TEXAS A&M UNIVERSITY

Cyclotron Institute

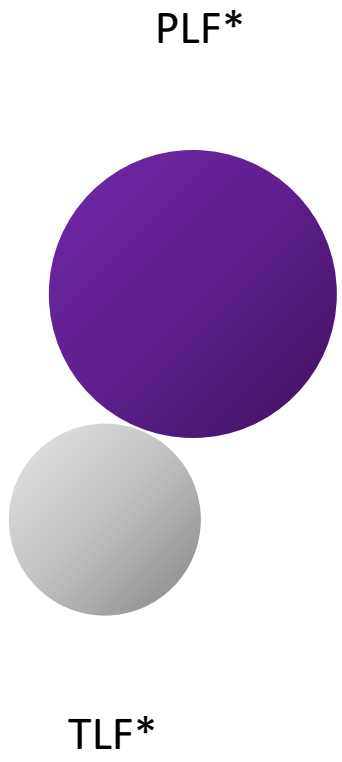
Investigating Resonant State Modification with a Coulomb Trajectory Model

Travis Hankins

Yennello (SJY) Group

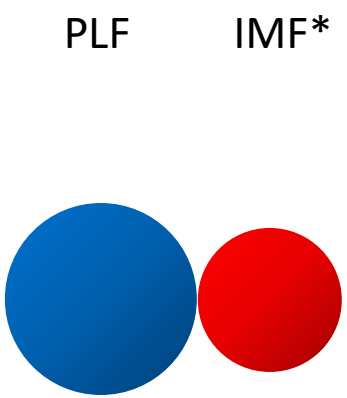
Heavy Ion Collisions (HICs)

- HICs in the right energy regime can produce excited projectile-like fragments (PLF*).



Heavy Ion Collisions (HICs)

- HICs in the right energy regime can produce excited projectile-like fragments (PLF*).
- These PLF* may de-excite by intermediate mass fragment (IMF) emission.
  - If the IMF is also excited (IMF*), it will decay based on the available pathways.



Experiment

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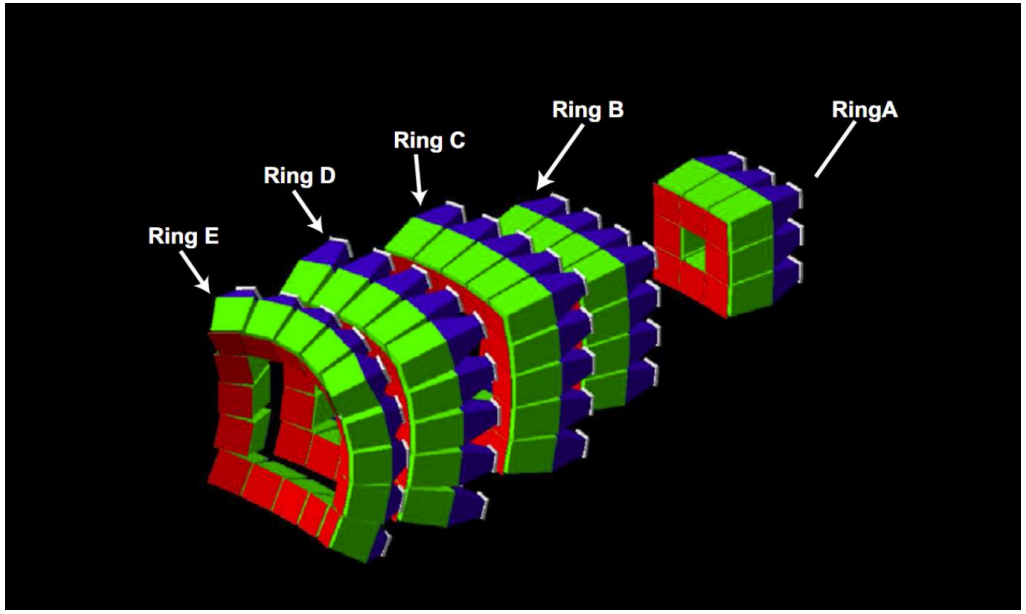
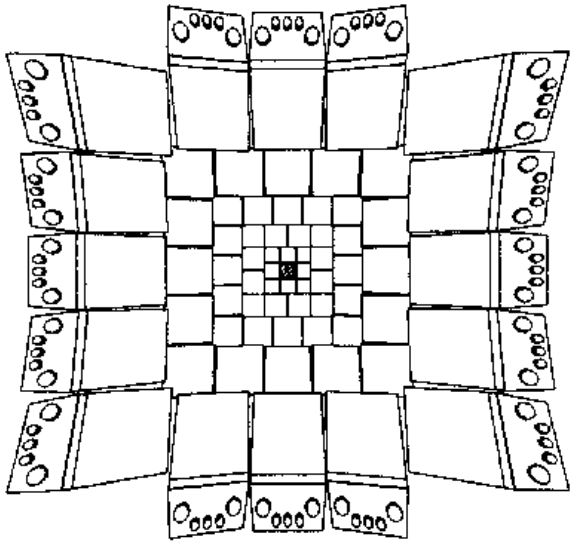
- FAUST – Forward Array Using Silicon Technology

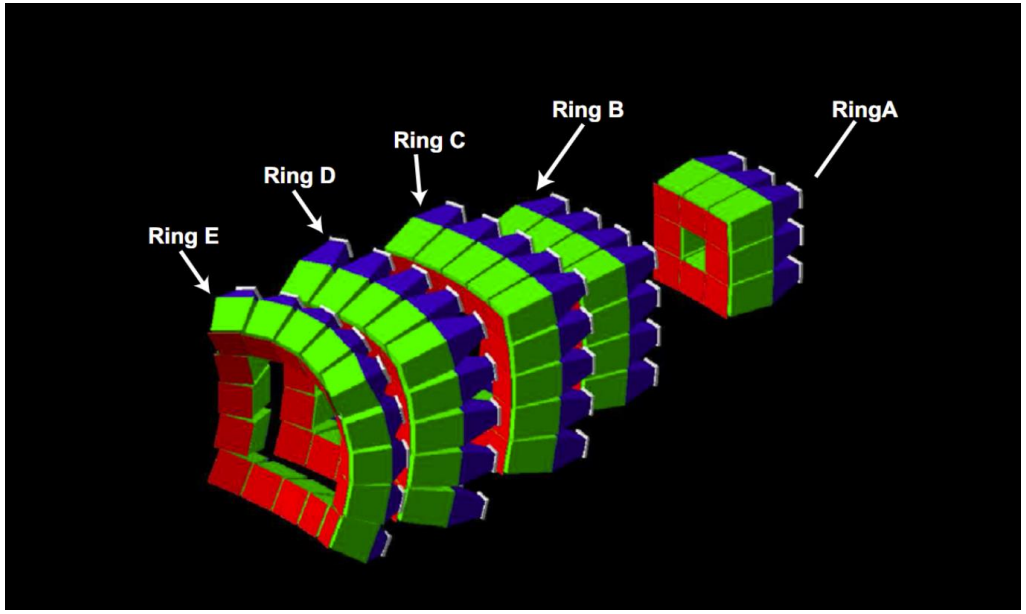


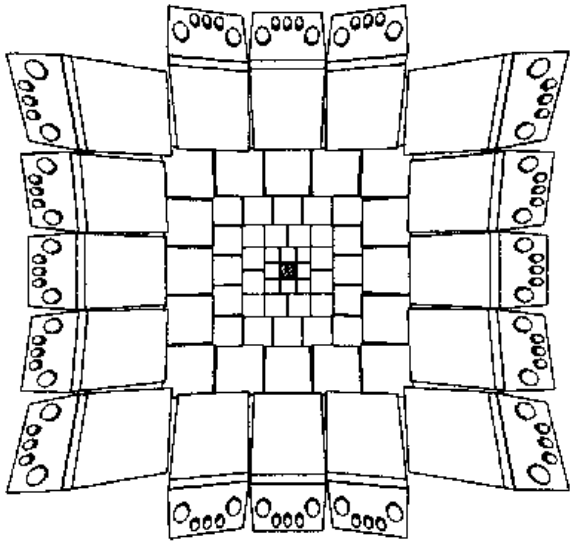


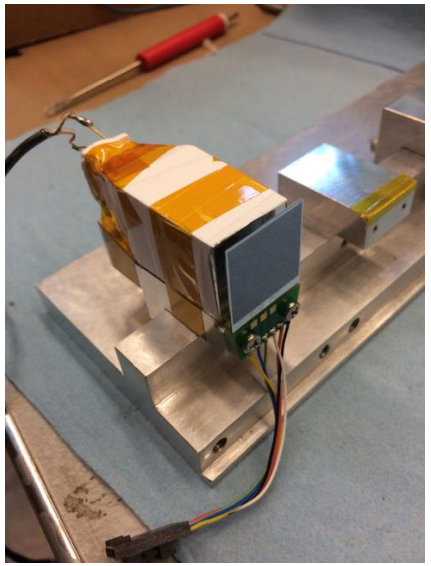
L.A. McIntosh, et. al., Nucl. Instrum. Methods A 985 (2021) 164642.
F. Gimeno-Nogues, et. al., Nucl. Instrum. Methods A 399 (1997) 94 100.

Experiment

- FAUST – Forward Array Using Silicon Technology
  - 68 *ΔE-E* telescopes; covers most of 1.6° - 45.5° with good position and energy resolution
  - $^{28}Si + {}^{12}C$ @ 35 MeV/u







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Resonant States

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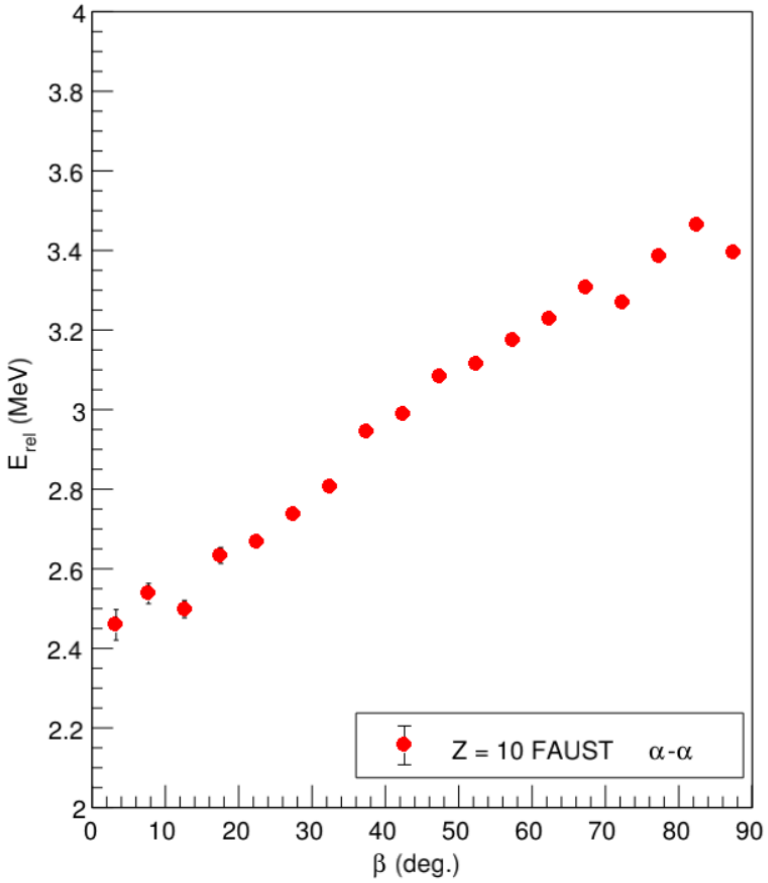

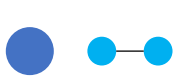

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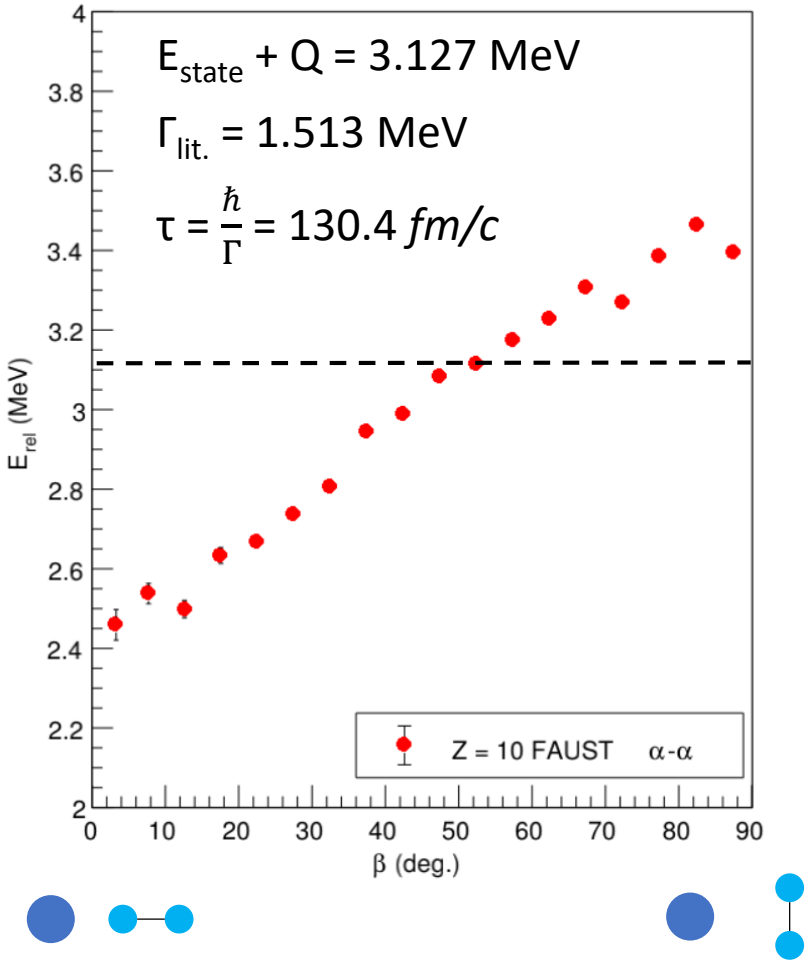

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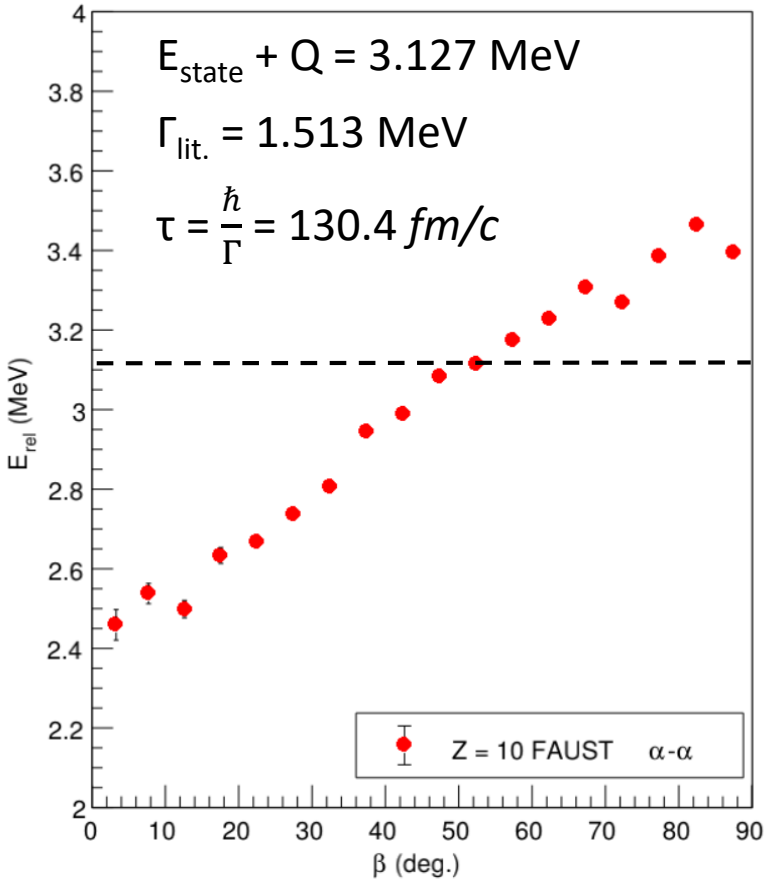

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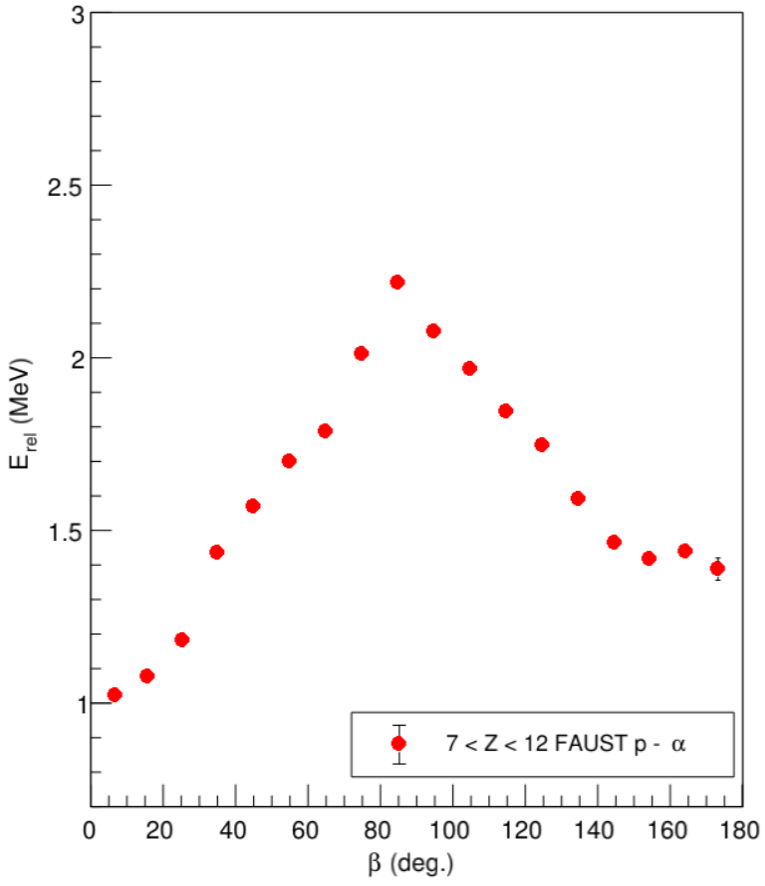

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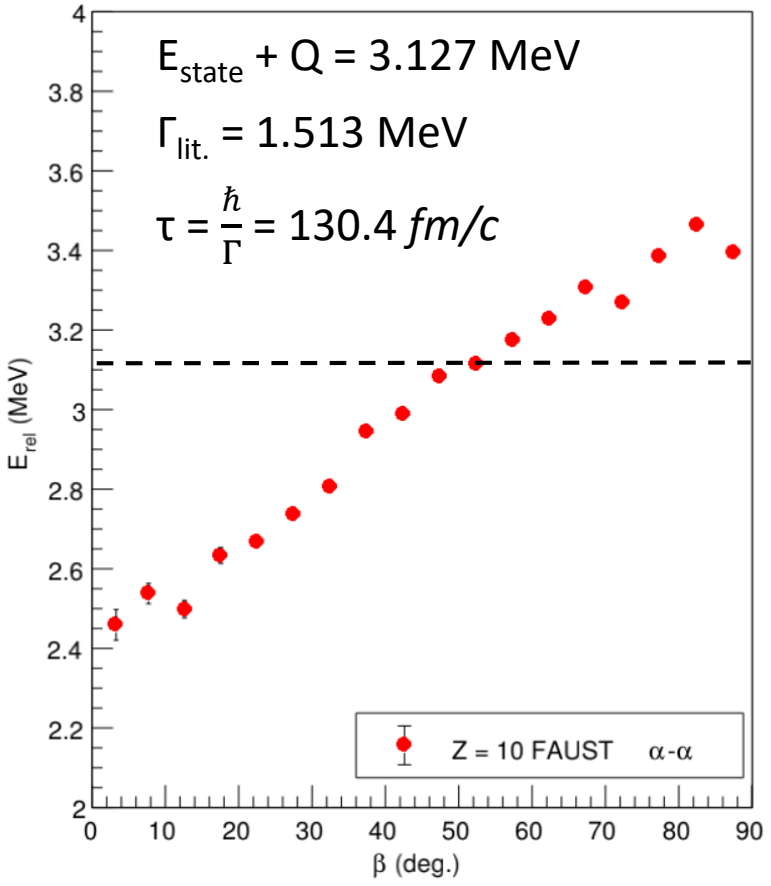

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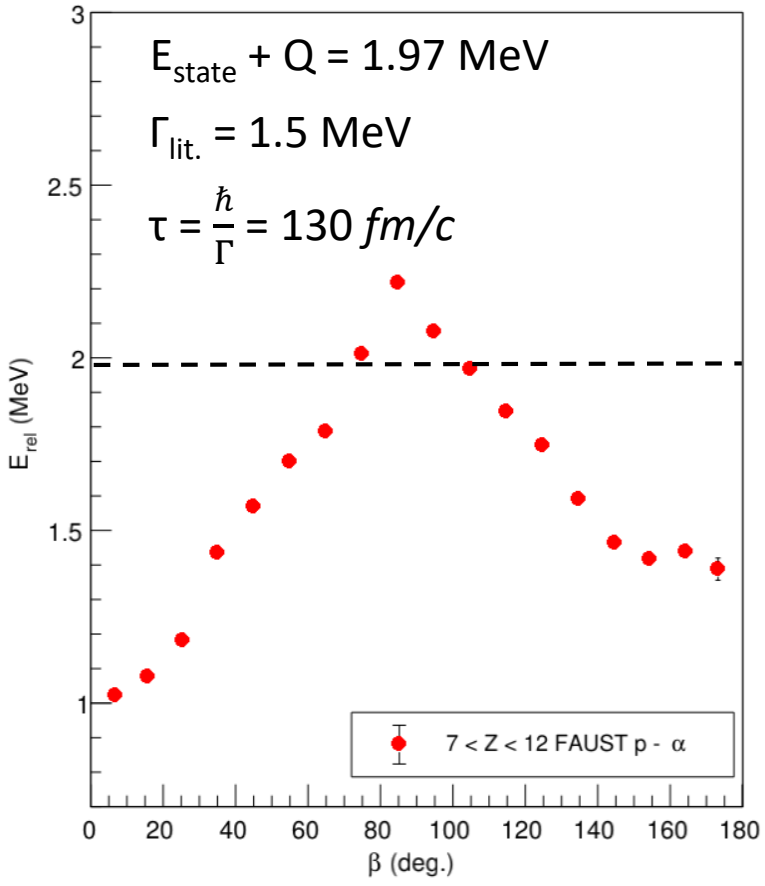

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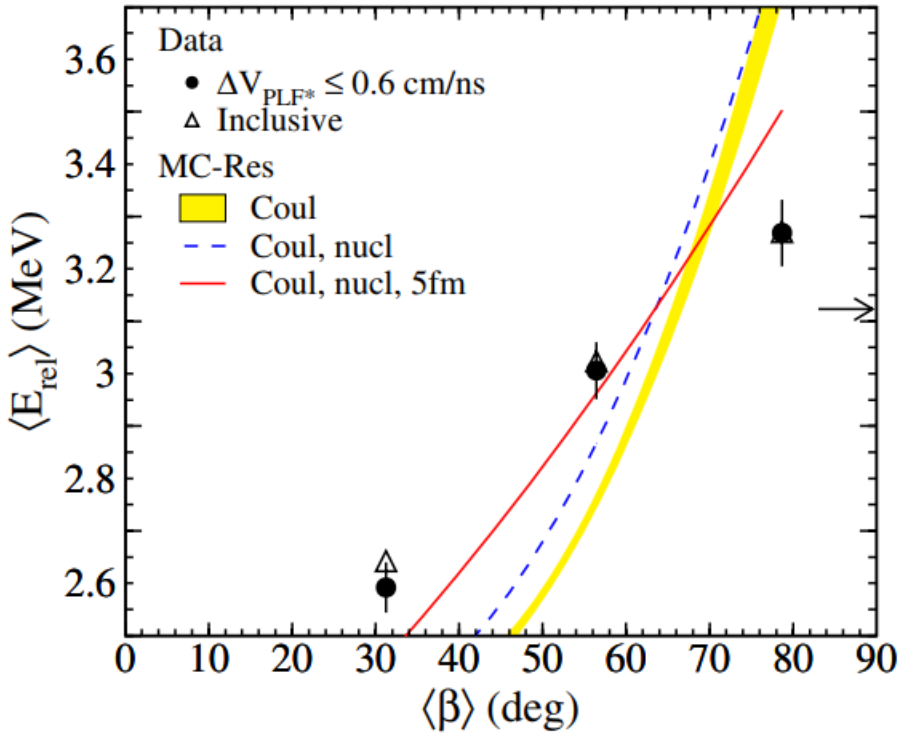
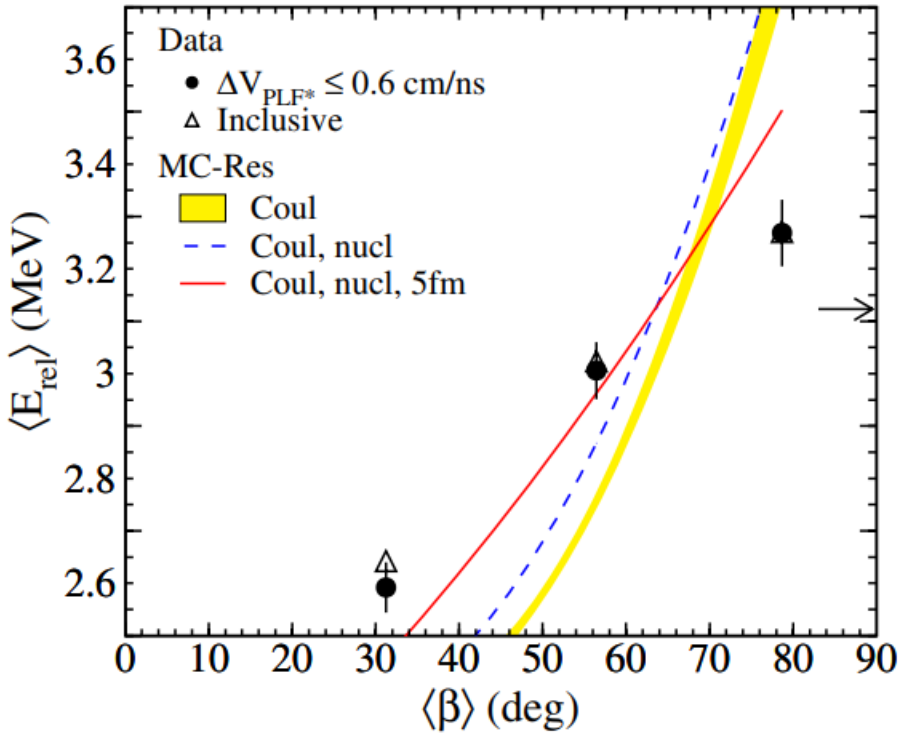
- Understanding of dynamic interaction incomplete
- Preliminary research may suggest nuclear surface interaction
  - Past model replicates trend of increasing E_{rel} vs. breakup angle
  - Magnitude of effect not captured



A.B. McIntosh *et. al.,* Phys. Rev. Lett. **99**, 132701 (2007).

Research Focus

- Understanding of dynamic interaction incomplete
- Preliminary research may suggest nuclear surface interaction
  - Past model replicates trend of increasing E_{rel} vs. breakup angle
  - Magnitude of effect not captured
- Investigate well-known resonant states (^{8}Be (2+)); extend to other candidates (^{5}Li (3/2-), etc.)



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- Simulation parameters
  - Emission energy distribution
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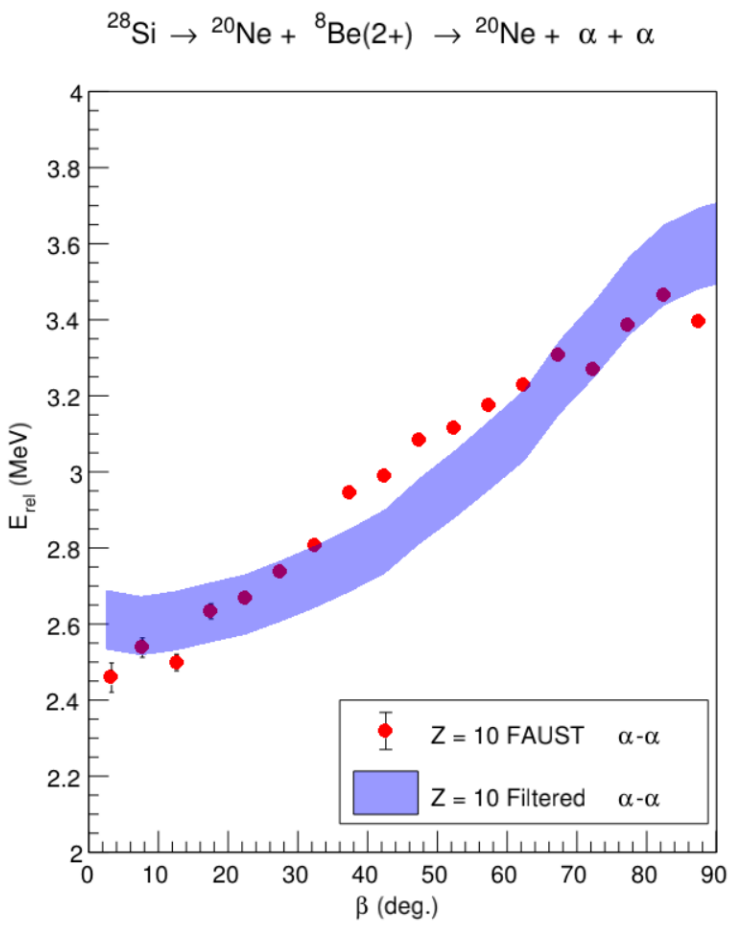

EC: Touching Spheres
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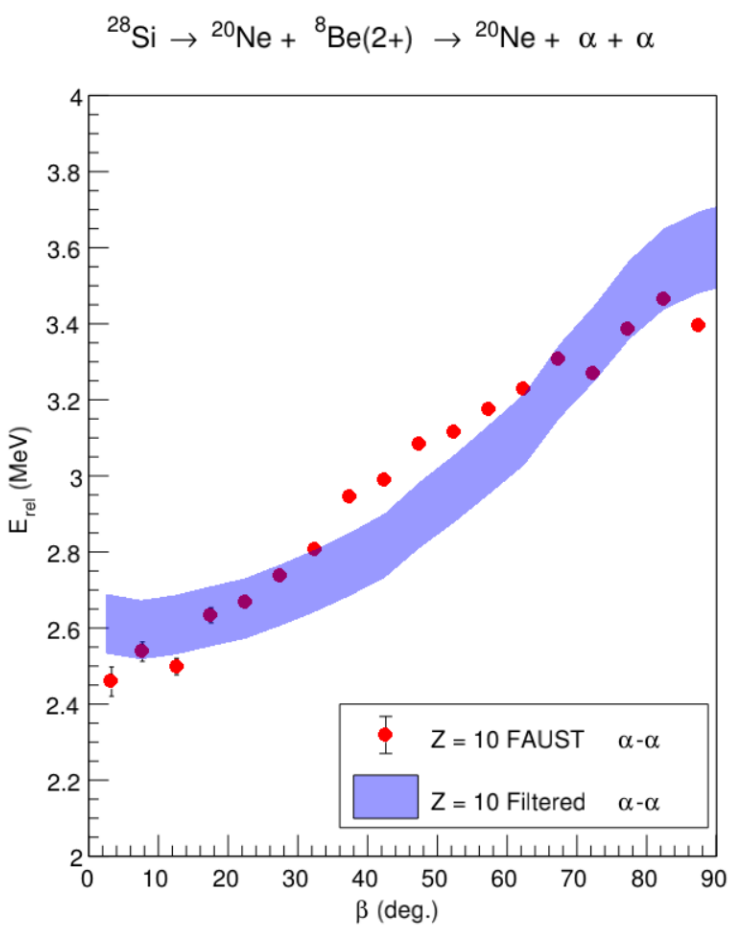

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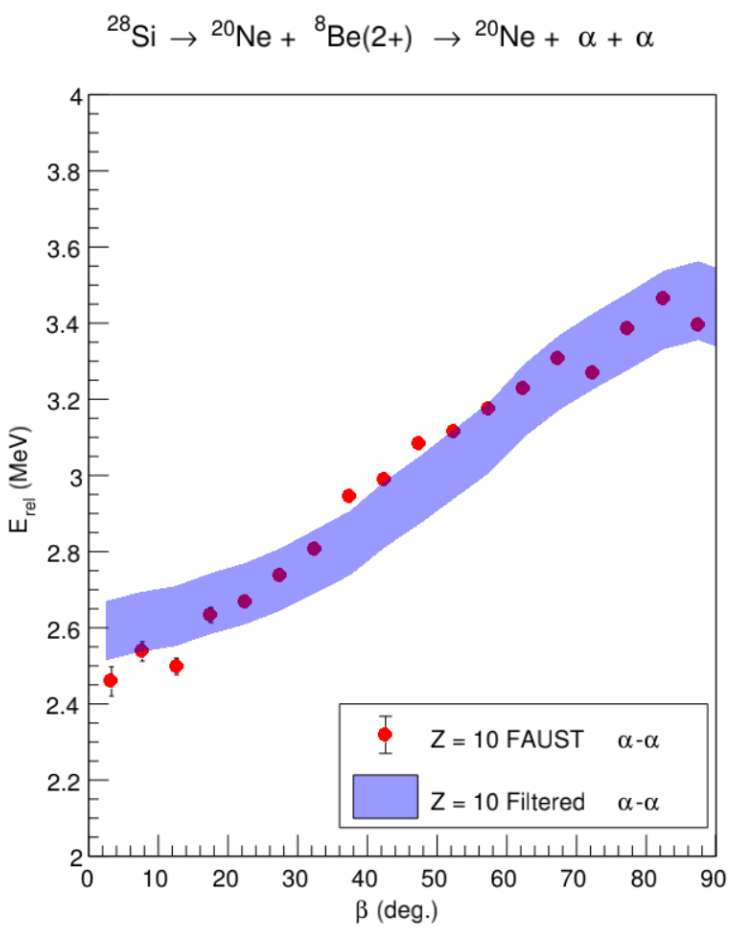

EC: 4.0 fm surface-surface
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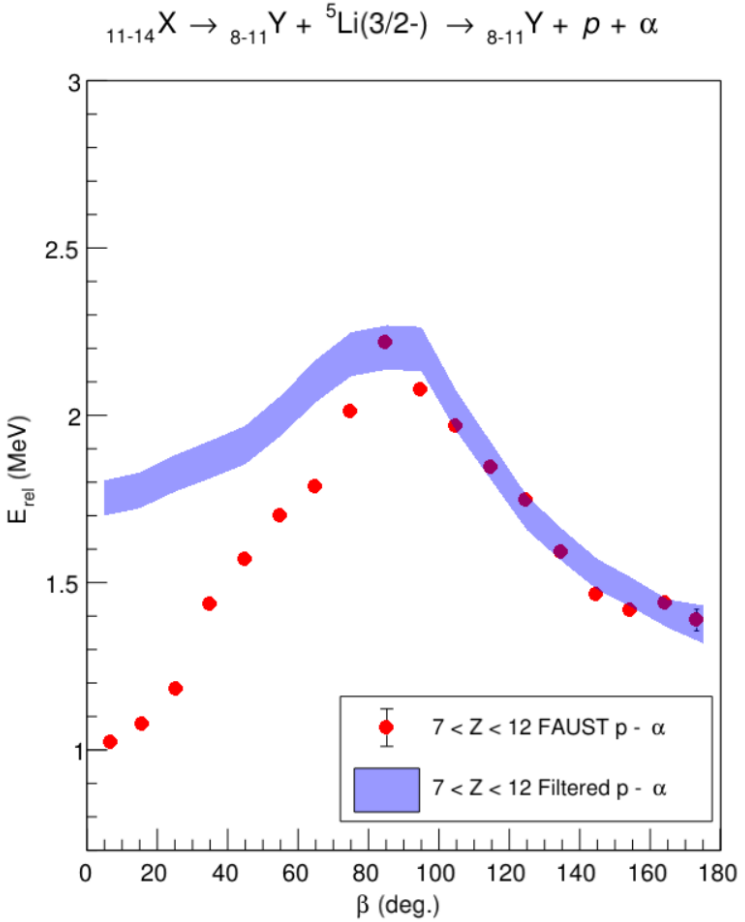

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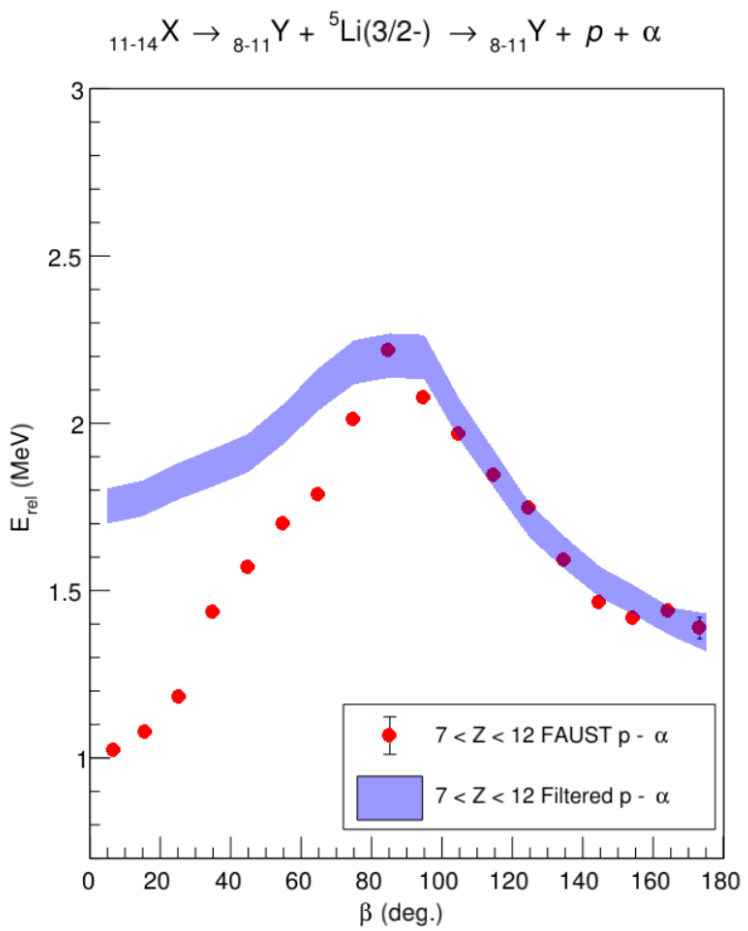

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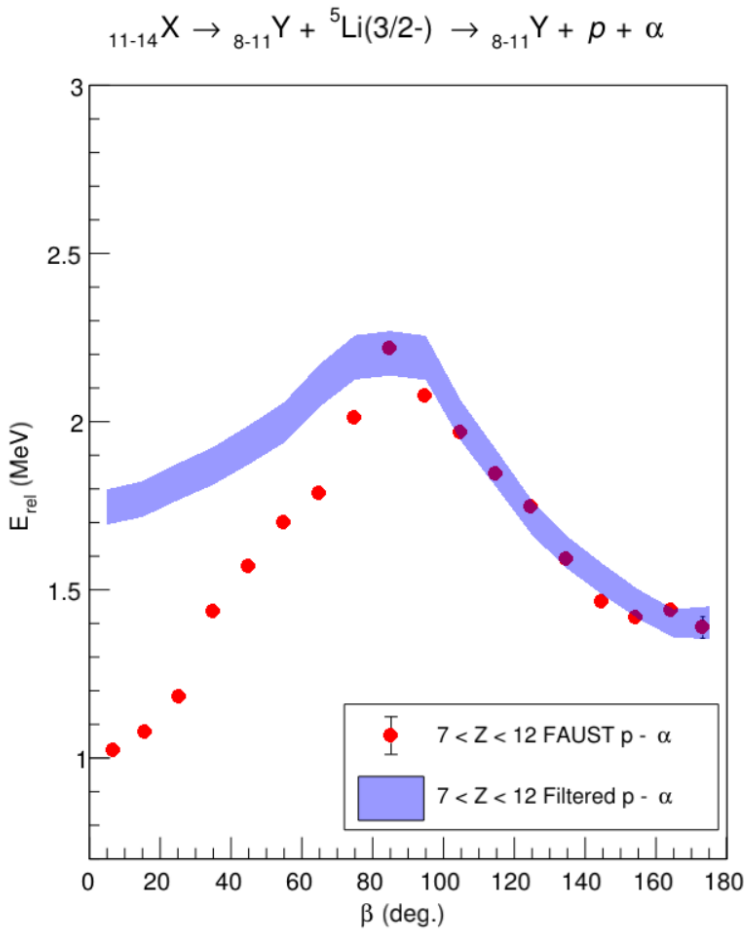

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Future Direction

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  - Can previous results be replicated?
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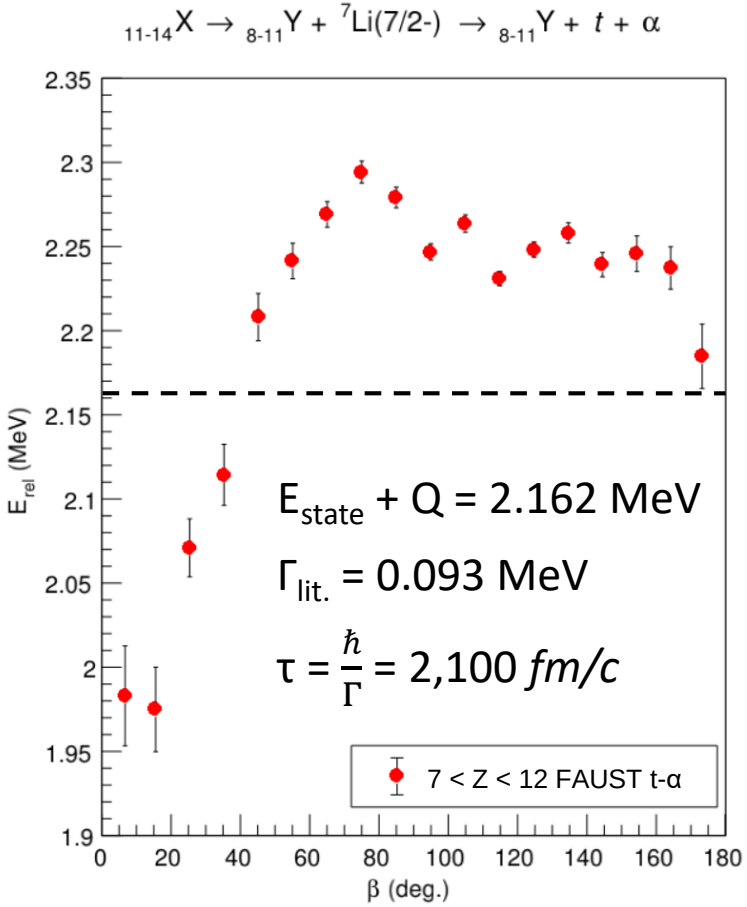

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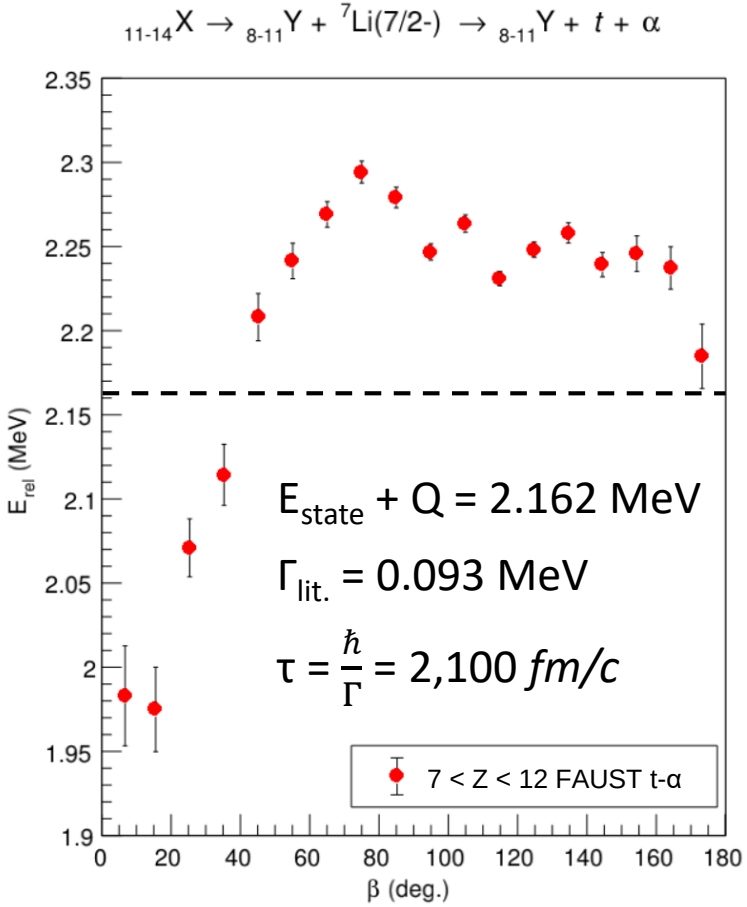
  - Can previous results be replicated?
  - Surface stabilization + other model properties
- Investigation of other resonant states
- Extension to > 3-body breakup (ex. $^{9}B \rightarrow p + \alpha + \alpha$)



Acknowledgements

- TAMU personnel: B.M. Harvey, A. Hannaman, A.B. McIntosh, K. Hagel, Z. Tobin, S.J. Yennello; P. Adsley
- Cyclotron Operations & Rad Safety Staff
- US-DOE DE-FG02-93ER40773

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Model

- Fully customizable – decay scheme, propagating algorithm, time step size, sampling methodologies, etc.
- For results listed herein:
  - Propagation: velocity-verlet algorithm, *dt* = 1 *fm/c*
  - Simulation length: 2000 *fm/c* beyond decay step
  - Energy conservation during unstable ejectile breakup + event rejection
  - Total ^{8}Be simulation efficiency: ~50-60%

Lestone Distribution

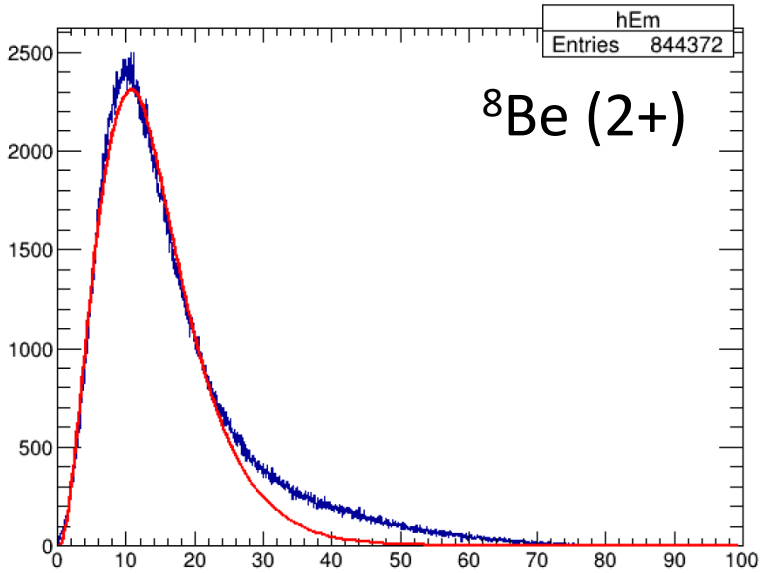
- Maxwell-Boltzmann with a diffuse barrier
  - Experimental spectra fit, then parameters passed to simulation and used for sampling

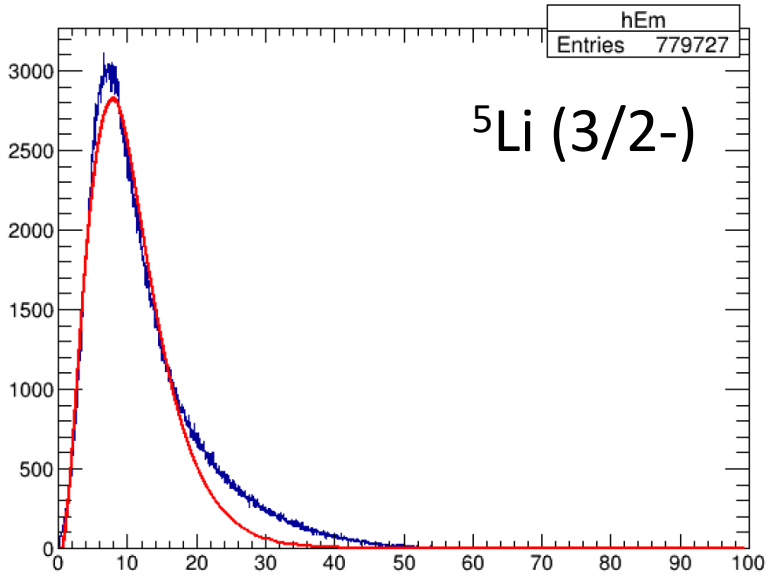
$$Y(E) = 0; E < B'$$

$$Y(E) \propto C'(E - B')^D \exp\left(-\frac{E}{T}\right); B' < E < B + T \qquad C' = \frac{T}{(DT)^D}$$

$$Y(E) \propto (E - B) \exp\left(-\frac{E}{T}\right); E \geq B + T \qquad B' = (1 - D)T + B$$

- B – particle-emission barrier
- D – barrier diffuseness and penetrability
- T – high-energy region; nuclear temperature

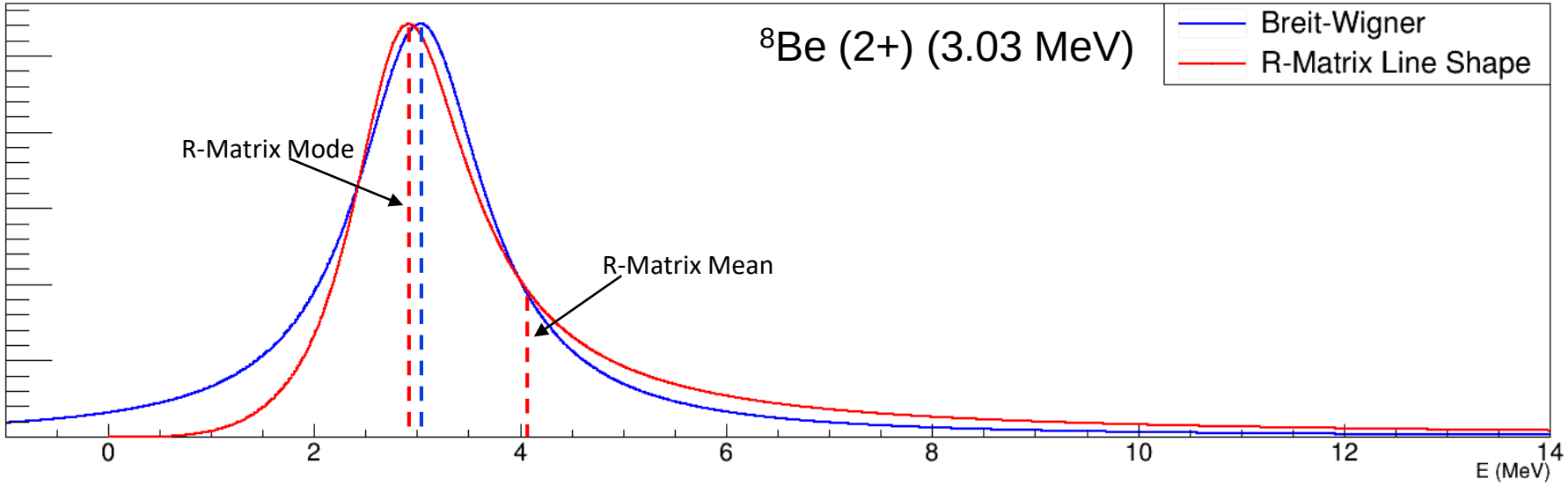




J.P. Lestone, *et. al.*, Nuclear Physics A559, 277-316 (1993)

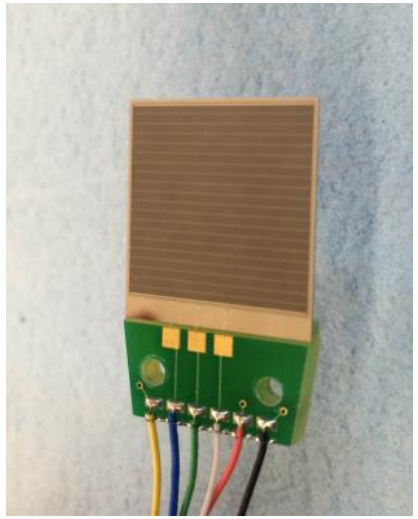
R-matrix Line Shapes

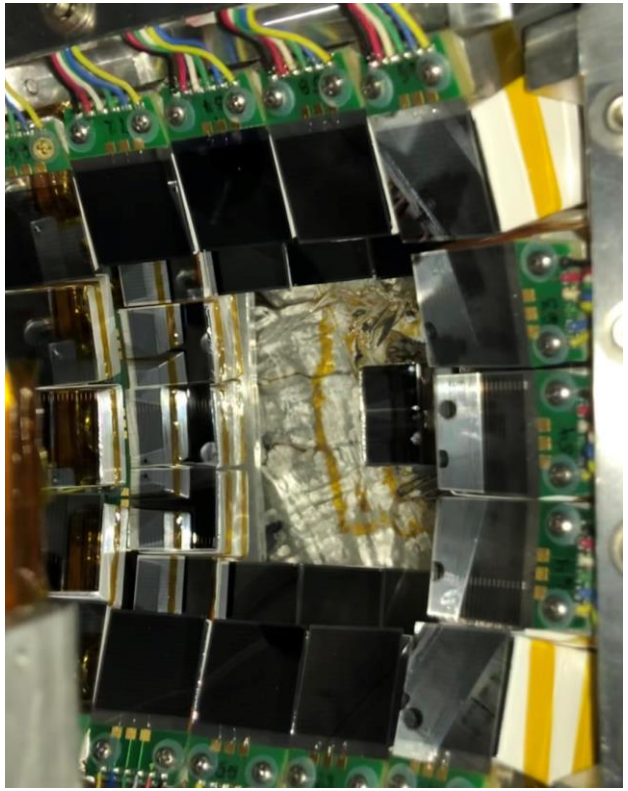
- Appropriate physical treatment of resonances – common Breit-Wigner parameterization holds for limited contexts
  - In an energy region where states are narrow and the level shifts are small, the line shape will tend towards the BW form near the resonance energy.



FAUST Experiment

- FAUST – 68 *ΔE-E* telescopes, Dual-Axis Duo-Lateral (DADL) Si + CsI(Tl)
  - Angular coverage: 1.6° – 45.5° (~90% coverage 2.0° – 34.0°)
  - 200 μm position resolution
  - 1.0 – 2.0% energy resolution
- Experiment: ^{28}Si + ^{12}C @ 35 MeV/u
  - 6 days on target
  - > 150 M events w/ charged particle

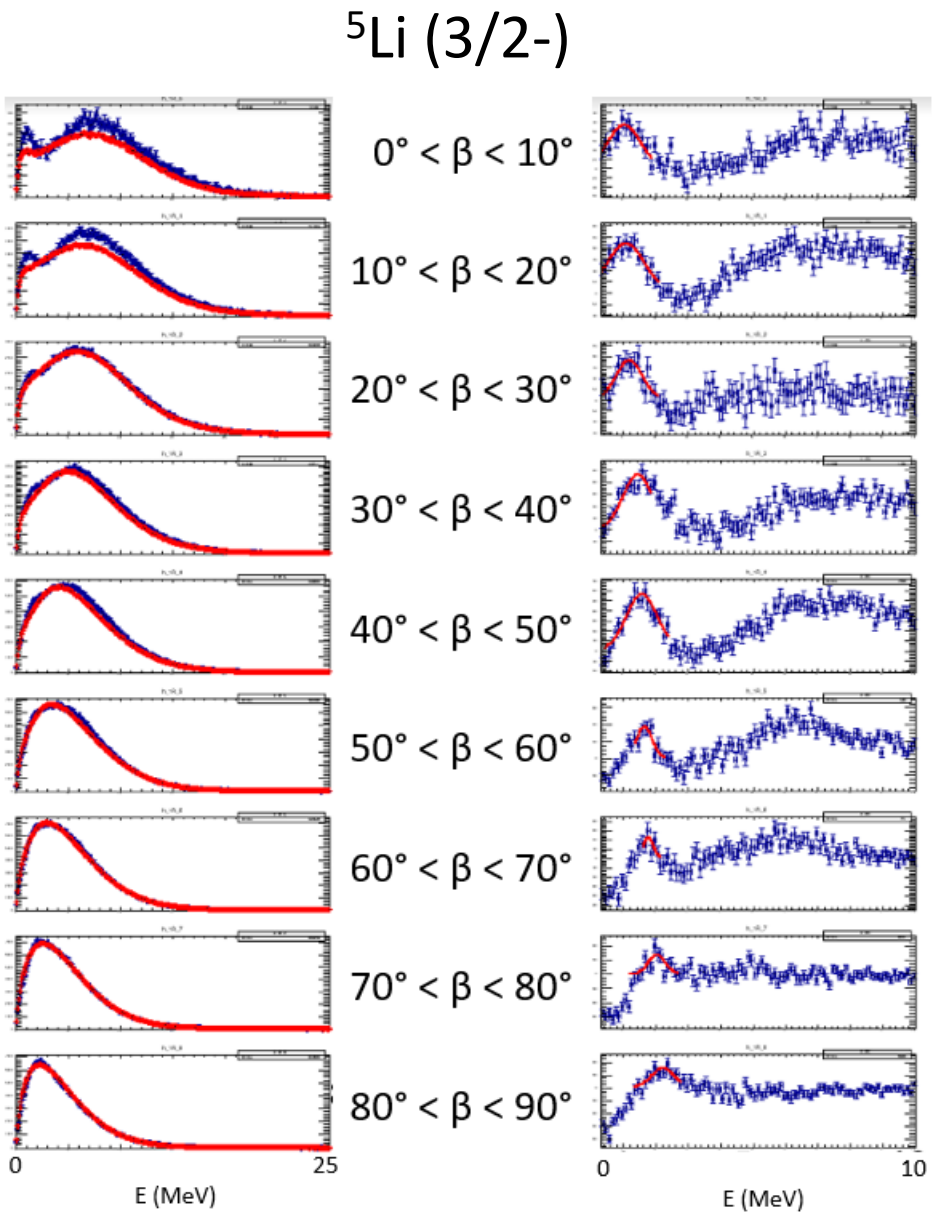




L.A. Heilborn. Doctoral dissertation, Texas A&M University (2018).

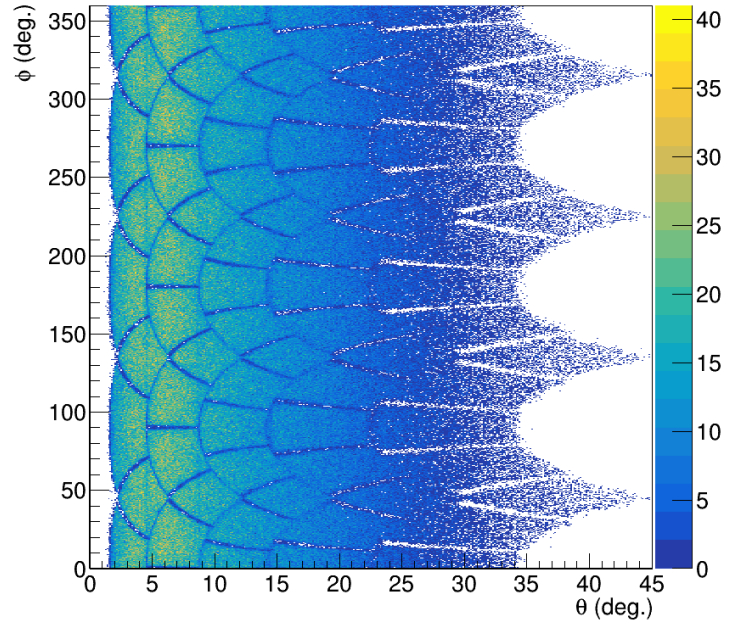
Experimental Analysis

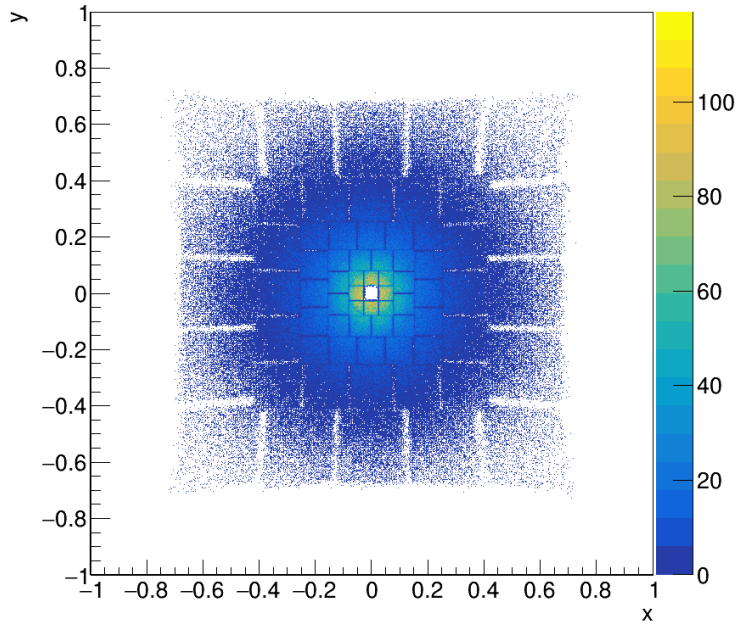
- Nonresonant contribution accounted for via mixed-event analysis
- Spectra produced for several angular regions in β
- Gaussian peak fitting of subtracted spectra – extract mean energy and width
  - “Resonant states” diagrams



Comparing to Experiment

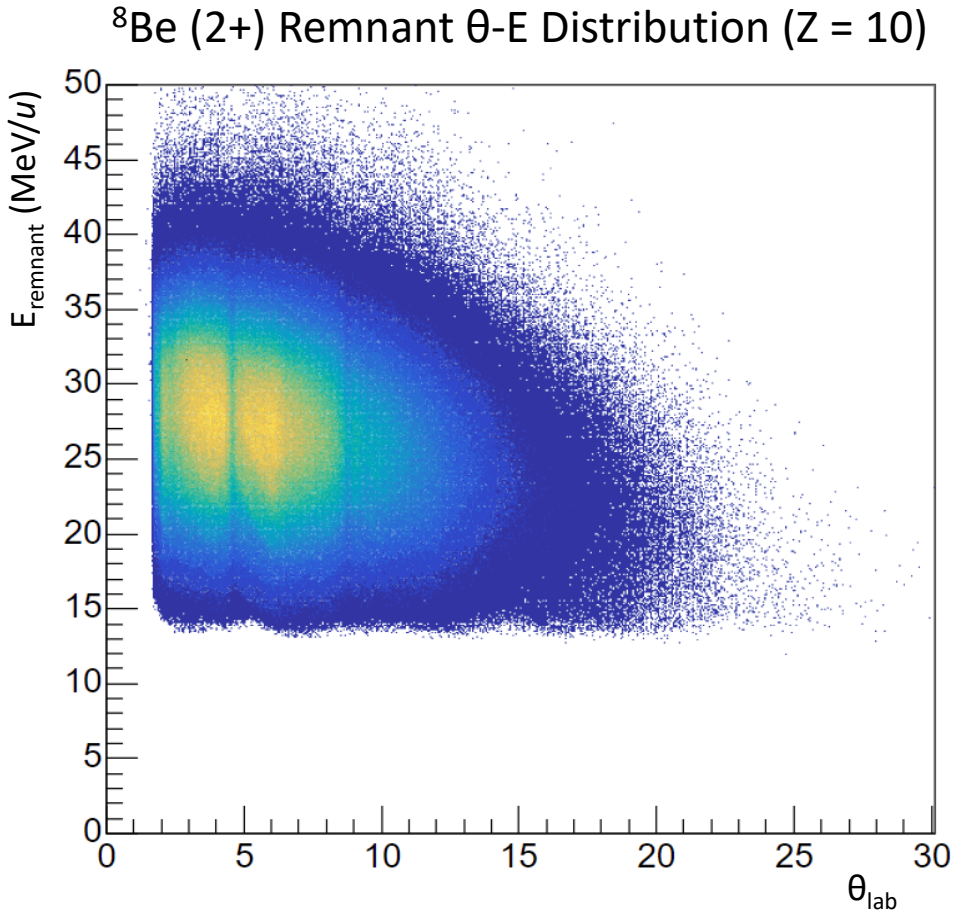
- Simulate in COM, frame change + θ/ϕ randomization (2D → 3D), boost to lab velocity
  - Randomization assumes surface emission isotropy
- Pass boosted events through FAUST filter
  - Filter replicates energy and position smearing on particle-by-particle basis
  - Simulated events filtered in accordance with experimental parameters
- Perform fits similar to exp. on regions of β





Frame Conversions

- Event boost determined by sampling experimental remnant θ-E distribution
  - Define remnant properties, everything else defined accordingly
- Systems with multiple *Z* require several distributions to fully parameterize



FAUST Filter

- First principles to recreate position resolution and low-energy threshold in DADL
  - Resistive charge splitting
  - Gaussian noise – replicate fast noise that aids in triggering
  - Uncorrelated slow noise – energy and position smearing