Update on α clustering analysis with nuclear emulsions

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Outline

- Data analysis updates for $^{8}Be_{g.s.}$ production cross section measurements with 200 MeV/n oxygen beams
  - Additional cuts on track quality
  - Recap of emulsion charge ID techniques
  - Effects of Charge ID on cross-section measurement and improvement of the efficiency

- Reconstructed MC improvements (on-going!)
  - Fine tuning angular and positional smearing after the simulation
  - Modelling emulsion distorsions and thermal treatments
  - Improving the statistics for a final estimate of the reconstruction efficiency
  - To be discussed with more details in the future Physics Meeting

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

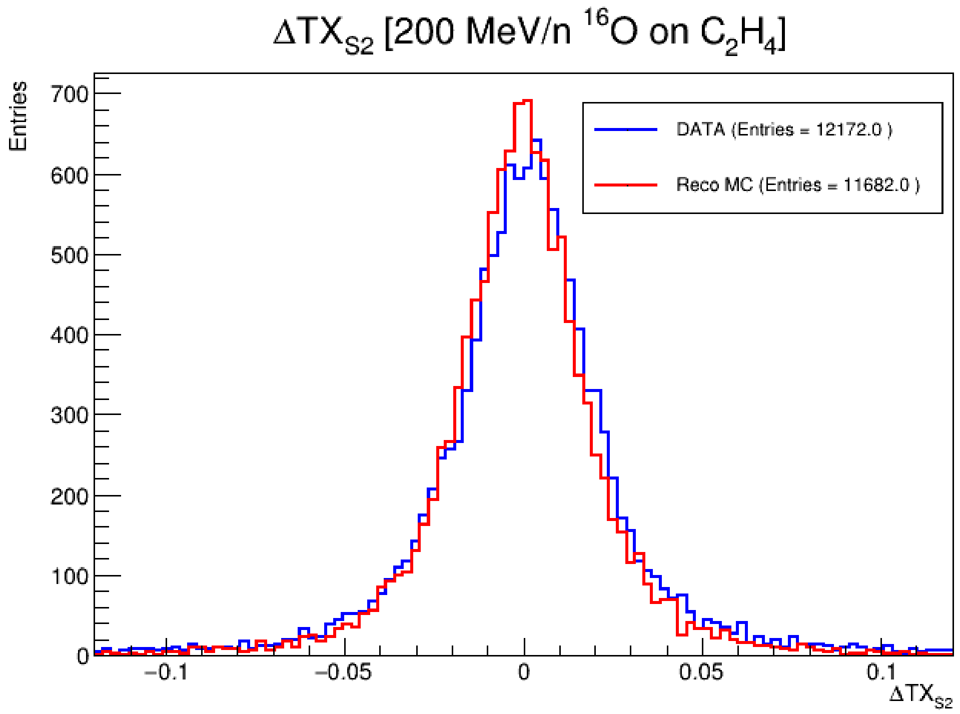
- α clustering has not been thoroughly explored in the energy regime accessed by FOOT

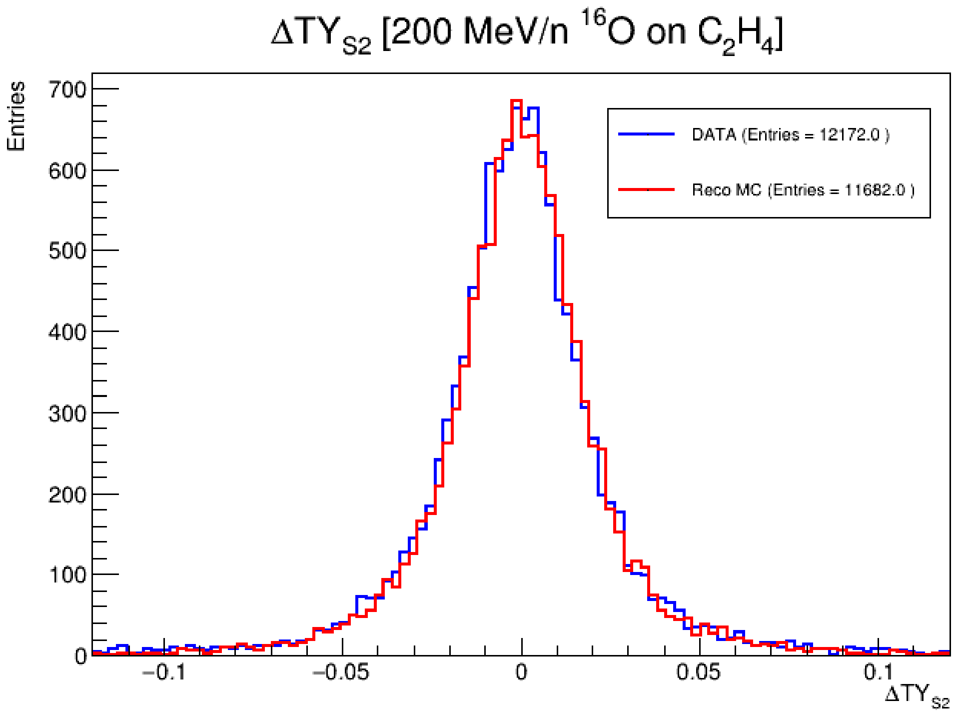
- We are currently analyzing 2019 emulsion data (^{16}O @ $200\ \mathrm{MeV/n}$ on carbon and polyethylene targets) in order to prove the existence of clusters at intermediate energies
  - The analysis focuses on finding correlated α particles couples that reveal the production of ^{8}Be in the fragmentation 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

Data Analysis Improvements

- Displays of selected $^{8}Be_{g.s.}$ events have shown that in rare instances merging between S1 and S2 tracks could be prone to errors
- An additional cut on the maximum angular difference between the first segment in S1 and the first segment in S2 has been introduced ($\Delta TX_{S2} < 75\ mrad$ and $\Delta TY_{S2} < 75\ mrad$)
  - In GSI2 (polyethylene target), the number of correlated Z=2 couples decreases from 75 to 72
  - After background subtraction, the effect on the $^{8}Be_{g.s.}$ signal is negligible



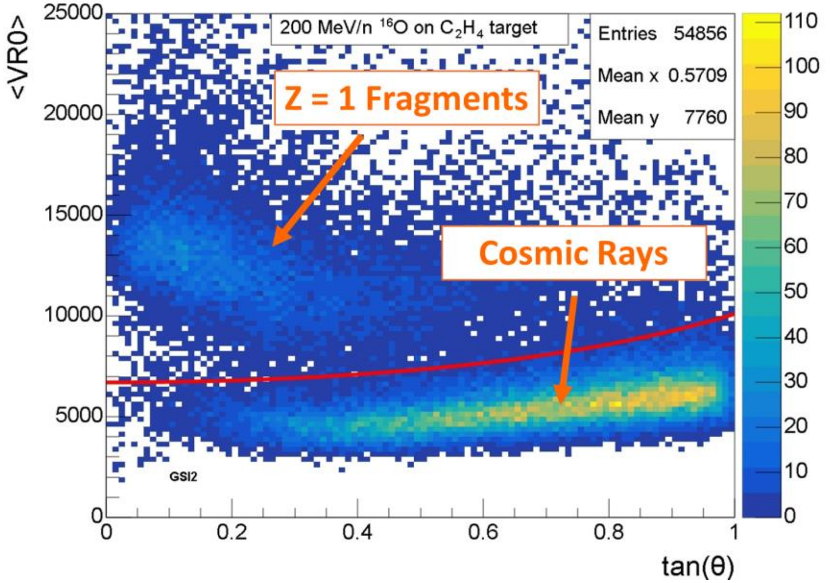


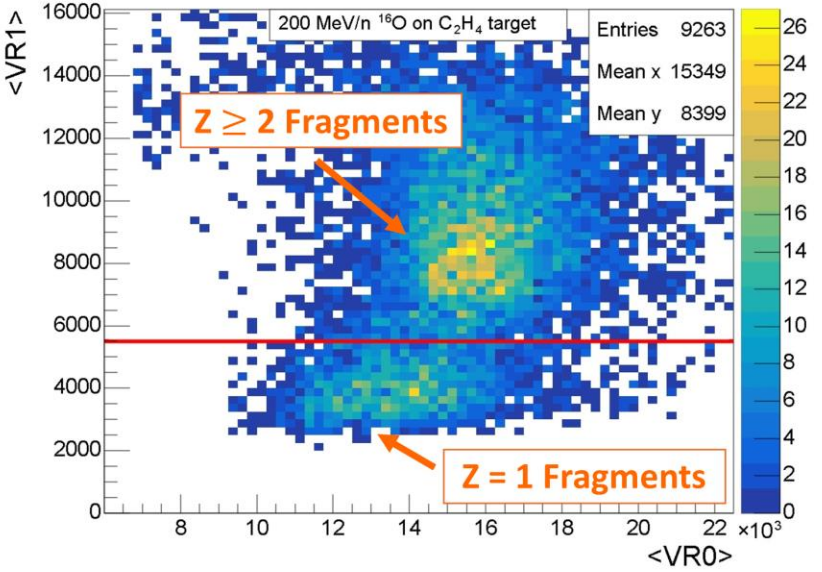
Minor effect → less than 4% of «good» MC tracks (tracks with segments belonging to the same event) excluded!

Summary of Charge ID with Emulsions

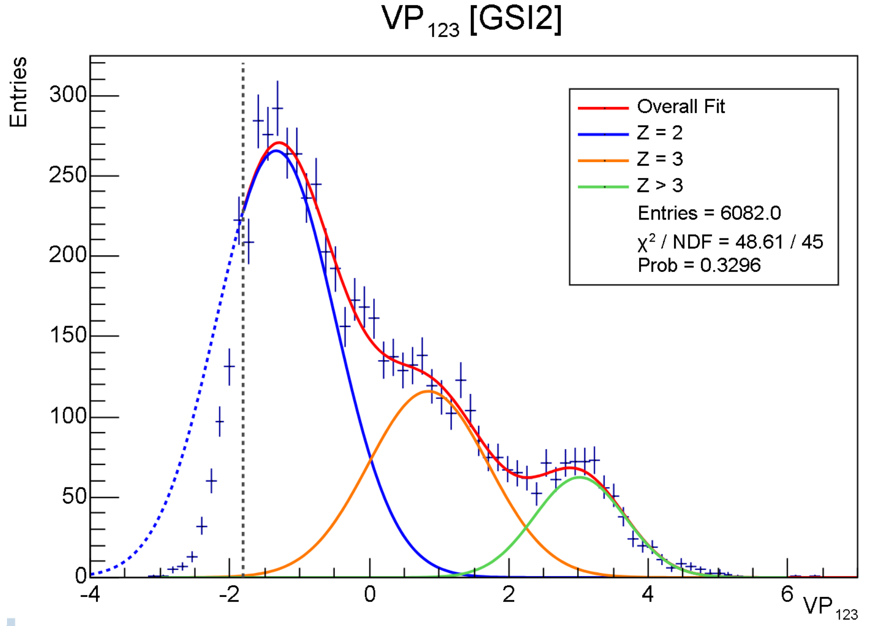
- In the analysis carried out so far, the details of charge identification in DATA have been neglected
- However, @200 MeV/n there is a significant overlap between the $Z = 2$ and $Z = 3$ populations and this can lead to a loss of efficiency
- In DATA, charges are identified by a combination of cuts and PCA relying on «volume variables», describing the ionization of the particles in emulsion films undergoing different treatments
- For both targets (carbon and polyethylene) more than 75% of Z=2 are identified via PCA

Cut-Based Analysis





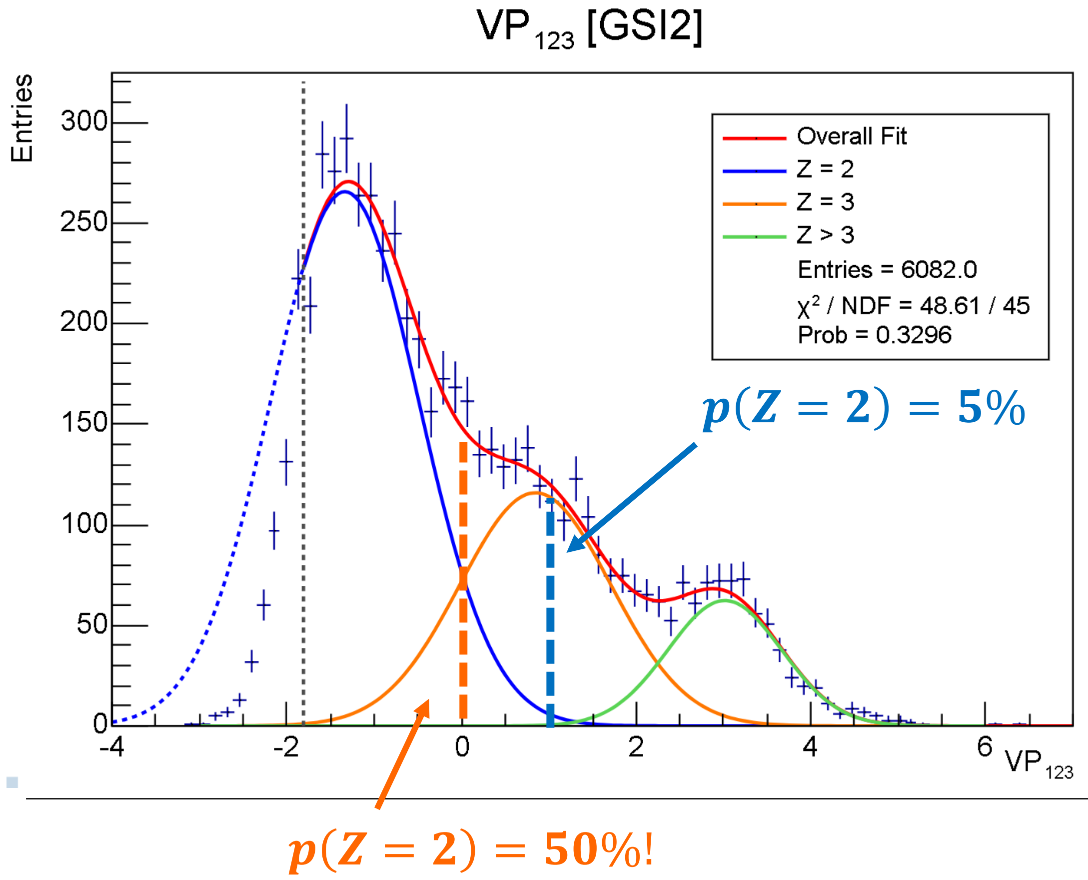
PCA (>75% Z=2)



More details in G.Galati et al «Charge identification of fragments produced in ^{16}O beam interactions at 200 MeV/n and 400 MeV/n on C and C_2H_4 targets»

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:

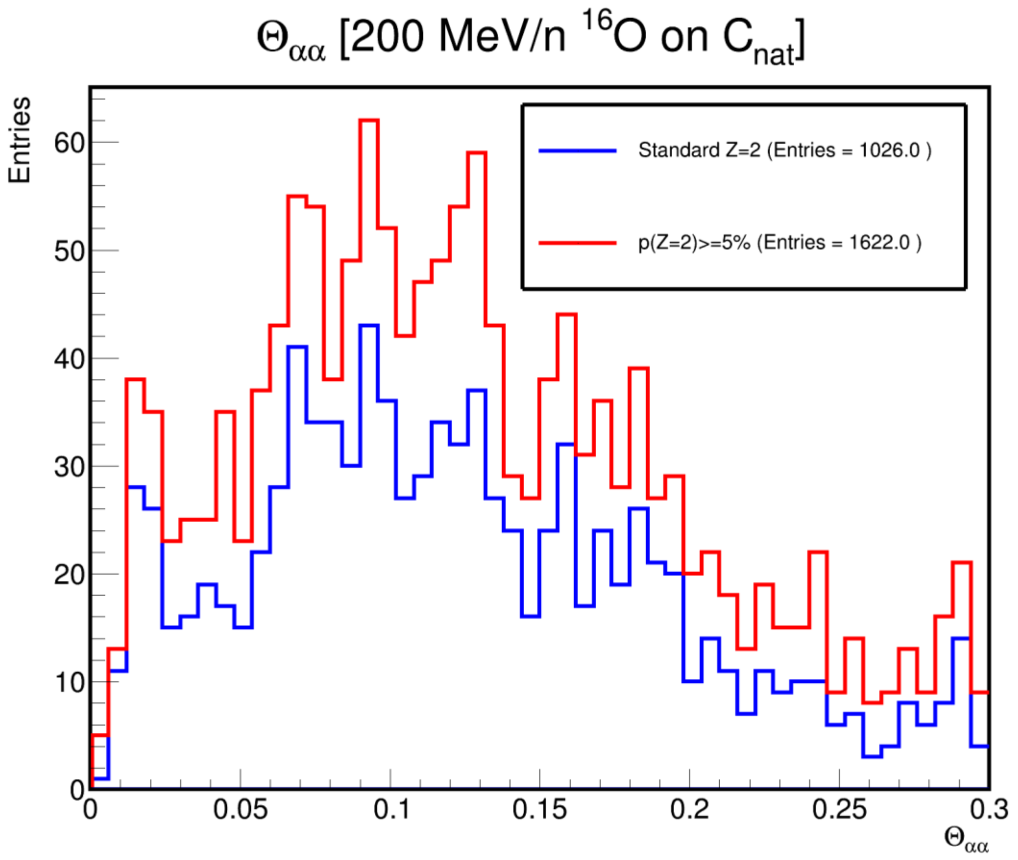
1. $Z_{true} = 2$ misclassified as $Z = 3$ are discarded
2. $Z_{true} = 3$ mislassified as $Z = 2$ contribute to the final background estimate

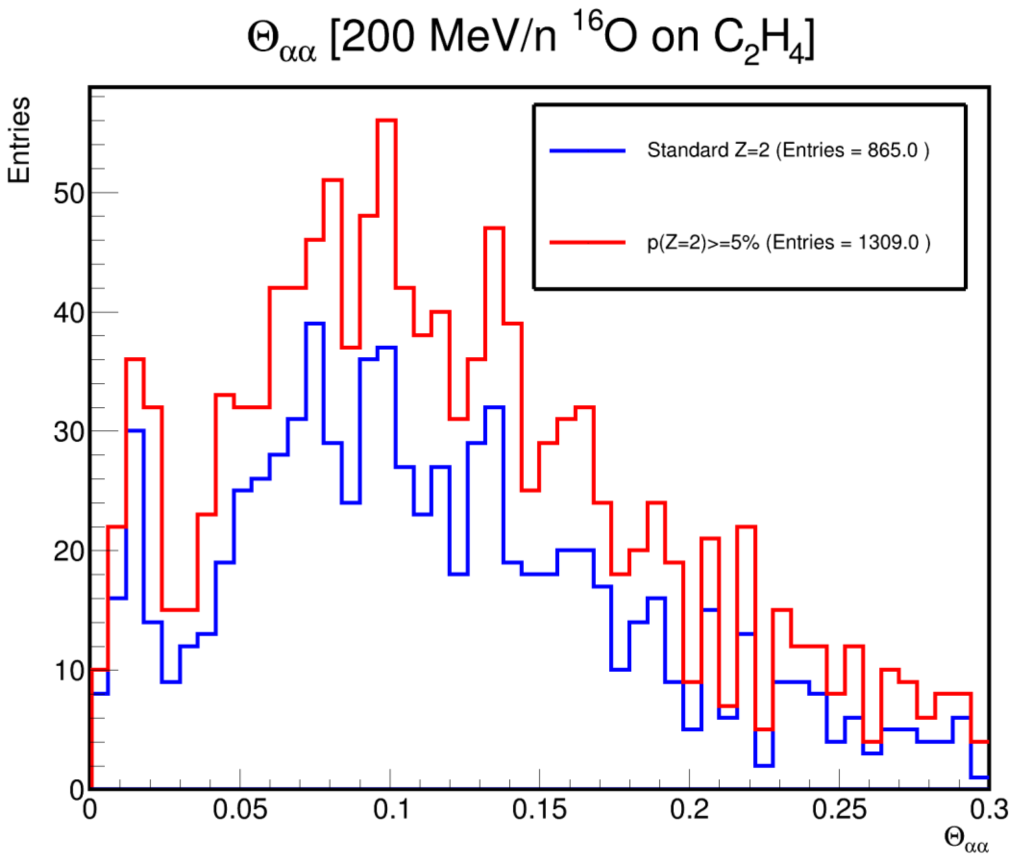
No expected correlation peak at small angles between true $Z_{true} = 2$ and $Z_{true} = 3$
→ consider all tracks that have $\boldsymbol{p(Z = 2) \geq X\%}$

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

Updated Opening Angle Plots in DATA

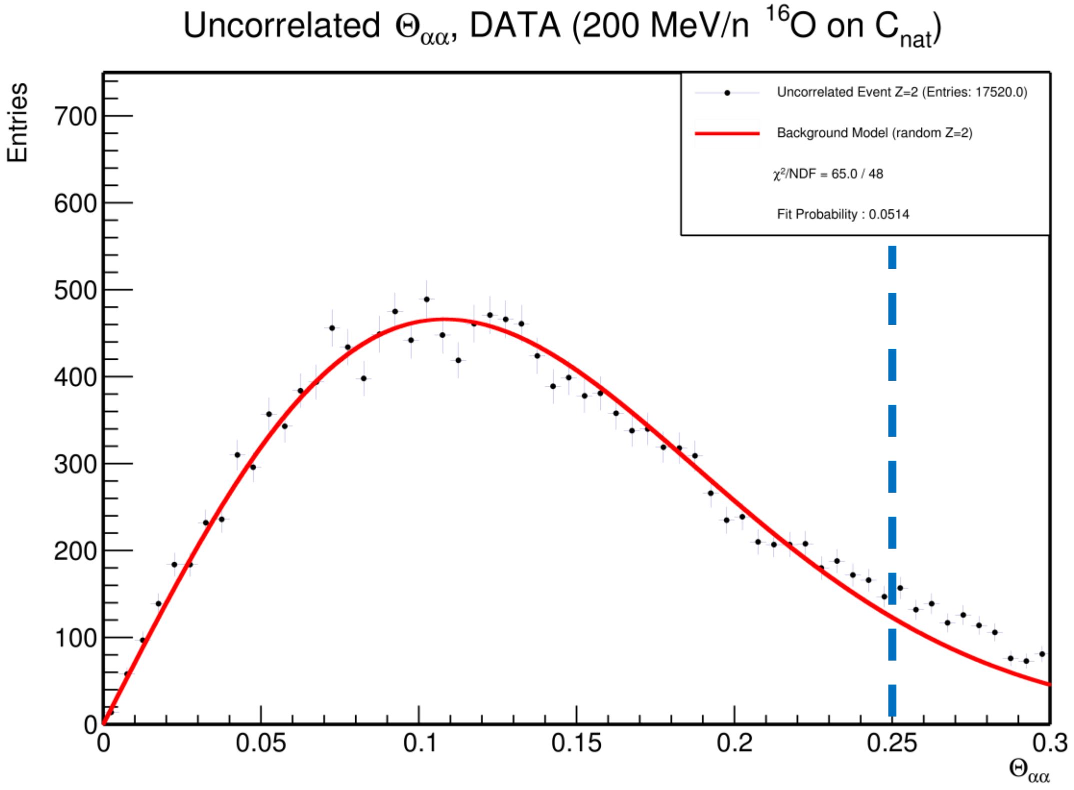
- Following the previous observations, distributions of the opening angles between Z=2 pairs have been updated by also including tracks that satisfy $p(Z=2) \geq 5\%$
- As discussed, both an increase in the signal as well as the background is recorded

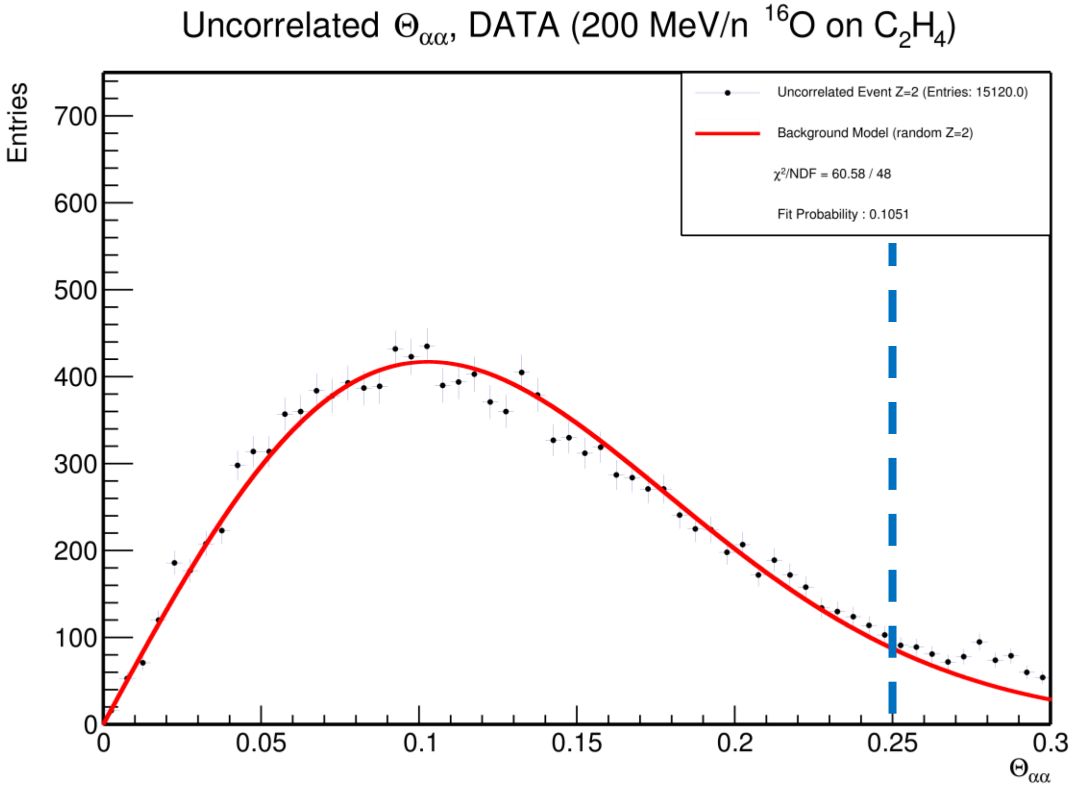




Improved Background Modelling

- To assess whether the increase of signal entries is significant, background subtraction is needed
- To improve the statistics of the background model fit, the opening angles between each track and other 20 random tracks were evaluated (**new**)
- The background model struggles to reproduce data at $\Theta_{\alpha\alpha} > 0.25\, rad$, especially in the dataset with the polyethylene target





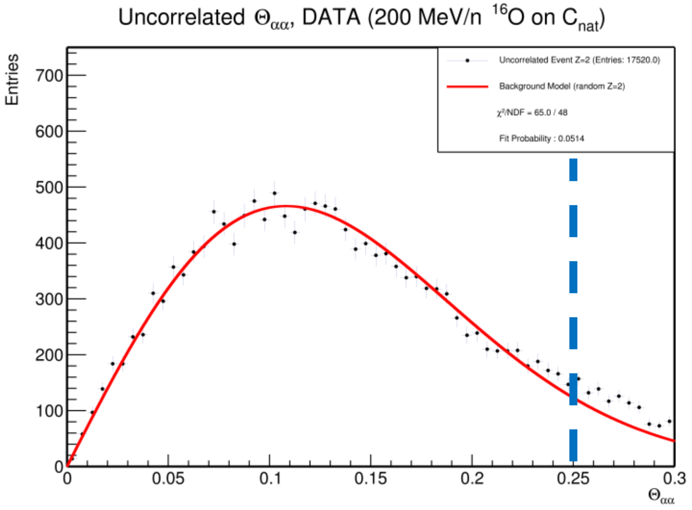
Fit Function: $f(x) = A \cdot xe^{-Bx^2}$

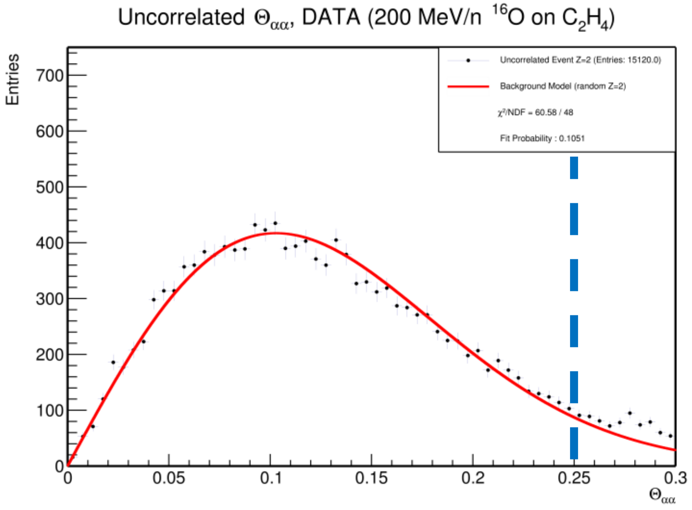
Effect of New Track Selection on Background Model

- The introduction of $Z = 3$ tracks to the analysis worsens the fit quality (signal region is still correctly reproduced)

Standard Z=2 Classification

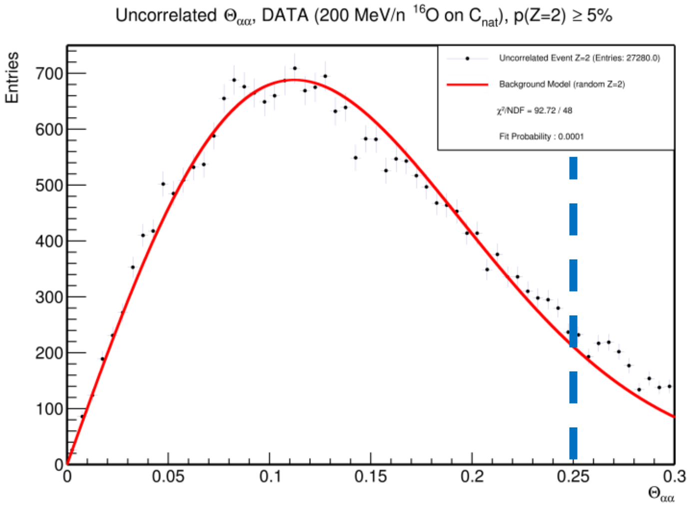
Estimated Background $(C_{nat}) = 22 \pm 5$
Estimated Background $(C_2H_4) = 21 \pm 5$

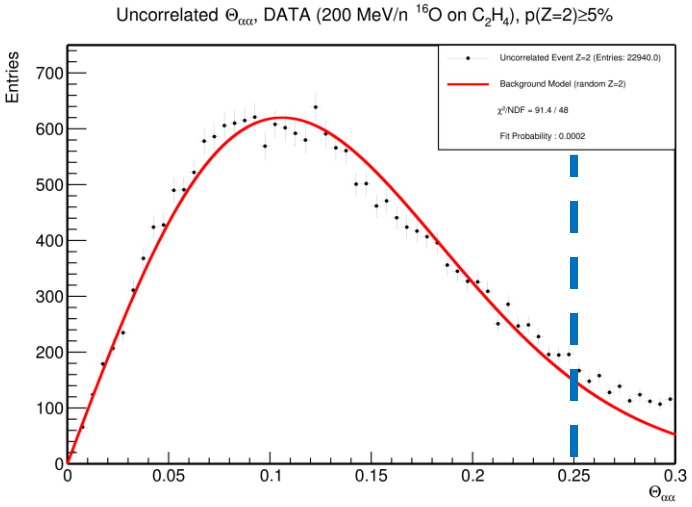




$\boldsymbol{p(Z = 2) \geq 5\%}$

Estimated Background $(C_{nat}) = 31 \pm 6$
Estimated Background $(C_2H_4) = 30 \pm 6$

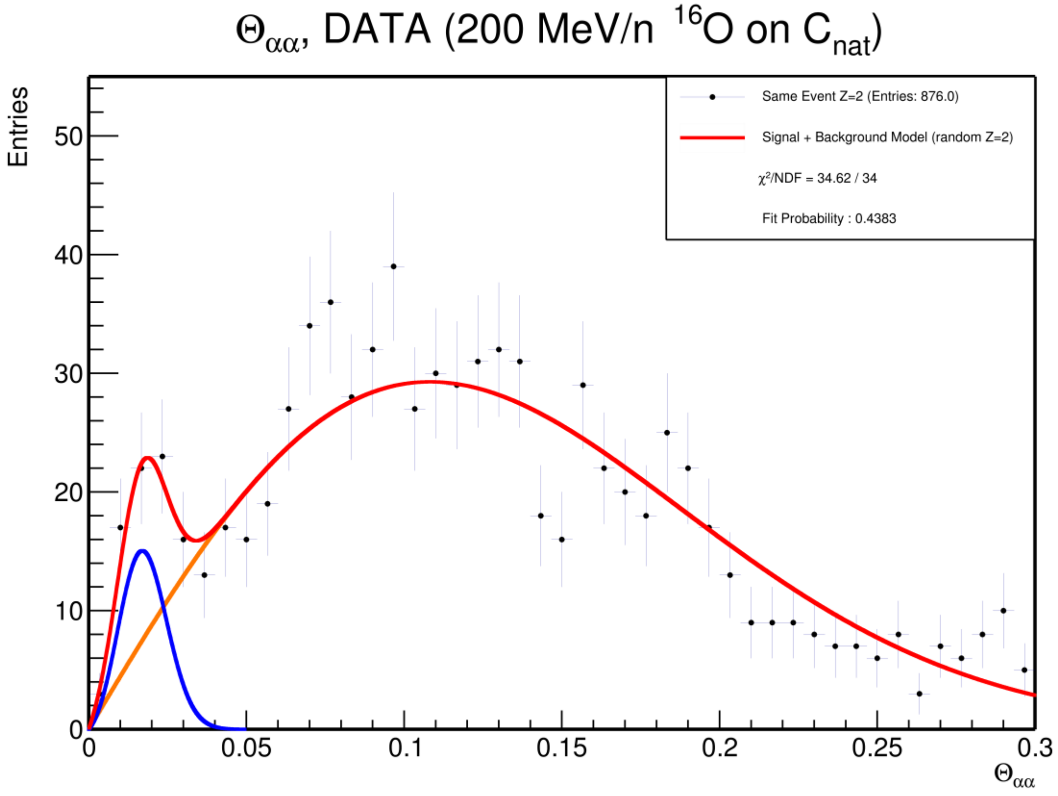




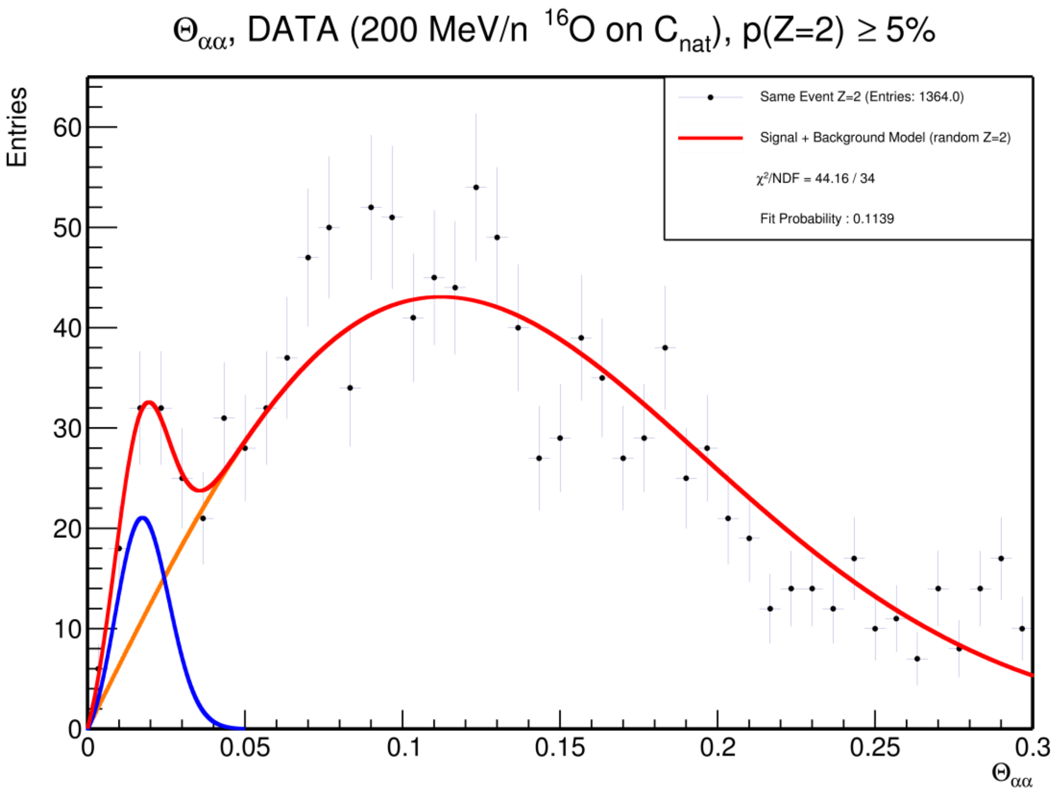
Fit Function: $f(x) = A \cdot xe^{-Bx^2}$

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

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

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

- In order to obtain the final estimate, a fit including both the signal and background model was used
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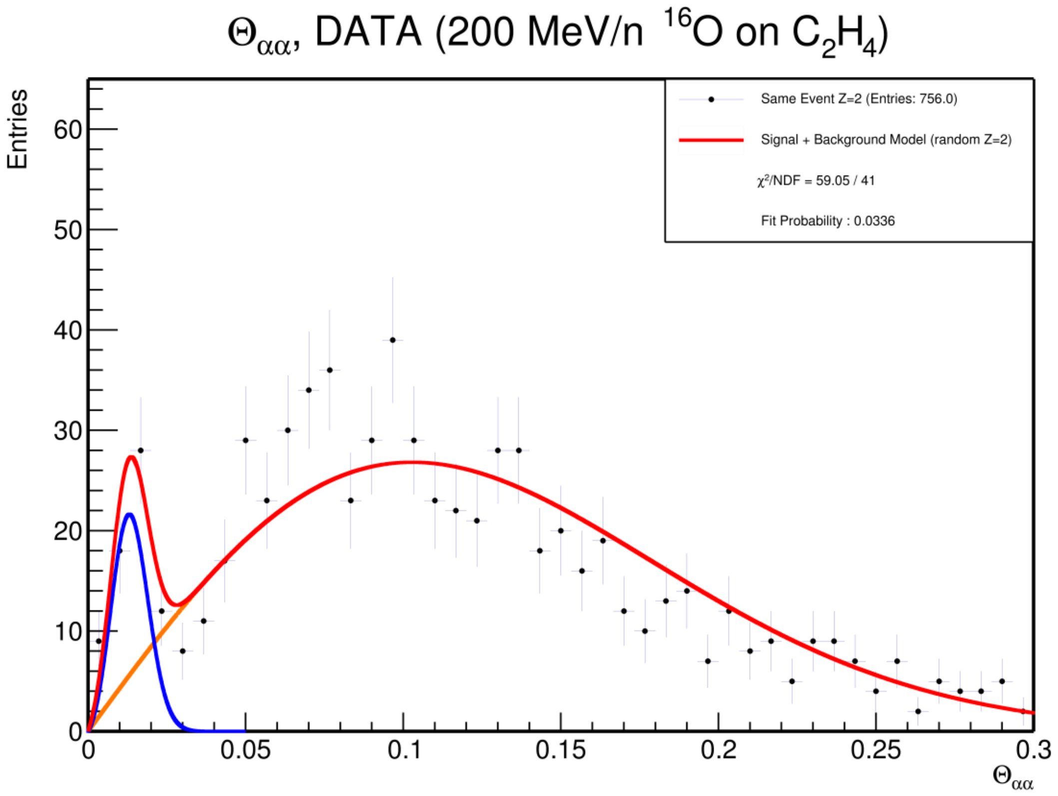
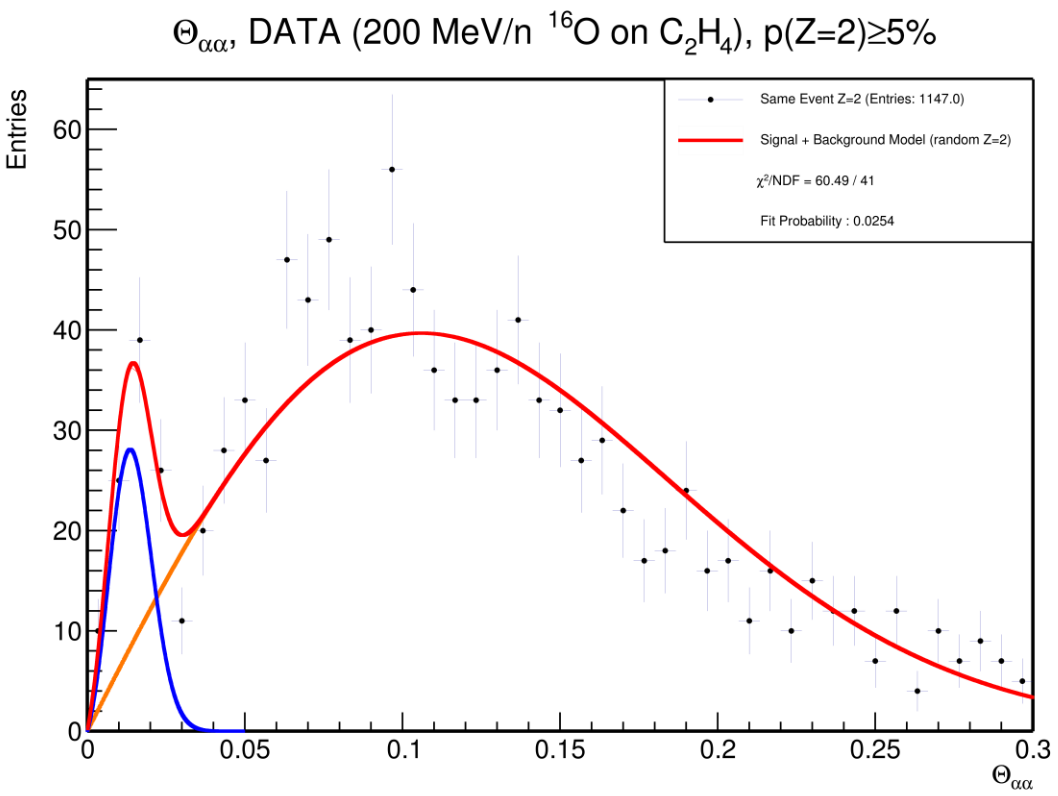


Estimated Signal = 44 ± 9



Estimated Signal = 61 ± 11

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

Conclusions

- Improved background model and signal fitting
  - Larger statistics for background model fit (20 random uncorrelated pairs)
  - Fit of the correlated distribution with fixed background shape and free normalization

- Alternative Track Selection for clustering measurements → improved efficiency
  - Overlap between $Z = 2$ and $Z = 3$ populations in PCA analysis → consider all tracks with a minimum probability of being Z

- Work on-going in reconstructed MC to obtain a final estimate of the reconstruction efficiency

Thank You!