FPGA helix tracking algorithm with STT

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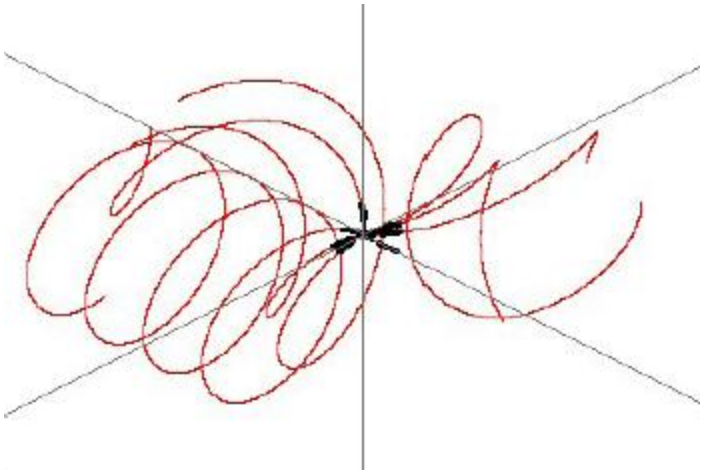
Motivation

- Finding helix shaped tracks in the magnetic field
- Implement the algorithm on FPGA, as part of the online trigger for PANDA



Method: Using transformations to simplify calculations

Helical track → circle in 2D (momentum←→radius) → straight line(by conformal transformation) → obtain line parameters(by Hough transformation)

Based on David's previous work (using MC truth position as input), we studied the performance of the algorithm using information from STT detector.

As the first step:
Only consider the XY plan now (no stereo layers used),
Study in C++ on PC.

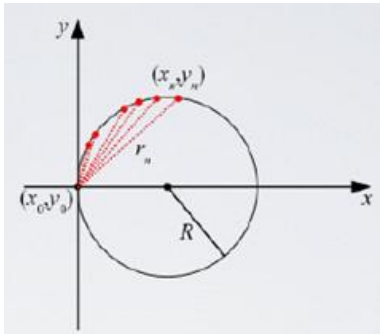
Conformal Transformation

Used for projection perpendicular to the beam direction

Transform circles to straight lines

$$x' = \frac{x - x_0}{r^2}$$

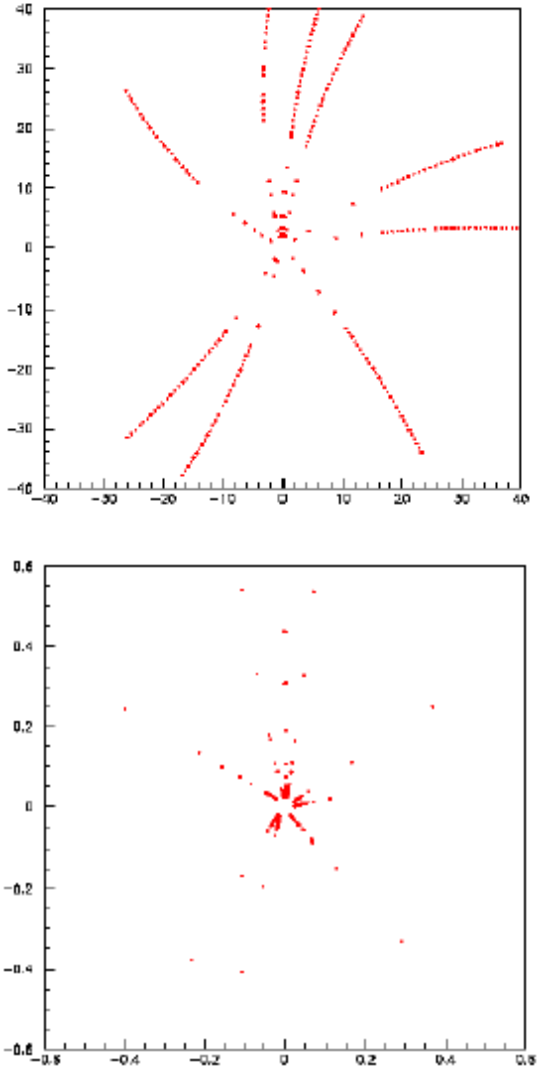
$$y' = \frac{y - y_0}{r^2}$$



$$r^2 = (x - x_0)^2 + (y - y_0)^2$$

Finding straight lines is less complex than finding circles

Transform circles to straight lines



Hough Transformation

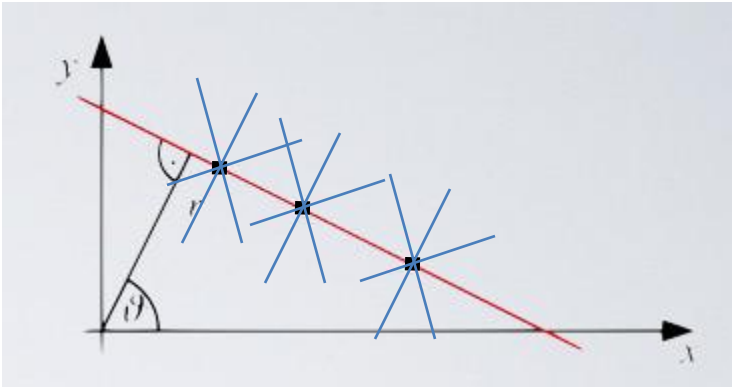
Describing points in real space by parameters

For lines: $y = mx + b$

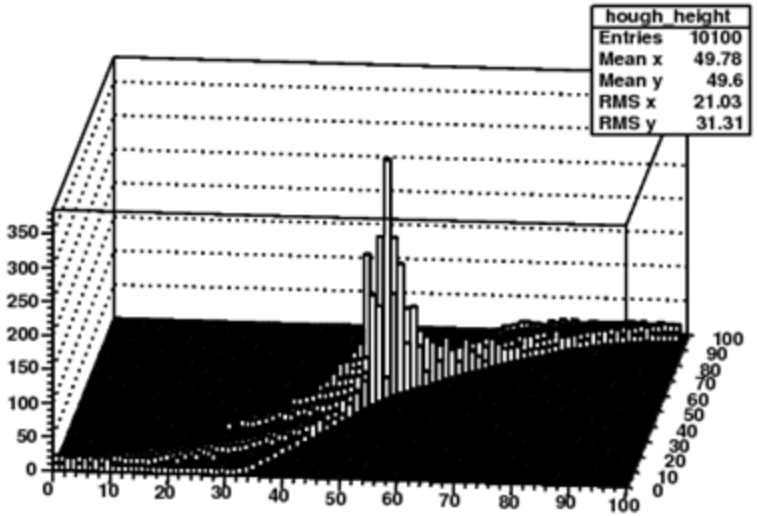
$(x1, y1), (x2, y2), \ldots \rightarrow (m,b)$

or (r, θ)

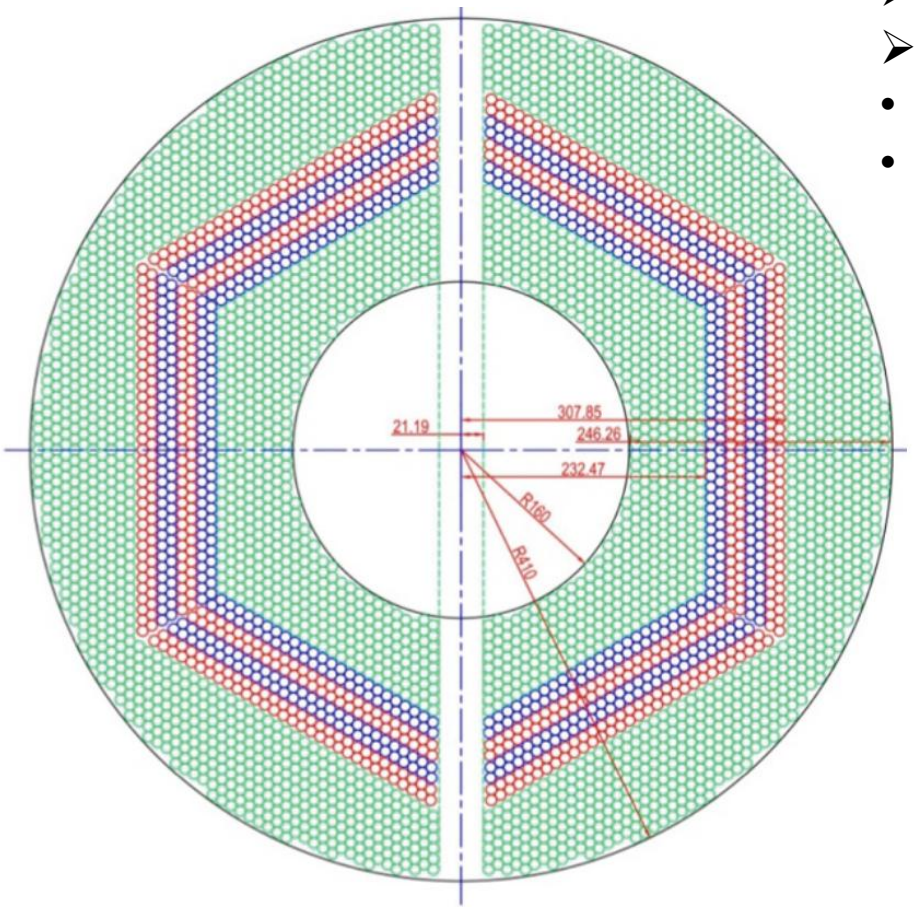
$R = x \cos(\theta) + y \sin(\theta)$



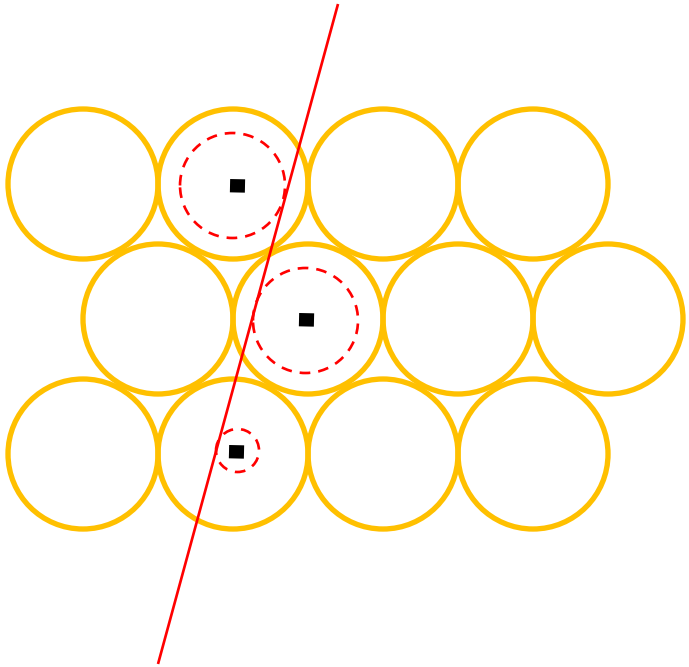
- Use all possible angles
- Save data in histogram
- Peaks in histogram represent possible lines in point set



Straw Tube Tracker (STT)



- ➢4636 Straw tubes
- ➢23-27 planar layers
- 15-19 axial layers(green) in beam direction
- 4 stereo double-layers for 3D reconstruction, with ±2.89 skew angle(blue/red)



From STT : Wire position + drift time

Three cases used in this study

1. Ideal case: Use MC truth position.
   The previous algorithm uses this MC truth position as input.

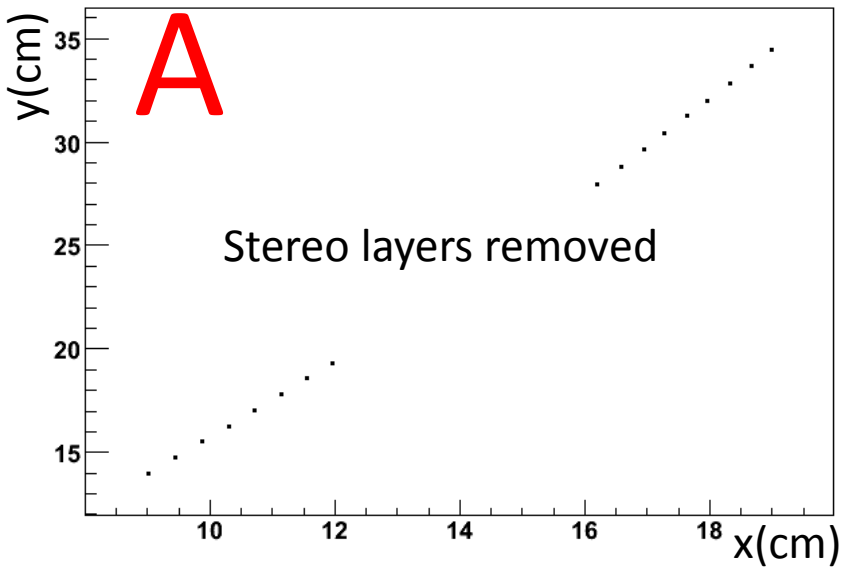
2. Worst case: Use only wire position of STT

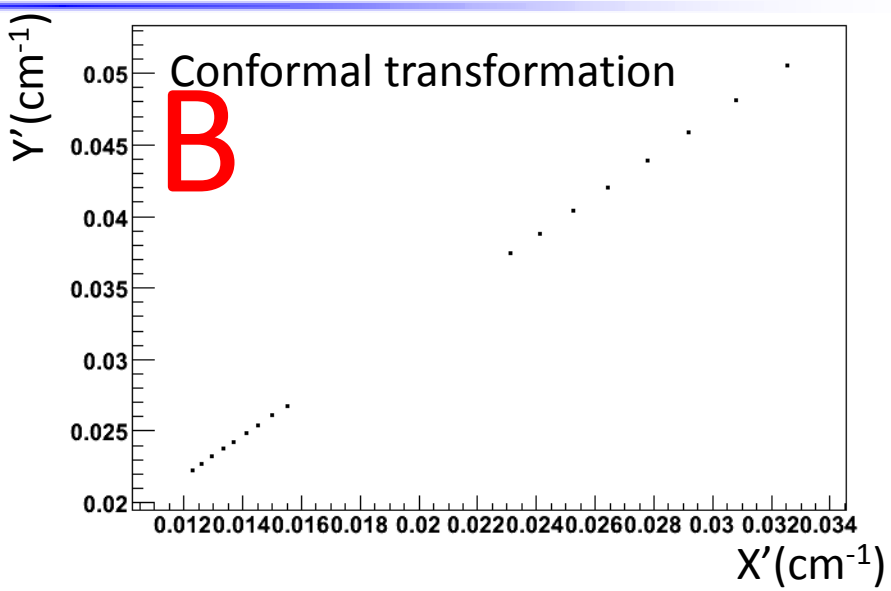
3. Realistic case: Use drift distance information from drift time.

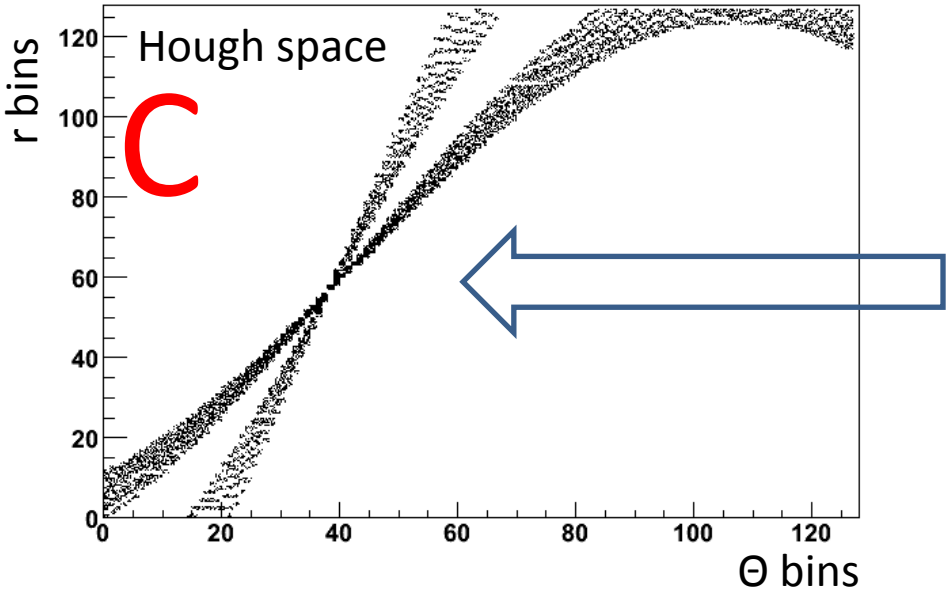
   First Method
   - method A
   - method B

   Second Method

One example using MC truth position from STT – Ideal case

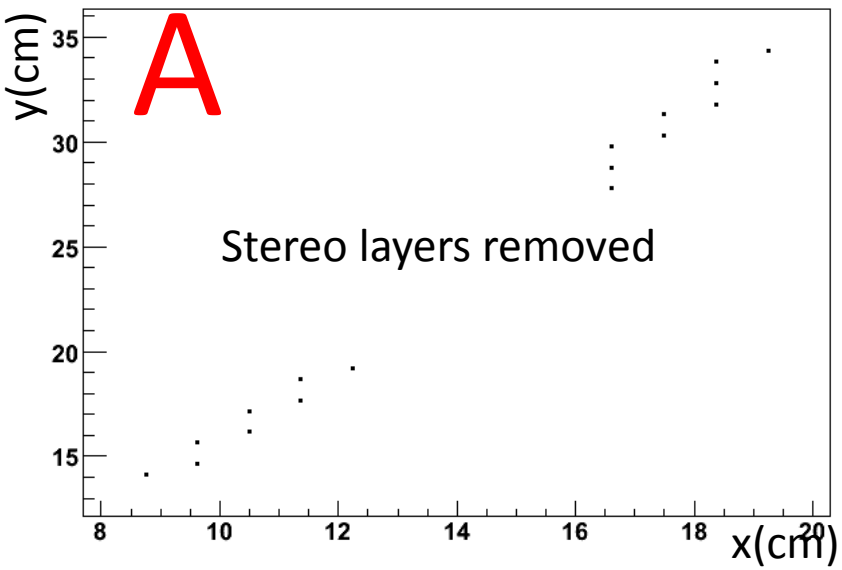


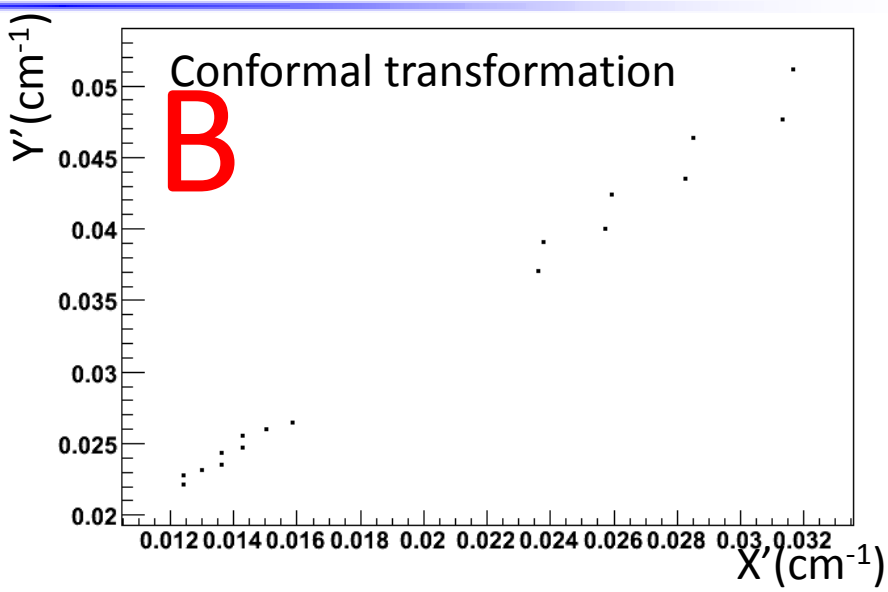


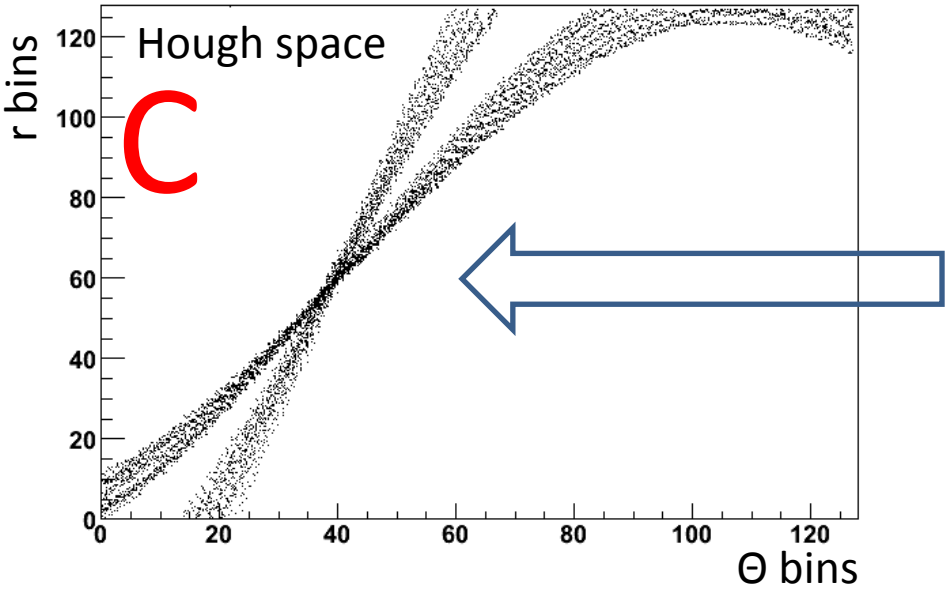


The cross point forms peak in histogram

One example using wire position of STT – worst case

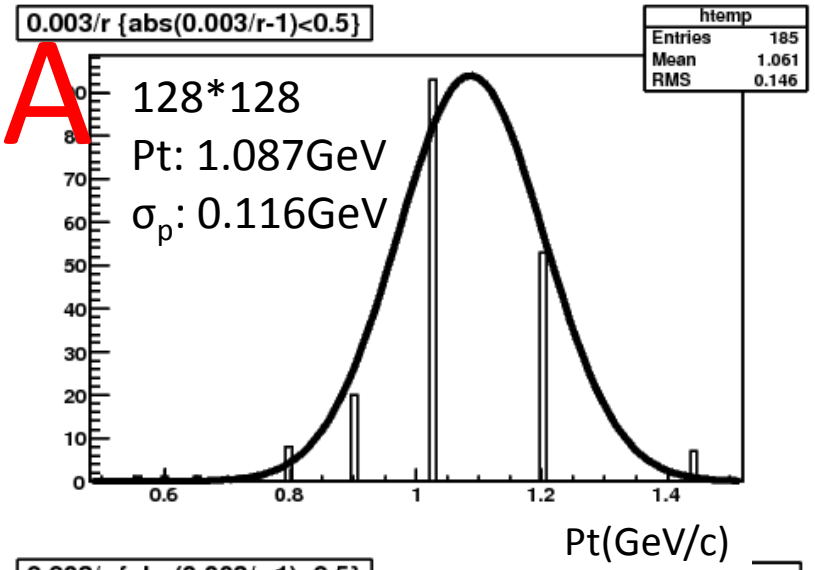


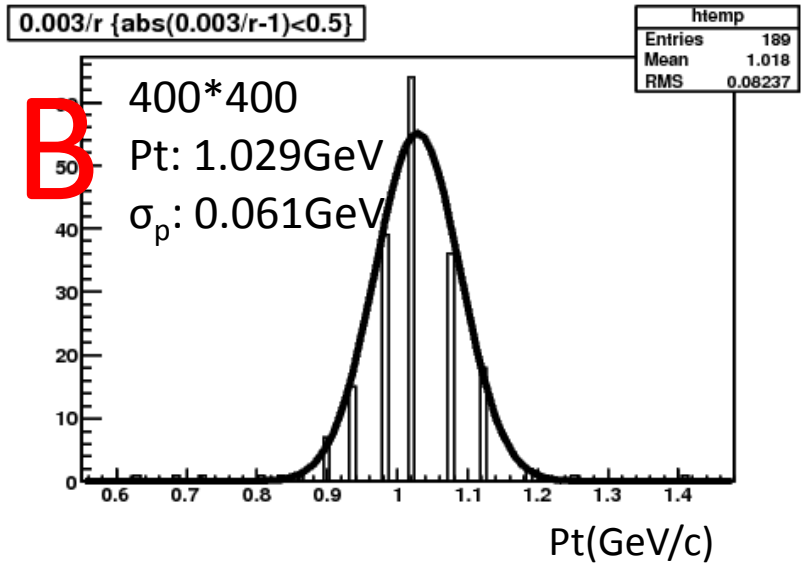


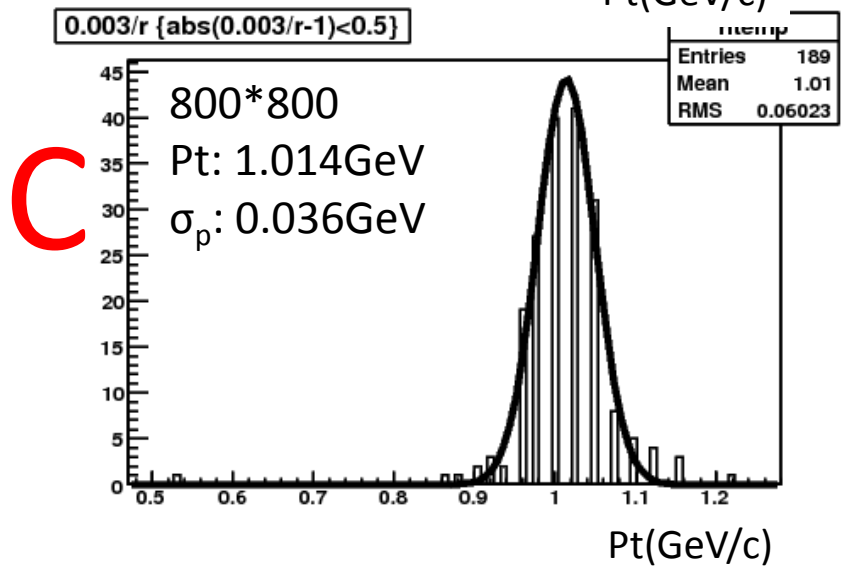


The cross point still exist, but more broad.

Momentum resolution using MC truth – varying bin size of Hough space





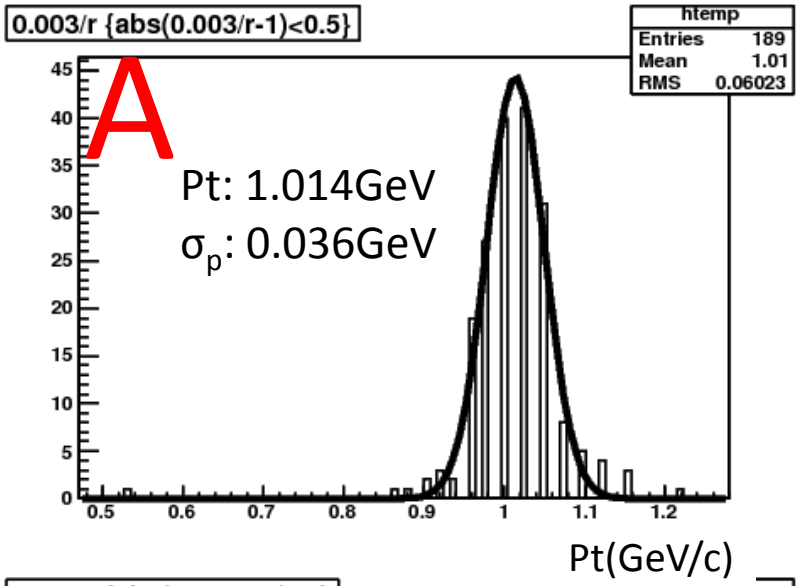


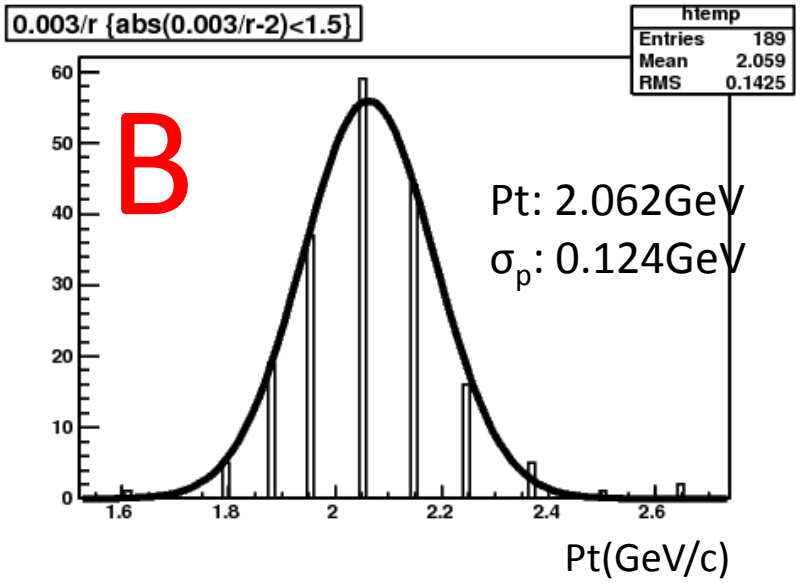
Input: single mu+, 200 events
Pt: 1GeV, θ(15,120), Φ(0,360)

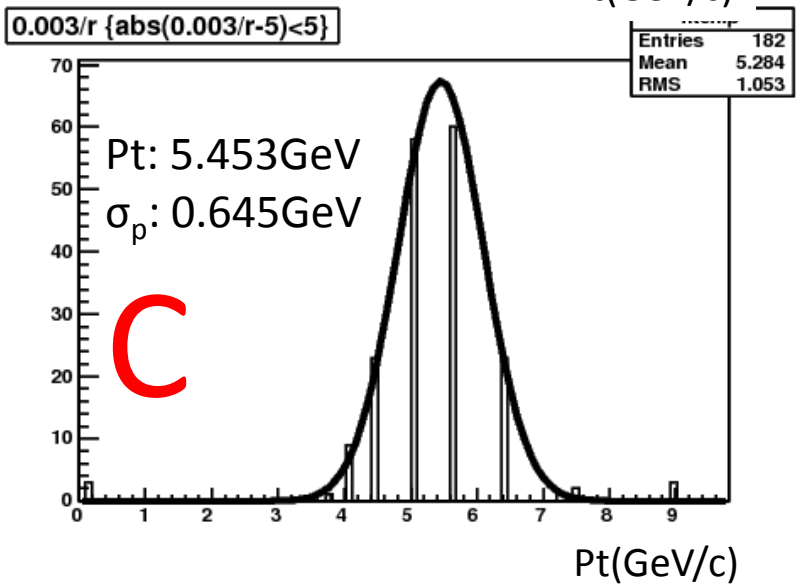
Using MC truth position in a straw tube.
Only pick up the highest bin in each event

The momentum resolution improves obviously using more bins.

Momentum resolution using MC truth – varying Pt







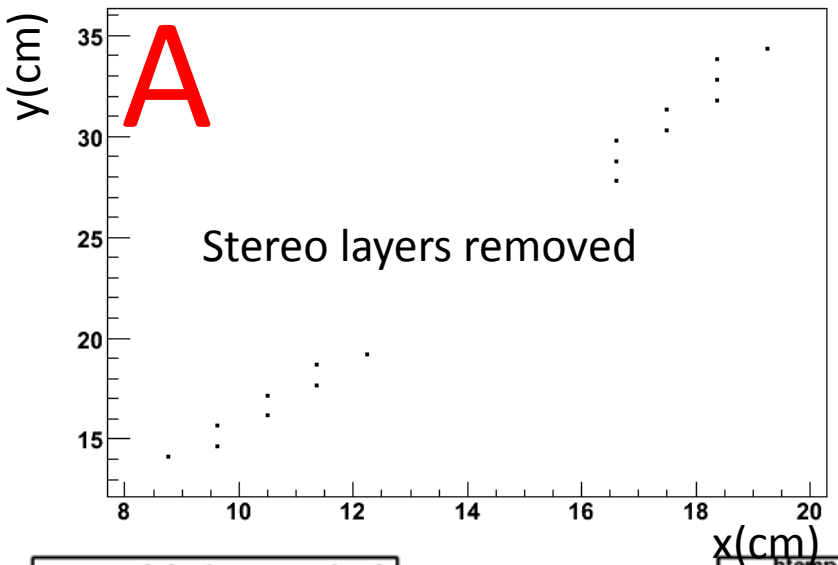
Momentum resolution:

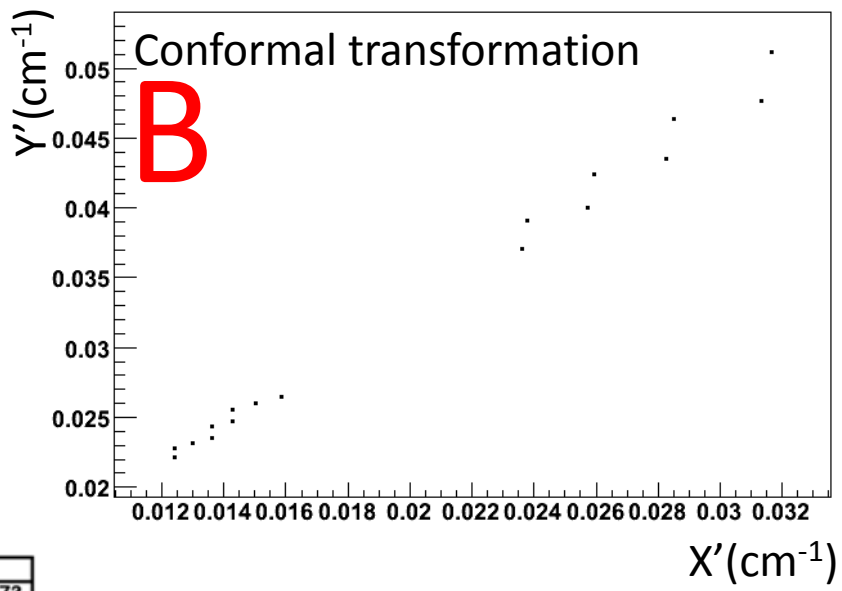
1GeV: ~3.6%

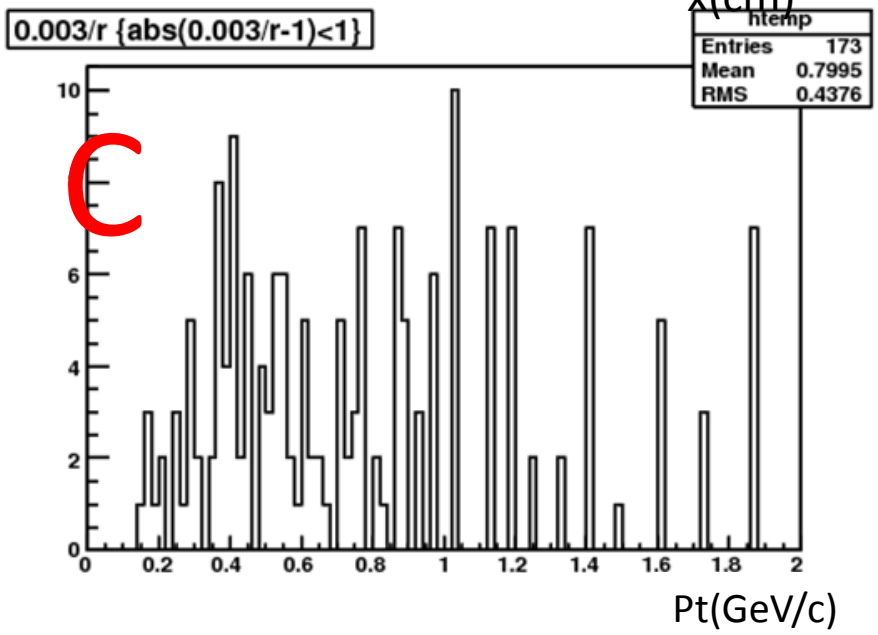
2GeV: ~6.2%

5GeV: ~12.9%

Performance of using STT information– only wire position





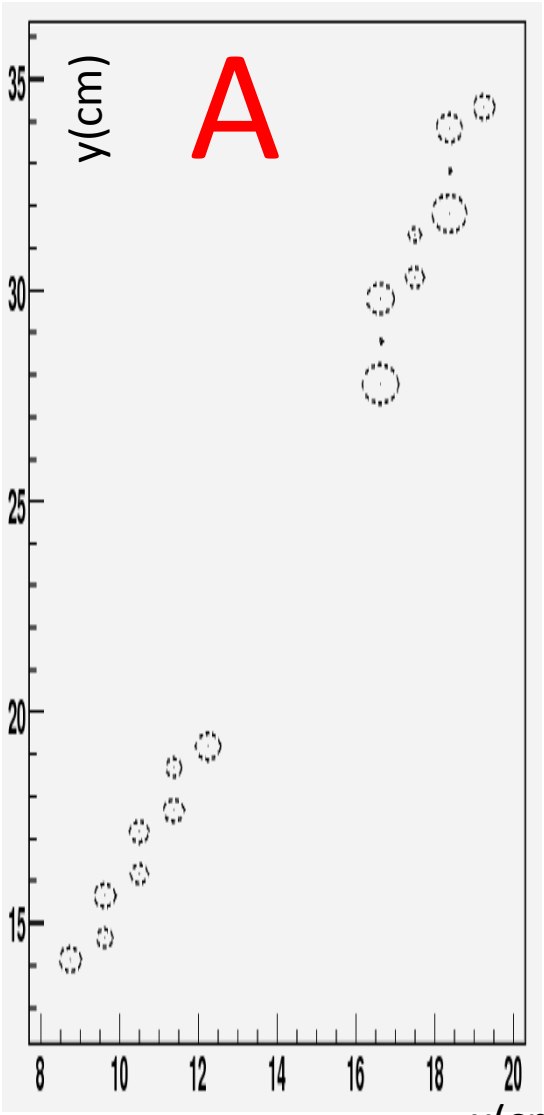


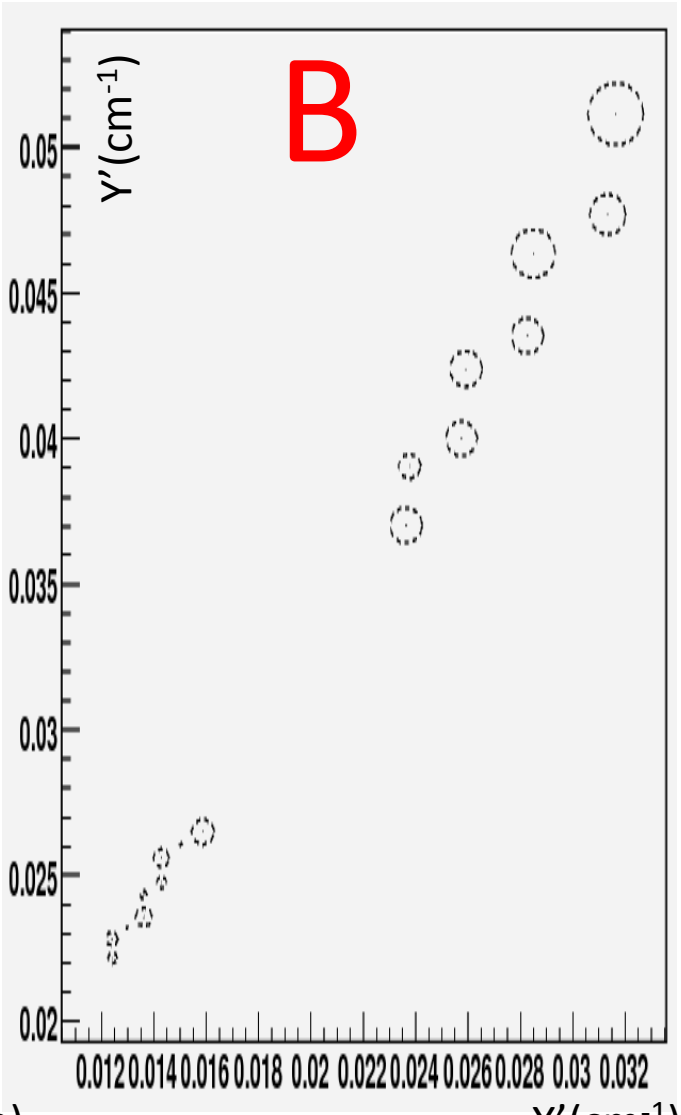
Input: single mu+, 200 events
Pt: 1GeV, θ(15,120), Φ(0,360)

Using STT center position only.
Only pick up the highest bin in each event

The output momentum is too bad.

Attempt to include drift distance



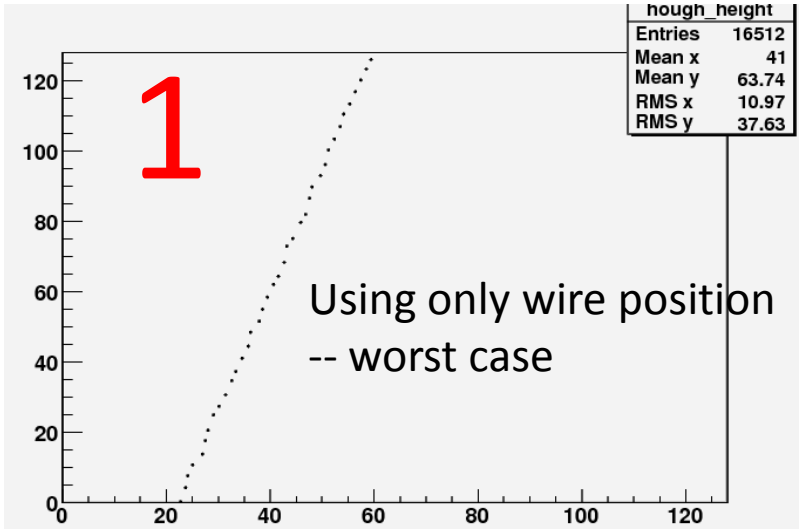


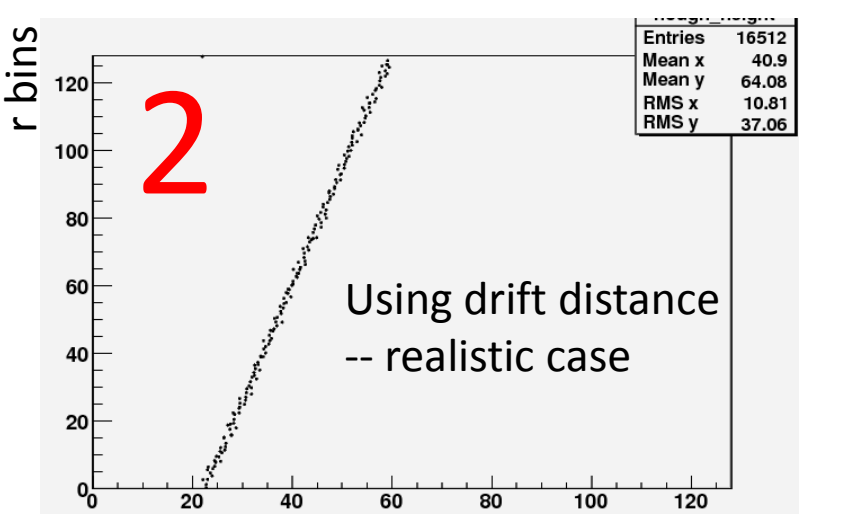
Method:
(x_center, y_center) ± (drift distance)

Conformal:
(x', y') ±(error)

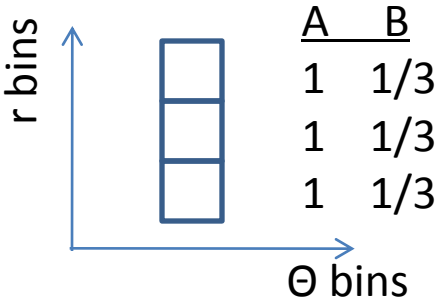
Hough:
Before: Θ -> r
Now: Θ -> r ± Δr

Attempt to include drift distance



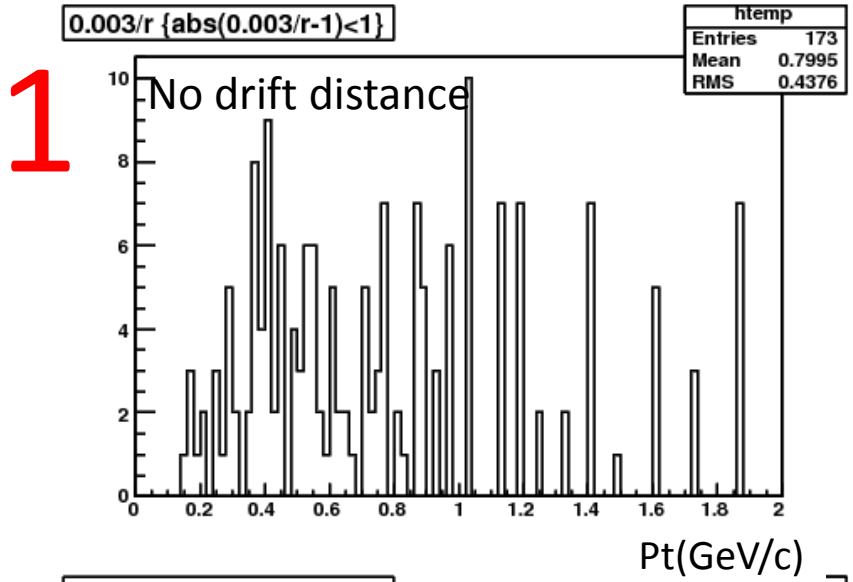


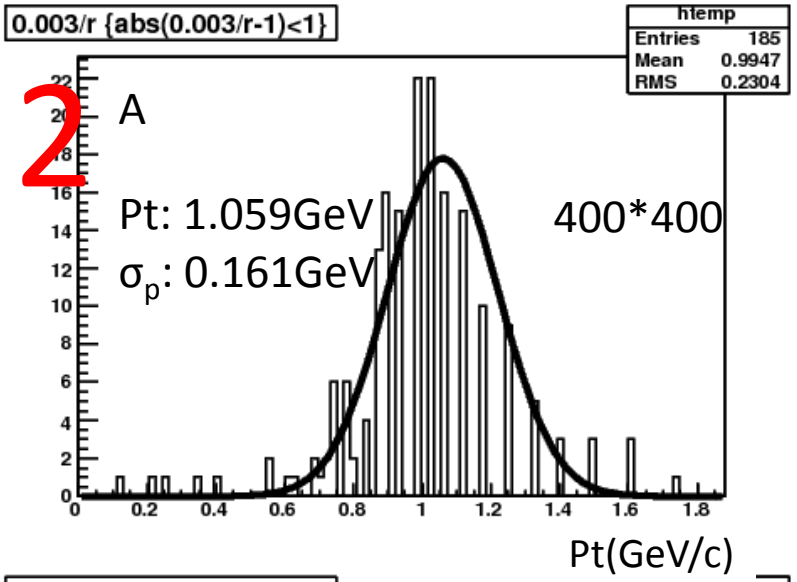
Two ways to fill the histogram:
A: fill "1" to each possible (Θ, r) bin
B: fill a weighted value 1/N_r(Θ) to each bin possible (Θ, r). N_r(Θ) stands for the number of r bins need to fill at Θ angle.

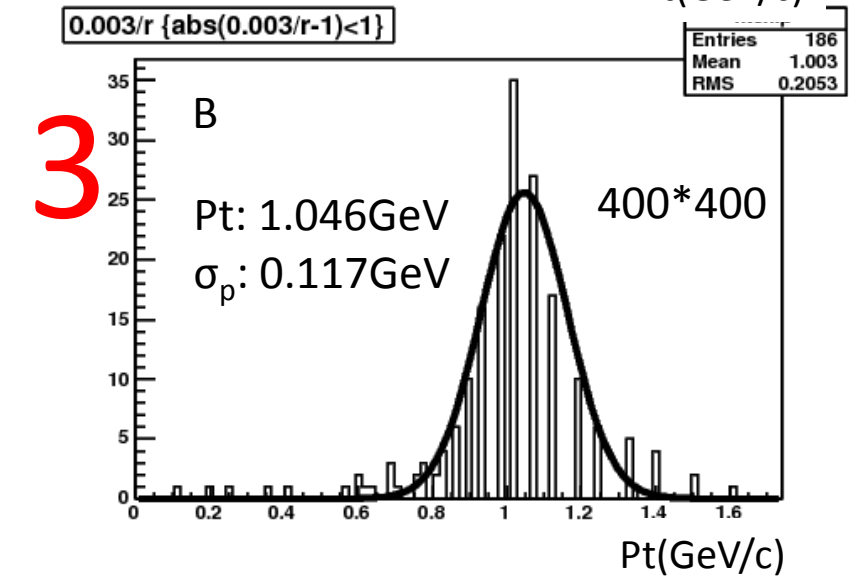


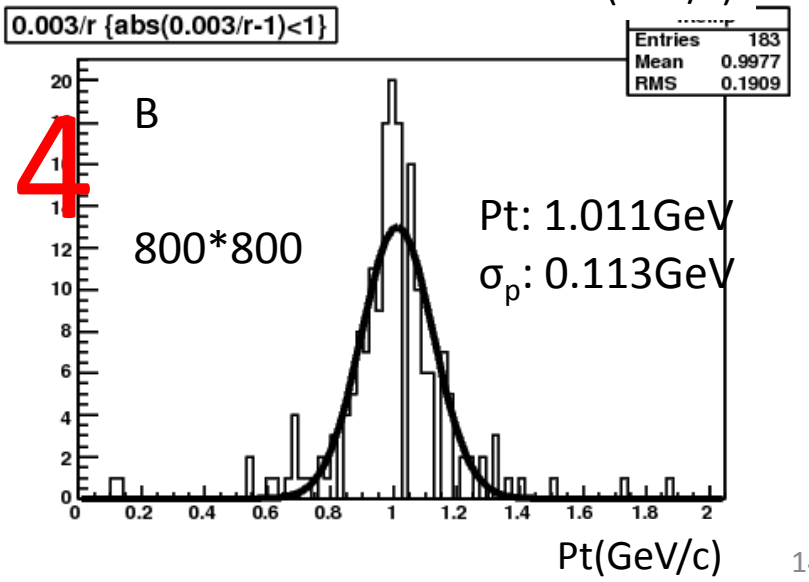
A	B
1	1/3
1	1/3
1	1/3

Different methods of using drift distance



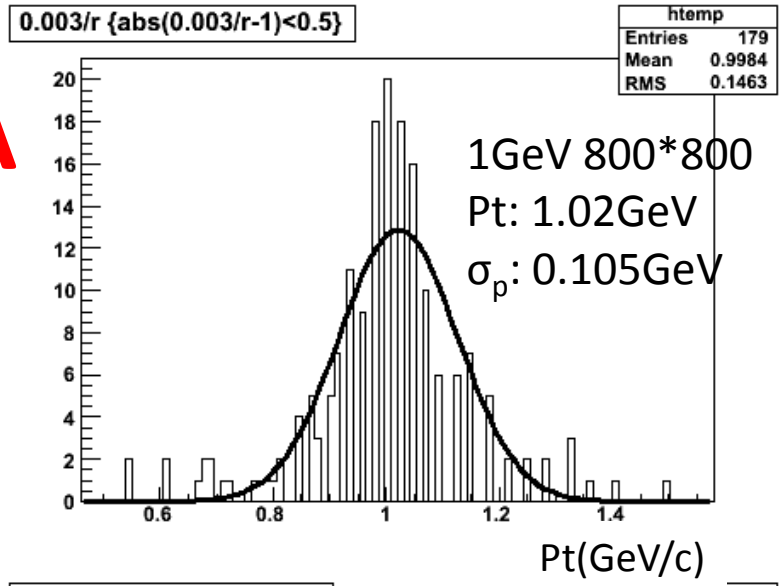






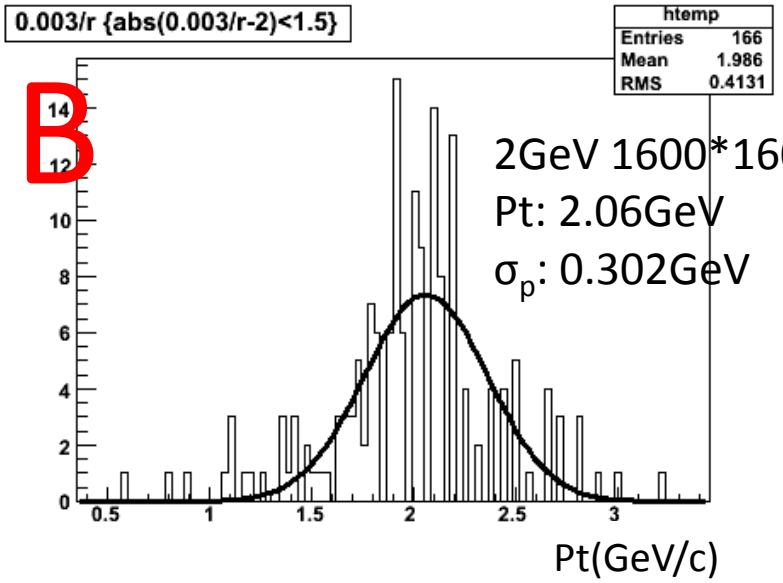
Momentum resolution using STT— drift distance method B

A



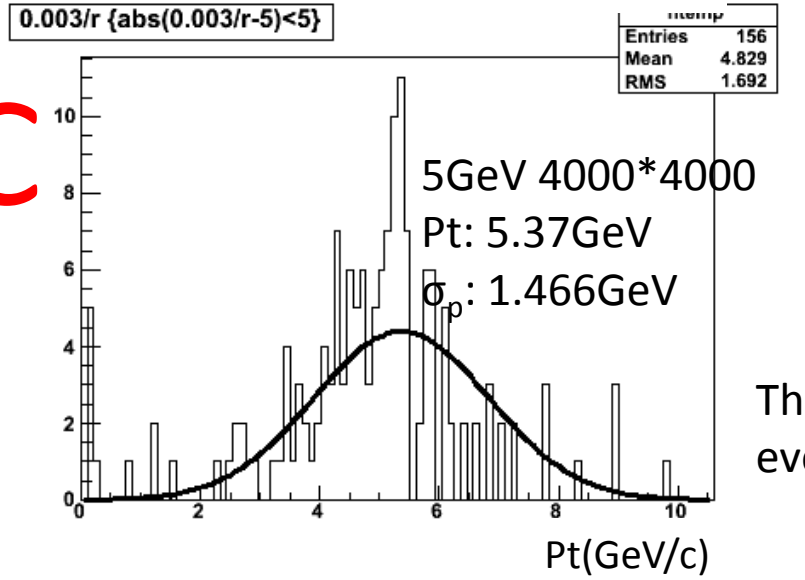
1GeV 800*800
Pt: 1.02GeV
σ_p: 0.105GeV

B



2GeV 1600*1600
Pt: 2.06GeV
σ_p: 0.302GeV

C

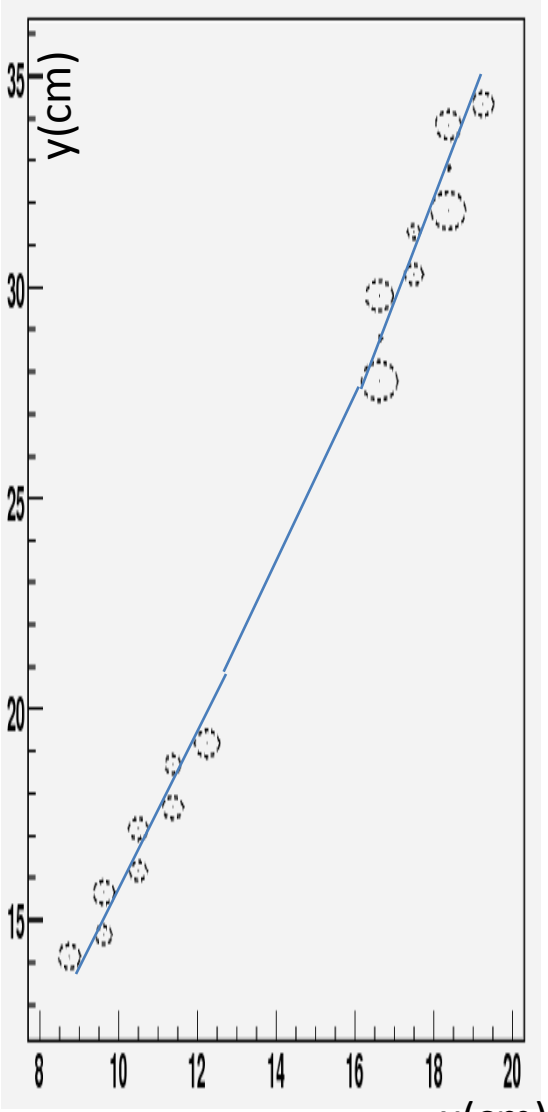


5GeV 4000*4000
Pt: 5.37GeV
σ_p: 1.466GeV

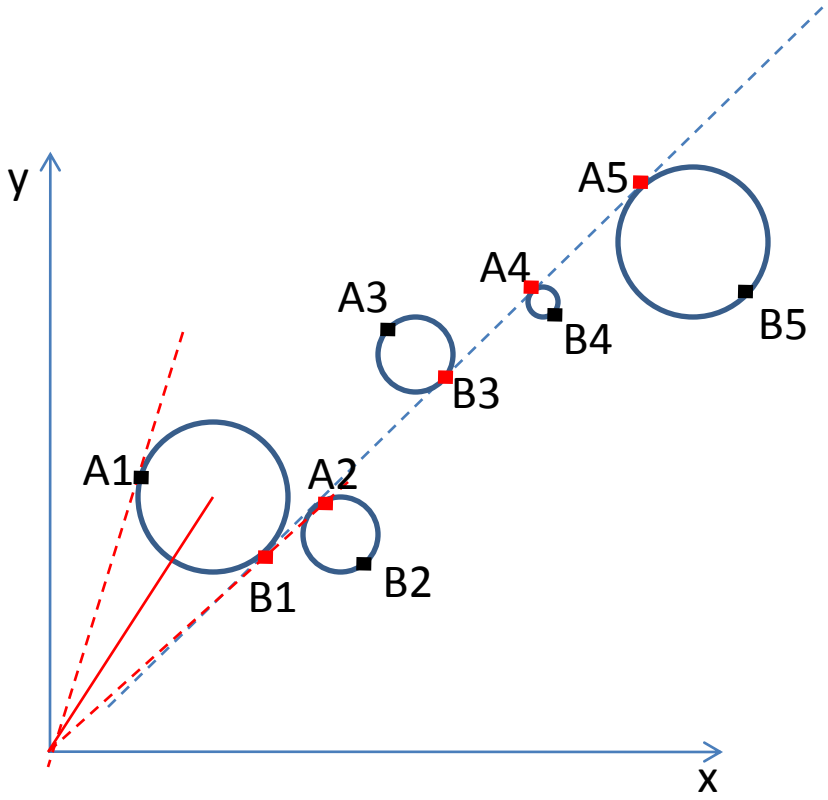
Momentum resolution:
1GeV: 10.5%
2GeV: 15.1%
5GeV: 30%

The momentum resolution at high Pt is very bad, even though we use 4000*4000 bins.

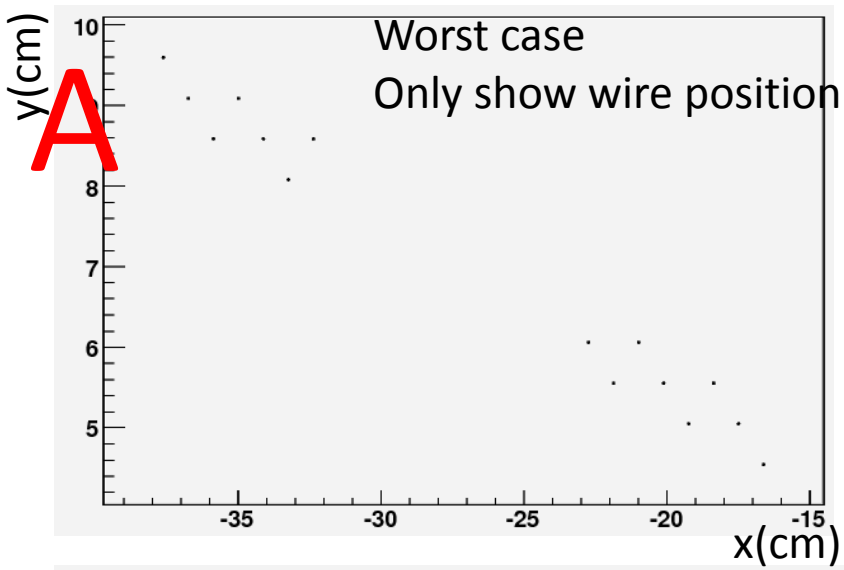
A try of new method to include drift distance

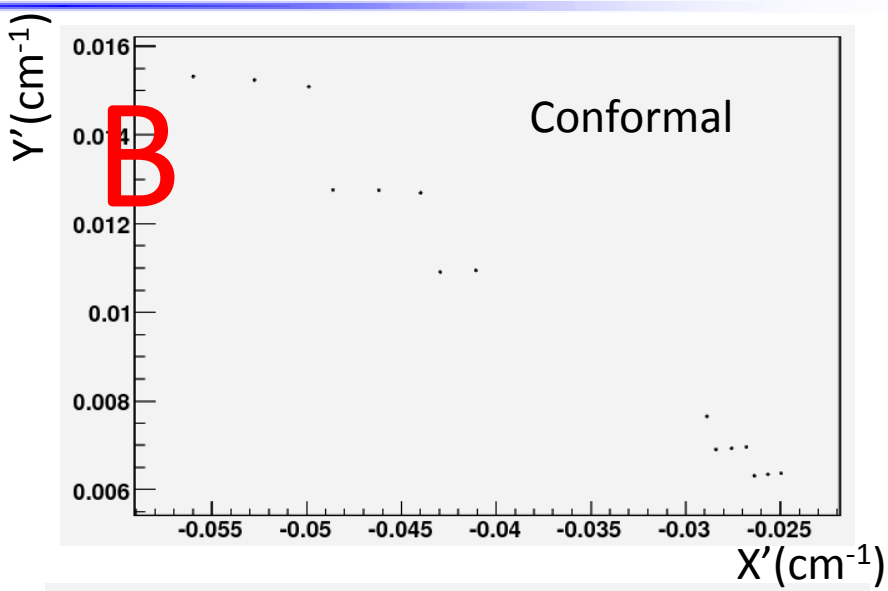


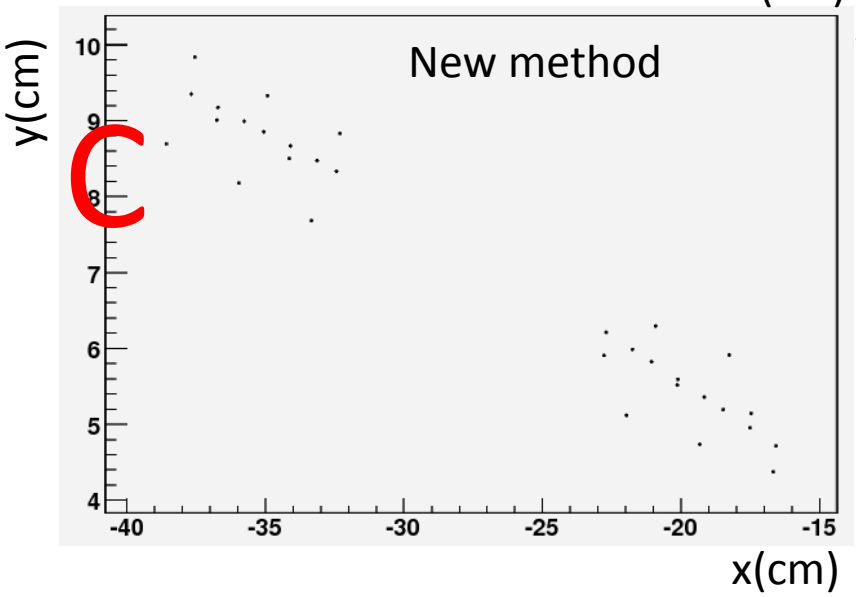
The last method: points inside the error box!
The new method: points on the circle!

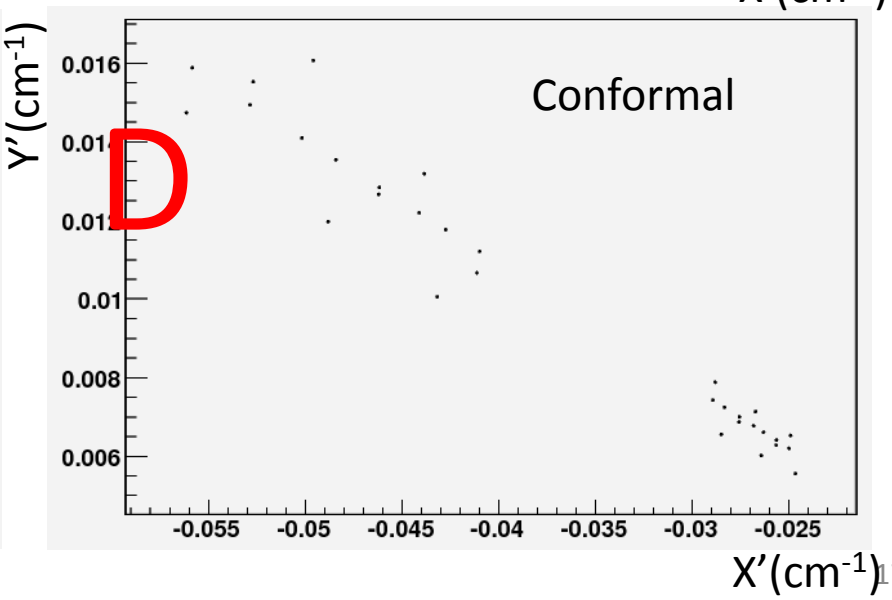


One example event using the new method

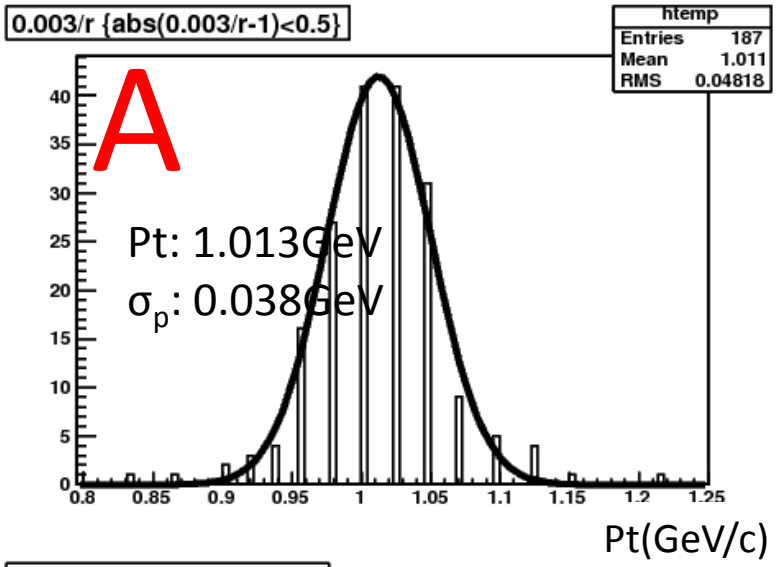


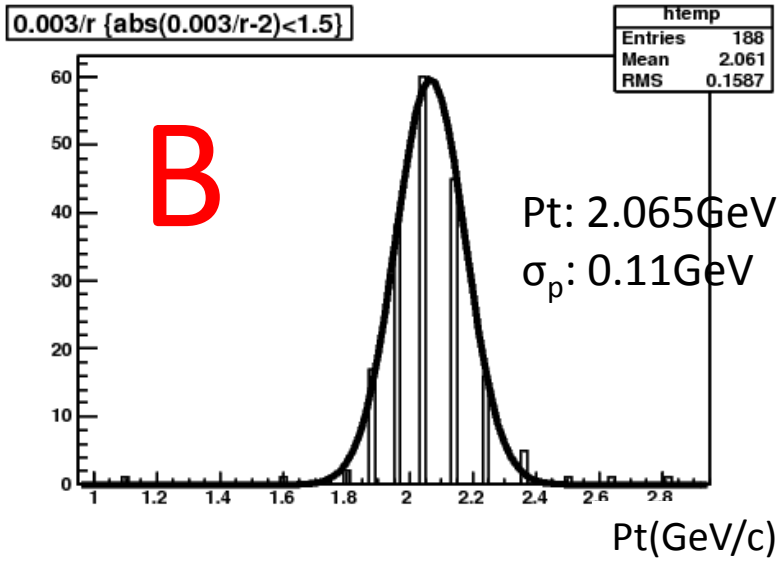


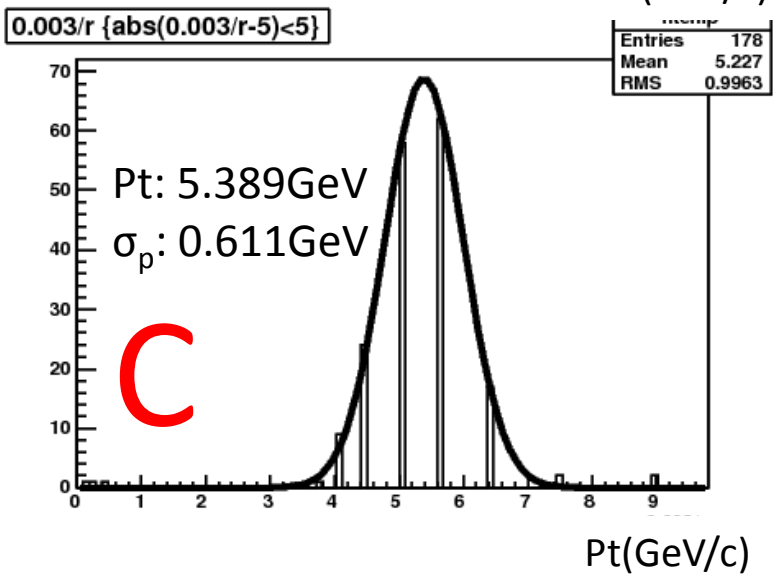




Momentum resolution using this new method







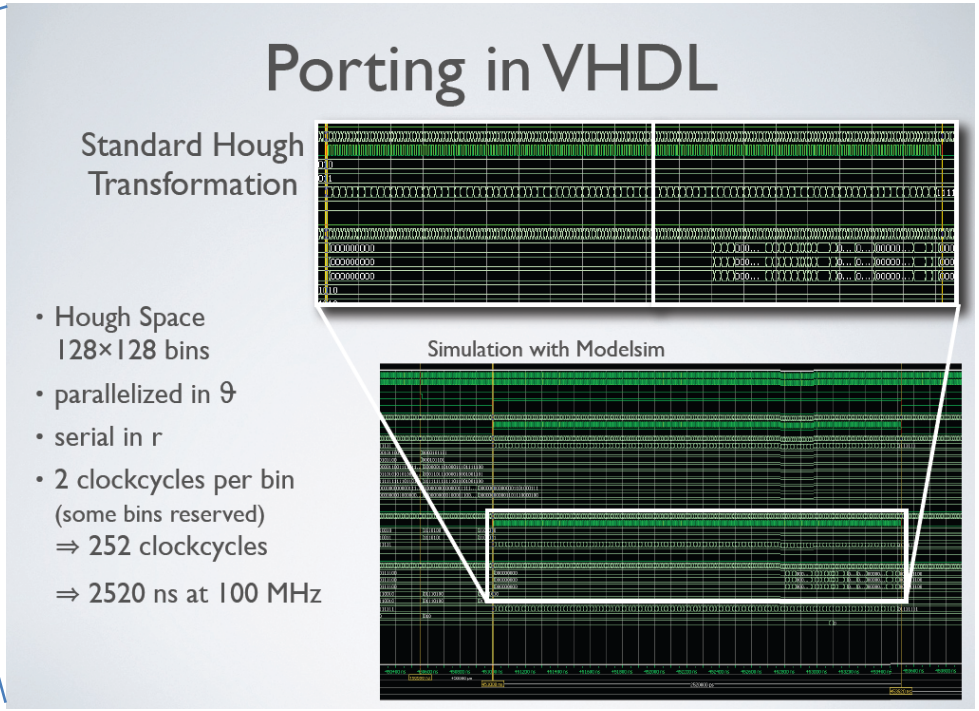
σ_p

New method	First method	
	Realistic	Ideal case:
1GeV: ~3.8%	10.5%	~3.6%
2GeV: ~5.5%	15.1%	~6.2%
5GeV: ~12.2%	30%	~12.9%

Status of this algorithm

David had implemented the algorithm in VHDL, in which the input is ideal positions.

The new method introduced here has only been studied in C++ on PC, to show the capability of this algorithm. We will implement this in VHDL in future.



Summary

1. The performance using only STT wire position is too bad.

2. First method: Including drift distance, filling weighted value in histogram, momentum resolution is bad.
   σ_{pt}: 10% @ 1GeV, 15% @ 2GeV, 30% @ 5GeV

3. Second method: Draw tangent line from interaction point…
   σ_{pt}: 3.8% @ 1GeV, 5.5% @ 2GeV, 12.2% @ 5GeV

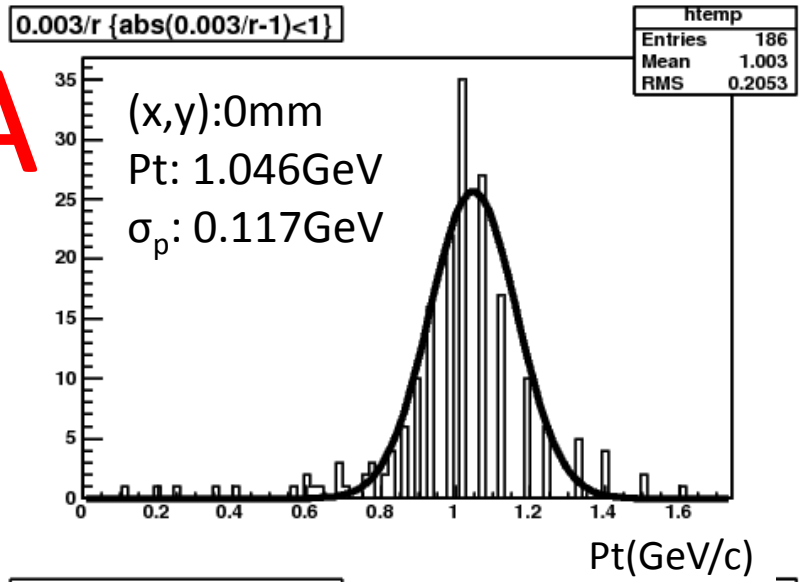
First method: depend on Vertex
Second method: depend on Vertex, not suit for very low momentum

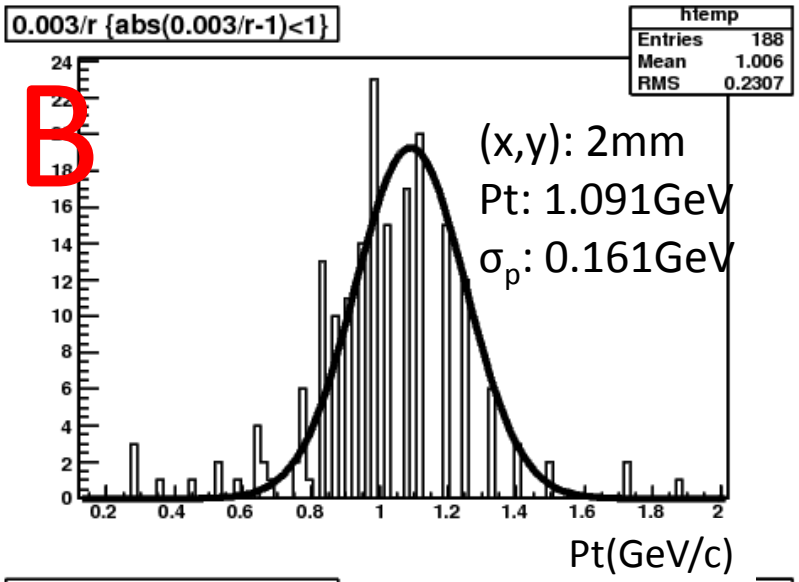
Next to do:
1. Combine MVD information to improve the momentum resolution, could also be used as vertex.

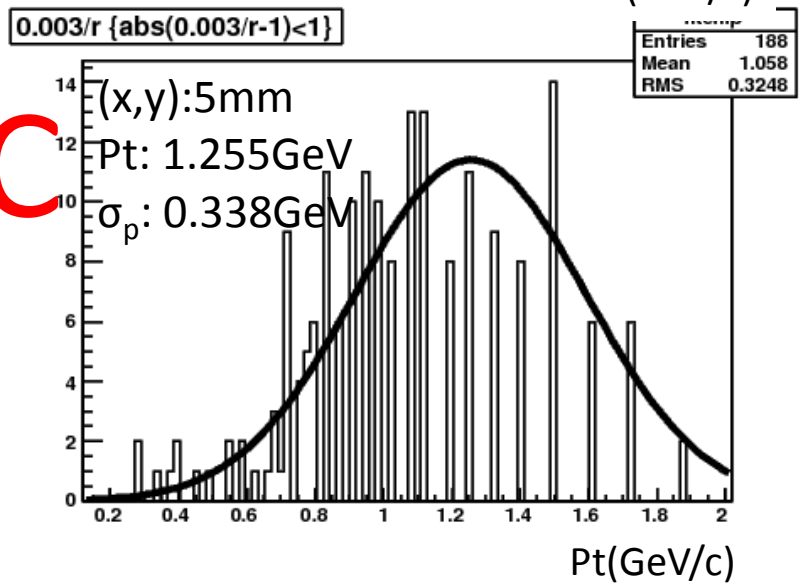
2. Inclusion of stereo layers. 3. Implement on FPGA

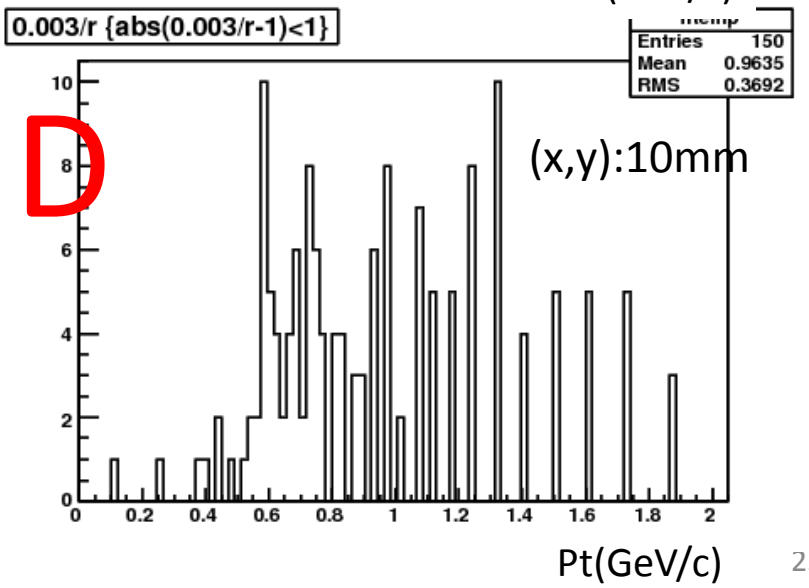
Thank you

Displaced vertex --old method



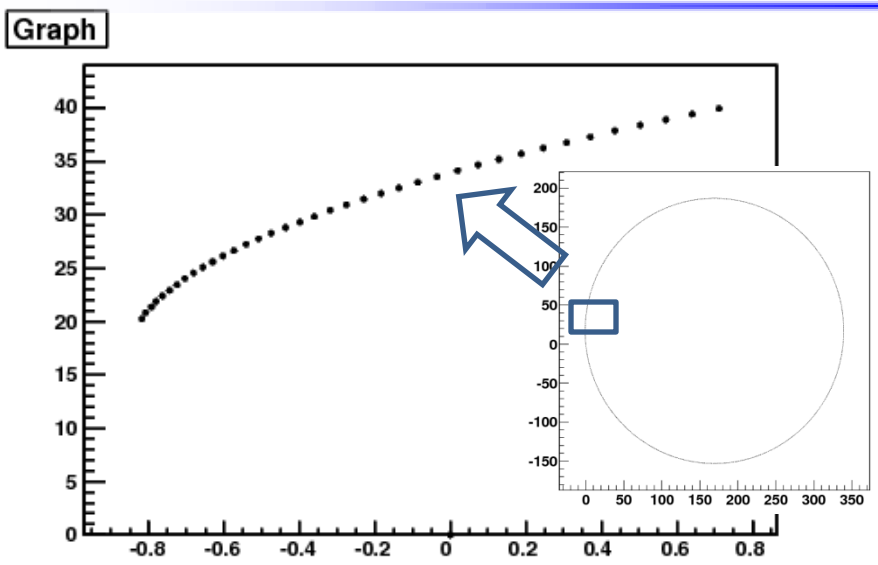


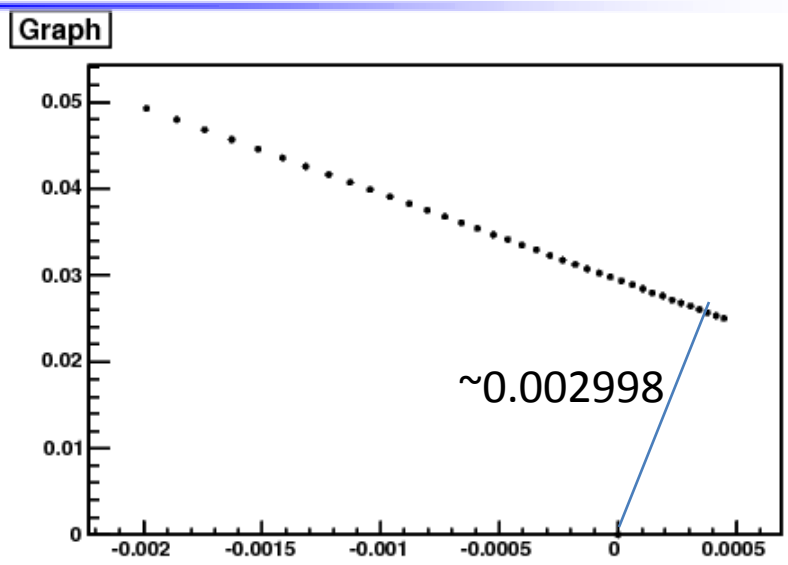


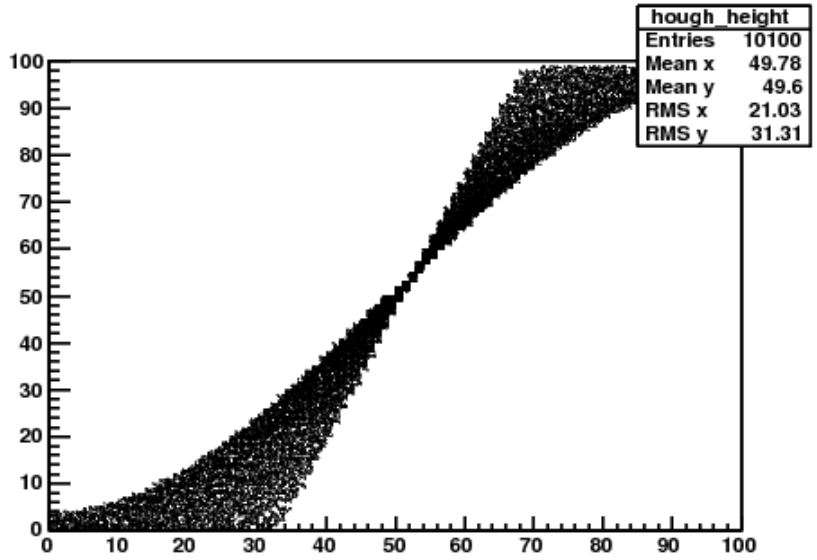


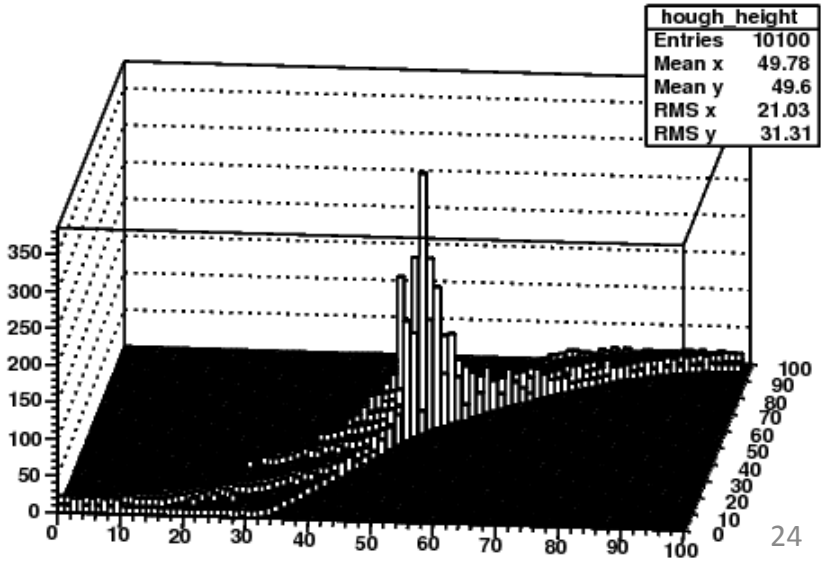
Behavior of transformations

P = 1GeV phi = 100



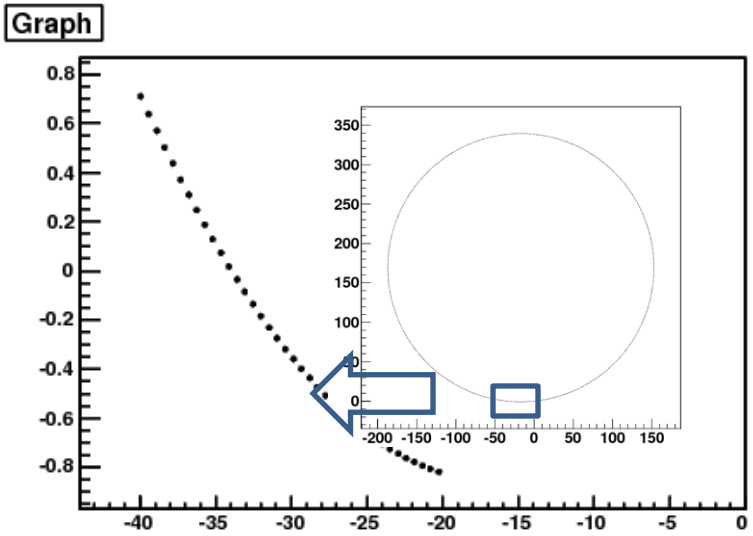


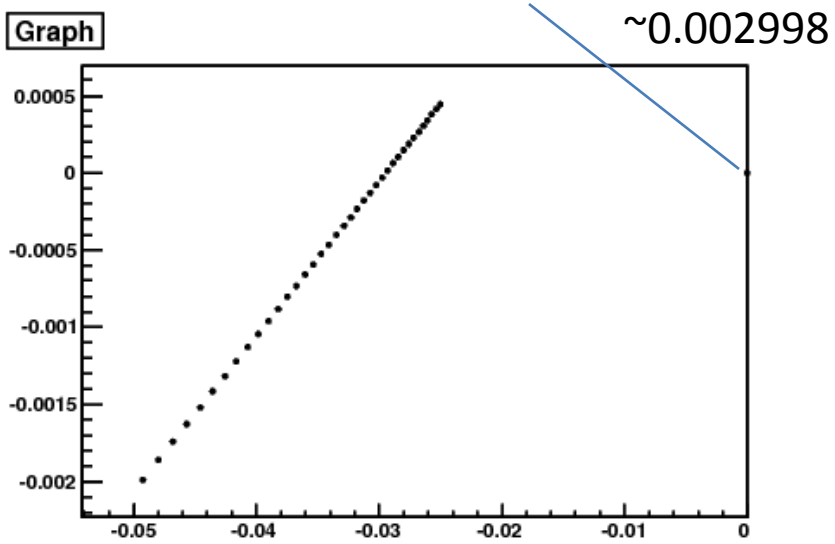


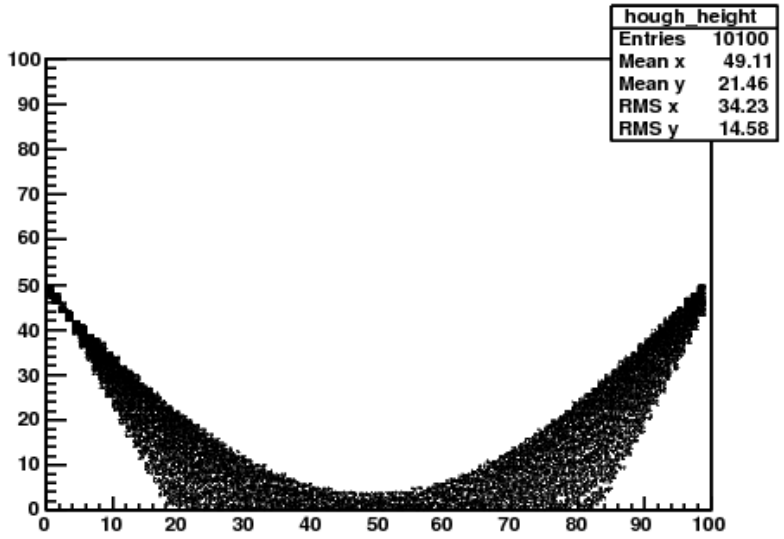


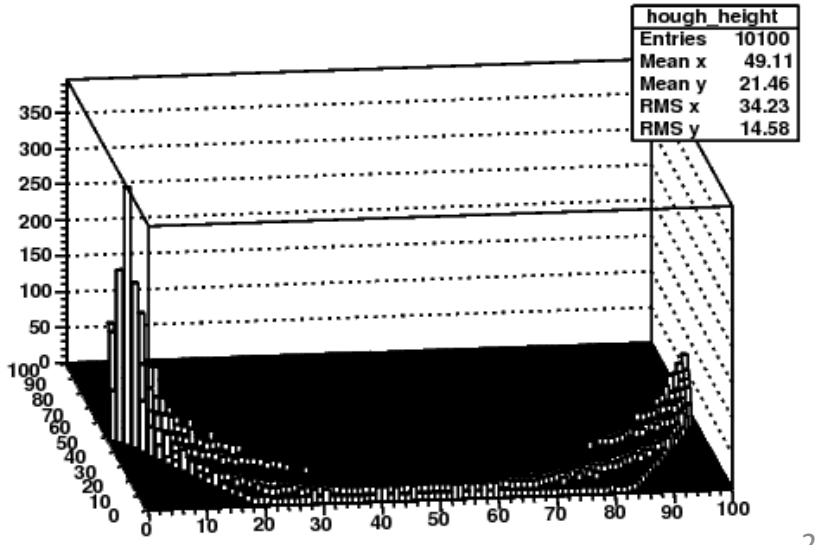
Behavior of transformations

P = 1GeV phi = 190



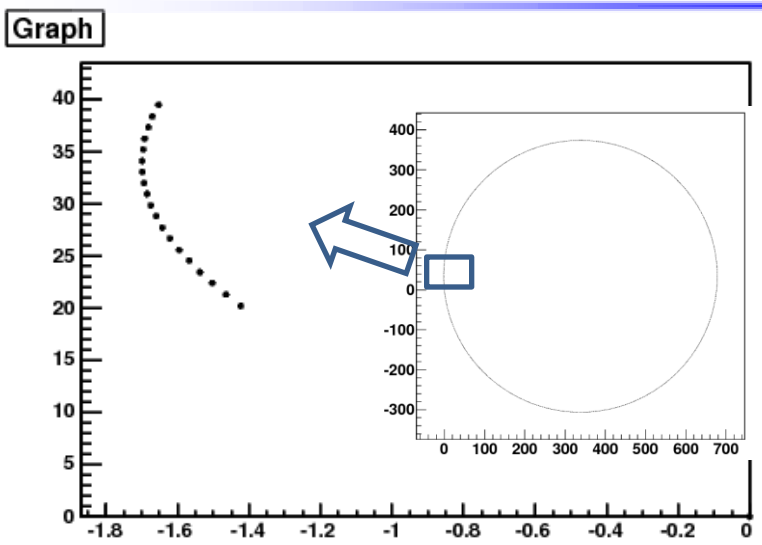


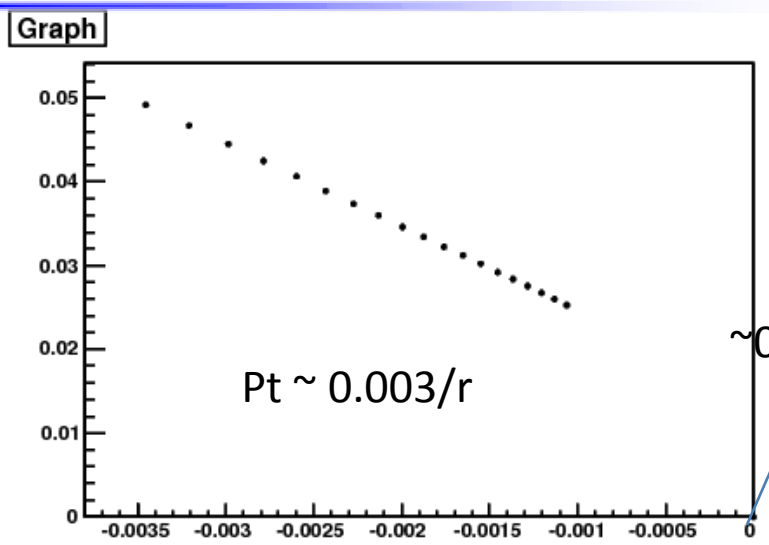


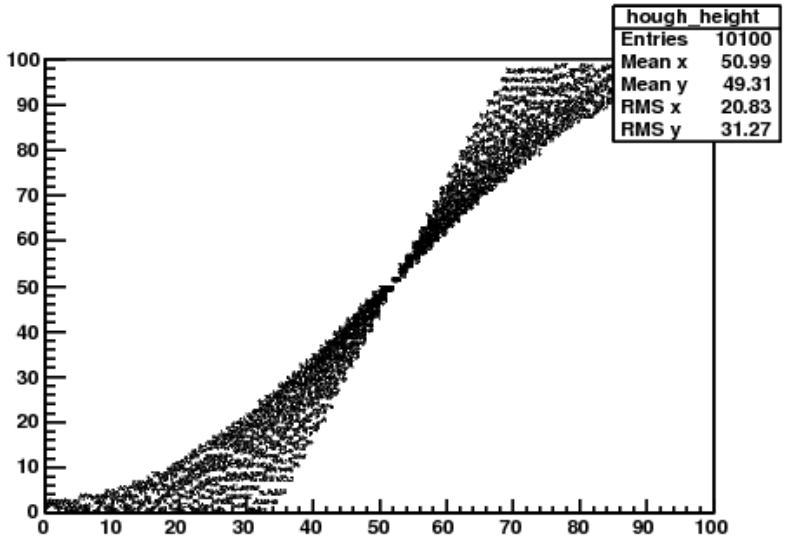


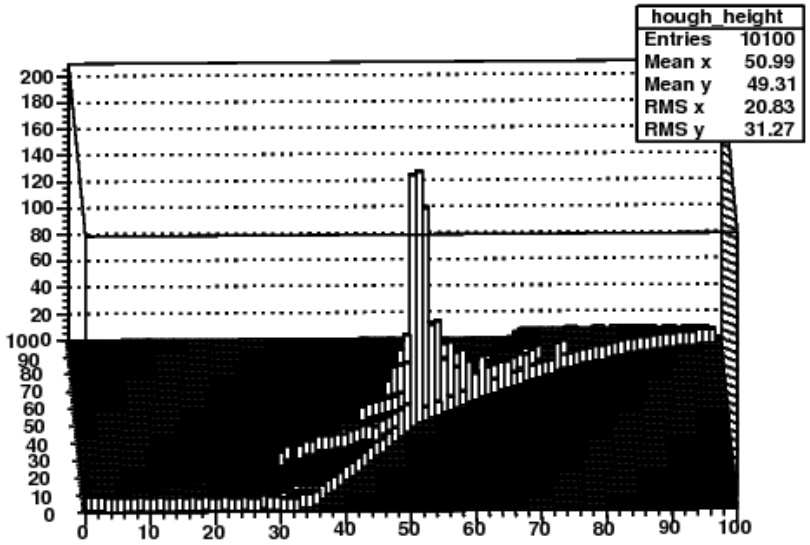
Behavior of transformations

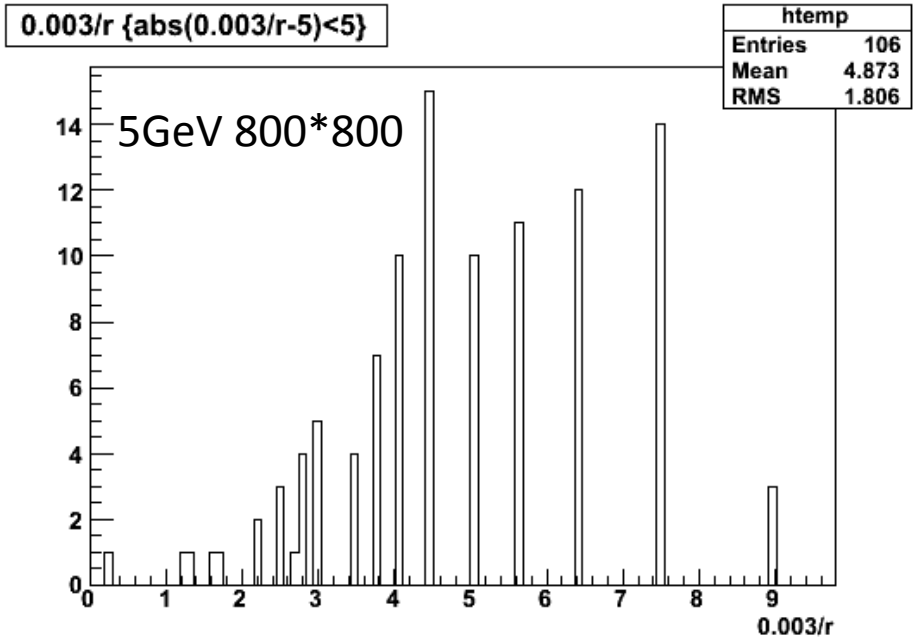
P = 2GeV phi = 100







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Mean 4.873
RMS 1.806
5GeV 800*800
0.003/r