# Cross sections update from GSI 2021 data

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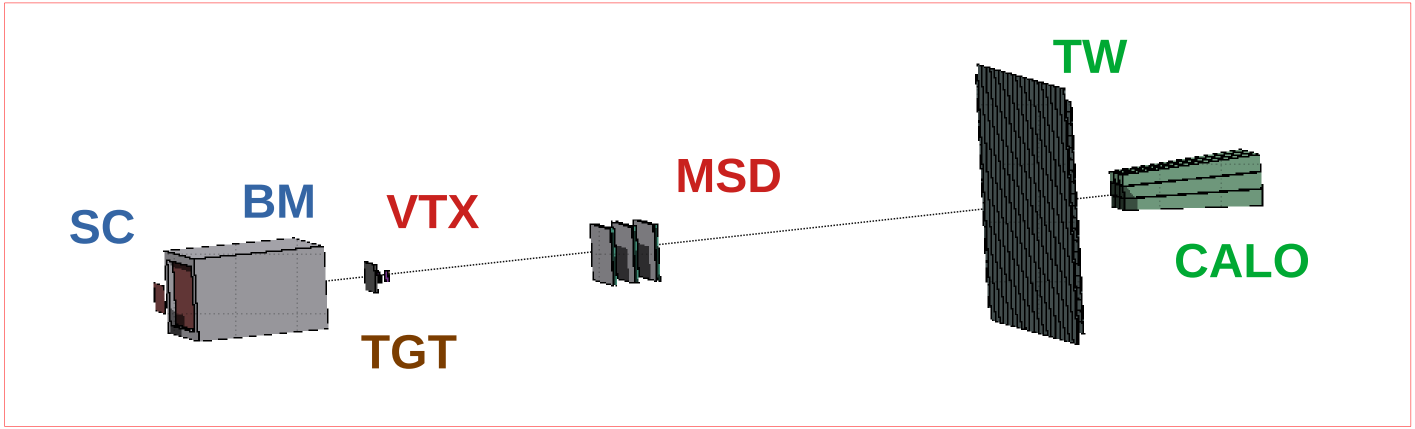
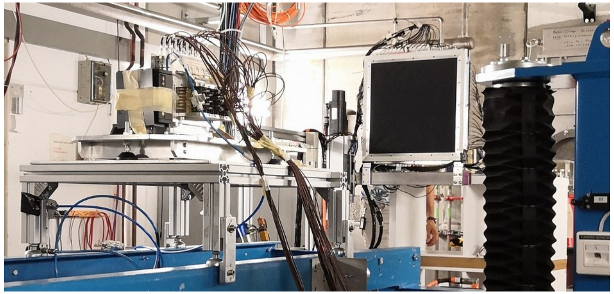
**XIII FOOT Collaboration Meeting**, Perugia

13/12/2022

# GSI 2021 Analysis

- Data-taking at GSI (Darmstadt, Germany) in 2021
- **$^{16}$O 400 MeV/u** on 5 mm **C target**
- Partial setup: no magnet, only one module of calorimeter



**My analysis goal:**

- Elemental fragmentation cross section measurements
- Angular differential cross section measurements for every charge

# Analysis procedure

To compute elemental cross section and angular differential cross section:

$$\sigma(Z) = \frac{Y(Z) - B(Z)}{N_{beam}\, N_{target}\, \epsilon(Z)}$$

$$\frac{d\sigma}{d\theta}(Z,\theta) = \frac{Y(Z,\theta) - B(Z,\theta)}{N_{beam}\, N_{target}\, \Omega_\theta\, \epsilon(Z,\theta)}$$

***Y:*** fragment counts
***Bkg:*** background source counts
***$N_{beam}$:*** n° of primary events
***$N_{target}$:*** n° of scattering centers per unit area
**ε:** efficiency
**$\Omega_\vartheta$:** angular phase space

- Event reconstruction in **SHOE** with ***Global Tracking*** (Matteo F., Roberto Z.)
- Analysis procedure in **Python** code

# Analysis procedure

$$\sigma(Z) = \frac{Y(Z) - B(Z)}{N_{beam}\, N_{target}\, \epsilon(Z)}$$

1) Starting from a **MC dataset** of $10^6$ events generated by FLUKA to simulate detectors and beams of GSI 2021 campaign.

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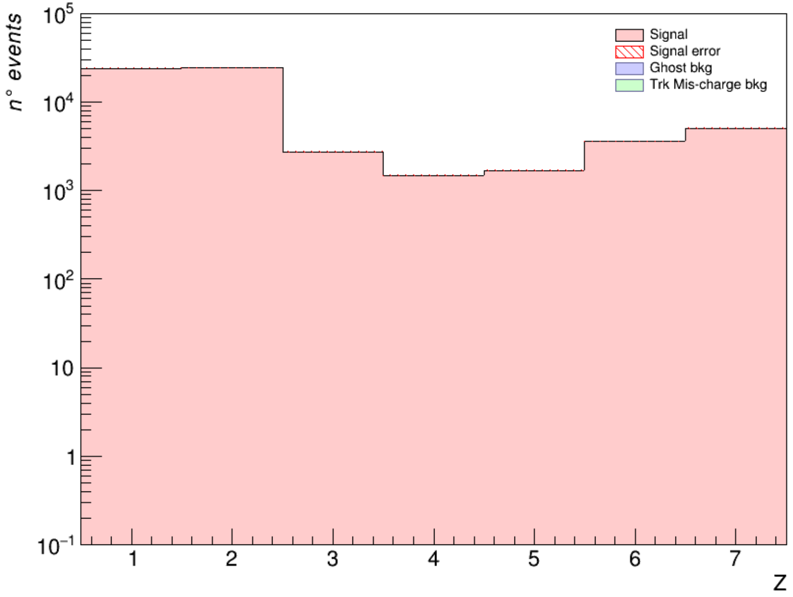
2) **Yield of Z** obtained from **reconstructed tracks**
   - Exploiting **tracking** reconstruction algorithm
   - Simulating a **"trigger"** in order to consider only fragments

Z yield and Bkg sources



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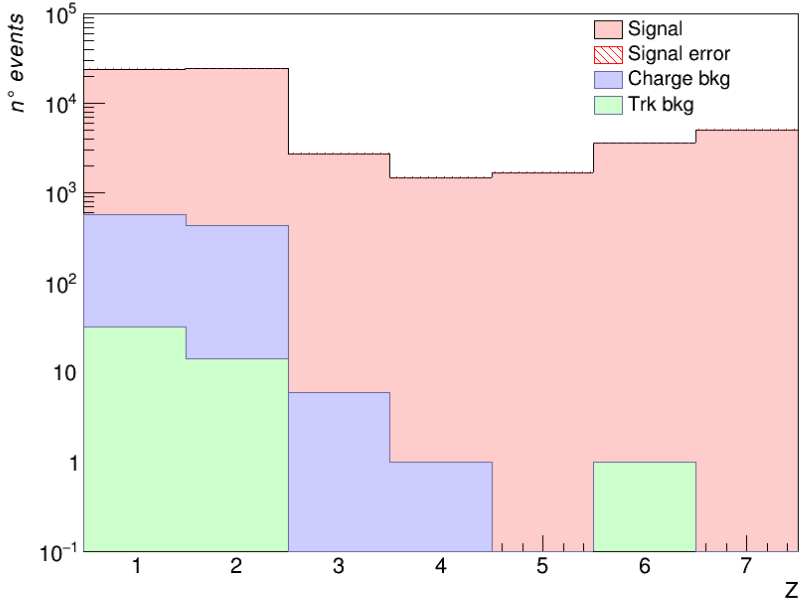
3) **Background** obtained from MC cuts on:
   - **Charge** algorithm mis-reconstruction
   - **Tracking** algorithm mis-reconstruction

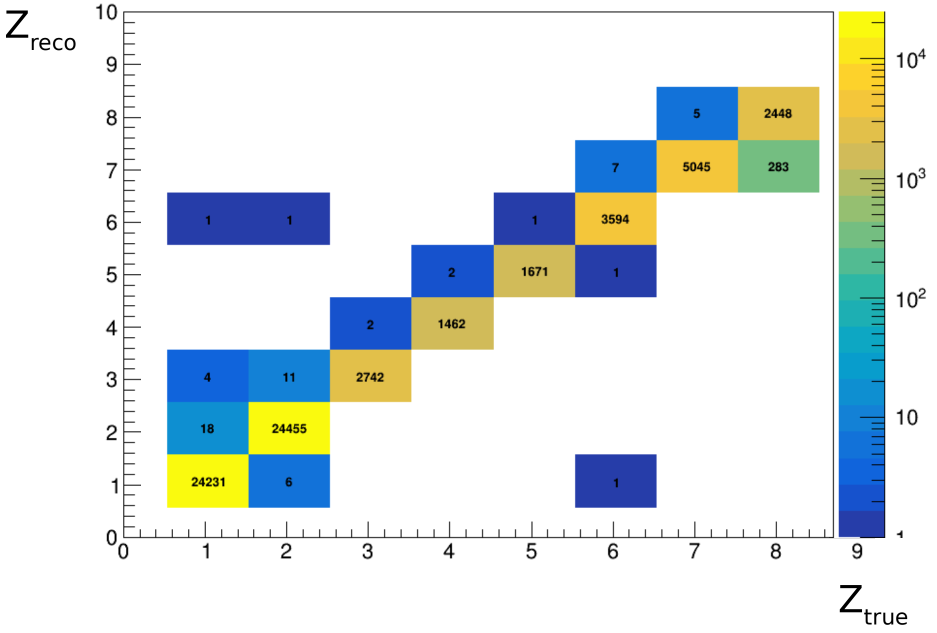
Z yield and Bkg sources

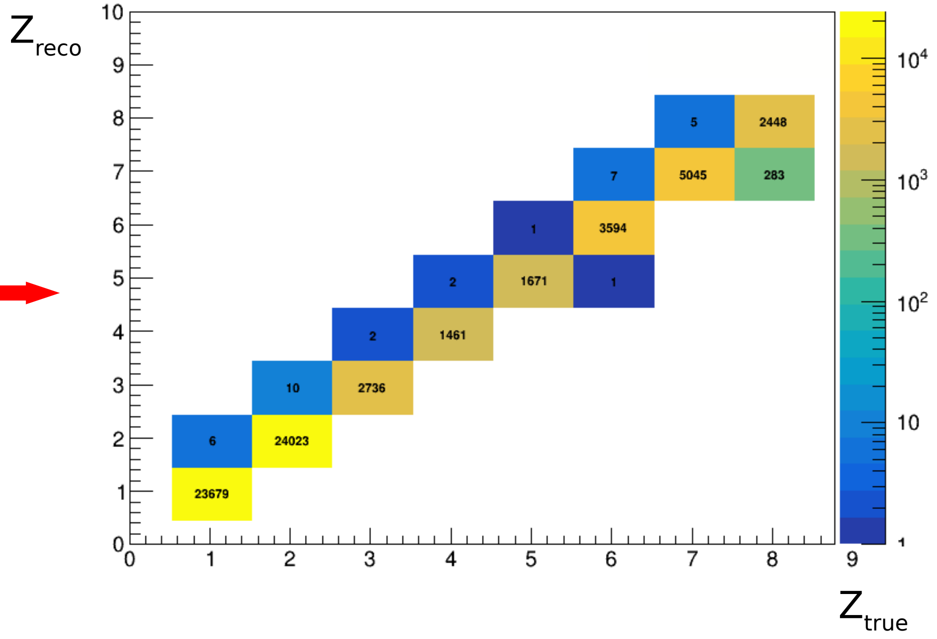


# Analysis procedure

$$\sigma(Z) = \frac{Y(Z) - B(Z)}{N_{beam}\ N_{target}\ \epsilon(Z)}$$

Before and after background removal: more diagonal migration matrix → **less noise sources**



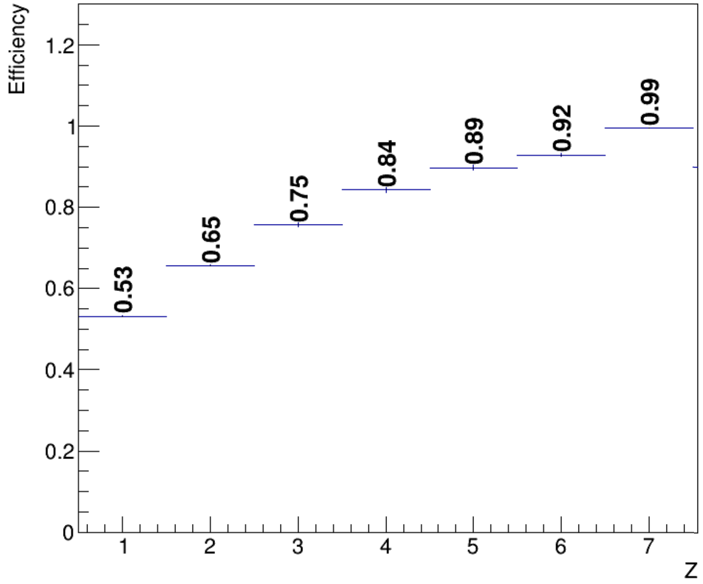



# Analysis procedure

$$\sigma(Z) = \frac{Y(Z) - B(Z)}{N_{beam}\, N_{target}\, \epsilon(Z)}$$

**4) Track efficiency** obtained as:

$$\epsilon(Z) = \frac{N_{track}(Z)}{N_{true}(Z)}$$



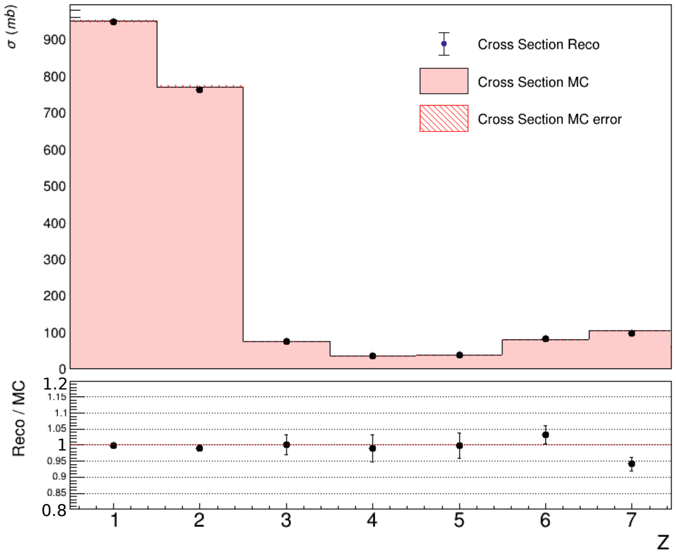

where

- $N_{track}$ is obtained by tracking algorithm
- $N_{true}$ are generated particles from the simulation with angular acceptance **θ≤8°**

# MC Closure test - elemental cross section

$$\sigma(Z) = \frac{Y(Z) - B(Z)}{N_{beam}\, N_{target}\, \epsilon(Z)}$$

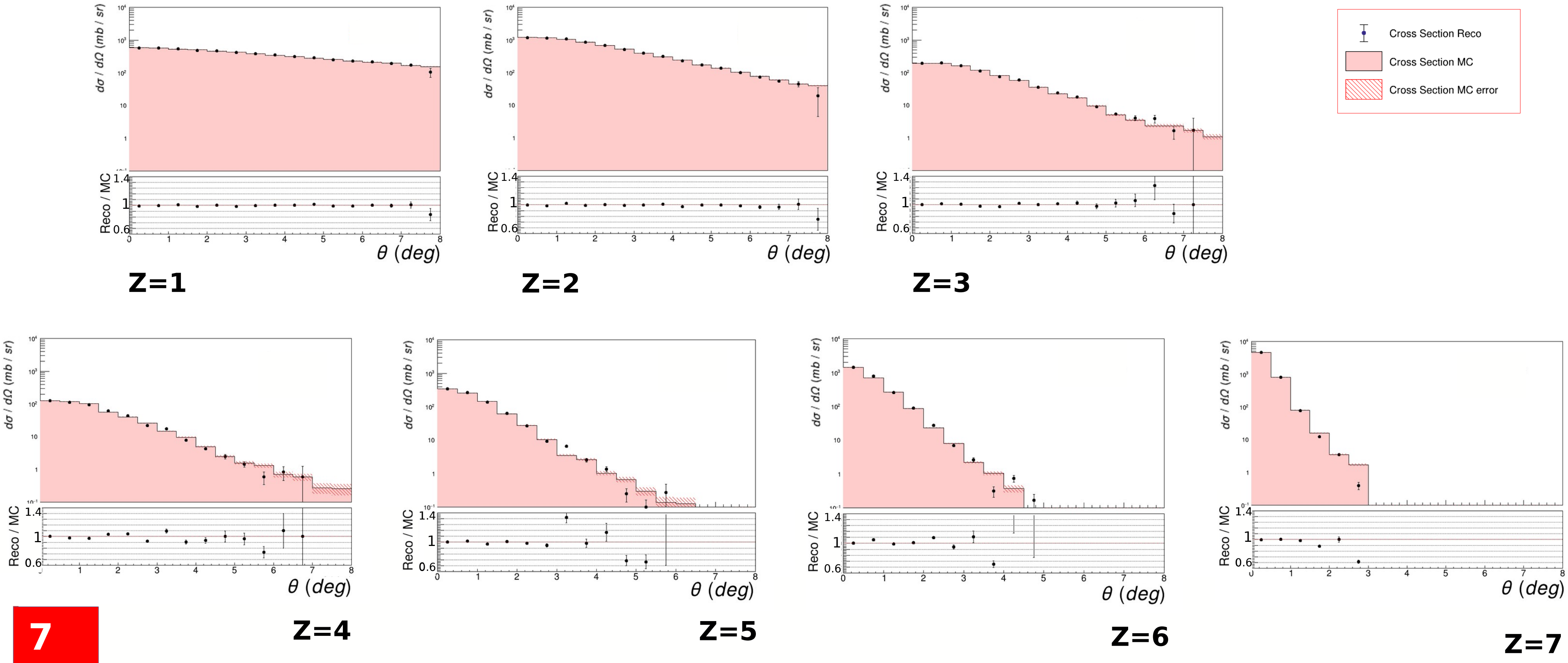
- **Fiducial** (**θ≤8°**) elemental cross section
- Only statistical errors
- comparing the MC data-like cross sections with the MC generated ones.
- understanding the **reliability** of the analysis chain and algorithms ➔ **solid analysis**




| Charge | $\sigma_{reco}$(mb) | $\sigma_{MC}$(mb) |
|---|---|---|
| Z = 1 | $946 \pm 9$ | $949 \pm 4$ |
| Z = 2 | $762 \pm 7$ | $770 \pm 4$ |
| Z = 3 | $74.1 \pm 1.3$ | $74.1 \pm 1.2$ |
| Z = 4 | $35.3 \pm 1.5$ | $35.2 \pm 1.2$ |
| Z = 5 | $37.4 \pm 1.6$ | $37.2 \pm 1.7$ |
| Z = 6 | $82.8 \pm 1.7$ | $79.3 \pm 1.2$ |
| Z = 7 | $97.3 \pm 1.4$ | $103.0 \pm 1.5$ |

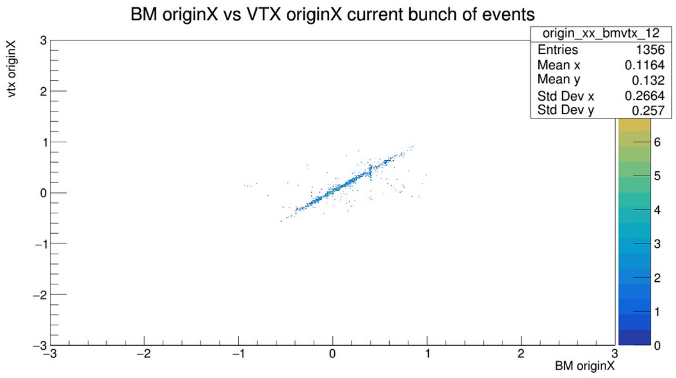
# MC Closure test - angular differential cross section

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\theta} \cdot \frac{1}{sen(\theta) \cdot 2\pi}$$

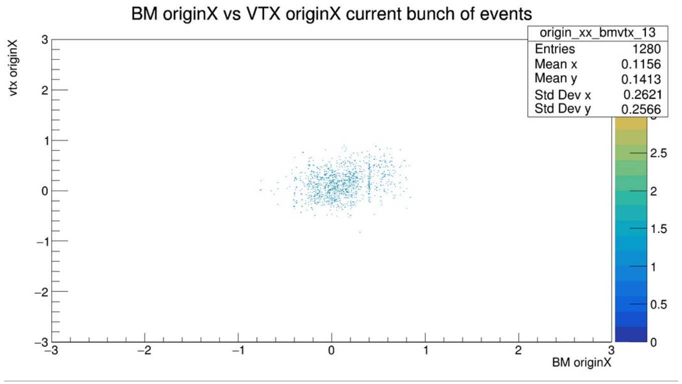


# Experimental data

- **run 4306 (Minimum Bias)**
- Vertex synchronization lost after 65k events:




Bm-vtx correlation up to 65 k evts



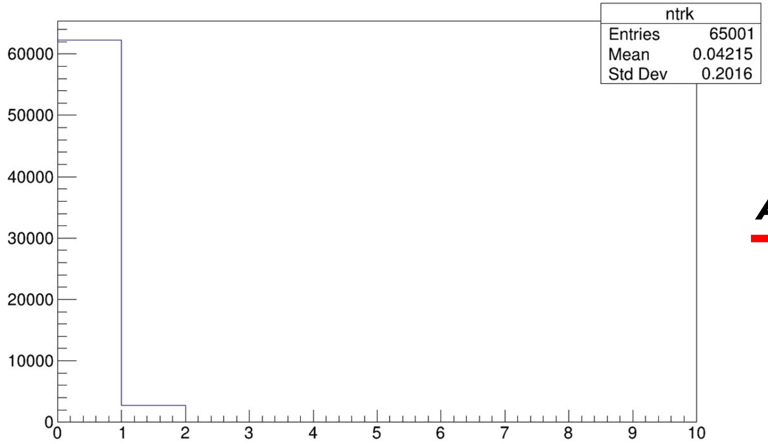

Bm-vtx correlation from 65k to 75 k evts

Thanks to Yun

- Using a sampling of 65k evts in the following analysis → it could be **small statistics**

# Alignment

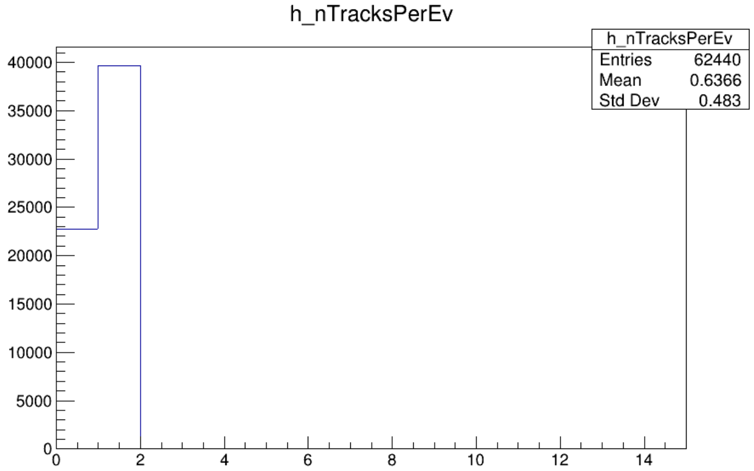
- At the beginning, very low ability in ***global tracking*** reconstruction
  → important improvements with new alignment of detectors in geometry




Only **3%** of events reconstructed with > 1 track

***AlignFOOTMain.C***

Thanks to Yun




More than **60%** of events reconstructed with > 1 track

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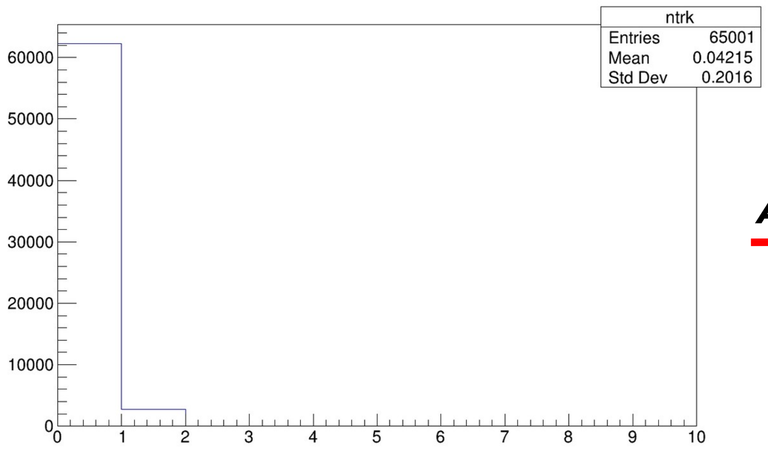


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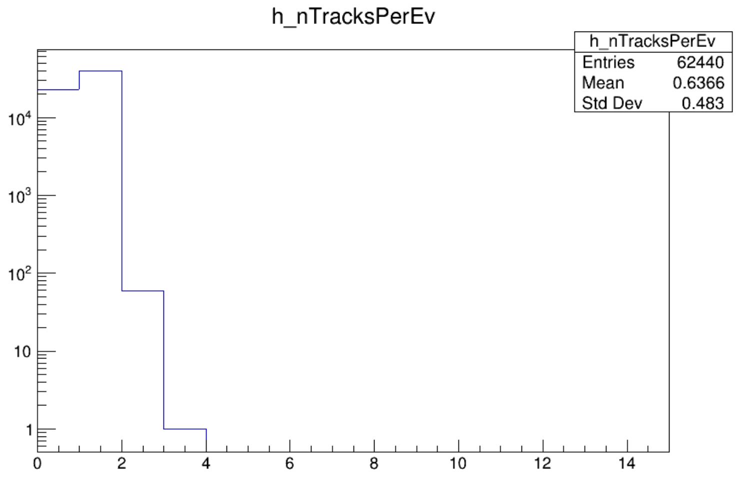


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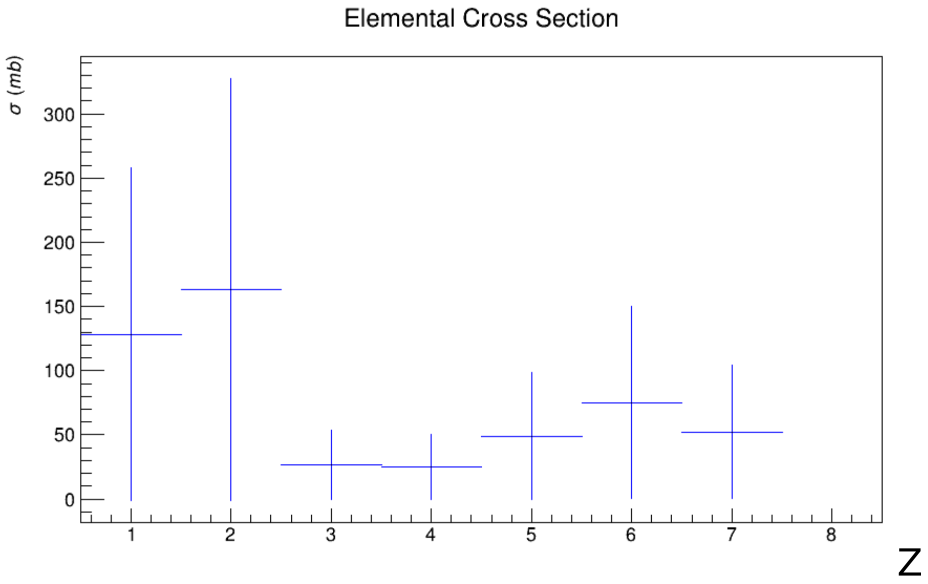
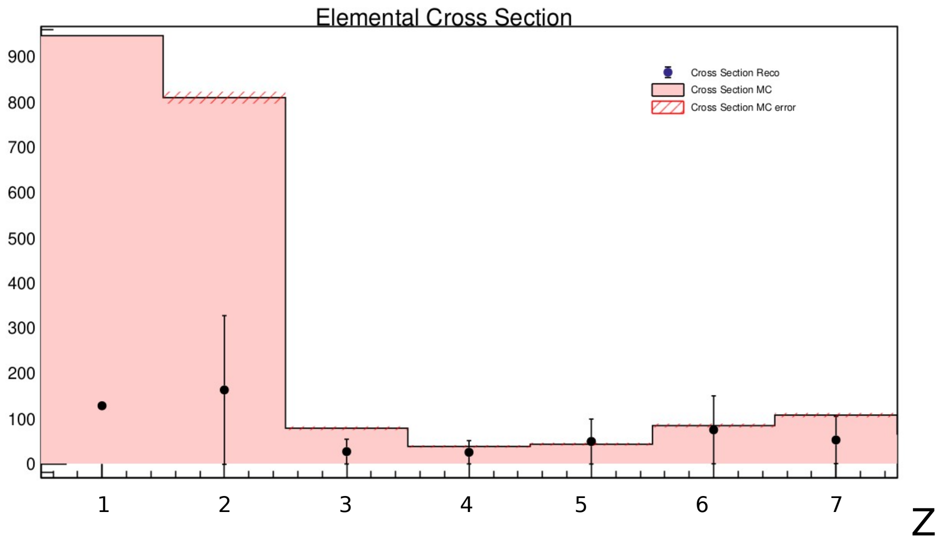
# Experimental results - elemental cross section

$$\sigma(Z) = \frac{Y(Z) - B(Z)}{N_{beam}\ N_{target}\ \epsilon(Z)}$$

- experimental results




- experimental results and comparison with MC

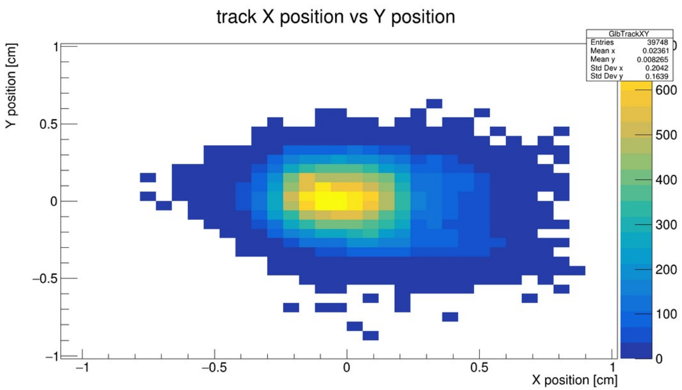



Highest discrepancy for elements with high angular distribution (see next)

# Alignment – global track

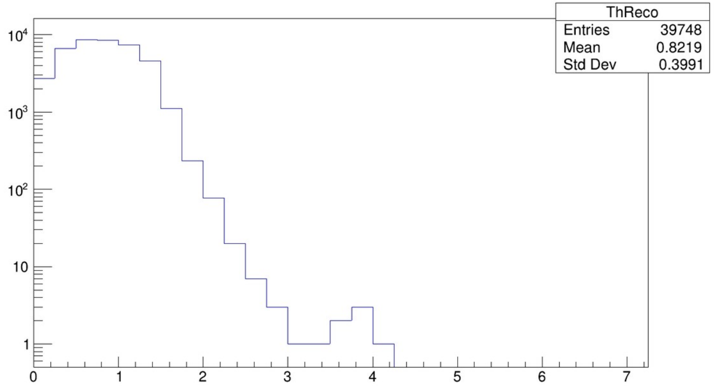
## Reference system with beam (X,Y) in (0,0)

- Global tracks XY profile




The beam is shifted on X axis of ~0.01 cm

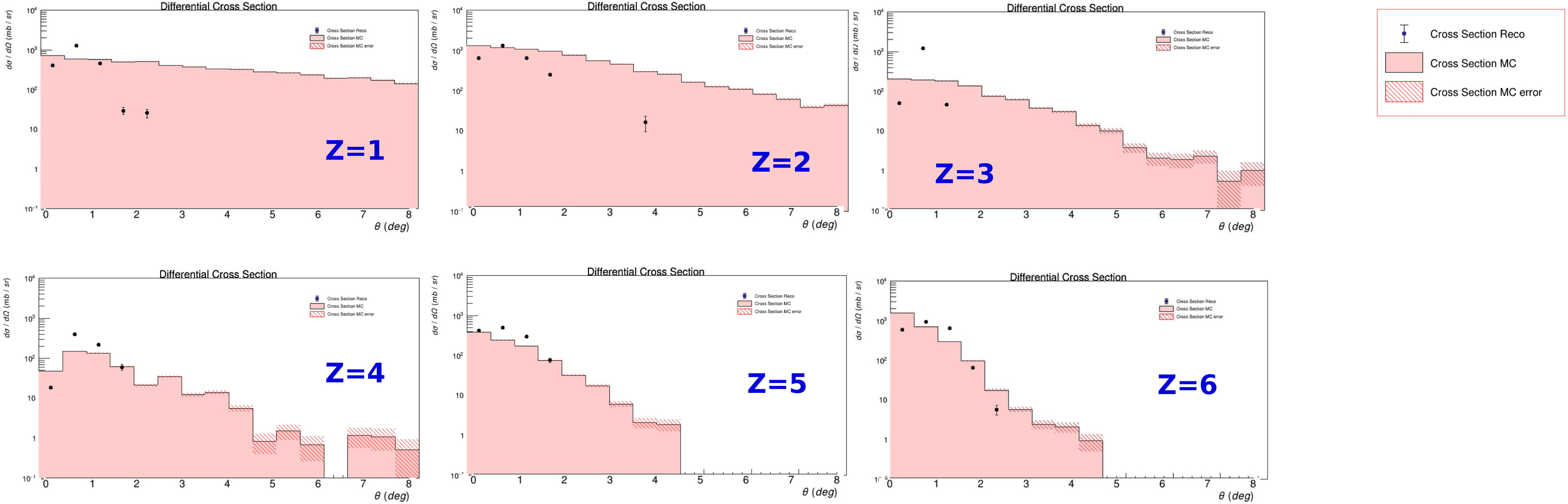
- Global tracks theta angle

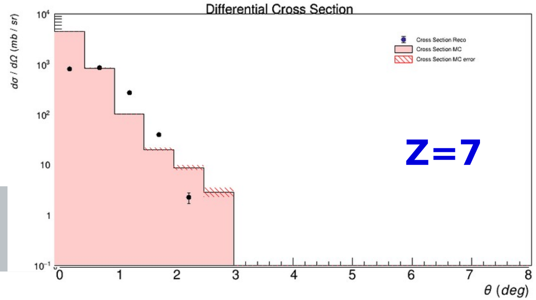



It seems only “straight” (<3°) tracks are reconstructed (however the statistics is low)

# Experimental results - angular differential cross section

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\theta} \cdot \frac{1}{sen(\theta) \cdot 2\pi}$$




- Highest agreement with high Z, whose angular distribution is more focalized around low angles

# Conclusions

- Analysis strategy checked by **MC** events with a **solid closure test**
- First preliminary results of **experimental** cross sections with full reconstruction algorithm

**Future perspectives:**

- **For the analysis:**

Increase the statistics
Including systematic uncertainties
Including unfolding to correct for migrations

- **For the global tracking reconstruction:**

Deeper studies about alignment and detector components

*Thank you for the attention*

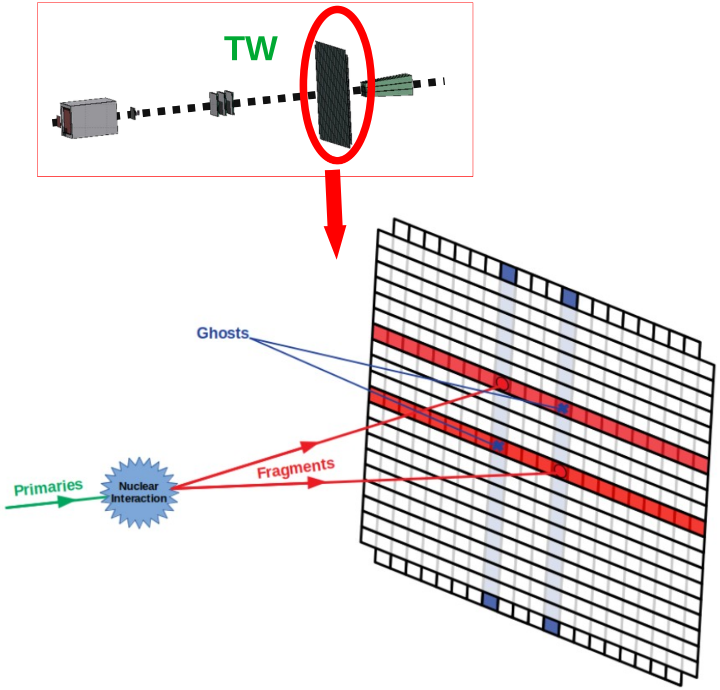
# Backup slides

# Backup slides

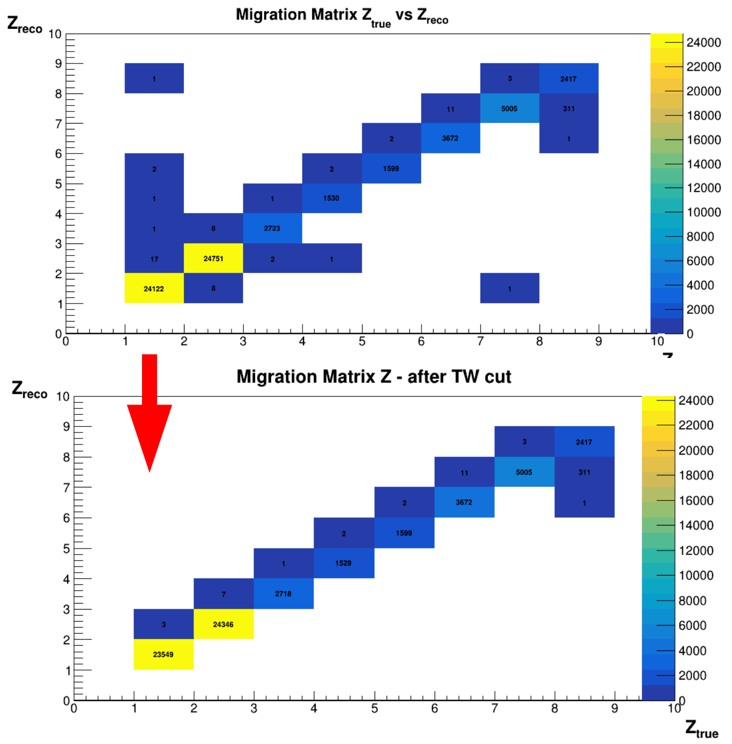
Analysis

# Example: Track reconstruction

- It is possible that every bar layer of the TW is hit by more than a fragment at the same time: **multiple hits / ghost hits mis-reconstruction**

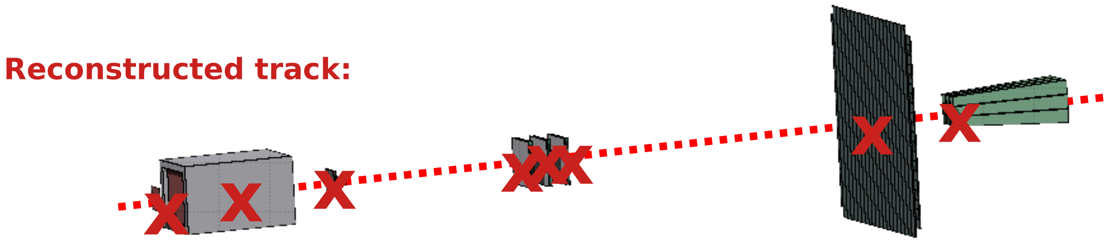



**Applying TW cut:**
Matrix more diagonal



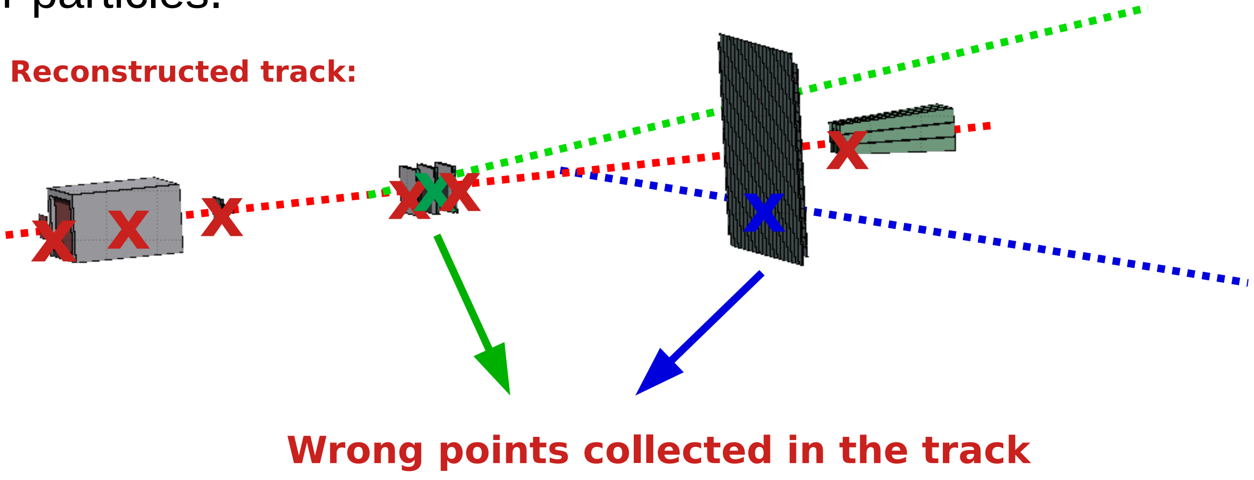
# Reconstruction, Track Algo

- Another source of systematics can be the way points are collected in a track
- In the best scenario, all points belong to the same particle:



# Reconstruction, Track Algo

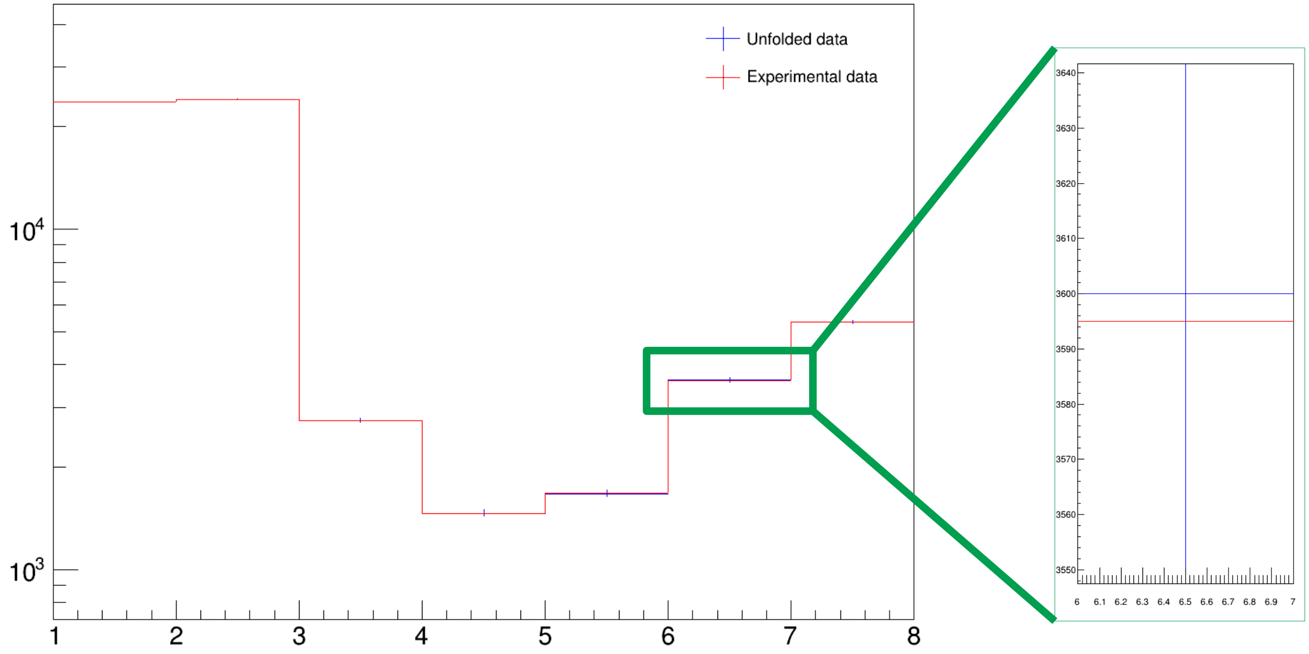
- However, due to the presence of a lot of secondary fragmentation, some points can belong to other particles.




- The McId of the track is given by the most present particle in the collection
- However, if the TWPoint is of another particle → **its McId is different**
- → filter out all the tracks in which **$McId_{track} \neq McId_{TWPoint}$**

# Implementation of Unfolding

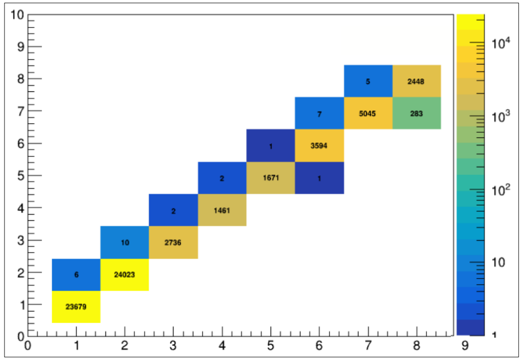
$$\sigma(Z) = \frac{(Y(Z) - B(Z))^U}{N_{beam}\ N_{target}\ \epsilon(Z)}$$




$$y_i = M_{ij}\ x_j$$

$$\rightarrow x_j = M_{ij}^{-1}\ y_i$$

- Little variation because the migration matrix is very diagonal




Thanks to Sofia C.

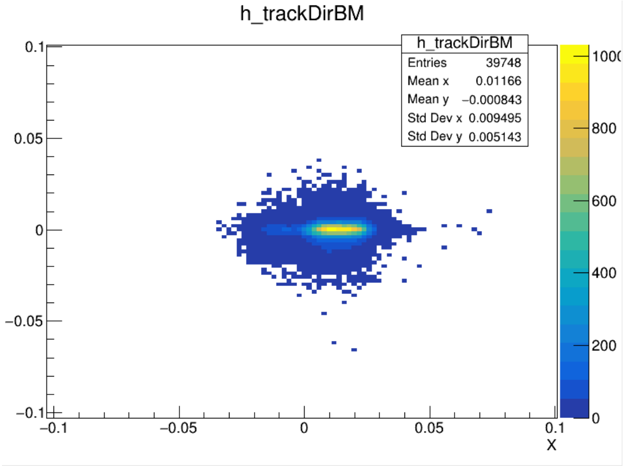
# Backup slides

Alignment studies

# Alignment – global track wrt BM direction

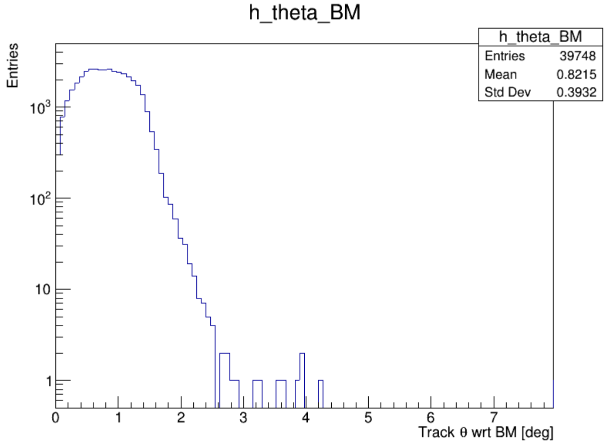
## Reference system with beam (X,Y) in (0,0)

- Global tracks XY profile



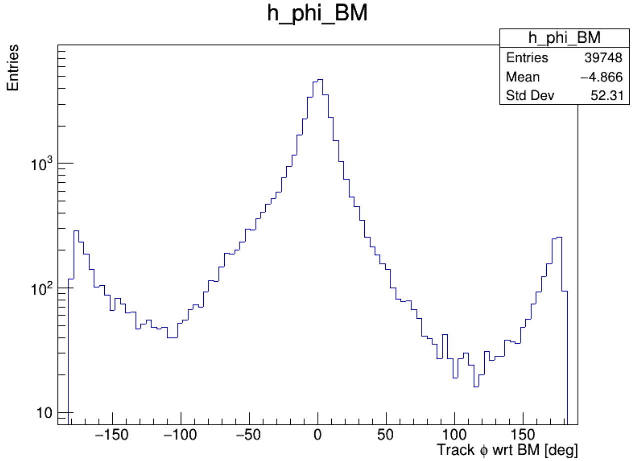

The beam is shifted on X axis of ~0.01 cm

- Global tracks theta angle



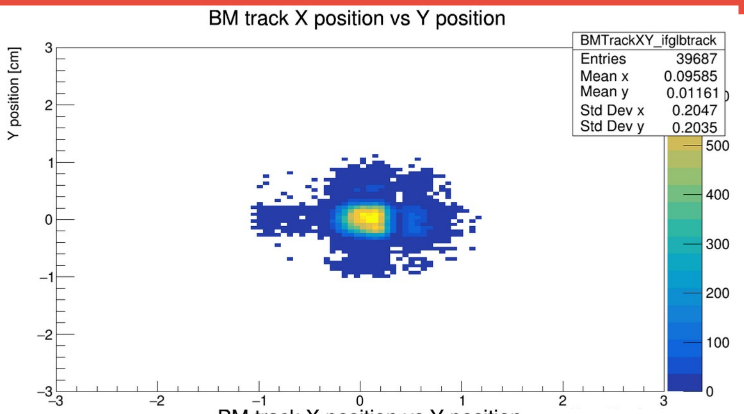

It seems only “straight” tracks are reconstructed
(however the statistics is low)

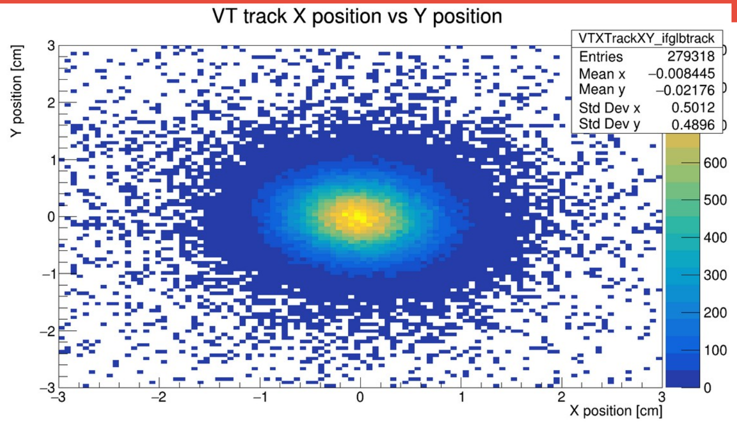
- Global tracks phi angle



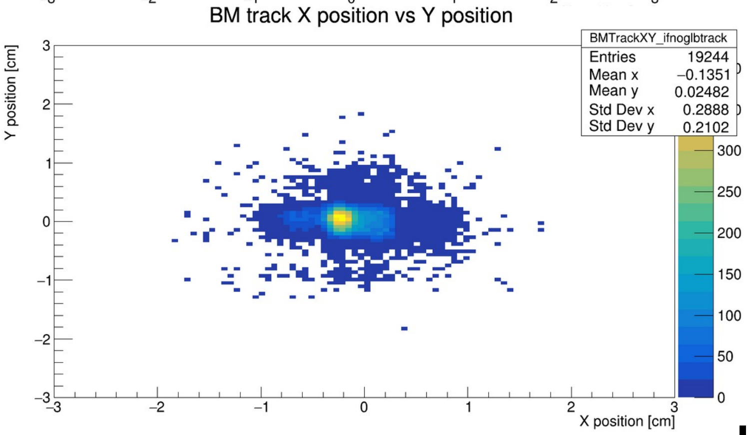

Due to profile shape → favored direction

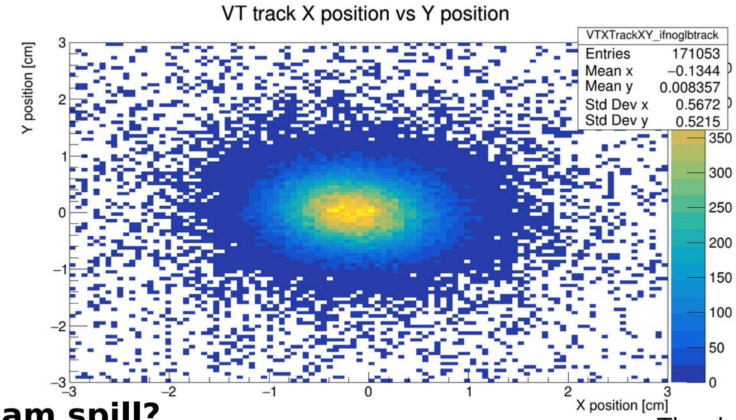
# BM and VT XY PROFILE




If global Track reconstructed

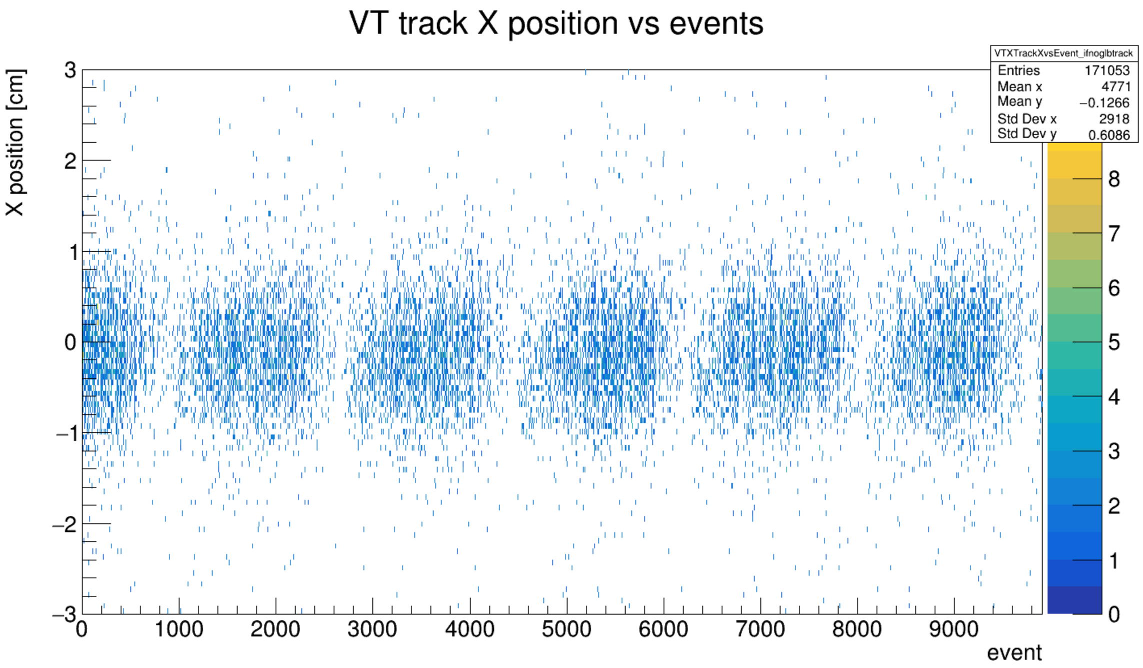



If global Track **NO** reconstructed

**Inefficiency due to beam spill?**

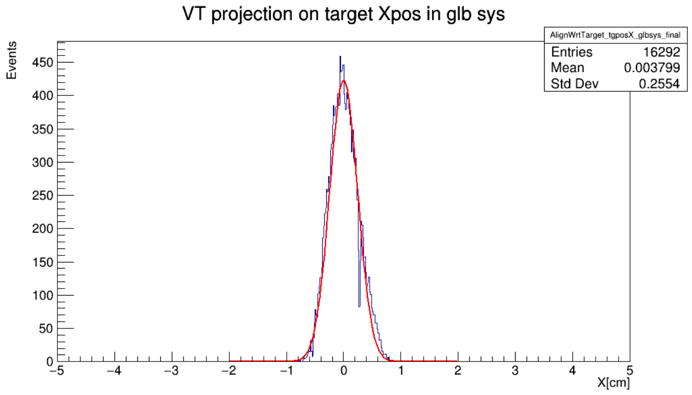
Thanks to Roberto Z.

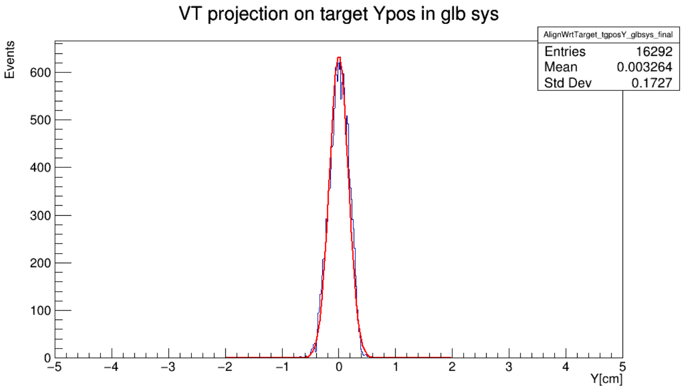



Position of VT track
When no global track
Reconstruction vs event

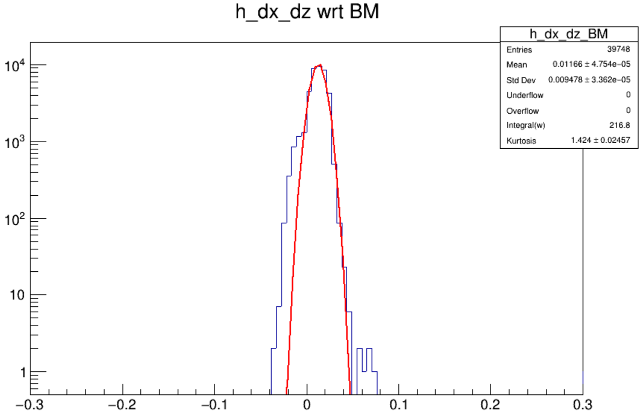
→ specific pattern
beam spill?

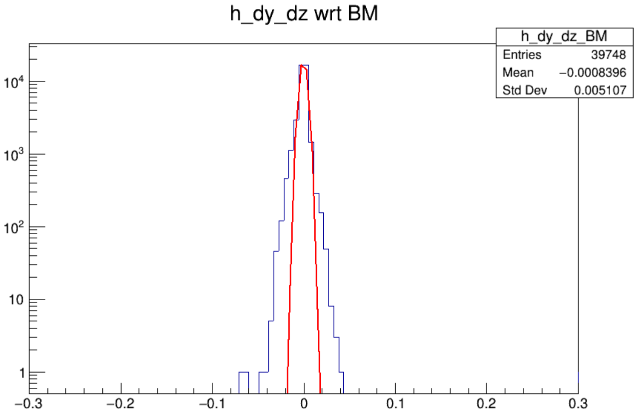
# Alignment - residuals




- VTX tracklets position wrt X,Y




- Global tracks position wrt X,Y
  - Shift on X of 0.01 cm

# Alignment

vertex