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XXII ～2つのニュートリノを放出する二重ベータ崩壊事象の観測実験装置の性能評価

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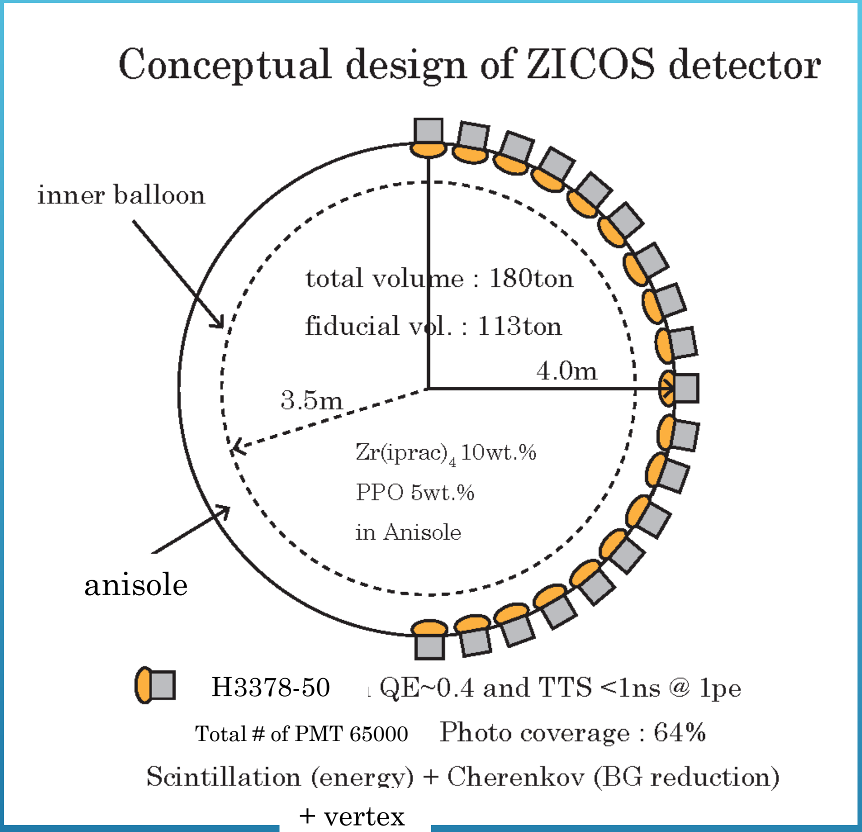
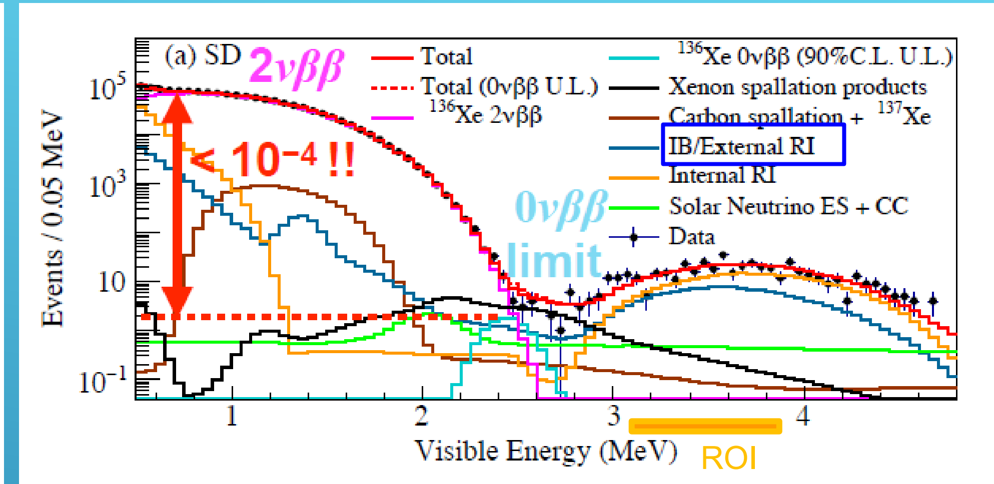
Conceptual design of ZICOS detector





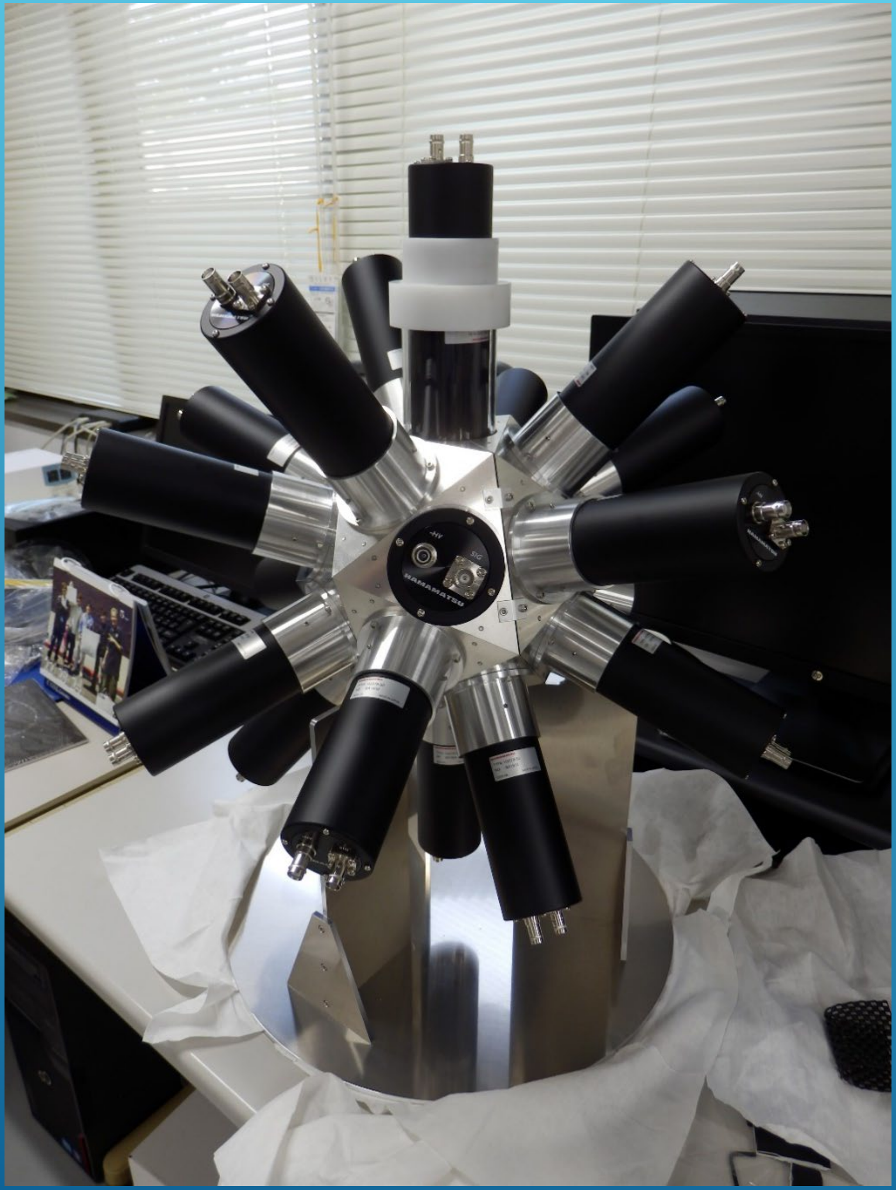
I.Shimizu, Plenary talk at Neutrino2024 conference.

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

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

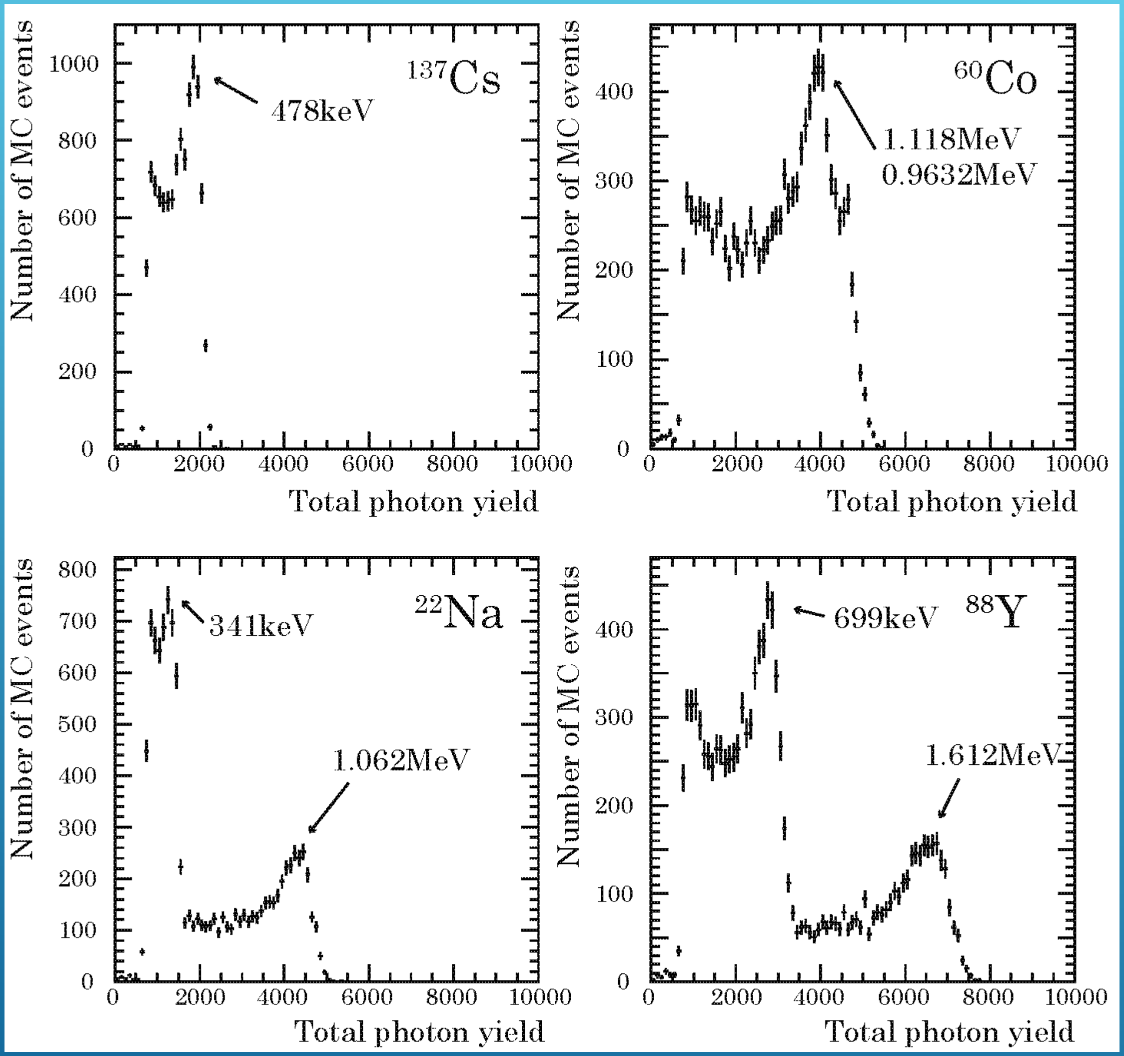
$T_{1/2}^{0\nu} > 4 \times 10^{25}$ yrs → 2×10^{26}yrs → ~1 × 10^{27}yrs

2ν-ZICOS for measurement of 2νββ half-life



- 16 cm diameter round bottom flask using ultra-pure quartz GE214.
- 20 low BG 2” PMT Hamamatsu H3378-50.
- Regular icosahedron for mounting PMT jig using Aluminum.
- 0.73L ZICOS LS loaded 73g of $Zr(iPrac)_4$ which includes 0.3g of ^{96}Zr. (NEMO3:10g)
- Expected number of 2νββ events is ~70 per year.
- NEMO-3 obtained half life $T_{1/2}$ =2.35±0.14±0.16

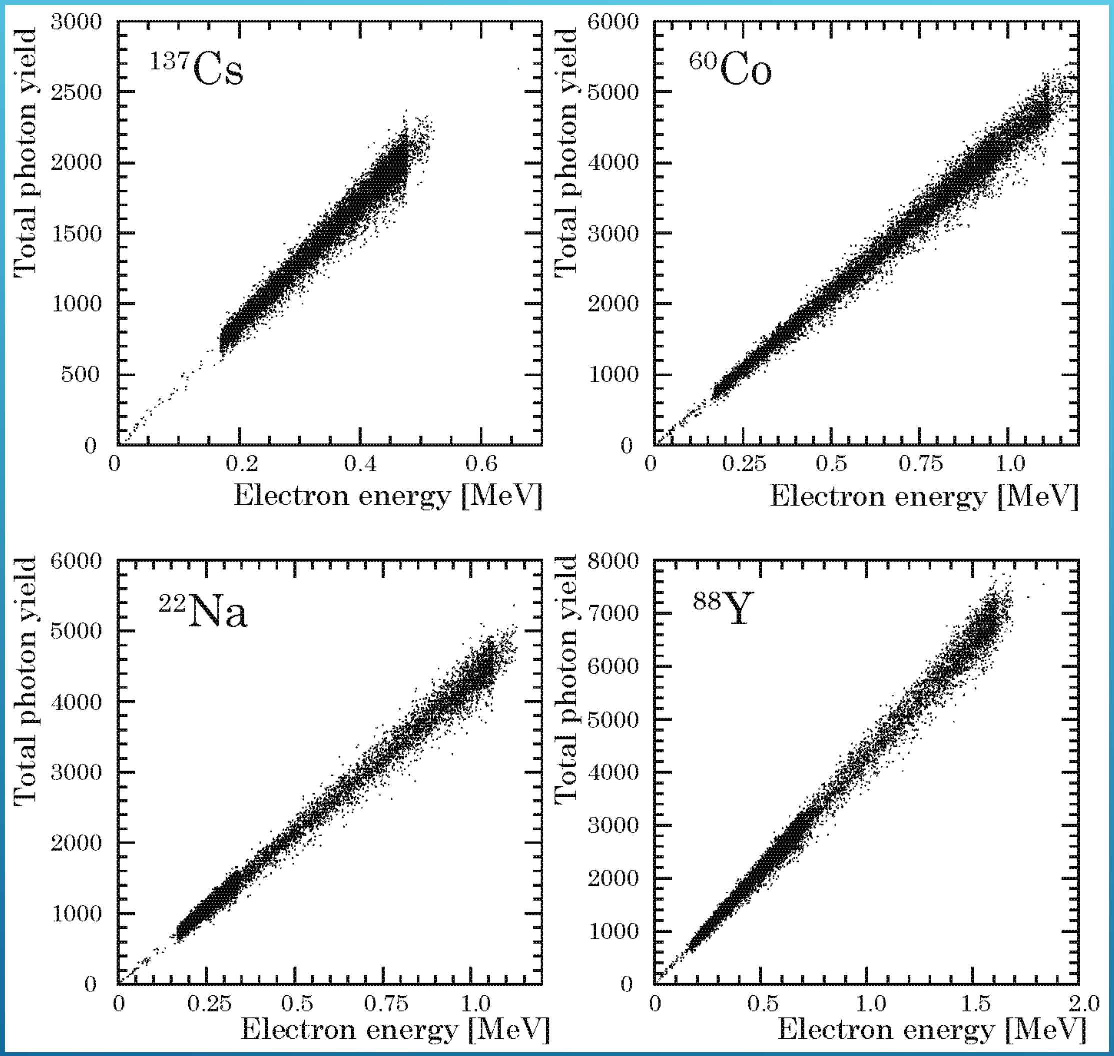
Calibration of energy scale



- Assuming RI source located at (30cm,0,0) outside of 2ν-ZICOS detector in simulation.
- All electrons were generated by Compton scattering.
- Only scintillation emitted in liquid scintillator
- Cherenkov light emitted both LS and Anisole buffer.

Total photon yield seems to good energy scale

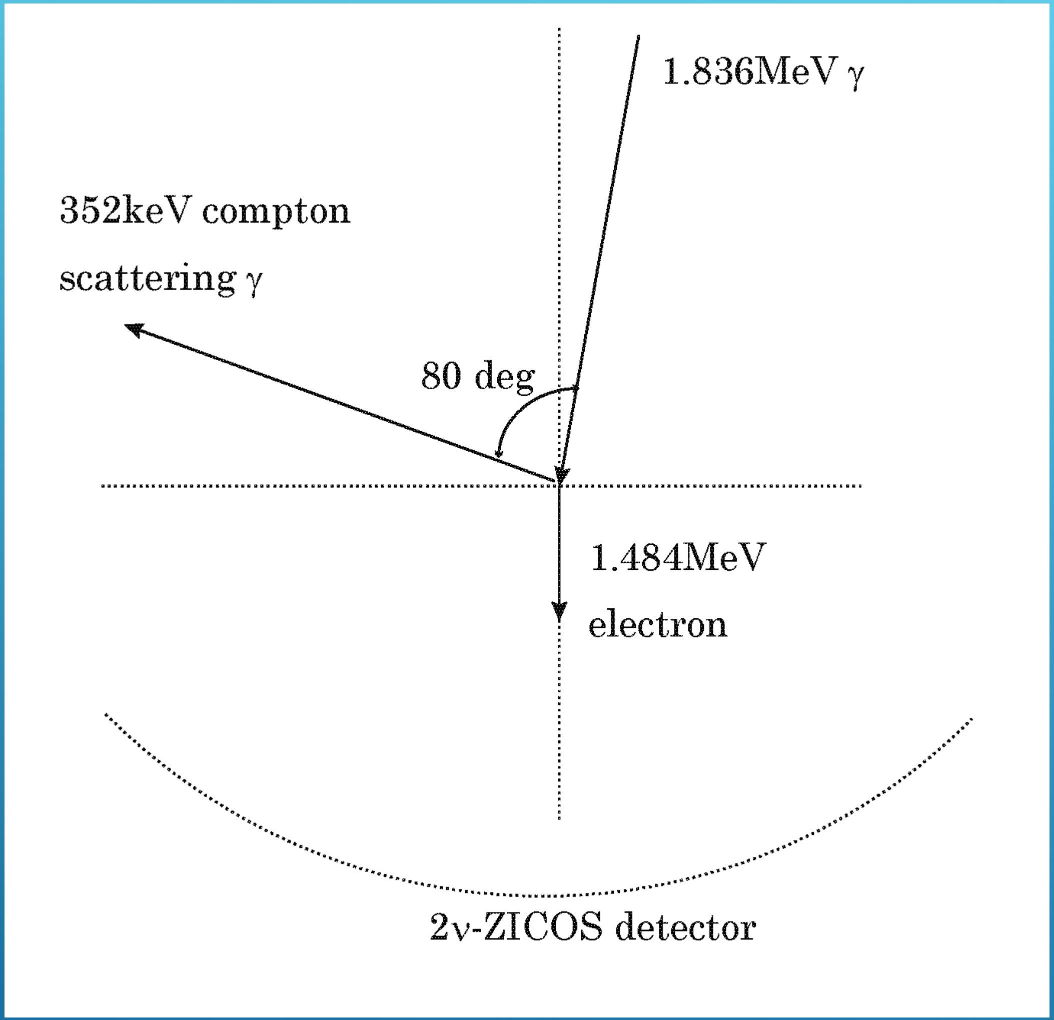
Linearity of energy scale

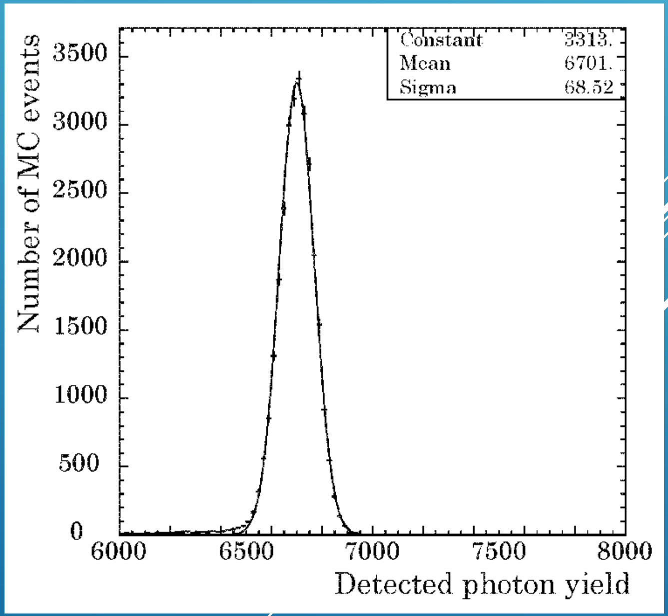


In fact, total photon yield has good linearity with respect to the energy, since simulation knows actual energy deposit of electron.

Total photon yield = total PMT charge will use for the energy scale of events.

Direct measurement of Energy resolution





The MC energy resolution seems to be almost 1%, but we did not consider any experimental condition in this case.

How to reconstruct vertex position

3. Vertex reconstruction and resolution

The method of a vertex reconstruction was developed for such small detector UNI-ZICOS as described in Ref.[10], however there was no clear explanation of the method in the paper.

The scintillation photon emits uniformly at the generated position of charged particle. In the simulation, the charged particle (electron) was tracked at adequate step. and corresponding number of photons were generated with uniform direction. Each photon was also tracked and the PMT which counts photon if the photon goes into the photo cathode area. In this time, total amount of photon corresponding energy could be tuned by 10000 photon/MeV for scintillation and 100 photon/MeV for Cherenkov light, but we did not take into account the photoelectric efficient of the PMT cathode.

Using detected number of photon (DNP) for i-th hitted PMT, we calculated the corrected number of photon (CNP) as following equation;

$$\mathrm{CNP}_i = \mathrm{DNP}_i \times (\frac{r}{d})^2 \frac{1}{\cos\theta_i} \tag{1}$$

where d and r show the distance between PMT and possible vertex position and the radius of the detector, respectively. θ_i is the opening angle between the direction of photon and the direction to i-th hitted PMT from center. After this calculation, we summed total number of corrected photon for all hitted PMTs, and obtained averaged value for total corrected ohoton (AveQ) as following;

$$\mathrm{AveQ} = \frac{1}{Nhit} \sum_{i=1}^{Nhit} \mathrm{CNP}_i \tag{2}$$

where $Nhit$ is number of hitted PMT. Then we took the variance (VAR), the standard deviation (STD), and the resolution (RES) as following steps.

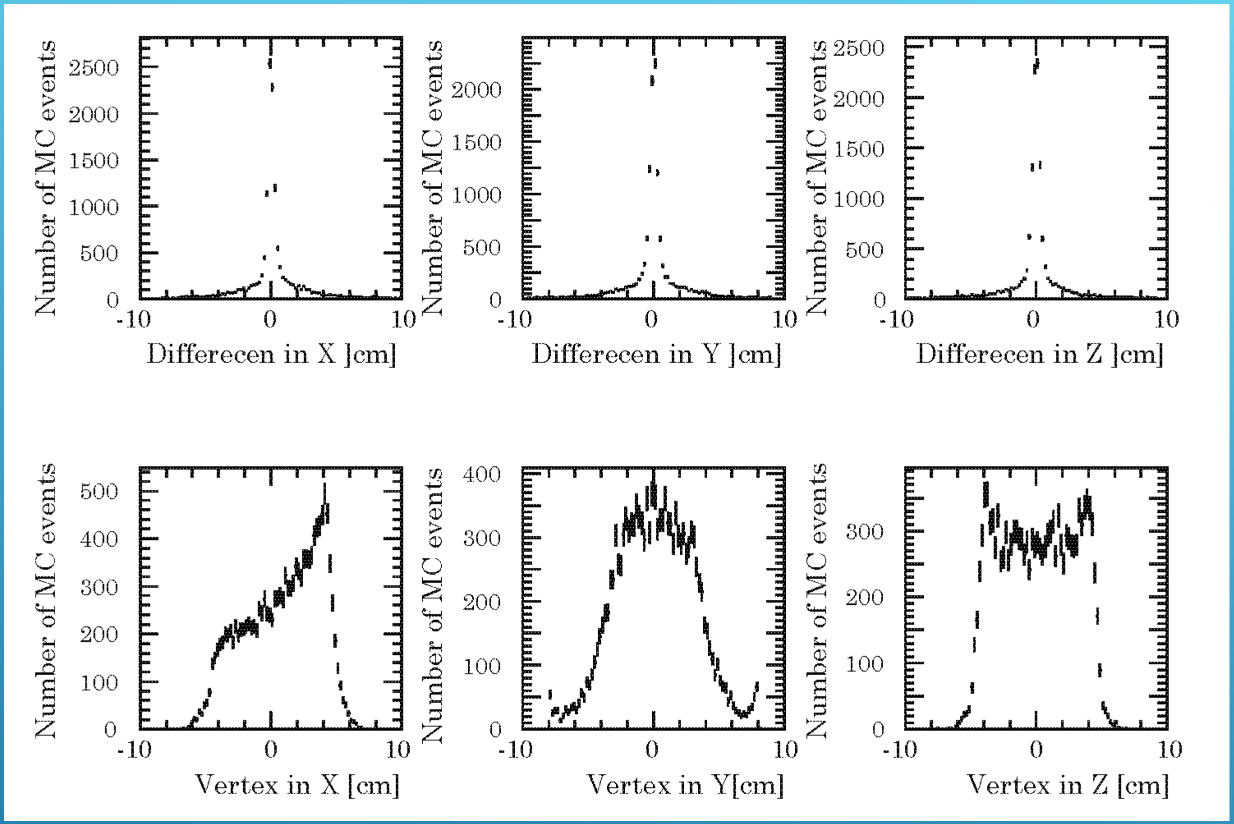
$$\mathrm{VAR} = \frac{1}{Nhit} \sum_{i=1}^{Nhit} (\mathrm{CNP}_i - \mathrm{AveQ})^2 \tag{3}$$

$$\mathrm{STD} = \sqrt{\mathrm{VAR}} \tag{4}$$

$$\mathrm{RES} = \frac{\mathrm{STD}}{\mathrm{AveQ}} \tag{5}$$

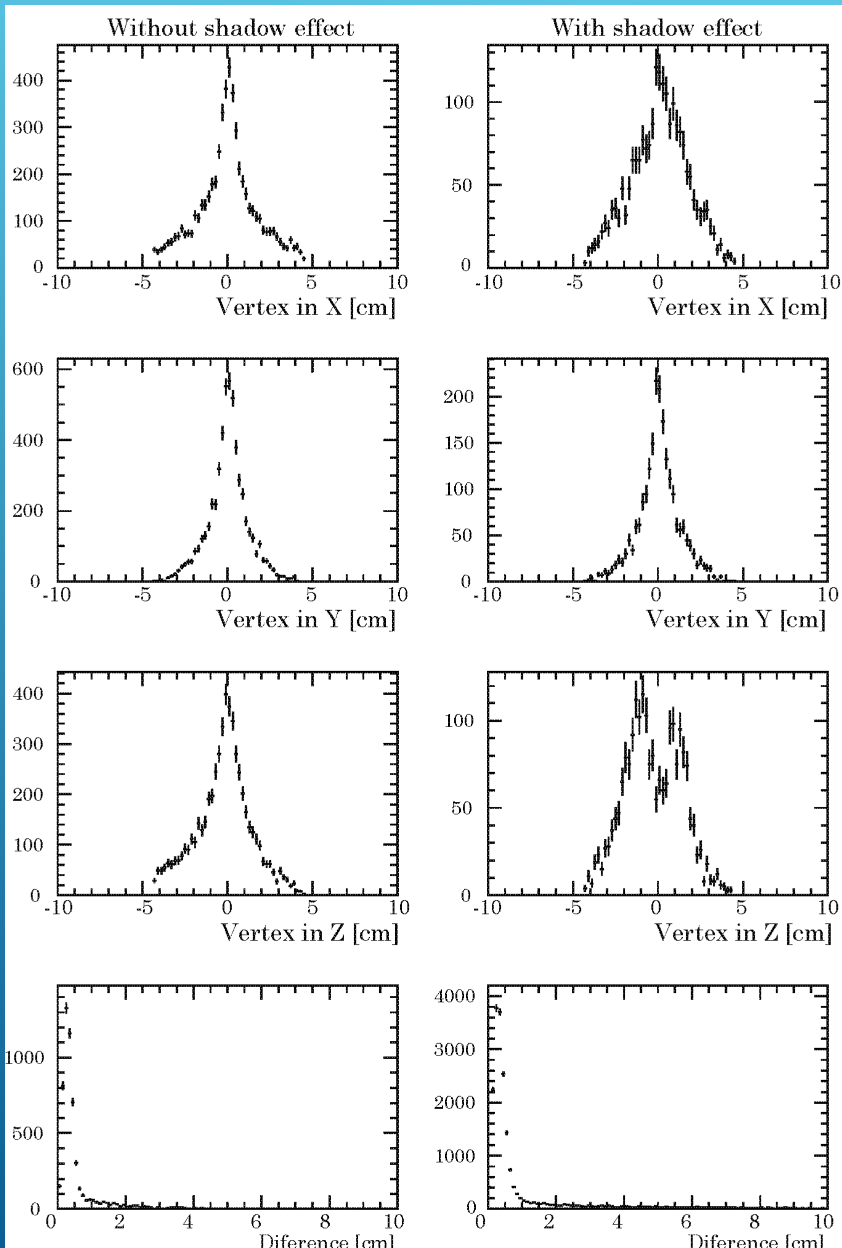
Above calculation should be performed on huge grid as a possible vertex position in whole detector region. Exactly speaking, we divided the detector into 0.1cm step for 3 dimension.

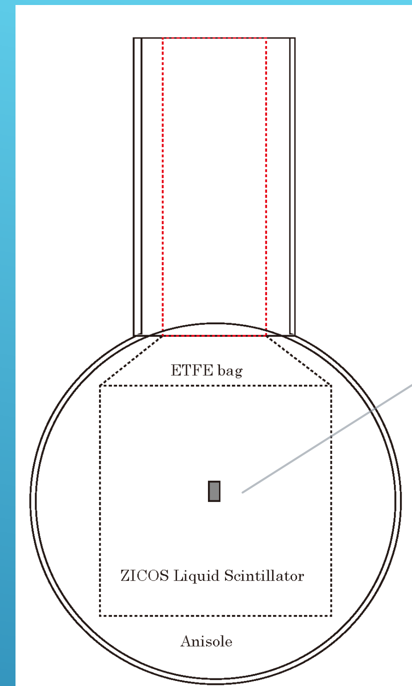
Response of vertex reconstruction

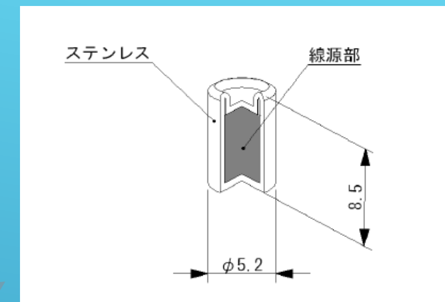


- Assuming again RI source located at (30cm,0,0) outside of 2ν-ZICOS detector in simulation.
- Obtained vertex positions were well reconstructed with 0.3cm resolution in any direction.

Calibration of vertex reconstruction



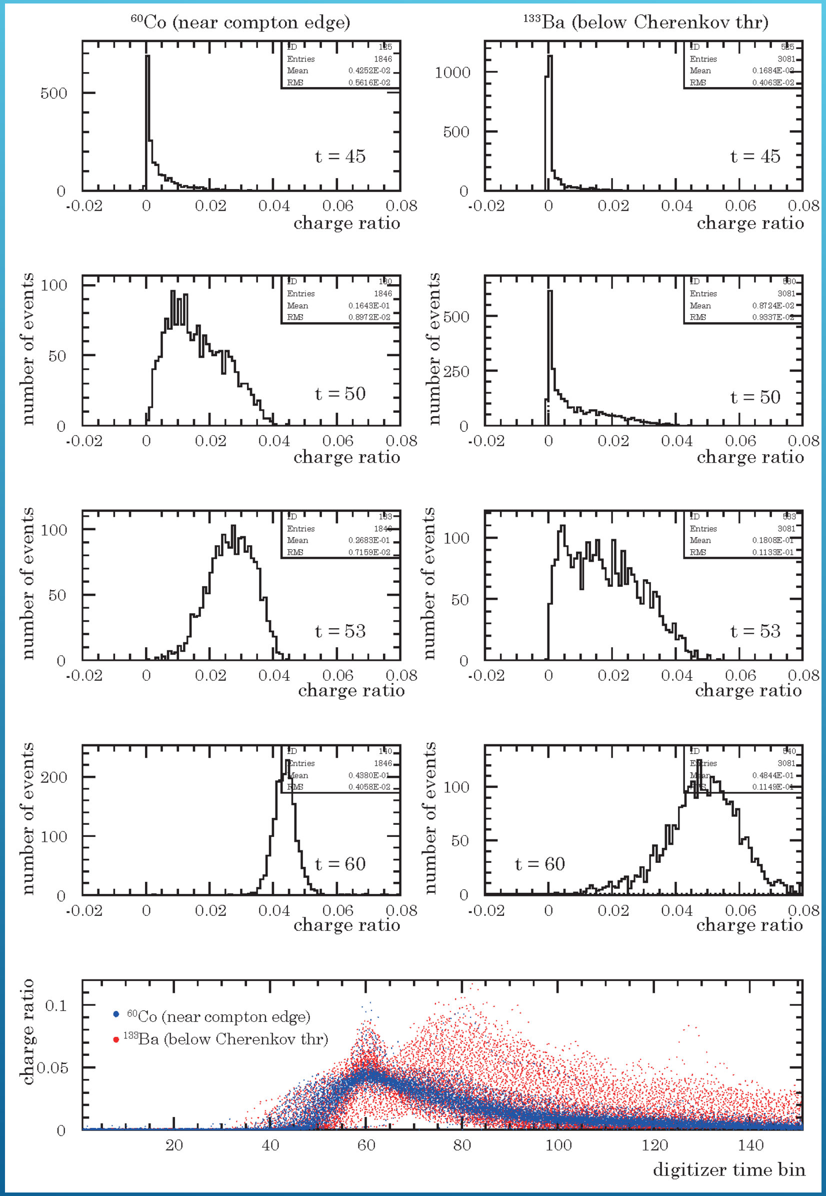




日本アイソトープ協会　標準ガンマ線　516タイプ
100kBq！

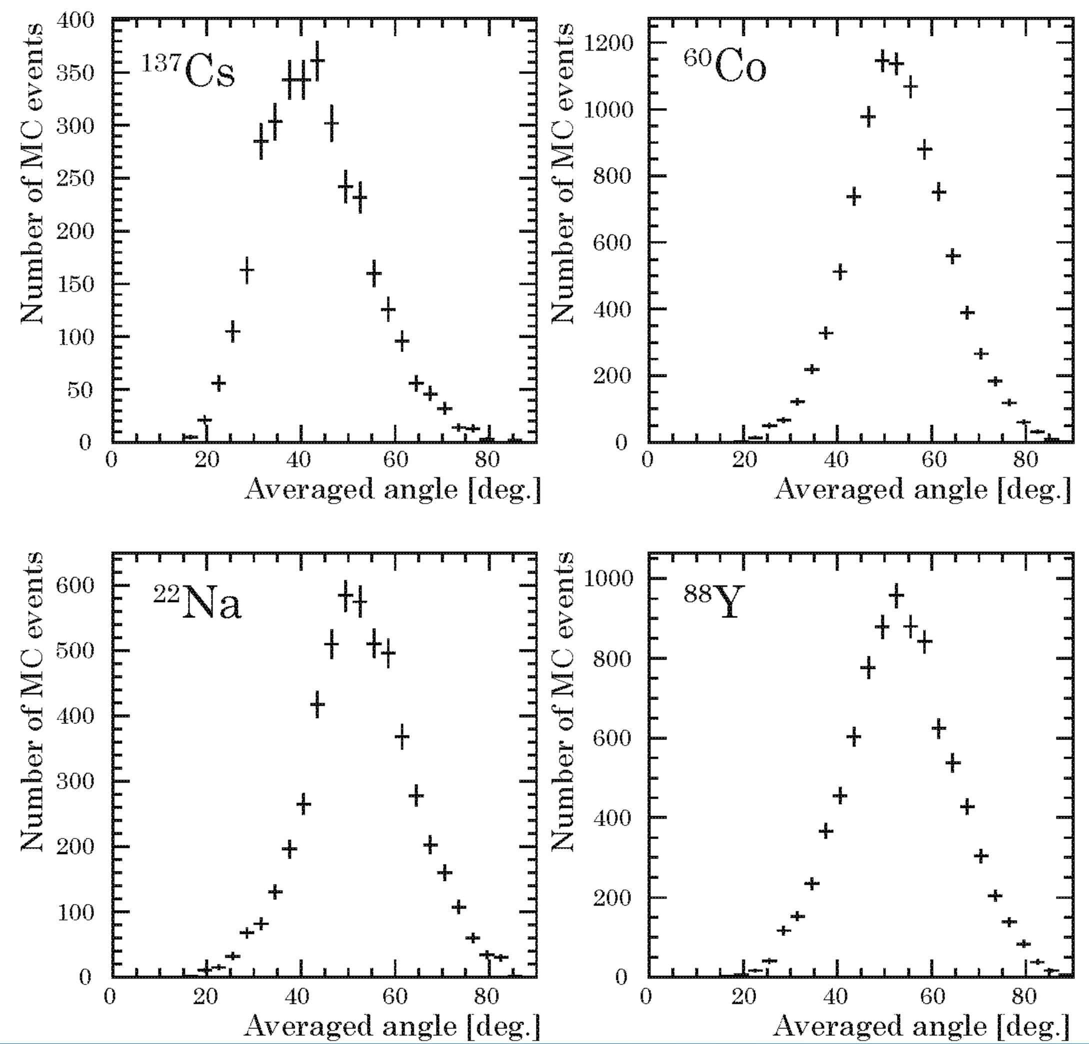
Larger pulse signal from ^{137}Cs type 516 source will be used for calibration of vertex reconstruction.

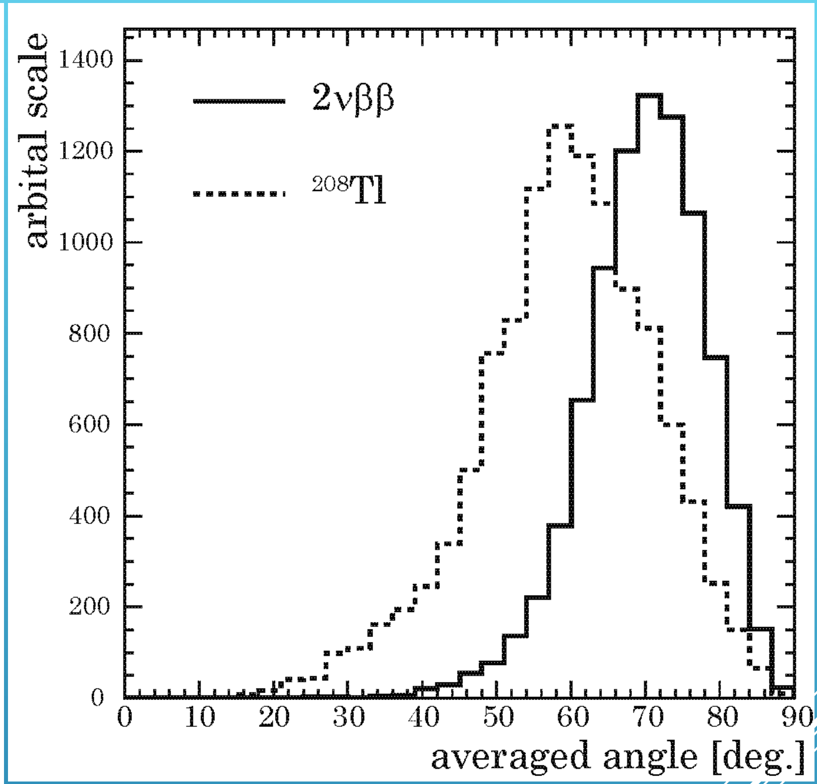
PSD using V1742 + H3378-50



- Returning for faster PMT H3378-50 and 5Gs/s digitizer V1742.
- Used for controlled samples with only scintillation and with both scintillation and Cherenkov light.
- PSD should clearly be realized using charge ratio distribution at each timing.
- χ^2 method will be used for selection of PMT which receives Cherenkov light or not.

Calibration of averaged angle

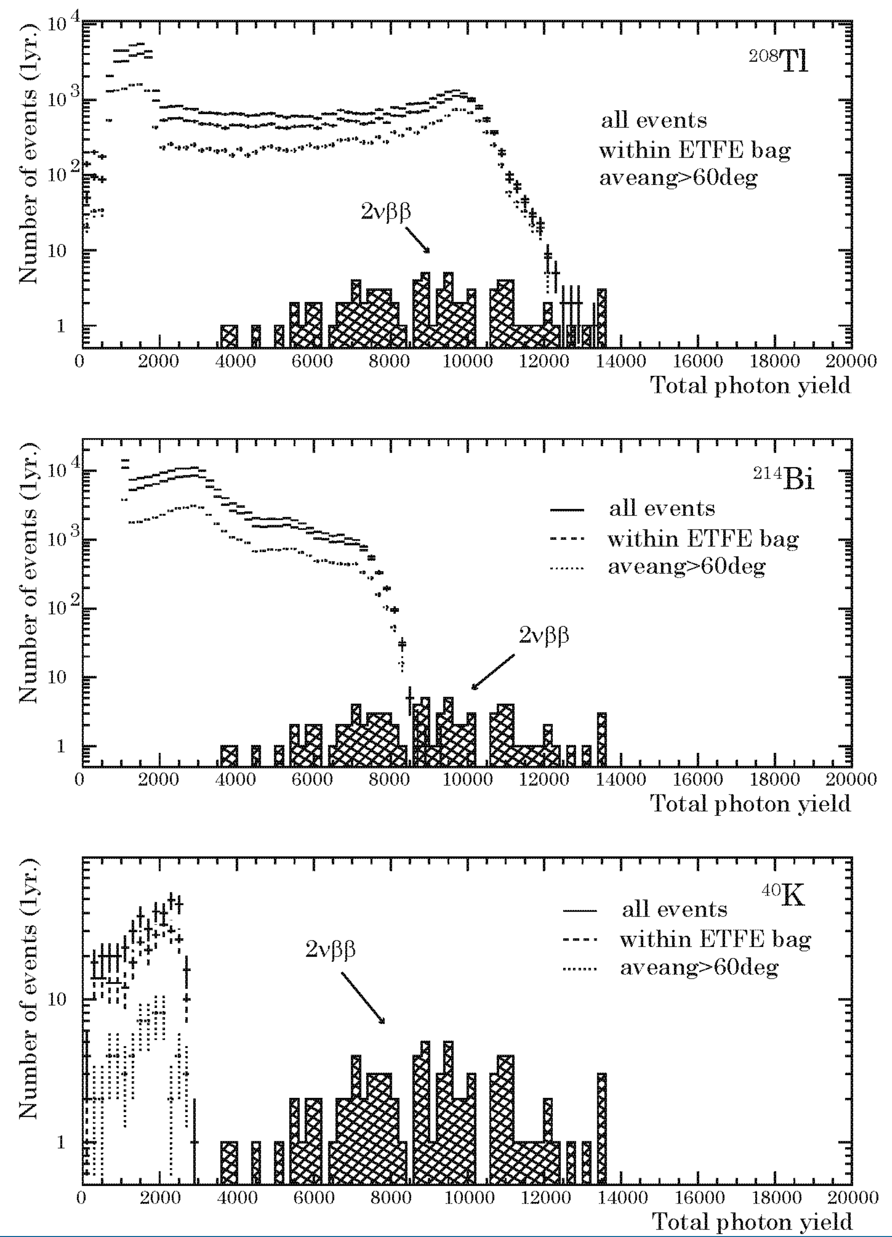




The peak position were seen at 58 and 70 degree for $2\nu\beta\beta$ and ^{208}Tl β decay, respectively.

Once the vertex position was reconstructed, we can select PMTs which receive Cherenkov lights for the averaged angle.

BG simulation assuming ETFE cubic bag

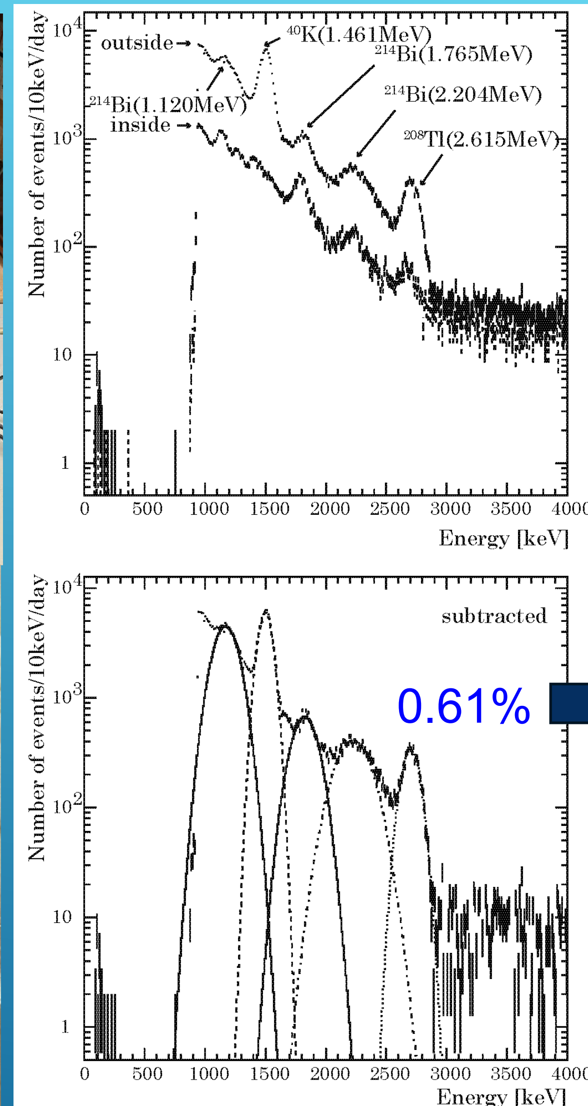


Assuming BGs from flask

- ^{40}K affects only part of 2νββ observation.
- ^{214}Bi is significant BG, but small fraction of 2νββ events should be observed.
- ^{208}Tl is most serious BG for 2νββ. A few events might be observed.

Need 1/100 U/Th contamination in ultra-pure Quartz.

10cm mini Pb shield and CsI detector



Backgrounds such as ^{214}Bi and ^{208}Tl for U/Th series, and ^{40}K are found.

0.61% → ～30,000events/yr

Assuming 20cm Pb : 0.0037%

～200events/yr

Due to limit of number of Pb block, we will use 15cmm thickness

Conclusion

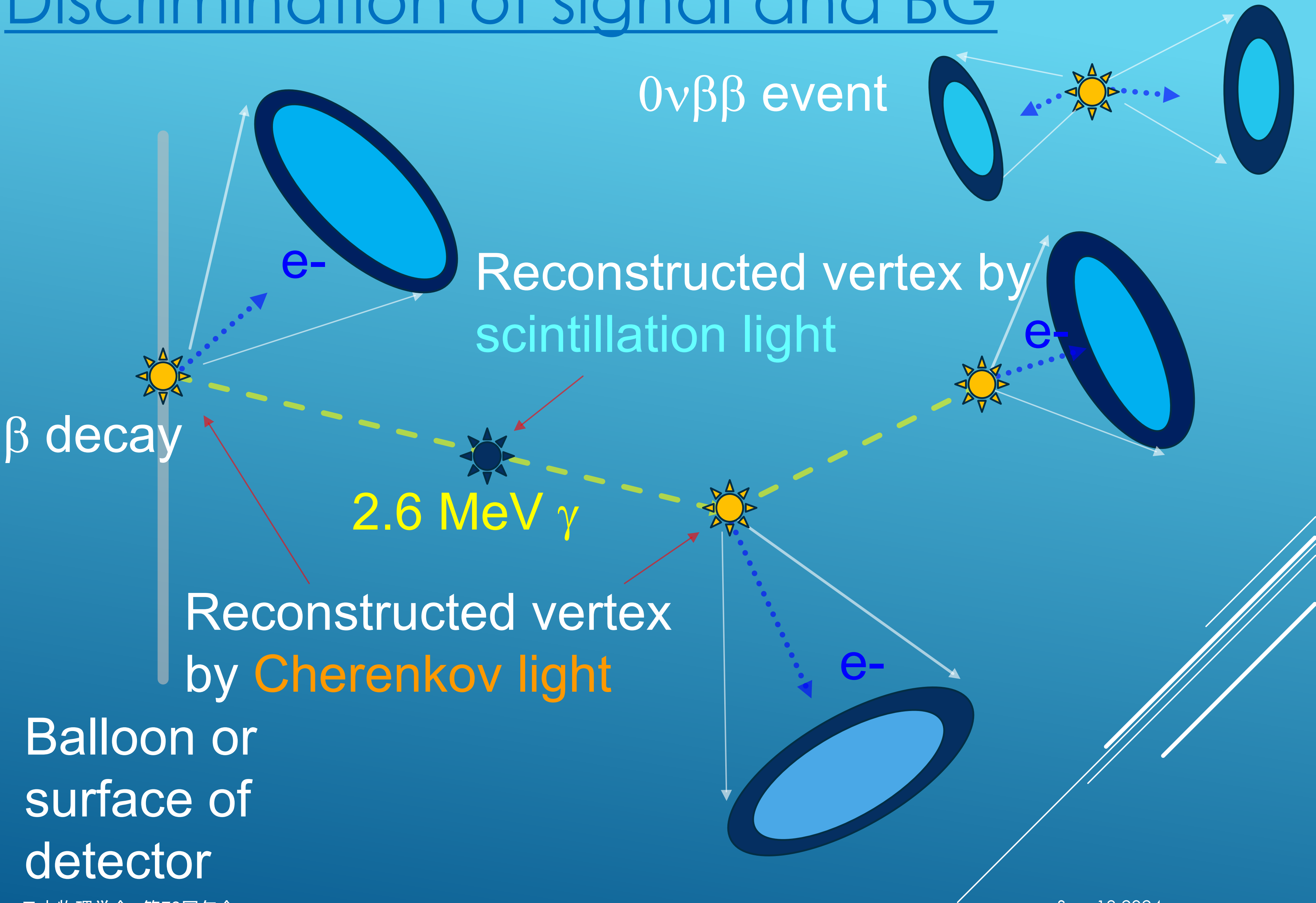
- Construction schedule after the permission.
  1. Move all stuffs to LAB-A in Kamioka mine within this fiscal year.
  2. Install clean booth and setup Pb shield inside the clean booth at LAB-A.
  3. Setup 2ν-ZICOS detector and move inside Pb shield.
  4. Install some WEB cameras and temperature monitors including email alarm for the slow monitor.
  5. Data taking hopefully will start in early summer next year.

Measurement of world highest sensitivity for half-life of ^{96}Zr 2$\nu\beta\beta$

- Need more clean Quartz than GE214 to reduce ^{208}Tl background to be 1/100.
- Need more ^{96}Zr isotope. 30cm diameter flask will contain 8L LS corresponding to 3g ^{96}Zr, which is a bit smaller amount than NEMO-3.
- Need 32 photomultipliers to get better resolution of averaged angle.
- Need liquid-liquid extraction for liquid scintillator, if necessary. (caution : Humid for $Zr(iPrac)_4$)
- Need enrichment of ^{96}Zr using Gas Centrifuge with $ZrCl_4$ for 0$\nu\beta\beta$ in future. Also need to know sublimation point at vacuum in advance.

backup

Discrimination of signal and BG



Background estimation

U/Th in GE214 using ICP Mass spectrometer :

^{232}Th : 15ng/g corresponds to 6.09×10^{-5}Bq/g

^{238}U : 29ng/g corresponds to 3.58×10^{-4}Bq/g

^{40}K : 0.021ng/g corresponds to 5.59×10^{-6}Bq/g

Assuming radiation (perpetual) equilibrium :

$\lambda_A N_A = \lambda_B N_B$ (Decay rate should be same)

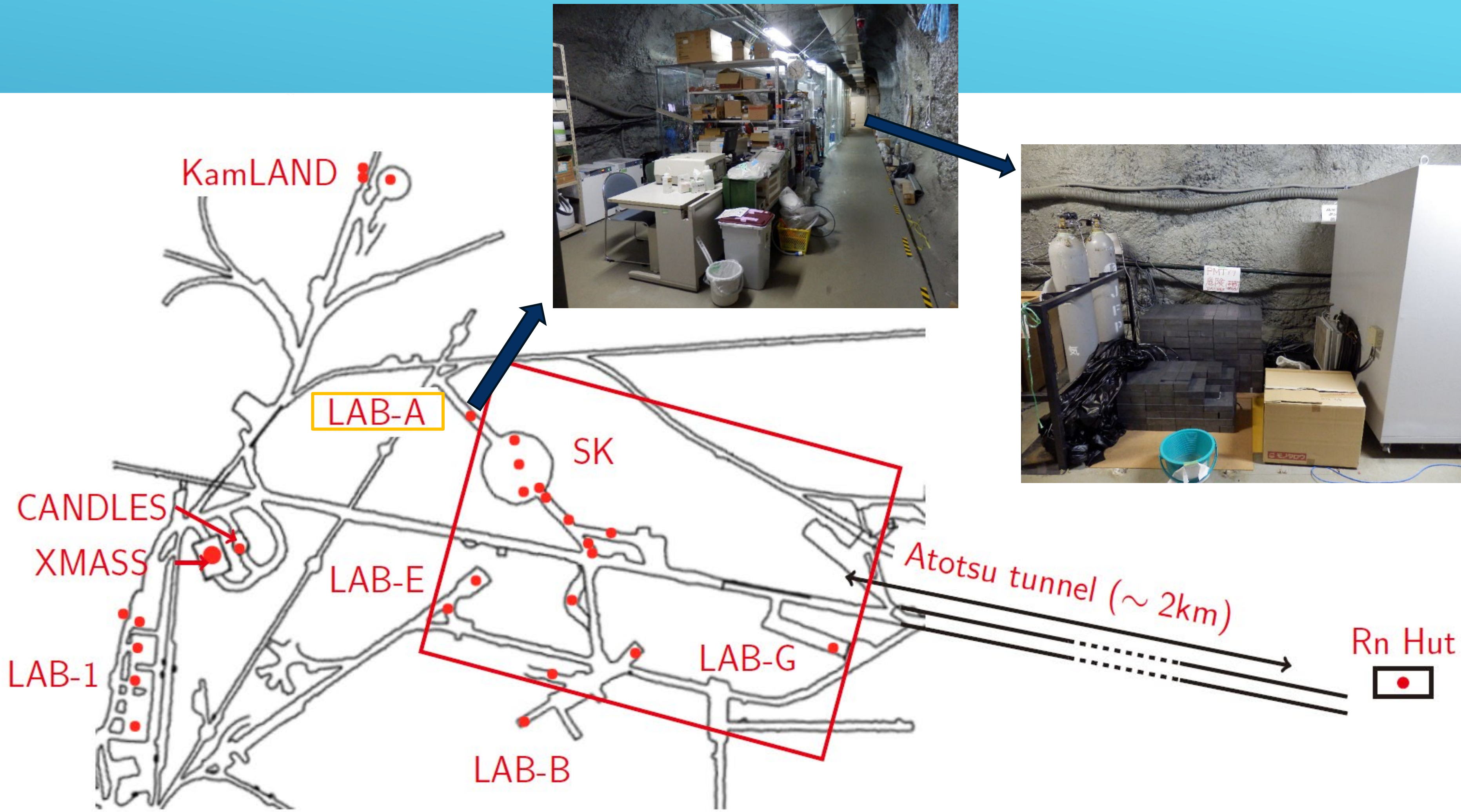
The detector flask uses 530g of GE214.

^{208}Tl : 1017908 events per year

^{214}Bi : 5988404 events per year will occur.

^{40}K : 93556 events per year

Underground laboratory in Kamioka mine



LAB-A : Behind of LINAC control room