ZICOS – A NEW EXPERIMENT FOR NEUTRINOLESS DOUBLE BETA DECAY WITH ZIRCONIUM-96

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Miyagi University of Education Y.Fukuda, Y.Kamei, Naringelile*, A.Obata*

University of Tokyo, ICRR S.Moriyama

Fukui University I.Ogawa

Tokyo University of Science T.Gunji, S.Tsukada, R.Hayami

ZICOS- Zirconium Complex in Organic Liquid Scintillator for neutrinoless double beta decay

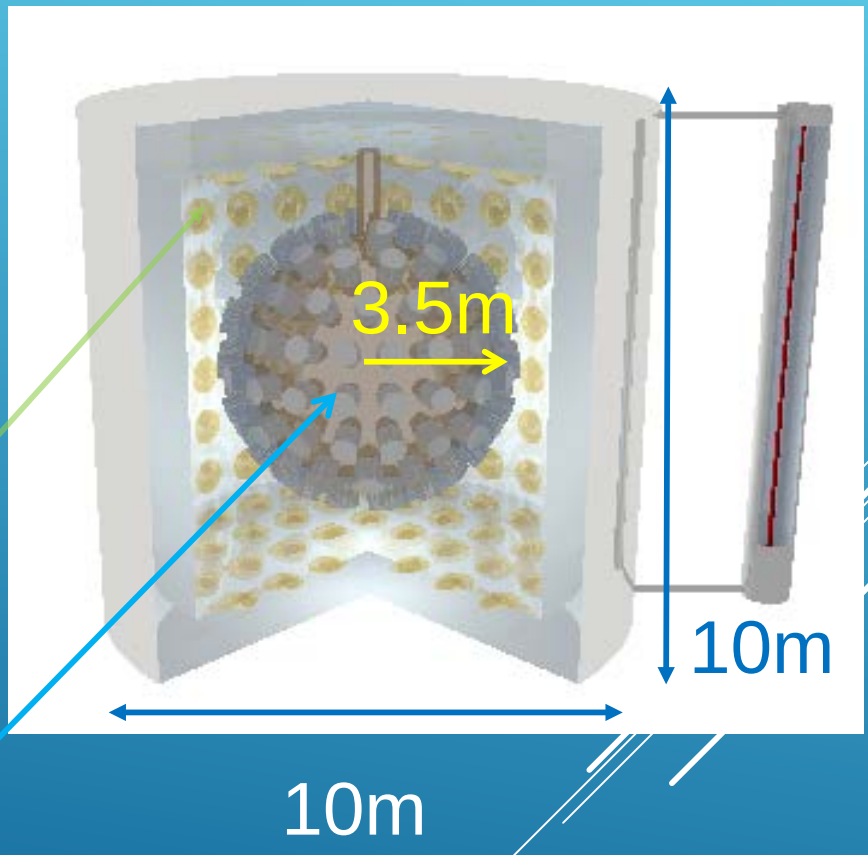
Liquid Scintillator:

(1) 10 wt.% $Zr(iprac)_4$ loaded in anisole

(2) 49% of BC505 for Light Yield and 3.5% at 3.35MeV for energy resolution with 40% photo coverage.

Pure water surrounding inner detector in order to veto muons and external backgrounds.

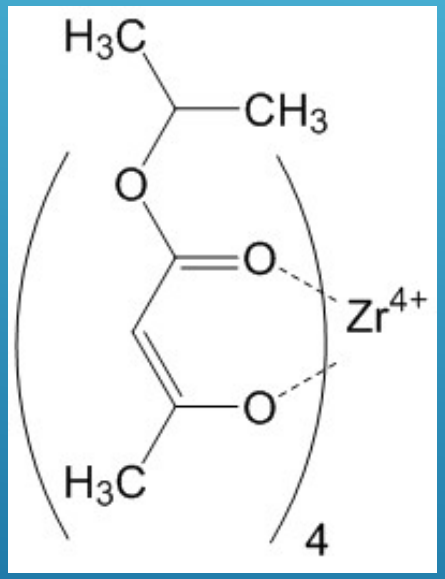
Inner detector with 64% photo coverage with 20" PMT including 1.7ton Zirconium loaded 113 tons LS in fiducial volume. (Total vol. : 180 tons)

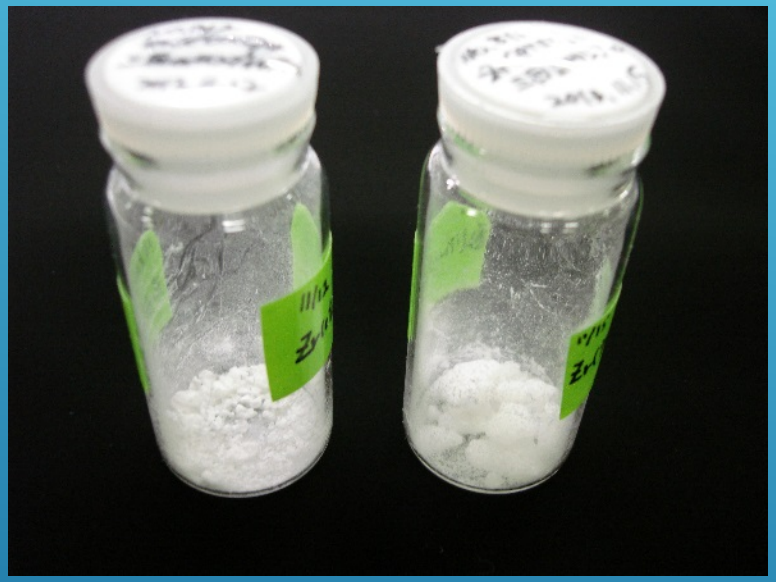


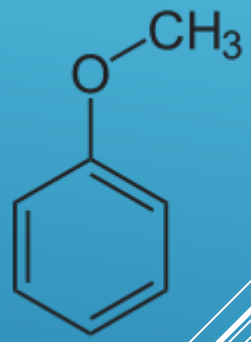
tetralkis(isopropyl acetoacetate) zirconium

$Zr(CH_3COCHCOOCH(CH_3)_2)_4$: $Zr(iprac)_4$

Molecular weights : 663.87

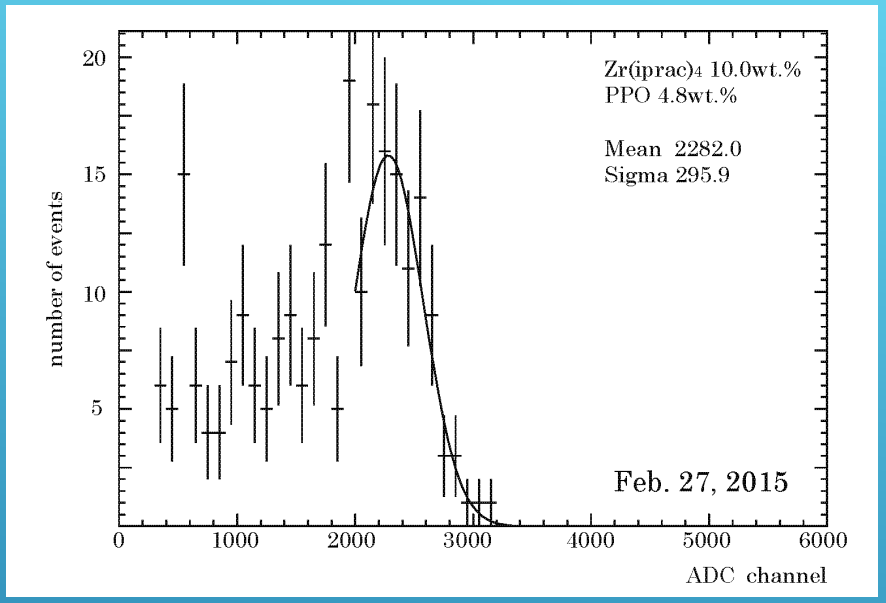






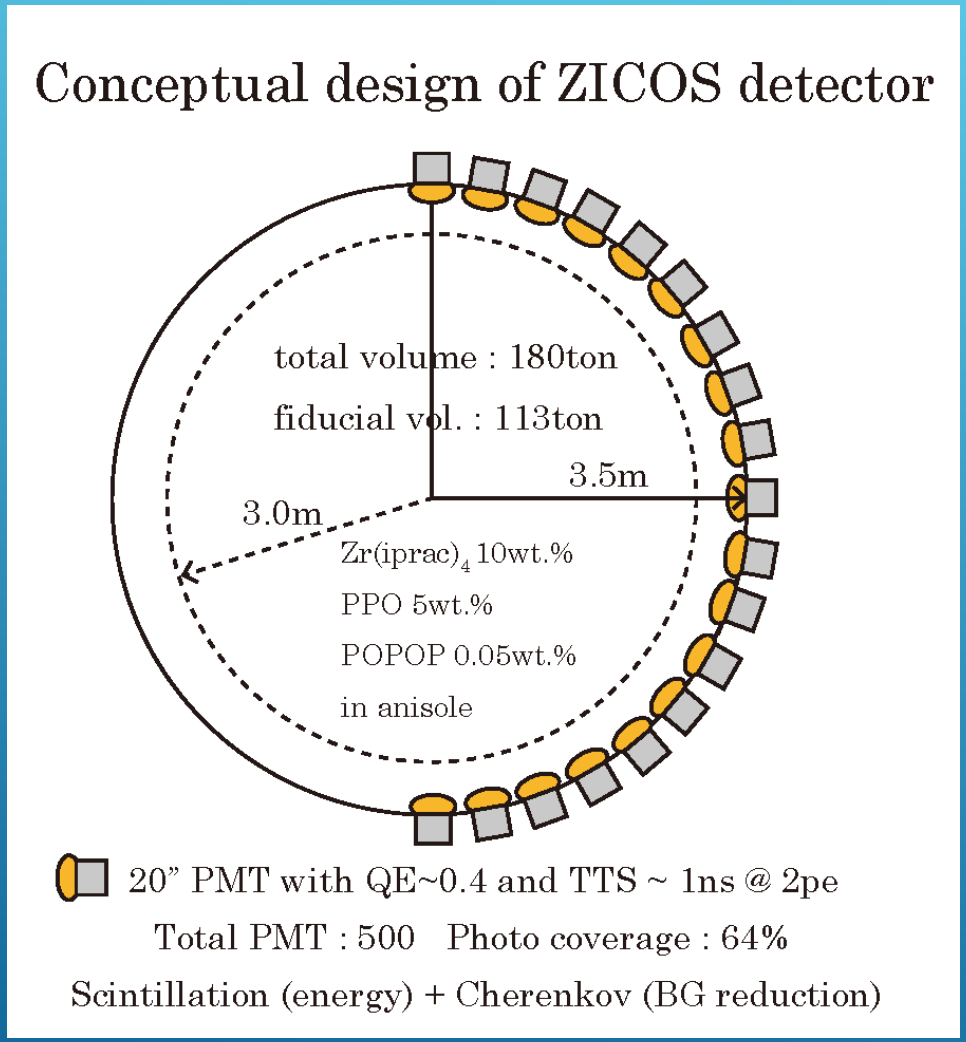
Solubility was obtained by 31.2 wt.% in anisole. (usually 10wt.% for LS)

Liquid scintillator containing $Zr(iprac)_4$



Light yield of 48.7±7.1% for BC505, and an energy resolution of 4.1±0.6% at 3.35 MeV assuming 40% photo coverage of the photomultiplier are obtained at 10wt.% concentration of $Zr(iprac)_4$ with 5 wt.% of PPO and 0.5wt.% of POPOP in anisole.

Design of ZICOS detector



Detector :

1) 180tons LS : 10 wt.% $Zr(iprac)_4$ with PPO/POPOP in anisole Need 500 of 20" PMT with high QE >0.3 and TTS < ~1ns = 64% photo coverage

Expected performance :

1) Energy resolution ~2.8%@3.35MeV
2) $T_{1/2}(0\nu\beta\beta) > 10^{26}$years, if both 1/20 BG reduction and 50% ^{96}Zr enrichment could be achieved.

Neutrino mass sensitivity of ZICOS experiment

Total mass : 180ton (fiducial volume : 113ton)
10wt.% $Zr(iprac)_4$ = 12.6ton
includes 1.7ton of Zirconium
= 45 kg of ^{96}Zr **(natural abundance 2.6%)**

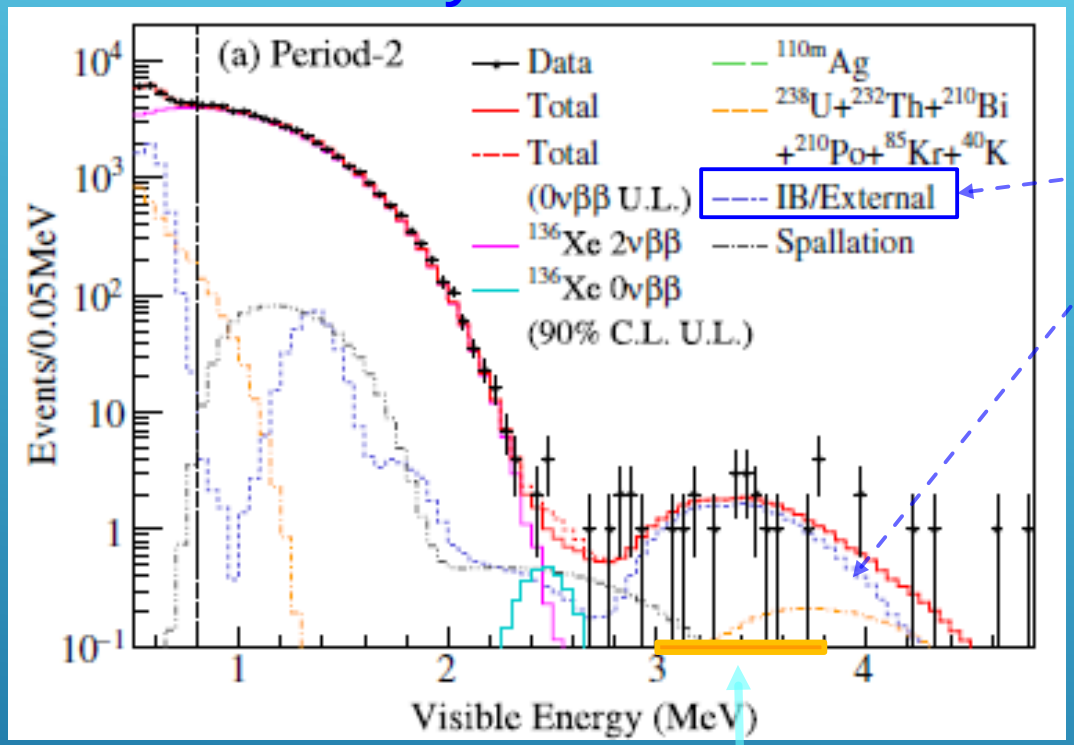
$T_{1/2}^{0\nu} > 1.2 \times 10^{25}$y ← Not enough for $0\nu\beta\beta$ search

1) Zr enrichment
58.5% enrichment of ^{96}Zr (e.g. 57.3% for NEMO-3)
^{96}Zr will be 1.0 ton then $T_{1/2}^{0\nu} > 5 \times 10^{25}$y

2) Lowering BG level (^{208}Tl /^{214}Bi)
i.e. < 1/20 × KL-Zen (~1.0events/ton/year)
then $T_{1/2}^{0\nu} > 5 \times 10^{25}$y Today's talk

Backgrounds around Q-value

Measured by KamLAND-Zen



^{208}Tl
In balloon

Lowering BG (^{208}Tl)
< 1/20 × KL-Zen
(~1.0events/ton/year)

$T_{1/2}^{0\nu} > 5 \times 10^{25}$y

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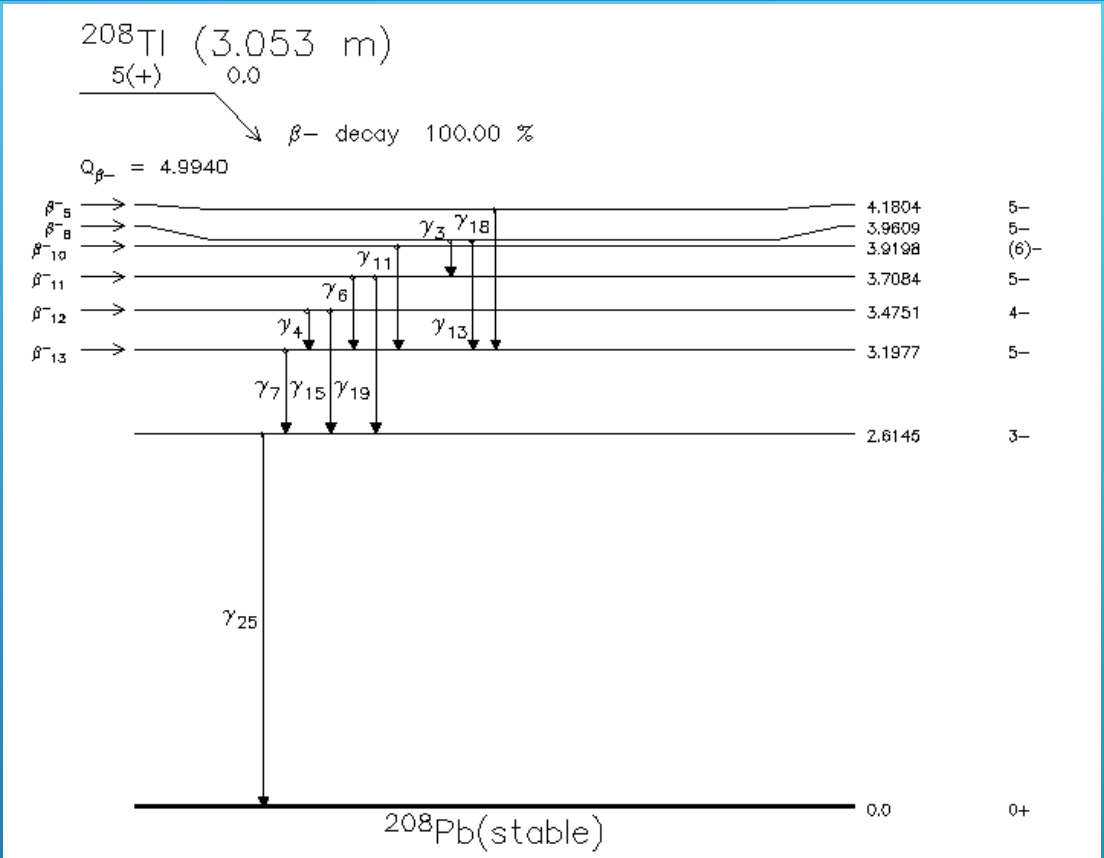
$0\nu\beta\beta$ signal region for ^{96}Zr

Need additional technique other than the energy spectral shape obtained by scintillation.

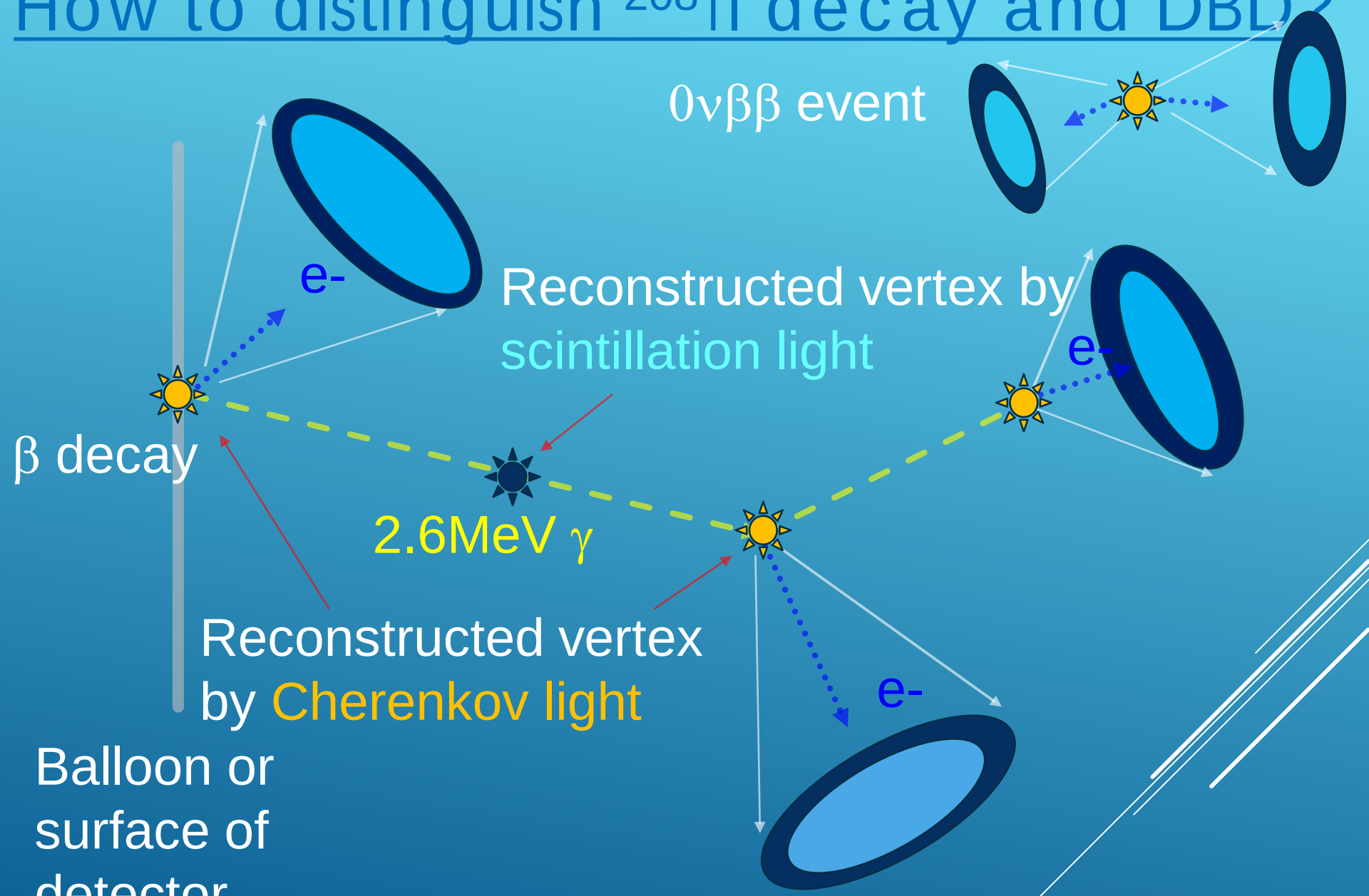
Radiation branch of Thallium-208



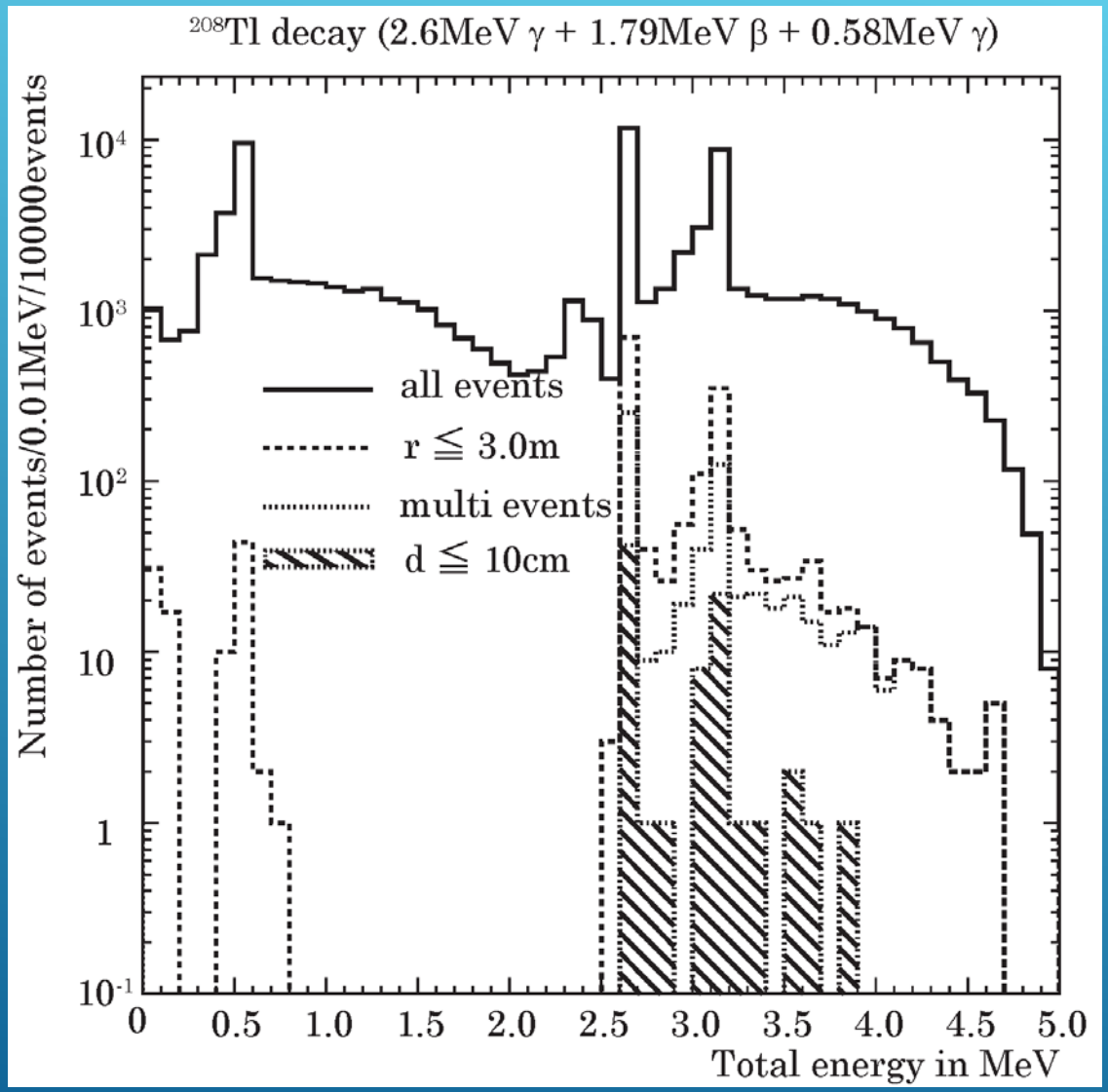
Radiations	y(i) $(Bq\text{-}s)^{-1}$
beta- 5	2.27×10^{-03}
beta- 8	3.09×10^{-02}
beta- 10	6.30×10^{-03}
beta- 11	2.45×10^{-01}
beta- 12	2.18×10^{-01}
beta- 13	4.87×10^{-01}
ce-K, gamma 3	4.04×10^{-03}
gamma 4	6.31×10^{-02}
ce-K, gamma 4	2.84×10^{-02}
ce-L, gamma 4	4.87×10^{-03}
gamma 6	2.26×10^{-01}
ce-K, gamma 6	1.97×10^{-02}
ce-L, gamma 6	3.32×10^{-03}
gamma 7	8.45×10^{-01}
ce-K, gamma 7	1.28×10^{-02}
ce-L, gamma 7	3.51×10^{-03}
gamma 13	1.81×10^{-02}
gamma 15	1.24×10^{-01}
ce-K, gamma 15	2.80×10^{-03}
gamma 19	3.97×10^{-03}
gamma 25	9.92×10^{-01}

The vertex reconstructed by scintillation lights could be contaminated within fiducial volume due to gammas.

How to distinguish ^{208}Tl decay and DBD?



Reduction of ^{208}Tl decay

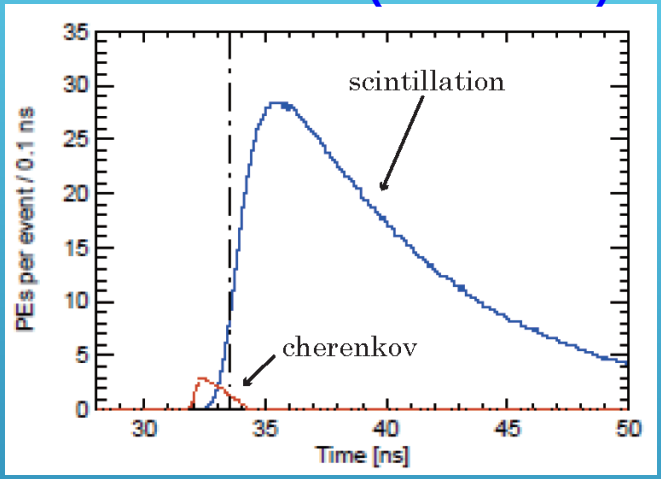


1) E : 3.0-3.7MeV
   17925 events
2) Fiducial volume
   628 events
3) Multi events
   263 events
4) Closer events
   (d≦10cm)
   35 events

1/20 BG reduction could be realized by identifying vertex.

Separation of Cherenkov light and scintillation

arXiv:1609.0986(simulation)

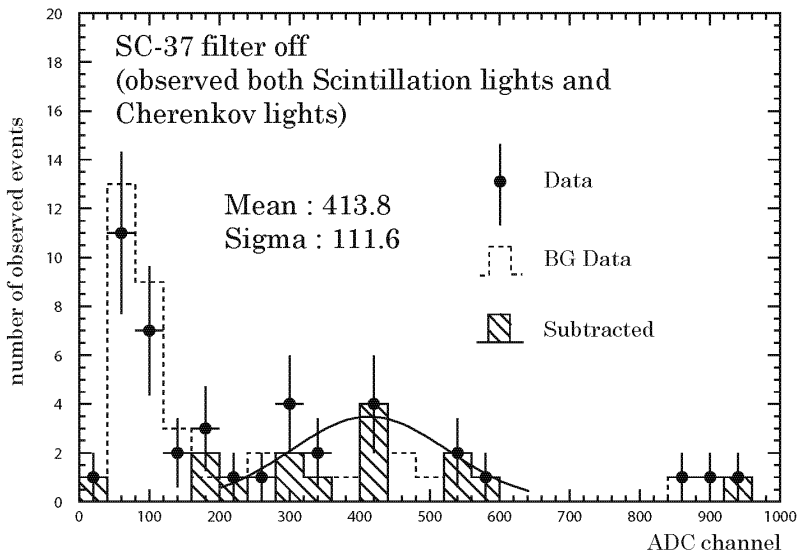


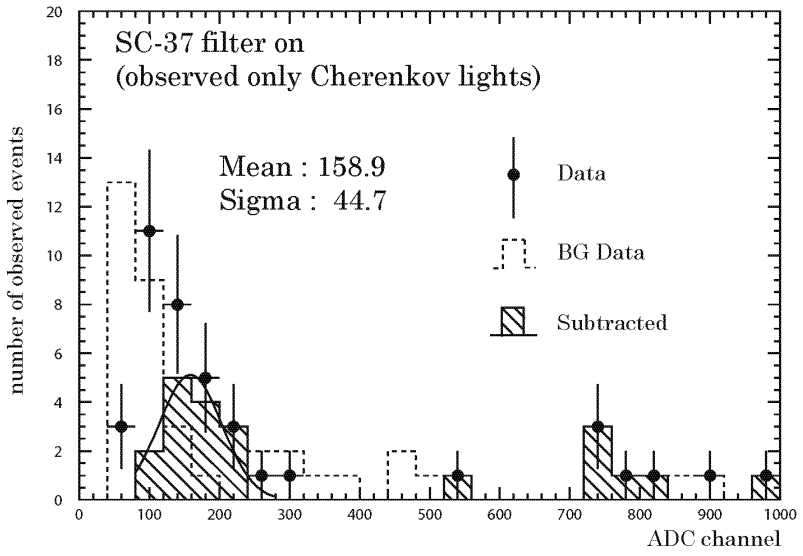
- Rise time of Cherenkov light : an order of 100 pico seconds due to electro-magnetic process
- Rise time of Scintillation : an order of a few nano seconds due to energy transport of fluorescent material.

Possible to extract hits of PMT received Cherenkov lights by Pulse Shape Discrimination.

- CAEN V1721 8 channel 8bit 500MS/s FADC
- CAEN V2718 VME-PCI Optical Link Bridge

Light yield of Cherenkov lights

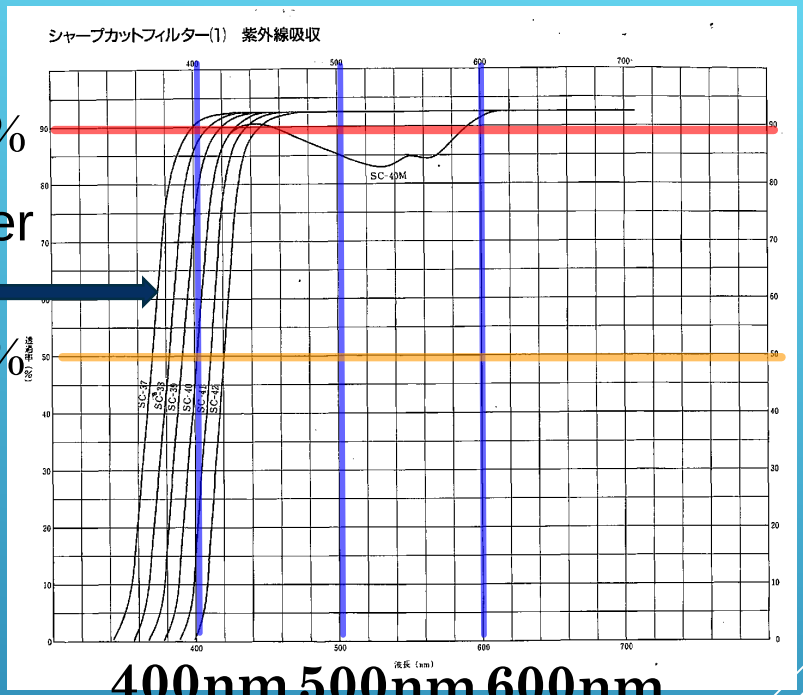




90%

SC-37 filter

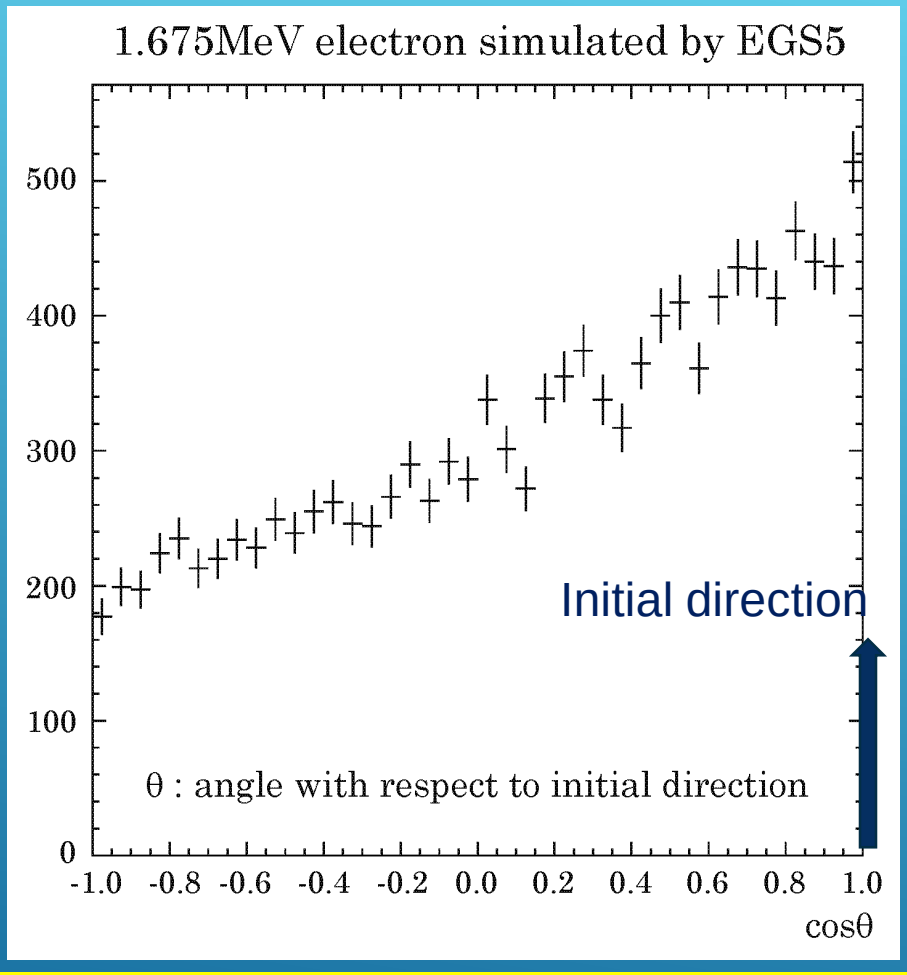
50%

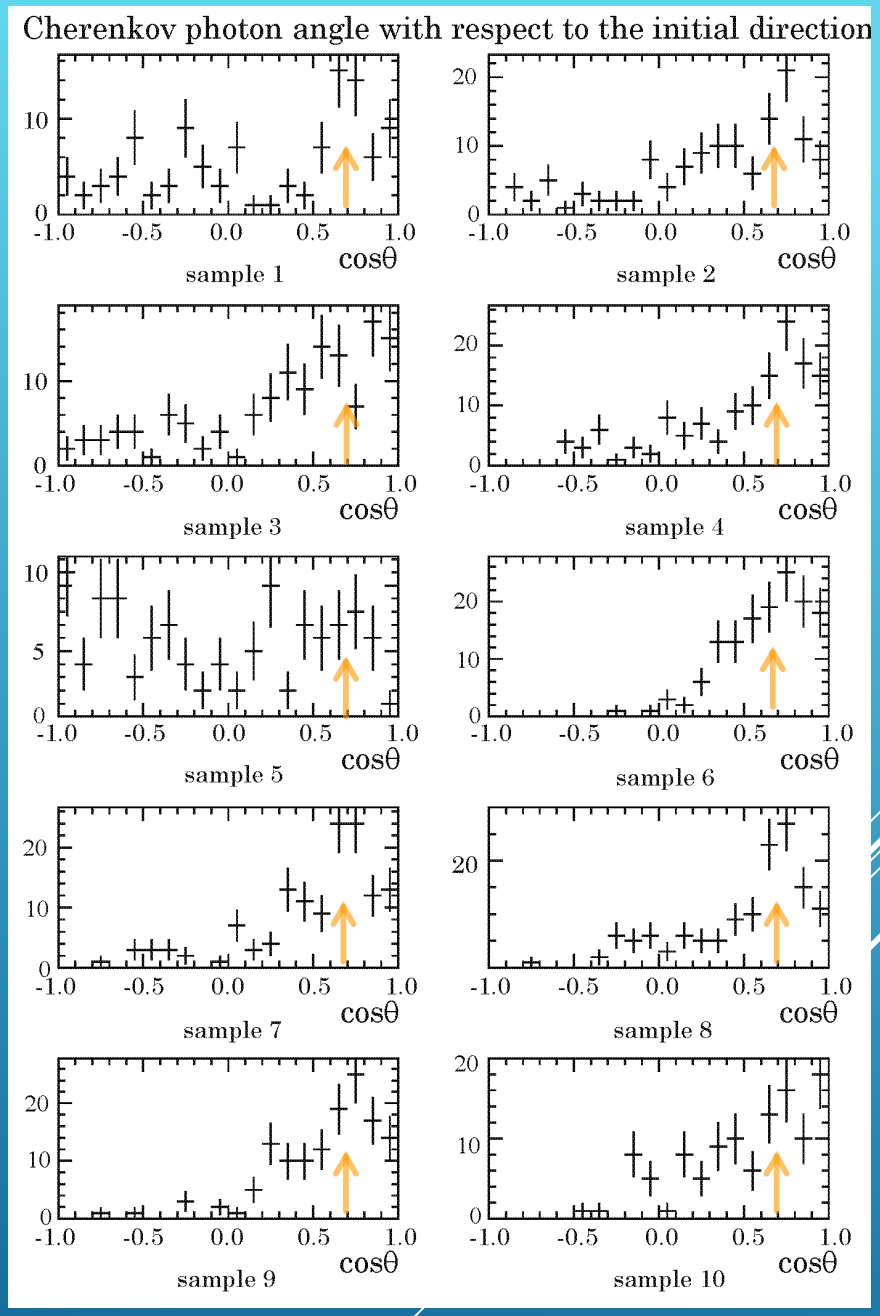


Cherenkov light yield (λ>400nm)
Scintillation light yield of anisole

= ~0.02 ≡ ~200 photon/MeV

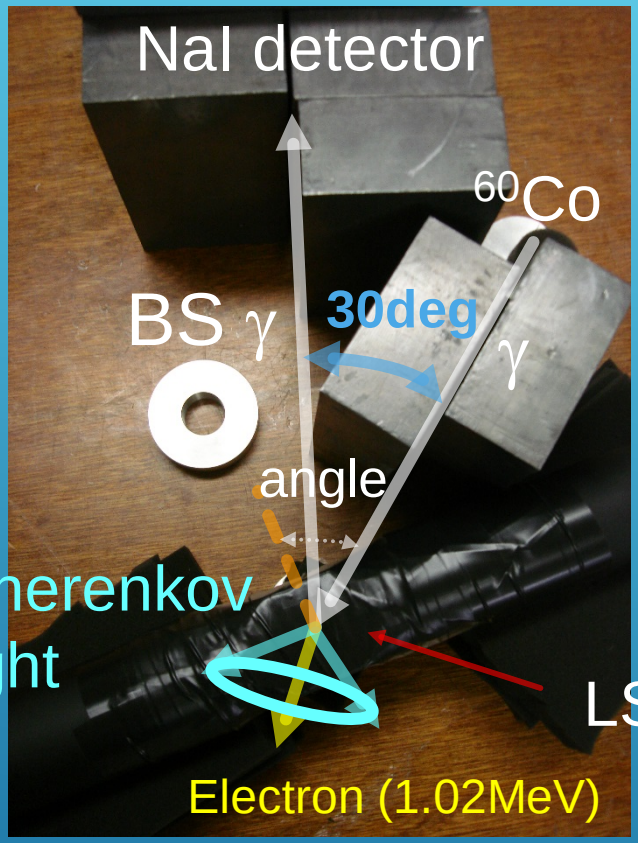
Multiple scattering





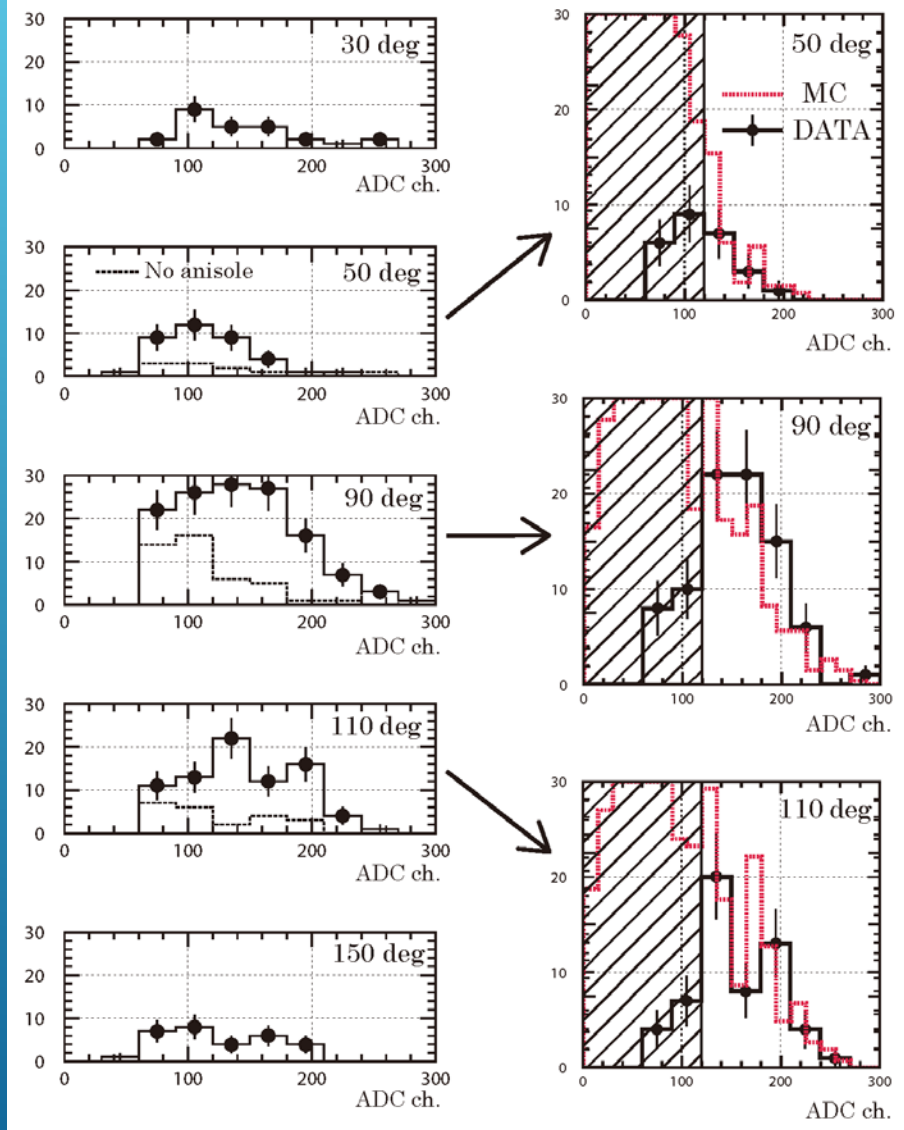
Even though multiple scattering of electrons, Cherenkov photons look have some clusters.

Angular dependence



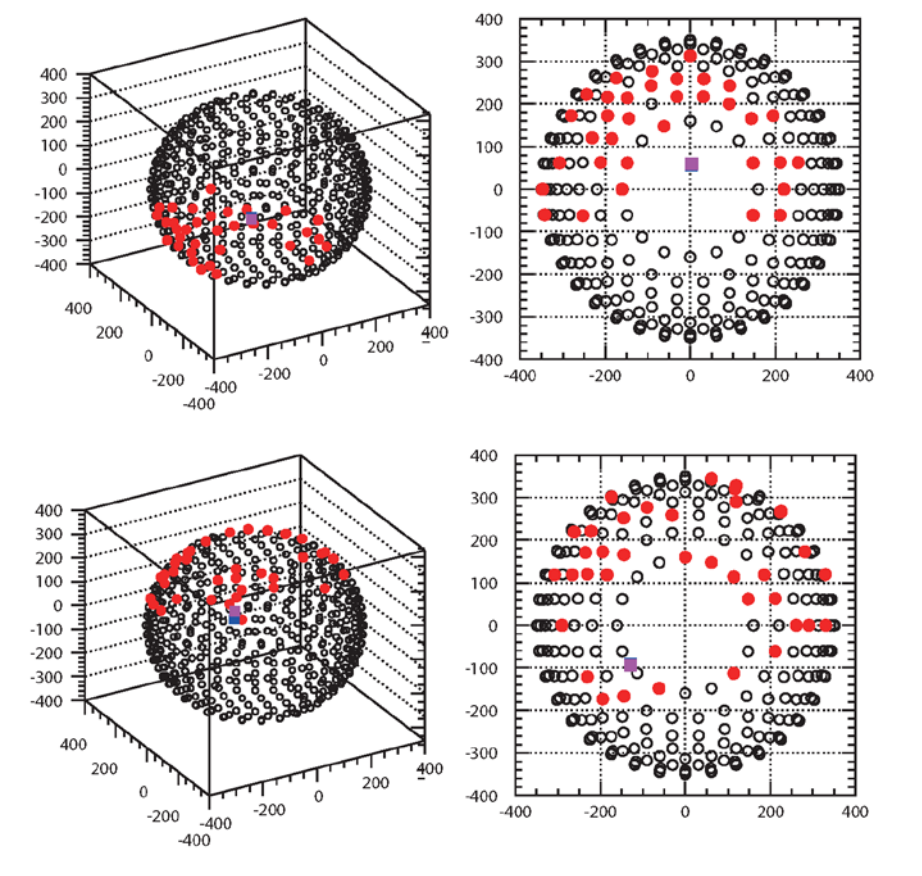
Cherenkov light emitted by 1MeV e^- actually has an angular dependence.

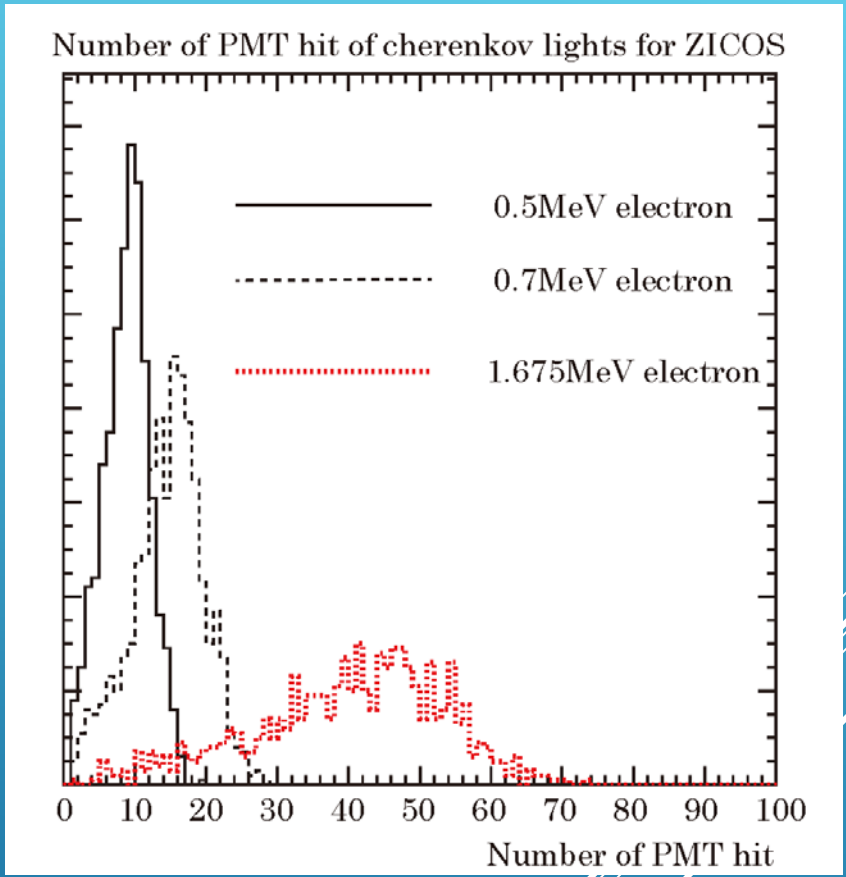
MC reproduced angular dependence.



Simulation of Cherenkov lights

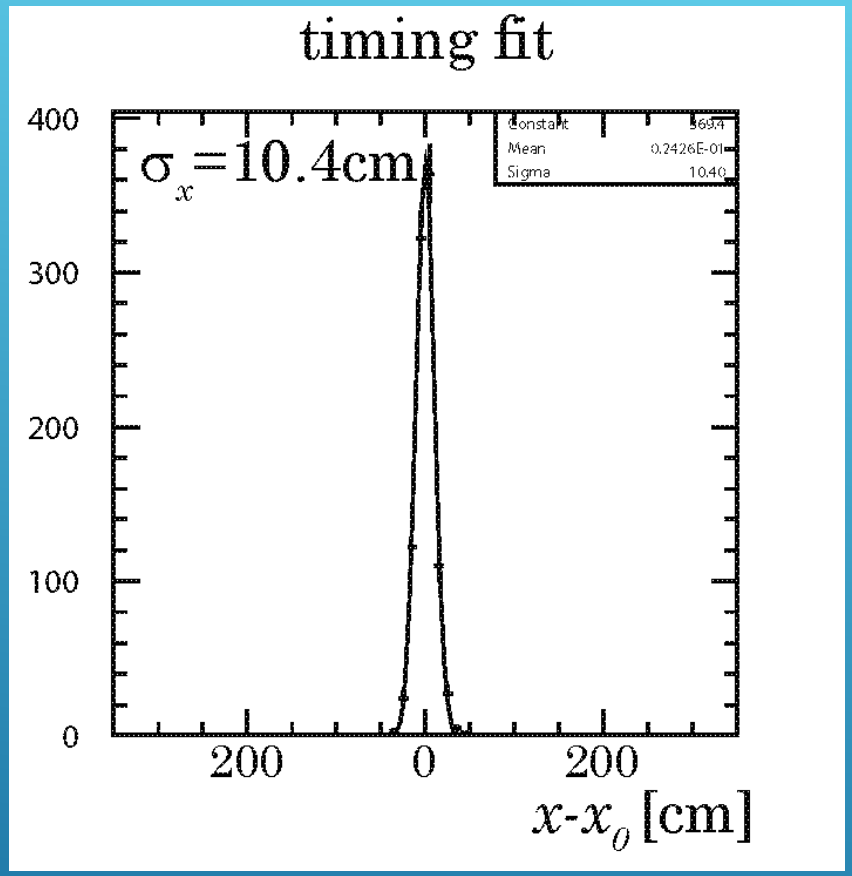
Simulated by EGS5 (kinetic energy 1.675MeV)





Hard to detect Cherenkov events below 0.5MeV.

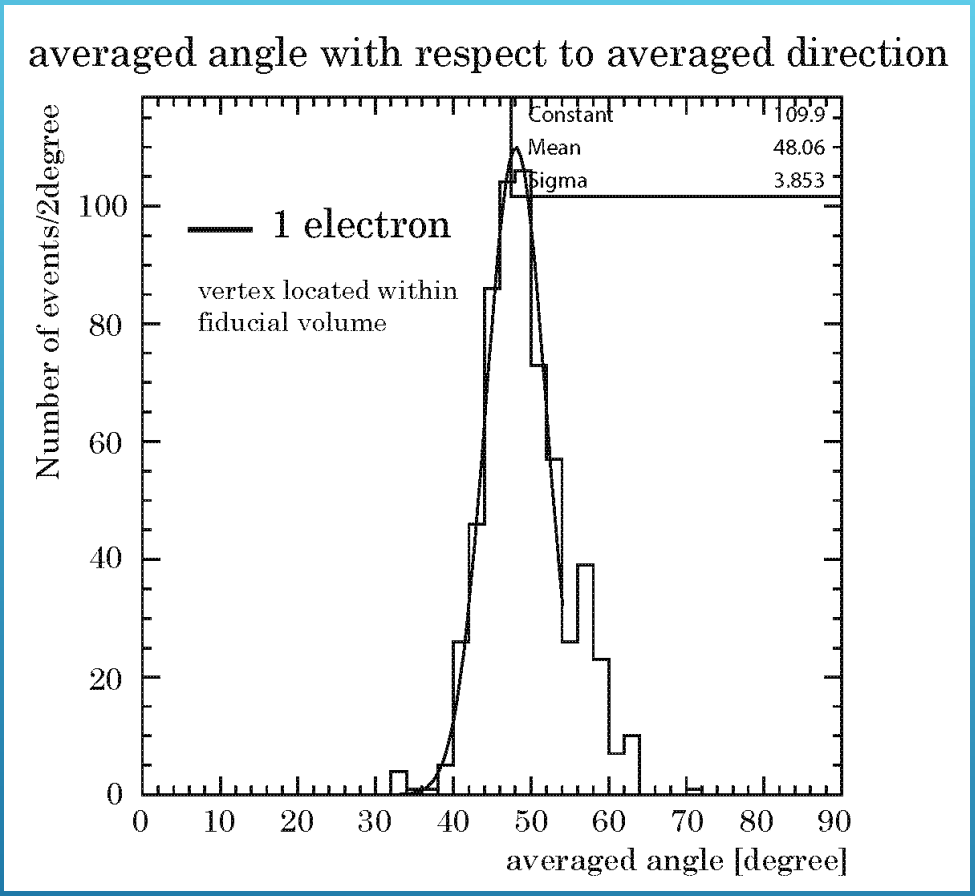
Reconstruction of vertex position



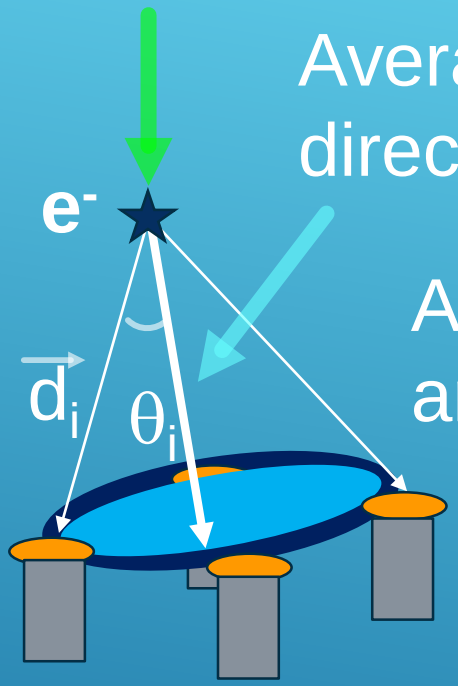
- Vertex position for single e^- could be reconstructed by only Cherenkov light with resolution σ=10cm.
- However, it needs non-overlap PMT hits for multi events.

Vertex position reconstructed by scintillation light is almost same as the position reconstructed by Cherenkov lights for single e^- and DBD event.

Averaged angle



Vertex position obtained by scintillation



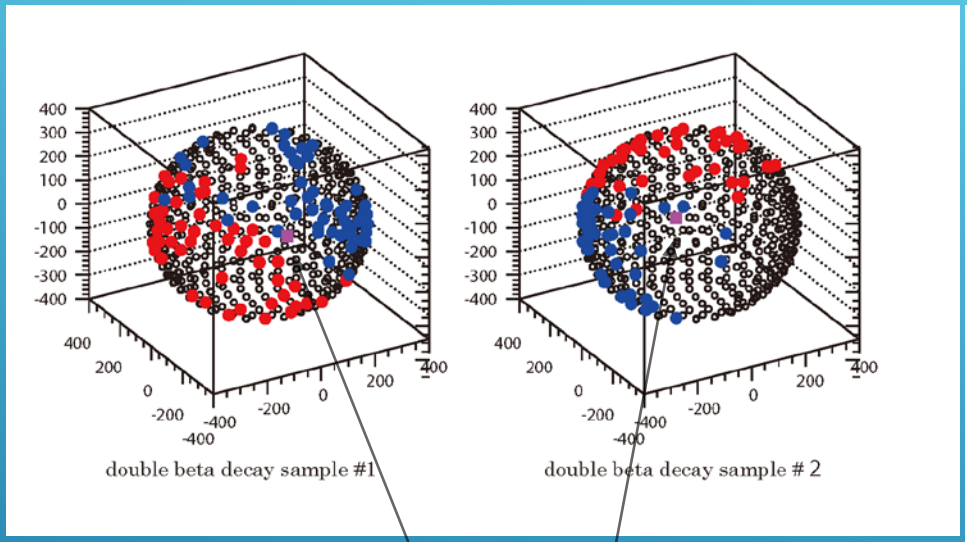
Averaged direction = $\Sigma \vec{d}_i$

Averaged angle= $\frac{\Sigma \theta_i}{\text{Nhit}}$

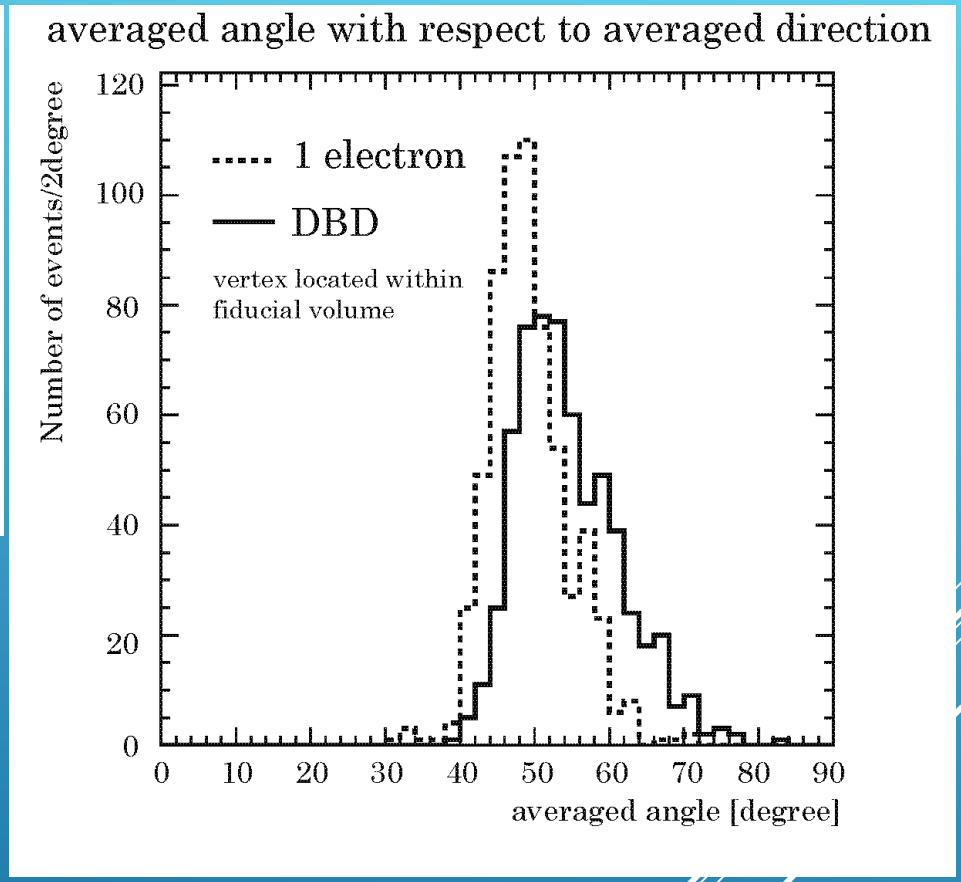
Averaged angle with respect to averaged direction for single e^- seems to have a peak at ~48 degree which is almost same as Cherenkov angle.

Hit pattern of DBD (opposite and half E)

Simulated by EGS5 (kinetic energy 1.675MeV)

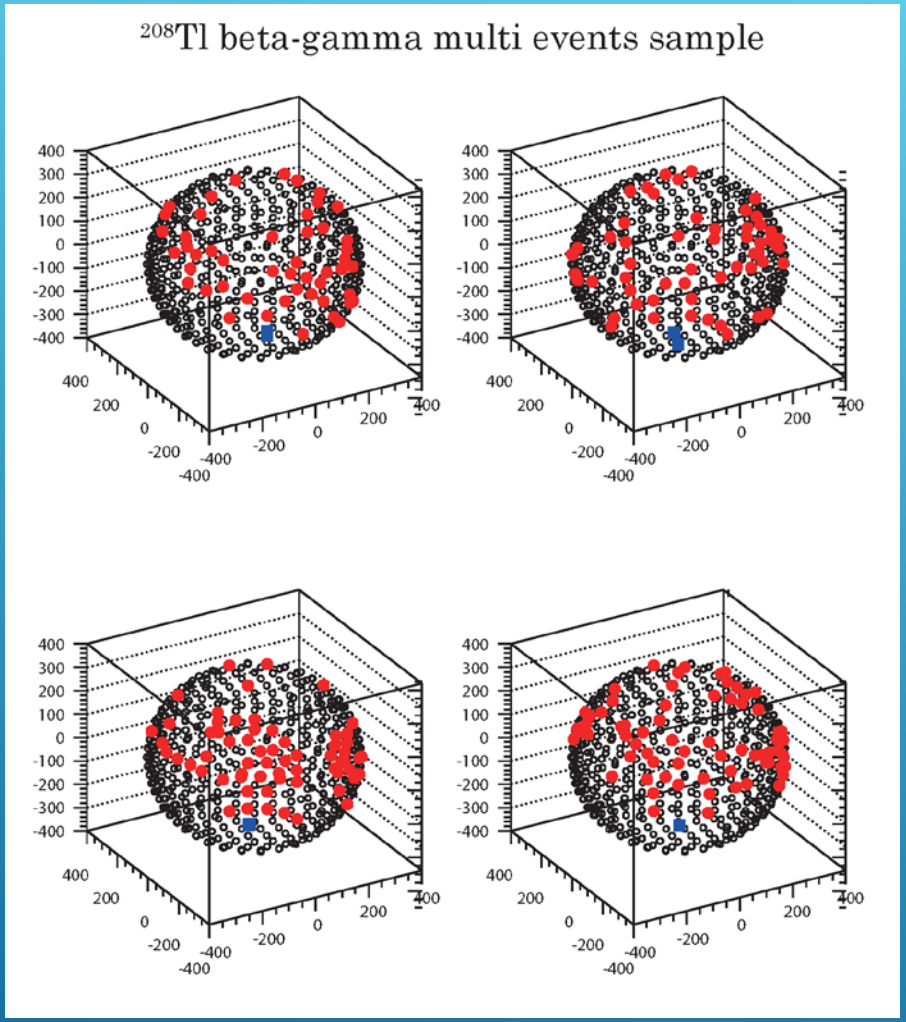


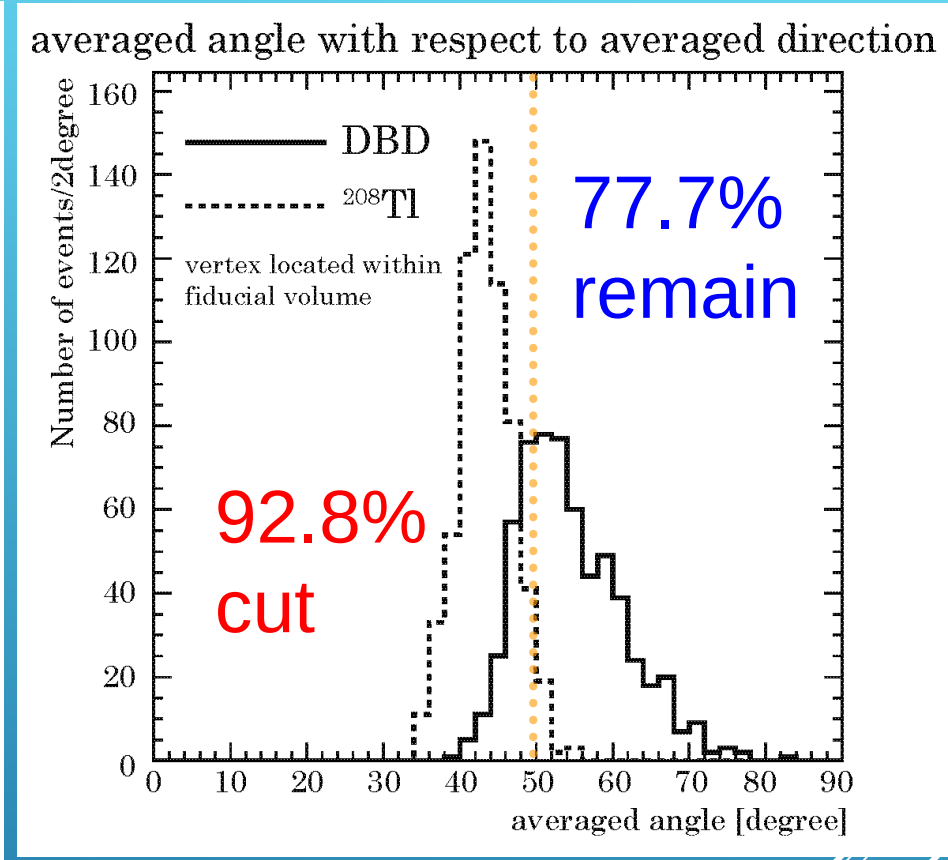
Generate position of DBD



Multi events from DBD tend to have a slightly larger values of averaged angle than single e^-.

Hit pattern of ^{208}Tl (2.6MeVγ+ β+γ)





Cherenkov hit pattern can be used for BG reduction.

Multi events from ^{208}Tl decay tend to have a smaller values of averaged angle than DBD.

Summary

- Conceptual design for ZICOS detector using 20" PMT with 64% photo coverage for detecting Cherenkov light is presented.
- Simulated Cherenkov lights with EGS5 show some directionalities and it could reproduce the angular dependence which was observed by real data.
- Need to develop PMT with high QE (>30%) and fast timing (TTS < ~1ns) in order to separate Cherenkov hits and obtain vertex resolution $\sigma \sim 10$cm.
- Further 1/20 reduction of ^{208}Tl (and ^{214}Bi) decay backgrounds could be realized by Cherenkov hit pattern even using vertex obtained by scintillation. (we should confirm using proto-type detector.)