Assessment for the evaluation method of Space Charge Effect

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- Explanation of the method to evaluate space charge effect
- Assessment for the evaluation method of Space Charge Effect
  -comparison of simulation results between uniform field case and field with space charge
  -comparison between simulation results and the direct calculation of the space charge effect from Field Map
- conclusion so far

Method to evaluate space charge effect

- Particles from accelerator which will be injected to 6x6x6 have well defined direction

  *assumed beam line is

  - incident at (x,y,z)=(-300[cm], -300[cm], 108.063[cm])
  - pass through (x,y,z)=(0[cm], 0[cm], 50.7[cm])
    (Need to check the latest information about beam information)
  - Divergence is assumed to be 0 for this study
    (Need to check the reality of divergence)

- To evaluate space charge effect, reconstructed charge position (with assumed uniform field strength of 500V/cm) is compared with the ideal beam line geometry, namely, systematic shift of the position and dispersion

Method to evaluate space charge effect

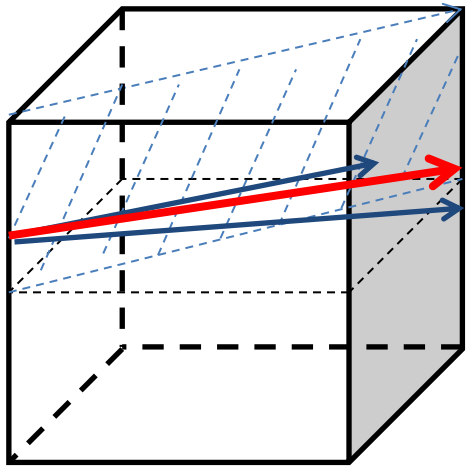
- Assumption of drift field for the simulation data
  1. Uniform field of 500V/cm as a reference
  2. Field map: COMSOL simulation, Applied field of 500V/cm, with backflow from LEM 0%
  3. Field map: COMSOL simulation, Applied field of 500V/cm, with backflow from LEM 10%
- 100events of 4GeV/c and 10GeV/c μ^+ for each configuration
- Although, the simulation includes the field distortion, not only Z but also X, Y direction, for this study, as a first attempt, the comparison of reconstructed position with ideal beamline geometry is conducted, with assuming there is only Z directional distortion effect.

  *Need to check appropriateness of this assumption.

Method to evaluate space charge effect

Examine whether we will see the difference between uniform field case and field with Space charge effect

settings
Particle
: mu+
Momentum
: 4GeV/c,10GeV/c
Number of events
:100events
for each samples



incidence position
(x,y,z)=(-300[cm], -300[cm], 108.063[cm])

→ : **Ideal Beamline**
pass through (x,y,z)=(0[cm], 0[cm], 50.7[cm])

→ : **track of simulated/reconstructed Beam**
could be different from Ideal beamline due to multiple scattering and field distortion

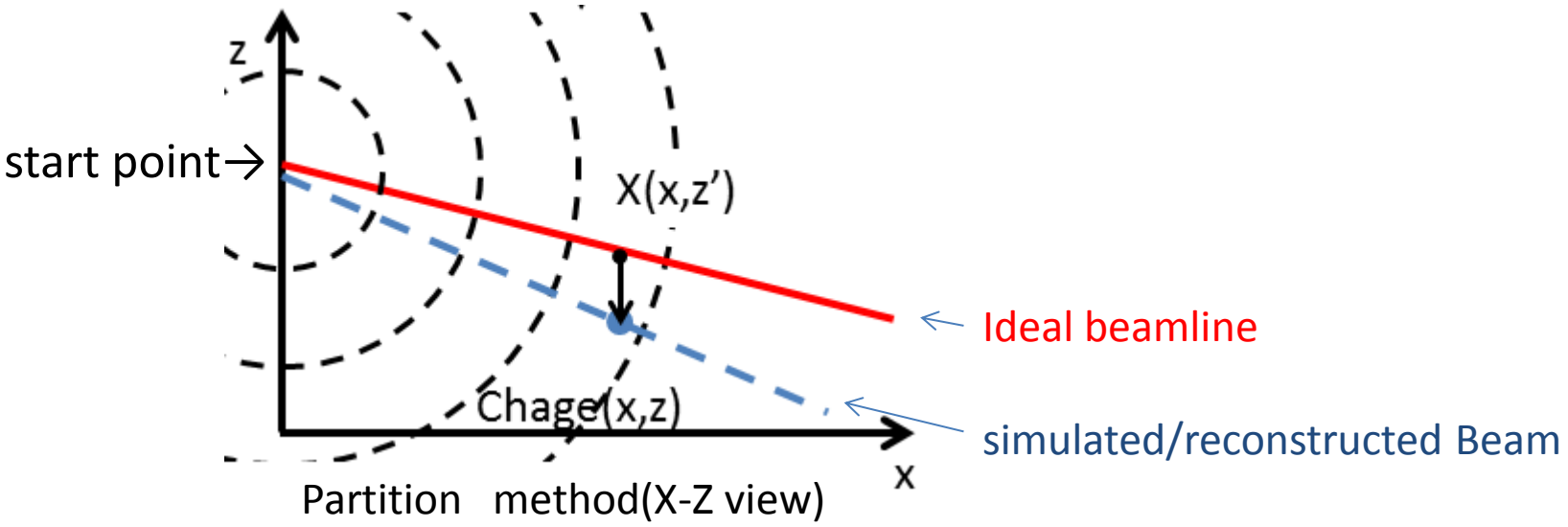
⇩

Make histogram of the difference between reconstructed z position and Ideal Beamline (Assumed that influence of x and y distortion is 0)

In addition to the M.C. simulation, expected Z position which is calculated directly from FieldMap is evaluated (Verification of Consistency)

Evaluation of the space charge effect

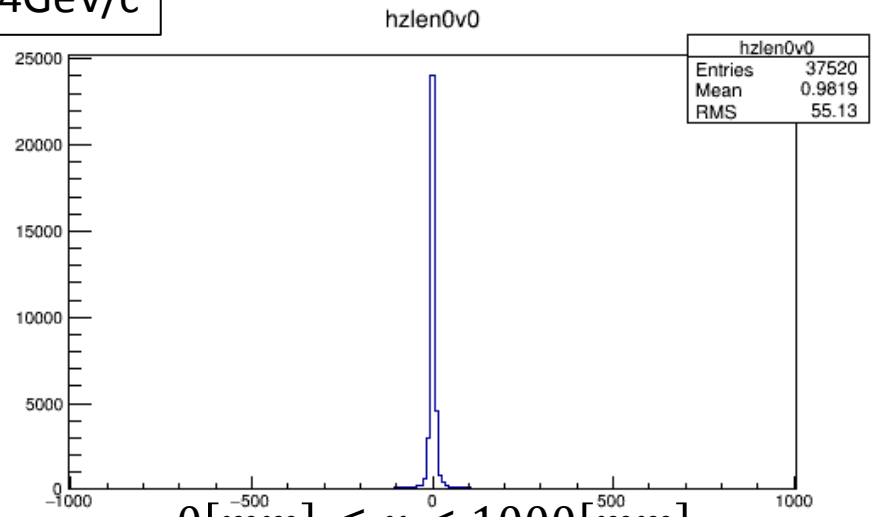
The difference in z position between the ideal beamline and
the simulated/reconstructed Beam is calculated for each region on the ideal beamline.
The ideal beamline is divided each 1000 mm in x (y).
(here, it is referenced by as X Y coordinate)



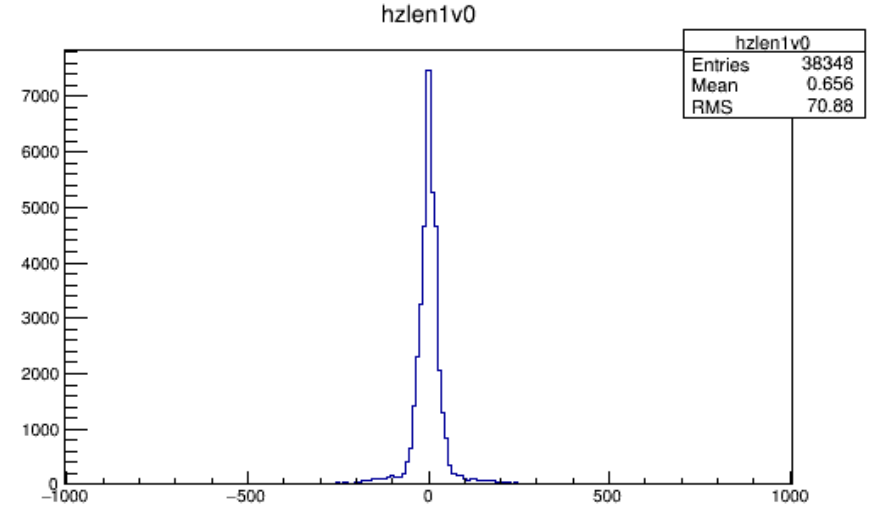
- X-Z view and Y-Z view information are independently evaluated for these configuration.
  1. Uniform field of 500V/cm as a reference
  2. Field map: COMSOL simulation, Applied field of 500V/cm, with backflow from LEM 0%
  3. Field map: COMSOL simulation, Applied field of 500V/cm, with backflow from LEM 10%

The difference in z position (Uniform field of 500V/cm)

4GeV/c

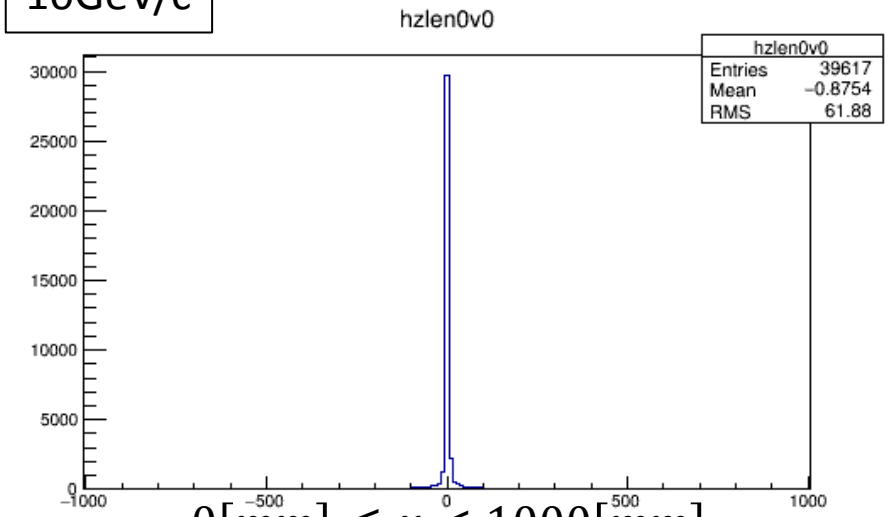


$0[mm] \leq x < 1000[mm]$

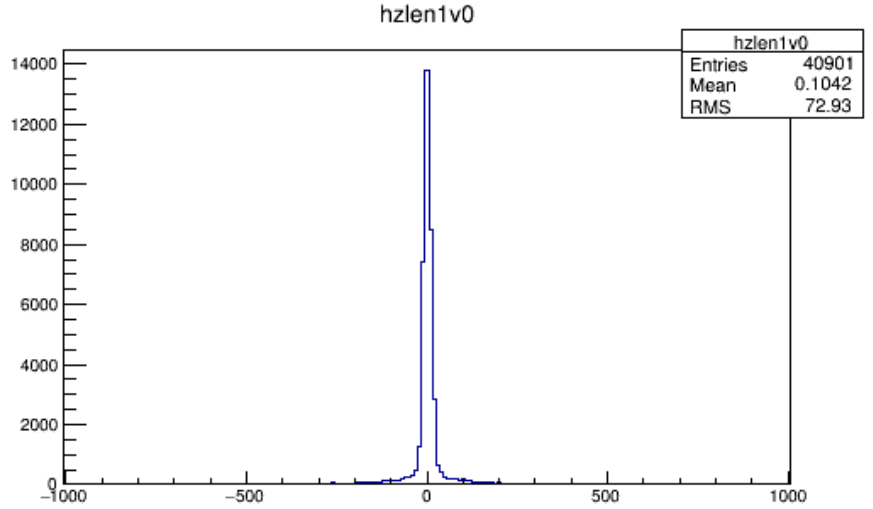


$1000[mm] \leq x < 2000[mm]$

10GeV/c



$0[mm] \leq x < 1000[mm]$

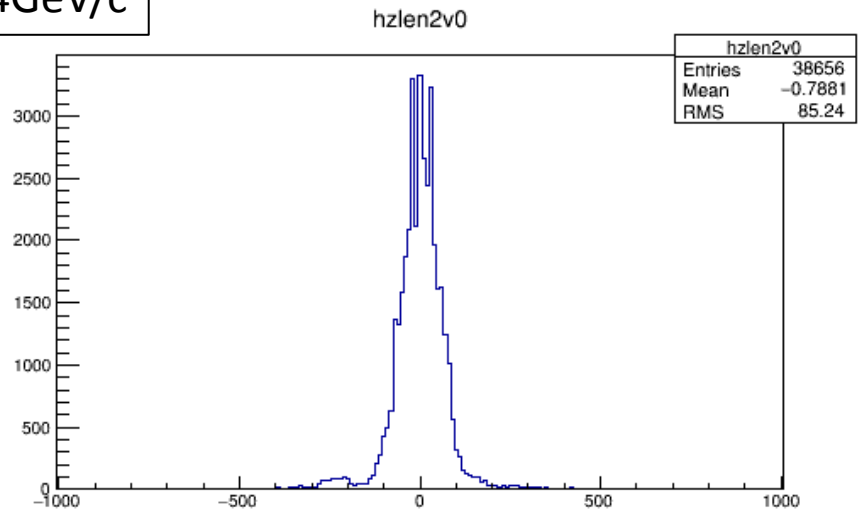


$1000[mm] \leq x < 2000[mm]$

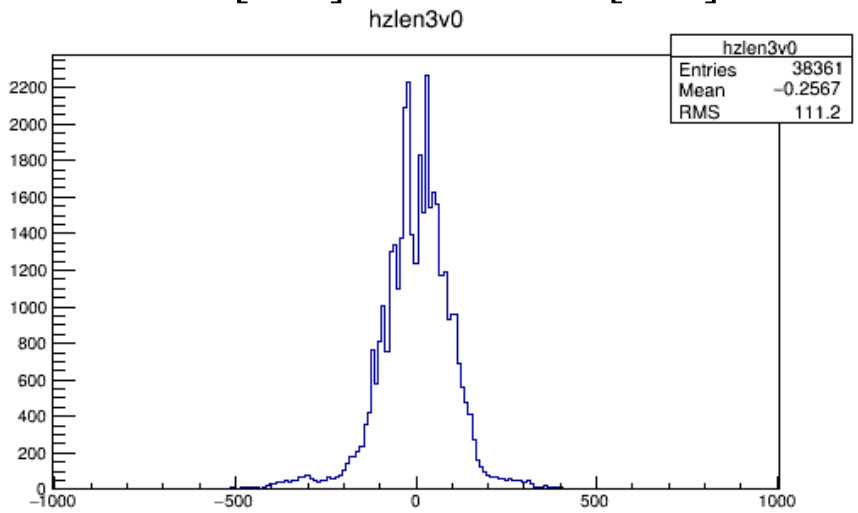
- central value is on the ideal line
- Larger dispersion for larger length from start point
- More dispersion for 4GeV/c than 10GeV/c

The difference in z position (Uniform field of 500V/cm)

4GeV/c

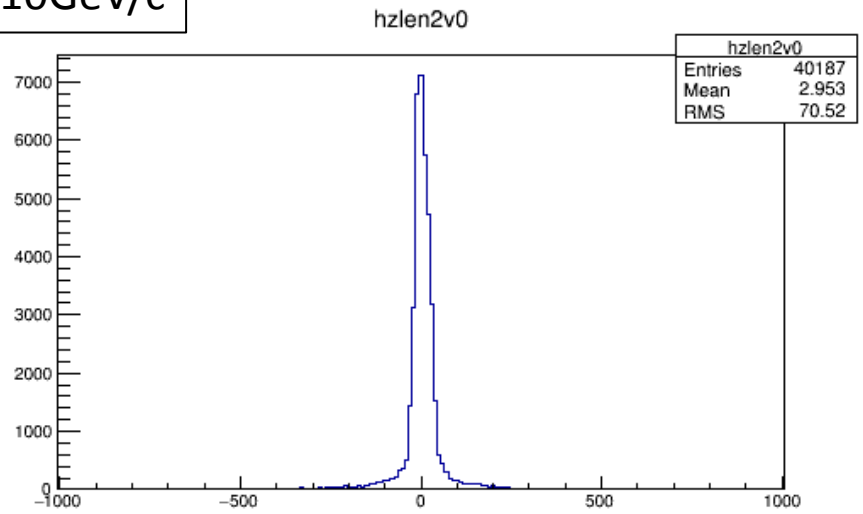


$2000[mm] \leq x < 3000[mm]$

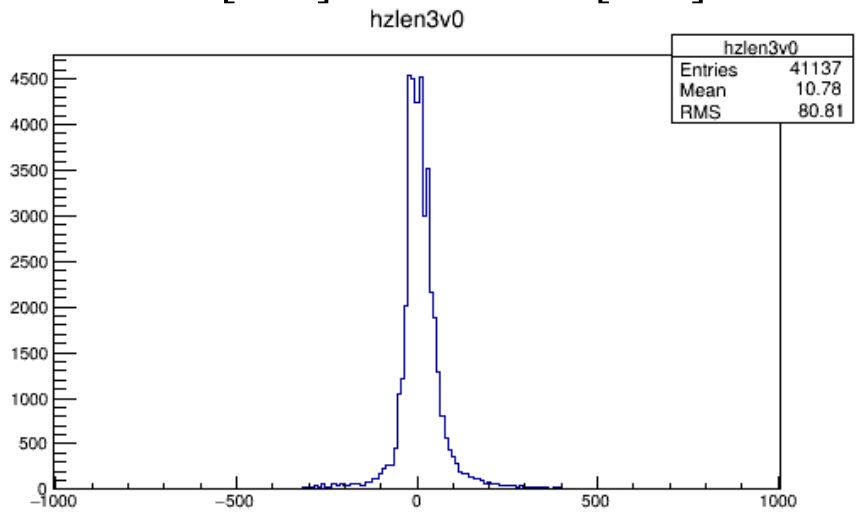


$3000[mm] \leq x < 4000[mm]$

10GeV/c



$2000[mm] \leq x < 3000[mm]$

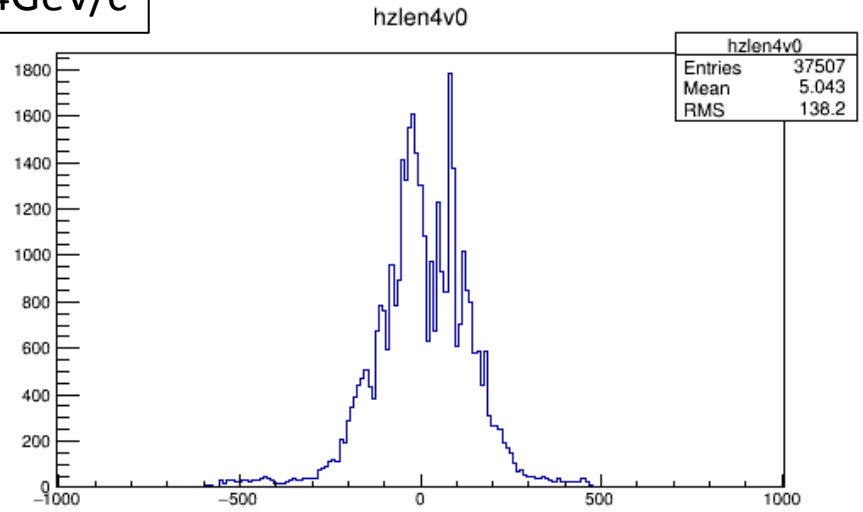


$3000[mm] \leq x < 4000[mm]$

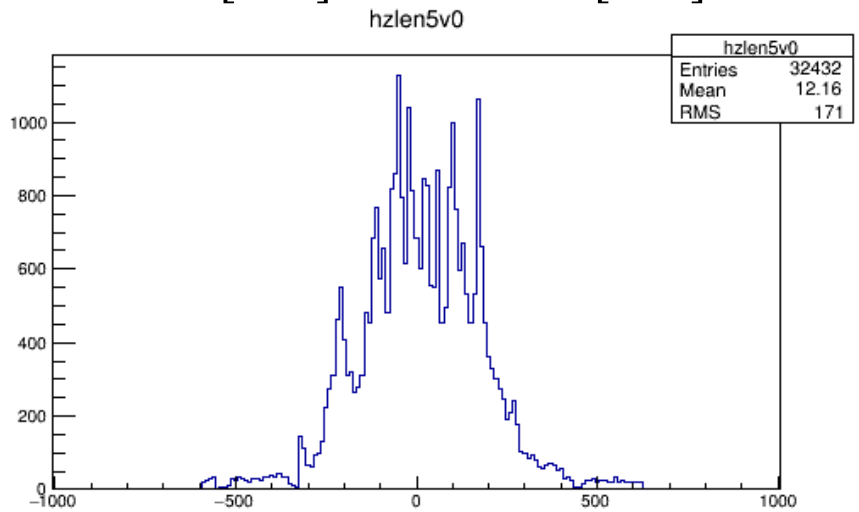
Funny periodical structure, to be understood

The difference in z position (Uniform field of 500V/cm)

4GeV/c

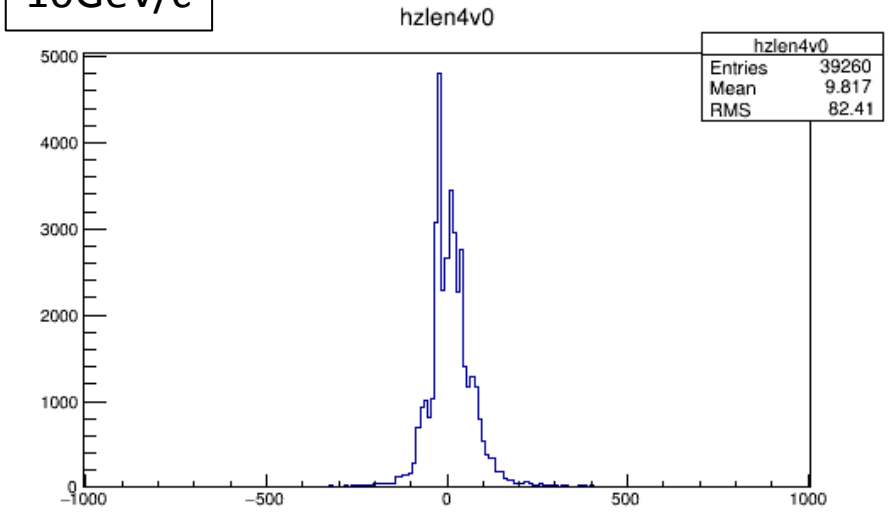


$4000[mm] \leq x < 5000[mm]$

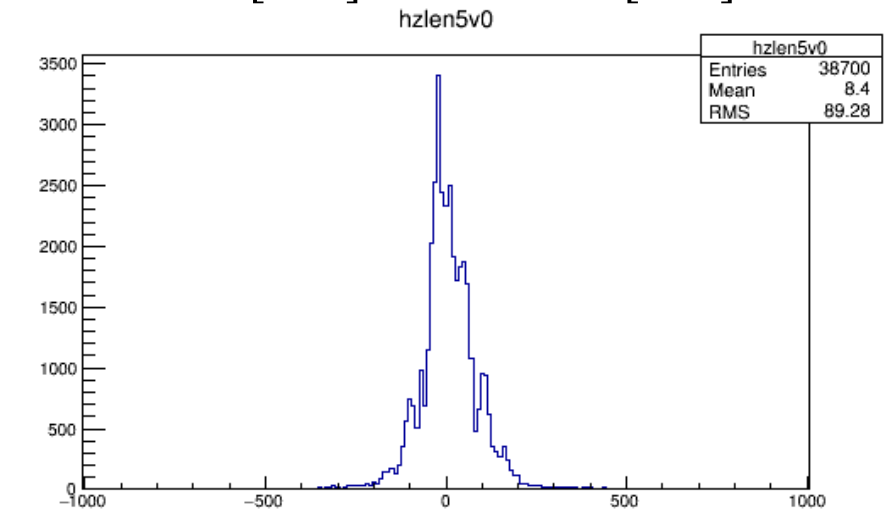


$5000[mm] \leq x \leq 6000[mm]$

10GeV/c



$4000[mm] \leq x < 5000[mm]$

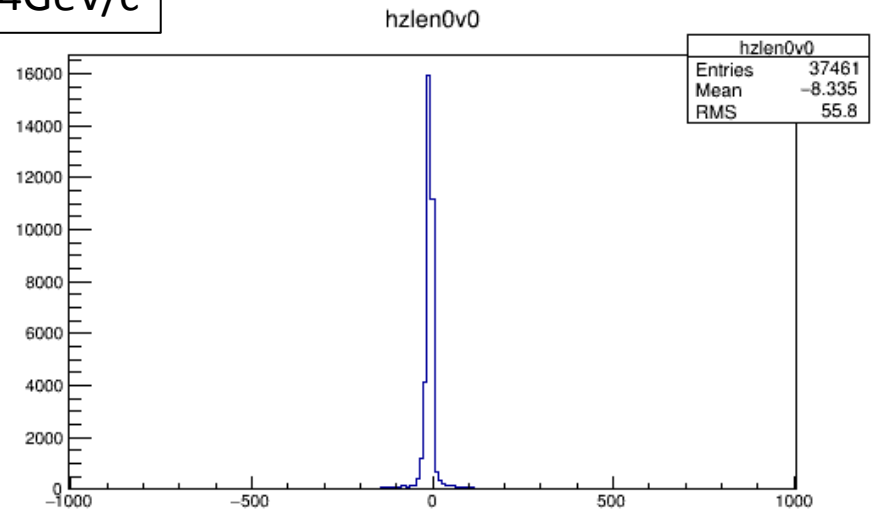


$5000[mm] \leq x \leq 6000[mm]$

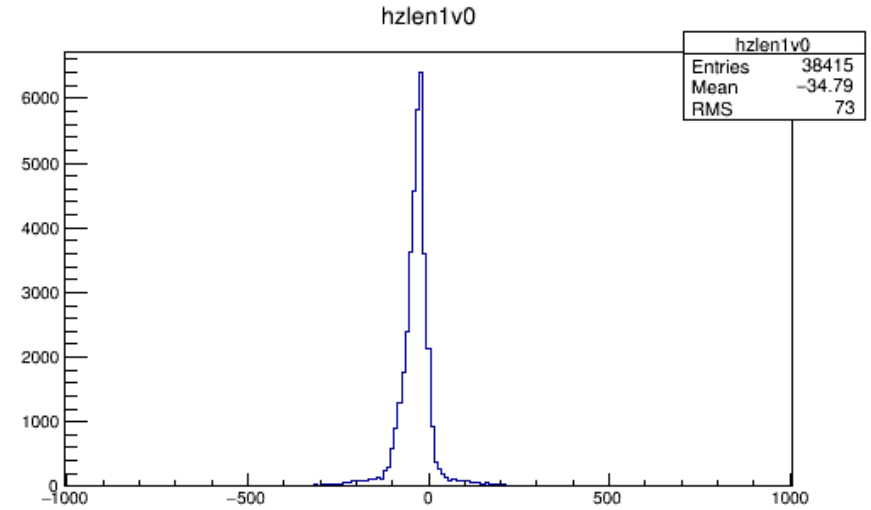
Funny periodical structure, to be understood

The difference in z position(FieldMap : 500V/cm nominal, no backflow)

4GeV/c

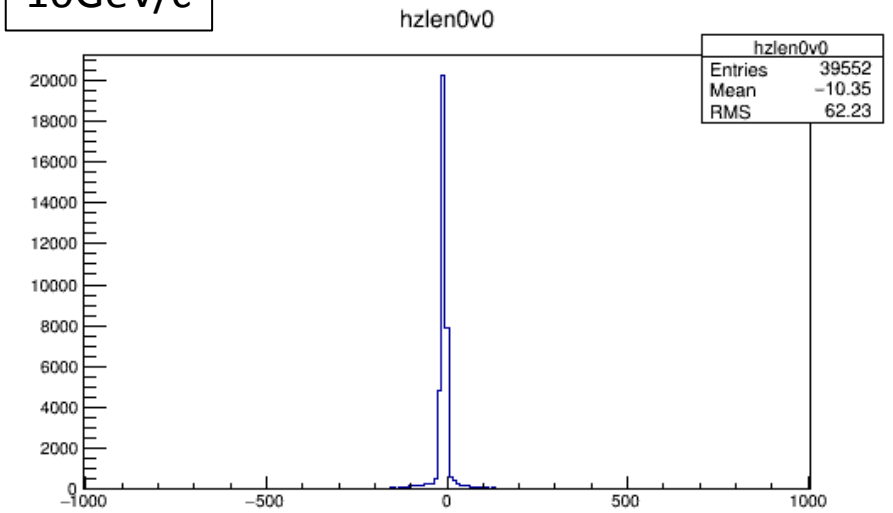


$0[mm] \leq x < 1000[mm]$

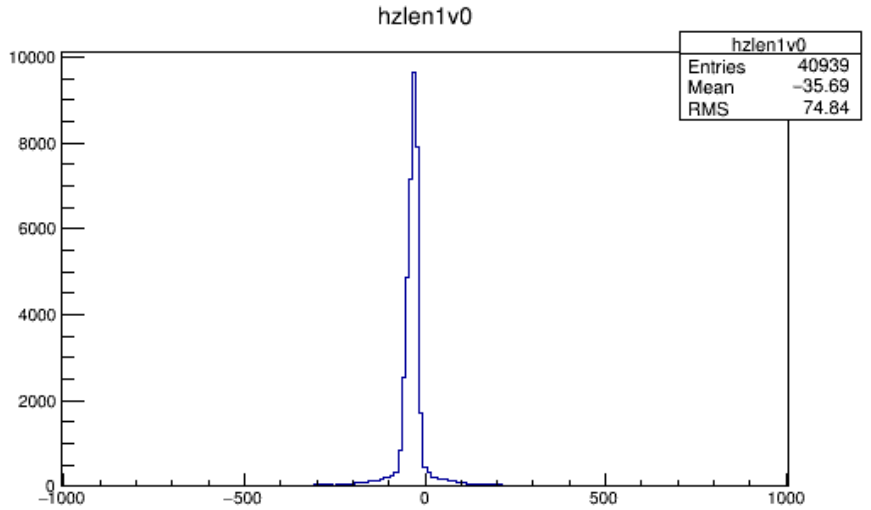


$1000[mm] \leq x < 2000[mm]$

10GeV/c



$0[mm] \leq x < 1000[mm]$

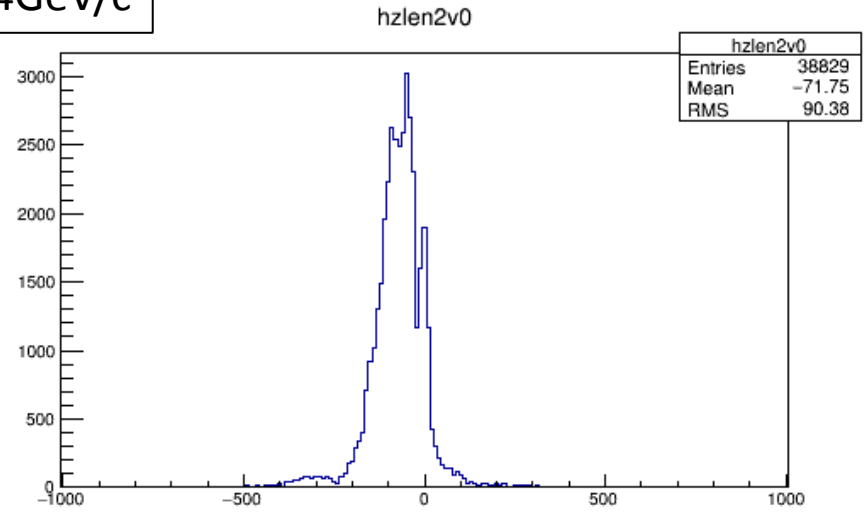


$1000[mm] \leq x < 2000[mm]$

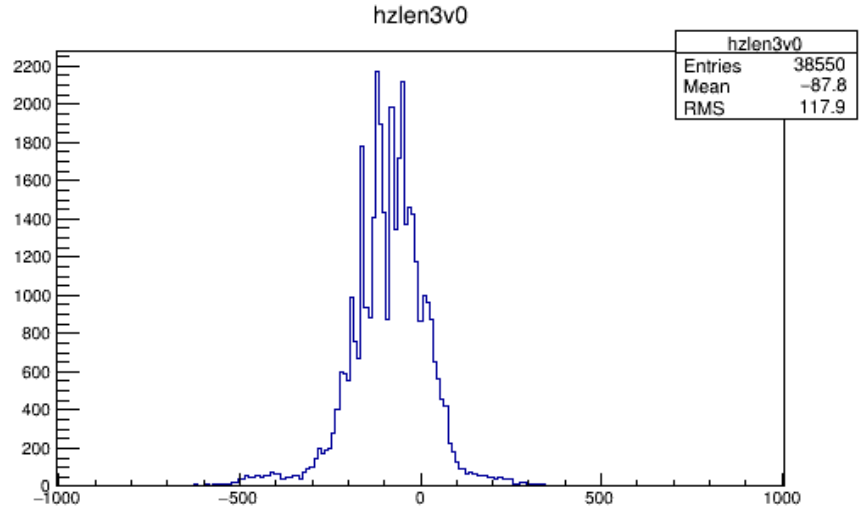
- Shift of central value is observed

The difference in z position(FieldMap : 500V/cm nominal, no backflow)

4GeV/c

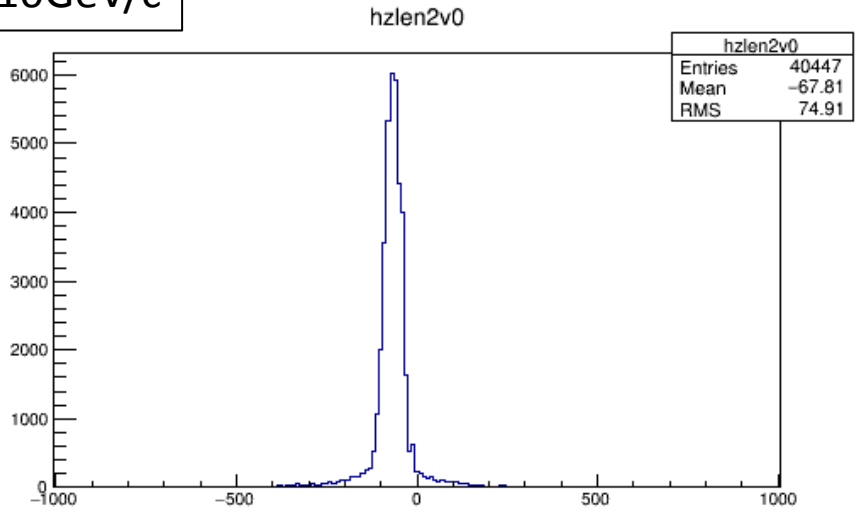


$2000[mm] \leq x < 3000[mm]$

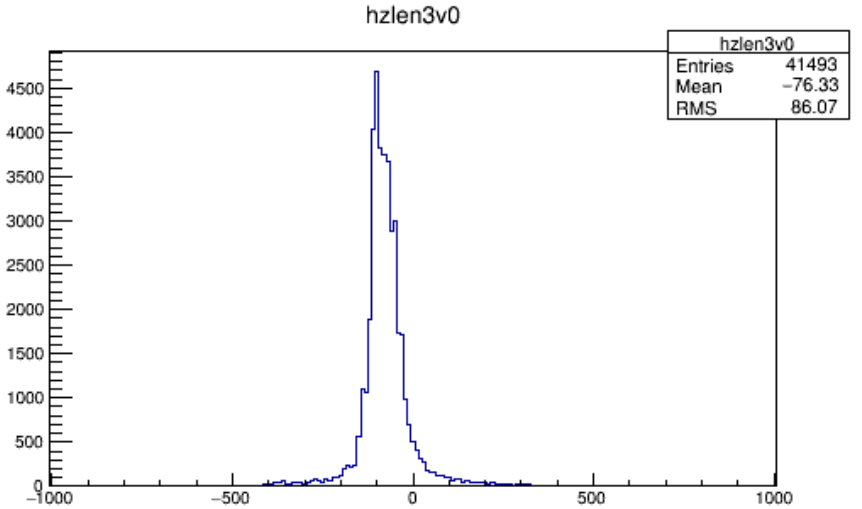


$3000[mm] \leq x < 4000[mm]$

10GeV/c



$2000[mm] \leq x < 3000[mm]$

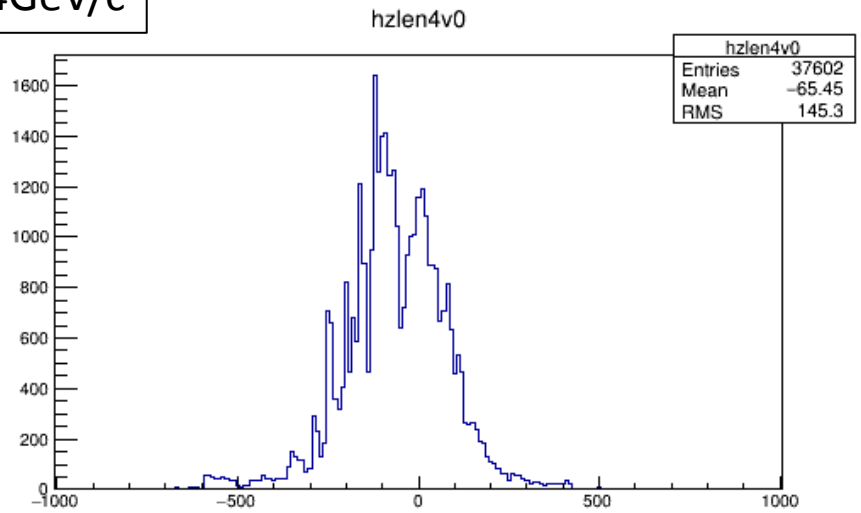


$3000[mm] \leq x < 4000[mm]$

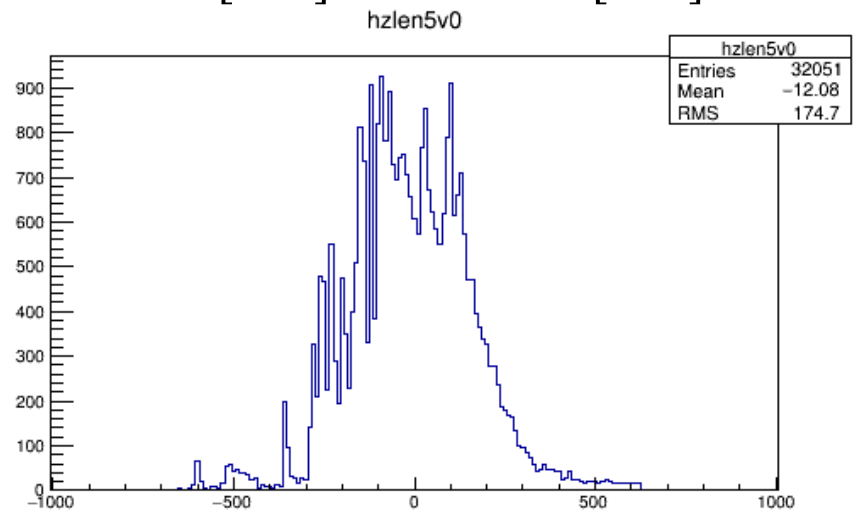
Funny periodical structure, to be understood

The difference in z position(FieldMap : 500V/cm nominal, no backflow)

4GeV/c

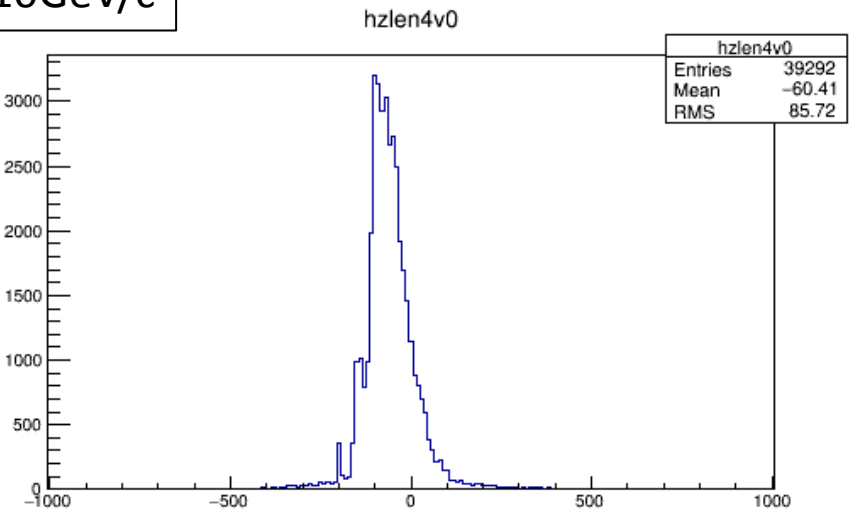


$4000[mm] \leq x < 5000[mm]$

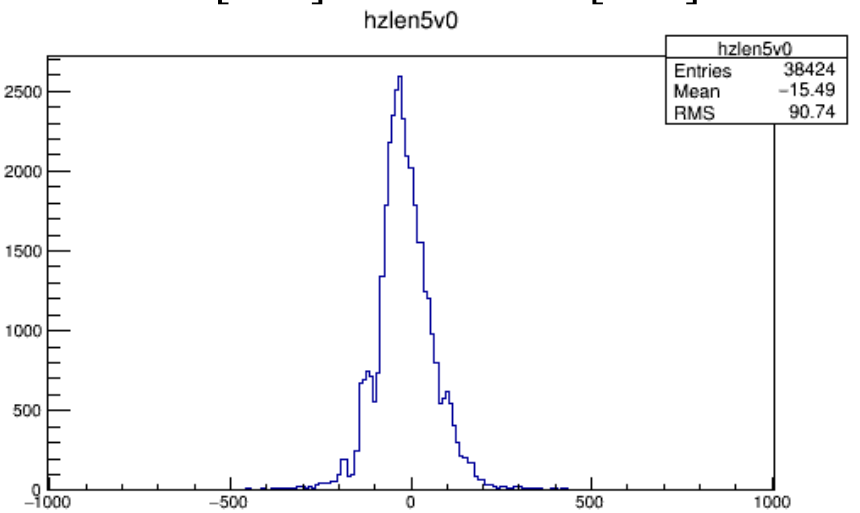


$5000[mm] \leq x \leq 6000[mm]$

10GeV/c



$4000[mm] \leq x < 5000[mm]$

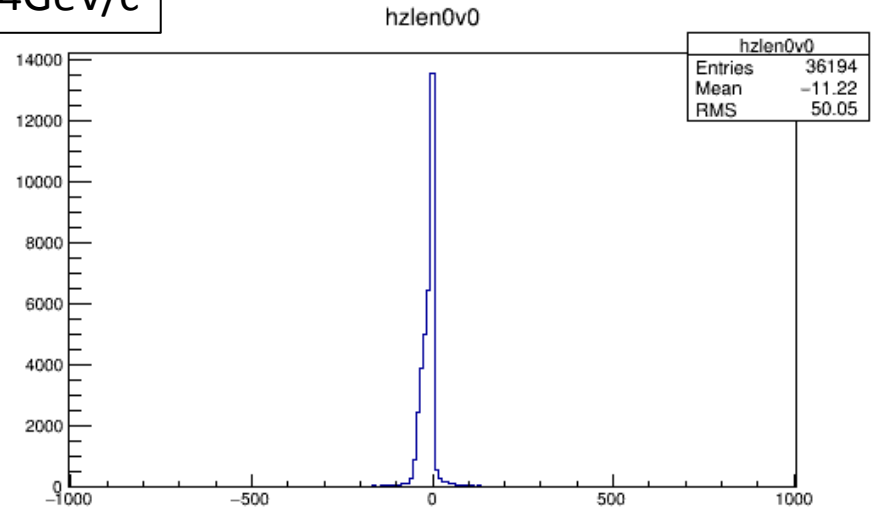


$5000[mm] \leq x \leq 6000[mm]$

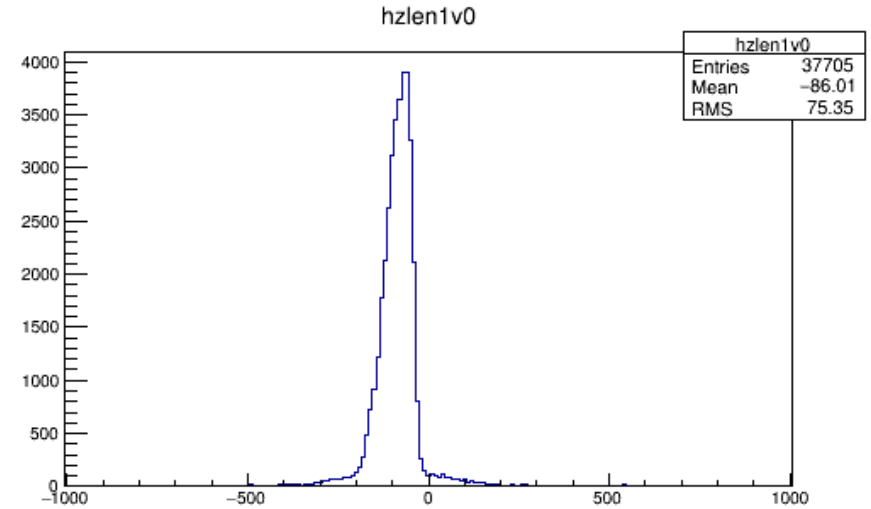
Funny periodical structure, to be understood

The difference in z position(FieldMap : 500V/cm nominal, backflow 10%)

4GeV/c

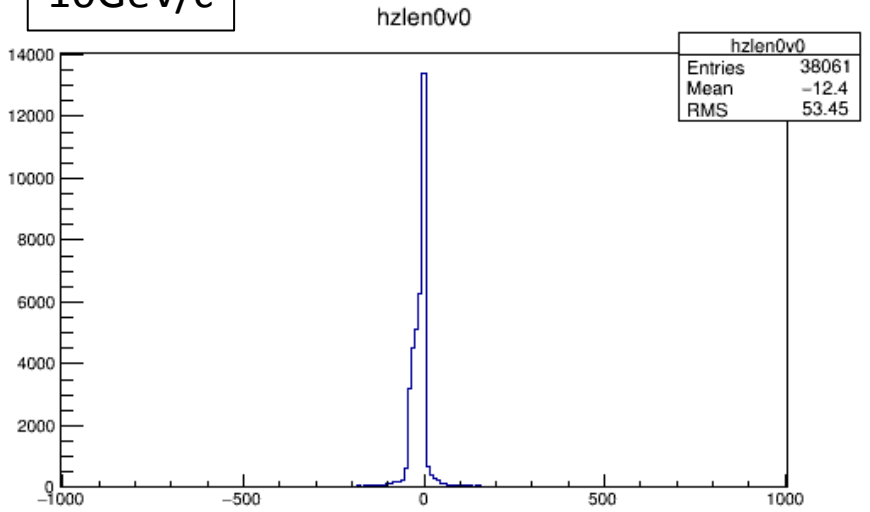


$0[mm] \leq x < 1000[mm]$

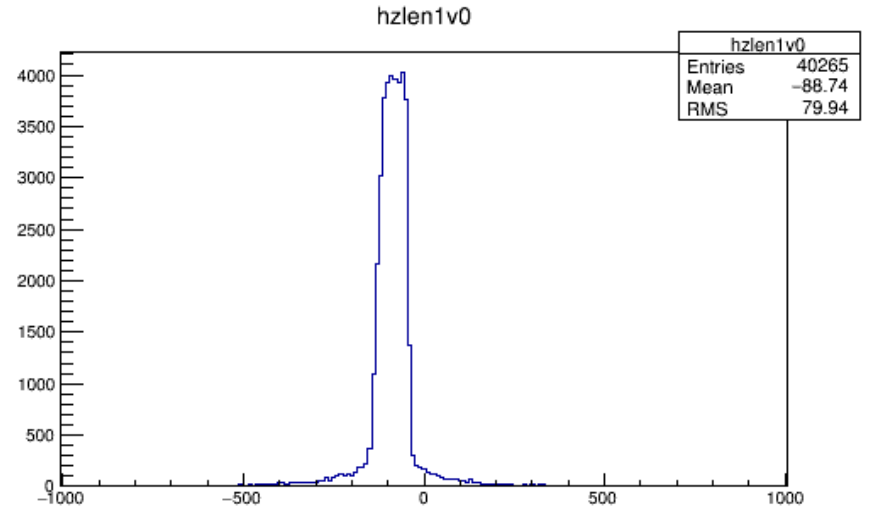


$1000[mm] \leq x < 2000[mm]$

10GeV/c



$0[mm] \leq x < 1000[mm]$

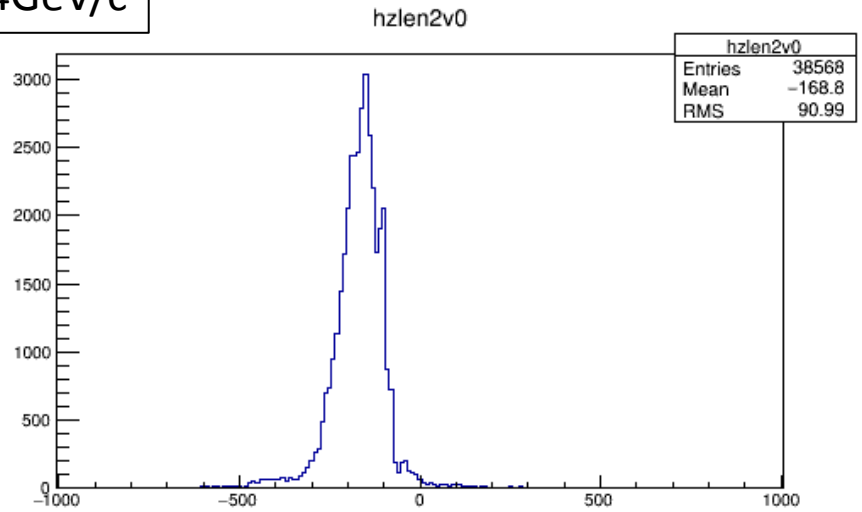


$1000[mm] \leq x < 2000[mm]$

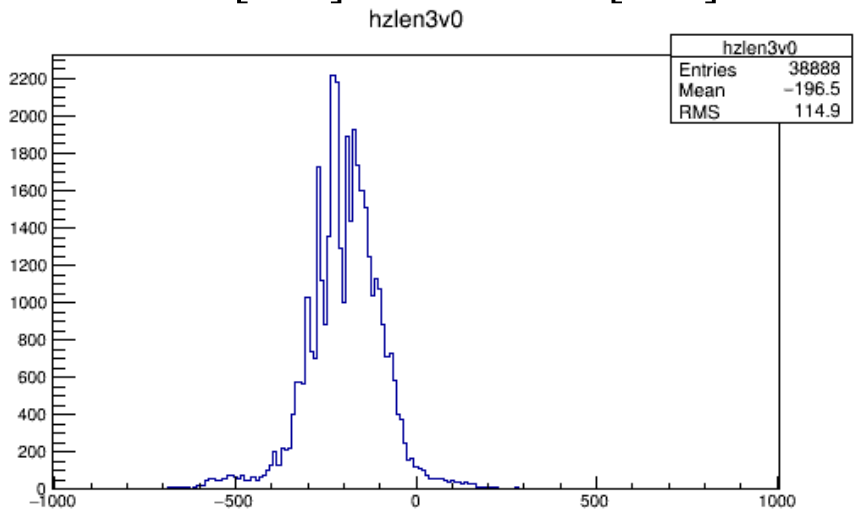
- Shift of central value is observed
- Bigger shift for 10%backflow than 0% backflow as is expected

The difference in z position(FieldMap : 500V/cm nominal, backflow 10%)

4GeV/c

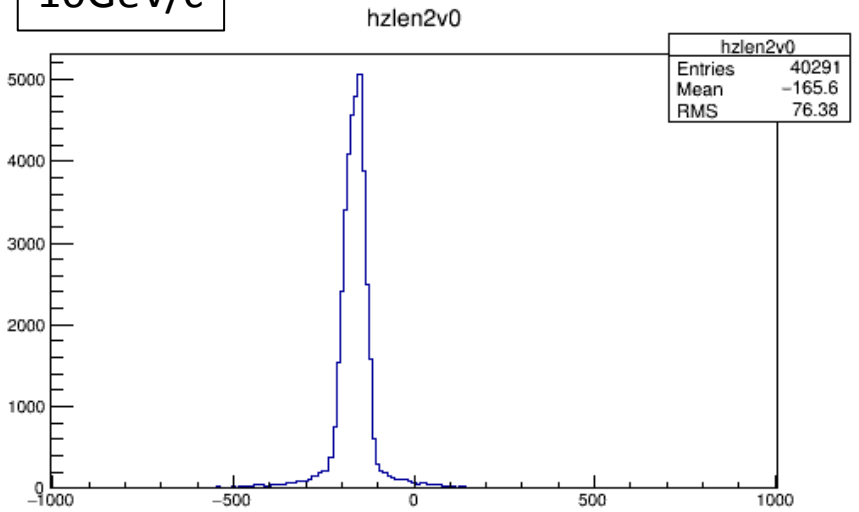


$2000[mm] \leq x < 3000[mm]$

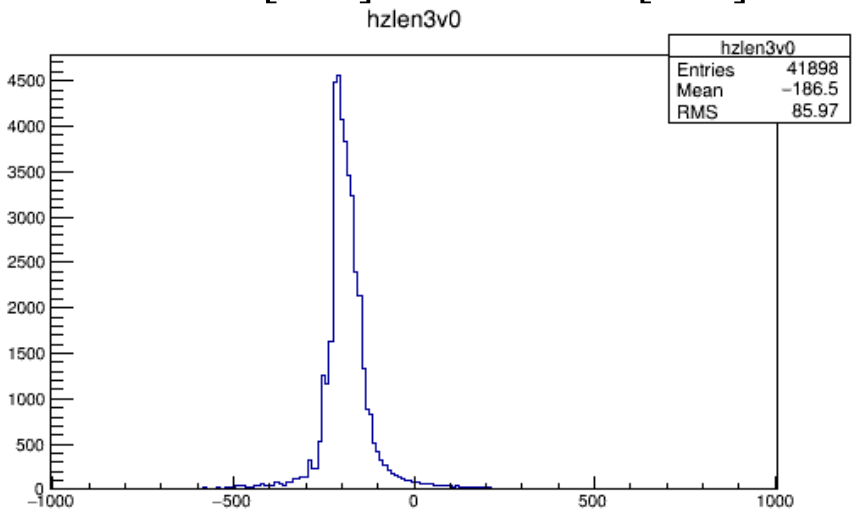


$3000[mm] \leq x < 4000[mm]$

10GeV/c



$2000[mm] \leq x < 3000[mm]$

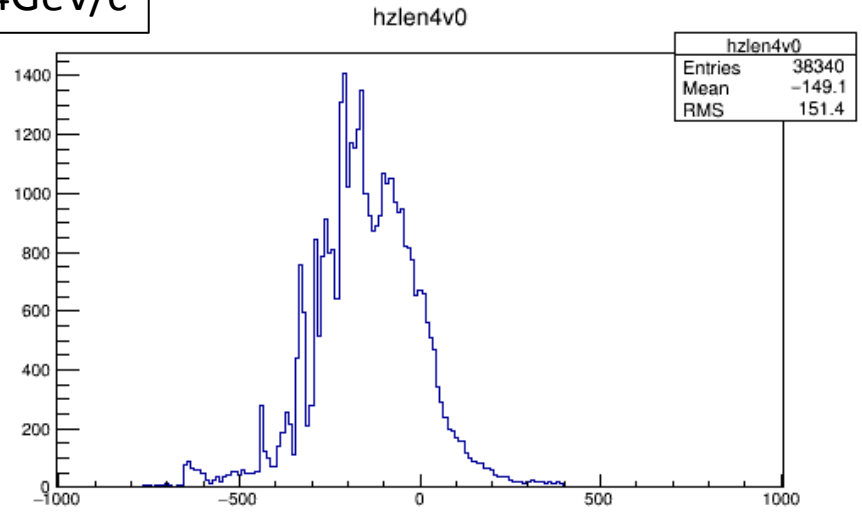


$3000[mm] \leq x < 4000[mm]$

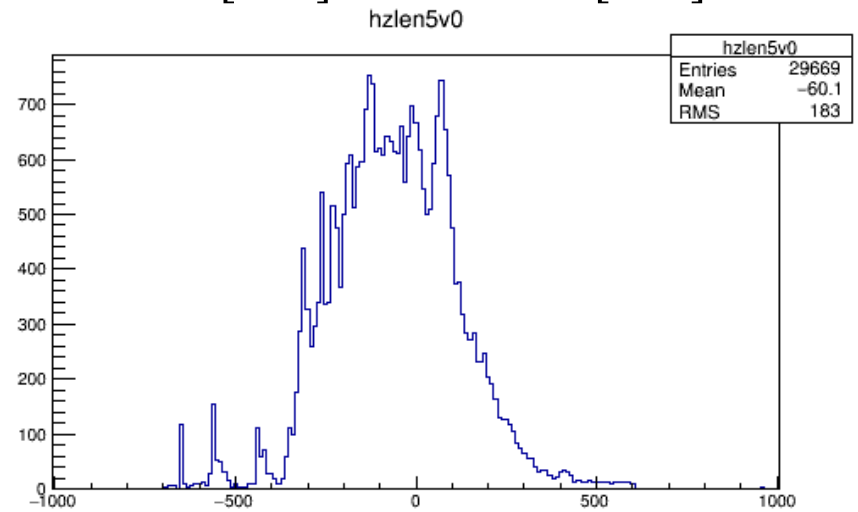
Funny periodical structure, to be understood

The difference in z position(FieldMap : 500V/cm nominal, backflow 10%)

4GeV/c

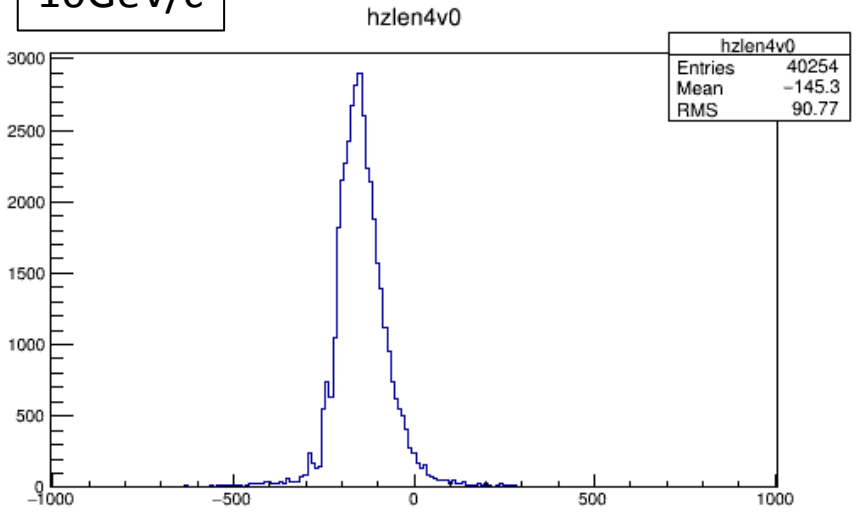


$4000[mm] \leq x < 5000[mm]$

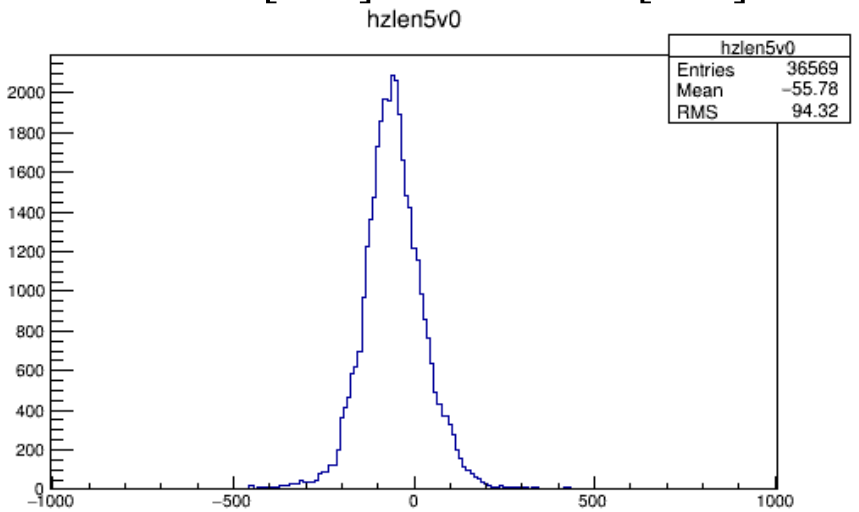


$5000[mm] \leq x \leq 6000[mm]$

10GeV/c



$4000[mm] \leq x < 5000[mm]$



$5000[mm] \leq x \leq 6000[mm]$

Funny periodical structure, to be understood

Observation

- Uniform field
  - central value is on the ideal line
  - Larger dispersion for larger length from start point
  - More dispersion for 4GeV/c than 10GeV/c
- Field map with space charge
  - Shift of central value is observed
  - Bigger shift for 10%backflow than 0% backflow as is expected
- Funny periodical structure, to be understood

Result(X-Z view, 4GeV/c)

Mean value (arithmetic) and peak value of Gaussian fit are summarized in a table

	X	0 < X < 1000[mm]	1000 < X < 2000[mm]	2000 < X < 3000[mm]	3000 < X < 4000[mm]	4000 < X < 5000[mm]	5000 < X < 6000[mm]
Uniform 500V/cm	Peak	0.56	0.89	2.09	5.61	9.83	13.32
	Mean	1.65	1.08	-0.45	1.14	6.98	8.11
use Field Map① (500V/cm nominal, no backflow)	Peak	-7.66	-33.67	-69.68	-80.83	-53.57	-29.79
	Mean	-7.53	-34.10	-70.61	-86.13	-63.94	-18.26
use Field Map② (500V/cm nominal, backflow 10%)	Peak	-17.21	-88.27	-168.4	-190.8	-135.5	-43.12
	Mean	-11.22	-86.01	-168.8	-196.5	-149.1	-60.10

unit[mm]

・When using FieldMap, z distance changes greatly to negative direction, indicating the space charge effect

・ When using FieldMap②, z distance is about 2~3 times larger than using FieldMap①

NOTE:

* This is the first attempt to quantify the peak value.

*Quantitative evaluation of the peak position to be better defined with understanding uncertainty.(Need to understand funny structure of the distribution)

Result(Y-Z view, 4GeV/c)

Mean value (arithmetic) and peak value of Gaussian fit are summarized in a table

	Y	0 < Y < 1000[mm]	1000 < Y < 2000[mm]	2000 < Y < 3000[mm]	3000 < Y < 4000[mm]	4000 < Y < 5000[mm]	5000 < Y < 6000[mm]
Uniform 500V/cm	Peak	0.62	1.60	1.70	7.50	9.20	16.82
	Mean	1.18	1.43	-0.02	3.11	6.53	6.50
use Field Map① (500V/cm nominal, no backflow)	Peak	-7.62	-32.76	-69.98	-79.79	-57.29	8.70
	Mean	-8.12	-33.94	-70.26	-84.04	-64.37	-19.84
use Field Map② (500V/cm nominal, backflow 10%)	Peak	-17.60	-87.61	-168.7	-190.5	-136.1	-45.83
	Mean	-11.58	-86.41	-168.3	-194.5	-148.9	-61.26

unit[mm]

・When using FieldMap, z distance changes greatly to negative direction indicating the space charge effect

・ When using FieldMap②, z distance is about 2~3 times larger than using FieldMap①

NOTE:

* This is the first attempt to quantify the peak value.

*Quantitative evaluation of the peak position to be better defined with understanding uncertainty.(Need to understand funny structure of the distribution)

Result(X-Z view, 10GeV/c)

Mean value (arithmetic) and peak value of Gaussian fit are summarized in a table

	X	0 < X < 1000[mm]	1000 < X < 2000[mm]	2000 < X < 3000[mm]	3000 < X < 4000[mm]	4000 < X < 5000[mm]	5000 < X < 6000[mm]
Uniform 500V/cm	Peak	0.53	1.55	4.47	7.70	10.76	6.93
	Mean	-0.88	0.10	2.95	10.78	9.82	8.40
use Field Map① (500V/cm nominal, no backflow)	Peak	-8.93	-34.76	-66.79	-79.08	-60.10	-14.46
	Mean	-10.35	-35.69	-67.81	-76.33	-60.41	-15.49
use Field Map② (500V/cm nominal, backflow 10%)	Peak	-17.10	-88.64	-164.7	-189.7	-146.0	-55.78
	Mean	-12.40	-88.74	-165.6	-186.5	-145.3	-55.86

unit[mm]

・When using FieldMap, z distance changes greatly to negative direction indicating the space charge effect

・ When using FieldMap②, z distance is about 2~3 times larger than using FieldMap①

NOTE:

* This is the first attempt to quantify the peak value.

*Quantitative evaluation of the peak position to be better defined with understanding uncertainty.(Need to understand funny structure of the distribution)

Result(Y-Z view, 10GeV/c)

Mean value (arithmetic) and peak value of Gaussian fit are summarized in a table

	Y	0 < Y < 1000[mm]	1000 < Y < 2000[mm]	2000 < Y < 3000[mm]	3000 < Y < 4000[mm]	4000 < Y < 5000[mm]	5000 < Y < 6000[mm]
Uniform 500V/cm	Peak	0.38	1.45	4.68	7.94	8.12	8.32
	Mean	1.27	0.13	4.05	11.46	9.55	7.79
use Field Map① (500V/cm nominal, no backflow)	Peak	-8.94	-34.65	-66.28	-79.48	-61.34	-15.61
	Mean	-10.97	-35.82	-66.54	-75.38	-60.86	--15.84
use Field Map② (500V/cm nominal, backflow 10%)	Peak	-17.54	-88.67	-164.5	-189.9	-146.7	-55.66
	Mean	-12.88	-89.27	-164.3	-186.8	-145.0	-56.05

unit[mm]

・When using FieldMap, z distance changes greatly to negative direction indicating the space charge effect

・ When using FieldMap②, z distance is about 2~3 times larger than using FieldMap①

NOTE:

* This is the first attempt to quantify the peak value.

*Quantitative evaluation of the peak position to be better defined with understanding uncertainty.(Need to understand funny structure of the distribution)

Direct calculation of the space charge effect from Field Map

Calculate z distance from Ideal beamline from FieldMap information

procedure

1.Export drift time from Map data which is the closest to ideal beamline.

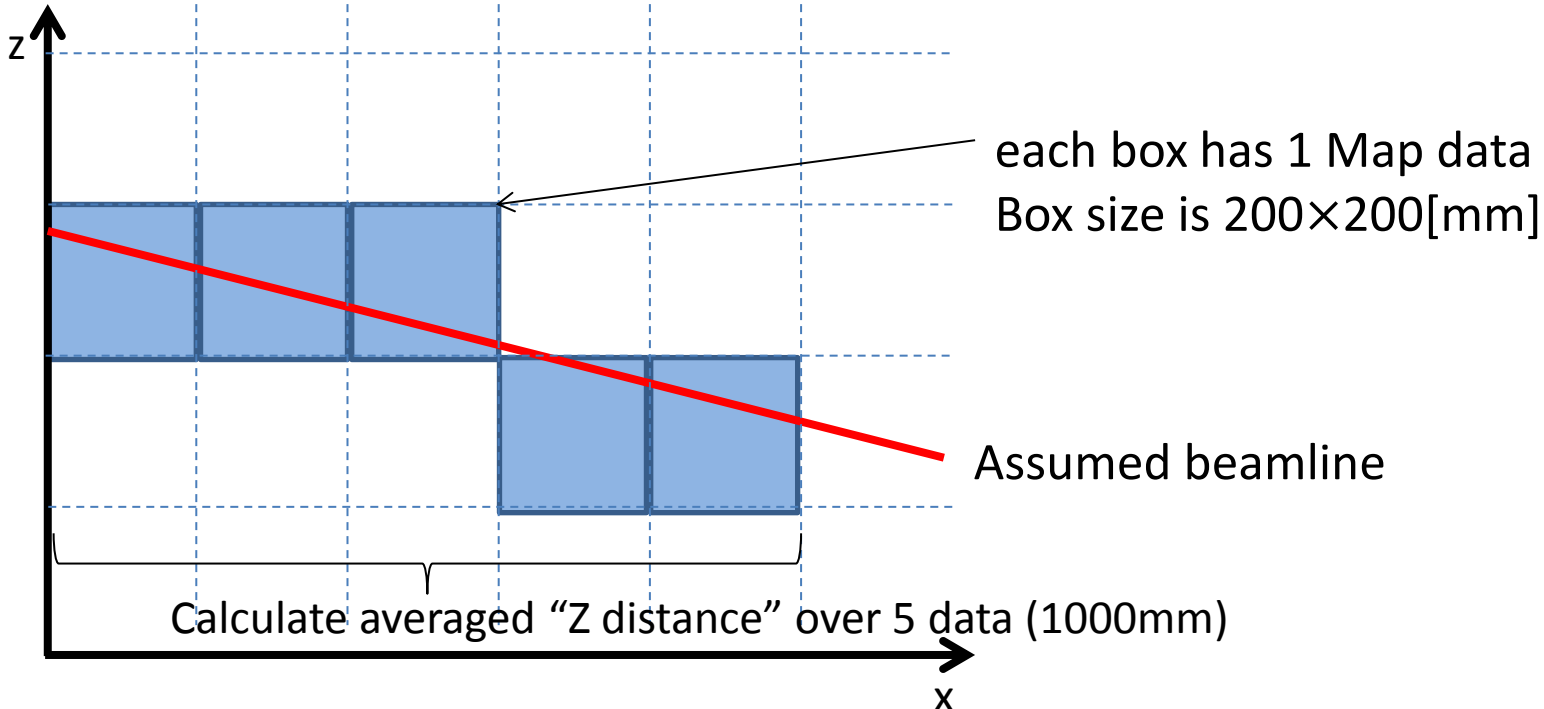
2. The drift length is calculated by drift time×drift velocity

→This should corresponds to the z coordinate of the reconstructed charge position

3. Calculate the difference between this calculation and reconstructed z information

→The difference is “Z distance”

4. Partitioning is based on same as shown before (1000mm each)



Result

		0 < X < 1000[mm]	1000 < X < 2000[mm]	2000 < X < 3000[mm]	3000 < X < 4000[mm]	4000 < X < 5000[mm]	5000 < X < 6000[mm]
use Field Map① (500V/cm nominal, no backflow)	Peak	-7.66	-33.67	-69.68	-80.83	-53.57	-29.79
	Mean	-7.53	-34.10	-70.61	-86.13	-63.94	-18.26
Calculated value		-8.86	-41.54	-72.88	-84.21	-64.37	-19.7

unit[mm]

		0 < X < 1000[mm]	1000 < X < 2000[mm]	2000 < X < 3000[mm]	3000 < X < 4000[mm]	4000 < X < 5000[mm]	5000 < X < 6000[mm]
use Field Map② (500V/cm nominal, backflow 10%)	Peak	-17.21	-88.27	-168.44	-190.82	-135.49	-43.12
	Mean	-11.22	-86.01	-168.8	-196.5	-149.10	-60.10
Calculated value		-29.28	-115.8	-180.58	-190.08	-138.28	-44.73

unit[mm]

・Direct calculation are mostly corresponds to the simulation results

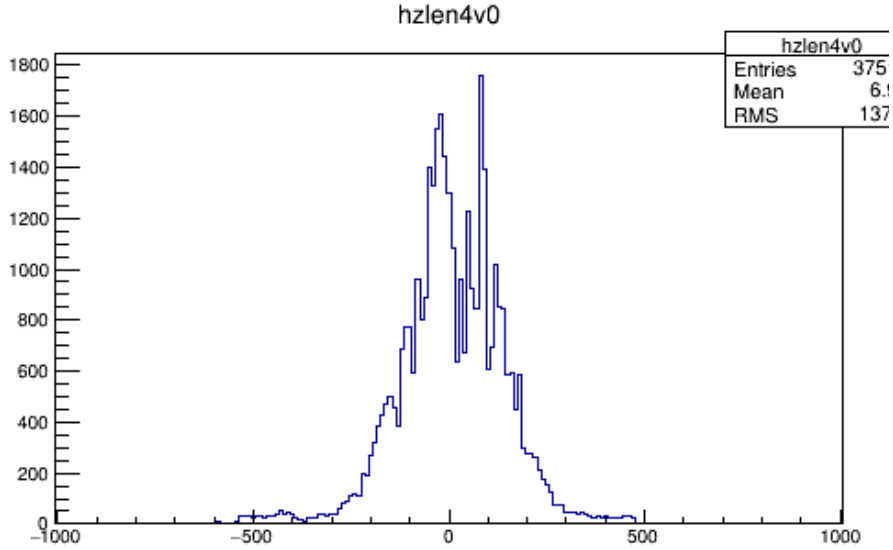
NOTE:

* This is the first attempt to quantify the peak value.

*Quantitative evaluation of the peak position to be better defined with understanding uncertainty.(Need to understand funny structure of the distribution)

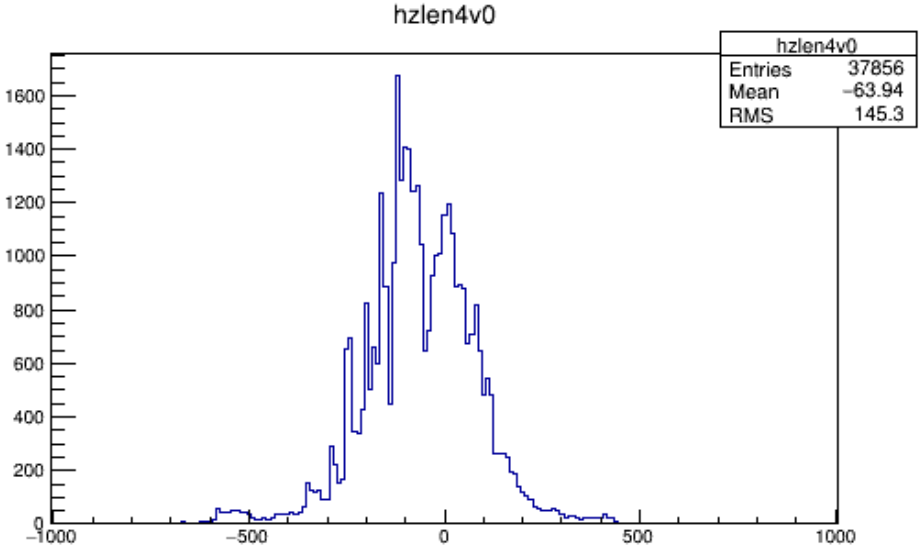
Funny structure of the distribution

Uniform field of 500V/cm



$4000[mm] \leq x < 5000[mm]$

FieldMap : 500V/cm nominal, no backflow



$4000[mm] \leq x < 5000[mm]$

There are strange periodical structure.

Summary

evaluation method of Space Charge Effect is assessed

Evaluated space charge effect looks reasonably reflects the input field distortion value.

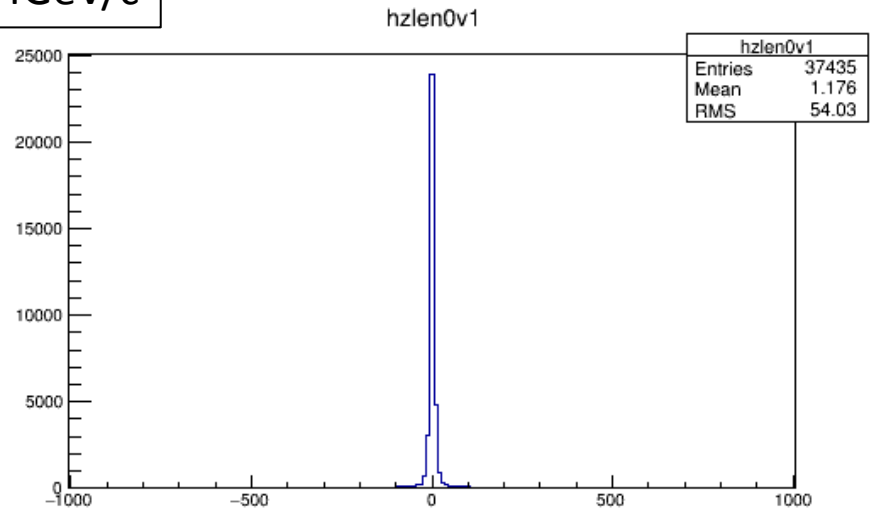
Next:

- Understand the cause of funny structure of the distribution.
- Need to better quantify the effect with understanding uncertainty.
- Need to check the latest information about beam information including beam divergence.
- Need to check relative magnitude of X,Y components of distortion, with respect to Z component

backup

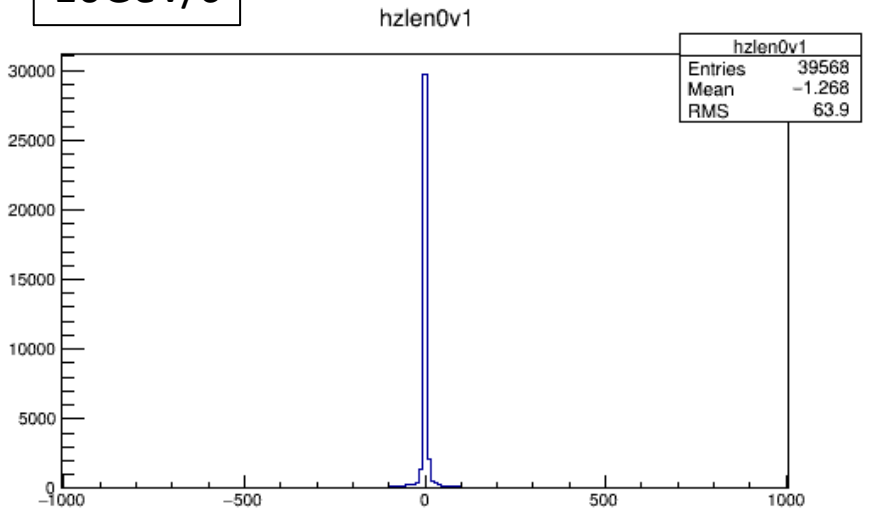
Comparison of histogram(Uniform field of 500v/cm)

4GeV/c

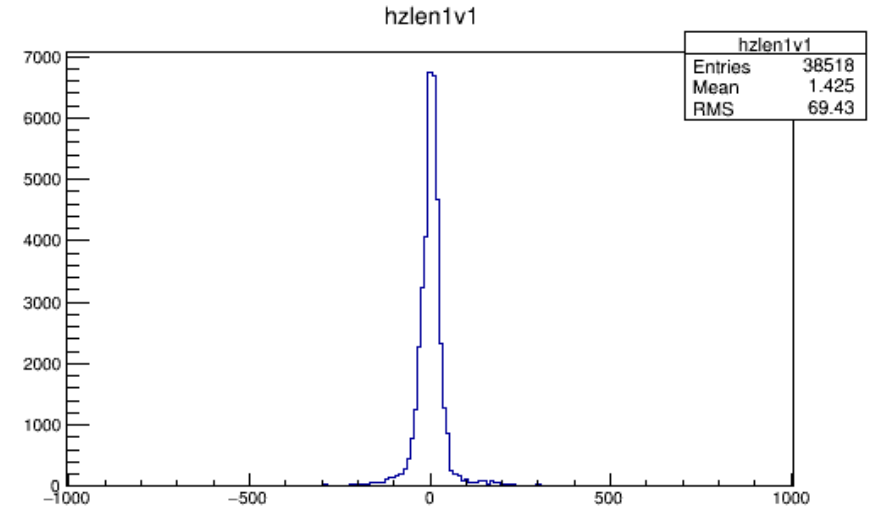


$0[mm] \leq y < 1000[mm]$

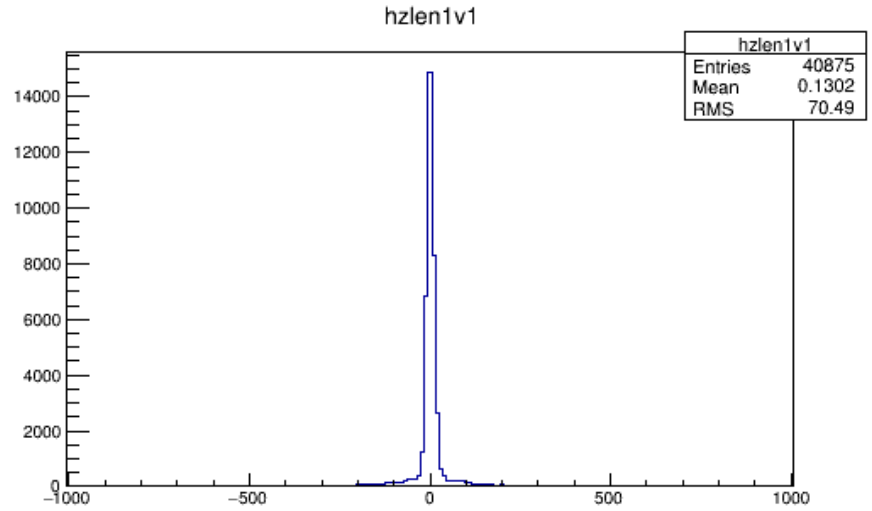
10GeV/c



$0[mm] \leq y < 1000[mm]$



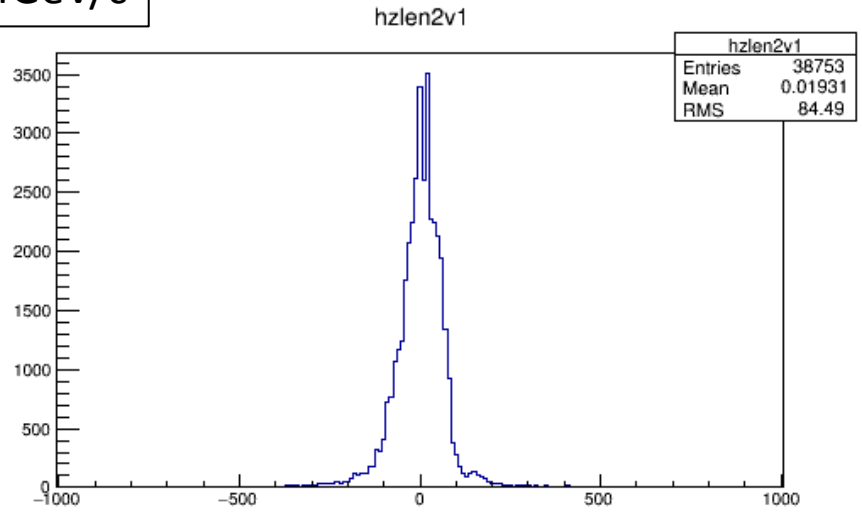
$1000[mm] \leq y < 2000[mm]$



$1000[mm] \leq y < 2000[mm]$

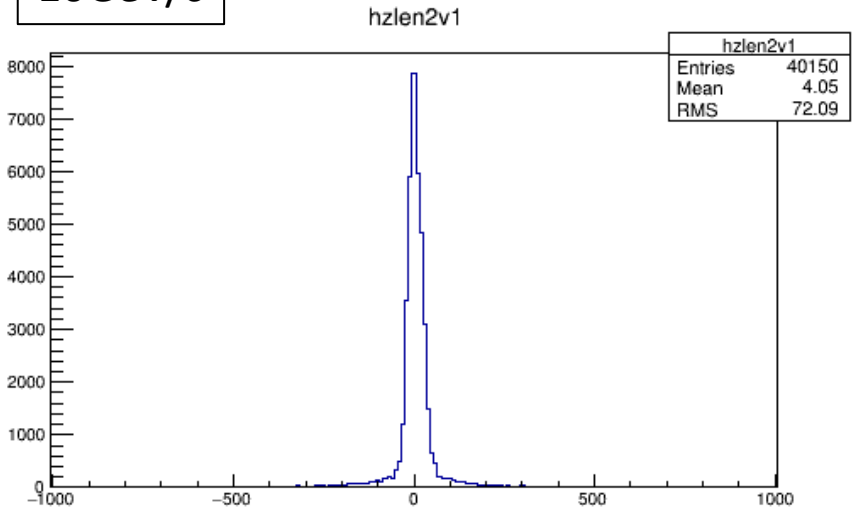
Comparison of histogram(Uniform field of 500v/cm)

4GeV/c

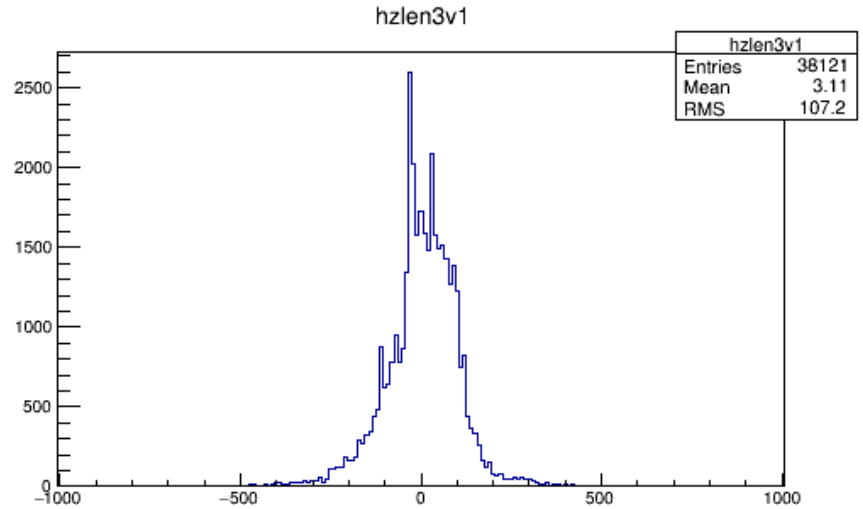


$2000[mm] \leq y < 3000[mm]$

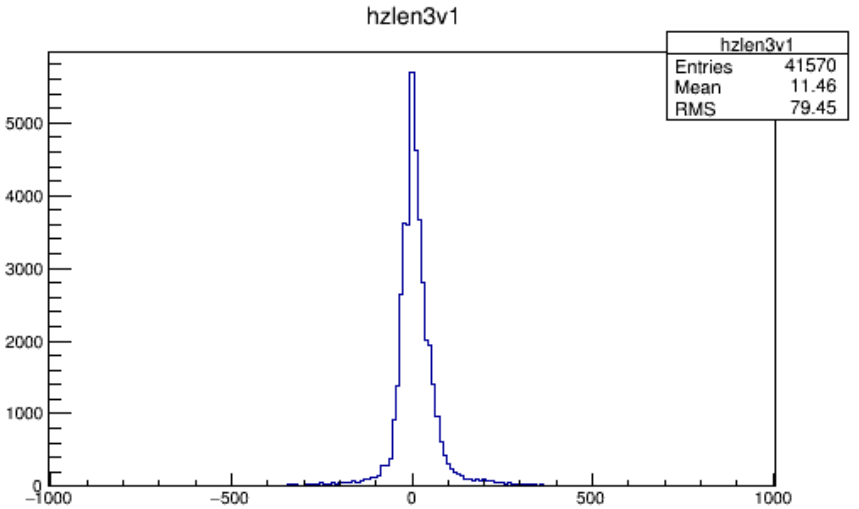
10GeV/c



$2000[mm] \leq y < 3000[mm]$



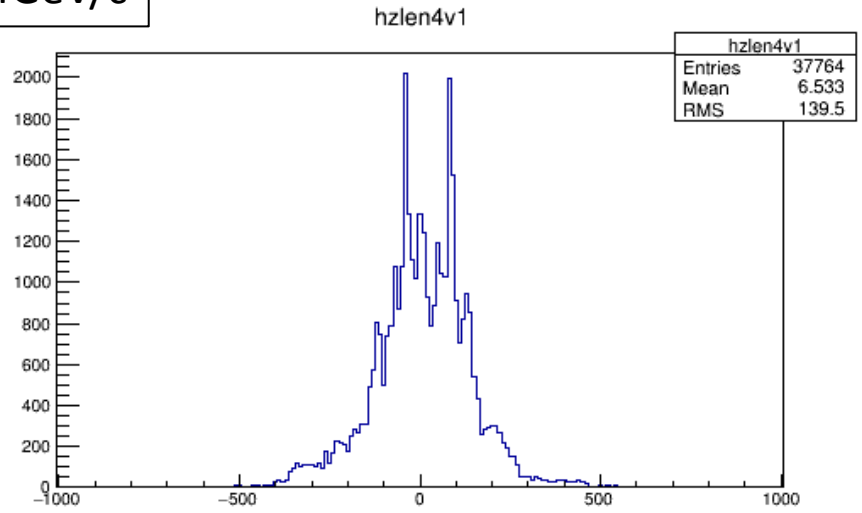
$3000[mm] \leq y < 4000[mm]$



$3000[mm] \leq y < 4000[mm]$

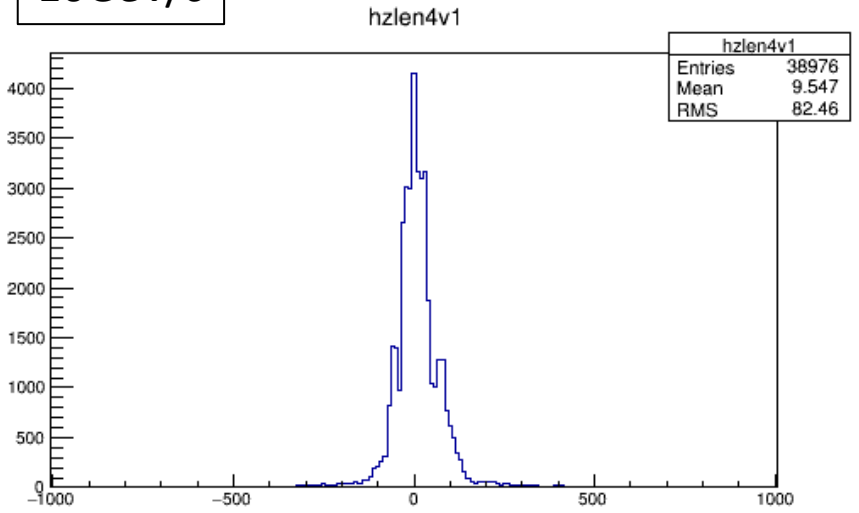
Comparison of histogram(Uniform field of 500v/cm)

4GeV/c

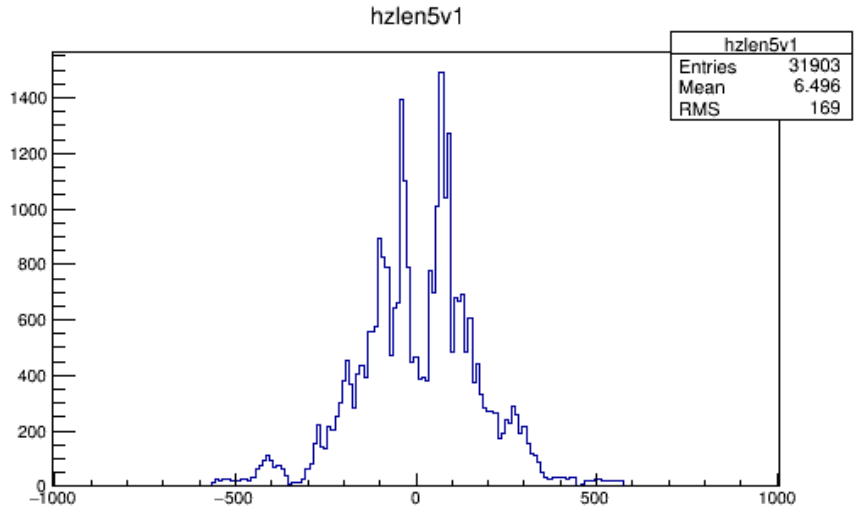


$4000[mm] \leq y < 5000[mm]$

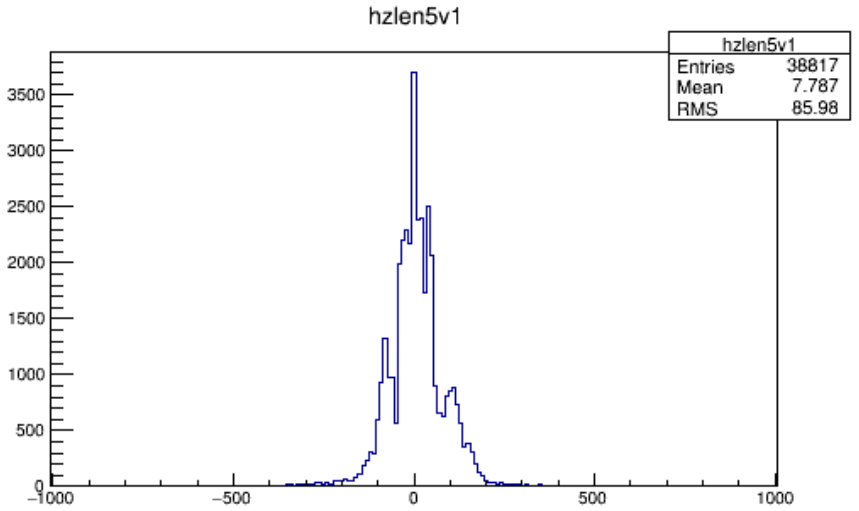
10GeV/c



$4000[mm] \leq y < 5000[mm]$



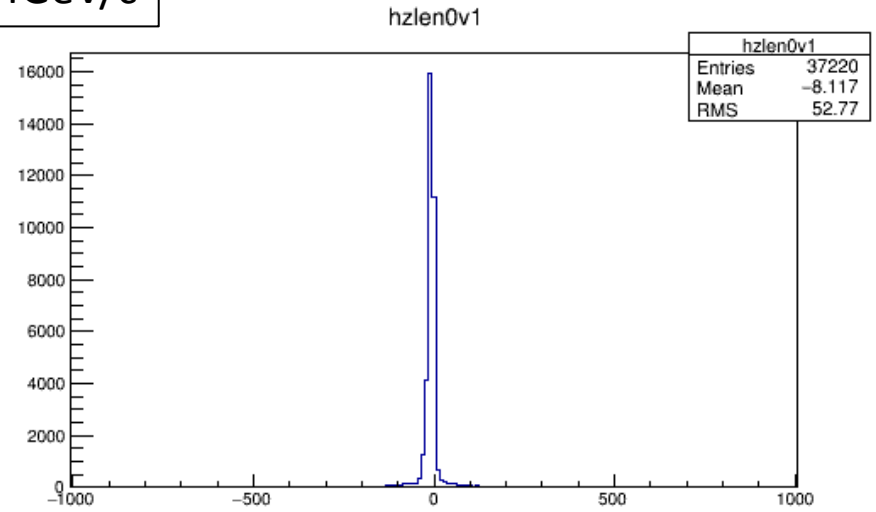
$5000[mm] \leq y \leq 6000[mm]$



$5000[mm] \leq y \leq 6000[mm]$

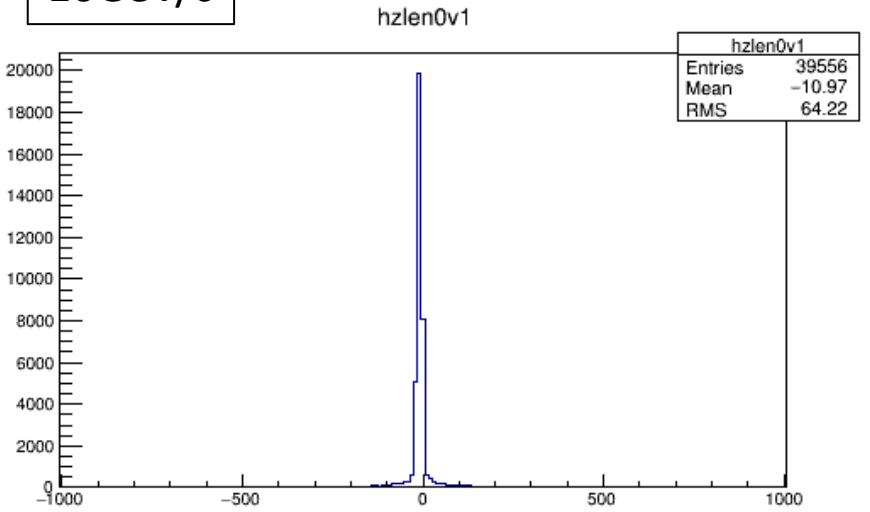
Comparison of histogram(FieldMap : 500V/cm nominal, no backflow)

4GeV/c

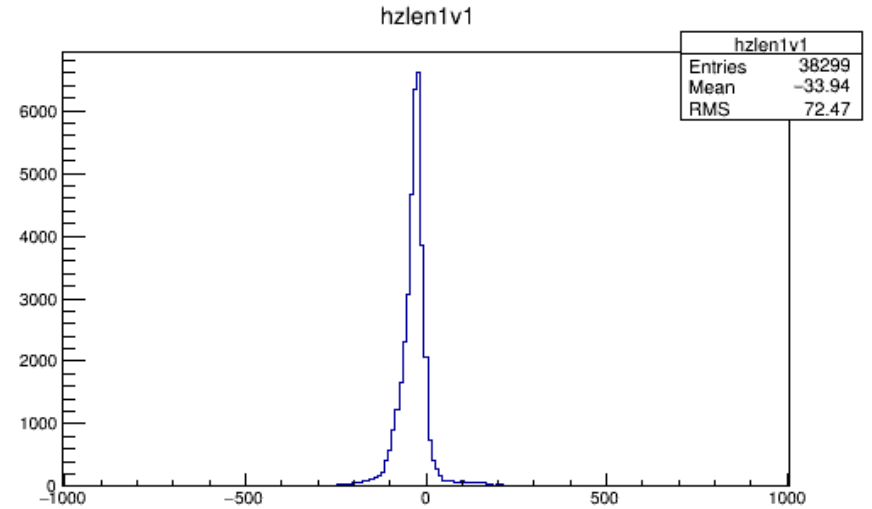


$0[mm] \leq y < 1000[mm]$

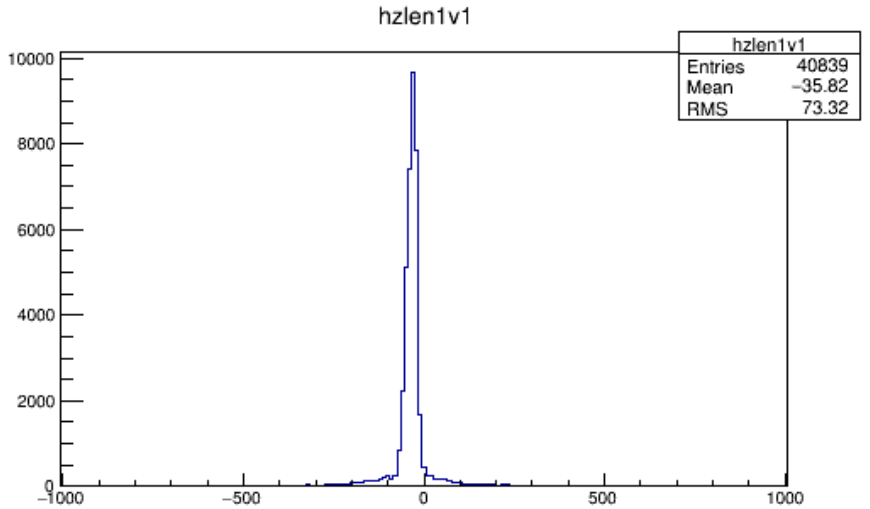
10GeV/c



$0[mm] \leq y < 1000[mm]$



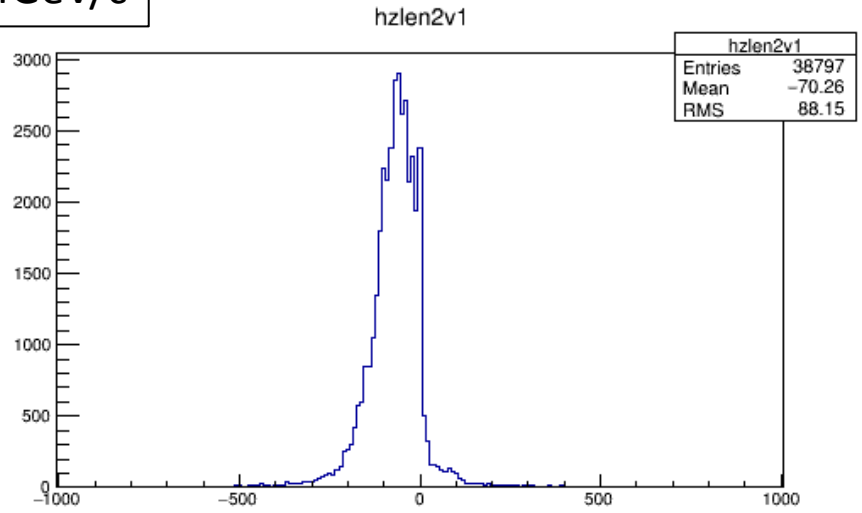
$1000[mm] \leq y < 2000[mm]$



$1000[mm] \leq y < 2000[mm]$

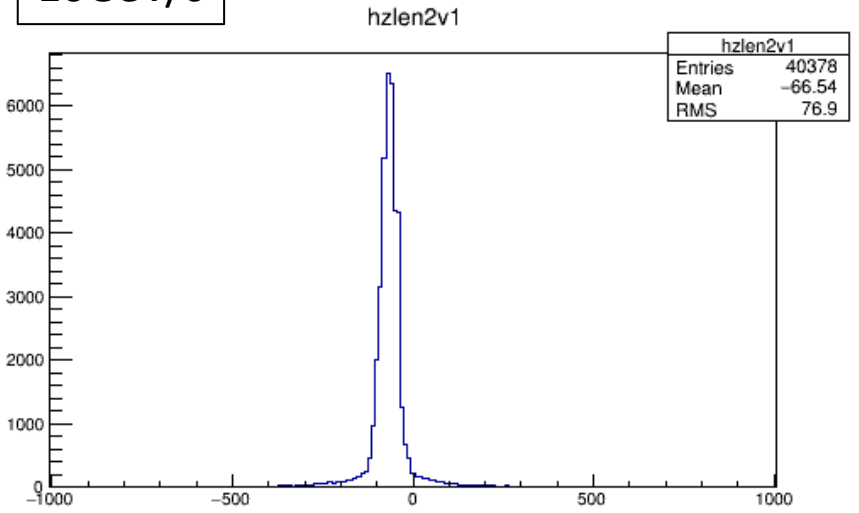
Comparison of histogram(FieldMap : 500V/cm nominal, no backflow)

4GeV/c

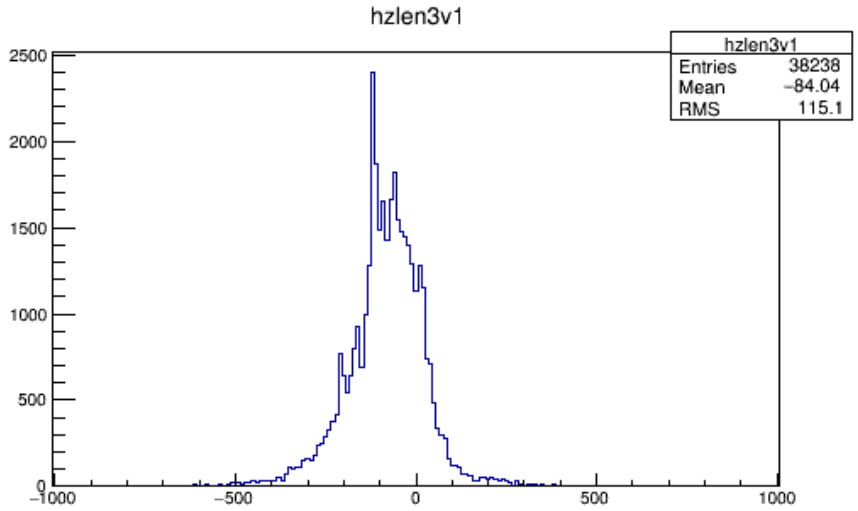


$2000[mm] \leq y < 3000[mm]$

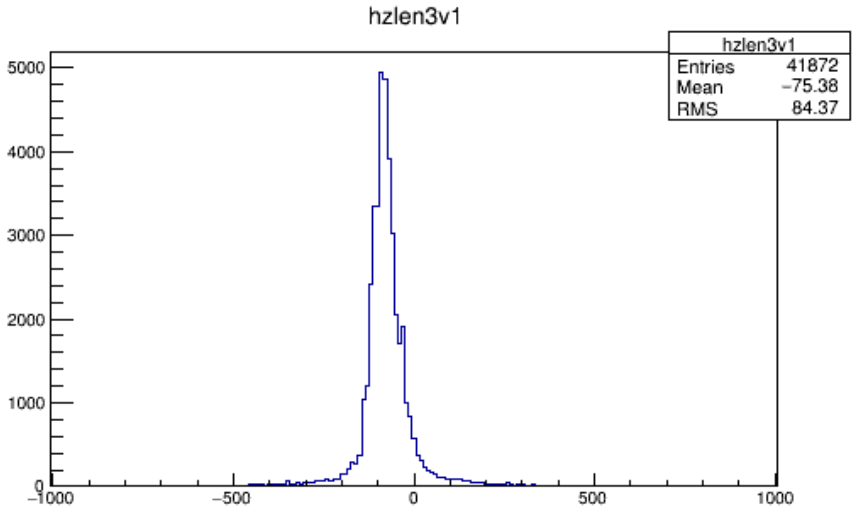
10GeV/c



$2000[mm] \leq y < 3000[mm]$



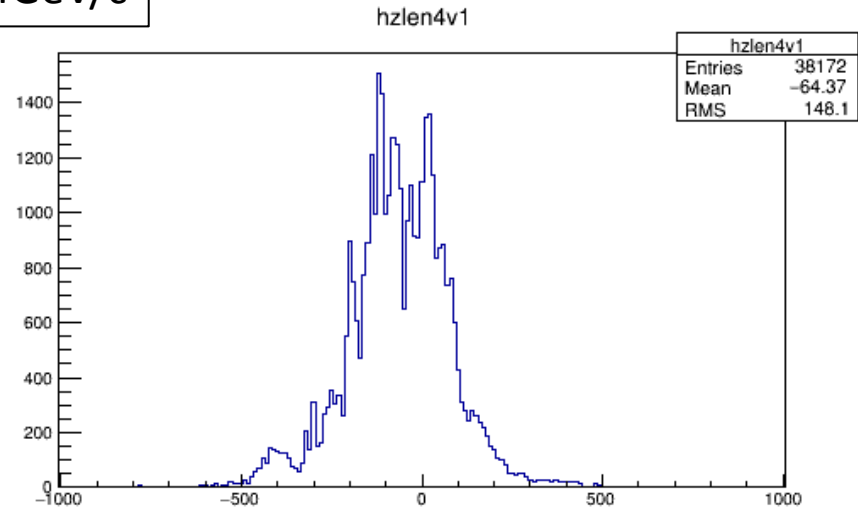
$3000[mm] \leq y < 4000[mm]$



$3000[mm] \leq y < 4000[mm]$

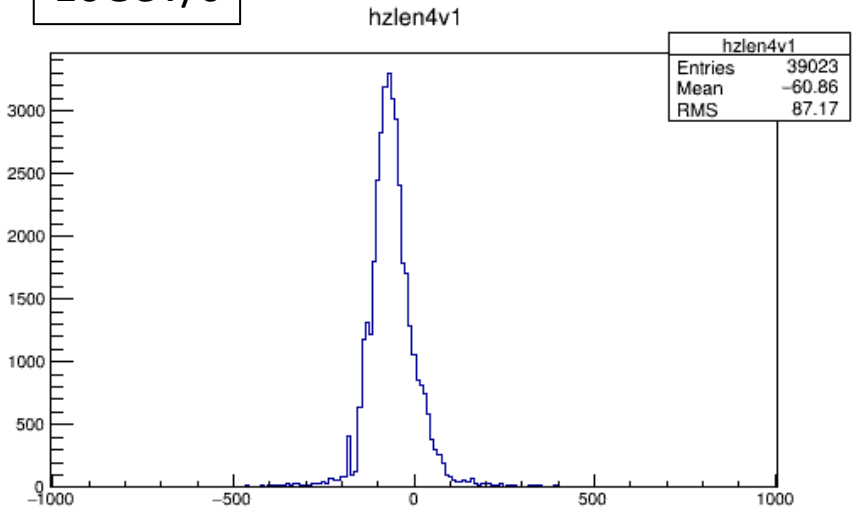
Comparison of histogram(FieldMap : 500V/cm nominal, no backflow)

4GeV/c

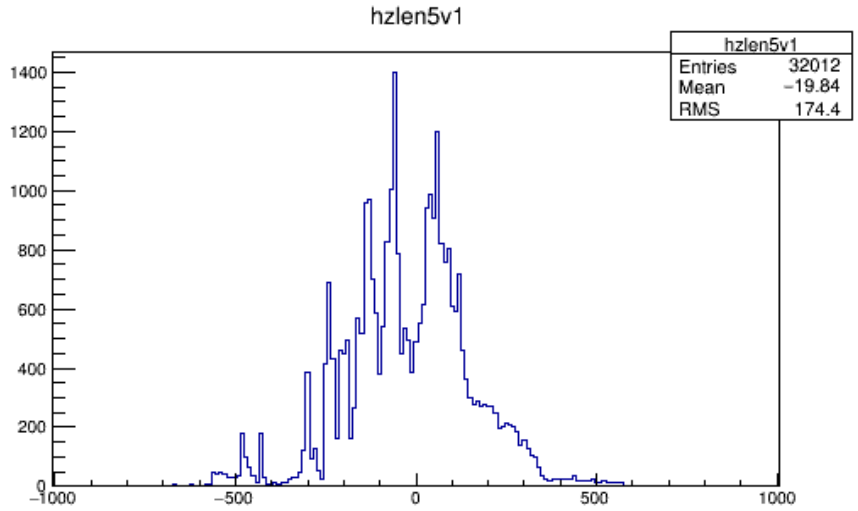


$4000[mm] \leq y < 5000[mm]$

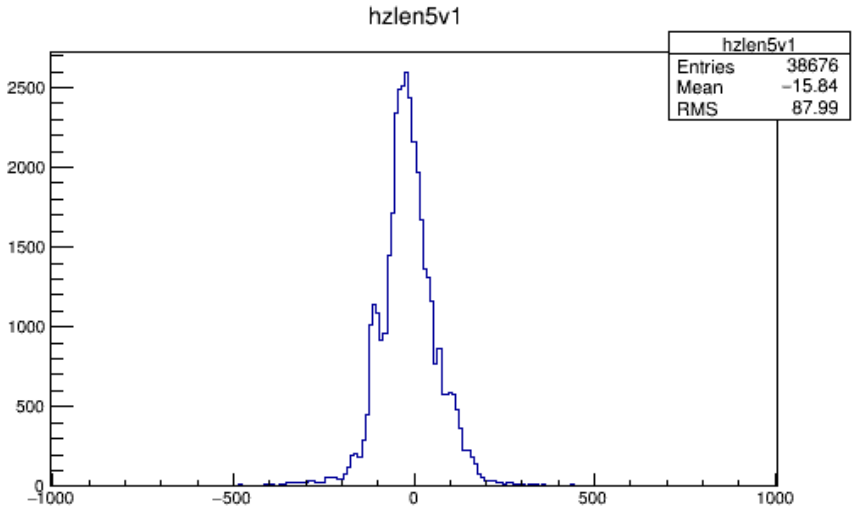
10GeV/c



$4000[mm] \leq y < 5000[mm]$



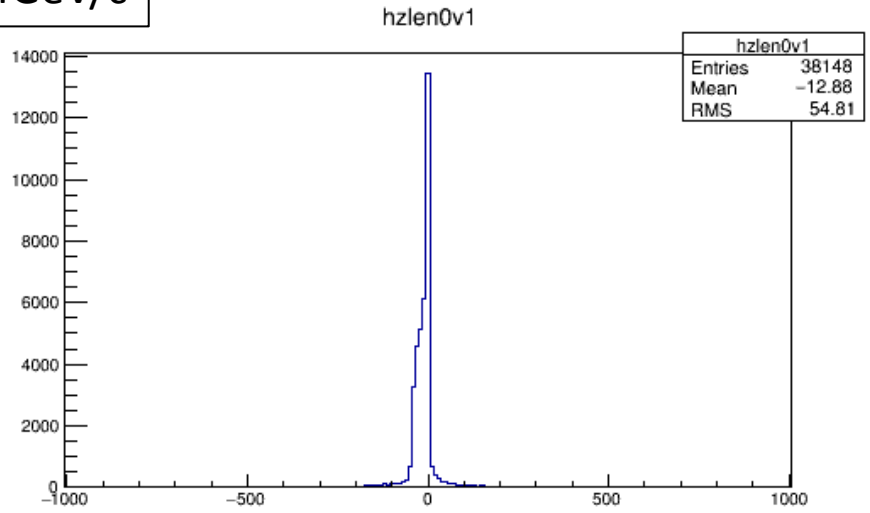
$5000[mm] \leq y \leq 6000[mm]$



$5000[mm] \leq y \leq 6000[mm]$

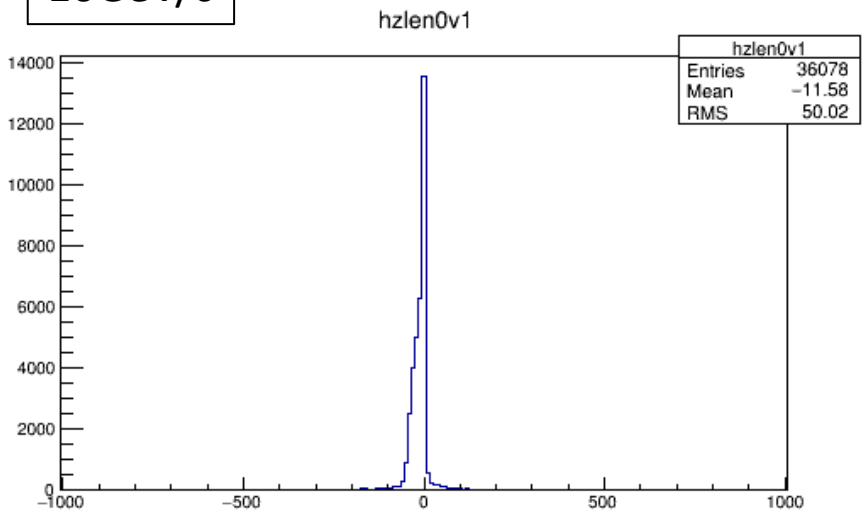
Comparison of histogram(FieldMap : 500V/cm nominal, backflow 10%)

4GeV/c

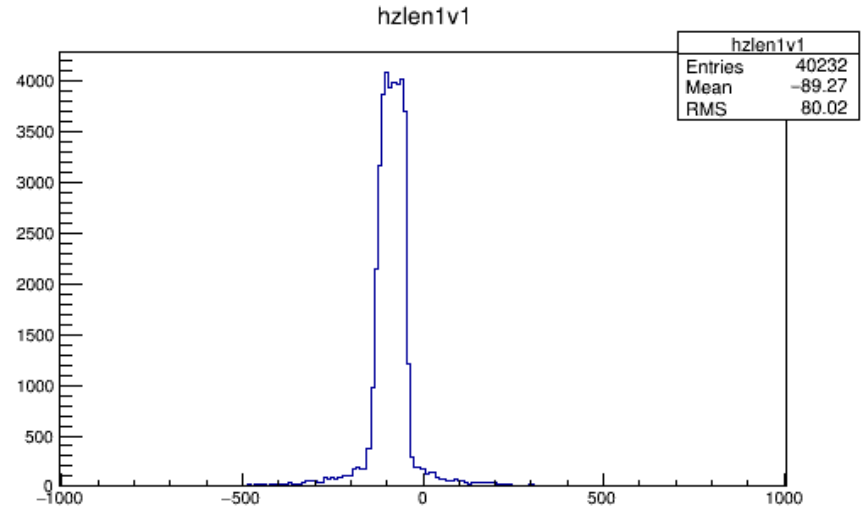


$0[mm] \leq y < 1000[mm]$

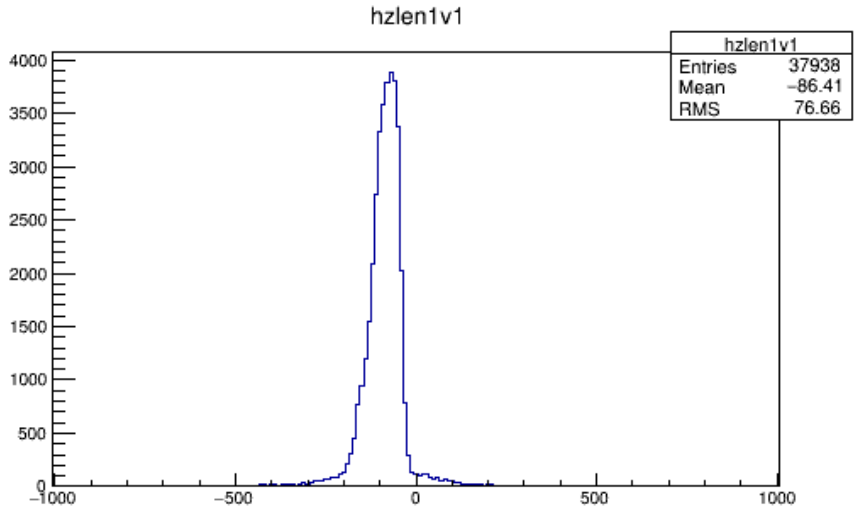
10GeV/c



$0[mm] \leq y < 1000[mm]$



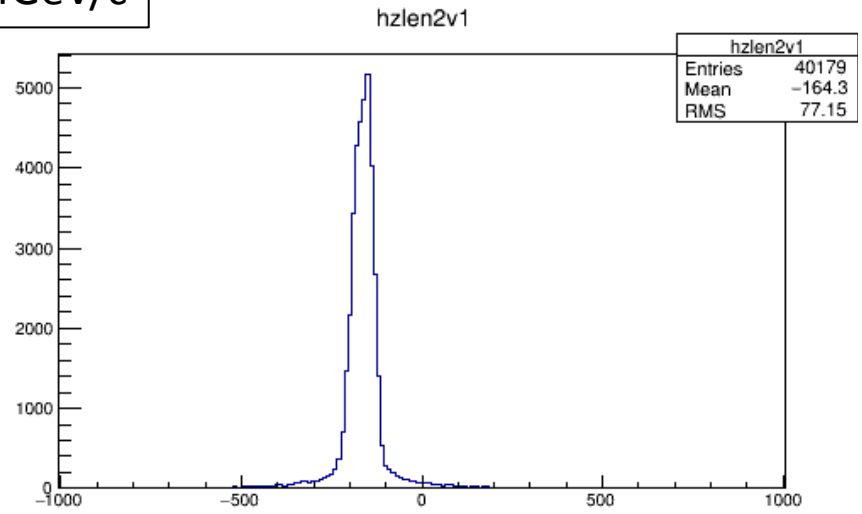
$1000[mm] \leq y < 2000[mm]$



$1000[mm] \leq y < 2000[mm]$

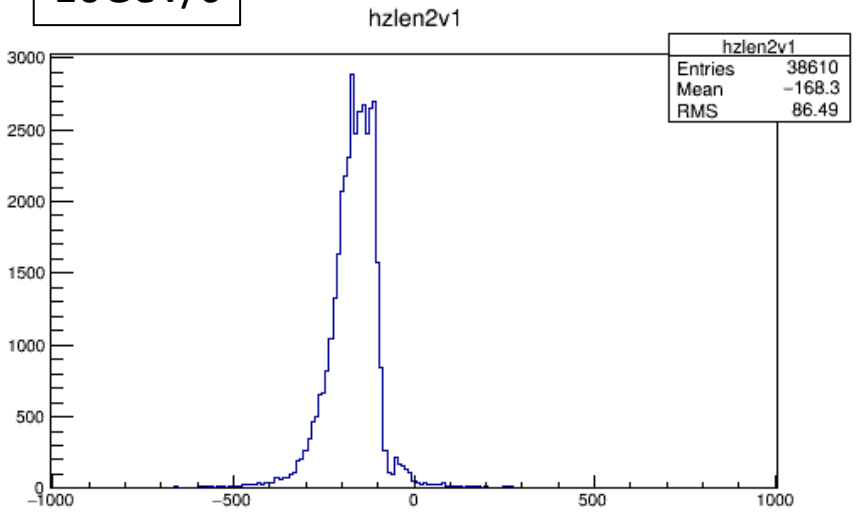
Comparison of histogram(FieldMap : 500V/cm nominal, backflow 10%)

4GeV/c

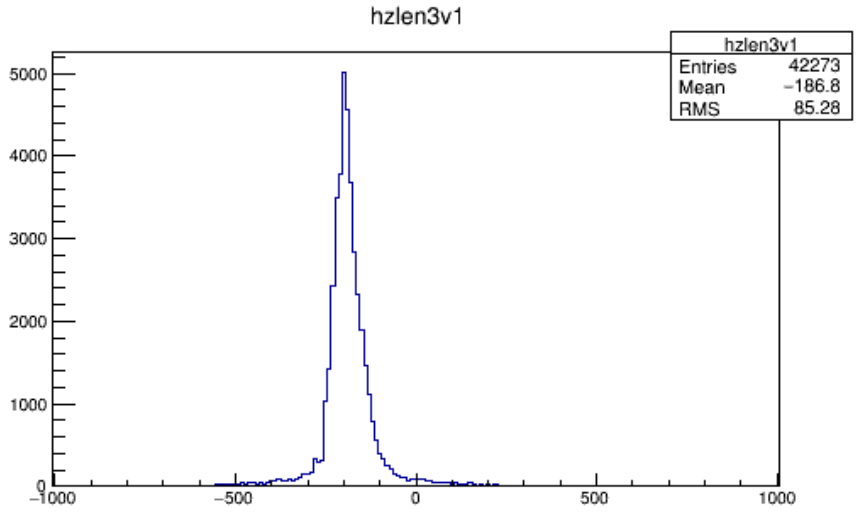


$2000[mm] \leq y < 3000[mm]$

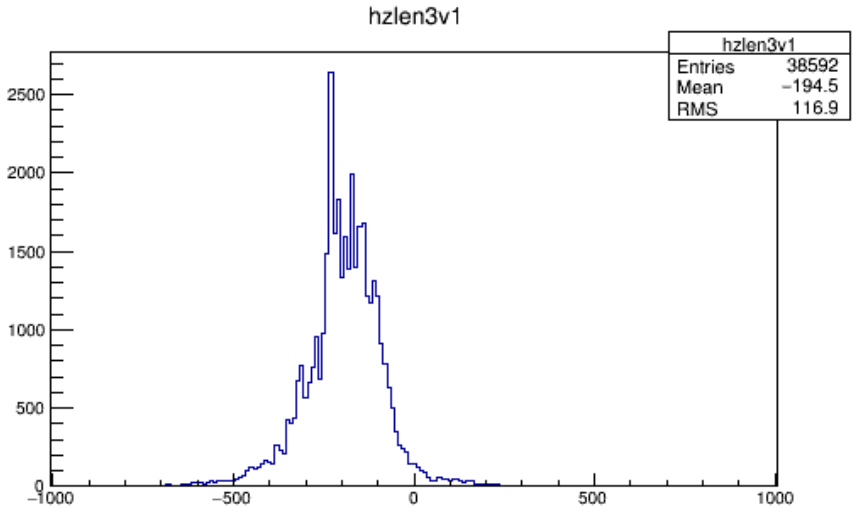
10GeV/c



$2000[mm] \leq y < 3000[mm]$



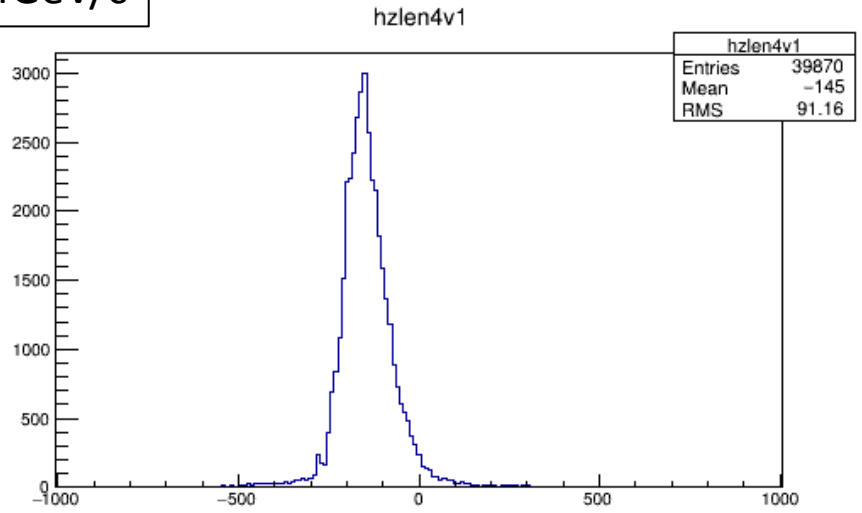
$3000[mm] \leq y < 4000[mm]$



$3000[mm] \leq y < 4000[mm]$

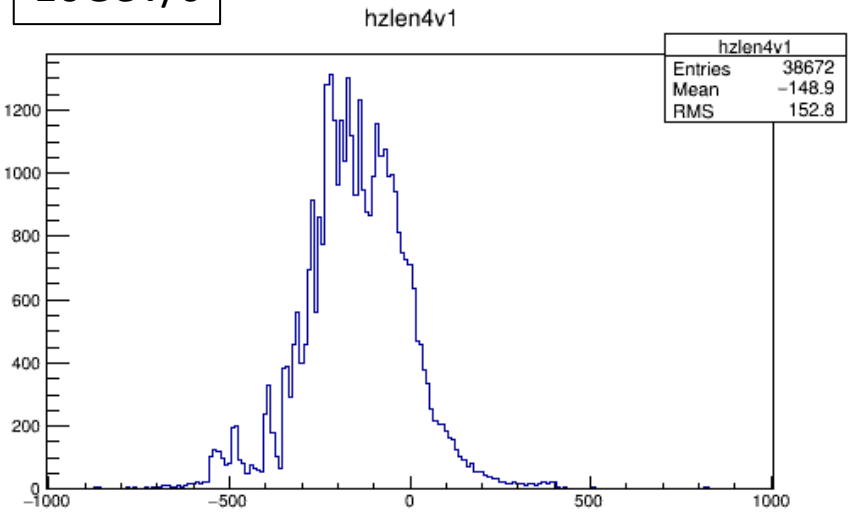
Comparison of histogram(FieldMap : 500V/cm nominal, backflow 10%)

4GeV/c

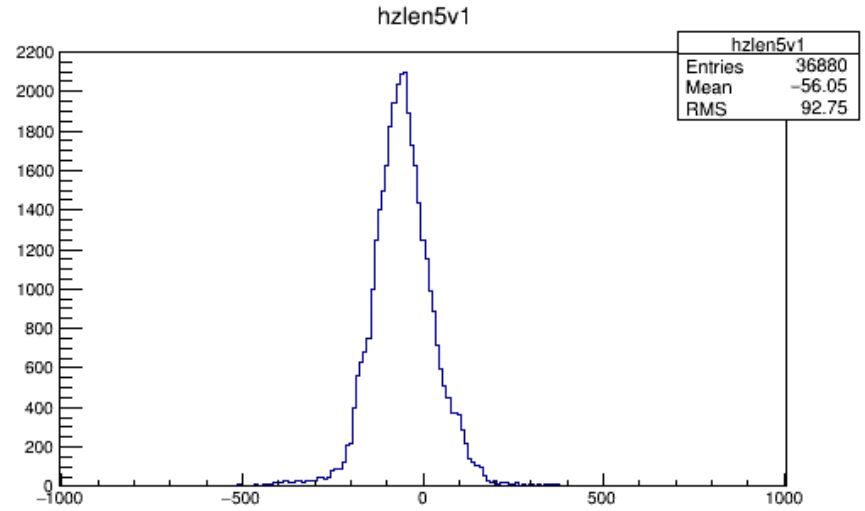


$4000[mm] \leq y < 5000[mm]$

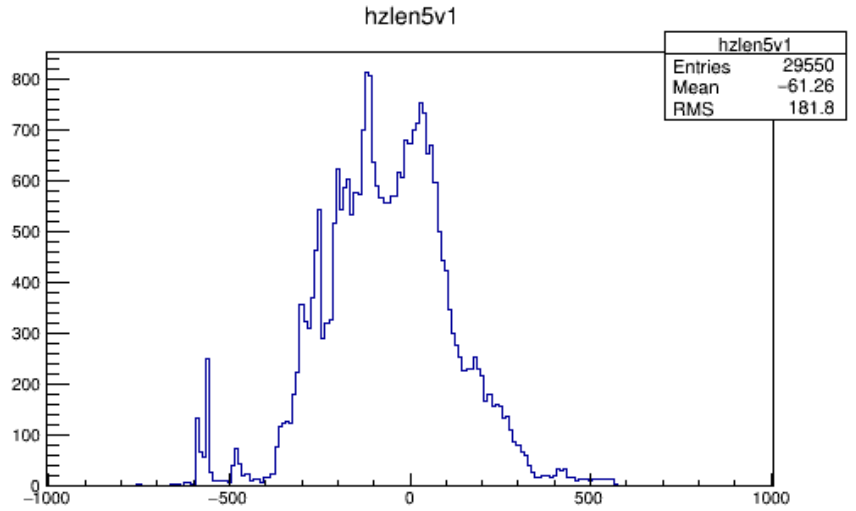
10GeV/c



$4000[mm] \leq y < 5000[mm]$



$5000[mm] \leq y \leq 6000[mm]$



$5000[mm] \leq y \leq 6000[mm]$