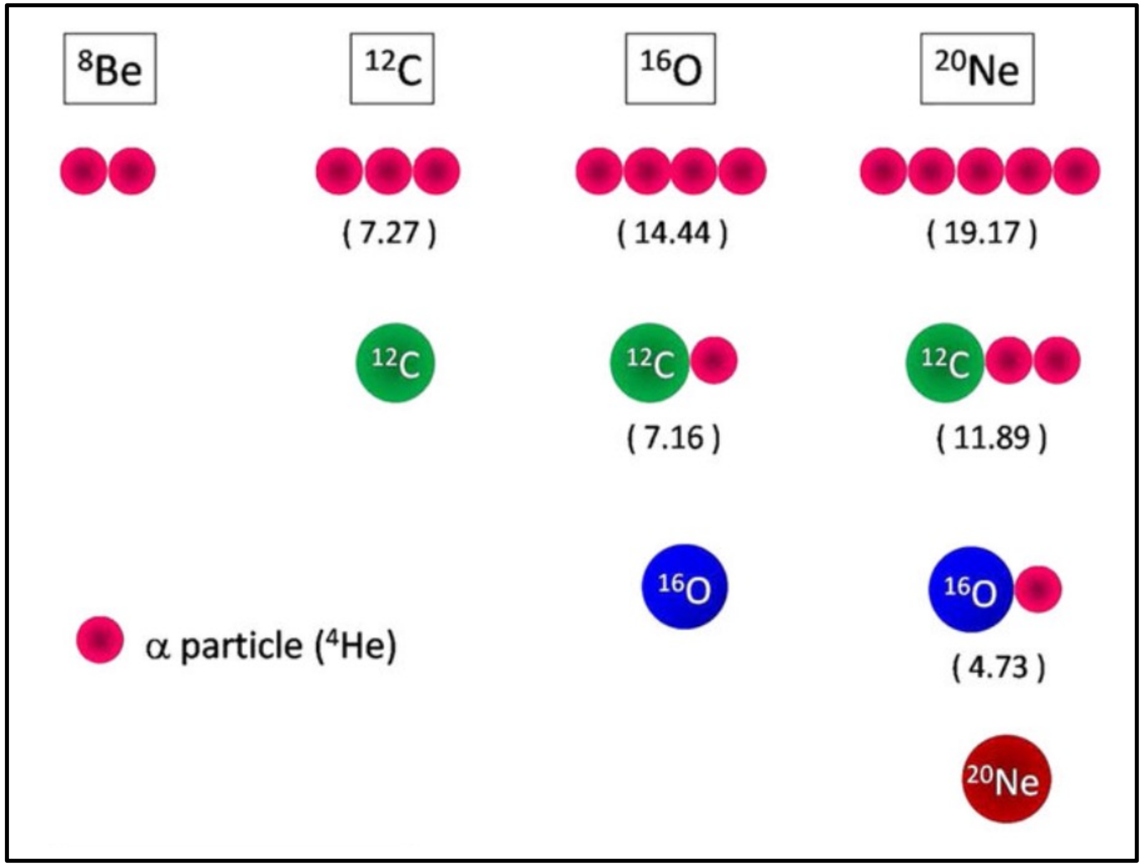


Search for ^{16}O fragmentation in multiple Alphas at GSI2021: MC results

INFN Milano

Introduction

- First attempts to analyze multi-α production in ^{16}O interactions (campaign GSI2021) was presented in Dec. 2021 and May 2022 meetings

- At that time global track reconstruction was still primitive, and event selection criteria were not yet defined

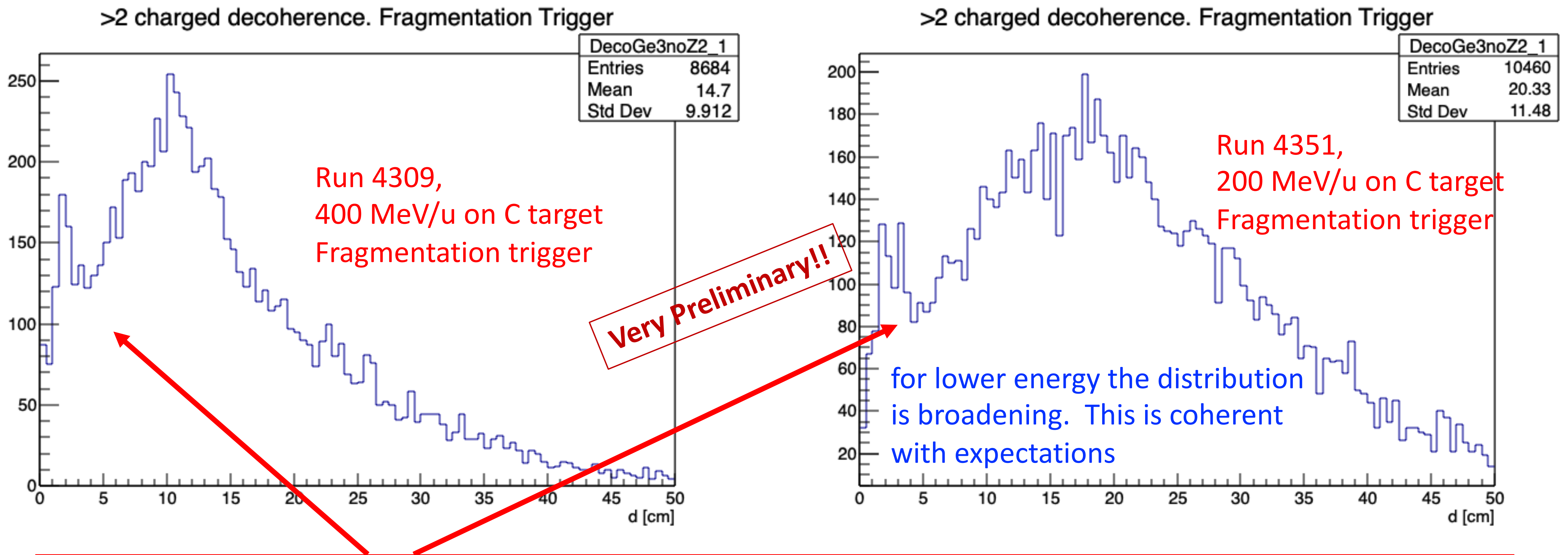
- At the Dec. 2023 meeting we presented the 1st detailed MC study for multi-α production in ^{12}C interactions with full detector, mostly to prepare for CNAO2023 analysys

- Here we present the results for the last GSI2021 Simulation (GSI21PS_MC campaign), in view of the possibility of using global track reconstruction on real GS2021 experimental data and compare with the emulsion analysys for ^{16}O at 200 MeV/u (GSI2019).

- The implemented Event and Track selection cuts have been defined during the discussions in the Physics and Analysis group

From Dec 2021 meeting:

Events with ≥ 3 tracks selected



These were artefacts from non-properly working reconstruction at that time!!! Alignment was missing, etc….

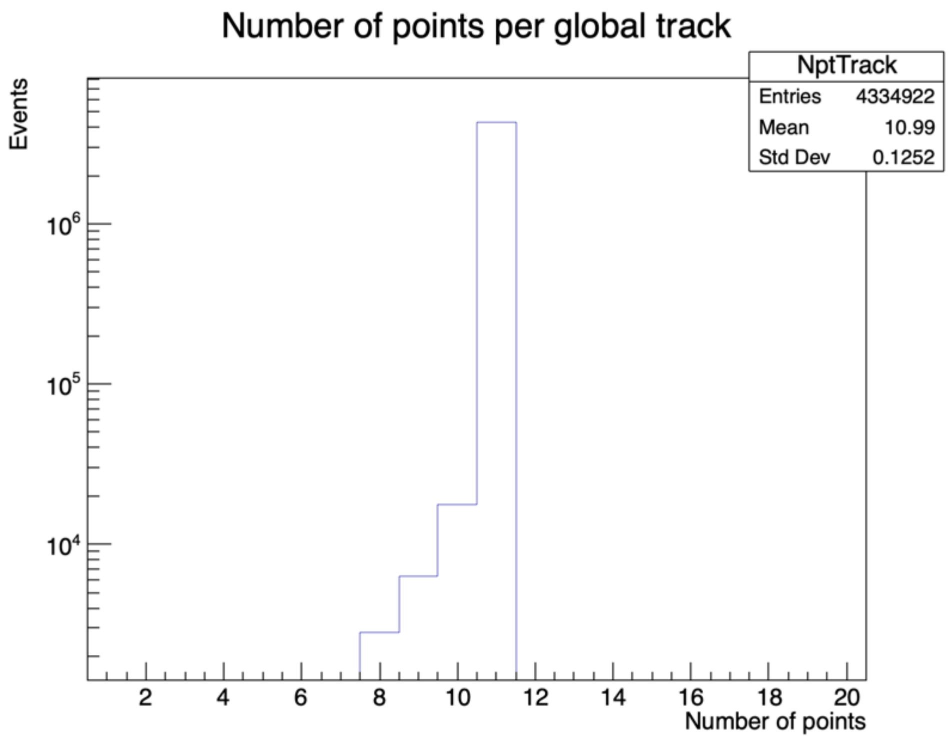
Today's MC sample and Event Reconstruction

- GSI21PS_MC campaign run 400 (5 10^6 primary events, ^{nat}C target)
- GenFit:

```
Tracking Systems Considered:    all
Kalman preselection strategy: Standard
N measure in global tracking: 8
```

- 1st Event Selection:

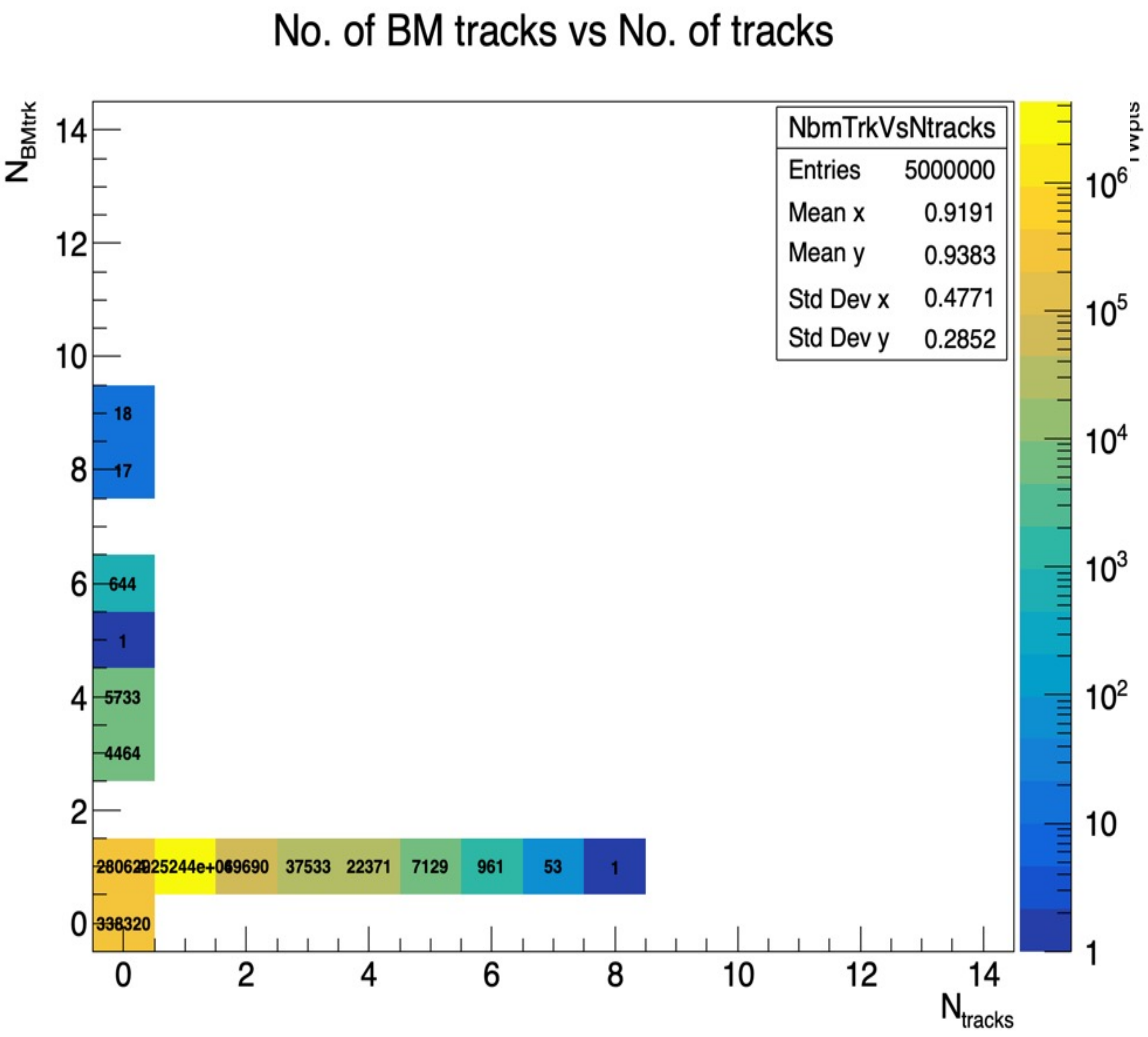
1 Beam Monitor track	4 650 803 evts
≥ 1 reconstructed global track	4 307 174 evts
$N_{tracks} = N_{TW\ points}$	**4 245 209 evts**
	($\varepsilon_{evt\ select.}$= 84.9%)

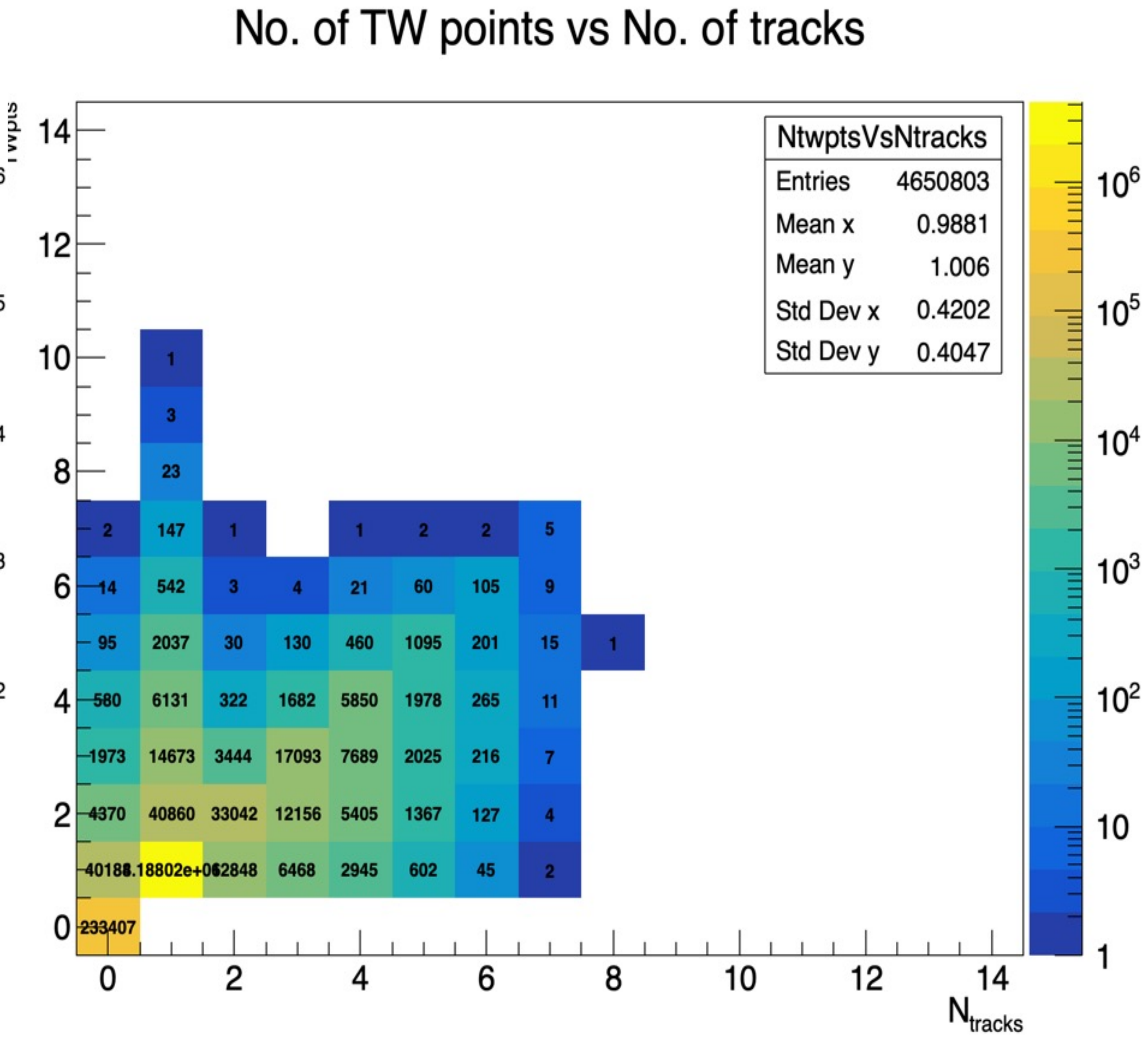


Surviving no. of candidate tracks:

4334922 tracks (evidently mostly events with a single rec. track)

Back

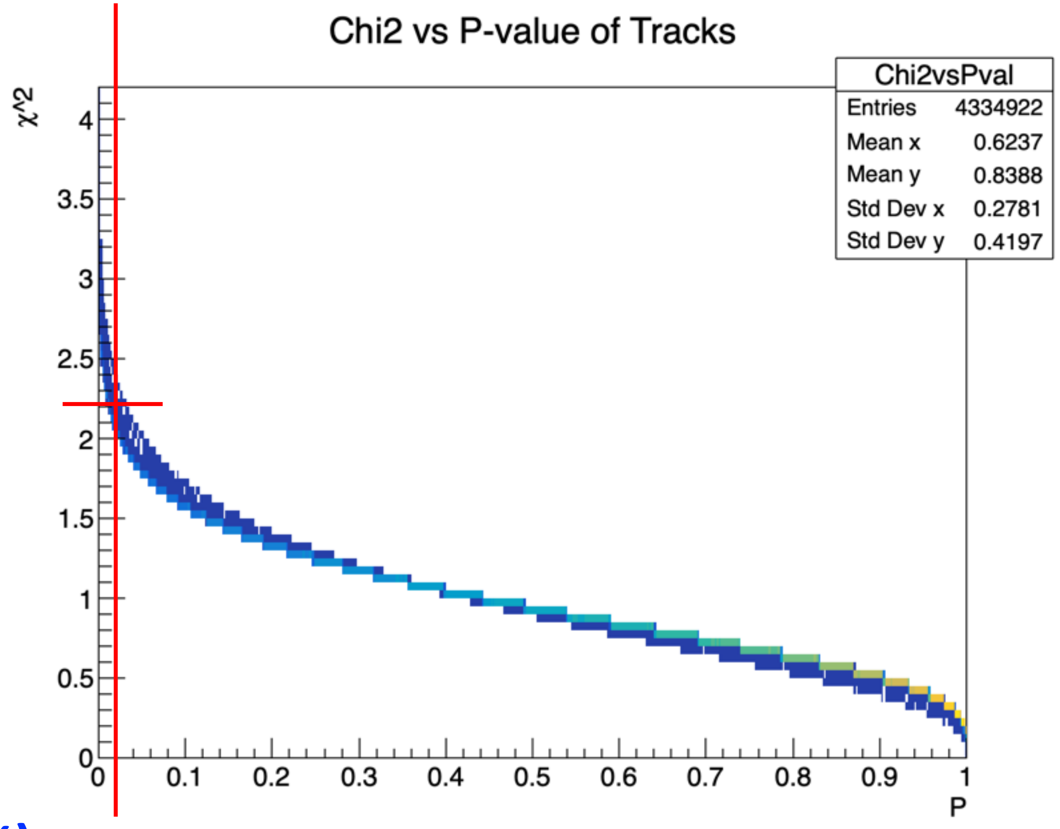

No. of BM tracks vs No. of tracks
NbmTrkVsNtracks
Entries 5000000
Mean x 0.9191
Mean y 0.9383
Std Dev x 0.4771
Std Dev y 0.2852
N_{BMtrk}
N_{tracks}


No. of TW points vs No. of tracks
NtwptsVsNtracks
Entries 4650803
Mean x 0.9881
Mean y 1.006
Std Dev x 0.4202
Std Dev y 0.4047
N_{tracks}

Track Selection Cuts

1. P-value > 0.02 — 4 242 805 tracks
2. 1 TW point — 4 230 721 tracks
3. Reconstructed Vertex within target — **3 716 571 tracks**
4. Max(XY Fitted point – XY Meas. Point) in tracking det. < 0.015 cm — **3 686 771 tracks**

($\varepsilon_{track\ select.}$=85.0%)



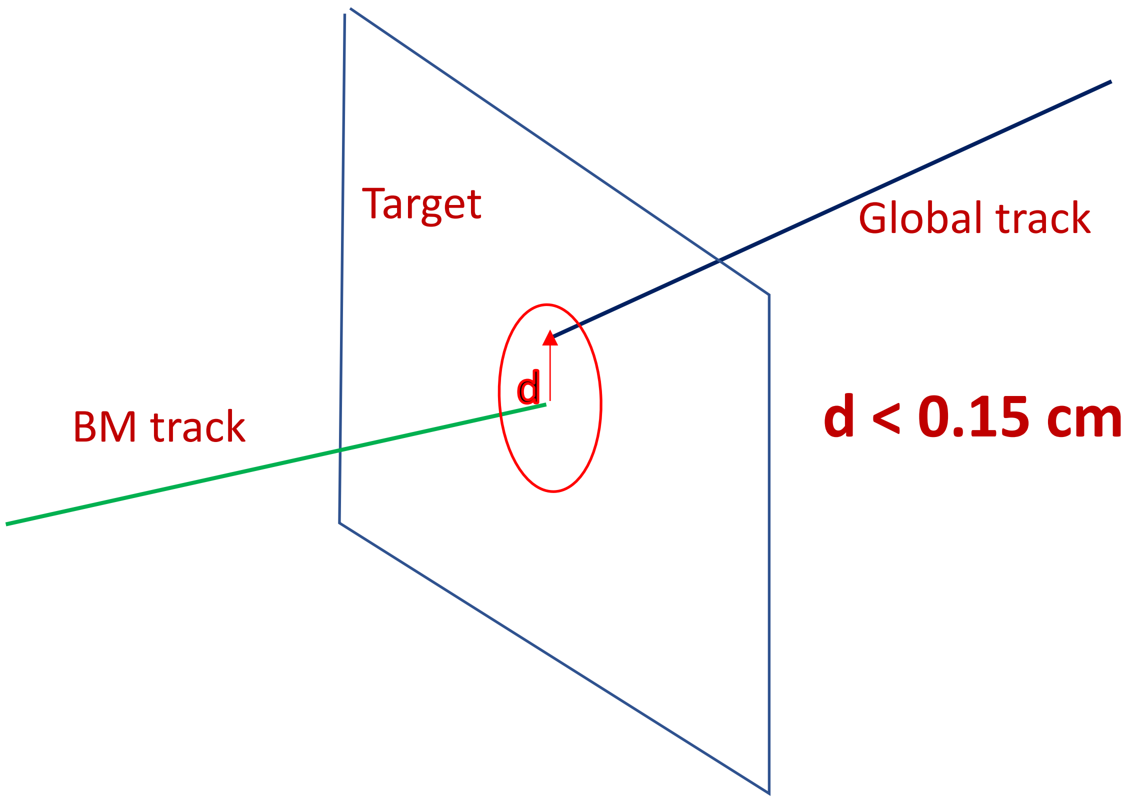
All selected global tracks are found to have ToF < ToF(50 MeV/u)

Warning: noise was not activated in MC reconstruction, so all this could be still optimistic

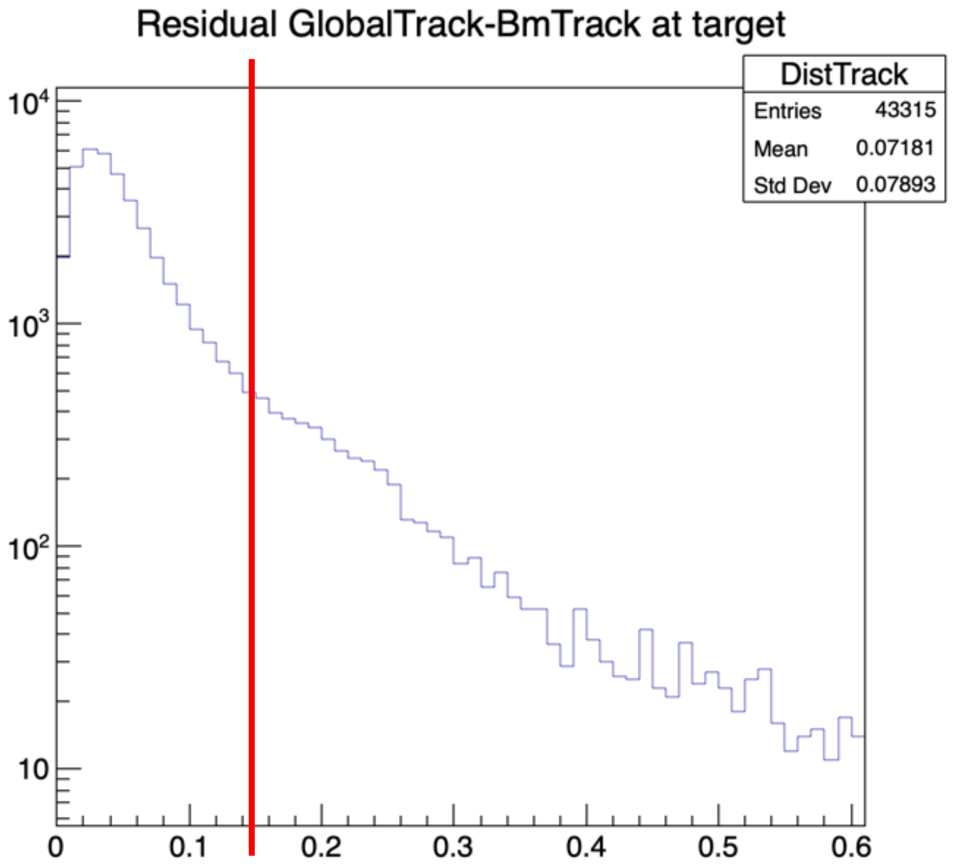
Next

Track Selection: implementation of cut # 3

The requirment of having a Reconstructed Vertex within target has been implemented also including a match with the Beam Monitor Track

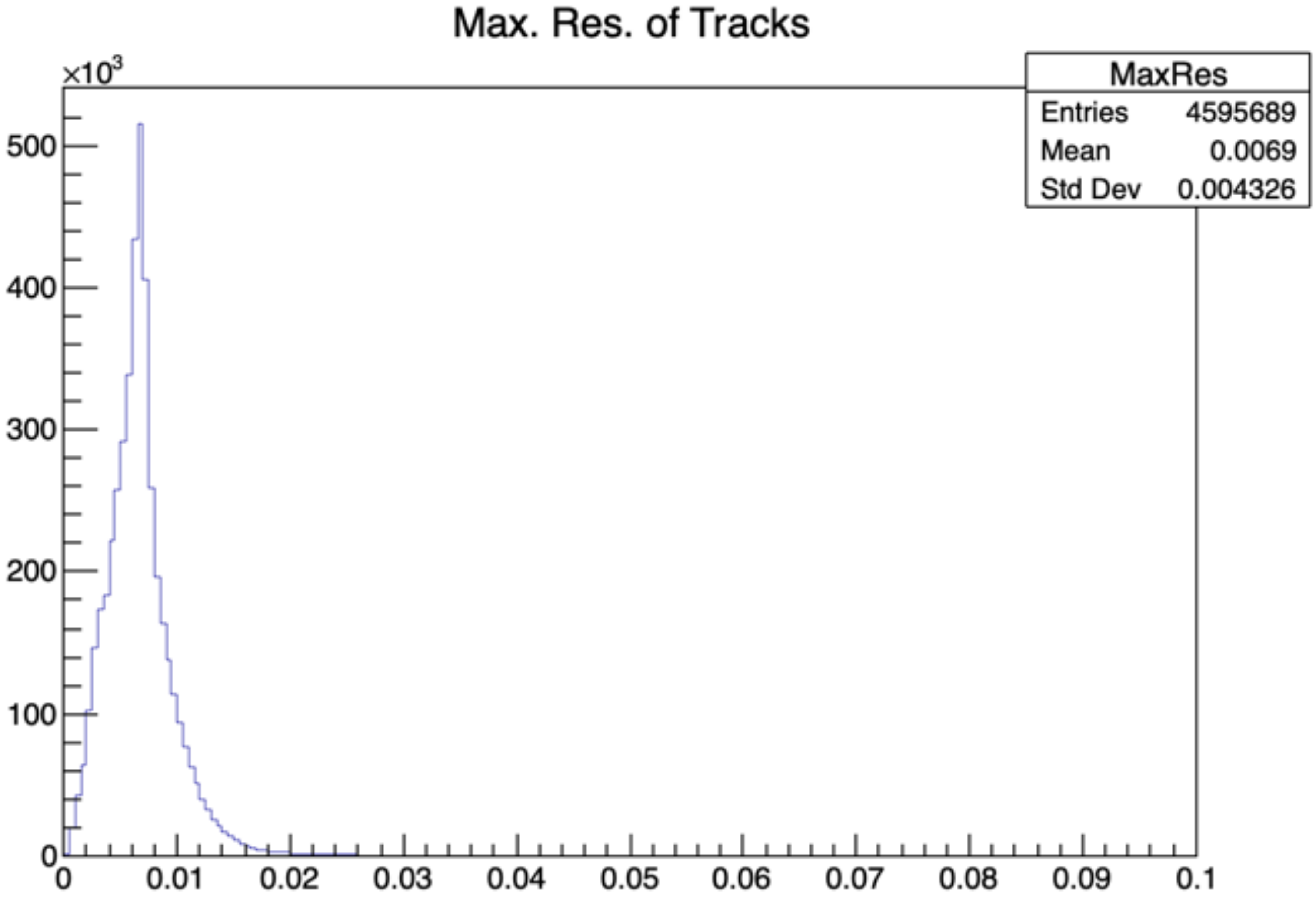


d < 0.15 cm



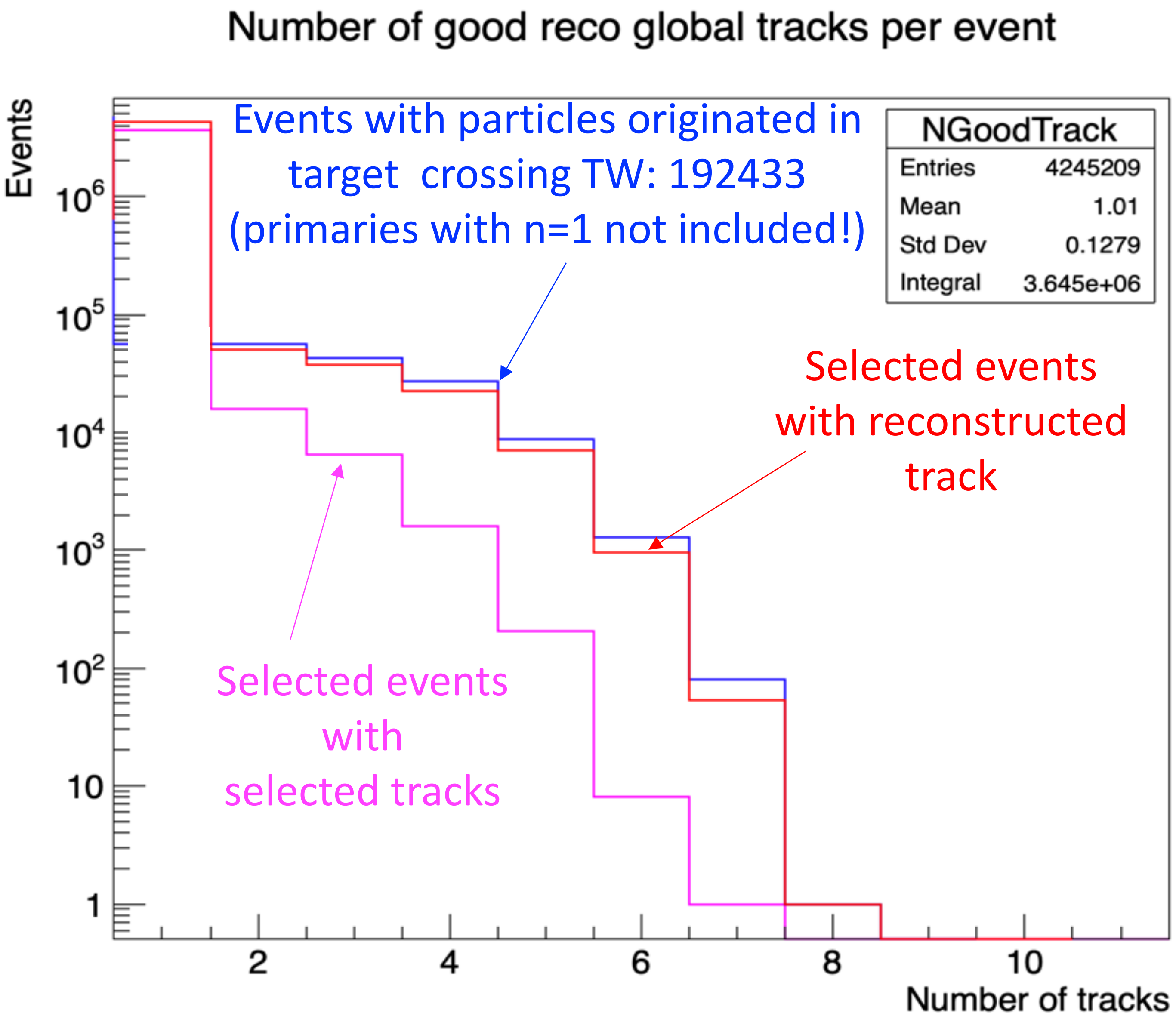
Back

Why such a wide distribution?


Max. Res. of Tracks
×10^3
MaxRes
Entries 4595689
Mean 0.0069
Std Dev 0.004326
500
400
300
200
100
0
0 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.1

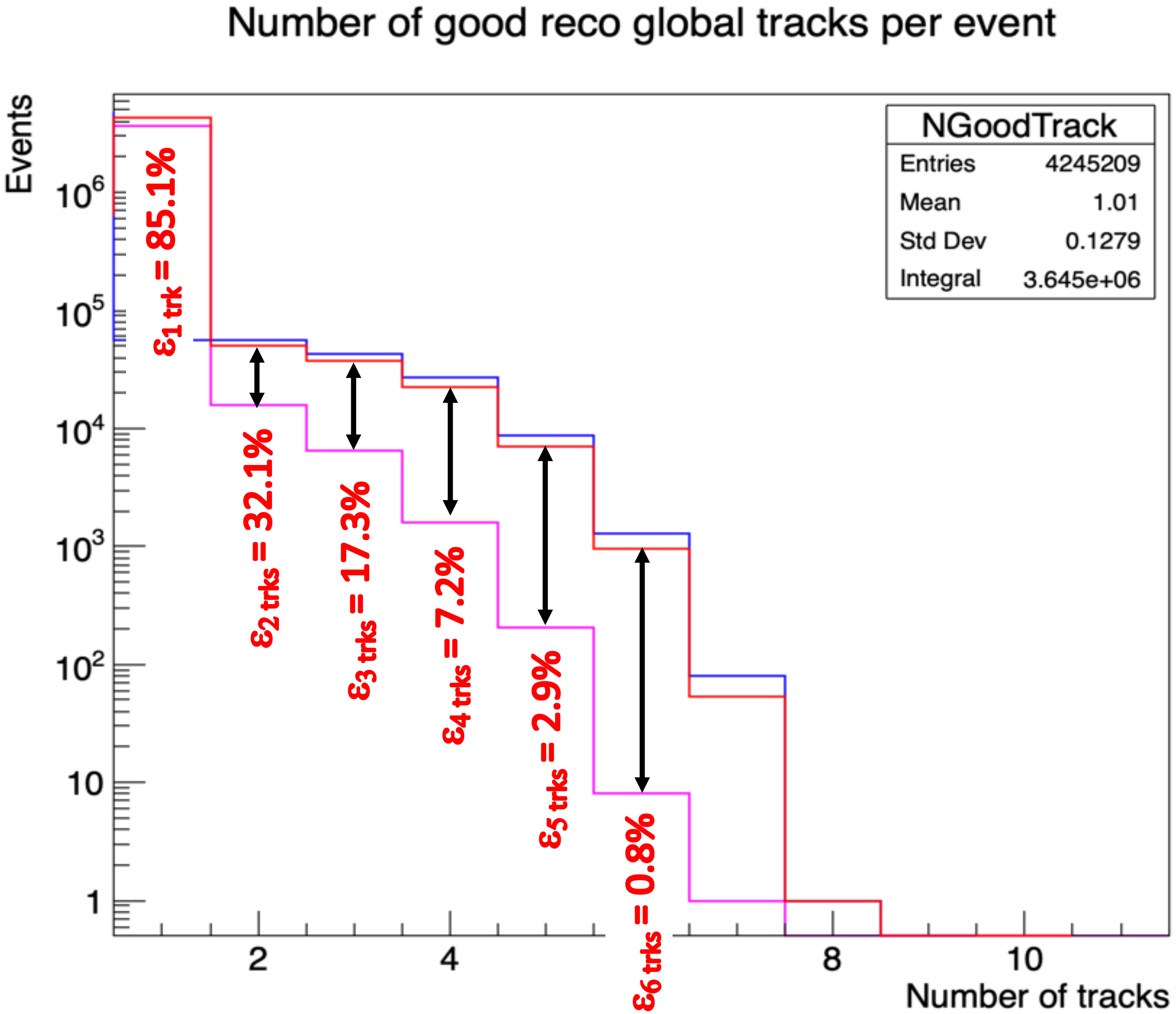
Back

Track multiplicity per event



Multiplicity>1 highly penalized!

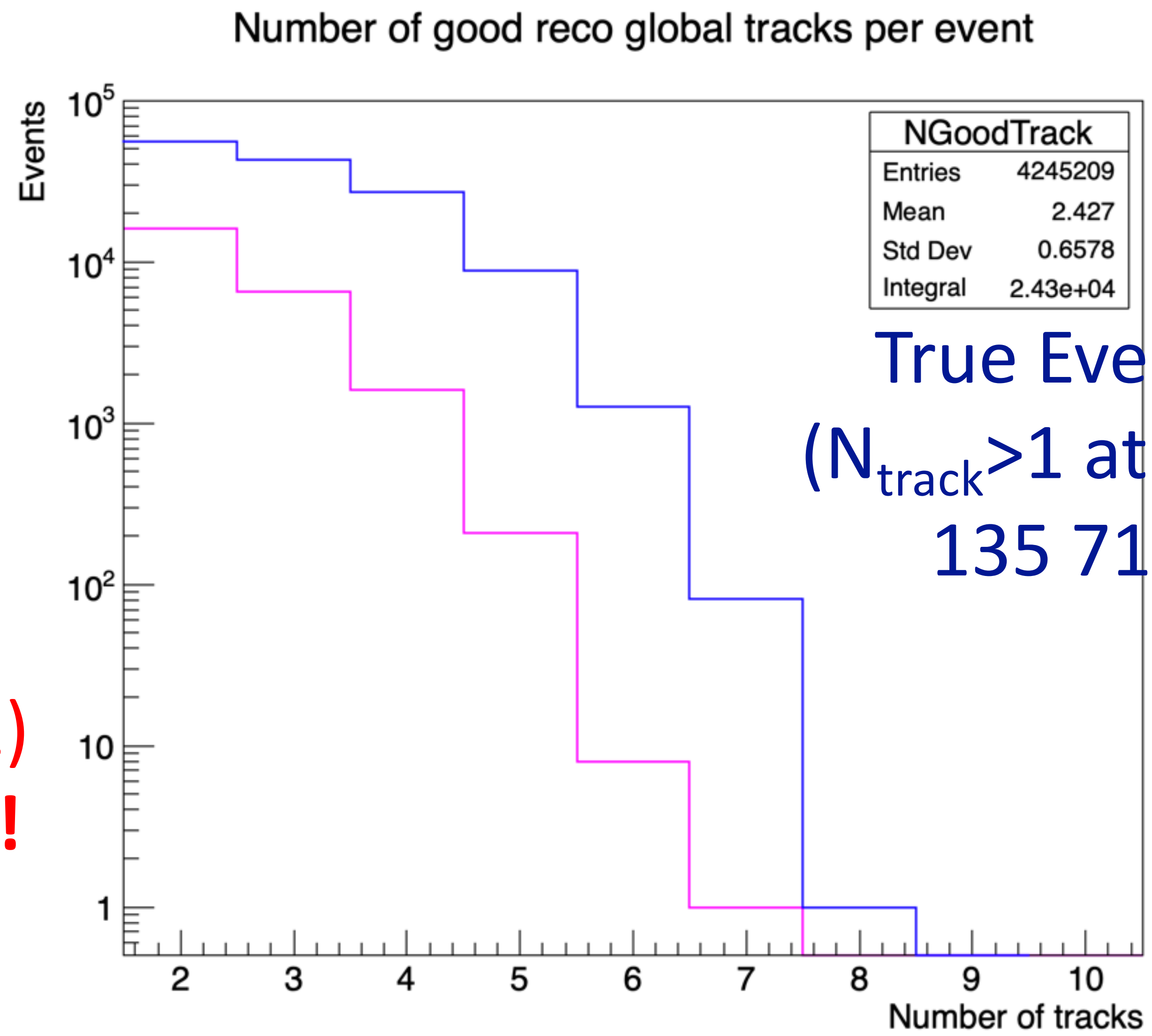
Track multiplicity per event



Multiplicity>1 highly penalized!

Track multiplicity per event (N_{tr}>1)

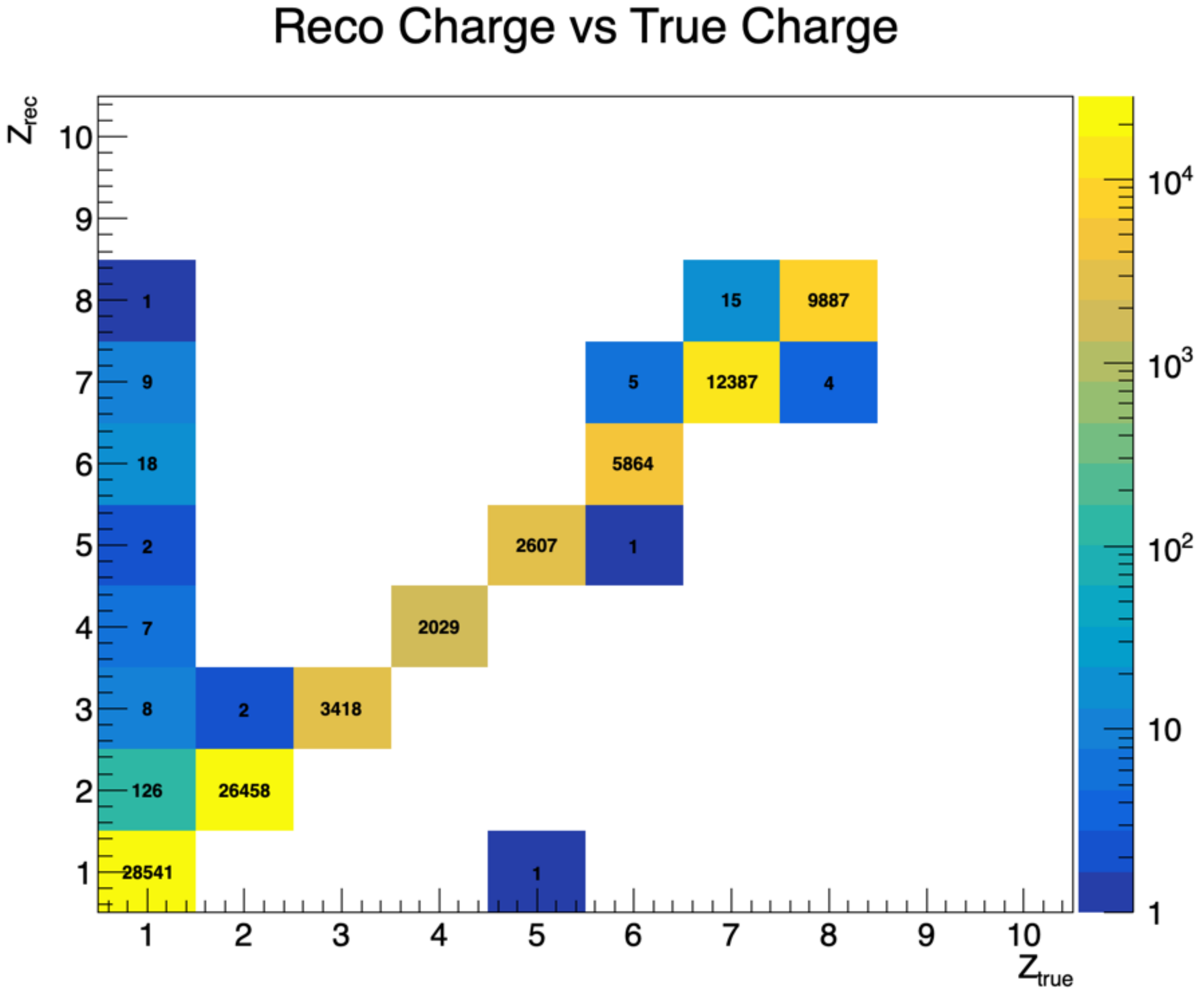
Final event selection
for this analysis



True Events
(N_{track}>1 at TW):
135 715

Selected Events(N_{track}>1)
Only 24 299 events left!

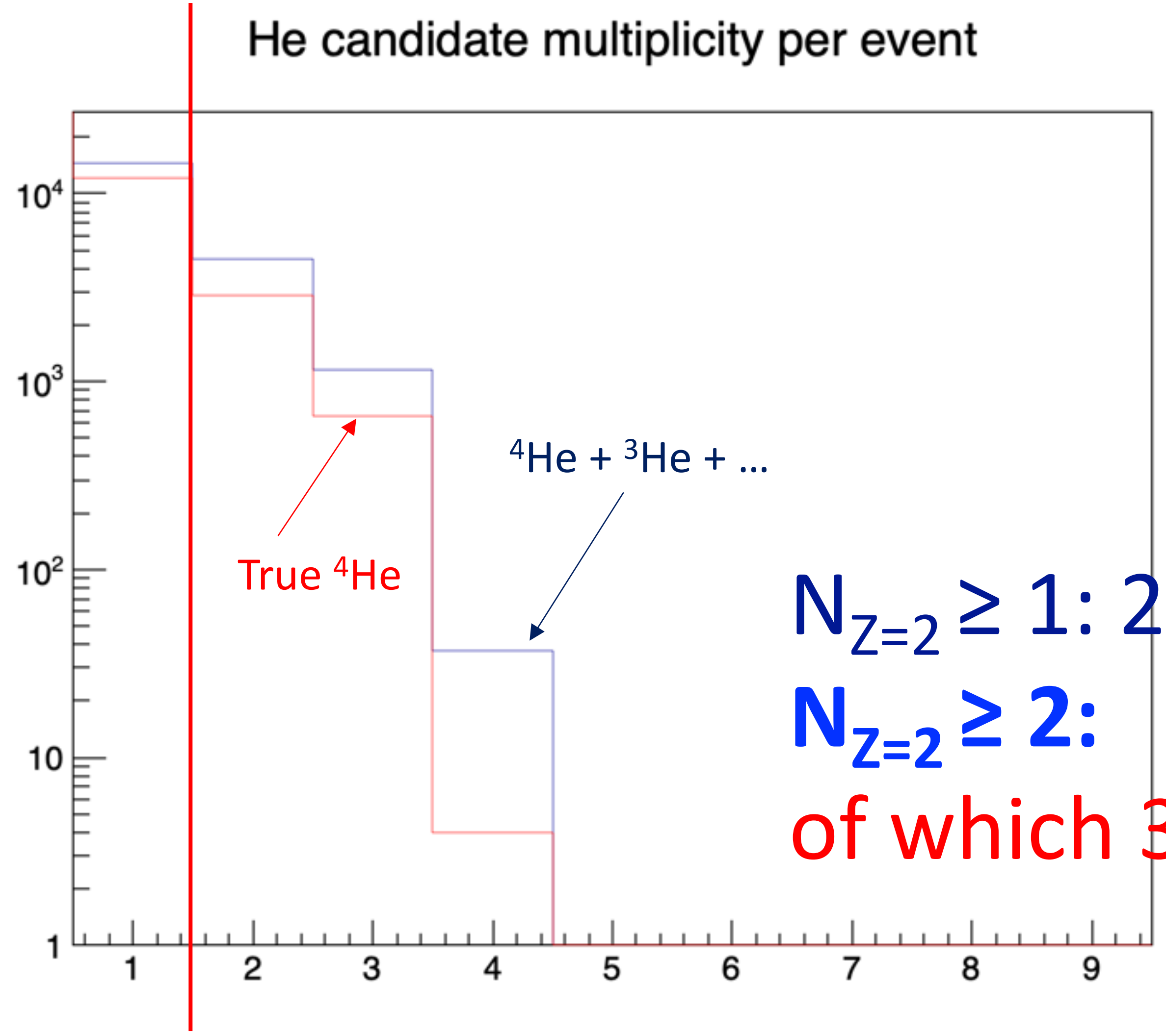
Z reconstruction



As a compensating reward the Z-migration matrix is <u>very clean and diagonal for Z>1</u>

In particular, Z = 2 is failed with <0.8% probabily

Z=2 Multiplicity per event

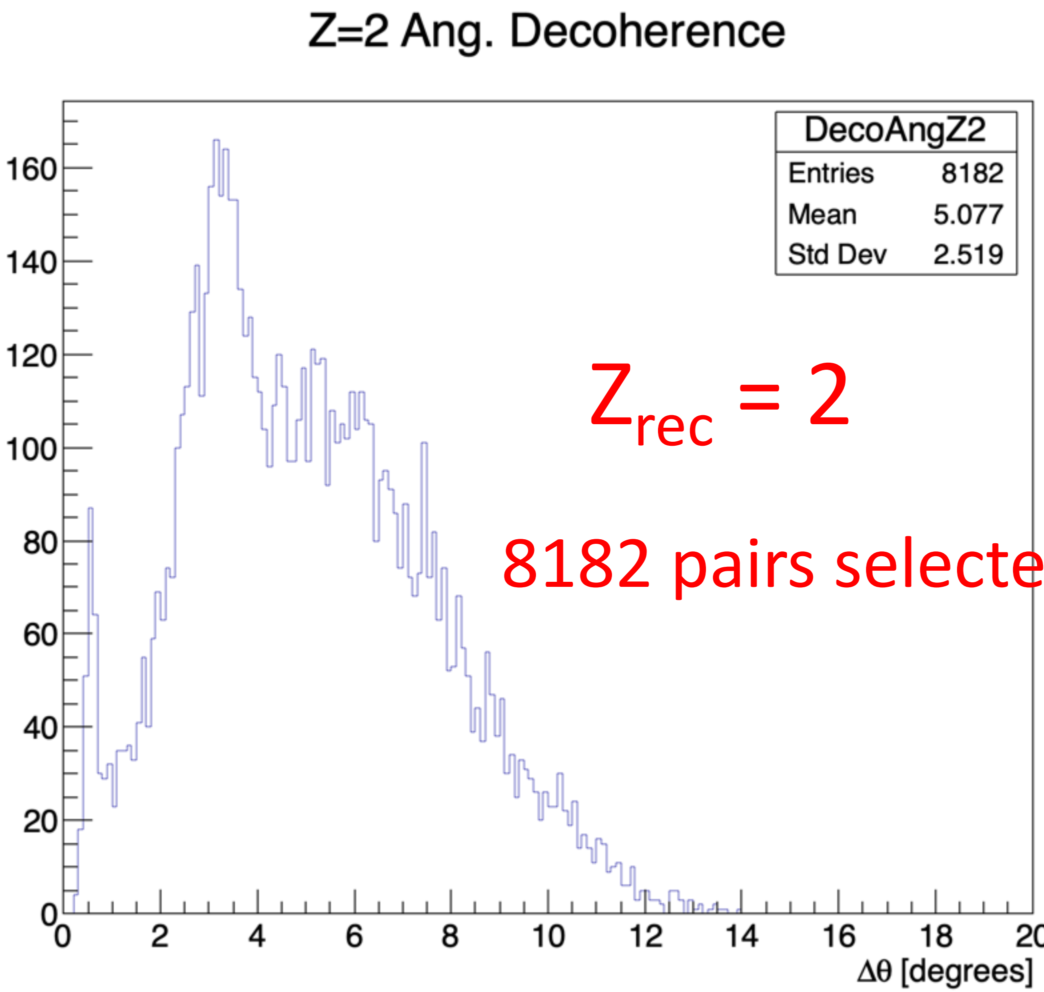


$N_{Z=2} \geq 1$: 20180 events

$N_{Z=2} \geq 2$: 5685 event

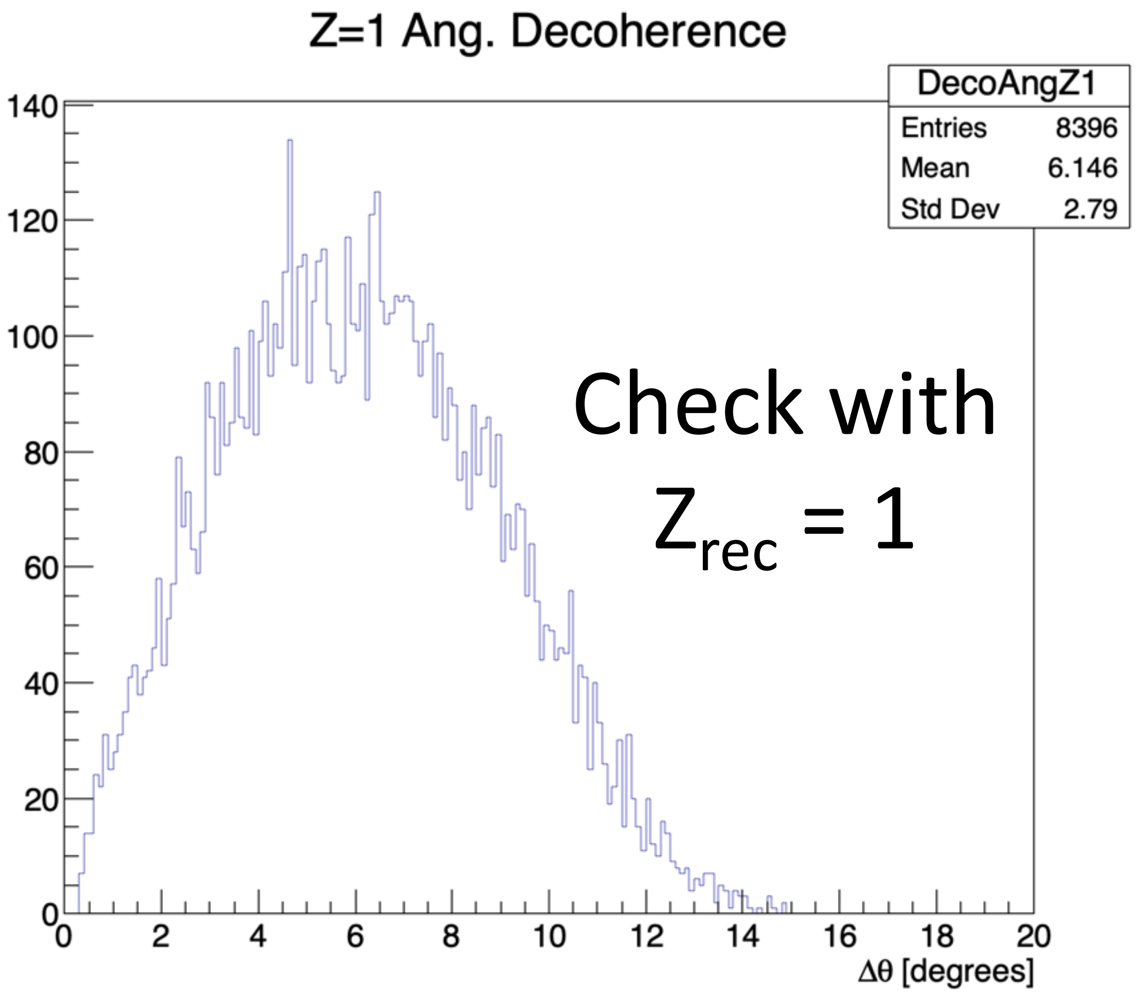
of which 3542 are true ^{4}He

Distribution of angular separation between 2 tracks



$Z_{rec} = 2$

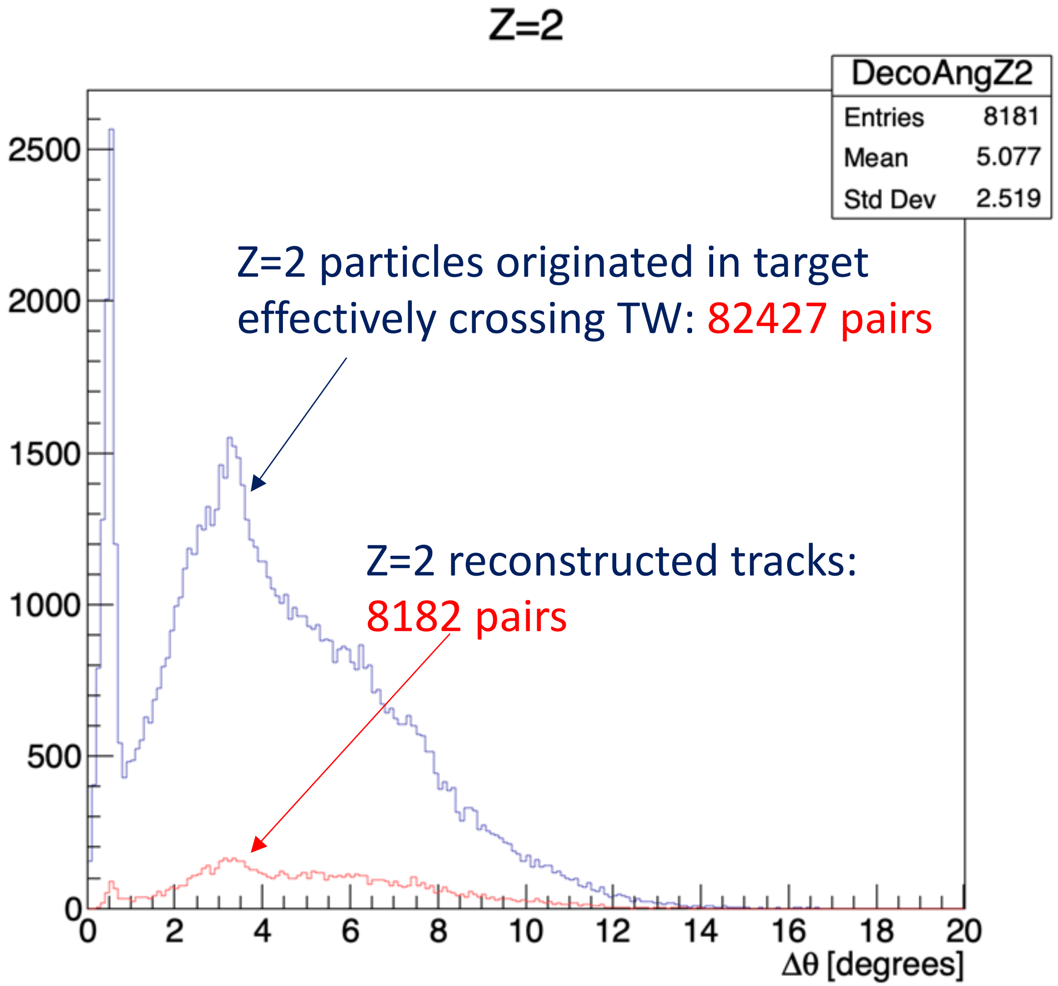
8182 pairs selected

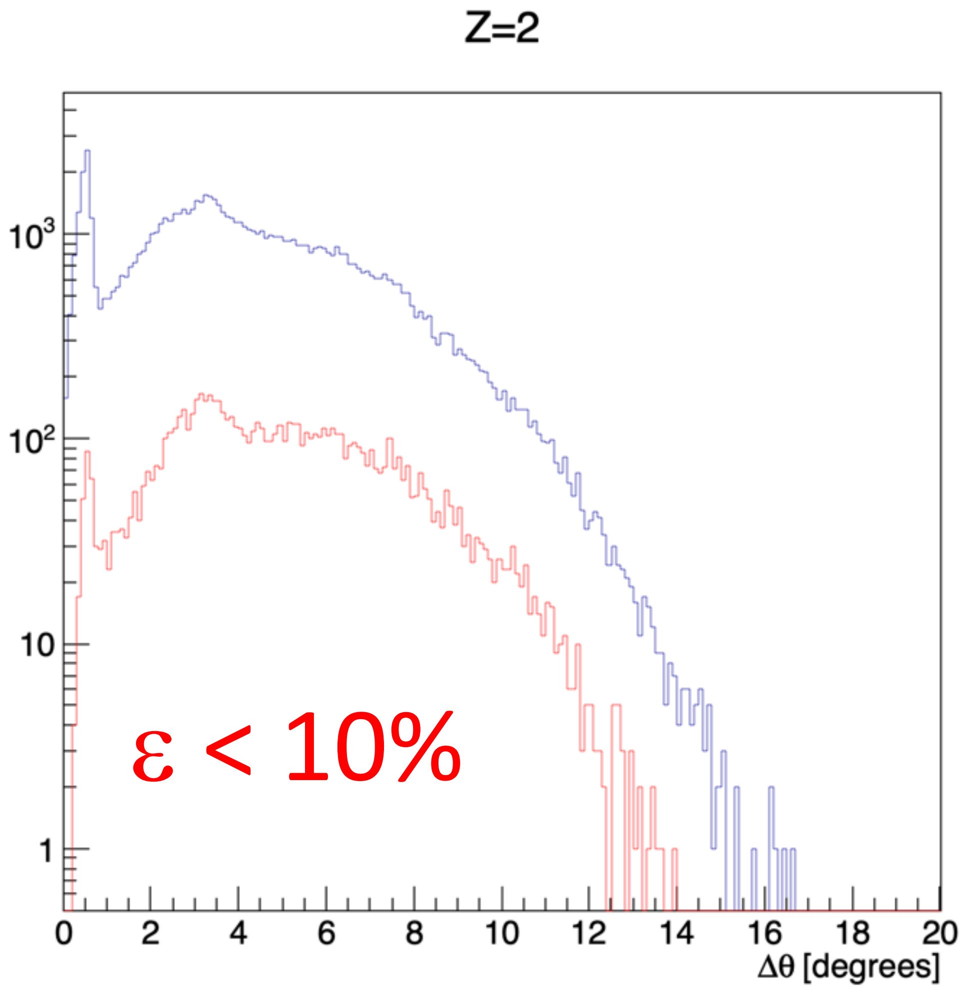


Check with $Z_{rec} = 1$

Althout it might seem a small number, 8000 pairs seem enough for a good analysis

Effect on this analysis of ε due to reconstruction and selection cuts





However, this number of pairs, or even half of that, could be sufficient for the fundamental analysis

Mass reconstruction?

Shoe attempts P reconstruction: on the basis of ToF and Z_{rec}, P is calculated assuming that the track is due to the most abundant isotope for that Z

Surpringly, it turns out that a high fraction of selected tracks match the true Z and A of particles! 73.5% for He

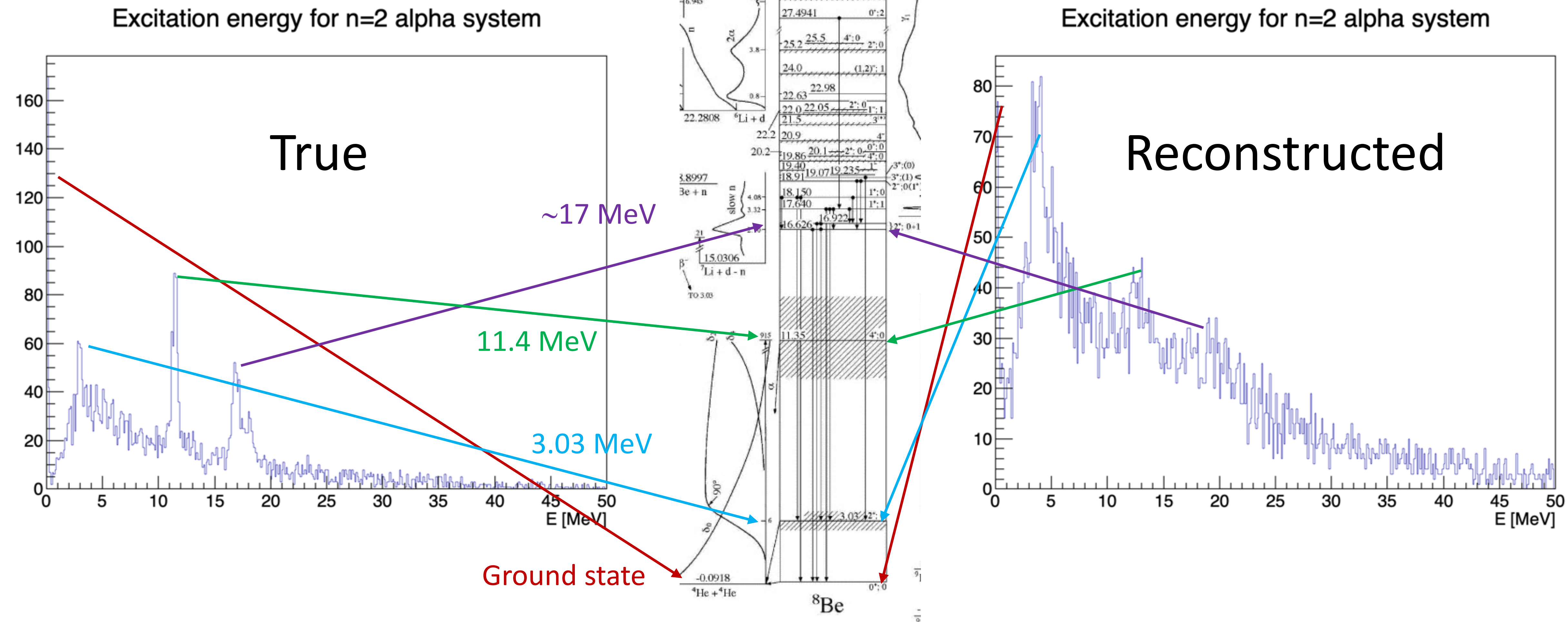
With the only purpose of investigating the features of our MC model, we made the exercise of selecting those tracks which match Z and A. Combining the evaluated P+ reconstructed Tof we derive M for the subsample of reconstructed α's

$$M = \frac{P}{c\beta\gamma}$$

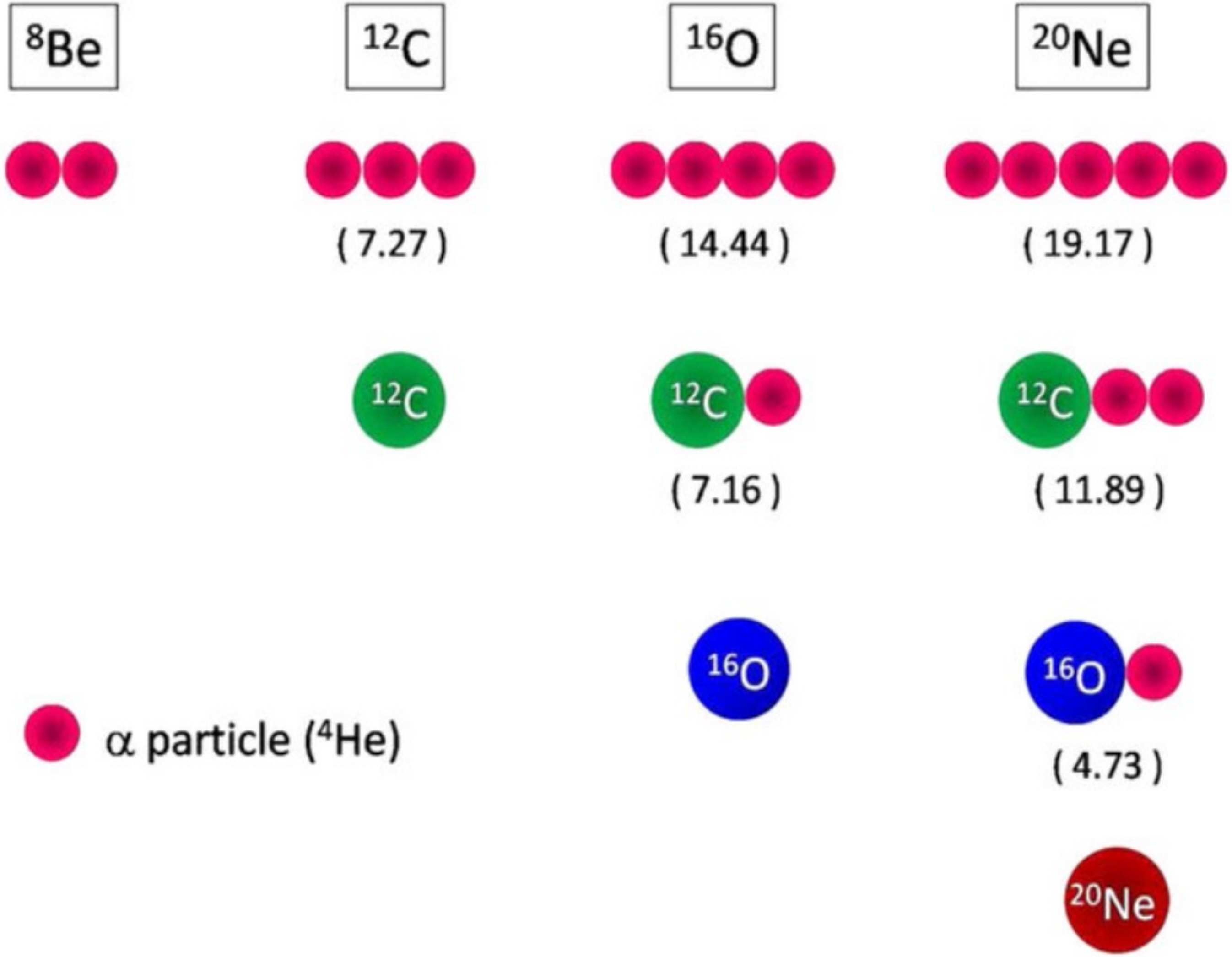
This allows us to try to build invariant mass and get the excitation energy *(see A. Caglioni talk at Trento meeting for details)*

Excitation Energy for 2 α system

$$E_{ex} = \sqrt{(E_i^{kin} + E_j^{kin} + 2m_\alpha)^2 - (\vec{p_i} + \vec{p_j})^2} - m_{^8Be}$$



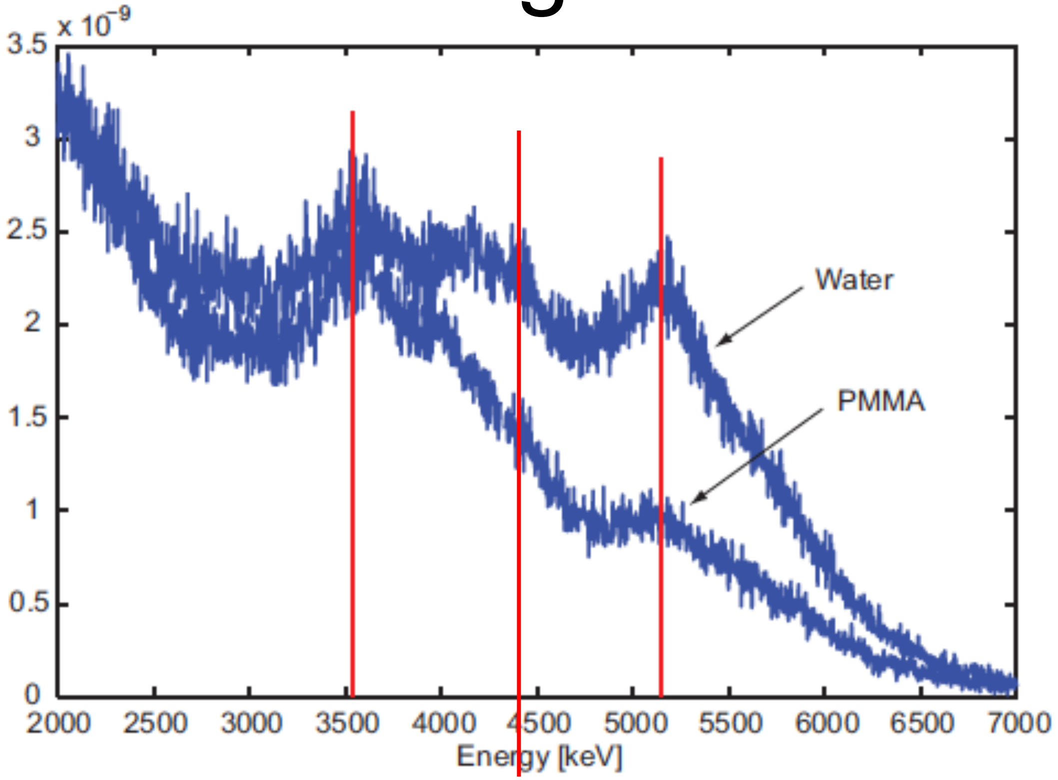
Angular Separation of α pairs vs Ex. Energy

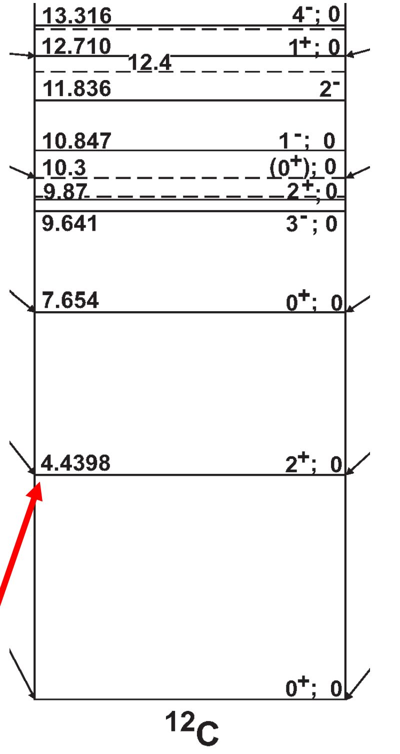


The relevance of this exercise is that, while for ^{12}C, FLUKA includes explicitely the $^{12}C \rightarrow {}^{8}Be + \alpha$ channel with an expected frequency, in the case of ^{16}O there is a pure phase space fragmentation
(see talk at Bergamo General Meeting)

This results, which cleary highlights the ^{8}Be energy levels, suggests that the sequential fragmentation channels
$^{16}O \rightarrow {}^{12}C + \alpha \rightarrow {}^{8}Be + \alpha + \alpha$
should be the dominant one in the model

Prompt γ-ray spectrum from Water and PMMA using a small LYSO crystal





In the spectrum, single- and double-escape peaks are visible for the 4.44 MeV peak

Peak energy (MeV)	Interpretation
$3.42 = 4.44 - 2 \times 0.511$	$^{12}C(p,p^*)^{12}C^*$
$3.93 = 4.44 - 0.511$	$^{16}O(p,x)^{12}C^*$
4.44	$^{12}C(p,sp)^{11}B^*$
$5.107 = 6.129 - 2 \times 0.511$	$^{19}O(p,p^*)^{16}O^*$

In water: $^{16}O \rightarrow {}^{12}C^* + \alpha$

Excitation energy Analysis for 3 system in ^{12}C events

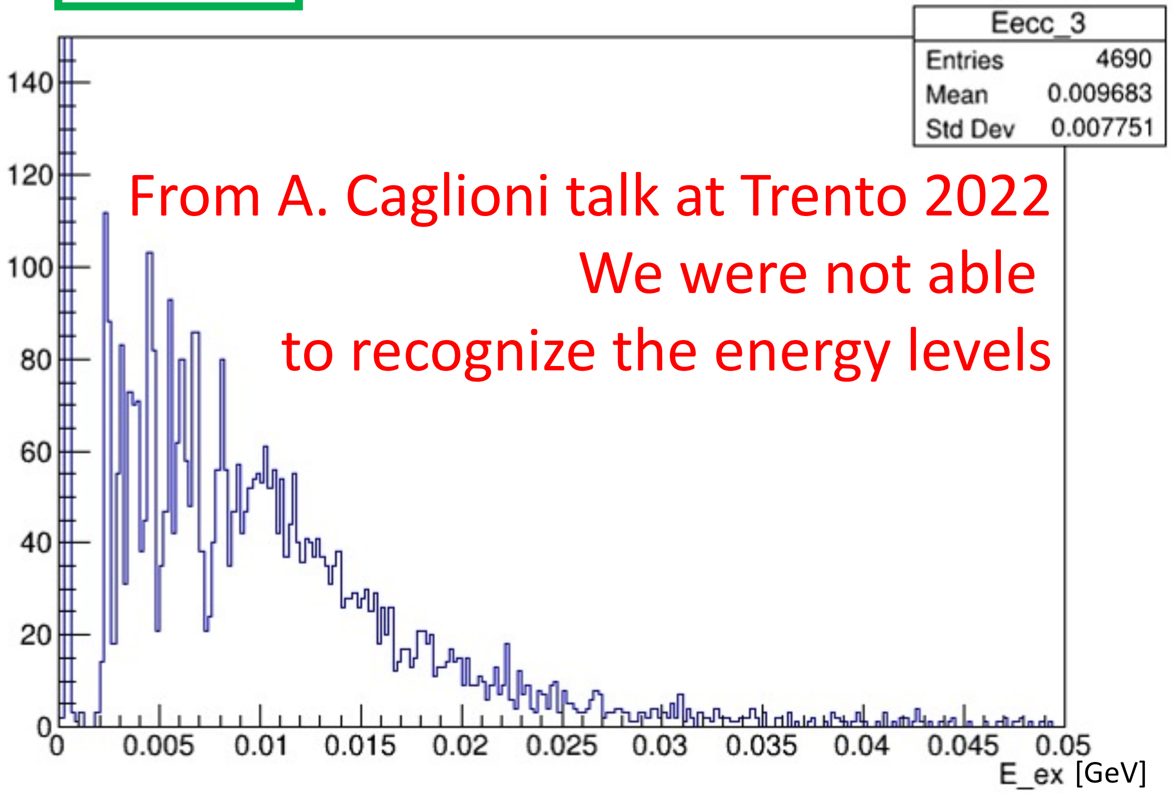
$$E_{ex} = \sqrt{(E_i^{kin} + E_j^{kin} + E_k^{kin} + 3m_\alpha^2)^2 - (\vec{p_i} + \vec{p_j} + \vec{p_k})^2} - 3m_\alpha$$

$^{12}C(\alpha, 2\alpha)$

MC Truth

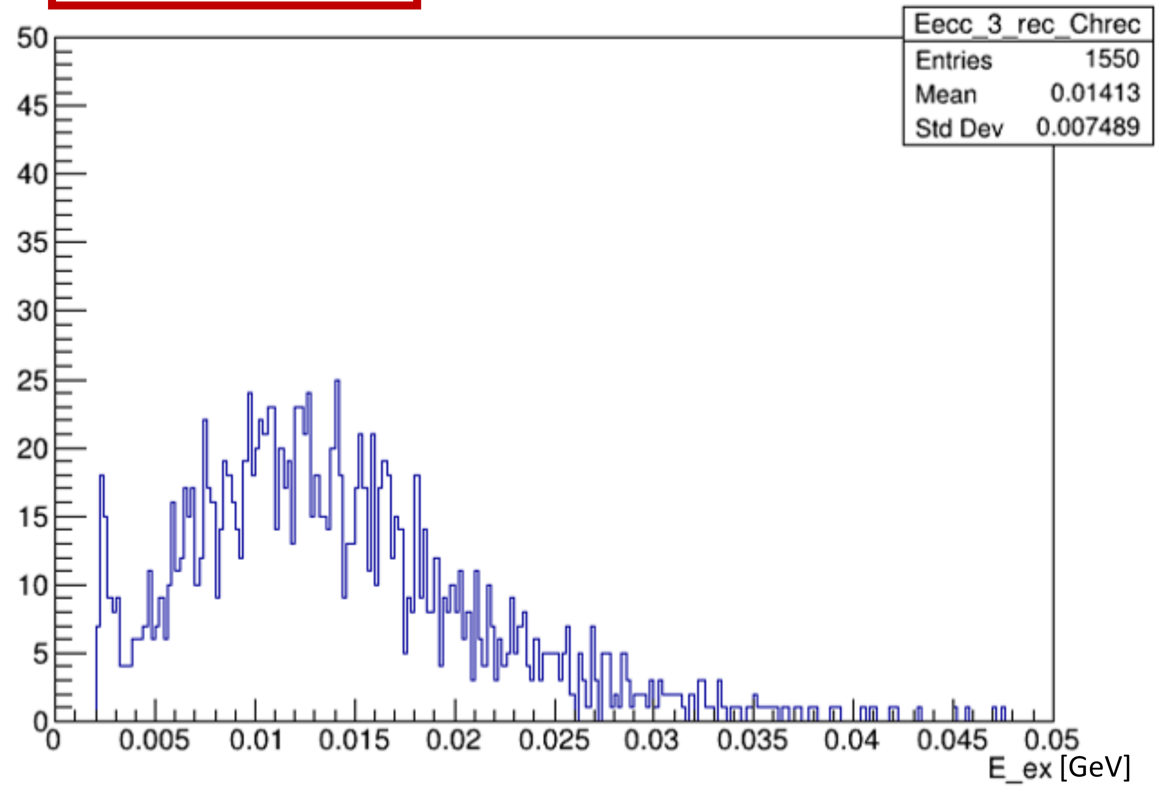
From A. Caglioni talk at Trento 2022

We were not able to recognize the energy levels



Excitation energy spectrum for the breakup of ^{12}C into 3 α particles from MC Truth α particles analysis.

Reconstruction

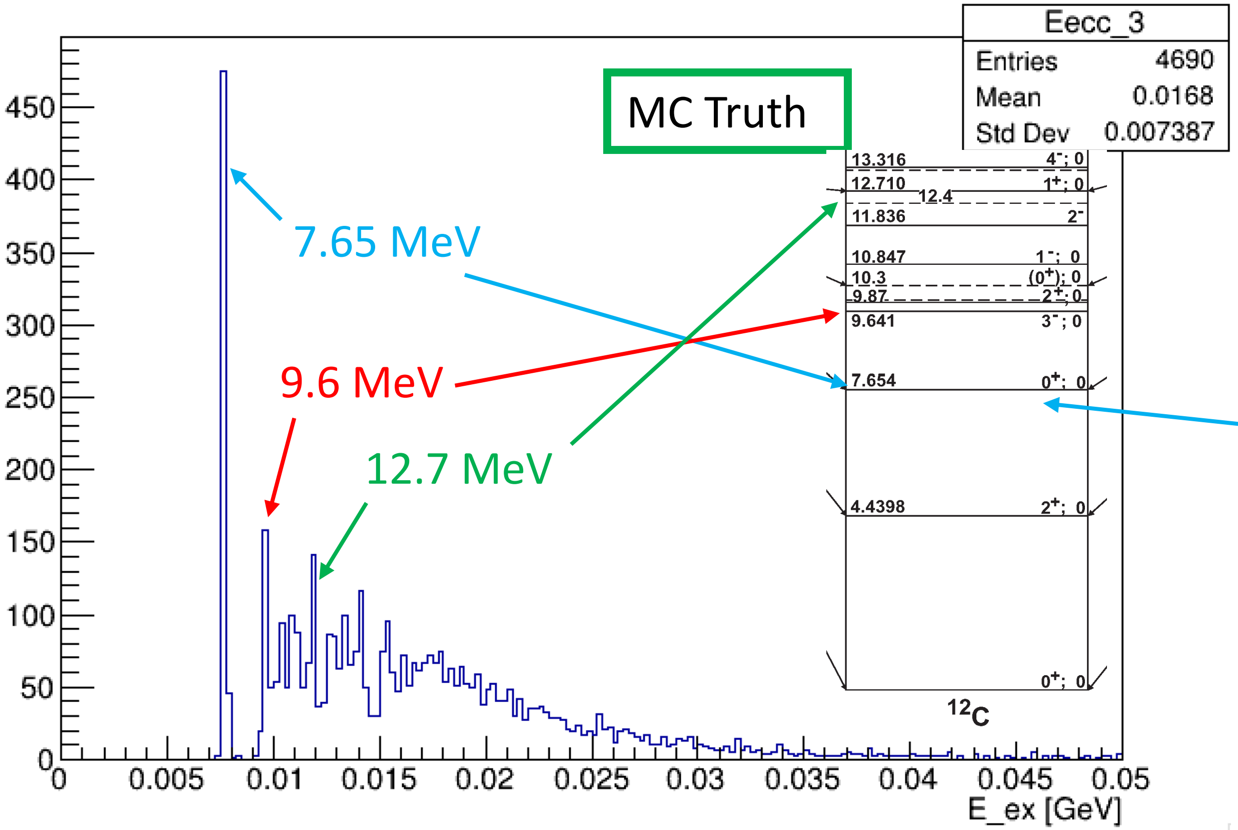


Excitation energy spectrum for the breakup of ^{12}C into 3 α particles from Reconstruction α particles analysis.

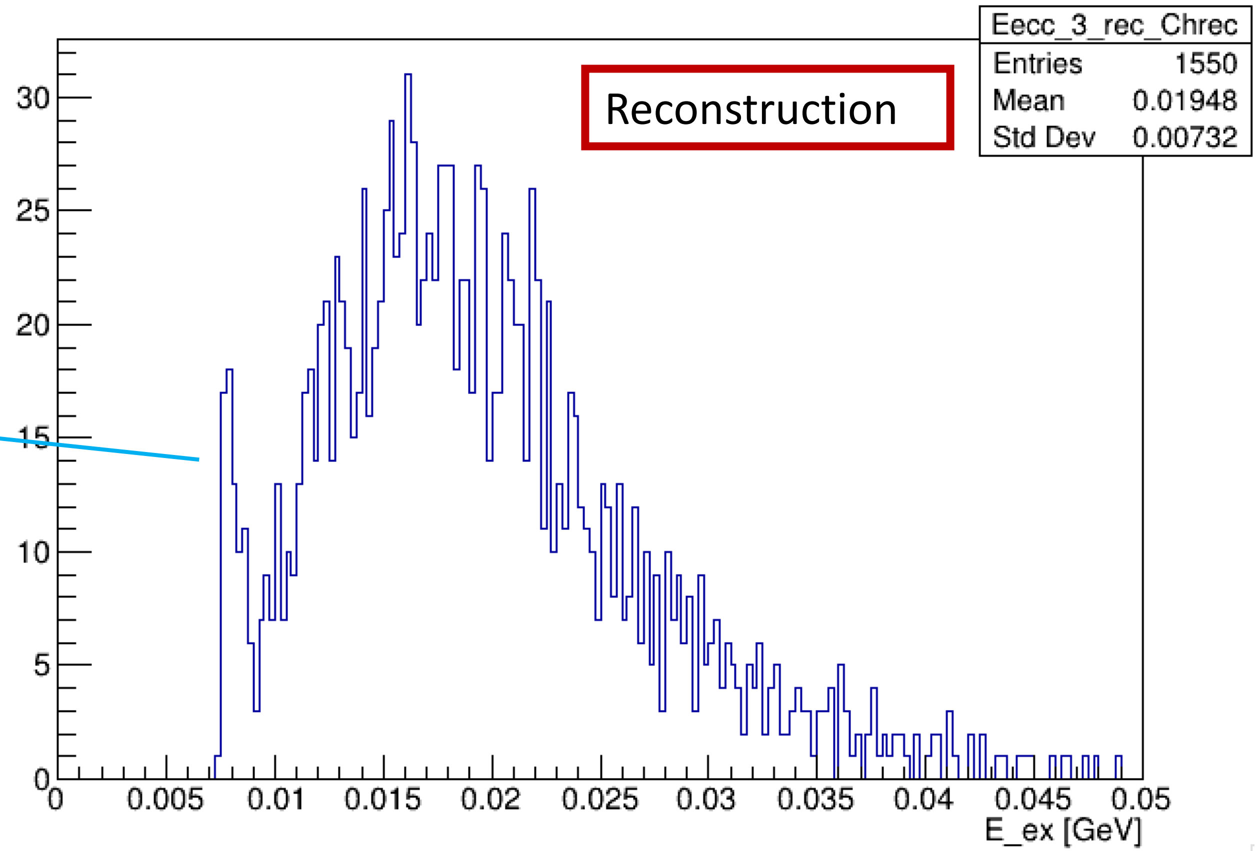
Correct way to calculate Exc. energy in the ^{12}C hypothesis

Nuclear mass of ^{12}C = 11.174875 Gev/c^2

$$E_{ex} = \sqrt{(E_i^{kin} + E_j^{kin} + E_k^{kin} + 3m_\alpha)^2 - (\vec{p_i} + \vec{p_j} + \vec{p_k})^2} - m_{^{12}C}$$



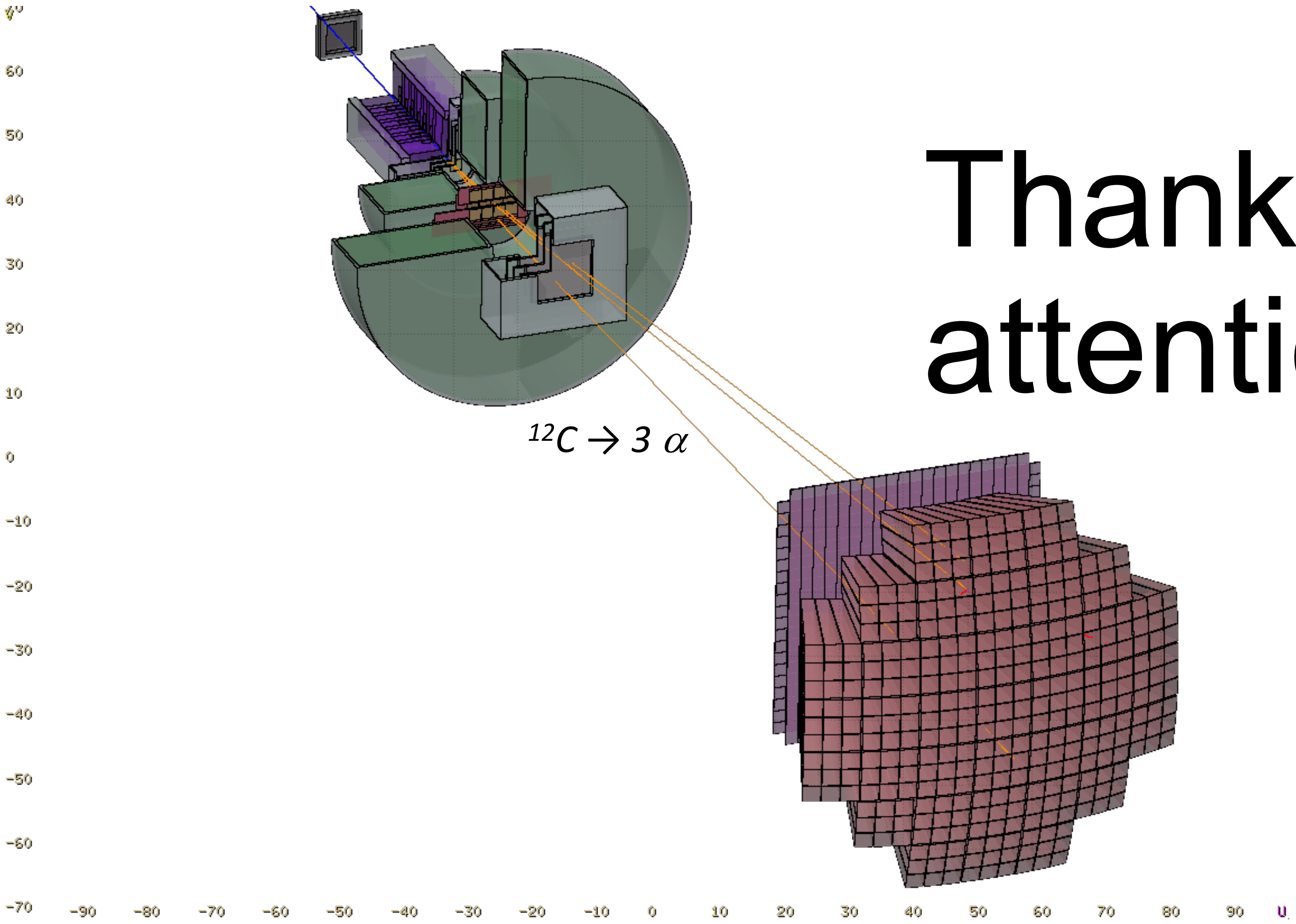
Excitation energy spectrum for the breakup of ^{12}C into 3 α particles from **MC Truth** α particles analysis.



Excitation energy spectrum for the breakup of ^{12}C into 2 α particles from **Reconstruction** α particles analysis with **RECO charge** selection **without MC hp**.

Conclusions

- The status of track reconstruction for GSI2021 has been positively tested on MC
- Although the efficiency for multi-track events is evidently low, the resulting Z-id should be very accurate
- Provided that at least 2 – 3 million primary events are available for the analysis, and TW efficiency for Z=2 detection is sufficient, it should be possible to obtain a statistically significant analysis of multi-α production
- Goals: multiplicity distribution, angular separation distribution for a 2 α system.
- For next data runs with full magnetic setup, the excitation energy analysis is viable
- We have also theoretically understood how to perform 3-α analysis, but this seems not viable for GSI2021



Thanks for the attention