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世界最高感度観測実験

第11回「極低放射能技術」研究会

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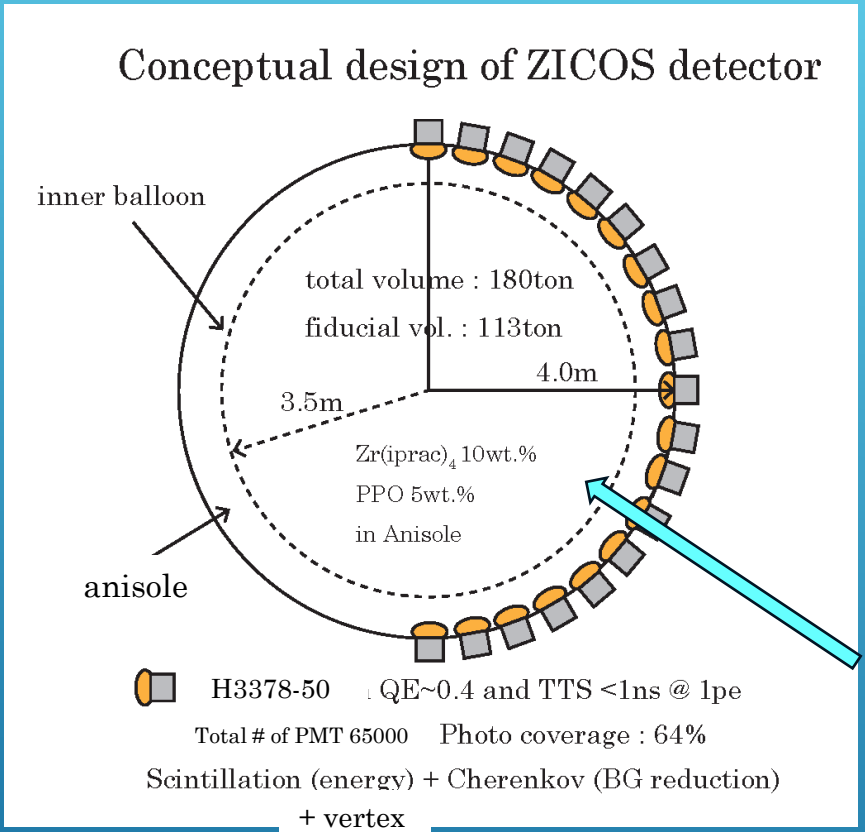
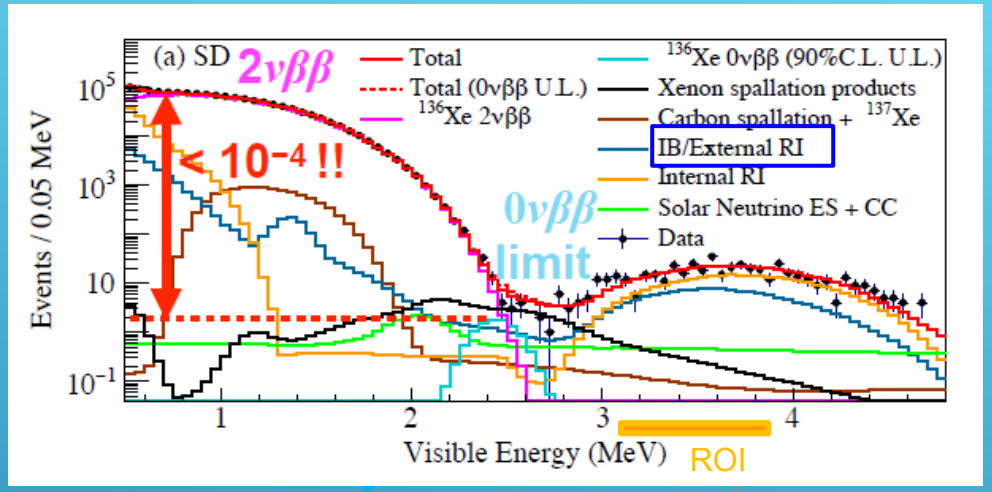
ZICOS experiment for ^{96}Zr 0νββ observation





I.Shimizu, Plenary talk at Neutrino2024 conference.

Liquid scintillator loaded ^{96}Zr

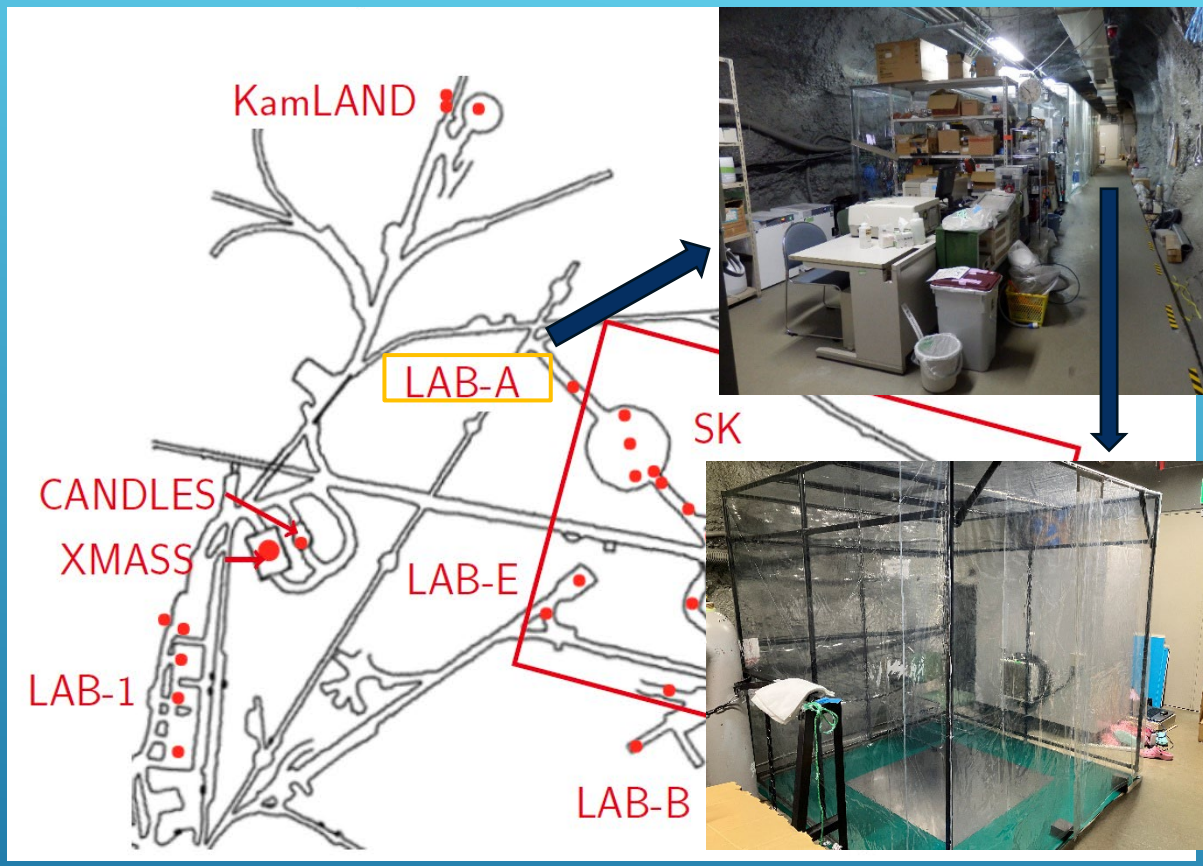
NEMO3 : $T_{1/2}^{0\nu} > 9.1 \times 10^{21}$ yrs

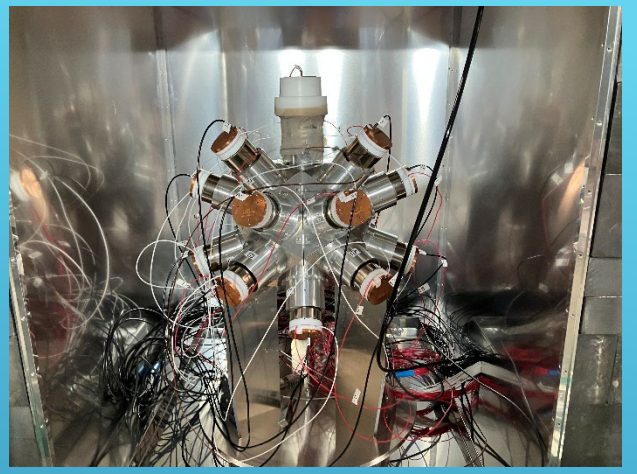
^{96}Zr : 45 kg (nat.) → 865 kg(50 % enrich)→1/20 BG

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

Mar 6,2026

2ν-ZICOS for measurement of ^{96}Zr 2νββ events

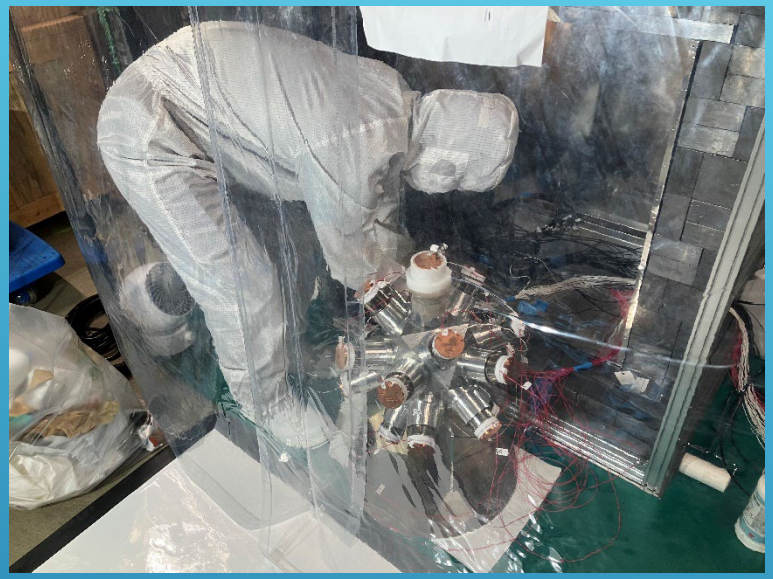


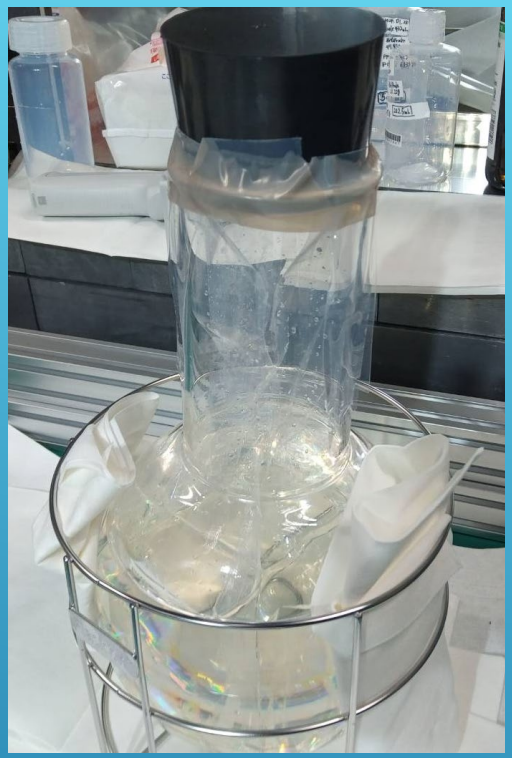


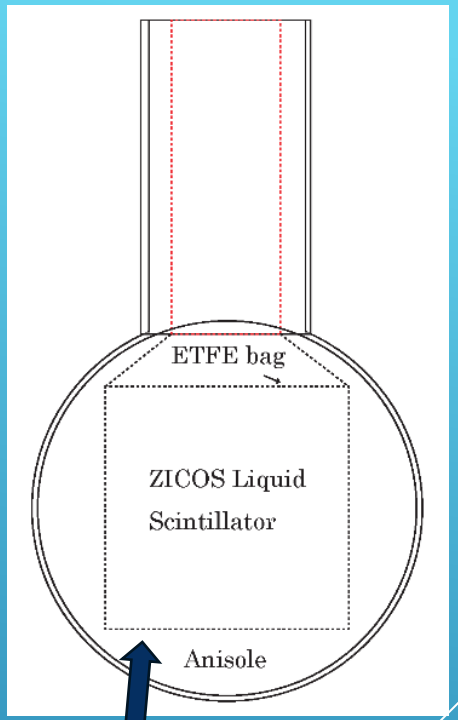
- Clean booth was built in Lab-A at Kamioka mine.
- 650 Pb blocks was used for radiation shield with 15cm thickness.
- All safety issues such as fire alarm, leak sensor etc were installed before starting experiment.

The first data taking implemented over 50 hours from November 22nd to 25th.

2ν–ZICOS detector



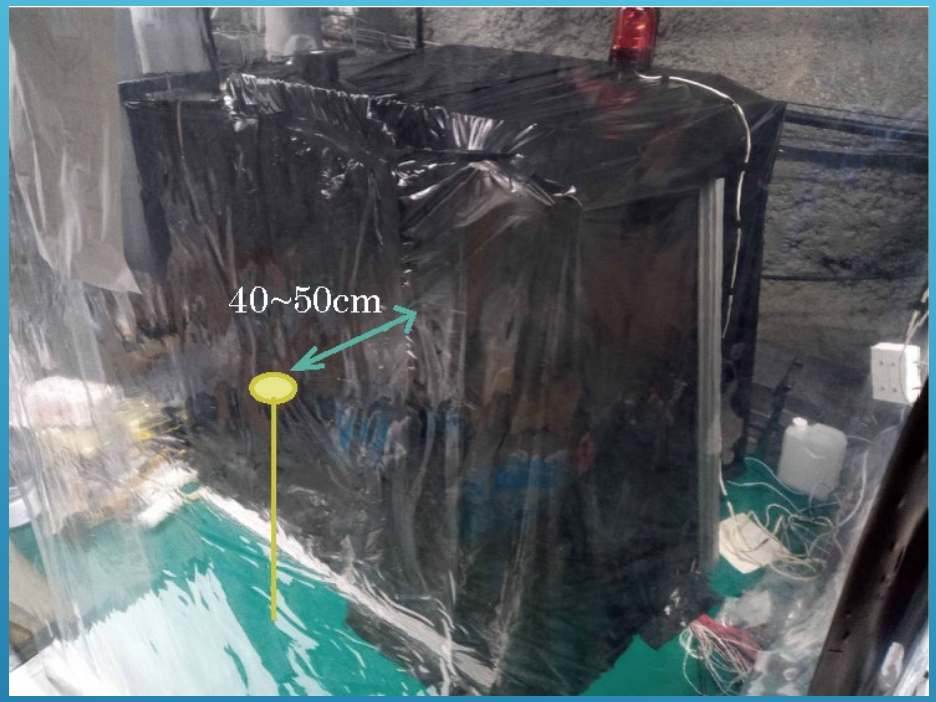




- 20 2” Ultra Low BG PMT Hamamatsu R10789.
- 16 cm diameter round bottom flask using pure Quartz GE214.
- 0.724L of ZICOS LS loaded 69g of $Zr(iPrac)_4$ including ^{96}Zr 0.27g.
- Expected $2\nu\beta\beta$ events ~70/yr

9cm cubic ETFE bag for reducing external BG events

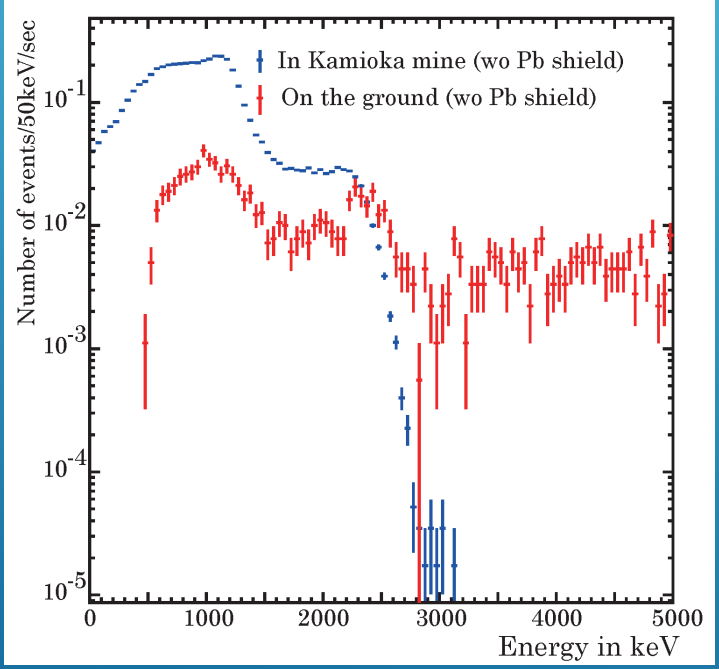
Energy calibration and DAQ for 2ν-ZICOS detector



- ^{137}Cs, ^{60}Co and ^{22}Na source were used for energy calibration. (please look at Kato-san's poster P4)
- Those sources were located at front of Al wall.
- All data were recorded by V1742 digitizer.

Data taking in 2025

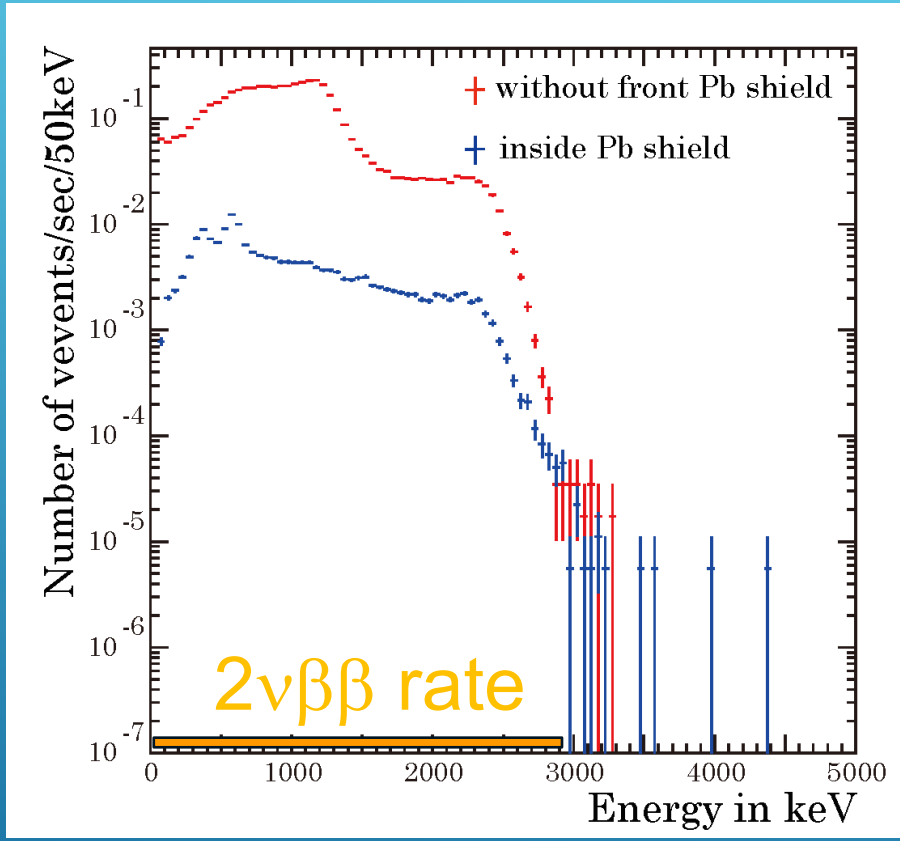
- Period : 2025.Nov.22nd – 26th
- Calibration was done before and after BG run.
- Background run without front Pb shield : 100800sec
- Background run inside Pb shield : 180000 sec



- Only few muons were observed even half day measurement.
- Environmental γ events from ^{40}K and ^{208}TI were observed in case of without front Pb shield.
- Those amount was about 10 times higher than events on the ground.

At maximum, an environment γ event rate might be 100 times higher than event rate on the ground.

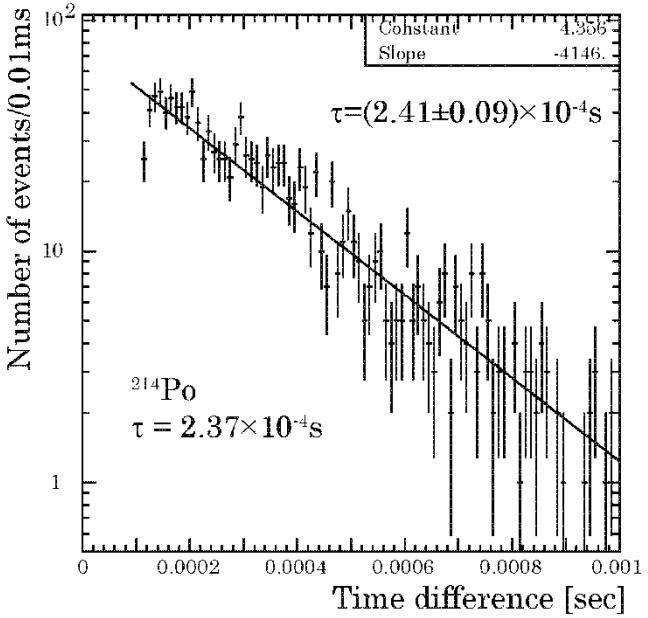
Background events observed in Pb shield

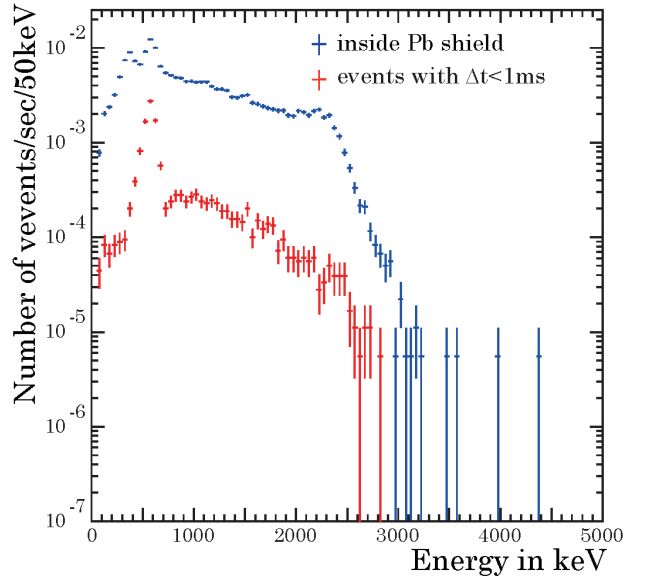


- 2.615MeV γ events from ^{208}Tl were observed.
- Despite of 10^{-4} reduction for environmental γ with 15cm Pb shield, BG rate was 3 order magnitude higher than expected rate.
- Peak around 600keV.
- Shoulder events above 2.6MeV

Measured event rate is over 4 order magnitude higher than expected 2νββ event rate (~10^{-7} event/s/50keV)

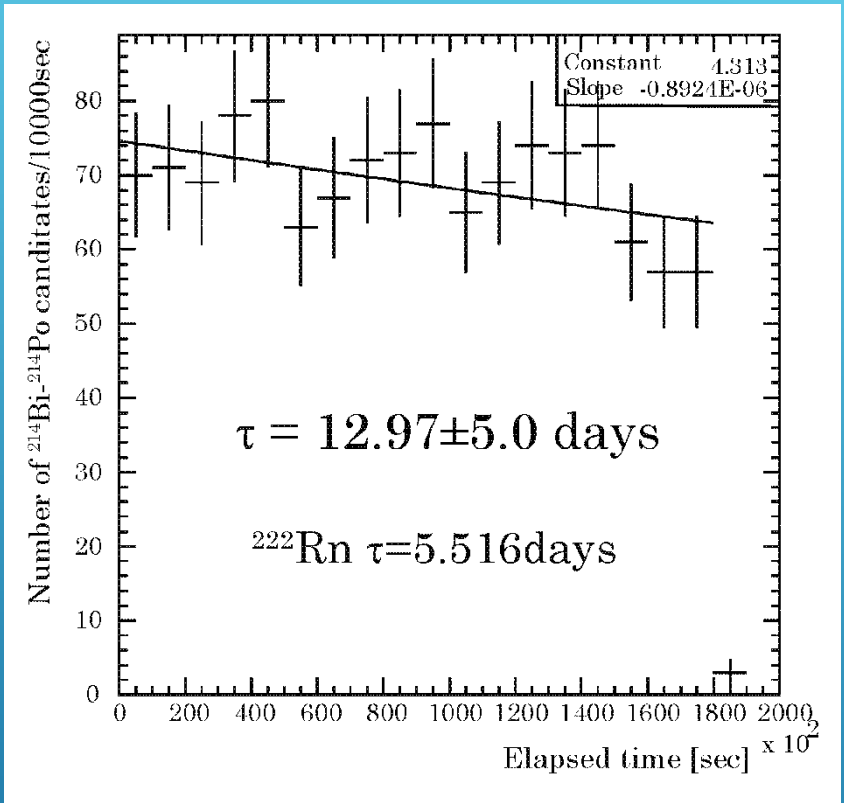
^{214}Bi-^{214}Po candidates

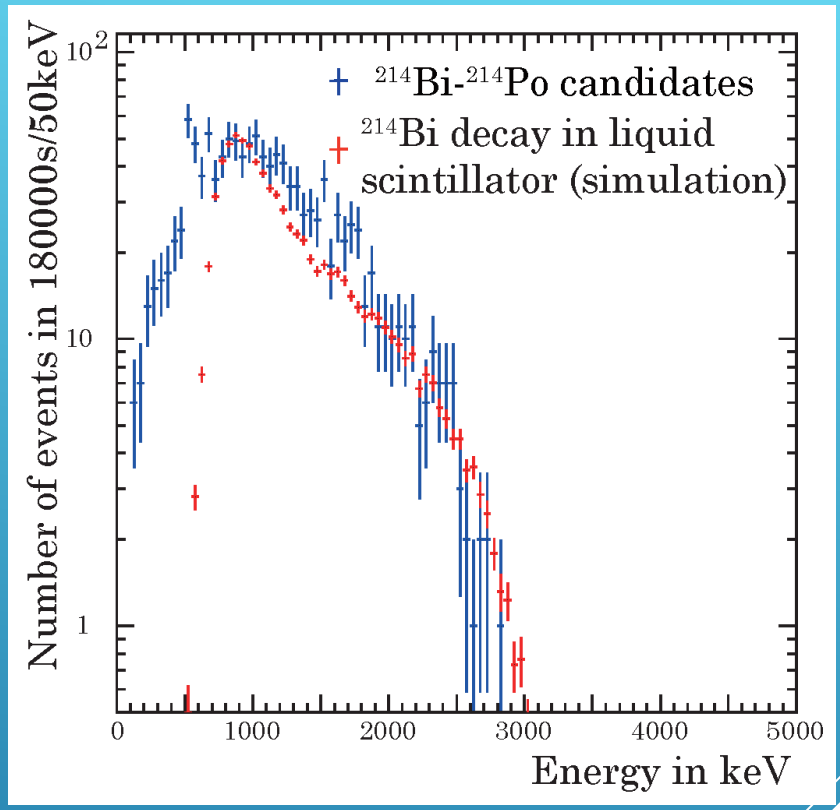




- 0.1ms< Δt<1ms 1250events (+650events). No event Δt<0.1ms due to dead time.
- Time slop is consistent with ^{214}Po lifetime.
- Parent events look have a β spectrum of ^{214}Bi decay.
- Peak at ~600keV should be caused by αs of ^{214}Po decay.
- Amount of ^{214}Bi β decay events are 3 order magnitude higher than 2νββ event rate.

^{222}Rn contaminated in liquid scintillator?

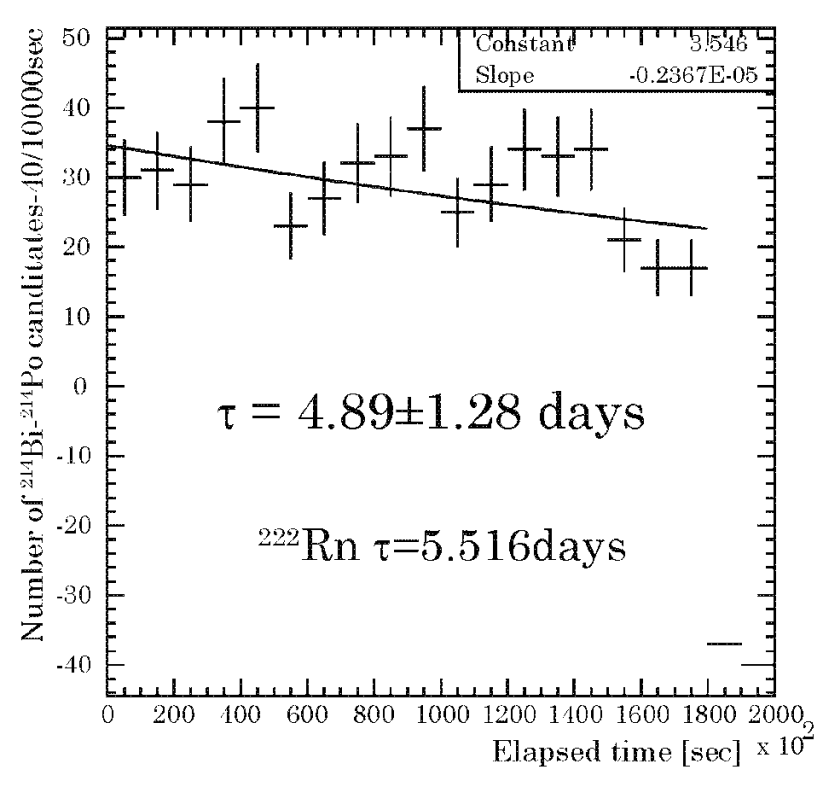


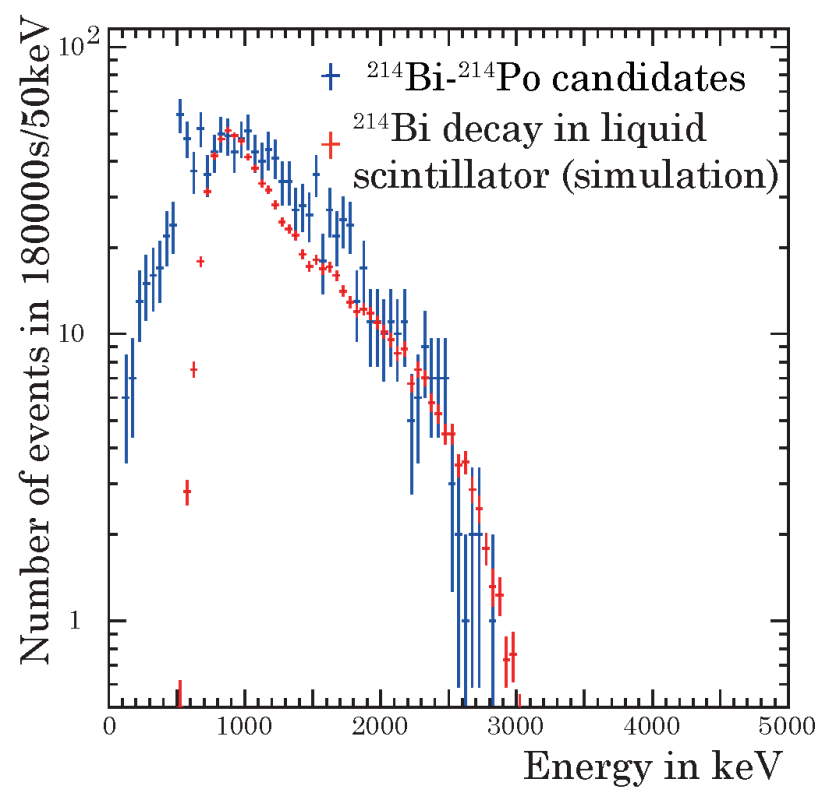


Slope is inconsistent with lifetime of ^{222}Rn decay.($T_{1/2}$=3.8235days)

Spectral shape is almost consistent with ^{214}Bi β decay in LS obtained by simulation.

^{222}Rn contaminated in liquid scintillator?





Slope is consistent with lifetime of ^{222}Rn decay, if 40events/10000s due to ^{226}Ra decay constantly.

Spectral shape is almost consistent with ^{214}Bi β decay in LS obtained by simulation.

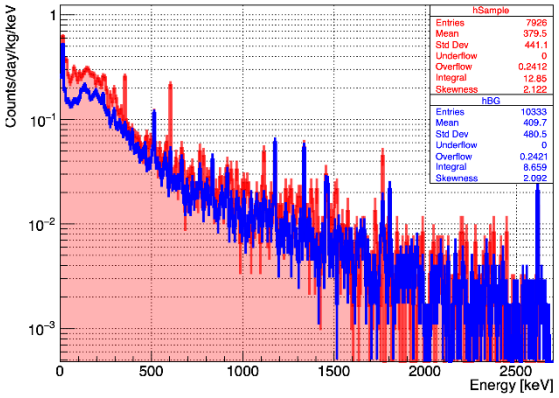
Background measurement using Ge detector

2024/11/07 LabC02

ZICOS LS

sample 224.6g, 35.2days

Unit: mBq/kg



summary table

unit : mBq/kg

U	value	error	limit
234Th	−8.75	10.21	13.07
234Pa	49.10	55.15	119.69
226Ra	−13.43	90.67	116.06
214Pb	0.26	3.30	4.48
214Bi	2.72	1.33	4.42
210Pb	98.94	55.91	170.51
Mid.U-chain	2.72	1.33	4.42
UpperU-ch	−6.83	10.04	12.85

Th	value	error	limit
228Ac	1.85	1.96	4.36
212Pb	2.38	1.66	4.51
212Bi	0.69	7.94	10.85
208Tl	−2.20	1.43	1.83
Th-chain	−2.11	1.41	1.80

	value	error	limit
60Co	−0.063	0.607	0.777

	value	error	limit
40K	6.03	7.40	15.50

	value	error	limit
137Cs	−0.14	0.76	0.97
134Cs	0.04	0.53	0.72

	value	error	limit
235U	0.56	5.01	6.97
231Th	7.46	10.10	20.38
231Pa	−26.28	39.40	50.44
227Th	3.94	9.07	15.55
below223Ra	−3.86	2.57	3.28

	value	error	limit
54Mn	−0.63	0.58	0.75
58Co	0.19	0.50	0.83
176Lu	−0.57	0.52	0.66

	value	error	limit
138La	0.41	1.40	2.20

BG：BG_20240909.dat

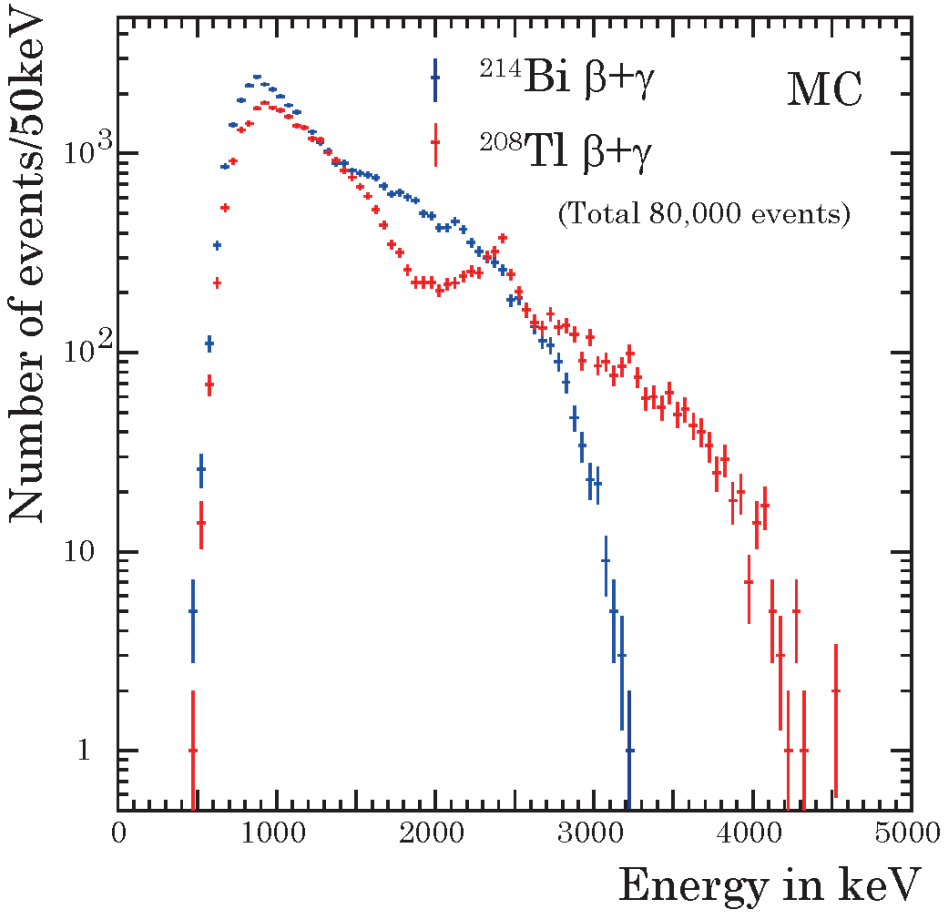
eff：20241107_ZICOS_LS.eff

^{238}U upper (^{238}U)	^{238}U middle (^{226}Ra)	Th-chain (^{228}Ra)	Th-chain (^{228}Th)	U-235 (^{235}U)	U-235 (below^{223}Ra)	K-40	Co-60	Cs-137	Lu-176
<12.85	2.72±1.33	<4.36	<1.80	<6.97	<3.28	<15.50	<0.777	<0.97	<0.66

2.72±1.33mBq/kg ⟺ 5.7mBq/kg (constant)

Almost consistent with measured value by Ge

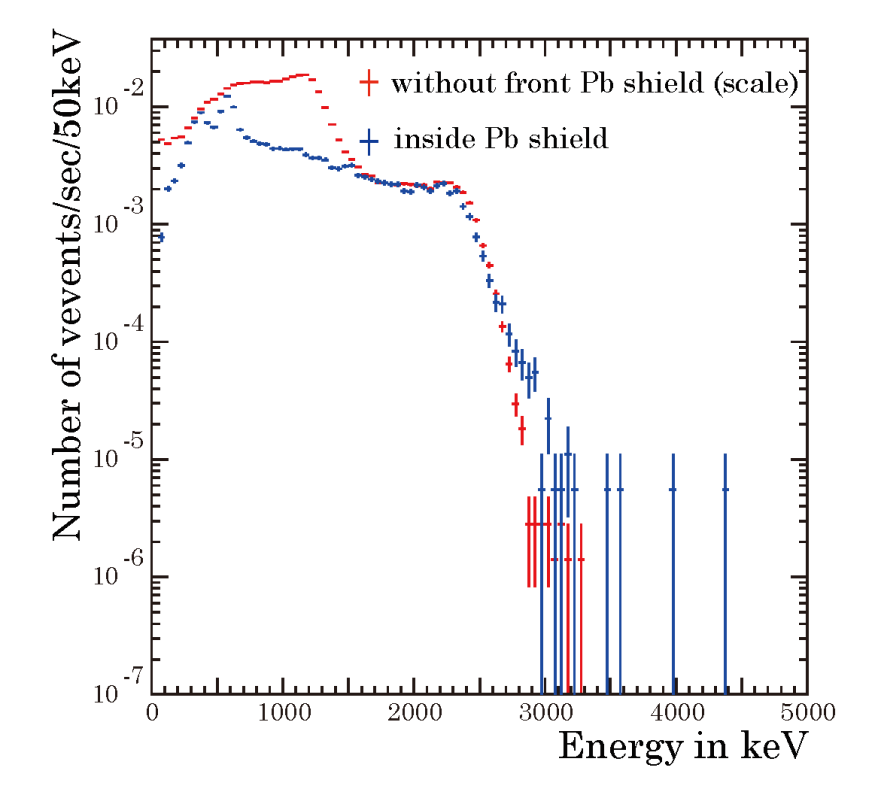
How much amount of Th-chain in LS?

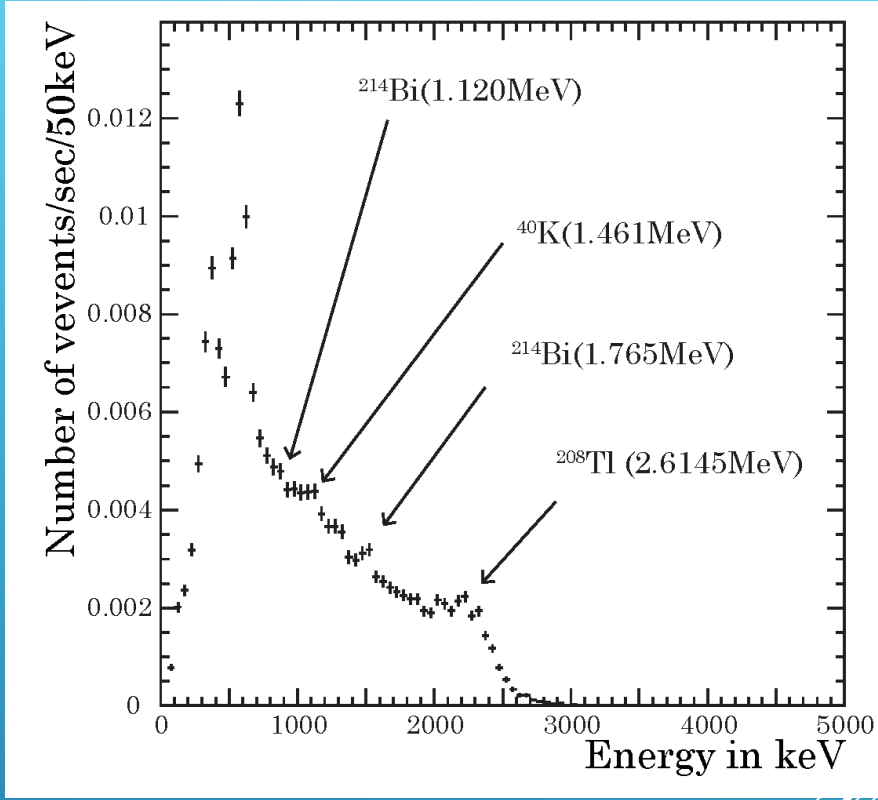


Energy spectrum of ^{208}Tl beta decay should have a higher energy tail than that of ^{214}Bi beta decay.

Not so much Th-chain background exist in liquid scintillator.

What is major source of measured events ?





Spectral shape around 2.4MeV is consistent with 2.6145MeV γ from ^{208}Tl.

Major gamma spectra from U/Th series and ^{40}K were observed.

Background γ events from Quartz

単位：ng/g

試料名	K	Th	U
テトラキス（アセト酢酸イソプロピル）ジルコニウム	-	-	-
定量下限	400	50	50

※表中の「－」表記は、定量下限以下であることを示します。

単位：ng/g

試料名	K	Th	U
四塩化ジルコニウム	-	-	-
定量下限	200	50	50

※表中の「－」表記は、定量下限以下であることを示します。

単位：ng/g

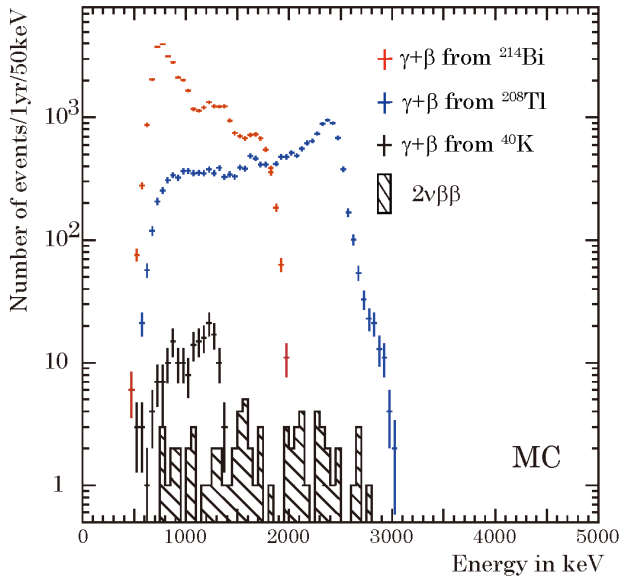
試料名	K	Th	U
RQ200	330	42	64
GE214	180	15	29
定量下限	5	1	1

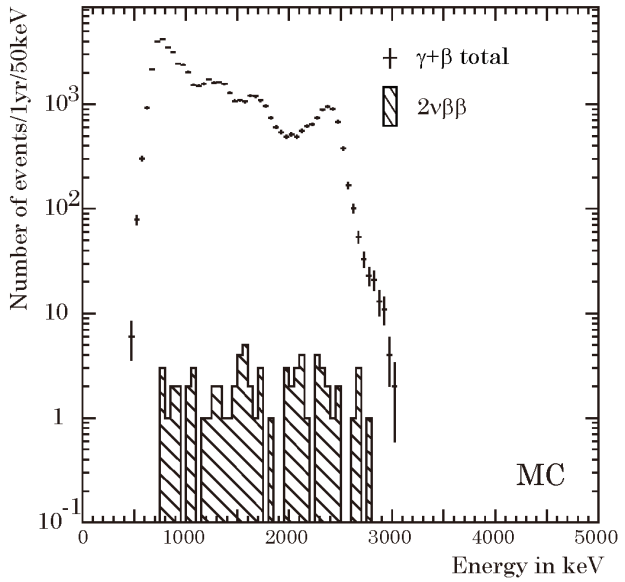
^{232}Th : 6.09 × 10^{-5}Bq/g

^{238}U : 3.58 × 10^{-4}Bq/g

^{40}K : 5.59 × 10^{-6}Bq/g

3 order magnitude higher level



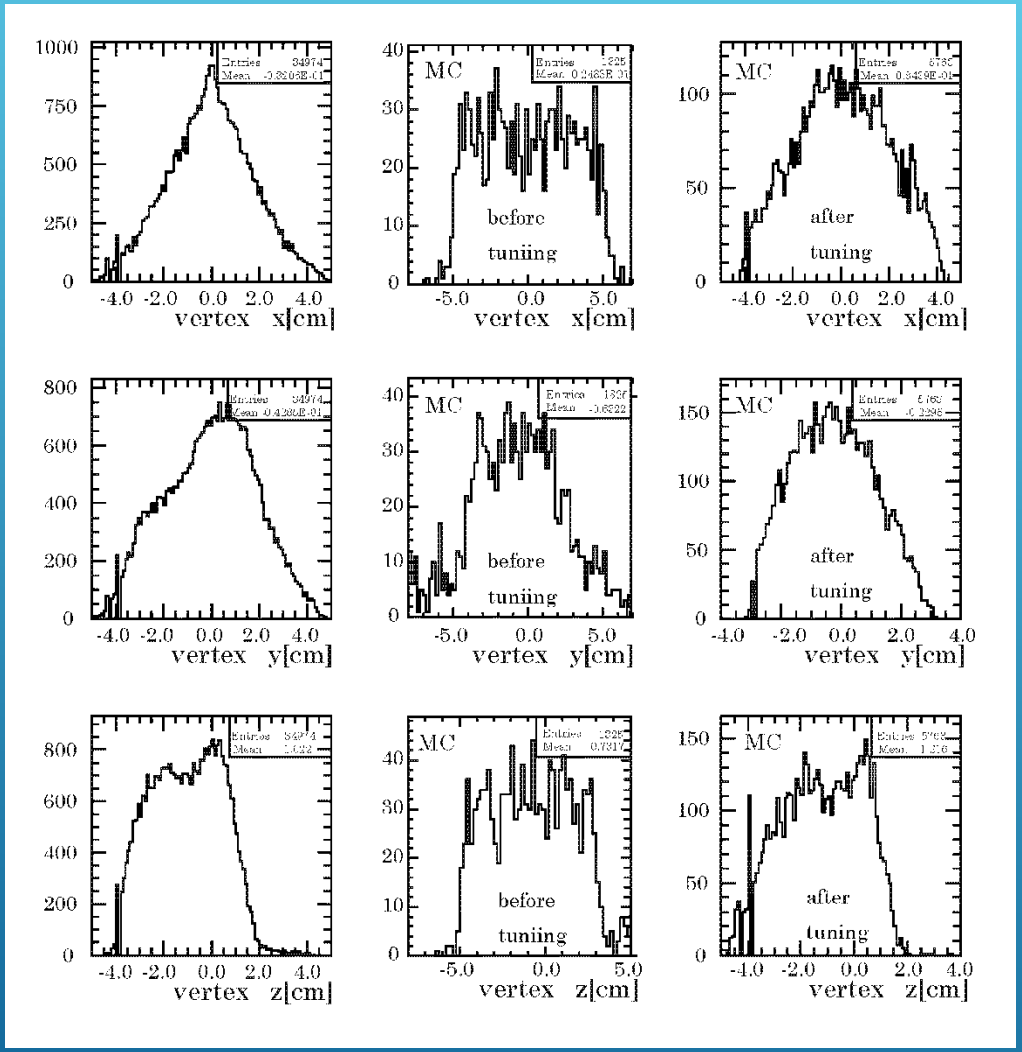


Present status and future plan

- Measured background event rate is over 4 order magnitude higher than expected $2\nu\beta\beta$ event rate.
- Clear 1250 events of ^{214}Bi-^{214}Po candidates were observed. It is almost 3 order magnitude higher, so we need distillation for Anisole and review for synthesis process of $Zr(iPrac)_4$ to reduce ^{226}Ra contamination.
- External γ events from Quartz could be 3 order magnitude higher. However, major γs might come from Al structure of PMT mounting jig? Need clean material such as ultra-pure synthetic quartz and oxygen free cupper as scheduled of this project.
- Need 20cm Pb shield (15+5cm thickness) to reduce sufficiently events from environmental γs.

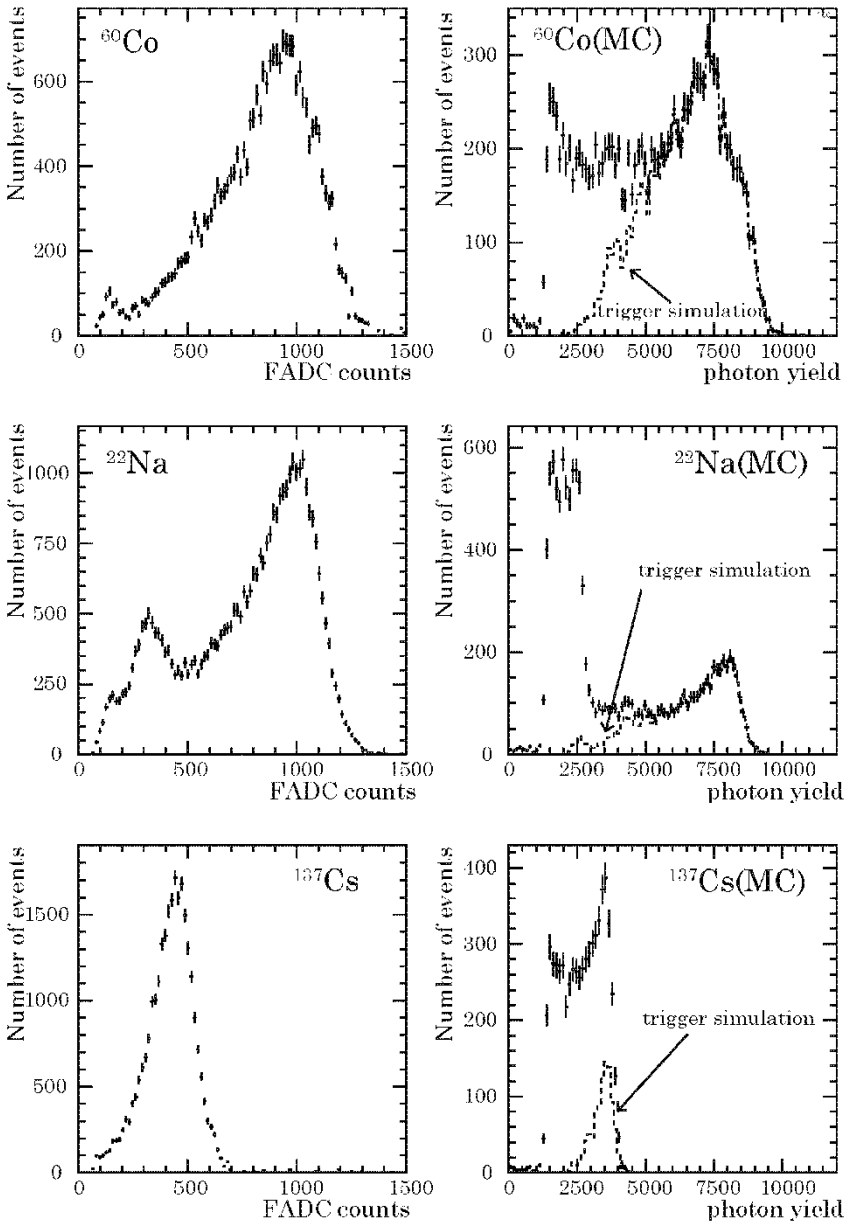
backup

Monte Carlo tuning using calibration source



- MC tuning was used for ^{60}Co data.
- Tuning parameters are refractive index of LS for reflection + refraction of light between liquid and air and liquid scintillator level.
- Vertex position of data are almost reproduced by MC after tuning.

Trigger simulation using calibration source



- Trigger simulation was used for number of photon received by PMT#1 and PMT#20.
- Typical trigger efficiency around 600keV is 70%.
- Therefore ^{214}Bi-^{214}Po candidates could be lost about 30% in DAQ.
- Calibration constant for MC was also obtained by same method as data.