CNAO2024 Global Tracking Analysis Updates

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MAECI-MOFFIITS / XVIII FOOT General Meeting

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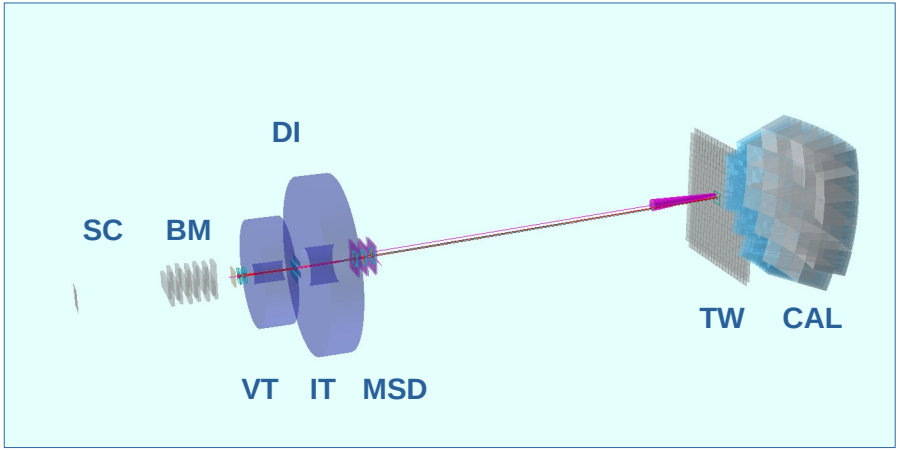
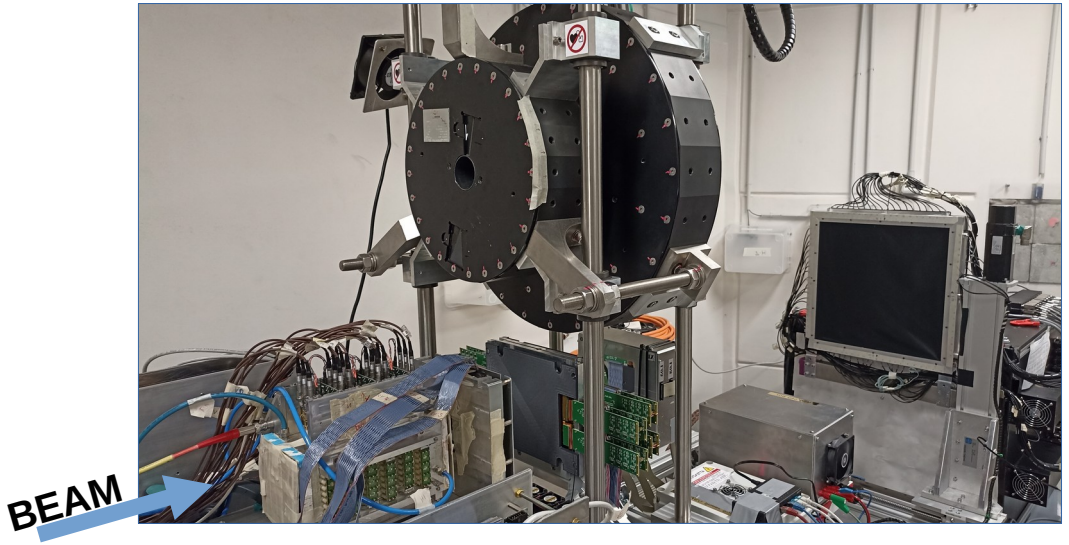
MC: Cross Section Closure Test

CNAO2024 closure test

Comparison of FLUKA simulated data results (**CNAO24PS_MC**) with *reference* values to estimate systematic uncertainties (***closure test***) of the analysis procedure

- 10M events simulation of Data-taking at CNAO 2024
- **^{12}C 200 MeV/u** on 5 mm **C target**
- Total setup





- **VT, MSD, IT, TW** considered
- Track reconstruction using GENFIT **global tracking**
- Comparison for **angular distribution**

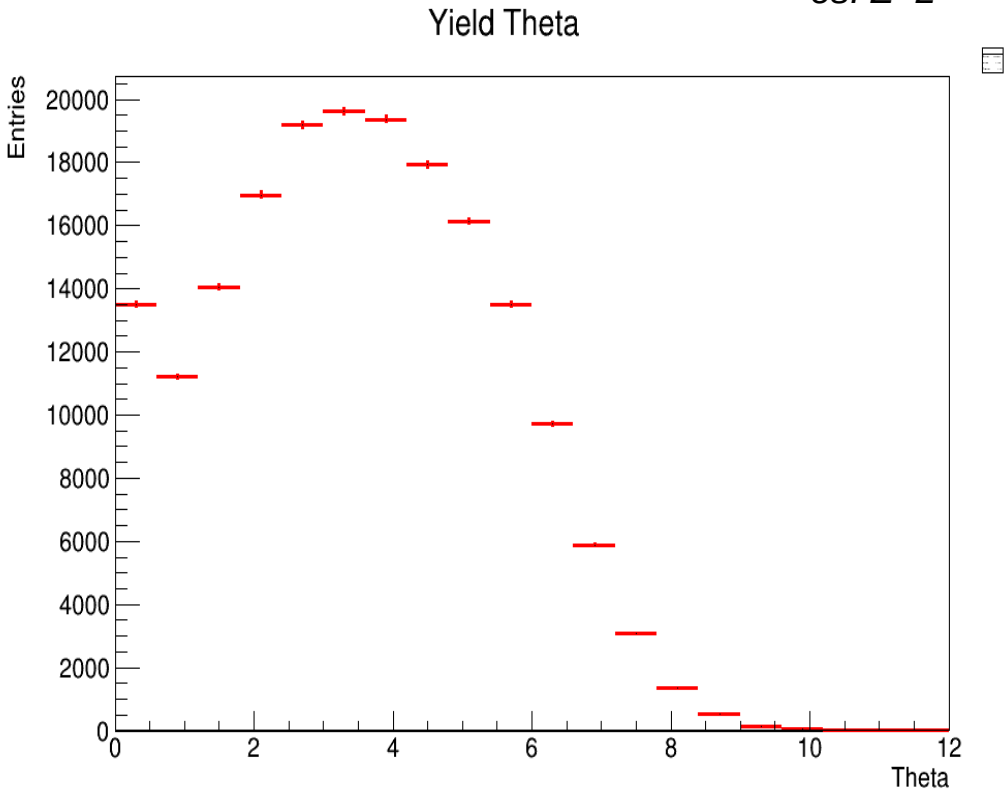
Yield cuts

The following cuts are used in the analysis:

Reconstruction

- global track using Kalman Filter-based algorithm **GENFIT**
- it has a **VTX tracklet**
  BM – VT tracklet match
  BM has only 1 track for the event
- it is made of at least **9 clusters** (~70% of totals)
- it considers **MSD** and **IT** clusters
- it has a **TW point**

es. Z=2



Yield cuts

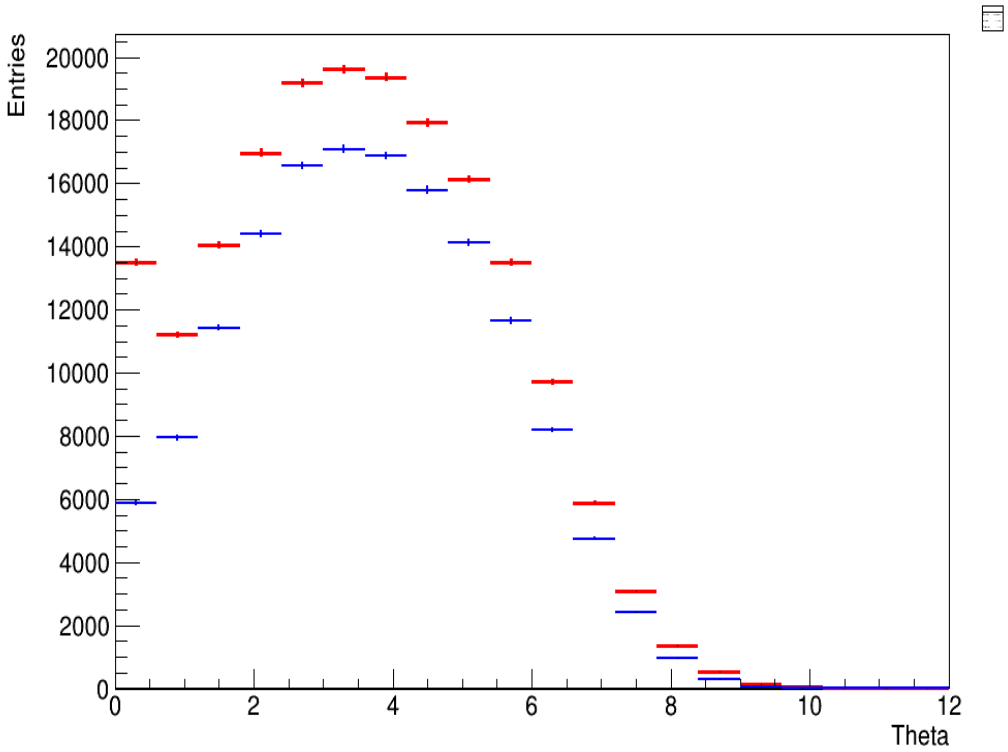
The following cuts are used in the analysis:

Reconstruction

Quality cut

- p value > 0.01
- worst cluster residual < 0.01 cm

es. Z=2

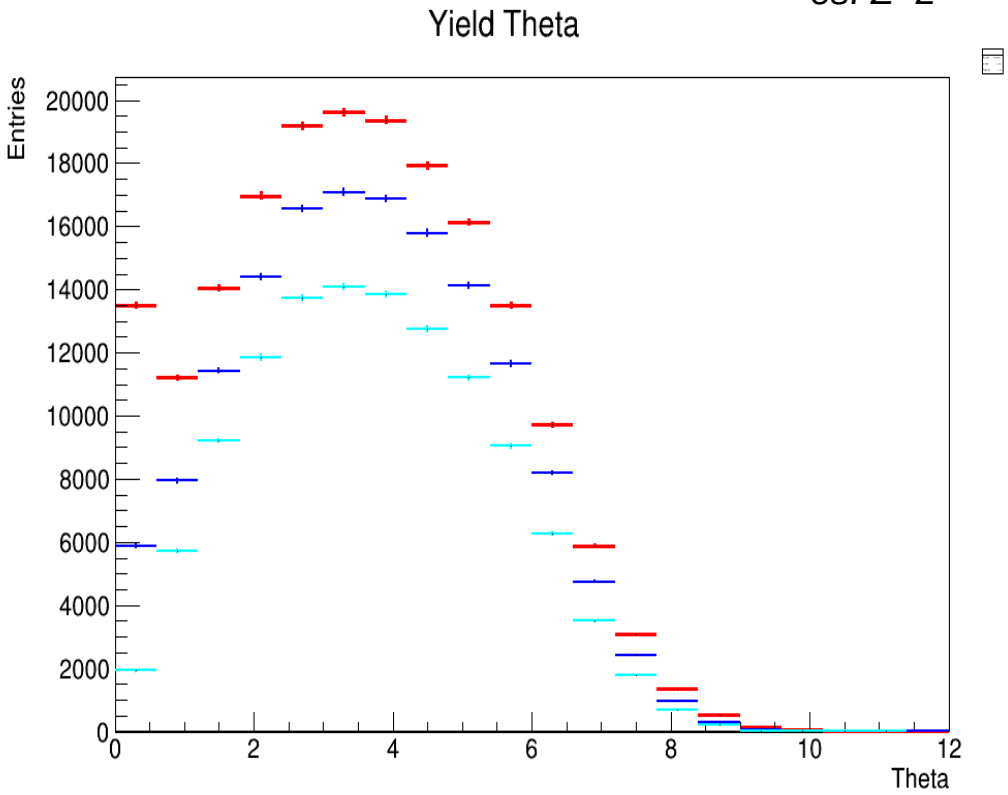


Yield cuts

The following cuts are used in the analysis:

Reconstruction
Quality cut
Multi-tracks cut
- the event has more than 1 track

es. Z=2



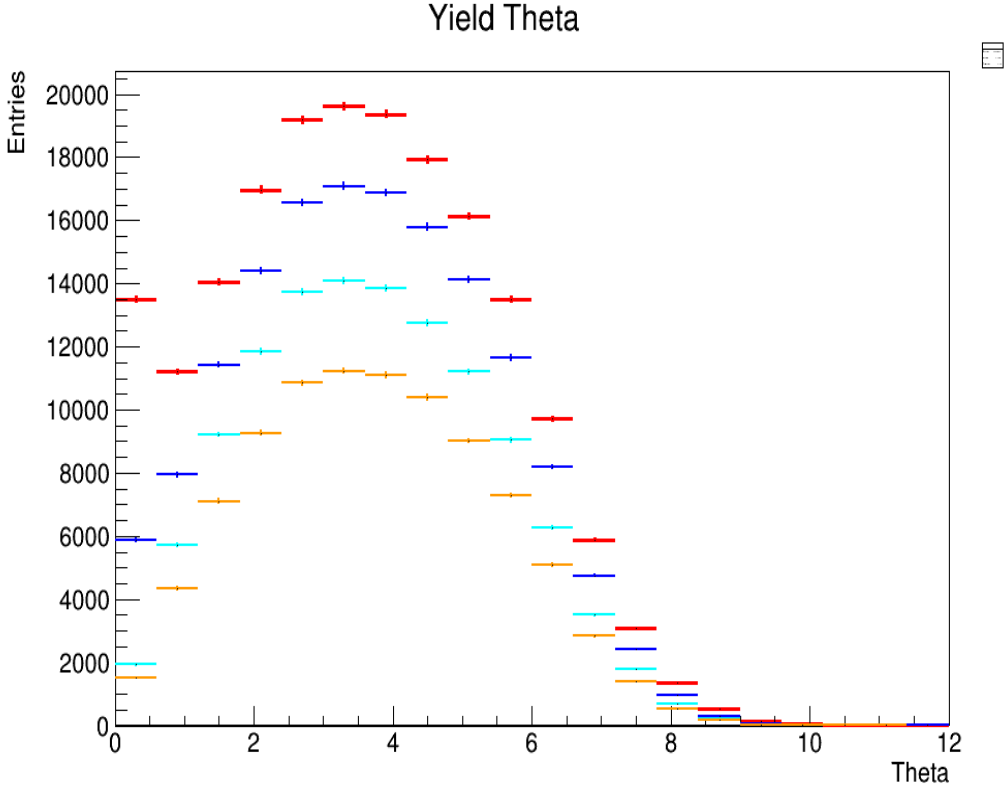
Yield cuts

The following cuts are used in the analysis:

Reconstruction
Quality cut
Multi-tracks cut
TW point cut

- consider only tracks with different TW points
- the number of tracks is the same of TW points

es. Z=2



the rationale shown at XV GM
https://agenda.infn.it/event/37748/contributions/217797/

Cross Section closure test

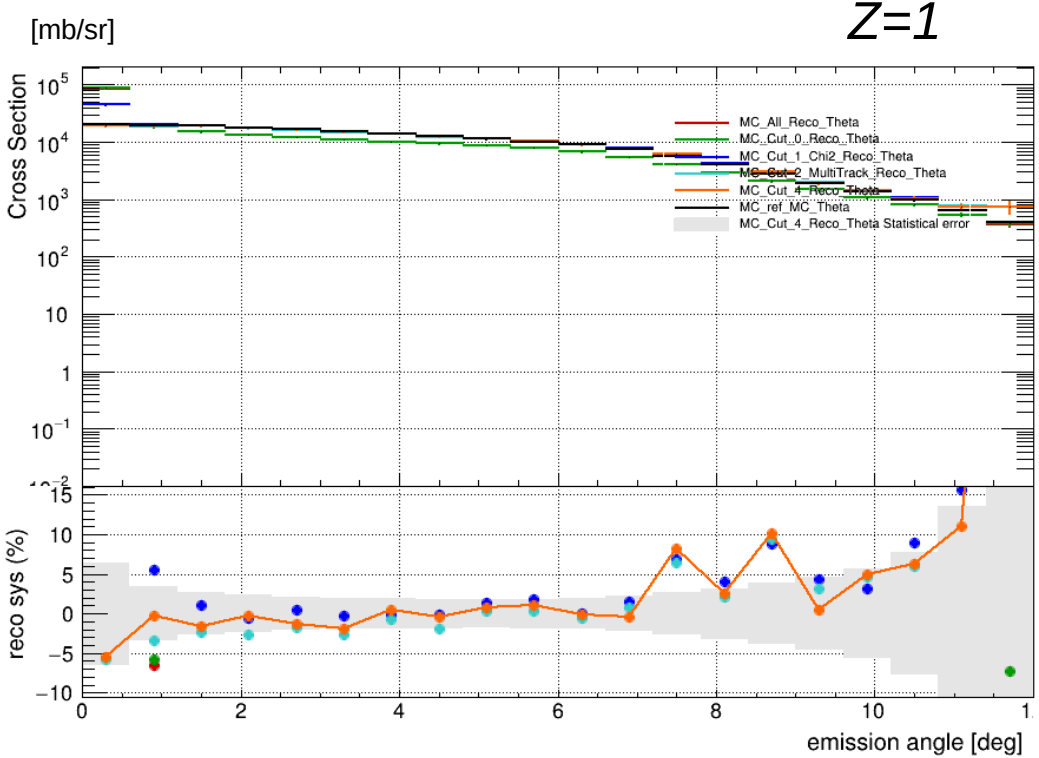
$$\frac{d\sigma}{d\theta}(Z,\theta) = \frac{Y(Z,\theta)}{N_{beam}\ N_{target}\ \Omega_\theta\ \epsilon(Z,\theta)}$$

- Comparison of the Reco cross sections with the MC reference one

$$\text{ratio plot} = \frac{\sigma_{reco} - \sigma_{MC}}{\sigma_{MC}}$$

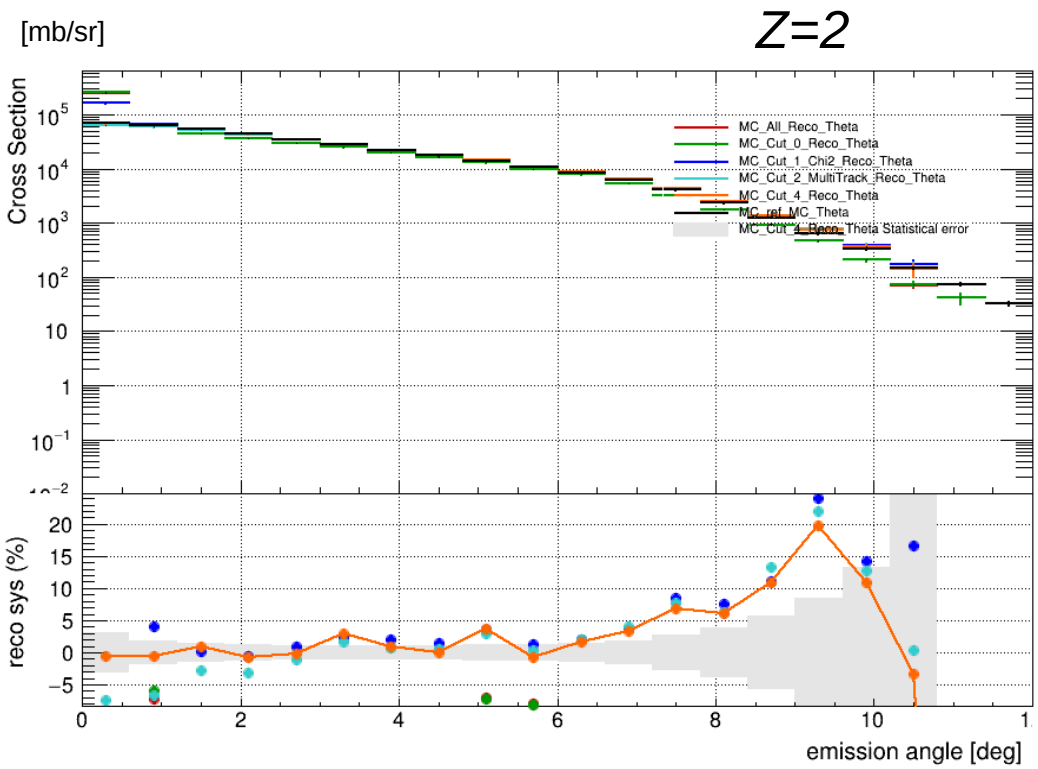
- In gray the statistical error of the last cut

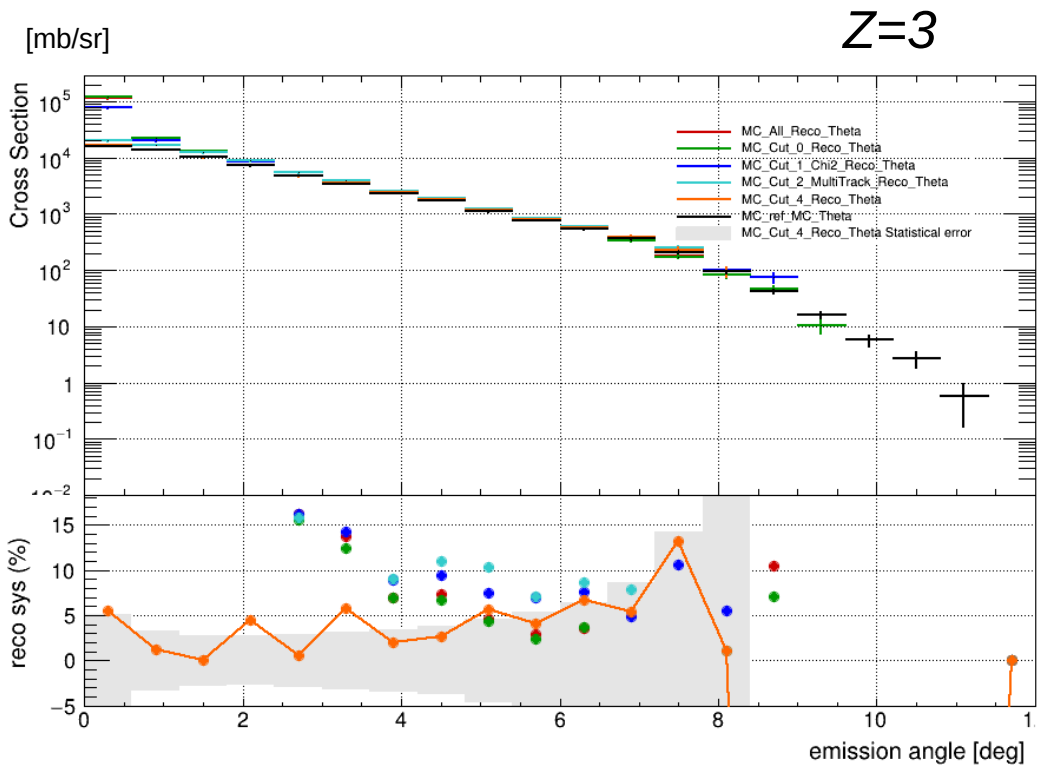
Z=1



Reconstruction
Quality cut
Multi-tracks cut
TW point cut

Cross Section closure test



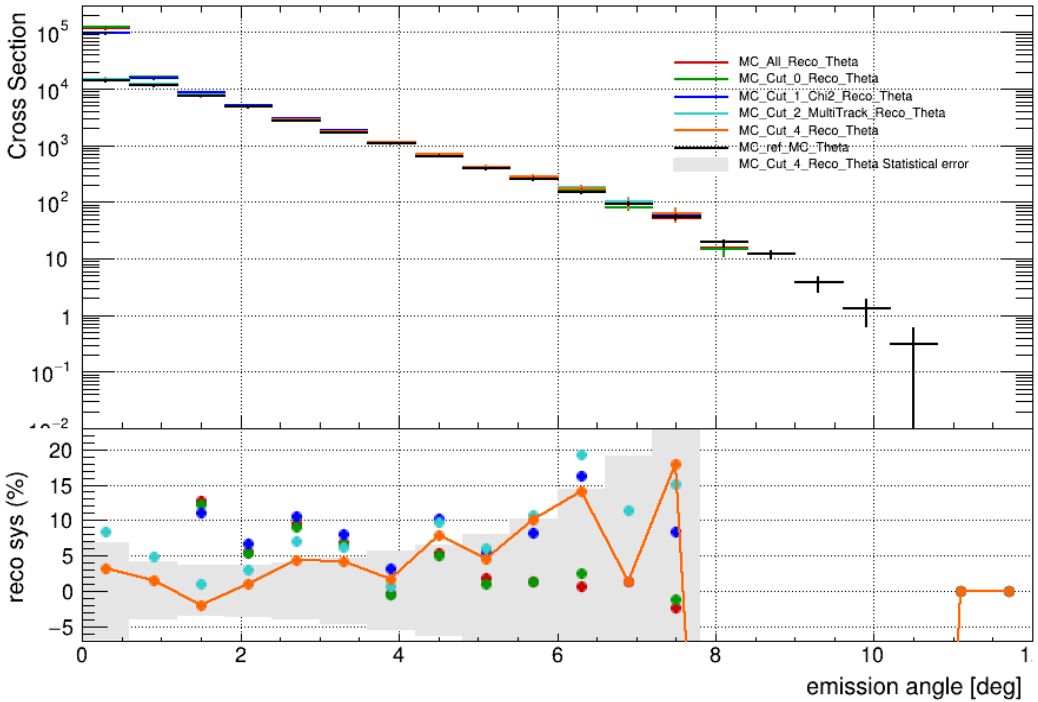


Reconstruction
Quality cut
Multi-tracks cut
TW point cut

Cross Section closure test

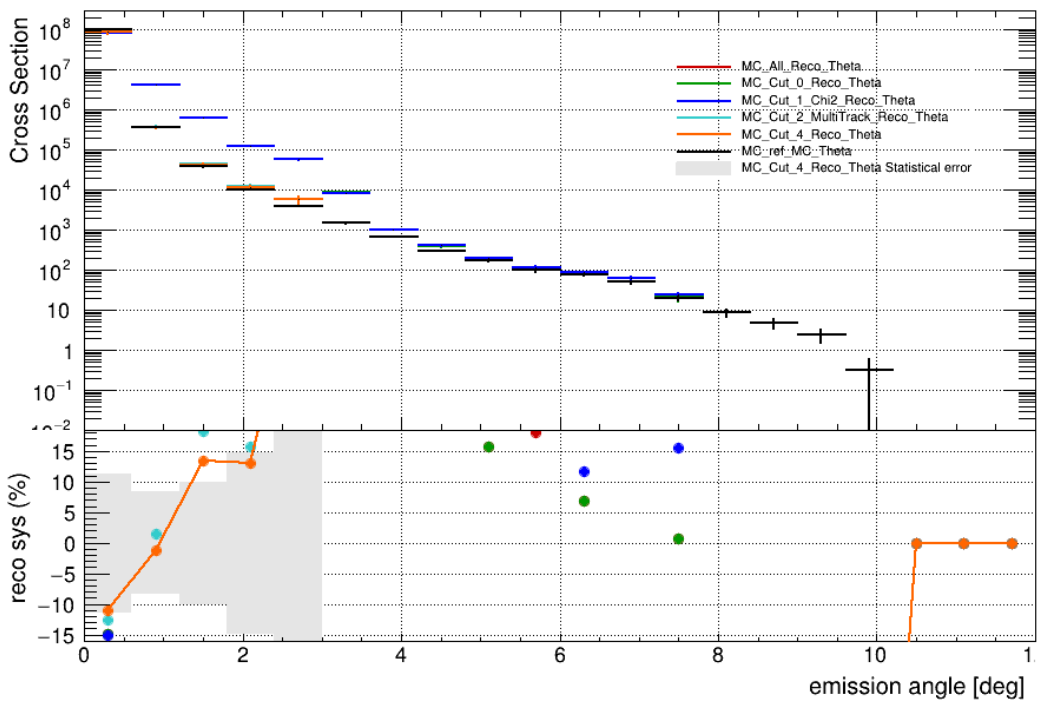
[mb/sr]

Z=4



[mb/sr]

Z=5



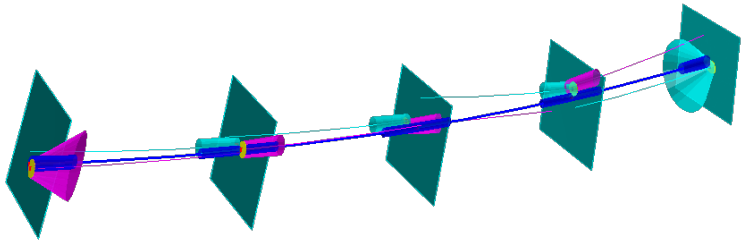
Reconstruction
Quality cut
Multi-tracks cut
TW point cut

Closure test considerations

- **Closure test** of CNAO24PS_MC
- Systematic discrepancy **inside the stat error**, **lower than ±5%** up to highest angles
- For **VT-MSD-TW tracking**, less points mean lower tracking capability.
  Underestimation of H, in general worse than full setup (mainly for low angles) but still **around 5%**
- To do: new comparison with CNAO MC **without magnetic field**, to see bending contribution to the systematics (CNAO22PS_MC ready in the near future)
- Good starting state, which must be compared with the experimental data (CNAO2024 and CNAO2023)

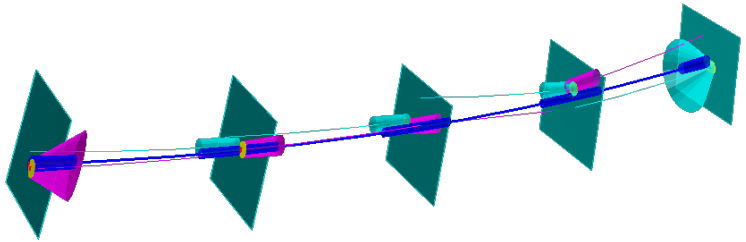
MC: Momentum and mass reconstruction

Momentum Reconstruction



From the (bending of the) reconstructed **global track**,
knowing the map of the **magnetic field**,
GENFIT aims to compute the **momentum of the track**

Momentum Reconstruction



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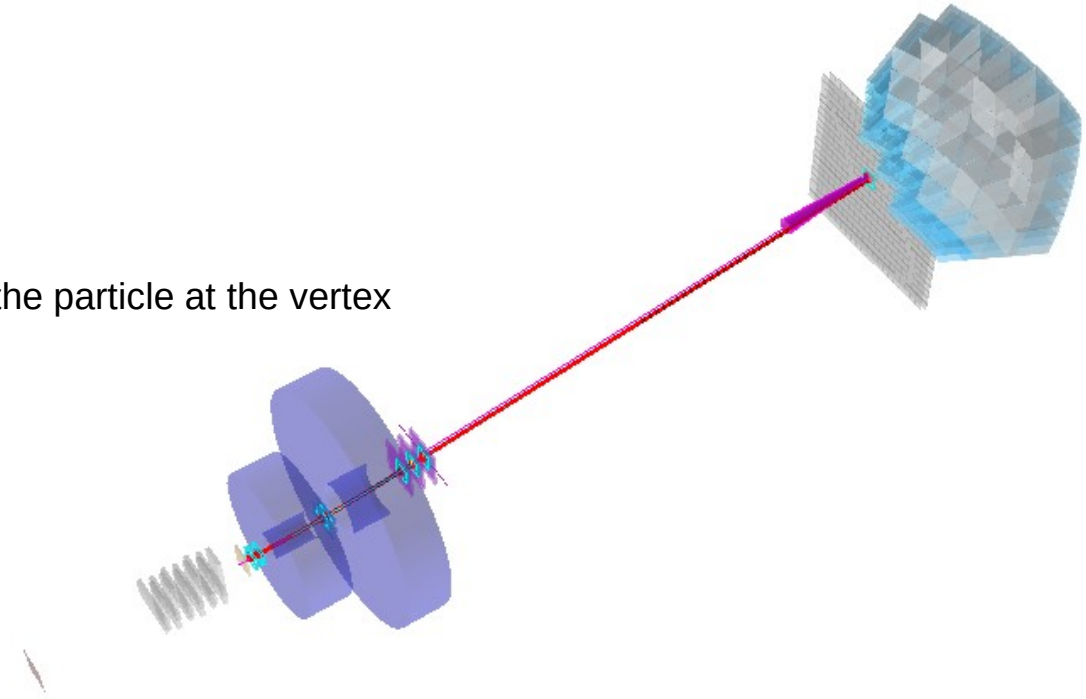
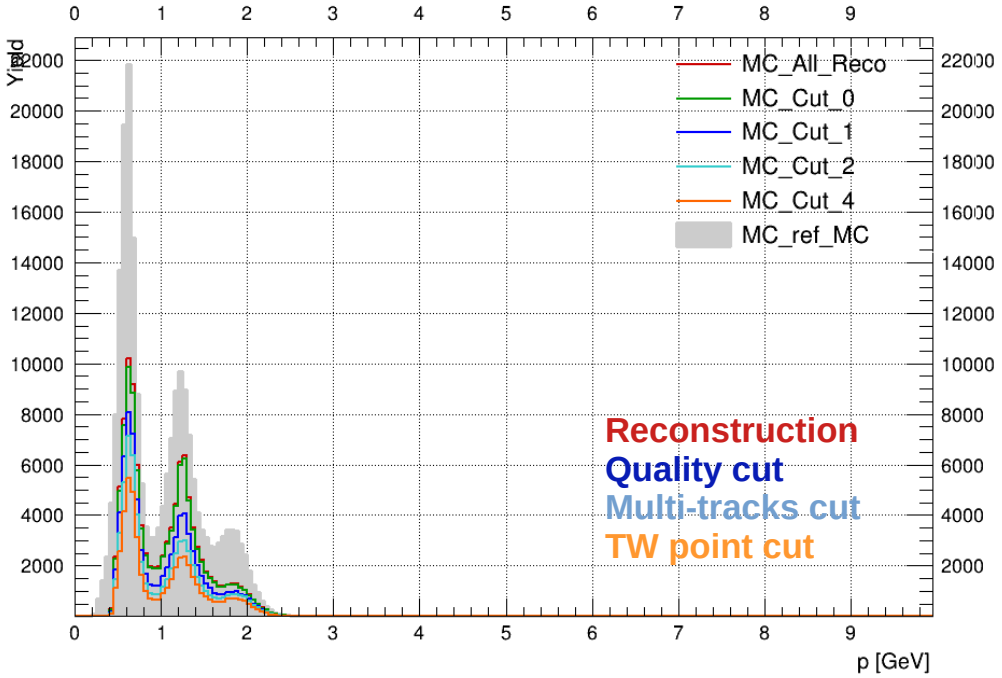


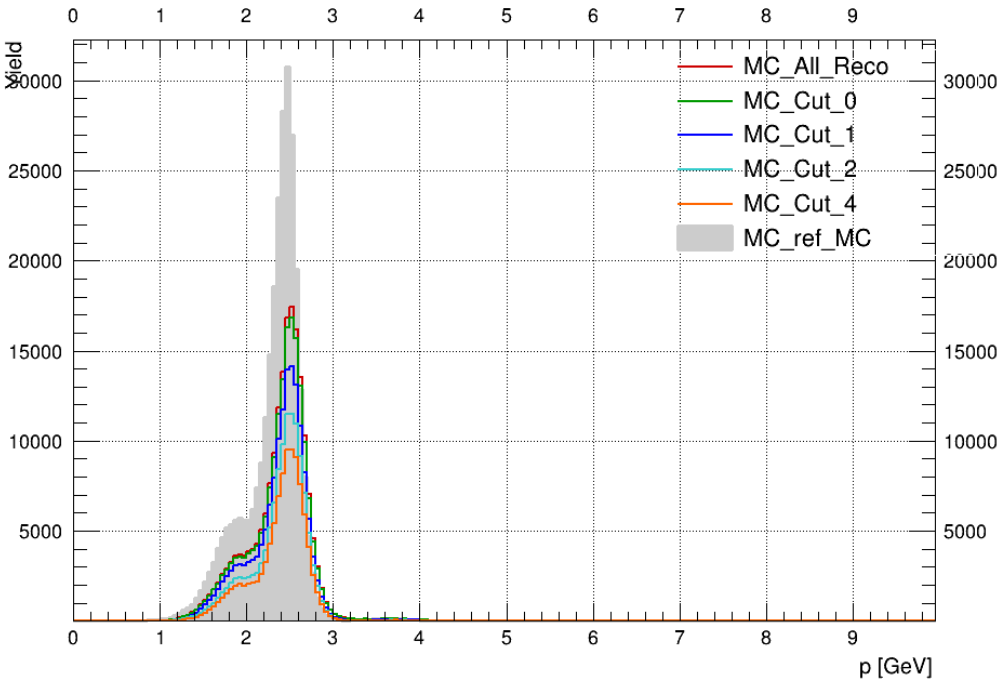
What it is interesting for FOOT is the momentum of the particle at the vertex of the fragmentation reaction, i.e. the **target.**

Momentum with the **previous reconstruction cuts** will be compared to MC reference

Momentum Reconstruction



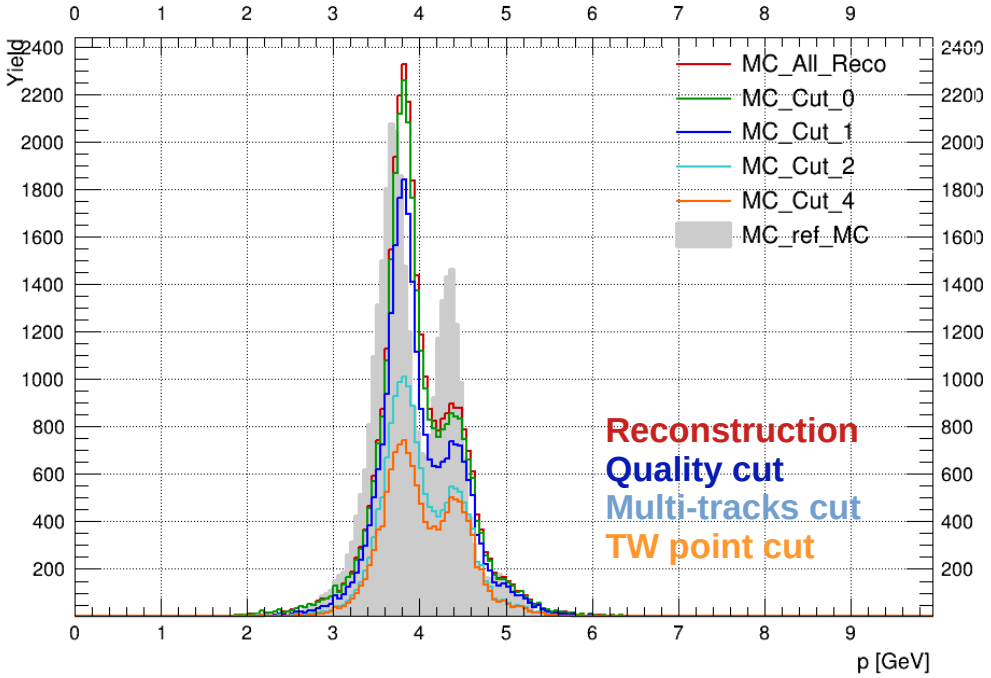
Z=1



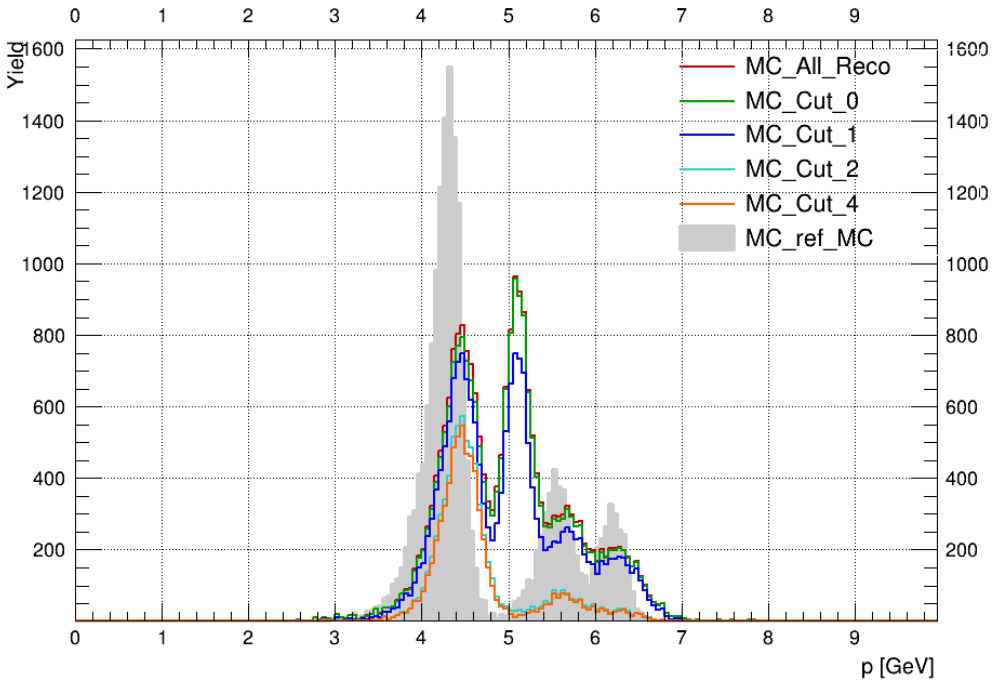
Z=2

In gray the value from the MC reference is reported

Momentum Reconstruction



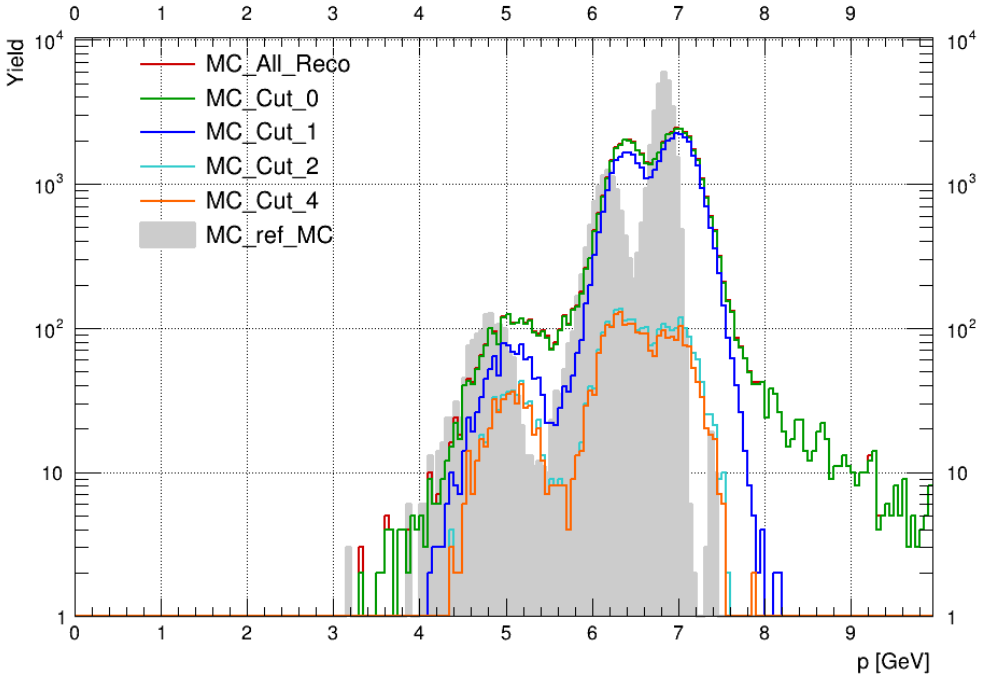
Z=3



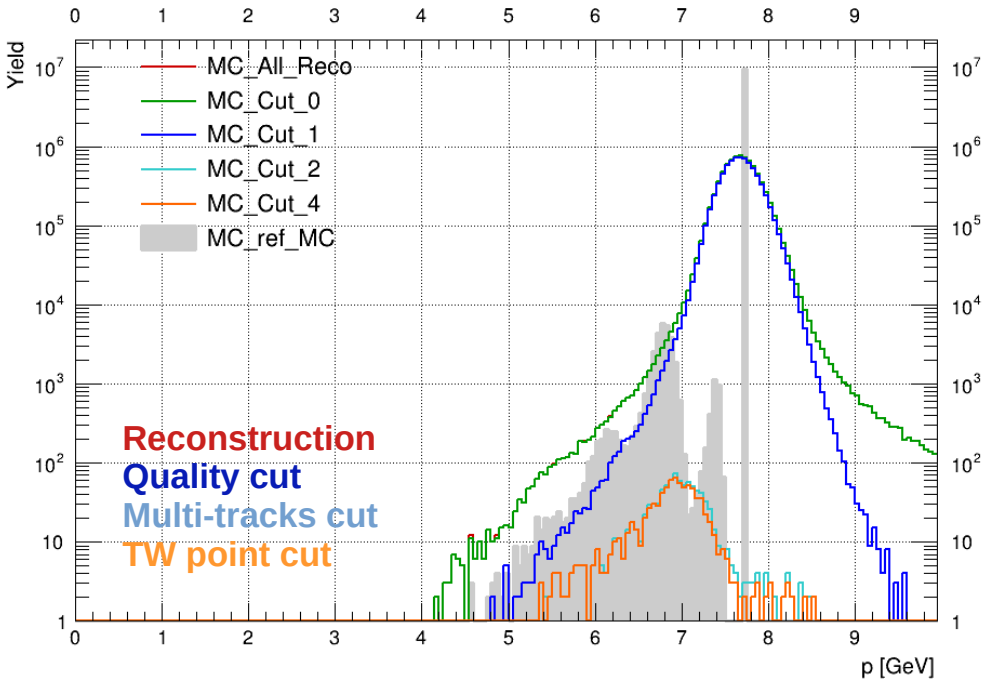
Z=4

Peak due to misreconstruction deleted after cuts

Momentum Reconstruction



Z=5



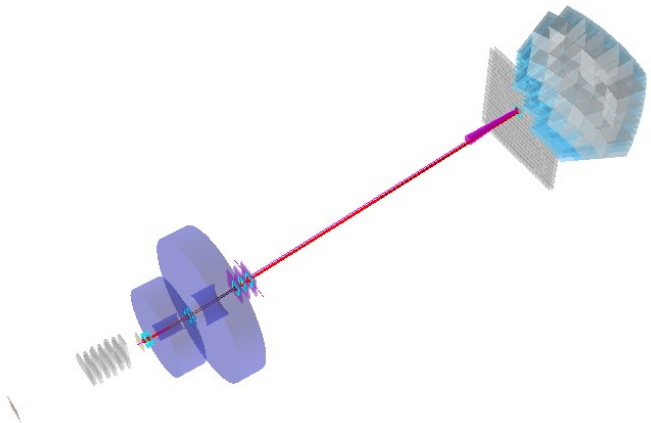
Z=6

For Z=6, after the cuts, only not 12C isotopes survive.

Mass Reconstruction

$$A = \frac{p}{\beta\gamma m_u}$$

Using the information from the track,
the **atomic mass A** can be computed combining
momentum **p** from GENFIT global track
and **TOF** from TW point



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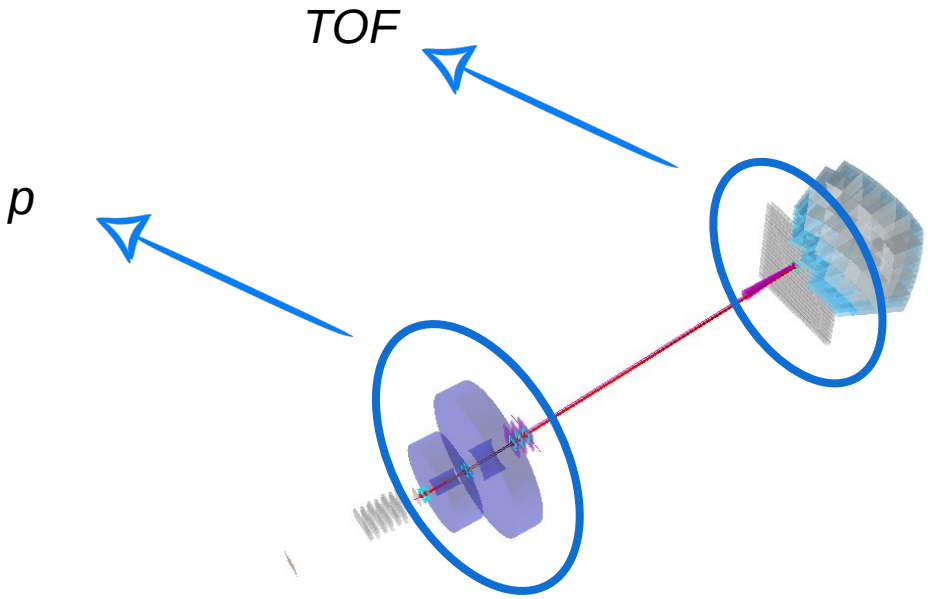
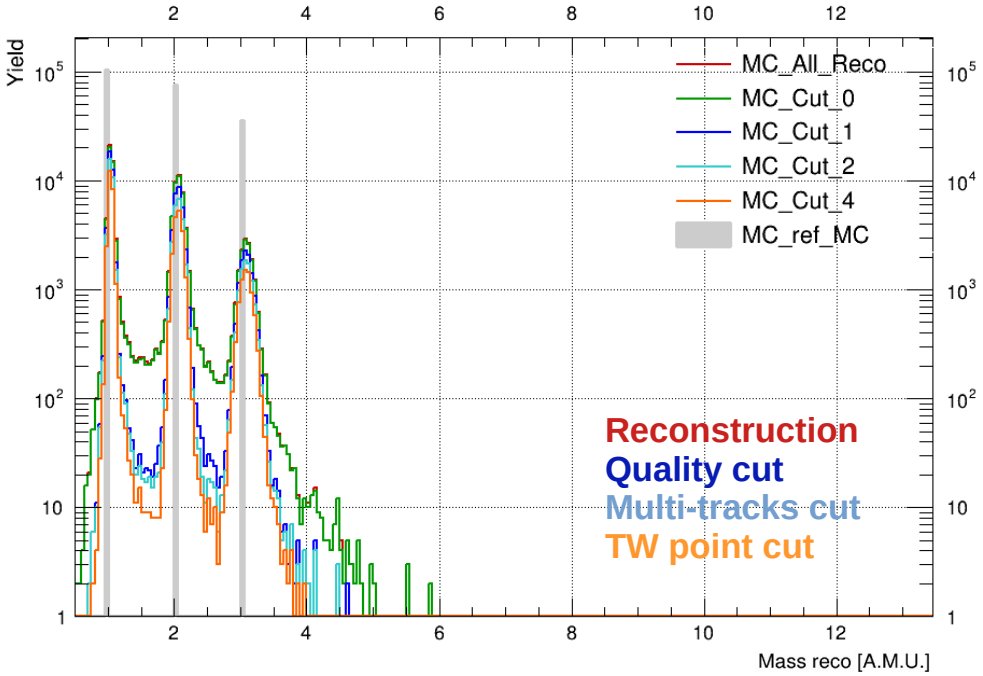
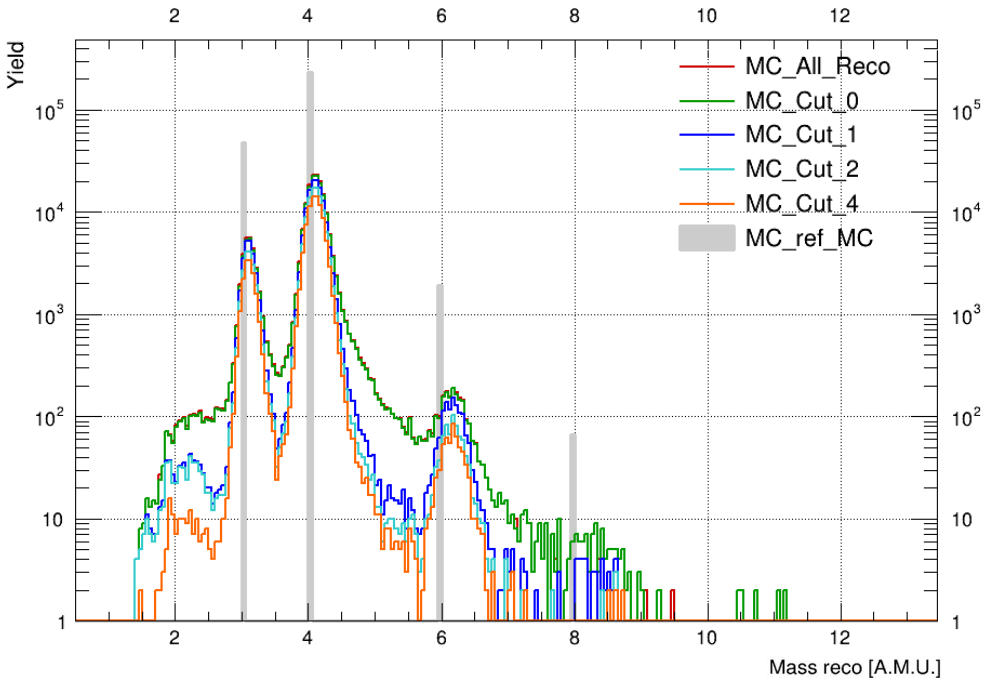


Mass Reconstruction



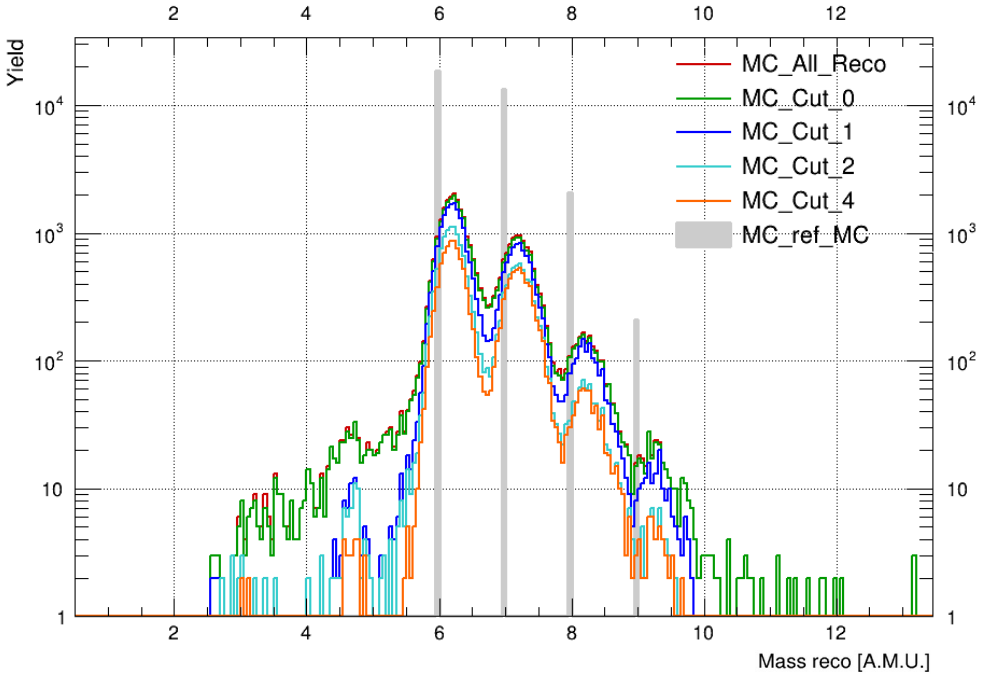
Z=1



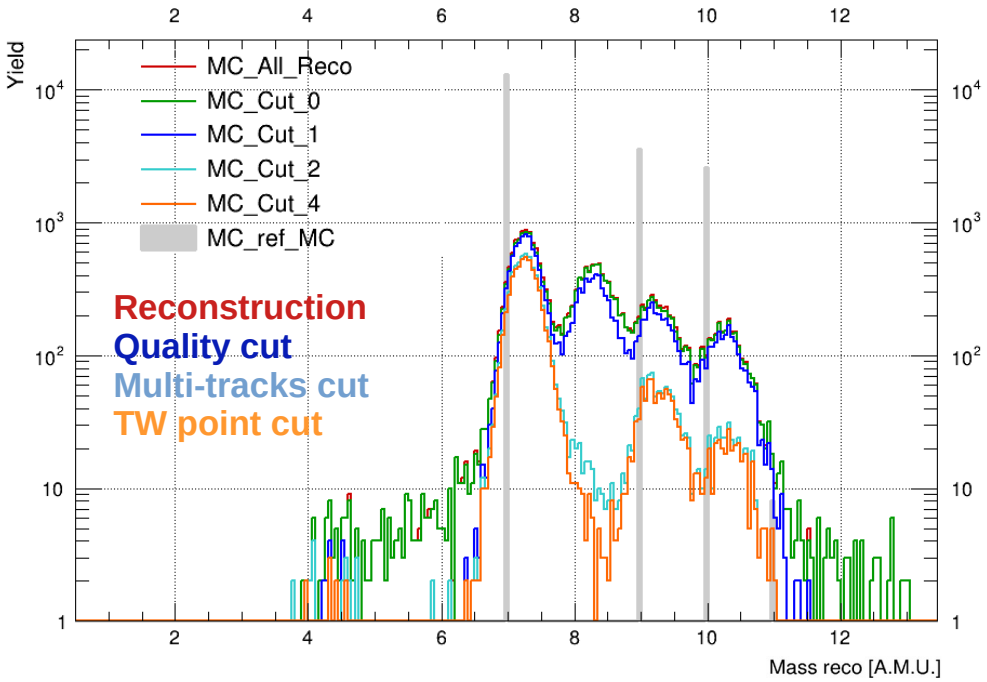
Z=2

In gray the value from the MC reference is reported

Mass Reconstruction



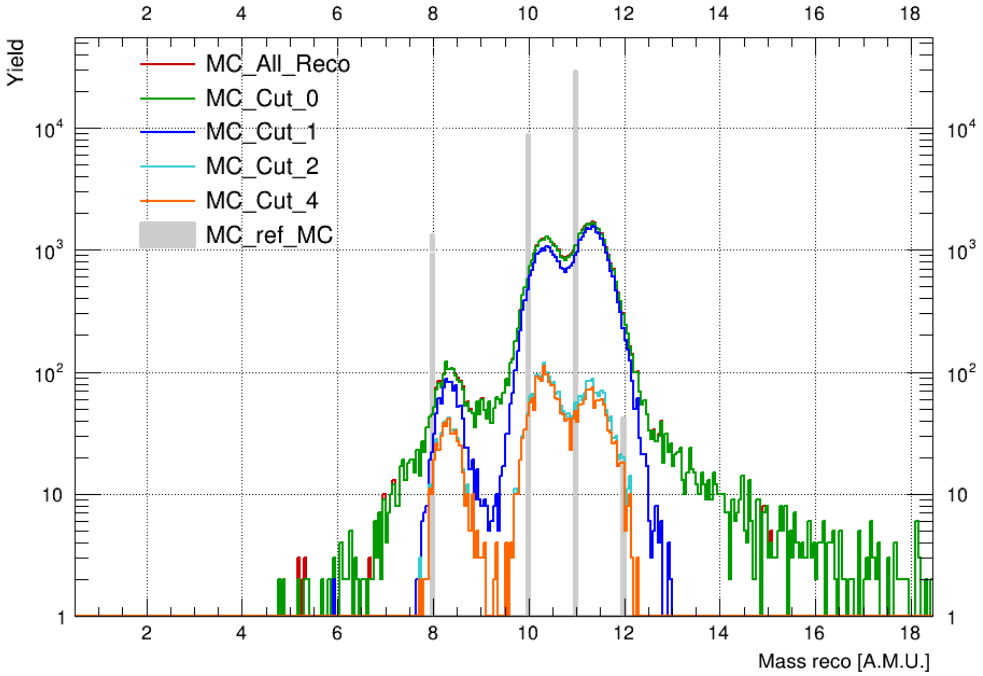
Z=3



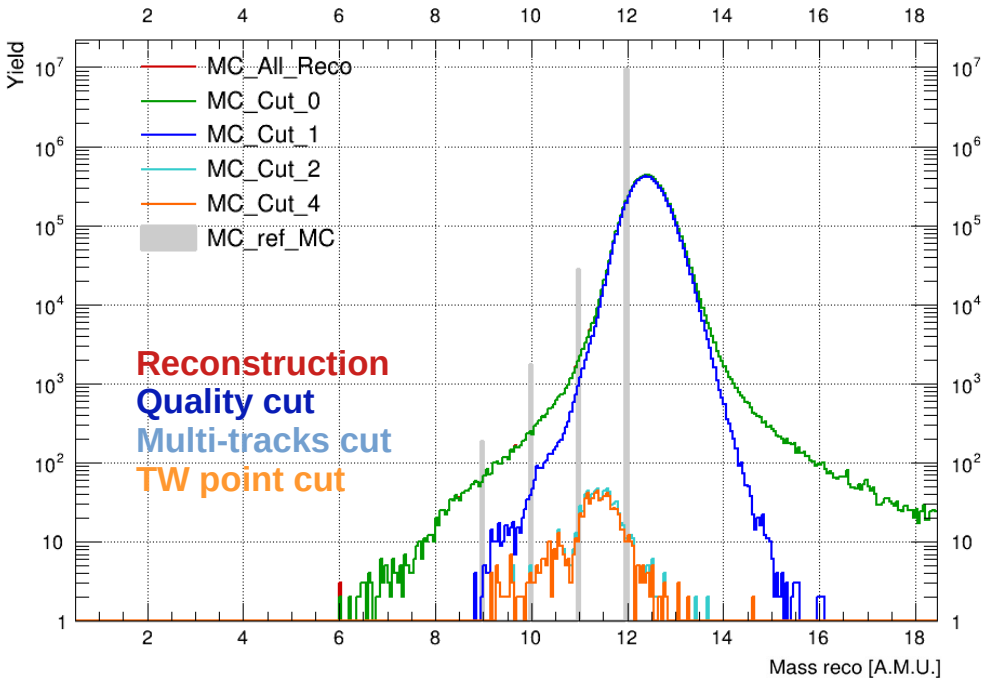
Z=4

8Be has a short half-life ($\tau \sim 10^{-16}$ s), not feasible for the crossed path length in the detector
It corresponds to fragmentation out of target of the primary, for which the rigidity $p/Z \propto m/Z \propto A/Z \propto 2$

Mass Reconstruction



Z=5



Z=6

Momentum and mass considerations

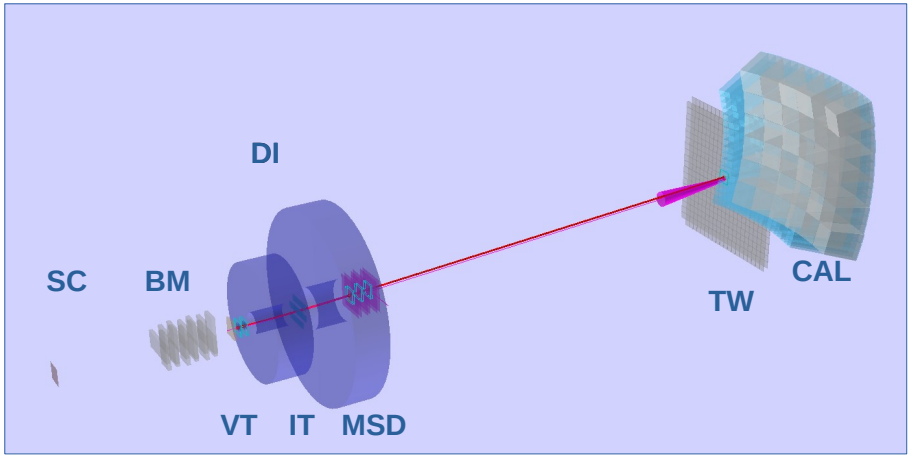
- **Momentum reconstruction** from global tracking
- Despite data reduction after cuts, good capability to distinguish **main peaks** and to remove misreconstruction
- **Mass reconstruction** from global tracking
- Capability to distinguish the peaks generated by different isotopes for all Z observed
- General positive discrepancy wrt MC value, due to p overestimation
- Future comparison with mass from Ekin of Calorimeter

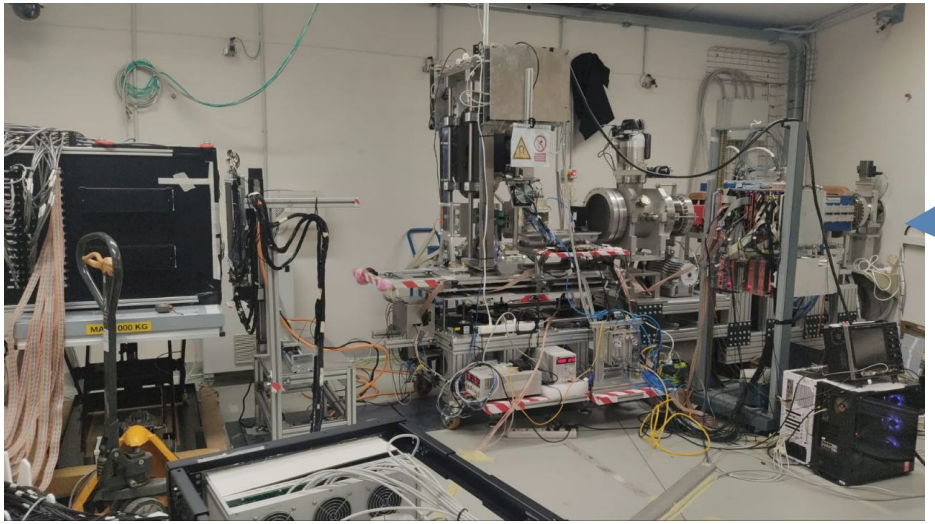
`-exp CNAO24PS_MC`

`-exp CNAO2024`

CNAO2024

- Data-taking at CNAO in November 2024
- **^{12}C 200 MeV/u** on 5 mm **C target** with **B** field
- Total setup
- Runs 6958, 6959, 6960, 6962 (*390 k ev*) + 7072, 7076, 7077 (*790 k ev*) *~ 1 M ev*





- **VT, MSD, TW** considered
- **Global tracking** reconstruction

Exp: Tracking Reconstruction and Cuts

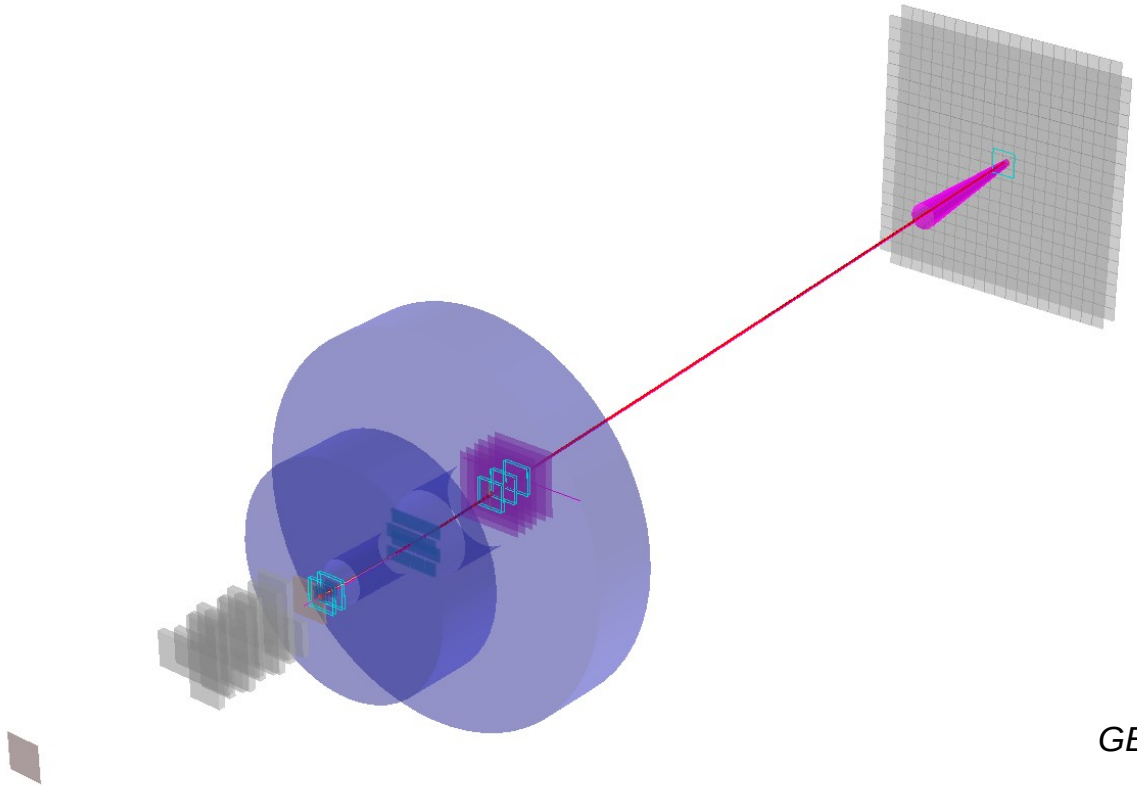
Tracking reconstruction

First tracking reconstruction in magnetic field in experimental data!

Tracking reconstruction

First tracking reconstruction in magnetic field in experimental data!

The primary...

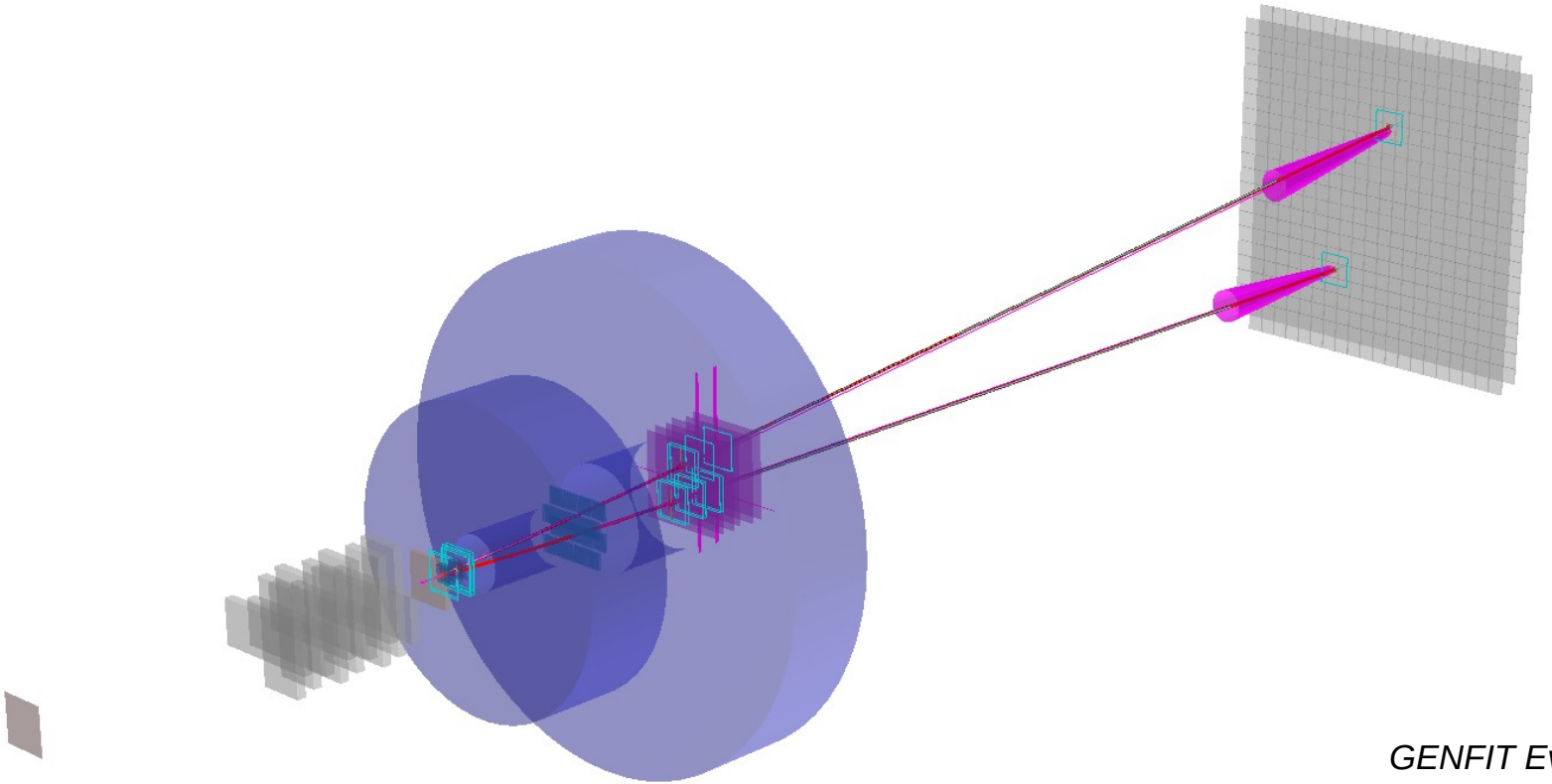


GENFIT Event display, run 7077

Tracking reconstruction

First tracking reconstruction in magnetic field in experimental data!

2 fragments...

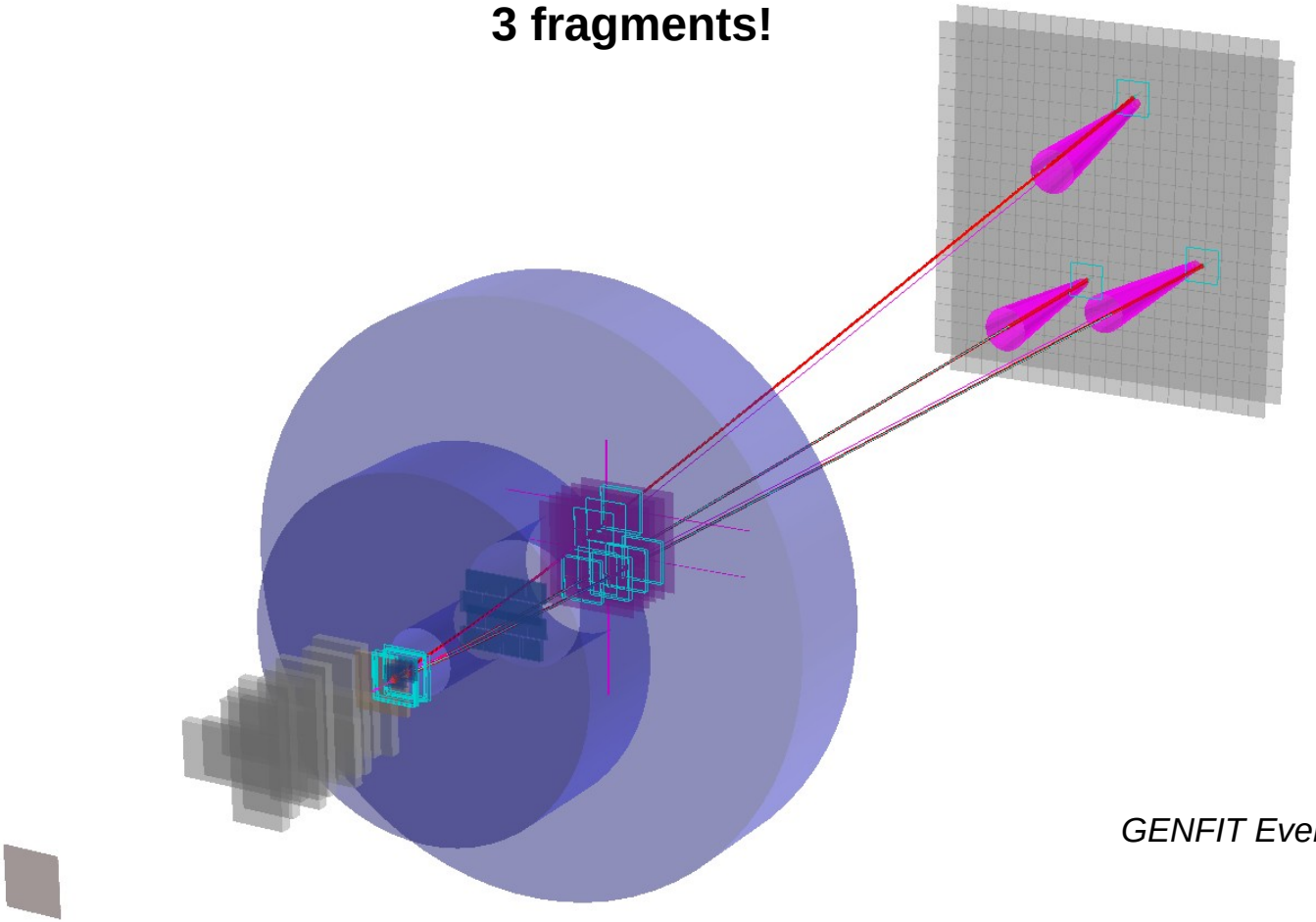


GENFIT Event display, run 7077

Tracking reconstruction

First tracking reconstruction in magnetic field in experimental data!

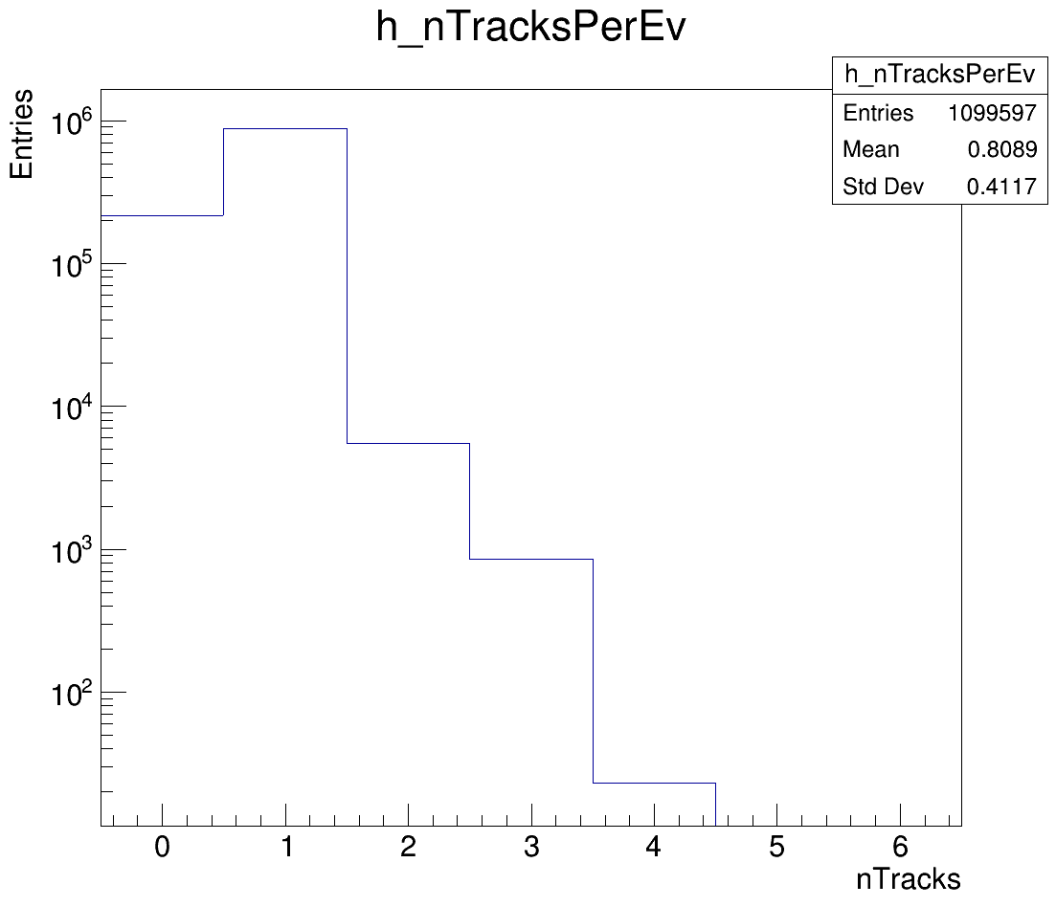
3 fragments!



GENFIT Event display, run 7077

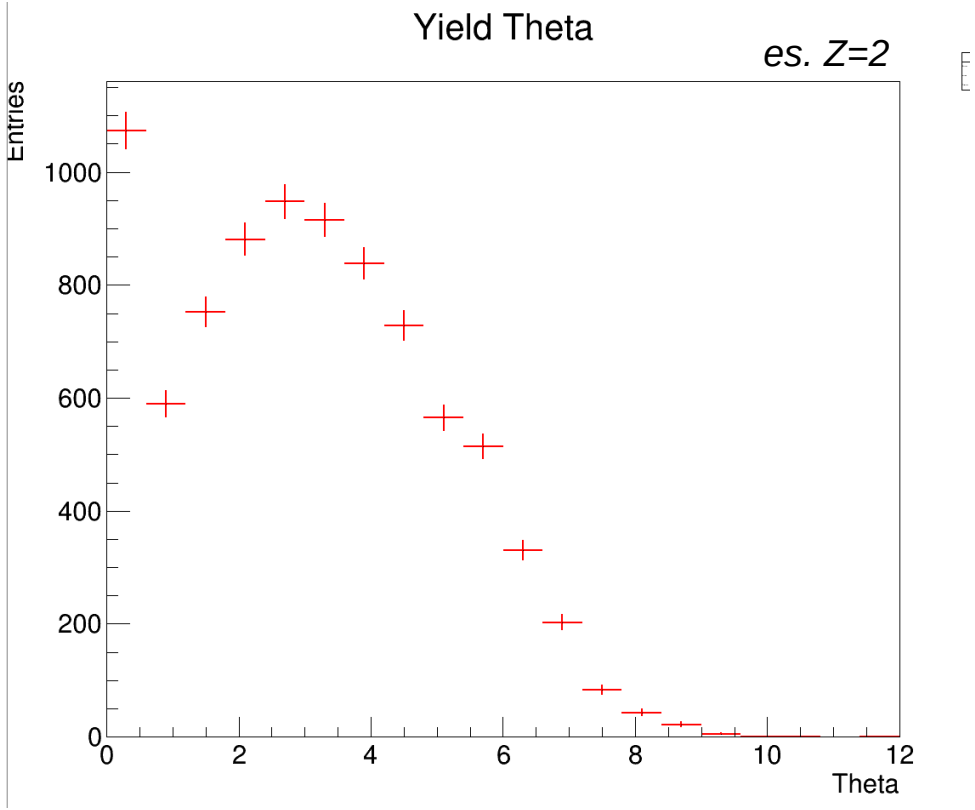
Tracking reconstruction

Successful tracking reconstruction in magnetic field in experimental data!



Yield cuts

The same cuts of MC are used in Exp data:



Reconstruction

Yield cuts

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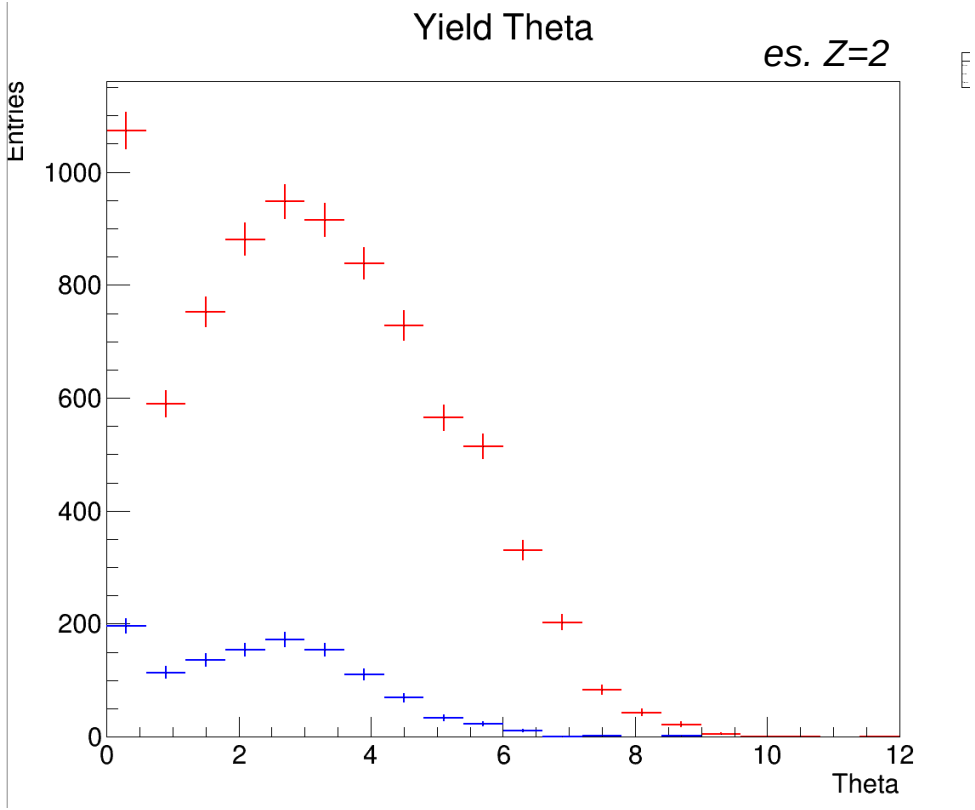

Reconstruction
Quality cut

Yield cuts

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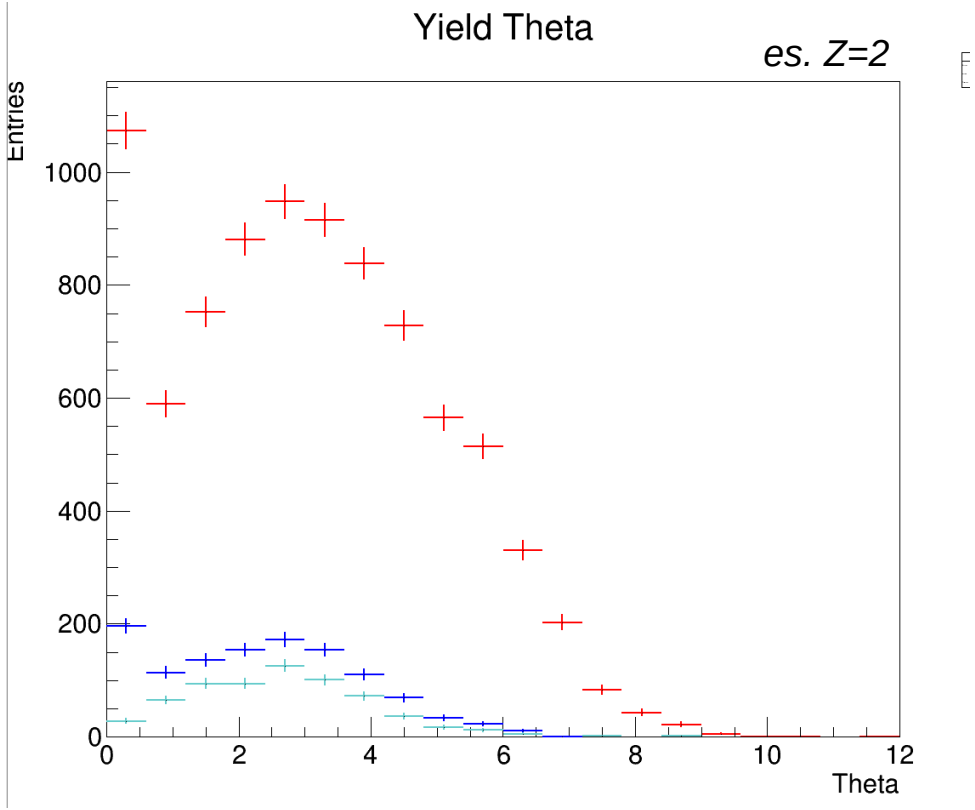
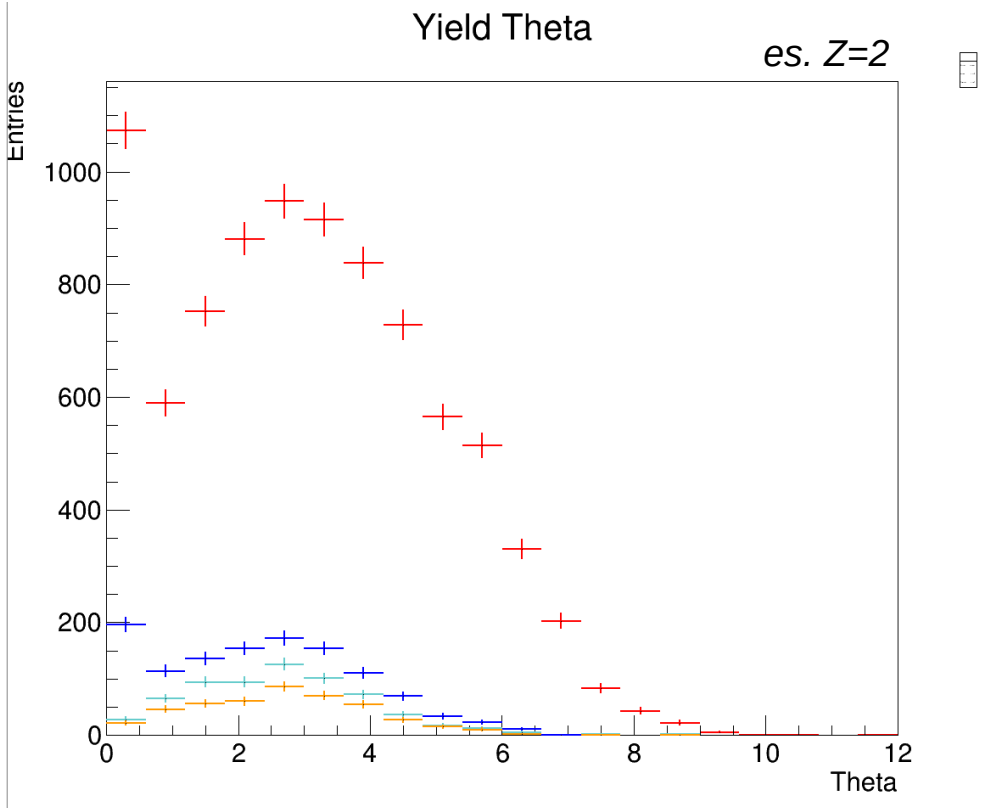


Reconstruction
Quality cut
Multi-tracks cut

Yield cuts

The same cuts of MC are used in Exp data:



Reconstruction
Quality cut
Multi-tracks cut
TW point cut

Yield cuts

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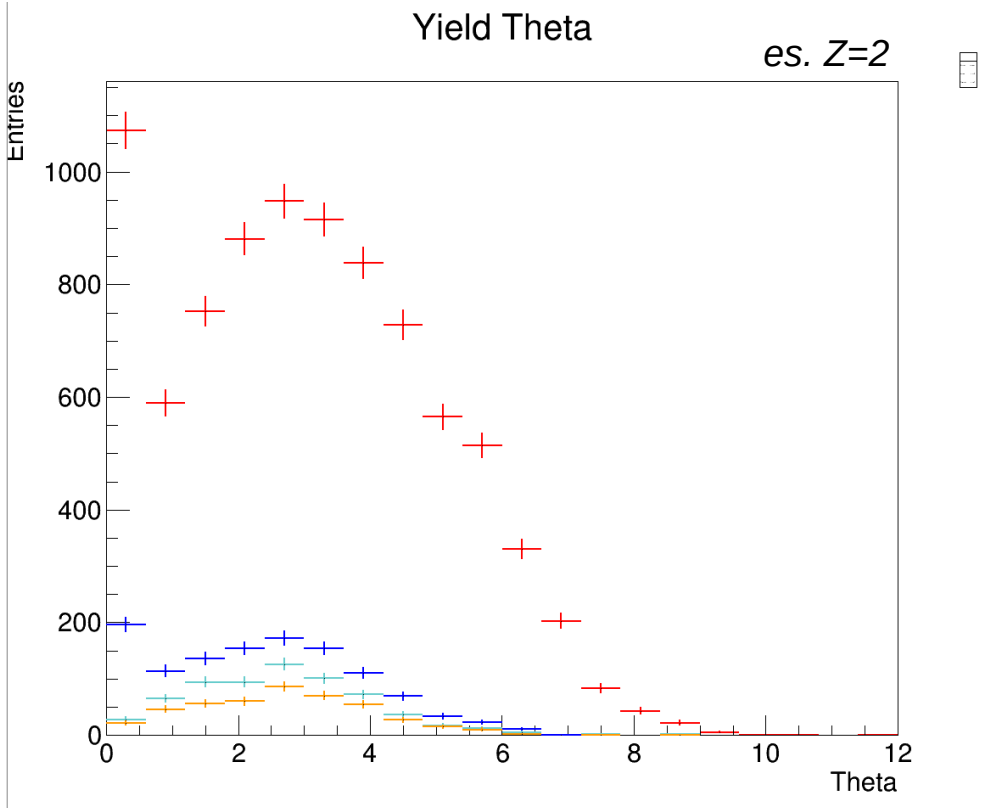


Reconstruction
Quality cut
Multi-tracks cut
TW point cut

Big drop of statistics after **Chi2 cut**!

Several causes to investigate:

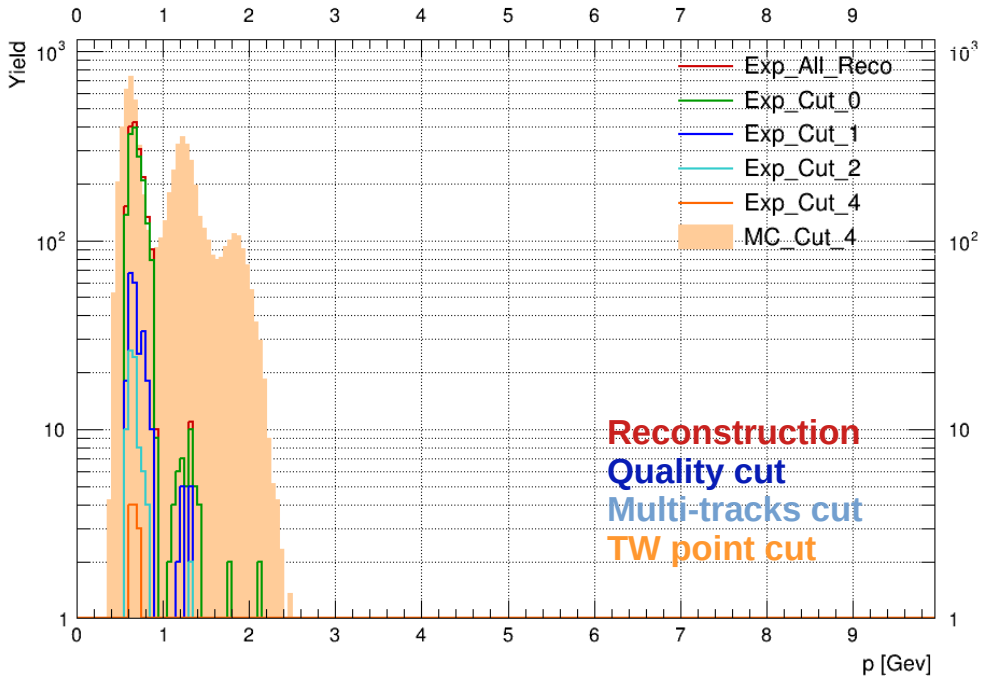
- VTX efficiency ?
- MSD efficiency ?
- GENFIT Glb Tracking efficiency / systematics ?
- Alignment (Detectors + **B field**) ?
- Pile up?

Tracking considerations

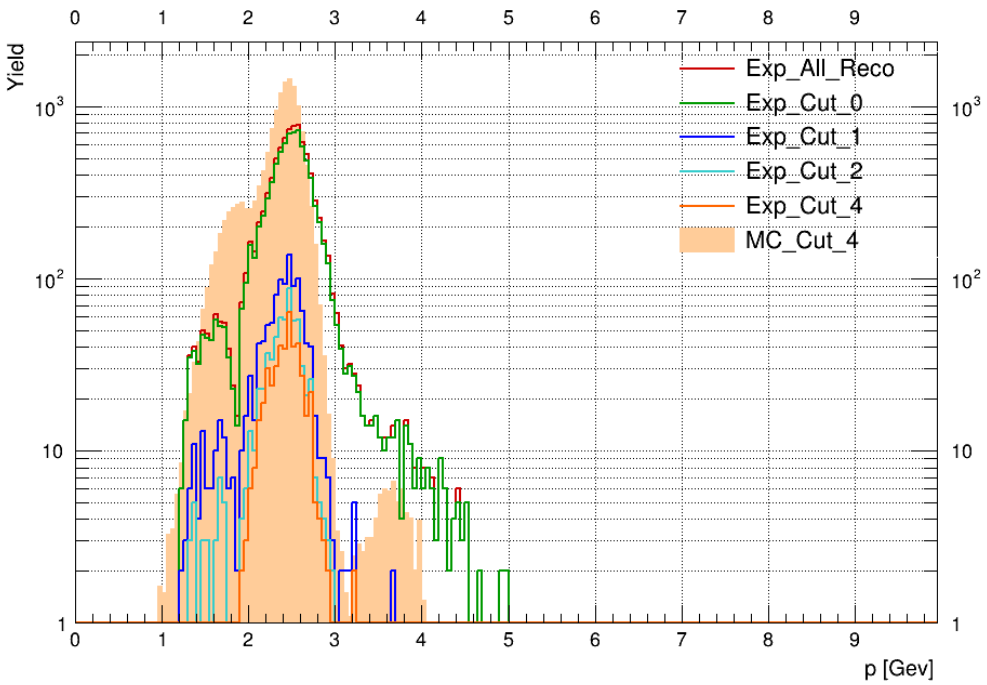
- Assessed Tracking reconstruction capability
- Big improvement after **aligment** (see Monthly Meeting 04/25)
- Efford to improve clusters / tracks reconstruction (f.e. **noise** from MSD)
- Interest in introducing tracking detector efficiency (see Luana presentation)
- Interest in a comparison of Glb Cross Section with BM – TW Cross Section to estimate GENFIT capability (/out B field)
- Check the reliability of Simulation with Exp (f.e. **digitization**, detector efficiency...)

Exp: Momentum and mass Reconstruction

Momentum Reconstruction



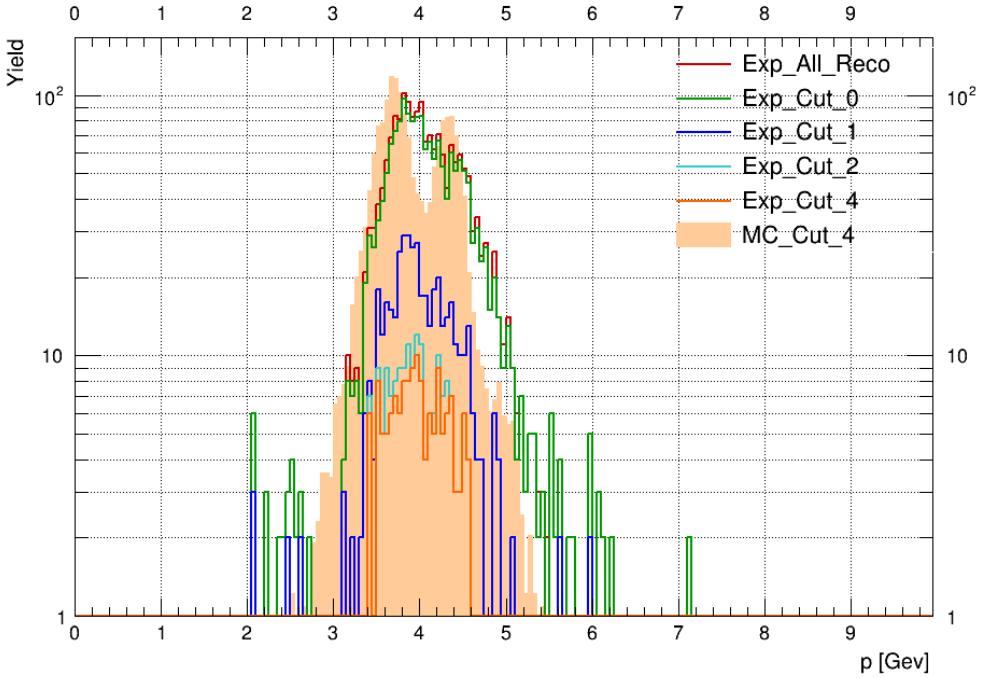
Z=1



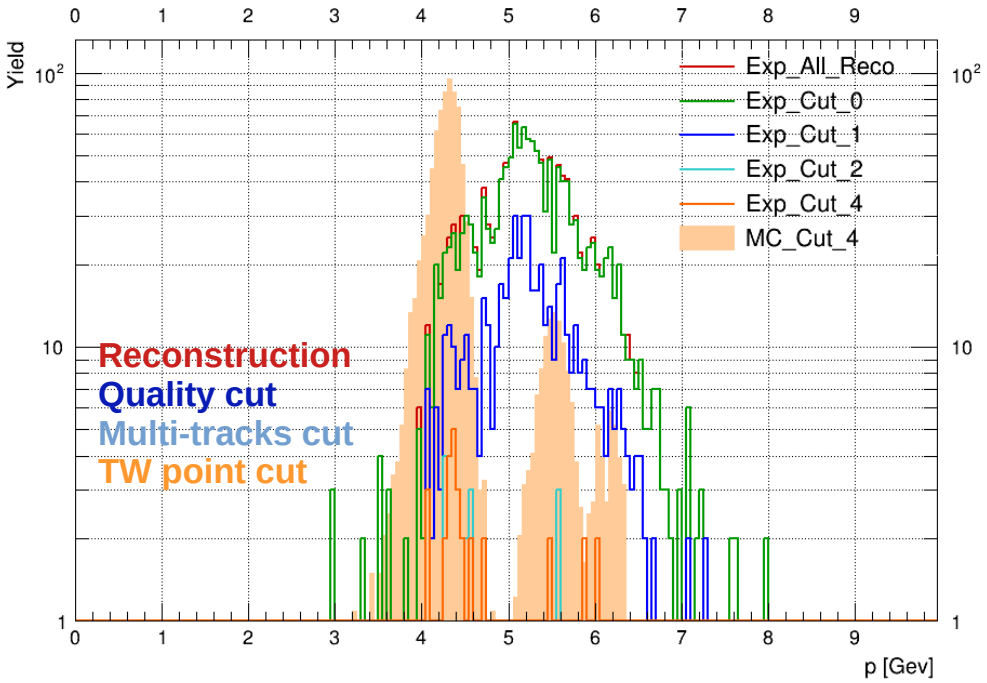
Z=2

In orange the reco value from simualtion of TW point cut, normalized to data events

Momentum Reconstruction

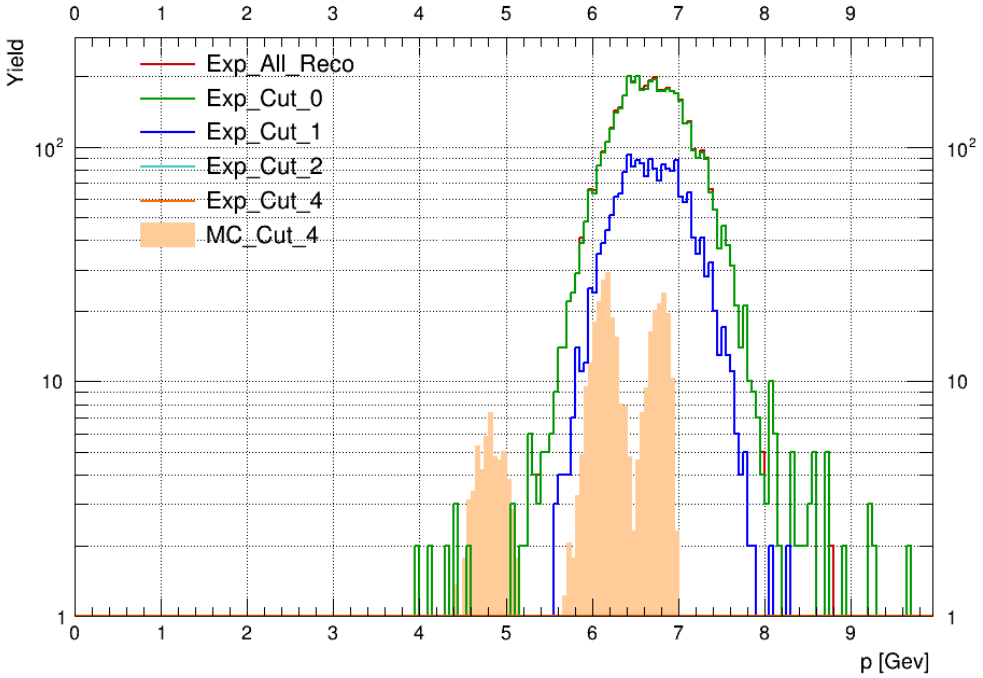


Z=3

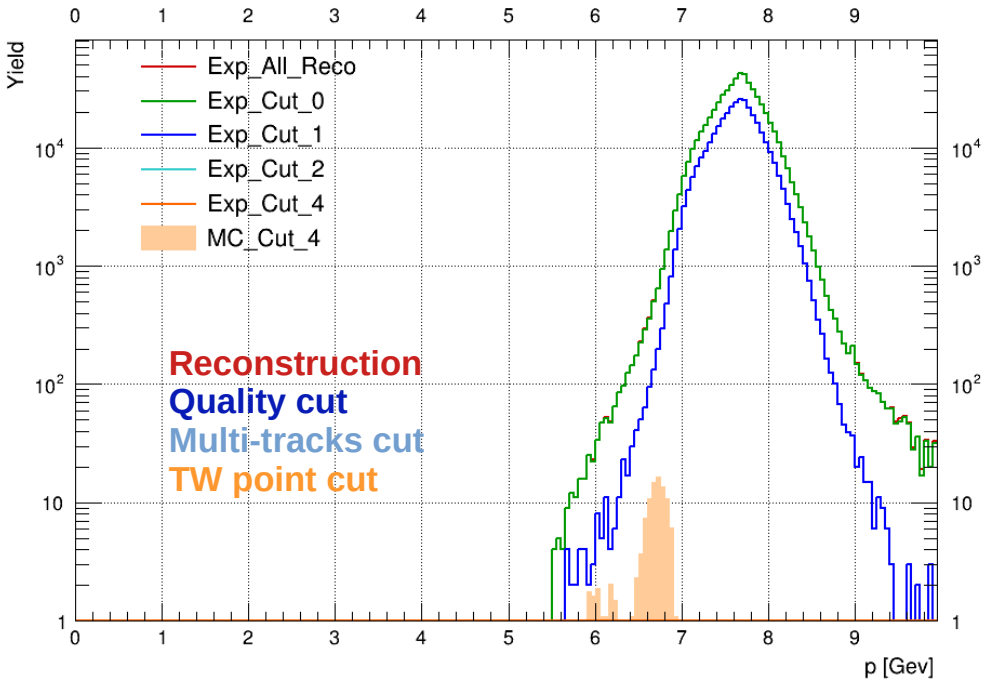


Z=4

Momentum Reconstruction

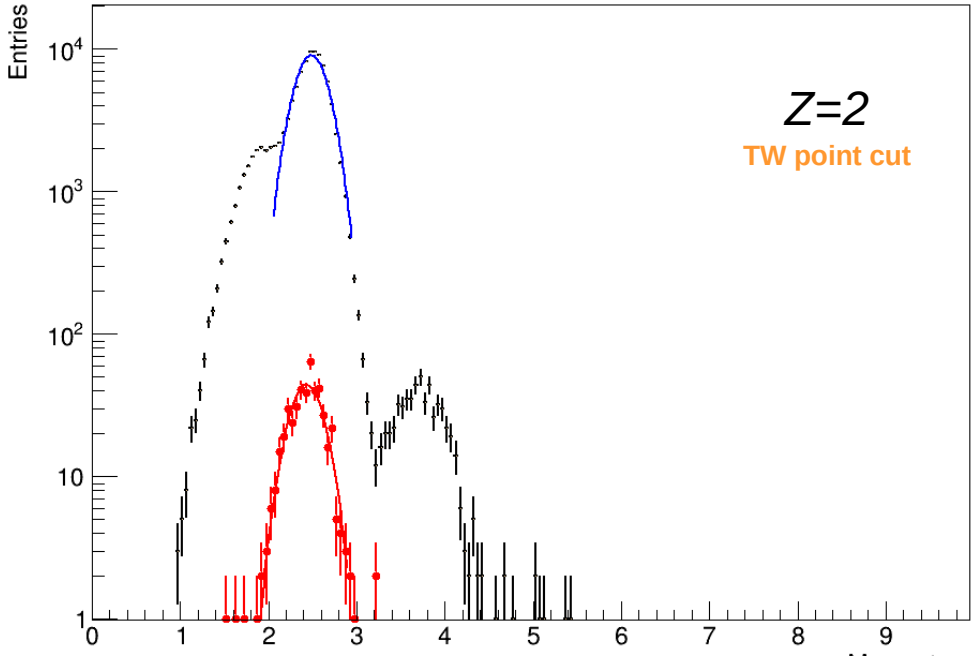


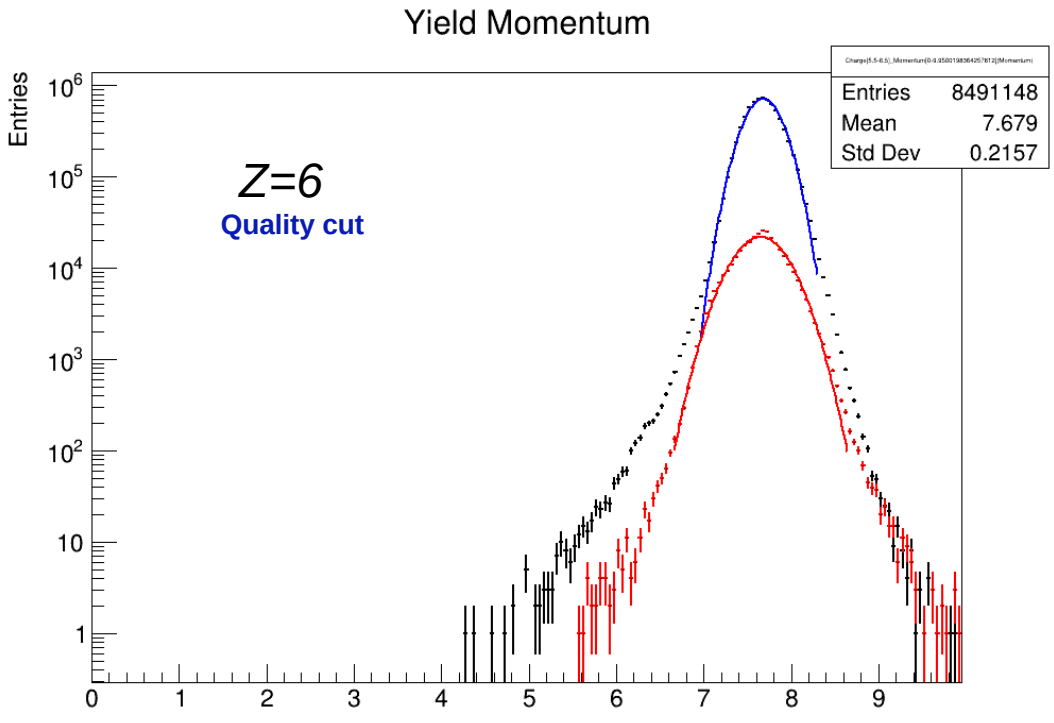
Z=5



Z=6

Momentum Resolution

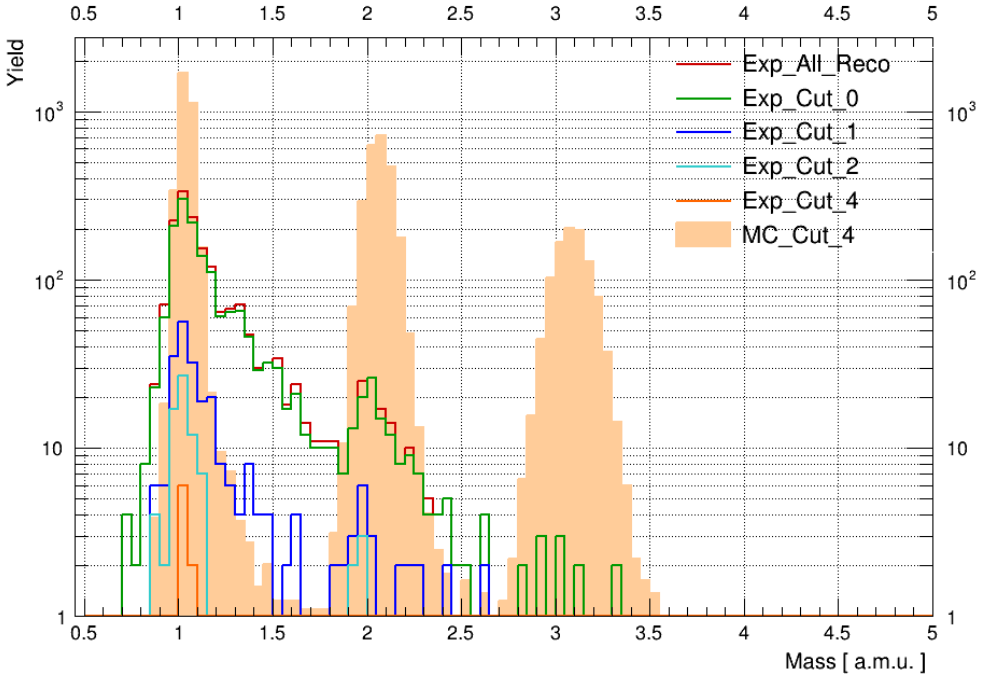




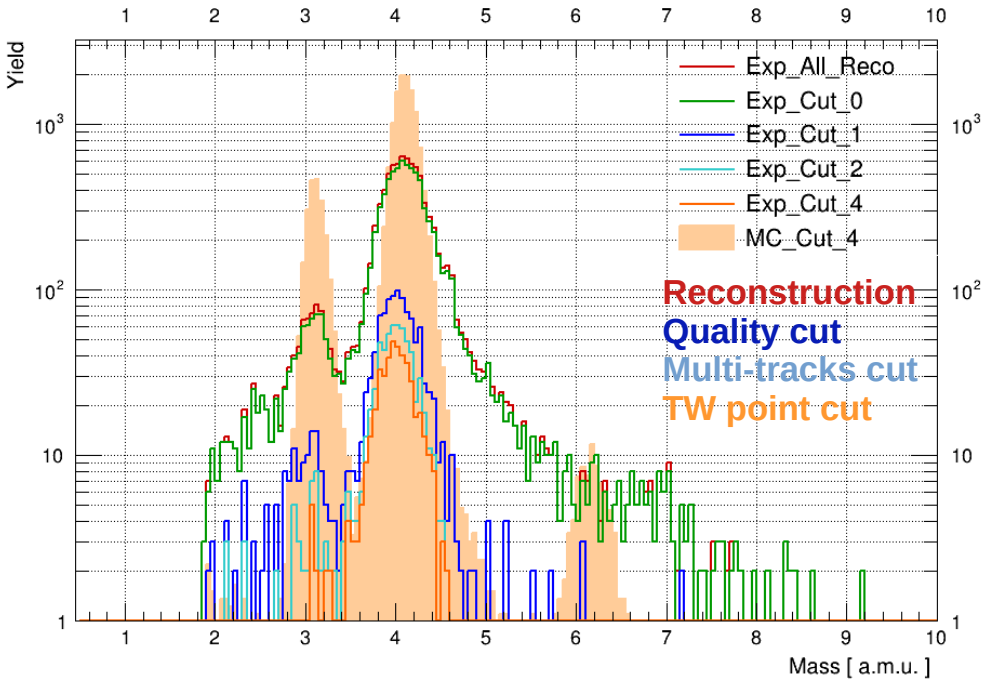
^{4}He peak
from MC: 2.48 ± 0.18 (**7.2%**)
from Exp: 2.42 ± 0.19 (**7.8%**)

^{12}C peak
from MC: 7.7 ± 0.2 (**2.6%**)
from Exp: 7.6 ± 0.3 (3**.8%**)

Mass Reconstruction



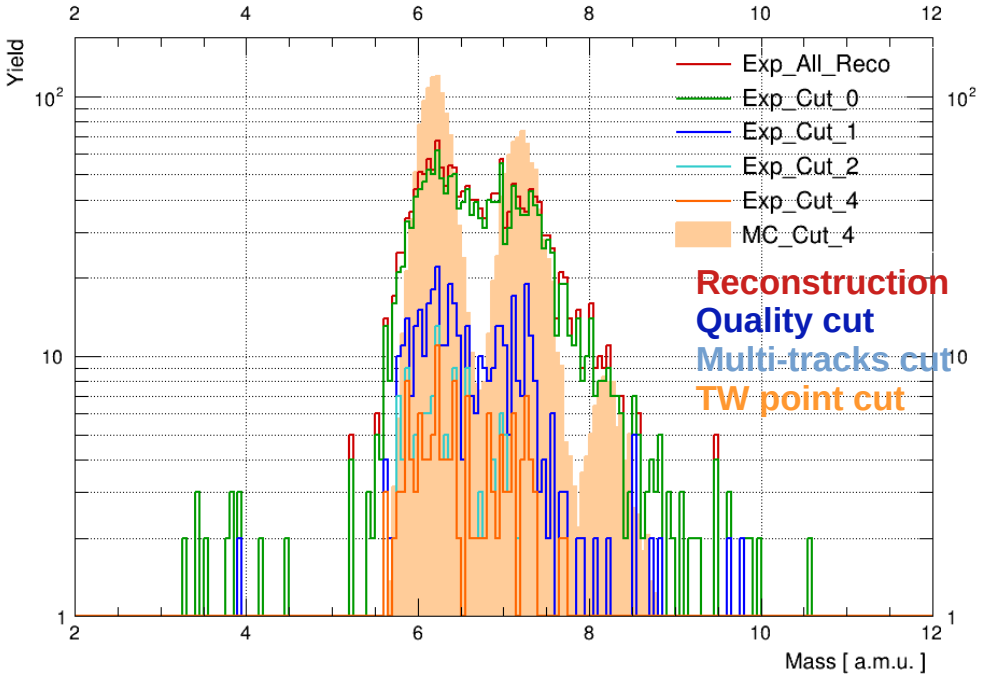
Z=1



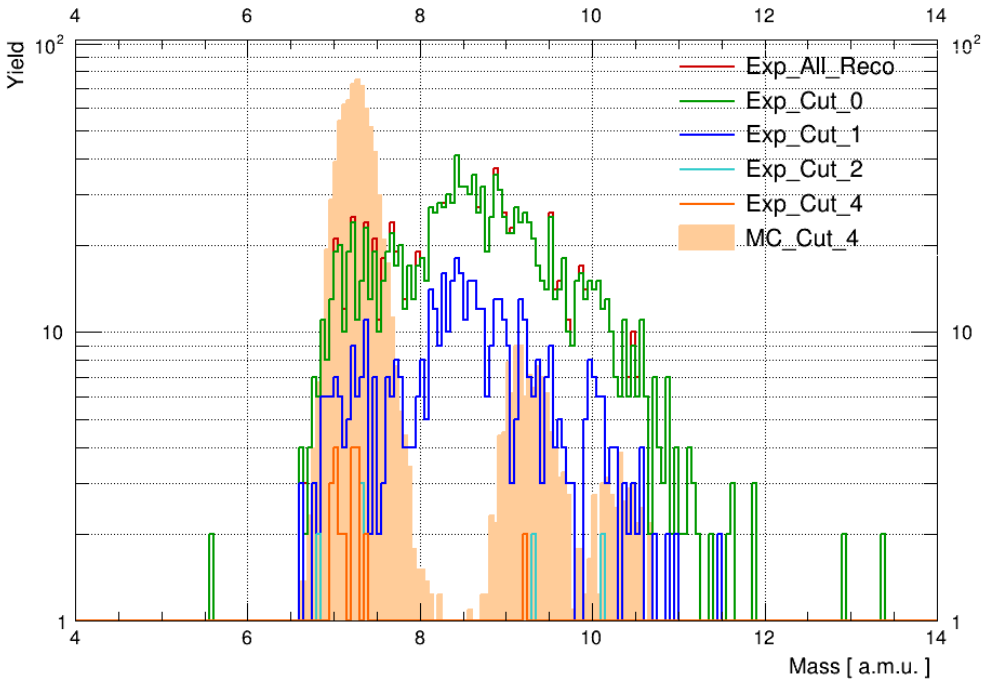
Z=2

In orange the reco value from simualtion of TW point cut, normalized to data events

Mass Reconstruction

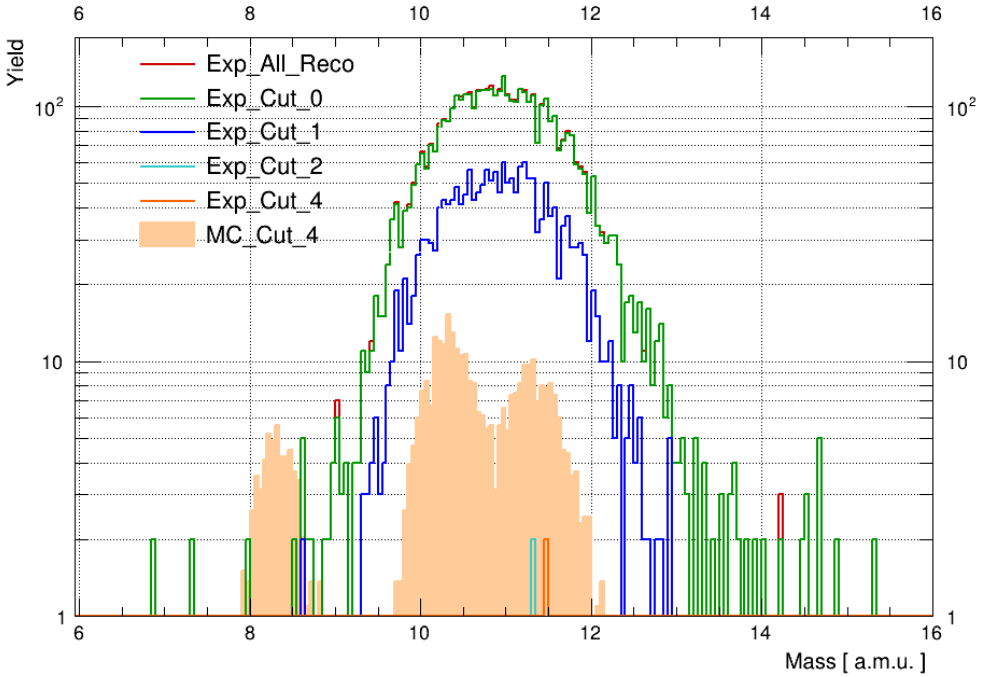


Z=3

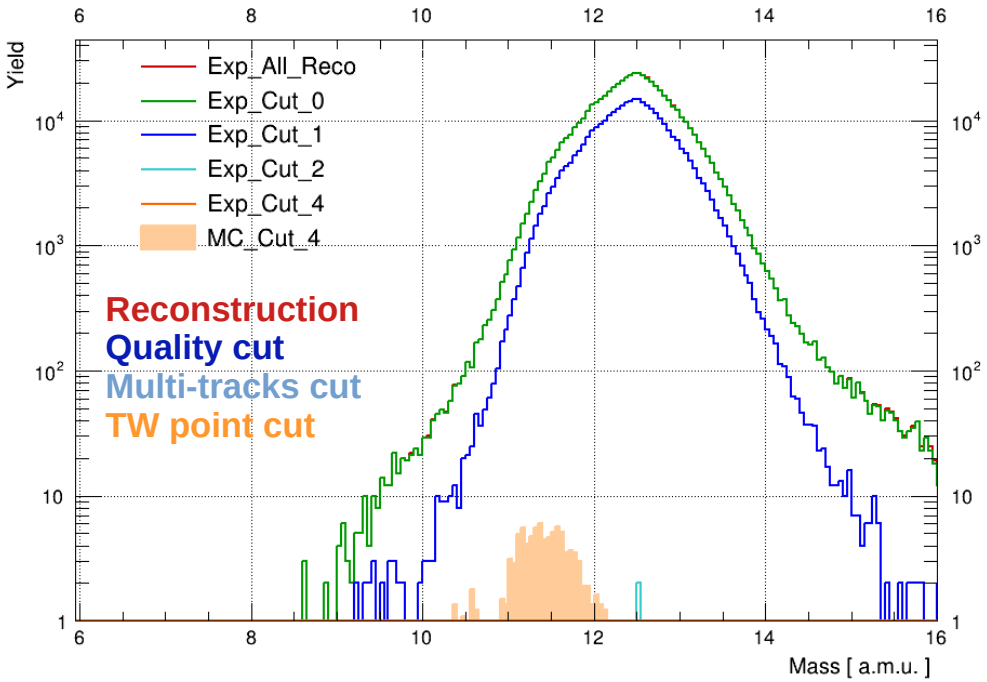


Z=4

Mass Reconstruction

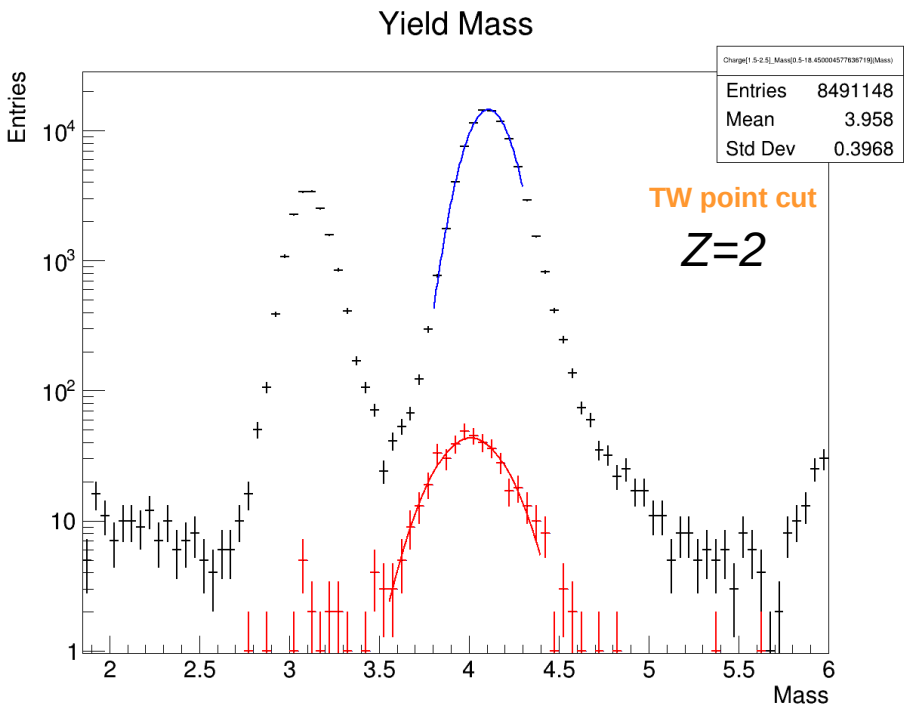


Z=5

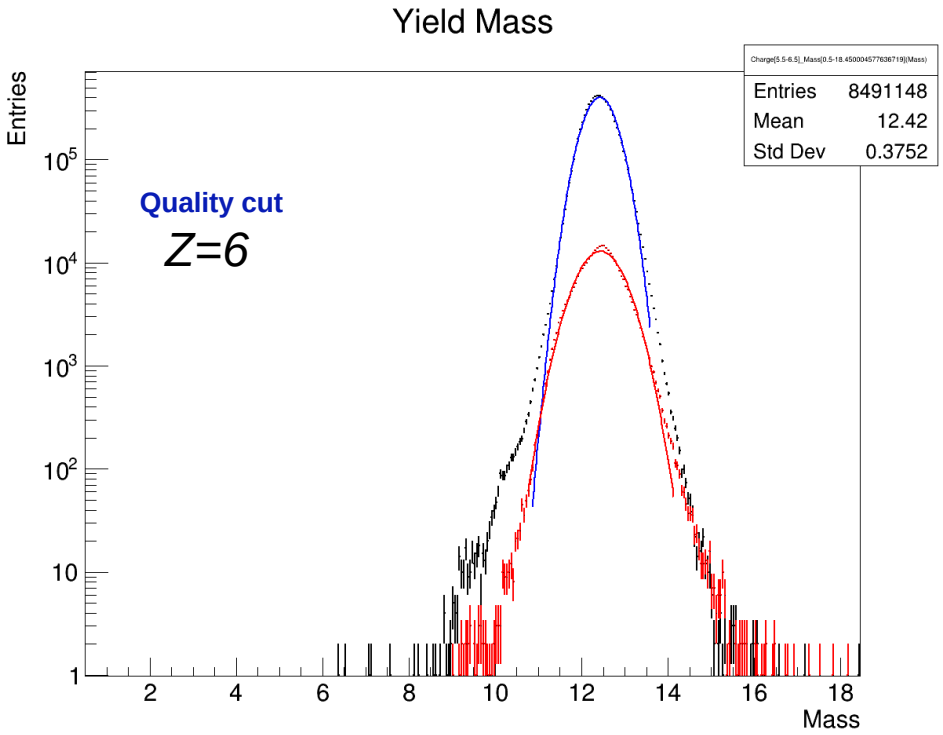


Z=6

Mass Resolution



^{4}He peak
from MC: 4.11 ± 0.11 (**2.6%**)
from Exp: 4.01 ± 0.18 (**4.5%**)



^{12}C peak
from MC: 12.41 ± 0.36 (**2.9%**)
from Exp: 12.43 ± 0.51 (**4.1%**)

Momentum and mass considerations

- Cuts drop limits the **statistics**
- Reconstruction of the **main isotopes**
- **Resolution comparable** to MC, in agreement with FOOT requirements
- Study possibilities of improvements in GENFIT reconstruction algorithm (f.e. isotopes guess)

Conclusions and future perspectives

- Good reliability of GENFIT global tracking according to MC results and performance
- From data, convolution of different causes to be studied carefully, from detector performance to alignment
- Compare global tracking (with no B field) with BM-TW analysis
- Introduce and study detector efficiencies
- **Resolution comparable** to MC, in agreement with FOOT requirements
- Study possibilities of improvements in GENFIT reconstruction algorithm (f.e. isotopes guess)
- SHOE **TANAactCrossSection** class in continuous development!


The peak
The expedition crew

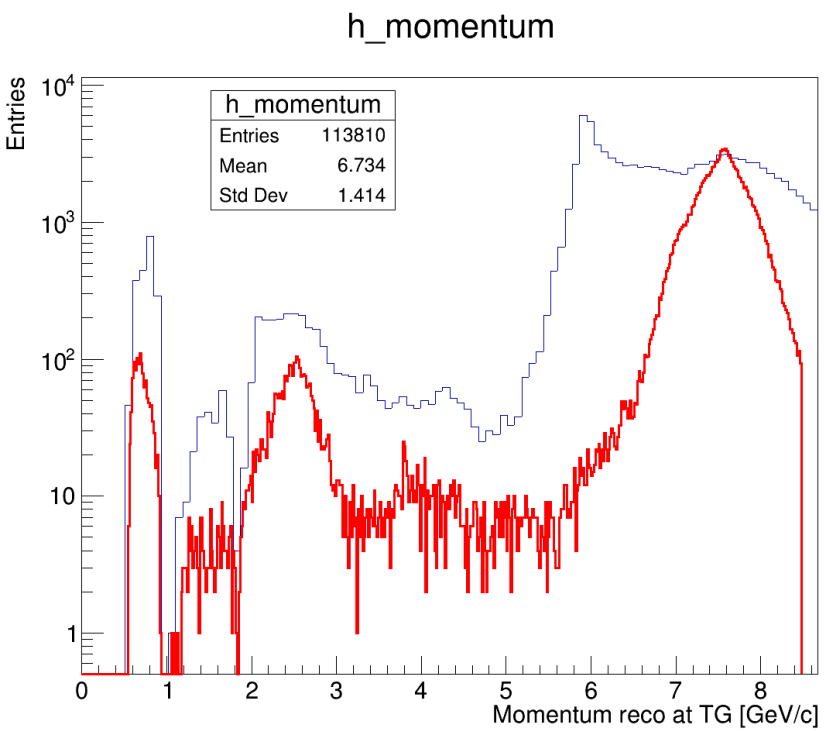

The peak
The FOOT collaboration


The peak
of Isotopic Cross Section
distributions
The FOOT
collaboration

Thank you for the attention!

Back up slides

momentum, run 7076



Analysis strategy

In the analysis, I am considering the following levels:

MC DATASET

Reference (MC)

From FLUKA MC quantities:
all ***TAMCParticles***

- primary beams
- primary fragments generated in the TG which cross the end of TW

(all the particle inside the geometrical acceptance of the setup without secondary fragmentation beneath the detectors)

Reco

All reconstructed ***global tracks*** by GENFIT

- BM with one track
- VT – BM match
- VT IT MSD TW involved
- at least 9 points for every track
- **+ cuts**

Comparison via **MC ID** of the global track

- needed to study *efficiency*

Good Reco

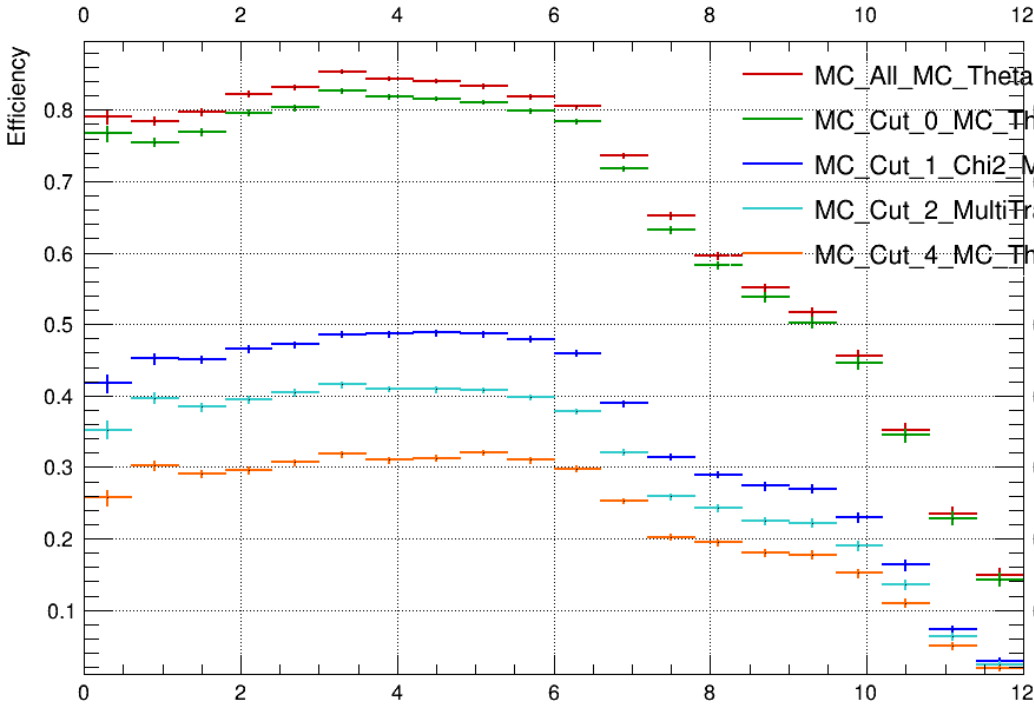
(Tracks with MC_ID which satisfies MC GENERATION requests)

Efficiency

$$\epsilon(Z,\theta) = \frac{\text{Good Reco tracks}}{\text{Reference MC tracks}}$$

- only events with BM track are considered
- the loss in efficiency is balanced by an increase in purity (close to 100% for every Z)

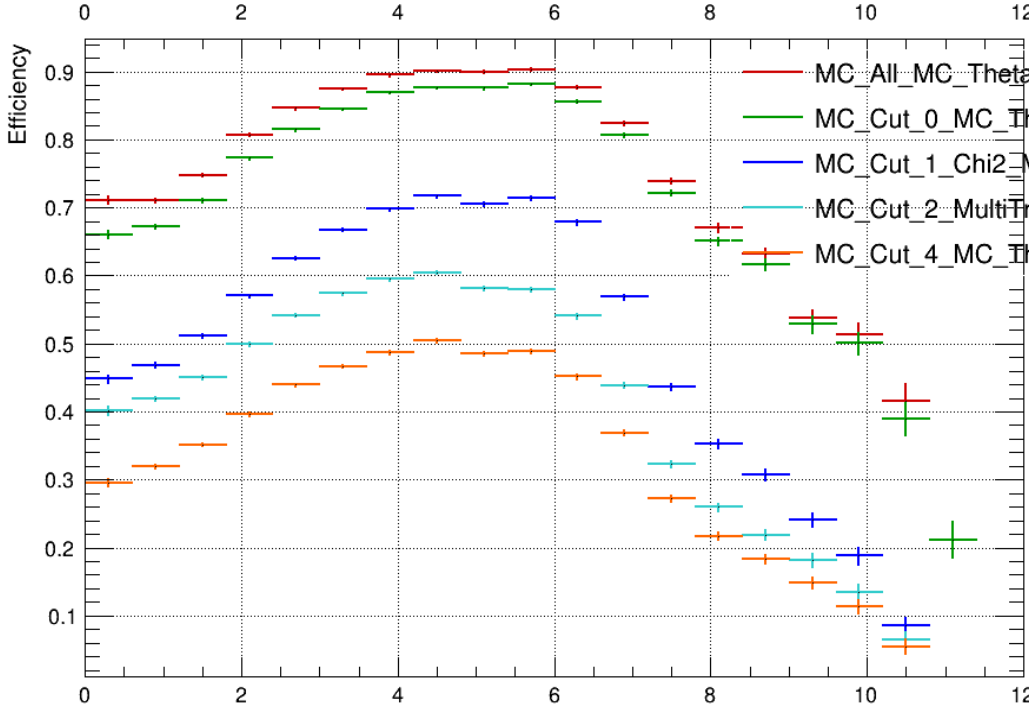
Z=1



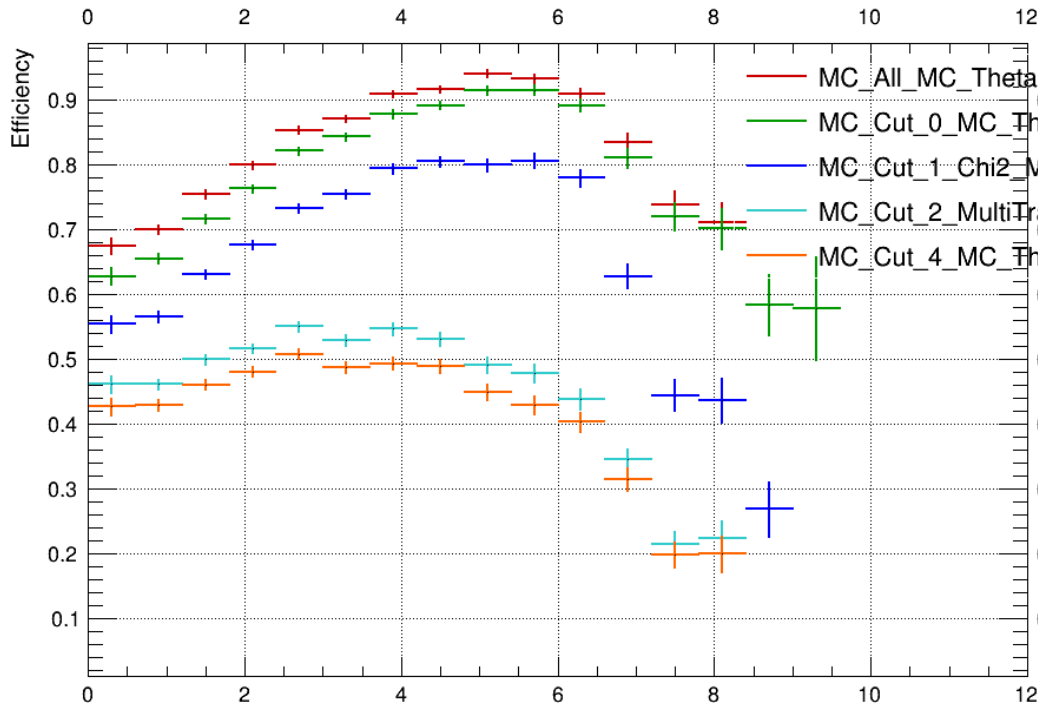
Reconstruction
Quality cut
Multi-tracks cut
TW point cut

Efficiency

Z=2



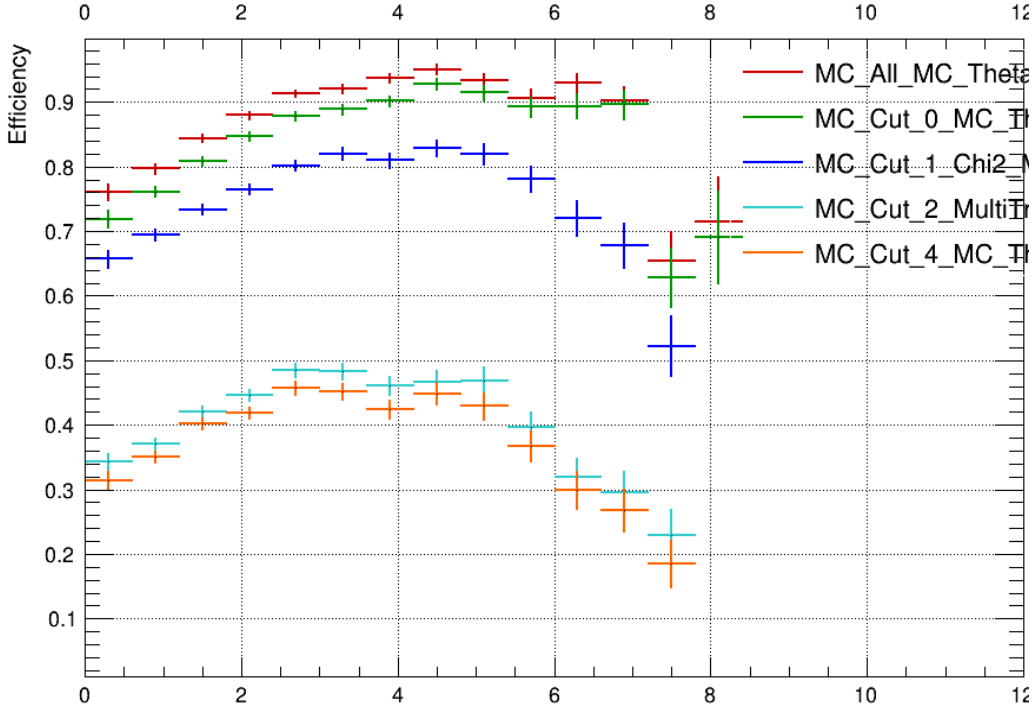
Z=3



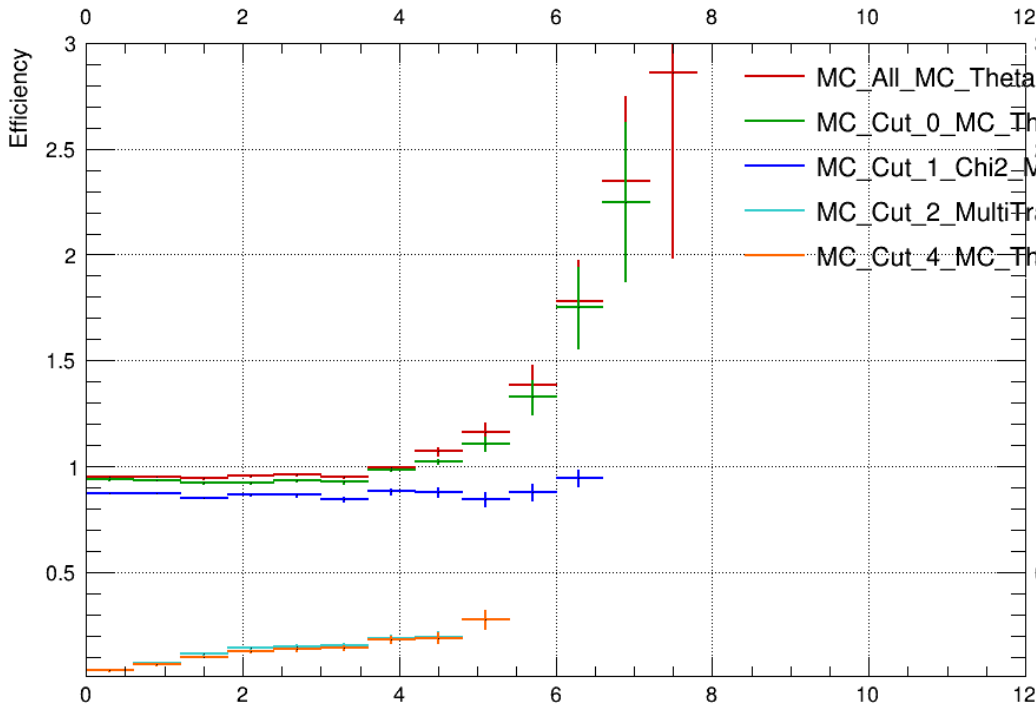
Reconstruction
Quality cut
Multi-tracks cut
TW point cut

Efficiency

Z=4



Z=5

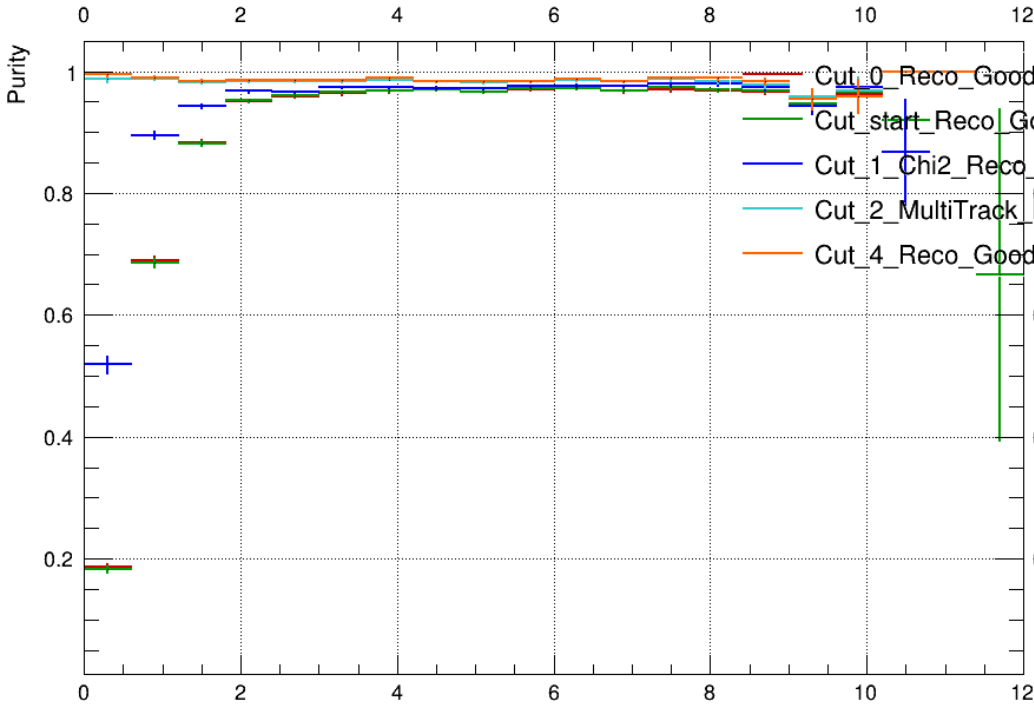


Reconstruction
Quality cut
Multi-tracks cut
TW point cut

Purity

$$\text{purity} = \frac{\text{Good Reco tracks}}{\text{All Reco tracks}}$$

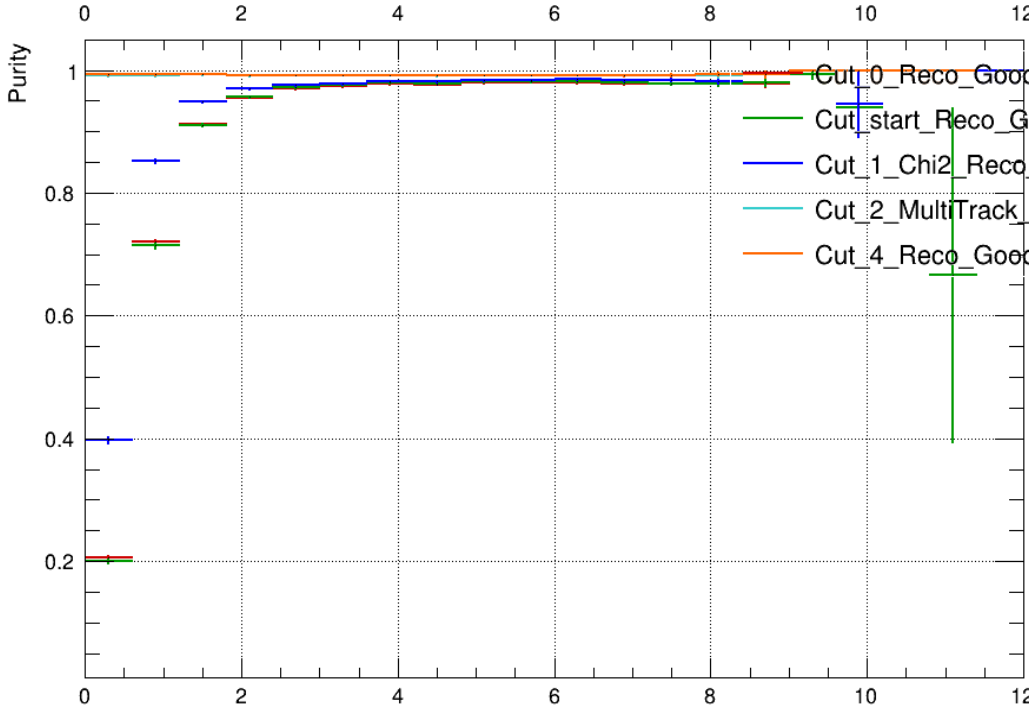
Z=1



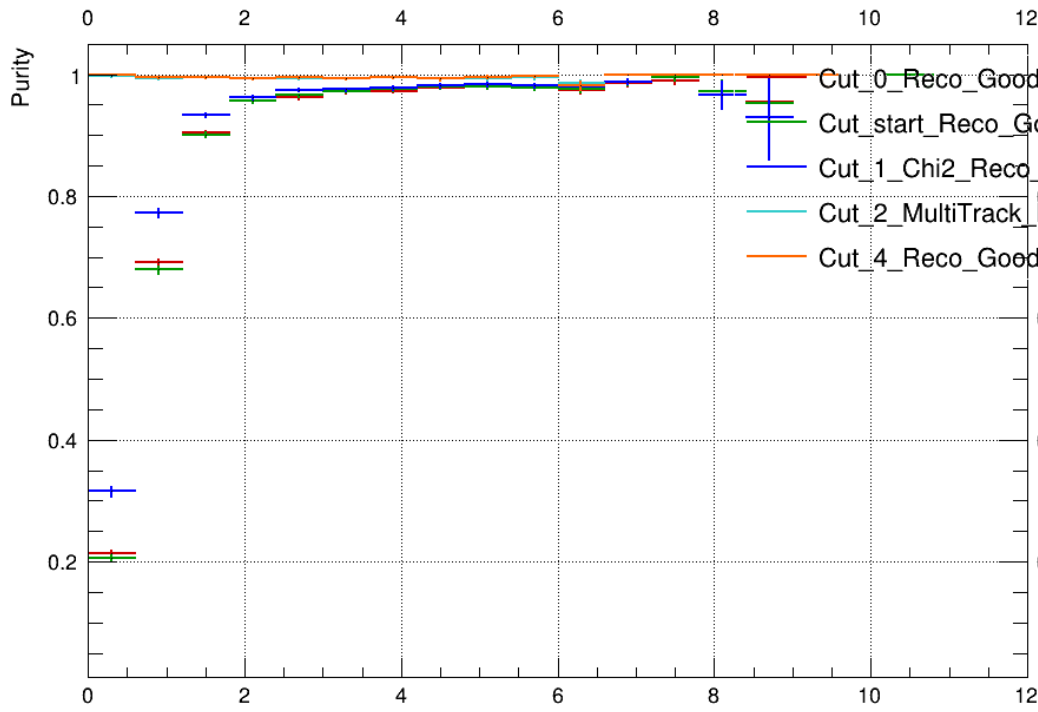
Reconstruction
Quality cut
Multi-tracks cut
TW point cut

Purity

Z=2



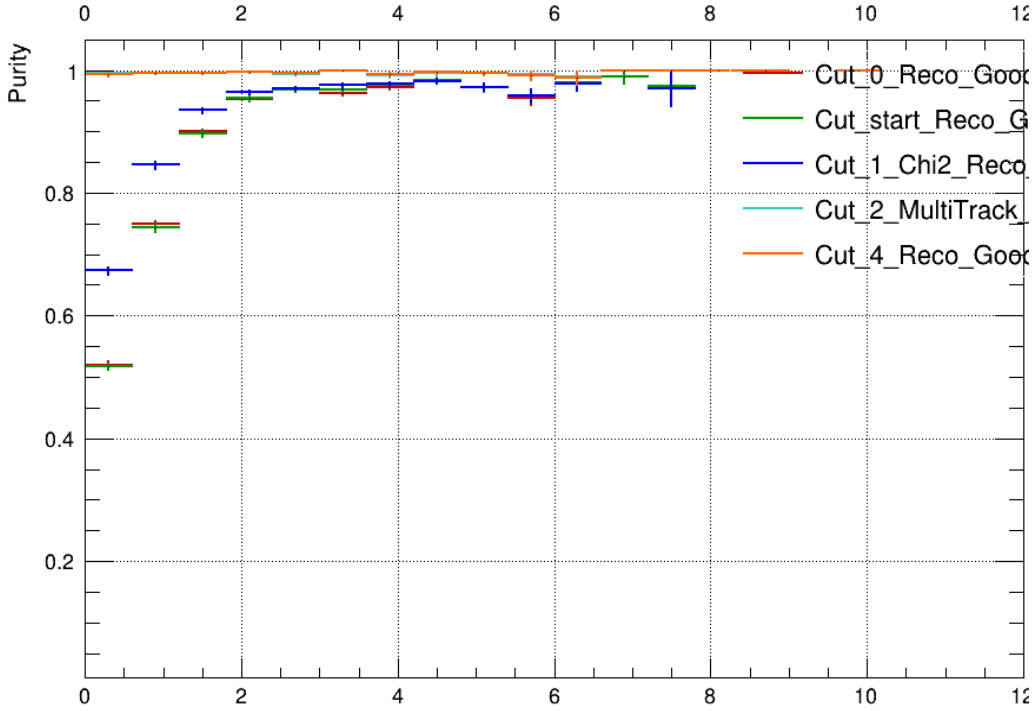
Z=3



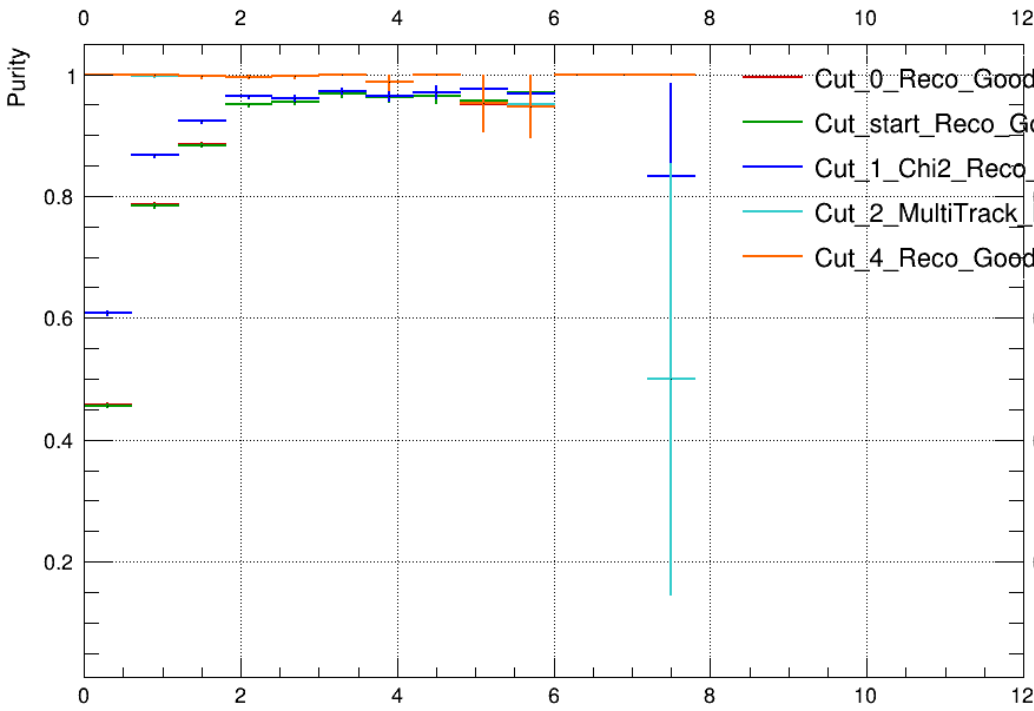
Reconstruction
Quality cut
Multi-tracks cut
TW point cut

Purity

Z=4



Z=5



Reconstruction
Quality cut
Multi-tracks cut
TW point cut

Cross Section closure test

A lot of effort is done to make IT suitable for CNAO24 analysis,
meanwhile **VT**, **MSD** and **TW** will be used.
How does the closure test change?

full tracking setup

Reconstruction
global track using Kalman Filter-based algorithm
GENFIT
it has a **VTX tracklet**
BM – VT tracklet match
BM has only 1 track for the event
it is made of at least **9 clusters** (~70% of totals)
it considers **MSD** and **IT** clusters
it has a **TW point**

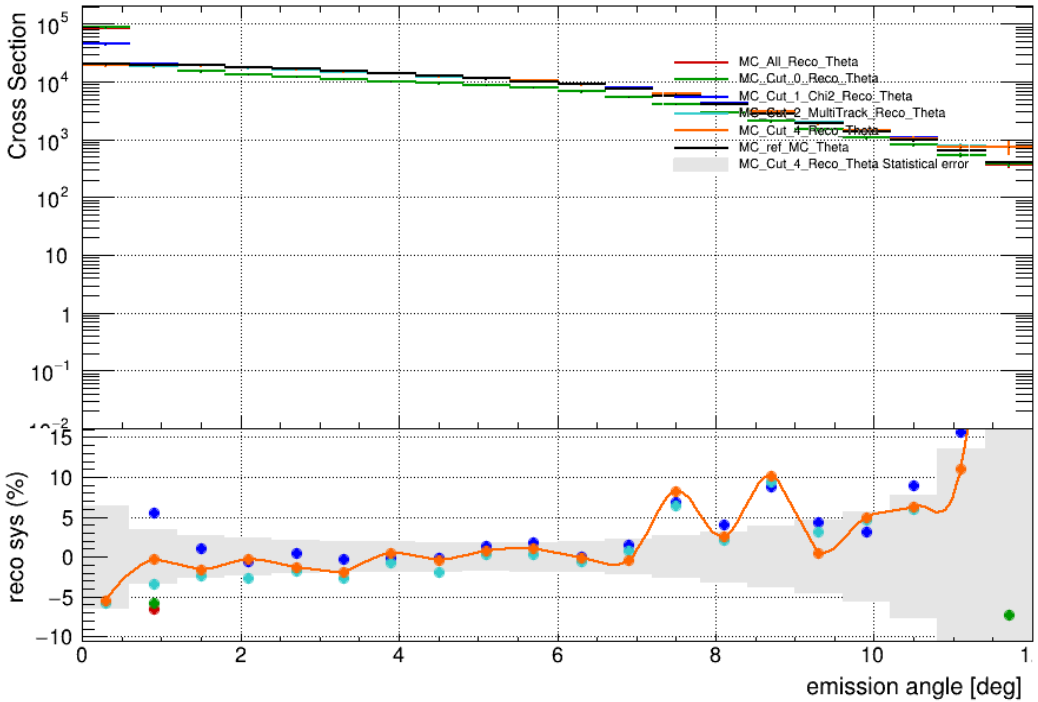
VT MSD tracking setup

Reconstruction
global track using Kalman Filter-based algorithm
GENFIT
it has a **VTX tracklet**
BM – VT tracklet match
BM has only 1 track for the event
it is made of at least 8 **clusters** (~70% of totals)
it considers **MSD** clusters
it has a **TW point**

Cross Section closure test

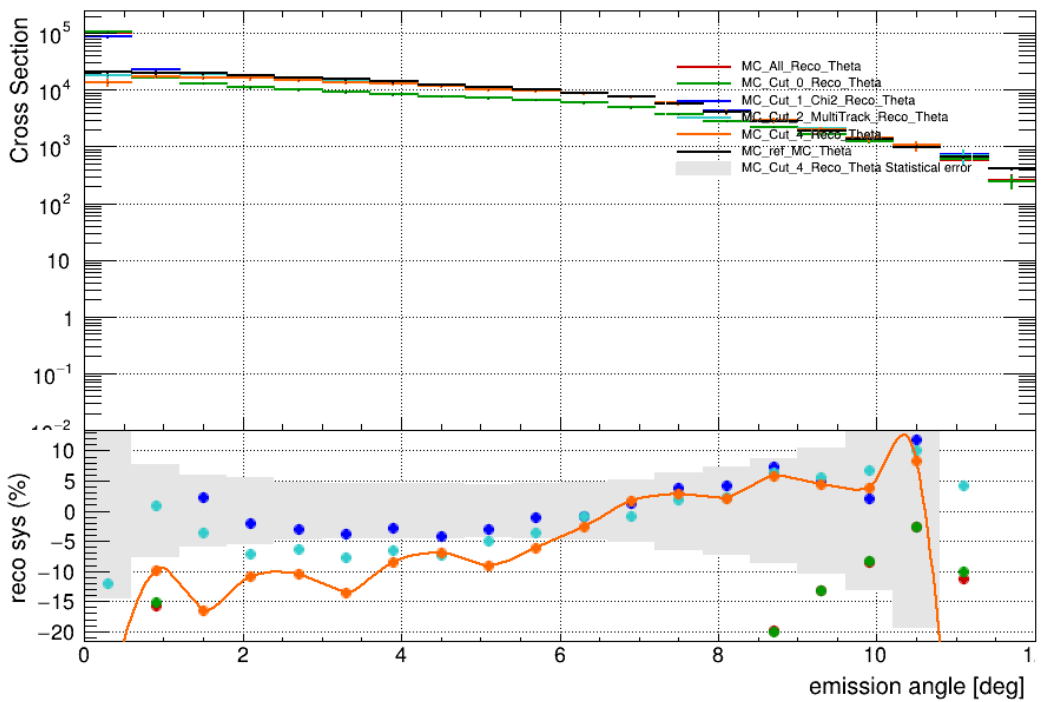
[mb/sr]

full tracking setup



[mb/sr]

VT MSD tracking setup

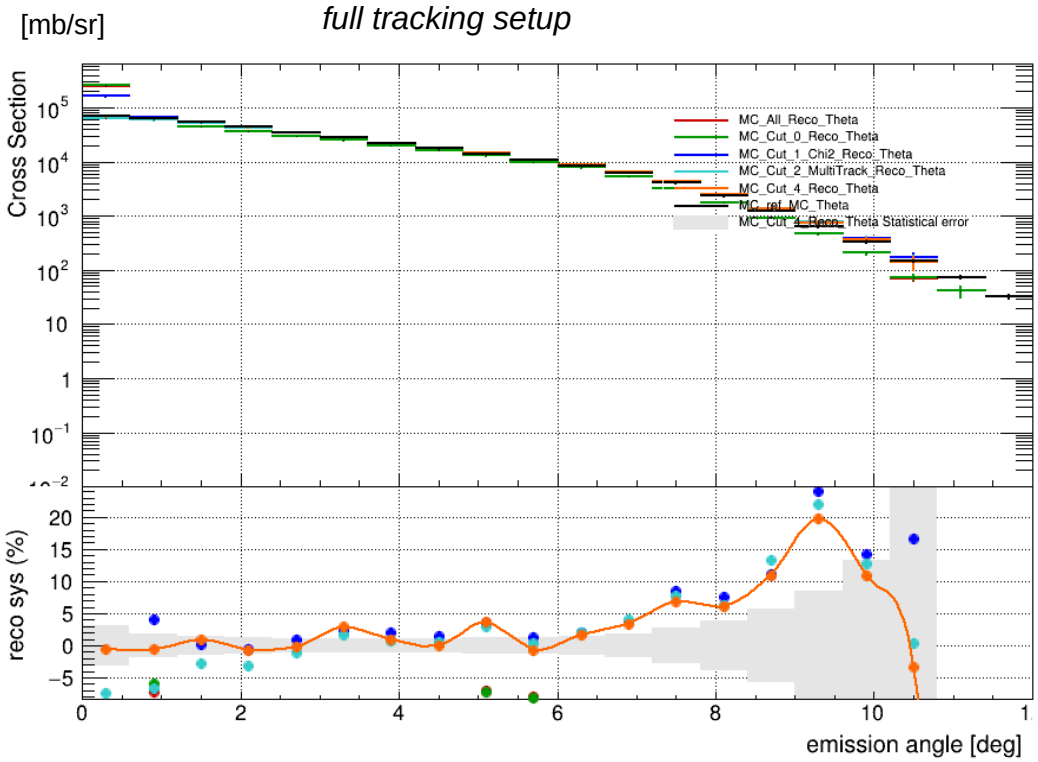


Z=1

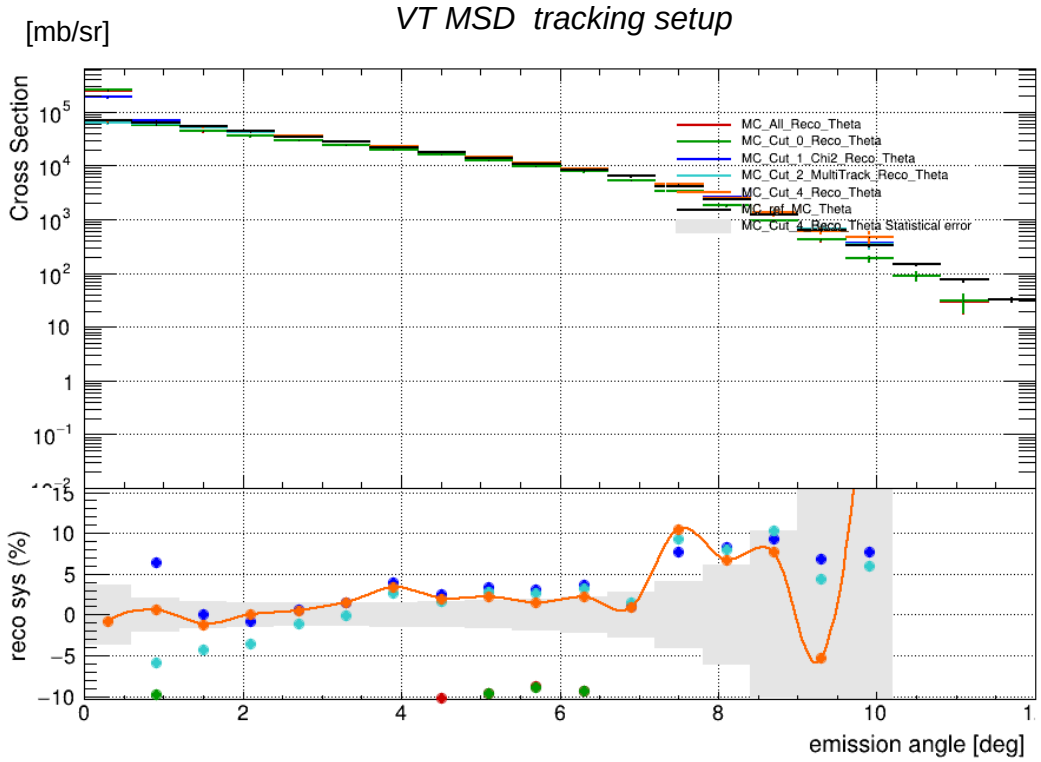
Reconstruction
Quality cut
Multi-tracks cut
TW point cut

Cross Section closure test

full tracking setup



VT MSD tracking setup

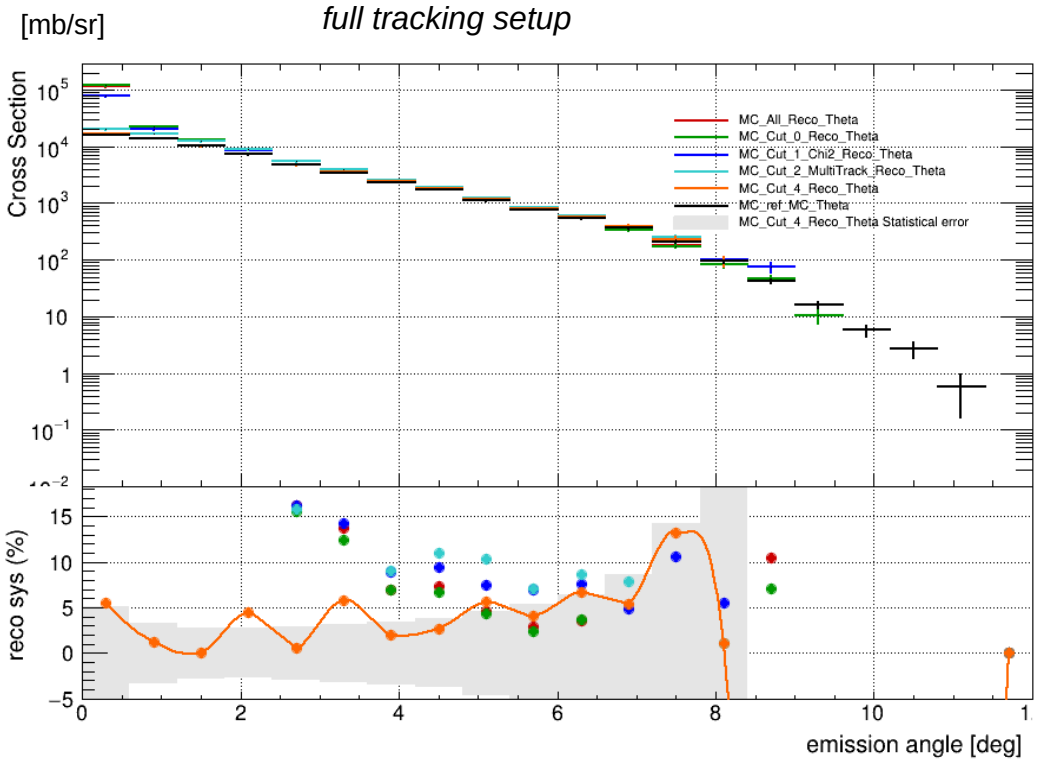


Z=2

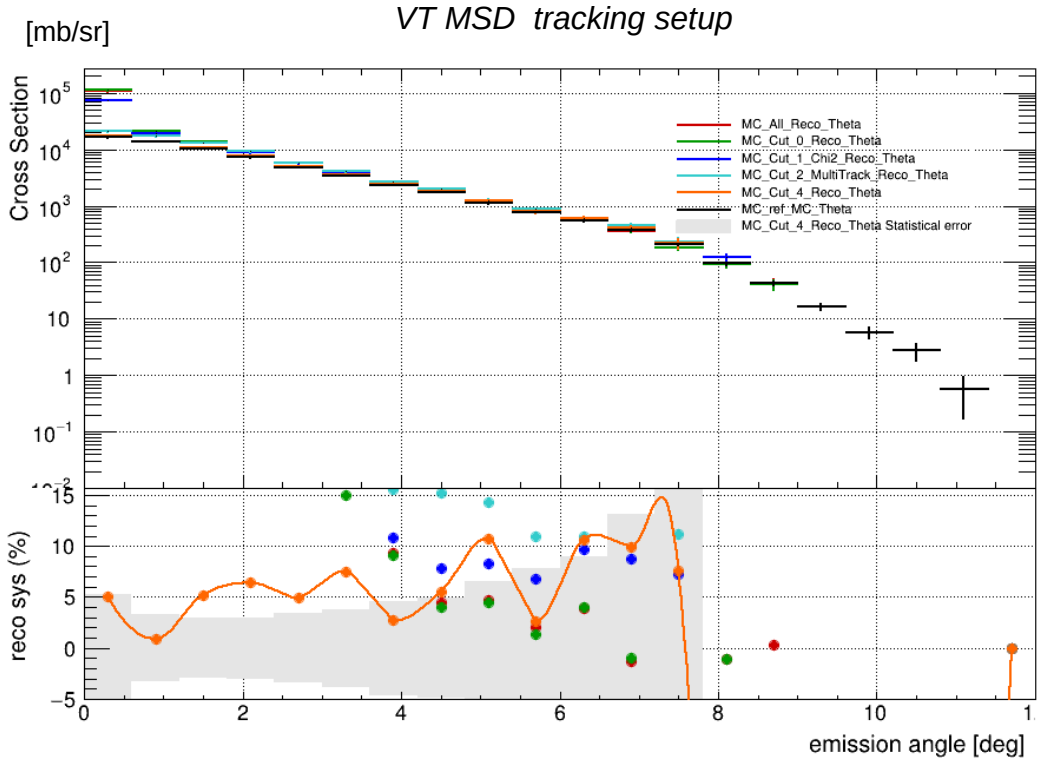
Reconstruction
Quality cut
Multi-tracks cut
TW point cut

Cross Section closure test

full tracking setup



VT MSD tracking setup



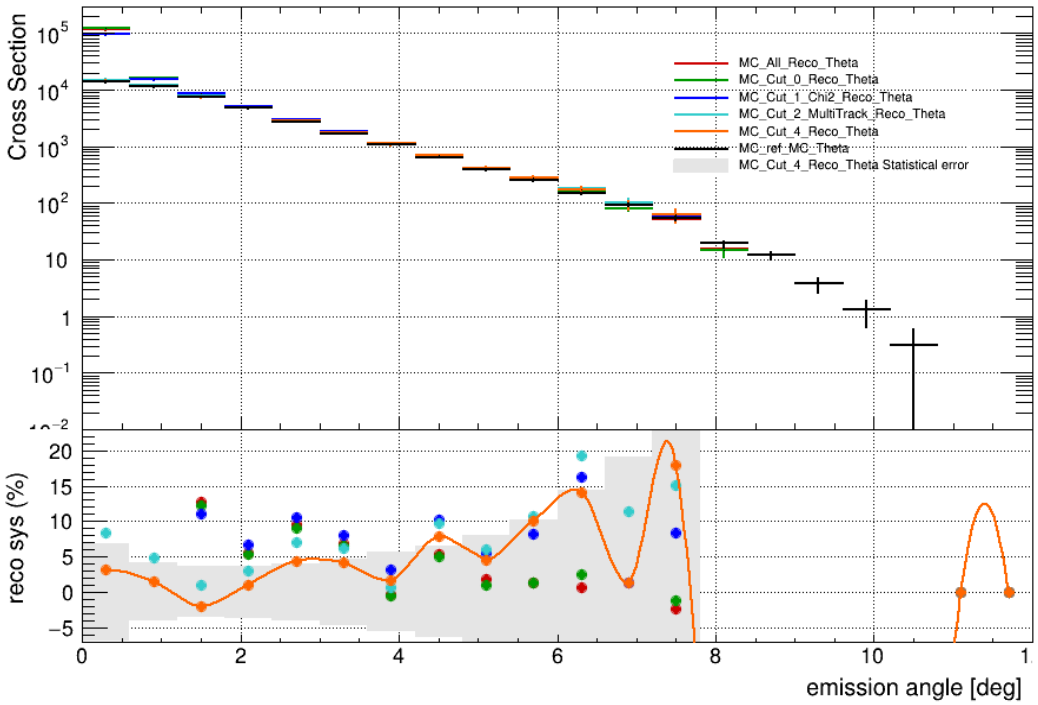
Z=3

Reconstruction
Quality cut
Multi-tracks cut
TW point cut

Cross Section closure test

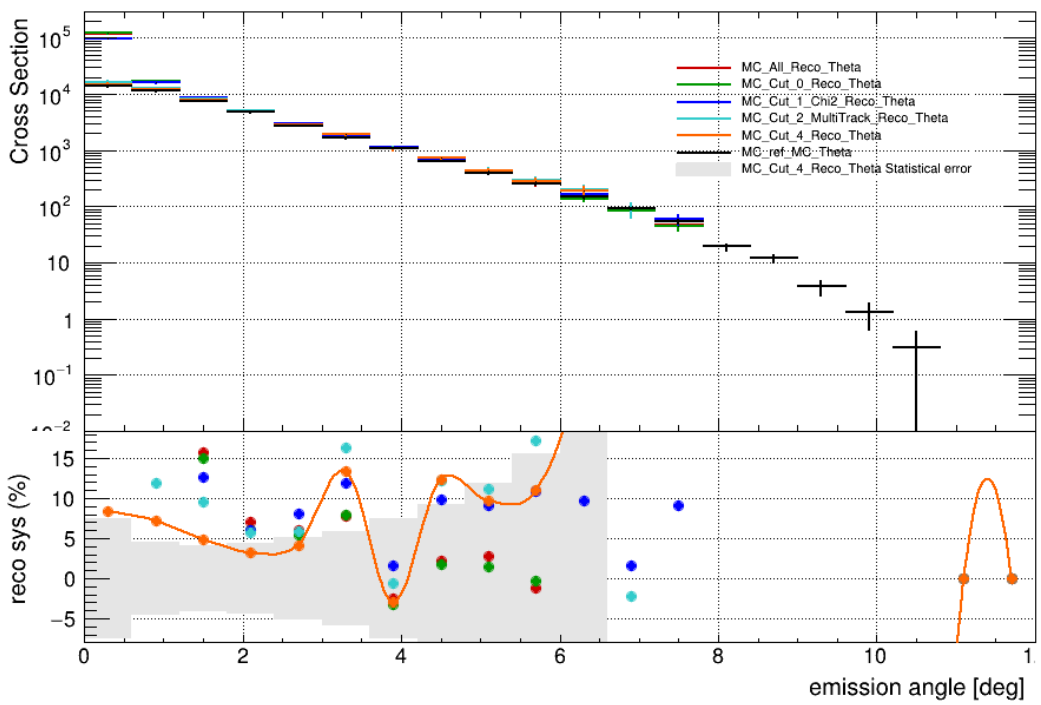
[mb/sr]

full tracking setup



[mb/sr]

VT MSD tracking setup

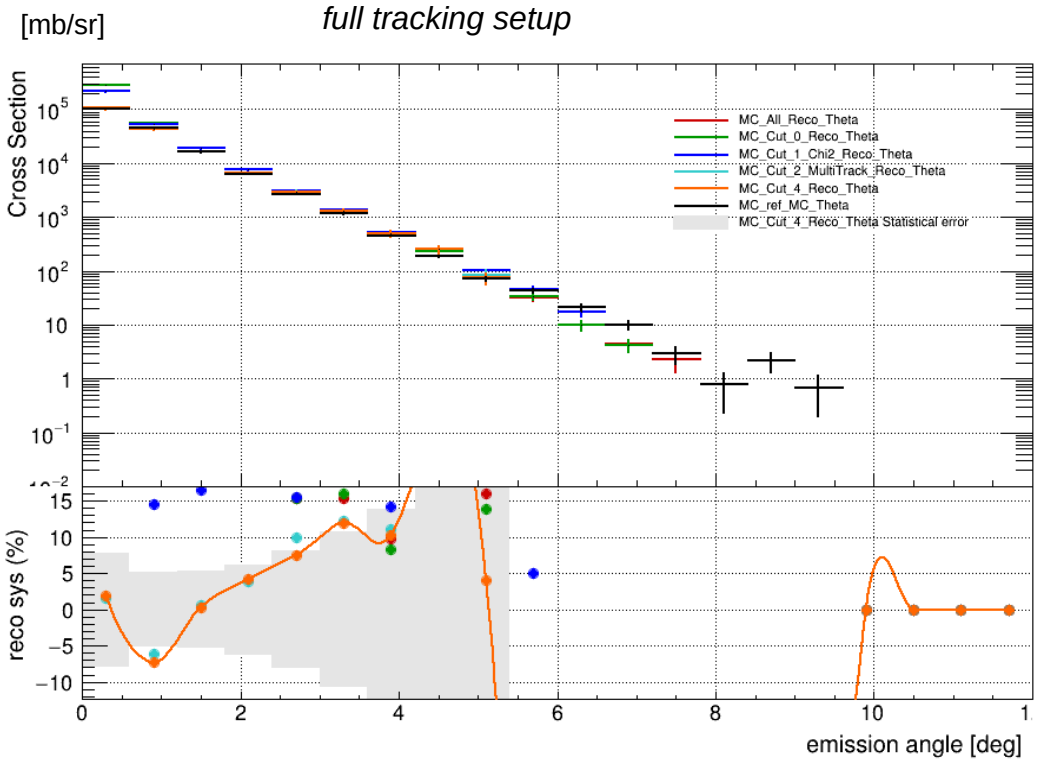


Z=4

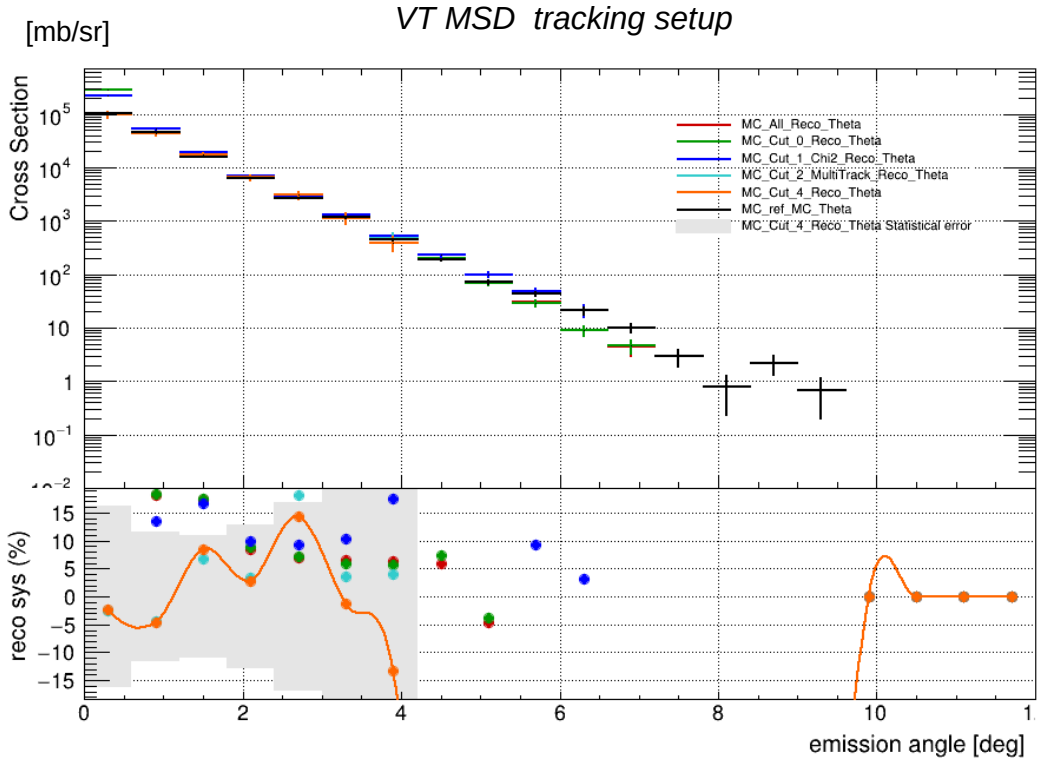
Reconstruction
Quality cut
Multi-tracks cut
TW point cut

Cross Section closure test

full tracking setup



VT MSD tracking setup



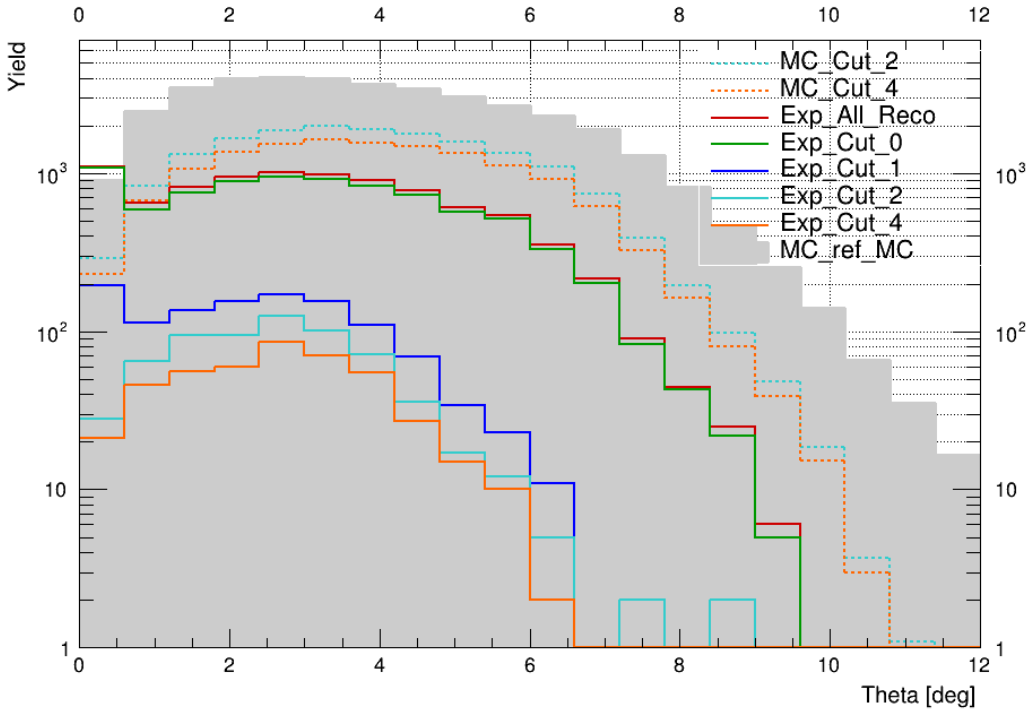
Z=5

Reconstruction
Quality cut
Multi-tracks cut
TW point cut

Yield cuts

The same cuts of MC are used in Exp data:

es. Z=2



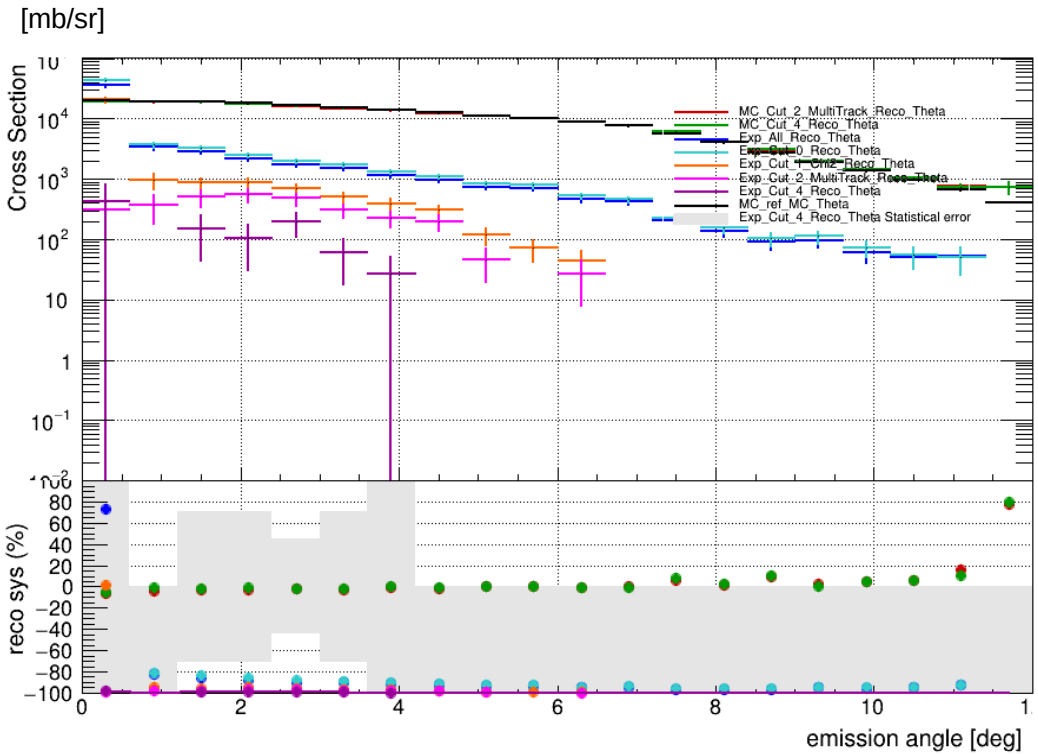
Reconstruction
Quality cut
Multi-tracks cut
TW point cut

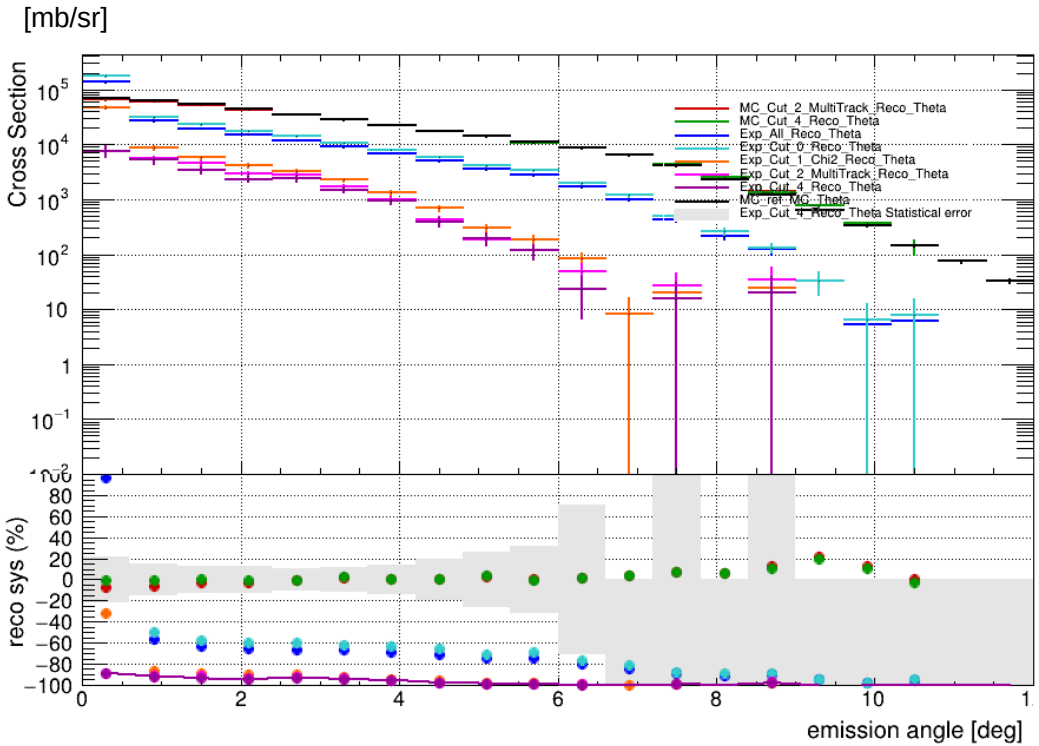
Big drop of statistics after **Chi2 cut**!

Several causes to investigate:

- VTX efficiency ?
- MSD efficiency ?
- GENFIT Glb Tracking efficiency / systematics ?
- Alignment (Detectors + B field) ?

Data Cross Section comparison (super prelim

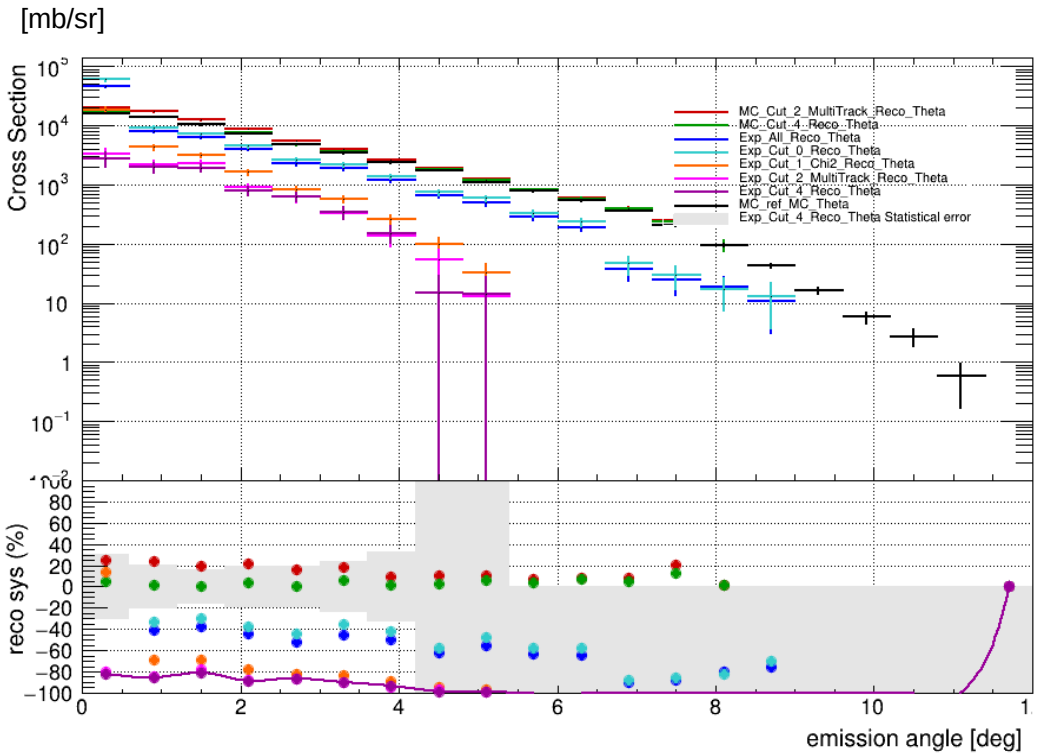


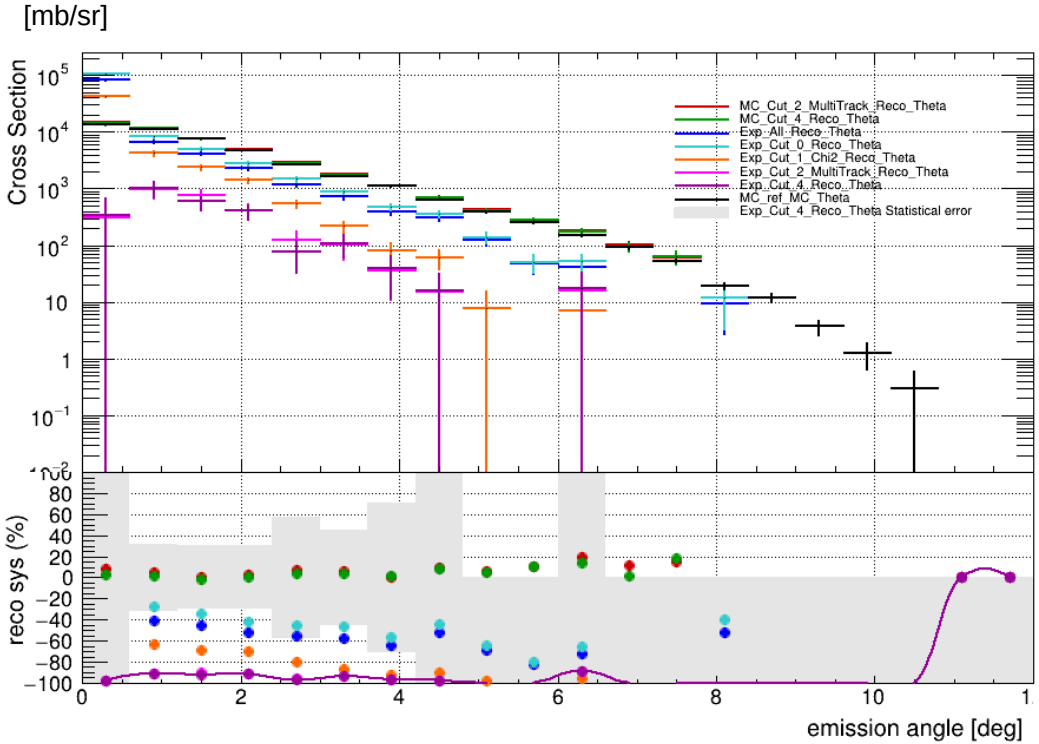


Z=1

Z=2

Data Cross Section comparison (super prelim



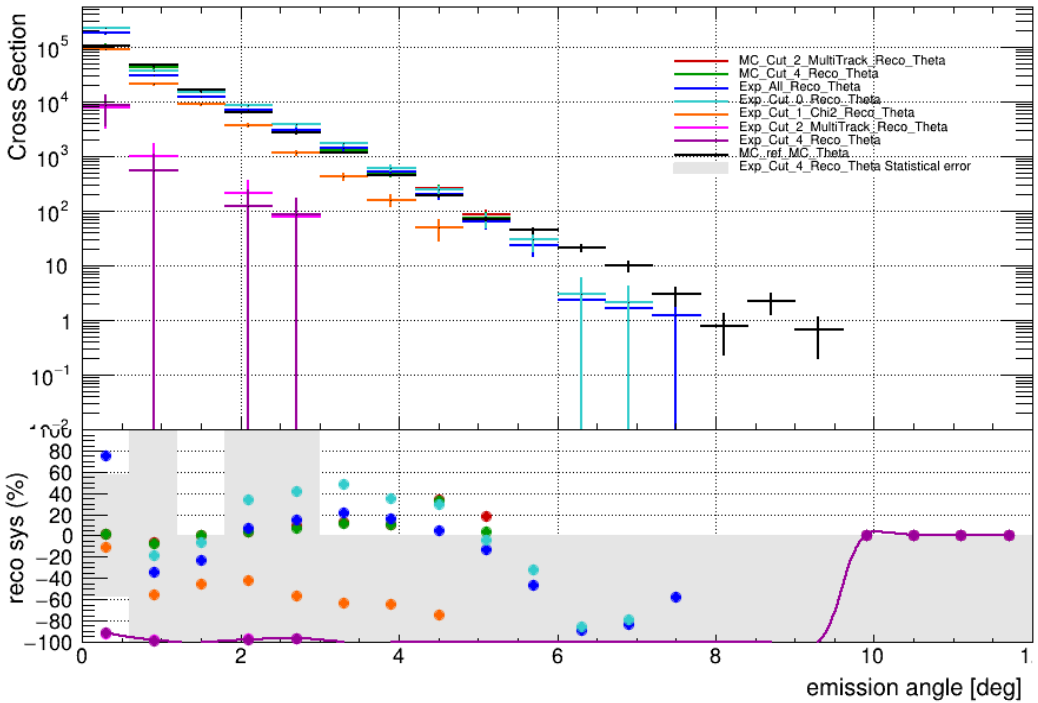


Z=3

Z=4

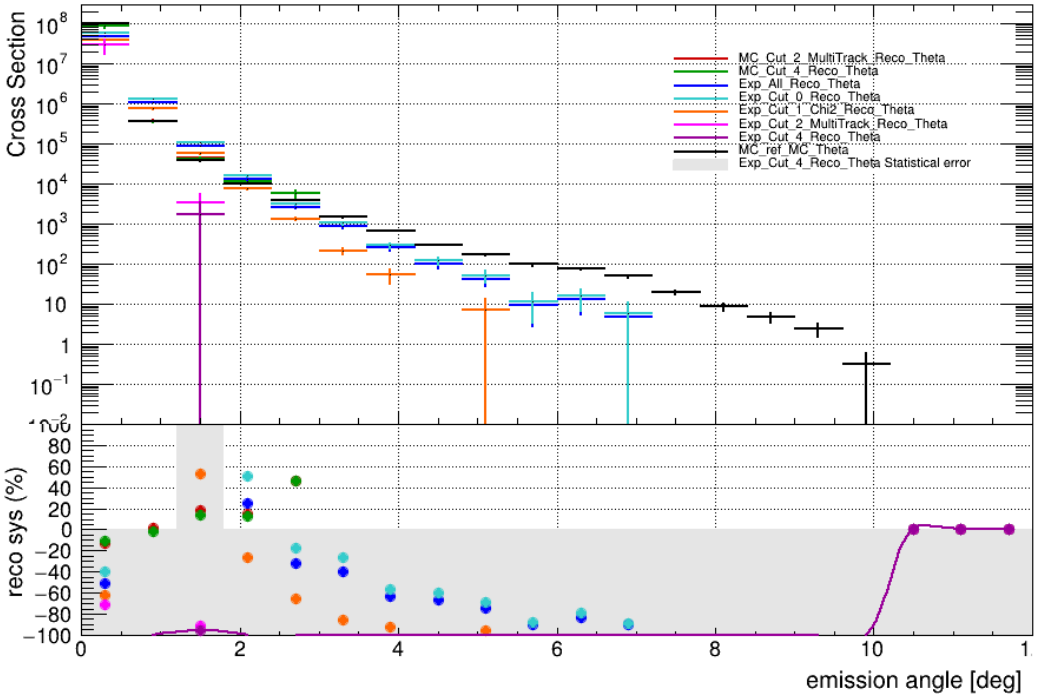
Data Cross Section comparison (super prelim

[mb/sr]



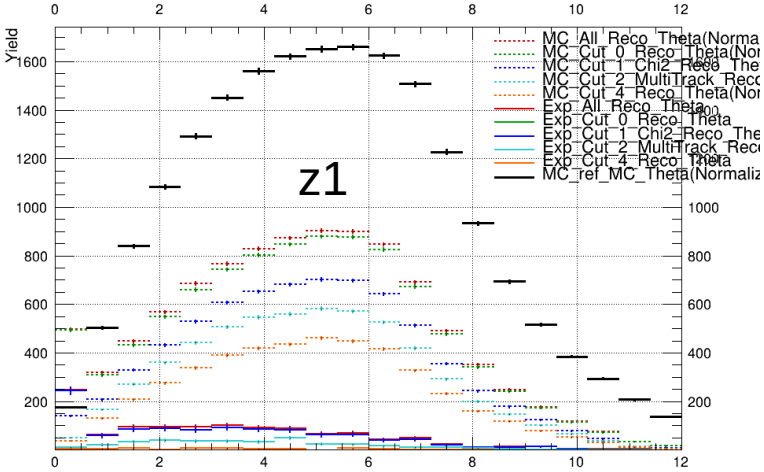
Z=5

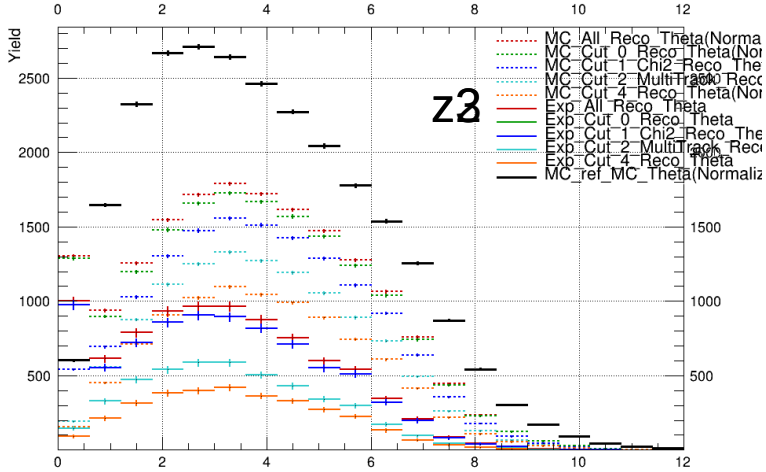
[mb/sr]

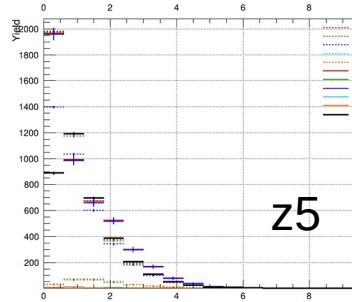


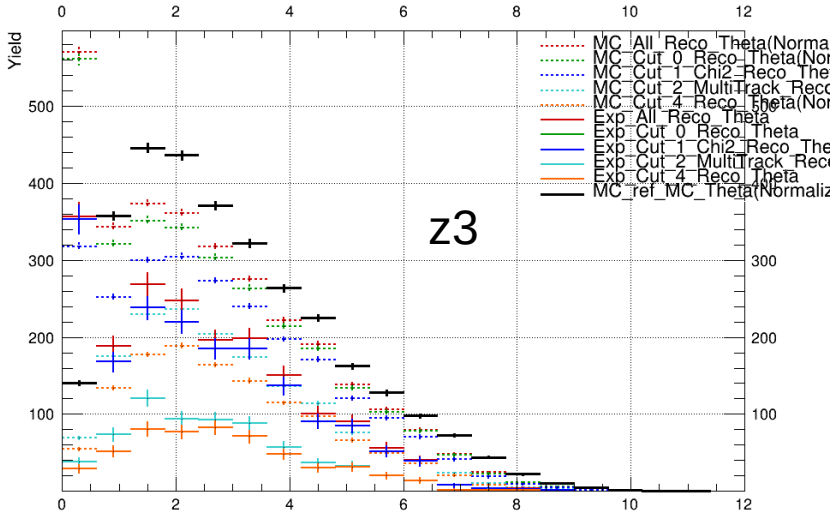
Z=6

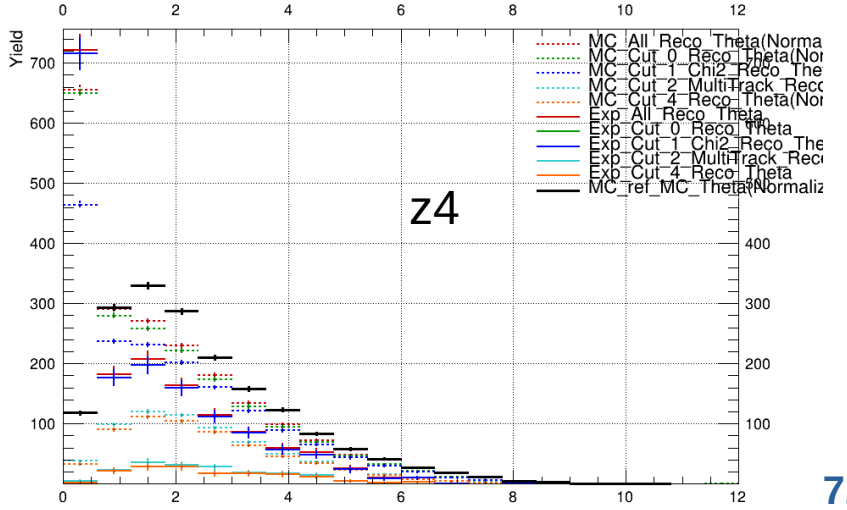
All Yields


Yield
MC_All_Reco_Theta(Norma
MC_Cut_0_Reco_Theta(Nor
MC_Cut_1_Chi2_Reco_The
MC_Cut_2_MultiTrack_Recc
MC_Cut_4_Reco_Theta(Nor
Exp_All_Reco_Theta
Exp_Cut_0_Reco_Theta
Exp_Cut_1_Chi2_Reco_The
Exp_Cut_2_MultiTrack_Rec
Exp_Cut_4_Reco_Theta
MC_ref_MC_Theta(Normaliz
z1

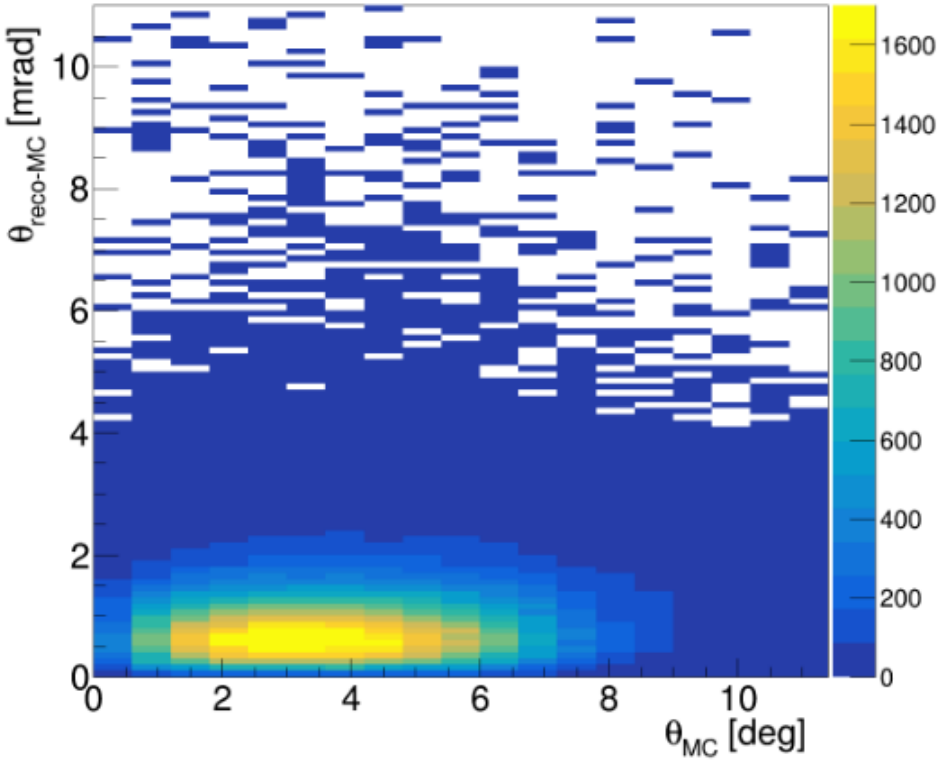

Yield
MC_All_Reco_Theta(Norma
MC_Cut_0_Reco_Theta(Nor
MC_Cut_1_Chi2_Reco_The
MC_Cut_2_MultiTrack_Recc
MC_Cut_4_Reco_Theta(Nor
Exp_All_Reco_Theta
Exp_Cut_0_Reco_Theta
Exp_Cut_1_Chi2_Reco_The
Exp_Cut_2_MultiTrack_Rec
Exp_Cut_4_Reco_Theta
MC_ref_MC_Theta(Normaliz
z2

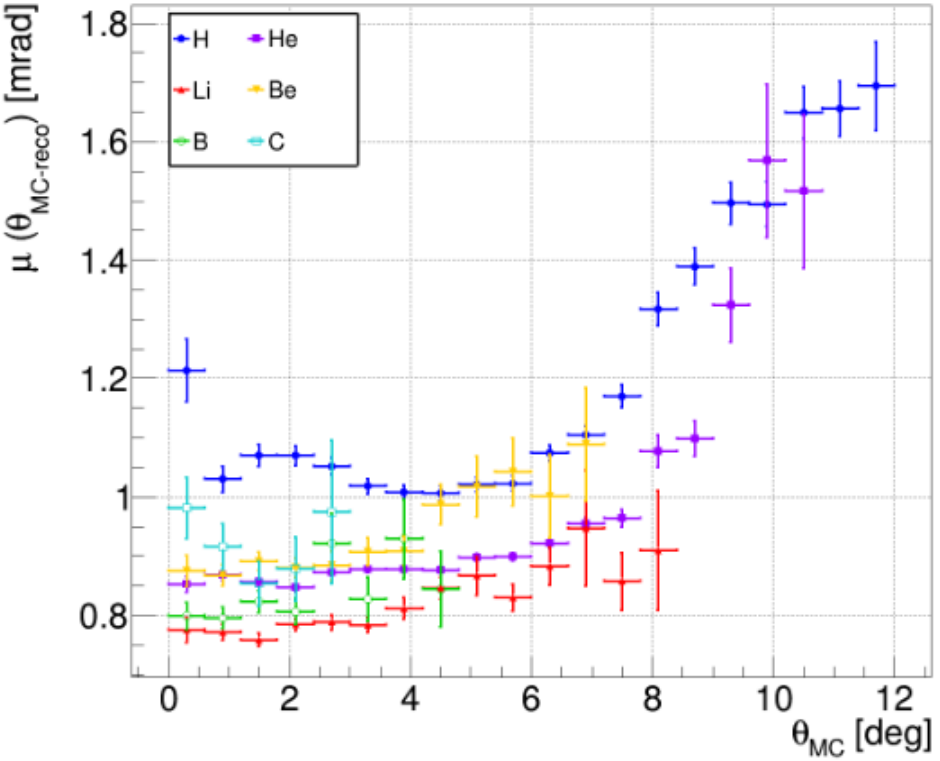

Yield
z5


Yield
MC_All_Reco_Theta(Norma
MC_Cut_0_Reco_Theta(Nor
MC_Cut_1_Chi2_Reco_The
MC_Cut_2_MultiTrack_Recc
MC_Cut_4_Reco_Theta(Nor
Exp_All_Reco_Theta
Exp_Cut_0_Reco_Theta
Exp_Cut_1_Chi2_Reco_The
Exp_Cut_2_MultiTrack_Rec
Exp_Cut_4_Reco_Theta
MC_ref_MC_Theta(Normaliz
z3


Yield
MC_All_Reco_Theta(Norma
MC_Cut_0_Reco_Theta(Nor
MC_Cut_1_Chi2_Reco_The
MC_Cut_2_MultiTrack_Recc
MC_Cut_4_Reco_Theta(Nor
Exp_All_Reco_Theta
Exp_Cut_0_Reco_Theta
Exp_Cut_1_Chi2_Reco_The
Exp_Cut_2_MultiTrack_Rec
Exp_Cut_4_Reco_Theta
MC_ref_MC_Theta(Normaliz
z4

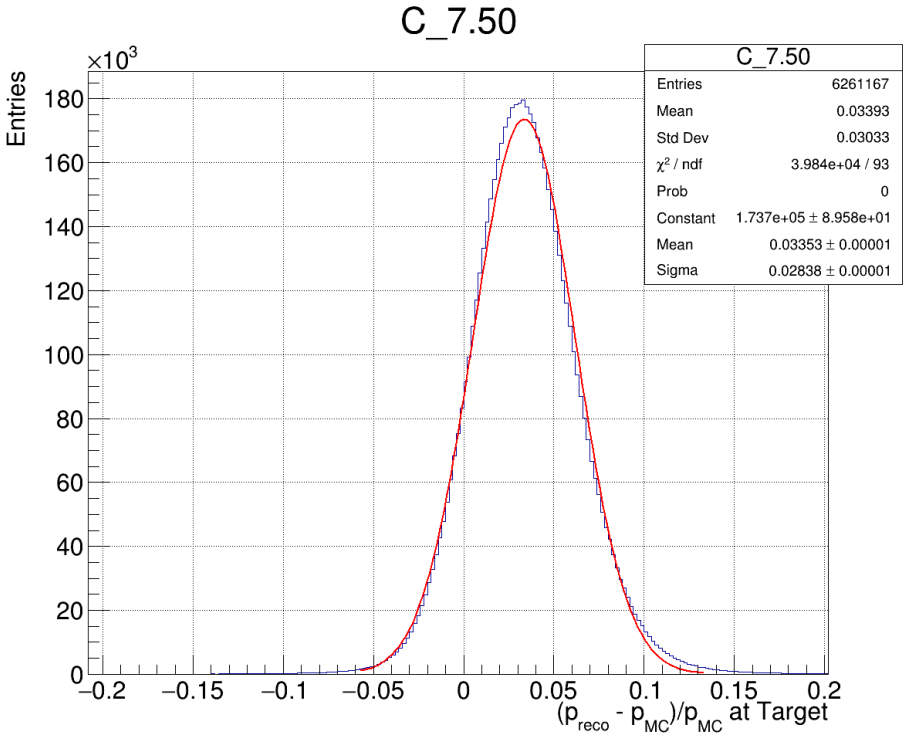
Theta Resolution





Momentum performance

$$\frac{\Delta p}{p} = \frac{p_{reco} - p_{MC}}{p_{MC}}$$

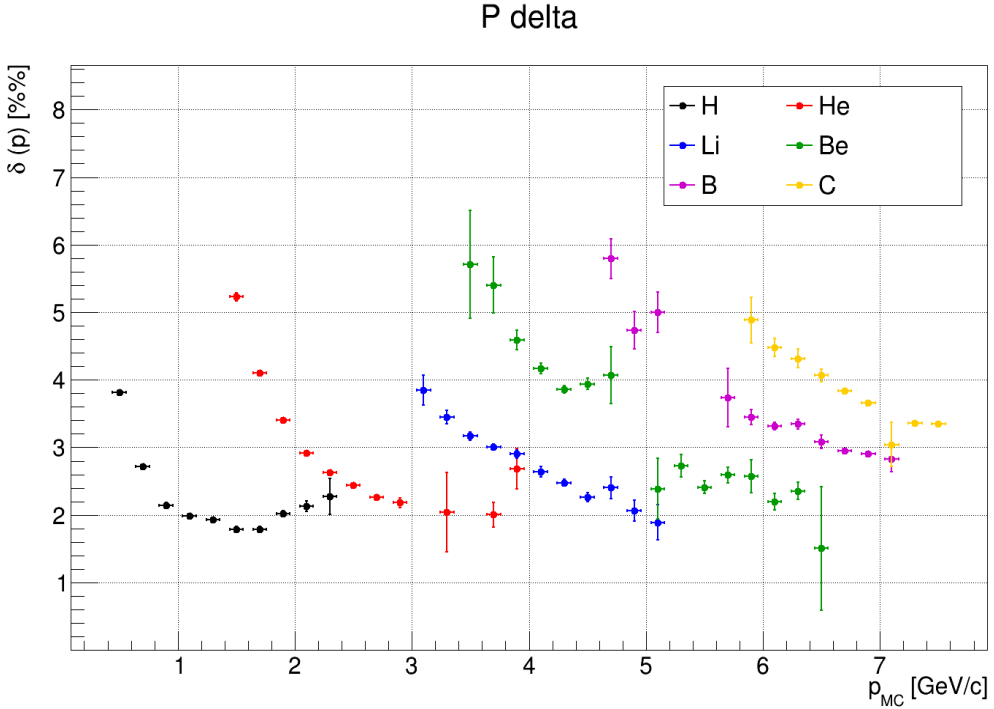


For every charge and
in different intervals of momentum,
Δp/p performance is measured in terms of
mean ± sigma
as the relative difference between reconstructed and MC momentum value

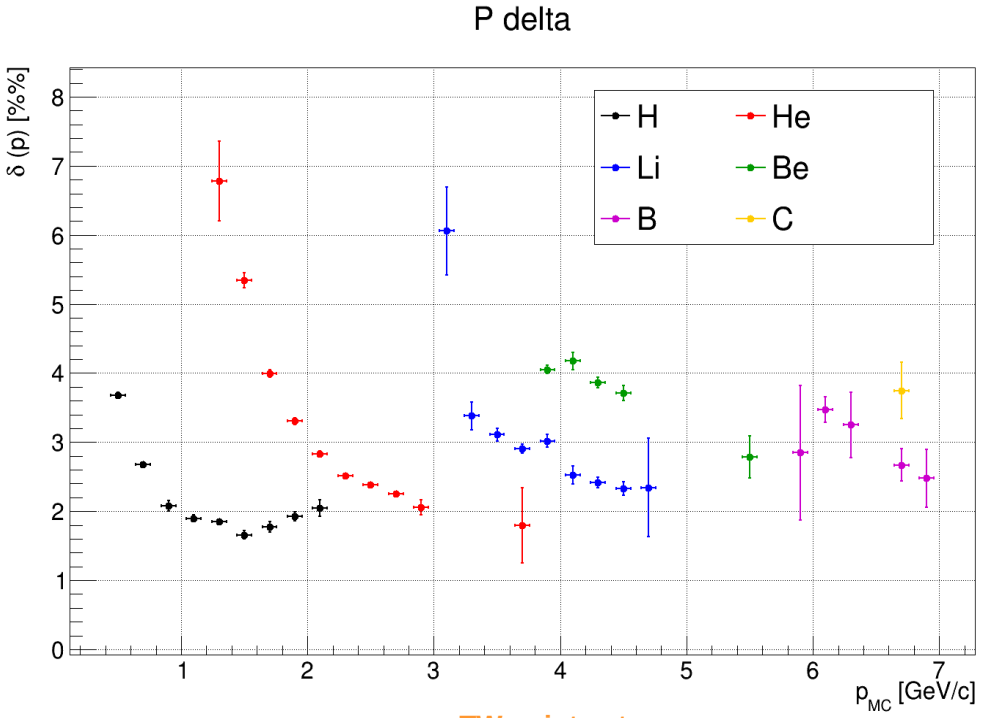
Momentum performance

$$\frac{\Delta p}{p} = \frac{p_{reco} - p_{MC}}{p_{MC}}$$

mean value



Reconstruction

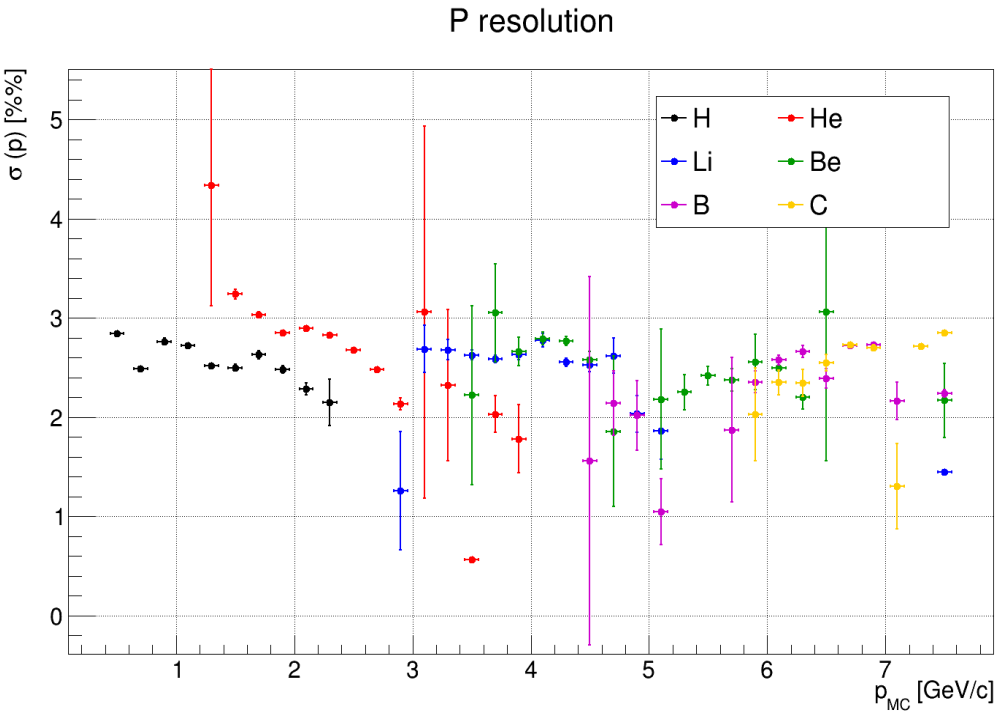


TW point cut

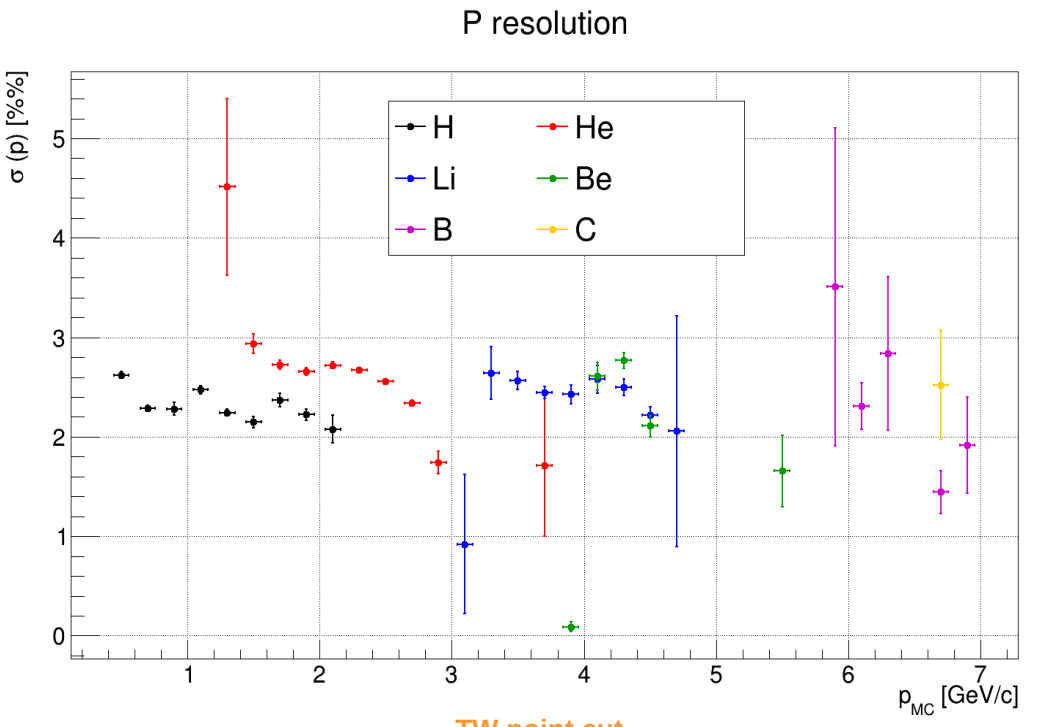
Momentum performance

$$\frac{\Delta p}{p} = \frac{p_{reco} - p_{MC}}{p_{MC}}$$

sigma value, resolution



Reconstruction



TW point cut

Momentum considerations

-
- Overestimation of the momentum, from the perfomance a discrepancy around **2-3%**, worse for lower p
- Resolution of the order of **3%**, in agreement with the requirements of the experiment

MSD thresholds cuts