ジルコニウム96を用いたニュートリノを放出しない二重ベータ崩壊事象の探索XVII ～HUNI-ZICOSを用いたチェレンコフ光の位相幾何学情報の測定～

日本物理学会　第76回年次大会

2021年3月13日

Grant-in-Aid for Scientific Research on Innovative Areas
19H05093 and 20H05241
Scientific Research (C) 18K03664

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

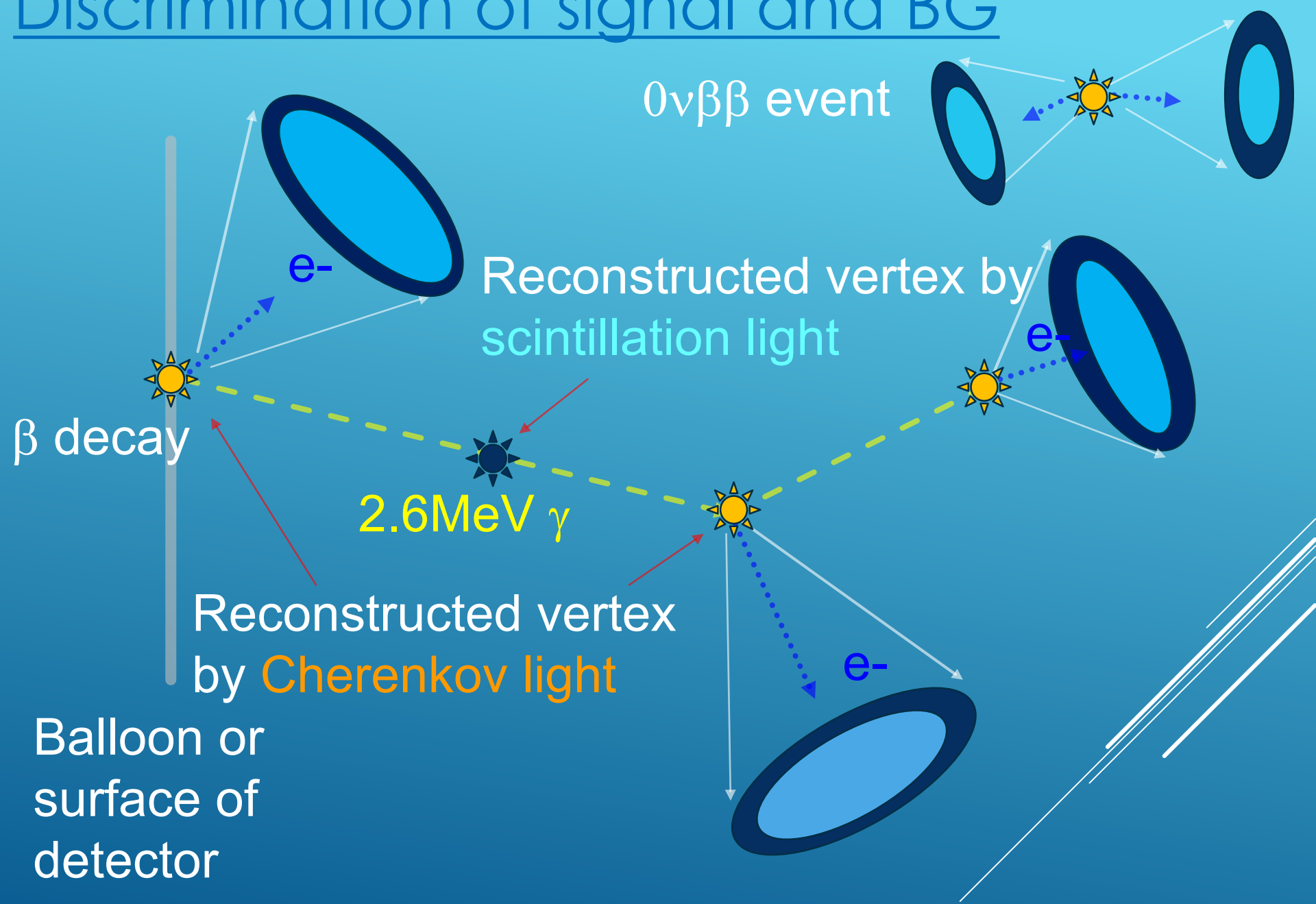
Kamioka Observatory, ICRR, Univ. of Tokyo　S. Moriyama, K. Hiraide

Fukui University　I. Ogawa

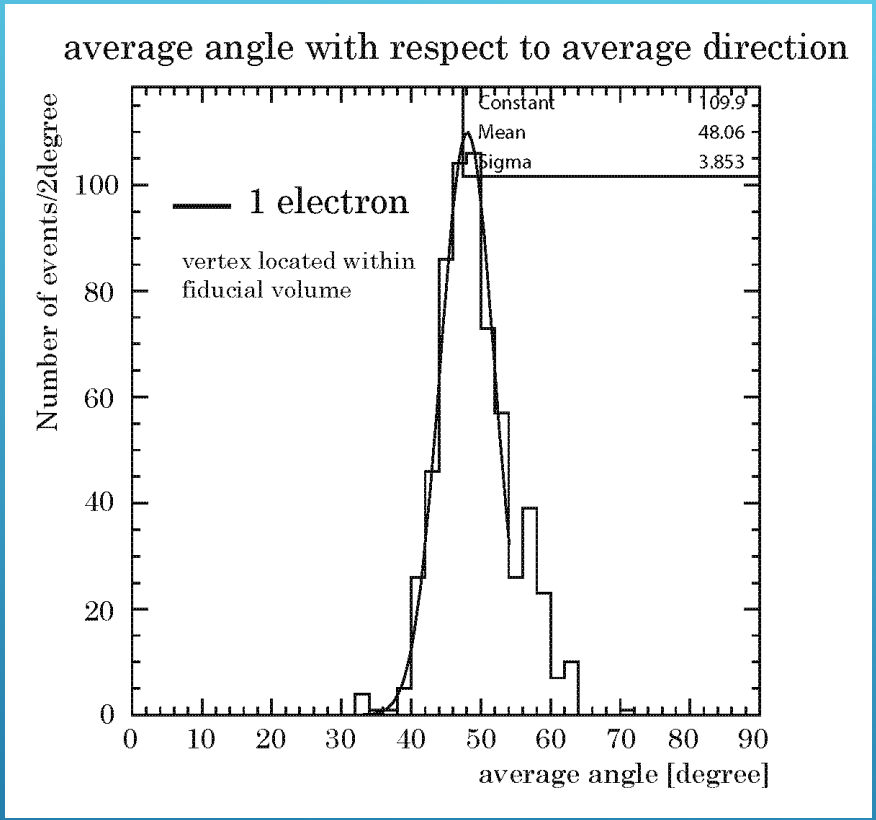
Tokyo University of Science　T. Gunji, S. Tsukada, R. Hayami

Institute for Materials Research, Tohoku University　S. Kurosawa

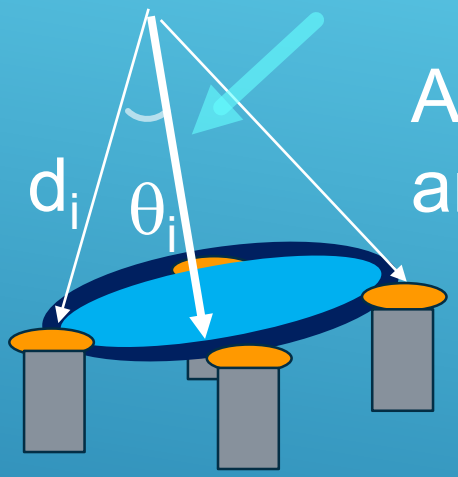
Discrimination of signal and BG



Topological info : averaged angle



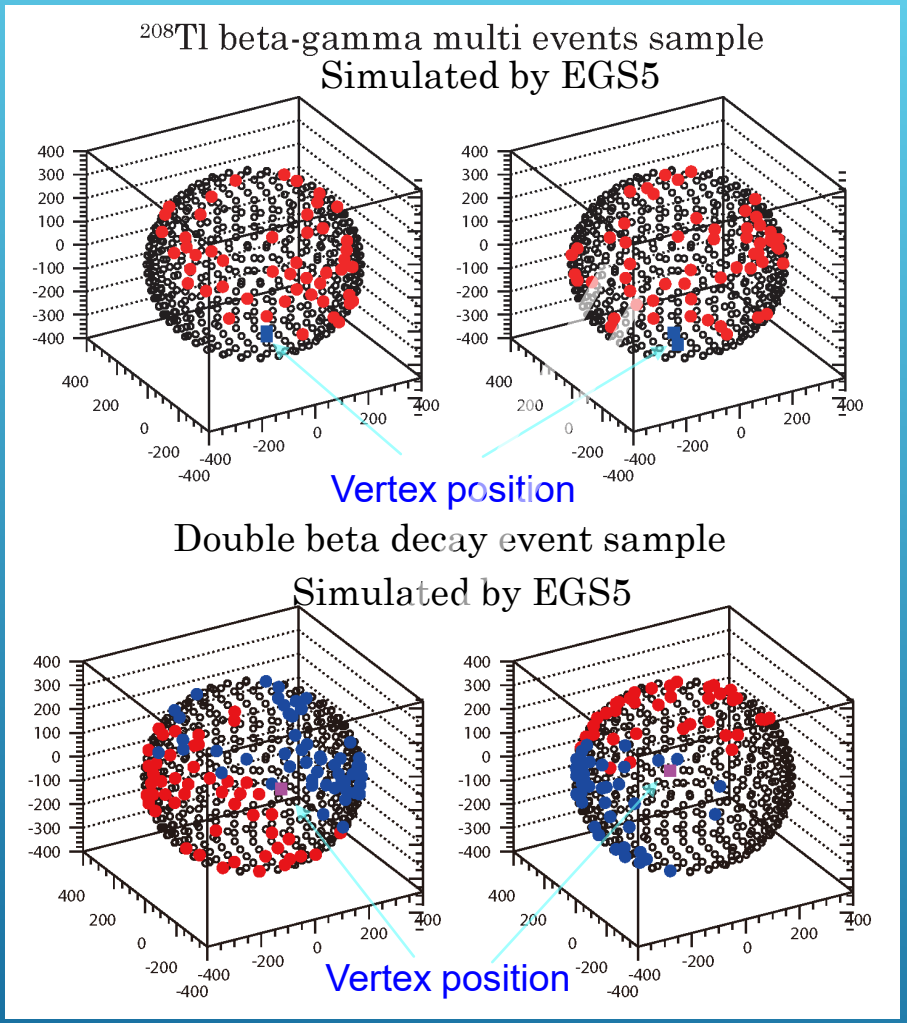
Average direction
$e^- = \Sigma d_i$

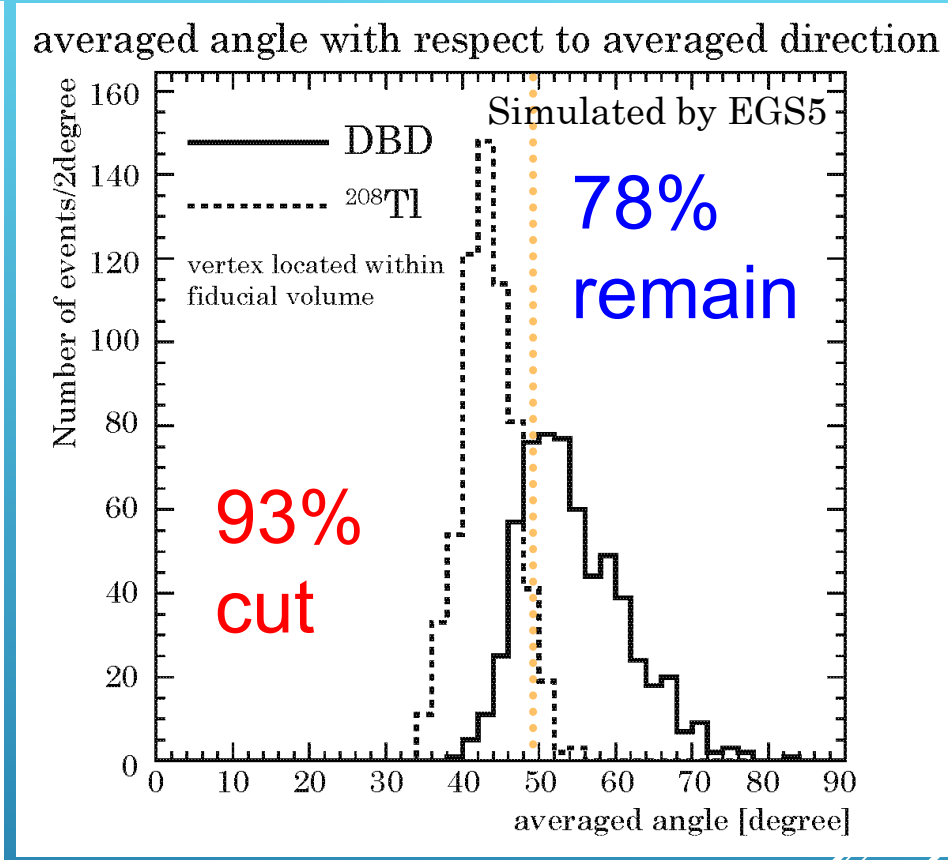


Averaged angle= $\frac{\Sigma \theta_i}{Nhit}$

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.

BG reduction using topological information

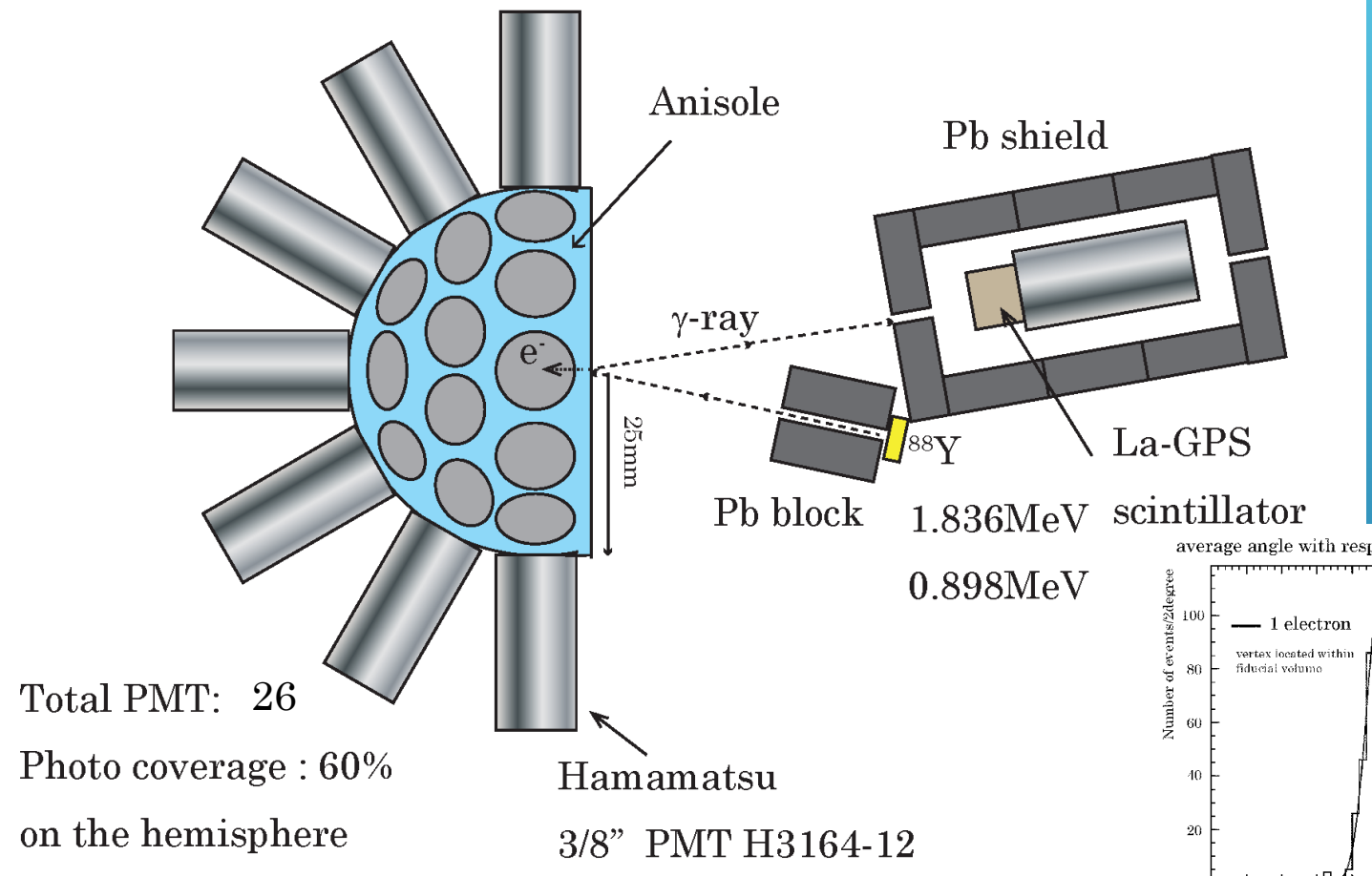


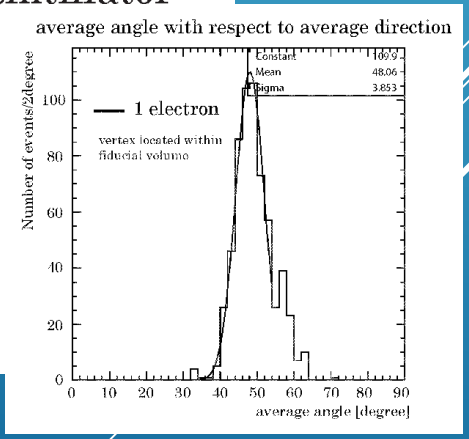


PMT hit pattern of ^{208}Tl BG and 0νββ signal

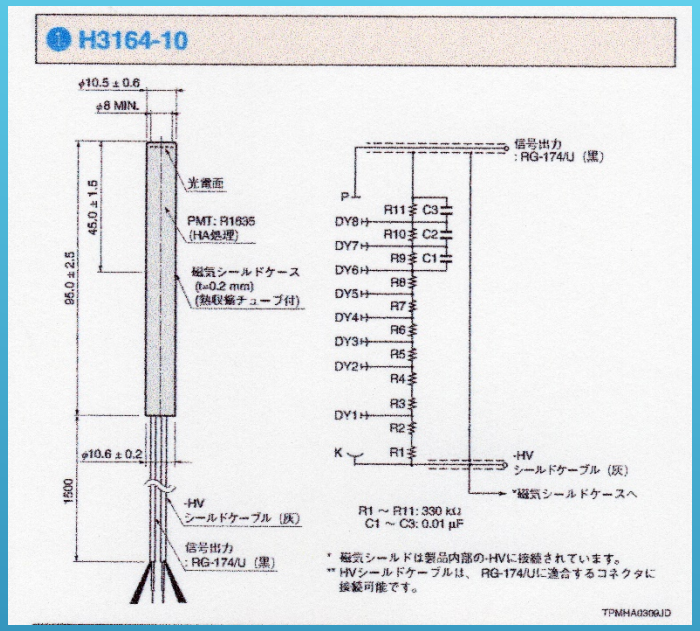
Topological information from PMT position which received Cherenkov lights could be used for reduction of ^{208}Tl BG.

Measurement of topological information (averaged angle) using HUNI-ZICOS



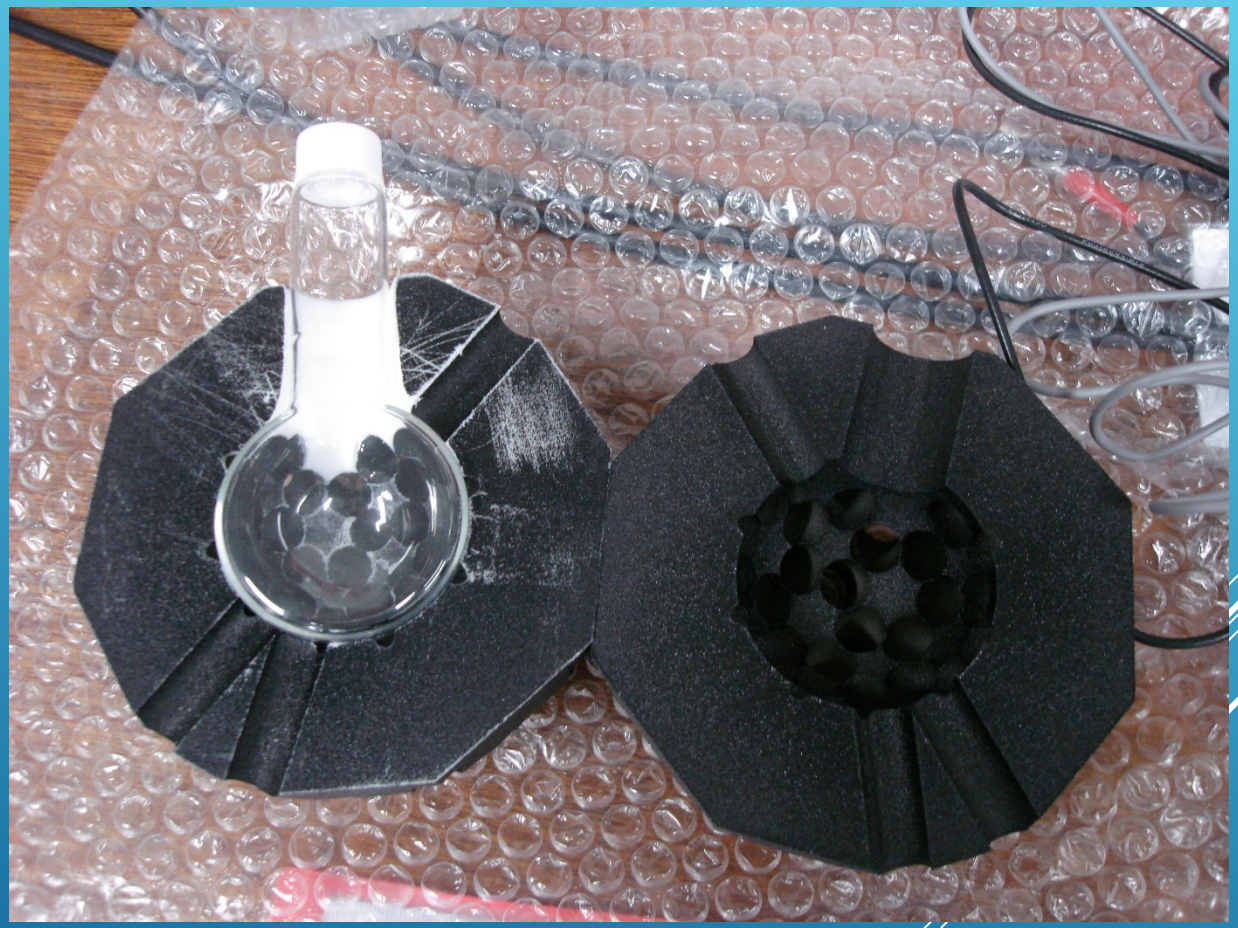


3/8” photomultiplier H3164-12(R1635)



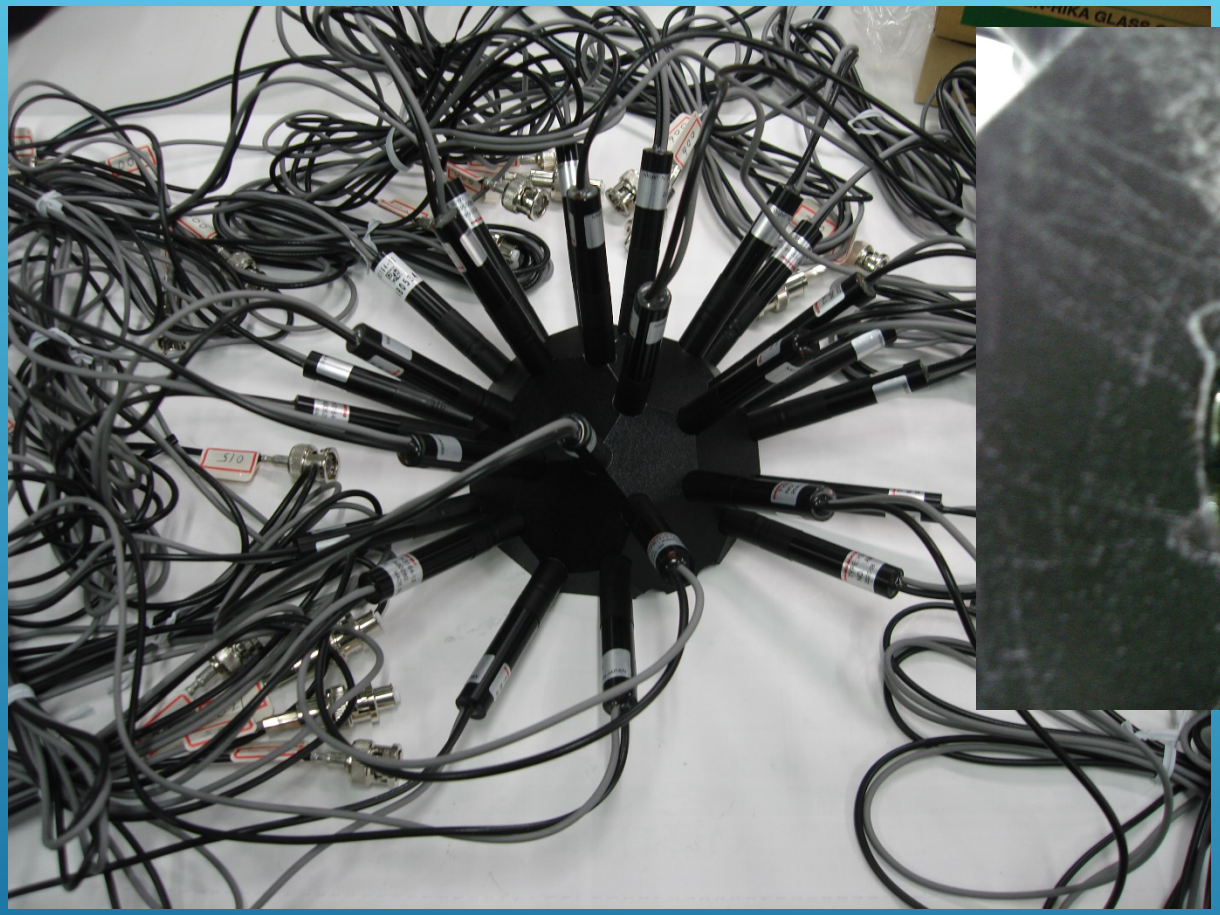
- Sensitivity：400K
- Dynode type : Line focus/8dynode
- Applied voltage：1250V
- Gain：1.0×10^6 Dark current: 50nA
- Time characteristics：0.5ns(TTS) 0.8ns（rise time）

Hemisphere flask and PMT mounting jig for HUNI-ZICOS



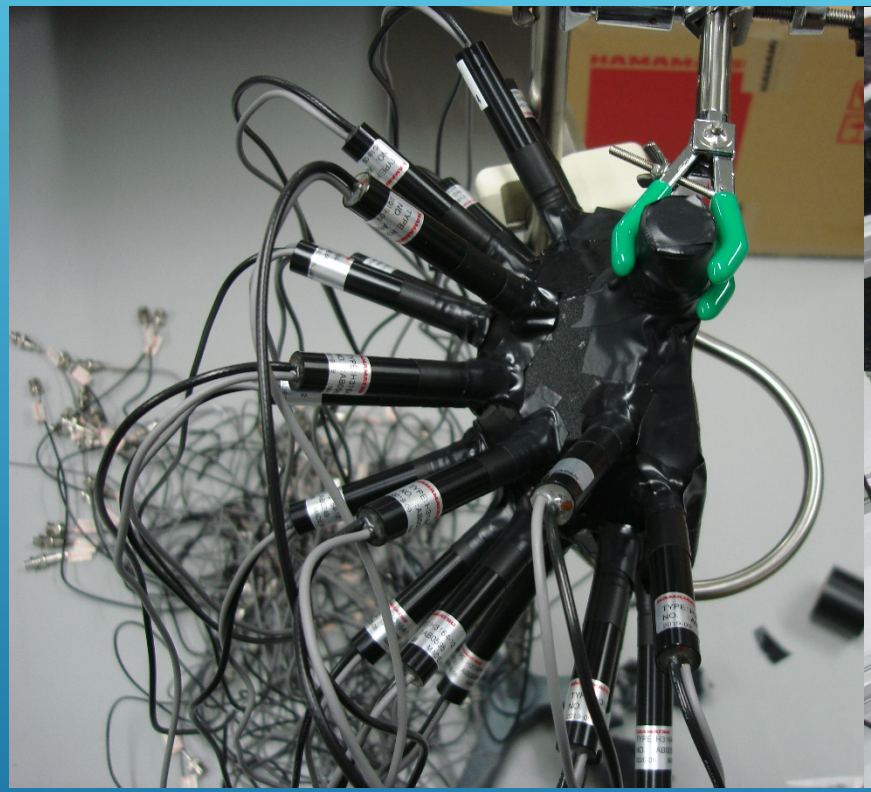
- Extension sharpening for hemisphere flask.
- Some extensions for PMT hole.

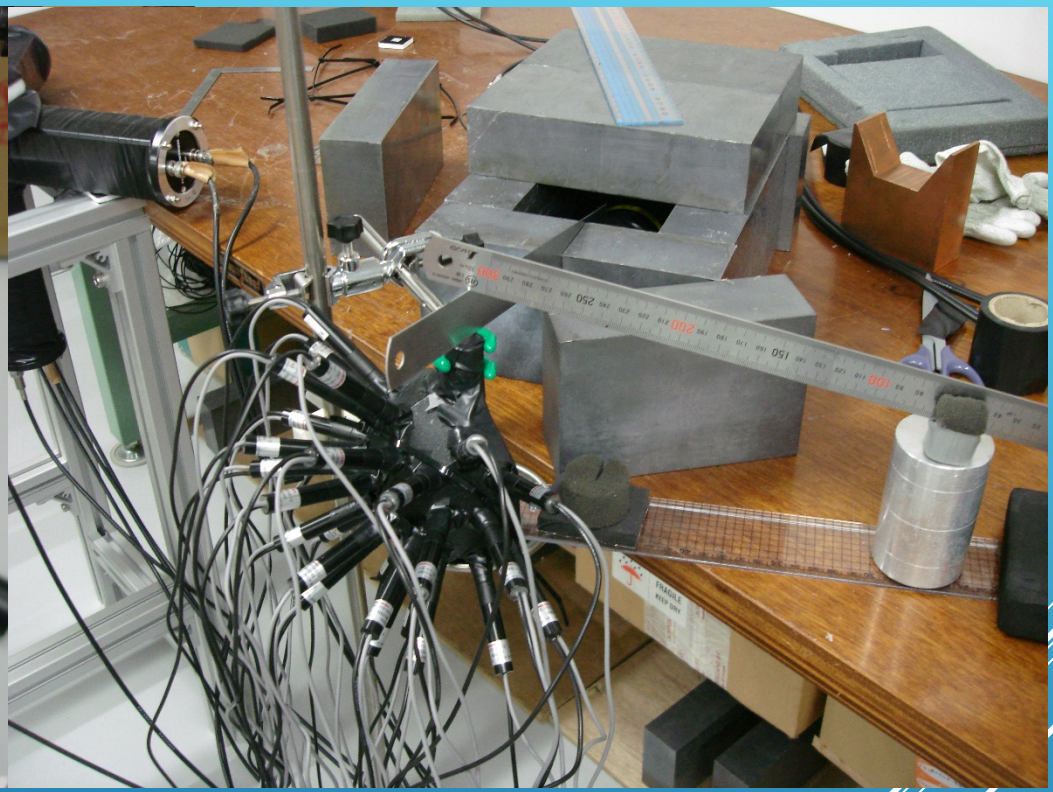
Mounting PMTs on jig for hemisphere flask



- Total 26 H3164-12 PMTs were used for HUNI-ZICO8.
- No PMT at center of hexagon location.
- Light shield was necessary for Nylon.

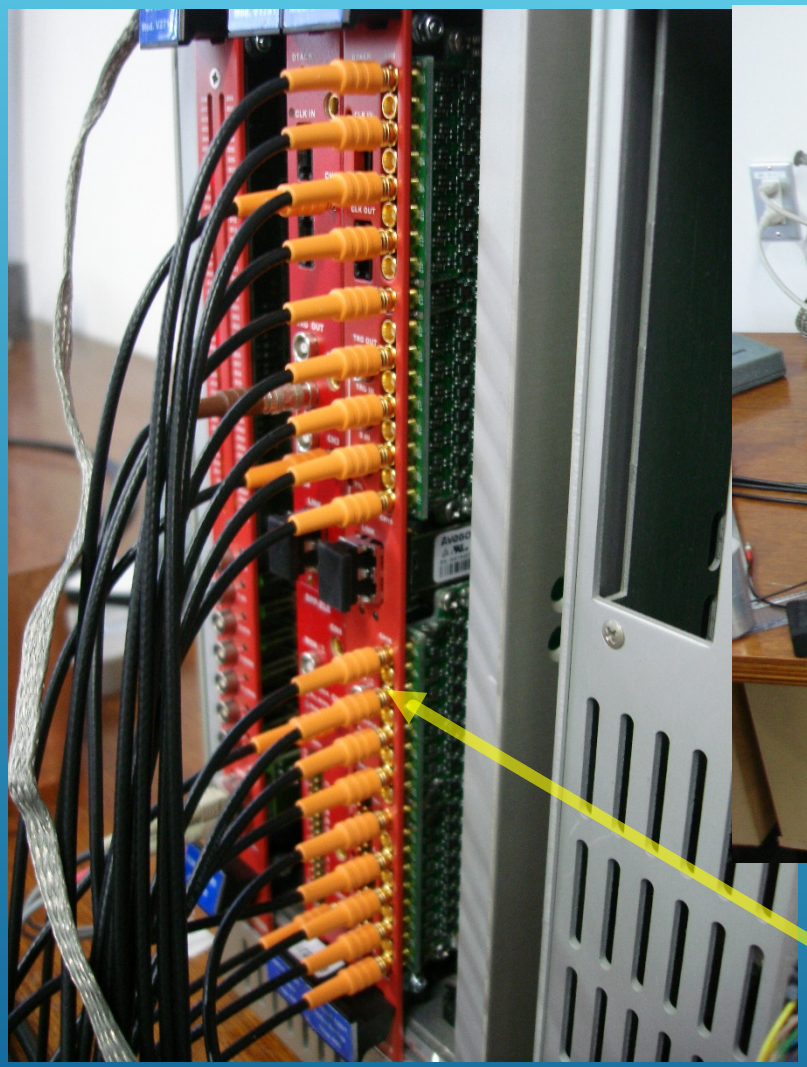
Setting hemisphere flask to jig and locate on supporting stand

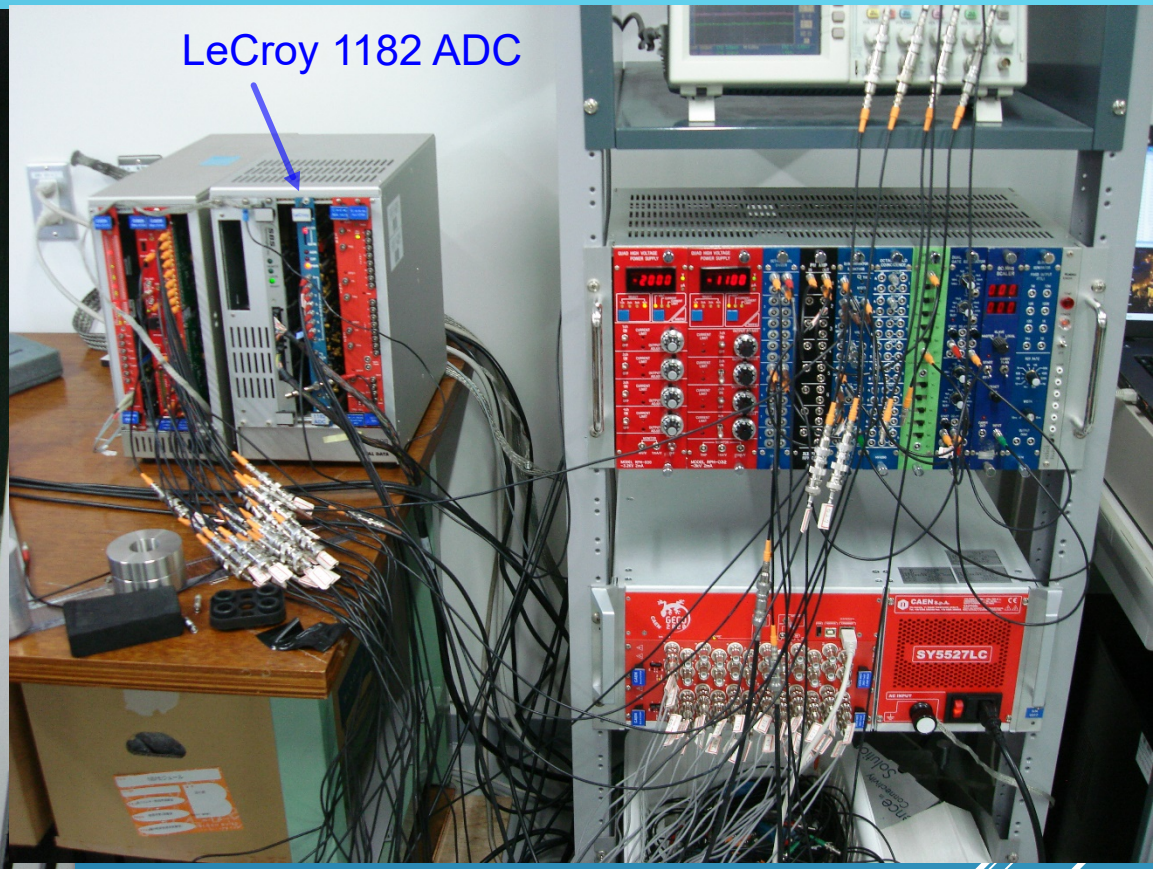




- HUNI-ZICOS was putted on flask clip and the chimney was pinched by clamp.
- Entered gamma was scattered at center position of jig (not hemisphere flask).

Cable connection to FADC and HV

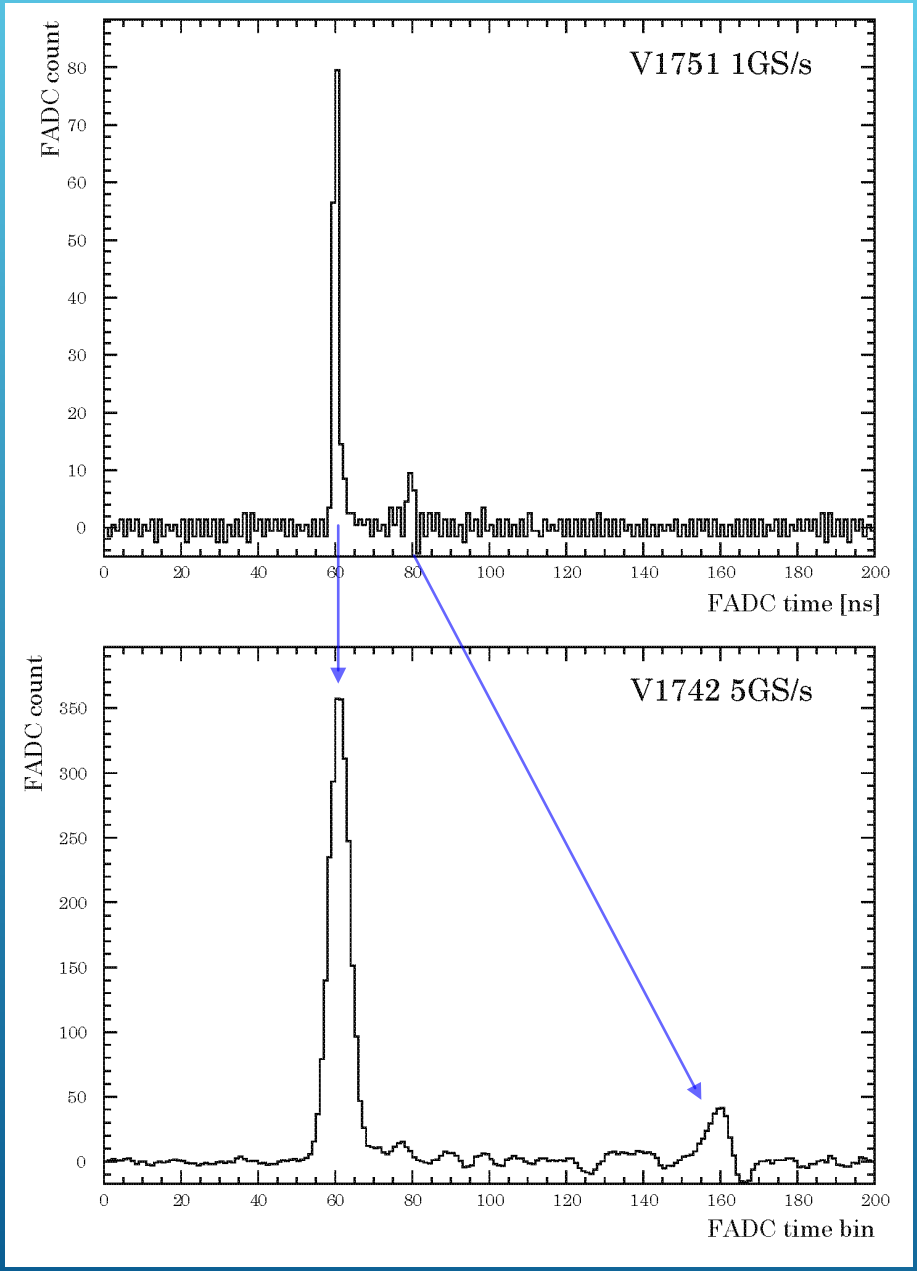




Problem : MCX cables were connected only half channel due to lager thickness!

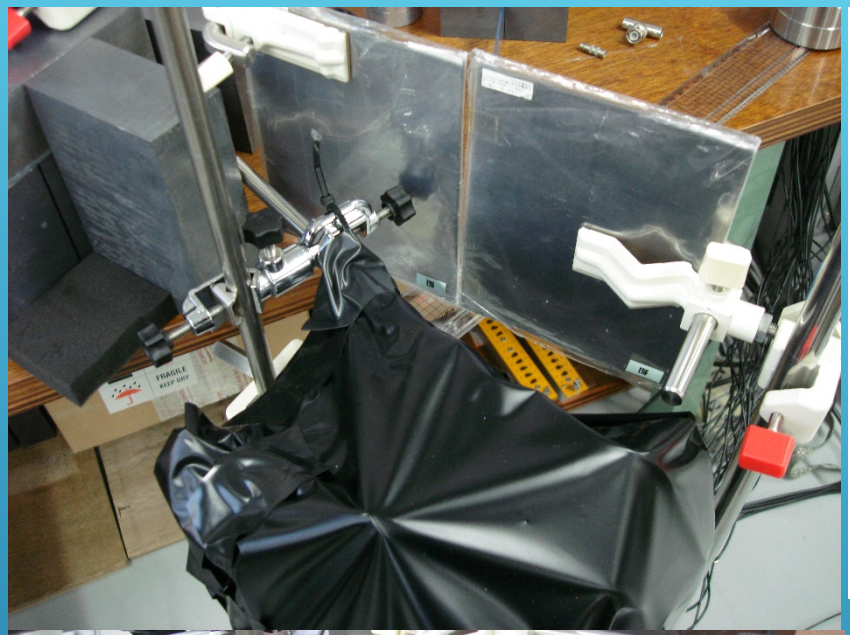
Need V1751 8ch

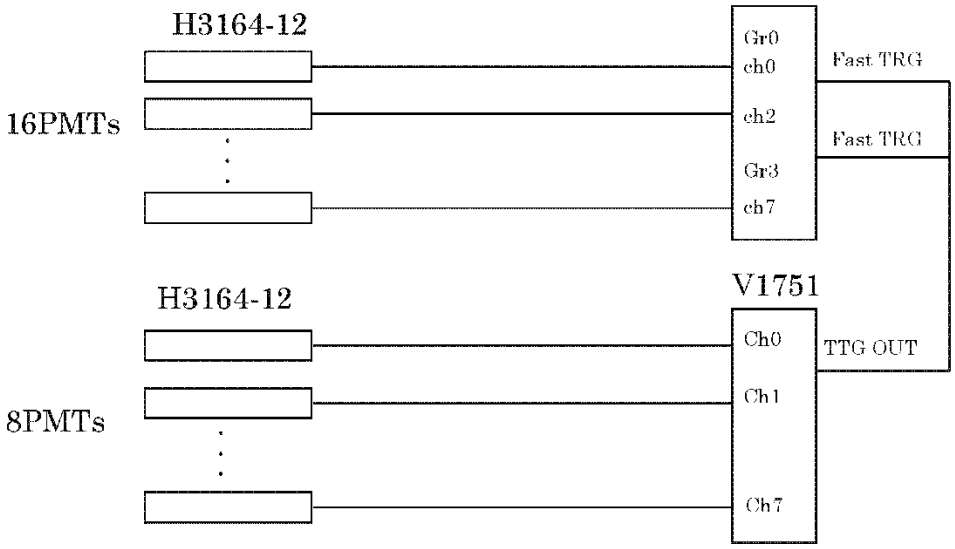
Check V1742 sampling waveform

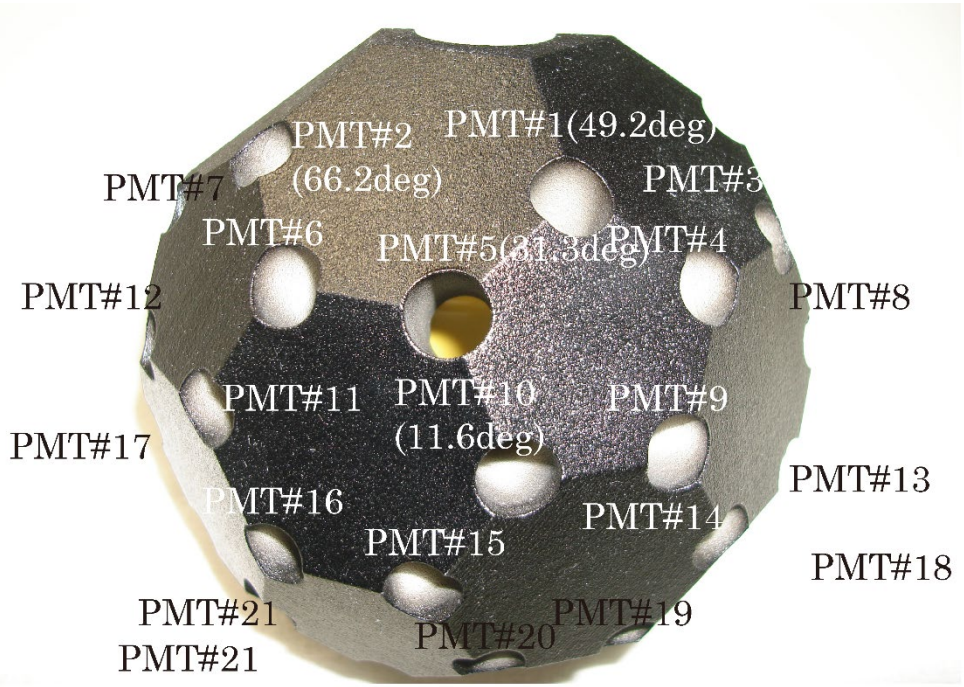


- Sampling frequency of V1742 was set as 5GS/s (fastest mode)
- Sampling frequency of V1751 was set as 1GS/s due to 8ch read.(No DES mode)
- Waveform of same Cherenkov pulse was completely same shape.
- Detailed pulse structure analysis is available using V1742.

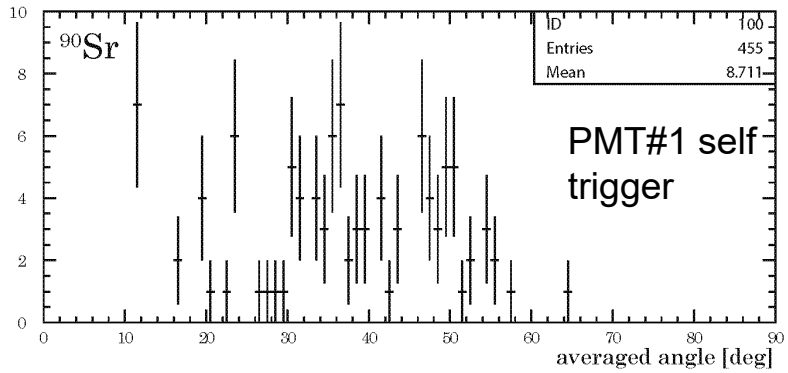
Measurement of averaged angle using ^{90}Sr

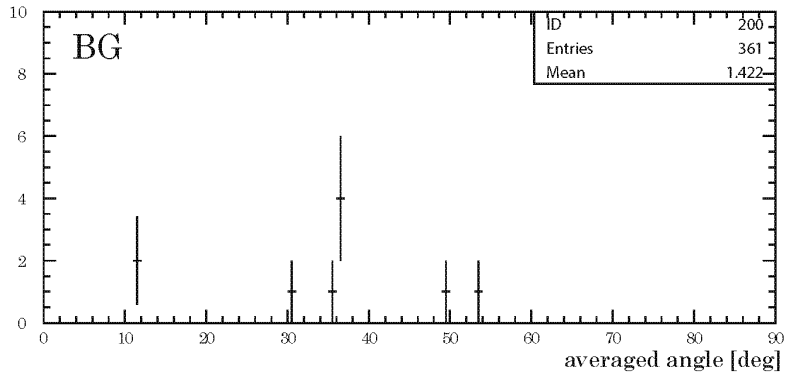


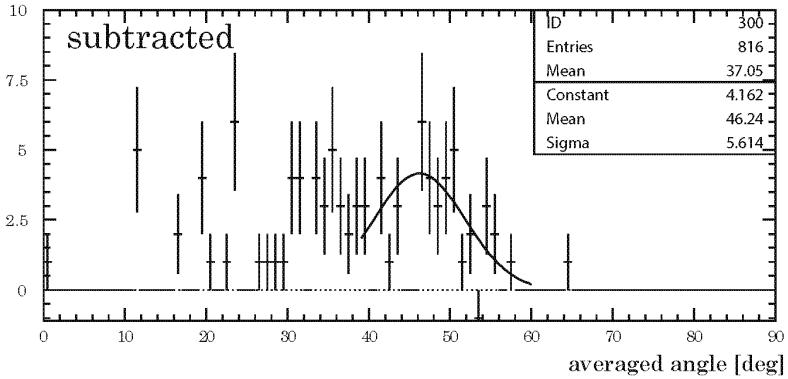


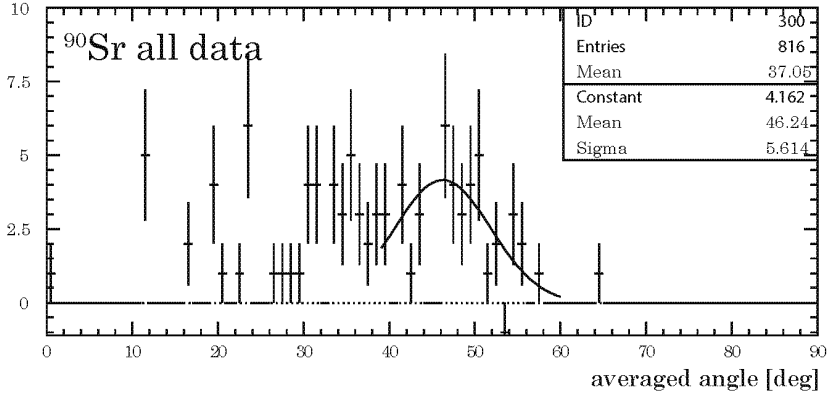


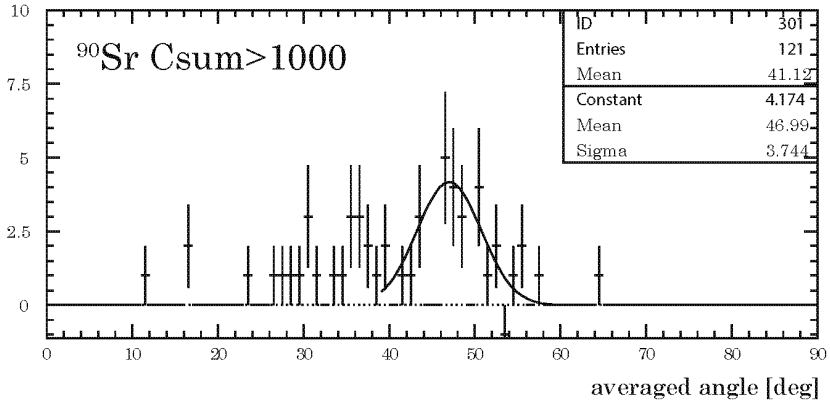
Measurement of averaged angle using ^{90}Sr





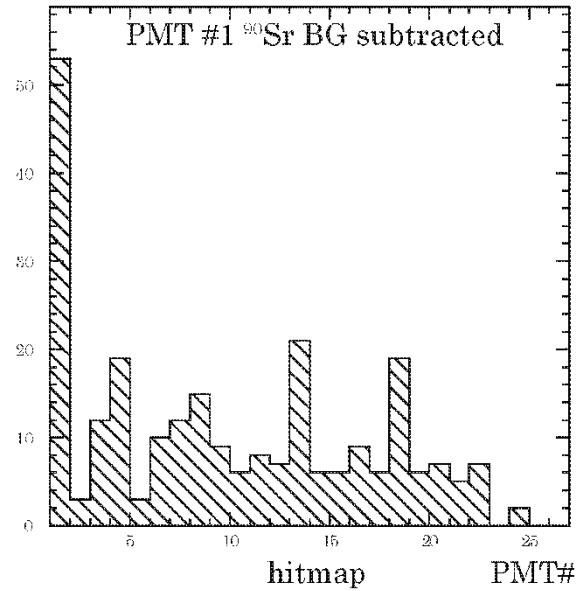


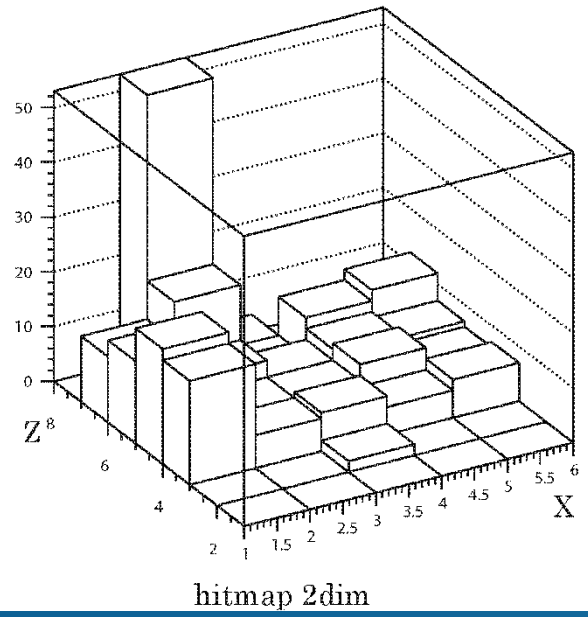


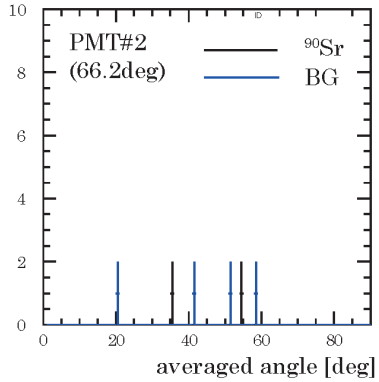


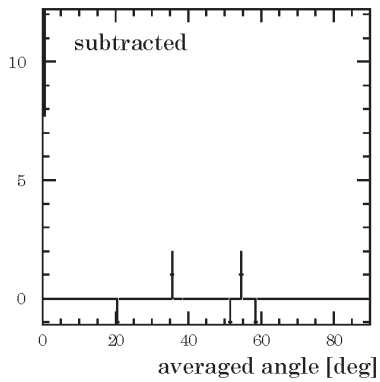
Observed averaged angle seems to be clustered around expected value.

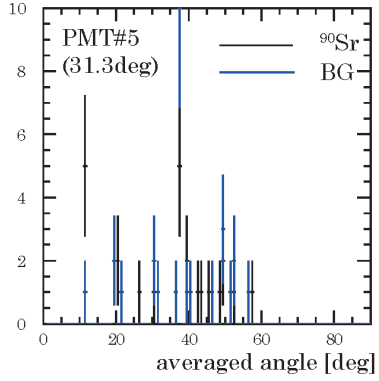
Measurement of averaged angle using ^{90}Sr

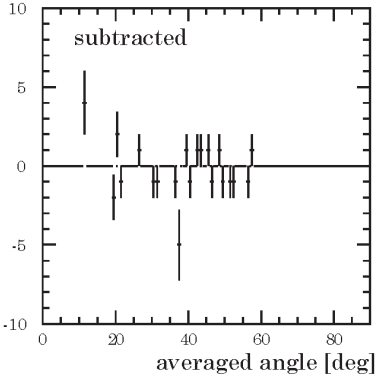


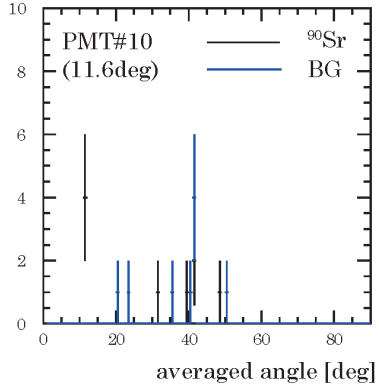


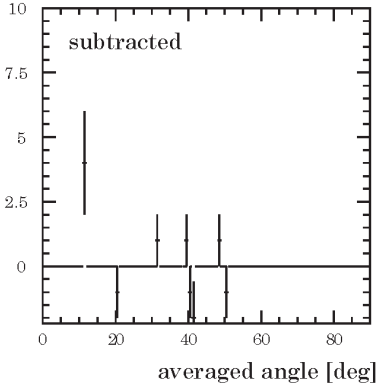






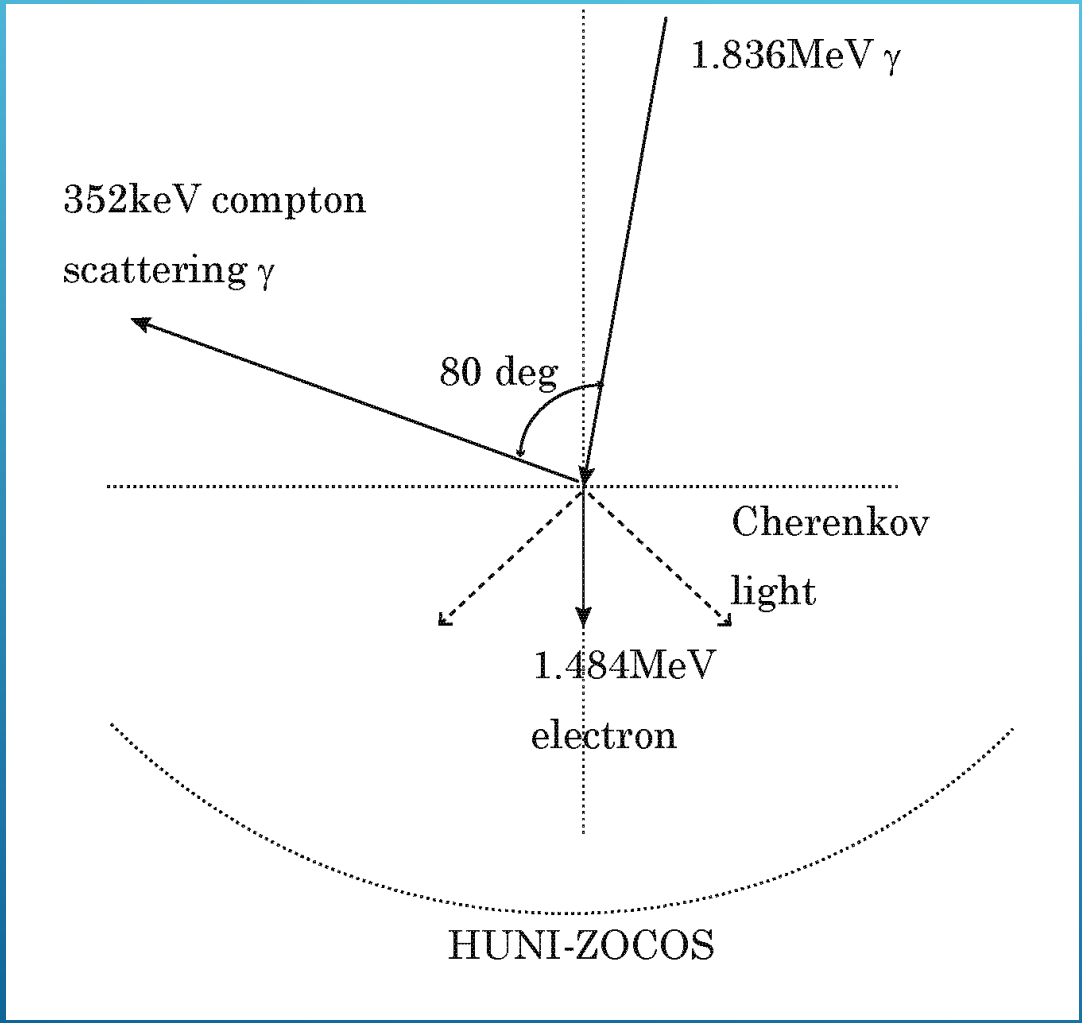






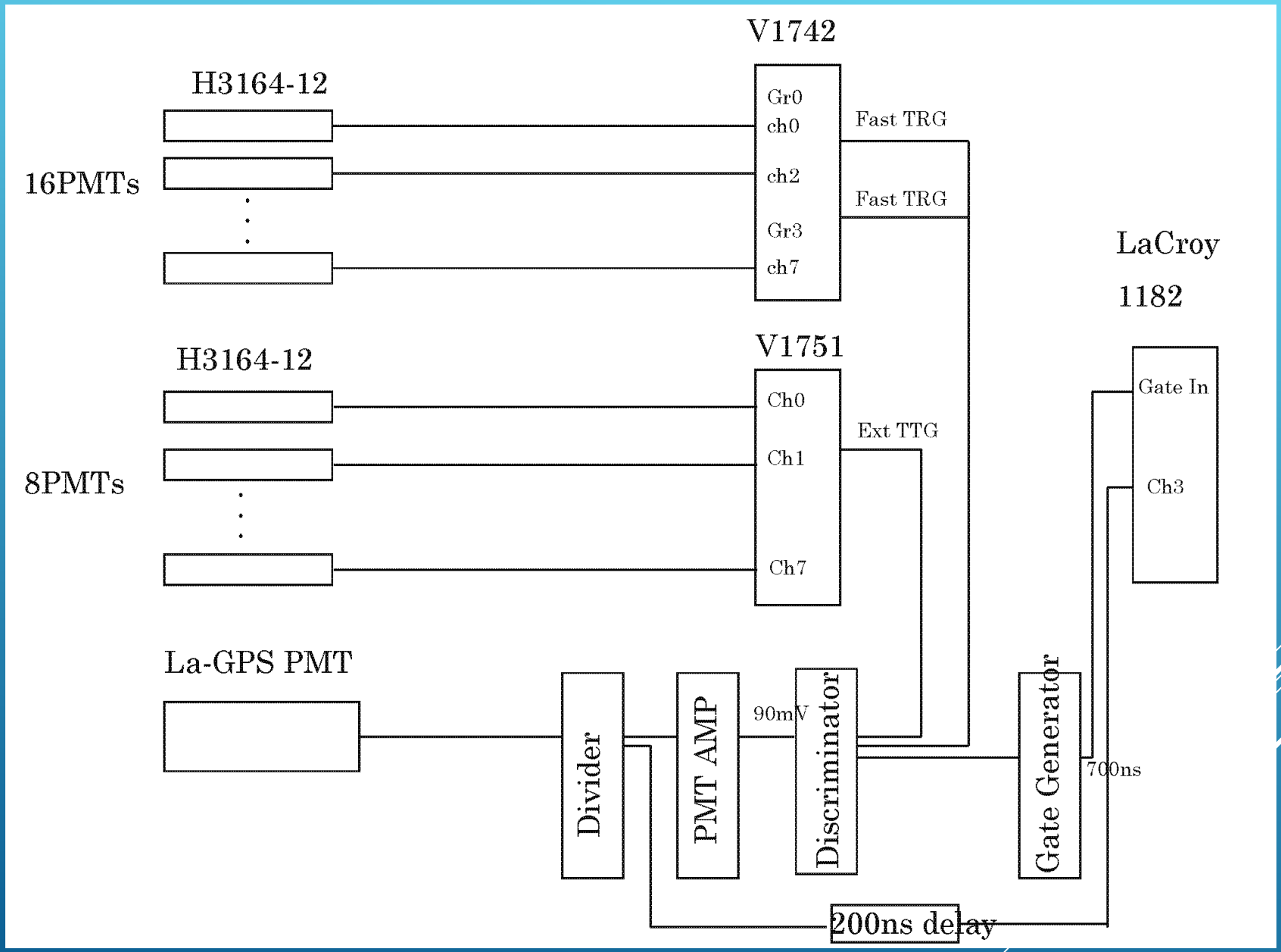
Ring like structure in hitmap for C_{sum} >1000. Need more check.
No cluster (nor no event) was found for other PMT which connected to V1751.

Electron with fixed direction and fixed energy using ^{88}Y gamma source

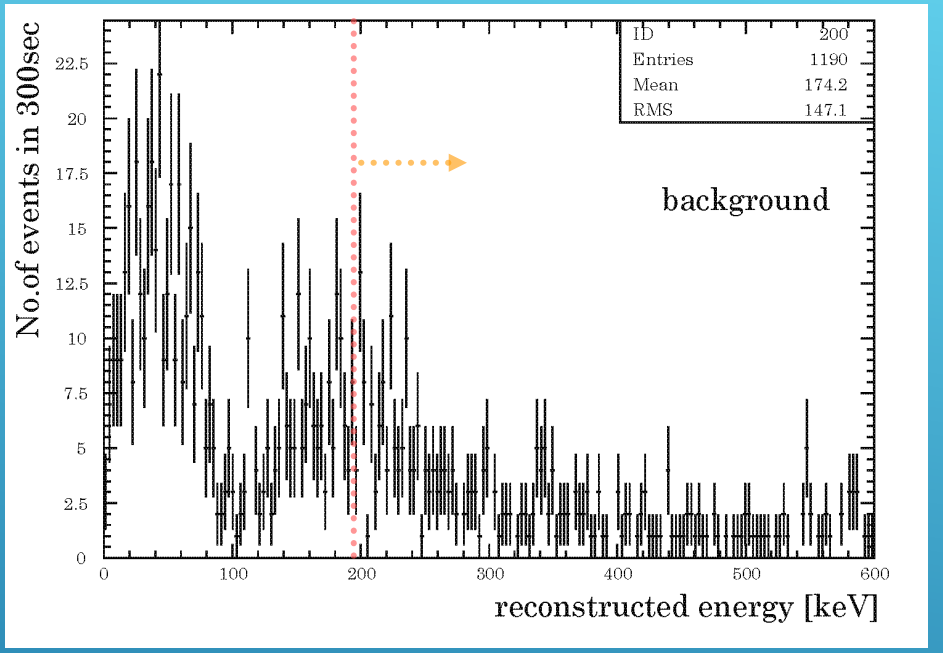


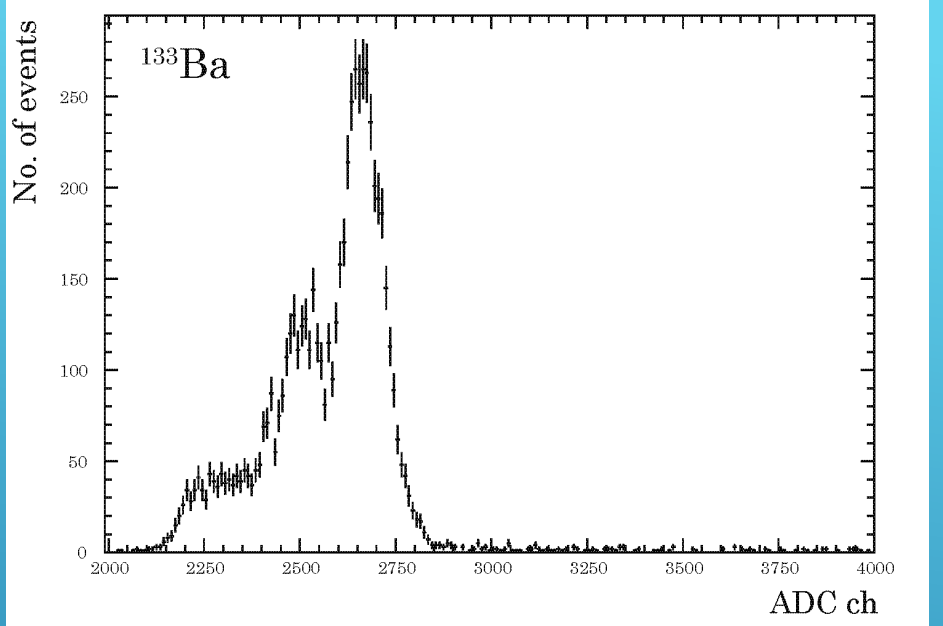
- Compton scattering with fixed direction generate fixed direction and fixed energy electron.
- Compton angle 100 degree corresponds to 352keV γ and 1.484MeV electron.
- Cherenkov angle is 47 degree.

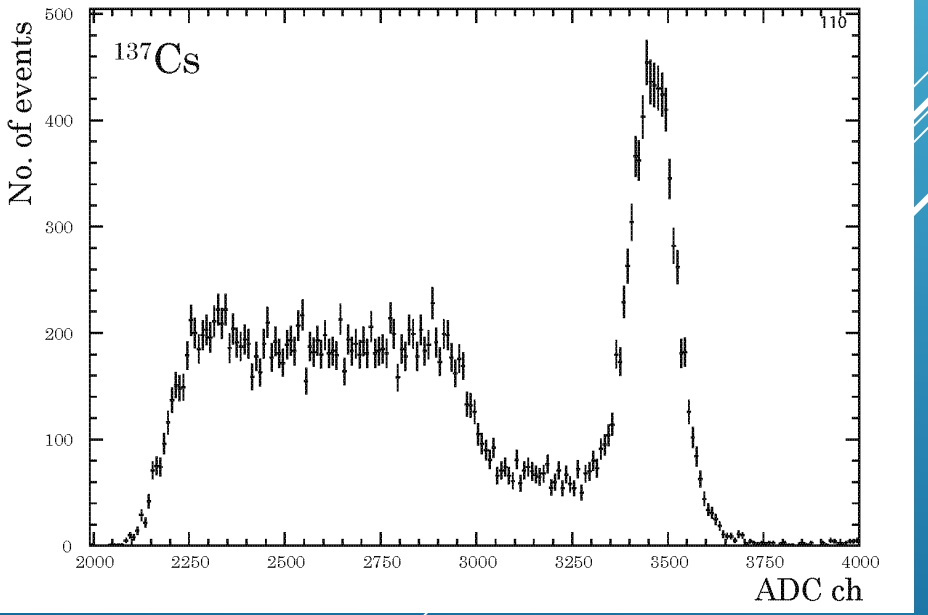
Trigger logic for data taking using ^{88}Y



Calibration for La-GPS scintillator







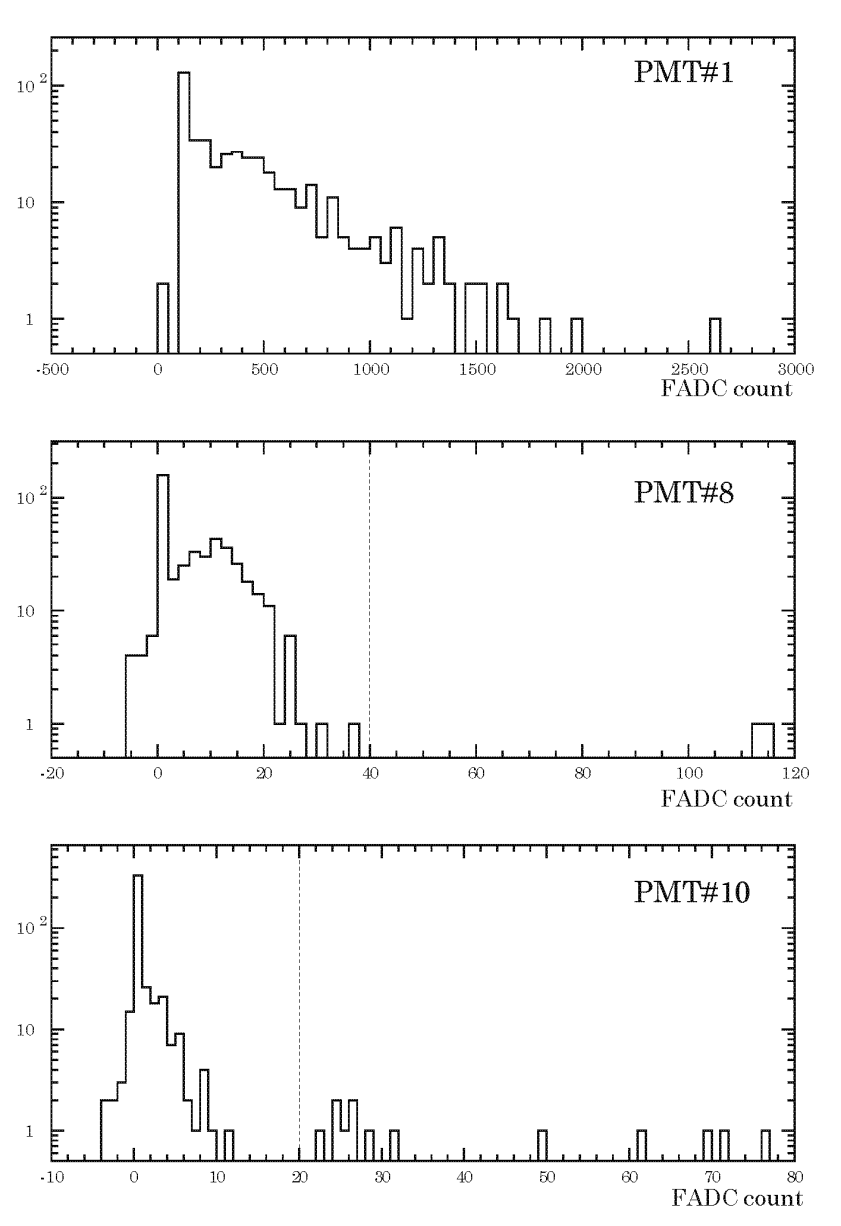
- It is difficult to take all triggers due to V1742 access speed.
- Threshold was set around 200keV.
- Data taking is going on.

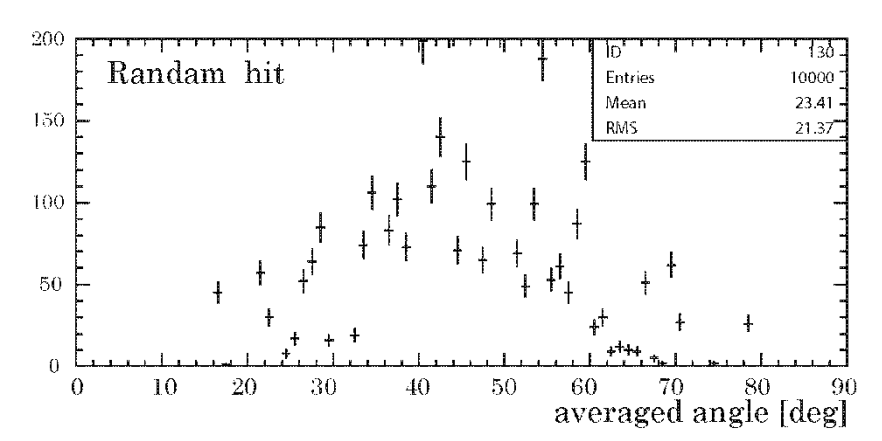
Summary

- HUNI-ZICOS for measurement of topological information using actual ~1MeV electron was done.
- Total 26 3/8” photomultipliers (Hamamatsu H3164-12), CAEN V1742 digitizer and AG7030SN HV were prepared.
- PMT supporting jig was designed by truncated icosahedron and produced by 3D printer using Nylon.
- Prepared MCX cable had a thicker socket than pitch of V1742 input channel. Only half of PMT was connected.
- Measurement of averaged angle using ^{90}Sr was done and obtained value looks expected value. Need careful check.
- Measurement of averaged angle using fixed direction and fixed energy using ^{88}Y is going on.
- We will confirm that averaged angle of Cherenkov light from ~1MeV electron should be around 47 degree soon.

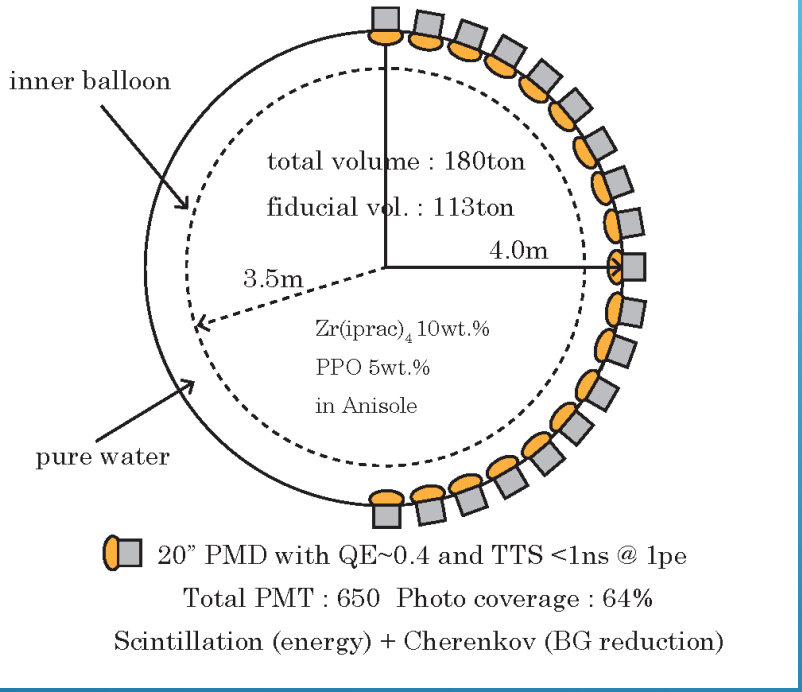
Backup slides

Measurement of averaged angle using ^{90}Sr

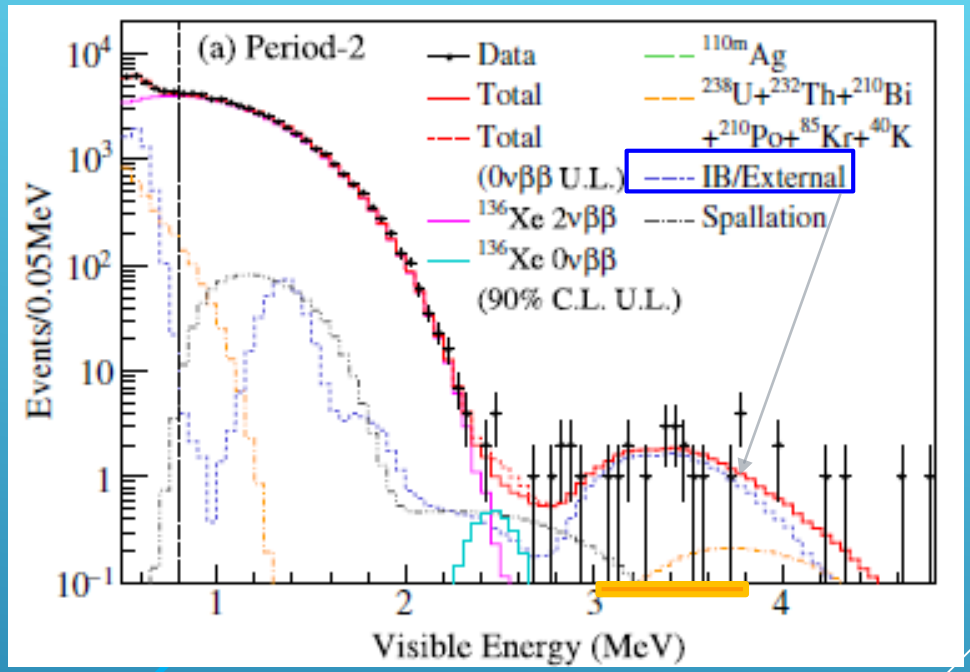




Conceptual design of ZICOS detector



Phys.Rev.Lett. 117 (2016) 082503



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

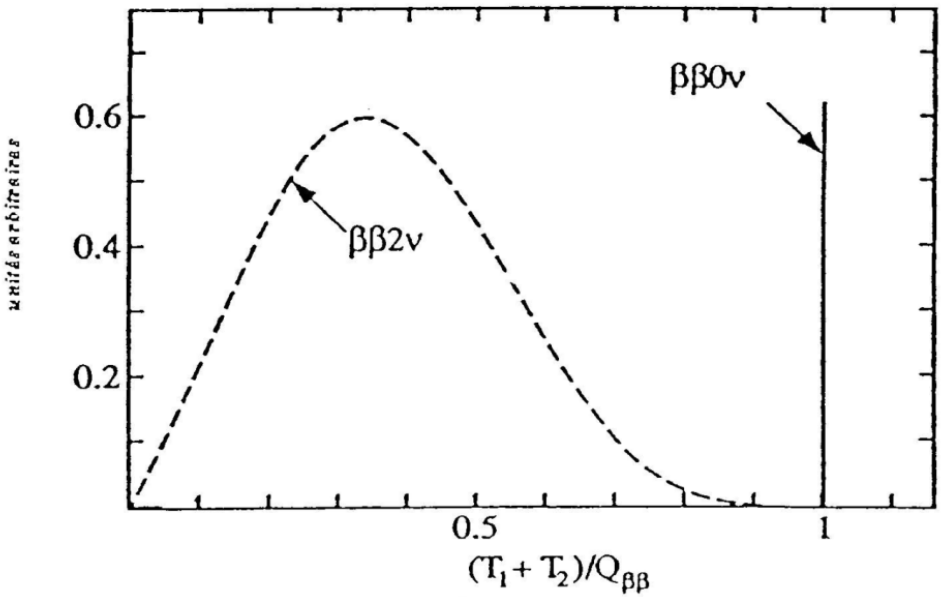
^{96}Zr : 45kg (nat.) → 865kg(50% enrich)→1/20 BG

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

Neutrinoless double 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



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

$T_{1/2} \sim a(Mt/\Delta E \cdot B)^{1/2}$ a: abundance M: target mass

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

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

Flash ADC V1742 and PMT HV system

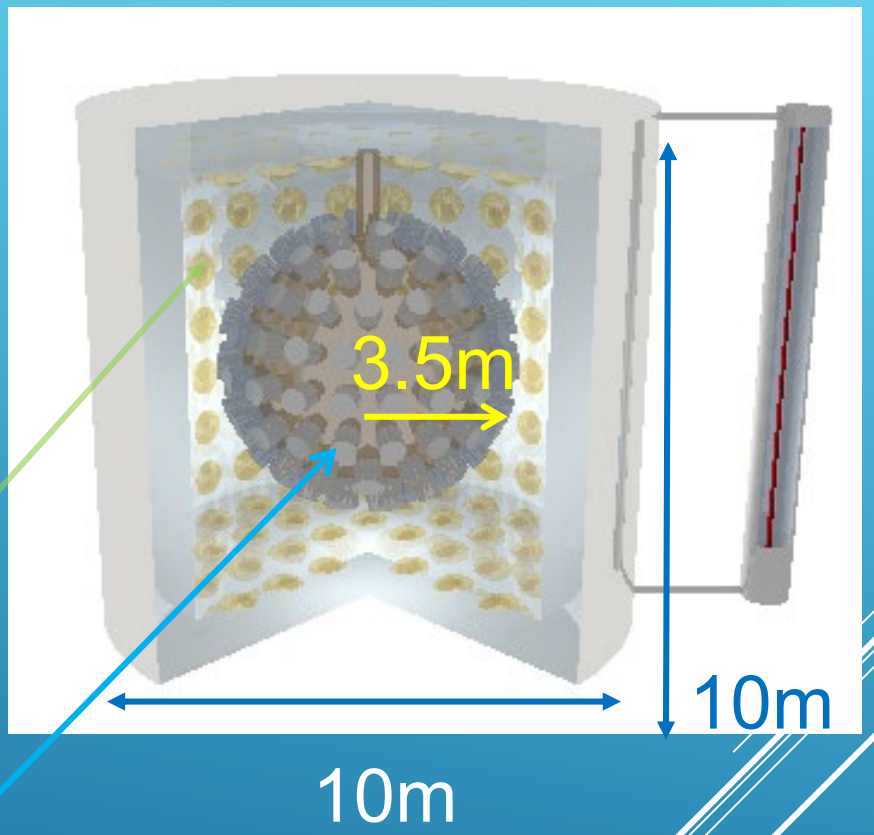
Both CAEN HV AG7030SN and FADC V1742 32ch (5Gs/s!) were checked and ready for the measurement.

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)

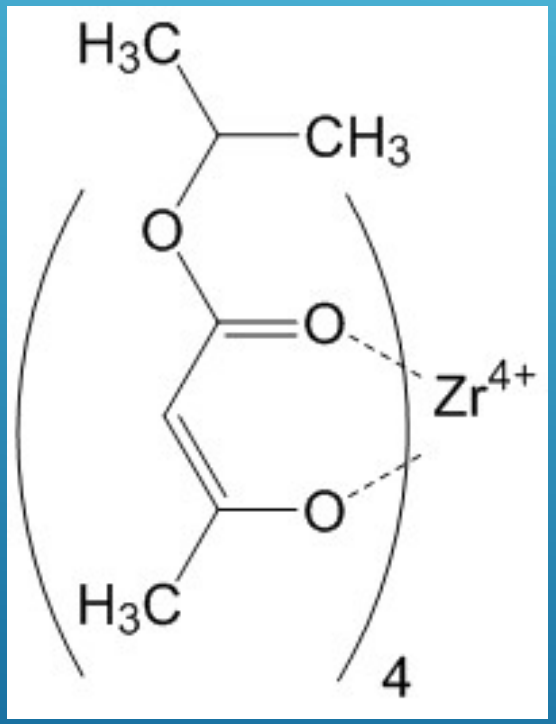


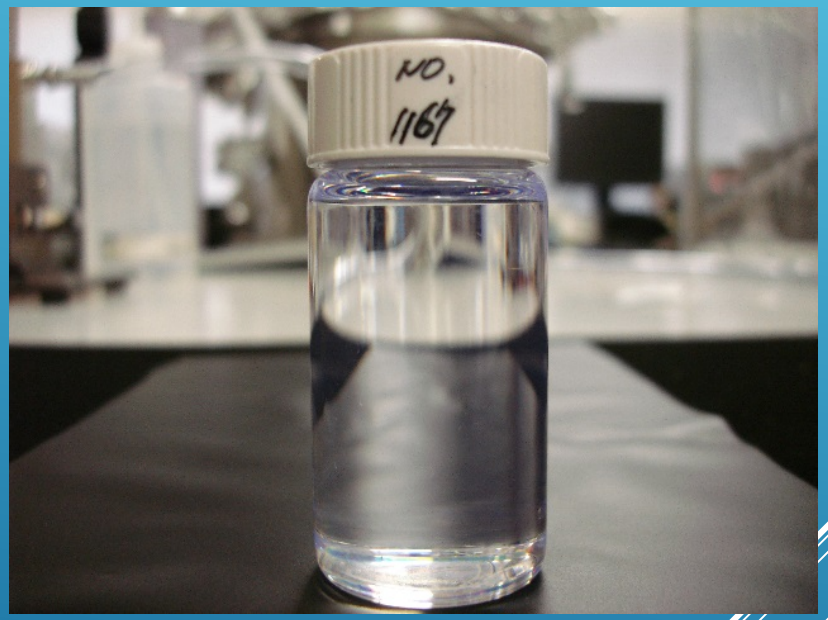
Purpose:
① **Direct measurement of $0\nu\beta\beta$**
② **Confirm parameter of nuclear matrix element model**

Liquid Scintillator solving $Zr(iPrac)_4$

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

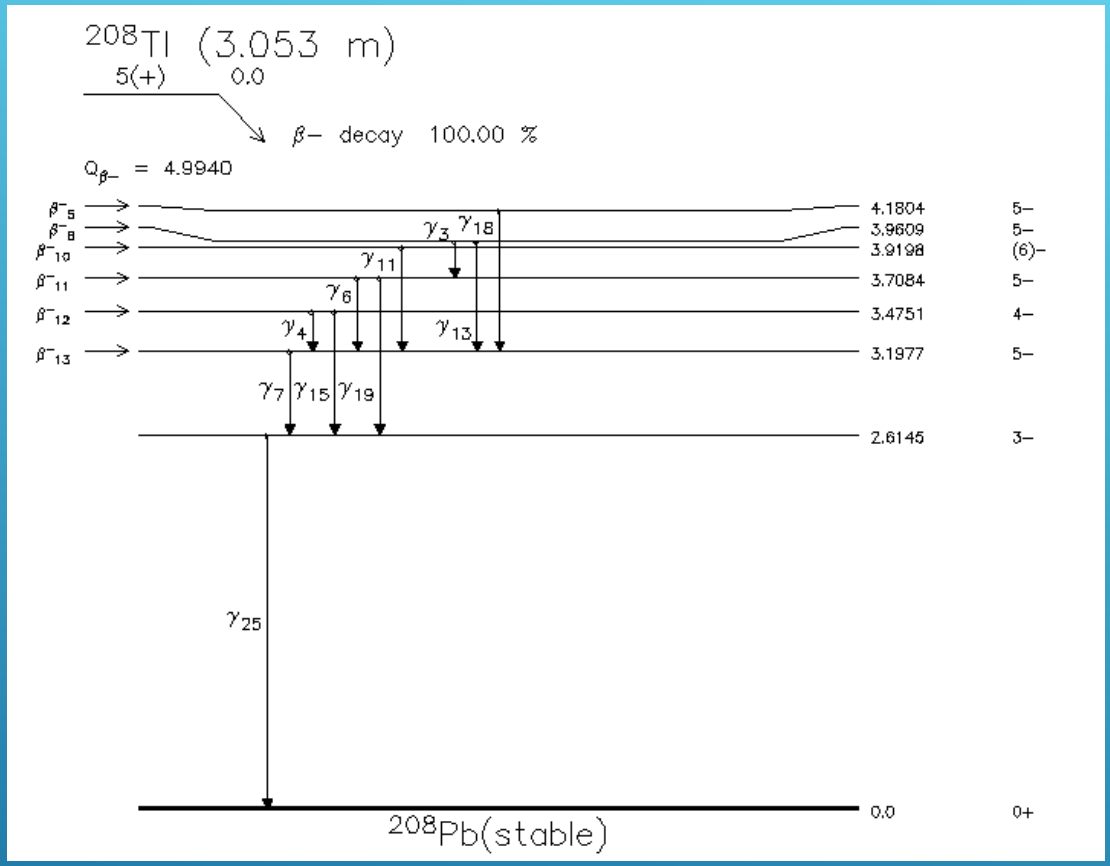
$Zr(iprac)_4$ 2242mg, PPO 999mg and POPOP 10mg solved in 20mL Anisole





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

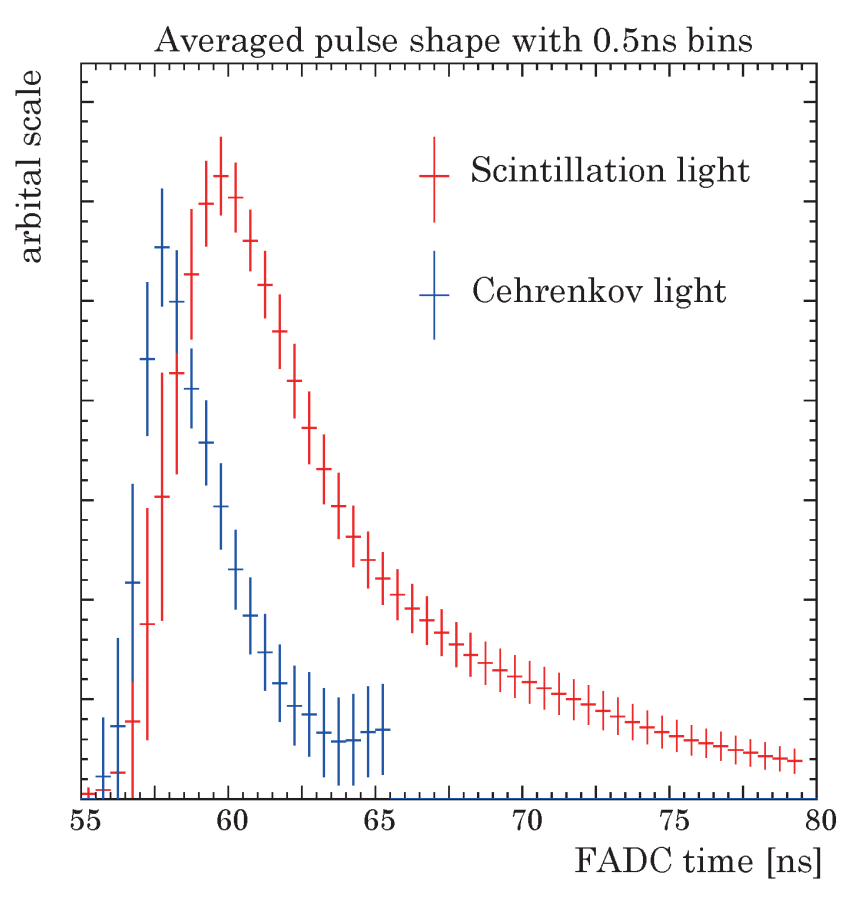
Decay scheme of ^{208}Tl



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

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}

Pulse shape of Cherenkov and scintillation

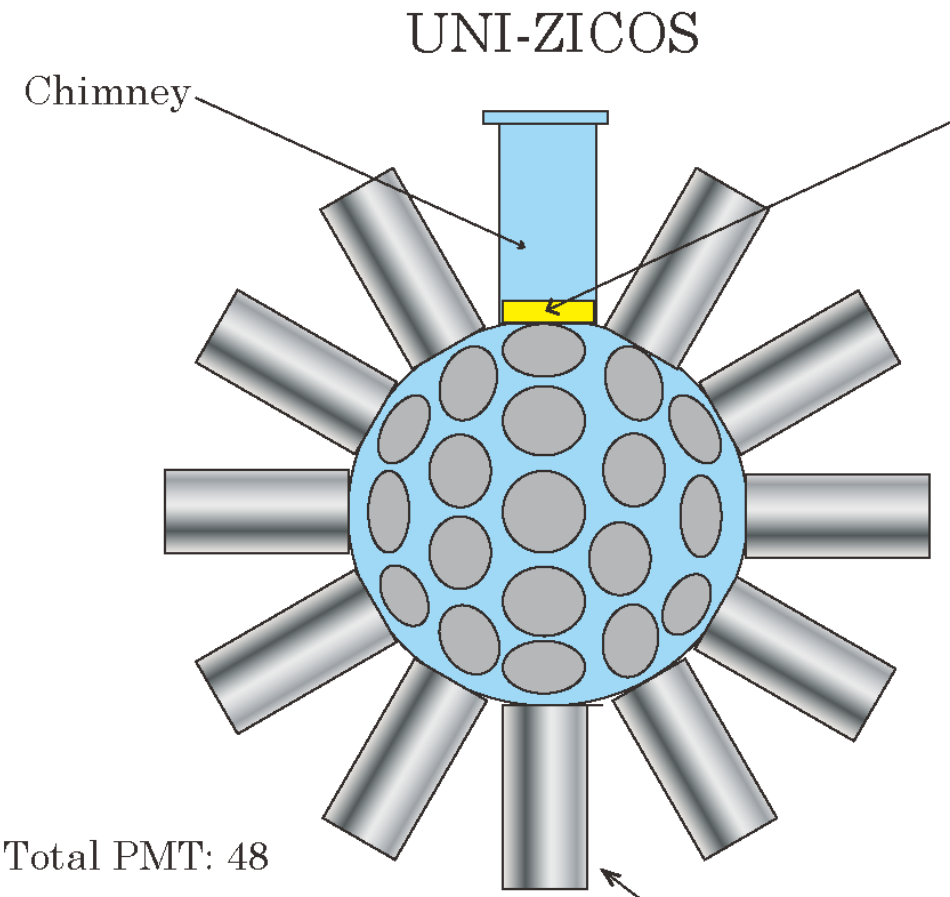


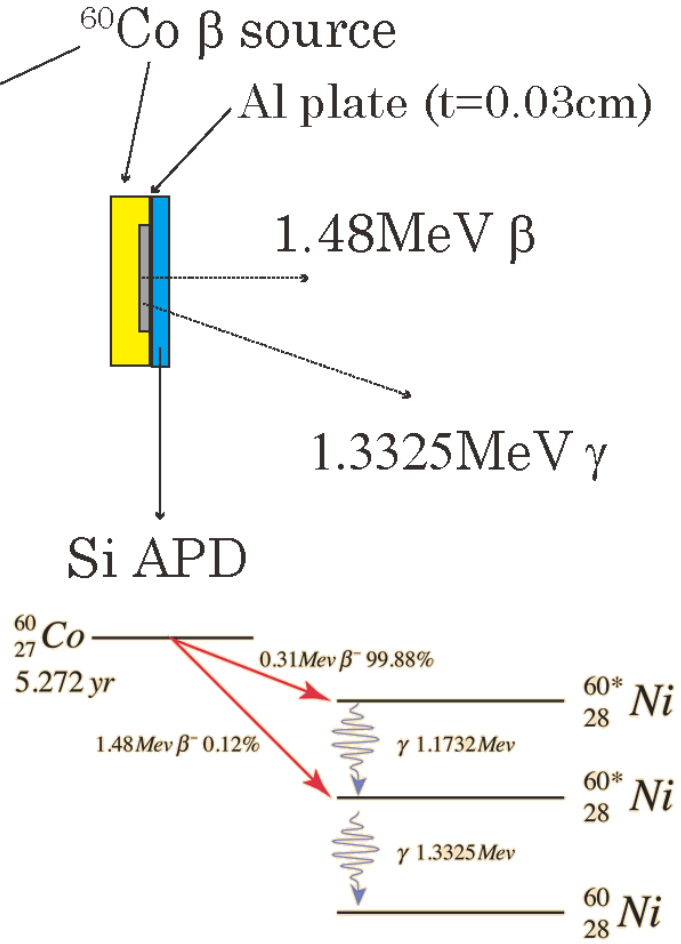
- Pulse shape of ^{90}Sr using H2431-50 measured by V1751 with DES mode (2GS/s)
- Decay time of scintillation : 4.57ns and 8.38ns
- Rise time of scintillation : 1.45ns
- Rise time of Cherenkov : 0.75ns

Use the charge ratio Q_{time}/Q_{total}. Here, Q_{time} is FADC value in each time, and Q_{total} is sum of FADC value between 55ns and 80ns.

Verification of ^{208}Tl BG reduction

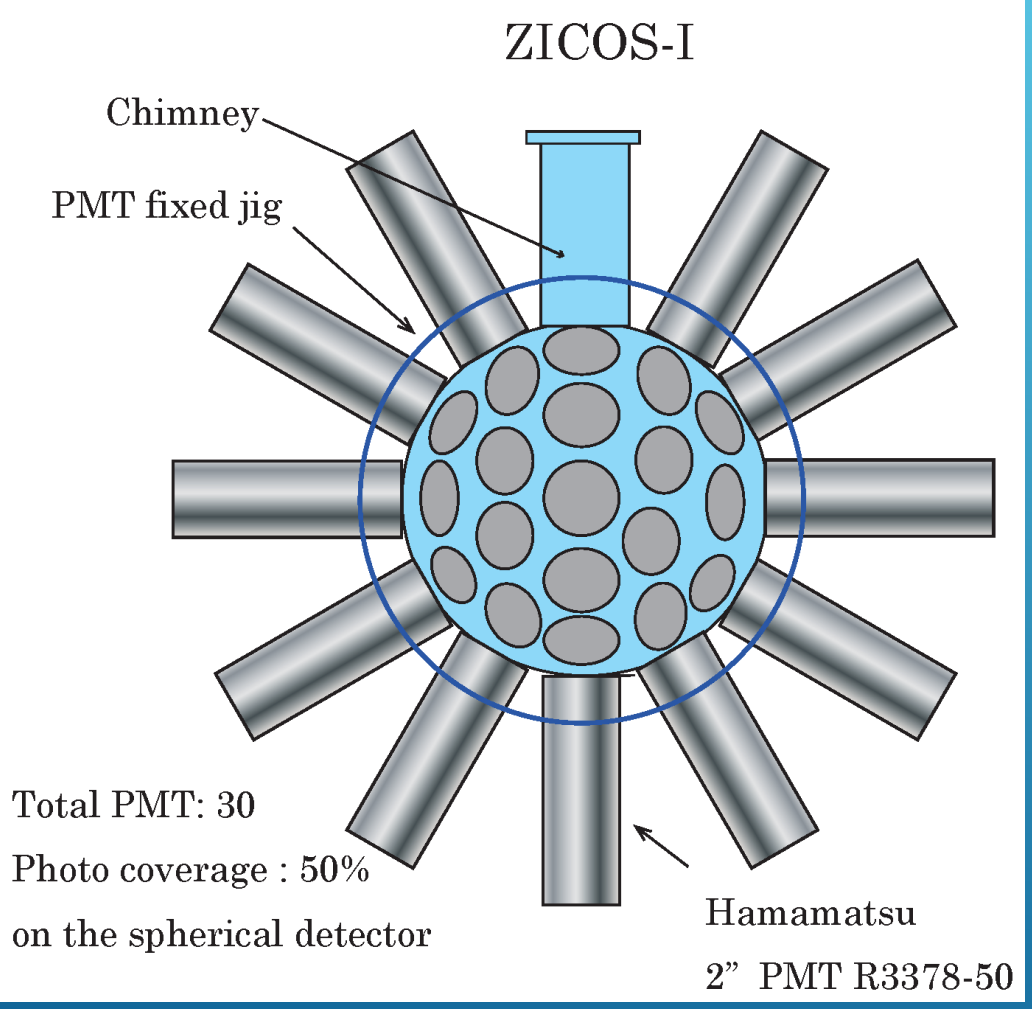
- Direct measurement using βγ events by UNI-ZICOS





Measurement of $T^{2\nu}_{1/2}$ for ^{96}Zr using ZICOS-I

- First physics program to measure $T^{2\nu}_{1/2}$ for ^{96}Zr

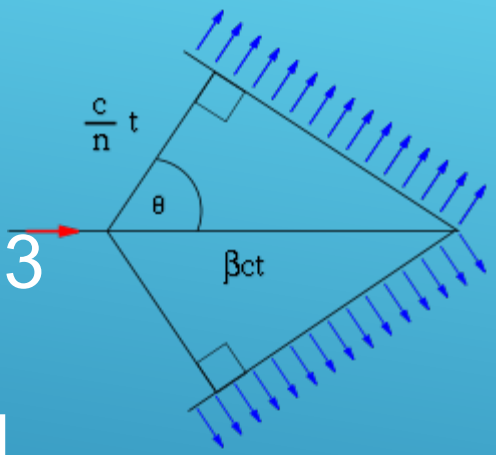


・20cm diameter flask using Ultra-pure quartz and 30 low BG 2” PMT R3378-50 (R2083)
・Synthesis $Zr(iPrac)_4$ 300g which corresponds to ^{96}Zr isotope1g
・According to NEMO-3 result, expect 200 $2\nu\beta\beta$ events/year
・Location: Kamioka mine

Stay tuned!

Property of Cherenkov light

- Refractive index of anisole : n=1.518
- Cherenkov angle is determined by $\cos\theta = 1/n\beta$
- Assuming 1.65MeV electron, then β=0.972 and Cherenkov angel θ=47.3 degree are expected.
- Cherenkov light should be measured. (400nm – 600nm : 100 photon/MeV)



$$\frac{dN}{dx} = 2\pi z^2 \alpha \sin^2\theta_c \int_{\lambda_1}^{\lambda_2} \frac{d\lambda}{\lambda} = 475 z^2 \sin^2\theta_c \text{photon/cm}$$

c.f. Light yield of Scintillation : ~12000photon/MeV

Cherenkov light = 1~2% of scintillation light