Australian National University

Interplay of charge-clustering and weak binding in direct reactions of ^{8}Li

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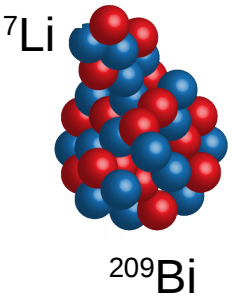
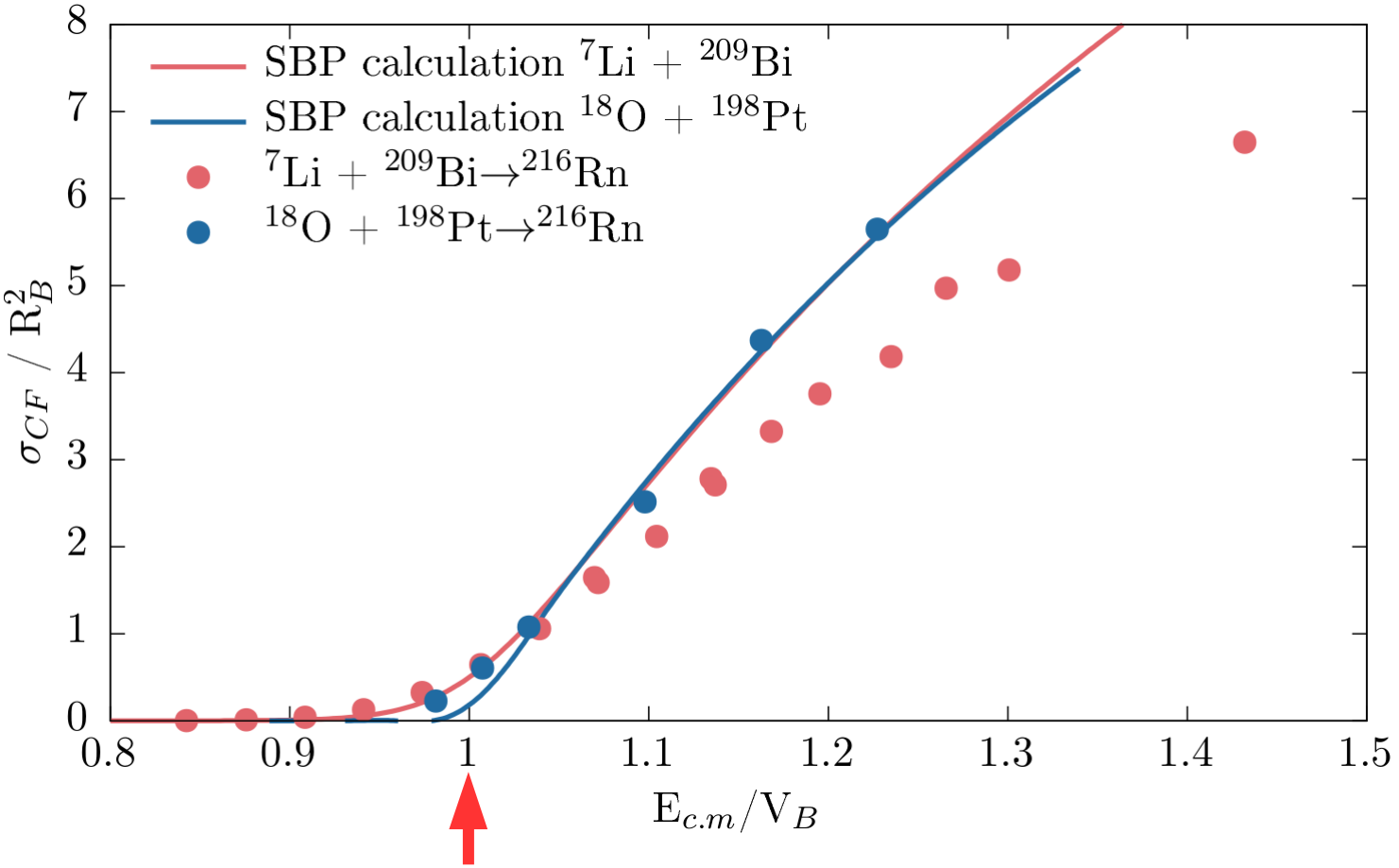
Australian National University

6 June 2018

Suppression of complete fusion



Single Barrier Penetration model calculation vs Experiment

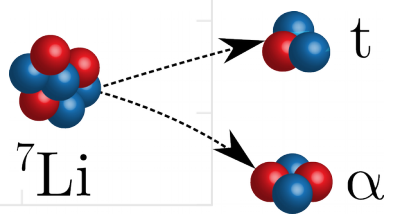


Precision measurements at ANU (average barrier determination)
→ Unambiguous determination of suppression

Dasgupta, PRC 70, 024606 (2004)
Signorini Eur. Phys. J. A 5 (1999)
Canto Phys. Reports 596 (2015)

Suppression of complete fusion

Can the observed suppression of CF be explained by breakup followed by capture of one charged fragment?



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Precision measurements at ANU (average barrier determination)
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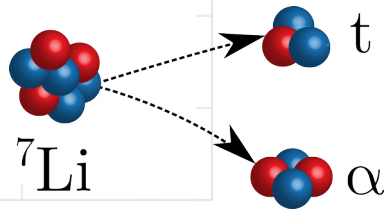
Suppression of complete fusion

Can the observed suppression of CF be explained by breakup followed by capture of one charged fragment?

Mechanism that causes breakup and time-scale crucial.



Mechanisms:

Rafiei PRC 81 024601 (2010),
Luong PLB 695 105-109 (2011)
Luong PRC 88 034609 (2013)
Cook PhD 2017

Timescales:

Cook PhD Thesis (2017)
Cook et. al. PRC 93, 064604 (2016)
Kalkal et. al. PRC 93, 044605 (2016)
Simpson et. al. PRC 93, 024605 (2016)

Suppression of complete fusion

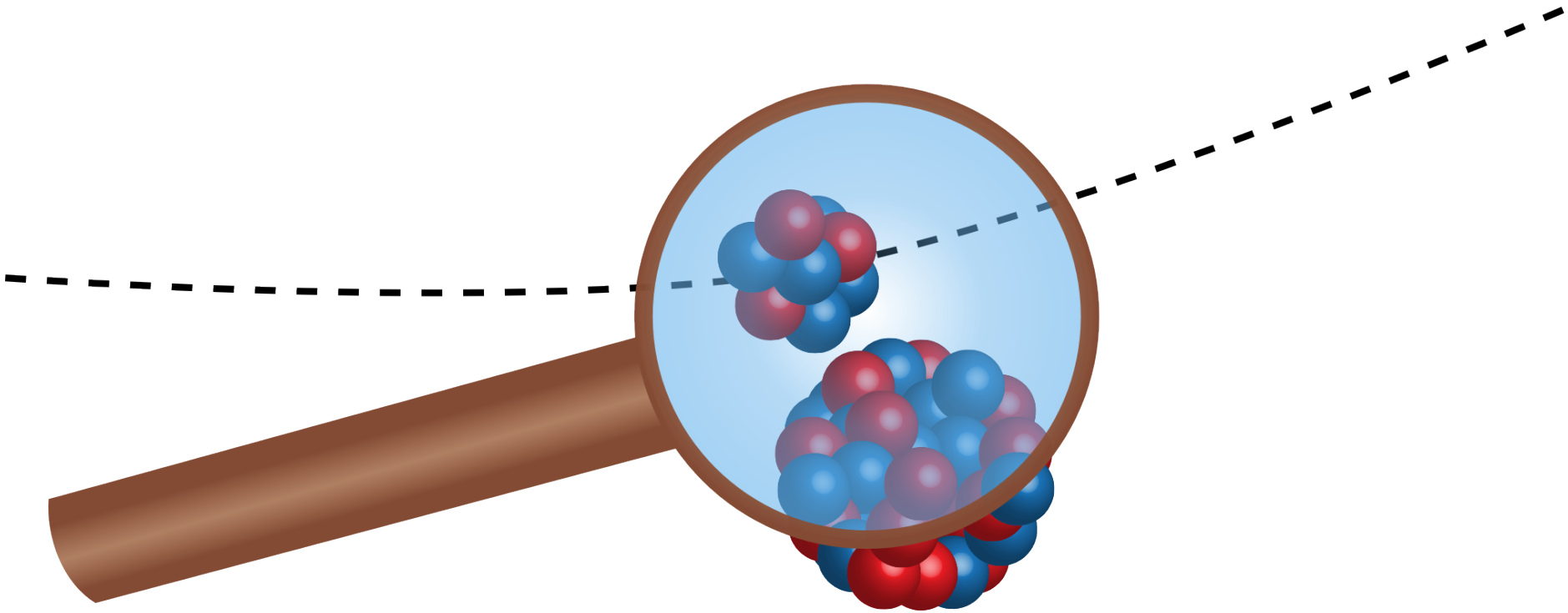
Focus has been on
breakup into charged clusters → fusion suppression

- How does the picture evolve as we go towards more neutron rich beams, e.g. ^{8}Li … ^{11}Li?
- ^{8}Li, CF observed to be suppressed by ~31% (Aguilera PRC 80 044605 (2009))
- Lowest BU threshold:
  ^{8}Li → ^{7}Li +n (2.03 MeV). Can't suppress CF!

Aguilera et. al. PRC 80 044605 (2009)

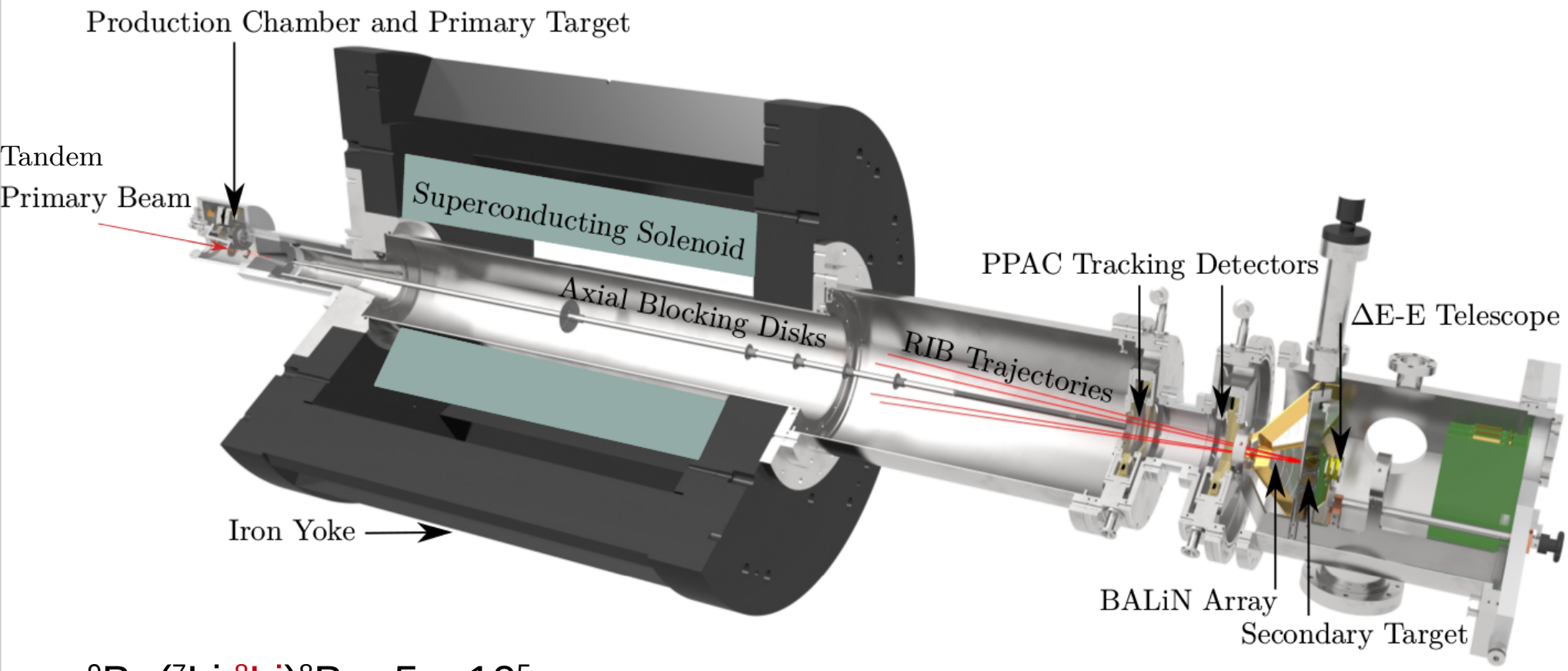
^{8}Li breakup in reactions with ^{209}Bi

- Mechanisms?
- Timescales?



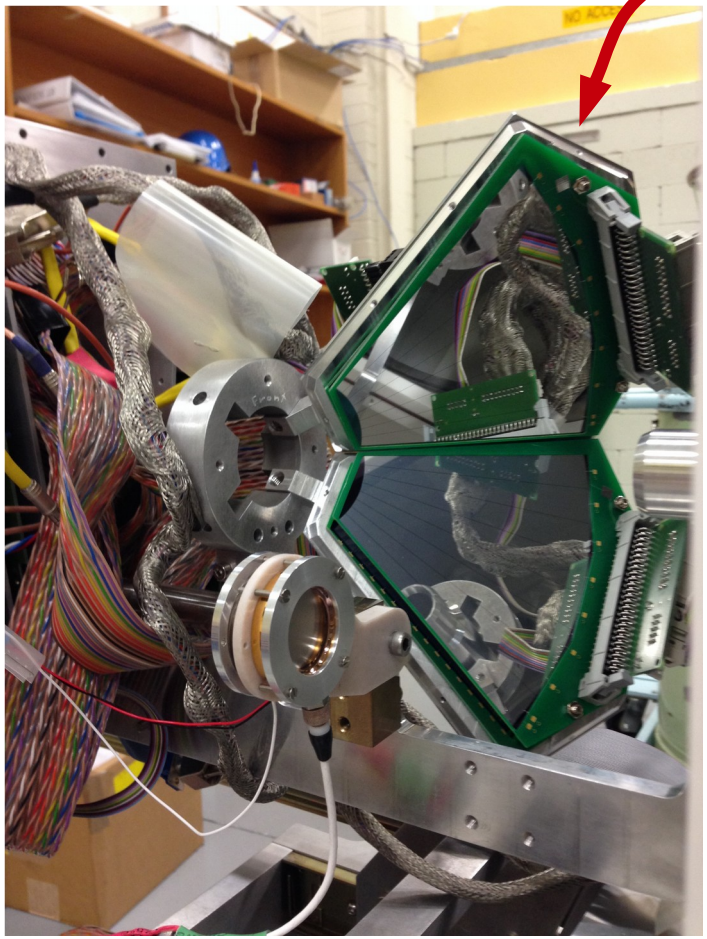
SOLEROO – solenoidal exotic rare isotope separator

(In-flight transfer)



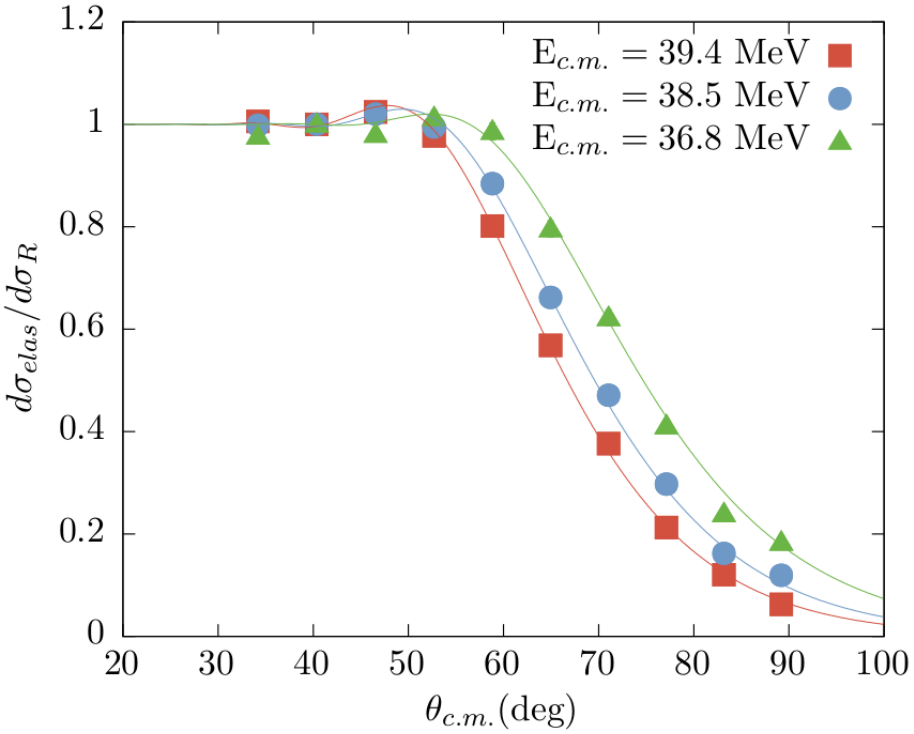
- $^{9}Be(^{7}Li,^{8}Li)^{8}Be$, 5 x 10^{5} pps
- ^{8}Li + ^{209}Bi, 38.4 – 40.94 MeV (1.27-1.36 E/V_B)
- Raw purity 83%, further purification through ToF, PPAC ΔE

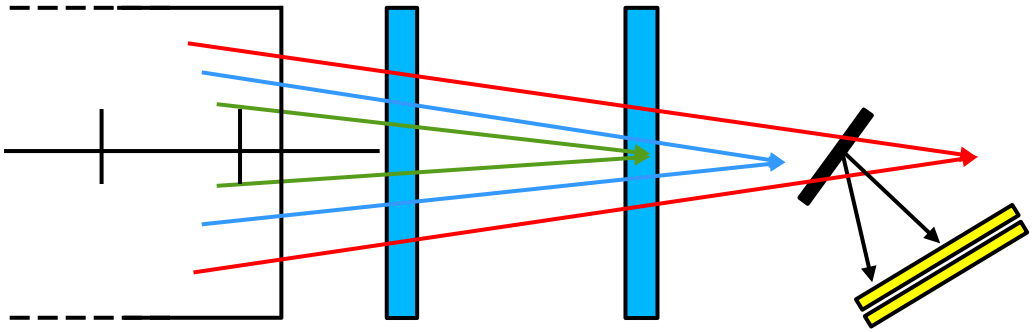
Breakup Array for Light Nuclei (BALiN)



- 2 pairs of ΔE – E telescopes (ΔE 400 μm + E 500 μm)
- DSSDs → (θ,φ)
- Large angular acceptance crucial for coincidences
- Particle ID with E + ΔE, ToF
- Identified singles ^{8}Li, ^{9}Be, ^{7}Li, α, coin α+Z=1, α+α

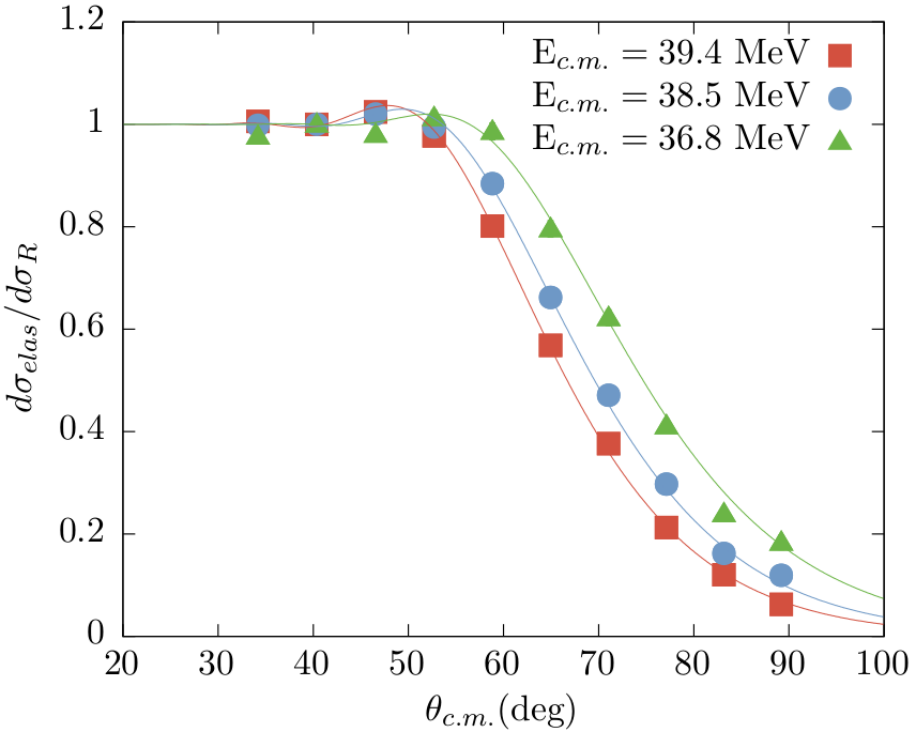
Elastic scattering



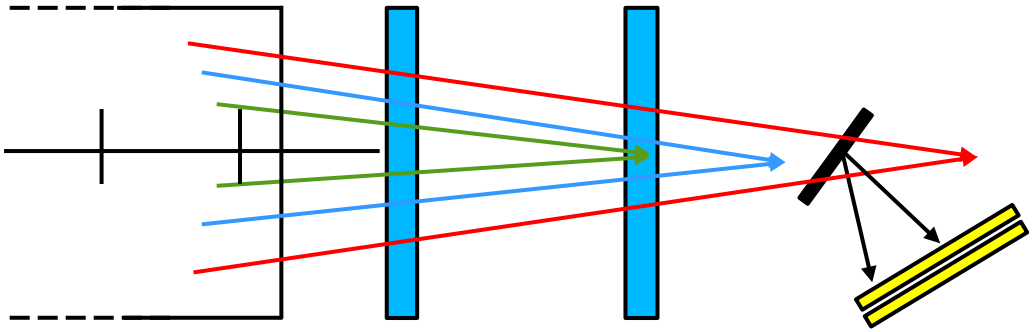


Cook et. al. PRC 97, 021601(R) (2018)

Elastic scattering



- Reaction cross-section from OM fit: 1423 ± 9 ± 20 mb at E_{CM} = 38.6 MeV



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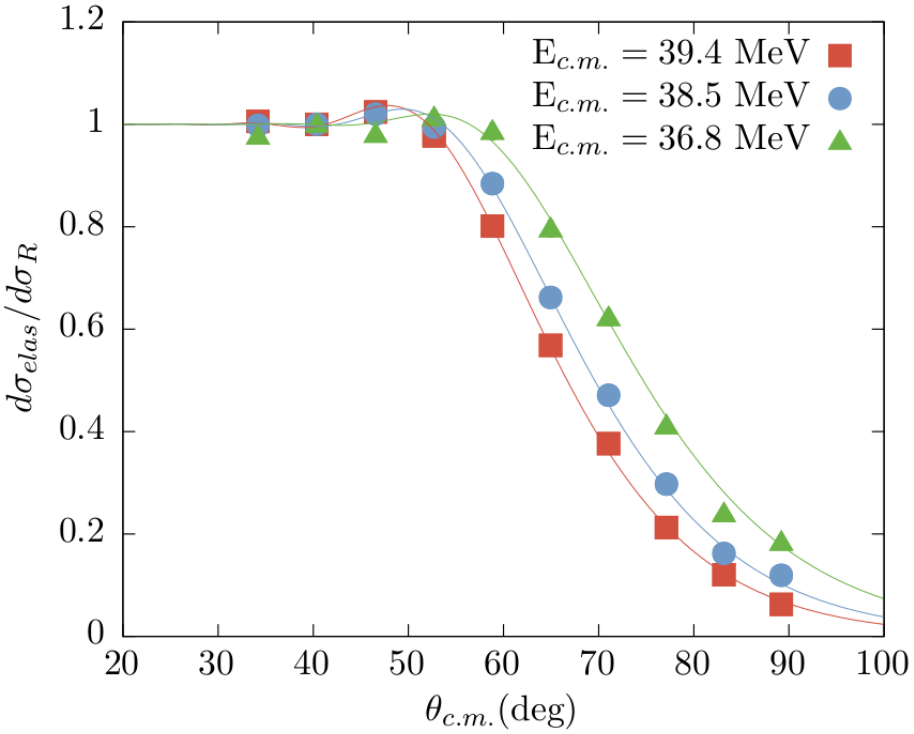

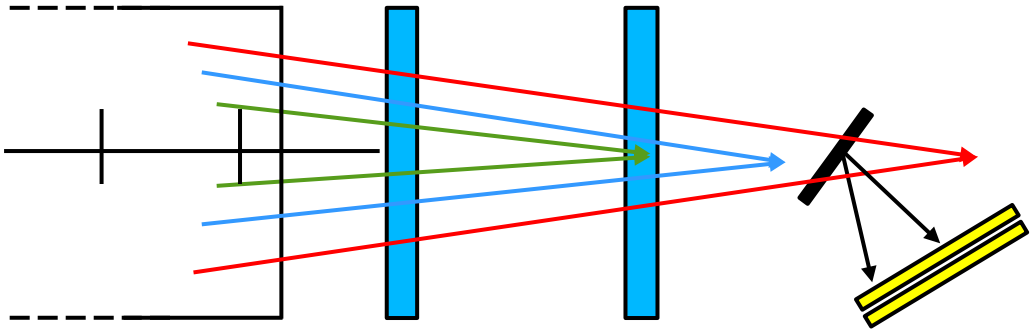

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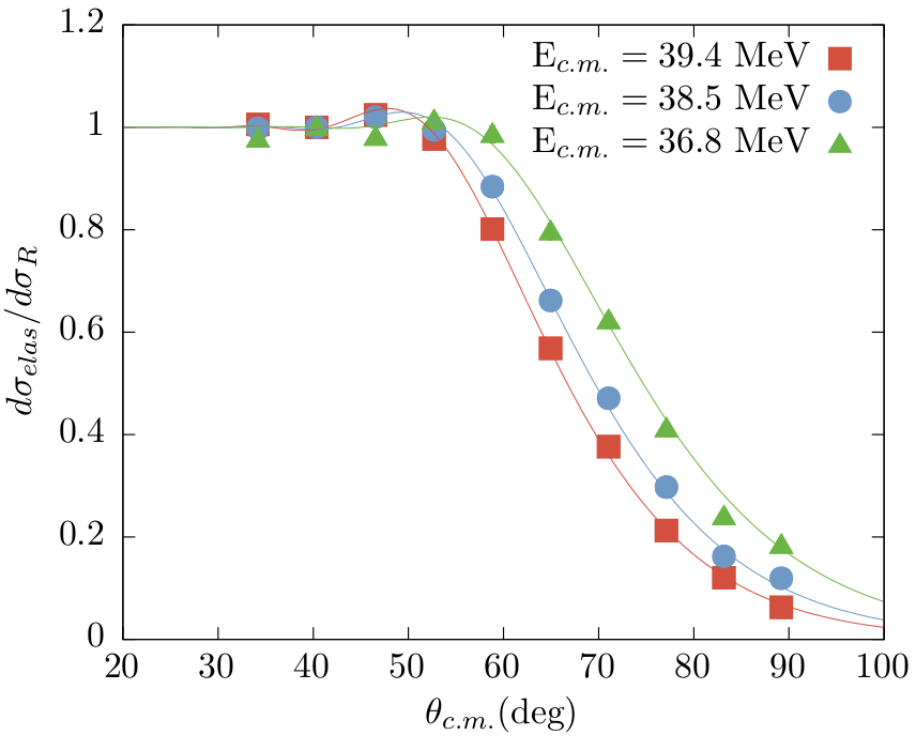
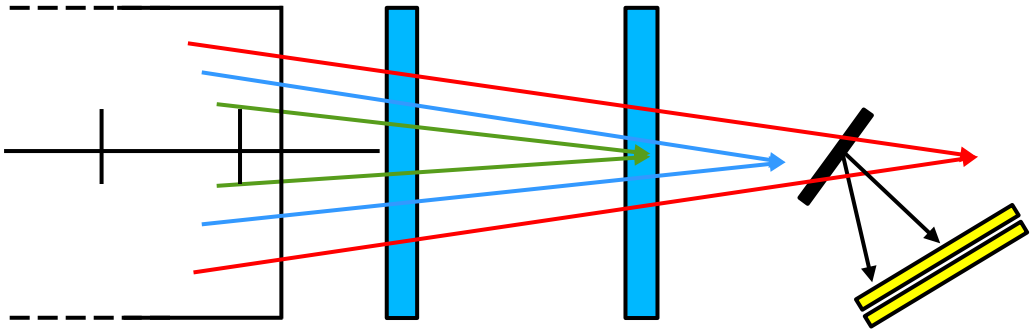


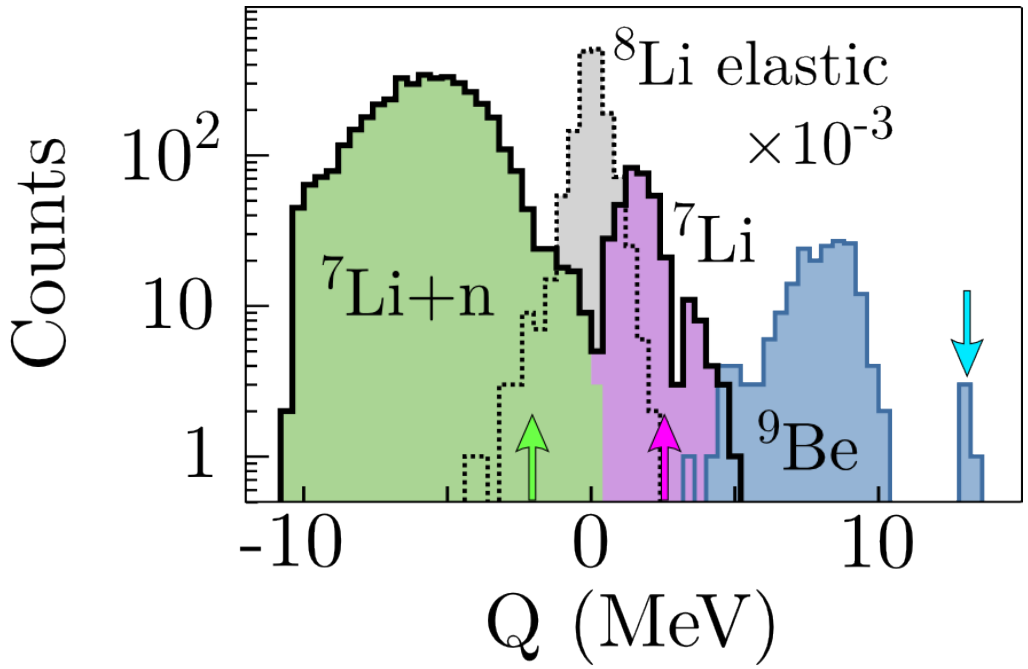


- Reaction cross-section from OM fit: 1423 ± 9 ± 20 mb at E_{CM} = 38.6 MeV
- Calculated Total Fusion ~ 1045 mb
- Direct reactions?

Cook et. al. PRC 97, 021601(R) (2018)

Direct reaction mechanisms → ^{7}Li, ^{9}Be

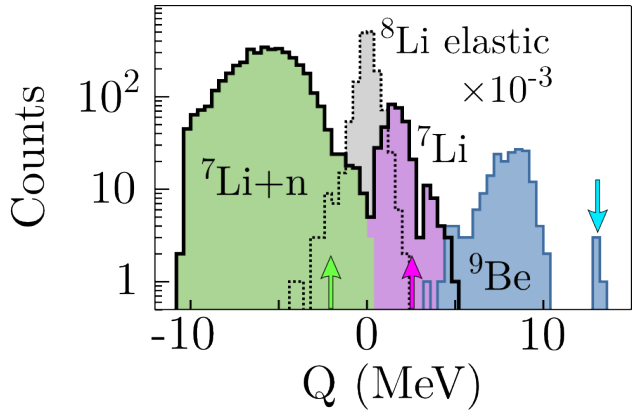
- ^{7}Li from 1n stripping vs
  ^{7}Li from direct breakup
  distinguished via Q

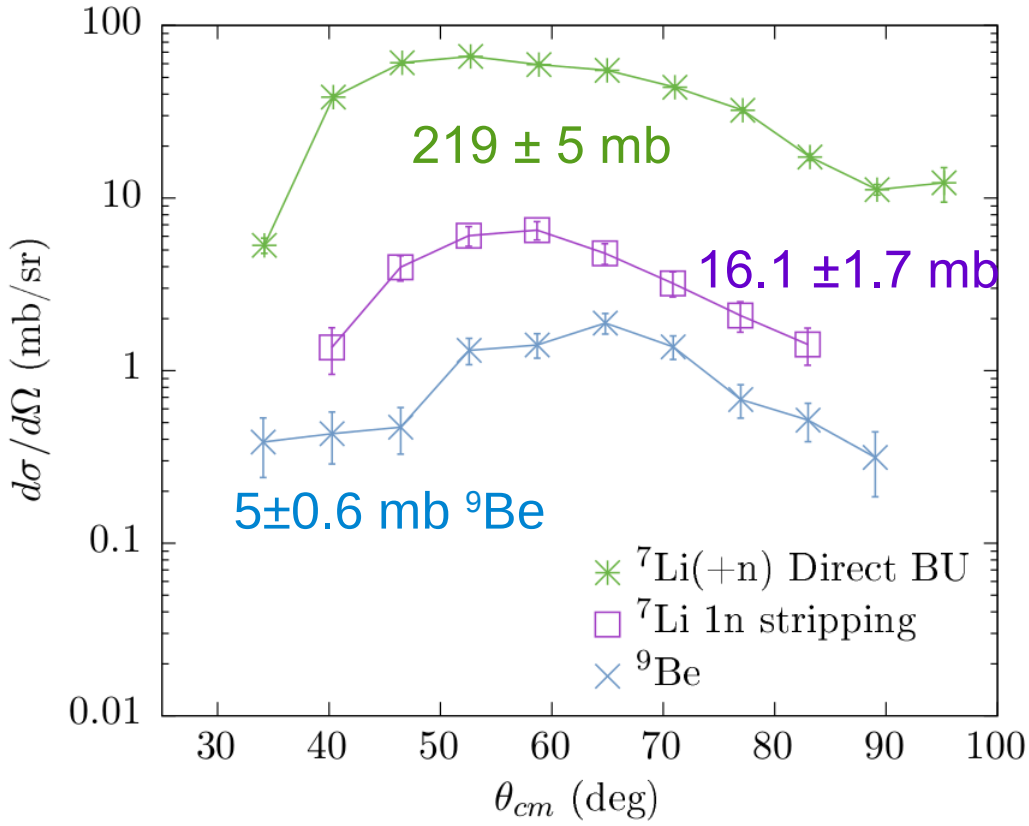


Cook et. al. PRC 97, 021601(R) (2018)

Direct reaction mechanisms → ^{7}Li, ^{9}Be

- ^{7}Li from 1n stripping vs ^{7}Li from direct breakup distinguished via Q
- Peaked ~ grazing angle
- None of this leads to ICF...

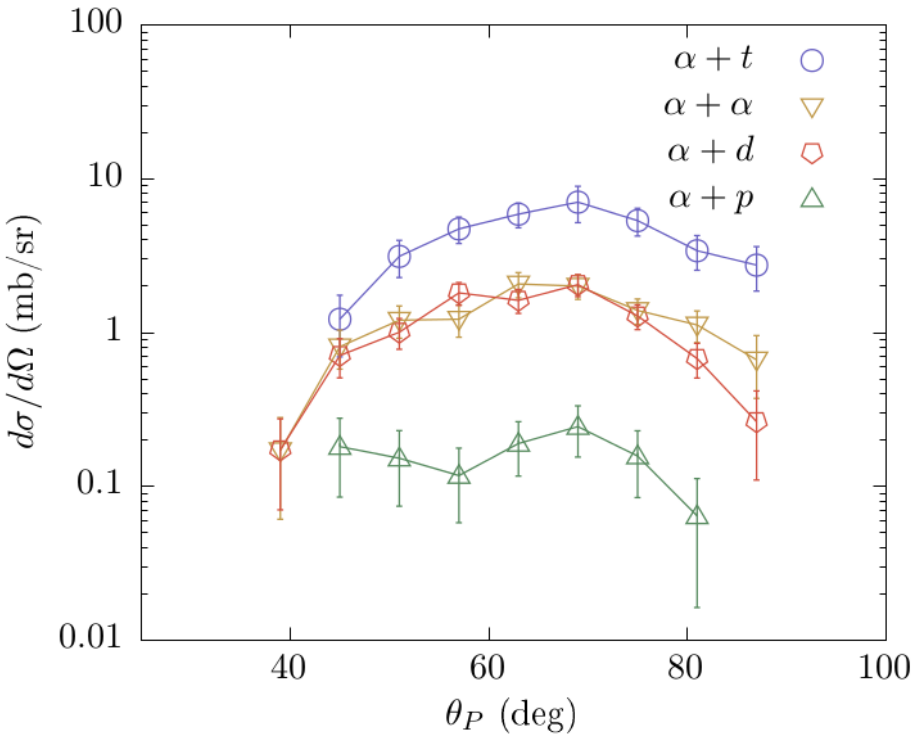




Cook et. al. PRC 97, 021601(R) (2018)

Direct reactions – No Capture Breakup

- α+t dominant (19 ± 2 mb)
  - α+α (6.2 ± 0.9 mb)
  - α+d (5.6 ± 0.7 mb)
  - α+p (0.9 ± 0.4 mb).
- Can these BU modes suppress complete fusion?

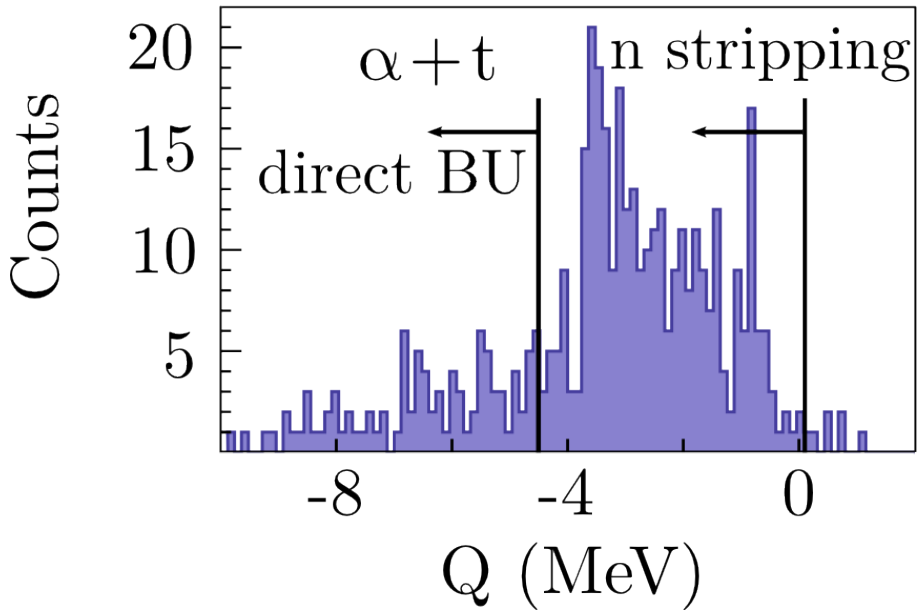


Cook et. al. PRC 97, 021601(R) (2018)

What leads to α + t?

- Reconstructed Q-value – excitation of target-like nucleus
- >78±6 % neutron stripping

$^{8}Li + {}^{209}Bi \rightarrow {}^{7}Li(\alpha+t) + {}^{210}Bi$



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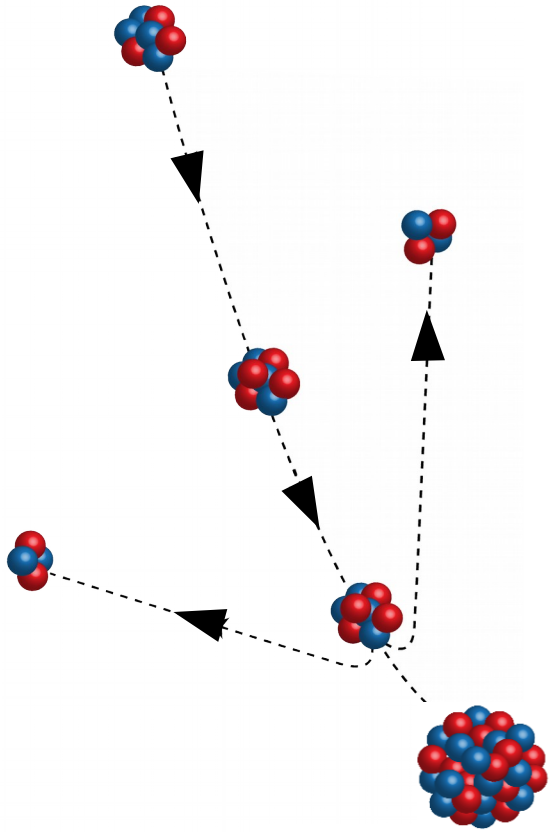
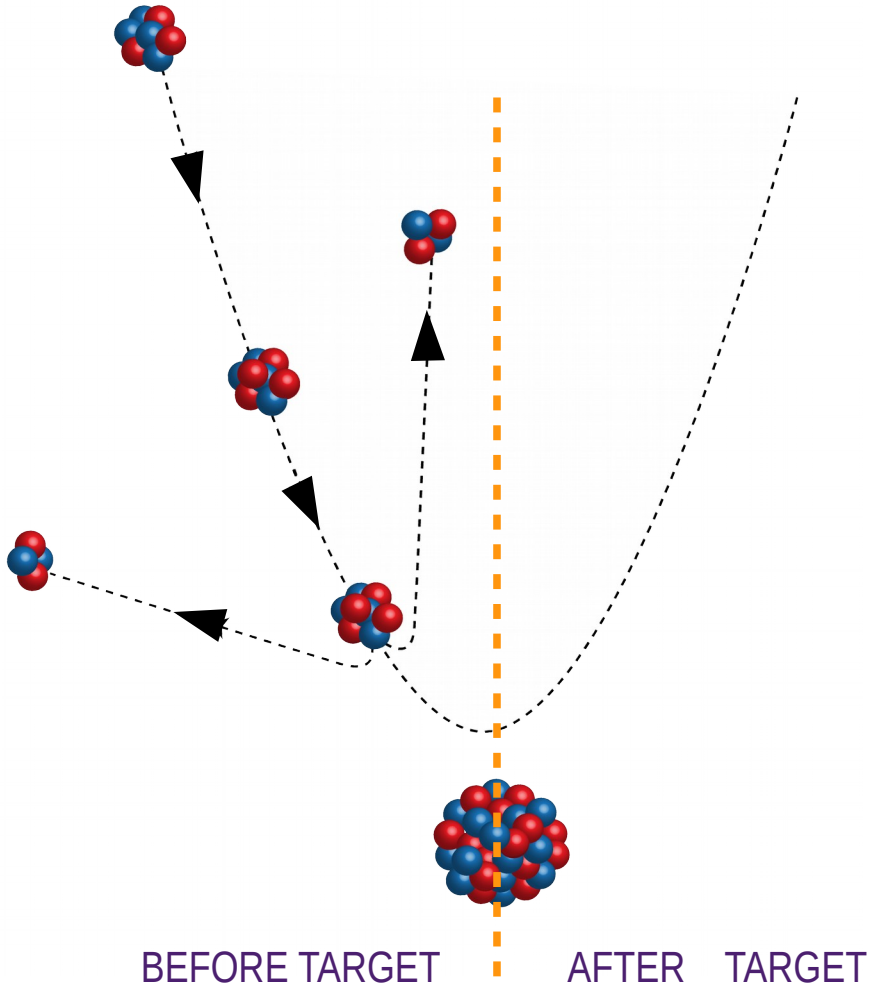
Incoming vs outgoing trajectories

Central trajectories: breakup must occur prior to reaching the fusion barrier



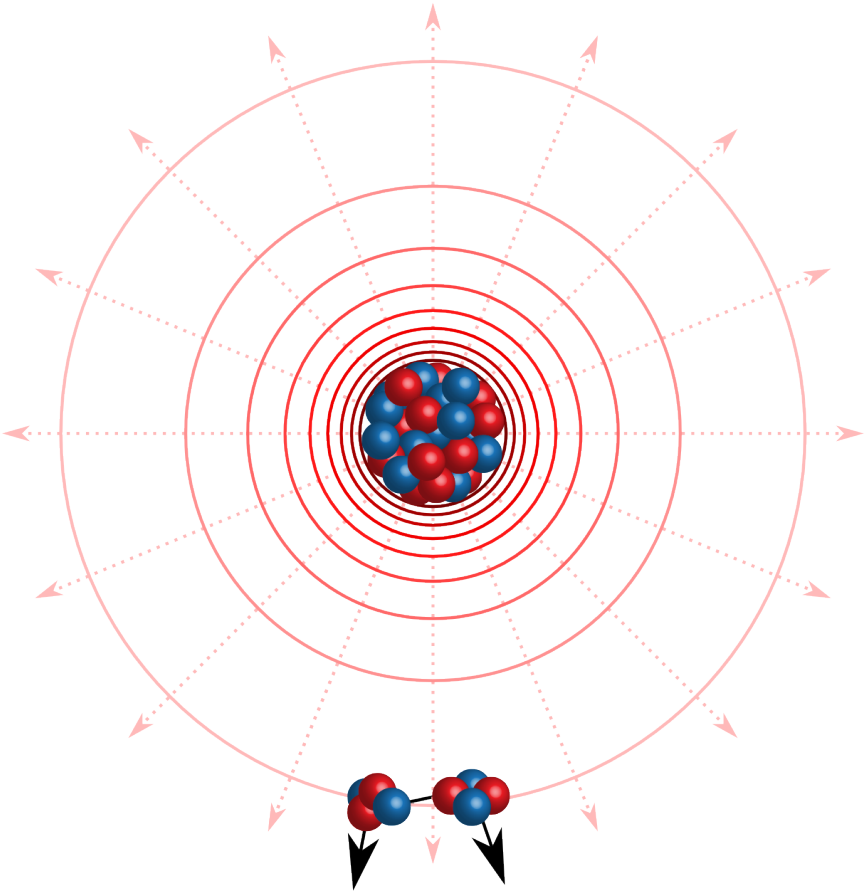
Incoming vs outgoing trajectories

Equivalently, outside the grazing angle: breakup must occur prior to reaching the distance of closest approach



Relative Energy $E_{rel} = \frac{1}{2} \mu v_{rel}^2$

Asymptotic breakup



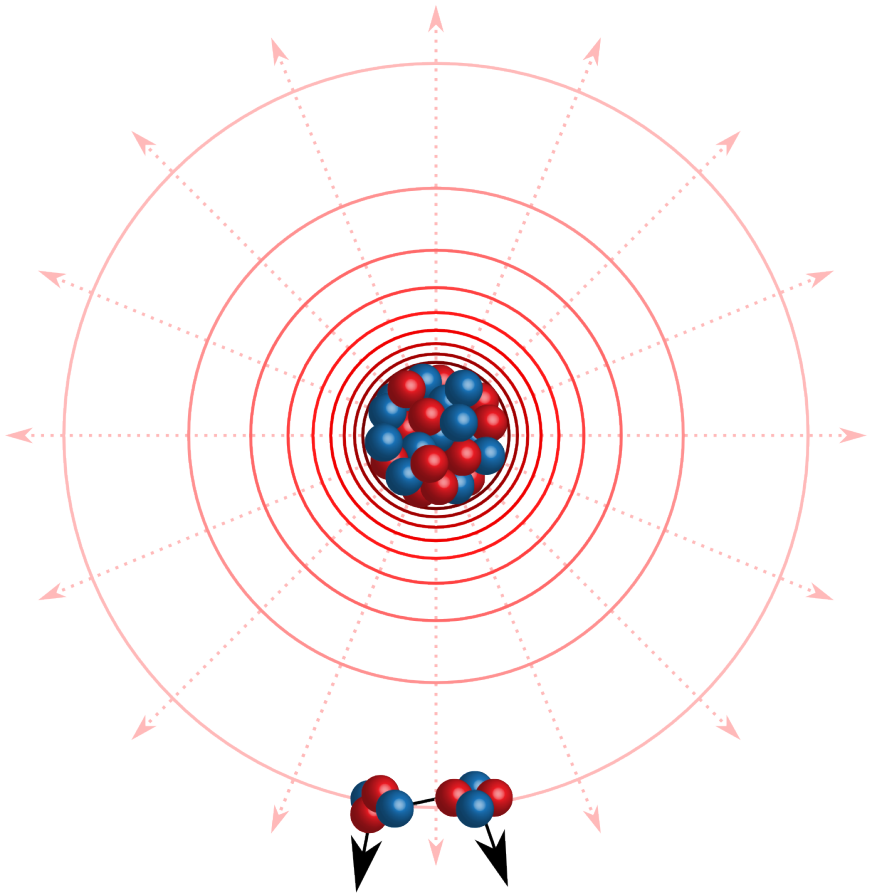
Breakup far from the target

No change to E_{rel}

$$E_{rel} = Q_{BU} + E_p^*$$

Relative Energy $E_{rel} = \frac{1}{2} \mu v_{rel}^2$

Asymptotic breakup

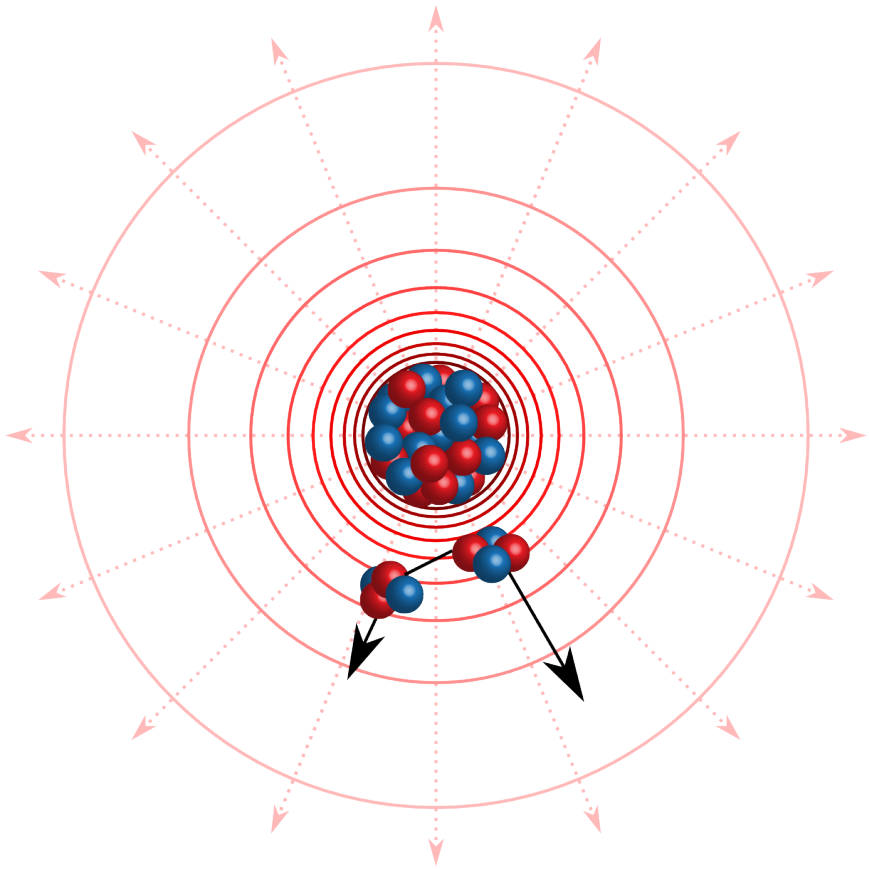


Breakup far from the target

No change to E_{rel}

$E_{rel} = Q_{BU} + E^*_p$

Near target breakup



Breakup close to the target

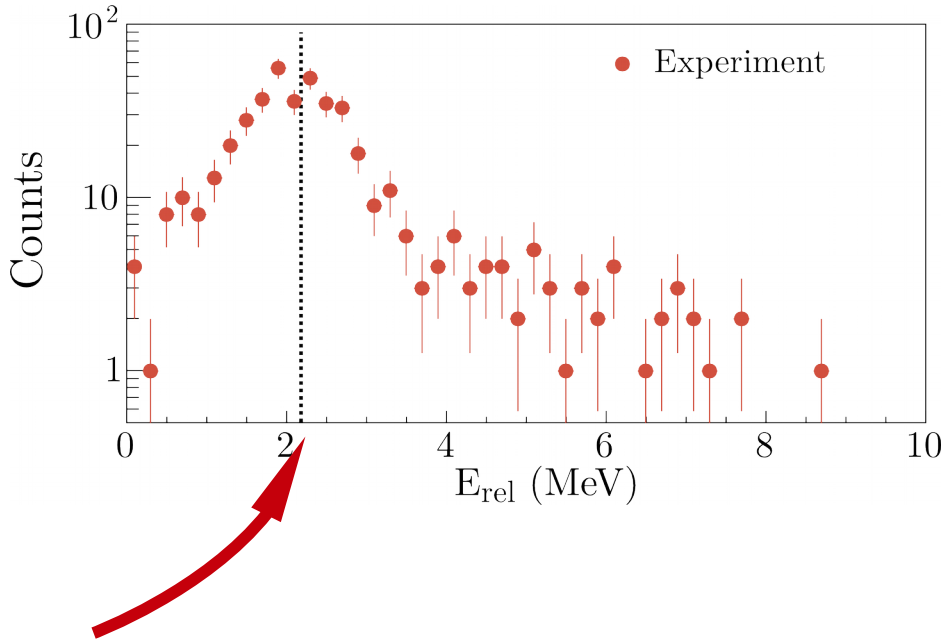
Modified E_{rel}

$E_{rel} = Q_{BU} + E^*_p + \Delta E_{acc} \gtrless Q_{BU} + E^*_e$

Is the breakup happening quickly enough?

- Peak in $E_{rel} \rightarrow$ long-lived resonance, BU far from target. $E_{rel} = E_p^* + Q_{BU}$

Is the breakup happening quickly enough?



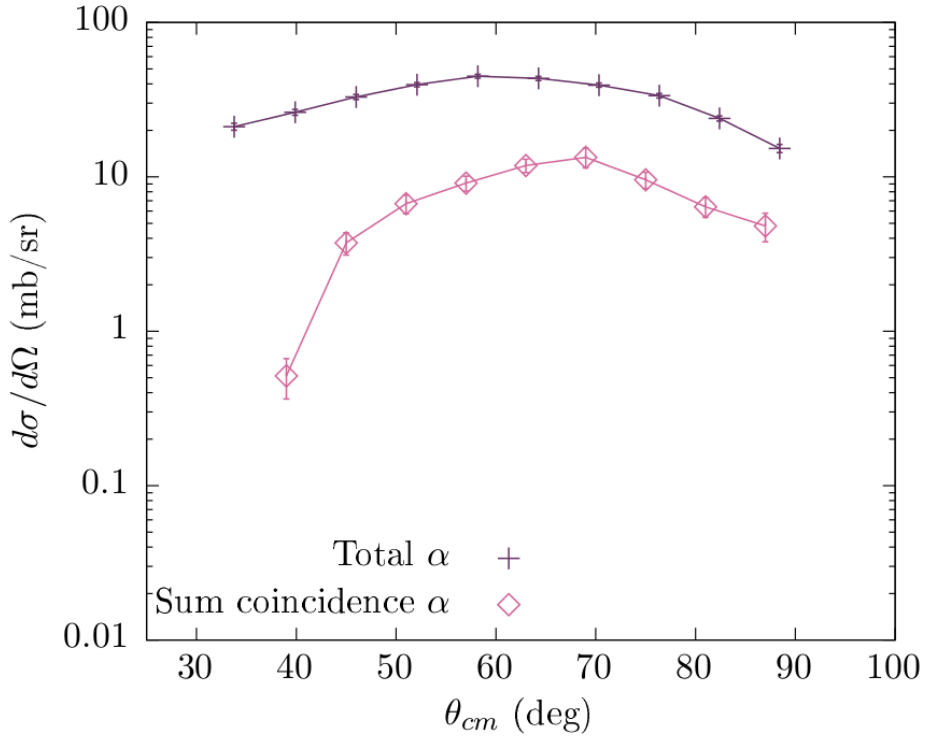
Breakup from 7/2- state of ^{7}Li (Ex = 4.652 MeV, τ = 10^{-20} s, much longer than fusion timescale)

- Peak in E_{rel} → long-lived resonance, BU far from target. $E_{rel} = E_p^* + Q_{BU}$
- How much is fast enough to suppress CF?
  - Classical model simulation (see next talk): only 7%!

Singles alpha vs BU alpha

Unaccompanied α = Inclusive α – NCBU α

161±6 mb = 198 ± 6 mb – 37 ± 2 mb



By Z conservation, unaccompanied α → polonium production → “Incomplete fusion” → CF suppression?

Speculation

- Unaccompanied α (+CF suppression) + NCBU timescales:

  → CF suppression mechanism clearly more complex than BU + capture

- CF suppression mechanism – charged cluster transfer?
  - Relevant for n-rich nuclei? (e.g. Kanada-En'yo PTEP (2012))
  - How does transfer of one cluster stop the other one fusing? Next challenge!

Summary

- First ^{8}Li measurement at ANU

✓ σ reaction

✓ σ nucleon transfer to bound states

✓ σ nucleon transfer to unbound states.

  – Lots of modes!

  – α+t too slow.

  – α+α, α+d also too slow, α+p too small

Search still on for CF suppression mechanism!

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Acknowledgements

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