# ZR-96を用いたニュートリノの放出を伴う二重ベータ崩壊事象の観測実験

学術変革「地下稀事象」領域研究会

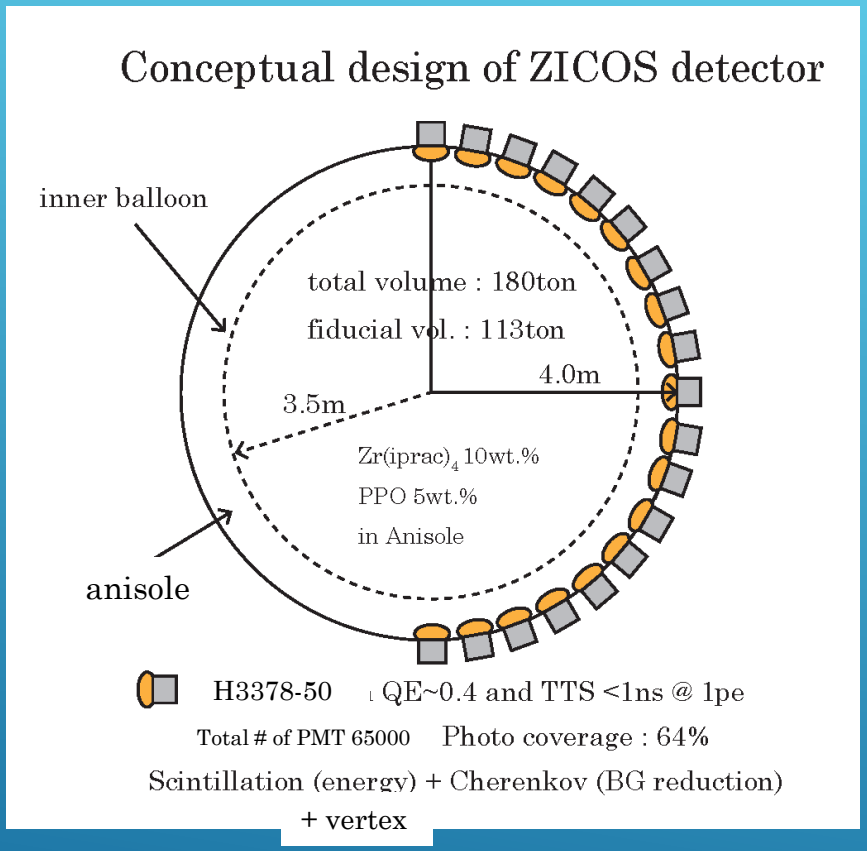
**July 4, 2024**

Grant-in-Aid for Scientific Research on Innovative Areas
19H05093 and 20H05241
Scientific Research (B) 22H01243 and 23K22514

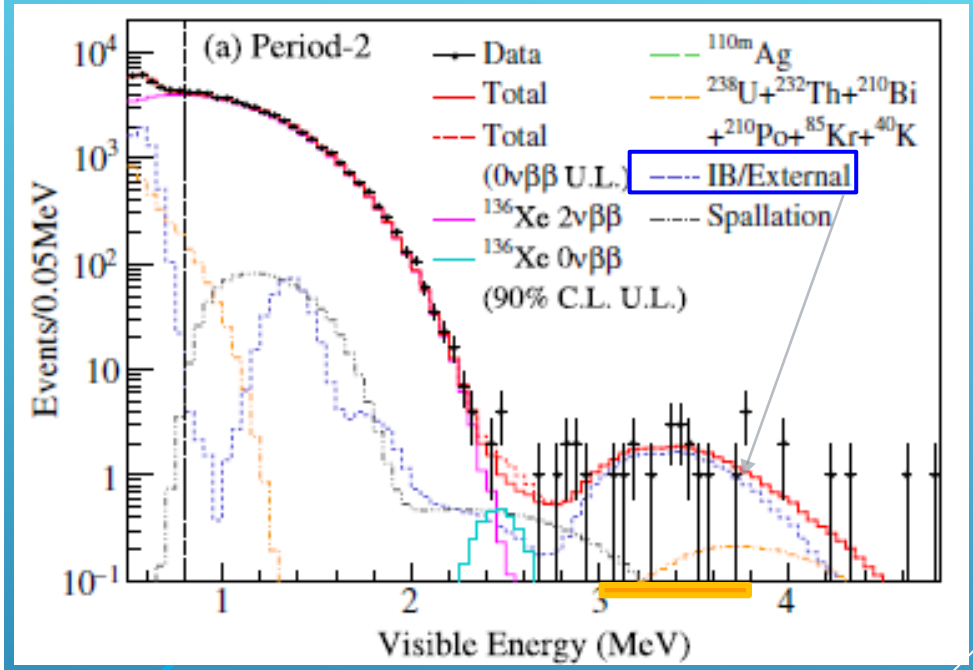
Miyagi University of Education Y. Fukuda, R. Sato, K. Takemura,
K. Sugawara, K. Toyama
Kamioka Observatory, ICRR, Univ. of Tokyo S. Moriyama, K. Hiraide
University of Fukui I. Ogawa
Tokyo University of Science T. Gunji
Institute for Materials Research, Tohoku University S. Kurosawa
University of Toyama Y. Nakano

**and We need more collaborators**

# Conceptual design of ZICOS detector




Phys.Rev.Lett. 117 (2016) 082503

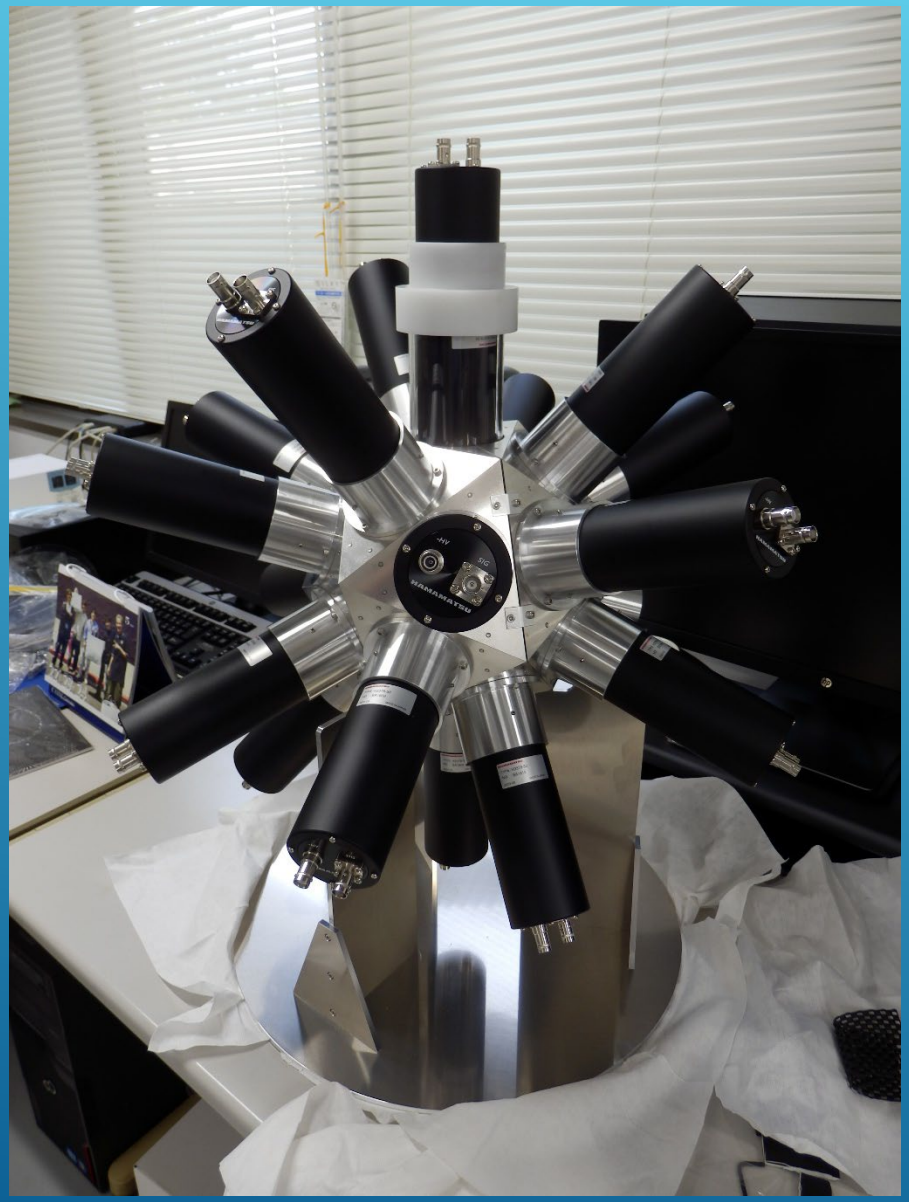



NEMO3 : $T_{1/2}^{0\nu} > 9.1 \times 10^{21}$ yrs

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

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

# Observation of 2νββ events using $^{96}Zr$



- 16 cm diameter round bottom flask using Ultra-pure quartz (GE214).
- 20 low BG 2” PMT Hamamatsu H3378-50.
- Designed regular icosahedron jig for PMT
- 0.73L ZICOS LS loaded 73g of $Zr(iPrac)_4$ ($^{96}Zr$ corresponds to 0.3g).
- Expected number of events is ~80 per year.

# Underground laboratory in Kamioka mine

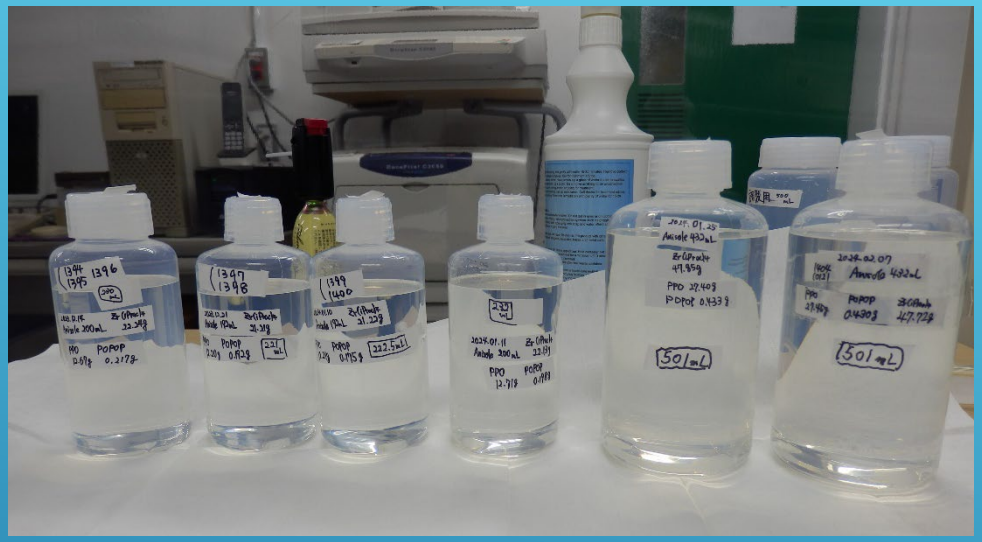



LAB-A : Behind of LINAC control room

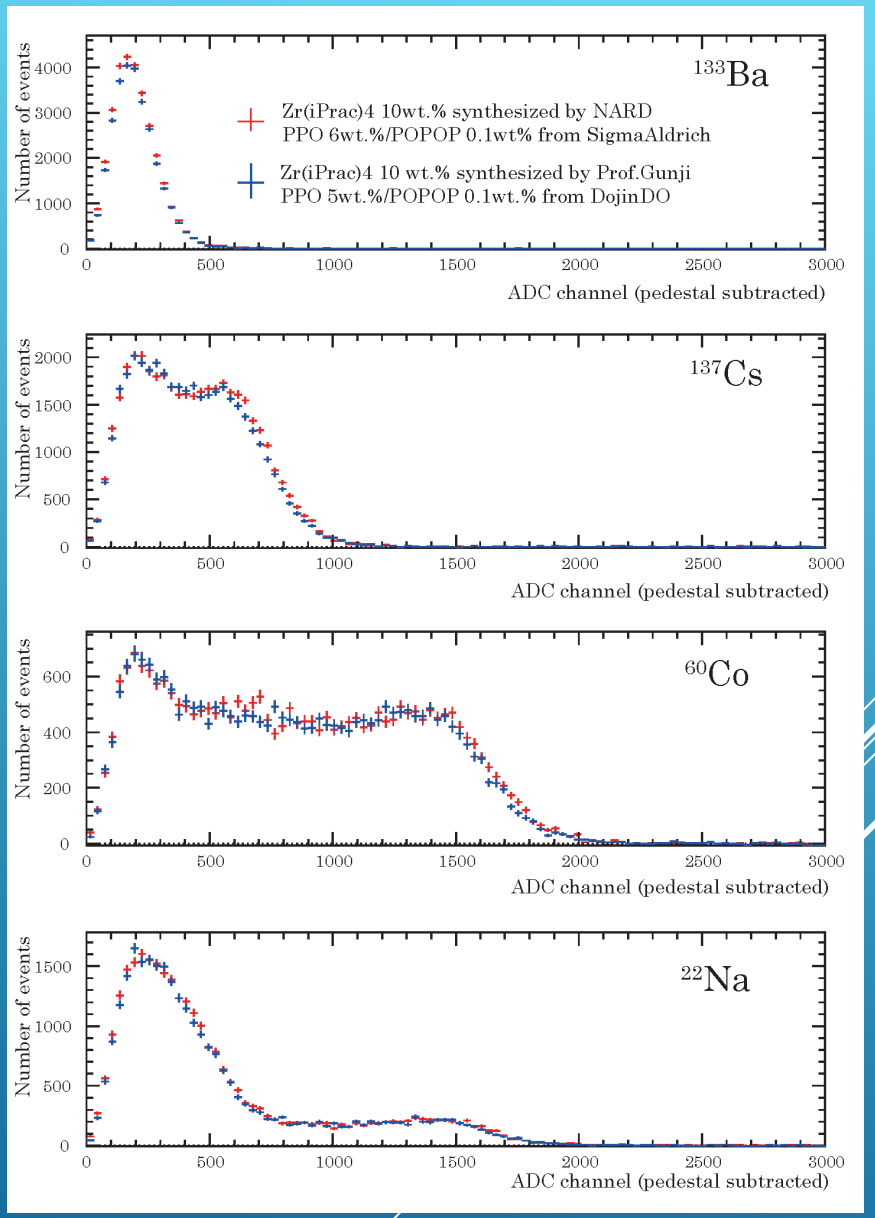
# Current status

- 2 Little of ZICOS Liquid Scintillator was prepared for 4 months.
  i. 10 wt.% for $Zr(iPrac)_4$ into Anisole in the globe box under $N_2$ gas atmosphere
  ii. 6 wt.% for PPO and 0.1wt.% for POPOP
  iii. All procedures done in class 1000 Clean booth using PFA SSC bottle.
- 9cm ETFE cubic bag was produced by Taiyo Kogyo Corporation using 100μm film.
  i. 95% transparency was obtained by LS
  ii. Chemical stability against Anisole was promised.
- Radiation Shield will consist of 10cmt Pb blocks, 3mmt OFC plates and 20mmt Al plate on Fe basis.

# Preparation of ZICOS liquid scintillator



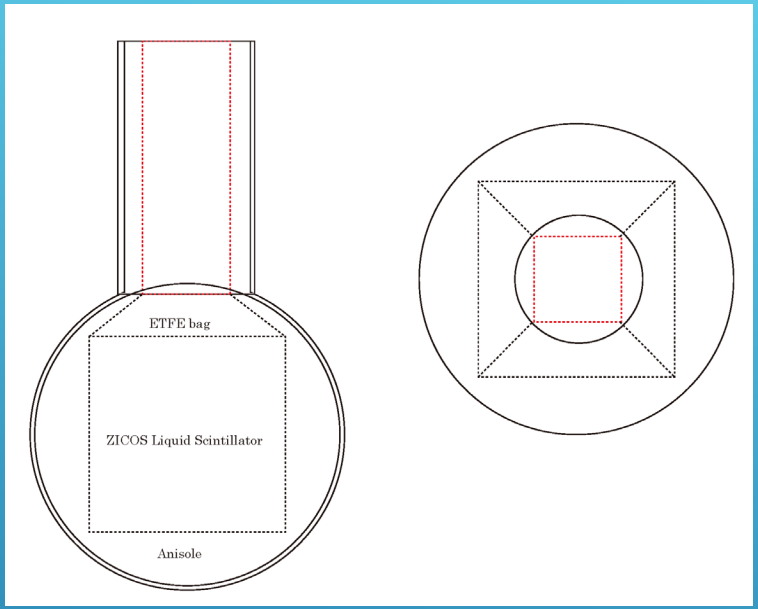
No difference for ZICOS LS between using old $Zr(iPrac)_4$ synthesized by Prof.Gunji and using new $Zr(iPrac)_4$ synthesized by NARD.

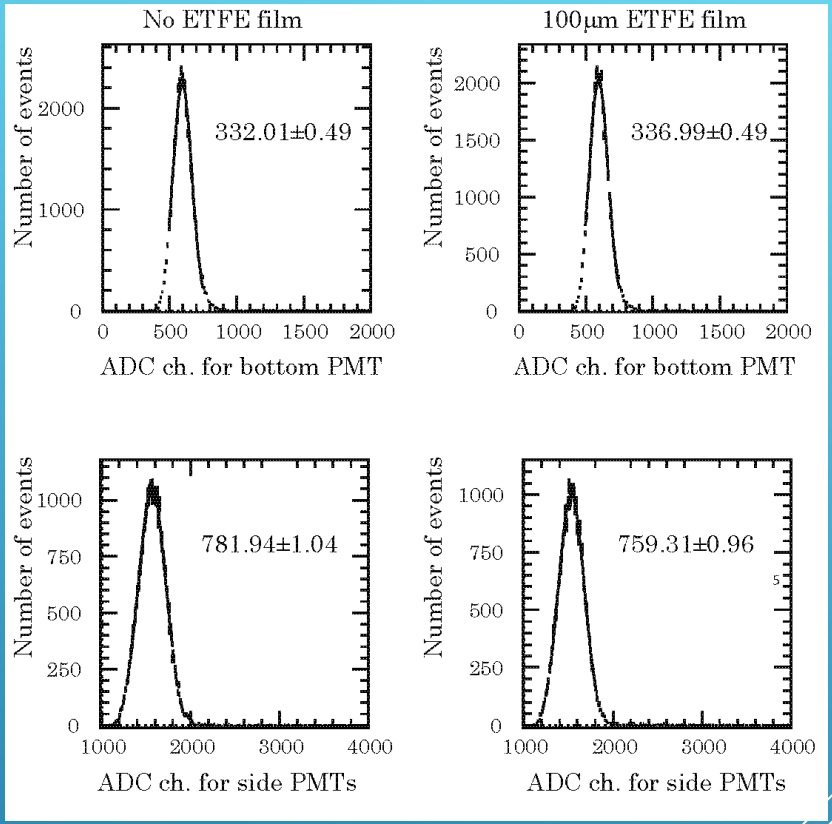


# Current status

- 2 Little of ZICOS Liquid Scintillator was prepared for 4 months.
  i. 10 wt.% for $Zr(iPrac)_4$ into Anisole in the globe box under $N_2$ gas atmosphere
  ii. 6 wt.% for PPO and 0.1wt.% for POPOP
  iii. All procedures done in class 1000 Clean booth using PFA SSC bottle.
- 9cm ETFE cubic bag was produced by Taiyo Kogyo Corporation using 100μm film.
  i. 95% transparency was obtained by LS
  ii. Chemical stability against Anisole was promised.
- Radiation Shield will consist of 10cmt Pb blocks, 3mmt OFC plates and 20mmt Al plate on Fe basis.

# ETFE cubic bag



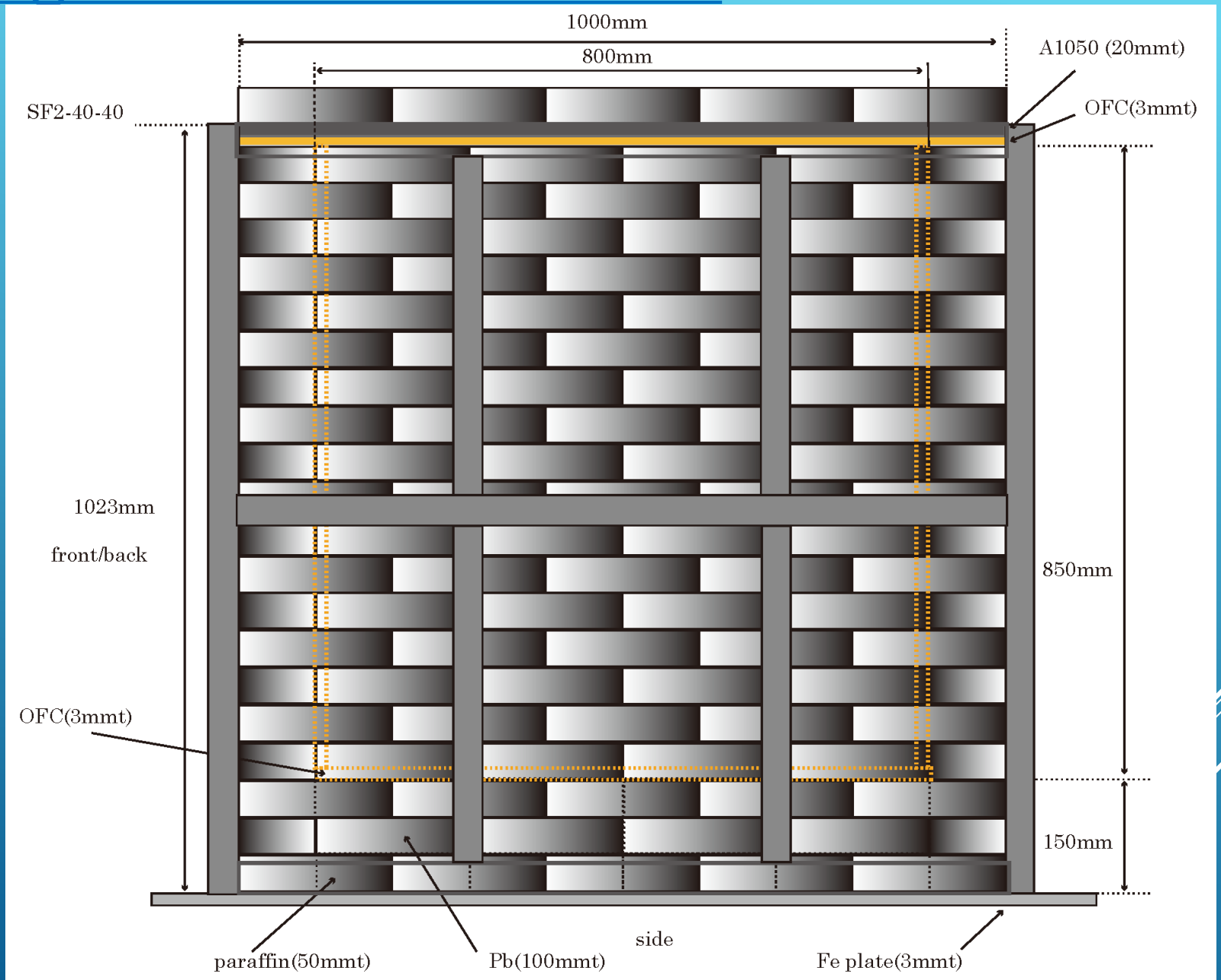




**The transparency of 100mm ETFE sheet : 0.9566 ±0.00275**

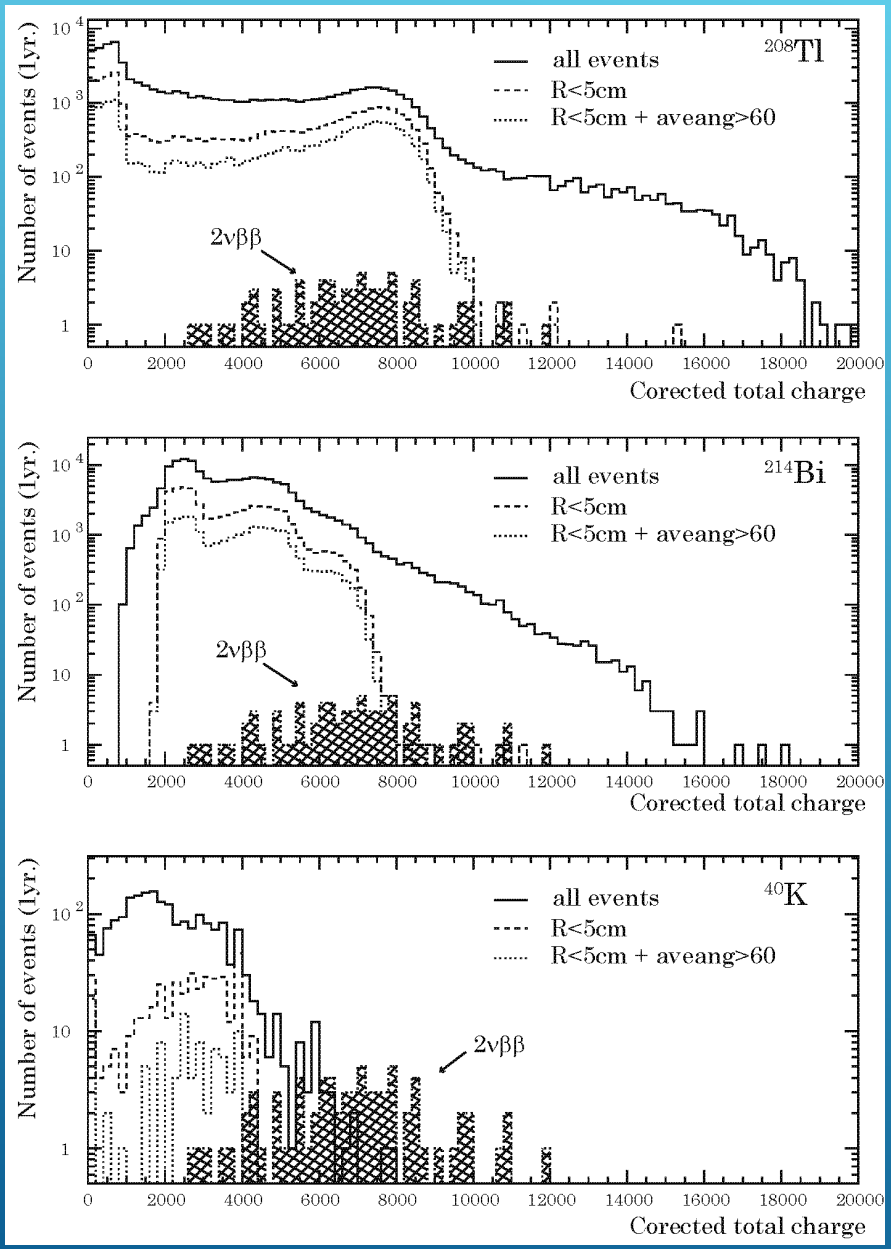
# Current status

- 2 Little of ZICOS Liquid Scintillator was prepared for 4 months.
  i. 10 wt.% for $Zr(iPrac)_4$ into Anisole in the globe box under $N_2$ gas atmosphere
  ii. 6 wt.% for PPO and 0.1wt.% for POPOP
  iii. All procedures done in class 1000 Clean booth using PFA SSC bottle.
- Prototype 10cm ETFE cubic bag was produced by Taiyo Kogyo Corporation using 100μm film.
  i. 95% transparency was obtained by LS
  ii. Chemical stability against Anisole was promised.
- Radiation Shield will consist of 10cmt Pb blocks, 3mmt OFC plates and 20mmt Al plate on Fe basis.

# Designed Radiation Shield



# BG simulation assuming ETFE cubic bag




## Assuming BGs from flask

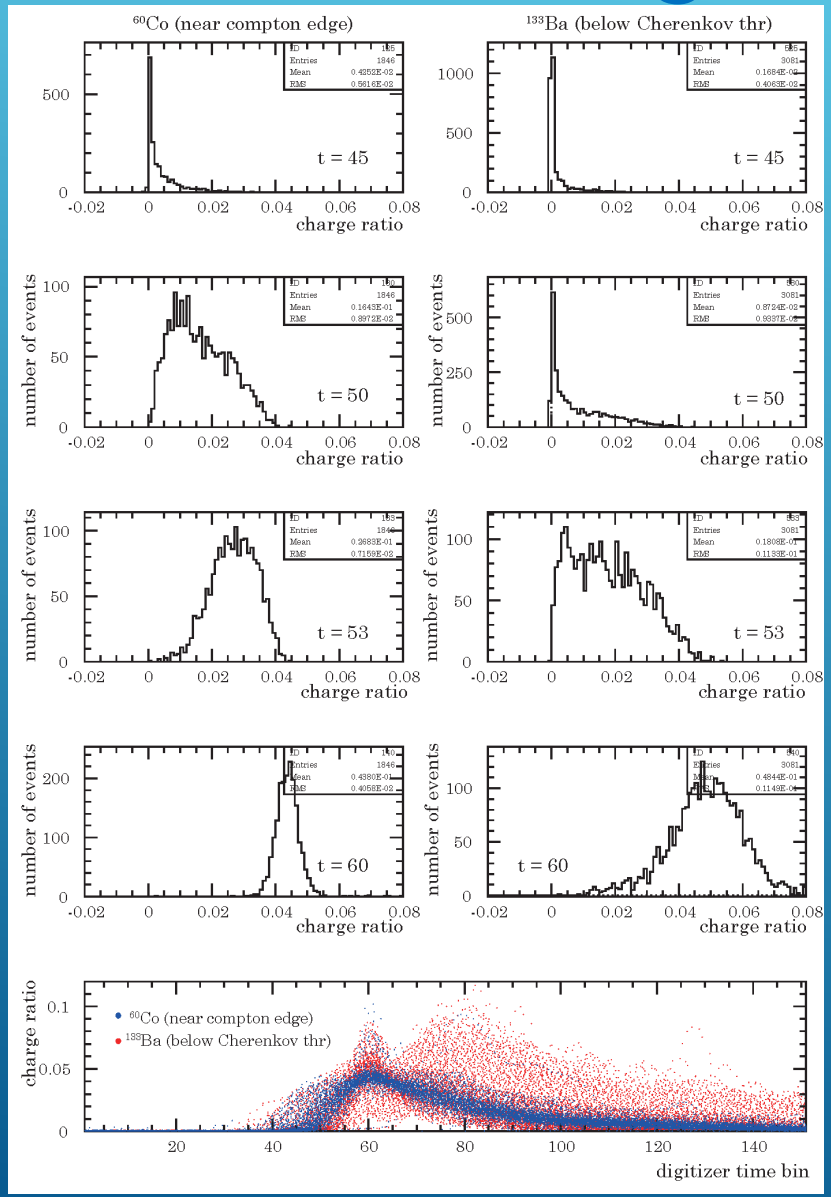
- $^{40}$K affects only part of 2νββ observation.
- $^{214}$Bi is significant BG, but small fraction of 2νββ events should be observed.
- $^{208}$Tl is most serious BG for 2νββ. A few events might be observed.

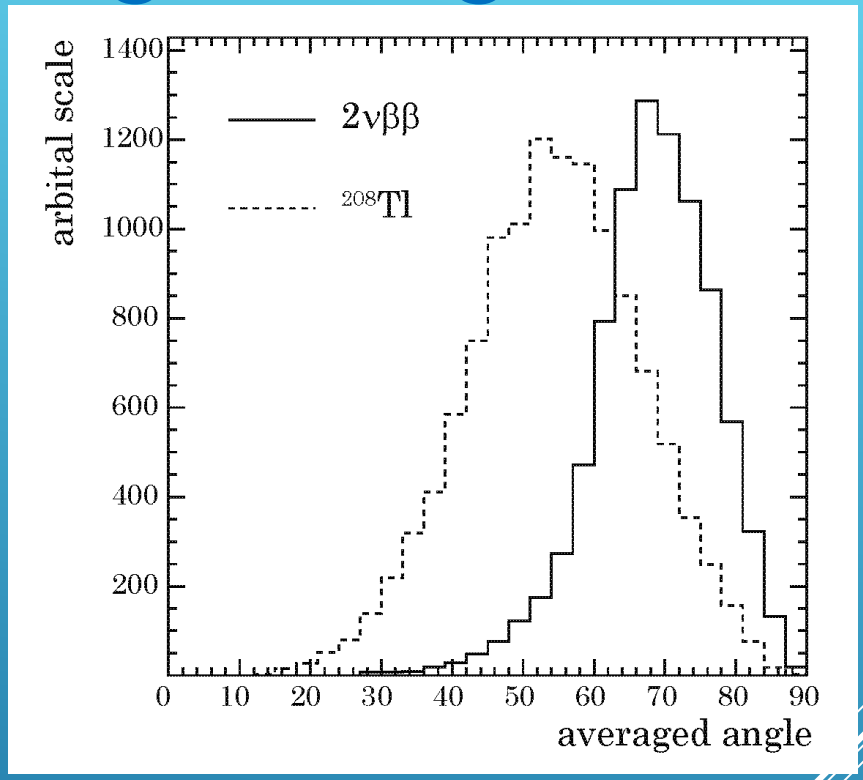
ETFE cubic bag could be useful in order to avoid beta intrusion.

# Future plans

- Accepted for ICRR Inter-University Research Program. Need permission from Kamioka Steering Committee (need to clarify both safety management and detector performance as expected).
- Detector performances such as the energy response, the vertex reconstruction, and the averaged angle will be measured as soon as possible.
- Environmental background events inside of 10cm Pb shield will be estimated by the CsI detector. (Roughly same level as flask. Need 20cm Pb shield at least)
- Actual background events should be measured by 2$\nu$-ZICOS like detector (ZICOS LS contained in ultra-pure Quartz vial with H3378-50) inside of Pb shield.

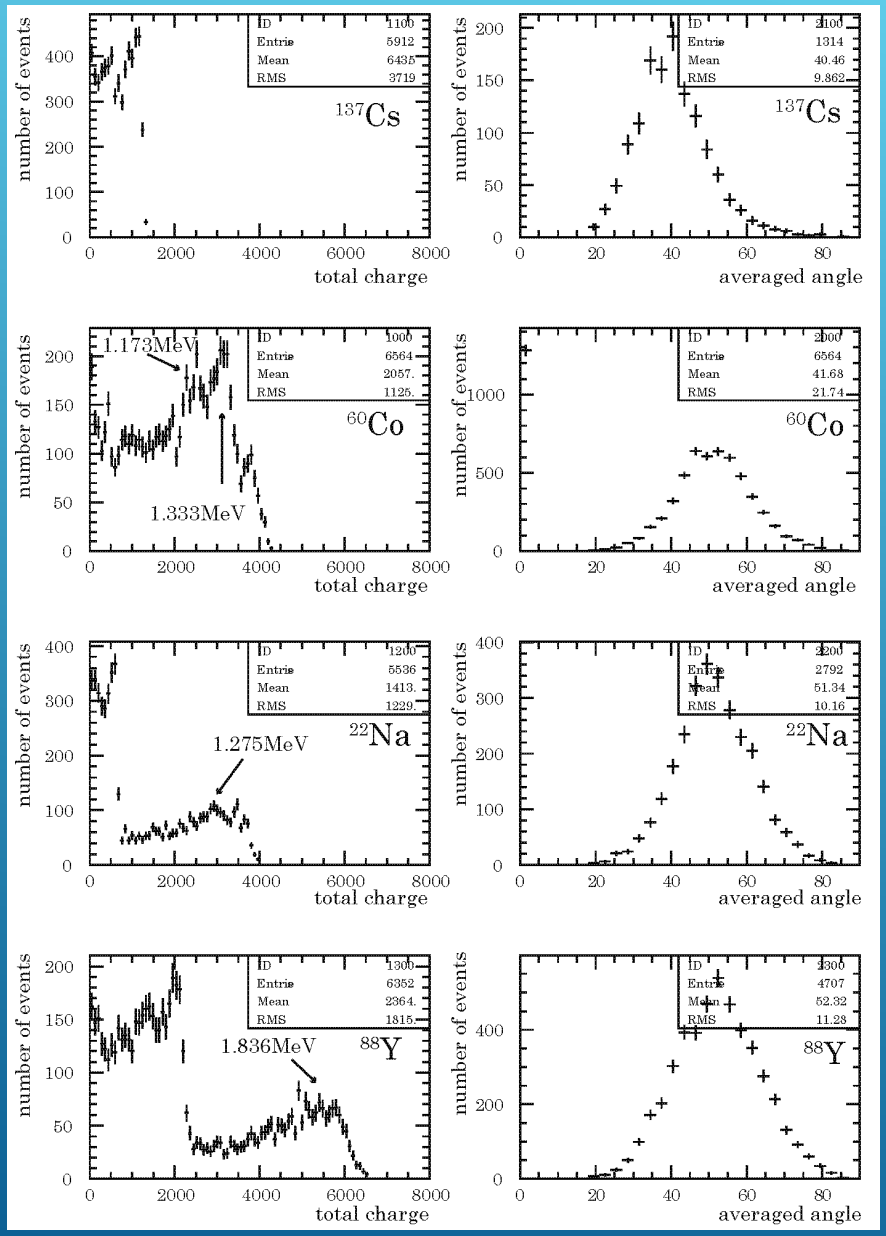
# PSD using V1742 + H3378-50 and BG reduction using averaged angle




PSD is clearly realized but BG reduction not effective due to small # of PMT.

# Response of Energy and averaged angle

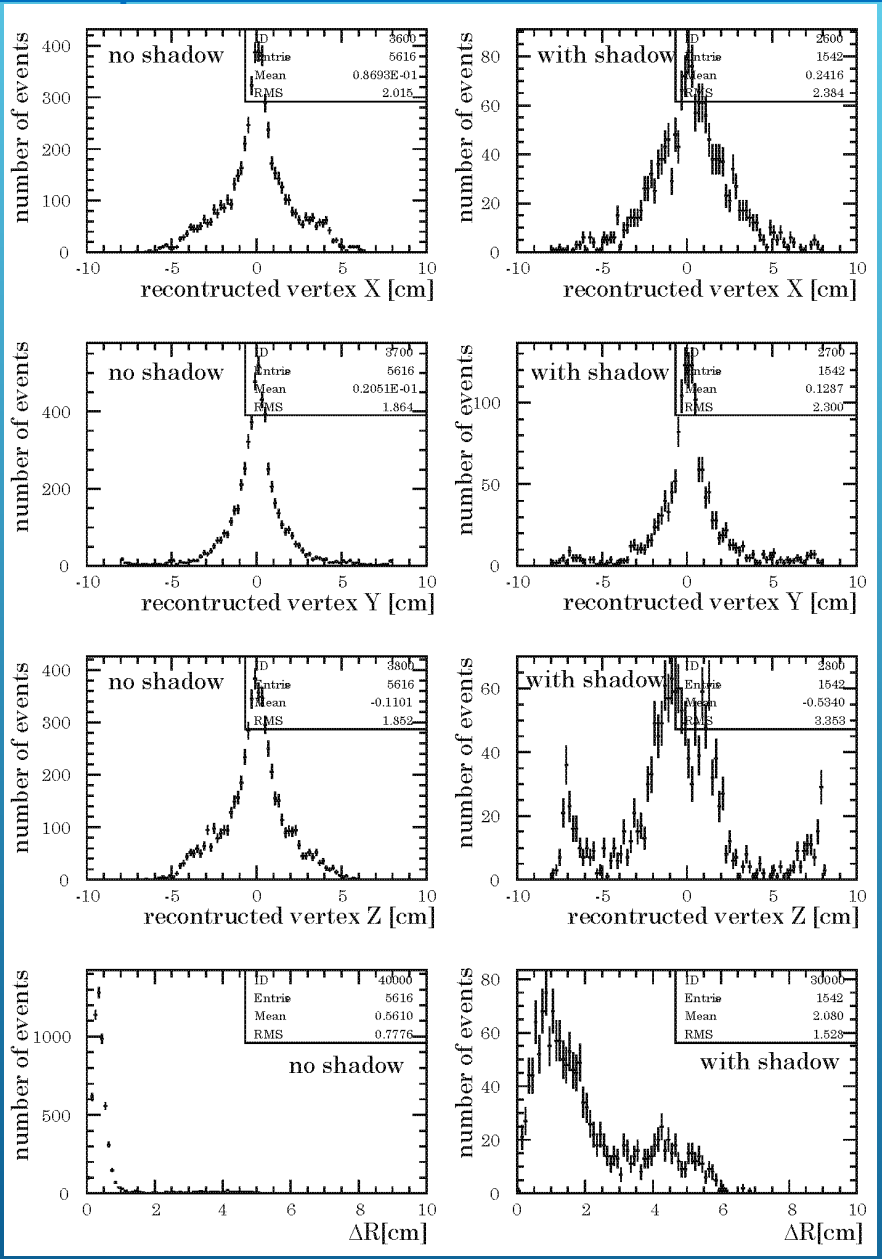


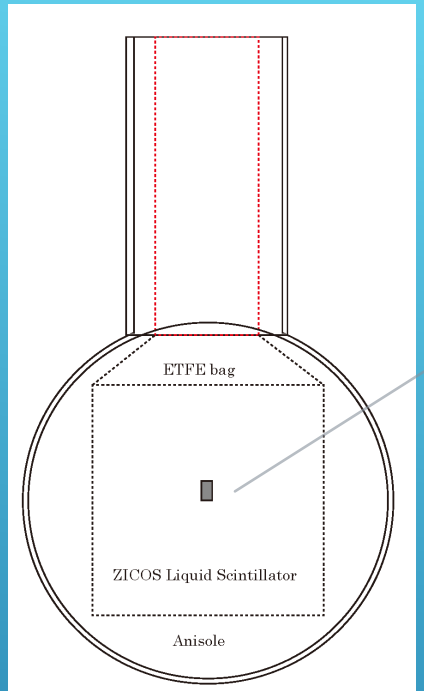

An event with E >1MeV looks have a linearity between energy and scintillation light yield. (E < 1MeV does not have a peak.)

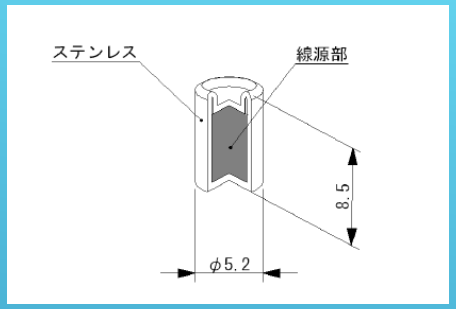
Averaged angle should be appeared around 50 degree as expected.

Both will be calibrated directly by each RI.

# Response of vertex reconstruction




日本アイソトープ協会　標準ガンマ線　516タイプ
100kBq！

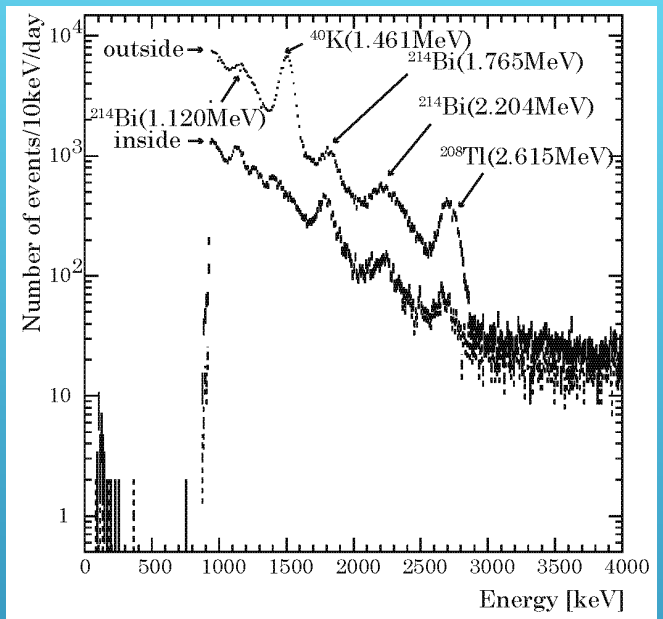
Larger pulse signal from $^{137}$Cs type 516 source will be used for calibration of vertex reconstruction.

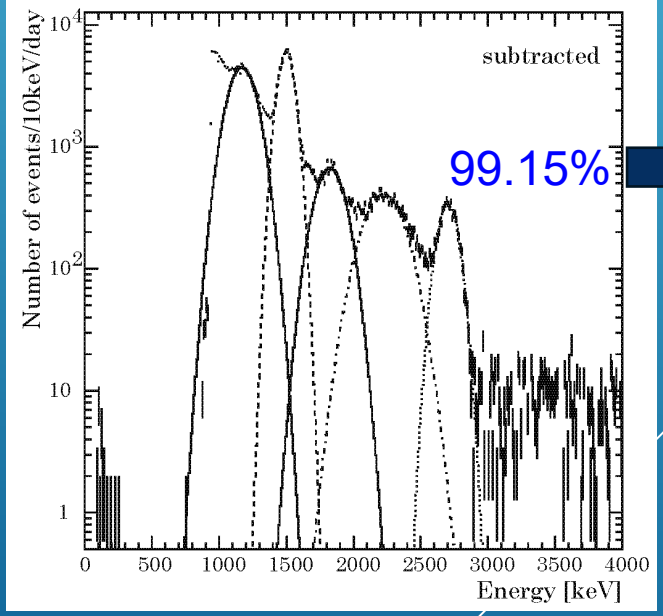
# Future plans

- Accepted for ICRR Inter-University Research Program. Need permission from Kamioka Steering Committee (need to clarify both safety management and detector performance as expected).
- Detector performances such as the energy respons, the vertex reconstruction, and the averaged angle will be measured as soon as possible.
- Environmental background events inside of 10cm Pb shield will be estimated by the CsI detector. (Roughly same level as flask. Need 20cm Pb shield at least)
- Actual background events should be measured by 2ν-ZICOS like detector (ZICOS LS contained in ultra-pure Quartz vial with H3378-50) inside of Pb shield.

# 10cm mini Pb shield and CsI detector






**20cmPb**
**99.993%**

# Future plans

- Accepted for ICRR Inter-University Research Program. Need permission from Kamioka Steering Committee (need to clarify both safety management and detector performance as expected).
- Detector performances such as the energy respons, the vertex reconstruction, and the averaged angle will be measured as soon as possible.
- Environmental background events inside of 10cm Pb shield will be estimated by the CsI detector. (Roughly same level as flask. Need 20cm Pb shield at least)
- Actual background events should be measured by 2ν-ZICOS like detector (ZICOS LS contained in ultra-pure Quartz vial with H3378-50) inside of Pb shield.

# Future plans (cont.)

- Construction schedule after the permission.
  i. Order 3mmt OFC plates, 20mmt A1050 plate and other related stuffs to Pb shield. (a few months)
  ii. Move all stuffs to LAB-A in the mine. (within this year)
  iii. Install clean booth and setup Pb shield inside the clean booth at LAB-A. (~1 month on Jan 2025)
  iv. Install some WEB cameras and temperature monitors for the slow remote monitor.
  v. Setup 2$\nu$-ZICOS detector and move inside Pb shield. (1~2 months until the end of March 2025)
  vi. Data taking hopefully will start in April 2025 with my sabbatical (?).

# For measurement of world's longest half-life of $^{96}$Zr 2νββ and search for 0νββ events

- Need more clean Quartz than GE214 to reduce $^{208}$Tl BG. There should exist more pure Quartz.
- Need more $^{96}$Zr. 30cm diameter flask will contain 8L LS corresponding to 3g $^{96}$Zr which is a bit larger amount as NIMO-3. Also No. of mounting PMT should be 50 which is same # as UNI-ZICOS.
- Need enrichment of $^{96}$Zr. Try to Gas Centrifuge using $ZrCl_4$ to be 3 times concentration with JNFL. 10g $^{96}$Zr will be much larger amount than NIMO-3.
- Might need distillation of Anisole, PPO and POPOP.
- 100g $^{96}$Zr will be first target for 0νββ search with 100cm diameter flask even without the enrichment.

# Other Ultra-Pure Quartz candidates

製品グレード

Momentive Tech.

| | |
|---|---|
| グレード | 214™ |
| 概要 | 標準的な高純度石英 |
| 純度 | >99.995% $SiO_2$ |
| アプリケーション | ランプ、半導体、光ファイバーなど幅広く対応 |
| グレード | 224™/224LD |
| 概要 | 低Al＋低アルカリ石英 |
| 純度 | >99.995% $SiO_2$, Na/K/Li <0.5ppm |
| アプリケーション | 高純度半導体用途 |
| グレード | 244™ |
| 概要 | 低Al＋低アルカリ石英 |
| 純度 | >99.995% $SiO_2$, Al<8 ppm, Na/K/Li <0.5ppm |
| アプリケーション | 高純度半導体用途、プロジェクションランプ |
| グレード | 219 |
| 概要 | Tiドープ石英による紫外線カット |
| 純度 | >99.998% $SiO_2$ |
| アプリケーション | 紫外線からの保護が必要なランプの用途 |
| グレード | 021™ |
| 概要 | 合成超高純度石英 |
| 純度 | >99.9999% $SiO_2$ |
| アプリケーション | UV清浄化；超高純度半導体用途 |

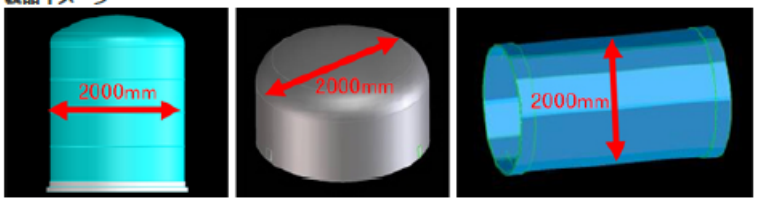
nalysis of quartz (ppm)

| | | | | |
|---|---|---|---|---|
| 1.1 | <1.0 | 2.8 | 6.5 | 3.5 |
| <0.05 | | | | |
| 0.2 | 1.0 | | | |
| <0.10 | 1.0 | | | |
| | | 0.1ppb | 0.1ppb | <0.03ppb |

**最大サイズΦ2000mm級チューブの実現！！**

設備能力的には外径2000mmを超えるチューブ状製品の製造が可能です。 クアーズテック

製品イメージ




※角型タイプへの対応も可能ですのでご相談下さい。

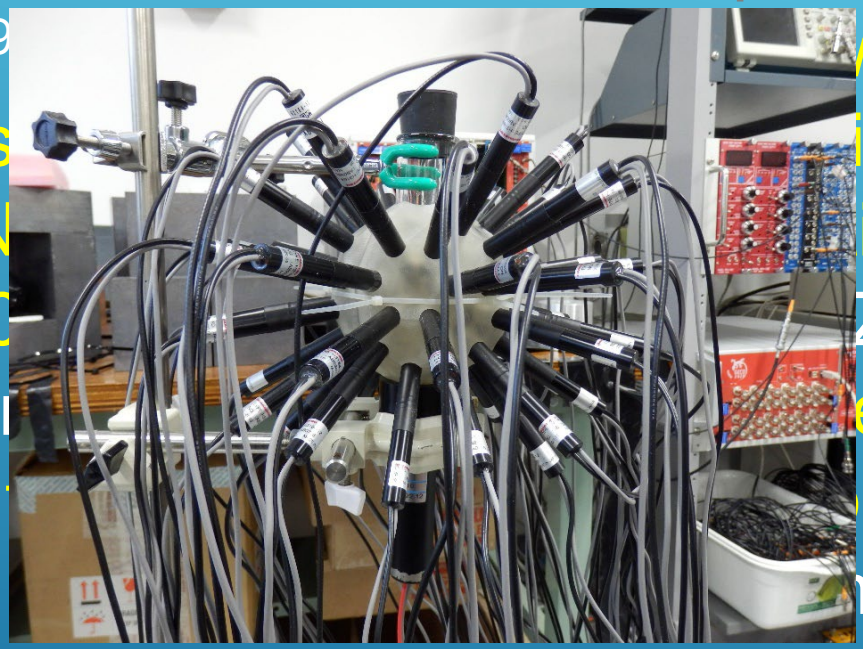
グレード別化学分析例

[ppm]

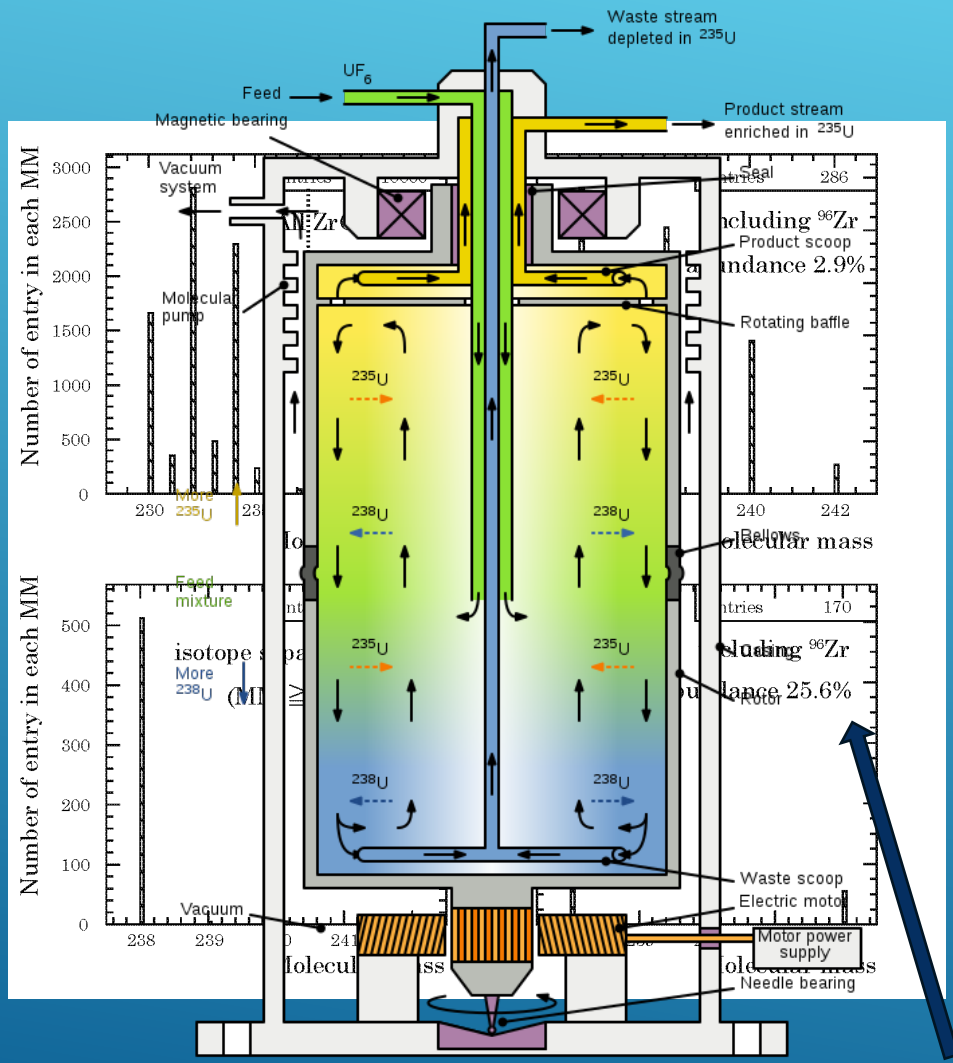
| グレード | Al | Fe | Na | K | Cu |
|---|---|---|---|---|---|
| T-1030 | 8 | 0.3 | 0.8 | 0.2 | 0.02 |
| T-1630S | 8 | 0.3 | 0.05 | 0.05 | <0.01 |
| T-1930S | 8 | 0.3 | 0.05 | 0.05 | <0.01 |
| T-4040 | 0.1 | 0.05 | 0.05 | 0.05 | <0.01 |
| T-6040 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| T-2030 | 8 | 0.5 | 1.0 | 1.0 | 0.02 |
| T-2630 | 8 | 0.3 | 0.4 | 0.2 | <0.01 |

# For measurement of world's longest half-life of $^{96}$Zr 2νββ and search for 0νββ events

- Need more clean Quartz than GE214 to reduce $^{208}$Tl BG. There should exist more pure Quartz.
- Need more $^{9}$ will contain 8L LS corres is a bit larger amount as N ing PMT should be 50 ZICOS.
- Need enrichi entrifuge using $ZrCl_4$ n with JNFL. 10g $^{96}$Zr will han NIMO-3.
- Might need distillation of Anisole, PPO and POPOP.
- 100g $^{96}$Zr will be first target for 0νββ search with 100cm diameter flask even without the enrichment.



# $^{96}$Zr isotope separation by Gas Centrifuge




JNFL staffs of Technical Development Center for Uranium Enrichment are looking for new idea for isotope separation using their Centrifuge plant.

Proposed $^{96}$Zr separation using $ZrCl_4$ (bp 331 ℃)

Sublimation pressure :

100 ℃ ⟺ 0.25Pa?

50 ℃ ⟺ $1.4 \times 10^{-3}$Pa?

Need measurement!

25% enrichment may be possible by gas centrifuge.

# Thermo Gravimetric Analysis(TGA)

2024/07/04 22:54 真空制御差動型示差熱天秤 - 技術紹介 | i³-opera(アイキューブオペラ)

i³-opera
トップ
i³-operaについて
事業内容
技術紹介
新着情報
施設概要 / アクセス
文科省プロジェクト
お問い合わせ
プライバシーポリシー
科研費規程
EN
JP

## 住化分析センター

## 九州大学　i3-OPERA

【熱重量分析】

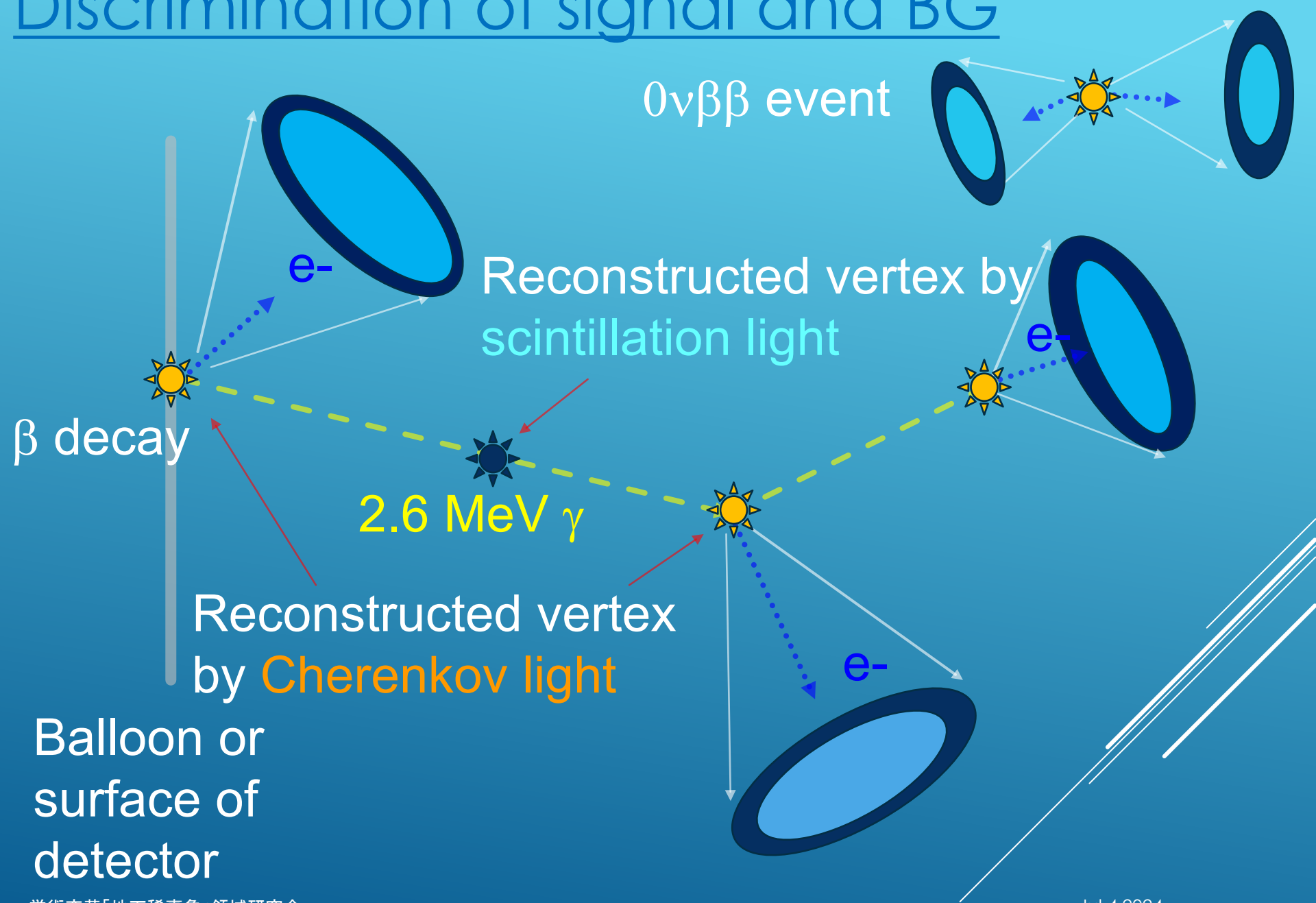
有機EL材料の真空下における熱重量分析(Thermo Gravimetric Analysis: TGA)は、揮発成分の有無や材料分解温度の確認ができるため、蒸着膜作製プロセスや昇華精製プロセスの設計のための情報収集には有効な測定方法です。

# For measurement of world's longest half-life of $^{96}$Zr 2νββ and search for 0νββ events

- Need more clean Quartz than GE214 to reduce $^{208}$Tl BG. There should exist more pure Quartz.
- Need more $^{96}$Zr. 30cm diameter flask will contain 8L LS corresponding to 3g $^{96}$Zr which is a bit larger amount as NIMO-3. Also No. of mounting PMT should be 50 which is same # as UNI-ZICOS.
- Need enrichment of $^{96}$Zr. Try to Gas Centrifuge using $ZrCl_4$ to be 3 times concentration with JNFL. 10g $^{96}$Zr will be much larger amount than NIMO-3.
- Might need distillation of Anisole, PPO and POPOP.
- 100g $^{96}$Zr will be first target for 0νββ search with 100cm diameter flask even without the enrichment.

# backup

# Discrimination of signal and BG



# Background estimation

U/Th in GE214 using ICP Mass spectrometer :

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

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

$^{40}$K : 0.021ng/g corresponds to $5.59 \times 10^{-6}$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