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

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FOOT Physics Meeting – 05/05/2021

Available data @ GSI

- **^{16}O beam @ 400 MeV/nucleon on a 5 mm Carbon TG**
- Available detectors: SC + BM + (VTX) + TW

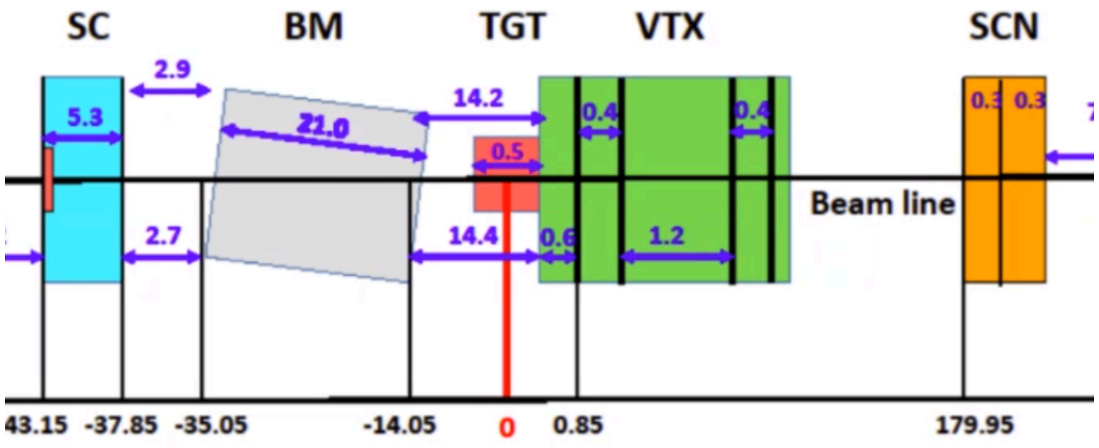
Run	Type	Target	Events
2210	calibration	no	20463
2211	calibration	no	62782
2212	calibration	no	116349
2242	calibration	no	202728
2239	physics	C	20821
2240	physics	C	20004
2241	physics	C	20041
2251	physics	C	6863

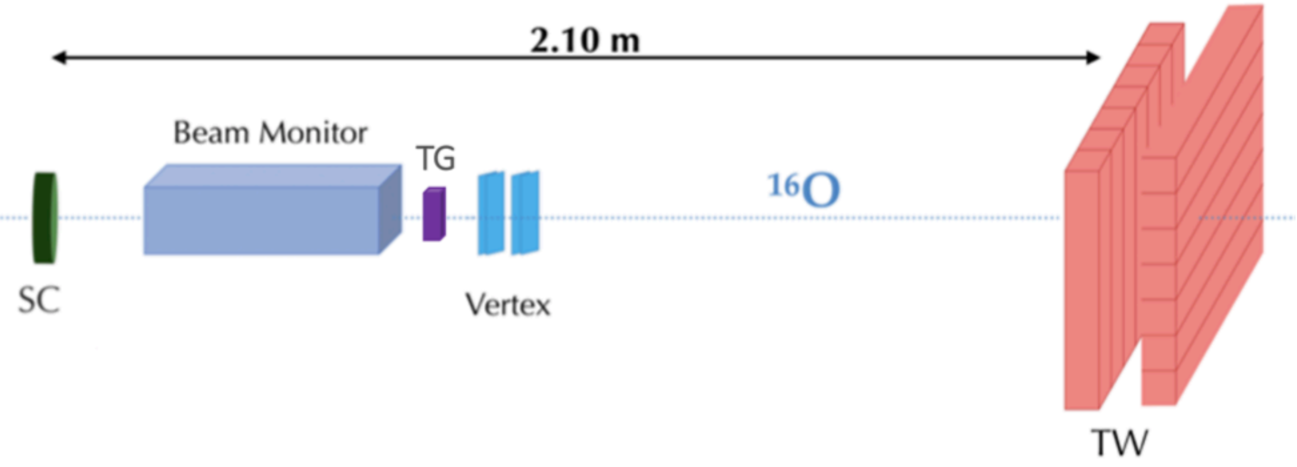
- **Very low statistics and no detectors for mass identification -> only the measurement of elemental (charge-changing) cross section integrated in angular and kinetic energy interval is feasible**

Steps for cross sections measurement

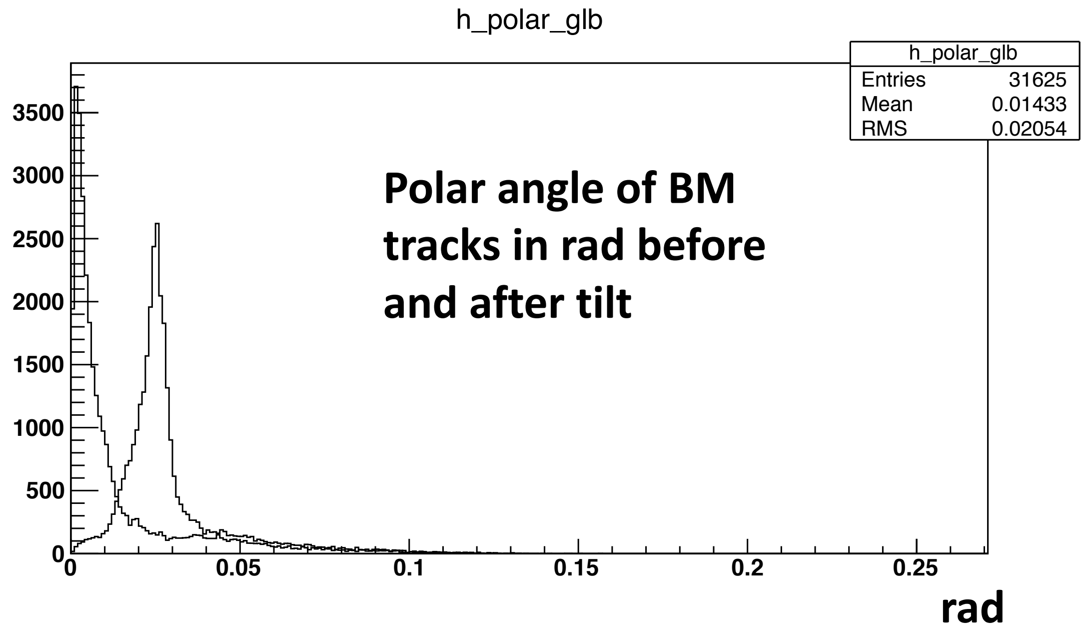
- Align FOOT detector at GSI and select angular acceptance for cross section integration (thanks Yun)
- Extract the fragments yields from ZID and TW clustering algorithms
- Compute MC efficiencies for each fragment
- Estimate fragmentation out of target for background subtraction
- Systematics study

Beam and Beam Monitor at GSI



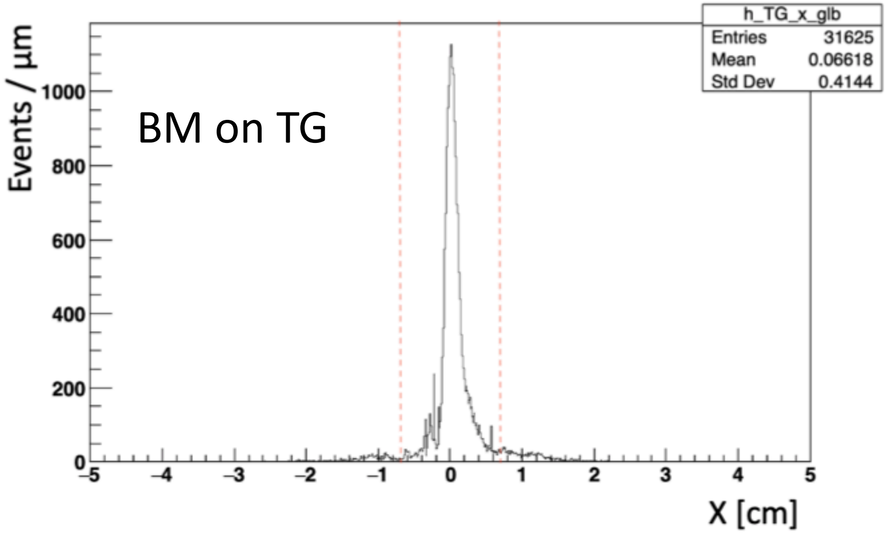


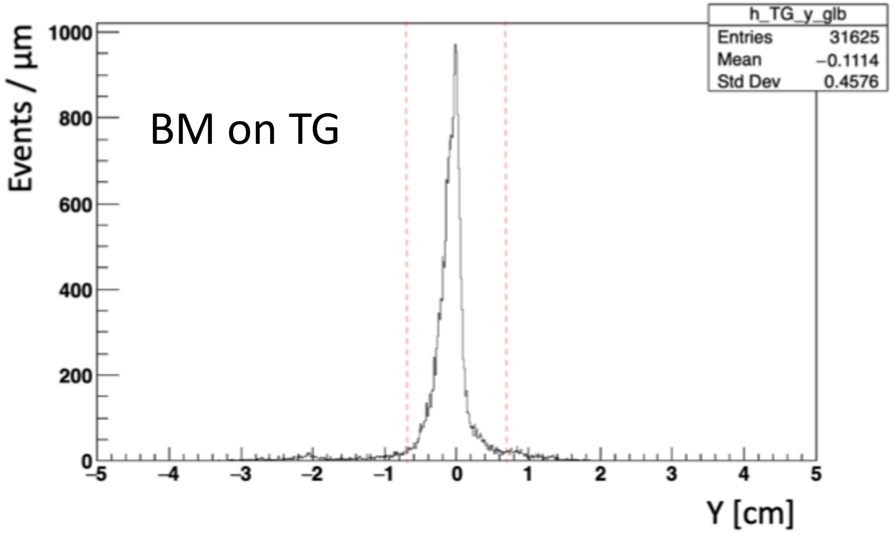
GSI setup (BM/TW) has needed to be aligned for Physics runs (2239,40,41,51) using run 2242 -> straight oxygen ions without TG



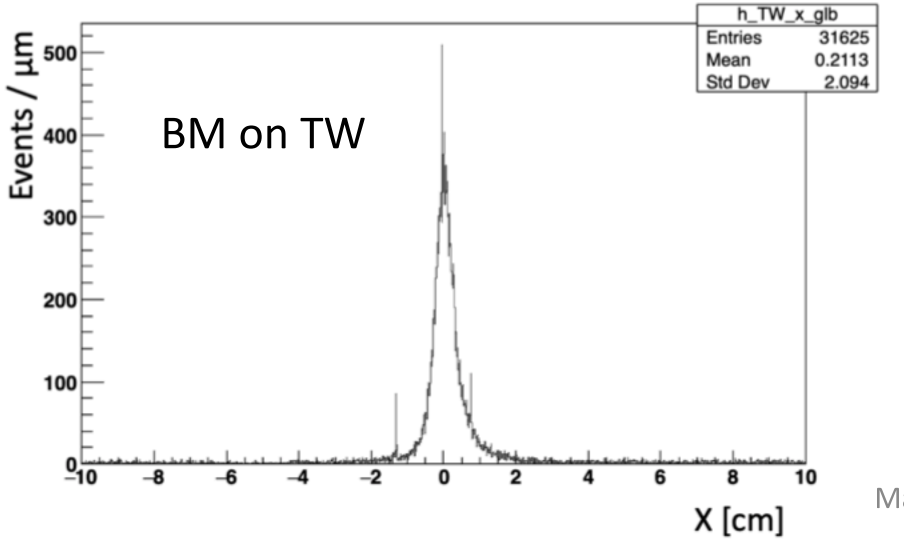
Angular resolution from TW bars crossing < 1.2mrad (0.6°)

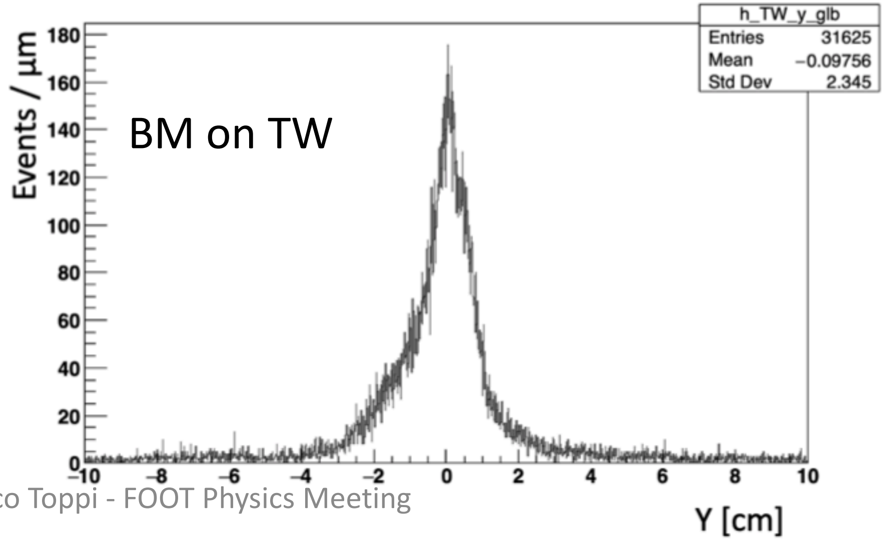
Beam and Beam Monitor at GSI





The beam structure, even if not Gaussian, is centered at (x,y) = (0,0) in the global reference frame

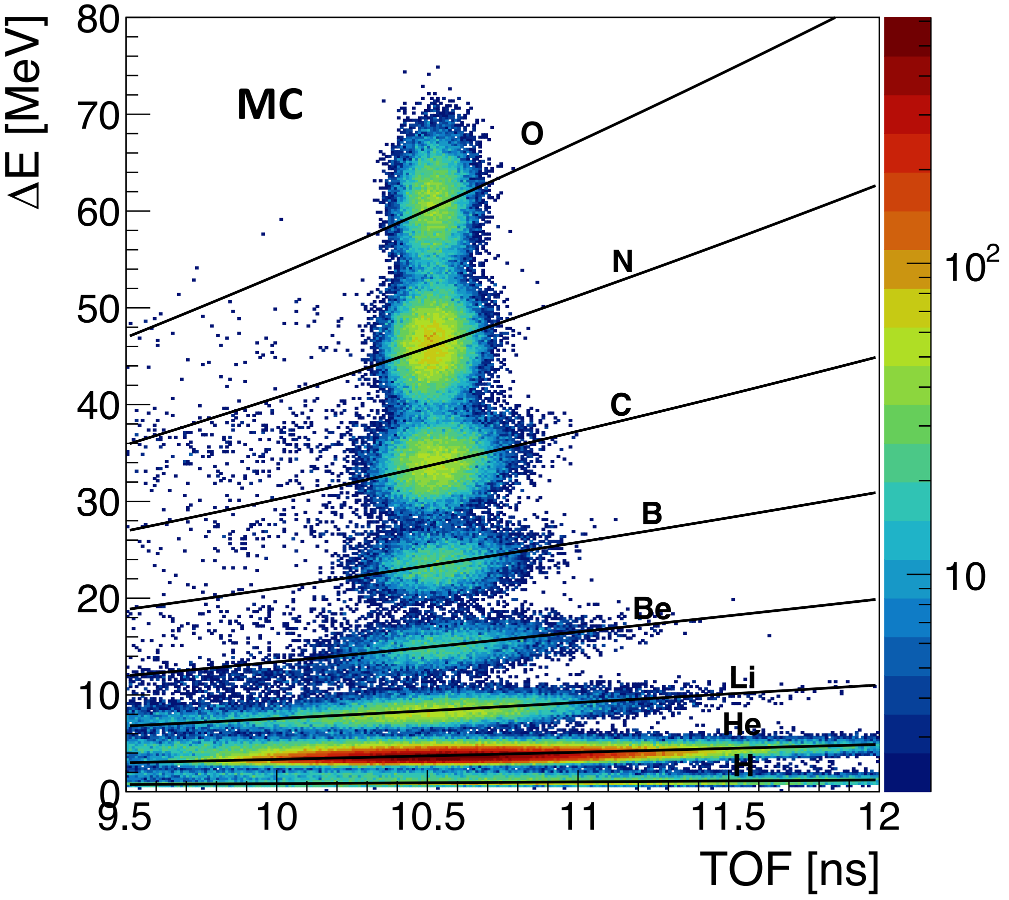


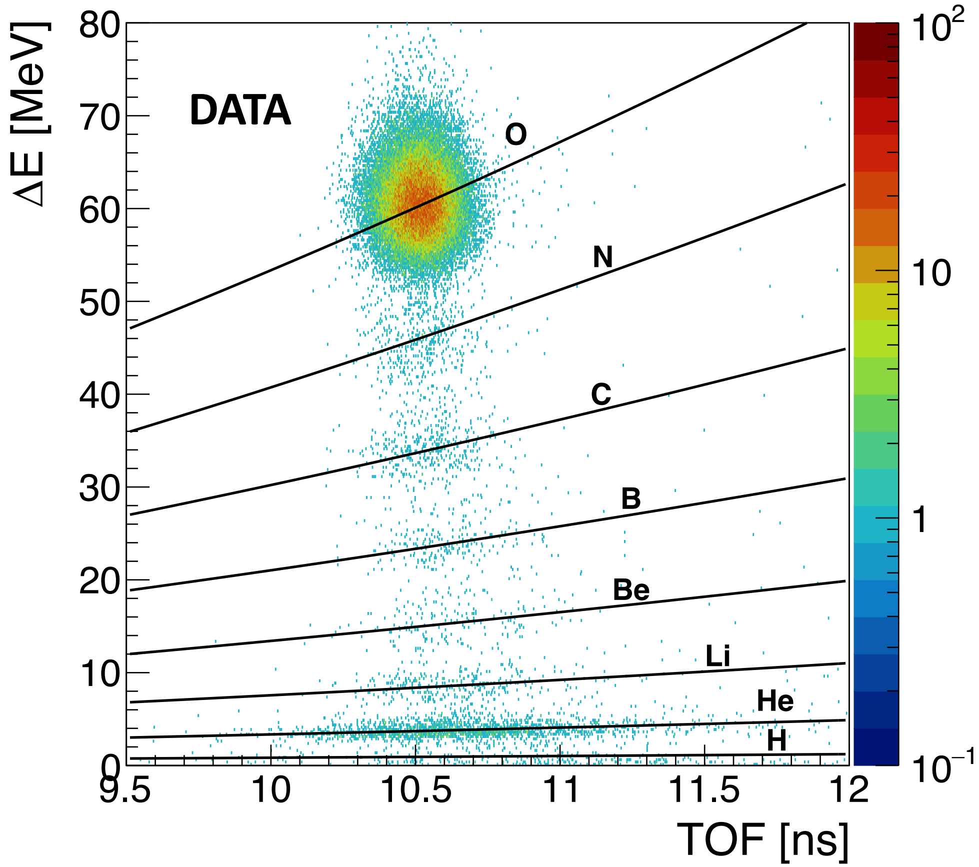


The broadening of the distribution on the TW shows a divergence of the beam of ~ 5 mrad (about 0.3°) in X and Y → to be considered in systematics

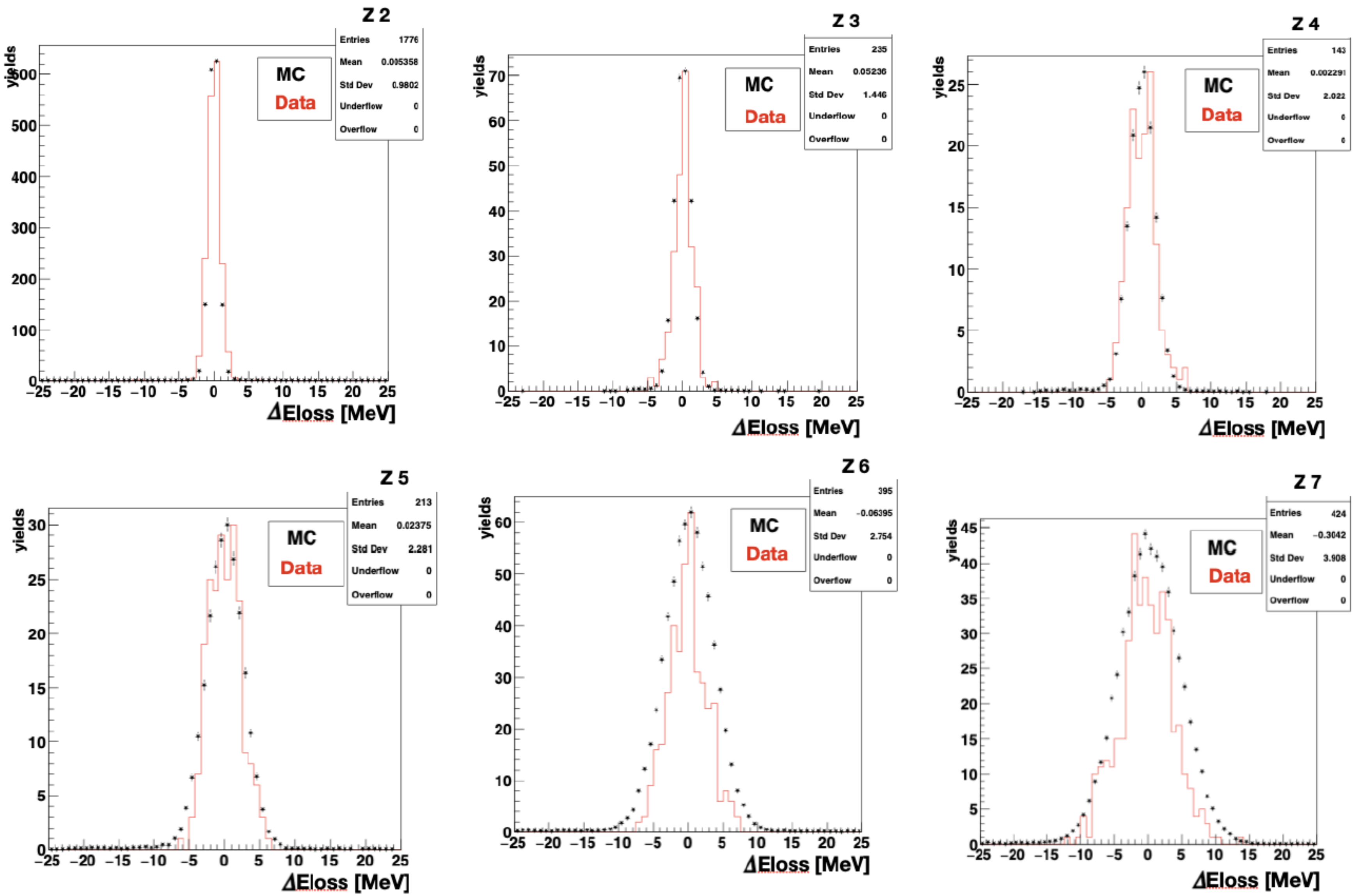
Charge identification (ZID) algorithm

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





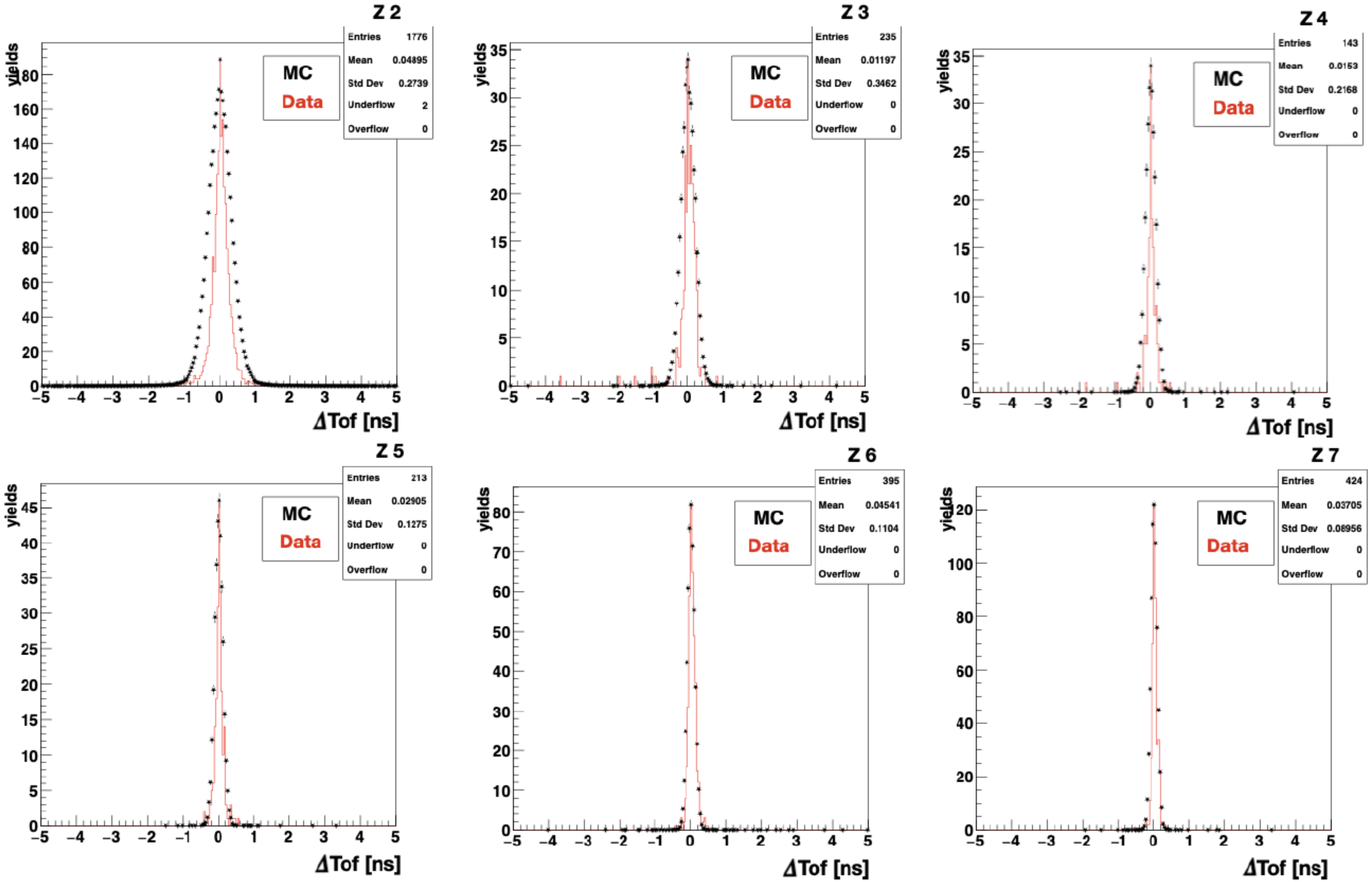
TW clustering algorithm



Clustering algorithm associates hit bars in front and rear layer to reconstruct fragments impinging on TW

Checking TW ZID+clustering algorithm comparing Eloss and Tof of hits matched to the cluster

TW clustering algorithm



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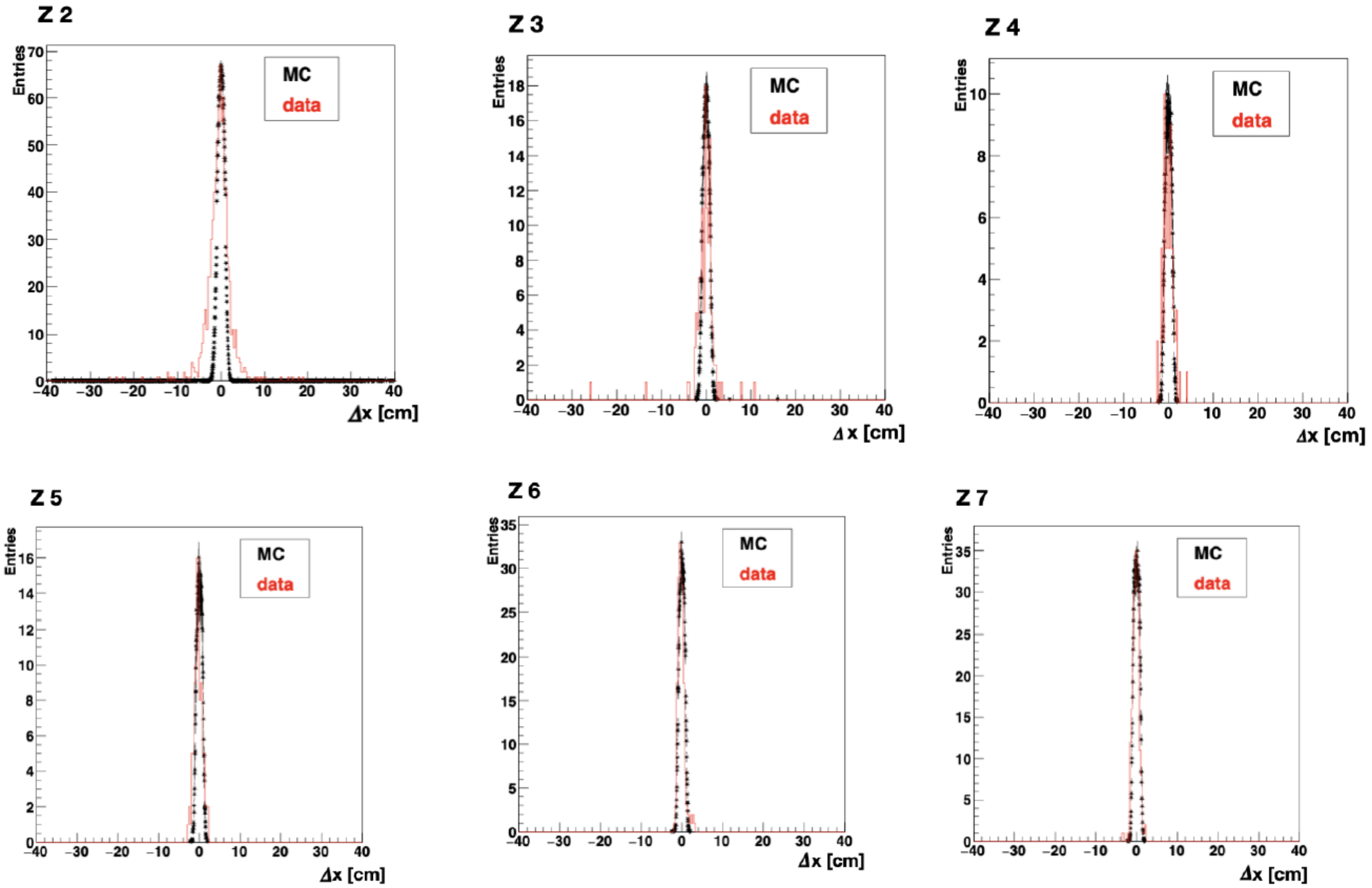

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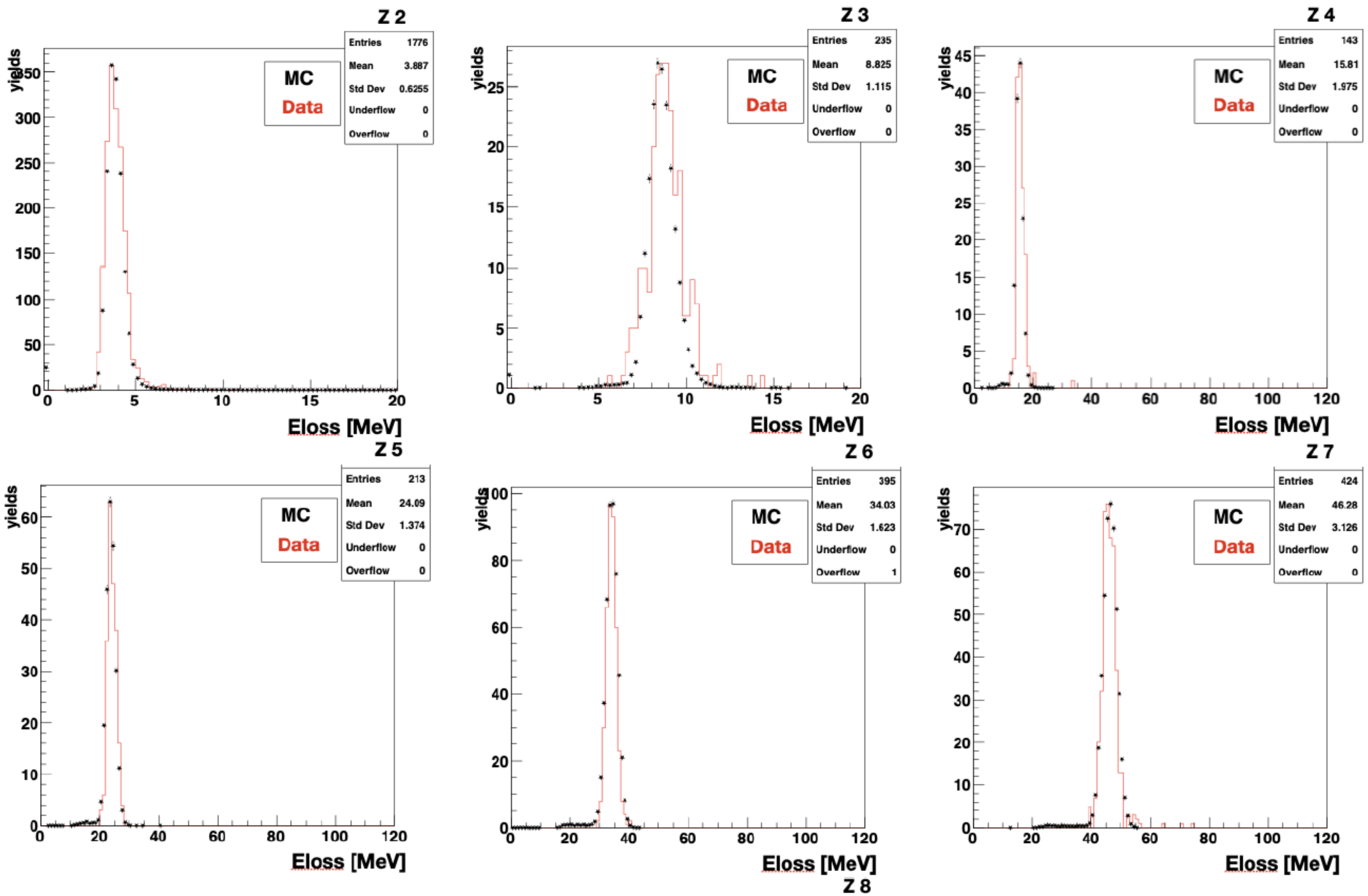
Fragments identification with TW



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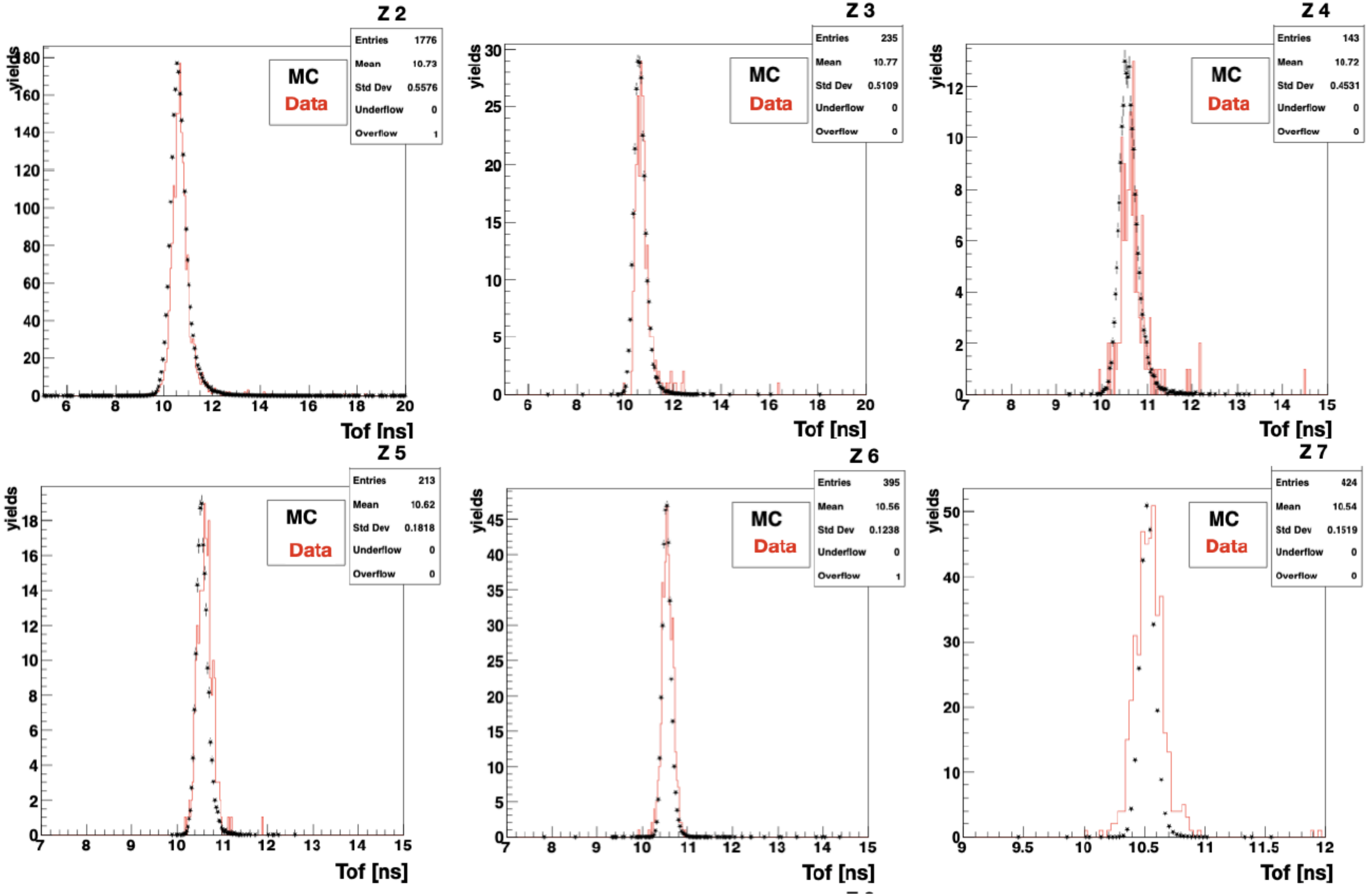
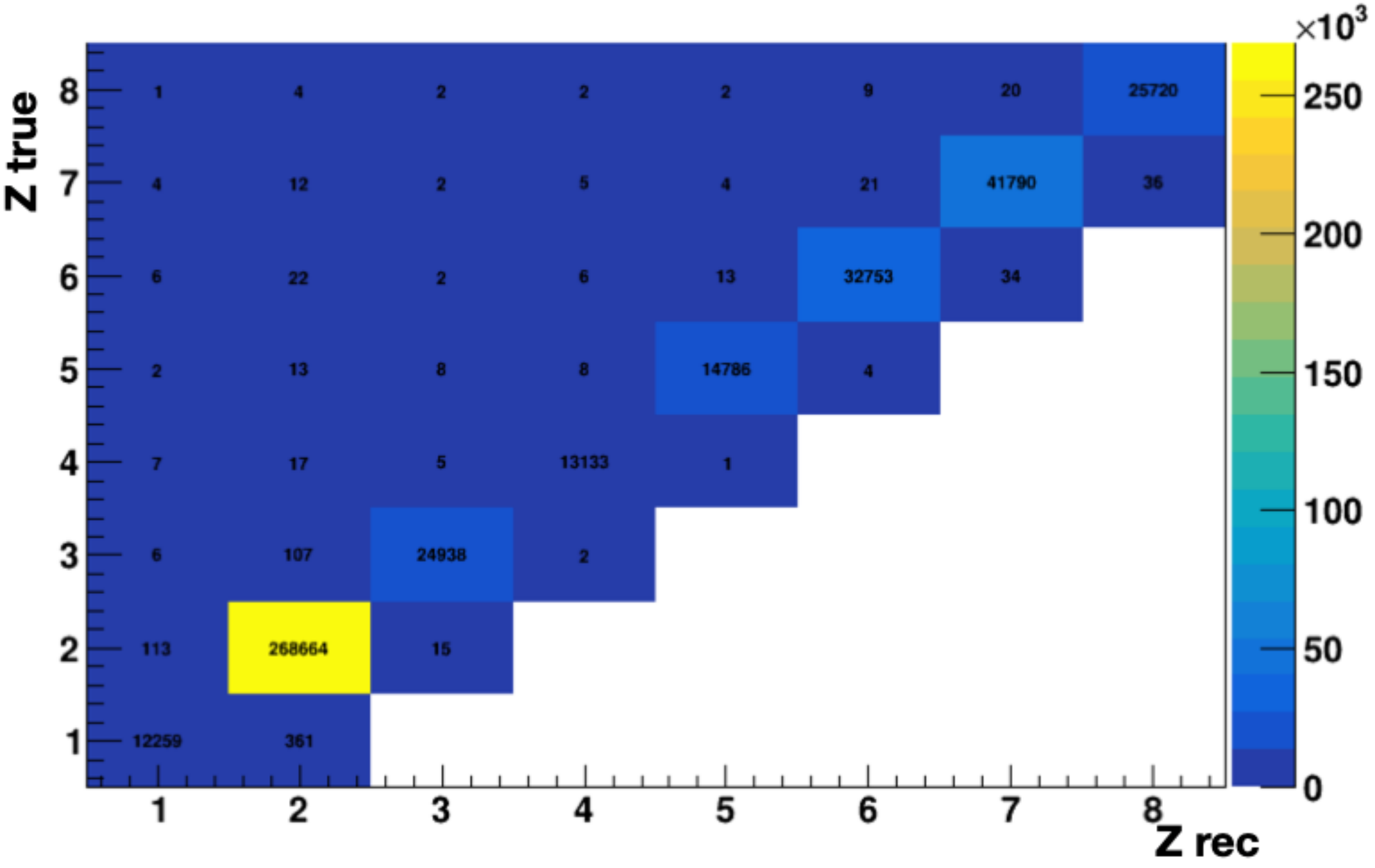


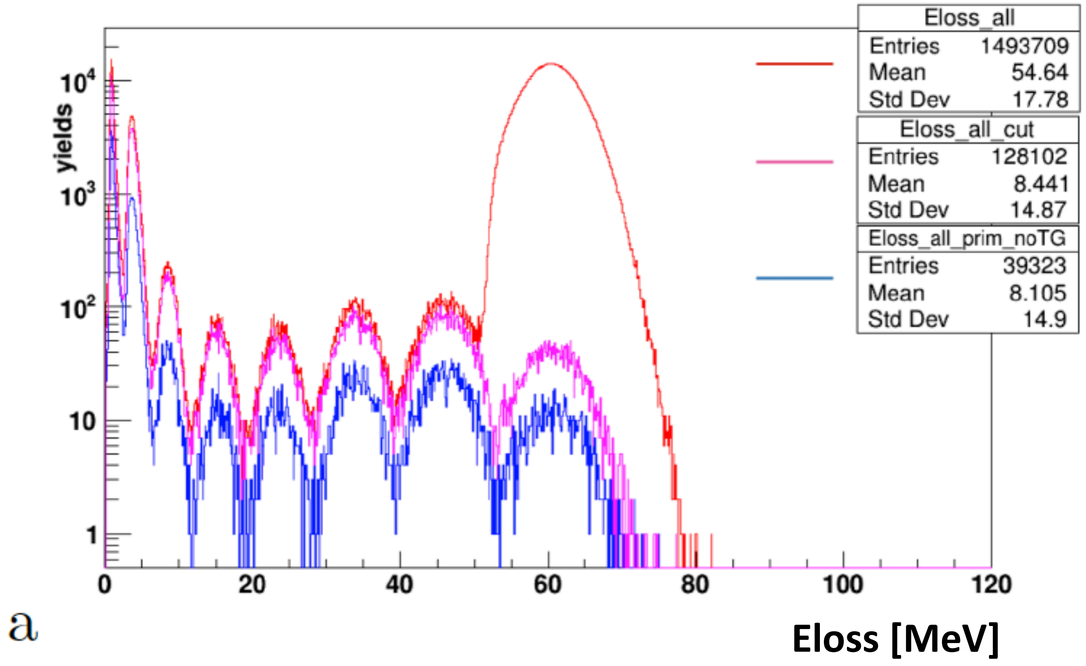
Clustering algorithm associates hit bars in front and rear layer to reconstruct fragments impinging on TW

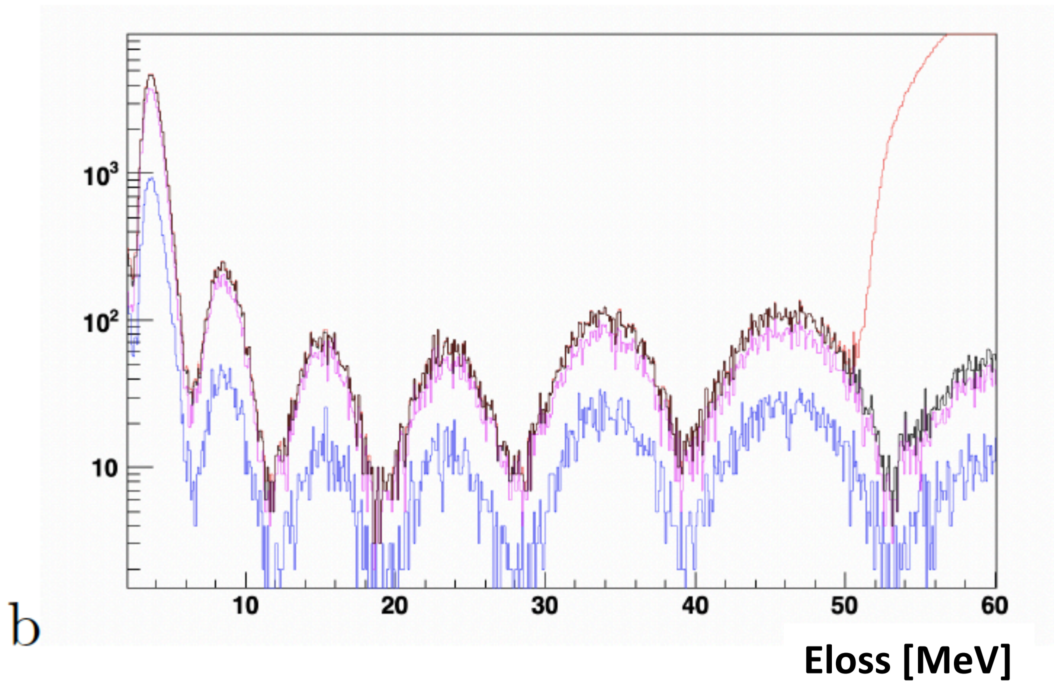
Checking TW ZID+clustering algorithm comparing Eloss and Tof of hits matched to the cluster

TW algorihms performances

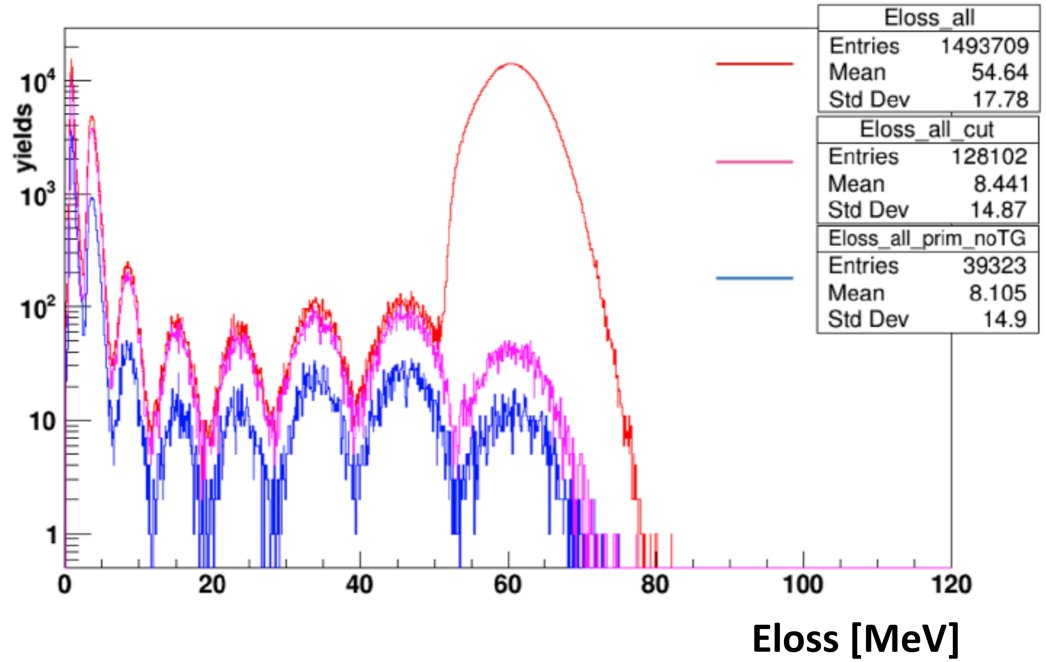


Background subtraction





Background subtraction



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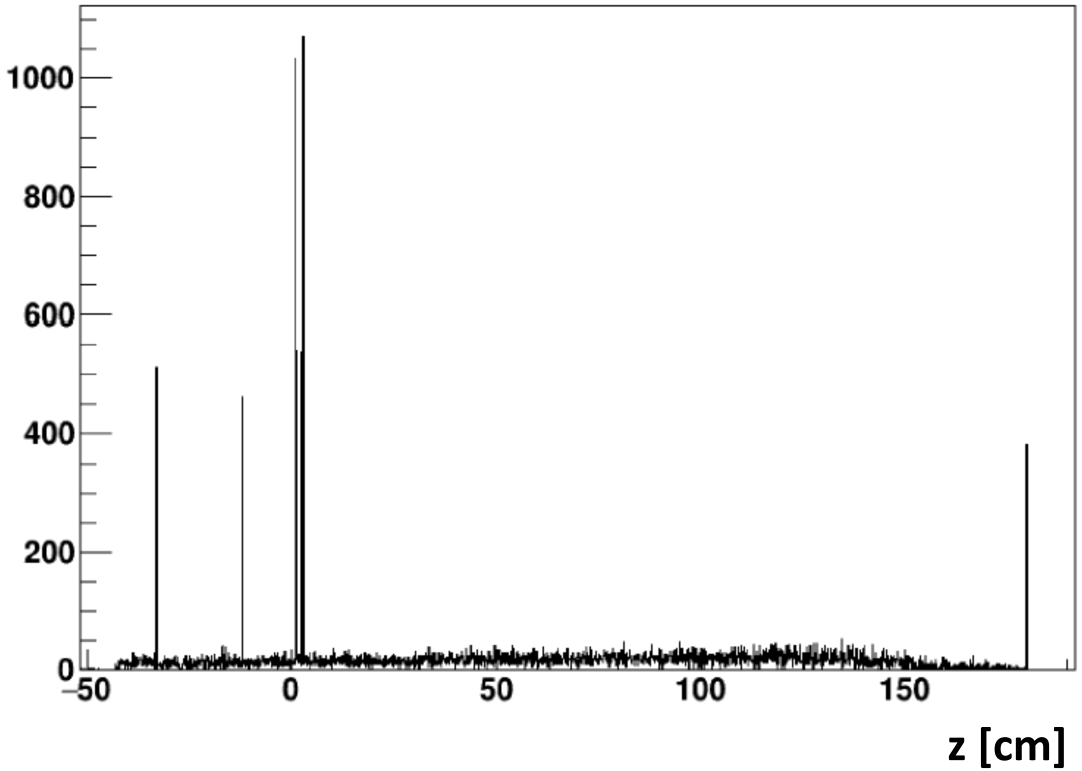
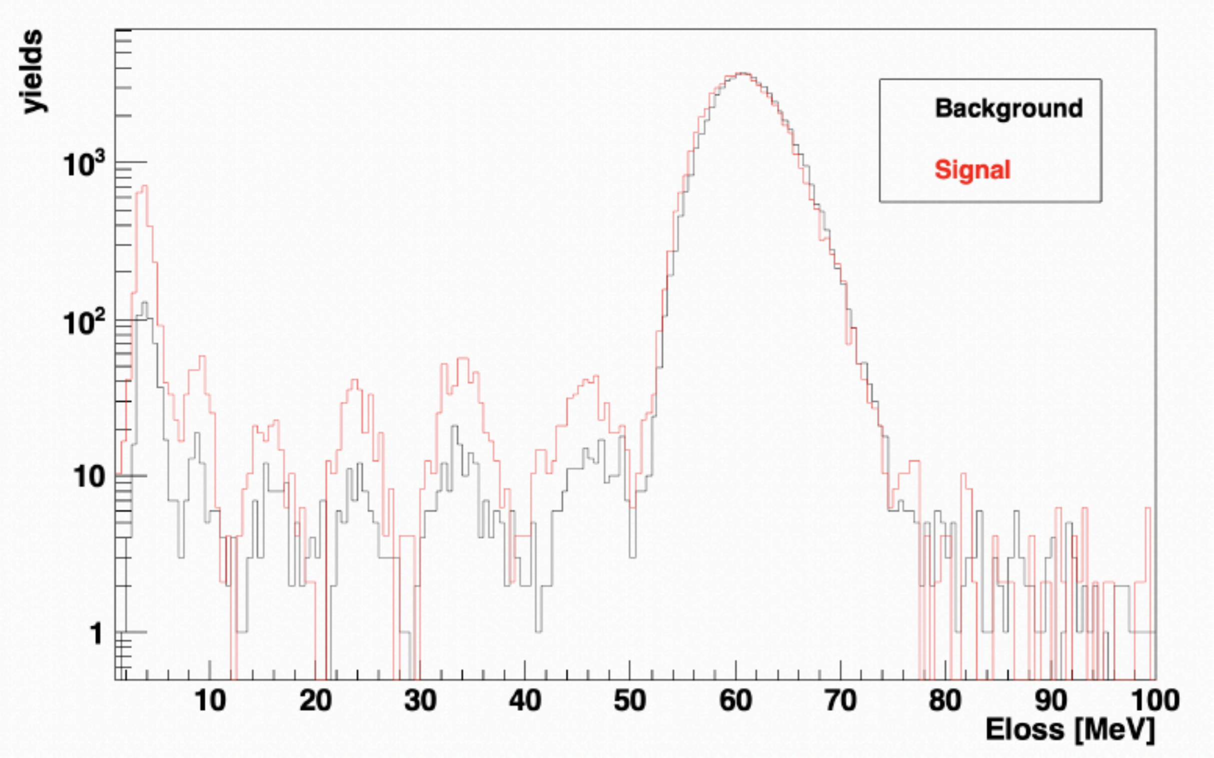


Background subtraction in data



Background subtraction in data from runs 2210, 2211, 2212 without TG

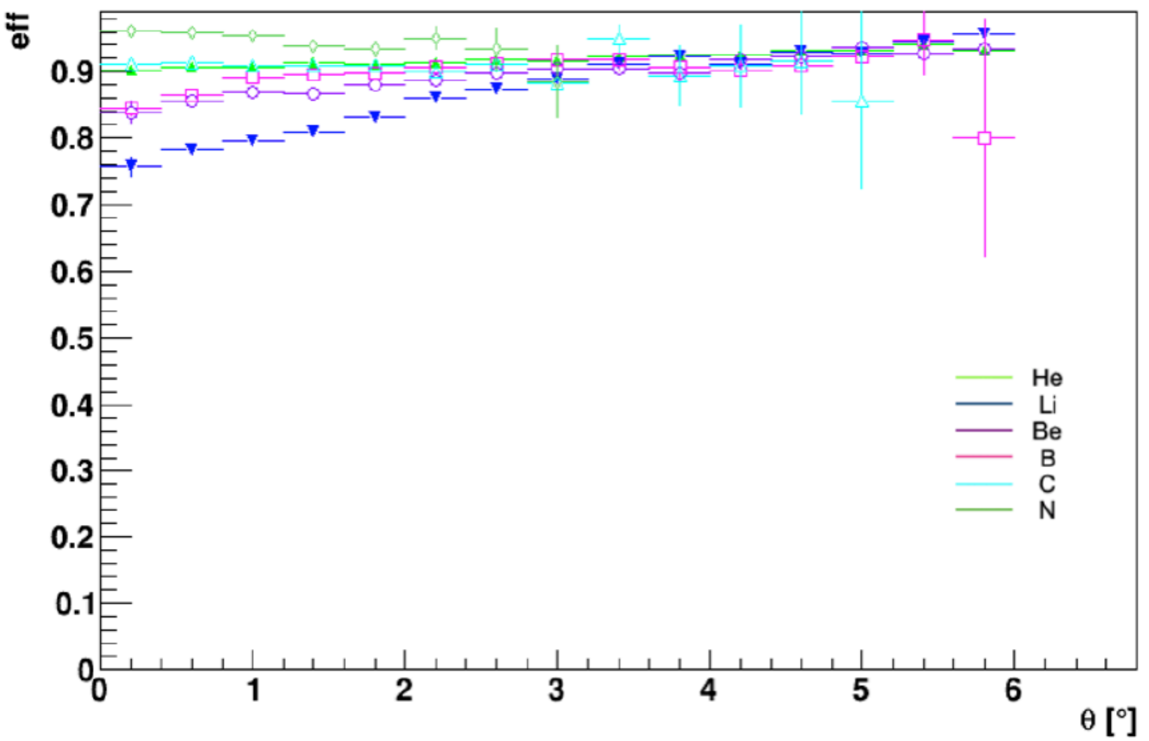
Cross section measurement

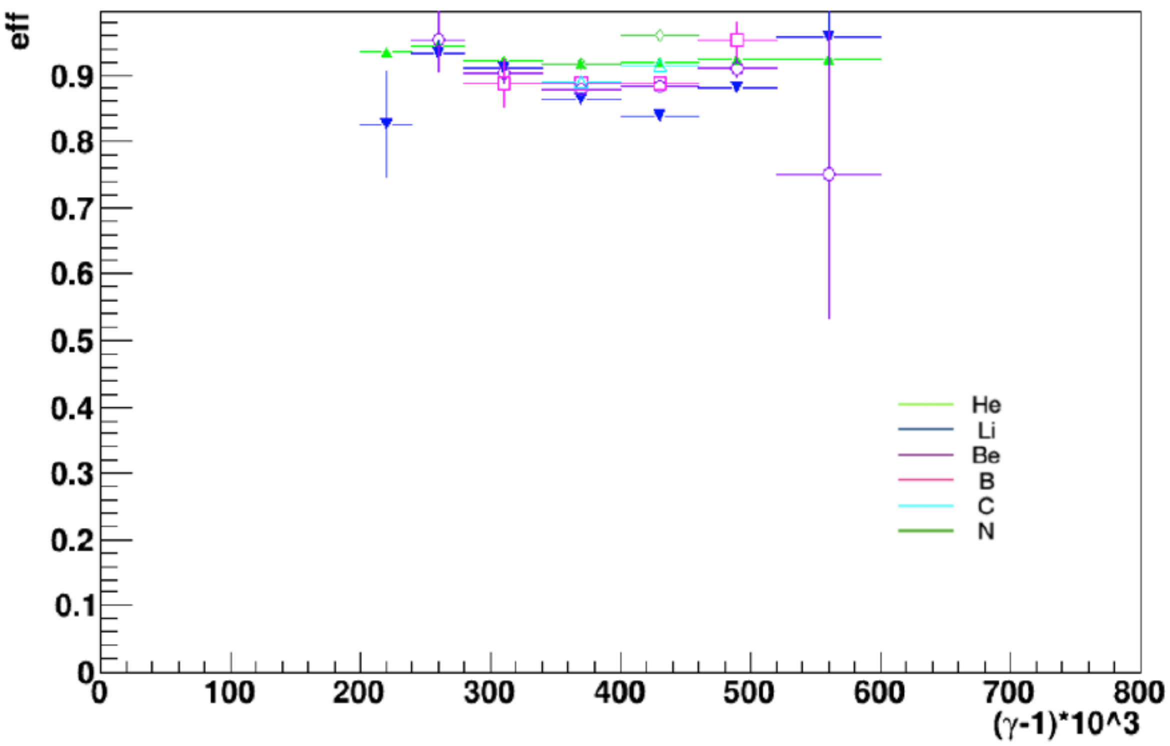
$$\sigma(Z) = \int_{E_{min}}^{E_{max}} \int_0^{\Delta\theta} (\frac{\partial^2 \sigma}{\partial\theta \partial E_{kin}})\, d\theta dE_{kin} = \frac{N_{frag}(Z)}{N_{prim} \cdot N_{TG} \cdot \epsilon(Z)}$$

$$N_{TG} = \frac{\rho \cdot dx \cdot N_A}{A}$$

Element	$Yields_{bkg}$	$Yields_{signal}$
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

Efficiencies in angle and “Ekin”





Efficiencies

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

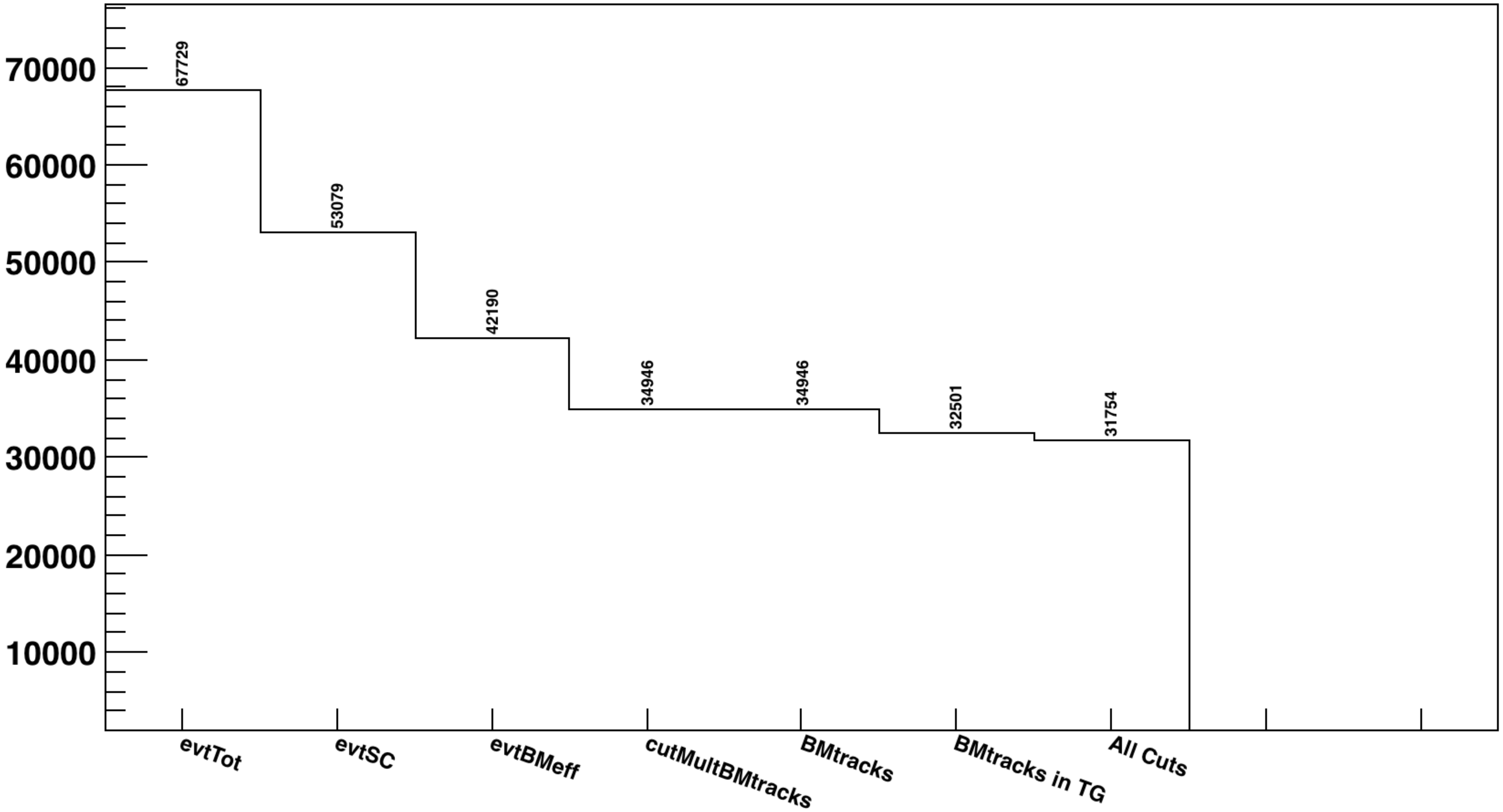
Element	Efficiency(%)
He	91.92 ± 0.05
Li	85.38 ± 0.20
Be	88.32 ± 0.26
B	88.75 ± 0.24
C	91.13 ± 0.15
N	95.88 ± 0.09

Numerator: Asking for a good TWpoint matched to primary fragments with origin in Target with production angle < 5.7° , beam projection on TG in [-1,1] and production Ekin in the range [100,600] MeV/n.

In reconstructed MC **Pile-Up is switched off and Z=Ztrue** (not reconstructed Z)

Denominator: Asking for only primary fragments with origin in Target produced on the TG in [-1,1] and escaping from it with θ<5.7° and an Ekin in the interval 100-600 MeV/n (from data distribution)

Selections and available statistics

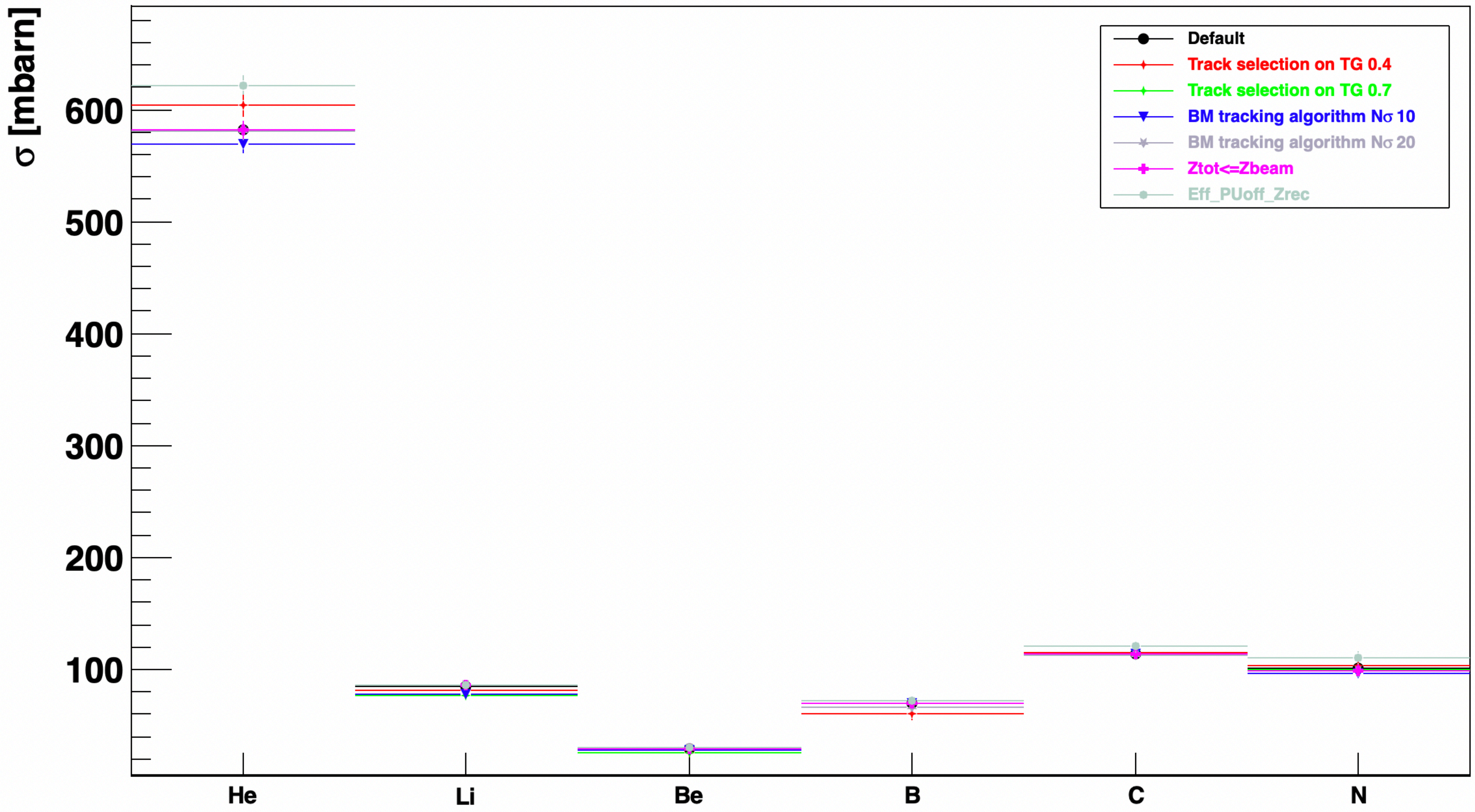


Charge-Changing cross sections 16O+C @ 400 MeV/n

$$\sigma(Z) = \frac{1}{N_{TG} \cdot \epsilon(Z)} [\frac{N_{TG}(Z)}{N_{TG}^{prim}} - \frac{N_{noTG}(Z)}{N_{noTG}^{prim}}]$$

Element	$\sigma_{frag} \pm \Delta_{stat} \pm \Delta_{sys} [mbarn]$	$\Delta_{stat}/\sigma_{frag}$	$\Delta_{sys}/\sigma_{frag}$	$\sigma_{MC}[mbarn]$
He	$625 \pm 22 \pm 47$	3.6%	8.1%	621
Li	$85 \pm 10 \pm 11$	11.9%	12.6%	67
Be	$31 \pm 10 \pm 6$	31.8%	19.7%	33
B	$70 \pm 10 \pm 11$	14.9%	16.3%	38
C	$113 \pm 12 \pm 7$	10.9%	6.1%	81
N	$101 \pm 14 \pm 11$	13.7%	10.8%	105

Charge-Changing cross sections 16O+C @ 400 MeV/n



Conclusions

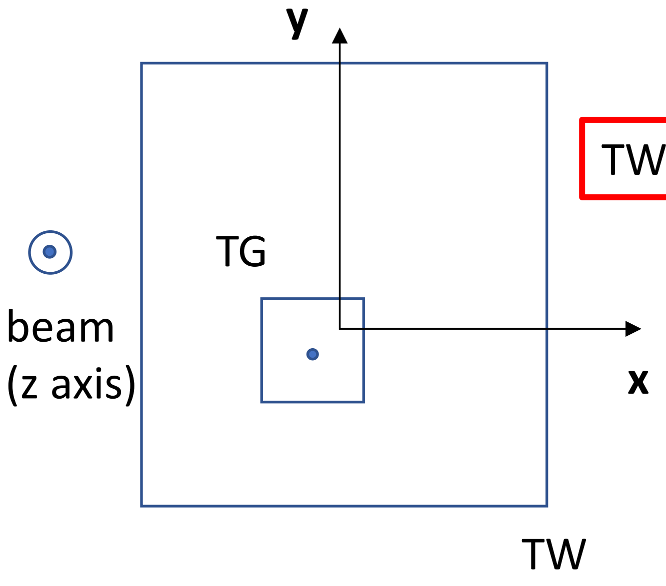
- Preliminary measurement of the GSI cross section O+C at 400 MeV/n has been shown → very nice agreement with literature and similar ratio btw fragments of FLUKA
- Some algorithms developed in SHOE for this analysis, useful for the future

What is missing:

- Perform all systematics studies about MC tuning and pile-up
- Cross check measurement trying to enlarge the data sample
- (Apply Charge mixing matrix)
- Check “flat” MC efficiencies (to be produced with Giuseppe)
- From run 2242 estimate secondary fragmentation in VTX and air and compute CC cross section

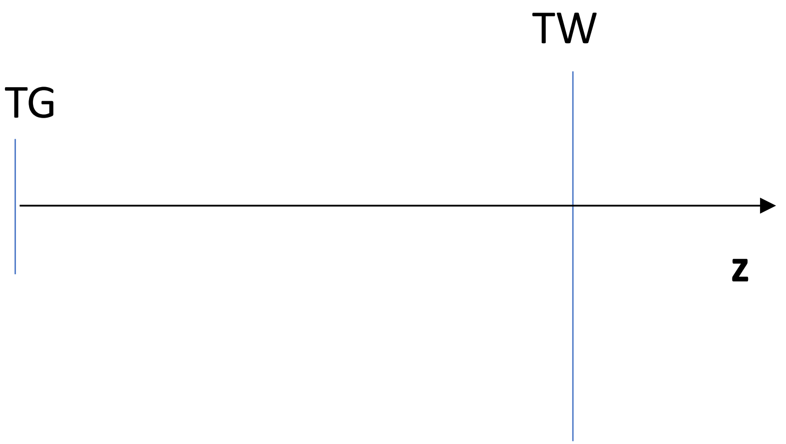
Spare slides

Angular acceptance



$\boxed{\text{TW center glb} \sim [-1,-1]}$

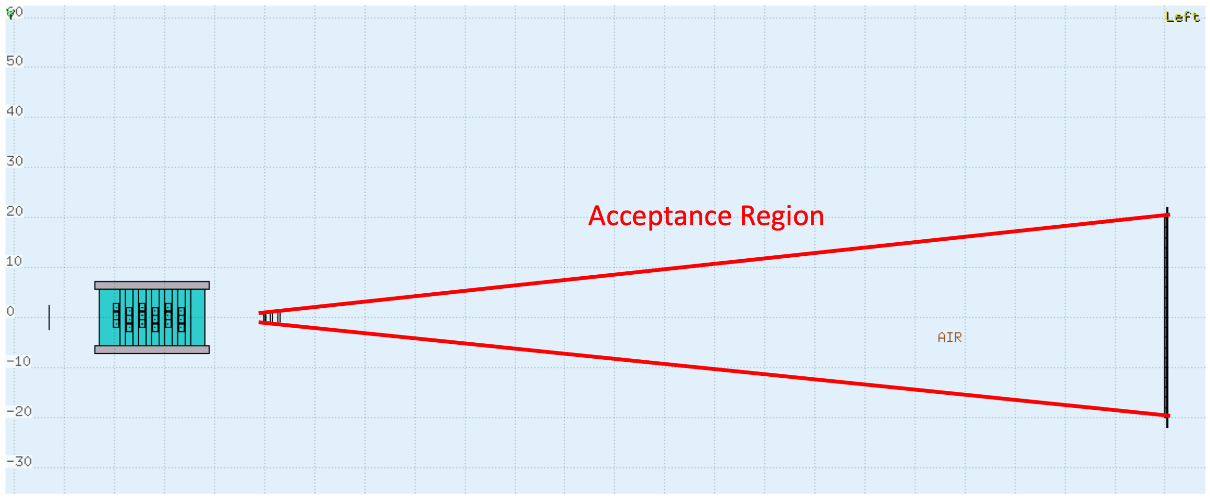
Small shift between BM and TW



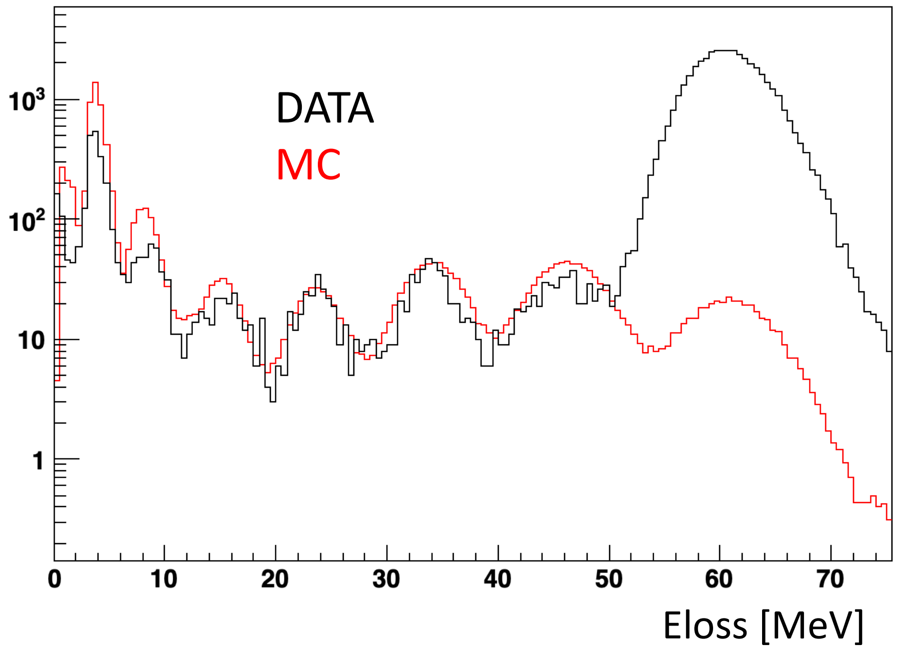
$$\boxed{0° \leq \theta \leq 5.7°}$$

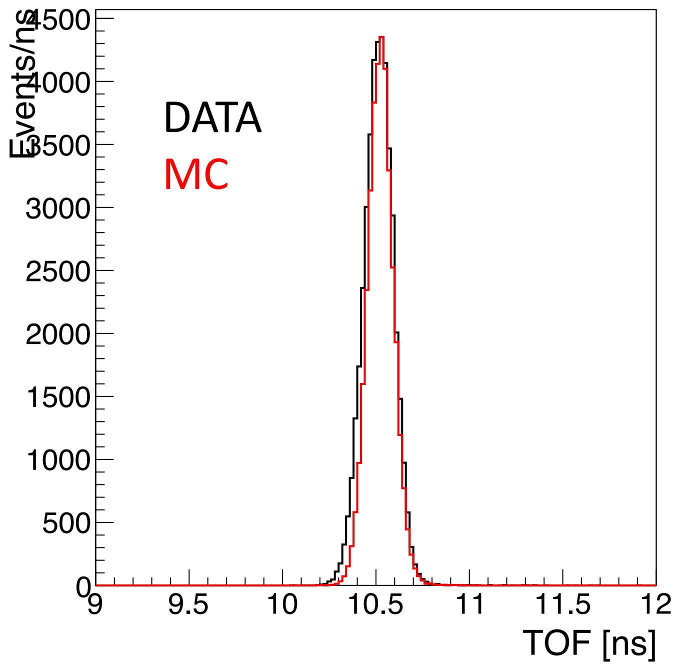
Selecting fragments from TG region [-0.7,0.7] cm

$$\boxed{0° \leq \varphi \leq 360°}$$



Calibration and tuning of MC on GSI DATA





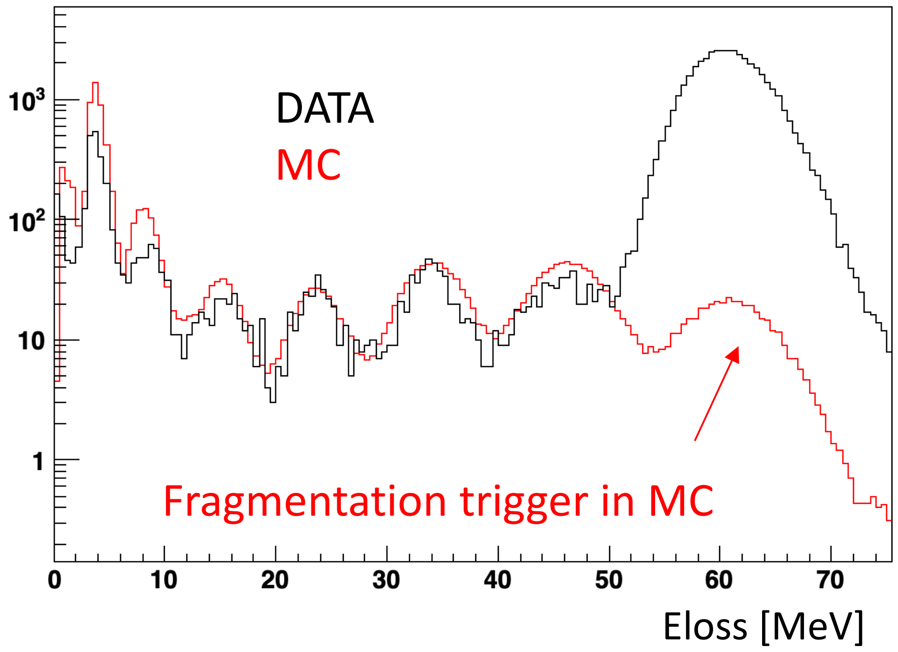
Eloss Calibration:

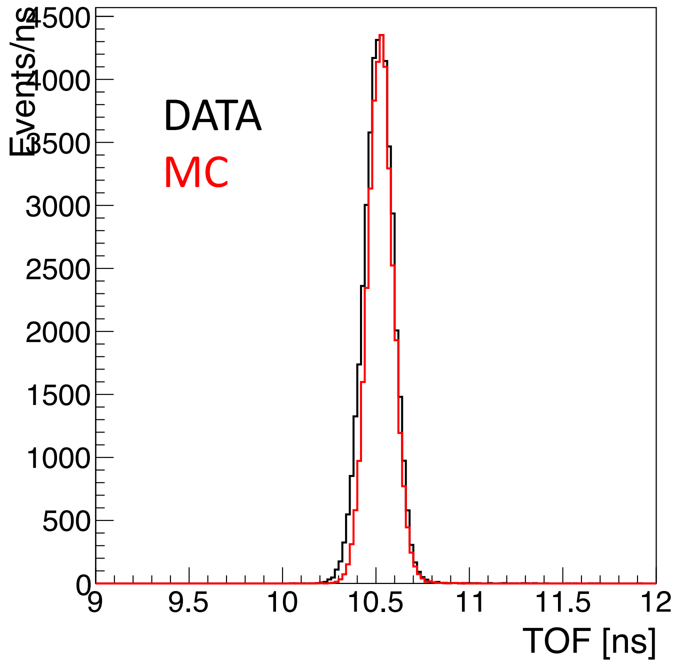
- "Tuned" and applied CNAO Pisa-calibration to GSI data
- Cross-checked with a GSI standalone calibration

ToF calibration:

- Calibration from 2242 for runs 2239,2240,2241
- Standalone calibration for run 2251

Calibration and tuning of MC on GSI DATA





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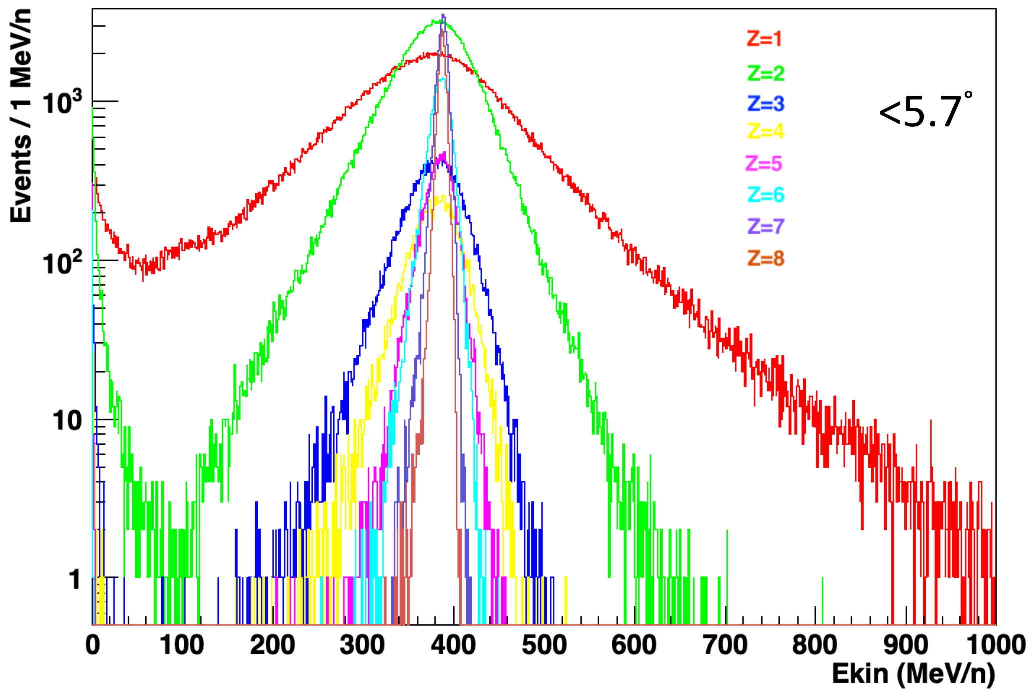
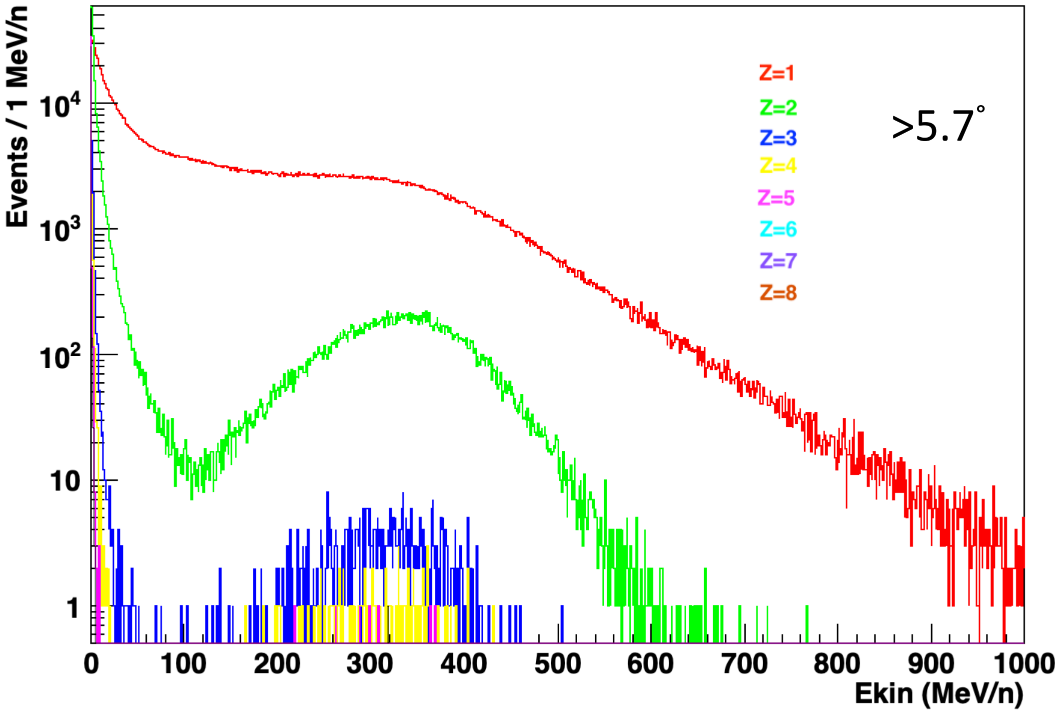
- Standalone calibration for run 2251

In SHOE implemented reconstructed MC takes into account:

- Eloss, Tof and t_{TW} resolutions from CNAO data. Eloss threshold (cut away most of the protons) and dead bars @ GSI
- Time and position reconstruction from times Ta and Tb (data-like)
- Pile-up (multi-hit in the same bar per event) and fragment charge from ZID algorithm.

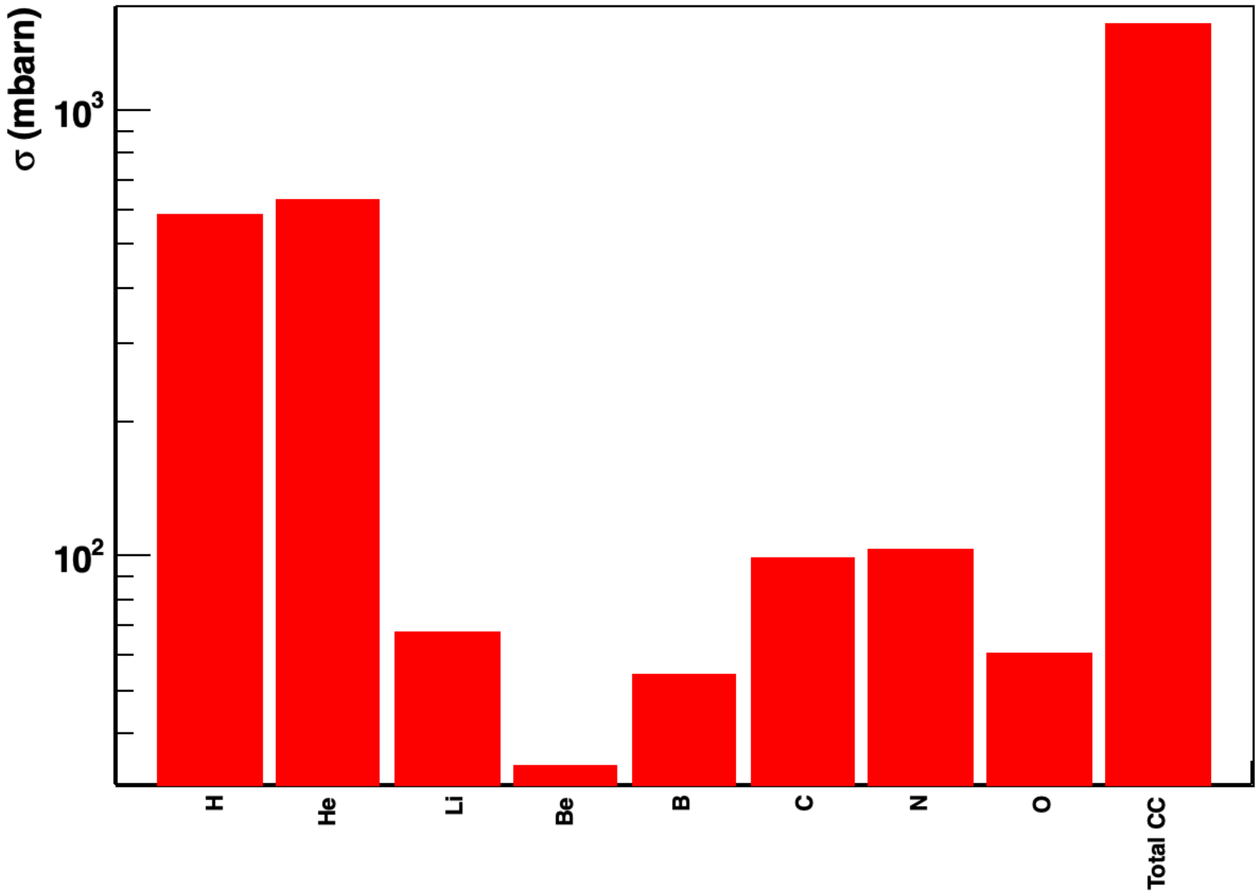
FLUKA: E_{kin} distribution fragments in TG





Asking for only primary fragments with origin in Target

$\sigma_{Production}$ in TG (between 0° and 5.7°)

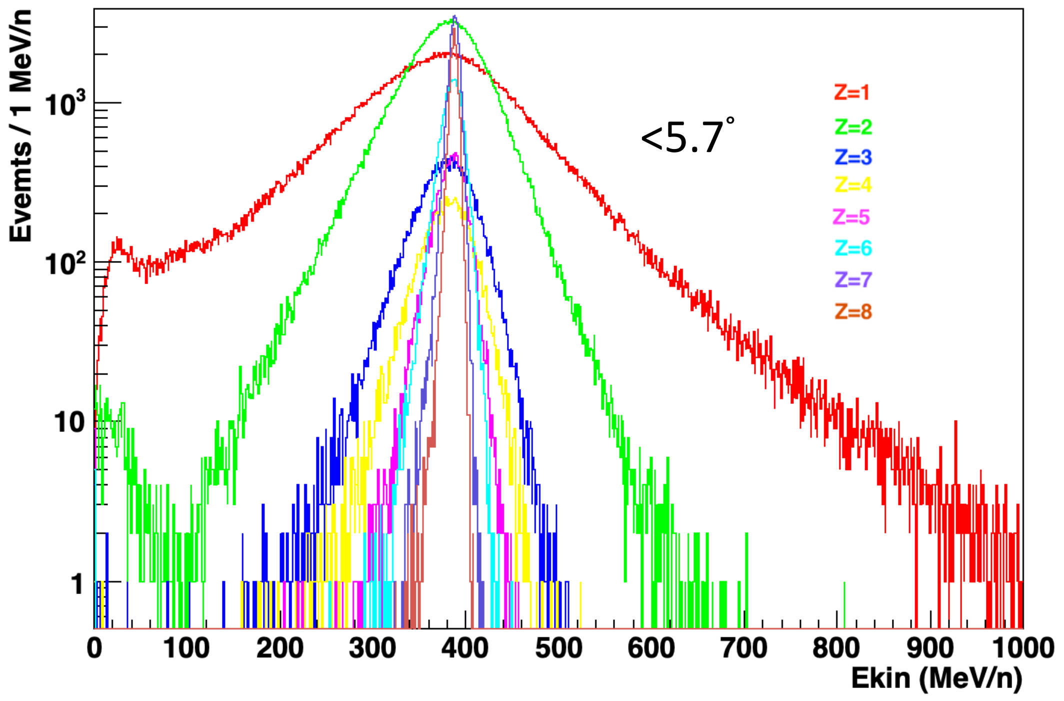


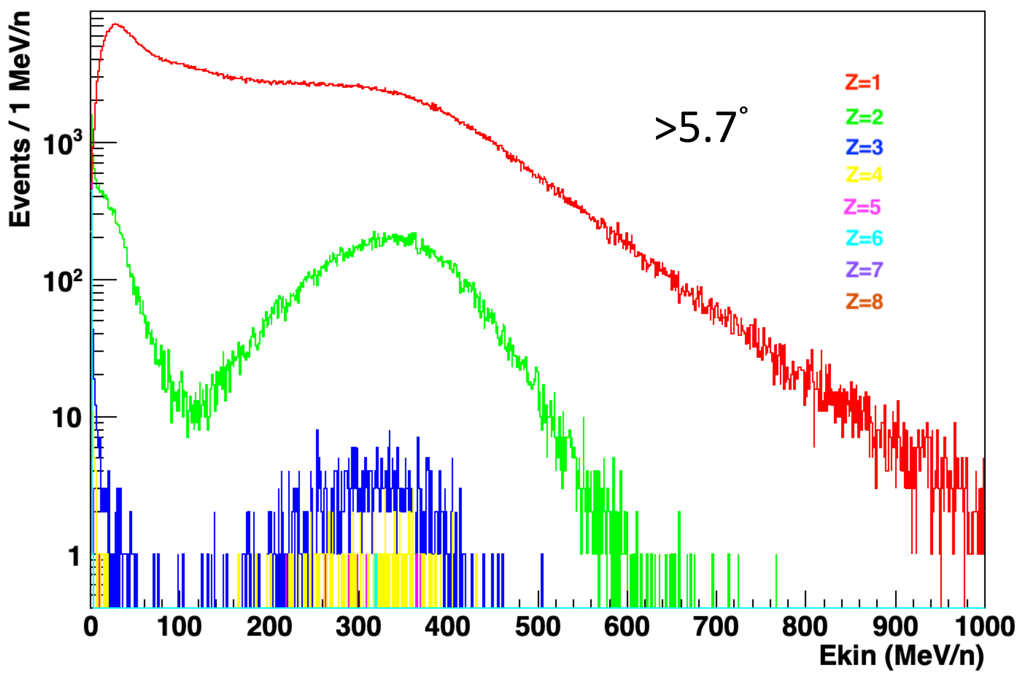
$$\sigma = \int_{0°}^{7°} \frac{d\sigma}{d\theta}\Big|_{0°-7°} d\theta = \frac{N_f}{N_{oxy} * N_t}$$

Where: $N_t = \frac{\rho * dx * N_A}{A}$

Charge	Cross section (mbarn)
1	582.237098
2	624.328050
3	67.443612
4	33.971387
5	54.391275
6	98.731728
7	103.810543
8	60.529448
Total CC	1564.913692

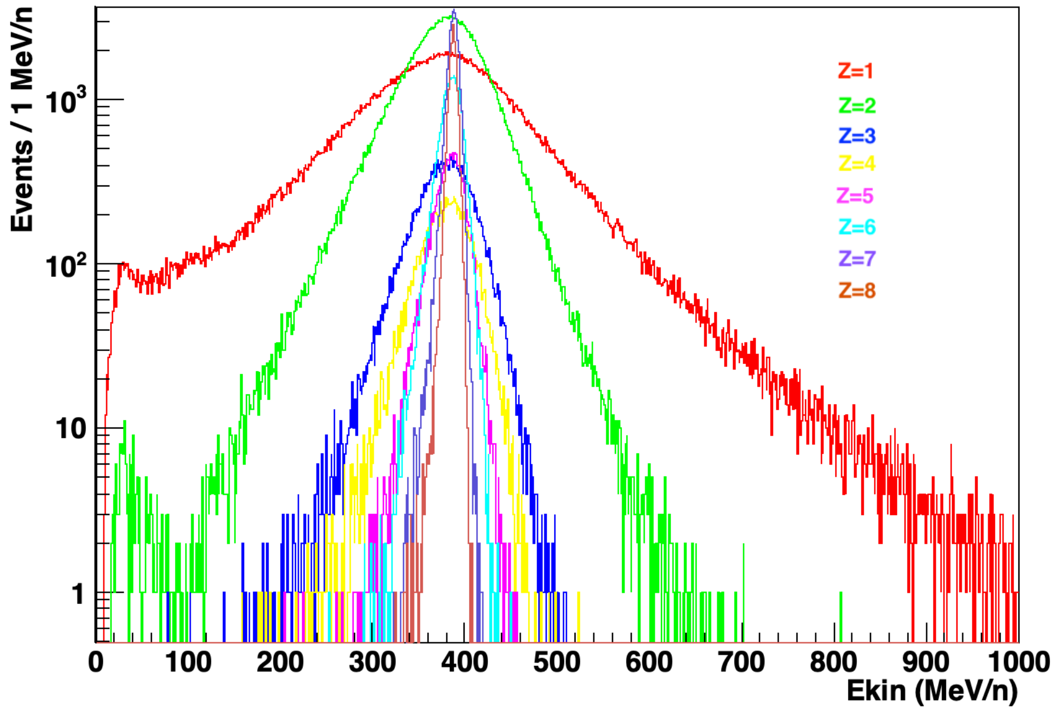
E_{kin} distribution fragments out TG





Asking for only primary fragments with origin in Target produced on the TG in [-0.7,0.7].

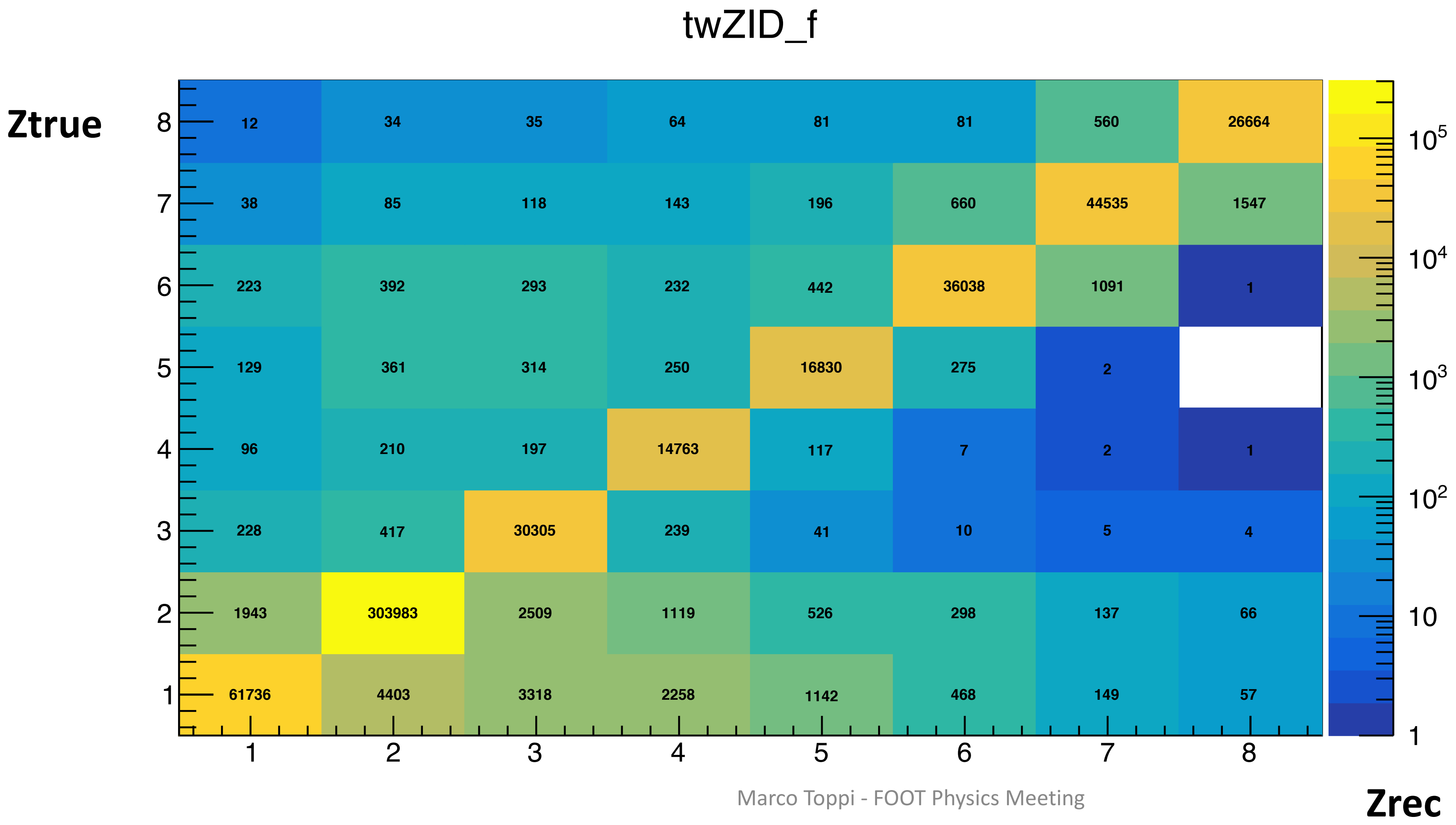
E_{kin} distribution TW hit



E_{kin} production

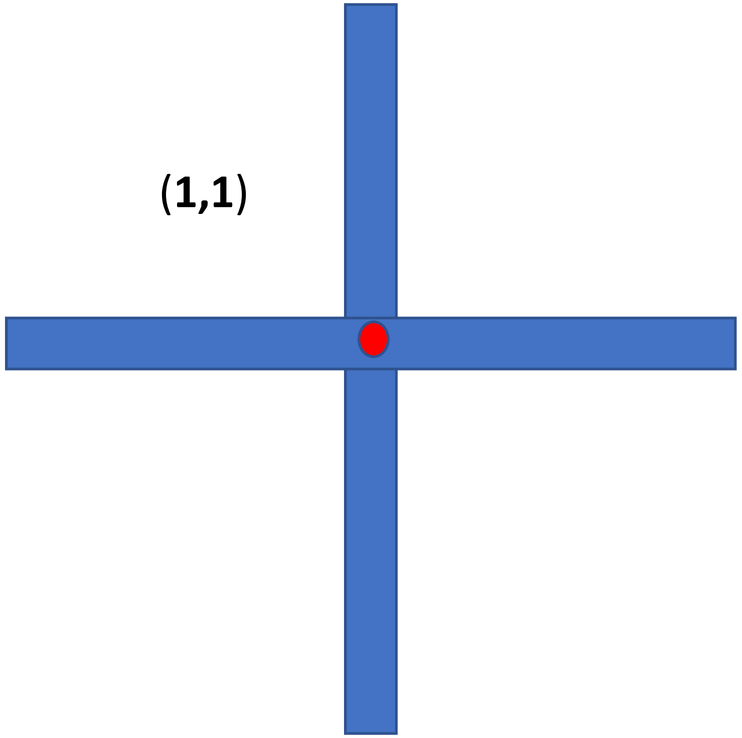
Asking for only primary fragments with origin in Target (over threshold) with production angle < 5.7° and beam progection on TG in [-0.7,0.7] matching a TW hit

Charge mixing matrix for TW hits



Yields extraction and TW Clustering

In order to extract fragment yields from cross sections measurement front and rear TW hits have to be clusterized.
New algorithm implemented in SHOE.



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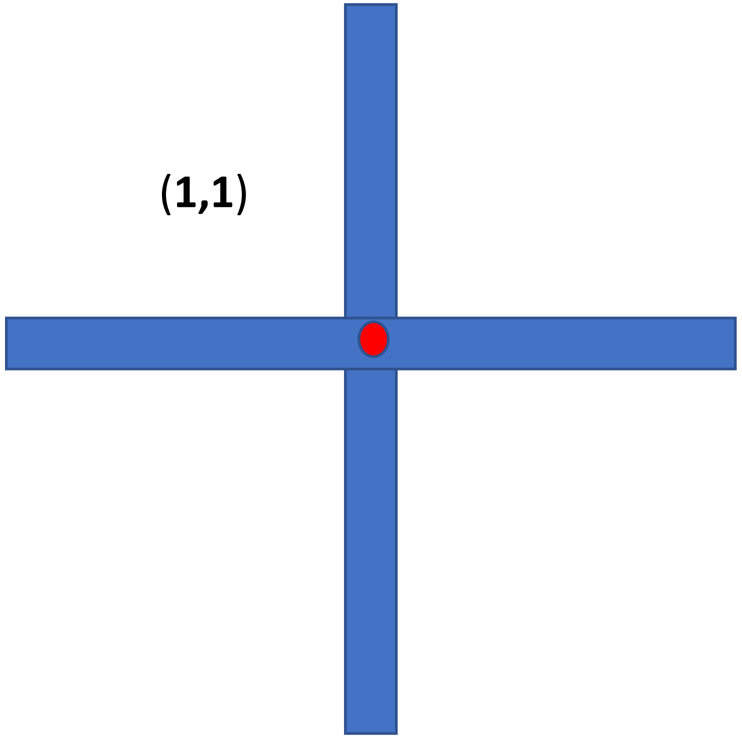
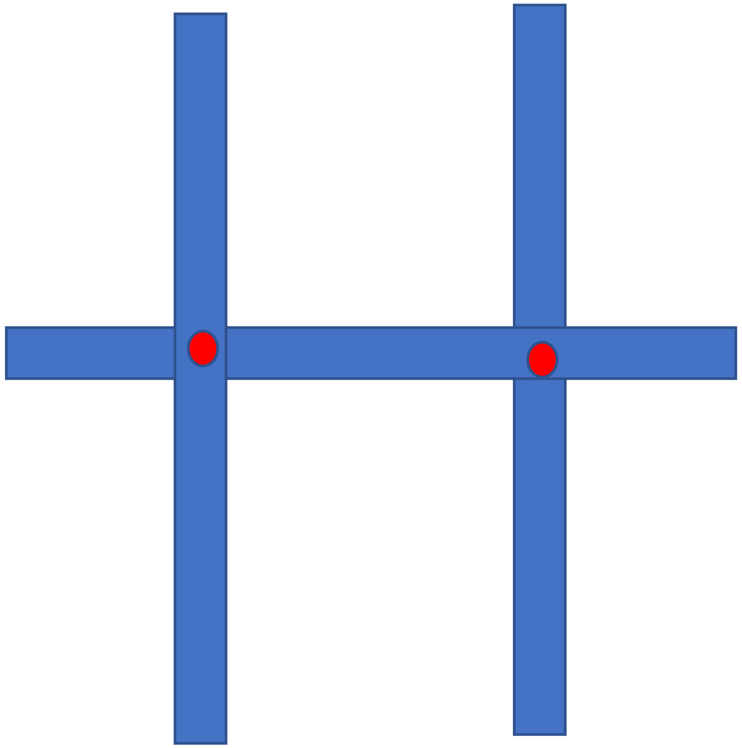
(1,N), (N,1), with N>1

(1,1)





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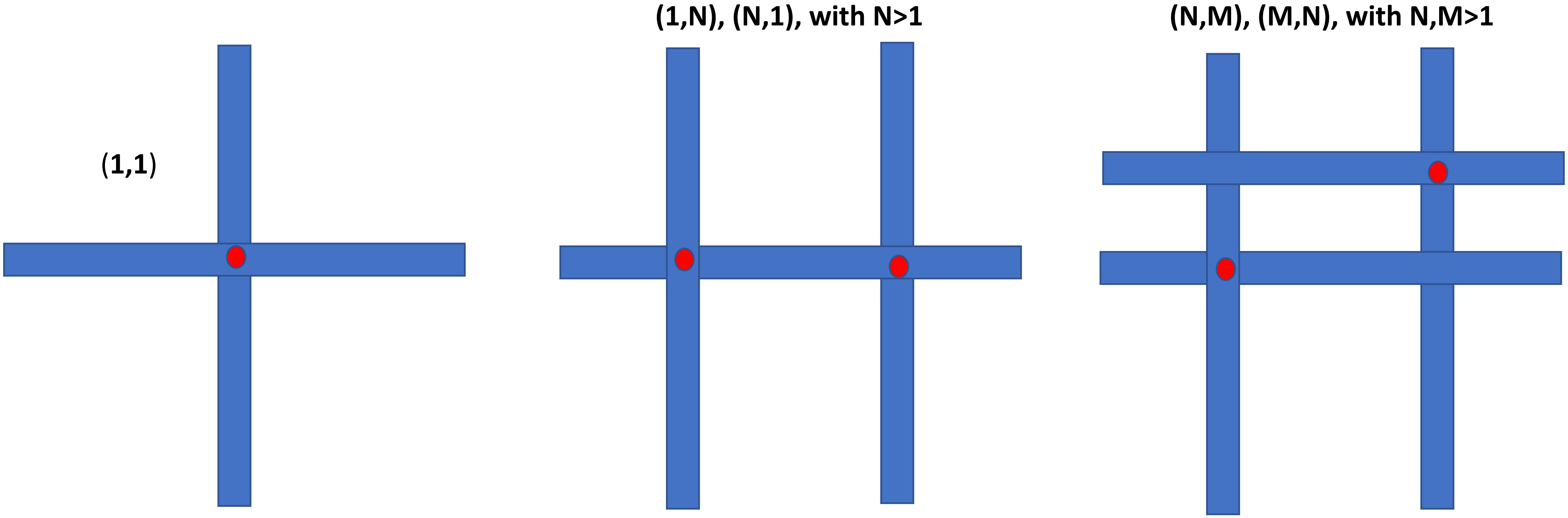

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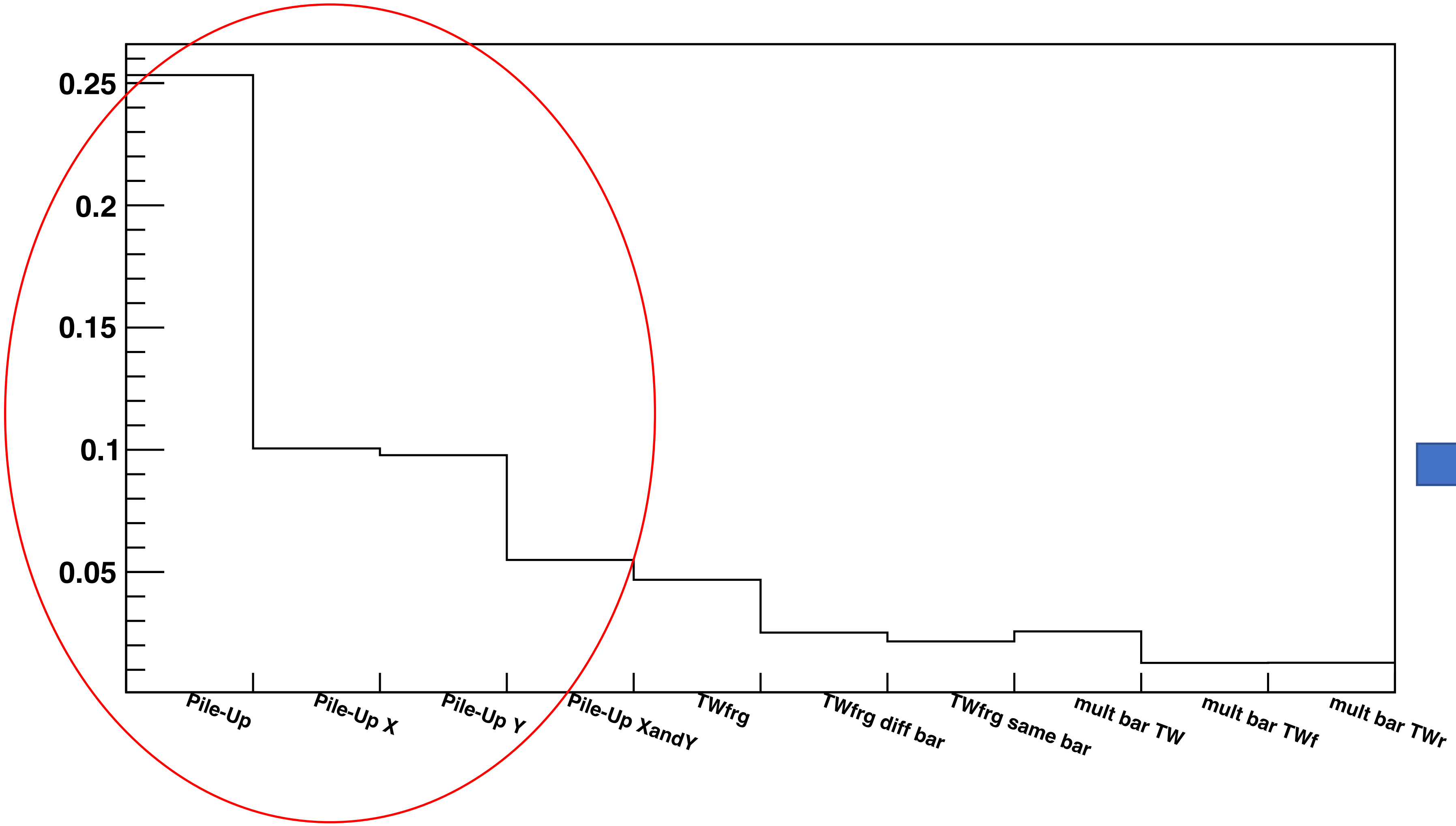
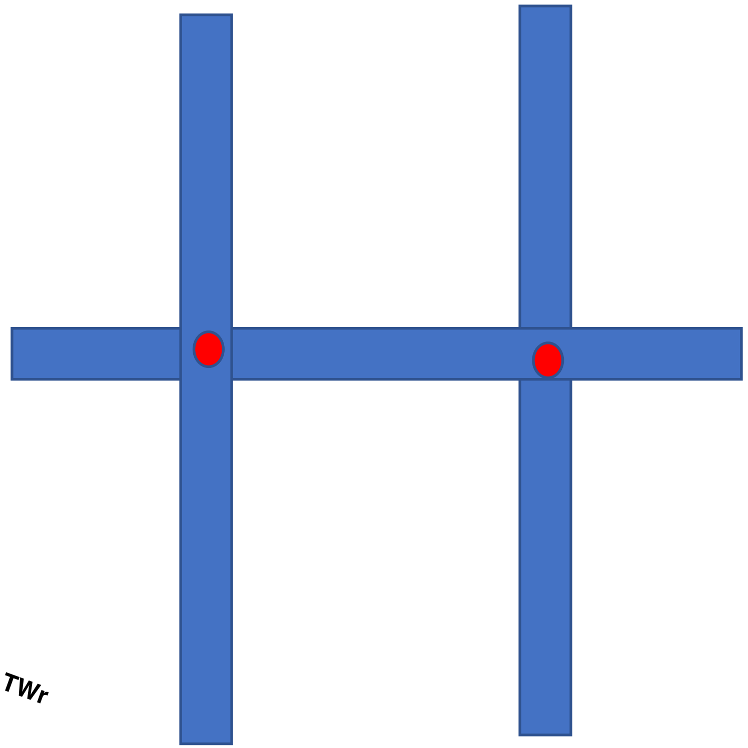


Pile-Up (multi-hits)



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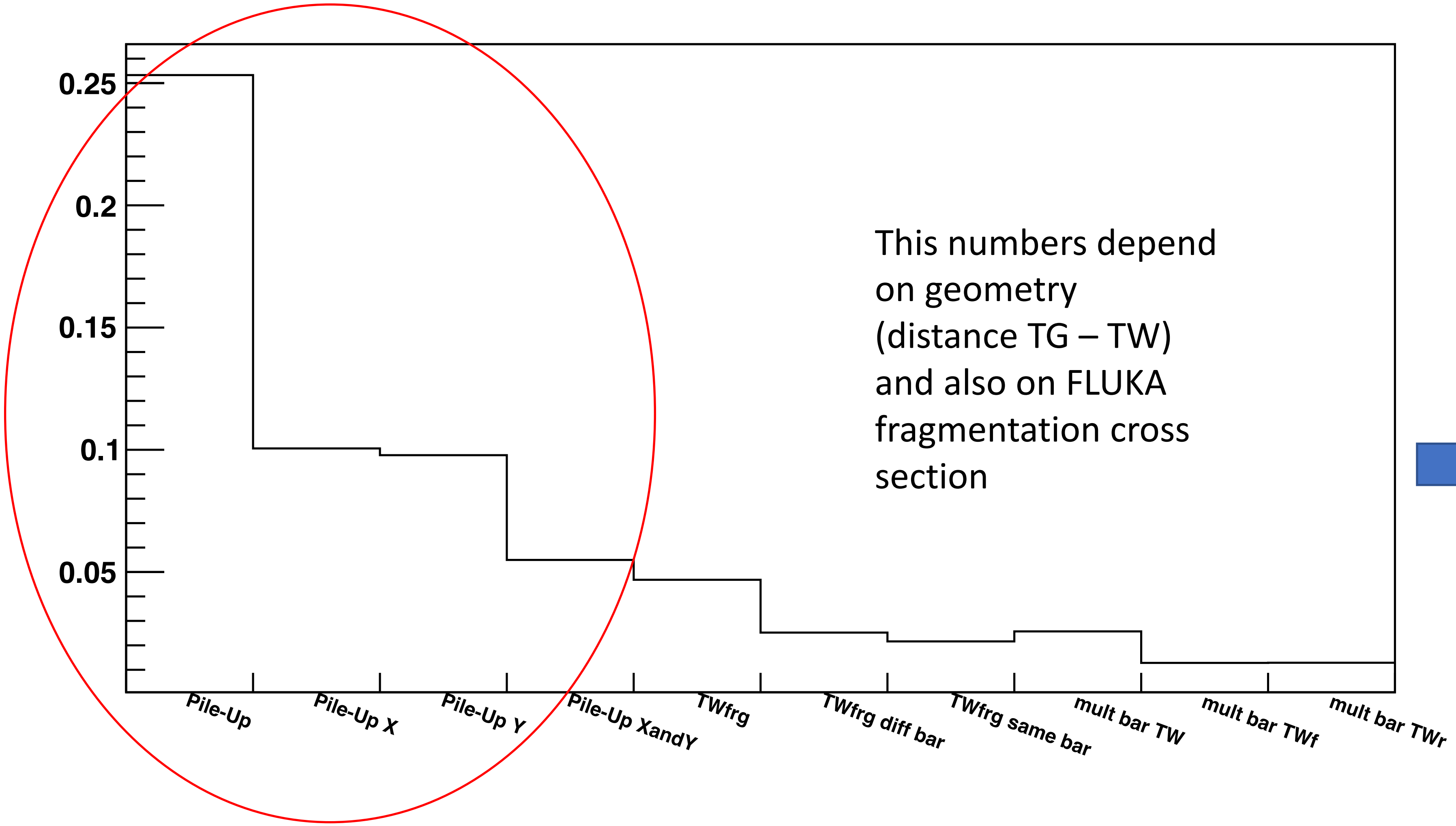
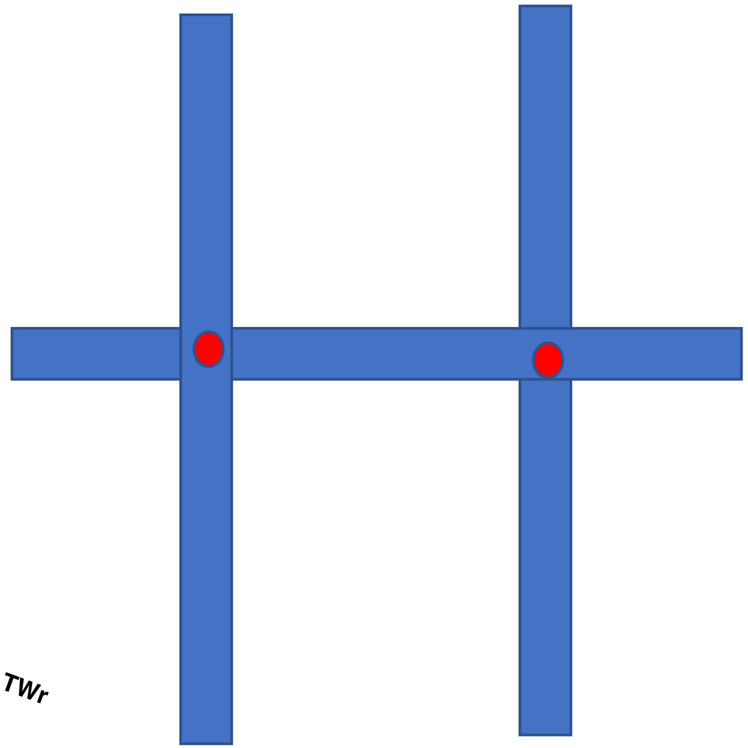


This numbers depend on geometry (distance TG – TW) and also on FLUKA fragmentation cross section

Pile-Up (multi-hits)



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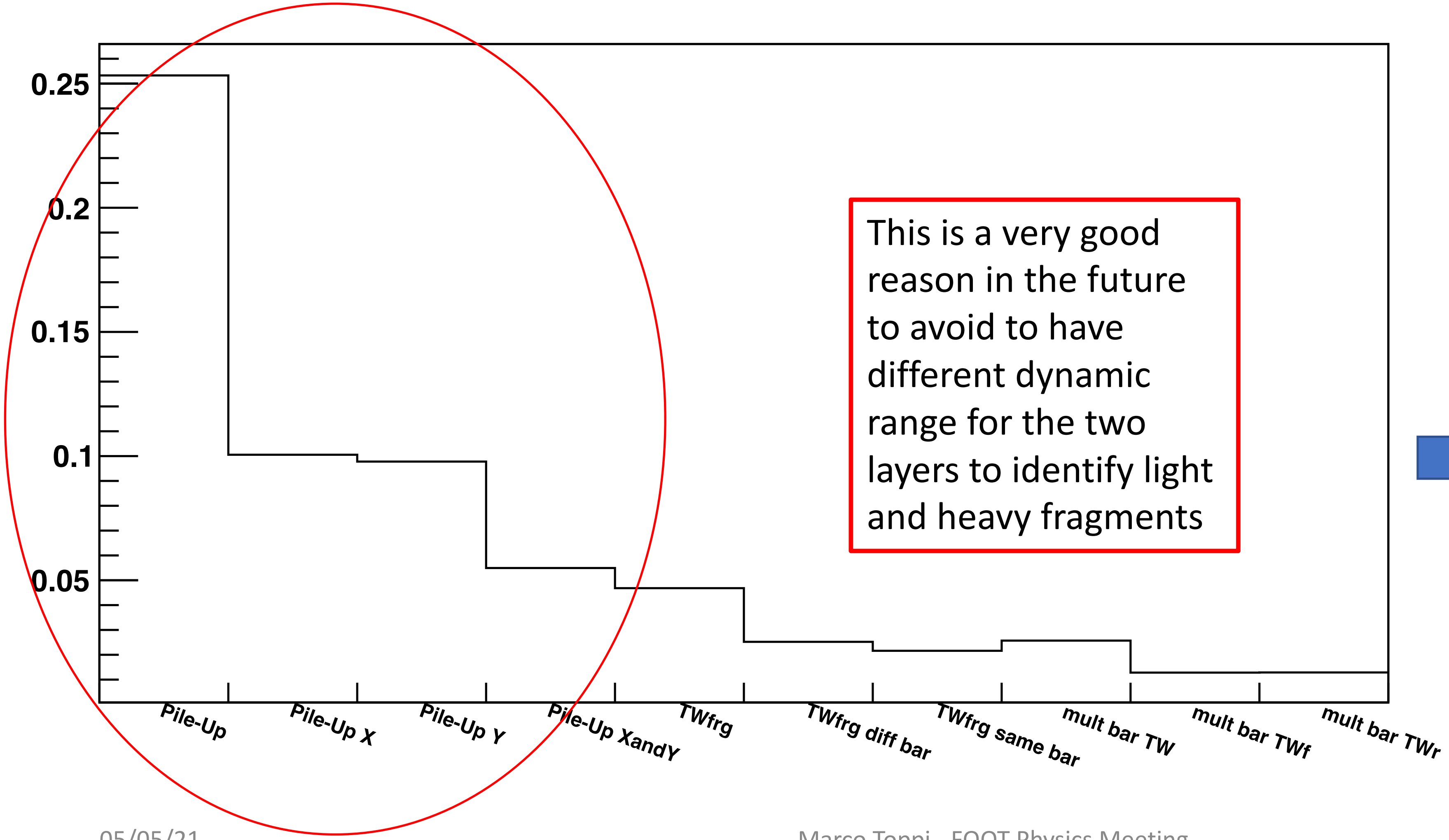

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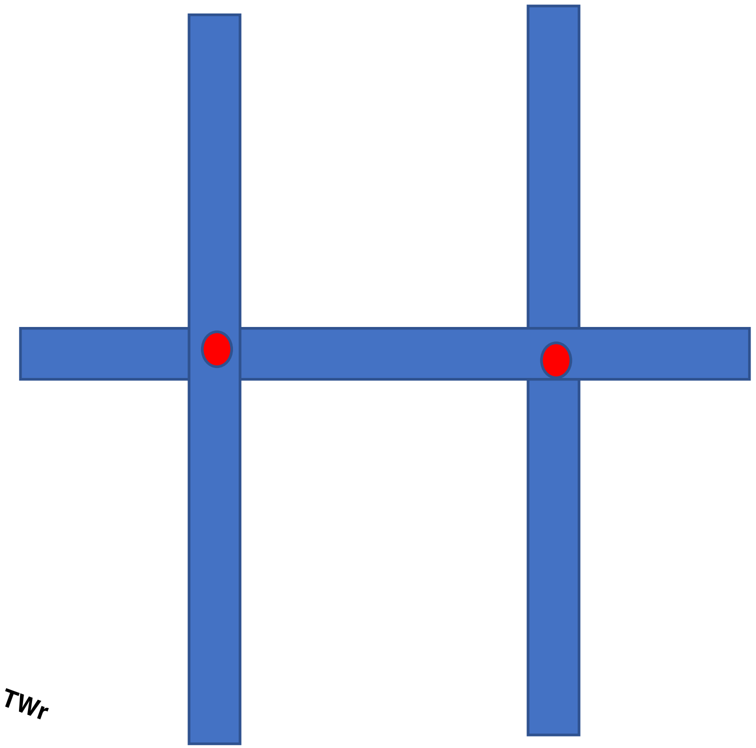

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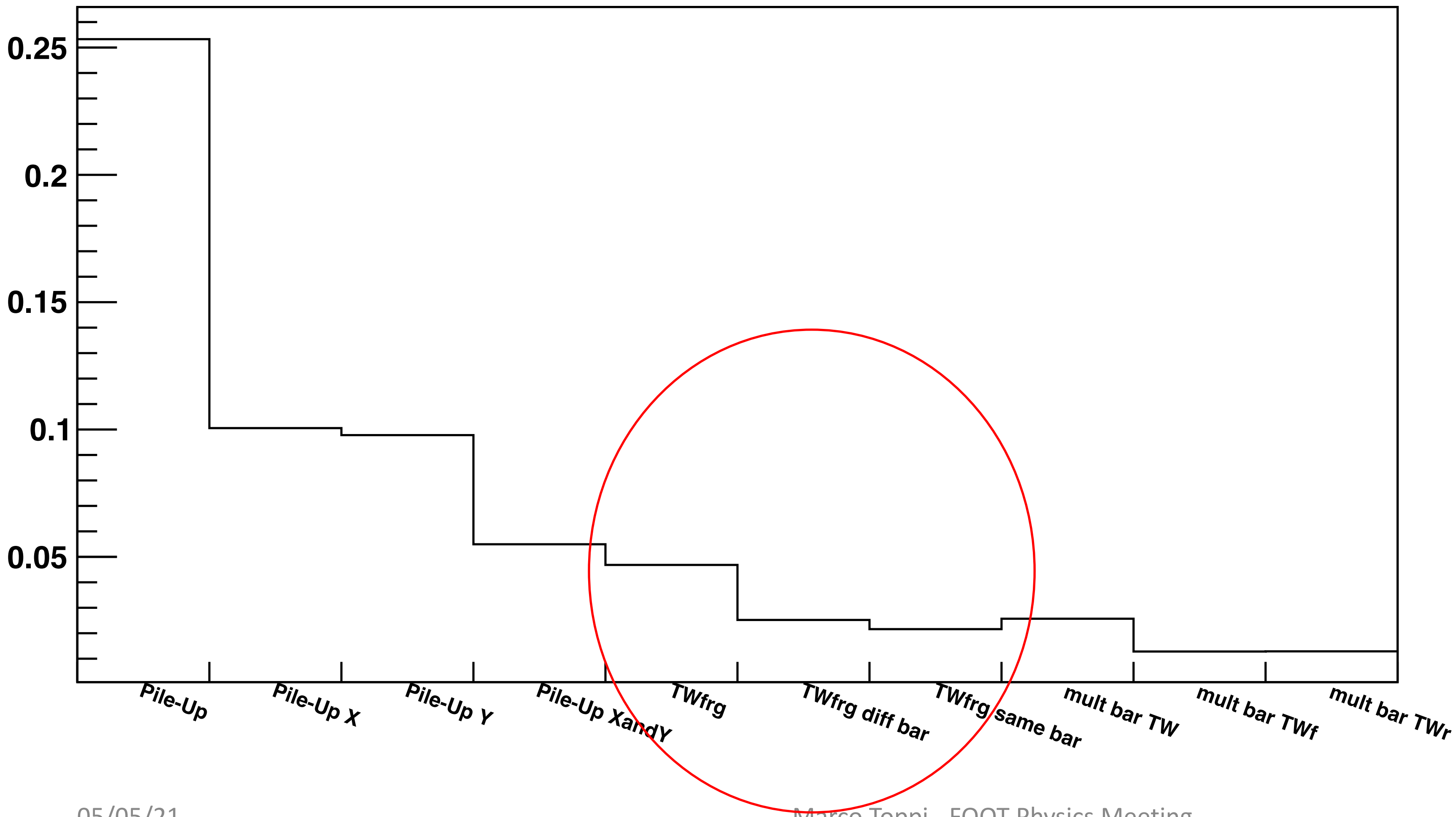
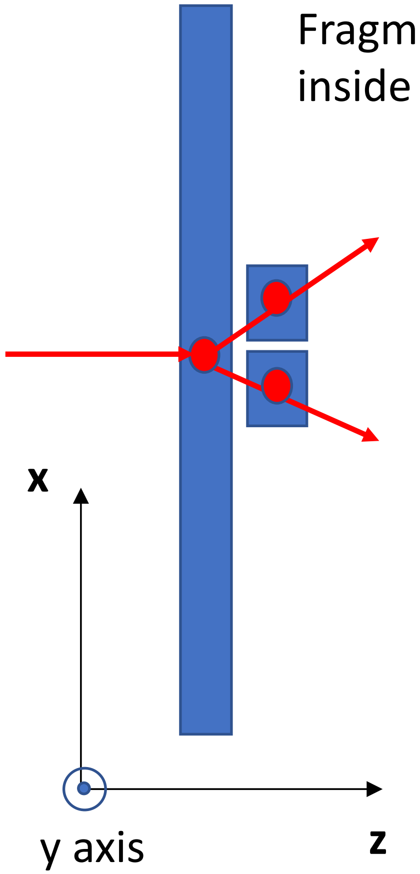


Fragmentation inside TW ~ 2.5%



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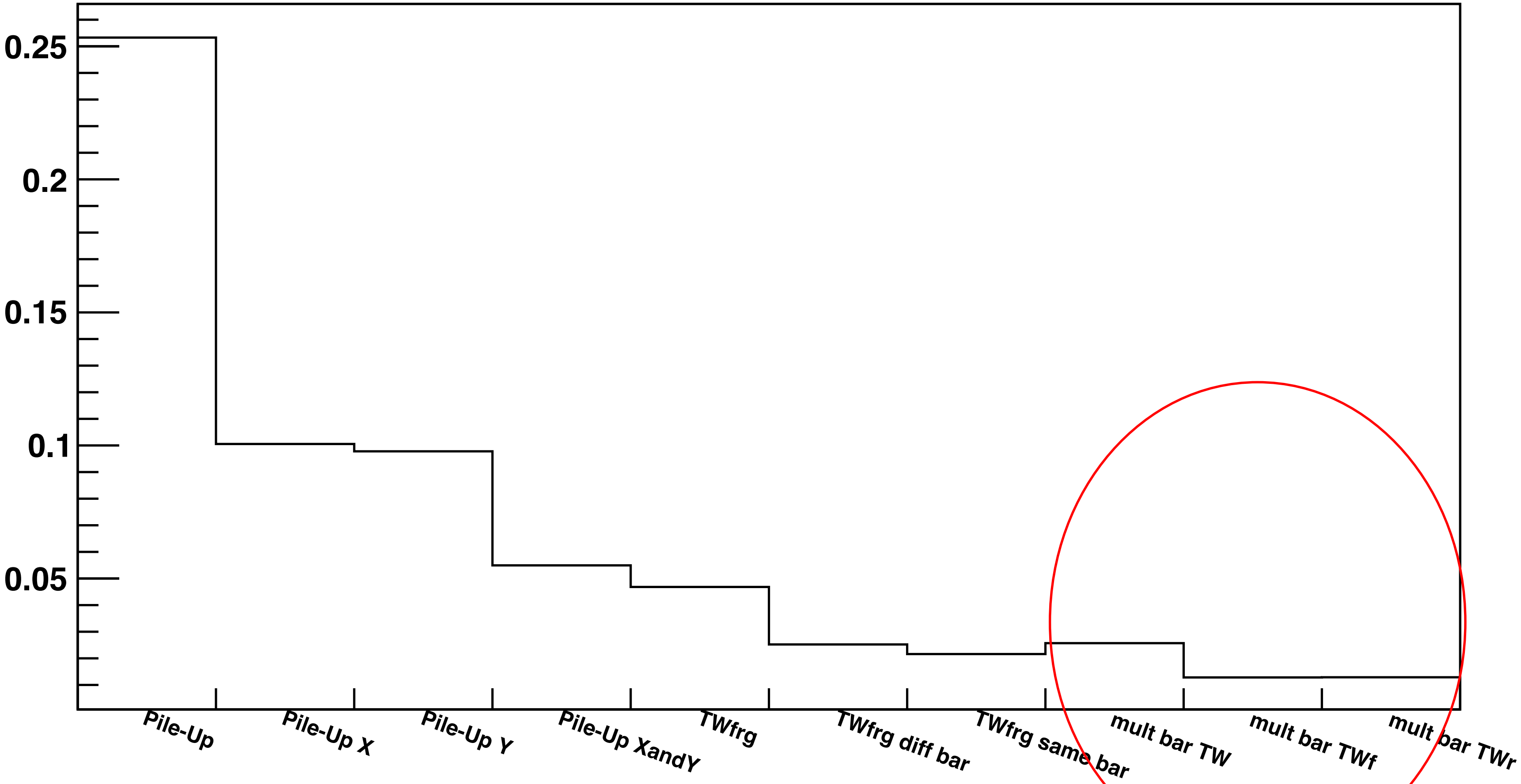
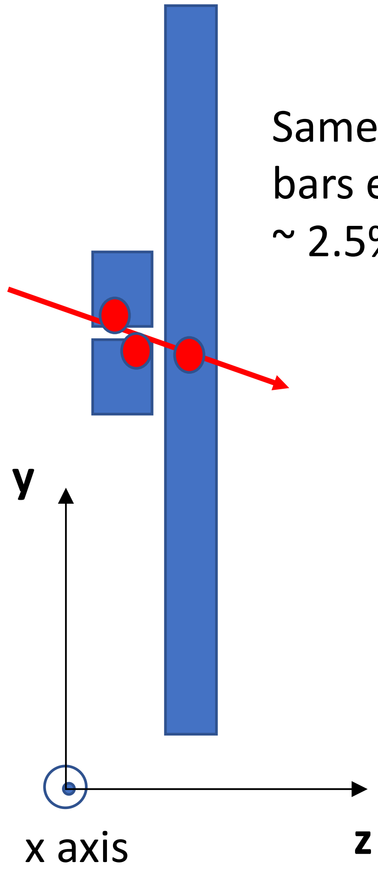
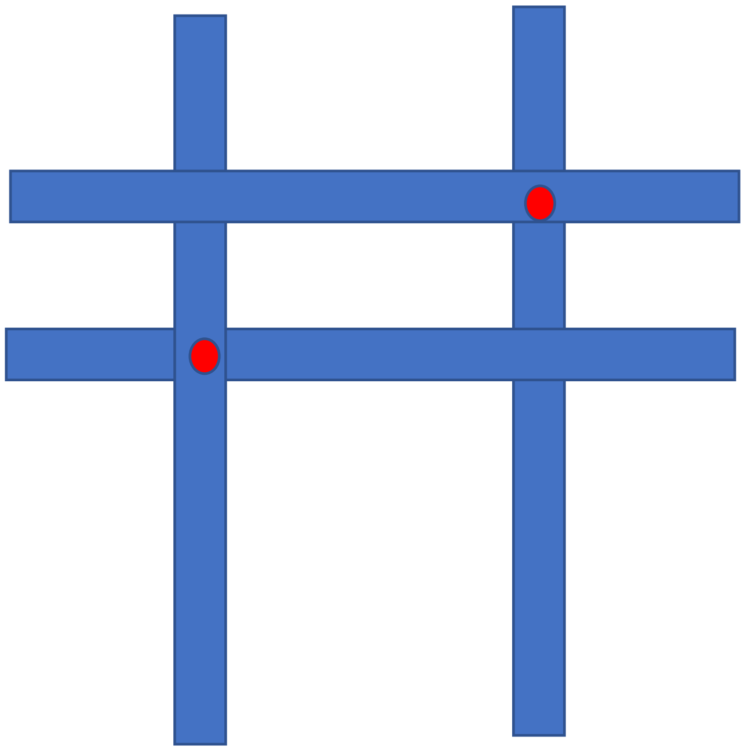




Same layer multi-bars events ~ 2.5%

Yields extraction and TW Clustering

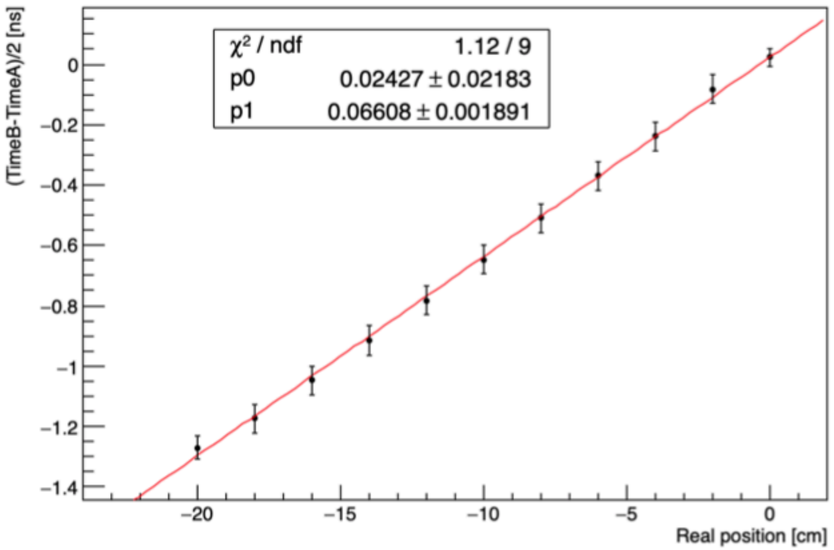
Same situation of above + problem of the ghosts→ to be managed with measurement of the position along the bar exploiting the time difference DeltaT at the edges of the bar



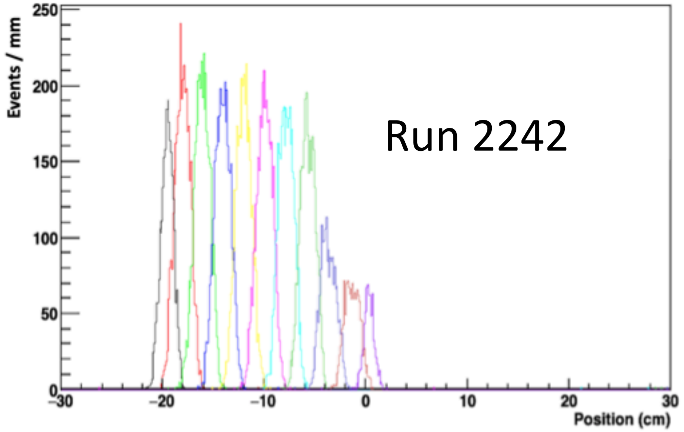
(N,M), (M,N), with N,M>1

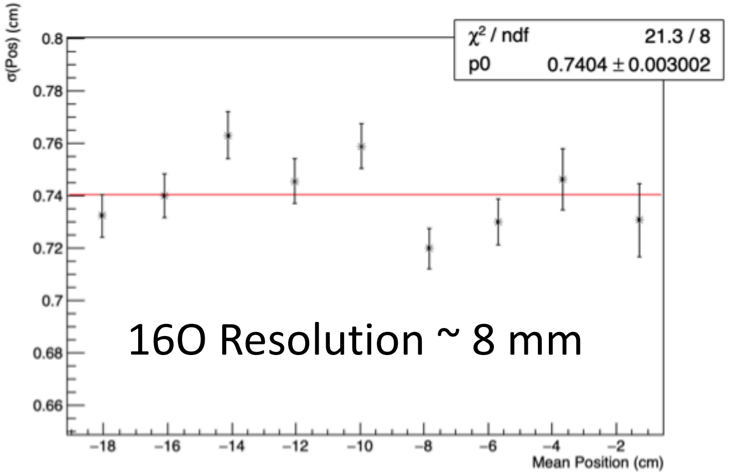
Yields extraction and TW Clustering

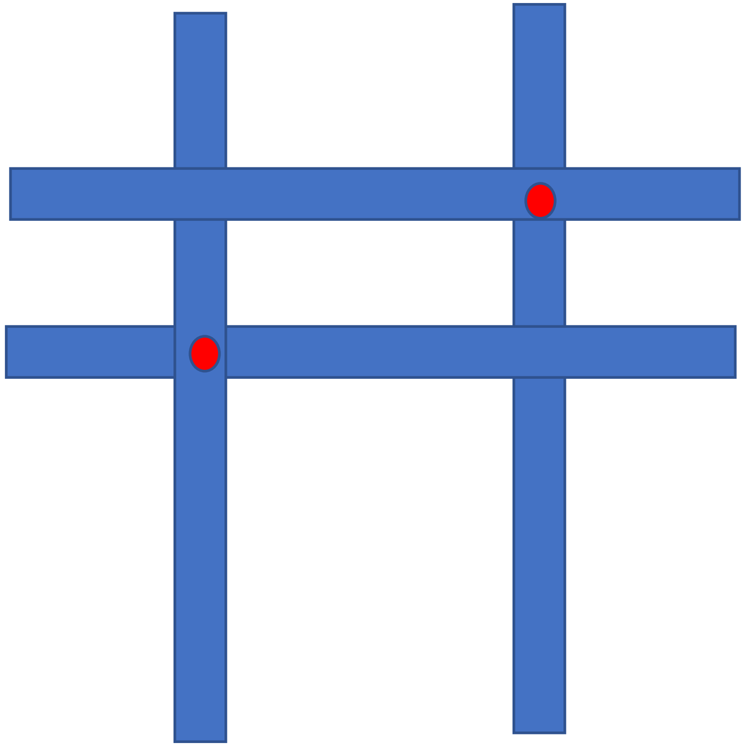
Same situation of above + problem of the ghosts→ to be managed with measurement of the position along the bar exploiting the time difference DeltaT at the edges of the bar



Light speed in the bars v:
1/v ~ 66 ps/cm







(N,M), (M,N), with N,M>1

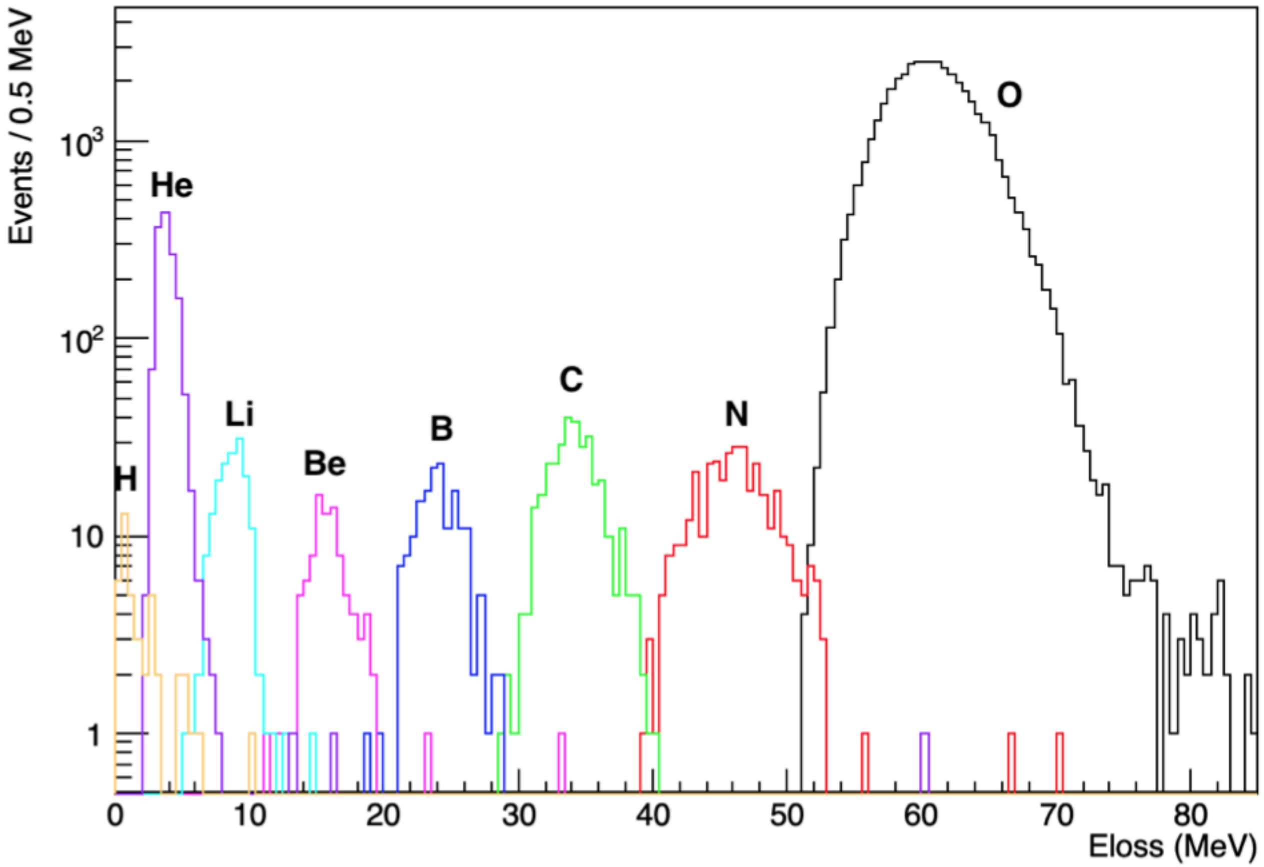
TW Clustering algorithm

- From these simple observations I follow the simple idea to train the TW cluster/point with the hits from the TW layer with higher occupancy to avoid to drop 25% of events due to pile-up
- When there is the same number of hits in the two layers the front hits train the clusters
- Noise can be further strongly reduced asking Zfront = Zrear (best choice in the end)

In SHOE: for each TWpoint the charge of the training hit and its MC track ID (useful for efficiencies evaluation) are assigned to the point

This fact, matched with the good position resolution from deltaT (better than bar crossing resolution), is a good reason in the future to keep as in GSI horizontal bars in the front layers and vertical in rear → actually this study should be repeated in presence of the magnetic field

Implementation of TW Clustering in SHOE

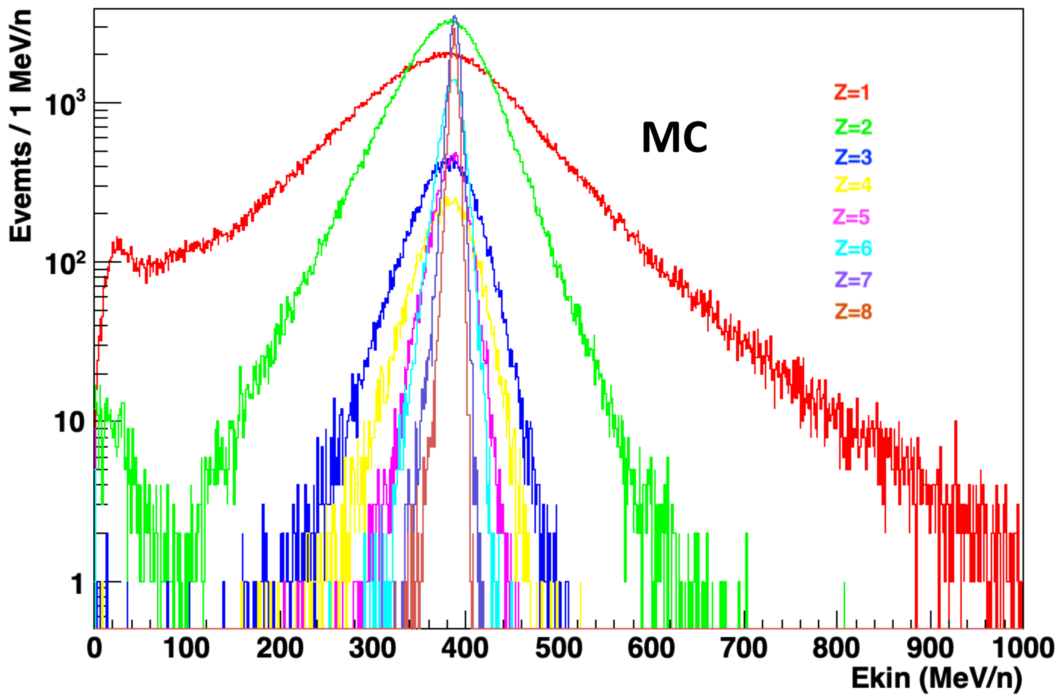


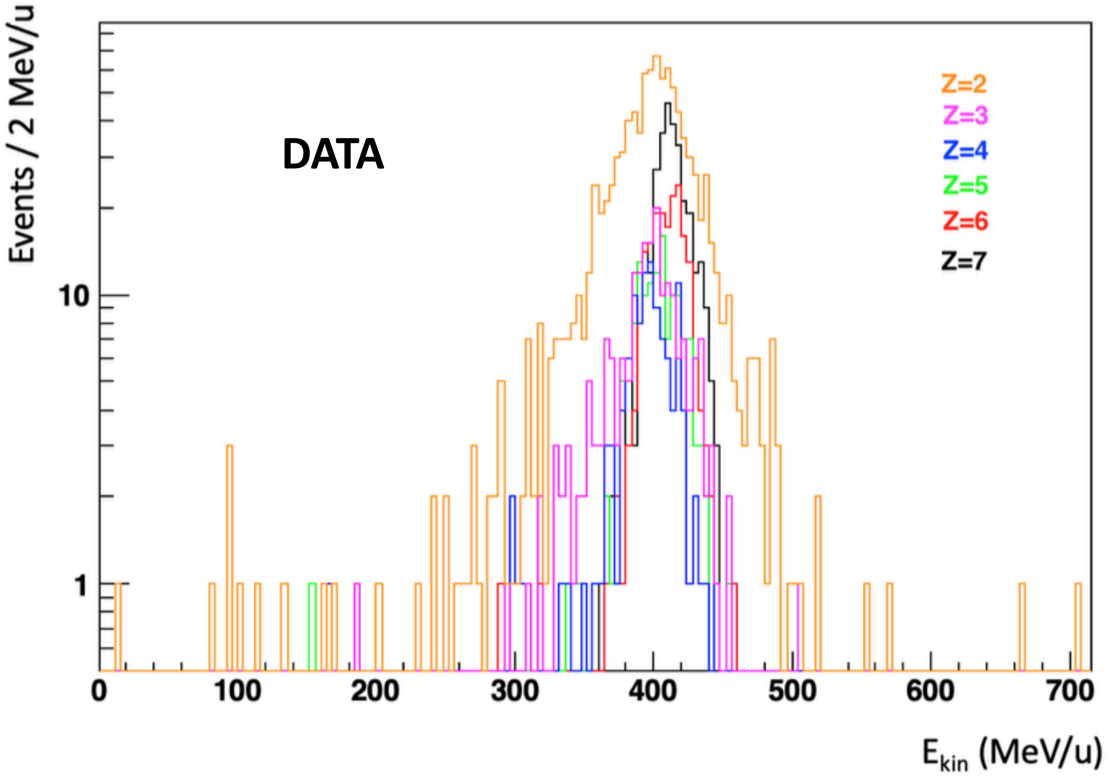
The combination of the Z identification and clustering algorithms implemented in SHOE provide a very good fragment charge identification on an event-by-event basis (DATA!!)

Provide the fragment yields for the measurement of the cross section

Efficiencies: denominator

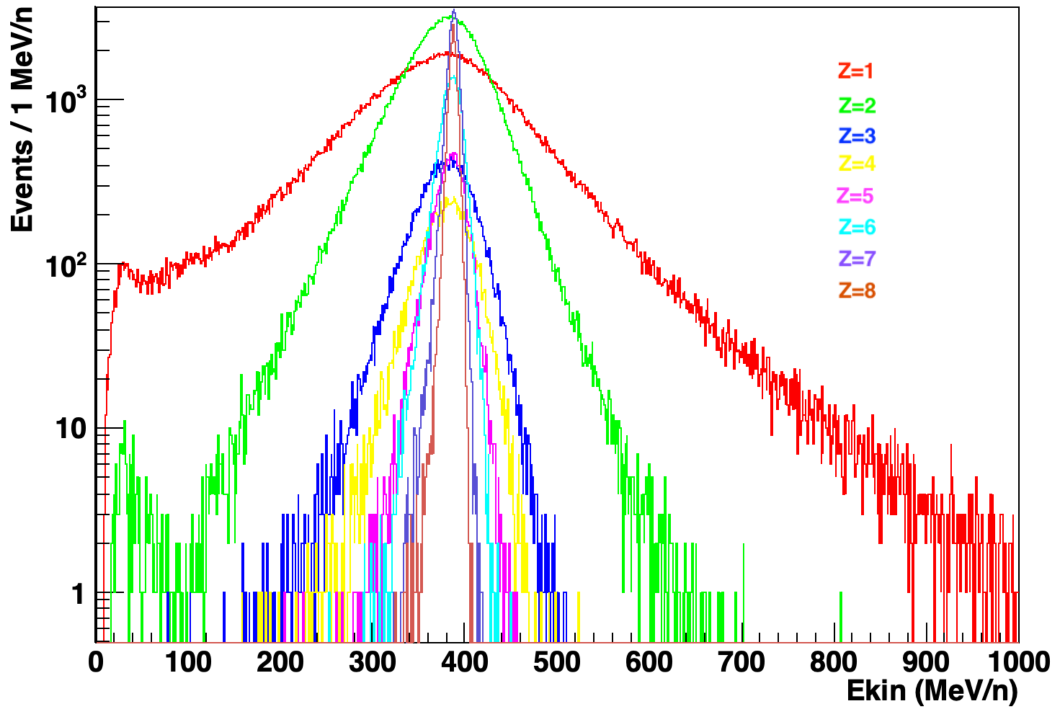
Production E_{kin} distribution of fragments out of TG





Denominator: Asking for only primary fragments with origin in Target produced on the TG in [-1,1] and escaping from it with θ<5.7° and an Ekin in the interval 100-600 MeV/n (from data distribution)

Efficiencies: numerator

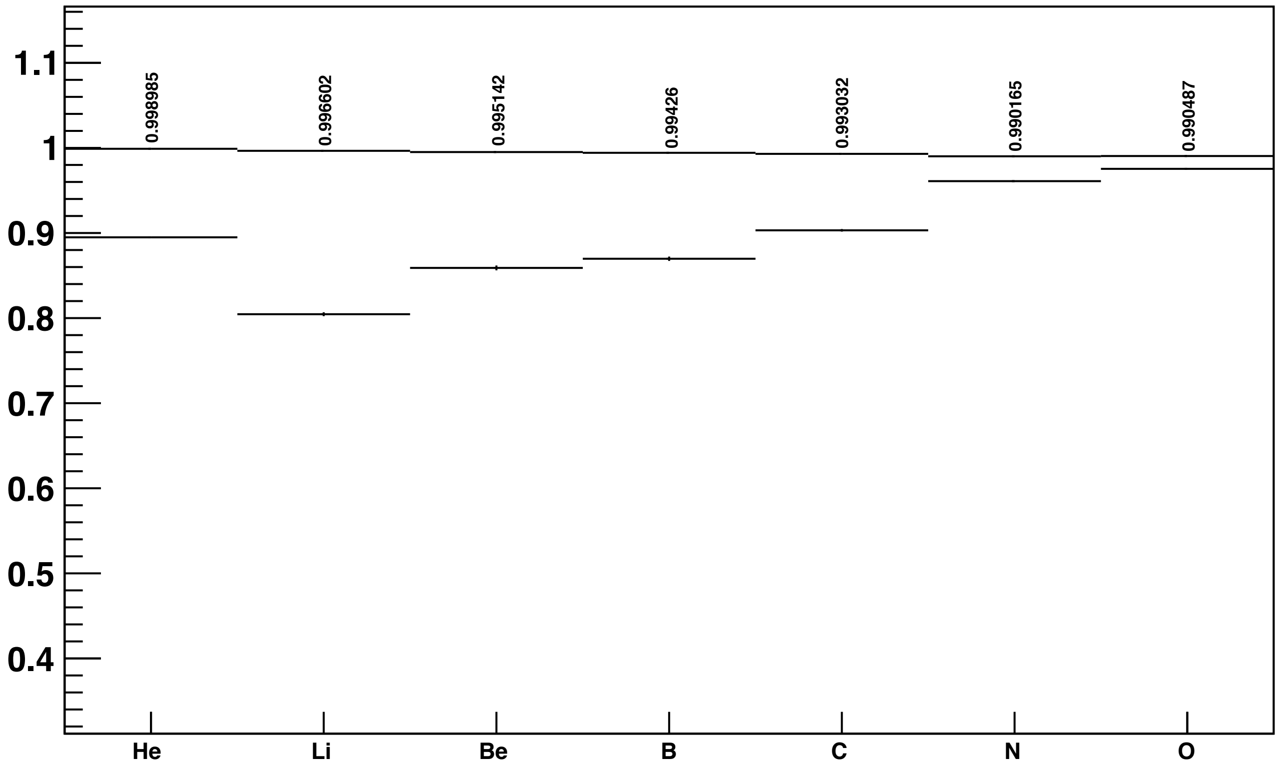


Numerator: Asking for a good TWpoint matched to primary fragments with origin in Target with production angle < 5.7° , beam projection on TG in [-0.7,0.7] and production Ekin in the range [200,600] MeV/n.

In reconstructed MC **Pile-Up is switched off and Z=Ztrue** (not reconstructed Z)

ON/OFF Request: Z_front = Z_rear

"Integral" efficiencies



Intrinsic efficiencies folded with TW clustering efficiency