{d}R}{\mathrm{d}t} = \Phi_p N_t l \sigma(E) \tag{4}$$

$$Y = n_p N_t l \Delta\Omega \sigma(E) \tag{5}$$

projectile count	n_p
interaction len.	l
solid angle cov.	$\Delta\Omega$
kinematic solid angle	$\frac{\mathrm{d}\Omega}{\mathrm{d}\Omega'}$
target num. dens.	N_t

Thick Target Yield

$$Y_\infty = \frac{n_p N_A \omega_x \Delta\Omega}{4\pi M} \int_{E_l}^{0} \sigma(E) \left(\frac{\mathrm{d}E}{\mathrm{d}x}\right)^{-1} \left(\frac{\mathrm{d}\Omega}{\mathrm{d}\Omega'}\right)^{-1} \mathrm{d}E \tag{6}$$

Differential Yield

$$\frac{\mathrm{d}Y_\infty}{\mathrm{d}E} = \frac{n_p N_A \omega_x \Delta\Omega}{4\pi M} \sigma(E) \left(\frac{\mathrm{d}E}{\mathrm{d}x}\right)^{-1} \left(\frac{\mathrm{d}\Omega}{\mathrm{d}\Omega'}\right)^{-1} \tag{7}$$

Cross Section from Yield

$$\sigma(E) = \frac{4\pi M}{n_p N_A \omega_x \Delta\Omega} \frac{\mathrm{d}Y_\infty}{\mathrm{d}E} \frac{\mathrm{d}E}{\mathrm{d}x} \frac{\mathrm{d}\Omega}{\mathrm{d}\Omega'} \tag{8}$$

$^1H + ^7Li$ Measurements in Litterature

Beam	Target	Measured U_e (eV)	Ref.
^7Li	Kapton	<600	[2]
	$^1H-Pd_{2.34}$	<300	
	Graphite ($^1HC_{16.9}$)	10 003(400)	[3]
	$^1HPd_{4.76}$	3 600(700)	
	TiH	3 900(400)	
	$^1HW_{23.8}$	5 900(900)	
^1H	$^7LiPd_{99}$	3 790(330)	[4]
	$^7Li_2WO_4$	185(150)	
	^7Li	1 280(60)	

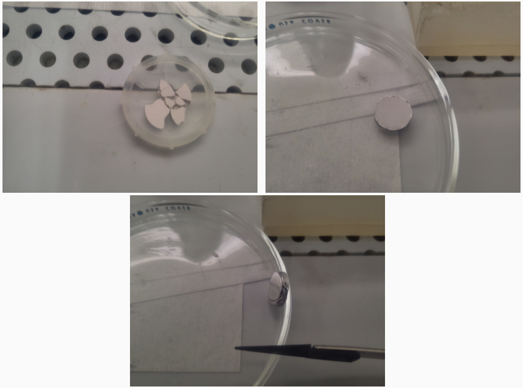
Initial Results

Samples Tested

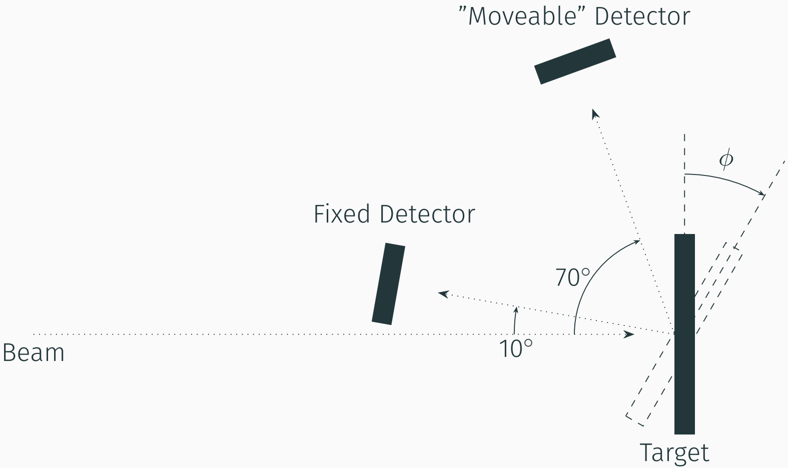
Material	Chem. Form.	No. Samples	Angle Range (°)
Lithium Tungstate	Li_2WO_4	4	0
Lithium Manganate	$LiMn_2O_4$	4	
Lithium Titanate	$Li_4Ti_5O_{12}$	4	
Lithium Iron Phosphate	$LiFePO_4$	4	
Lithium Flouride	LiF	1	-0.5 - 1
Lithium Niobate	$LiNbO_3$	2	

Sample Preparation

- Powdered samples pressed
- Aluminum cup for support
- 15 min under 10^4 kg
- Processed and shipped under atmosphere
- measurements contracted out to Western University



Western Beamline Configuration

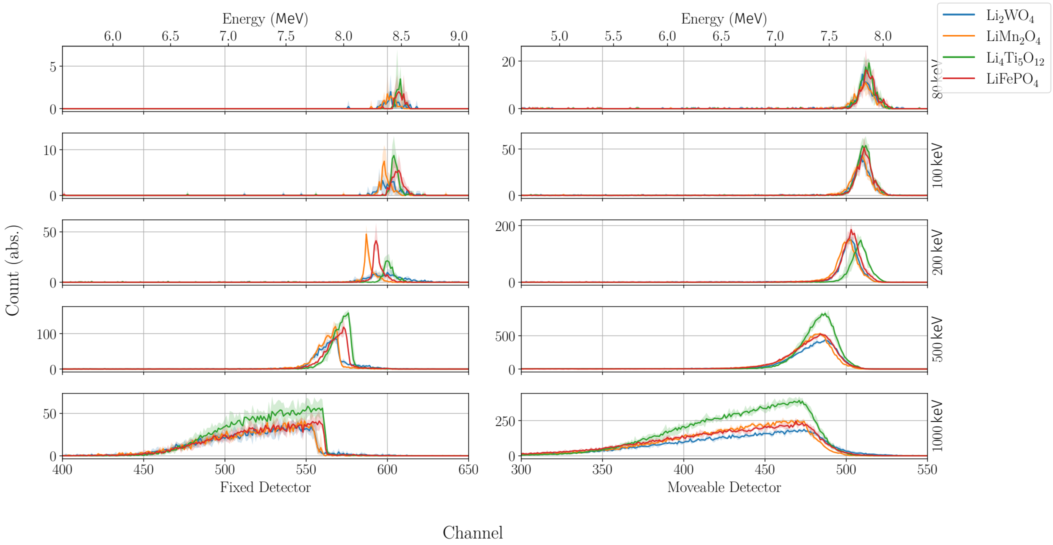


Western Experiment Parameters

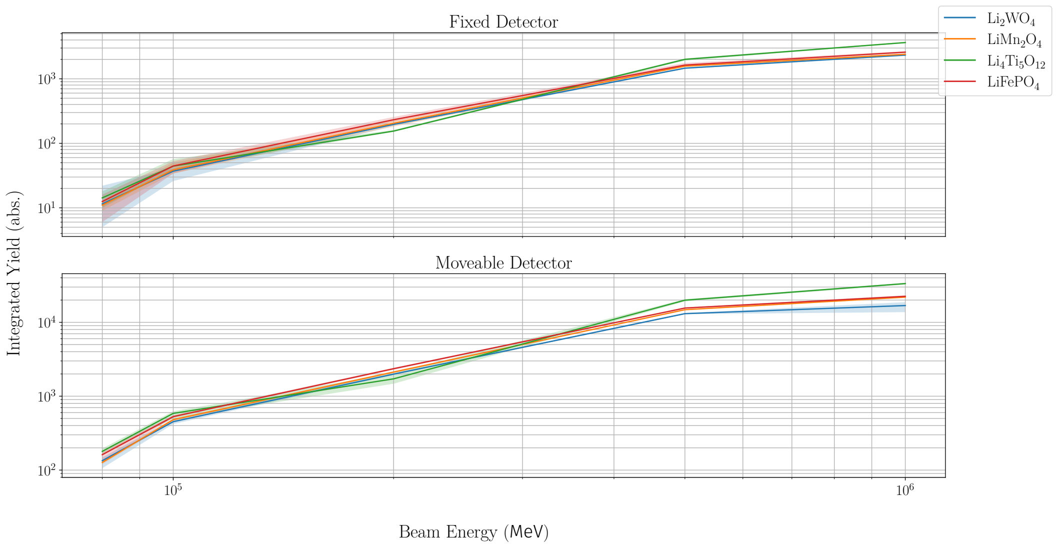
Energy keV	Dose μC
80	100
100	100
200	20
500	5
1000	1

	Fixed	Moveable
Area mm^2	50	450
Solid Angle sr	0.037	0.380
Dist. to Targ. cm	6.9	6.9
Angle. °	10	70

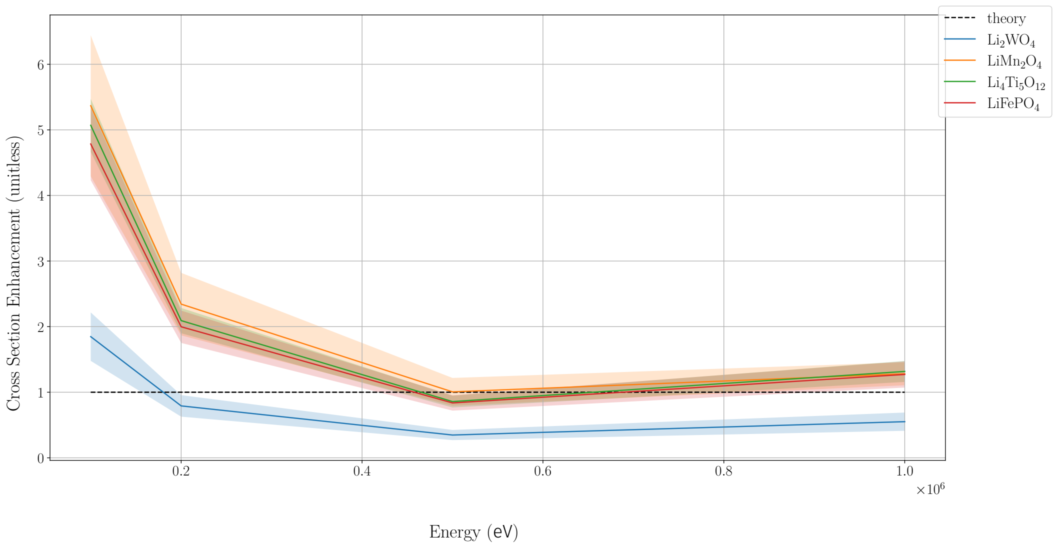
Measured Results: Raw Yield



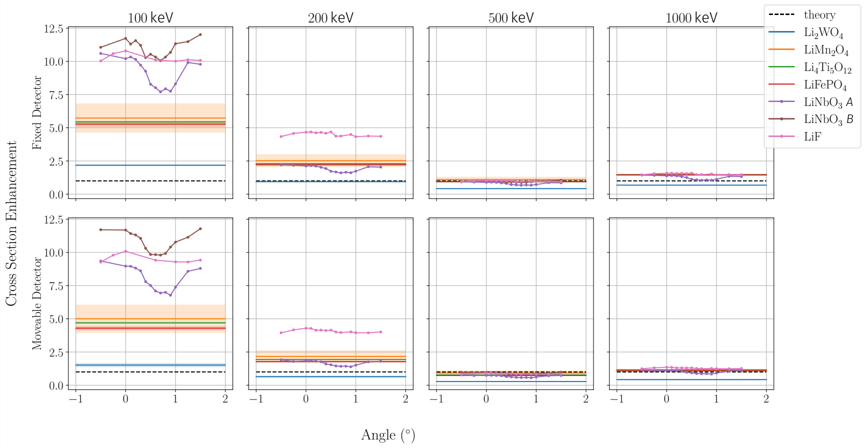
Measured Results: Integrated Yield



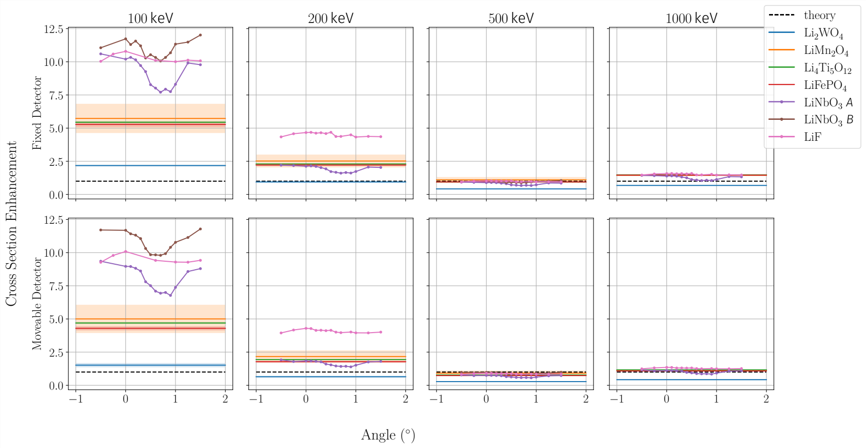
Measured Results: Amorphous



Measured Results: With Crystalline Targets



Measured Results: With Crystalline Targets

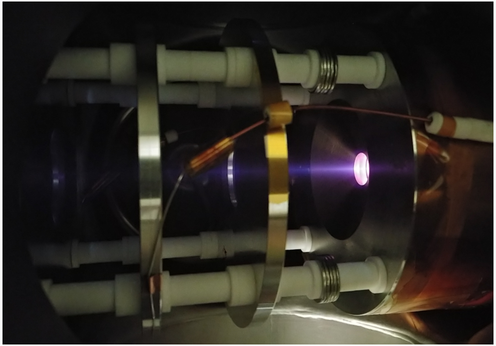


- Beam current nA— long runs
- High cost limited runtime
- low counts at low energies
- need more energy steps

Next Steps

Transitioning to in-house beamline

- higher current 1 mA
- will conduct more measurements in smaller energy steps



Acknowledgements— Funding

mitacs

SOLEINIUM

Natural Sciences and Engineering Research Council of Canada

Conseil de recherches en sciences naturelles et en génie du Canada

Canada

Thank You— Questions?

Backmatter

References i

[1] E. Bagli, D. De Salvador, L. Bacci, *et al.*, **"Enhancement of the Inelastic Nuclear Interaction Rate in Crystals via Antichanneling,"** *Phys. Rev. Lett.*, vol. 123, no. 4, p. 044 801, Jul. 2019, ISSN: 1079-7114. DOI: `10.1103/PhysRevLett.123.044801`.

[2] M. Lipoglavšek, I. Čadež, S. Markelj, P. Pelicon, and P. Vavpetič, **"Electron screening in the 1H(7Li,α)4He reaction,"** *European Physical Journal A*, vol. 44, no. 1, pp. 71–75, Apr. 2010, ISSN: 1434-601X. DOI: `10.1140/epja/i2010-10937-7`.

[3] A. Cvetinovic, M. Lipoglavsek, S. Markelj, and J. Vesic, **"Molecular screening in nuclear reactions,"** *Physical Review C*, vol. 92, no. 6, p. 065 801, Dec. 2015, ISSN: 2469-9993. DOI: `10.1103/PhysRevC.92.065801`.

[4] J. Cruz, Z. Fülöp, G. Gyürky, *et al.*, "Electron screening in 7Li(p,α)α and 6Li(p,α)3He for different environments," *Physics Letters B*, vol. 624, no. 3, pp. 181–185, Sep. 2005, ISSN: 0370-2693. DOI: `10.1016/j.physletb.2005.08.036`.

Extras

Nuclear Reactions Table

Reactants			Energy and Pathways	Products		
^{1}H	+	^{7}Li	$\xrightarrow[17.2\,\text{MeV}]{}$	2 ^{4}He 8.6 MeV	+	
^{1}H	+	^{11}B	$\xrightarrow[8.68\,\text{MeV}]{}$	3 ^{4}He 2.9 MeV		
^{2}H	+	^{2}H	$\xrightarrow[4.03\,\text{MeV}]{50\,\%}$	^{3}H 1.01 MeV		^{1}H 3.02 MeV
	+		$\xrightarrow[3.27\,\text{MeV}]{50\,\%}$	^{3}He 0.82 MeV	+	n^{0} 2.45 MeV