ZICOS EXPERIMENT FOR NEUTRINOLESS DOUBLE BETA DECAY SEARCH USING ZIRCONIUM-96

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Miyagi University of Education **Y. Fukuda, Narengerile, A. Obata, Y. Kamei, D. Anzai**

Kamioka Observatory, ICRR, Univ. of Tokyo **S. Moriyama, K. Hiraide**

Fukui University **I. Ogawa**

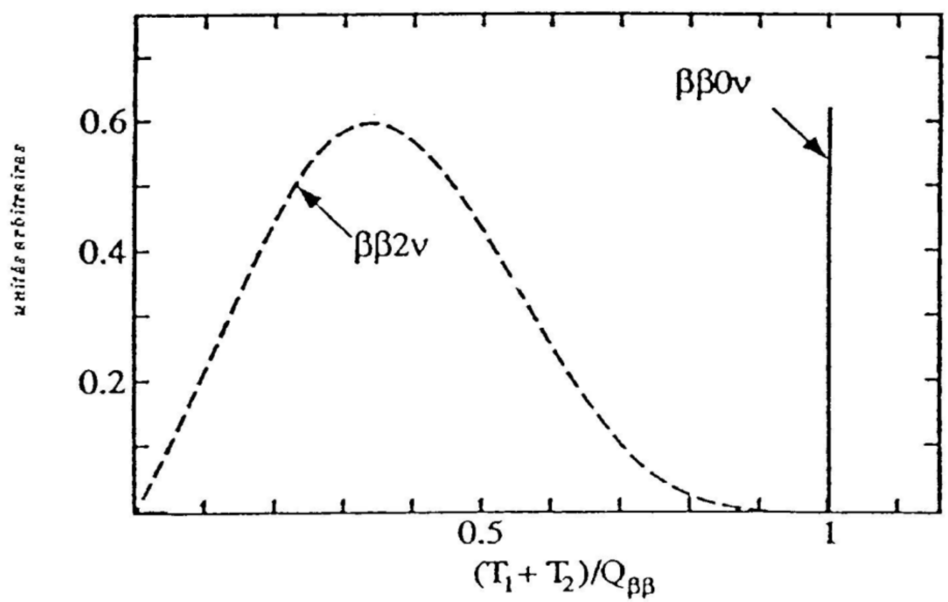
Tokyo University of Science **T. Gunji, S. Tsukada, R. Hayami**

Institute for Materials Research, Tohoku University **S. Kurosawa**

Neutrinoless doube beta decay

$\beta\beta$ emitters with $Q_{\beta\beta}$ >2 Mev

Transition	$Q_{\beta\beta}$ (keV)	Abundance (%) ($^{232}Th = 100$)
$^{110}Pd \rightarrow ^{110}Cd$	2013	12
$^{76}Ge \rightarrow ^{76}Se$	2040	8
$^{124}Sn \rightarrow ^{124}Te$	2288	6
$^{136}Xe \rightarrow ^{136}Ba$	2479	9
$^{130}Te \rightarrow ^{130}Xe$	2533	34
$^{116}Cd \rightarrow ^{116}Sn$	2802	7
$^{82}Se \rightarrow ^{82}Kr$	2995	9
$^{100}Mo \rightarrow ^{100}Ru$	3034	10
$^{96}Zr \rightarrow ^{96}Mo$	3350	3
$^{150}Nd \rightarrow ^{150}Sm$	3667	6
$^{48}Ca \rightarrow ^{48}Ti$	4271	0.2



$$[T_{1/2}^{0\nu}(0^+ \rightarrow 0^+)]^{-1} = G_{0\nu}(E_0,Z)\,|M_{0\nu}|^2 \langle m_\nu \rangle^2 / m_e^2$$

$$T_{1/2} \sim a(Mt/\Delta E \cdot B)^{1/2}$$

a: abundance M: target mass

t: measuring time ΔE: energy resolution B: BG rate

Requirement : Low BG, Large target mass, High E-resolution

^{96}ZICOS experiment for neutrinoless double beta decay using ^{96}Zr

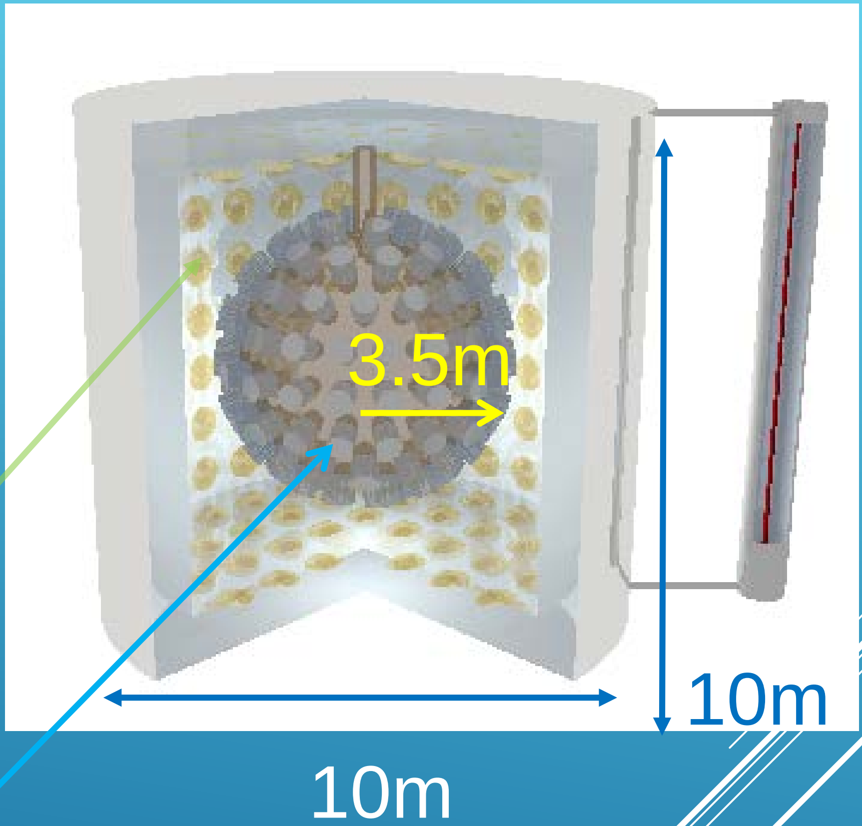
Liquid Scintillator:

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

(2) 3~4% at 3.35MeV of energy resolution with 64% photo coverage and long attenuation length.

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

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



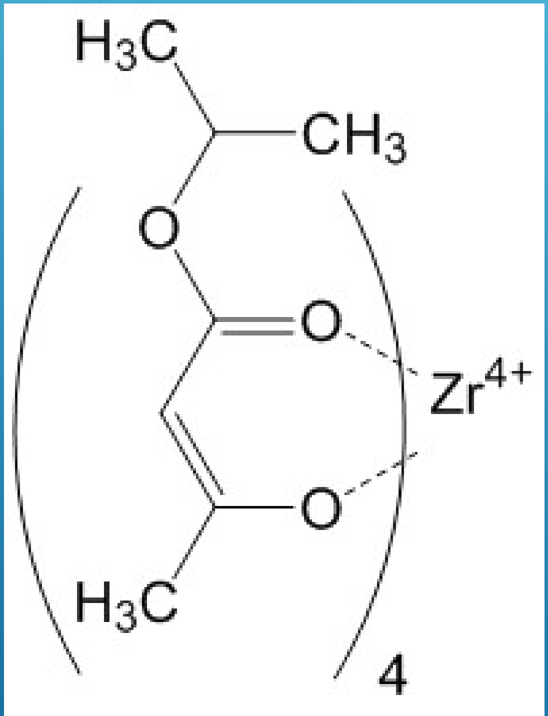
Purpose:

① Direct measurement of 0νββ

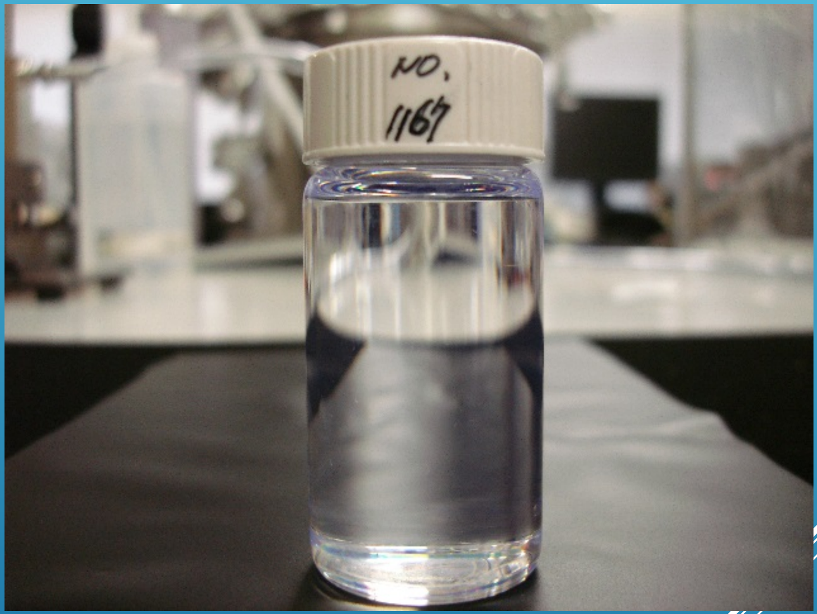
② Confirm parameter of nuclear matrix element model

Liquid Scintillator solving $Zr(iPrac)_4$

$Zr(CH_3COCHCOOCH(CH_3)_2)_4$
$= Zr(iPrac)_4$
mw : 663.87



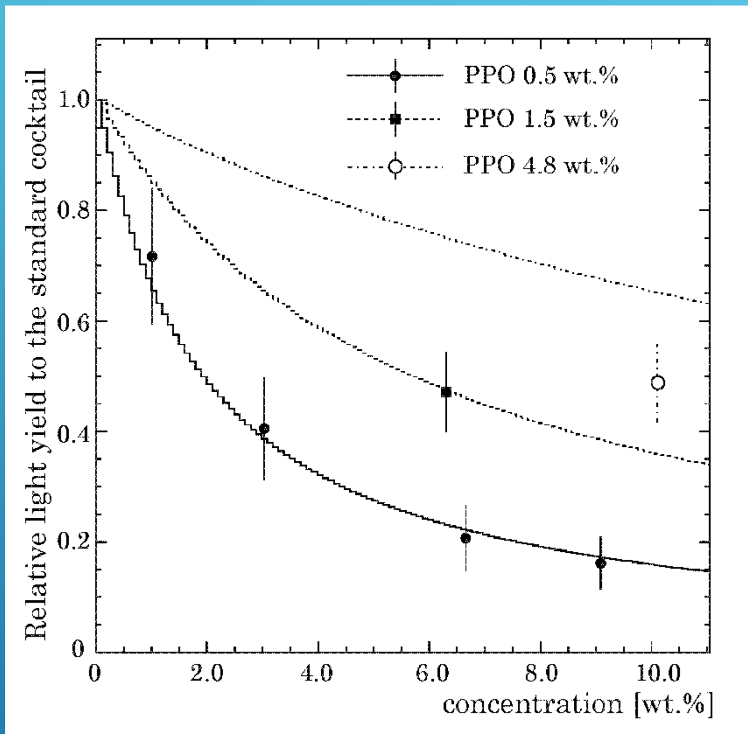
$Zr(iprac)_4$ 2242mg, PPO 999mg and POPOP 10mg solved in 20mL Anisole

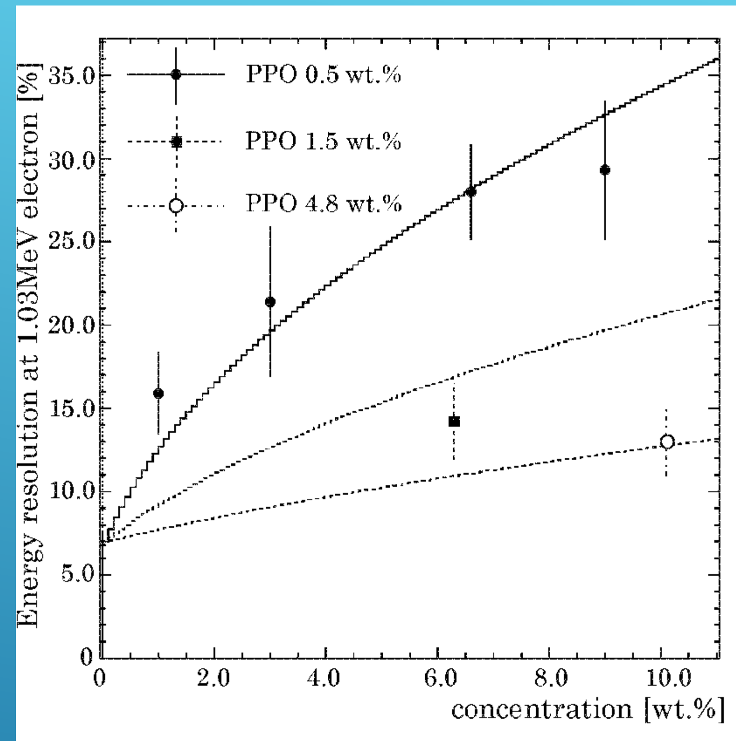


> 70g/L of Zirconium could be solved in anisole.

Performance of liquid scintillator

Measured at several conditions of PPO concentration





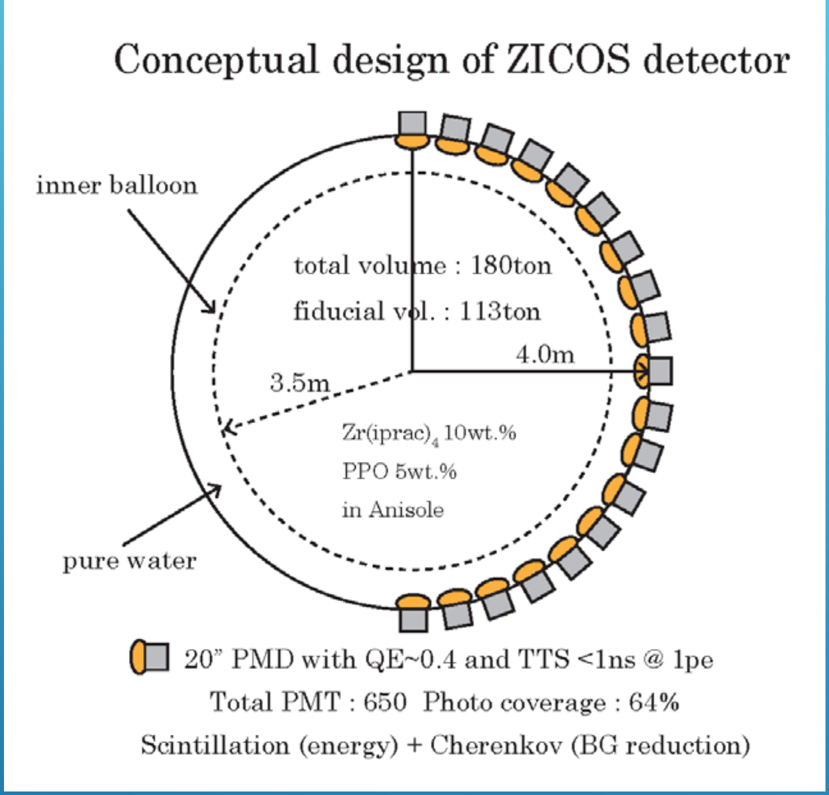
48.7±7.1% light yield to standard cocktail was obtained at 10wt.% concentration.

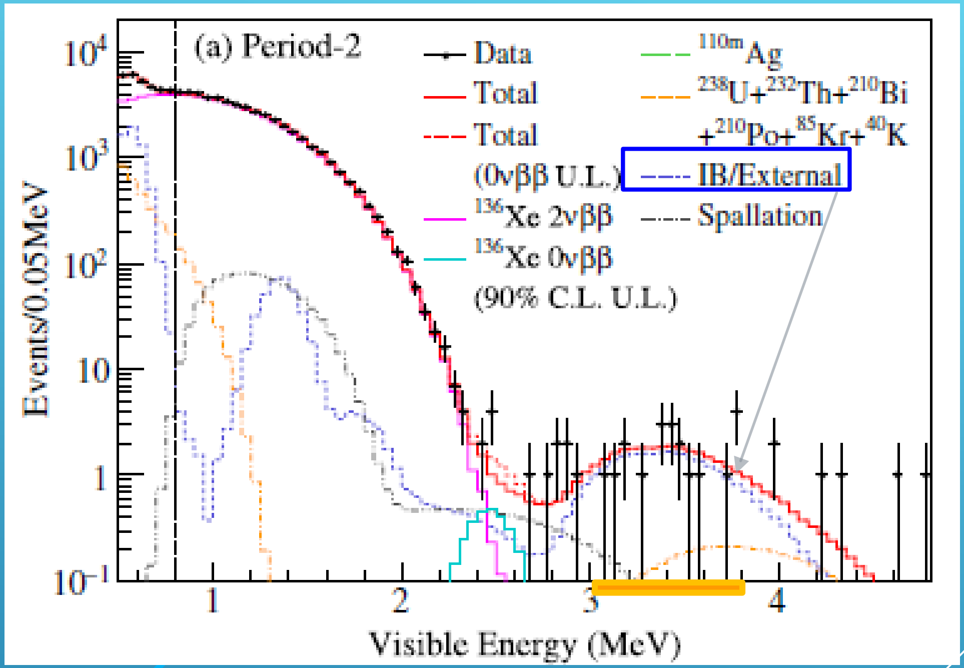
$$\frac{13.0 \pm 2.0\%}{\sqrt{(64\%/9.2\%) \times (3.35\text{MeV}/1.03\text{MeV})}}$$

$= 2.7 \pm 0.4\%$ at 3.35MeV

Conceptual design of ZICOS detector

Phys.Rev.Lett. 117 (2016) 082503



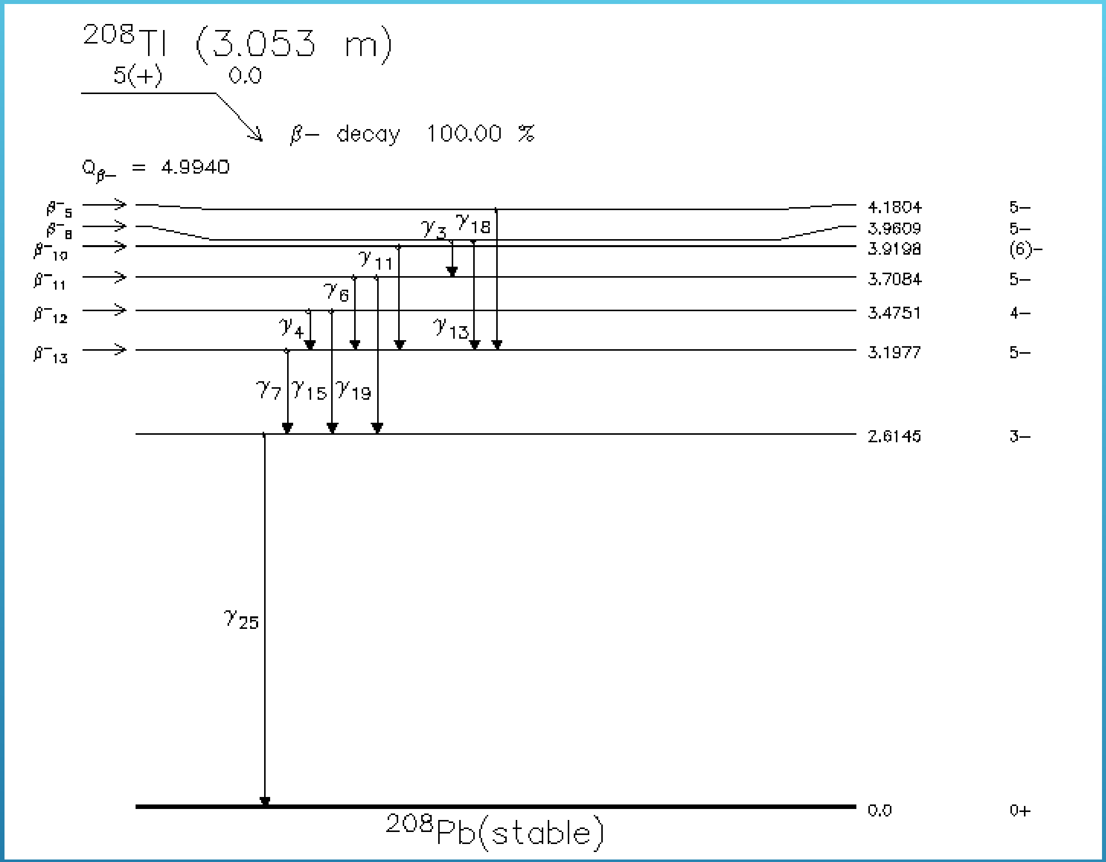


NEMO3 : $T^{0\nu}_{1/2} > 9.1 \times 10^{21}$ yrs

^{96}Zr : 45kg (nat.) → 865kg(50% enrich)→1/20 BG

$T^{0\nu}_{1/2} > 4 \times 10^{25}$ yrs → 2×10^{26}yrs → ~1×10^{27}yrs

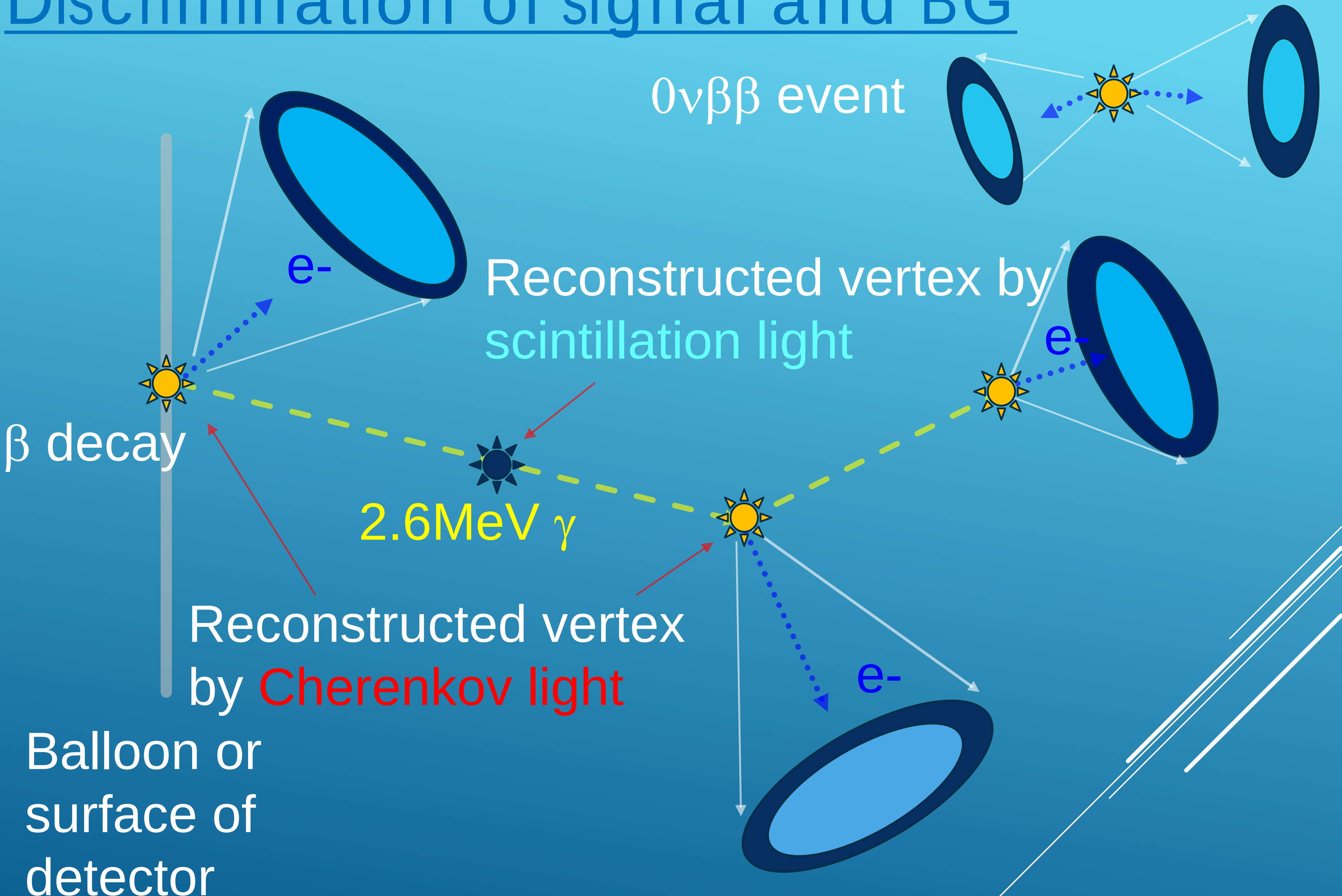
Decay scheme of ^{208}Tl



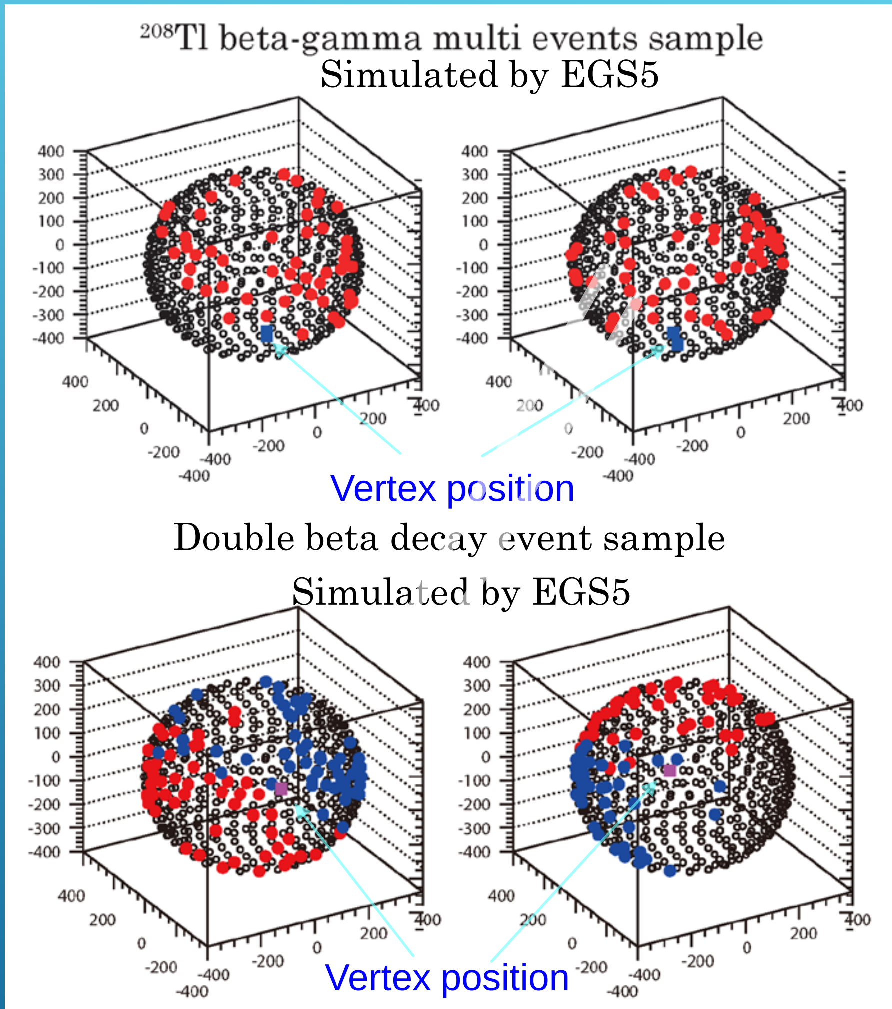
Radiations	y(i) (Bq-s)$^{-1}$
beta- 5	2.27×10^{-03}
beta- 8	3.09×10^{-02}
beta- 10	6.30×10^{-03}
beta- 11	2.45×10^{-01}
beta- 12	2.18×10^{-01}
beta- 13	4.87×10^{-01}
ce-K, gamma 3	4.04×10^{-03}
gamma 4	6.31×10^{-02}
ce-K, gamma 4	2.84×10^{-02}
ce-L, gamma 4	4.87×10^{-03}
gamma 6	2.26×10^{-01}
ce-K, gamma 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}

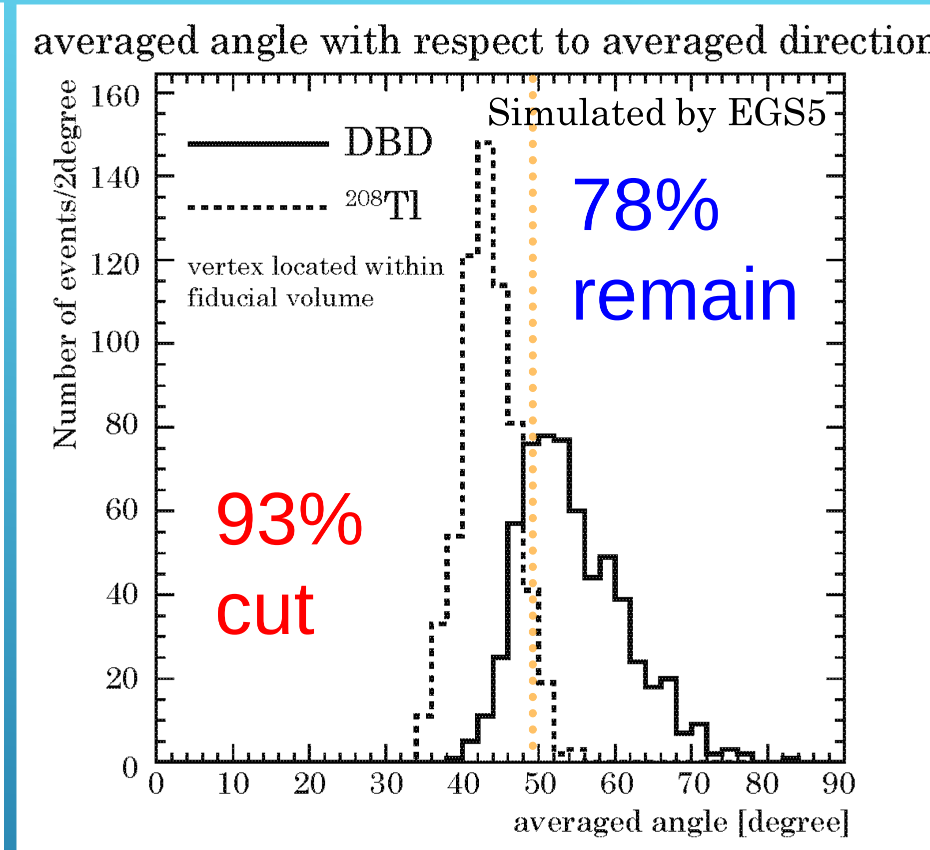
The vertex position reconstructed by scintillation might be within fiducial volume due to gammas.

Discrimination of signal and BG



BG reduction using topological information



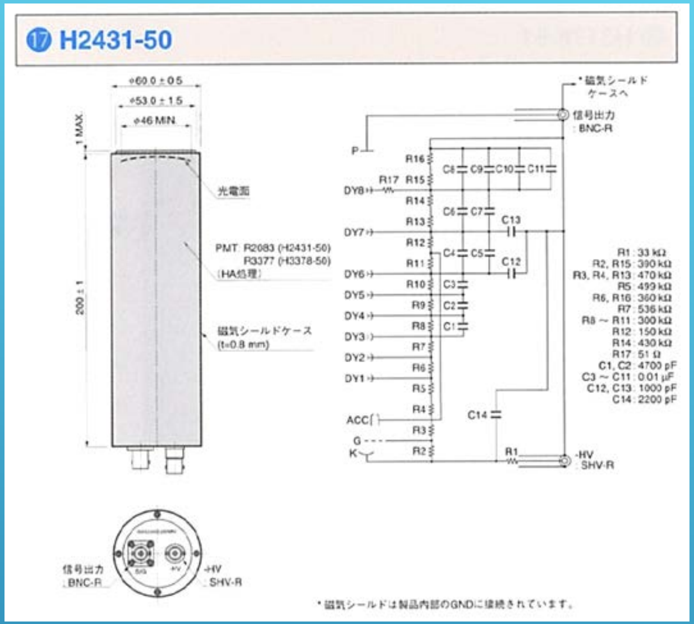


Topological information from PMT position which received Cherenkov lights could be used for the reduction of 208Tl BG event.

PMT hit pattern of ^{208}Tl BG and $0\nu\beta\beta$ signal

Measurement of pulse shape difference

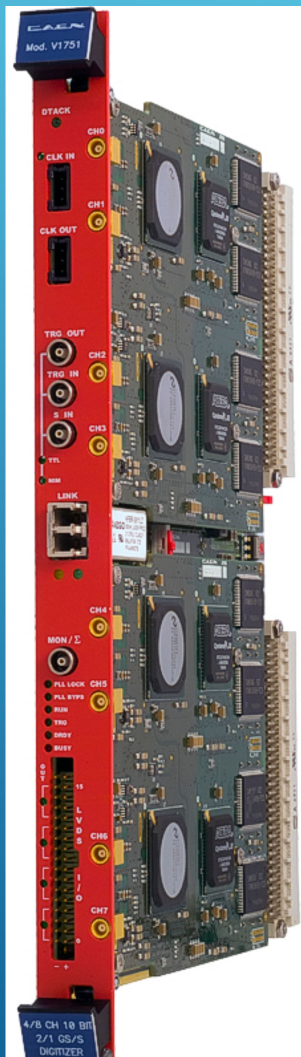
Photomultiplier : Hamamatsu H2431-50 (R2083)



- Spectral response ：400K QE: 25% at peak
- Dynode structure : linear focused/8 dinodes
- High voltage ：3000V
- Gain：2.5×10^6 dark current :100nA (H6410:10nA)
- Time response ：0.37ns(TTS) 0.7ns（rise time）

Measurement of pulse shape difference

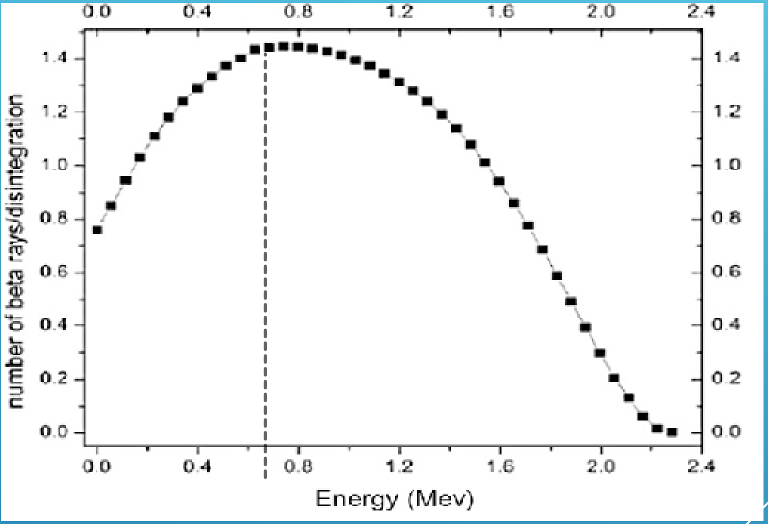
FADC digitizer: CAEN V1751



- 10 bit 2 GS/s (interleaved) – **1 GS/s ADC**
- 4-8 channel
- FPGA for real time Digital Pulse Processing:
  - Pulse Shape Discrimination (DPP-PSD)
  - **Zero Length Encoding (DPP-ZLEplus)**
- 0.2 or 1 Vpp input dynamics single ended or 1 Vpp differential
- 16-bit programmable DC offset adjustment: ±0.5 V / ±0.1 V
- Trigger Time stamps
- Memory buffer: up to 14.4 MS/ch (28.8 MS/ch @2 GS/s)
- Programmable event size and pre-post trigger adjustment
- Analog Sum/Majority and digital over/under threshold flags for Global Trigger logic
- Front panel clock In/Out available for multiboard synchronisation (direct feed through or PLL based synthesis)
- 16 programmable LVDS I/Os
- Optical Link interface (CAEN proprietary protocol)
- VME64X compliant interface
- **A2818(PCI) / A3818 (PCIe) Controller available for handling up to 8/32 modules Daisy chained via Optical Lin**
- Firmware upgradeable via VME/Optical Link
- Libraries, Demos (C and LabView) and Software tools for Windows and Linux

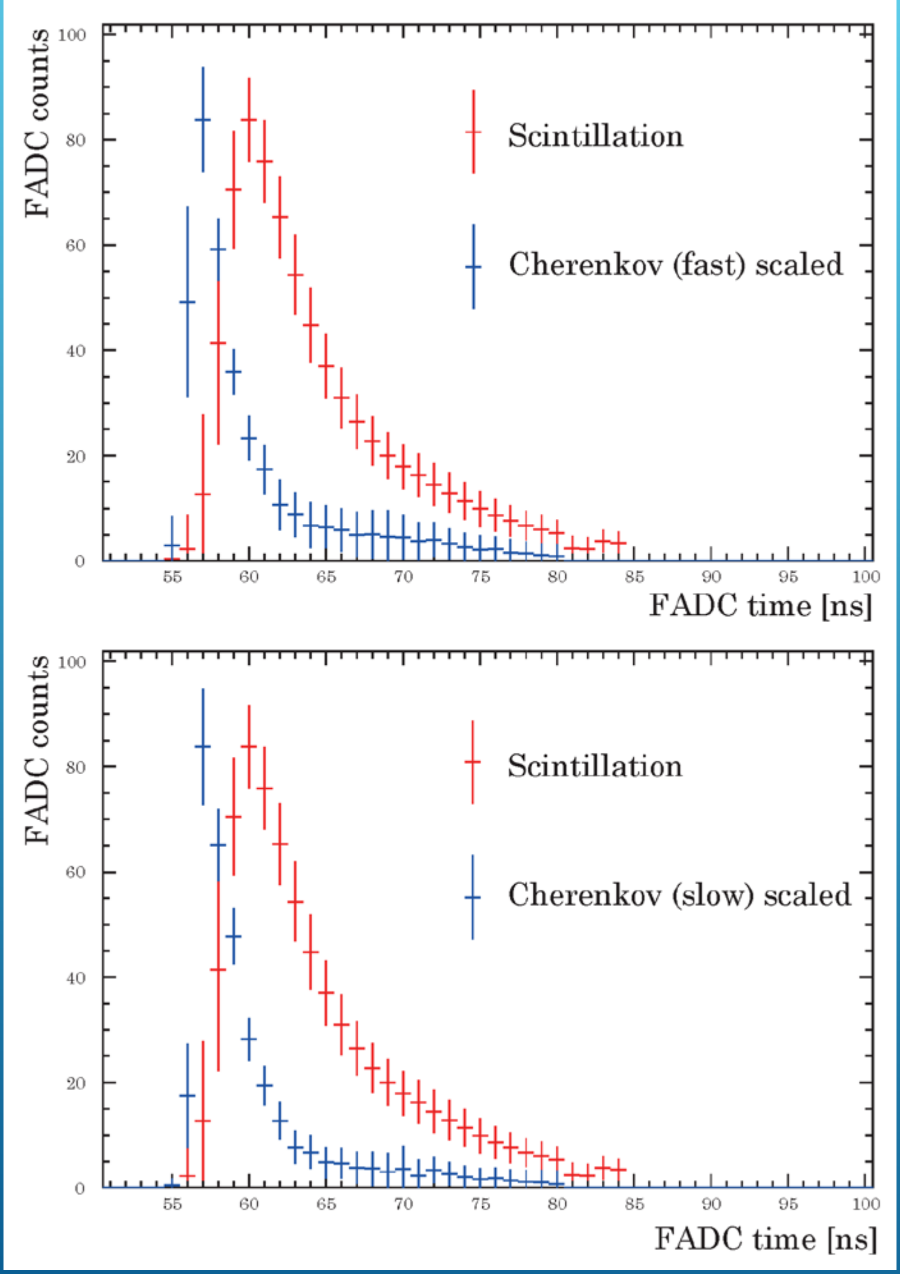
Pulse shape using $^{90}Sr/^{90}Y$ beta decay

- Electrons from ^{90}Y decay could have an energy above Cherenkov threshold.



Possible to measure pulse shape using high statistics electrons for Cherenkov light.

Pulse shape for Cherenkov and Scintillation



- Decay time of scintillation : 6.5ns
- Decay time of Cherenkov : 2.4ns (fast) 2.7ns (slow)
- Rise time of scintillation : 1.6ns
- Rise time of Cherenkov : light : 0.8ns

Possible pulse shape discrimination for selection of PMTs whether including Cherenkov light or not.

R&D and Physics program

① R&D（2019～21）

- Development of pulse shape discrimination
- Energy resolution with 60% photo coverage
- Topological info. (averaged angle)
- Demonstration of BG reduction

② Physics program I（2022～26）

- 2”PMT proto-type detector（R~35cm)
- 6.5kg $Zr(iPrac)_4$ ~80g of ^{96}Zr（Nat.）
- Use for water veto tank
- ^{96}Zr $2\nu\beta\beta$ measurement $T_{1/2}^{2\nu}$~2.1x10^{19}y
- ^{96}Zr $0\nu\beta\beta$ update NEMO3 $T_{1/2}^{0\nu} > 9.1 \times 10^{21}$ yrs
- ^{96}Zr enrichment→need some techniques

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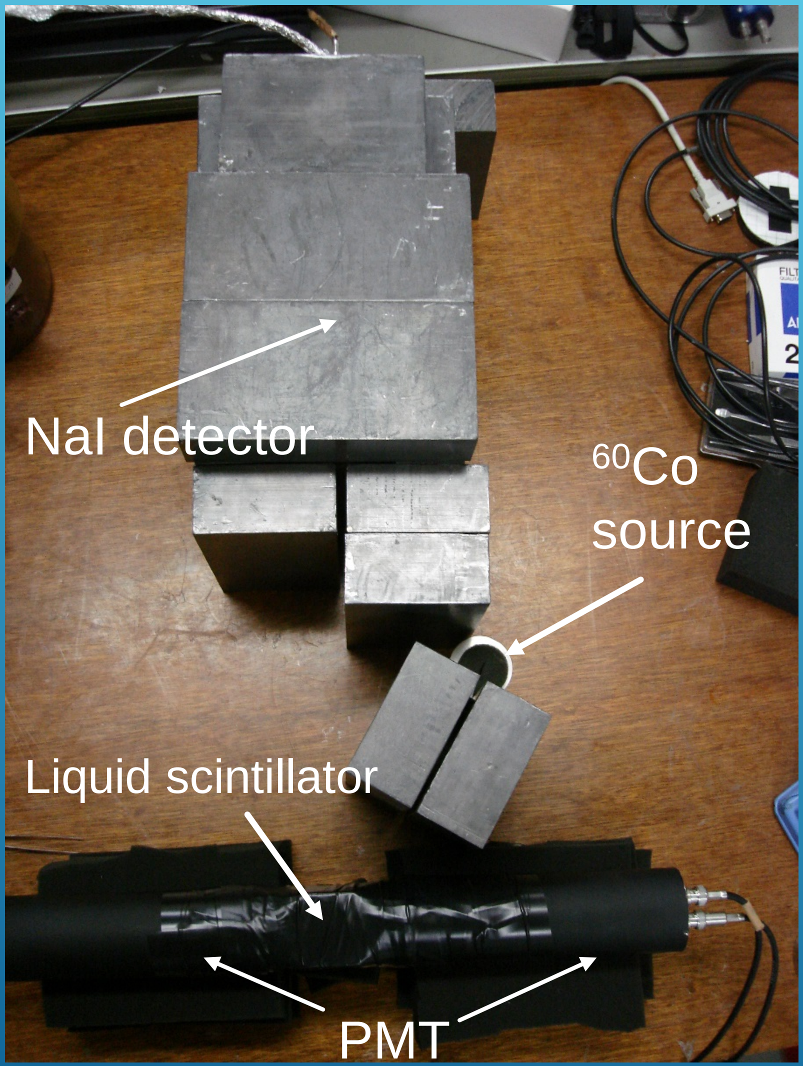
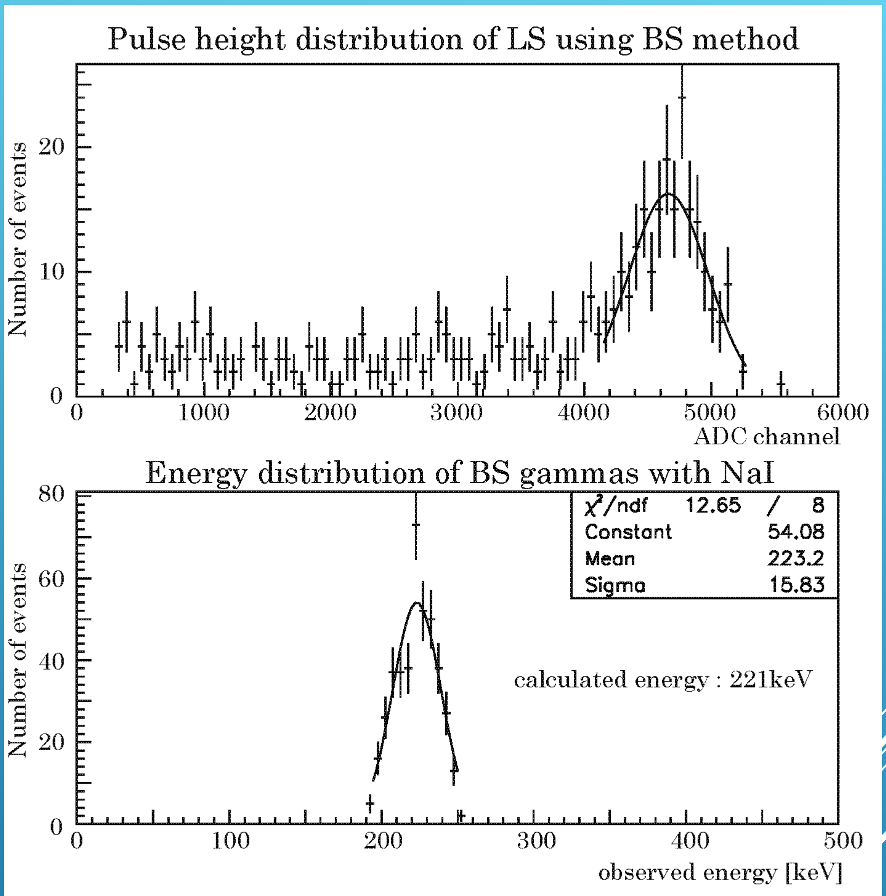
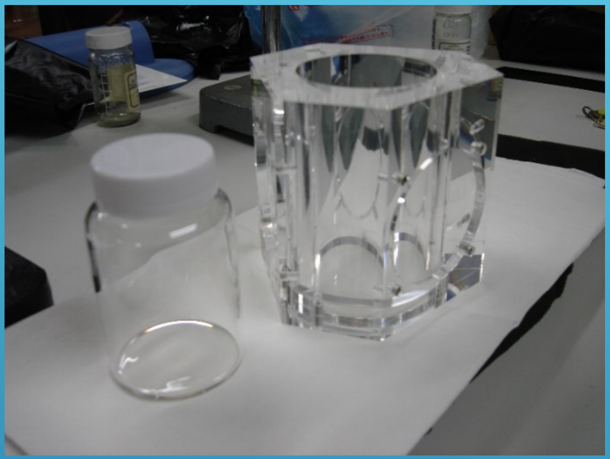
BACK SCATTERING METHOD

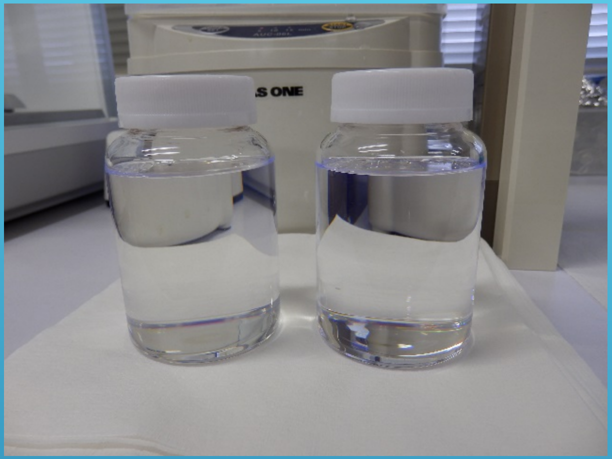


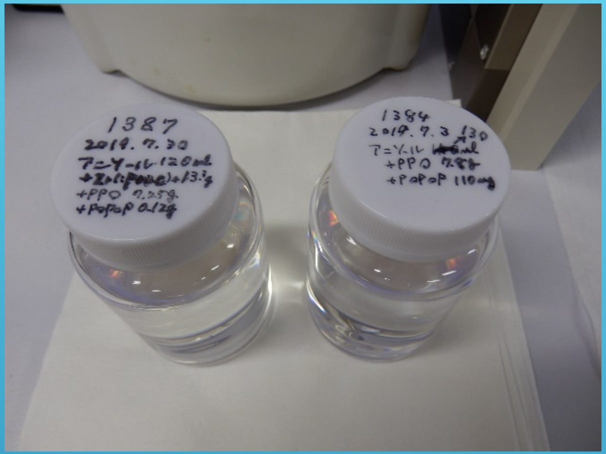


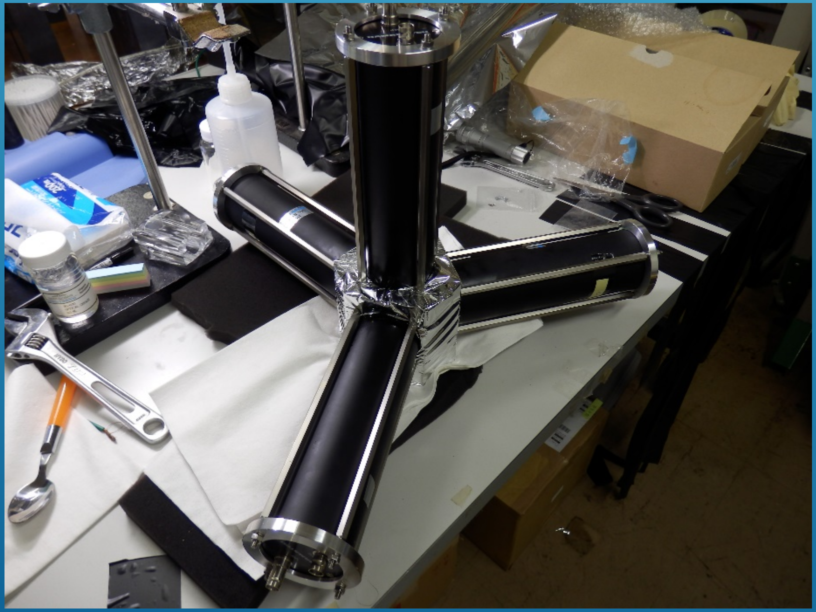
Single peak could be used even in liquid scintillator.

Measurement for energy resolution with 60 % photo coverage









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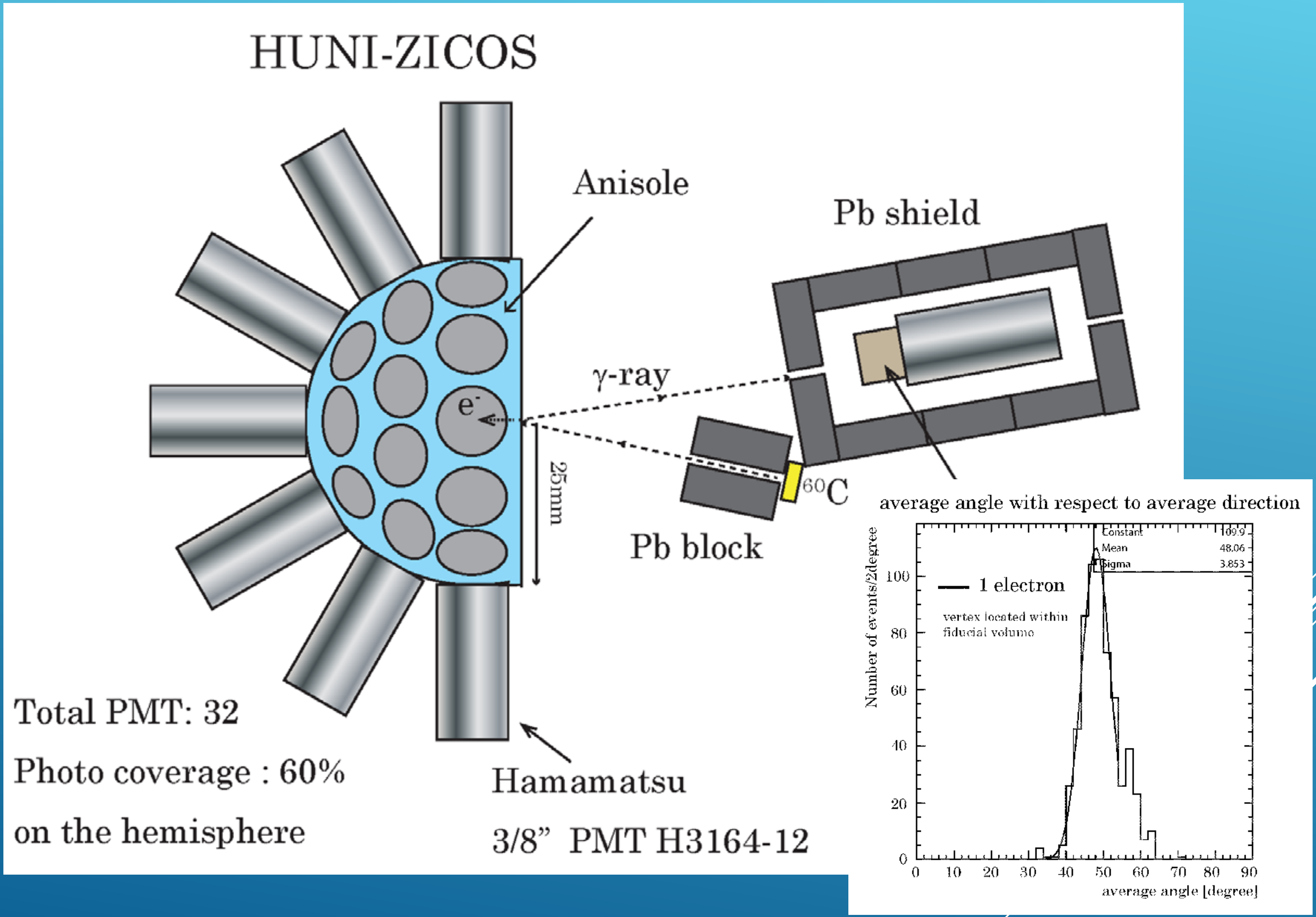
Measurement of topological information

- Measurement of averaged angle by HUNI-ZICOS



R&D and Physics program

① R&D（2019～21）
- Development of pulse shape discrimination
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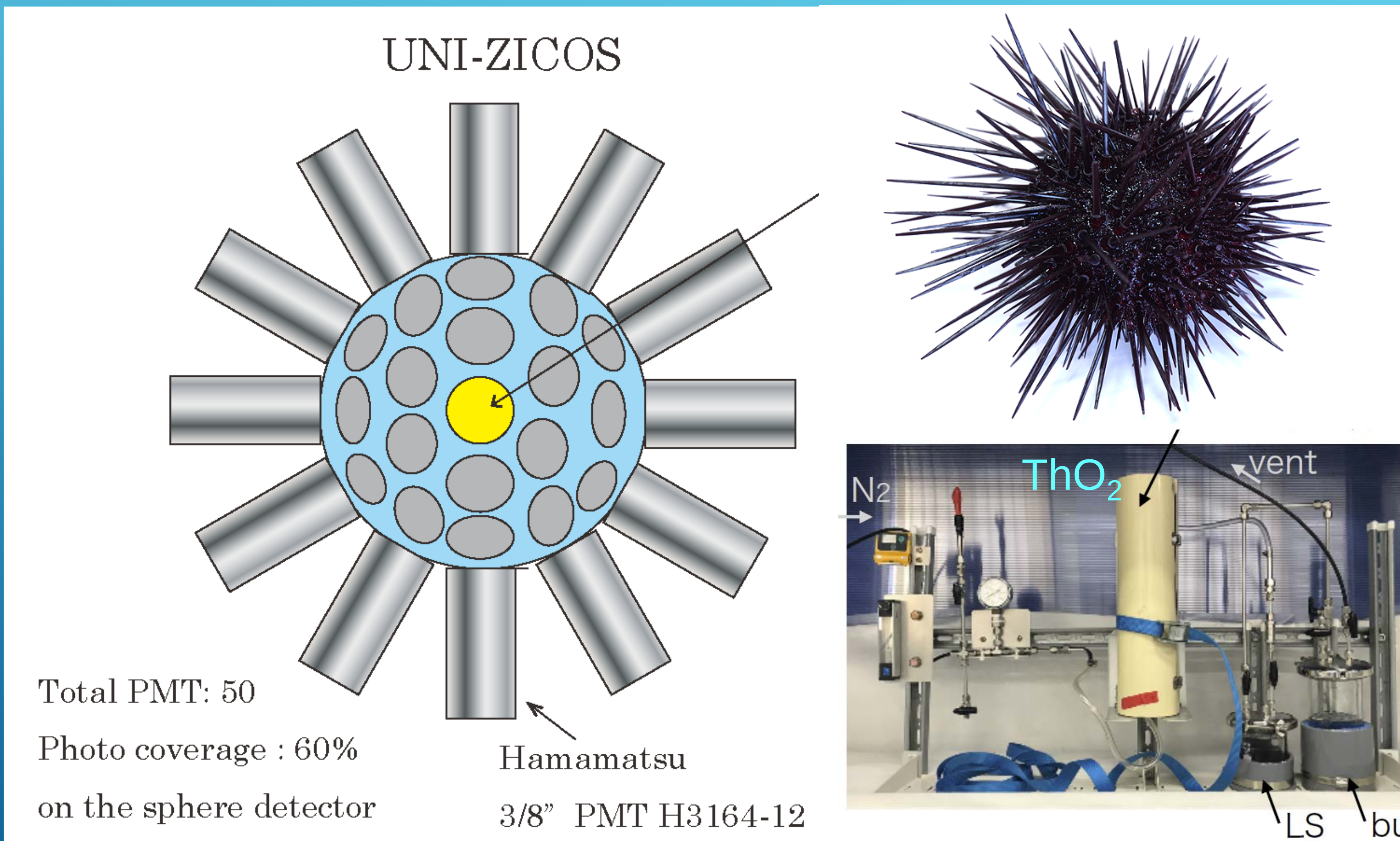
Demonstration of BG reduction

- Direct reduction for βγ events by UNI-ZICOS



R&D and Physics program

① R&D（2019～21）

- Development of pulse shape discriminaiton
- Energy resolution with 60% photo coverage
- Topological info. (averaged angle)
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② Physics program ZICOS-I（2022～26）

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- 6.5kg $Zr(iPrac)_4$ ~80g of ^{96}Zr（Nat.）
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- ^{96}Zr $0\nu\beta\beta$ update NEMO3 $T_{1/2}^{0\nu} > 9.1 \times 10^{21}$ yrs
- ^{96}Zr enrichment→need some techniques

③ Physics program ZICOS-II（2027～）

- Goal : $T_{1/2}$>10^{27}years m_ν~3meV
- Detector design
- Kamioka mine/need radisu12ｍ water tank
- ^{96}Zr enriched $Zr(iPrac)_4$
- International collaboration?
- Budget（total 10M$）

① ^{96}Zr enrichment : a few M$??

② First 20” PMT (rise time<1ns)

650 PMTs X 6000$ = 4M$

③ Detector (no excavation)＋electronics : less 10M$

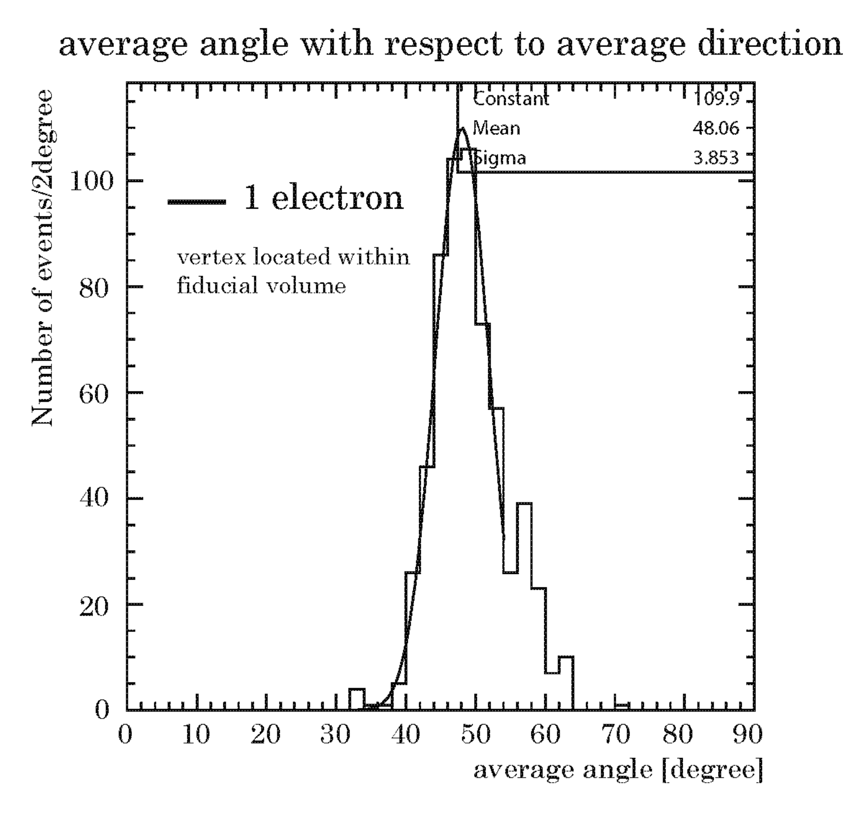
④ Synthesis of 12ton $Zr(iPrac)_4$: a few M$

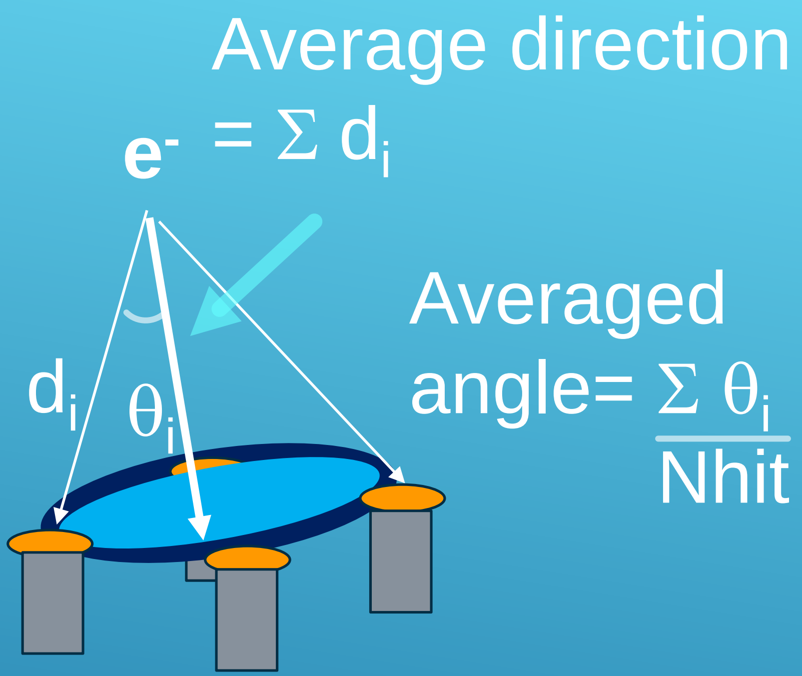
Summary

- High Zr concentrated liquid scintillator is available.
- Expected energy resolution ~3%@3．35MeV
  → need to confirm with 60% Photo coverage
- Need reduction technique for backgrounds from ^{208}Th decay
  → topological info using Cherenkov lights
  ① Pulse shape discrimination for selection of PMT which receives Cherenkov lights.
  ② Confirmation of topological information
  ③ Demonstration of βγ events reduction using topological information
- Physics program with proto-type detector will start within 3~4 years. Stay tuned!

Backup slides

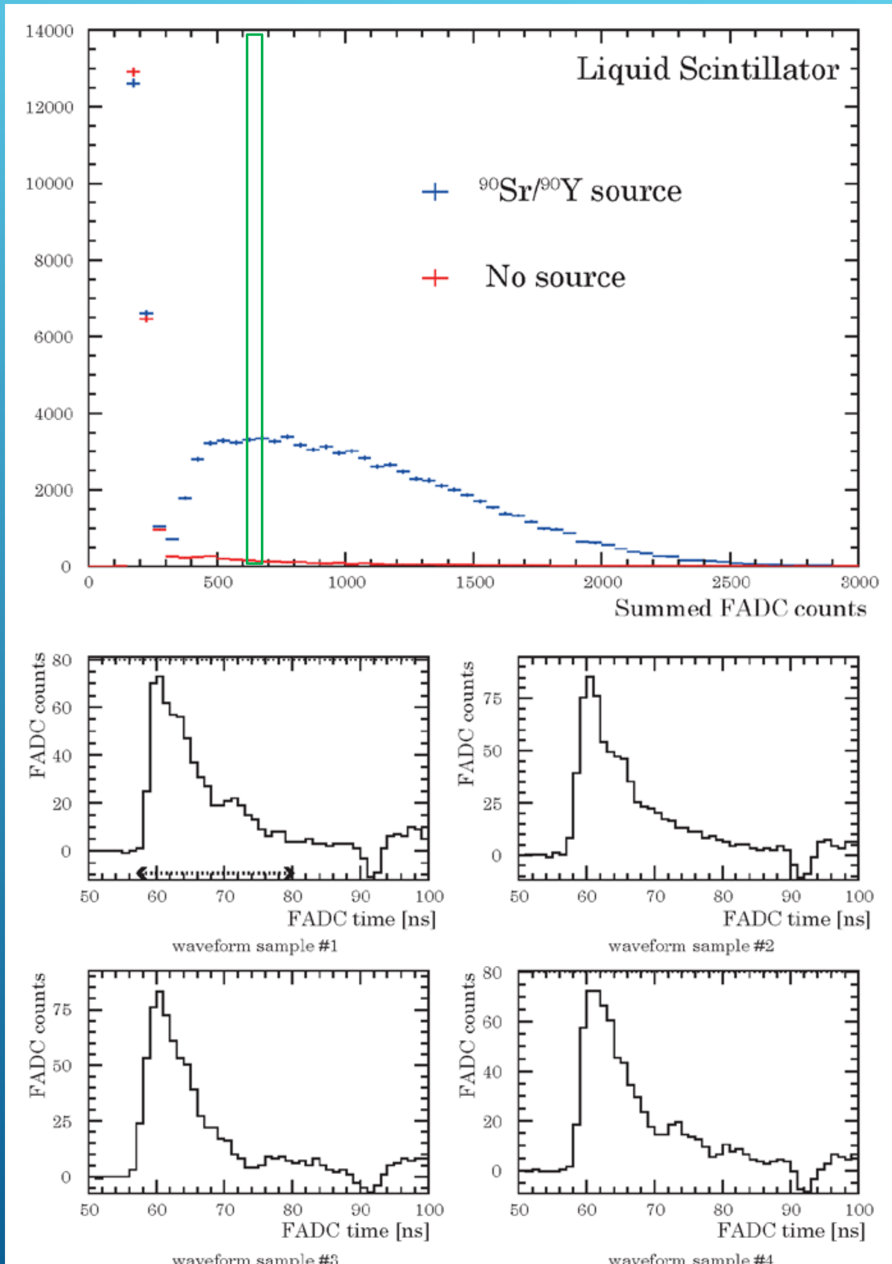
Topological info. : averaged angle

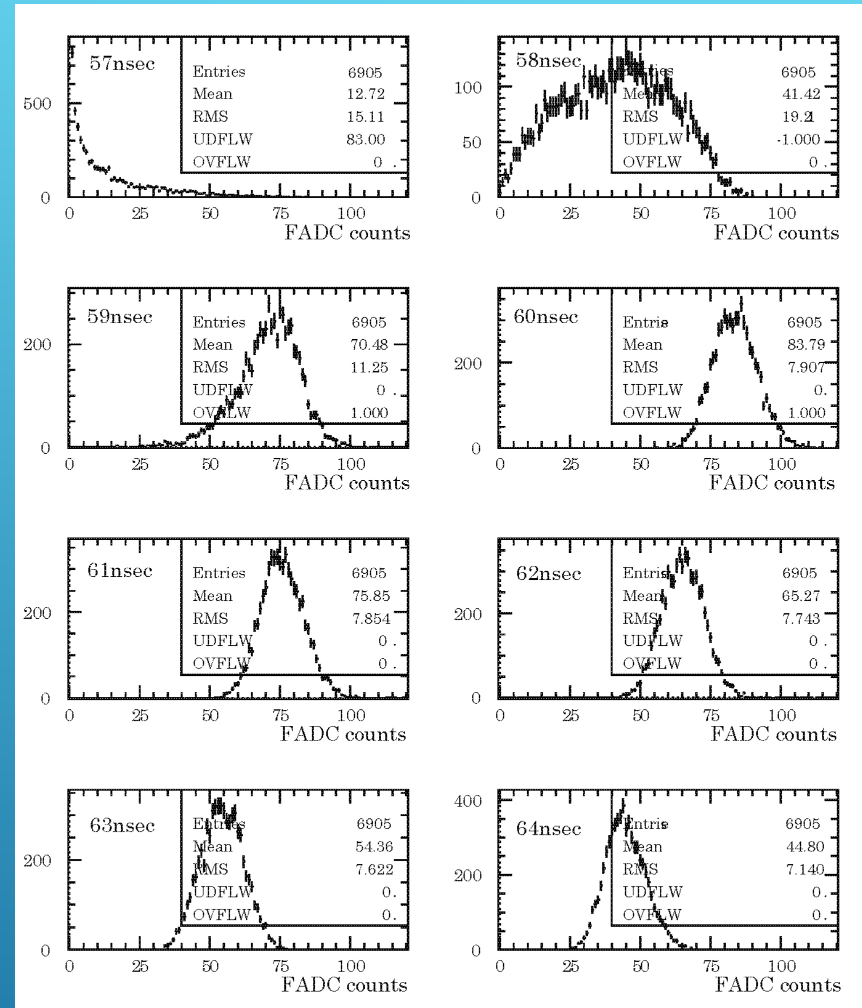




Average angle with respect to averaged direction for single electron seems to have a peak at 48 degree which is almost same as Cherenkov angle.

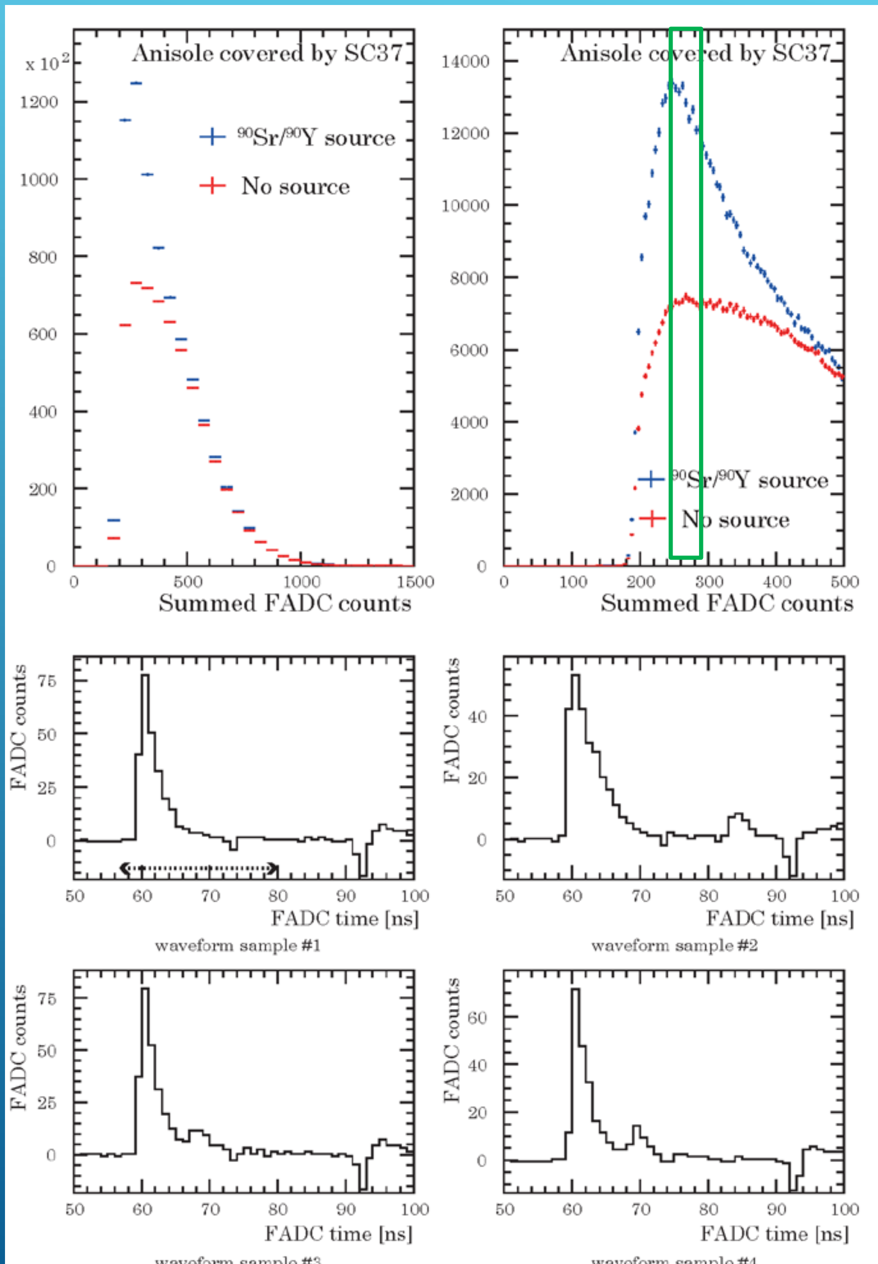
Time profile of scintillation

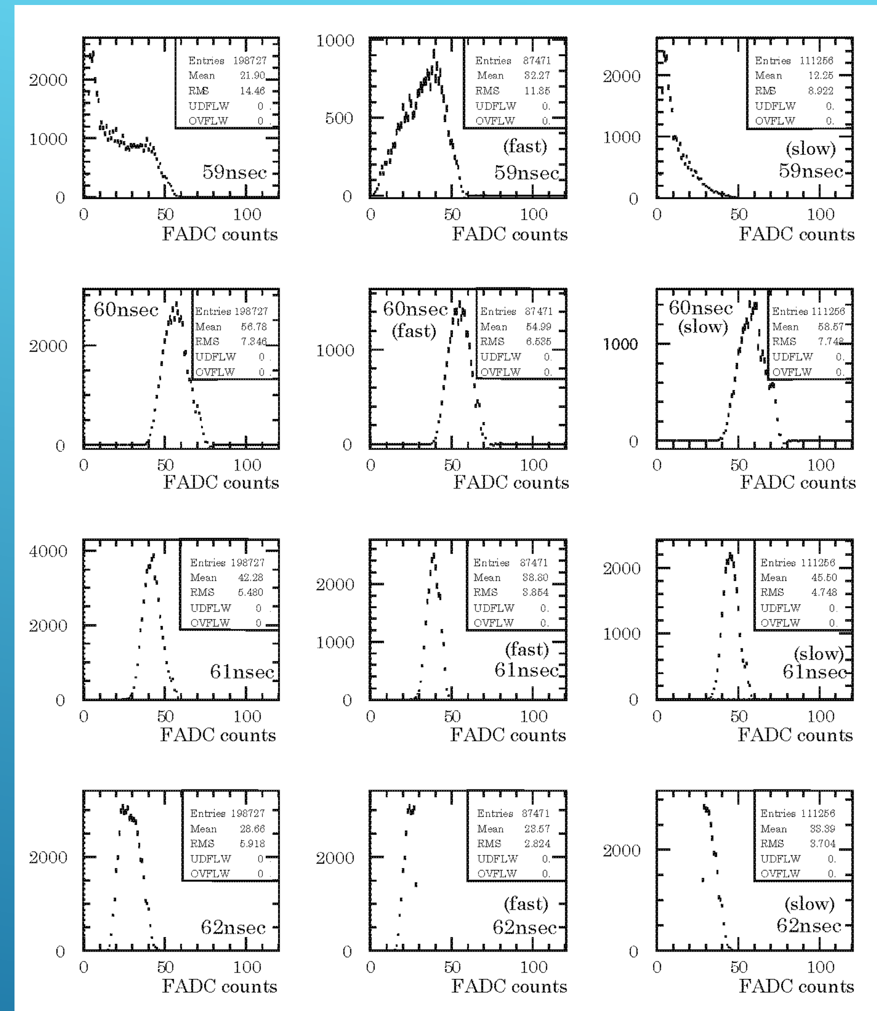




Time profile distribution was obtained by single peak.

Time profile of Cherenkov light





Time profile distribution was separated by two peaks.