VTX Detector and Cross Section Measurements at GSI2021

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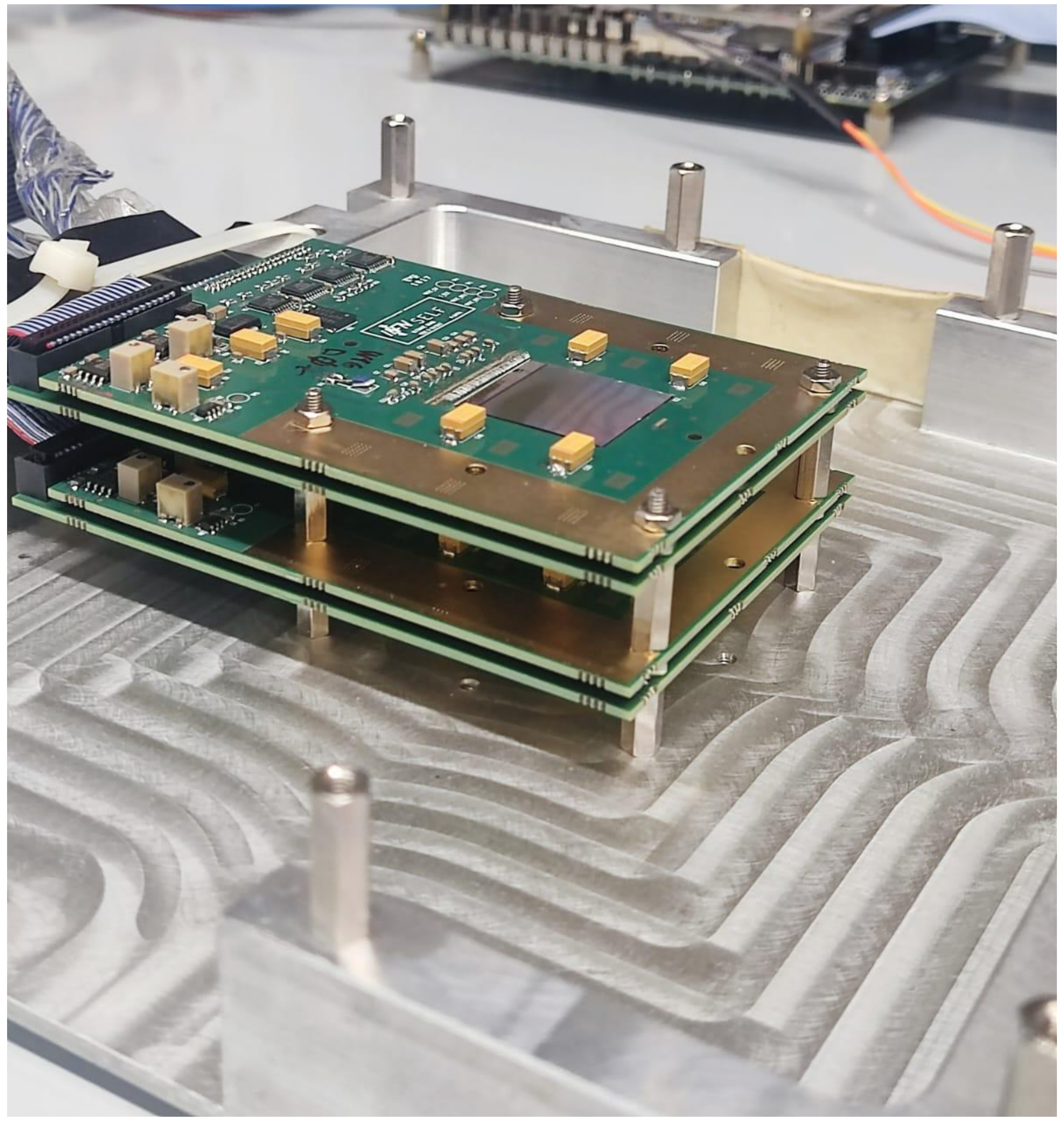
Can the VTX be used for Cross Section measurement at GSI2021?

This work investigates whether it is possible to **include the VTX detector** for cross section measurements, despite the **high pile-up conditions** (~70% of the events have PileUp) and the use of **default thresholds** during GSI2021.

The final results will be compared to the XS measured with the SC+BM+TW analysis of GSI2021

Angular differential and elemental fragmentation cross sections of a 400 MeV/nucleon ^{16}O beam on a graphite target with the FOOT experiment



Analysis strategy

Detectors used: **ST + BM + VTX + TW**

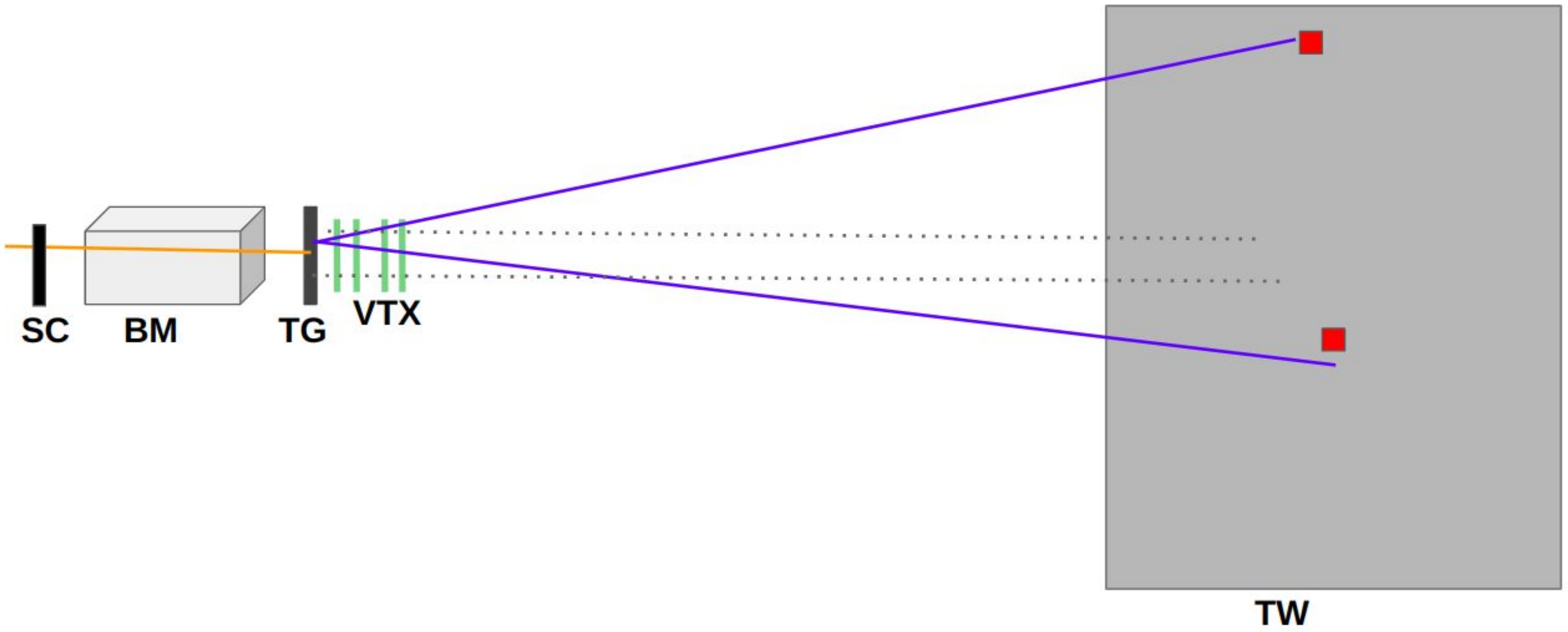
$$\frac{d\sigma}{d\Omega}(Z,\theta) = \frac{Y(Z,\theta)}{N_{\mathrm{prim}} \cdot N_{\mathrm{TG}} \cdot \varepsilon(Z,\theta) \cdot \Delta\Omega}$$

- $Y(Z, \theta)$ corresponds to the number of reconstructed fragments with charge Z at a given angle θ
- N_{prim} is the number of primary particles incident on the target and within the acceptance of the VTX
- N_{TG} is the number of interaction centers in the target per unit area
- $\epsilon(Z, \theta)$ is the efficiency
- $\Delta\Omega$ is the width of the solid angle bin

Yield selection

Given an event with only 1BM track in VTX acceptance (a primary):

- Discard events with **Z = 8** detected in TW
- Check for the presence of a **fragmentation vertex** in the VTX
- If a vertex is found → **project VTX tracks** onto the TW plane
- Search for a **TW point within 2 cm** of the projected track position

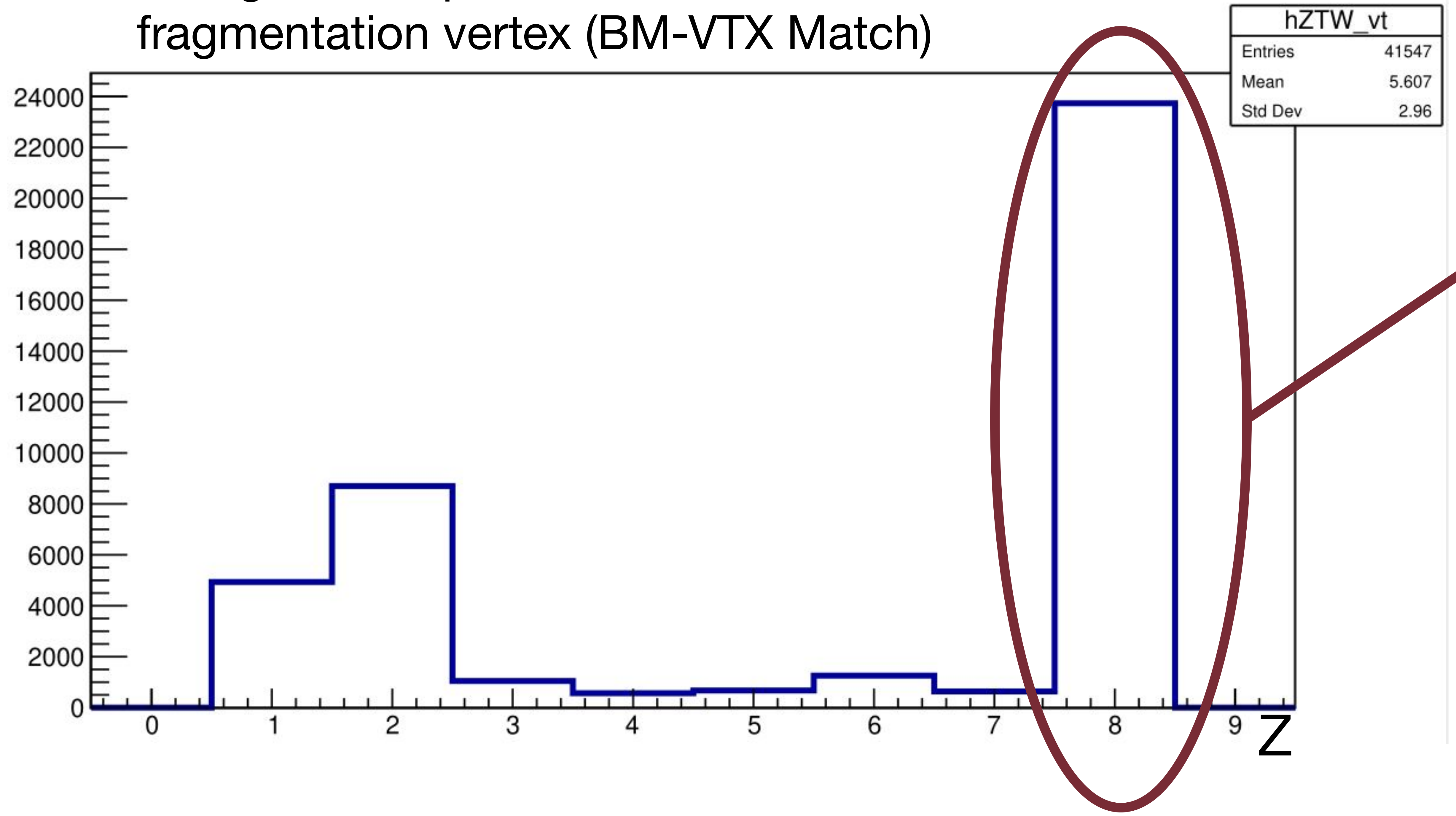


Selection Cuts applied in the analysis

❖ **No BM match**

High pile-up and detector resolution limits can cause mismatches.

Charge of TW points when there is a matched fragmentation vertex (BM-VTX Match)



Z = 8 peak

Indicates a mismatch: the matched fragmentation vertex is incorrect and comes from pile-up. The true match is with a primary that reaches the TW

Matching errors can also occur in reverse: a real fragmentation vertex may be wrongly discarded!!

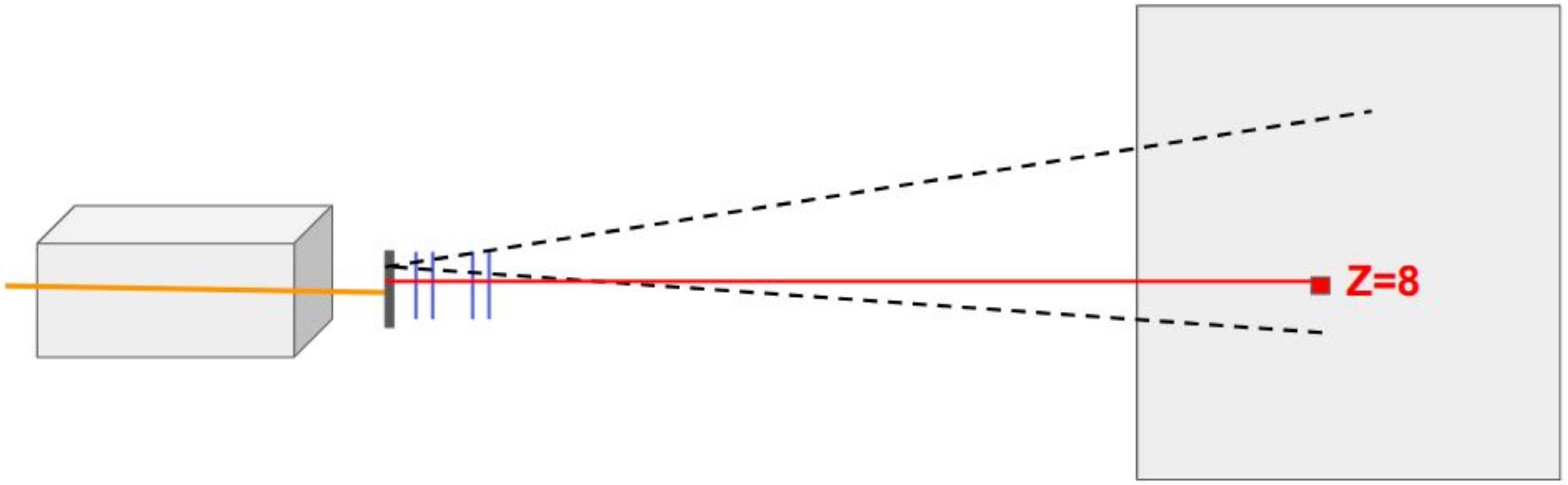
Selection Cuts applied in the analysis

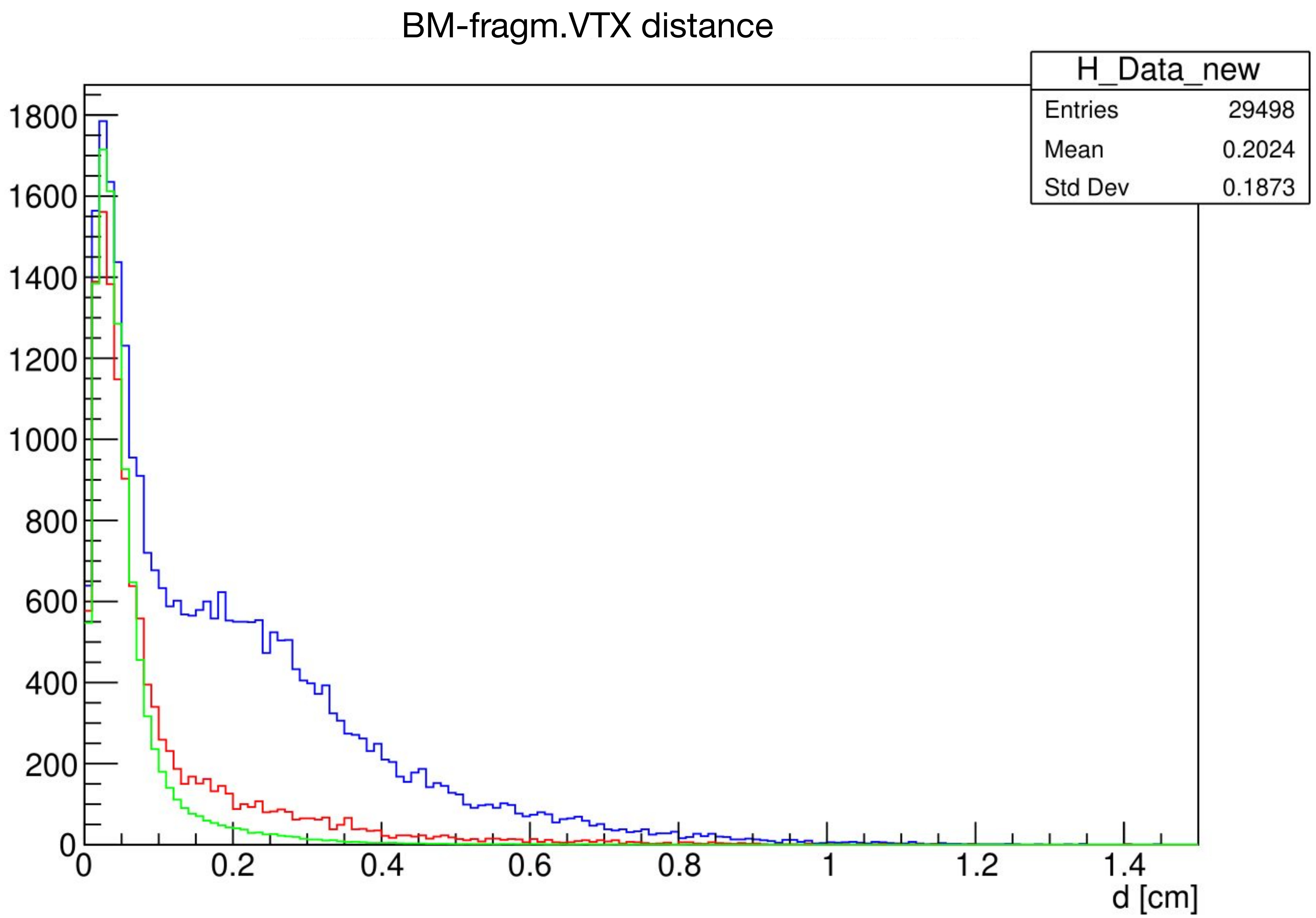
❖ **Fragmentation vertexes discarded if Z=8 is found in TW**

If a **Z = 8** is detected in TW, it means that a **primary particle** reached the TW. Any fragmentation vertex found is due to **pile-up**.

Distance between BM track and fragmentation VTX

- all fragmentation VTX
- fragmentation VTX with no Z=8 TW point
- MC (no PileUp)





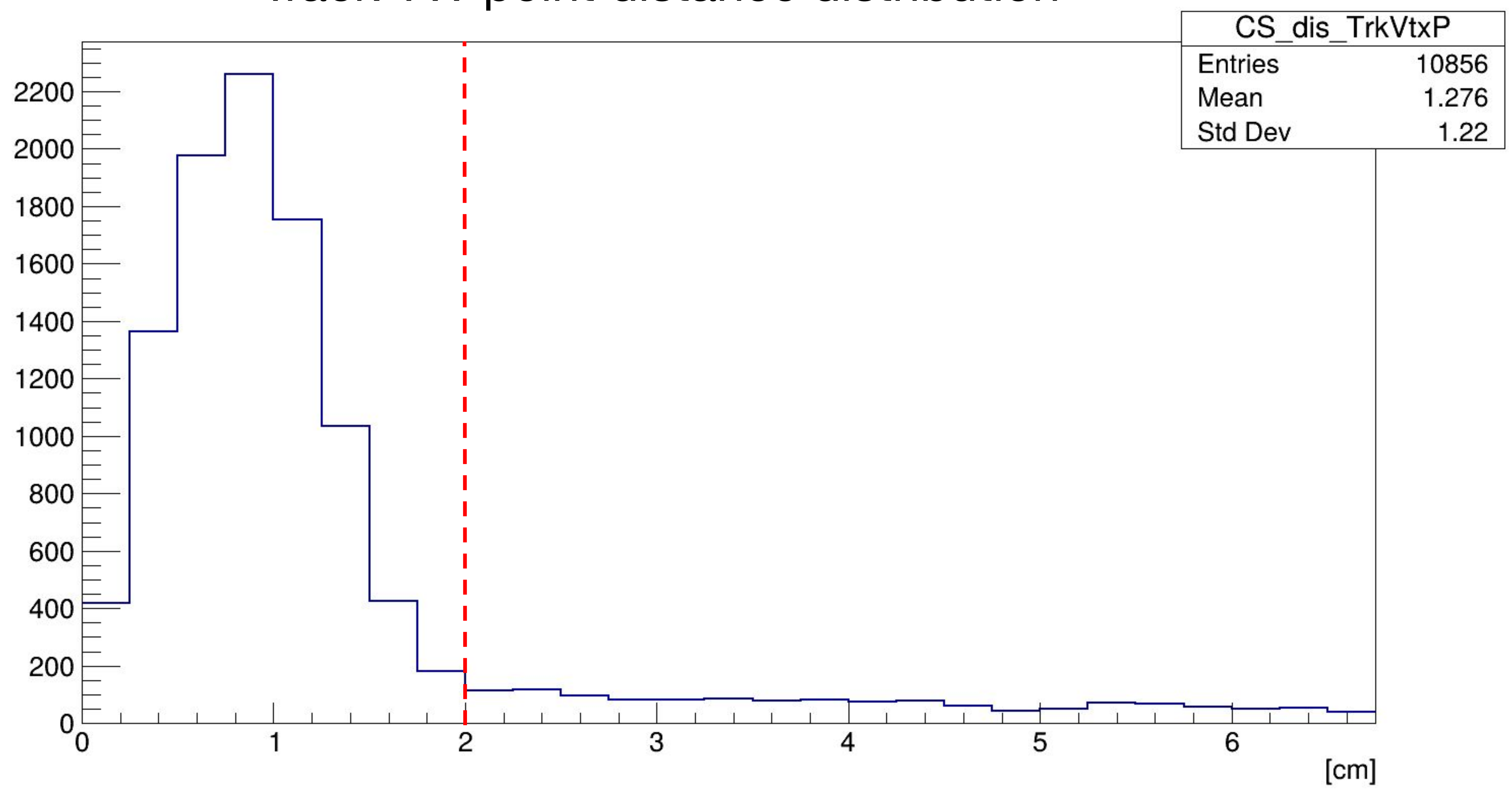
Selection Cuts applied in the analysis

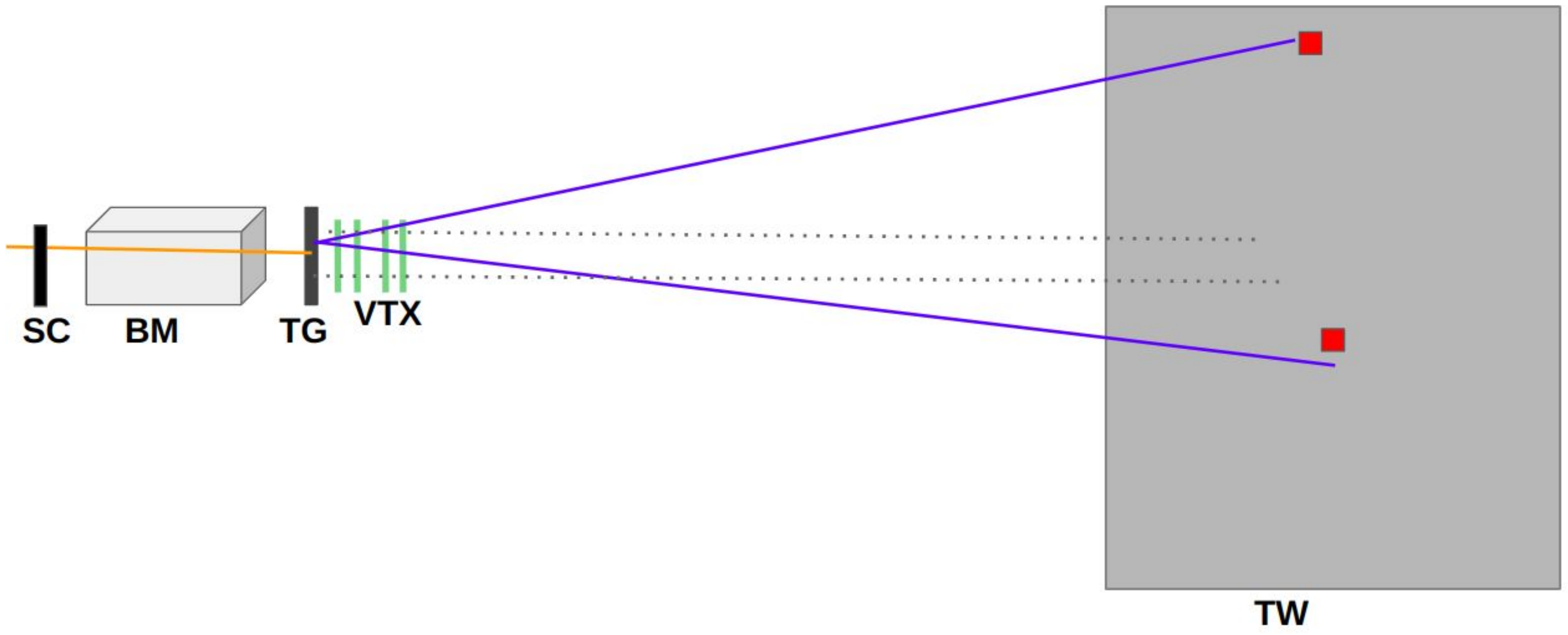
❖ Track–TW Point Distance < 2 cm

The reconstructed VTX tracks are projected onto the TW detector plane. For each projected track, the closest TW point is searched.

→ If the **distance is less than 2 cm**, the TW point is **associated** to that track.

Track-TW point distance distribution



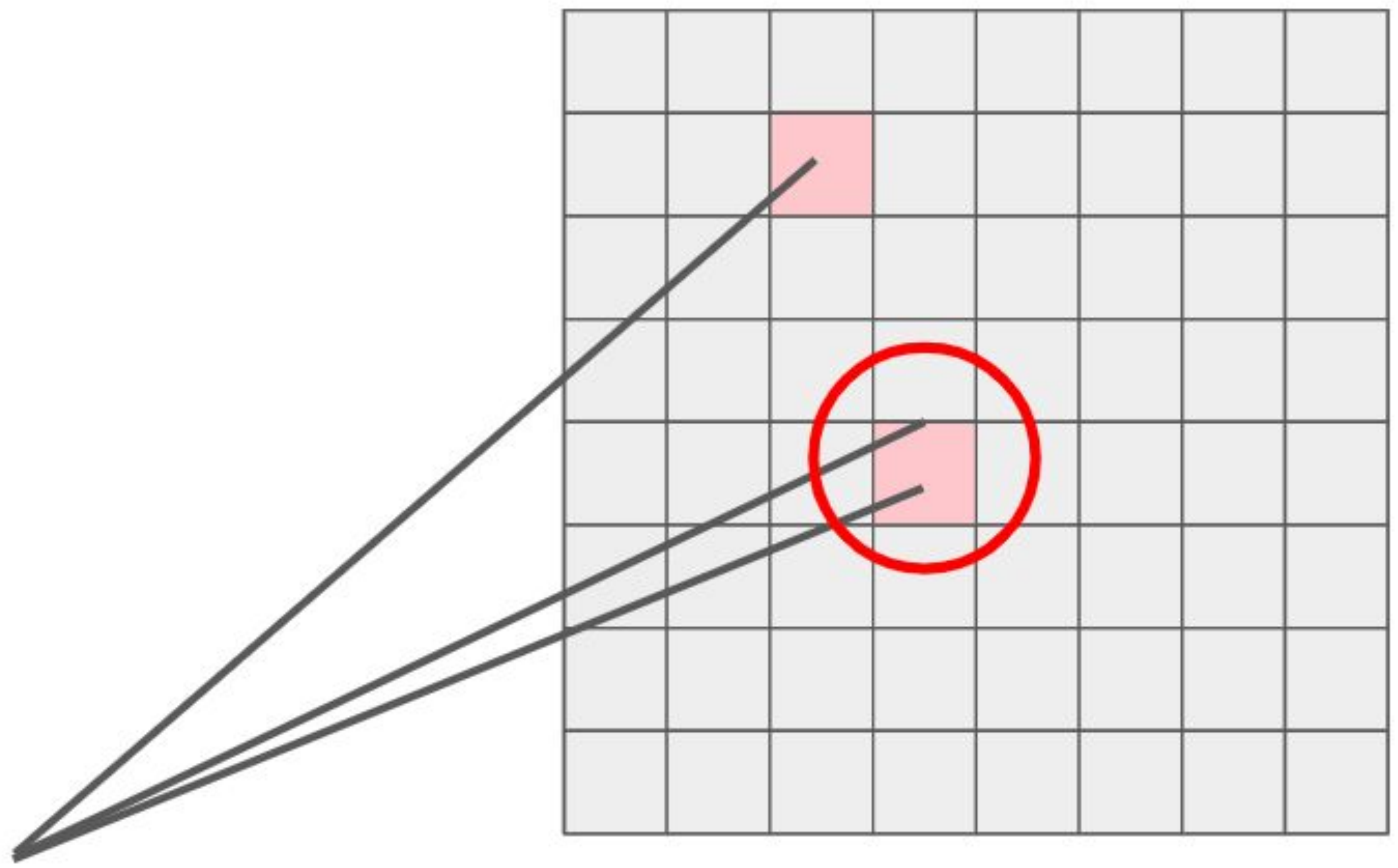


Selection Cuts applied in the analysis

❖ **Shared TW Point Between Two Tracks**

If two VTX tracks projected onto the TW are matched with the same TW point, **both tracks and the TW point are discarded.**

This cut removes cases where two particles hit the same TW bar, causing the TW to reconstruct a single particle with a charge equal to the sum of the two, leading to misidentification.



MC study

Efficiency Evaluation:

Given an event with a fragmentation in the target (N_{true_frag}):

1. Check whether the fragments are reconstructed by the VTX and associated to a fragmentation vertex (N_{reco_VTX})

$$\varepsilon_1(Z,\theta) = \frac{N_{\mathrm{reco\_VTX}}}{N_{\mathrm{true}}}$$

2. Verify how many of these VTX-reconstructed fragments cross the TW detector (N_{cross_TW})

$$\varepsilon_2(Z,\theta) = \frac{N_{\mathrm{cross\_TW}}}{N_{\mathrm{reco\_VTX}}}$$

3. Among the crossing fragments, check how many are reconstructed as TW points (N_{reco_TW})

$$\varepsilon_3(Z,\theta) = \frac{N_{\mathrm{reco\_TW}}}{N_{\mathrm{cross\_TW}}}$$

4. Finally, for the reconstructed TW points check for a match between the VTX track and the TW point (N_{match_TW})

$$\varepsilon_4(Z,\theta) = \frac{N_{\mathrm{match\_TW}}}{N_{\mathrm{reco\_TW}}}$$

MC study

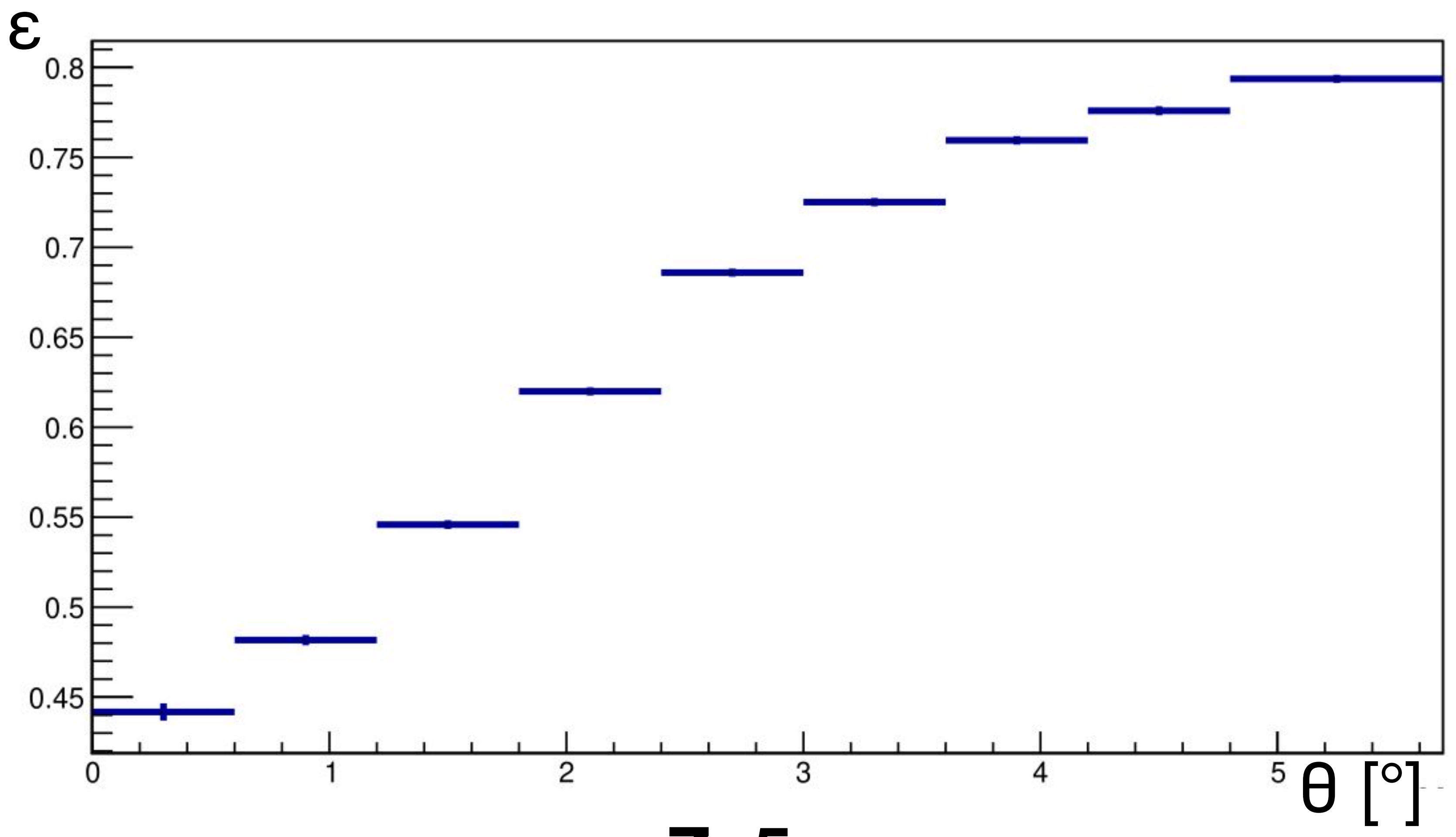
Efficiency Evaluation:

Thus, the total efficiency is given by the ratio between the reconstructed fragments and the true fragments, which can be expressed in terms of the previously described efficiencies as:

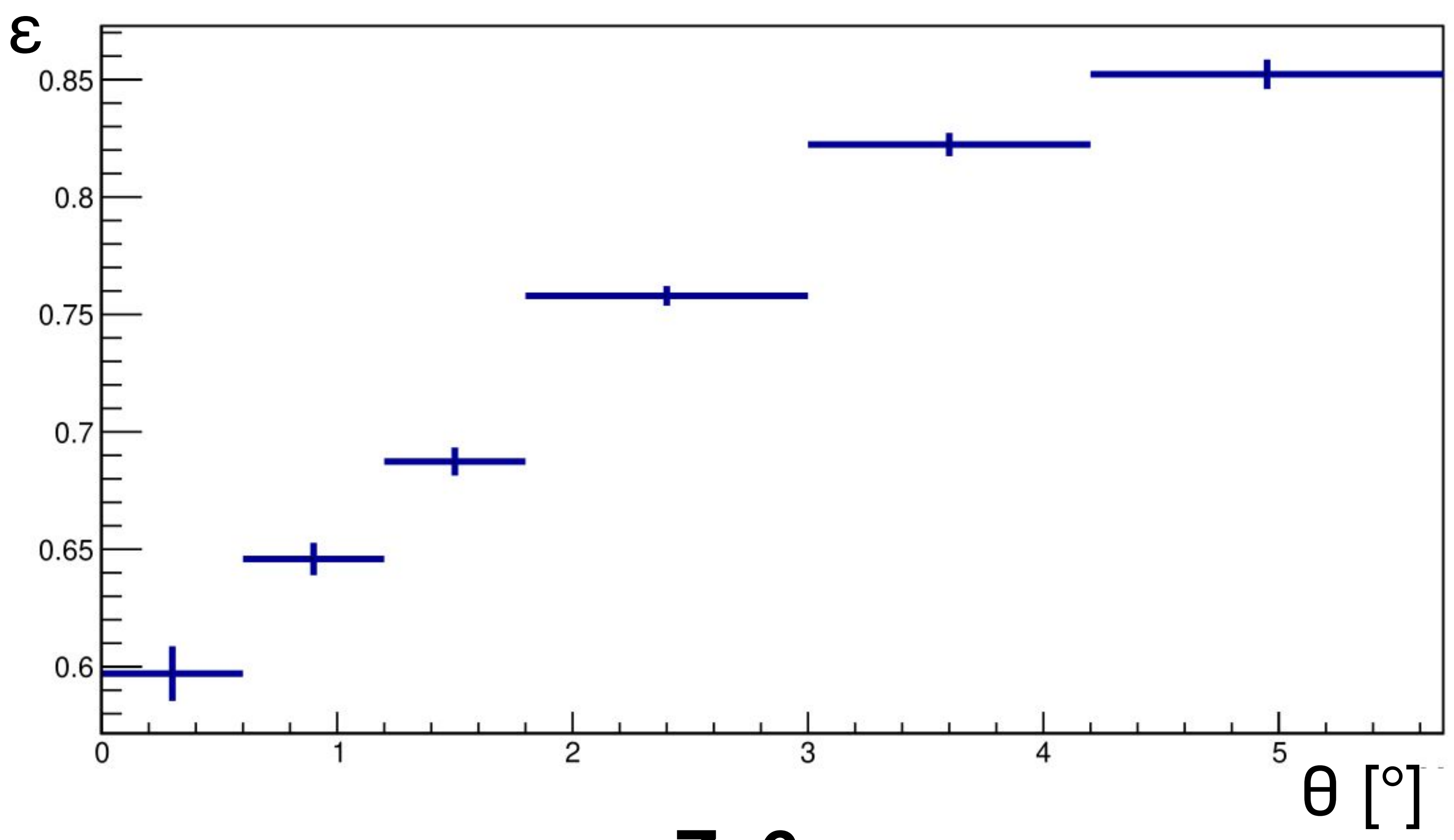
$$\boxed{\varepsilon(Z,\theta) = \frac{N_{\text{reco\_frag}}}{N_{\text{true\_frag}}} = \varepsilon_1(Z,\theta) \times \varepsilon_2(Z,\theta) \times \varepsilon_3(Z,\theta) \times \varepsilon_4(Z,\theta)}$$

Efficiencies

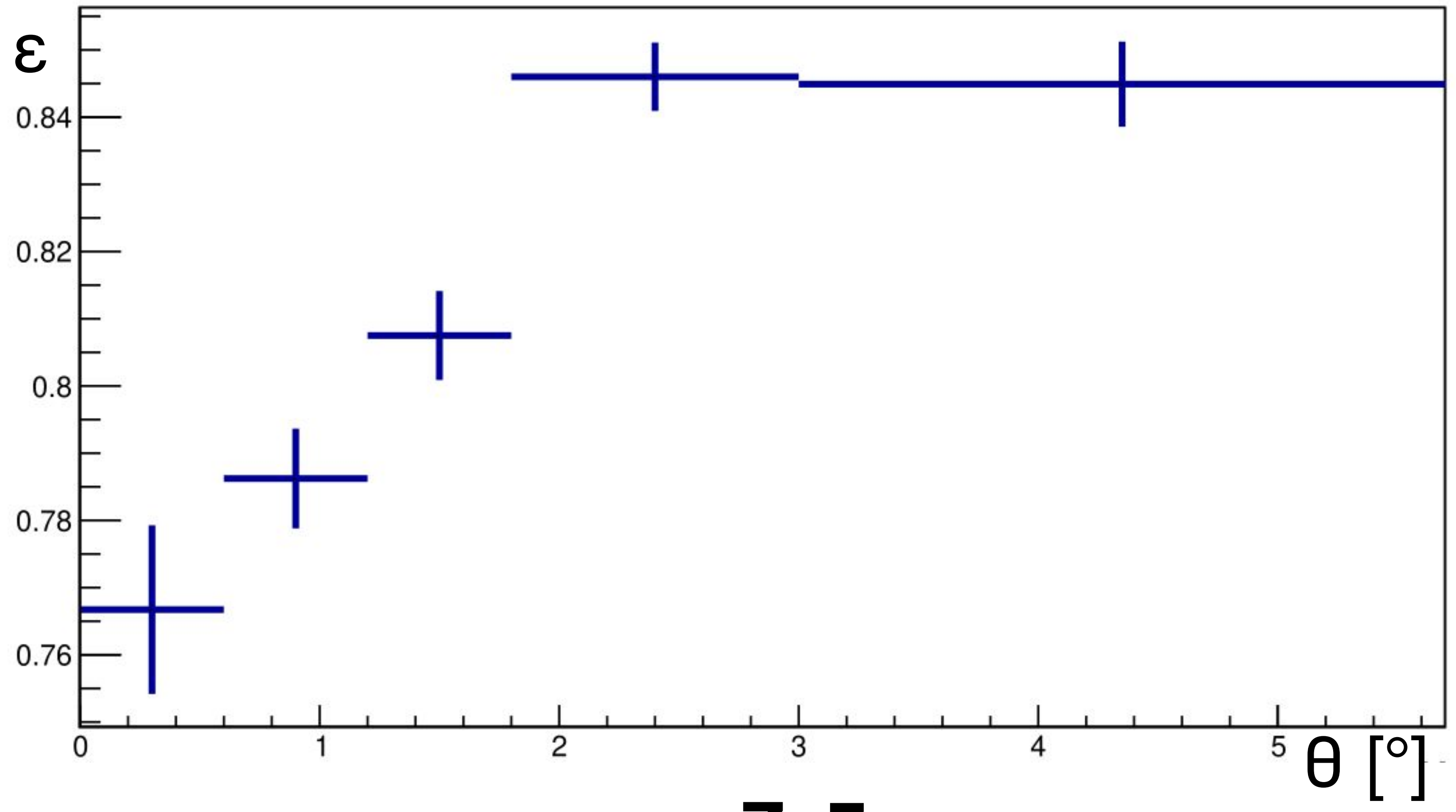
Z=2



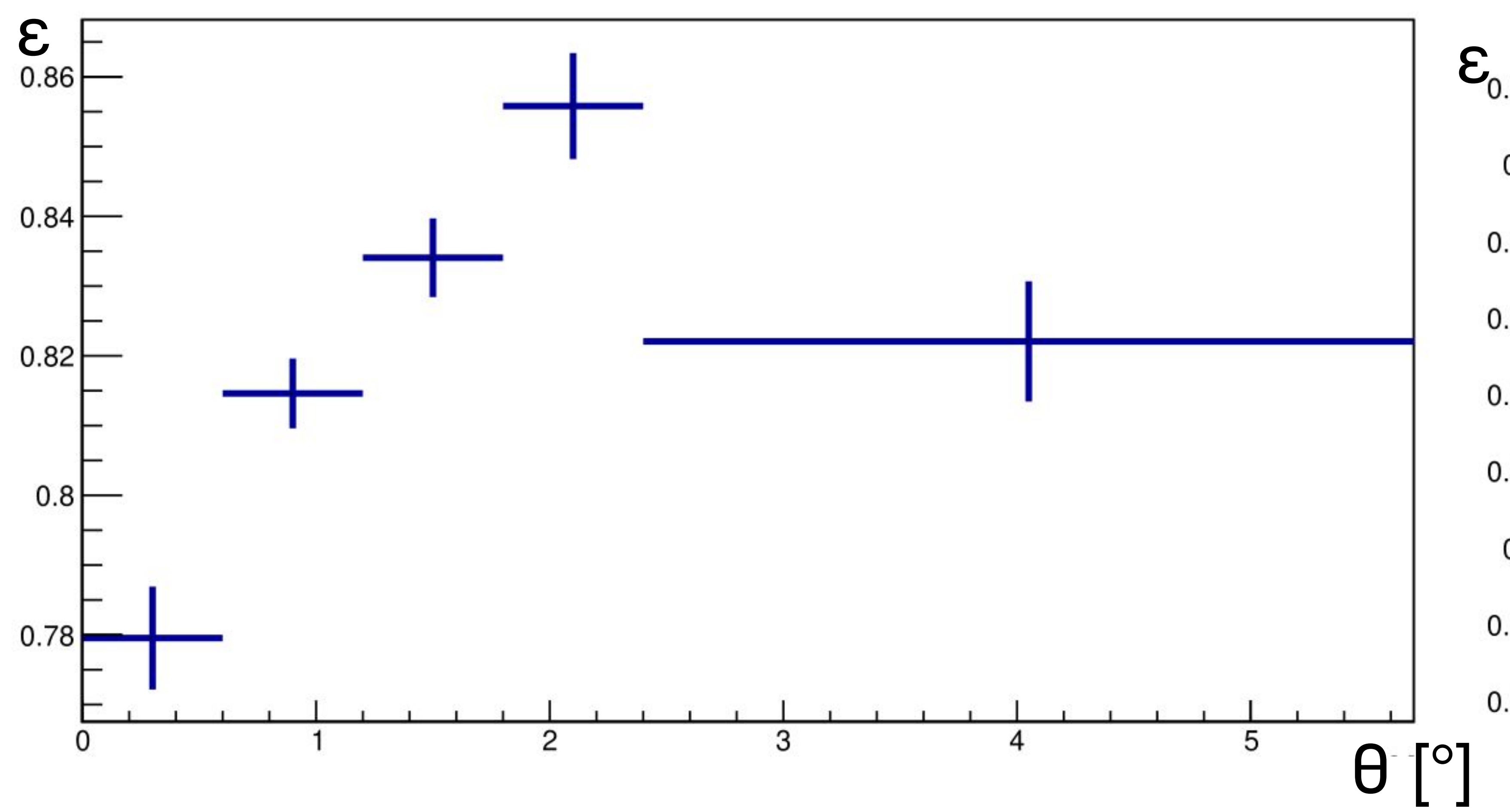
Z=3



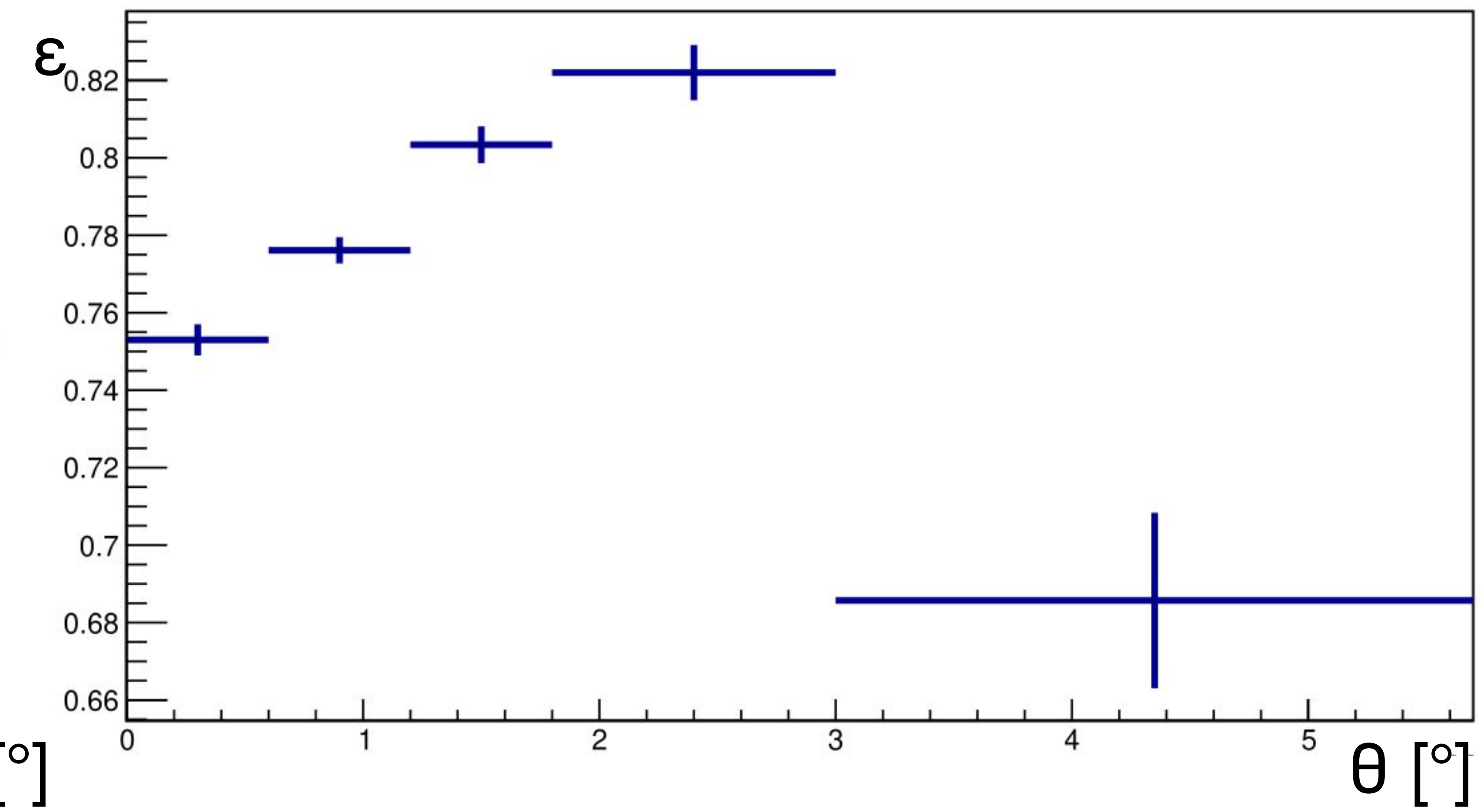
Z=4



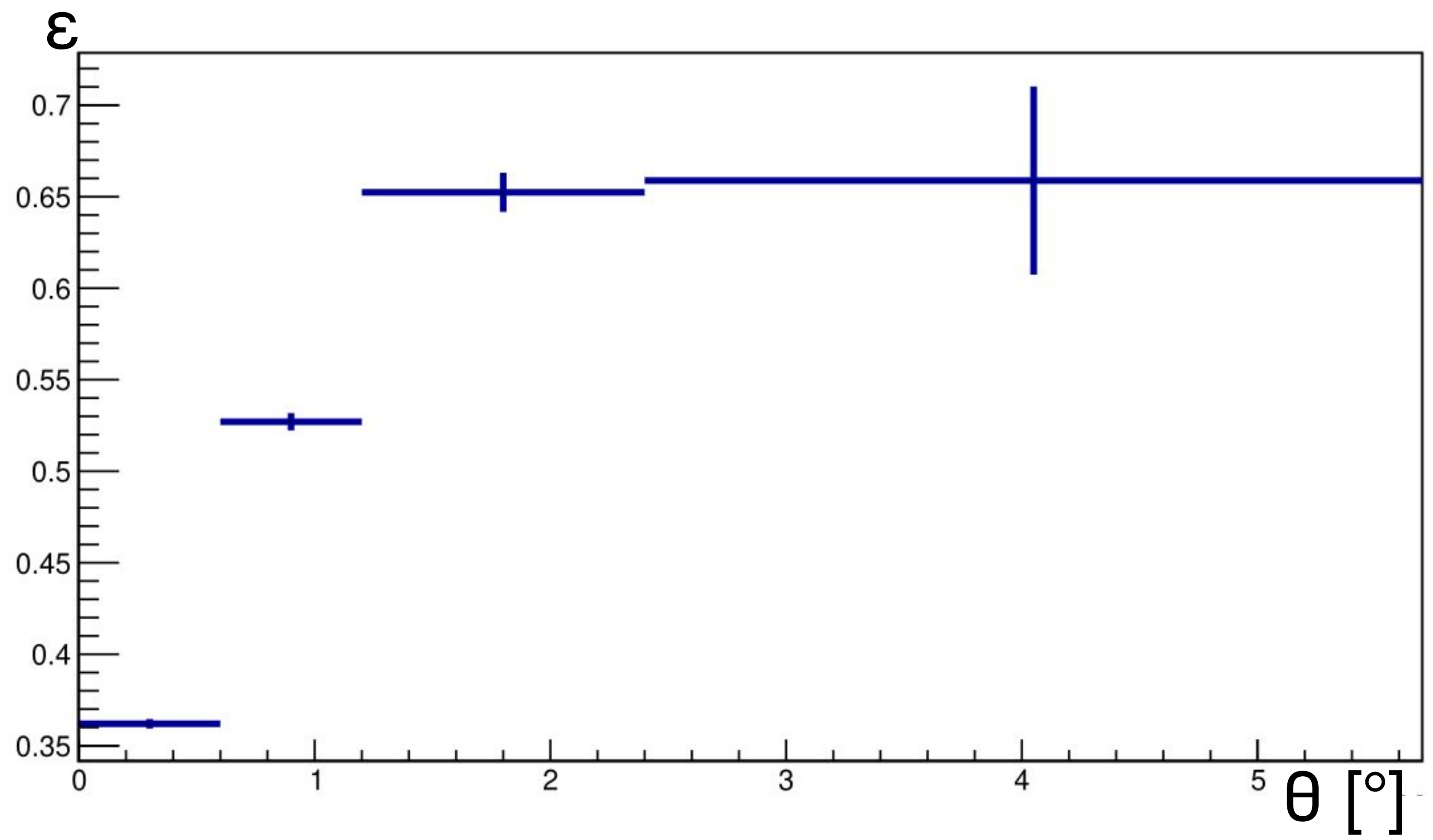
Z=5



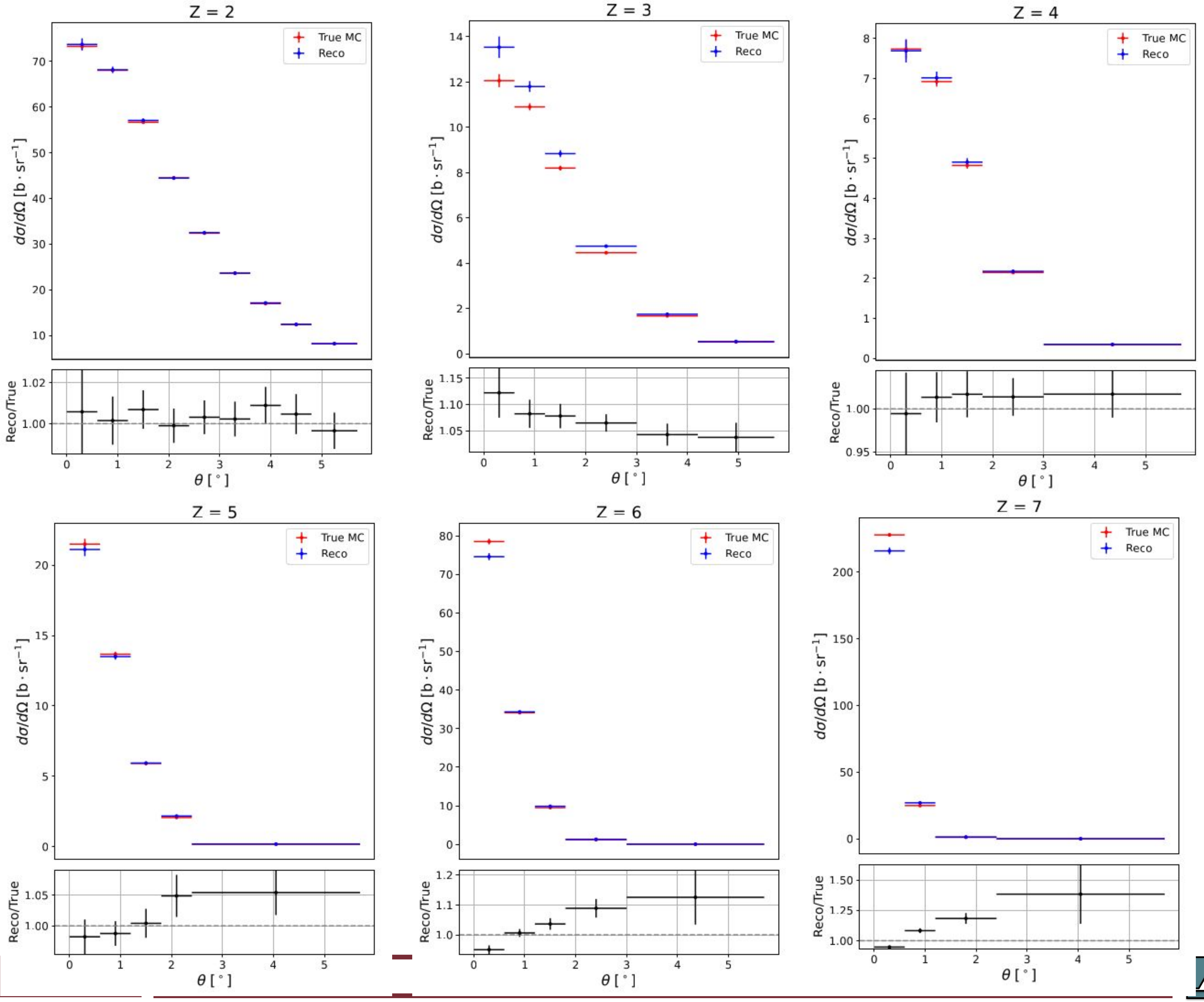
Z=6



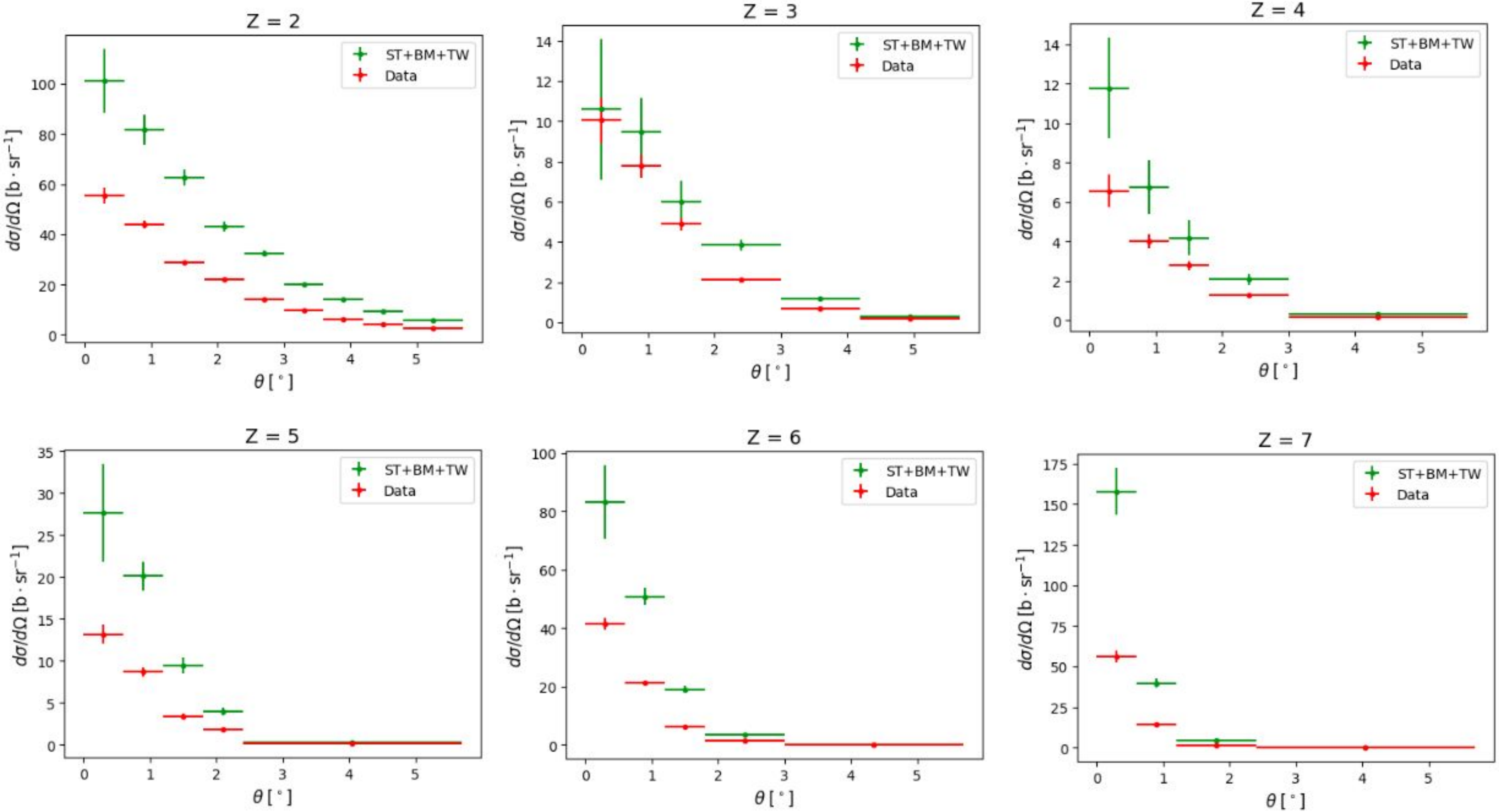
Z=7



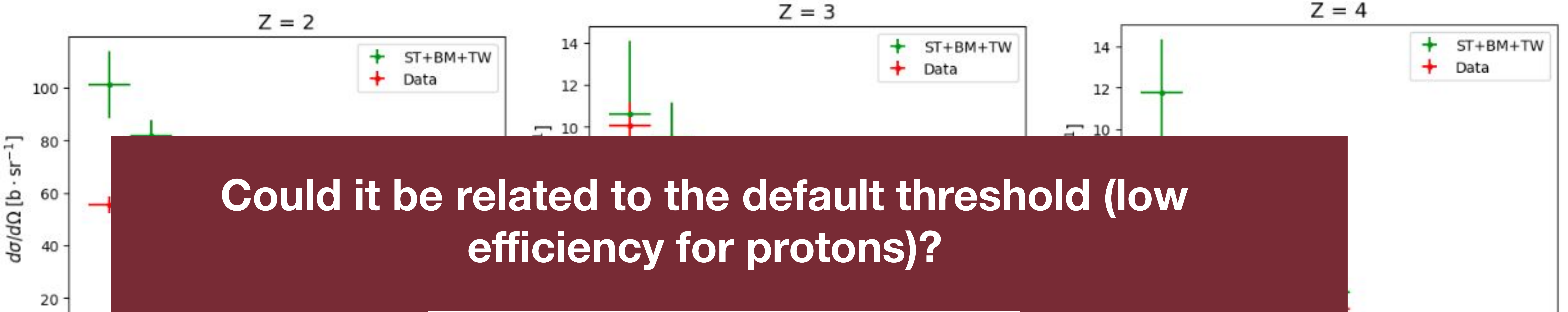
MC Closure Test



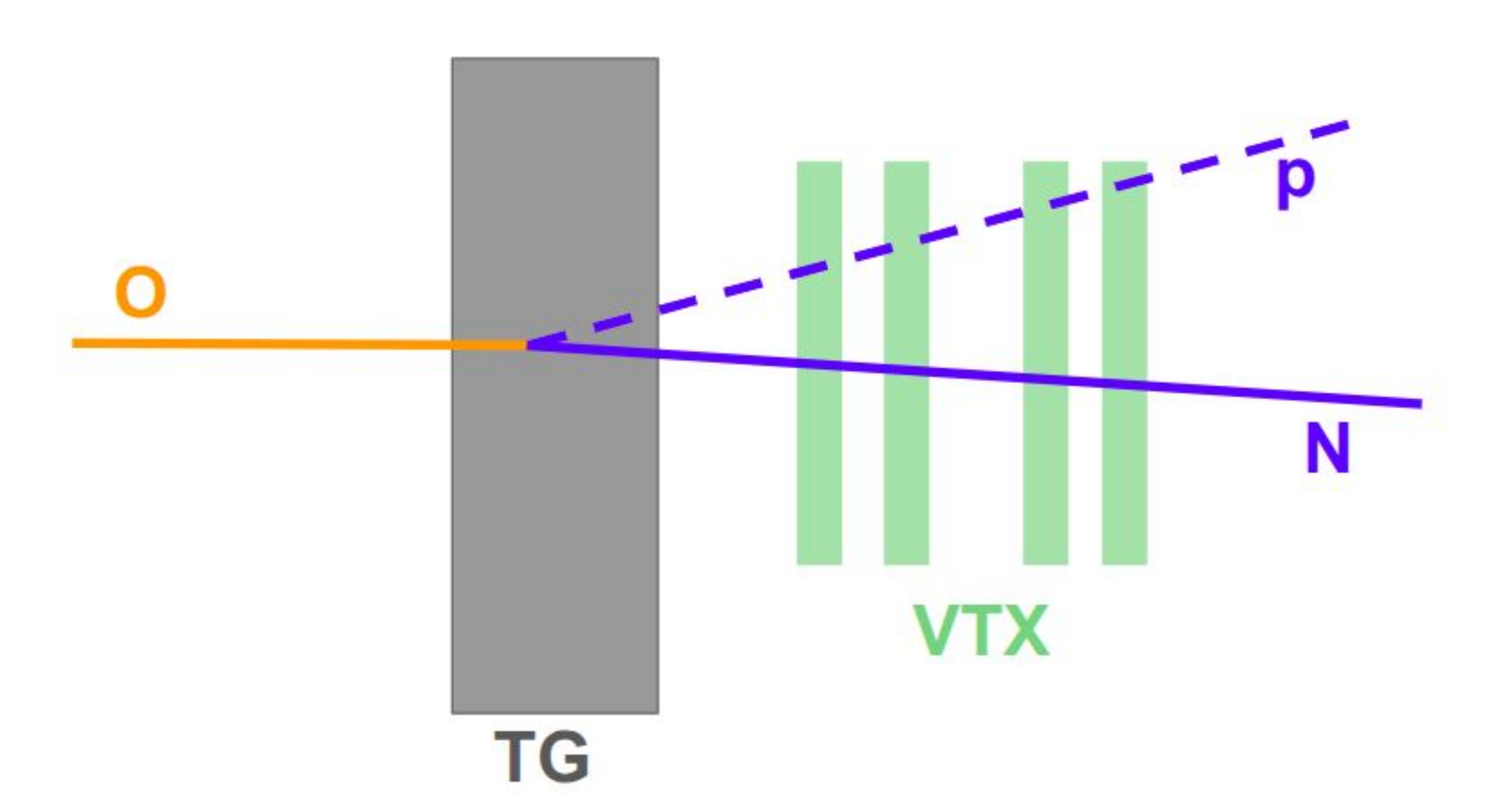
Data

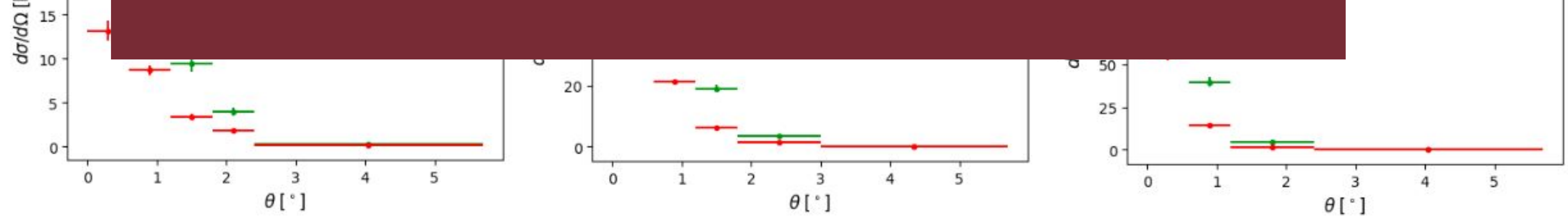


Data



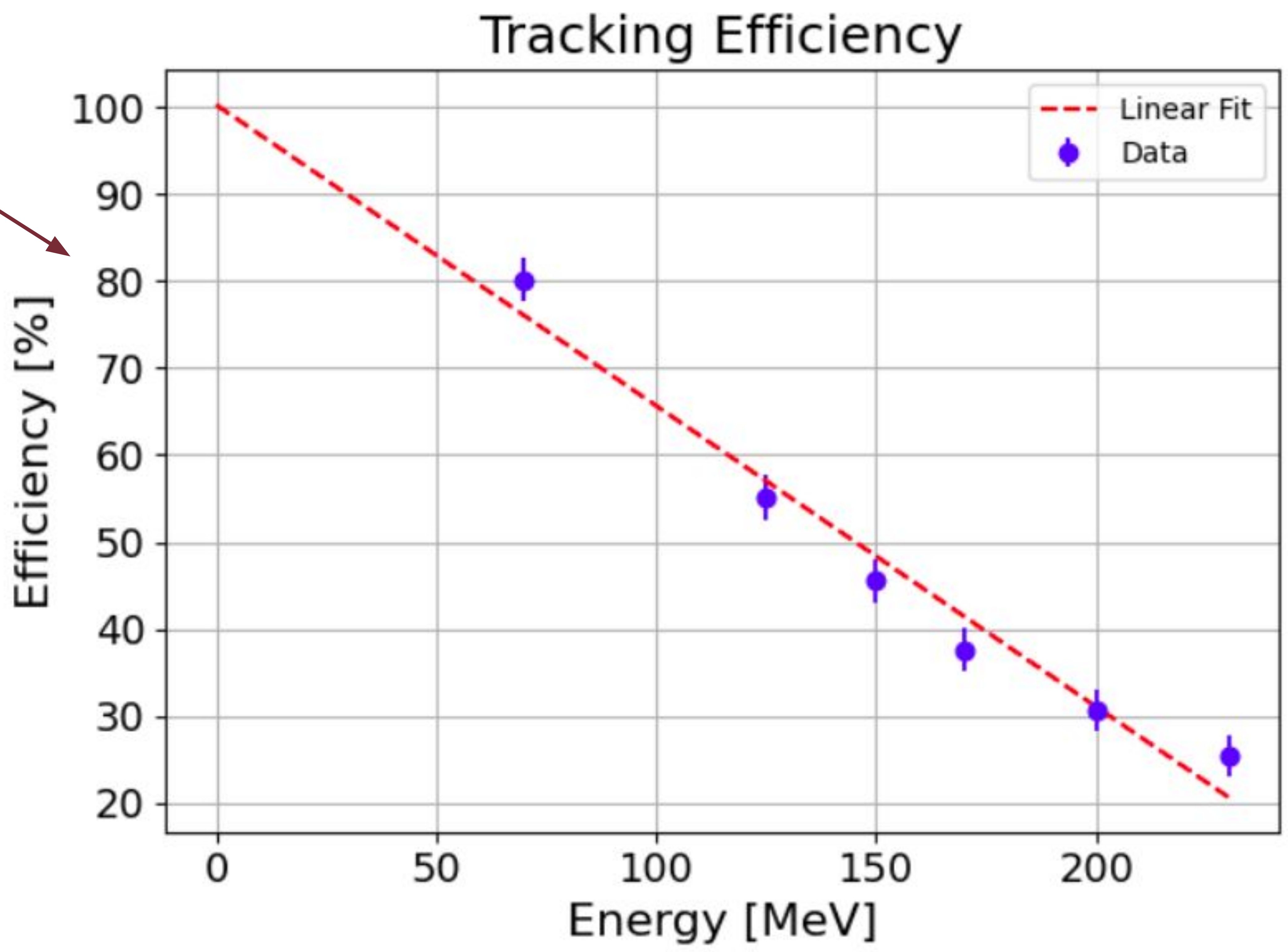
Could it be related to the default threshold (low efficiency for protons)?





Protons efficiency

- At CNAO2024, VTX efficiency for protons was measured



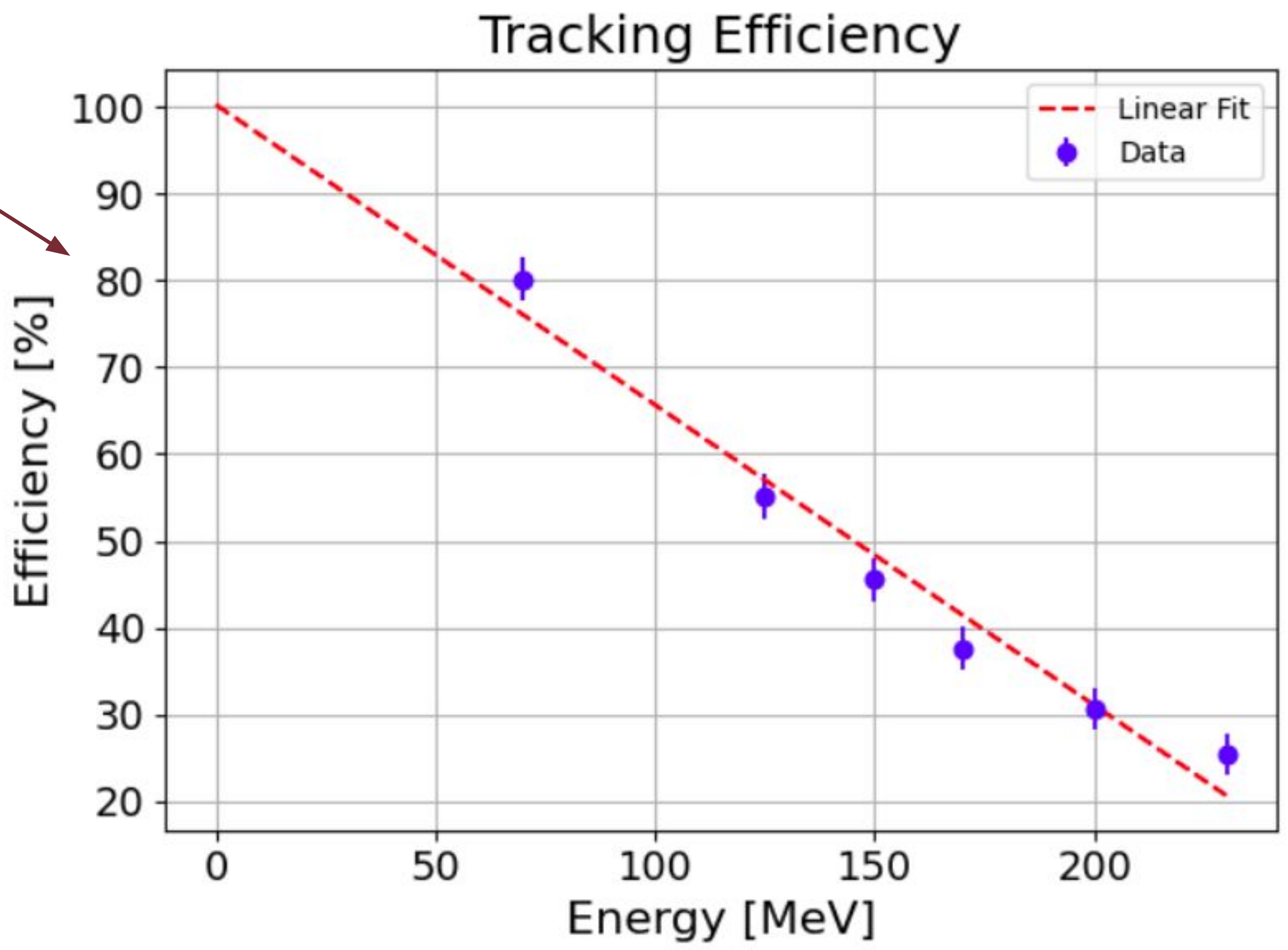
Protons efficiency

- At CNAO2024, VTX efficiency for protons was measured

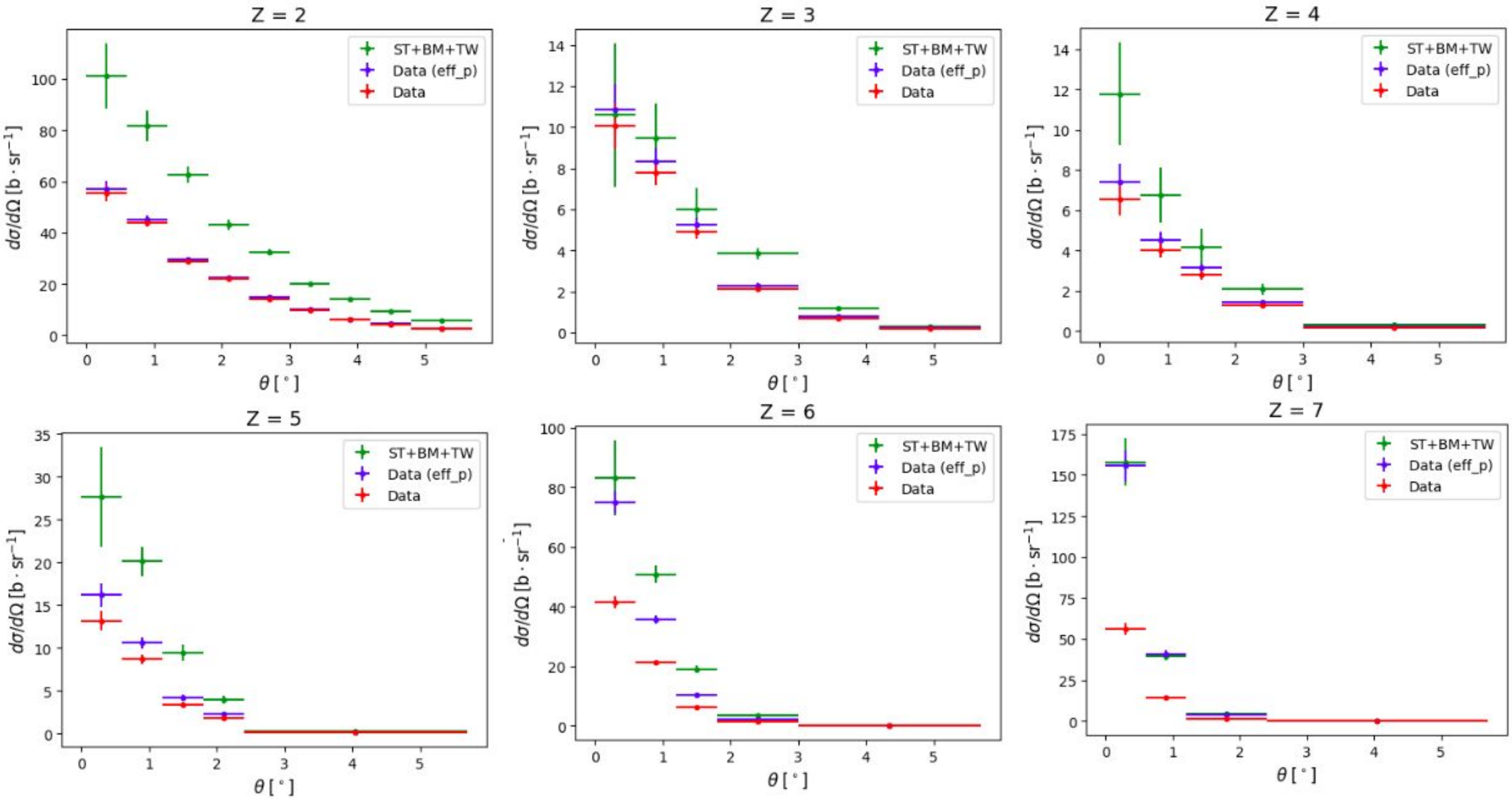
Use these measurements in the MC to recalculate ε(Z, θ)

for each proton, detection was determined probabilistically based on its kinetic energy and the measured efficiency.

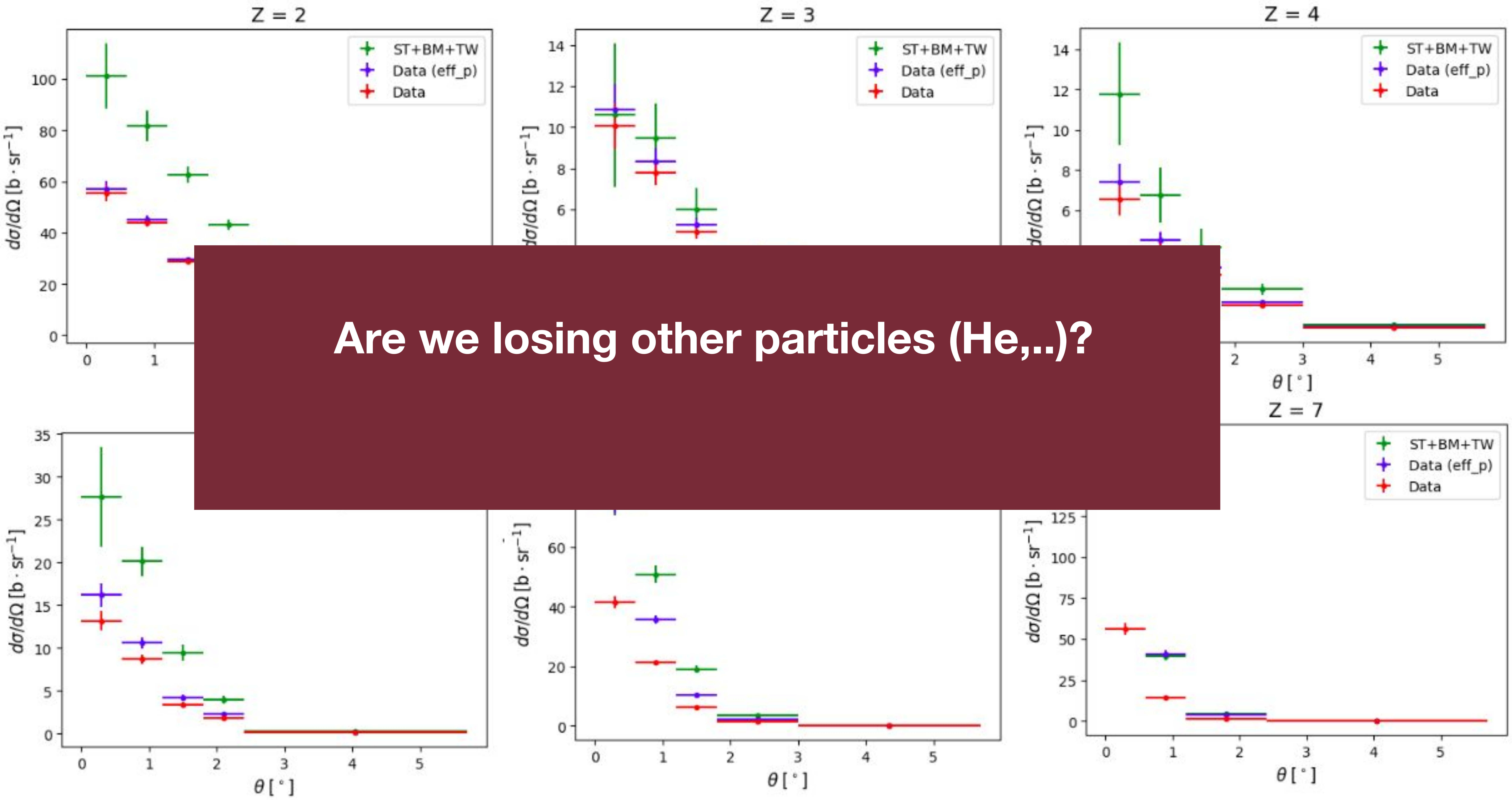
Main limitation: the measurements do not cover the full energy range of interest
Use a linear fit up to 230 MeV; constant efficiency assumed above 230 MeV (value at 230 MeV).



Data

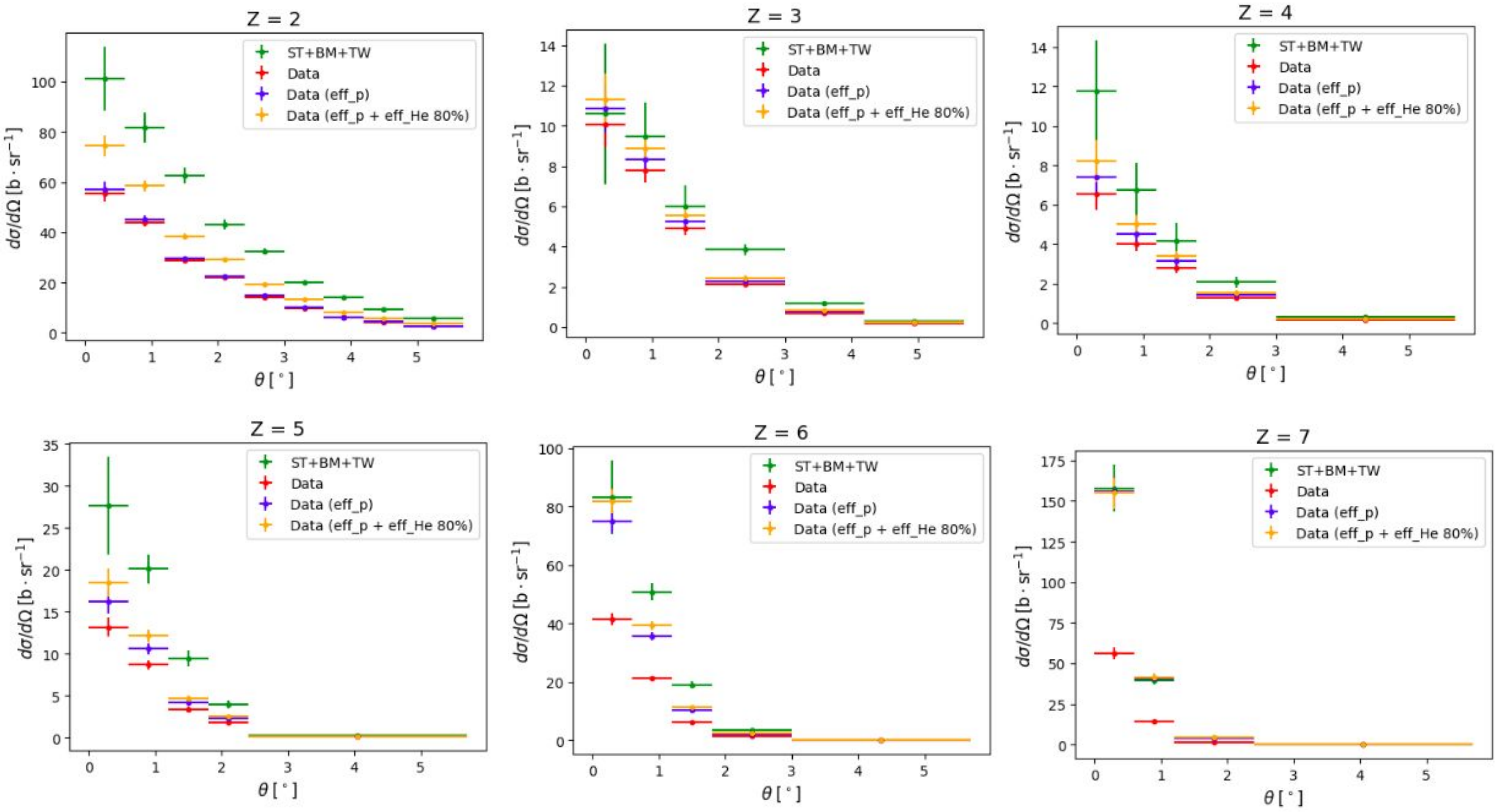


Data

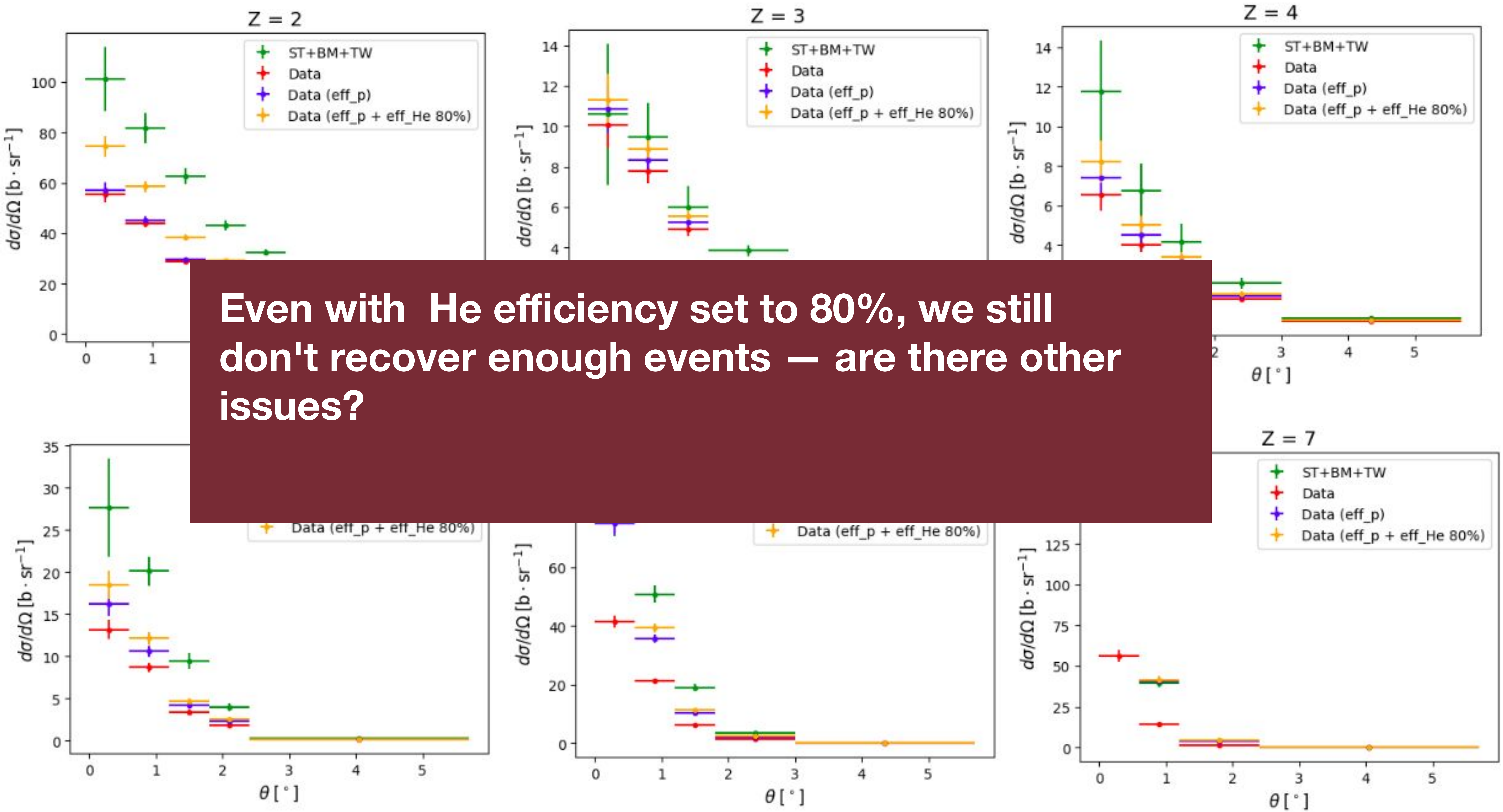


Are we losing other particles (He,..)?

Data


Z = 2
Z = 3
Z = 4
Z = 5
Z = 6
Z = 7
ST+BM+TW
Data
Data (eff_p)
Data (eff_p + eff_He 80%)
dσ/dΩ [b · sr^{-1}]
θ [°]

Data



Even with He efficiency set to 80%, we still don't recover enough events — are there other issues?

Are there other issues?

- Could the **higher pile-up level** in data (absent in the MC) make fragmentation vertex reconstruction more difficult?

- Do **residual misalignments** in the data (absent in the MC) further degrade reconstruction performance?

➡ **Are we losing more fragmentation vertexes in data than in MC?**

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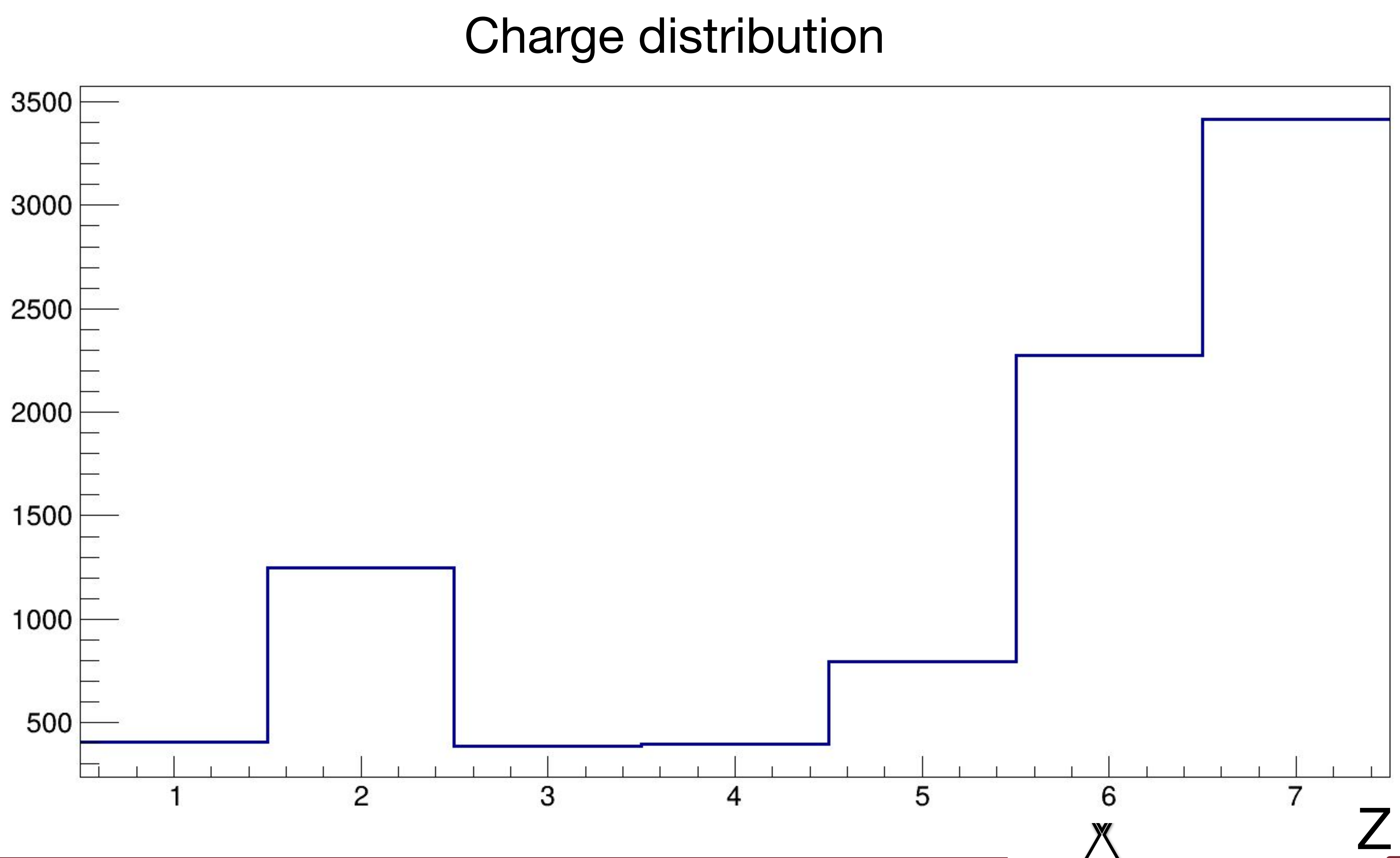
- Do **residual misalignments** in the data (absent in the MC) further degrade reconstruction performance?

➡ **Are we losing more fragmentation vertexes in data than in MC?**

<u>**Idea**</u>: Analyze **not valid VTX** to identify missed fragmentation vertexes and possibly recover lost fragments.

Focused on events where:
- No primary fragments (Z = 8) are detected in TW
- No valid fragmentation vertex is reconstructed

For these events, we project **single-track of not valid vertexes** onto the TW plane, and check if there is a match with 1 TW point.



Next steps

Use of not valid vertexes:

- Study whether fragments of interest (currently lost due to pile-up and misalignment) can be recovered by analyzing events with not valid vertex.
- Estimate the associated reconstruction efficiency.
- Assess if, with this addition, the cross section becomes compatible with the ST+BM+TW analyses.

Move to other data (like CNAO2022):

- Lower pile-up conditions may improve vertex reconstruction and reduce ambiguities

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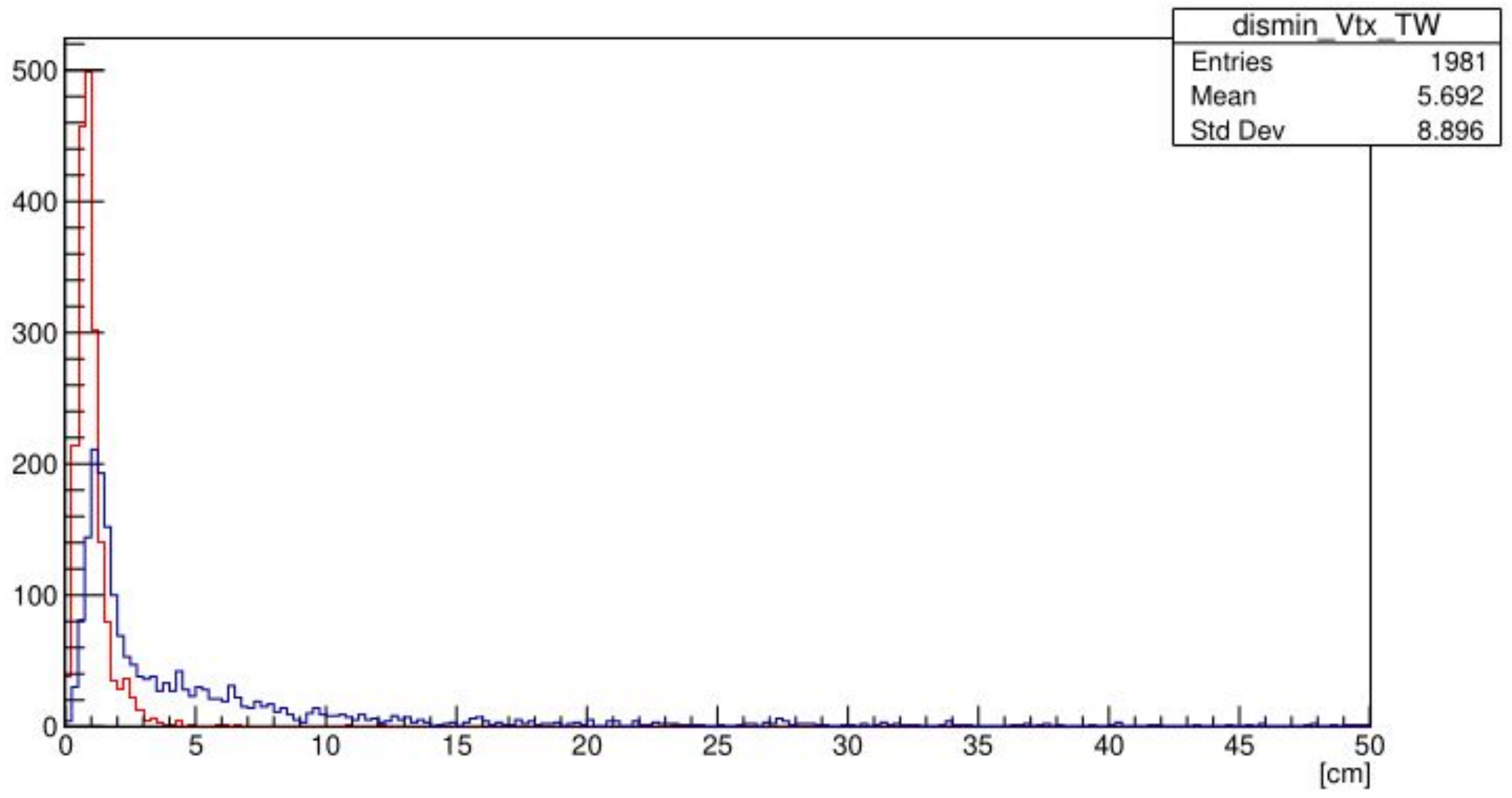
Selection Cuts applied in the analysis

1. **No BM match**

   High pile-up and detector resolution limits can cause mismatches.

   - Events observed where a fragmentation vertex is matched to the BM track, but the TW shows only a Z=8 point, implying a primary particle reached TW → the primary should be matched with the BM track.



For these events two distances were studied:

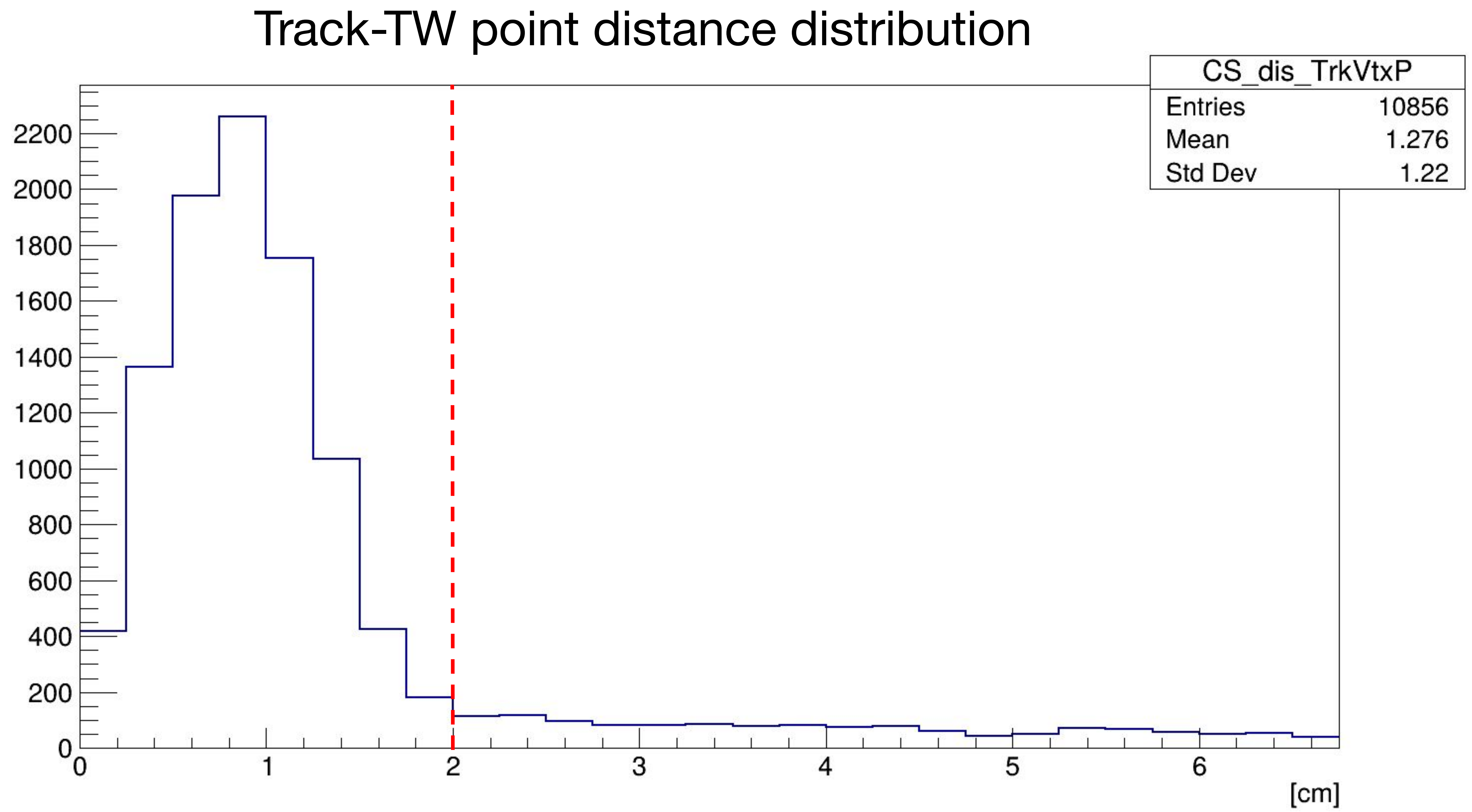
- **Red**: Between TW point and the closest projection from **unmatched (not valid) vertexes**
- **Blue**: Between TW point and the closest projection from **BM-matched fragmentation vertex**

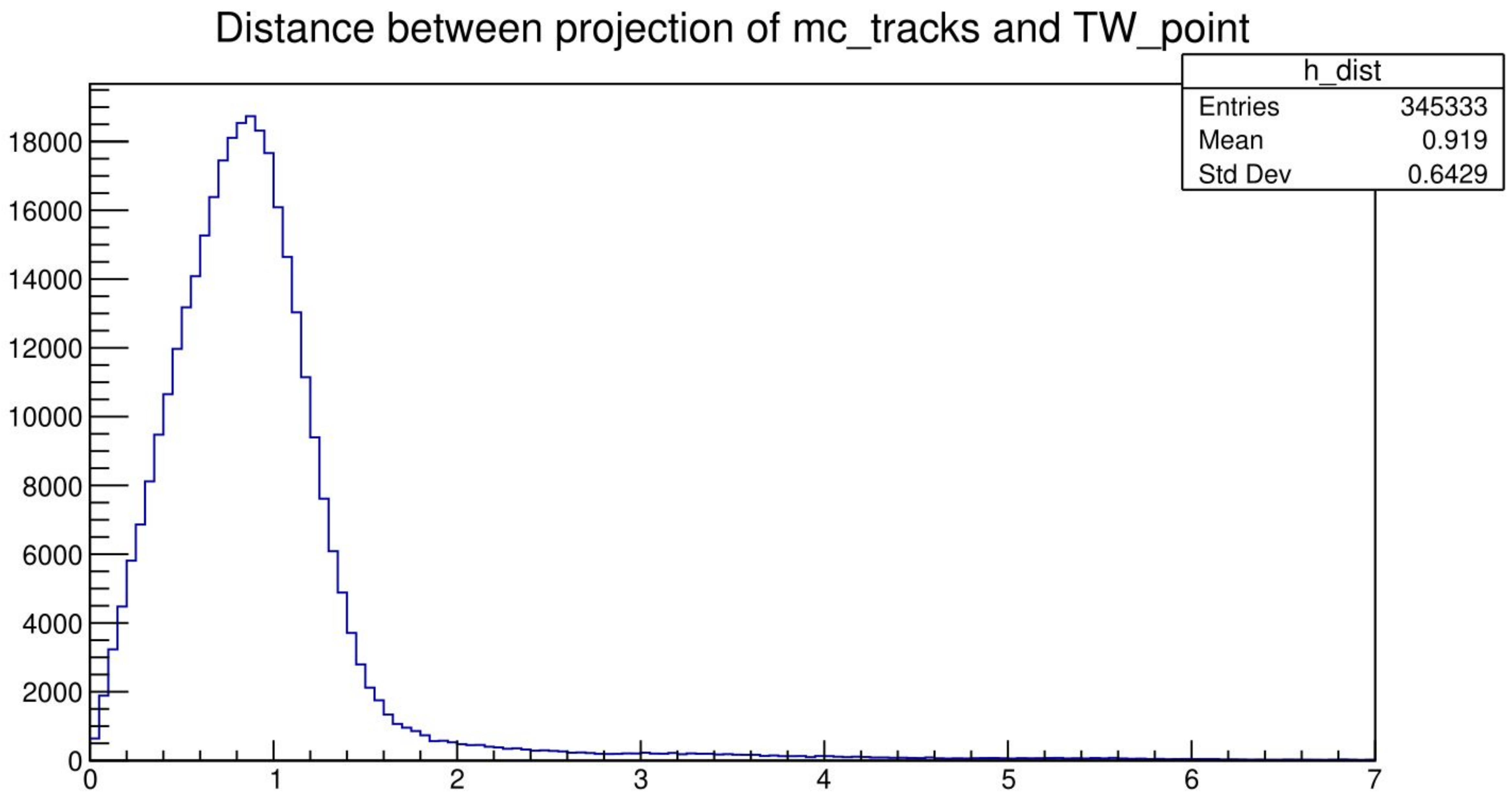
Selection Cuts applied in the analysis

❖ Track–TW Point Distance < 2 cm

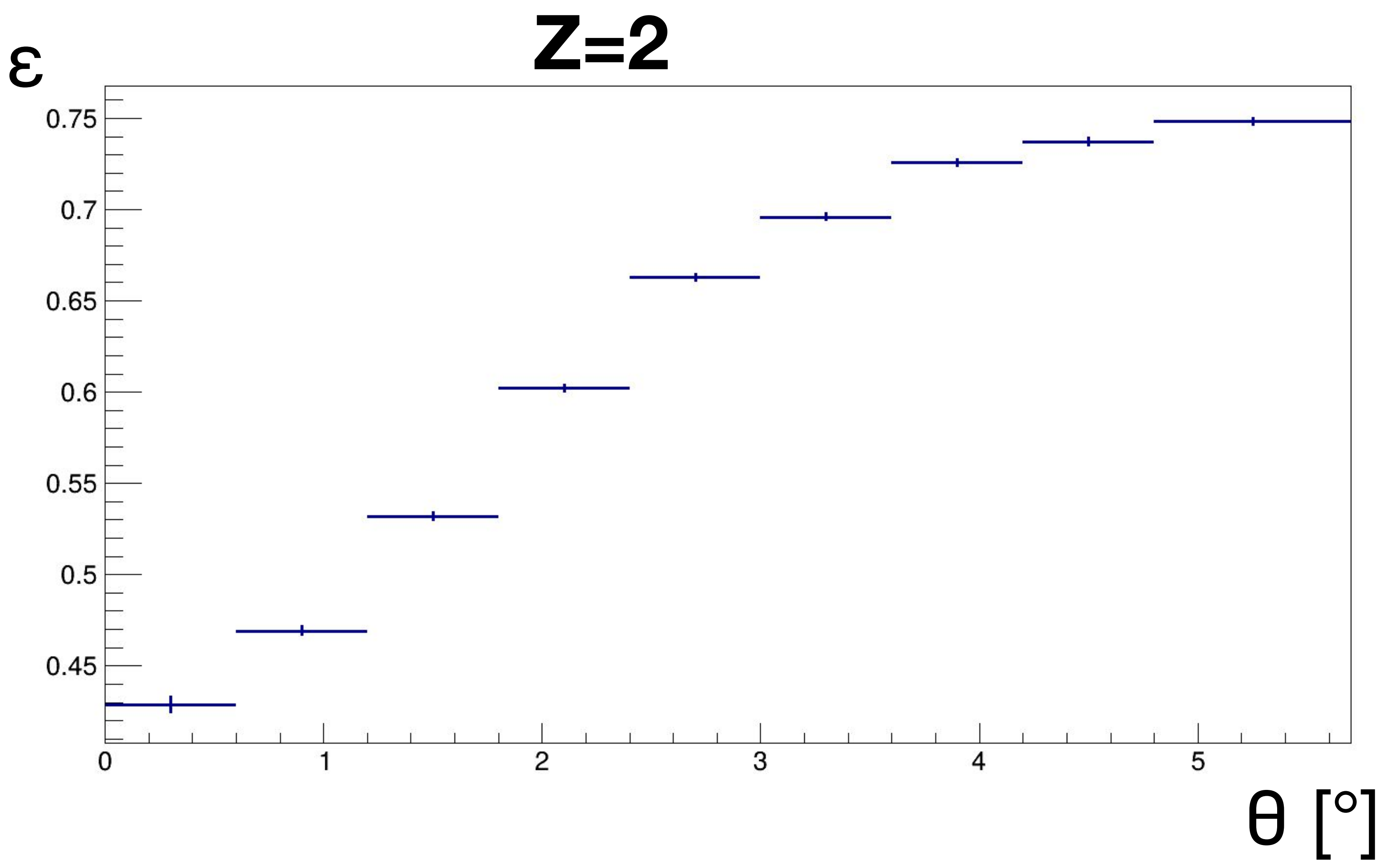
The reconstructed VTX tracks are projected onto the TW detector plane. For each projected track, the closest TW point is searched.

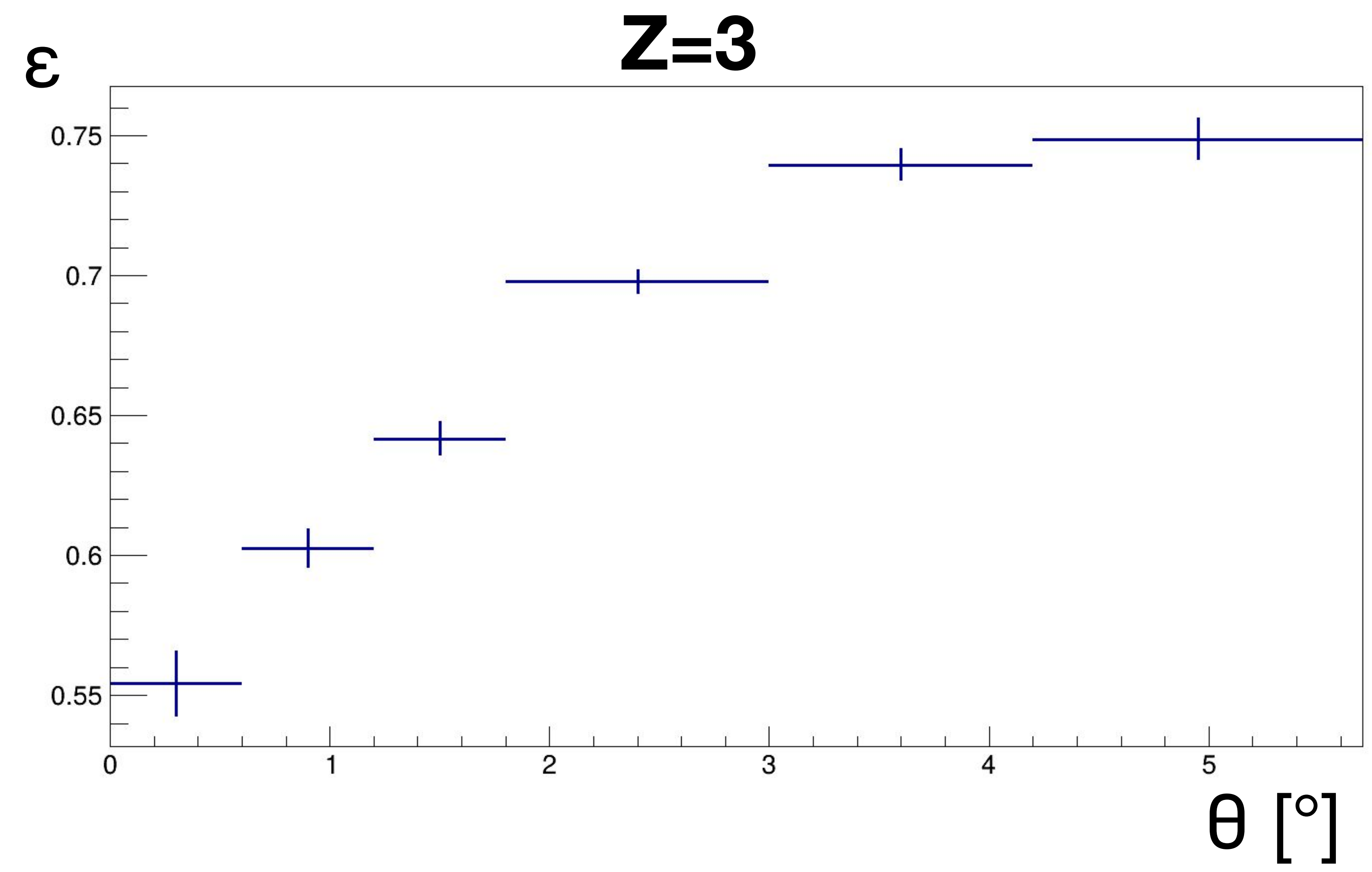
→ If the **distance is less than 2 cm**, the TW point is **associated** to that track.

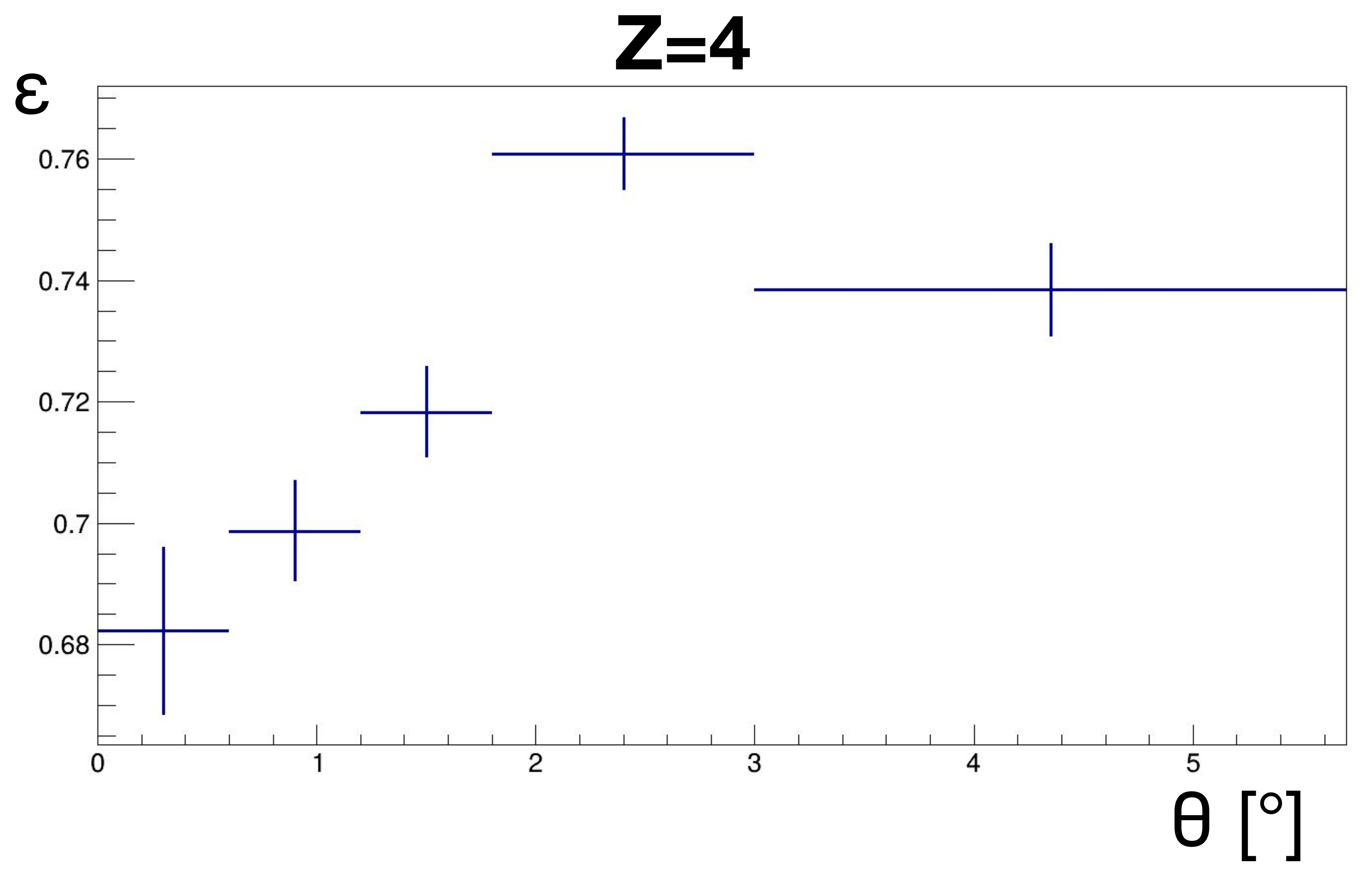


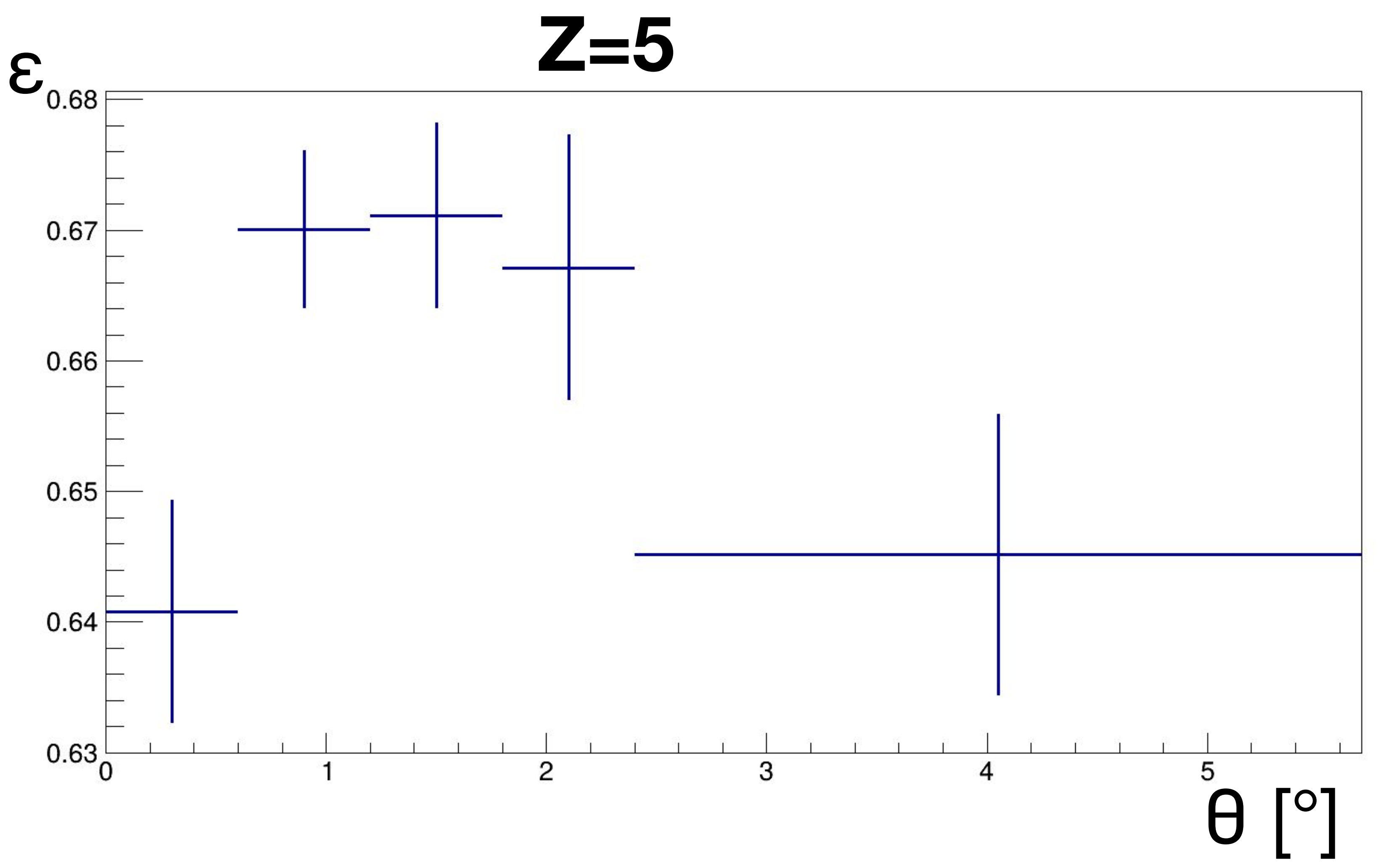


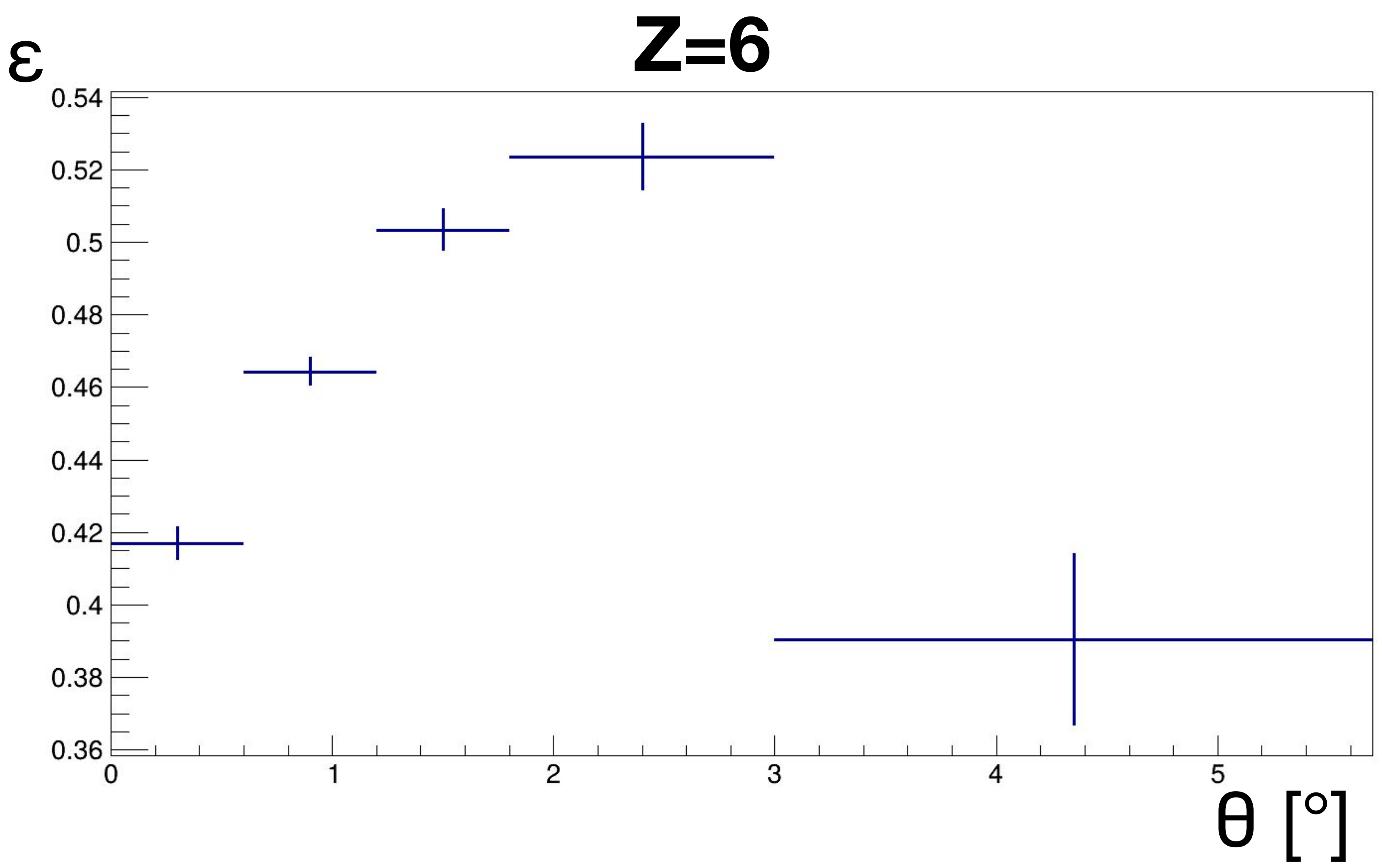
Efficiencies (considering p_eff)

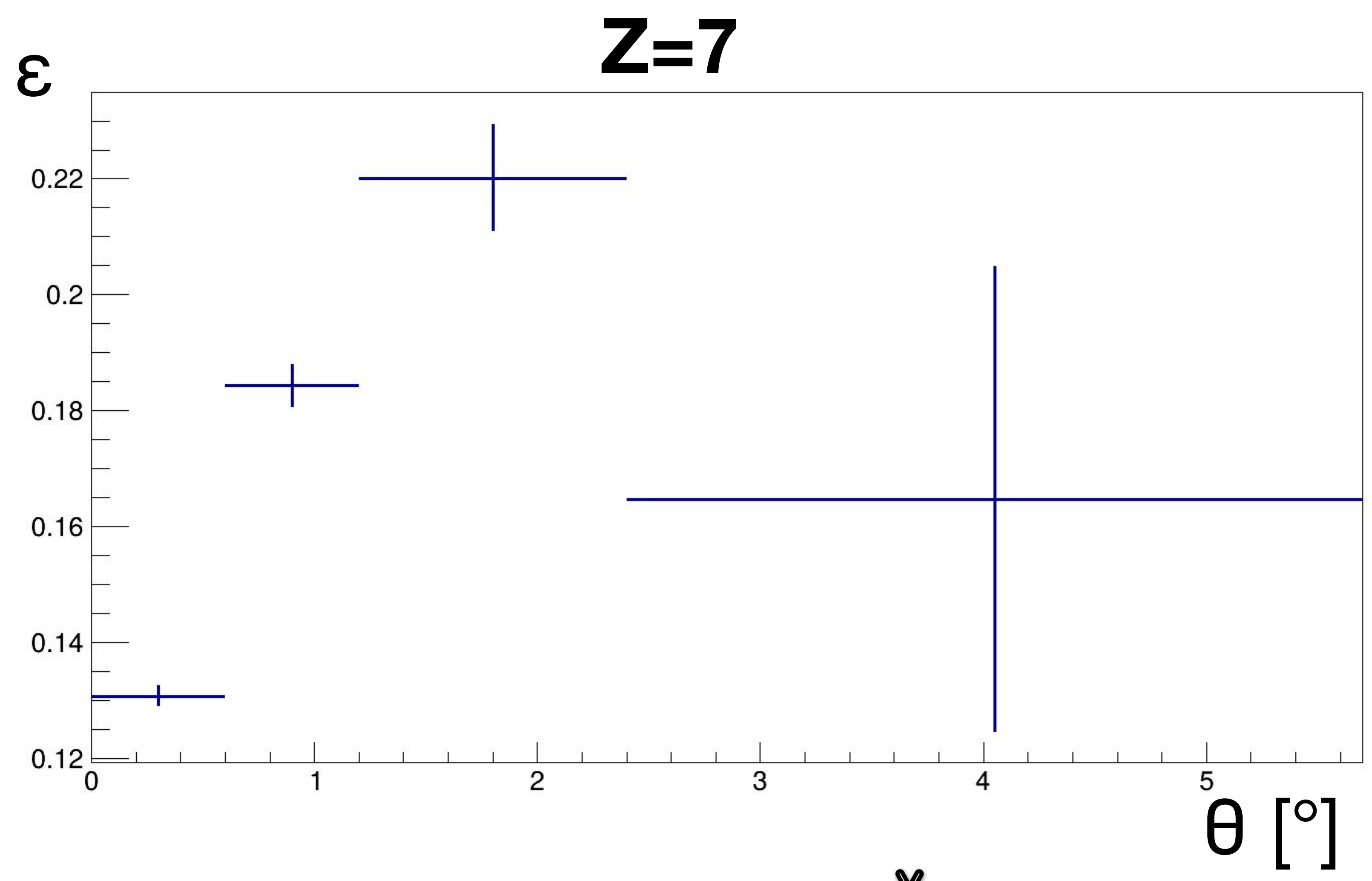




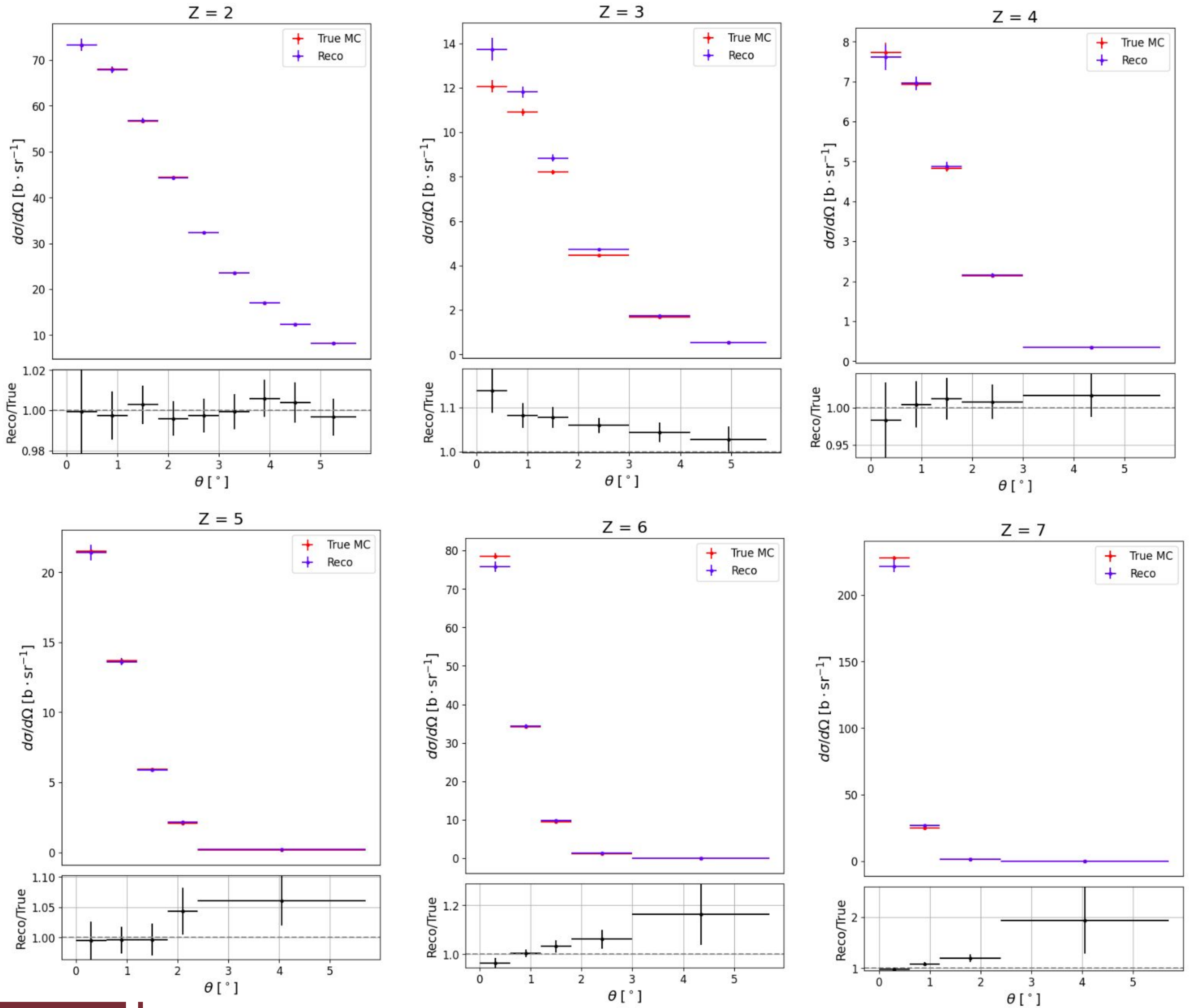






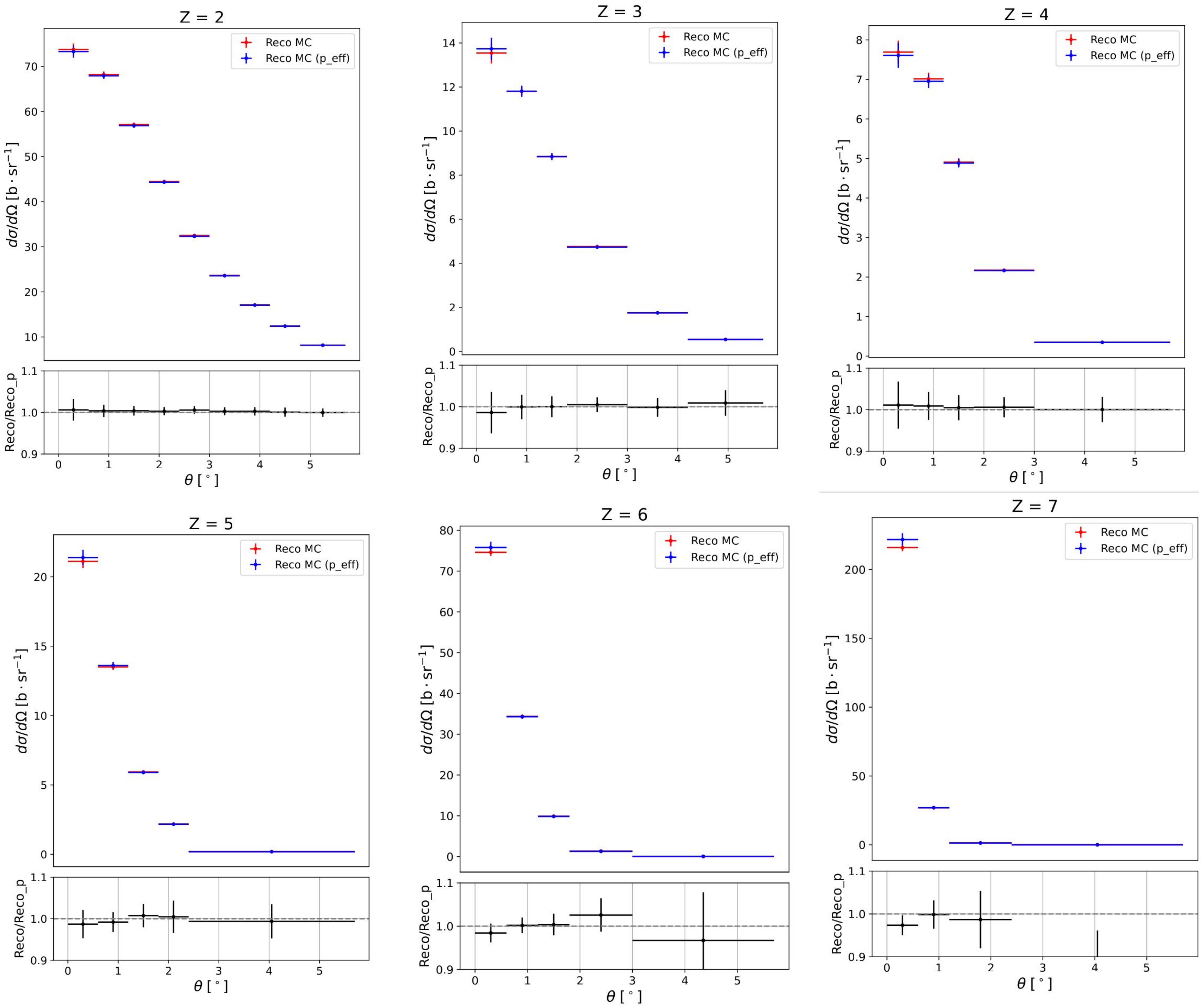


MC Closure Test
p_eff



MC Closure Test

reco vs reco+p_eff



Are we losing other particles (He,..)?

Using NIST tables of energy loss in silicon (ΔE):

- ΔE(He, Ek = 950 MeV) ~ ΔE(p, Ek = 35 MeV)
- ΔE(He, Ek = 700 MeV) ~ ΔE(p, Ek = 27.5 MeV)

<u>Problem</u>: we have no efficiency measurements for protons at such low energies.We would need to extrapolate from the linear fit.

→ before applying the efficiency from the extrapolation, we test a **constant 80% efficiency** for He in MC.
This is not a realistic efficiency, real measurements are needed, but it helps assess potential improvements