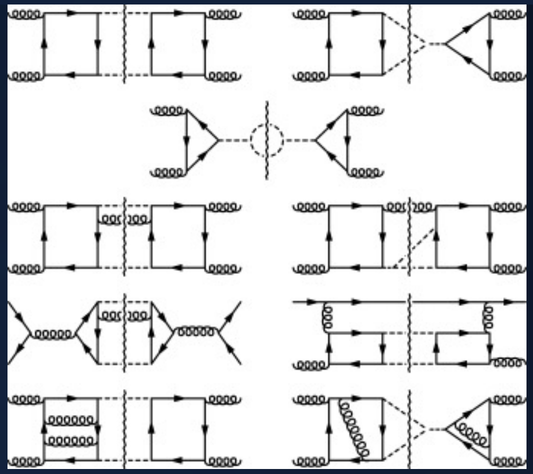
Clustering fragmentation: a 1st analysis of CNAO2021 data. Comparison with MC

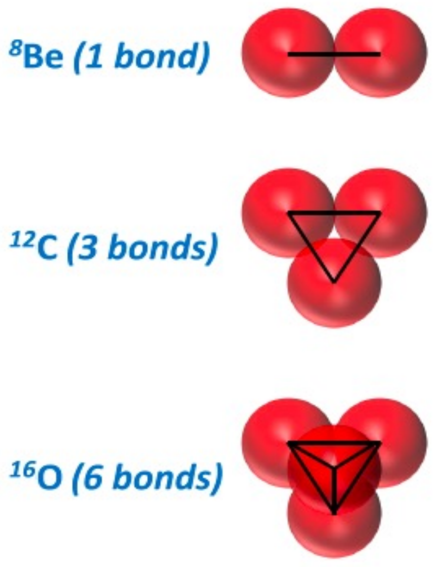
Giuseppe, Aafke, Silvia

A NNNLO analysis

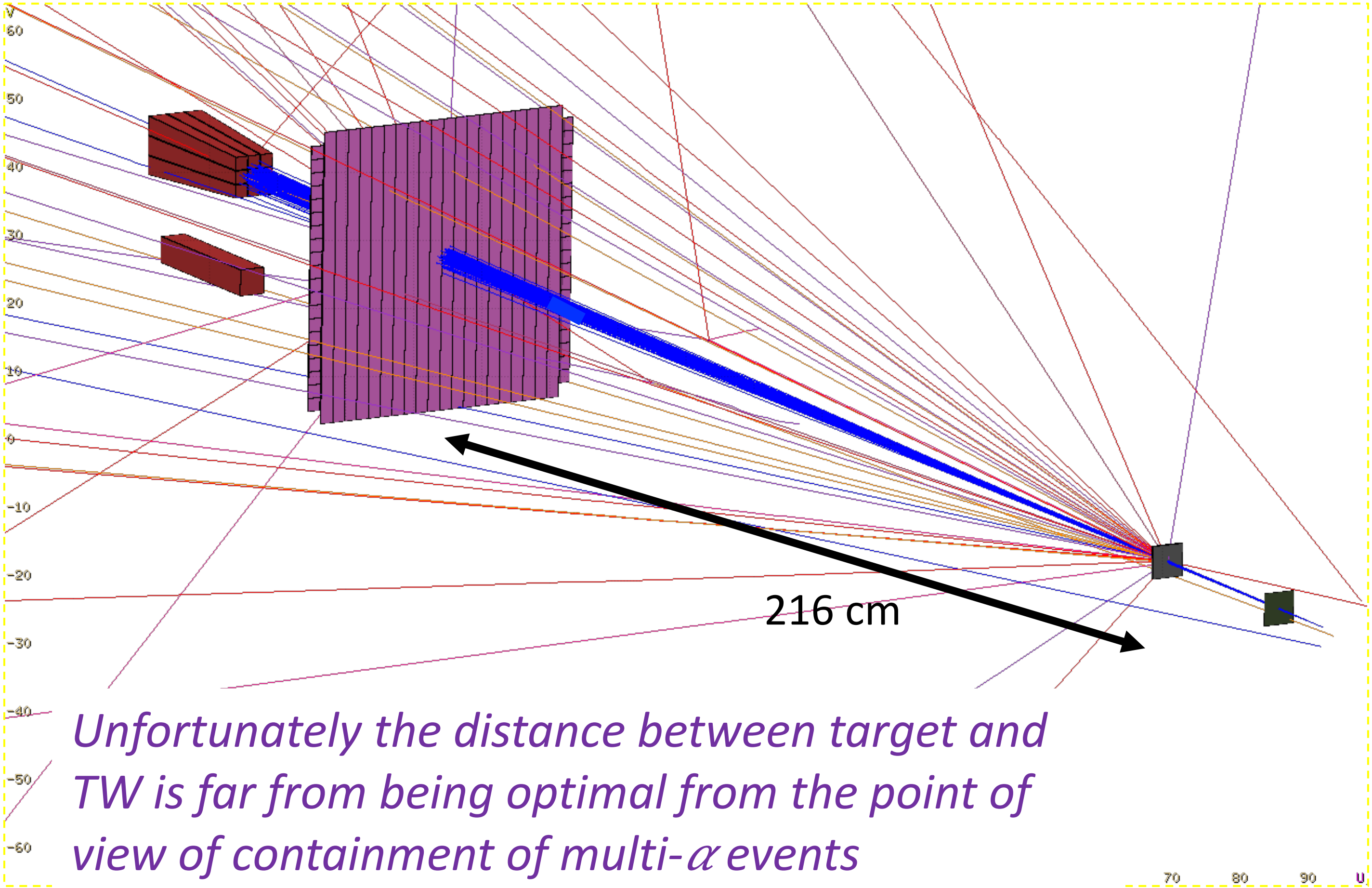


Just a quick reminder

- Nucleons in nuclei tend to organize themselves in a close packing of rigid spheres: α-particles, which are highly symmetric and bound systems
- "self-conjugated" (or α-conjugated) configurations (even-even nuclei) can be thought as aggregates α-particles.
- Clustering appears in preferential dissociation channels like: $^{12}C \rightarrow 3\ \alpha$, $^{16}O \rightarrow 4\ \alpha$, etc.
- These tend to proceed through intermediate channels. For instance: $^{12}C \rightarrow {}^{8}Be + \alpha \rightarrow 3\ \alpha$
- Data taken at CNAO in November 2021 with just SC+TW can be used to test the capability of FOOT to study the dependence on energy of multi- α fragmentation of ^{12}C
- Very preliminary multiplicity distributions were presented at previous physics meetings



Experiment geometry and analysis goals



Unfortunately the distance between target and TW is far from being optimal from the point of view of containment of multi-α events

Having a very limited calo, we cannot identify α's. We can just identify Z=2 fragments. There is a contamination from ^{3}He (few) and ^{6}He (very very few)

Analysis goals:

- Count the number of Z=2 particles produced in target arriving at TW
- How many ^{12}C → 3 Z=2 are we able to identify (they are very probaby 3 α's)?
- Does the multiplicity distribution change with energy?
- Can we analyse the distribution of relative distances of Z=2 fragments and indentify the peak due to ^{12}C → ^{8}Be + α → 3 α ?

Data set CNAO2021

- Exp. Data Selection:

For this preliminary analysis we selected a first batch of data from the 3rd night (CNAO2021), when 4 different energies were considered (150, 200, 300, 400 MeV/u). For the moment we limited ourselves only to runs where the majority trigger was used ("Trig. 40")

150: runs 10650-10850 (402k events)
200: runs 10900-11000 (201k events)
300: runs 11100-11231 (264k events)
400: runs 11300-11368 (138k events)

Analysis of multiplicity of exp. data has been performed using both shoe and an independent stand-alone reconstruction (in shoe, exp. data are decoded using DecodeWD)

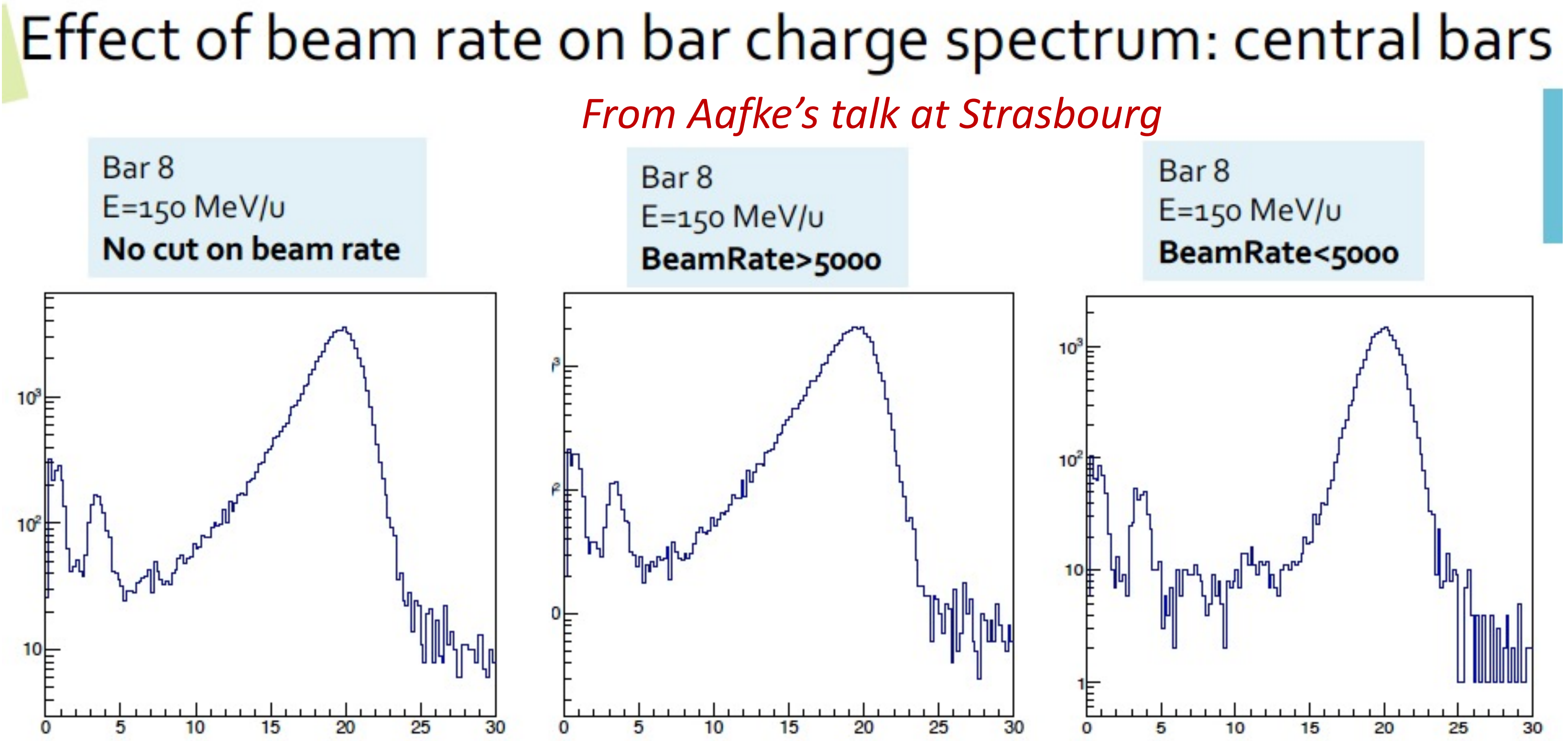
- MC Data:

MC data: only shoe reconstruction is available

2.e+6 events for each energy (CNAO2021_MC campaign)

Data selection (1)

Exp. Data Selection: at Strasbourg meeting it was shown that also for CNAO2021 data the quality of TW data may depend on beam rate. However, while this is important for Z>2, the capability of identifying the Z=2 charge peak seems to remain almost independent of rate



➔ therefore, for the moment, no cut on beam rate has been applied in data selection

Data selection (2)

- Looking for reconstructed TW points with Z_{rec}=2
  - In configuration file: EnableTWZmc n (using the same algorithm as for real data)
- Look at:
  - Multiplicity of Z=2 TWpoints
  - Distance between Z=2 TWpoints

For both experimental data and MC data:

a) The whole TW surface is used

b) We include also the count of N=0 events

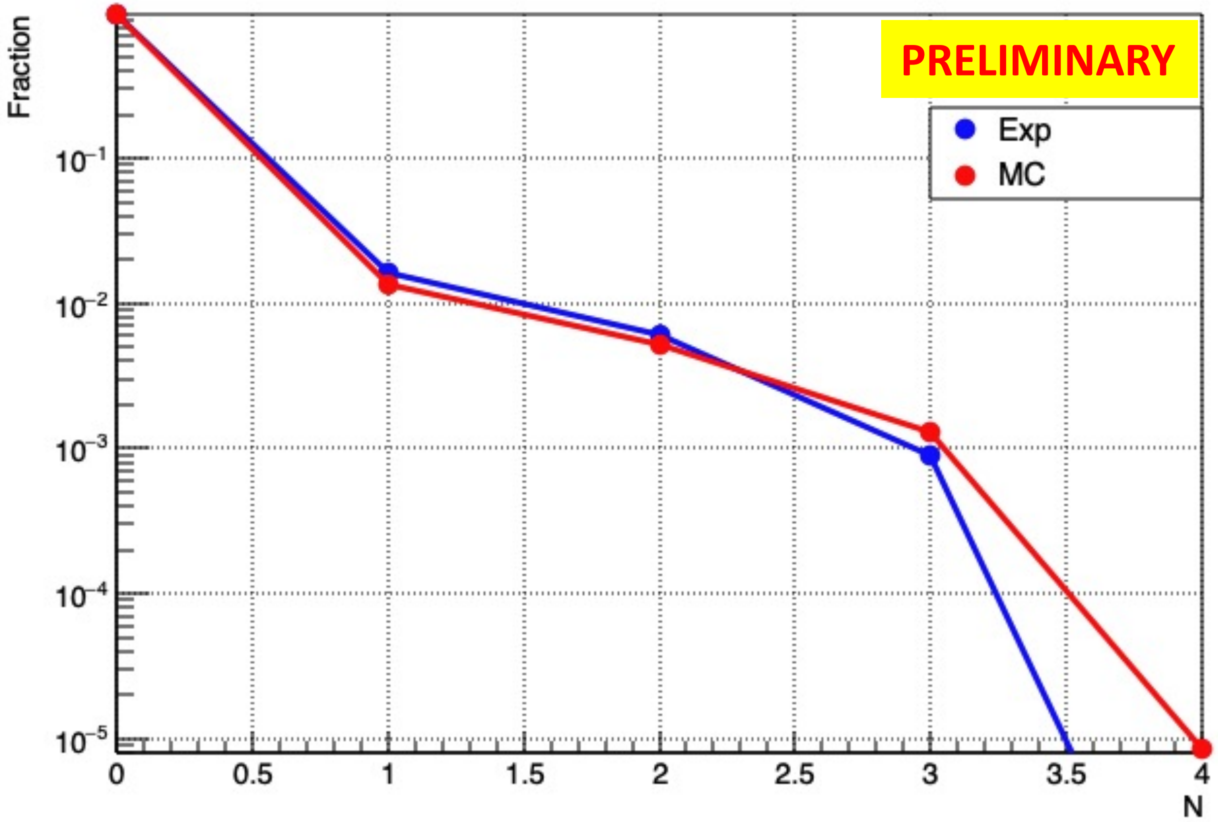
A first comparison with experimental data: 150 MeV/u

- Fraction of the total no. of primaries

- Only the statistical exp. error is reported. Statistical error on MC is lower by a factor of ~4
- Systematics and efficiency not yet evaluated

- The inclusion of N=0 allows to consider the absolute rate (cross section)

Multiplicity of TW points with Z_{rec}=2



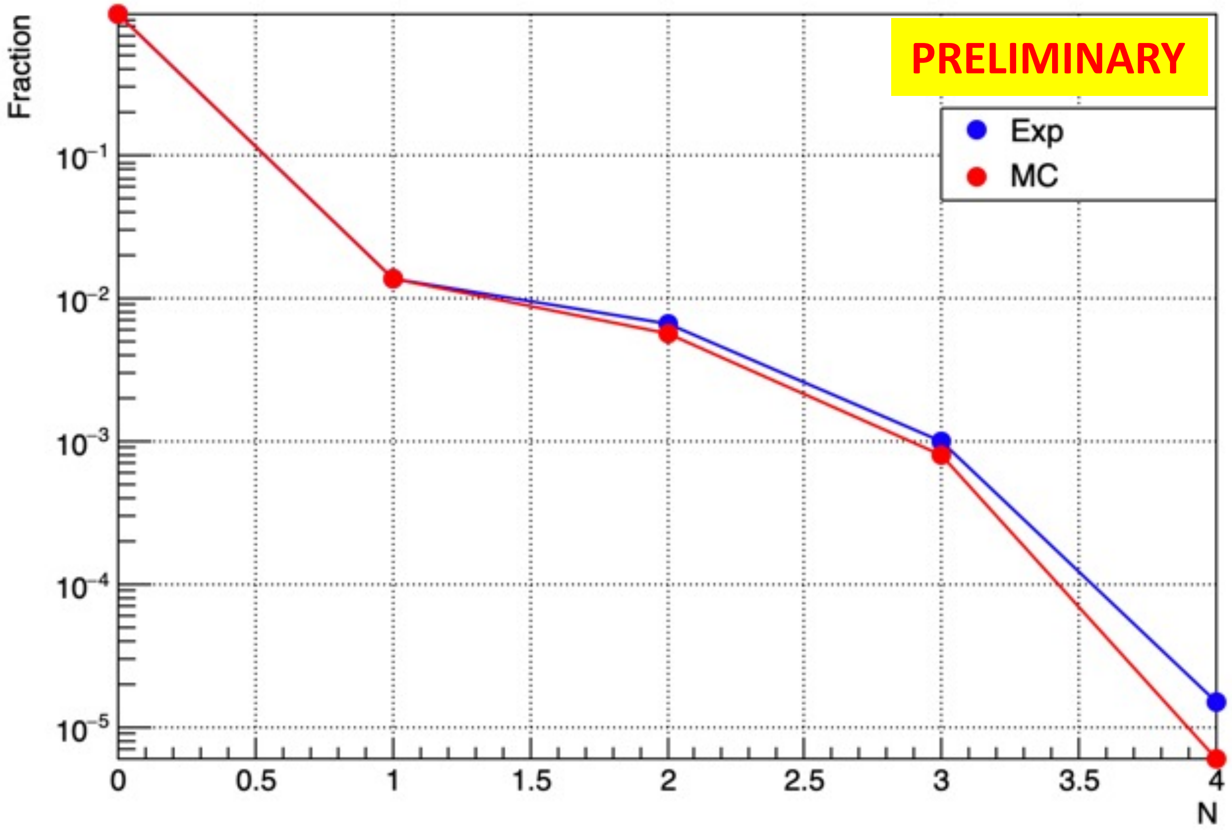
A first comparison with experimental data: 200 MeV/u

- Fraction of the total no. of primaries

- Only the statistical exp. error is reported. Statistical error on MC is lower by a factor of ~4
- Systematics and efficiency not yet evaluated

- The inclusion of N=0 allows to consider the absolute rate (cross section)

Multiplicity of TW points with Z_{rec}=2



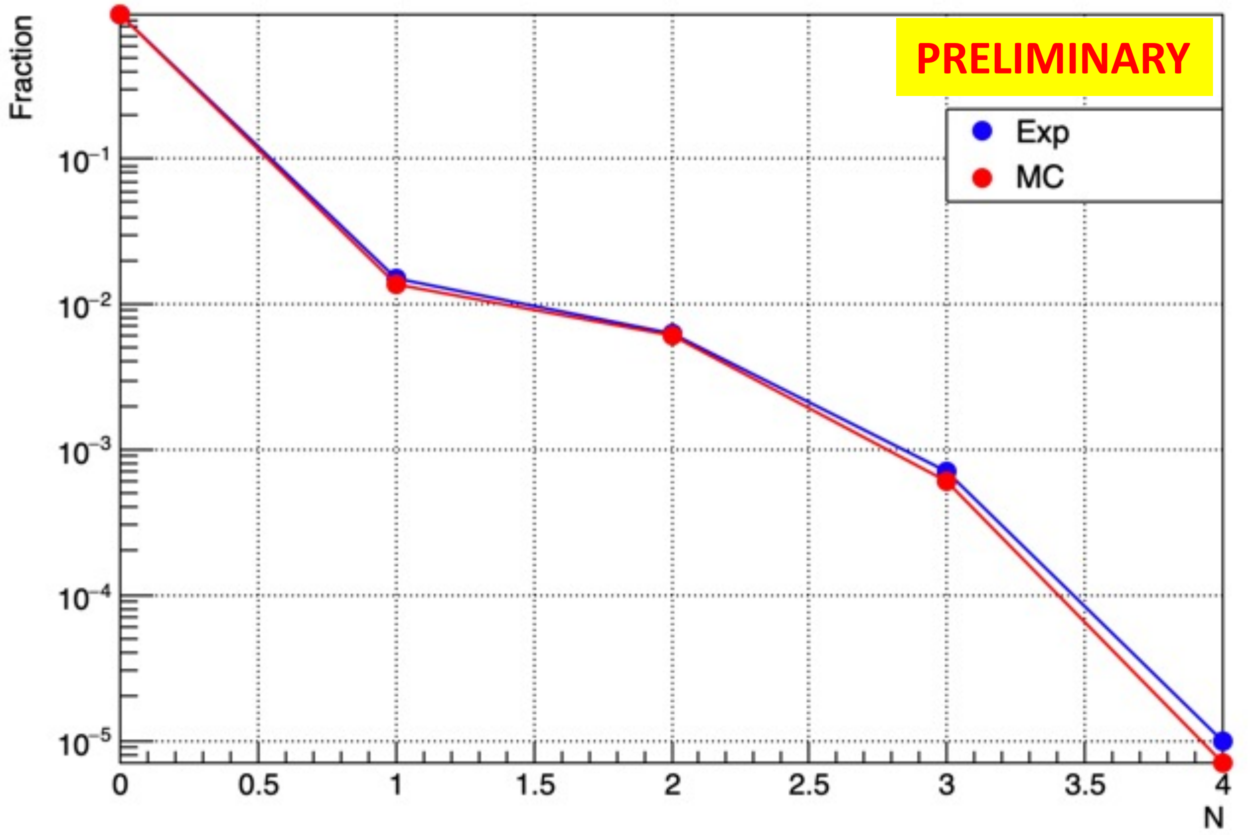
A first comparison with experimental data: 300 MeV/u

- Fraction of the total no. of primaries

- Only the statistical exp. error is reported. Statistical error on MC is lower by a factor of ~4
- Systematics and efficiency not yet evaluated

- The inclusion of N=0 allows to consider the absolute rate (cross section)

Multiplicity of TW points with Z_{rec}=2



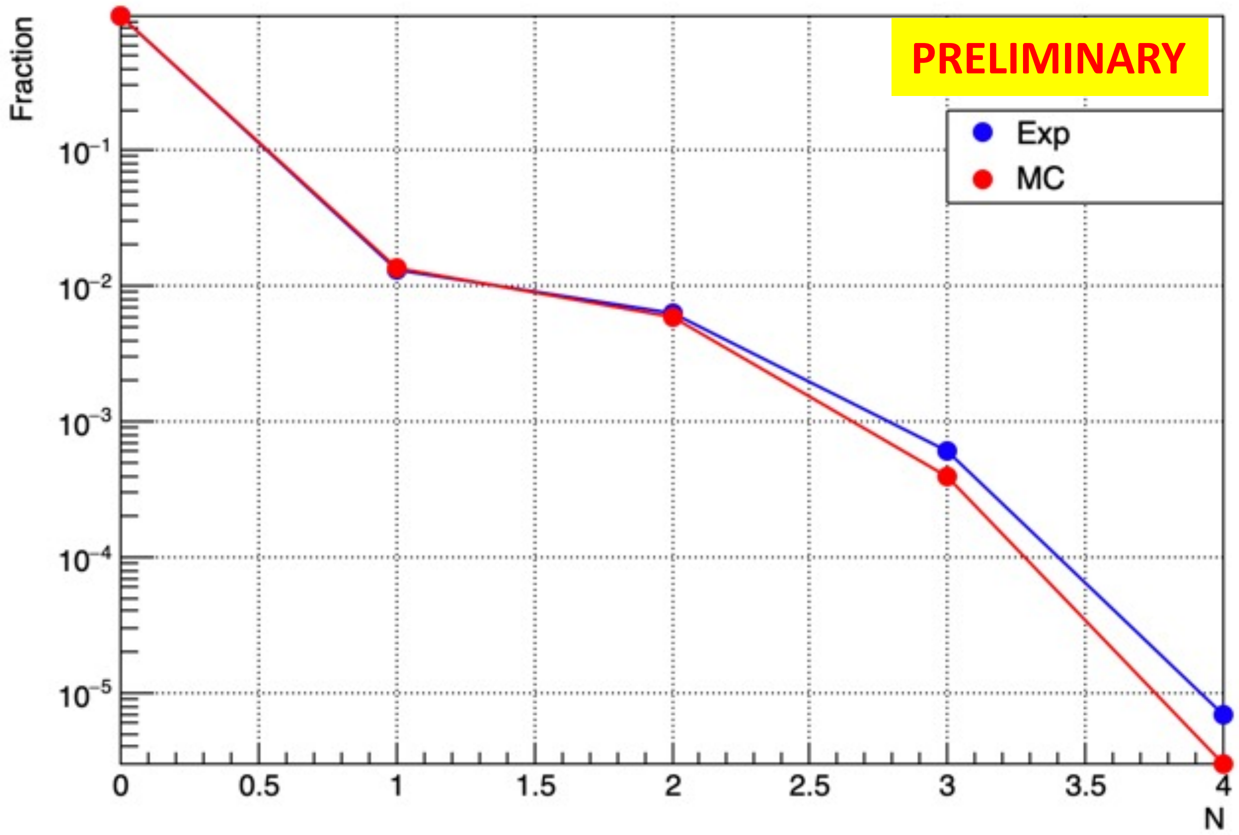
A first comparison with experimental data: 400 MeV/u

- Fraction of the total no. of primaries

- Only the statistical exp. error is reported. Statistical error on MC is lower by a factor of ~4
- Systematics and efficiency not yet evaluated

- The inclusion of N=0 allows to consider the absolute rate (cross section)

Multiplicity of TW points with Z_{rec}=2



Summary of multiplicity of Z=2 for all energies

Data

N	150 MeV/u	200 MeV/u	300 MeV/u	400 MeV/u
0	0.9767 ± 0.0016	0.9785 ± 0.0022	0.9782 ± 0.0019	0.9798 ± 0.0019
1	0.0162 ± 0.0002	0.0139 ± 0.0003	0.0149 ± 0.0002	0.0162 ± 0.0002
2	0.0061 ± 0.0001	0.0067 ± 0.0001	0.0062 ± 0.0002	0.0061 ± 0.0002
3	0.0009 ± 0.0001	0.0010 ± 0.0001	0.0007 ± 0.0001	0.0009 ± 0.0001
4	1e-7 $\pm 0.9e-7$	1.5e-5 ± 0.0001	0.00001 ± 0.0001	1.e-7 ± 0.0001

Stat error

Monte Carlo

N	150 MeV/u	200 MeV/u	300 MeV/u	400 MeV/u
0	0.9799	0.9797	0.9797	0.9798
1	0.0136	0.0138	0.0137	0.0138
2	0.0052	0.0057	0.0060	0.0060
3	0.0013	0.0008	0.0006	0.0004
4	8.5e-6	6e-6	7e-6	3.e-6

- Numbers with respect to nr primaries
- Numbers pretty similar!
- No strong energy dependence
- No error evaluation included

Stat error about 4 x smaller

Distribution of spatial separation between Z=2 fragments

- As shown in previous talks about clustering, the analysis of spatial (or angular) correlations between α's allows a first investigation of 2-step processes, like the expected $^{12}C \rightarrow {}^{8}Be + \alpha \rightarrow 3\ \alpha$

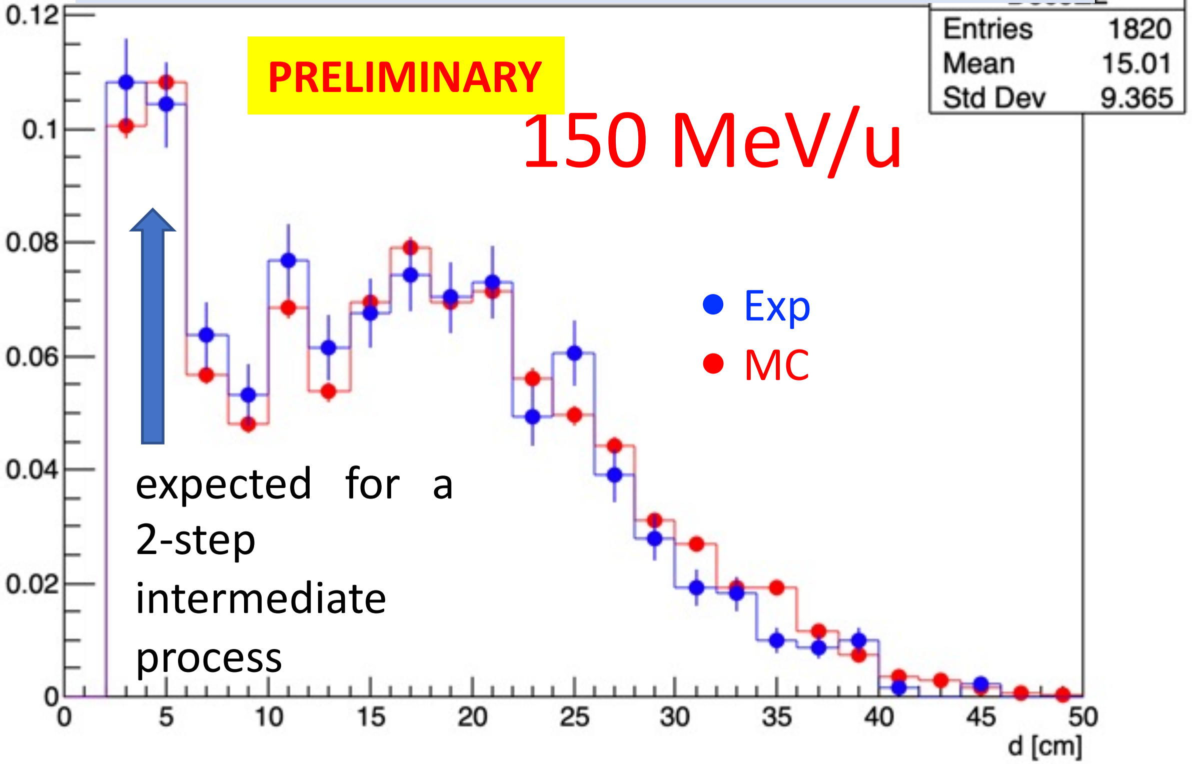
→Studying the relative distance between the TWpoints with Z_{rec}=2 allows us to investigate the Monte Carlo modelling of these processes

- Without precision tracking detectors we can only measure the relative distances between reconstructed TW points with Z_{rec}=2 ➔ 2 cm resolution ("Decoherence" distribution)

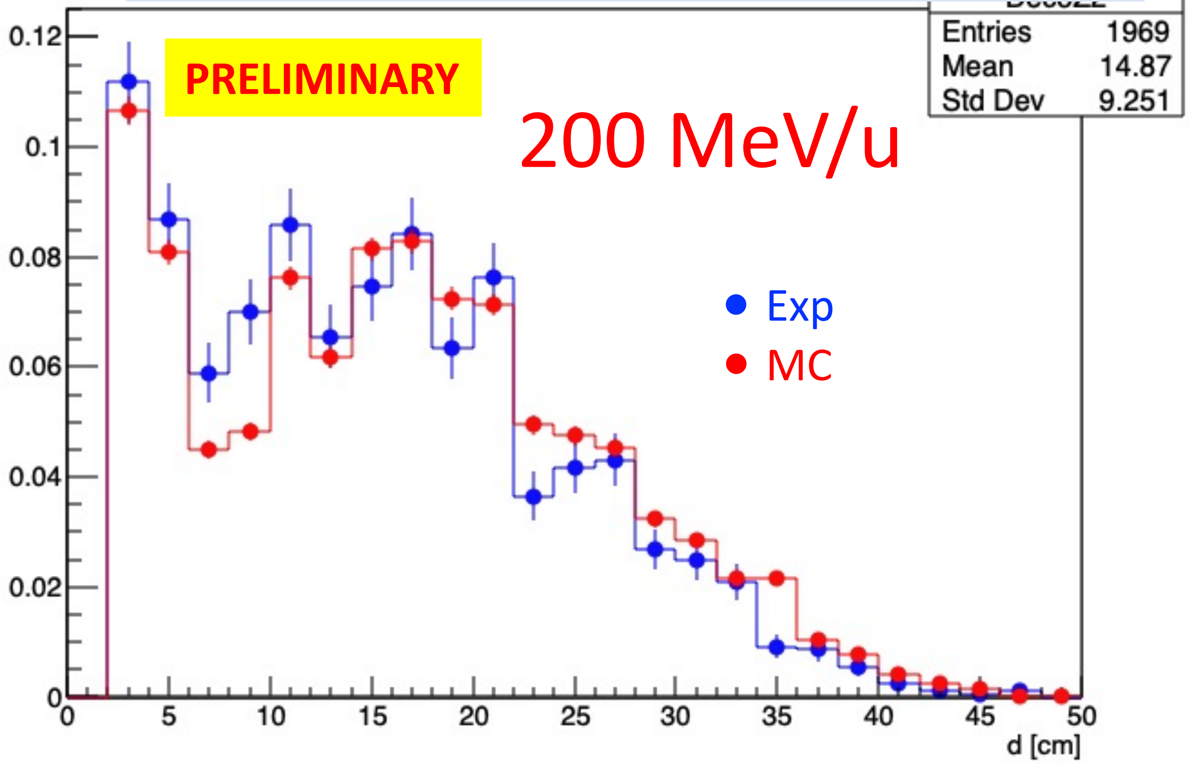
A first comparison with experimental data

Normalized to same area

Distance between TW points with Z_{rec}=2



Distance between TW points with Z_{rec}=2

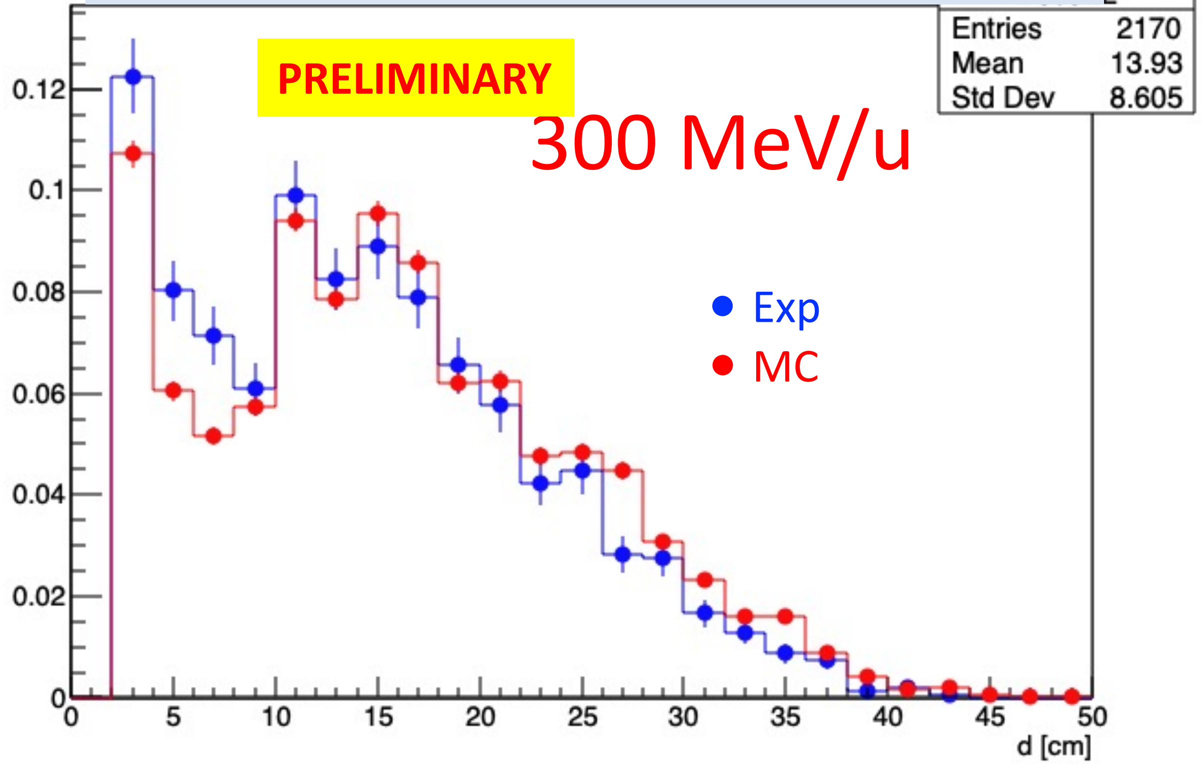


Data and MC seem to match (at least with this rough 2 cm resolution)

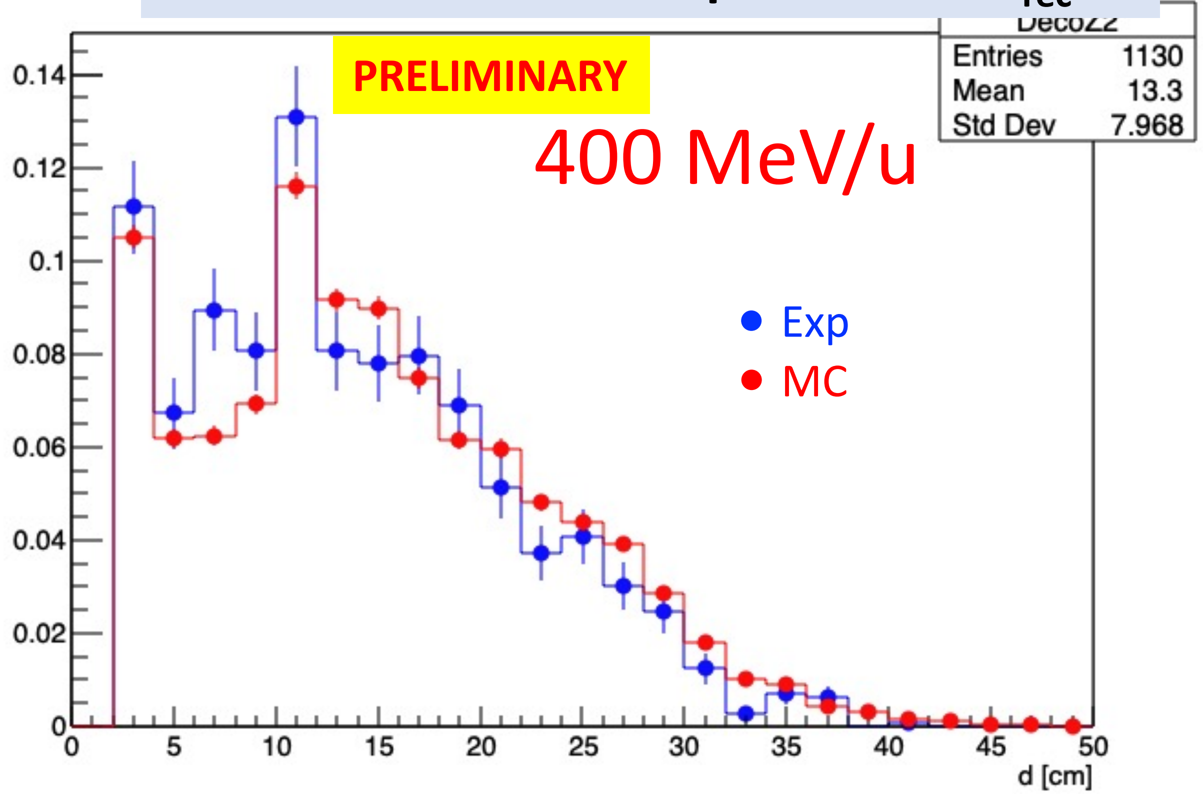
A first comparison with experimental data

Normalized to same area

Distance between TW points with Z_{rec}=2



Distance between TW points with Z_{rec}=2



Data and MC seem to match (at least with this rough 2 cm resolution)

A first comparison with experimental data

Analysis goals:

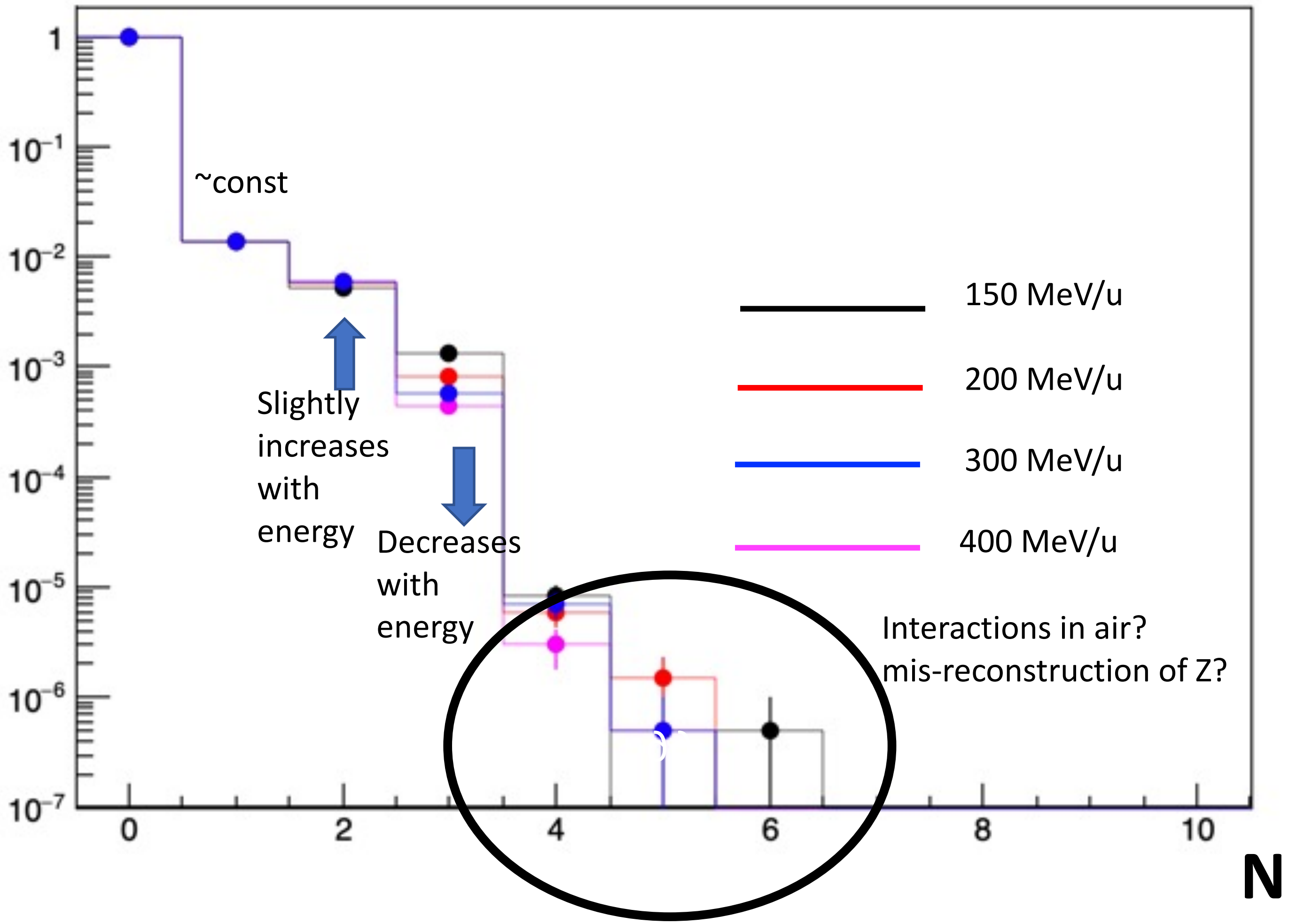
- Count the number of Z=2 particles produced in target arriving at TW
  - ✓ Done
- How many $^{12}C \rightarrow$ 3 Z=2 are we able to identify (they are very probaby 3 α's)?
  - Can count Z=2 but we cannot count 3 ^{4}He
- Does the multiplicity distribution change with energy?
  - ✓ Does not seem so, but more data needed
- Can we analyse the distribution of relative distances of Z=2 fragments and indentify the peak due to $^{12}C \rightarrow {}^{8}Be + \alpha \rightarrow 3\ \alpha$?
  - ✓ Yes, we can

Conclusions

- Geometrical acceptance of CNAO2021 setup was not the optimal for the containment of multi-α events, however a preliminary analysis in terms of clustering was possible.
- The detector allowed the identification of Z=2 (no mass)
- The experimental data in the primary energy range from 150 to 400 MeV/u do not show anomalous values in the probability of producing multi-Z=2 fragments wrt MC
- Spatial distribution of relative distances exhibit a peak at short distances, as expected
- The shape of the distribution of experimental data, concerning both multiplicity ad spatial correlation, are very close to those predicted by the nuclear physics model of FLUKA
- We are still lacking an analysis of efficiency and systematics (for instance: probability of assigning the wrong charge, possible effects due to beam rate, …)
- Near Future: will repeat analysis on CNAO2022 data
- Next-to-Near future: use calorimeter to distinguish ^{2}He, ^{3}He and ^{4}He
- Next-to-Next-to-Near future: new data? Now 200 MeV/u, more energies needed.
- Next-to-Next-to-Next-to-Near future: publication? (efficiency, systematics and other aspects must be included)

MC prediction

Multiplicity of TW points with Z_{rec}=2

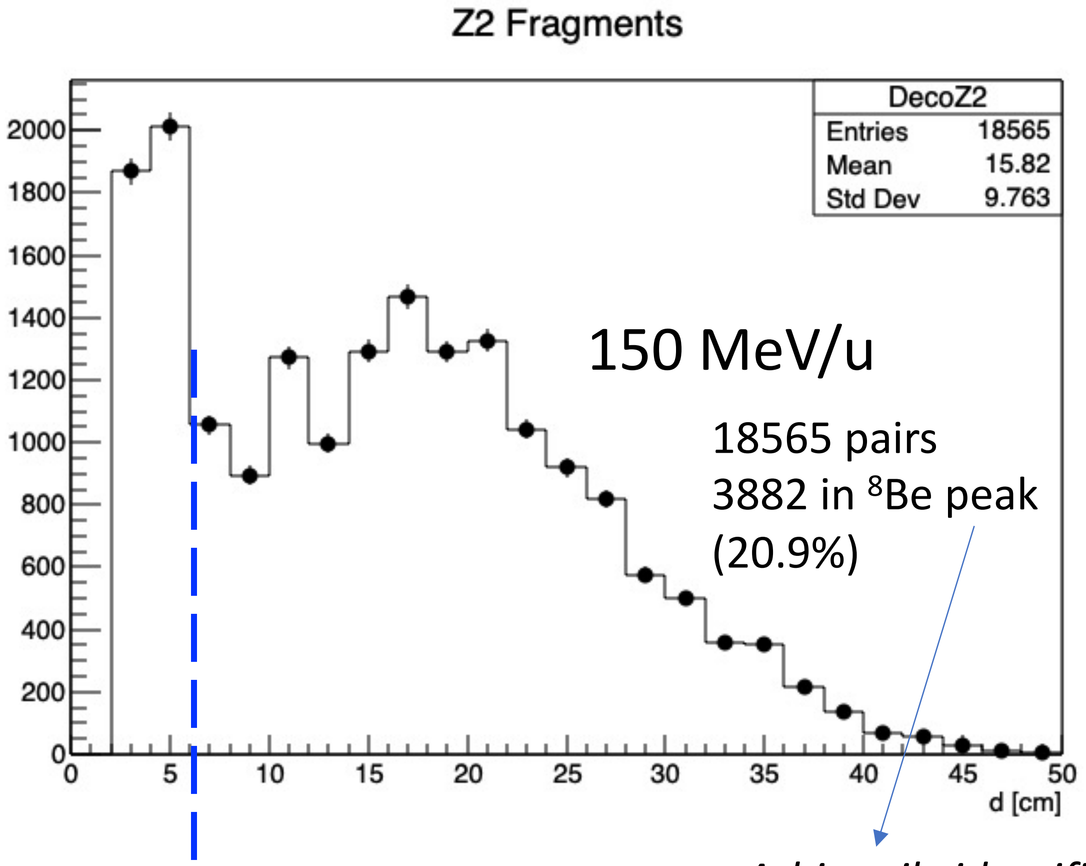


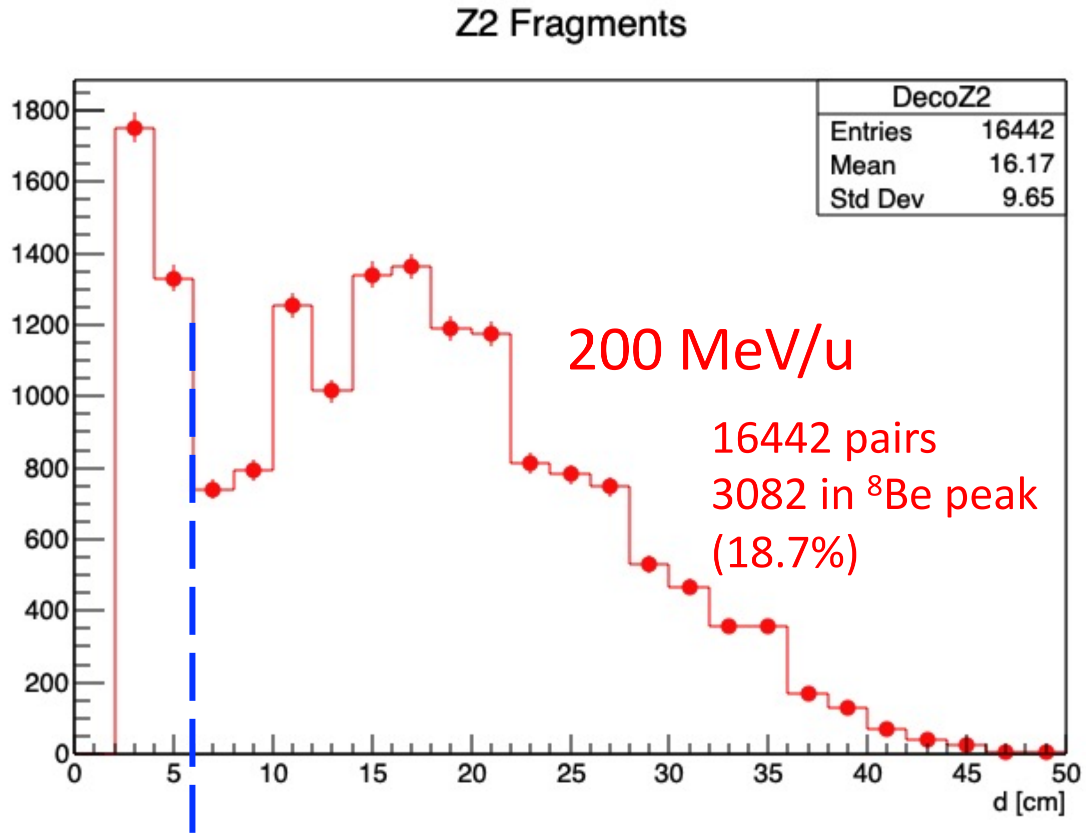
Integral normalized to 1

MC Decoherence of Z=2 fragments

EnableTWZmc n

Relative distance of TW points with Zrec=2



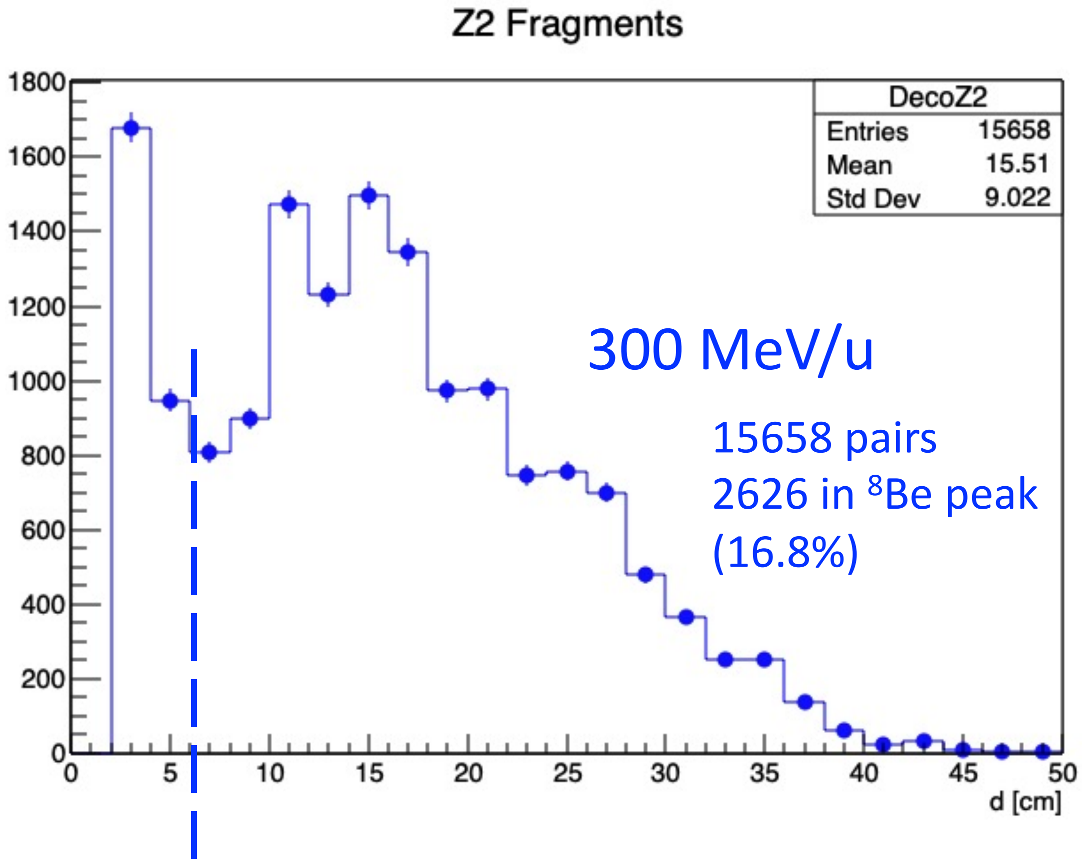


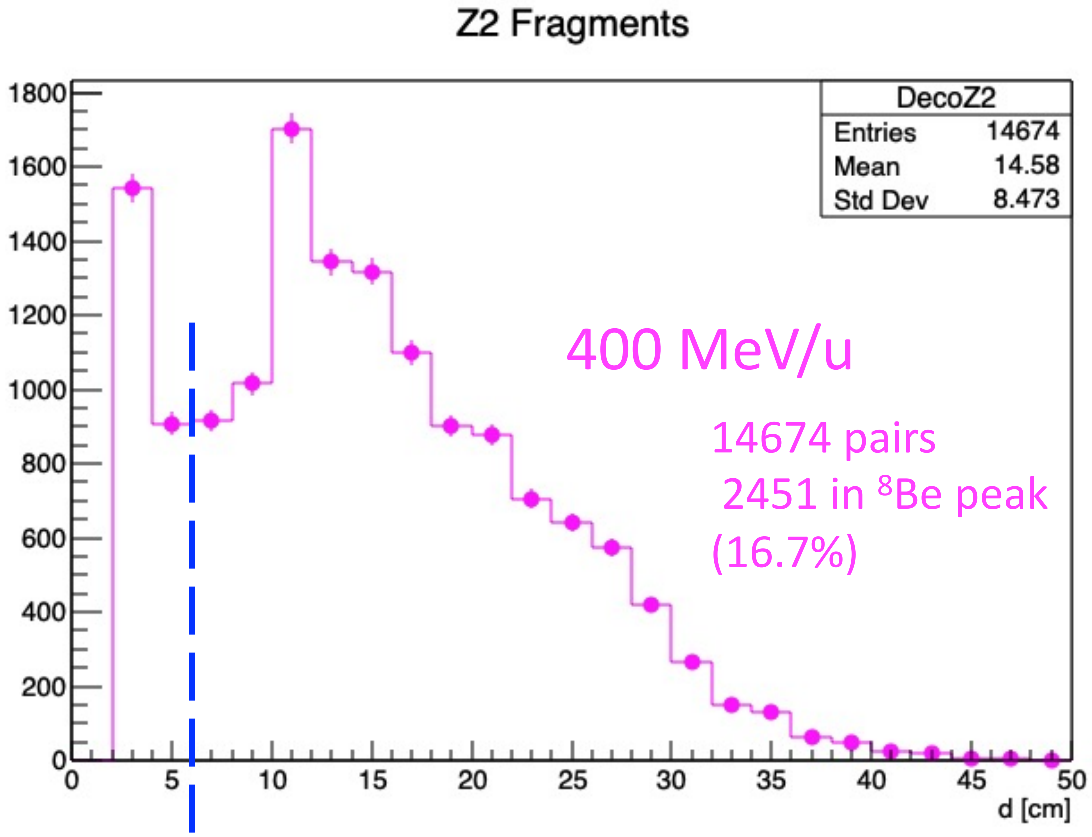
Arbitrarily identified with d<6 cm!

MC Decoherence of Z=2 fragments

EnableTWZmc n

Relative distance of TW points with Zrec=2

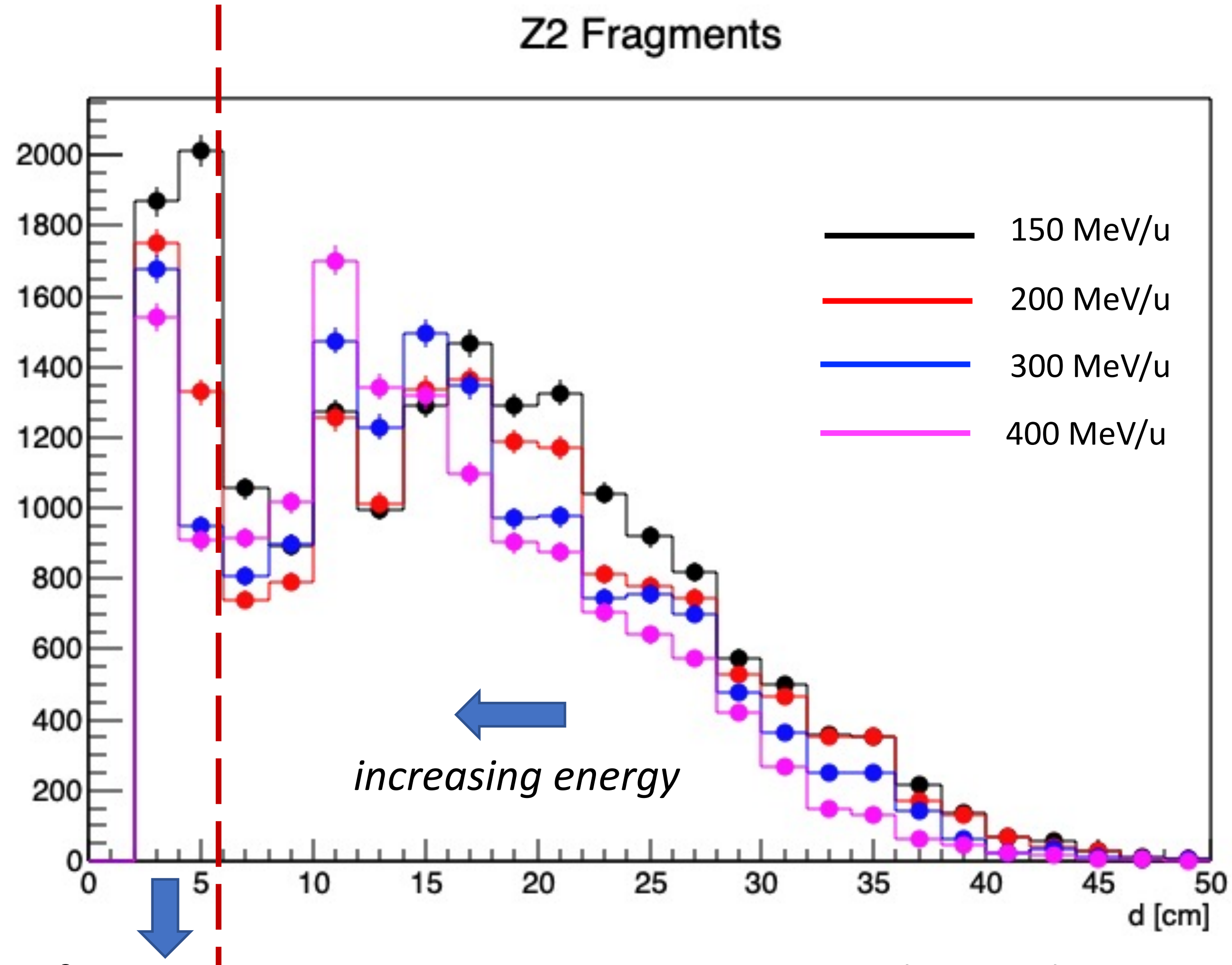




MC Decoherence of Z=2 fragments

EnableTWZmc n

Relative distance of TW points with Zrec=2



^{8}Be peak: *Empirically identified with d<6 cm! (21-17%)*

Some shrinkening of the distance distribution, including the ^{8}Be peak, is predicted for increasing energy

It seems also that the ^{8}Be peak is less populated at higher energy:
Notice that also in this case it could be either physics, or an effect of acceptance, since the probability of having 2 α in the same bar increases with energy