半減期１０の２７乗年以上の二重B崩壊観測を実現するＴＬ－２０８背景事象除去の検証

「第七回極低放射能技術」研究会

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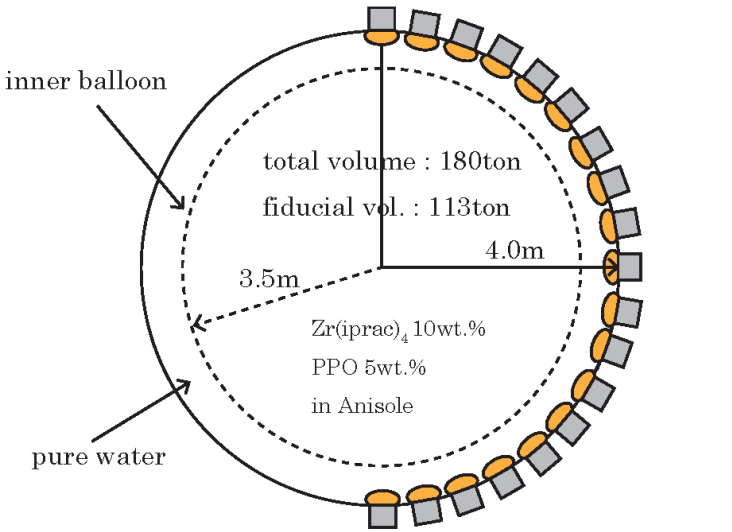
Conceptual design of ZICOS detector



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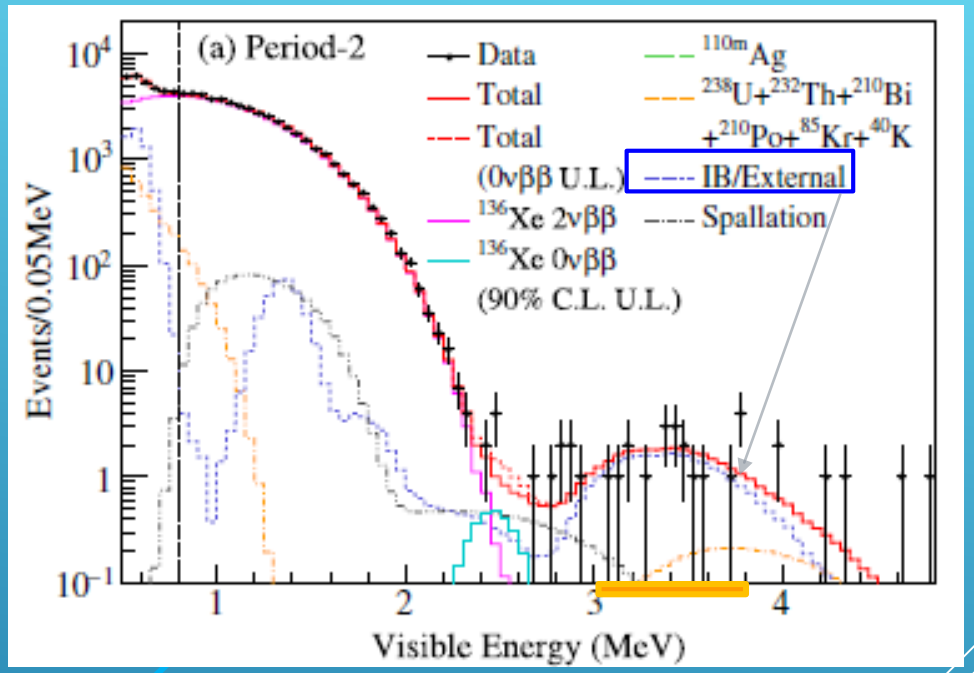
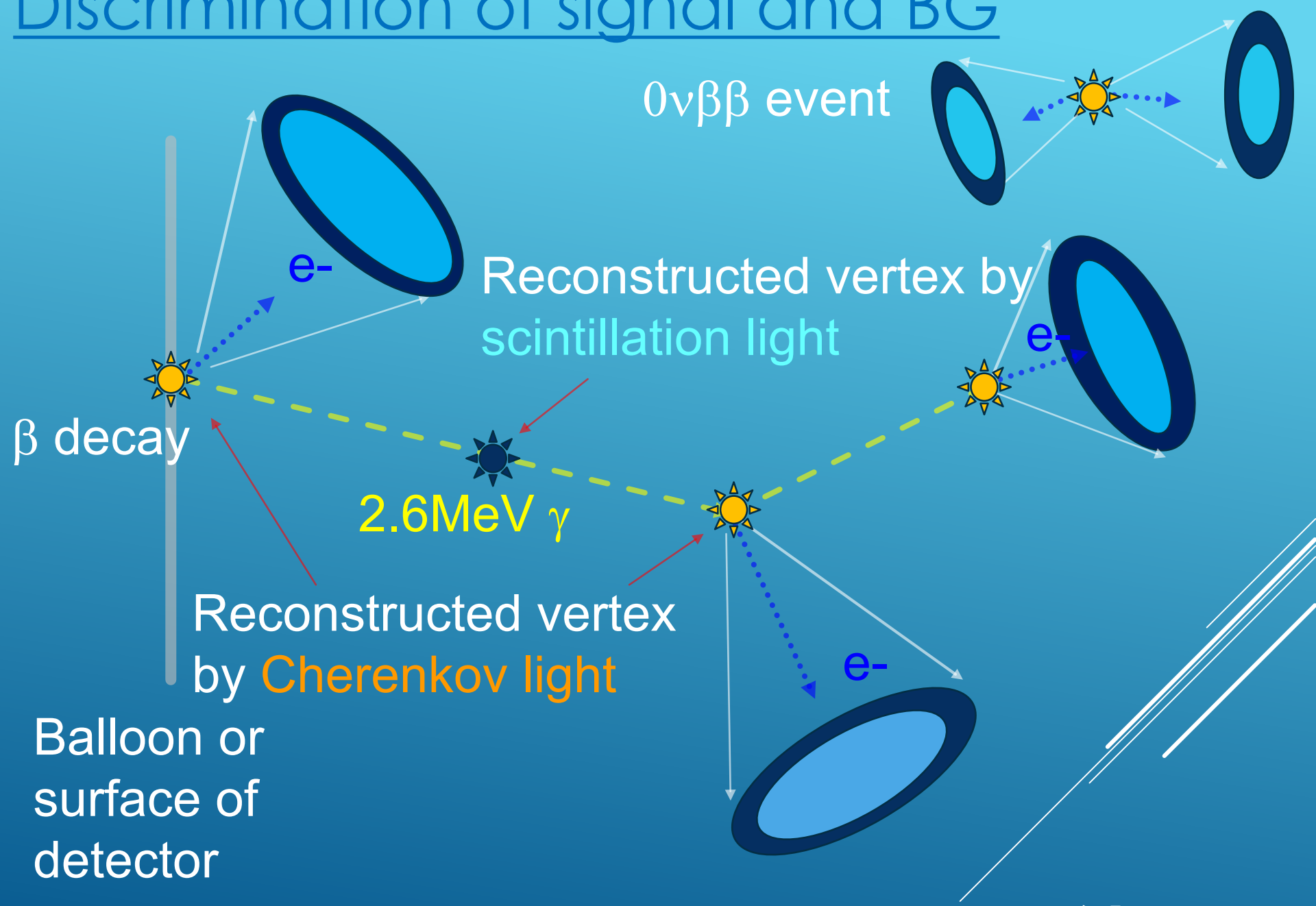


NEMO3 : $T_{1/2}^{0\nu} > 9.1 \times 10^{21}$ yrs

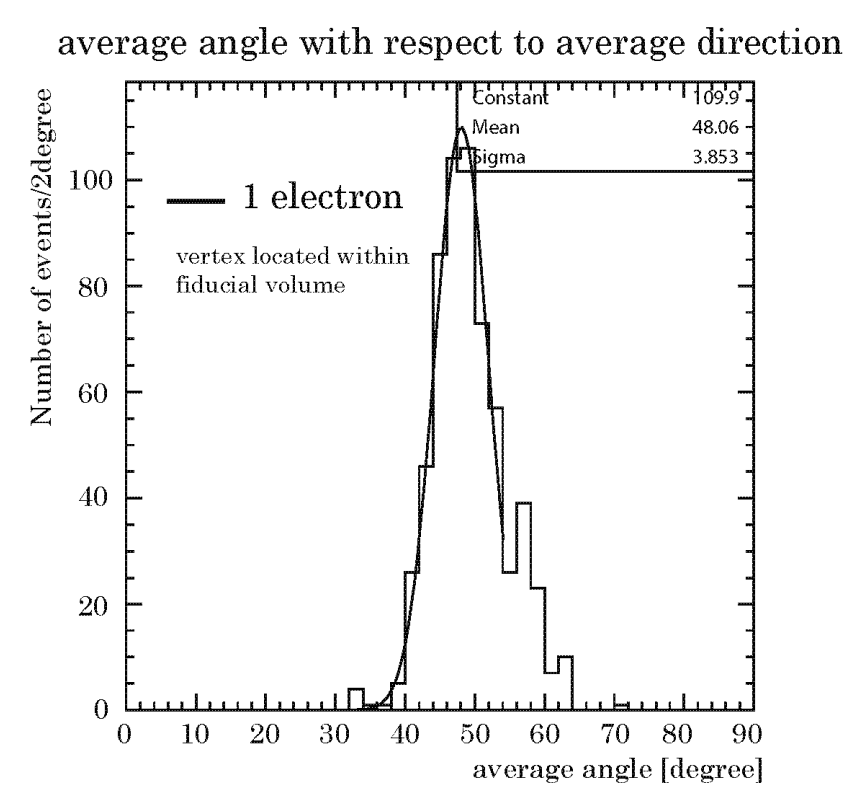
^{96}Zr : 45kg (nat.) → 865kg(50% enrich)→1/20 BG

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

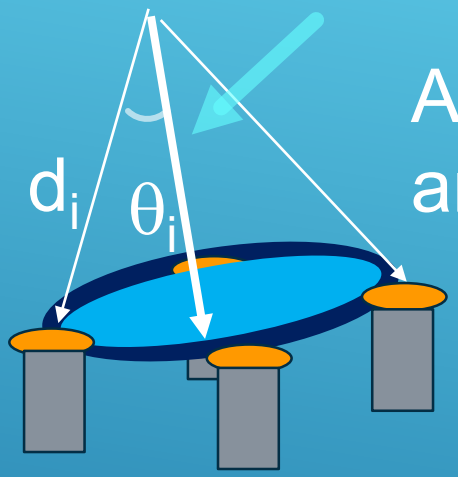
Discrimination of signal and BG



Topological info : averaged angle



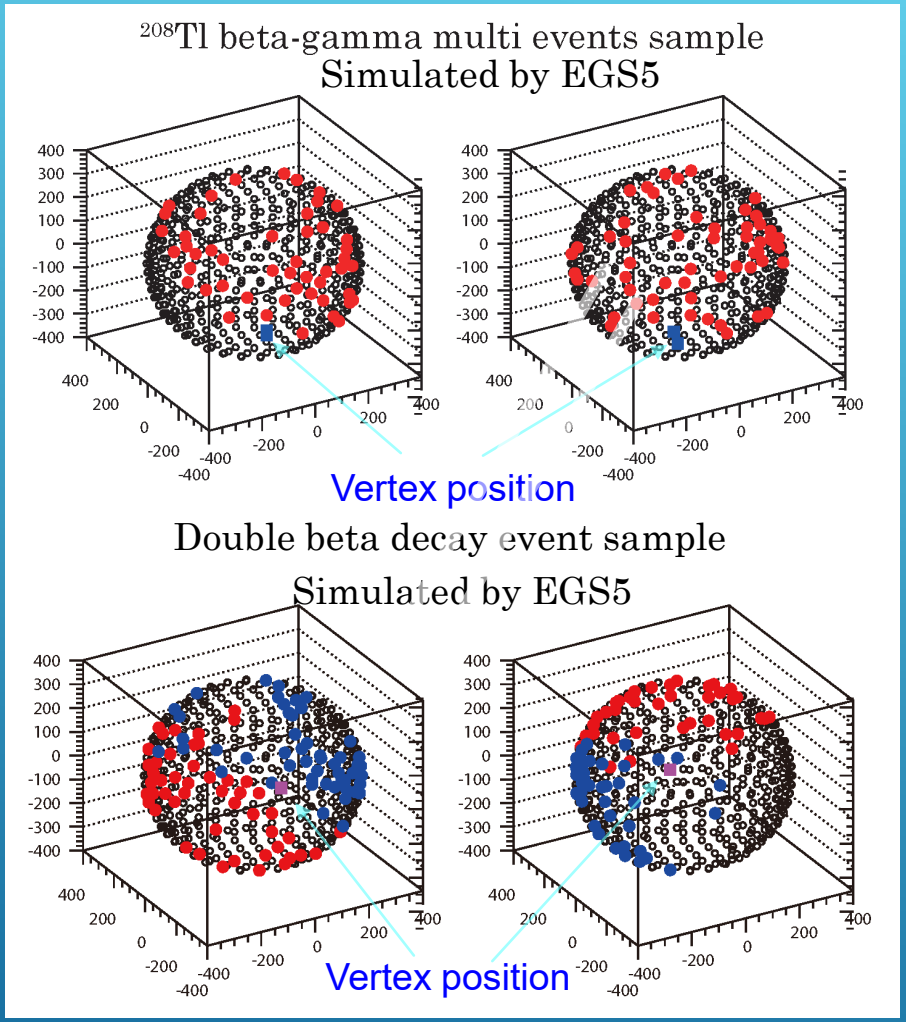
Average direction
e^- = Σd_i

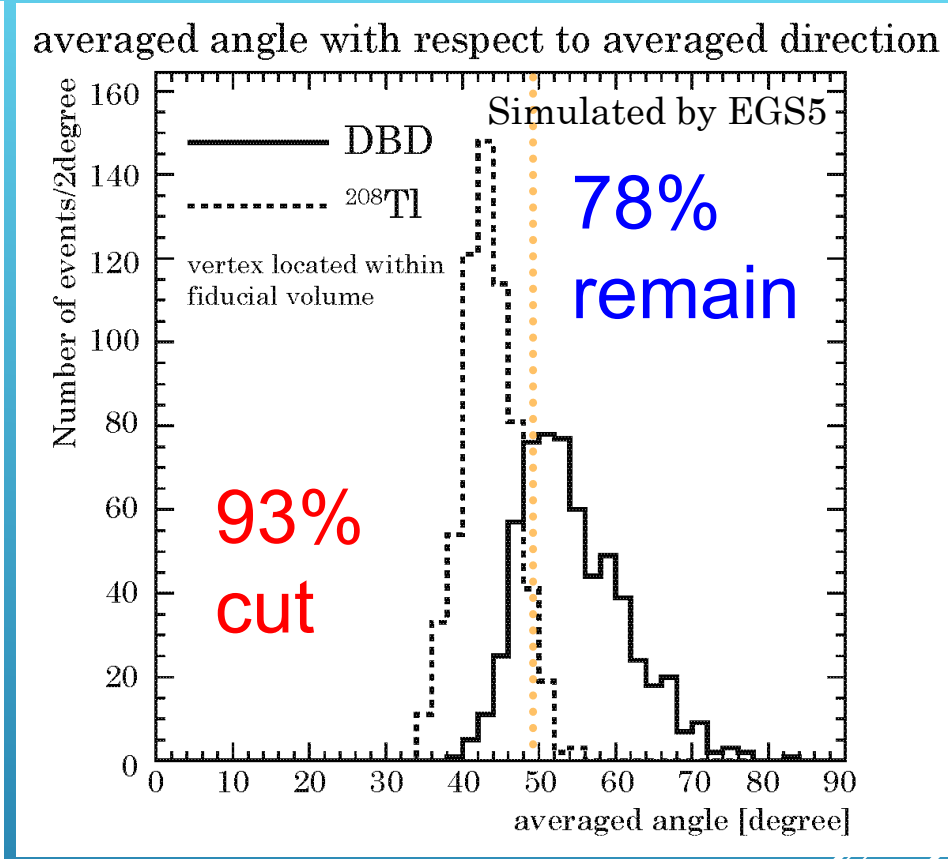


Averaged angle= $\frac{\Sigma \theta_i}{\text{Nhit}}$

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





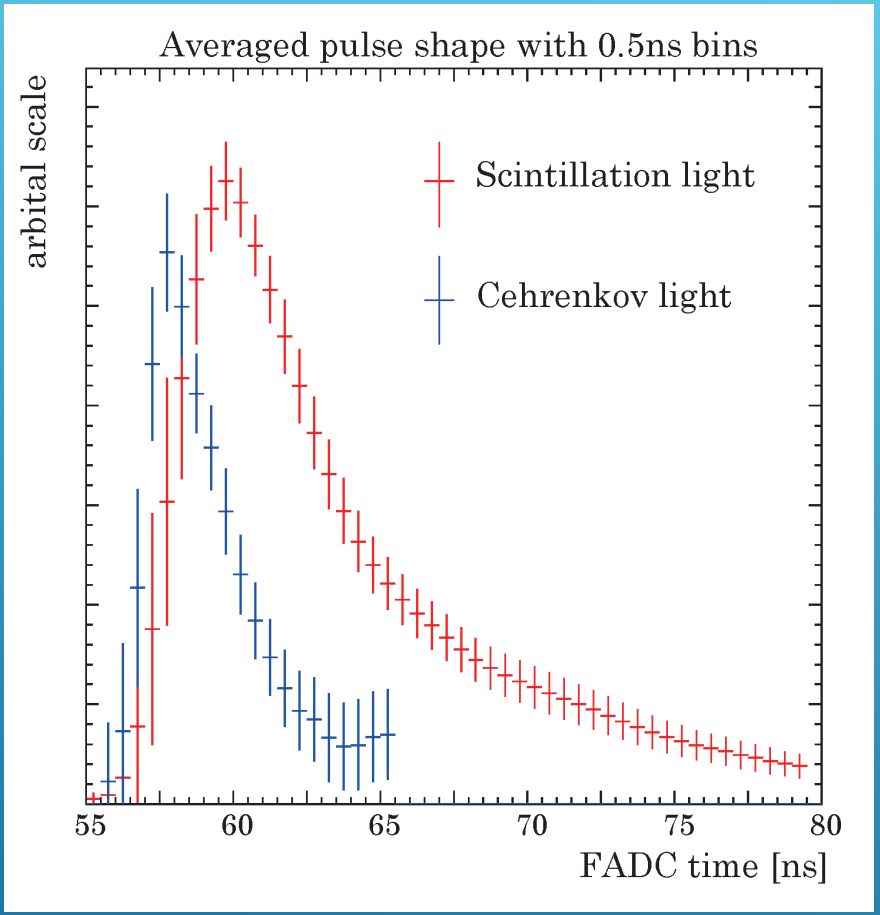
PMT hit pattern of ^{208}Tl BG and 0νββ signal

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

Strategy to realize BG reduction using Cherenkov lights

1. Selection of PMT which receives Cherenkov lights among Scintillation detection.
   - Pulse shape discrimination (done)
2. Confirm topology of Cherenkov lights
   - Directional difference of event selection (done)
   - Direct measurement of topological information (averaged angle)
3. Demonstrate BG reduction using beta-gamma sources with topological information (averaged angle) of Cherenkov lights

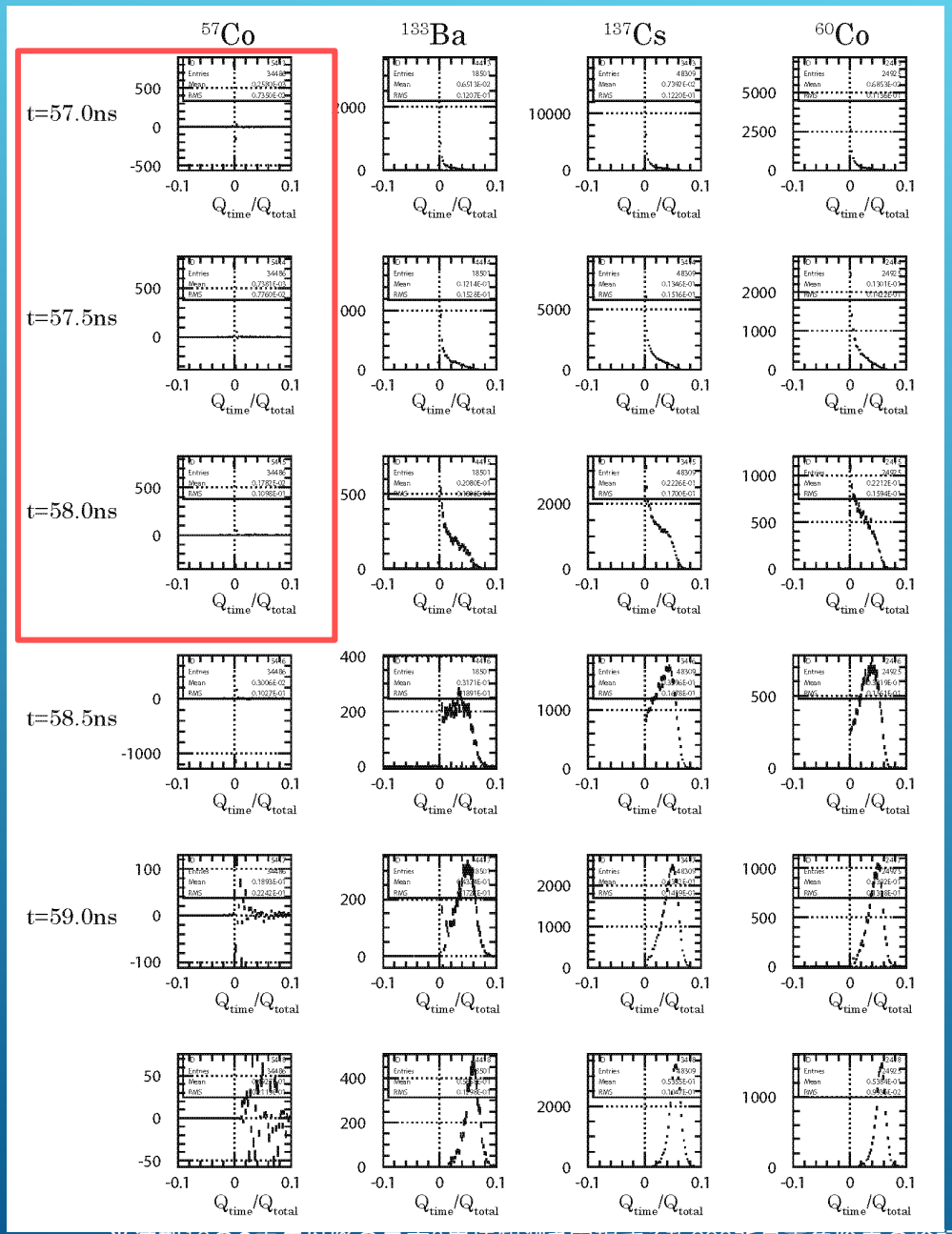
Pulse shape of Cherenkov and scintillation



- 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.

Charge ratio in rise time using ZICOS LS

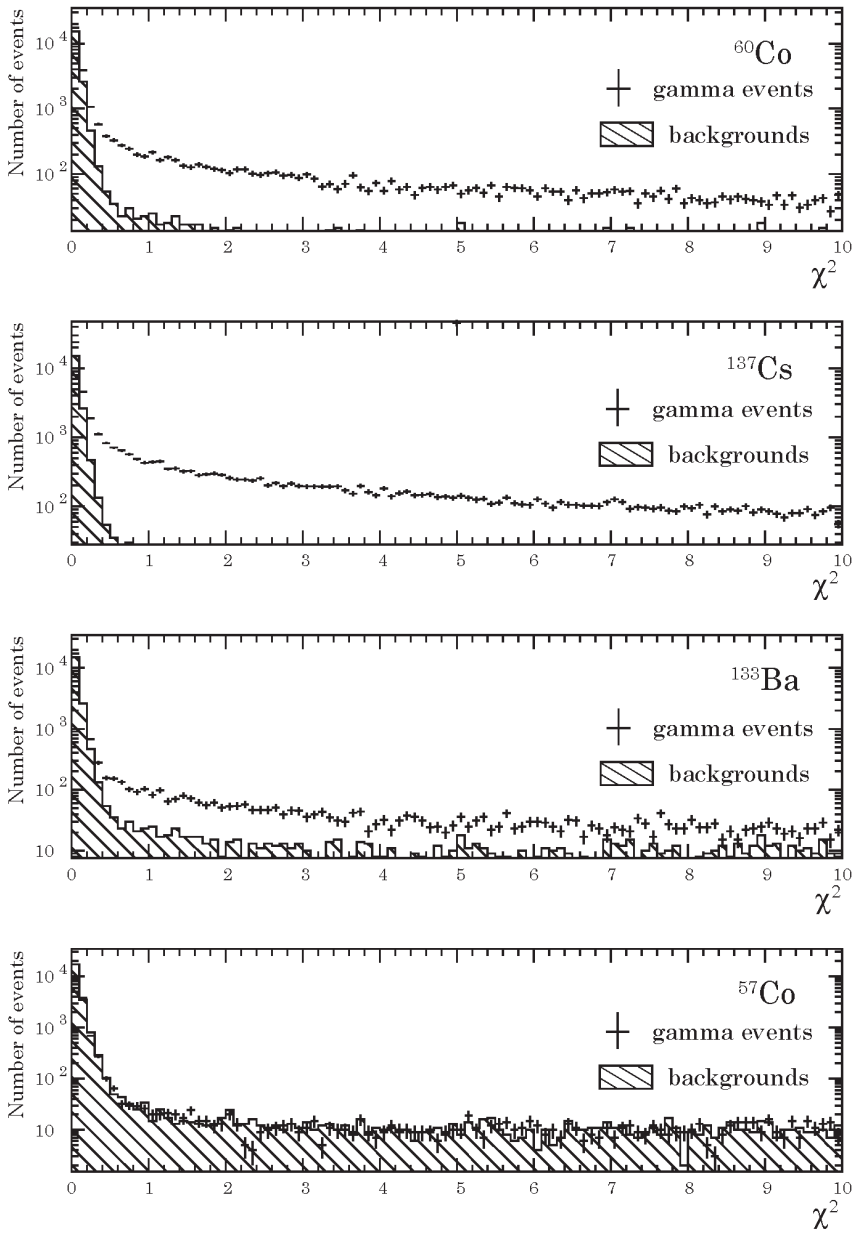


- There is difference of shape between t=57ns and 58ns
- Charge ratio looks depend on the energy
- For t>58.5ns, all shapes were almost same.

Cherenkov looks dominant between 57ns and 58ns.

Template waveform of scintillation between 57.0ns and 58.0ns for ^{57}Co.

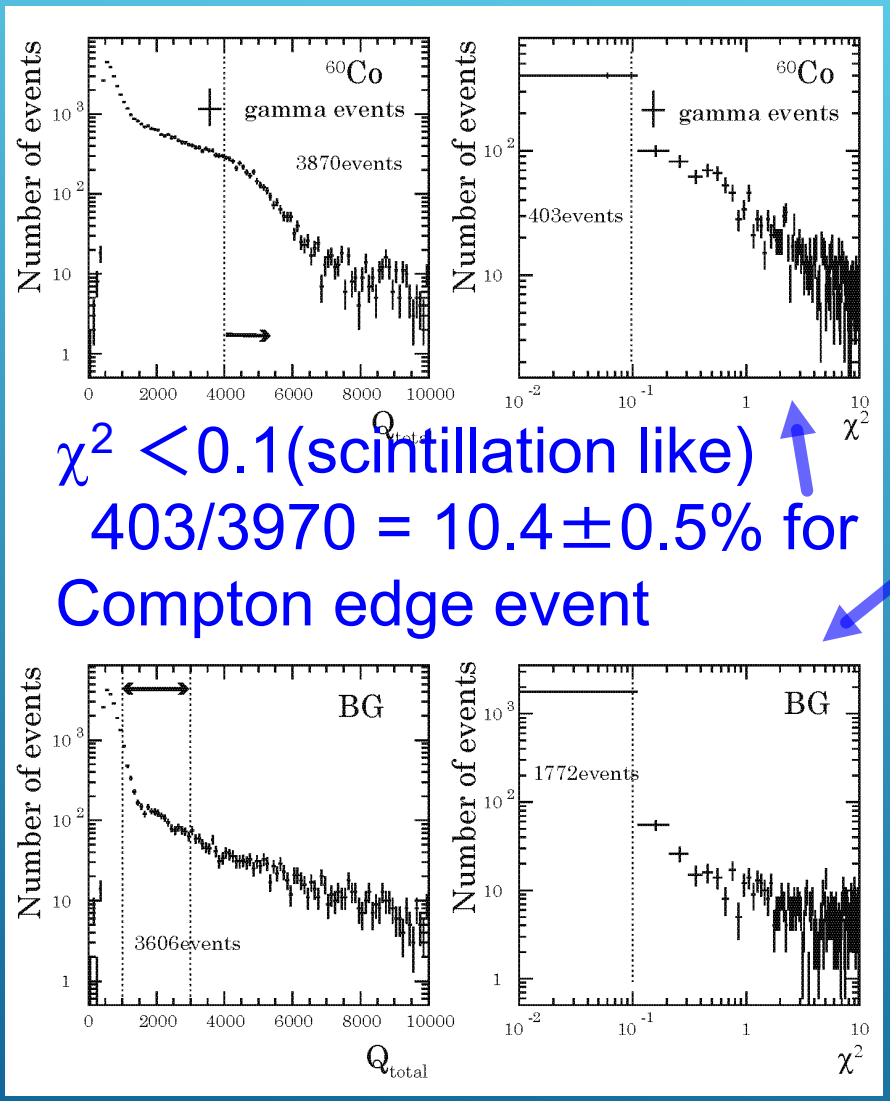
χ^2distribution using ^{57}Co template



- Most of backgrounds have lower χ^2 than 1.0
- Most of backgrounds have lower energy than Cherenkov threshold, then only scintillation was seen.

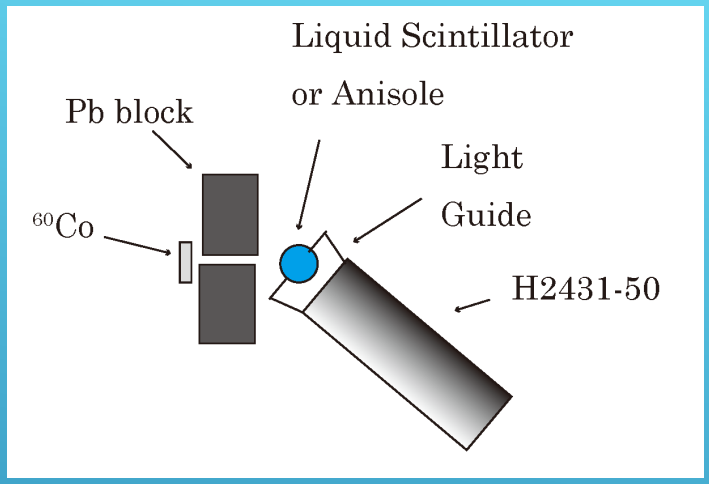
It seems to events with Cherenkov lights should have large χ^2 value.

Measured by Compton edge event and BG sample



χ^2 ＜0.1(scintillation like)

403/3970 = 10.4±0.5% for Compton edge event

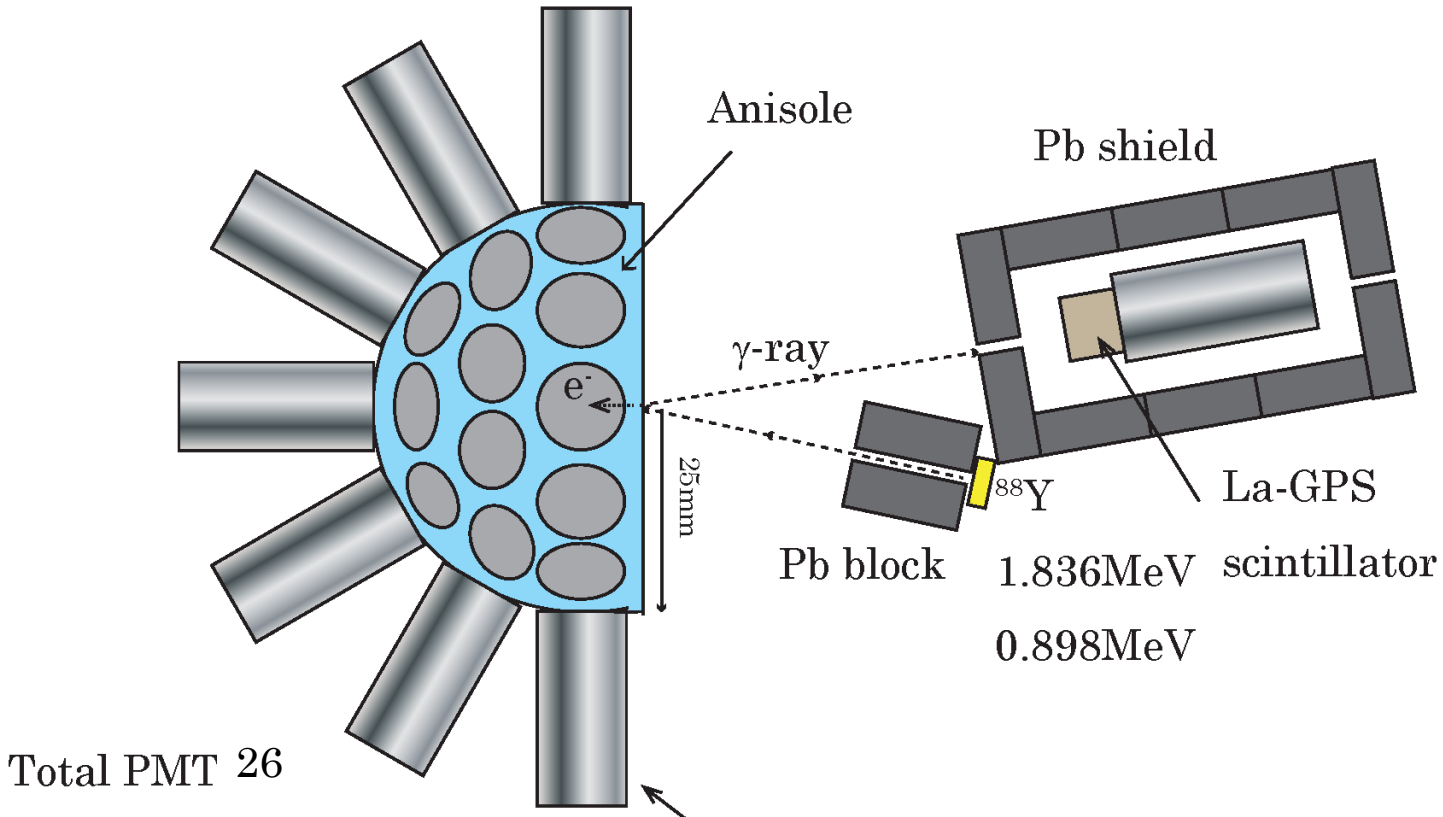


1772/3606=49.1±1.4% for BG sample

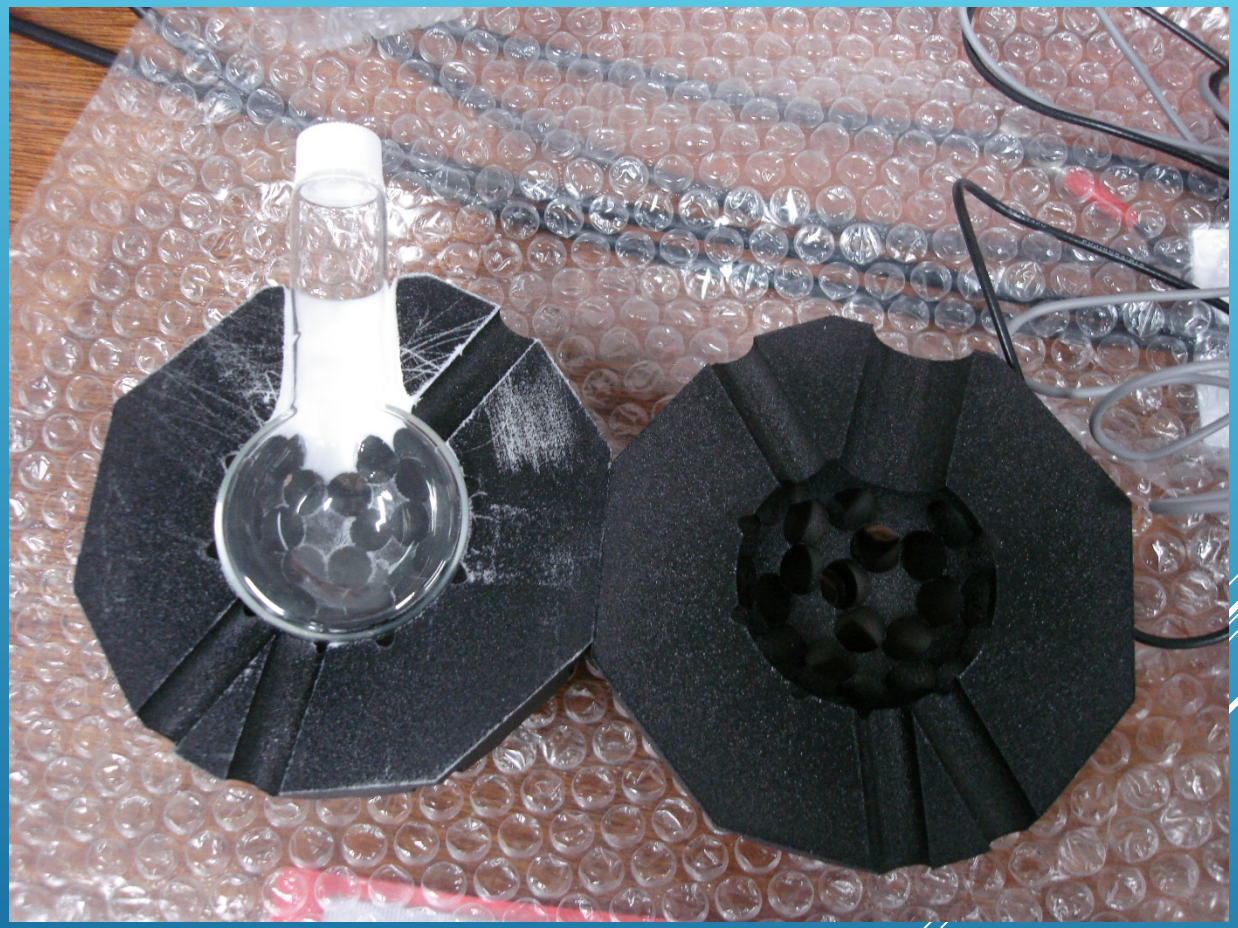
Inefficiency value between Compton edge and BG sample differs with 2.86σ.

Topology of Cherenkov lights for ~1MeV e^- was strongly indicated.

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

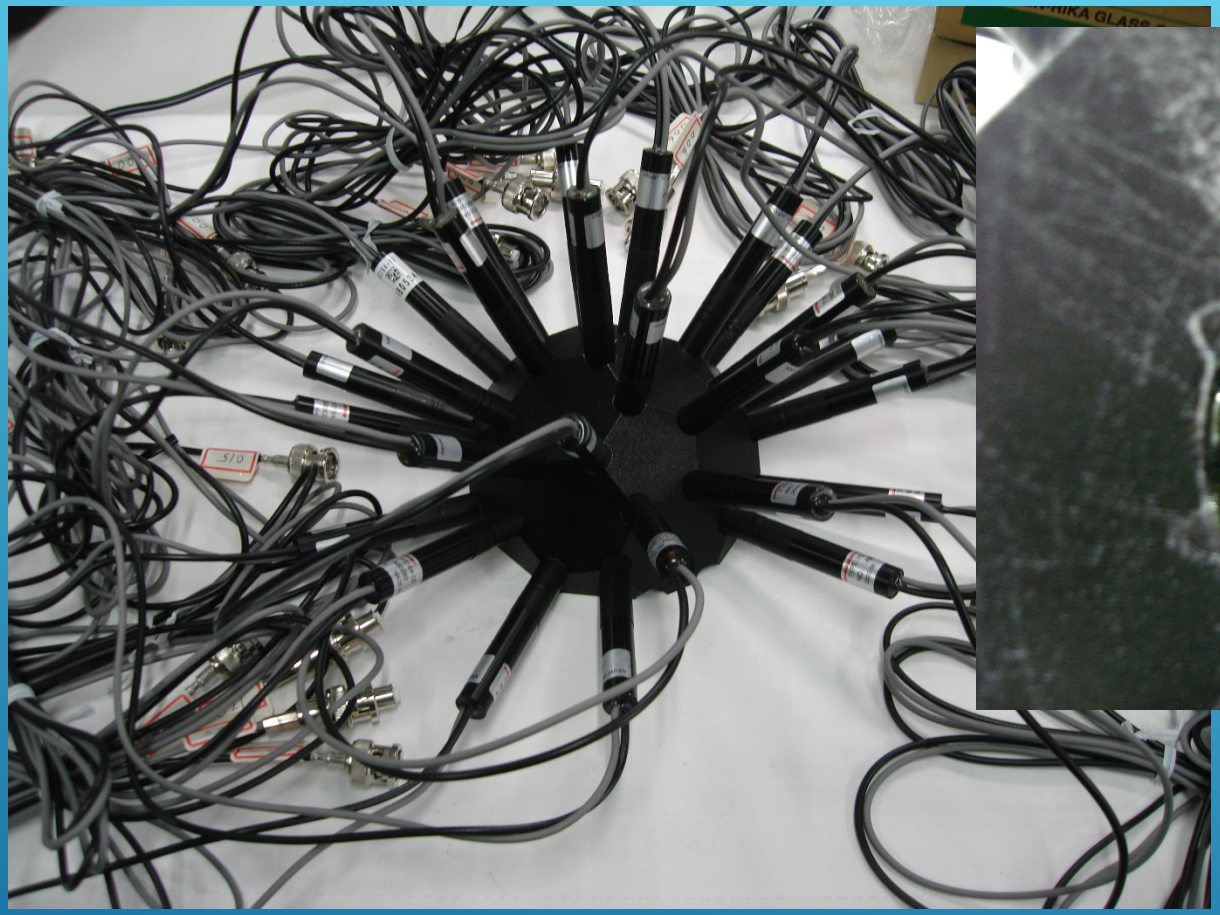


Hemisphere flask and PMT mounting jig for HUNI-ZICOS



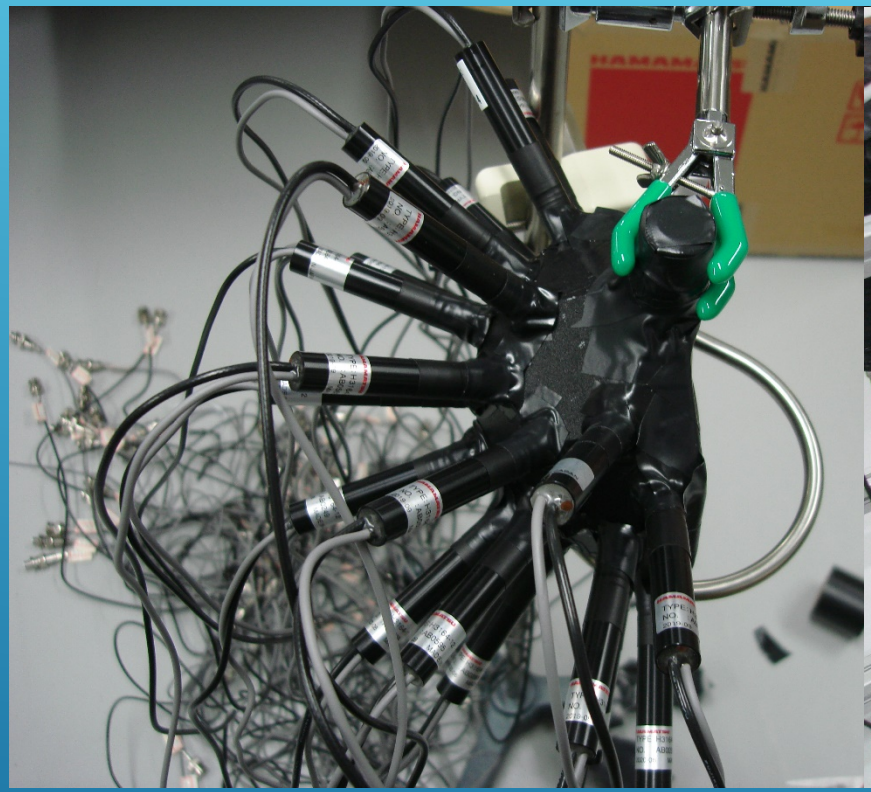
- Extension sharpening for hemisphere flask.
- Some extensions for PMT hole.

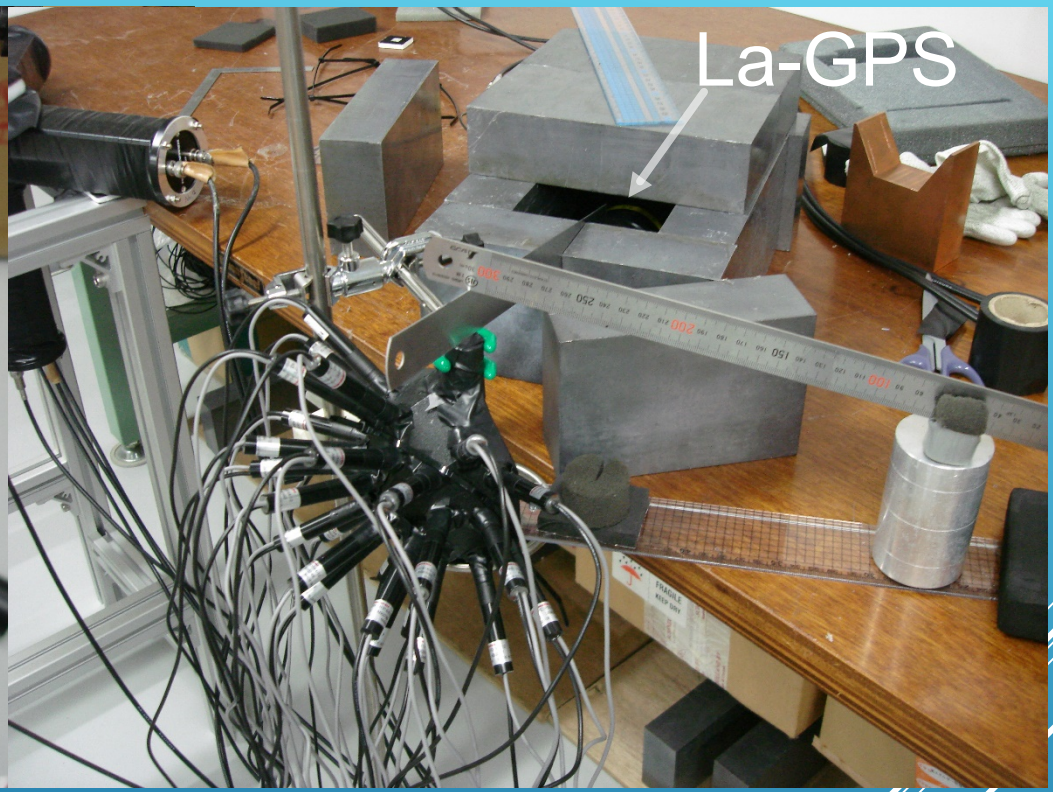
Mounting PMTs on jig for hemisphere flask



- Total 26 H3164-12 PMTs were used for HUNI-ZICOS.
- No PMT at center of hexagon location.
- Light shield was necessary due to jig material Nylon.

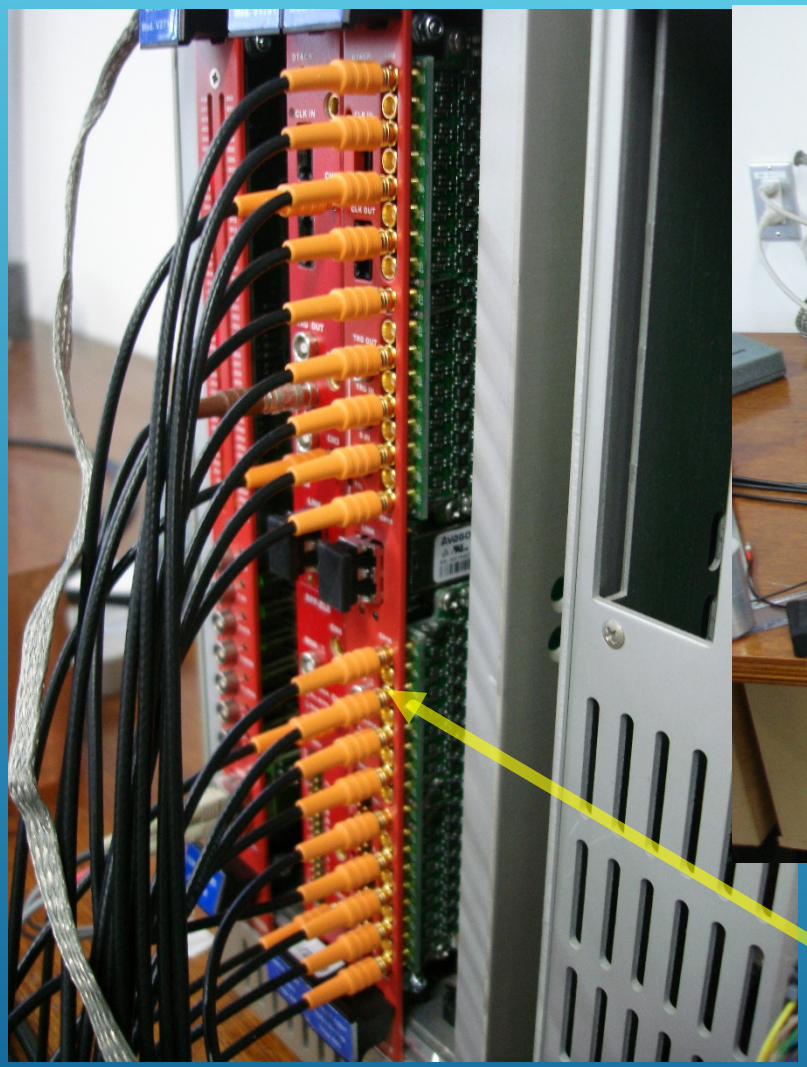
Setting hemisphere flask to jig and locate on supporting stand

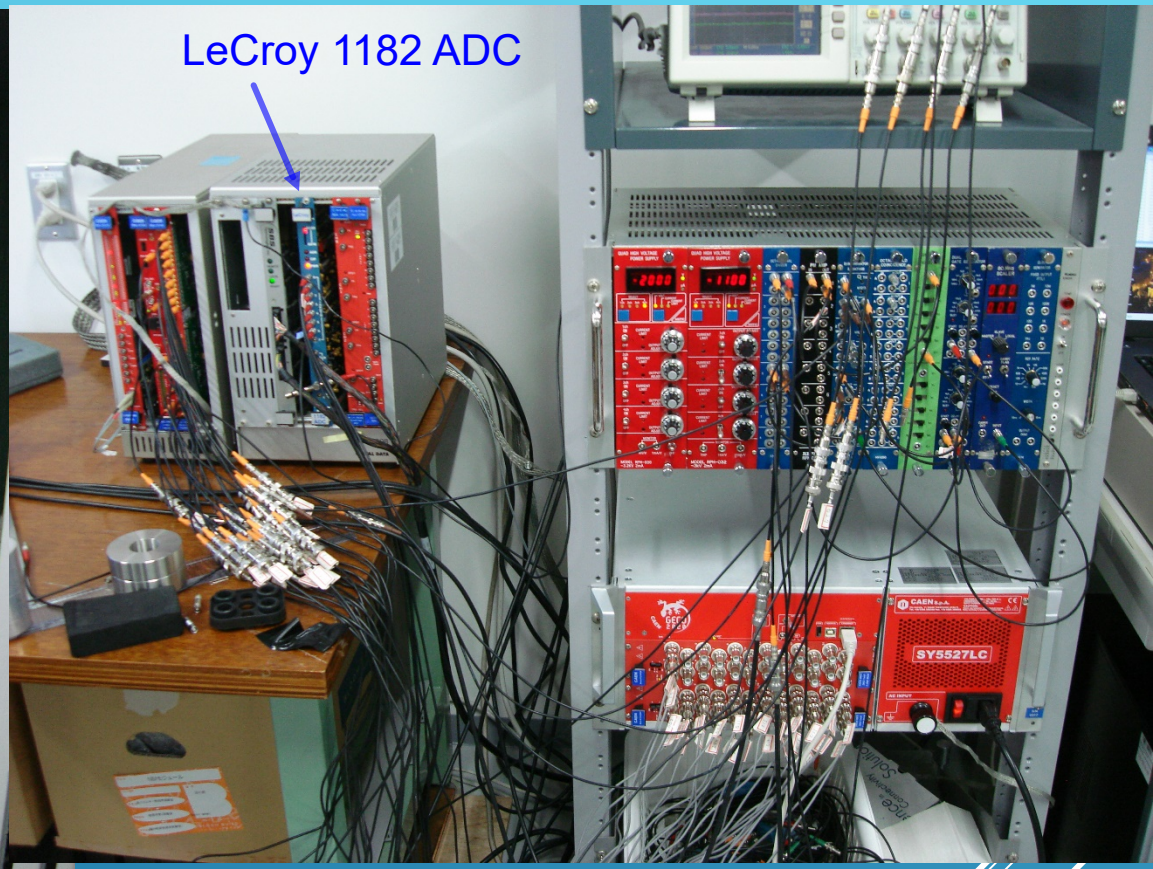




- HUNI-ZICOS was putted on flask clip and the chimney was pinched by clamp.
- Assuming vertex position to be center of truncated icosahedron jig (not hemisphere flask).

Cable connection to FADC and HV

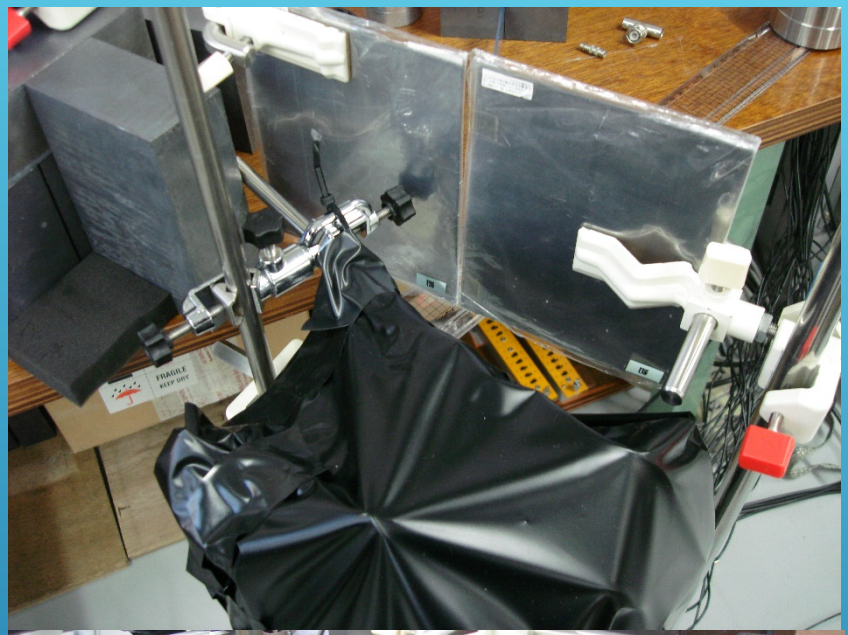


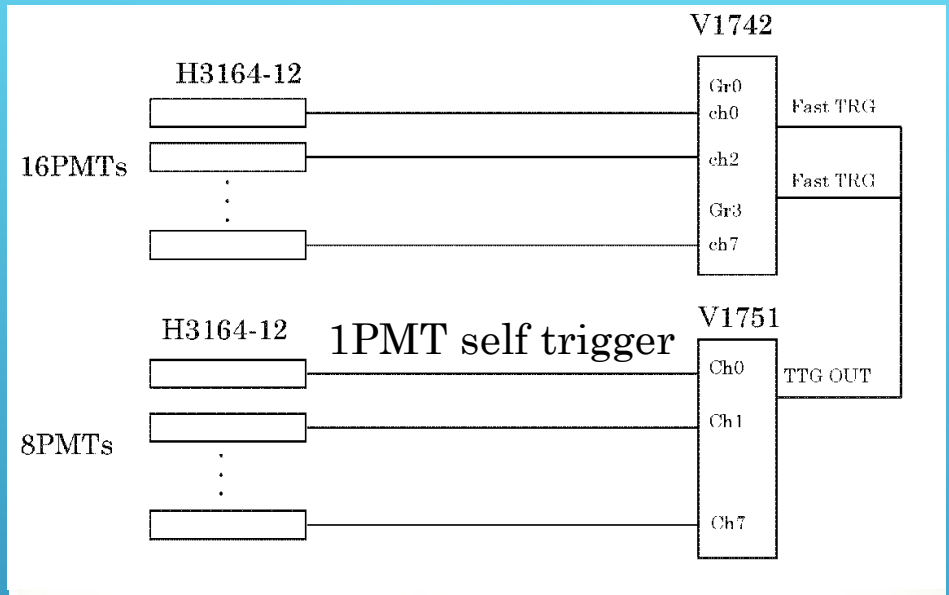


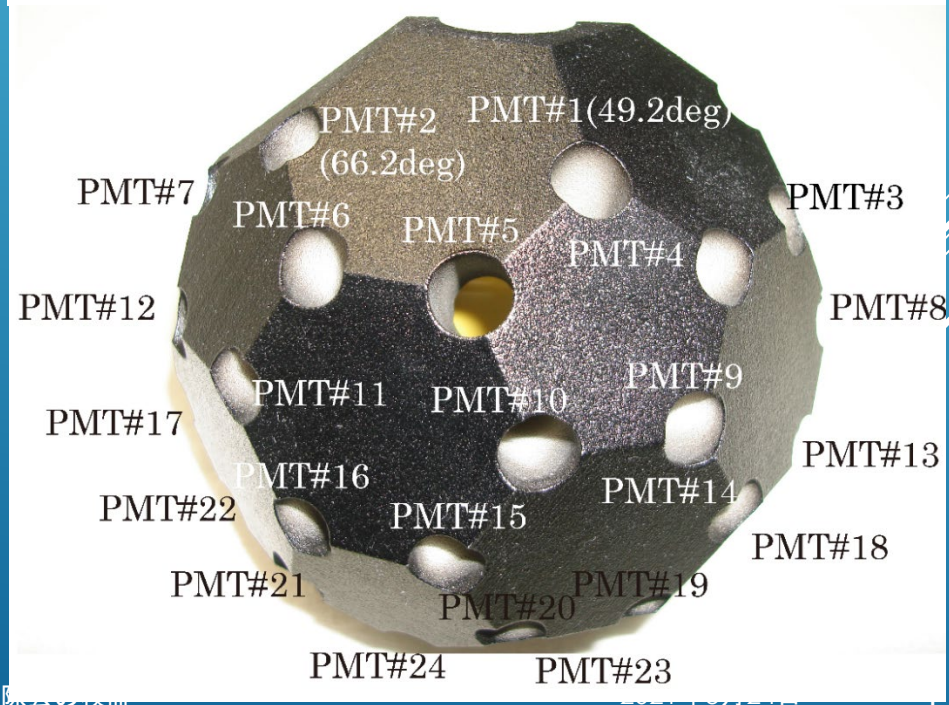
Problem : MCX cables were connected only half channel due to thick socket!

Need V1751 8ch

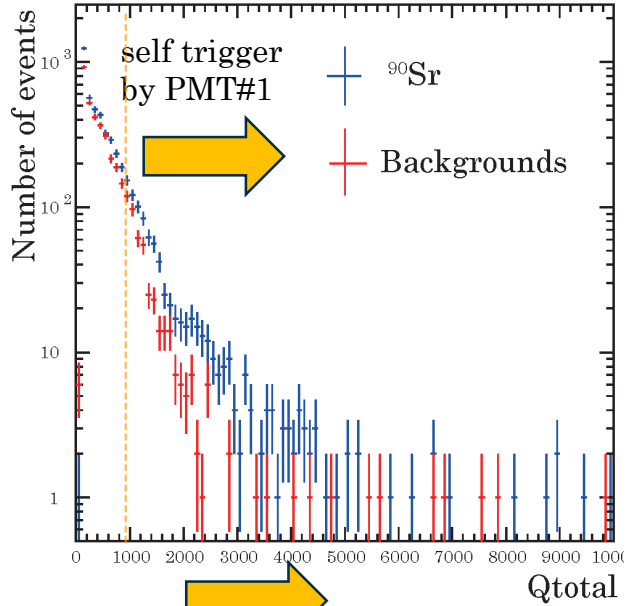
Measurement of averaged angle using ^{90}Sr

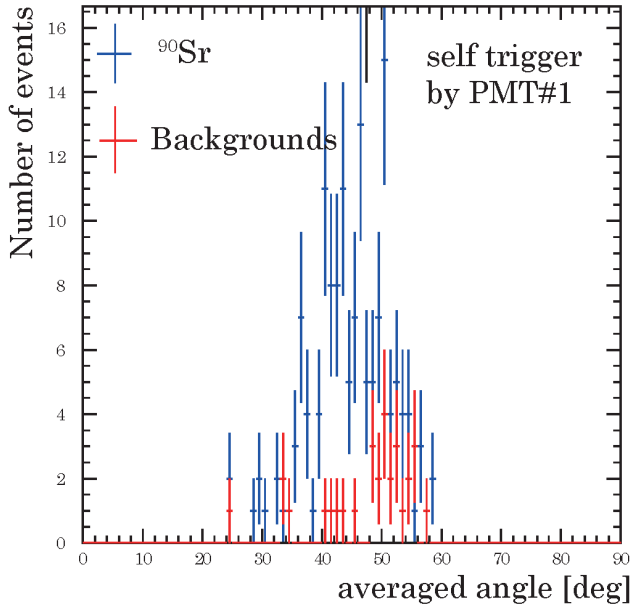


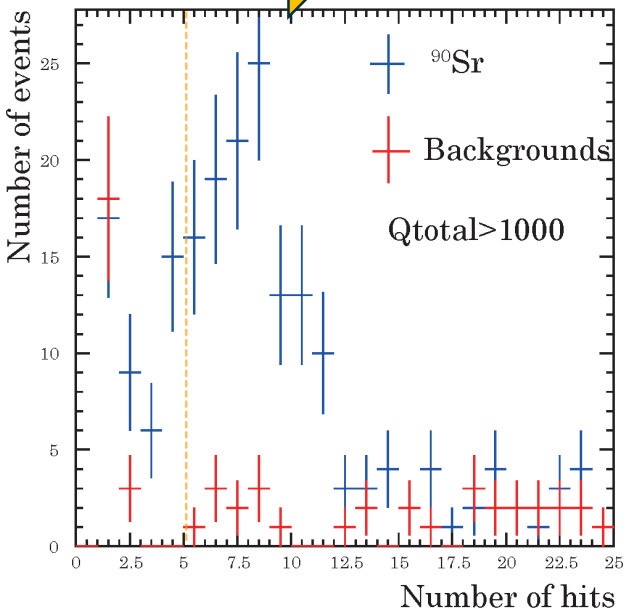


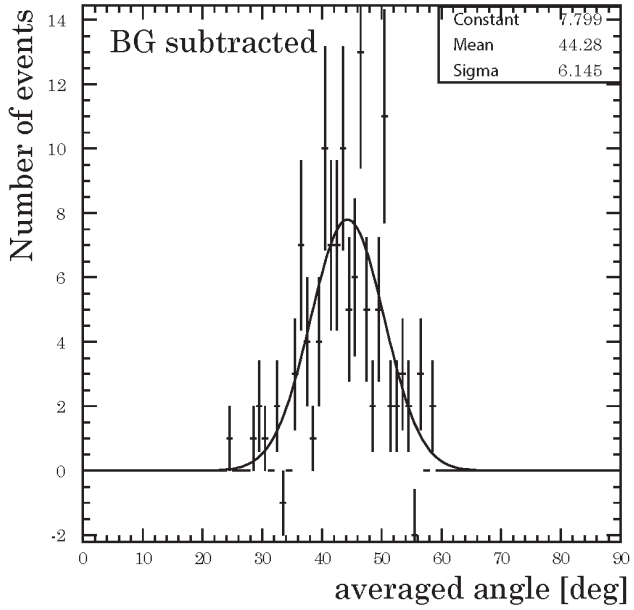


Measurement of averaged angle using ^{90}Sr



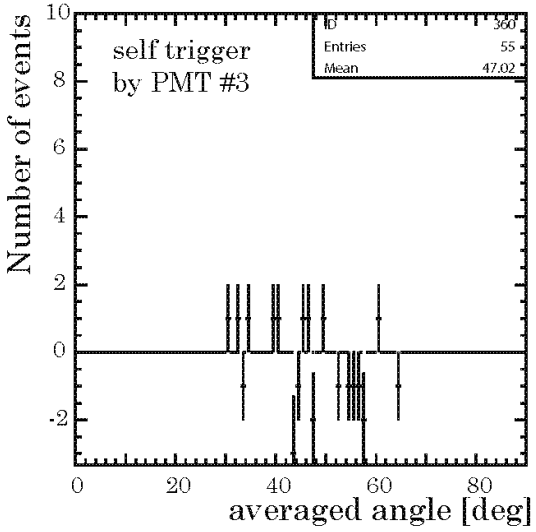


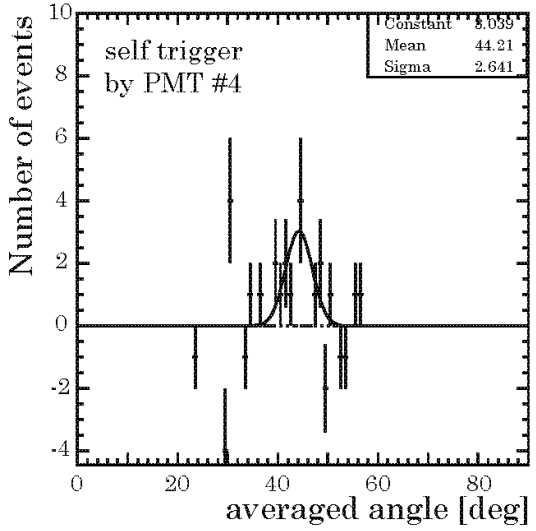


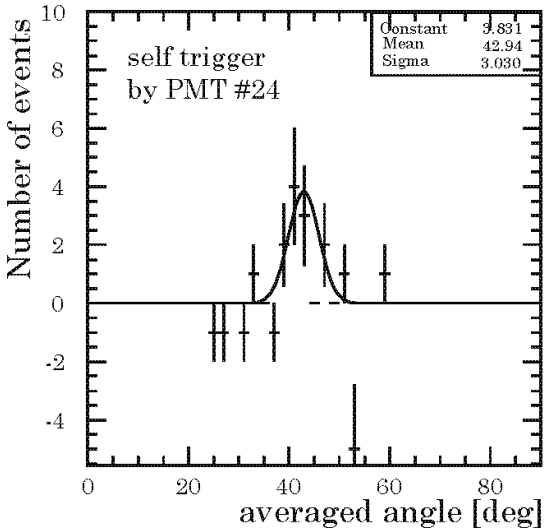


Observed averaged angle for selected events (Q_{total}>1000 and Nhit≧5) seems to be clustered and the peak value agree with an expected value (47 degree) within statistical error.

Measurement of averaged angle using ^{90}Sr

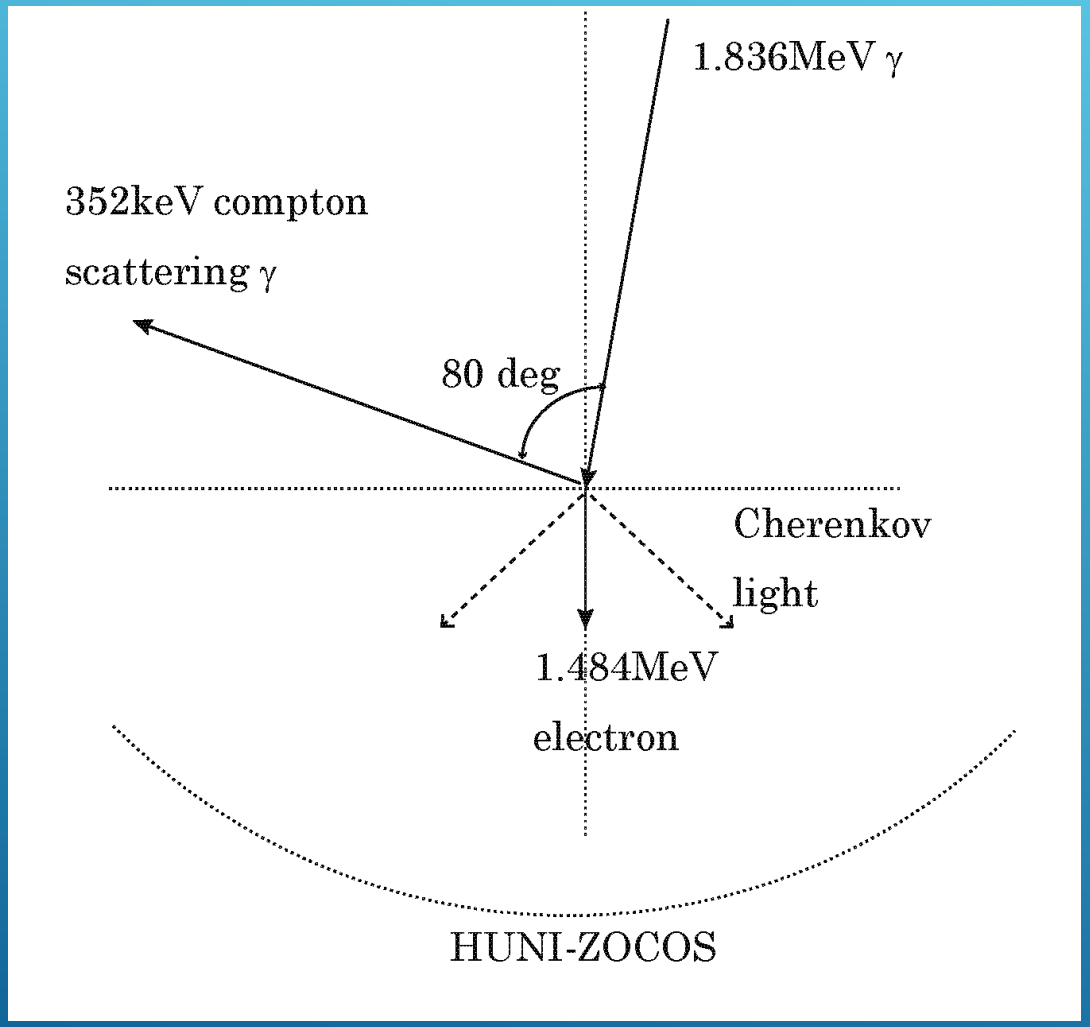






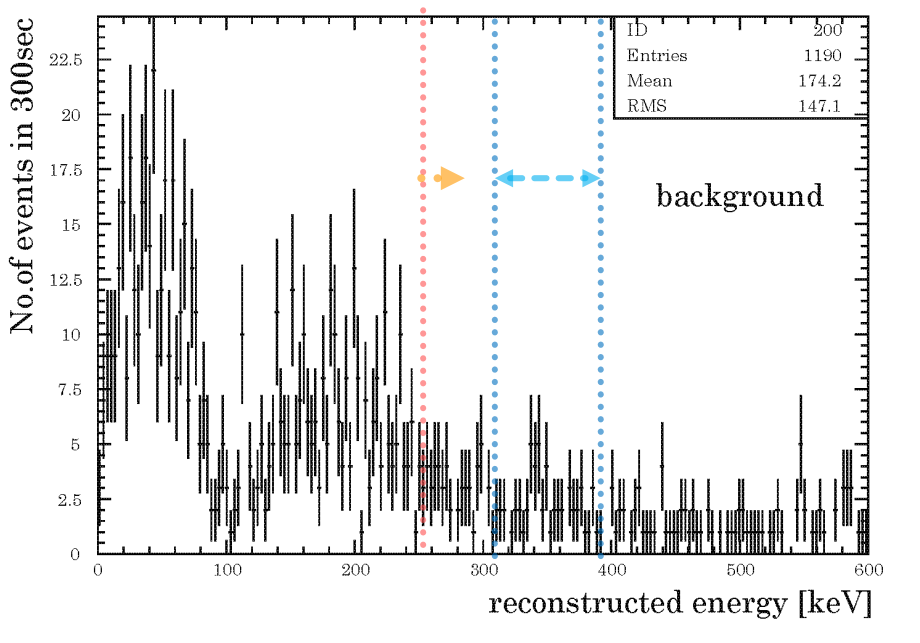
Same clusters were found for other PMTs. Those peak values also agree with an expected value. On the other hands, no cluster was found for side edge PMT. This PMT should not receive Cherenkov lights due to collimated direction of incident electron by Pb sheet.

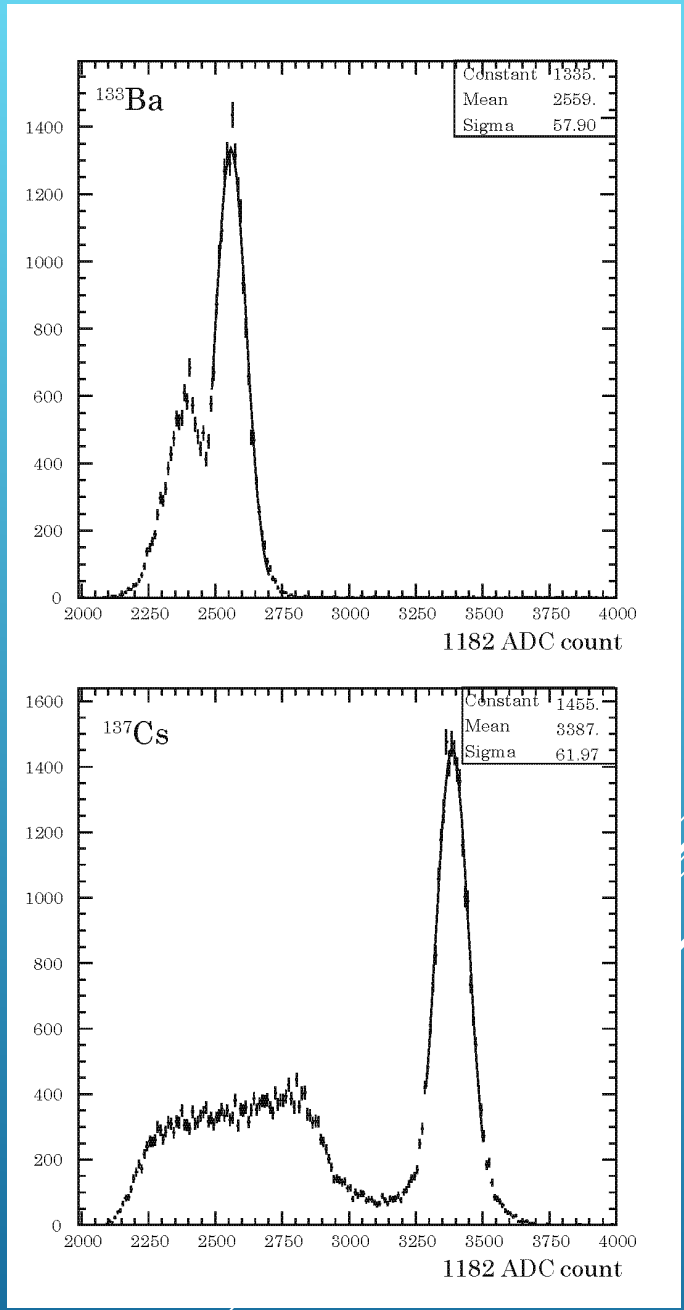
Electron with fixed direction and fixed energy using ^{88}Y gamma source



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

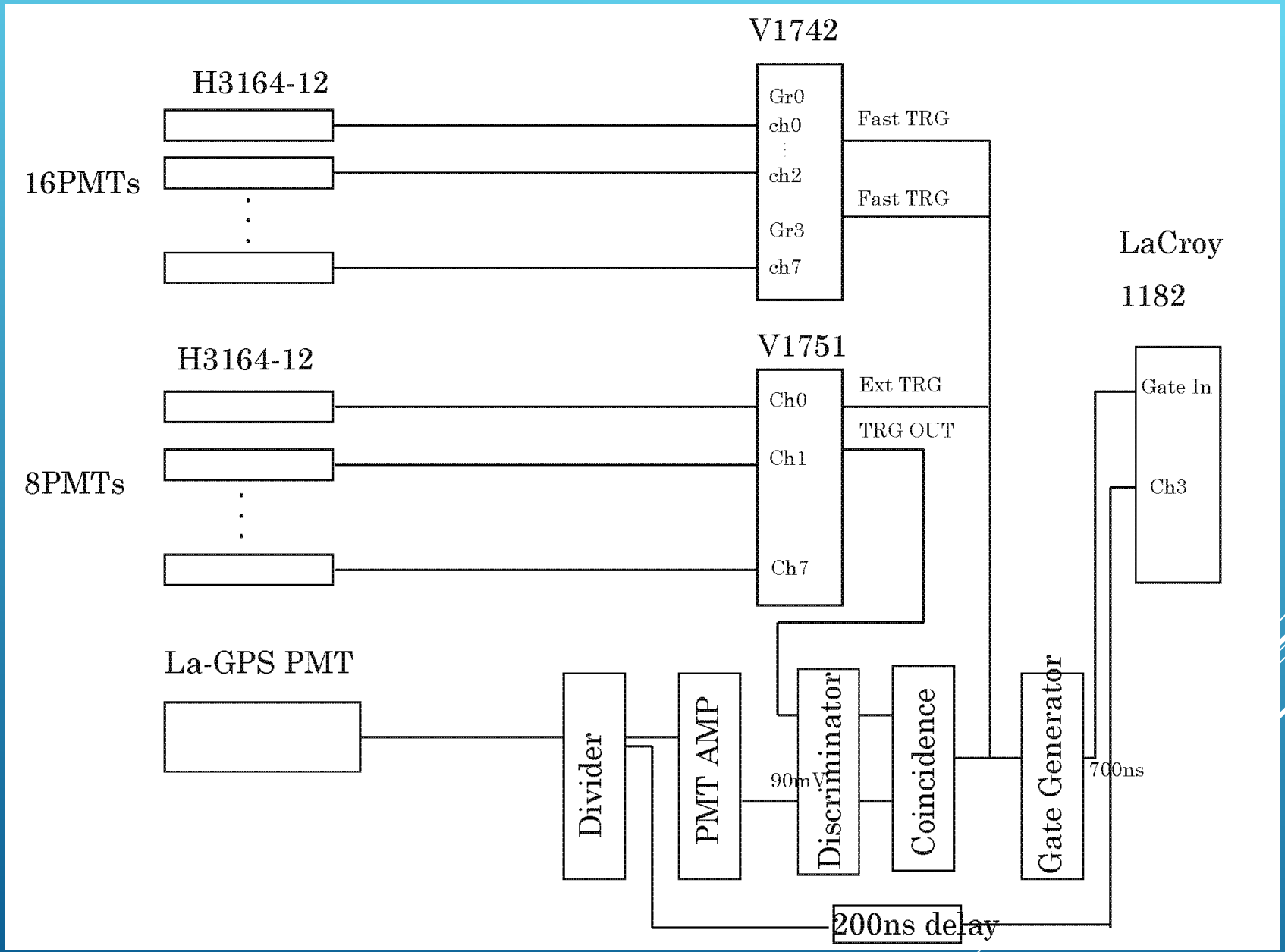
Setup for La-GPS scintillator



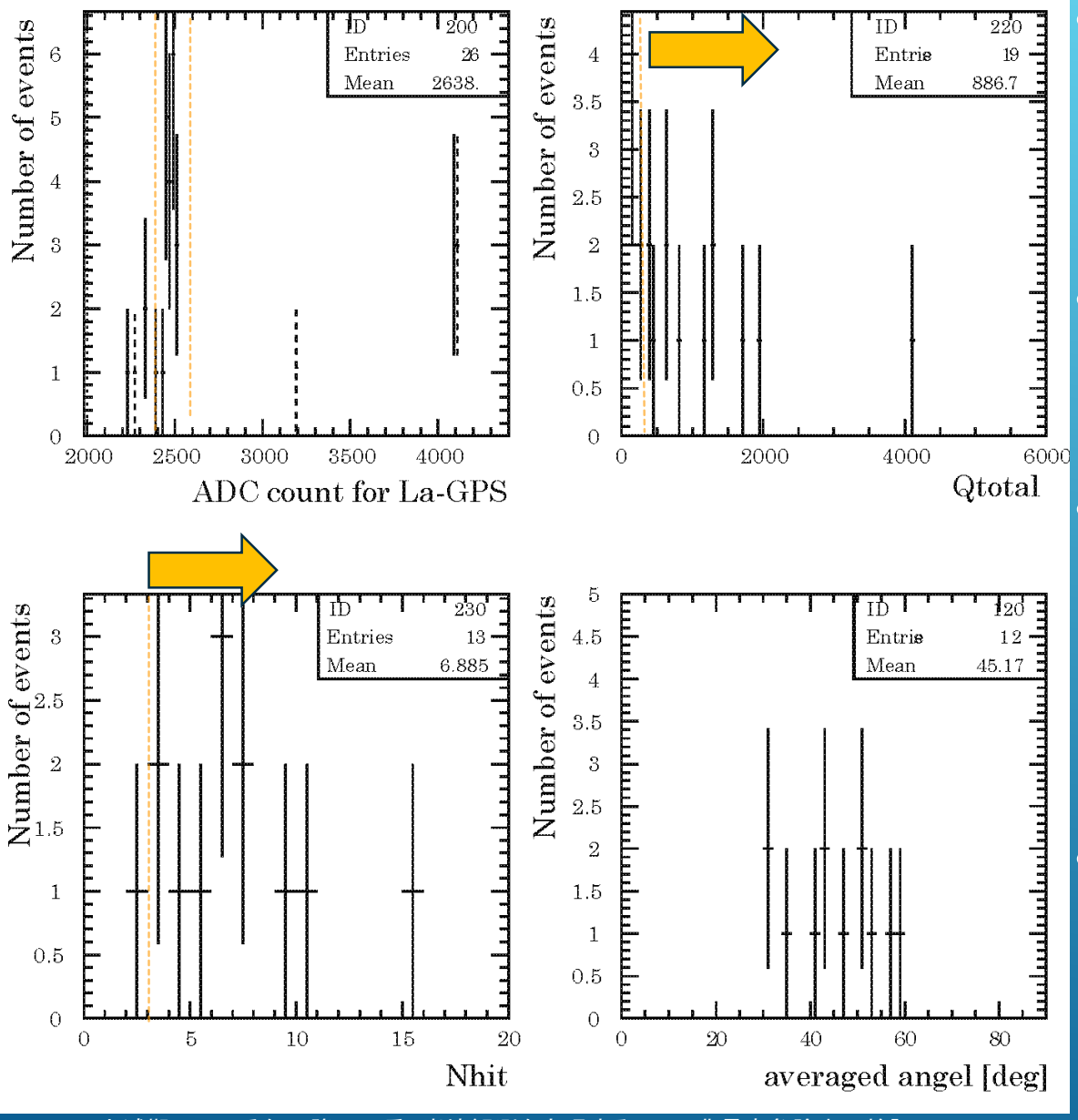


- La-GPS threshold around 250keV.
- Trigger coincidence between La-GPS PMT and HUNI-ZICOS PMTs which connected to V1751.
- Event selection for 1182 ADC count between 2400 and 2600 as scattered γ.

Trigger logic for data taking using ^{88}Y



Measurement of averaged angle using ^{88}Y



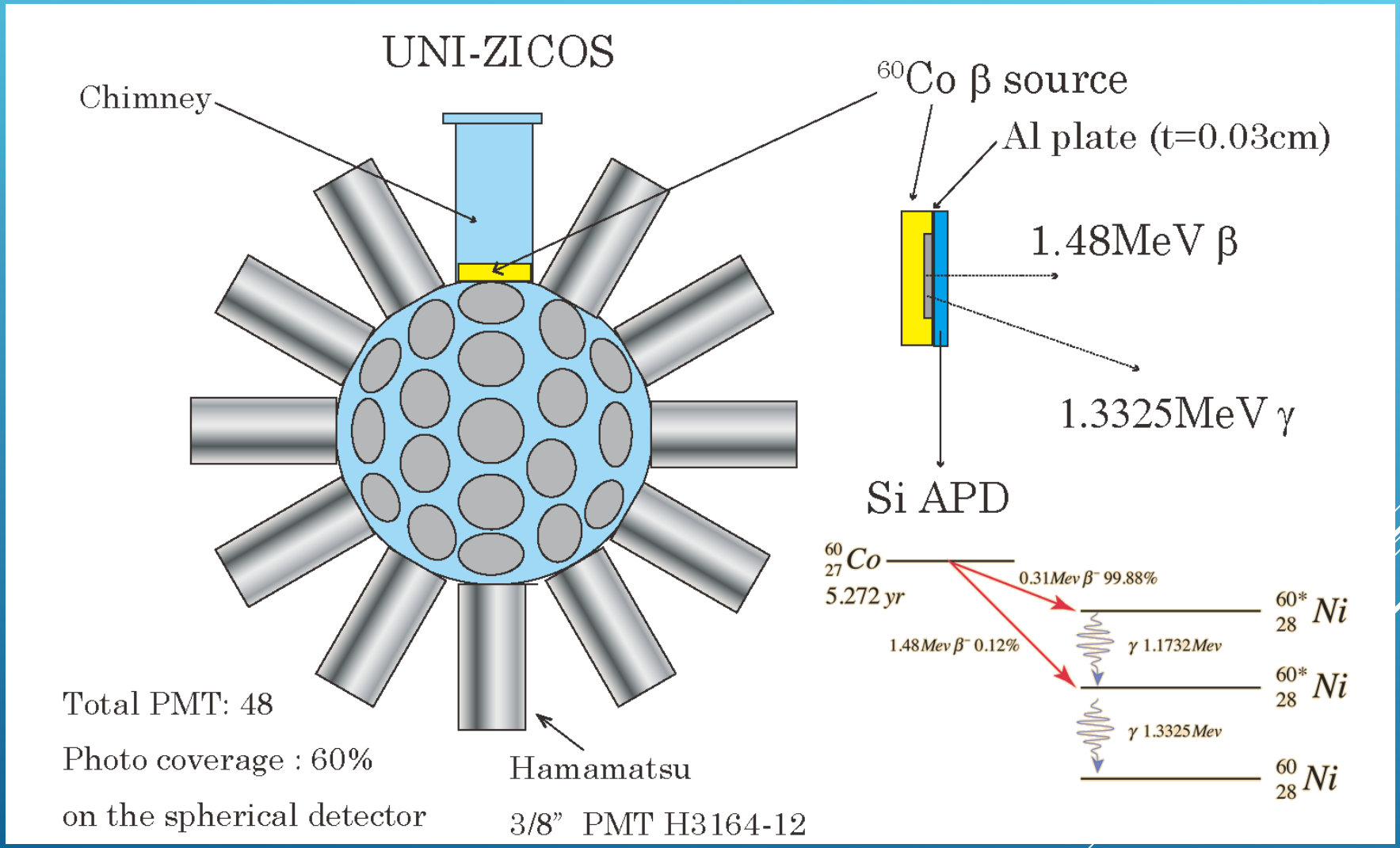
- Scattering γ from ^{88}Y was clearly observed around ADC count 2500.
- Event selection Qtotal>300 and Nhit≧3 was applied.
- Observed averaged angle distribution was spread. The mean value was almost 45 deg.
- Need both statistics and some systematic evaluations using Pb collimation or MC.

Summary

- Most serious background ^{208}Tl beta decay for ZICOS could be removed by topology of Cherenkov lights.
- PMTs received Cherenkov lights could be selected by PSD.
- Topology of Cherenkov lights was directly indicated by ~1MeV electron event selection using PSD.（基盤C目標達成）
- Topological information (averaged angle) of Cherenkov lights was measured by HUNI-ZICOS using actual ~1MeV electron.
- Averaged angle using ^{90}Sr was measured and it seems to agree with an expected angel 47deg within statistical error.
- Averaged angle distribution using fixed direction and fixed energy using^{88}Y was spread. The mean value was 45deg.
- Need both more statistics and some systematic evaluations using Pb block collimation or MC.（**他方の新学術の目標達成**）
- We almost confirmed the topology of Cherenkov light emitted from ~1MeV electron. Next step is to demonstrate βγ BG reduction technique using UNI-ZICOS.（**本新学術の目標**）

Demonstration of ^{208}Tl BG reduction

- Direct measurement using βγ events by UNI-ZICOS

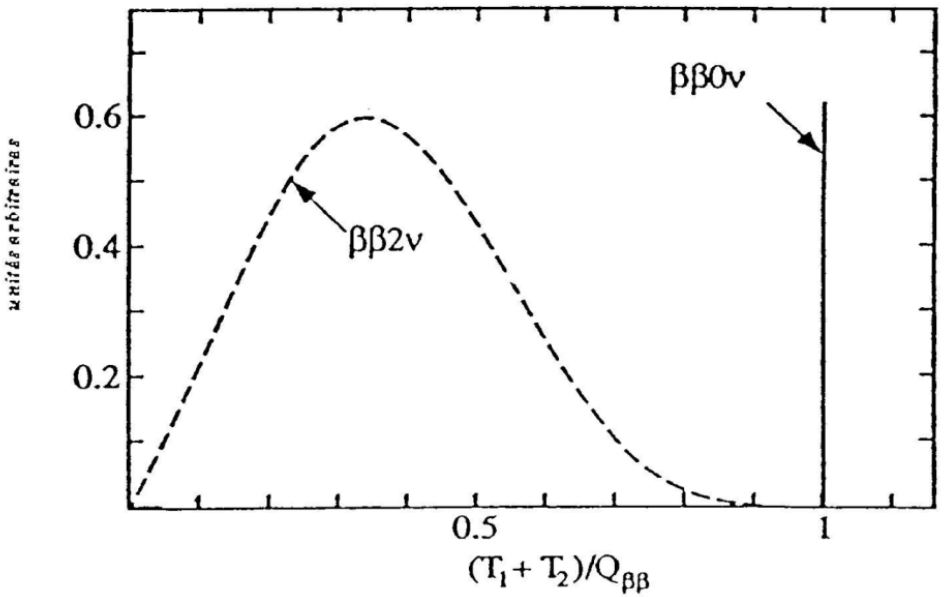


Backup slides

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

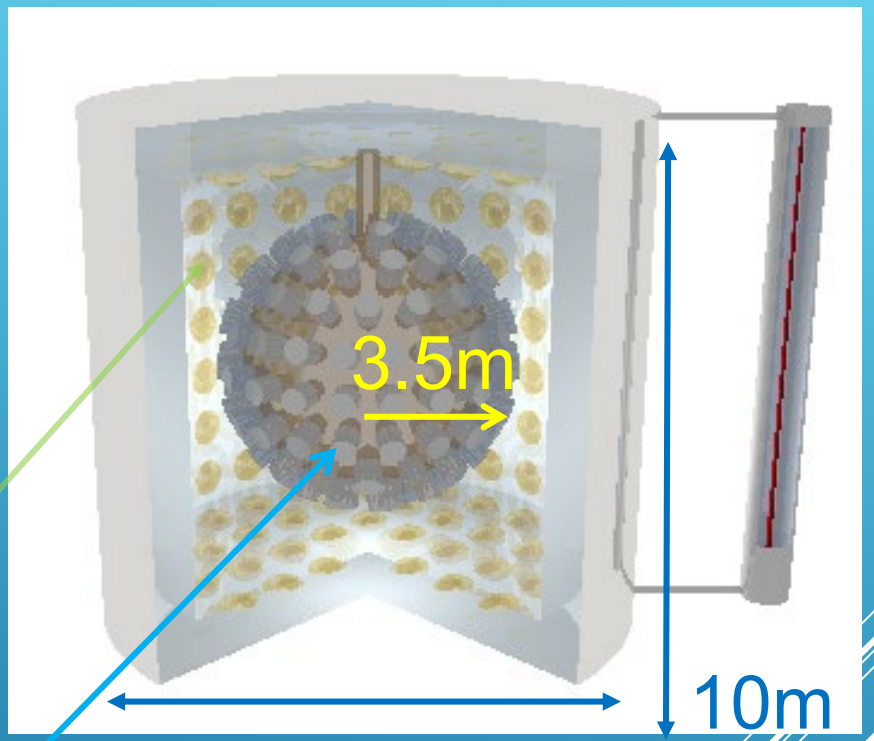
Requirement : Low BG, Large target mass, Good E-resolution

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)

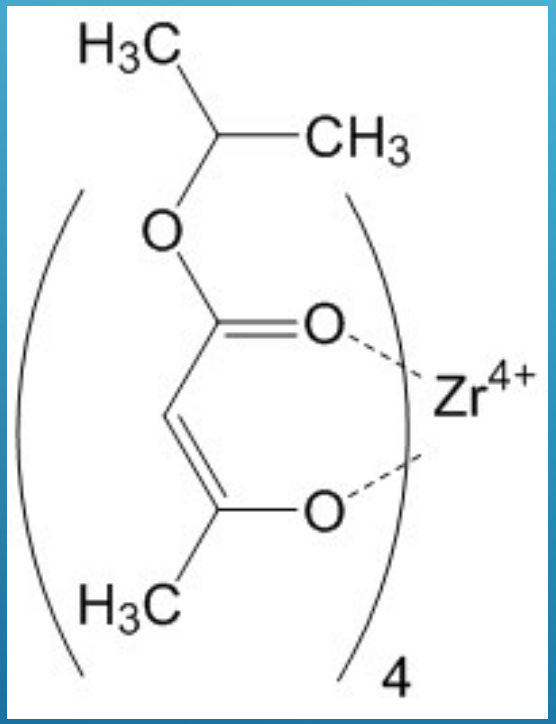


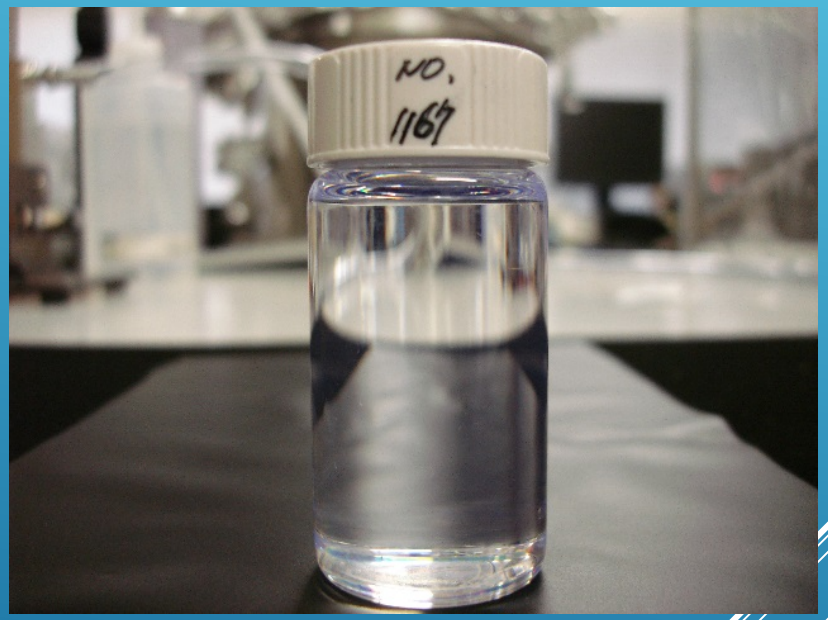
Purpose:
① **Direct measurement of $0\nu\beta\beta$**
② **Confirm parameter of nuclear matrix element model**

Liquid Scintillator solving $Zr(iPrac)_4$

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

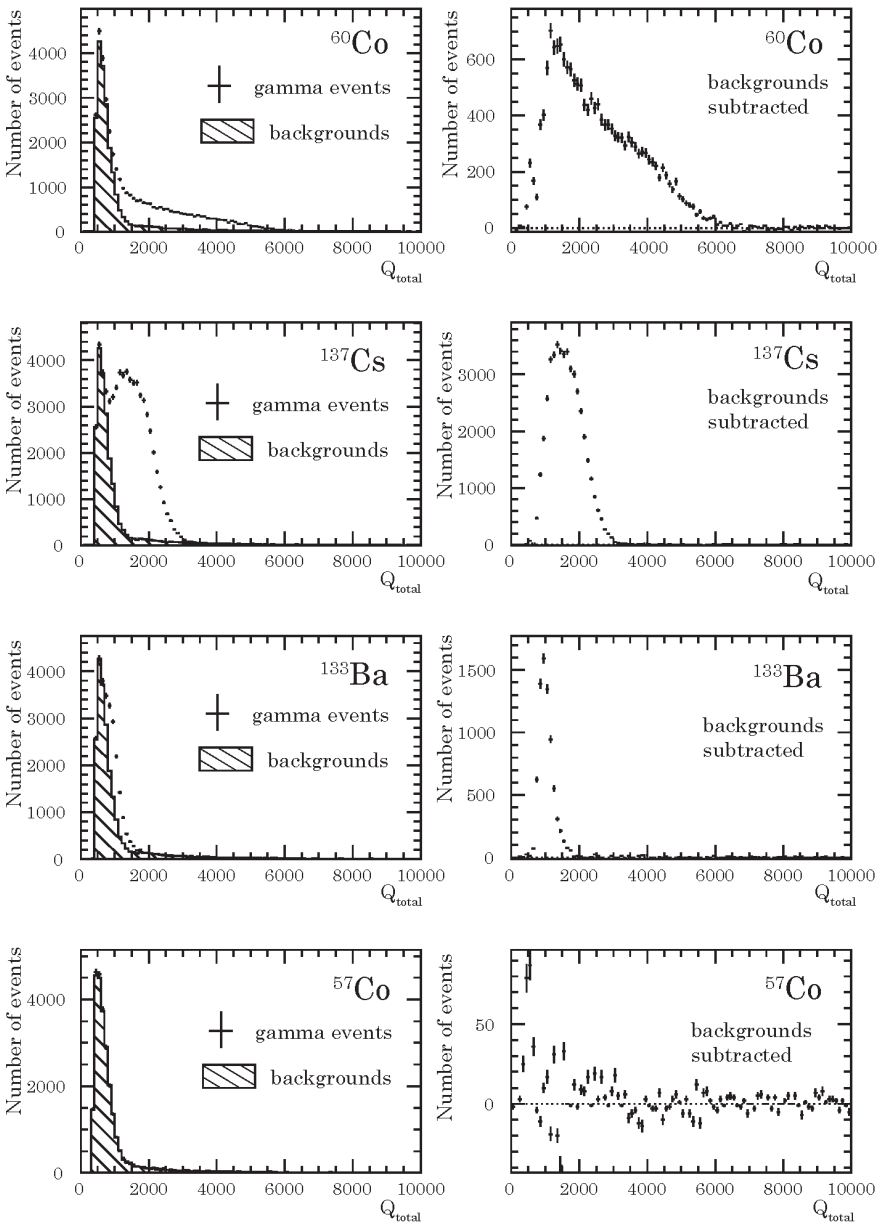
$Zr(iprac)_4$ 2242mg, PPO 999mg and POPOP 10mg solved in 20mL Anisole

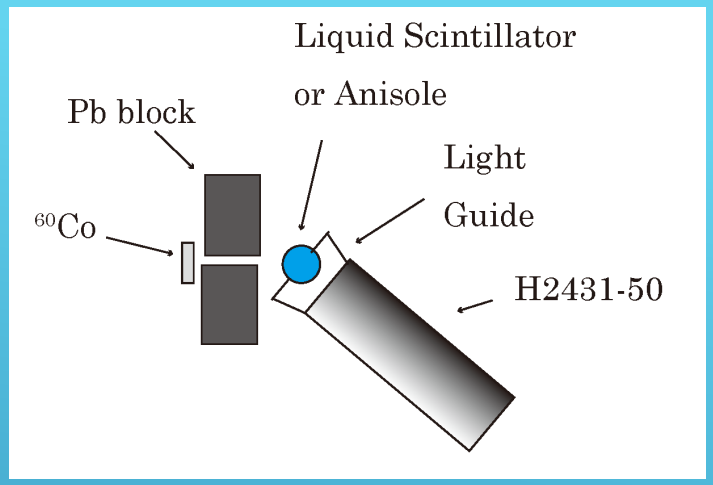




> 70g/L of Zirconium could be solved in anisole.

Q_{total} distribution for γ sources

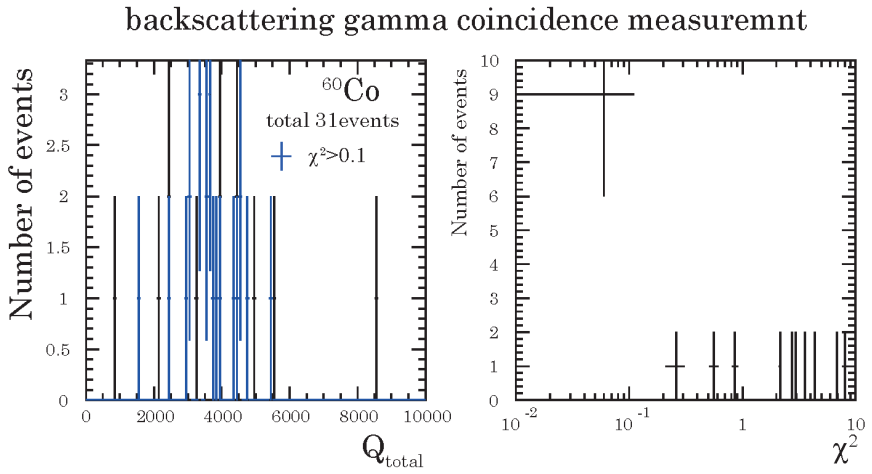




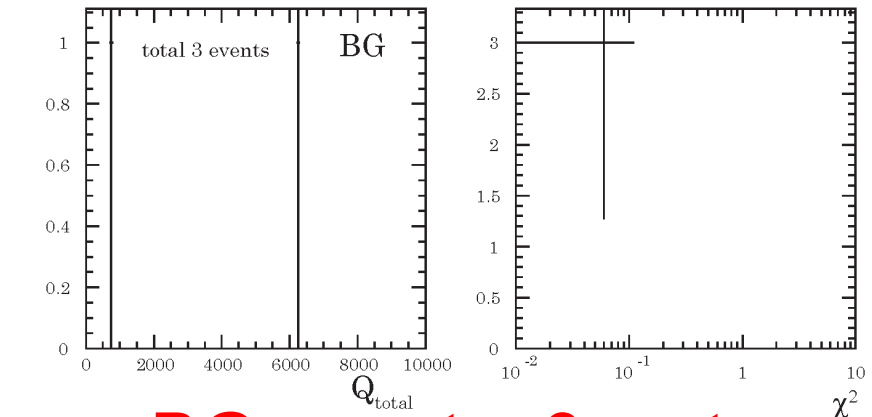
- ^{60}Co (1.17MeV/1.33MeV)
  Compton edge： 1.04MeV
- ^{137}Cs (662keV)
  Compton edge： 478keV
- ^{133}Ba (356keV)
  Compton edge： 207keV
- ^{57}Co (122keV)
  Under Cherenkov threshold (169kev)

Pulse shape with charge ratio in each FADC time.

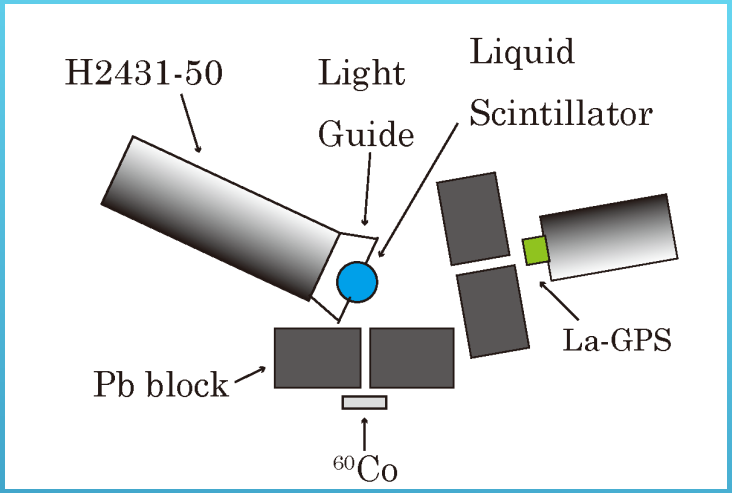
Measured by fixed energy fixed direction events



χ^2>0.1：22events/28events =78.6%



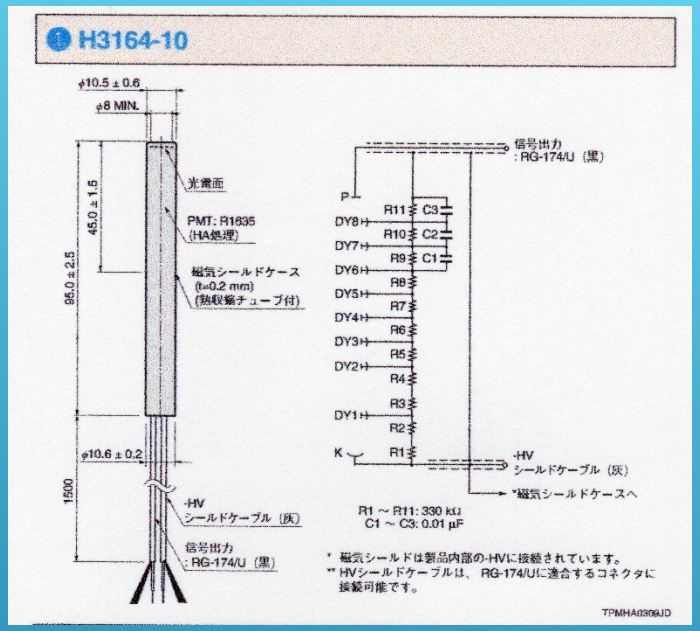
BG events=3evets



Fixed energy : 835keV
ADC ch~3400cn

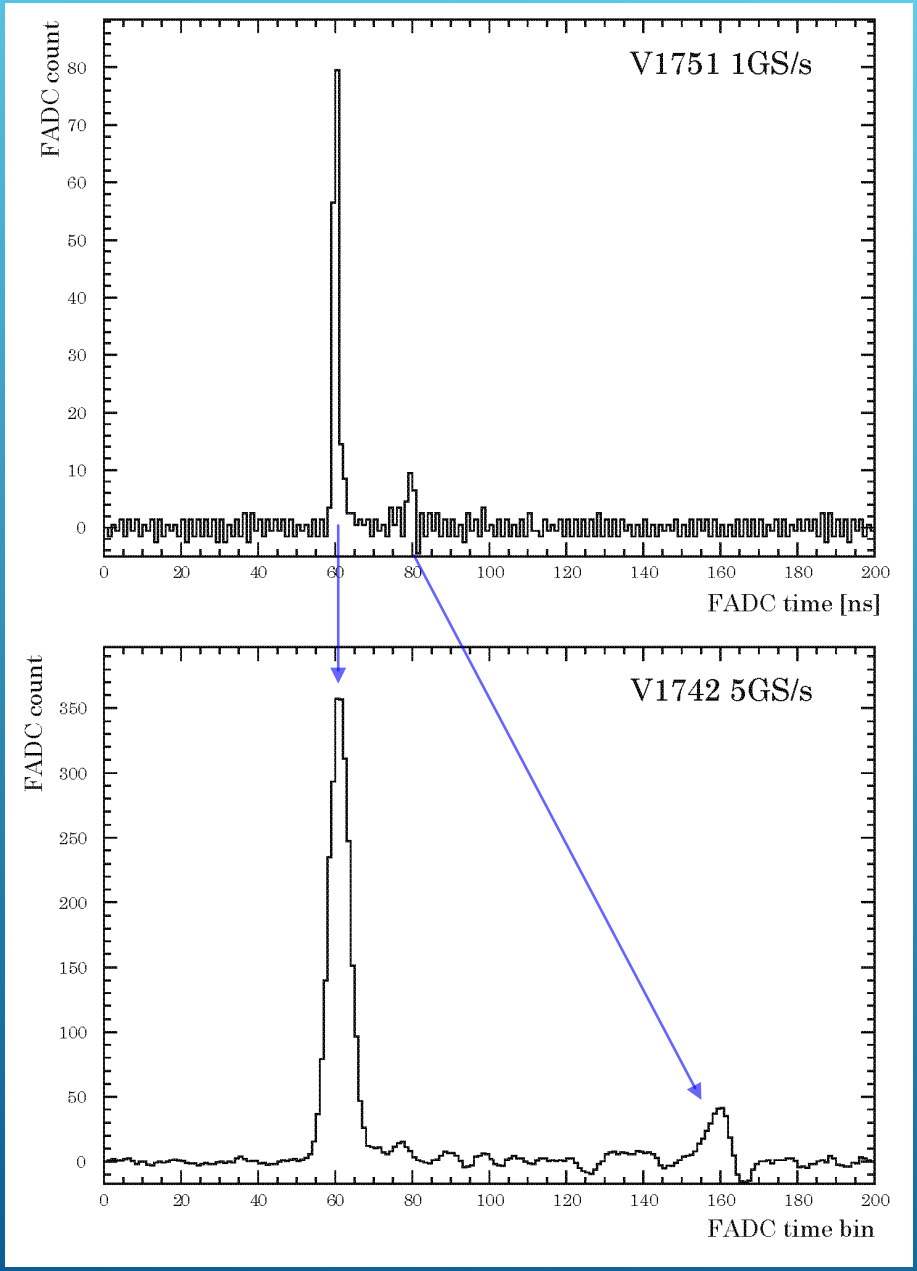
If the events with χ^2>0.1 should have Cherenkov lights, is this inefficiency 21.4±9.6% correct?

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）

Check V1742 sampling waveform

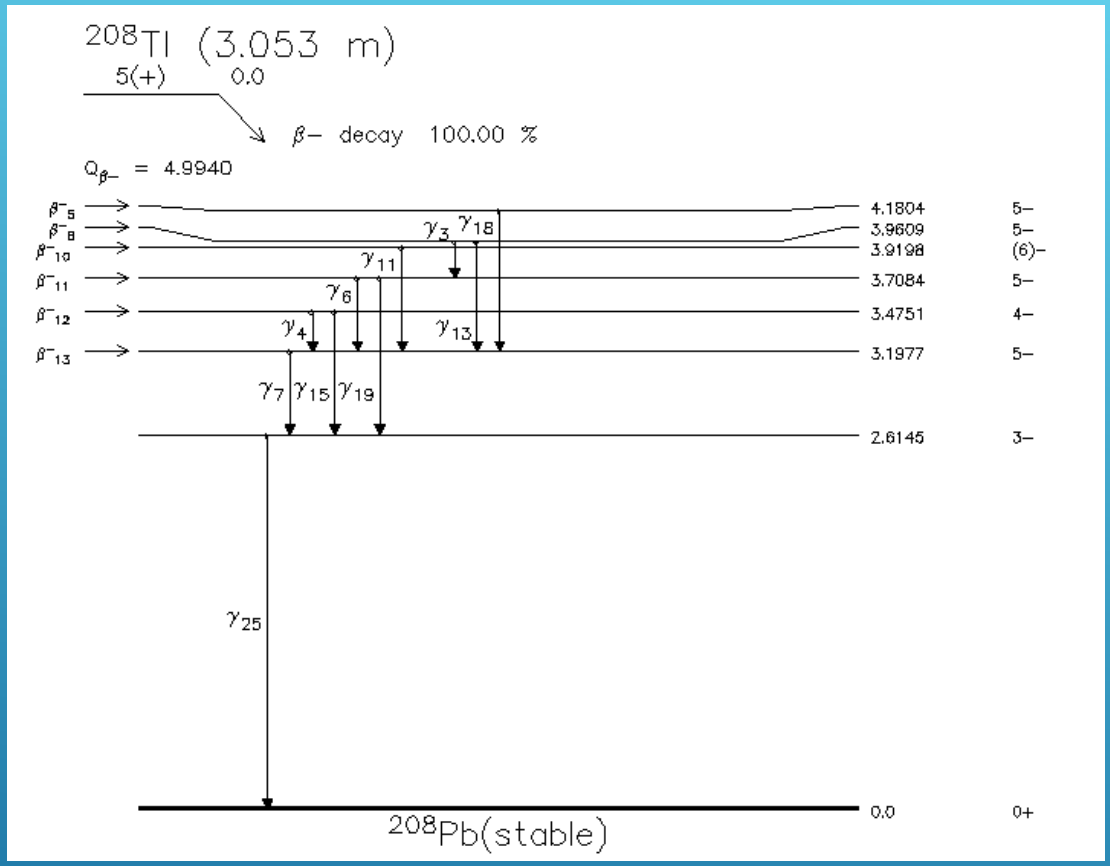


- Sampling frequency of V1742 was set as 5GS/s (fastest mode)
- Sampling frequency of V1751 was set as 1GS/s due to 8ch read.(No DES mode)
- Waveform of same Cherenkov pulse was completely same shape.
- Detailed pulse structure analysis is available using V1742.

Flash ADC V1742 and PMT HV system

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

Decay scheme of ^{208}Tl

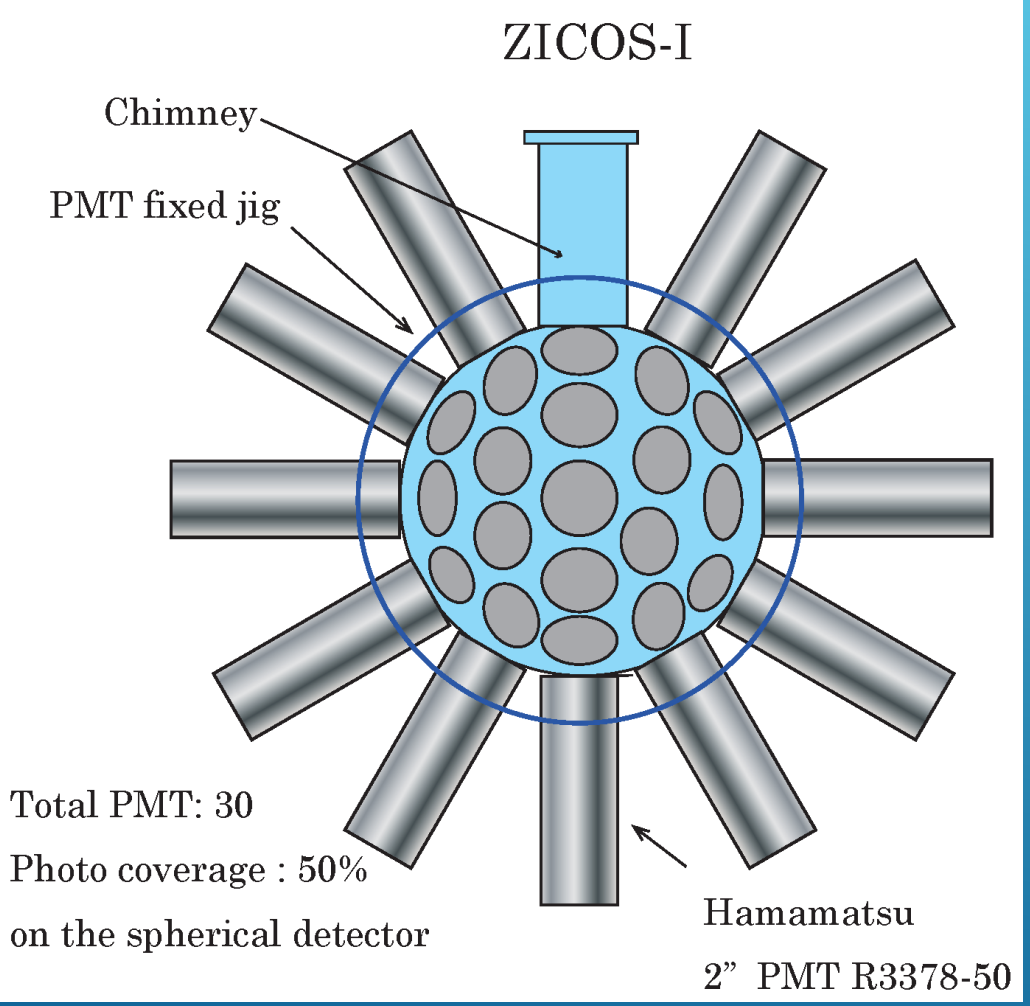


The vertex position reconstructed by scintillation might be within fiducial volume due to gammas.

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}

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

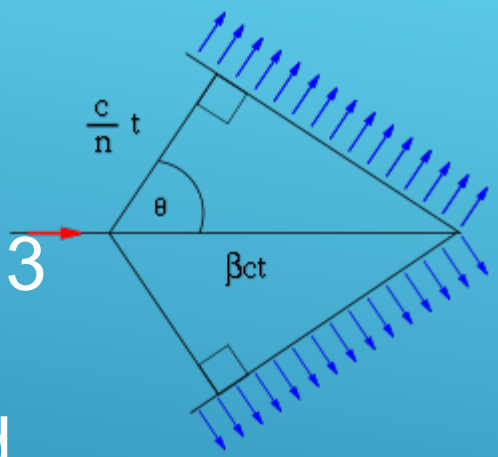


・20cm diameter flask using Ultra-pure quartz and 30 low BG 2” PMT R3378-50 (R2083)
・Synthesis $Zr(iPrac)_4$ 300g which corresponds to ^{96}Zr isotope1g
・According to NEMO-3 result, expect 200 $2\nu\beta\beta$ events/year
・Location: Kamioka mine

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