Study of Halo $K_L \to 2\gamma$ Background in the KOTO experiment

Yuya Noichi

Year End Presentation 2019

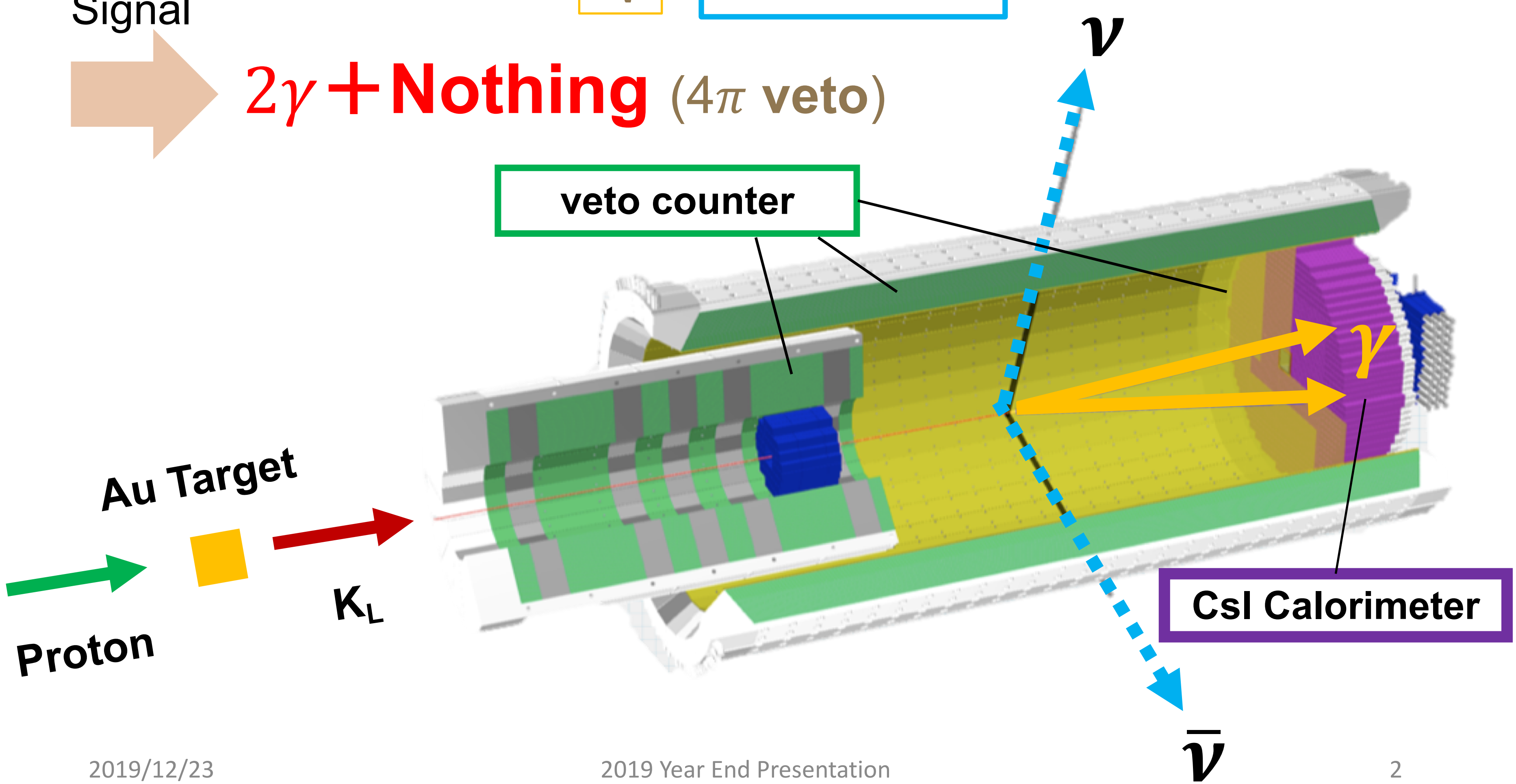
KOTO Experiment

- Search for $K_L \rightarrow \pi^0 \nu\bar{\nu}$ decay

2γ undetectable

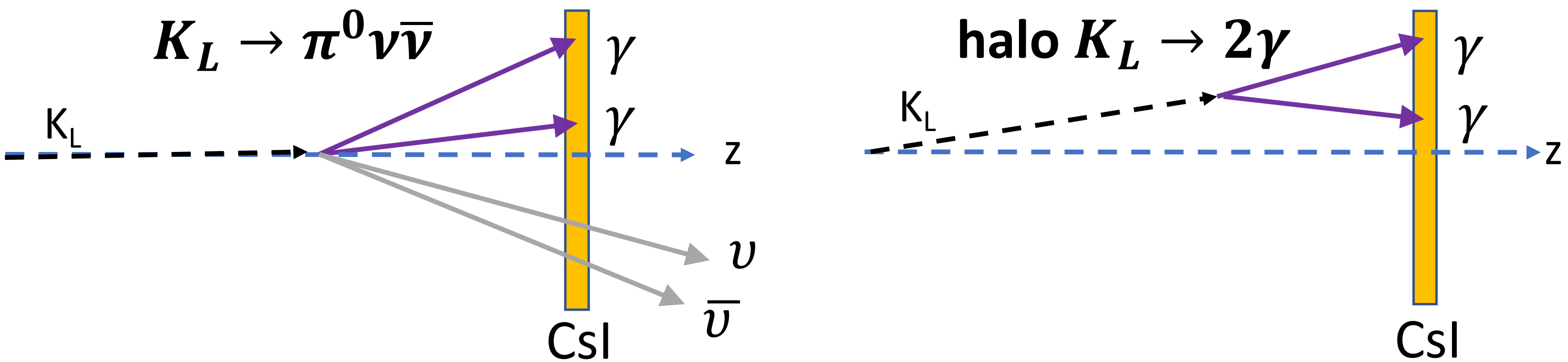
Signal

2γ + **Nothing** (4π veto)



Halo $K_L \rightarrow 2\gamma$ Background

- If beam halo K_L decay for 2γ, it may be confused with $K_L \rightarrow \pi^0 \nu\bar{\nu}$ signal.



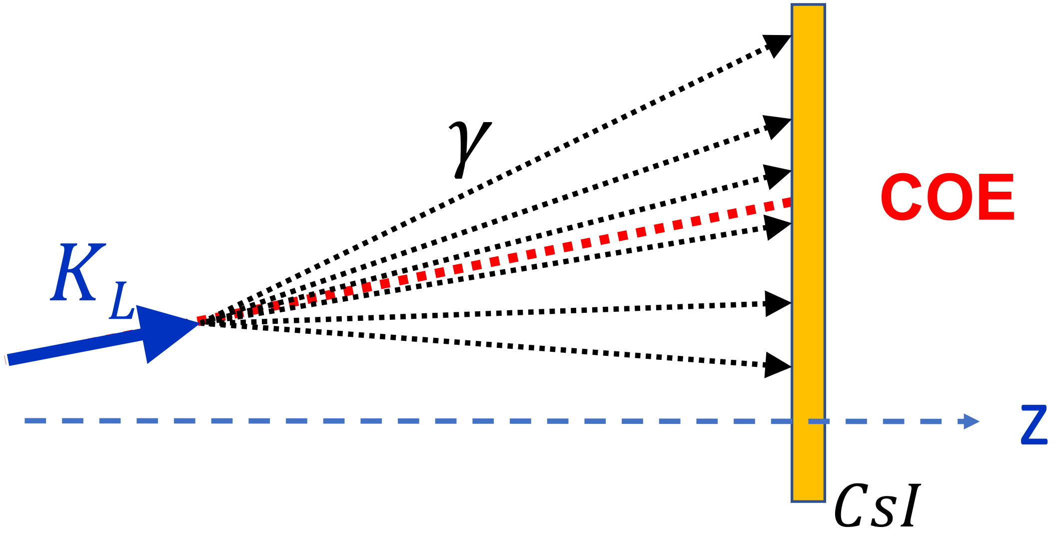
- P_T of Halo K_L must be measured correctly because it may cause Halo $K_L \rightarrow 2\gamma$ background.

COE(Center of Energy)

- COE can be calculated from CsI information; Hit position and energy of each gamma.

$$Xcoe = \frac{\sum (HitX_i \, E_i)}{\sum E_i} \qquad Ycoe = \frac{\sum (HitY_i \, E_i)}{\sum E_i}$$

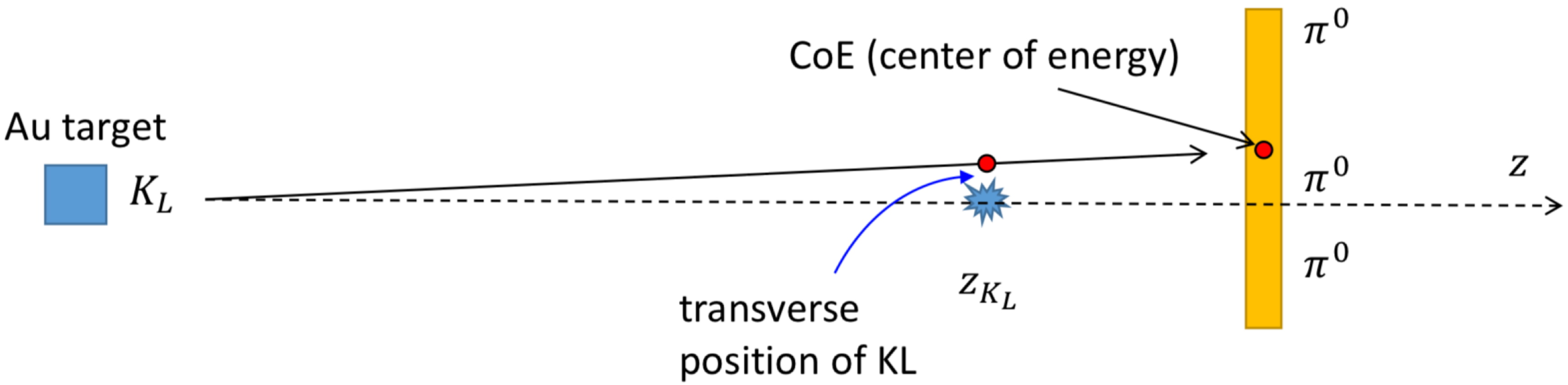
- This can be indicator of halo K_L because COE represents the arrival point of K_L for the case angle between P_T and P_Z is small.



Motivation

- Conventional reconstruction method assumes mass of each 2gamma is m_{π_0} and vertex position is on z axis.

- Transverse position of K_L was determined by the interpolation between target and COE.



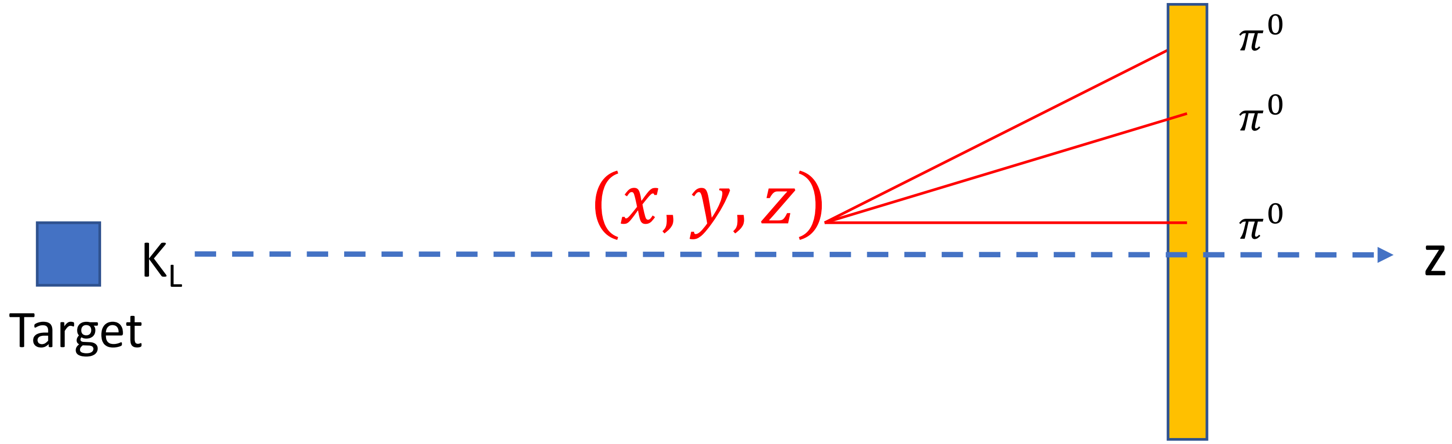
- However, assumption that K_L fly from target to COE may not be correct because K_L can scatter at the downstream of target.

We want to develop new method without using this assumption.

New Method

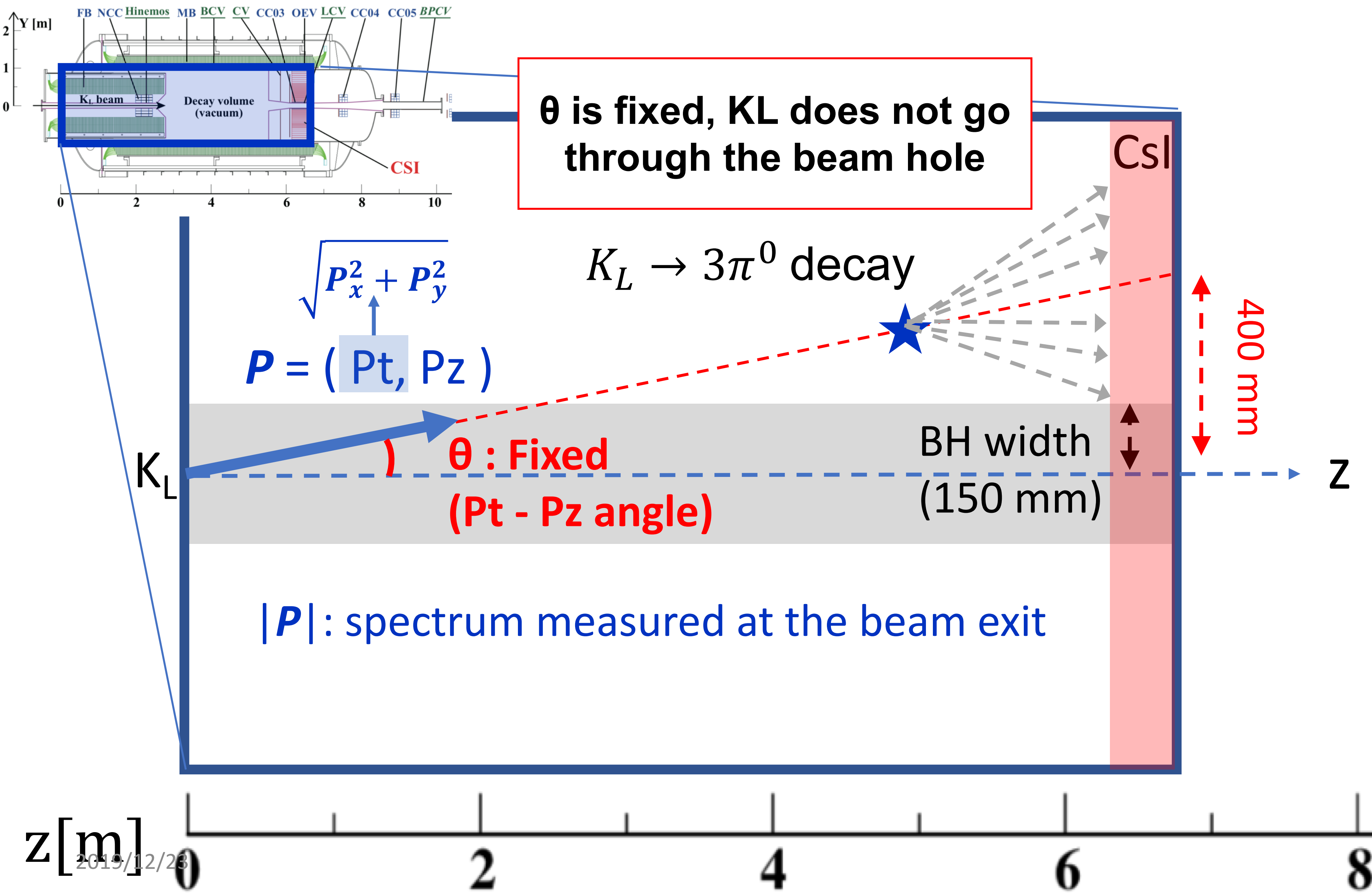
Decay position of K_L may be determined by minimizing χ^2 of following formula.

$$\chi^2(x,y,z) = \left(\frac{p_1^2(x,y,z) - {m_{\pi^0}}^2}{\sigma_1}\right)^2 + \left(\frac{p_2^2(x,y,z) - {m_{\pi^0}}^2}{\sigma_2}\right)^2 + \left(\frac{p_3^2(x,y,z) - {m_{\pi^0}}^2}{\sigma_3}\right)^2$$



I checked the precision of this new method by using toy simulation.

$K_L \to 3\pi^0$ Toy Simulation



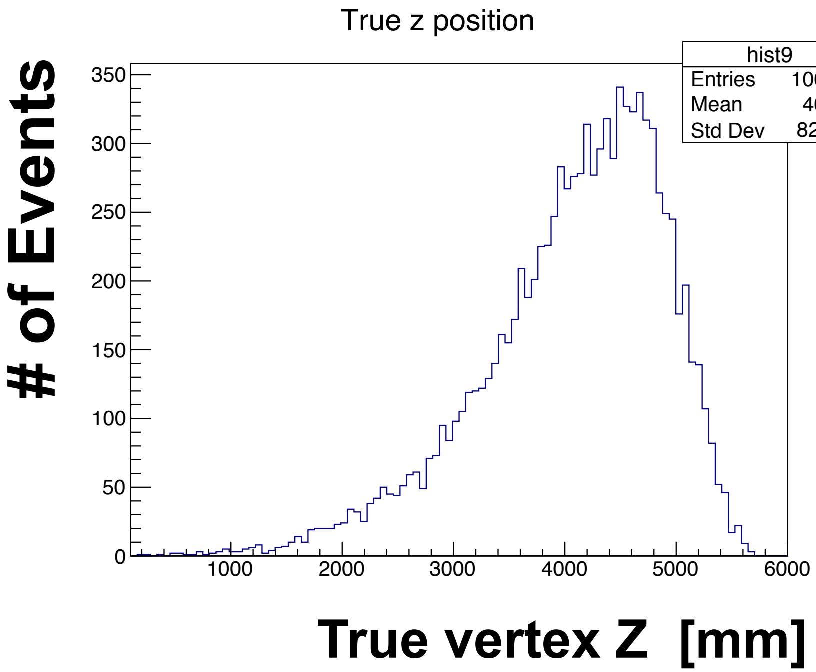
2019/12/23

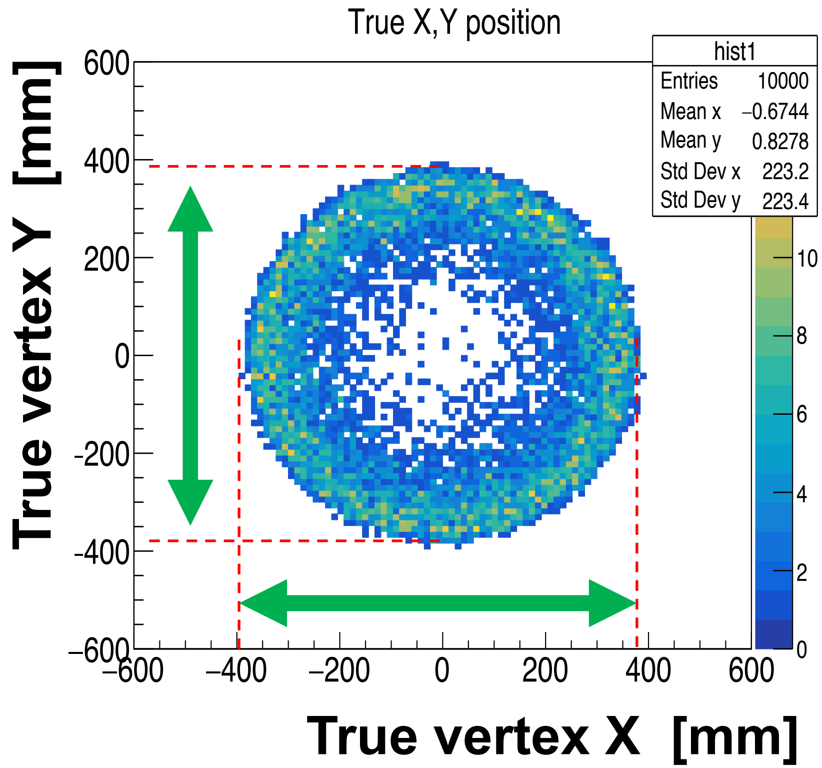
Event Selection Criteria

- 6 gamma positions are all inside the fiducial region of the CsI
- Minimum gamma energy > 150 MeV
- Minimum 2 gamma distance > 150 mm
- 0 < Decay z < CsI (6168 mm)

➡ Using this toy simulation, I checked whether this new method can reconstruct the decay position.

True information of Toy Simulation

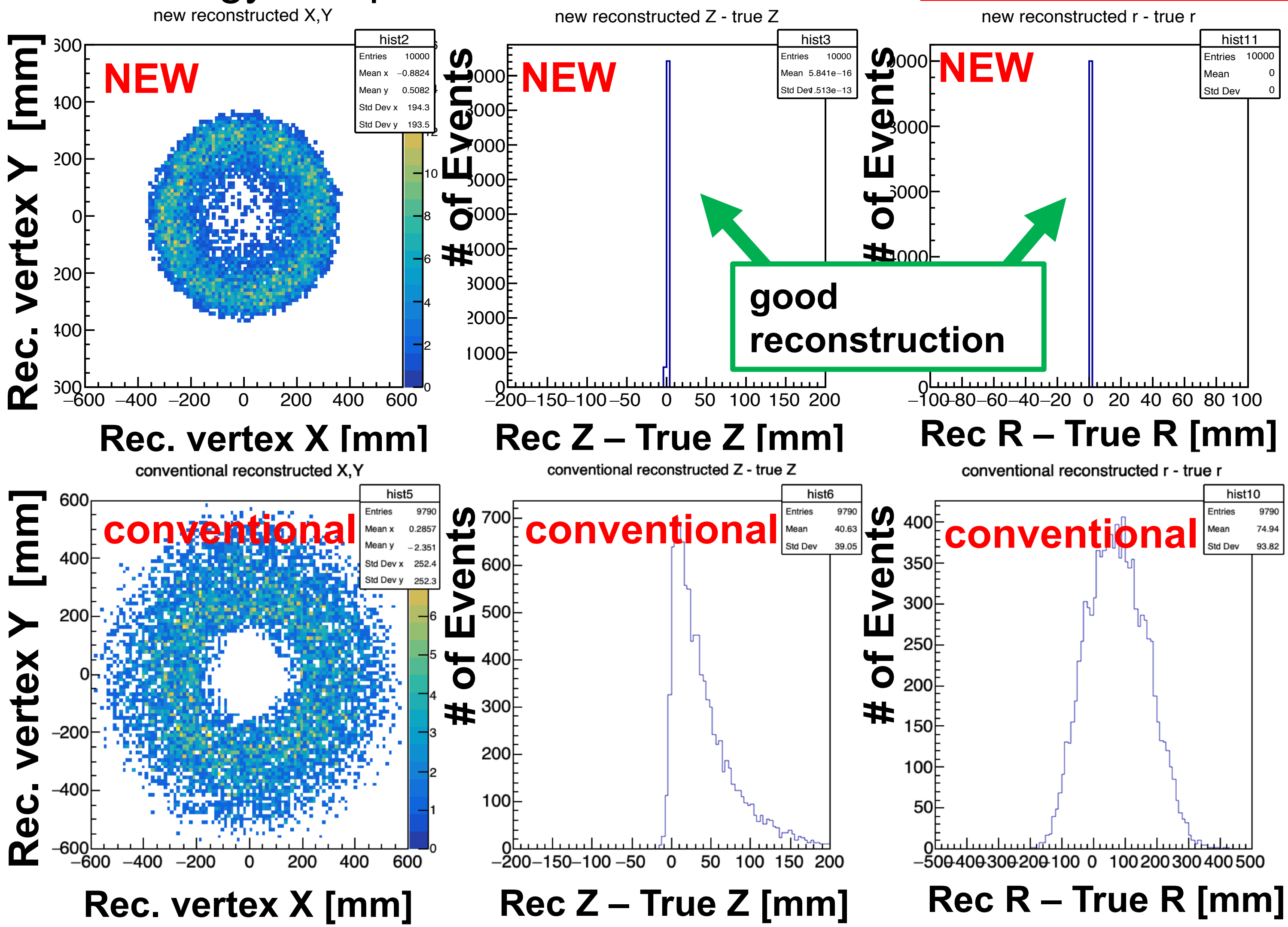




➡ We want to reconstruct these vertex positions

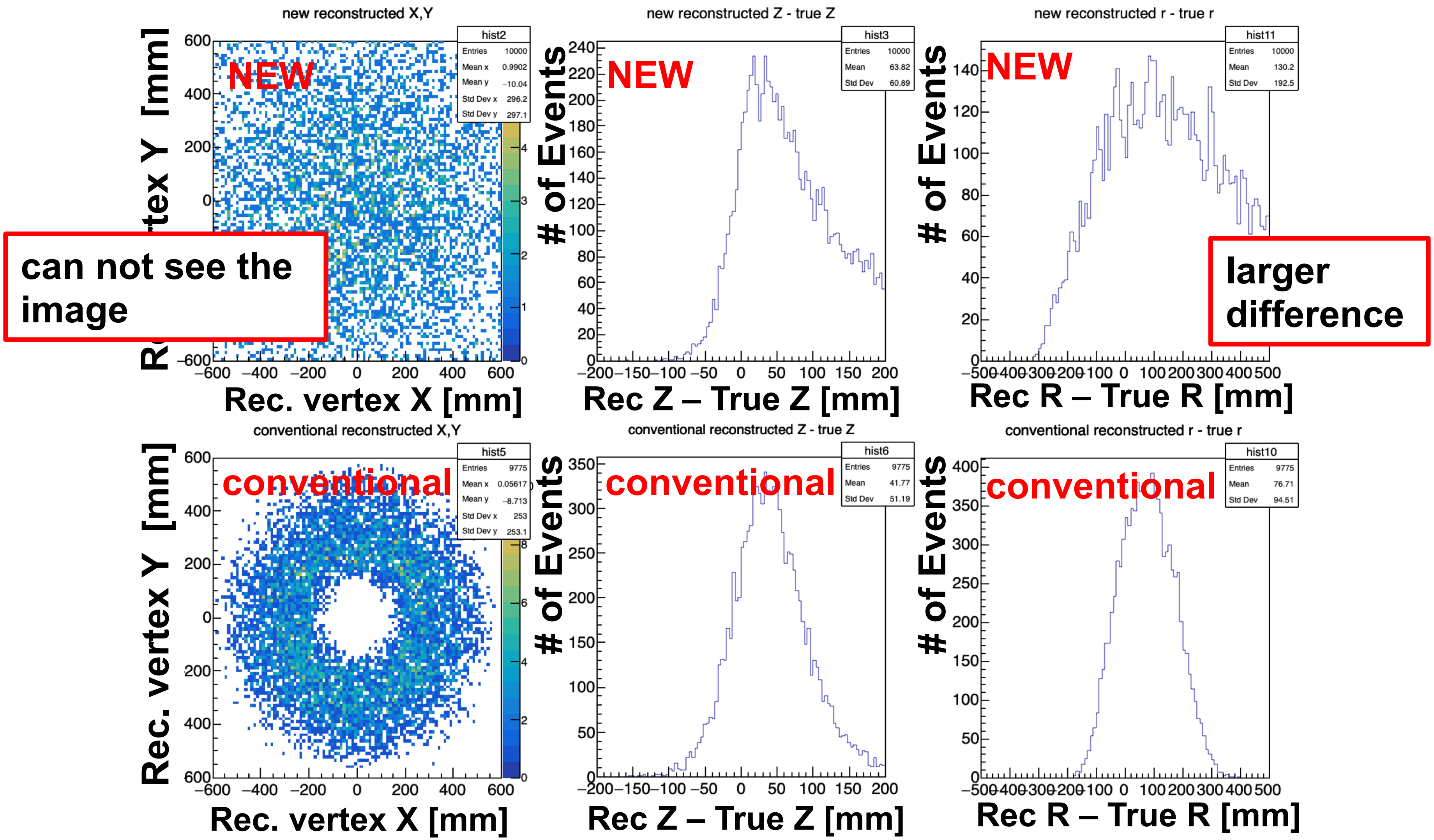
Reconstructed Vertex position(1)

- Energy and position resolution of CsI... neither considered



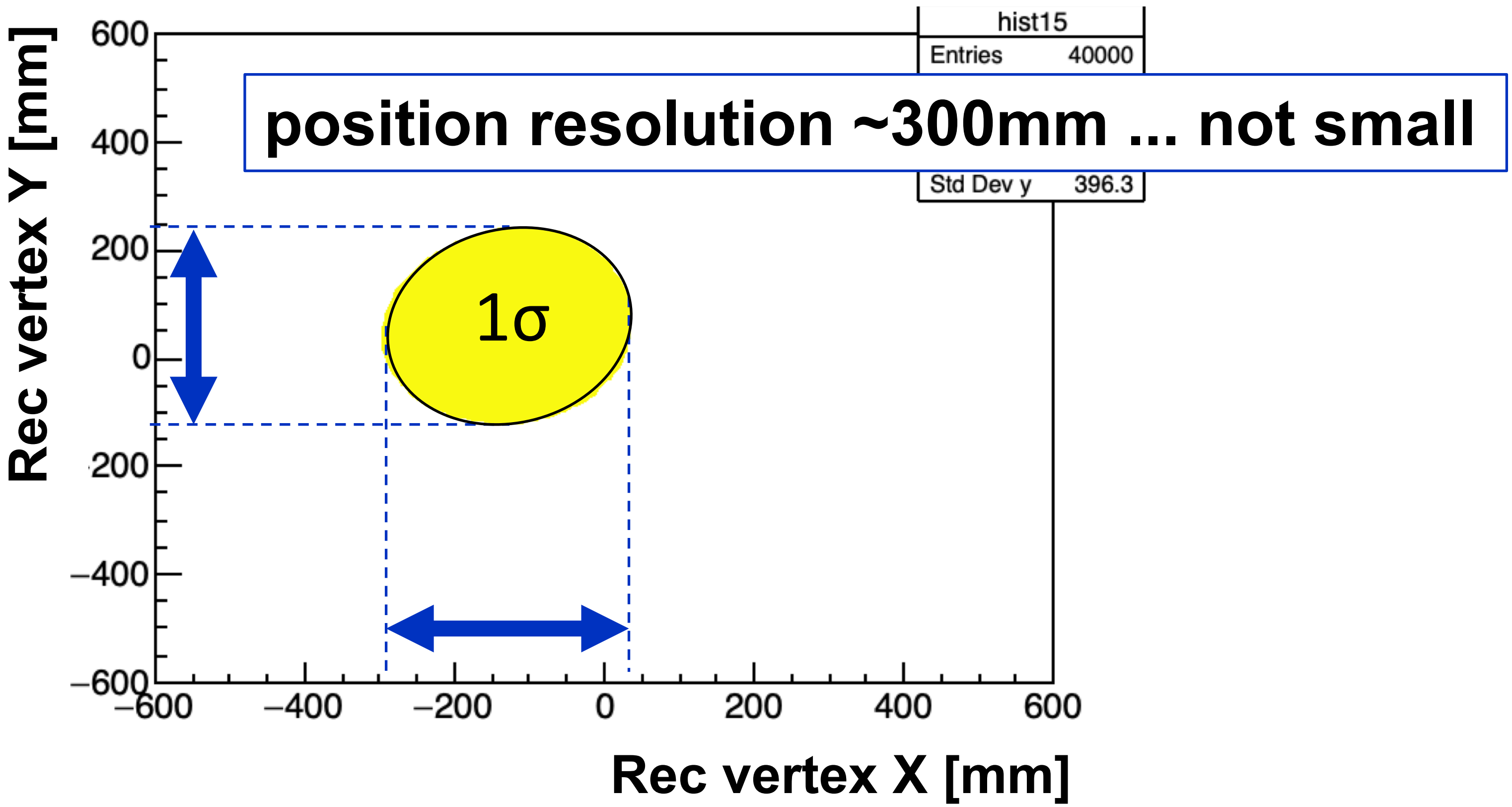
Comparison of new and conventional

- Energy and position resolution of CsI... <u>both considered</u>



Chi2 distribution

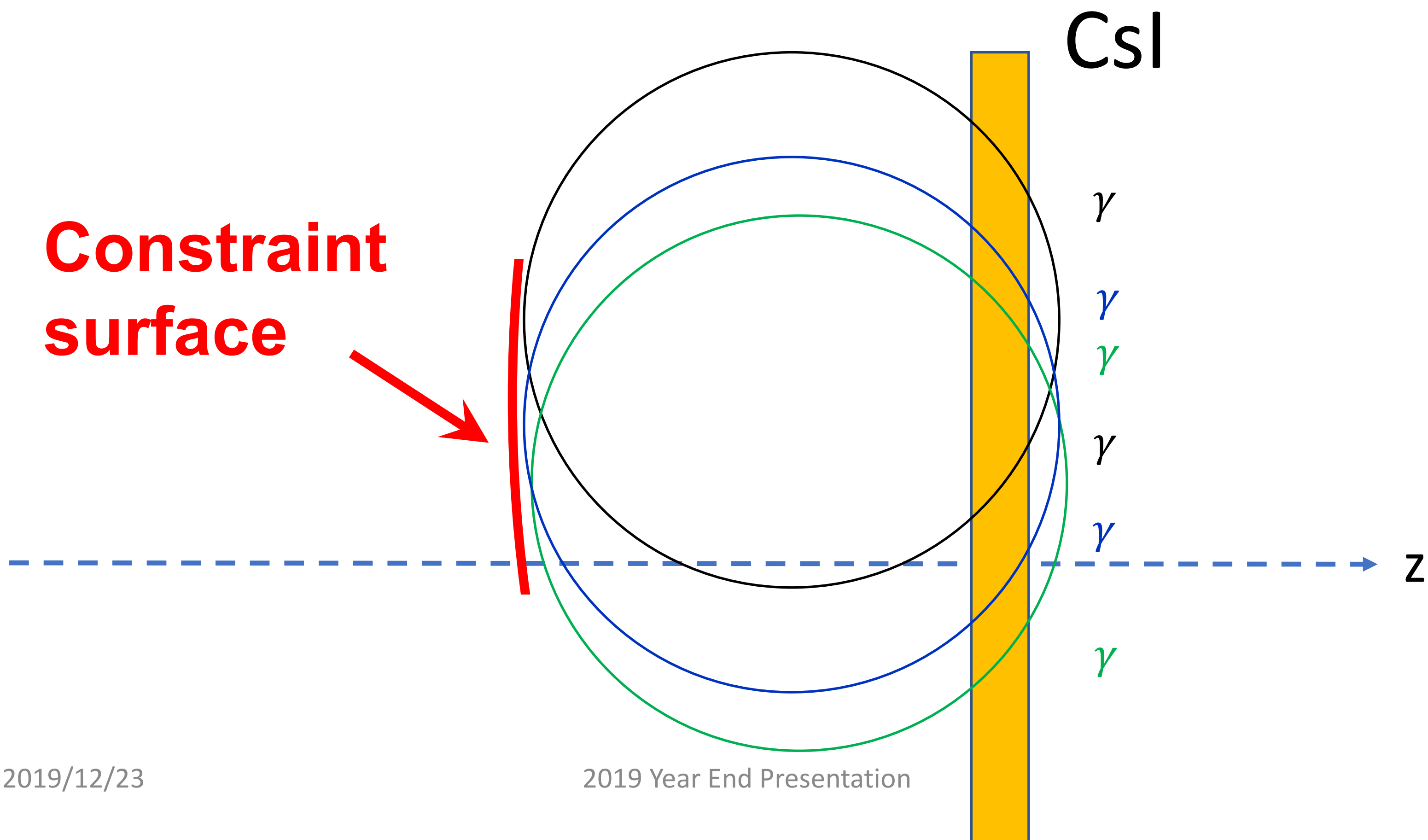
1 sigma(ΔChi2 = 2.3) contour (for example 1 event)



- The failure of reconstruction using new method is due to this bad position resolution.

Reason for bad resolution

- Constraint from 6 gamma looks like sphere, and sum of them become too shallow to minimize.



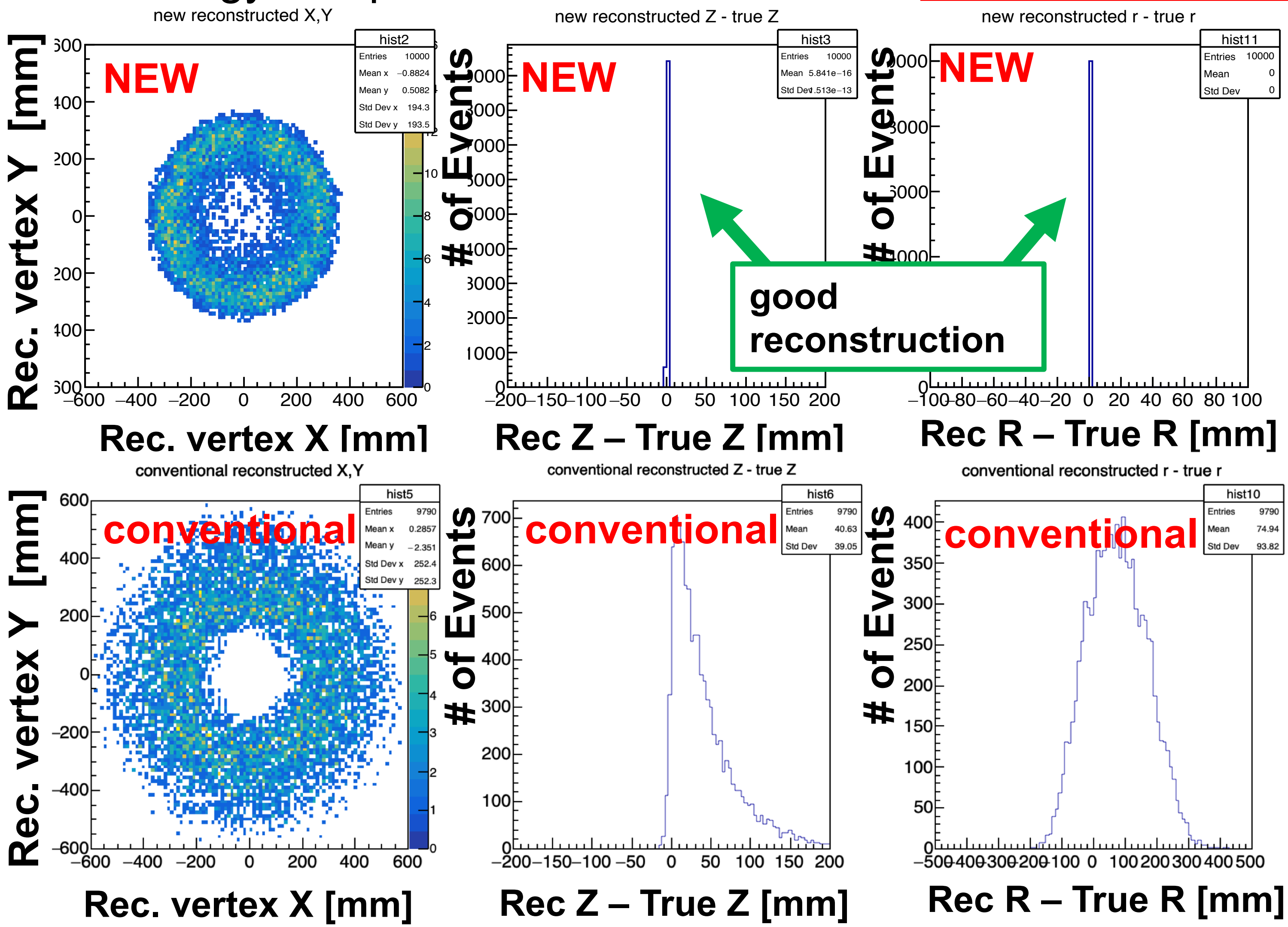
Summary and Next

- Halo K_L cause $K_L \rightarrow 2\gamma$ background, so we need to measure halo K_L correctly.
- I tried to develop new reconstruction method minimizing chi2 function of reconstructed mass of π^0 .
- Position resolution of new method was not enough to reconstruct vertex position correctly.
- To know whether we need to develop more reconstruction method, I'm checking discrepancy of COE between data and MC.

Backup

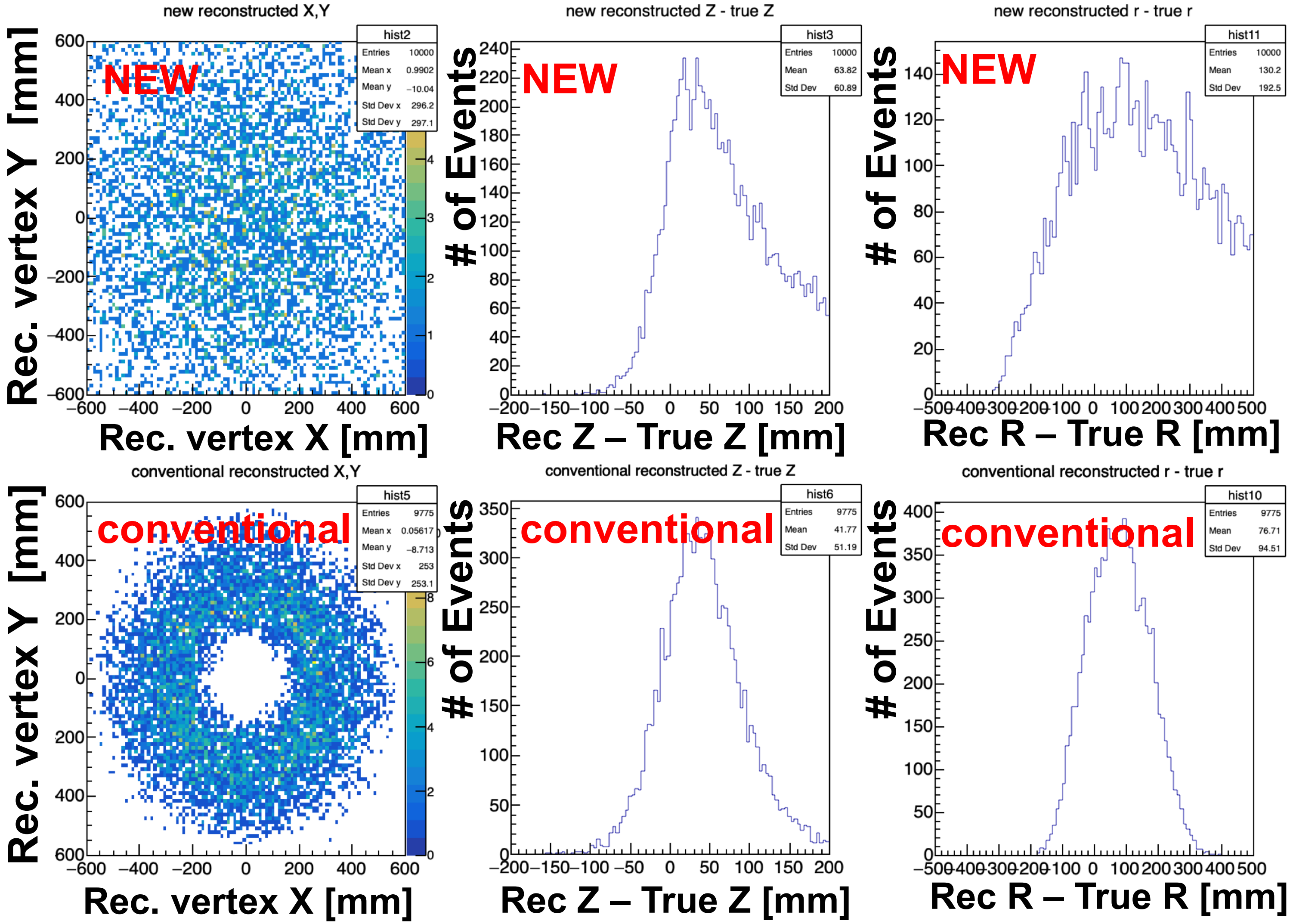
Reconstructed Vertex position(1)

- Energy and position resolution of CsI... neither considered



Reconstructed Vertex position(2)

- Energy and position resolution of CsI... both considered

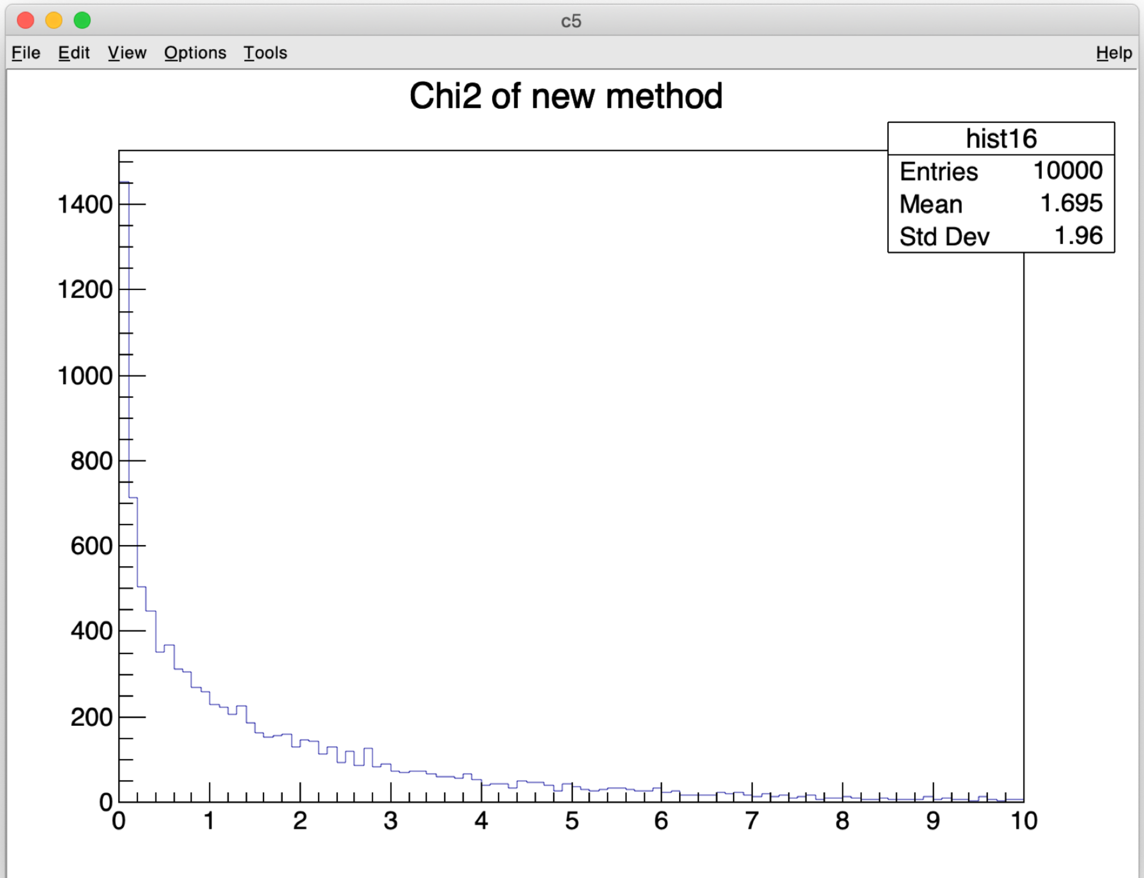


Sigma of M^2

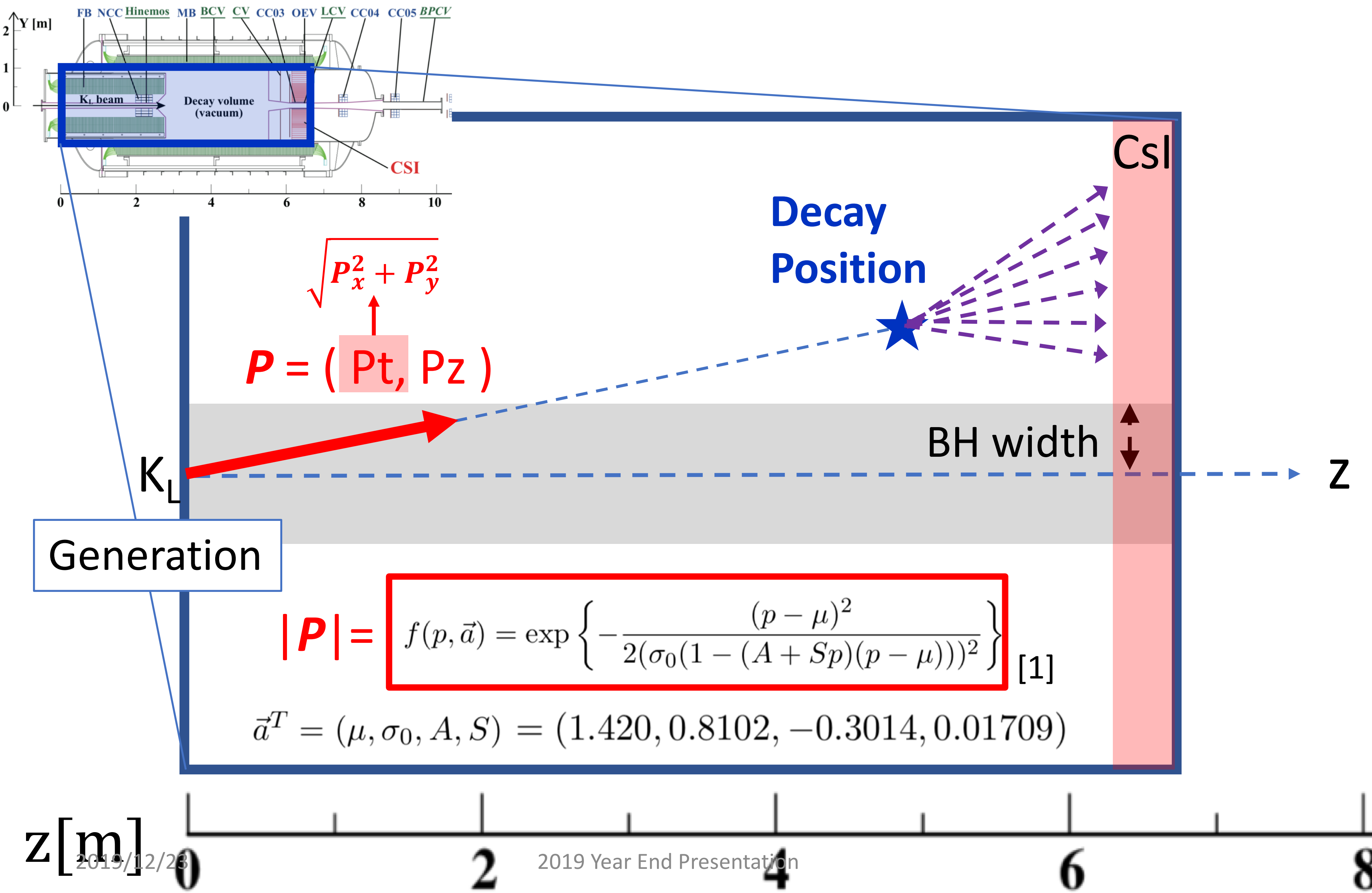
$$\sigma_{M2} = \left(\frac{\partial M^2(E_1,x_1,y_1,E_2,x_2,y_2)}{\partial E_1}\right)\sigma_{E_1} + \left(\frac{\partial M^2(E_1,x_1,y_1,E_2,x_2,y_2)}{\partial x_1}\right)\sigma_{x_1} + \ldots + \left(\frac{\partial M^2(E_1,x_1,y_1,E_2,x_2,y_2)}{\partial y_2}\right)\sigma_{y_2}$$

$$\frac{\partial M^2(E_1,x_1,y_1,E_2,x_2,y_2)}{\partial E_1} = \frac{M^2(E_1+\epsilon\ ,x_1,y_1,E_2,x_2,y_2) - M^2(E_1\ ,x_1,y_1,E_2,x_2,y_2)}{\epsilon}$$

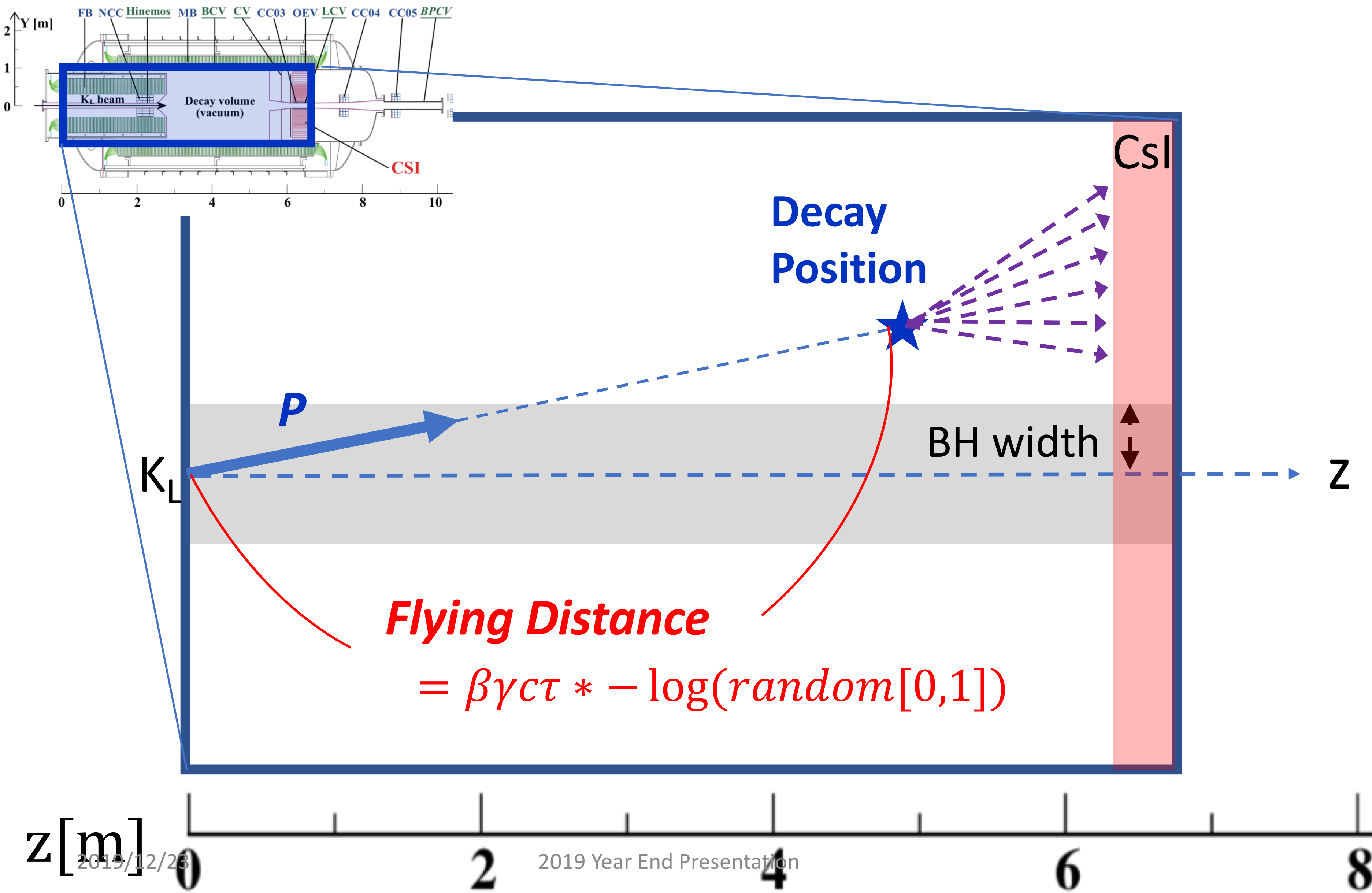
Chi2 distribution



KL Generation in Toy Simulation(2)



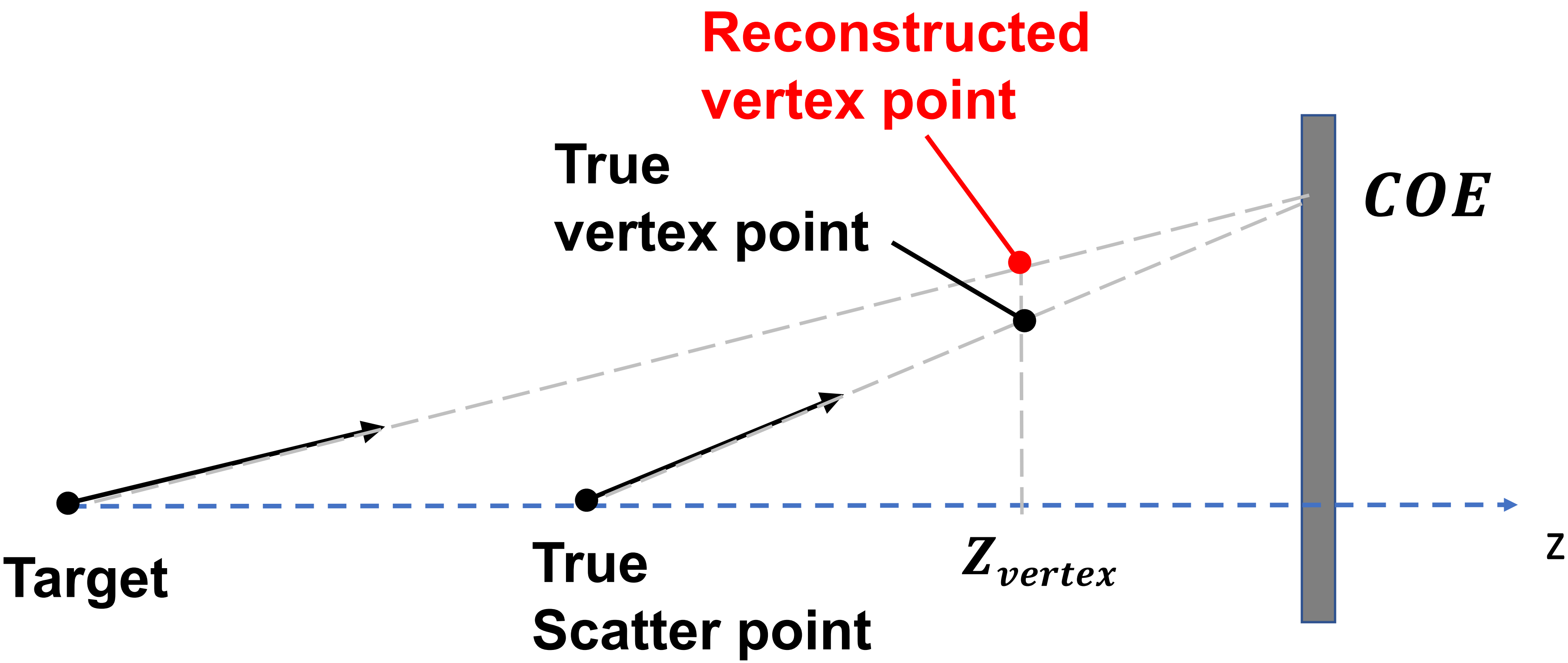
KL Generation in Toy Simulation(3)



MINUIT Detail

- used “MIGRAD” minimizer (also checked HESSE,MINOS)
- used some limits in order to prevent the parameter from taking on unphysical values
  e.g.) 0 < z < CsI, -1000< x,y <1000
- fitting step width of (x,y,z)... (10,10,100)
- max call ... 1000 times (500~ not chenged)

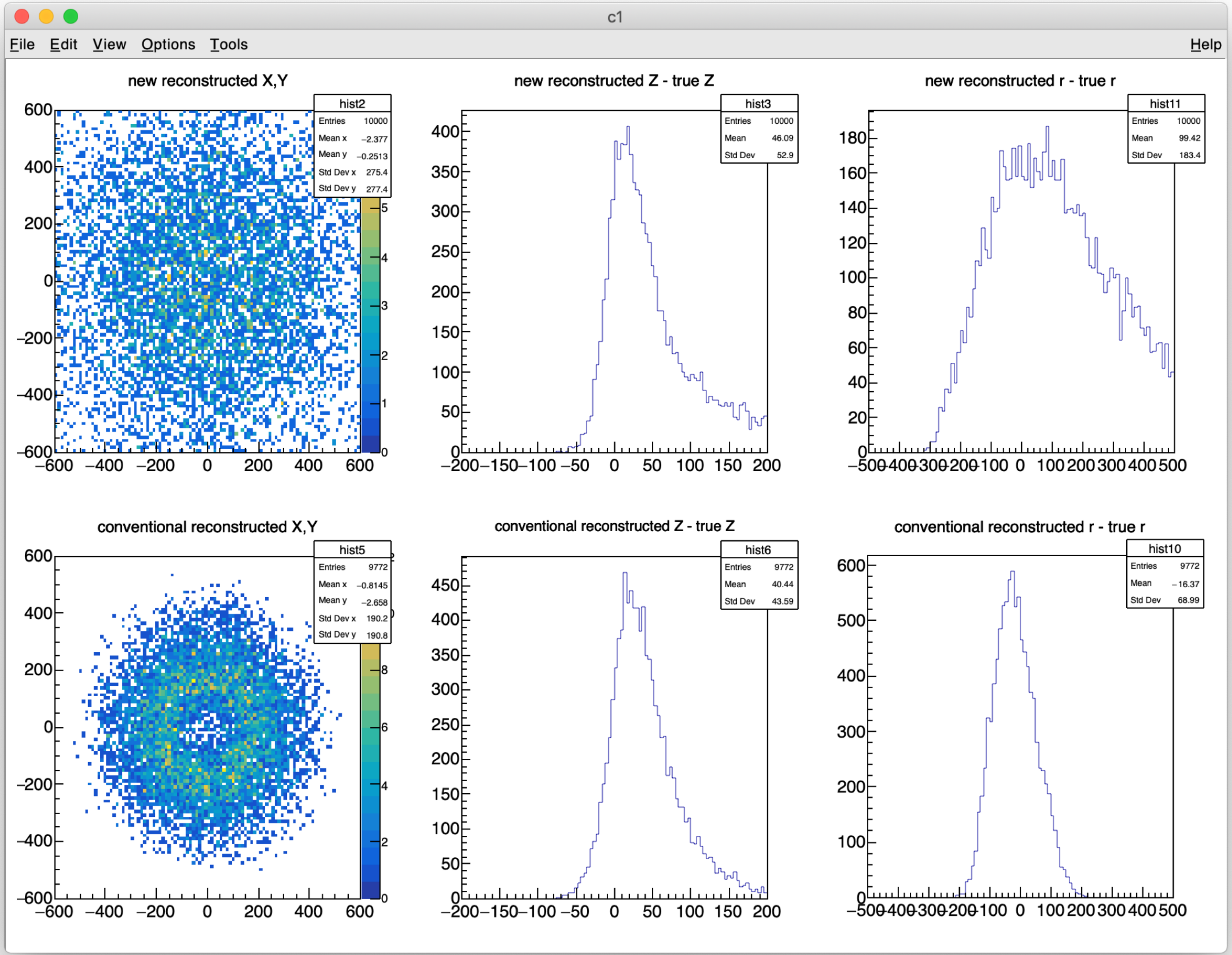
Problem of Conventional Reconstruction Method



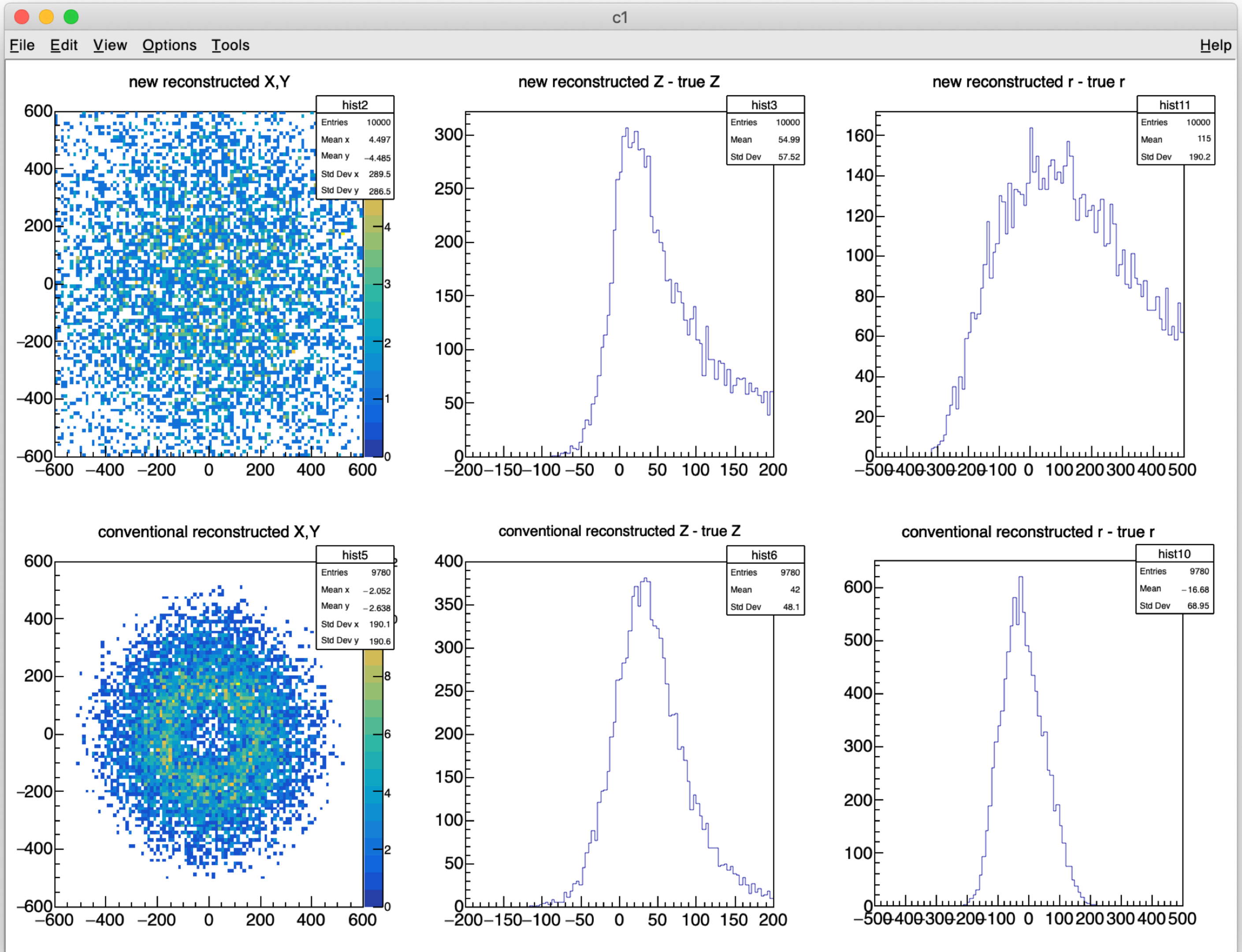
Resolution of CsI

```
// See https://journals.jps.jp/doi/pdf/10.7566/JPSCP.8.024007
double GetEres(double Edep){
        double e = Edep/1000; // in GeV
        double sigE_E = sqrt(0.99*0.99+1.74*1.74/e)/100.0;
        return Edep*sigE_E;
};
double GetPosres(double Edep){
        double e = Edep/1000; // in GeV
        double sigpos = sqrt(2.5*2.5+4.4*4.4/e); // in mm
        return sigpos;
}
```

Only Position Resolution of CsI



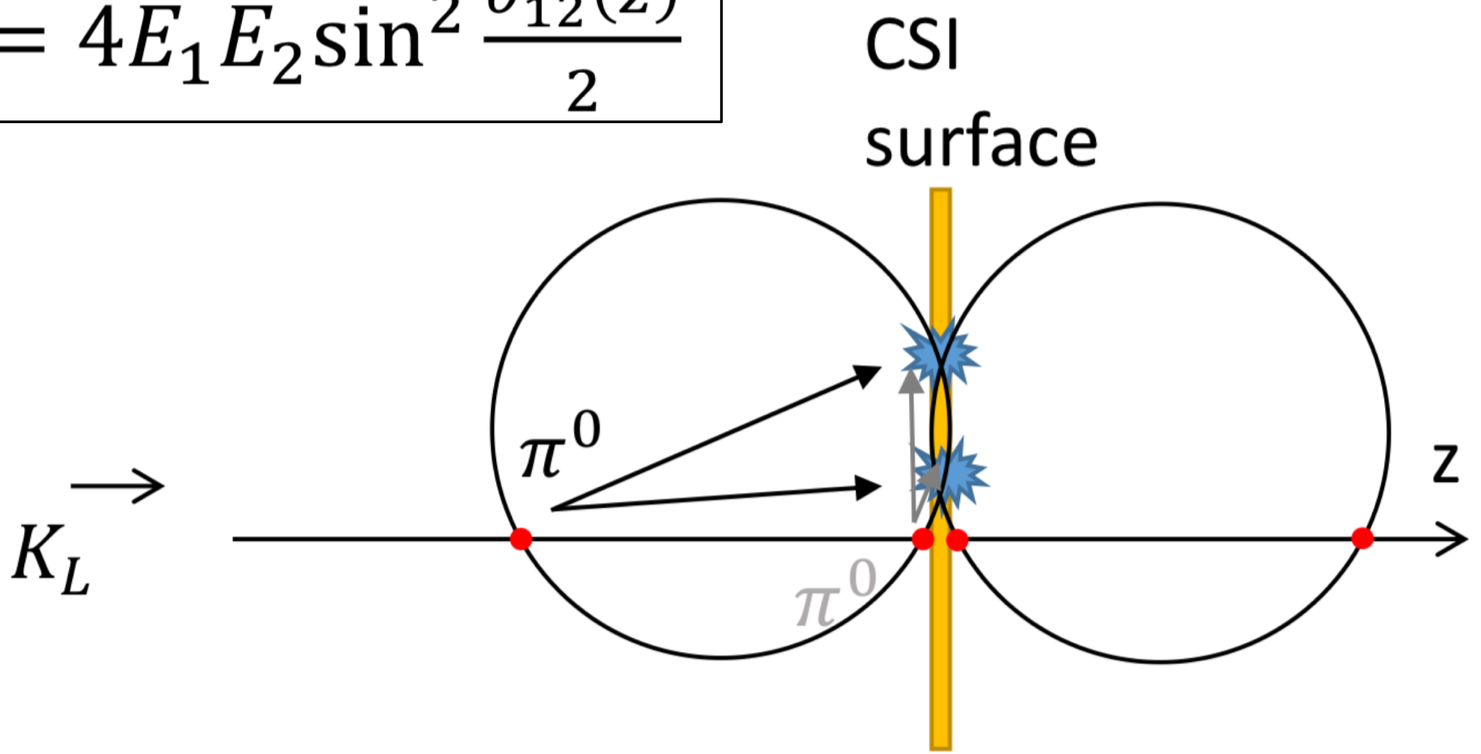
Only Energy Resolution of CsI



Conventional method

First, we reconstruct a $\pi 0$ assuming mass of $\gamma\gamma$ is $m_{\pi 0}$ and vertex position is on z axis.

$$m_{\pi^0}^2 = 4E_1E_2\sin^2\frac{\theta_{12}(z)}{2}$$



(from shimizu-san's slide)