^{6,7}Li(α,γ)^{10,11}B reaction

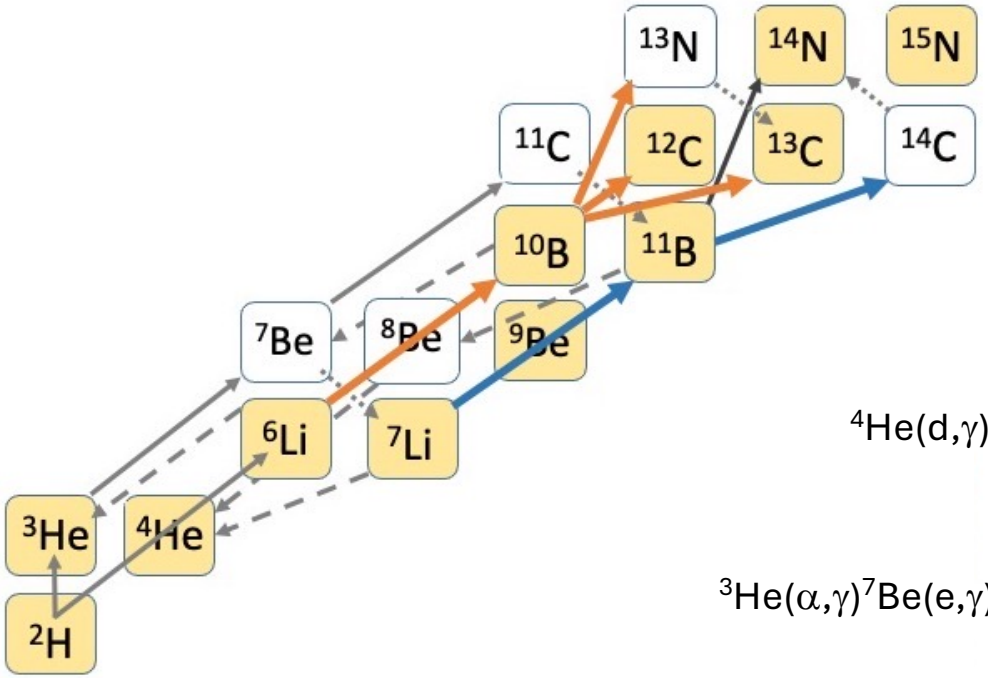
Current status overview

ERC-NUCLEAR Kick-off Event

nucleαr
nuclear clustering effects
in astrophysical reactions

https://www.erc-nuclear.uk

Astrophysical Motivation



nucleosynthesis in first-generation stars:

- alternative path to CNO mass region
- influence on primordial lithium abundance
- clustering effects near alpha-threshold

^{4}He(d,γ)^{6}Li(α,γ)^{10}B(α,d)^{12}C deuterons as catalyst isotope

^{10}B(α,p)^{13}C

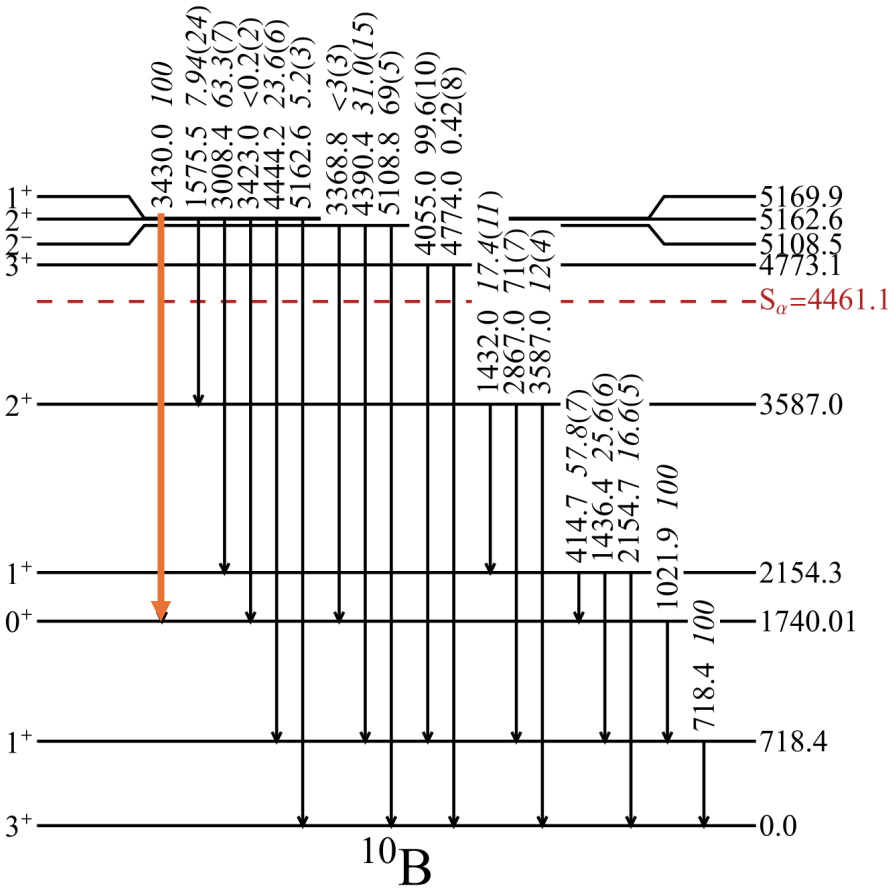
^{10}B(α,n)^{13}N possible neutron source

^{3}He(α,γ)^{7}Be(e,γ)^{7}Li(α,γ)^{11}B(a,p)^{14}C

^{11}B(α,n)^{14}N possible neutron source

requirement: strong enhancement of (α,γ) reaction rates

$^{6}Li(\alpha,\gamma)^{10}B$ reaction



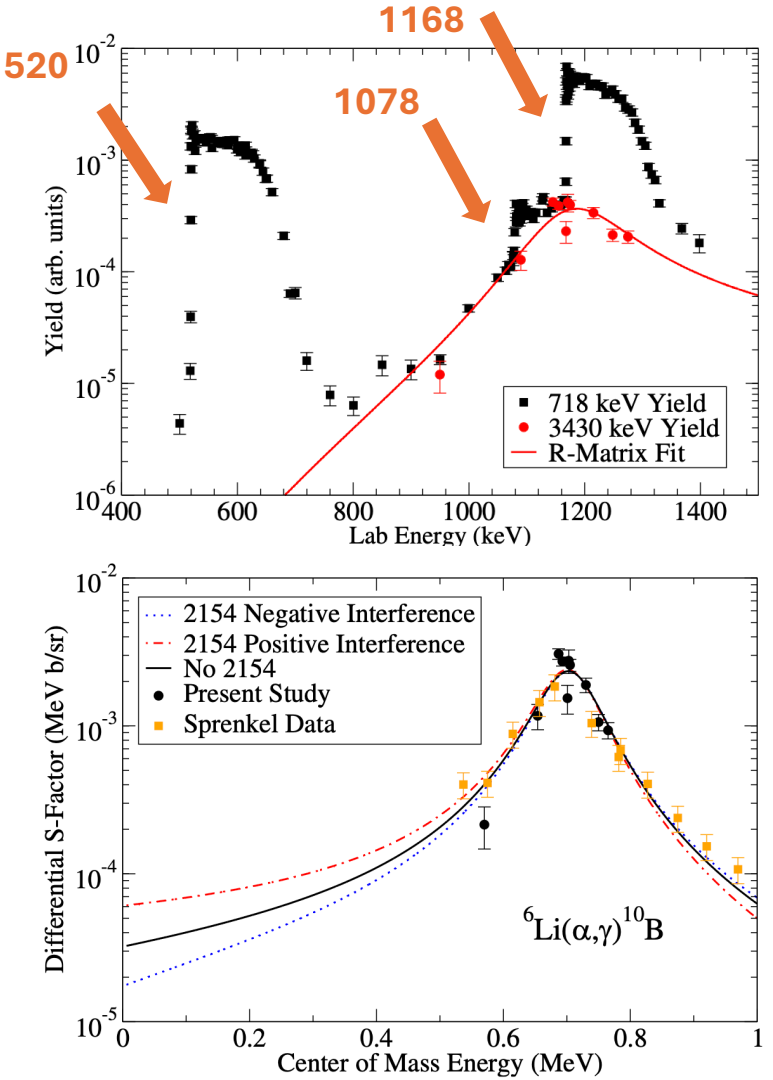
- Q-value: 4.461 MeV
- Narrow resonance corresponding to the E_x = 4.773 MeV state ($J^{\pi}=3^{+}$, E_{α}= 520 keV), dominant component in the range $0.05 \leq T \leq 0.3$ GK
- Two narrow resonances at Ex = 5.109 and 5.162 MeV ($\Gamma \leq 1$ keV, E_{α}= 1.078, 1.168 MeV)
- A broad resonance ($\Gamma \approx 100$ keV) corresponding to the E_x = 5.170 MeV ($J^{\pi}=1^{+}$), the tail is relevant for $T \leq 0.1$ GK
- Unknown direct capture component

Gula et al. PRC 106, 065801 (2022)

$^{6}Li(\alpha,\gamma)^{10}B$: State of the Art

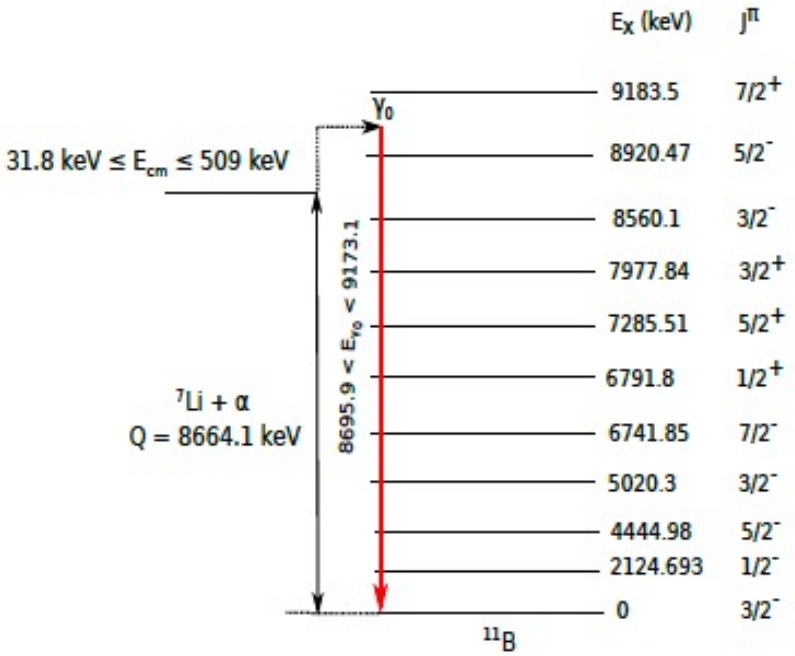
Gula et al. (2022):

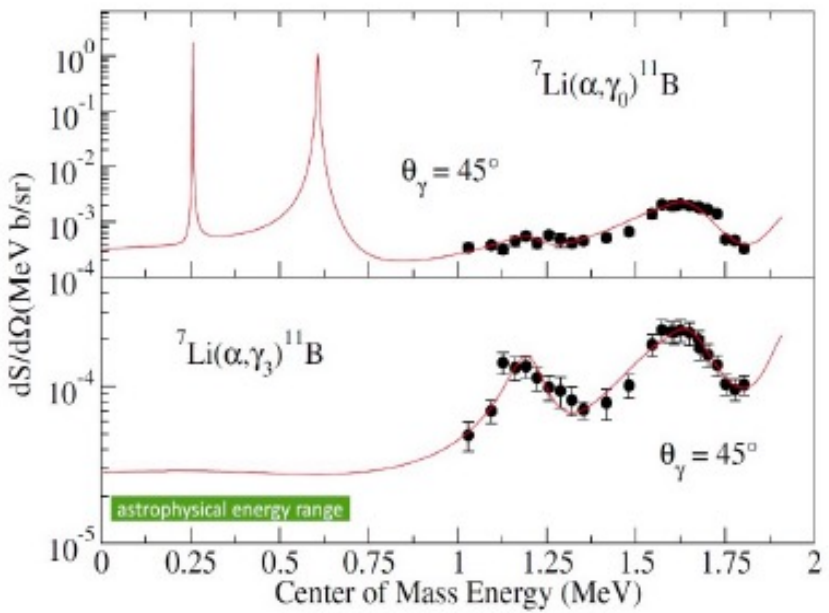
- Study performed @ the 5U Pelletron of University of Notre Dame, E_α= 460 – 1400 keV
- ^{6}LiF enriched targets degrade after ≈ 60 mC
- Excitation function with CeBr detector and tail of broad resonance with HPGE detector
- angular distributions for E_α=1.07 and 1.17 MeV resonances



Gula et al. PRC 106, 065801 (2022)

$^{7}Li(\alpha,\gamma)^{11}B$ reaction

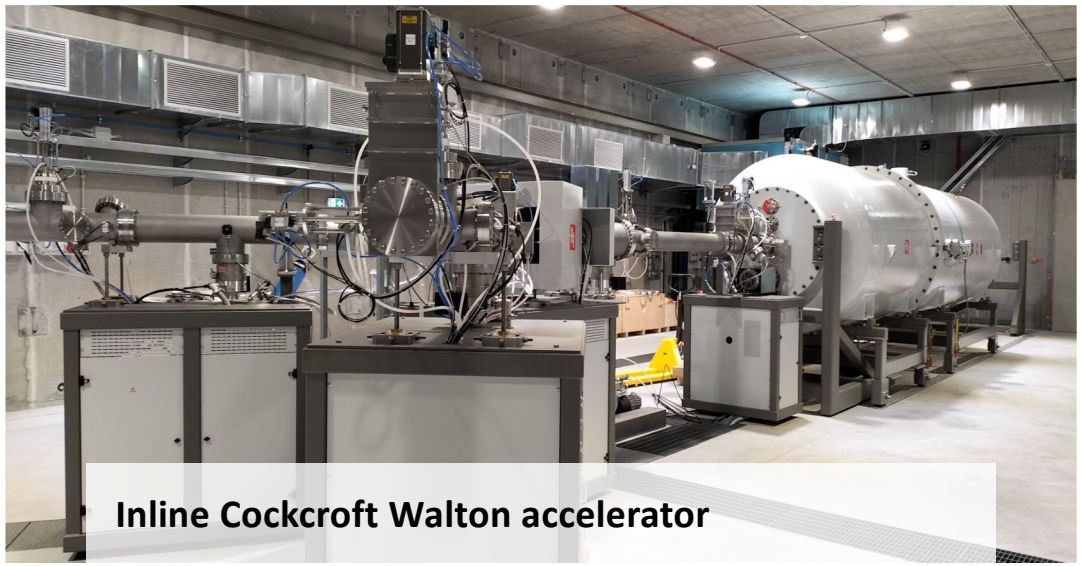




- Q-value: 8.664 MeV
- Low energy resonances at E_{α}= 460, 814 and 953 keV fairly well known, broad overlapping resonances at higher energies
- Recently measured at Notre Dame between 1.6 and 2.8 MeV (Gilardy 2018, PhD thesis, unpublished)

^{6,7}Li(α,γ)^{10,11}B measurement at Bellotti Ion Beam Facility

$^{6,7}Li(\alpha,\gamma)^{10,11}B$ Reaction at the Bellotti Ion beam facility



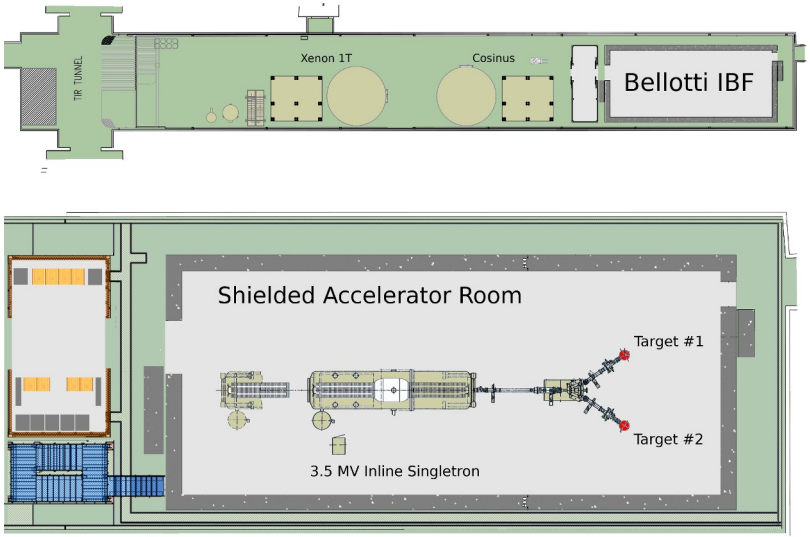
Inline Cockcroft Walton accelerator

TERMINAL VOLTAGE: 0.3 – 3.5 MV

Beam energy reproducibility: 0.01% TV or 50V

Beam energy stability: 0.001% TV / h

Beam current stability: < 5% / h



H^+ beam: 500 - 1000 µA

He^+ beam: 300 - 500 µA

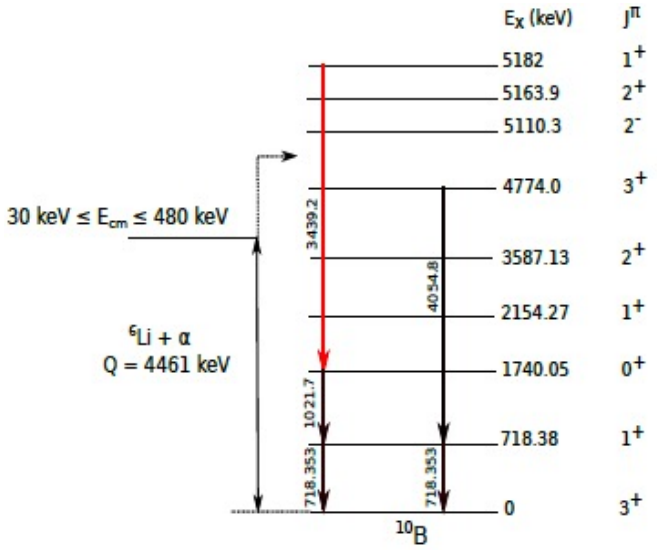
C^+ beam: 100 - 150 µA

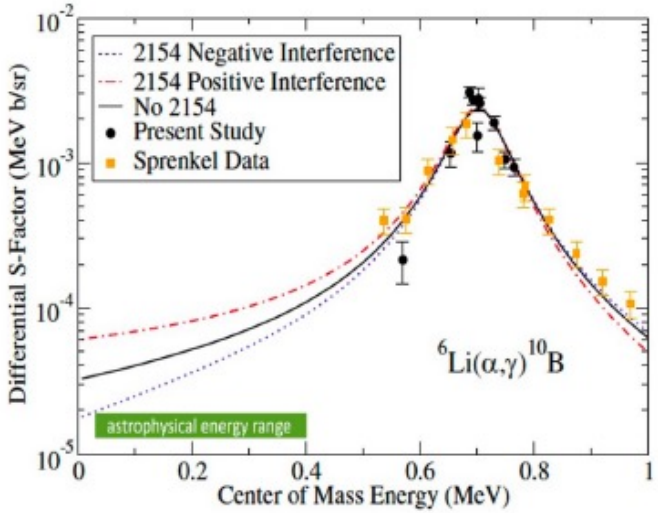
C^{++} beam: 50 pµA

Targets

- LiF evaporated
- Metallic Lithium (LiOH)
- Implantated Lithium? (Surrey IBC, Lisbon IST)

$^{6}Li(\alpha,\gamma)^{10}B$: Expected count rates

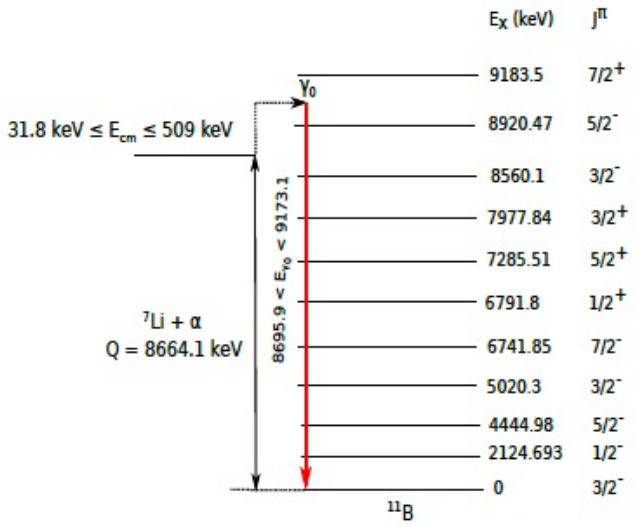


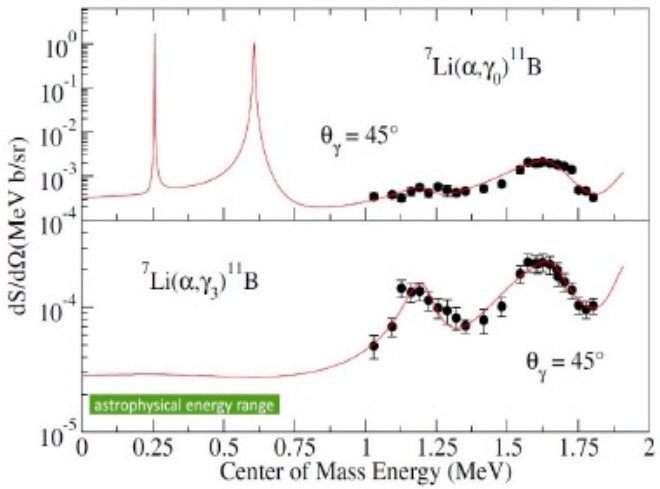


- 100 μA beam current
- 40 μg/cm^2 target thickness

E_{lab} [keV]	E_{cm} [keV]	beam	cross section [b]	rate [counts/day]	net rate [counts/day]	time [days]
650	390	He^{++}	9.23×10^{-10}	24.97	11.97	34
700	420	He^{++}	1.71×10^{-9}	46.33	33.83	12
750	450	He^{++}	3.13×10^{-9}	84.68	72.68	6
800	480	He^{++}	5.63×10^{-9}	152.48	140.89	3
Total time						**2 months**

$^{7}Li(\alpha,\gamma)^{11}B$: Expected count rates





- 100 μA beam current
- 40 μg/cm^2 target thickness

channel (α,γ_0)	E_{lab} [keV]	E_{cm} [keV]	beam	cross section [b]	rate [counts/day]	net rate [counts/day]	time [days]
	300	191	He^+	3.30×10^{-10}	15.3	15.3	26
	330	211	He^+	1.99×10^{-9}	92.2	92.2	4
	350	223	He^+	5.89×10^{-9}	273.32	273.32	1.5
	380	243	He^+	9.25×10^{-8}	4291.53	4291.53	2.2h
	400	255	He^+	8.42×10^{-6}	3.91×10^5	3.91×10^5	1.5m
	Total time						**~ 1 month**
(α,γ_3)	330	211	He^+	1.99×10^{-10}	9	9	11
	400	255	He^+	1.99×10^{-10}	9	9	11
	Total time						**~ 22 days**

Outlook

- The measurement of the ^{6,7}Li(α,γ)^{10,11}B in the framework of the NUCLEAR project offers a compelling opportunity to study α clustering effects near threshold in the context of nucleosynthesis in first-generation stars.
- Planned to start data taking in mid 2027
- One PhD student (Lavinia Dalla Vedova) on the project starting in September
- Development and characterization needed for the targets, to be done in 2026