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

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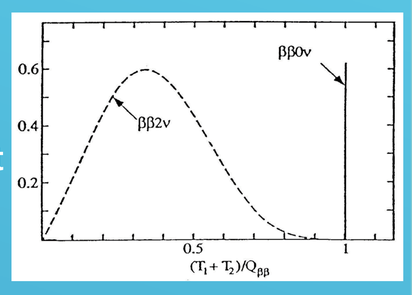
1. ZICOS (^{96}Zr DBD experiment)

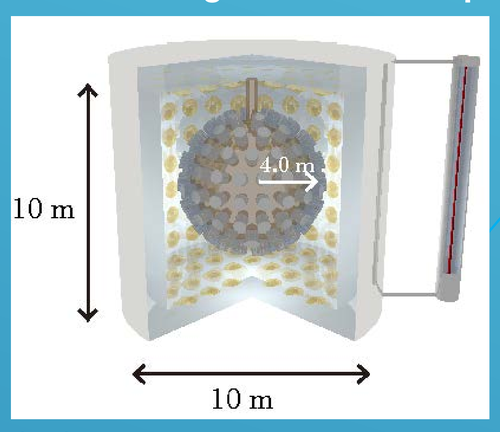
◆ Neutrinoless double beta decay

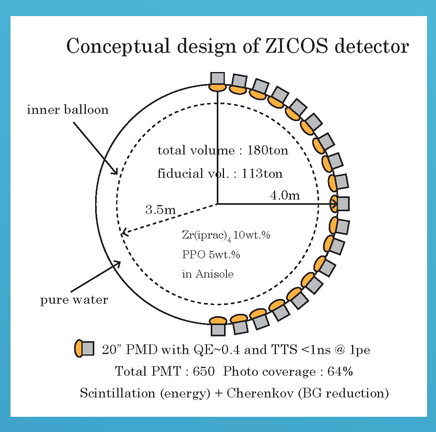
- Lifetime and neutrino mass
  $[T_{1/2}^{0\nu}(0^+ \to 0^+)]^{-1} = G_{0\nu}(E_0,Z)|M_{0\nu}|^2 \langle m_\nu \rangle^2$
- Energy spectrum and lifetime measurement
  - monochromatic energy at Q-value
  - $T_{1/2}$~a(Mt/ΔEB) a: abundance M: mass
    t: meas.time ΔE: energy res. B: BG rate



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

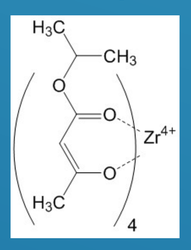
- Total mass : 180ton (fiducial volume : 113ton)
- Measurement time: 2years
- 10wt.% of $Zr(iPrac)_4$ = 12.6ton of $Zr(iPrac)_4$ includes 1.7ton of Zirconium = 45 kg of ^{96}Zr (using natural abundance 2.6%)

$T_{1/2}^{0\nu} > 4 \times 10^{25}$y ← Not enough for 0νββ search

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

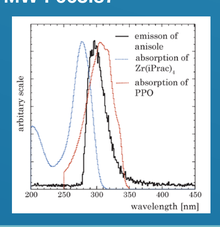
1) 50% enrichment of ^{96}Zr (e.g. 57.3% for NEMO-3) then ^{96}Zr will be 865kg → $T_{1/2}^{0\nu} > 2 \times 10^{26}$y
2) ^{208}Tl background reduction BG level < 1/20 × KL-Zen → $T_{1/2}^{0\nu} > 1 \times 10^{27}$y

◆ Development of Zr loeaded Liquid Scintillator

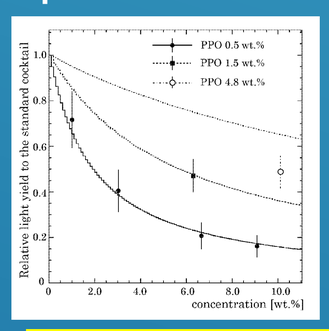


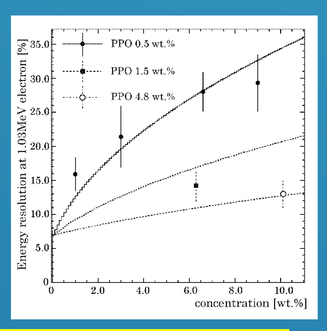
tetrakis (isopropyl acetoacetate) Zirconium : $Zr(iPrac)_4$ MW : 663.87

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



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





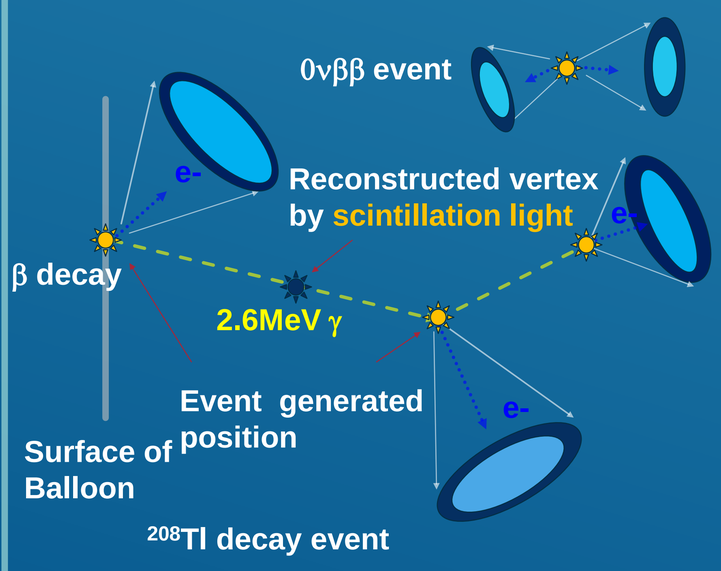
1) Light yield : 48.7 ±7.1% of BC505
2) energy resolution :

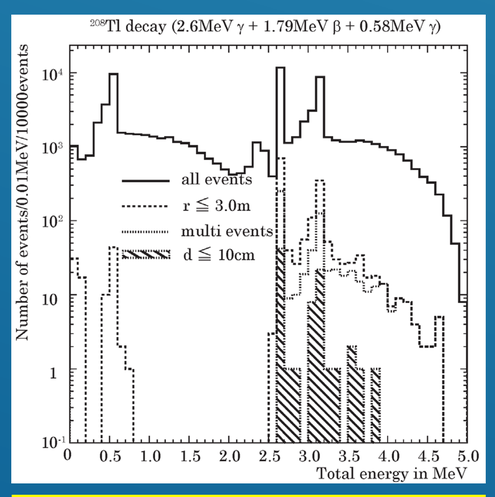
$$\frac{13.0 \pm 2.0\%}{\sqrt{(64\%/9.2\%) \times (3.35\text{MeV}/1.03\text{MeV})}} = 2.7 \pm 0.4\% \text{ at } 3.35\text{MeV} \quad (6.4\% \text{ FWHM})$$

Need to measure real energy resolution

2. How to reduce backgrounds

◆ Conceptional idea using Cherenkov lights





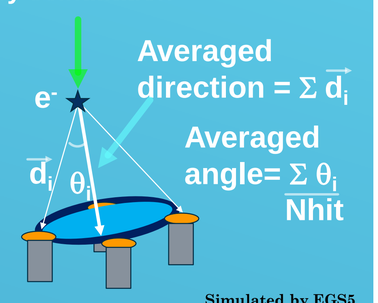
~1/20 BG reduction could be achieved by using a topology information of Cherenkov light.

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

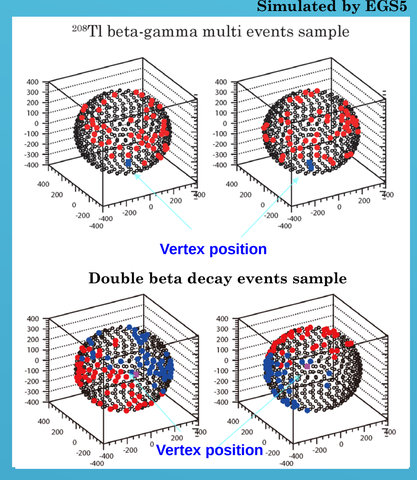
3. Development of reduction technique

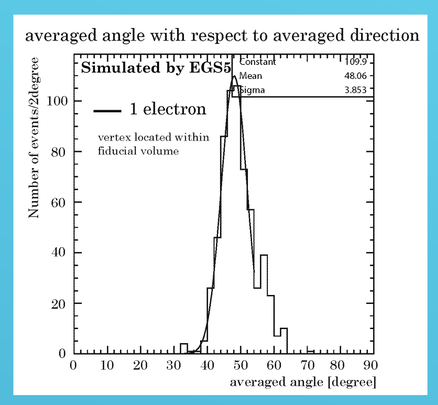
◆ Reduction of ^{208}Tl events using Cherenkov Lights

Vertex position obtained by scintillation

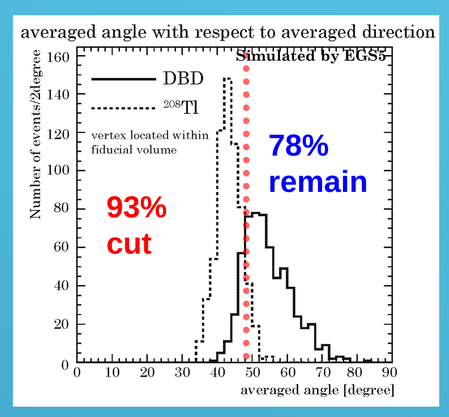


Simulated by EGS5





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.

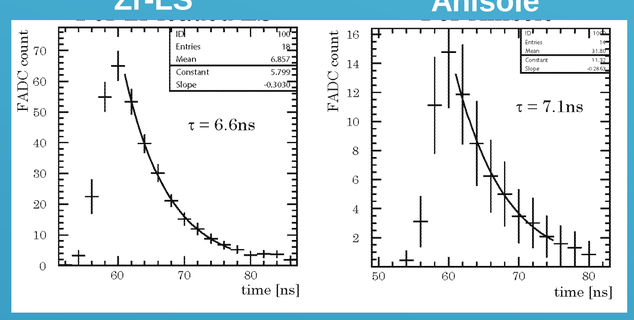
4. Observation of Cherenkov lights

◆ Pulse shape measured by FADC V1729 digitizer

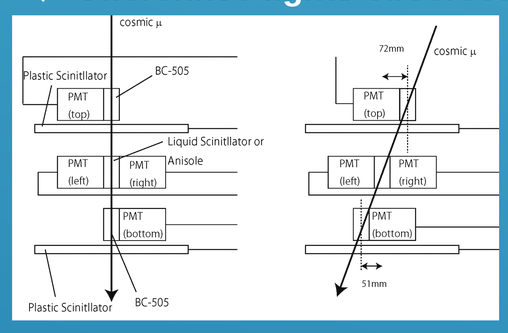
Specification

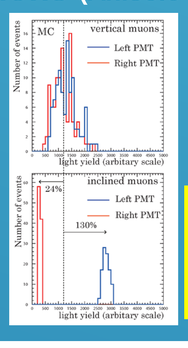
- 4channel
- 12bit ADC
- 500MS/s sampling
- Auto/External trigger

Pulse shape of scintillation lights



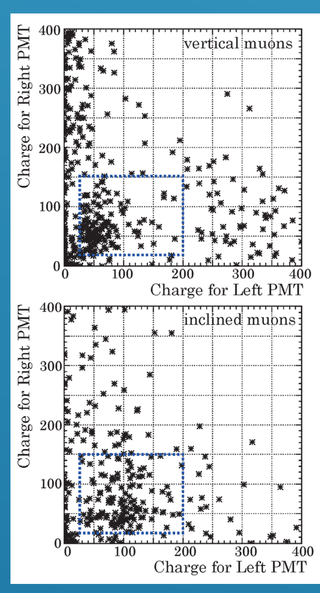
◆ Cherenkov lights observed by cosmic muons (Anisole with UV cut filter)

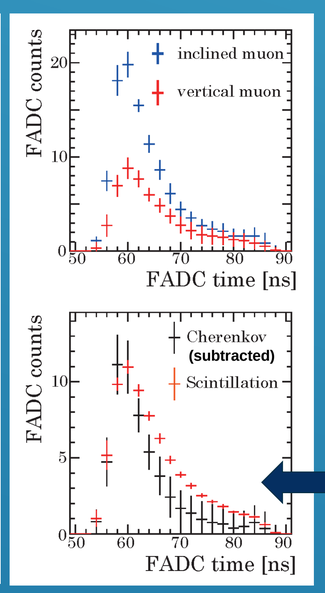


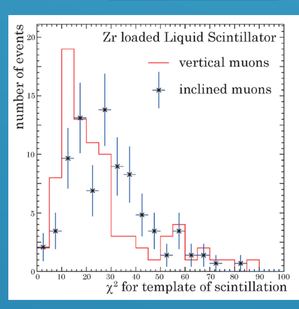


Observed Cherenkov light yield depends on muon tracks.

The pulse shape of Cherenkov lights should be observed directly.







χ^2 distribution of pulse shape for Zr-LS using scintillation template looks different between vertical and inclined muons.

Pulse shape discrimination could be useful for identification of PMT which receives Cherenkov lights.

Pulse shape of Cherenkov lights is different from that of scintillation lights.

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 lights using cosmic muons was done, and the shape was quite different from that of scintillation lights.
- Pulse shape of Zr $(iPrac)_4$ loaded Liquid Scintillator looks different whether the pulse includes Cherenkov lights or not.
- Pulse shape discrimination could be useful for the identification of PMT which receives Cherenkov lights.
- Real energy resolution will be measured using 64% photo coverage of PMT within this year.
- Pulse shape and directionality of Cherenkov light from *O*(1MeV) electrons will be measured by much faster PMT (Hamamatsu H2431-50 TTS~0.37ns) and CAEN V1751 digitizer (10bit ADC 2GS/s sampling) soon.