

B13

高圧キセノンガス検出器を用いた ニュートリノレス二重ベータ崩壊探索

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neutrino-less double-beta ($0\nu\beta\beta$) decay

ニュートリノがマヨラナ粒子であるのかどうか？

最重要課題の一つ

ニュートリノの質量の軽さ、大統一理論のモデル選定、
物質・反物質非対称な宇宙の理由

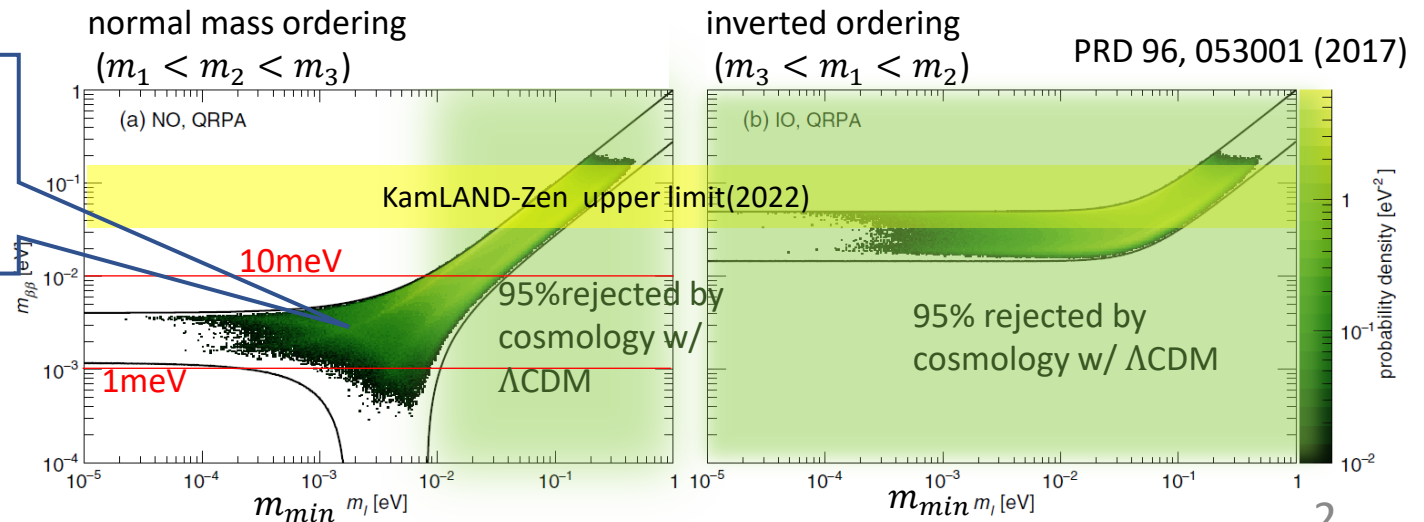
ニュートリノを伴わない二重ベータ崩壊探索が重要

ニュートリノがマヨラナ質量を持つ場合にのみ起きる

寿命： ニュートリノ質量の2乗に反比例

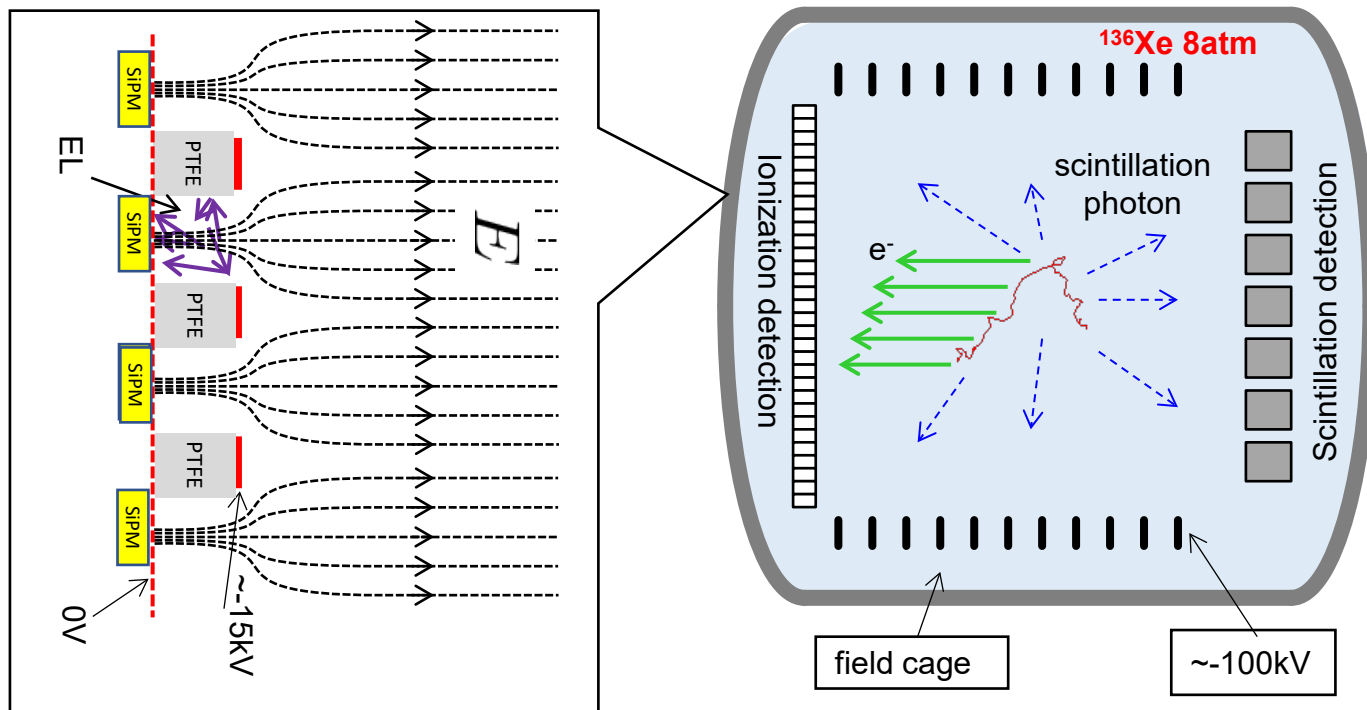
Need **> 1 ton** double-beta nuclei and **background free**

Posterior distribution
given the knowledge
on neutrino mixing
parameters





A Xenon ElectroLuminescence Detector



ELCC : Unique readout mechanism
It enables high energy resolution with a **large** detector

Road Map

10 ton scale

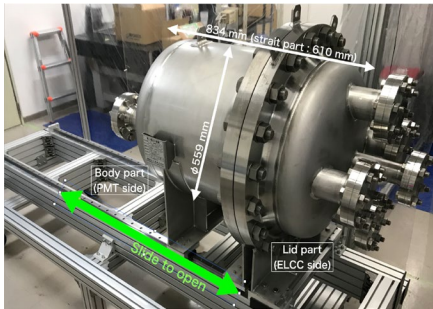
1 ton scale

100kg scale

1000L(24 kg) scale

~2030
physics data taking

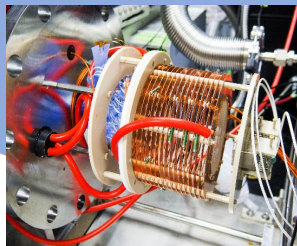
2025-
physics data taking



10-L prototype

2014-2018

- ~0.05kg @8bar
- ELCC proof of principle



180-L prototype

2018-2024

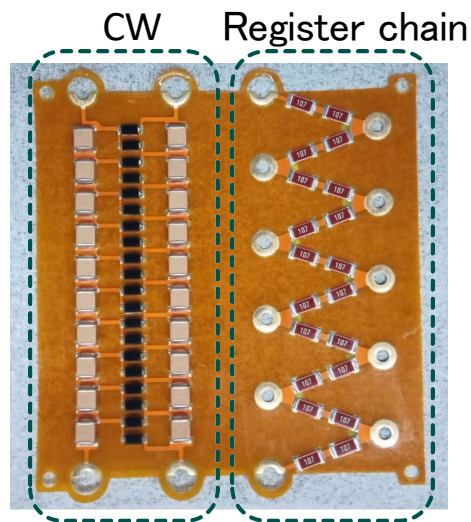
- ~4.5kg @8bar
- phase-1 : 168 ch
- phase-2 : 672ch



Kamioka observatory

Development for
1000L and 100kg
detector in FY2024

Cathode high voltage by Cockcroft-Walton generator in Chamber



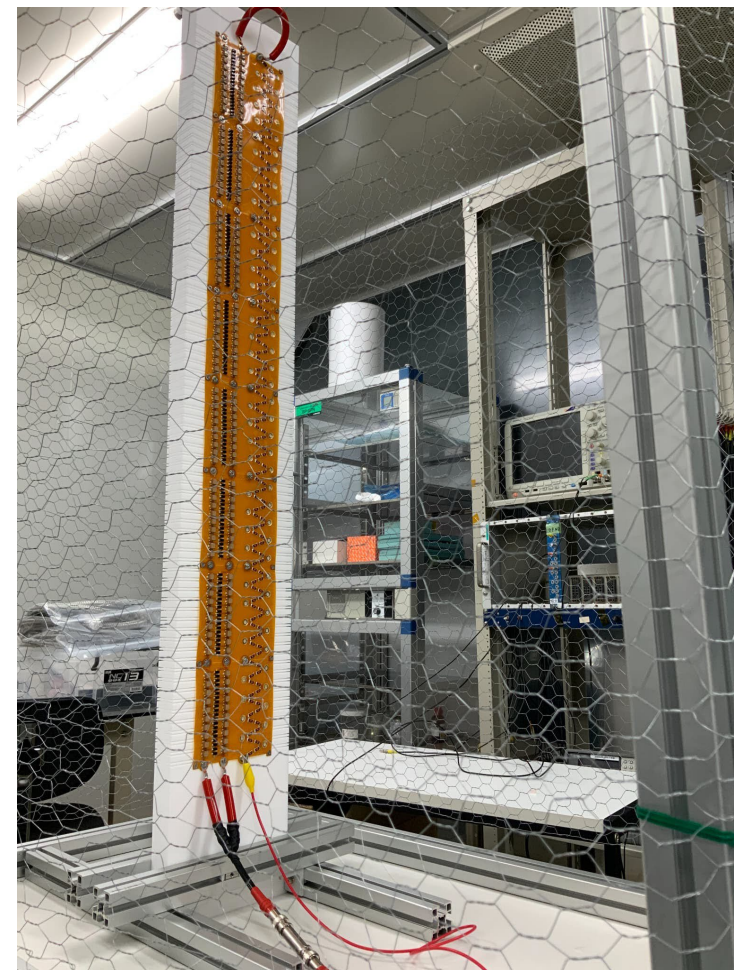
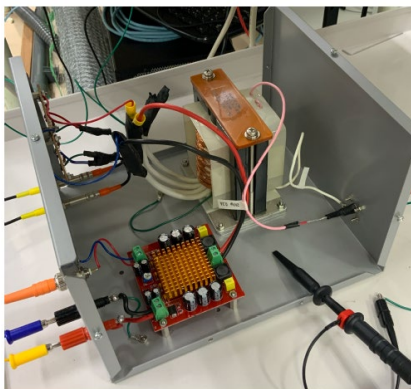
1000L detector Design value : 76.4 kV

make recombination negligible

Cockcroft-Walton generator in chamber!

No feedthrough for super-high voltage

76kV achieved! in atmosphere
input $1.8kV_{pp}$, 13kHz



Cathode high voltage by Cockcroft-Walton generator in Chamber with 180L prototype

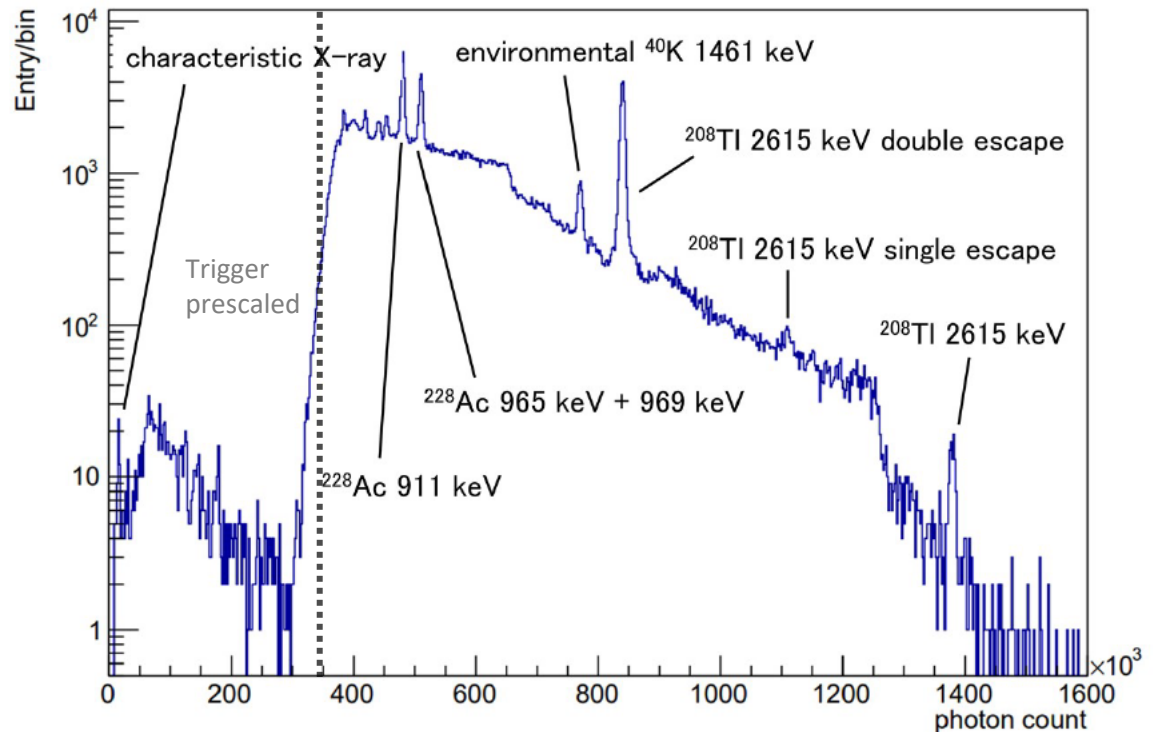
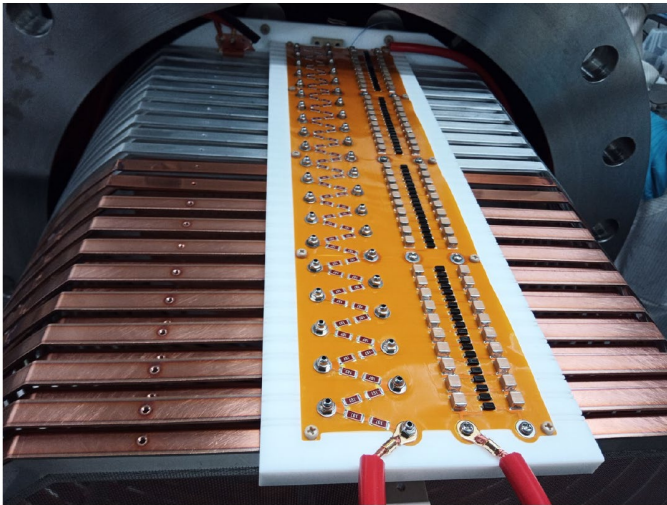
World first demonstration

Submitted to a journal

<https://arxiv.org/abs/2501.08554>

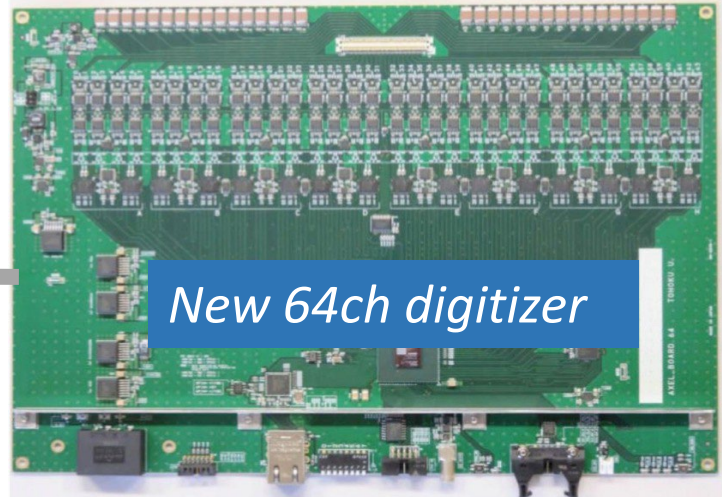
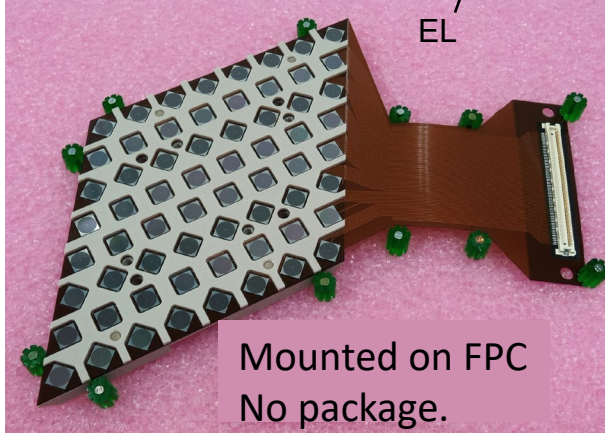
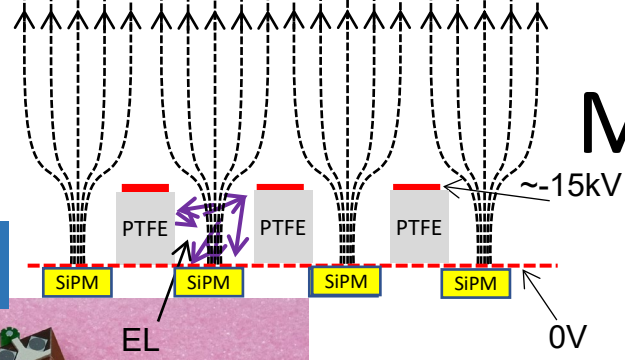
No noise effect

~1 month operation



MPPC & electronics

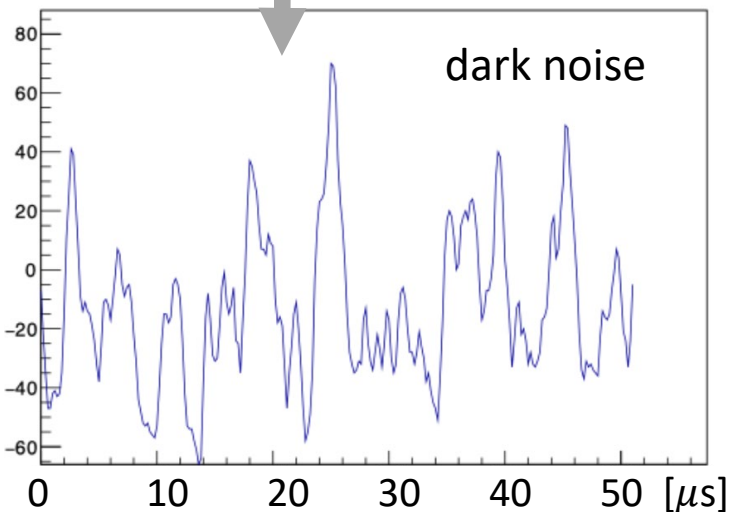
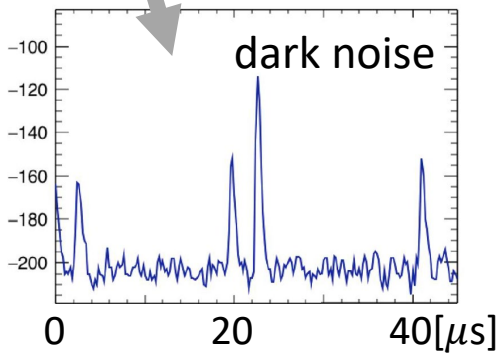
New MPPC



3mm x 3mm



4.7 mm dia.
(c.f. ELCC cell
dia.=4.5)



Firmware development on-going

- Data compression

VUV Scintillation(t_0) detection

50 × 50 mm^2 Wavelength-shifter plate + 6 × 6 mm^2 MPPC

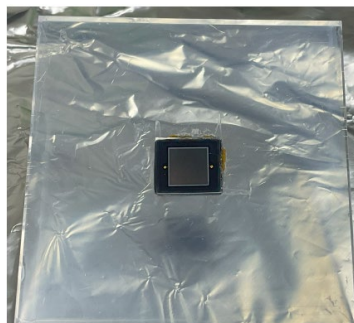
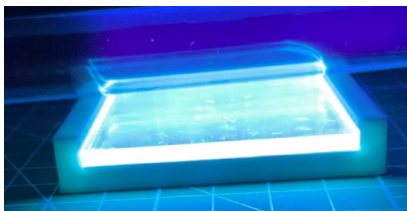
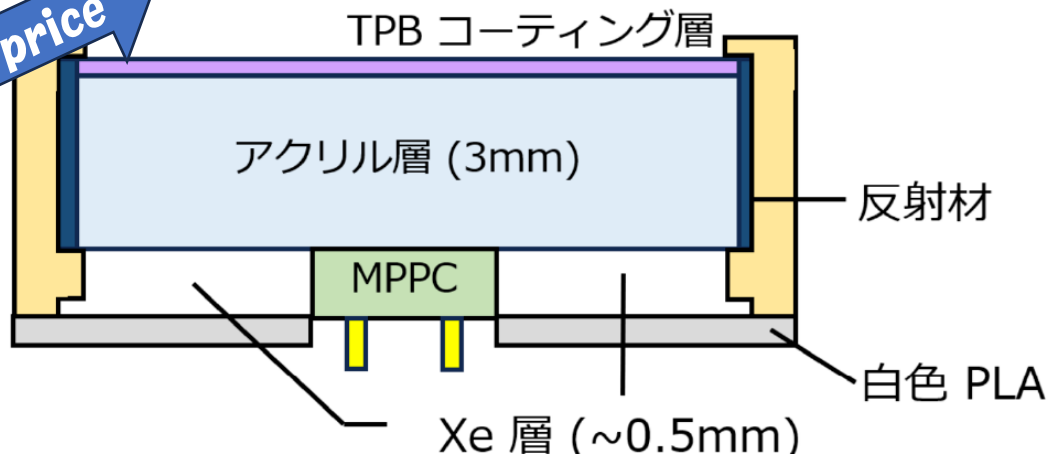
Expect 11 photon/plate @Q-value(2.5 MeV)

X16 w/ 1/10 price



HPK R8520-406

- VUV sensitive
- High-press. compatible.
- ~0.7 photon/PMT @Q-value(2.5 MeV)



To be demonstrated w/
180L detector

(キセノンガスでこのエネルギーでは) 世界最高のエネルギー分解能のさらなる向上

Breakdown of energy resolution at 1863 keV (昨年度報告)

	FWHM	今年度達成
Error in the time variation correction	0.32 %	→ 解析の改良等で0.12%に
Fluctuation of the number of initial ionization electrons	0.29 %	Intrinsic
Fluctuation of the EL generation and detection	0.24 %	
Error in the EL gain correction	0.23 %	→ 解析の改良で0.02%に
Recombination	0.22 %	
Fluctuation of the MPPC non-linearity	0.18 %	
z mis-reconstruction	0.13 %	
Variation in time bin of time variation correction	\lesssim 0.16 %	
Error in the z -dependence correction	\lesssim 0.11 %	
Accuracy of the MPPC recovery times	\lesssim 0.11 %	
Offset of the baseline	\lesssim 0.09 %	
Fluctuation of the attachment	\lesssim 0.02 %	
Position dependence of the EL gain	0 %	
Waveform processing in the FEB	0 %	
Estimation total	0.63 % to 0.67 %	
Data total	$(0.73 \pm 0.11) %$	

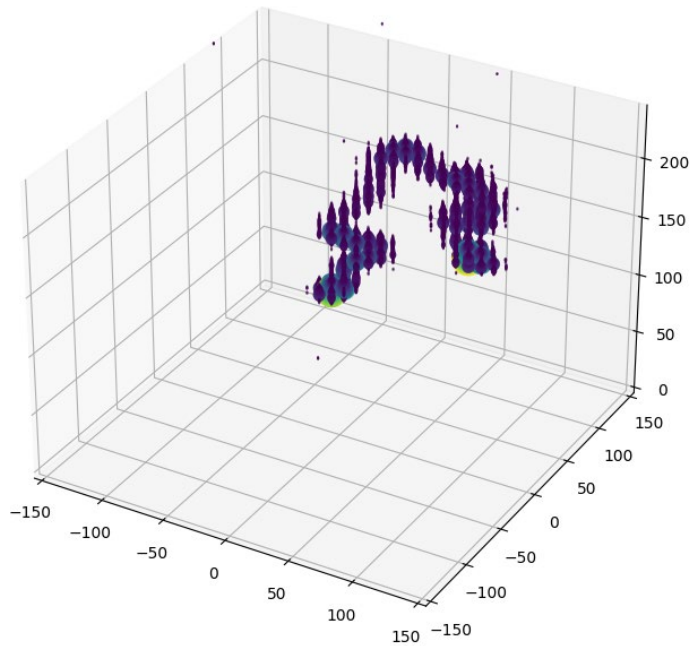
(キセノンガスでこのエネルギーでは) 世界最高のエネルギー分解能のさらなる向上

Breakdown of energy resolution at 1863 keV (昨年度報告)

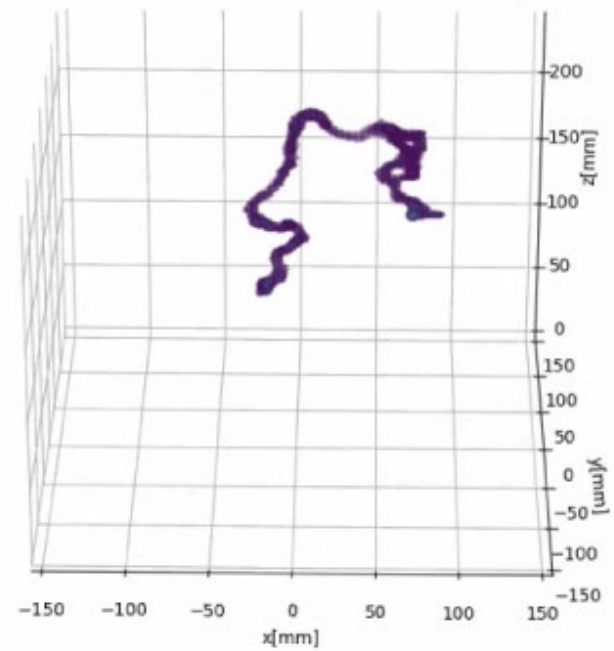
	FWHM	今年度達成	来年度目論見
Error in the time variation correction	0.32 %	→	解析の改良等で0.12%に
Fluctuation of the number of initial ionization electrons	0.29 %		Intrinsic
Fluctuation of the EL generation and detection	0.24 %	→	新MPPCで0.14%に
Error in the EL gain correction	0.23 %	→	解析の改良で0.02%に
Recombination	0.22 %	→	目標電場で~0%に
Fluctuation of the MPPC non-linearity	0.18 %		シンチ検出効率を上
z mis-reconstruction	0.13 %	→	げることので~0%に
Variation in time bin of time variation correction	\lesssim 0.16 %		
Error in the z -dependence correction	\lesssim 0.11 %		
Accuracy of the MPPC recovery times	\lesssim 0.11 %		
Offset of the baseline	\lesssim 0.09 %		
Fluctuation of the attachment	\lesssim 0.02 %		
Position dependence of the EL gain	0 %		
Waveform processing in the FEB	0 %		
Estimation total	0.63 % to 0.67 %		
Data total	$(0.73 \pm 0.11) %$		

Track convolution

original event



RL deconvoluted, Elevation: 26.5deg, Azimuth: 271.0deg



Sensitivity - 1 ton case -

Estimation (with old geometry)

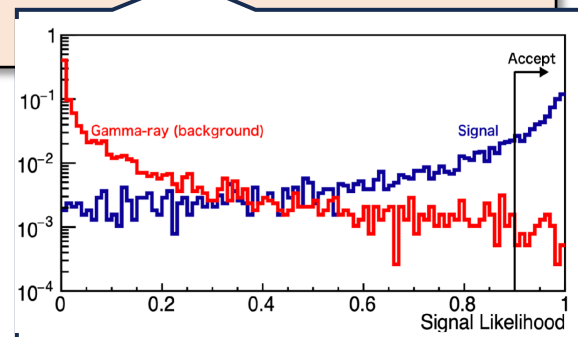
Event generation (Geant4)

Fully-contained
ROI: Q-value $\pm 0.5\%$
- $36 \times 36 \times 36$ pixels

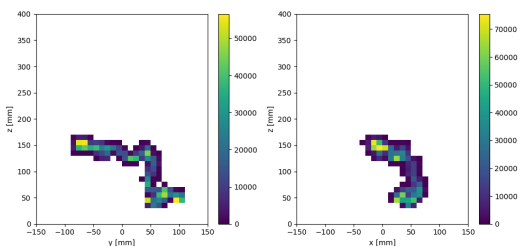
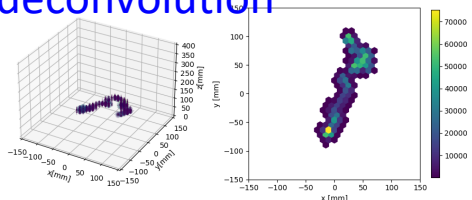
Signal acceptance: 50%
Bkg rejection: 99.95%

Signal acceptance: 27%
Bkg rejection: 99.9996%

Selection by CNN



- Background assumption
10 tons of oxygen free copper as inner wall
- 10-years operation would give 90% lower limit of
 - 1.2×10^{27} yrs w/ 0.6% E resolution
 - 2.5×10^{27} yrs w/ 0.32% E resolution
 c.f. KamLAND-zen limit 2.3×10^{26} yrs
- Plan to improve ML selection with a combination of **deconvolution**

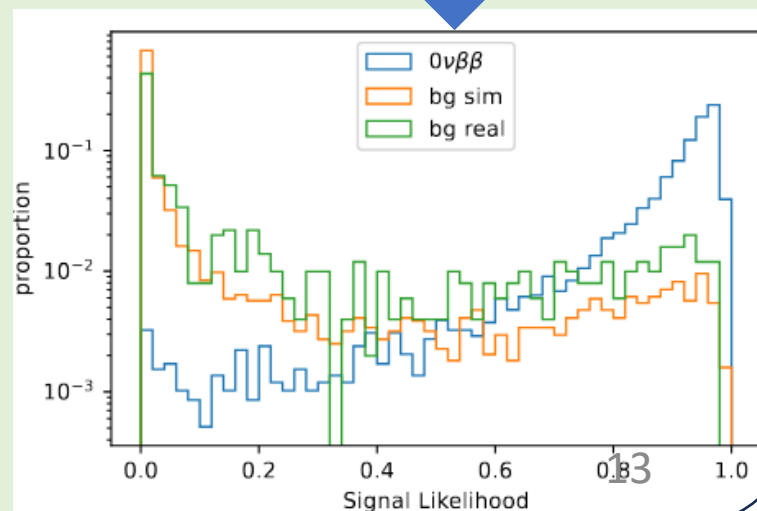


example of "mimic" event

This year update

w/ more realistic simulation
w/ recent 3D CNN

comparison w/
data for bkg



まとめ

性能評価 w/ 180L試作機@京都

- ✓ ~0.6% (FWHM) energy resolution
元の目標は0.5%だったが、今は0.4%以下を目指している。
- ✓ Cockcroft-Walton in chamber 成功!

1000Lデモンストレーター@神岡の準備

- ✓ 75kV CW 大気中で成功
- ✓ 新型シンチレーション検出器
- ✓ 64chディジタイザのファームウェア開発
- ✓ 放電対策、ガス制御系、低放射化コネクタ

来年度の計画

- ✓ 64ch MPPCボード + ディジタイザを180L試作機で動かす



神岡へ

今年度の採択額：20万円。（旅費の予定だったが、まだ執行していない。）