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

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CRC将来計画タウンミーティング

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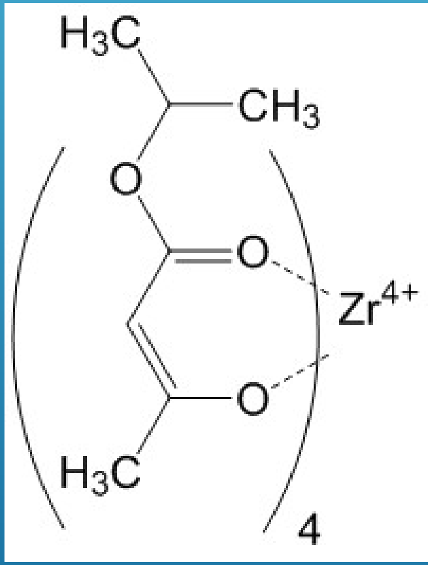
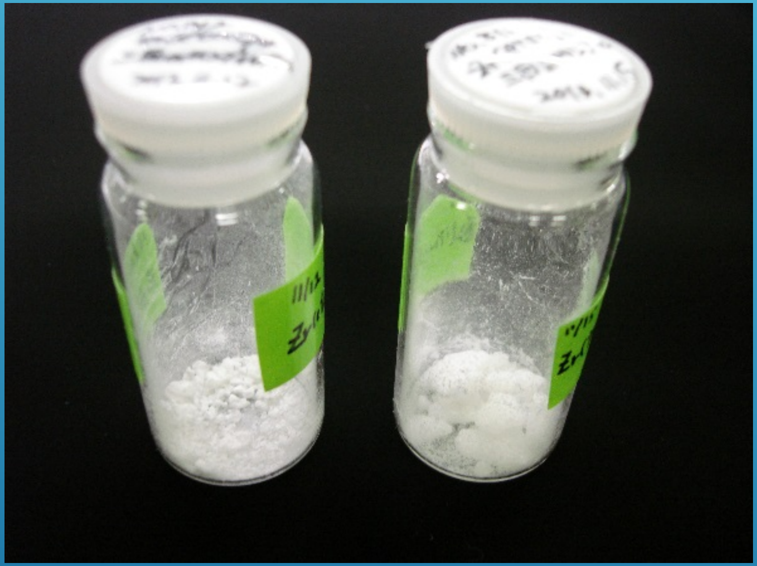
tetralkis(isopropyl acetoacetate) zirconium

$Zr(CH_3COCHCOOCH(CH_3)_2)_4$: $Zr(iprac)_4$
Molecular weights : 663.87





$Zr(iprac)_4$: 10 wt.% PPO: 5wt.% POPOP: 0.05wt.%

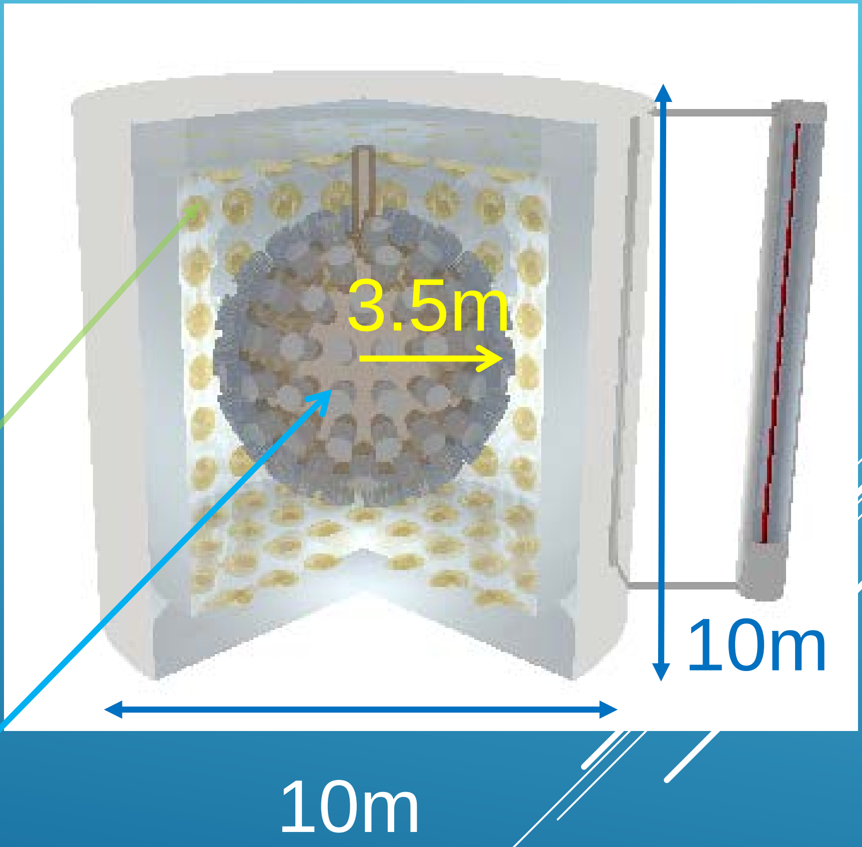
ZICOS- Zirconium Complex in Organic Liquid Scintillator for neutrinoless double beta decay

Liquid Scintillator:

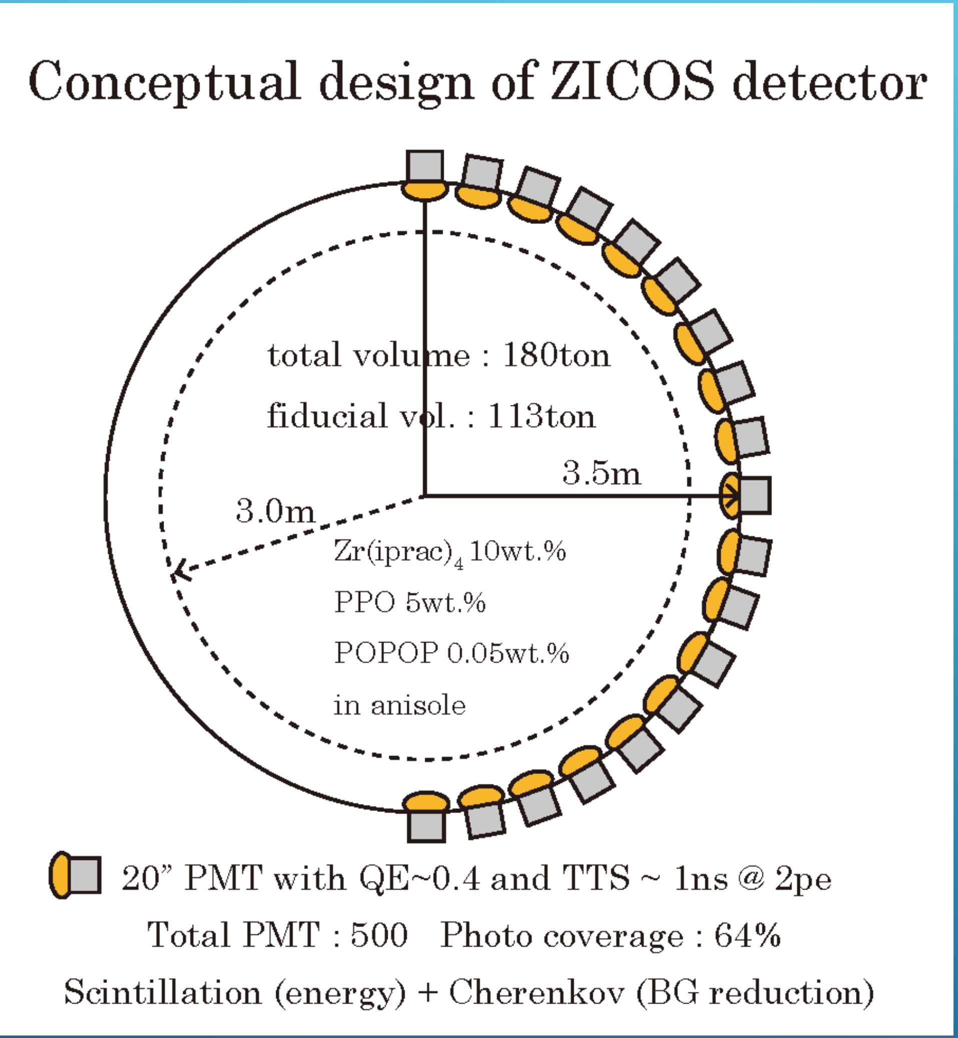
49% of BC505 for Light Yield and 3.5% at 3.35MeV for energy resolution assuming 40% photo coverage.

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)



Design of ZICOS detector



Natural abundance of ^{96}Zr : 3%

Detector :

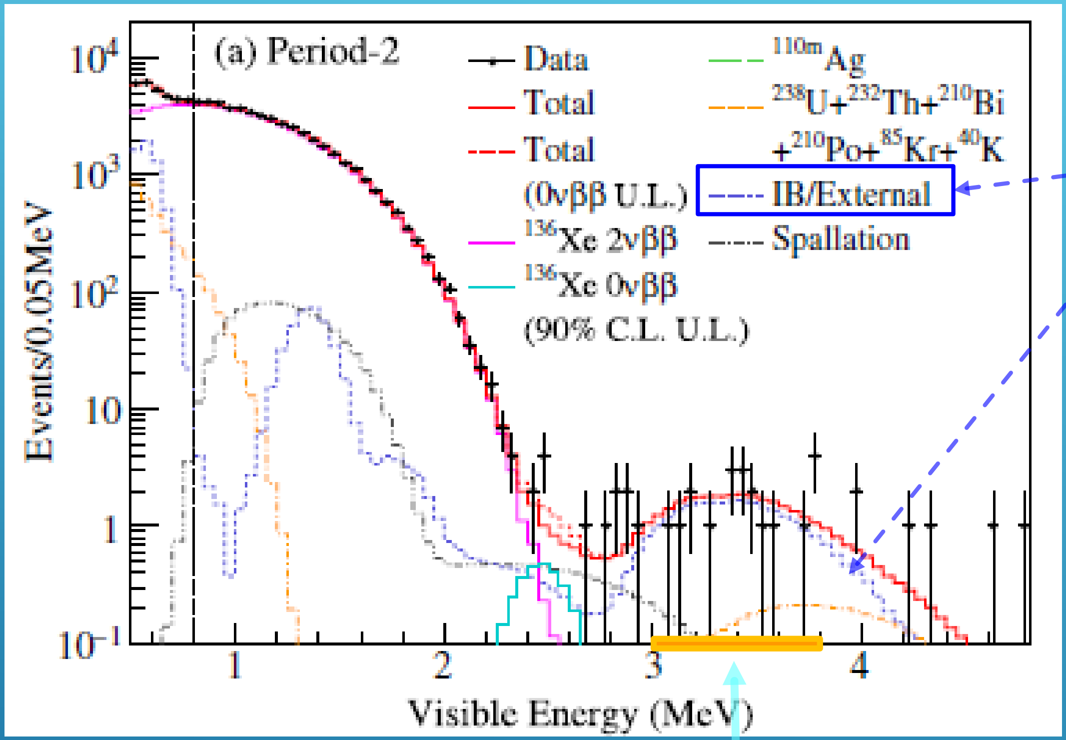
1) 180tons LS : 10 wt.% Zr(iprac)$_4$ with 5wt.% PPO in anisole
2) Need 500 of 20" PMT with high QE >0.3 and TTS < ~1ns = 64% photo coverage

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.

Backgrounds around signal region

Measured by KamLAND-Zen



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^{208}Tl on surface of balloon

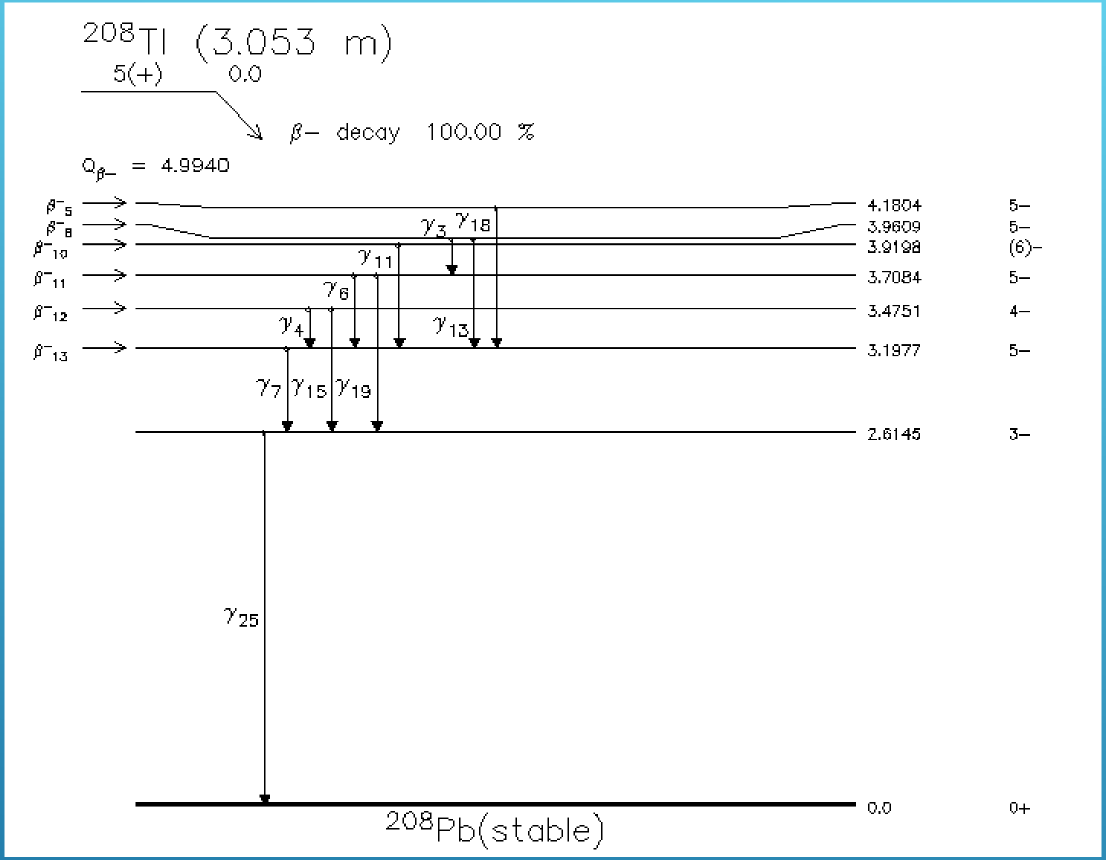
Lowering BG (^{208}Tl) < 1/20 ×KL-Zen (~1.0events/ton/year)

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

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

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

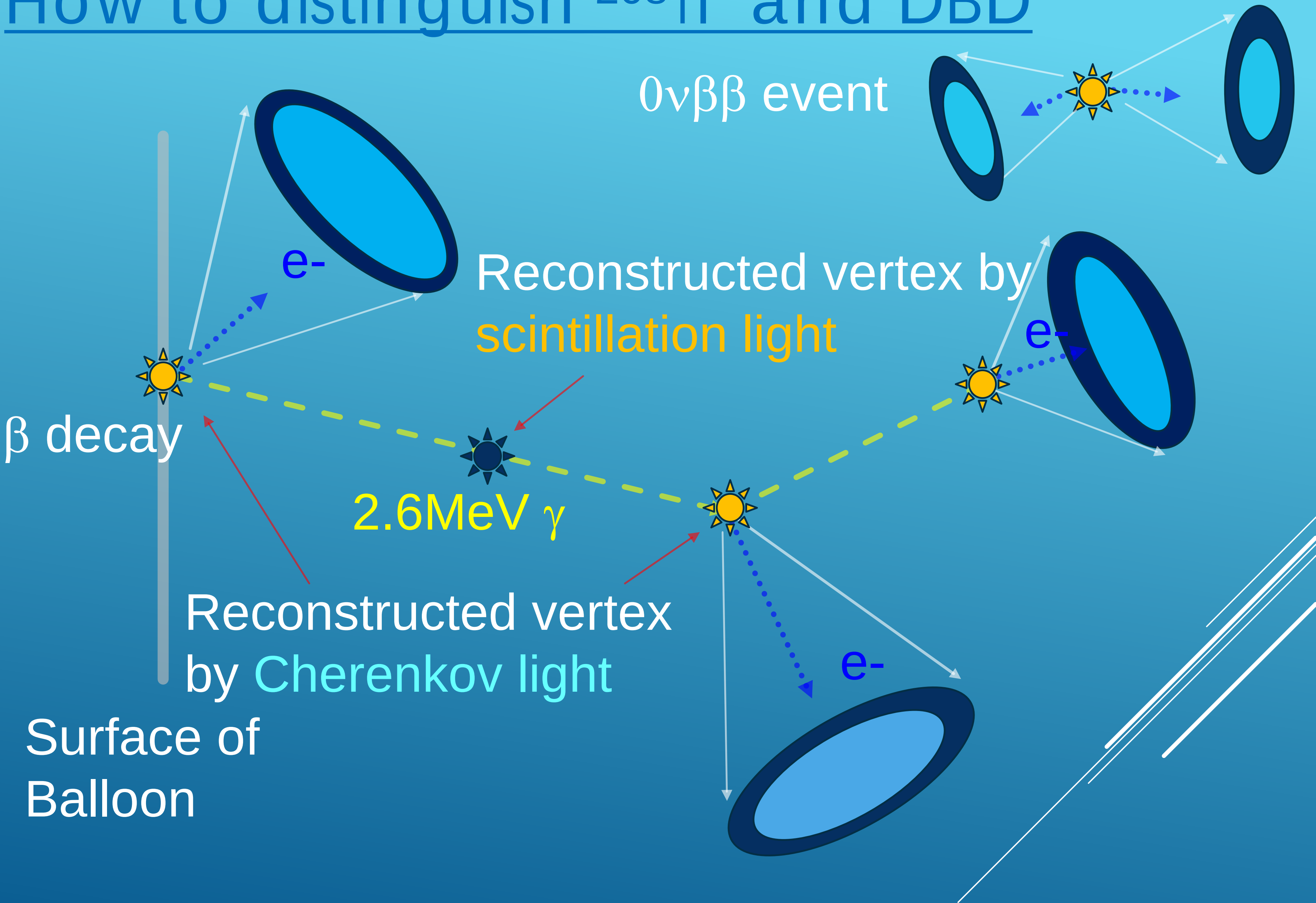
Radiation branch of Thallium-208



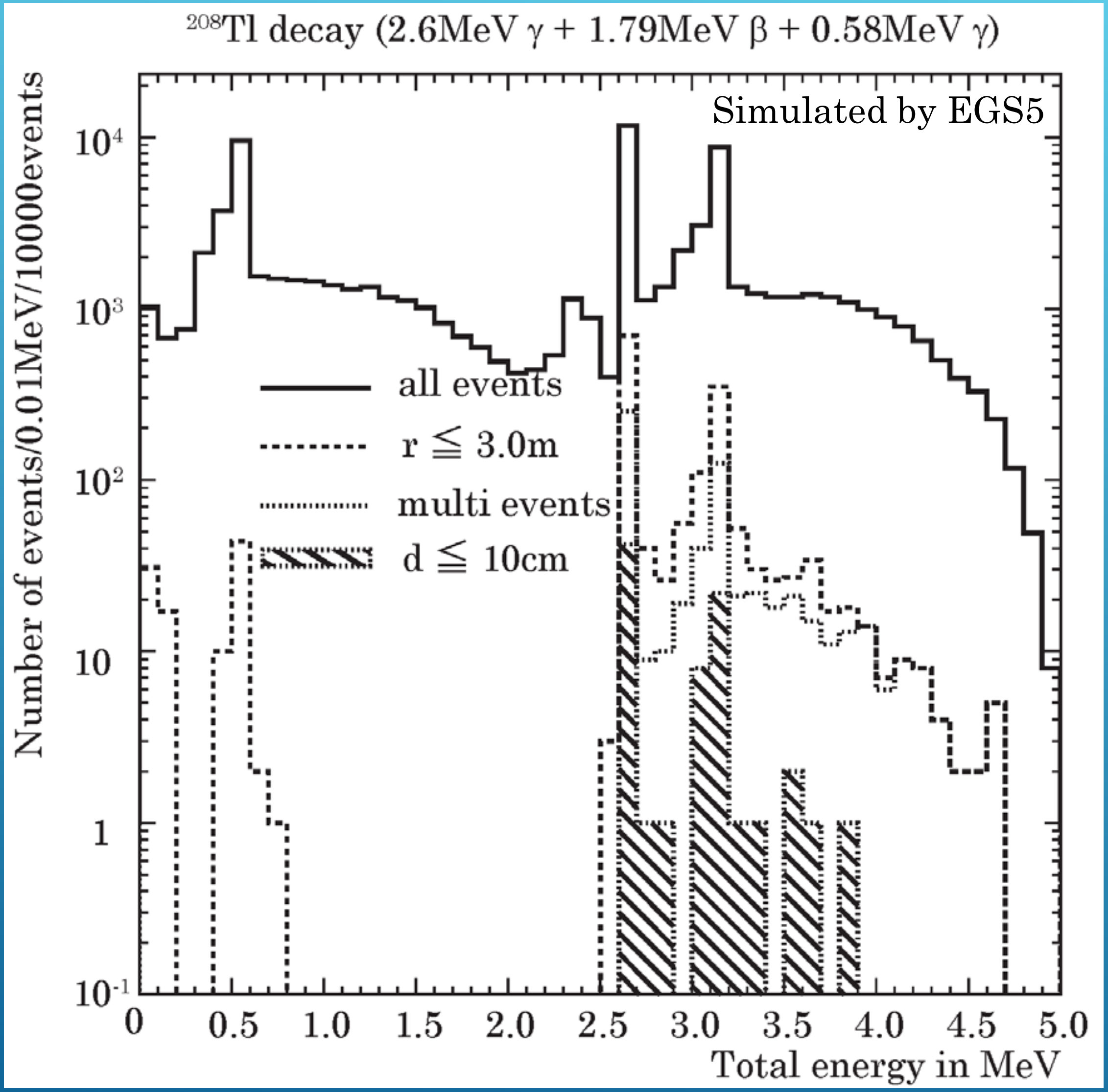
Radiations	y(i) $(Bq\text{-}s)^{-1}$
beta- 5	2.27×10^{-03}
beta- 8	3.09×10^{-02}
beta- 10	6.30×10^{-03}
beta- 11	2.45×10^{-01}
beta- 12	2.18×10^{-01}
beta- 13	4.87×10^{-01}
ce-K, gamma 3	4.04×10^{-03}
gamma 4	6.31×10^{-02}
ce-K, gamma 4	2.84×10^{-02}
ce-L, gamma 4	4.87×10^{-03}
gamma 6	2.26×10^{-01}
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 locate within fiducial volume due to mis-fitting of gammas.

How to distinguish ^{208}Tl and DBD



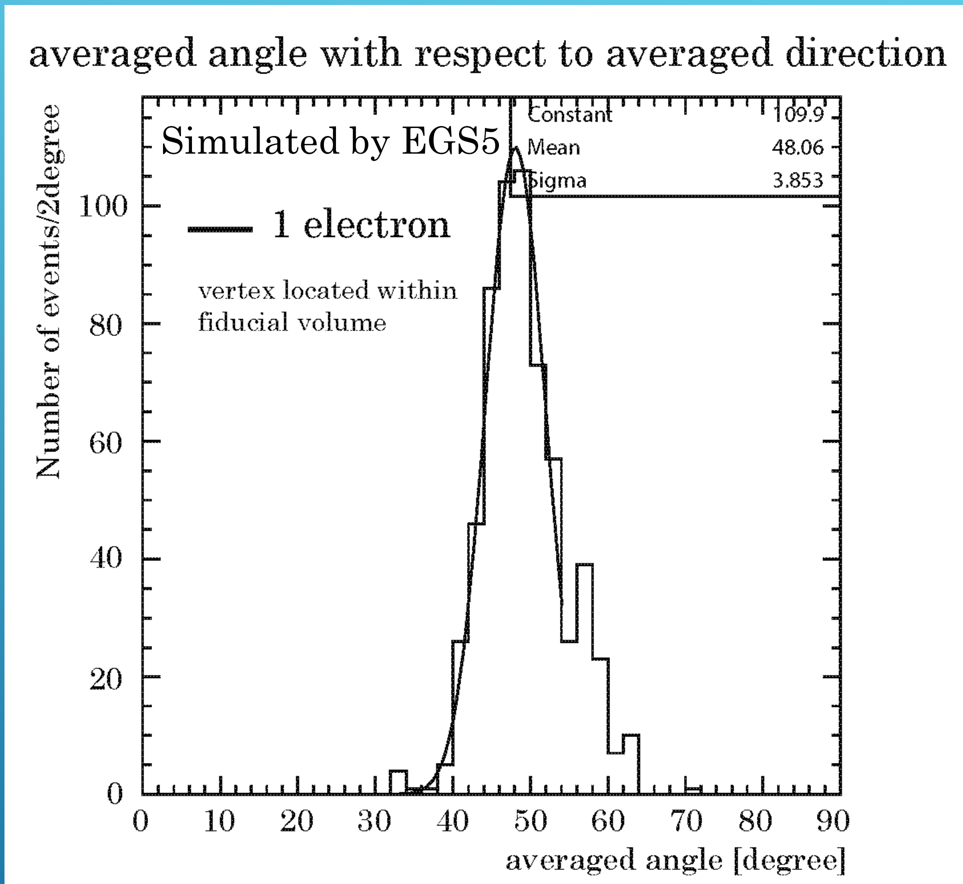
Reduction of ^{208}Tl decay



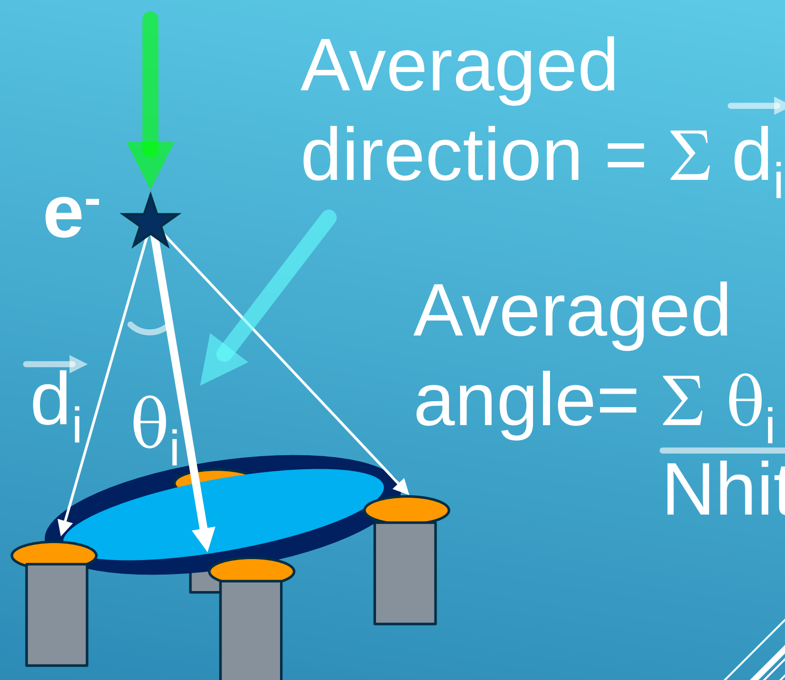
1) E : 3.0-3.7MeV
   17925 events
2) Fiducial volume
   628 events
3) Multi events
   263 events
4) Closer events (d≦10cm)
   35 events

~1/20 BG reduction could be achieved by vertex reconstruction.

Averaged angle of Cherenkov hit

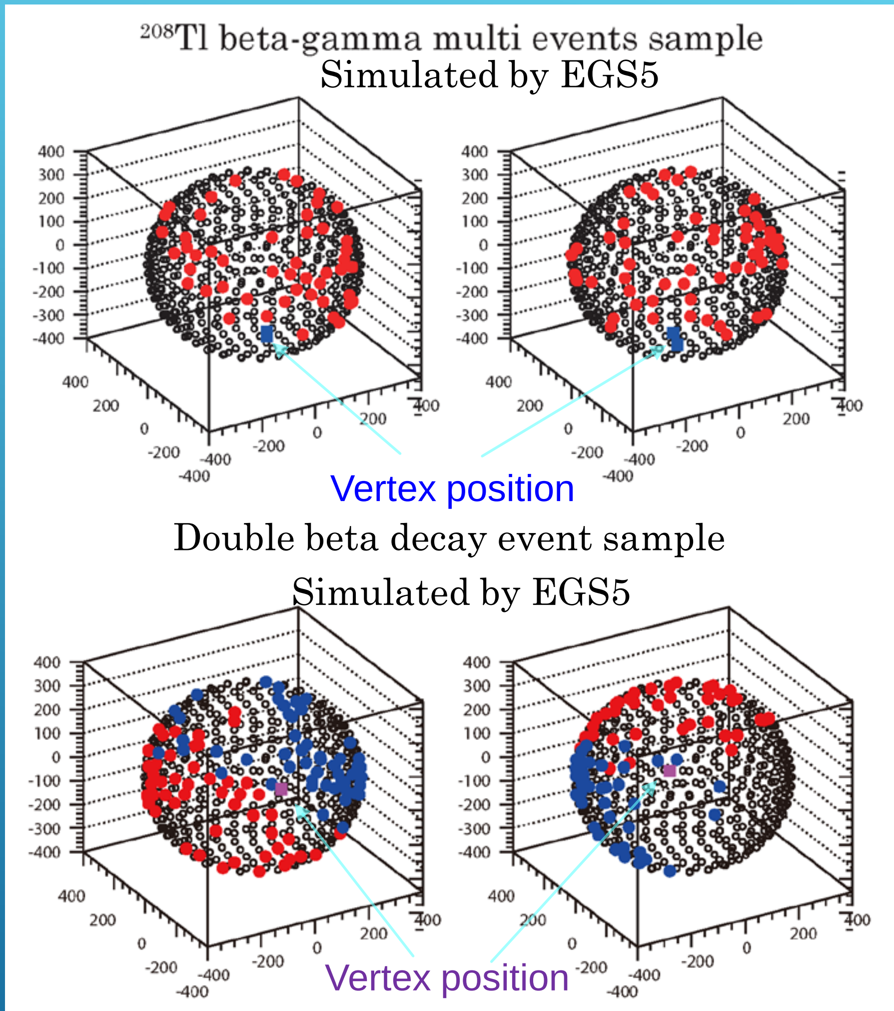


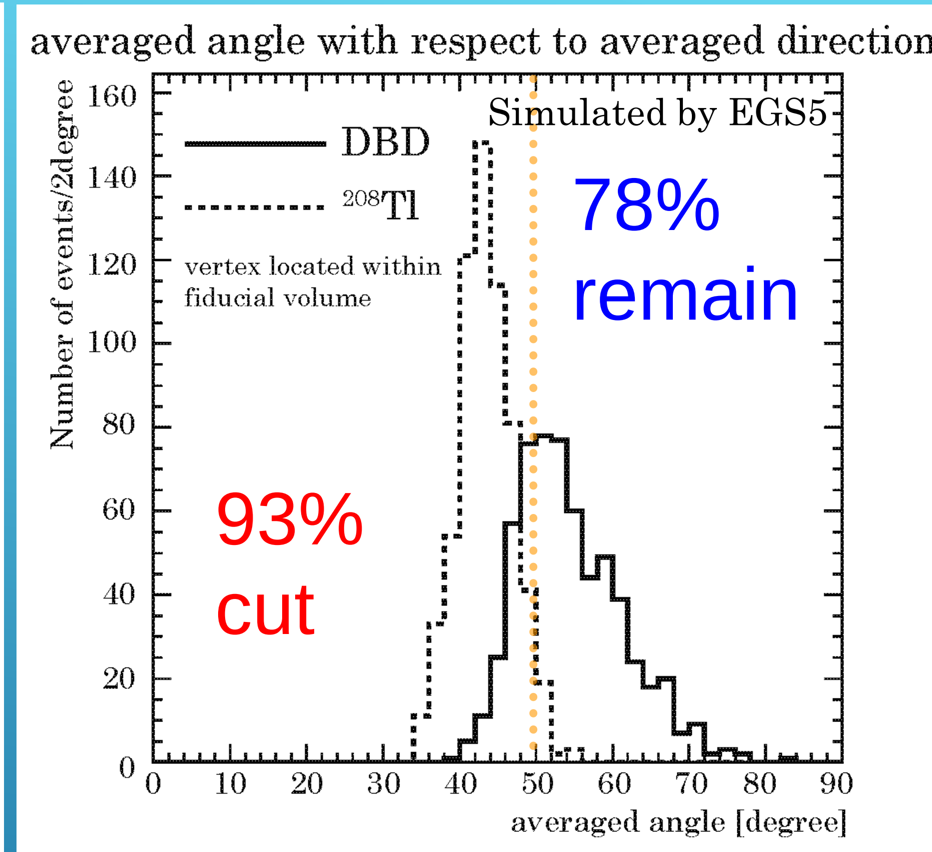
Vertex position obtained by scintillation



Averaged angle distribution with respect to averaged direction for single electron has a peak at ~48 degree, which is almost same as Cherenkov angle.

Hit pattern of ^{208}Tl decay and DBD



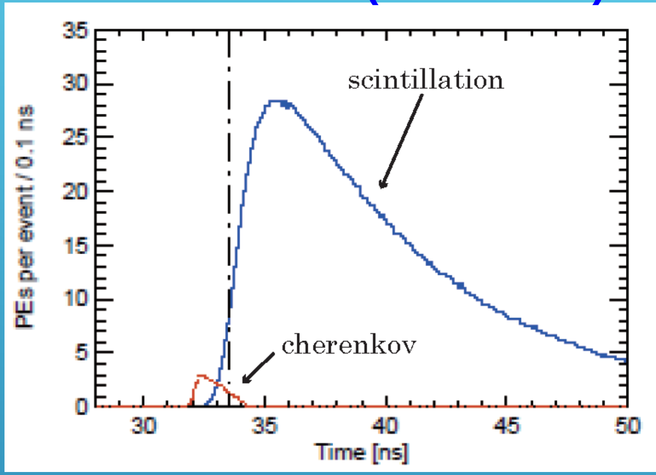


Cherenkov hit pattern of ^{208}Tl decay looks different from DBD .

Averaged angle of ^{208}Tl decay is smaller values than that of DBD.

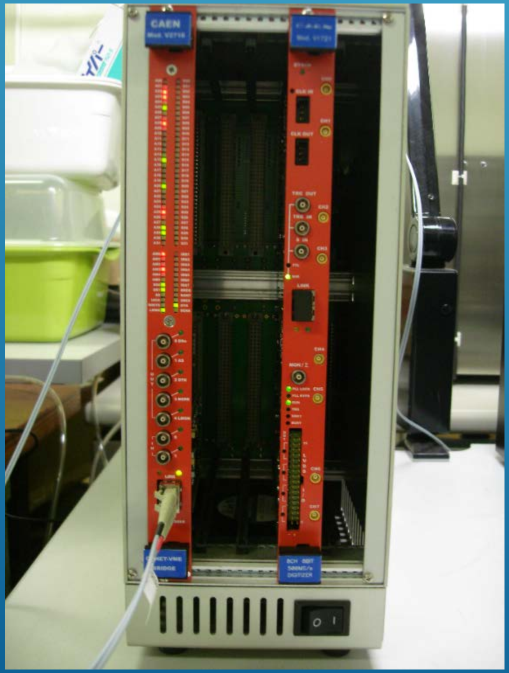
Separation of Cherenkov and Scintillation

arXiv:1609.0986(simulation)



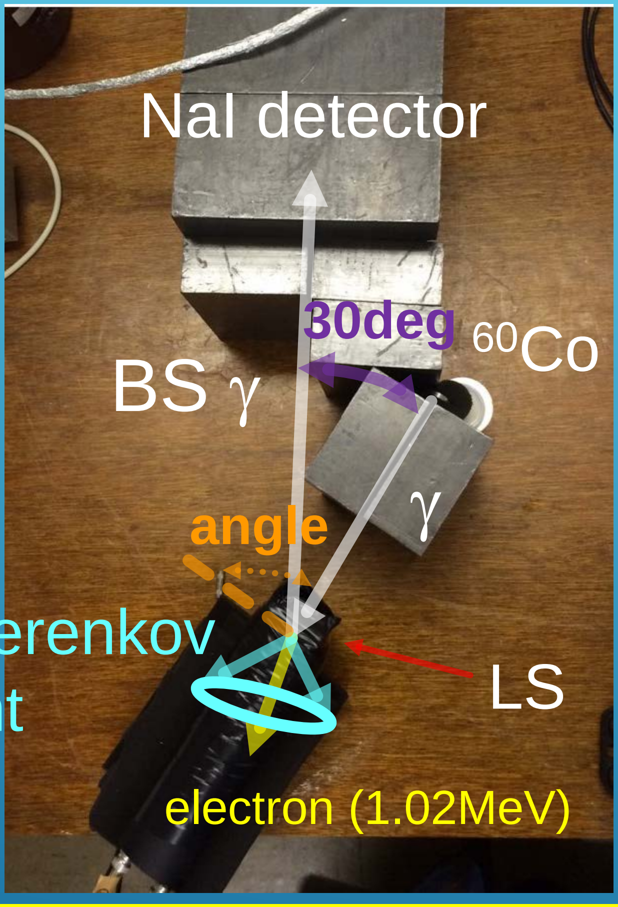
- Rise time of Cherenkov light : an order of 100 ps due to the electro-magnetic process
- Rise time of Scintillation light: an order of ns in general.

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



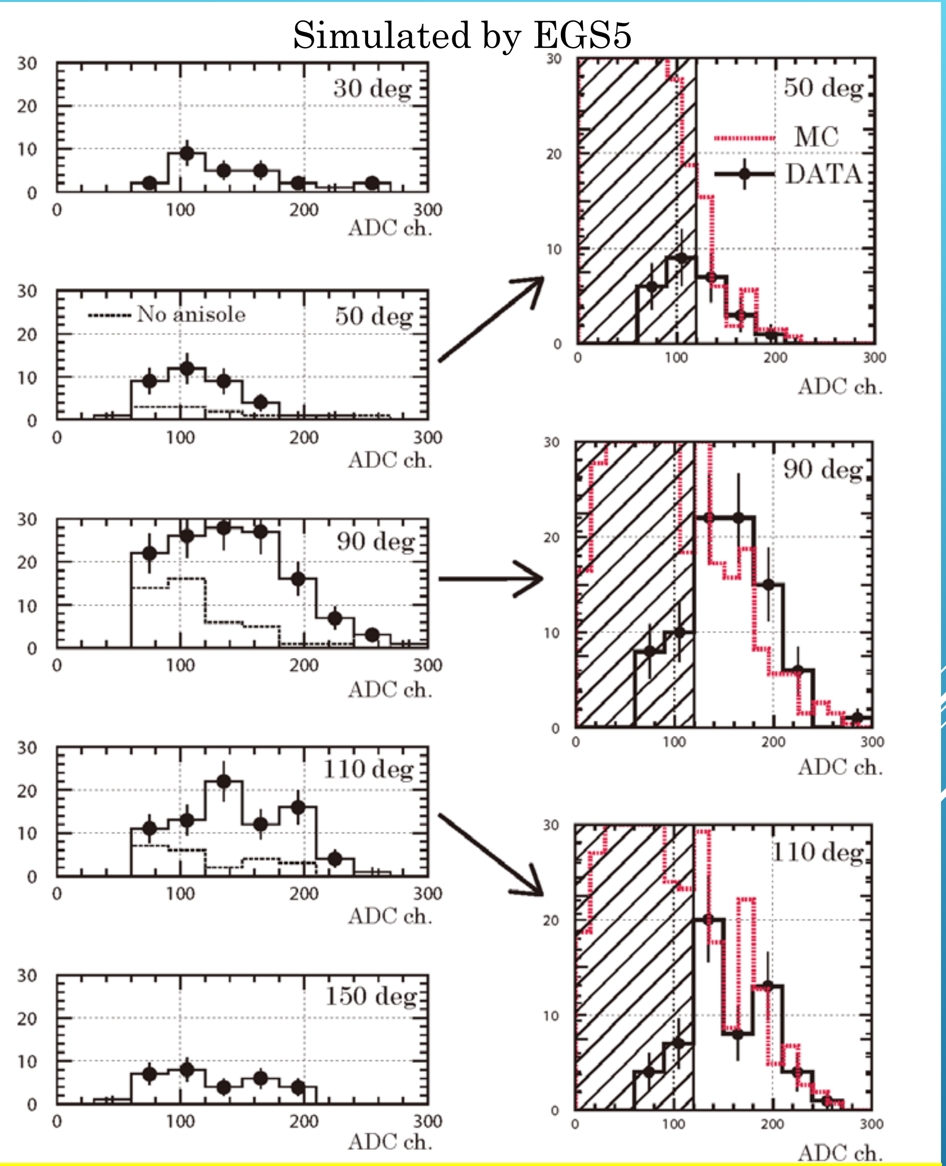
・CAEN V1721 8 channel 8bit 500MS/s FADC
・CAEN V2718 VME-PCI Optical Link Bridge

Directionality



Cherenkov light from ~1MeV electron seems to have a directionality.

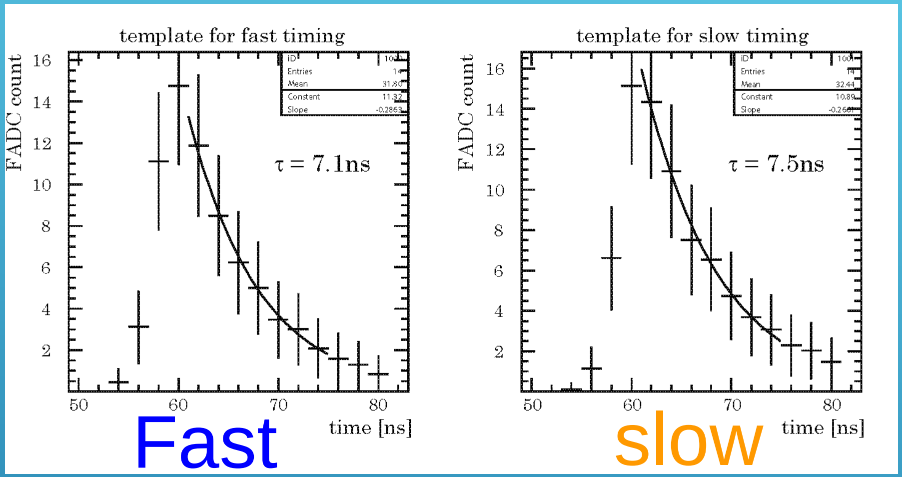
Anisole only



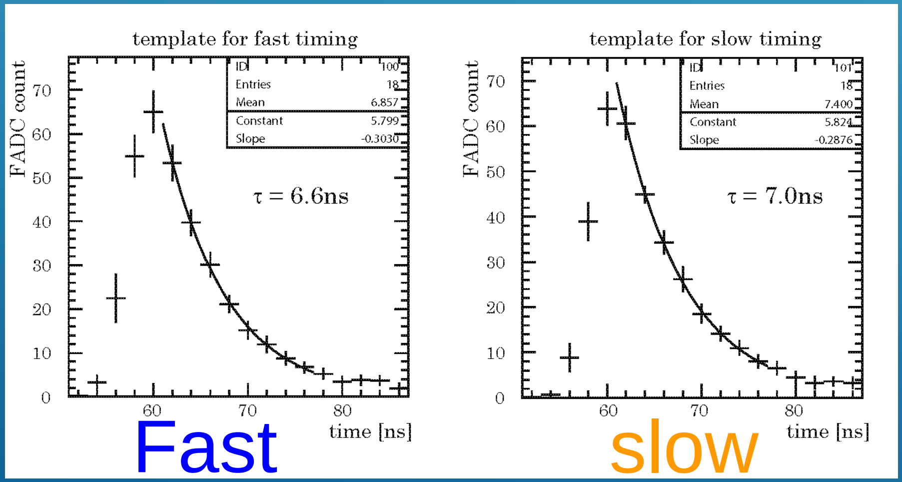
MC reproduced such a directionality.

Pulse shape of timing information

Anisole only



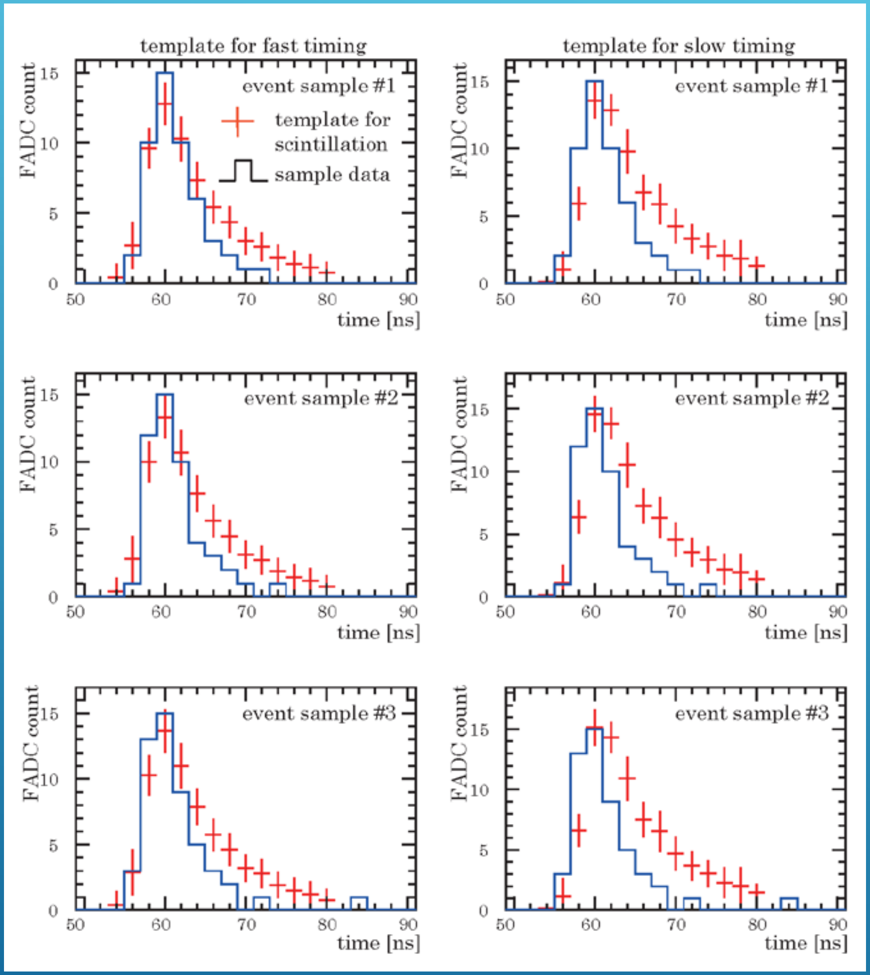
Zr(iprac)$_4$ loaded LS



- Templates of pulse shape of timing information for scintillation light were obtained by FADC.
- Fast and slow rise time component were observed due to FADC resolution.
- Both decay time of scintillation light are about 7ns.

Pulse shape observed in anisole only

90deg



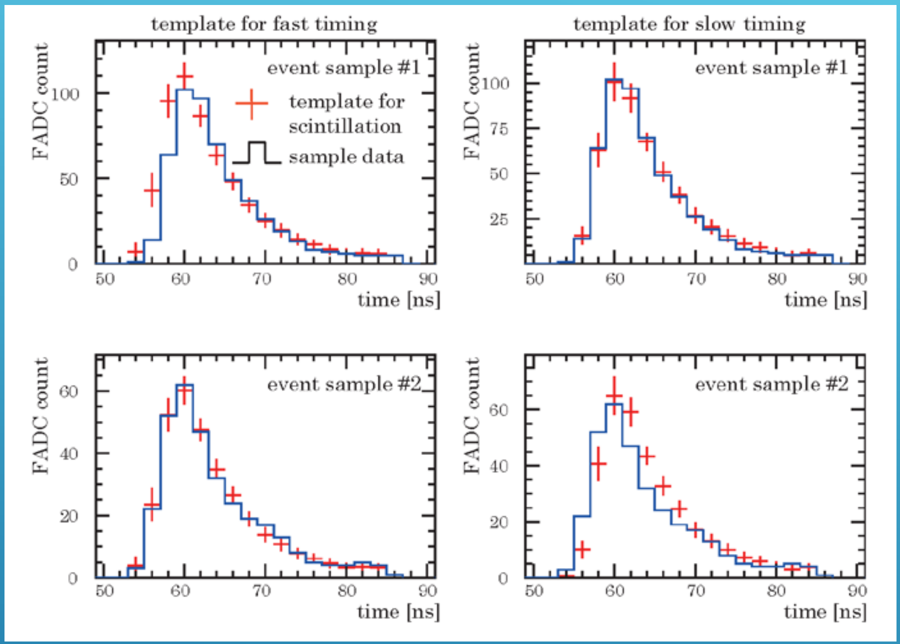
- 70% of events have a different pulse shape of timing from scintillation.
- It is shorter rise time and decay time.

Those events might mainly consist of Cherenkov lights, because of low QE for wave length of scintillation.

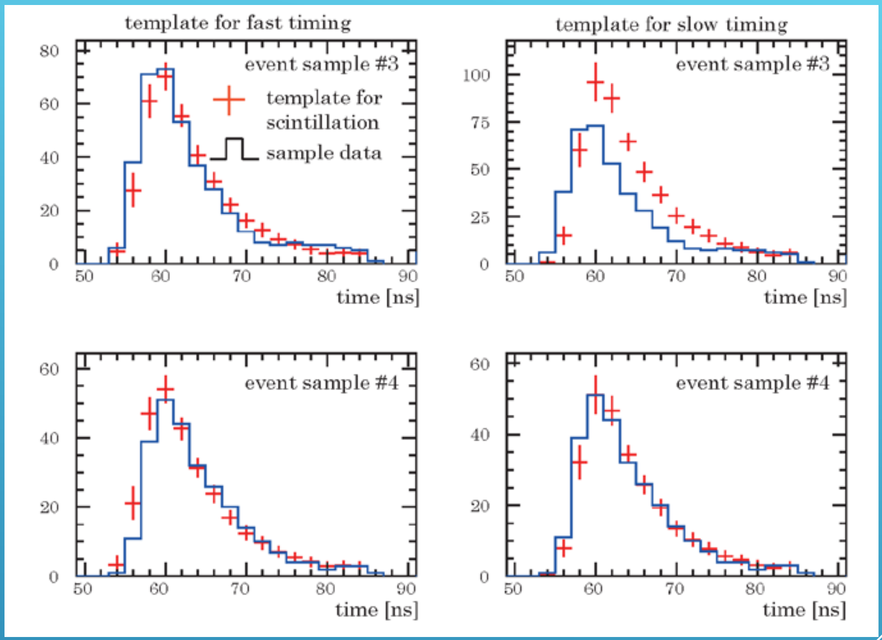
Same pulse shapes were also observed in H_2O.

Pulse shape observed in Zr loaded LS

Scintillation-like



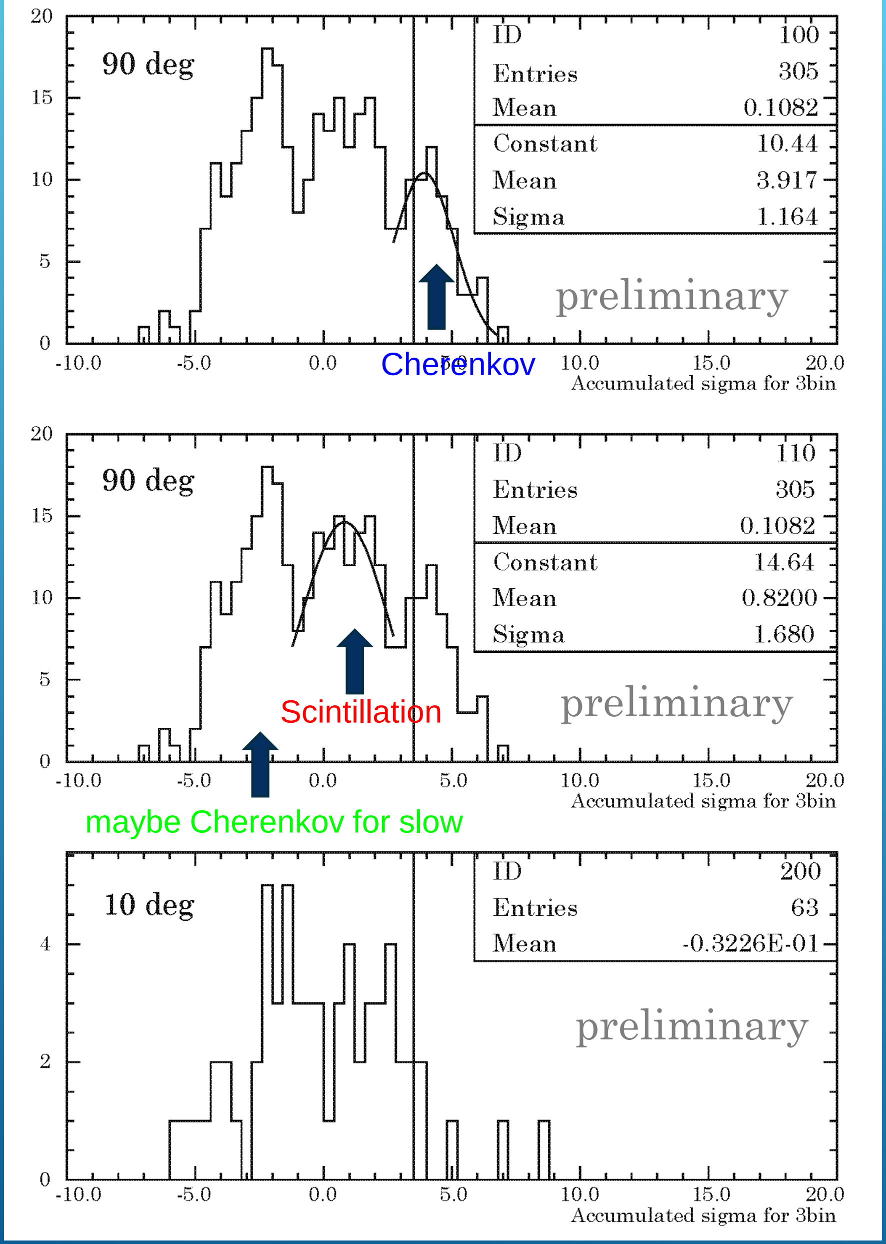
Cherenkov-like



Two types of pulse shape (Scintillation-like and Cherenkov-like) were observed.

Differences of sigma between data and template were accumulated by first 3bins.

Accumulated sigma

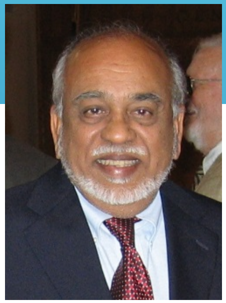


- 90deg (total 305 events)
  Cherenkov-like 49 events
  16.1 ± 2.3 %
- 10deg (total 63 events)
  Cherenkov-like 6 events
  9.5 ± 3.9 %

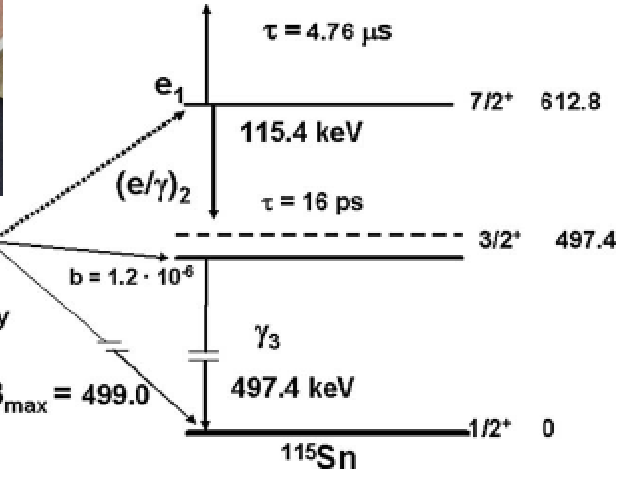
Stat. Significance : 2.2σ
(need more study)

Probably Cherenkov light could be discriminated by pulse shape of timing.

pp solar neutrino measurement using ^{115}In



R.S.Raghavan Phs.Rev.Lett37(1976)259



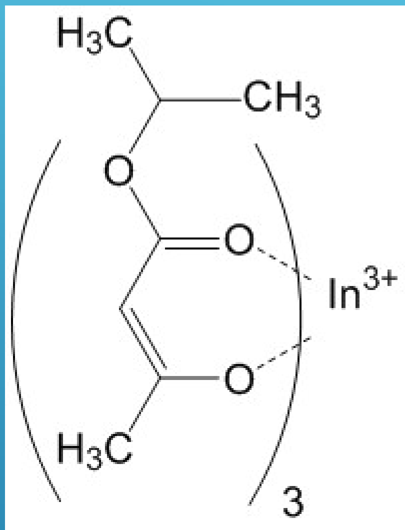
^{115}In + $\nu_e \rightarrow$ $^{115}Sn^*$ + e^-
$^{115}Sn^*(4.76\mu s) \rightarrow$ ^{115}Sn +
$\gamma_1(115keV) + \gamma_2(497keV)$

● Advantage
- large natural abundance (95.7%)
- large cross section (~640SNU)
- direct counting (real-time measurement)
- sensitive to low energy solar neutrinos ($E_\nu \geqq 125keV$)
- energy measurement ($E_e = E_\nu - 125keV$)
- triple fold coincidence to extract neutrino signal from BG ($e_1 + \gamma_2 + \gamma_3$)

● Disadvantage
- natural β-decay of ^{115}In ($\tau_{1/2} = 4.4 \times 10^{14}$ yr , $Ee \leqq 498keV$)
- possible BG due to correlated coincidence by radiative Bremsstrahlung

Requirement :
1. Good energy resolution : ~10%@100keV(FWHM)
2. High efficiency γ detection
3. (High granularity)

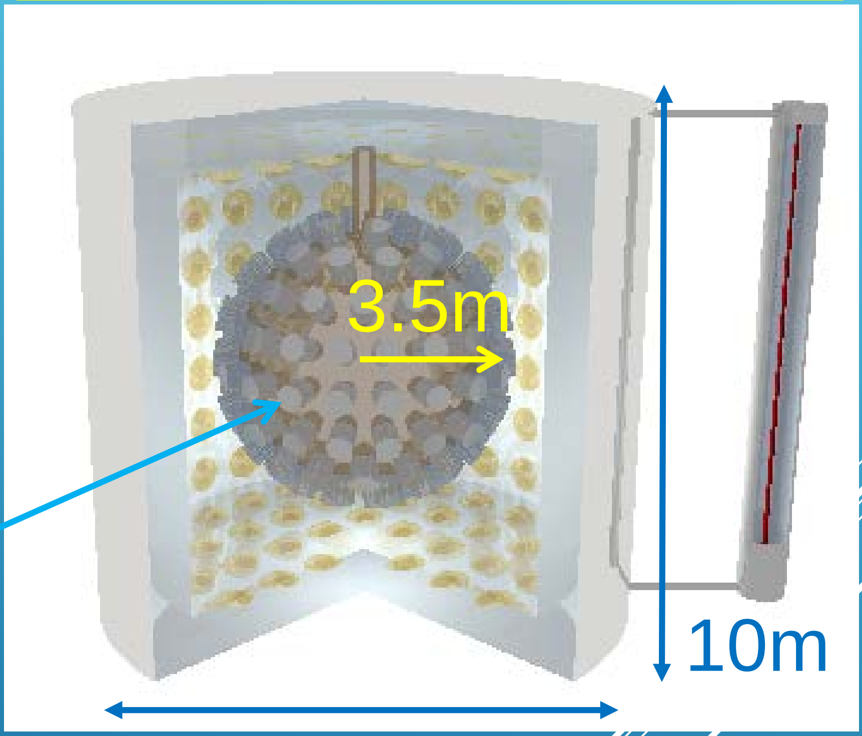
ZICOS : Zirconium - Indium Complex in Organic liquid Scintillator



Tris(isopropyl acetoacetate) indium : $In(iprac)_3$

MW : 544.3

Liquid Scintillator：10 wt.% $In(iprac)_3$ loaded in anisole.



2.53 ton of ^{115}In loaded LS in 113ton fiducial volume. (0.73 event/day)

Estimated energy resolution ~16%@100keV (not so bad!)

pp solar ν is possible physics target .

Summary

- Conceptual design for ZICOS detector (10 wt.% Zr(iprac)$_4$ loaded Liquid Scintillator with 64% photo coverage of 20” PMT) for ^{96}Zr DBD search (and ^{115}In pp solar ν measurement).
- Monte Carlo simulation indicated the directionality of Cherenkov light even from *O*(1MeV) electron.
- Further 1/20 backgrounds reduction for ^{208}Tl (and also ^{214}Bi) could be achieved by the vertex position or the hit pattern obtained by Cherenkov light.
- Probably we will be able to extract Cherenkov signals using the pulse shape discrimination.