Update on α clustering analysis with nuclear emulsions

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Outline

- Short summary of α clustering analysis with nuclear emulsions
- Study of He-Li opening angles in True MC and Reconstructed MC
- Study of He multiplicity in clustered events
- Next steps

Introduction

From last February Physics Meeting

- According to alpha clustering models, nuclei (in particular, self-conjugated ones) can be thought of as aggregates of transient clusters (α particles)

- Cluster structures can be investigated by probing preferential dissociation channels such as $^{12}C \rightarrow 3\alpha$, $^{16}O \rightarrow 4\alpha$
  - These tend to proceed through intermediate channels like $^{12}C \rightarrow {}^{8}Be + \alpha \rightarrow 3\,\alpha$

- α clustering has not been thoroughly explored in the energy regime accessed by FOOT

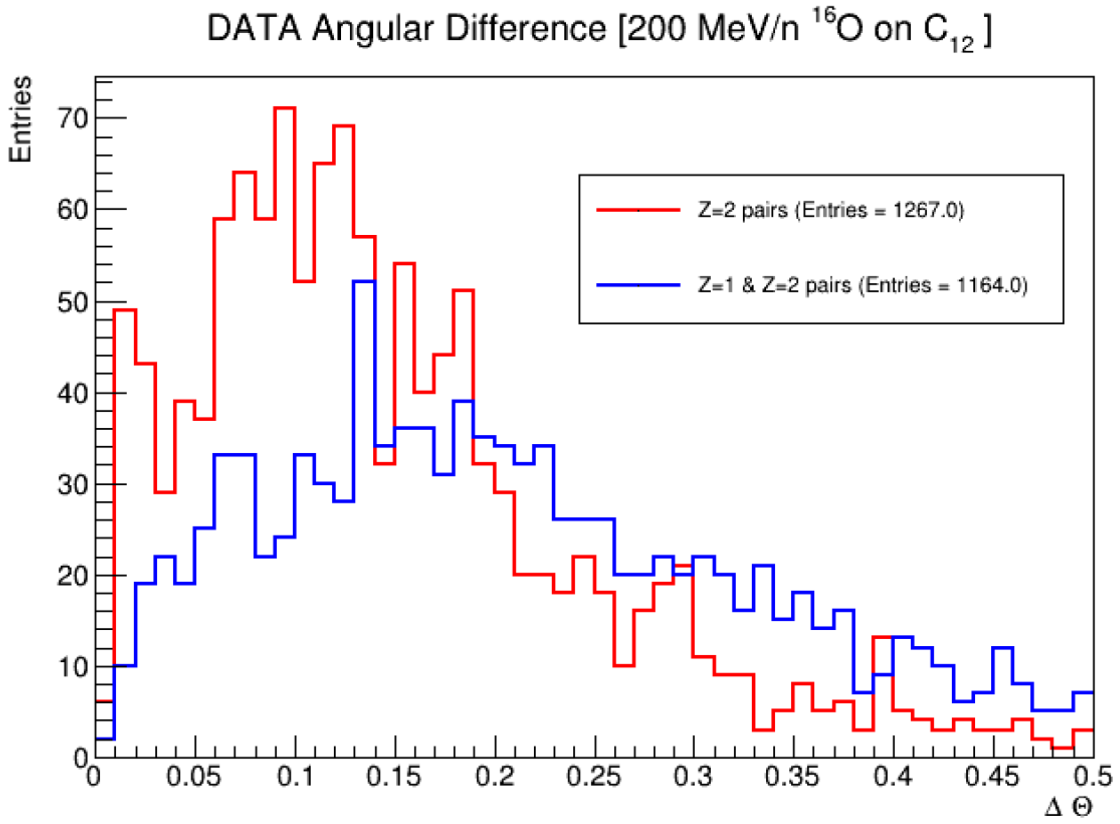
- We are currently analyzing 2019 emulsion data (^{16}O @ $200\ \mathrm{MeV/n}$ on carbon and polyethylene targets) in order to prove the existence of clusters at intermediate energies
  - The analysis focuses on finding correlated α particles couples that reveal the production of ^{8}Be in the fragmentation of the oxygen nucleus
  - No information about the momentum of these particles is being used at this time

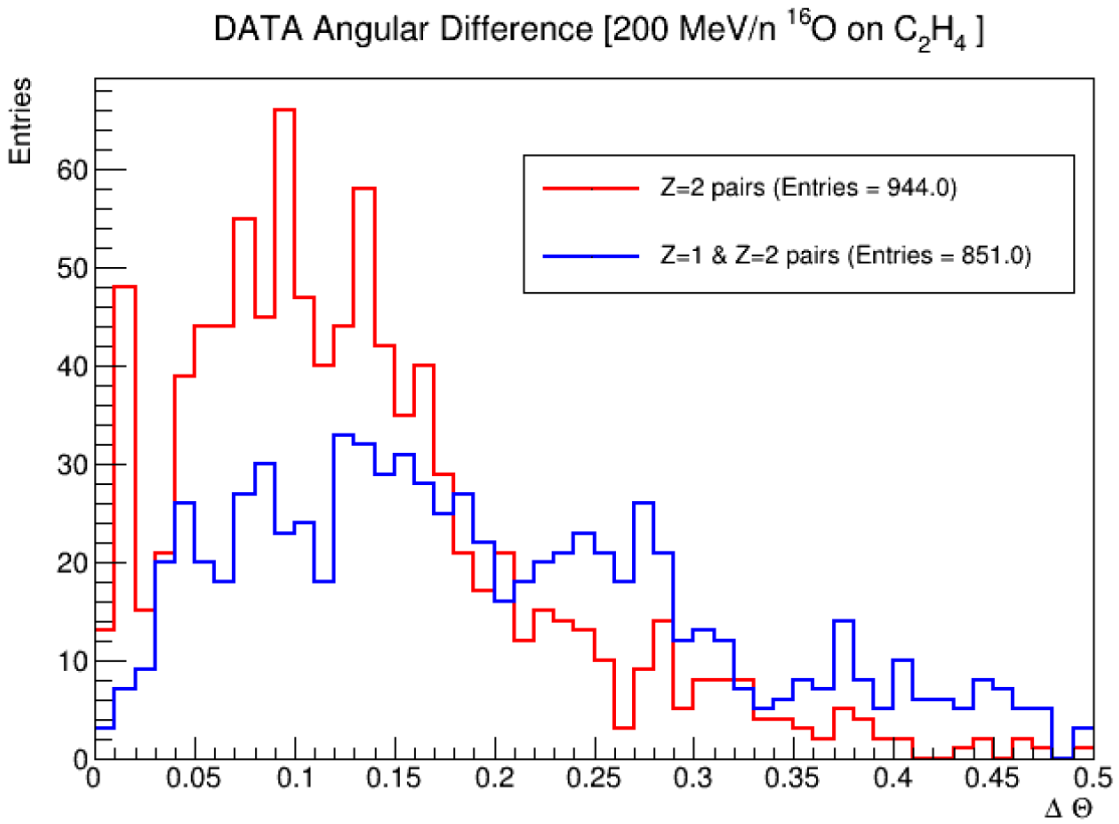
- A much more detailed introduction to α clustering can be found in the following presentations:
  - https://agenda.infn.it/event/37748/contributions/217798/attachments/114168/163750/Presentazione%20GM%20Alice.pdf
  - https://agenda.infn.it/event/35352/contributions/201149/attachments/106123/149798/AlphaClustering.pdf
  - https://agenda.infn.it/event/30579/contributions/168437/attachments/91804/124825/Clustering_may2022.pdf

Opening angle distributions (DATA)

From previous General Meeting

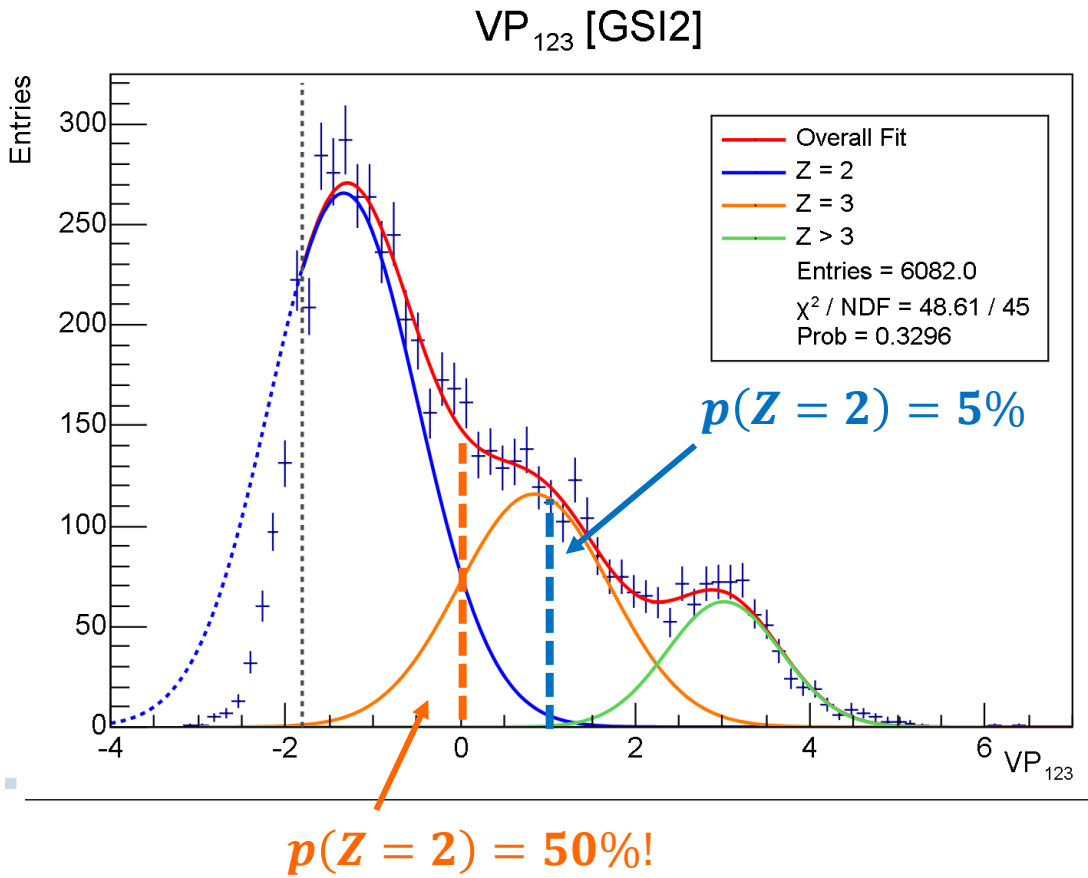
- The plots show the difference between the angles of couples of Z=2 tracks per reconstructed event <u>with at least 2 Z=2 tracks</u>
- The background is estimated with the comparison of the angular differences between Z=1 and Z=2 tracks





Z=2 Identification via Principal Component Analysis

- Most of the $Z \geq 2$ tracks are identified by using the VP_{123} distribution, combining the information of all the thermal treatments (R1, R2, R3)
  - Each track is assigned a charge through a probabilistic approach based on the shape of the fitted Gaussians
- While this approach is correct on a «global» level, there is a significant fraction of tracks for which the charge assignment is ambiguous (overlap between Gaussians)



Two main consequences:

1. $Z_{true} = 2$ misclassified as $Z = 3$ are discarded
2. $Z_{true} = 3$ mislassified as $Z = 2$ contribute to the final background estimate

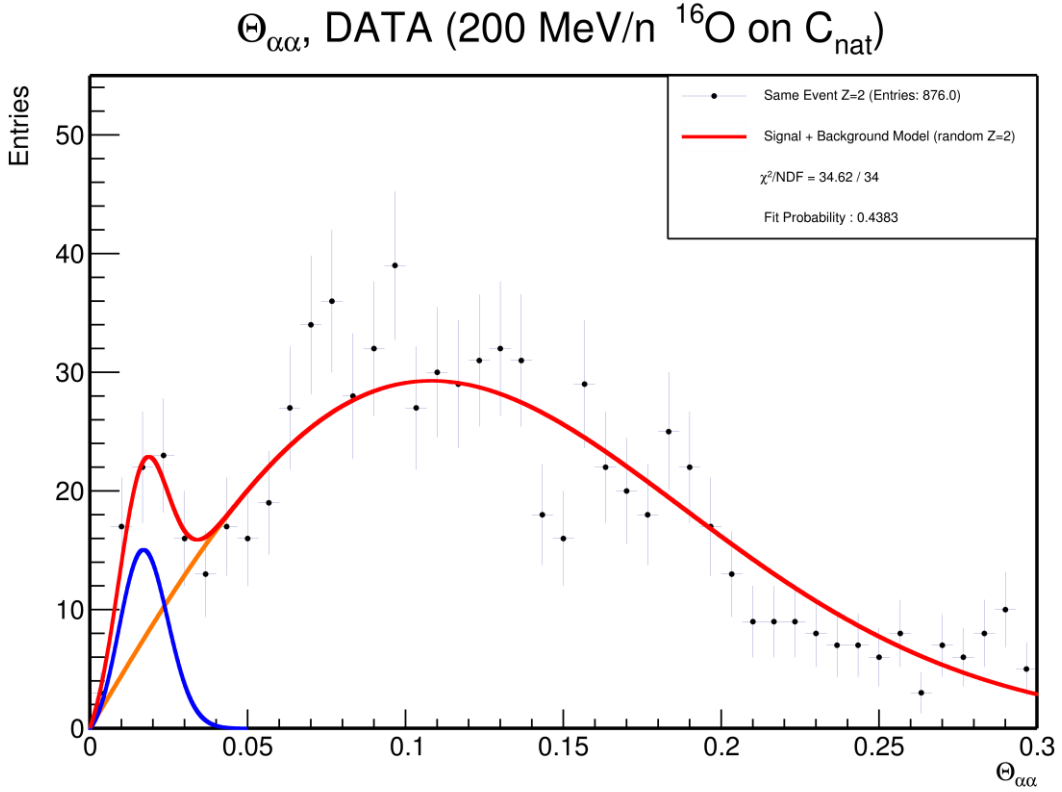
No expected correlation peak at small angles between true $Z_{true} = 2$ and $Z_{true} = 3$
→ consider all tracks that have $\boldsymbol{p(Z = 2) \geq X\%}$

In the following analysis, $X = 5$ (~ 2σ of the Z=2 Gaussian)

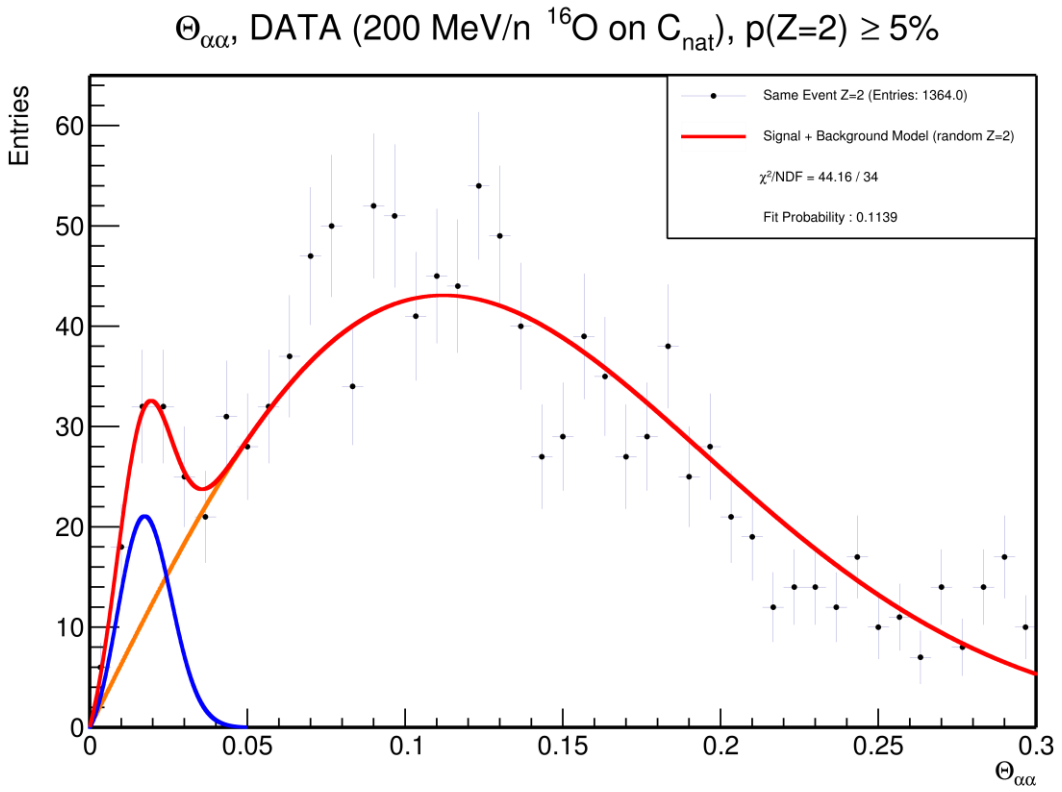
From last April Physics Meeting

Correlation Peak Comparisons: 200 MeV/n ^{16}O on C_{nat}

- In order to obtain the final estimate, a fit including both the signal and background model was used
  - The shape of the background contribution («B» parameter) was fixed
- After background subtraction, the correlation peak is more populated → efficiency improvement!



Estimated Signal = 35 ± 9



Estimated Signal = 50 ± 11

Fit Function: $g(x) = N_1 x e^{-Bx^2} + N_2 x e^{-(x-C)^2/D^2}$

From last April Physics Meeting

Correlation Peak Comparisons: 200 MeV/n ^{16}O on C_2H_4

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  - The shape of the background contribution («B» parameter) was fixed
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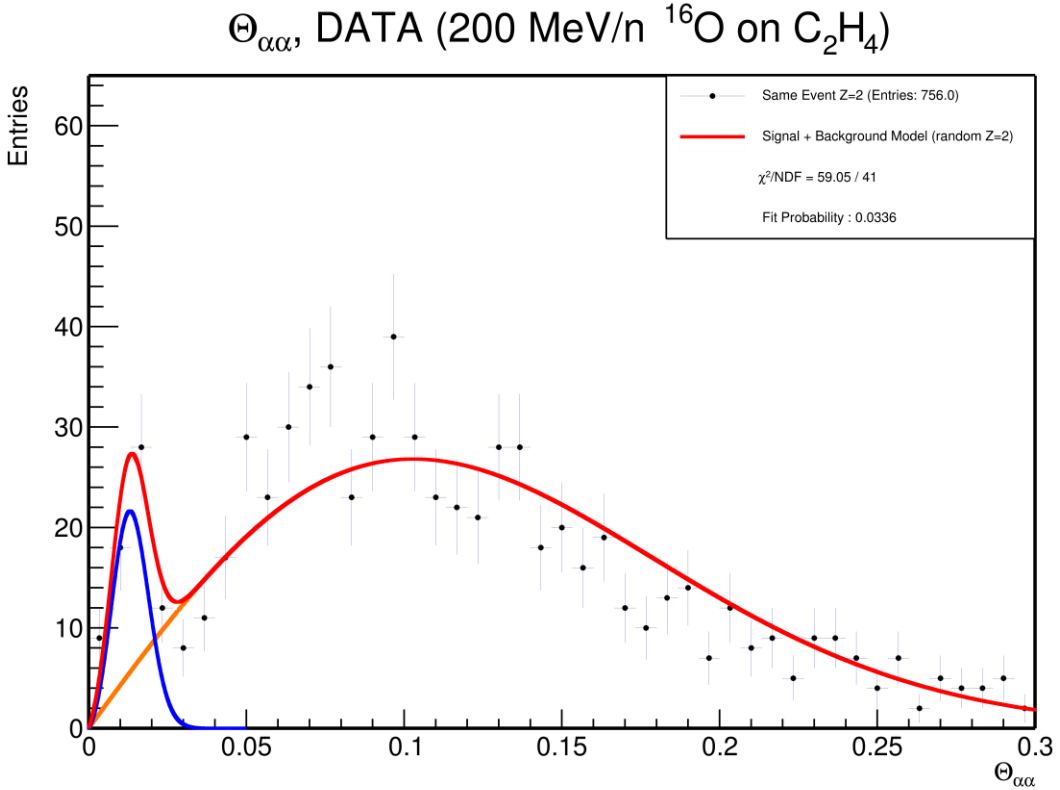
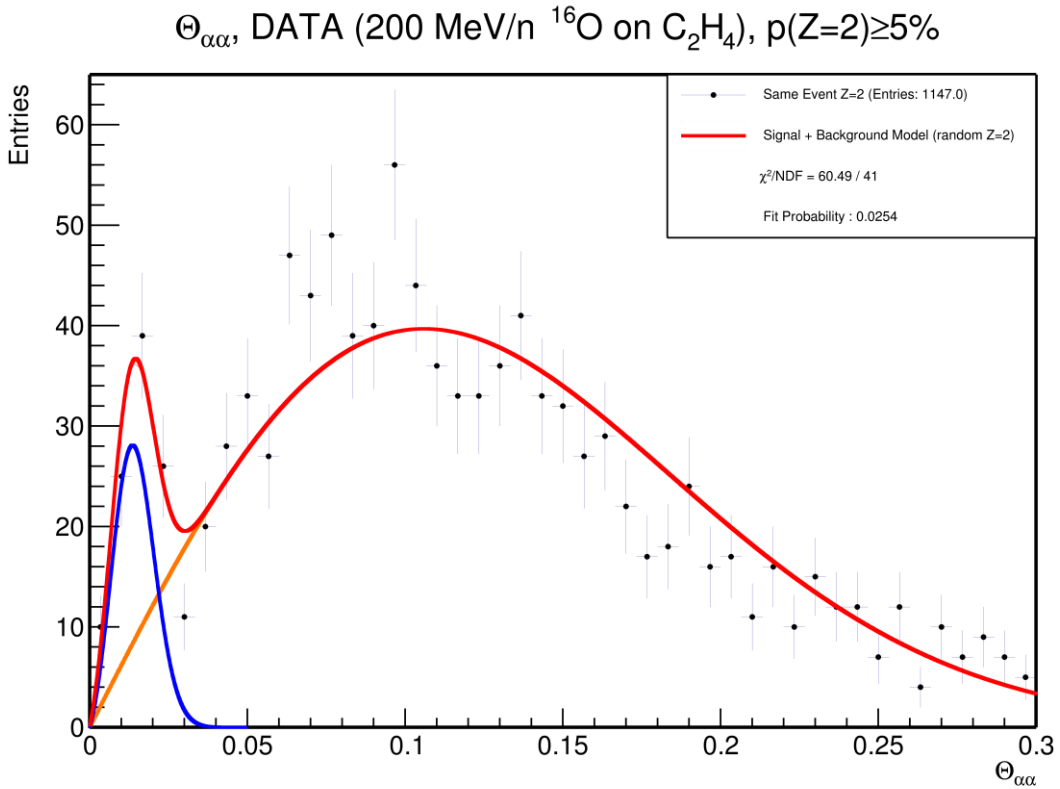


Estimated Signal = 44 ± 9



Estimated Signal = 61 ± 11

Fit Function: $g(x) = N_1 x e^{-Bx^2} + N_2 x e^{-(x-C)^2/D^2}$

From last April Physics Meeting

On-going

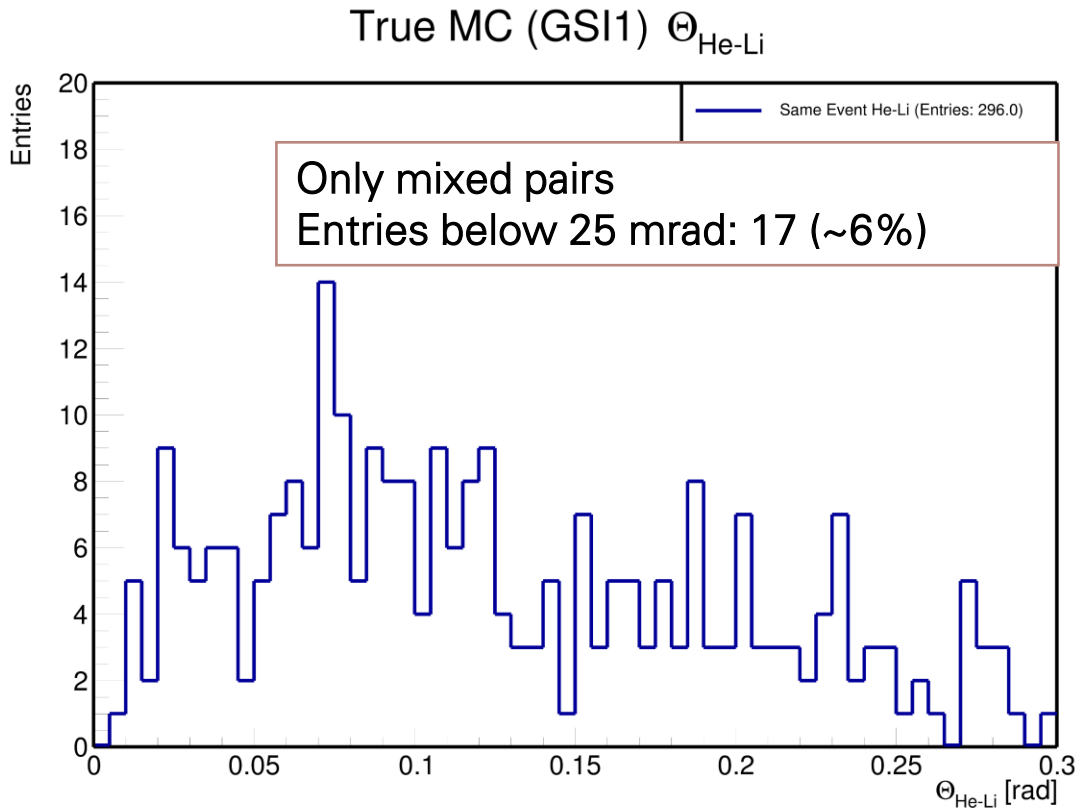
- The improvements shown in the previous update were obtained by reducing the purity of the track sample to compensate for limits in the charge ID procedure → **MC study of He-Li opening angles**

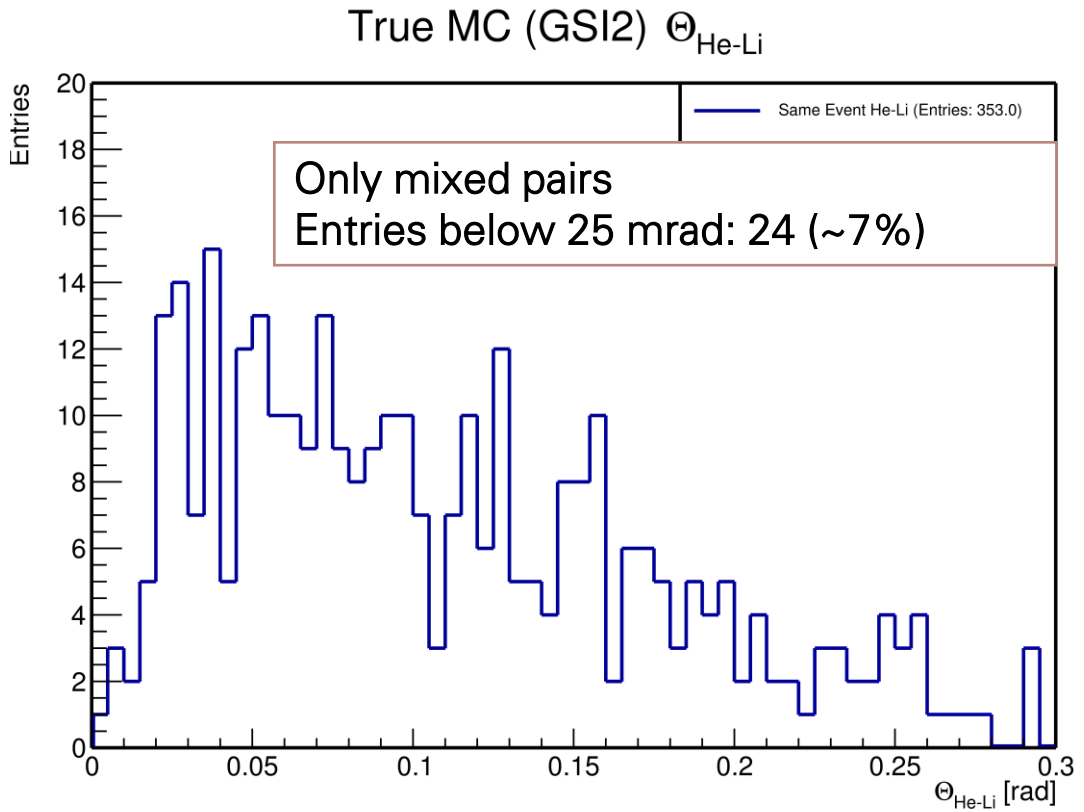
- In order to test the current models of nuclear fragmentation for ^{16}O → study of He multiplicity (DATA and MC) in events with production of $^{8}Be_{g.s.}$

- Improvements in the estimate of the reconstruction efficiency with higher statistics and systematic error evaluation

MC True He-Li Opening Angles

- The improvements shown in the previous update were obtained by reducing the purity of the track sample to compensate for limits in the charge ID procedure
- The events were selected by requiring at least one He and Li track reaching S2
- Only mixed pairs (one He track and one Li track) are shown



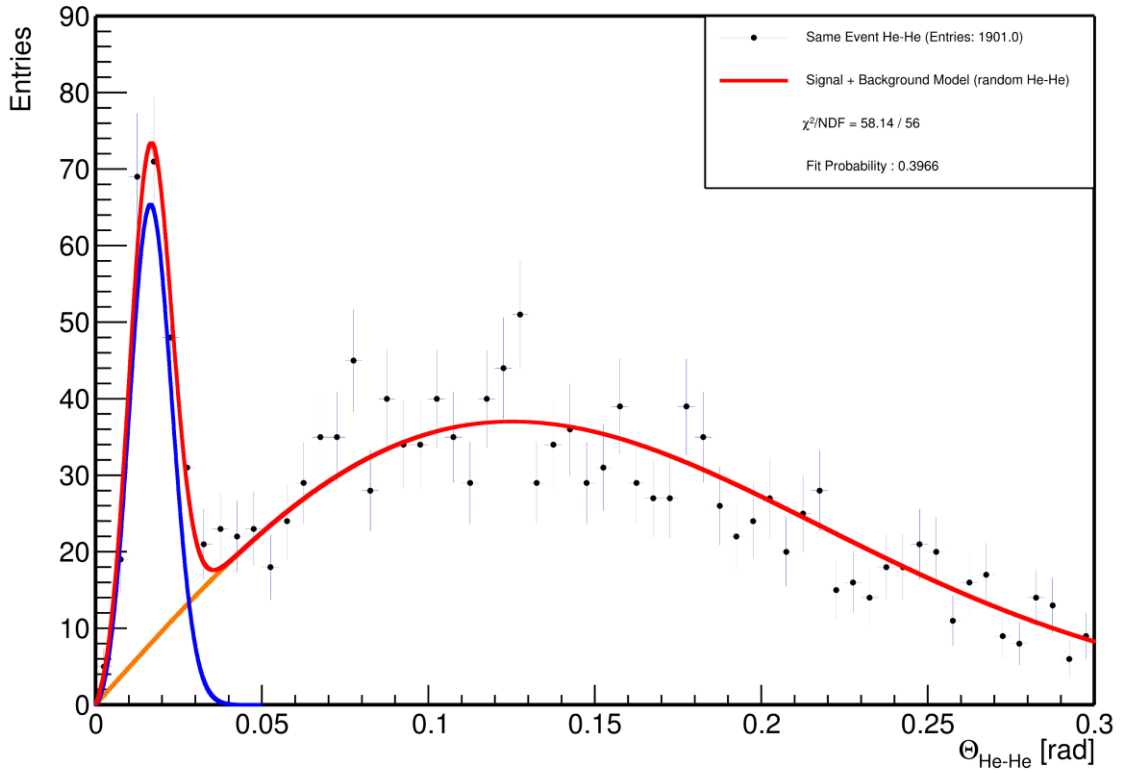


GSI1 = 200 MeV/n ^{16}O on C_{nat}, GSI2 = 200 MeV/n ^{16}O on C_2H_4

Correlation Peak with He-Li (MC True)

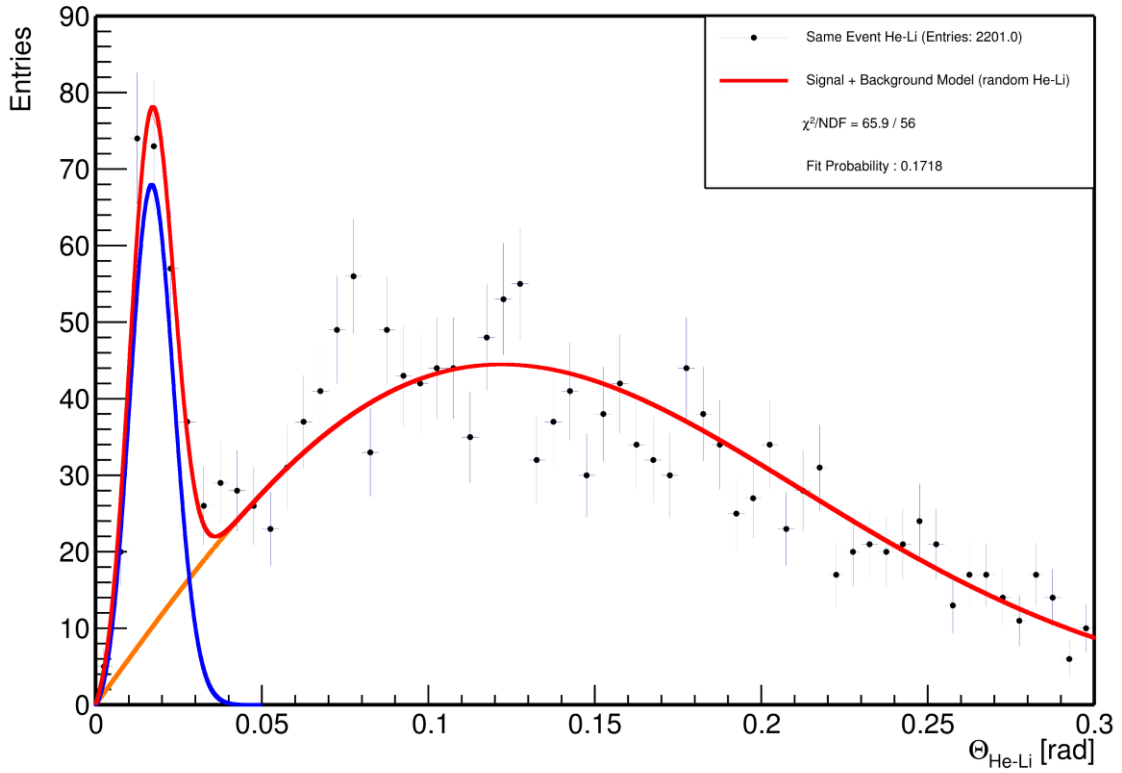
- The clustering analysis was repeated in MC True after the inclusion of **all the available** He-Li pairs
- In this case, the increase in the background only partially compensates the additional pairs
- As a result, an increase in the signal can be observed (smaller than the counting error!)

MC True (GSI1) $\Theta_{\text{He-He}}$



Estimated signal (He pairs) = 183 ±14

MC True (GSI1) $\Theta_{\text{He-Li}}$



Estimated signal (He pairs) = 193 ±15

GSI1 = 200 MeV/n $^{16}\boldsymbol{O}$ on $\boldsymbol{C_{nat}}$, Fit Function: $g(x) = N_1 x e^{-Bx^2} + N_2 x e^{-(x-C)^2/D^2}$

Correlation Peak with He-Li (MC True)

- The clustering analysis was repeated in MC True after the inclusion of **all the available** He-Li pairs
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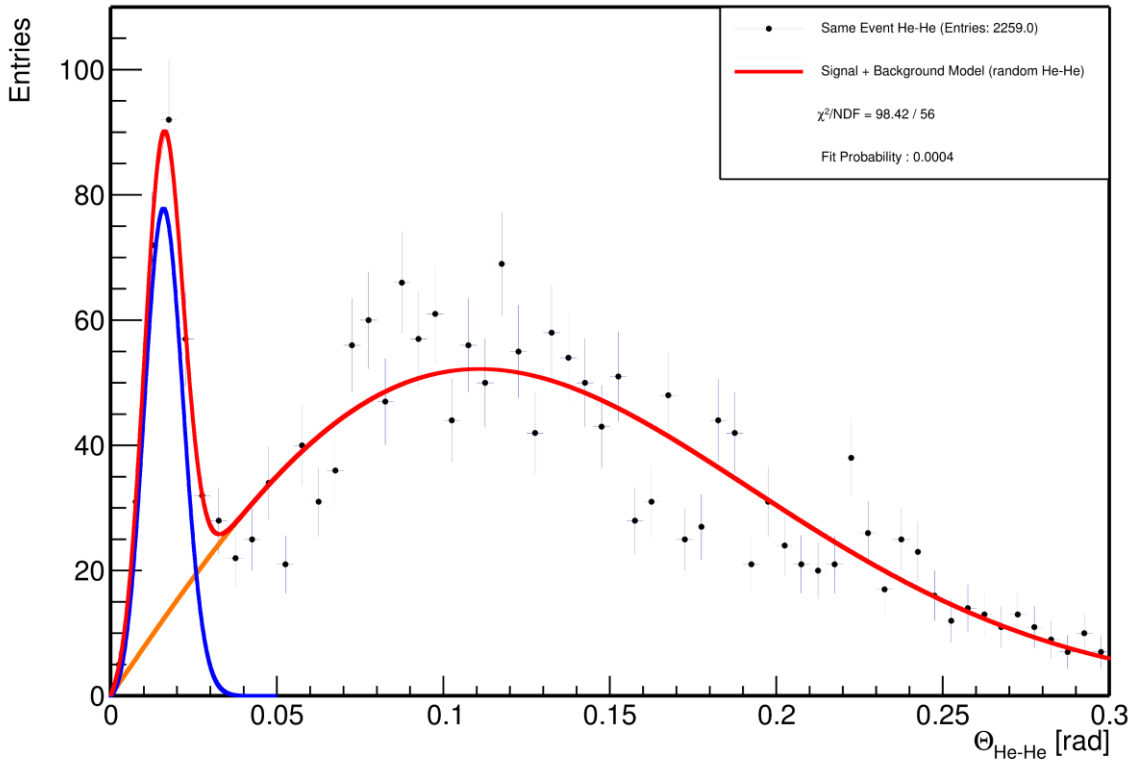
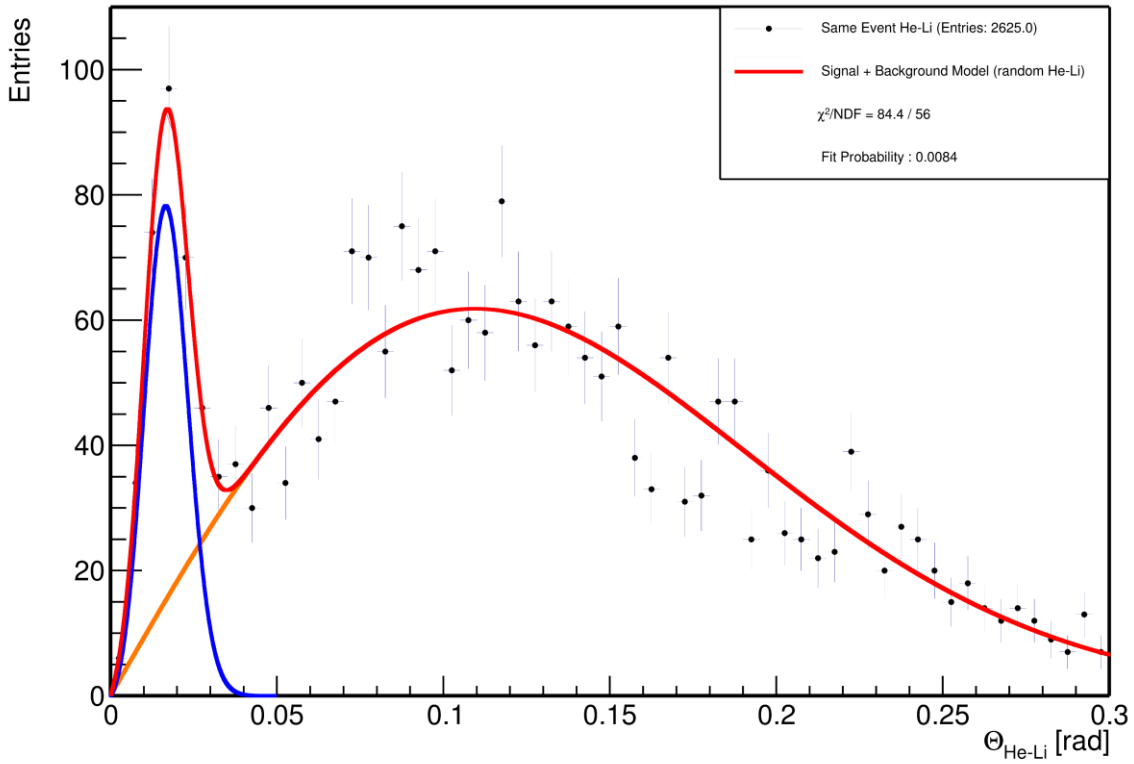
MC True (GSI2) $\Theta_{\text{He-He}}$



Estimated signal (He pairs) = 208 ±17

MC True (GSI2) $\Theta_{\text{He-Li}}$

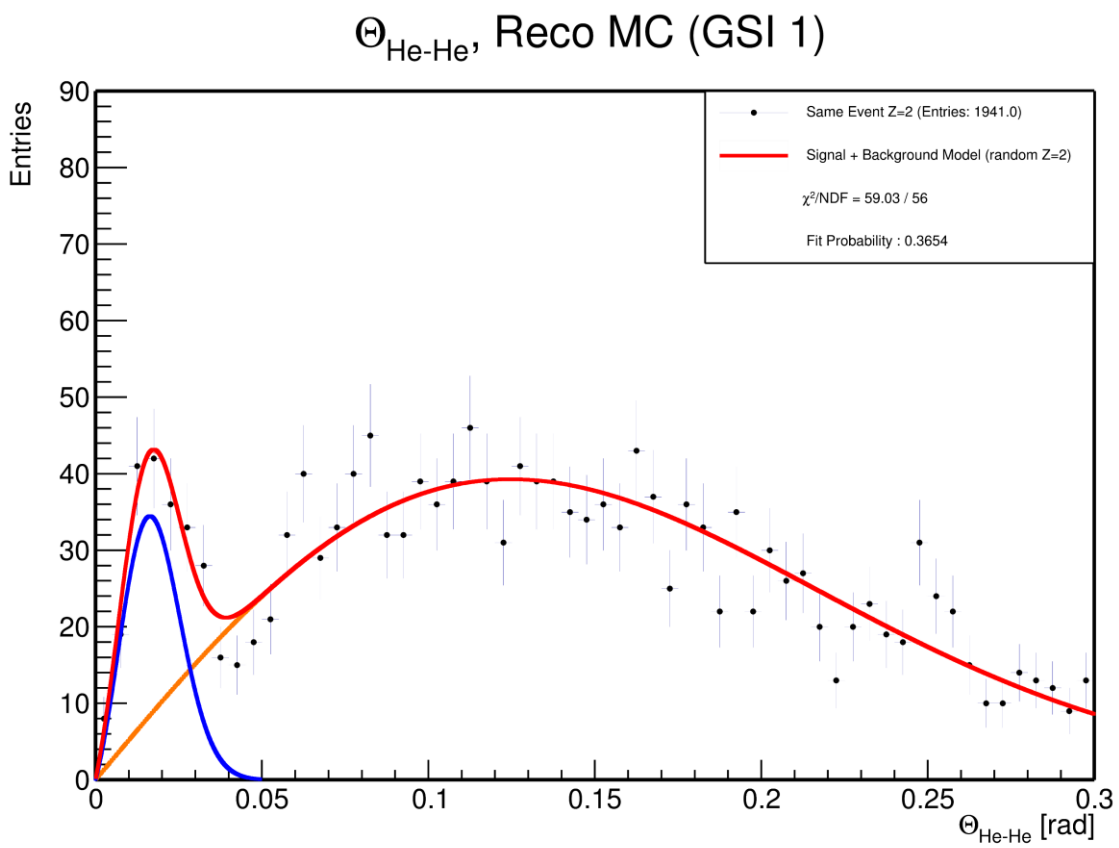


Estimated signal (He pairs) = 223 ±18

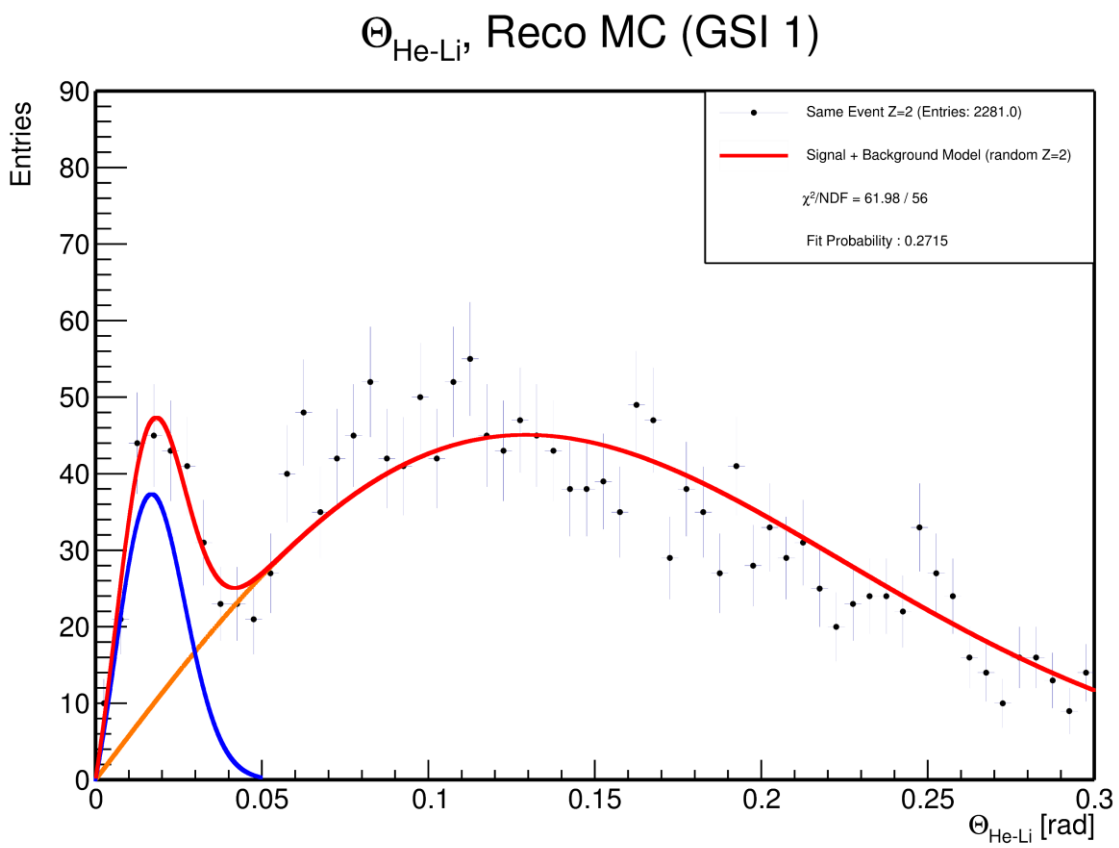
GSI2 = 200 MeV/n $^{16}\boldsymbol{O}$ on $\boldsymbol{C_2H_4}$, Fit Function: $g(x) = N_1 x e^{-Bx^2} + N_2 x e^{-(x-C)^2/D^2}$

Correlation Peak with He-Li (Reco MC)

- A similar approach (inclusion of **all the available** He-Li pairs) was followed in Reconstructed MC
- Once again, the increase in the background only partially compensates the additional pairs
- As a result, an increase in the signal can be observed (comparable to the counting error!)



Estimated signal (He pairs) = 116 ±16



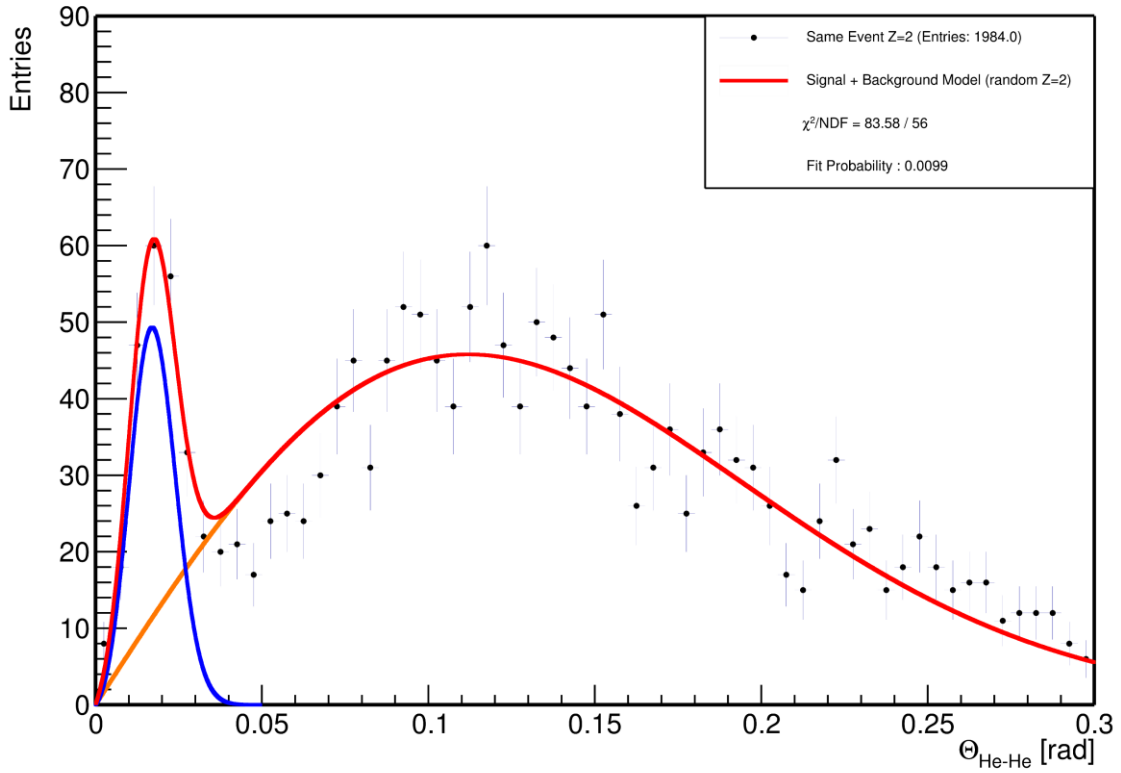
Estimated signal (He pairs) = 129 ±17

GSI1 = 200 MeV/n $^{16}\boldsymbol{O}$ on $\boldsymbol{C_{nat}}$, Fit Function: $g(x) = N_1 x e^{-Bx^2} + N_2 x e^{-(x-C)^2/D^2}$

Correlation Peak with He-Li (Reco MC)

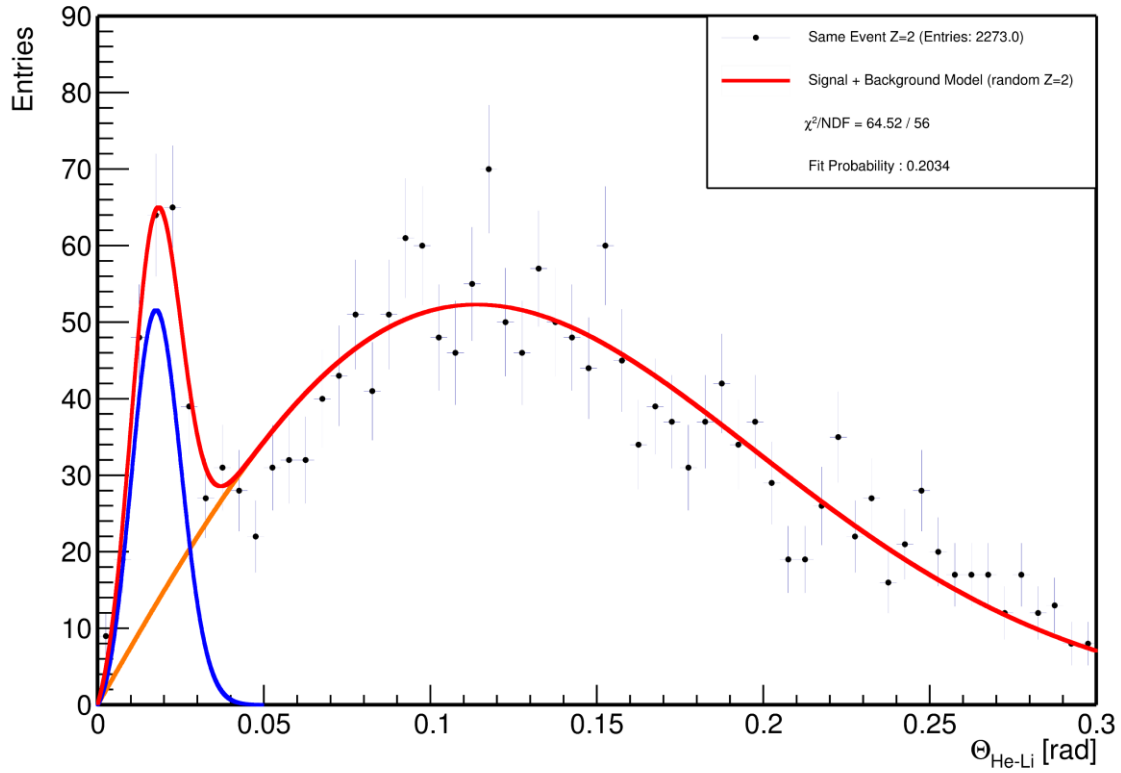
- A similar approach (inclusion of **all the available** He-Li pairs) was followed in Reconstructed MC
- Once again, the increase in the background only partially compensates the additional pairs
- As a result, an increase in the signal can be observed (comparable to the counting error!)

$\Theta_{He\text{-}He}$, Reco MC (GSI 2)



Estimated signal (He pairs) = 143 ±18

$\Theta_{He\text{-}Li}$, Reco MC (GSI 2)



Estimated signal (He pairs) = 153 ±19

GSI2 = 200 MeV/n $^{16}\boldsymbol{O}$ on $\boldsymbol{C_2H_4}$, Fit Function: $g(x) = N_1 x e^{-Bx^2} + N_2 x e^{-(x-C)^2/D^2}$

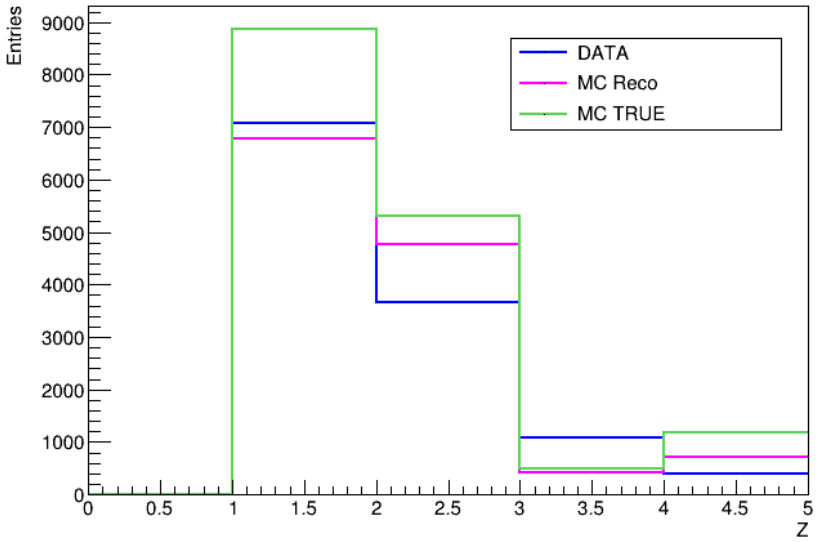
Discussion

- If the Li contamination estimates from True MC could be applied to DATA then an increase of ~ 6% would be expected with the inclusion of all He-Li pairs

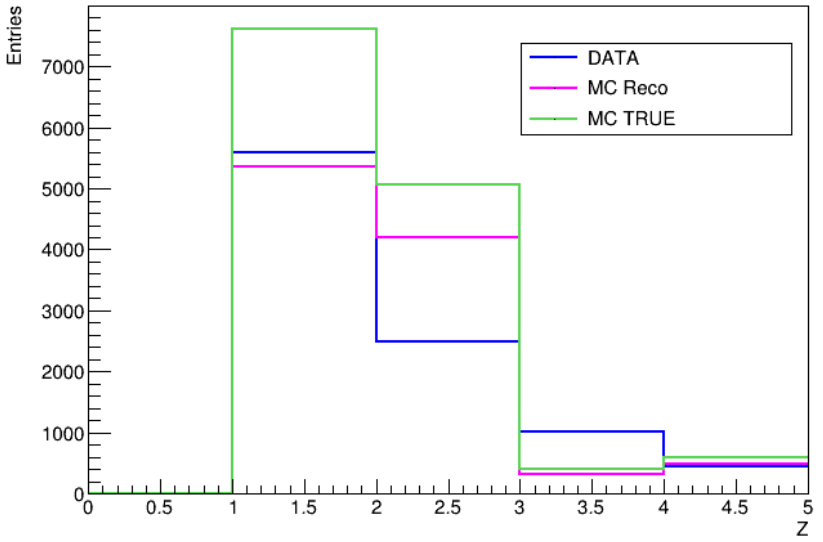
- The actual increase observed in DATA is around 30/35%!

- However, the expected contamination in DATA is still being studied
  - The relative abundancies of He, Li in DATA do not match those in MC
  - The selection of tracks in DATA cannot be easily translated to MC because it is linked to volume variables which are not simulated
  - An approximated selection (for example, same fraction of tracks) ignores the possible correlation between angles and ionization of each particle

GSI1: Charge of secondaries



GSI2: Charge of secondaries

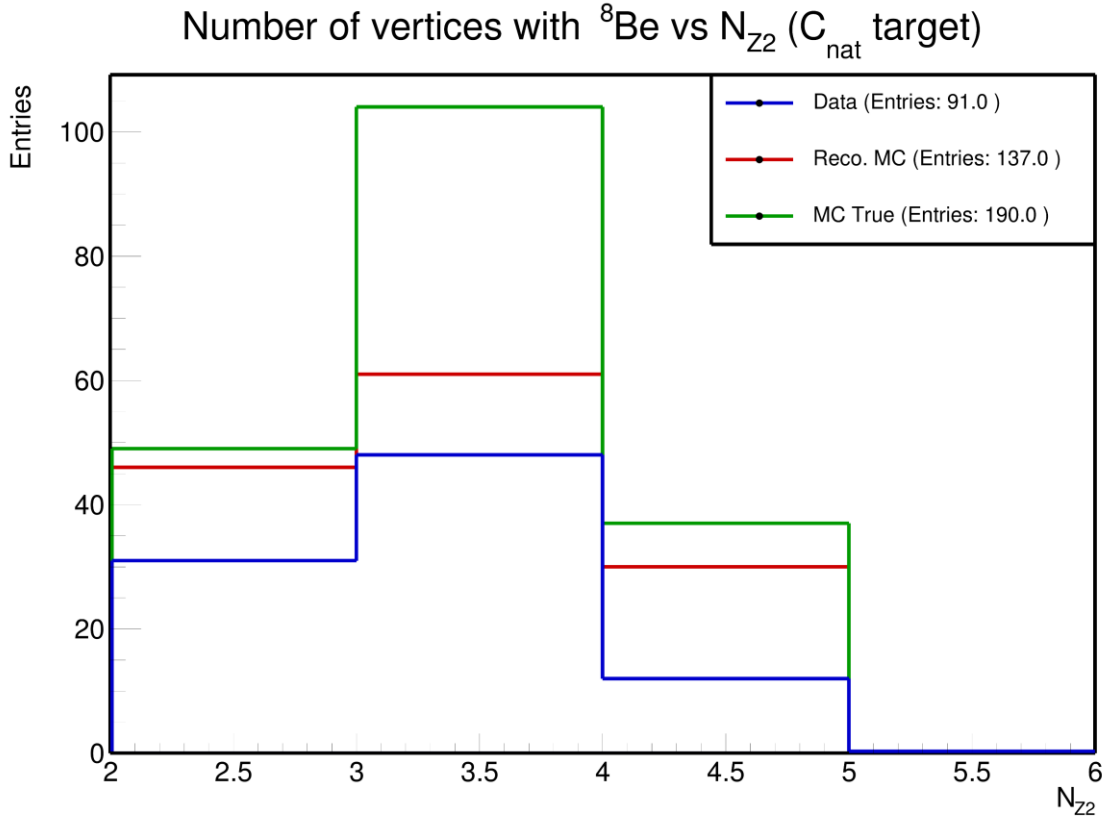


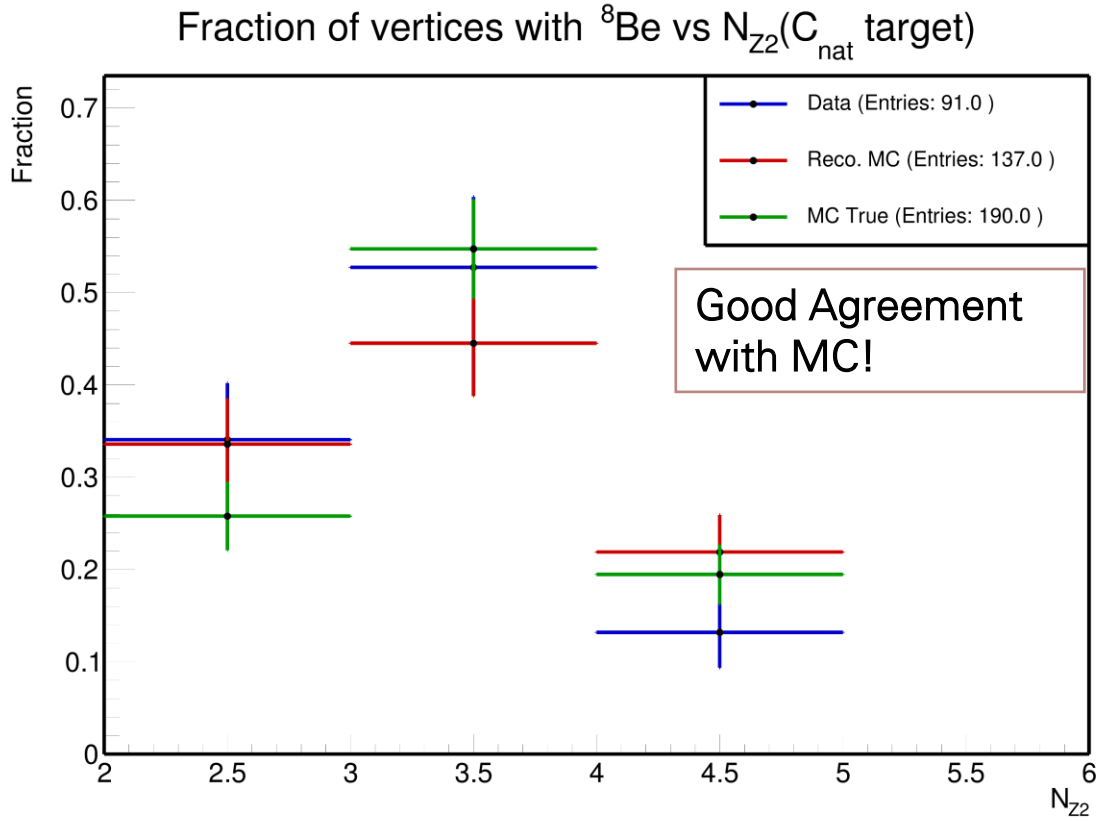
GSI1 = 200 MeV/n ^{16}O on C_{nat}, GSI2 = 200 MeV/n ^{16}O on C_2H_4

Selection: tracks reaching S2, vertices with $n \geq 3$

He Multiplicity Study (GSI1)

- The number of He was evaluated in DATA, Reconstructed MC and True MC in the events where at least one correlated pair was found
- No background subtraction used for these plots





GSI1 = 200 MeV/n ^{16}O on C_{nat}, GSI2 = 200 MeV/n ^{16}O on C_2H_4

He Multiplicity Study (GSI2)

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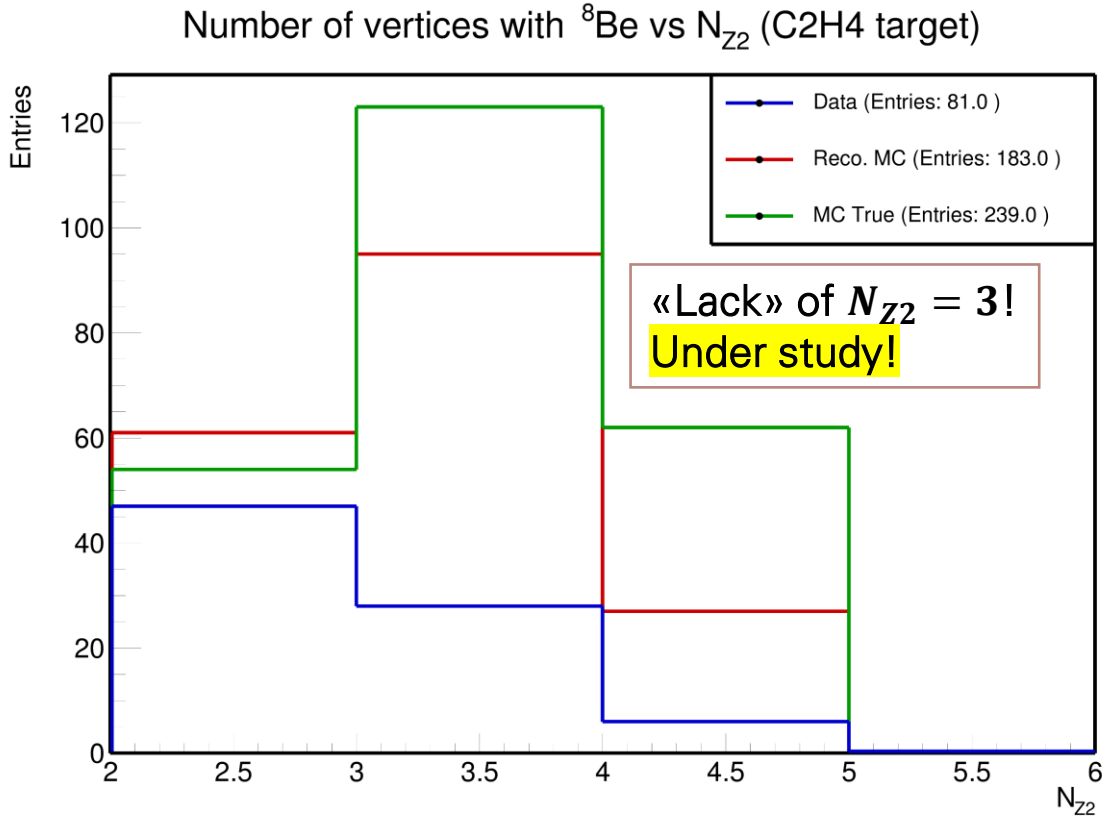
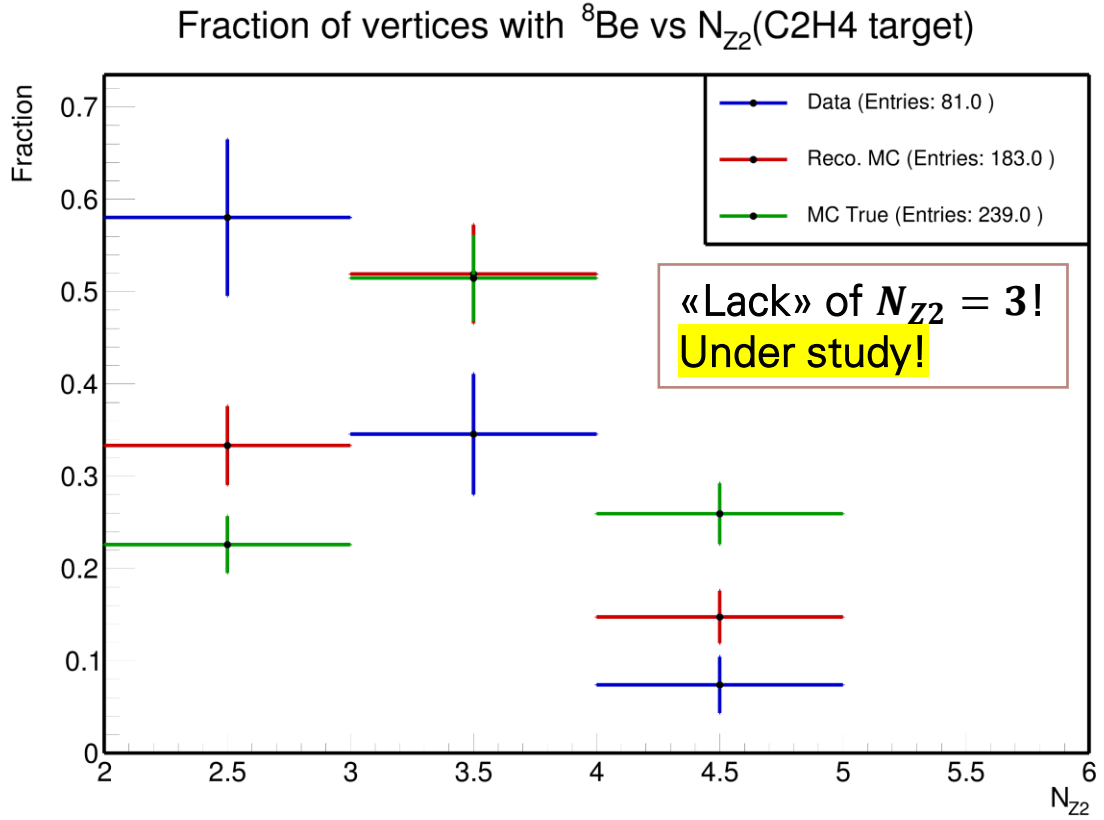
- No background subtraction used for these plots





GSI1 = 200 MeV/n ^{16}O on C_{nat}, GSI2 = 200 MeV/n ^{16}O on C_2H_4

Conclusions

- The contamination of the correlation peak by the addition of He-Li pairs was studied in MC, but the expected contribution in DATA is still unclear

- First comparisons of He multiplicity in clustered events between DATA and MC show a good agreement for GSI1
  - Worse agreement for GSI2 → under investigation!

- Next steps: finalize open issues and repeat clustering analysis with higher MC statistics to obtain final $^{8}Be_{g.s.}$ cross section estimates (on-going)

Thank You!