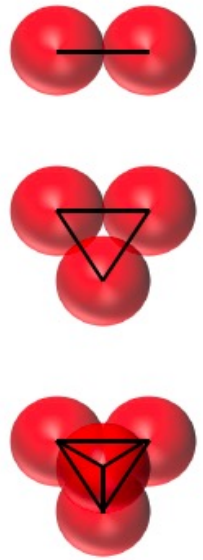
Clustering fragmentation: a 1st analysis of CNAO2021 data. Comparison with MC

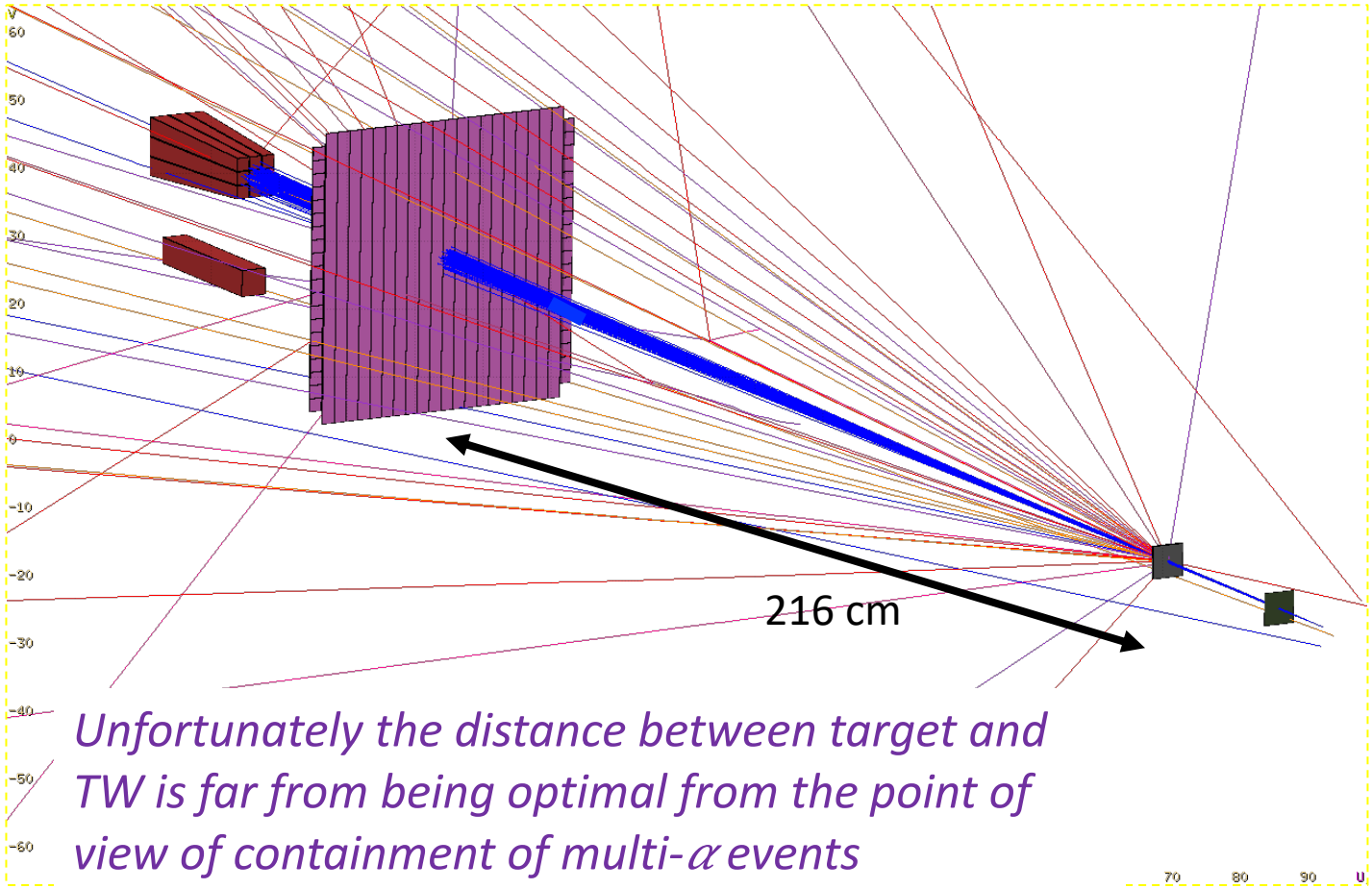
Giuseppe, Aafke, Silvia

Just a quick remind

- 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 the physics meeting of July 27



Experiment geometry, analysis goals and preliminary selection - 1



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 cannnot 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 ?

Experiment geometry, analysis goals and preliminary selection - 2

- Exp. Data Selection:

For this preliminary analysis we selected a first batch of data from the 3rd night, 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

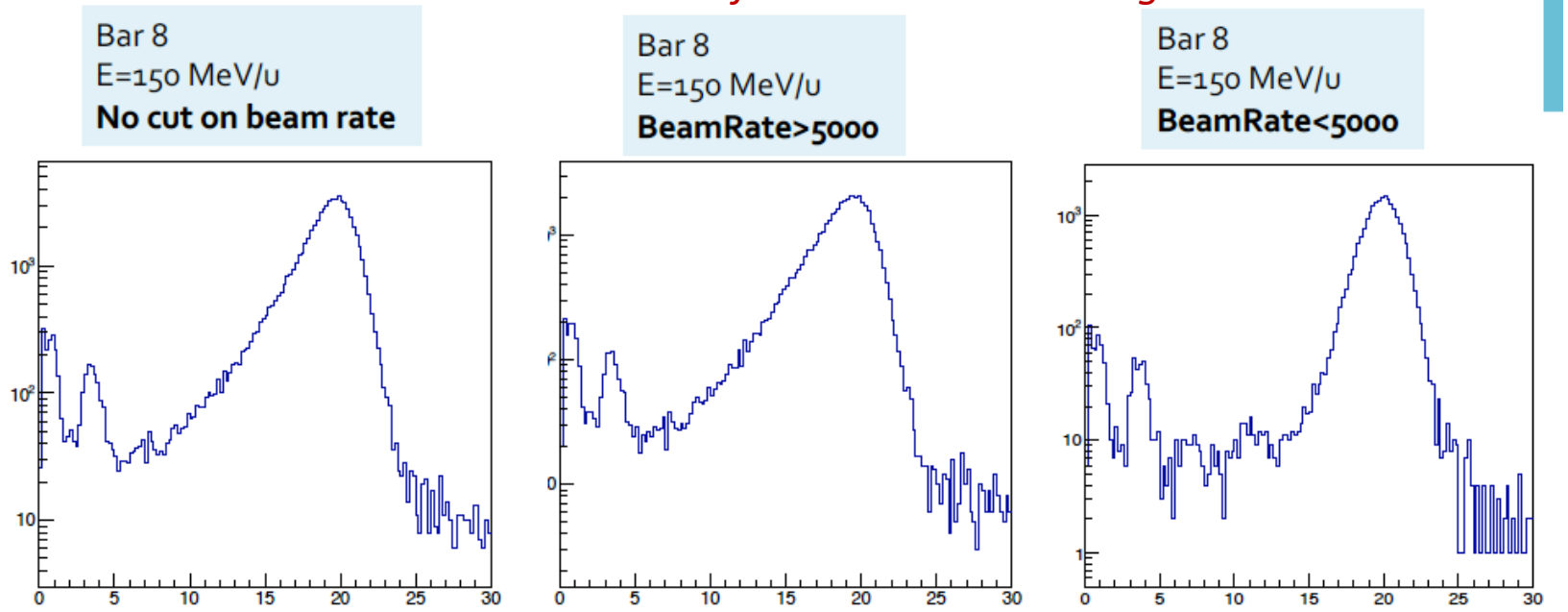
2.e+6 events for each energy (CNAO2021_MC campaign)

Experiment geometry, analysis goals and preliminary selection - 3

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

Effect of beam rate on bar charge spectrum: central bars

From Aafke's talk at Strasbourg



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

MC predictions. Multiplicity distribution

Looking for reconstructed TW points with Z_{rec}=2

There are 2 ways to have Z_{rec}:

1) EnableTWZmc y (using Z_MC)
2) EnableTWZmc n (using the same algorithm as for real data)

For both exp. and MC data:

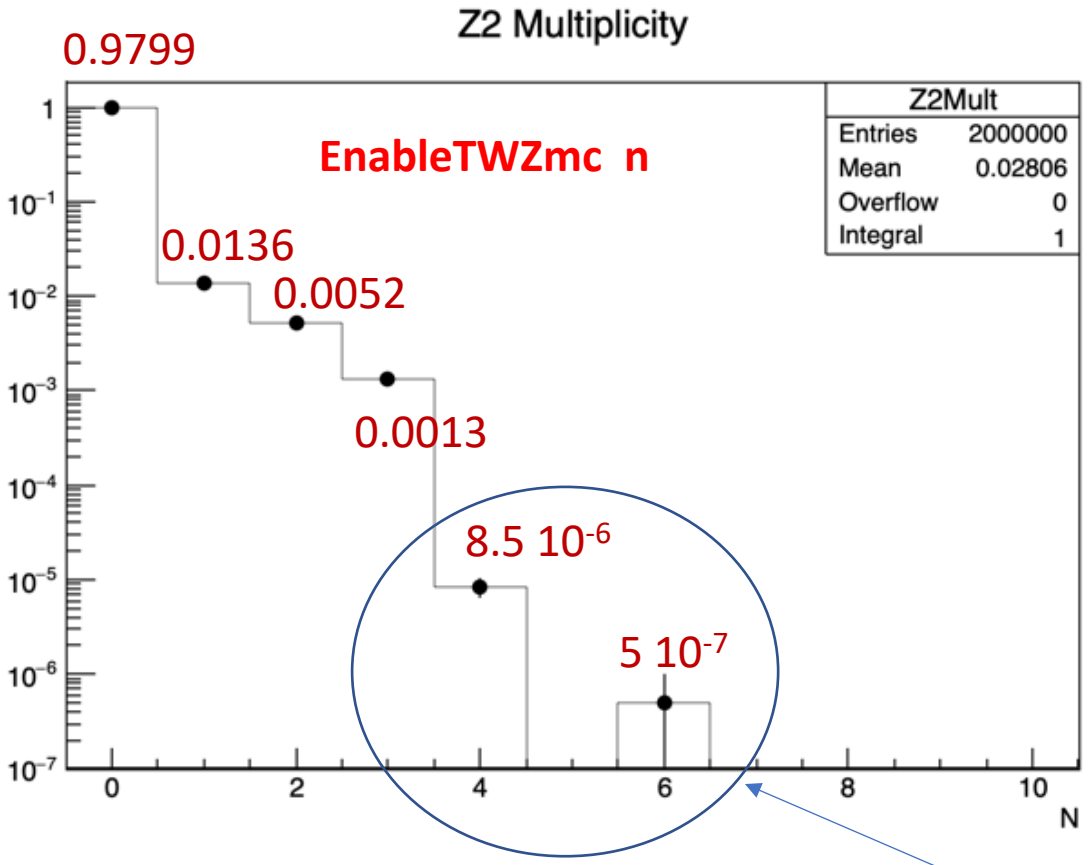
a) All the TW surface is used

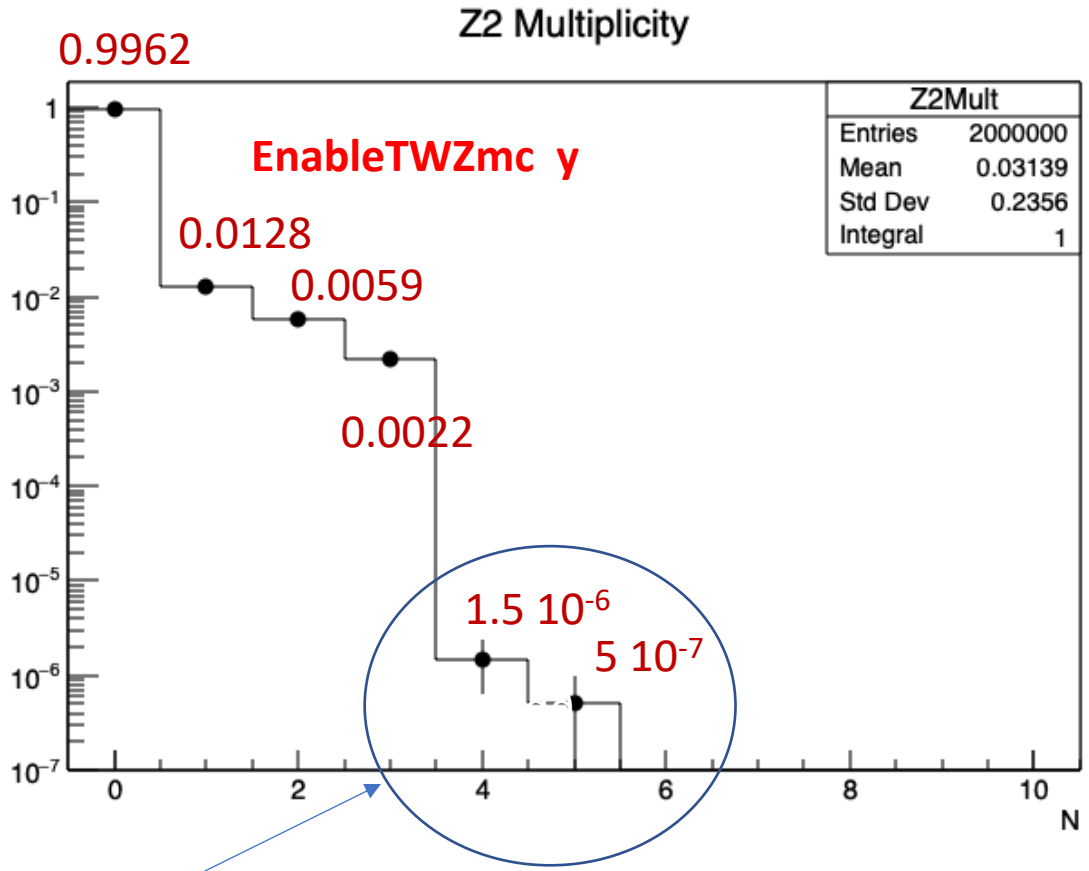
b) We include also the count of N=0 events

MC prediction

150 MeV/u

Multiplicity of TW points with Zrec=2





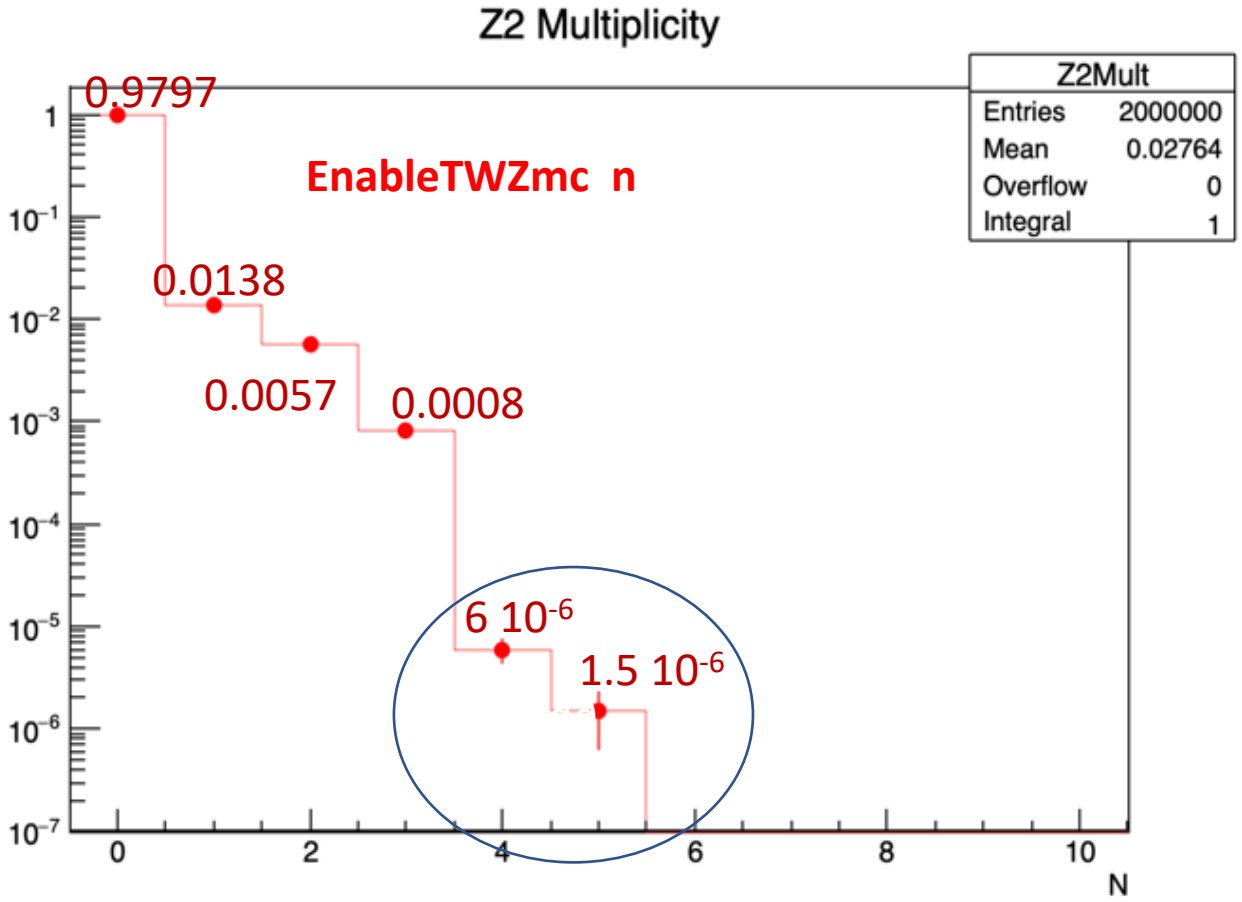
Integral normalized to 1

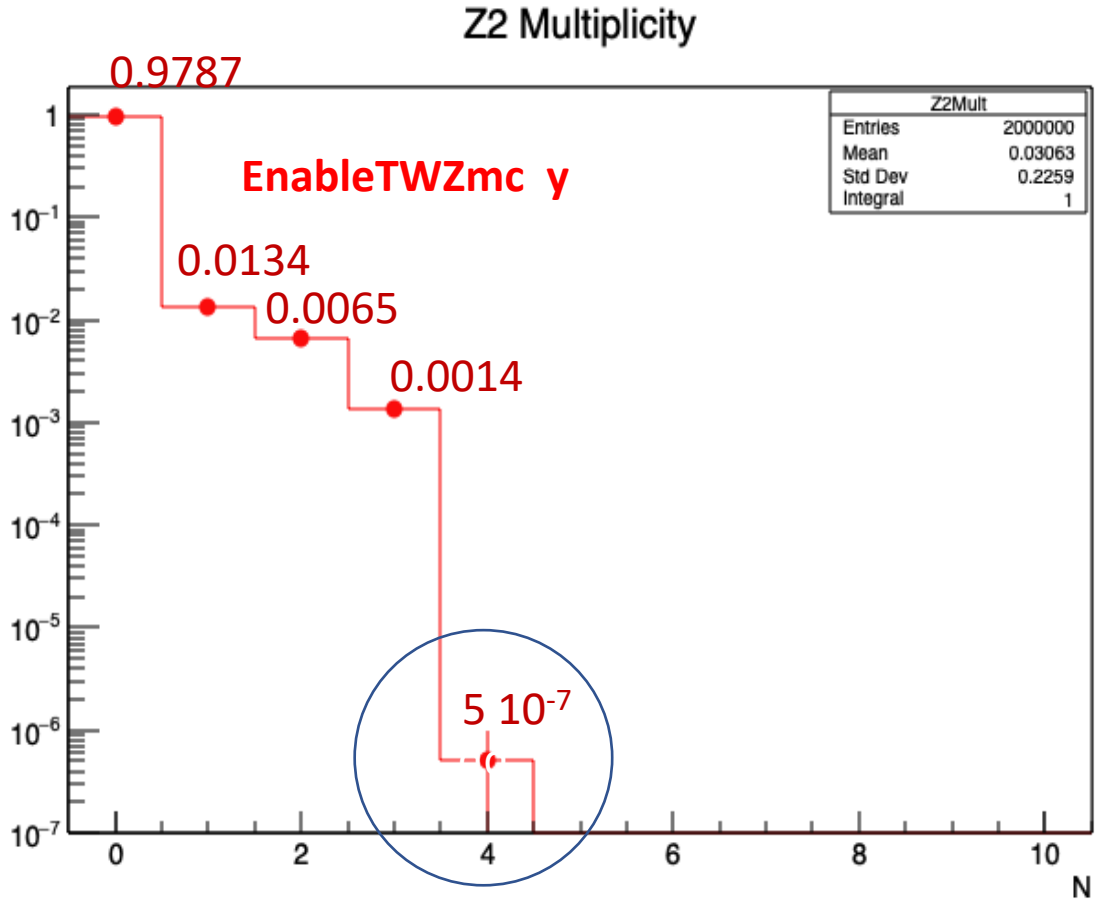
Interactions in air?
mis-reconstruction of Z?

MC prediction

200 MeV/u

Multiplicity of TW points with Zrec=2

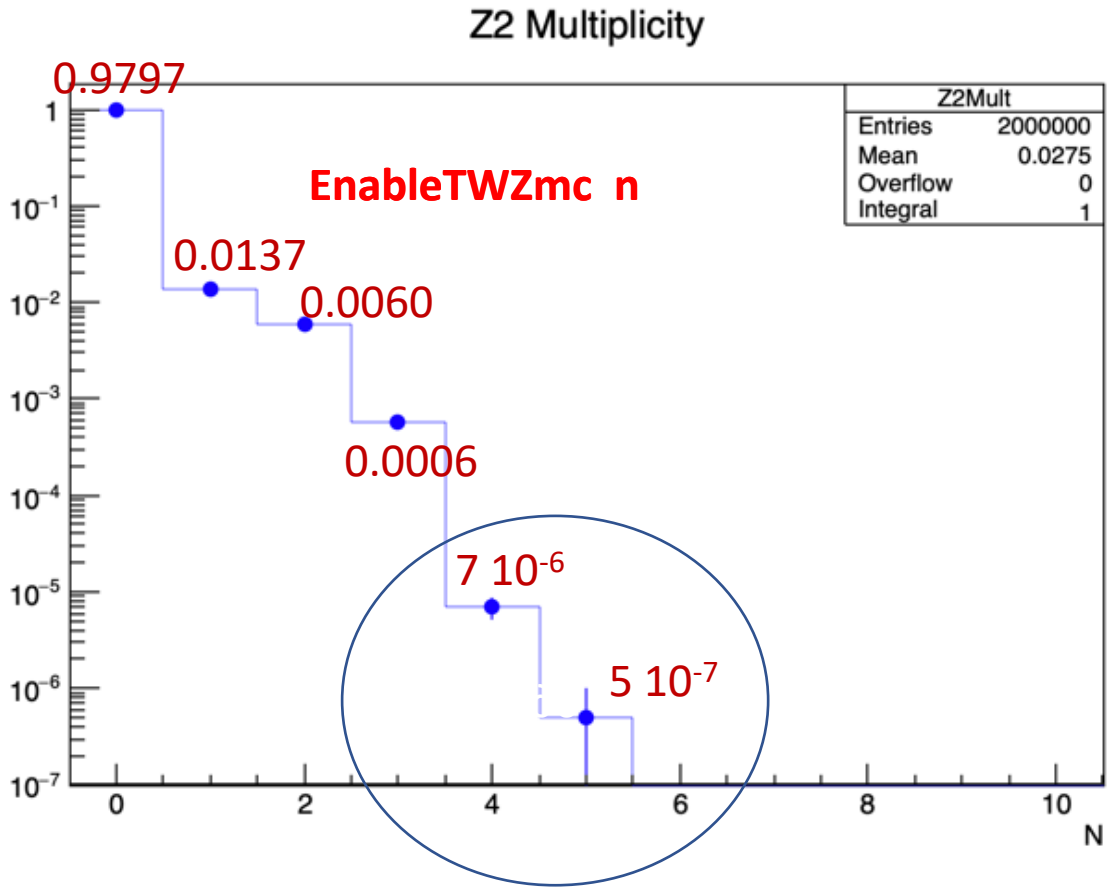


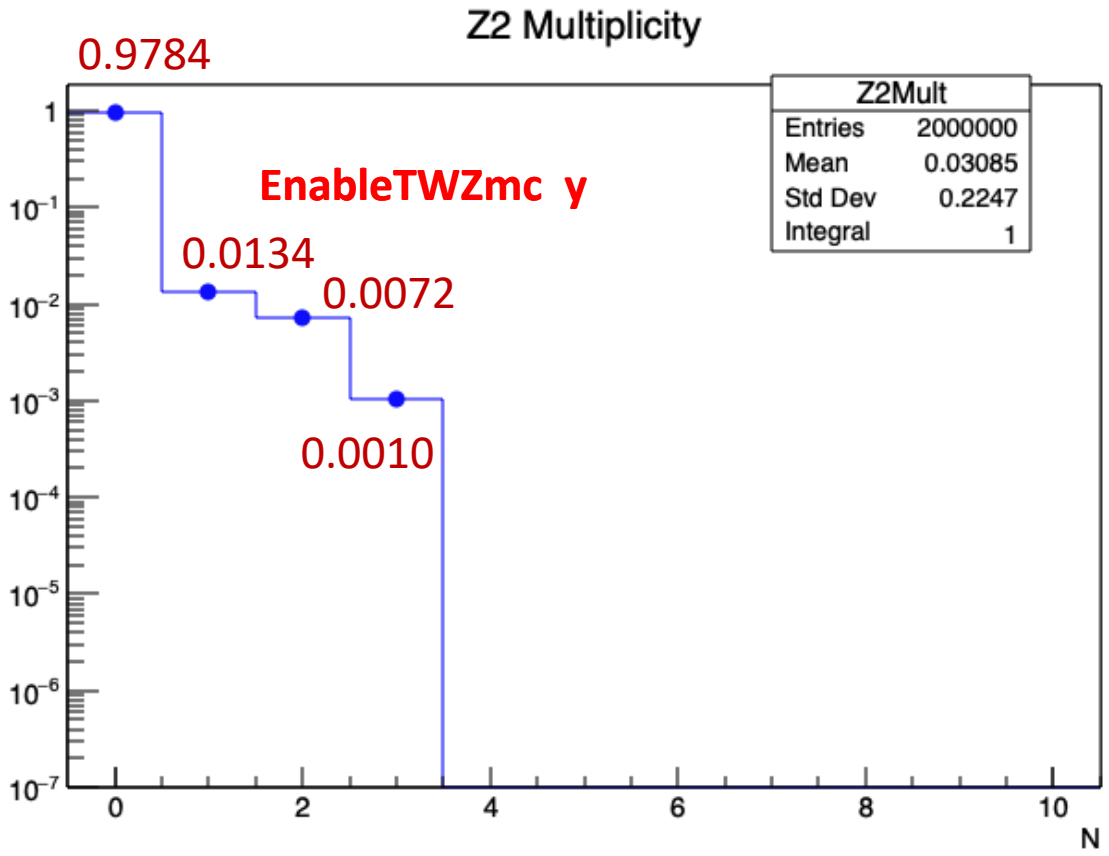


MC prediction

300 MeV/u

Multiplicity of TW points with Zrec=2

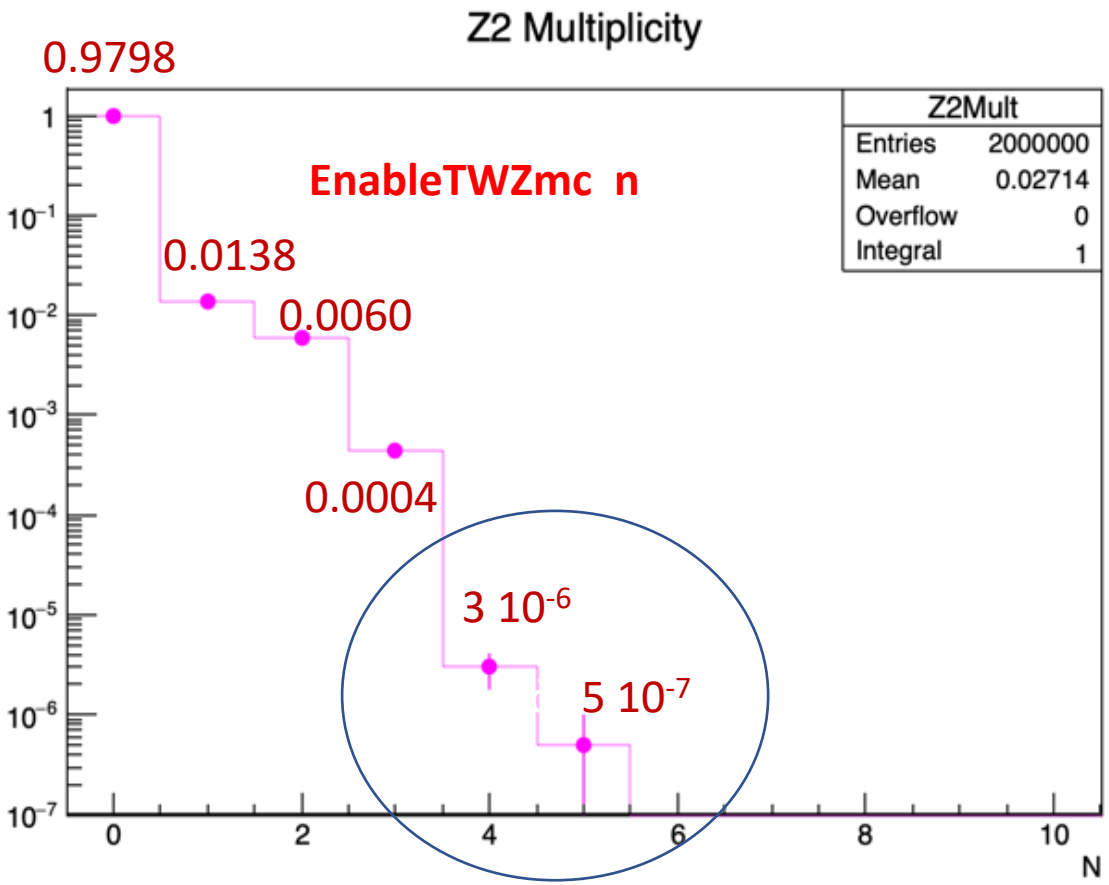


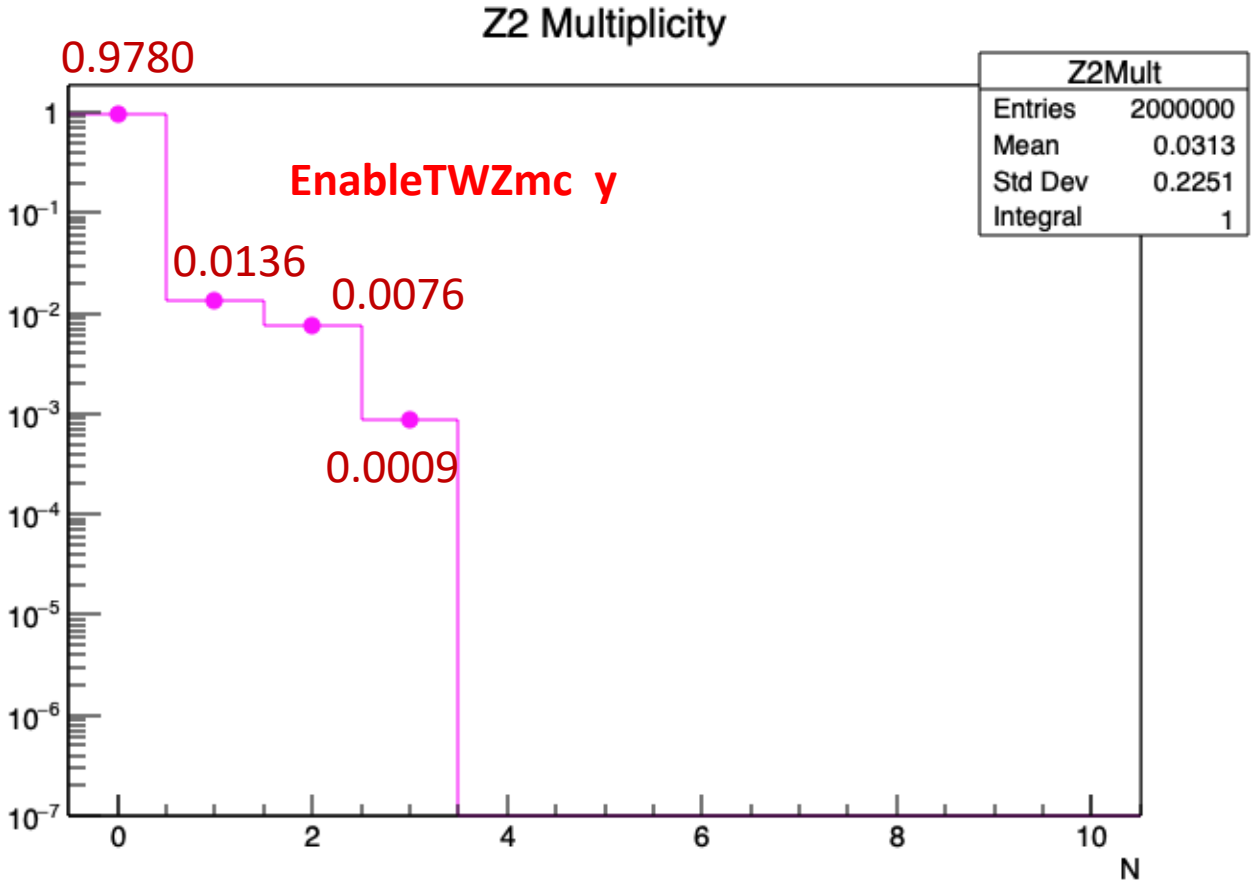


MC prediction

400 MeV/u

Multiplicity of TW points with Zrec=2

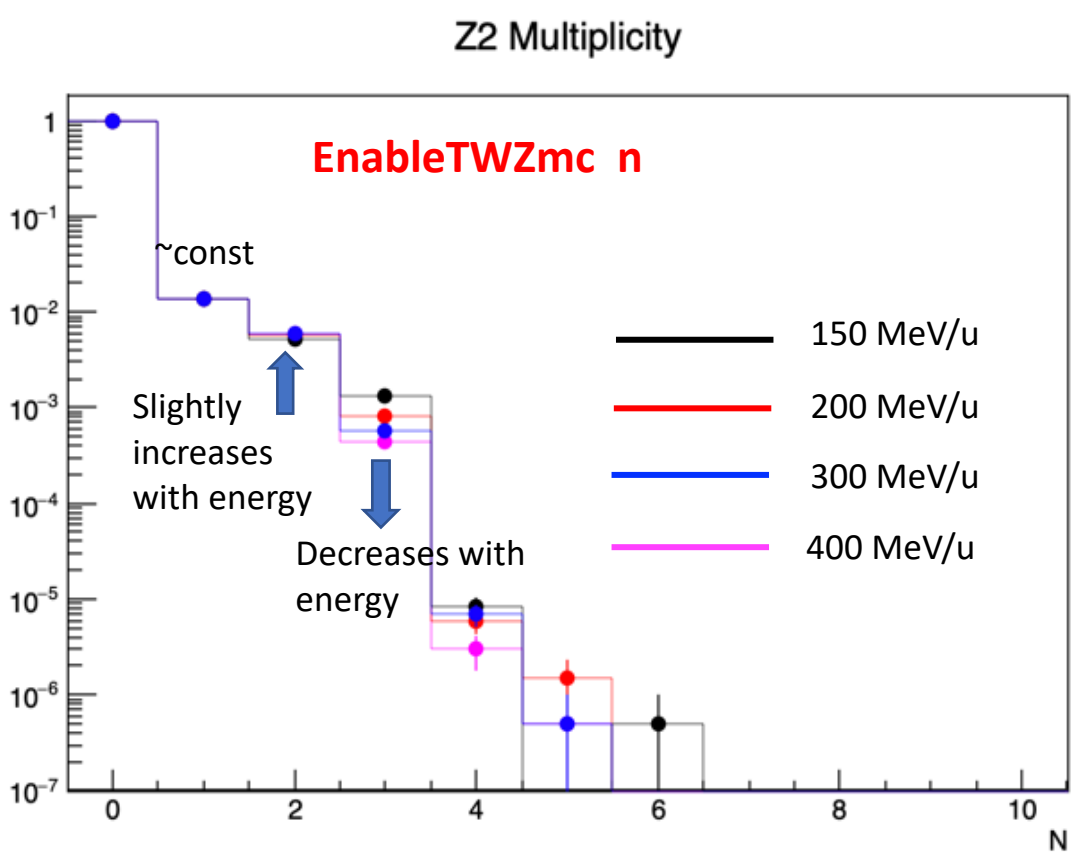


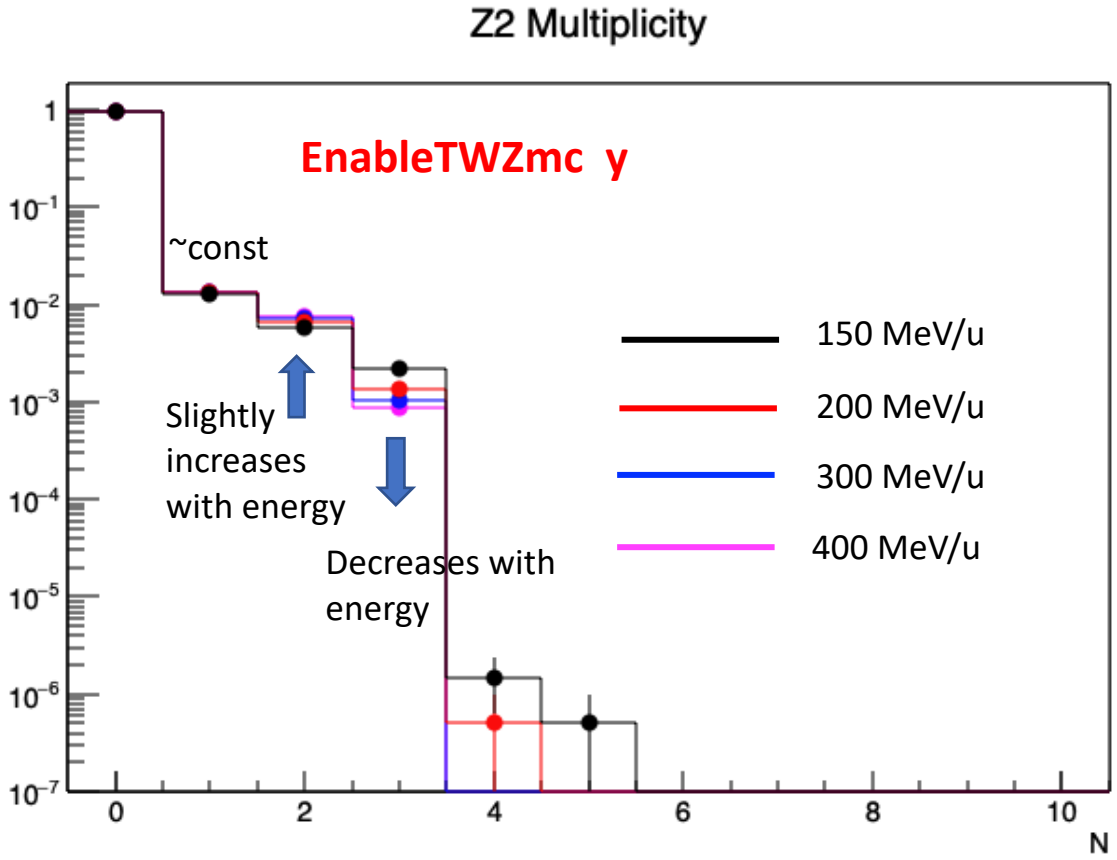


MC prediction

All energies

Multiplicity of TW points with Zrec=2





Summary of MC prediction for multiplicity

The multiplicity distribution is predicted to remain substantially unchanged as a function of energy We observe a slight decreasing of N=3 multiplicity for increasing energy. *It could be either physics, or an effect of acceptance, since the probability of having 2 α in the same bar increases with energy. It cannot be due to the overall geometrical acceptance, since the emission cone shrinks for increasing energy.*

The overall fraction of Z=2 events is ~constant when primary energy is increased:

- from 2.1% at 150 MeV/u to 2.2% at 400 MeV/u for EnableTWZmc = y
- ~2.0% at all energies for EnableTWZmc = n

There are differences when using Z(MC) or Z_{rec} for the charge assignement to TW point. For EnableTWZmc = y :

- the fraction of N=2 and N=3 events is smaller
- there are more cases of evidently wrong charge assignments at all energies
- the average multiplicity is lower

We choose the case EnableTWZmc = n to perform comparisons with exp data

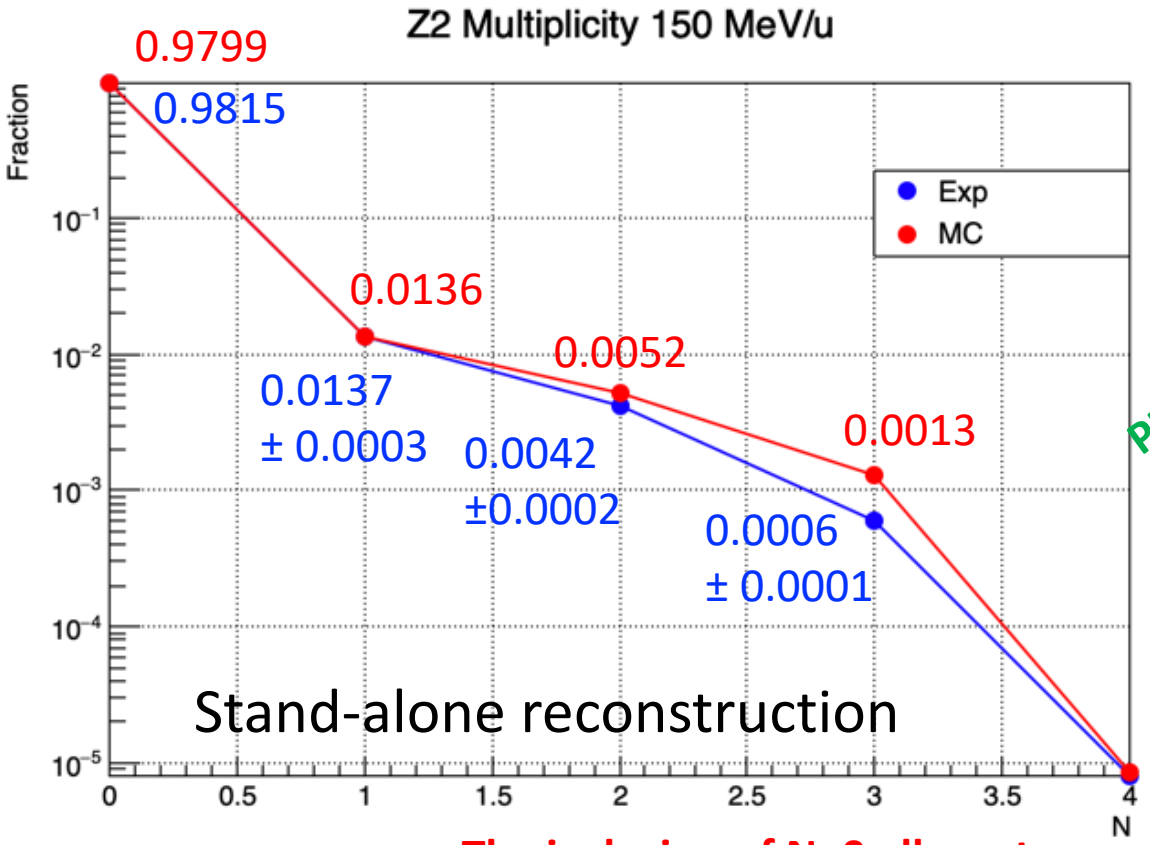
A first comparison with experimental data

Exp: Standalone + Shoe analysis - MC: Multiplicity of TW points with Zrec=2 (EnableTWZmc n)

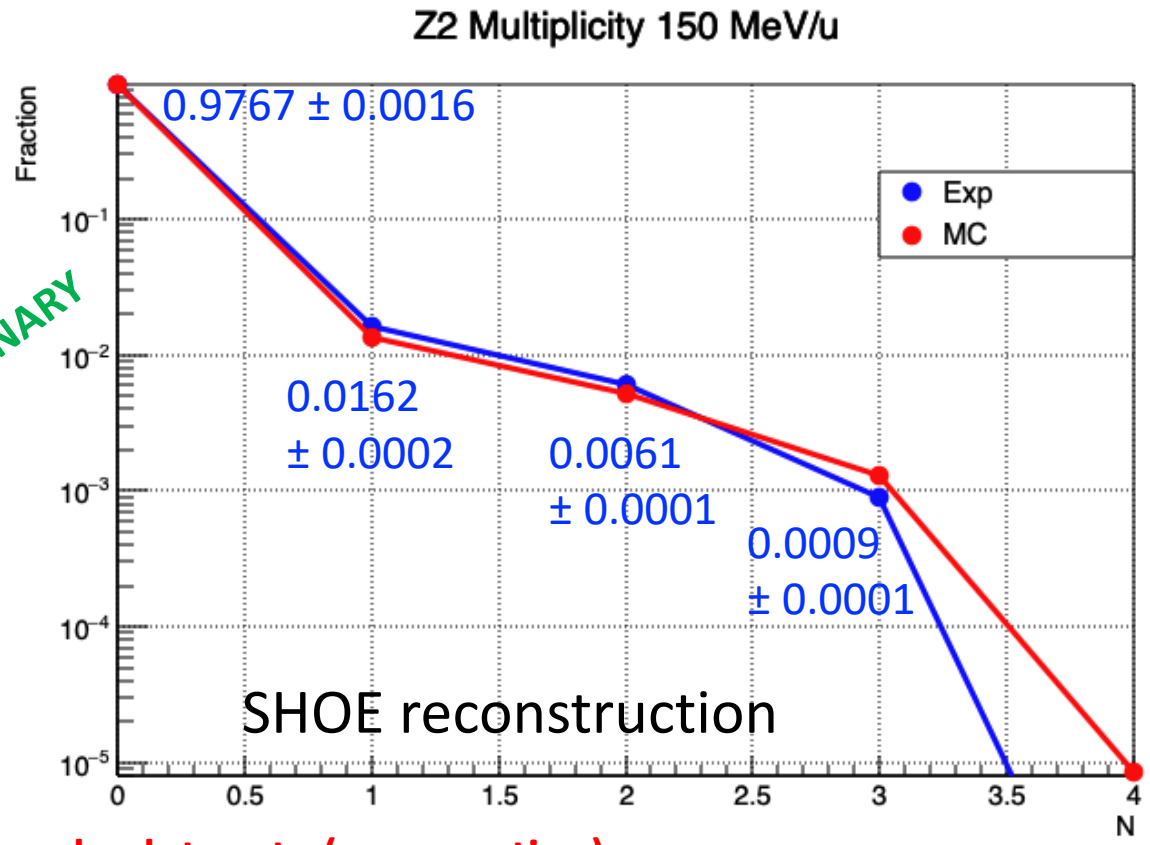
Fraction of the total no. of primaries

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

150 MeV/u



PRELIMINARY



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

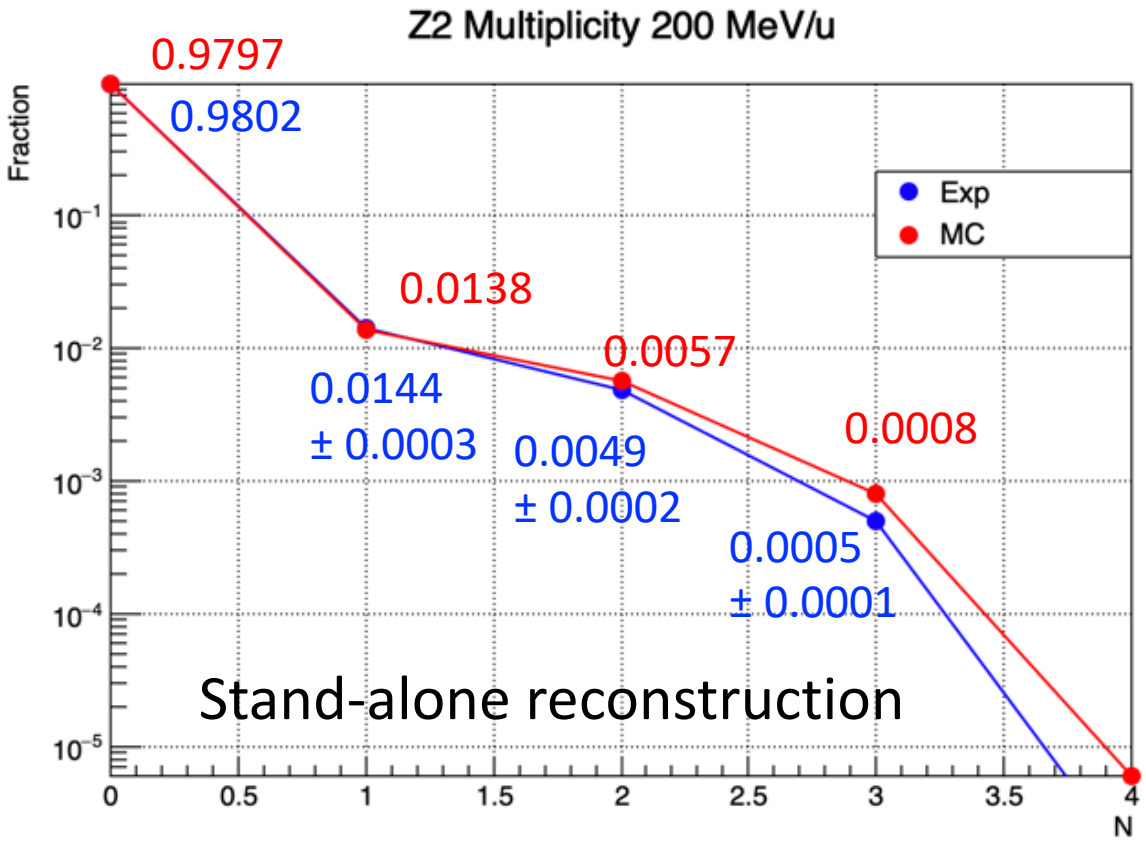
A first comparison with experimental data

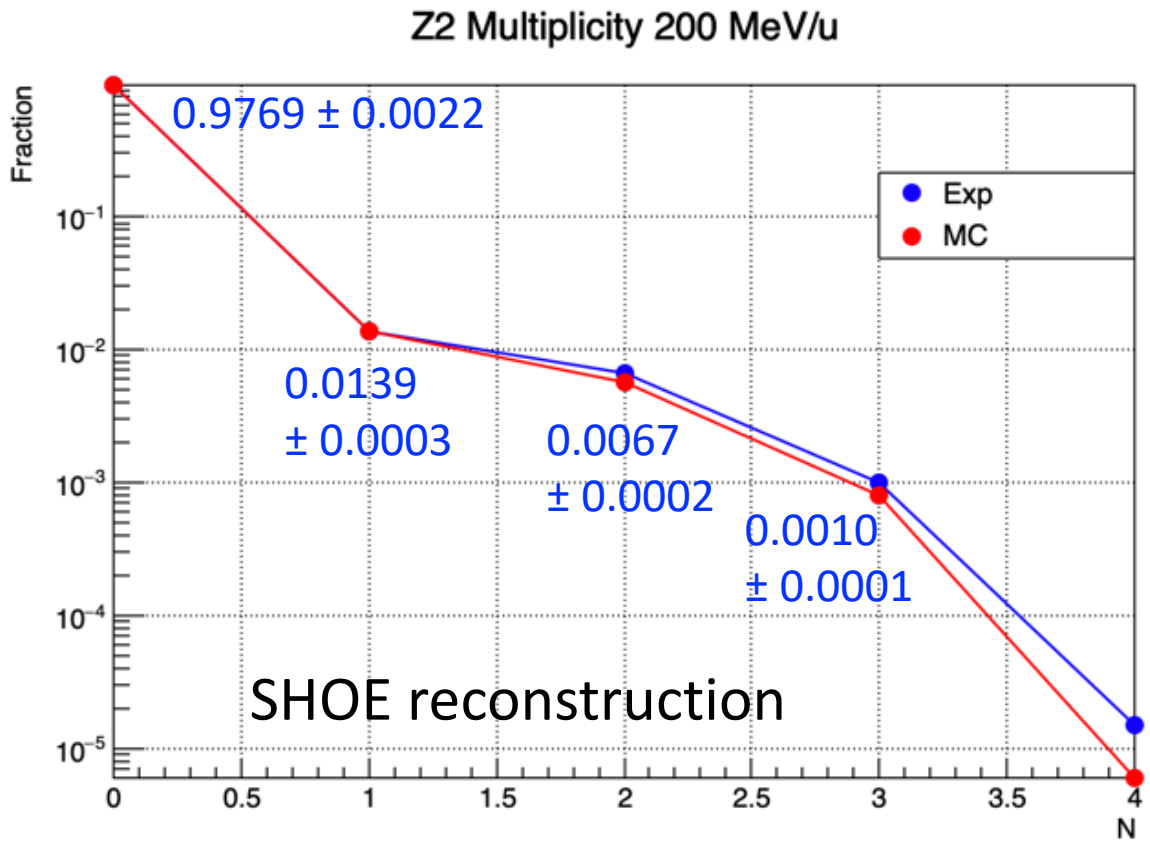
Exp: Standalone + Shoe analysis - MC: Multiplicity of TW points with Zrec=2 (EnableTWZmc n)

Fraction of the total no. of primaries

PRELIMINARY

200 MeV/u





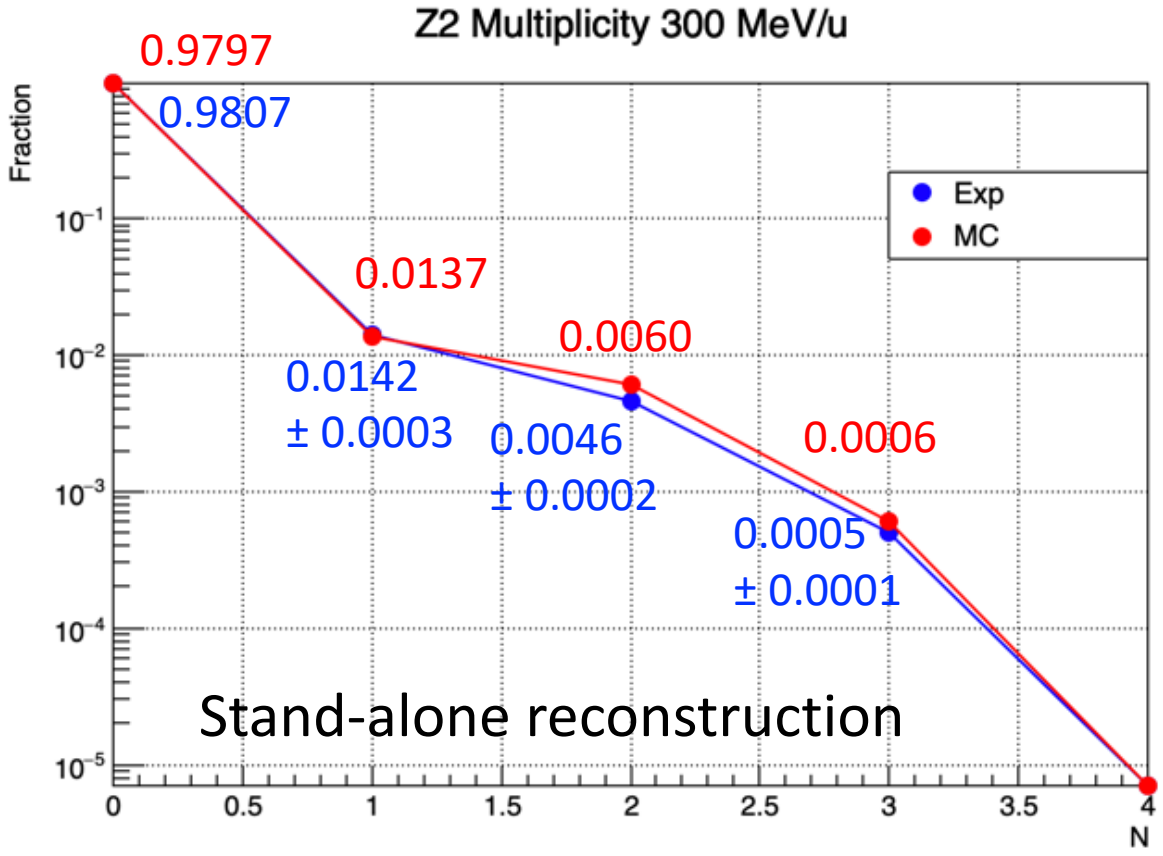
A first comparison with experimental data

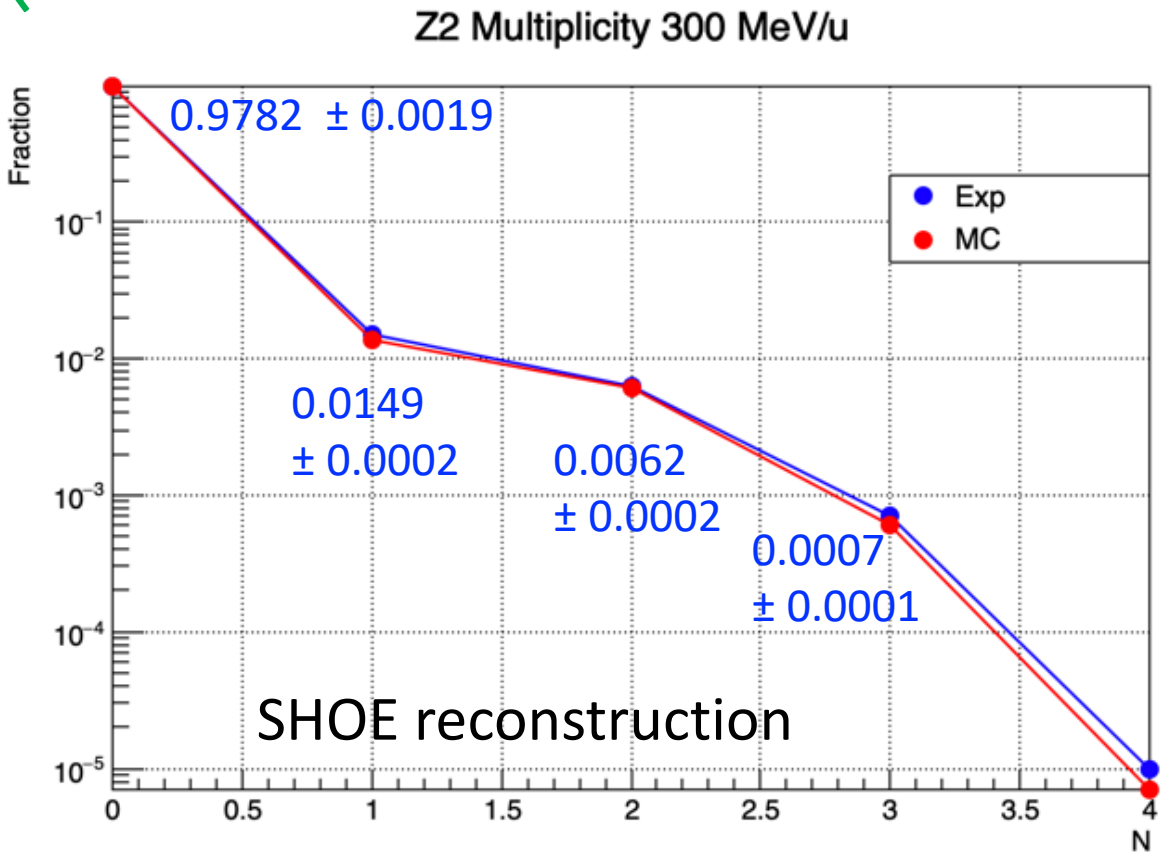
Exp: Standalone + Shoe analysis - MC: Multiplicity of TW points with Zrec=2 (EnableTWZmc n)

Fraction of the total no. of primaries

PRELIMINARY

300 MeV/u





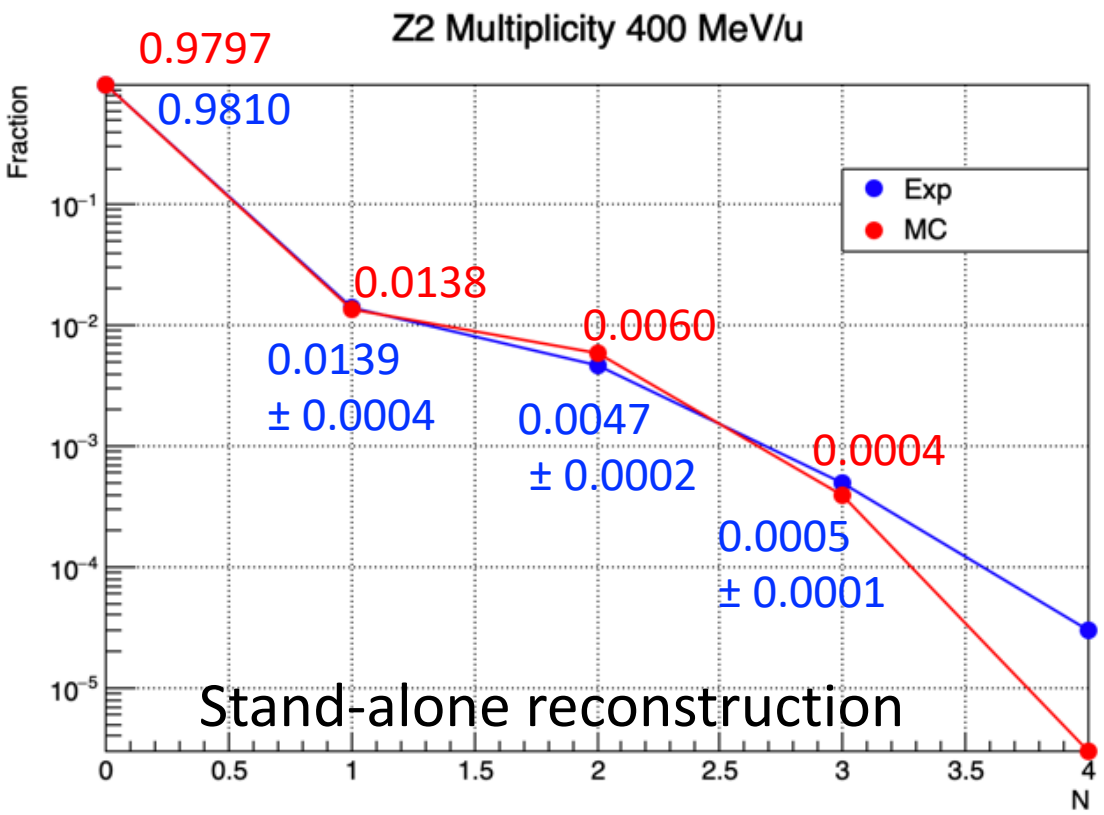
A first comparison with experimental data

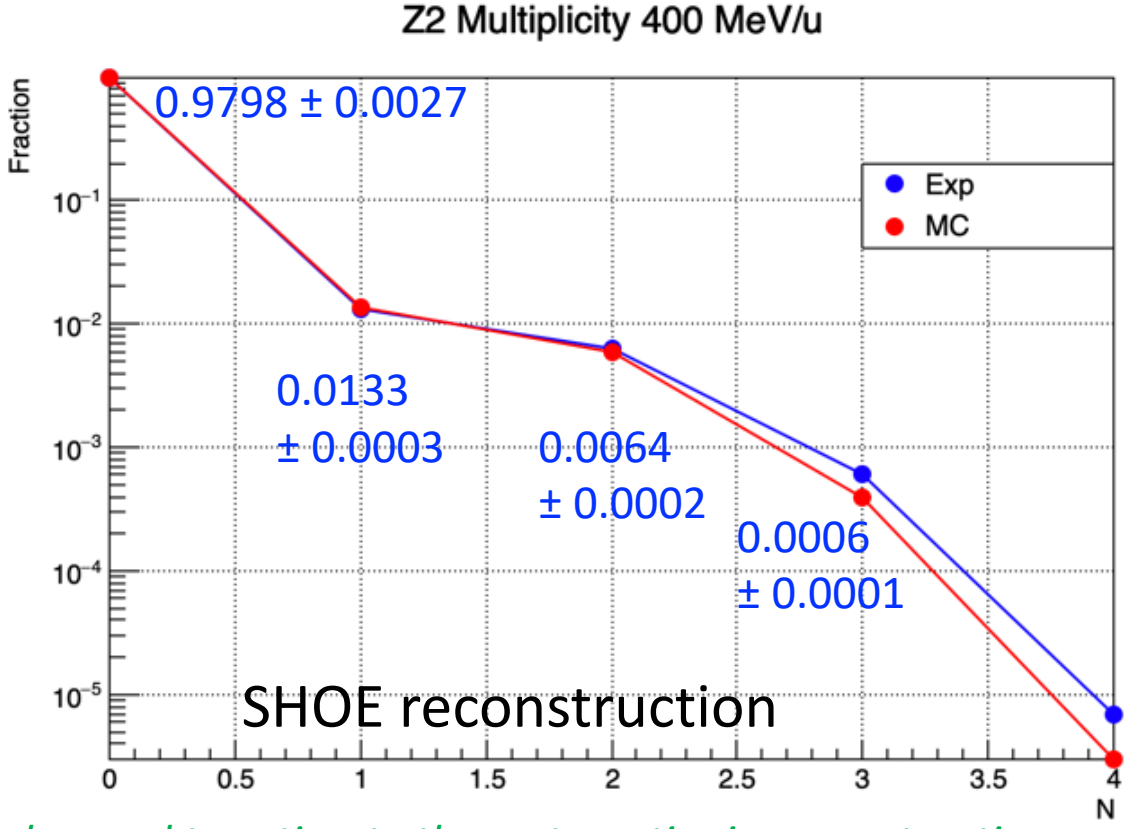
Exp: Standalone + Shoe analysis - MC: Multiplicity of TW points with Zrec=2 (EnableTWZmc n)

Fraction of the total no. of primaries

PRELIMINARY

400 MeV/u





The differences between shoe and standalone analysis can be used to estimate the systematics in reconstruction

MC predictions. Distribution of spatial separation between Z=2 fragments

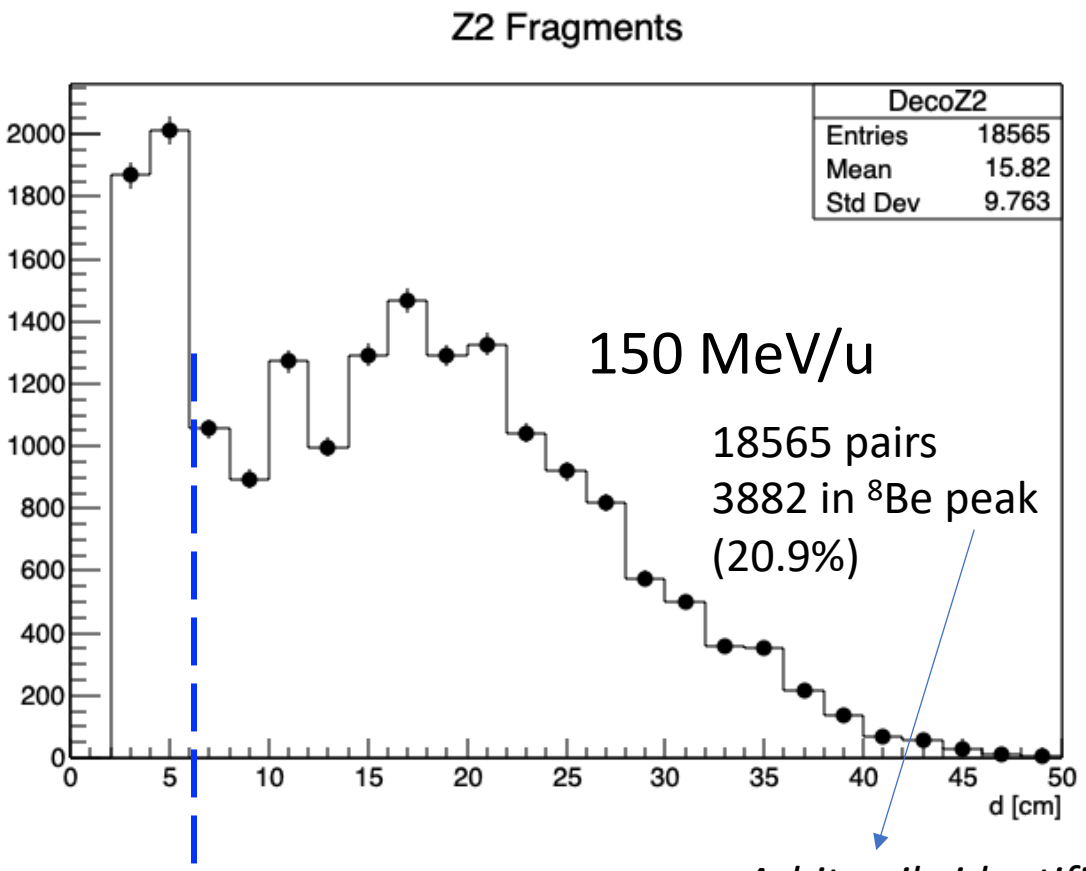
As shown in previous talk about clustering, the analysis of spatial (or angular) correlations between α's allows a first investigation of 2-step processes, like the expected $^{12}C \rightarrow {}^{8}Be + \alpha \rightarrow 3\ \alpha$

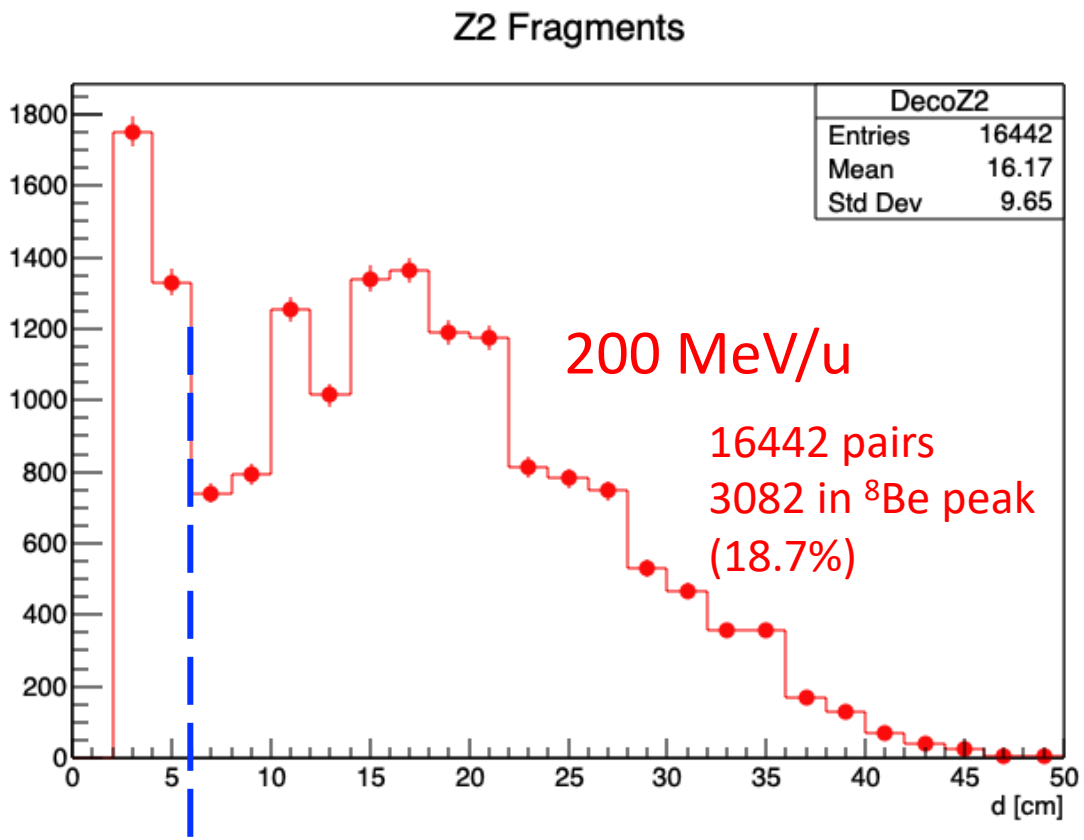
Without precision tracking detectors we can only measure the relative distances between reconstructed TW points with $Z_{rec}=2$ ➔ 2 cm resolution ("Decoherence" distribution)

MC Decoherence of Z=2 fragments

EnableTWZmc n

Relative distance of TW points with Zrec=2



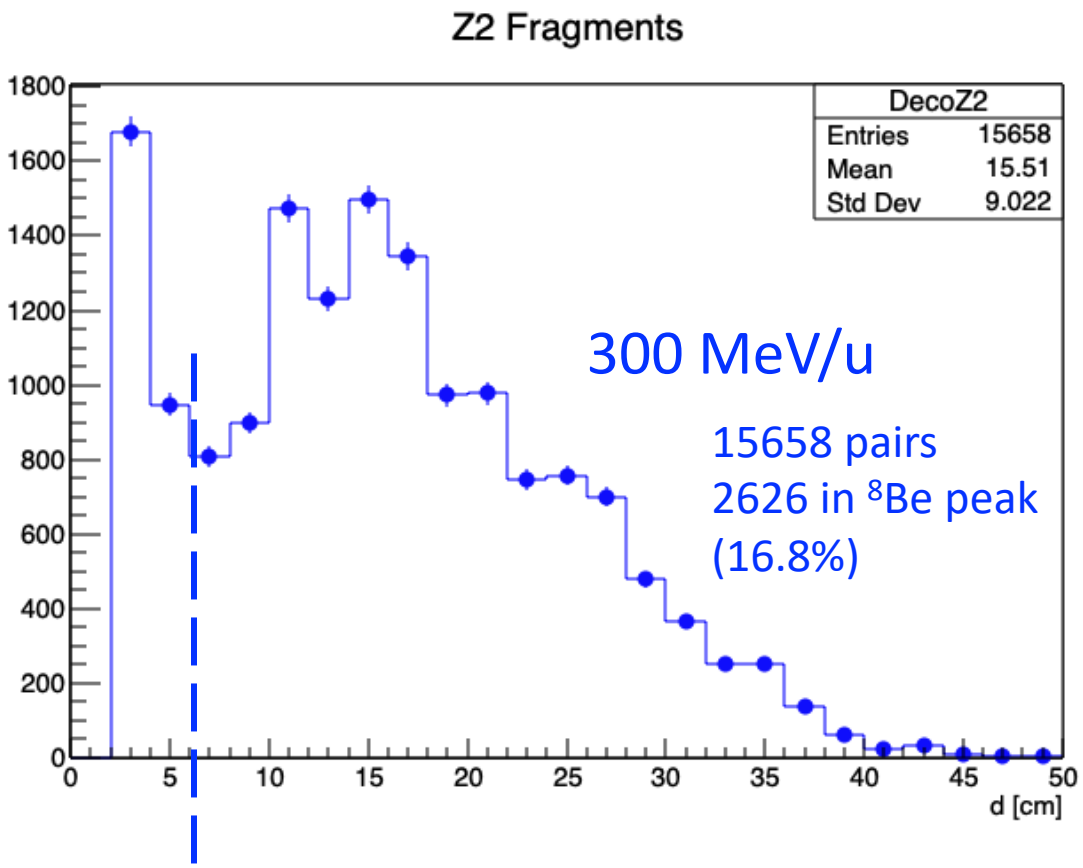


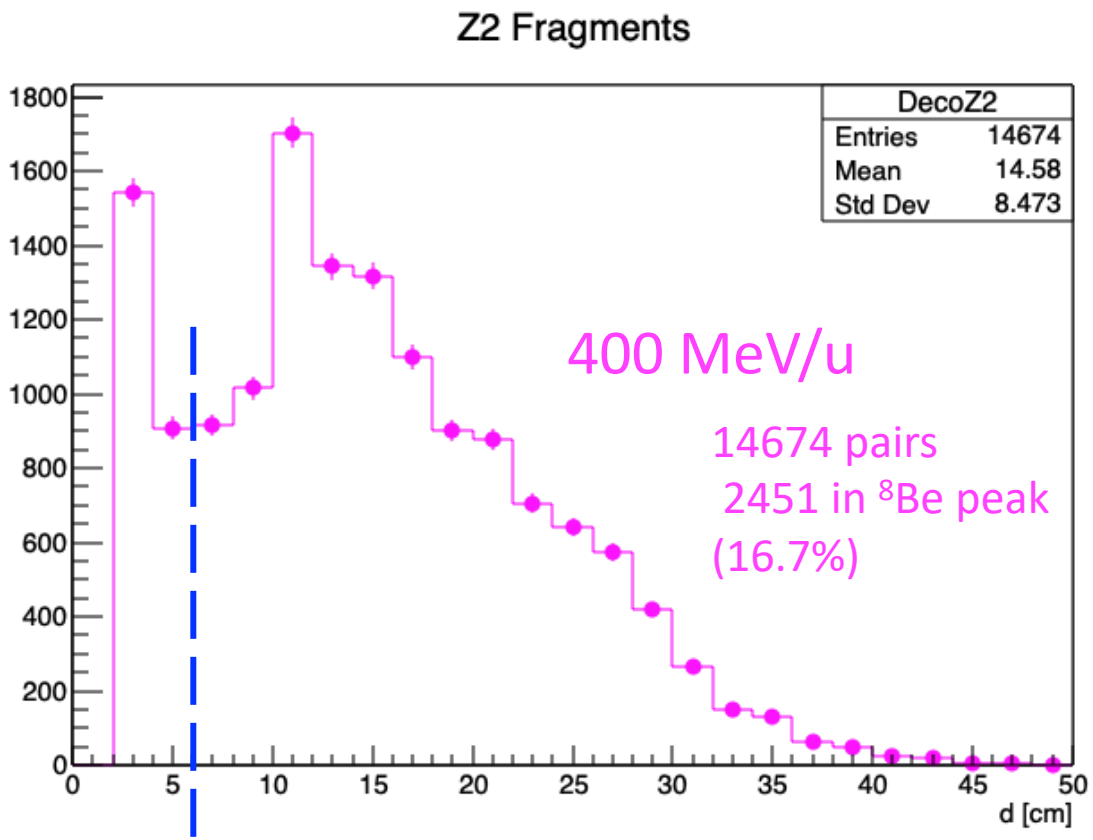
<u>Arbitrarily</u> identified with d<6 cm!

MC Decoherence of Z=2 fragments

EnableTWZmc n

Relative distance of TW points with Zrec=2

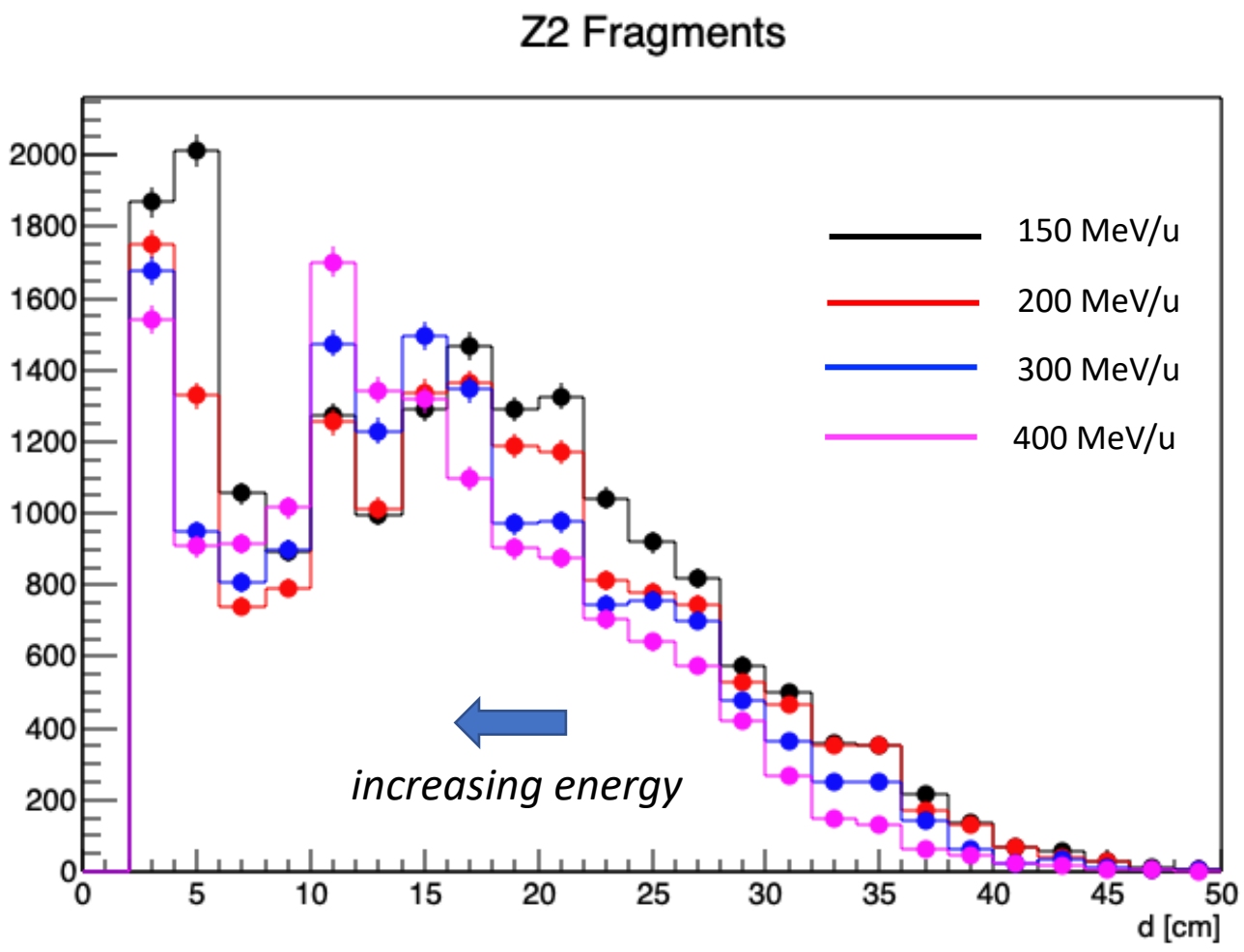




MC Decoherence of Z=2 fragments

EnableTWZmc n

Relative distance of TW points with Zrec=2



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

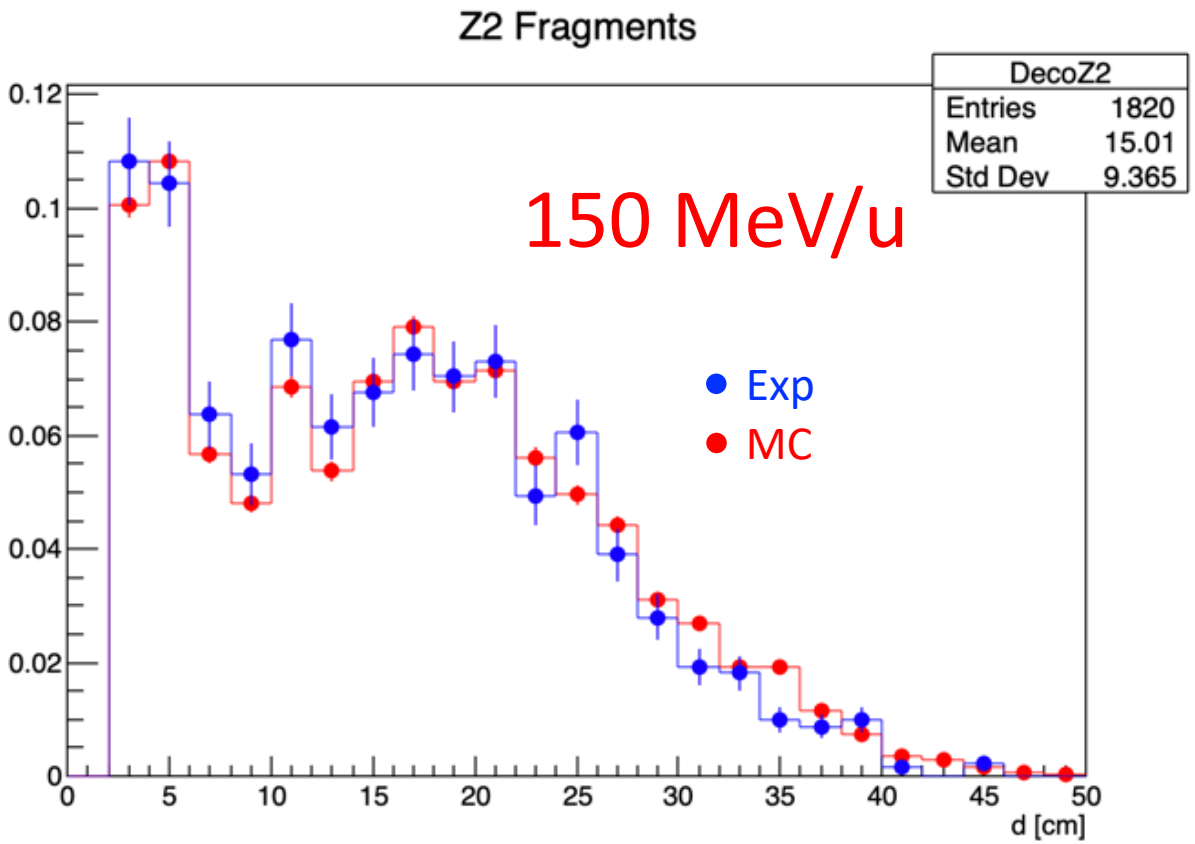
It seems also that the ^{8}Be peak is less populated at higher energy:
Notice that also in this case it could be either physics, or an effect of acceptance, since the probability of having 2 α in the same bar increases with energy

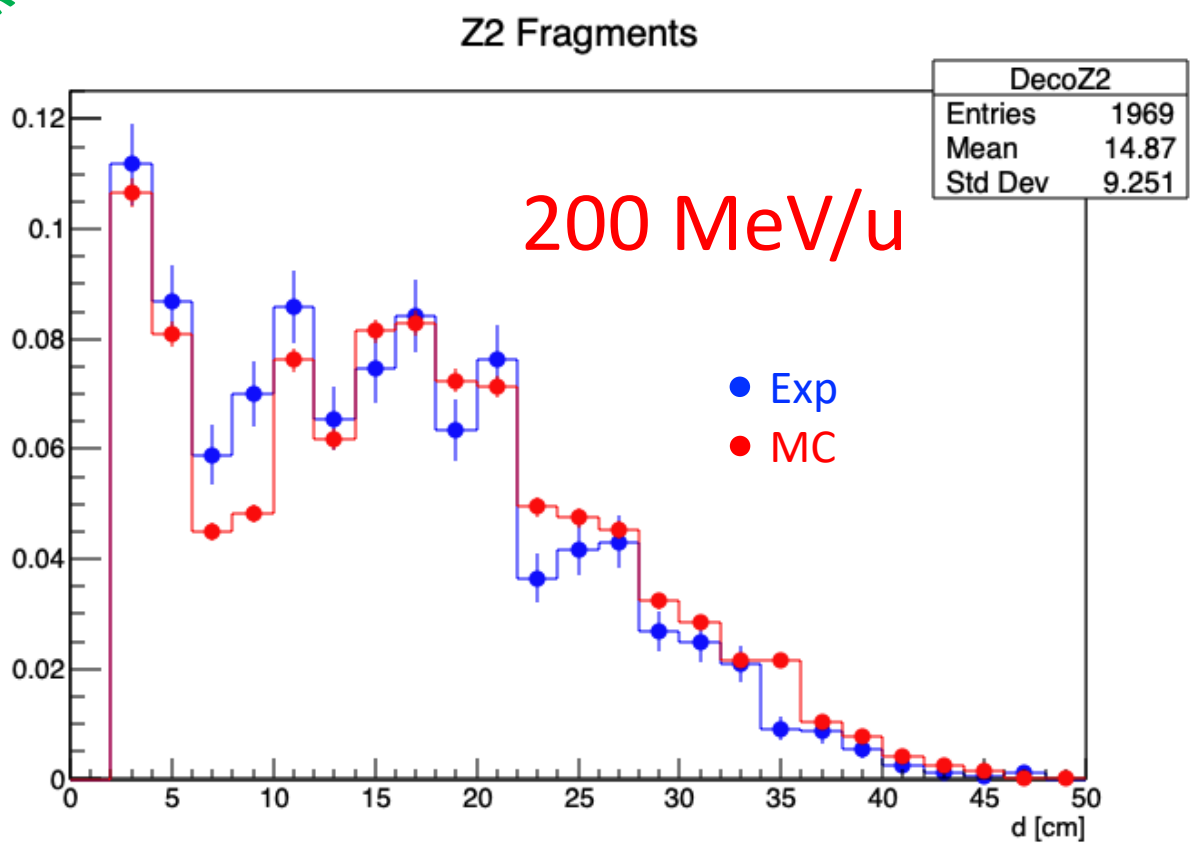
A first comparison with experimental data

Exp: Shoe analysis - MC: Multiplicity of TW points with Zrec=2 (EnableTWZmc n)

Normalized to same area

PRELIMINARY





A first comparison with experimental data

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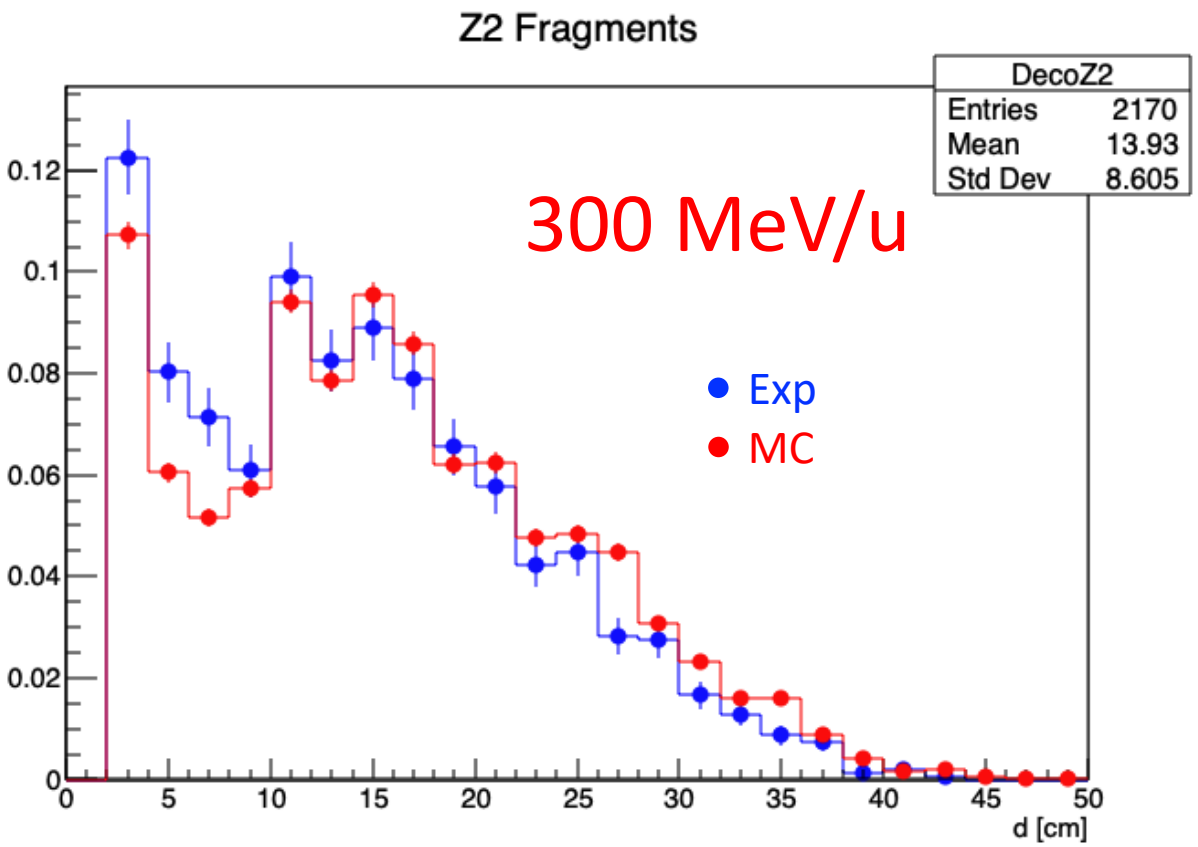
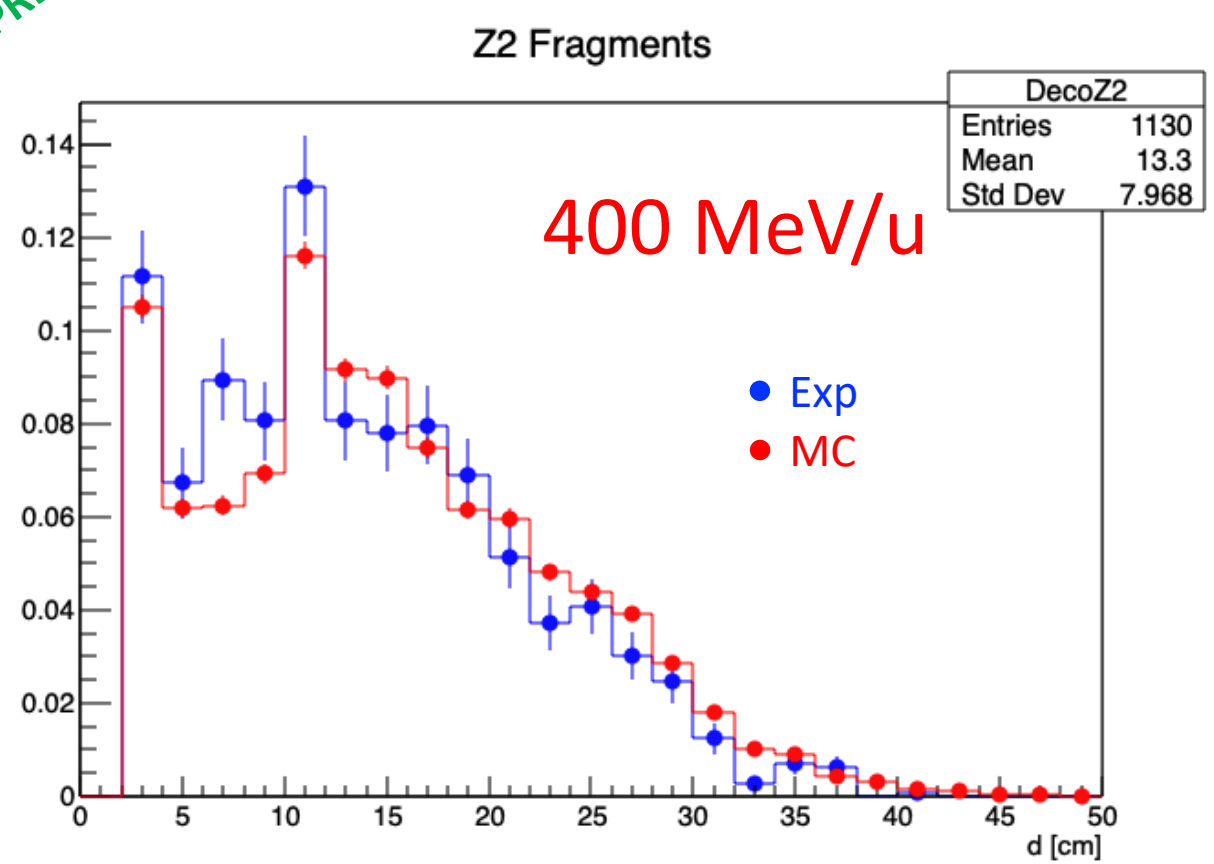
PRELIMINARY





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

Some conclusions

1) The geometrical acceptance of CNAO2021 setup was not the optimal one for the containment of multi-α events, however a preliminary analysis in terms of clustering was possible.
2) The detector could only allow the identification of Z=2, without complete identification of true α particles
3) The experimental data in the primary energy range from 150 to 400 MeV/u do not show any important change in the probability of producing multi-Z=2 fragments
4) The spatial distribution of relative distances exhibit a peak at short distances, as expected for a 2-step intermediate process
5) 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 MC (too much close, maybe, suspicious?). An exception to this is observed in multiplicity at 150 MeV/u
6) We are still lacking an analysis of efficiency and systematics (for instance: probability of assigning the wrong charge, possible effects due to beam rate, …)
7) This is the first attempt of using FOOT to analyse ^{12}C interactions in terms of nuclear clustering. The possibility of a preliminary publication (provided that the analysis of efficiency, systematics and other aspects is finalized) can be discussed: first demonstration of FOOT potentiality in this topic.