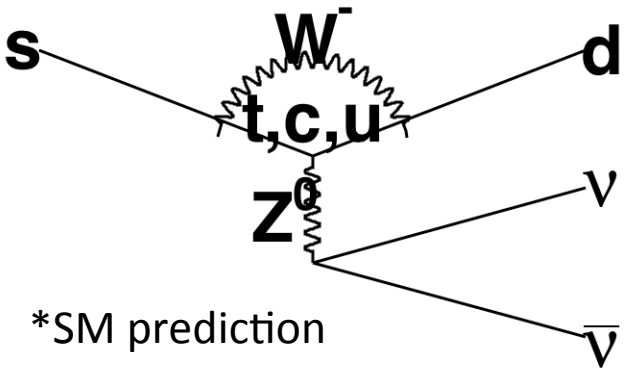
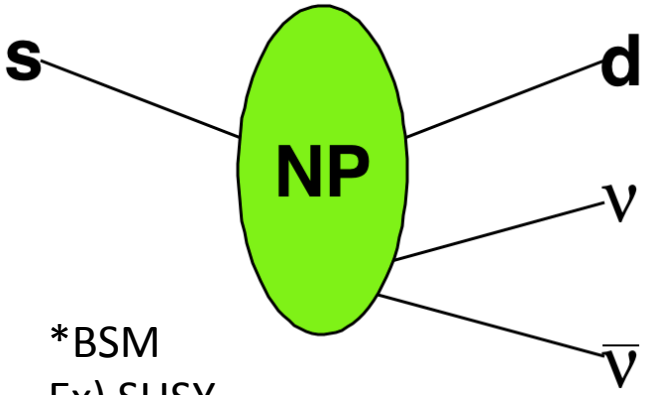
Performance of New Sampling Calorimeter Detector in E14 experiment with $K_L \to 3\pi^0$

$K_L \to \pi^0 \nu\bar{\nu}$ decay

- FCNC process in Standard model
- $Br(K_L \to \pi^0 \nu\bar{\nu}) = (2.8 \pm 0.4) \times 10^{-11}$ predicted by SM
- Clean mode to explore New Physics



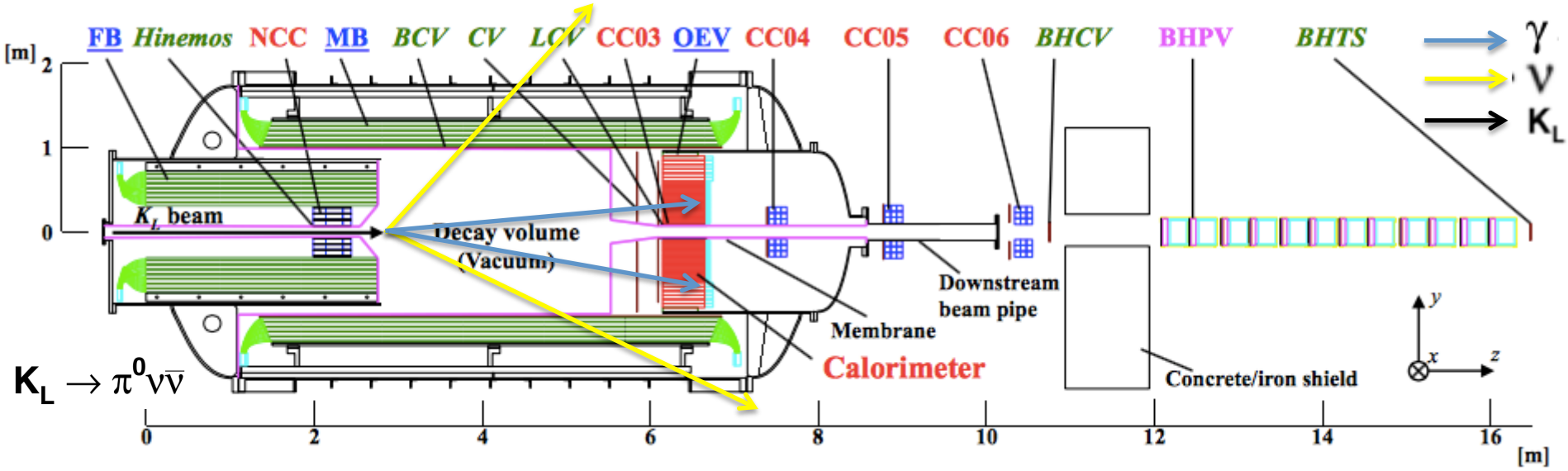
*SM prediction



*BSM
Ex) SUSY

KOTO experiment

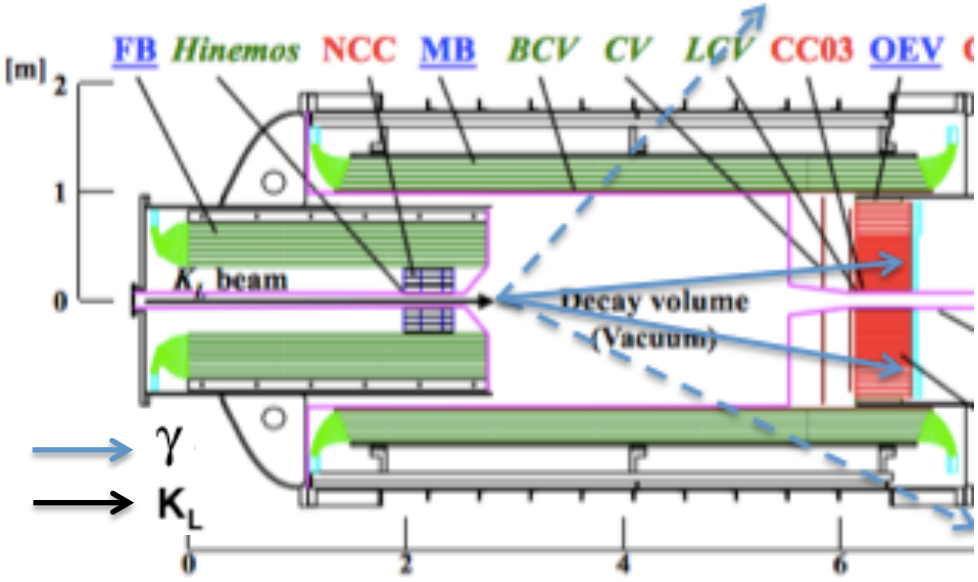
- KL beam line of Hadron Hall at J-PARC



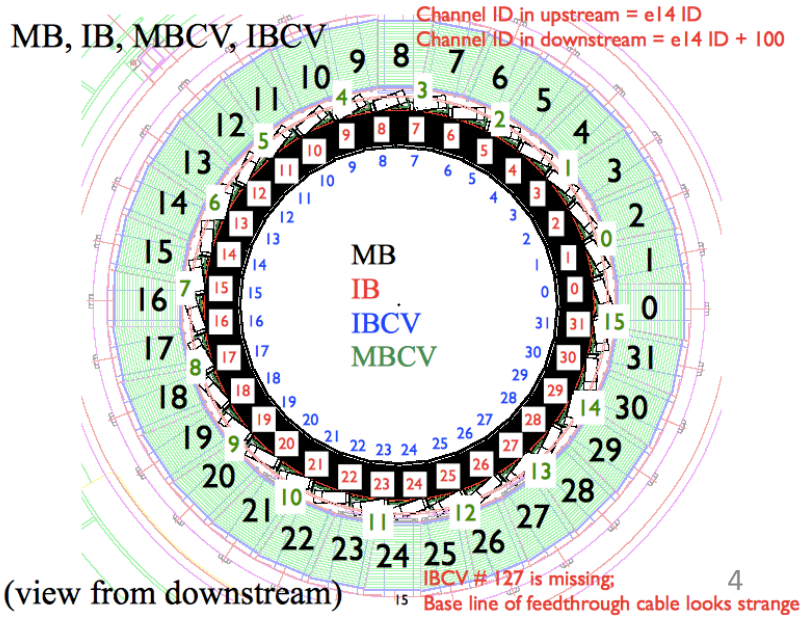
- $\mathbf{K_L \rightarrow \pi^0 \nu\bar{\nu}}$ decay leaves 2ϒ hit only.
- CsI Calorimeter detects 2ϒ
- Hermetic veto counters confirm no additional particles.

New Pb/Scint Calorimeter

- Better suppression of background events associated with $K_L \rightarrow 2\pi^0$ decay
- Better timing resolution to identify back-splash events

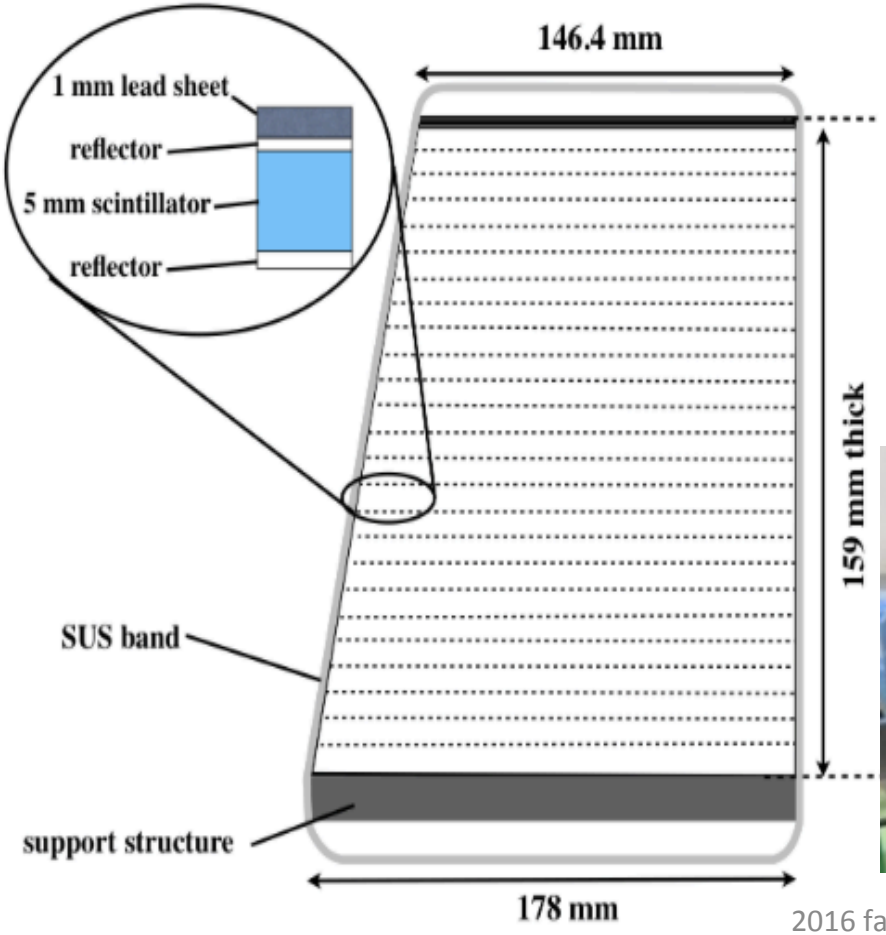


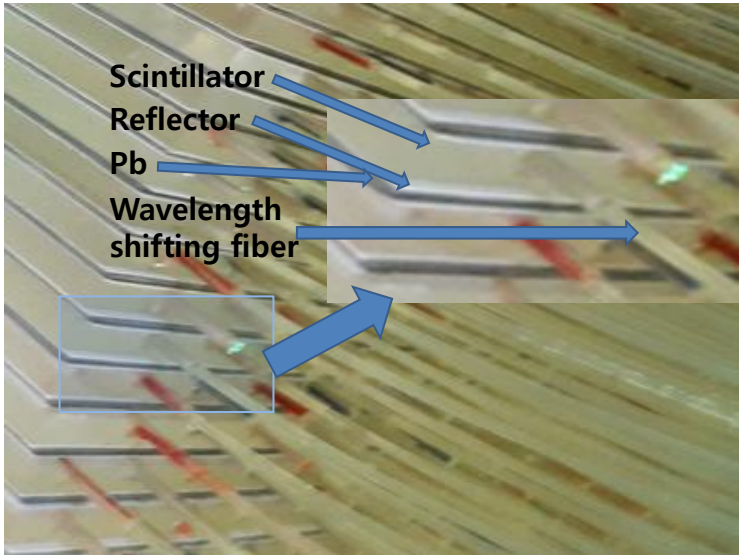
Not detected 2γ (inefficiency of barrel)

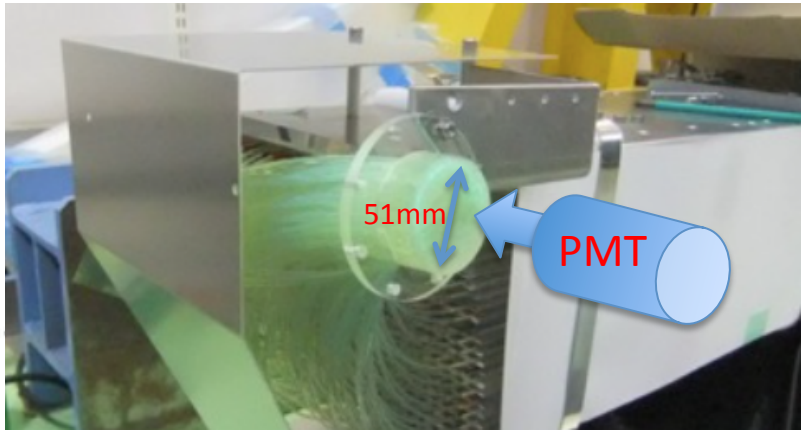


New Pb/Scint Calorimeter

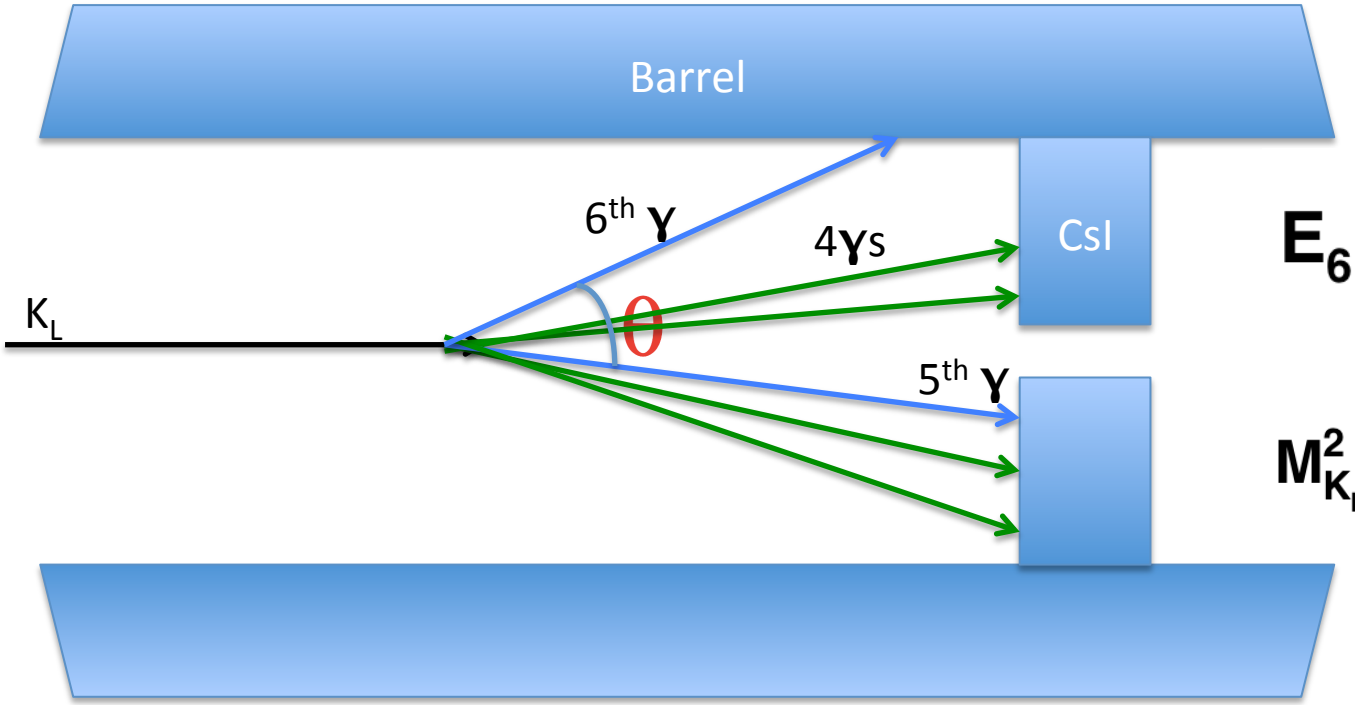
- 25 layers of 1-mm thick Pb sheet and 5-mm thick plastic scintillator







$K_L \to 3\pi^0$ Reconstruction



$$E_6 = \frac{M_\pi^2}{2E_5(1-\cos\theta)}$$

$$M_{K_L}^2 = \left(\sum_{i=1}^{6} E_i\right)^2 - \left(\sum_{i=1}^{6} \vec{p}_i\right)^2$$

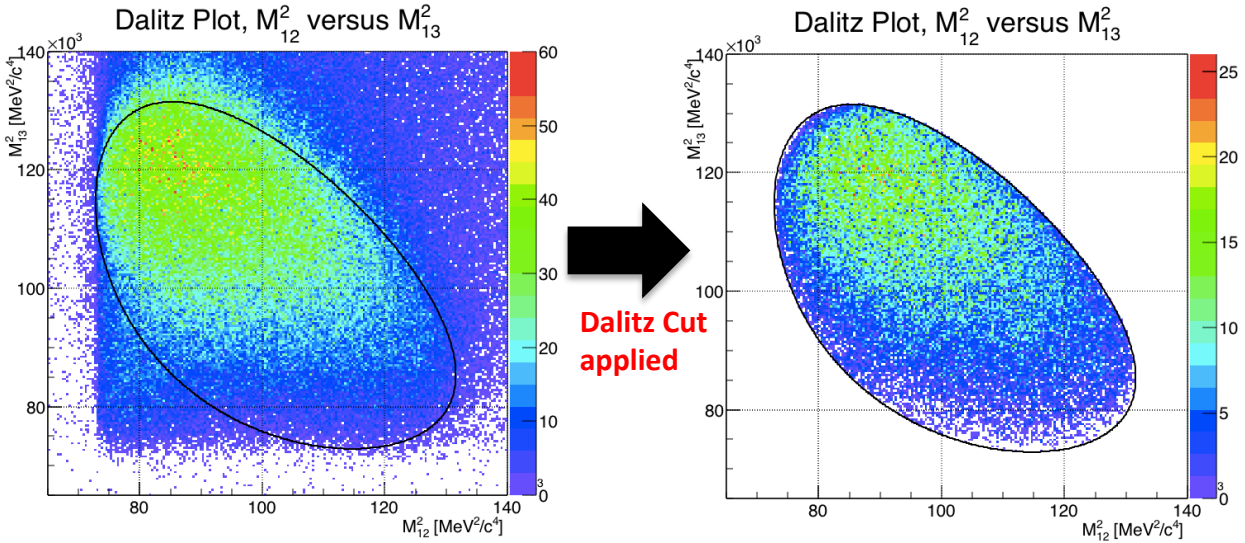
- 1) Reconstruct Vertex of 2pi0
- 2) Reconstruct energy of 6th gamma
  - Assumption of pi0 mass
  - Time information of barrel detector
- 3) Reconstruct X, Y of Klong Vertex using CoE of 6 gammas
- 4) Reconstruct Klong Mass

Iteration

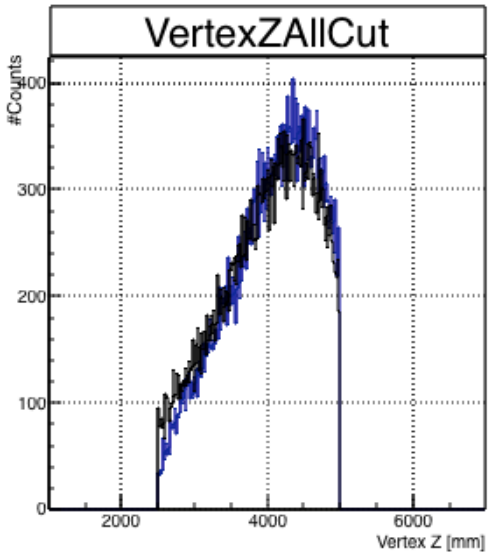
Selection

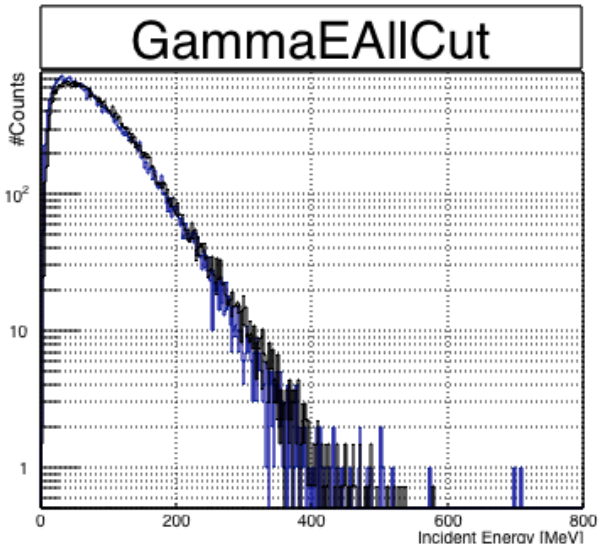
Cut Variable	Selected Region	note
Gamma Energy	100<e<2000 [MeV	γ Quality
Distance between Gamma	d>175 [mm]	
Radial Position of Gamma in CsI	150<r<900 [mm]	
Shapeχ^2	χ^2<10	
Pi0 Mass	129.98<m<139.98 [MeV/c^2]	π^0 Quality
Differece of two Pi0s	-5<$m_1 - m_2$<5 [MeV/c^2]	
Klong Vertex	2500<VTZ<5000 [mm]	K_L^0 Quality
1st Vertex χ^2	$\chi^2 < 4$	
2nd Vertex χ^2	$\chi^2 > 10$	
Klong Pt	$p_t < 40$ [MeV/c]	
Dalitz Cut	Graphical Cut	Kinematic Boundary

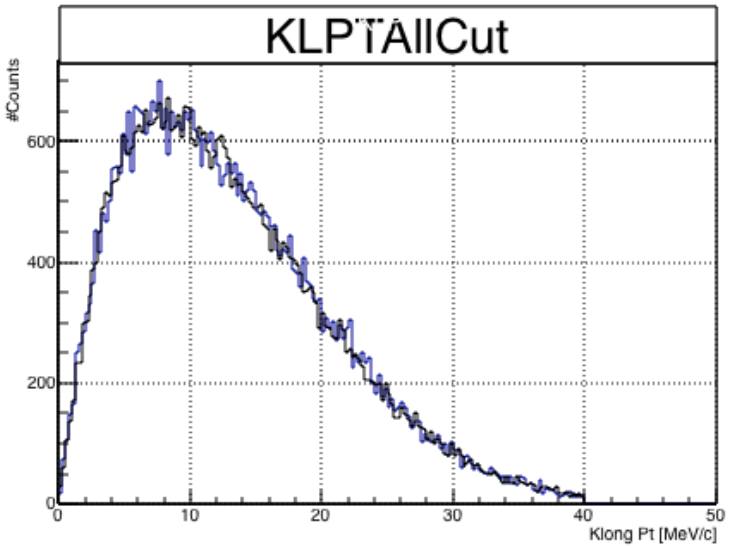
- Rejection of events located outside boundary



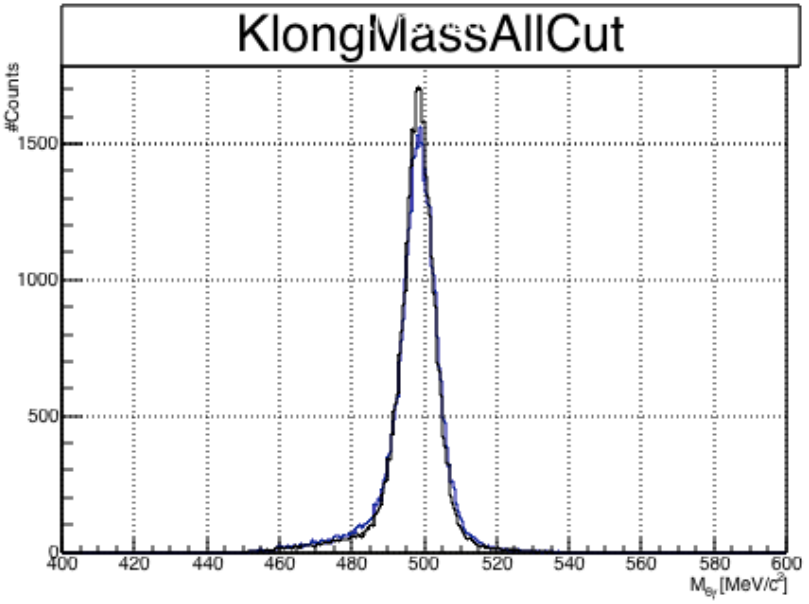
Reconstruction variables





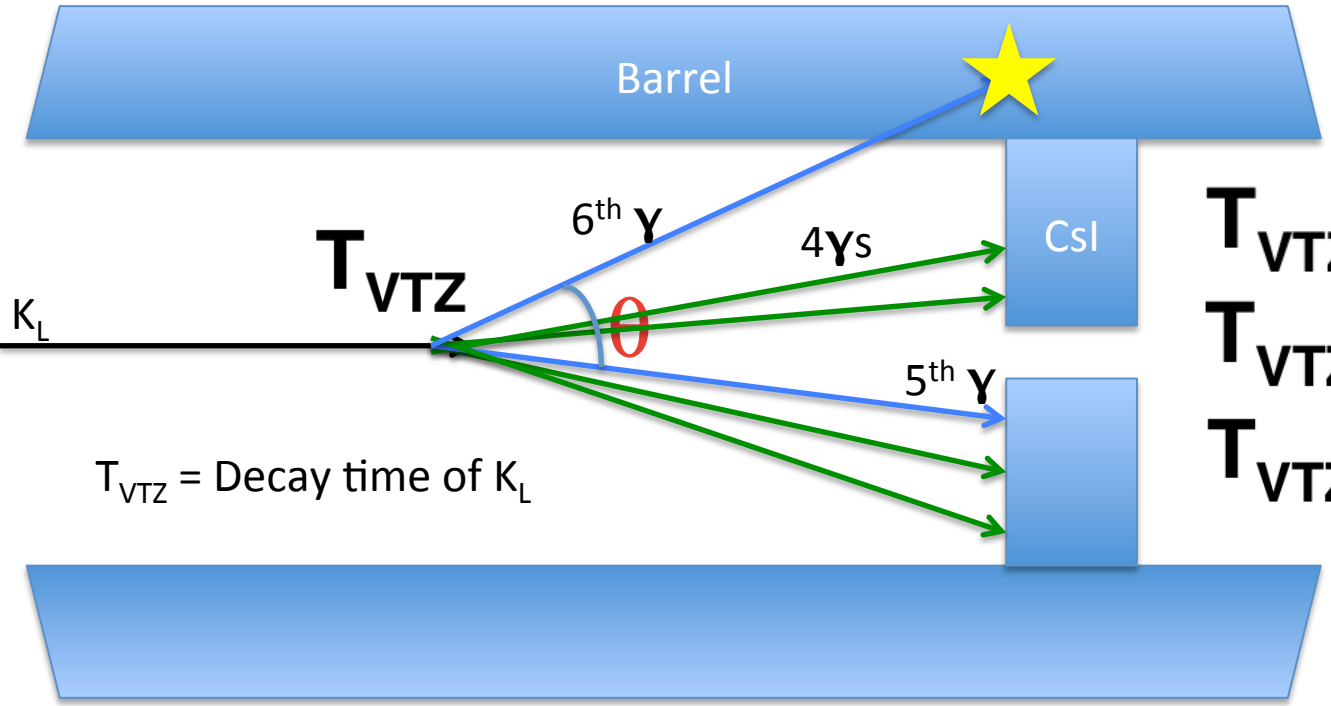


$$\frac{\#K_L^0 \text{ in M.C.}}{\#K_L^0 \text{ in Data}} = 0.99$$



- All selections are applied

K_L Vertex Time



$$ToF = \frac{L}{c}$$

L : path length of photons

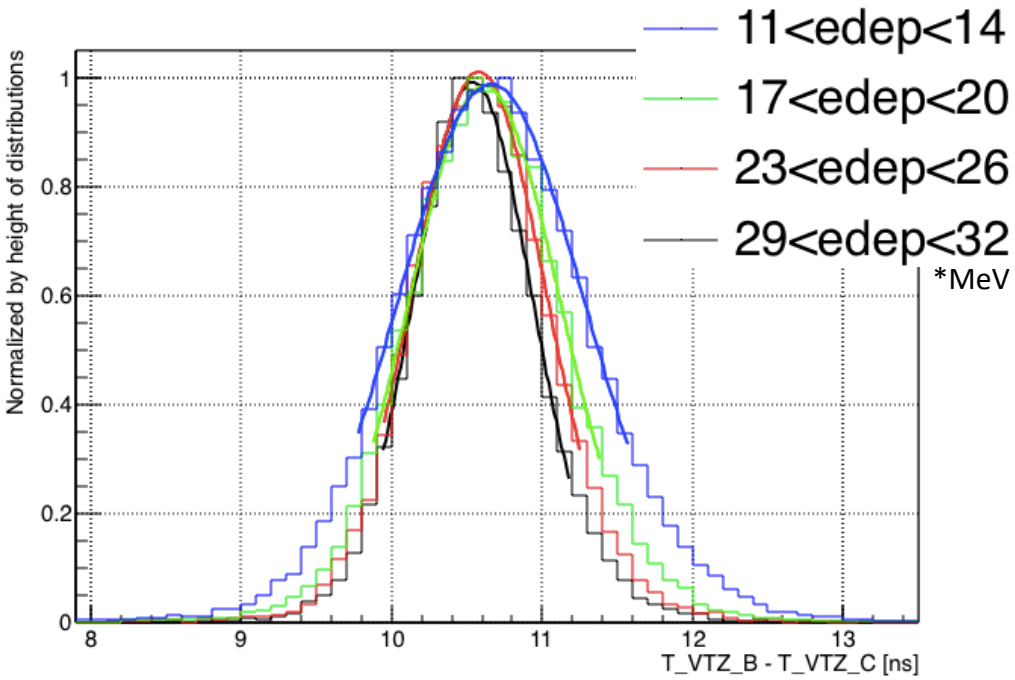
$$T_{VTZ_B} = T_{Barrel} - ToF$$

$$T_{VTZ_C} = T_{CsI} - ToF$$

$$T_{VTZ_B} = T_{VTZ_C}$$

- Estimation of decay time of K_L using Barrel Detector and CsI Detector independently.
  - With clean selection of γ signal

T_{VTZ_B} - T_{VTZ_C}



Entries	12177	Entries	18586
Mean	10.56	Mean	10.6
RMS	0.5203	RMS	0.5486
χ^2 / ndf	8.212 / 10	χ^2 / ndf	11.27 / 11
Prob	0.6081	Prob	0.4213
Constant	1170 ± 15.6	Constant	1612 ± 17.4
Mean	10.54 ± 0.00	Mean	10.58 ± 0.00
Sigma	0.3944 ± 0.0057	Sigma	0.4426 ± 0.0055

Entries	28253	Entries	43585
Mean	10.63	Mean	10.67
RMS	0.6325	RMS	0.7545
χ^2 / ndf	33.61 / 12	χ^2 / ndf	13.98 / 15
Prob	0.0007783	Prob	0.5267
Constant	2151 ± 19.4	Constant	2710 ± 19.8
Mean	10.62 ± 0.00	Mean	10.66 ± 0.00
Sigma	0.4979 ± 0.0056	Sigma	0.6117 ± 0.0057

- Evaluated Centre of T_{VTZ_B}-T_{VTZ_C}
- Deposited energy on barrel affects timing resolution

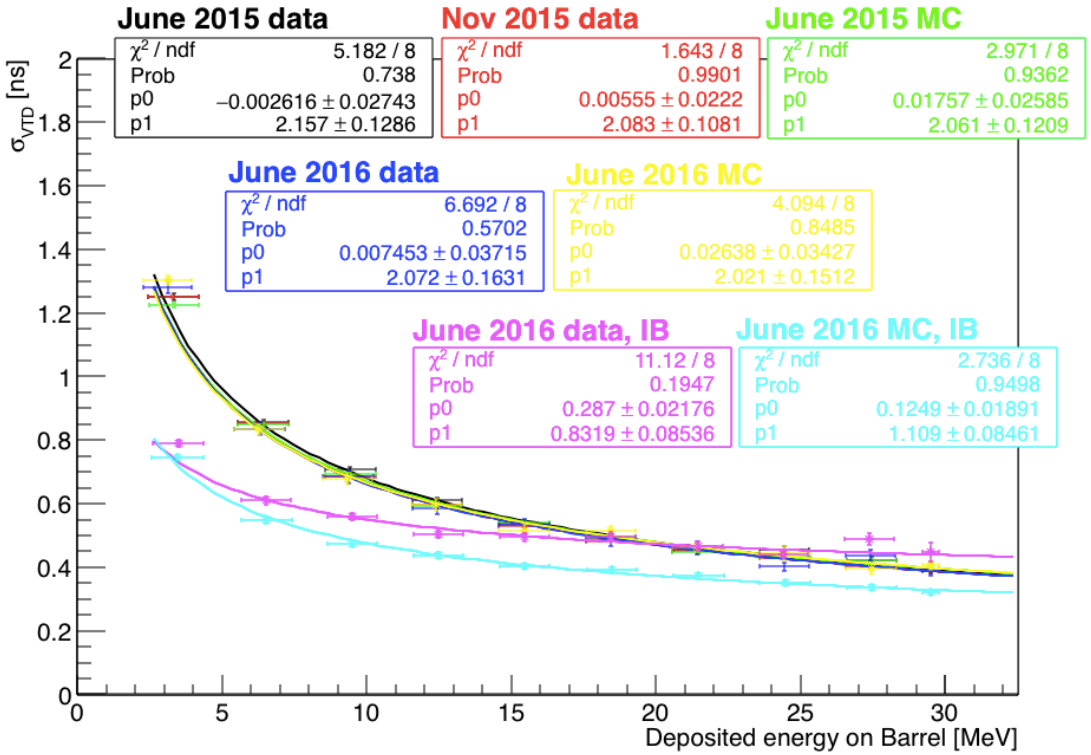
$$T_{VTZ_B} - T_{VTZ_C} = \text{Offset}$$

$$\delta(\text{Offset}) = \sqrt{\delta T^2_{VTZ_B} + \delta T^2_{VTZ_C}}$$

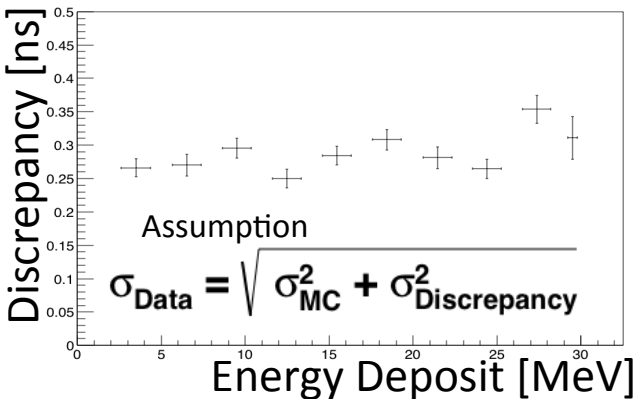
Timing Resolution of Barrel

$$\sigma_{VTZ} = \sqrt{p_0 + \frac{p_1}{Edep}}$$

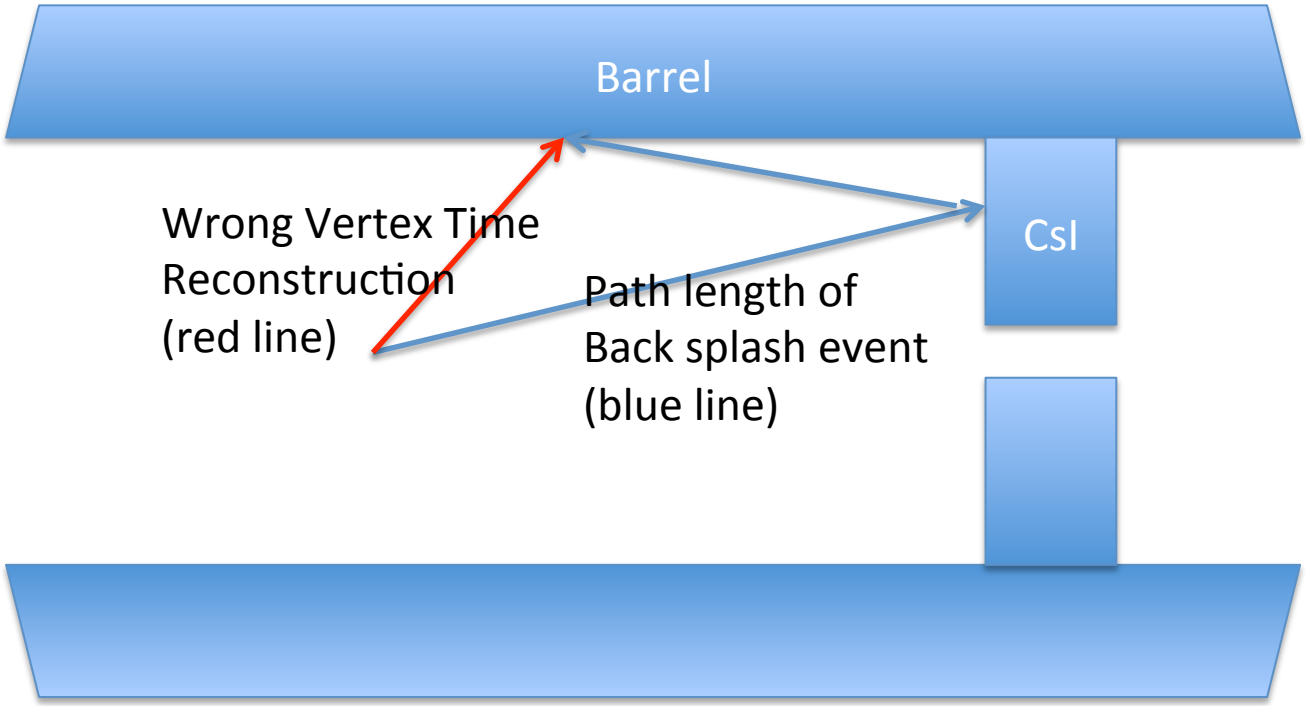
- Function for consideration of photon statistics



- Consistent result between M.C. and data for MB
- Understanding discrepant result for IB is ongoing



Back-splash event

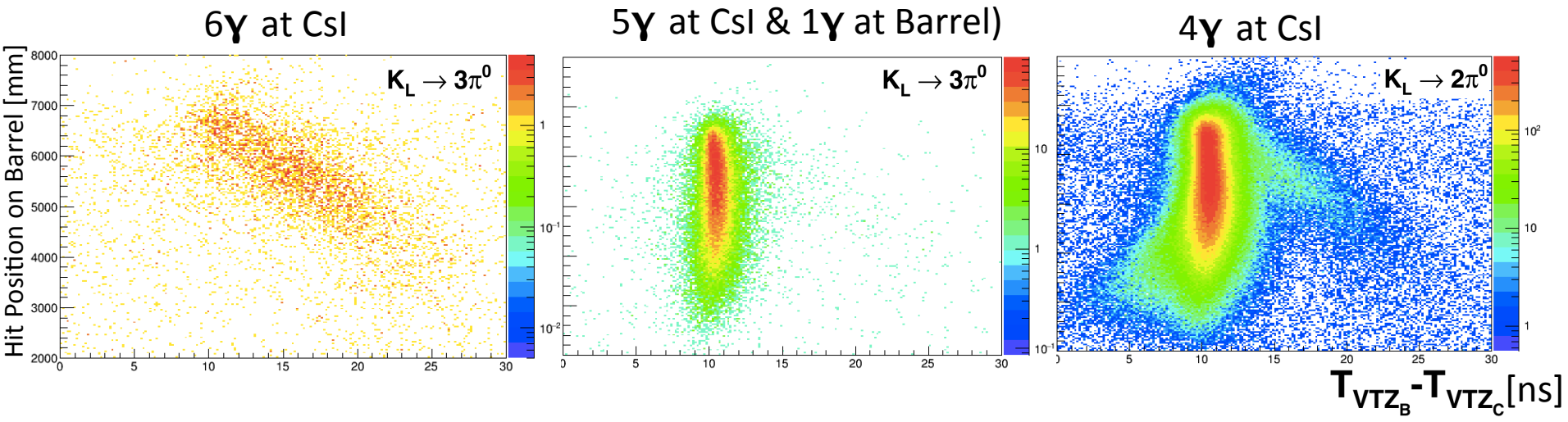


$$ToF_{VTZ_{Wrong}} = | \text{KlongVertexPosition-BarrelHitPosition} | / c$$

$$ToF_{VTZ_{Right}} = | \text{KlongVertexPosition-CsIHitPosition} | / c + | \text{CsIHitPosition-BrrelHitPosition} | / c$$

- Back-splash event identified by looking into ToF

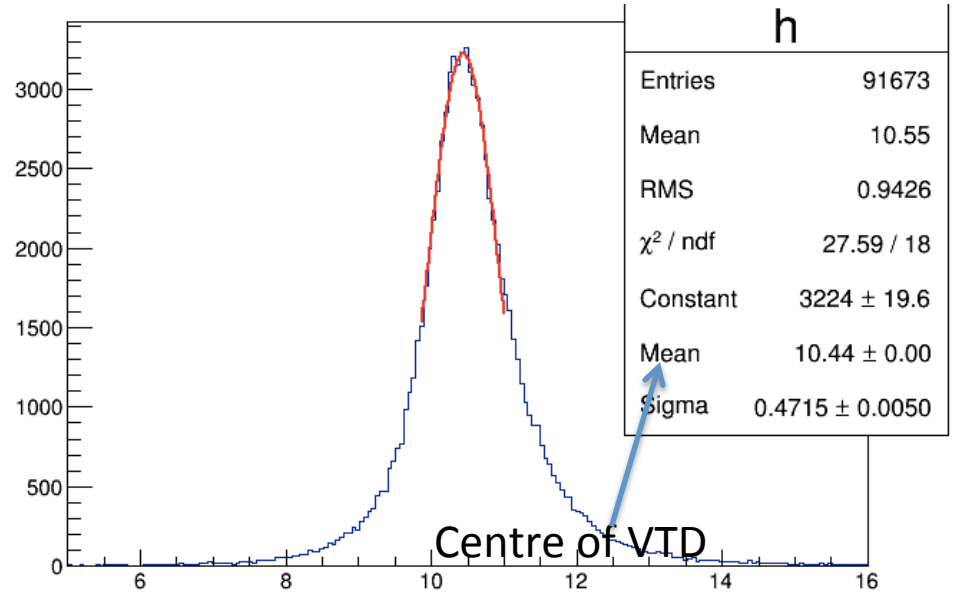
Event property



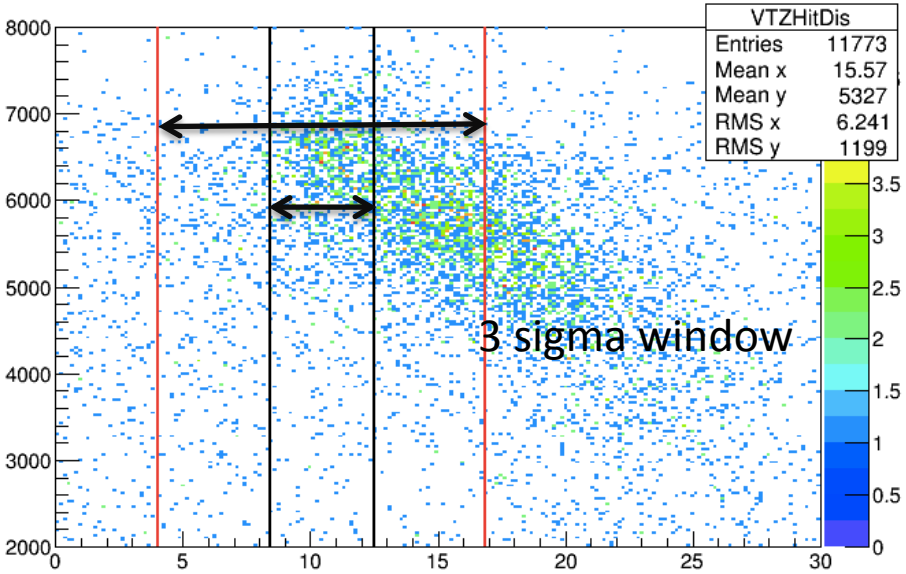
- In 6γ analysis, all γs are detected at CsI
- In 5γ analysis, 5γs are detected at CsI with 1γ at Barrel
- In 4γ analysis, 4γs are detected at CsI
  - Back splash event
  - γs from $K_L \to 3\pi^0$

analysis	Back splash event	K_L signal
6γ	O	X
5γ+1γ	X	O
4γ	O	O

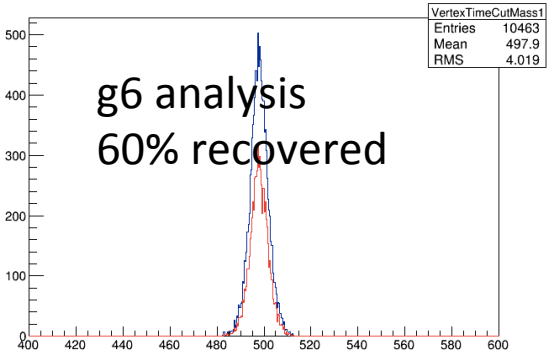
Get Centre & Set Veto window

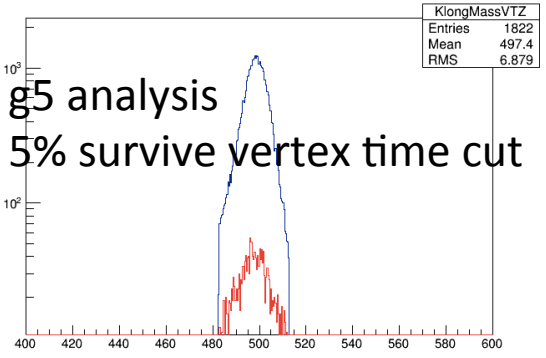


Black : 10MeV Veto window
Red : 1MeV Veto window



- Vertex Time Veto / Mean Time Veto
  - = 1.62
  - 62% Recovery done





Summary

- Reconstruction of KL3pi0 using Barrel detector and CsI is done
  - With x% uncertainty
- Inner Barrel has superior time resolution in low deposited energy region
  - Trying to understand discrepancy between M.C. and data
- New Veto cut recovered 62% KL3pi0 from old Veto cut