Standalone track finding in GEMs

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Motivation

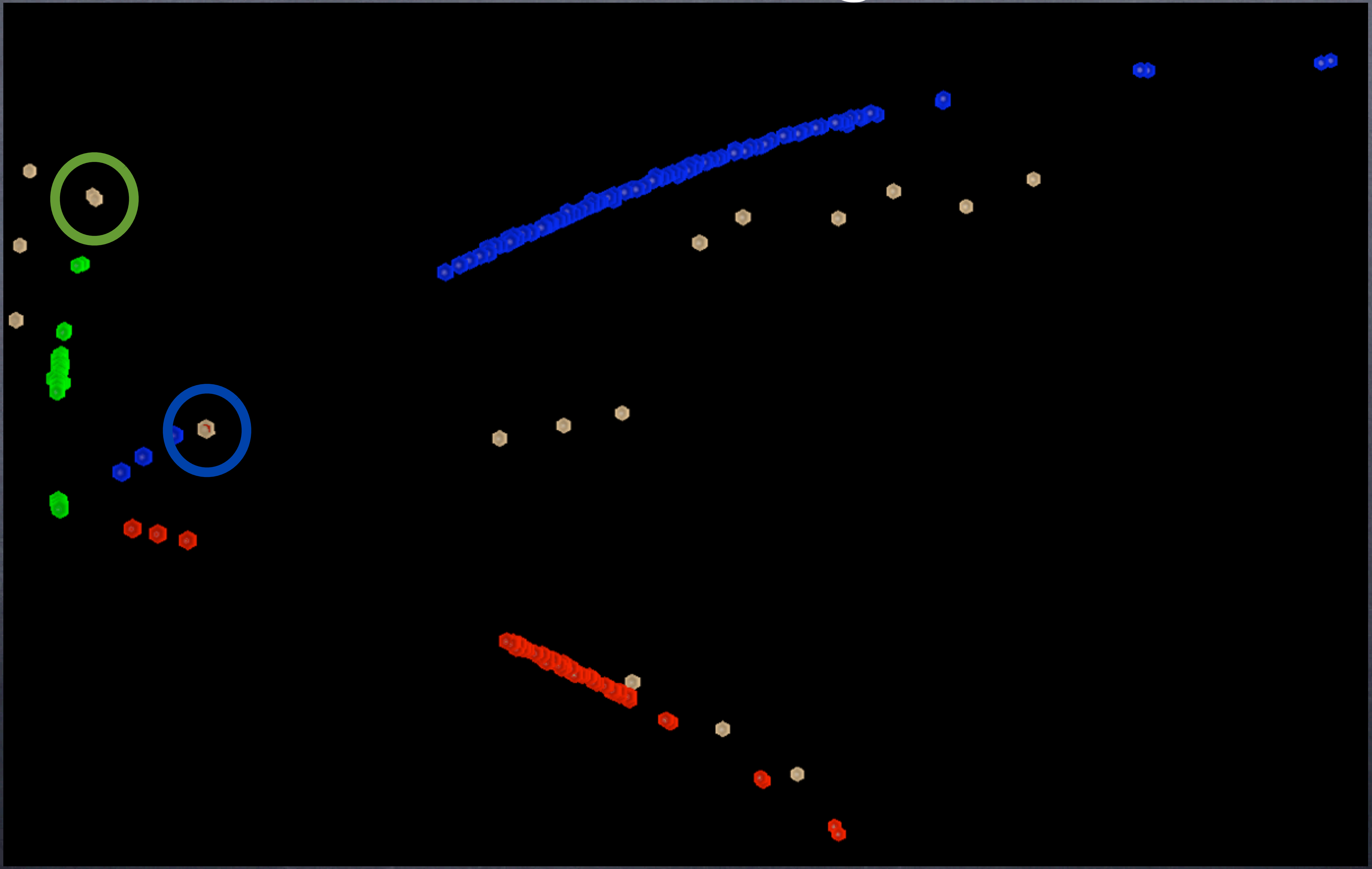
- Obvious: no track finding task in GEM
- Subtle: there is the LHE track finding
- Problem: I did not like the results I got using LHE
- Quality: QA is missing for LHE
- Combinatorial: fake hits are created in the GEM detector by combining strips fired by different MC tracks

Example plots from LHE track finding

3 muons shot in forward direction

EVENT 1

“good” event



Example plots from LHE track finding

3 muons shot in forward direction

EVENT 0

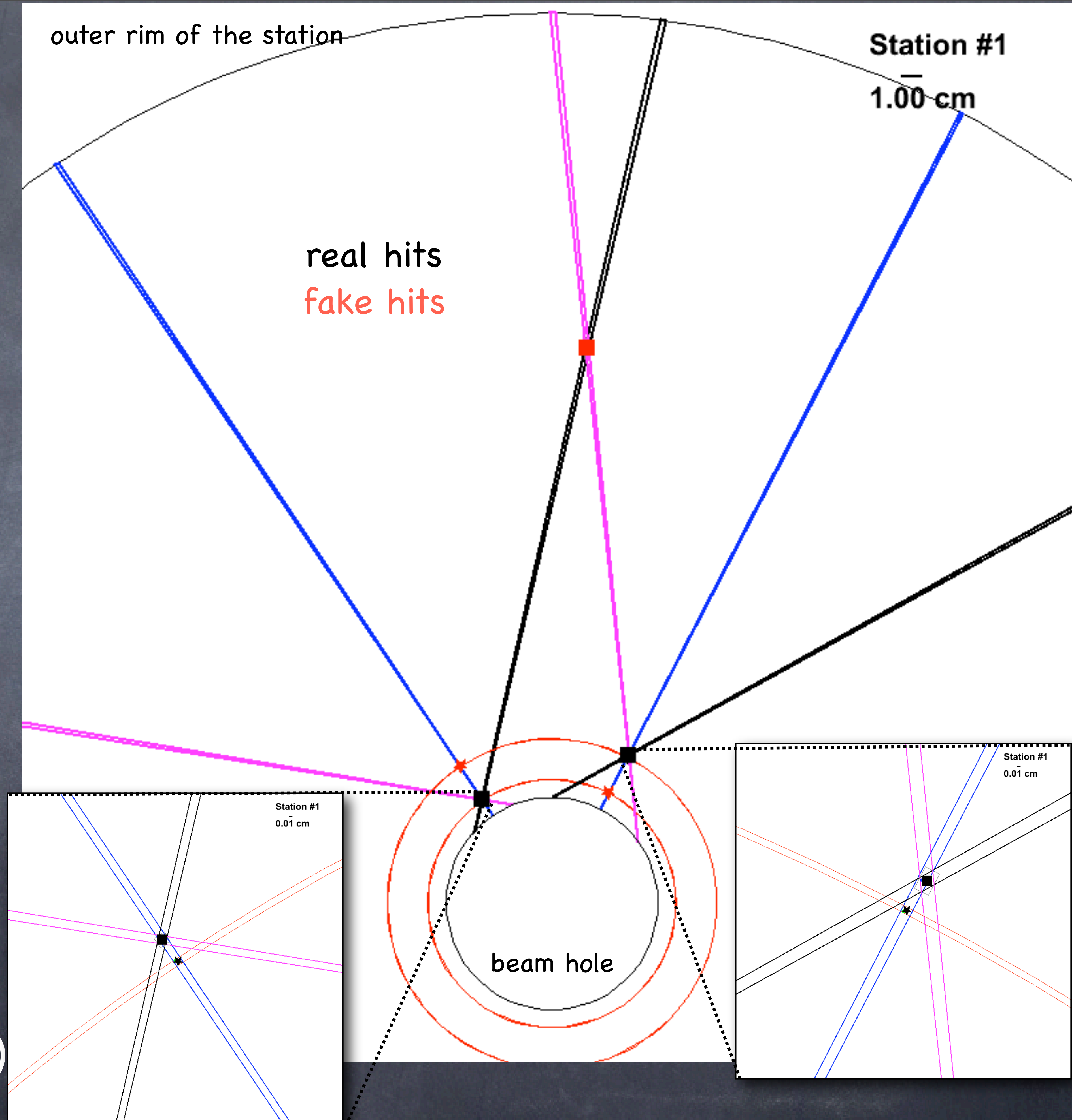
"bad" event

Track finding chain

- Hit matching in individual stations
- Hit matching between stations - creation of track segments
- Merging track segments into tracks
- Removal of spurious and obviously wrong tracks
- Creating array of PndTrackCand's

Hits in the GEM

- Two sensitive layers per station ~4cm apart in z
- Two views per sensitive layer:
  - 1st: radial and concentric views (blue&red strips)
  - 2nd: tilted views (pink&black strips)



Hit matching in individual stations

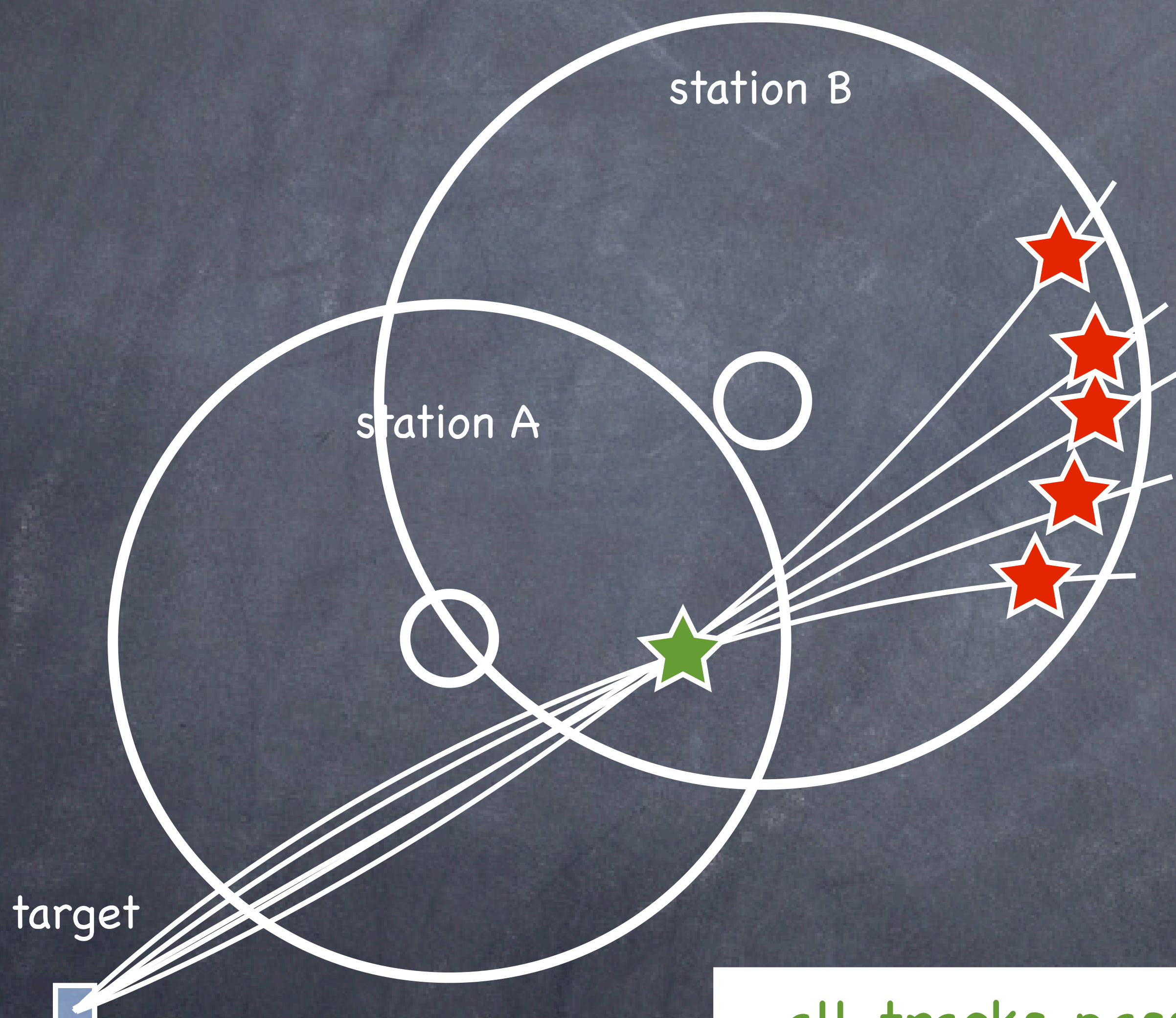
- First step of the tracking is to find pairs of hits (in front and back layers of a station) that are close enough to be considered as “real” and left by one track

- Method:
  - loop over hits on front layer
  - find closest hit on back layer, but not farther than the error of the two hits’ positions

Matching hits from different stations

- Imagine a track with infinite momentum emitted from the target at some angle
- Hit left by this particle's trajectory on station A will let you calculate the position of the track on some other station B (simply a linear extrapolation)
- Now consider all the tracks emitted from the target that pass through the point on station A. Where do they land on station B?

Matching hits from different stations cont'd



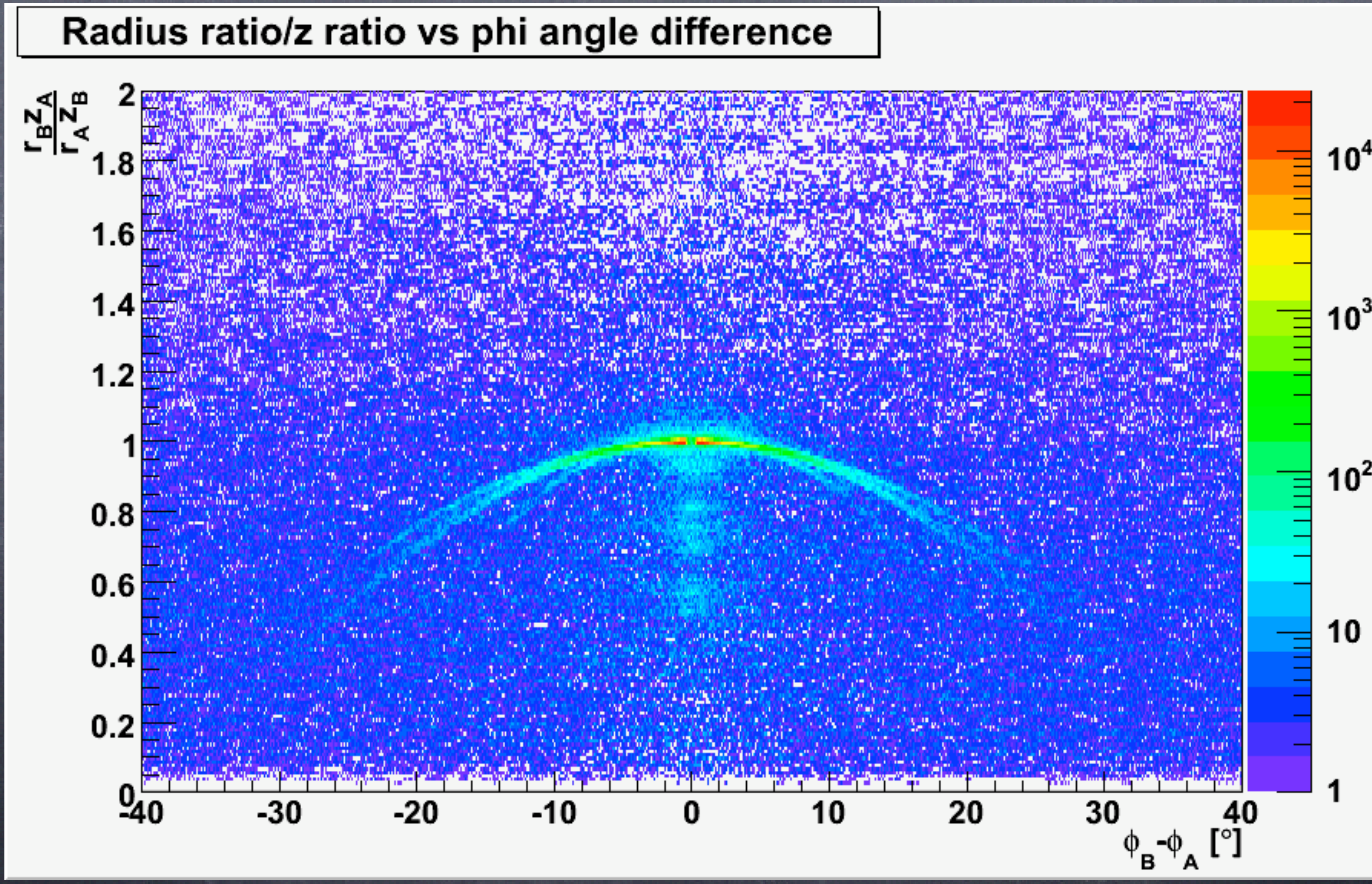
- these points lie on a parabolic curve
- the farther from the center, the smaller momentum
- the farther from the center, the more different phi emittance angle is
- one side is for negative, the other for positive charged particles

- all tracks passing through this point have similar theta emittance angle

Matching hits from different stations cont'd

Combine hits from each pair of stations, calculate radius and phi angle, put them on a plot. Observe:

-middle of the curve (0°) -> infinite momenta
-the larger the phi the smaller the momenta
-negative/positive phi-> negative/ positive charge
-different bands-> different station combinations

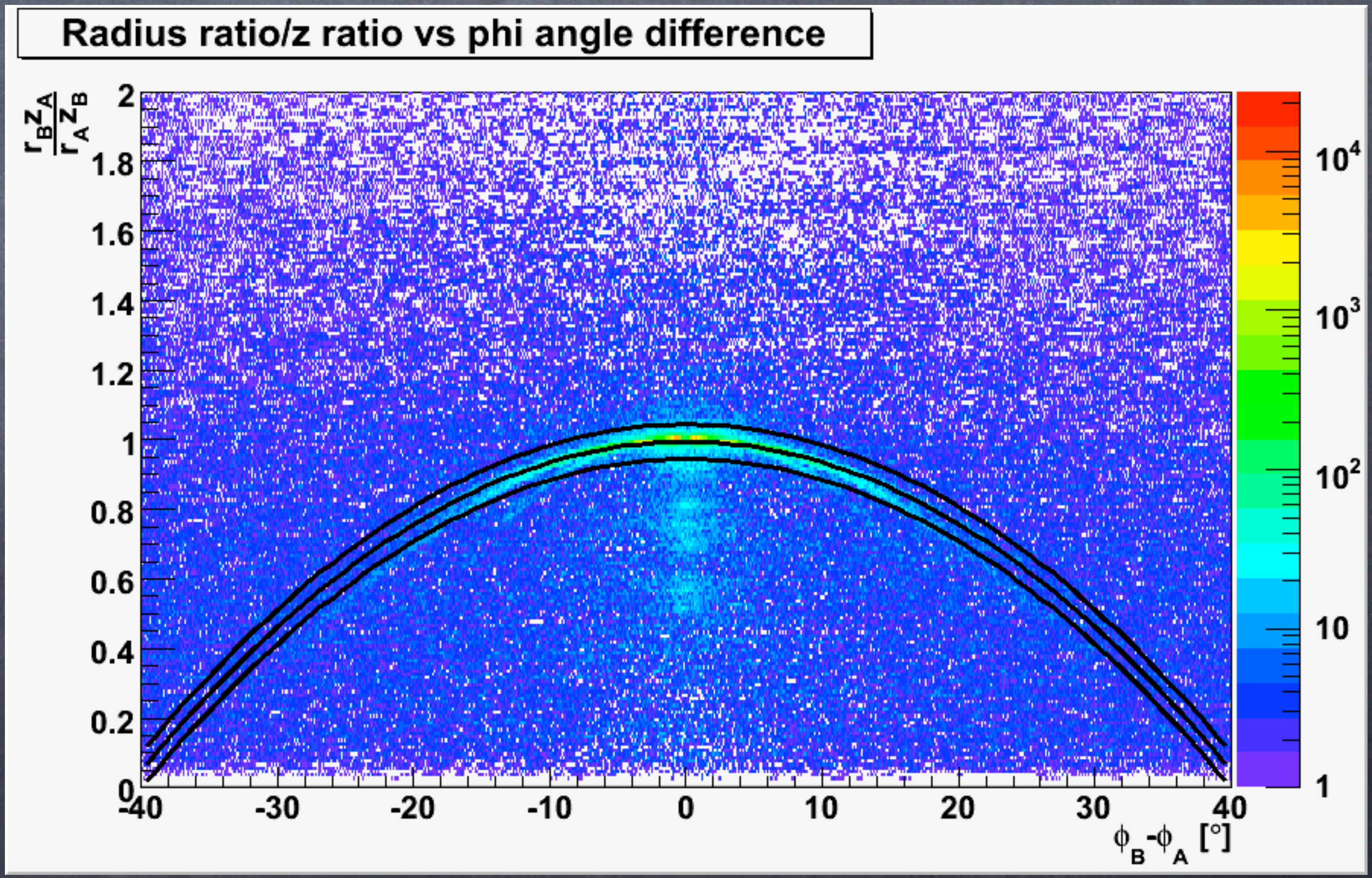


Matching hits from different stations cont'd

The curve is fitted with a symmetric parabola:

$r_B z_A / r_A z_B = 0.9944432 - 0.000590706(\varphi_B - \varphi_A)^2$

Track segment: pair of hits on different stations, with actual radius laying close to the radius calculated using the above formula.



Track segment

The distance of the hit to the beam center together with the difference of the hits' phi angles on both stations let me calculate the actual track segment momenta.

Empiric formulae:

$\varphi=\varphi_A + (\varphi_A-\varphi_B)\cdot z_A/(z_B-z_A)$

$z_1= z_B - z_A$

$z_2= z_B\cdot z_B - z_A\cdot z_A$

$z_3= z_B\cdot z_B\cdot z_B - z_A\cdot z_A\cdot z_A$

$c_1=-2.3\cdot 10^{-6}z_3+6.7\cdot 10^{-4}z_2+1.0\cdot 10^{-1}z_1$

$c_2=-7.5\cdot 10^{-10}z_3-6.7\cdot 10^{-7}z_2+7.4\cdot 10^{-4}z_1$

$p=(c_1+c_2\cdot r_A)/(\varphi_A-\varphi_B)$

$d_1=56.1372$

$d_2=-0.00056$

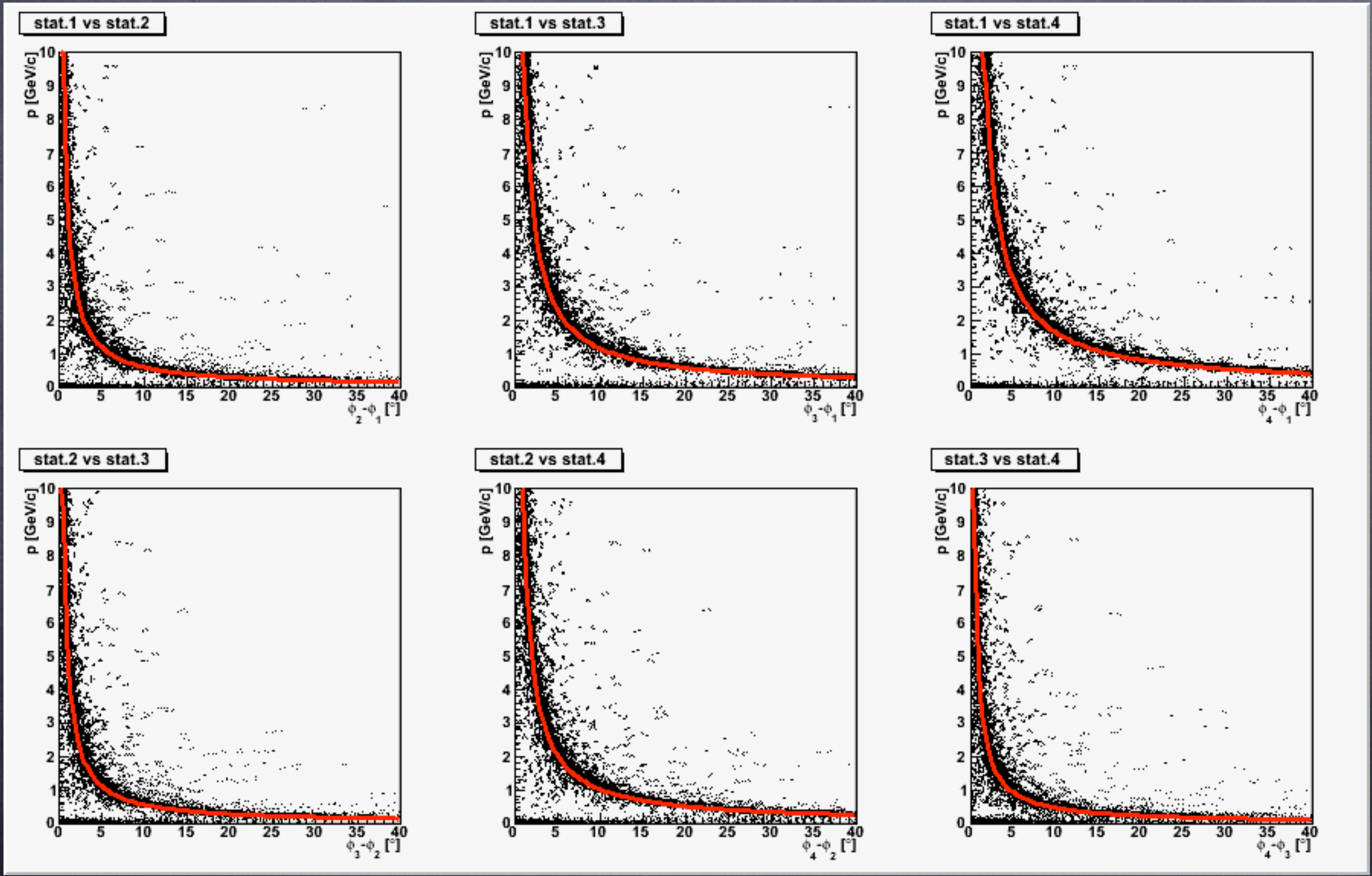
$d_3=-0.1818$

$d_4=0.2842$

$\vartheta=(d_1+1/(p+d_2{*}z_A+d_3))\cdot r_A/z_A+d_4$

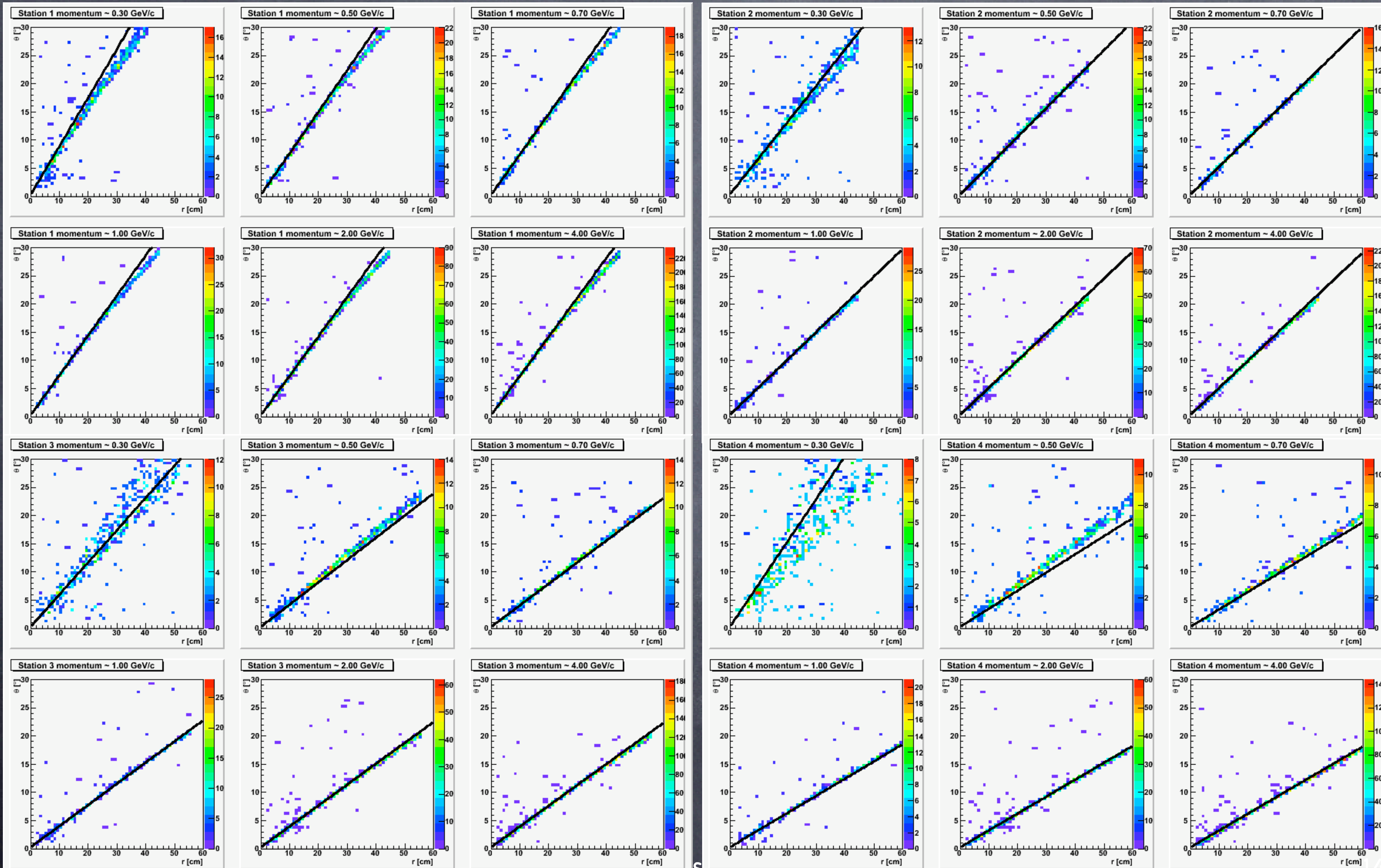
Track segment

track MC momentum vs hits' phi angle difference



Track segment

track MC theta vs hit radius



Creating track segments

Goal:

Find all possible track segments in the GEM geometry

Realization:

Two nested loops over hits, pick up pairs of hits from different stations, check if the 'back' hit is close to the search ellipse of the 'front' hit, calculate momentum, theta and phi angle of the found track segment

Creating track segments

Example of an event with three MC tracks.

GEM consists of 4 stations, there are 23 segments found:

momentum phi angle theta angle

found segment (stat. 0 & 1), hits 0, 9, 15, 24 >>> 3.75575 GeV, 113.256 deg, 7.6694 deg.
found segment (stat. 0 & 1), hits 4, 11, 19, 26 >>> 1.2846 GeV, 37.6379 deg, 12.857 deg.
found segment (stat. 0 & 1), hits 8, 14, 19, 26 >>> 0.177452 GeV, 142.133 deg, 15.5102 deg.
found segment (stat. 0 & 1), hits 8, 14, 23, 29 >>> 1.80182 GeV, 60.3243 deg, 15.5102 deg.
found segment (stat. 0 & 2), hits 0, 9, 30, 39 >>> 4.37074 GeV, 112.568 deg, 7.6694 deg.
found segment (stat. 0 & 2), hits 4, 11, 34, 41 >>> 1.28075 GeV, 37.2942 deg, 12.857 deg.
found segment (stat. 0 & 2), hits 8, 14, 34, 41 >>> 0.304688 GeV, 102.604 deg, 15.5102 deg.
found segment (stat. 0 & 2), hits 8, 14, 38, 44 >>> 1.81594 GeV, 59.9806 deg, 15.5102 deg.
found segment (stat. 0 & 3), hits 0, 9, 45, 54 >>> 4.41979 GeV, 112.339 deg, 7.6694 deg.
found segment (stat. 0 & 3), hits 4, 11, 49, 56 >>> 1.26929 GeV, 36.7213 deg, 12.857 deg.
found segment (stat. 0 & 3), hits 8, 14, 53, 59 >>> 1.83647 GeV, 59.4077 deg, 15.5102 deg.
found segment (stat. 1 & 2), hits 15, 24, 30, 39 >>> 5.35903 GeV, 111.423 deg, 7.67755 deg.
found segment (stat. 1 & 2), hits 19, 26, 34, 41 >>> 1.302 GeV, 36.7213 deg, 12.7958 deg.
found segment (stat. 1 & 2), hits 23, 29, 34, 41 >>> 0.16546 GeV, 173.069 deg, 15.4985 deg.
found segment (stat. 1 & 2), hits 23, 29, 38, 44 >>> 1.87522 GeV, 59.4077 deg, 15.4985 deg.
found segment (stat. 1 & 3), hits 15, 24, 45, 54 >>> 4.97978 GeV, 111.423 deg, 7.67755 deg.
found segment (stat. 1 & 3), hits 19, 26, 49, 56 >>> 1.28602 GeV, 35.8047 deg, 12.7958 deg.
found segment (stat. 1 & 3), hits 23, 29, 49, 56 >>> 0.277131 GeV, 117.613 deg, 15.4985 deg.
found segment (stat. 1 & 3), hits 23, 29, 53, 59 >>> 1.90212 GeV, 58.4911 deg, 15.4985 deg.
found segment (stat. 2 & 3), hits 30, 39, 45, 54 >>> 4.65867 GeV, 111.423 deg, 7.68244 deg.
found segment (stat. 2 & 3), hits 34, 41, 49, 56 >>> 1.29271 GeV, 34.4298 deg, 12.7037 deg.
found segment (stat. 2 & 3), hits 38, 44, 49, 56 >>> 0.142495 GeV, 204.922 deg, 15.4678 deg.
found segment (stat. 2 & 3), hits 38, 44, 53, 59 >>> 1.98068 GeV, 57.1162 deg, 15.4678 deg.

Merging track segments

Match segments according to the hit number, momentum, theta and phi angles. Results:

segments:

0 1 >	0	9	15	24	3.75575	113.256	7.6694
0 2 >	0	9	30	39	4.37074	112.568	7.6694
0 3 >	0	9	45	54	4.41979	112.339	7.6694
1 2 >	15	24	30	39	5.35903	111.423	7.67755
1 3 >	15	24	45	54	4.97978	111.423	7.67755
2 3 >	30	39	45	54	4.65867	111.423	7.68244

seems to belong to one track

segments:

0 1 >	4	11	19	26	1.2846	37.6379	12.857
0 2 >	4	11	34	41	1.28075	37.2942	12.857
0 3 >	4	11	49	56	1.26929	36.7213	12.857
1 2 >	19	26	34	41	1.302	36.7213	12.7958
1 3 >	19	26	49	56	1.28602	35.8047	12.7958
2 3 >	34	41	49	56	1.29271	34.4298	12.7037

seems to belong to one track

segments:

0 1 >	8	14	23	29	1.80182	60.3243	15.5102
0 2 >	8	14	38	44	1.81594	59.9806	15.5102
0 3 >	8	14	53	59	1.83647	59.4077	15.5102
1 2 >	23	29	38	44	1.87522	59.4077	15.4985
1 3 >	23	29	53	59	1.90212	58.4911	15.4985
2 3 >	38	44	53	59	1.98068	57.1162	15.4678

seems to belong to one track

Removing bad tracks

- Try to remove tracks, that do not satisfy following requirements:
  - track segment parameters (momentum, angles) have to be consistent in different segments
  - number of track segments have to be large enough
  - hits belonging to tracks should be uniquely used, only by one track

Creating PndTrackCand's

- Create PndTrackCand'idates, with track parameters being the mean of the parameters of different track segments

Results

Definitions:

efficiency(p) = #reco tracks matching these ones ☟ (p) / #MC tracks that hit at least 3 stations(p)

primaries: particles with vertex.Mag() < 1cm
secondaries: partiles with vertex.Mag() > 1cm
reference: particles with:

- plot vs p -> $5^\circ < theta < 20^\circ$
- plot vs theta -> p > 0.5 GeV/c
- plot vs #hits -> $5^\circ < theta < 25^\circ$ && p > 0.5 GeV/c

Momentum resolution:

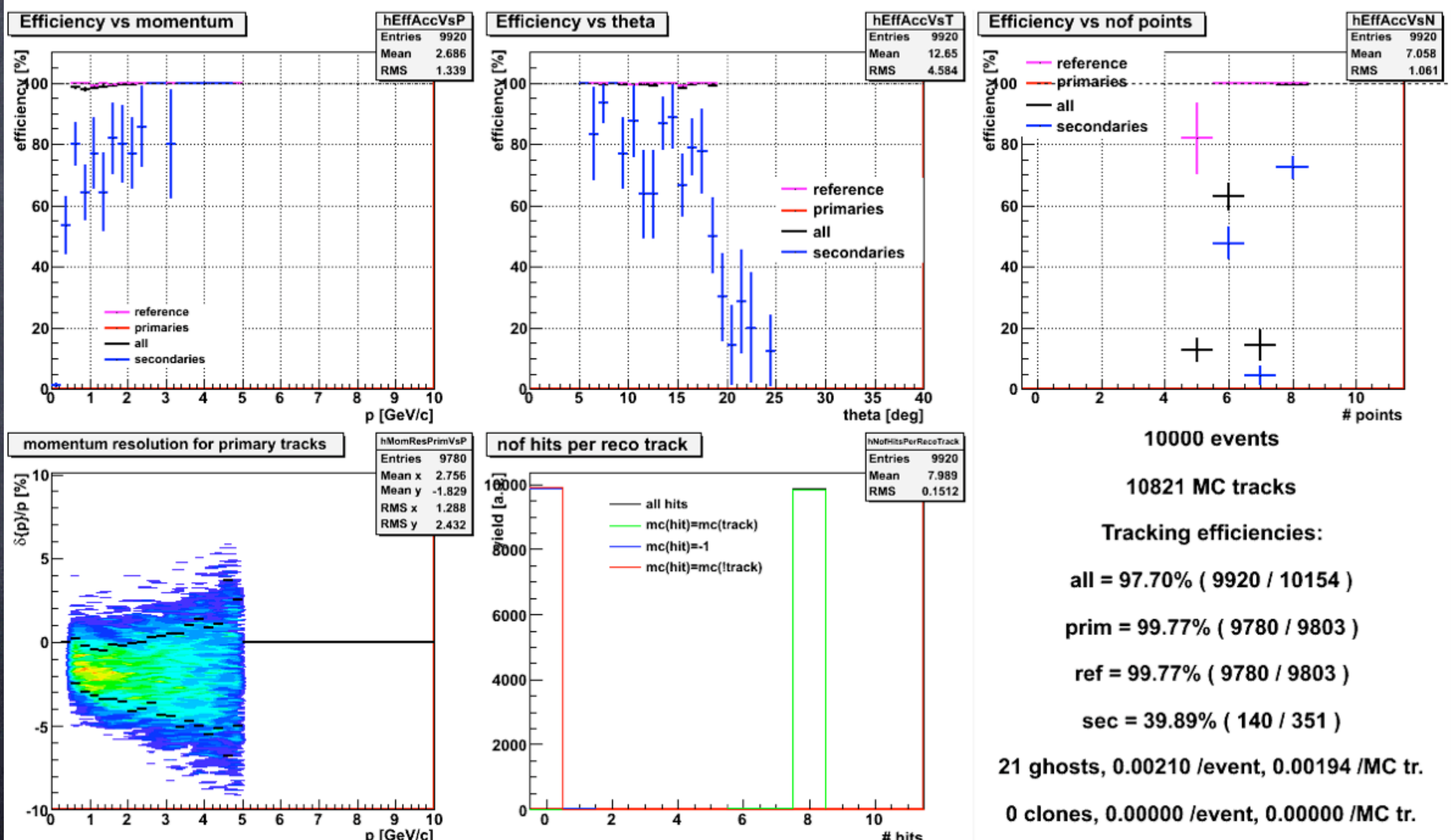
mom.res.= (MCMom.Mag()-RecoMom.Mag()) / MCMom.Mag() * 100%

Results

4 GEM stations, 1 pion per event

```
boxGen->SetThetaRange(6,19);
boxGen->SetPhiRange   (0.,360.);
boxGen->SetPRange     (0.5,5.);
```

Gem Track Finder QA

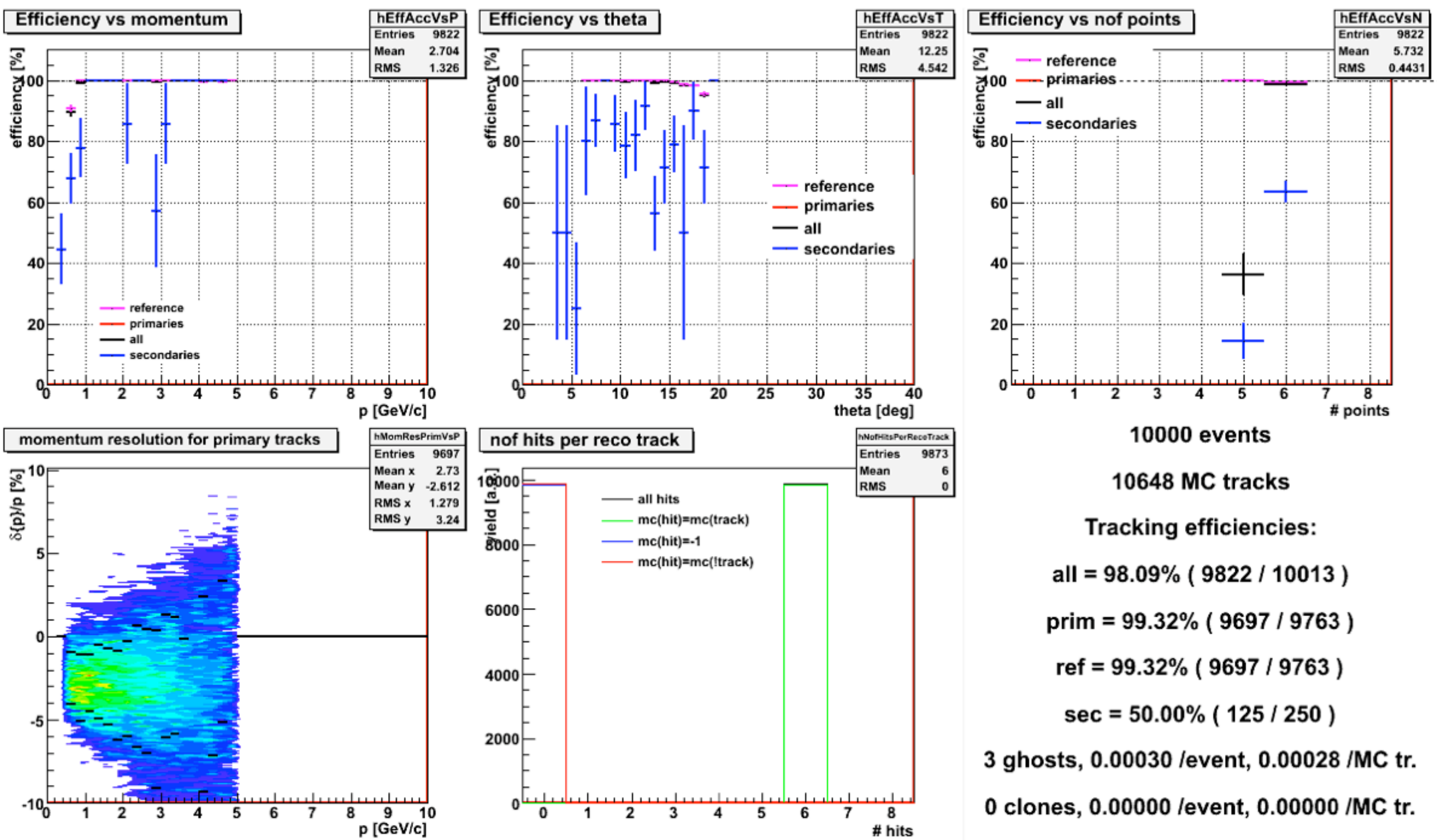


Results

3 GEM stations, 1 pion per event

```
boxGen->SetThetaRange(6,19);
boxGen->SetPhiRange   (0.,360.);
boxGen->SetPRange     (0.5,5.);
```

Gem Track Finder QA

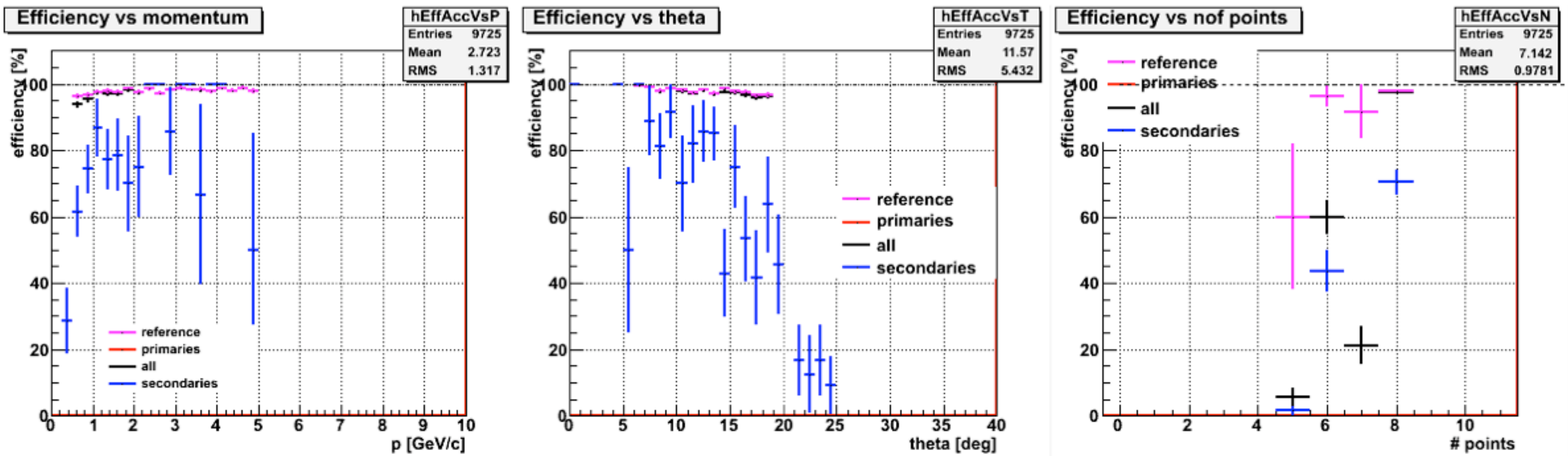


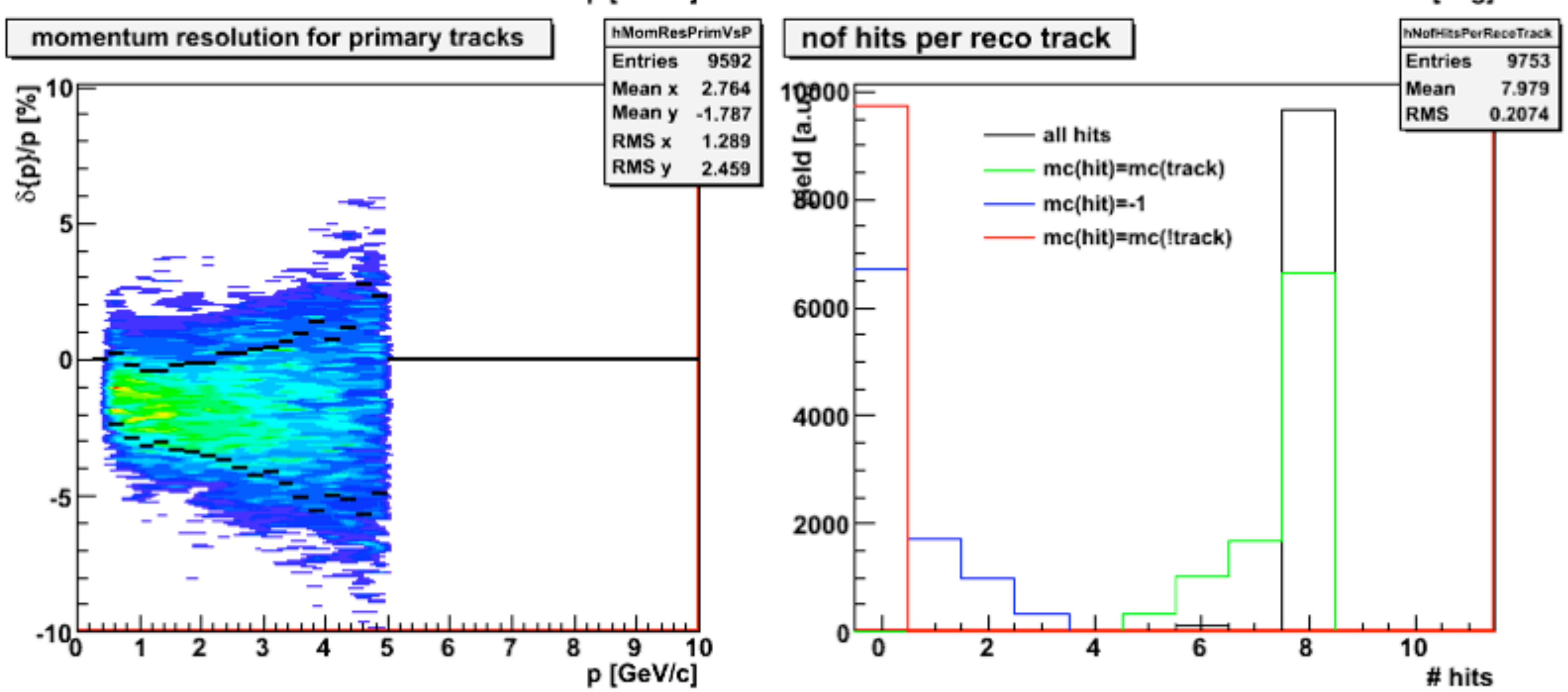
Results

4 GEM stations, 10 pions per event

```
boxGen->SetThetaRange(6,19);
boxGen->SetPhiRange   (0.,360.);
boxGen->SetPRange     (0.5,5.);
```

Gem Track Finder QA





1000 events

10803 MC tracks

Tracking efficiencies:

all = 95.84% (9725 / 10147)

prim = 97.91% (9592 / 9797)

ref = 97.91% (9592 / 9797)

sec = 38.00% (133 / 350)

391 ghosts, 0.39100 /event, 0.03619 /MC tr.

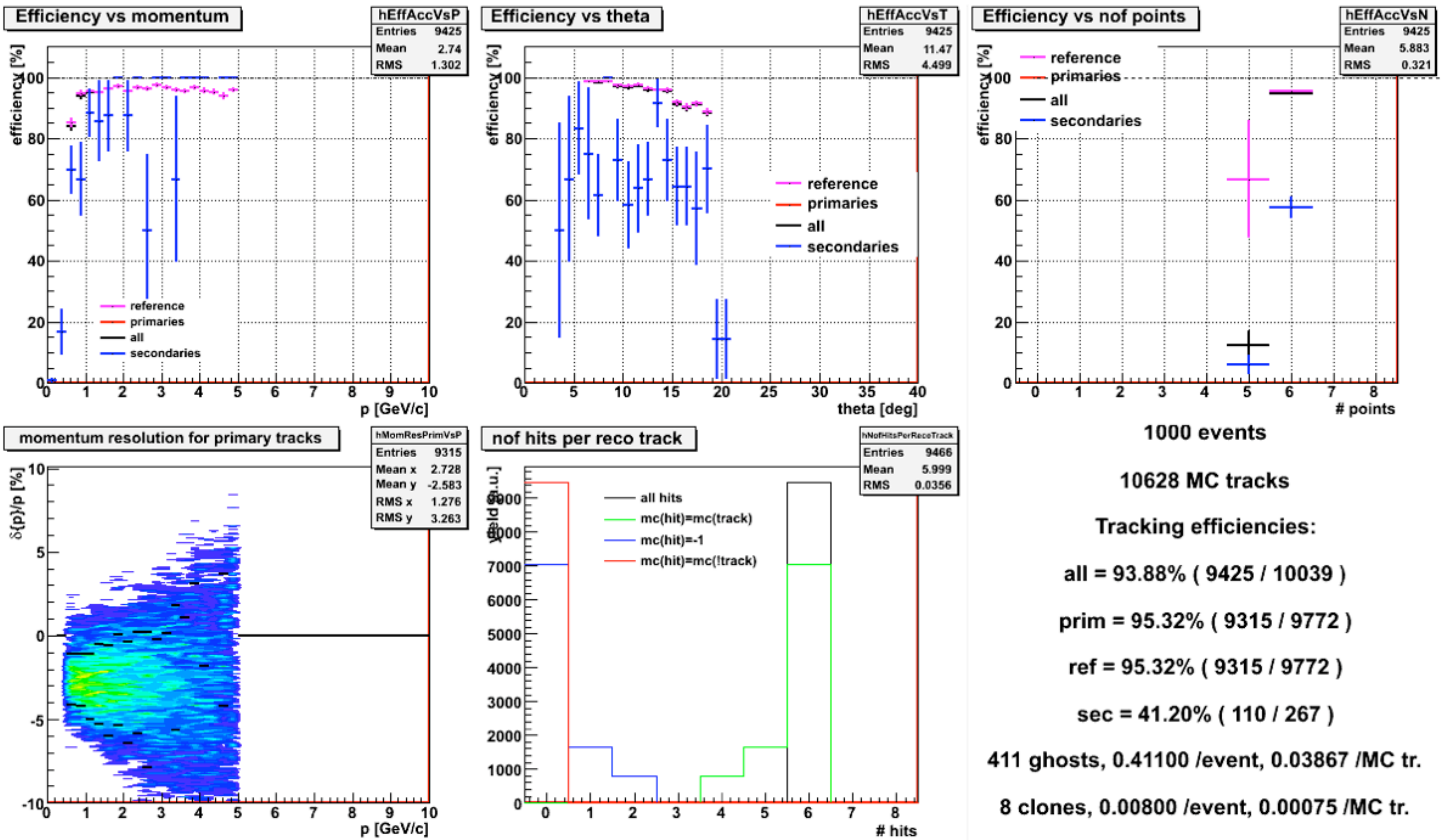
52 clones, 0.05200 /event, 0.00481 /MC tr.

Results

3 GEM stations, 10 pions per event

```
boxGen->SetThetaRange(6,19);
boxGen->SetPhiRange   (0.,360.);
boxGen->SetPRange      (0.5,5.);
```

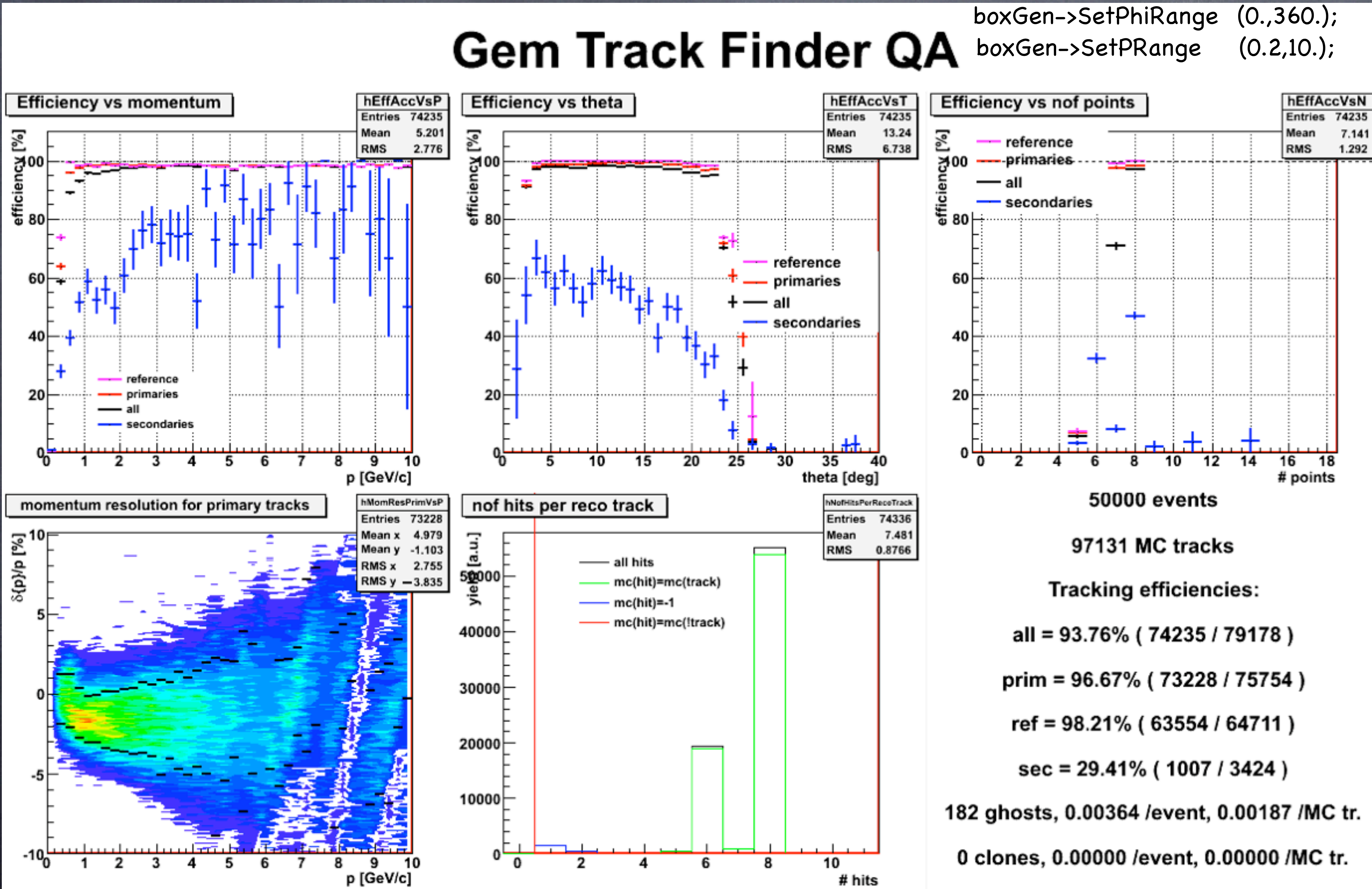
Gem Track Finder QA



Results

4 GEM stations, 2 pions per event

```
boxGen->SetThetaRange(2,30);
boxGen->SetPhiRange   (0.,360.);
boxGen->SetPRange     (0.2,10.);
```

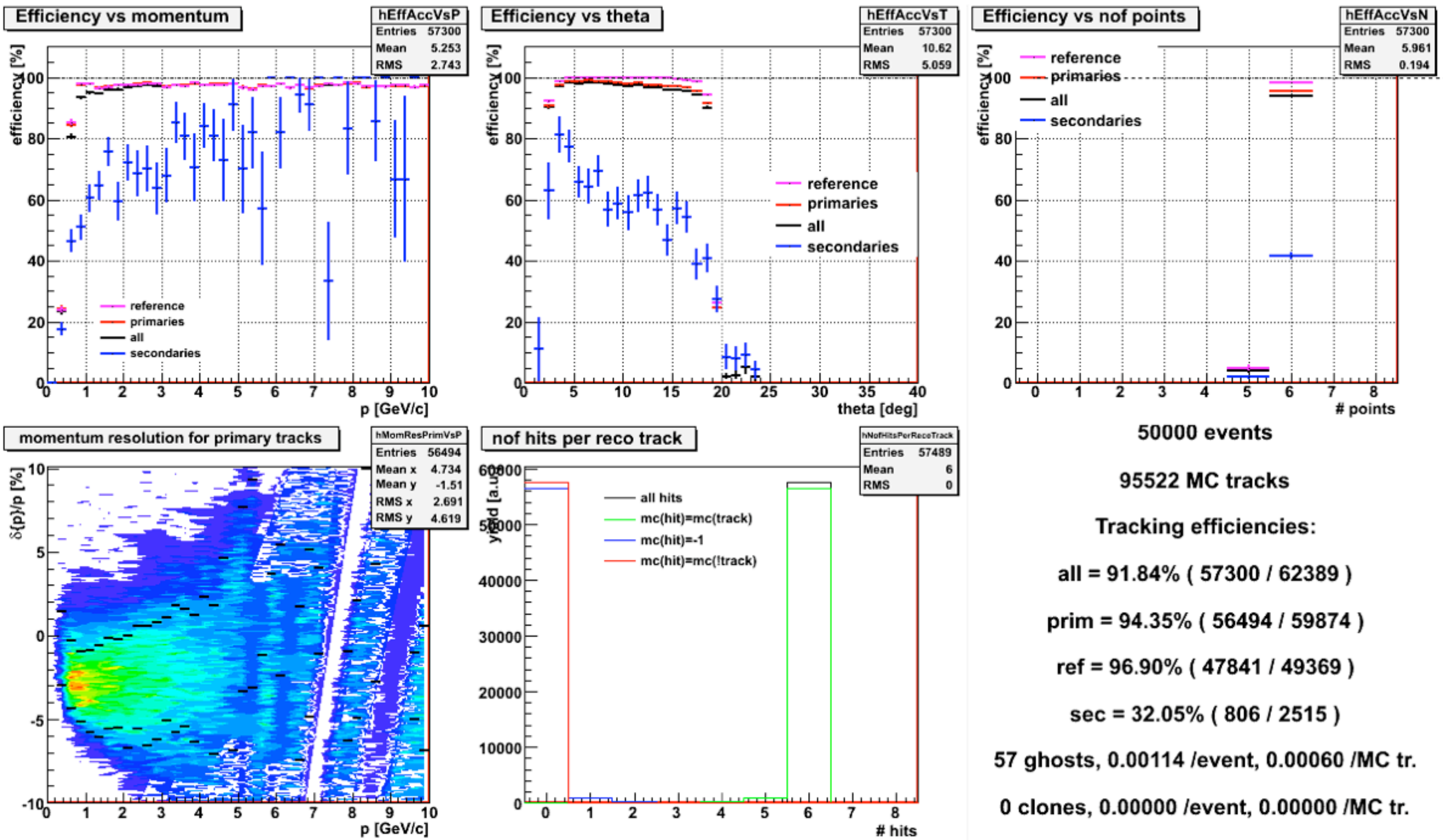


Results

3 GEM stations, 2 pions per event

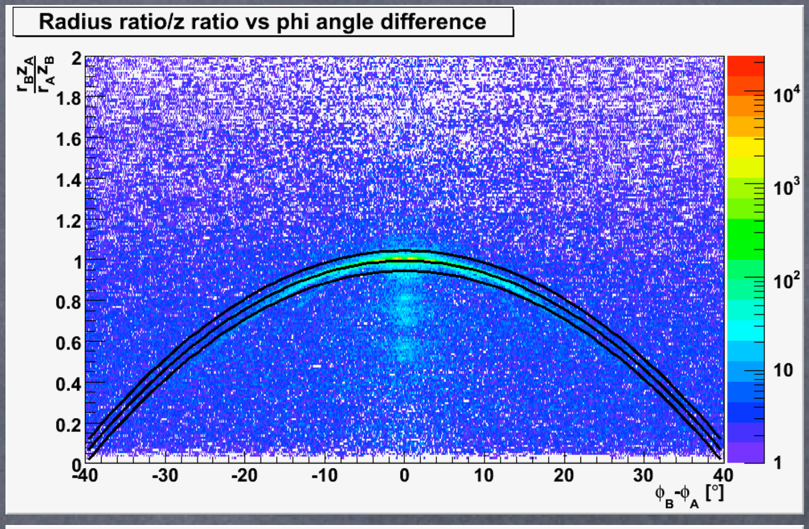
```
boxGen->SetThetaRange(2,30);
boxGen->SetPhiRange   (0.,360.);
boxGen->SetPRange     (0.2,10.);
```

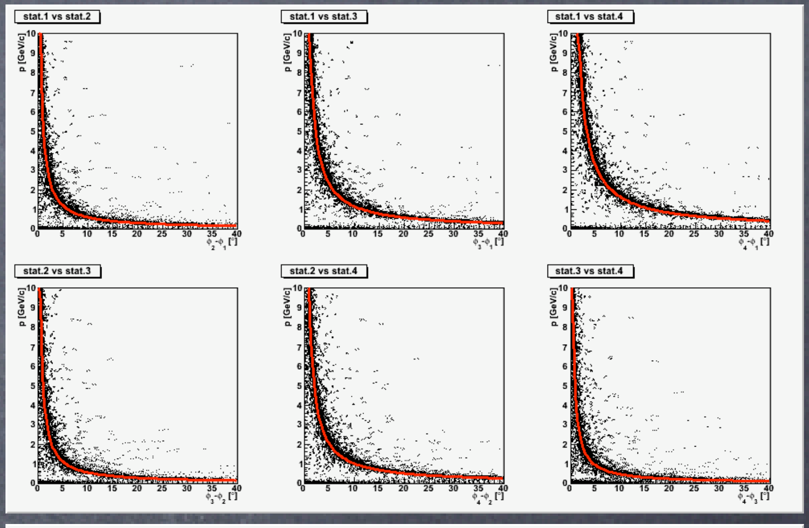
Gem Track Finder QA

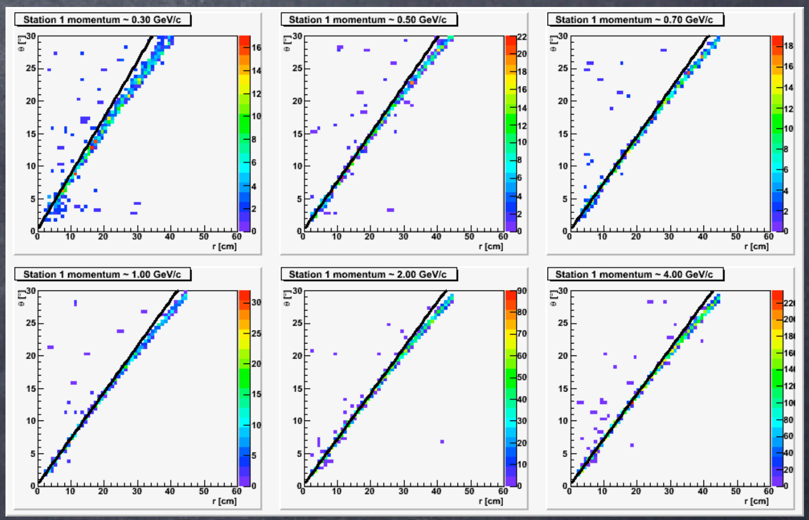


Problems

- The code will not work with different magnetic field.
- But I've created a dedicated task to see if the track finding parameters match the magnetic field
- Any hit finding inefficiencies will probably have a bad effect on track finding efficiency - the code does not extra-/intrapolate tracks to stations without hits

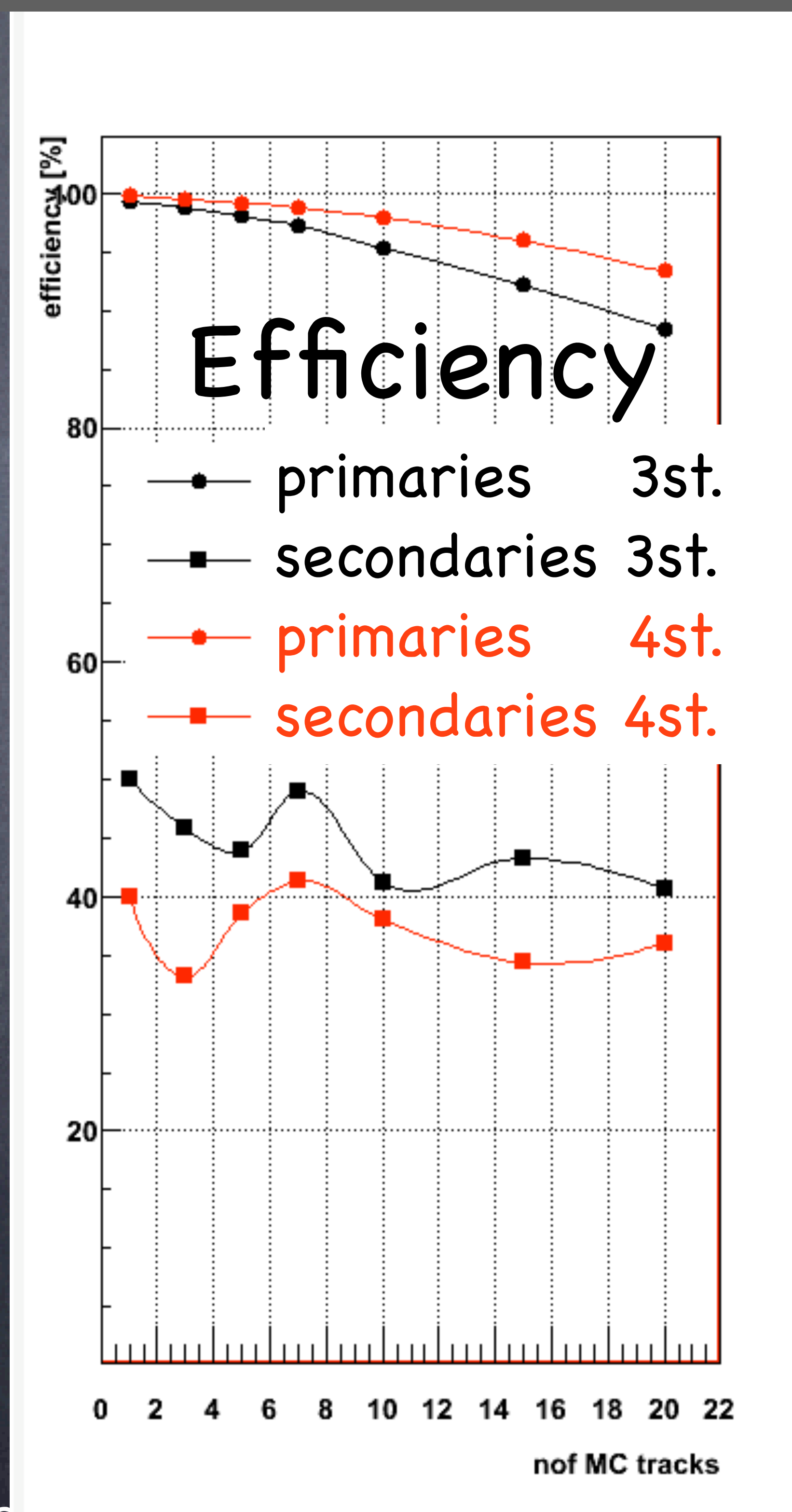




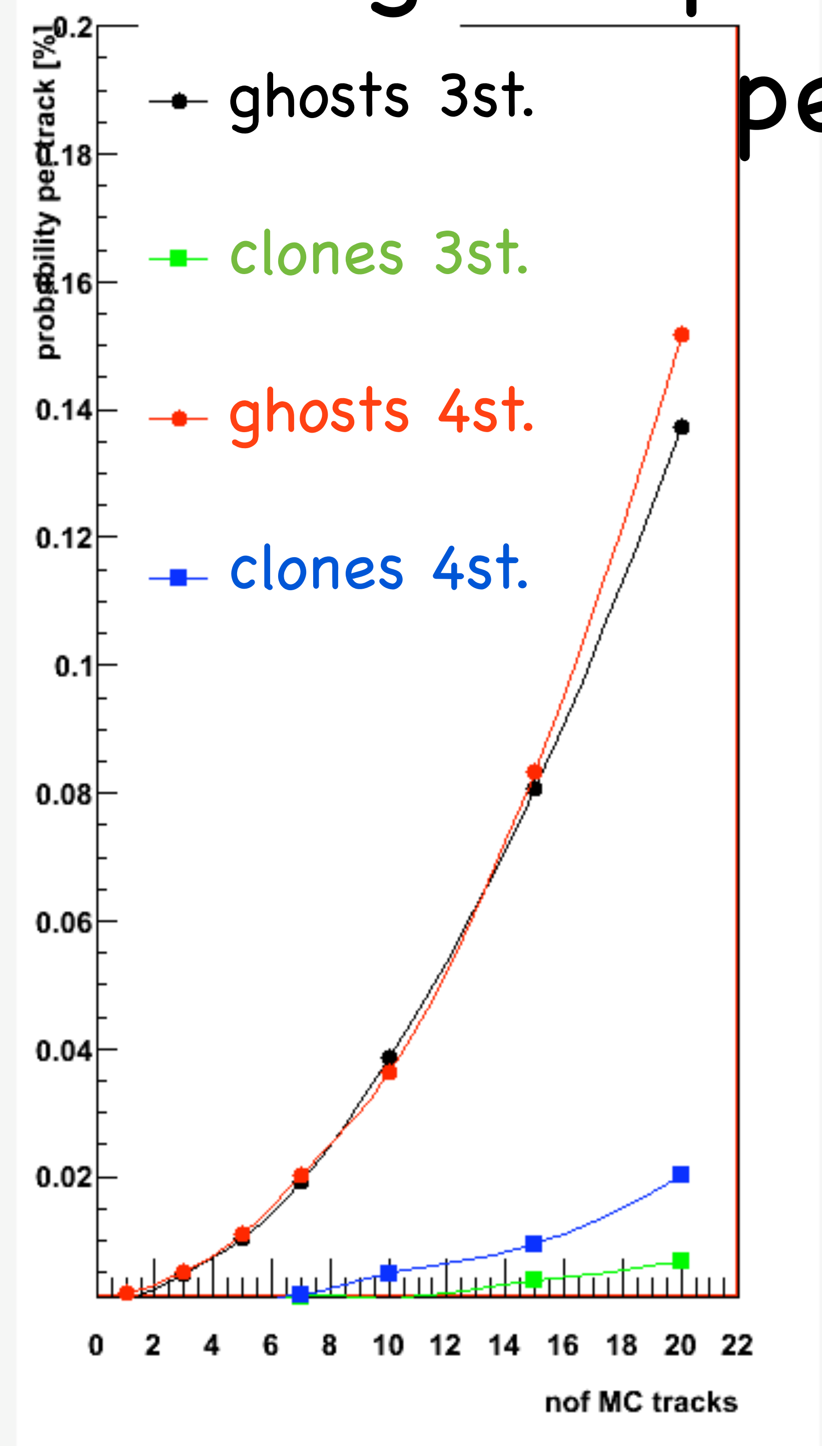


Bonus: 4 vs 3 GEM stations,

dependence on the number of MC tracks



Clone/ghost probability per track



Time performance

The bad news is that it strongly depends on the number of track to reconstruct.
The more tracks, the slower the code.

The good news is that still it is faster I've ever expected:

with 2 tracks per event:

```
-------------------- PndGemFindTracks : Summary ------------------
 Events:          10000
 Tracks:          22760      ( 2.276 per event )
 Time:            2.72827s   ( 0.000272827s per event )
                             ( 0.000119871s per track )
------------------------------------------------------------------
```

with 10 tracks per event:

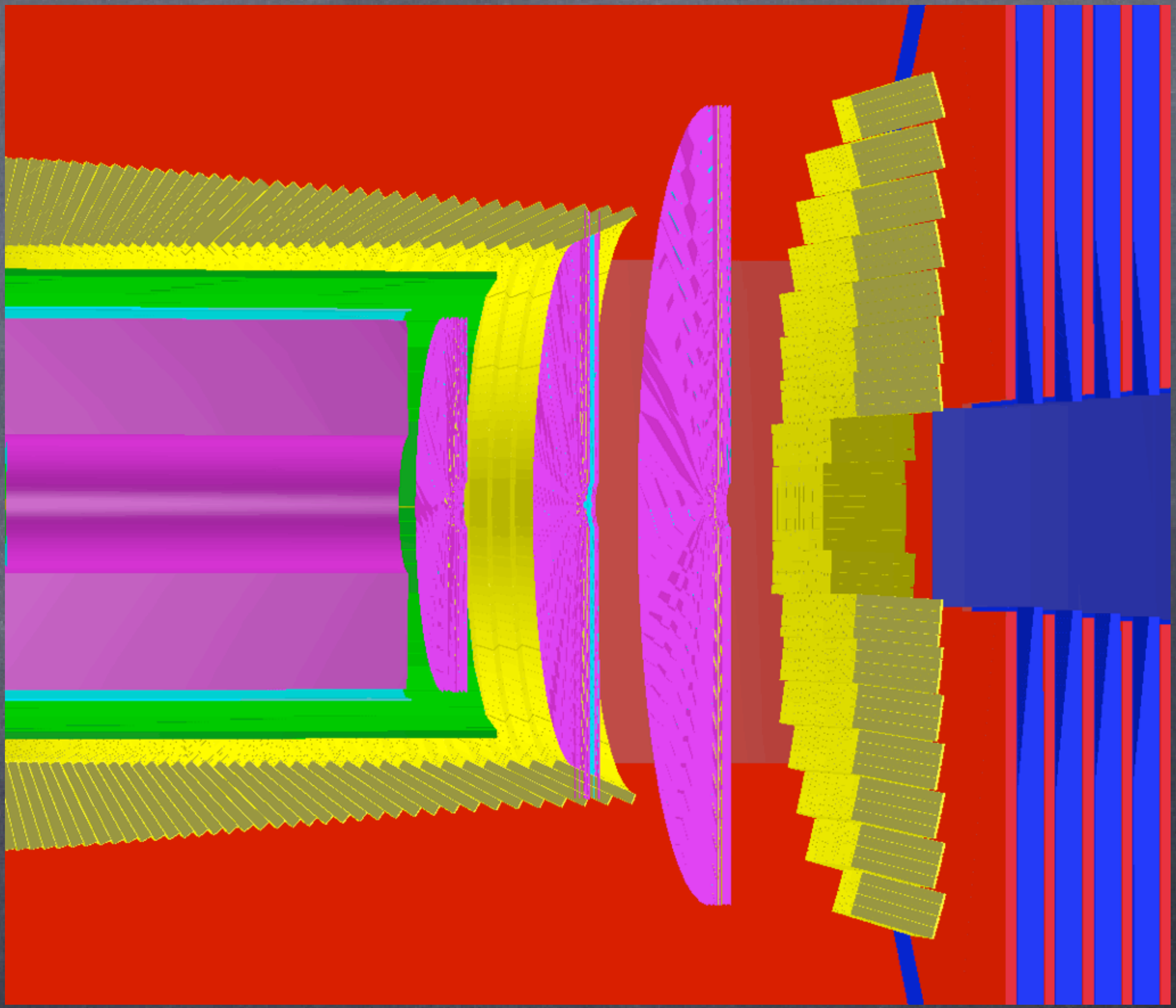
```
-------------------- PndGemFindTracks : Summary ------------------
 Events:          1000
 Tracks:          9735       ( 9.735 per event )
 Time:            9.09496s   ( 0.00909496s per event )
                             ( 0.000934254s per track )
------------------------------------------------------------------
```

Conclusions

- A first, running version of track finder for GEM detector has been developed
- It is tested, has efficiency of some 95% efficiency for events with reasonable number of tracks
- Momentum seed for the genfit is ~2% away from the mean, with resolution of less than 5%
- Without any time optimization about 1000-1000 tracks are found per second (0.1-1 miliseconds per track)

Problem with GEM geometry

Reported by Stefano, there is overlap between middle GEM station and EMC detector.



Update on GEM geometry

Previous/updated GEM:

	z position	radius
1st station	120cm	42cm
	117cm	45cm
2nd station	150cm	66cm
	153cm	56cm
3rd station	180cm	90cm
	189cm	74cm