

# Geant4 MC simulation for the next JLab hypernuclear project

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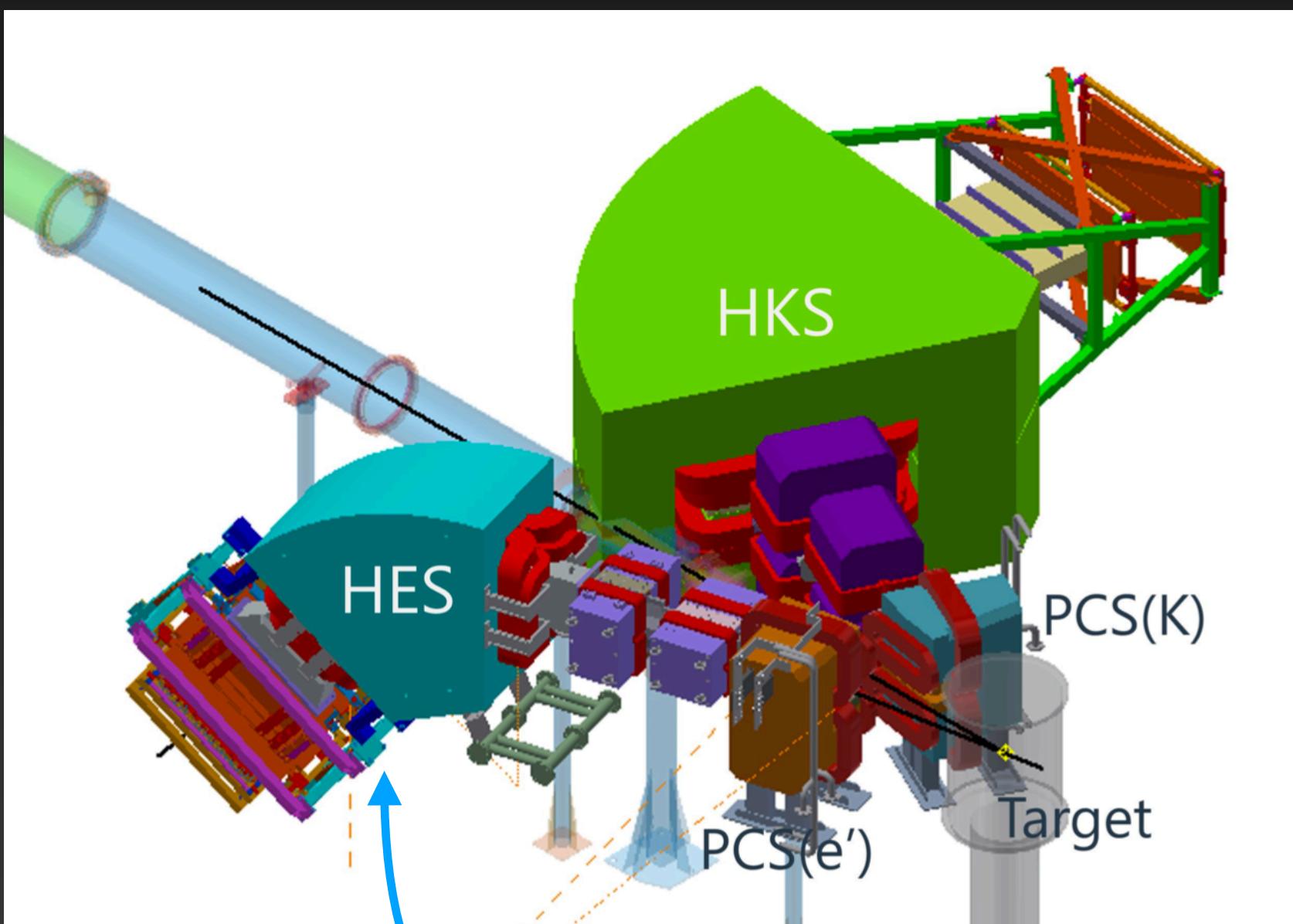
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  - Hypernuclear yield
  - Missing mass spectrum
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# Introduction

# Setup of next experiment at JLab Hall C

## Vertical HES & Horizontal HKS

- Good for Z-vertex resolution
- Possible for solid & gas target

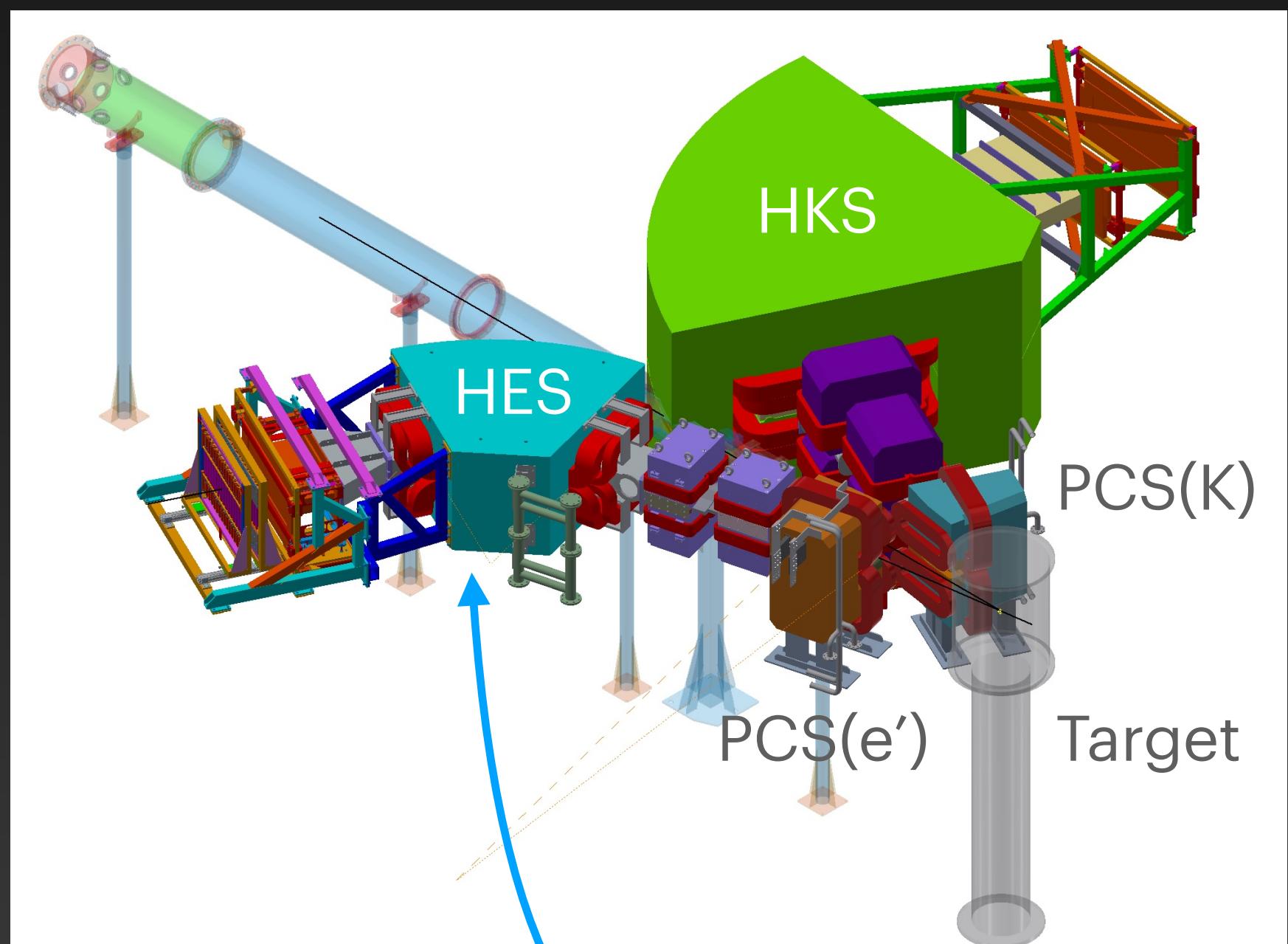


HES is aligned vertically

## Horizontal HES & Horizontal HKS

- Good for Momentum resolution
- Possible for solid target

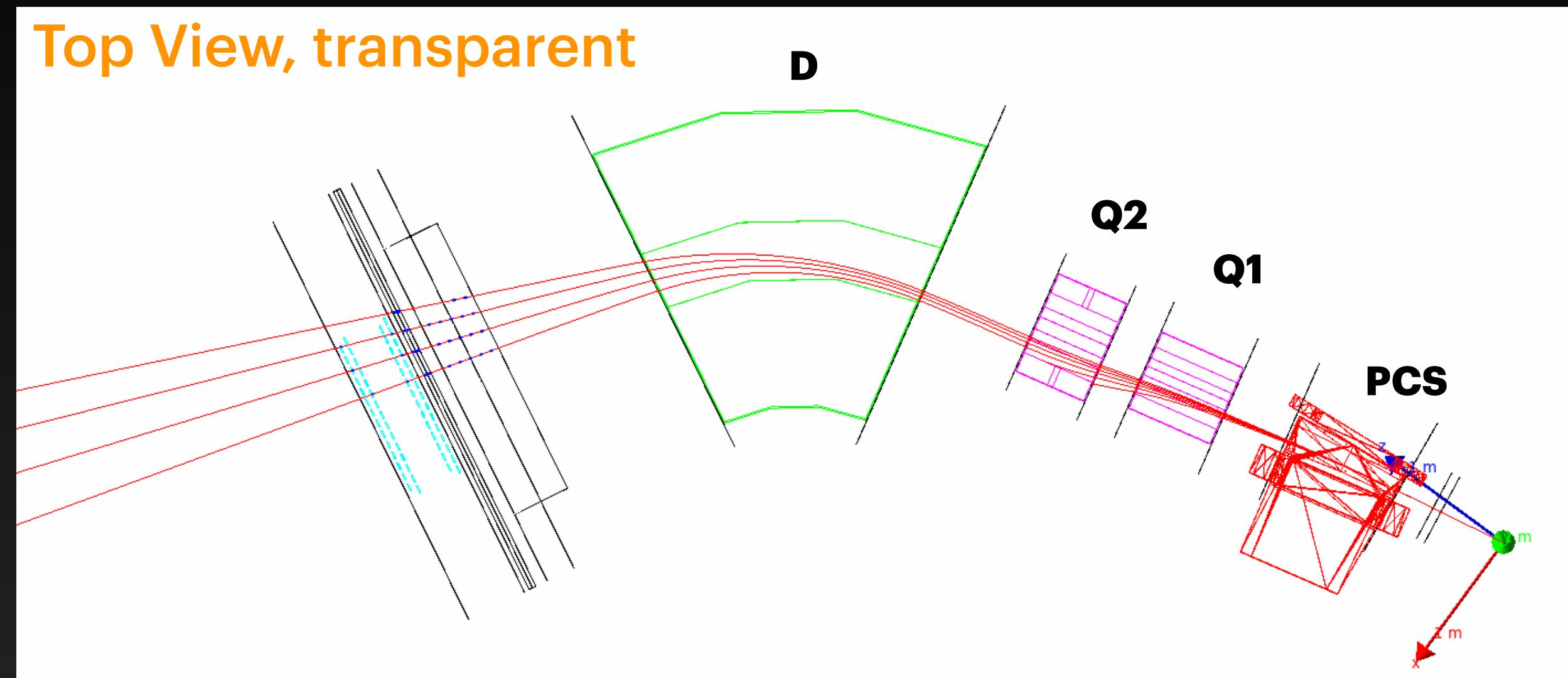
**Expect better missing mass resolution**



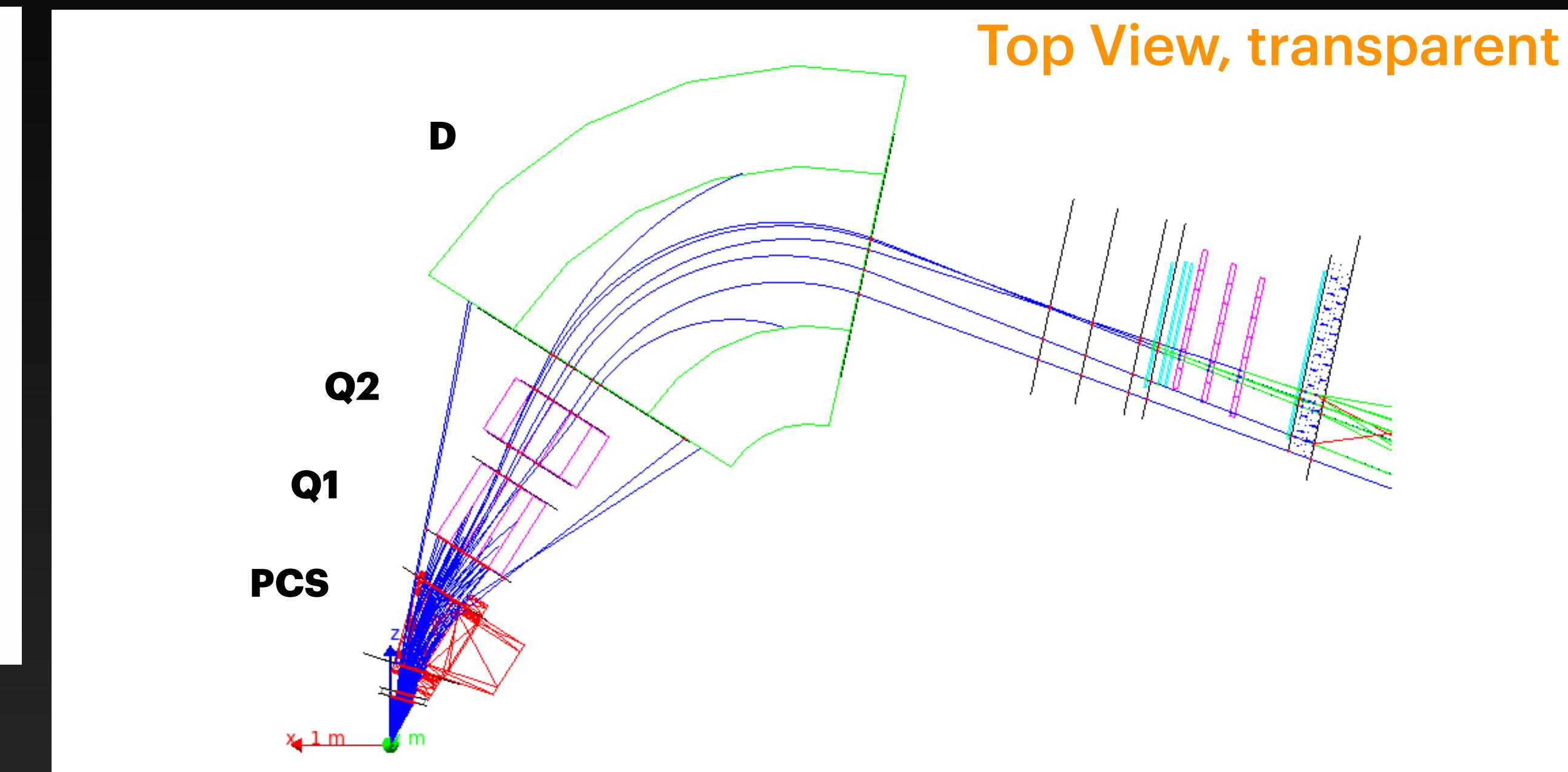
HES is aligned horizontally

# Simulation

Horizontal HES



Horizontal HKS



- Simulation of one side arm by Geant4
- Magnets & Detectors are aligned properly
- Solid angle, momentum resolution are expected to be realistic

# How to Estimate

## Momentum resolution

$$p_t = a_1 x_{FP} + a_2 y_{FP} + a_3 x'_{FP} + a_4 y'_{FP} + a_5 x_{FP} y_{FP} + \dots$$

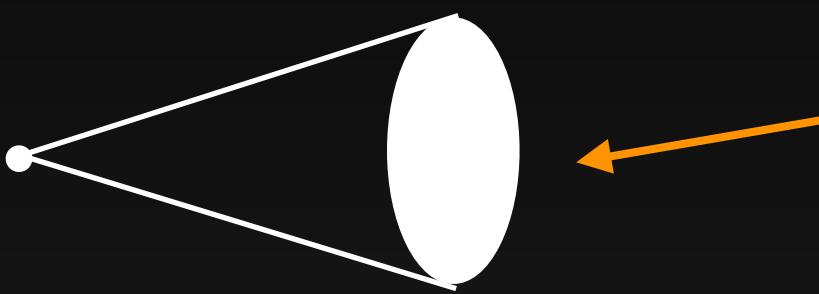
$$= \sum_{a+b+c+d \leq m} C(a, b, c, d) (x_{FP})^a (y_{FP})^b (x'_{FP})^c (y'_{FP})^d$$

Determine coefficients  $a_i (i = 0 \dots l)$  by solving coefficient vector from

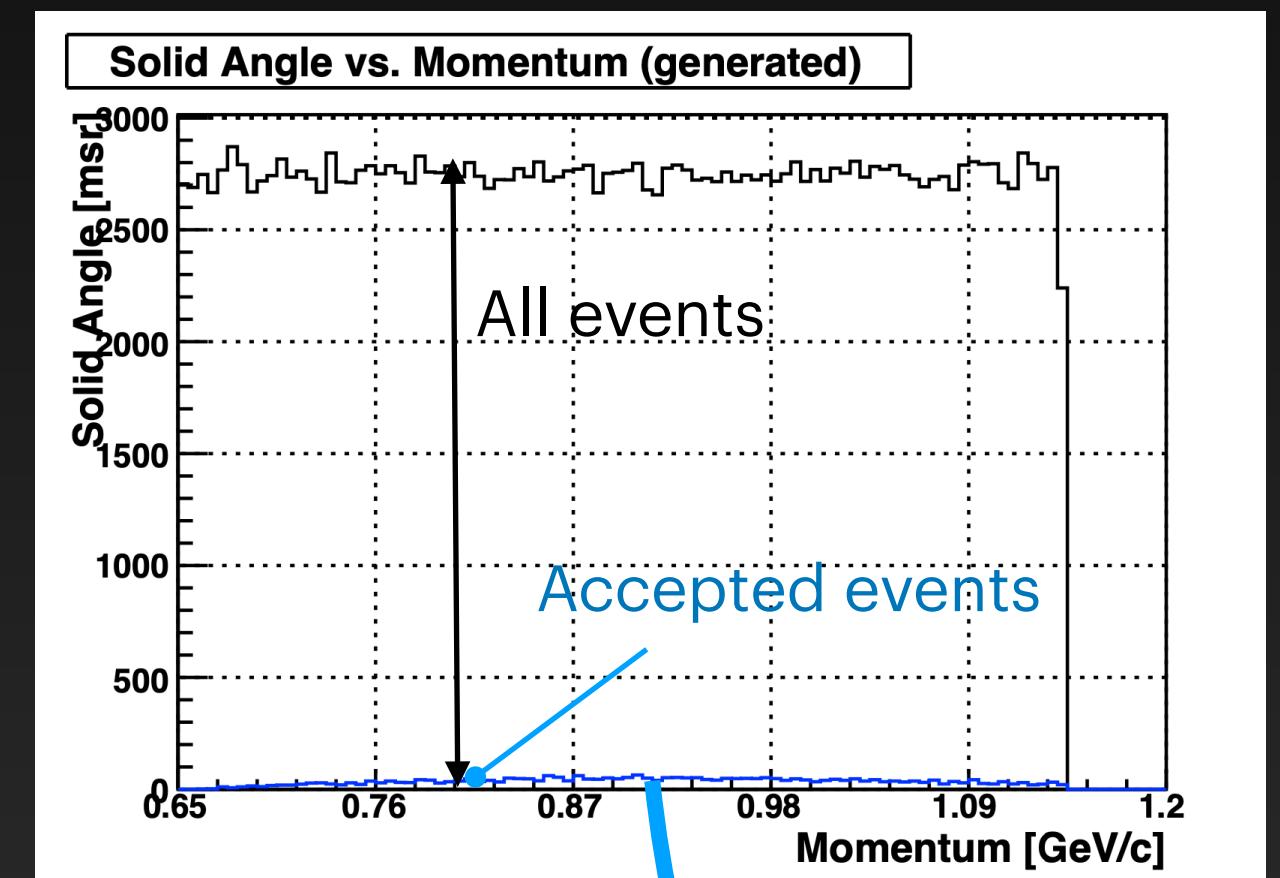
$$\text{Number of event} \left| \begin{pmatrix} p_t^{(1)} \\ p_t^{(2)} \\ \vdots \\ p_t^{(n)} \end{pmatrix} \right. = \overbrace{\begin{pmatrix} x_{FP}^{(1)} & y_{FP}^{(1)} & \dots & (y'_{FP}^{(1)})^6 \\ x_{FP}^{(2)} & y_{FP}^{(2)} & \dots & (y'_{FP}^{(2)})^6 \\ \vdots & \vdots & \ddots & \vdots \\ x_{FP}^{(n)} & y_{FP}^{(n)} & \dots & (y'_{FP}^{(n)})^6 \end{pmatrix}}^{\text{Number of possible combination of } (a, b, c, d)} \begin{pmatrix} a_1 \\ a_2 \\ \vdots \\ a_m \end{pmatrix}$$

$$\frac{\text{Actual value}}{p_t^{true}} - \frac{\text{Value calculated above}}{p_t^{calc}} = \Delta p/p$$

## Solid angle

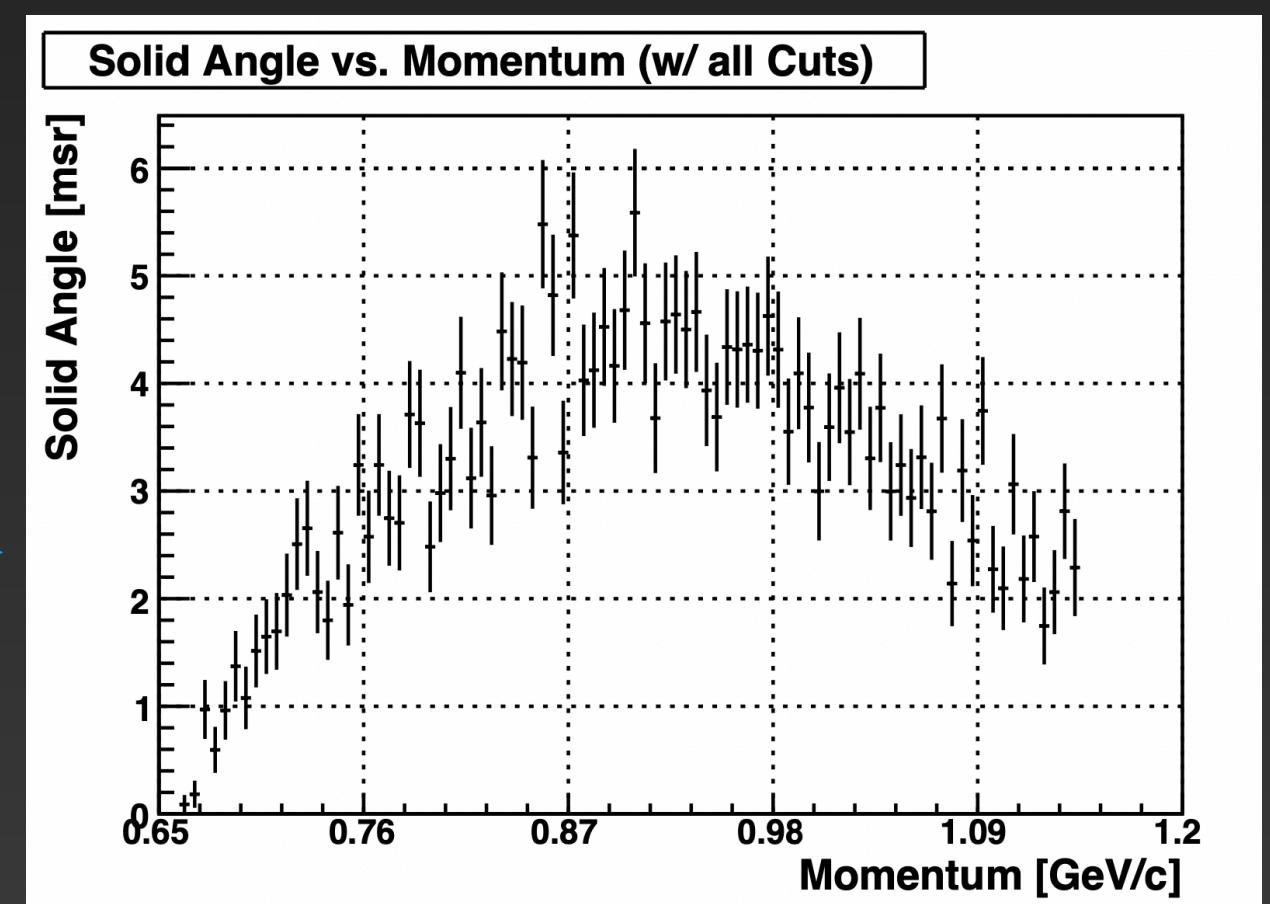


Cone range of emitted particles distributed uniformly in angle range  $\Delta\theta, \Delta\phi$



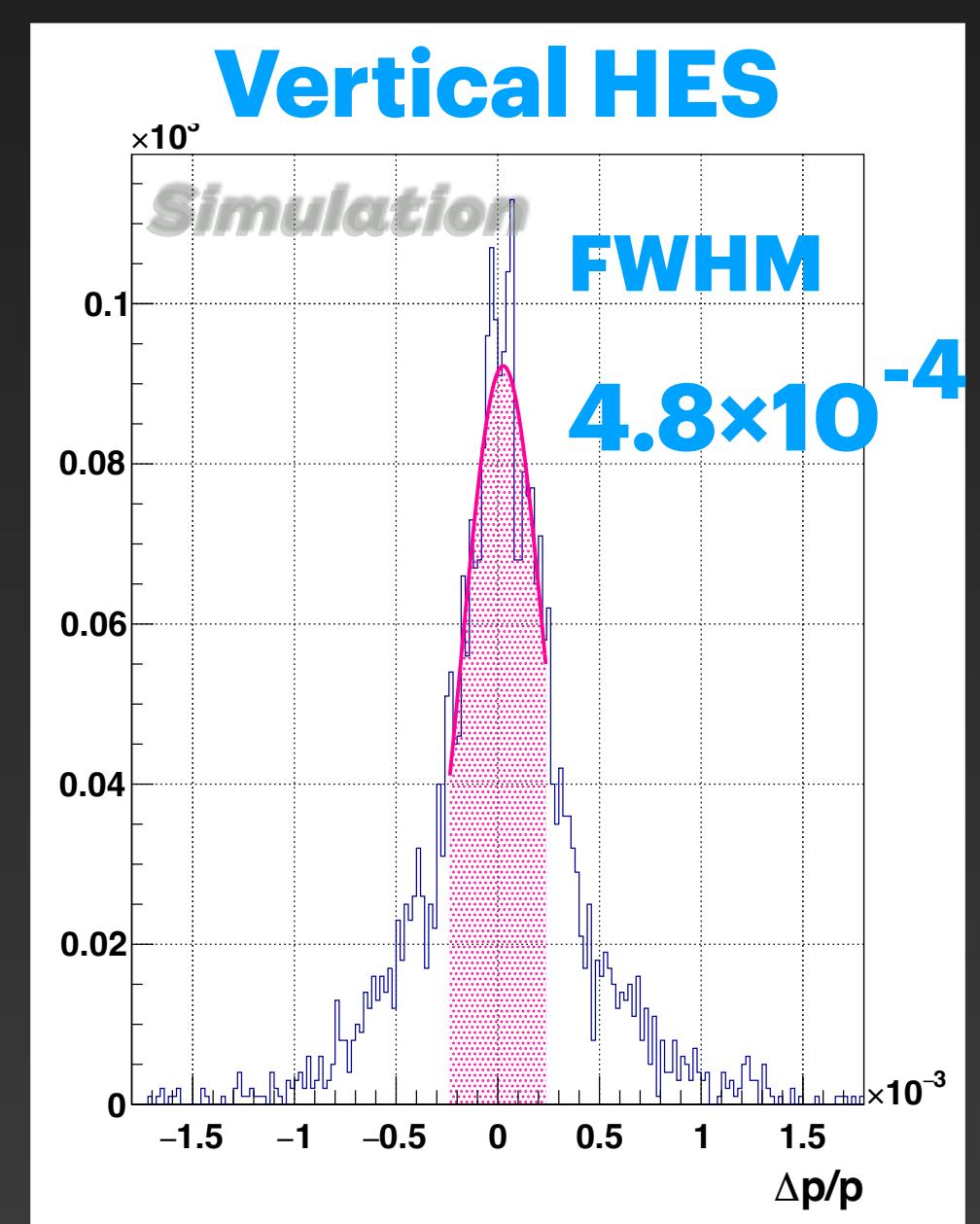
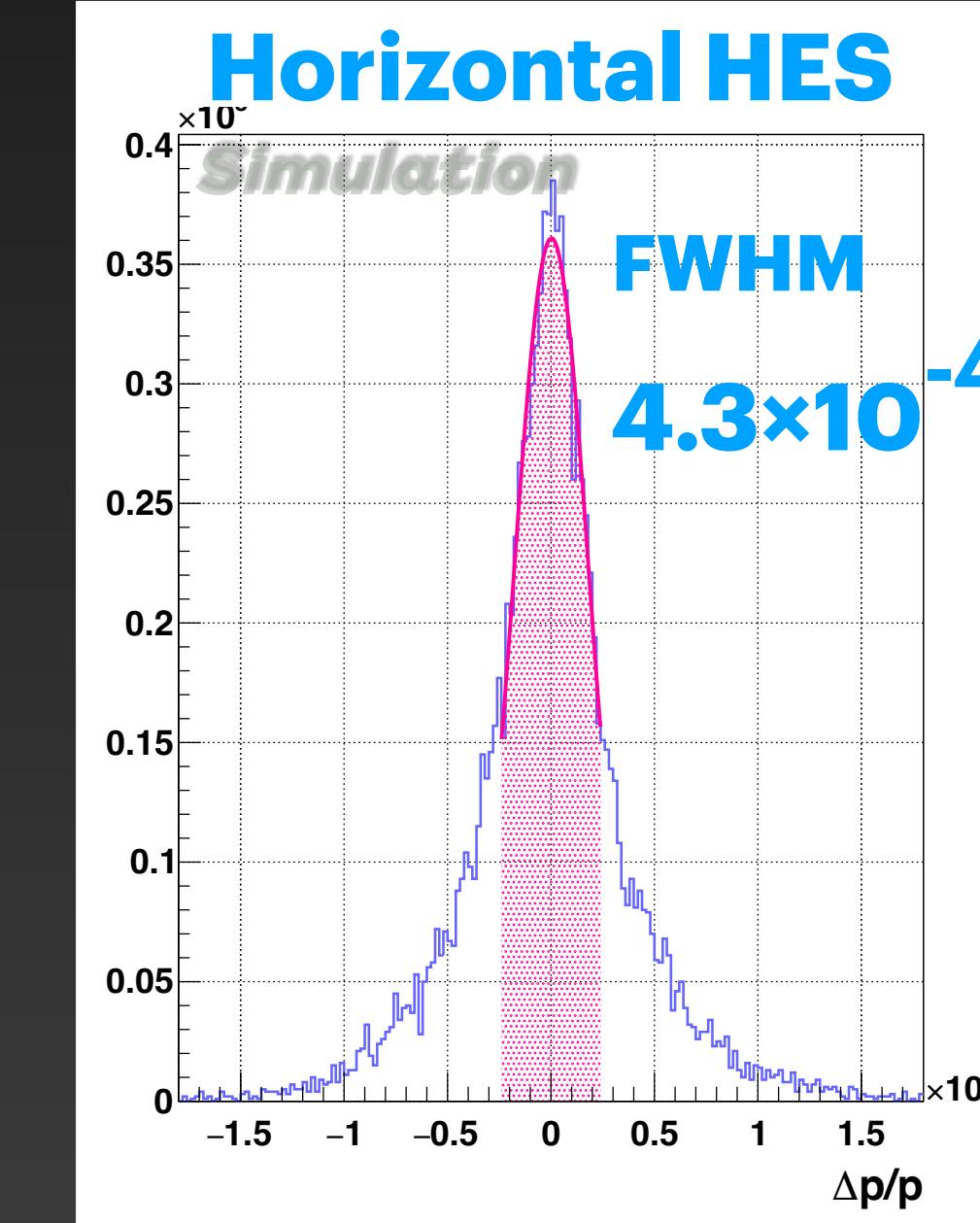
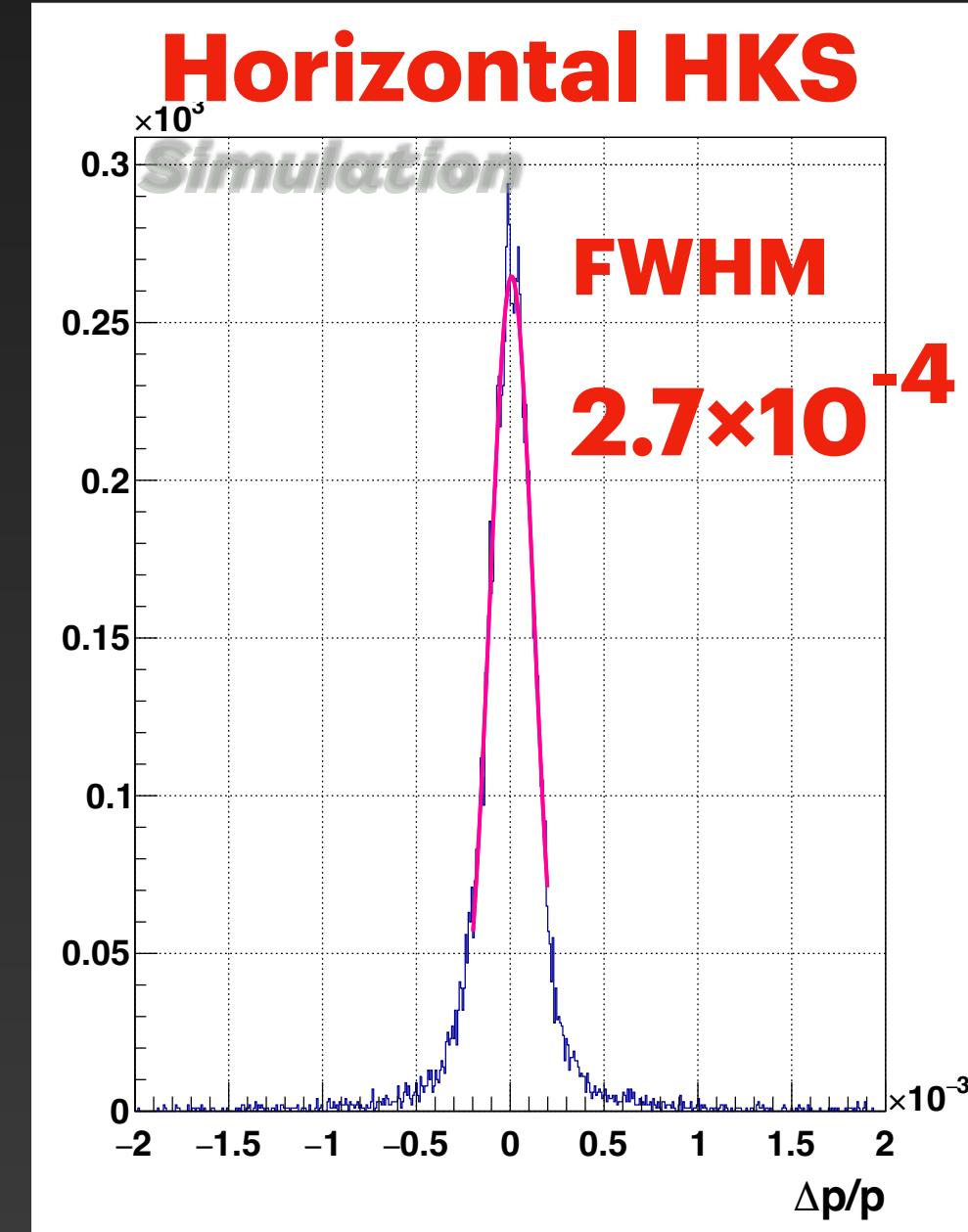
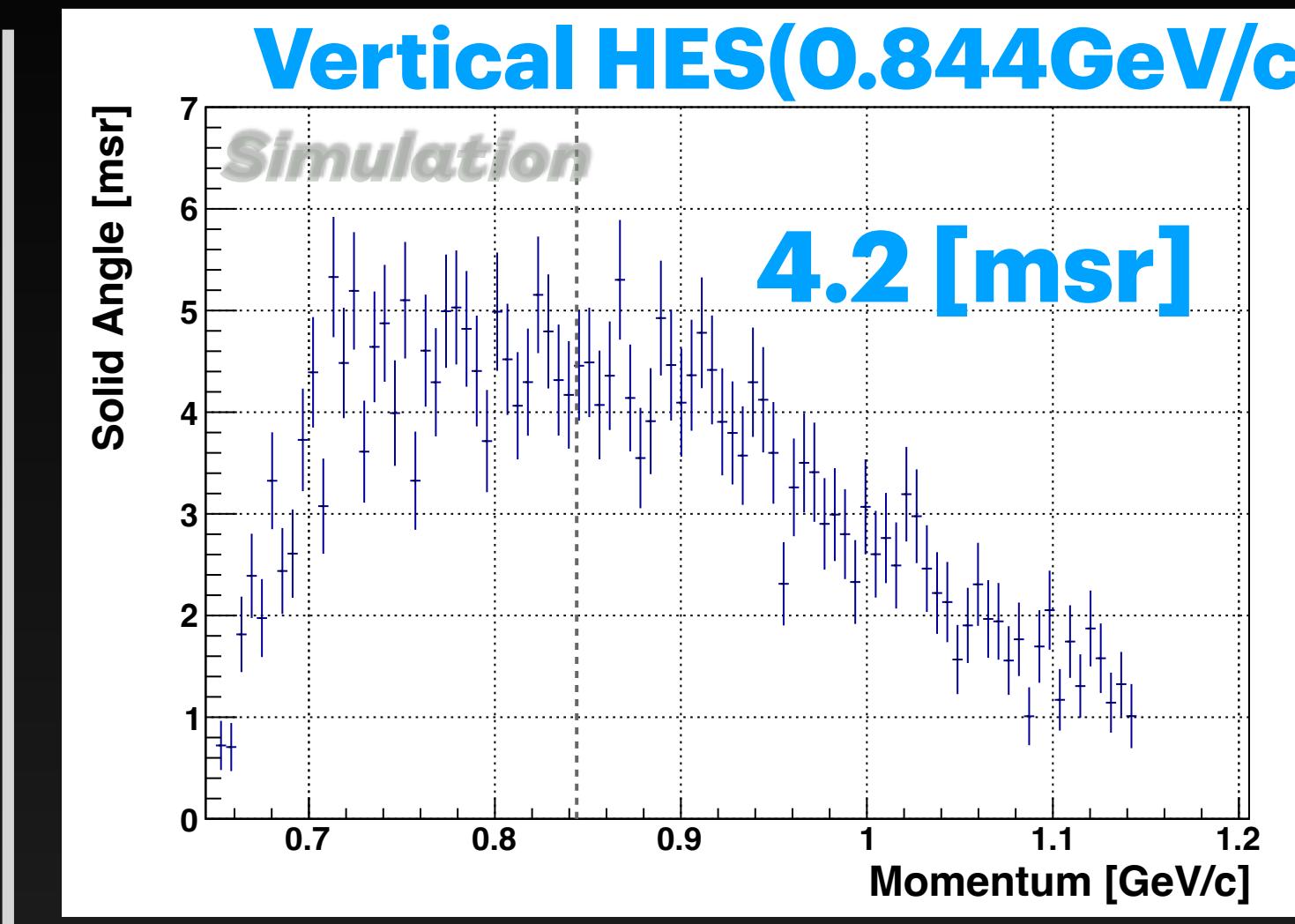
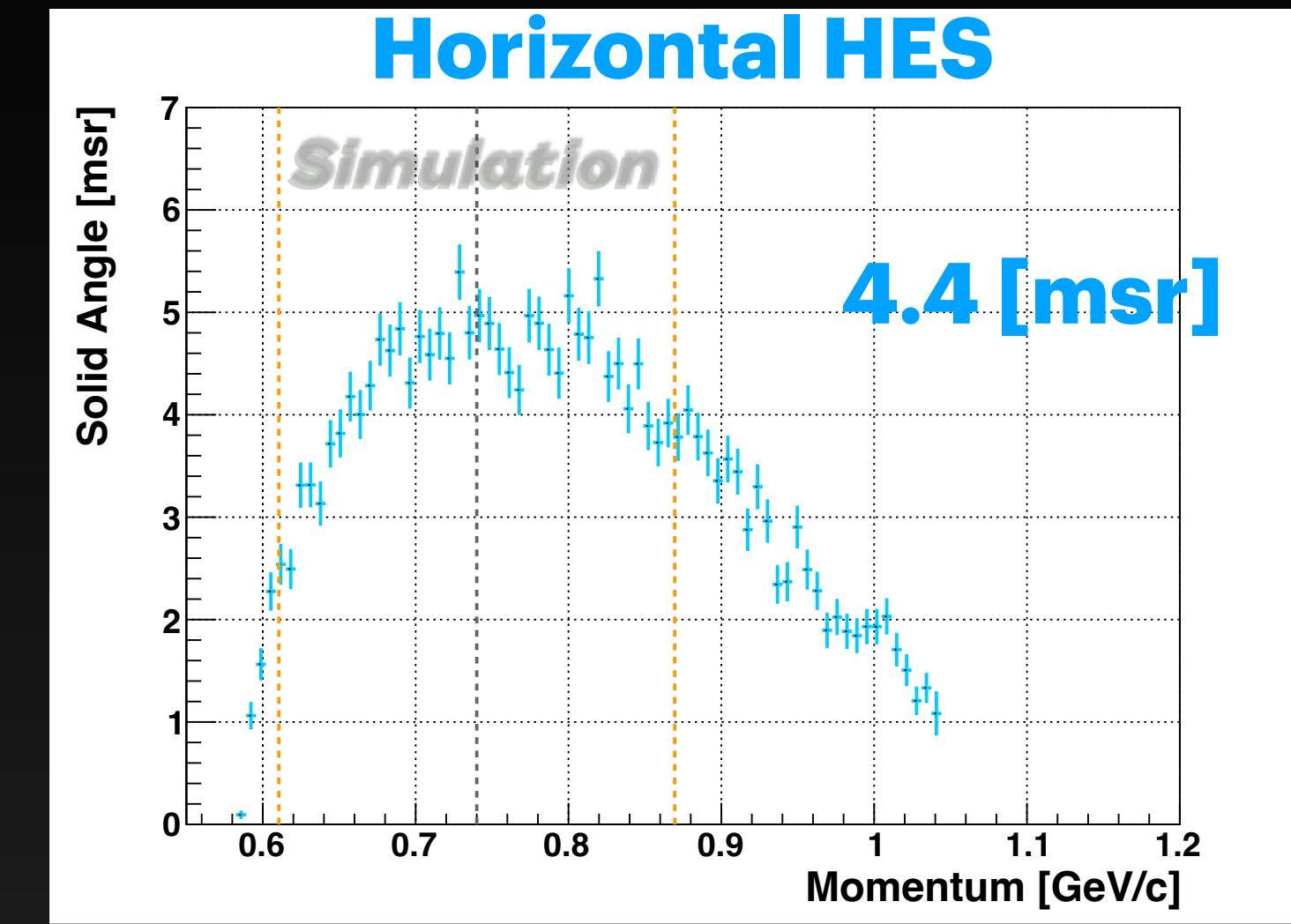
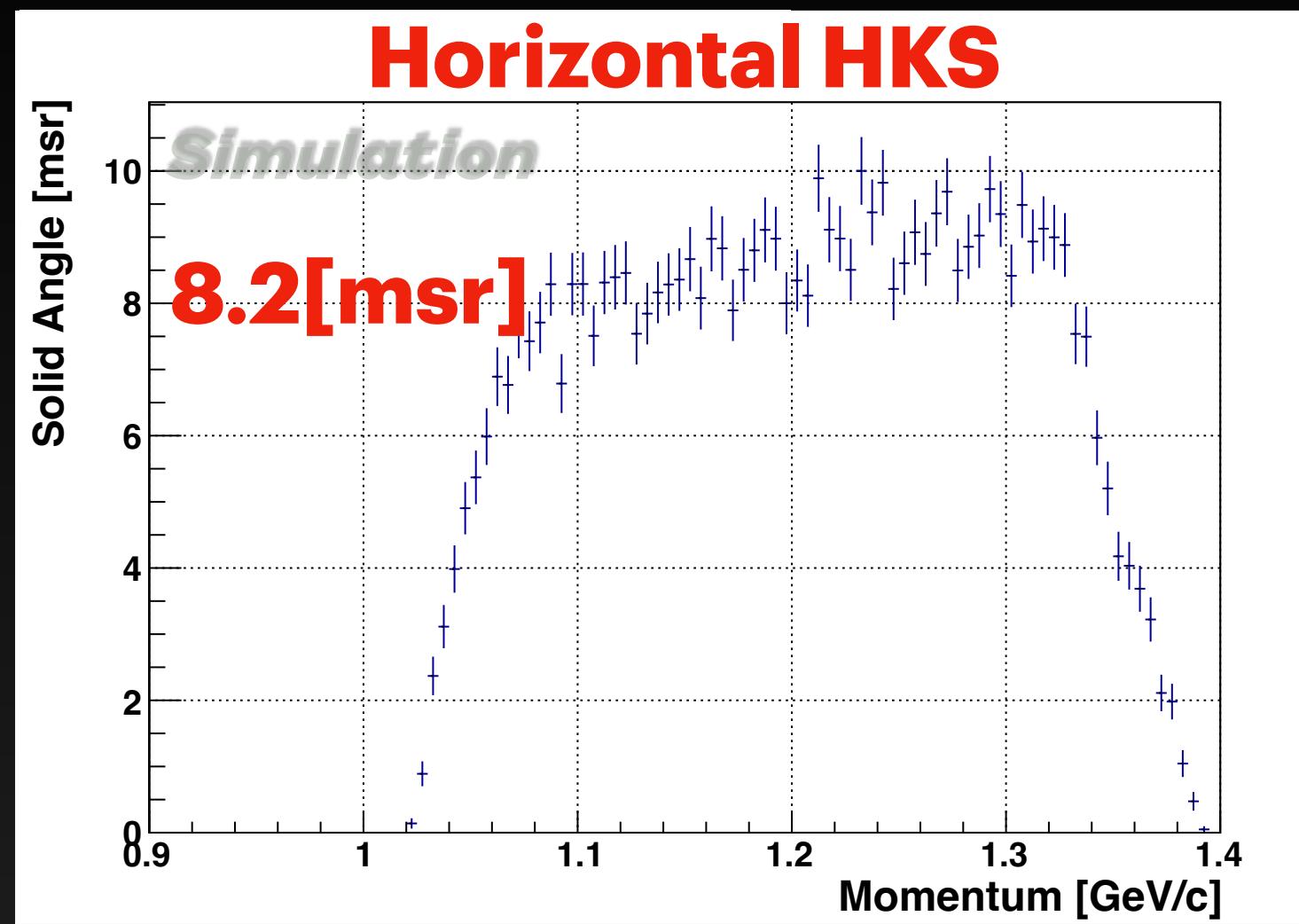
In every momentum bin,

$$\sin \theta \Delta\theta \Delta\phi \times \frac{\text{accepted events}}{\text{all events}}$$



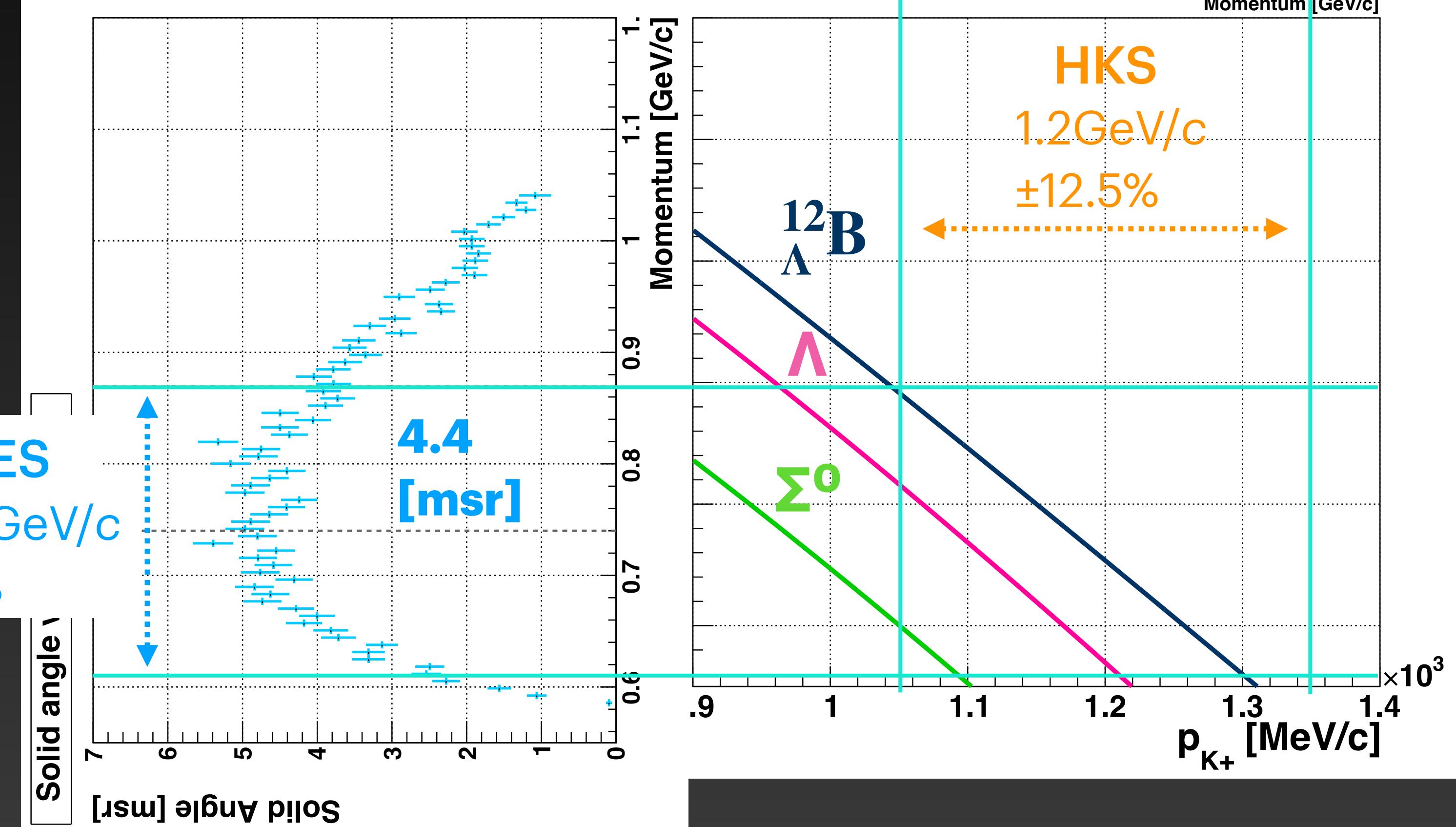
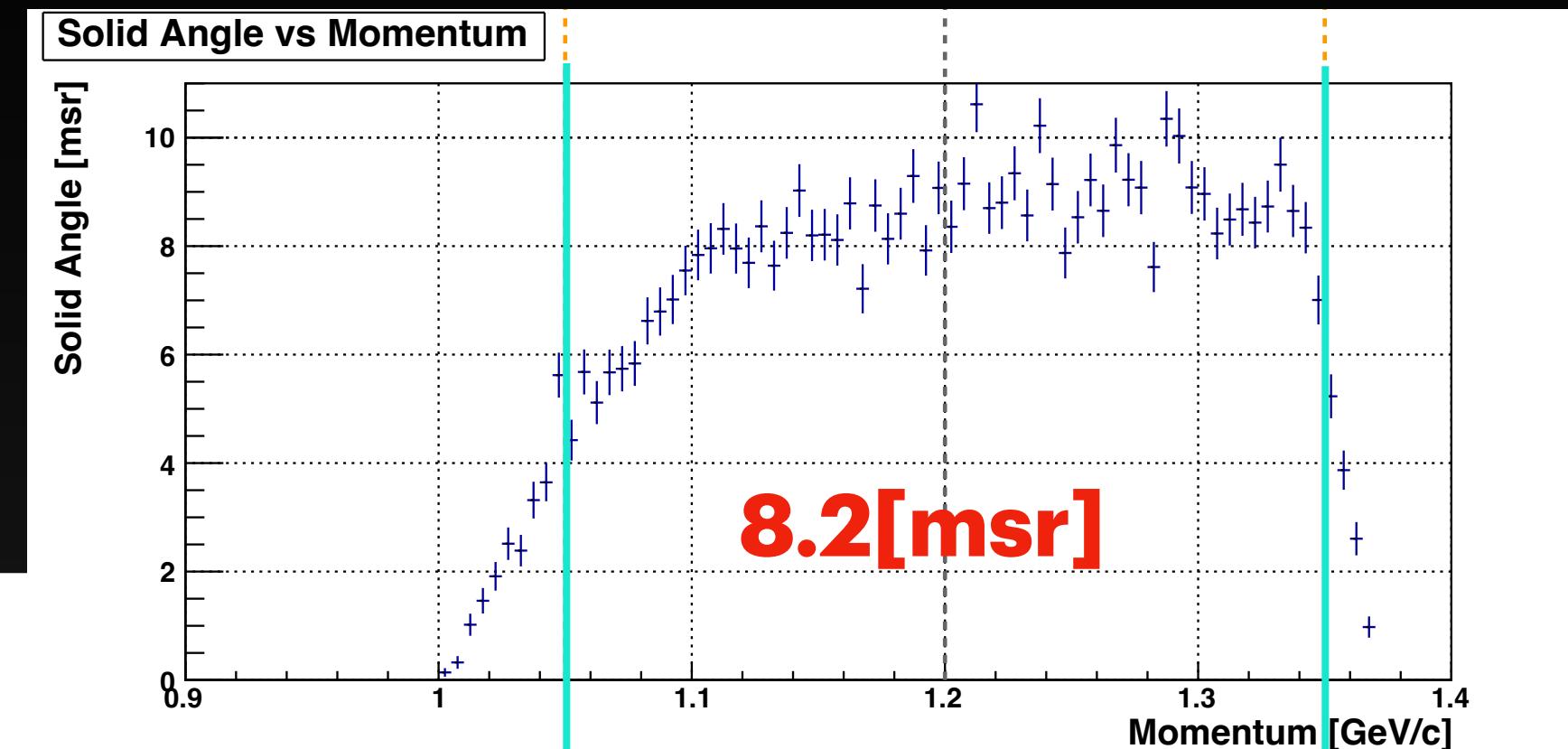
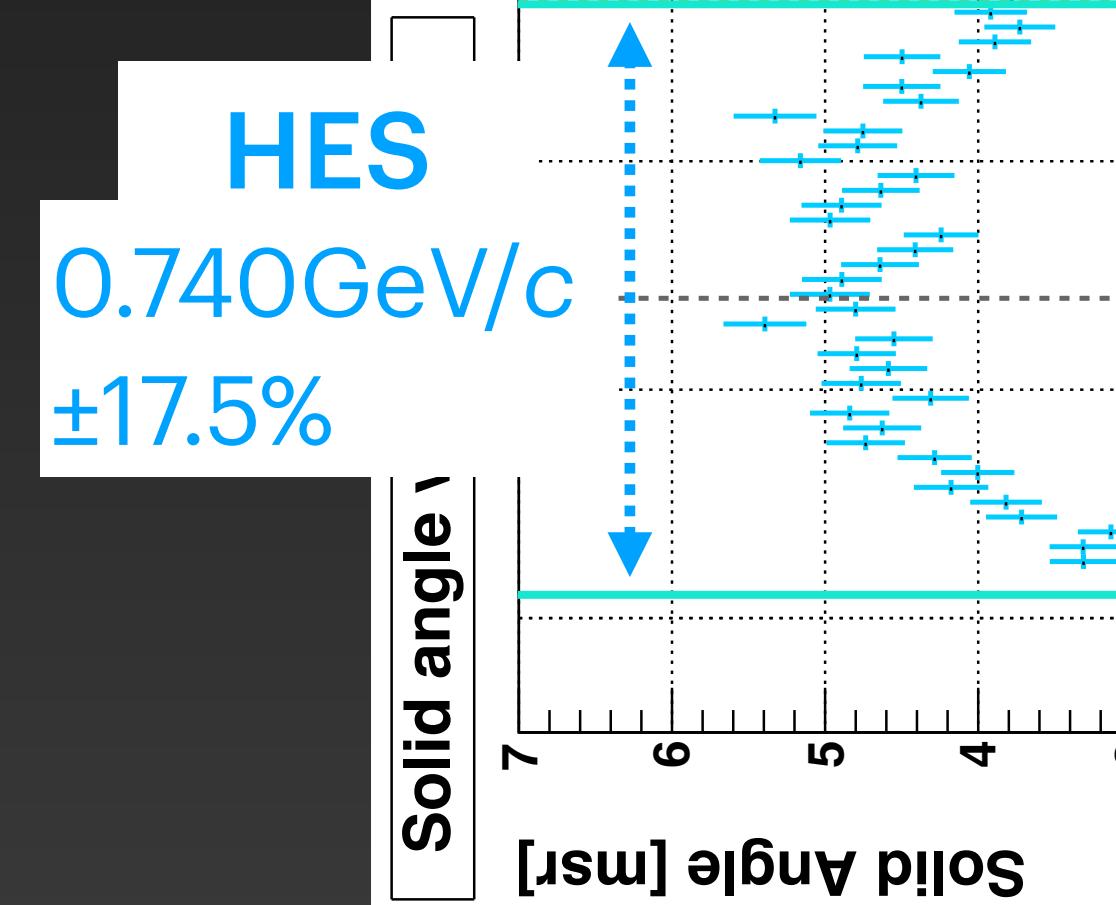
# Result

# Solid Angle & Momentum resolution



# Momentum Acceptance

- $E_e = 2.240 \text{ GeV}$ ,  $p_{e'} = 0.740 \text{ GeV}/c$
- Made by Missing mass formula below:
  - $M_{HYP} = \sqrt{(E_e + M_{target} - E_{e'} - E_K)^2 - (\vec{p}_e - \vec{p}_{e'} - \vec{p}_K)^2}$
- Momentum acceptance covers  $\Sigma$  and  $\Lambda$  peak slightly
- → Need adjusting HKS acceptance to lower momentum side



# Hypernuclear Yield

- Condition
  - Assume the typical cross section for each target
  - HES central momentum: 0.740GeV/c
  - HES theta: 8deg
  - Current: 10μA
  - Thickness: 100 mg/cm<sup>2</sup>
  - Beam time: 4.2 days

**Hypernuclear yield for typical cross section**

Li7 (10nb/sr)	C12 (90nb/sr)	Al27 (20nb/sr)	Ca40 (50nb/sr)	Pb208 (90nb/sr)
17	88	9	14	5

$$N_{HYP} = N_{\gamma^*} \times N_{target} \times \frac{d\sigma_{prod.}}{d\Omega} \times \Delta\Omega_K$$

$N_{\gamma^*}$  : Num. of virtual photons per sec.(Int. VP flux \* Ne)

$N_{target}$  : Num. of target atoms

$\frac{d\sigma_{prod.}}{d\Omega}$  : diff. cross section of  $(\gamma, K^+)$  reaction

$\Delta\Omega_K$  : Acceptance of solid angle

# How to calculate MM spectrum

- Calculated  $M_{HYP}$  event by event, with setup parameters randomly varied within their resolutions, like  $E_e \rightarrow E_e + \Delta E$ ,  $p_{e'} \rightarrow p_{e'} + \Delta p_{e'}$ ,  $p_K \rightarrow p_K + \Delta p_K$ ,  $\theta_{ee'} \rightarrow \theta_{ee'} + \Delta \theta_{ee'}$ ,  $\theta_{eK} \rightarrow \theta_{eK} + \Delta \theta_{eK}$ ,  $\phi_{ee'} \rightarrow \phi_{ee'} + \Delta \phi_{ee'}$ ,  $\phi_{eK} \rightarrow \phi_{eK} + \Delta \phi_{eK}$

$$M_{HYP} = \sqrt{(E_e + M_{target} - E_{e'} - E_K)^2 - (\vec{p}_e - \vec{p}_{e'} - \vec{p}_K)^2}$$

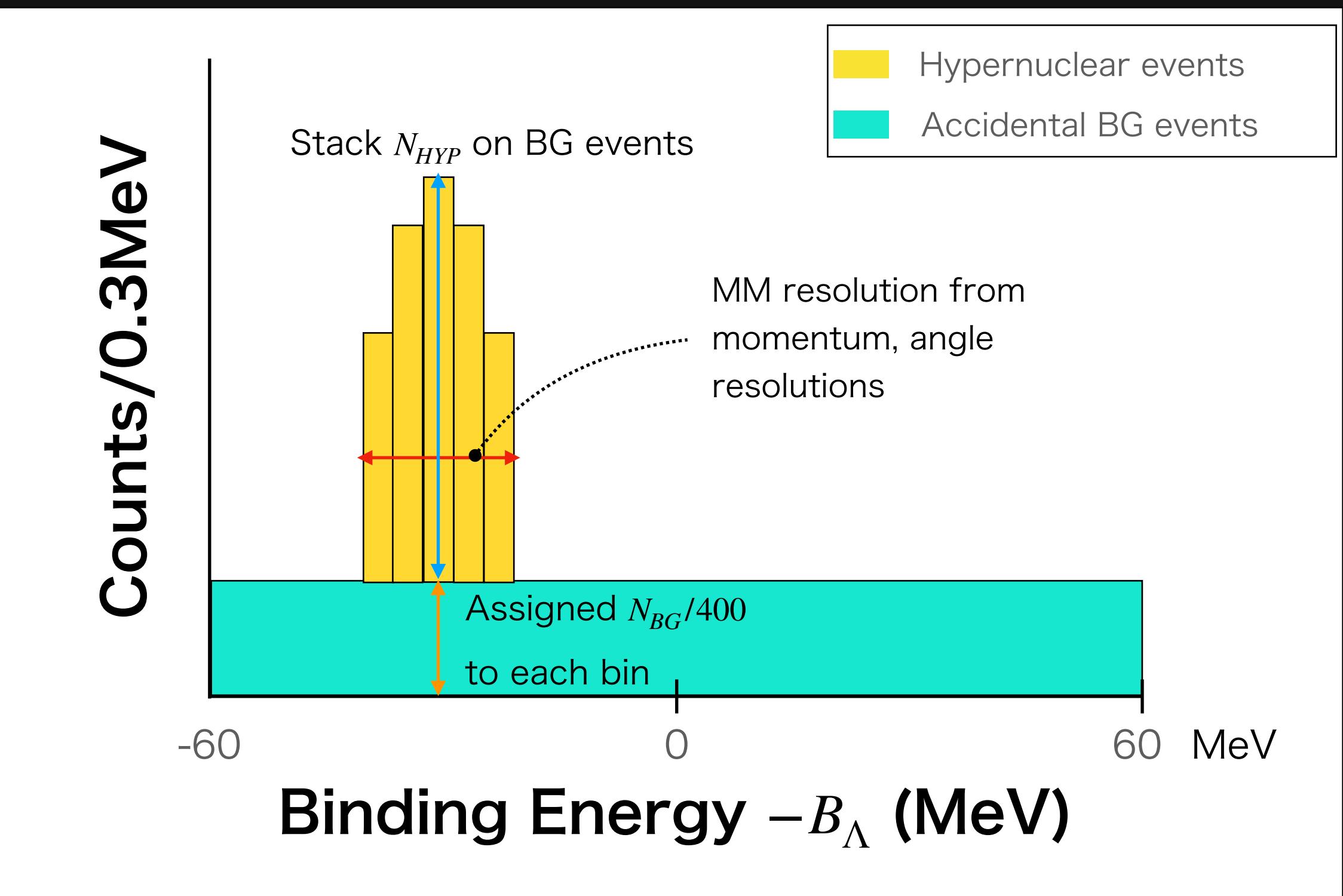
$$N_{HYP} = N_{\gamma^*} \times N_{target} \times \frac{d\sigma_{prod.}}{d\Omega} \times \Delta\Omega_K$$

$$N_{e'} = N_{beam} \times N_{target} \times \frac{d\sigma_{brems}}{d\Omega} \times \Delta\Omega_e \times \epsilon_e$$

$$N_K = N_{beam} \times N_{target} \times \left( \frac{d\sigma_\pi}{d\Omega} + \frac{d\sigma_K}{d\Omega} + \frac{d\sigma_p}{d\Omega} \right) \times \Delta\Omega_K \times \epsilon_K$$

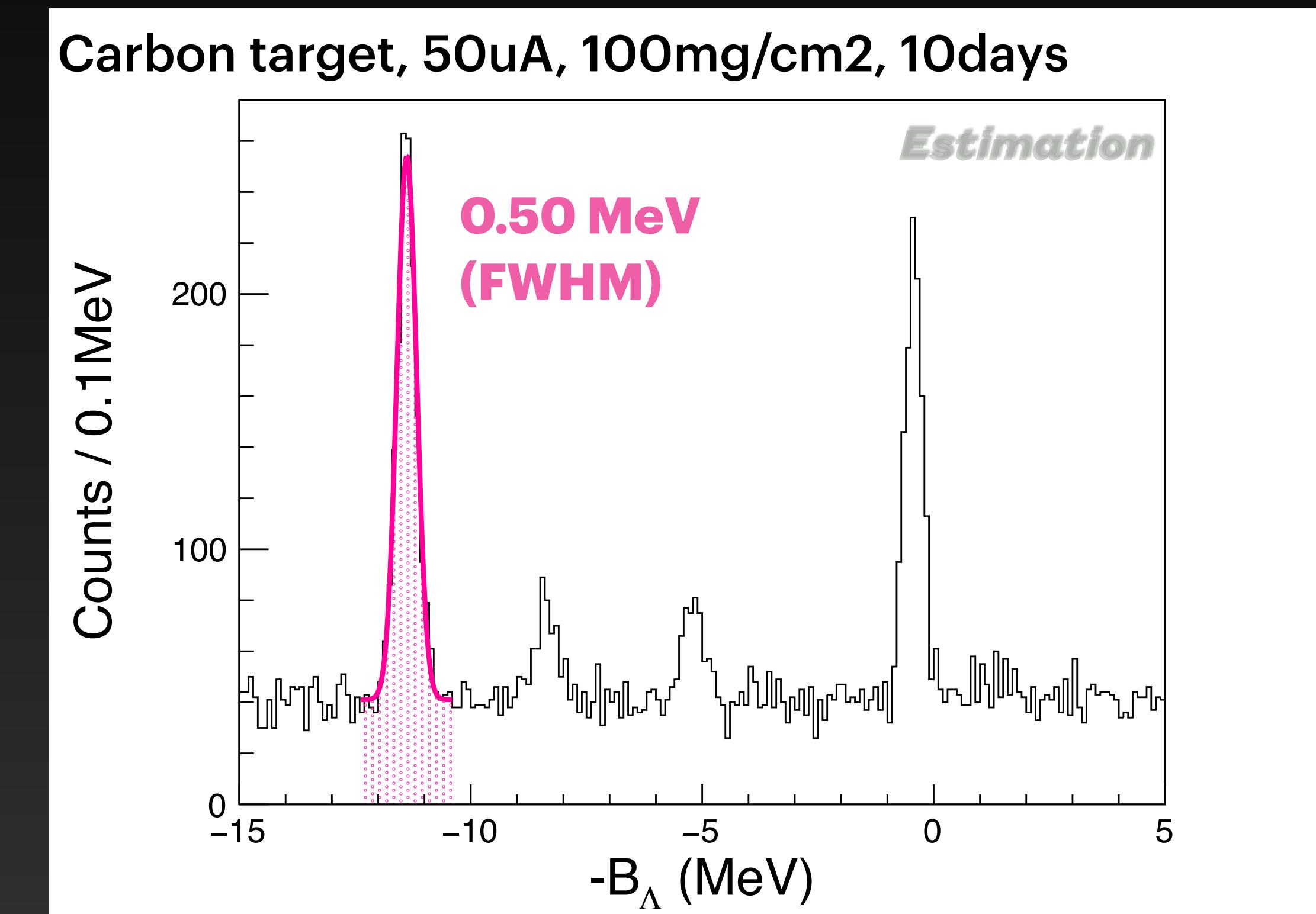
$$N_{BG} = N_{e'} \times N_K \times t_{window}$$

Schematics drawing of missing mass spectrum calculated



# MM for Carbon target

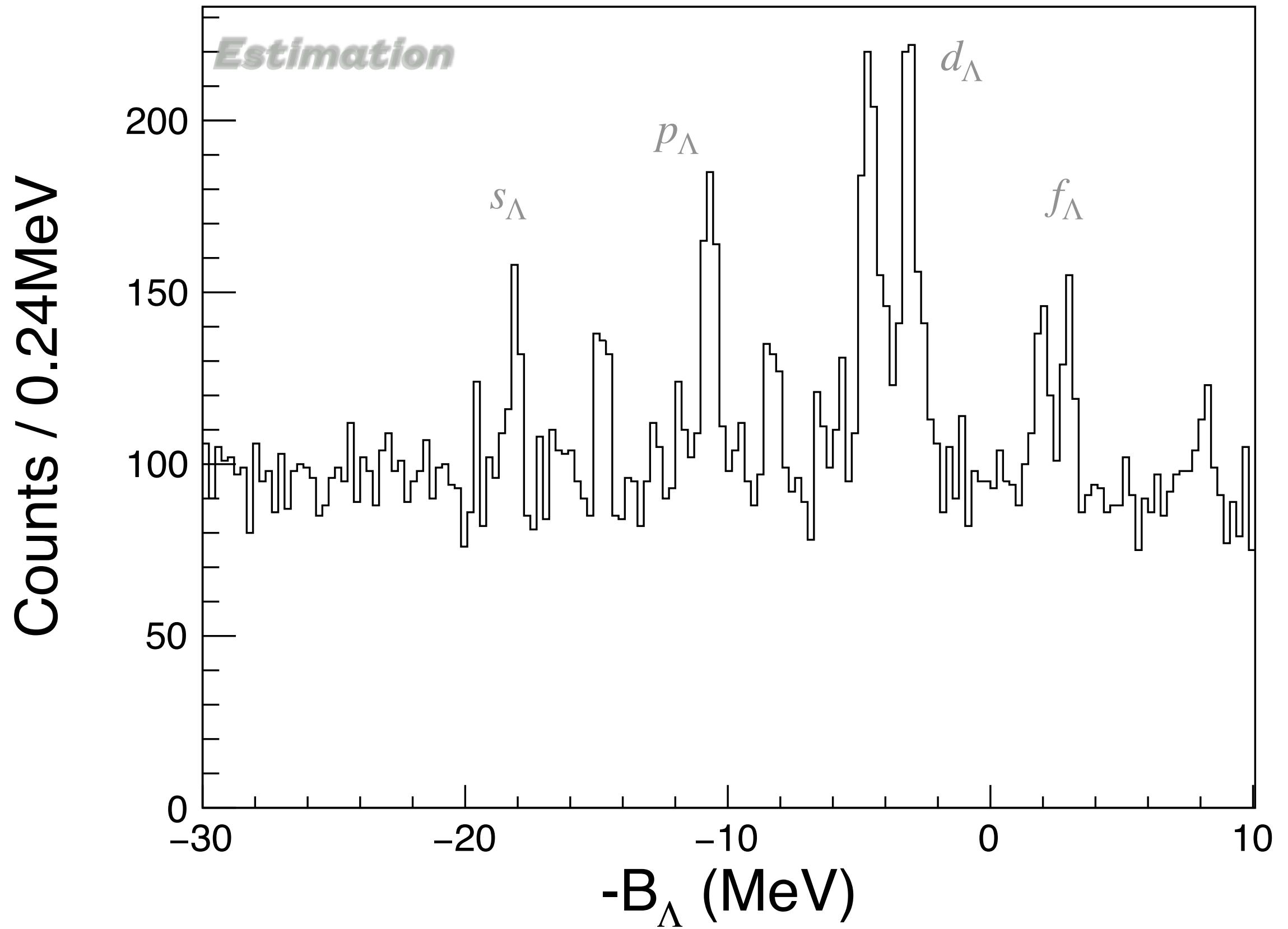
- Condition
  - HES central momentum: 0.740GeV/c
  - Current: 20 $\mu$ A
  - Thickness: 100 mg/cm<sup>2</sup>
  - Time: 10days (to get high statistics)
  - Fit func. : Gaussian + Constant
  - No energy straggling



We can expect the MM resolution around 0.5 MeV

# Another MM spectrum ( $^{40}\Lambda$ K)

Ca40 target, 50uA, 100mg/cm<sup>2</sup>, 230h(9.6days)



- My calculation is supposed to be realistic amount of BG, and Yield 1-1.5 times larger
- We can see the peaks of each orbit

# HES single rate

$$N_{e'} = N_{beam} \times N_{target} \times \frac{d\sigma_{brems}}{d\Omega} \times \Delta\Omega$$

$N_{e'}$  : Num. of electrons per sec.

$N_{beam}$  : Num. of beam electrons per sec.

$N_{target}$  : Num. of target atoms

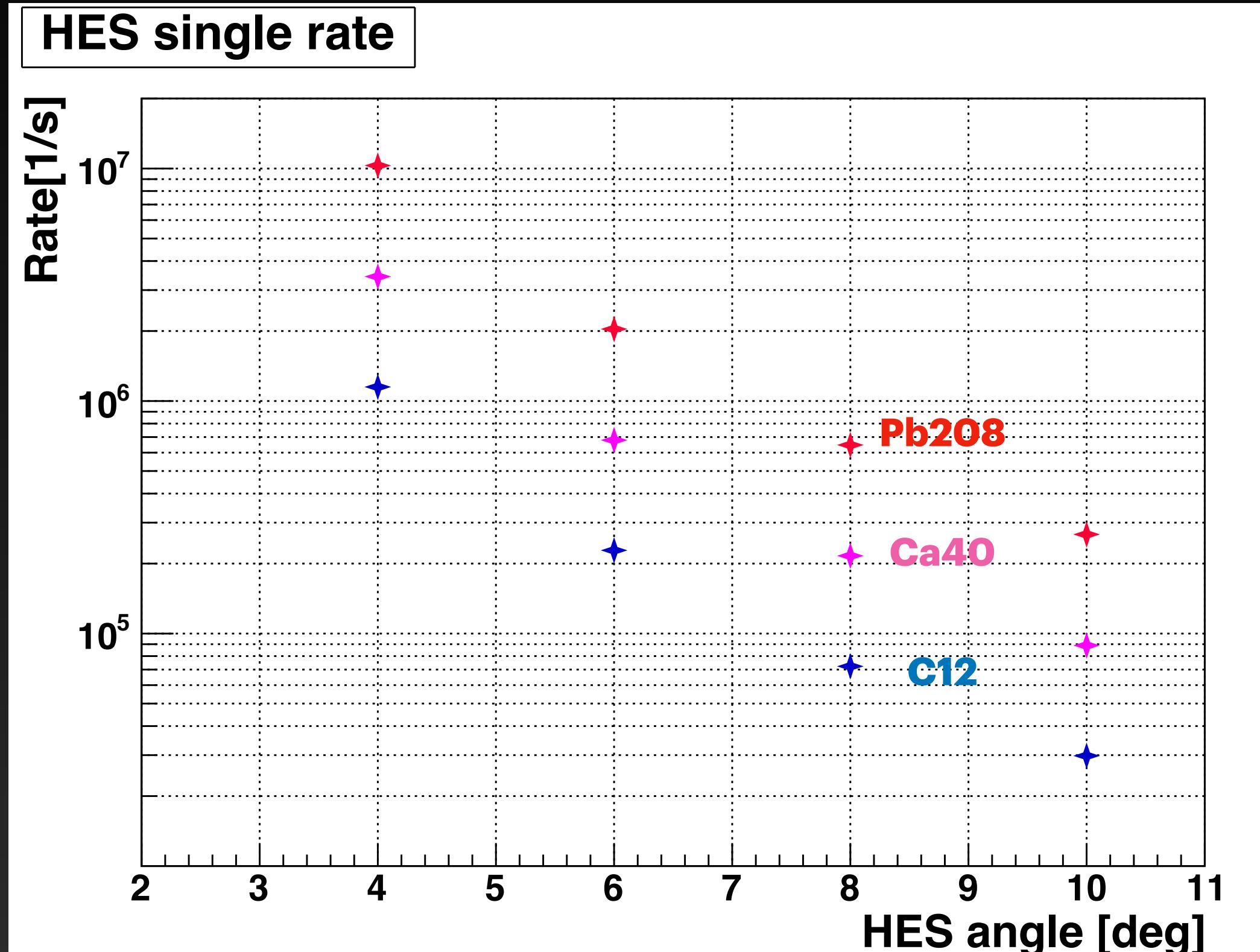
$\frac{d\sigma_{brems}}{d\Omega}$  : Differential cross section of brems. electron

$\Delta\Omega$  : Acceptance of solid angle

- Condition :

- $E_e = 2.240\text{GeV}$ ,  $p_{e'} = 0.740\text{GeV}/c$
- $10\mu\text{A}$ ,  $100\text{mg/cm}^2$ ,  $\Delta\Omega_e = 4.4\text{msr}$

- Rate of lead target will get lower than 1 MHz from ~8 degrees



# Summary

# Summary

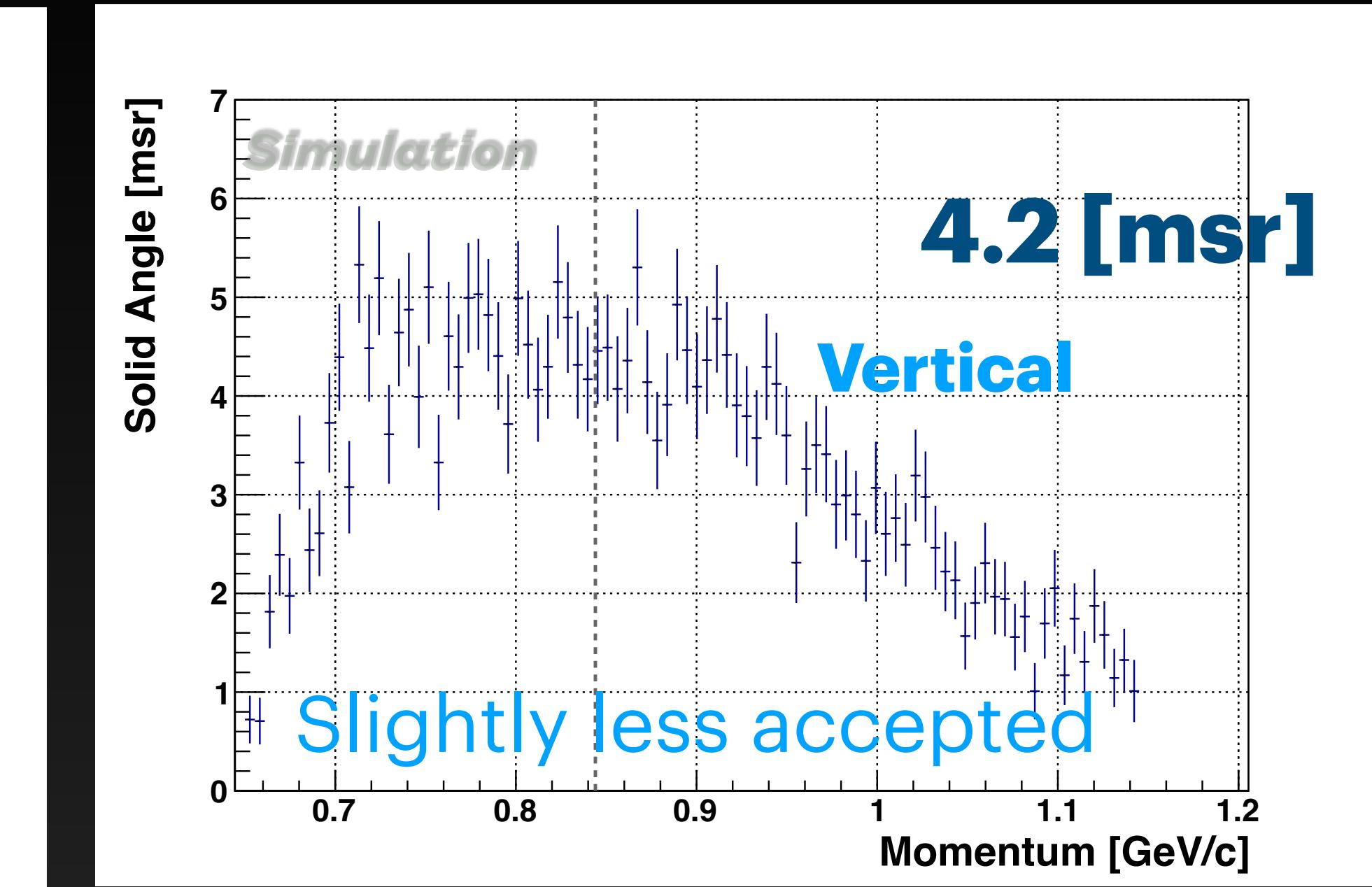
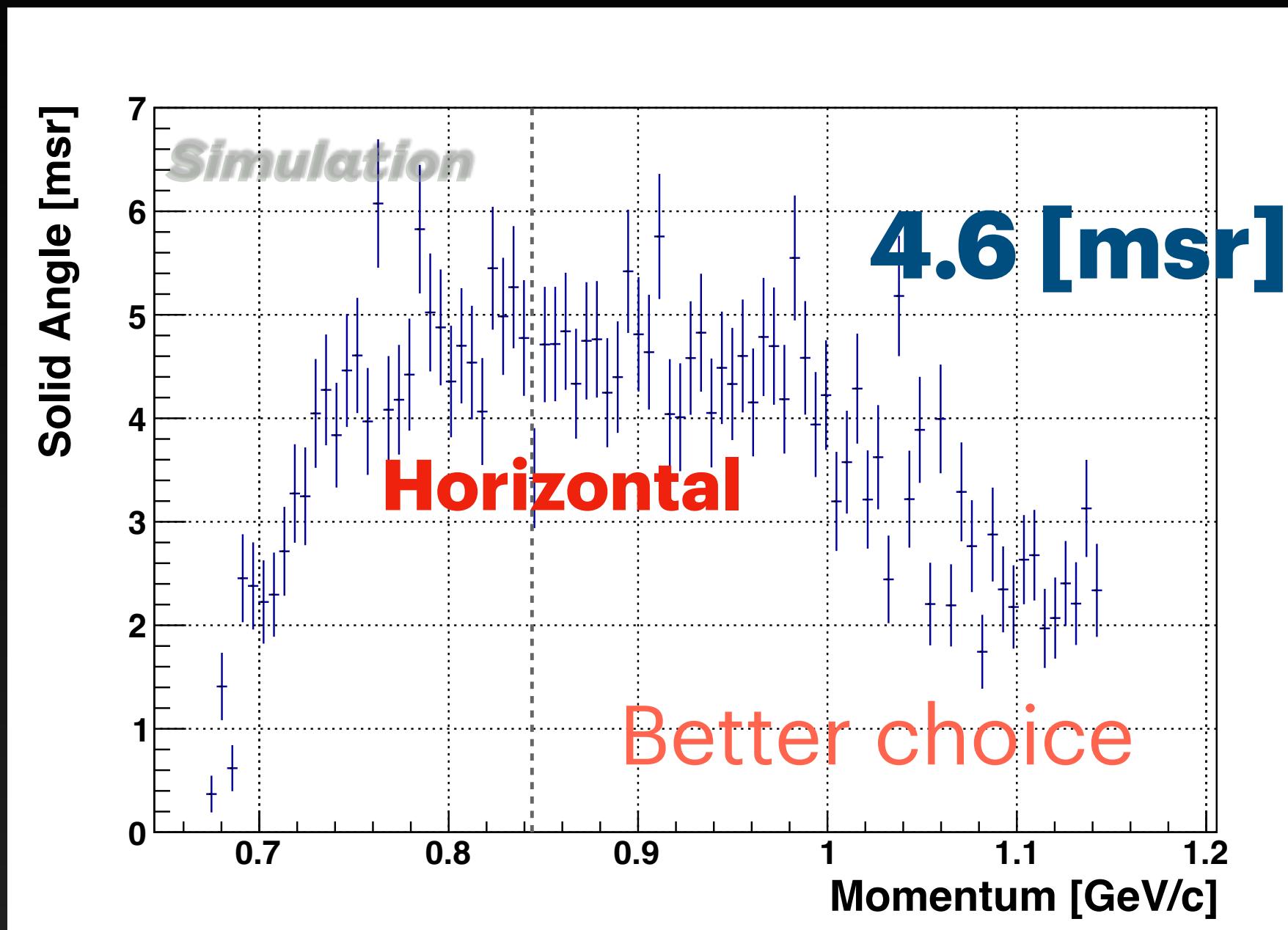
- Setup is PCS + horizontal HES + horizontal HKS
- I checked the performance of PCS+HES+HKS by Geant4
  - Solid angle: 8.2msr for HKS, 4.4msr for HES
  - Momentum resolution:  $2.7 \times 10^{-4}$  for HKS,  $4.3 \times 10^{-4}$  for HES
  - Better than vertical HES
- I estimated hypernuclear yield, MM resolution, and HES single rate
  - Missing mass resolution will be ~ 0.5 MeV
  - HES single rate will be lower than 1 MHz from 8 degrees at 10 uA condition

# Backup

# Solid Angle of HES

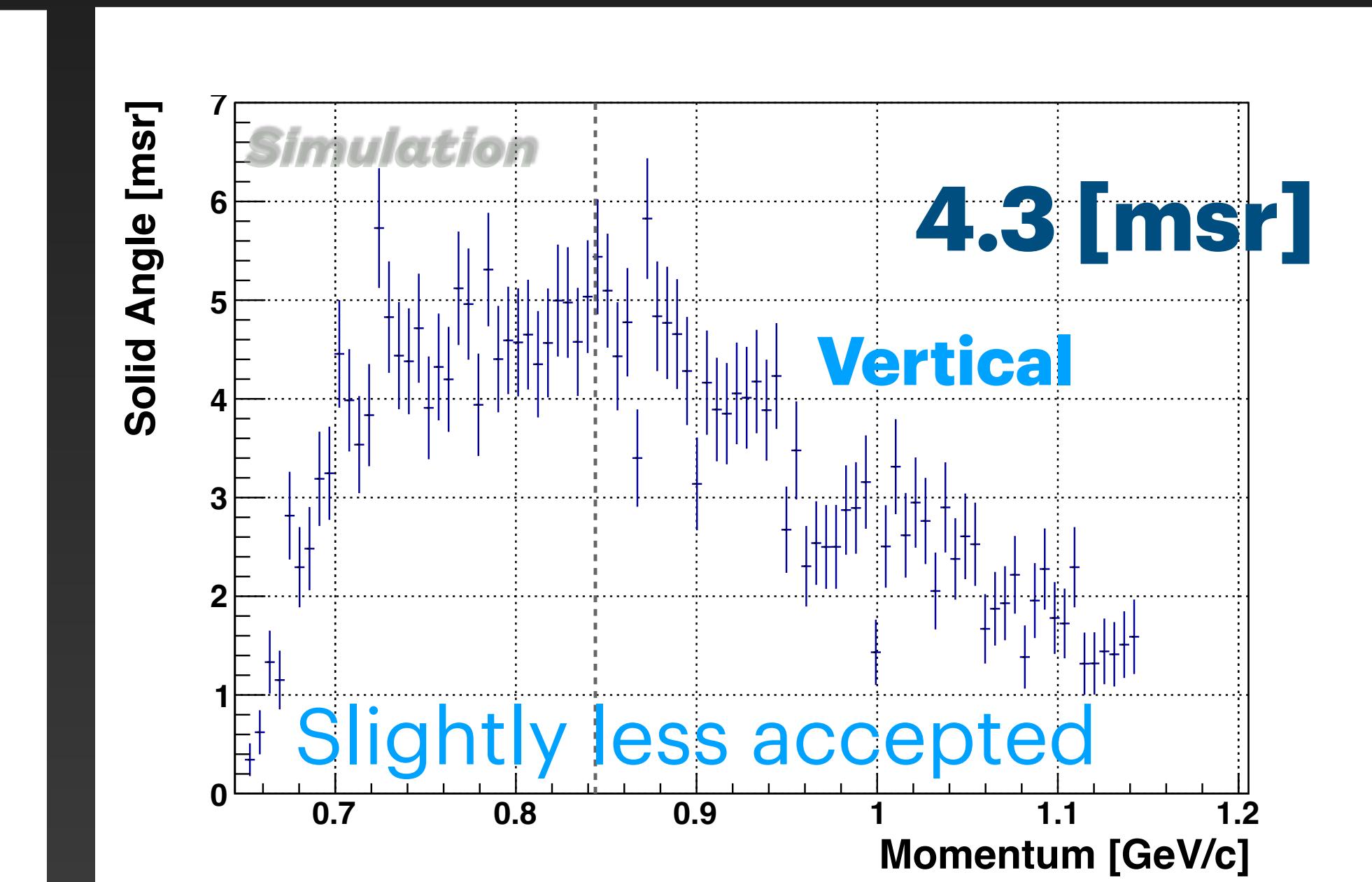
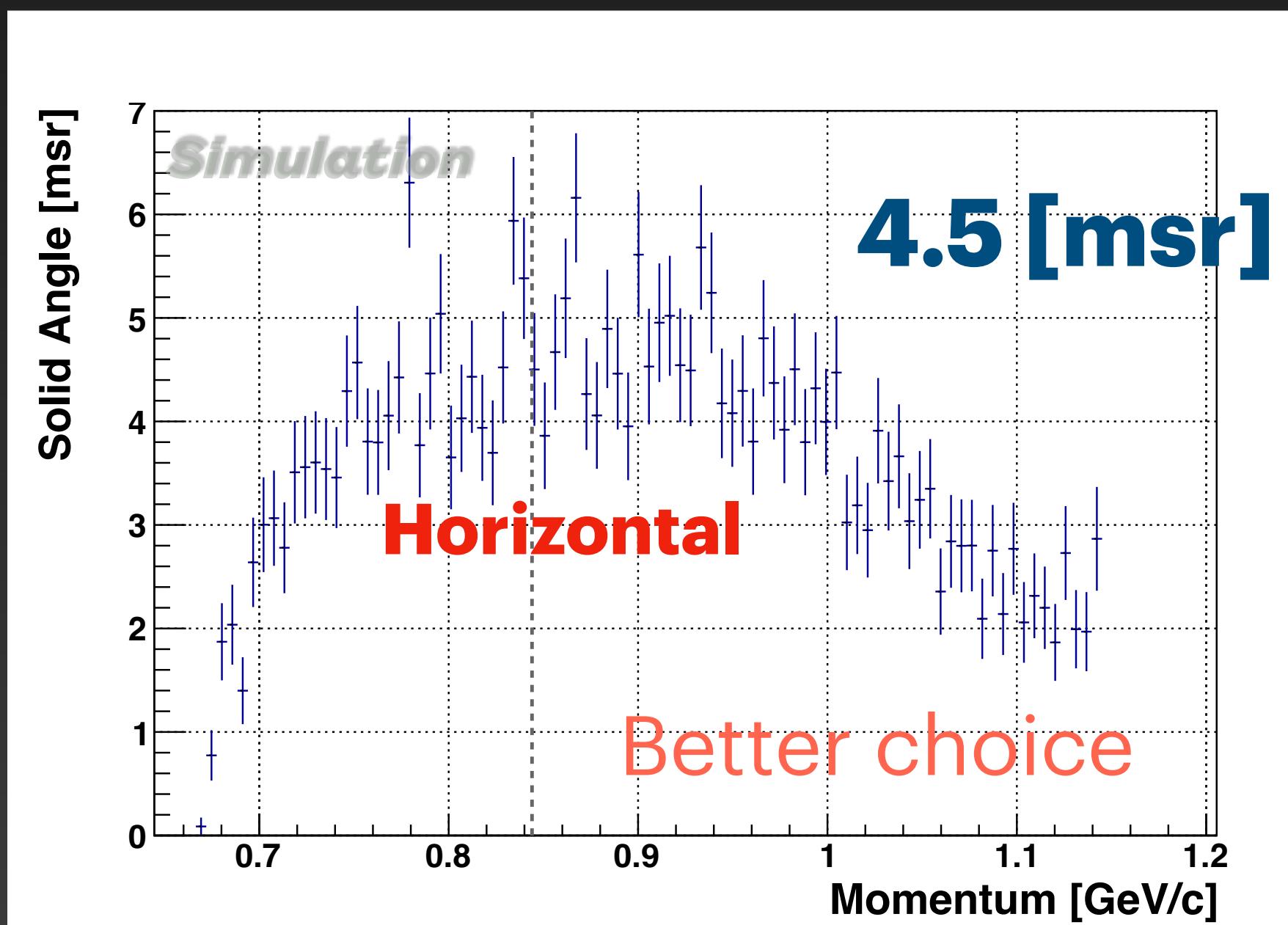
## Solid target

Horizontal-bending HES is still be better choice but vertical-bending HES can be adapted due to suppressing decreasing under 10%



## Gas target

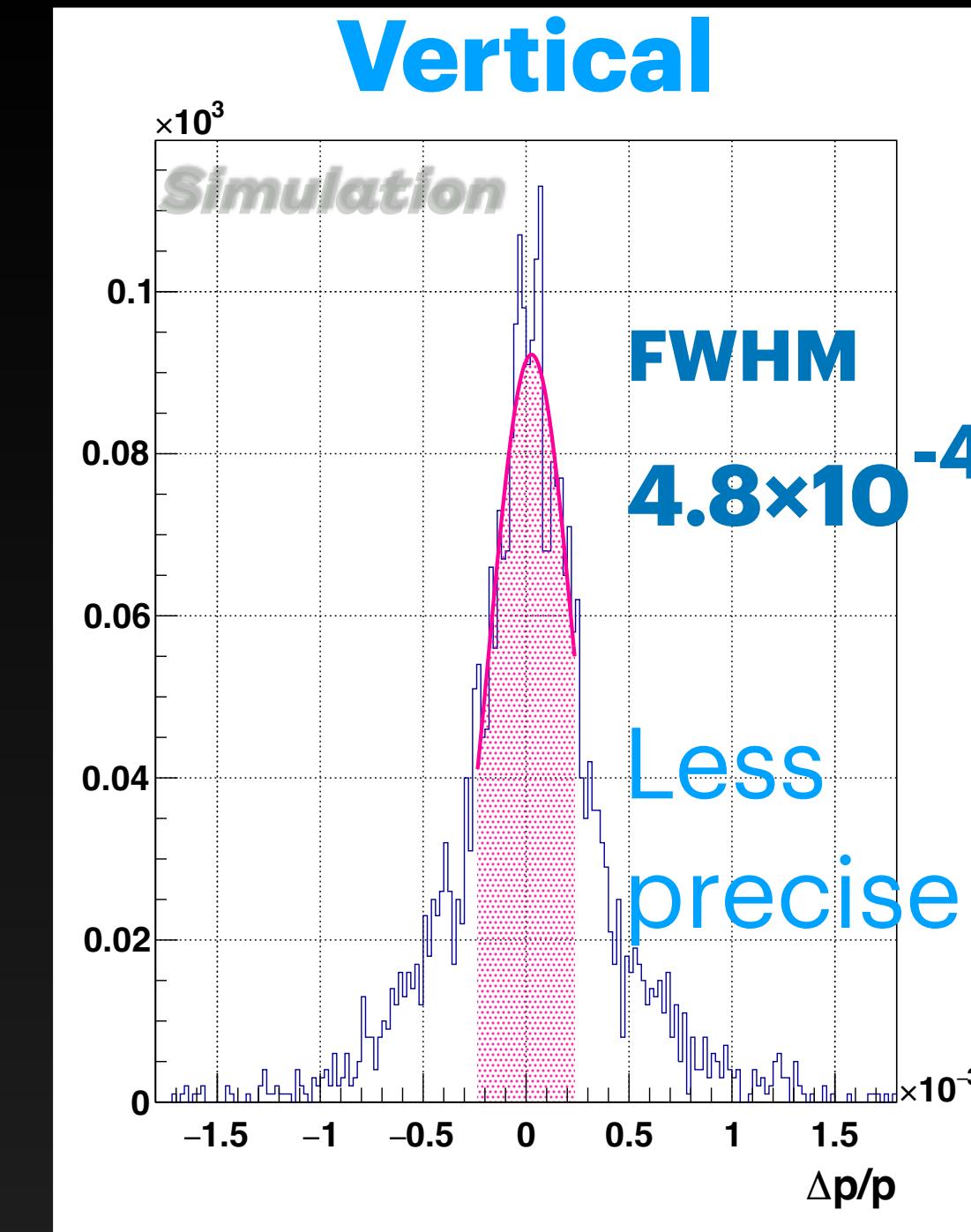
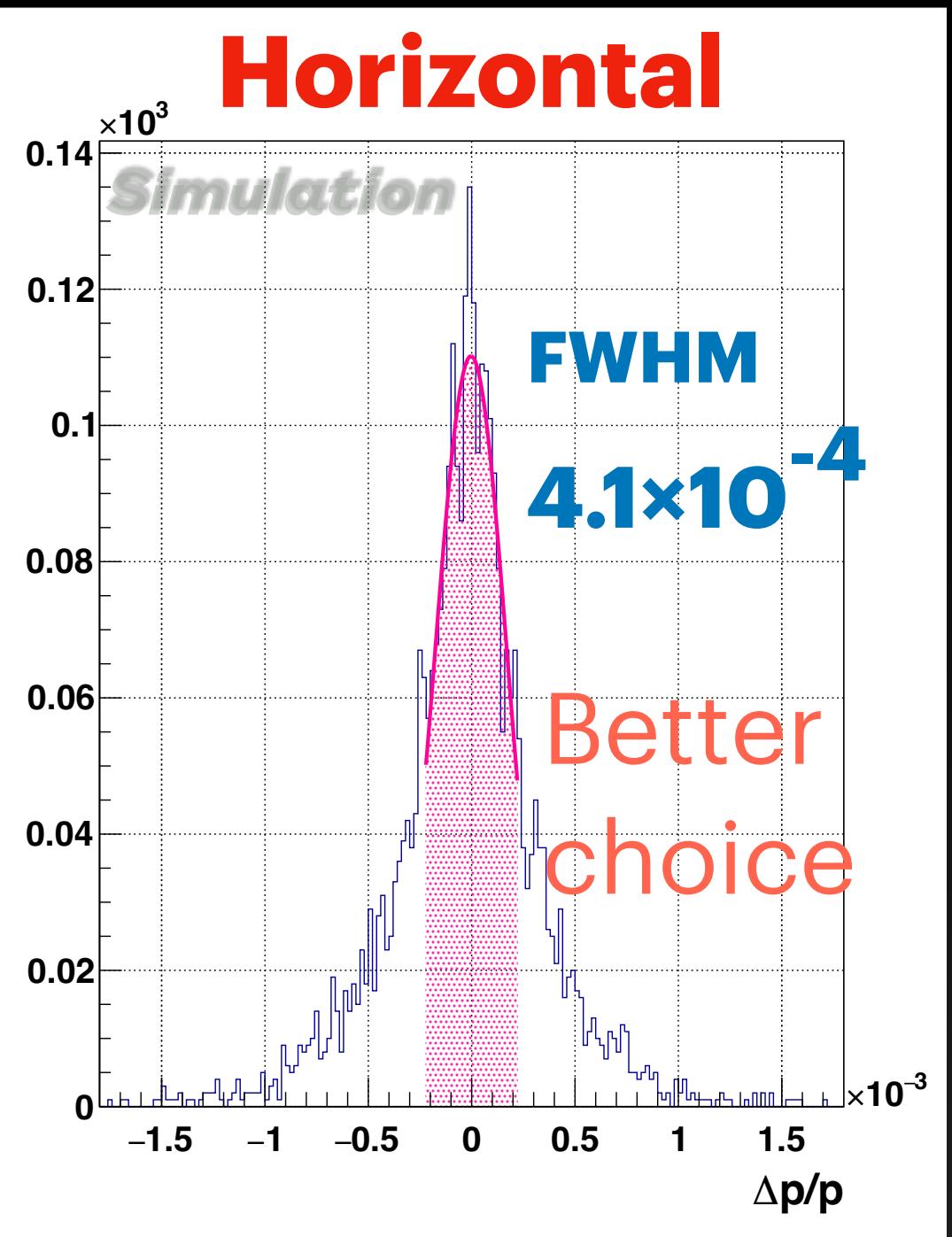
Horizontal-bending HES is still be better choice but vertical-bending HES can be adapted due to suppressing decreasing under 10%



# Momentum Resolution of HES

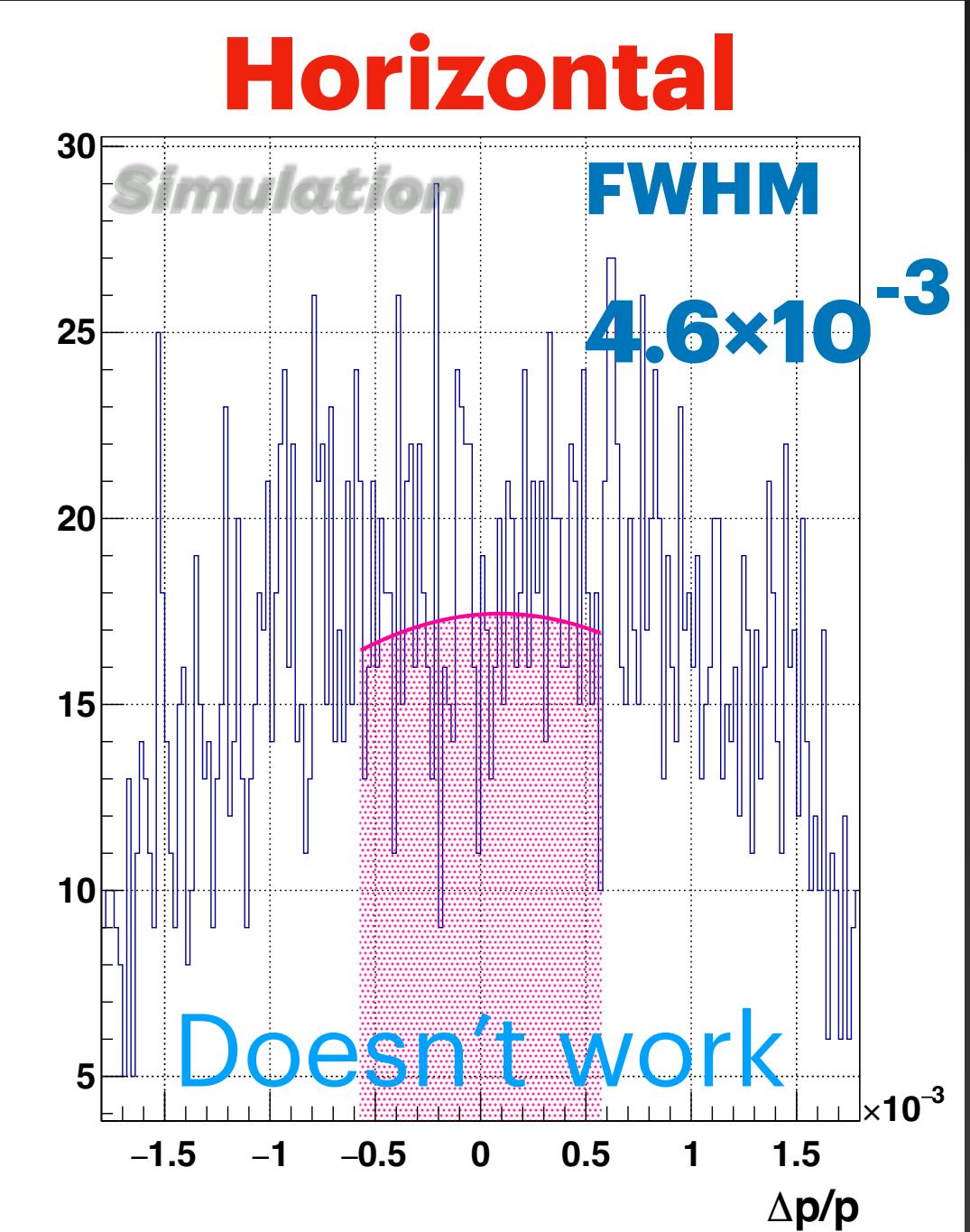
## Solid target

Vertical-bending HES should not be chosen due to 15% worse resolution

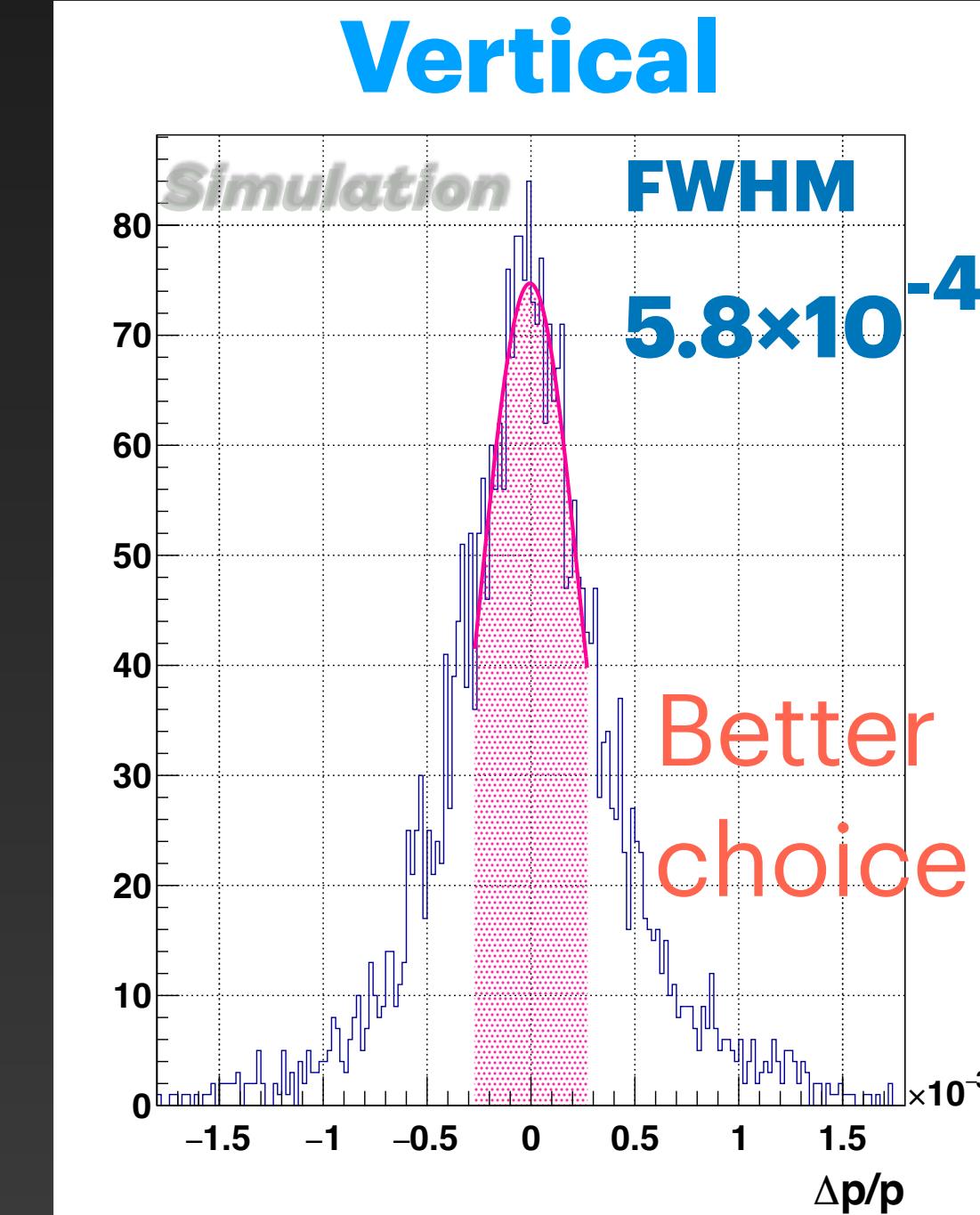


## Gas target

Vertical-bending is the better choice due to reviving its performance

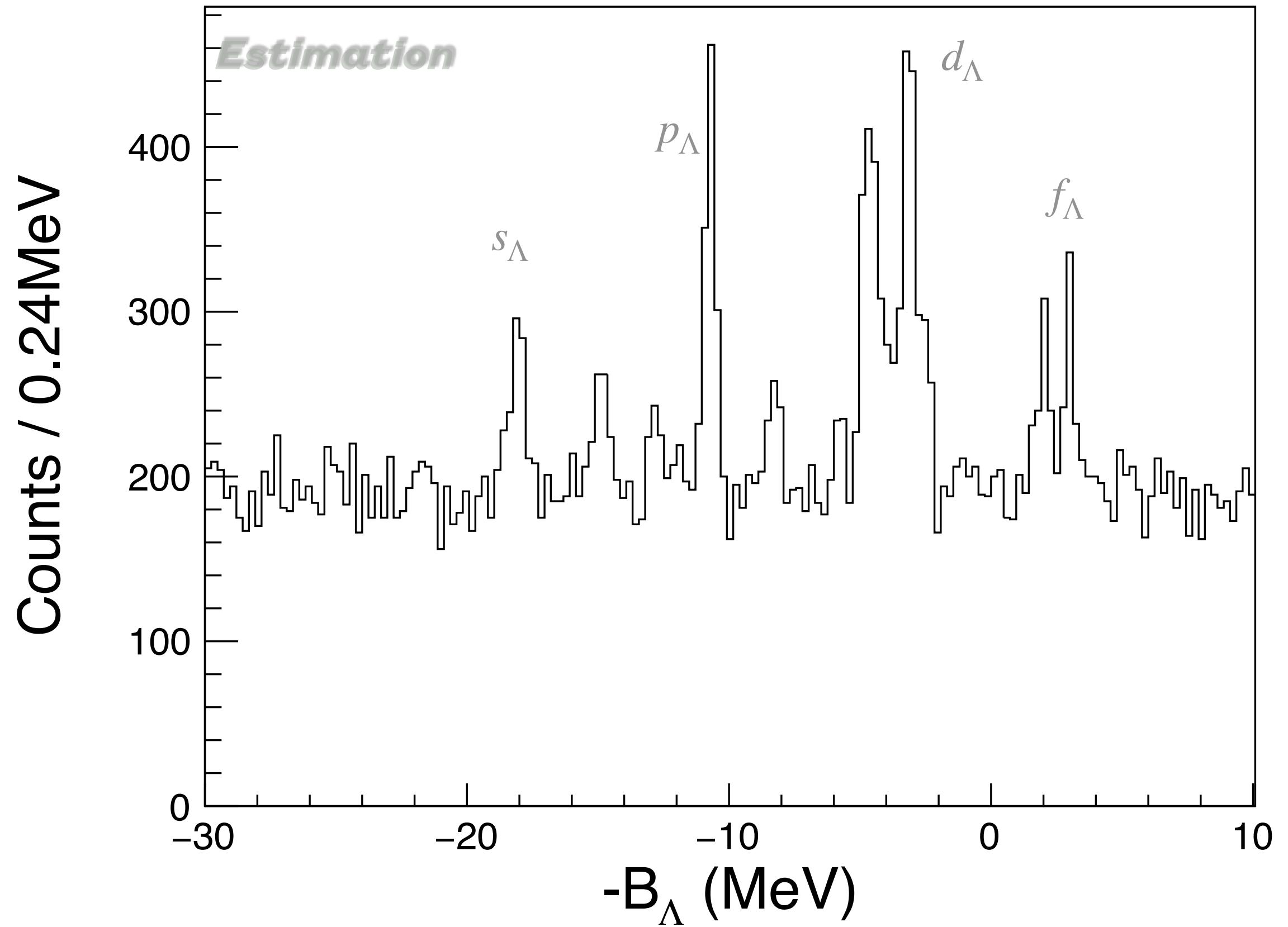


Reviving its performance!



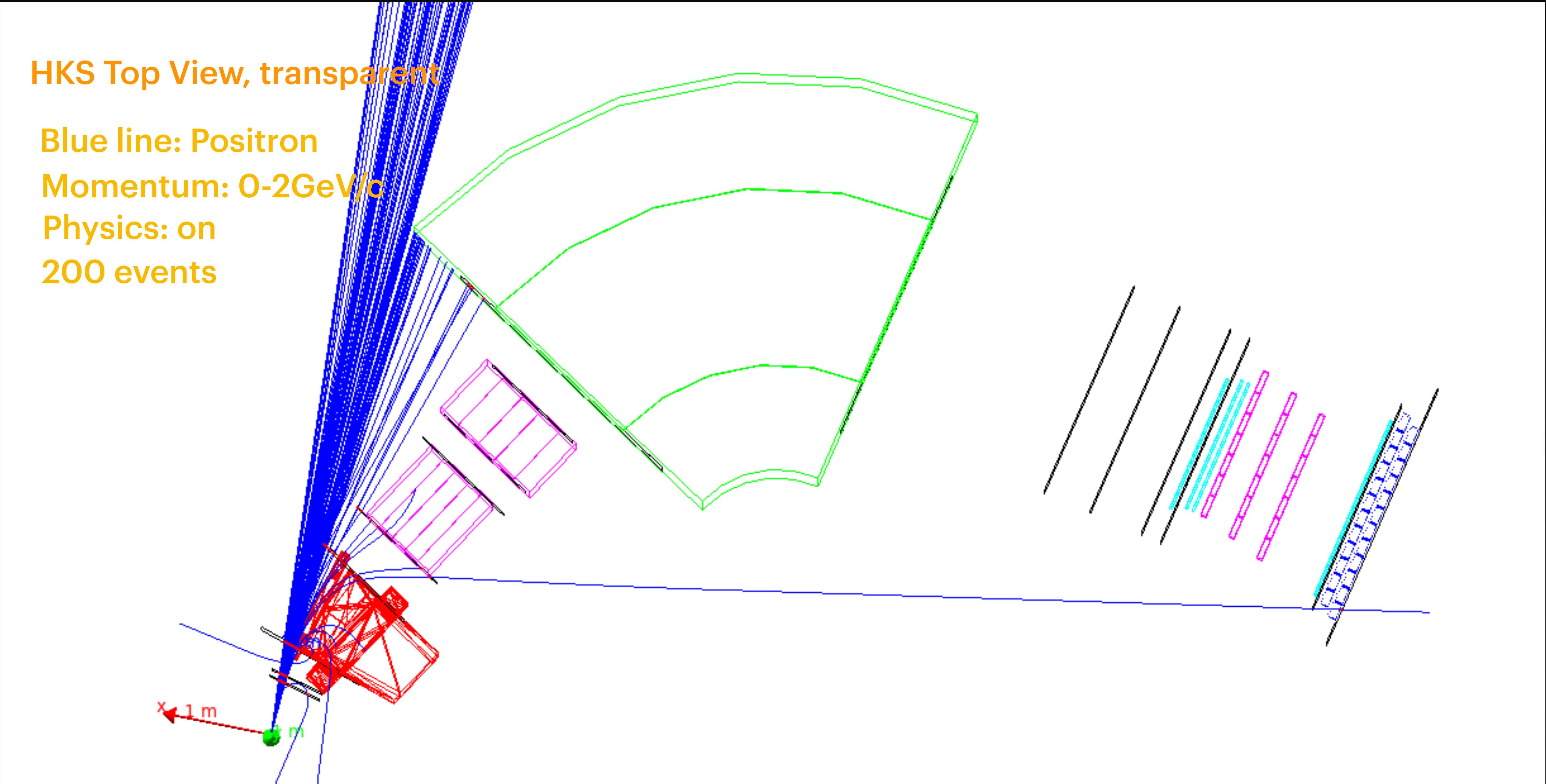
# Another MM spectrum ( $^{40}\Lambda$ )

Ca40 target, 50uA, 100mg/cm<sup>2</sup>, 460h(19.1days)



- My calculation is supposed to be realistic amount of BG, and Yield 1-1.5 times larger
- We can see the peaks of each orbit
- Peak significance is ~5.5

# Positron, 0-4deg



# Hit distribution and number at each magnet

