ZICOS - Neutrinoless Double Beta Decay experiment using Zr-96 with an organic liquid scintillator -

International Symposium on Revealing the history of the universe with underground particle and nuclear research 2019, 7 – 9 March 2019 Sendai Japan

Y.Fukuda[a] , D.Anzai[a], Y.Kamei[a,e], K.Hiraide[b], S.Moriyama[b], Narengerile[a], A.Obata[a], I.Ogawa[c], T.Gunji[d], S.Tsukada[d] , R.Hayami[d], S.Kurosawa[f]

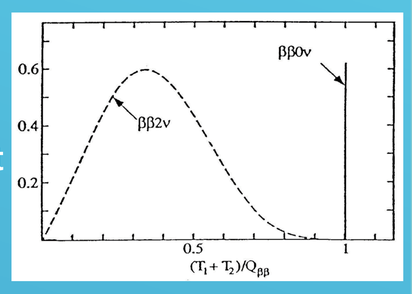
[a] Miyagi Univ. of Education [b] Kamioka Observatory, ICRR, Univ. of Tokyo [c] Univ. of Fukui [d] Tokyo Univ. of Science [e] RCCN Tohoku Univ. [f] IMR Tohoku Univ.

Supported by Grant-in-Aid for Scientific Research on Innovative Areas 26105502 and Scientific Research (C) 18K03664

1. ZICOS (^{96}Zr DBD experiment)

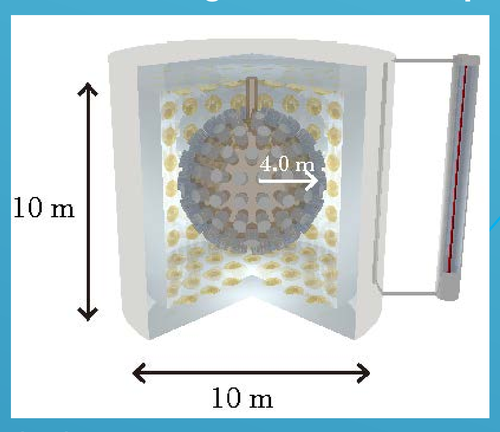
◆ **Neutrinoless double beta decay**

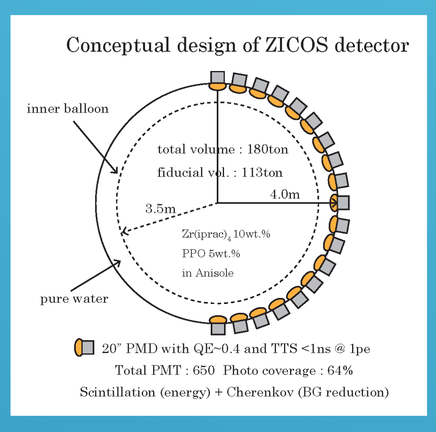
- **Lifetime and neutrino mass**
  $[T_{1/2}^{0\nu}(0^+ \to 0^+)]^{-1} = G_{0\nu}(E_0,Z)|M_{0\nu}|^2\langle m_\nu\rangle^2$
- **Energy spectrum and lifetime measurement**
  - **monochromatic energy at Q-value**
  - **$T_{1/2}$~a(Mt/ΔEB) a: abundance M: mass t: meas.time ΔE: energy res. B: BG rate**



Low background rate, Large target mass and High energy resolution

◆ **Detector design for ZICOS experiment**





Detector :
1)180tons LS : 1.5 wt.% Zr and 5wt.% PPO in Anisole .
2)Need 500 of 20" PMT with high QE ~0.4 and TTS ~300ps@1pe for 64% photo coverage.

Expected performance :
1)Energy resolution ~2.8%@3.35MeV

2)$T_{1/2}(0\nu\beta\beta) > 10^{27}$years if both 1/20 BG reduction and 50% ^{96}Zr enrichment could be achieved.

◆ **Neutrino mass sensitivity for ZICOS experiment**

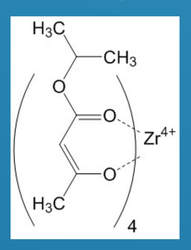
- **Total mass : 180ton (fiducial volume : 113ton)**
- **Measurement time: 2years**
- **10wt.% of $Zr(iPrac)_4$ = 12.6ton of $Zr(iPrac)_4$ includes 1.7ton of Zirconium = 45 kg of ^{96}Zr (using natural abundance 2.6%)**

$T_{1/2}^{0\nu} > 4\times10^{25}$y ← Not enough for 0νββ search

◆ **Requirements in order to realize 0νββ GEN-III experiment**

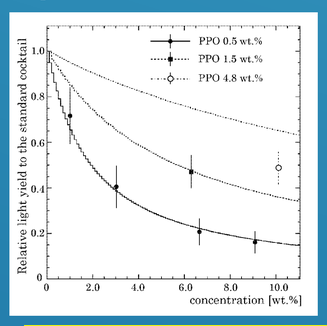
1) 50% enrichment of ^{96}Zr (e.g. 57.3% for NEMO-3)
then ^{96}Zr will be 865kg → $T_{1/2}^{0\nu} > 2\times10^{26}$y
2) ^{208}Tl background reduction
BG level < 1/20 × KL-Zen → $T_{1/2}^{0\nu} > 1\times10^{27}$y

◆ **Development of Zr loeaded Liquid Scintillator**



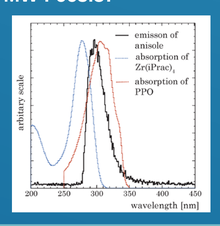
tetrakis (isopropyl acetoacetate)
Zirconium : $Zr(iPrac)_4$
MW : 663.87

Zr-LS: $Zr(iPrac)_4$ 10wt.%, PPO 5 wt.% and POPOP 0.2wt% solved in Anisole.



1) Light yield : 48.7 ±7.1% of BC505
2) energy resolution :
$$\frac{13.0\pm2.0\%}{\sqrt{(64\%/9.2\%)}\times(3.35\mathrm{MeV}/1.03\mathrm{MeV})} = 2.7\pm0.4\% \text{ at } 3.35\mathrm{MeV}\ (6.4\%\ \mathrm{FWHM})$$

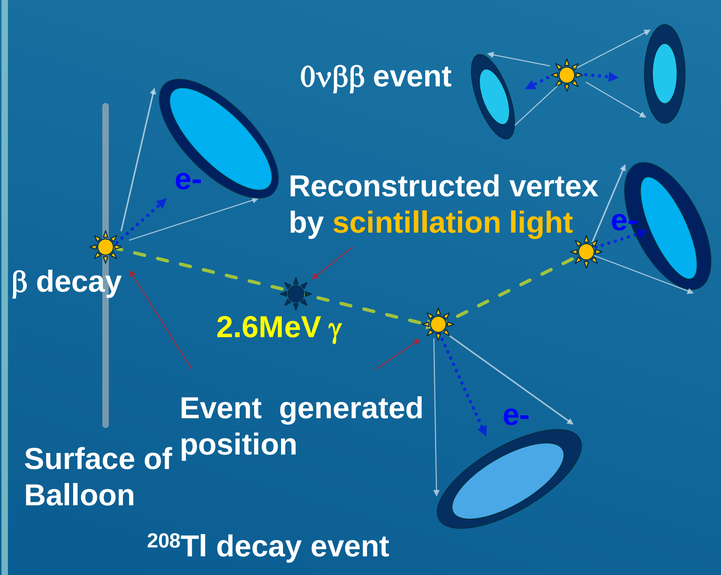
Need to measure real energy resolution

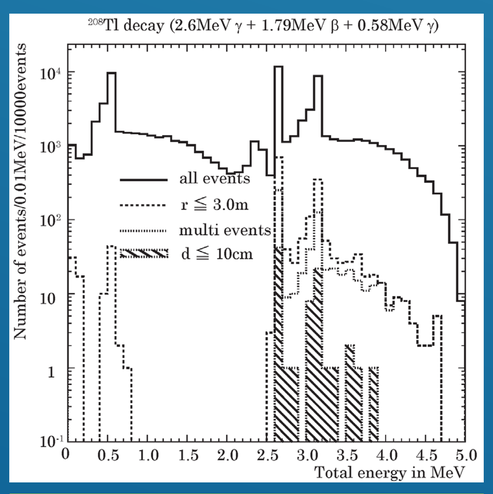


Shorter wavelength of absorption for $Zr(iPrac)_4$ and amount of PPO recover both light yield and energy resolution of Zr-LS .

2. How to reduce backgrounds

◆ **Conceptional idea using Cherenkov lights**





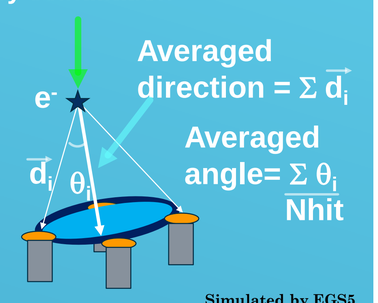
~1/20 BG reduction could be achieved by using a topology information of Cherenkov light.

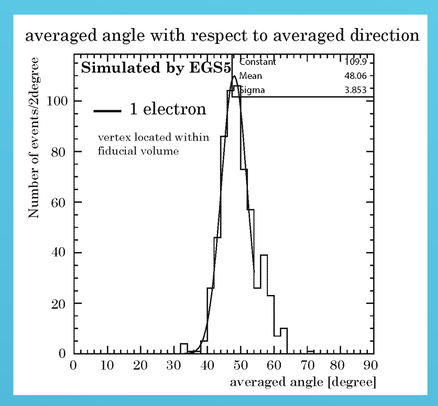
Cherenkov light could be used for tool of ^{208}Tl BG reduction.

3. Development of reduction technique

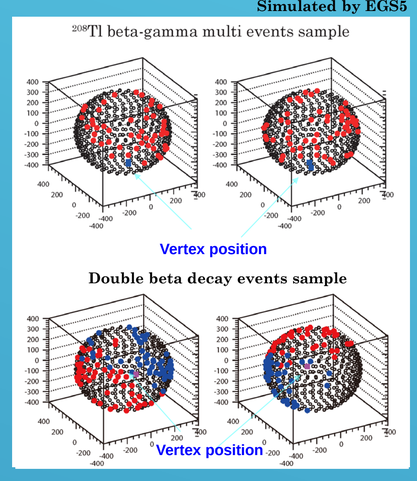
◆ **Reduction of ^{208}Tl events using Cherenkov Lights**

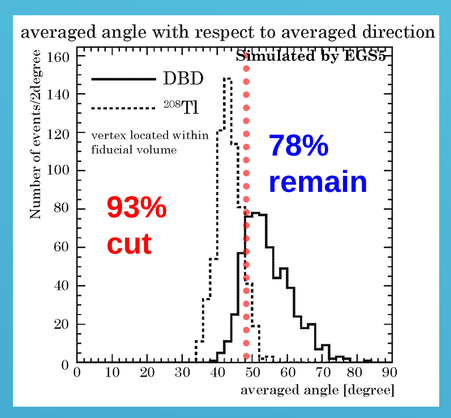
Vertex position obtained by scintillation





The averaged angle distribution with respect to the averaged direction of single electron has a peak at ~48 degree which is almost same value as Cherenkov angle in Anisole.





The averaged angle of ^{208}Tl decay is smaller than that of DBD.

Possible to reduce ^{208}Tl BG to be order of 1/20, if we can extract Cherenkov lights from scintillation.

4. Observation of Cherenkov lights

◆ **Pulse shape measured by fast FADC and PMT**

CAEN V1751 digitizer

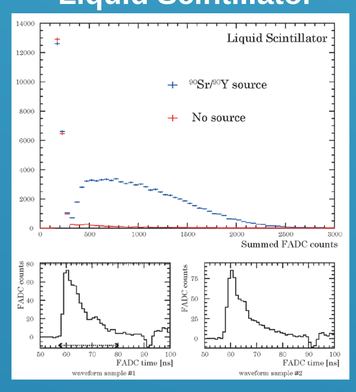
Specification
- 4channel
- 10bit ADC
- 1GS/s sampling
- Auto/External trigger

Hamamatsu H2431-50

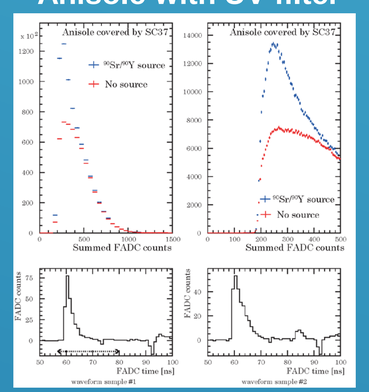
Specification
- Line focus 8
- 3000V
- 2.5×10^6 gain
- 0.37ns (TTS)
- 0.7ns (rise time)

◆ **Cherenkov lights observed by electrons from ^{90}Sr/^{90}Y source**

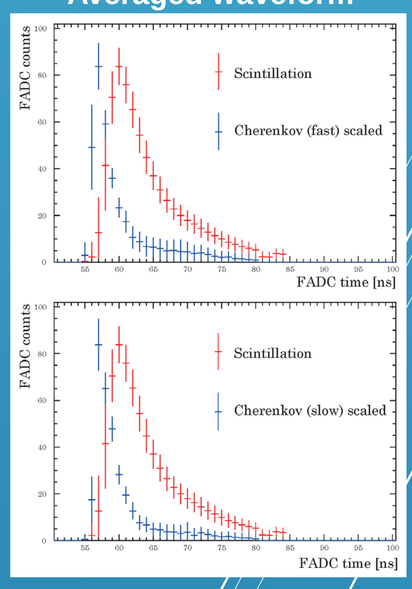
Liquid Scintillator



Anisole with UV filter

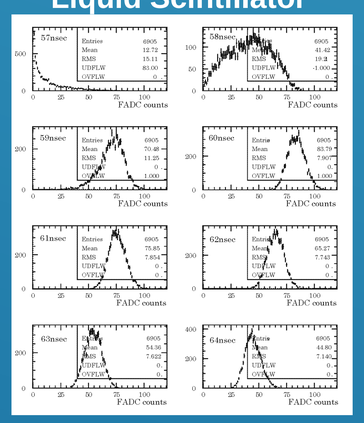


Averaged waveform

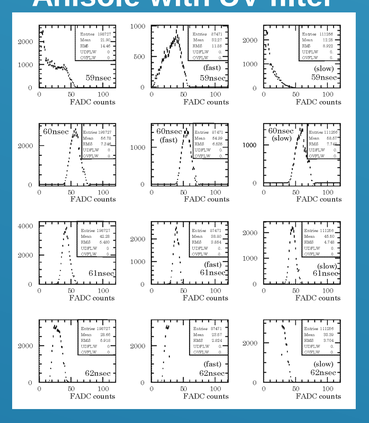


◆ **FADC counts plot at each FADC time**

Liquid Scintillator



Anisole with UV filter



There is clear difference for both rise and fall time between Cherenkov and Scintillation light.

PSD could be used for ID of PMT received Cherenkov .

5. Results and Future

- **Conceptual design of ZICOS detector with 10 wt.% $Zr(iprac)_4$ loaded Liquid Scintillator has 2.7% @3.35MeV energy resolution assuming 64% photo coverage of 20" Photo-multiplier.**
- **A technique further 1/20 reduction of ^{208}Tl backgrounds using PMT hit pattern of Cherenkov lights was developed.**
- **Direct measurement of pulse shape of Cherenkov and Scintillation light using electrons from ^{90}Sr/^{90}Y beta source was done, and both rise and fall time were quite different from each others.**
- **Pulse shape discrimination could be used for the identification of PMT which receives Cherenkov lights.**
- **Averaged angle will be measured by real proto-type detector HUNI-ZOCOS.**