REDUCTION OF TL-208 BACKGROUND FOR ZR-96 NEUTRINOLESS DOUBLE BETA DECAY EXPERIMENT USING TOPOLOGICAL INFORMATION OF CHERENKOV LIGHTS

41st International Conference on High Energy Physics

ICHEP2022

July 9, 2022

Grant-in-Aid for Scientific Research on Innovative Areas

19H05093 and 20H05241

Scientific Research (B) 22H01243

Miyagi University of Education **Y. Fukuda**, **T.Shimizu**

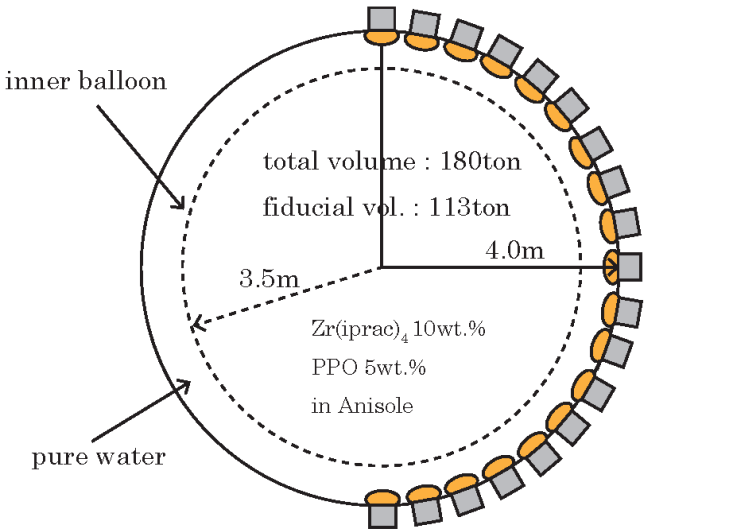
Kamioka Observatory, ICRR, Univ. of Tokyo **S. Moriyama, K. Hiraide**

University of Fukui **I. Ogawa**

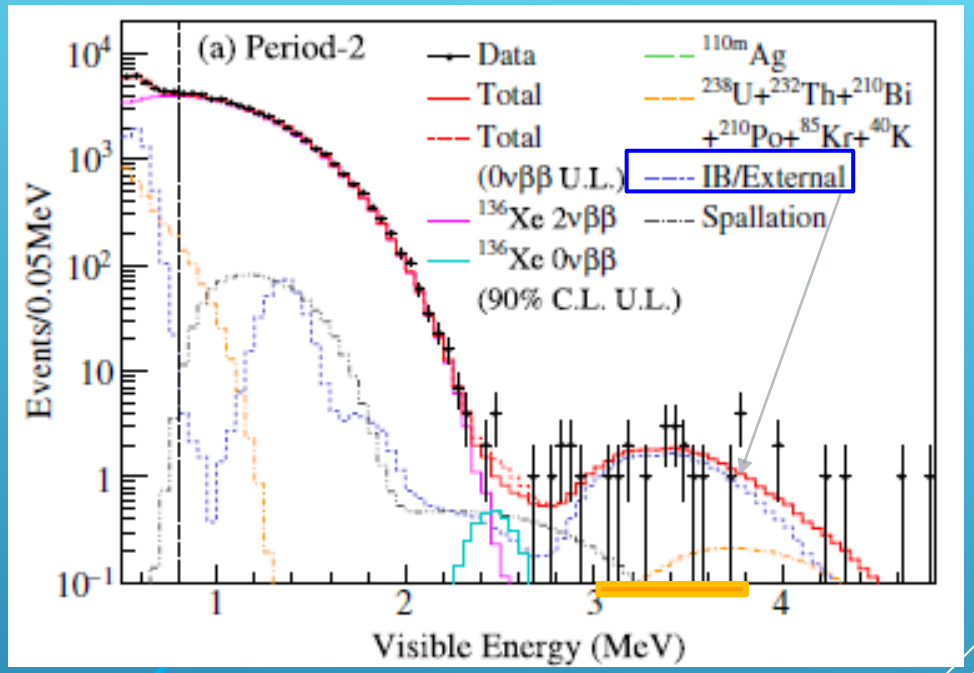
Tokyo University of Science **T. Gunji, S. Tsukada, R. Hayami**

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

Conceptual design of ZICOS detector



Phys.Rev.Lett. 117 (2016) 082503

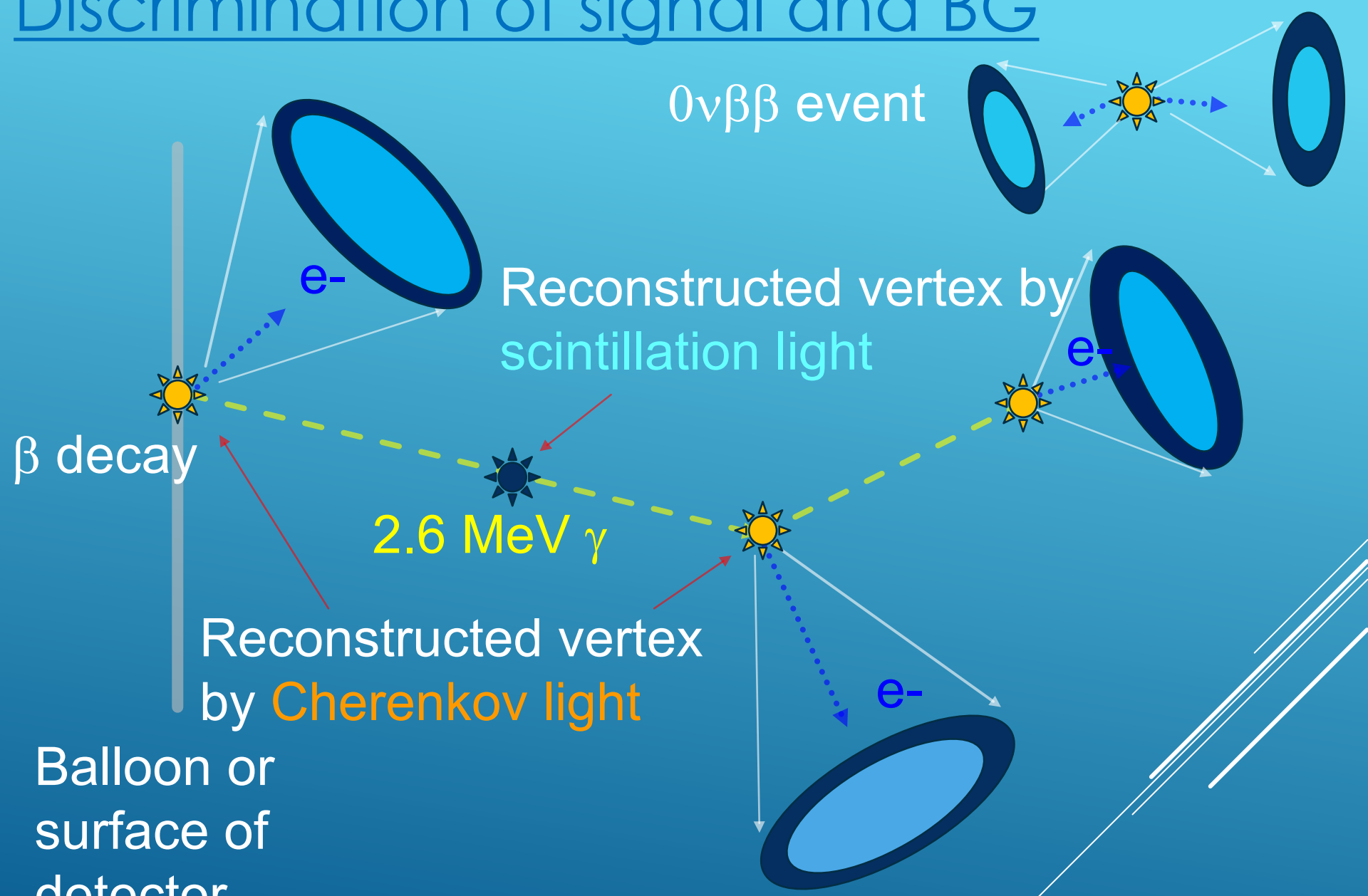


NEMO3 : $T_{1/2}^{0\nu} > 9.1 \times 10^{21}$ yrs

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

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

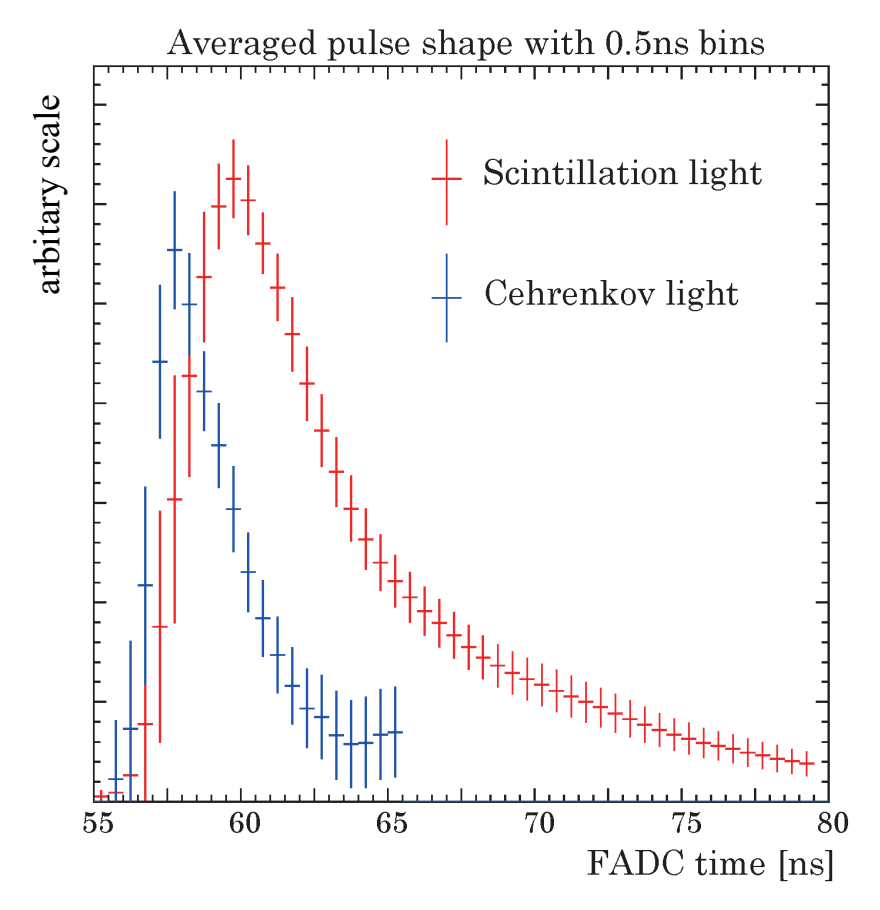
Discrimination of signal and BG



Verification of ^{208}Tl background reduction using Cherenkov lights

1. Selection of PMTs which receive Cherenkov lights among huge Scintillation lights.
   - Pulse shape discrimination
2. Confirm topology of Cherenkov lights
   - Directionality of Cherenkov lights
   - Direct measurement of topological information averaged angle
3. Demonstrate BG reduction using beta-gamma sources with topological information (averaged angle) of Cherenkov light.

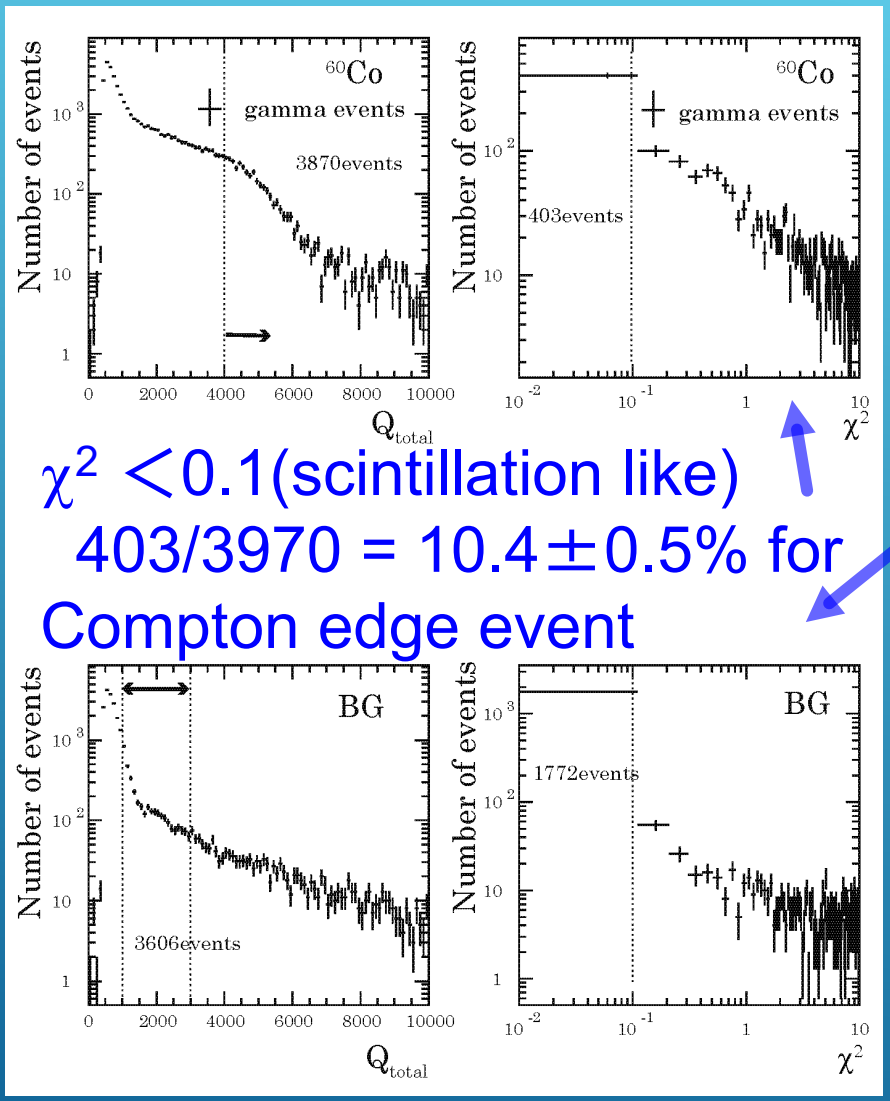
Pulse shape of Cherenkov and scintillation



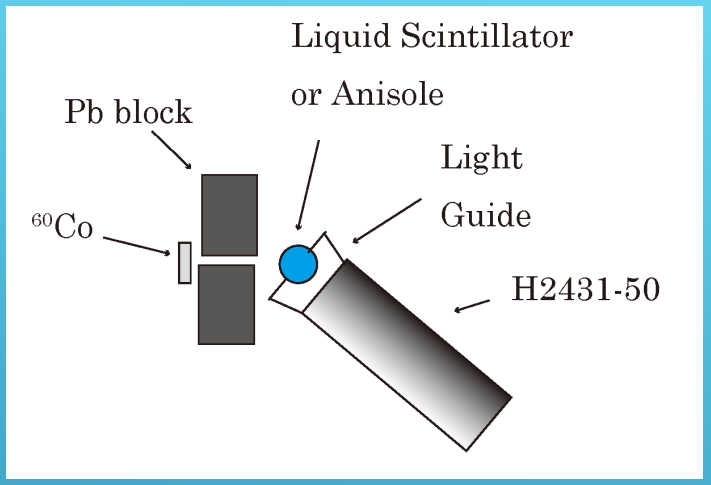
- Pulse shape of ^{90}Sr using H2431-50 measured by V1751 with DES mode (2GS/s)
- Decay time of scintillation : 4.57 ns and 8.38 ns
- Rise time of scintillation : 1.45 ns
- Rise time of Cherenkov : 0.75 ns

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

Measured by Compton edge event and BG sample



χ^2 <0.1(scintillation like)
403/3970 = 10.4±0.5% for Compton edge event

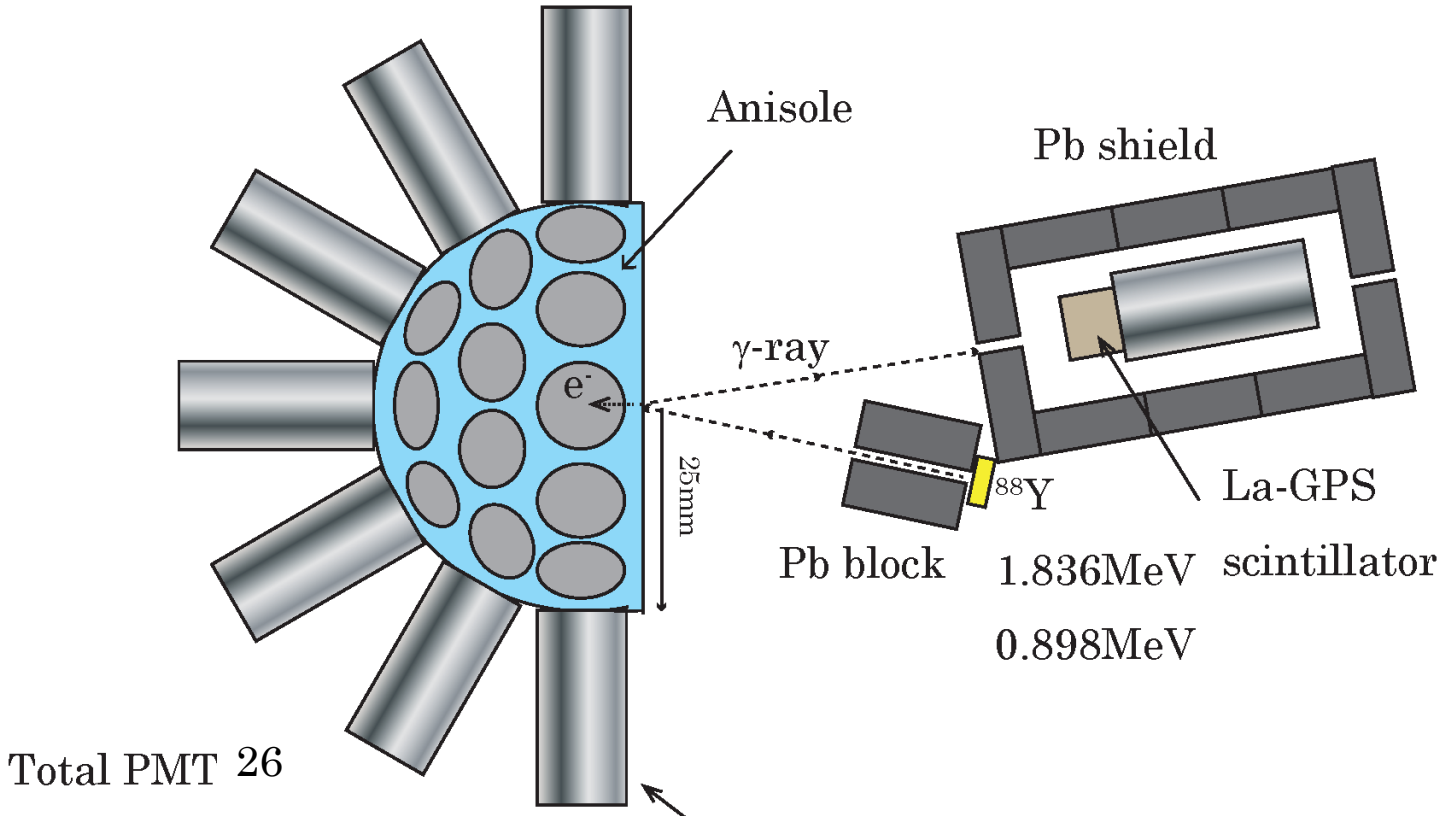


1772/3606=49.1±1.4 % for BG sample

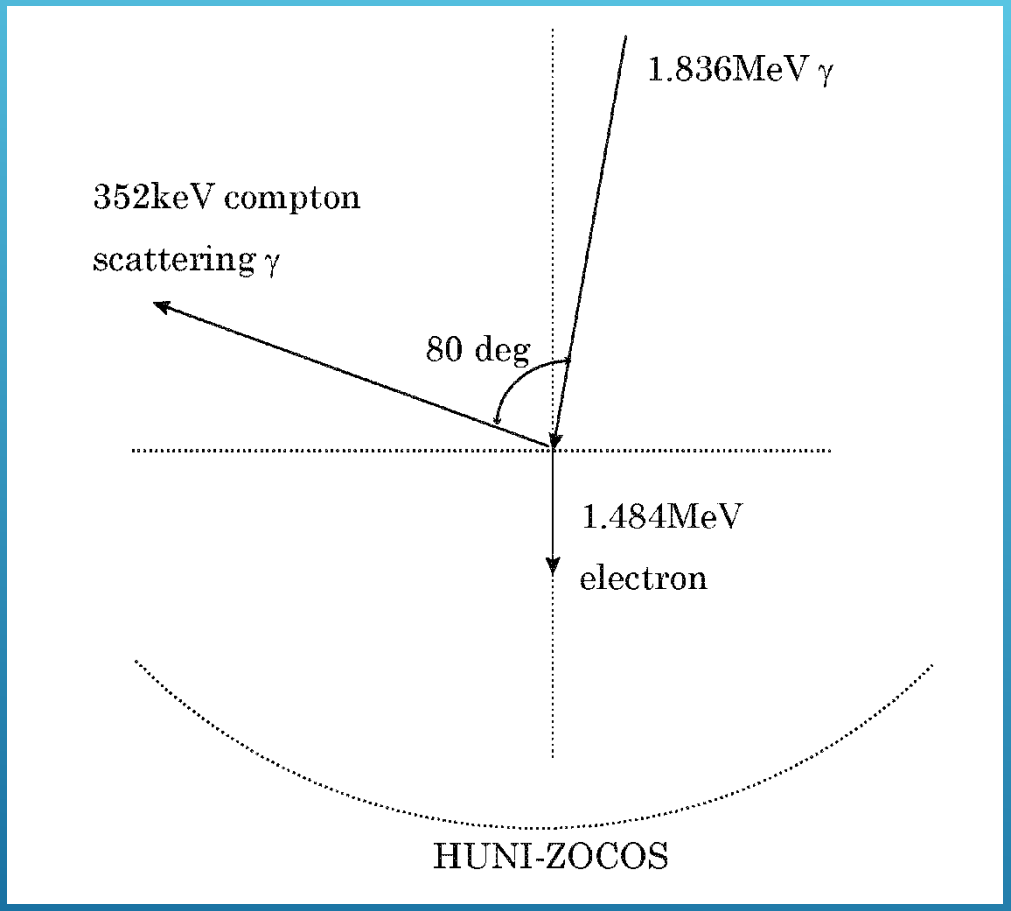
The difference between Compton edge events and BG sample is 2.9 σ.

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

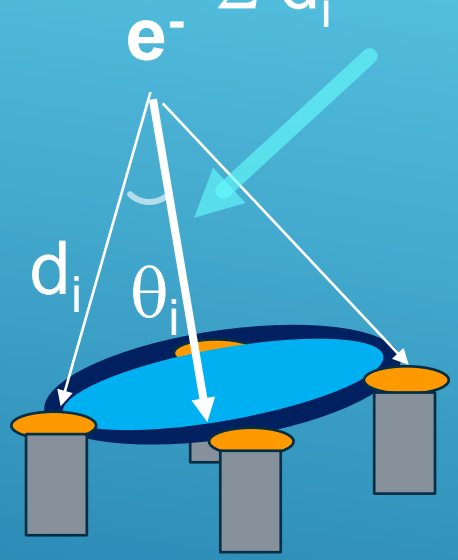
Direct measurement of topological information using HUNI-ZICOS



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



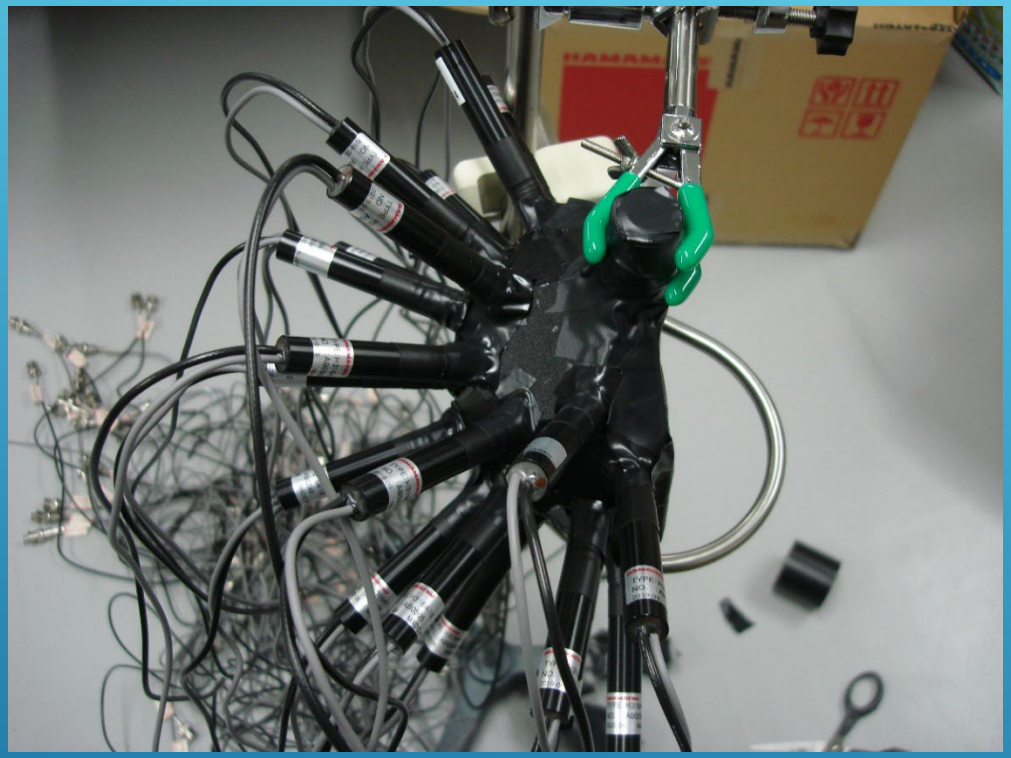
Average direction
$= \Sigma d_i$

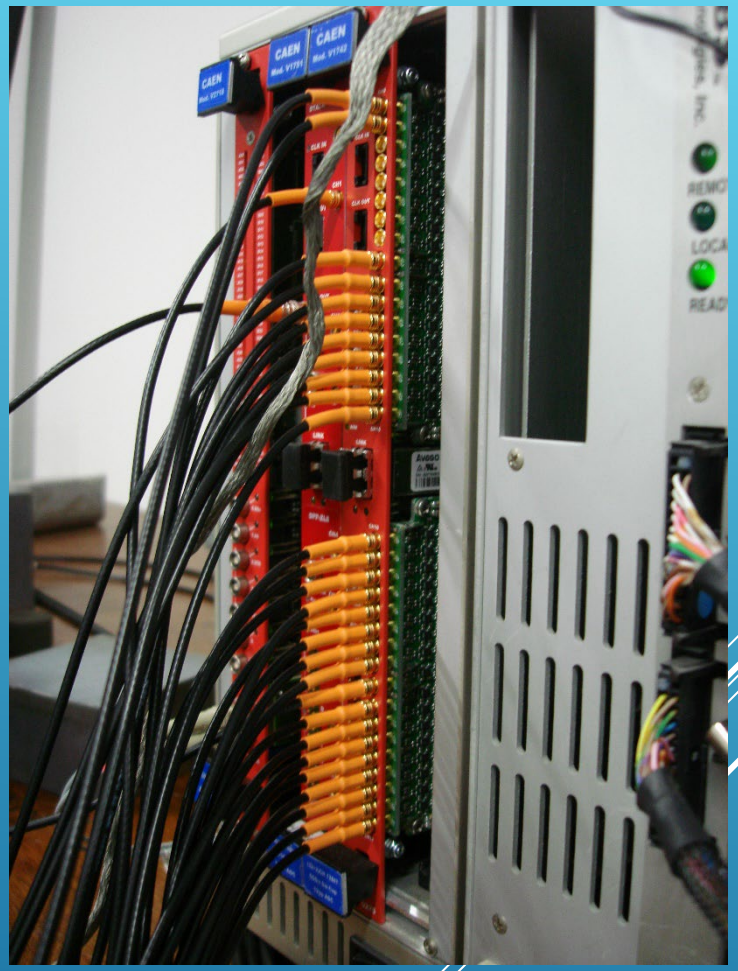


Averaged angle= $\frac{\Sigma \theta_i}{Nhit}$

Topological information of Cherenkov lights could be presented as averaged angle.

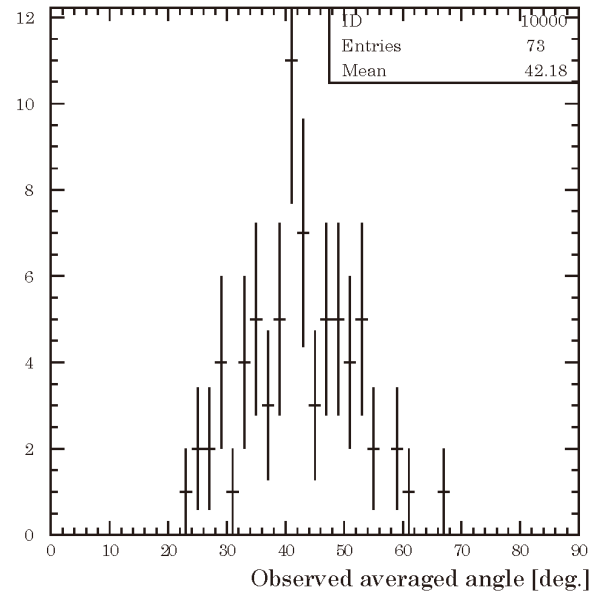
Setting hemisphere flask to jig and locate on supporting stand

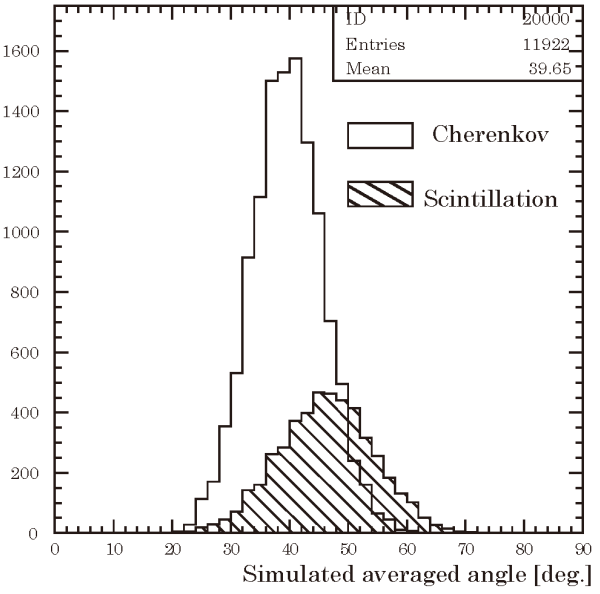




- HUNI-ZICOS was putted on flask clip and the chimney was pinched by clamp.
- Assuming e^- generated position to be center of the truncated icosahedron jig (not hemisphere flask).

Measured averaged angle and simulation

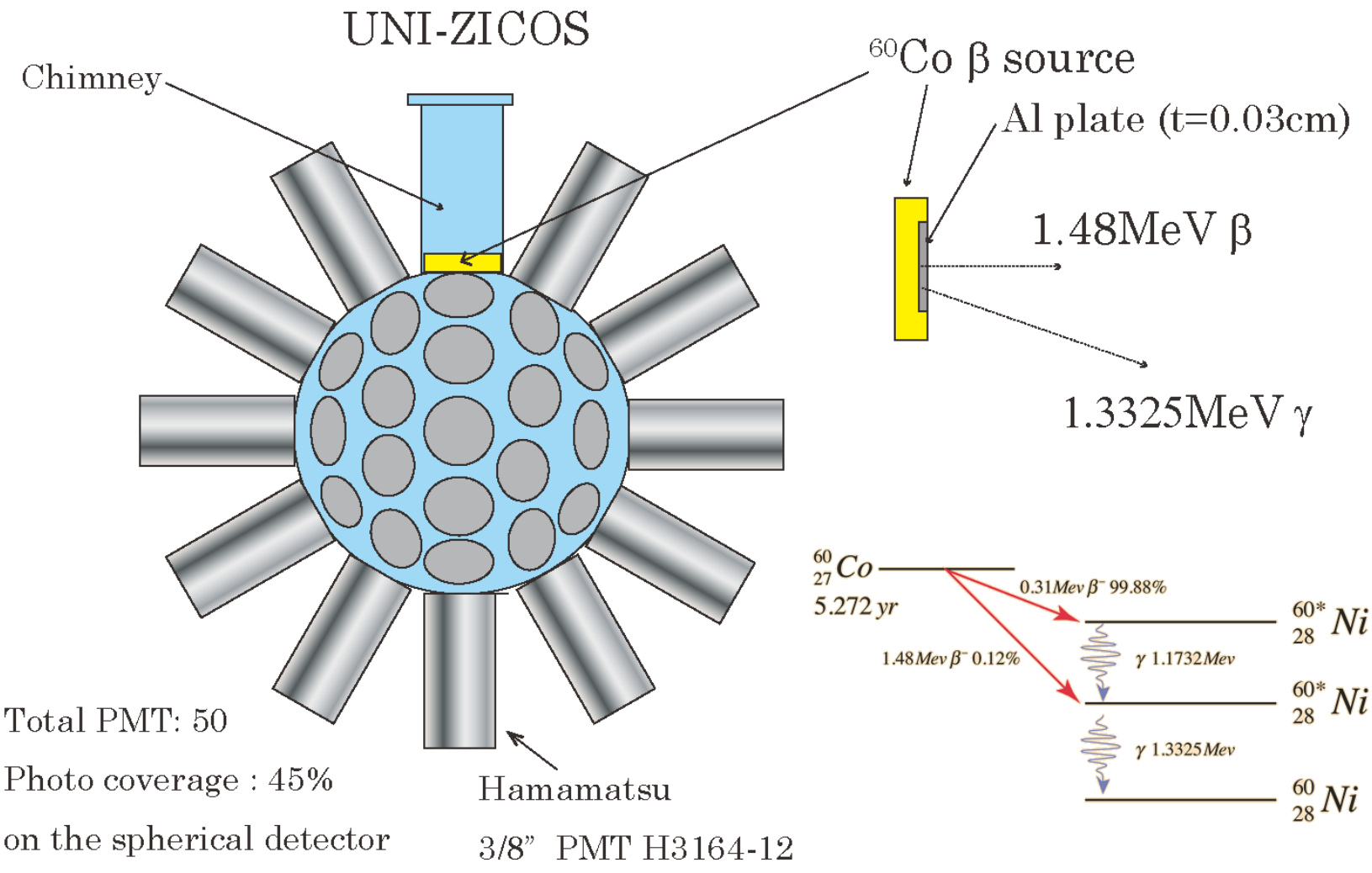




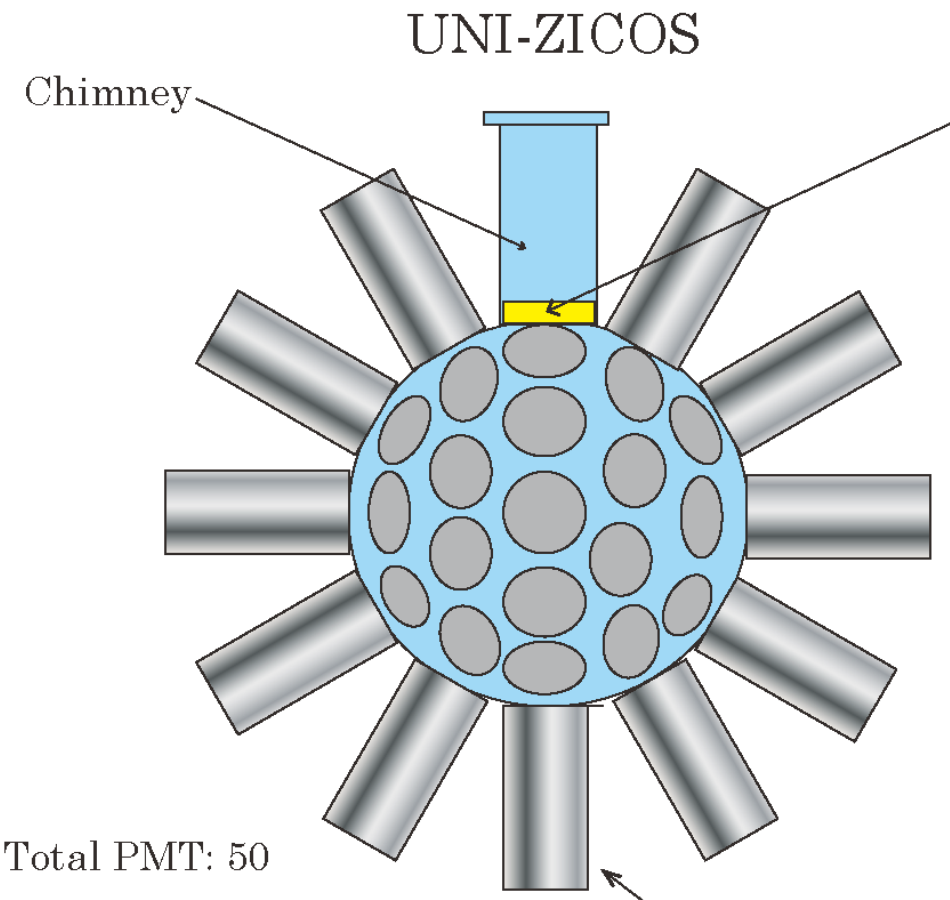
- Averaged angle measured by HUNI-ZICOS has a peak at 40 degree. This is due to PMT geometry of HUNI-ZICOS detector.
- Averaged angle obtained by EGS5 simulation of Cherenkov light has a peak at 40 degree. This is consistent with above measurement.
- Averaged angle obtained by EGS5 simulation of scintillation has a peak around 50 degree. This is quite different from Cherenkov light.

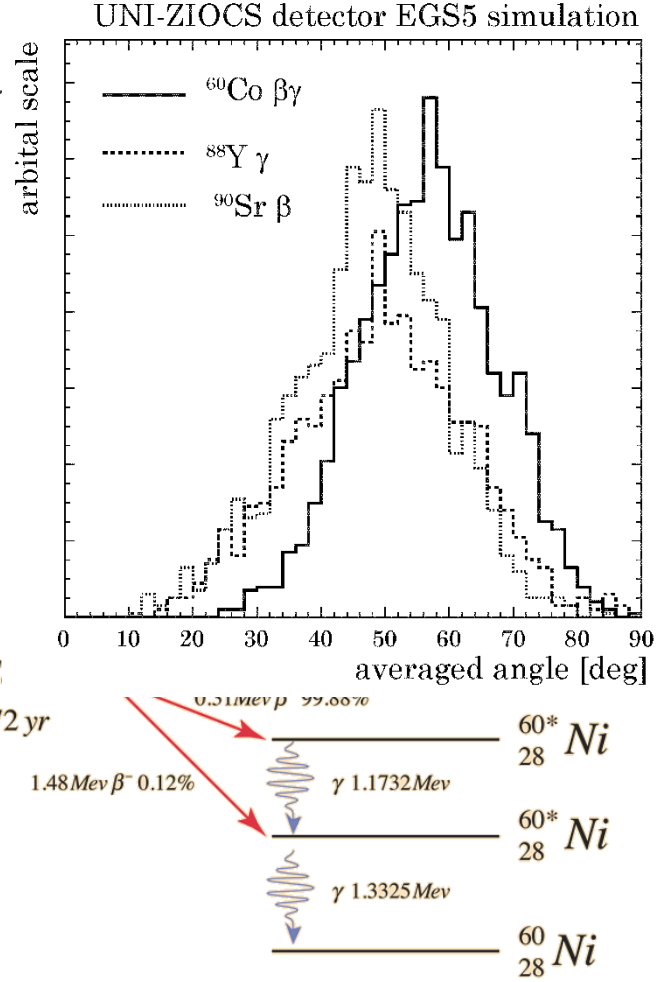
Verified Cherenkov lights emitted from 1.484 MeV electron really maintain their topology.

Demonstration of ^{208}Tl BG reduction



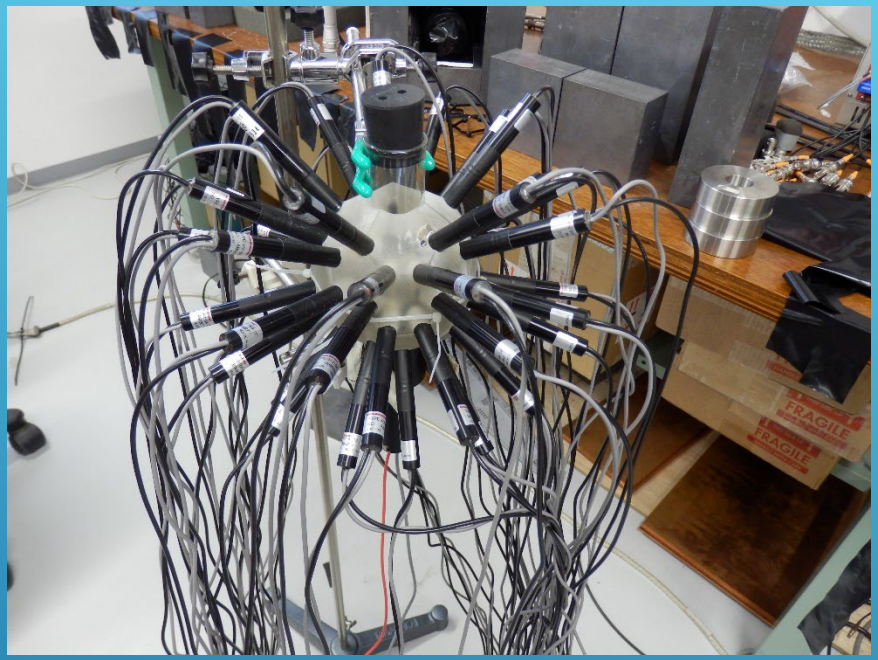
Demonstration of ^{208}Tl BG reduction

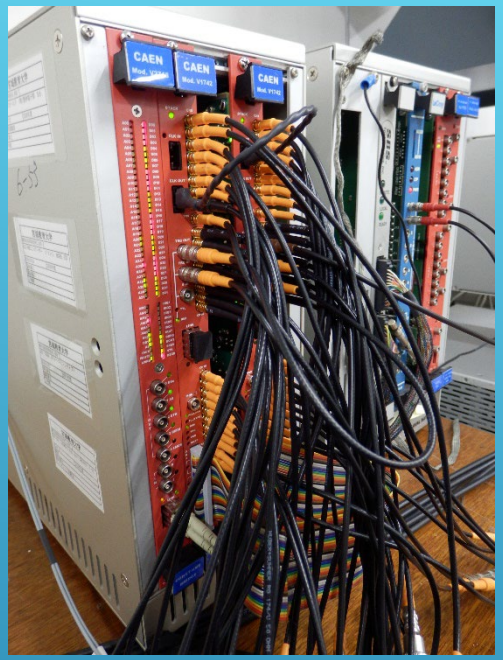


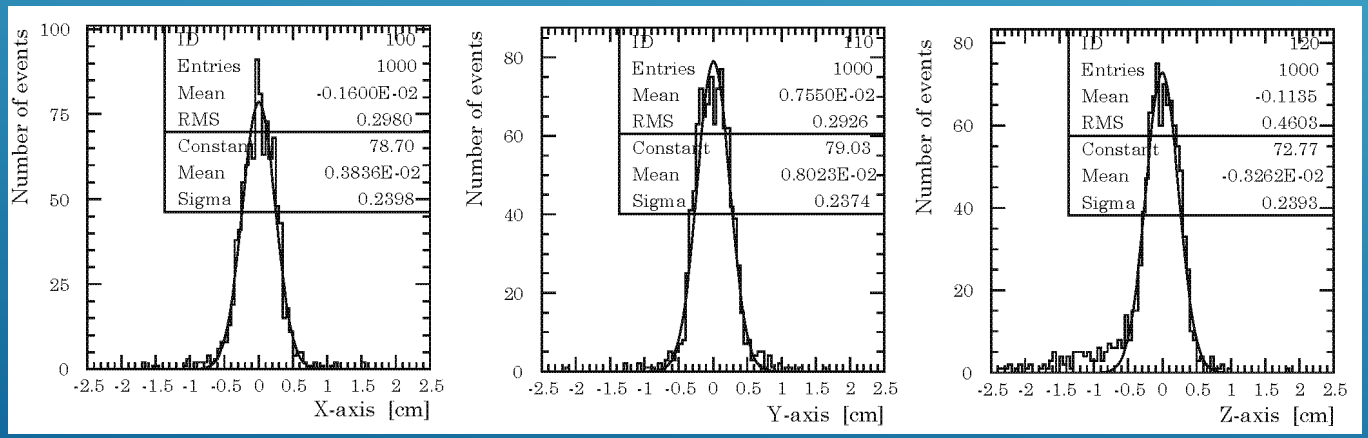


Due to March earthquake in Japan, we lost 5 PMTs.

Setup for the measurement using UNI-ZICOS



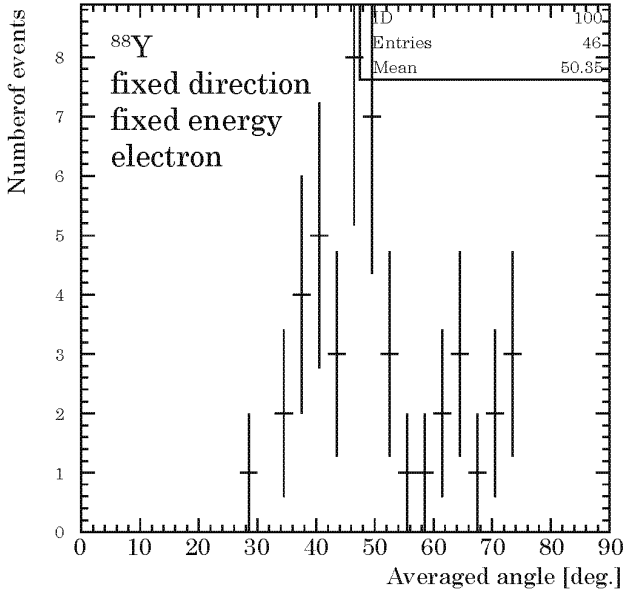


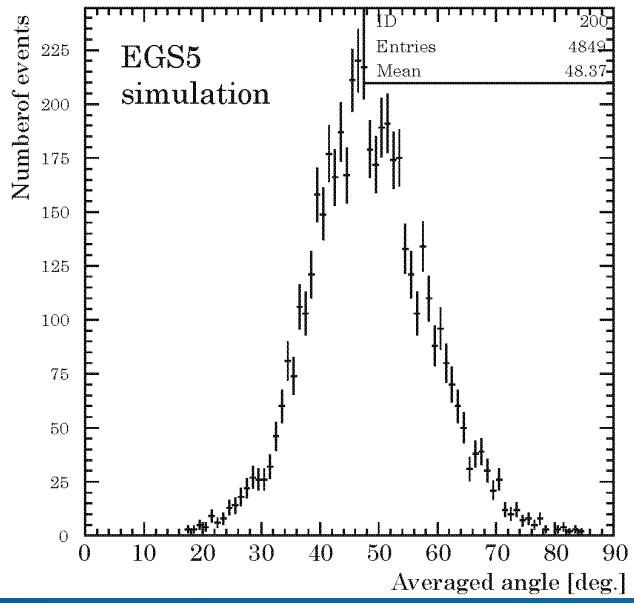


Source holder has a hole, and it can be covered by Al plate to terminate electron.

The vertex position could be reconstructed by assuming that all PMTs should have same effective charge which is corrected by the distance between PMT and vertex.

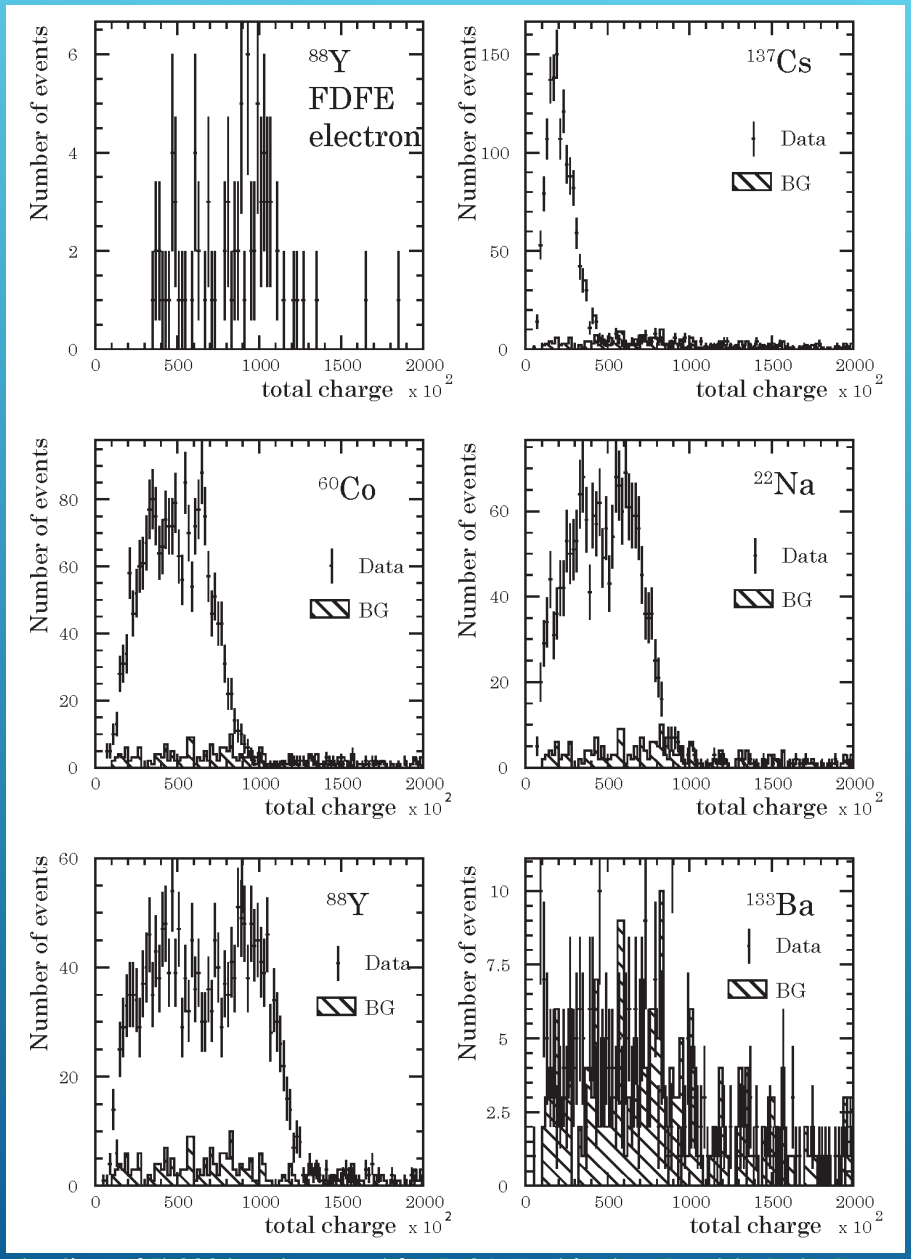
Observed averaged angle using FDFE events

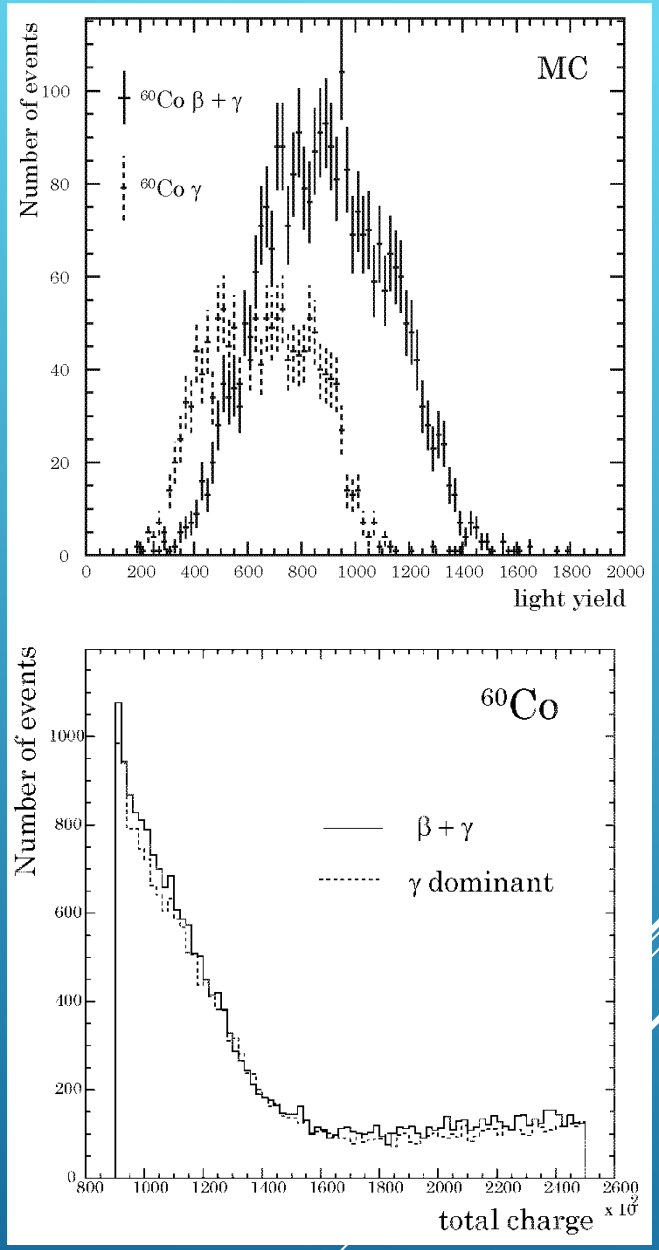




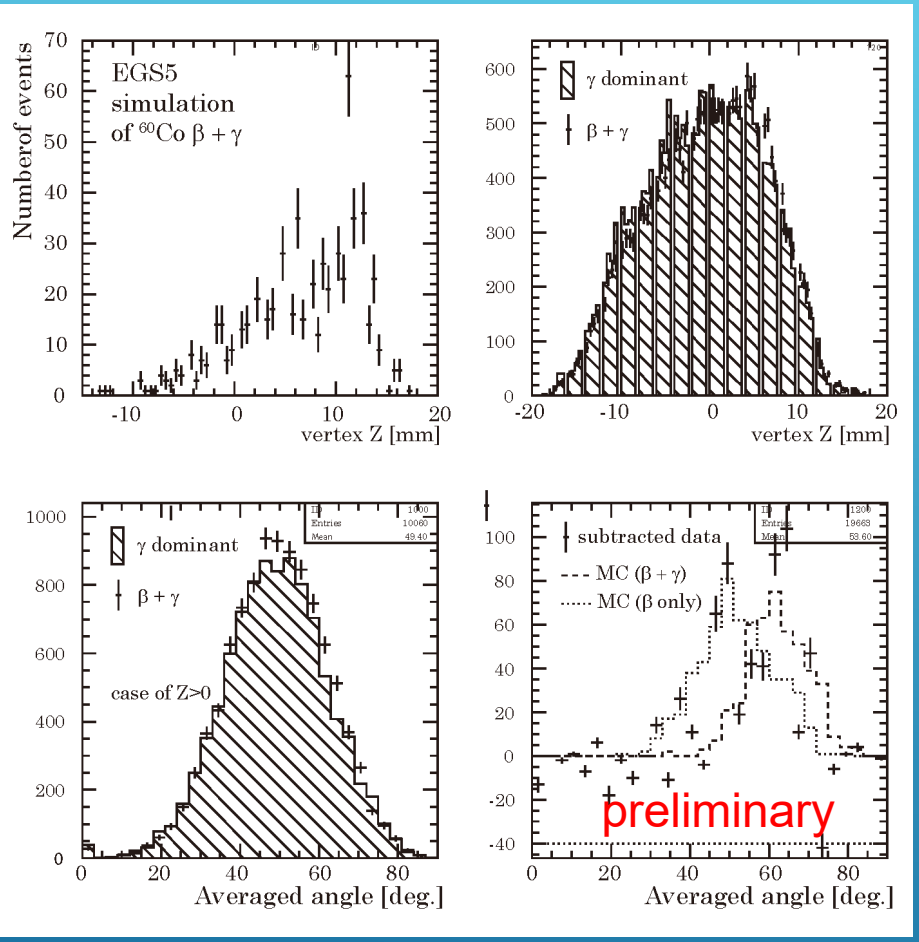
- The vertex position was reconstructed by charge information as explained.
- Extracted PMTs which include Cherenkov light by PSD technique.
- Using those PMTs and the vertex, the averaged angle of fixed direction fixed energy electron from ^{88}Y source was measured, and a peak was found around 50 degree.
- The averaged angle obtained by MC simulation has a peak around 48 degree. Within the statistical error, the peak position was almost reproduced.
- Measurement time was limited by March earthquake in Japan.

Events selection for beta-rich samples





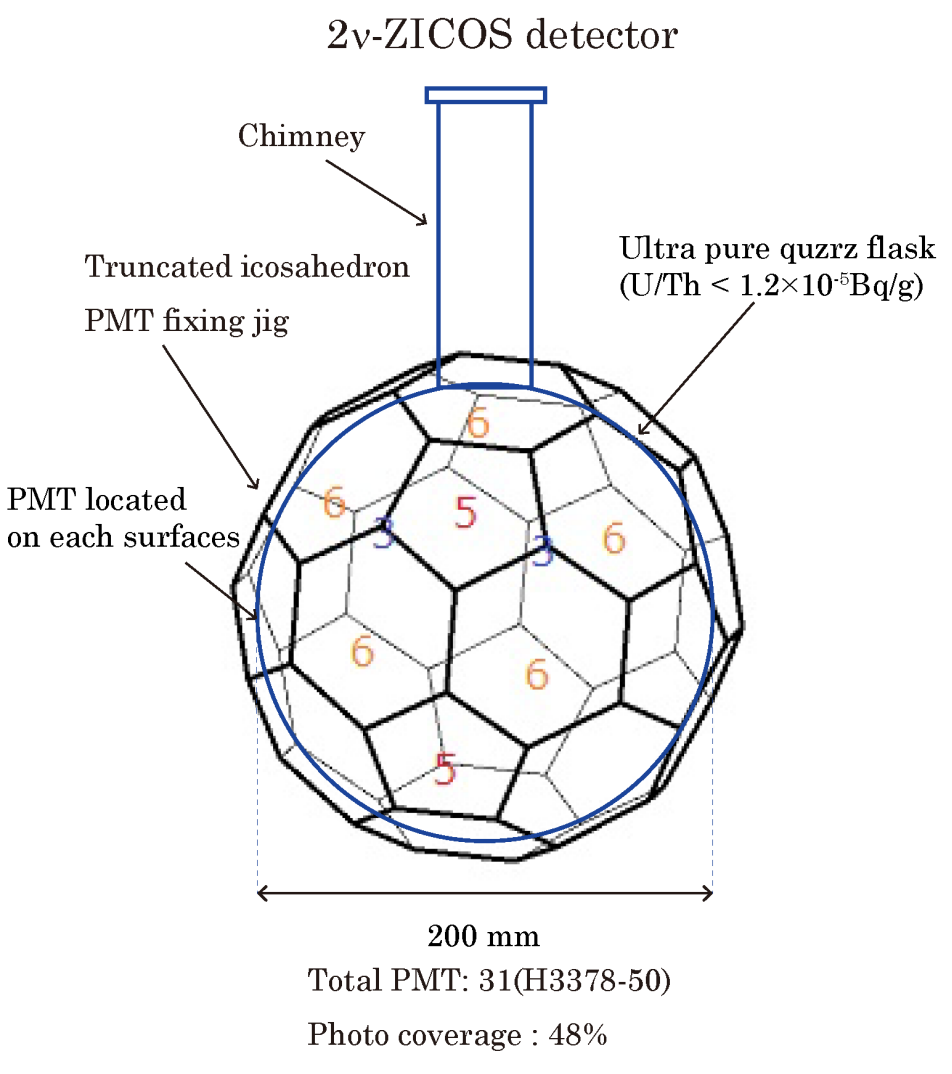
Observed averaged angle using β–γ events



- Averaged angle is obtained by z>0 and by subtracting β+γ and γ dominant data.
- Obtained averaged angle looks two peaks around 50 and 60 deg.
- Events should consists not only β+γ events but β only and γ only events.
- Averaged angles of MC for β+γ and β only events would reproduce those data.

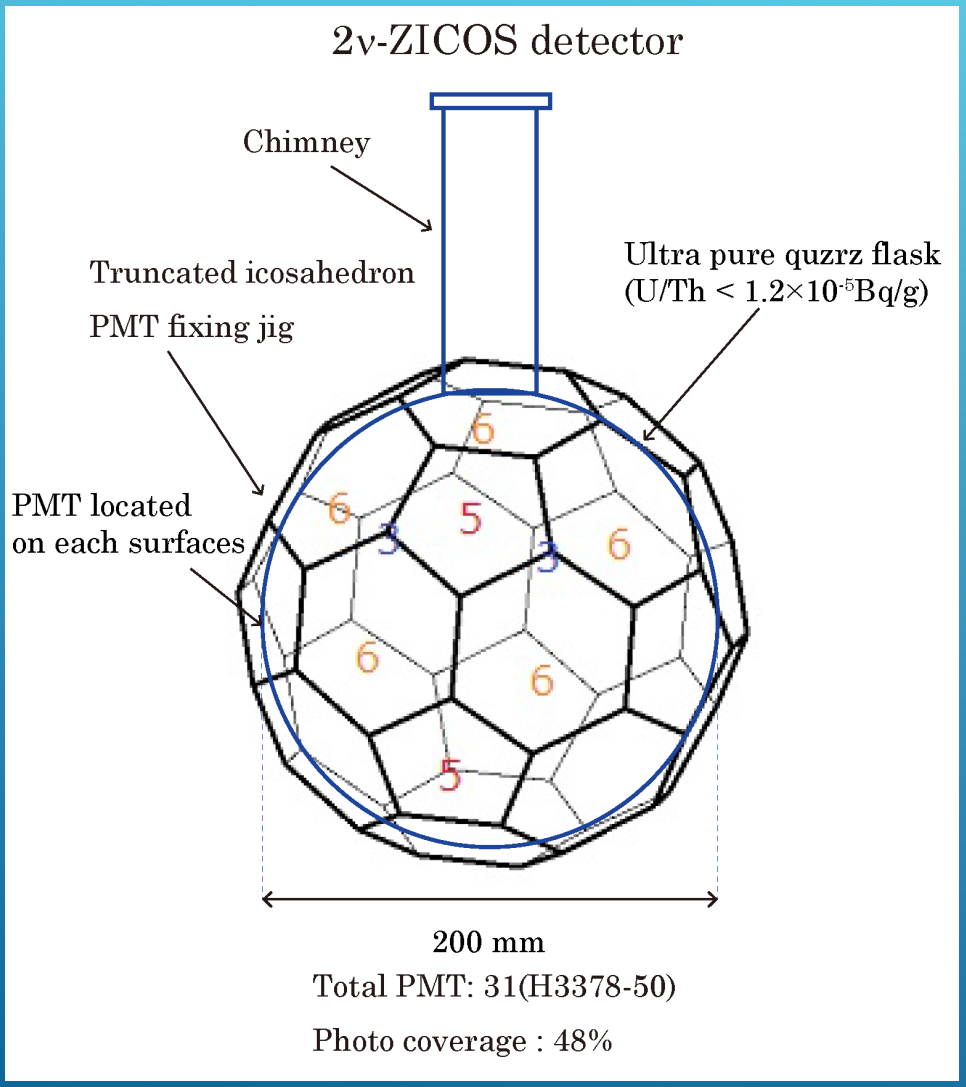
It would be possible to reduce β+γ evens such as ^{208}Tl backgrounds using the averaged angle.

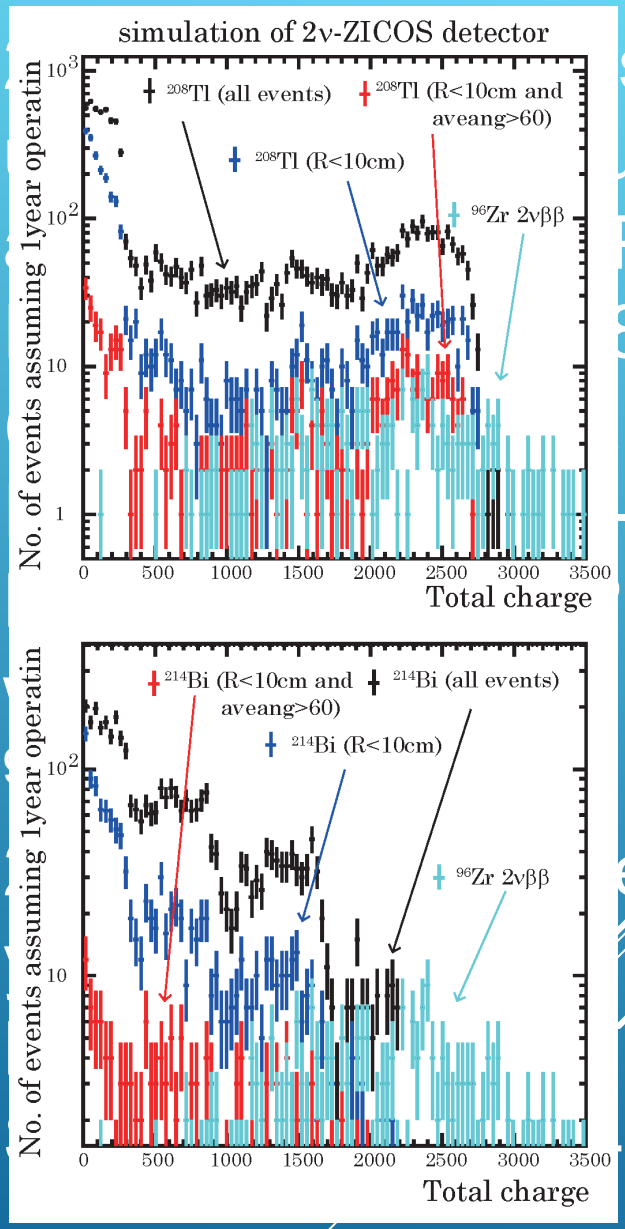
Observation of 2νββ signal using 2ν-ZICOS



- 20 cm diameter flask using Ultra-pure quartz and 31 low BG 2” PMT Hamamatsu R3378-50 (R2083) or SiPM arrays
- Filled 3L of ZICOS-LS
- Loaded 300g $Zr(iPrac)_4$ which contains 1.1 g ^{96}Zr
- 200 2νββ events per year is expected
- Location: Kamioka mine
- Start time: FY2024

Observation of 2νββ signal using 2ν-ZICOS





- sk
- uartz
- PMT
- 8-50
- rrays
- -LS
- $rac)_4$
- g
- er
- mine

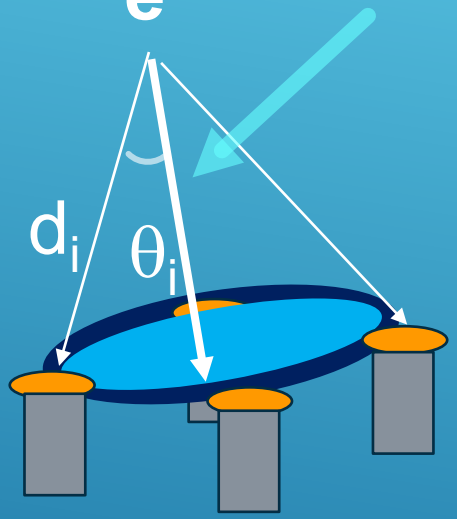
Summary

- Topological information (averaged angle) of Cherenkov light was directly measured by UNI-ZICOS using fixed direction / fixed energy (1.484MeV) electron from ^{88}Y source, and the averaged angle has a peak around 48 degree as expected by MC simulation. This is consistent with the Cherenkov angle.
- The averaged angle of $\beta+\gamma$ events from ^{60}Co source was measured by UNI-ZICOS, and the averaged angle has a peak around 60 degree as expected by MC simulation.
- We would be able to reduce $\beta+\gamma$ event such as ^{208}Tl BG using the averaged angle.
- Next program to observe ^{96}Zr $2\nu\beta\beta$ decay will start in FY2024 after the screening of low BG materials, the synthesis of $Zr(iPrac)_4$, and the construction of low BG environment using Pb shield in Kamioka mine. Stay tuned!

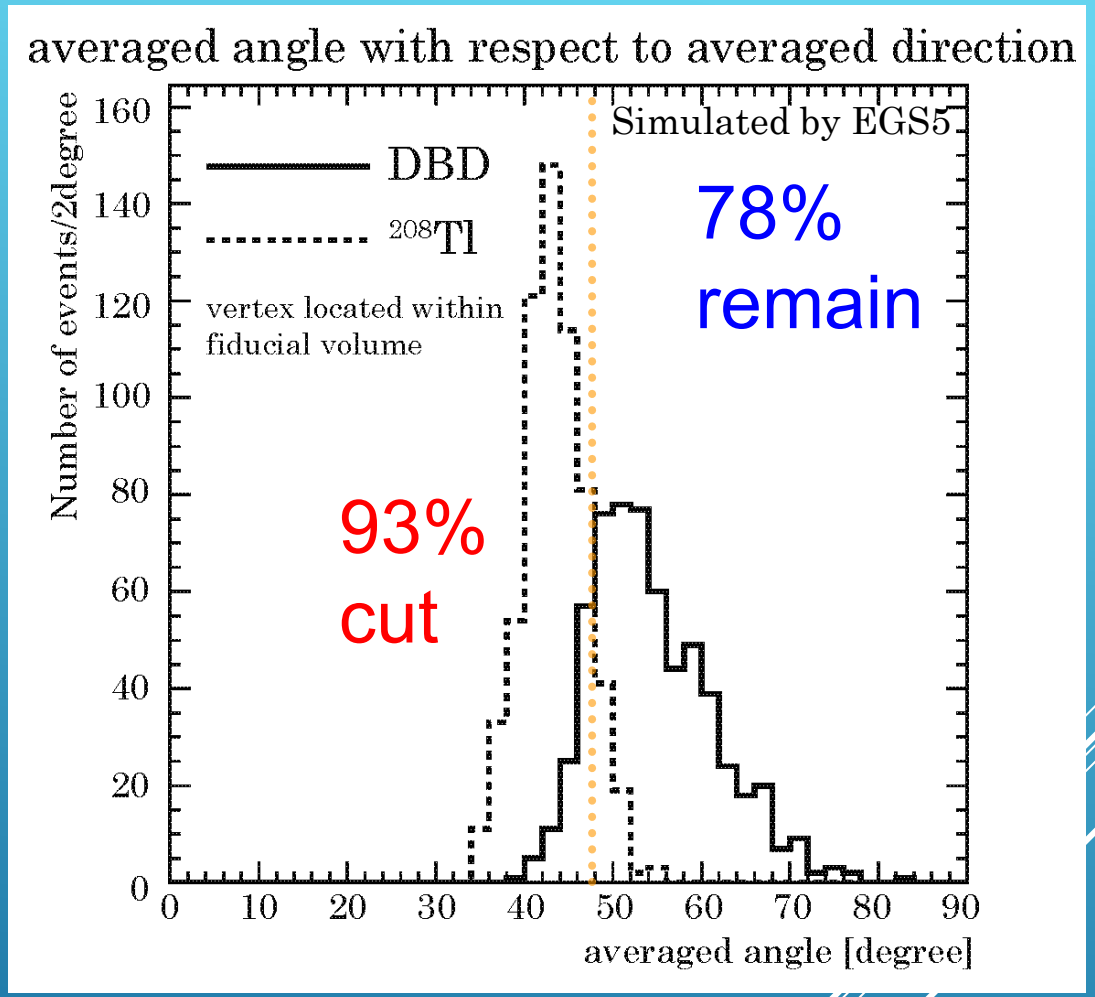
backup

BG reduction using topological information

Average direction
$= \Sigma\, d_i$

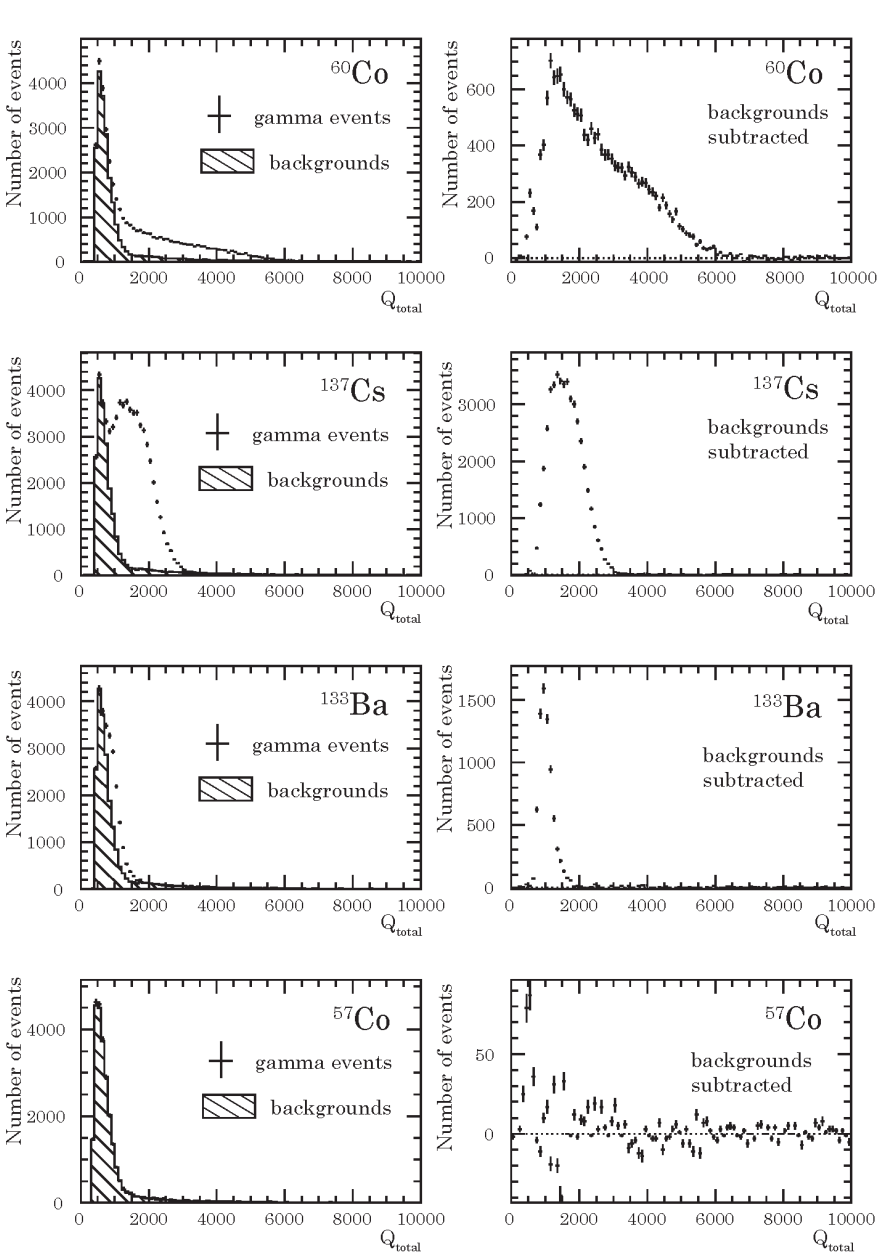


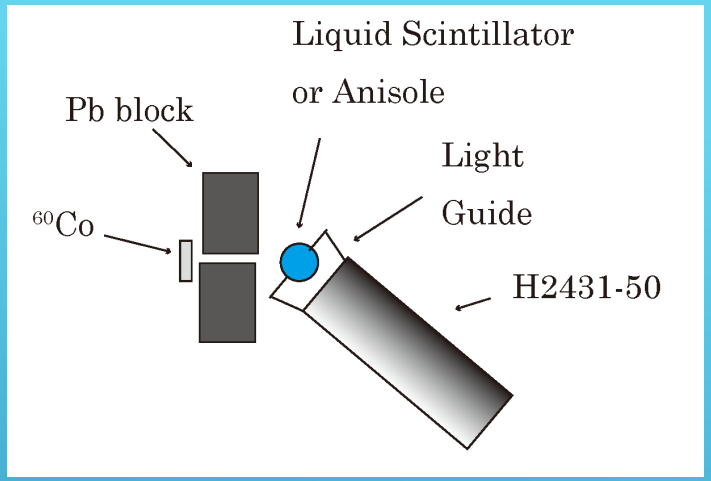
Averaged angle= $\dfrac{\Sigma\, \theta_i}{\text{Nhit}}$



Topological information (averaged angle) of Cherenkov lights could be used for reduction of ^{208}Tl backgrounds.

Q_{total} distribution for γ sources

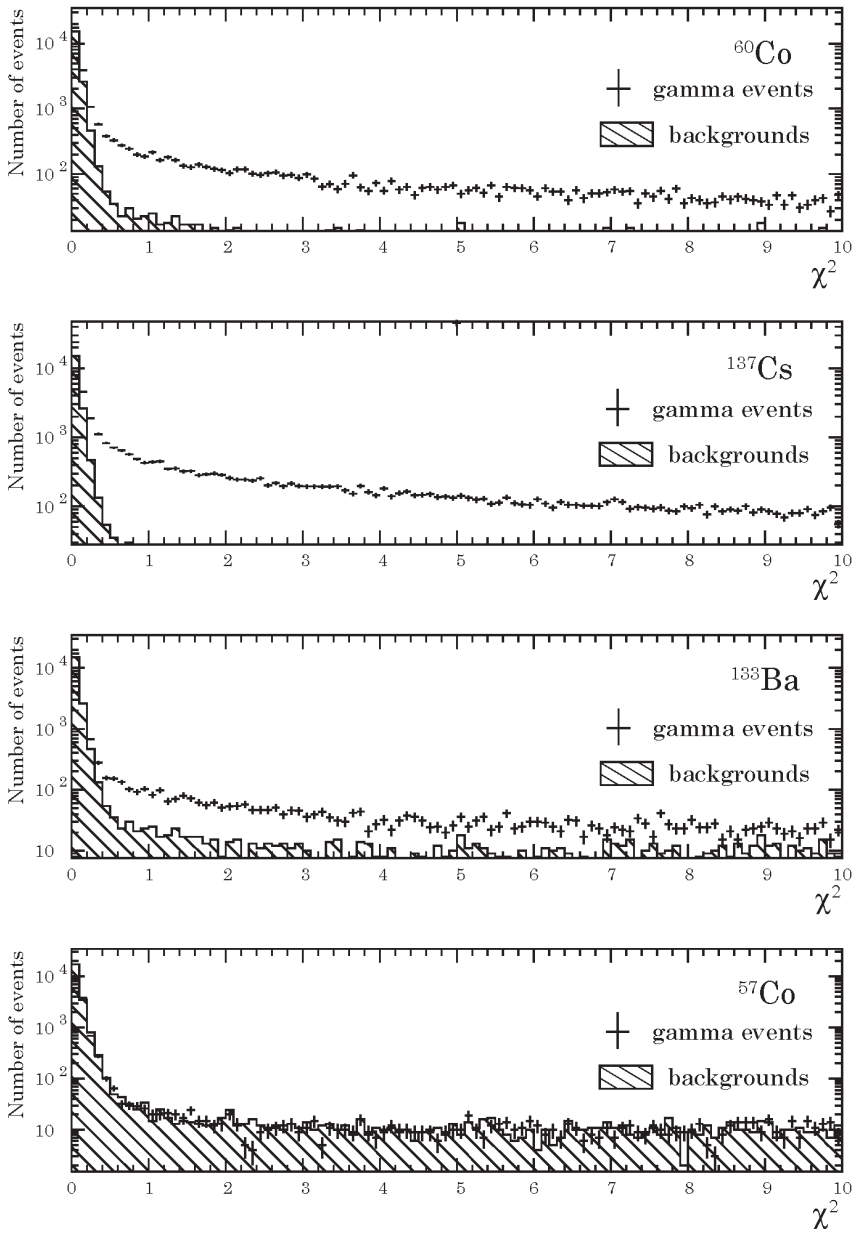




- ^{60}Co (1.17 MeV/1.33 MeV)
  Compton edge: 1.04 MeV
- ^{137}Cs (662 keV)
  Compton edge: 478 keV
- ^{133}Ba (356 keV)
  Compton edge: 207 keV
- ^{57}Co (122 keV which is under Cherenkov threshold "168 kev")

Pulse shape with charge ratio in each FADC time.

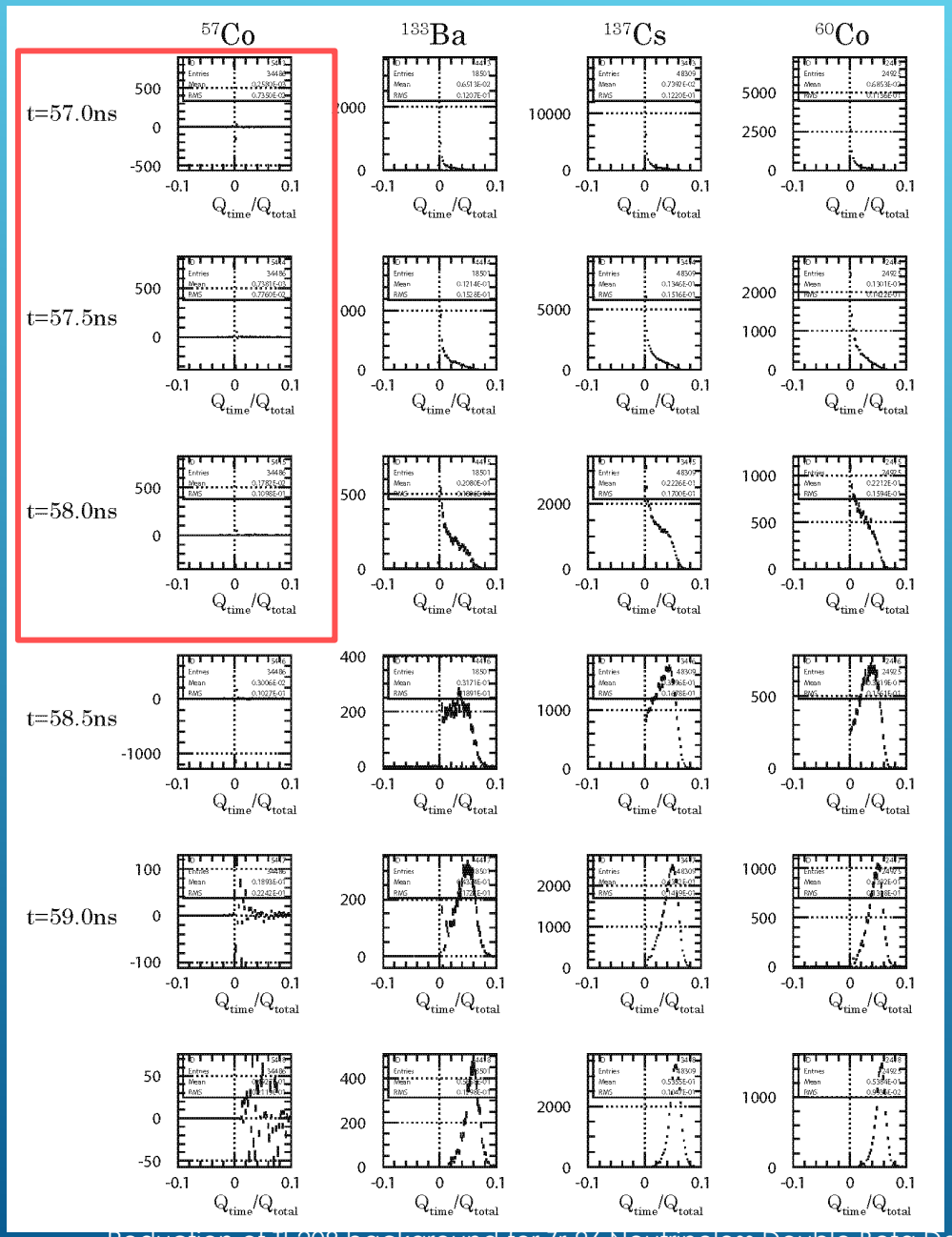
χ^2distribution using ^{57}Co template



- 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.

Charge ratio in rise time using ZICOS LS

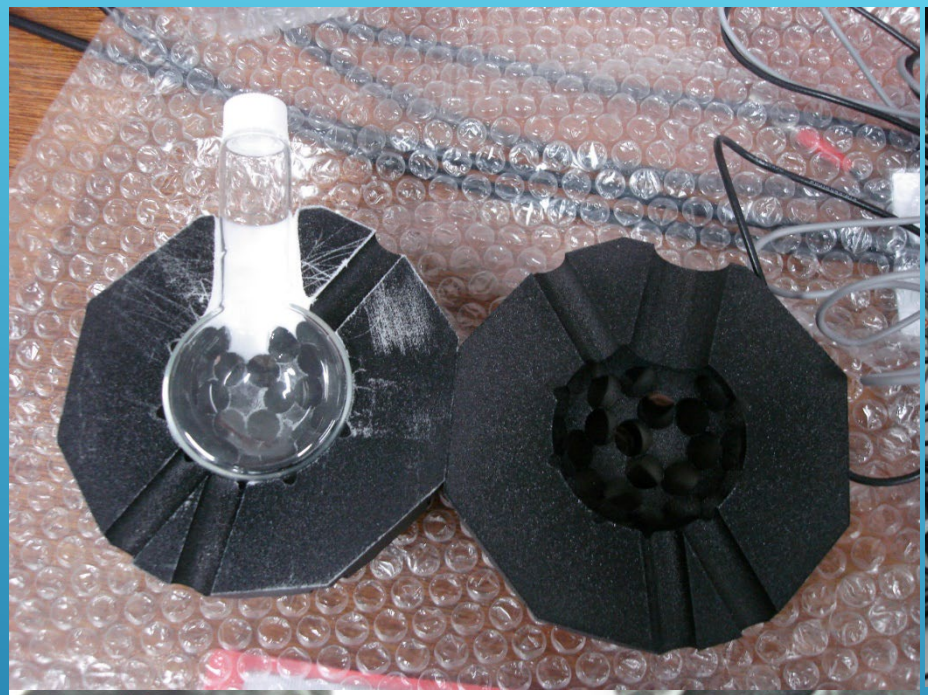


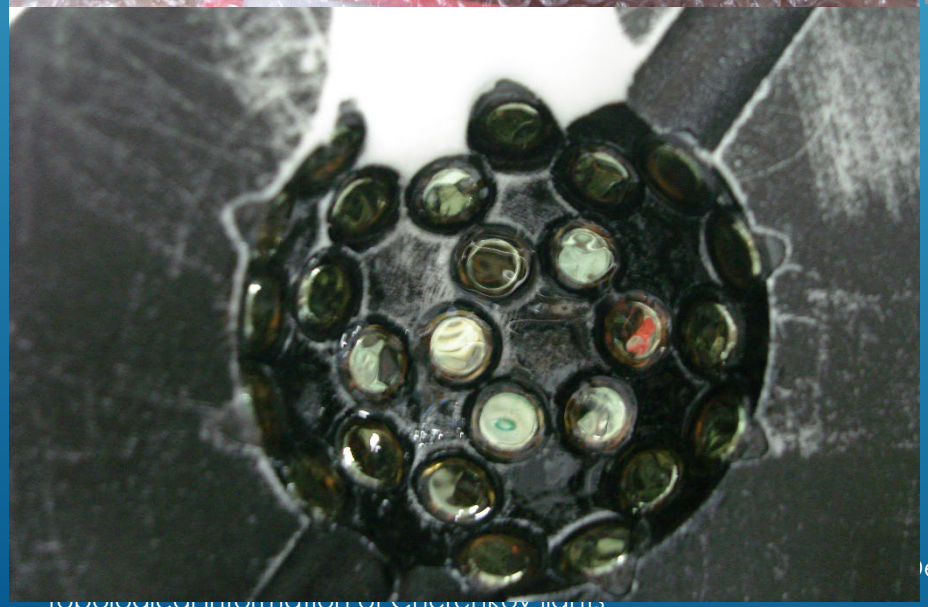
- There is difference in shape between t = 57 ns and 58 ns
- Charge ratio looks depend on the energy
- For t > 58.5 ns, all shapes were almost same.

Cherenkov looks dominant between 57 ns and 58 ns.

Template waveform of scintillation between 57 ns and 58 ns for ^{57}Co.

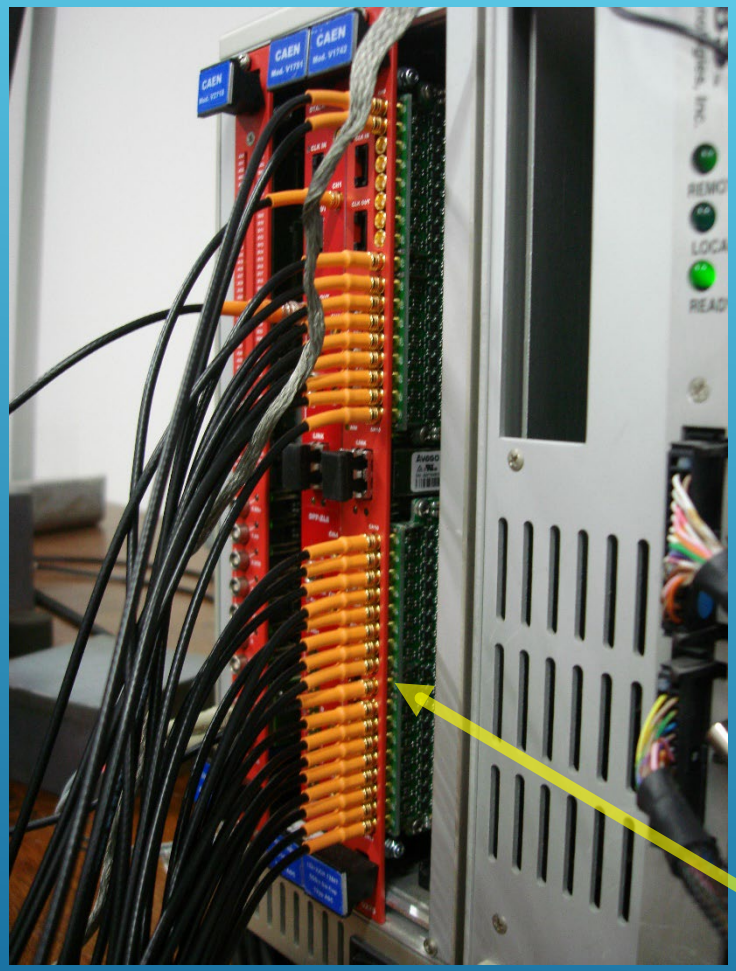
Mounting PMTs on jig for hemisphere flask

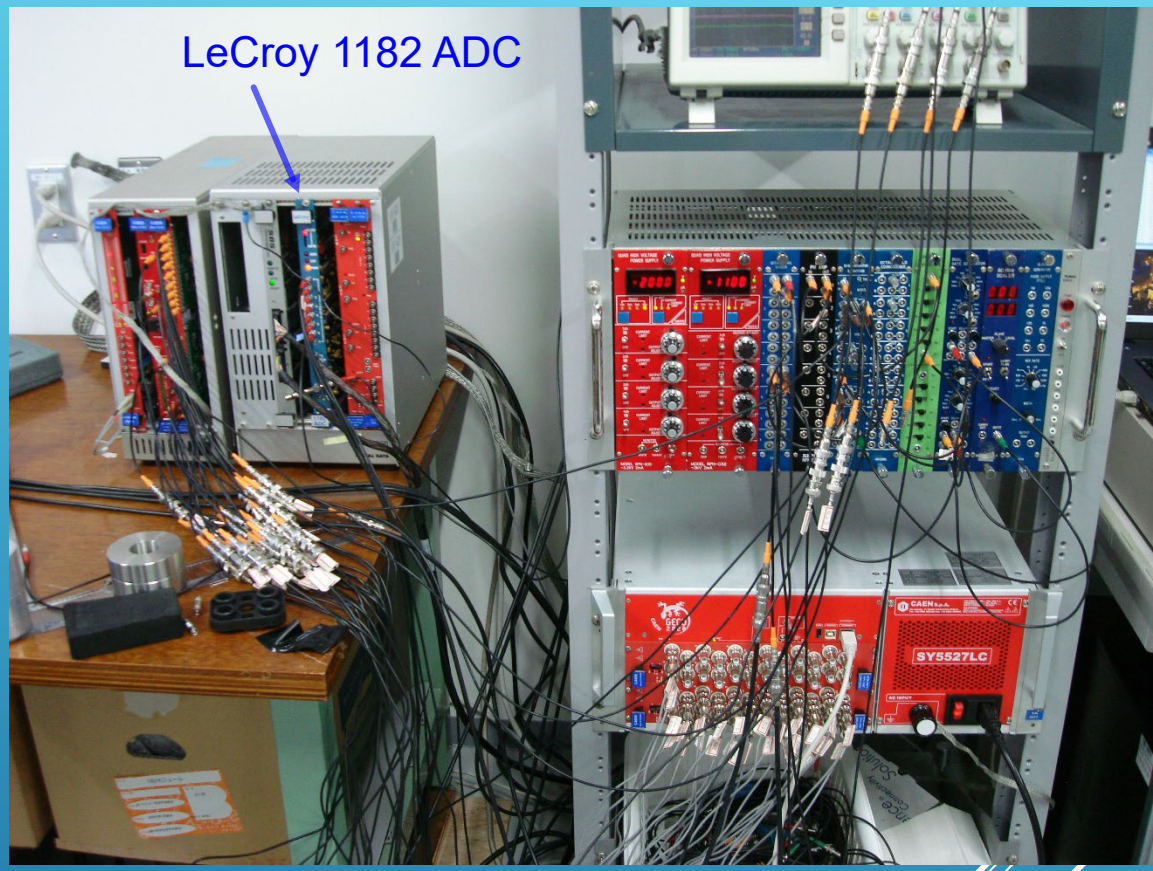




- Total 26 H3164-12 PMTs were used for HUNI-ZICOS.
- In order to remove scintillation light (~300nm), SC-37 filter was covered around the hemisphere flask in this time.

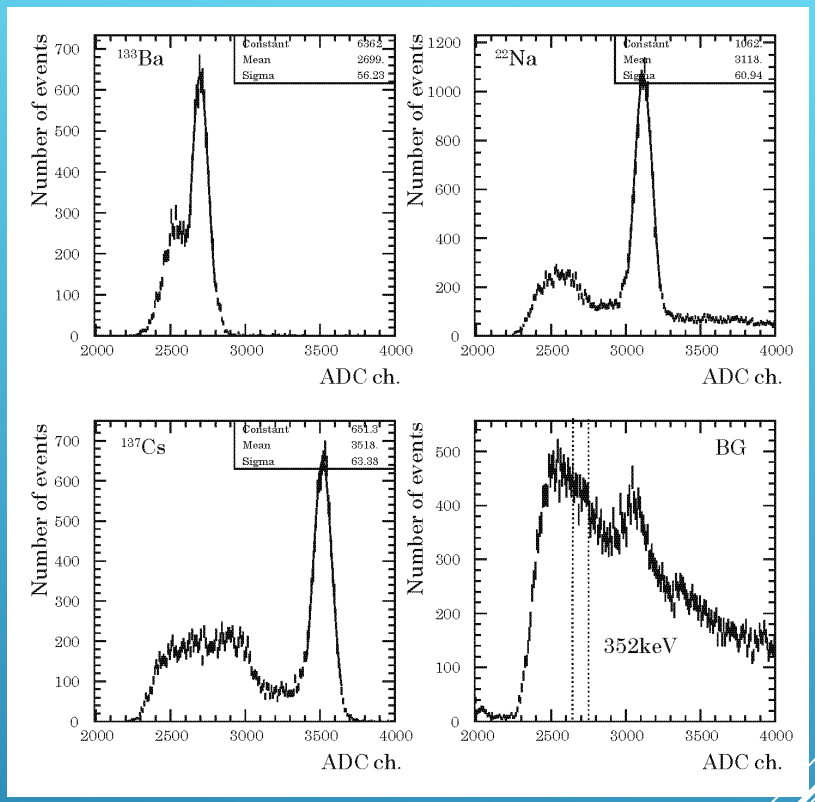
Cable connection to FADC and HV

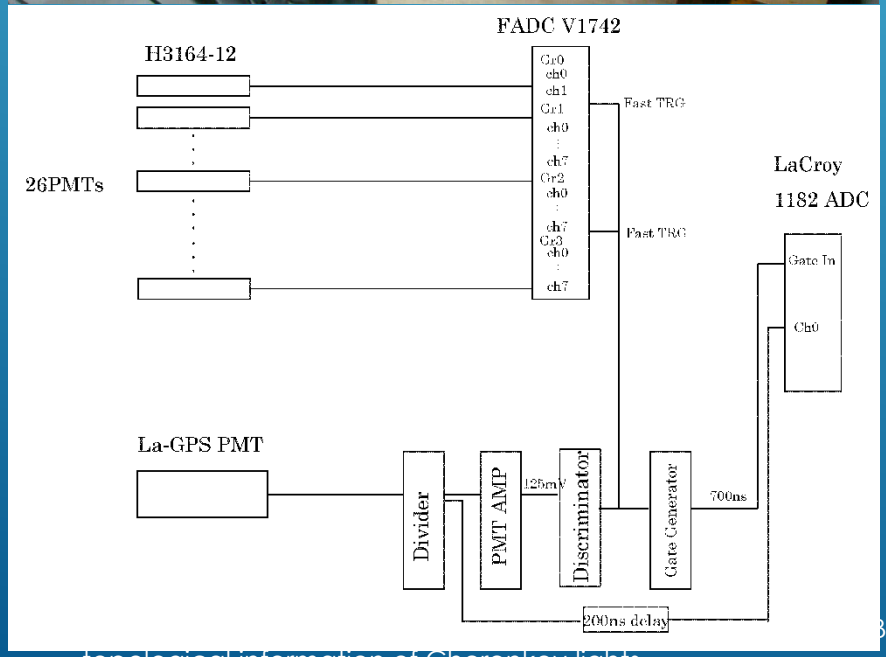




All channels are connected to FADC V1742 digitizer.

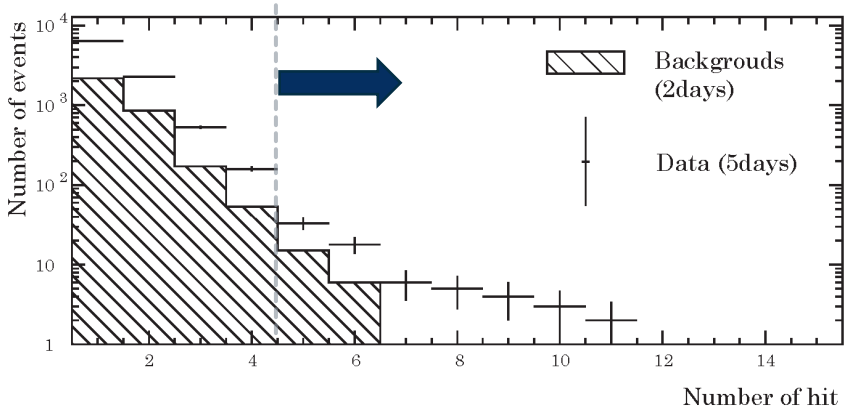
Measurement of averaged angle using ^{88}Y

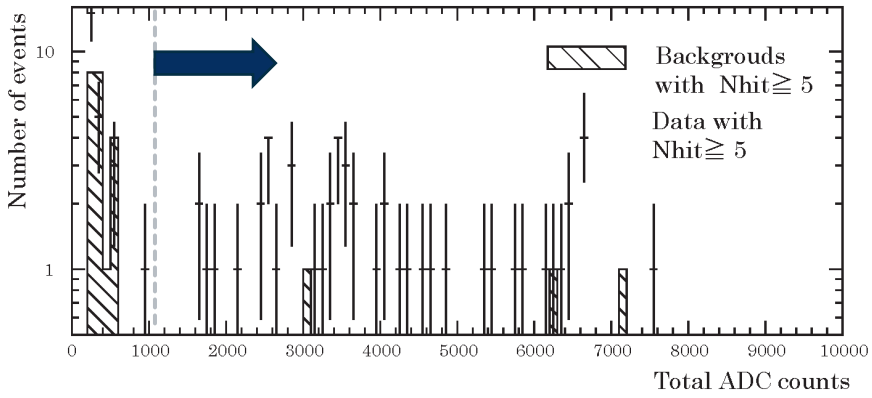


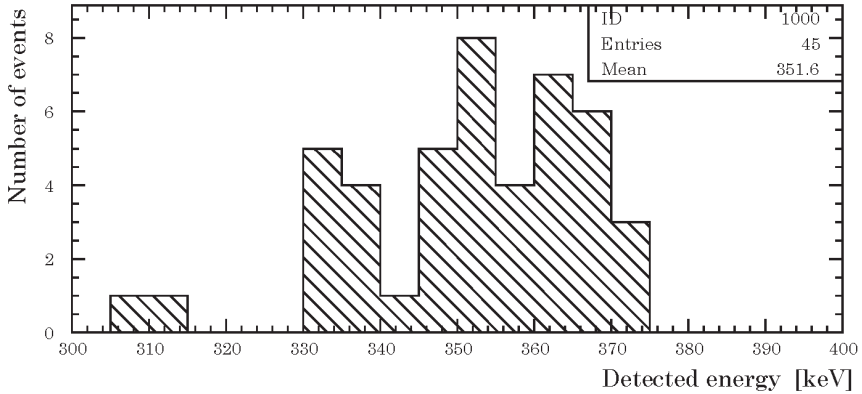


- Scattering gammas were detected by well calibrated La-GPS scintillator through the Pb collimation.

Event selection for scattered electron







Event selection criteria :

- Number of PMT hit for BG are clustered below 5 hit.
  1) Nhit ≧ 5
- Qtotal for BG are also clustered below 1000.
  2) Qtotal ≧1000
- Observed energy of scattering gamma is clustered around 352keV.
- Due to SC-37 (UV cut) filter, we observed almost only Cherenkov light in this time.