Alpha Clustering with Nuclear Emulsions

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Outline

- Previous Alpha Clustering Measurements with Emulsion Cloud Chambers (ECCs)

- Structure of FOOT ECCs

- Available datasets
  - 200 MeV/n ^{16}O on C_{12} (GSI1, 19375 primaries)
  - 200 MeV/n ^{16}O on C_2H_4 (GSI2, 20000 primaries)

- Multiplicity of Z=2 tracks per event

- Opening angle distributions among Z=2 tracks from the same event
  - Background estimation

- Future Steps

Previous Alpha Clustering Measurement with ECC (1)

- The previous alpha clustering measurement by our group was performed in 2011

- The ECC consisted of 73 units containing three emulsions interleaved with lexan plates
  - Two different thermal treatments were applied (R1, R2)

- The detector was exposed to 400 MeV/n Carbon ions with an estimated flux of 1.000 ions/cm^2

- A total of 2394 carbon interactions were reconstructed

- These interactions were used to measure the charge-changing cross section ($\Delta z = 1$ up to $\Delta z = 4$)

- The ^{8}Be production cross section was also measured

Measurement of the fragmentation of Carbon nuclei used in hadron-therapy

G. De Lellis [a,b,*], S. Buontempo [b], F. Di Capua [b], A. Di Crescenzo [a,b], P. Migliozzi [b], Y. Petukhov [a,1], C. Pistillo [a,2], A. Russo [b], P. Strolin [a,b], V. Tioukov [b], M. Durante [c,d], Y. Furusawa [e], T. Toshito [e], N. Yasuda [f], A. Ariga [g,2], N. Naganawa [g]
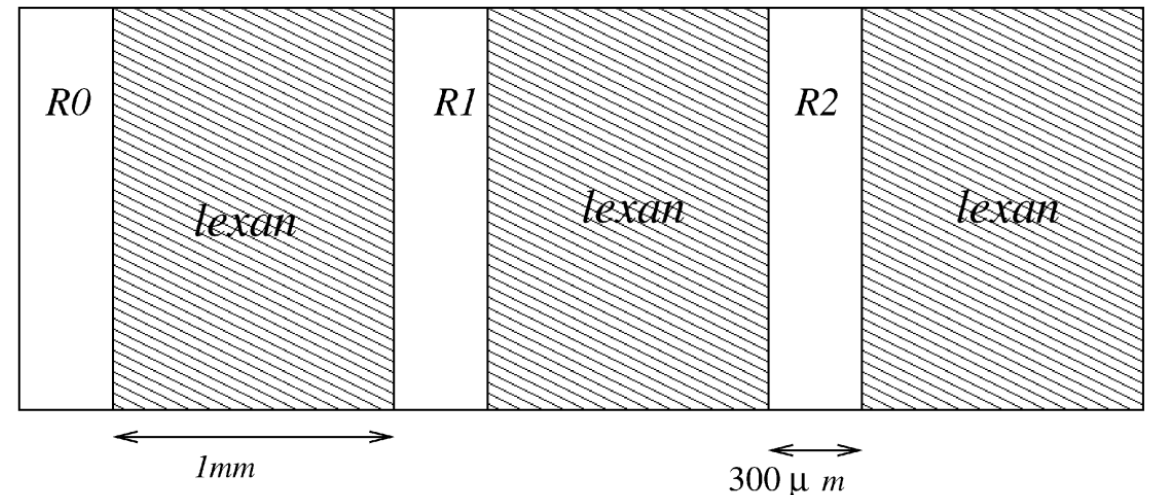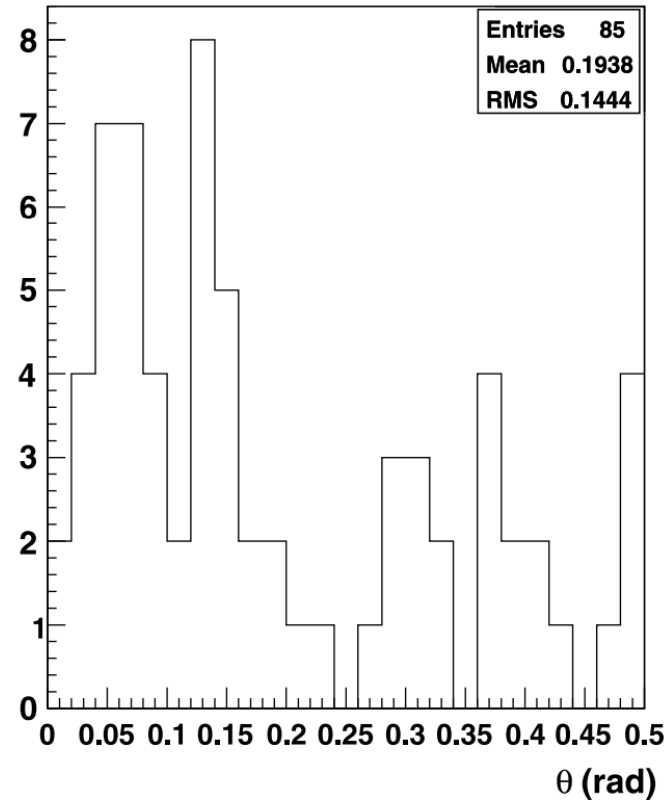
Previous Alpha Clustering Measurement with ECC (2)

- The study of the opening angles between pairs of Helium tracks enabled to find a correlation peak below 20 mrad

- By subtracting the background estimated with the opening angle distribution of H-Helium pairs, an excess of 25 ± 5 events was recorded

**Opening angle between He-He pairs**
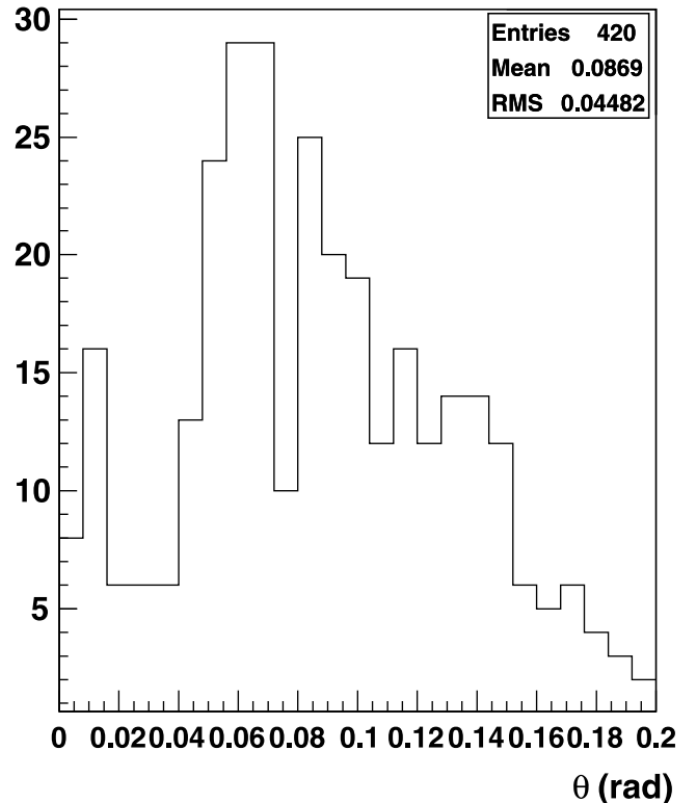
Opening angle between H-He pairs

Structure of the FOOT Emulsion Cloud Chambers

- Each ECC is composed of three sections, designed for three purposes: vertexing, charge identification and momentum measurement

- The following analysis focuses on the first two sections (i.e. vertexing + charge identification)

- Tracking is performed separately for each section and in order to form a track at least two segments must be found

- In order to measure the charge of a track, it must reach the second section

- Minimum track length: 1 layer of passive material + 2 emulsion films in Section 1 + 2 emulsion films in Section 2
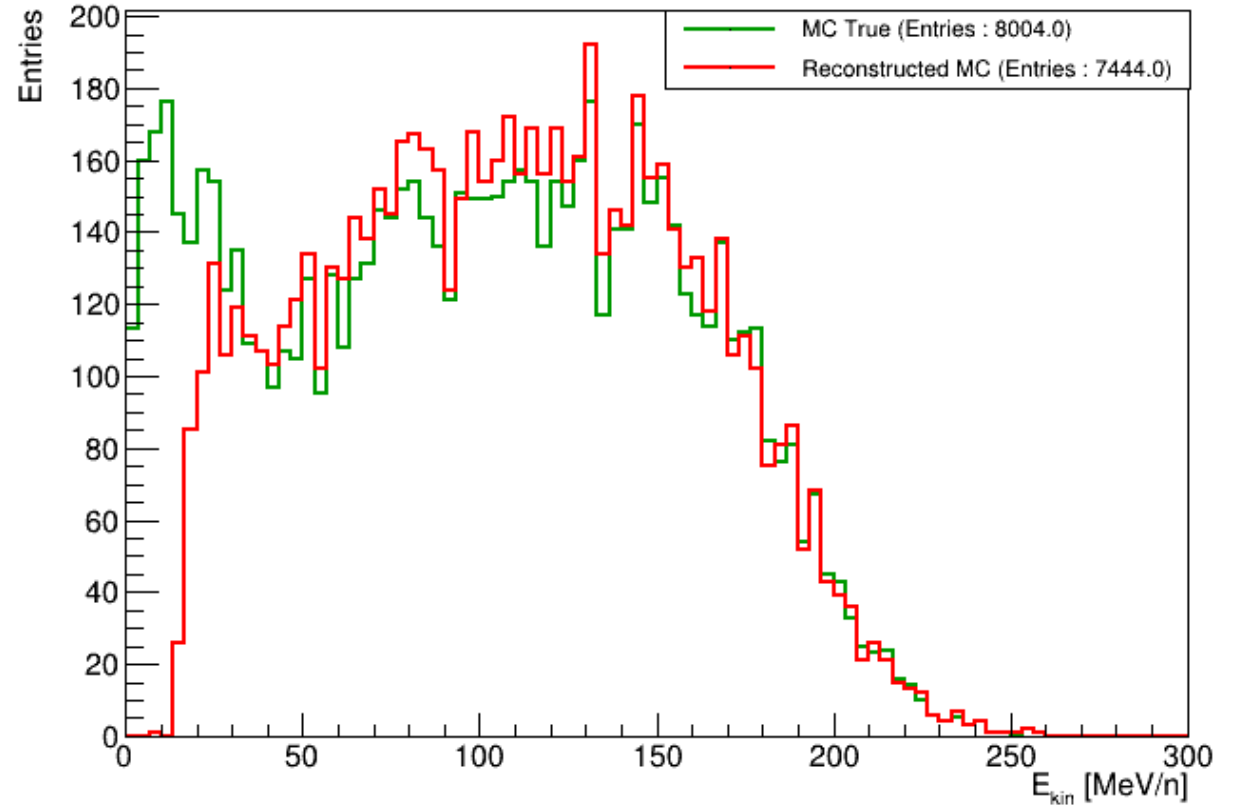 - At 50 MeV the CSDA range of an alpha particle in graphite is ~ 1 mm
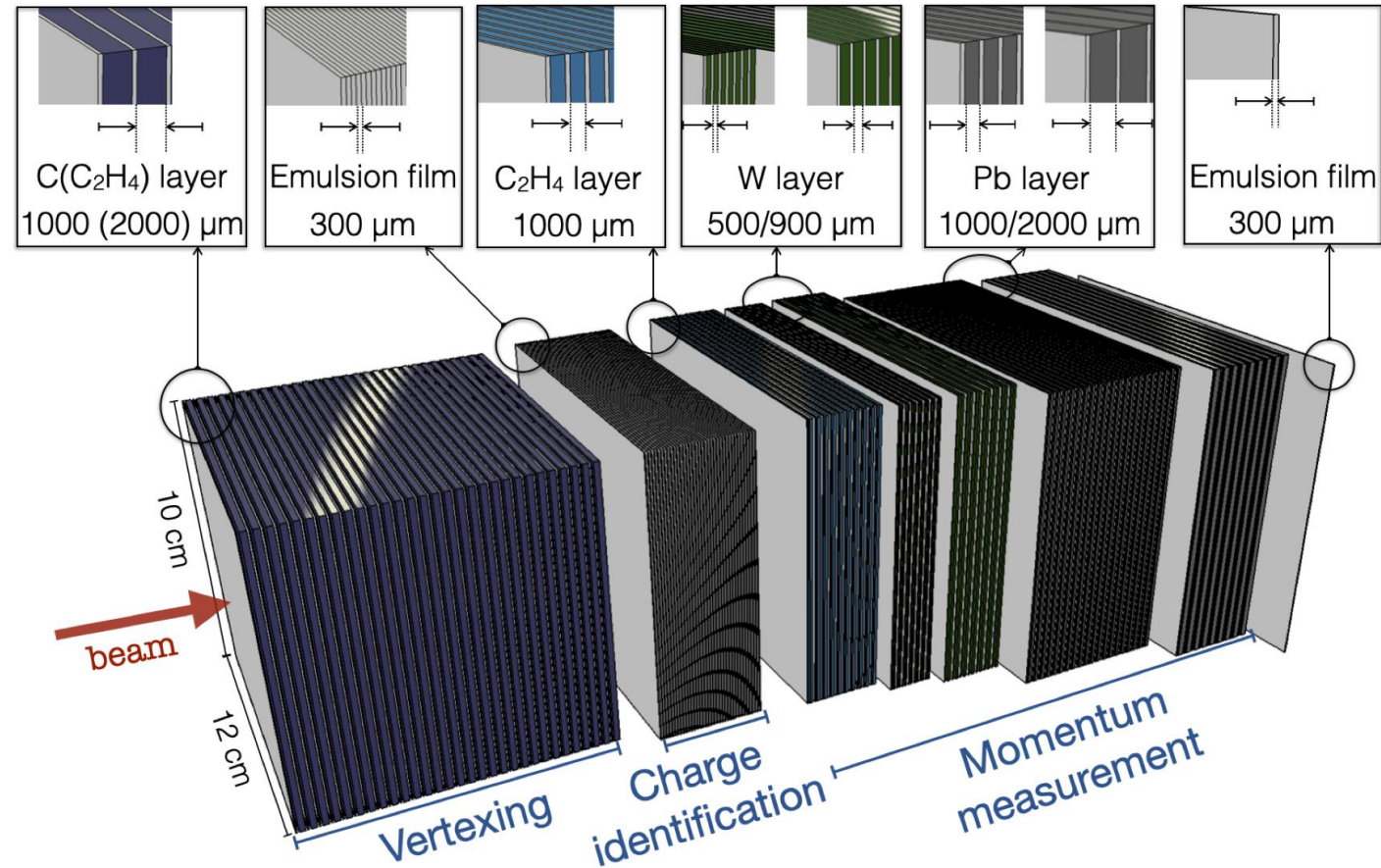
Expected Energy Distribution from MC

- Cut on Reconstructed MC: at least two segments in Section 1
- The intrinsic energy threshold in the tracking procedure eliminates most of the lower energy fragments
- This means that the expected contamination of target fragments in our sample is not significant
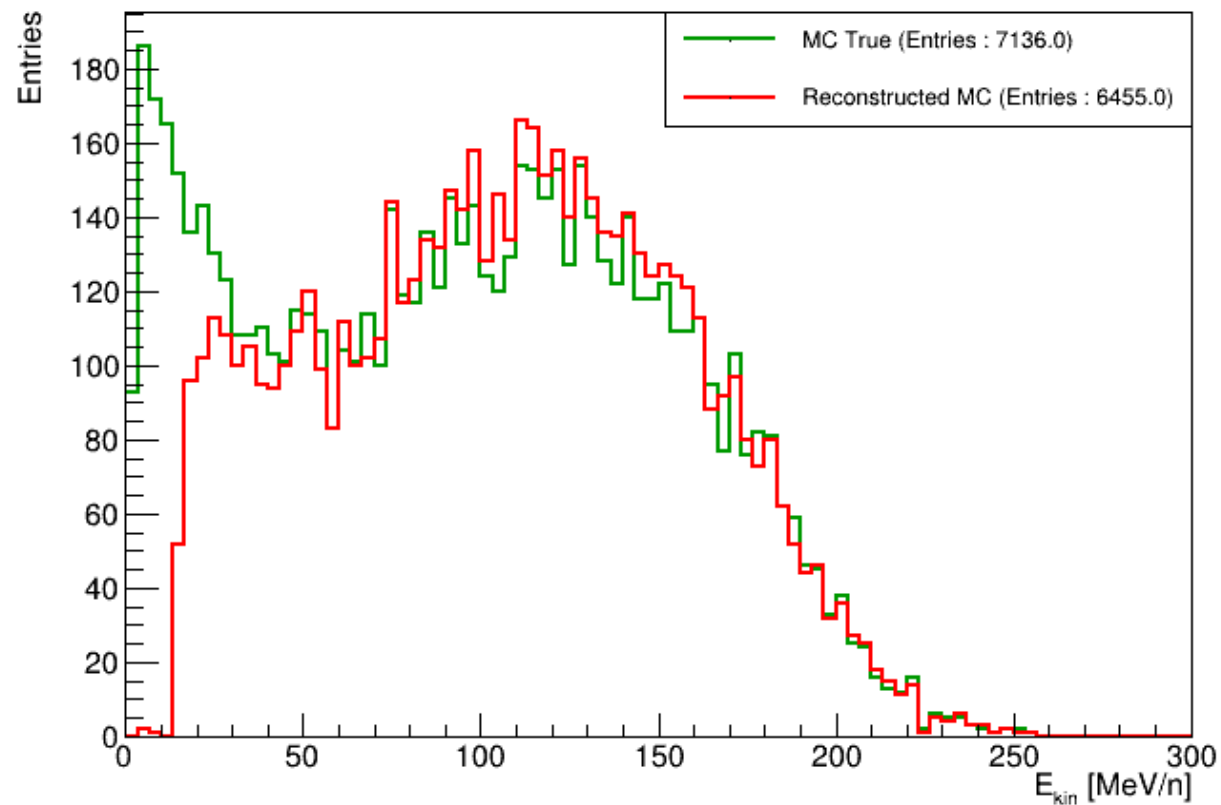
Multiplicity of Z=2 tracks per event

- The plots show the number of tracks identified as Z=2 (no info on mass or energy) per reconstructed event
- Estimated efficiency (reconstructed MC without disalignment)
  - 67% for GSI1 and 69% for GSI2 for events with 3 Z=2 tracks
  - 54% for GSI1 and 36% for GSI2 for events with 4 Z=2 tracks

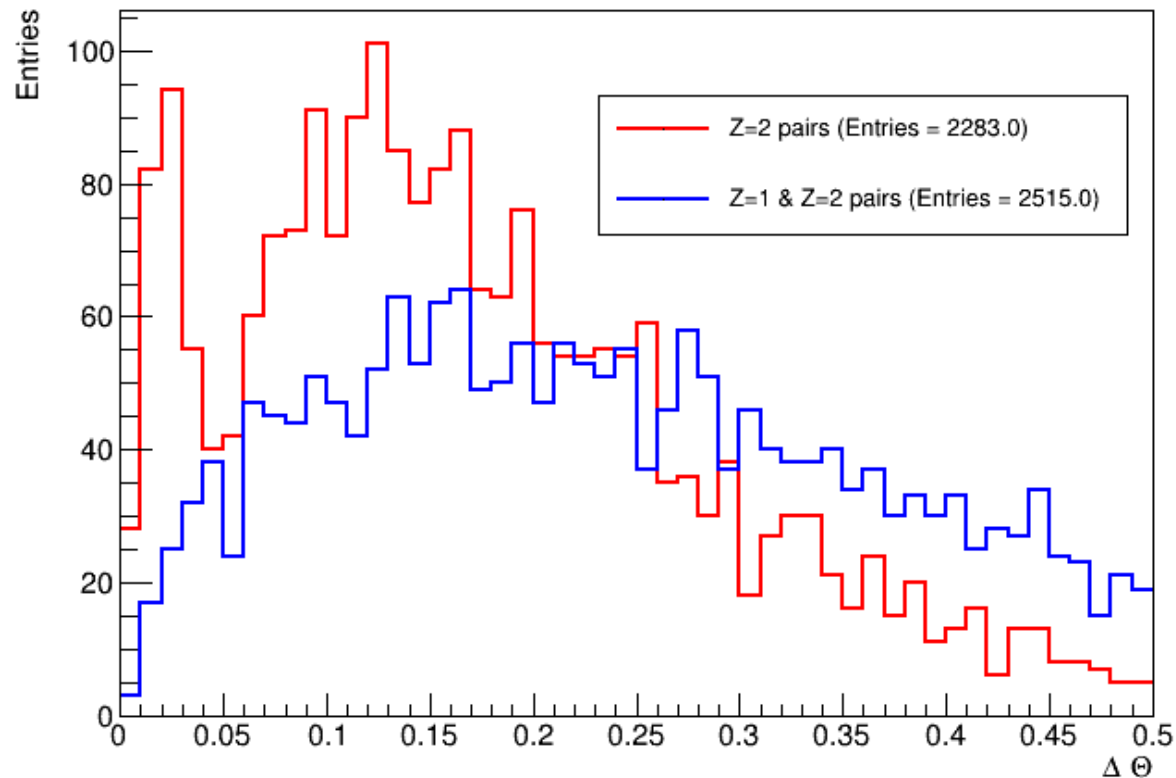Number of Z=2 Tracks [200 MeV/n ^{16}O on C$_{12}$]
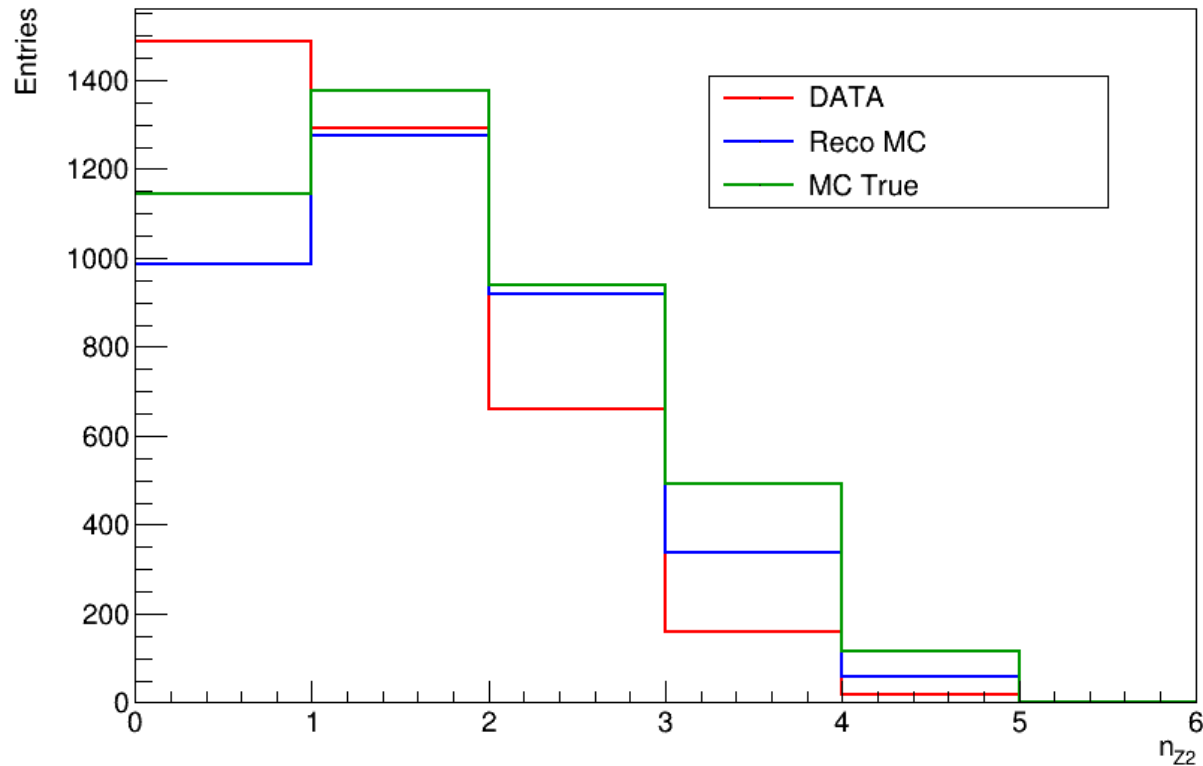
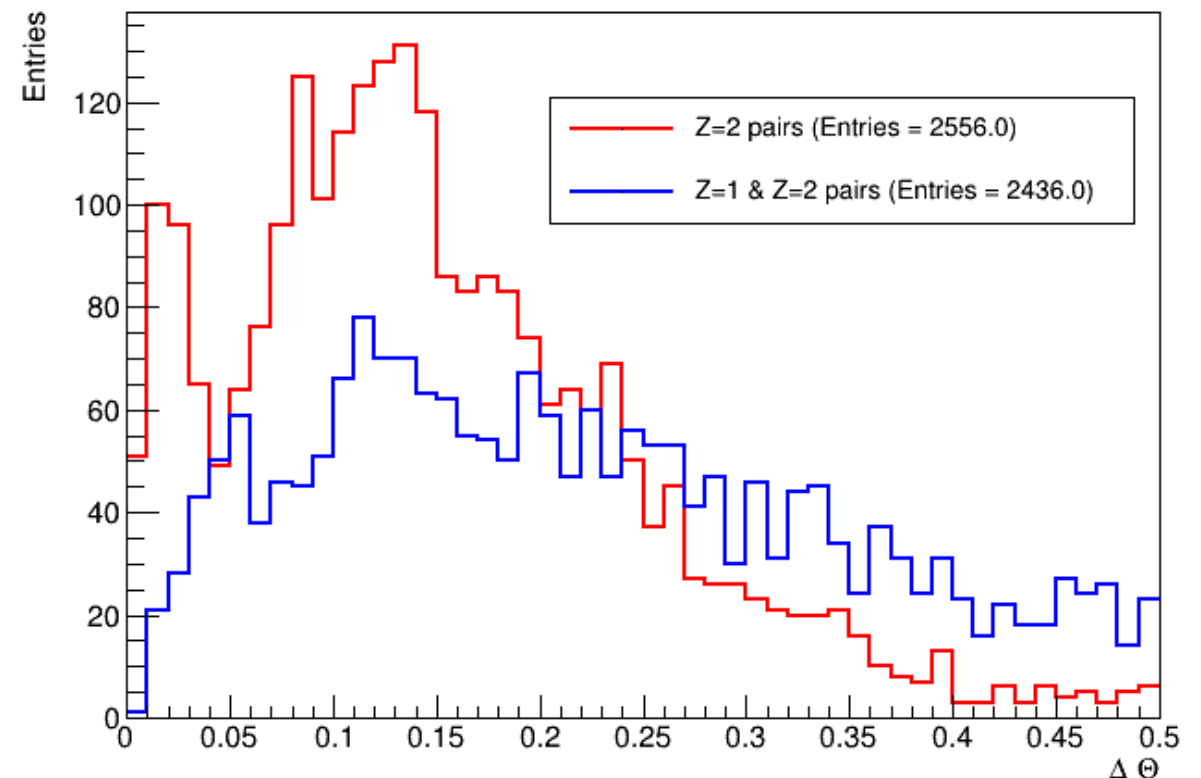Number of Z=2 Tracks [200 MeV/n ^{16}O on C$_2$H$_4$]
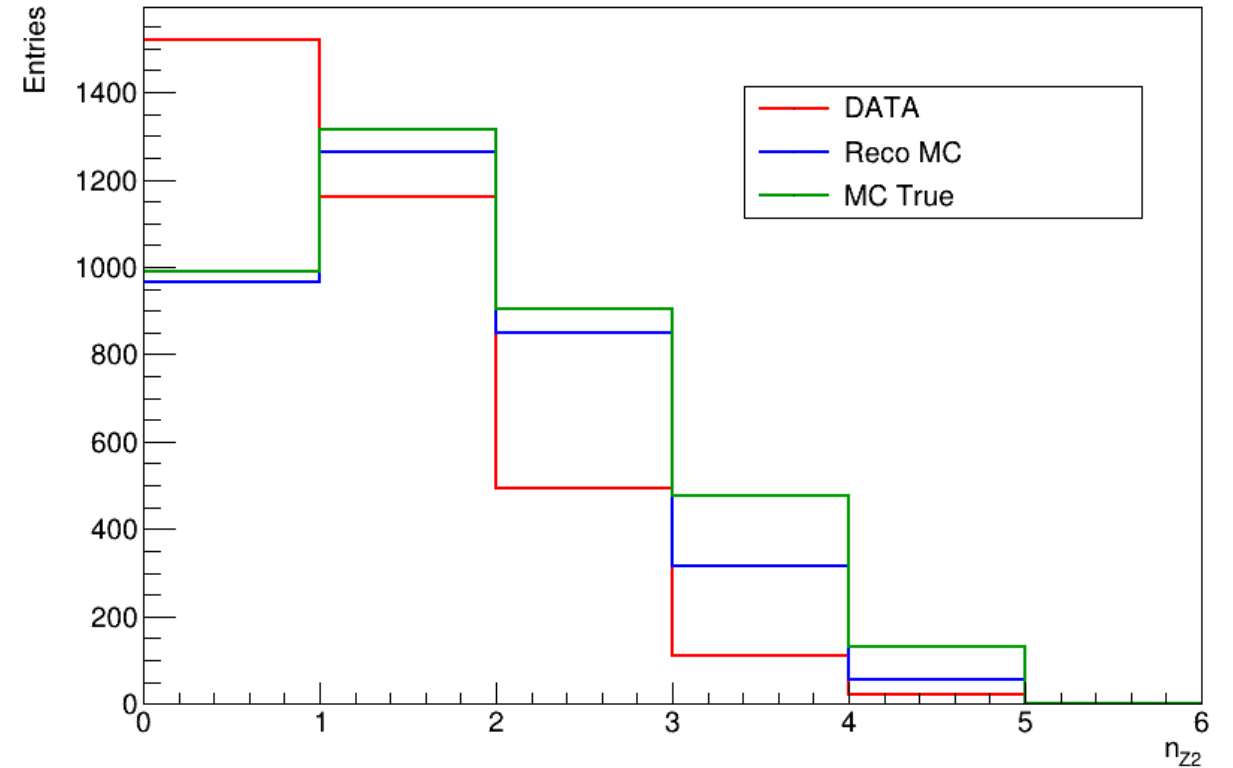
Opening angle distributions (Reconstructed MC)

- 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>
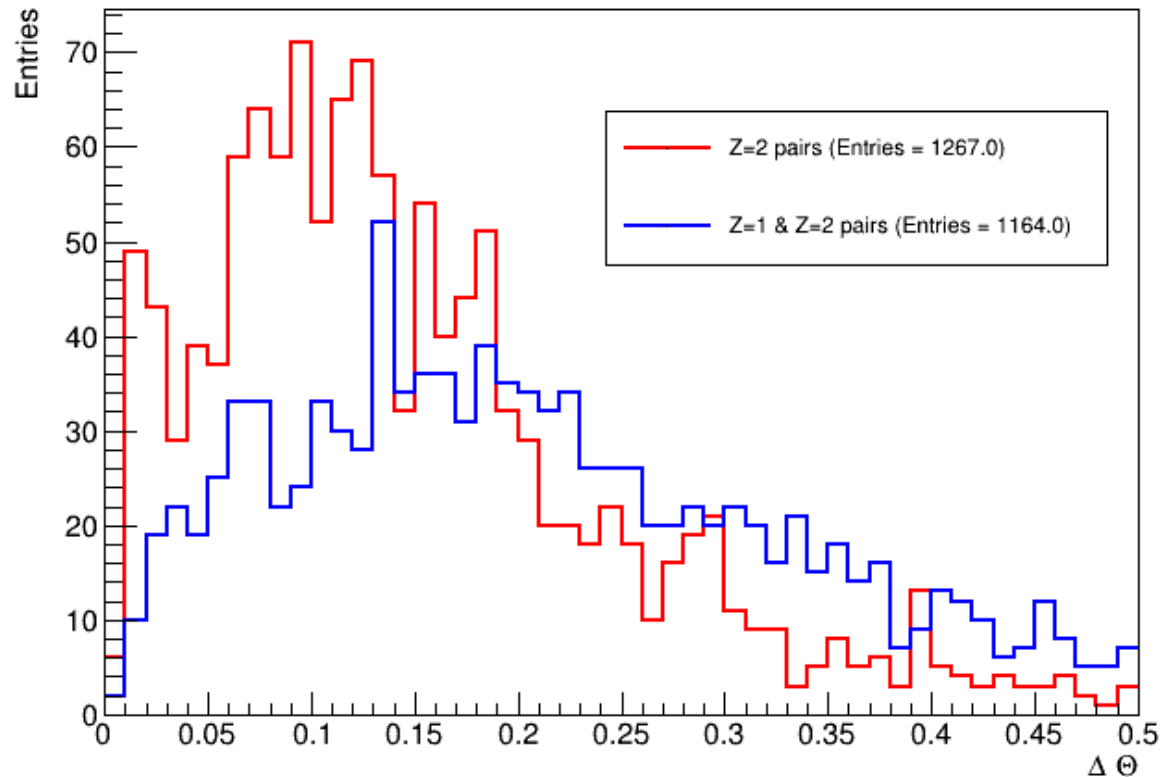- The background is estimated with the comparison of the angular differences between Z=1 and Z=2 tracks
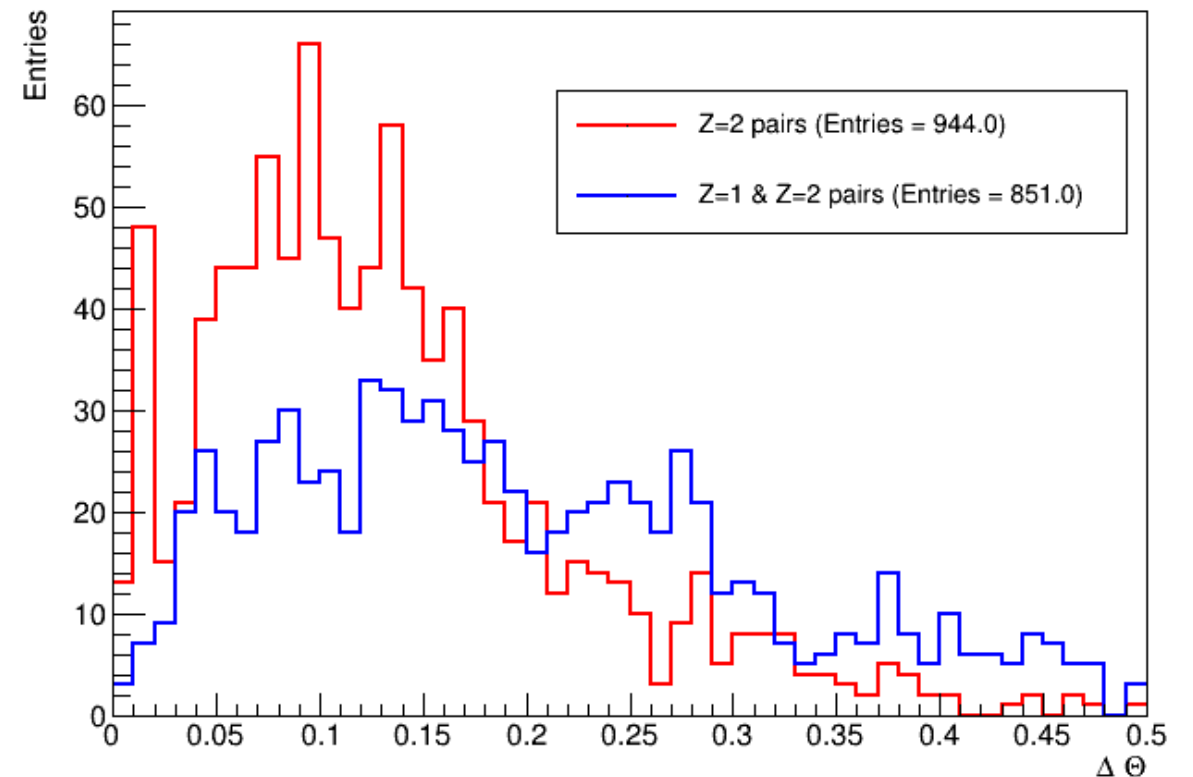
Opening angle distributions (DATA)

- 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

Preliminary Results

- Are these results statistically significant?
- If we consider the region below 30 mrad we find:
  - GSI1: 98 ± 10 signal events with respect to 31 ± 6 estimated background events -> 67 ± 16 events
  - GSI2: 76 ± 9 signal events with respect to 19 ± 4 estimated background events -> 57 ± 13 events
- The two estimated signals are compatible with each other within the margin of error
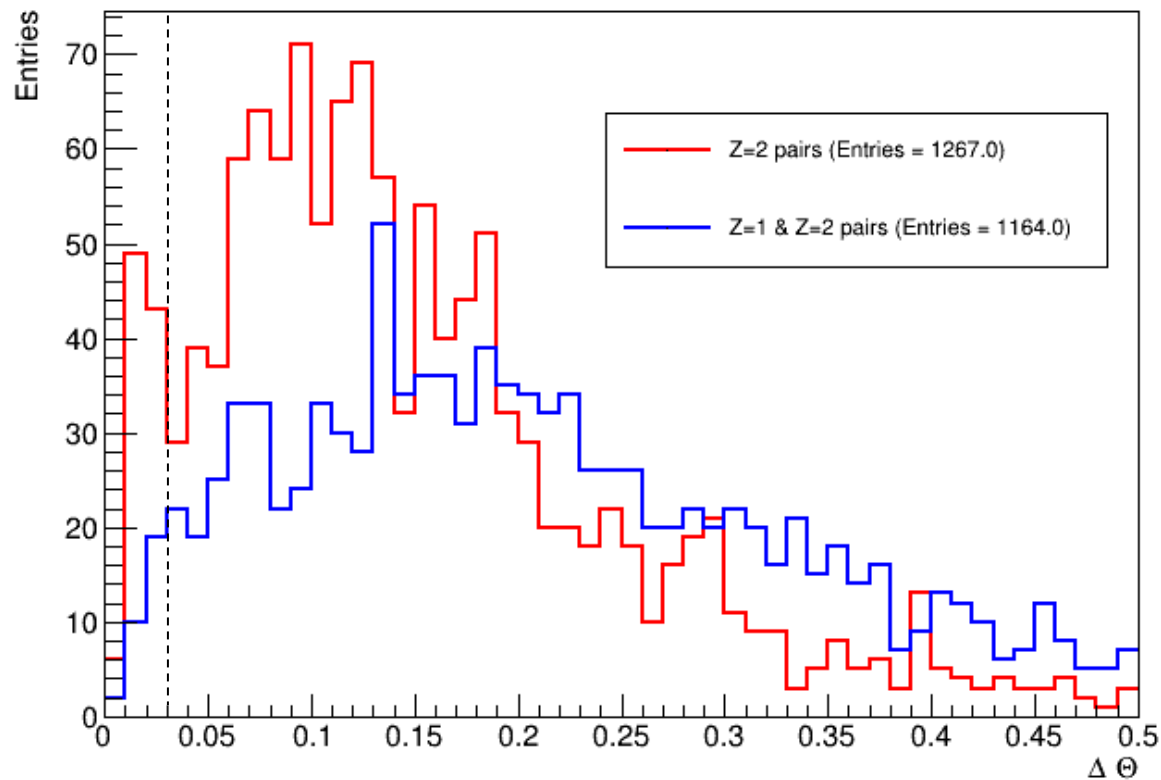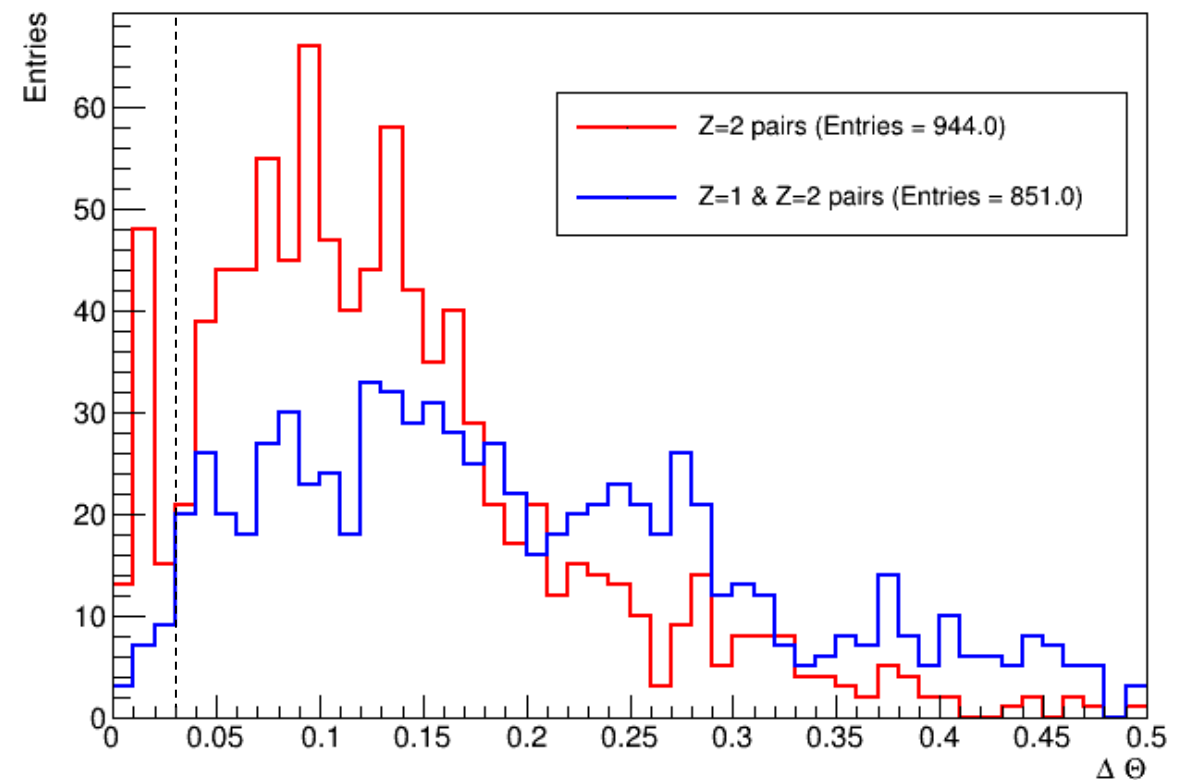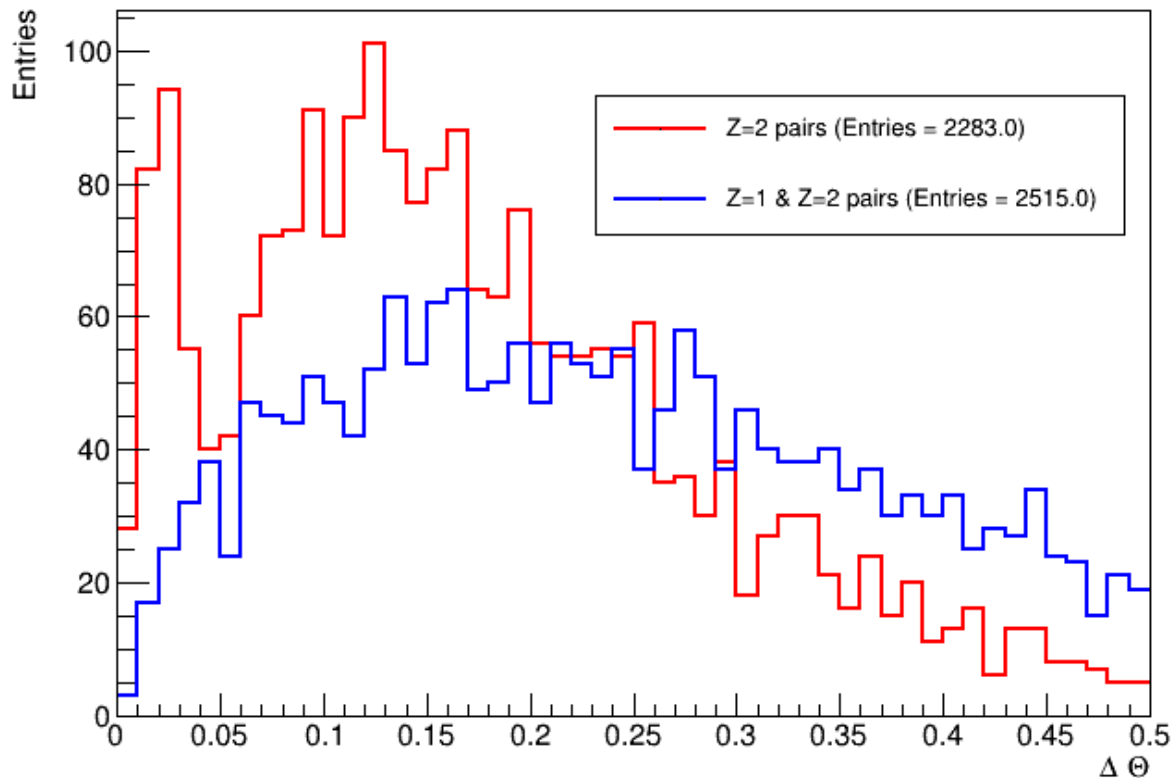
Conclusions

- Performed first analysis concerning alpha clustering with FOOT emulsion data

- A correlation peak can be found for the exposures at 200 MeV/n ^{16}O beams on both carbon and polyethylene targets
  - A more in-depth statistical analysis should be performed to reach a final result

- No statistically significant difference was recorded between the two datasets

- Can the statistics be improved?
  - Only about 5% of Z=2 tracks produced in Section 1 are expected to not reach Section 2 (Reconstructed MC)

- Future analysis
  - 400 MeV/n ^{16}O on carbon and polyethylene targets (GSI3, GSI4 from 2019)
  - CNAO 2023 data: 200 MeV/n ^{12}C on carbon and polyethylene targets
  - Momentum measurement

Back Up

Distribution of Angular Differences (GSI1)

- 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

MC Angular Difference [200 MeV/n ^{16}O on C_{12}]

Z=2 pairs (Entries = 2283.0)
Z=1 & Z=2 pairs (Entries = 2515.0)

DATA Angular Difference [200 MeV/n ^{16}O on C_{12}]

Z=2 pairs (Entries = 1267.0)
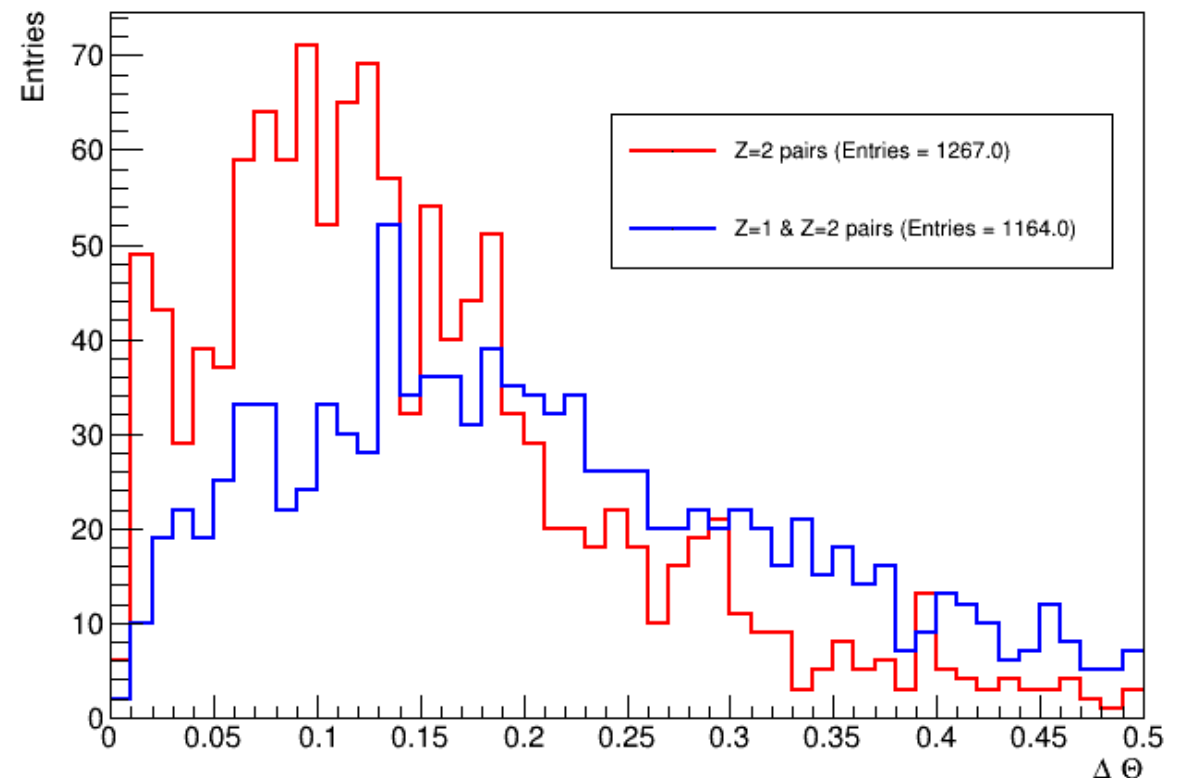Z=1 & Z=2 pairs (Entries = 1164.0)

Distribution of Angular Differences (GSI2)

- 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
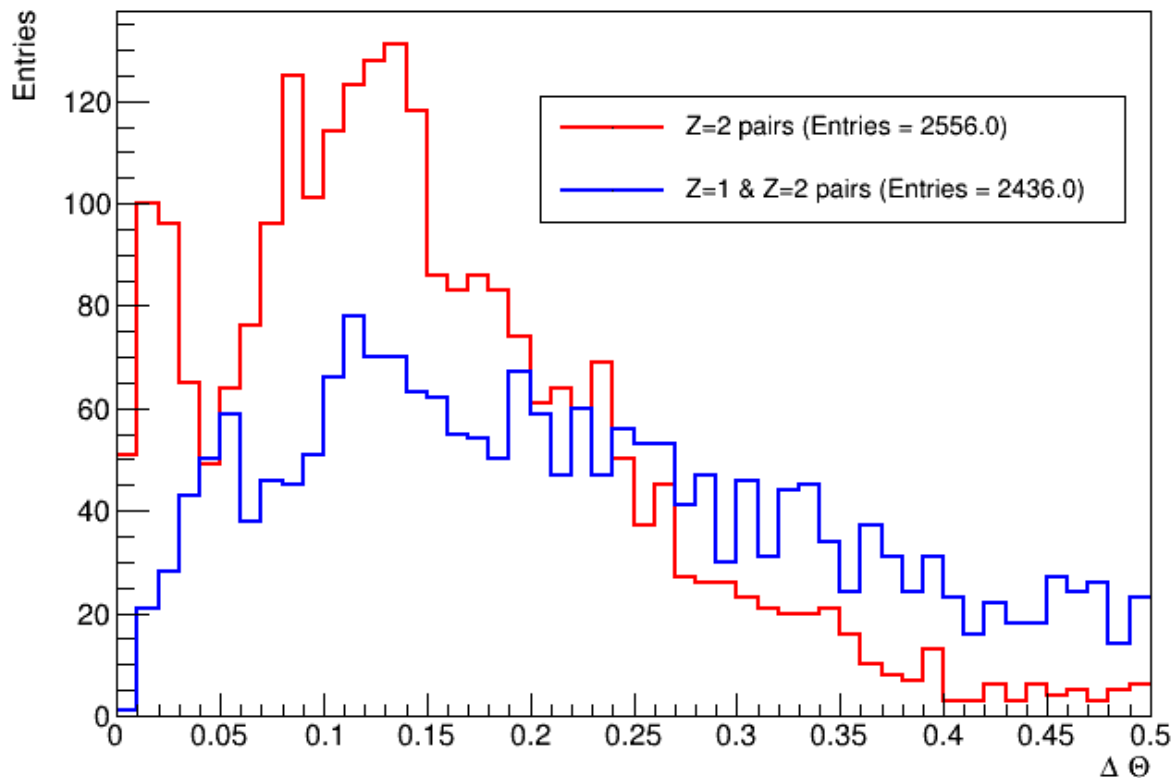

MC Angular Difference [200 MeV/n ^{16}O on C_2H_4]
Z=2 pairs (Entries = 2556.0)
Z=1 & Z=2 pairs (Entries = 2436.0)

DATA Angular Difference [200 MeV/n ^{16}O on C_2H_4]
Z=2 pairs (Entries = 944.0)
Z=1 & Z=2 pairs (Entries = 851.0)