TOF studies and simulation

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Summary

Several **checks of TOF and global variables** performed using

- **new TOF energy** (single slat corrections for quenching effects, added in data and in the simulation code)
- **single TDC/ADC channel calibration** (recovering of protons releasing low energy in a slat + recovering of some slats)
- **New ZID** from Samuel

- Cross-checks of the new charge identification
- Control of TOF resolutions and distributions with new TOF energy and Zid
- Control of global distributions with new TOF energy and ZID
- Changes in the TOF simulation
- Problems and plans

All the plots use the new TOF energy corrected for non-linearity effects (Eloss)

Study of charge identification

Cross check of TOF Charge Identification

Ch_MC – charge of the particle releasing more energy in the slat («true ch» from simulation)

Ch_TOF – charge assignment with new Eloss (Politecnico) + new Zid algorithm (Samuel)

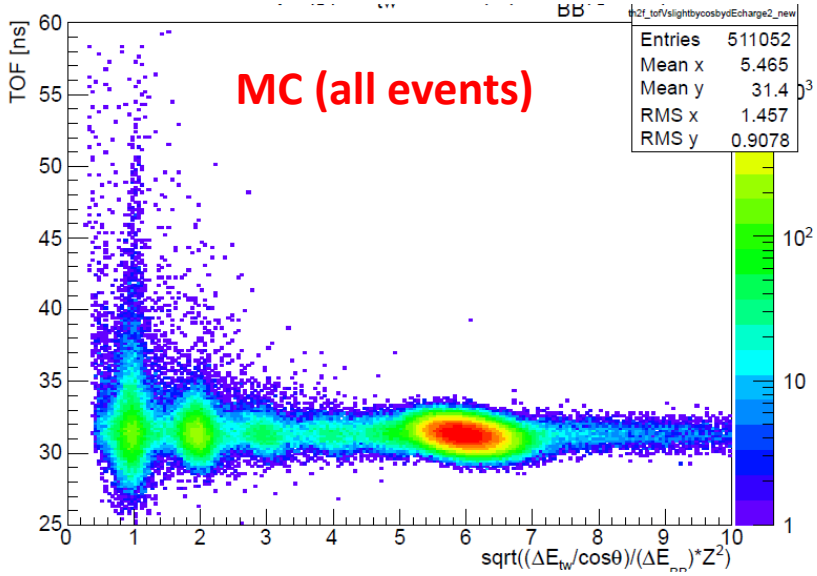
Ch_BB – calculation based on corrections based on Bethe-Block effects f(beta,cos(theta)) estimated using the β and the impact angle θ from the reconstruction for each track:

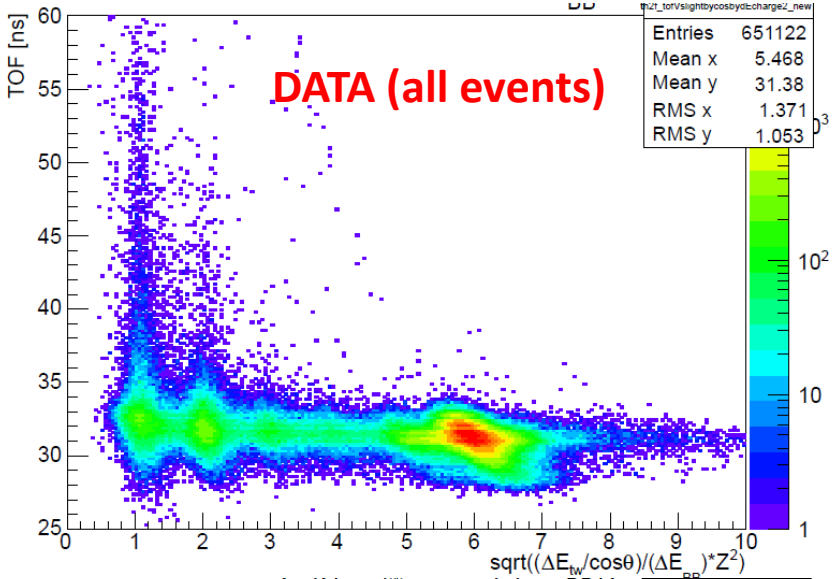
$$Ch_{BB} = \sqrt{\frac{E_{TOF}}{f(\beta, \cos(\theta))}}$$

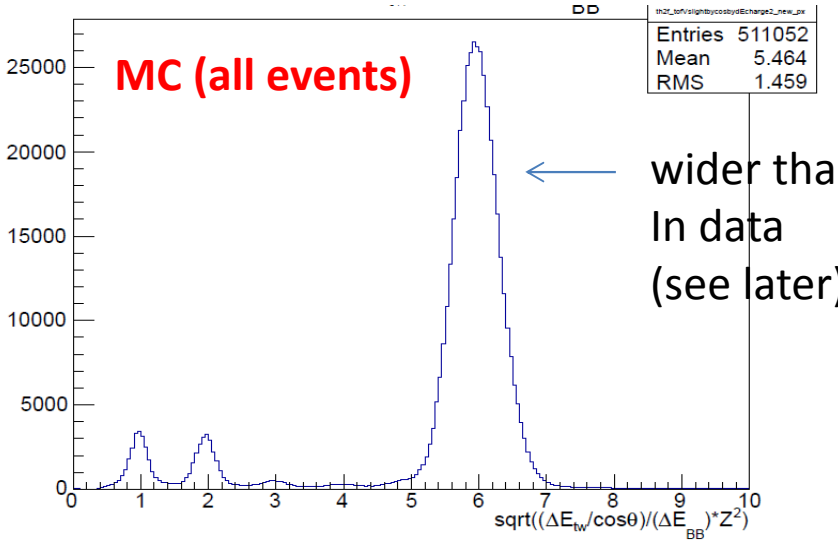
The Ch_BB distribution should not depend on the TOF value
Closest integer value selected for the charge (algorithm not optimized at all).

Fragmentation events: more than 1 track in the VTX detector

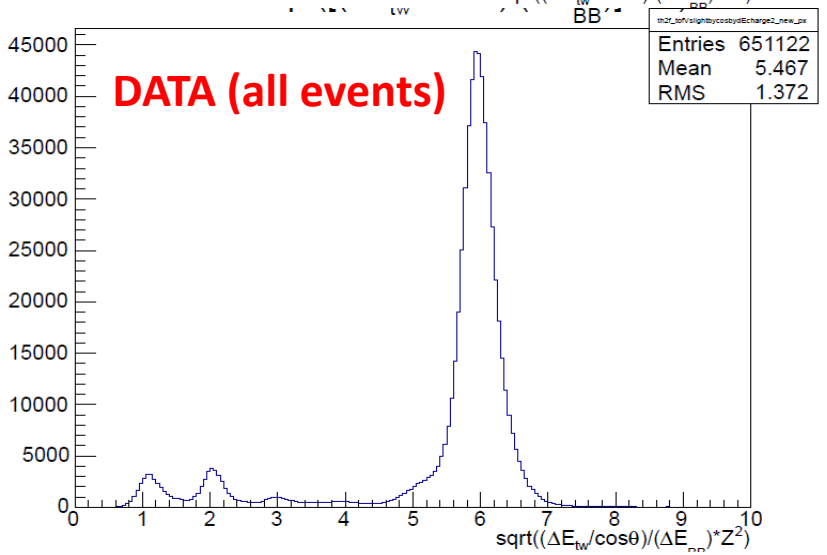
TOF vs Ch_BB distributions (all events)





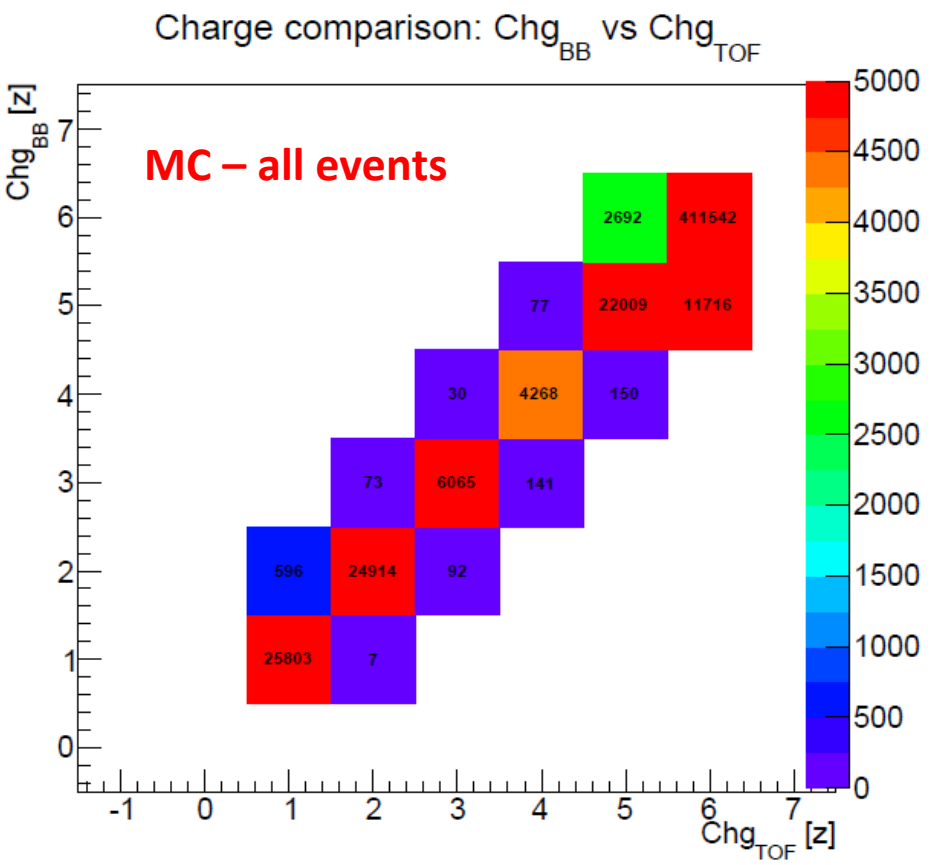


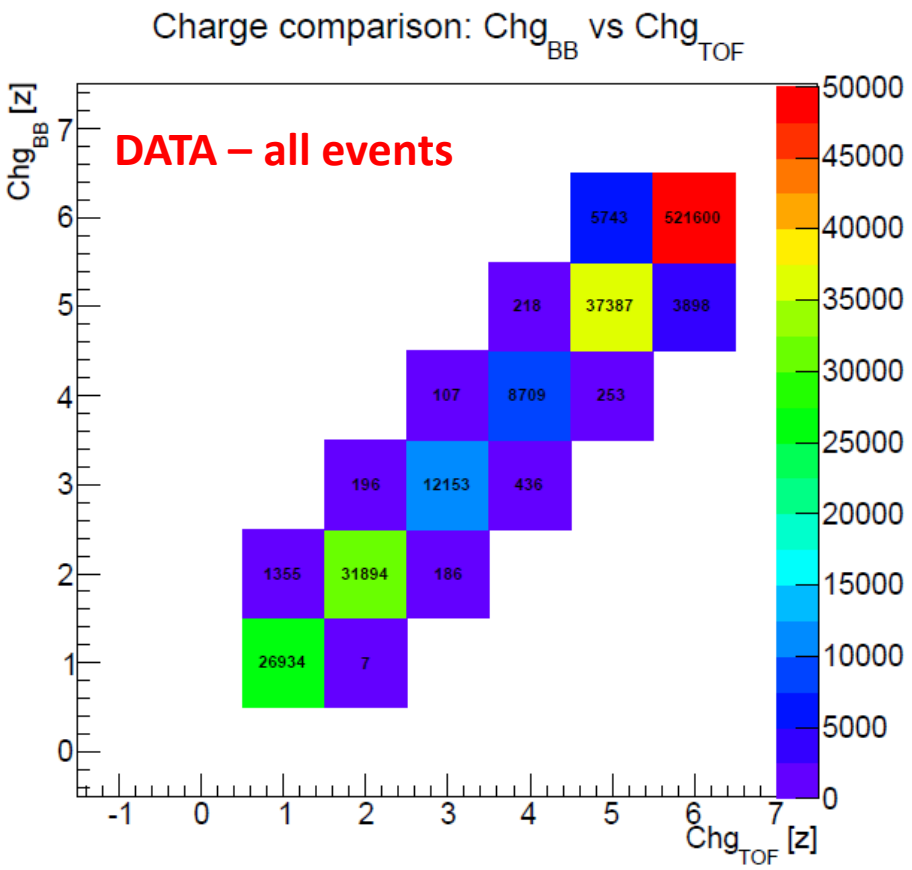
wider than
In data
(see later)



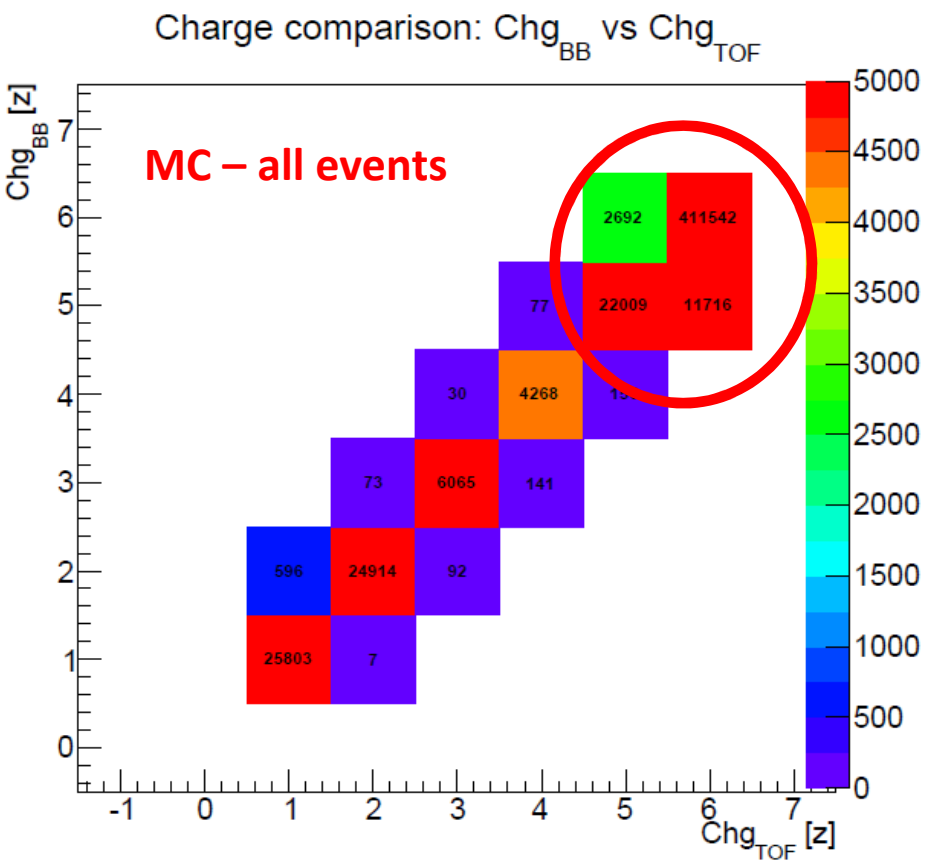
The high and wide C peak makes it difficult to separate Z=5 and Z=4 !

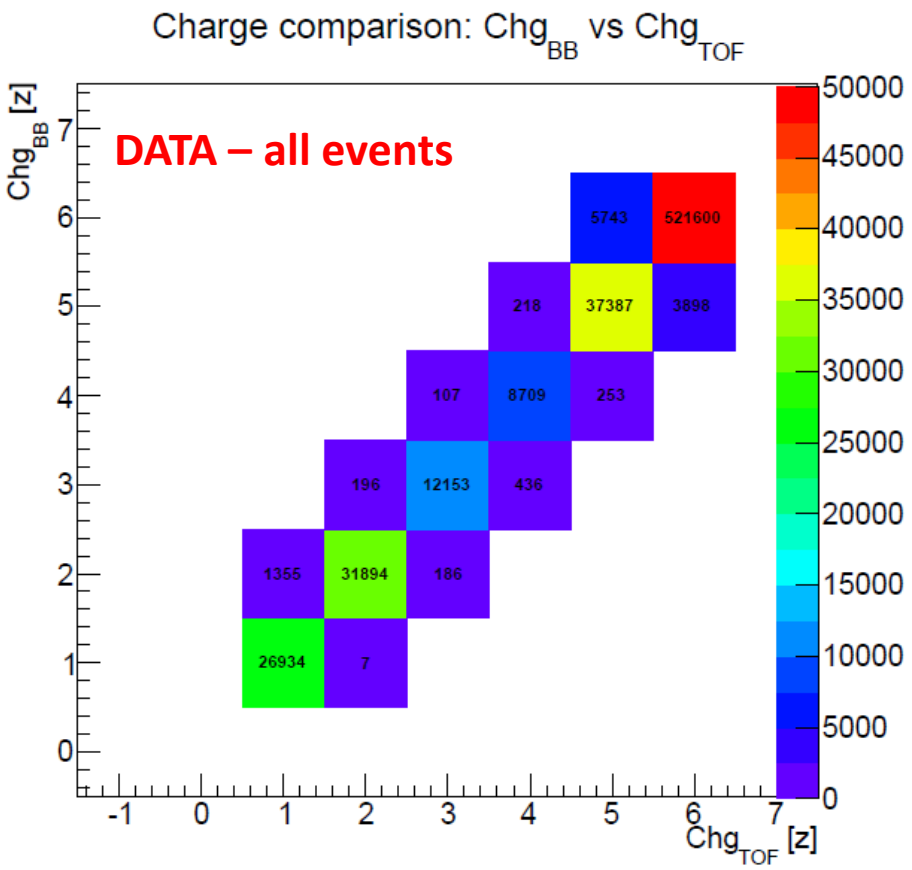
Comparison Ch_BB vs Ch_TOF (all events)





Comparison Ch_BB vs Ch_TOF (all events)

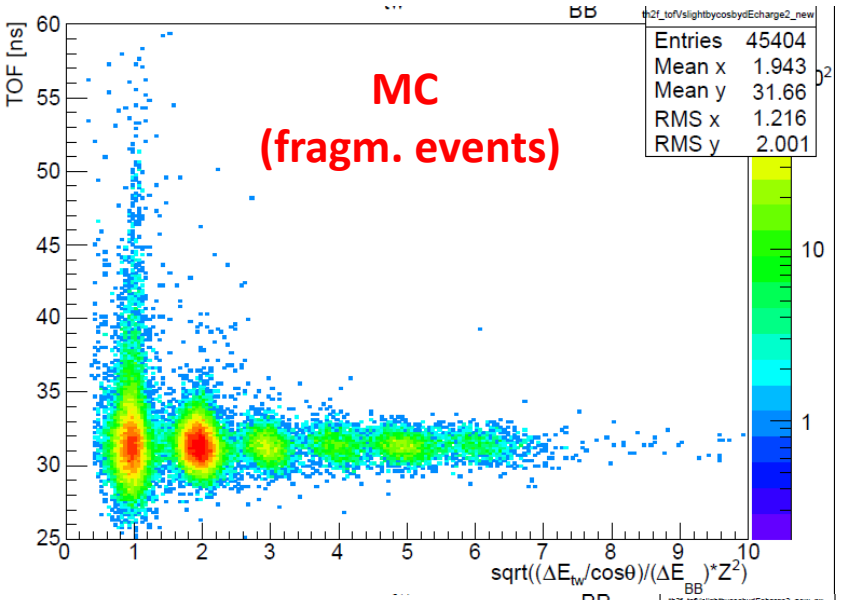


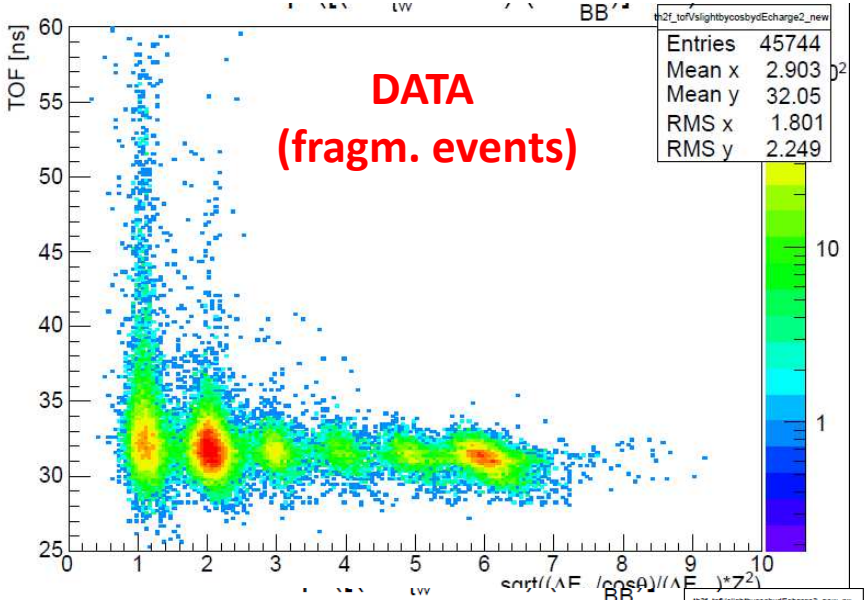


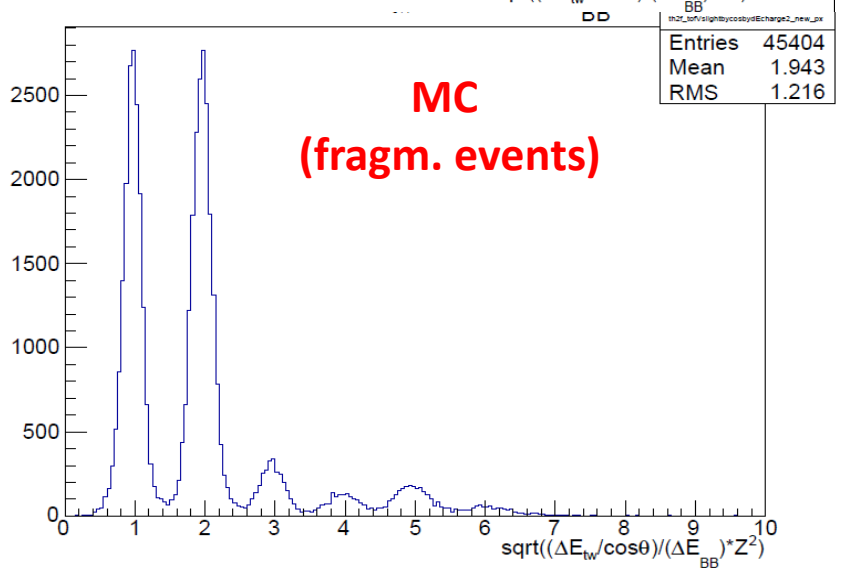
Discrepancy for Z=5 or Z=6 in MC

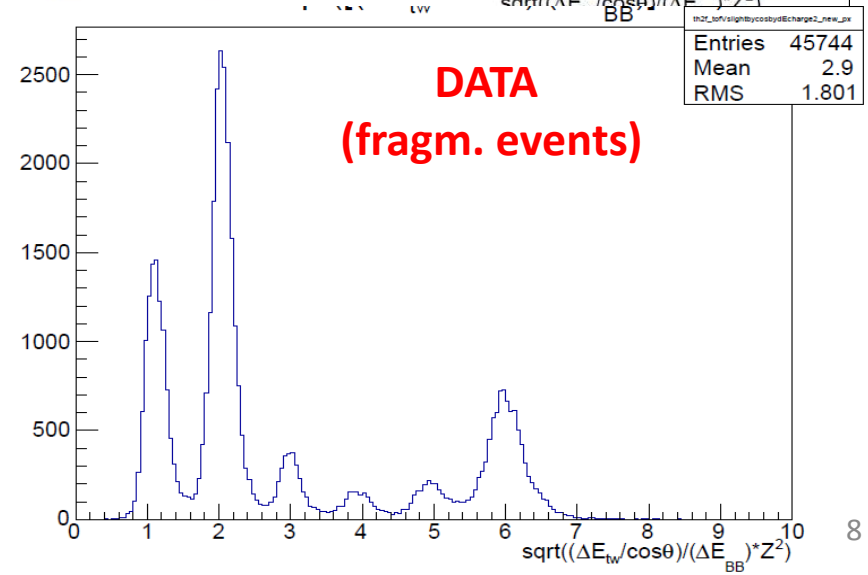
Better correlation for DATA !!!

TOF vs Ch_BB distributions (fragmentation events)

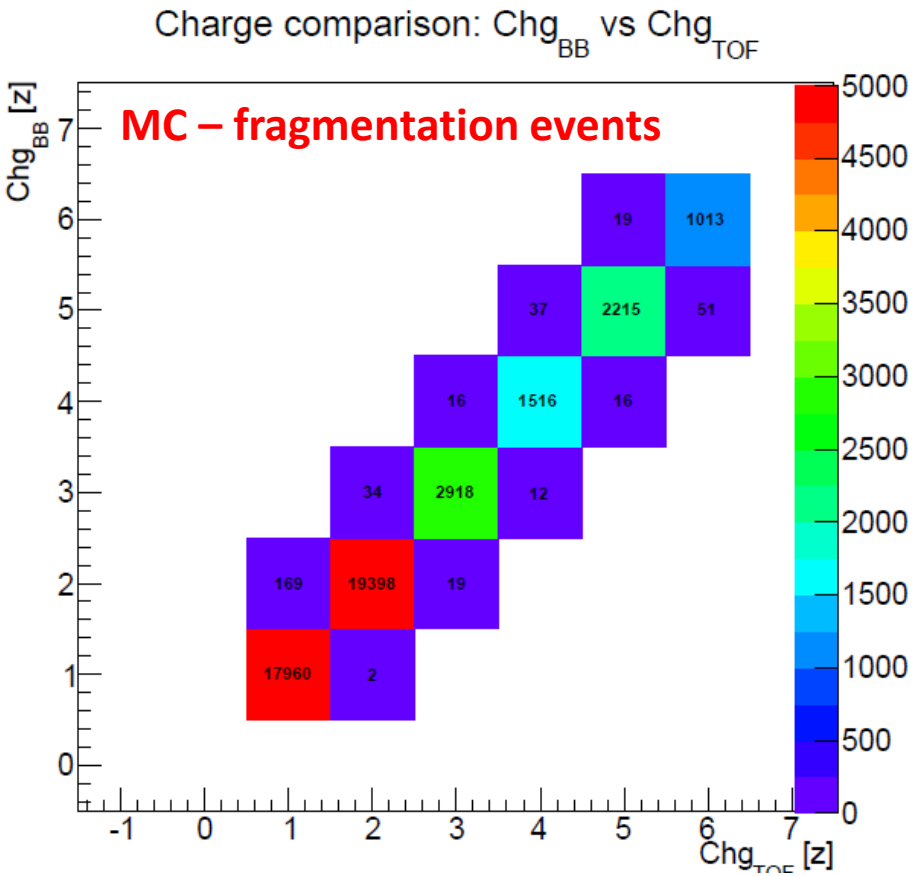


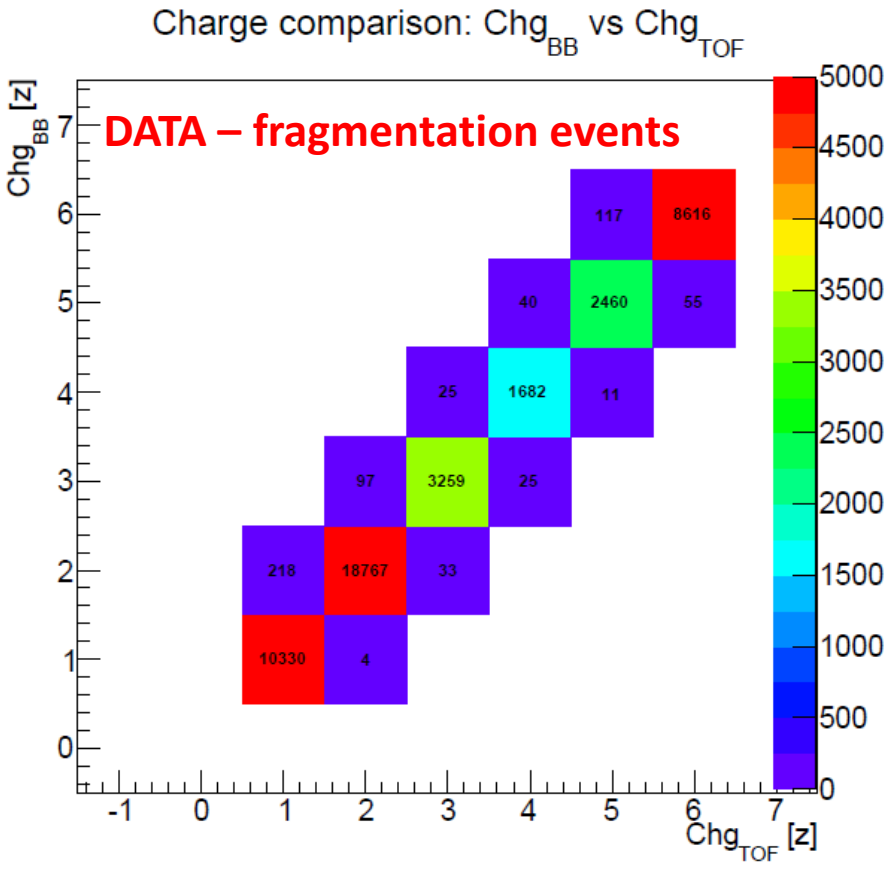






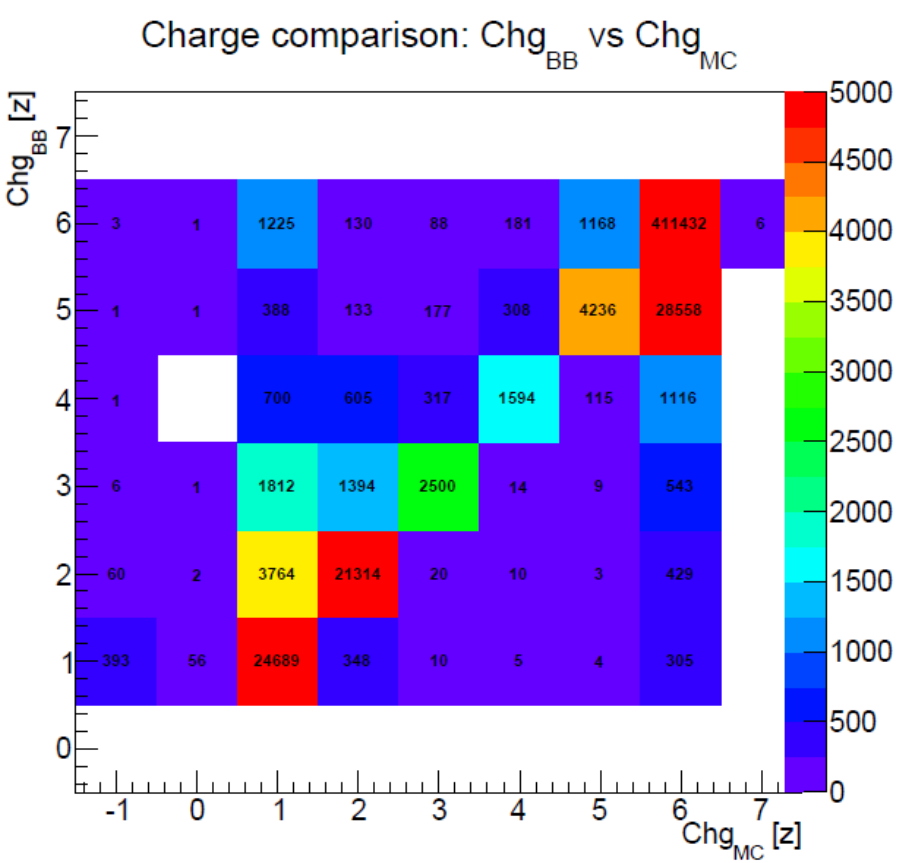
Comparison Ch_BB vs Ch_TOF (fragmentation events)

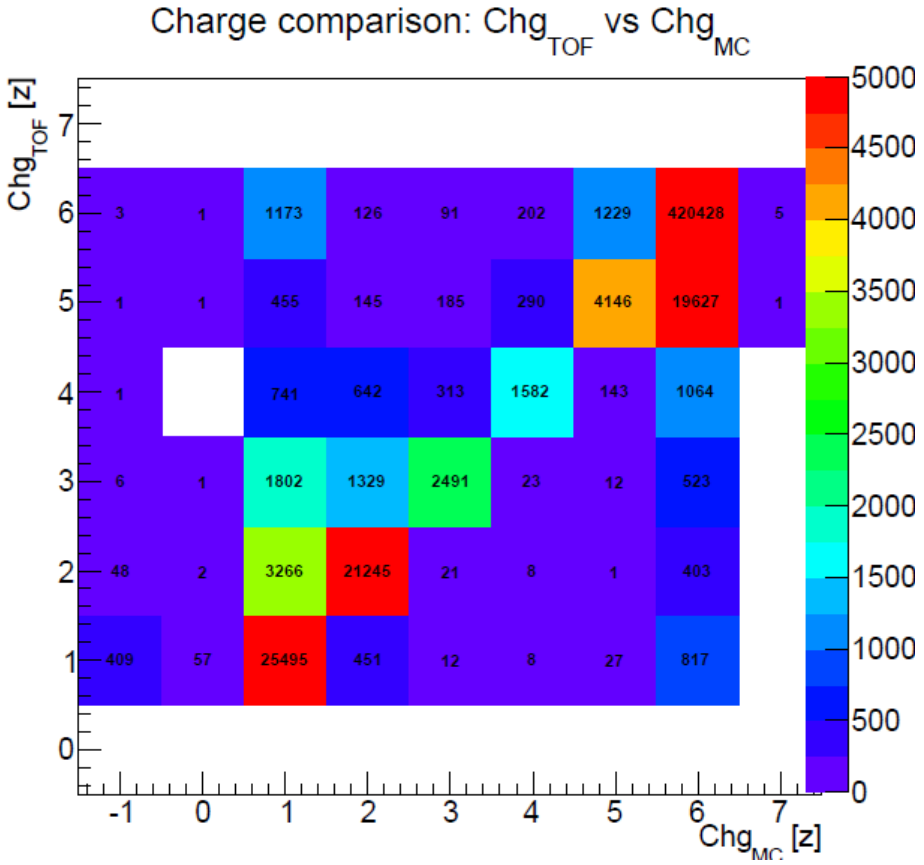




Very good correlation for fragmentation events

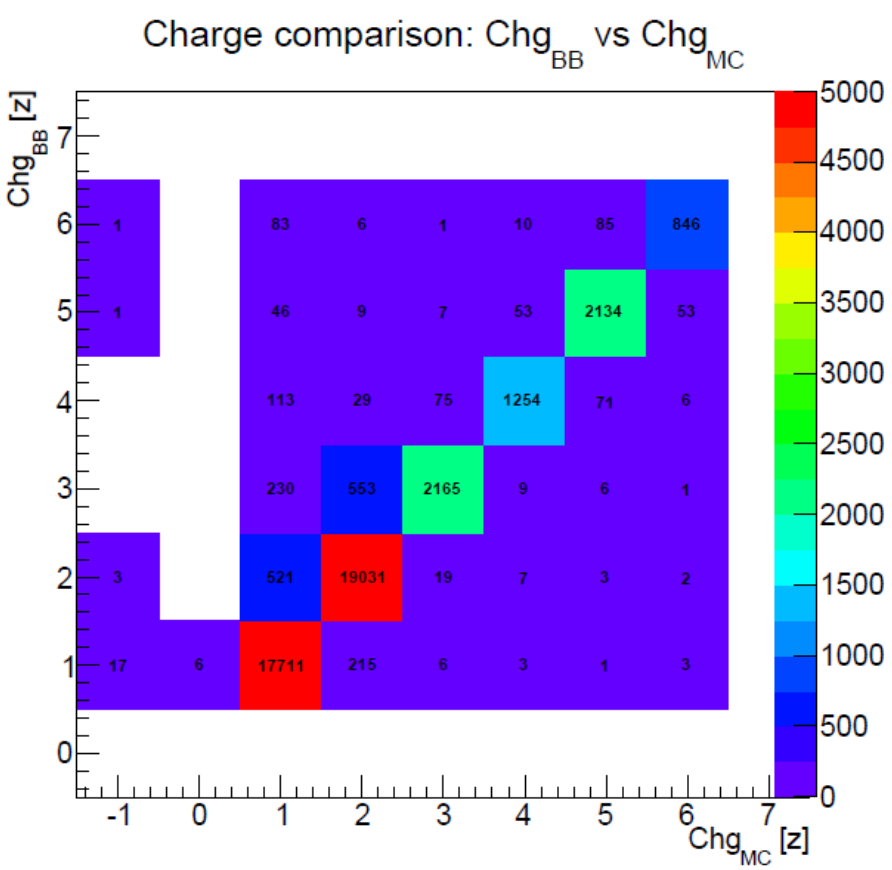
Comparison Ch_BB and Ch_TOF with Ch_MC (all events)

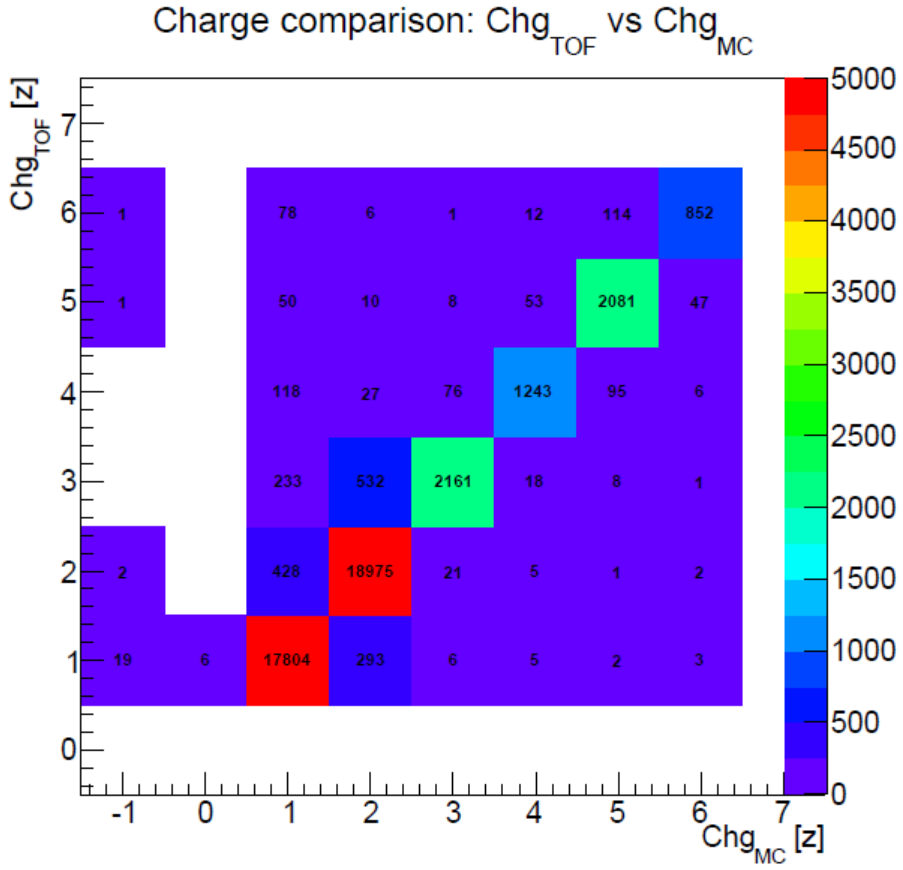




- **Most of the particles with Ch_BB or Ch_TOF =5 are Carbons according to MC (due to the tails of the huge C peak + hole in the central slats).**
- **Ch_TOF has a slight better agreement with MC than Ch_BB.**

Comparison Ch_BB and Ch_TOF with Ch_MC (fragmentation events)

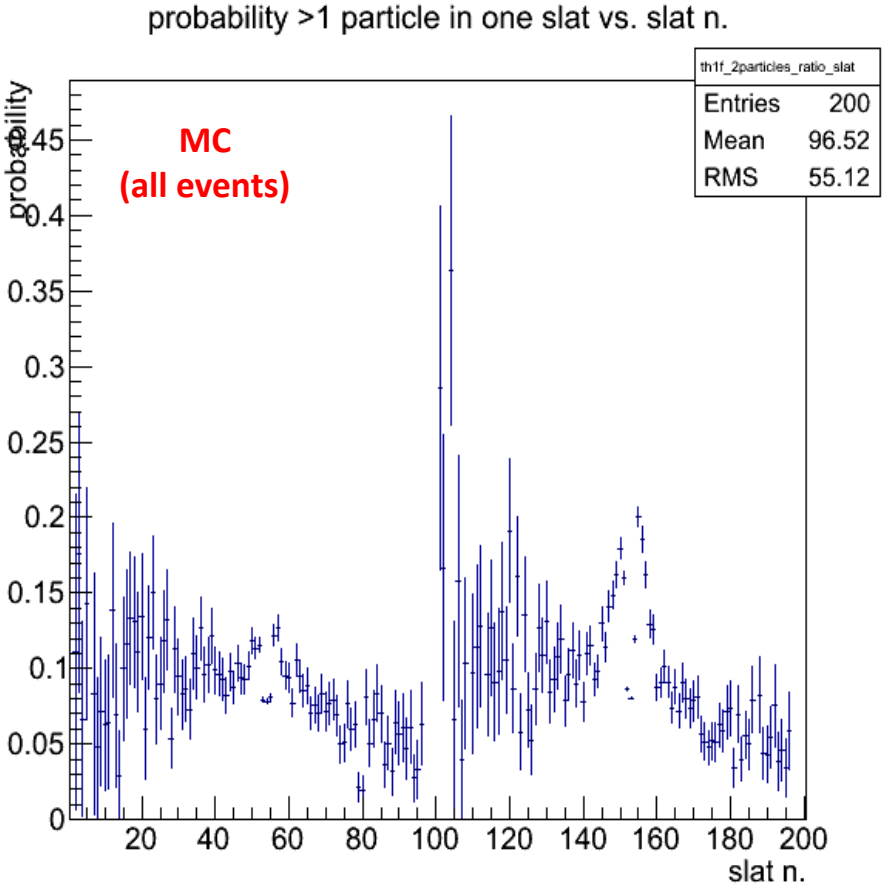


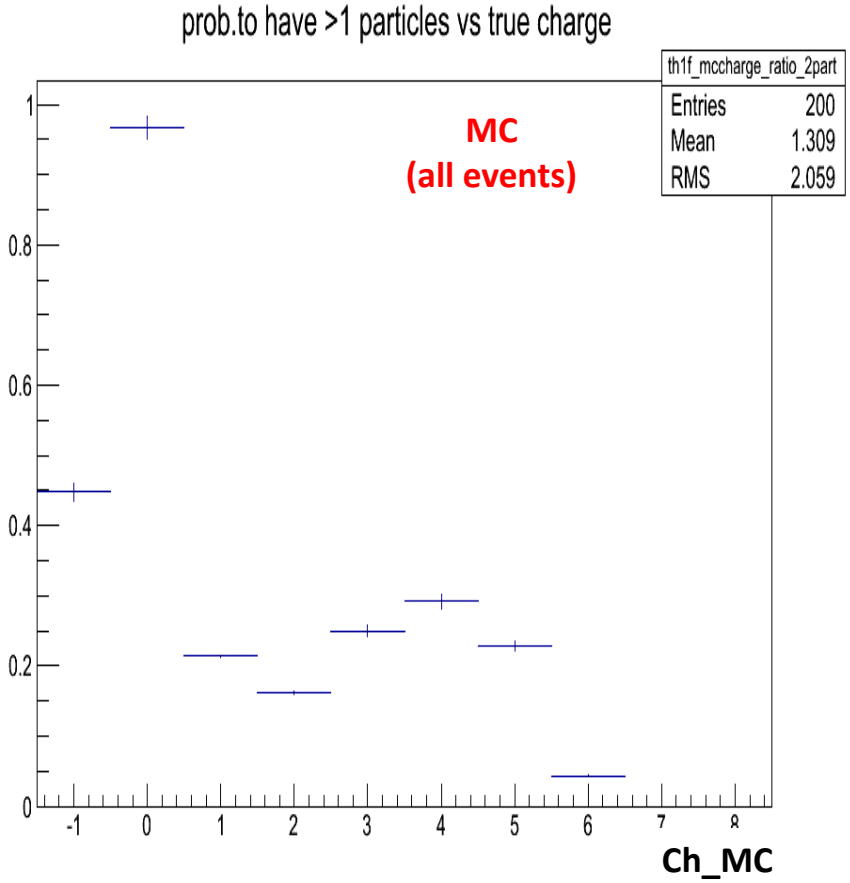


One of the problems is that more than one particle could hit the same slat.
This is a complication for the assignment of a «true charge» in the MC.

Fraction of TOF hits with > 1 particle (vs. slat and vs. Ch_MC)

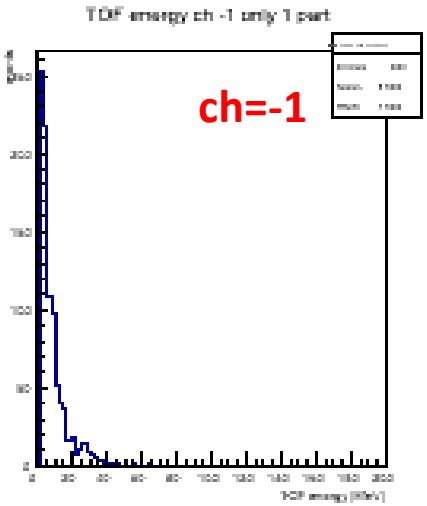
All events.

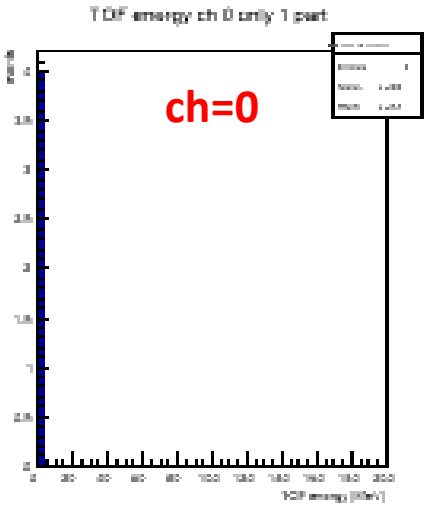


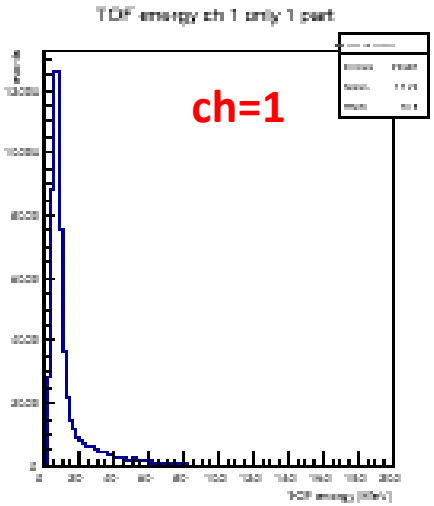


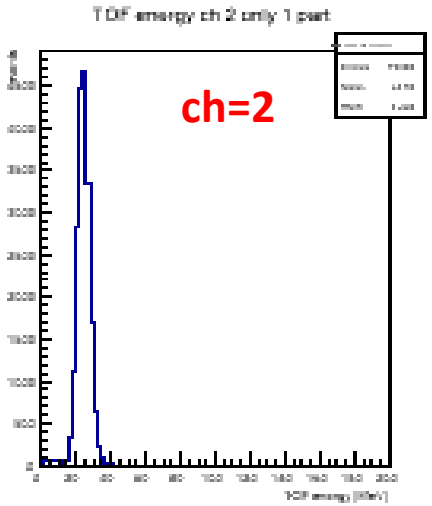
In the simulation about 10% of TOF hits (depending on Z) are triggered by more than 1 particle crossing the corresponding slat.

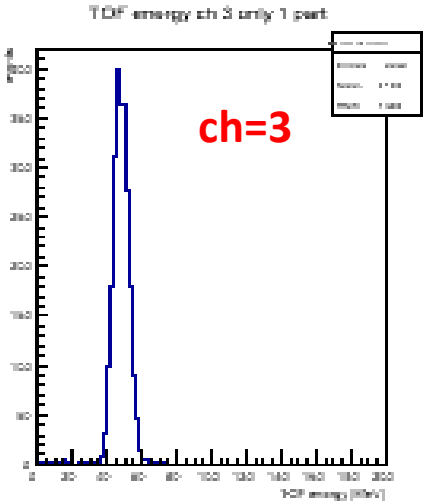
TOF energy distribution for each Ch_MC value (hits with 1 particle per slat)

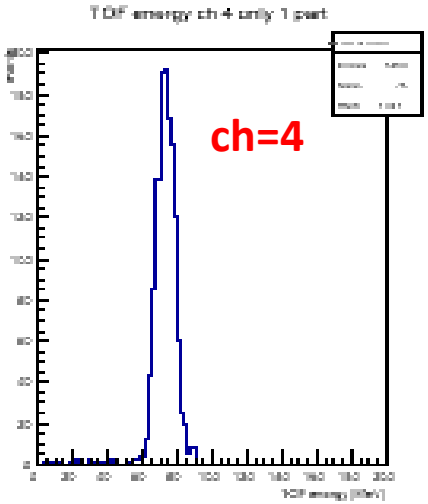


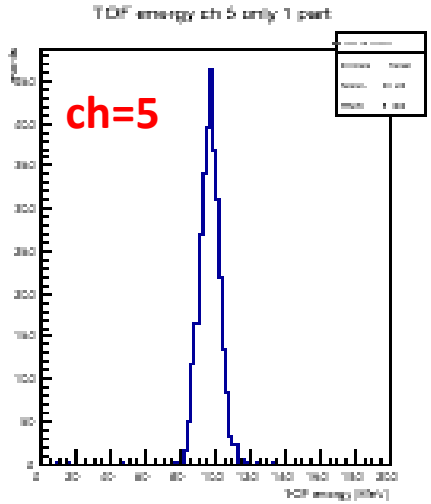


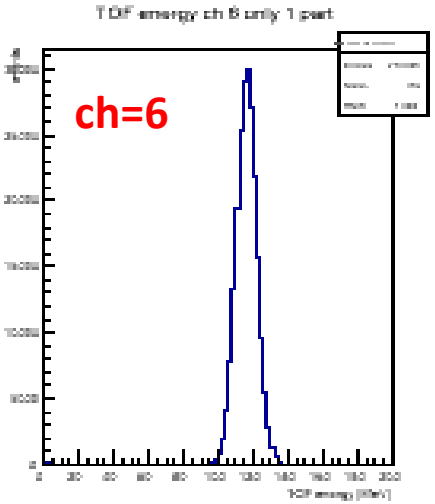




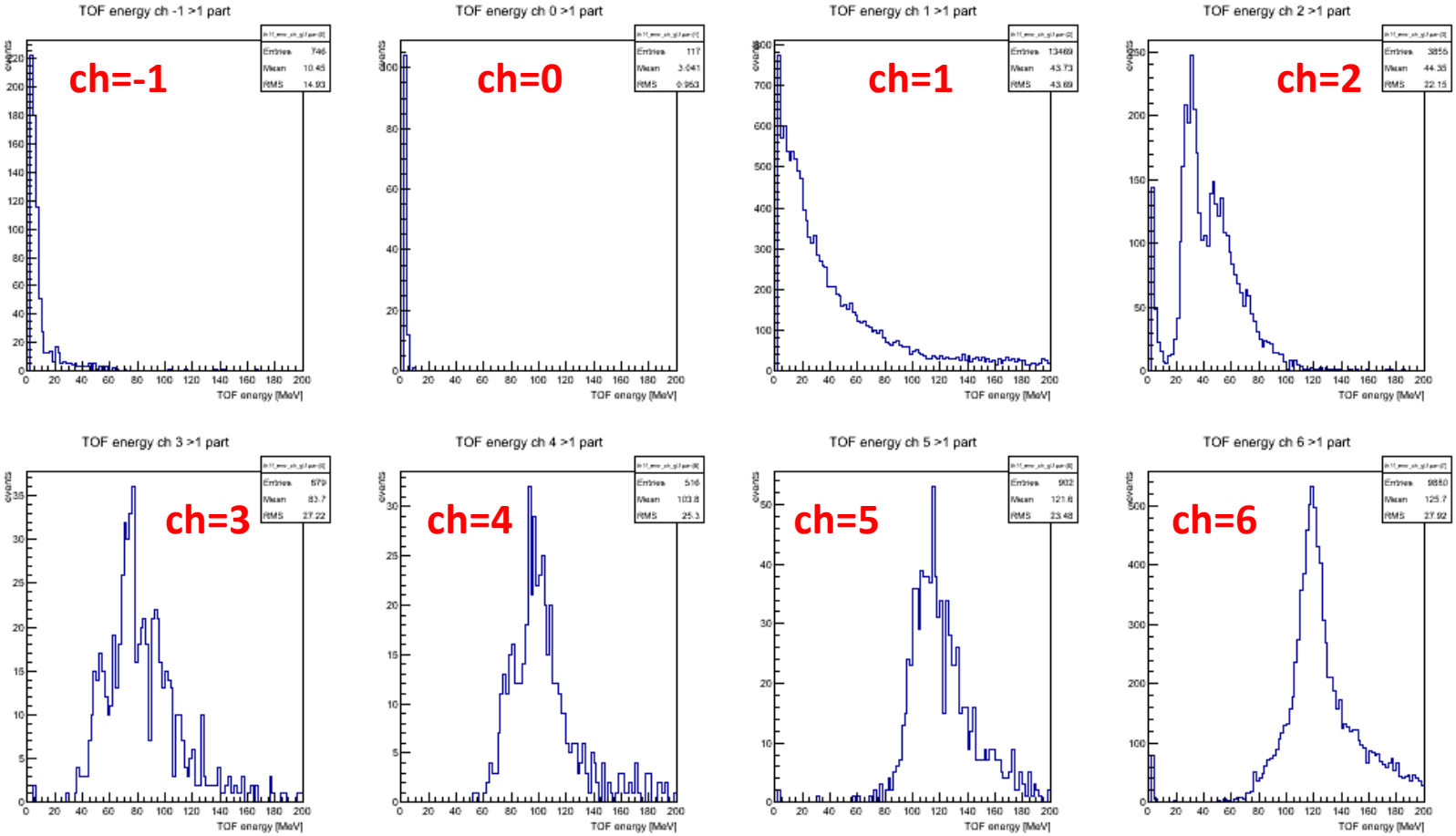






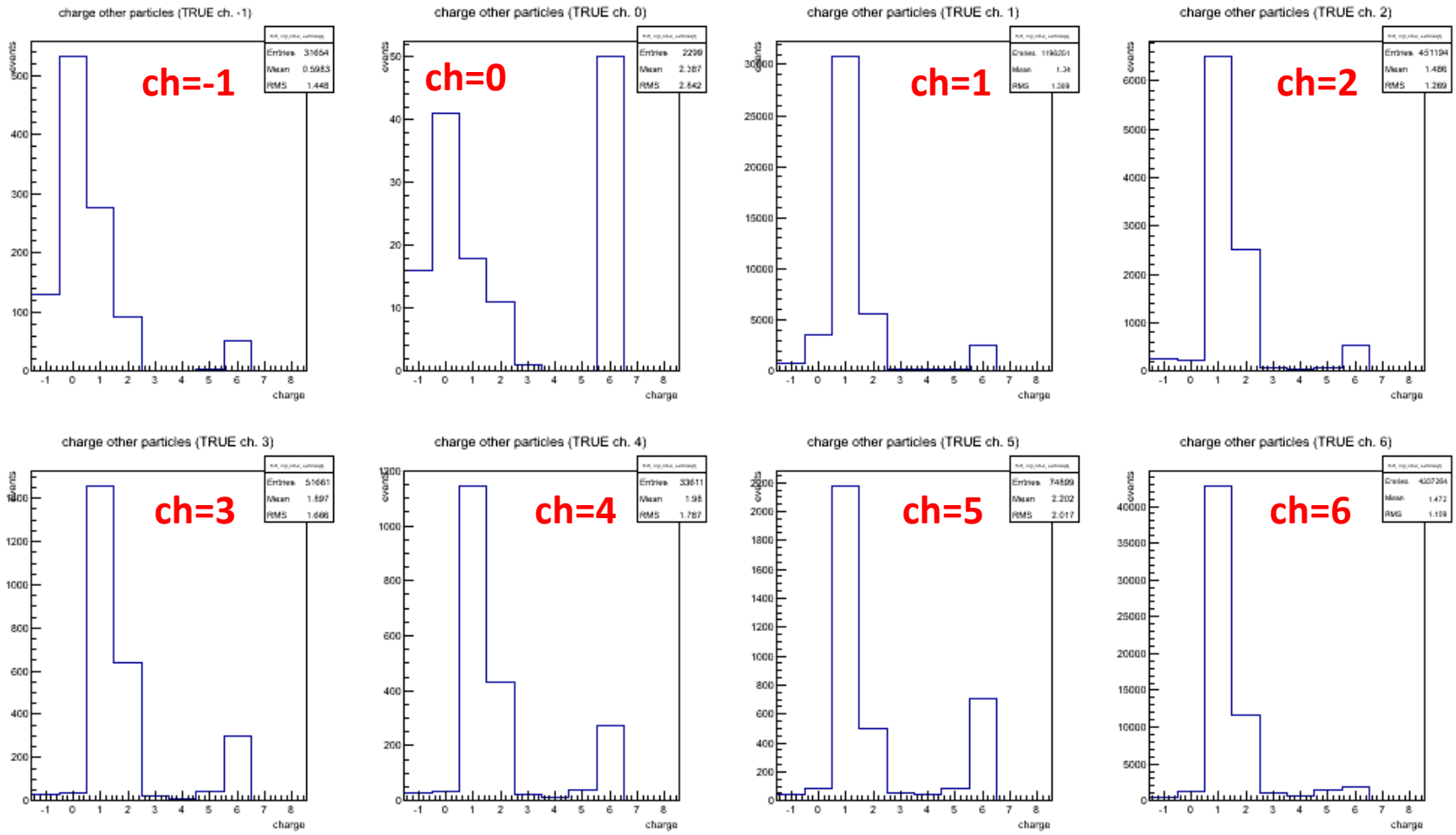


TOF energy distribution for each Ch_MC value (TOF hits with >1 particles)



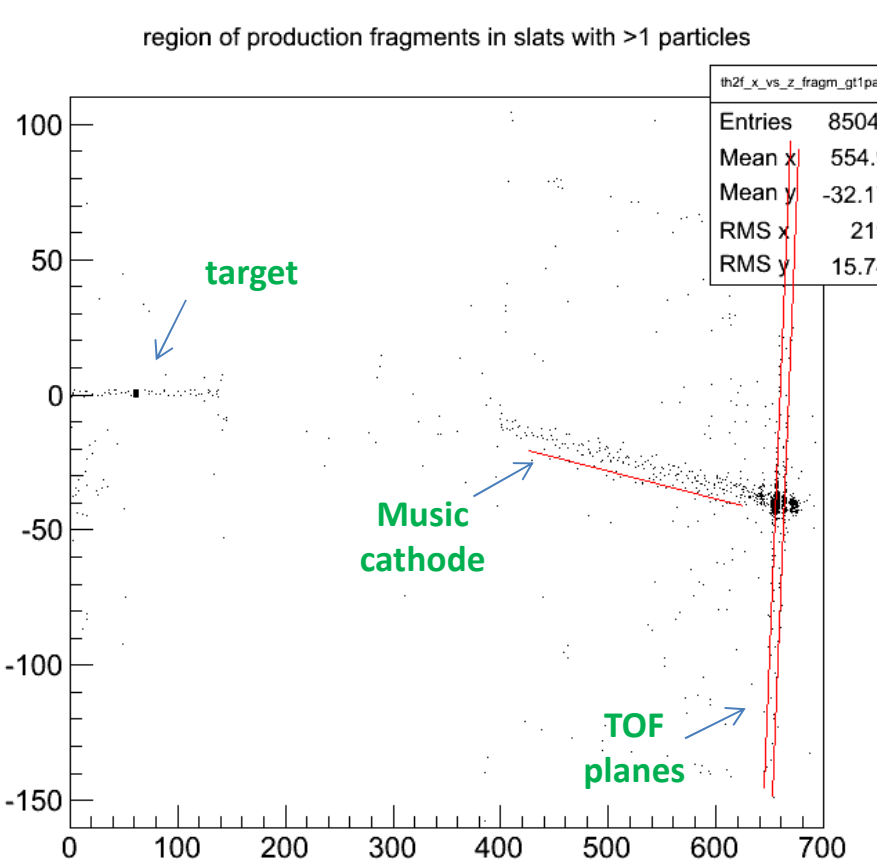
Distorted energy distributions for each Ch_MC value (it's difficult to assign a «true charge» value to these TOF hits). Effect on charge id to be studied.

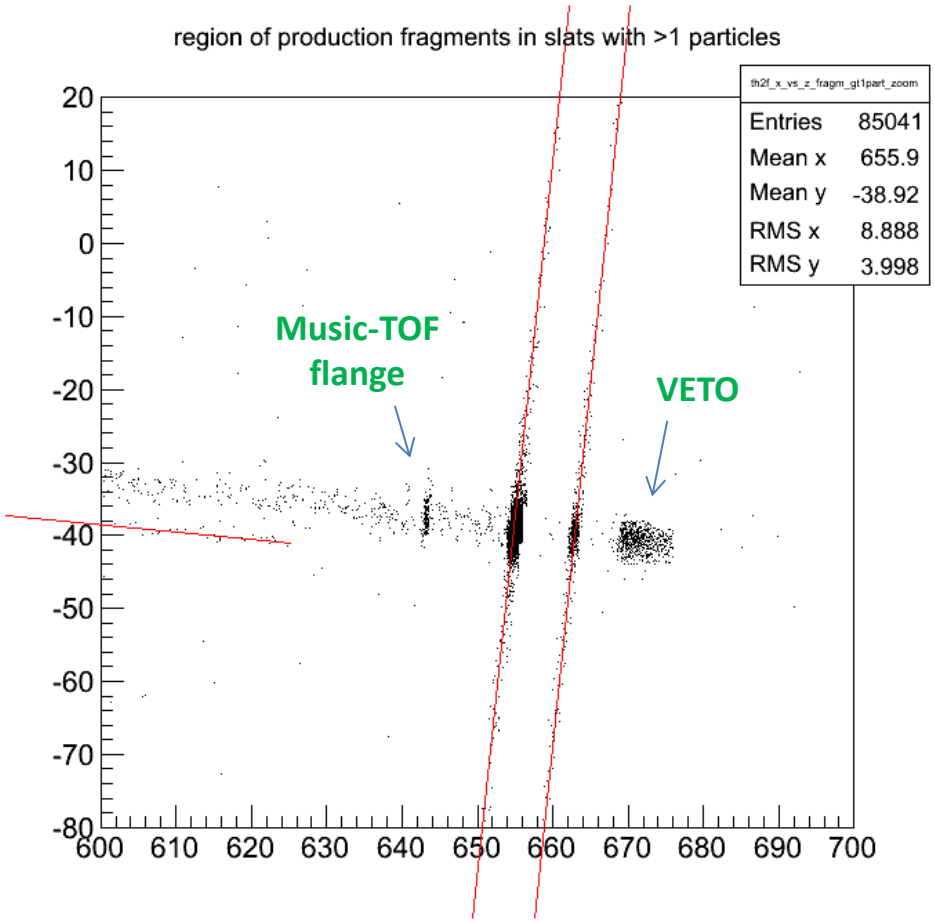
The following plots include only slats crossed by more than 1 particle.
The particle releasing more energy is excluded.
The distributions of the charges of the other particles (secondary particles) is shown for each Ch_MC value.



Most of the secondary particles crossing the slat are protons or helium, but in some cases there are also carbons (maybe crossing the slat boundary ?)

Regions of production of the secondary particles hitting slats with >1 particle (particle releasing more energy excluded)





Most of these secondary particles are produced in secondary interactions along the path.

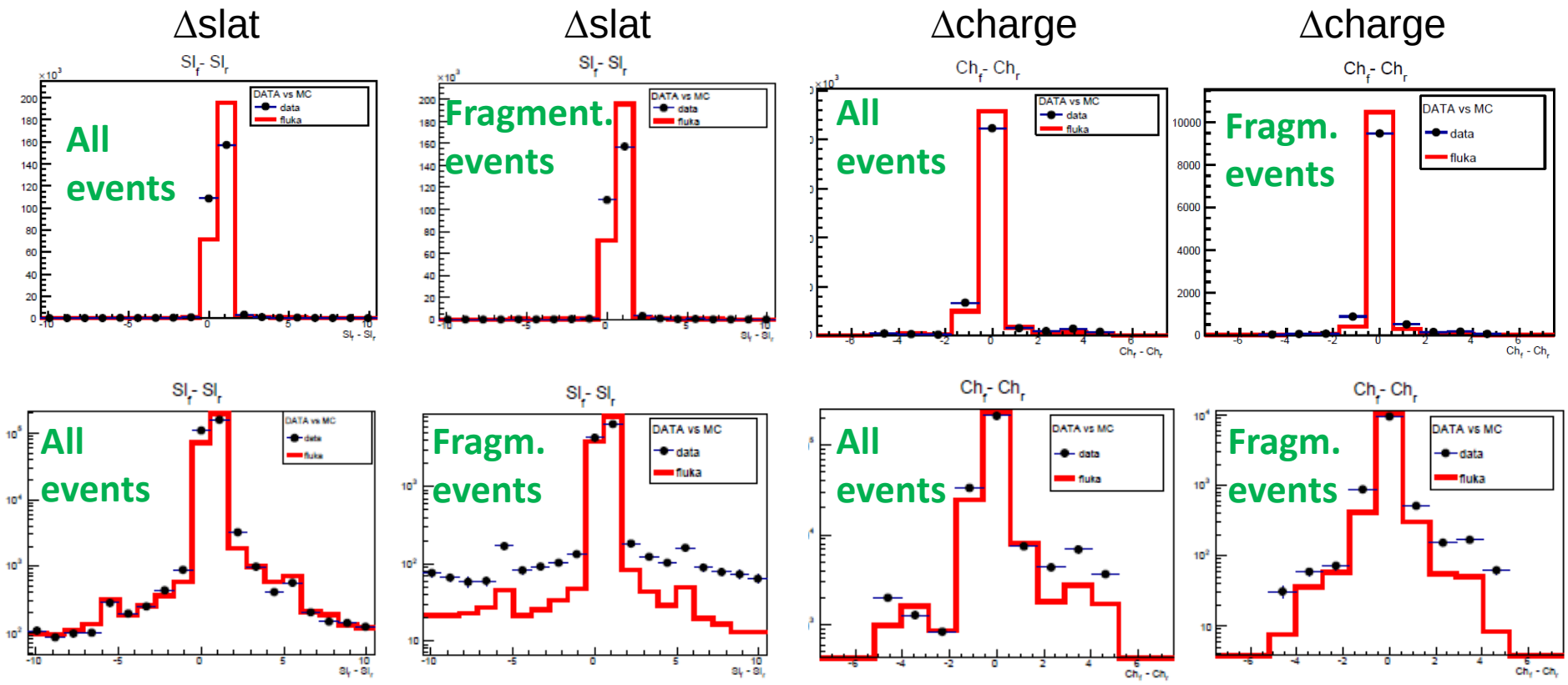
Comparison with charge at the target

We are interested in the correlations between the charge measured at the TOF and the charge of the particle produced at the target and associated to the TOF hit.
The TOF hit is associated to a MC track at the target by navigating back from the TOF hit to the target in the MC track chain.

Fraction of right charge assignments

MC charge	All events	Fragment.events
1	98,1 %	98,1 %
2	92,2 %	92,3 %
3	88,8 %	88,8 %
4	84,0 %	83,9 %
5	85,5 %	85,7 %
6	91,3 %	93,3 %

DATA/MC comparison of differences in slat number and in the charge (Ch_TOF) between the two TOF planes (TOF hit selection based on the match in Y with the VTX extrapolated track)



TOF front/rear comparison used to estimate the TOF resolutions (Δslat<=3 && ΔCh_TOF<=2 required)

Conclusions for ZID checks

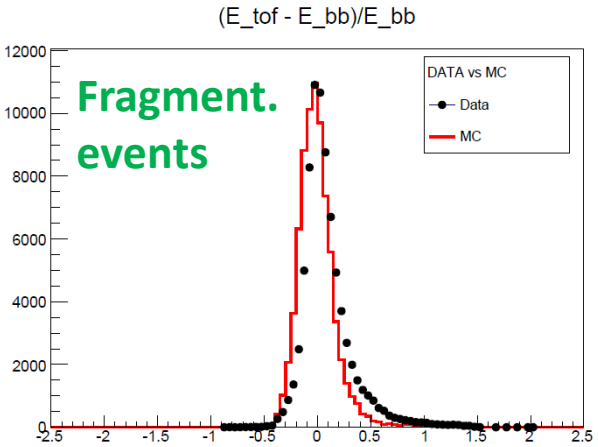
- **Good Z assignement with the new TOF energy retuned for each slats.**
- **We have to understand which is the probability to have a wrong charge (about 10 % with respect to the charge of the particles at the target).**
- **One of the reason for an error in the Z assignment (or for the difficulty to define a real charge) is the consisten fraction of slats crossed by more than 1 track (10-20% according to the simulation).**
- **Most of these tracks are low energy particles (mainly protons, helium) produced in the interactions with the dead material before and around the TOF and with the TOF itself.**
- **The energy distribution for these events with more than 1 track in a slat is distorted. Impact on the charge assignment to be carefully evaluated.**
- **Things are complicated by particles crossing the boundary between 2 slats .**
  The latter effect is not easy to disentangle from events where two neighbouring slats are crossed by different particles (under study to define a clustering criteria).

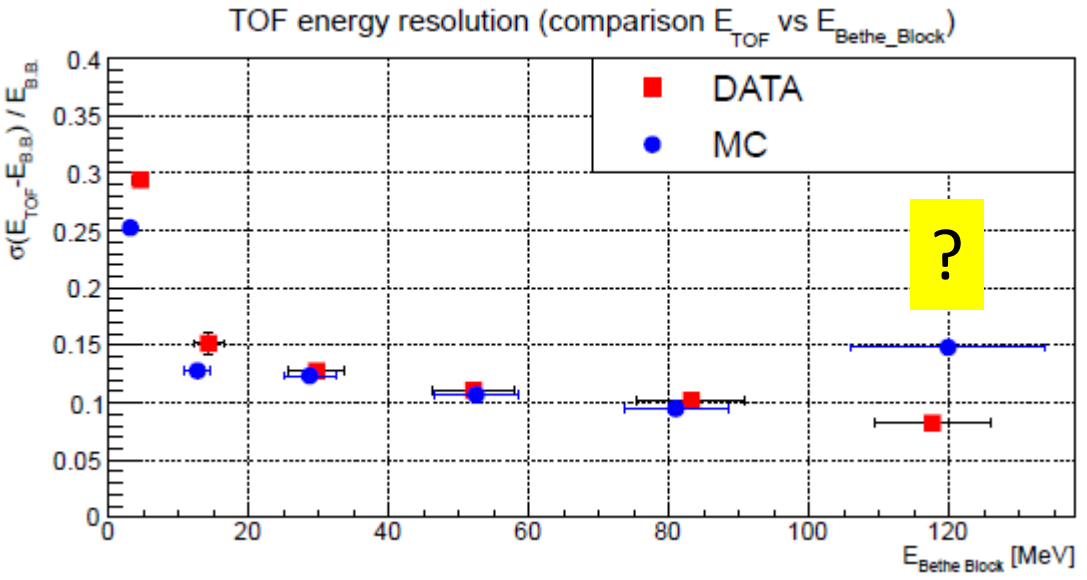
Study of TOF resolutions

TOF energy resolutions

TOF resolutions (tuned in MC using previous energy calibration and embedding previous slat variations) checked using Eloss and the new charge assignment

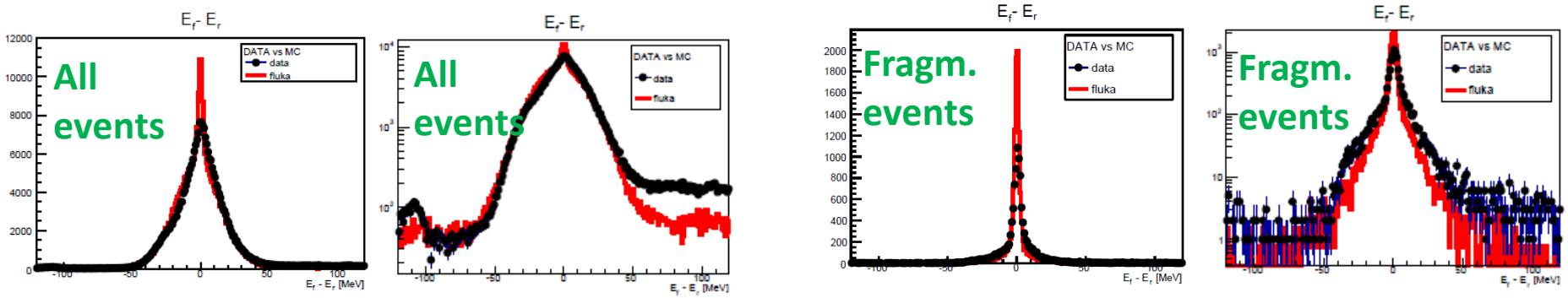
One possibility to estimate the energy resolution is the comparison of the energy released in the TOF with the energy predicted using the Bethe-Block after reconstruction. This prediction depends on the Z id. Fragmentation events are used.



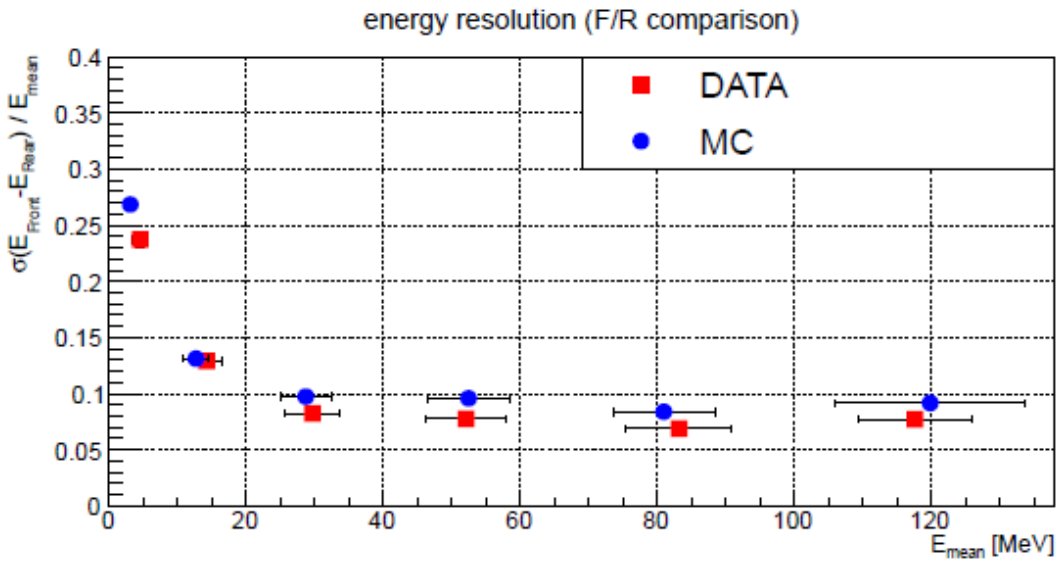


In the MC the energy resolution at the Carbon peak seems now worse than in the data. More reasonable agreement at lower energies.

Estimation of Energy resolution using the comparison of Rear and Front slats.



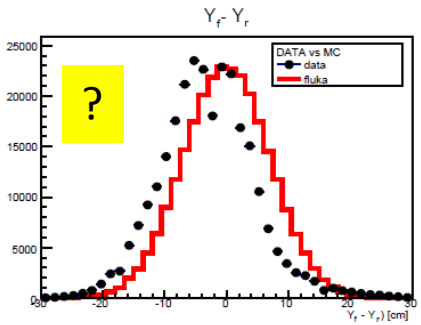
Resolutions estimated with fragmentation events

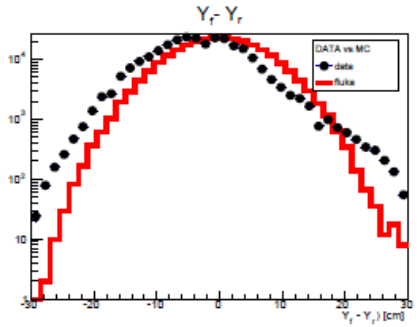


TOF energy resolution worse in MC than in DATA. This can affect the ZID in the simulation. A new tuning of TOF energy resolution in the MC is needed (to be done).

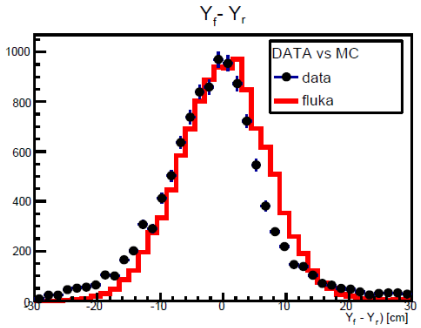
TOF Y resolution estimated using comparison of Front/Rear slats

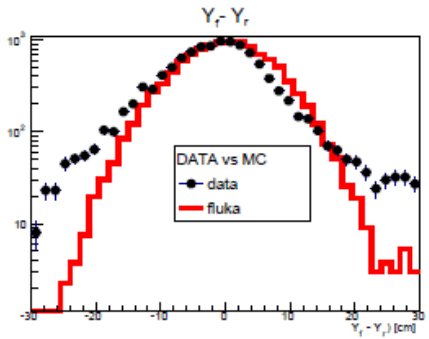
ΔY (all events)



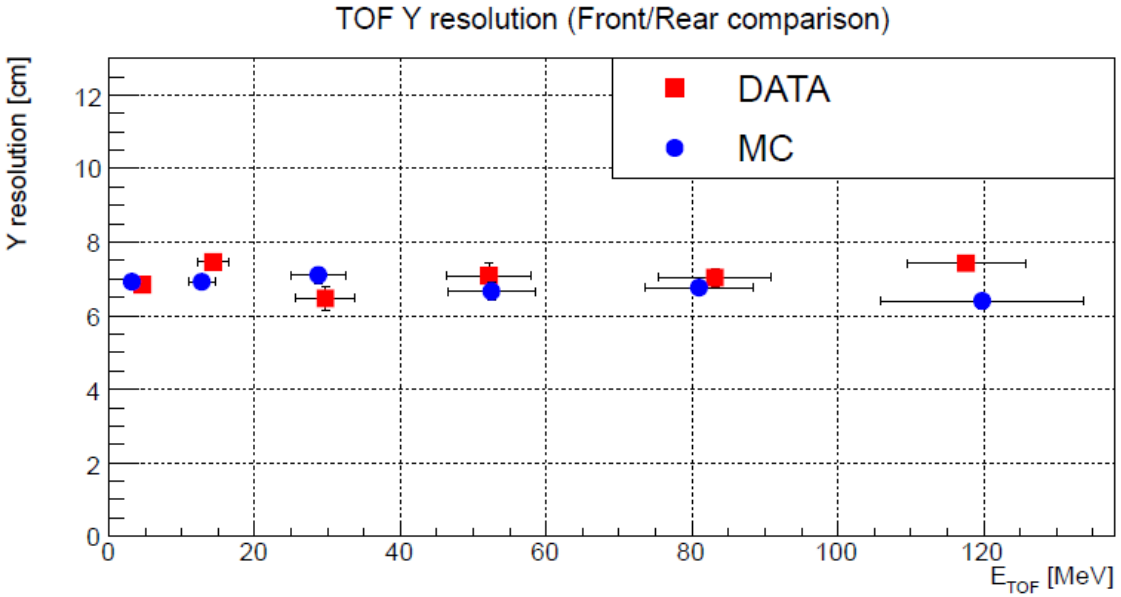


ΔY (fragmentation events)





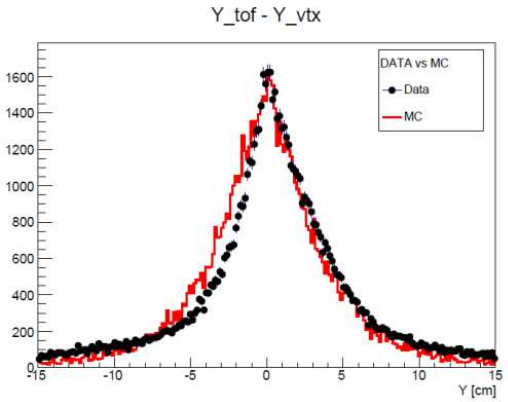
Resolutions estimated with fragmentation events

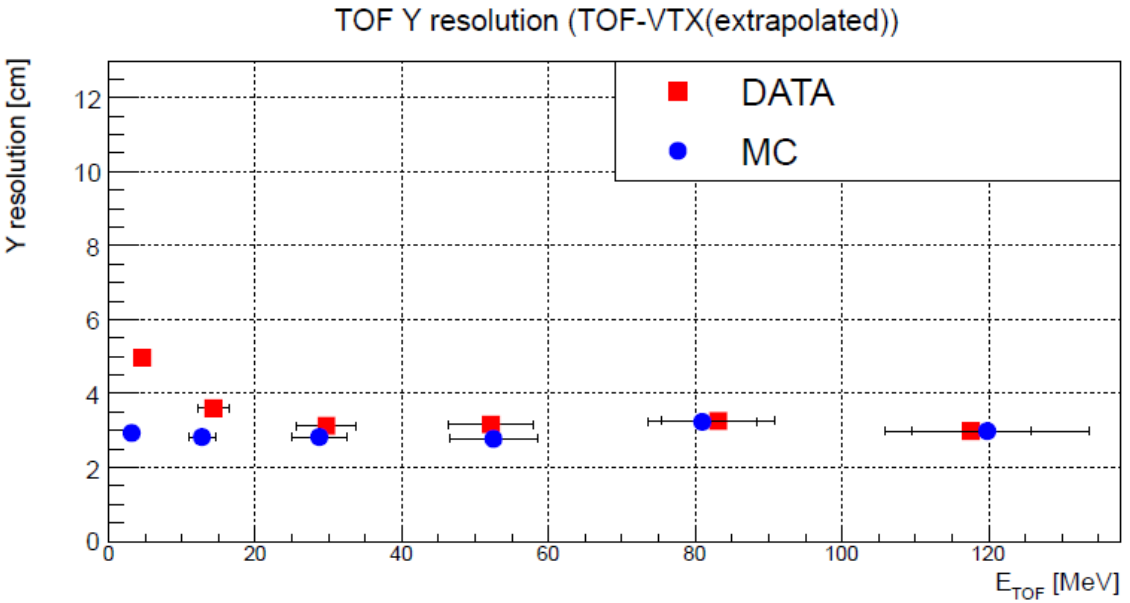


Reasonable data/MC agreement

Single TDC time resolution ~ 450 ps

TOF Y resolution estimated using extrapolation of VTX track



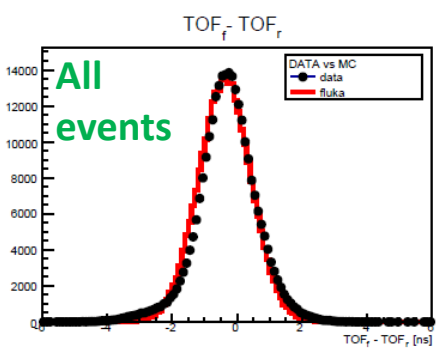


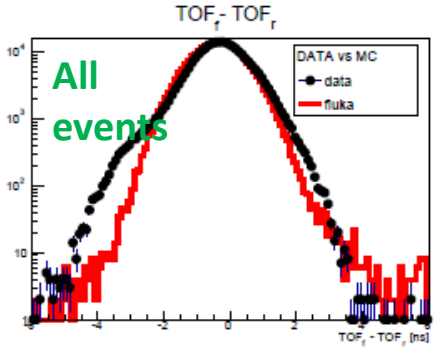
Reasonable data/MC agreement

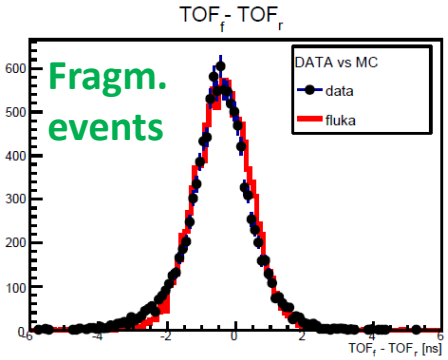
This resolution is understimated because in the reconstruction the TOF hit-VTX track matching is based on Y comparison. Not uses to tune the TDC time resolutions.

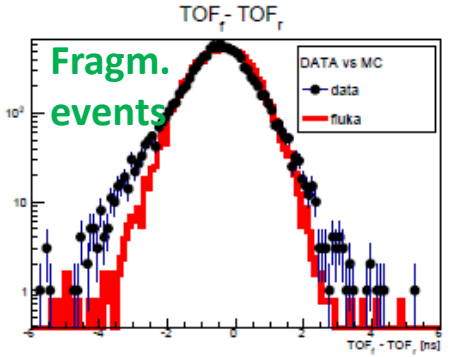
Time-of-flight resolution estimated using the comparison of Rear and Front slats.

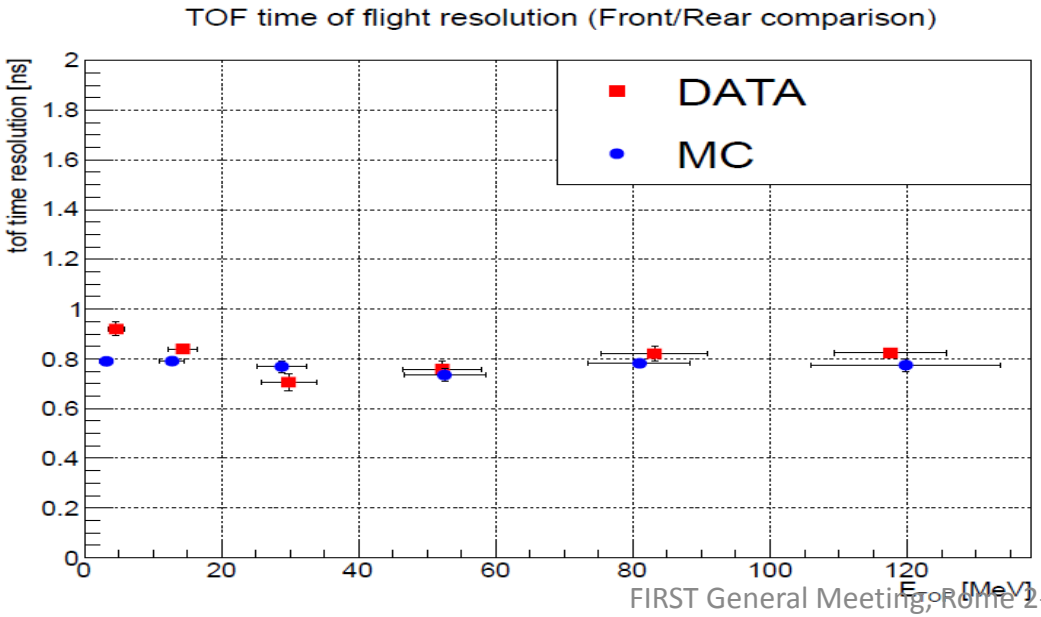
The TOF resolution results higher than expected using the TDC time resolution estimated with Y(front)/Y(rear) comparison. An additional error factor common to the bot and top TDCs has been added in the simulation to match the TOF resolution measured with data.









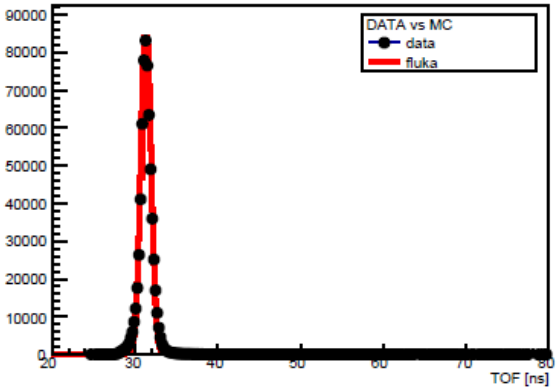


σ(TOF) ~ 800 ps

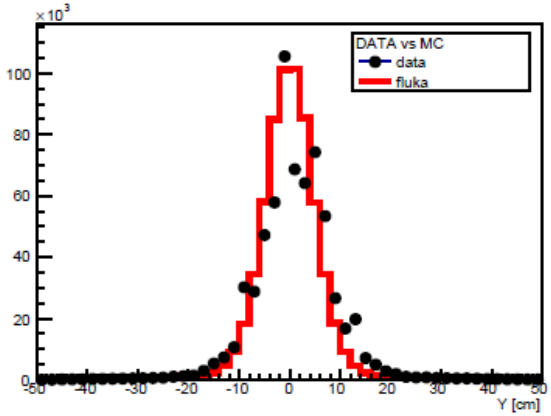
Reasonable data/MC agreement

TOF distributions: data/MC comparison (all events)

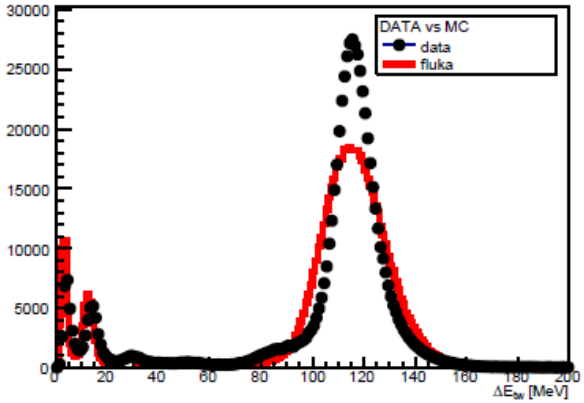
TOF



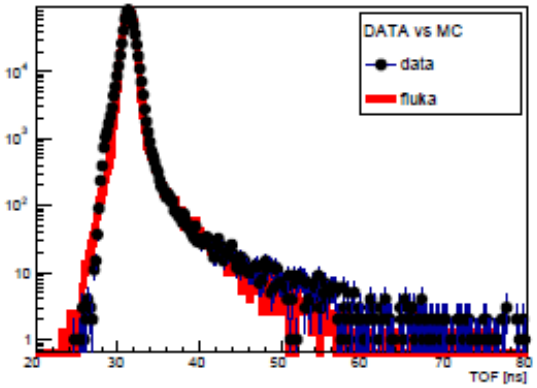
Y



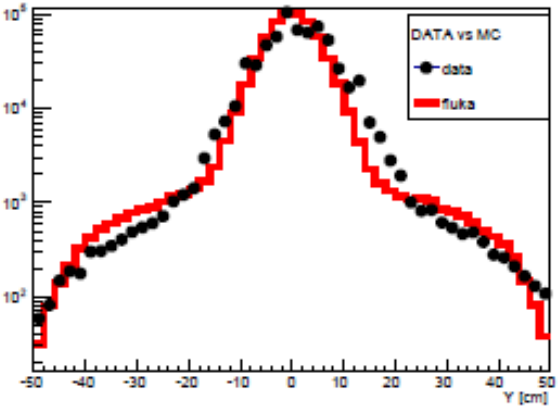
Eloss



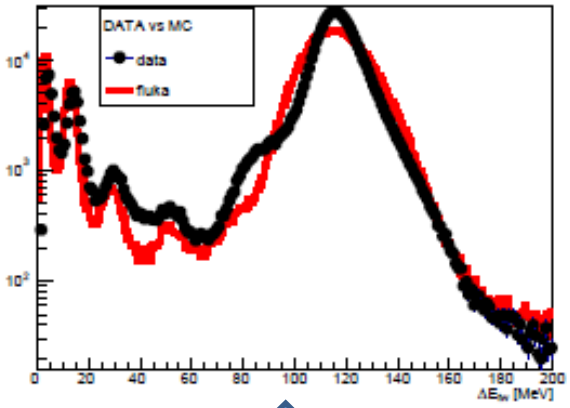
TOF (log)



Y (log)



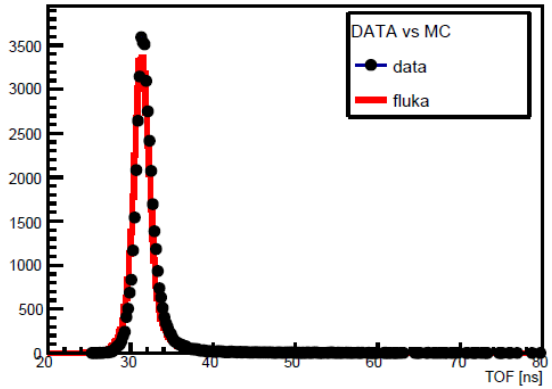
Eloss (log)



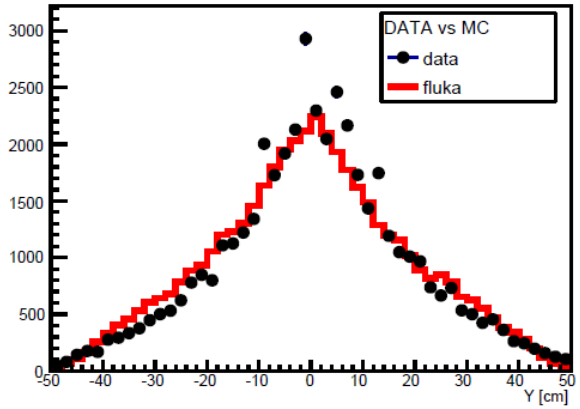
Energy distribution too wide in the simulation.

TOF distributions: data/MC comparison (fragmentation events)

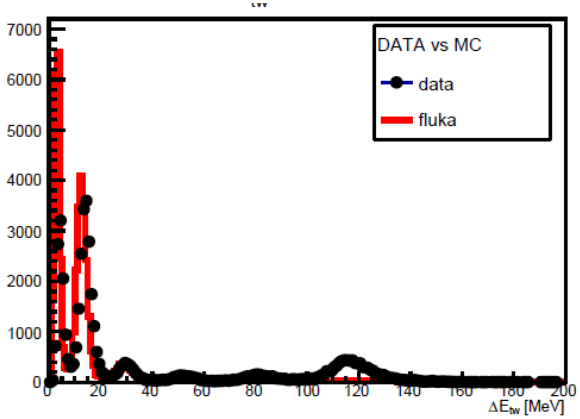
TOF



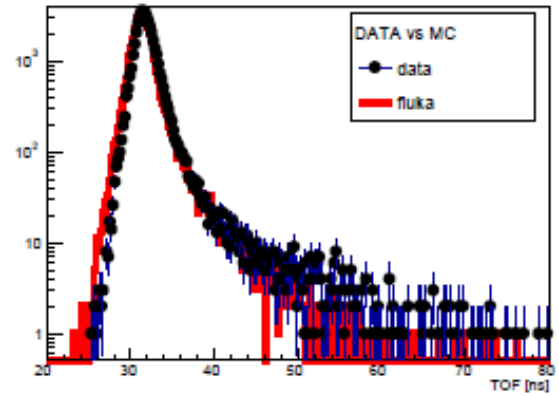
Y



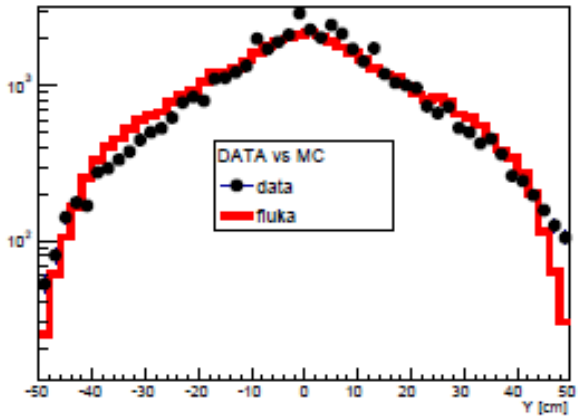
Eloss



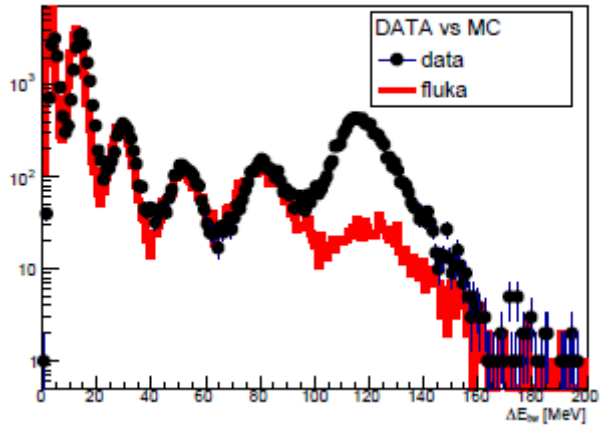
TOF (log)



Y (log)



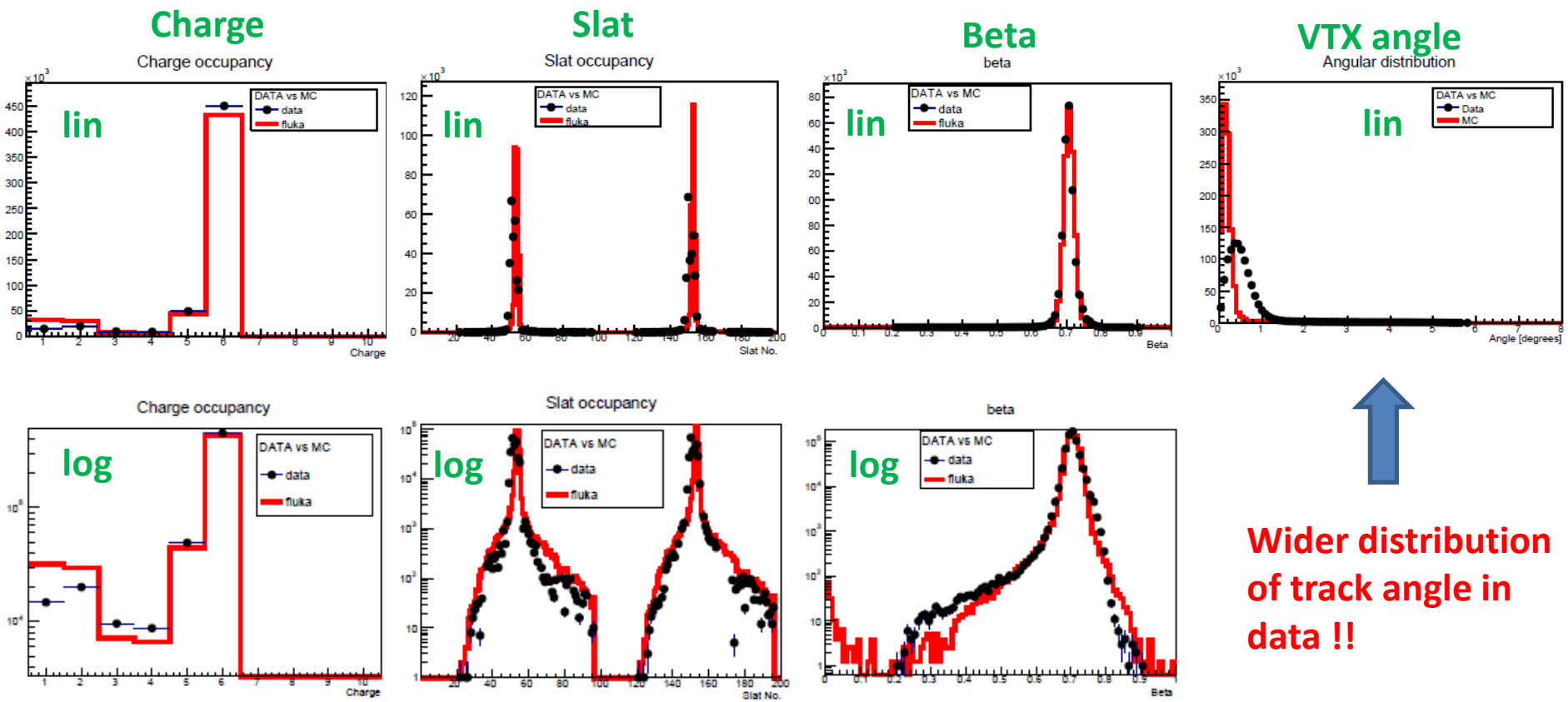
Eloss (log)



Peaks in the same position in data and MC.
Excess of carbons in the data !!

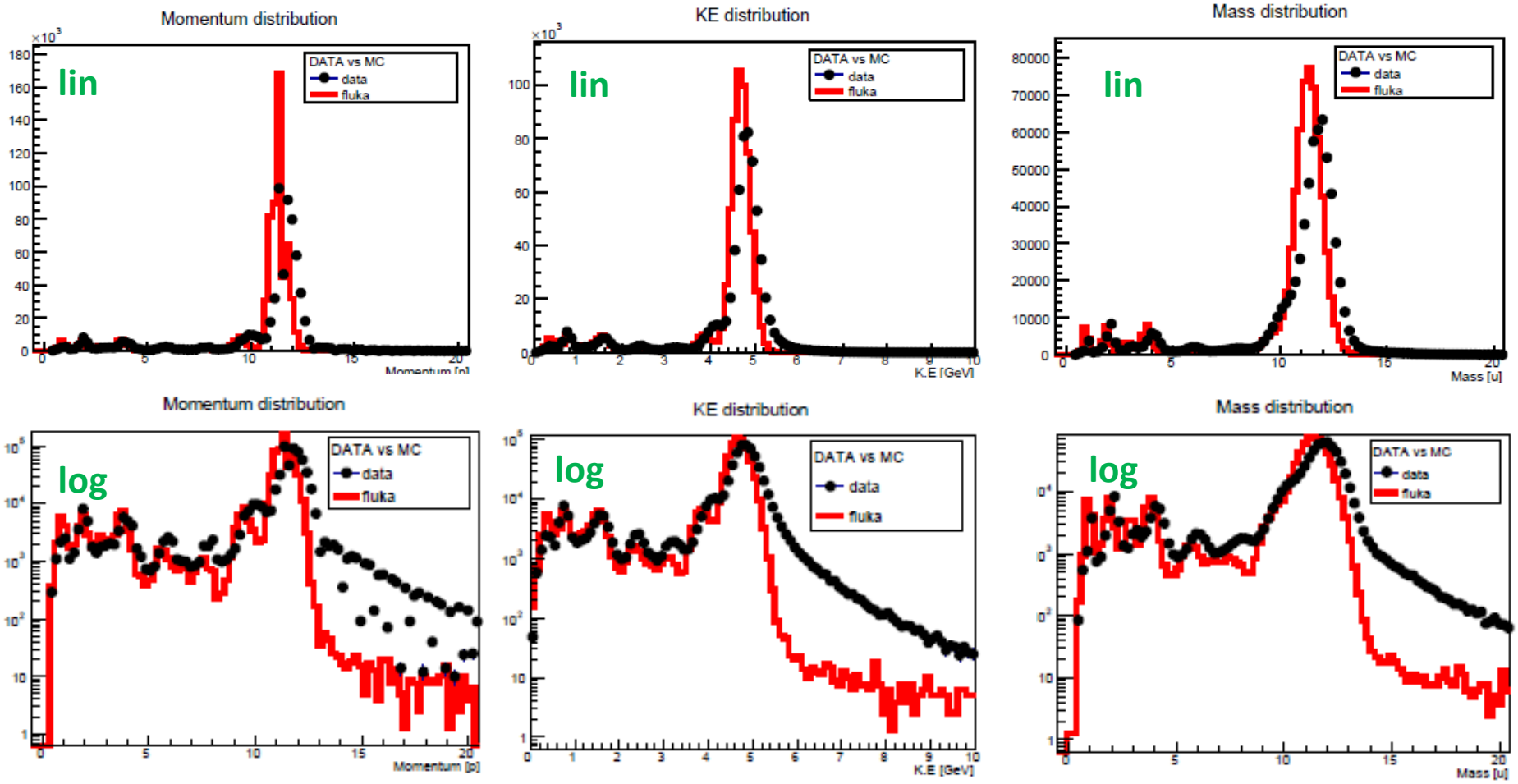
Check of reconstructed global variables

Data/MC comparisons (all events)



Wider distribution of track angle in data !!

Data/MC comparisons (all events)

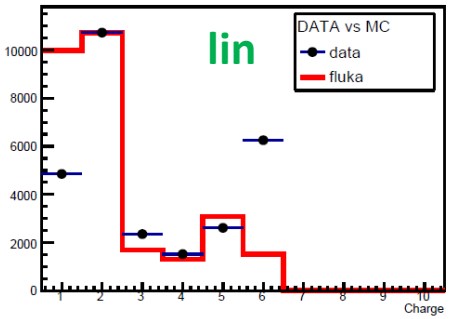


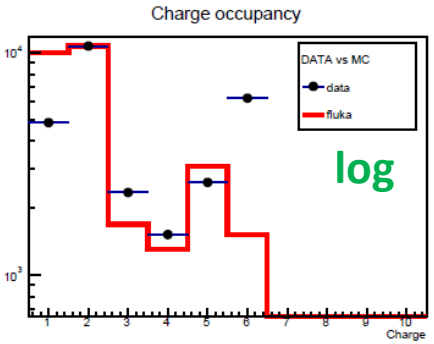
Peak shift and tails at high values not reproduced by the Monte Carlo

Separate comparison for each charge in the spare slides.

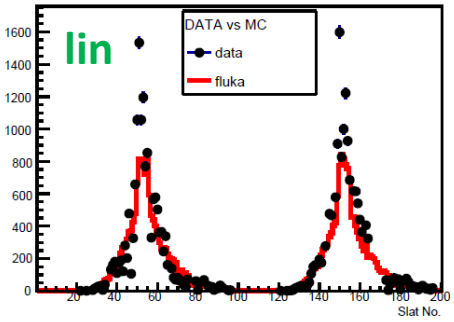
Data/MC comparisons (fragmentation events)

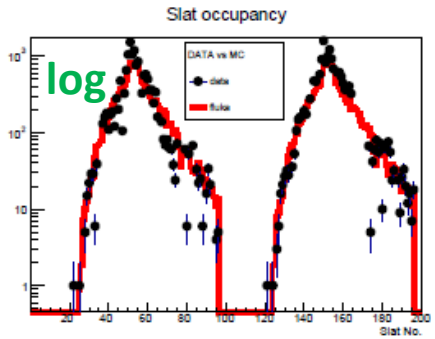
Charge



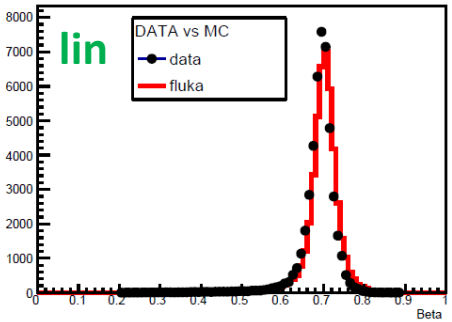


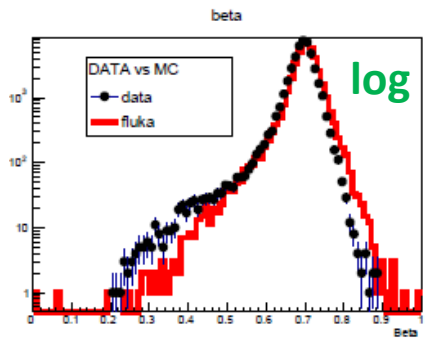
Slat



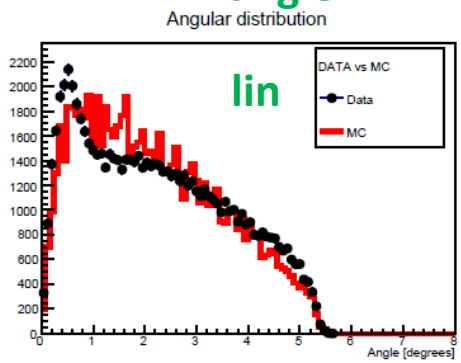


Beta



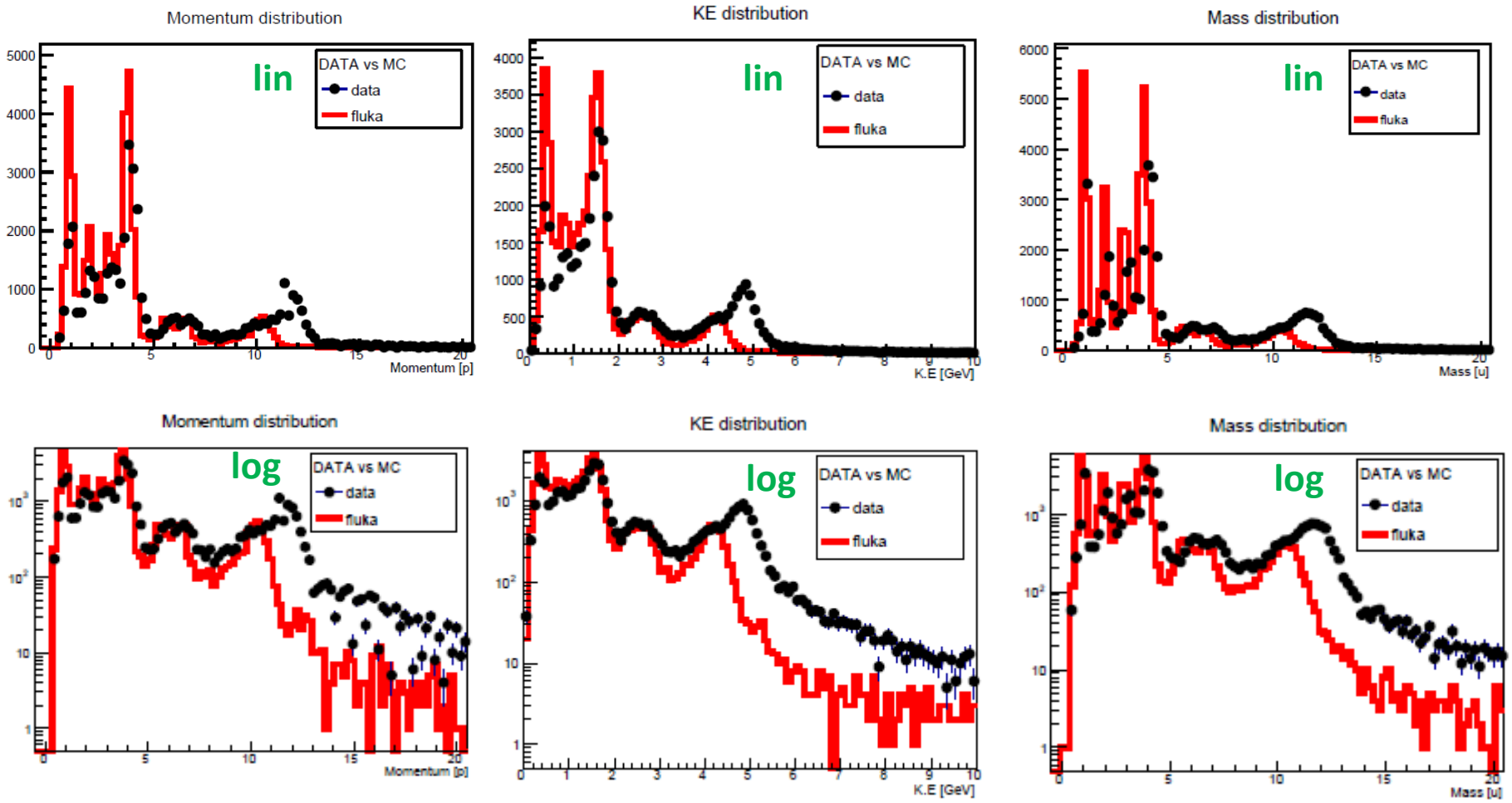


VTX angle



- **Higher number of protons in the simulation (see later).**
- **Higher number of carbons in the data.**

Data/MC comparisons (fragmentation events)



We observe not only a different number of carbons in data and simulation, but also a shift of the position of the corresponding peaks.

Simulation of proton detection efficiency in the TOF.

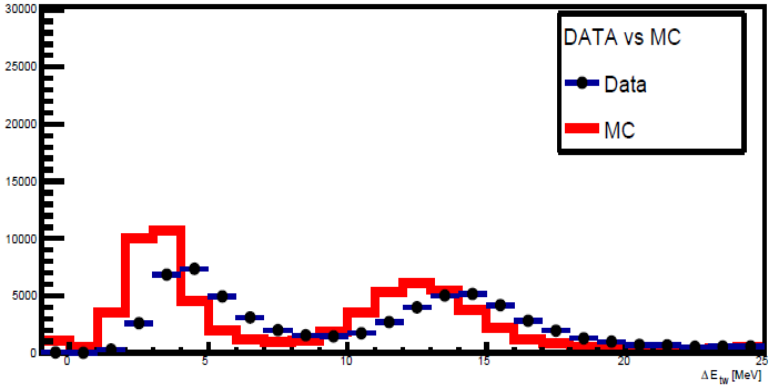
For the previous plots ,TOF hits requiring both the TDCs were used in the simulation (single channel calibration in the data). The energy threshold for a TDC hit was set to 1 MeV in the simulation.

MC changes (ready but not committed yet, under test):

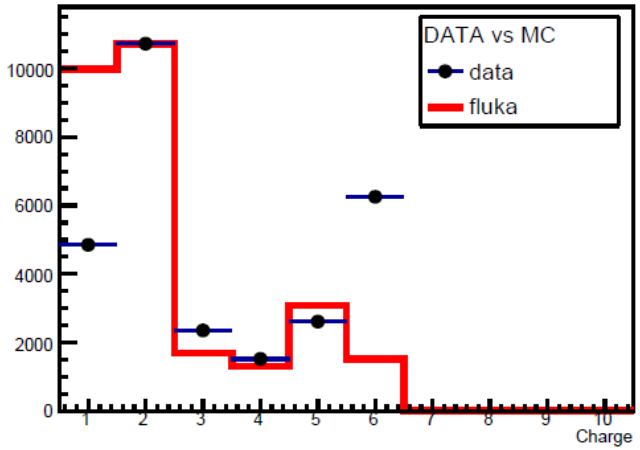
- **Implement energy thresholds for single TDC hits based on previous studies made on data for each slat**
- **Mask of not working slats in the simulation**
- **Implement single channel reconstruction as for the data**

Before MC changes:

TOF energy (zoom at low values)

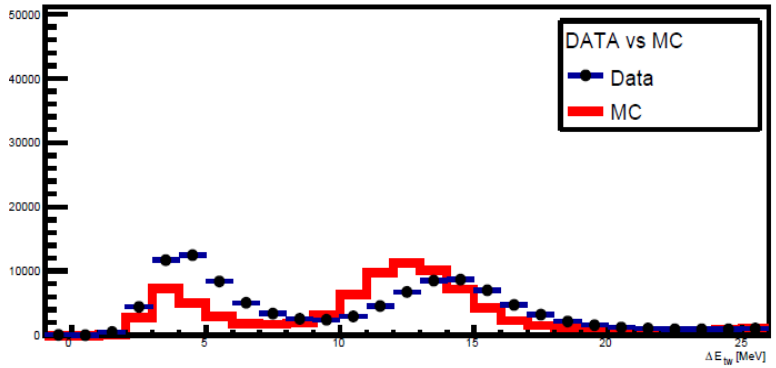


Charge occupancy

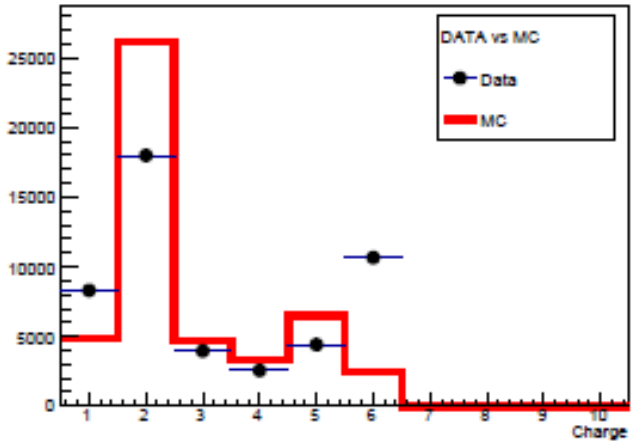


After MC changes:

TOF energy (zoom at low values)



Charge occupancy



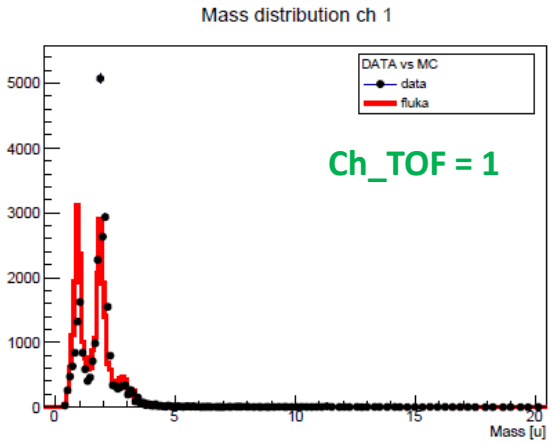
MC distributions normalized to the same number of events as the data. (different MC and data samples used in the two cases).

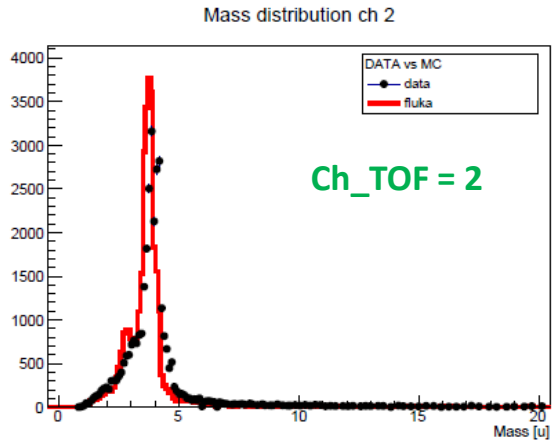
Comparison of generated and reconstructed quantities in the simulation.

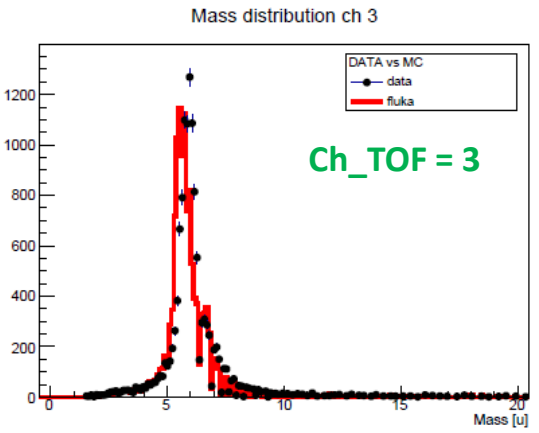
Some comparisons shown to understand the shift in the reconstructed variable distributions (momentum, mass, ..) between data and MC at the carbon peak.

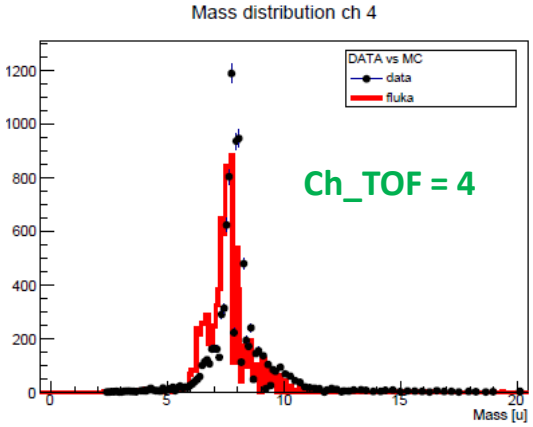
These comparison are also used to estimate resolutions and reconstruction efficiencies (preliminary results reported in the spare slides for comparison with other similar studies).

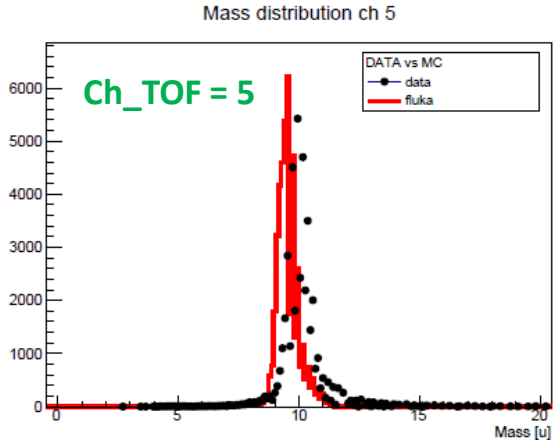
When looking at all the events a shift between data and MC is present for high Z.
Example for mass distribution (other plots in the spare slices)

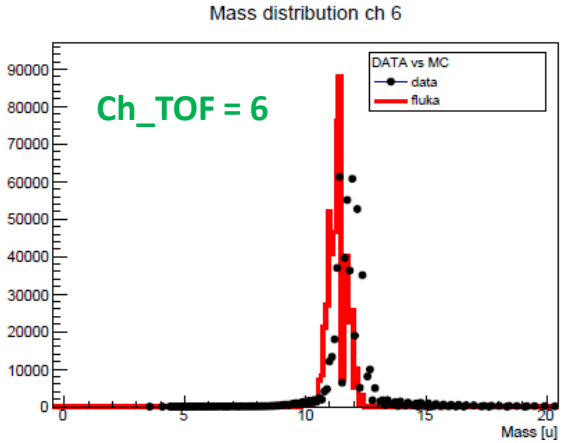








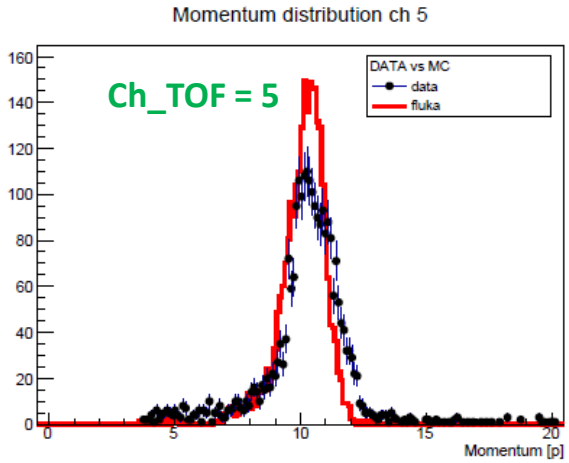


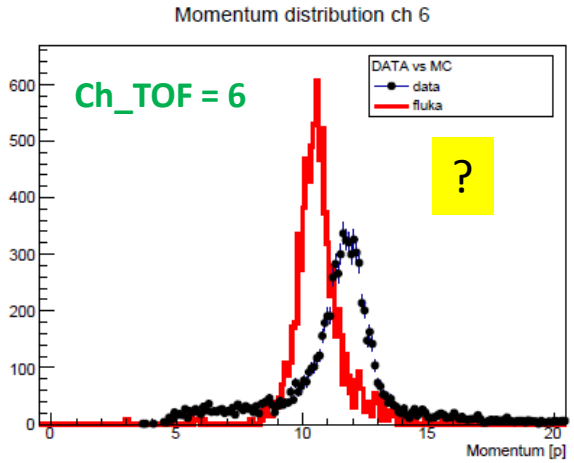


Is this effect due to a problem in the MC reconstruction for high charges ?

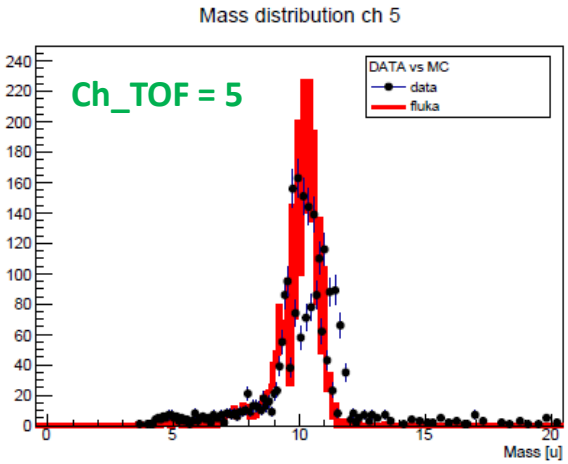
Many distributions look similar in the MC for Z=5 and Z=6 in fragmentation events, in costrast with what is seen in the data.

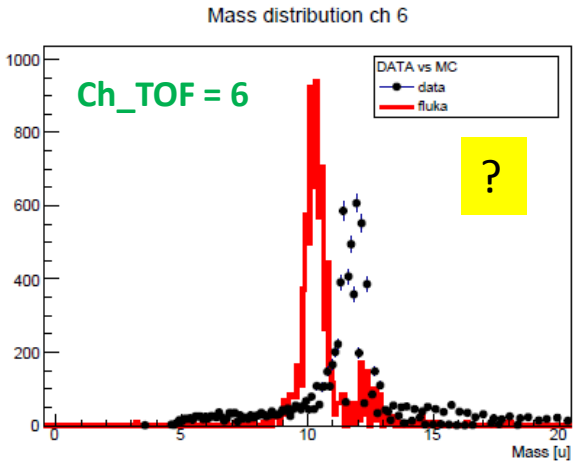
Momentum distribution (DATA/MC comparison, fragm. events)





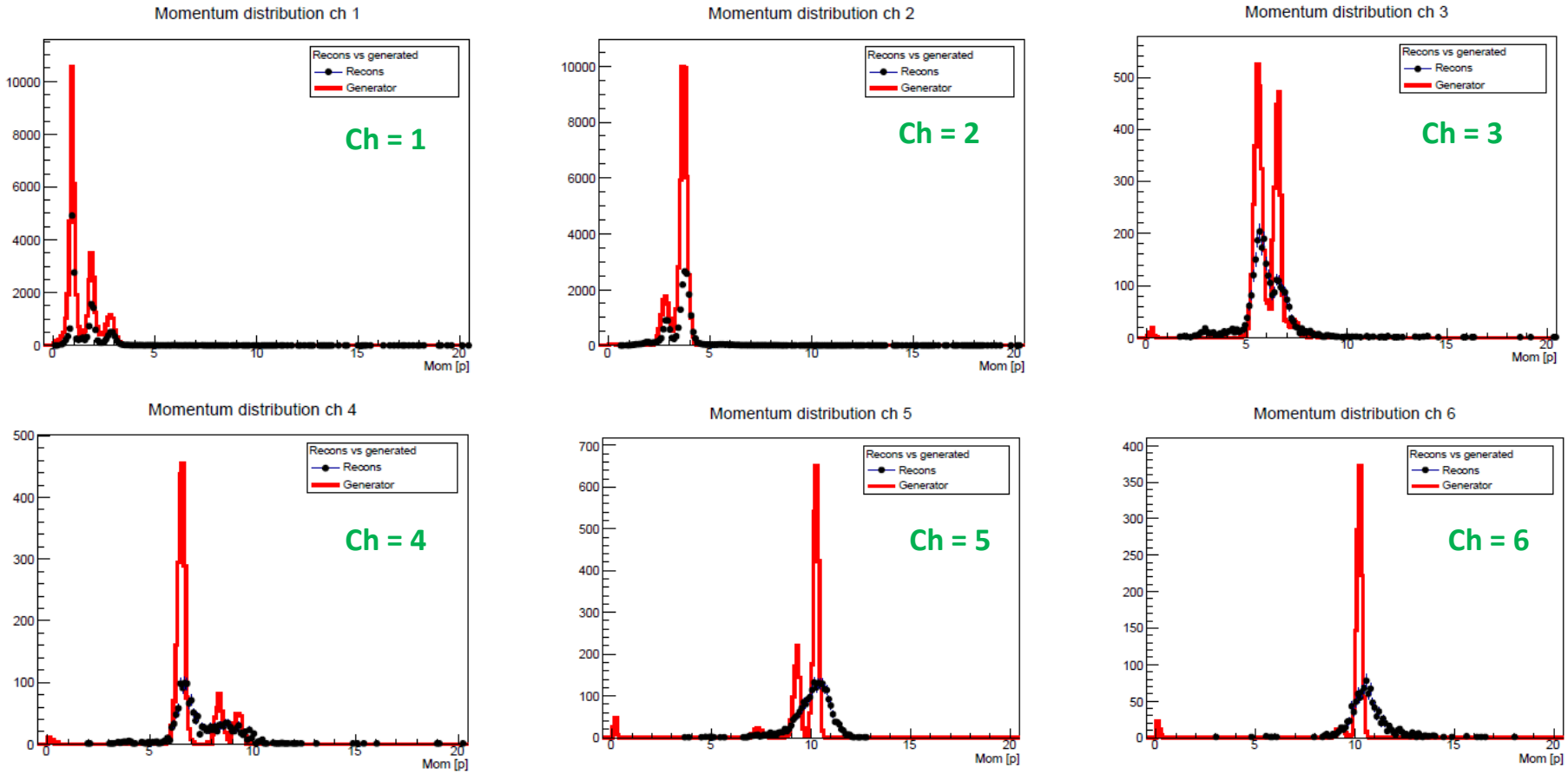
Mass distribution (DATA/MC comparison, fragm. events)





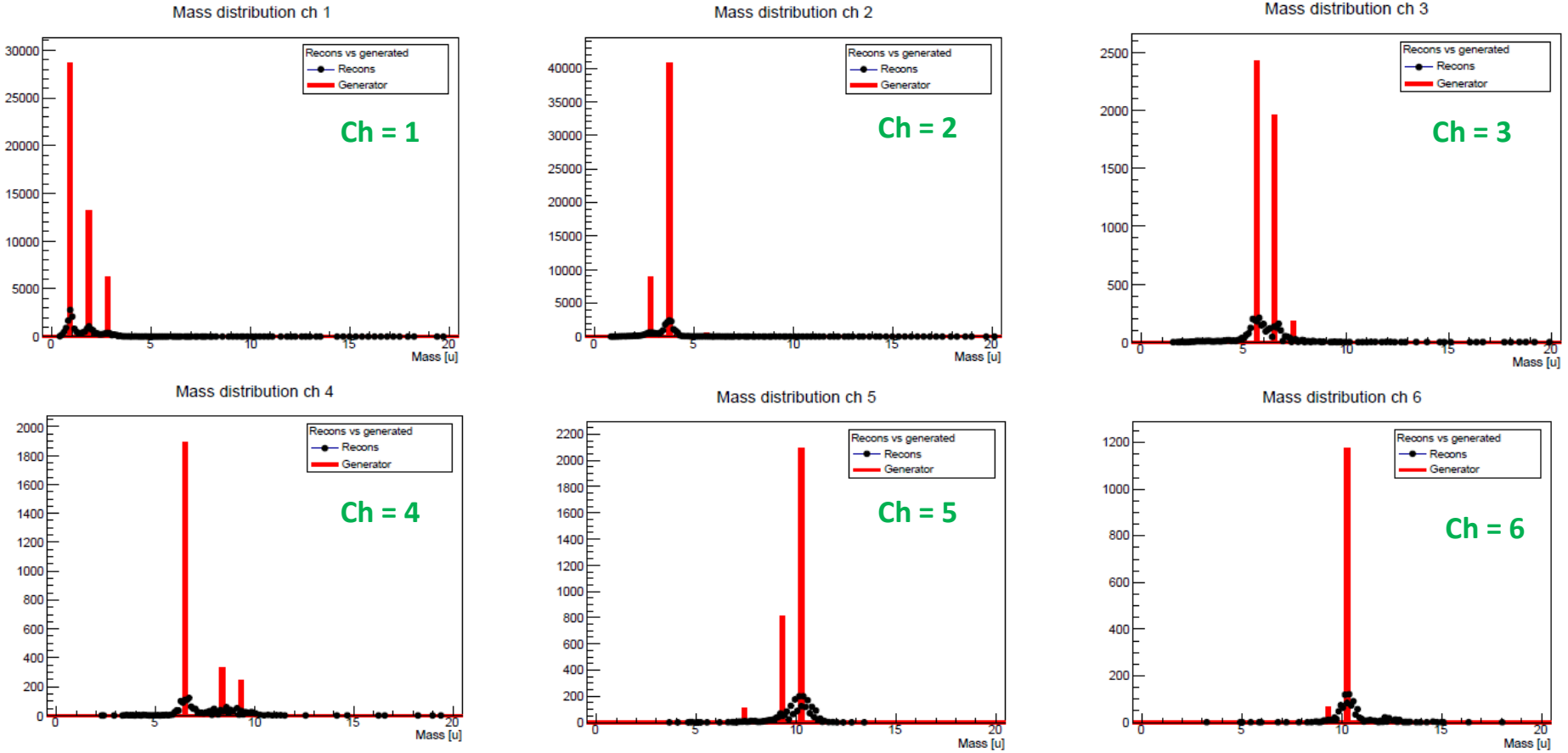
Is this effect due to a problem in the MC reconstruction for high charges ?

Momentum distributions (gen/reco – fragmentation events)



The reconstrutcted momentum for Z=6 is compatible with the generated momentum within its resolution. Momentum at generator level similar for Z=5 and Z=6.

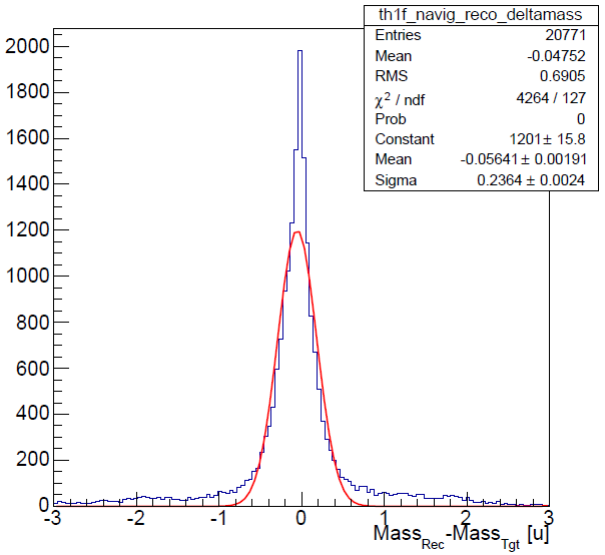
Mass distributions (gen/reco – fragmentation events)



It's not clear if the TOF resolution is enough to distinguish different masses for Z=5 and Z=6. In the MC only ^{10}C isotopes are produced when >1 VTX tracks are selected, apparently in contrast with what is seen from the data.

Resolution and offsets of reconstructed mass

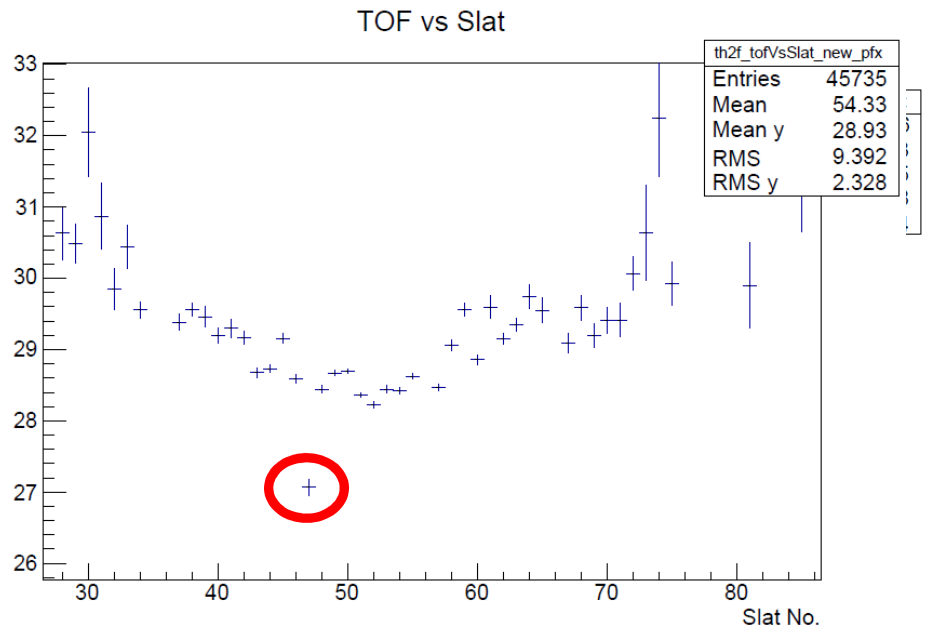
mass(reco) – mass(gen) [u]

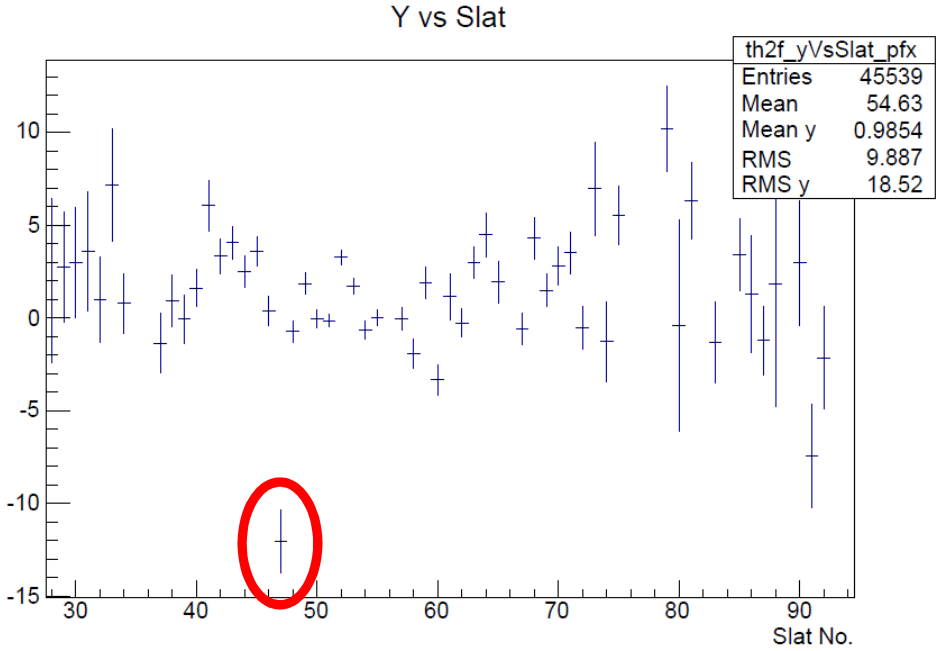


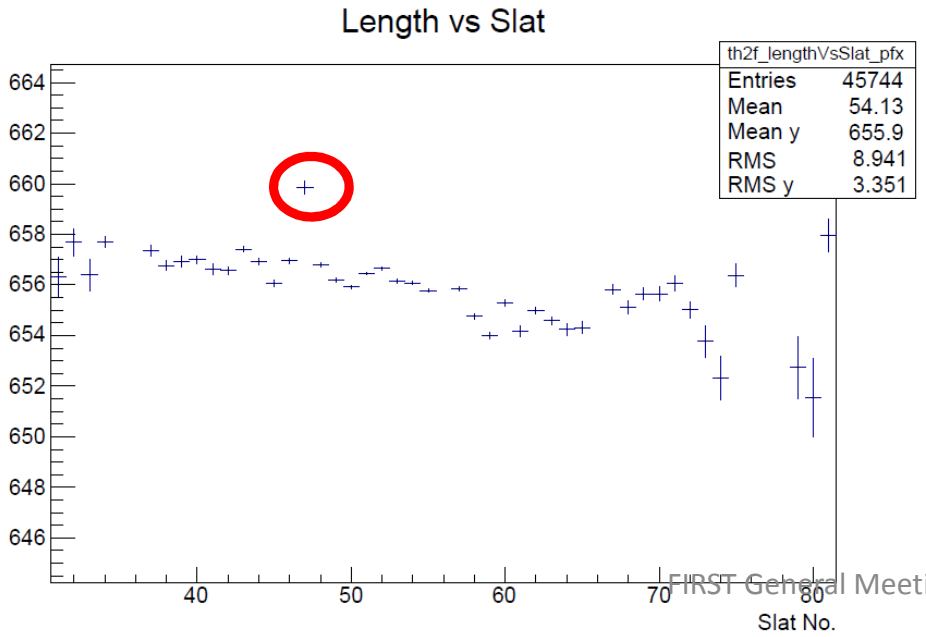
Charge	Sigma [u]	Offset [u]
1	0,0896 ± 0,0009	-0,0155 ± 0,0013
2	0,212 ± 0,002	-0,0545 ± 0,0021
3	0,353 ± 0,009	-0,102 ± 0,010
4	0,415 ± 0,011	-0,143 ± 0,014
5	0,584 ± 0,012	-0,210 ± 0,016
6	0,552 ± 0,018	-0,213 ± 0,032

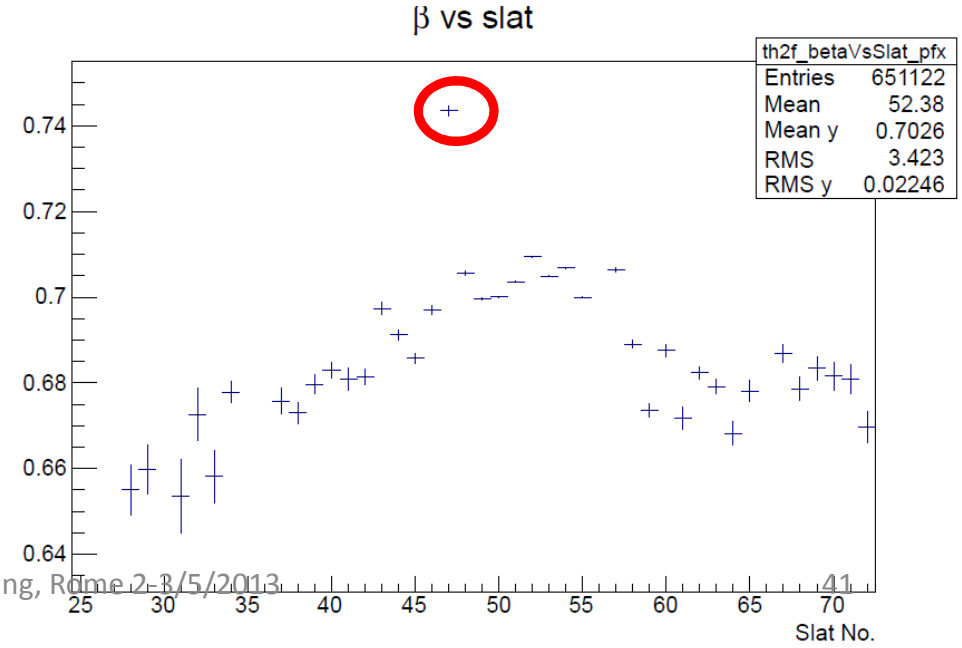
There is a offset between the reconstructed and generated masses in the simulation, increasing with Z. It seems compatible with a global time offset, but I am still not able to identify the source of this error.
This offset can not explain the difference between data and MC mass distributions for fragmentation events.

Other TOF issues: time calibration slat 47









Espiration of Fluka code

A major problem is the espiration of Fluka versions.

The last Fluka version does not allow to define a user version of the usrsco.f code (needed for the VTX simulation).

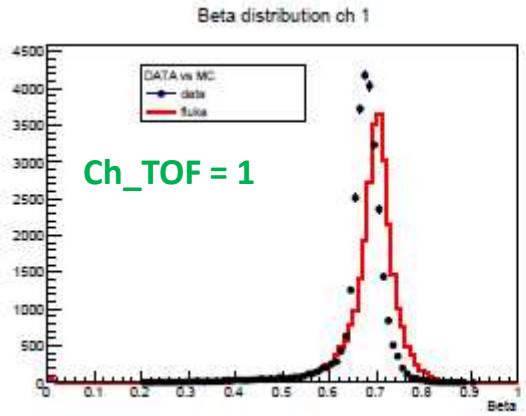
Till has provided a previous 64-bit version of the Fluka code that is still valid, but it will expire at some time in the future.

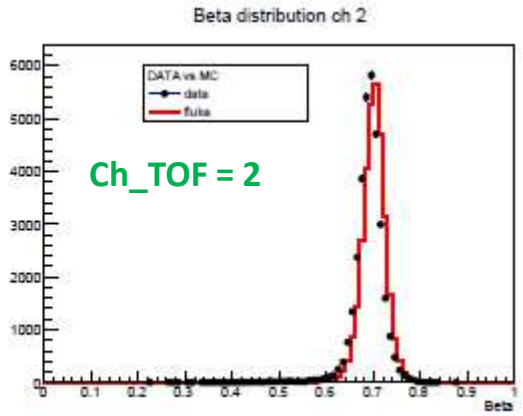
Should we ask for a «special» (previous) version of the Fluka code where usrsco.f can be defined by the user, or for a version without expiration ?

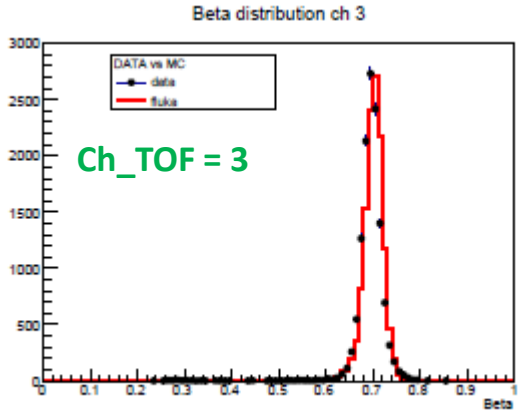
SPARE SLIDES
(DATA/MC comparisons)

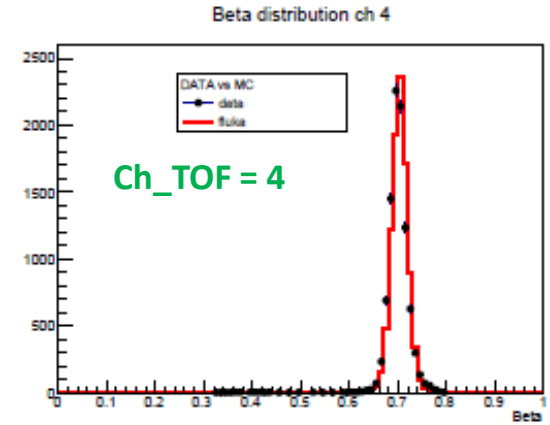
Histograms normalized to the same number of events for each Z.
Check of distribution shapes, not of normalizations.

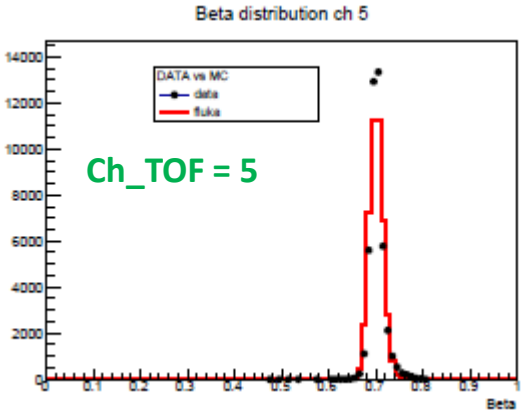
Beta distributions (data/MC – all events)

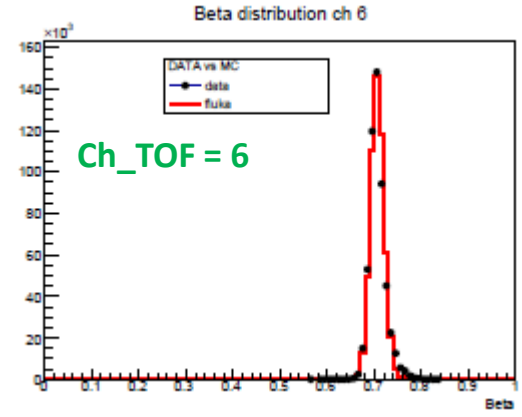




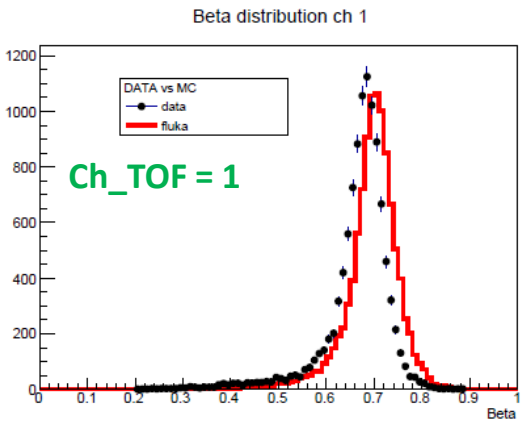


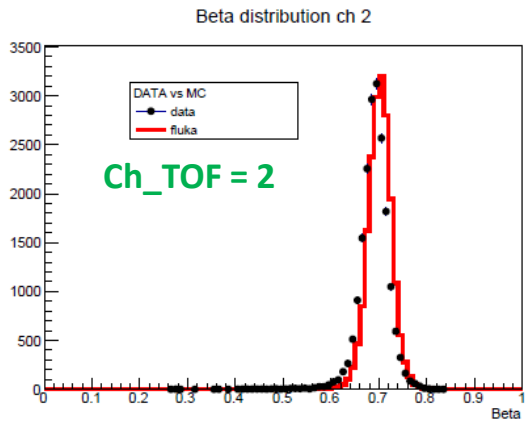


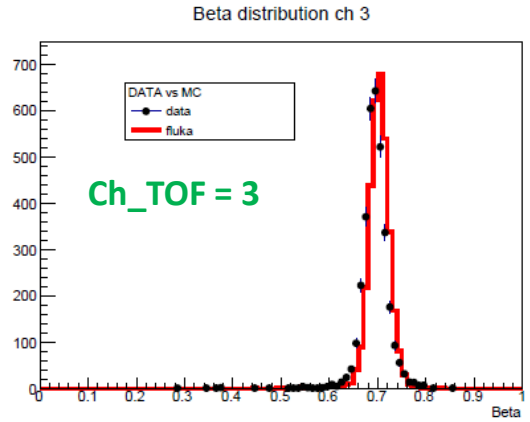


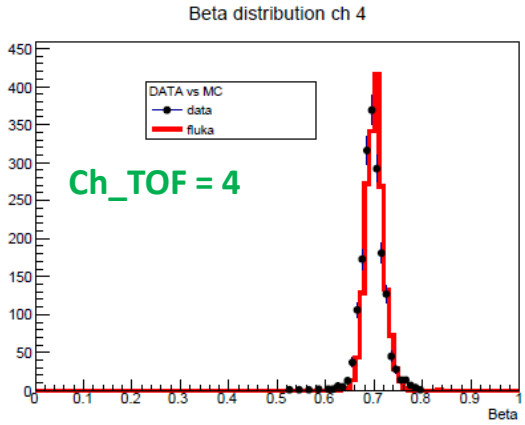


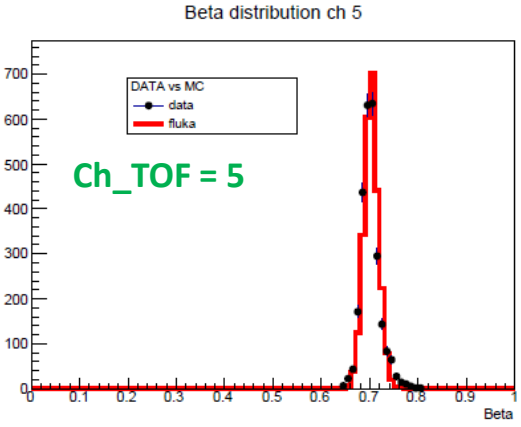
Beta distributions (data/MC -fragmented events)

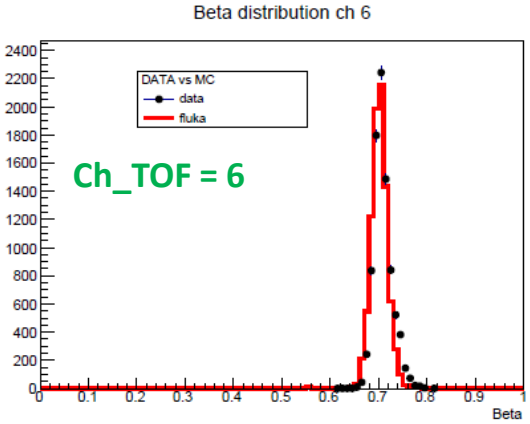




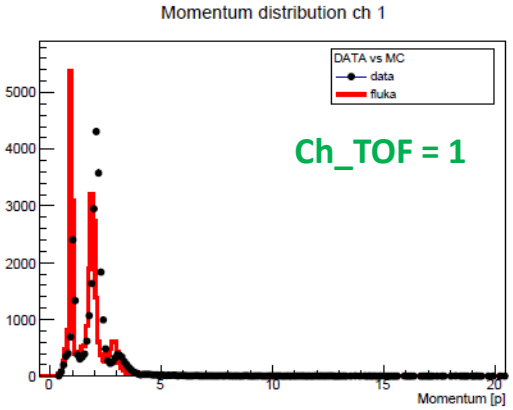


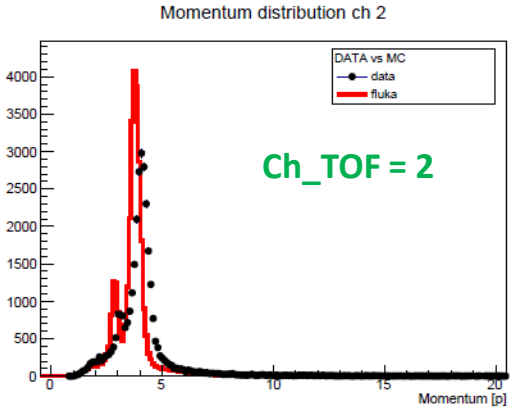


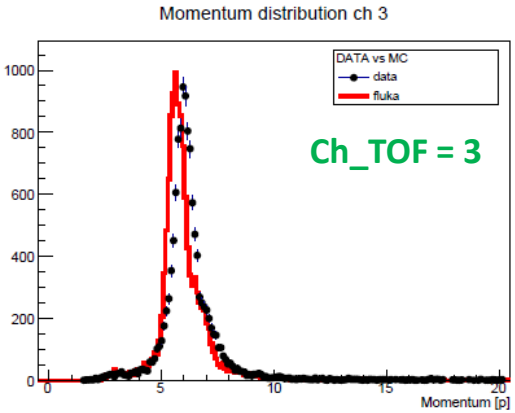


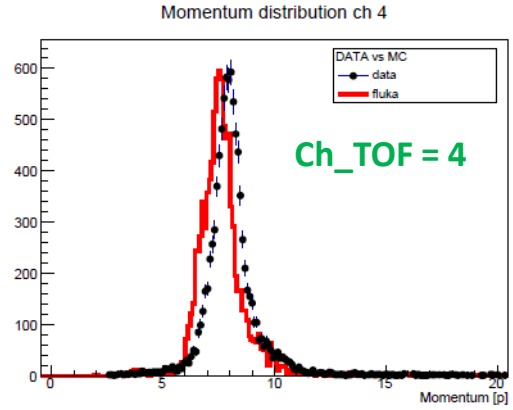


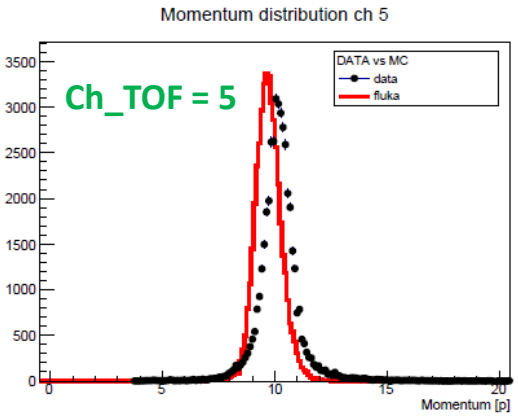
Momentum distributions (data/MC – all events)

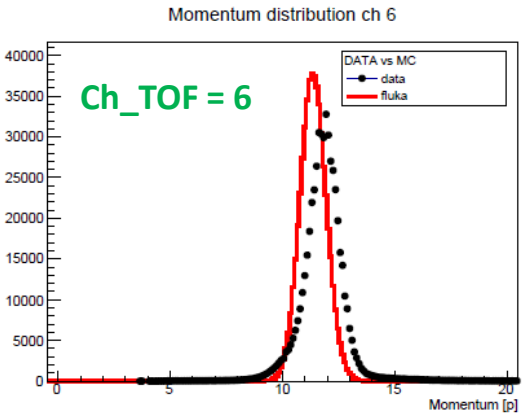






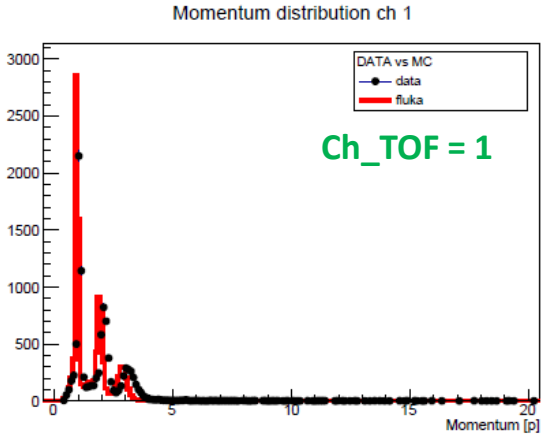


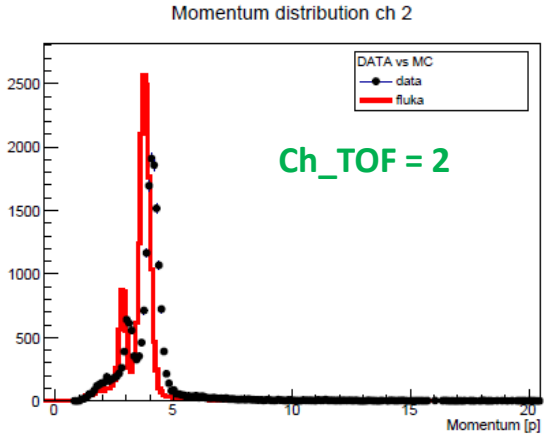


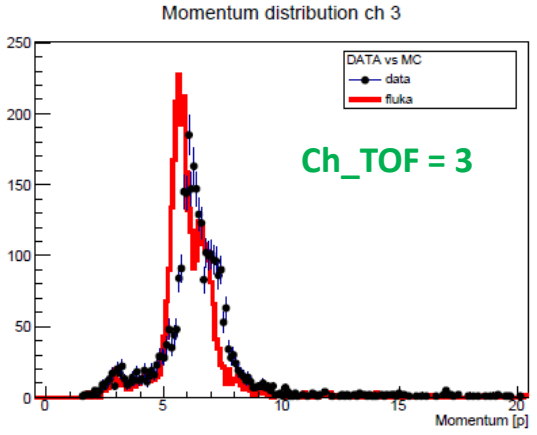


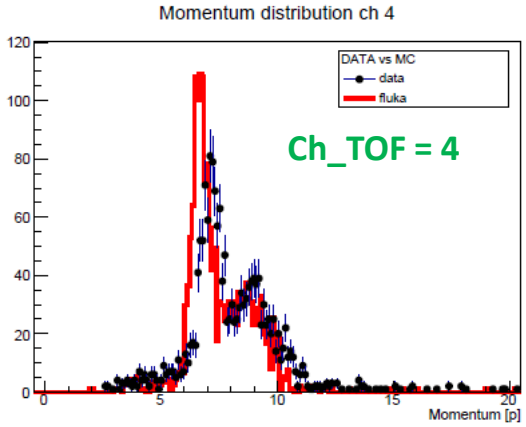
Offset for Z>=4

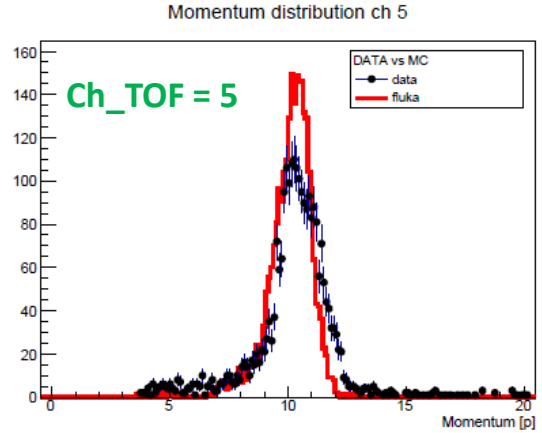
Momentum distribution (data/MC - fragmented events)

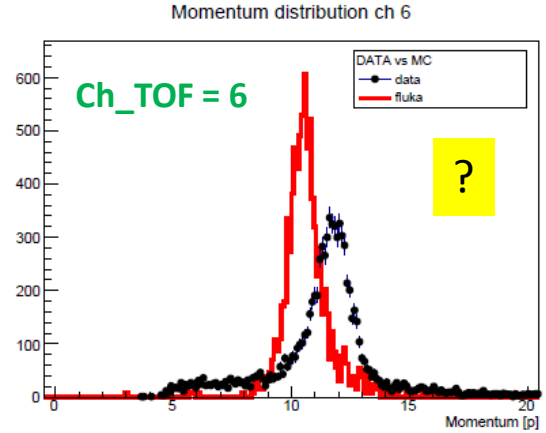






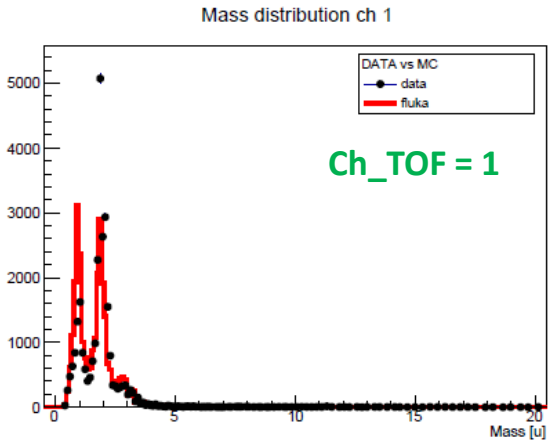


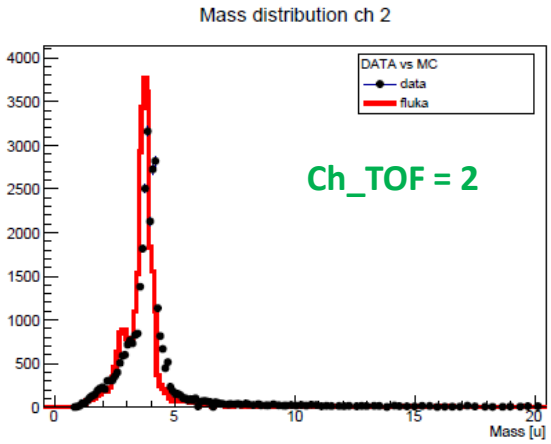


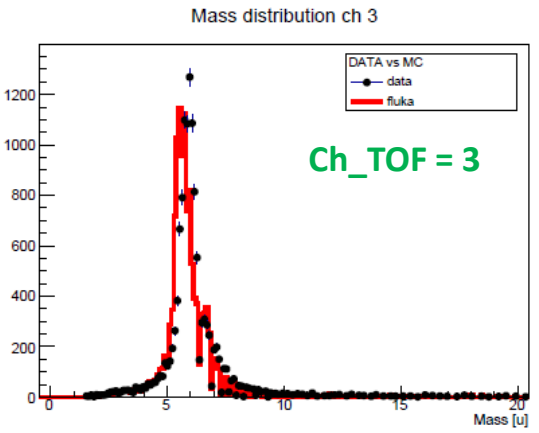


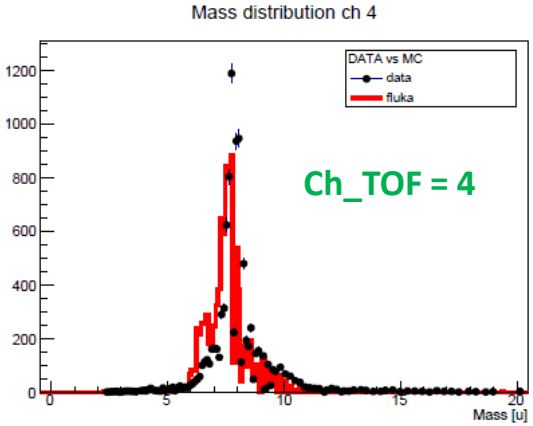
Similar MC distributions for Z=5 and Z=6.

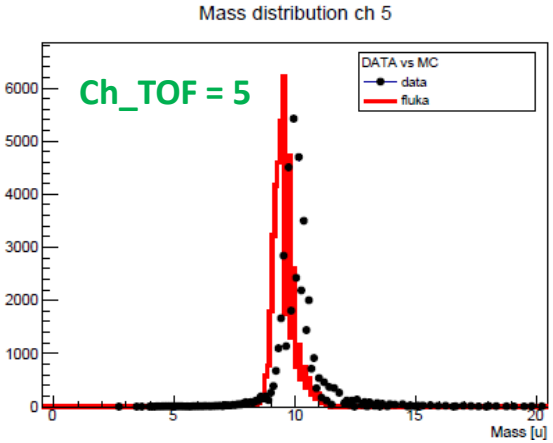
Mass distributions (data/MC - all events)

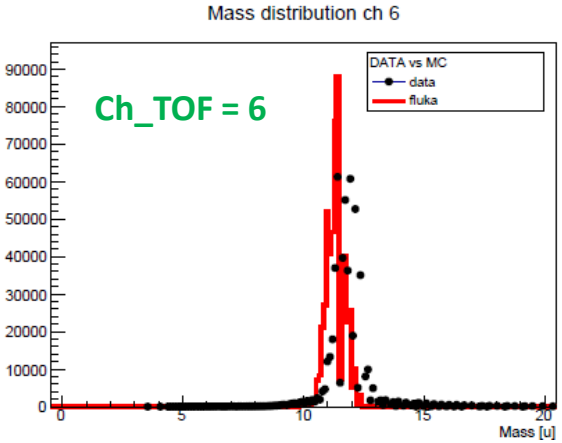




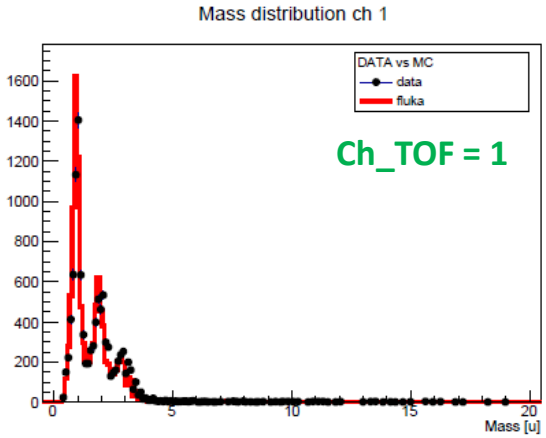


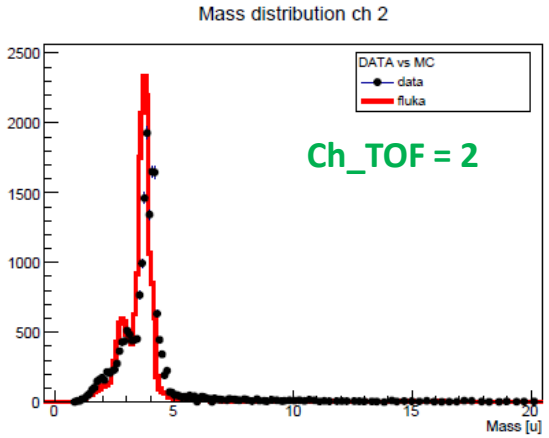


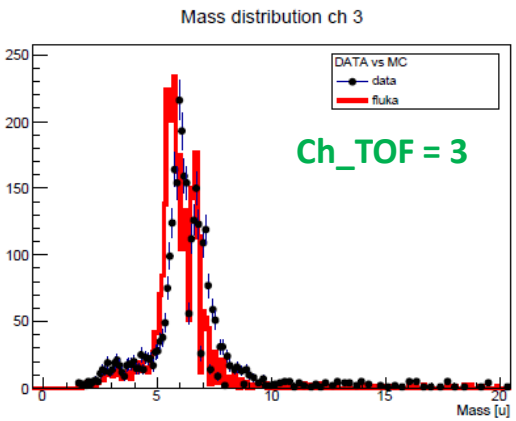


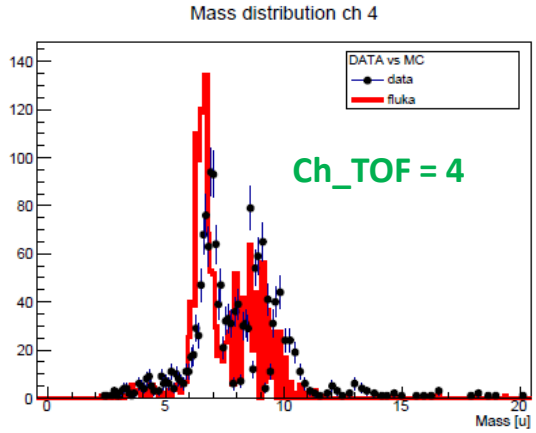


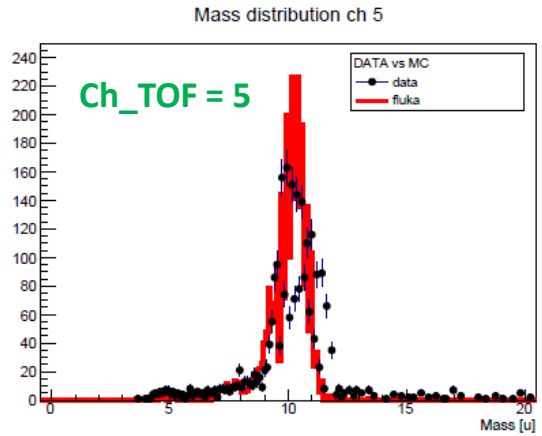
Mass distributions (data/MC - fragmentation events)

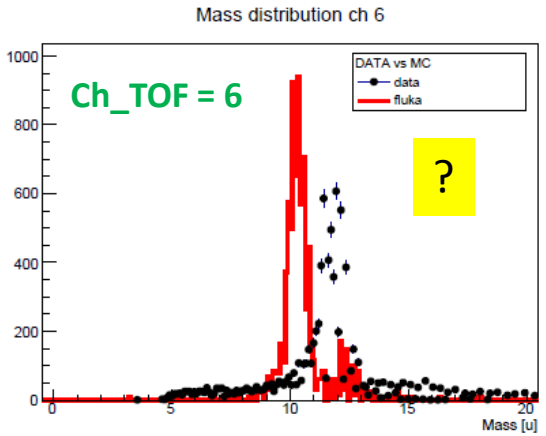






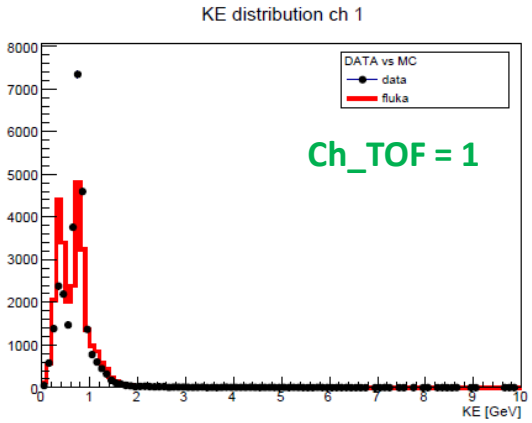


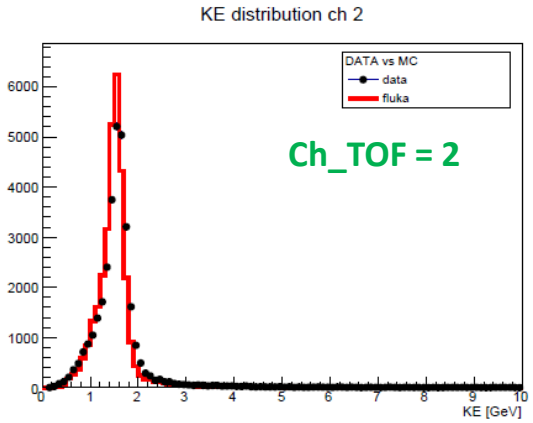


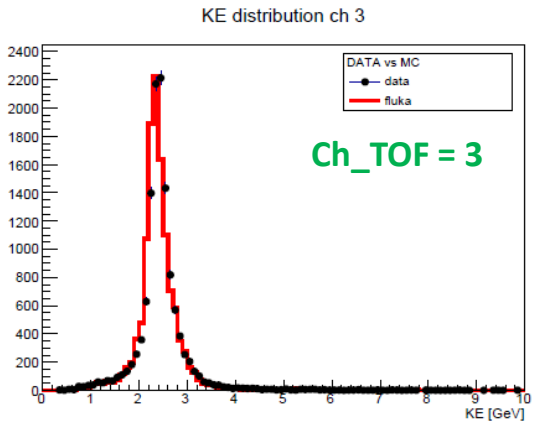


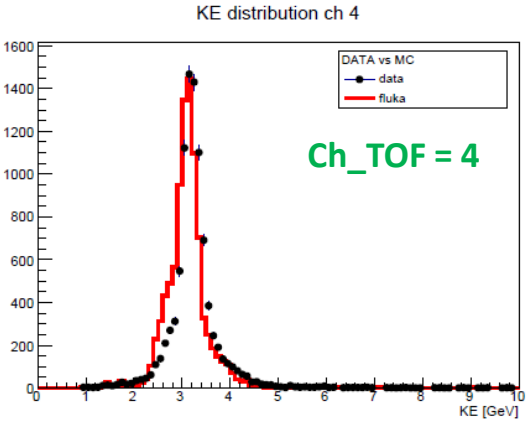
Similar MC distributions for Z=5 and Z=6.

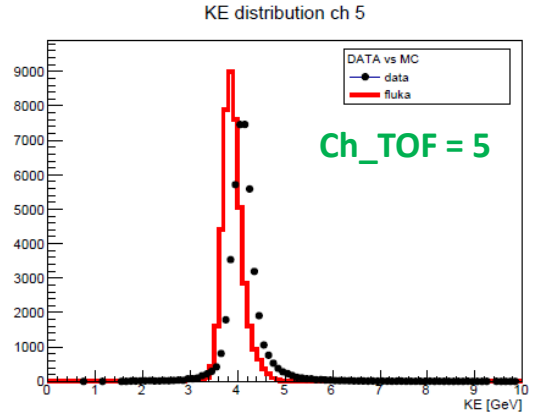
Kinetic energy distributions (data/MC - all events)

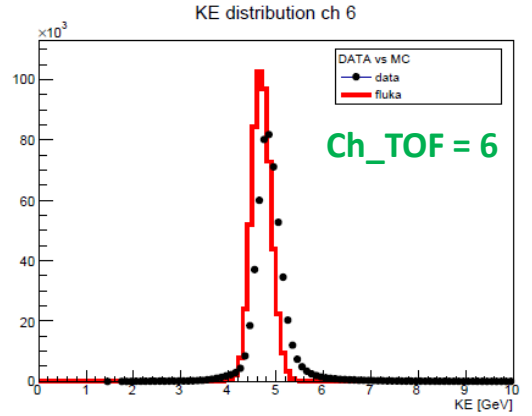




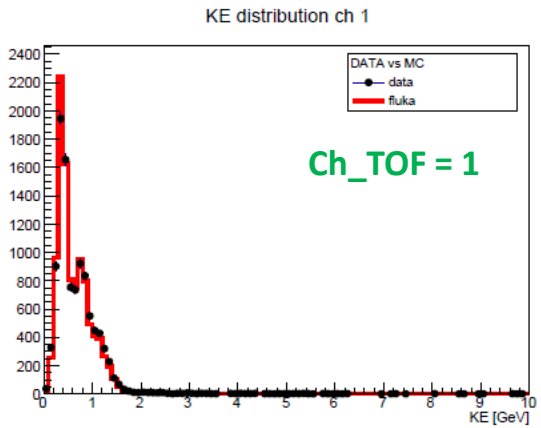


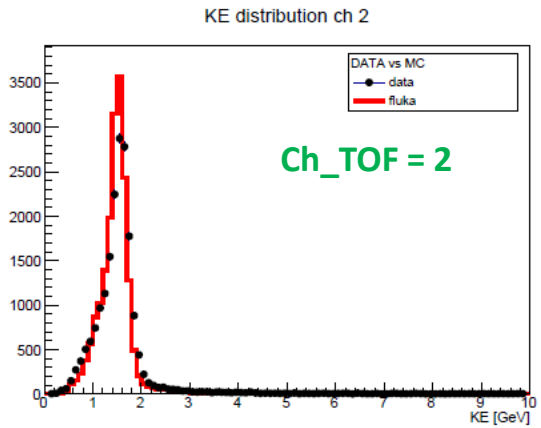


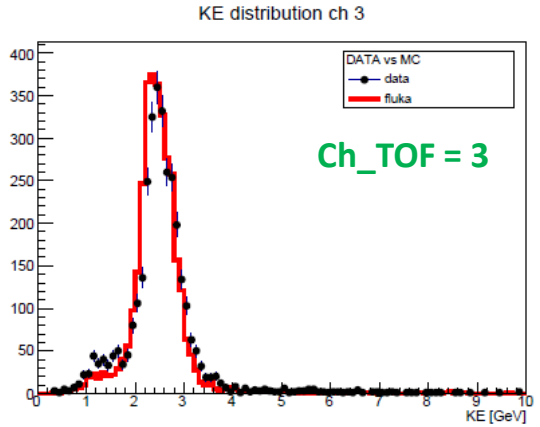


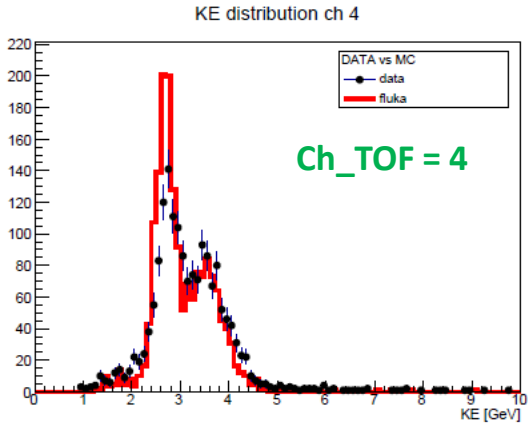


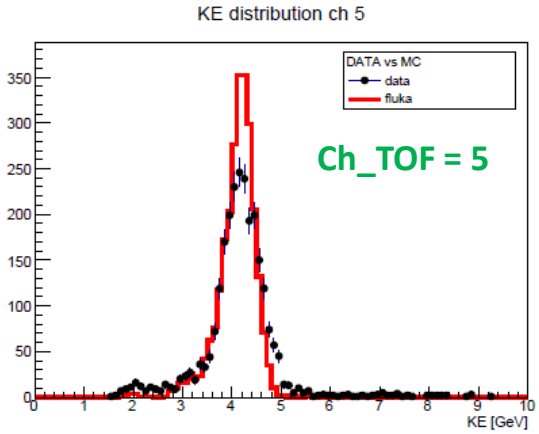
Kinetic energy (data/MC fragmented events)

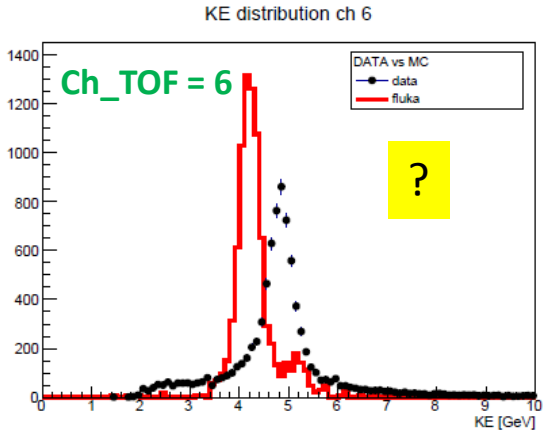






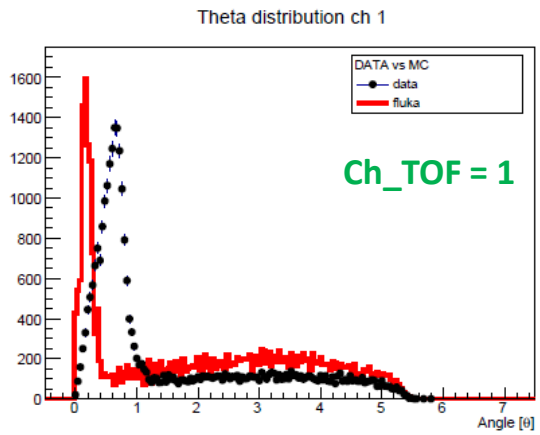


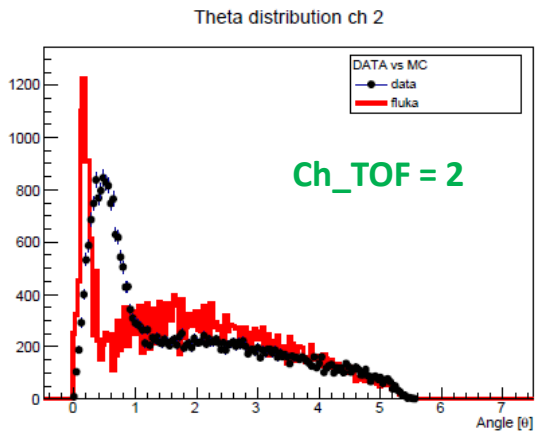


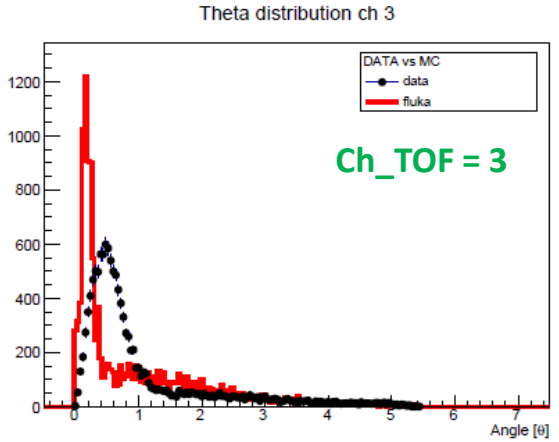


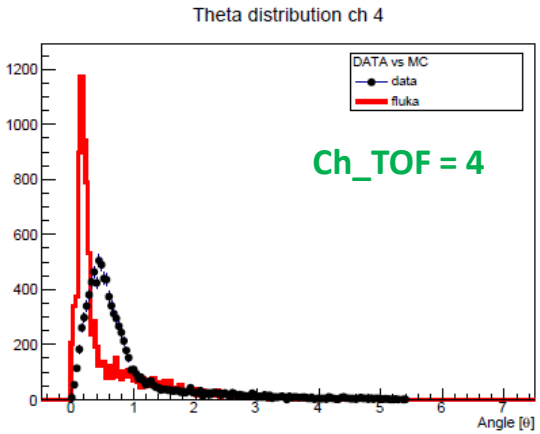
Similar MC distributions for Z=5 and Z=6.

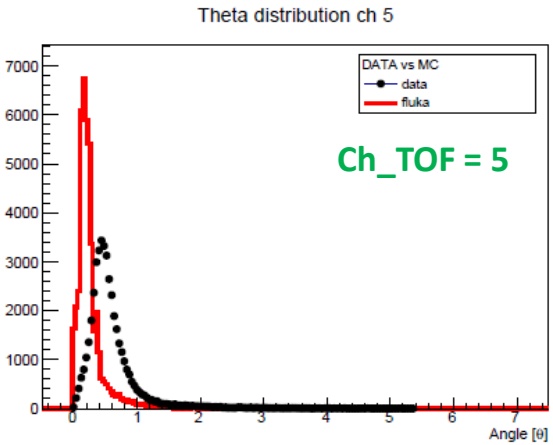
Theta distributions (data/MC - all events)

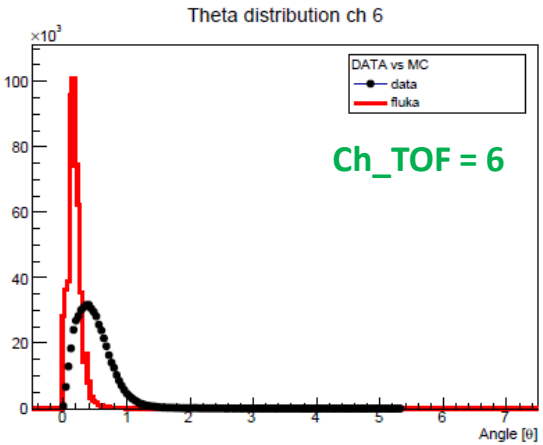




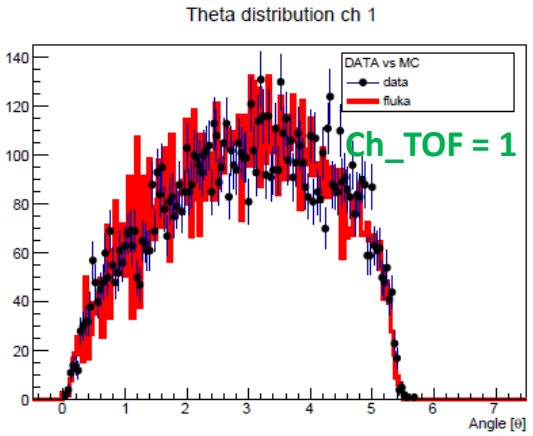


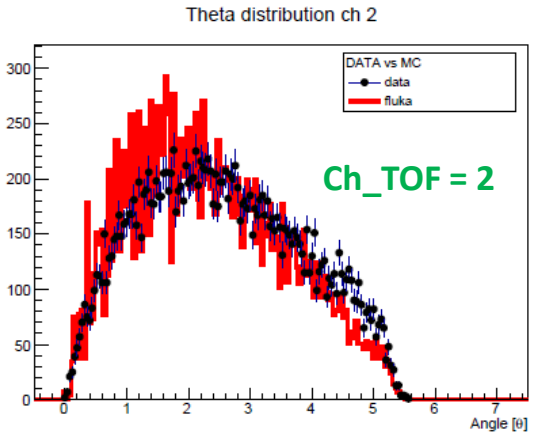


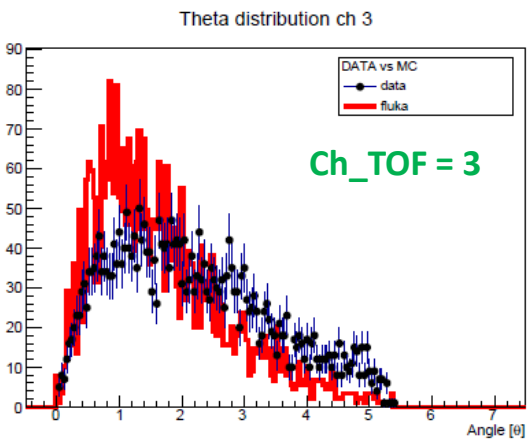


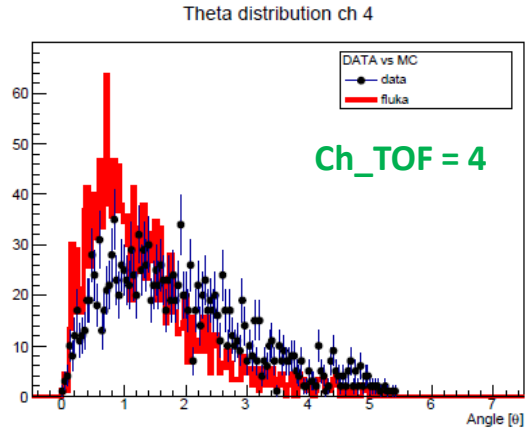


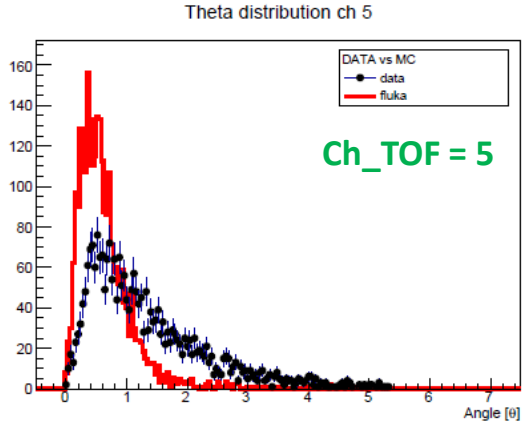
Theta distributions (data/MC - fragmented events)

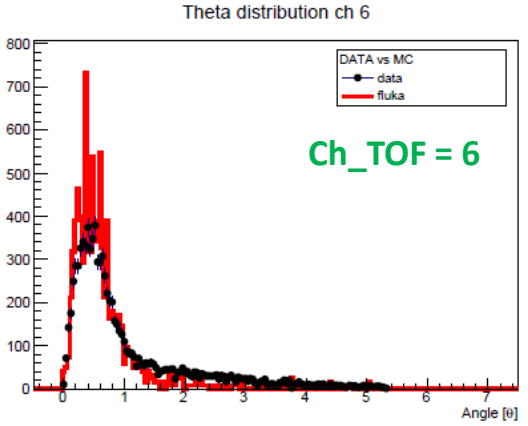












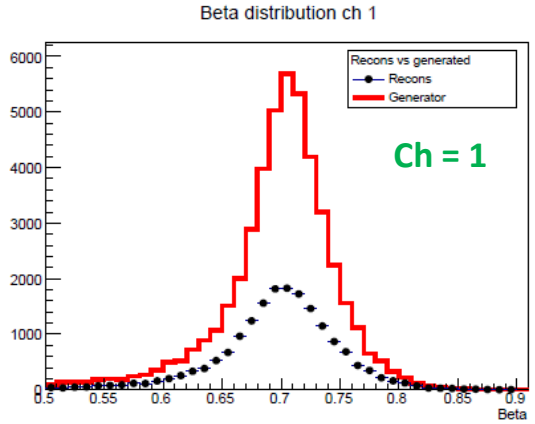
SPARE SLIDES
(generator/reconstruction comparison in the simulation, resolutions)

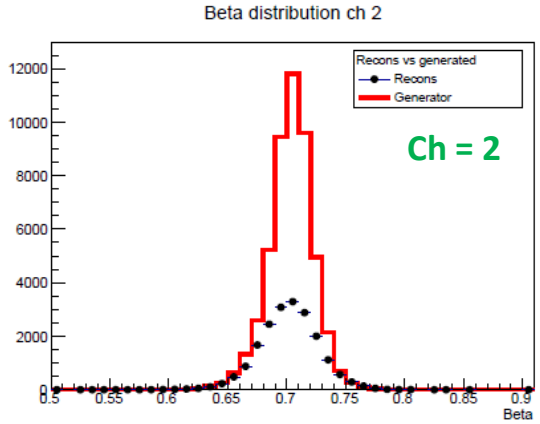
Generator tracks: MC tracks just after the target with $\theta < 6^{\circ}$
Reconstructed tracks: tracks from the reconstruction

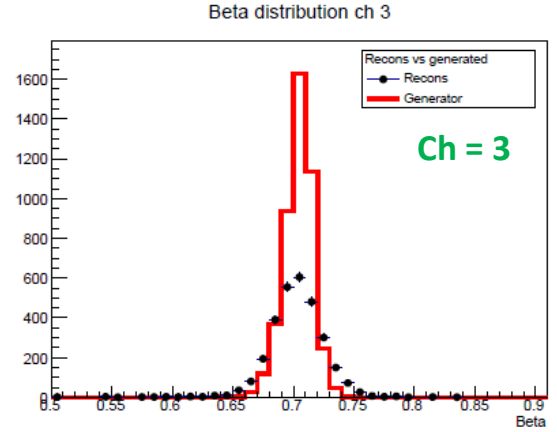
No normalization factor applied to the following histograms (same MC samples).

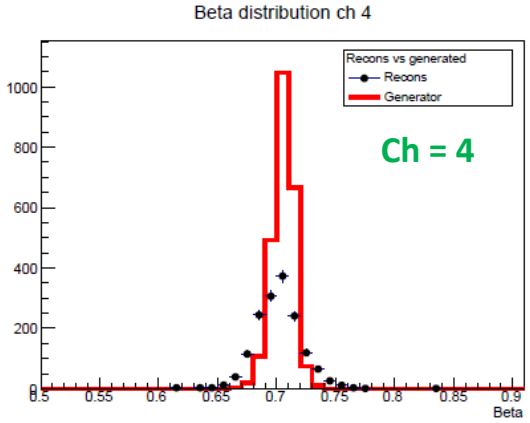
To evaluate resolutions, a generator track is associated to each reconstructed track by navigating back from the correspondign TOF hit to the target in the MC track chain.

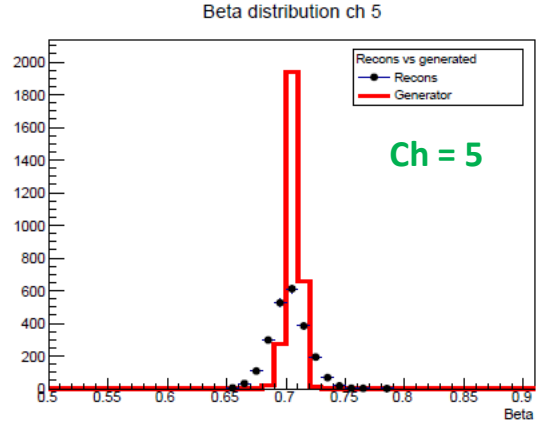
Beta distributions (gen/reco – fragm. events)

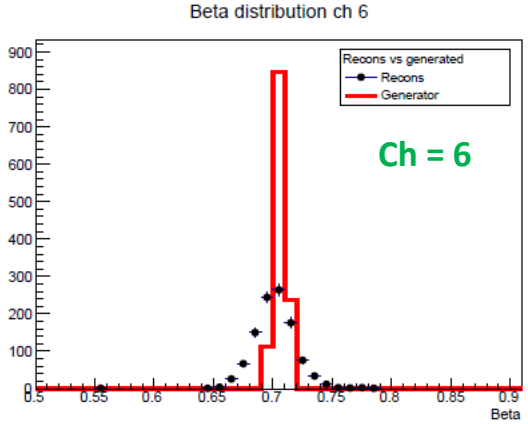






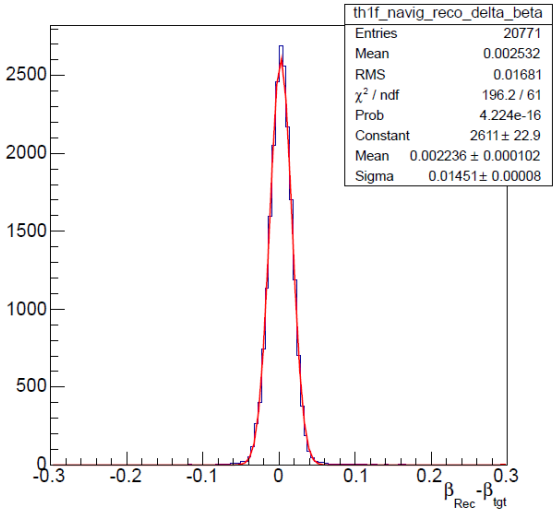






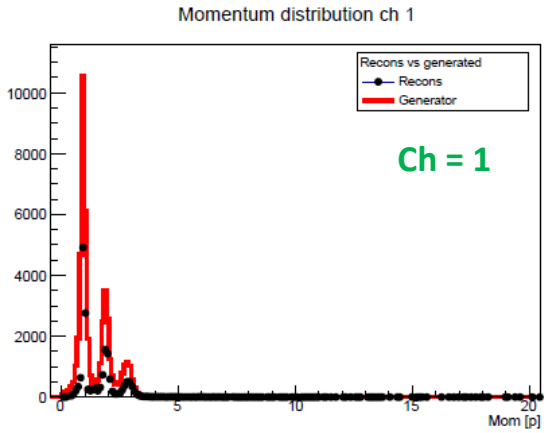
Beta resolutions (gene/reco - fragmentation events)

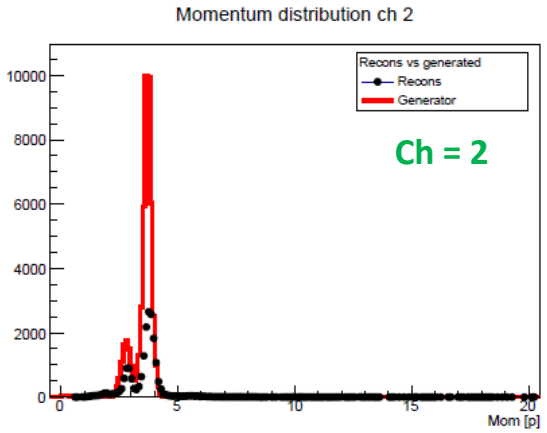
B(reco) – β(gene)

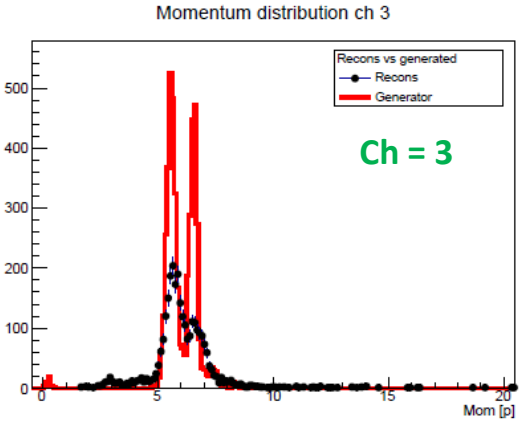


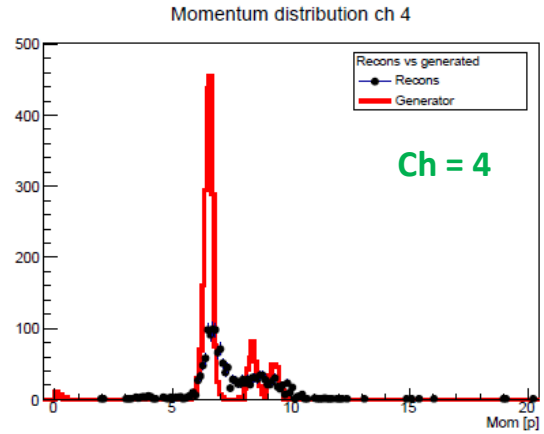
Charge	Sigma	Offset
1	0,01519 ± 0,00009	0,0031 ± 0,0002
2	0,01527 ± 0,00008	0,0015 ± 0,0001
3	0,0149 ± 0,0002	0,0023 ± 0,0004
4	0,0158 ± 0,0003	0,0041 ± 0,0005
5	0,0151 ± 0,0002	0,0035 ± 0,0004
6	0,0153 ± 0,0003	0,0062 ± 0,0006

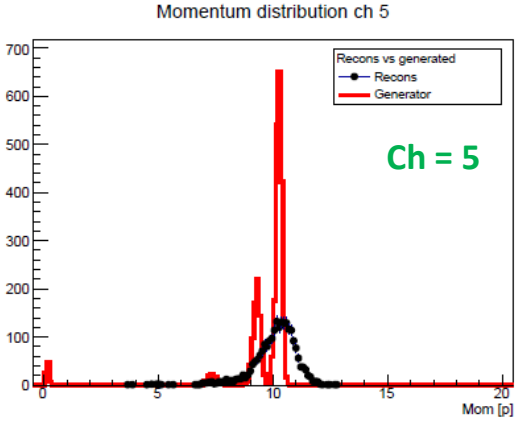
Momentum distributions (gen/reco – fragmentation events)

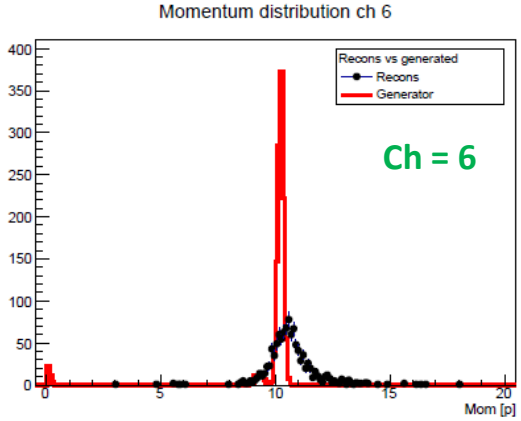






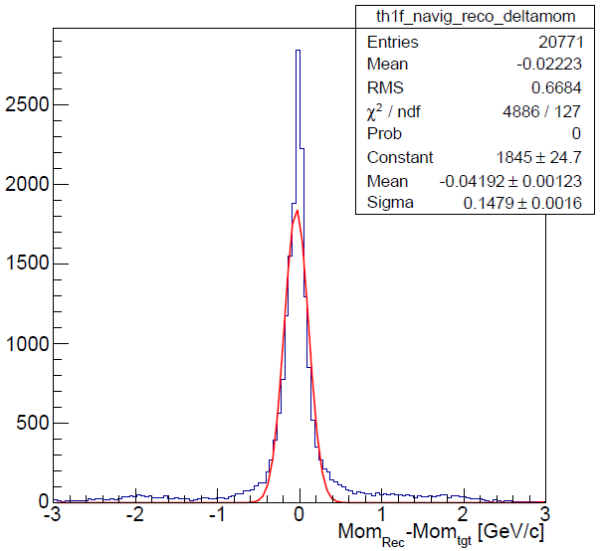






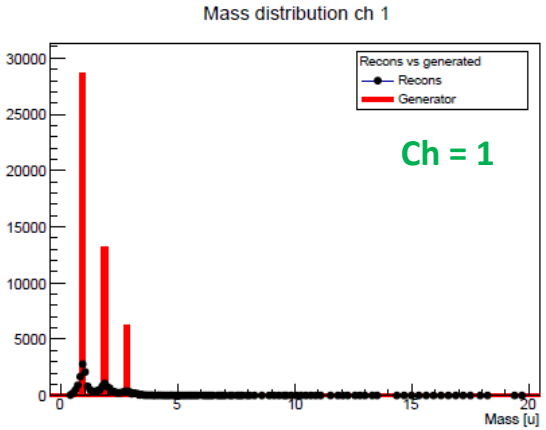
Momentum resolutions (gen/reco – fragmentation events)

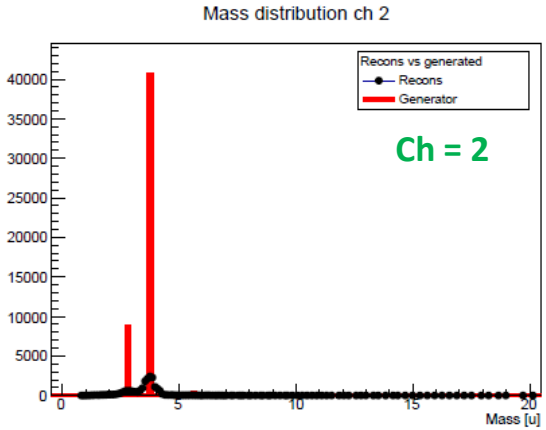
p(reco) – p(gen) [GeV/c]

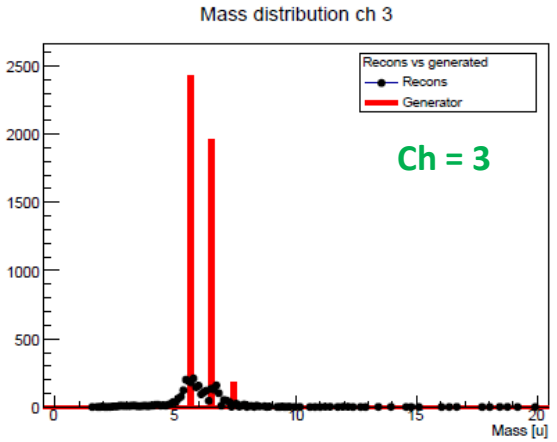


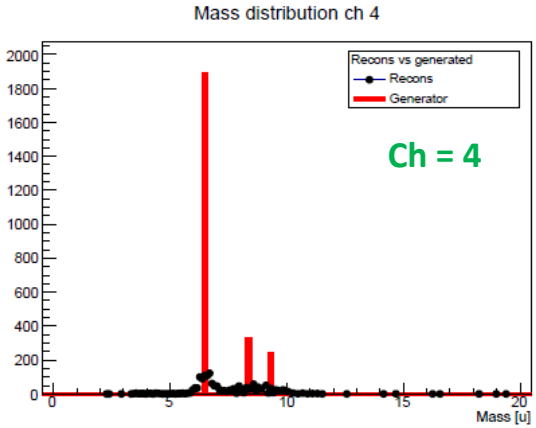
Charge	Sigma [GeV/c]	Offset [GeV/c]
1	0,0704 ± 0,0007	-0,0084 ± 0,0008
2	0,132 ± 0,001	-0,046 ± 0,001
3	0,220 ± 0,004	-0,069 ± 0,007
4	0,255 ± 0,007	-0,065 ± 0,009
5	0,368 ± 0,006	-0,113 ± 0,010
6	0,306 ± 0,007	-0,066 ± 0,016

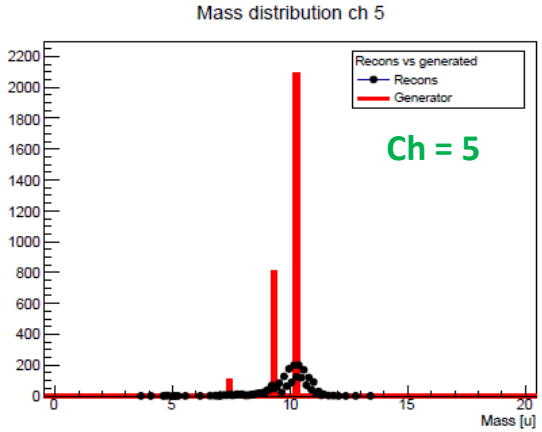
Mass distributions (gen/reco – fragmentation events)

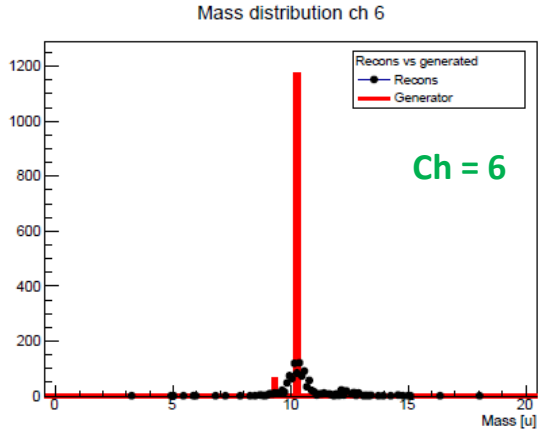






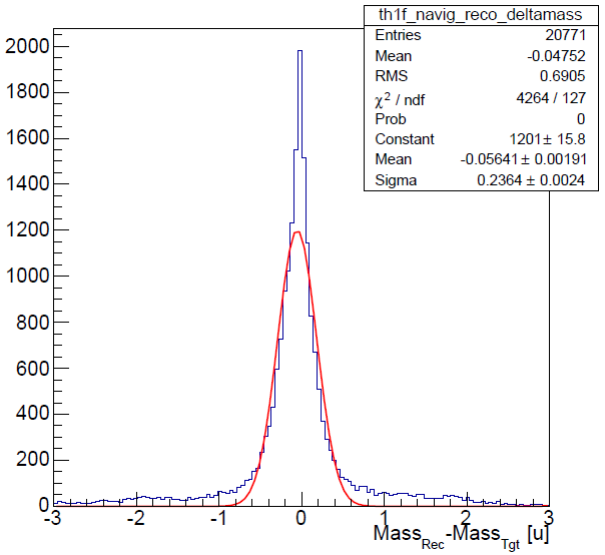






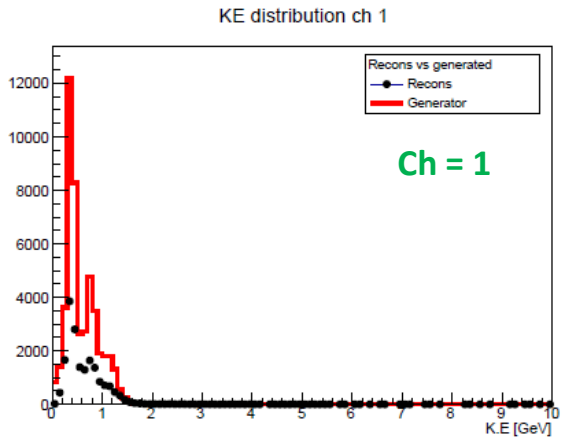
Mass resolutions (gen/reco – fragmentation events)

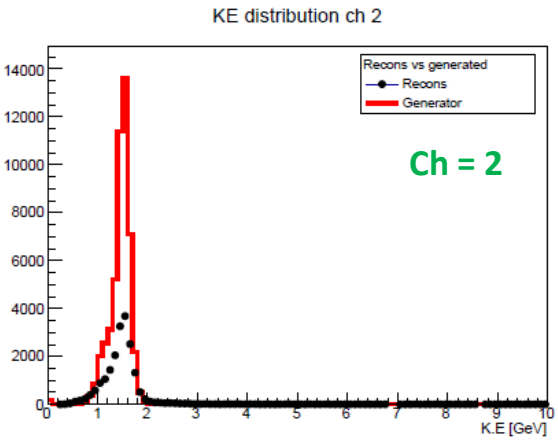
mass(reco) – mass(gen) [u]

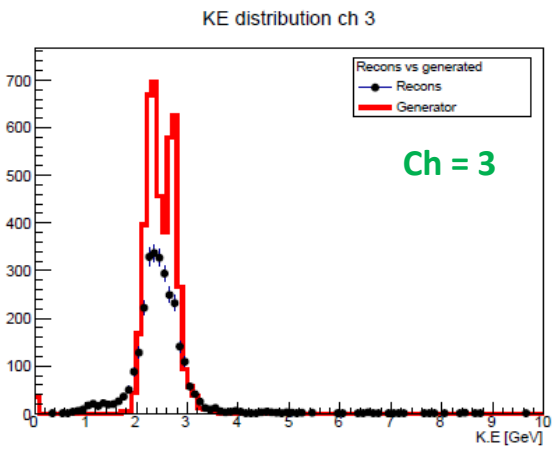


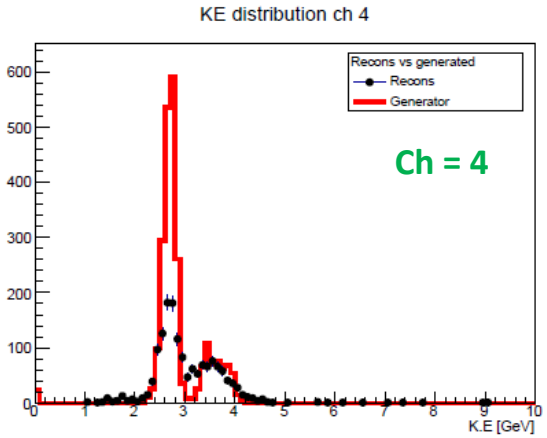
Charge	Sigma [u]	Offset [u]
1	0,0896 ± 0,0009	-0,0155 ± 0,0013
2	0,212 ± 0,002	-0,0545 ± 0,0021
3	0,353 ± 0,009	-0,102 ± 0,010
4	0,415 ± 0,011	-0,143 ± 0,014
5	0,584 ± 0,012	-0,210 ± 0,016
6	0,552 ± 0,018	-0,213 ± 0,032

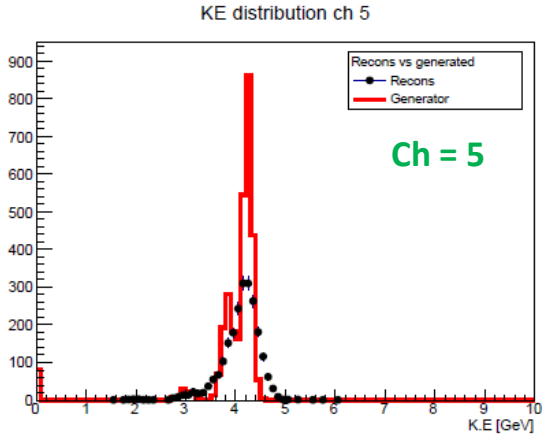
Kinetic energy distributions (gen/reco – fragm. events)

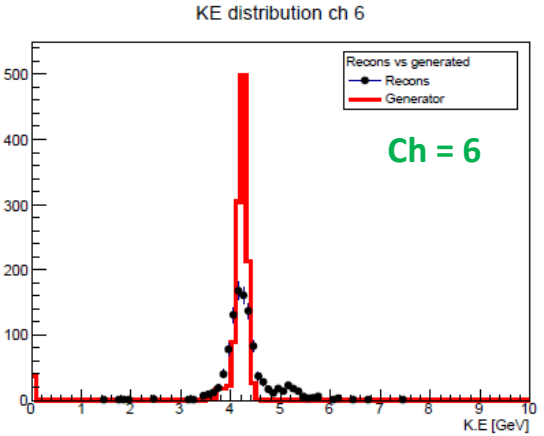






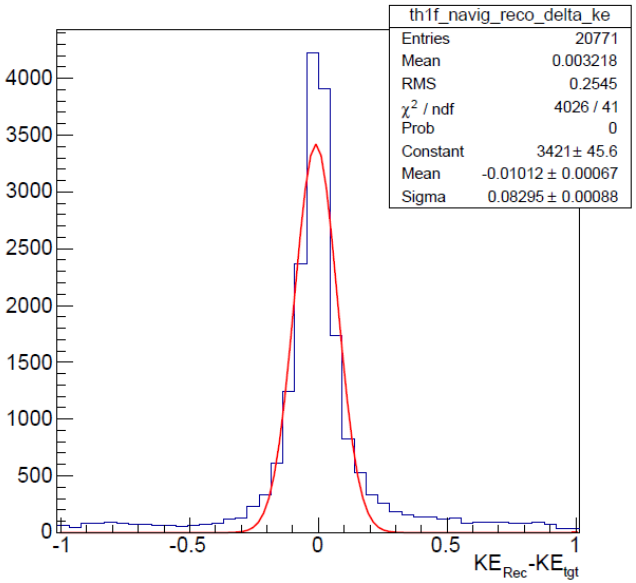






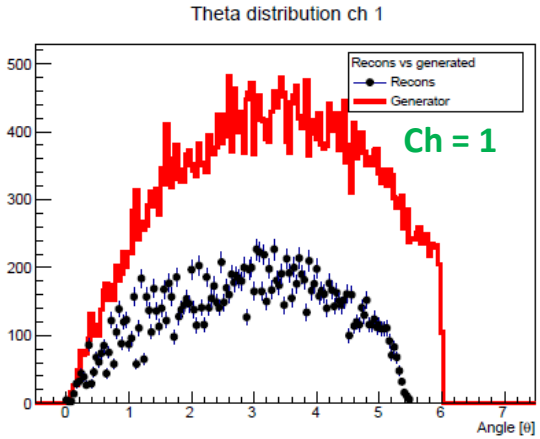
Kinetic energy resolutions (gen/reco – fragmentation events)

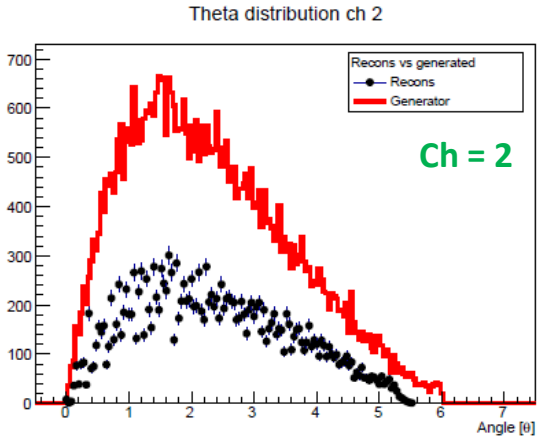
K.E.(reco) – K.E.(gen) [GeV]

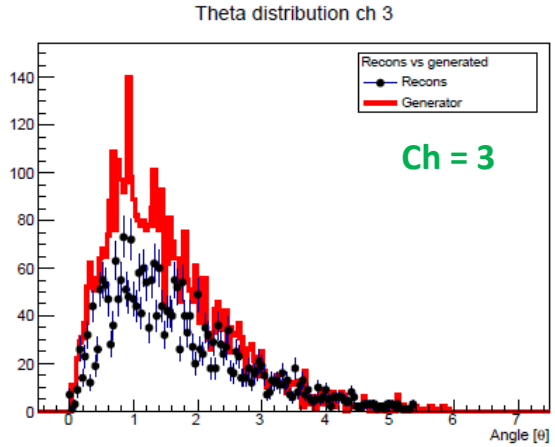


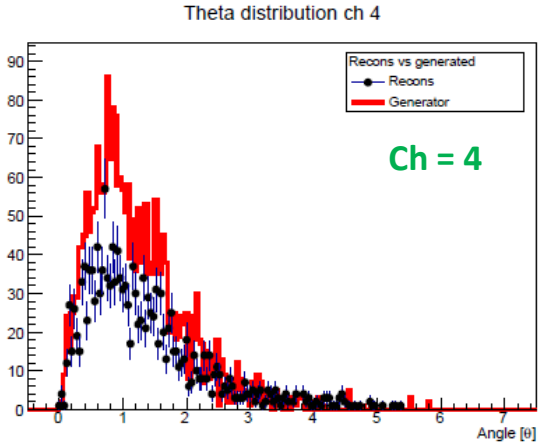
Charge	Sigma [GeV]	Offset [GeV]
1	0,0638 ± 0,0004	-0,0017 ± 0,0007
2	0,0794 ± 0,0006	-0,0132 ± 0,0008
3	0,120 ± 0,002	-0,015 ± 0,003
4	0,138 ± 0,004	-0,011 ± 0,006
5	0,203 ± 0,004	-0,027 ± 0,006
6	0,193 ± 0,005	-0,019 ± 0,006

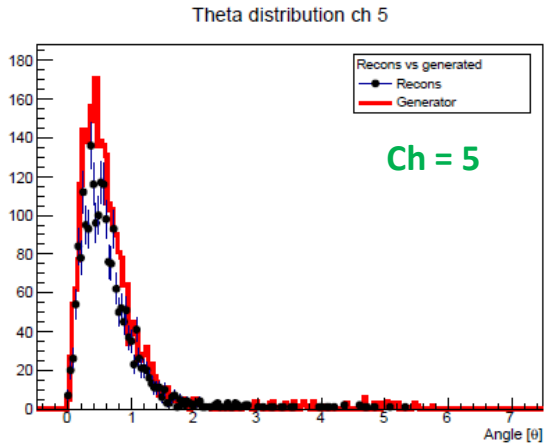
Angle distributions (gen/reco – fragment. events)

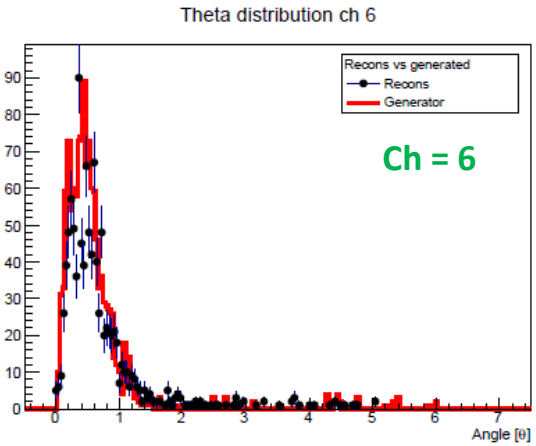






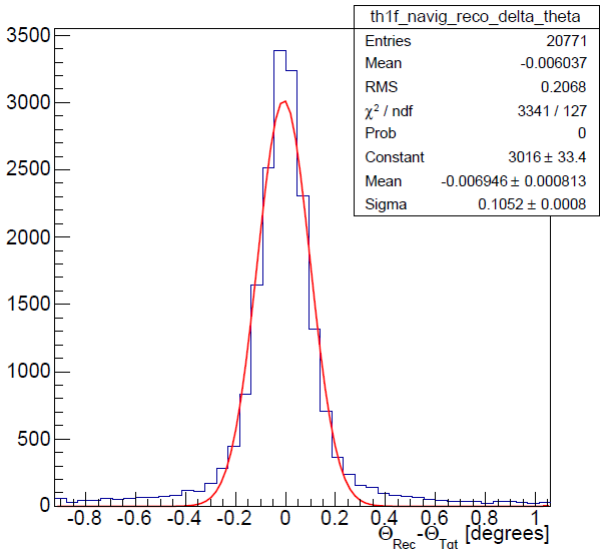






Angle resolutions (gen/reco - fragmentation events)

theta(reco) – theta(gen) [degrees]



Charge	Sigma [degrees]	Offset [degrees]
1	0,123 ± 0,001	-0,008 ± 0,002
2	0,1076 ± 0,0008	-0,005 ± 0,001
3	0,095 ± 0,002	-0,003 ± 0,003
4	0,110 ± 0,003	-0,015 ± 0,004
5	0,100 ± 0,002	-0,015 ± 0,002
6	0,101 ± 0,002	-0,017 ± 0,004