Cross section measurement of $^{16}O + C$ from 2019 GSI data taking

XI Foot General Meeting

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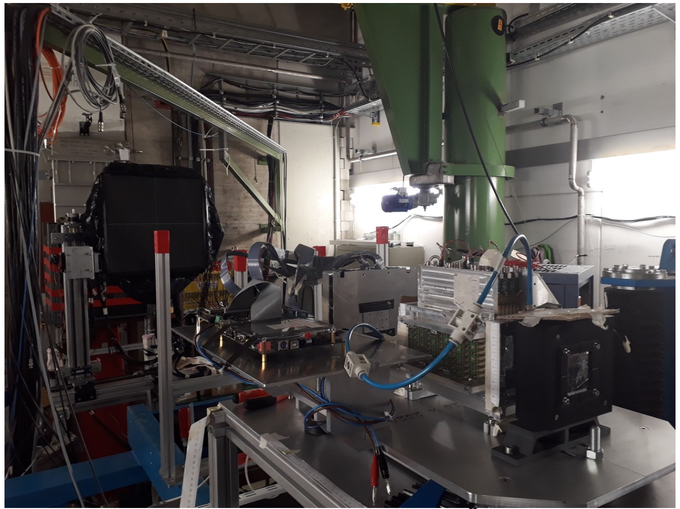
29/11/2021

Steps for cross sections measurement

^{16}O beam @ 400 MeV/u on a 5 mm C target

Very low statistics and no detectors for mass identification

Run	Type	Target	Events
2210	calibration	no	20463
2211	calibration	no	62782
2212	calibration	no	116349
2242	calibration	no	202728
2239	physics	C	20821
2240	physics	C	20004
2241	physics	C	20041
2251	physics	C	6863



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Cross section integrated in angular and kinetic energy interval is feasible

$$\sigma(Z) = \int_{E_{min}}^{E_{max}} \int_{0}^{\Delta\theta} (\frac{\partial^2\sigma}{\partial\theta\partial E_{kin}} d\theta dE_{kin}) = \frac{N_{frag}(Z)}{N_{prim} \cdot N_{TG} \cdot \epsilon(Z)}$$

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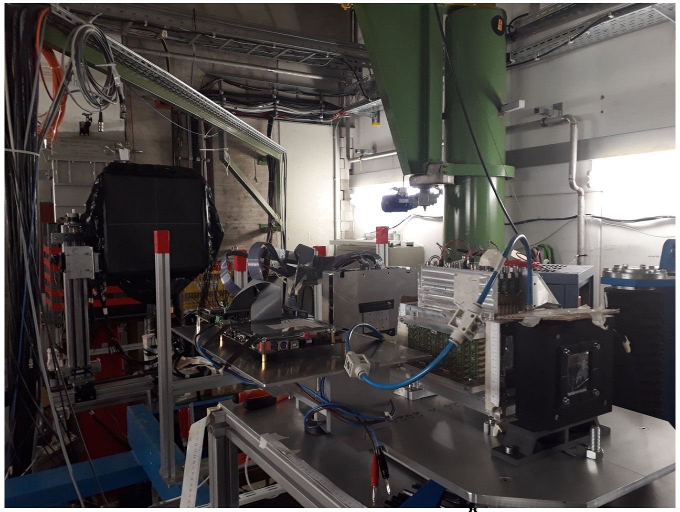

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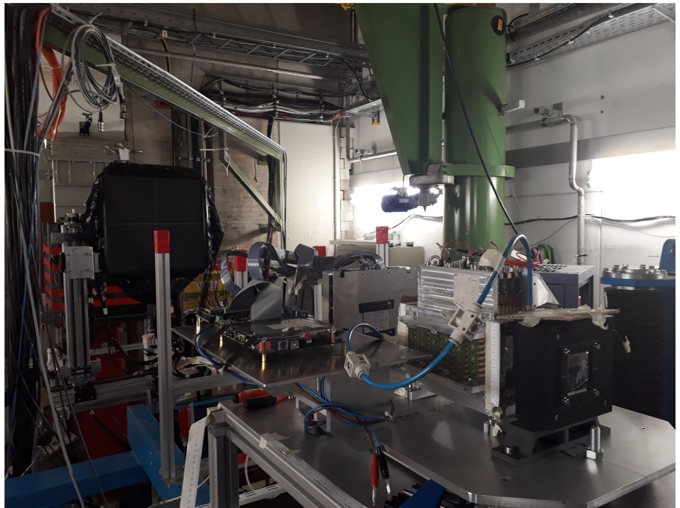
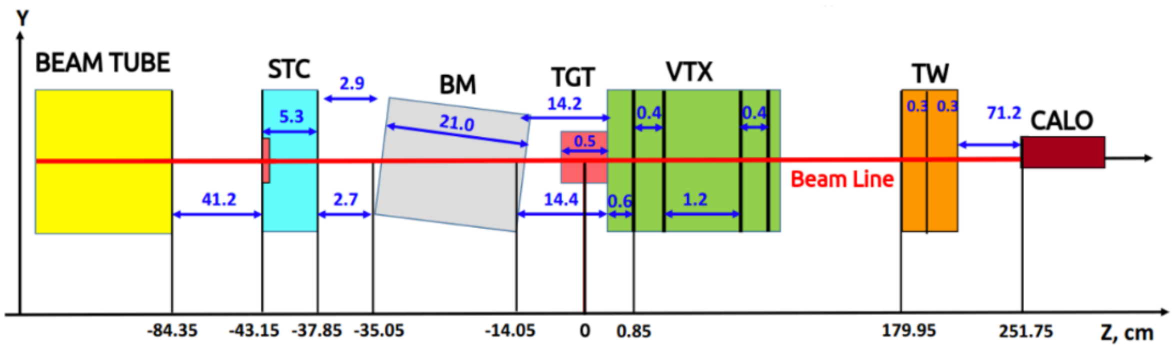
- Align FOOT detectors at GSI and select **angular acceptance** for cross section integration;
- Extract the **fragments yields** from Charge Identification and Clustering algorithms;
- Compute **MC efficiencies** for each fragment;
- Estimate **fragmentation out of target** for background subtraction;
- **Systematics** studies.



Beam and Beam Monitor at GSI



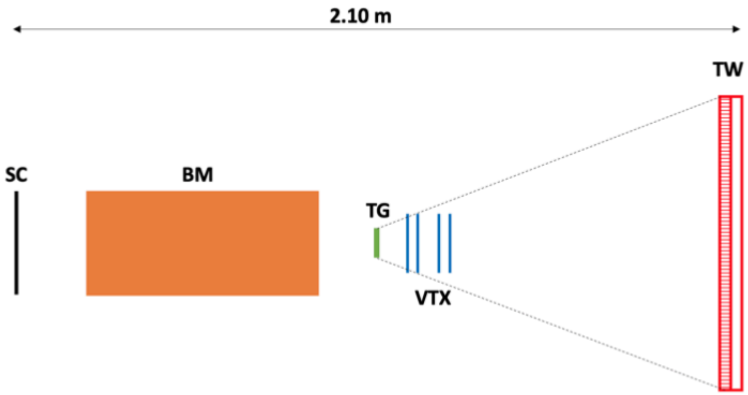
- To correctly measure the angles of the emitted tracks and estimate the angular acceptance the detectors must be properly aligned taking into account small shifts and rotations with respect to the global FOOT reference.

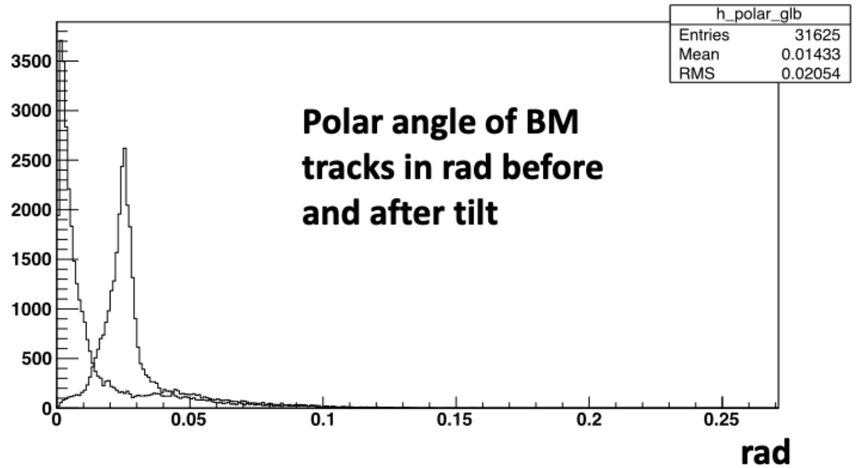
- To align BM and TW, the projection of the traces of the BM on the TG and TW planes was exploited.

- The TW detector was shifted in the global reference frame to irradiate at the center of the bars.

This relative displacement between TG and TW and the beam structure impose a limit on the angular acceptance of the set-up

$$\Delta\theta = 5.7\,^{\circ}$$



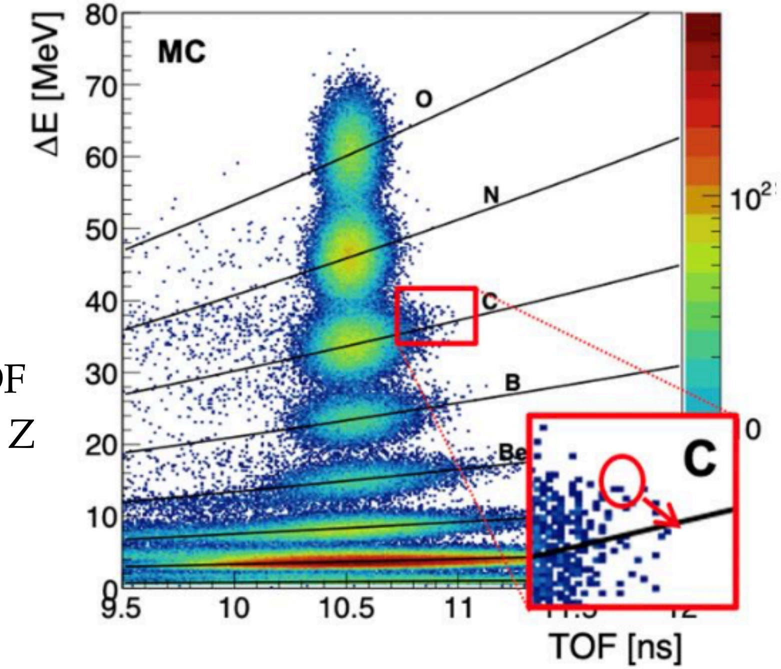


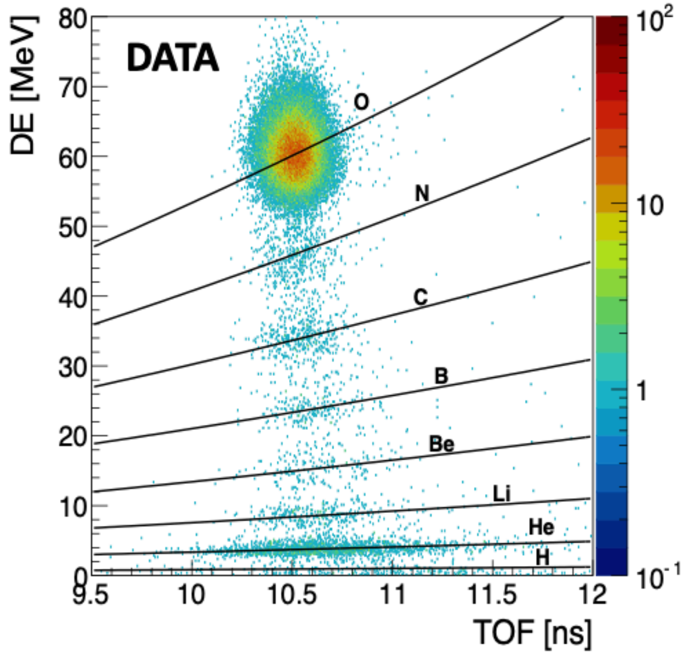
Charge identification algorithm (ZID)

For each TW hit (Eloss, ToF) the ZID algorithm assigns a fragment charge Z

- For each region (and so for each charge) the distribution was fitted with Bethe-Bloch formula.

- Plotting the TW hits on an ΔE vs TOF plain, we can **assign** to each one the Z corresponding to the **closest Bethe-Bloch** curve.

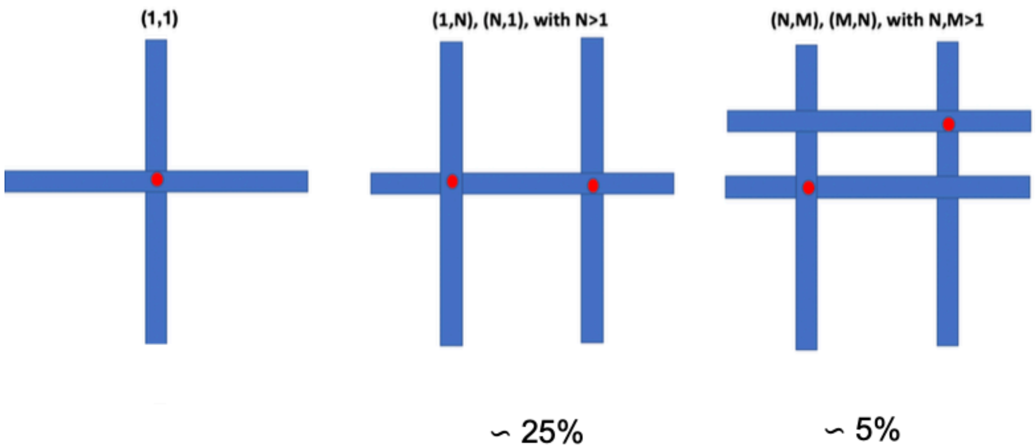


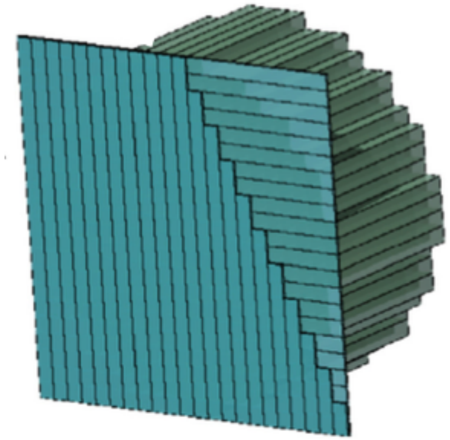


TW clustering algorithm

To reconstruct a fragment track impinging on the detector, the front and rear TW hits have to be clusterized.

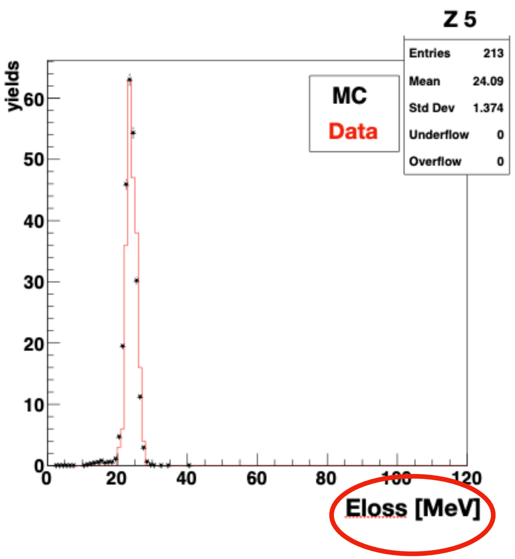
- The clustering algorithm has the task of **joining pairs of hits released in the two layers** corresponding to the same fragment in a unique TW point.

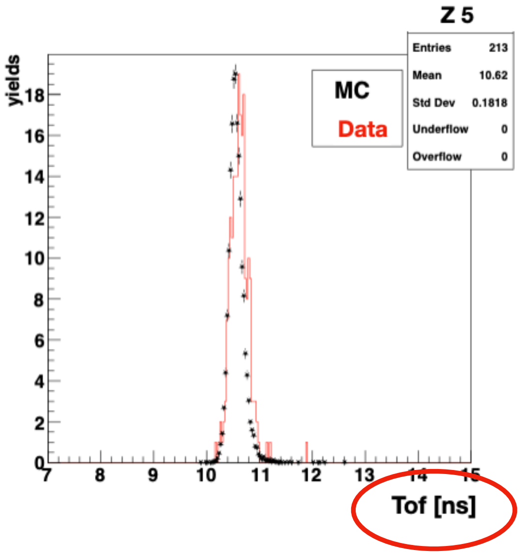


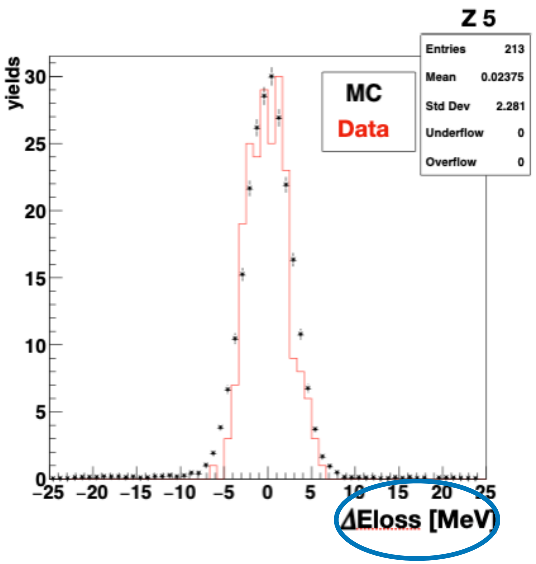


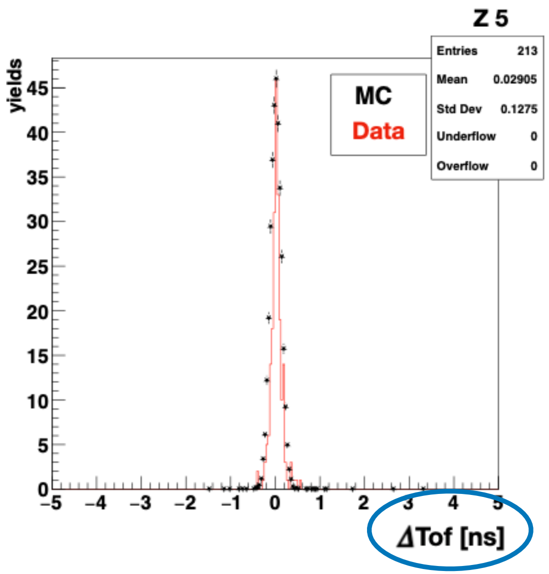
- The clustering algorithm drives the TW point reconstruction, dynamically, with the **hits from the TW layer with the higher occupancy**, in a given event in order to disentangle from multi hit in the same bar.

Fragments identification with TW









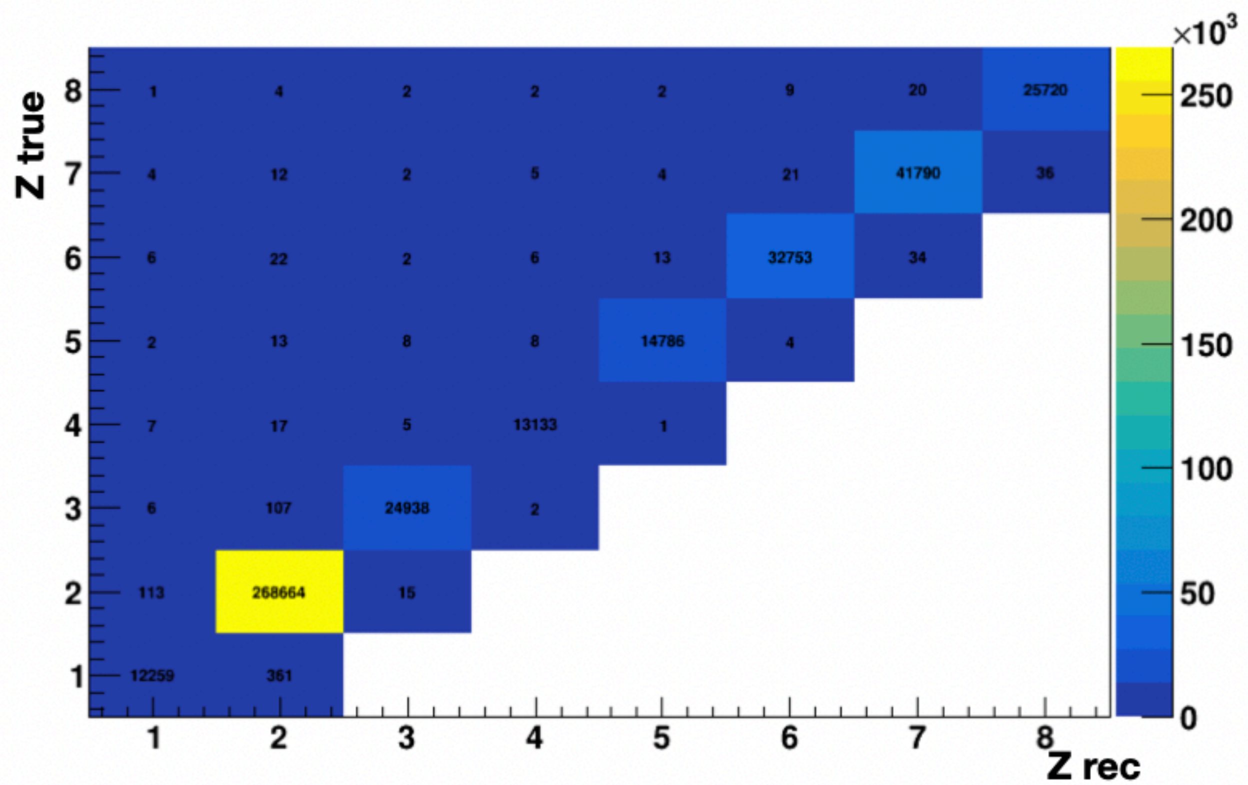
- To check the Charge identification and the TW clustering algorithms a **comparison** between E_{loss} **and TOF of the two hits matched** by the clustering was performed, compared in data end MC;

- In addition, the **quantities reconstructed** by the TW and associated to each reconstructed point have been compared in data and MC.

The reconstructed MC matches the data, providing a **good reproduction** of what happens in reality.

TW algorithm performances

It is possible to correlate in a charge mixing matrix (CMM) the reconstructed charge to the real one (for MC truth).

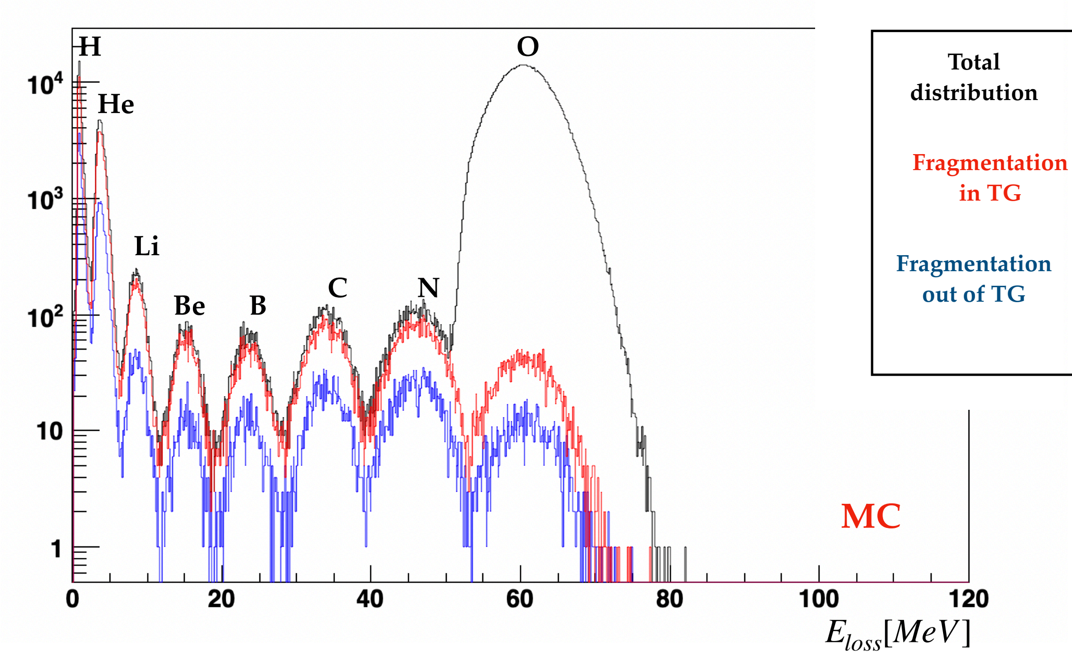


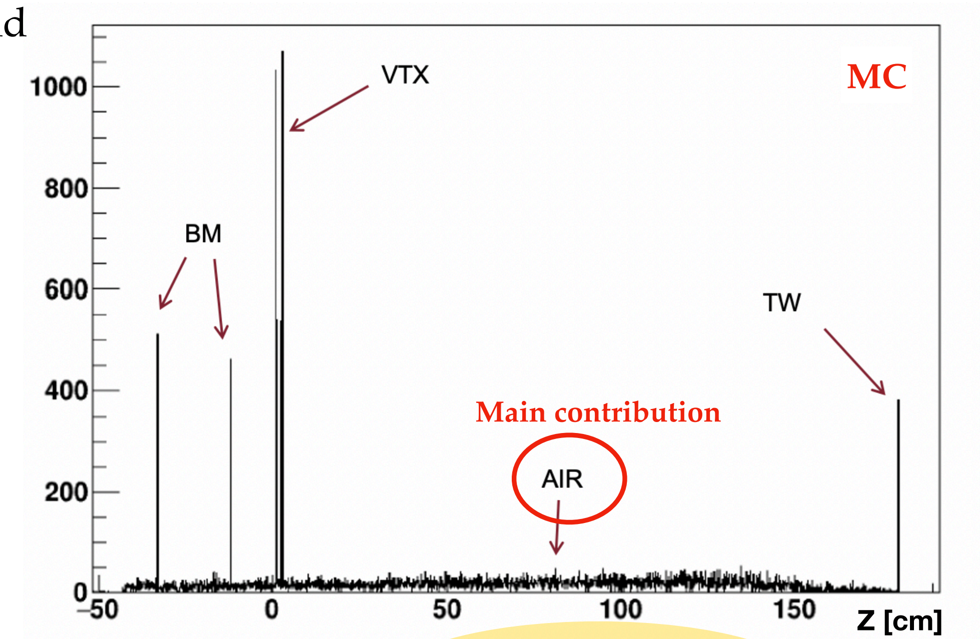
- The CMM is useful to observe **when the charge identification algorithm assigns a fragment to a wrong Z**.
- It's almost **perfectly diagonal**: some charge mixed events in the region above the diagonal.
- This is a good confirmation that the **charge identification and the clustering algorithms are able to identify efficiently** the different Z fragment populations.

Background subtraction

- The fragments yields extracted by the TW detector **mix primary fragmentation produced in the TG**, which corresponds to the signal in the cross section measurements, and **primary fragmentation out of target** that results in a source of background for our measurement.

To evaluate this effect, studies on the reconstructed MC are performed

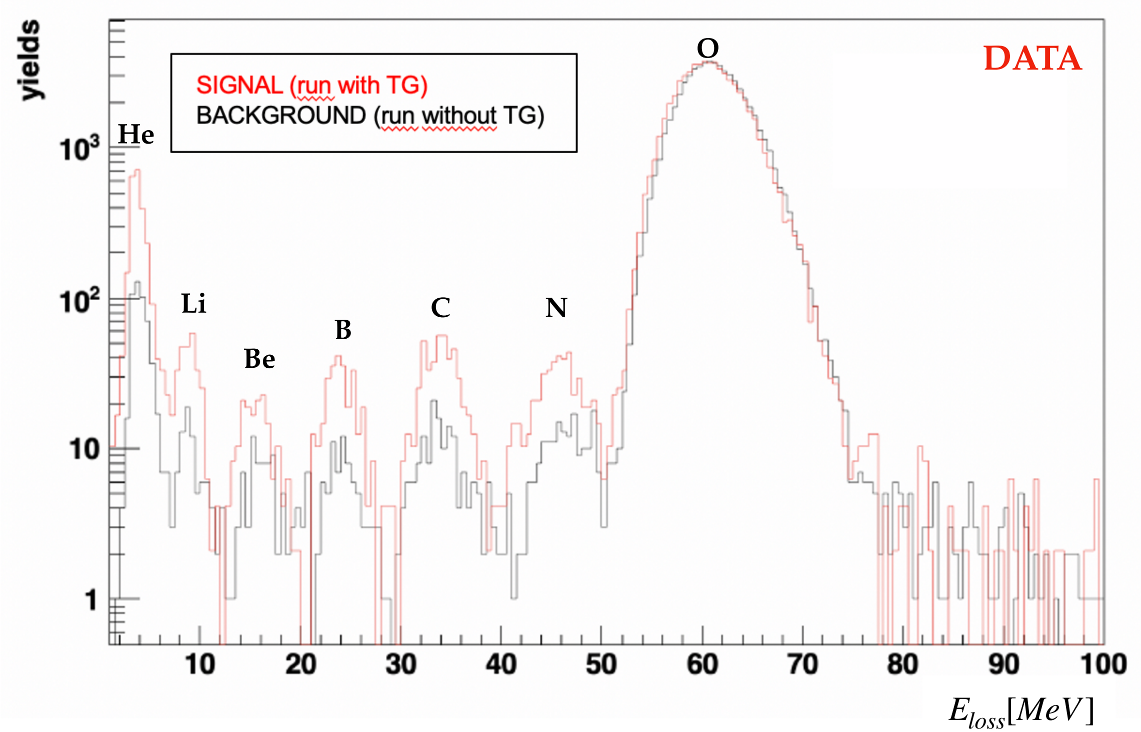




Background ~ **30%**

Yields extraction

- The **count of primary ions** of the beam interacting with the target is provided by the **Start Counter** (with a minimum bias trigger implemented as the majority of 4 channels of the detector).



- Requiring events with single tracks in BM with projection on the target within [-1,1] cm and θ < 5.7° for all the emitted fragments we got the **total number of primaries selected** for the cross section measurement.

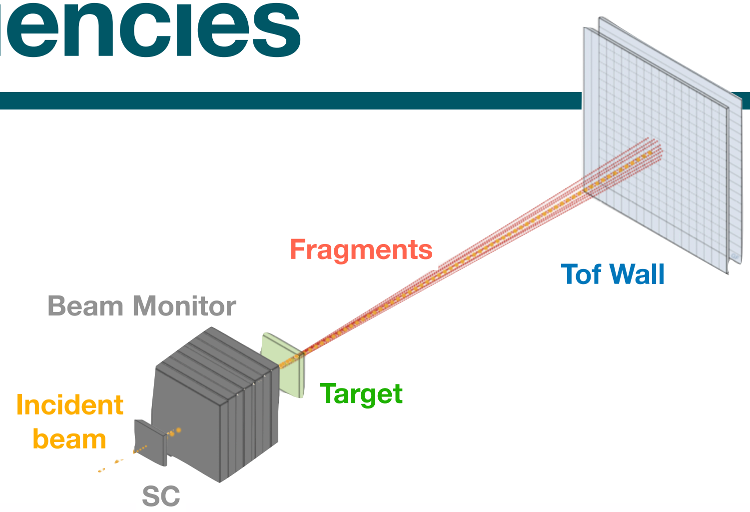
Element	$Yields_{signal}$	$Yields_{bkg}$
N_{prim}	31660	61516
He	484 ± 22	1087 ± 33
Li	89 ± 9	152 ± 12
Be	73 ± 9	77 ± 9
B	88 ± 9	136 ± 12
C	156 ± 13	231 ± 16
N	207 ± 14	248 ± 16

Reconstructed efficiencies

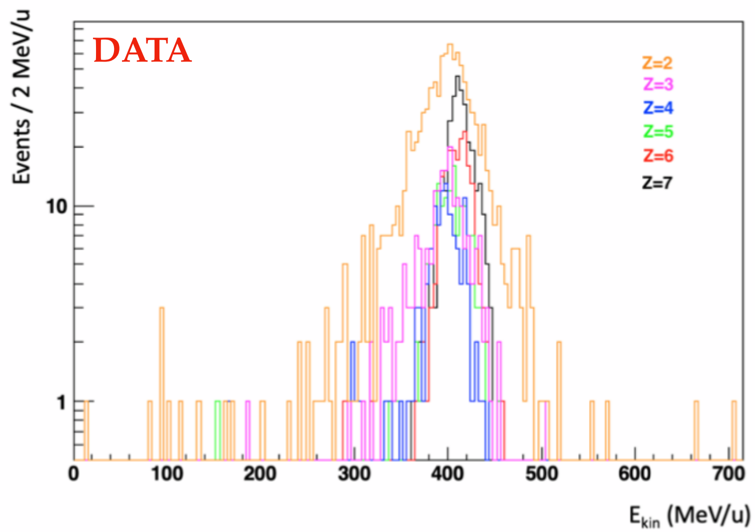
$$\epsilon(Z) = \frac{N(Z)_{TW}}{N(Z)_{prod}}$$

Numerator: asking for a good TW point matched to primary fragments with origin in TG with production angle < 5.7° and E_{kin} production range [100, 600] MeV/u

Denominator: asking for only primary fragments produced in TG and escaping with an angle < 5.7° and E_{kin} range [100, 600] MeV/u

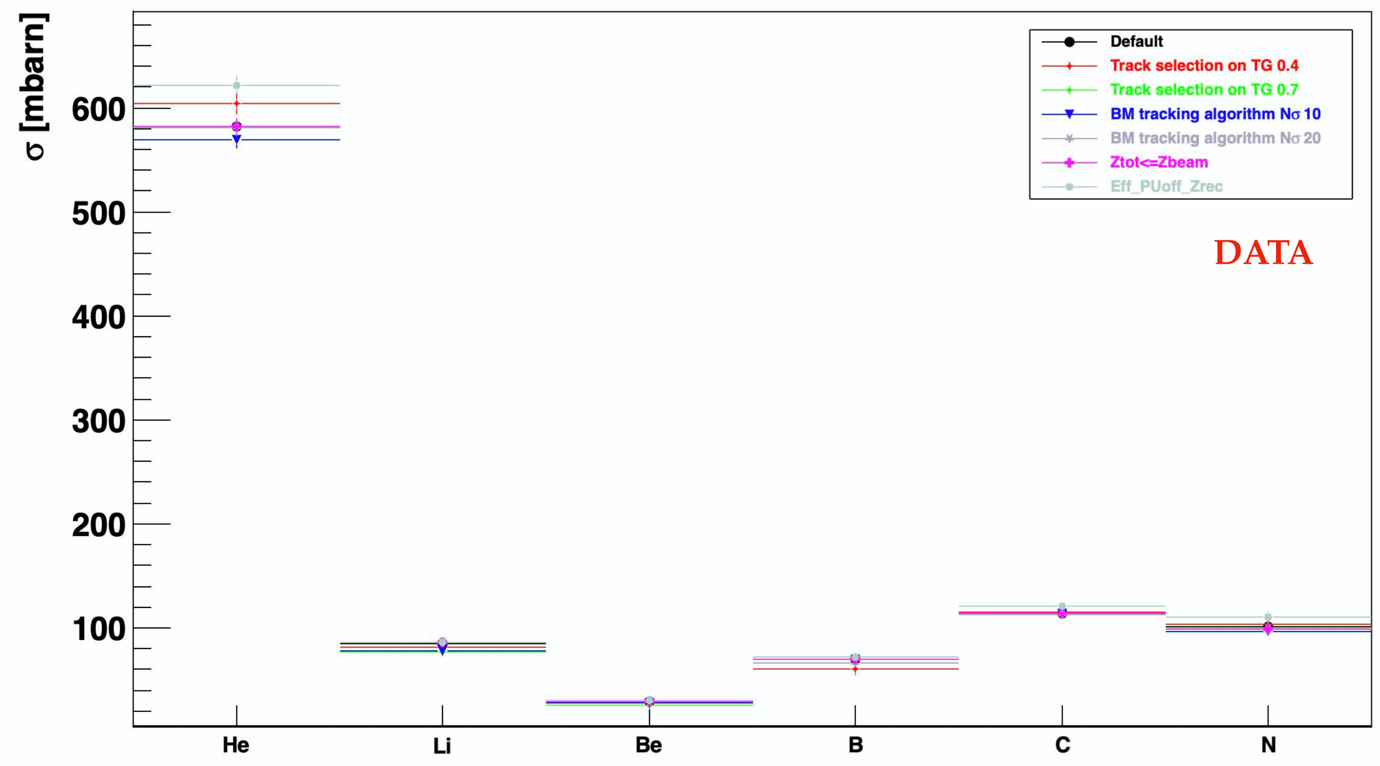


Element	Efficiency(%)
He	91.92 ± 0.05
Li	85.38 ± 0.20
Be	88.32 ± 0.26
B	88.75 ± 0.24
C	91.13 ± 0.15
N	95.88 ± 0.09



Charge-changing cross sections

- To check the validity of the measurement we tried to estimate the **sources of systematics**.



1. Different **selection criteria of the projection** of the beam direction **on TG**;
2. Quality of the **BM reconstructed tracks**;
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Charge-changing cross sections

$$\sigma(Z) = \int_{E_{min}}^{E_{max}} \int_{0}^{\Delta\theta} \left(\frac{\partial^2\sigma}{\partial\theta\partial E_{kin}} d\theta dE_{kin}\right) = \frac{N_{frag}(Z)}{N_{prim} \cdot N_{TG} \cdot \epsilon(Z)} = \frac{1}{N_{TG} \cdot \epsilon(Z)}\left[\frac{N_{TG}(Z)}{N_{TG}^{prim}} - \frac{N_{noTG}(Z)}{N_{noTG}^{prim}}\right]$$

$$N_{TG} = \frac{\rho \cdot dx \cdot N_A}{A} \quad \begin{cases} \rho = 1.83\ g/cm^3 \\ dx = 0.5\ cm \\ A = 12.0107 \end{cases}$$

Element	$\sigma_{frag} \pm \Delta_{stat} \pm \Delta_{sys} [mbarn]$	$\Delta_{stat}/\sigma_{frag}$	$\Delta_{sys}/\sigma_{frag}$	$\sigma_{MC} [mbarn]$
He	$625 \pm 22 \pm 21$	3.6%	3.6%	621
Li	$85 \pm 10 \pm 5$	11.9%	5.6%	67
Be	$31 \pm 10 \pm 3$	31.8%	8.8%	33
B	$70 \pm 10 \pm 5$	14.9%	7.3%	38
C	$113 \pm 12 \pm 3$	10.9%	2.7%	81
N	$101 \pm 14 \pm 5$	13.7%	4.8%	105

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There is also a good agreement with the cross sections calculated with the **reconstructed MC**

We are going to publish!

Almost ready to be submitted to Jinst

Contents

1. **Experimental setup**
   - Start Counter
   - Beam Monitor
   - Target and Vertex detector
   - TOF Wall
2. **Data sample and MC simulation**
   - Geometrical setup
   - GSI data taking trigger and event multiplicity
   - FLUKA simulation
3. **Analysis strategy and results**
   - Event Reconstruction
   - Cross section calculation

PREPARED FOR SUBMISSION TO JINST

Charge changing cross sections measured by the FOOT collaboration using 400 MeV/u ^{16}O ions impinging on a graphite target.

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Thank you for the attention

Systematics

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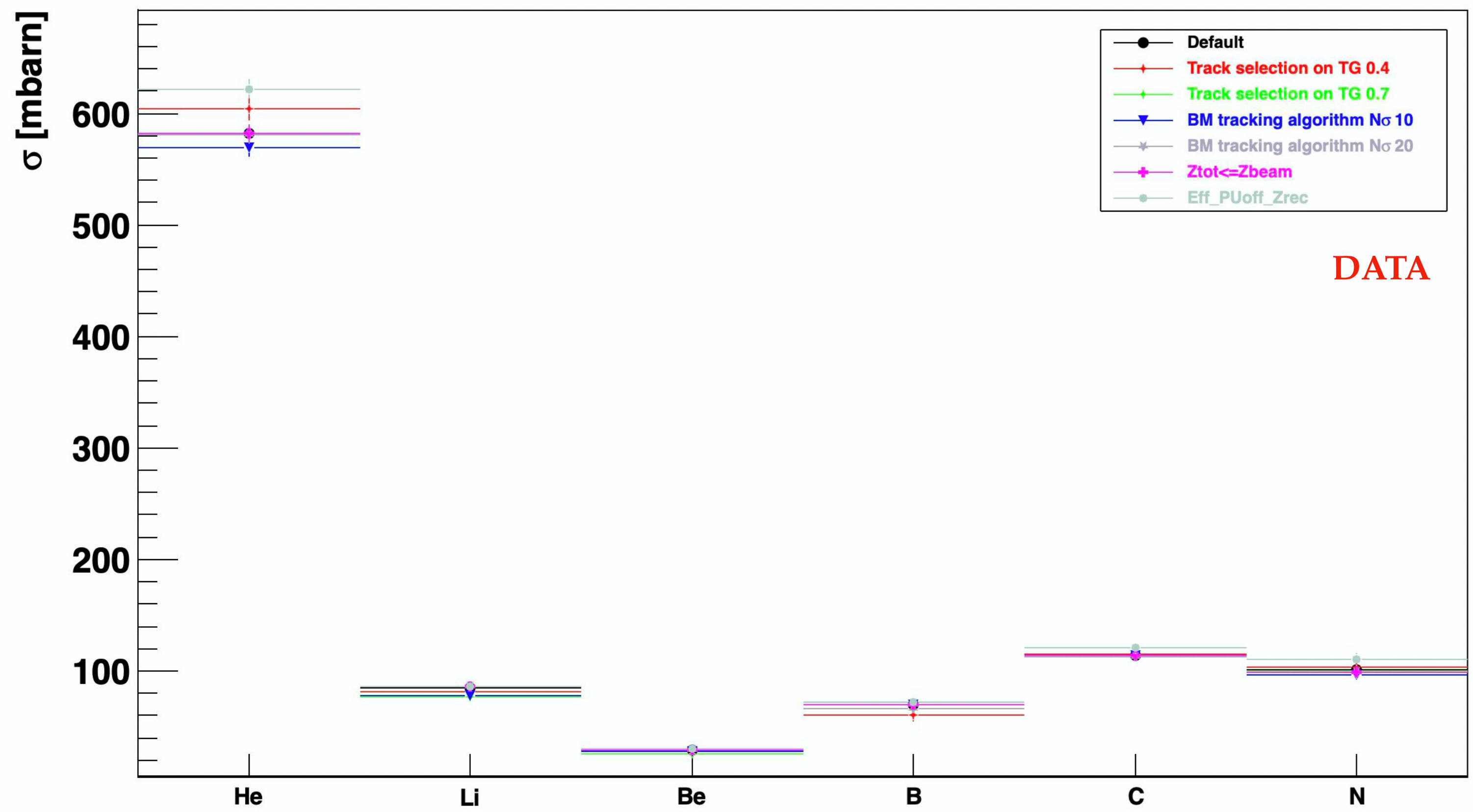

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