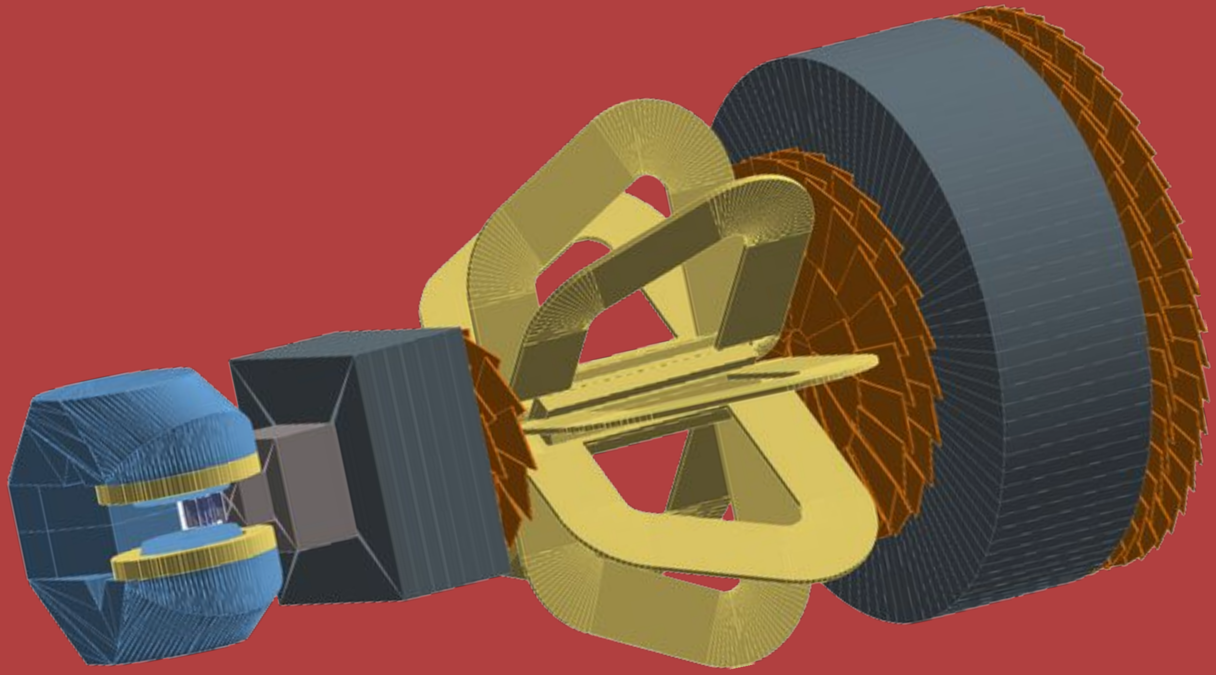


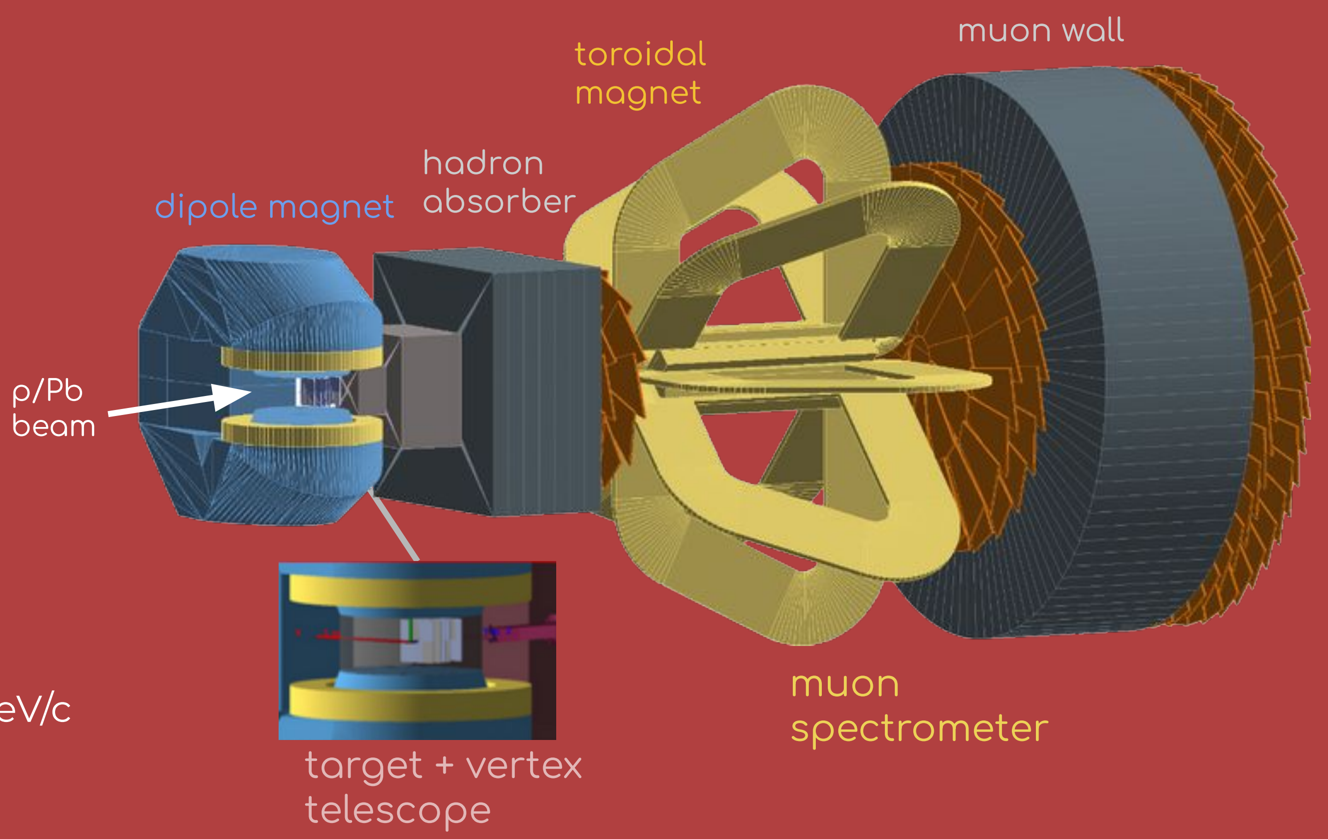
ACTS for the NA60+ muon spectrometer

29 July 2024

The NA60+ setup

Setup

- Muon spectrometer
- Vertex spectrometer



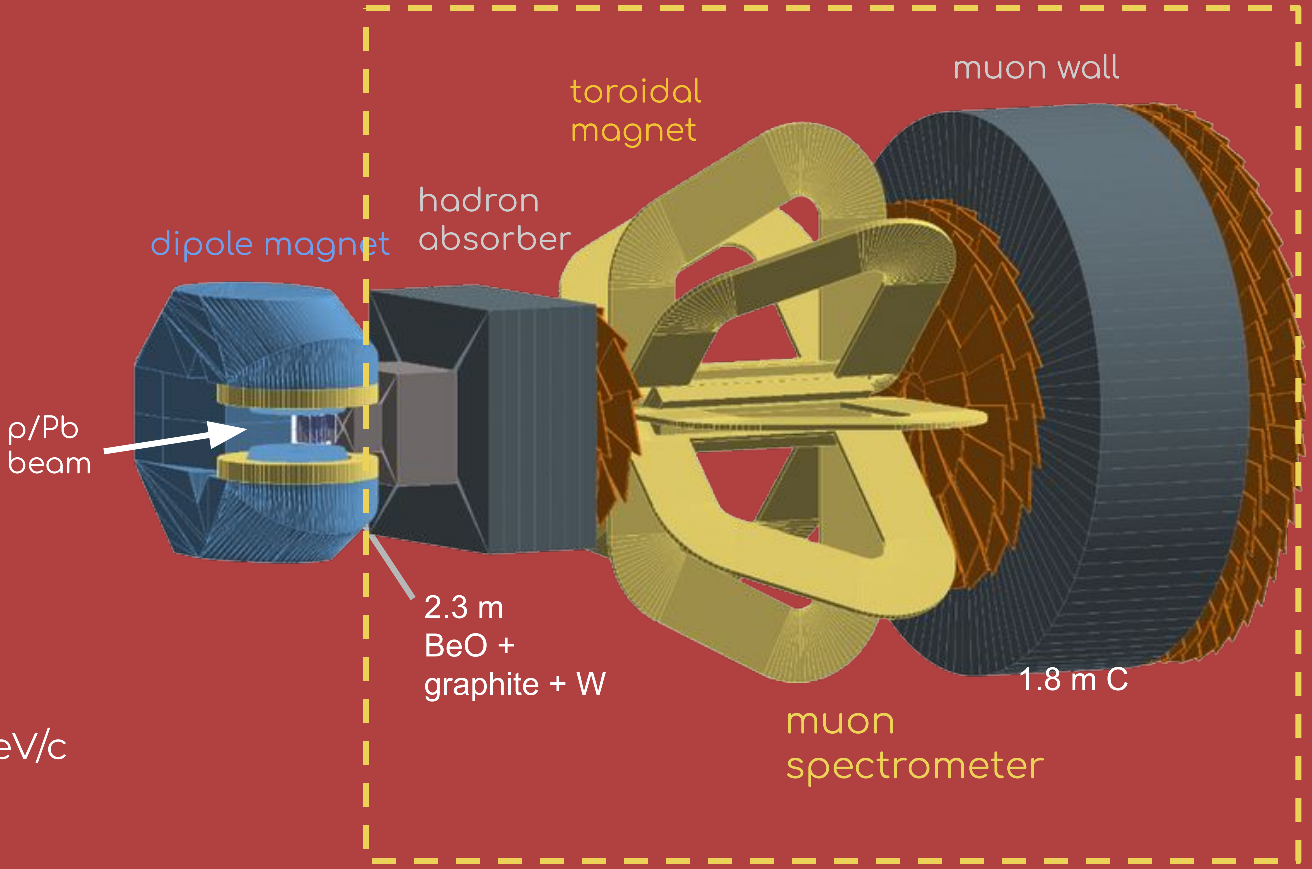
Energy/ systems

- Pb-Pb and p-A collisions
- energy scan $6 < \sqrt{s} < 17$ GeV/c ($20 < E_{lab} < 158$ GeV/c)
- high luminosity ~10^6 Pb/s

The NA60+ setup

Setup

- Muon spectrometer
- Vertex spectrometer

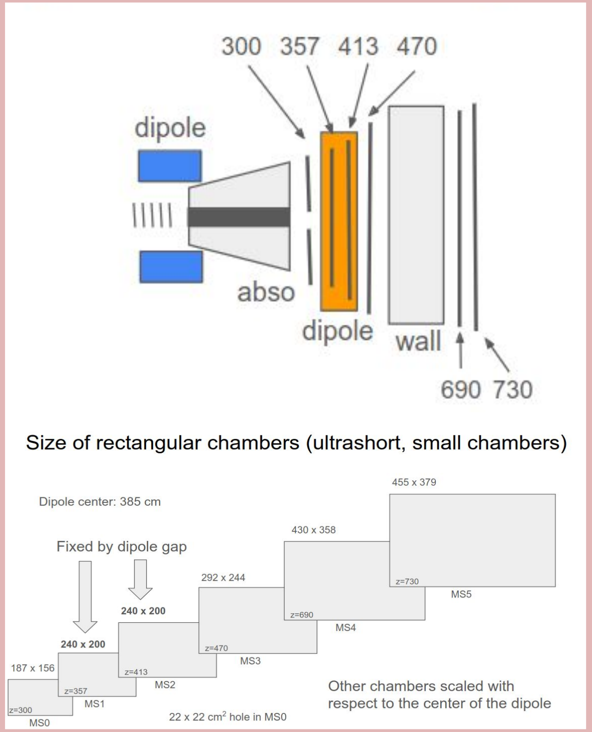


Energy/ systems

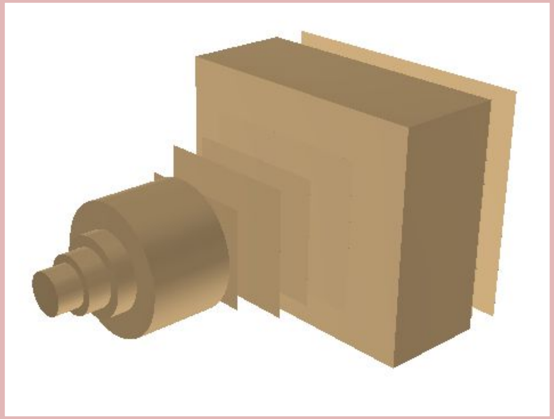
- Pb-Pb and p-A collisions
- energy scan $6 < \sqrt{s} < 17$ GeV/c ($20 < E_{lab} < 158$ GeV/c)
- high luminosity ~10^6 Pb/s

Geometry

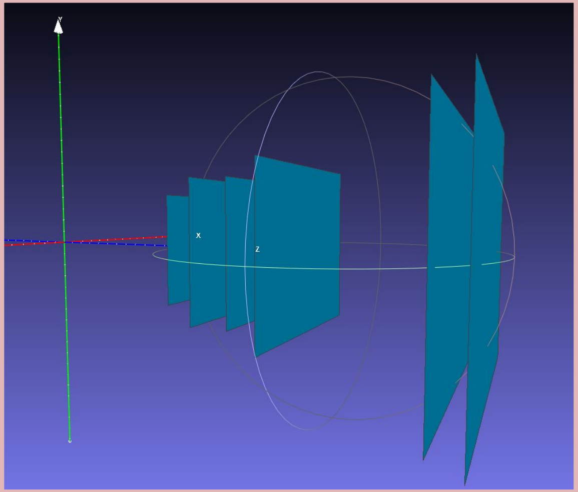
Simplified MS setup



geometry build via TGeo



ACTS geometry

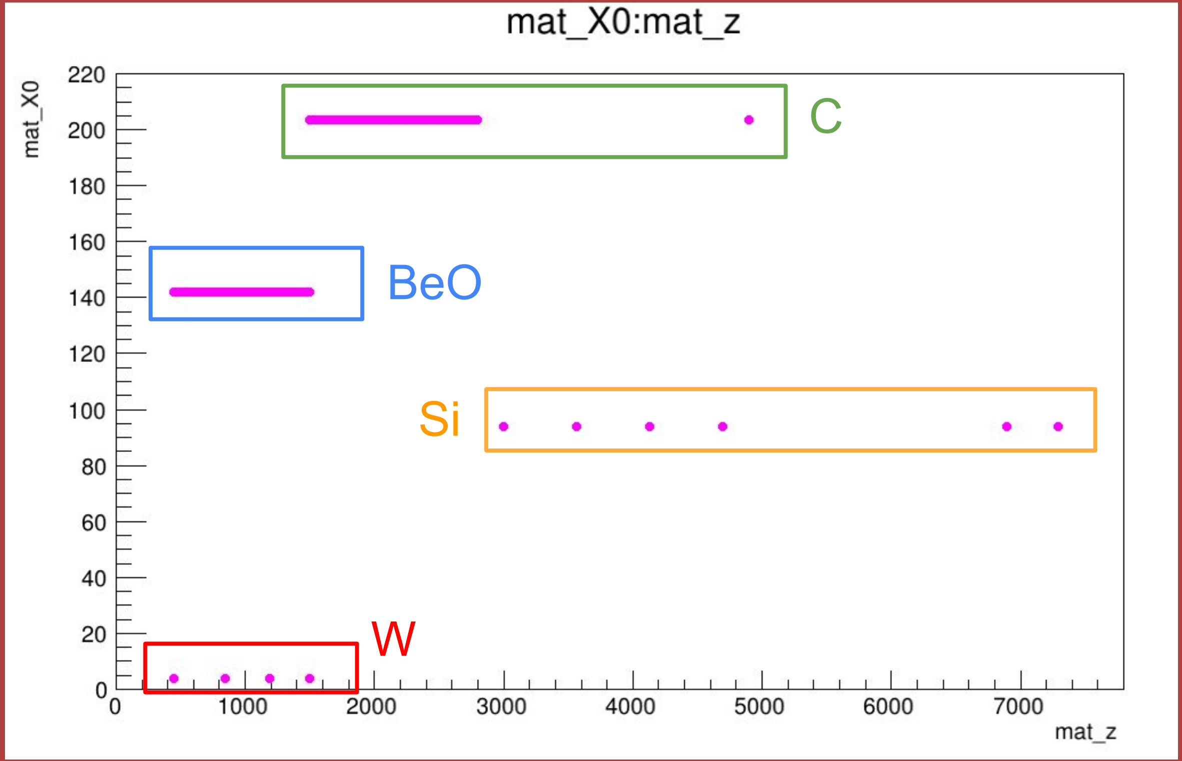


(Still old geometry used)

- Dipole magnet also in the muon spectrometer
- Rectangular chambers

Mapping

1) Geantino particles are propagated in the fully detailed geometry (gdml)
→ the material encountered by the geantinos is stored

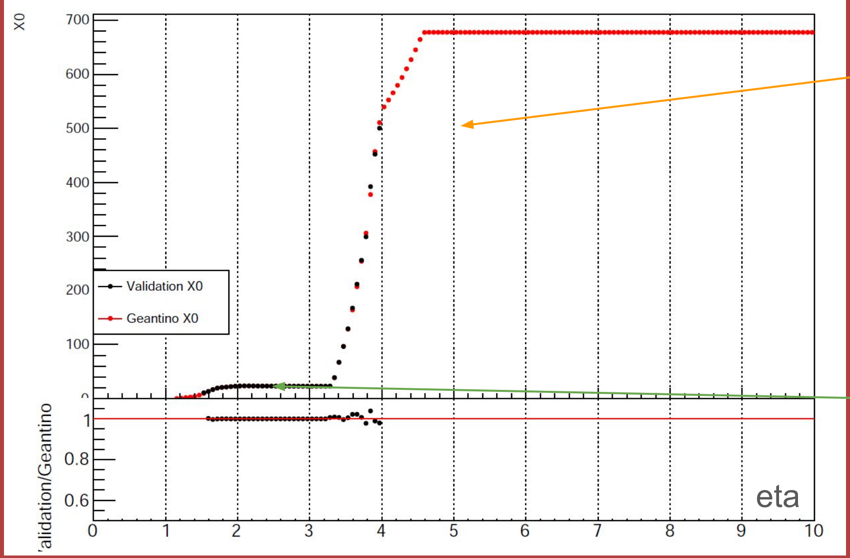


- plot shows the X0 of the material vs z (i.e. at the entrance of all subdetectors)
- continuum lines are due to particles which first cross, for example, the W plug at the z where the plug starts, and then they cross, at a random z, the absorber

Mapping

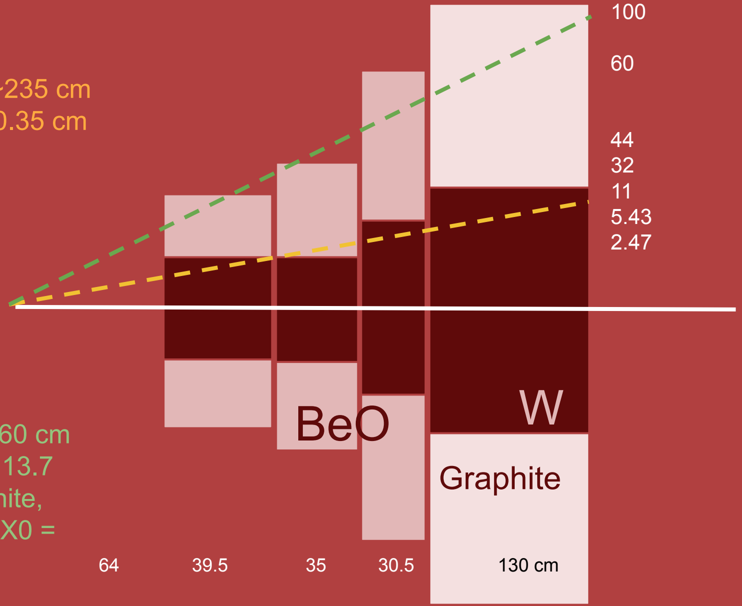
1) Geantino particles are propagated in the fully detailed geometry (gdml)
   → the material encountered by the geantinos is stored
2) Test particles are propagated in the simplified ACT geometry, assigning materials to layers
   → a material map is created
3) Propagation is now carried on in the decorated ACTS geometry
   → results are compared to those obtained with the full geometry, to validate the mapping

Compare amount of material (in X0) encounter by tracks vs eta



η = 4 crosses ~235 cm of W, X0_W = 0.35 cm → n. X0 = 670

η = 1.8 crosses ~160 cm of Be0, X0_BeO = 13.7 cm + 130 cm graphite, X0 = 19.3 cm→ n. X0 = 18



Magnetic field

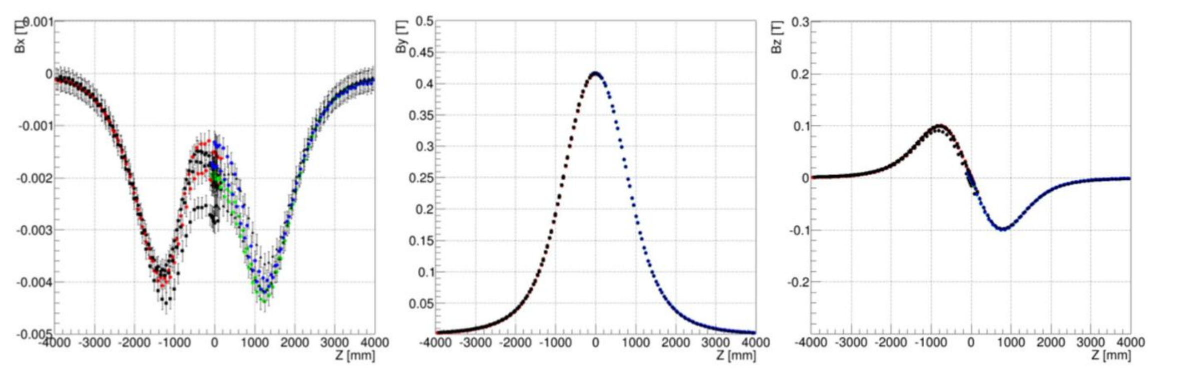
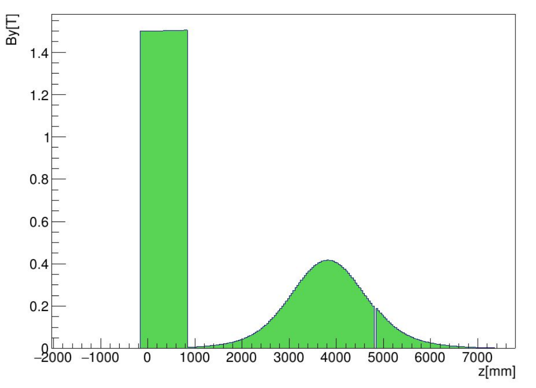


Figure 6. Plotted at $X = 40$, $Y = 360$ mm are: (left) B_X versus Z, (centre) B_Y versus Z and (right) B_Z versus Z. The different colours and symbols are used to enable points from different sensors to be distinguished.

MNP33 Magnetic field map from https://inspirehep.net/files/4706e9a213757975c85c3fdbedc6f5bc

Next step: add also the vertex telescope dipole in the B map



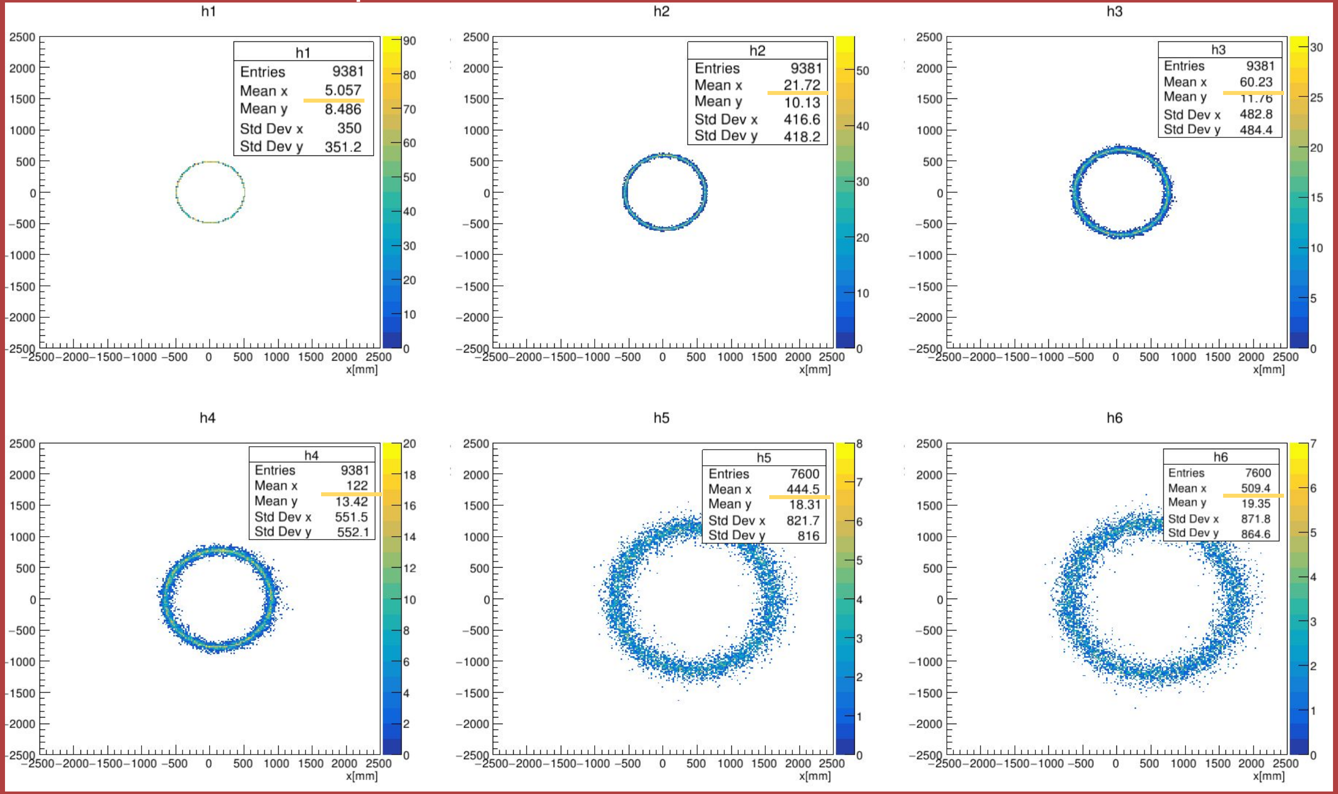
A magnetic field map (x, y, z) is created, covering the full volume of the ACTS geometry

Assume B = (0, By, 0)

```
field = acts.examples.MagneticFieldMapXyz("BField_MNP33.txt");
```

Test of B field

Hits in the 6 Muon spectrometer chambers



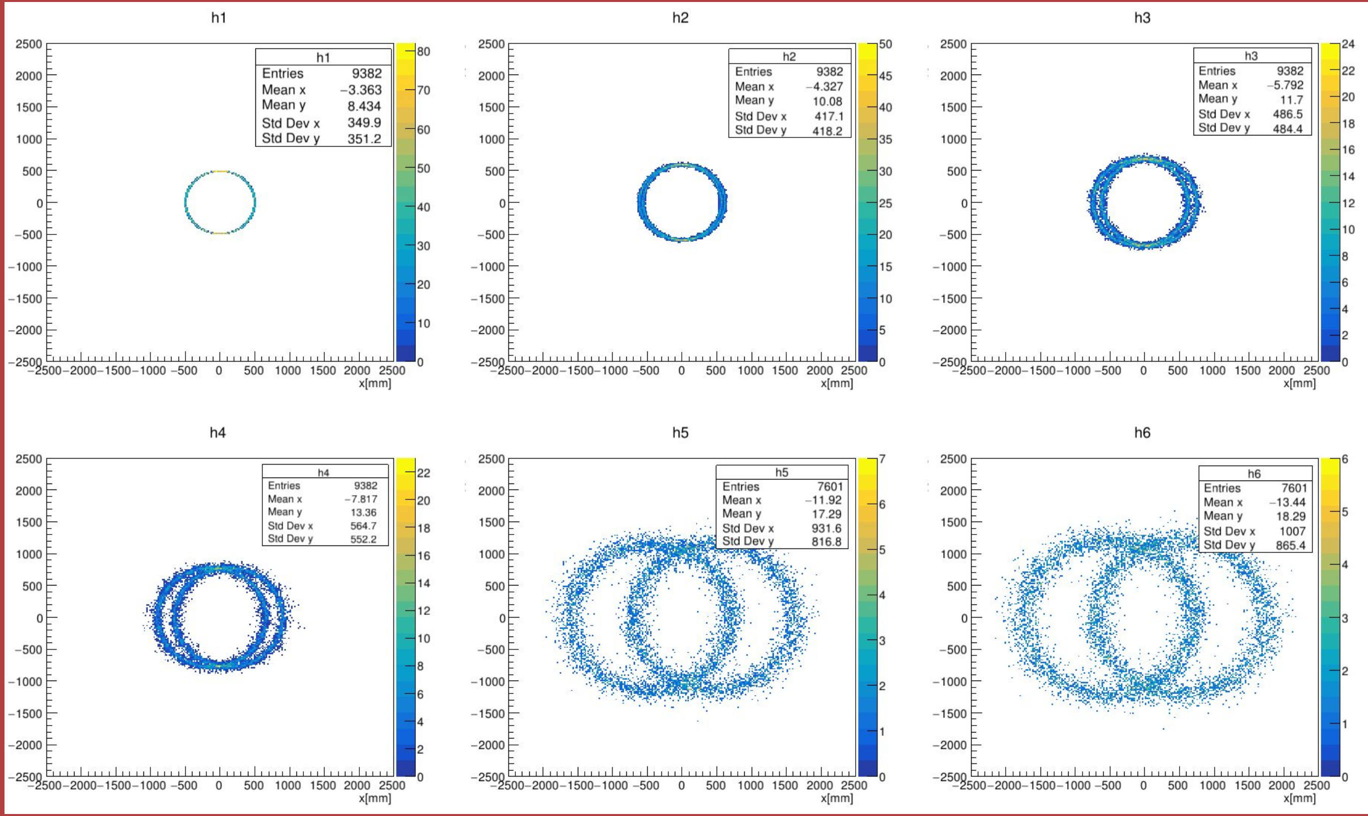
Particle gun

- LS muons
- pT = 0.5 GeV
- eta = 2.5

MNP33 B field map [0,By,0]

Hits after FATRAS tracking

Test of B field



Particle gun

- OS muons
- pT = 0.5 GeV
- eta = 2.5

MNP33 B field map [0,By,0]

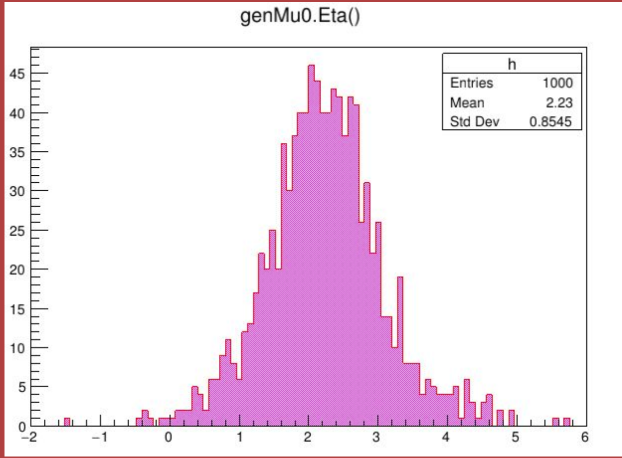
Hits after FATRAS tracking

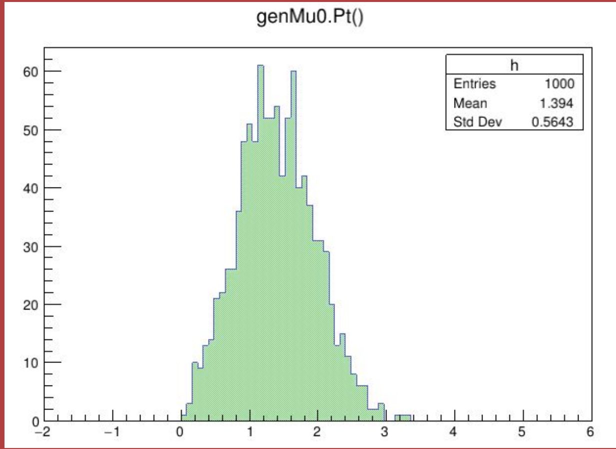
Input particles

Parametrisation of the muons from JPsi decay, as obtained from NA60+ fast simulation [Elab = 40 GeV]

Store the kinematics of the two decay muons in csv format

Use the csv as input in the sim/reco chain



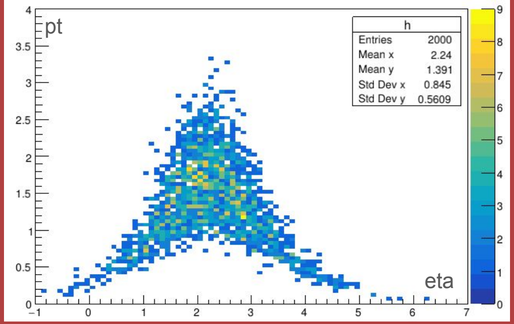


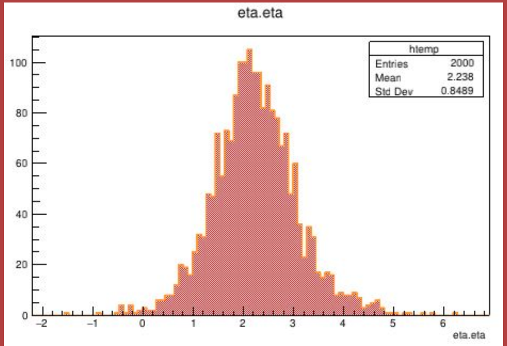
FATRAS tracking

Simulated particles are tracked in the setup via FATRAS

input

(particles.root)



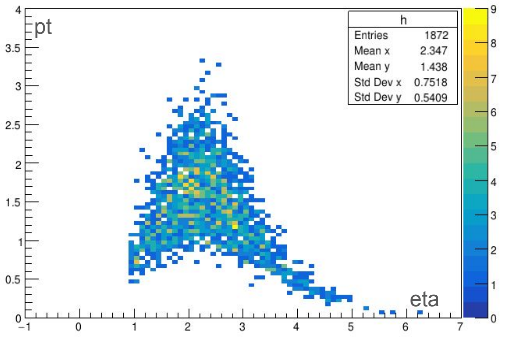


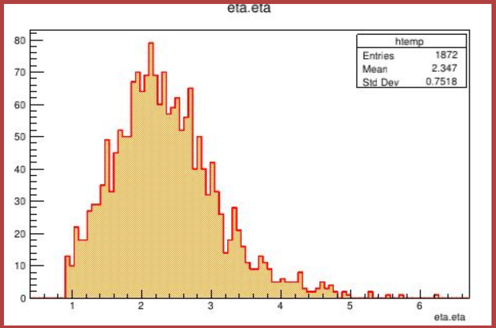
Few particles (~6%) lost at very low eta

Furthermore, several particles don't leave hits in the MS, because of the too small eta

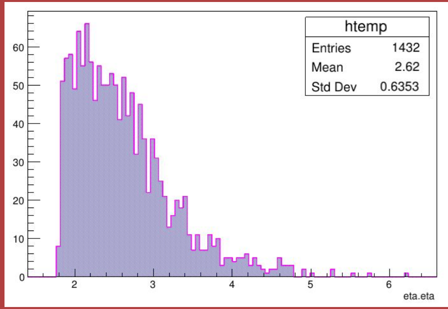
after tracking

(particles_simulation.root)



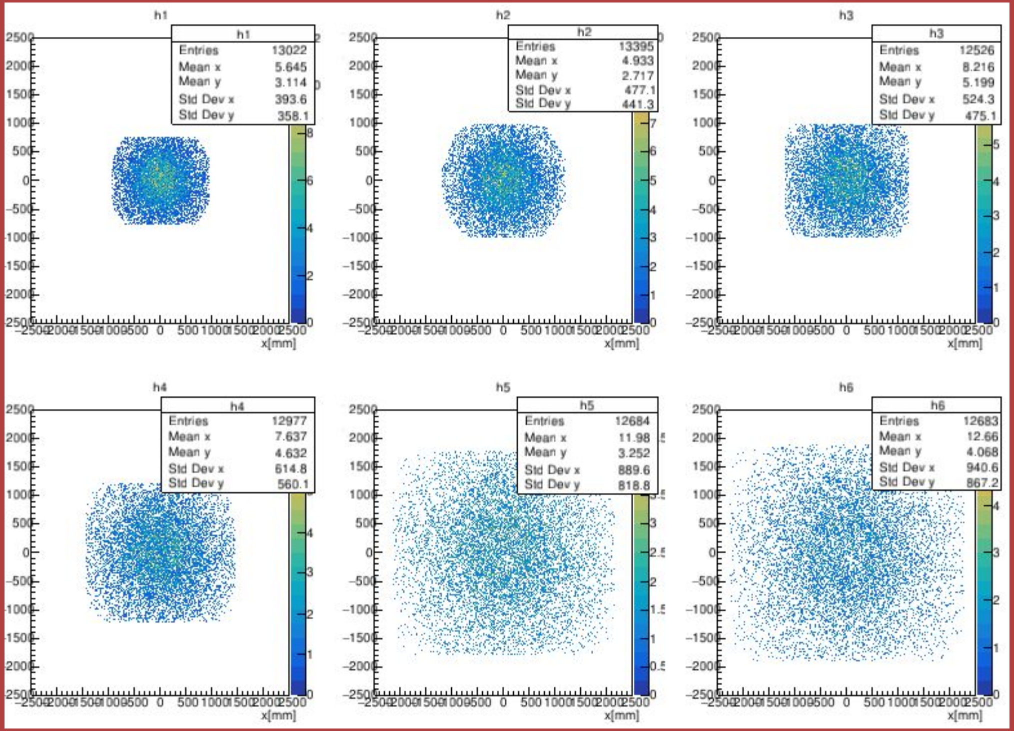


→ apply Fatras preselection cut eta=(1.8,10),



Hits on the MS chambers

Hits after FATRAS tracking
(particles_simulation.root)

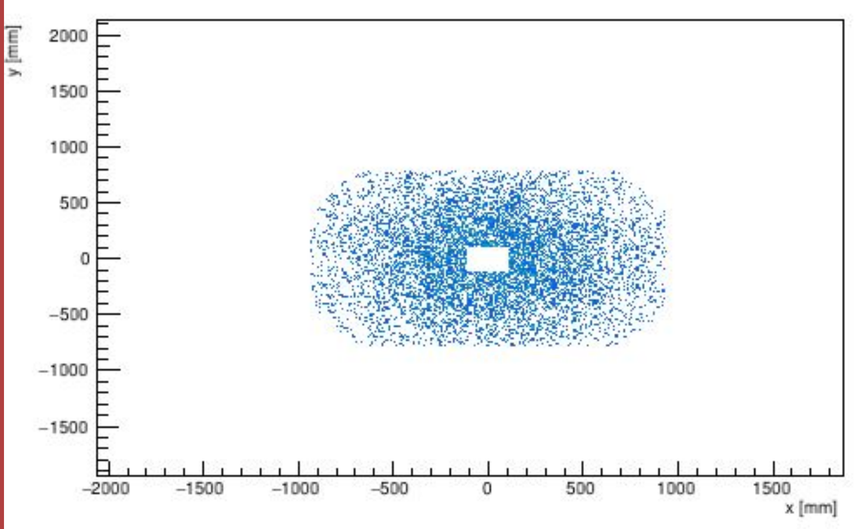


Statistics:
- 10000 events
- 20000 generated muons
- ~19000 after FATRAS tracking
- ~14000 if preselection (1.8,10) is applied
- ~13000 hits (due to the eta coverage of the MS)

We mostly lose hits from particles with eta<2

Hole in MCH0

The first chamber has a hole 22 x 22 cm2



The hole is not in the geometry, for the moment:

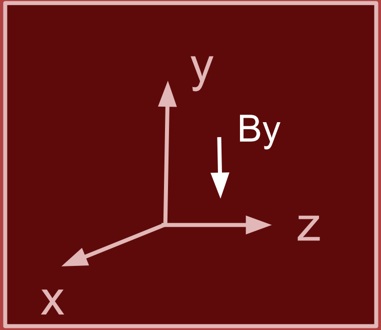
ignore measurements in a given x,y region (in the digitization step) [--> Giacomo]

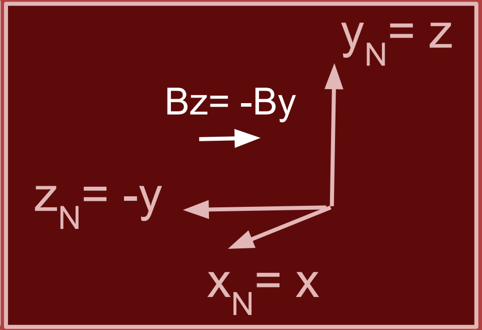
```
auto pos = simHit.fourPosition();
if (m_cfg.applyHole){
  if(abs(pos[0])<110 && abs(pos[1])<110 && pos[3]<3200 && pos[3]>2800){
   ACTS_VERBOSE("Skip hit because inside the hole")
   continue;
 }
```

Seeding

Digits smearing:

```
"smearing" : [
  {"index" : 0, "mean" : 0, "stddev" : 0.1, "type" : "Gauss"},
  {"index" : 1, "mean" : 0, "stddev" : 0.1, "type" : "Gauss"}
]
```





SP rotation

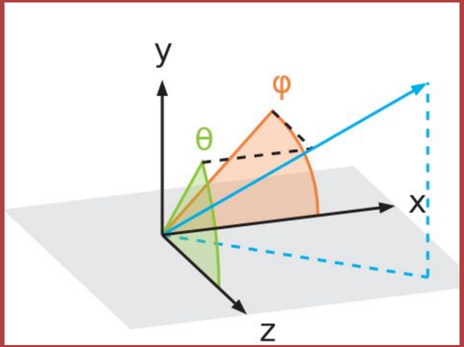
SP are rotated, as well as B field, from (0, By, 0) to (0, 0, -By)

```
Acts::Vector3 position{sp.x(), sp.z(), -sp.y()};
Acts::Vector2 covariance{0.1, 0.4};
```

Seed Grid

Not yet fine tuned
So far 1 bin in phi, 3 in z

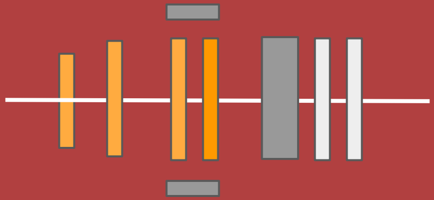
```
SpacePointGridConfigArg(
    rMax= 7500 * u.mm,
    zBinEdges=[-2500.,-1250.,1250.,2500.],
```

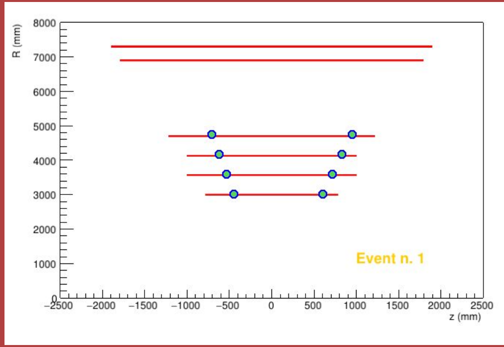


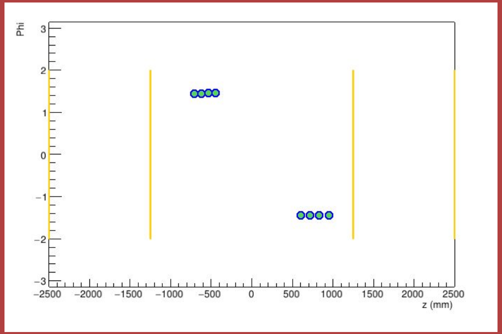
Seeding planes

→ use chambers 1, 2, 3, 4

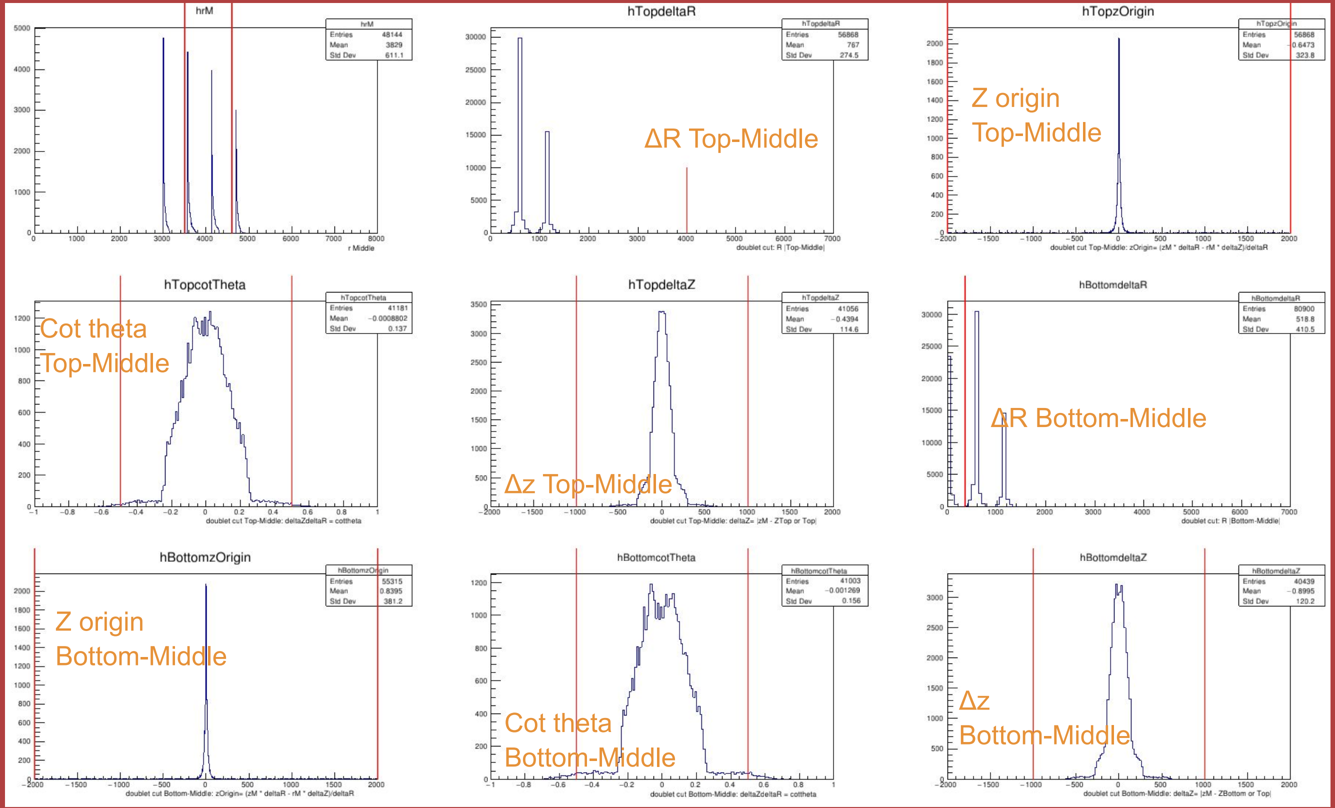
Seeding - first 4 chambers



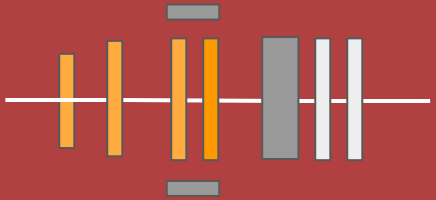




Tuning of seeding parameters (doublets)



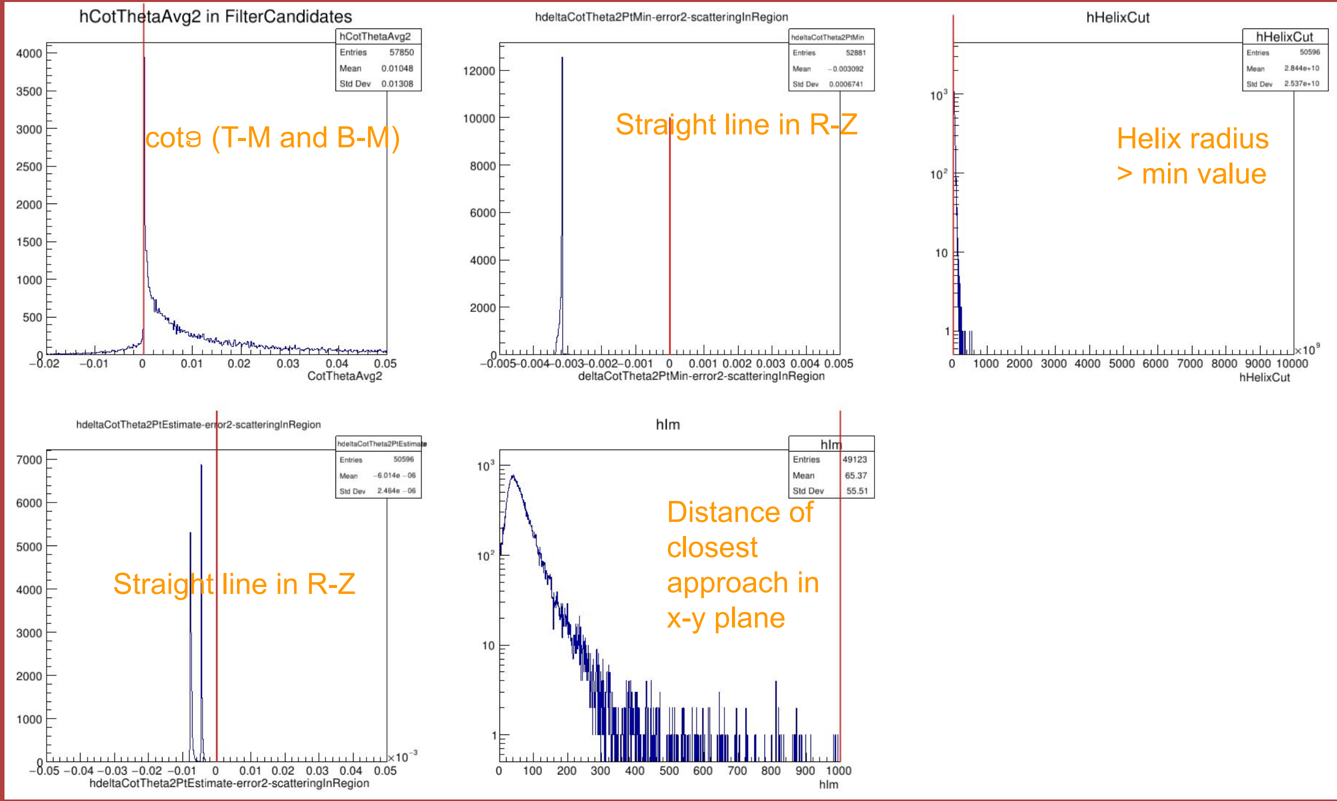
Seeding - first 4 chambers



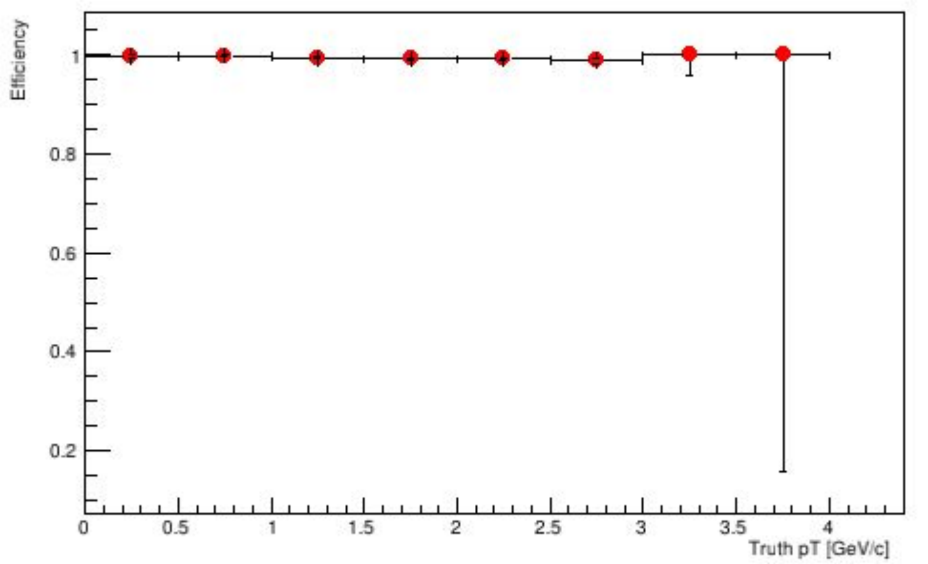
Tuning of seeding parameters (triplet)

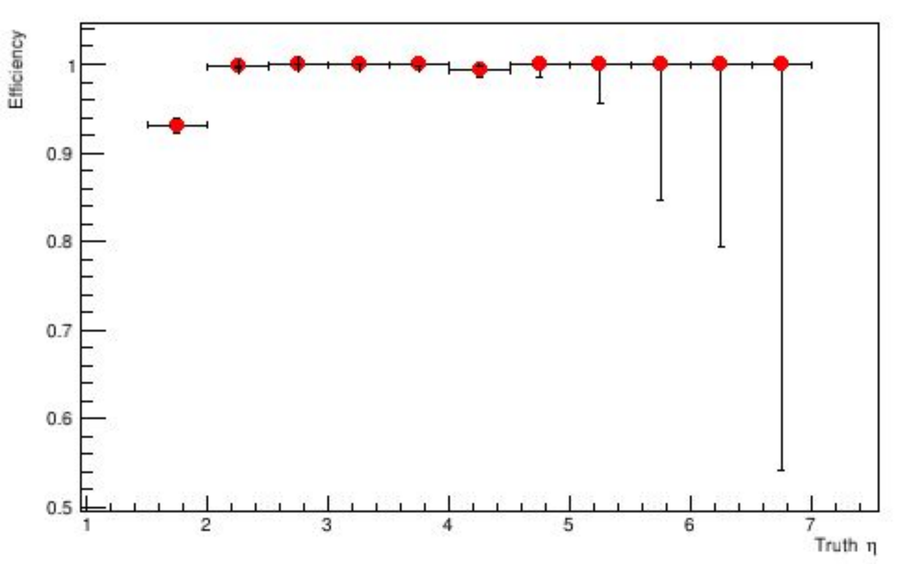
So far, very broad cuts, not really optimised

A more strict cut on the collision region has a significant impact on efficiencies at high eta



Seeding - first 4 chambers - performances

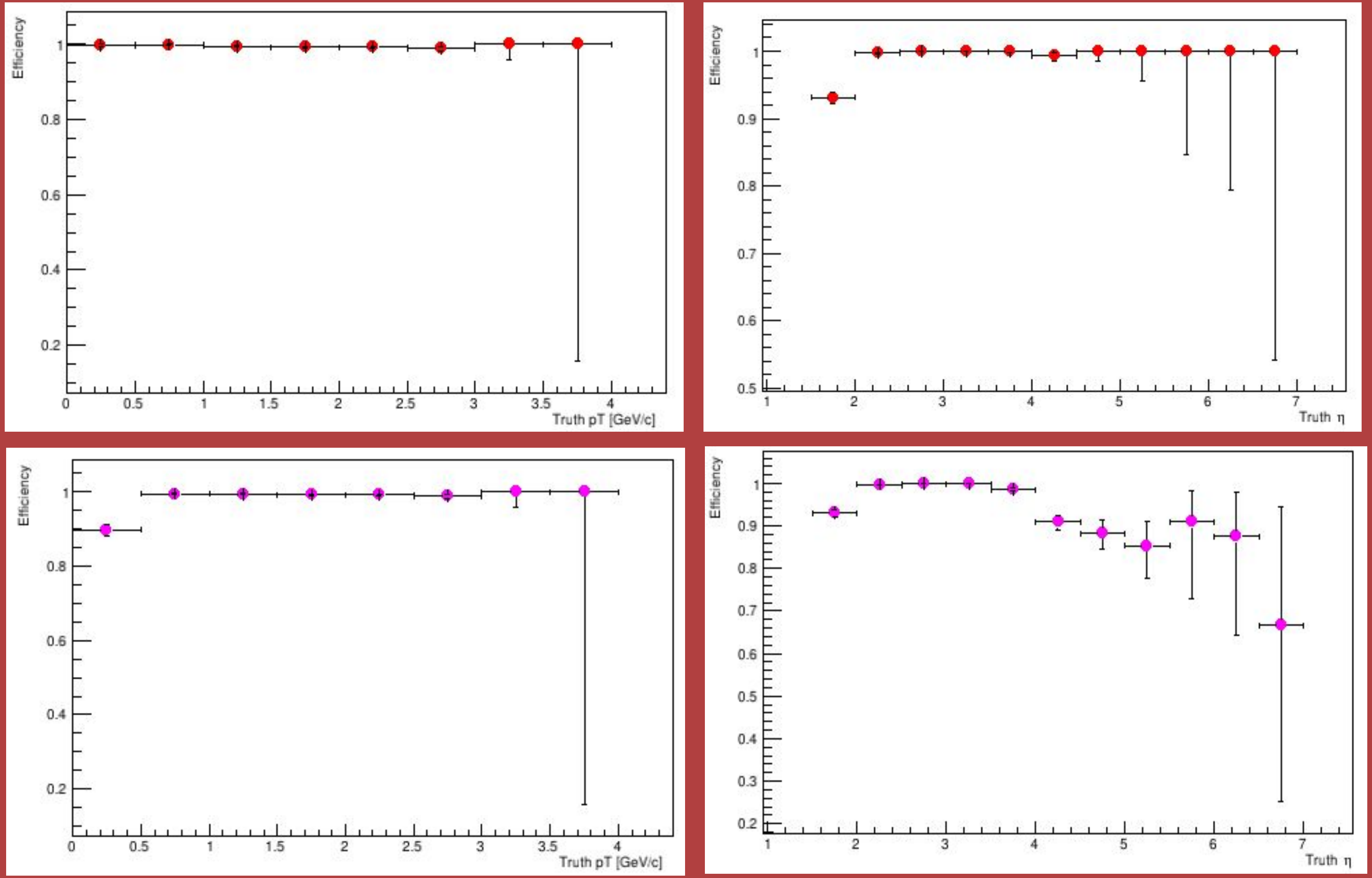




Efficiencies are rather flat everywhere

Efficiency = number of particles having a matched seed / nAllParticles (having at least 3 hits)

Seeding - first 4 chambers - performances



Without filtering and confirmation

With filtering and confirmation

Different behaviour at the edges
→ confirmation to be tuned

Seeding - comparisons

3 chambers

```
NA60+_Summary_nTotalSeeds= 11884
NA60+_Summary_nTotalMatchedSeeds= 11884
NA60+_Summary_nTotalParticles= 13013
NA60+_Summary_nTotalMatchedParticles= 11884
NA60+_Summary_nTotalDuplicatedParticles= 0
NA60+_Summary_Eff= 0.913241
NA60+_Summary_Fakerate= 0
NA60+_Summary_Purity= 1
NA60+_Summary_Duplication= 0
NA60+_Summary_nDuplicatedSeeds= 0
```

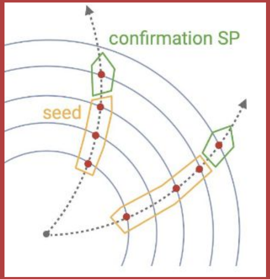
4 chambers

```
NA60+_Summary_nTotalSeeds= 48580
NA60+_Summary_nTotalMatchedSeeds= 48580
NA60+_Summary_nTotalParticles= 13013
NA60+_Summary_nTotalMatchedParticles= 12924
NA60+_Summary_nTotalDuplicatedParticles= 11890
NA60+_Summary_Eff= 0.993161
NA60+_Summary_Fakerate= 0
NA60+_Summary_Purity= 1
NA60+_Summary_Duplication= 0.919994
NA60+_Summary_nDuplicatedSeeds= 2.7589
```

4 chambers + confirmation

```
NA60+_Summary_nTotalSeeds= 24729
NA60+_Summary_nTotalMatchedSeeds= 24729
NA60+_Summary_nTotalParticles= 13013
NA60+_Summary_nTotalMatchedParticles= 12864
NA60+_Summary_nTotalDuplicatedParticles= 11865
NA60+_Summary_Eff= 0.98855
NA60+_Summary_Fakerate= 0
NA60+_Summary_Purity= 1
NA60+_Summary_Duplication= 0.922341
NA60+_Summary_nDuplicatedSeeds= 0.922341
```

- nTotalSeeds (tot number of seeds)
- **nTotalMatchedSeeds (seeds entirely matching a particle)**
- nTotalParticles (tot number of particles)
- nTotalMatchedParticles (particles having a matched seed)
- nTotalDuplicatedParticles (particles matching more than a seed?)
- **Efficiency (nMatchedParticles / nAllParticles)**
- Fake rate (nUnMatchedSeeds / nAllSeeds)
- Total seed purity (nTotalMatchedSeeds / nTotalSeeds)
- Duplication rate (nDuplicatedMatchedParticles / nMatchedParticles)
- **Average number of duplicated seeds**
  ((nMatchedSeeds - nMatchedParticles) / nMatchedParticles)



Seed Filter/ Confirmation

- compares middle and bottom SPs to other top SP (checking helix parameter, layers)
- assign a weight to the seed
- select seeds which can produce high quality tracks
- confirmation: check if z and r cuts are satisfied

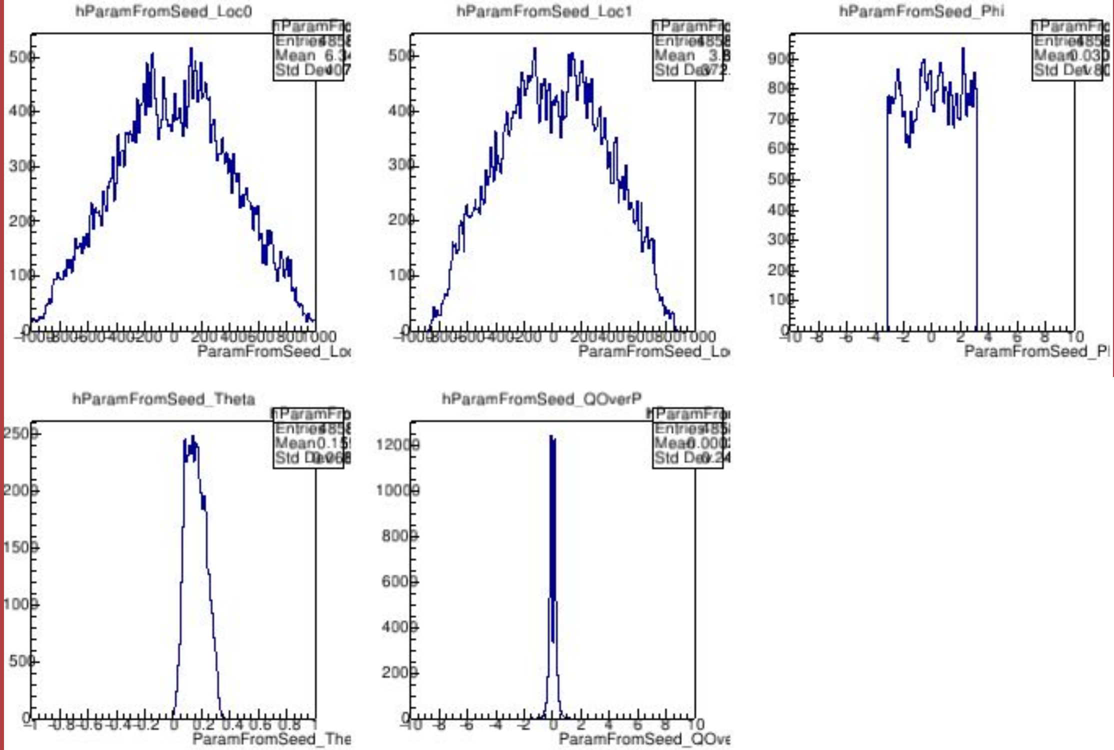
Weights to be tuned:

$$w = =c_1 \text{ x } d_0 + (c_2 \text{ x } N_t - |z_0|)$$

where

- d_0, z_0 are the transverse and longitudinal impact parameters
- N_t is the number of top SP compatible with a seed

Track parameters estimated from seeding



→ large Loc0 and Loc1 params

No requirements on the vertex position in the seeding step

Parameters are evaluated at the bottom SP

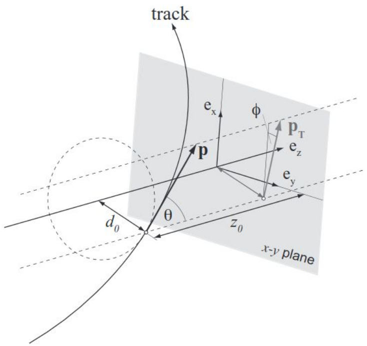


Figure 3: The perigee representation expressed in the ATLAS track parameterisation. The local expression of the point of closest approach is given by the signed transverse impact parameter d_0 and the longitudinal impact parameter z_0. The momentum direction is expressed in global coordinates using the azimuthal angle ϕ that is defined in the projected $x-y$ plane and the polar angle θ, which is measured with respect to the global z axis.

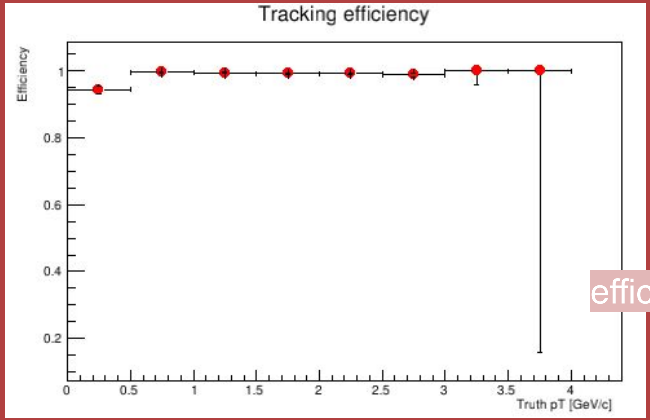
In the perigee representation, the loc0 and loc1 parameters are the d0 and z0 params

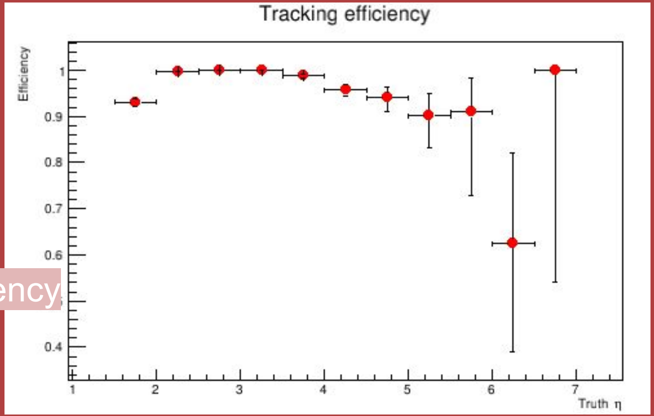
CKF

So far, no tuning on chi2 or on number of branches

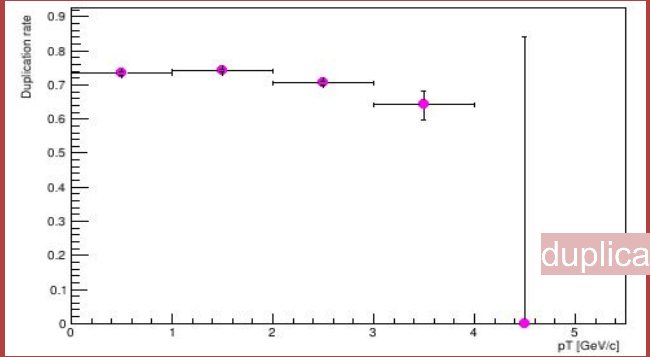
4 chambers

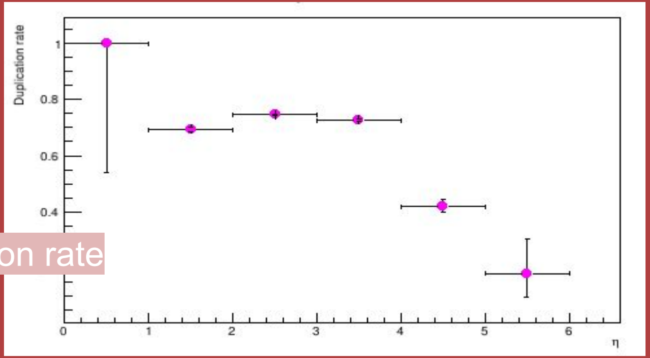
```
TrackFindingAlgorithm statistics:
- total seeds: 48580
- deduplicated seeds: 0
- failed seeds: 0
- failed smoothing: 0
- failed extrapolation: 68
- failure ratio seeds: 0
- found tracks: 48516
- selected tracks: 48516
- stopped branches: 0
```





efficiency





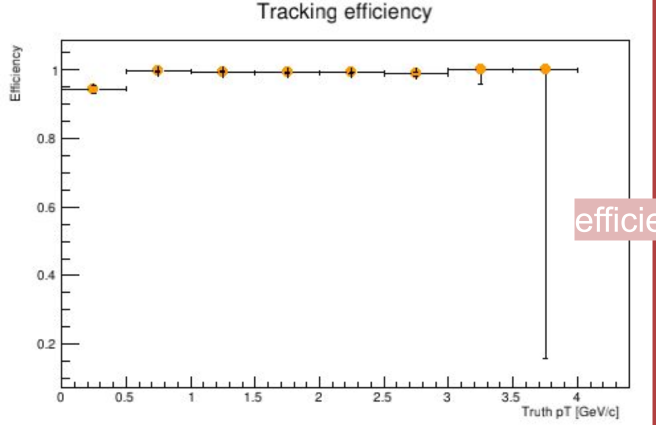
duplication rate

```
Efficiency with tracks (nMatchedTracks/ nAllTracks) = 1
Fake rate with tracks (nFakeTracks/nAllTracks) = 0
Duplicate rate with tracks (nDuplicateTracks/nAllTracks) = 0.734335
Efficiency with particles (nMatchedParticles/nTrueParticles) = 0.990471
Fake rate with particles (nFakeParticles/nTrueParticles) = 0
Duplicate rate with particles (nDuplicateParticles/nTrueParticles) = 0.913087
```

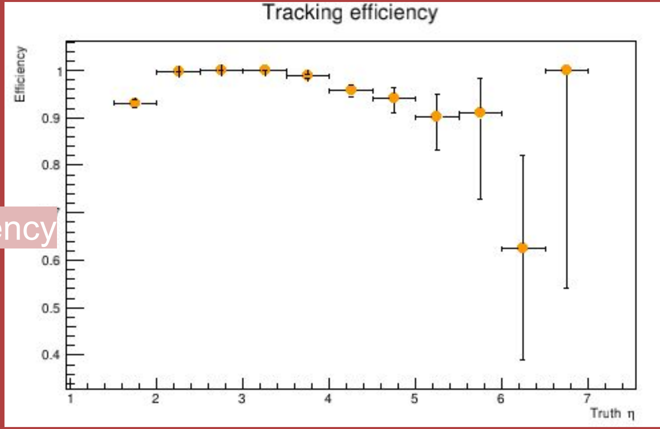
Ambiguity resolution

CKF does not solve ambiguities → ambiguity resolution is applied a posteriori

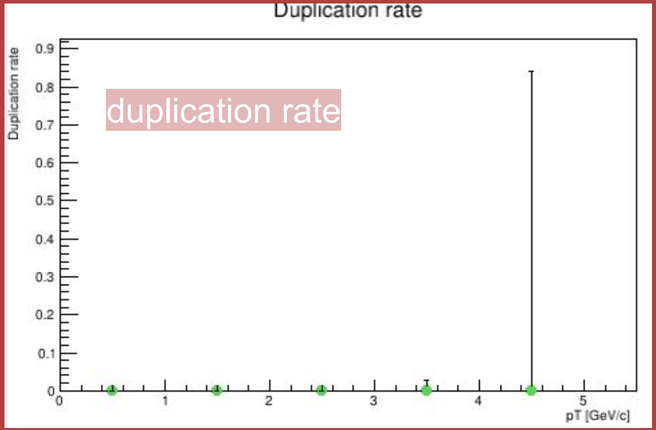
```
AmbiguityResolutionConfig(
  maximumSharedHits=1,
  maximumIterations=1000000
  nMeasurementsMin=3,
),
```



efficiency

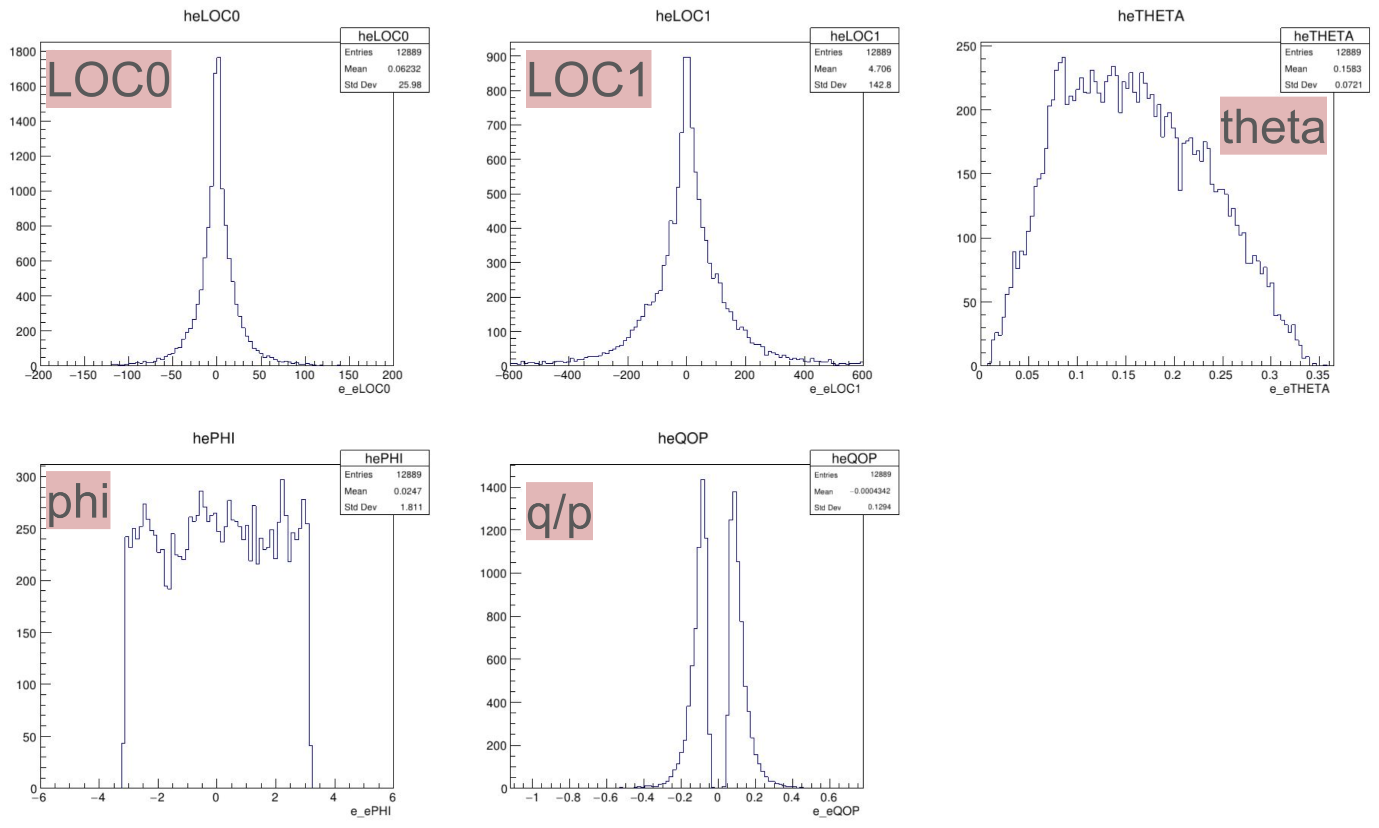



```
nTotalTracks                   = 12889
nTotalMatchedTracks            = 12889
nTotalDuplicateTracks          = 0
nTotalFakeTracks               = 0
Efficiency with tracks (nMatchedTracks/ nAllTracks) = 1
Fake rate with tracks (nFakeTracks/nAllTracks) = 0
Duplicate rate with tracks (nDuplicateTracks/nAllTracks) = 0
Efficiency with particles (nMatchedParticles/nTrueParticles) = 0.990471
Fake rate with particles (nFakeParticles/nTrueParticles) = 0
Duplicate rate with particles (nDuplicateParticles/nTrueParticles) = 0
```



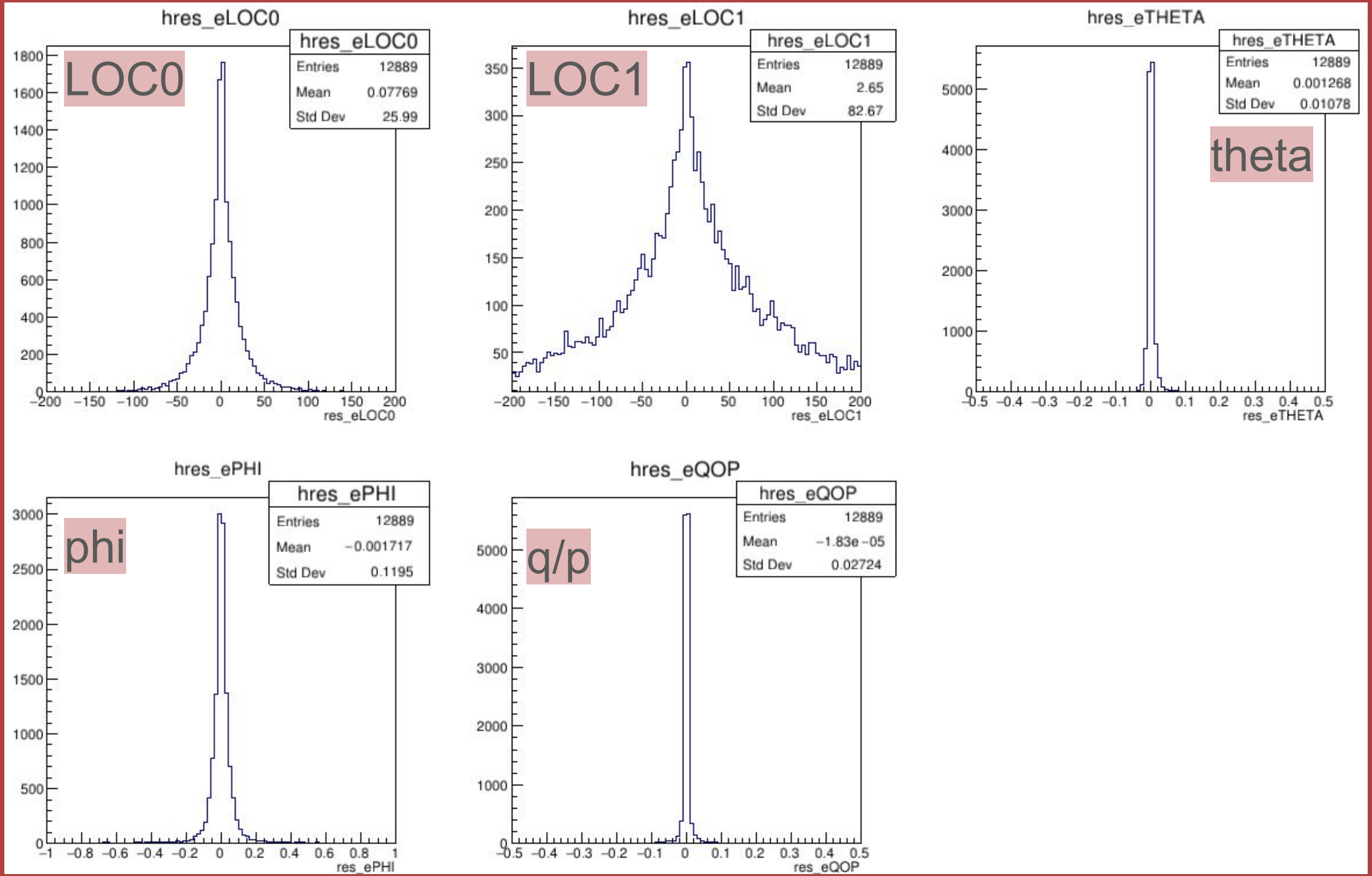
The duplicate rate is now zero

Parameters



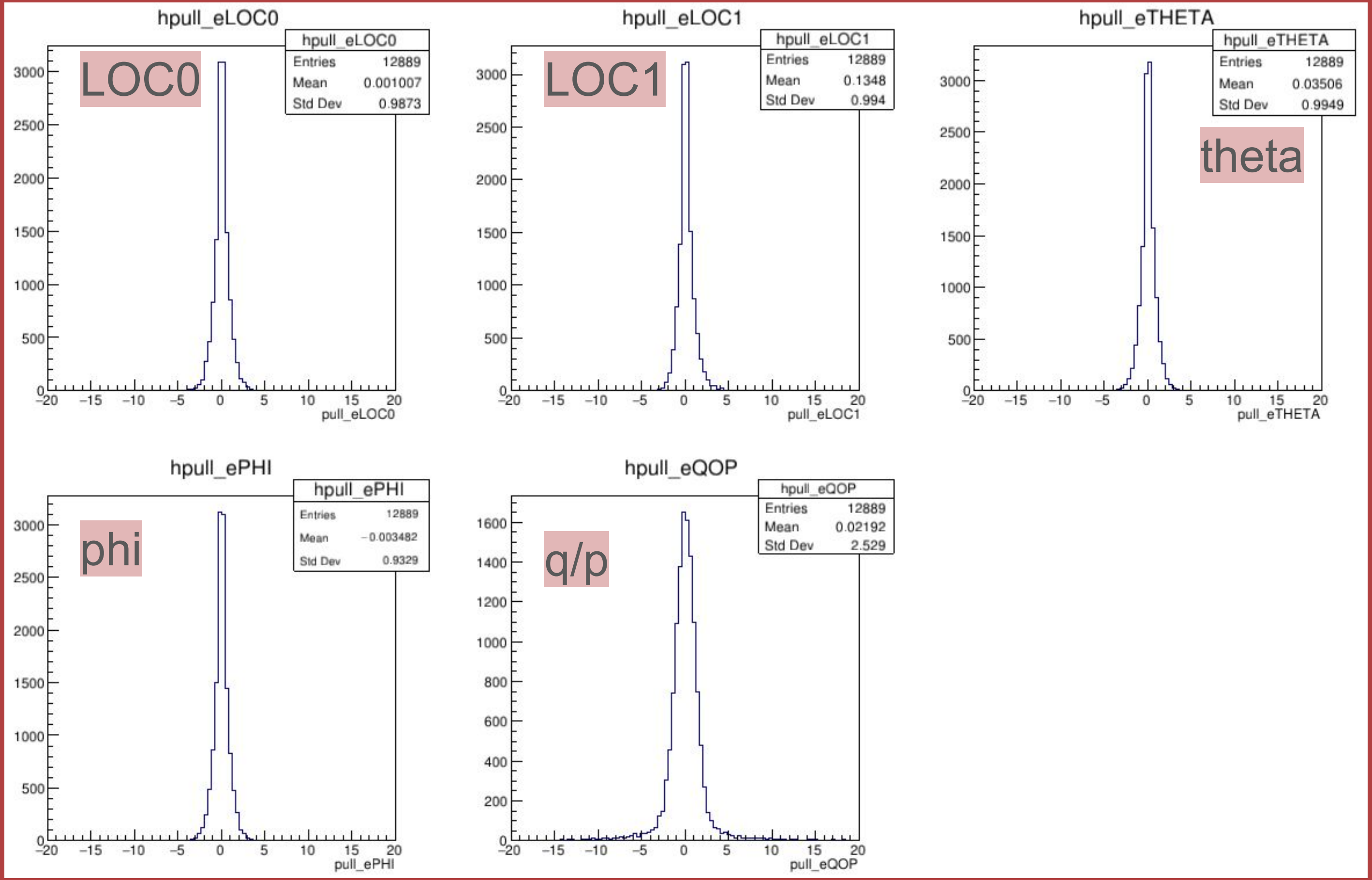
At the end of the CKF, the parameters of the track are evaluated in 0,0,0

Residuals



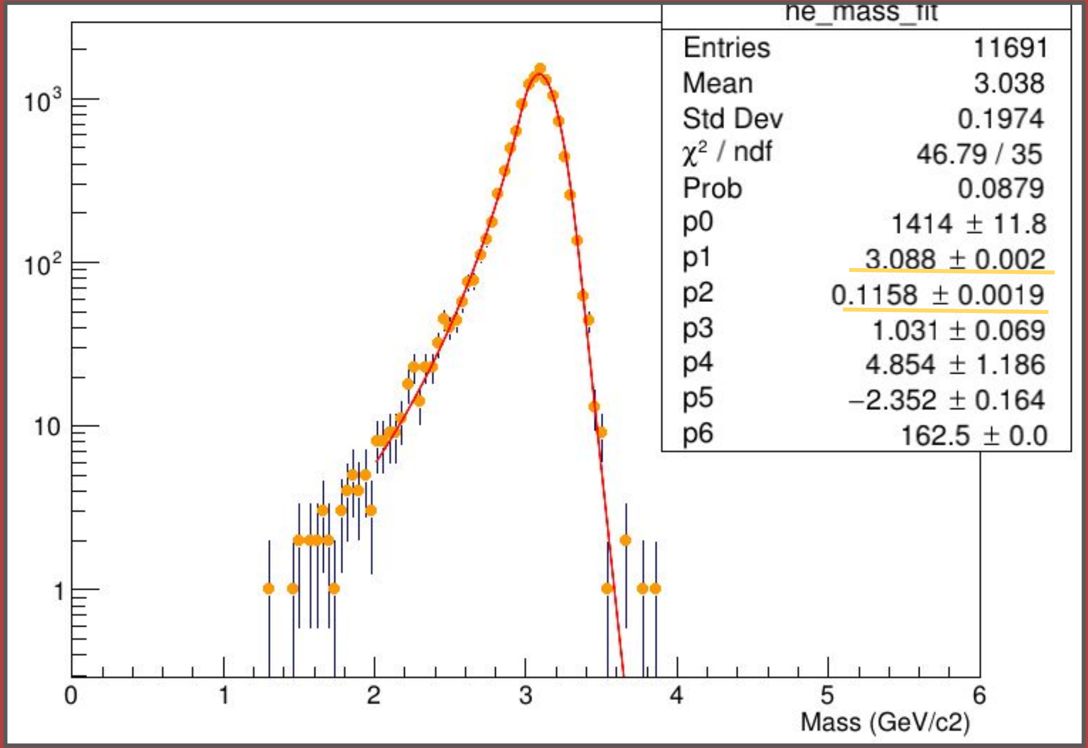
hres_eLOC0
LOC0
hres_eLOC0
Entries 12889
Mean 0.07769
Std Dev 25.99
res_eLOC0
hres_eLOC1
LOC1
hres_eLOC1
Entries 12889
Mean 2.65
Std Dev 82.67
res_eLOC1
hres_eTHETA
theta
hres_eTHETA
Entries 12889
Mean 0.001268
Std Dev 0.01078
res_eTHETA
hres_ePHI
phi
hres_ePHI
Entries 12889
Mean −0.001717
Std Dev 0.1195
res_ePHI
hres_eQOP
q/p
hres_eQOP
Entries 12889
Mean −1.83e−05
Std Dev 0.02724
res_eQOP

Pools



hpull_eLOC0
LOC0
hpull_eLOC0
Entries 12889
Mean 0.001007
Std Dev 0.9873
pull_eLOC0
hpull_eLOC1
LOC1
hpull_eLOC1
Entries 12889
Mean 0.1348
Std Dev 0.994
pull_eLOC1
hpull_eTHETA
theta
hpull_eTHETA
Entries 12889
Mean 0.03506
Std Dev 0.9949
pull_eTHETA
hpull_ePHI
phi
hpull_ePHI
Entries 12889
Mean −0.003482
Std Dev 0.9329
pull_ePHI
hpull_eQOP
q/p
hpull_eQOP
Entries 12889
Mean 0.02192
Std Dev 2.529
pull_eQOP

Invariant mass



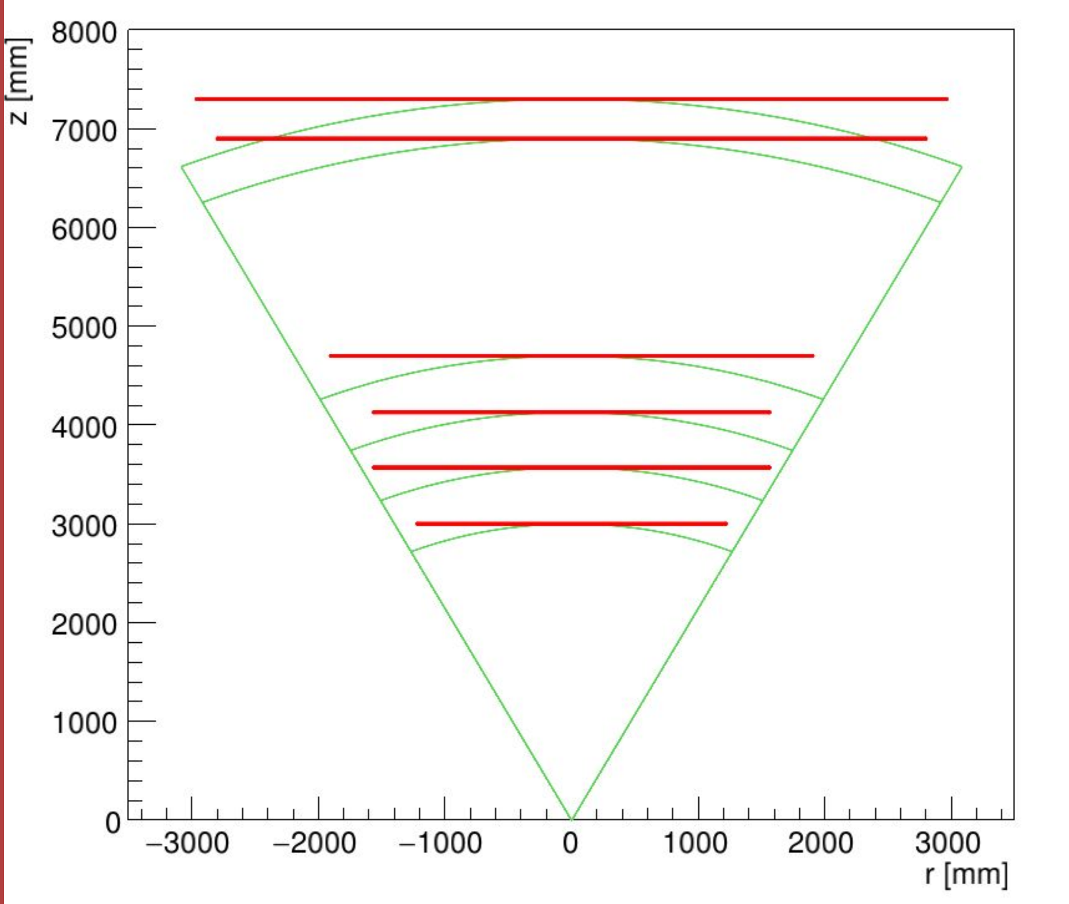
Given the two reconstructed muons, the JPsi invariant mass is obtained

To do

- Optimise all steps
- Test different seeding/CKF combinations (different number of planes)
- Add a realistic background to the JPsi signal

Backup

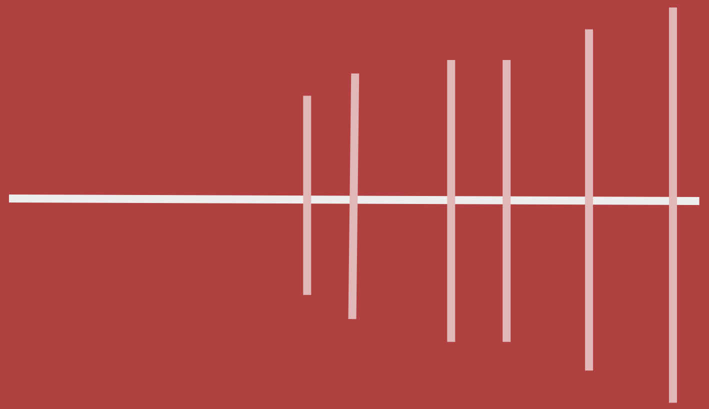
Seeding in r, z



When planes are close, the search in r does not identify in a unique way the planes

In all the planes the range in r where the search is allowed should be not too narrow

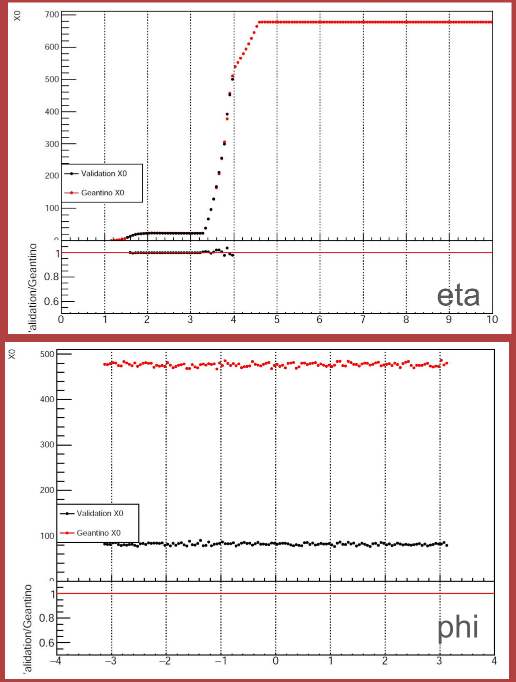
Eta of the MS chambers



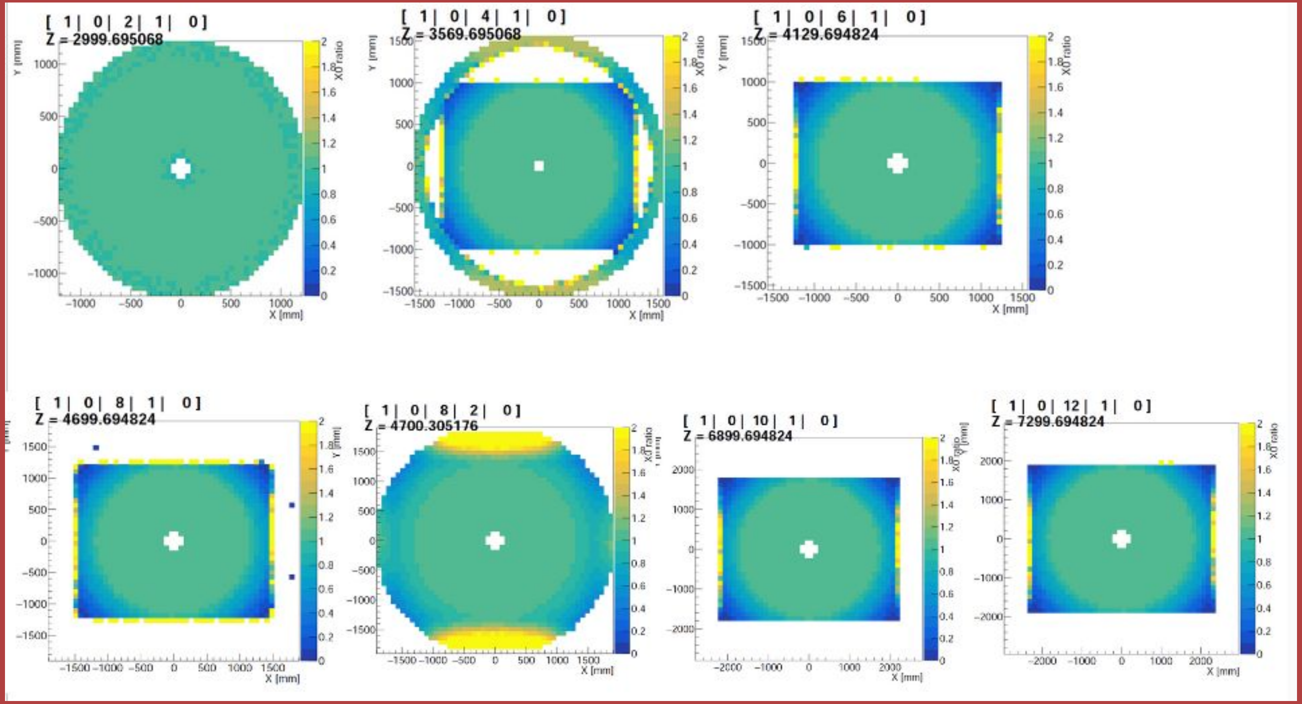
	Eta (x)	Eta (y)	Eta max
MCH0	1.88	2.5	4
MCH1	1.81	1.98	infinite
MCH2	1.95	2.12	infinite
MCH3	2.03	2.06	infinite
MCH4	1.88	2.06	infinite
MCH5	1.88	2.06	infinite

Mapping

Compare amount of material encounter by tracks vs eta and phi

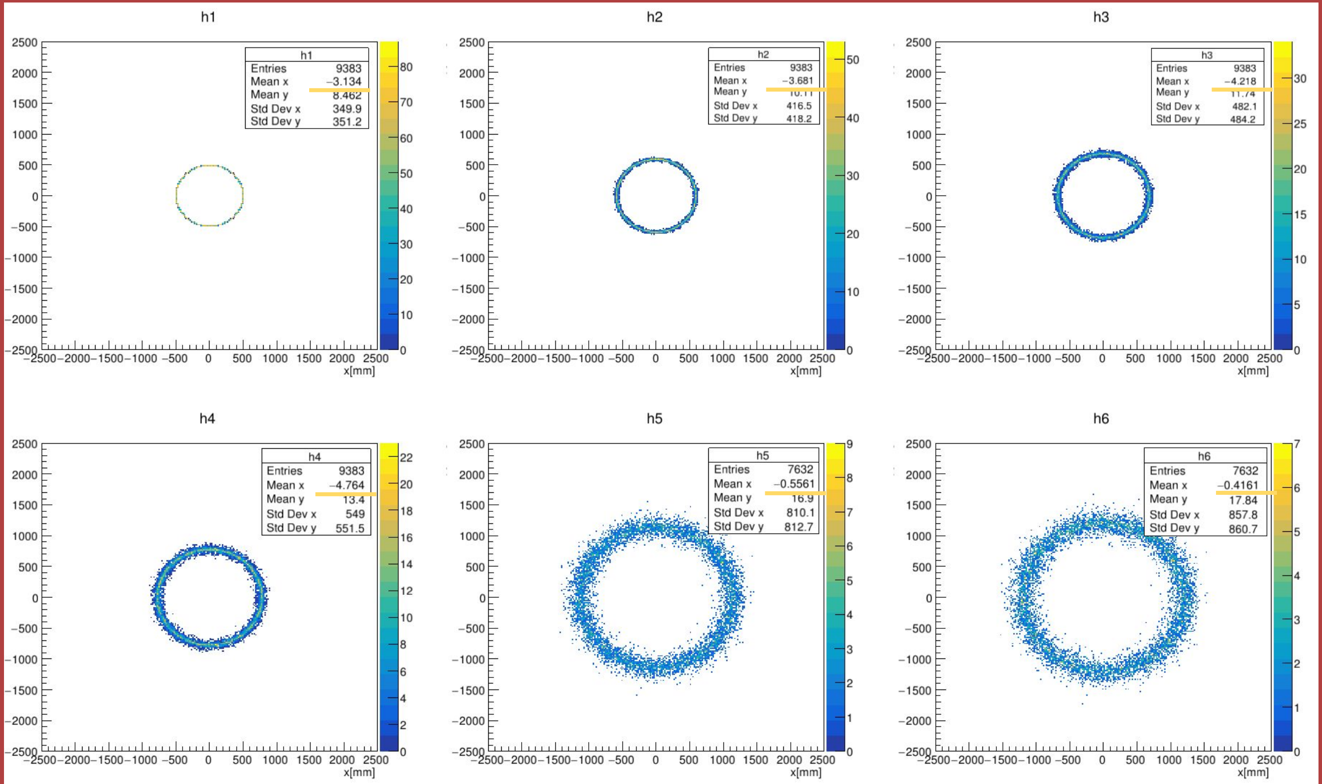


Ratio of crossed material in ACTS and in full geometry



mapping probably reflects the C radius (100cm), slightly larger than the rectangular chambers. MCH0 is 187 x 156 → CHECK

Test of B field (B = 0)



Particle gun

- OS muons
- pT = 0.5 GeV
- eta = 2.5

B field map [0,0,0] → assume ZERO B field

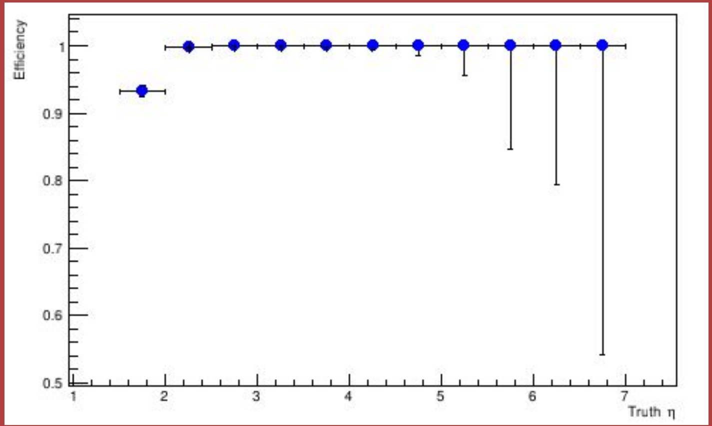
Hits after FATRAS tracking

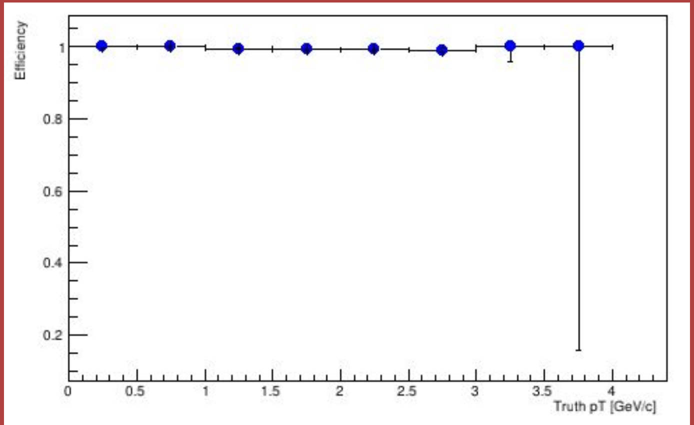
Truth estimate (seeding)

4 chambers

```
NA60+_Summary_nTotalSeeds= 12930
NA60+_Summary_nTotalMatchedSeeds= 12930
NA60+_Summary_nTotalParticles= 13013
NA60+_Summary_nTotalMatchedParticles= 12930
NA60+_Summary_nTotalDuplicatedParticles= 0
NA60+_Summary_Eff= 0.993622
NA60+_Summary_Fakerate= 0
NA60+_Summary_Purity= 1
NA60+_Summary_Duplication= 0
NA60+_Summary_nDuplicatedSeeds= 0
```

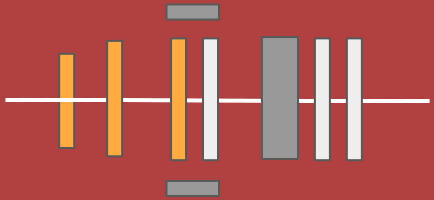
```
TrackFindingAlgorithm statistics:
- total seeds: 12930
- deduplicated seeds: 0
- failed seeds: 0
- failed smoothing: 0
- failed extrapolation: 38
- failure ratio seeds: 0
- found tracks: 12892
- selected tracks: 12892
- stopped branches: 0
```

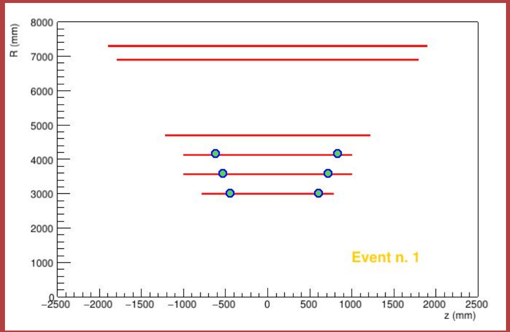


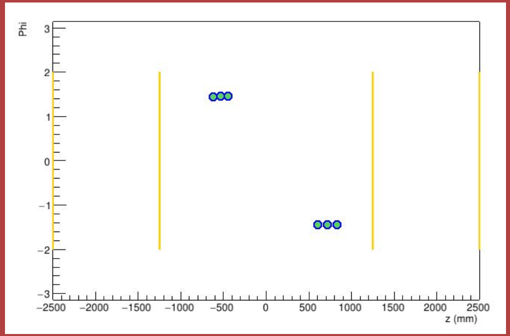


I'm requiring at least 3 hits at denominator

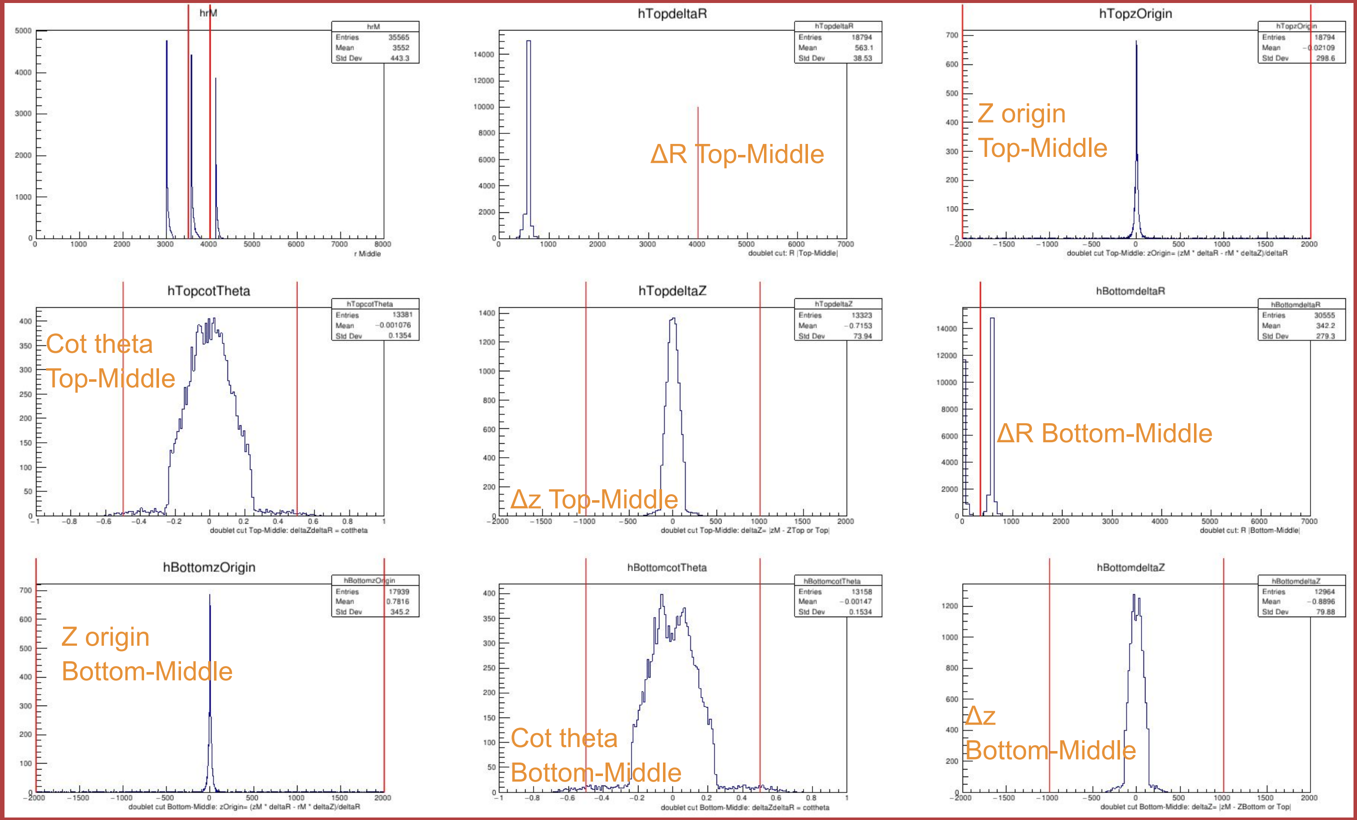
Seeding - first 3 chambers



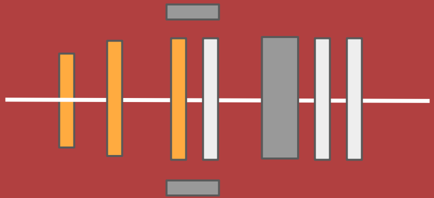




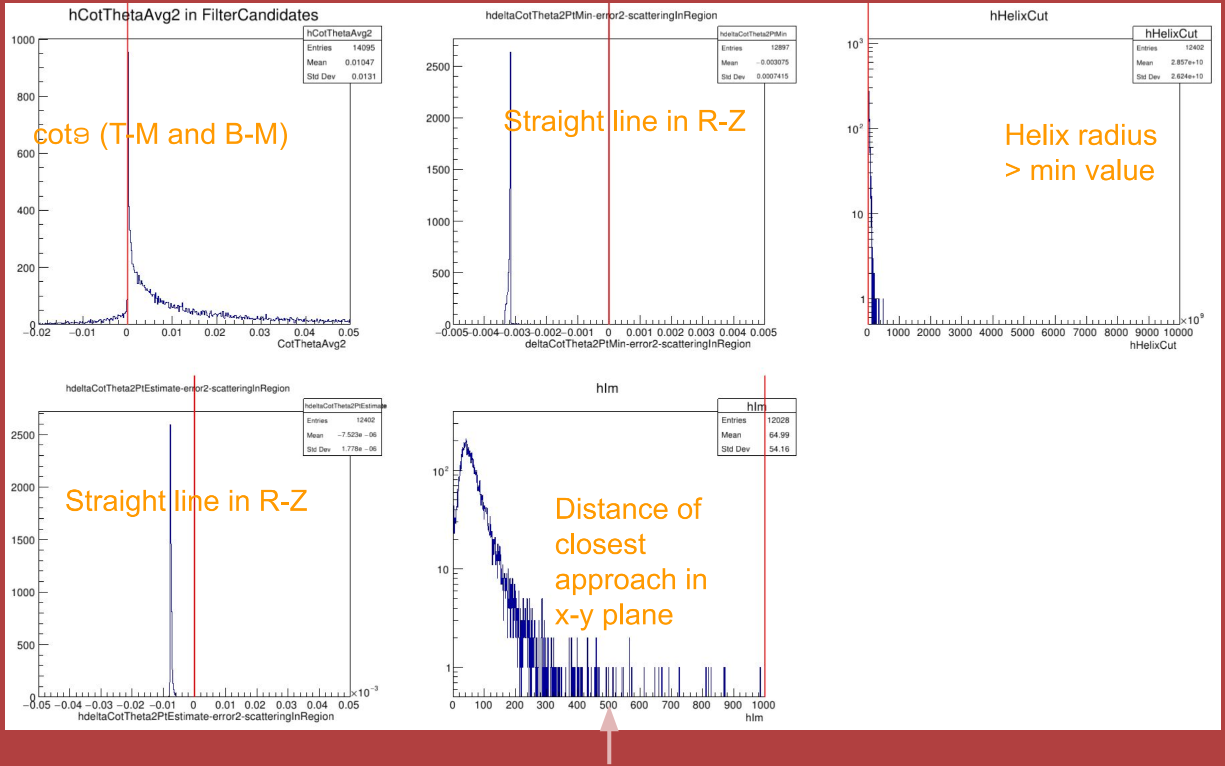
Tuning of seeding parameters (doublets)



Seeding - first 3 chambers



Tuning of seeding parameters (triplet)



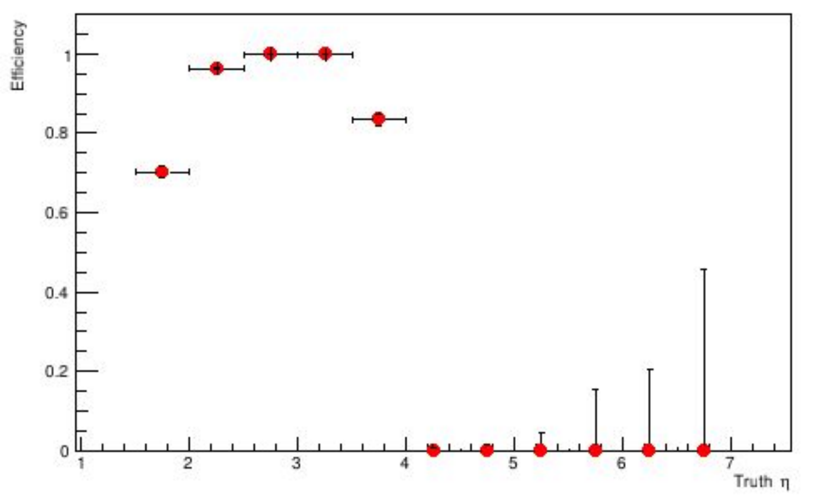
So far, very broad cuts, not really optimised

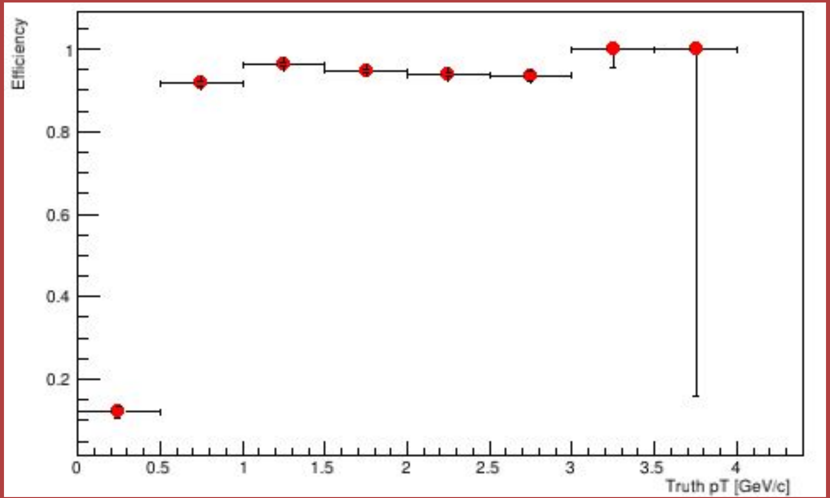
A more strict cut on the collision region has a significant impact on efficiencies at high eta

rMinMiddle and rMaxMiddle changed by hand in SeedFinderConfig.hpp

Very selective cut in the VT (cut at 0.1mm level)
Vertex not used in the seeding

Seeding - first 3 chambers - performances





Loss at high eta due t the hole in MCH0

```
NA60+_Summary_nTotalSeeds= 11884
NA60+_Summary_nTotalMatchedSeeds= 11884
NA60+_Summary_nTotalParticles= 13013
NA60+_Summary_nTotalMatchedParticles= 11884
NA60+_Summary_nTotalDuplicatedParticles= 0
NA60+_Summary_Eff= 0.913241
NA60+_Summary_Fakerate= 0
NA60+_Summary_Purity= 1
NA60+_Summary_Duplication= 0
NA60+_Summary_nDuplicatedSeeds= 0
```

tot number of seeds
seeds entirely matching a particle
tot number of particles
particles having a matched seed
particles matching more than a seed?
nMatchedParticles / nAllParticles
nUnMatchedSeeds / nAllSeeds
nTotalMatchedSeeds / nTotalSeeds
DuplicatedMatchedParticles / nMatchedParticles
Average number of duplicated seeds
((nMatchedSeeds - nMatchedParticles) / nMatchedParticles)

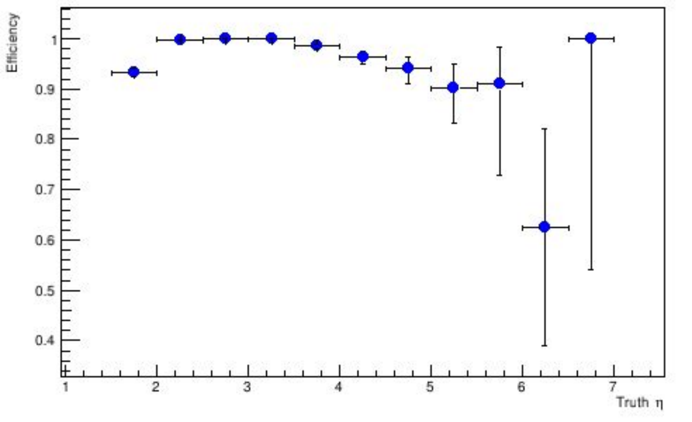
CKF

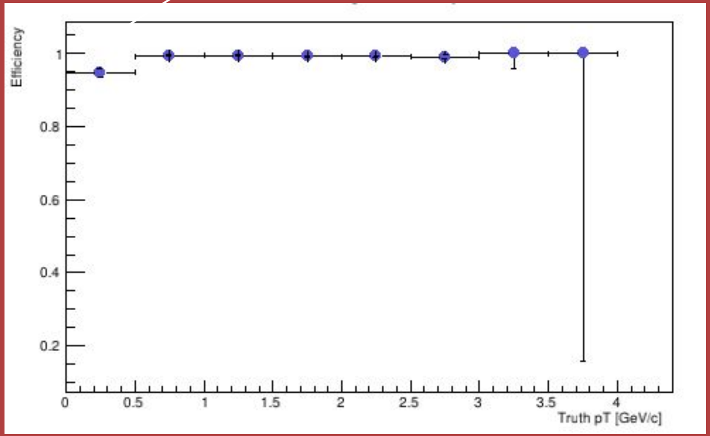
- So far, no tuning on chi2 or on number of branches
- In EstimateTrackParamsfromSeed.hpp I define bFieldMin = 0.01 T (the minimum magnetic field to trigger the track parameters estimation by default is 0.1T)
- No cut on nMeasurementMin

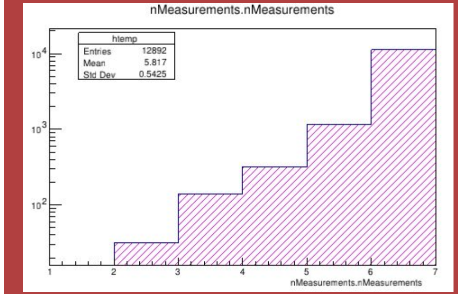
seeding:truth estimate

High eta particles are mostly concentrated at low pT

CKF efficiency

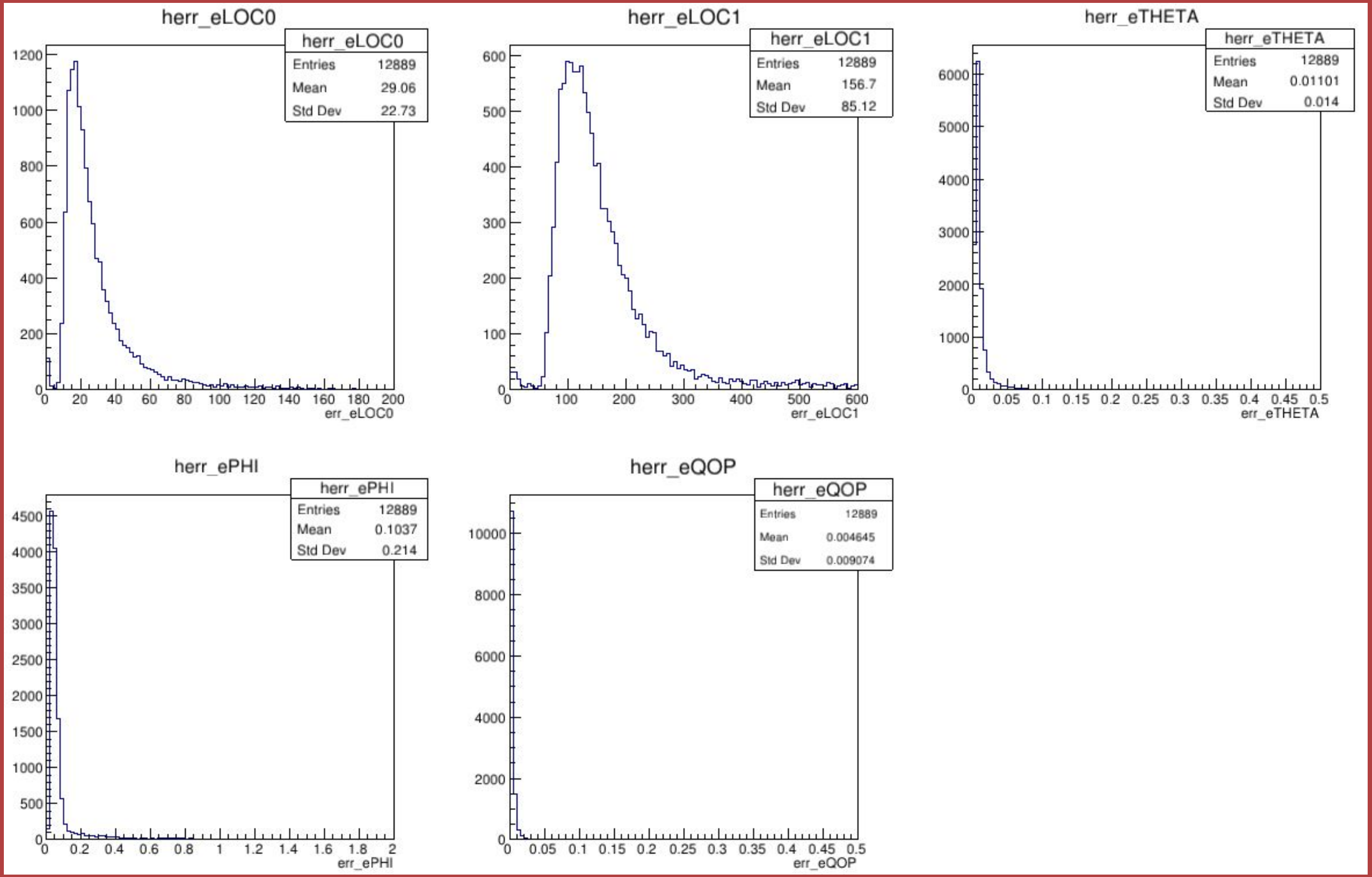






Not clear why I loose tracks at low pT, large eta

Parameter errors



Large errors on eLOC0 and eLOC1

At the end of the CKF, the parameters of the track are evaluated in 0,0,0