Track fitting performance in SpdRoot

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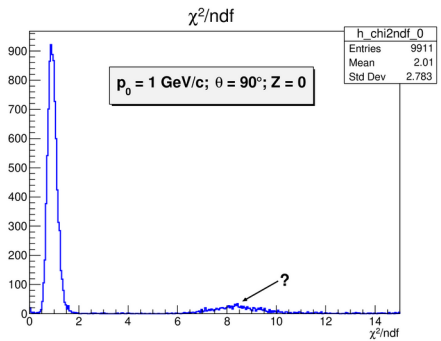
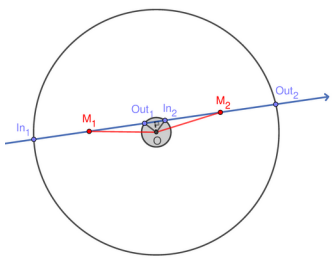
Introduction

- In this study I explore how well track fitting in SpdRoot works in a wide range of momenta and angles of tracks.
- The purpose of the study is to identify existing problems in the software, and try to fix them, or at least to find an explanation for the observed "anomalies".
- After that, a set of recommendations on which track quality cuts to use in physical analysis could be developed.

Introduction

- The first steps of the work in this direction were presented at the previous SPD Collaboration Meeting in April 2023.
- After that, a problem with additional hit in χ^2/ndf distribution due to incorrect drift radius calculation for hits when track crosses the wire was solved (see, e.g. SPD Physics Weekly meeting in September 19, 2023).
- Results, presented in this talk, have been already *partially* reported at the SPD Physics Weekly meetings in October 2023.

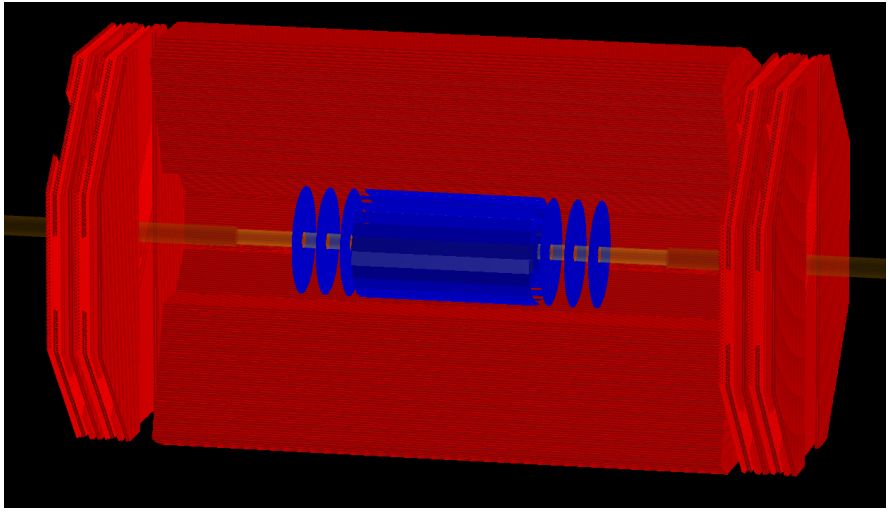




Simulation

- SpdRoot: branch **`geometry-update-spring-2023`**
  (was merged with the `master` branch just a few days ago)

- Trackers:
  - Inner tracker:
    DSSD (3 layers, with endcaps)
  - Straw tracker:
    - Barrel: 31 double layers
    - Endcaps: 8 double layers



- Artificial sample:
  π+, isotropical, p_0 = 0 .. 5 GeV/c (with step 0.05 GeV/c), $\mathbf{Z_{primary\ vertex} = 0}$,
  400k events (1 particle/event).

Reconstruction

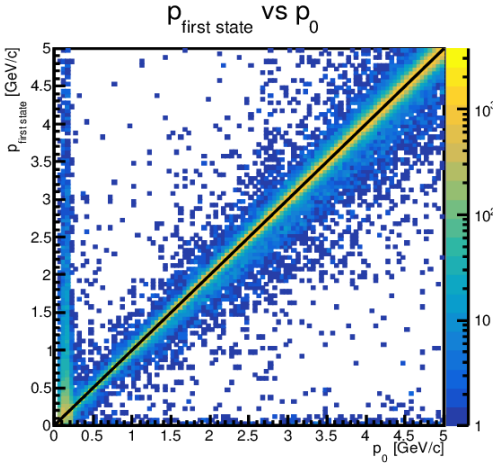
- The corrected function for the drift radius calculation is used (see my talk at SPD Physics Weekly Meeting, Sep 19, 2023).
- **Ideal track finding.**
- The only requirement for a particle to be accepted as a track (in `SpdMCTracksFinder`) is total **N hits >= 3**.
- For track fitting package **GenFit2** is used inside SpdRoot.

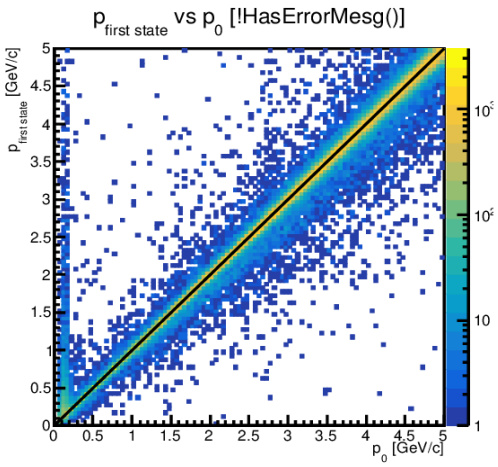
Track fit parameters

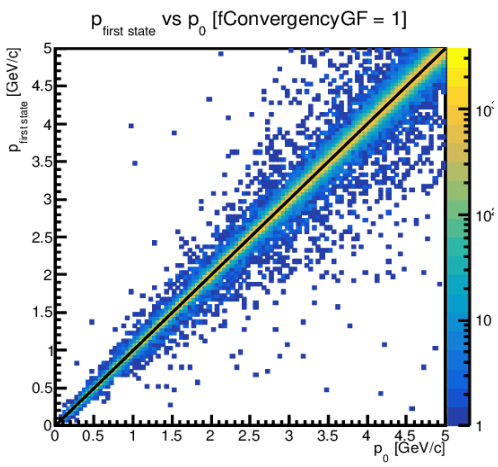
- Track fit quality characteristics are saved in `SpdTrackFitPar`:
  - Error message(s)
    `("RKTrackRep::RKutta","RKTrackRep::Extrap","MaterialEffects::getMomGammaBeta", "MaterialEffects::dEdxBetheBloch", ...)`
  - **Convergency flag:**
    - 0 — not converged
    - 1 — fully converged
    - -1 — partially converged
  - NFailedHits
  - χ^2
  - NDF

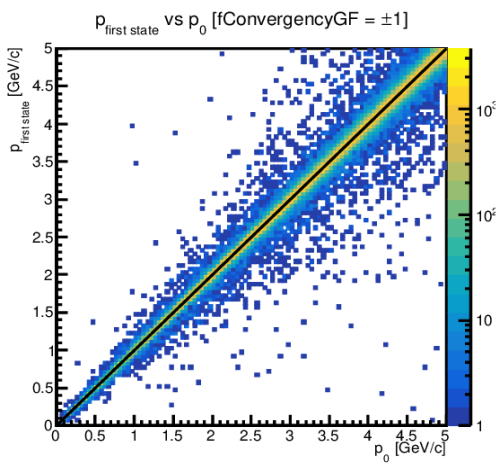
    → **χ^2 / NDF**
  - Forward / backward χ^2 deviation

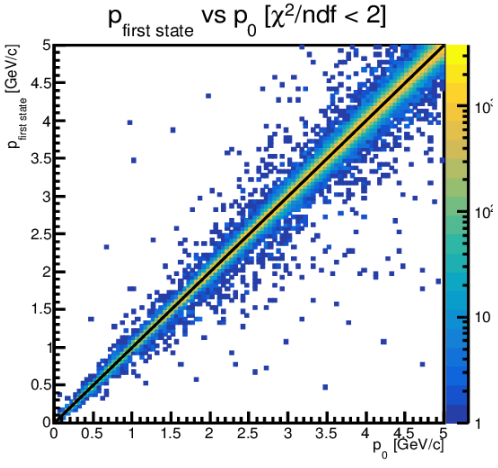
Reconstructed momentum vs true momentum

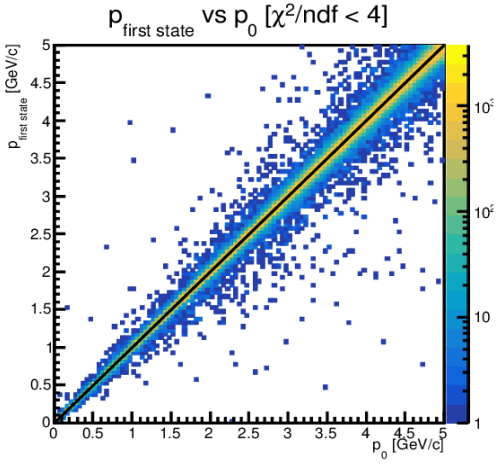


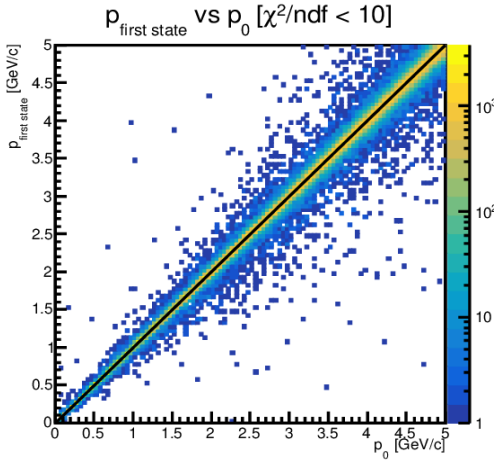


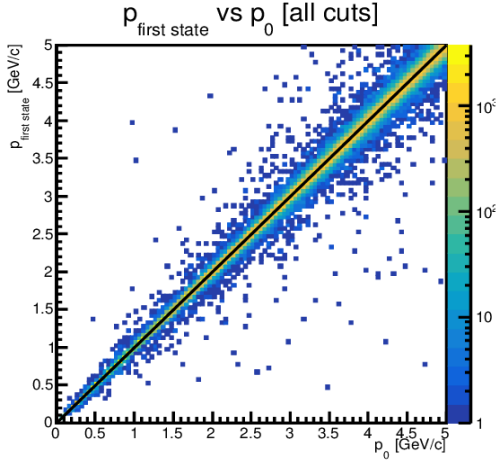






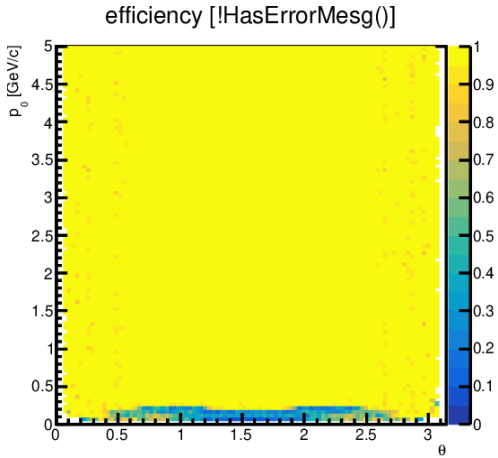


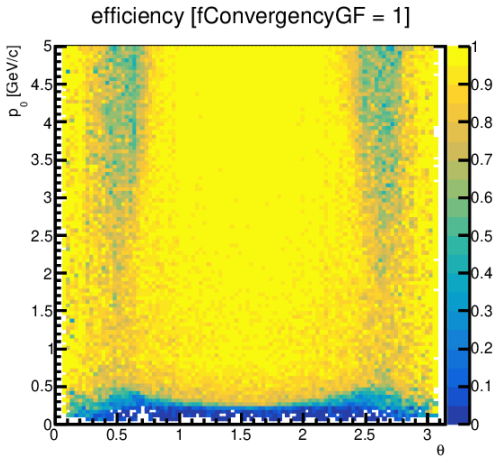


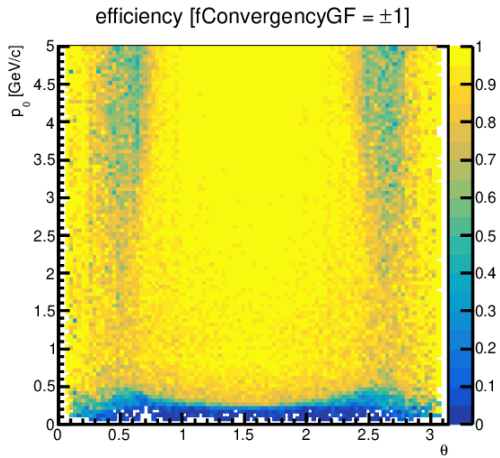


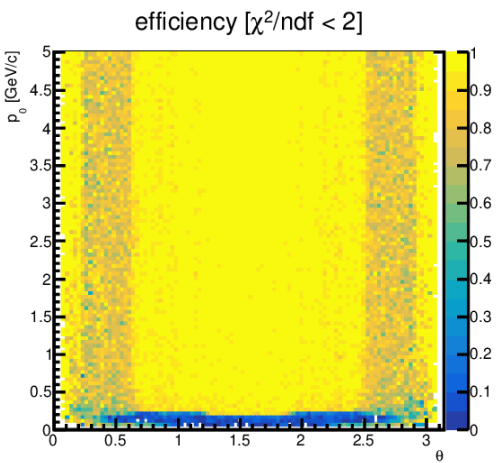
Efficiency of track quality cuts

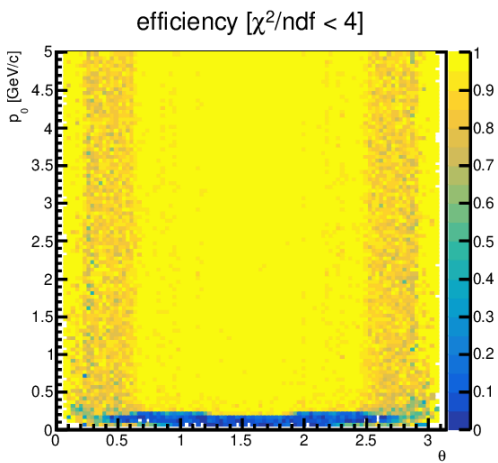
$$efficiency = \frac{N\ of\ tracks\ after\ cut}{N\ of\ tracks}$$

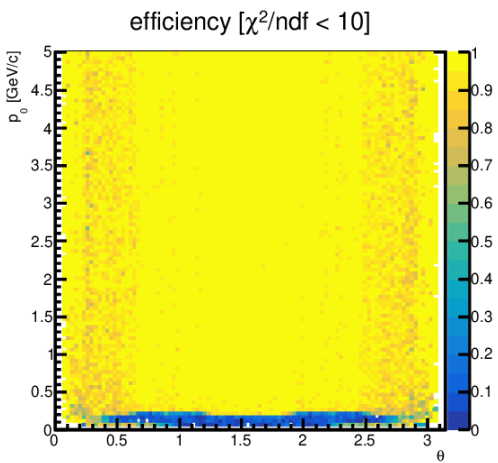


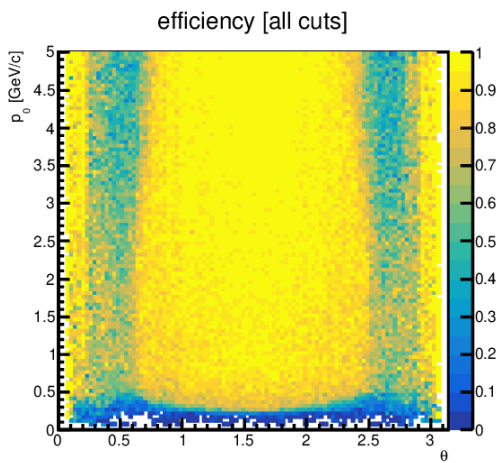




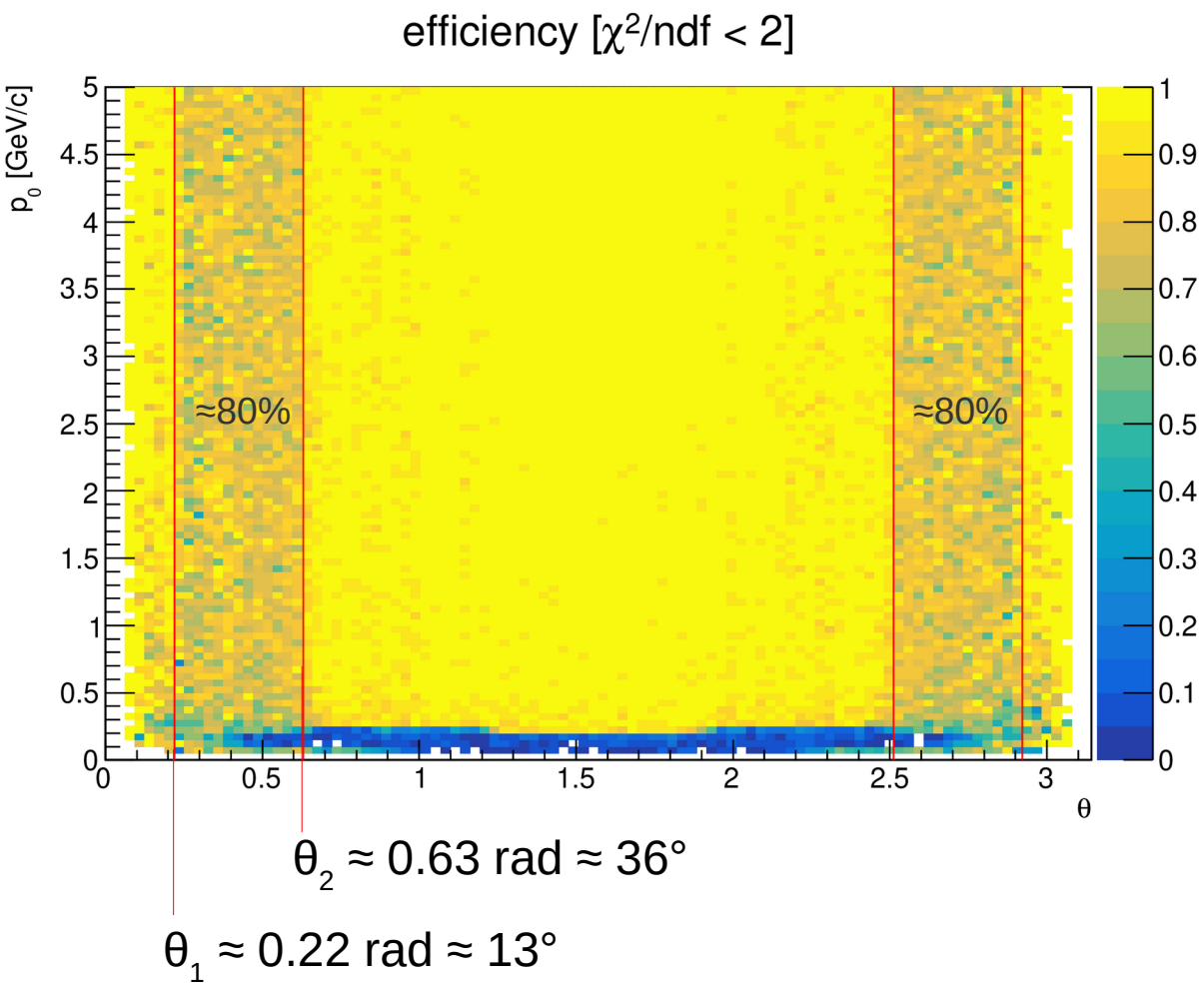


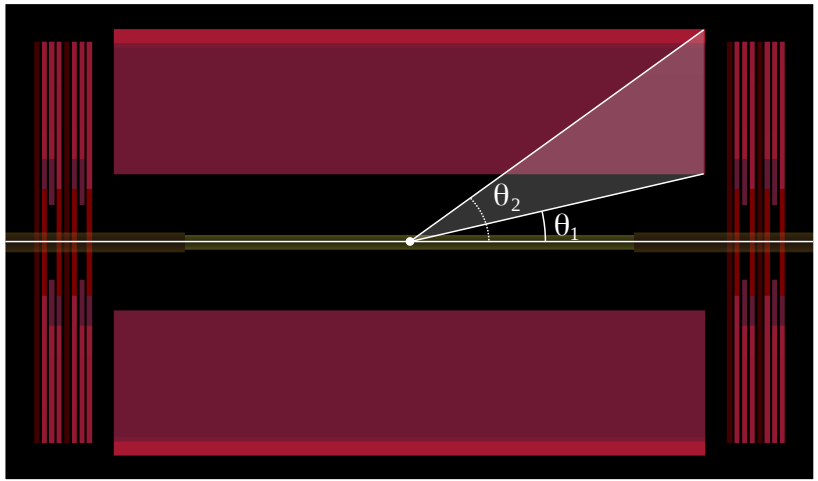


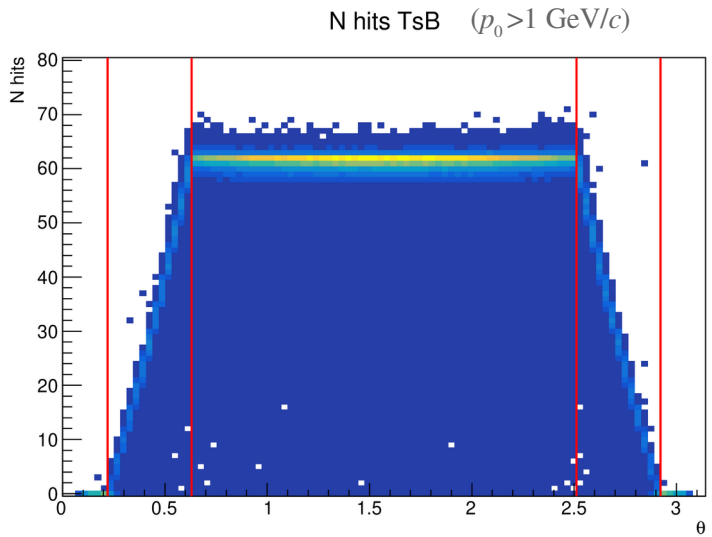




Efficiency of track quality cuts: χ^2/ndf







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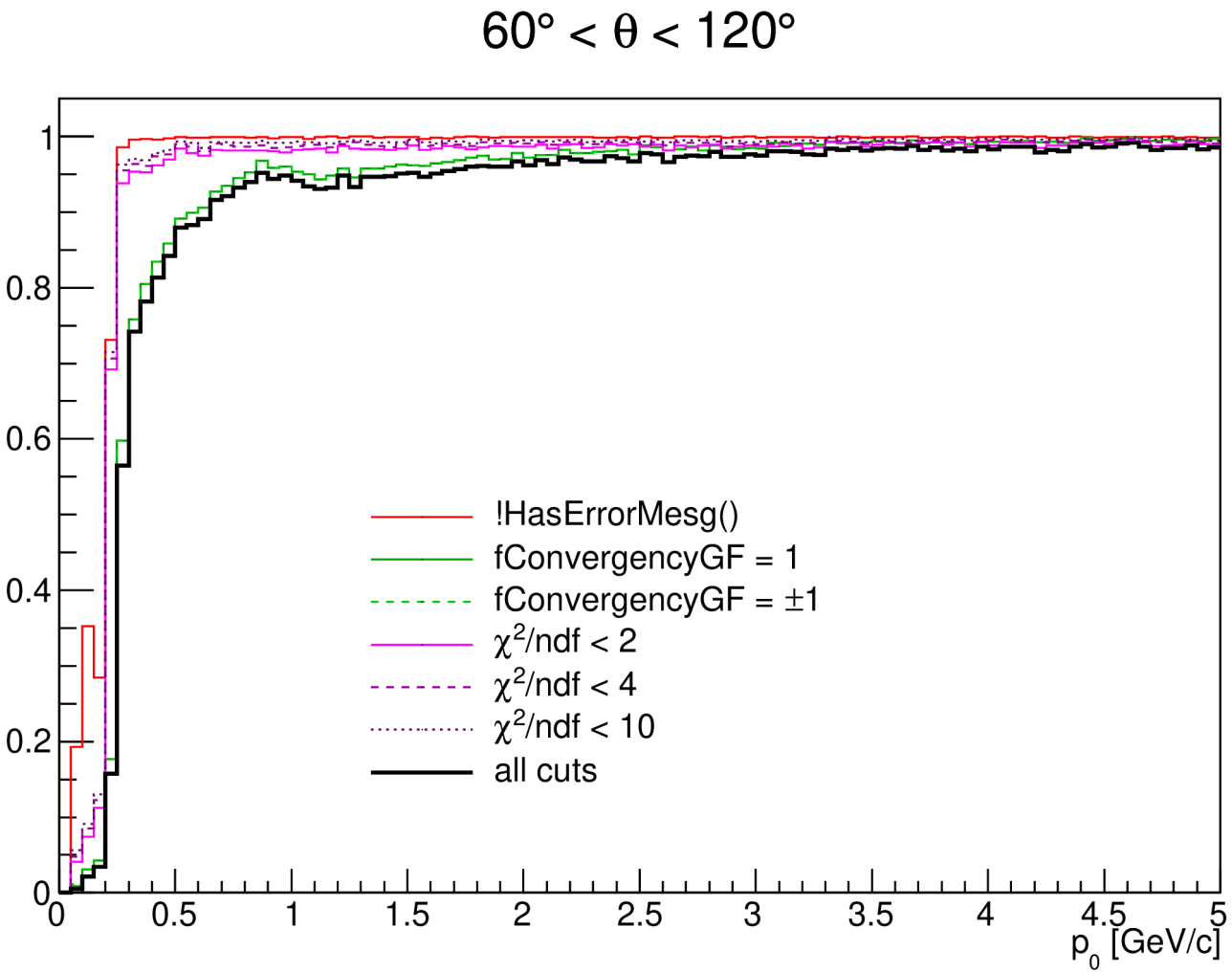

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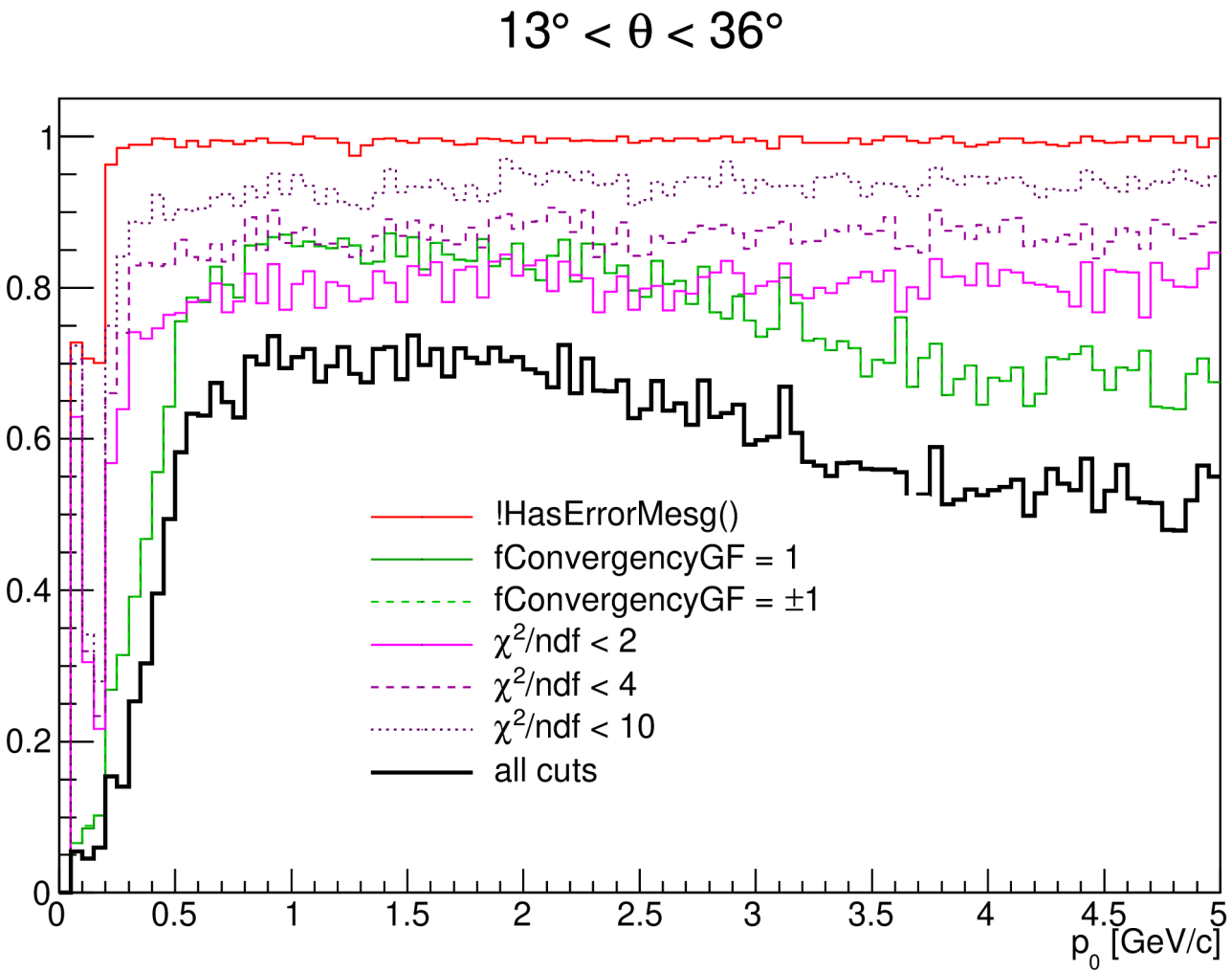
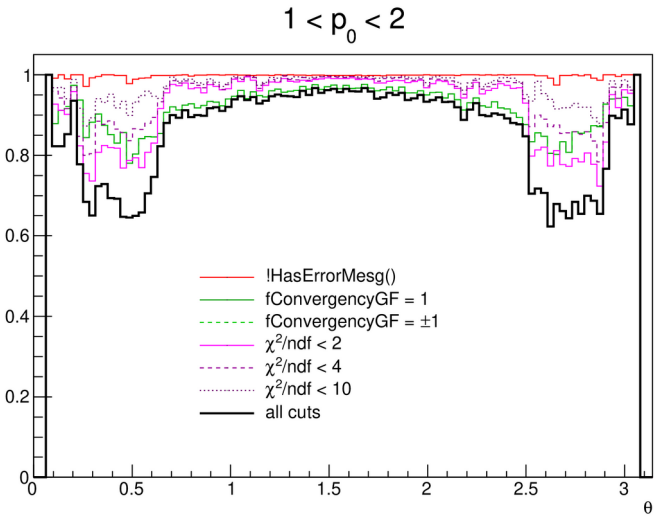
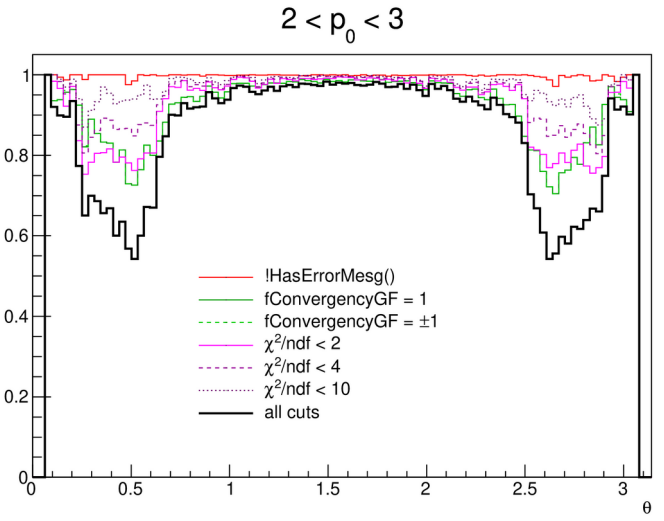
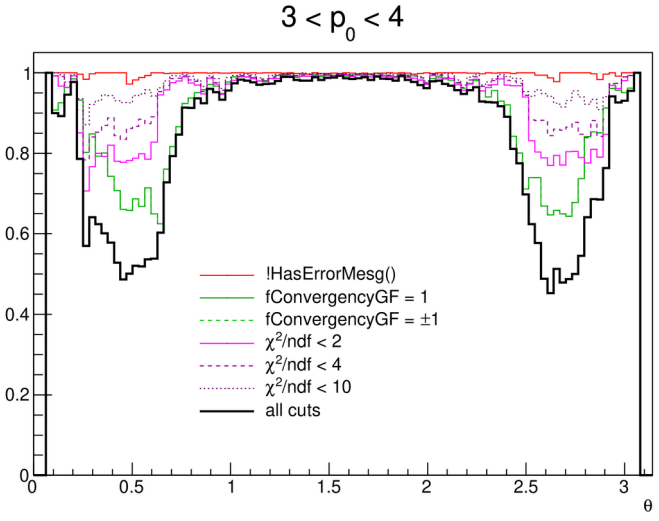
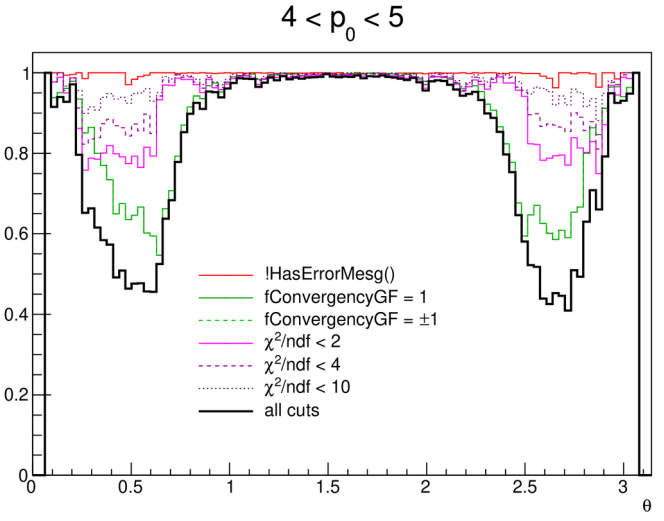


Efficiency of track quality cuts. Pions, $1 < p_0 < 5$ GeV/c, $Z_{\text{prim.vtx.}} = 0$.





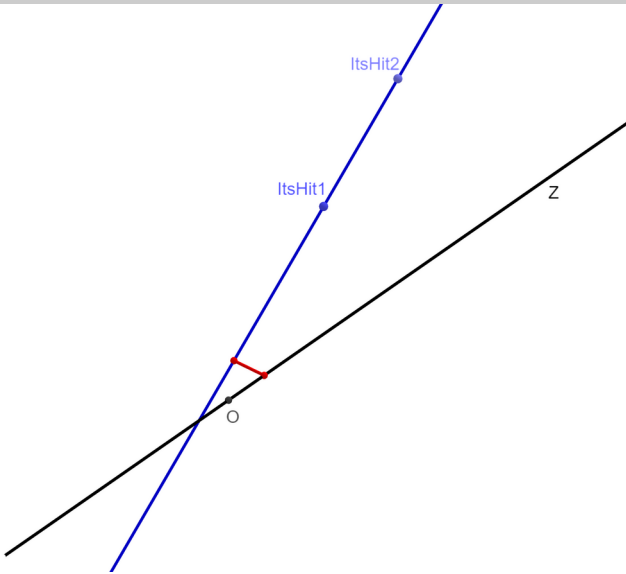




Initialisation procedure of the fit

Current initialisation procedure

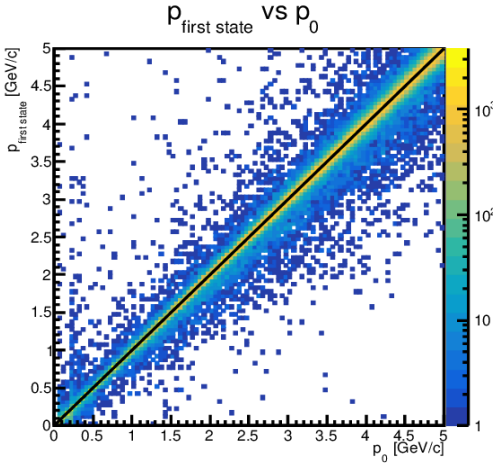
- $|p| \in [0.95; 1.05]$ GeV/c
- Momentum direction is defined from the first 2 hits in the inner tracker.
- As the vertex is taken some point on the segment connecting points of closest approach of Z axis and the line passing through the first 2 hits in the inner tracker.
- If this procedure fails (for example, if there are no hits in ITS), then program fallbacks to the second, simpler, method: $\bar{p}$ = (0, 0, 1) GeV/c, vertex = (0,0,0) with some smearing applied.

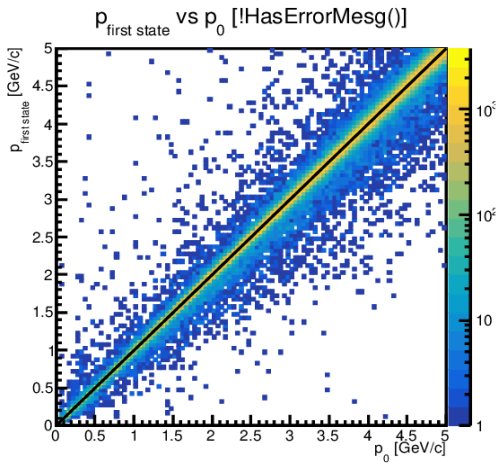


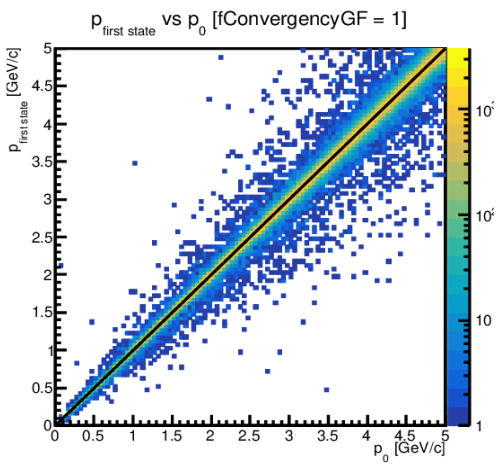
Initialisation from MC values

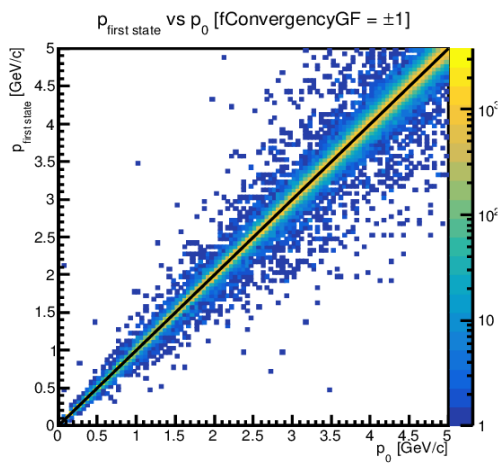
- It has been suggested, that the problem with convergency is caused by the bad initialisation procedure.
- To check this, we apply initialisation procedure, where initial values of momentum and position for the track fit are set **equal to the MC** values of initial momentum and production vertex of the particle.

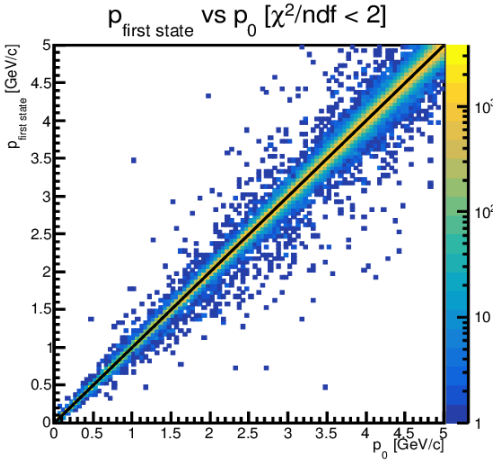
Reco momentum vs true momentum. Init. values = MC

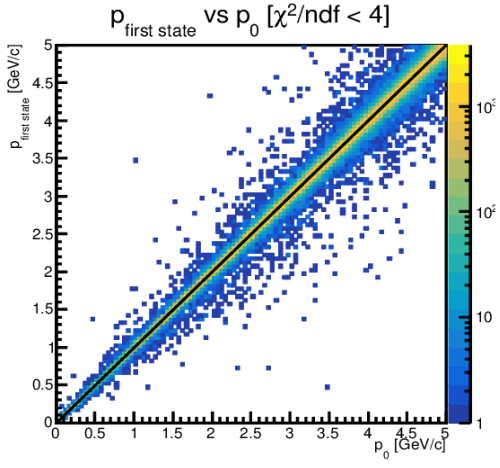


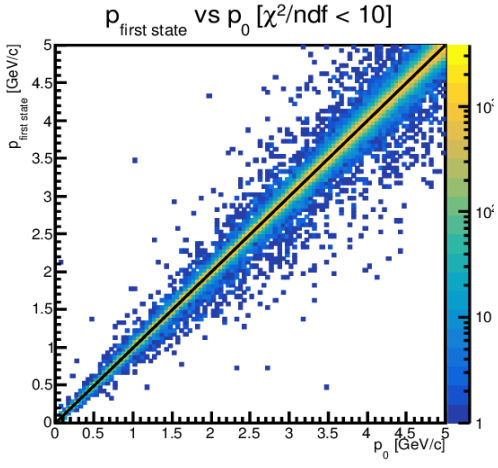


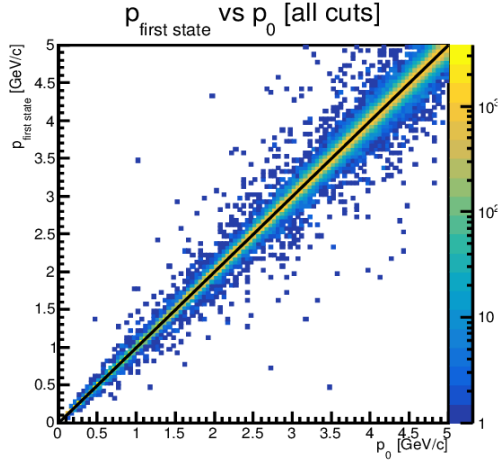






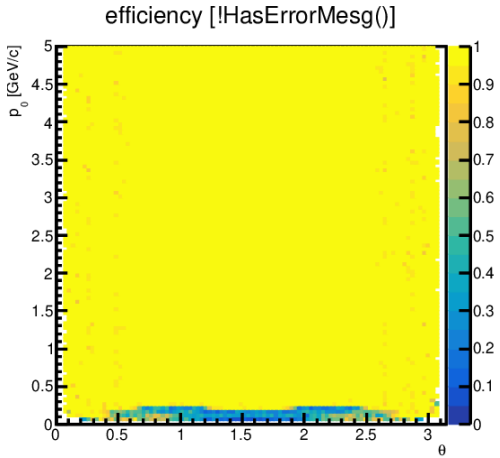


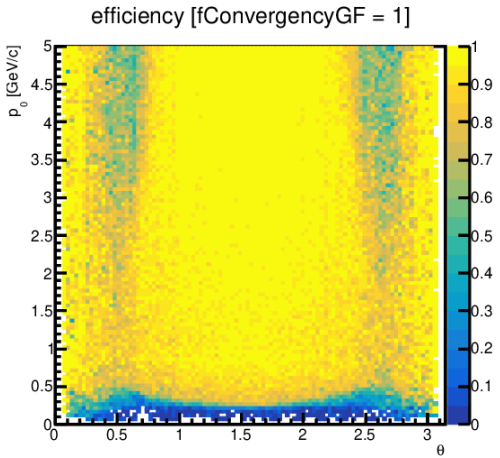


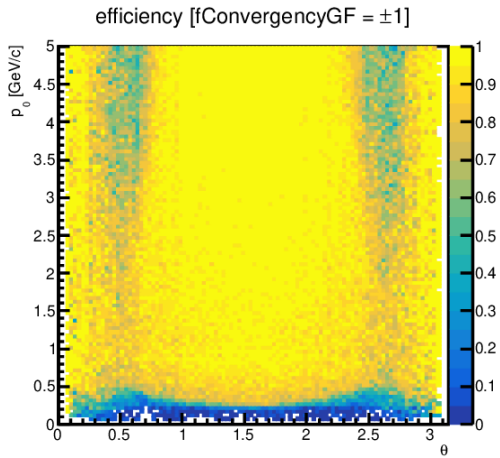


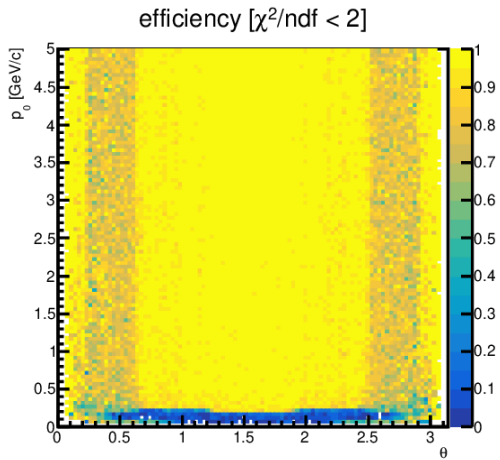
Efficiency of track quality cuts

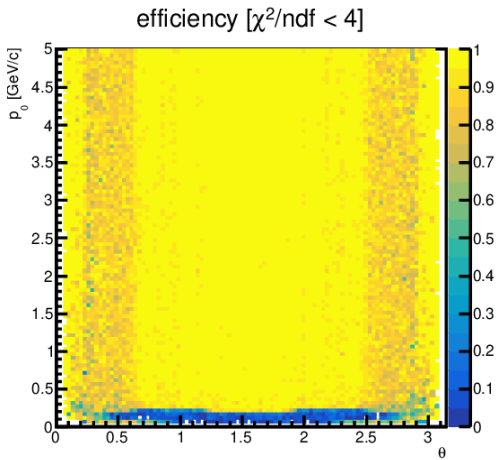
current initialisation procedure

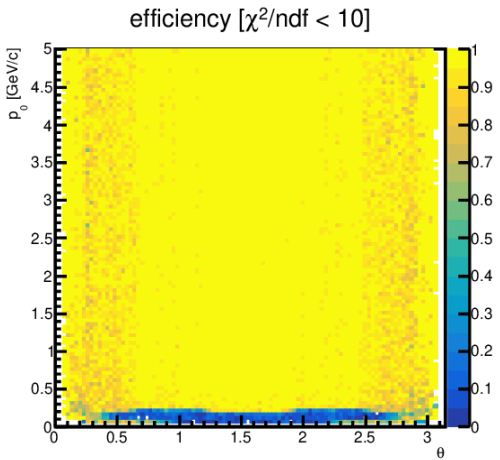


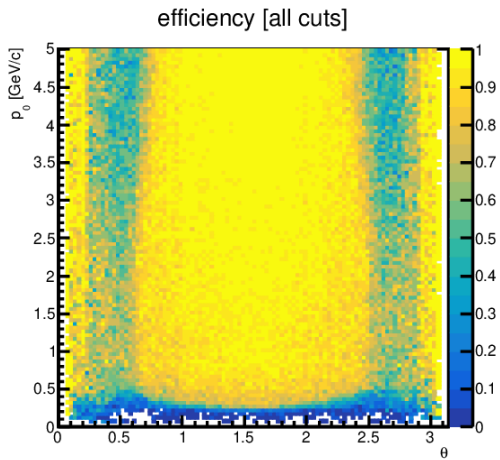






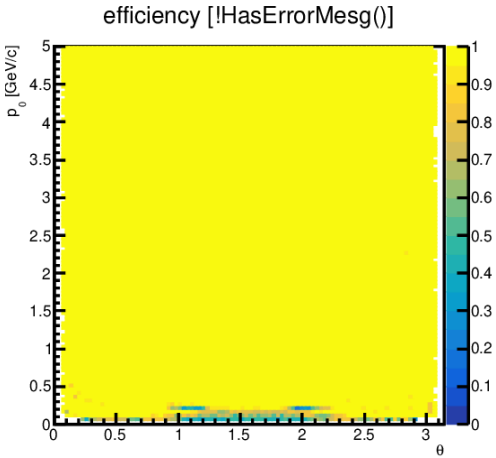


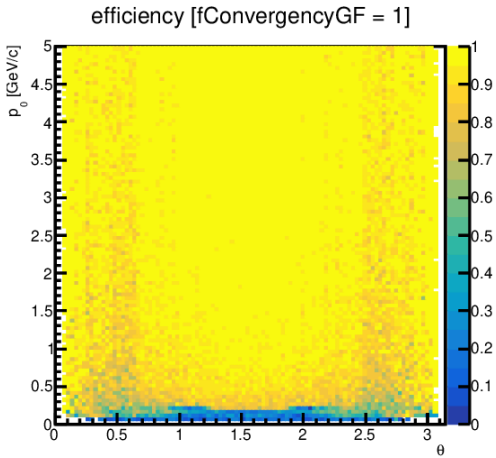


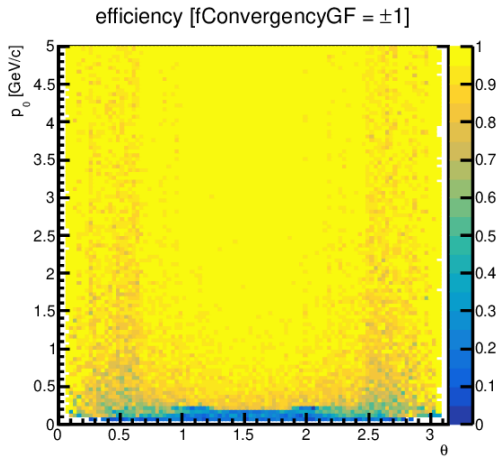


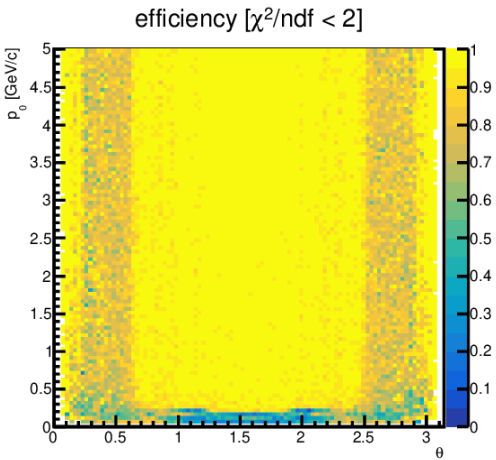
Efficiency of track quality cuts. Init. values = MC

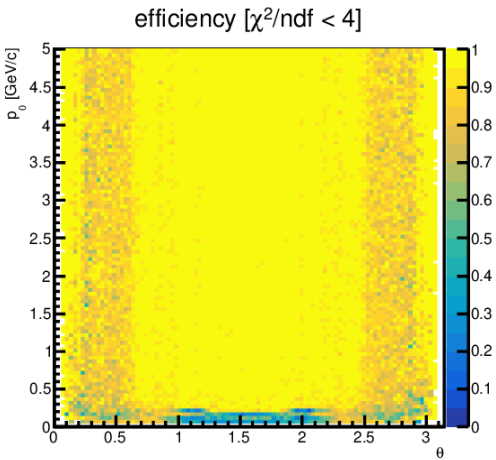
initial values
from MC

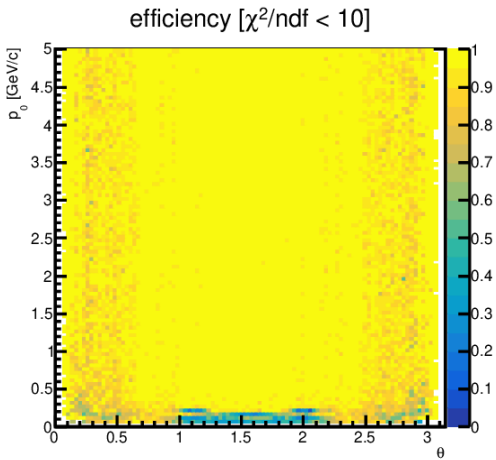


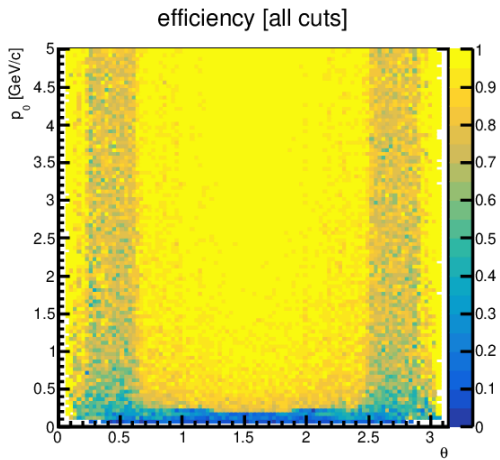




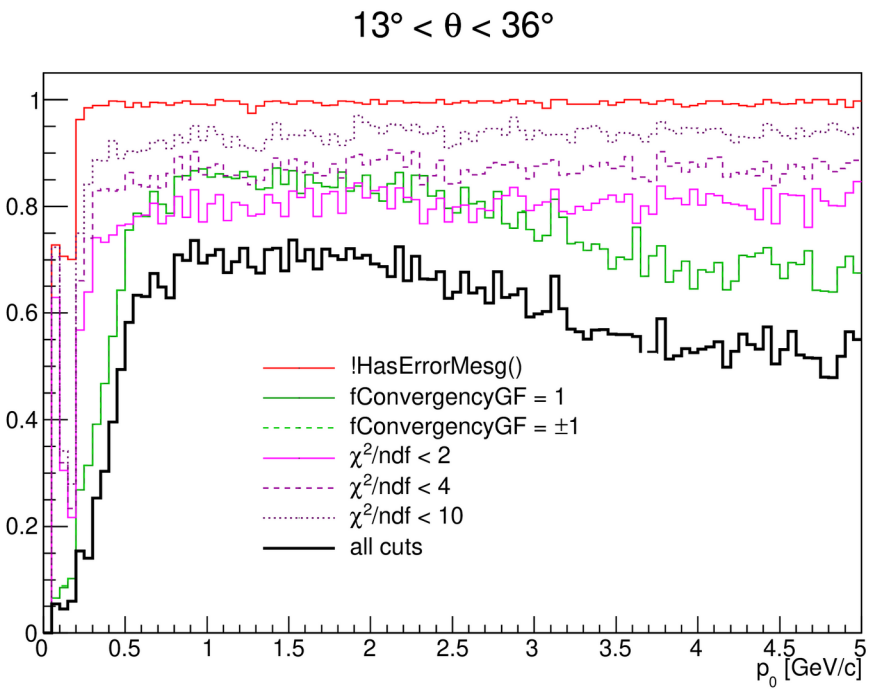




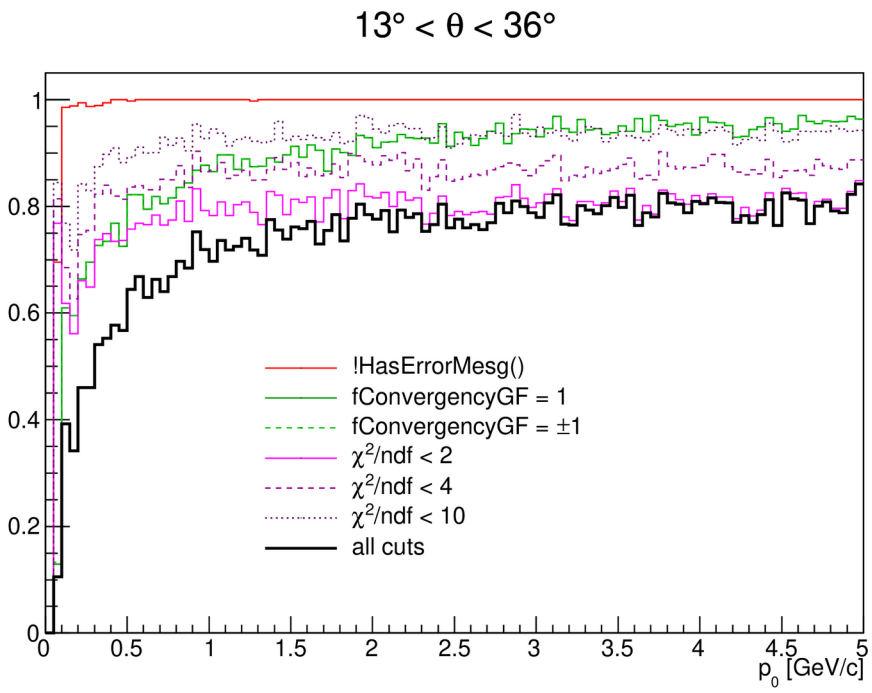




Efficiency of track quality cuts: 13° < θ < 36°



current initialisation procedure



initial values from MC

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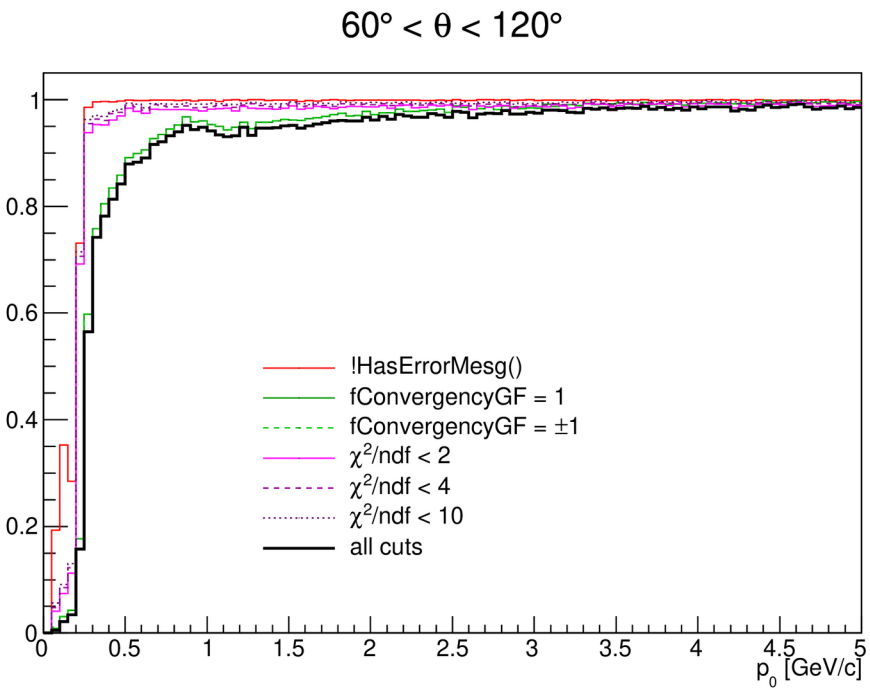

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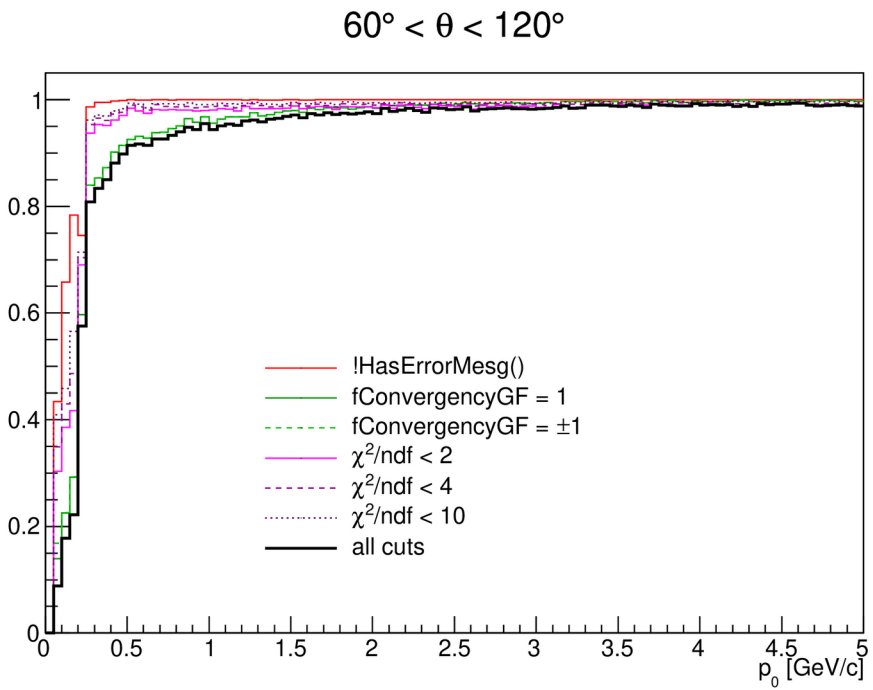
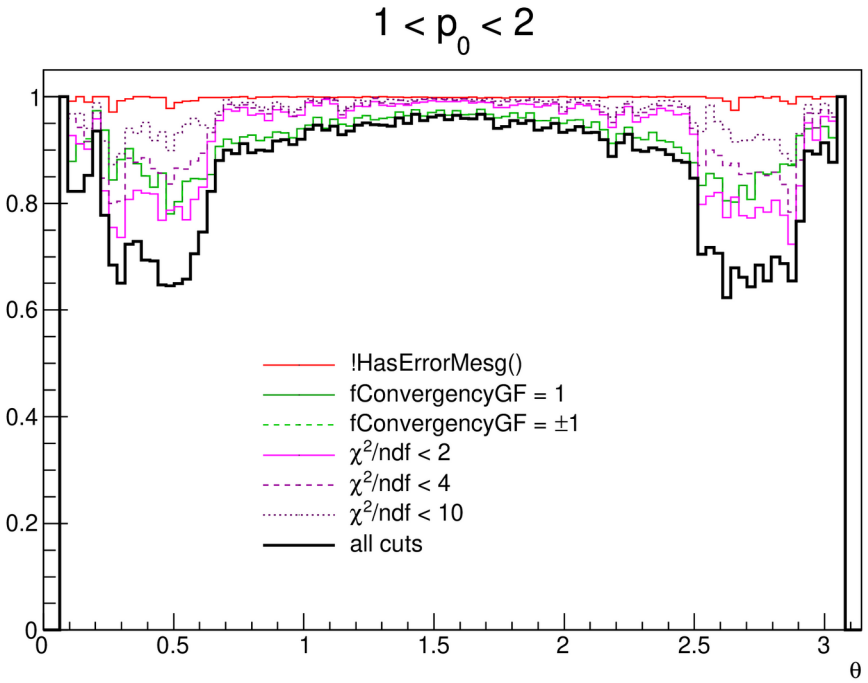
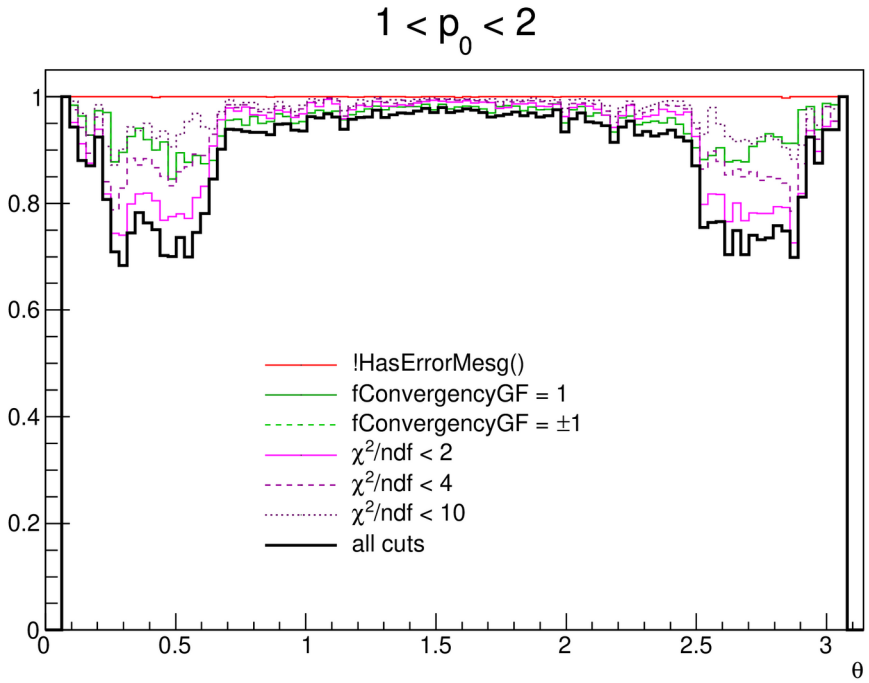


initial values from MC

Efficiency of track quality cuts. Pions, $1 < p_0 < 2$ GeV/c, $Z_{\text{prim.vtx.}} = 0$.

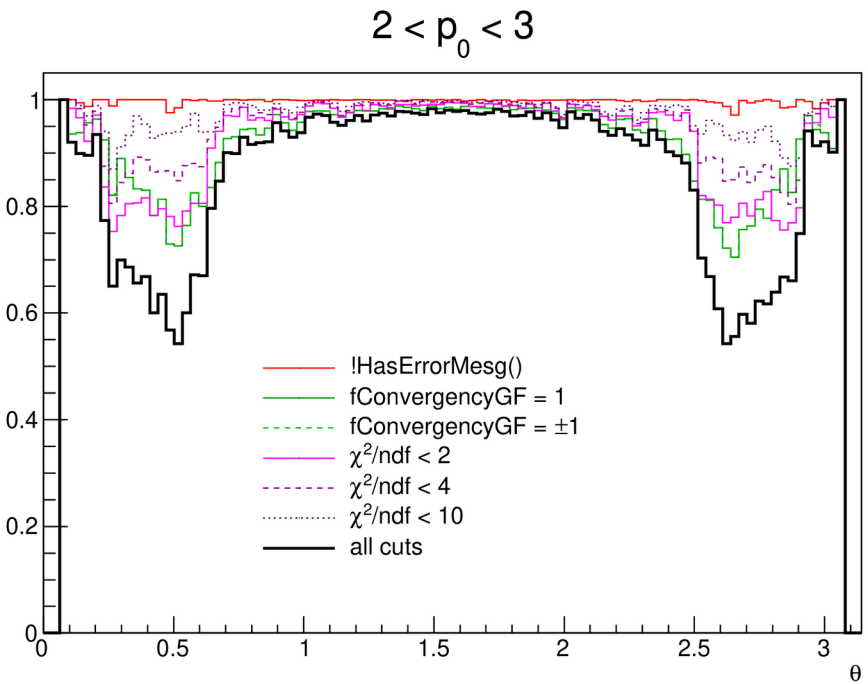


current initialisation procedure

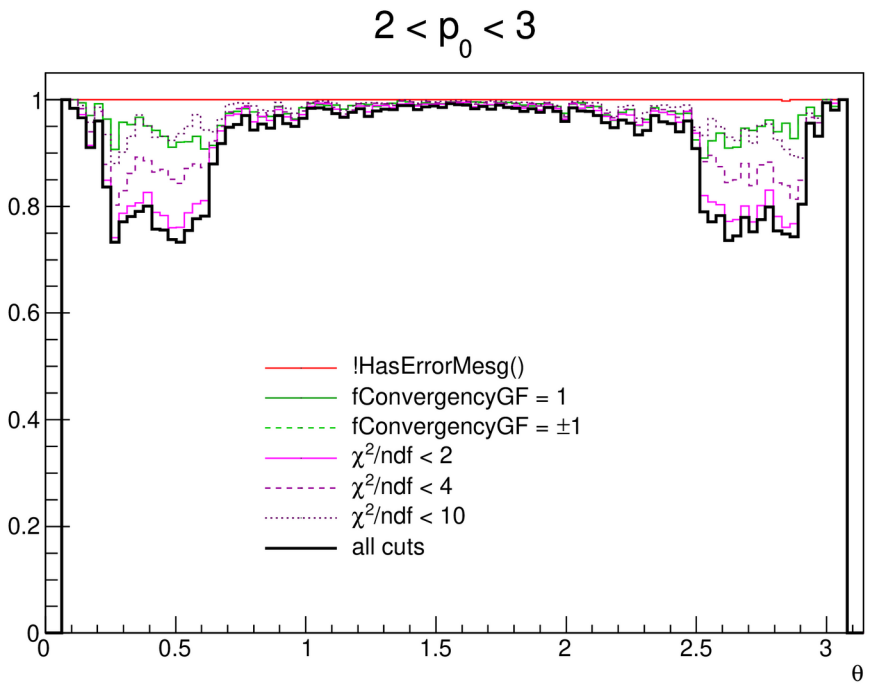


initial values from MC

Efficiency of track quality cuts. Pions, $2 < p_0 < 3$ GeV/c, $Z_{\text{prim.vtx.}} = 0$.

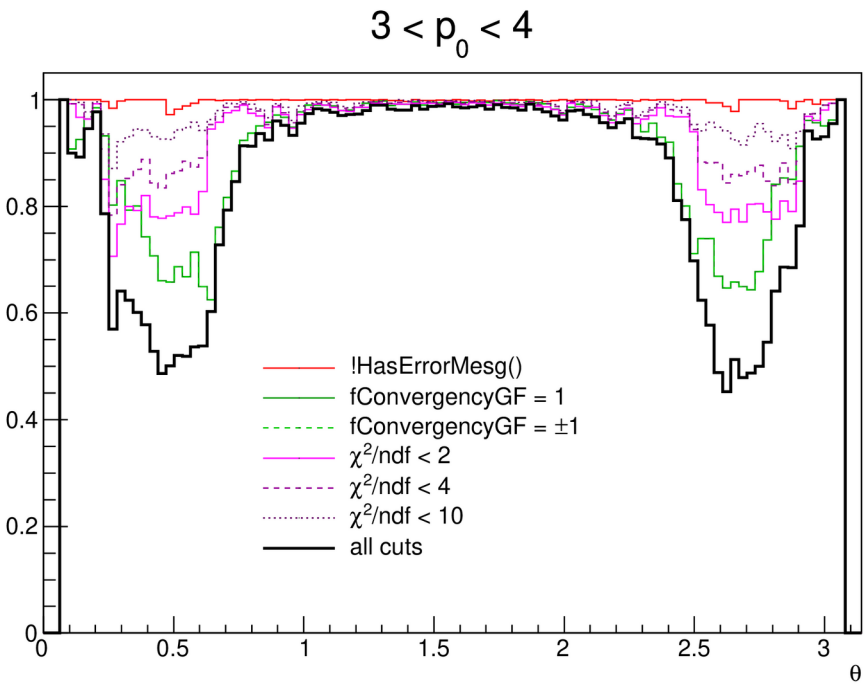


current initialisation procedure

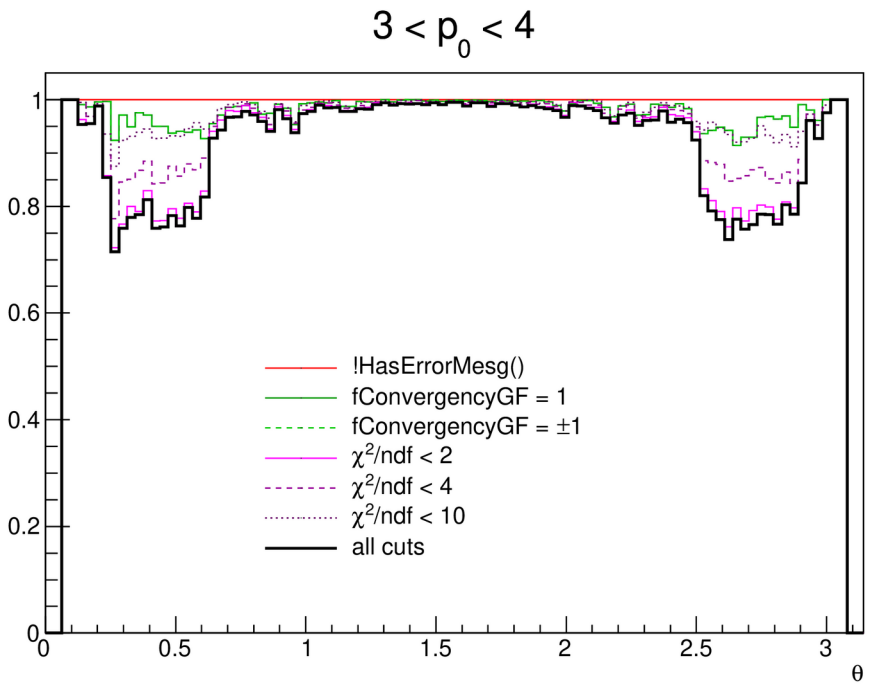


initial values from MC

Efficiency of track quality cuts. Pions, $3 < p_0 < 4$ GeV/c, $Z_{\text{prim.vtx.}} = 0$.

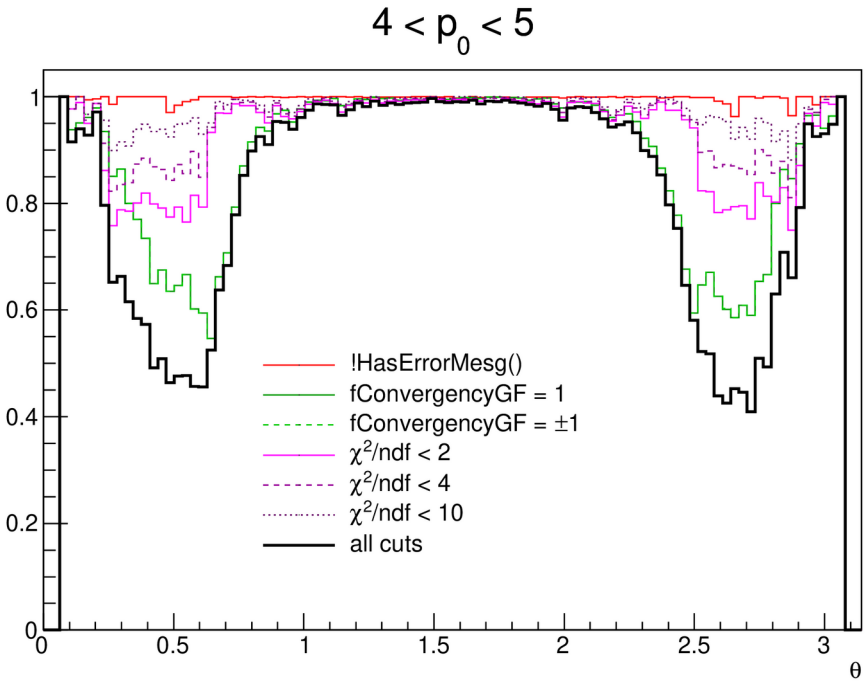


current initialisation procedure

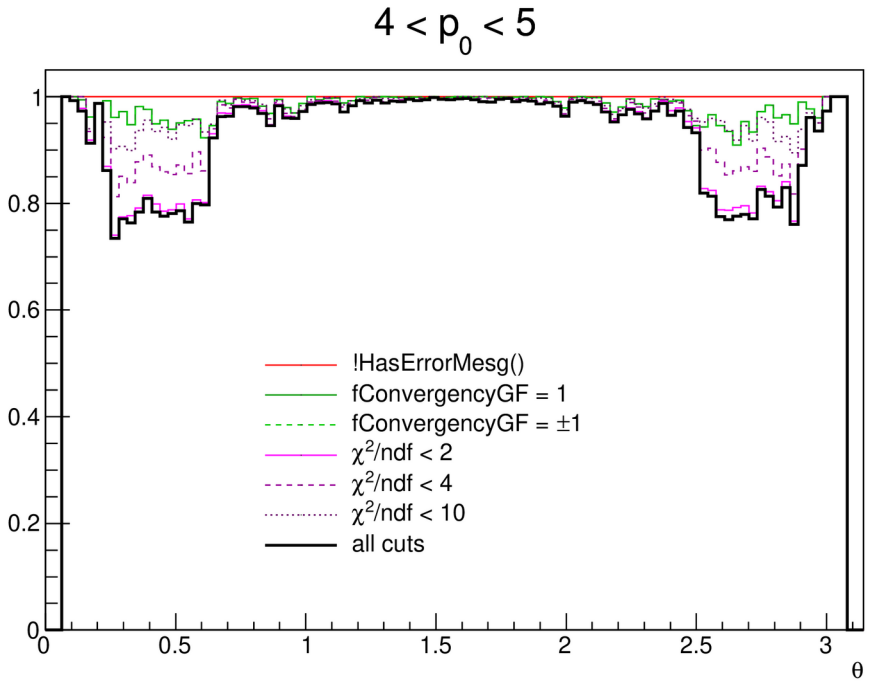


initial values from MC

Efficiency of track quality cuts. Pions, $4 < p_0 < 5$ GeV/c, $Z_{\text{prim.vtx.}} = 0$.



current initialisation procedure

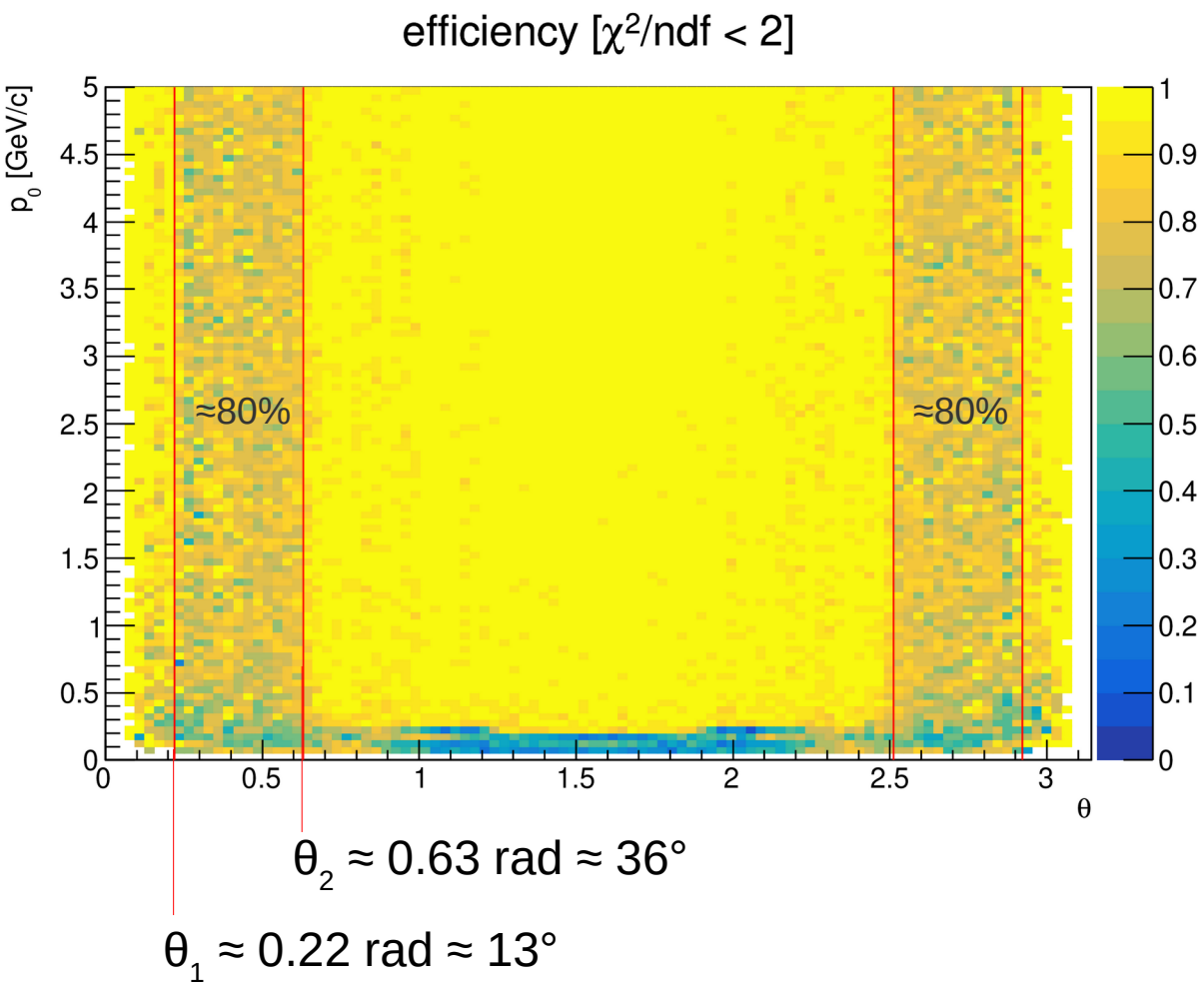


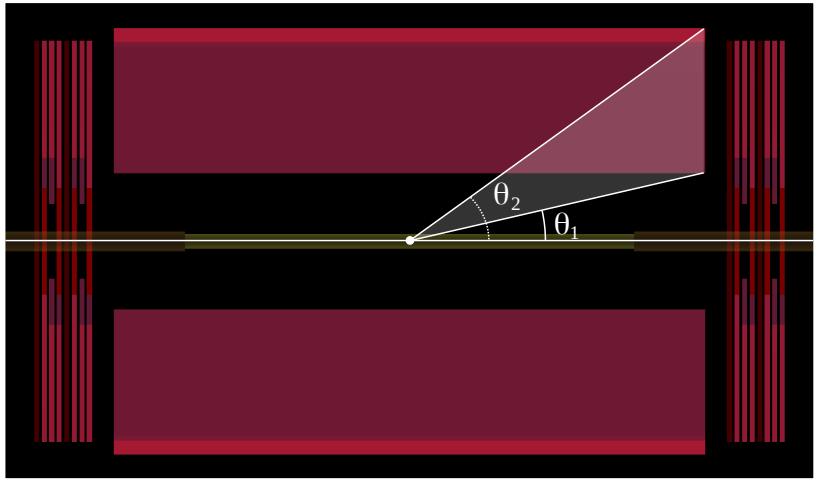
initial values from MC

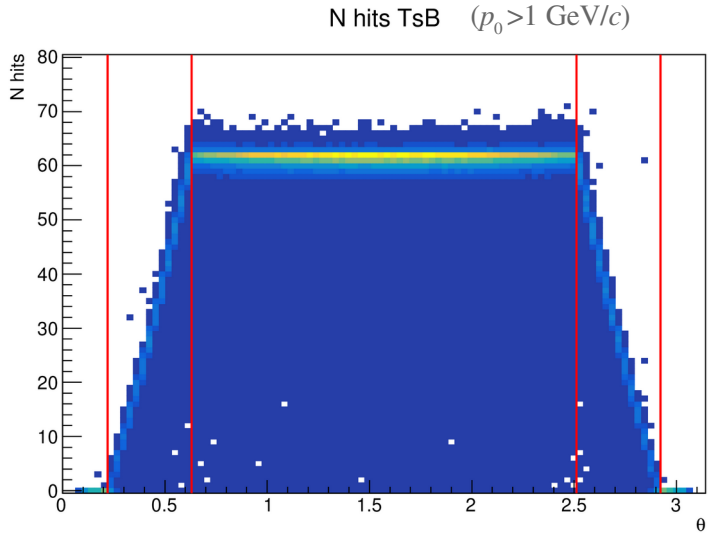
Conclusions on the initialisation procedure

- Problem with convergency at high momenta was caused by a bad choice of initial track parameters.
- **We need a better initialisation procedure!**
- During the discussions at the weekly meetings, it was proposed to use as the initial values MC values with some smearing applied.
- χ^2/ndf distiribution (at high momenta) is little affected by changing the initialisation procedure.

Efficiency of track quality cuts: χ^2/ndf

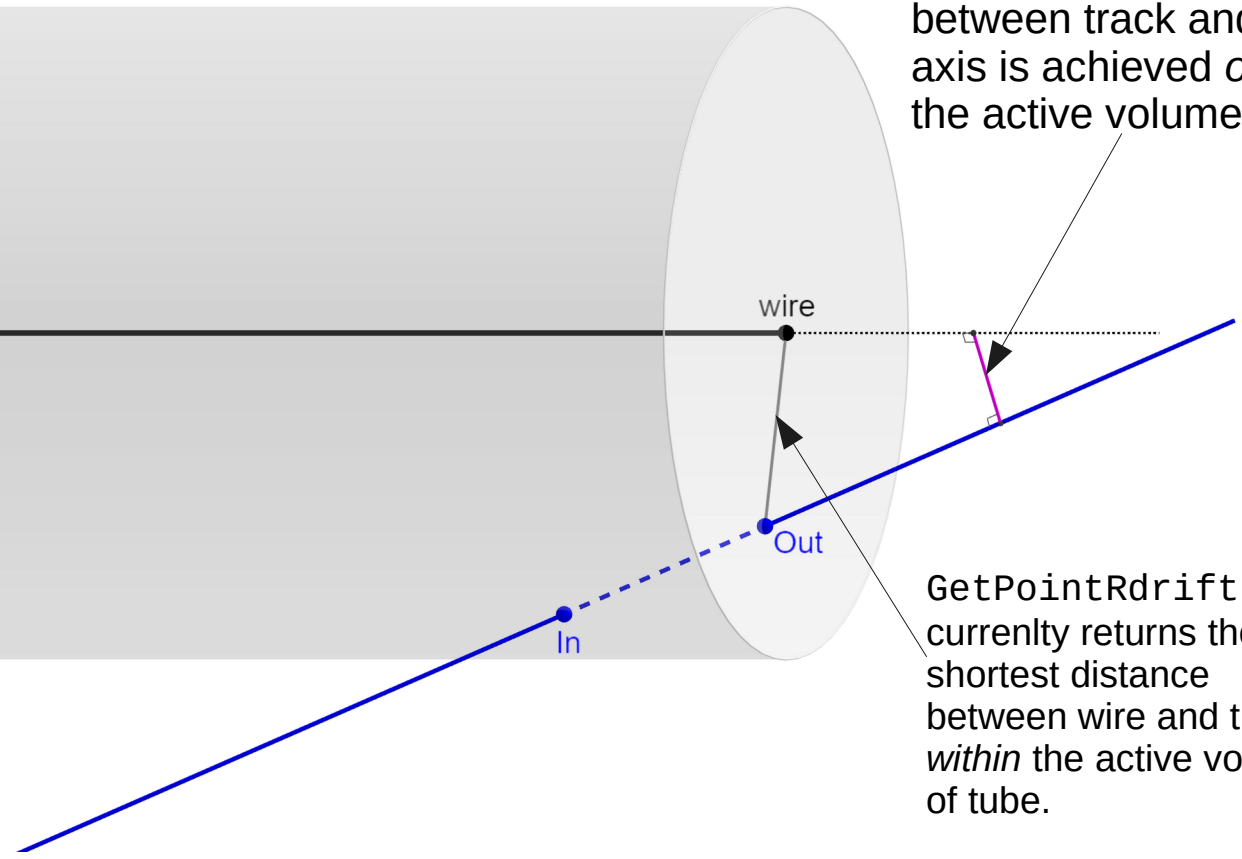




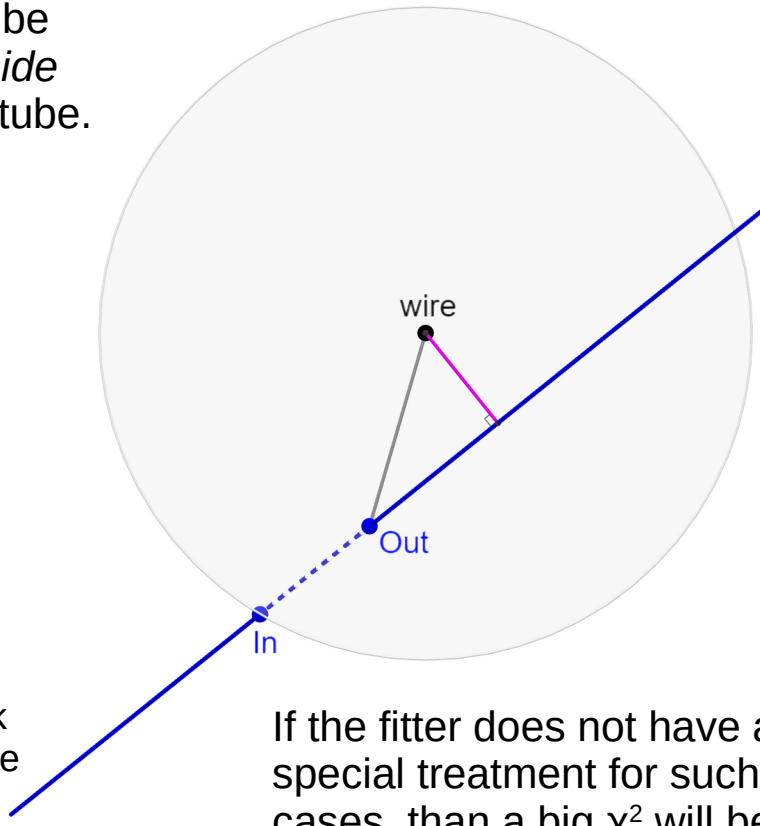


Tracks passing through the end of the tube

The shortest distance between track and tube axis is achieved *outside* the active volume of tube.



`GetPointRdrift()` currenlty returns the shortest distance between wire and track *within* the active volume of tube.

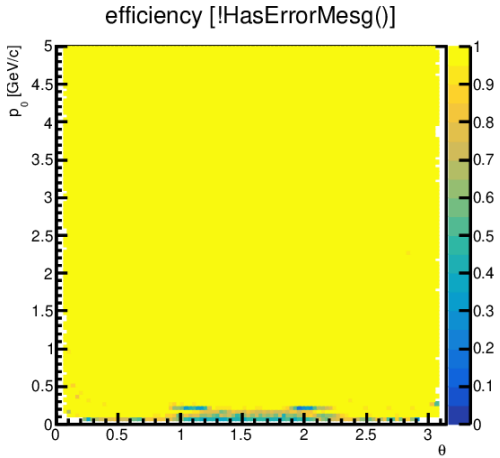


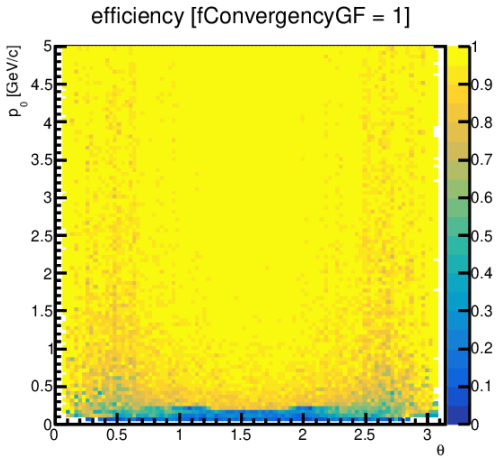
If the fitter does not have a special treatment for such cases, than a big χ^2 will be assigned to such track.

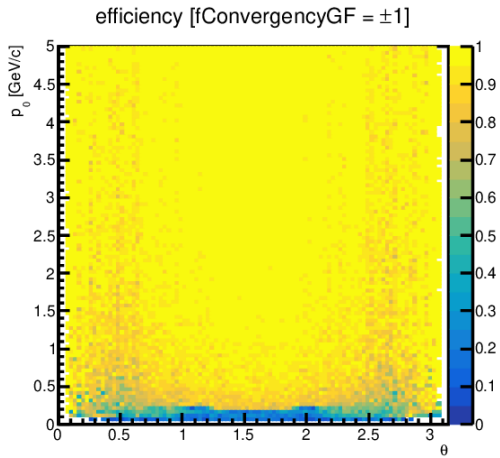
Efficiency of track quality cuts. "Ideal" Rdrift

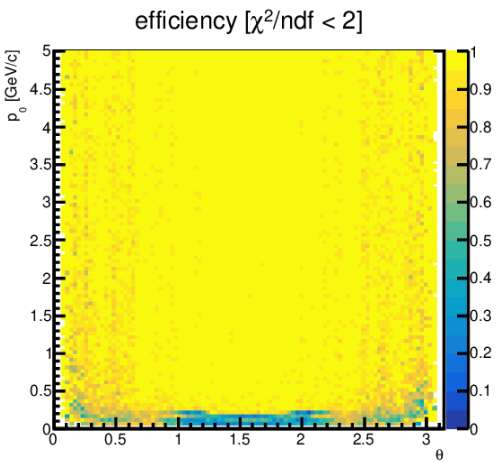
initial values
from MC

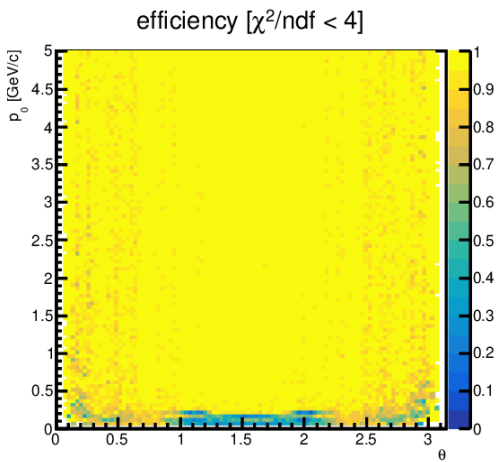
"ideal" Rdrift
(ignoring active volume bounds)

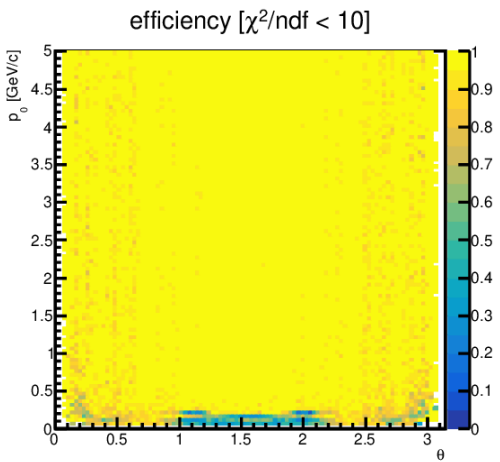


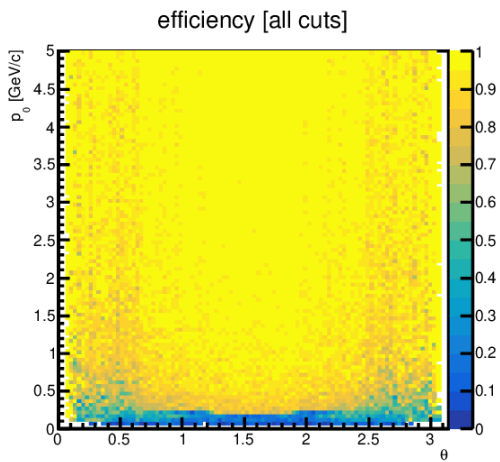




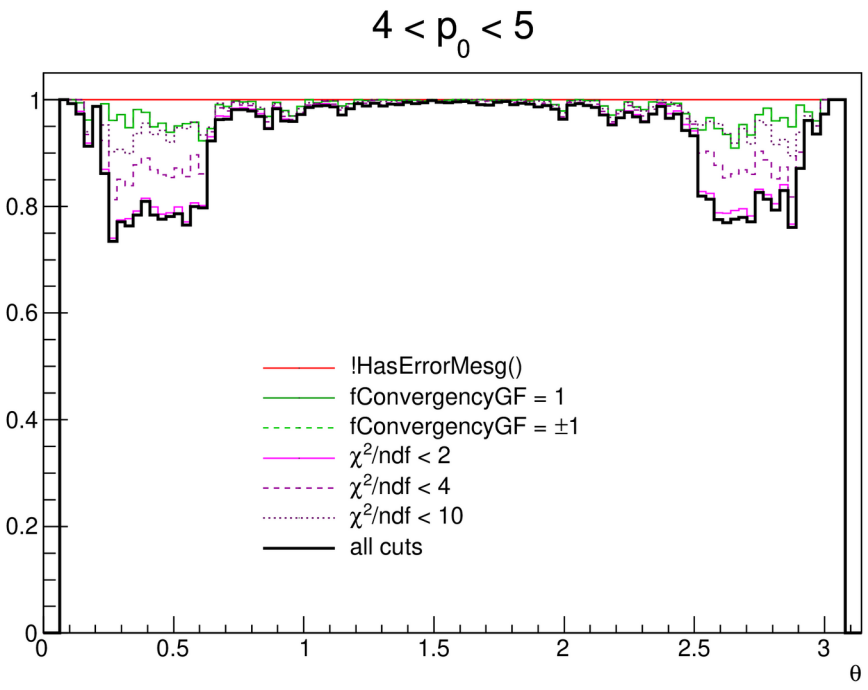


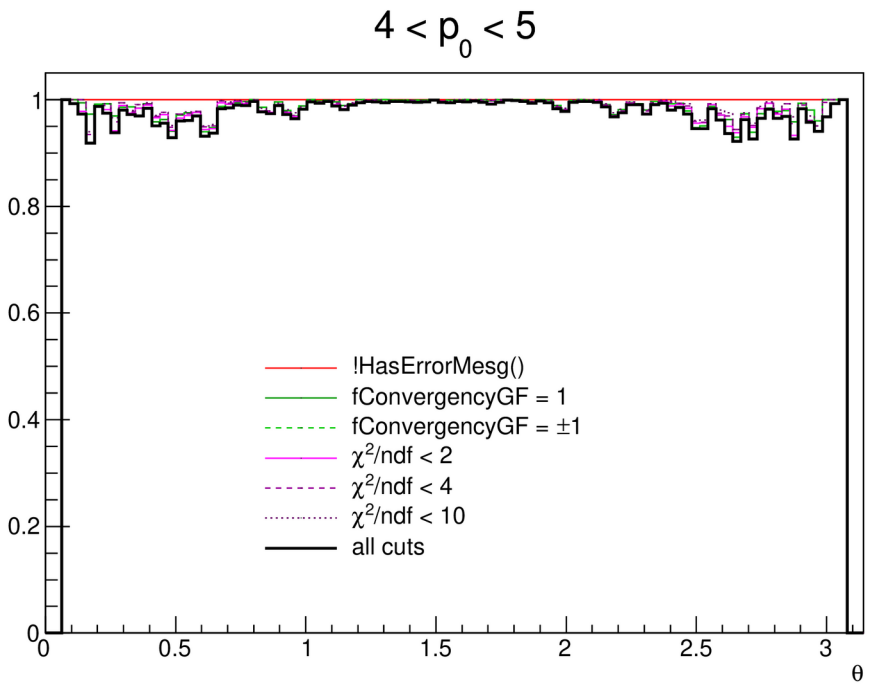






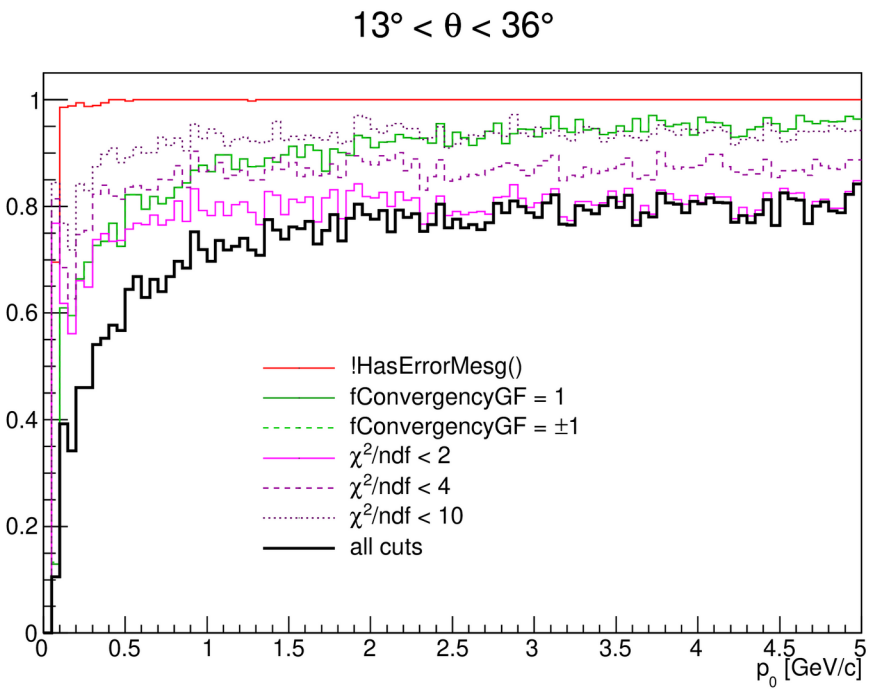
Efficiency of track quality cuts: $4 < p_0 < 5$ GeV/c

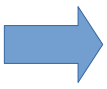


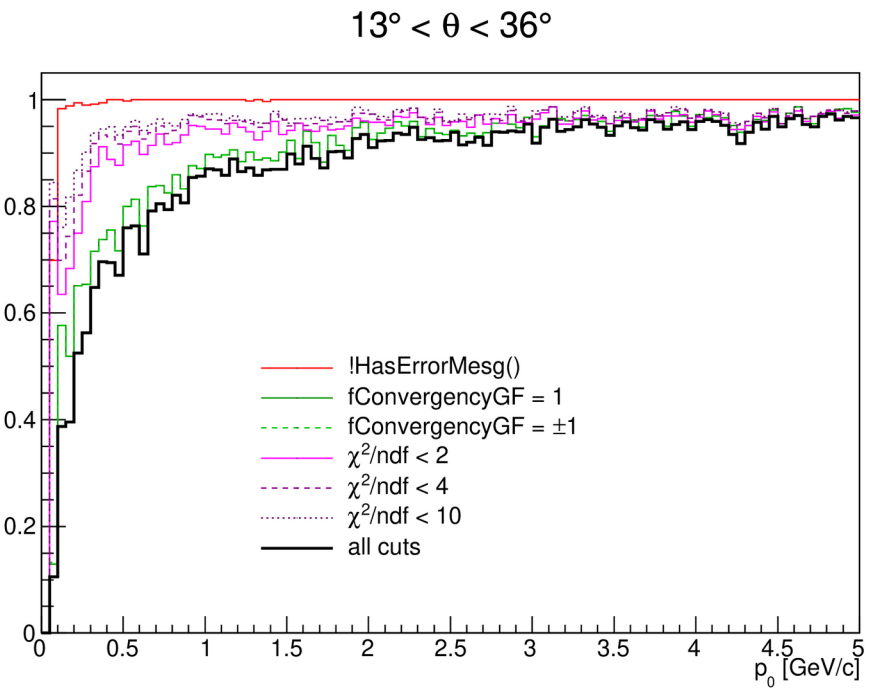


ignore active volume bounds
in R drift calculation

Efficiency of track quality cuts: 13° < θ < 36°







ignore active volume bounds
in R drift calculation

Material effects

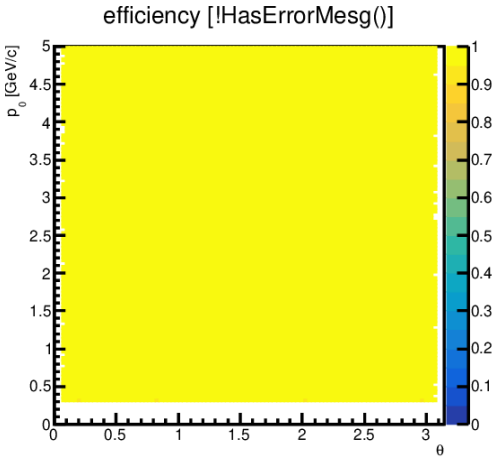
- To confirm that smaller efficiency of the track fit quality cuts at low momenta is due to material effects the following changes to simulation are applied:
  - Pipe is removed.
  - Material of the top volume is set to **vacuum**.
  - Materials of the inner tracker and the straw tracker are set to **vacuum**.

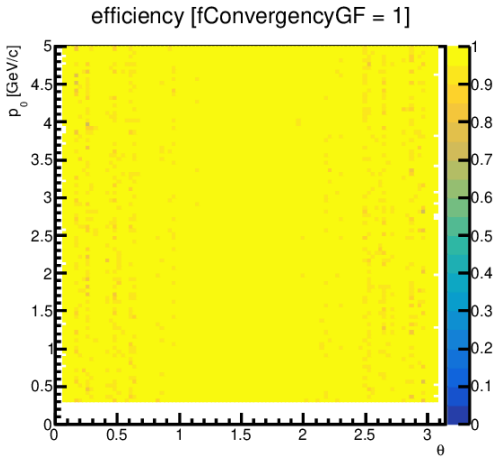
Efficiency of track quality cuts. No material.

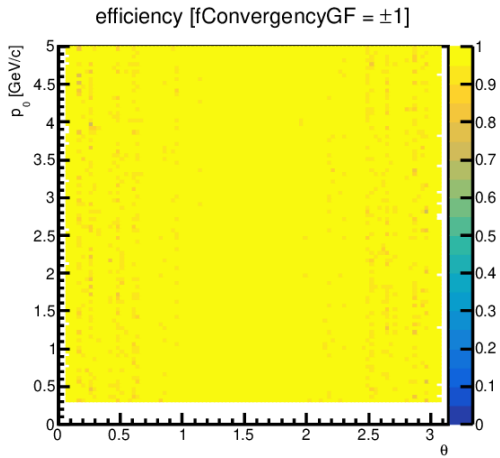
initial values
from MC

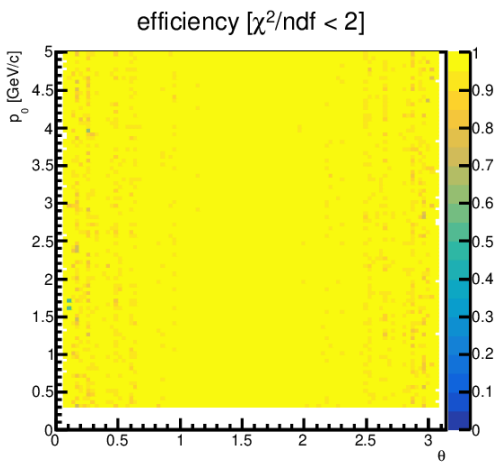
"ideal" Rdrift

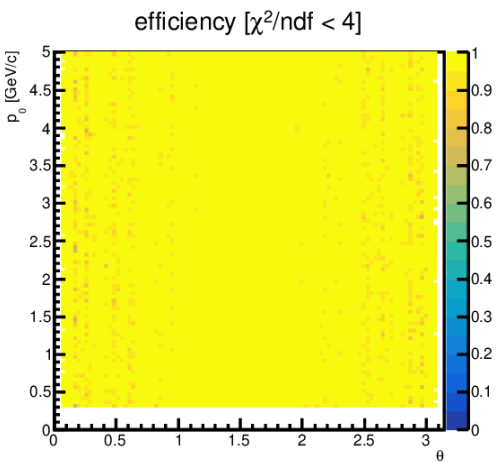
no material

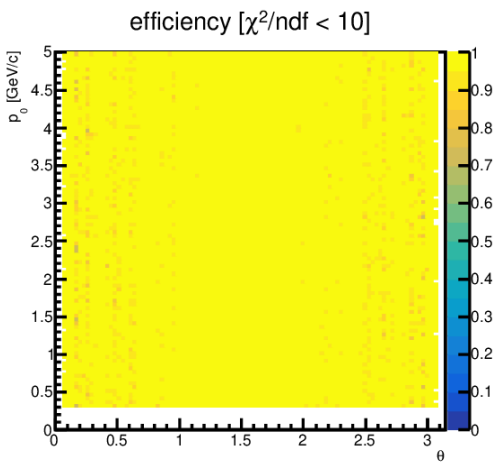


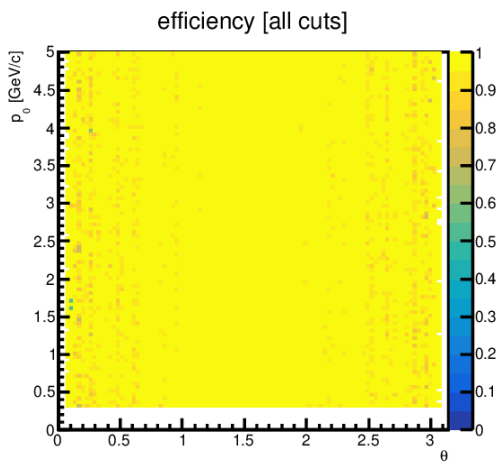




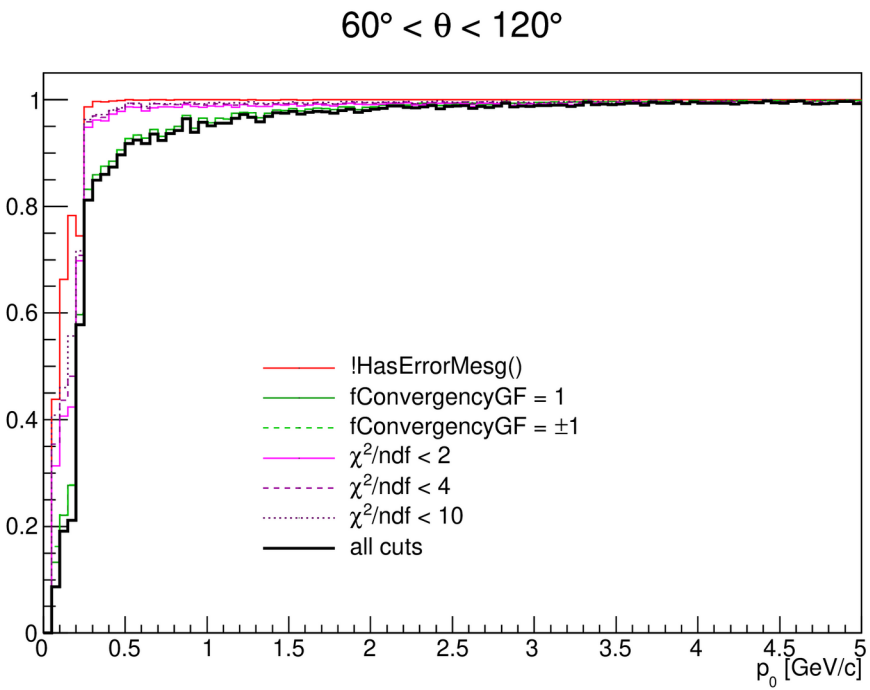


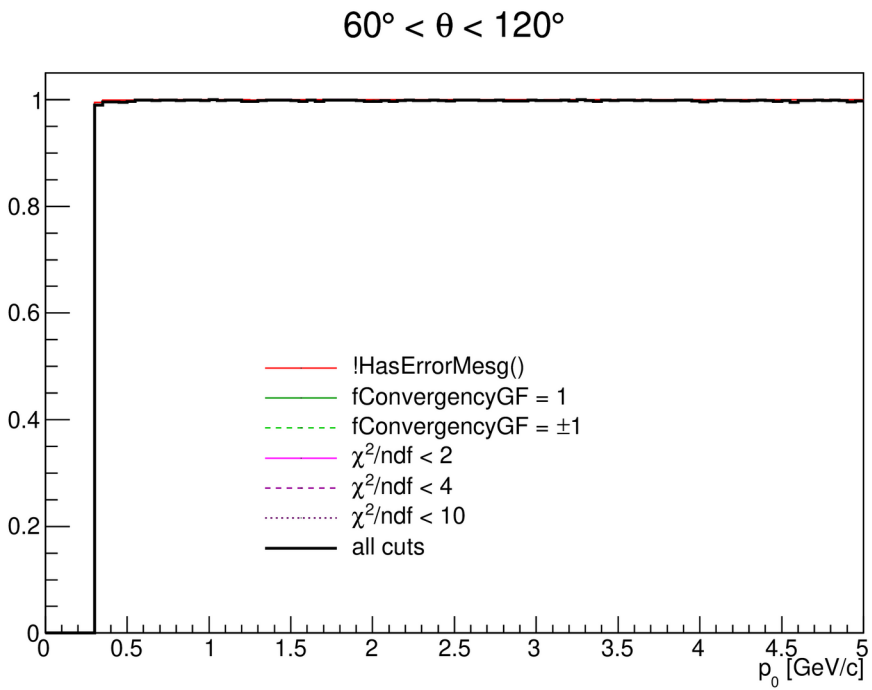






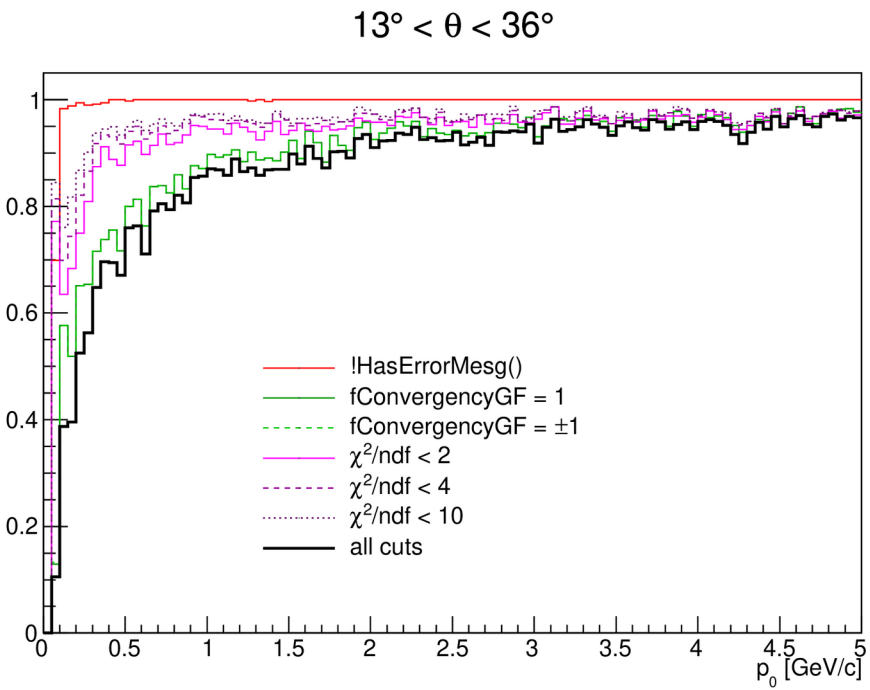
Efficiency of track quality cuts: 60° < θ < 120°

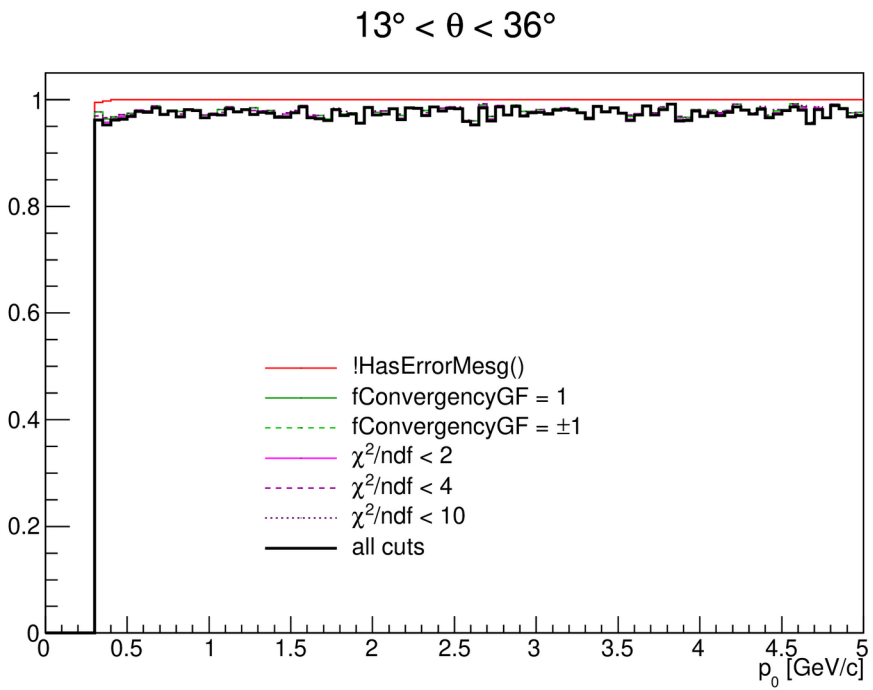




no material

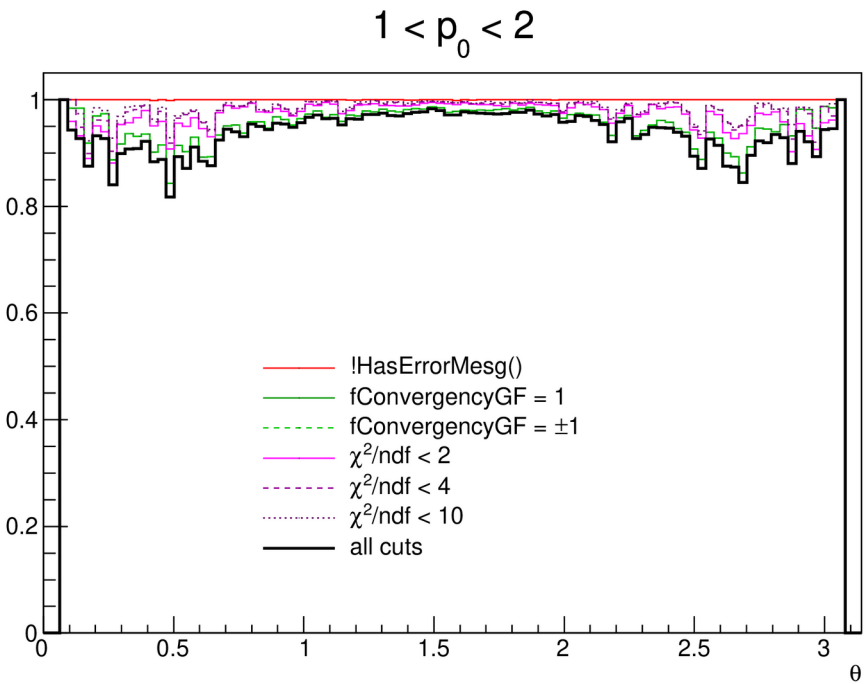
Efficiency of track quality cuts: 13° < θ < 36°

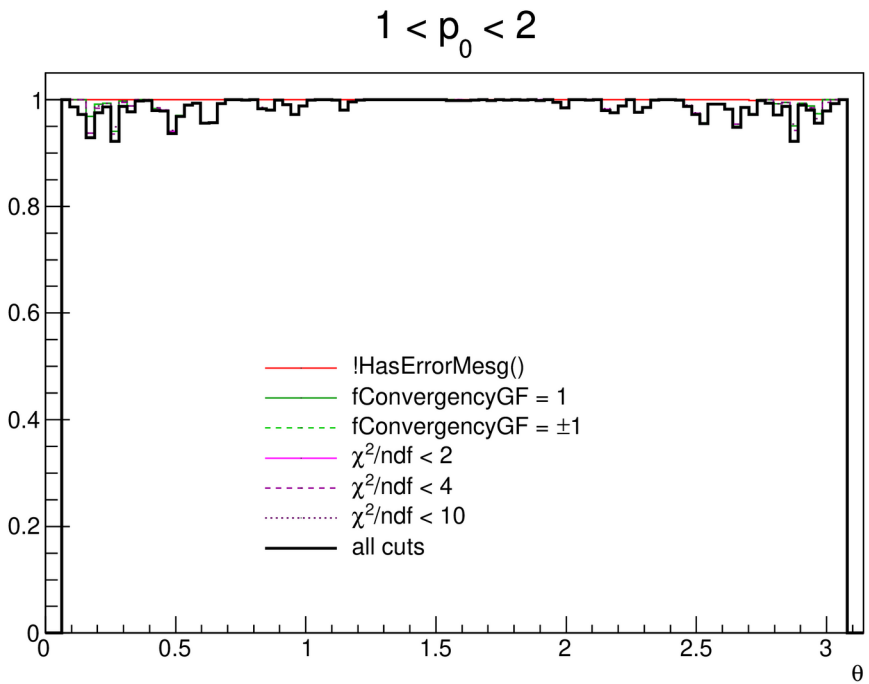




no material

Efficiency of track quality cuts: $1 < p_0 < 2$ GeV/c





no material

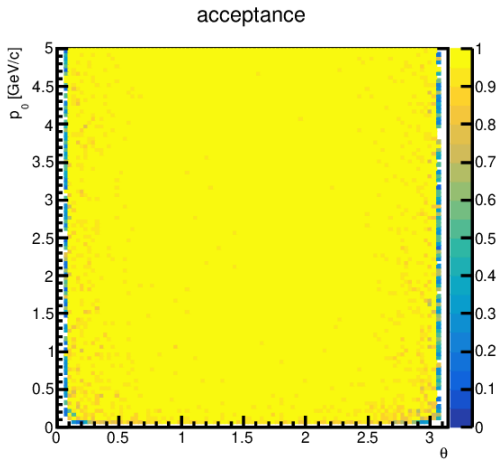
Conclusions

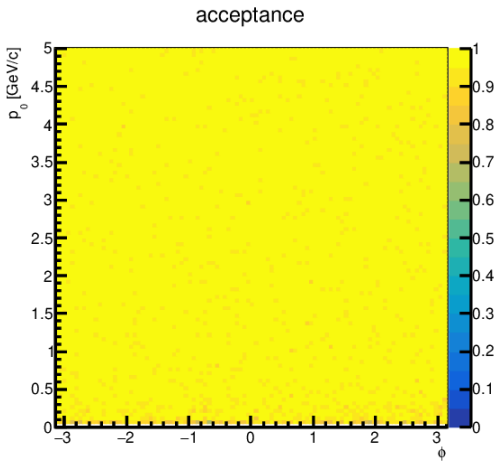
- Track fitting performance in SpdRoot is understood almost completely.
- Problem with convergency at high momenta was caused by a bad initialisation procedure of fit parameters.
- We need to rewrite the initialisation procedure!
- Tracks with $0.22 < \theta < 0.63$ have big χ^2/ndf values due to hits formed when the track crosses the end of the tube.
- Decreased efficiency of the cut on convergency at low momenta ($p \lesssim 1.5$ GeV/c) is explained by material effects.

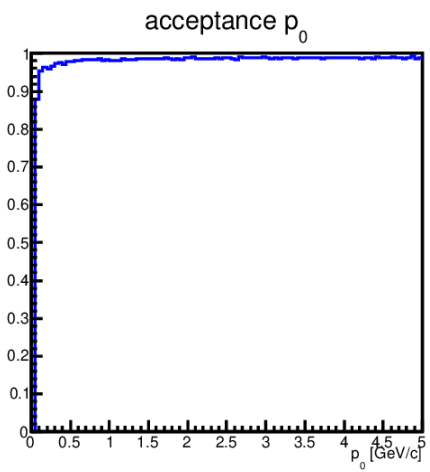
Thanks to my colleagues I. Denisenko, V. Andreev, A. Korzenev, A. Ivanov, and E. Zemlyanichkina for fruitful discussions!

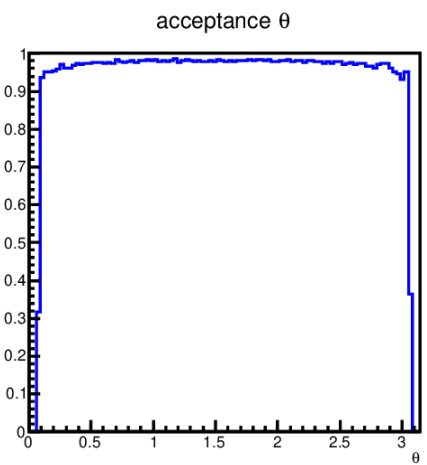
backup slides

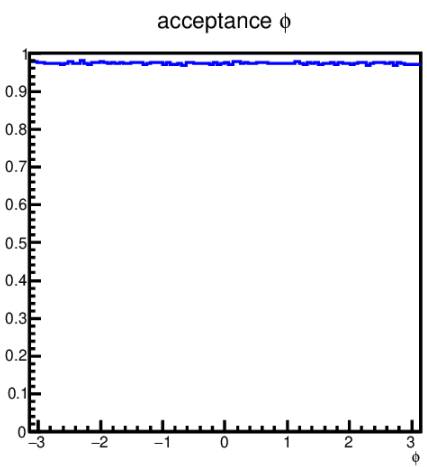
Acceptance


acceptance
p0 [GeV/c]
θ

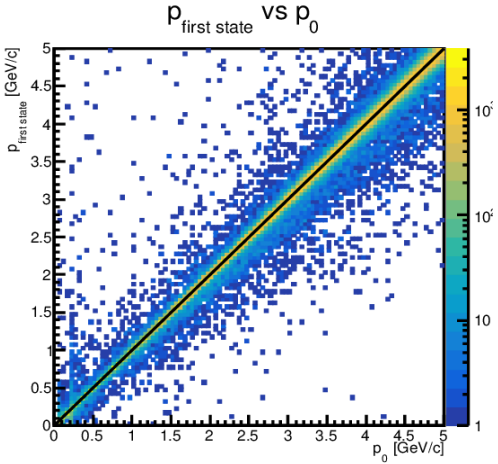

acceptance
p0 [GeV/c]
ϕ

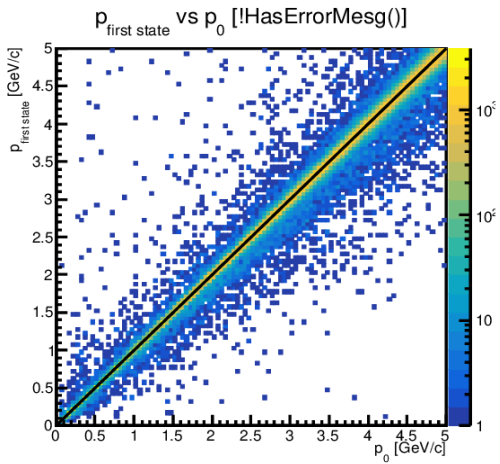

acceptance p0
p0 [GeV/c]

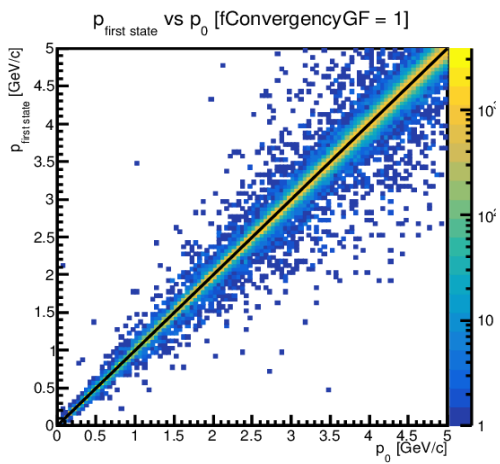

acceptance θ
θ

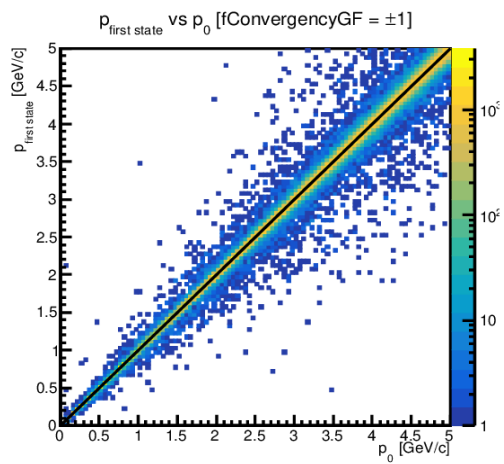

acceptance ϕ
ϕ

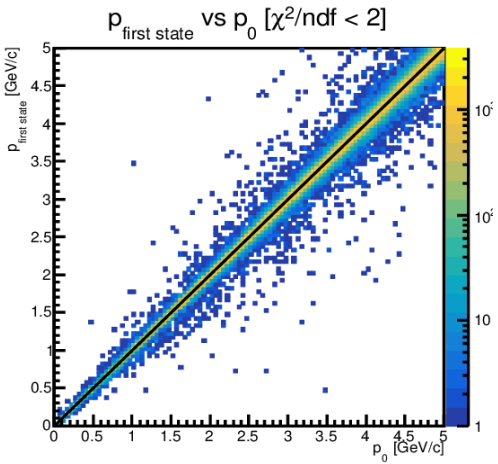
Reco momentum vs true momentum. "Ideal" Rdrift

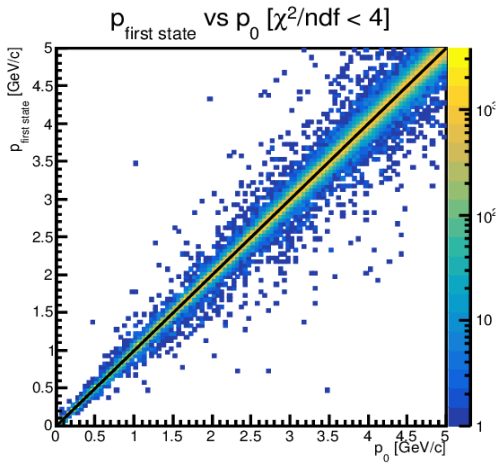


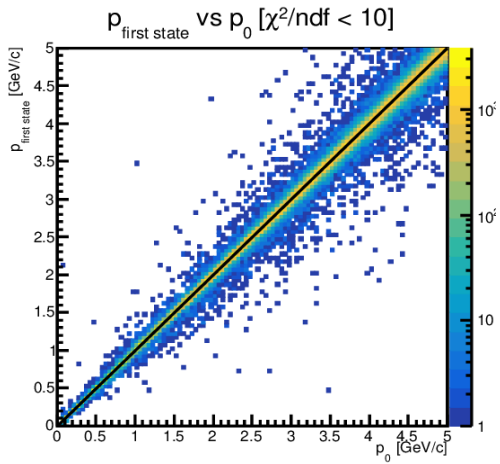


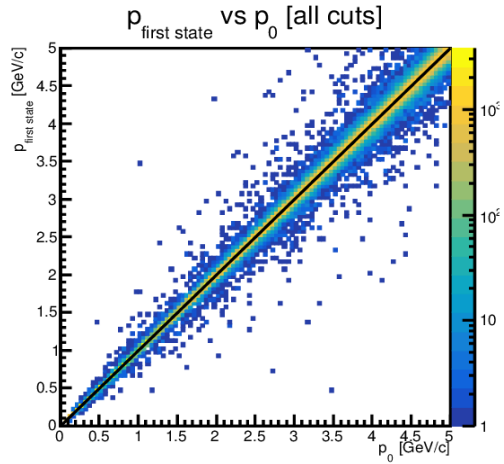




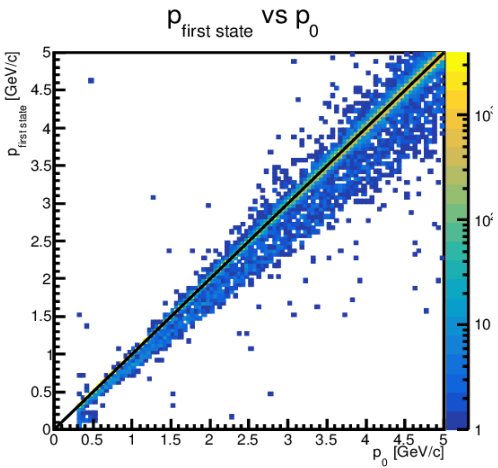


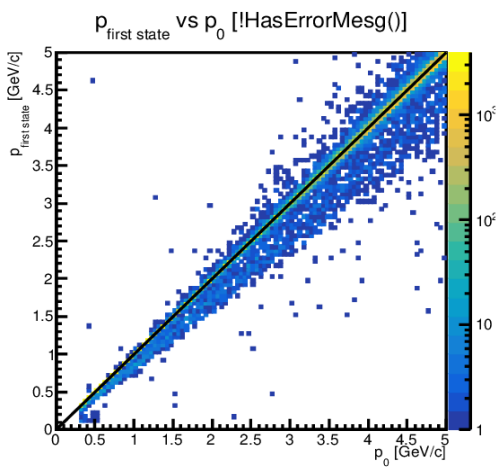


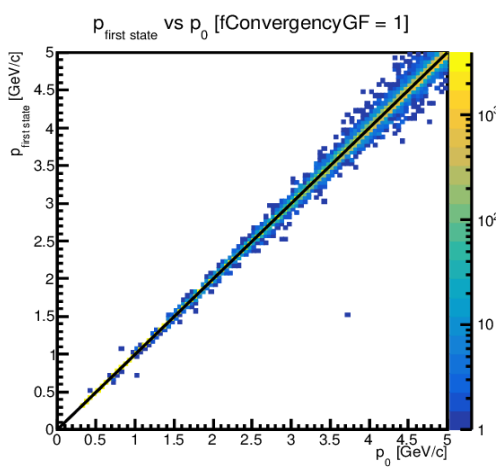


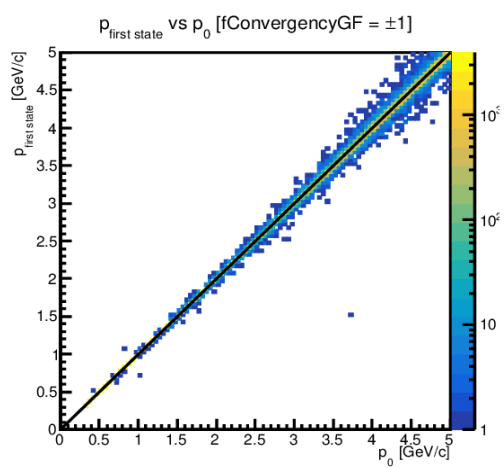


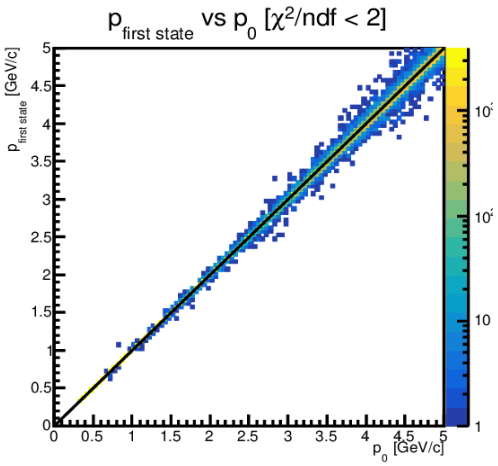
Reco momentum vs true momentum. No material

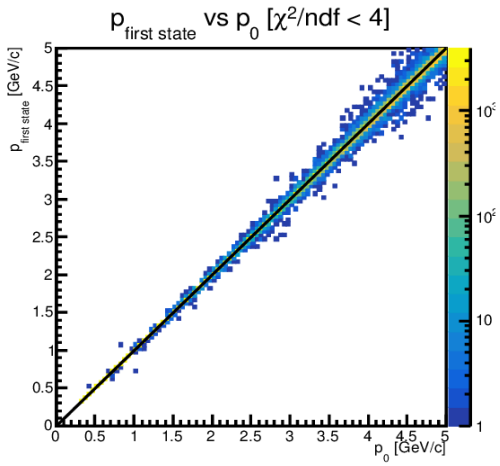


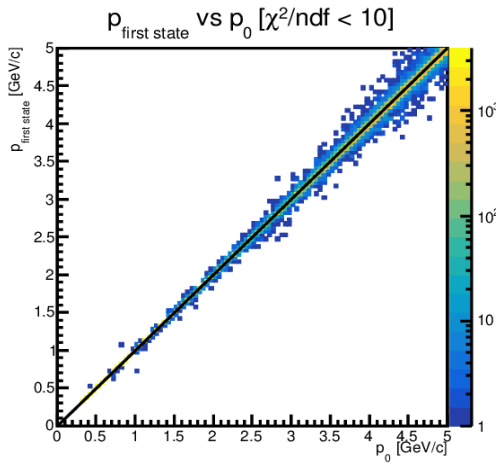


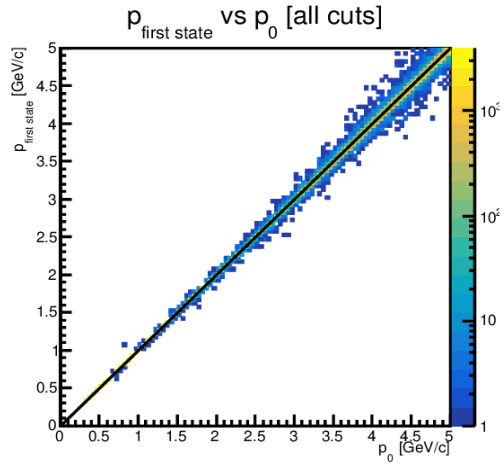






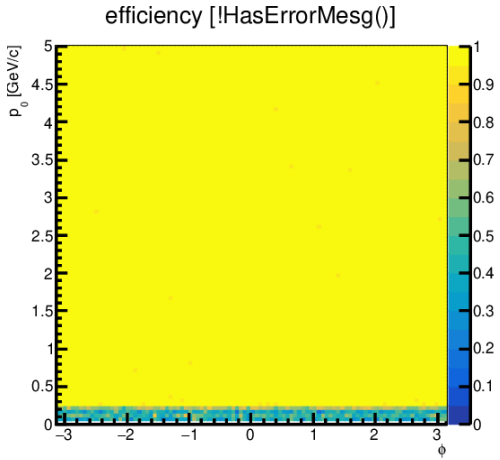


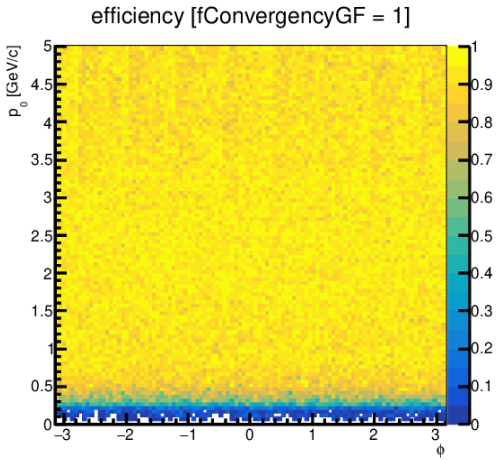


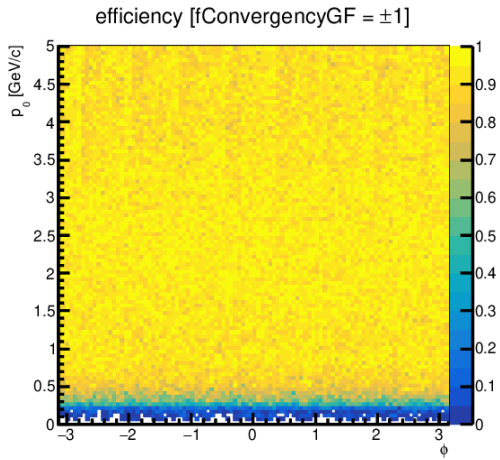


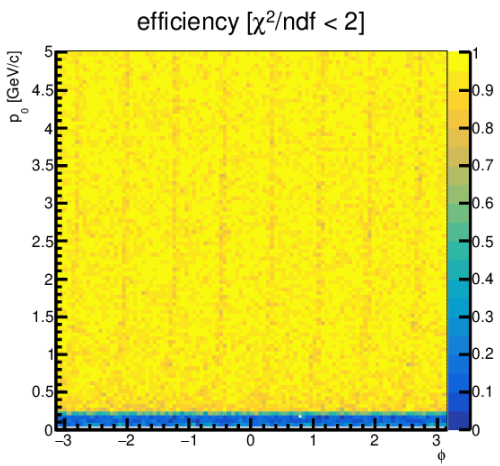
Efficiency of track quality cuts

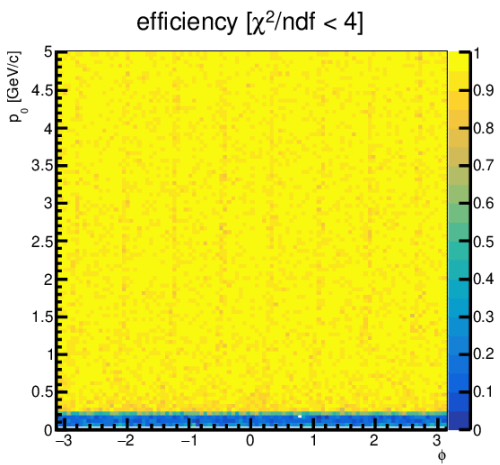
current initialisation procedure

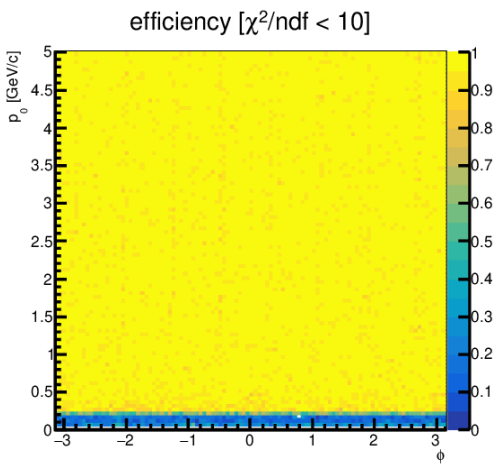


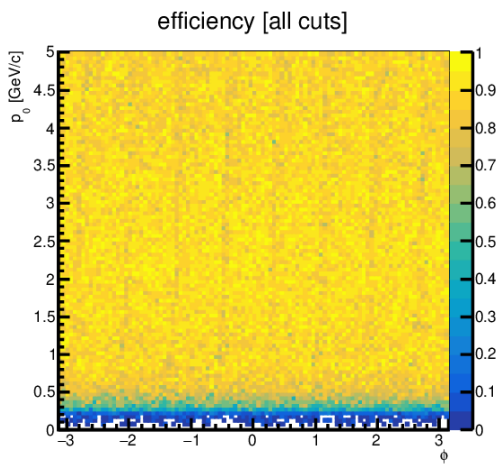






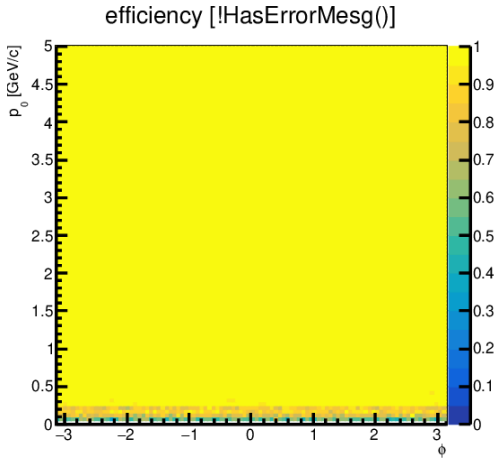


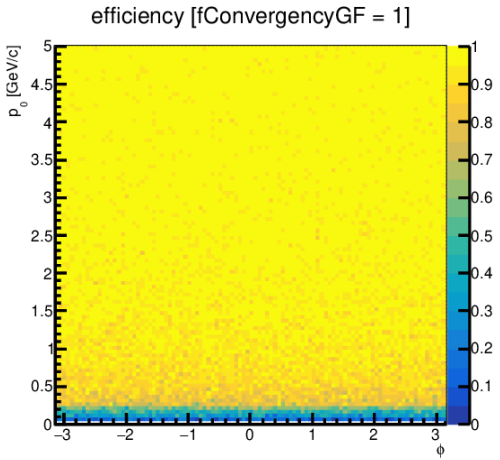


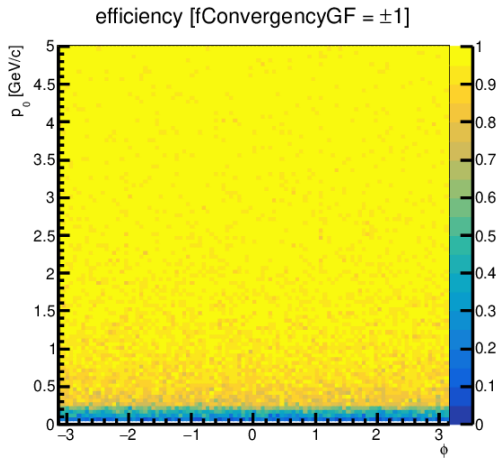


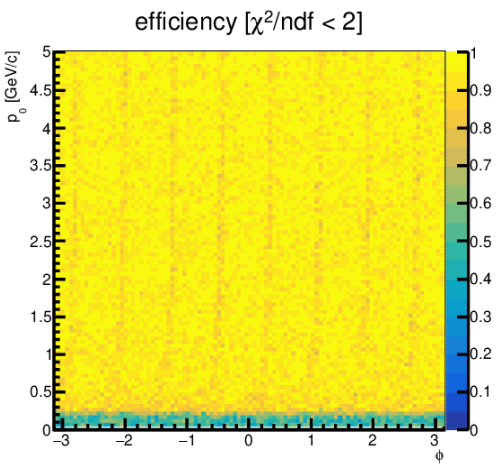
Efficiency of track quality cuts. Init. values = MC

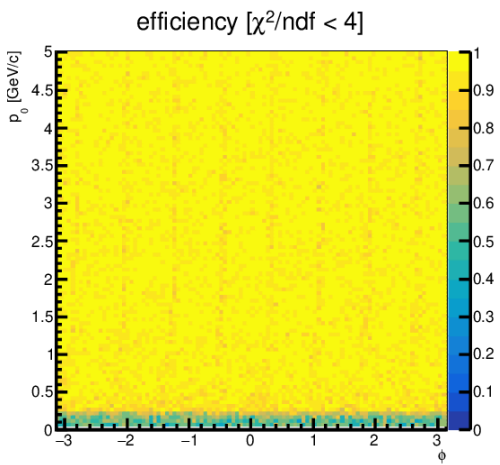
initial values
from MC

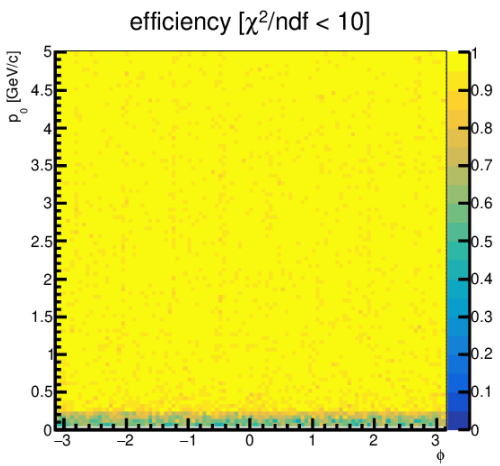


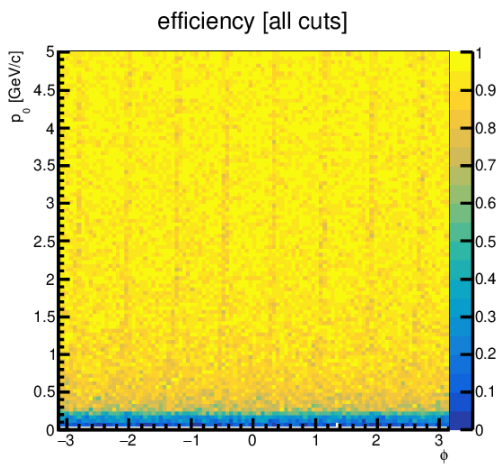








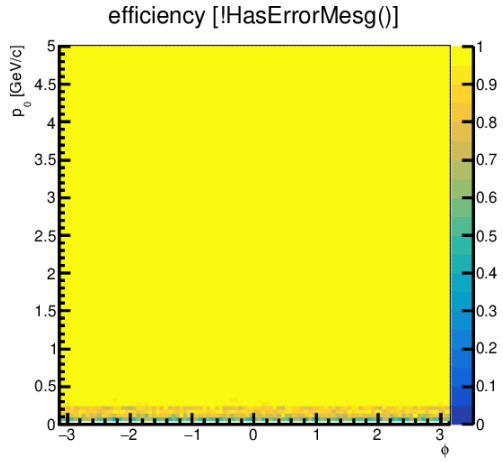


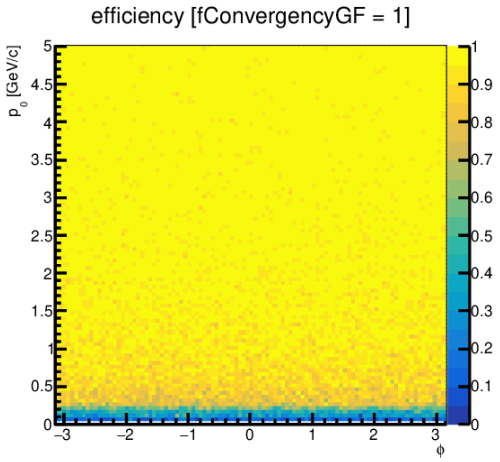


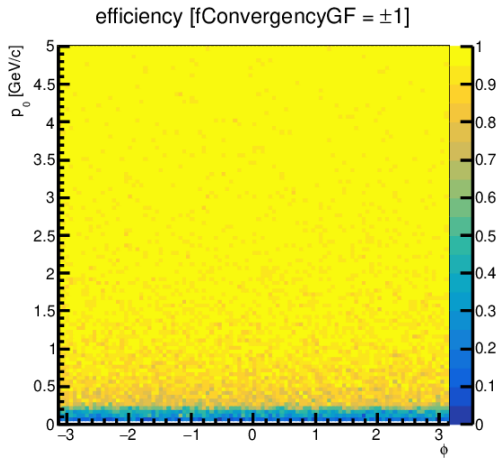
Efficiency of track quality cuts. "Ideal" Rdrift

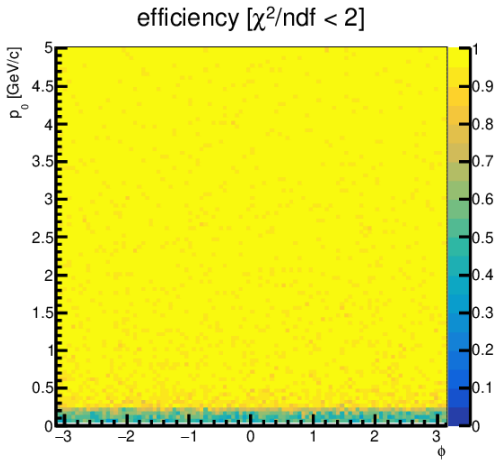
initial values
from MC

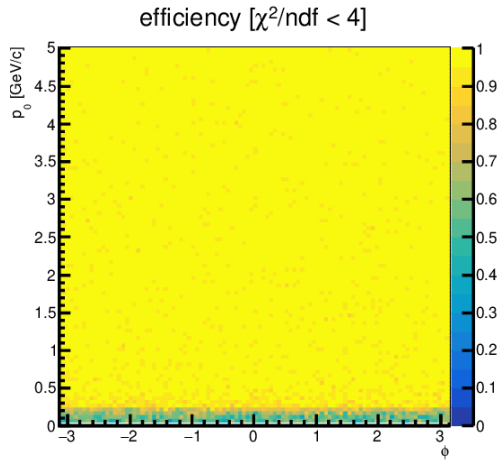
"ideal" Rdrift

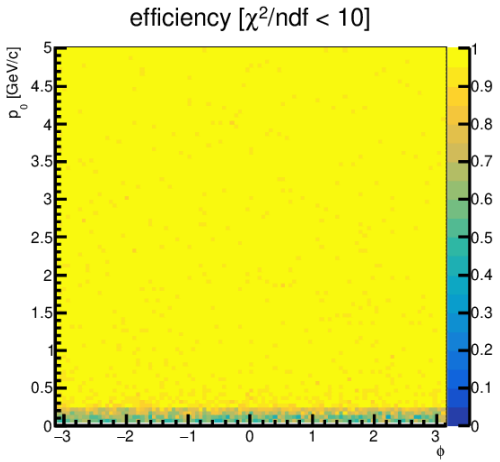


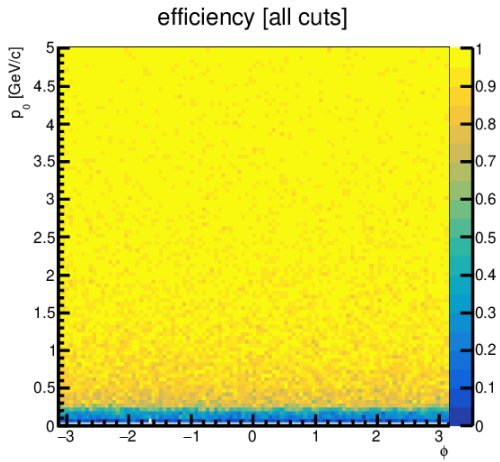










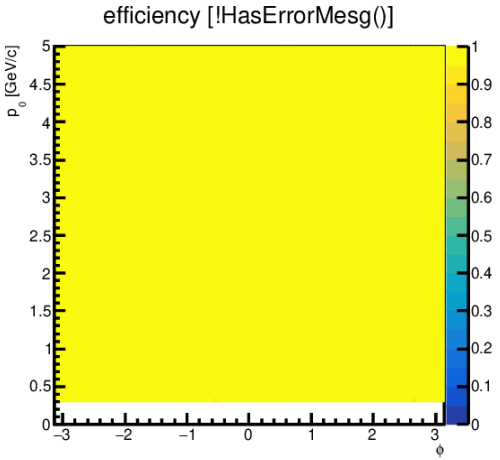


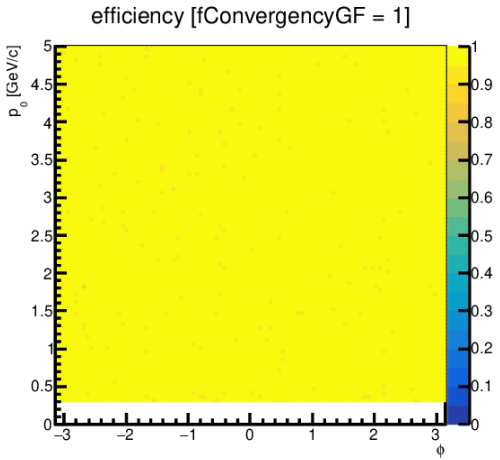
Efficiency of track quality cuts. No material

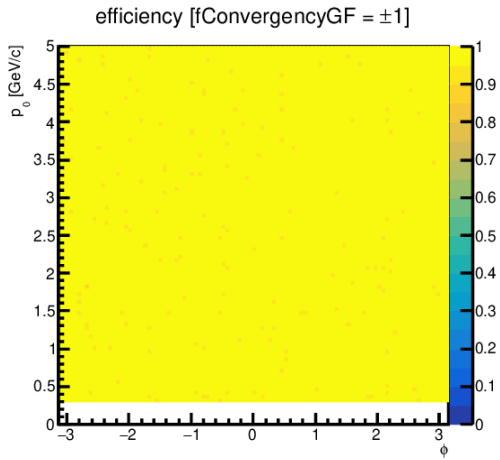
initial values
from MC

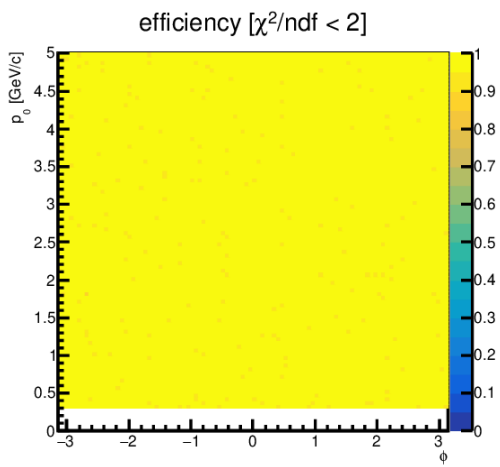
"ideal" Rdrift

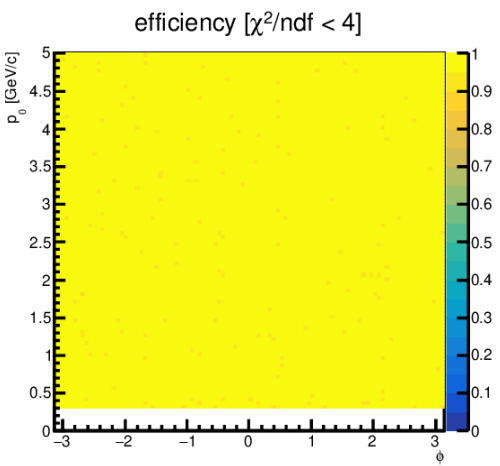
no material

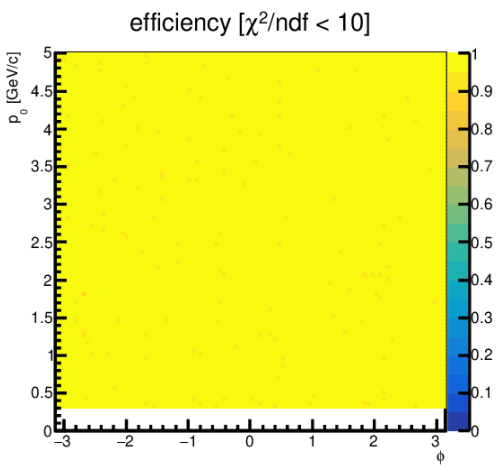


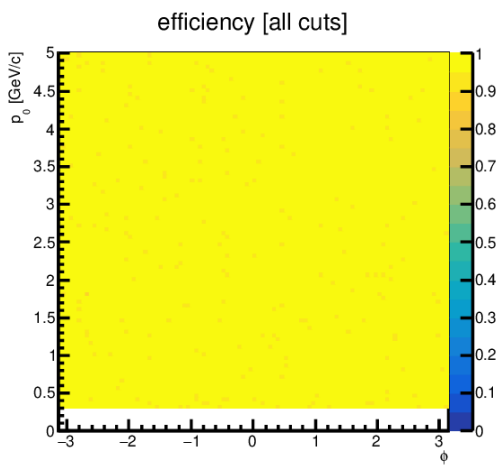




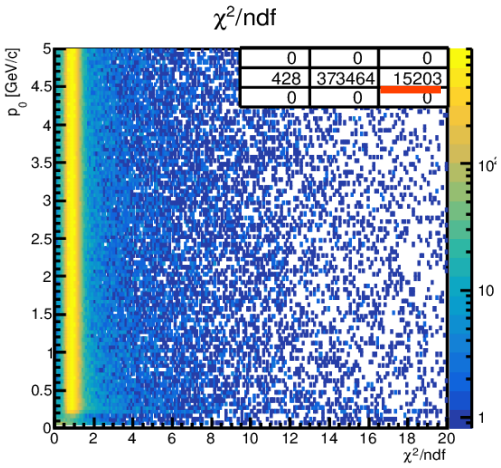


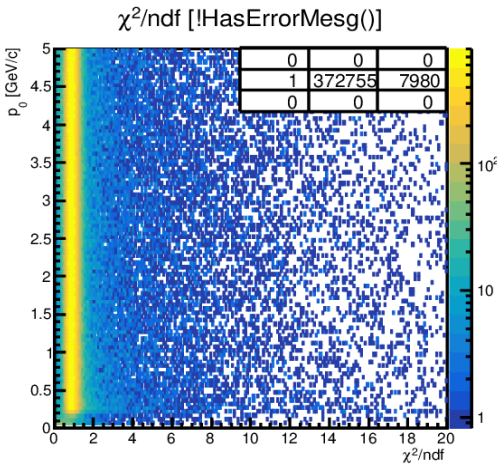


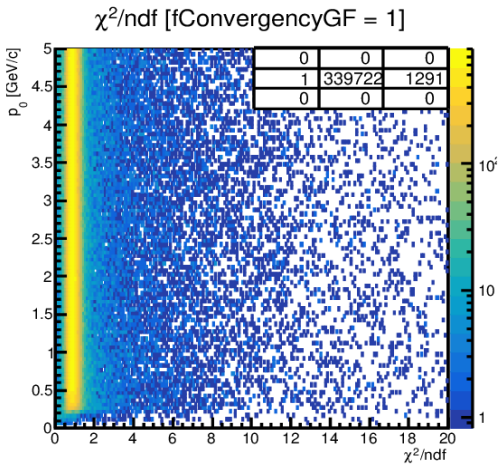


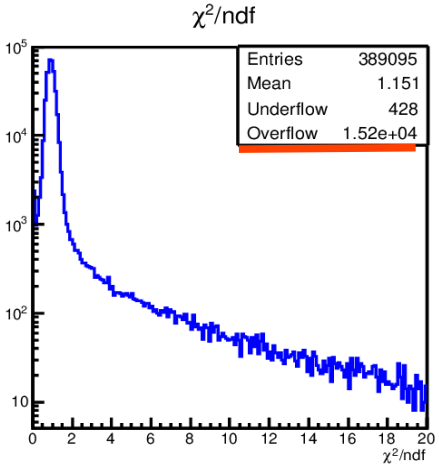


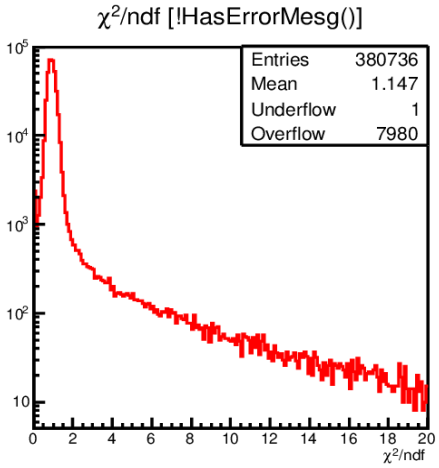
χ^2/ndf distribution

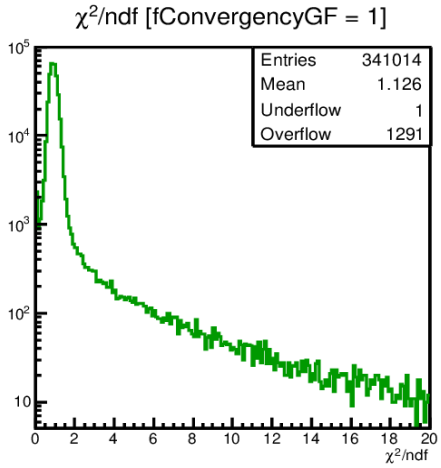






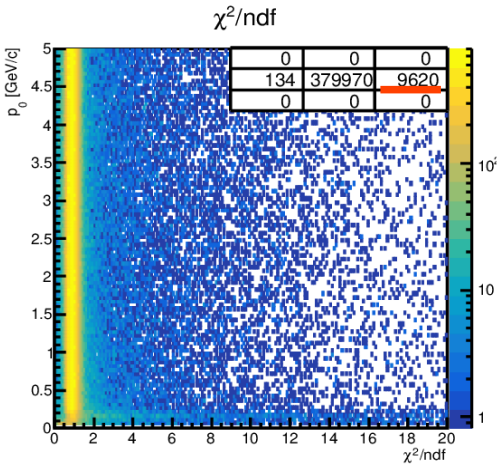


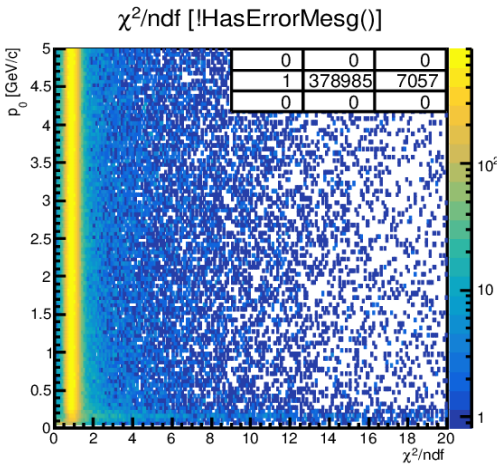


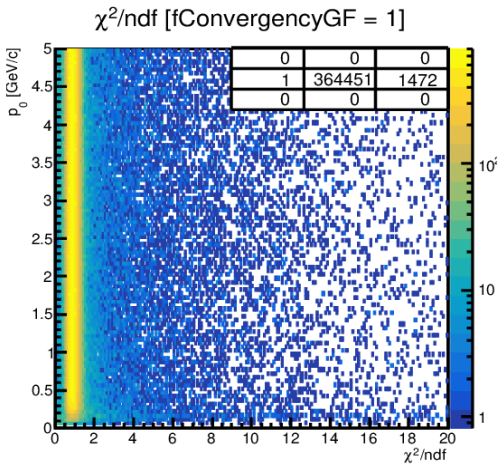


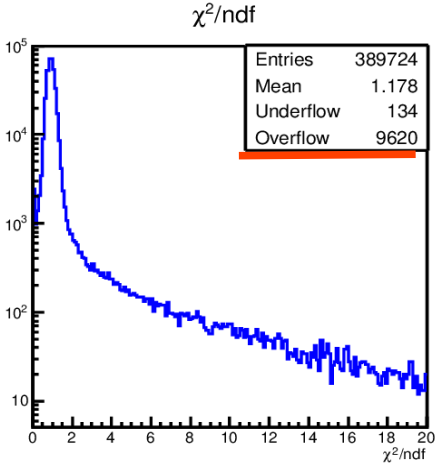
current initialisation procedure

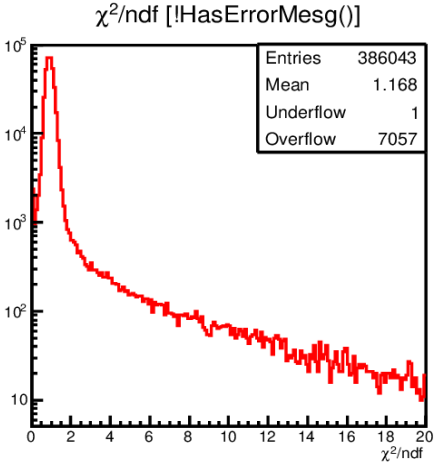
χ^2/ndf distribution. Initial values = MC.

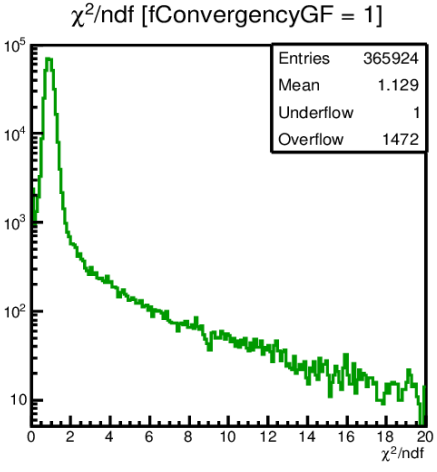






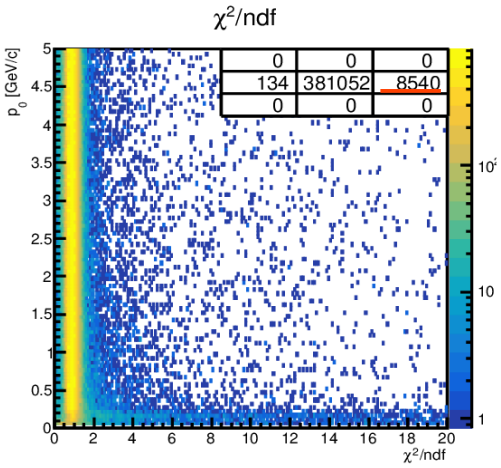


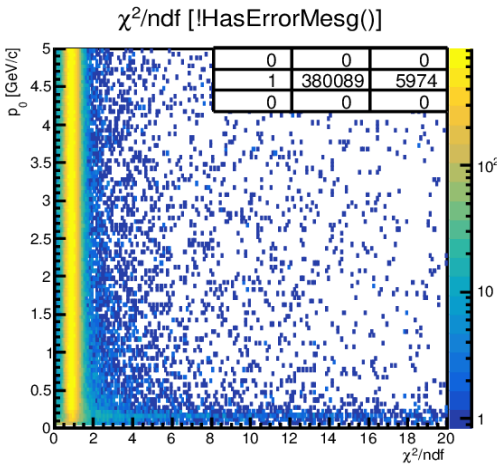


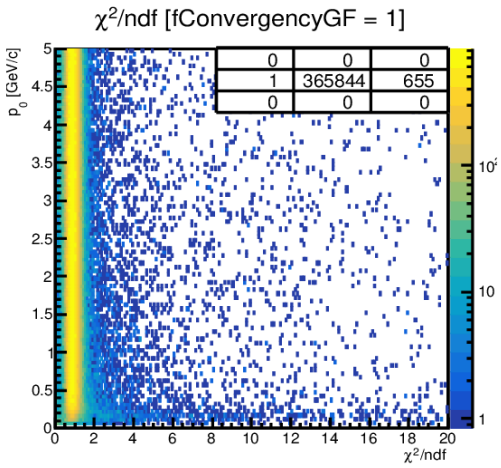


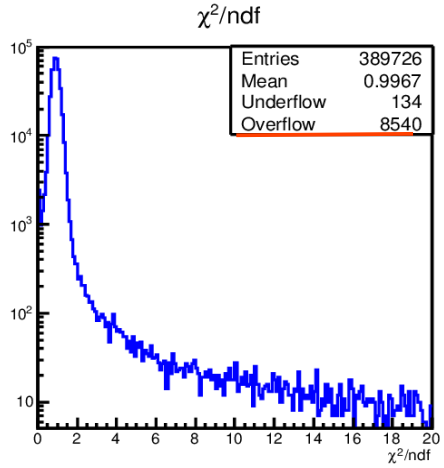
initial values from MC

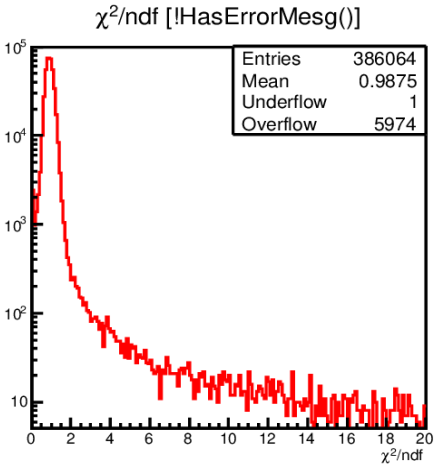
χ^2/ndf distribution. "Ideal" R drift.

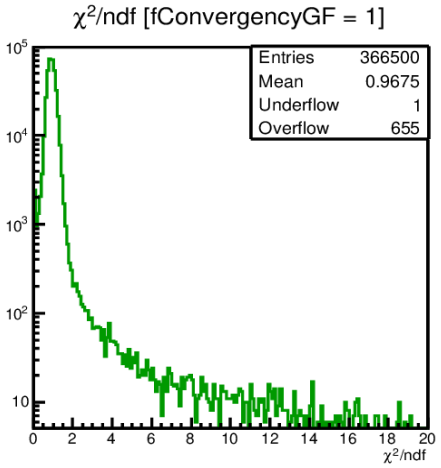








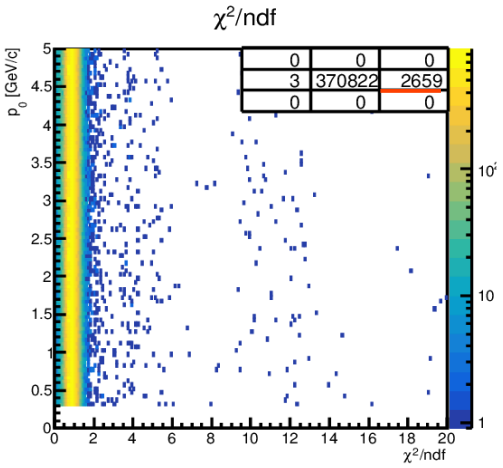


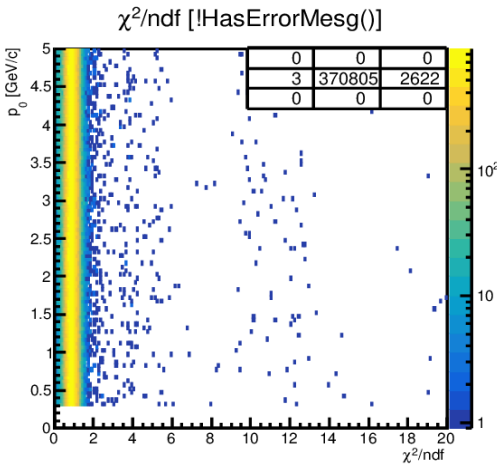


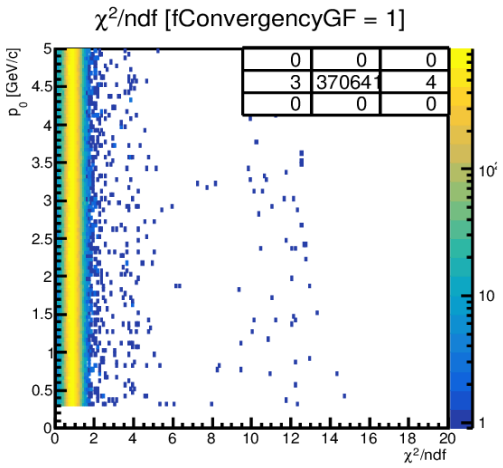
initial values from MC

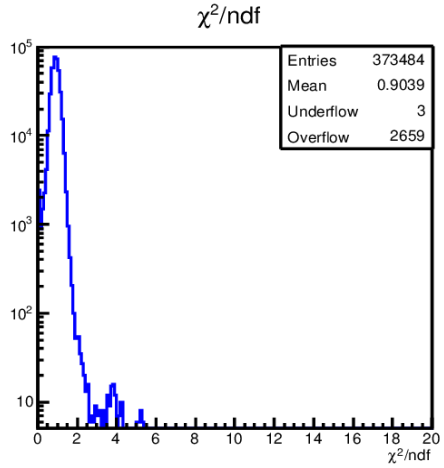
"ideal" Rdrift

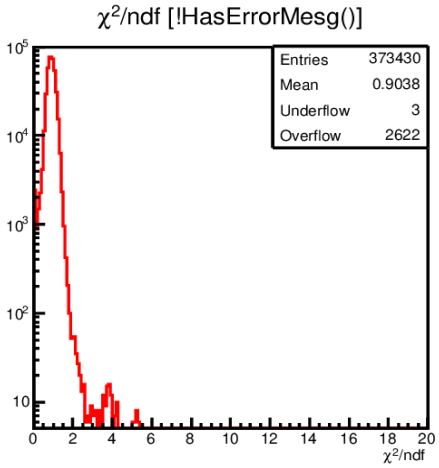
χ^2/ndf distribution. No material.

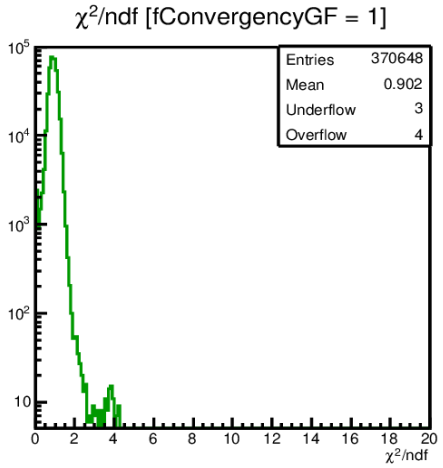












initial values from MC

"ideal" Rdrift

no material