

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XIX ～ベータ線とガンマ線によるチエレンコフ光の位相 幾何学情報の測定～

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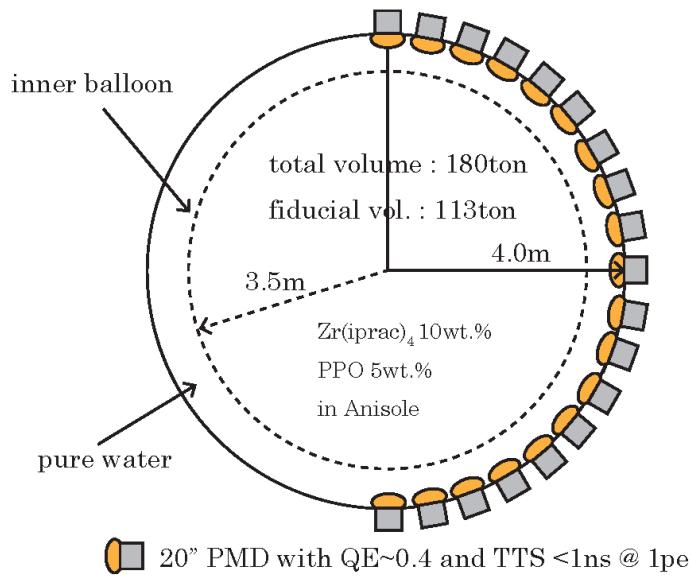
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Conceptual design of ZICOS detector

Phys.Rev.Lett. 117 (2016) 082503

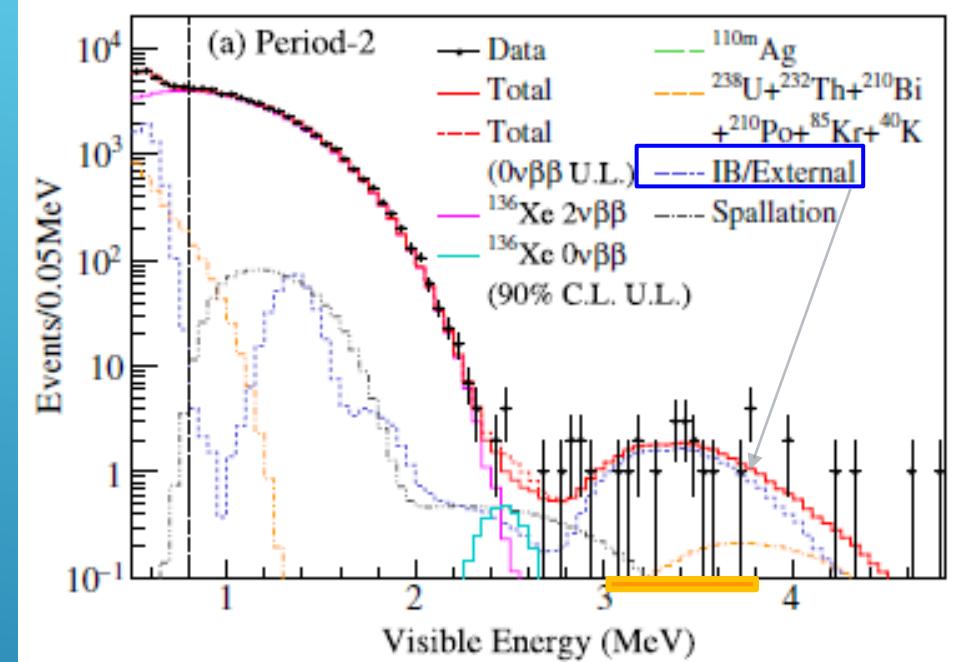
Conceptual design of ZICOS detector



20" PMD with QE~0.4 and TTS <1ns @ 1pe

Total PMT : 650 Photo coverage : 64%

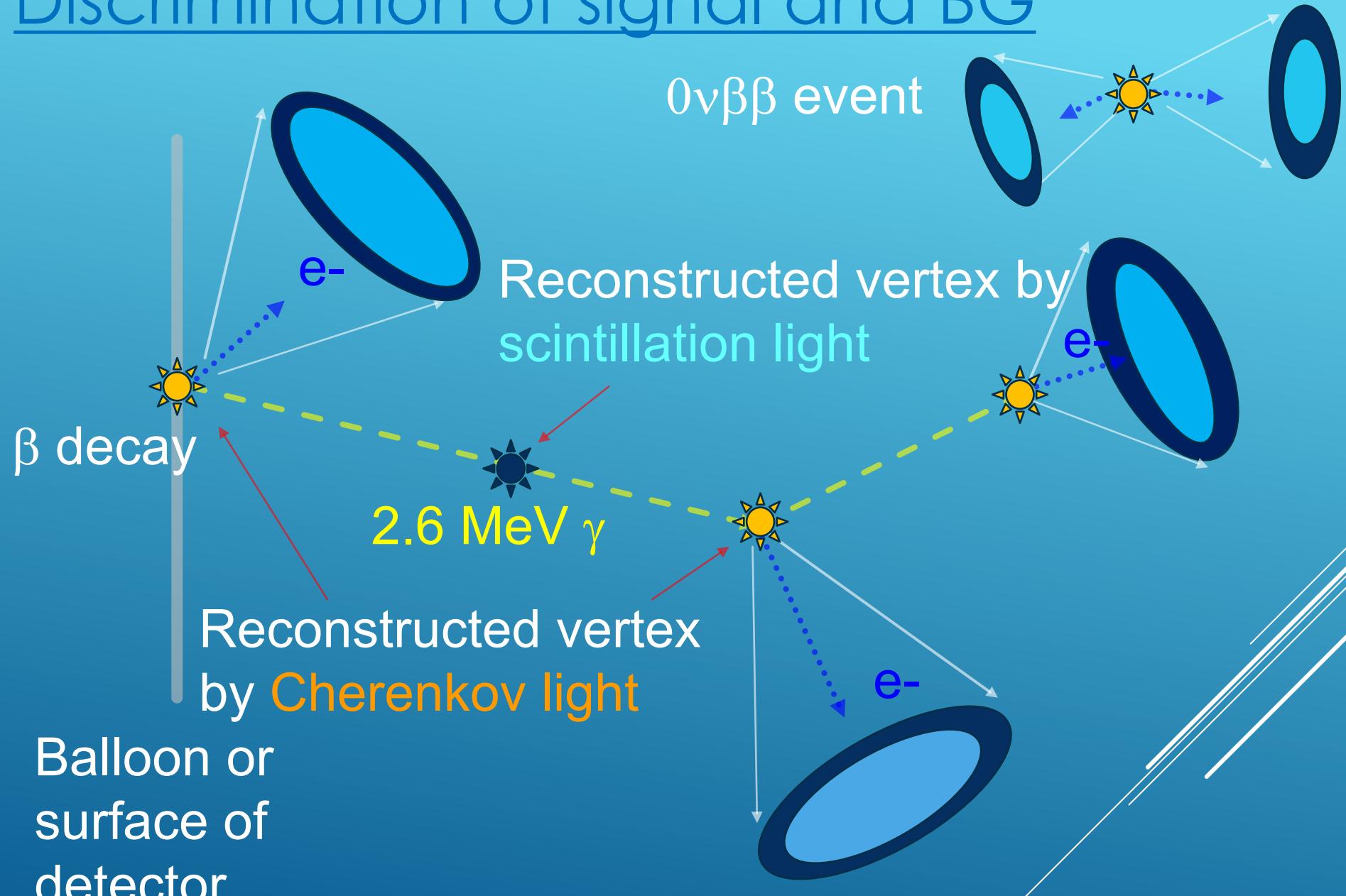
Scintillation (energy) + Cherenkov (BG reduction)



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

$^{96}\text{Zr} : 45\text{ kg (nat.)} \rightarrow 865\text{ kg(50 \% enrich)} \rightarrow 1/20\text{ BG}$
 $T_{1/2}^{0\nu} > 4 \times 10^{25}\text{ yrs} \rightarrow 2 \times 10^{26}\text{ yrs} \rightarrow \sim 1 \times 10^{27}\text{ yrs}$

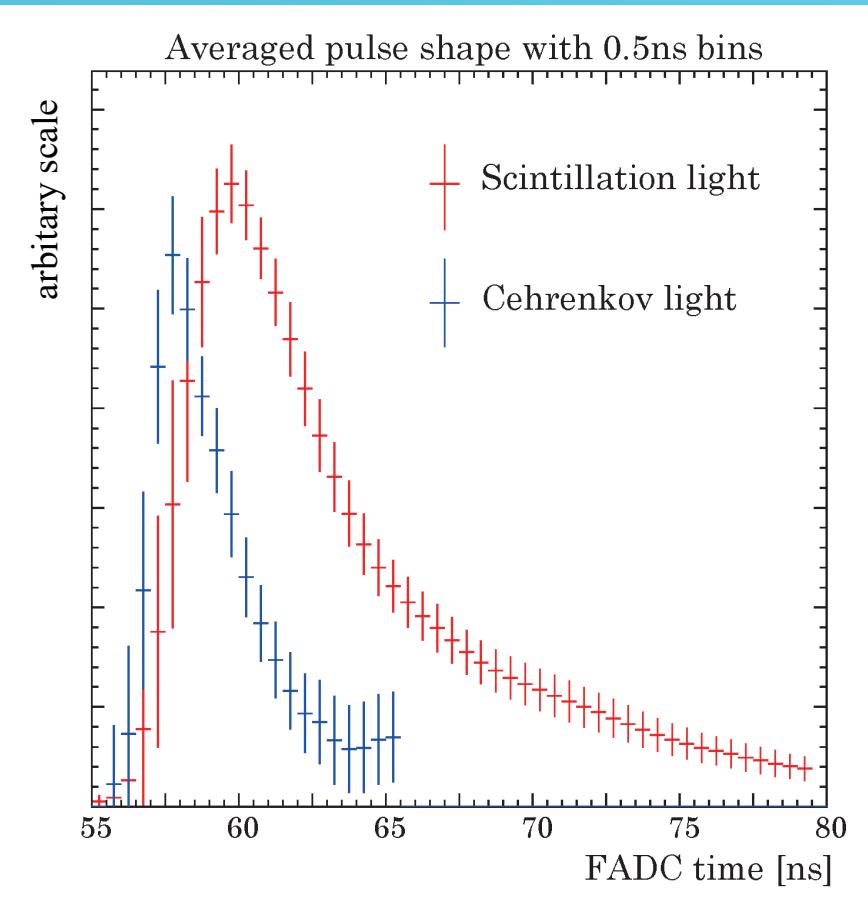
Discrimination of signal and BG



Verification of ^{208}TI 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.

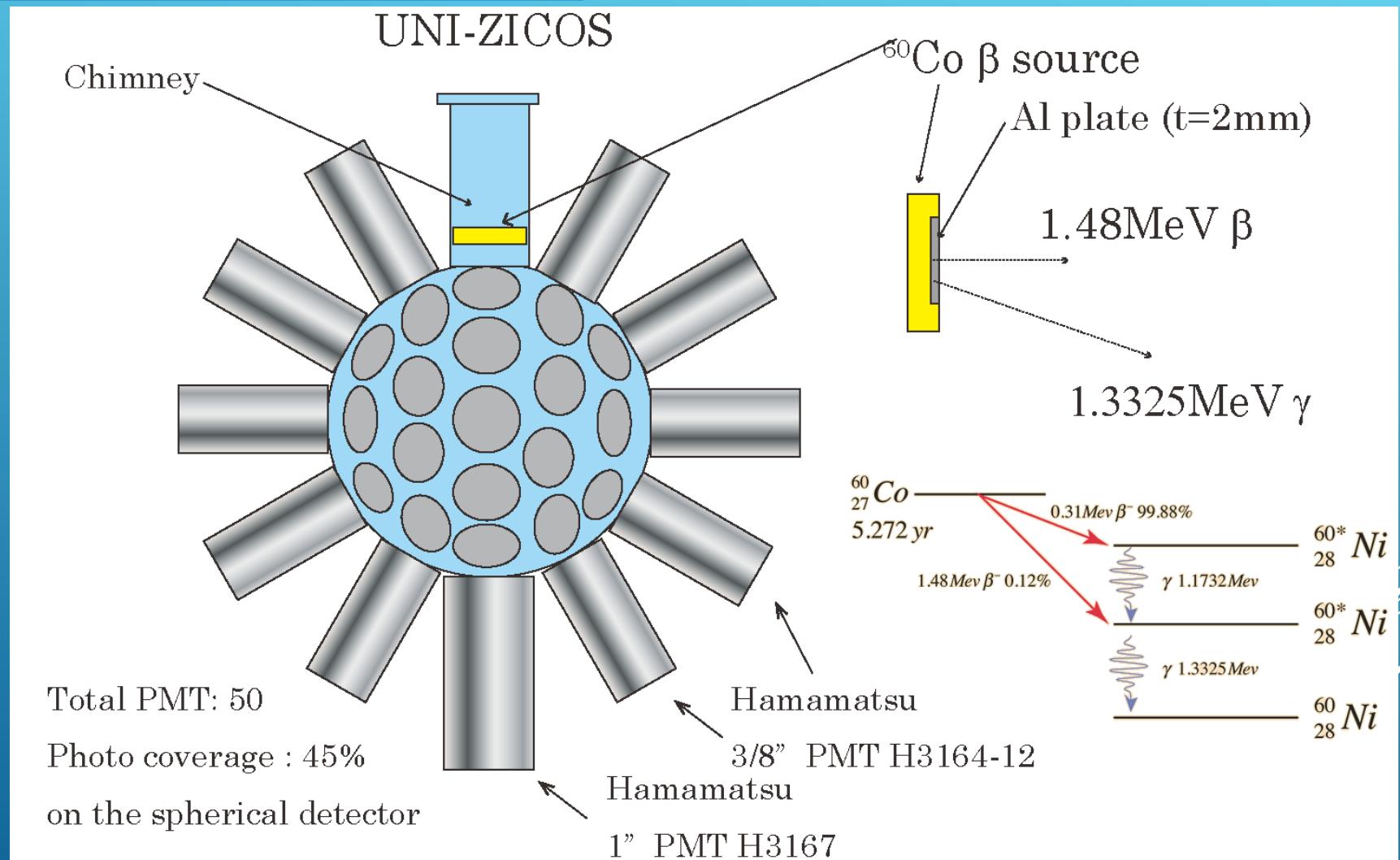
Pulse shape of Cherenkov and scintillation



- 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 $Q_{\text{time}}/Q_{\text{total}}$. Here, Q_{time} is FADC count in each time, and Q_{total} is sum count of FADC between 55 ns and 80 ns.

Demonstration of ^{208}TI BG reduction using UNI-ZICOS detector

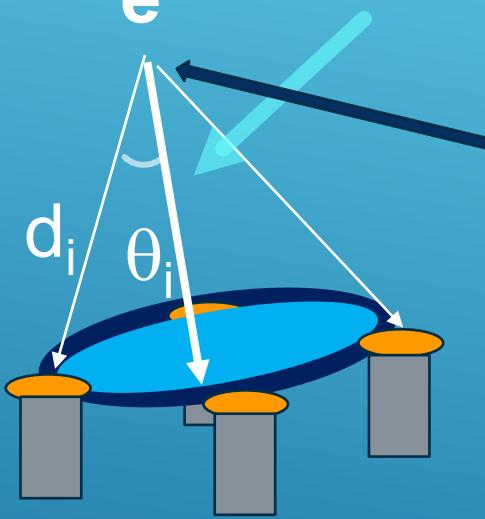


Due to the earthquake in March, we lost 5 PMTs.

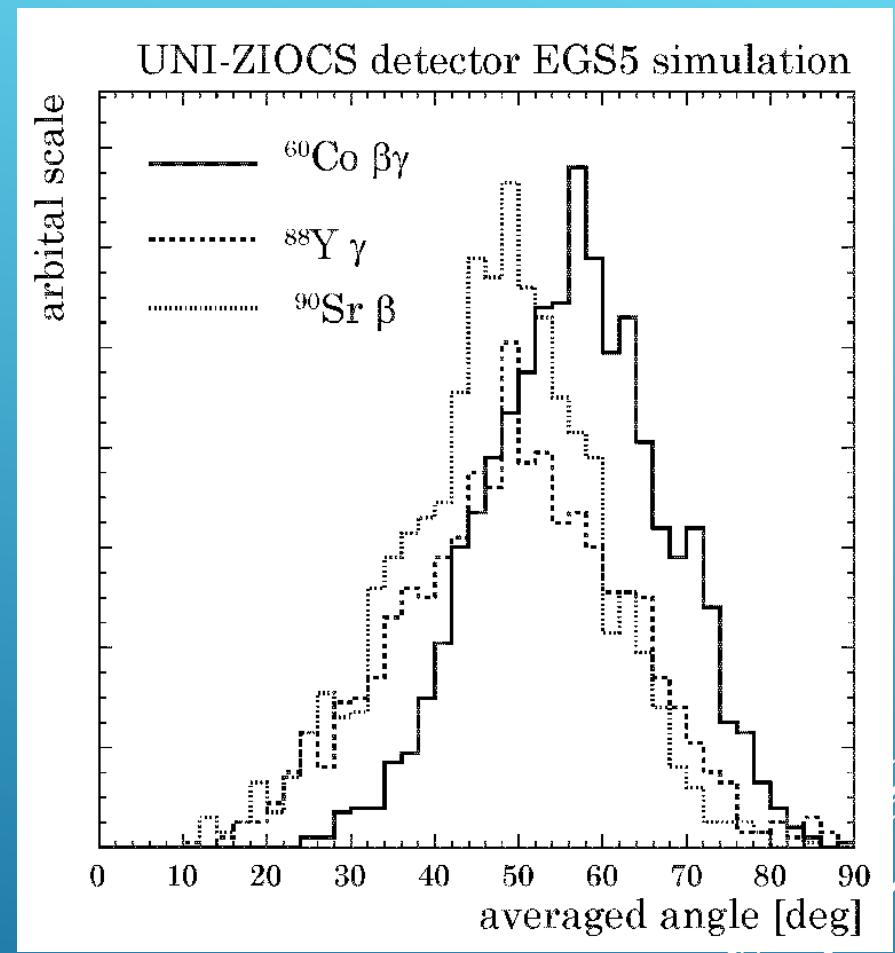
Topological information of Cherenkov lights

Average direction =

$$\mathbf{e} \cdot \sum \mathbf{d}_i \quad (\mathbf{d}_i : \text{unit vector})$$

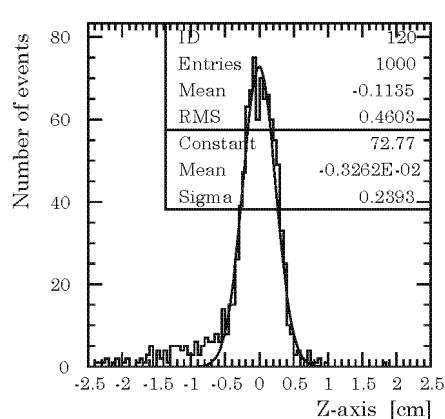
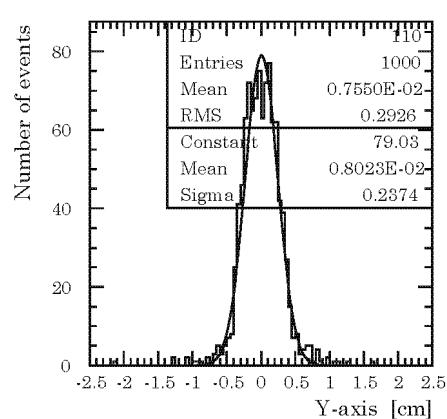
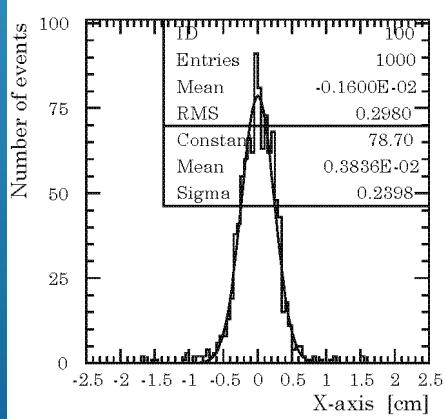
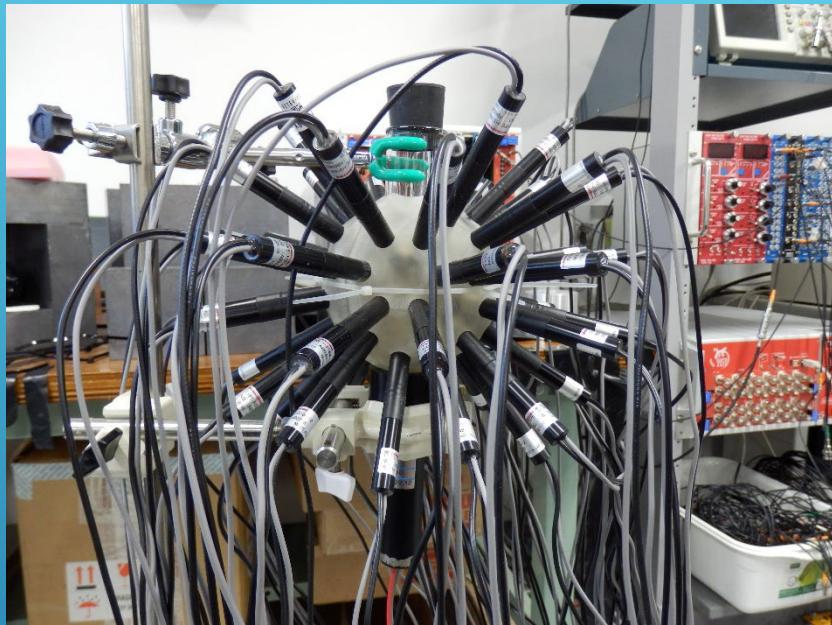


$$\text{Averaged angle} = \frac{\sum \theta_i}{N_{\text{hit}}}$$



Topological information (averaged angle) of Cherenkov lights should be different between β and $\beta + \gamma$ event.

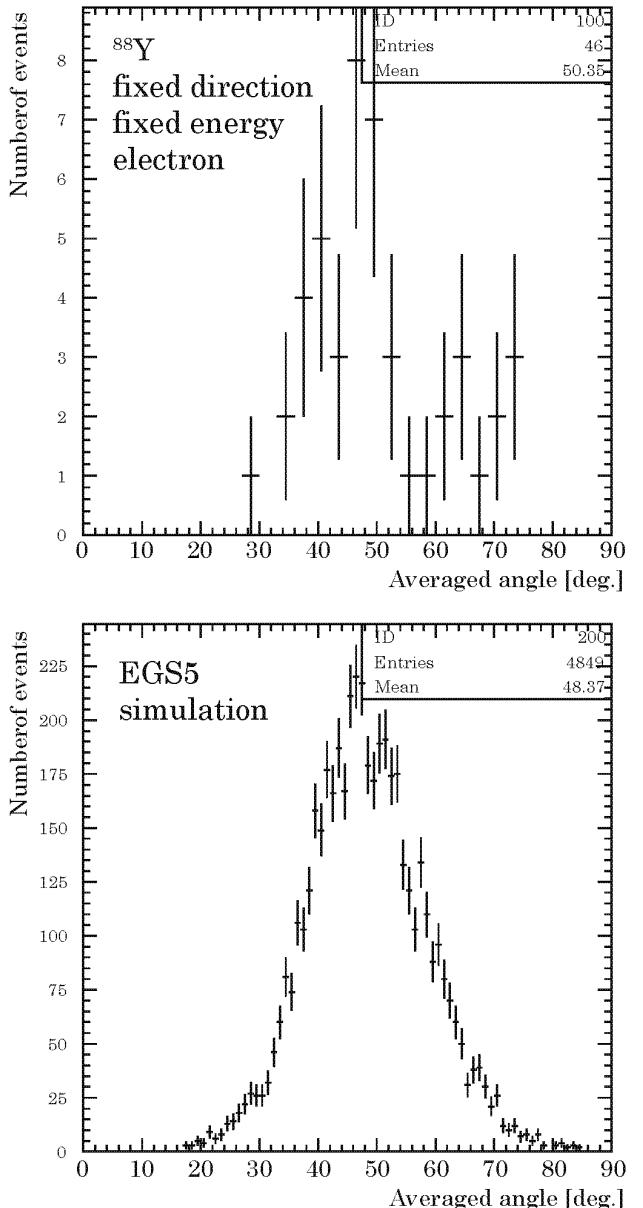
Setup for measurement with UNI-ZICOS



Source holder has a hole, and it can be covered by Al plate (0.3mm and 2mm) to terminate betas.

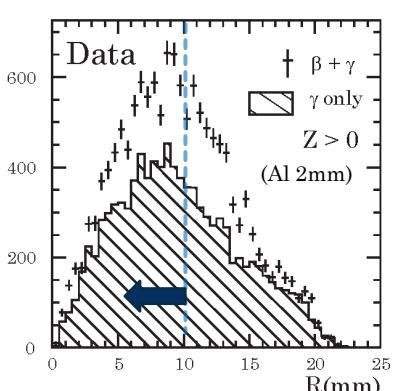
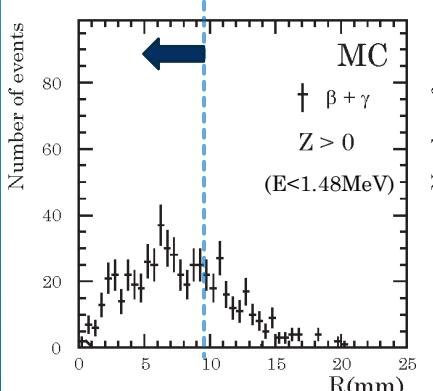
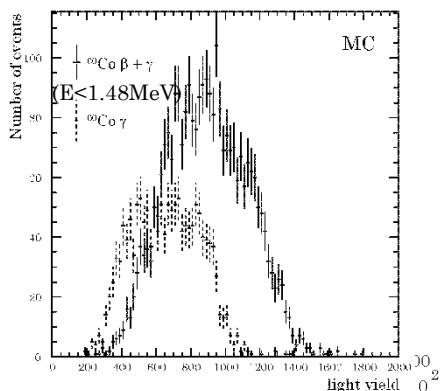
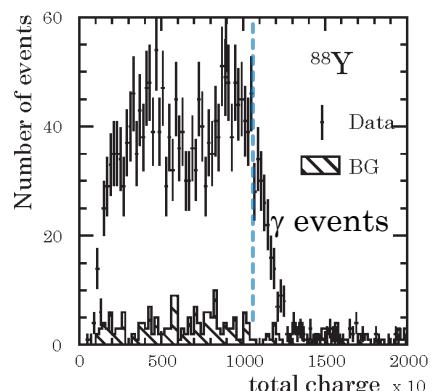
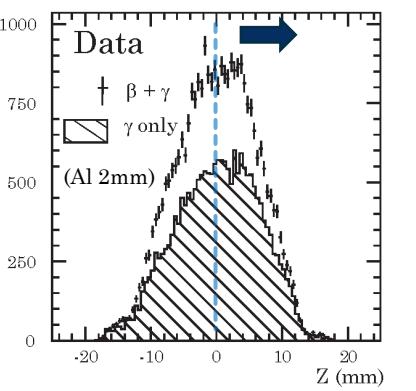
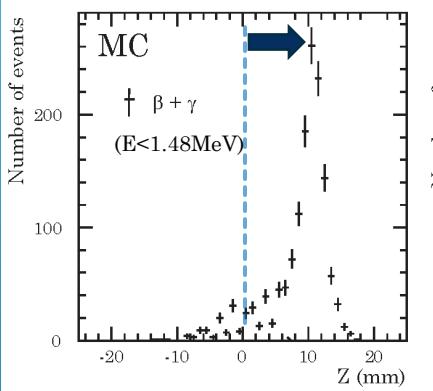
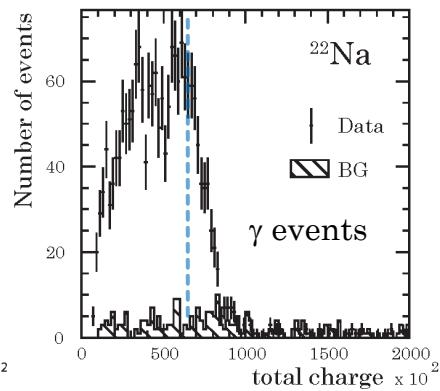
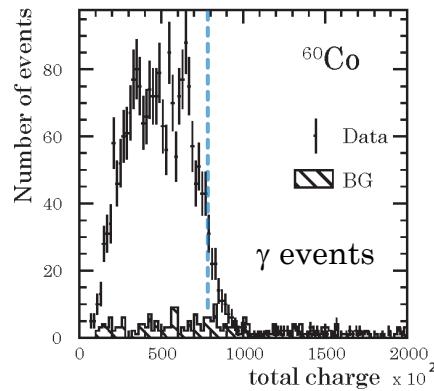
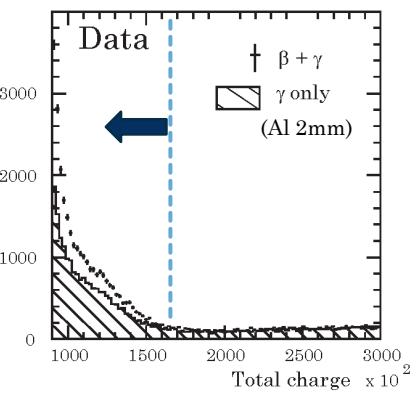
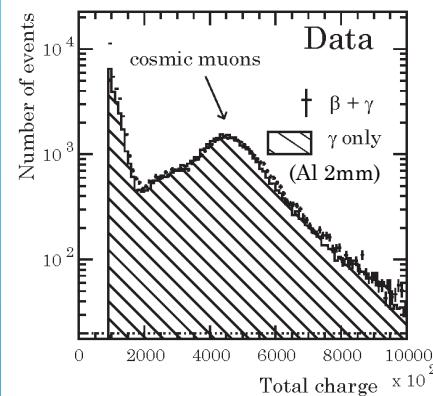
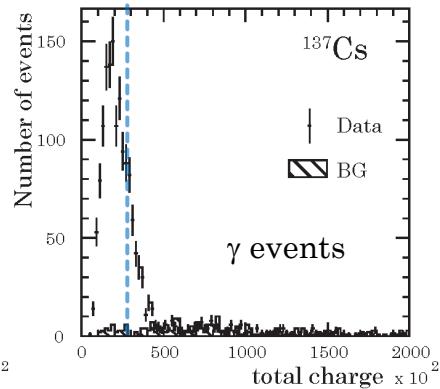
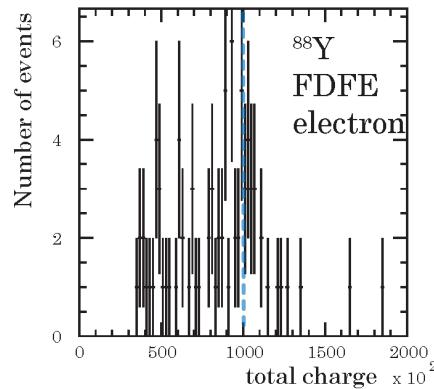
The vertex position could be reconstructed by assuming that all PMTs should have same effective charge which is corrected by the distance between PMT and vertex.

Observed averaged angle using FDFE events

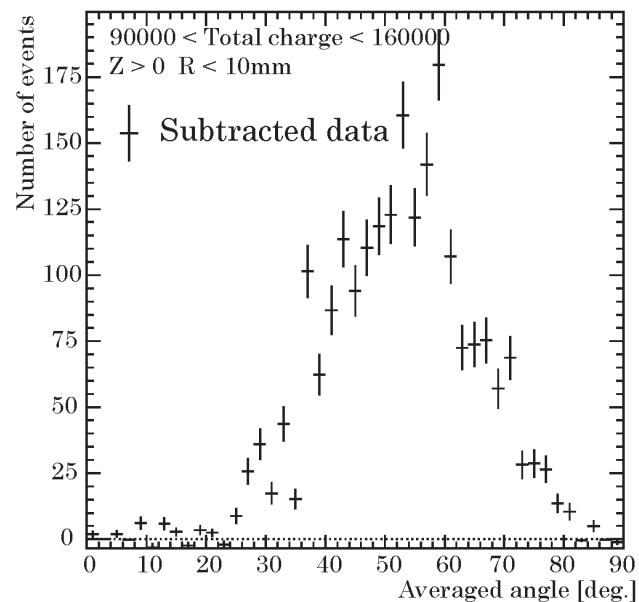
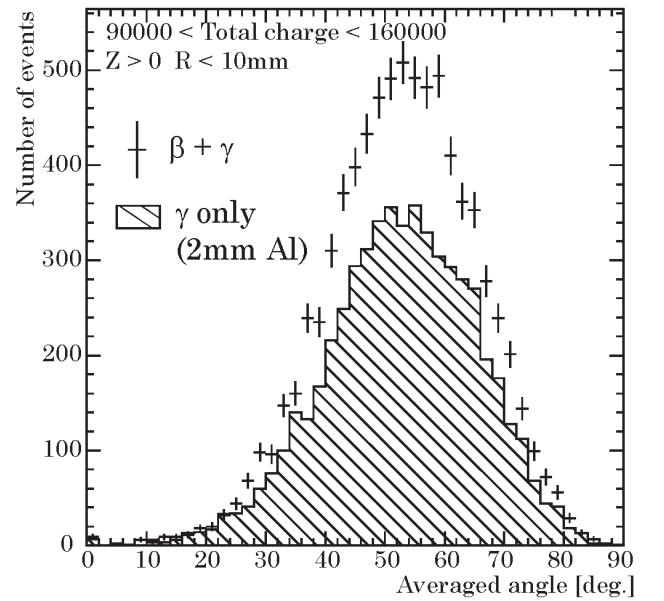


- The vertex position was reconstructed by charge information as explained.
- Extracted PMTs which include Cherenkov light by PSD technique.
- Using those PMTs and the vertex, the averaged angle of fixed direction fixed energy (1.484MeV) electron from ^{88}Y source was measured, and a peak was found 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 $\beta+\gamma$ rich samples

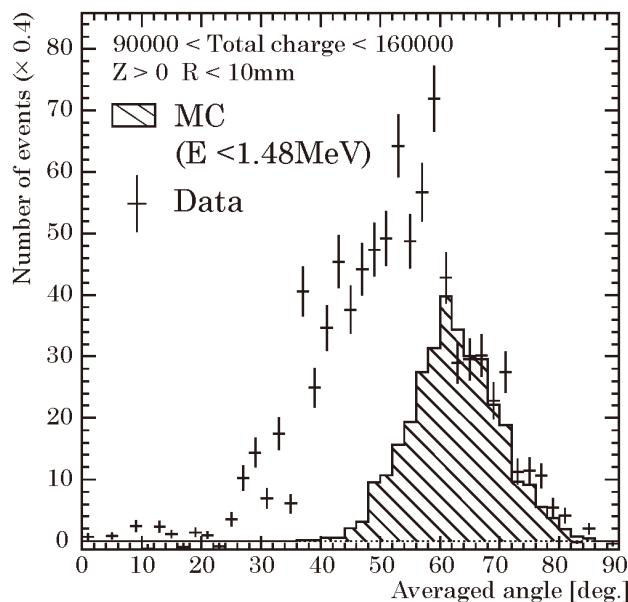
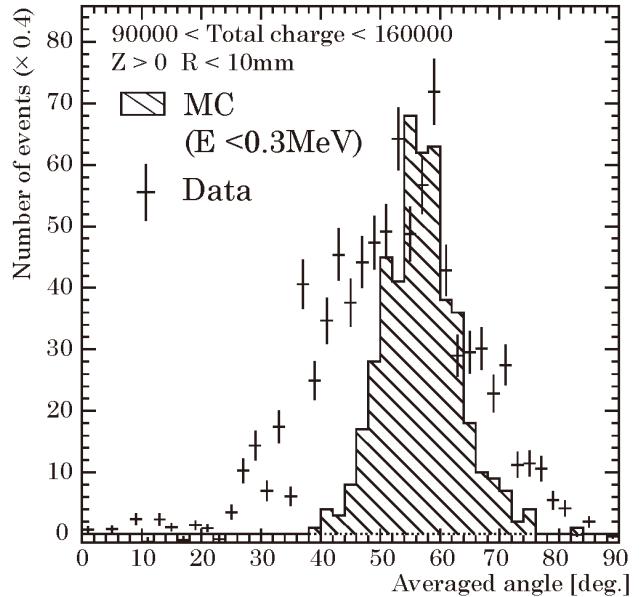


Observed averaged angle using β - γ events



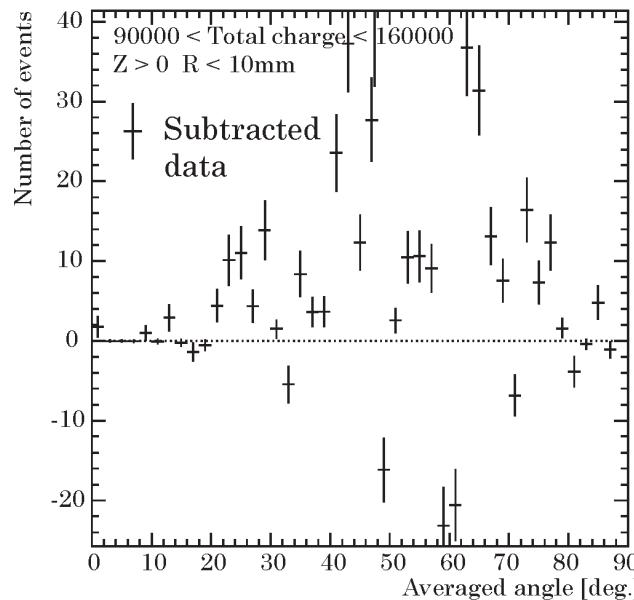
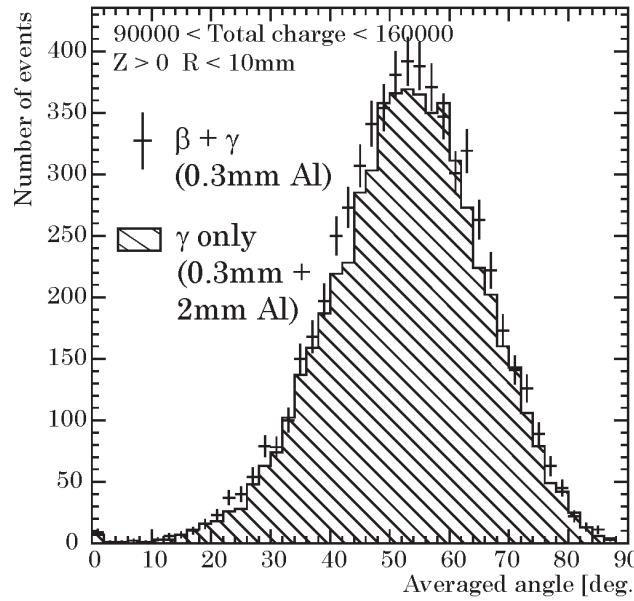
- Clear averaged angle of $\beta + \gamma$ events is obtained by subtraction of those data.
- Obtained averaged angle has a peak around 58 deg.
- Averaged angles of MC($\beta(E < 0.3\text{MeV}) + \gamma$) reproduce peak, but not reproduce shape.
- Averaged angle of MC($\beta(E < 1.48\text{MeV}) + \gamma$) may help to reproduce larger angle shape.

Observed averaged angle using β - γ events



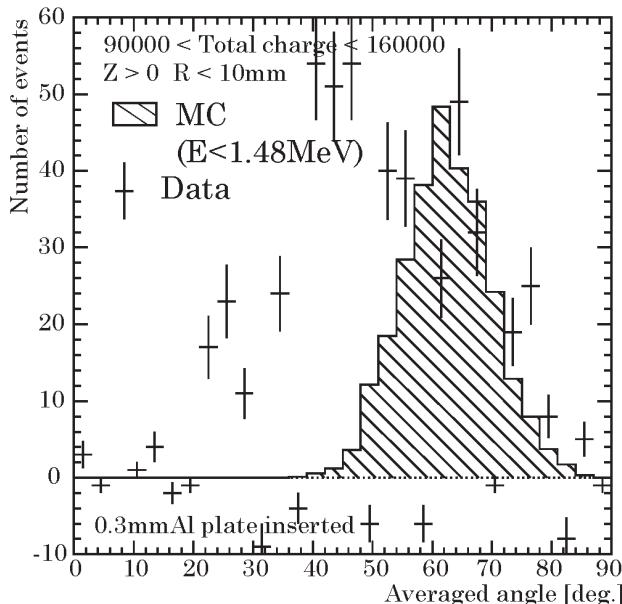
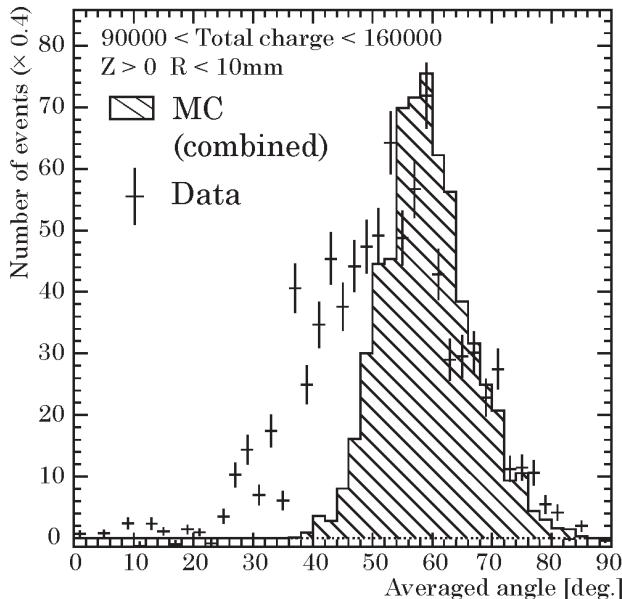
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Observed averaged angle using β - γ events



- 0.3mm Al plate terminates β ($E < 0.3\text{MeV}$) events.
- Small difference between 2mm Al on and off
- Obtained averaged angle has small peak around 60 deg.
- A peak of averaged angle in previous page is caused by mainly β ($E < 0.3\text{MeV}$).
- MC($\beta(E < 1.48\text{MeV}) + \gamma$) looks reproduce small peak without lower angle shape too.

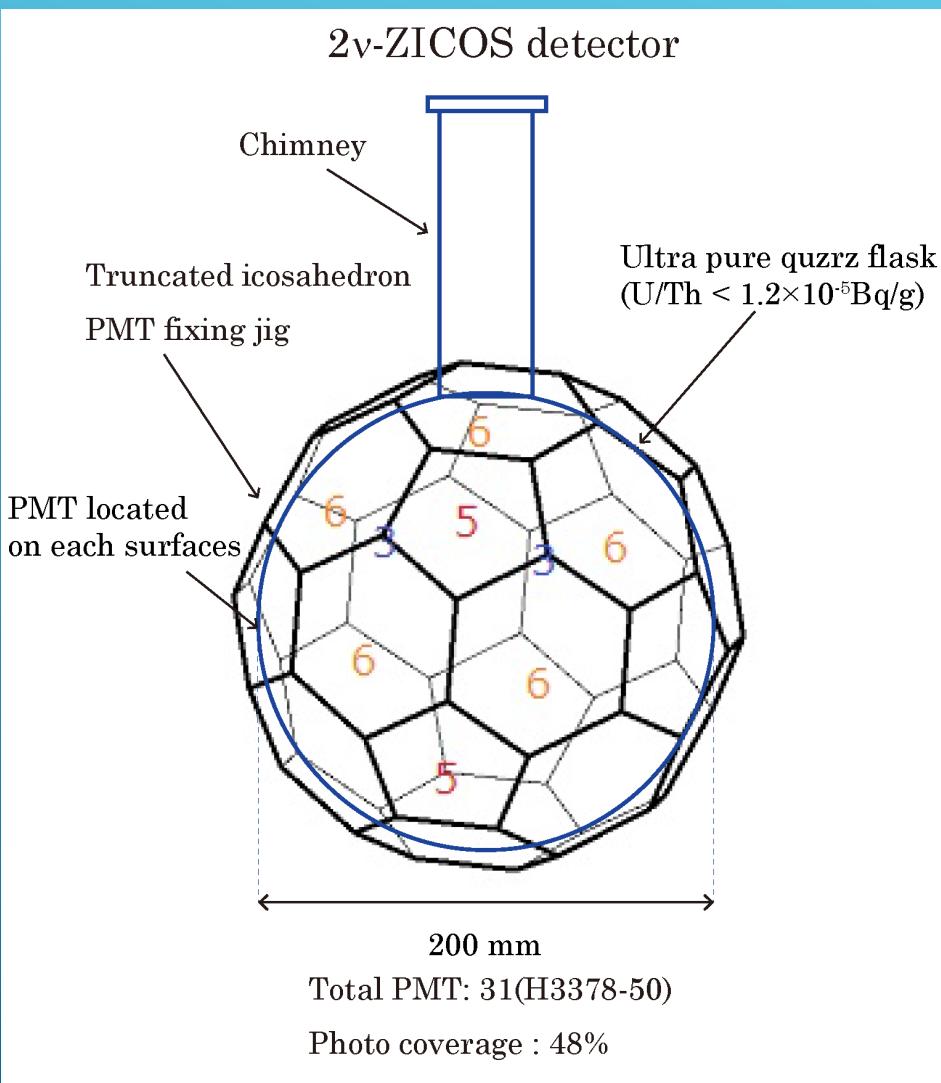
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Averaged angle could be used for reduction of $\beta + \gamma$ events such as ^{208}TI decay background.

Observation of $2\nu\beta\beta$ signal using 2v-ZICOS



- 20 cm diameter flask using Ultra-pure quartz and 31 low BG 2" PMT Hamamatsu R3378-50 (R2083)
- Filled 3L of ZICOS-LS
- Loaded 300g Zr(iPrac)₄ which contains 1.1 g ⁹⁶Zr
- 200 $2\nu\beta\beta$ events per year is expected
- Location: Kamioka mine
- Start time: FY2024

Observation of $2\nu\beta\beta$ signal using 2v-ZICOS

ask
quartz
' PMT
78-50

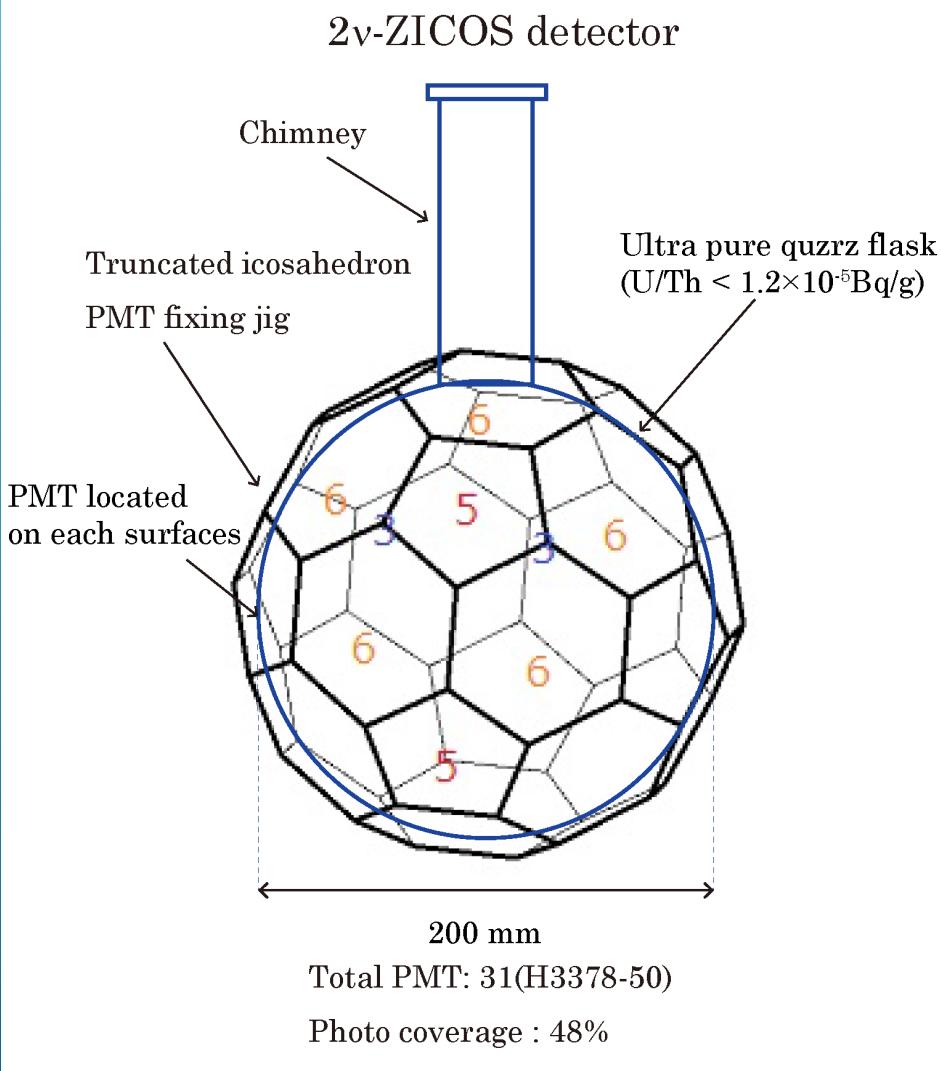
S-LS
Prac)₄

1 g

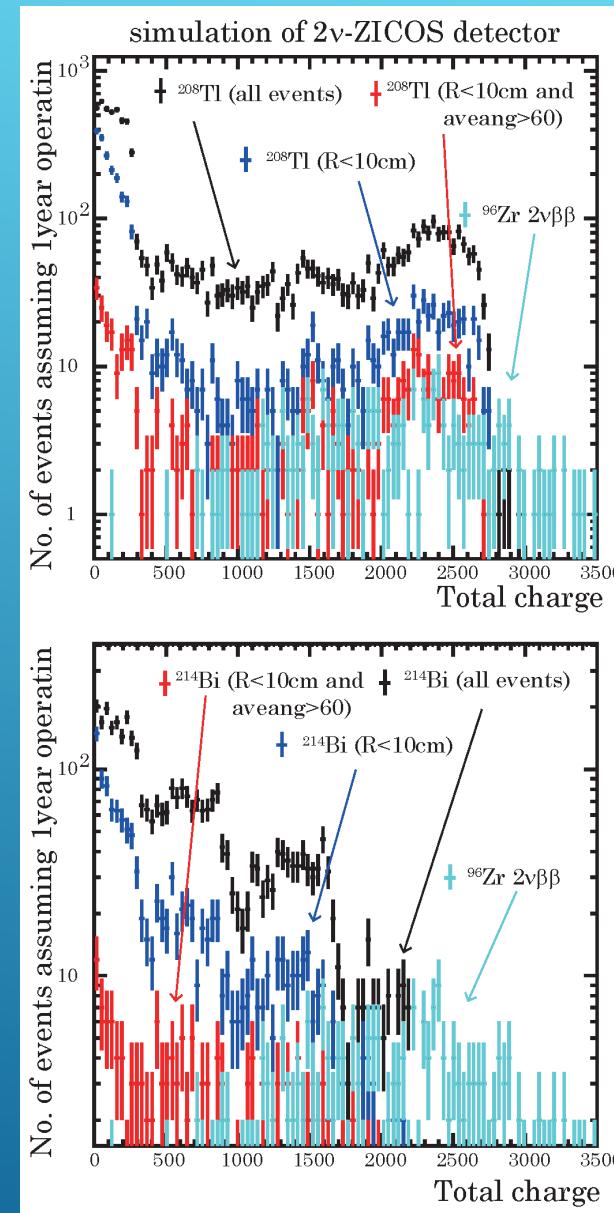
per

a mine

4



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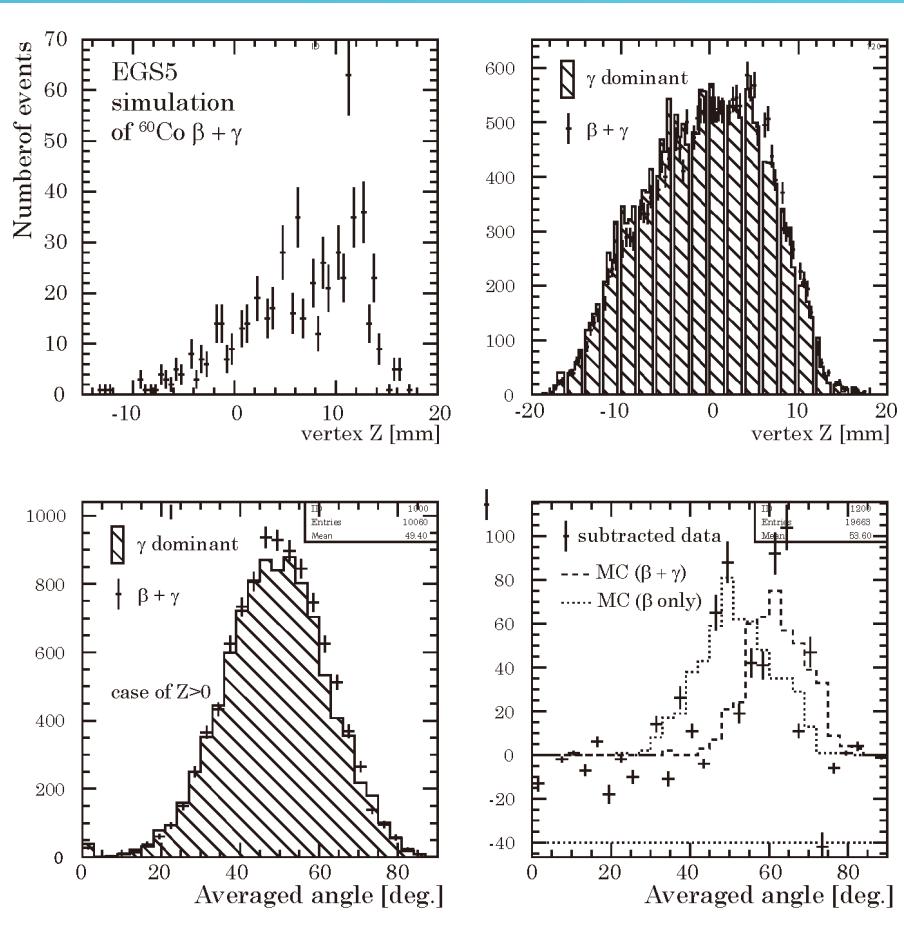


Summary

- 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 β ($E < 0.3\text{MeV}$) + γ events from ^{60}Co source was measured by UNI-ZICOS, and the averaged angle has a peak around **58 degree** as expected by MC simulation.
- We succeeded to demonstrate $\beta + \gamma$ event reduction such as ^{208}TI BG using the averaged angle!
- Next program to observe $2\nu\beta\beta$ decay of ^{96}Zr will start in FY2024 after the screening of low BG materials, the synthesis of $\text{Zr}(\text{iPrac})_4$, and the construction of low BG environment using Pb shield. Stay tuned!

backup

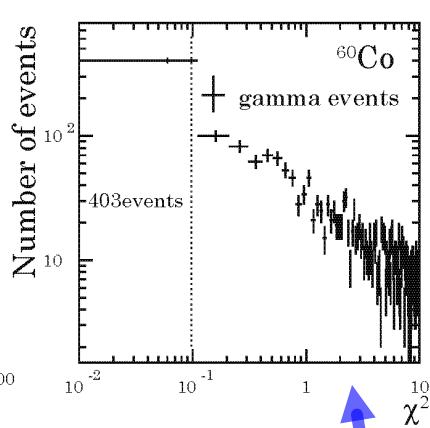
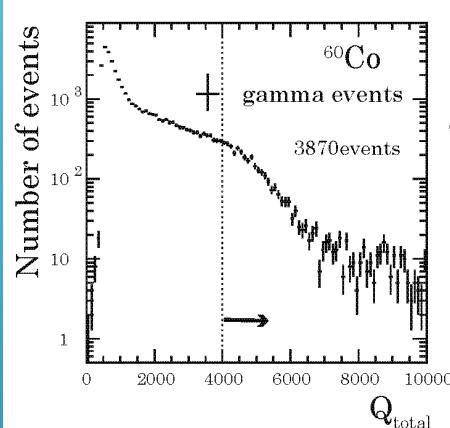
Observed averaged angle using β - γ events



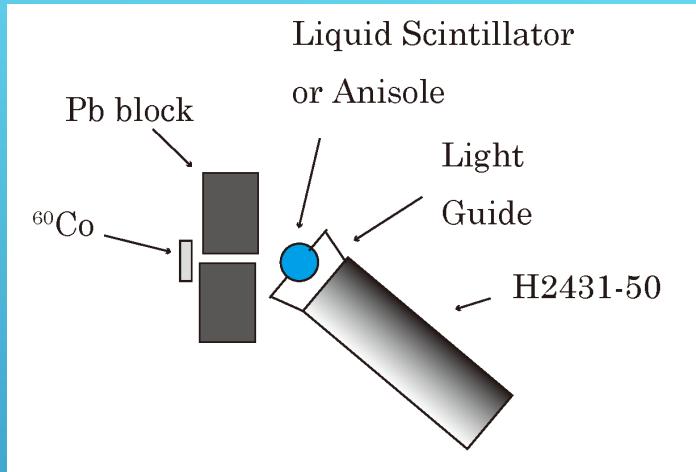
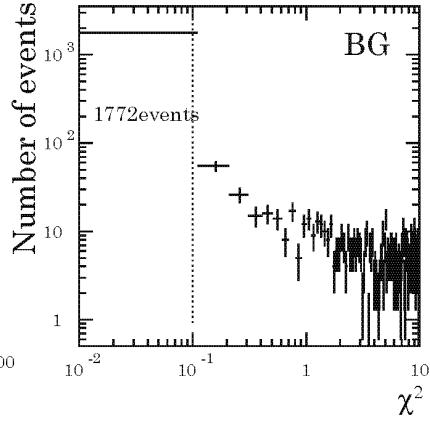
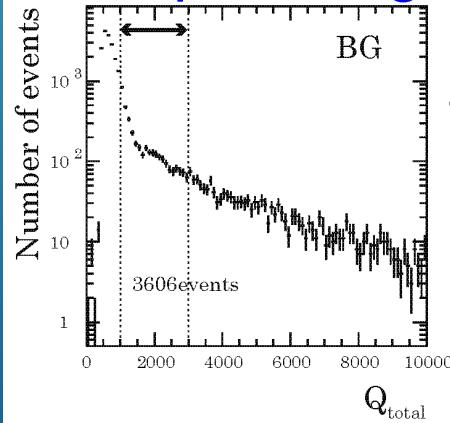
- Averaged angle is obtained by $z>0$ and by subtracting $\gamma+\beta$ and γ dominant data.
- Obtained averaged angle has two peaks around 50 and 60 deg.
- Events consists not only $\gamma+\beta$ events but β and γ only events.
- Averaged angles of MC for $\gamma+\beta$ and β and γ only events may reproduce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

It would be possible to reduce $\beta+\gamma$ events such as ^{208}Tl backgrounds using the averaged angle!

Measured by Compton edge event and BG sample



$\chi^2 < 0.1$ (scintillation like)
 $403/3970 = 10.4 \pm 0.5\%$ for
Compton edge event

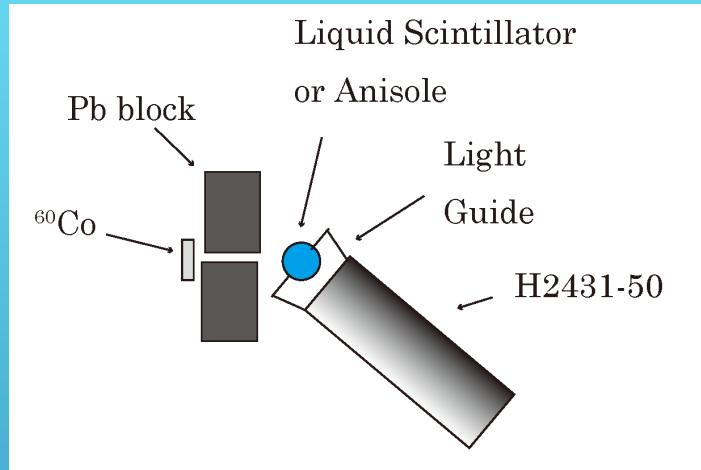
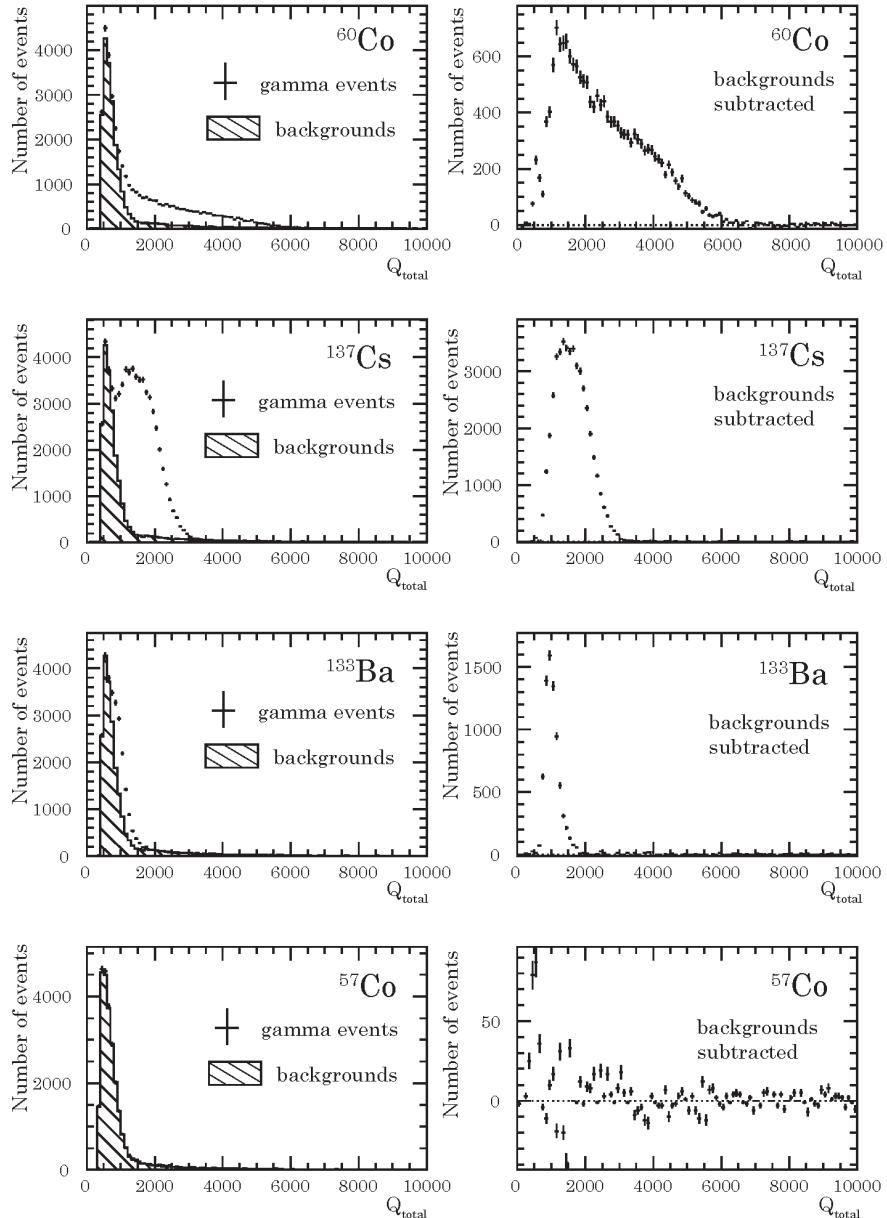


$1772/3606 = 49.1 \pm 1.4\%$
for BG sample

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

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

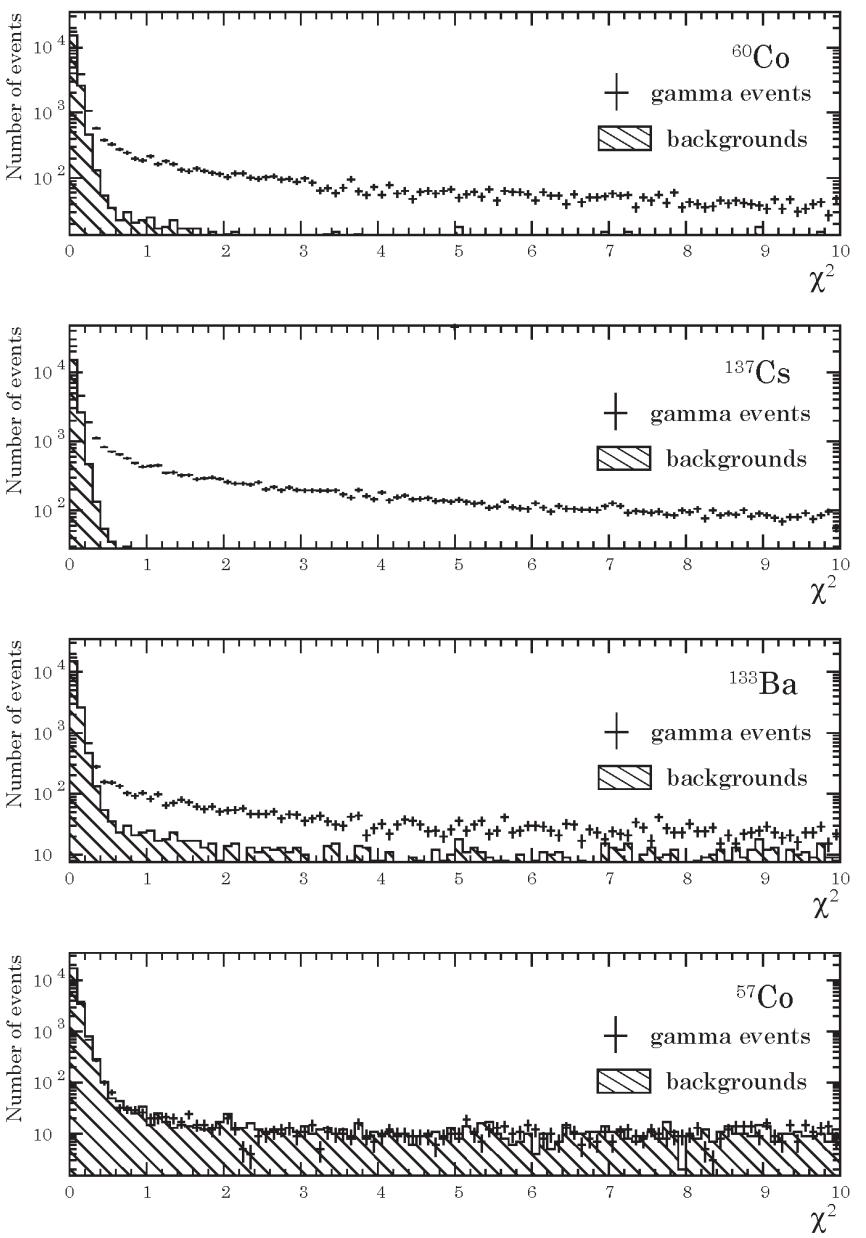
Q_{total} distribution for γ sources



- ^{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^2 distribution using ^{57}Co template

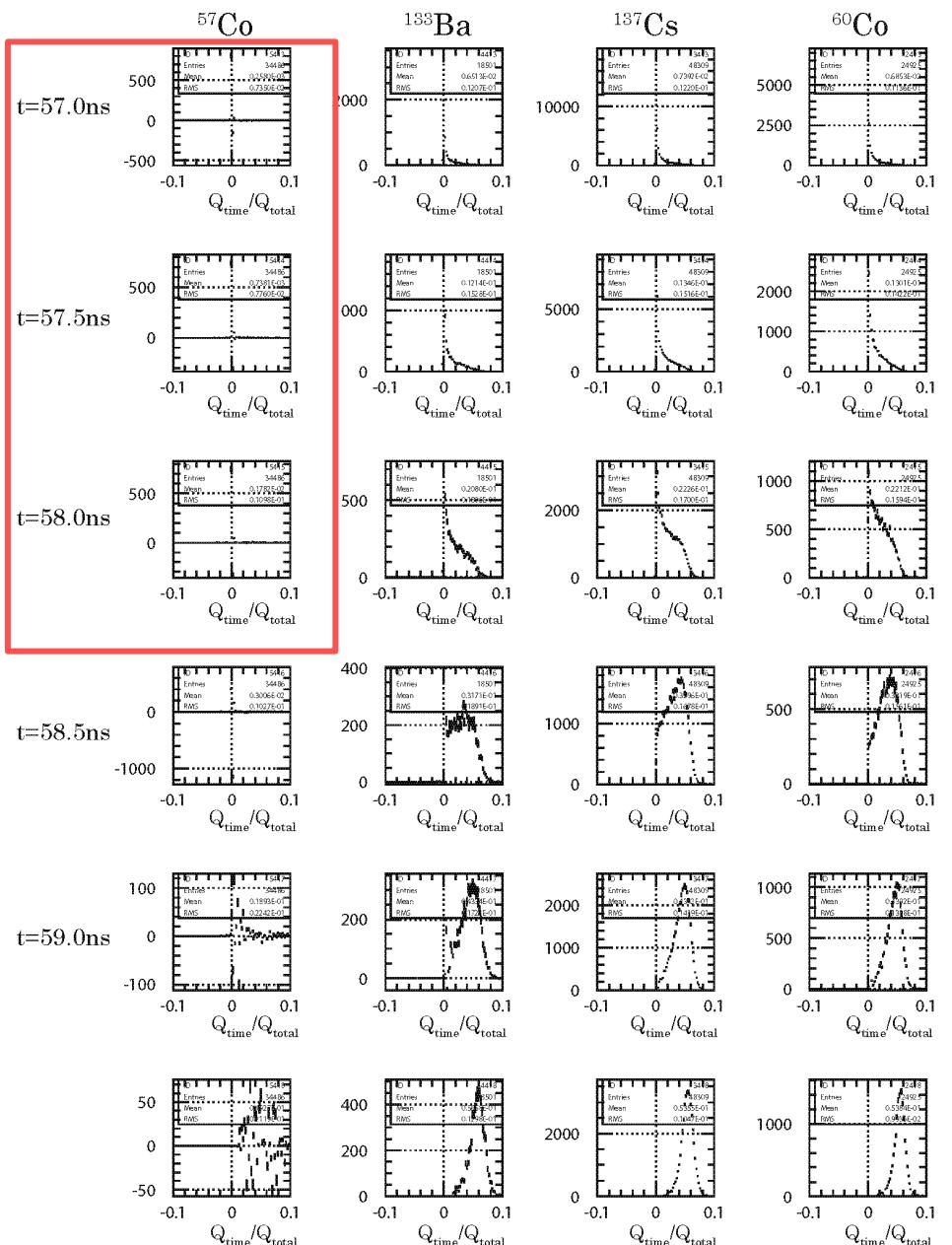


- Most of backgrounds have lower χ^2 than 1.0
- Most of backgrounds have lower energy than Cherenkov threshold, then only scintillation was seen.



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

Charge ratio in rise time using ZICOS LS



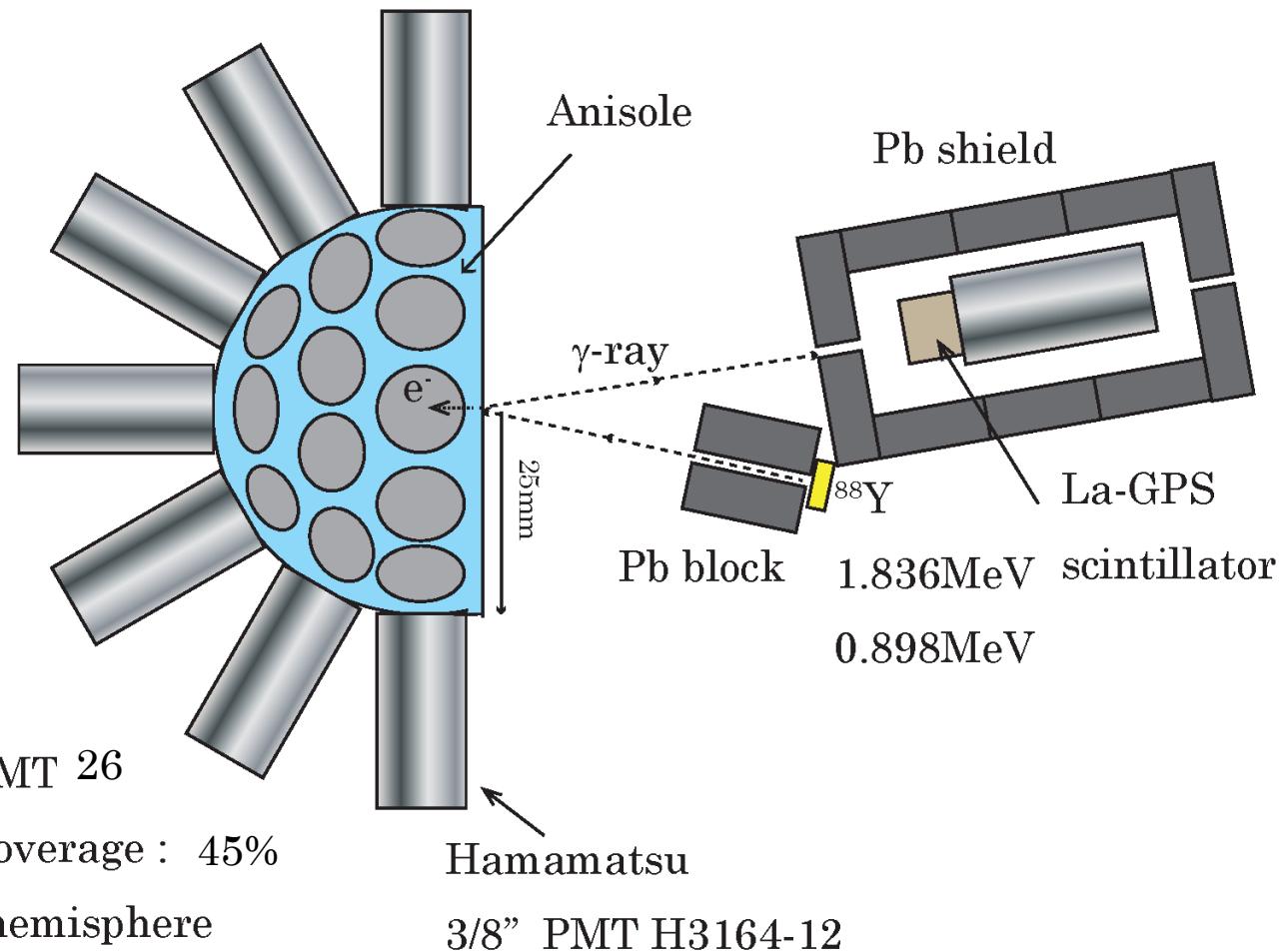
- There is difference in shape between $t = 57$ ns and 58 ns
- Charge ratio looks depend on the energy
- For $t > 58.5$ ns, all shapes were almost same.

Cherenkov looks dominant between 57 ns and 58 ns.

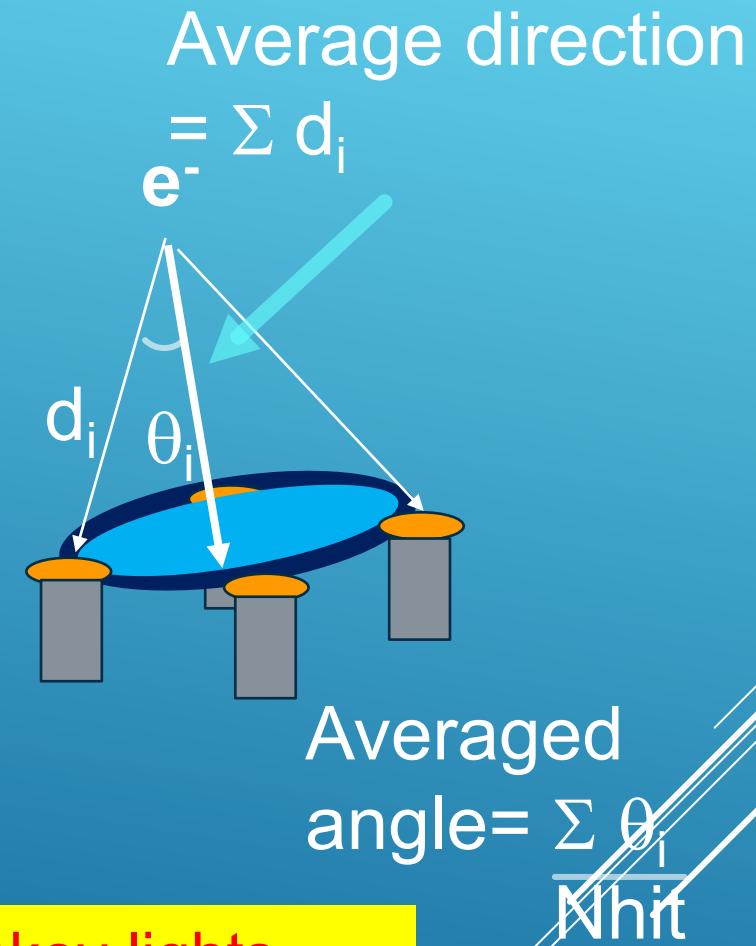
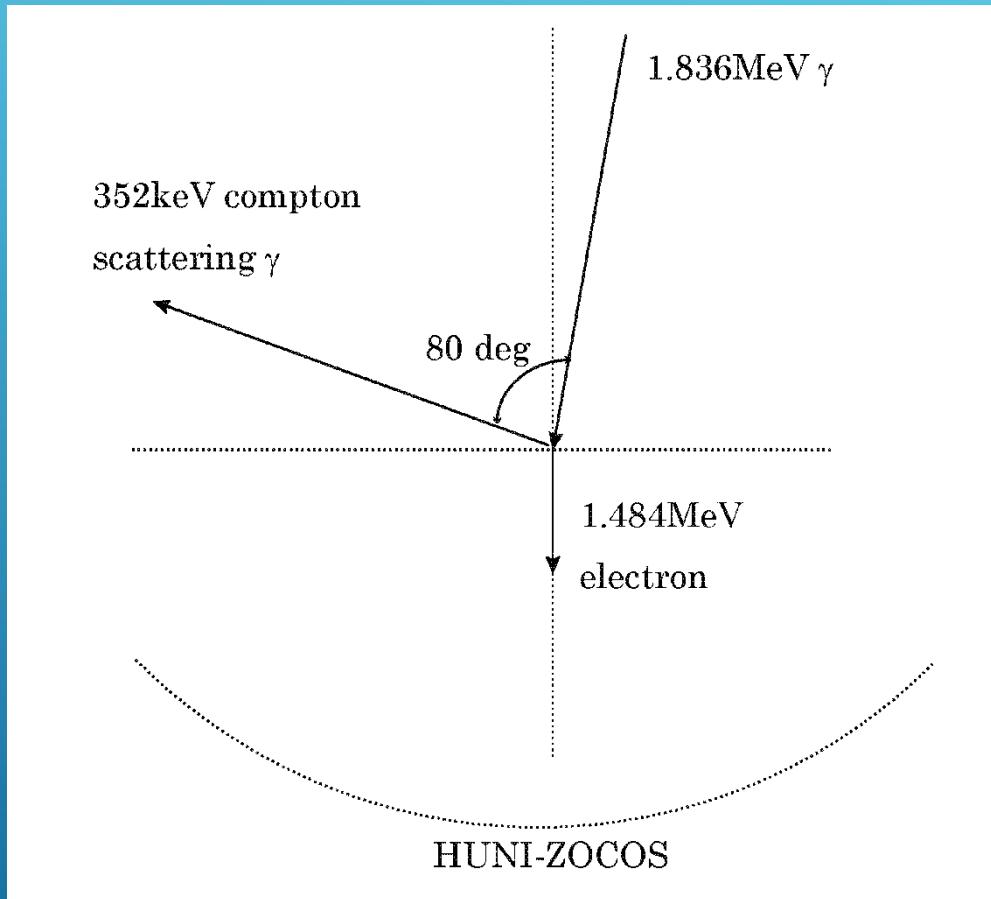
Template waveform of scintillation between 57 ns and 58 ns for ^{57}Co .

Direct measurement of topological information using HUNI-ZICOS

HUNI-ZICOS

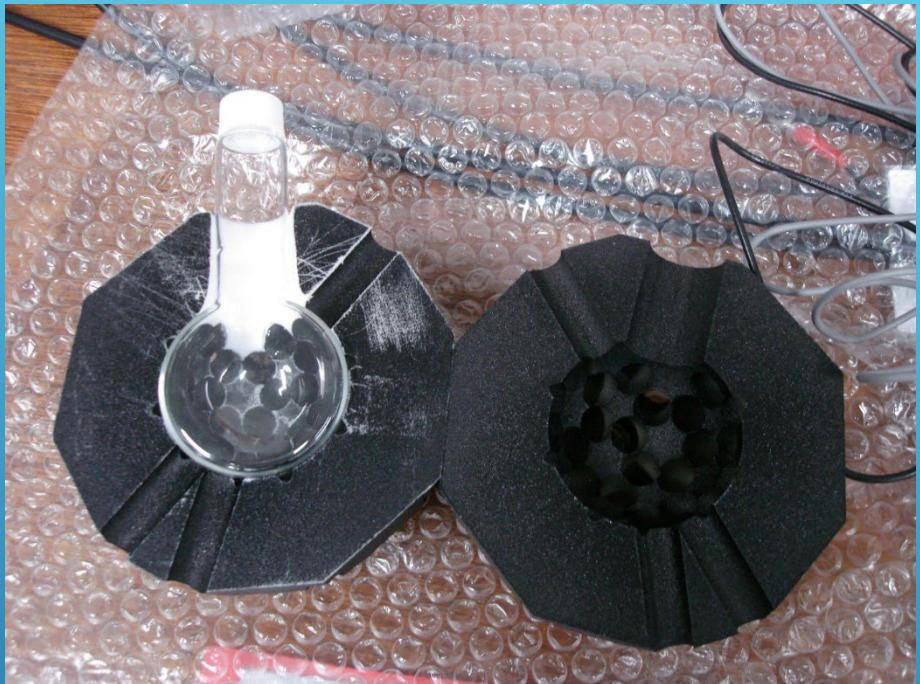


Electron with fixed direction and fixed energy using ^{88}Y gamma source



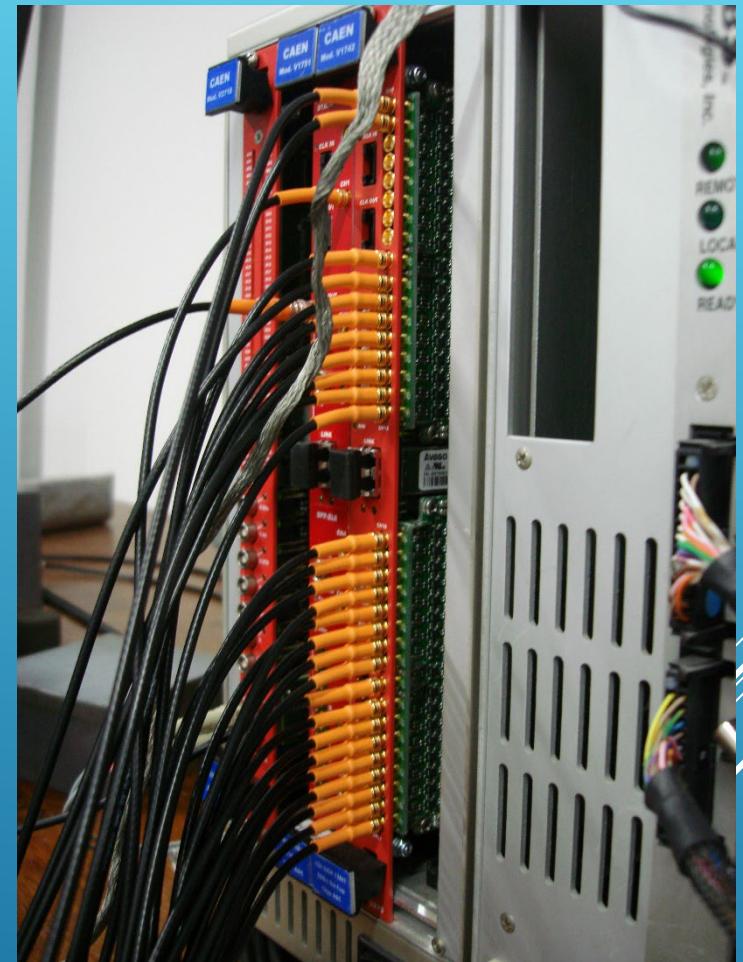
Topological information of Cherenkov lights could be presented as averaged angle.

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.

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).

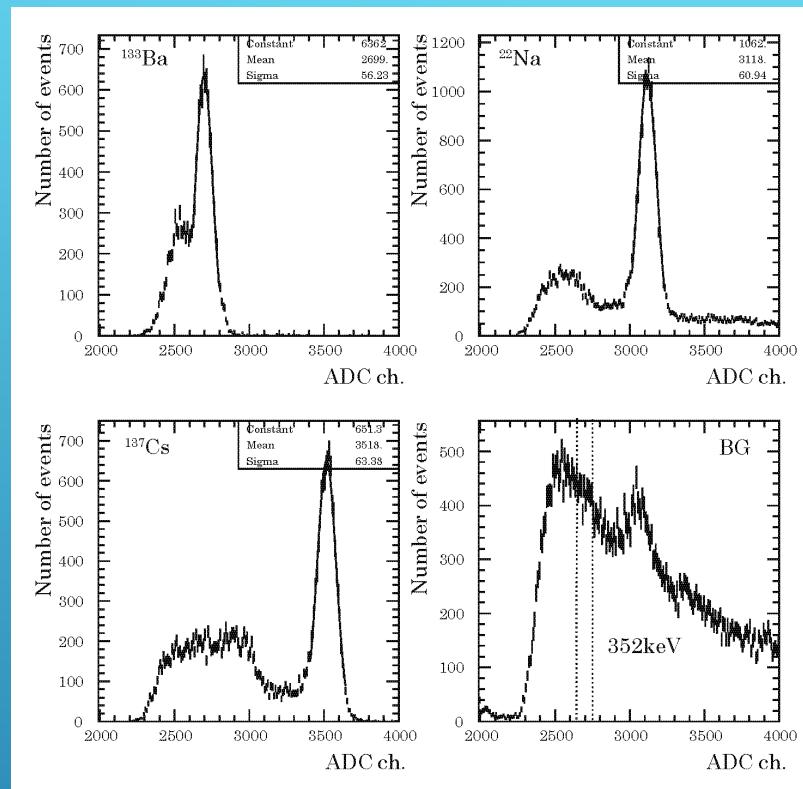
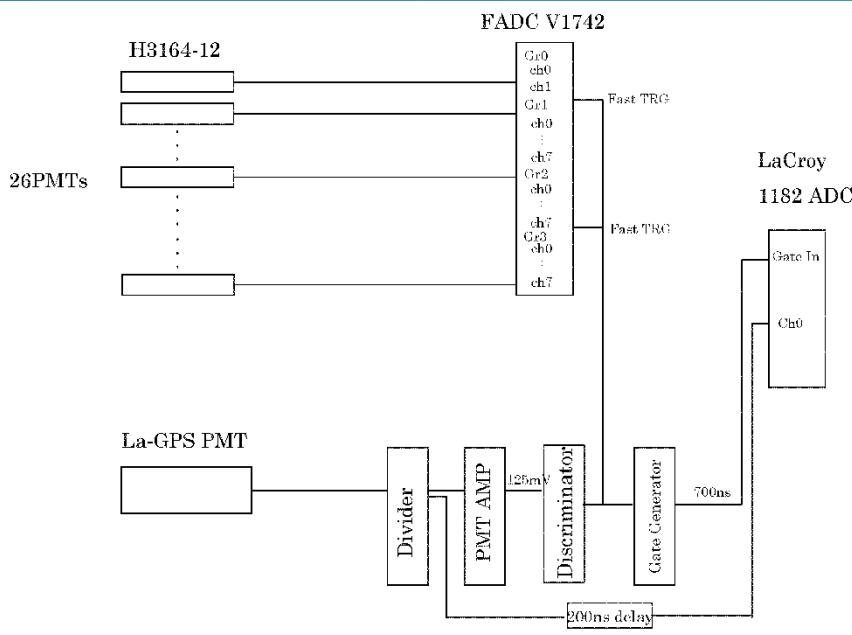
Cable connection to FADC and HV



All channels are connected
to FADC V1742 digitizer.

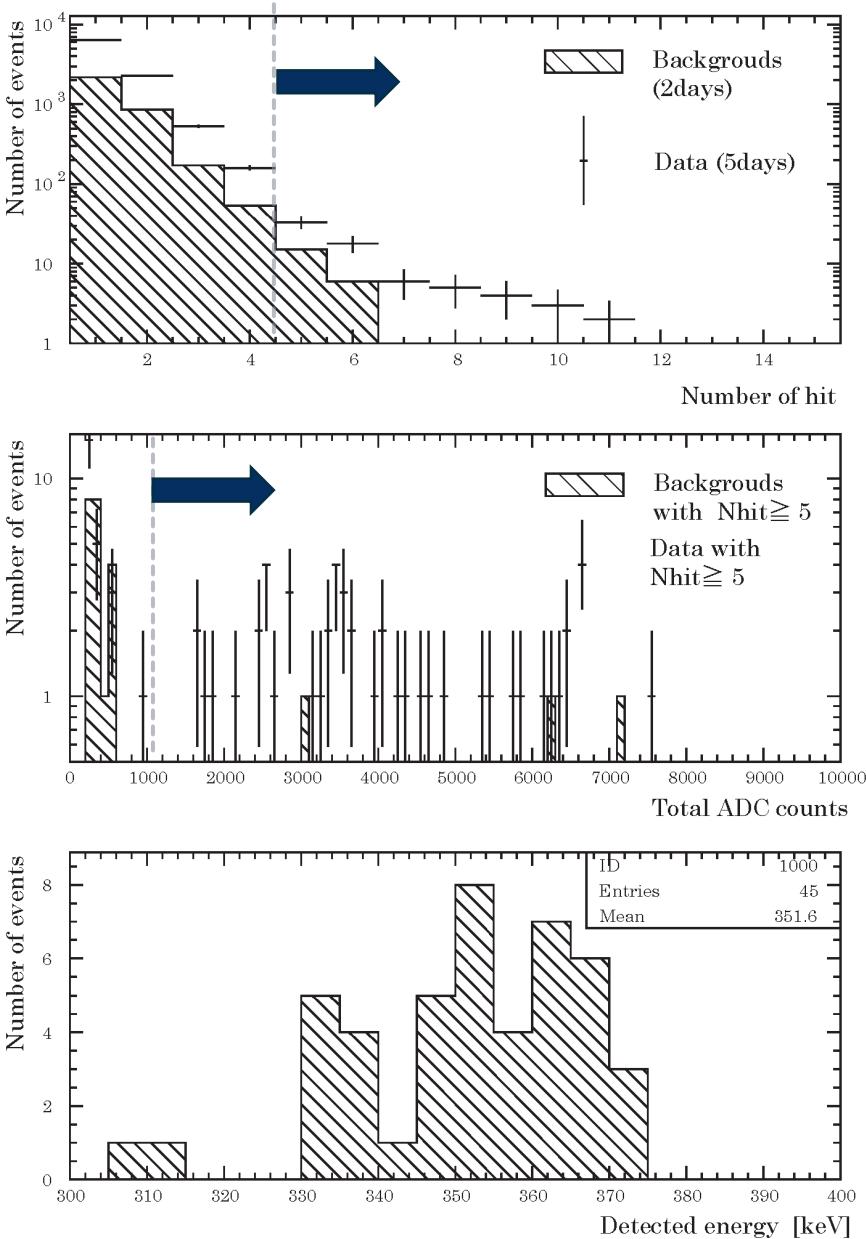
Measurement of averaged angle using ^{88}Y

La-GPS



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

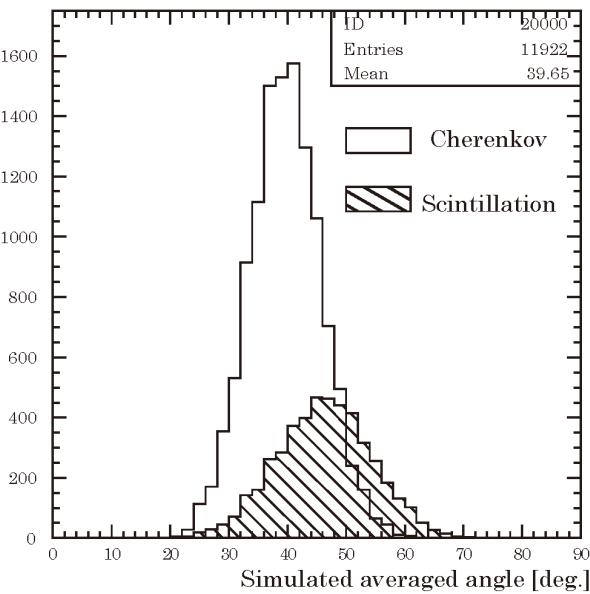
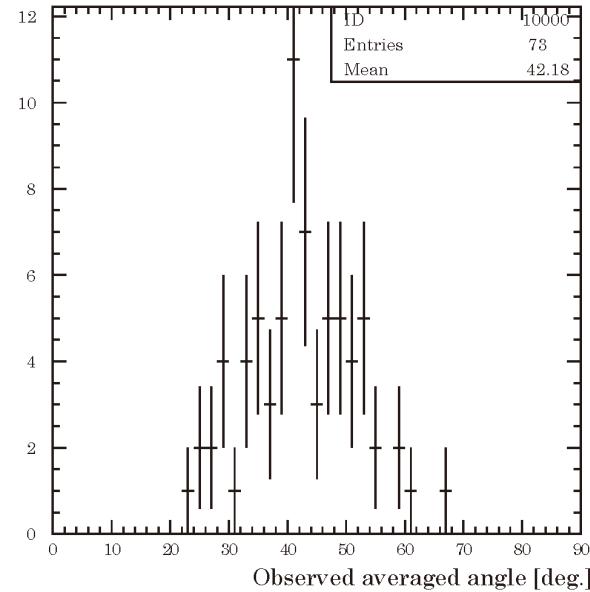
Event selection for scattered electron



Event selection criteria :

- Number of PMT hit for BG are clustered below 5 hit.
 - 1) $N_{hit} \geq 5$
- Qtotal for BG are also clustered below 1000.
 - 2) $Q_{total} \geq 1000$
- 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.

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.