A 3D Method for Assigning MVD Hits to Tracks Fitted in the STT

Jenny Regina

Uppsala University
Department of Physics and Astronomy

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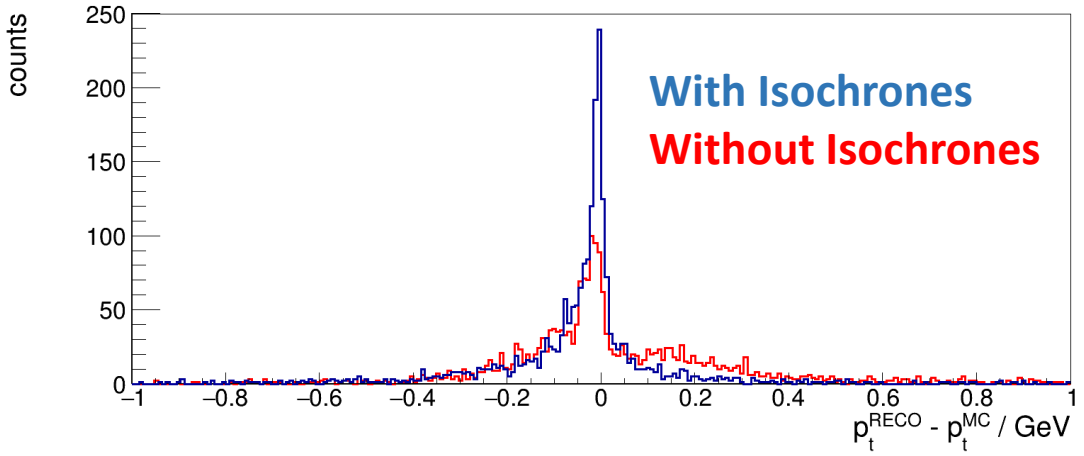
Computing Session

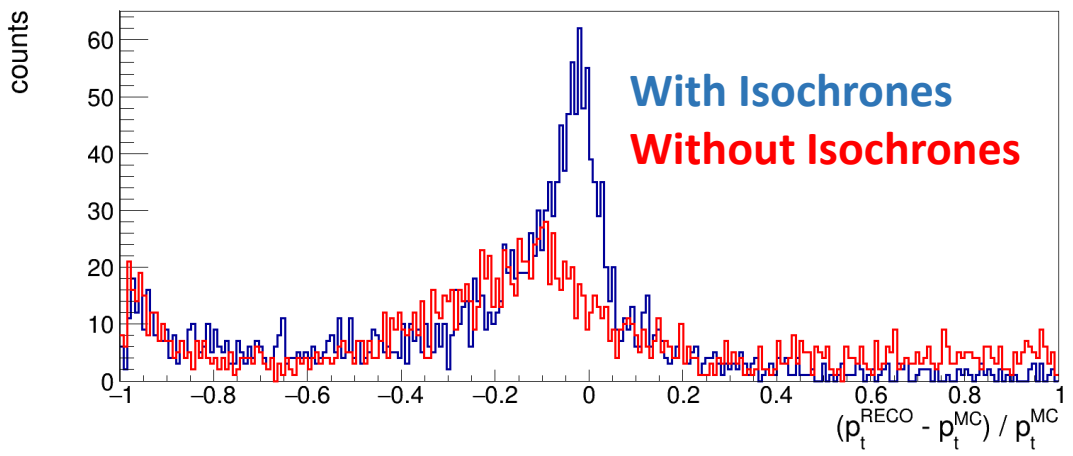
Outline:

1. **Momentum Resolutions Discussion**
2. **Background**
3. **3D Extrapolation Method**
4. **Results**
5. **Outlook**

Reason for Momentum Resolution Study

- SttCellTrackFinder basis for extrapolation procedure
- Right now also the most mature algorithm for running time-based
- Want (need!) to understand the absolute and relative momentum resolutions
  - Unexplained features in the distributions
    - One sub-structure in absolute momentum resolution when not using isochrones
    - A peak around -1 in relative momentum resolution independent of isochrones utilization
- The success of extrapolation for including hits from other detectors depend on how well the momentum was estimated



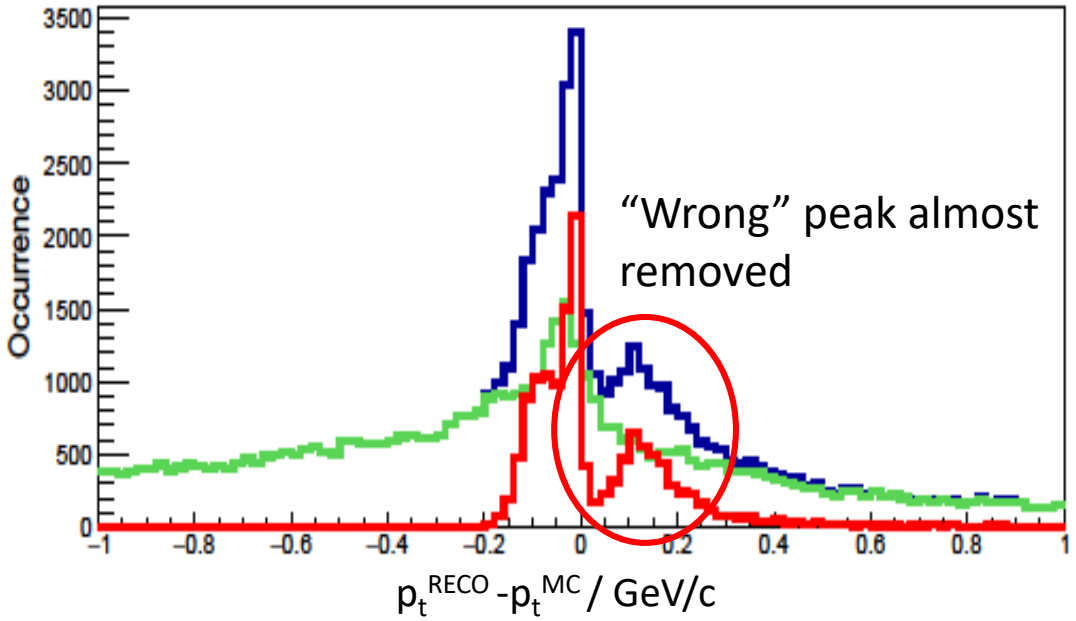


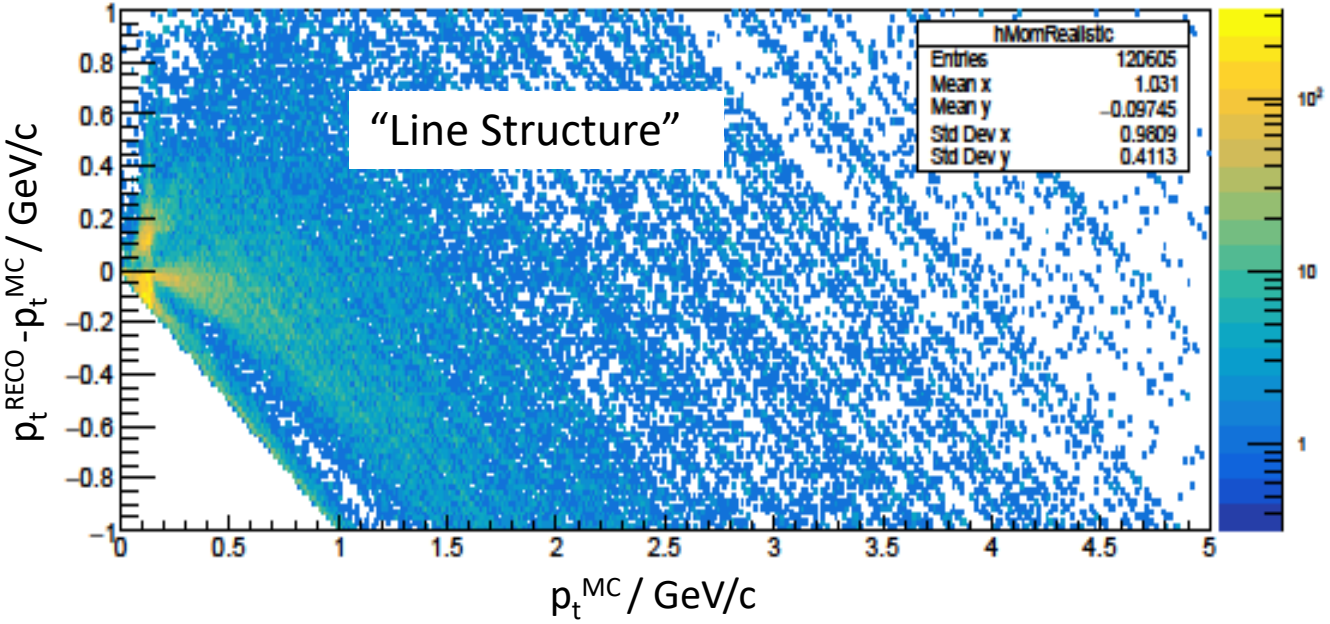
DPM, @ P_{beam}=6.2 GeV/c

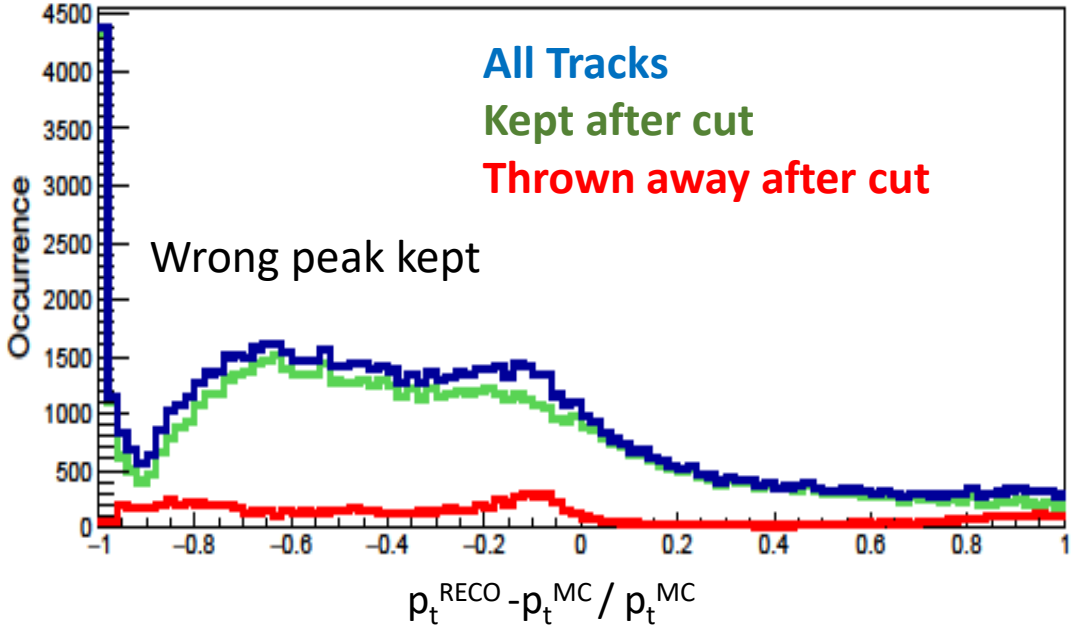
Simulation Details

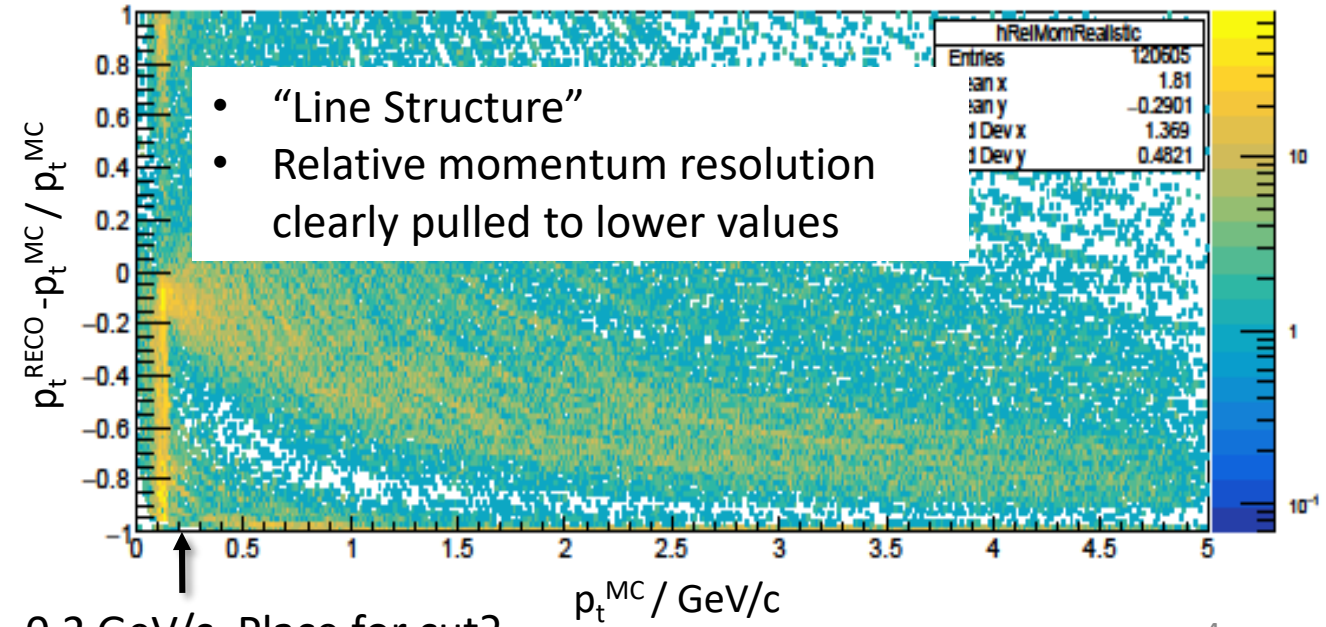
- 100 000 Events
- 1 Muon / Event
- All Muons from IP
- 0.1-5 GeV/c total particle momentum
- Apply SttCellTrackFinder

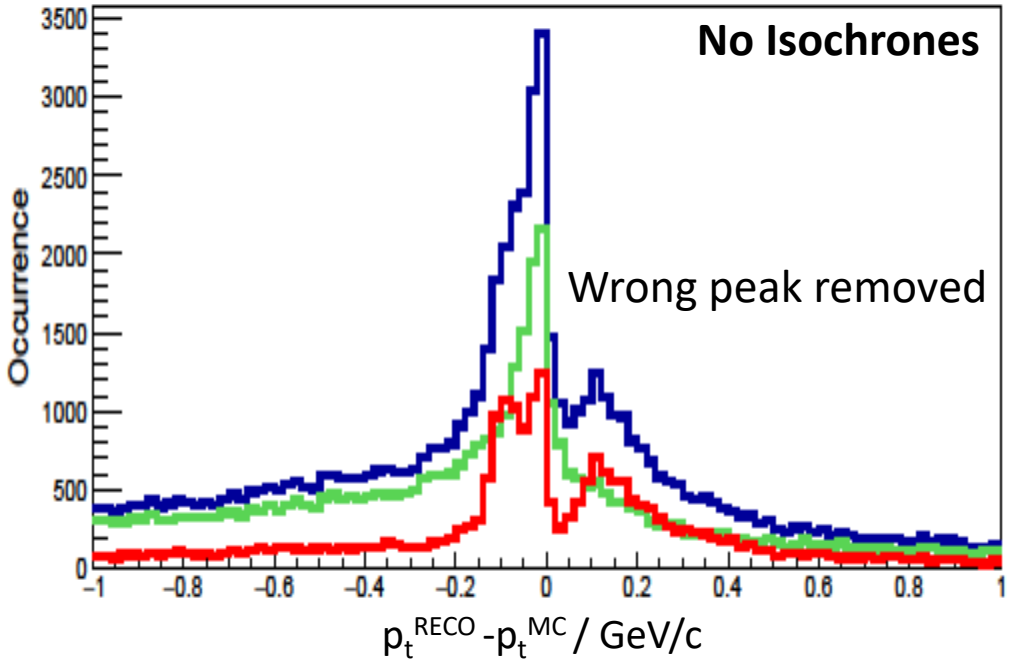
No Isochrones

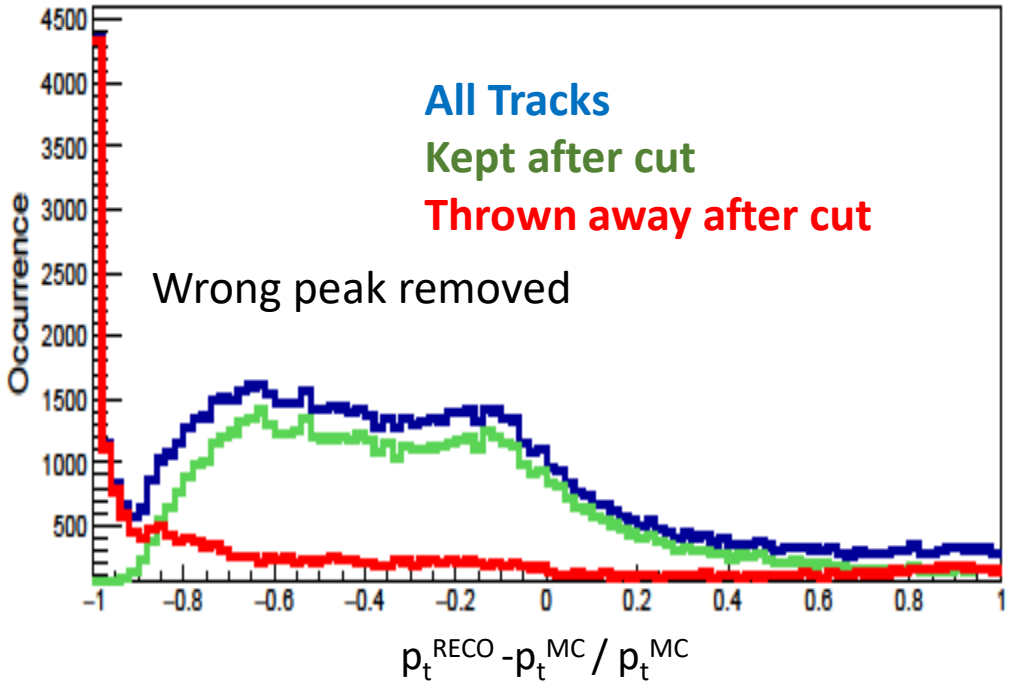


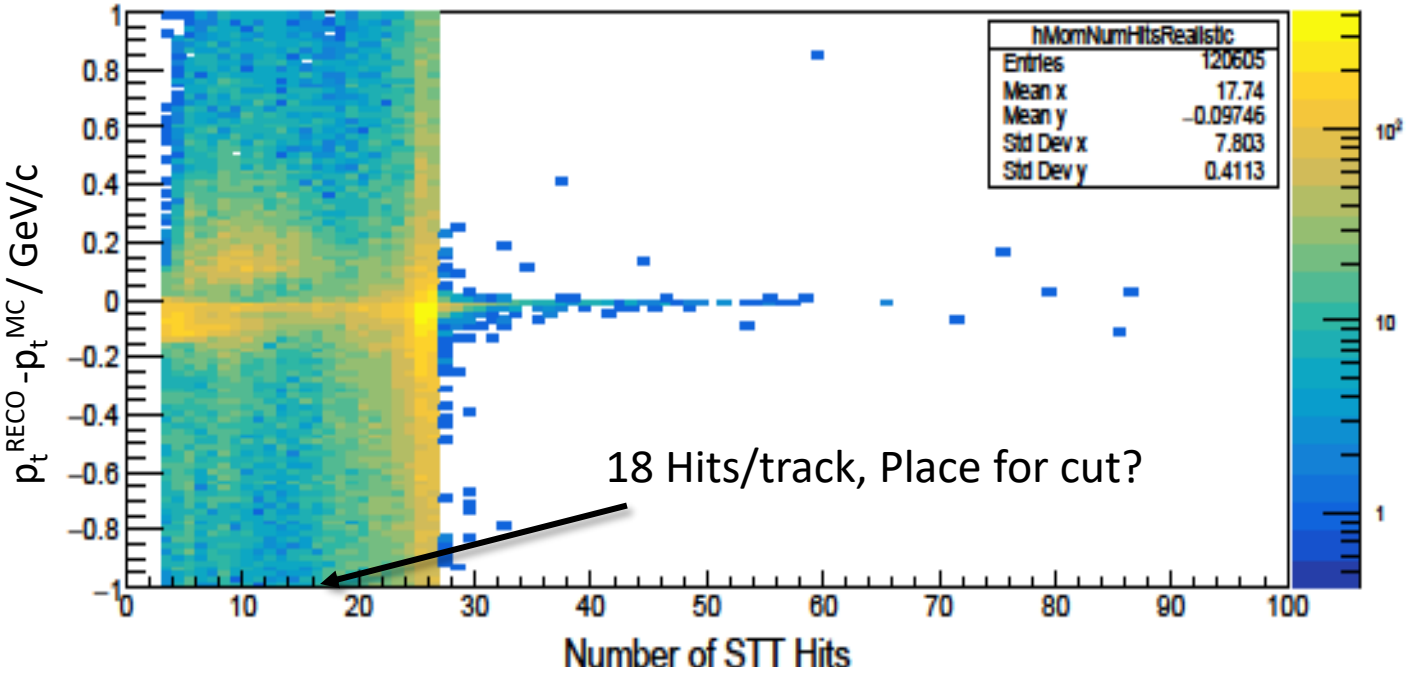


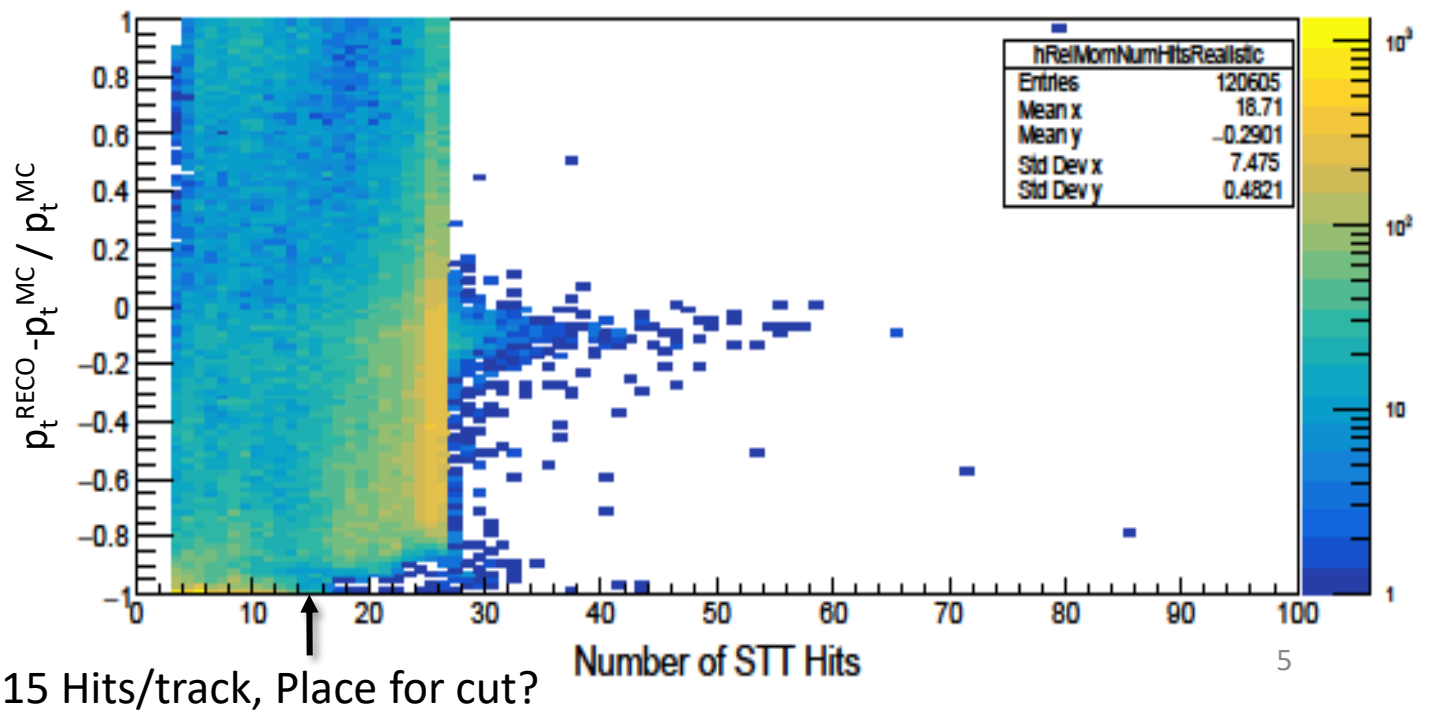


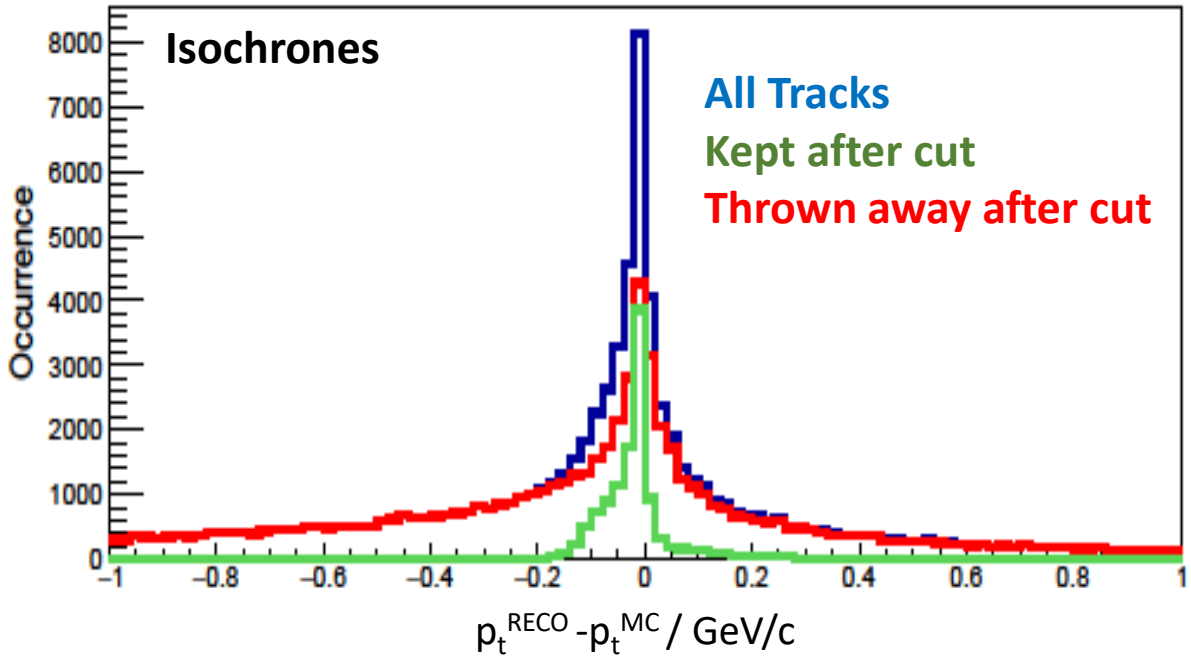


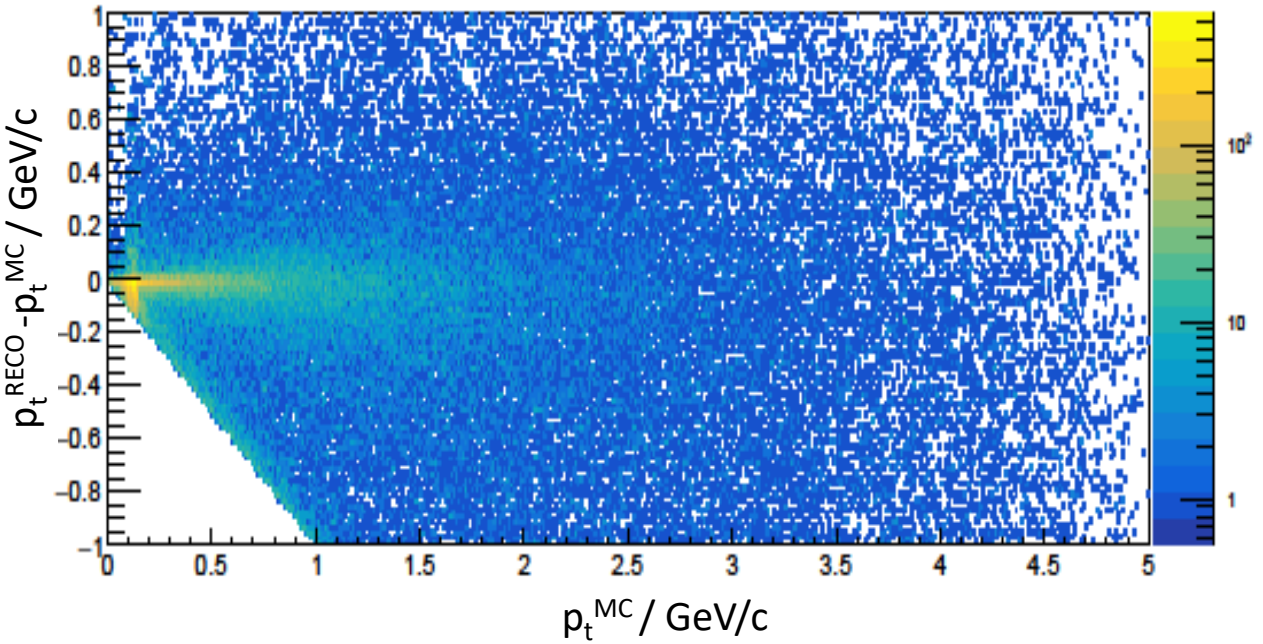

No Isochrones
Wrong peak removed
Occurrence
$p_t^{RECO} - p_t^{MC}$ / GeV/c

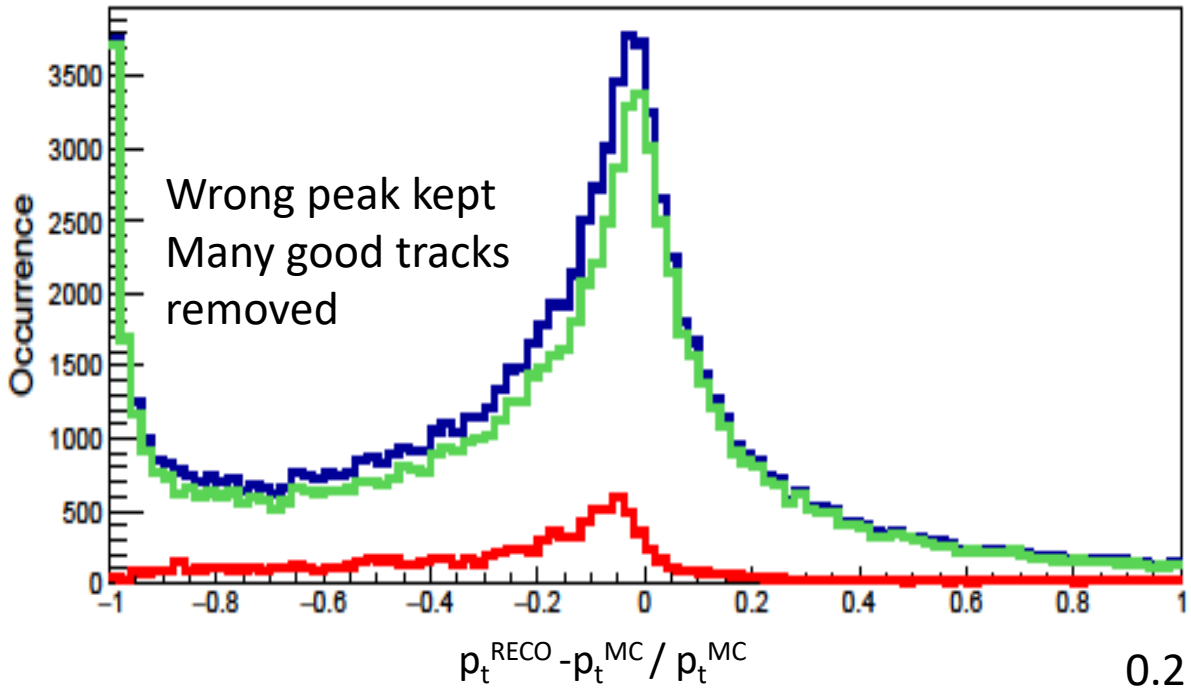

All Tracks
Kept after cut
Thrown away after cut
Wrong peak removed
Occurrence
$p_t^{RECO} - p_t^{MC}$ / p_t^{MC}

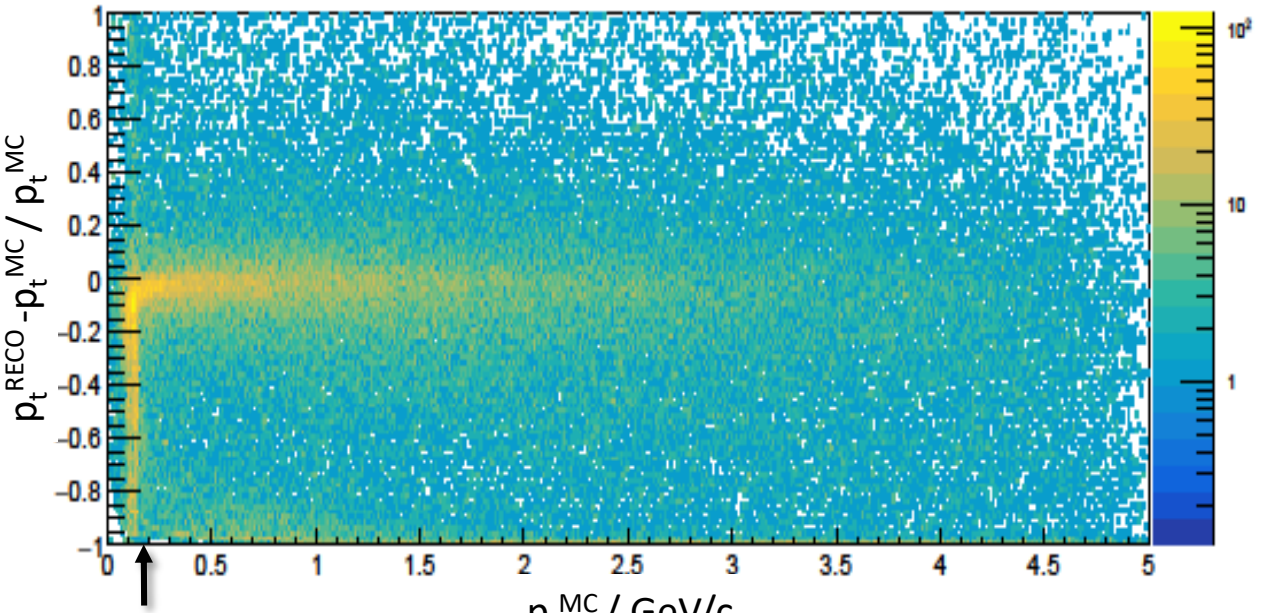

hMomNumHitsRealistic
Entries 120605
Mean x 17.74
Mean y −0.09746
Std Dev x 7.803
Std Dev y 0.4113
18 Hits/track, Place for cut?
$p_t^{RECO} - p_t^{MC}$ / GeV/c
Number of STT Hits

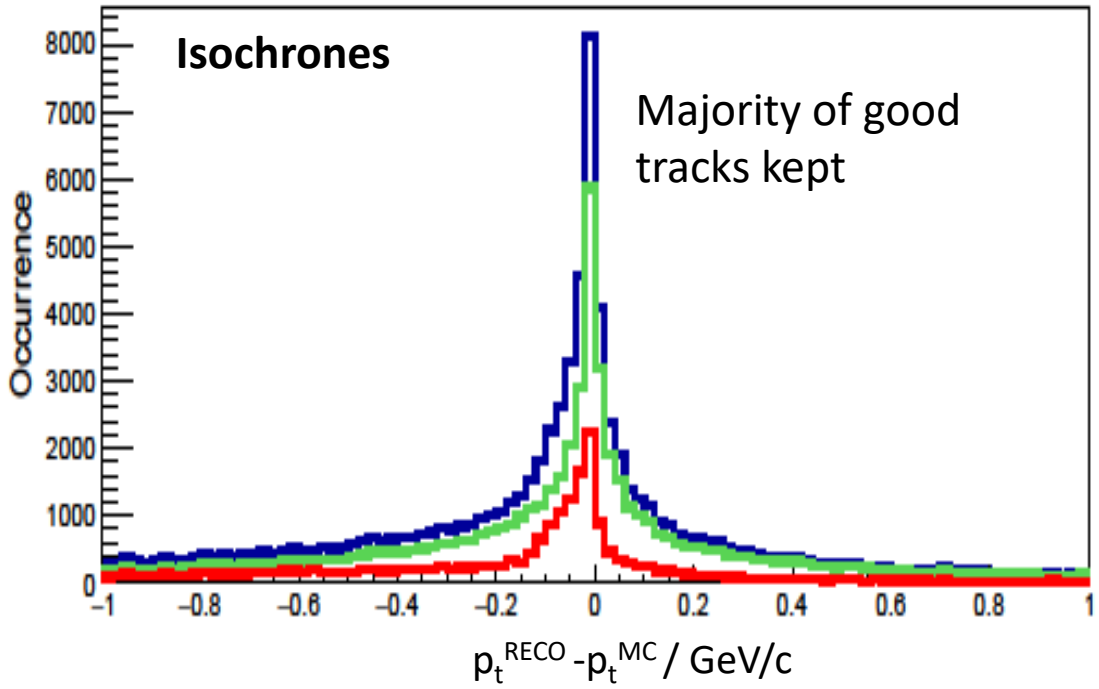

hRelMomNumHitsRealistic
Entries 120605
Mean x 18.71
Mean y −0.2901
Std Dev x 7.475
Std Dev y 0.4821
15 Hits/track, Place for cut?
$p_t^{RECO} - p_t^{MC}$ / p_t^{MC}
Number of STT Hits

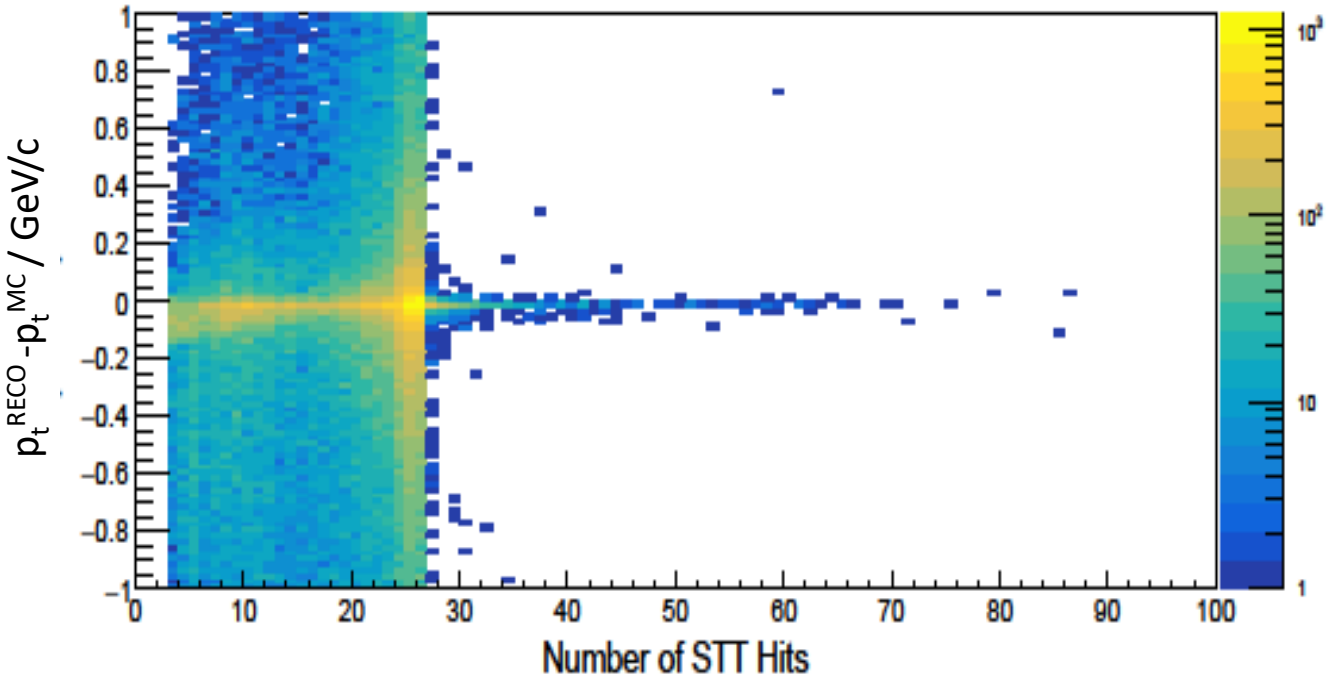

Isochrones
All Tracks
Kept after cut
Thrown away after cut
Occurrence
$p_t^{RECO} - p_t^{MC}$ / GeV/c

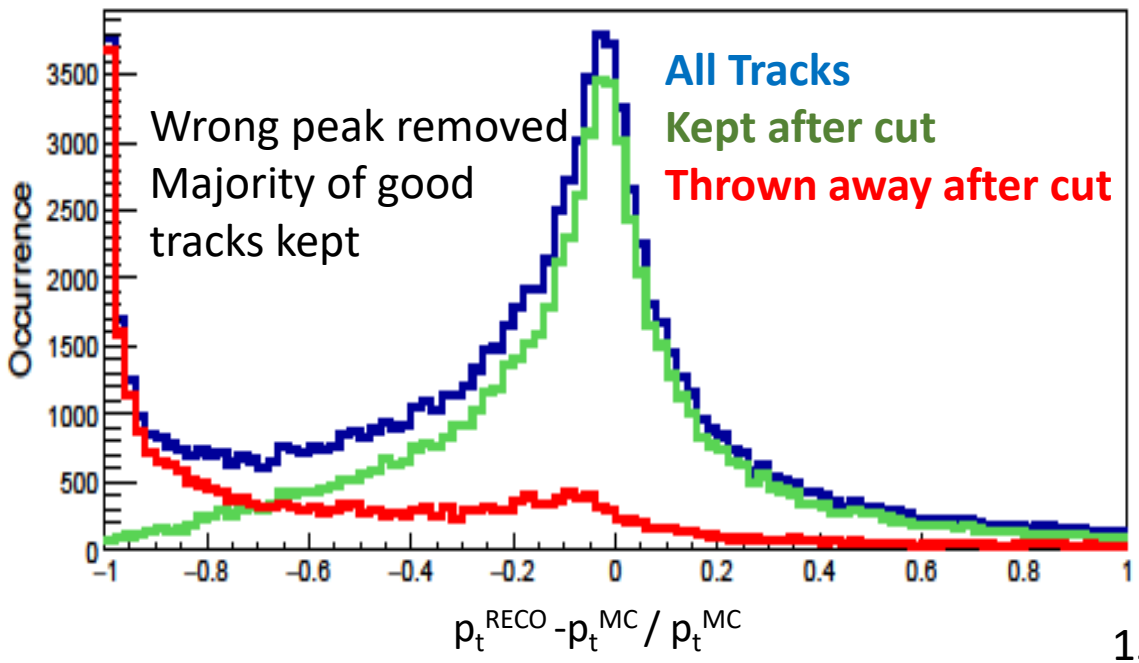

$p_t^{RECO} - p_t^{MC}$ / GeV/c
p_t^{MC} / GeV/c


Wrong peak kept
Many good tracks removed
Occurrence
$p_t^{RECO} - p_t^{MC} / p_t^{MC}$


$p_t^{RECO} - p_t^{MC} / p_t^{MC}$
p_t^{MC} / GeV/c
0.2 GeV/c, Place for cut?


Isochrones
Majority of good tracks kept
Occurrence
$p_t^{RECO} - p_t^{MC}$ / GeV/c


$p_t^{RECO} - p_t^{MC}$ / GeV/c
Number of STT Hits


Wrong peak removed
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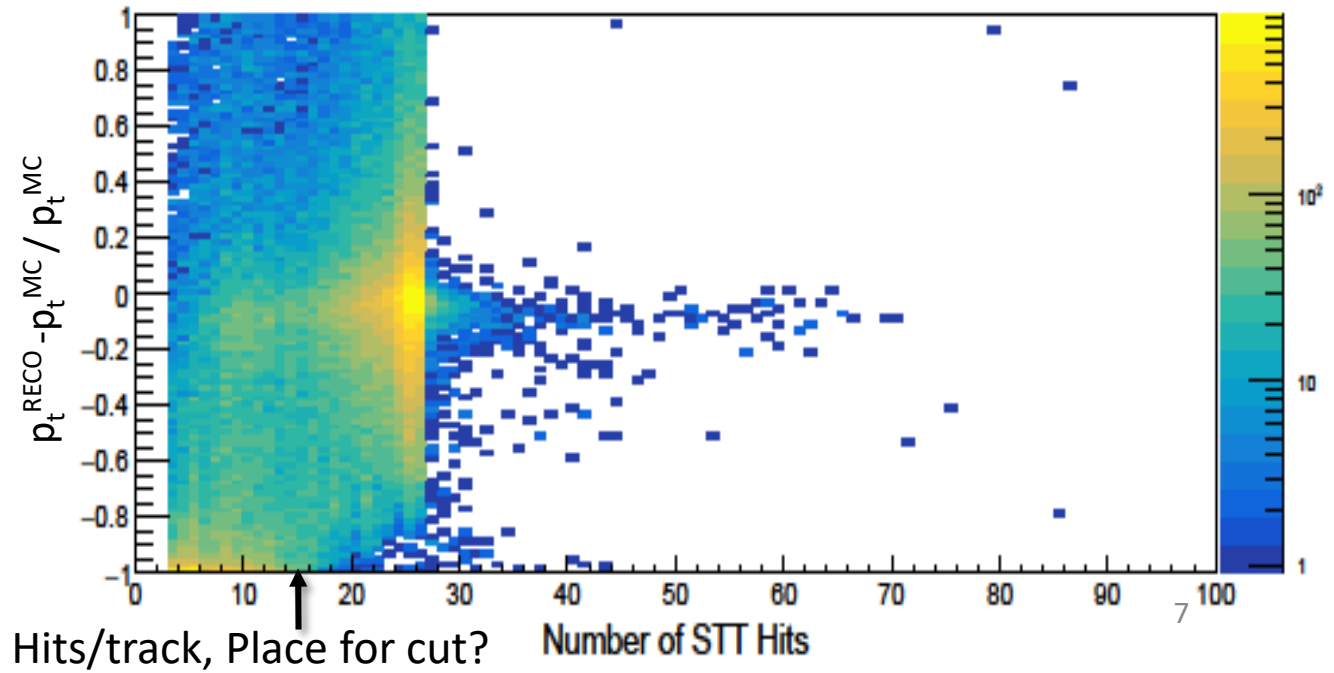
Kept after cut
Thrown away after cut
Occurrence
$p_t^{RECO} - p_t^{MC} / p_t^{MC}$


$p_t^{RECO} - p_t^{MC} / p_t^{MC}$
15 Hits/track, Place for cut?
Number of STT Hits

Background

Including MVD hits in STT fitted tracks, 3D

- Want to try to include MVD hits in STT fitted tracks for improved momentum resolution
- SttCellTrackFinder makes no assumptions on the origin of the particle
  - Suitable for tracks from displaced vertices
- Expansion of 2D method [1, 2, 3]

[1] https://arxiv.org/abs/1910.06086

[2] https://indico.gsi.de/event/7315/contributions/32857/attachments/23675/29668/Jenny_Regina_CM_Stockholm_2018.pdf

[3] https://indico.gsi.de/event/7584/contributions/33670/attachments/24365/30482/TrackingWorkshop_Jenny_Regina_V2.pdf

3D Method

- Take one Riemann track fitted in the STT
  - Can also be other type of tracks
- Take all MVD Hits in one event/burst
  - Add all hits to the track
- Calculate the χ^2/ndf
- Iteratively remove the hits with the largest contribution to the χ^2/ndf

$$\chi^2 = \sum \frac{d^2}{\sigma_{hit}^2}$$

Sum over all hits in track
d - 3D distance between track and hit
$\boldsymbol{\sigma_{hit}}$ - uncertainty in the hit position
ndf - number of hits in track minus number of constraints (2, radius and center)

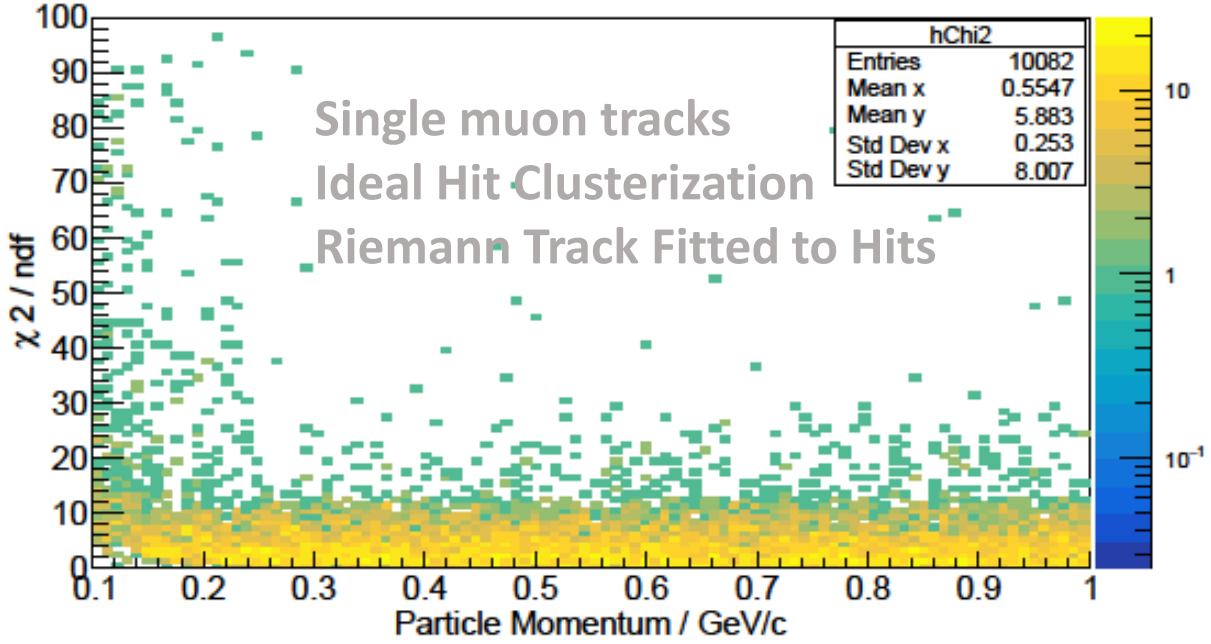
More detailed discussion on:

- Stopping condition
- Should **ALL** MVD hits be tested for compatibility?
  - Geometric considerations
- Weight

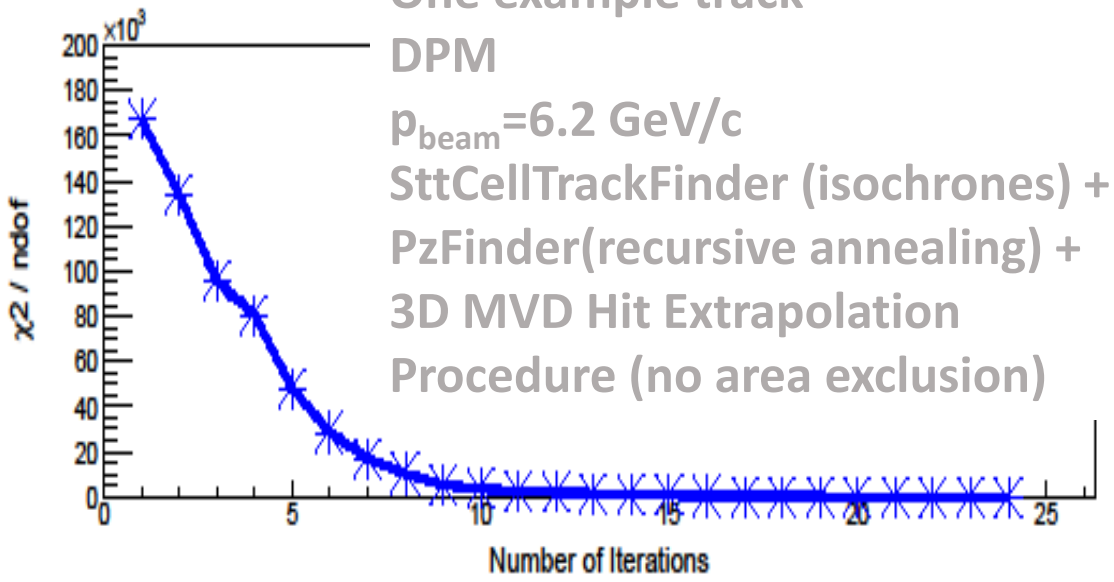
- Hits are **weighed** by inverse of their uncertainty **in the fit**
  - $\sigma_{x,y}$ = 0.002-0.0085 cm for MVD
  - $\sigma_{x,y}$ = 0.015 cm for STT

-> MVD will contribute with larger weight

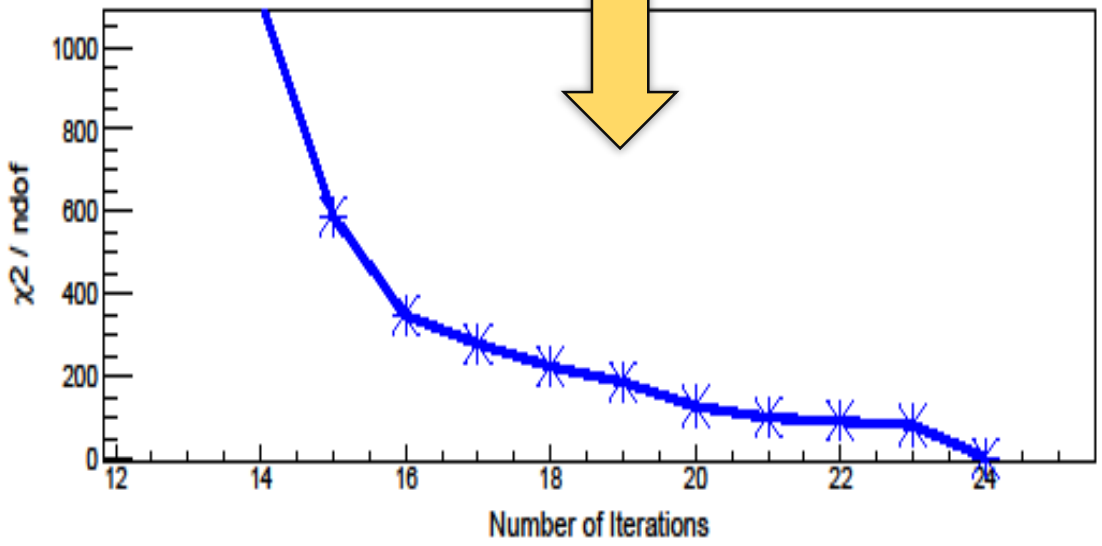
X^2 as stopping condition



One example track
DPM
p_{beam}=6.2 GeV/c
SttCellTrackFinder (isochrones) +
PzFinder(recursive annealing) +
3D MVD Hit Extrapolation
Procedure (no area exclusion)

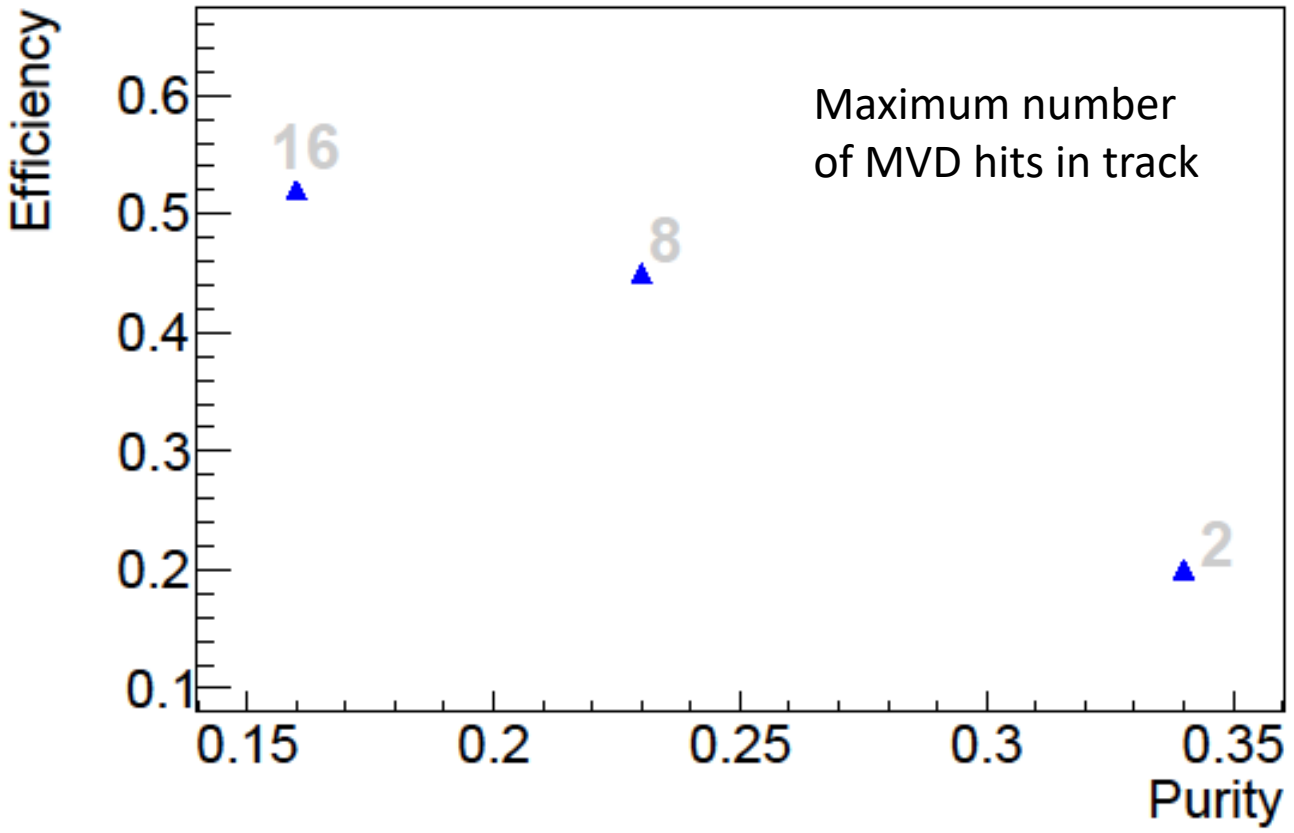


zoom



Trying different stopping conditions has not given a clue to what order of magnitude a stopping condition should be within

Stopping Condition

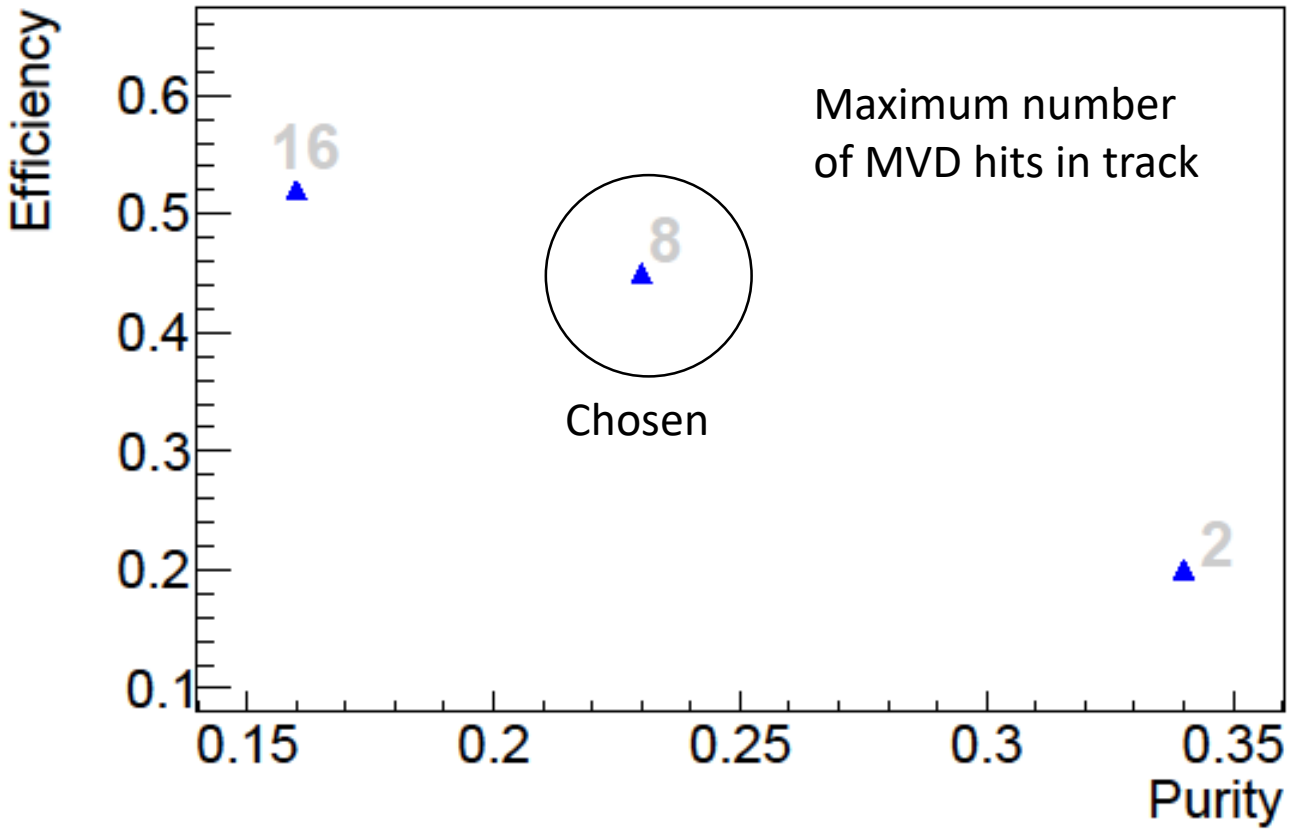


- MVD constructed to give around 4 hits / track
- Quite low efficiency and purity
- ROC curve might not be optimal tool in this case for choosing stopping condition
- Eff and Purity calculated for Pixel and Strip hits for entire track set

$$Eff = \frac{Num\ True\ Hits}{NumTrue\ Hits + Num\ Missing\ Hits}$$

$$Purity = \frac{Num\ True\ Hits}{NumTrue\ Hits + Num\ Fake\ Hits}$$

Stopping Condition



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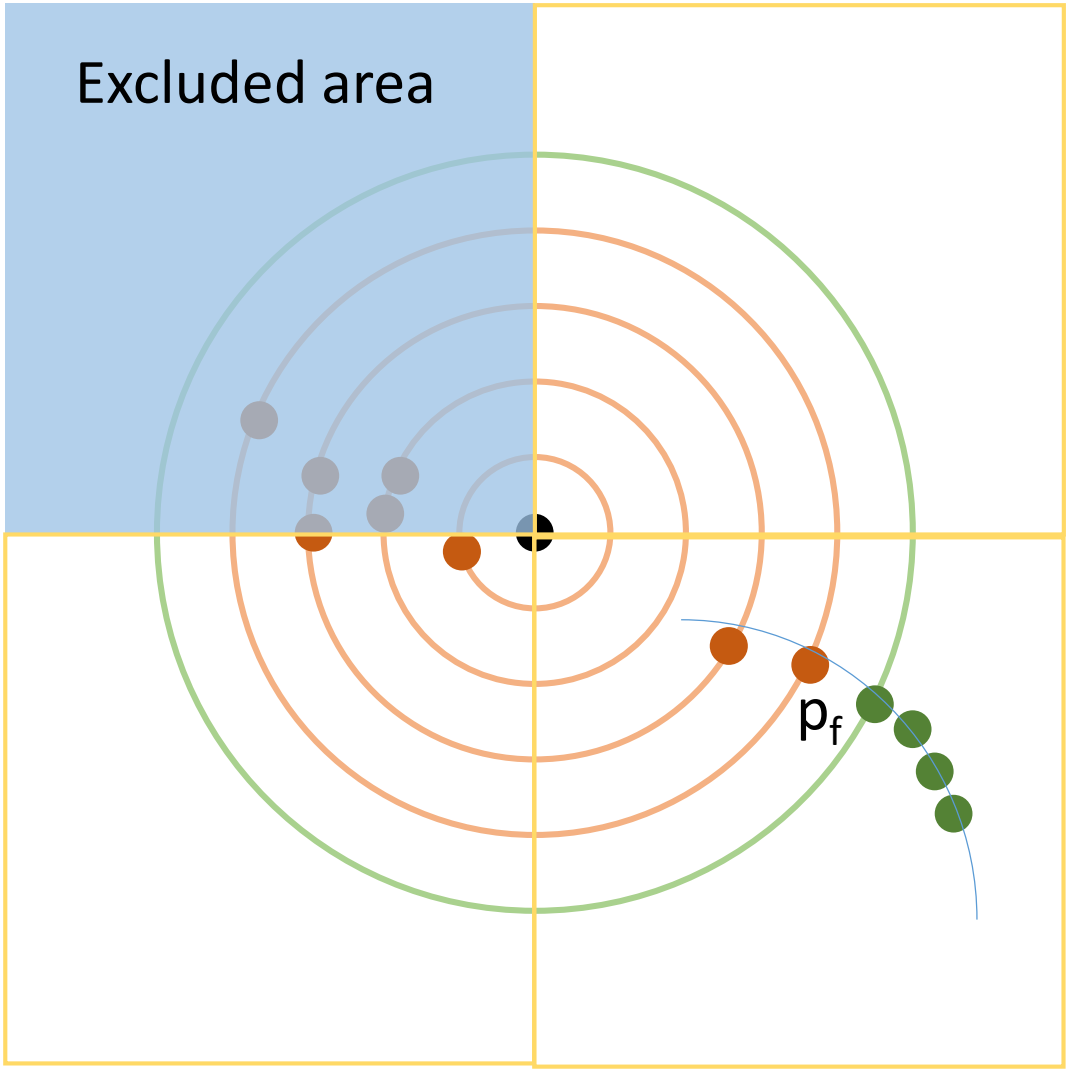
Area Exclusion



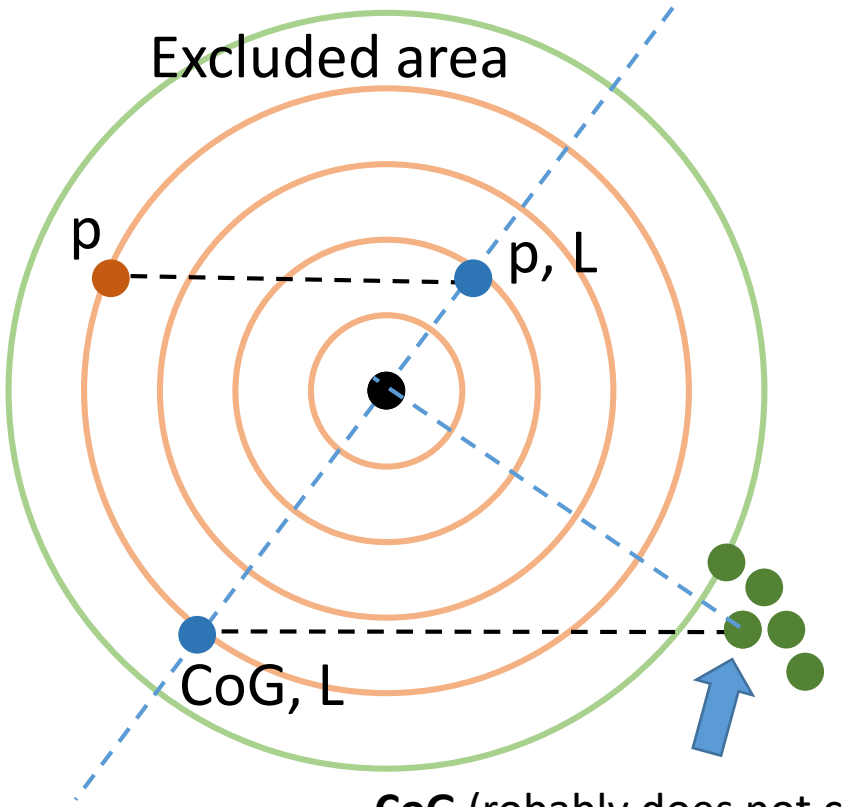
Method 1: Defining Quadrants

P_f: first hit in track
p: MVD hit to be tested

If $sign(x_{pf}) \neq sign(x_p)$ and $sign(y_{pf}) \neq sign(y_p)$
Reject Hit;
Else
Accept Hit;

Downsides of method:
"Non-adaptive" within the limits of the quadrants
Much power is given to only the first hit

Method 2: Defining Hemisphere



Calculate ***C***enter ***o***f ***G***ravity for all STT hits in track:

$$x_{CoG} = \sum_{i=0}^{N} \frac{x_i}{\sigma_{x_i}^2} \frac{1}{N}$$

$$y_{CoG} = \sum_{i=0}^{N} \frac{y_i}{\sigma_{y_i}^2} \frac{1}{N}$$

N – number of hits in track
x_i,y_i – 2D coordinate of hit i
σ_{xi}, σ_{xi} – uncertainty in coordinate

CoG (robably does not coincide with hit in track)

If p on opposite side of line L compared to CoG
Reject Hit;
Else
Accept Hit;

Upside of method:
Adaptive
Information from all hits taken into account

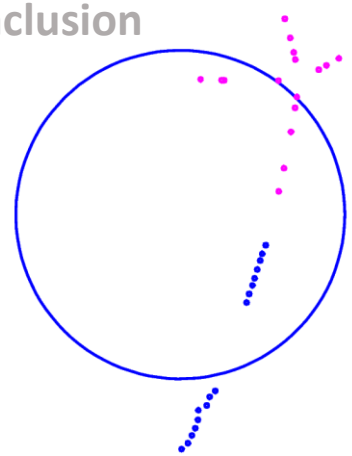
Mathematical derivations in Backup!

Weight of Hits

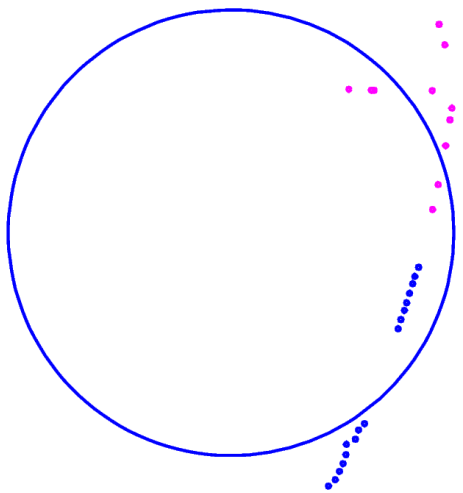
No Weights

Before MVD Hit Inclusion

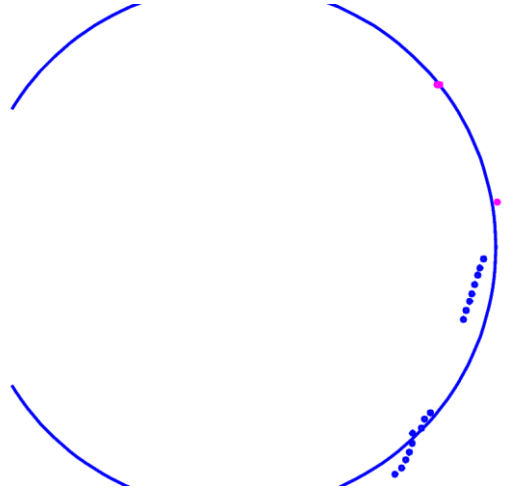
After MVD Hit Inclusion



After iteration 5

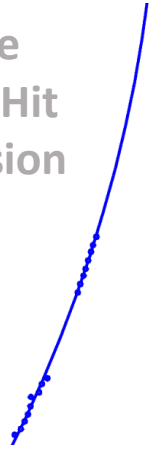


3 MVD Hits Left After iteration 13



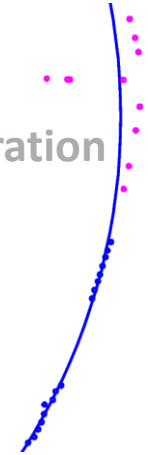
With Weight 10 corresponding to MVD hit uncertainty 0.1 cm

Before MVD Hit Inclusion



After MVD Hit Inclusion

After iteration 5



3 MVD Hits Left After iteration 13

Simulation Details for Results

- 10 000 DPM Events
- p_{beam} = 6.2 GeV/c
- Event Based digitization
- Reconstruction
  - SttCellTrackFinder with isochrone correction
  - P_z-finder with Recursive annealing fit
  - 3D Mvd Hit finder with weight = 10
- Quality Assurance
  - Standard Track Functor: ≥ 4 MVD or ≥ 6 MVD+STT+GEM hits

Results

	Pre-extrapolation	No Area Exclusion	Quadrant	Hemisphere
Number of possible tracks	29 493	29 493	29 493	29 493
Found Tracks:	11 347	9 503	9 648	10 574
Efficiency:	38 %	32 %	33 %	36 %

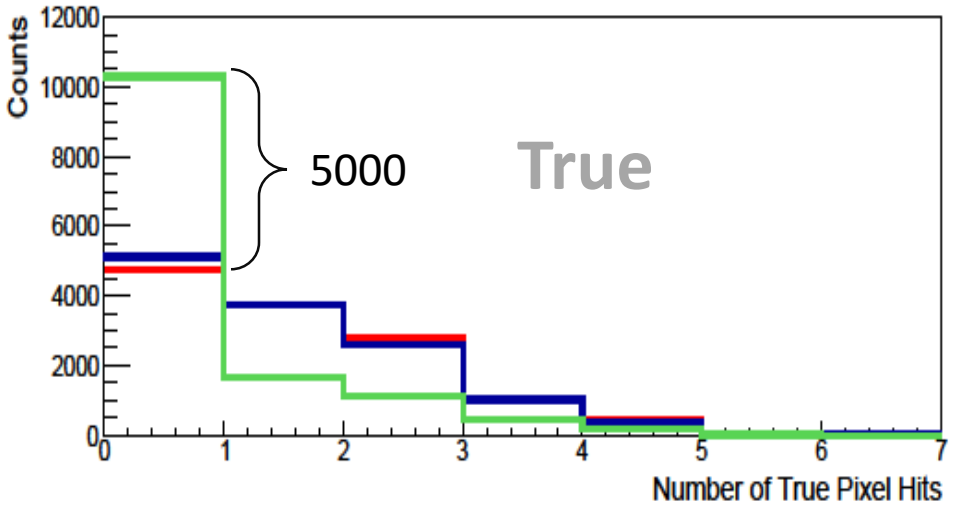
Track Category	Pre-extrapolation	No Area Exclusion	Quadrant	Hemisphere
Fully Pure	334	58	136	189
Fully Impure	0	0	0	0
Partially Pure	9 716	515	770	5 987
Partially Impure	1 297	8 930	8 742	4 398
Ghosts	1 489	4 056	3 871	2 579
Clones	1 932	1 915	1 919	1 924

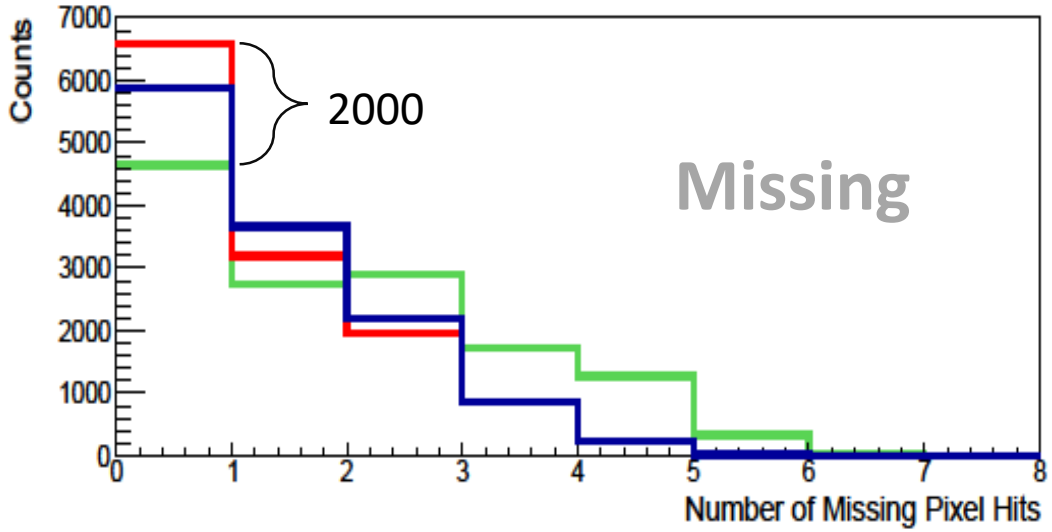
Main Improvements going from Quadrant to Hemisphere:

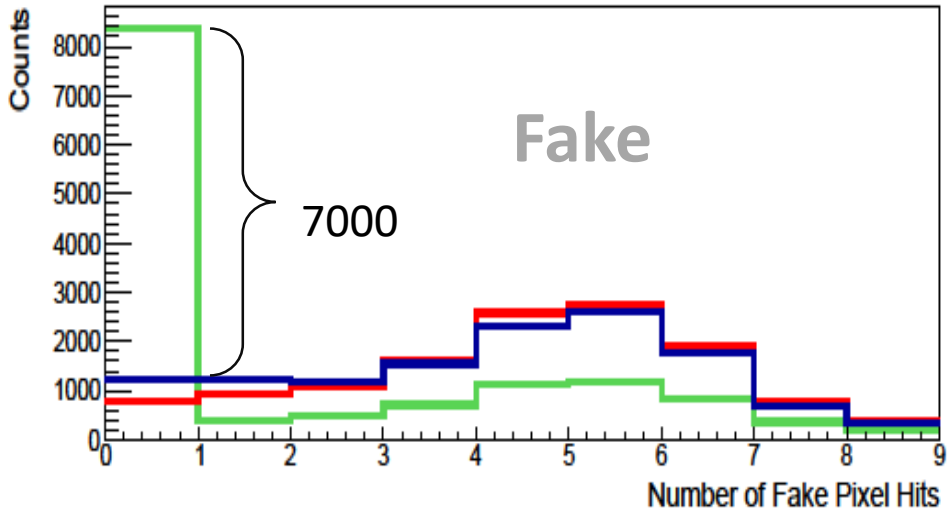
- Ghosts 13.1 % → 8.7 %
- More than half of all partially impure tracks pushed to partially pure category

Hit finding efficiency, pixels

No area excluded
Quadrant excluded
Hemisphere excluded



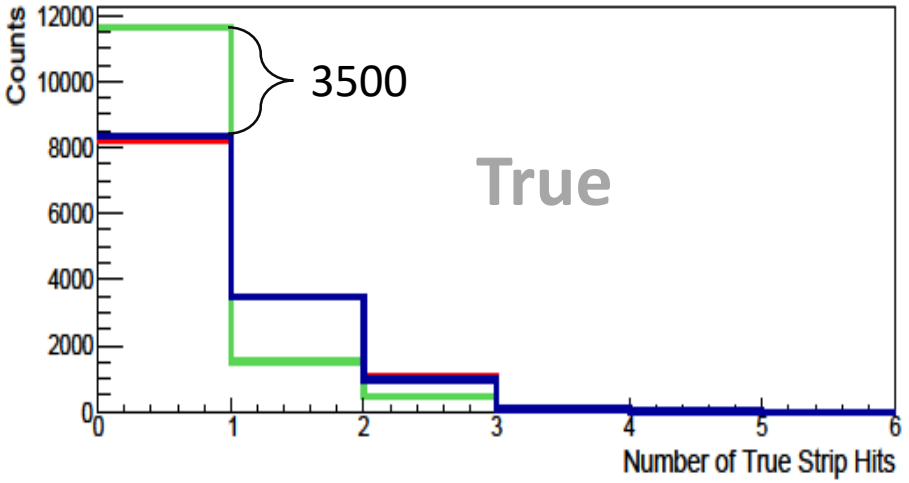


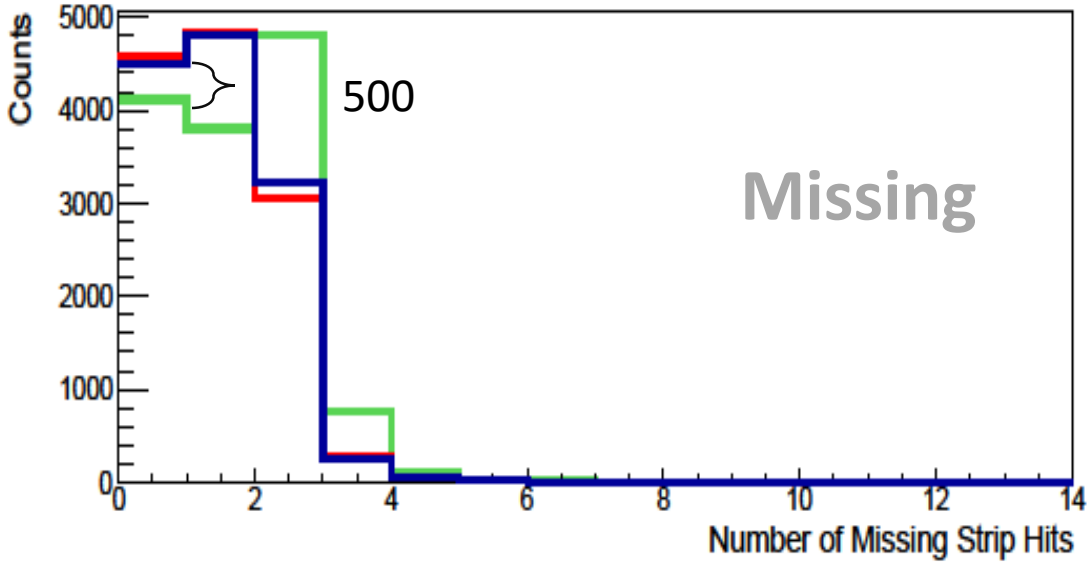


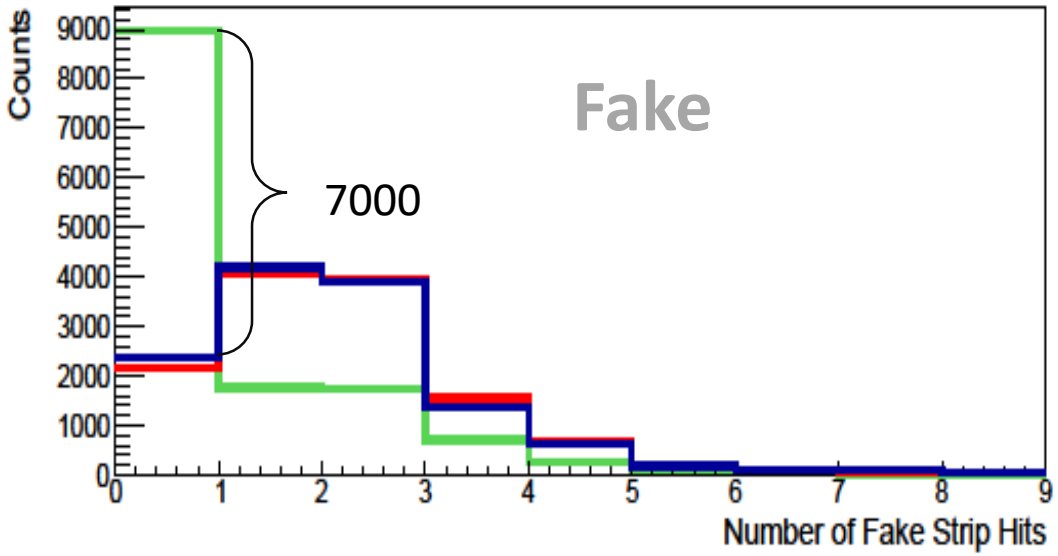
- Number of true hits/track somewhat reduced with hemisphere-method
- **Fake hits/track greatly reduced with hemisphere-method**
- Number of missing hits/track does not drastically increase with this method

Hit finding efficiency, strips

No area excluded
Quadrant excluded
Hemisphere excluded







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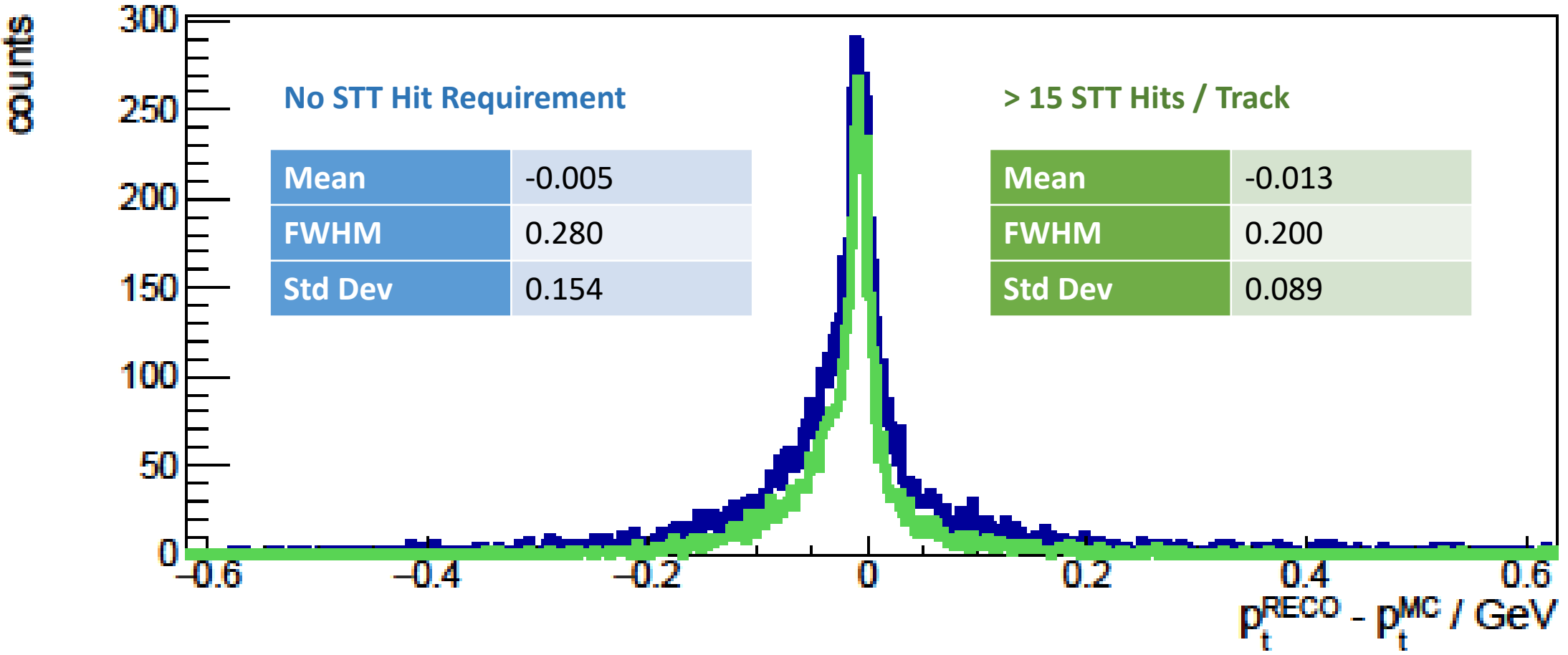
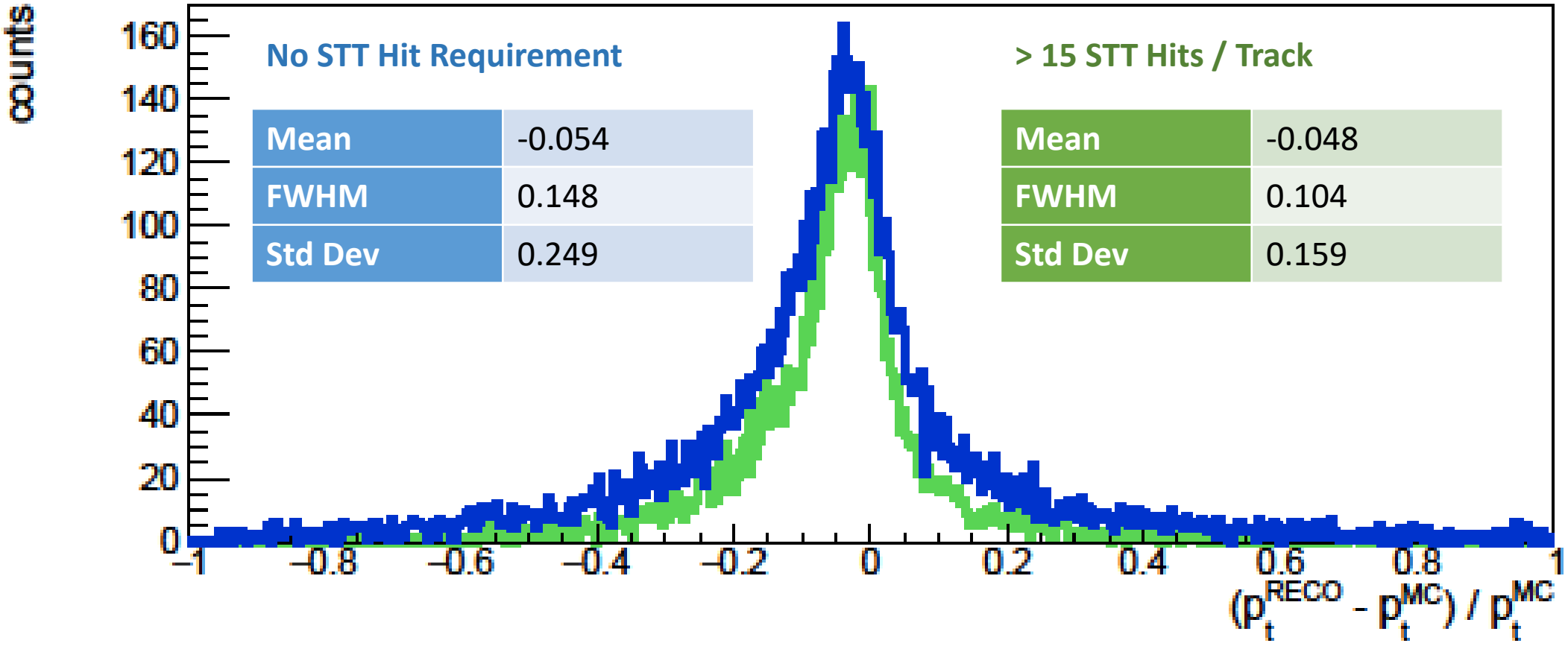
Transverse Momentum Resolution



Relative Transverse Momentum Resolution



Summary

- SttCellTrackFinder: Momentum resolution of tracks with > 15 hits tend to be better than for shorter tracks
- 2D and 3D methods have been developed for assigning MVD hits to tracks reconstructed in other detectors. Optimizations needed

Outlook

- Memo currently in progress
- Code cleanup and merging
- Improve the hit finding purity and efficiency by combining the extrapolation method with local hit clustering in the MVD
- Use together with a primary (=suitable mainly for tracks from IP) track finder

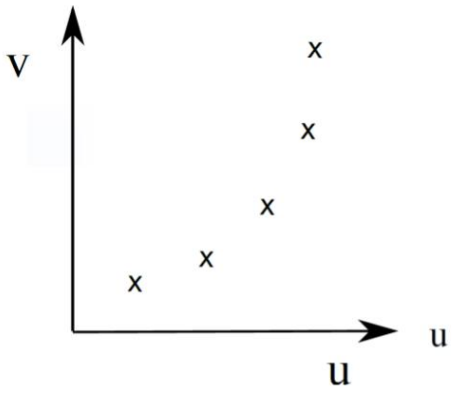
Summary

- SttCellTrackFinder: Momentum resolution of tracks with > 15 hits tend to be better than for shorter tracks
- 2D and 3D methods have been developed for assigning MVD hits to tracks reconstructed in other detectors. Optimizations needed

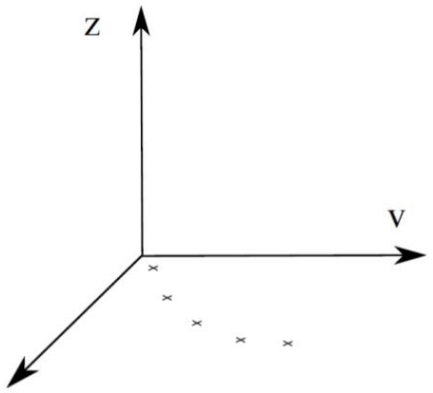
Thank You!

Backup

The Riemann Fit

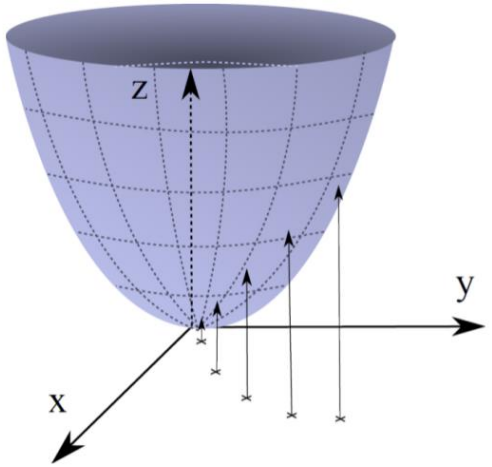


Points to be fitted



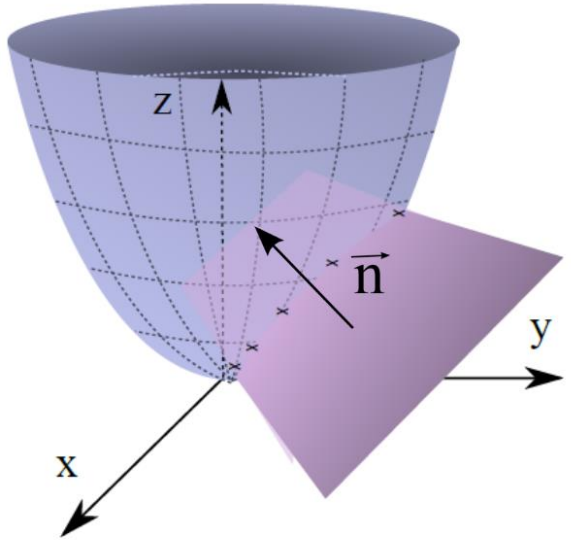
Add z-dimension

For STT, u=x, v=y



Map onto paraboloid

$z=x^2+y^2$



Calculation of plane through 3D points

simple eigenvalue determination

From $\vec{n}$, cirlcle parameters are known:

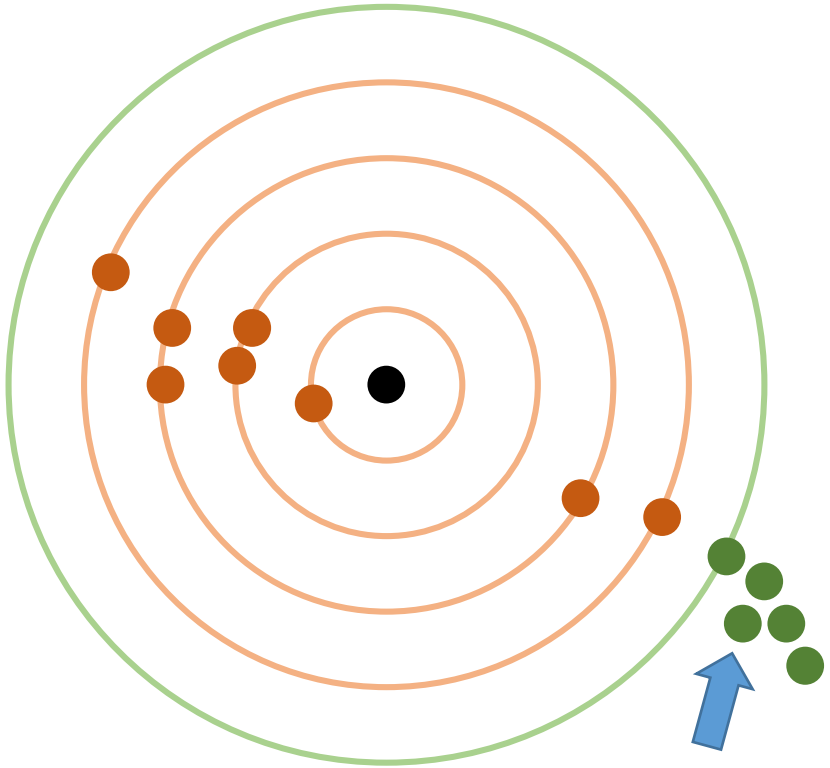
$$u_0 = -\frac{n_1}{2n_3}$$
$$v_0 = -\frac{n_2}{2n_3}$$

Circle center

$$\rho^2 = \frac{1 - n_3^2 - 4cn_3}{4n_3^2}$$ Radius

$c+n_1x+n_2y+n_3z=0$

Method 2: Defining Hemispheres

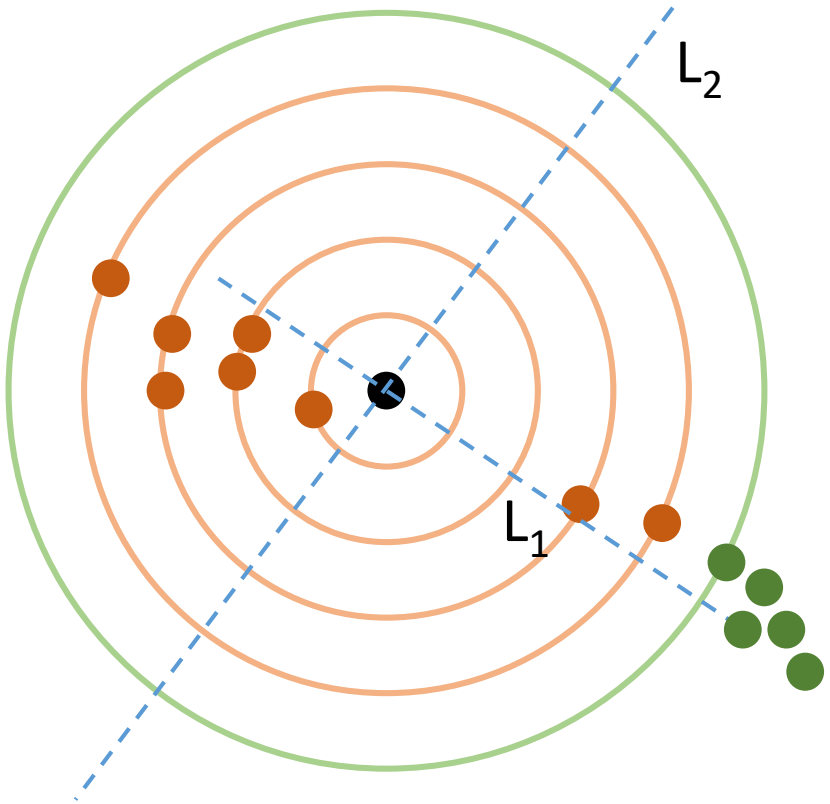


Calculate ***C***enter ***o***f ***G***ravity for all STT hits in track:

$$x_{CoG} = \sum_{i=0}^{N} \frac{x_i}{\sigma_{x_i}^2} \frac{1}{N}$$

$$y_{CoG} = \sum_{i=0}^{N} \frac{y_i}{\sigma_{y_i}^2} \frac{1}{N}$$

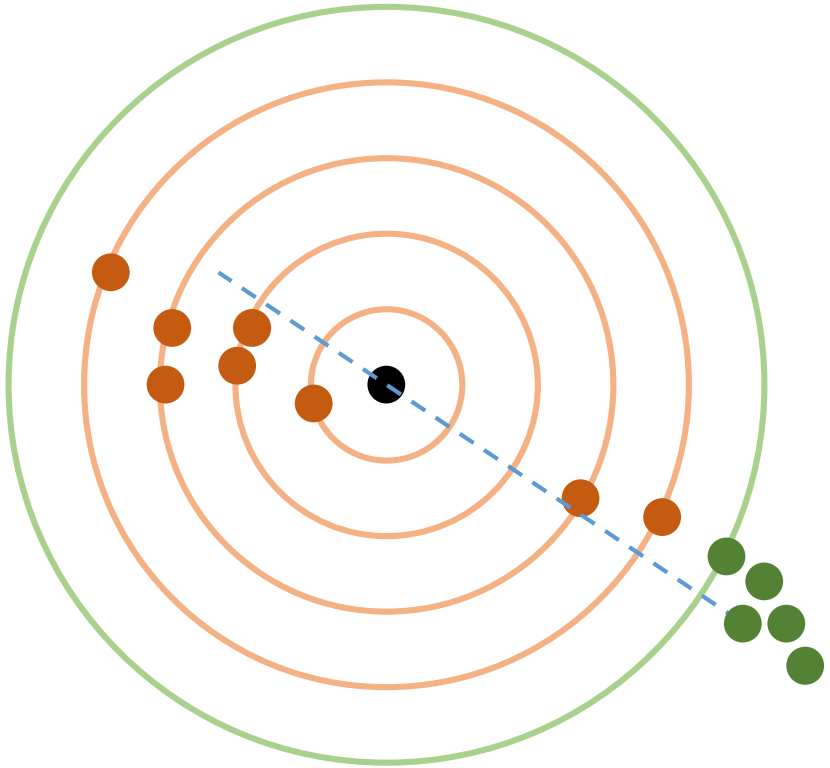
CoG (robably does not coincide with a hit in the track)



L_1: $y = \frac{y_{CoG}}{x_{CoG}} x$

L_2: $y = -\frac{x_{CoG}}{y_{CoG}} x$

Slope of L2 =-1/L1 since they are perpendicular



Calculate Center of Gravity for all STT hits in track:

$$x_{CoG} = \sum_{i=0}^{N} \frac{x_i}{\sigma_{x_i}^2} \frac{1}{N}$$

$$y_{CoG} = \sum_{i=0}^{N} \frac{y_i}{\sigma_{y_i}^2} \frac{1}{N}$$

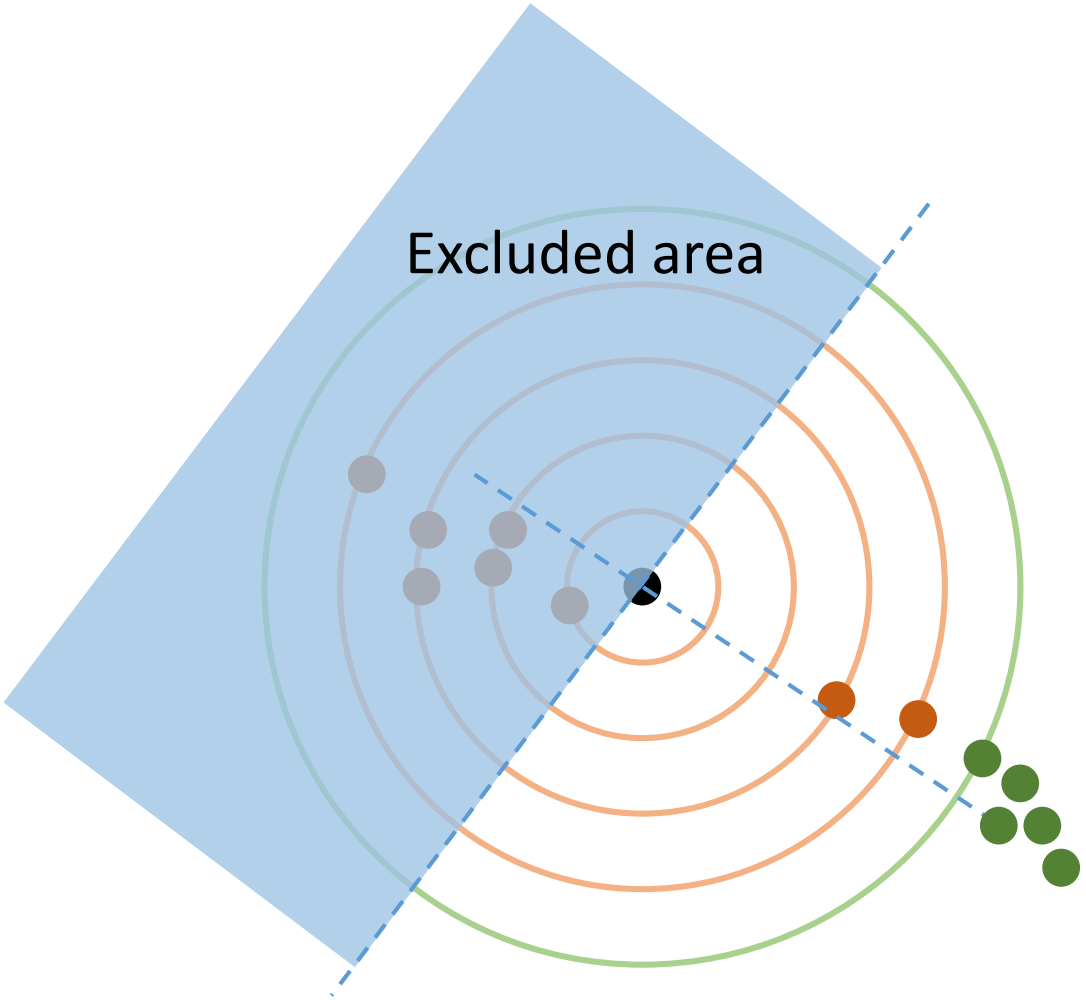
Find line going through CoG and Origin:

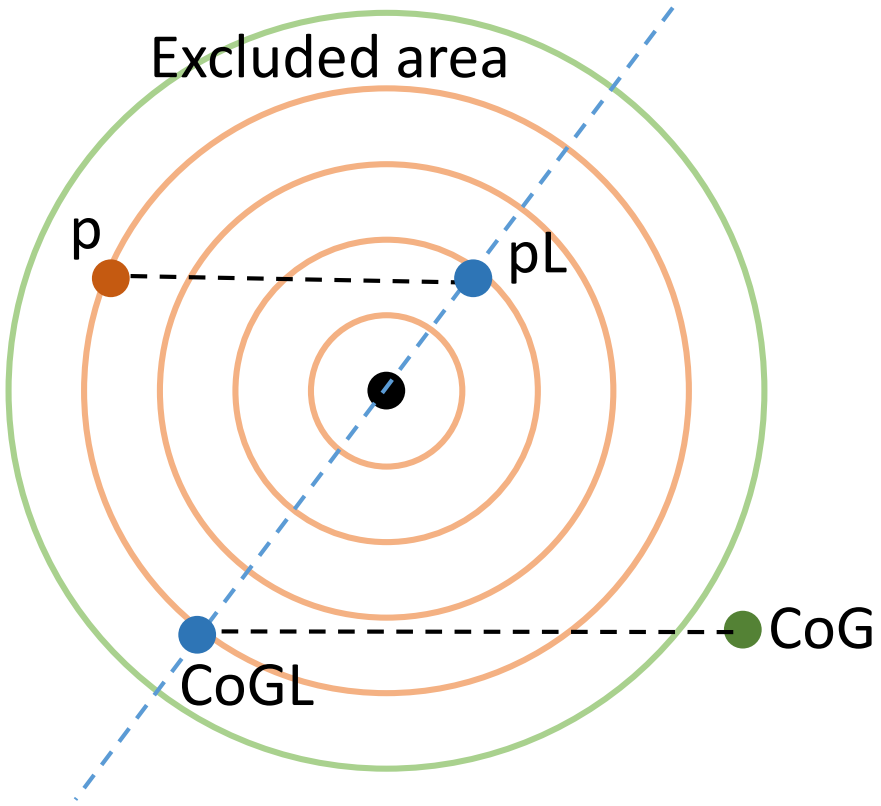
$$y = kx + m \rightarrow$$

$$y = \frac{y_1 - y_2}{x_1 - x_2} x + m$$

m=0 (line going through origin)

$$y = \frac{y_1}{x_1} x = \frac{y_{CoG}}{x_{CoG}} x$$


Excluded area



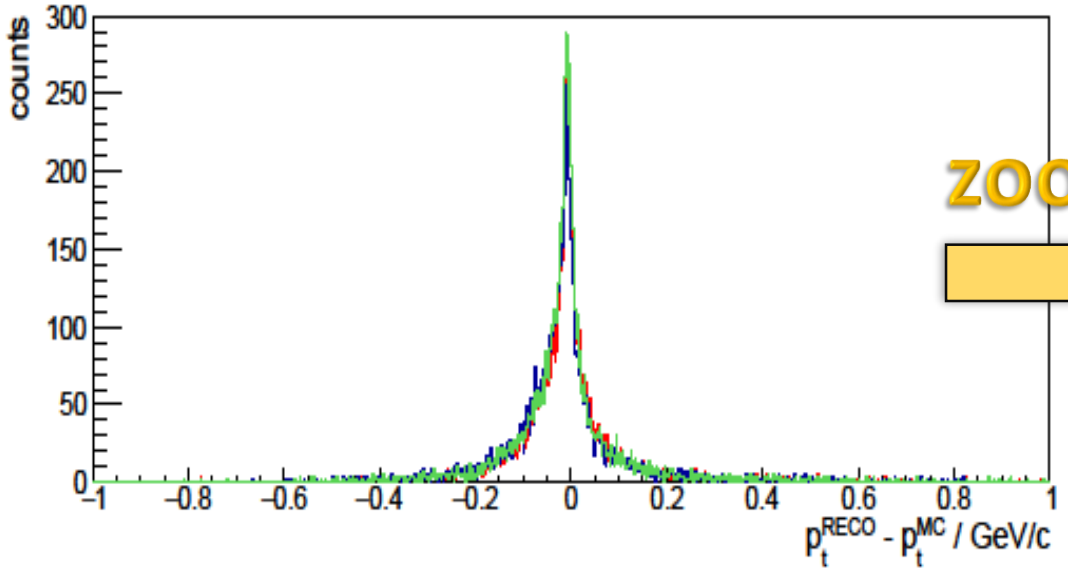
$$y = -\frac{x_1}{y_1}x \rightarrow x_{pL} = -\frac{y_1}{x_1}y_p$$

$$y = -\frac{x_1}{y_1}x \rightarrow x_{CoGL} = -\frac{y_1}{x_1}y_{CoG}$$

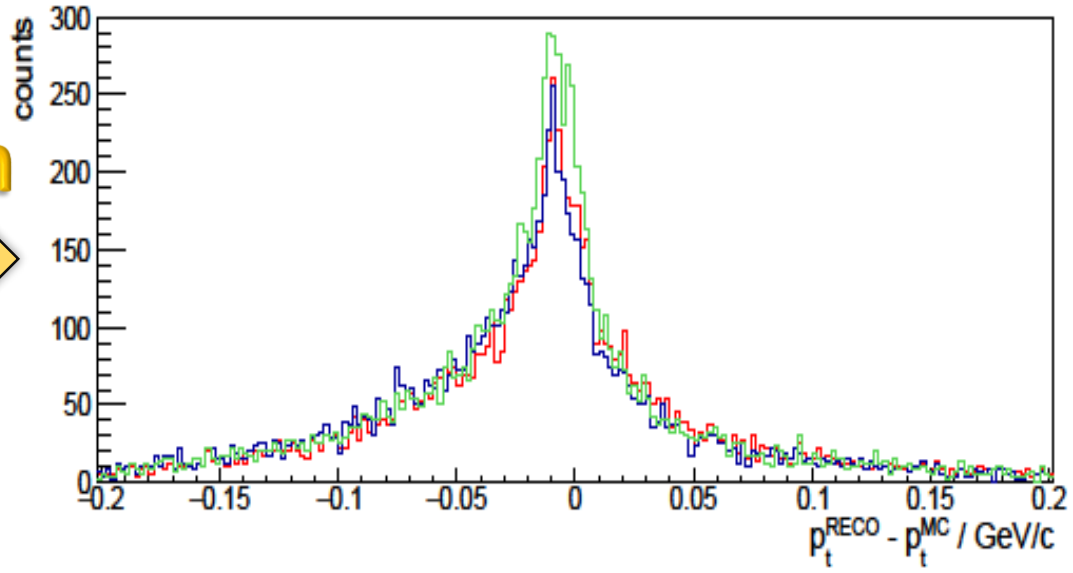
If $sign(x_{pL}-x_p)=sign(x_{CoGL}-x_{CoG})$
Accept Hit;
If $(x_{pL}-x_P)=0$ or $(x_{CoGL}-x_{CoG})=0$
Accept hit;
Else
Reject Hit;

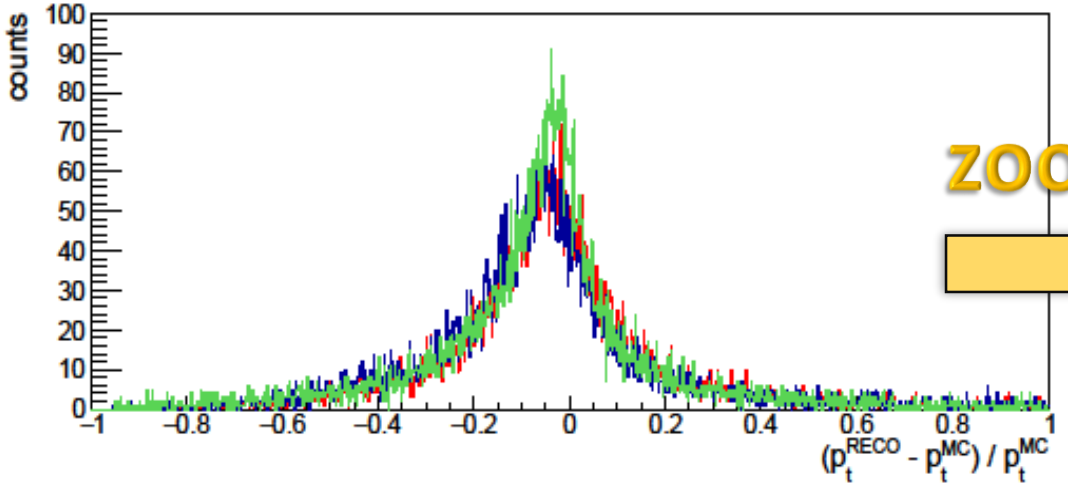
Momentum Resolutions

No area excluded
Quadrant excluded
Hemisphere excluded

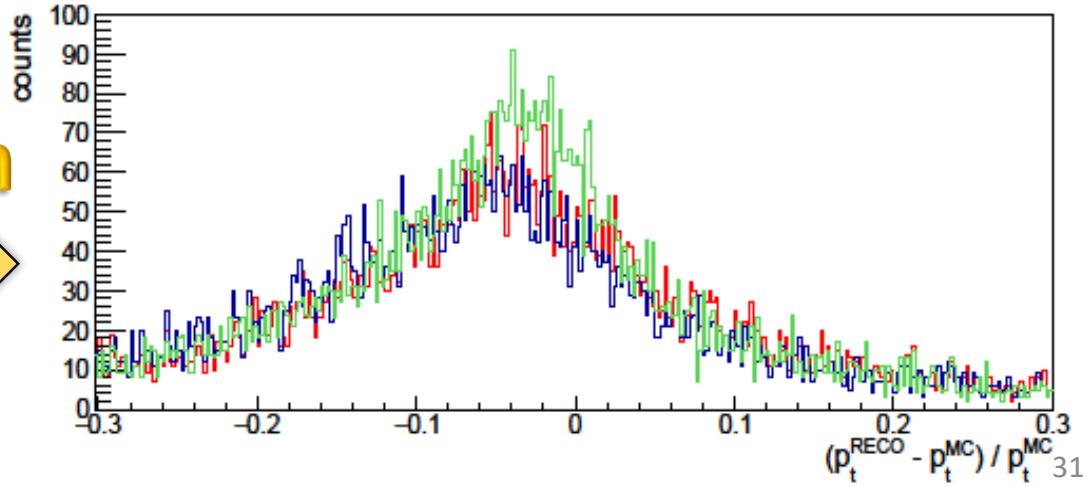


zoom



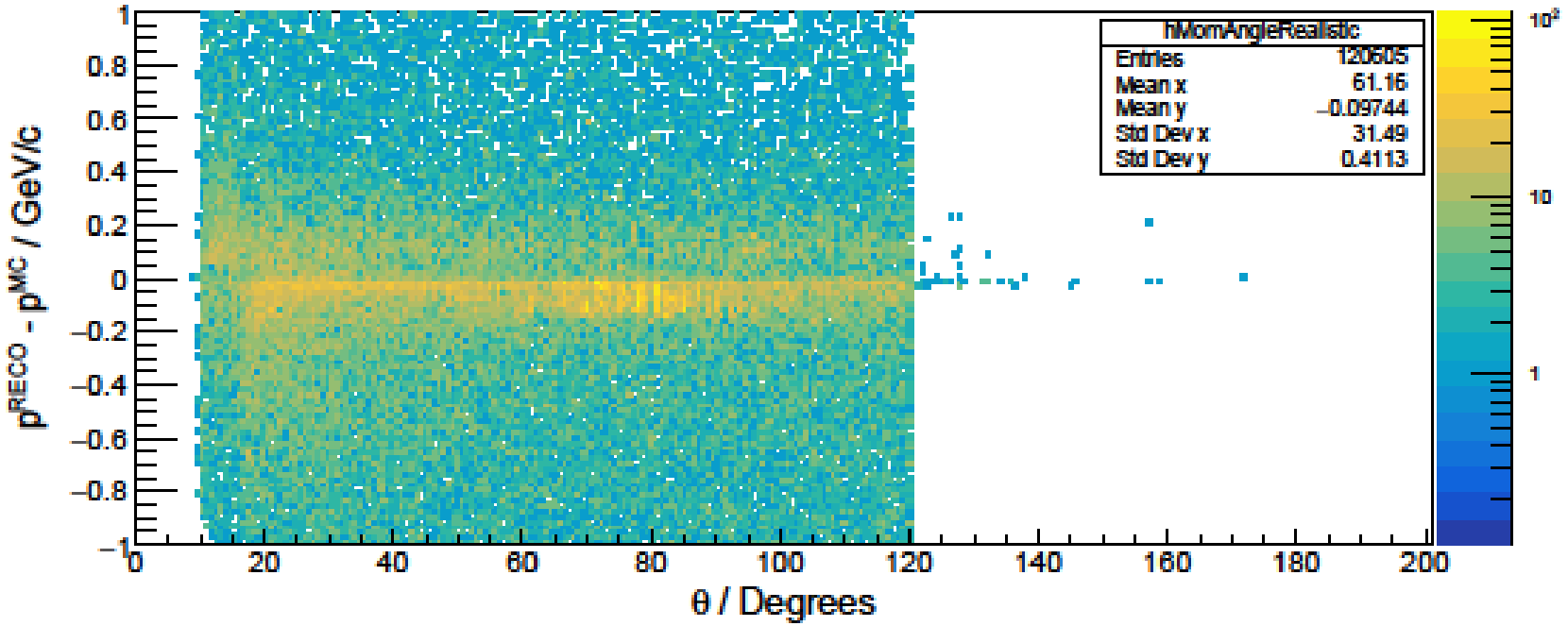


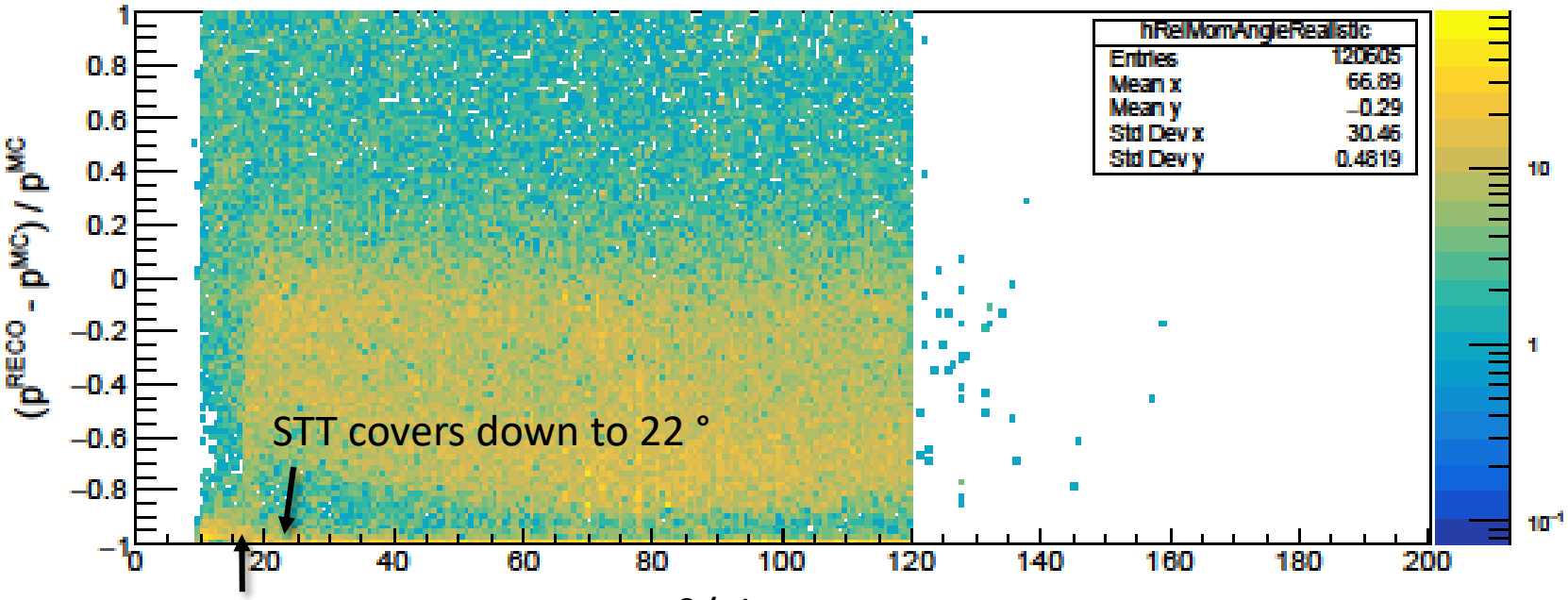
zoom



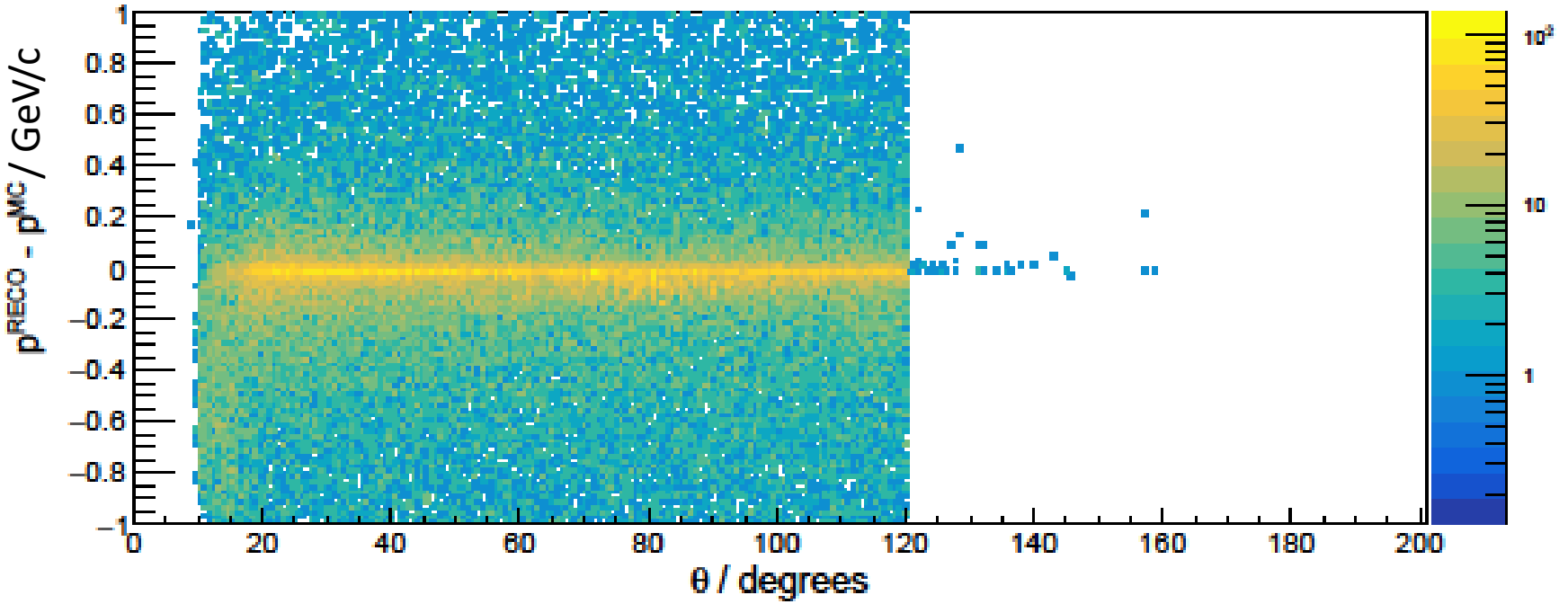
No Isochrones

- Not use as first cut
- Use as refining momentum resolution if needed

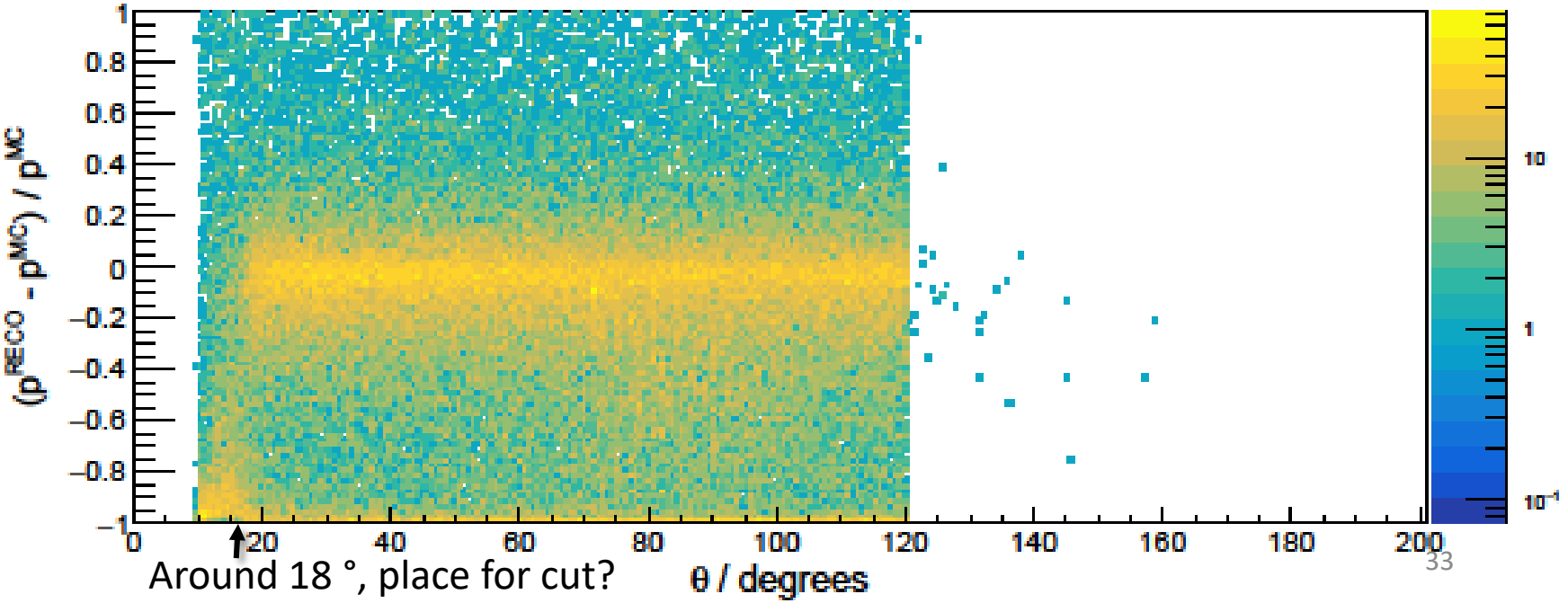




Isochrones



- Not use as first cut
- Use as refining momentum resolution if needed



Around 18 °, place for cut?