



Experimental performance study by Geant4 for the Hall C option

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for the JLab Hypernuclear Collaboration

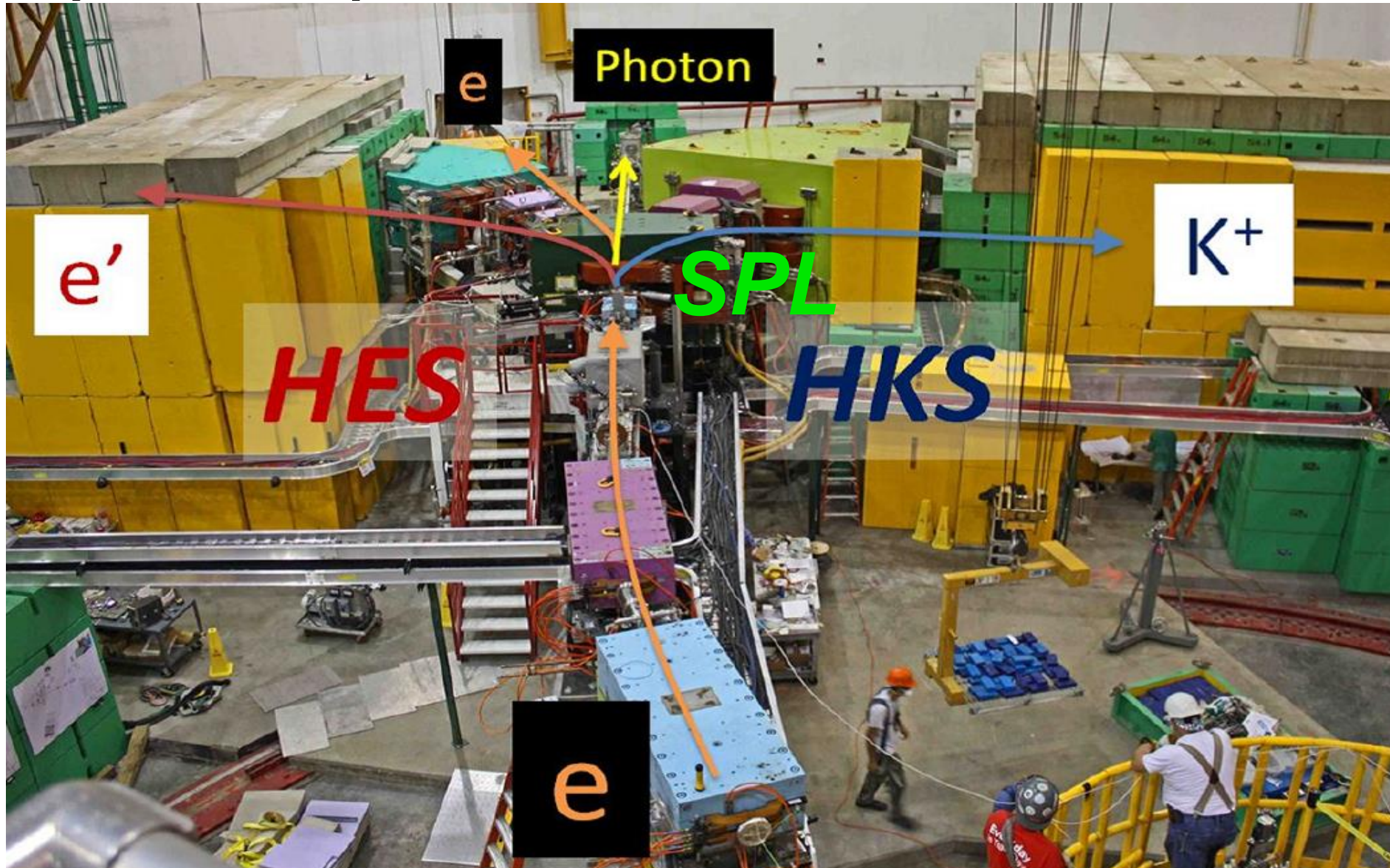
Graduate School of Science, Tohoku University, Japan

Graduate Program on Physics for the Universe (GP-PU), Tohoku University, Japan

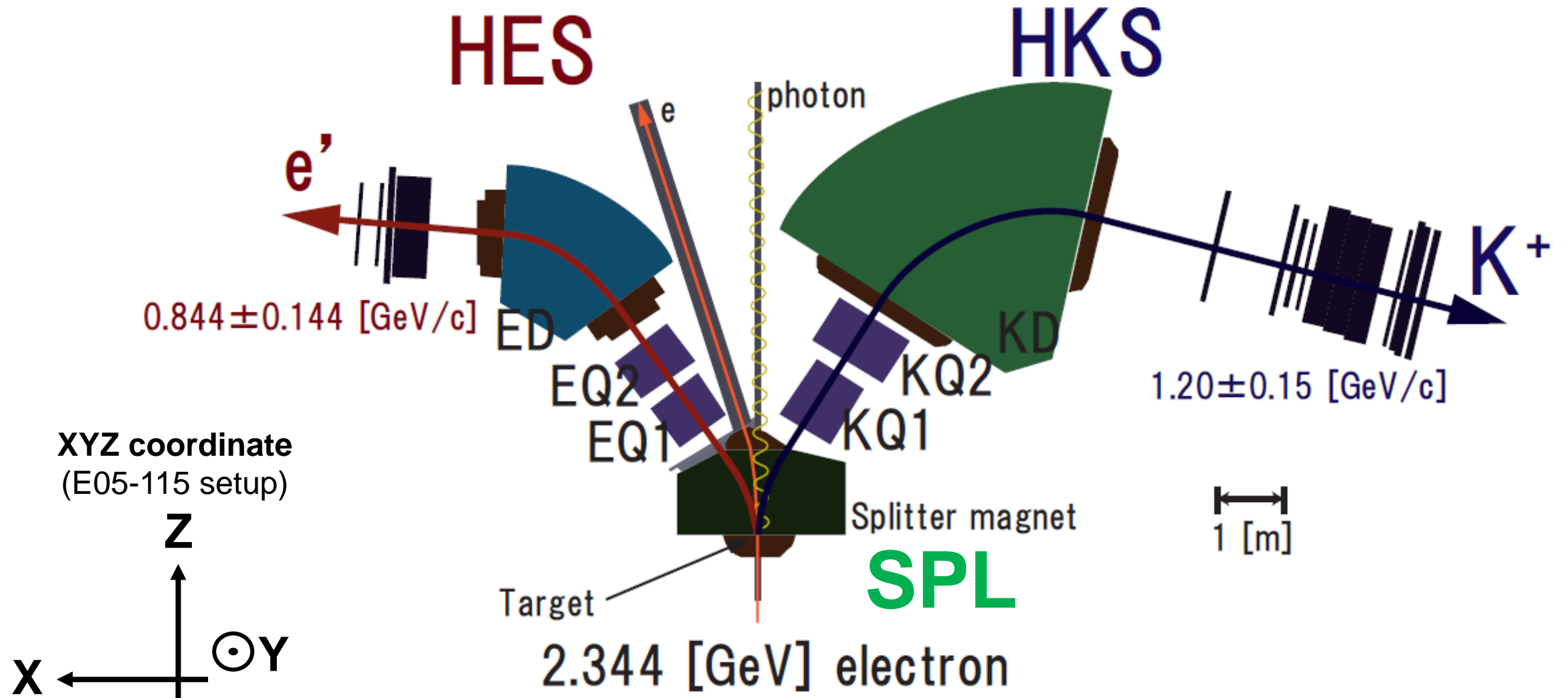
Contents

- E05-115: our latest experiment at JLab Hall-C
 - SPL + HKS(horizontal) + HES(horizontal)
- Hall-C option study by Geant4 simulation
 - Vertical bending spectrometer is essential to reconstruct Z-vertex
 - HKS: horizontal → vertical *(maybe mechanically difficult)*
 - HES: horizontal → vertical *(possible plan?)*
 - Z-vertex Resolution
 - Momentum Resolution
 - Acceptance

Our past experiment: E05-115 in 2009

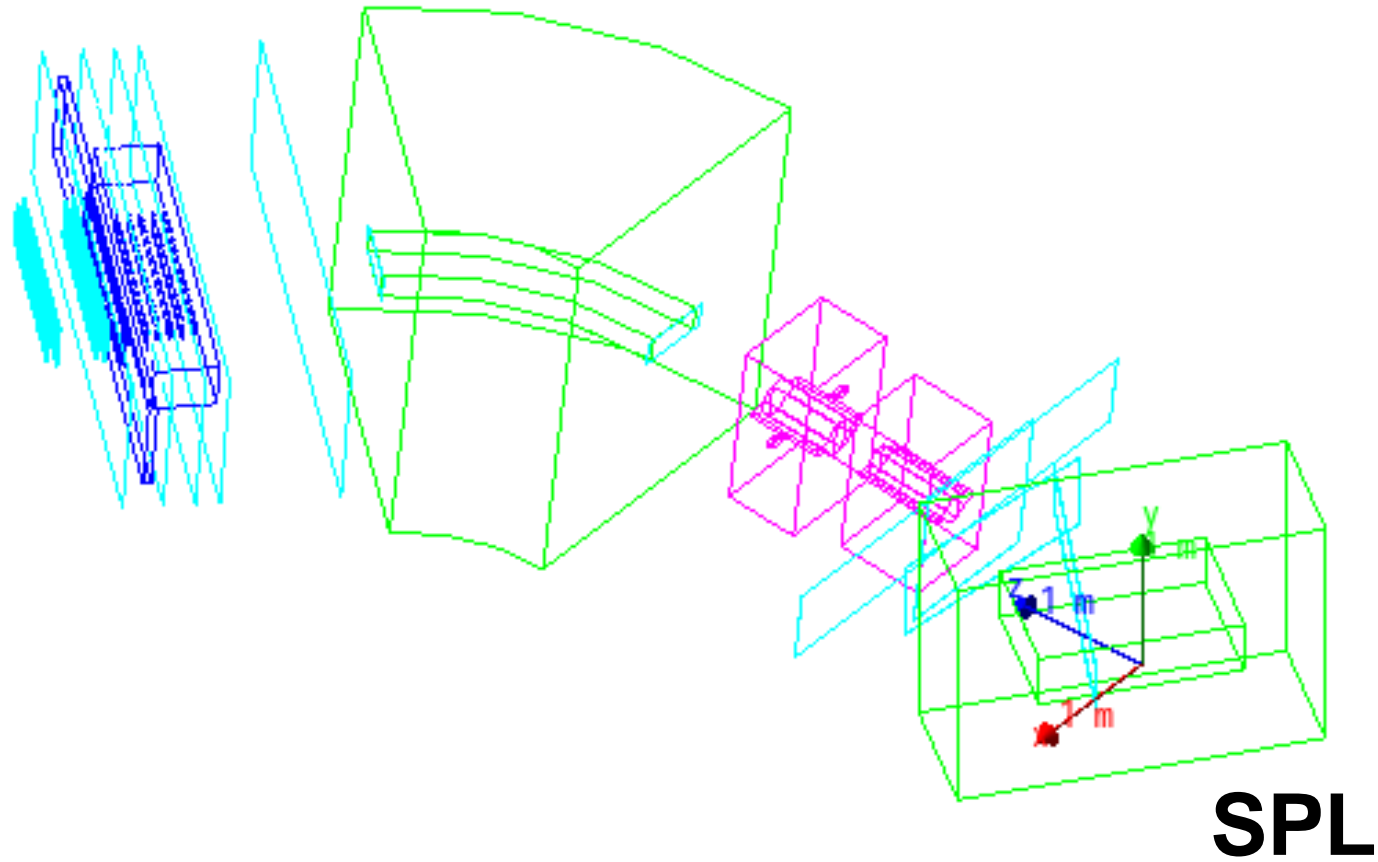


top view

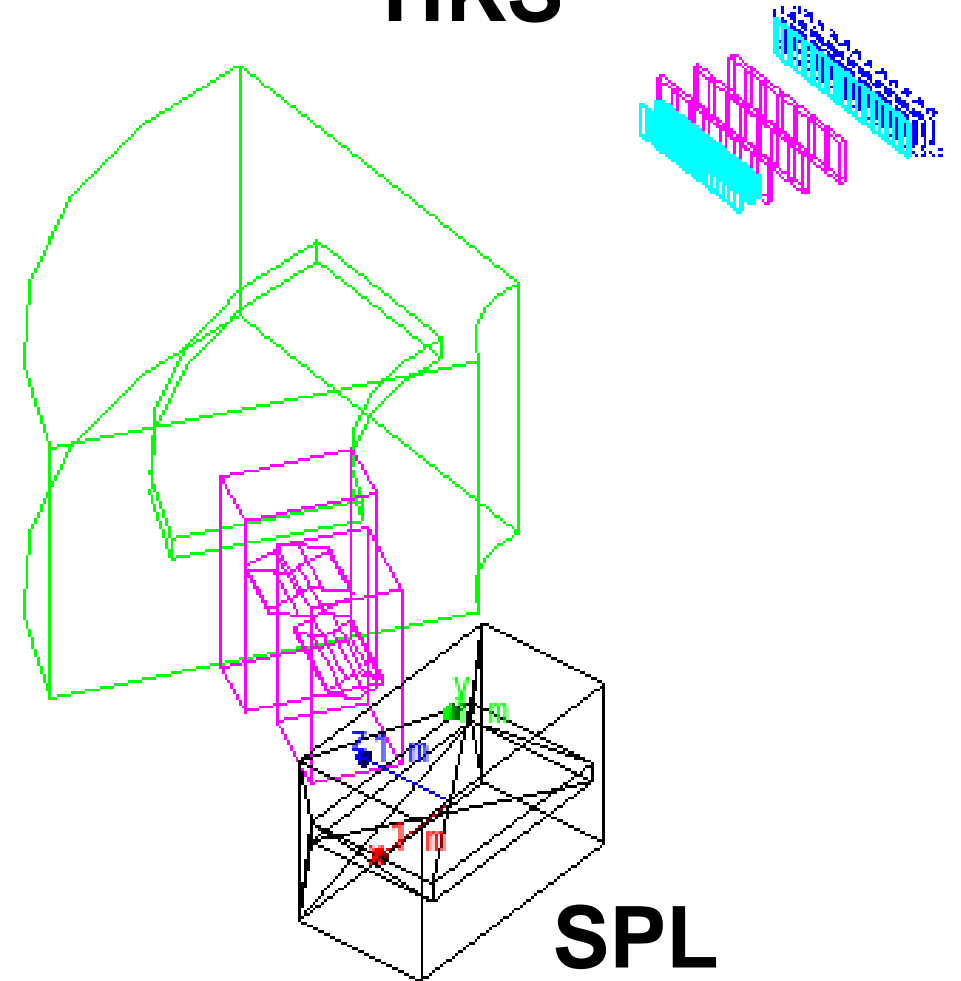


E05-115 setup in Geant4

HES

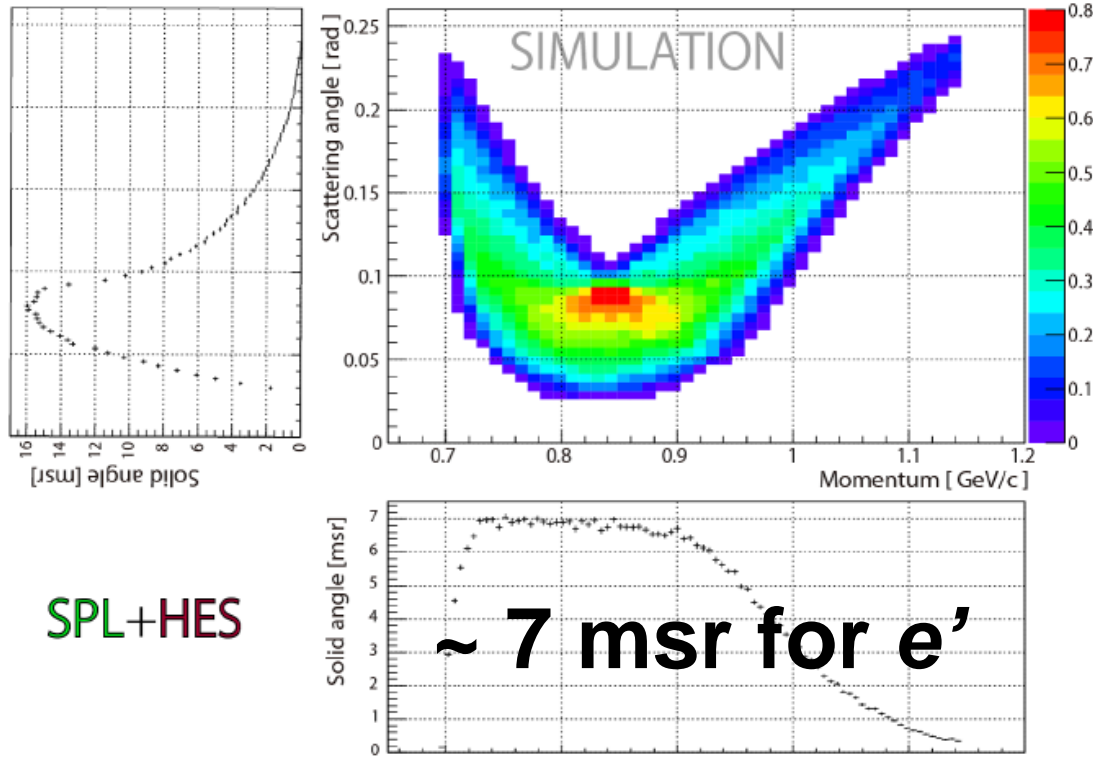


HKS



Experimental performance in E05-115

T. Gogami, Doctoral Thesis, Tohoku University (2015).

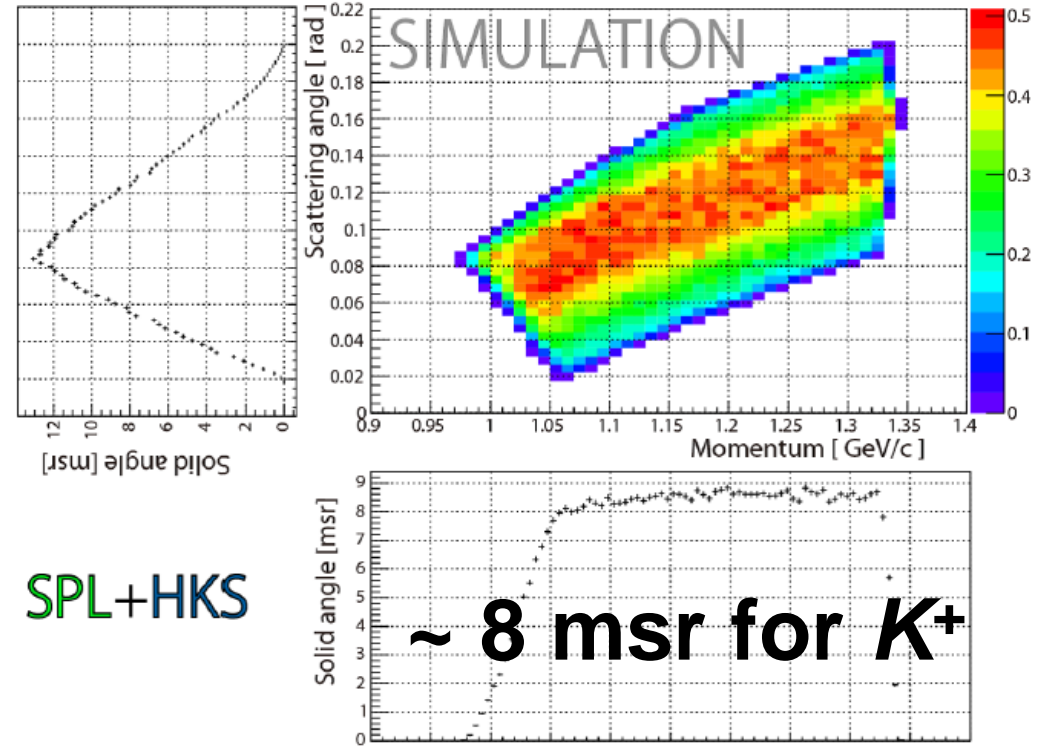


SPL+HES

$$\Delta p/p \text{ (FWHM)} = 4.2 \times 10^{-4}$$

$$\Delta \theta \text{ (RMS)} = 4.0 \text{ mr}$$

$$\rightarrow \Delta M \text{ (FWHM)} = 540 \text{ keV}/c^2 \quad ({}^{12}_{\Lambda}\text{B})$$



SPL+HKS

$$\Delta p/p \text{ (FWHM)} = 2.0 \times 10^{-4}$$

$$\Delta \theta \text{ (RMS)} = 0.4 \text{ mr}$$

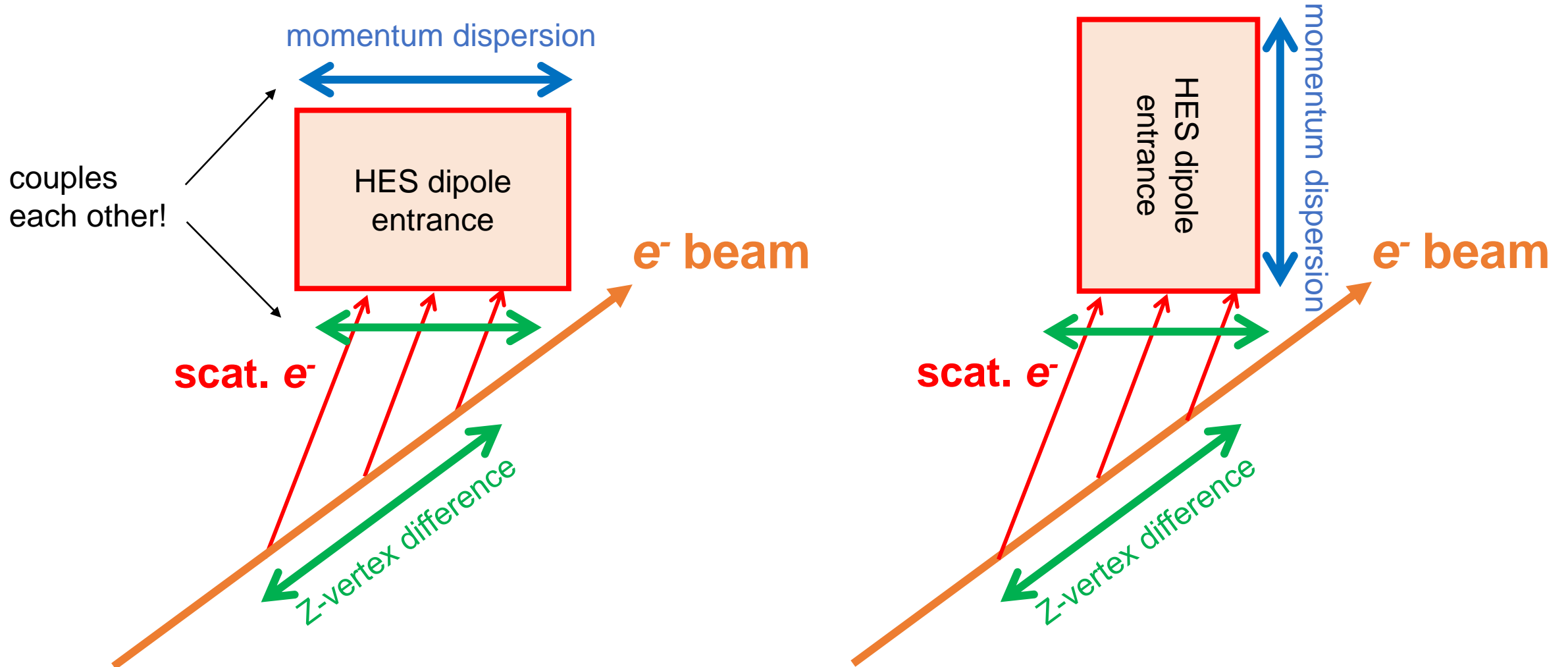
L. Tang *et al.*, Phys. Rev. C **90**, 034320 (2014).

Vertical bending spectrometer is essential

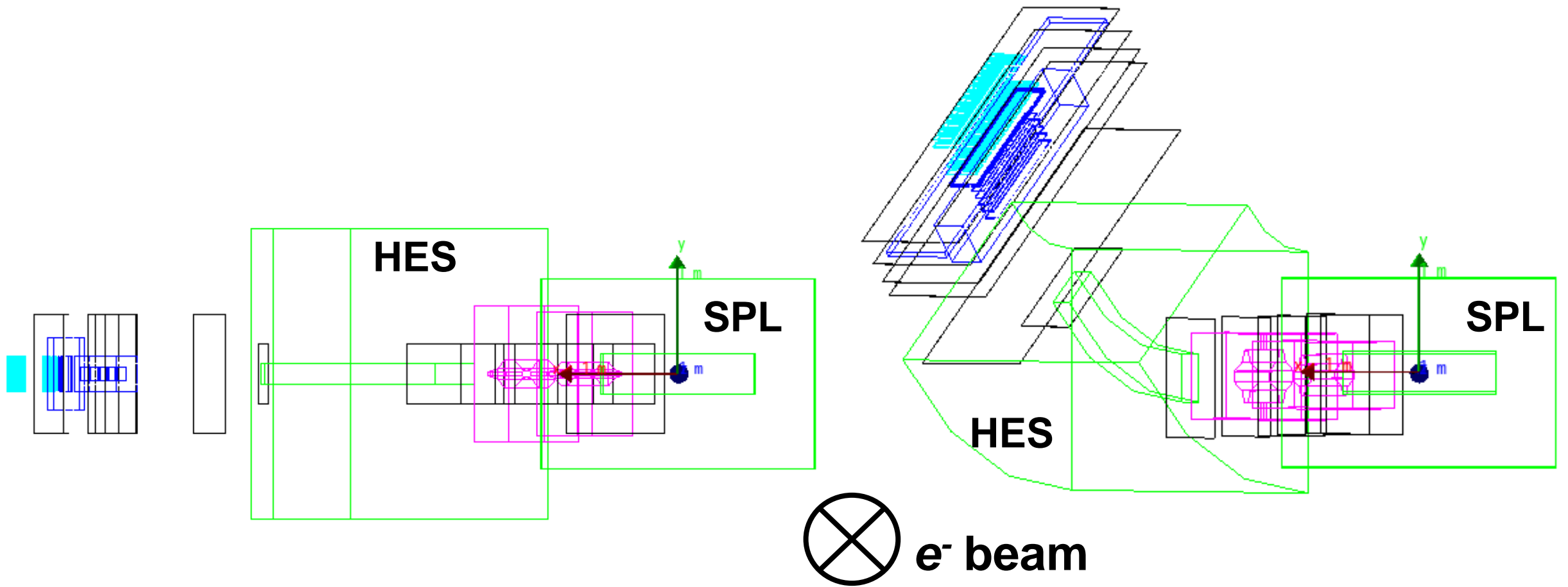
especially, for multi-foil target system (E12-15-008) and cryo-gas target (E12-19-002)

horizontal bending spectrometer

vertical bending spectrometer

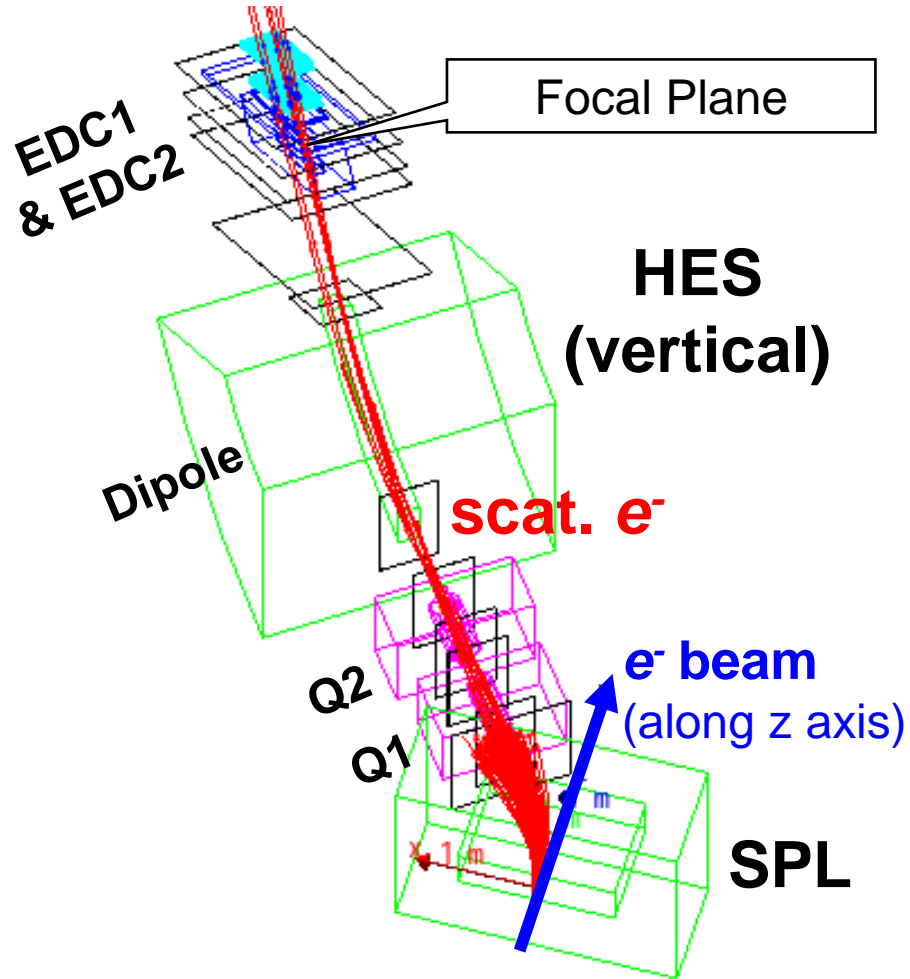


HES: Horizontal \rightarrow Vertical bending



Geant4 Simulation

Particle transportation by Geant4 simulation



at Target matrix element measured at Focal Plane

$$X'_T = \sum_{i+j+k+l=0}^n C_{X'}(i, j, k, l) (X_{\text{FP}})^i (X'_{\text{FP}})^j (Y_{\text{FP}})^k (Y'_{\text{FP}})^l$$

$$Y'_T = \sum_{i+j+k+l=0}^n C_{Y'}(i, j, k, l) (X_{\text{FP}})^i (X'_{\text{FP}})^j (Y_{\text{FP}})^k (Y'_{\text{FP}})^l$$

$$P = \sum_{i+j+k+l=0}^n C_P(i, j, k, l) (X_{\text{FP}})^i (X'_{\text{FP}})^j (Y_{\text{FP}})^k (Y'_{\text{FP}})^l$$

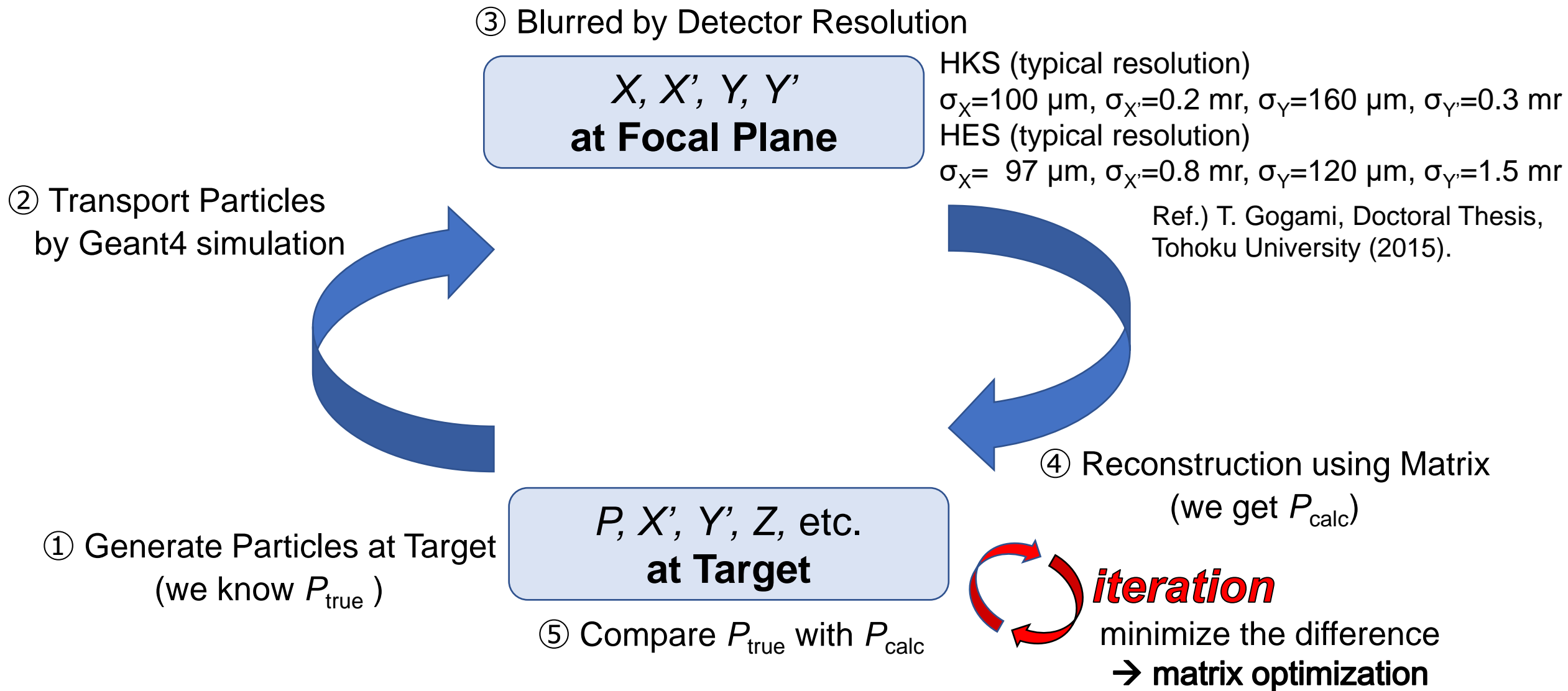
$$Z_T = \sum_{i+j+k+l=0}^n C_Z(i, j, k, l) (X_{\text{FP}})^i (X'_{\text{FP}})^j (Y_{\text{FP}})^k (Y'_{\text{FP}})^l$$

Z_T
↓

P
↓

Matrix Order (n)	0	1	2	3	4	5	6	7
Number of terms	1	5	15	35	70	126	210	330

Inverse Transfer Matrix Optimization



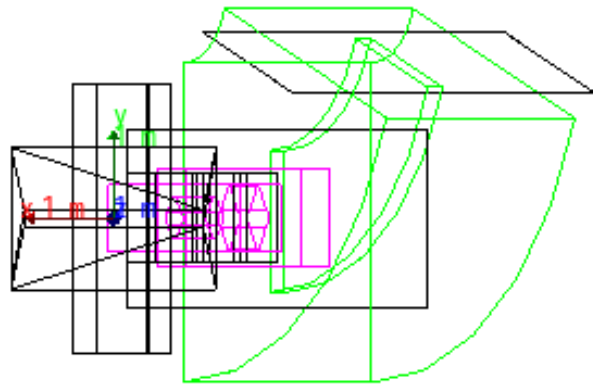
case 1

HKS: horizontal → vertical

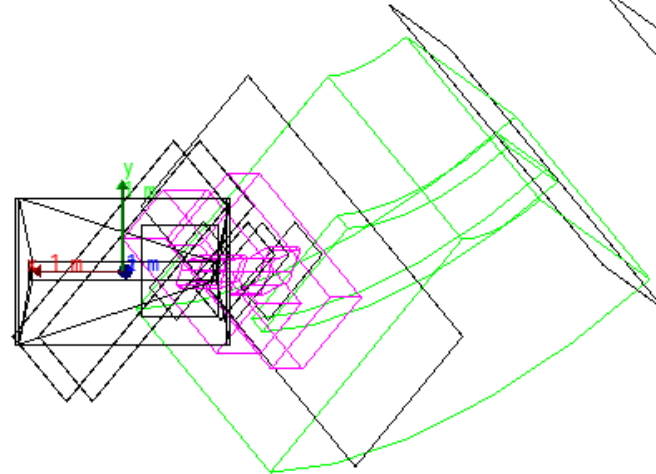
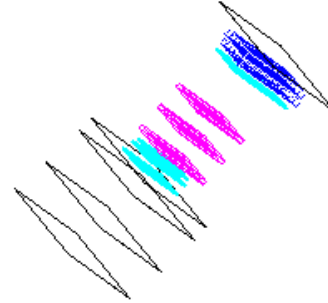
it may be mechanically difficult, though...

SPL+HKS (Φ : horizontal \leftrightarrow vertical)

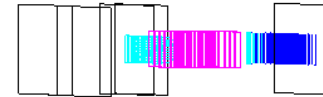
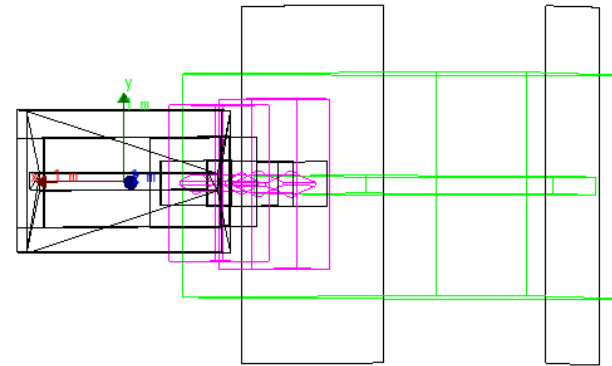
$\Phi = 90$ deg



$\Phi = 45$ deg



$\Phi = 0$ deg



σ_z : Φ -dependence (SPL+HKS)

$\Phi=0$ deg

$\Phi=15$ deg

$\Phi=30$ deg

$\Phi=45$ deg

$\Phi=60$ deg

$\Phi=90$ deg

Horizontal



Vertical

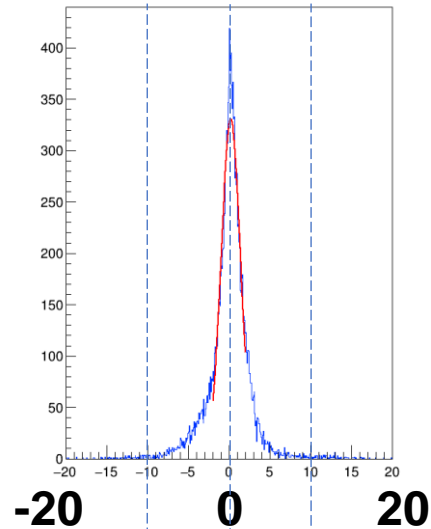
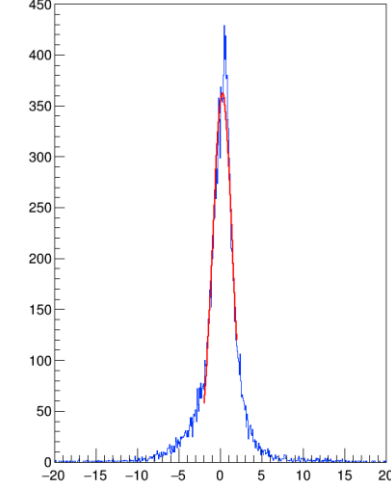
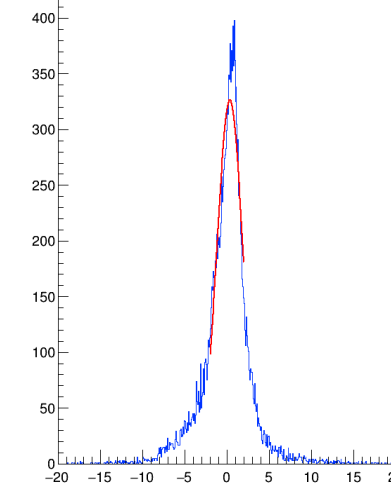
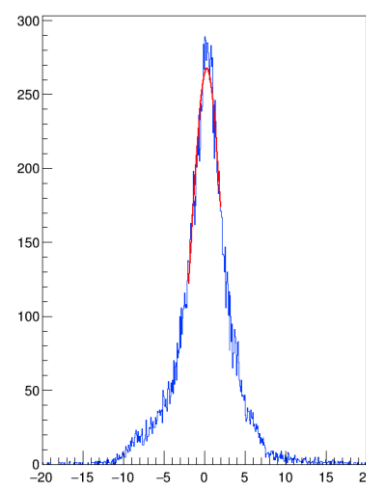
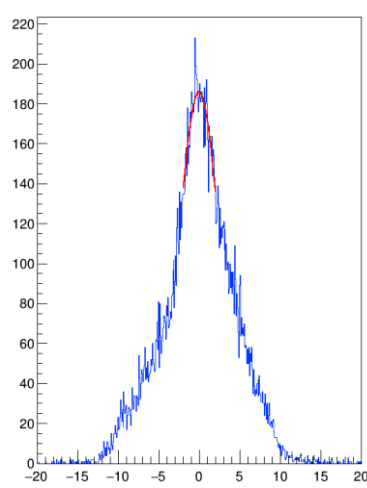
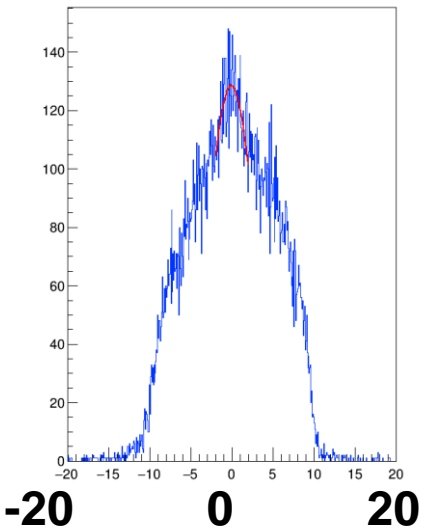
$\sigma_z=2.54$ cm

$\sigma_z=1.82$ cm

$\sigma_z=1.50$ cm

$\sigma_z=1.16$ cm

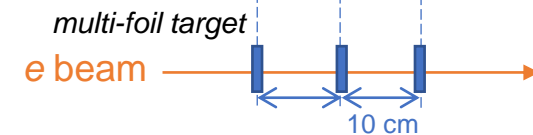
$\sigma_z=1.16$ cm



$$\Delta Z = Z_{\text{true}} - Z_{\text{calc}} \text{ [cm]}$$

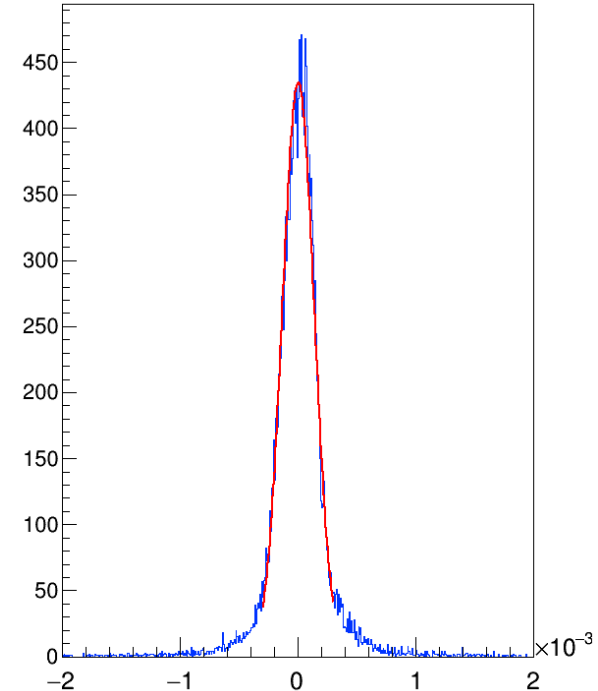
generated in Geant4

calculated using inverse transfer matrix



Momentum Resolution (SPL+HKS)

$\Phi=0$ (Horizontal)
 $\Delta p/p = 3.2 \times 10^{-4}$ (FWHM) $\rightarrow \Delta p \sim 0.3$ MeV/c



multifoil target-like analysis

gas target-like analysis

$\Delta p/p \times 10^4$ (FWHM)	Horizontal	Vertical
	$\Phi=0$ deg	$\Phi=90$ deg
Z = 0 (fixed)	3.2	4.3
Z = +10 cm (fixed)	3.4	4.2
Z = -10 cm (fixed)	3.5	4.3
Z \in [-10 cm, 10 cm]	9.3	5.6

$$\Delta p/p = (p_{\text{true}} - p_{\text{calc}}) / p_{\text{true}}$$

generated in Geant4

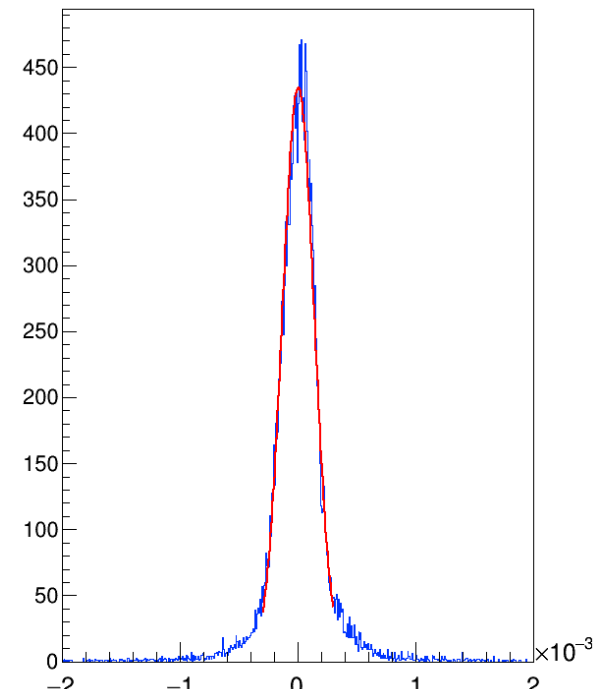
calculated using inverse transfer matrix

comments

① may be improved by changing Q1, Q2 magnetic field settings

Momentum Resolution (SPL+HKS)

$\Phi=0$ (Horizontal)
 $\Delta p/p = 3.2 \times 10^{-4}$ (FWHM) $\rightarrow \Delta p \sim 0.3$ MeV/c



multifoil target-like analysis

gas target-like analysis

	Horizontal	Vertical
$\Delta p/p \times 10^4$ (FWHM)	$\Phi=0$ deg	$\Phi=90$ deg
Z = 0 (fixed)	3.2	4.3
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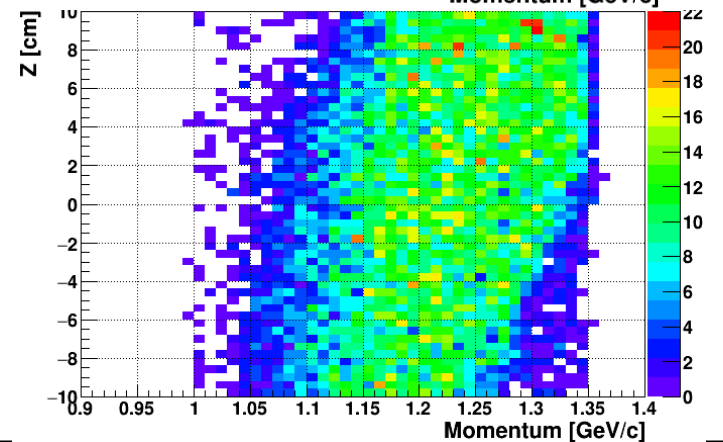
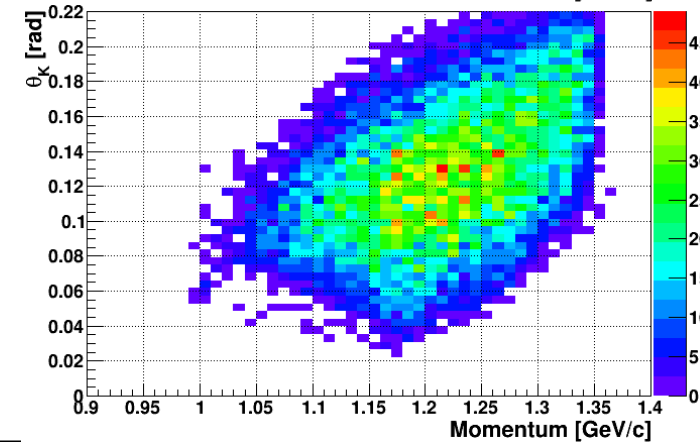
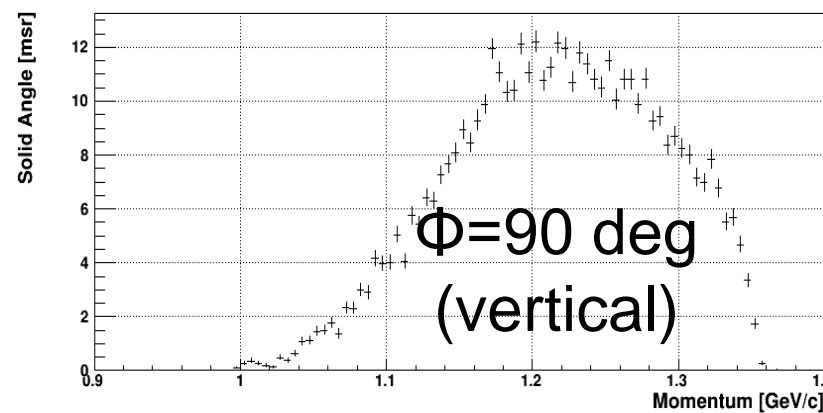
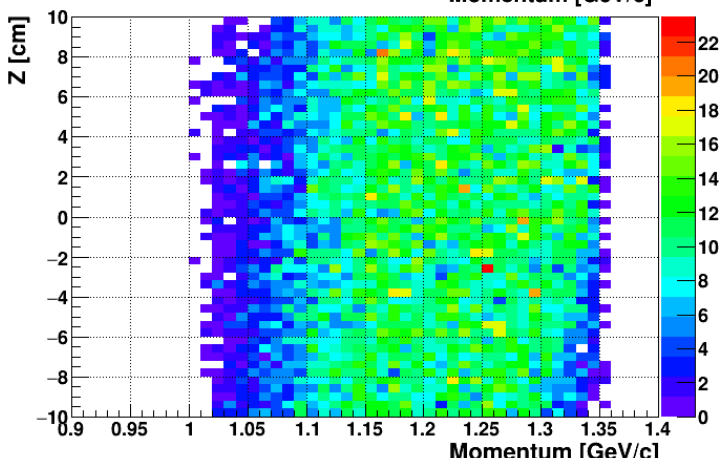
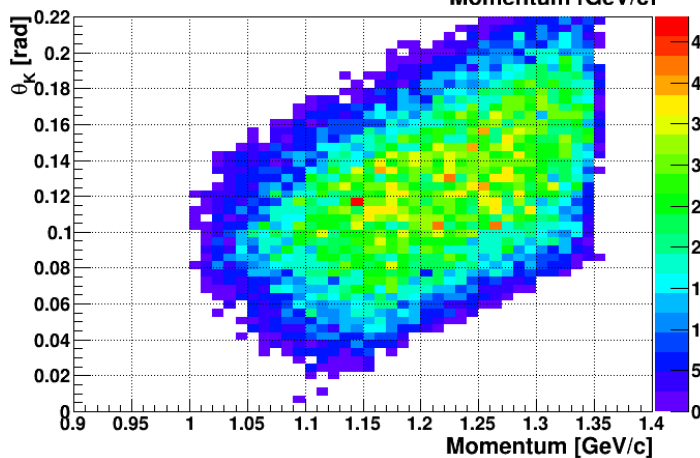
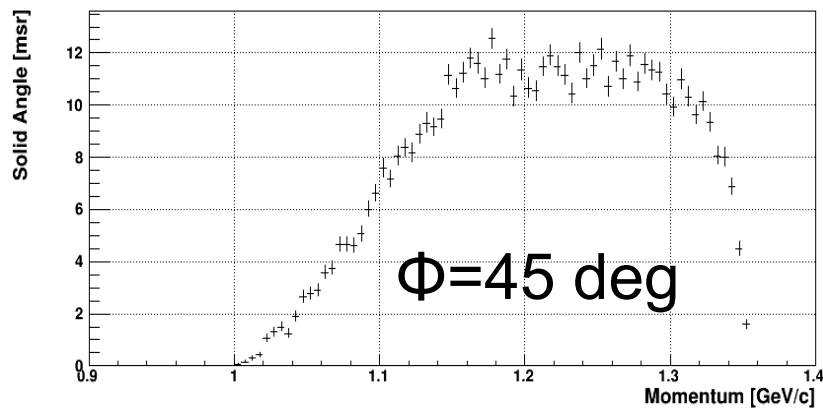
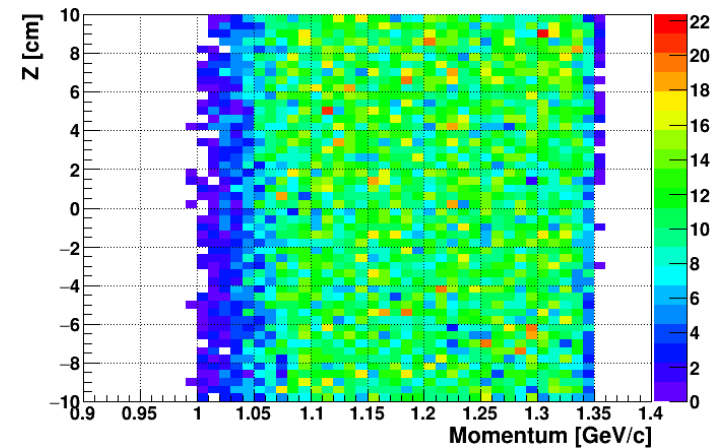
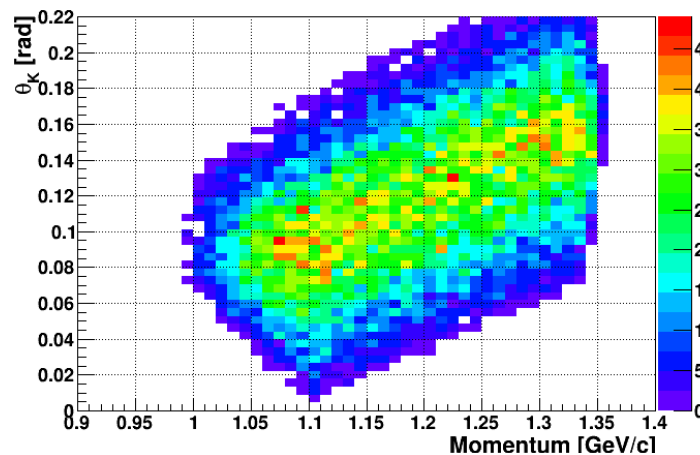
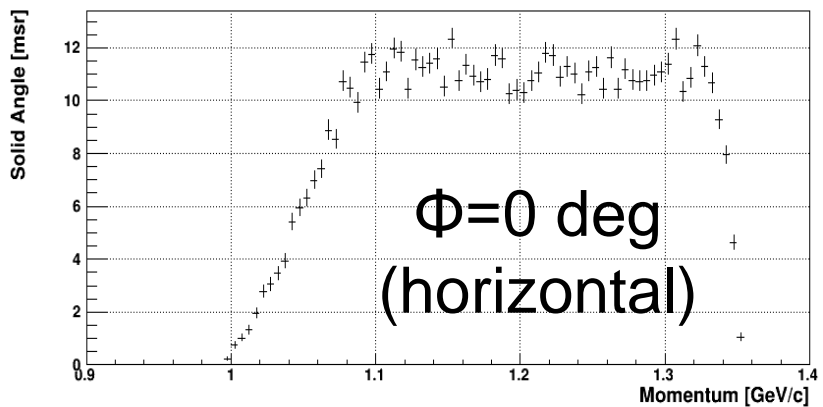
$$\Delta p/p = (p_{\text{true}} - p_{\text{calc}}) / p_{\text{true}}$$

generated in Geant4

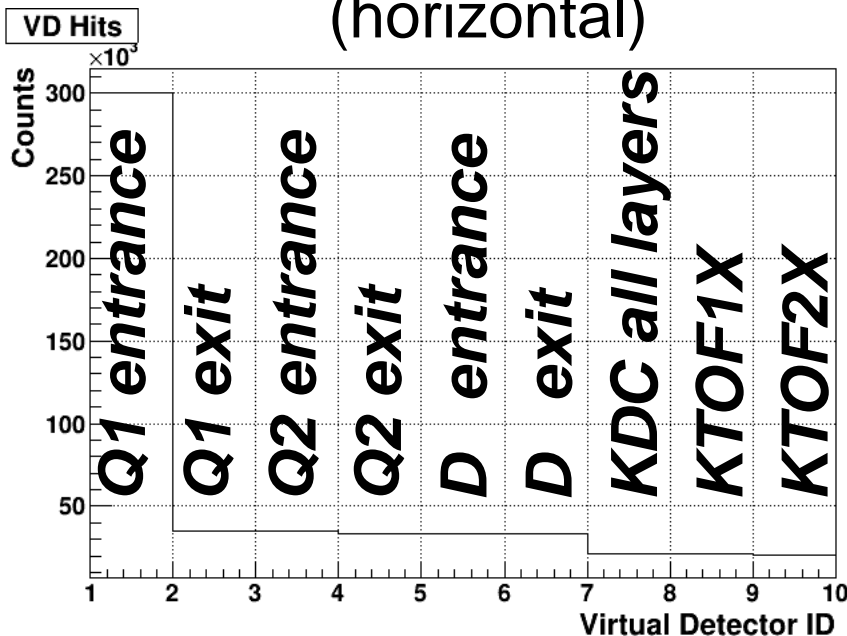
calculated using inverse transfer matrix

comments

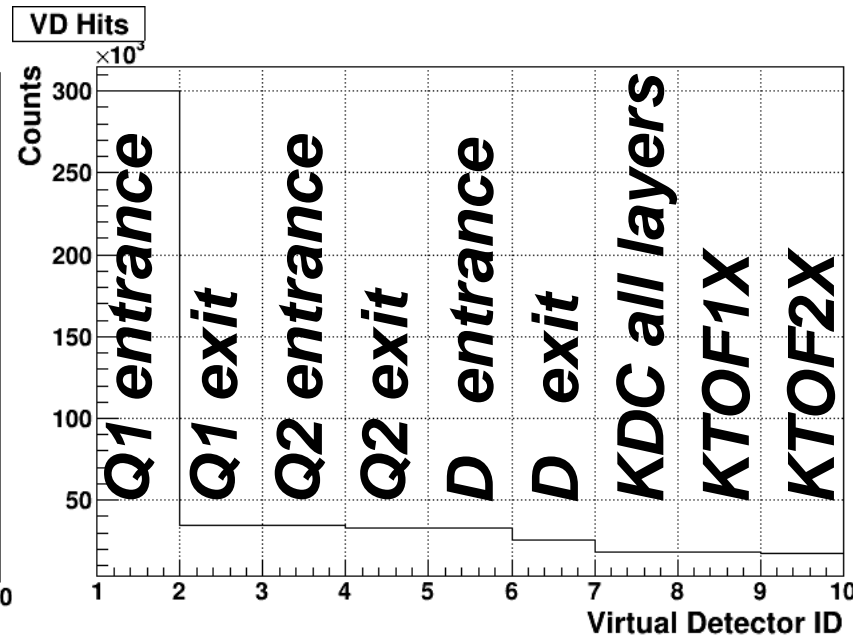
- ① may be improved by changing Q1, Q2 magnetic field settings
- ② may be improved by adding Z-term on P-matrix explicitly



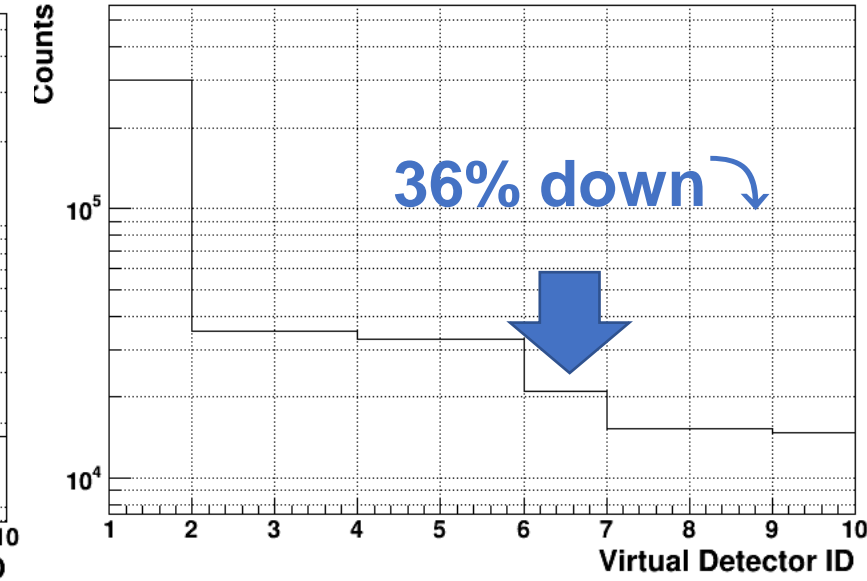
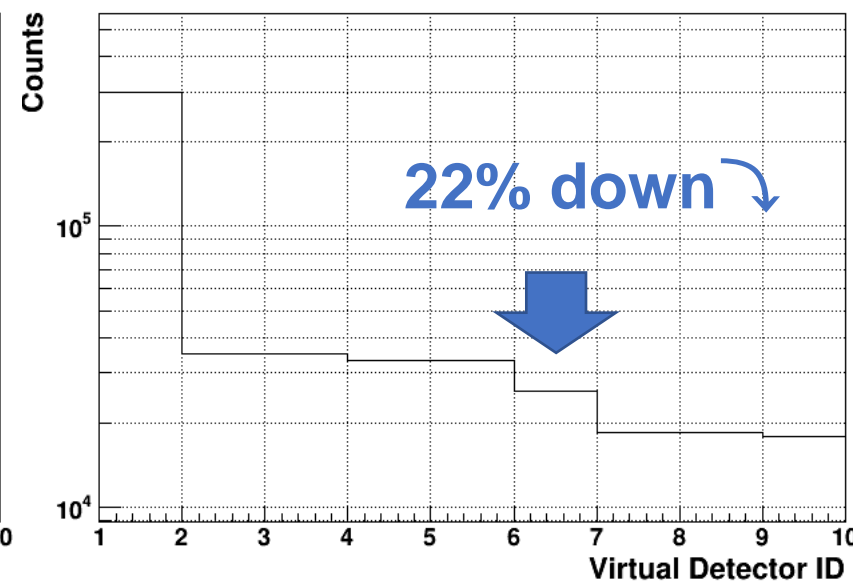
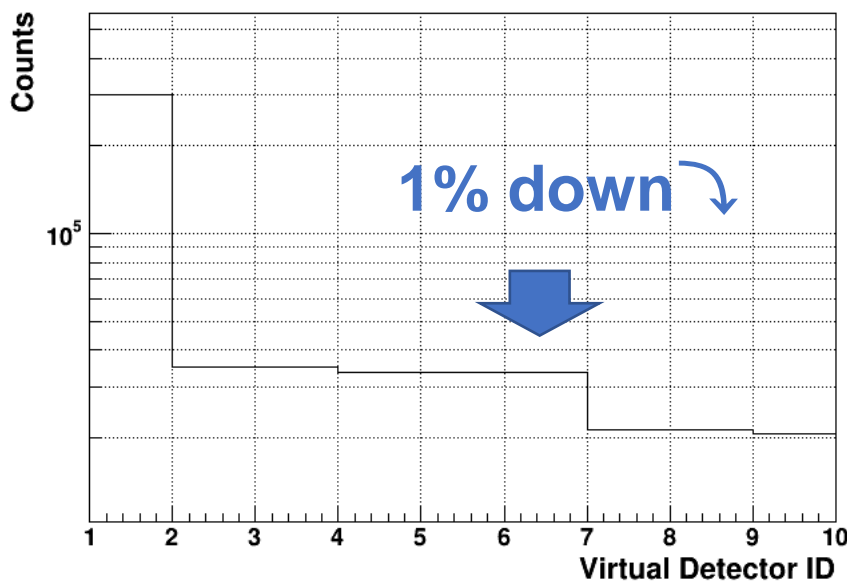
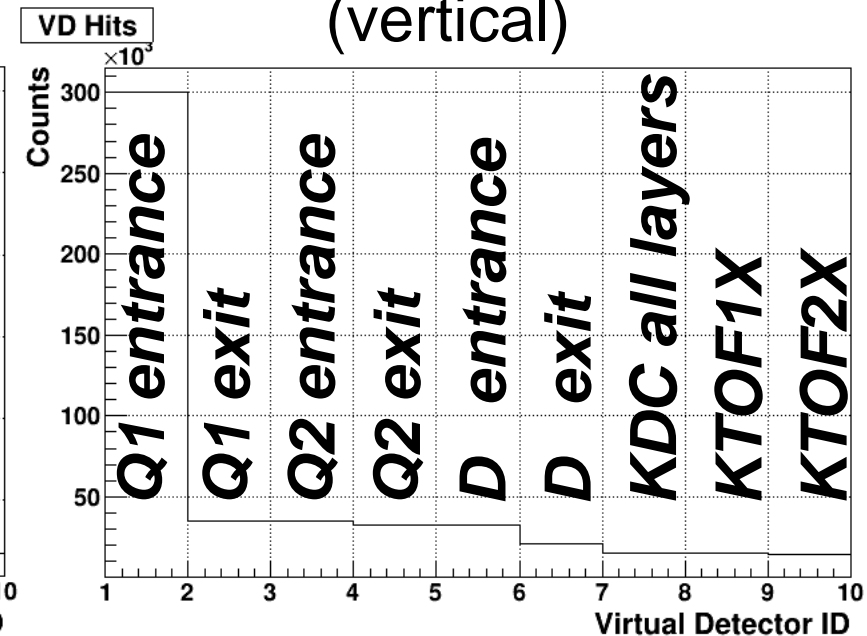
SPL+HKS $\Phi = 0$ deg
(horizontal)



$\Phi = 45$ deg



$\Phi = 90$ deg
(vertical)



HKS VD hits table

p: 1.2 +/- 0.25 GeV/c
θ: 0.125 +/- 0.125 rad
Φ: π +/- π/2 rad
Z: 0 +/- 10 cm

# VD	Φ=0 deg	Φ=45 deg	Φ=90 deg
Q1 entrance	300k	300k	300k
Q1 exit	35k	35k	35k
Q2 entrance	35k	35k	35k
Q2 exit	34k	33k	33k
D entrance	34k	33k	33k
D exit	33k	26k	21k
KDC all	21k	18k	15k
KTOF1X	21k	18k	15k
KTOF2X	21k	18k	15k



case 2

HES: horizontal → vertical

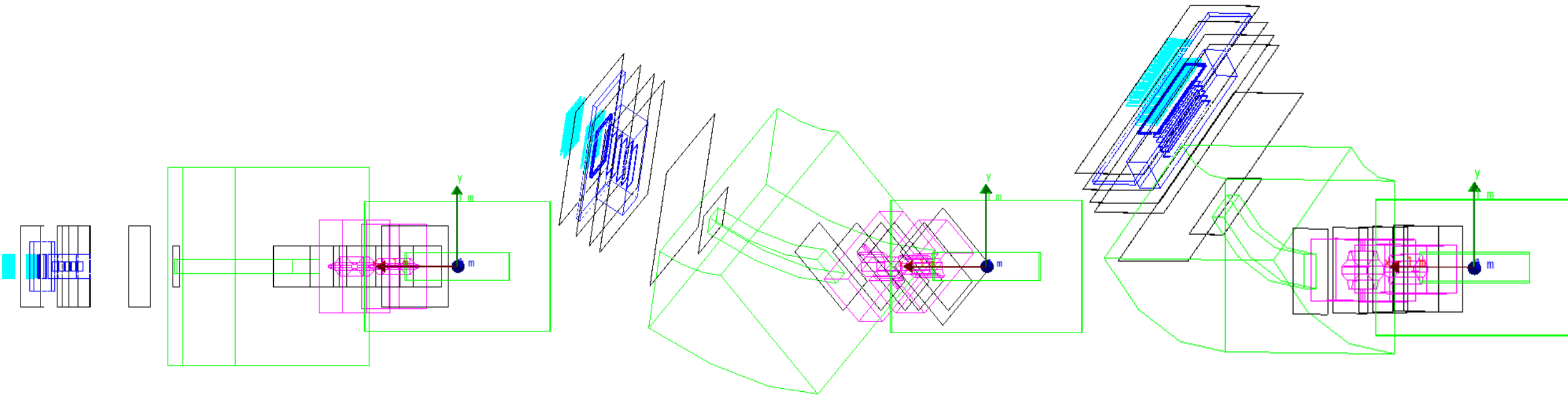
possible plan?

SPL+HES (Φ : horizontal \leftrightarrow vertical)

$\Phi = 0$ deg

$\Phi = -45$ deg

$\Phi = -90$ deg



σ_z : Φ -dependence (SPL+HES)

$\Phi=0$ deg

$\Phi=-15$ deg

$\Phi=-30$ deg

$\Phi=-45$ deg

$\Phi=-60$ deg

$\Phi=-90$ deg

Horizontal

σ_z -vertex resolution improved

worse?

Vertical

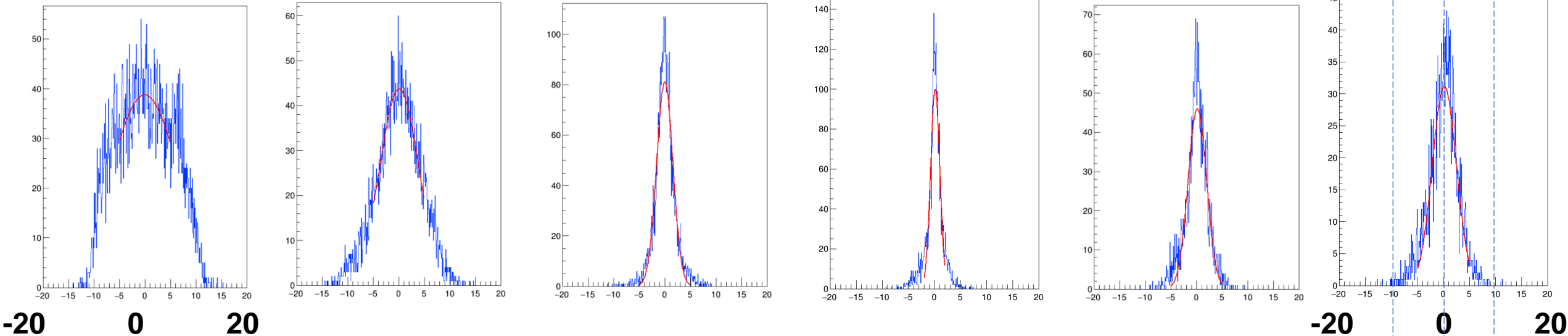
$\sigma_z=3.82$ cm

$\sigma_z=1.59$ cm

$\sigma_z=0.88$ cm

$\sigma_z=1.80$ cm

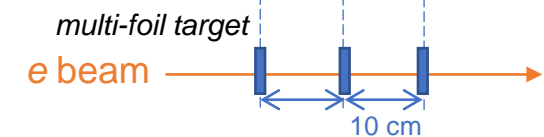
$\sigma_z=2.31$ cm



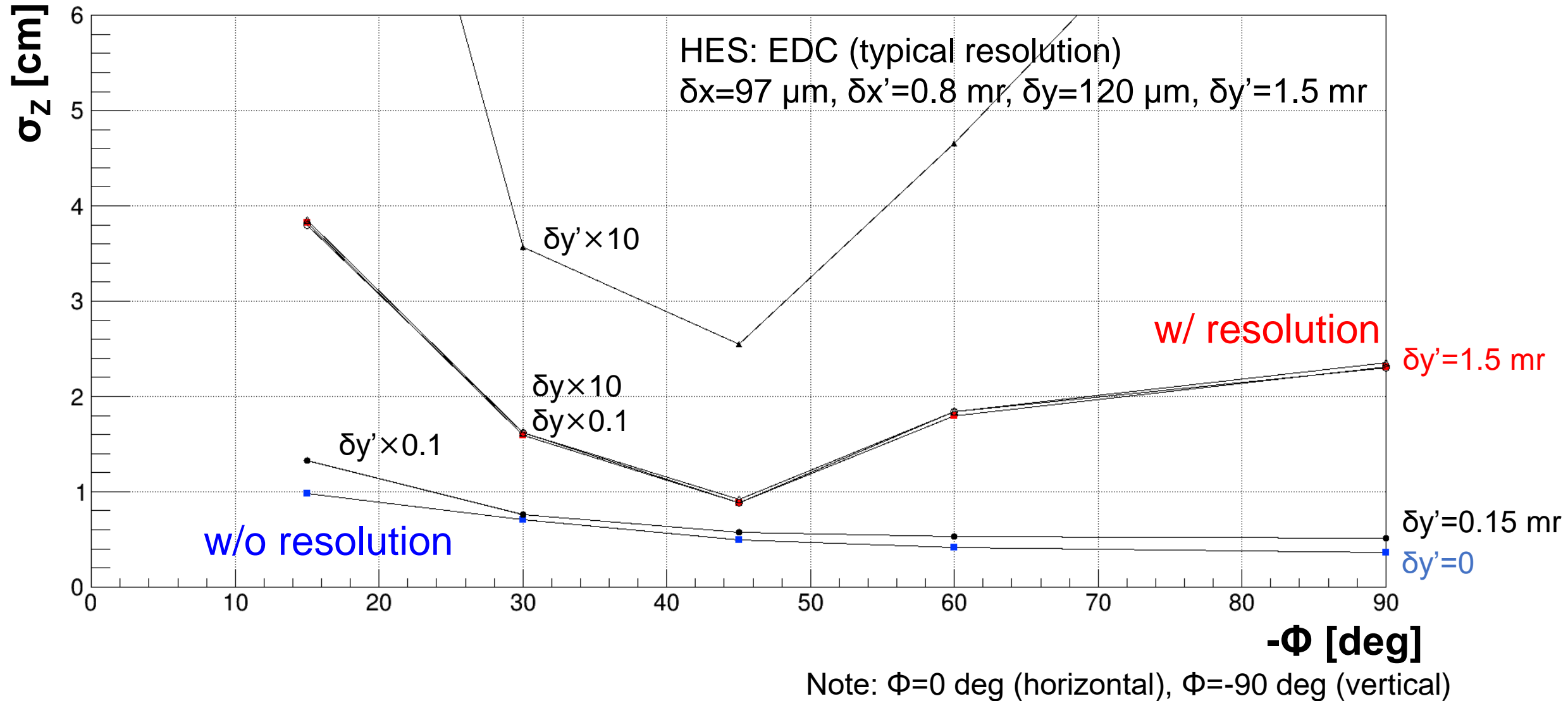
$$\Delta Z = Z_{\text{true}} - Z_{\text{calc}} \text{ [cm]}$$

generated in Geant4

calculated using inverse transfer matrix

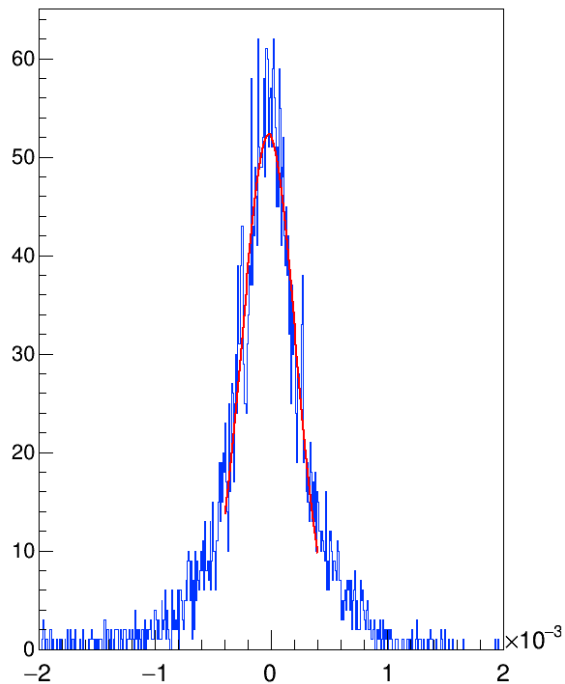


Effect of detector resolution ($\delta y'$, δy of EDC)



Momentum Resolution (SPL+HES)

$\Phi=0$ (Horizontal)
 $\Delta p/p = 5.4 \times 10^{-4}$ (FWHM) $\rightarrow \Delta p \sim 0.6$ MeV/c



multifoil target-like analysis

gas target-like analysis

	Horizontal	Vertical
$\Delta p/p \times 10^4$ (FWHM)	$\Phi=0$ deg	$\Phi=-90$ deg
Z = 0 (fixed)	5.4	7.5
Z = +10 cm (fixed)	5.3	11.0
Z = -10 cm (fixed)	5.9	6.8
Z \in [-10 cm, 10 cm]	>20	8.5

$$\Delta p/p = (p_{\text{true}} - p_{\text{calc}}) / p_{\text{true}}$$

generated in Geant4

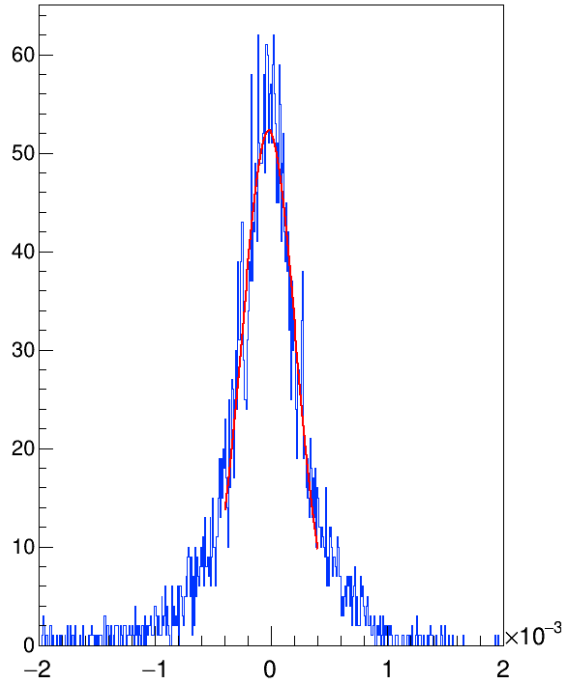
calculated using inverse transfer matrix

comments

① may be improved by changing Q1, Q2 magnetic field settings

Momentum Resolution (SPL+HES)

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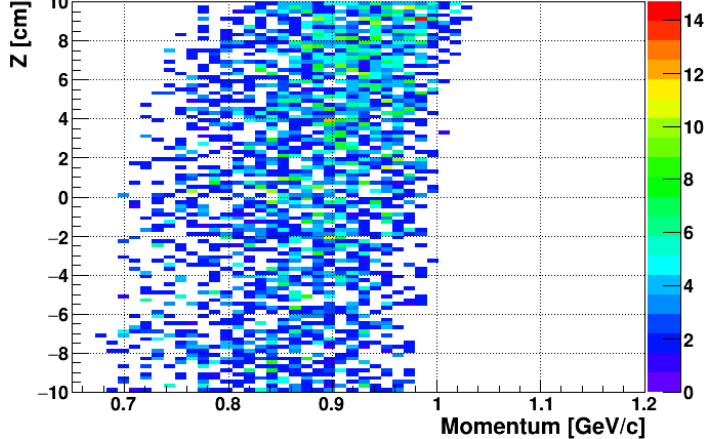
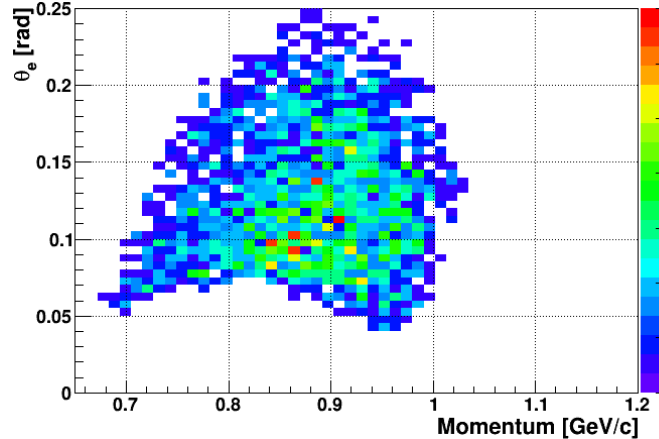
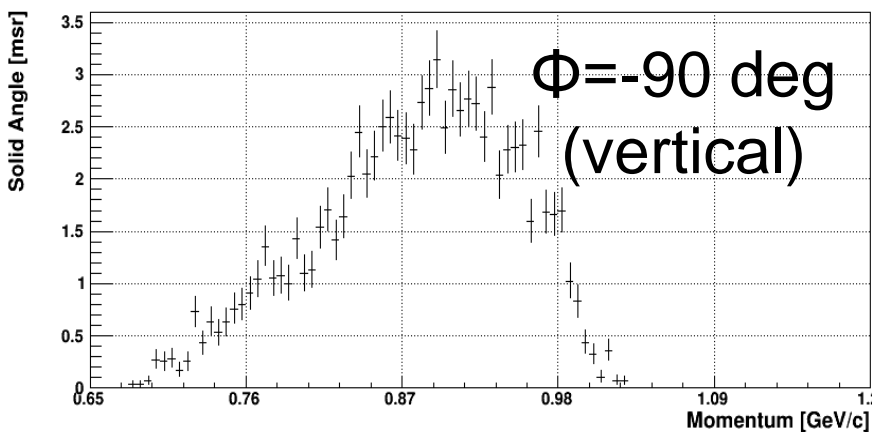
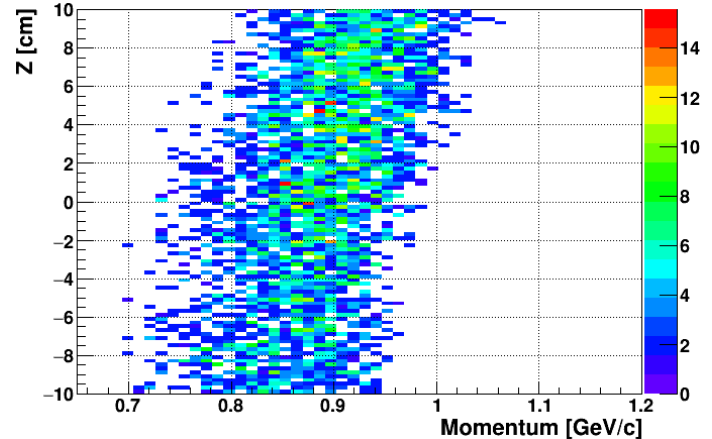
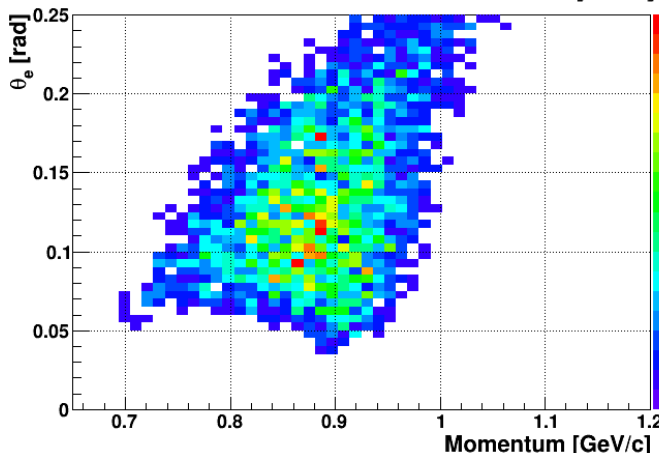
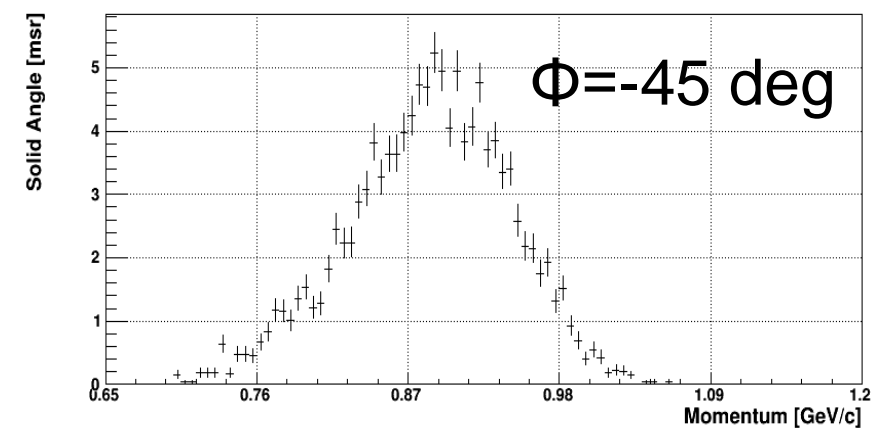
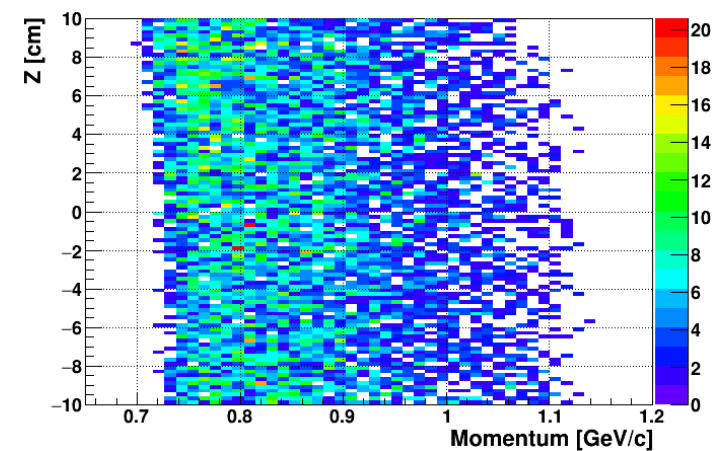
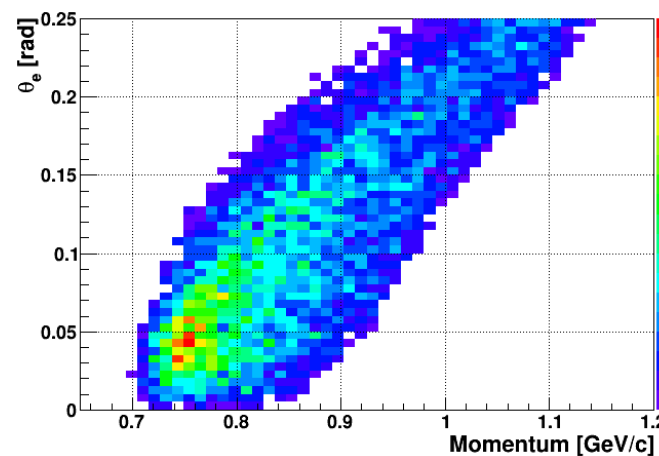
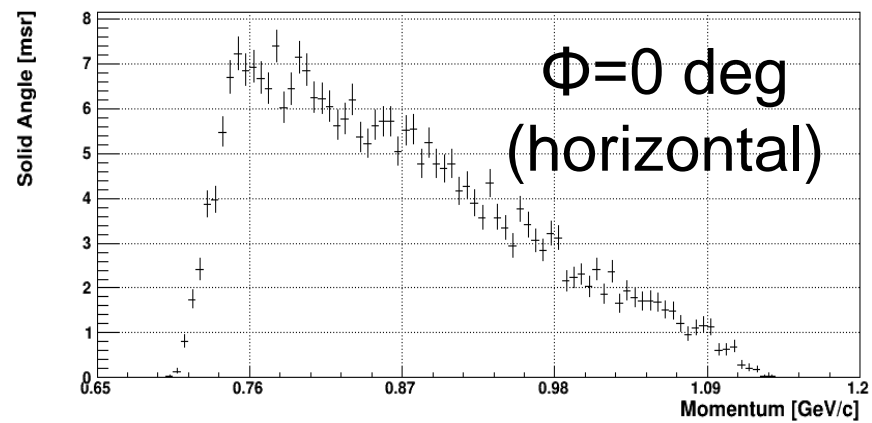
$$\Delta p/p = (p_{\text{true}} - p_{\text{calc}}) / p_{\text{true}}$$

generated in Geant4

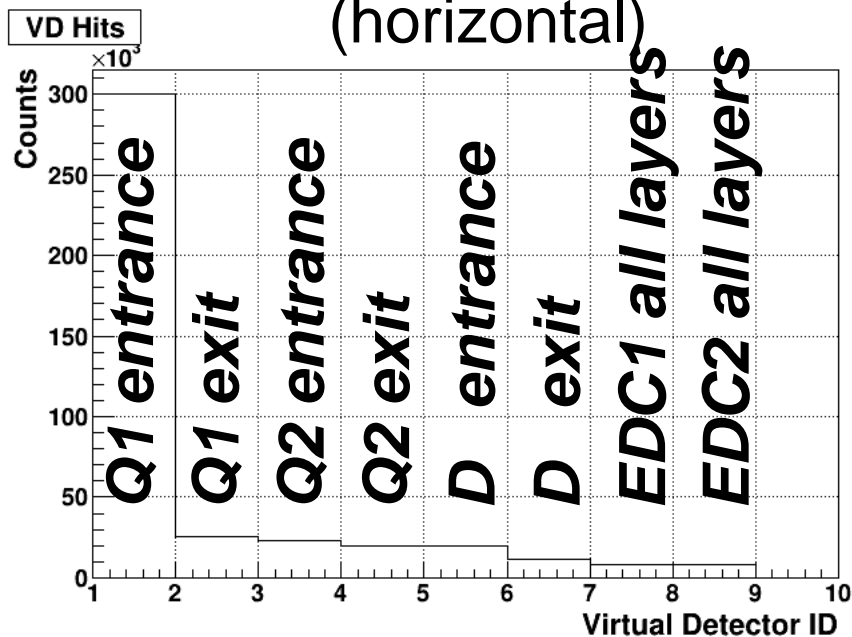
calculated using inverse transfer matrix

comments

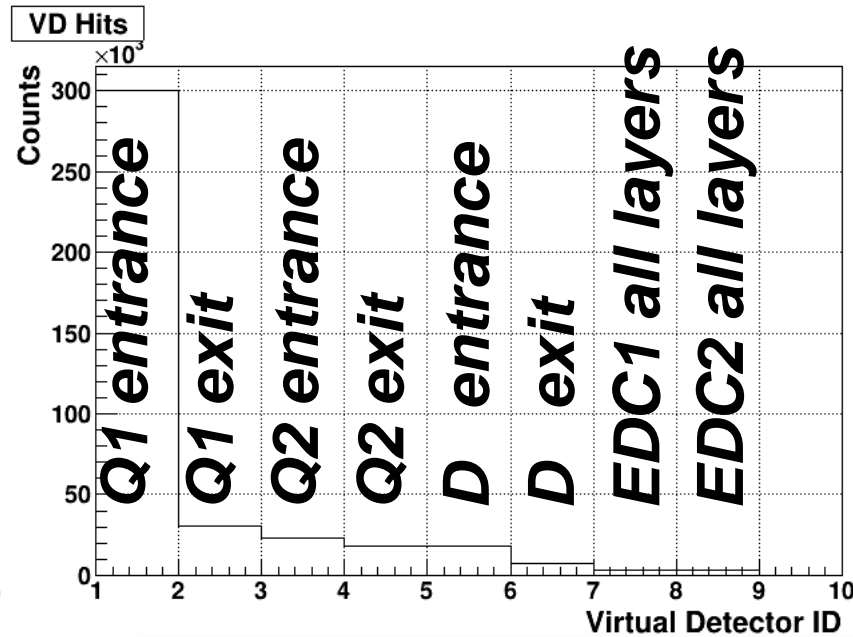
- ① may be improved by changing Q1, Q2 magnetic field settings
- ② may be improved by adding Z-term on P-matrix explicitly



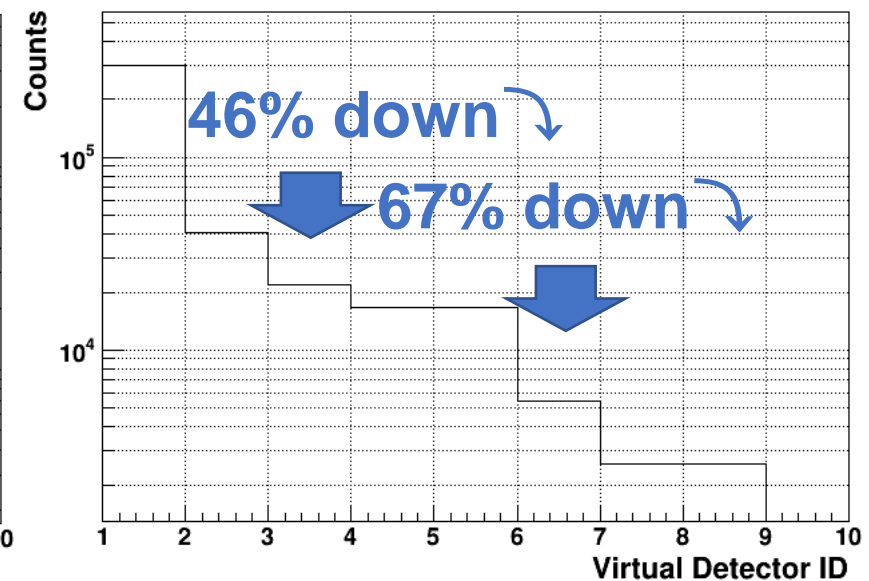
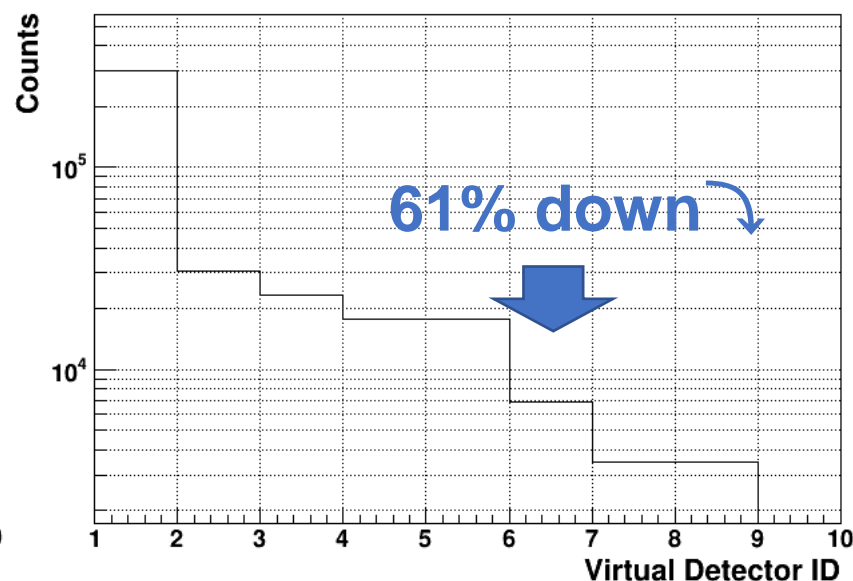
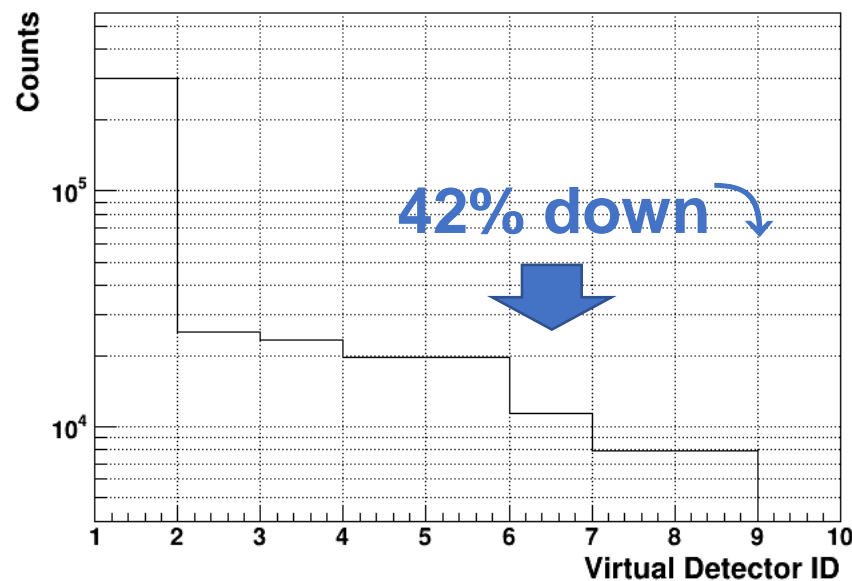
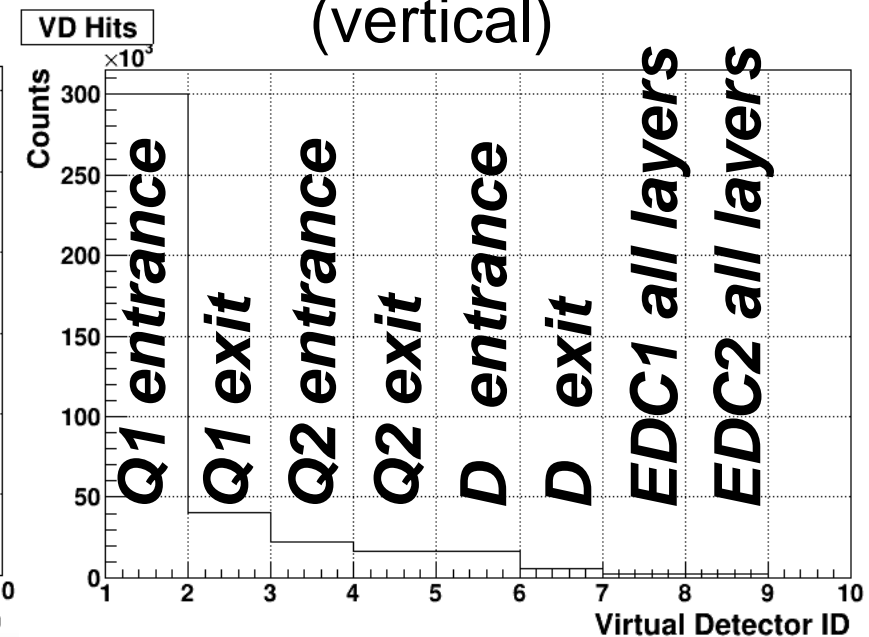
SPL+HES $\Phi = 0$ deg
(horizontal)



$\Phi = -45$ deg



$\Phi = -90$ deg
(vertical)



HES VD hits table

p : 0.844 +/- 0.3 GeV/c
 θ : 0.124 +/- 0.124 rad
 Φ : 0 +/- $\pi/2$ rad
 Z : 0 +/- 10 cm

# VD	$\Phi=0$ deg	$\Phi=-45$ deg	$\Phi=-90$ deg
Q1 entrance	300k	300k	300k
Q1 exit	25k	31k	41k
Q2 entrance	23k	23k	22k
Q2 exit	20k	18k	17k
D entrance	20k	18k	17k
D exit	11k	7k	5k
EDC1 all	8k	3k	3k
EDC2 all	8k	3k	3k



Summary

- Hall-C option study by Geant4 simulation
 - Vertical bending spectrometer is essential to reconstruct Z-vertex
 - HKS: horizontal → vertical
 - σ_z : ~1 cm
 - $\Delta p/p$: <1.5 times worse
 - Acceptance : ~ 3/4
 - HES: horizontal → vertical
 - σ_z : ~2.5 cm
 - $\Delta p/p$: <1.5 times worse
 - Acceptance : ~ 1/3
- magnetic field settings of Q1, Q2 will change the current results and improve the momentum resolution and solid angle → *future tasks*