Exploration of Nuclear Clustering via Compound Decay Pathways

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Motivation

- The structure of nuclear matter and the pathways in which nuclei both fuse and decay are parallel discussions.
- An example is ^{4}He burning

The forward direction largely benefits from the similarities of the nuclear structure.

$$3\alpha \rightarrow \alpha + {}^{8}\mathrm{Be}_{\mathrm{gs}} \rightarrow {}^{12}\mathrm{C}(0_2^+)$$

The backward direction is the primary way we study the Hoyle state.

$${}^{12}\mathrm{C}(0_2^+) \rightarrow \alpha + {}^{8}\mathrm{Be}_{\mathrm{gs}} \rightarrow 3\alpha$$

- **How can we investigate the compound decay pathways of larger nuclei as a probe to relate their structures to understood states?**

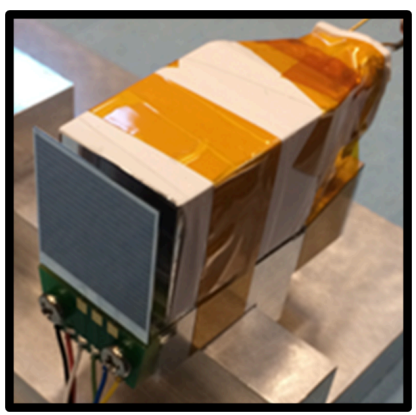
Experimental Data

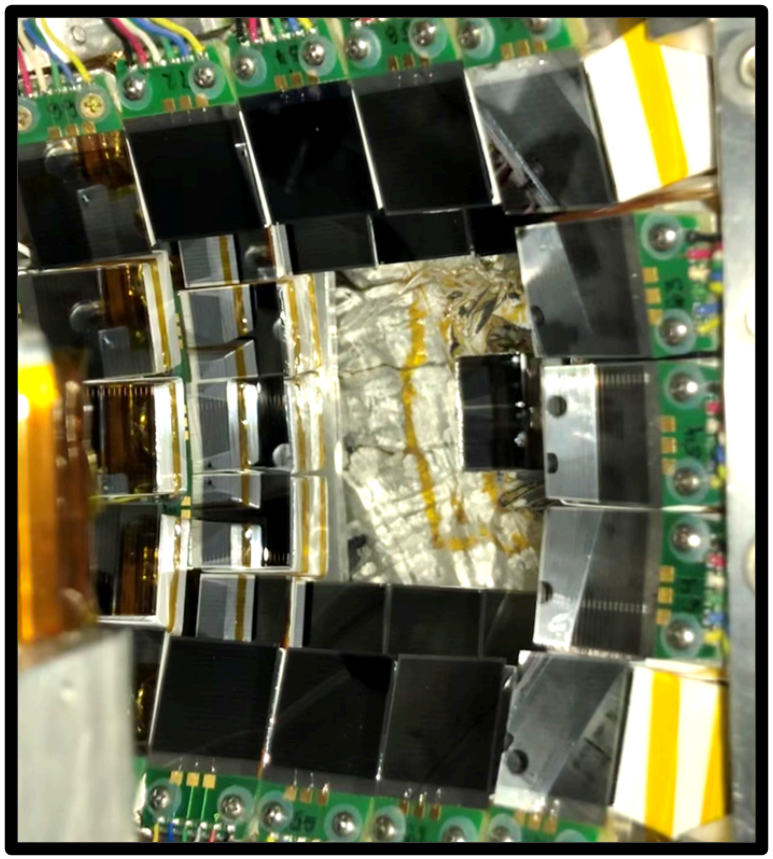
System

- $^{16}\mathrm{O} + {}^{12}\mathrm{C}$ @ 35 MeV/u
  - Also have $^{20}\mathrm{Ne}$, $^{24}\mathrm{Mg}$, $^{28}\mathrm{Si}$, $^{32}\mathrm{S}$, and $^{36}\mathrm{Ar}$ as projectiles

Forward Array Using Silicon Technology

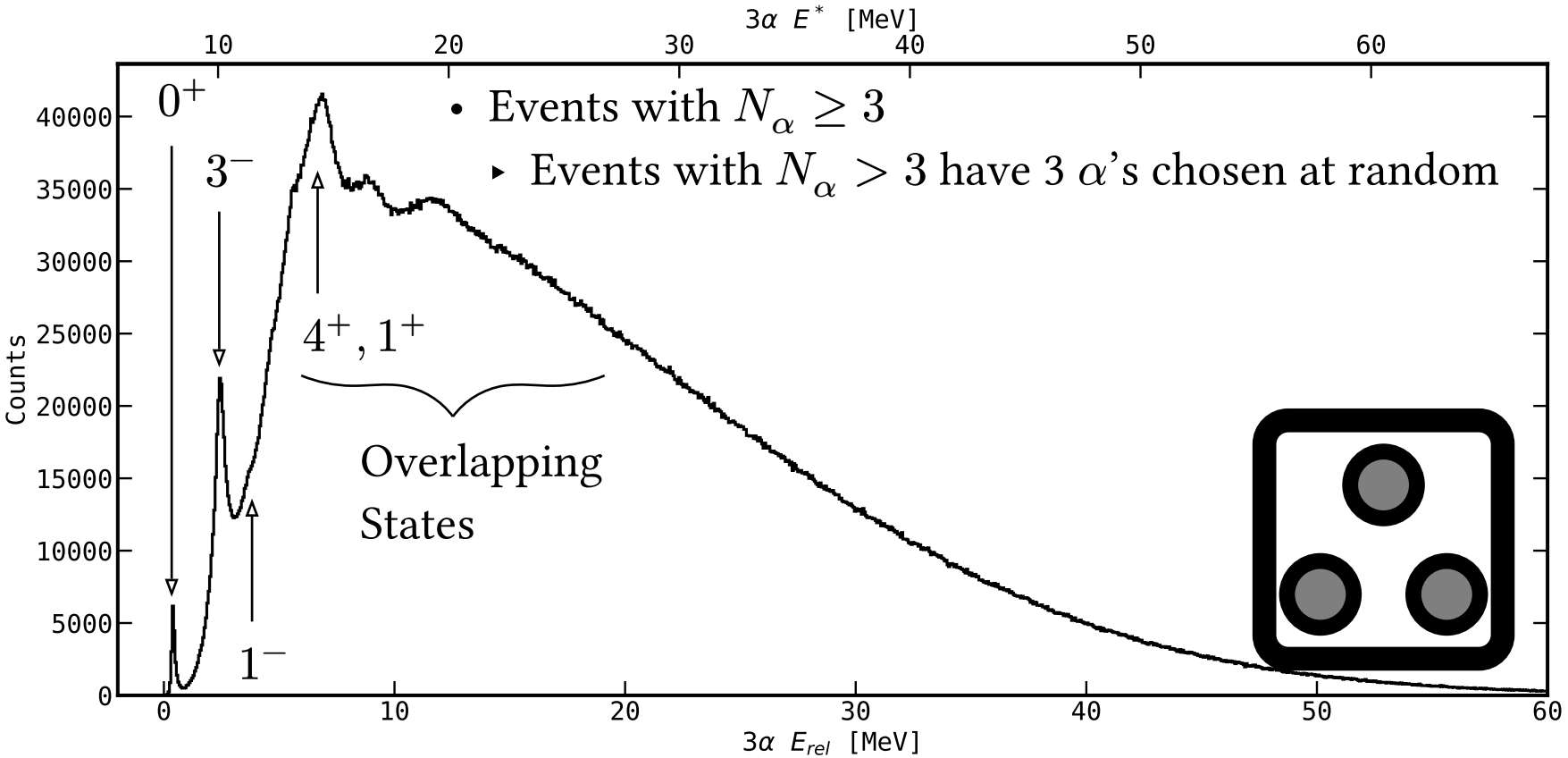
- Charged Particle ID
  - $(\Delta E, E) \rightarrow (Z, A)$
- Total Kinetic Energy
  - Particles stop in CsI
- Position
  - Silicon is resistive for position sensitivity



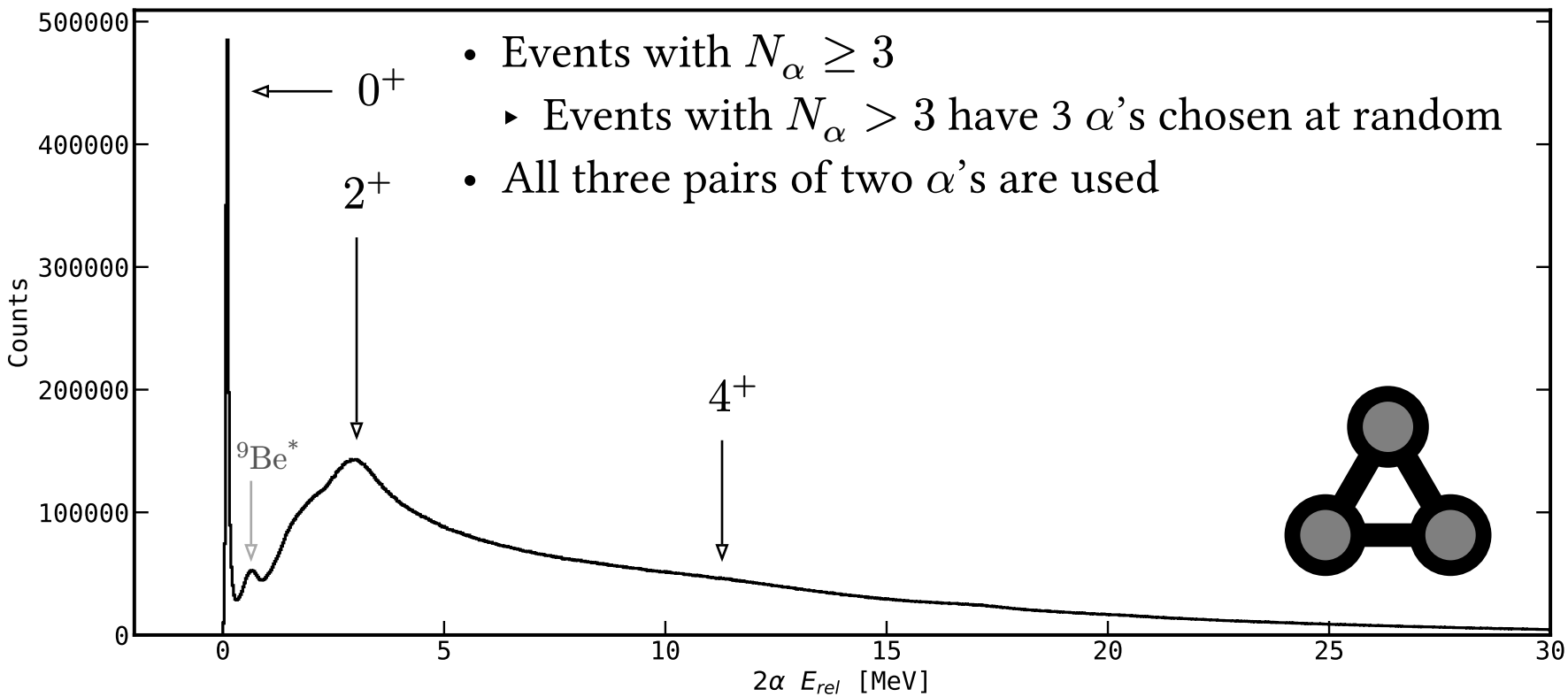


$$E_{\text{rel.}} = \sum_i \frac{p_{i,\text{cm}}^2}{2m_i} \qquad E^* = E_{\text{rel}} - Q_{\text{rxn}}$$

States of ^{12}C with $E_{3\alpha}$

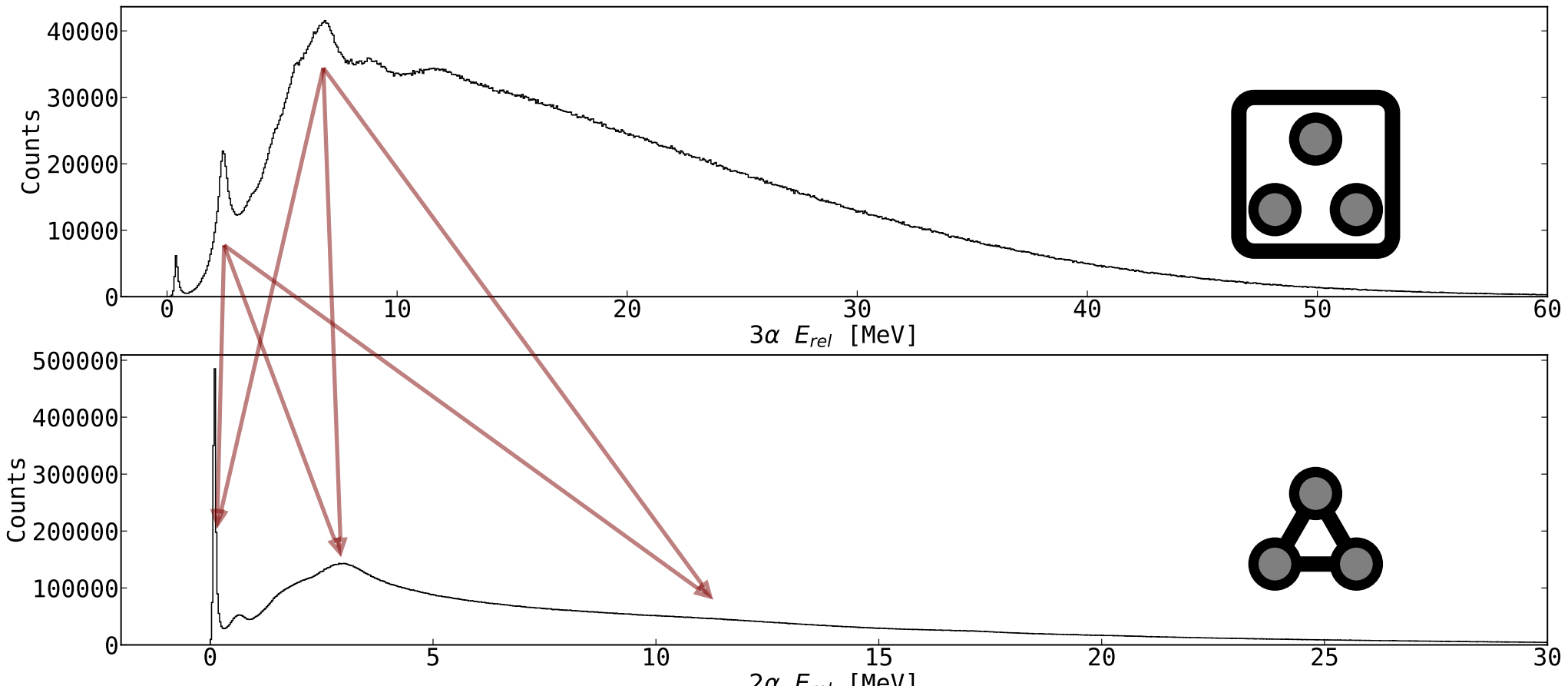


States of ^{8}Be with $E_{2\alpha}$

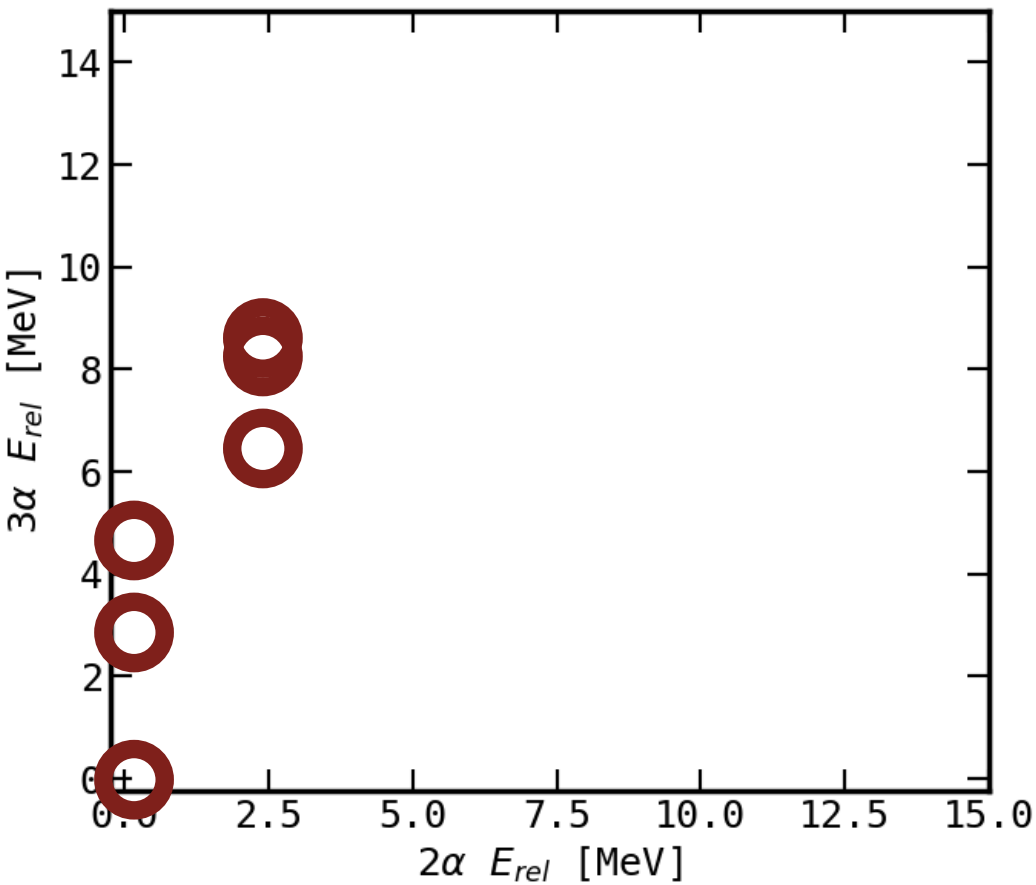


- Events with $N_\alpha \geq 3$
  - Events with $N_\alpha > 3$ have 3 α's chosen at random
- All three pairs of two α's are used

Which ^{12}C states feed which ^{8}Be states?

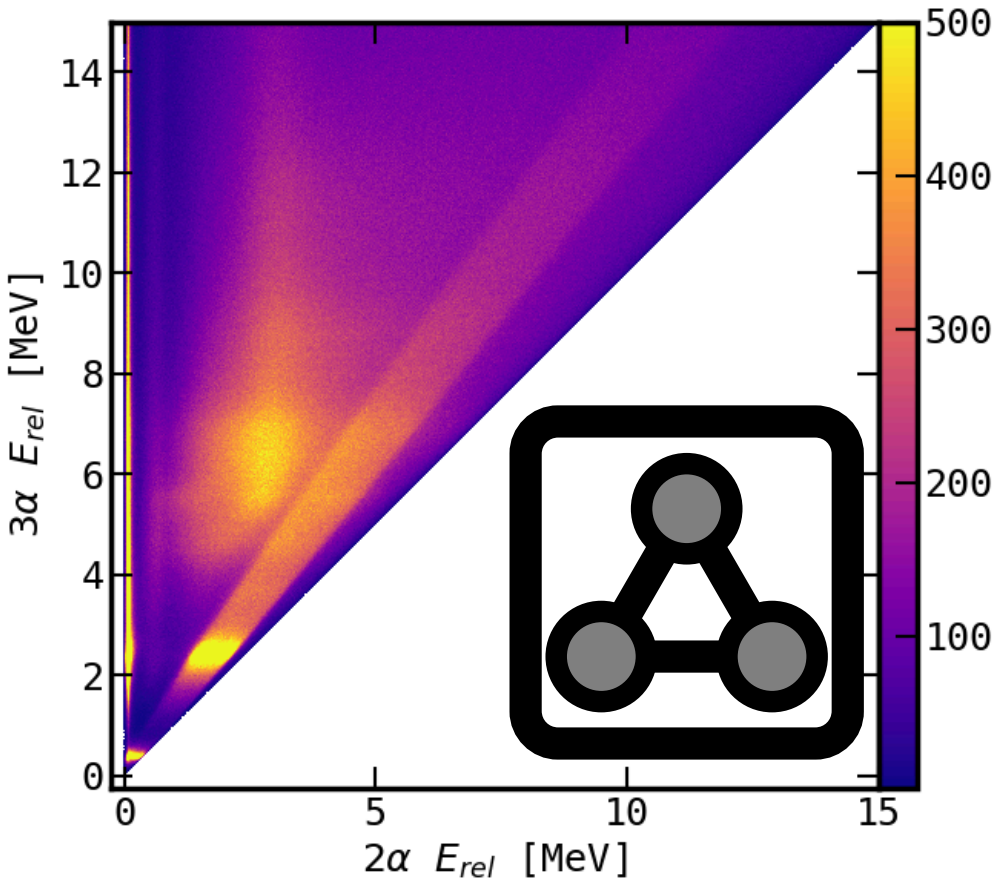


3α vs 2α



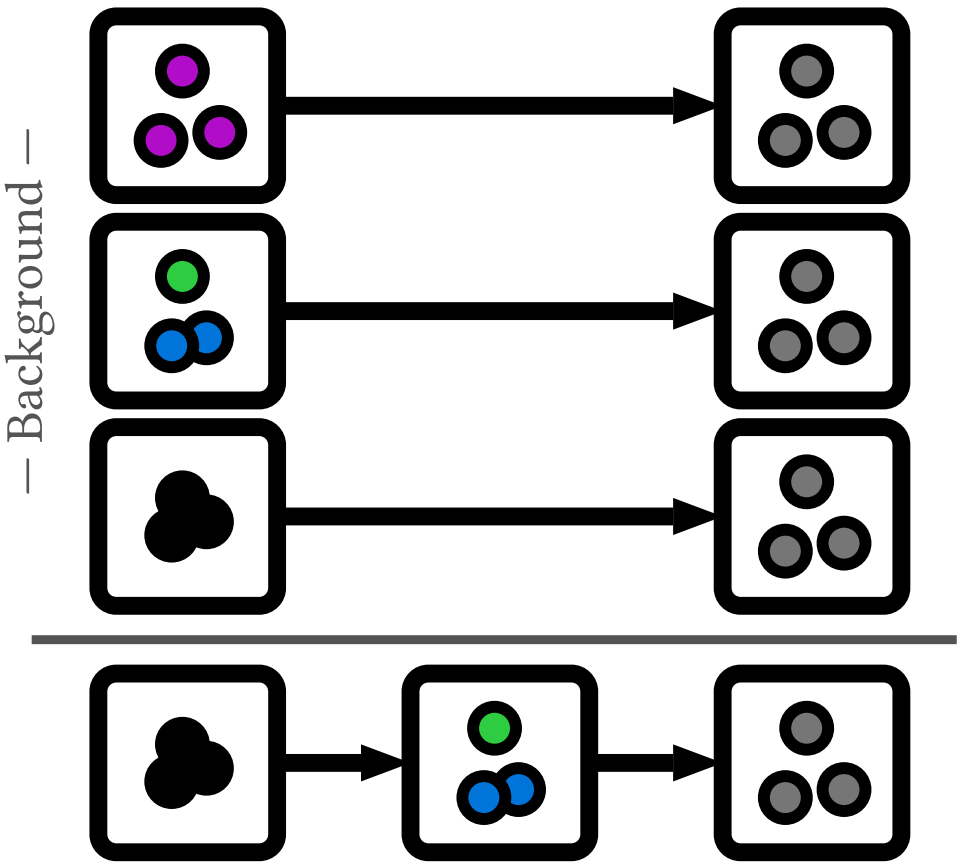
- Expect loci where a particular $^{12}C^{*}$ decays through a particular $^{8}Be^{*}$

3α vs 2α



- Several contributions to background
- An appropriate background subtraction must be found which accounts for all undesired features

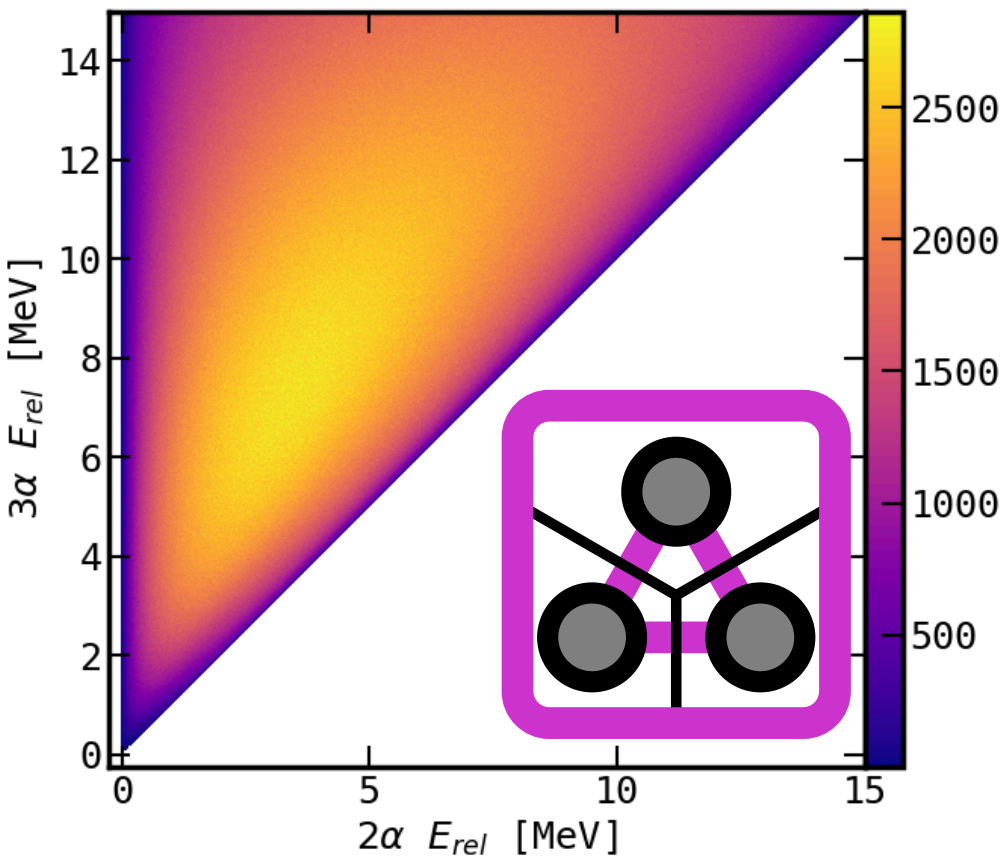
Sources of 3α background



- 3α (no $^{8}\mathrm{Be}$ or $^{12}\mathrm{C}$)
- $^{8}\mathrm{Be} + \alpha \rightarrow 3\alpha$ (no $^{12}\mathrm{C}$)
- $^{12}\mathrm{C} \rightarrow 3\alpha$ (no $^{8}\mathrm{Be}$)

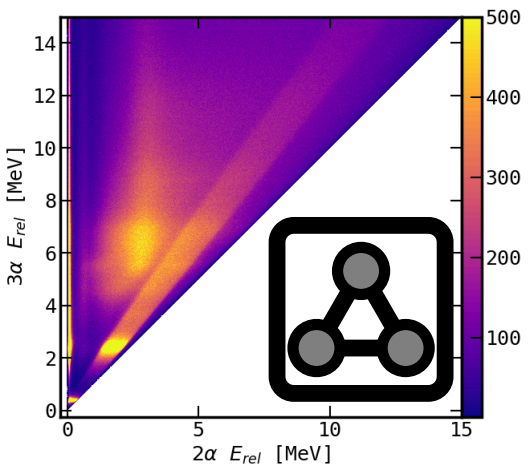
- $\boxed{^{12}\mathrm{C} \rightarrow {}^{8}\mathrm{Be} + \alpha \rightarrow 3\alpha}$

Mixed Events

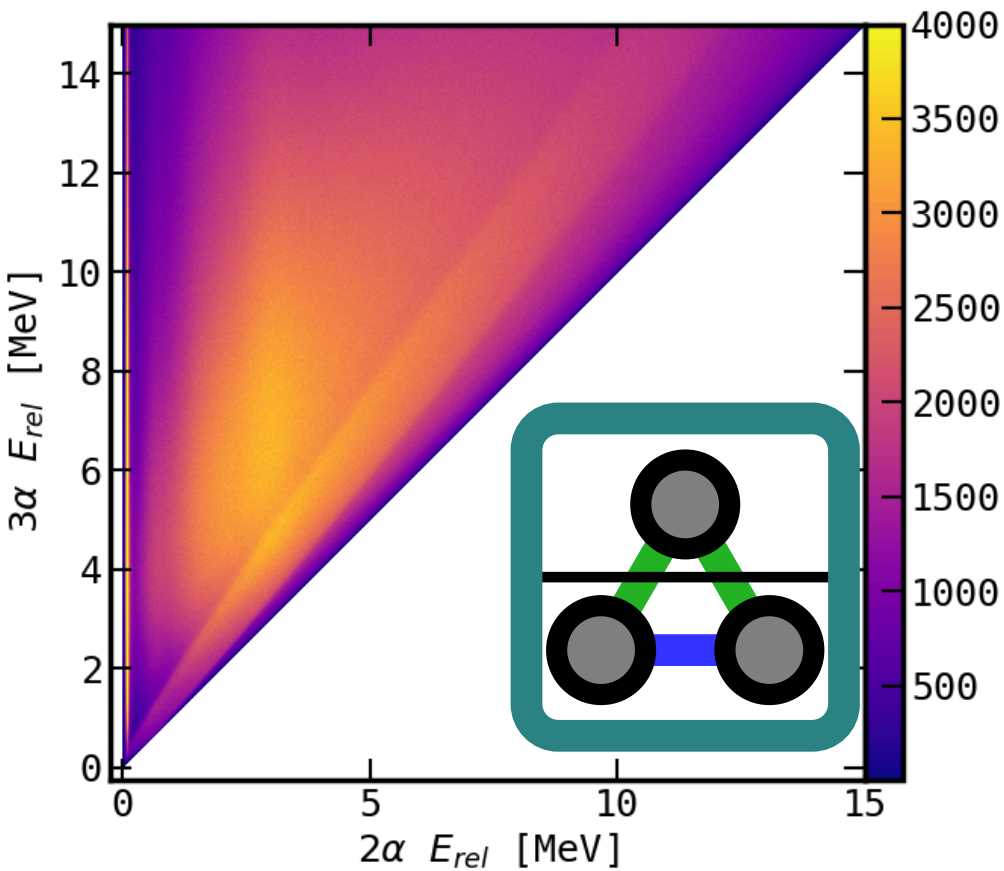


1. Find three events
2. From each, pick one α particle
3. Create an artificial event with those α's
4. Analyze as normal

- Only the very broad features of the real data are described

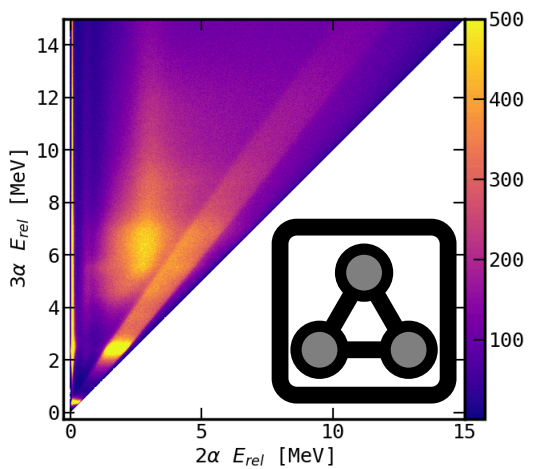


Partially Mixed Events

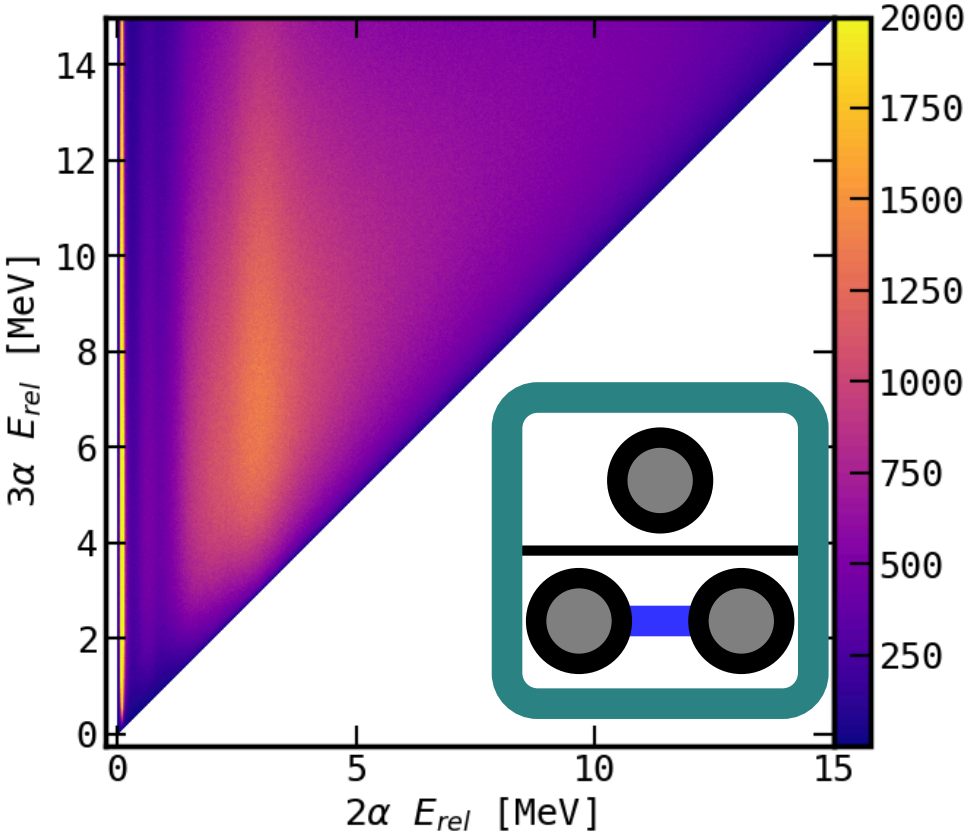


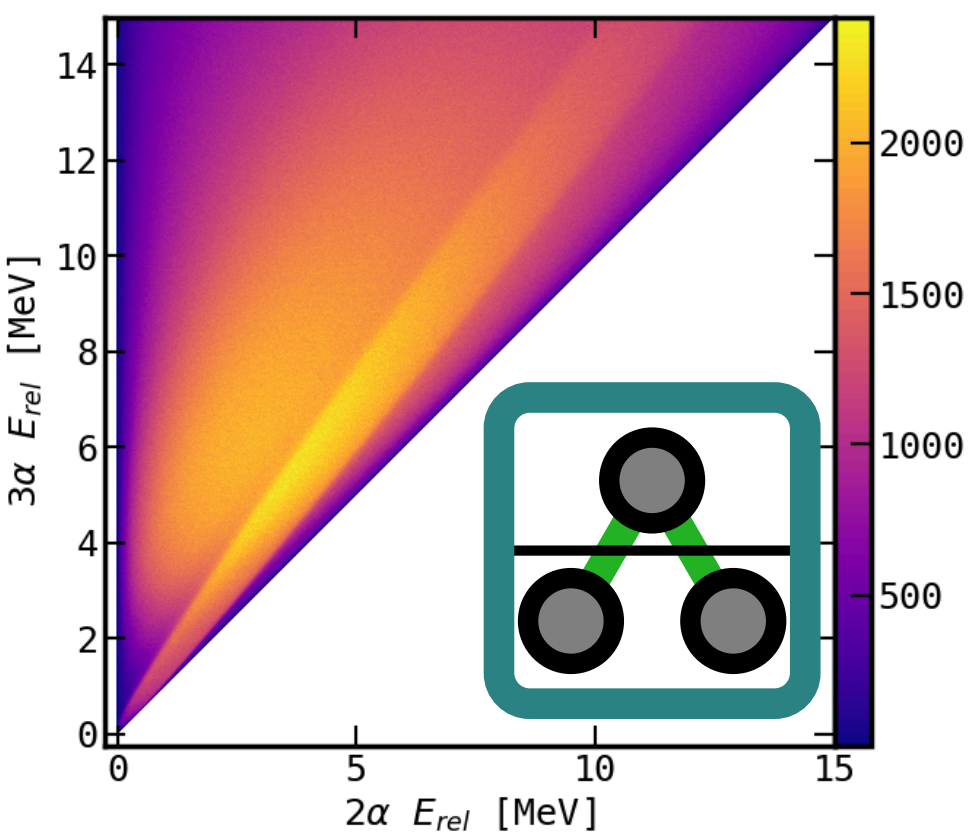
1. Find **two** events
2. From one, pick one α particle
3. From the other, pick two α particles
4. Create an artificial event with those α's
5. Analyze as normal

- The vertical and diagonal components are described by the 2α correlations

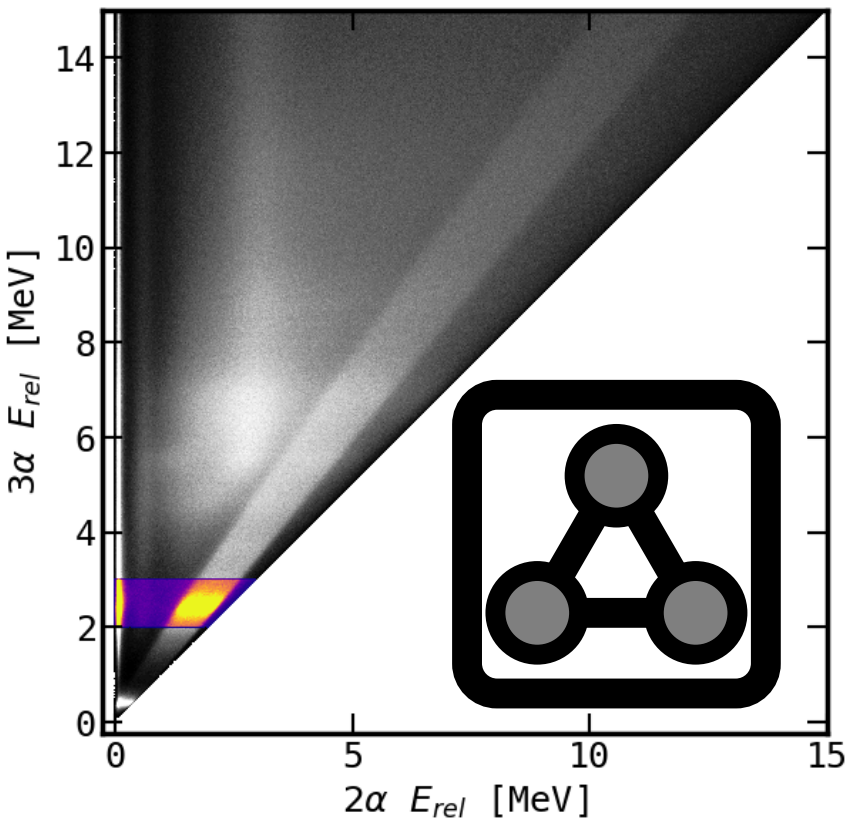


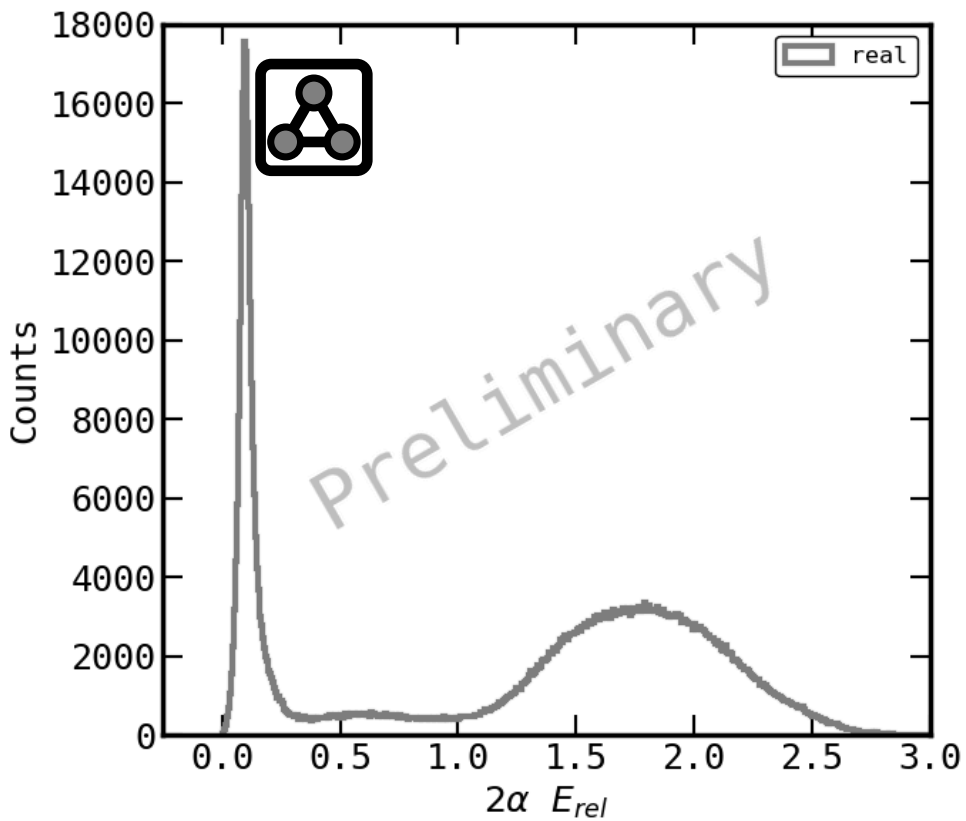
Understanding the correlations





Example Subtraction 1: $^{12}\mathrm{C}(3^-) \rightarrow {}^{8}\mathrm{Be}(0^+) + \alpha$





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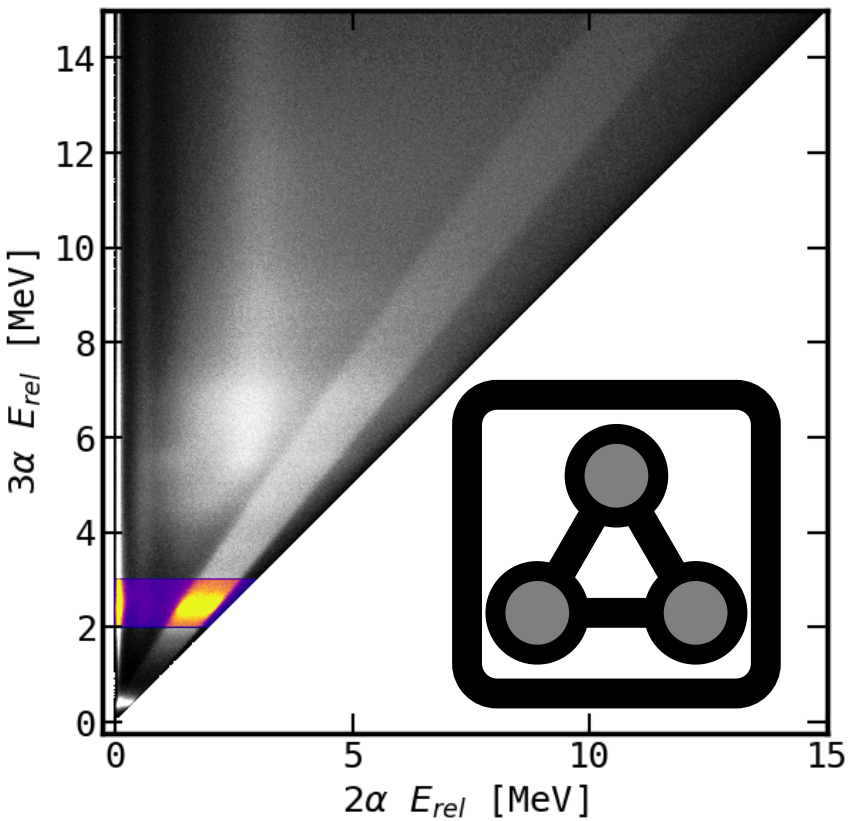

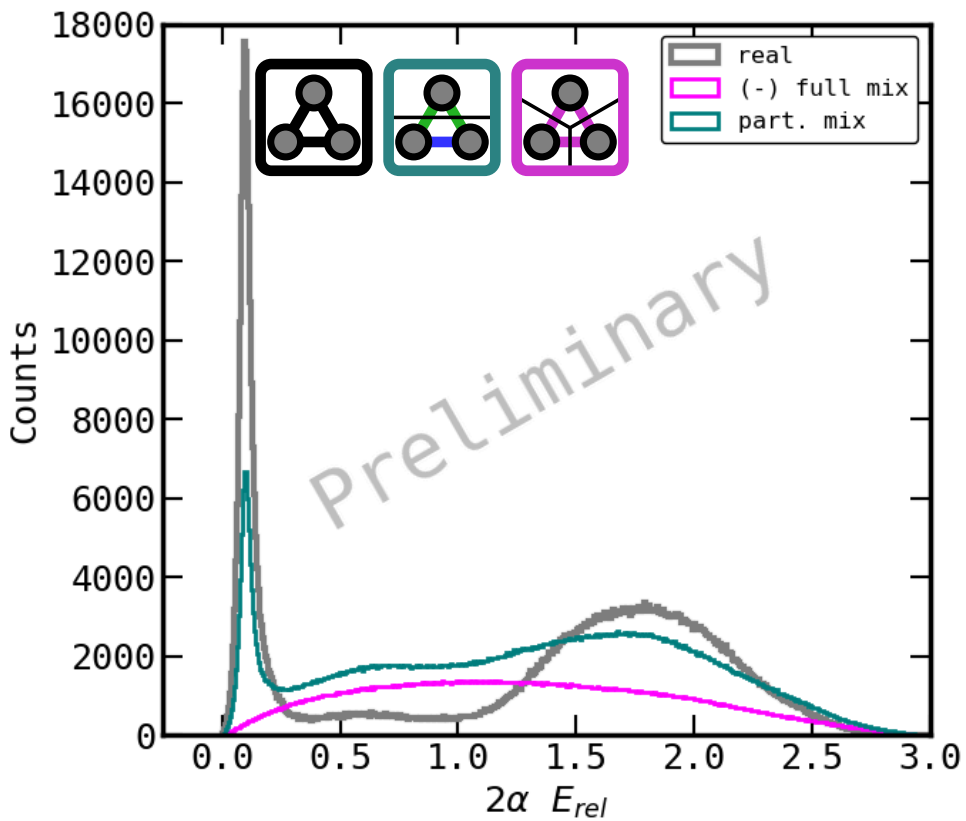

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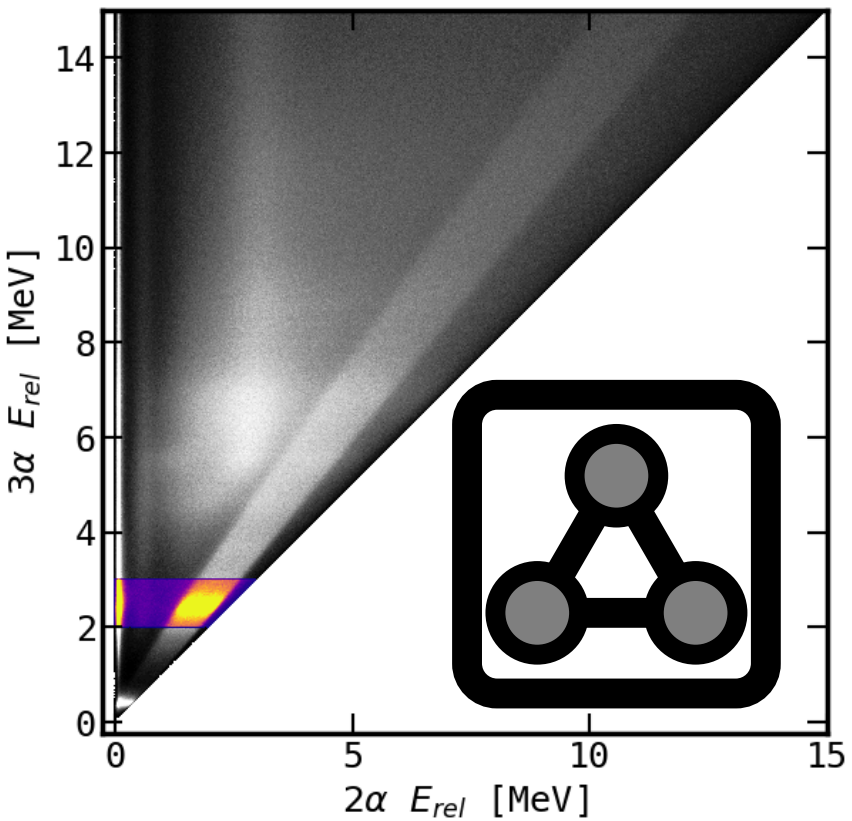

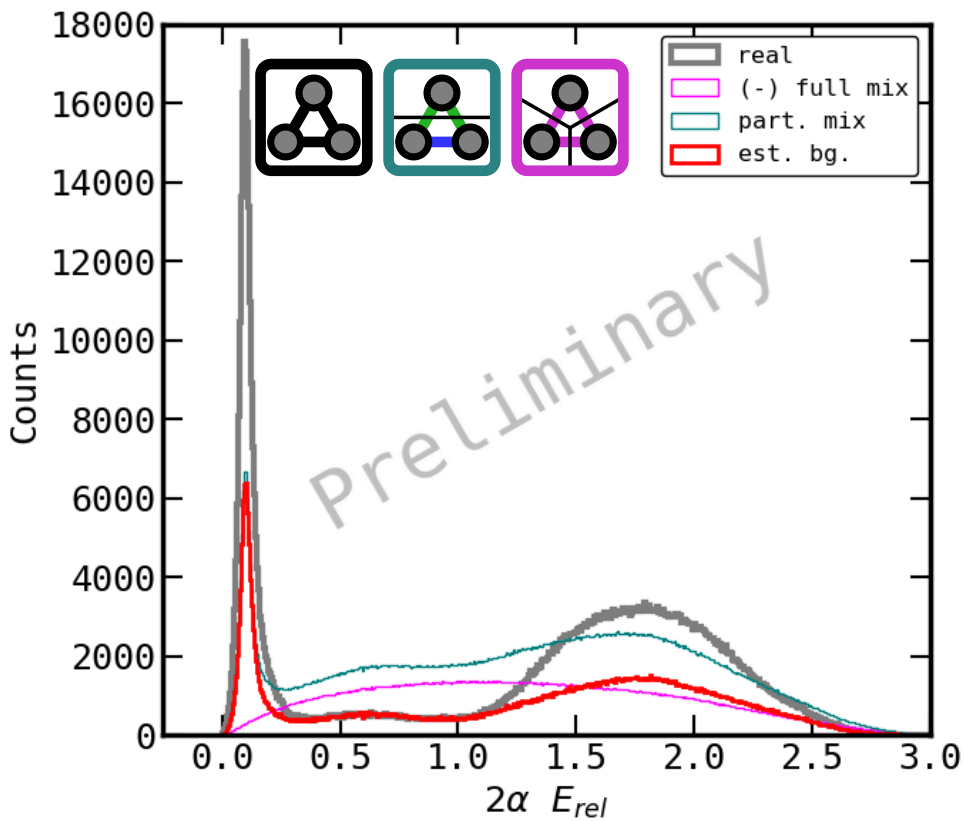

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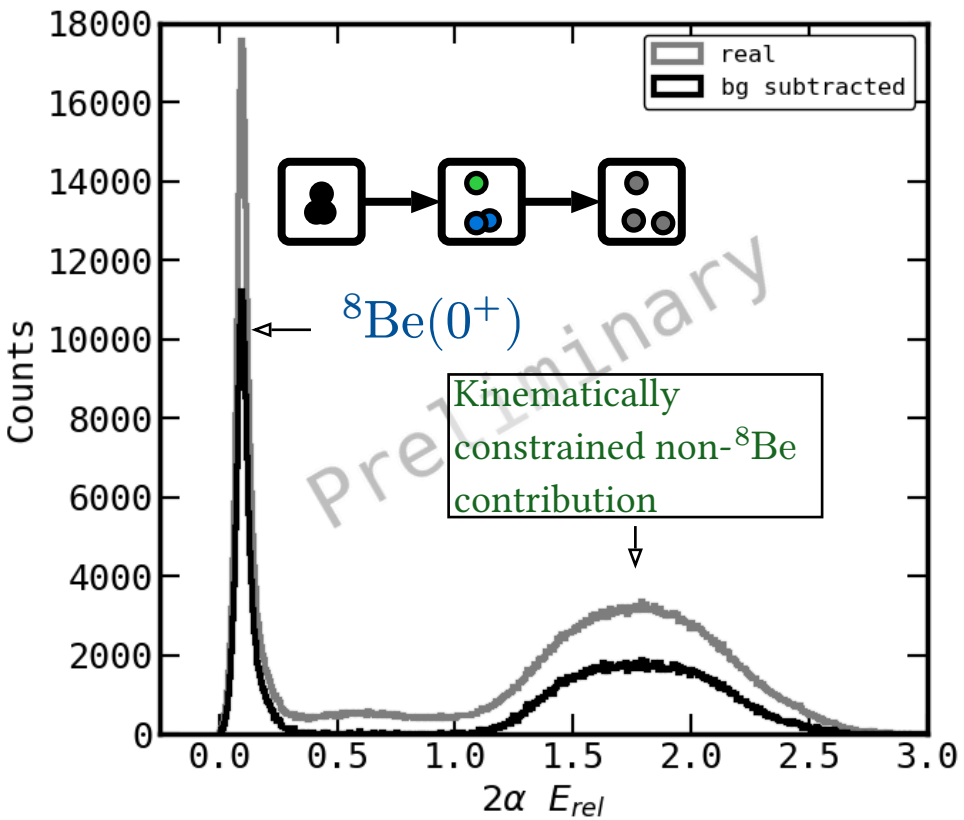

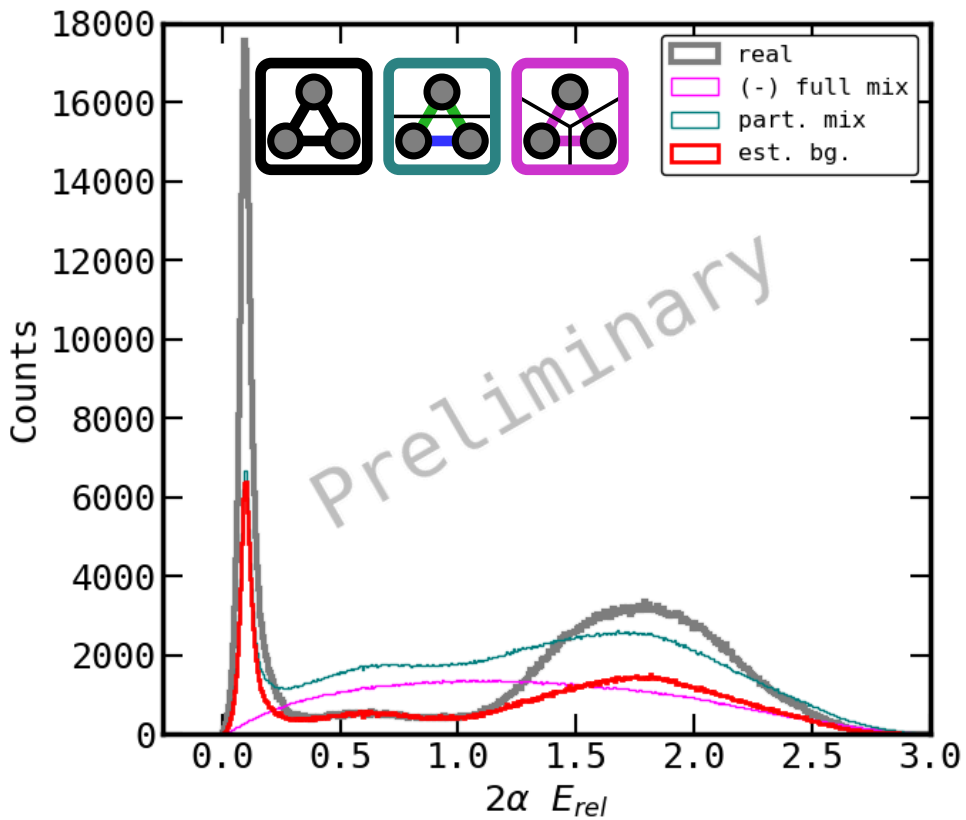

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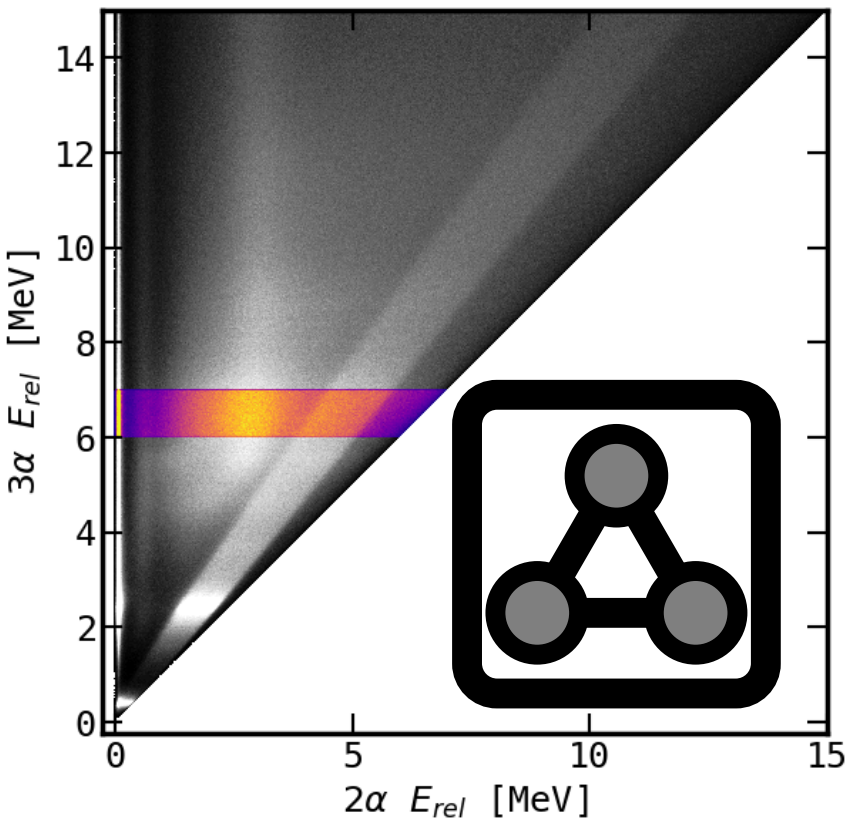

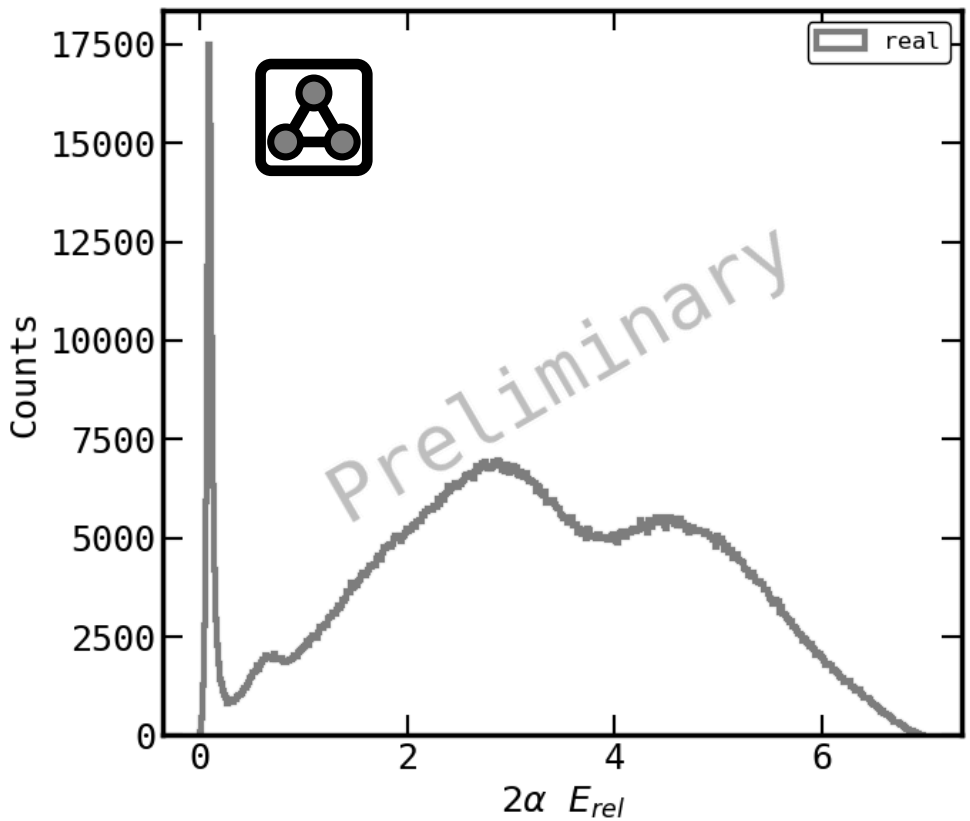

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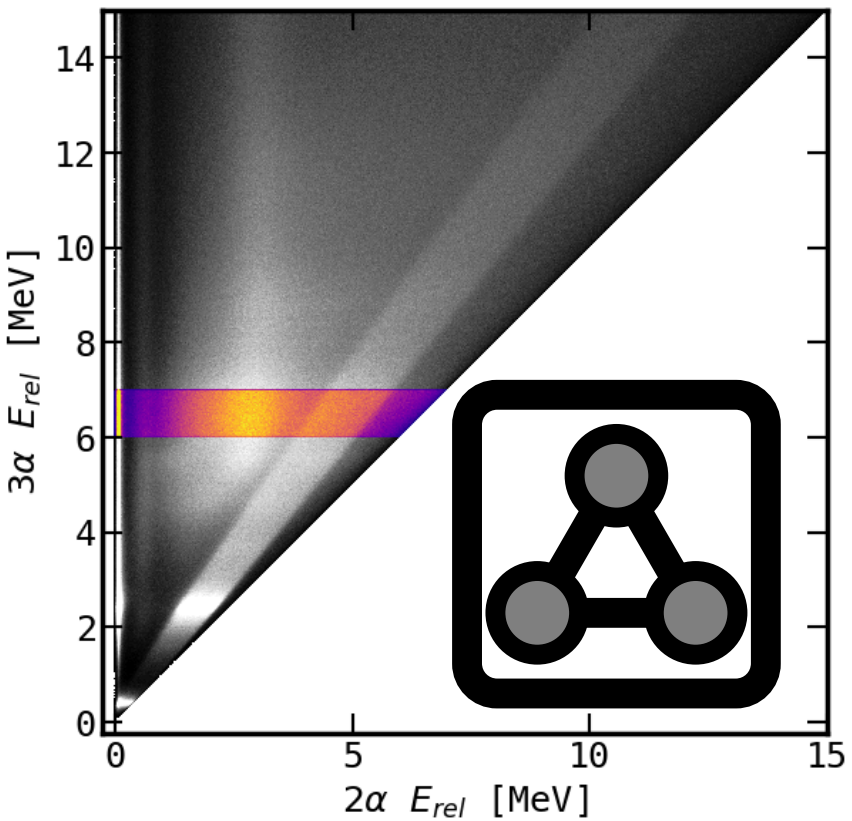

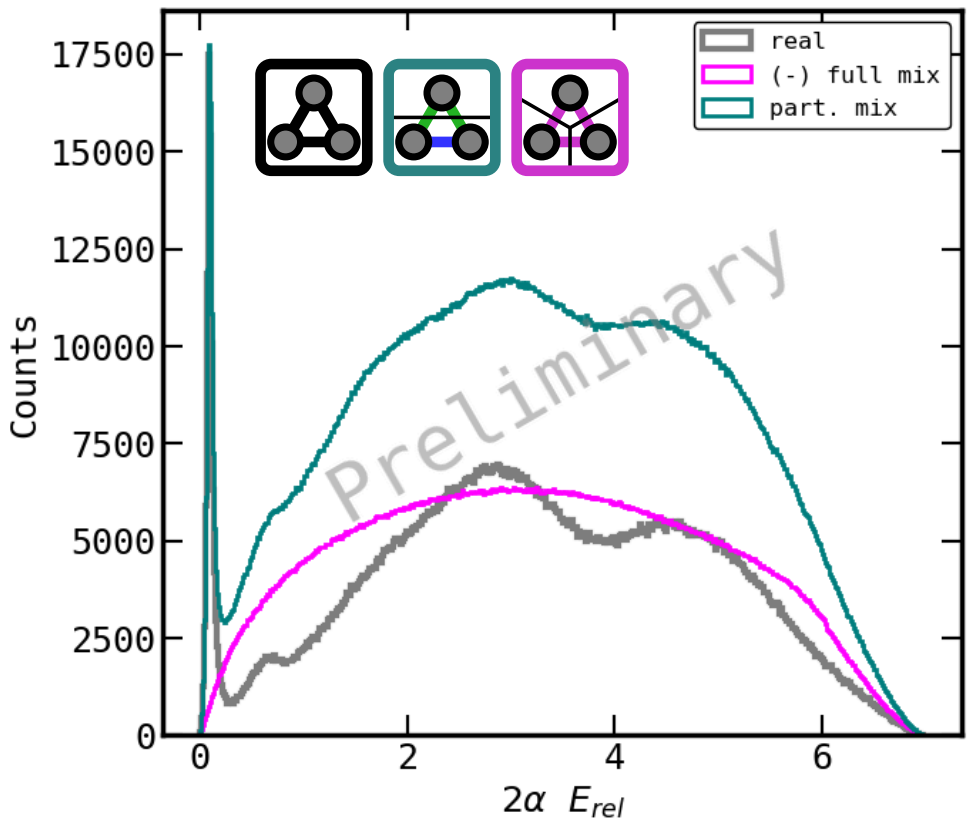

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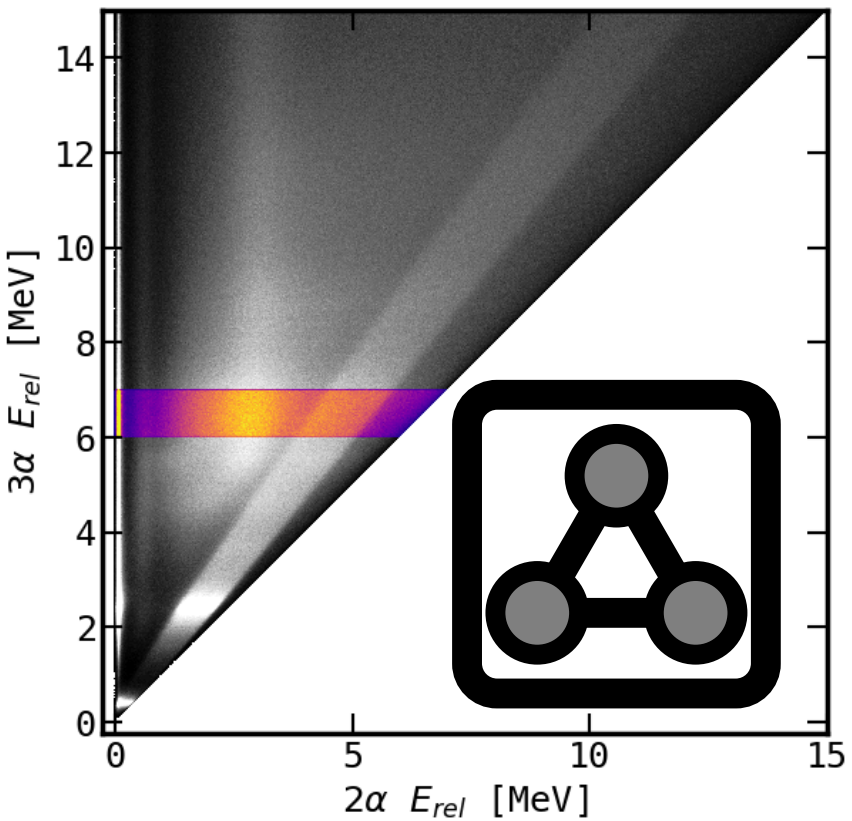

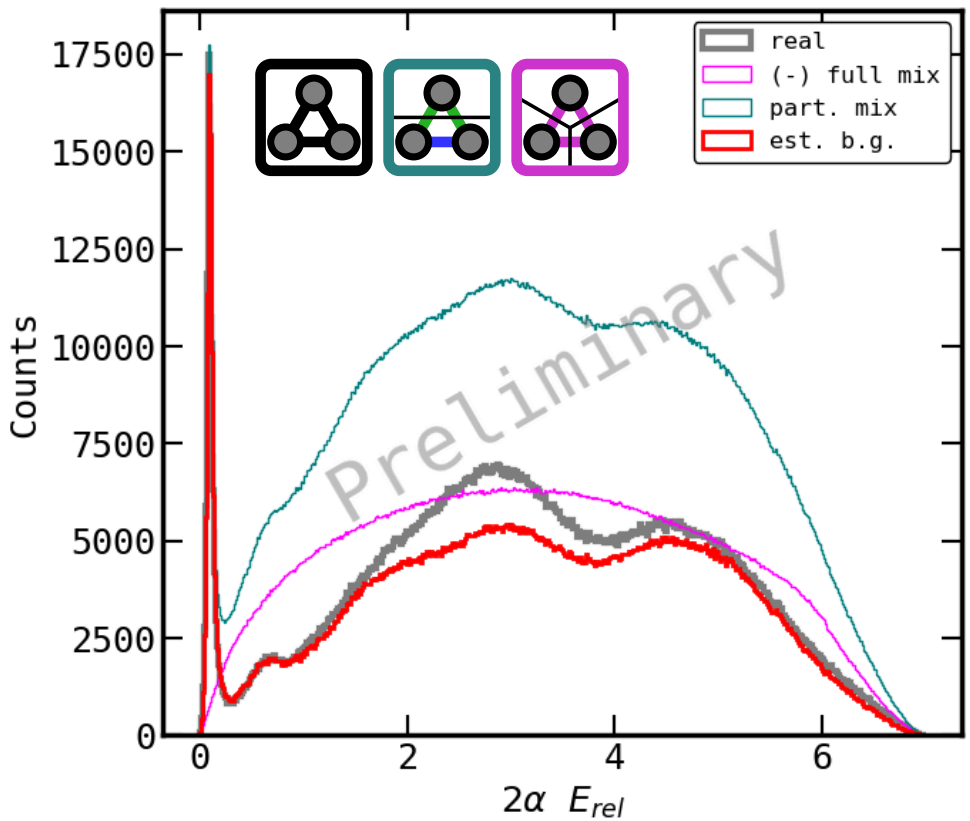

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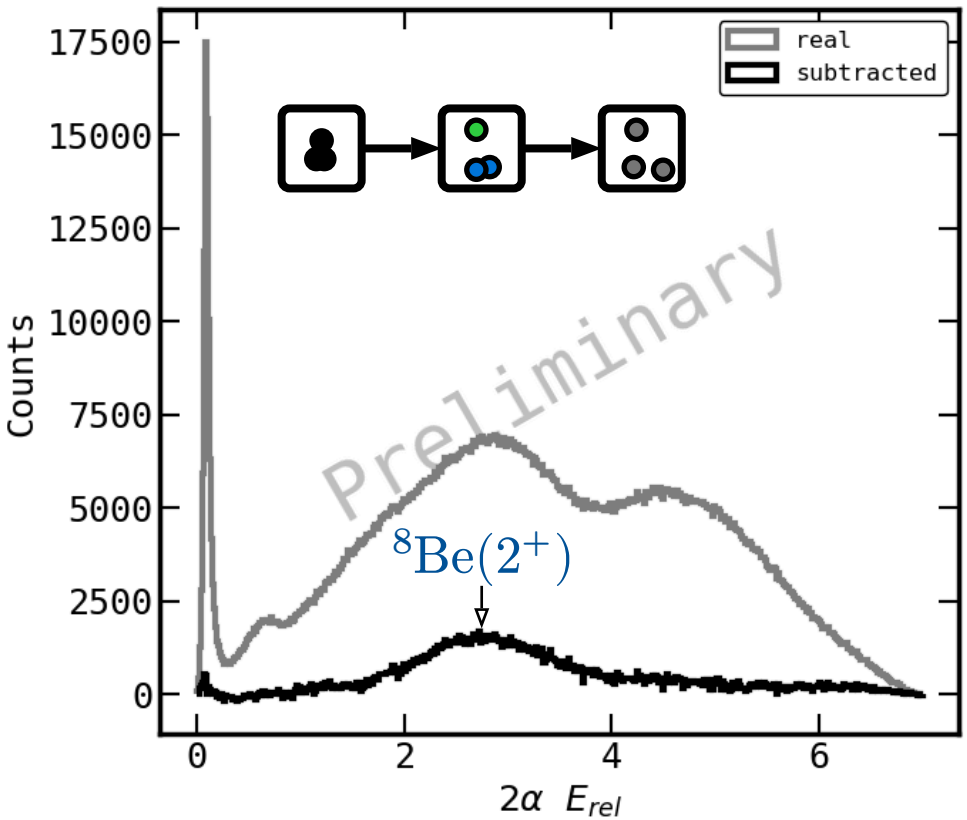

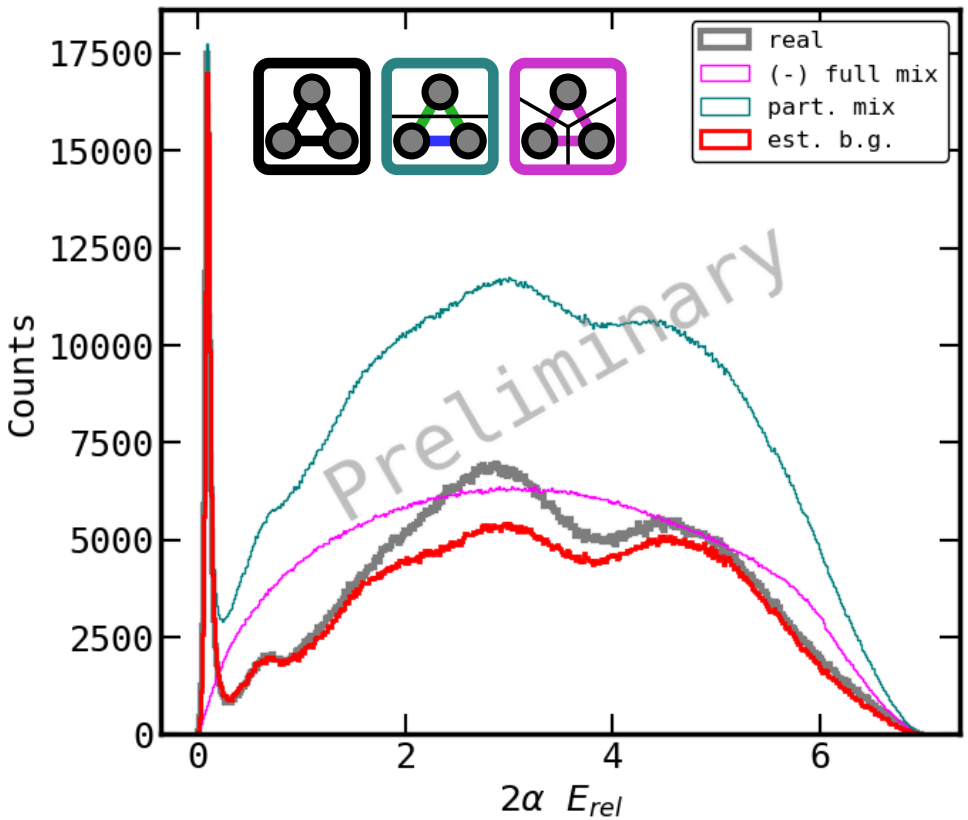

Conclusions

- **We are able to extract compound decay paths of excited nuclei through other excited nuclei.**
  - Inclusion of the semi-correlated background is critical

Future work

- Solve the remaining background in 2α E_{rel} from the non-^{8}Be contribution
- Generalize the process — Study other systems
  - $^{9}\text{B} \rightarrow p\alpha\alpha$ — in particular searching for the $\left(\frac{1}{2}\right)^{+}$ state and its decay path
  - $^{16}\text{O} \rightarrow 4\alpha$ — The higher dimensionality of the problem complicates the problem, but there are generalizations to the presented process to account for this.
  - And others

Acknowledgements

- Research Group
  - Sherry Yennello
  - Alan McIntosh
  - Kris Hagel
  - Travis Hankins
  - Andy Hannaman
  - *et al.*

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Cyclotron Institute

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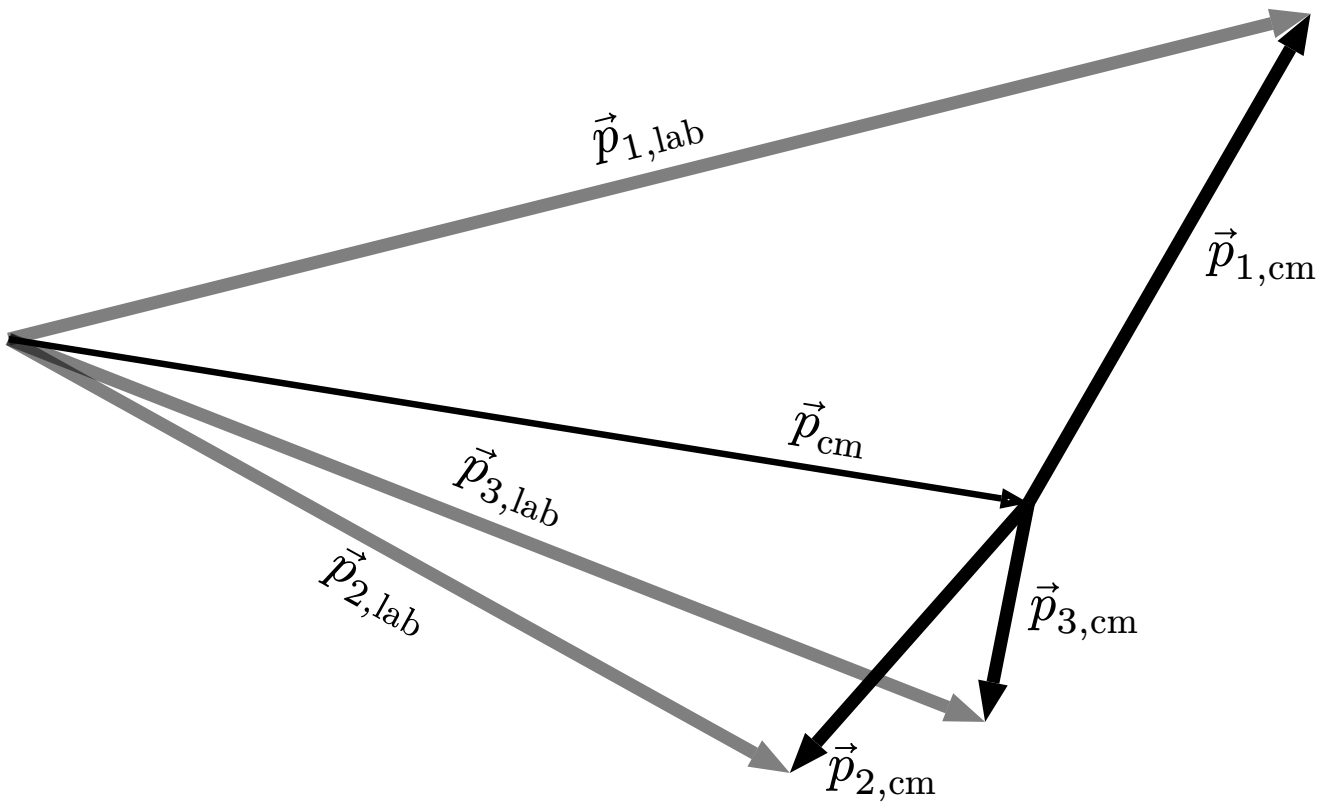
  - USA DOE #DE-FG02-93ER40773.

Thank You

Backup slides

E_{rel} definition slide



$$E_{\mathrm{rel}} = \sum_i \frac{p_{i,\mathrm{cm}}^2}{2m_i}$$

$$E^* = E_{\mathrm{rel}} + Q_{\mathrm{rxn}}$$