Update on α clustering analysis with nuclear emulsions

A. Alexandrov, T. Asada, V. Boccia, N. D'Ambrosio, A. Di Crescenzo, G. De Lellis, G. Galati, A. Iuliano, A. Lauria, M.C. Montesi, V. Tioukov

Università di Napoli "Federico II", INFN Napoli
Università di Bari "Aldo Moro", INFN Bari
INFN LNGS

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Outline

- Quick recap on alpha clustering measurements with FOOT emulsion data
- Updated Z=2 opening angle plots
  - Contamination from emulsion vertices
  - Uncorrelated Z=2 couples for background estimation
  - Comparisons with combined distributions in True MC, Reconstructed MC and DATA
- Brief discussion on ^{8}Be production cross section on C and C_2H_4
  - Definition of reconstruction efficiency
- Next steps

Introduction

- 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

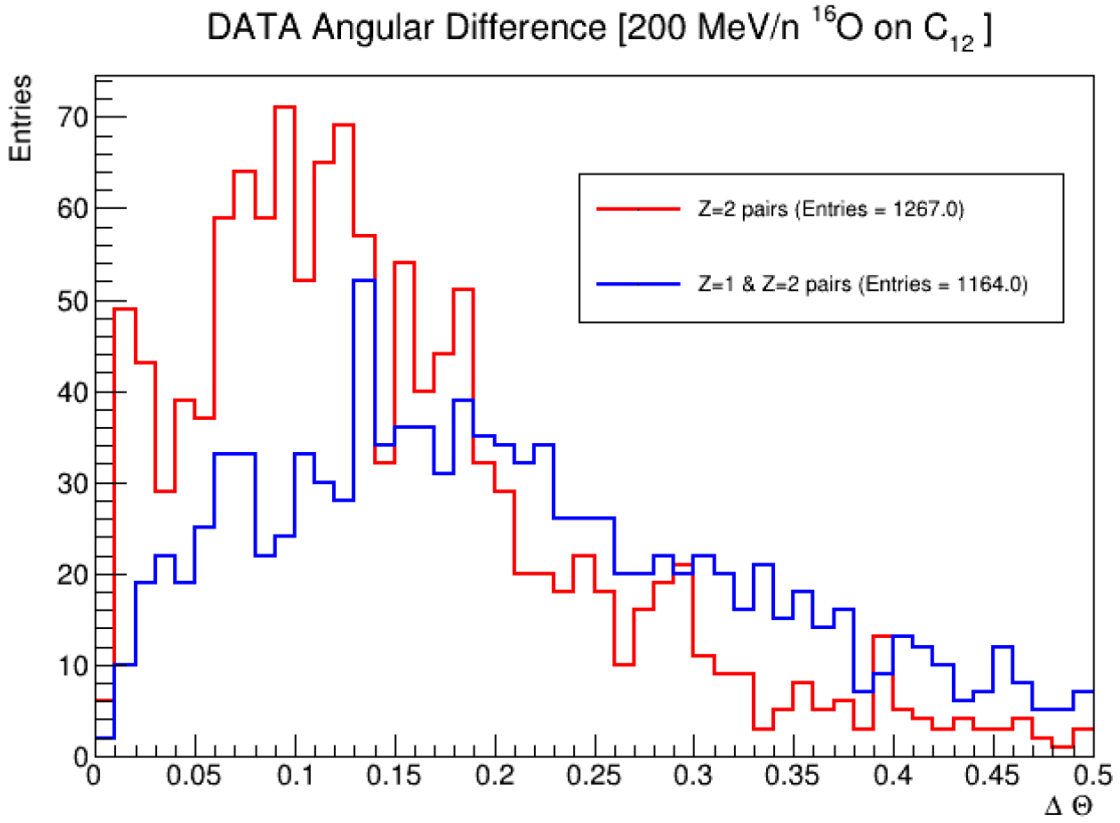
- We are currently analyzing 2019 emulsion data (^{16}O @ $200\ \mathrm{MeV/n}$ on carbon and polyethylene targets) in order to prove the existence of clusters at intermediate energies
  - The analysis focuses on finding correlated α particles couples that reveal the production of ^{8}Be in the fragmentation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

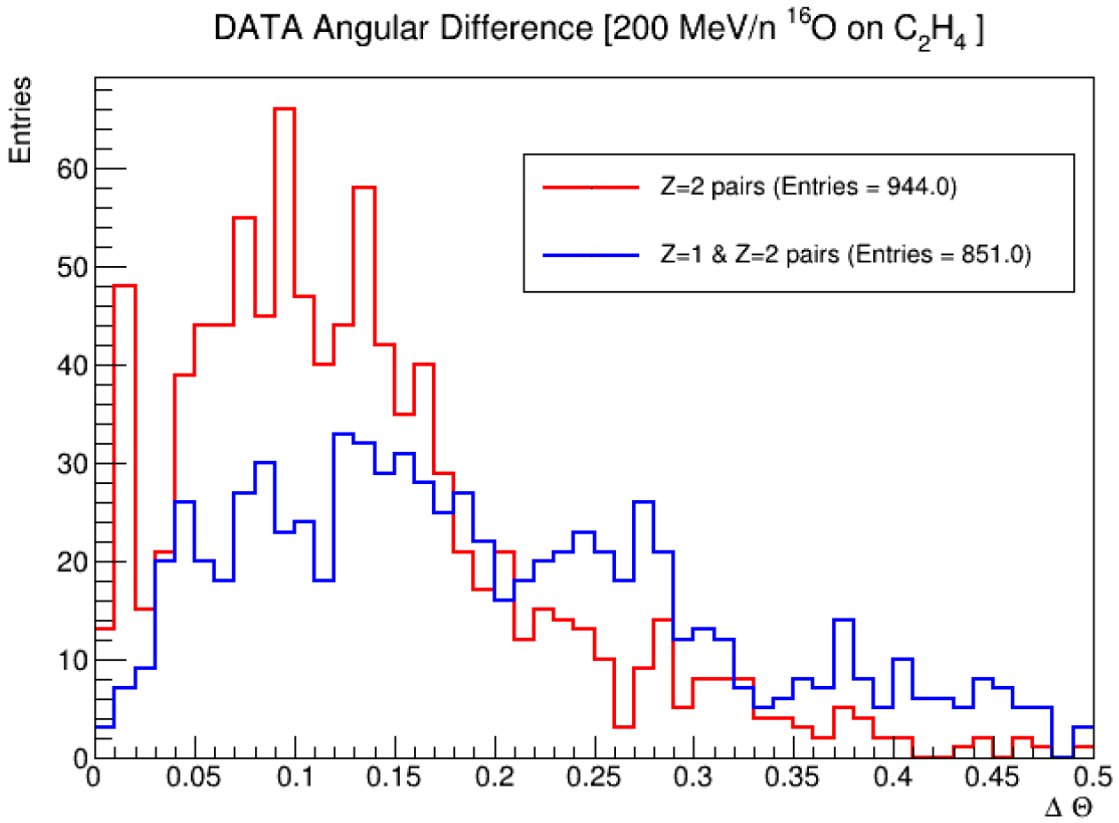
- A much more detailed introduction to α clustering can be found in the following presentations:
  - https://agenda.infn.it/event/37748/contributions/217798/attachments/114168/163750/Presentazione%20GM%20Alice.pdf
  - https://agenda.infn.it/event/35352/contributions/201149/attachments/106123/149798/AlphaClustering.pdf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

Opening angle distributions (DATA)

From the previous FOOT General Meeting (link)

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

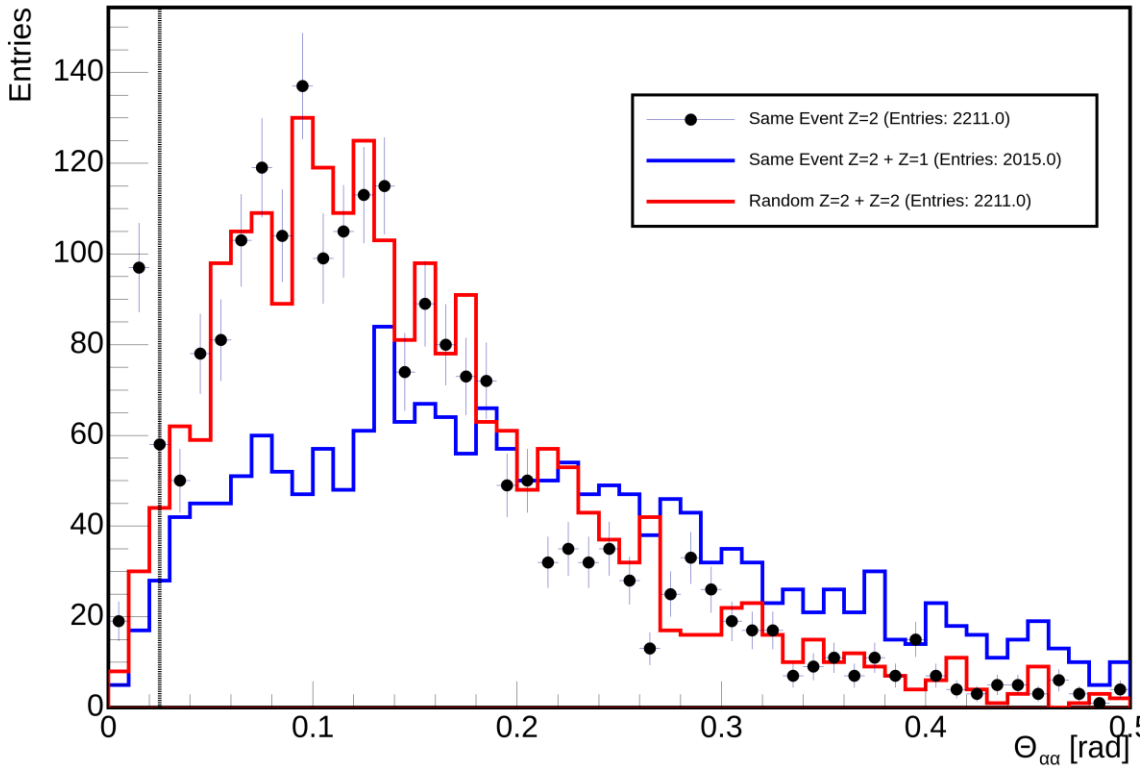




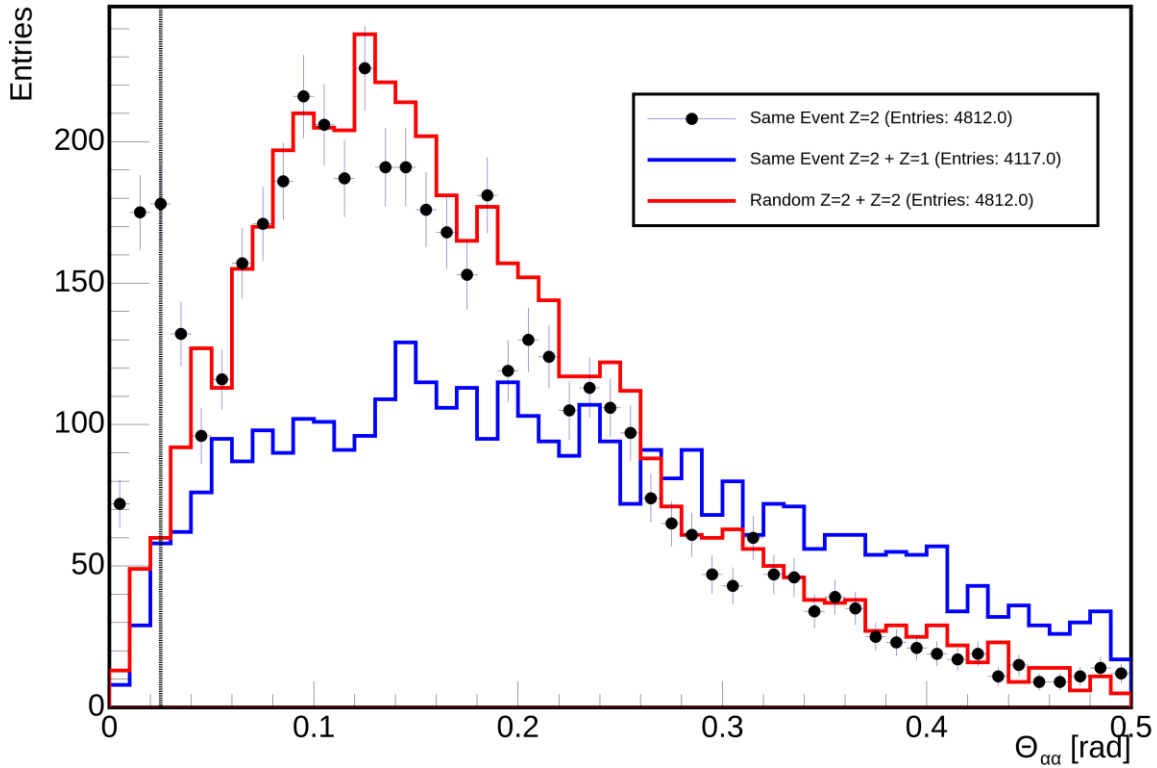
Background Estimation with uncorrelated Z=2 tracks

- Data from GSI1 (Carbon target) and GSI2 (Polyethylene target) from events with at least two Z=2 tracks
- The background is best described by random Z=2 combinations
- The signal region is defined as $\boldsymbol{\Theta_{\alpha\alpha} < 0.025\, rad}$

Combined opening angles distributions (DATA)



Combined opening angles distributions (RECO MC)

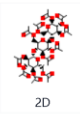


Out of Target Events

- The expected fraction of vertices originating from the emulsions is not negligible
  - Emulsion layers thickness ~ 24% of the total thickness in S1 (1 mm Carbon targets, 0.32 mm emulsions)
  - Emulsion layers thickness ~ 14% of the total thickness in S1 (2 mm C_2H_4 targets, 0.32 mm emulsions)

- The emulsions exposed in 2019 had a TAC plastic support (Oxygen, Carbon and Hydrogen)

Triacetylcellulose

PubChem CID	44263853
Structure	 2D
Chemical Safety	Laboratory Chemical Safety Summary (LCSS) Datasheet
Molecular Formula	$C_{40}H_{54}O_{27}$

- The estimated fraction of vertices inside the emulsion films in True MC is:
  - GSI1: Found $\frac{80}{349} \simeq 23 \pm 4\%$ of the vertices in the emulsion films
  - GSI2: Found $\frac{76}{462} \simeq 16 \pm 3\%$ of the vertices in the emulsion films

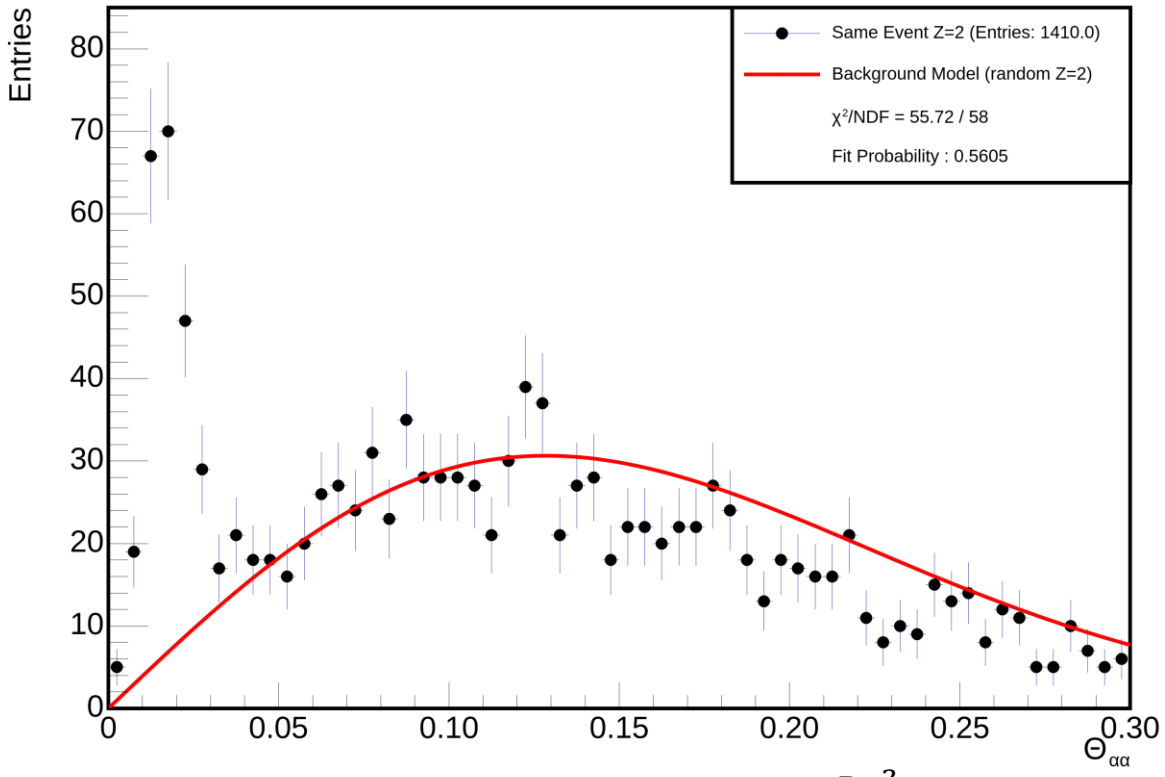
- The estimated fraction of vertices inside the emulsion films in DATA is:
  - GSI1: Found $\frac{11}{79} \simeq 14 \pm 6\%$ of the vertices in the emulsion films
  - GSI2: Found $\frac{6}{72} \simeq 8 \pm 4\%$ of the vertices in the emulsion films

- <u>All the vertices in the emulsions have been removed from the following plots</u>

Background Evaluation in True MC

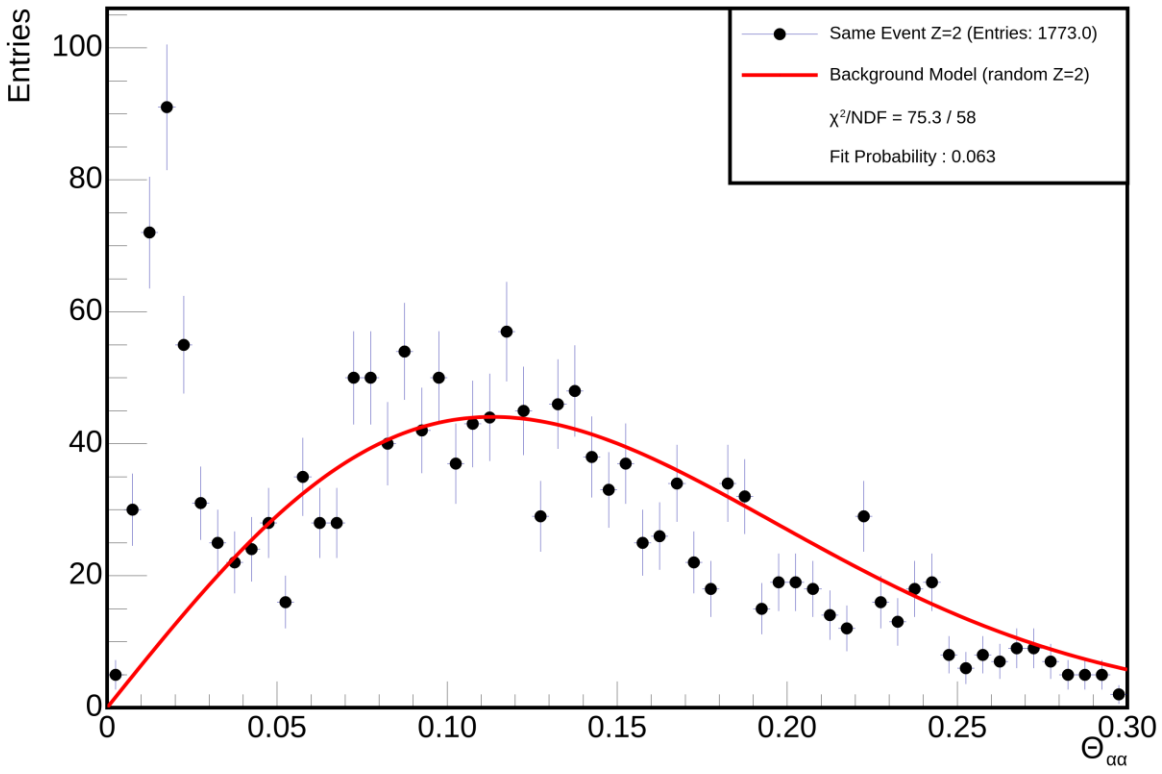
- No info about decay channel in current MC file → signal estimation from opening angles
- The combinatorial background should be taken into account in MC true as well
- Fitted the combined background distribution (random Z=2 couples) with a smooth function

MC True (GSI1) $\Theta_{\alpha\alpha}$ Distributions



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

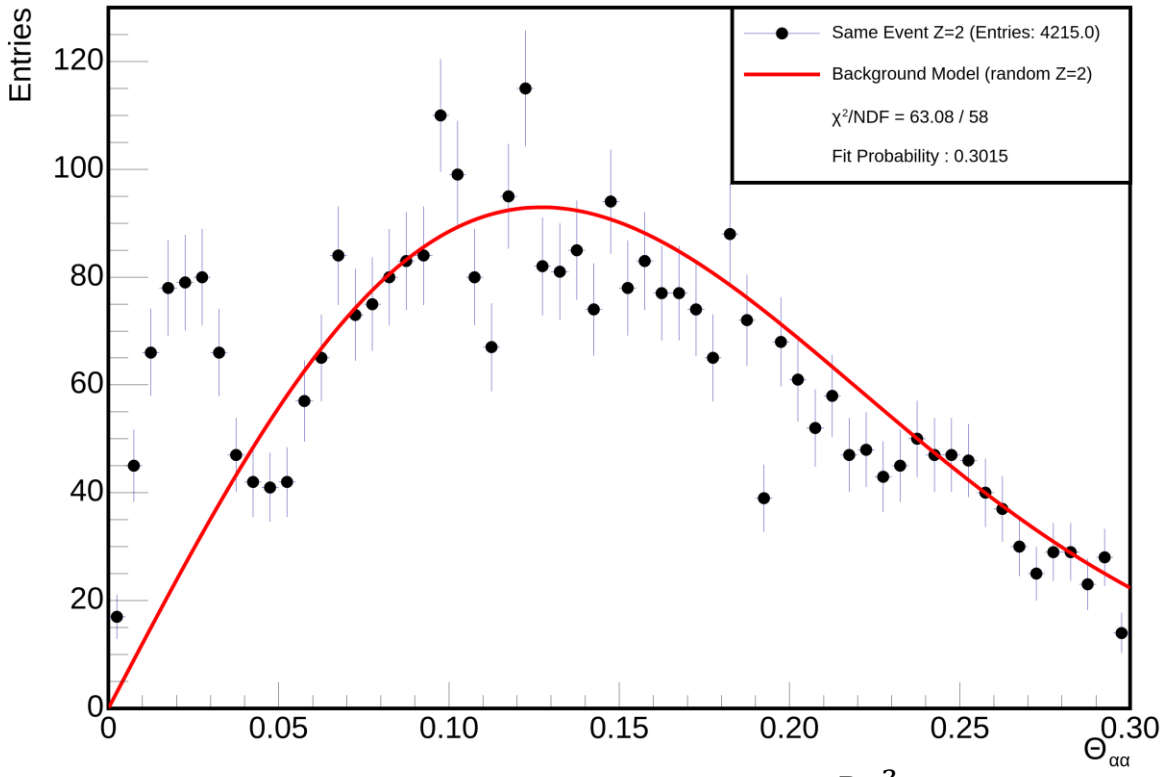
MC True (GSI2) $\Theta_{\alpha\alpha}$ Distributions



Background Evaluation in RECO MC (1)

- Fitted the combined background distribution (random Z=2 couples) with a smooth function in Reconstructed MC
- The estimated number of background events can be evaluated as the integral of the fit function
- The fit results on the combined distributions were compared to the fits performed separately on GSI1 and GSI2

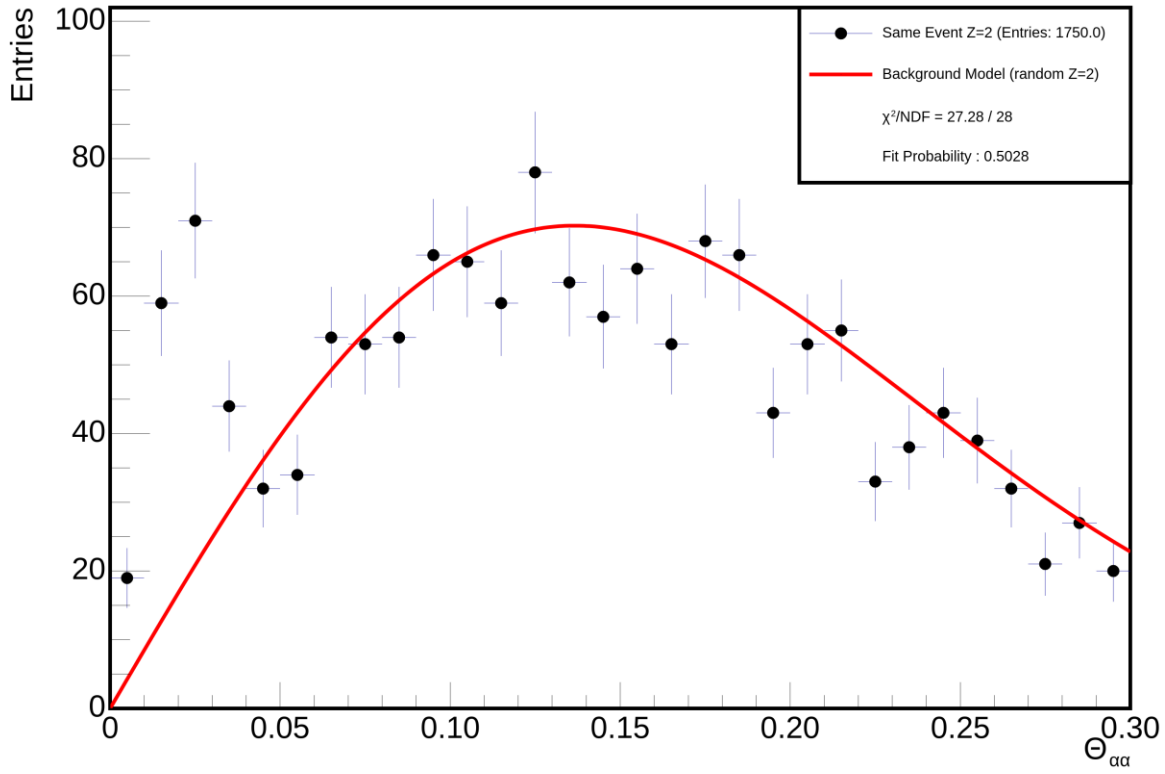
RECO MC Combined $\Theta_{\alpha\alpha}$ Distributions



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

$A = 1205 \pm 31, B = 30.9 \pm 0.8$

RECO MC (GSI1) $\Theta_{\alpha\alpha}$ Distributions



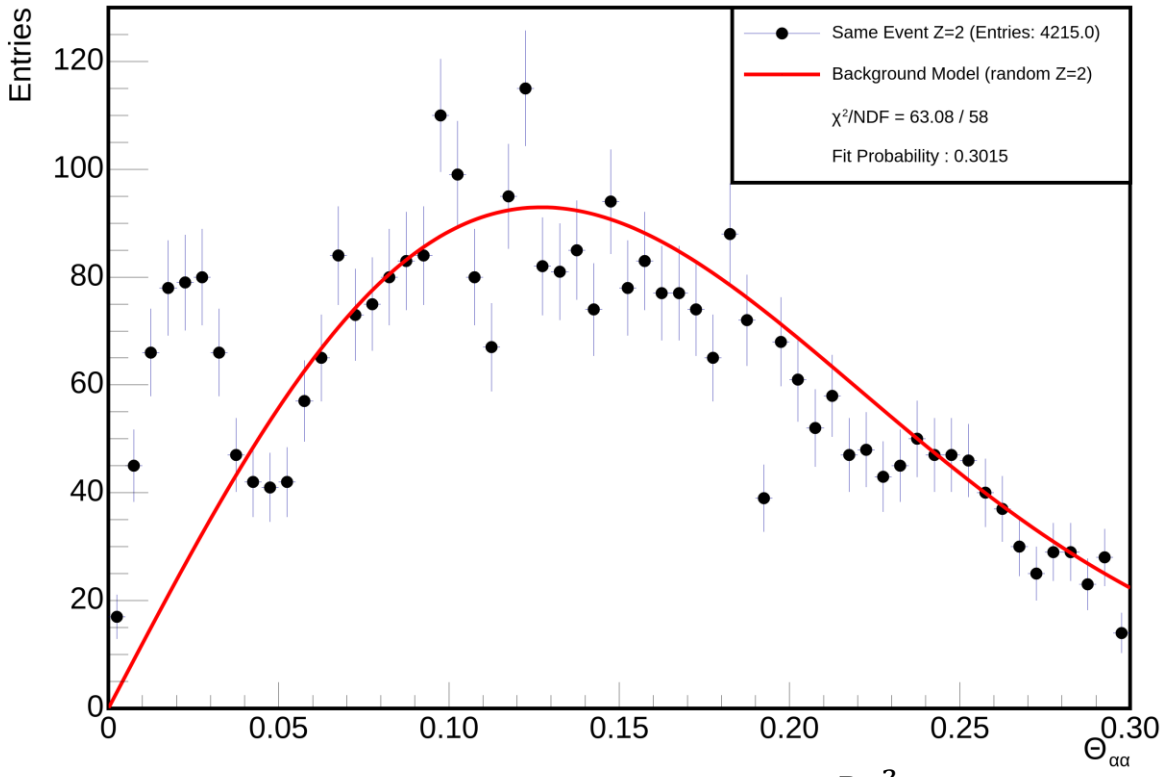
The parameters refer to a fit with the same binning

$A = 848 \pm 36, B = 26.8 \pm 1.2$

Background Evaluation in RECO MC (2)

- Fitted the combined background distribution (random Z=2 couples) with a smooth function in Reconstructed MC
- The estimated number of background events can be evaluated as the integral of the fit function
- The fit results on the combined distributions were compared to the fits performed separately on GSI1 and GSI2

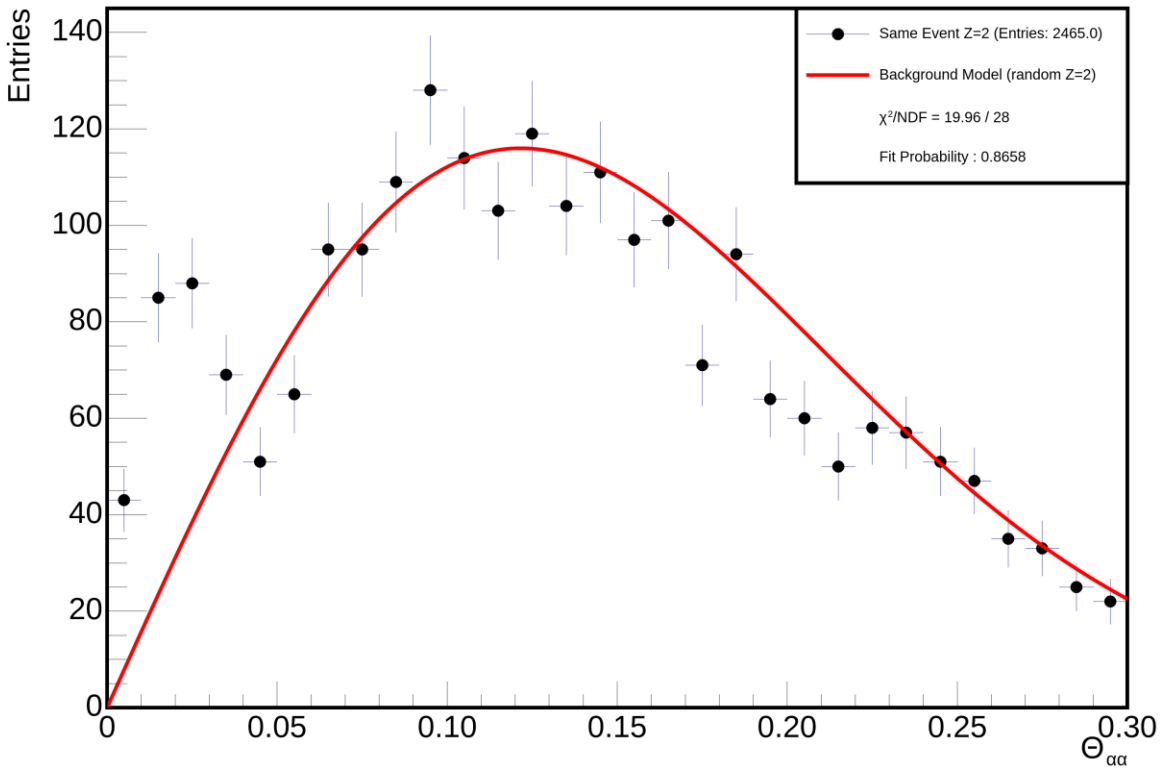
RECO MC Combined $\Theta_{\alpha\alpha}$ Distributions



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

$A = 1205 \pm 31, B = 30.9 \pm 0.8$

RECO MC (GSI2) $\Theta_{\alpha\alpha}$ Distributions



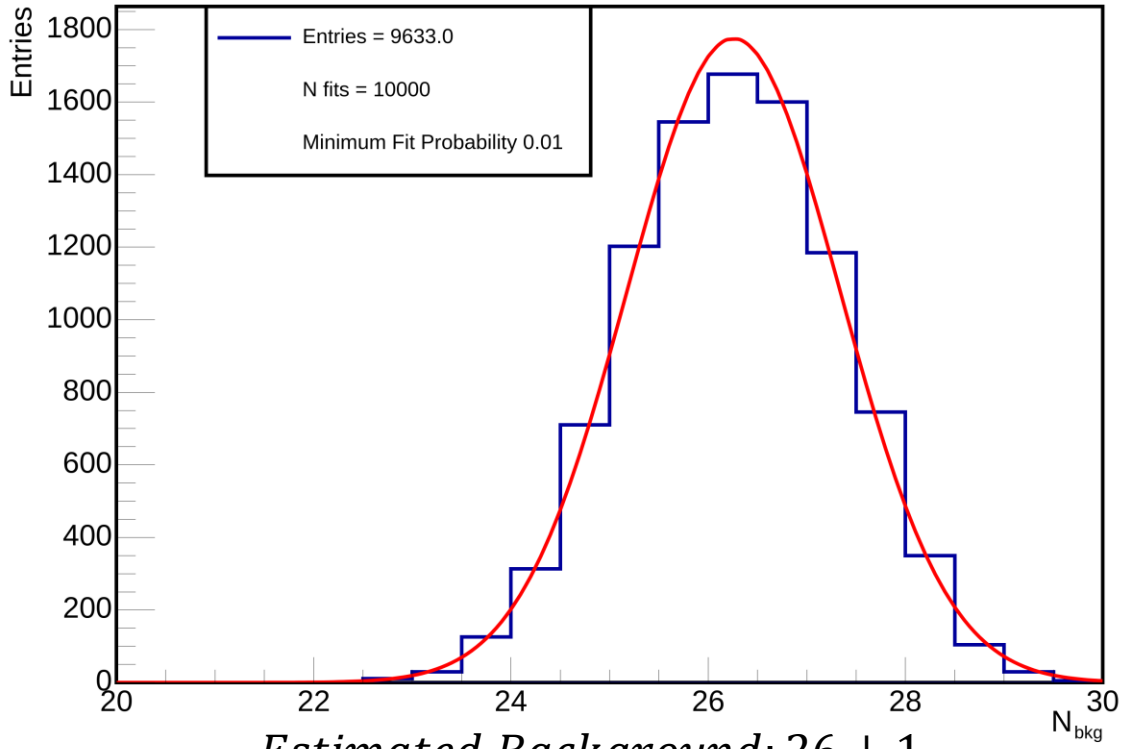
The parameters refer to a fit with the same binning

$A = 1572 \pm 52, B = 33.8 \pm 1.0$

Background Evaluation in RECO MC (3)

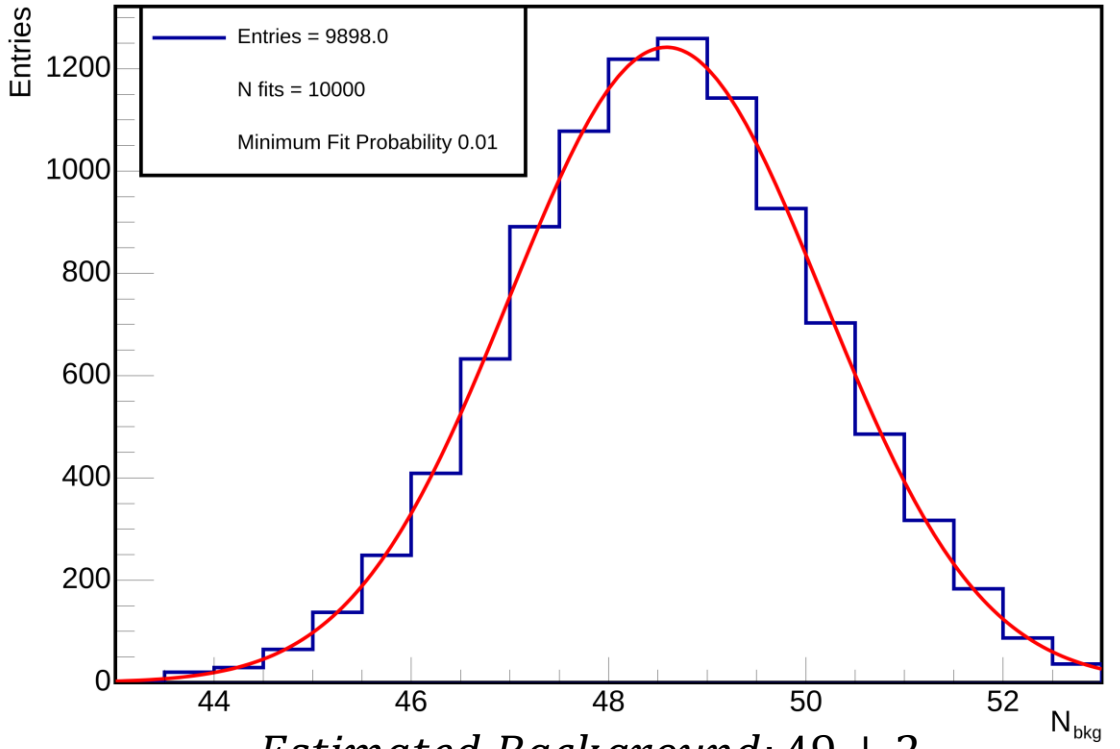
- The background was estimated by integrating the fit functions in the interval up to 0.025 rad
- The error was measured as follows:
  - Sample A,B within 1 σ of their original values and fix their values in the fit
  - Evaluate the integral again only using fits with probabilities greater than 0.01 and take the standard deviation

Estimated Background Counts (MC RECO GSI1)



$Estimated\ Background: 26 \pm 1$

Estimated Background Counts (MC RECO GSI2)

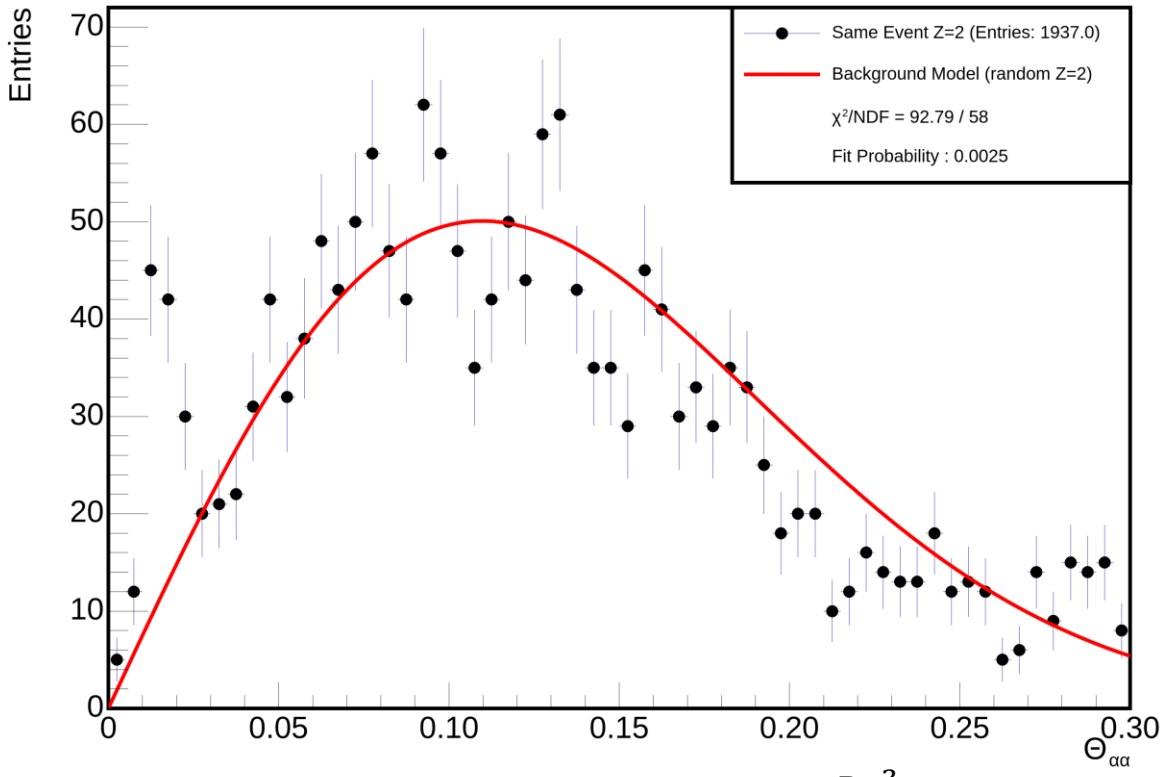


$Estimated\ Background: 49 \pm 2$

Background Evaluation in DATA (1)

- Fitted the combined background distribution (random Z=2 couples) with a smooth function in DATA
- The estimated number of background events can be evaluated as the integral of the fit function
- The fit results on the combined distributions were compared to the fits performed separately on GSI1 and GSI2

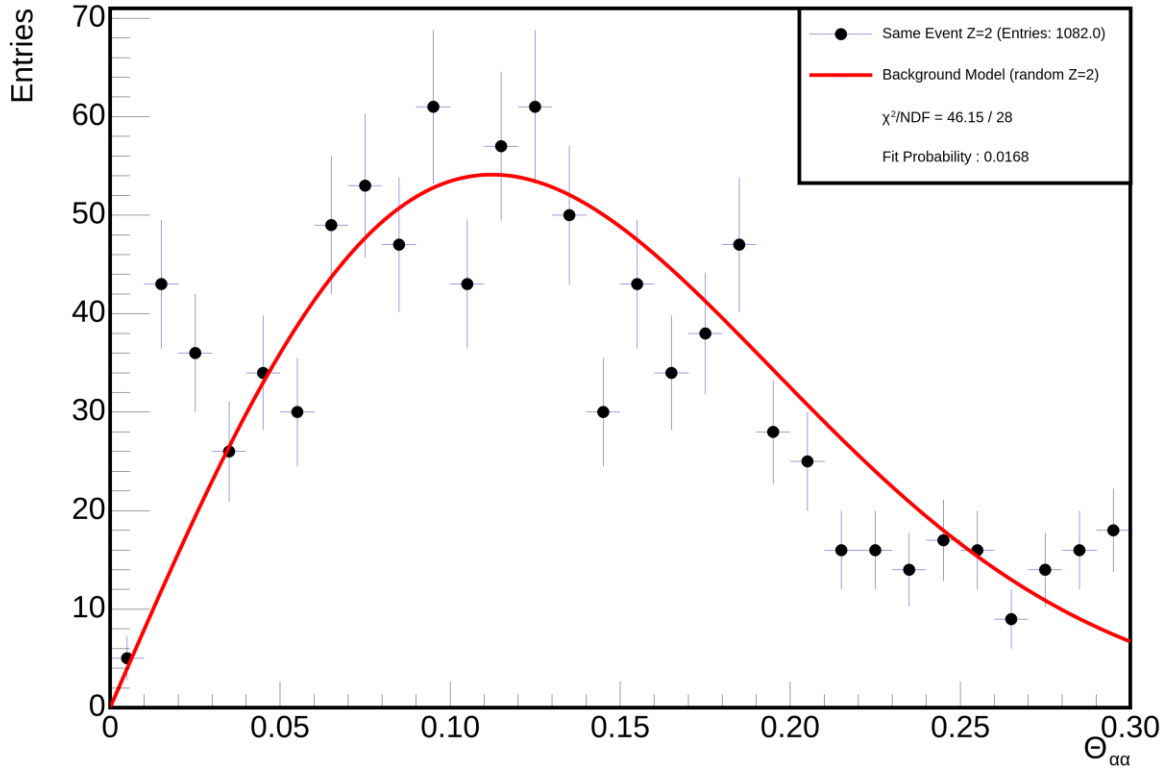
DATA Combined $\Theta_{\alpha\alpha}$ Distributions



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

$A = 752 \pm 27, B = 41.5 \pm 1.2$

DATA (GSI1) $\Theta_{\alpha\alpha}$ Distributions



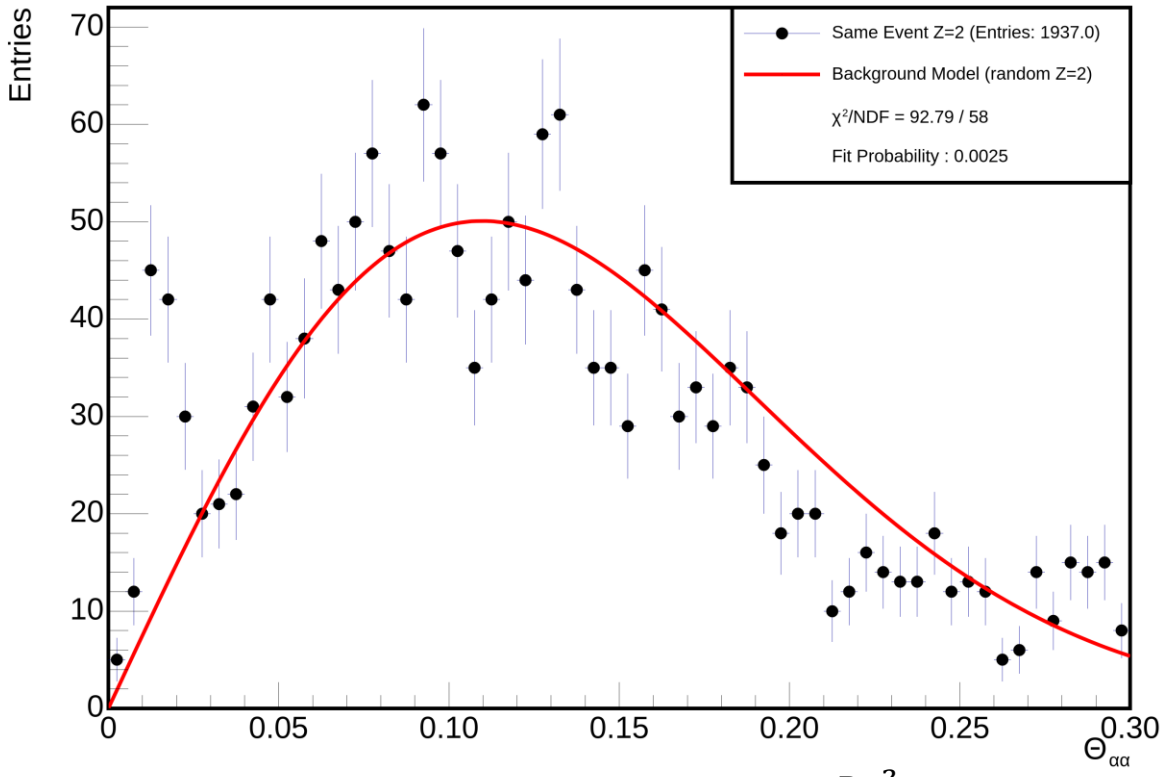
$Estimated\ Background: 24 \pm 1$

$A = 848 \pm 36, B = 39.7 \pm 1.6$

Background Evaluation in DATA (2)

- Fitted the combined background distribution (random Z=2 couples) with a smooth function in DATA
- The estimated number of background events can be evaluated as the integral of the fit function
- The fit results on the combined distributions were compared to the fits performed separately on GSI1 and GSI2

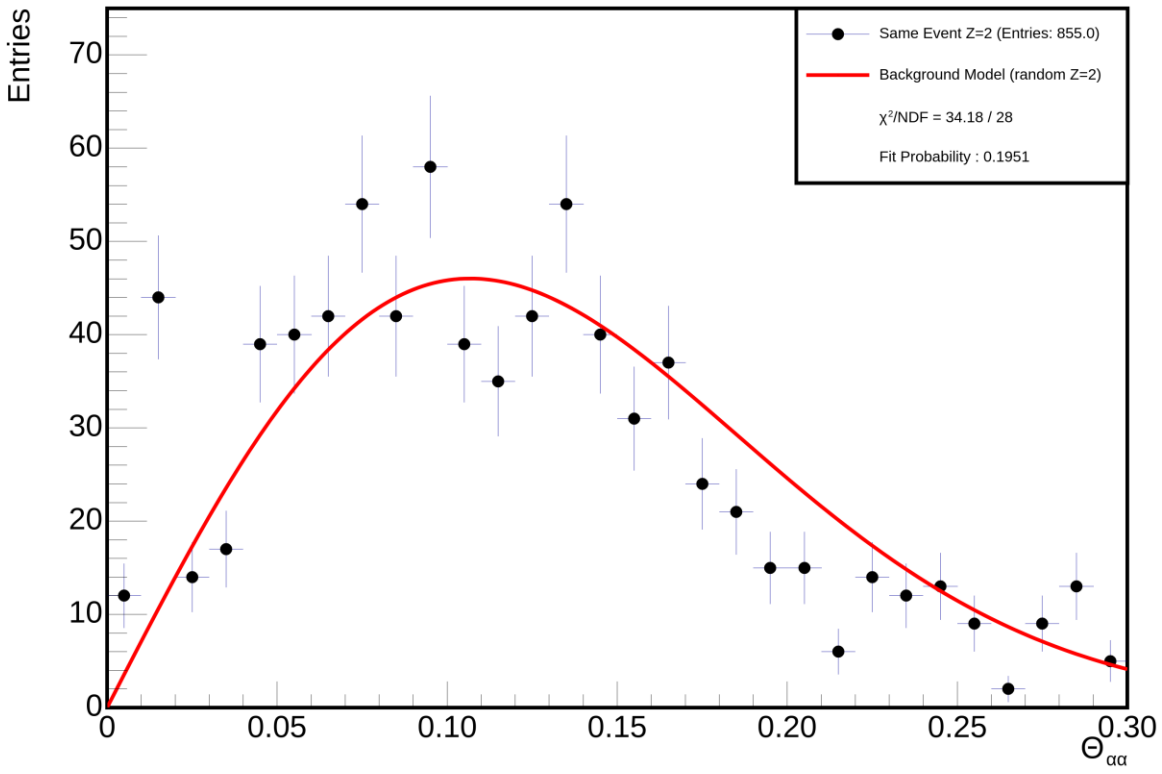
DATA Combined $\Theta_{\alpha\alpha}$ Distributions



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

$A = 752 \pm 27, B = 41.5 \pm 1.2$

DATA (GSI2) $\Theta_{\alpha\alpha}$ Distributions



$Estimated\ Background: 22 \pm 1$

$A = 710 \pm 38, B = 43.8 \pm 1.9$

^{8}Be Production Cross Section: Reconstruction Efficiency

- After background subtraction, it is possible to estimate the ^{8}Be production cross section on carbon and polyethylene

$$\sigma^{\,^{8}Be_{g.s.}} = \frac{N_{Be}}{N_B \cdot \rho \cdot d \cdot \frac{N_A}{A} \cdot \varepsilon_{reco} \cdot \varepsilon_{cuts}}$$

$N_{Be} \rightarrow$ Number of ^{8}Be

$N_B \rightarrow$ Number of primaries

$\rho, d, A \rightarrow$ Target features

- The measurement of the reconstruction efficiency is based on the comparison between RECO MC and True MC

$$\varepsilon_{reco} = \frac{Number\ of\ \Theta_{\alpha\alpha} < CUT\ in\ MC\ RECO}{Visible\ Number\ of\ \Theta_{\alpha\alpha} < CUT\ in\ MC\ True}$$

Not bounded to <=1! However, purity of the couples is estimated to be >95% in Reco MC

- Cuts used in True MC at this time: primary α particles produced in S1, momentum > 0.1 GeV/c, track length > 2 base-tracks, track reaching at least plate 39 for charge ID

$$\varepsilon_{cuts} = \frac{Visible\ of\ \Theta_{\alpha\alpha} < CUT\ in\ MC\ True}{Total\ Number\ of\ \Theta_{\alpha\alpha} < CUT\ in\ MC\ True}$$

Can only be evaluated with MC

^{8}Be Production Cross Section: Preliminary Results

- After background subtraction, it is possible to estimate the ^{8}Be production cross section on carbon and polyethylene

$$\sigma_{vis}^{^{8}Be_{g.s.}} = \frac{N_{Be}}{N_B \cdot \rho \cdot d \cdot \frac{N_A}{A} \cdot \varepsilon_{reco}}$$

$N_{Be} \rightarrow$ Number of ^{8}Be

$N_B \rightarrow$ Number of primaries

$\rho, d, A \rightarrow$ Target features

- These results were updated with the new background subtraction method in MC true as well

PRELIMINARY!

$$\varepsilon_{reco} = \frac{Number\ of\ \Theta_{\alpha\alpha} < CUT\ in\ MC\ RECO}{Visible\ Number\ of\ \Theta_{\alpha\alpha} < CUT\ in\ MC\ True}$$

$$\varepsilon_{reco}^{GSI1} = \frac{N_{\alpha\alpha}^{RECOMC}}{N_{\alpha\alpha}^{MCTrue}} = \frac{84 \pm 14}{188 \pm 14} = 45 \pm 10\%$$

$$\boxed{\sigma_{vis}^{^{8}Be_{g.s.}}(C) = 17 \pm 7\ mb}$$

$$\sigma_{vis,MC\ true}^{^{8}Be_{g.s.}}(C) = 33 \pm 2\ mb$$

$$Ratio\ to\ MC\ True = 0{,}51 \pm 0{,}26$$

$$\varepsilon_{reco}^{GSI2} = \frac{N_{\alpha\alpha}^{RECOMC}}{N_{\alpha\alpha}^{MCTrue}} = \frac{128 \pm 13}{213 \pm 16} = 60 \pm 12\%$$

$$\boxed{\sigma_{vis}^{^{8}Be_{g.s.}}(C_2H_4) = 36 \pm 15\ mb}$$

$$\sigma_{vis,MC\ true}^{^{8}Be_{g.s.}}(C_2H_4) = 101 \pm 7\ mb$$

$$Ratio\ to\ MC\ True = 0{,}35 \pm 0{,}17$$

Conclusions

- Improved background modelling by using random Z=2 couples in MC and DATA
  - Comparison of the fit functions shapes with the combined distributions
- Excluded the contribution from out of target events (only emulsion vertices)
- First estimates of the ^{8}Be production cross section
- Next steps
  - Study of the reconstruction efficiency
  - Charge ID systematic error in DATA