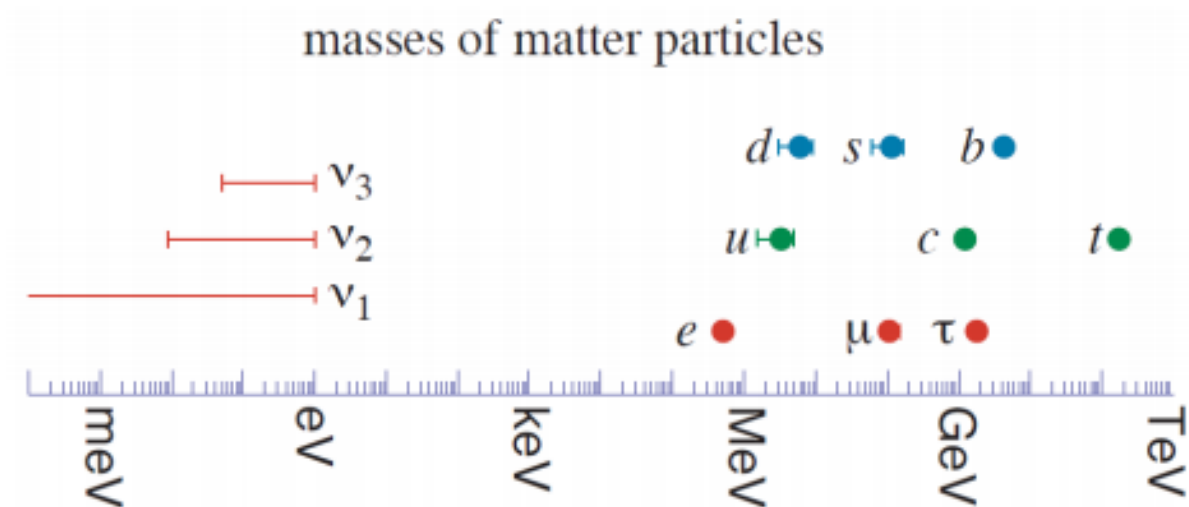


AXEL実験: $0\nu\beta\beta$ 探索に向けた 高圧キセノンガス検出器開発

中村 輝石(京都大学)

ニュートリノの質量

- ニュートリノ振動 \Rightarrow ニュートリノは質量を持つ
- 他のフェルミオンに比べ6桁以上も軽い(不自然)
- 質量の絶対値の測定は軽すぎて難しい(KATRINなどが挑戦中)



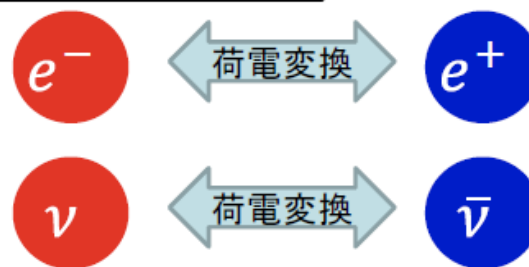
マヨラナ or ディラック

- ニュートリノがディラック粒子かマヨラナ粒子かわかっていない
- 中性フェルミオンはニュートリノだけ



エットレ・マヨラナ
1906年 - 1938年に行方不明
“中性フェルミオンは自身の反粒子になり得る”

ディラック・フェルミオン

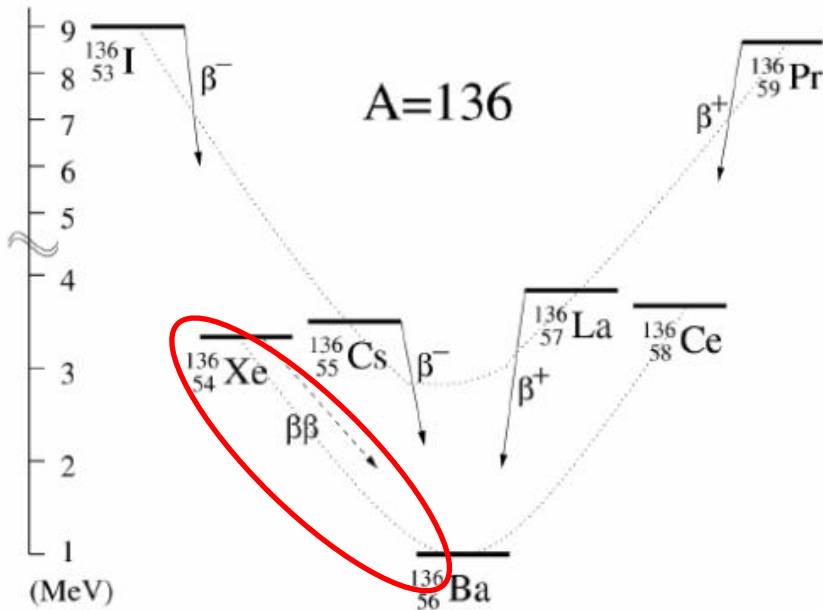


マヨラナ・フェルミオン

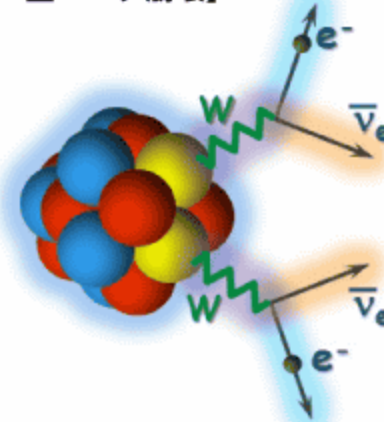


二重ベータ崩壊

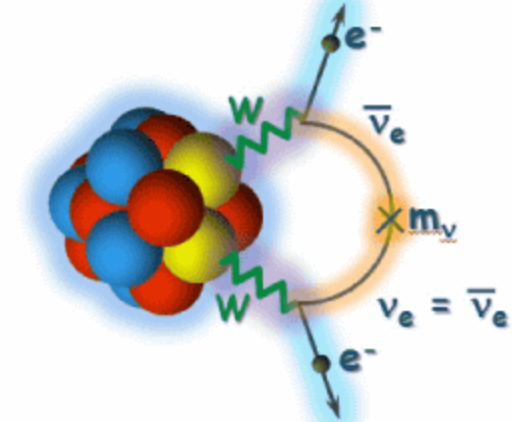
- 1回のベータ崩壊ではエネルギー的に損をするが、2回ベータ崩壊をするとエネルギー的に得をする原子核で起きる
- 2つの電子と2つの反電子ニュートリノが発生
- もしニュートリノがマヨラナ粒子だと対消滅でき、2つの電子のみが発生する。エネルギー和はQ値に等しくなる



【二重ベータ崩壊】



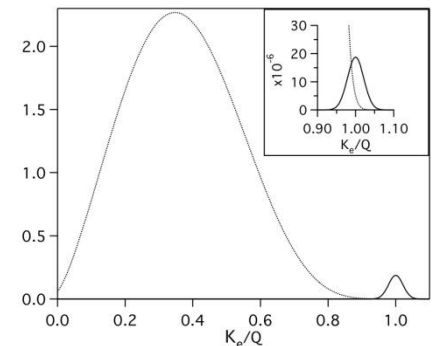
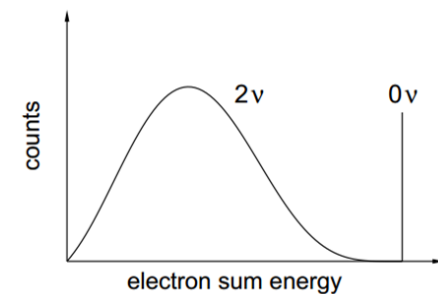
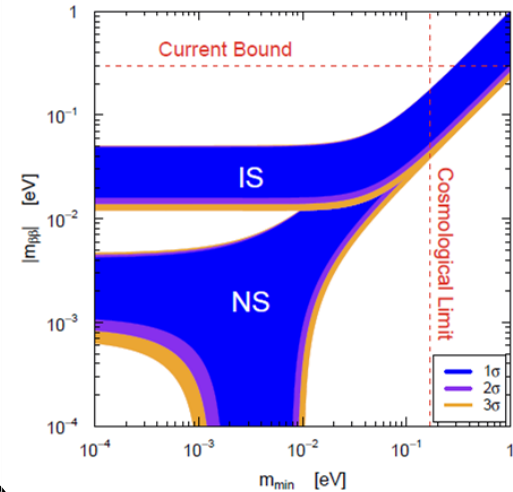
反ニュートリノを放出する
二重ベータ崩壊



ニュートリノを放出しない
二重ベータ崩壊

ニュートリノレス二重ベータ崩壊

- なぜ $0\nu\beta\beta$ を探すのか？
 - ニュートリノのマヨラナ性の検証(新！)
 - 質量階層性(10meV以下へ)
- $0\nu\beta\beta$ の特色
 - 珍しい(というかまだ未発見)
 - 信号は2つの電子(エネルギー和は一定)
- $0\nu\beta\beta$ 検出器への要請
 - エネルギー分解能が良い(bg除去)
 - 低放射能なモノでできている(bg除去)
 - バックグラウンド除去能力(bg除去)
 - 大質量(統計up)
 - 崩壊核の存在比、濃縮技術(統計up)

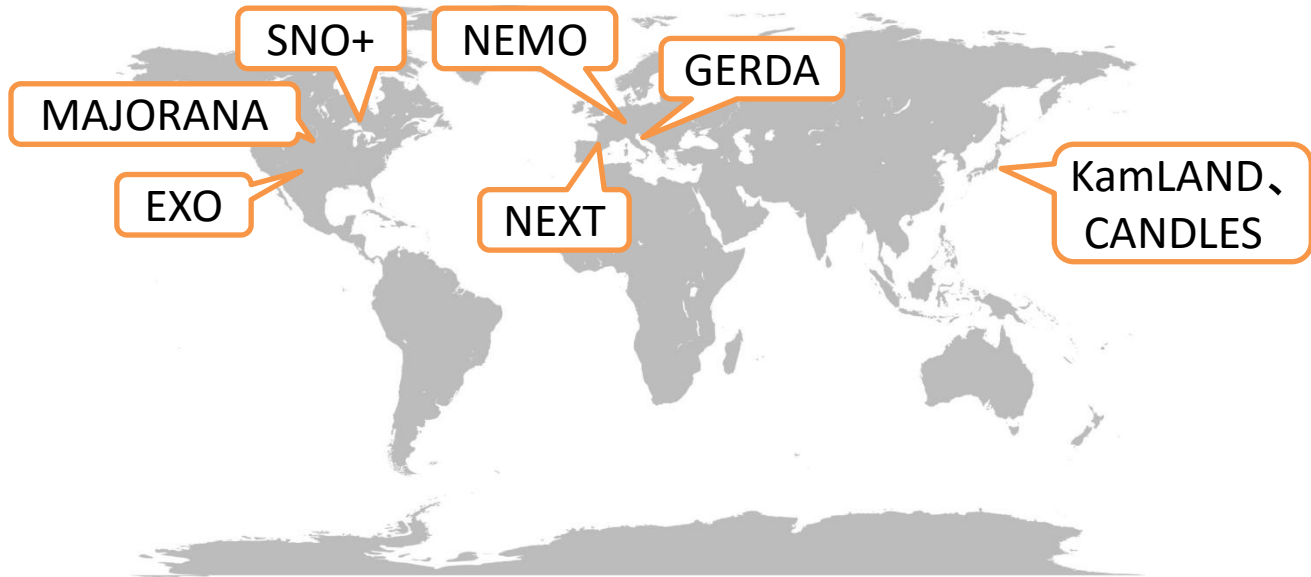


色々な実験があります

- 原子核選び

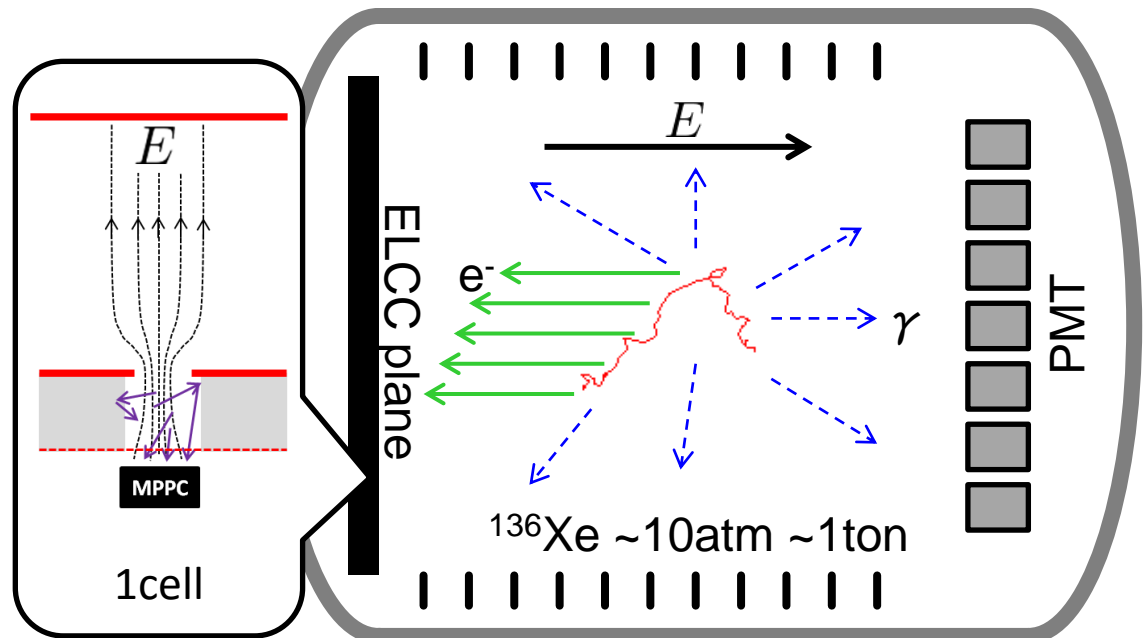
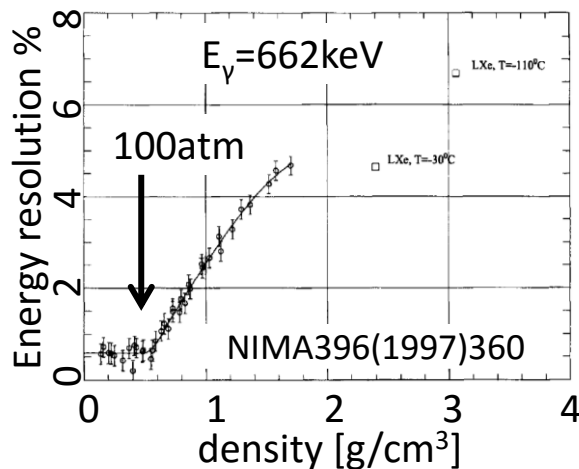
原子核	Q値 keV	自然存在比 %	実験
48Ca	4271	0.19	CANDLES
76Ge	2039	7.8	GERDA、MAJORANA
96Zr	3351	2.8	ZICOS
100Mo	3034	9.6	NEMO
130Te	2527	34.5	CUORE、SNO
136Xe	2457	8.9	EXO、KamLAND-Zen、NEXT

- 低放射能環境を求めて
地下へ



AXEL experiment

- High pressure xenon gas TPC for $0\nu\beta\beta$ search
 - High energy resolution : **0.5%** (FWHM) @2.5MeV
 - gaseous xenon + electroluminescence
 - Large mass : **1ton** ($\phi 3 \times 2.5\text{m}$, 10atm)
 - BG discrimination : **pixel readout** (15mm pitch)



- Similar idea as NEXT experiment
- We introduce a new idea for signal readout (ELCC)

EL readout idea: ELCC

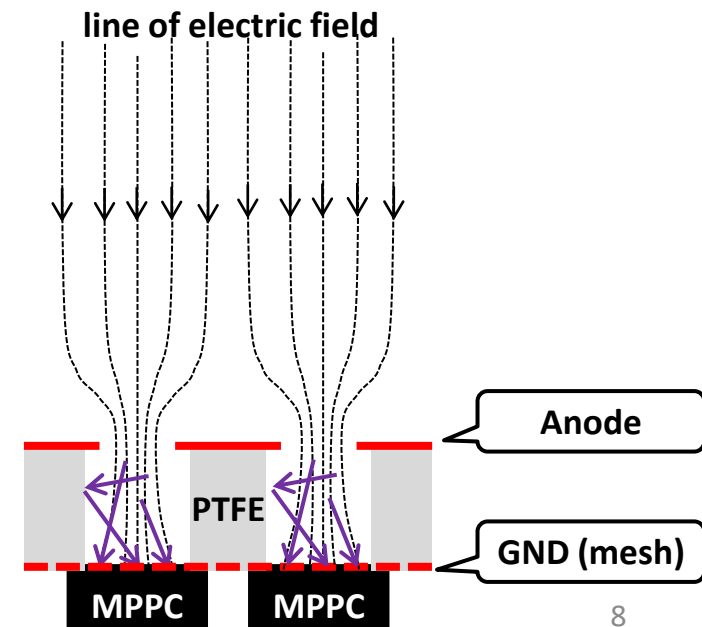
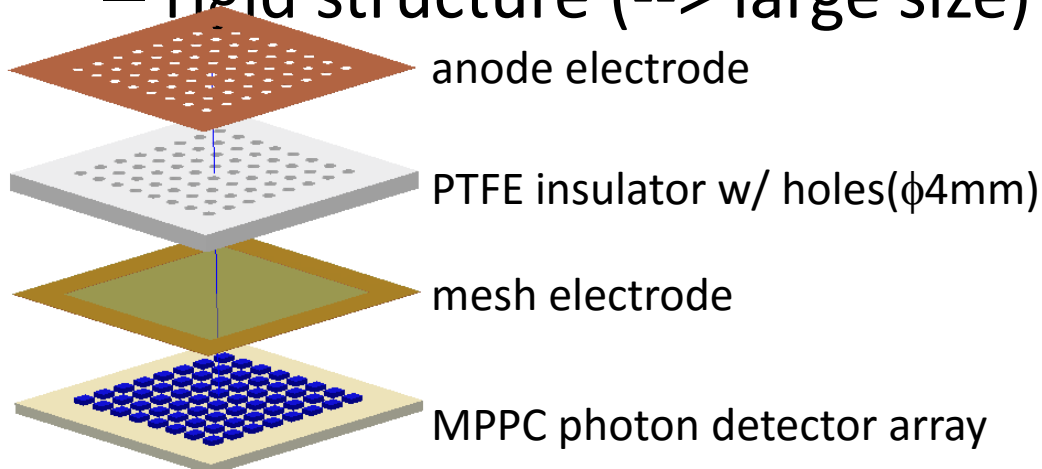
Electro Luminescence Collection Cell

- ELCC

- in the cell hole, electrons are collected and accelerated, then electroluminescence photons are generated
- photons are detected by MPPC(SiPM) in each cell

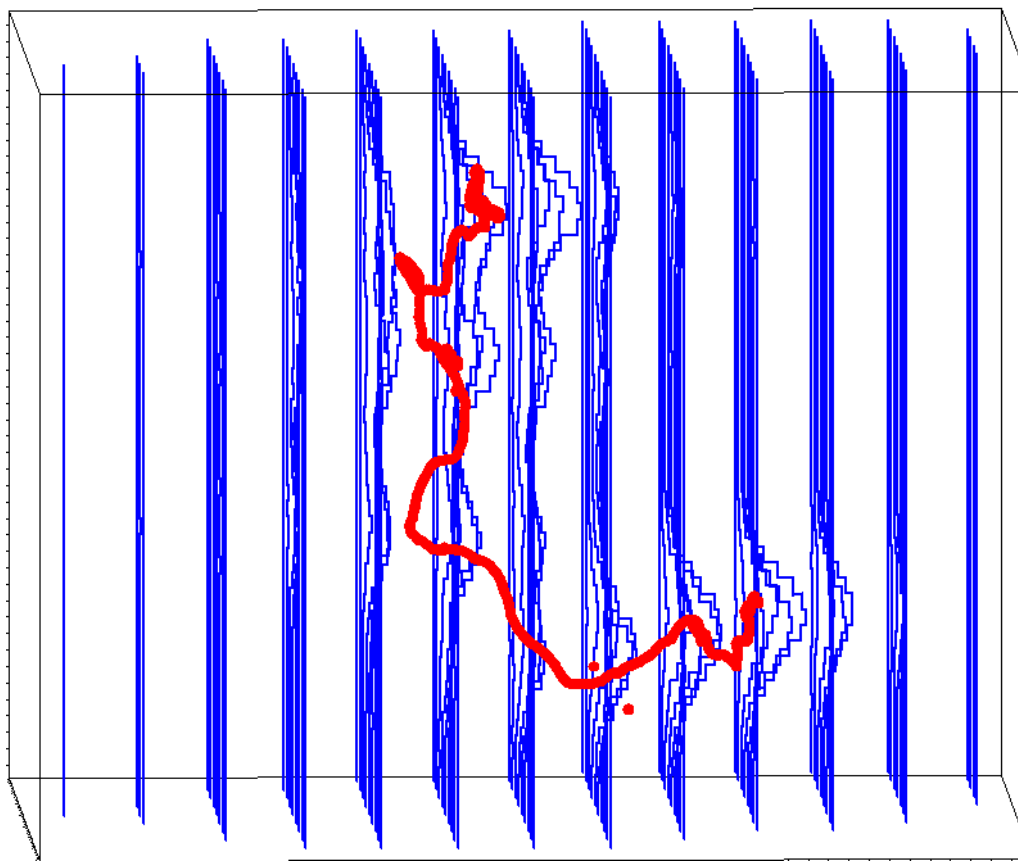
- Merit of ELCC

- uniform response in wide area
- rigid structure (--> large size)



What we want to observe

- $0\nu\beta\beta$ signal
 - energy: integrated FADC
 - track: waveforms (pixel readout TPC)

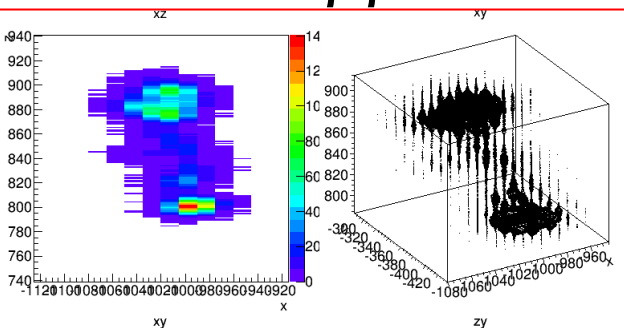


10atm
Xe100%
15mm pitch
1 μ s sampling (\sim 1mm)

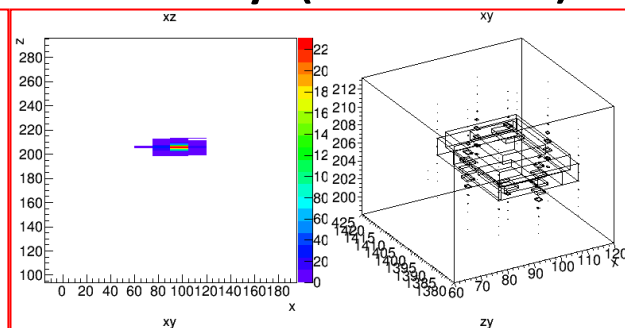
Tracking strategy

- energy resolution 0.5% --> reject non-2.5MeV
- tracking --> reject α, γ (98%: compton)

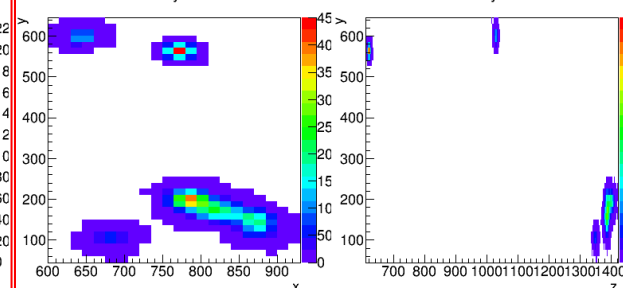
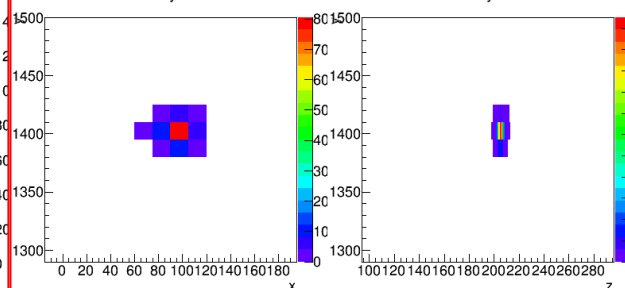
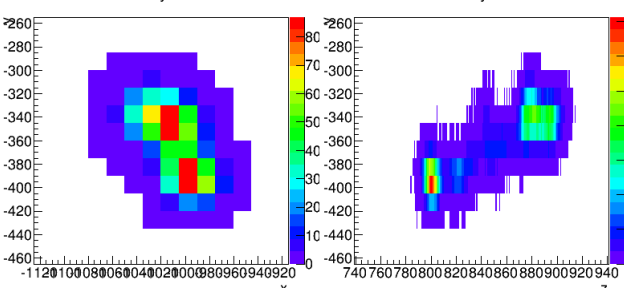
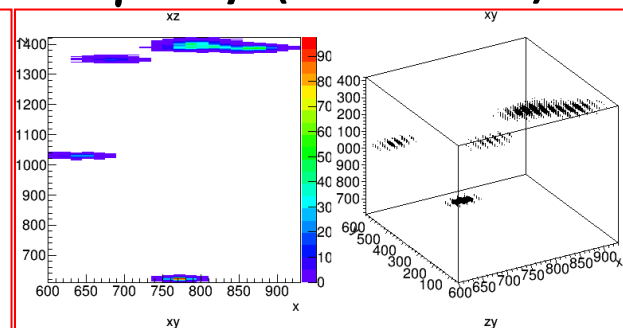
$0\nu\beta\beta$



α -ray (2.5MeV)



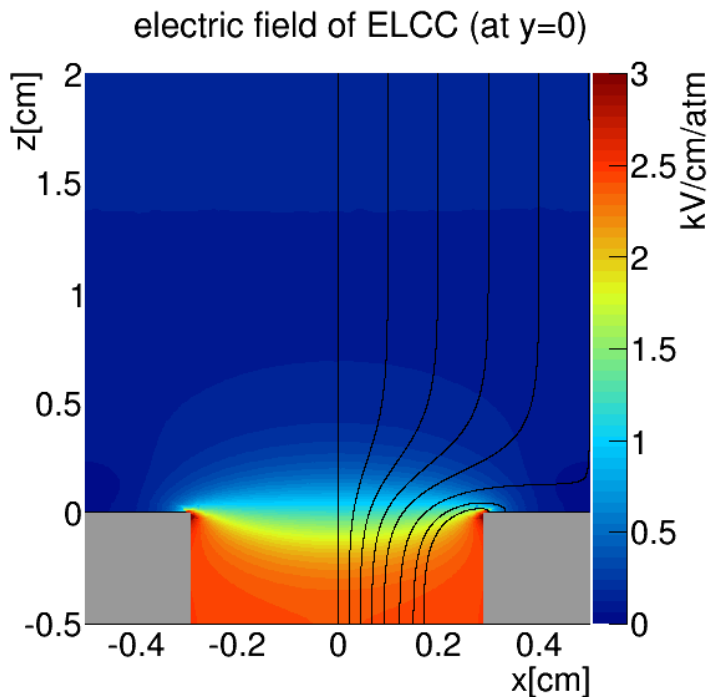
γ -ray (2.5MeV)



10atm, Xe100%, 15mm pitch, $1\mu\text{s}$ sampling ($\sim 1\text{mm}$)

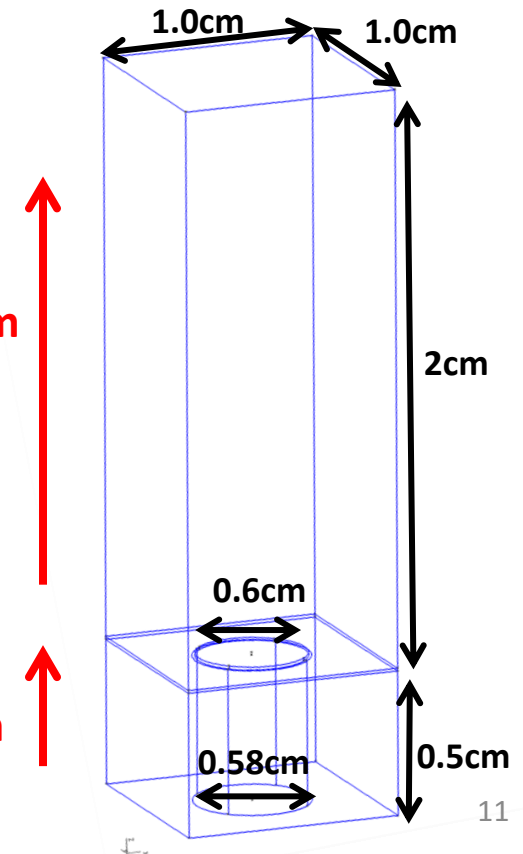
電場シミュレーション

- ドリフト電場: 再結合しないように
- EL電場: 1kV以上、放電しないように
- ⇒ 電気力線が穴に入っている



$$E_{\text{drift}} = 100 \text{ V/cm/atm}$$

$$E_{\text{anode}} = 3 \text{ kV/cm/atm}$$

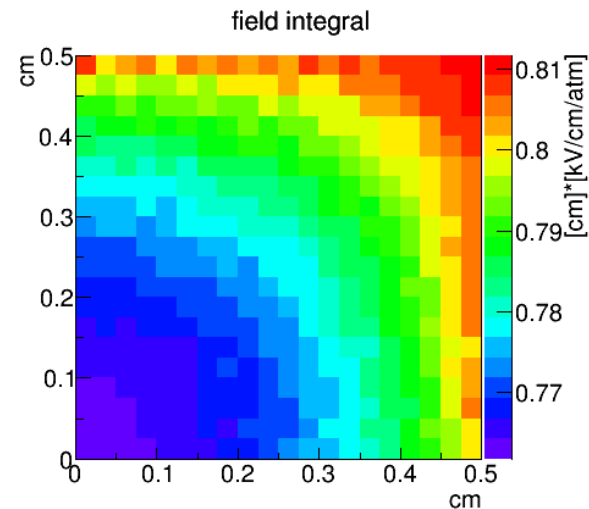
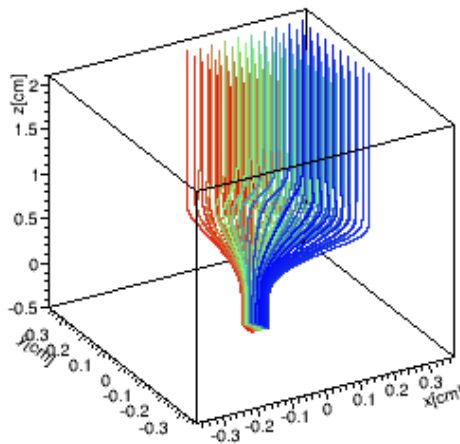
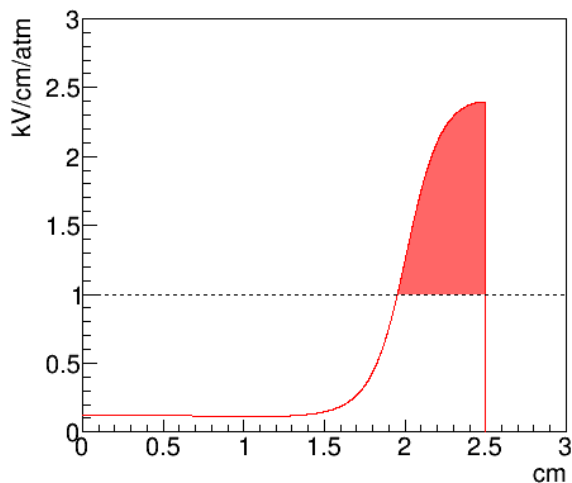


EL発光量の場所依存

- EL発光量は閾値以上の電場で、電場強度と電子の移動距離に比例する。(図中の赤部)

$$dN_{ph}/dx = 70(E/p - 1.0)p$$

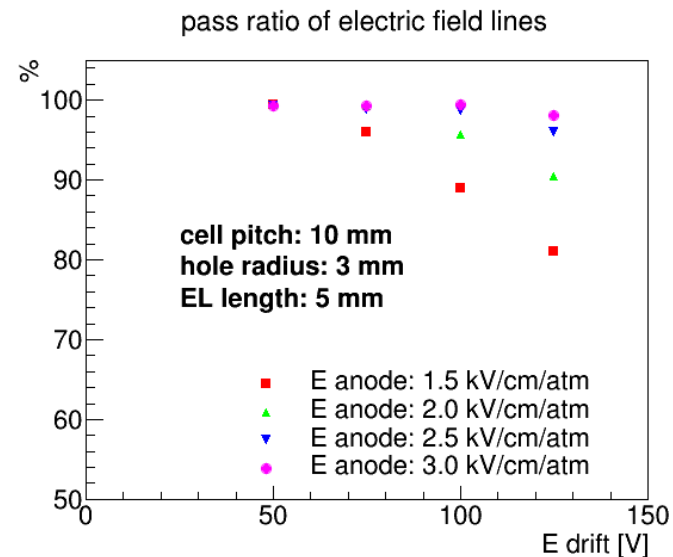
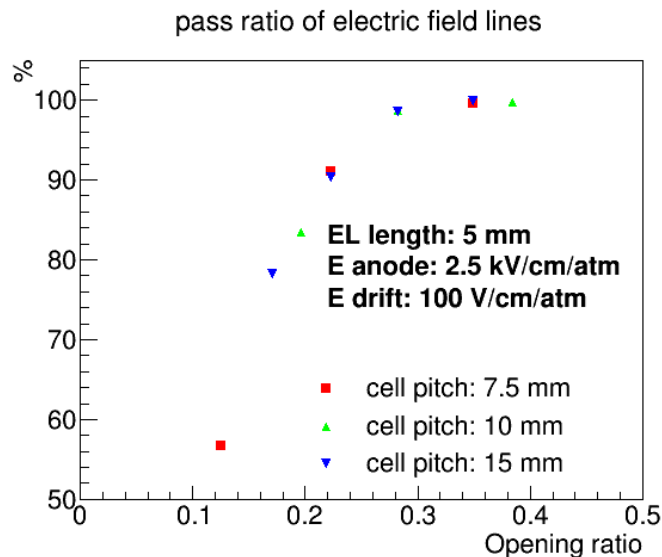
- 電子のドリフト開始位置を変えつつセル内の赤部積分値の場所依存性を計算： $\sigma=1.7\%$
 - 電子数が100000個なので $1.7/\text{sqrt}(100000)\sim 0.005\%$



ジオメトリ・電場の最適化

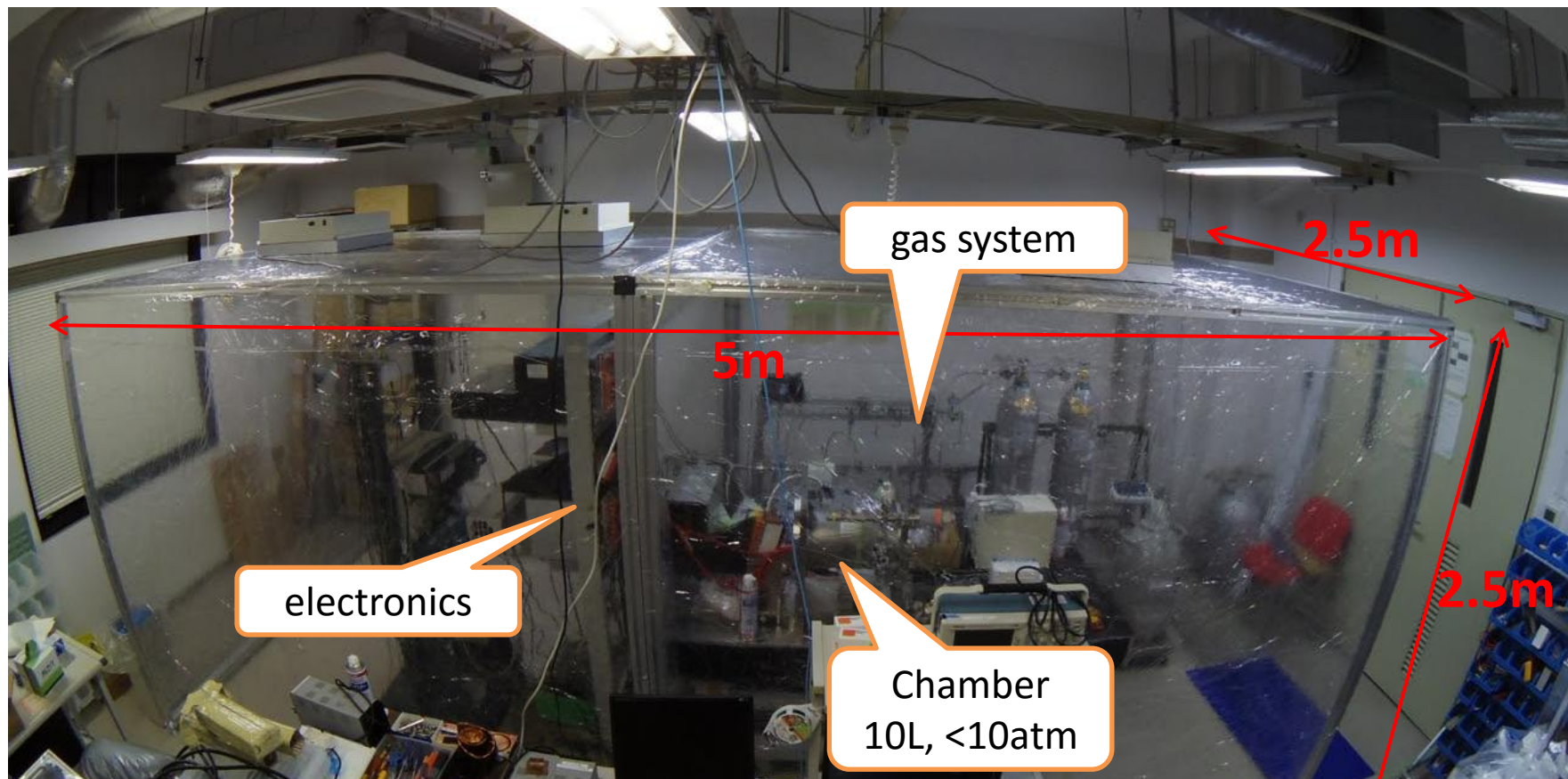
- 電気力線の収集効率

- 穴開口率依存性: 0.3以上の面積でOK。セルピッチ依存性はない
- 電場依存性: ドリフト電場に100V/cm/atmを課すとEL電場には2.5kV/cm/atm以上が必要



Overall view

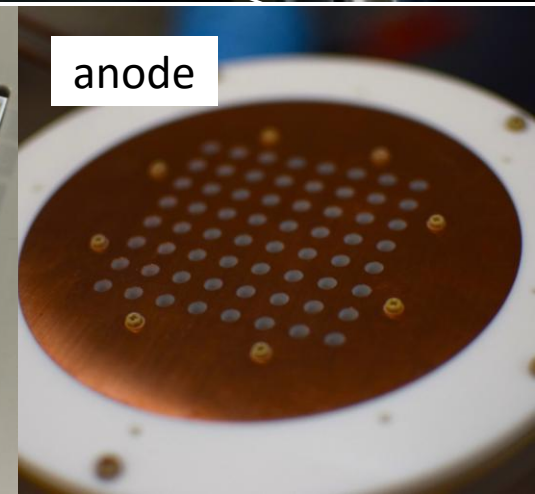
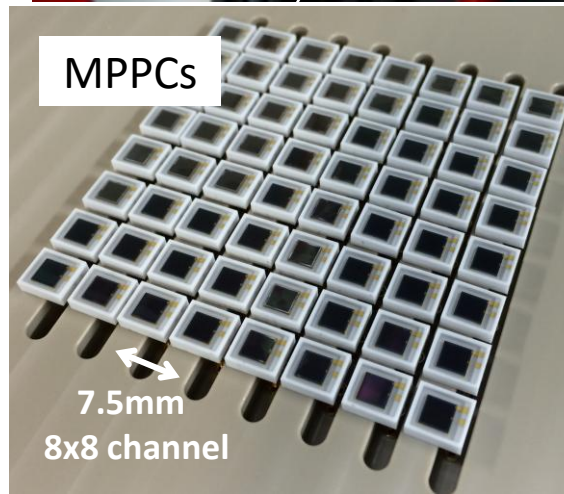
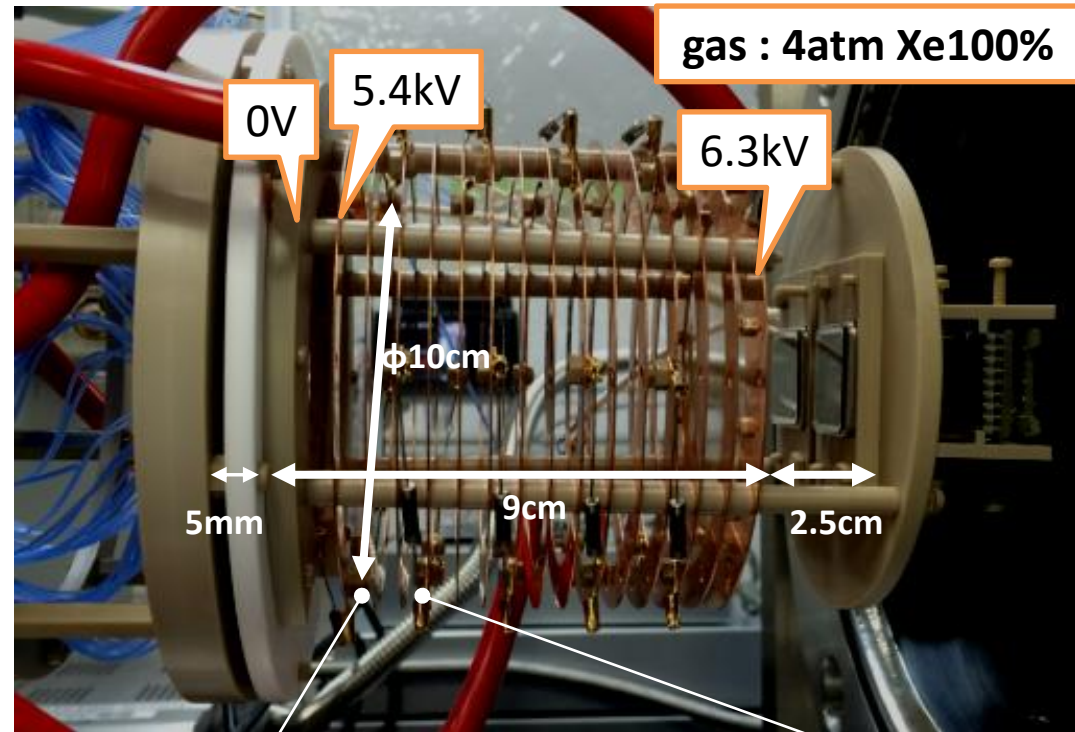
- Kyoto Univ. 3F (welcome!)



Name	filter class	filter num	filter flow	overall flow
CLL25 [Matsusada]	10000	4	7 m ³ /min	64 times/h

Prototype detector

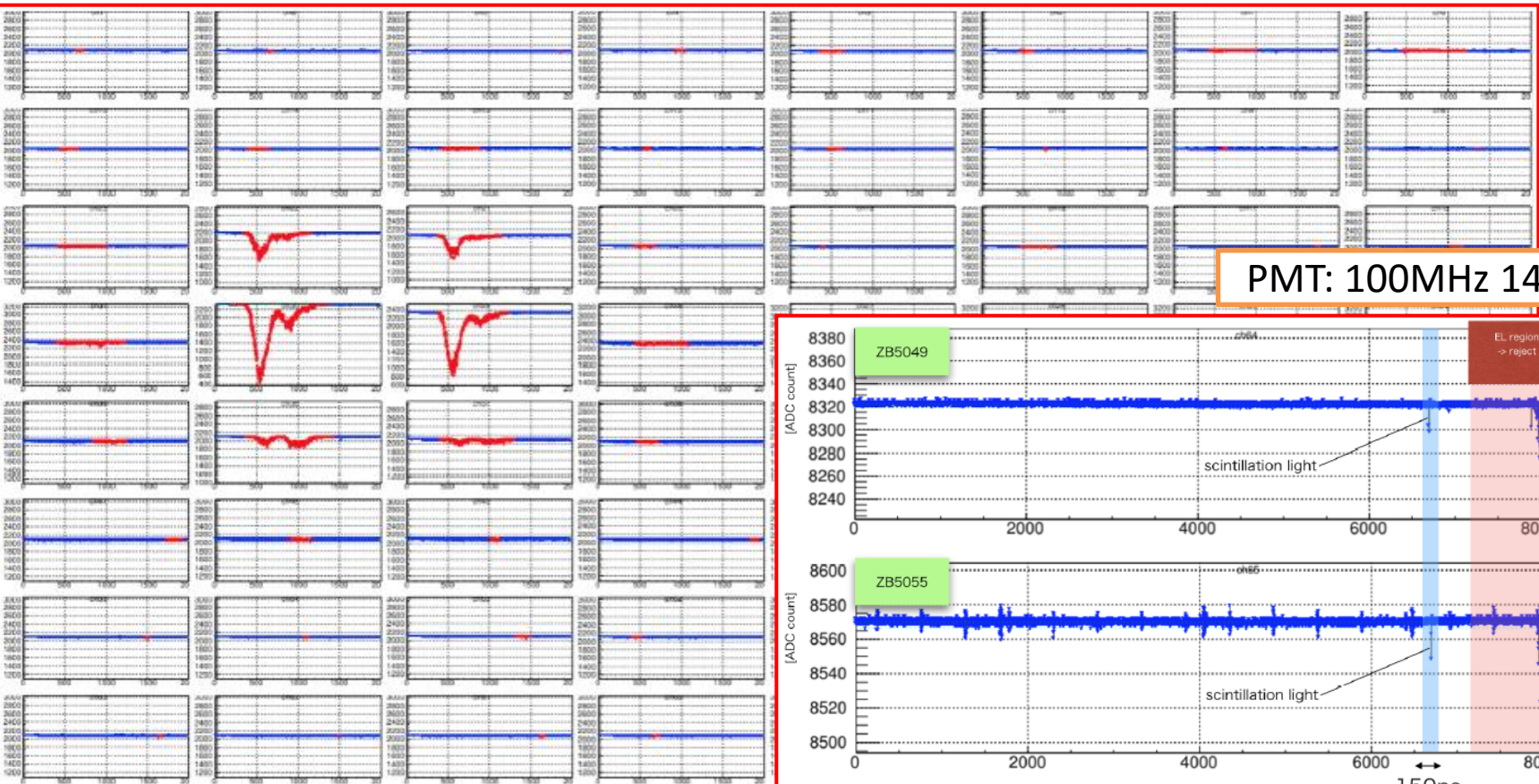
- Detection volume
 - $6*6*6\text{cm}^3$
 - 5.7g (4atm Xe)
- Sensor
 - WLS coated MPPC x64
 - VUV-PMT x2
- Electric field
 - EL: $2.4\text{kV}/\text{cm}/\text{atm}$
 - drift: $50\text{V}/\text{cm}/\text{atm}$



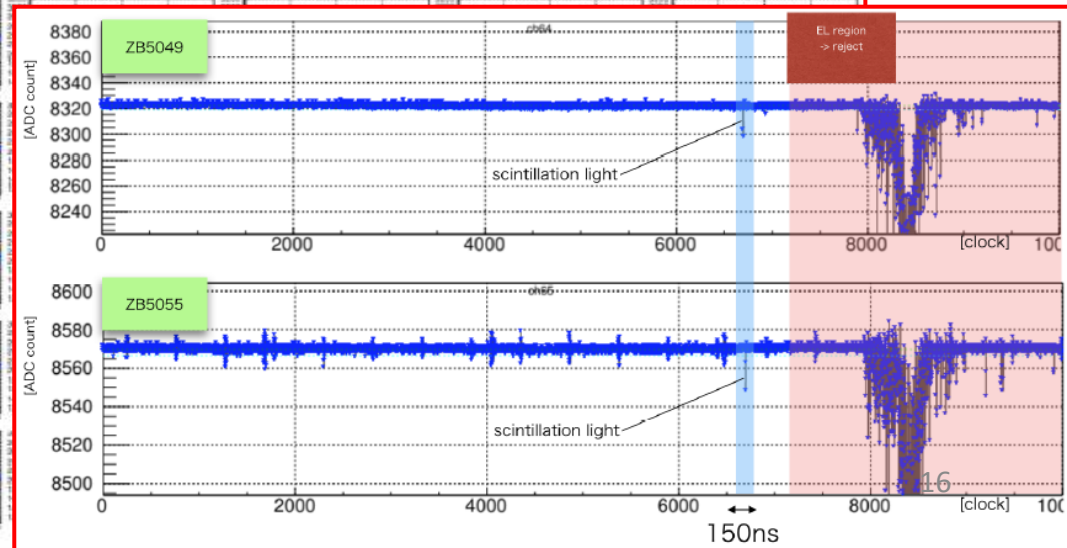
Event sample

- waveforms of MPPC and PMT
 - EL light & scintillation light are observed

MPPC: 65MHz 12bit 2Vpp



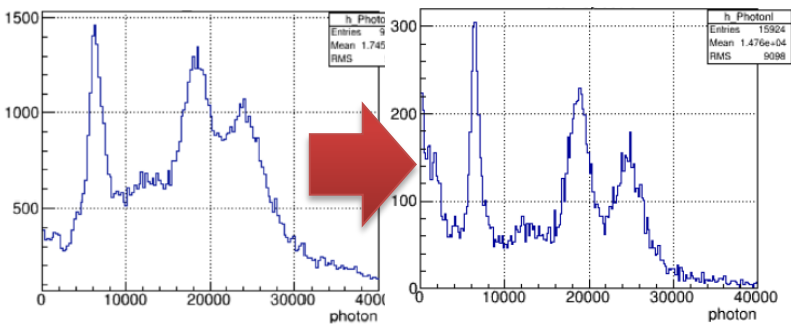
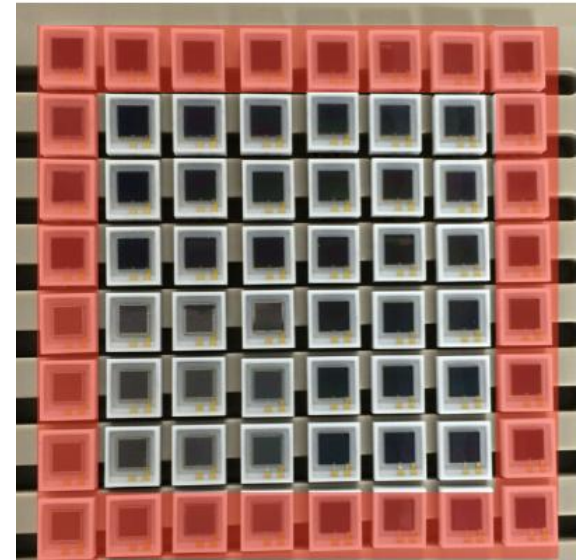
PMT: 100MHz 14bit 2Vpp



γ -ray measurement (^{57}Co 122keV)

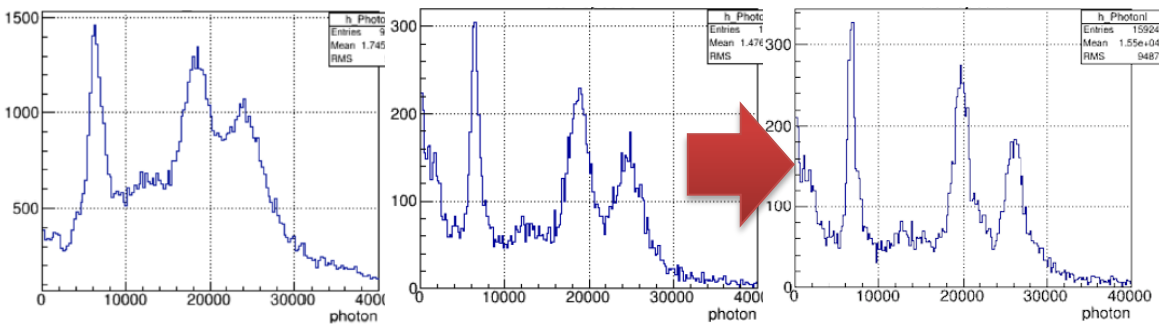
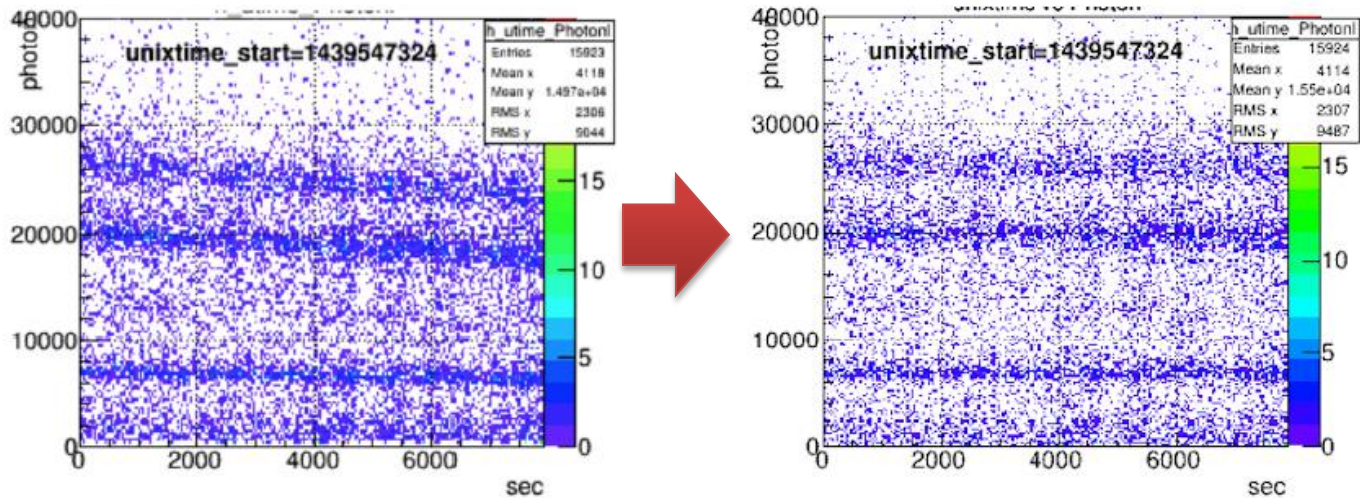
- Fiducial cut
 - veto region: outer 28 MPPCs

red: veto



γ -ray measurement (^{57}Co 122keV)

- Time dependence correction
 - Impurities decrease EL gain
 - Gas circulation system is now under construction

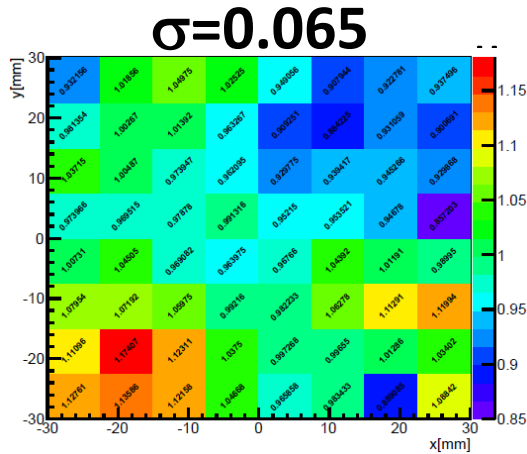
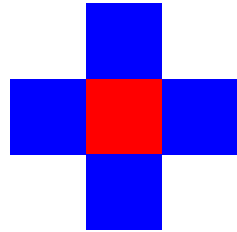


γ -ray measurement (^{57}Co 122keV)

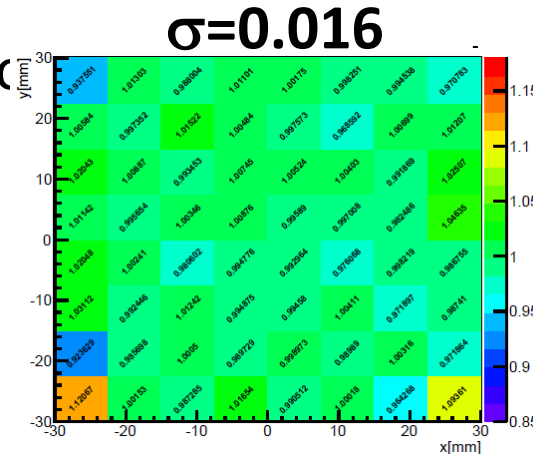
- EL-gain correction

- photon num of 30keV γ -ray for “each cell”

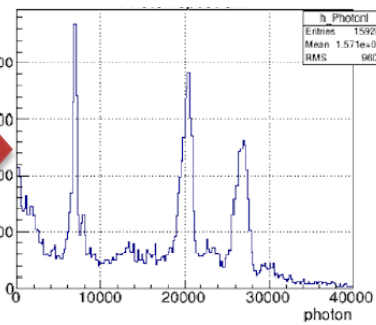
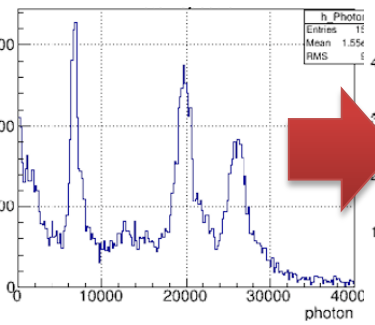
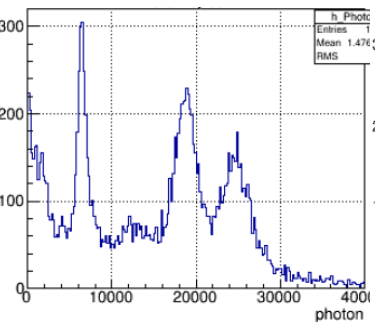
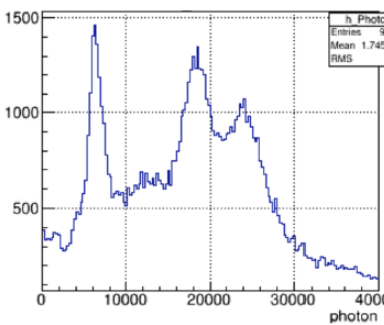
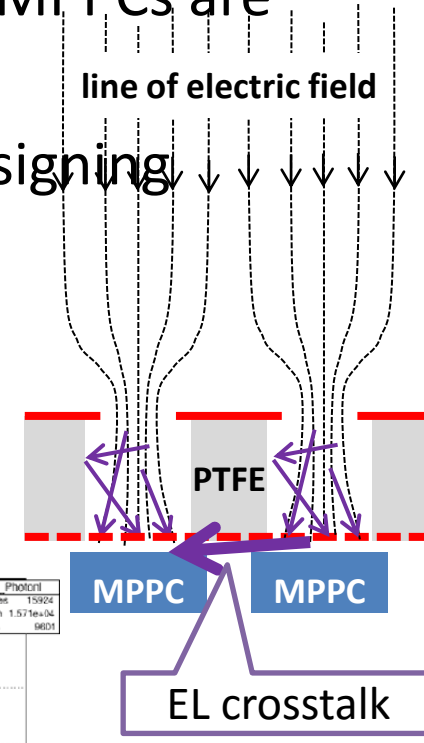
- One MPPC(red) selection is too strict, so blue MPPCs are allowed



suppressic

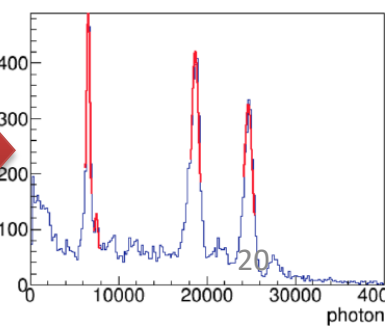
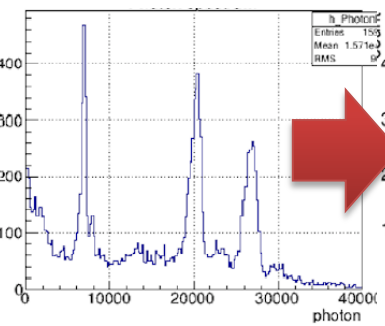
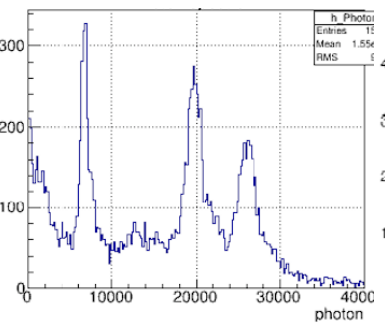
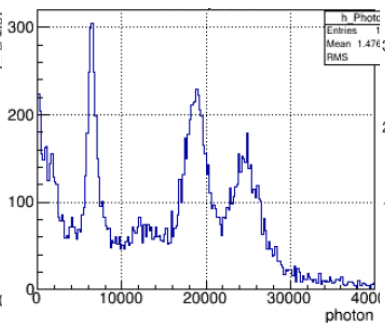
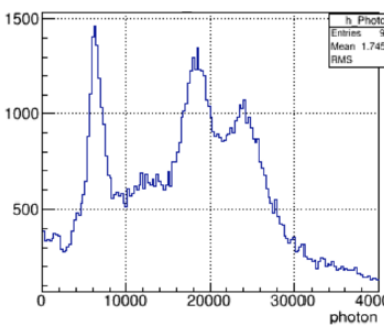
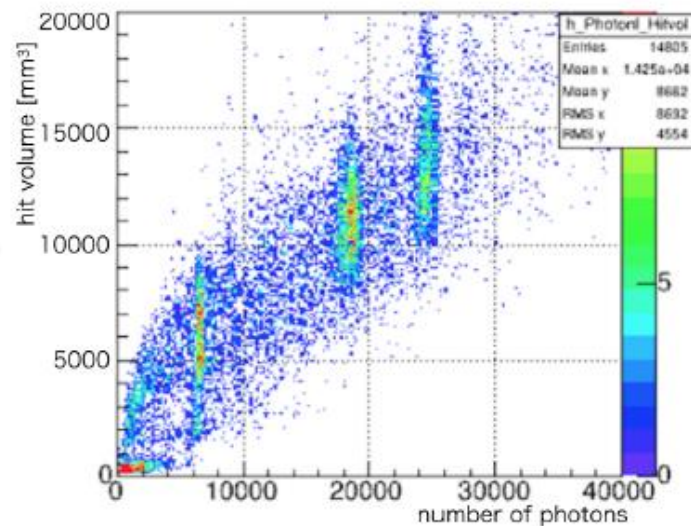
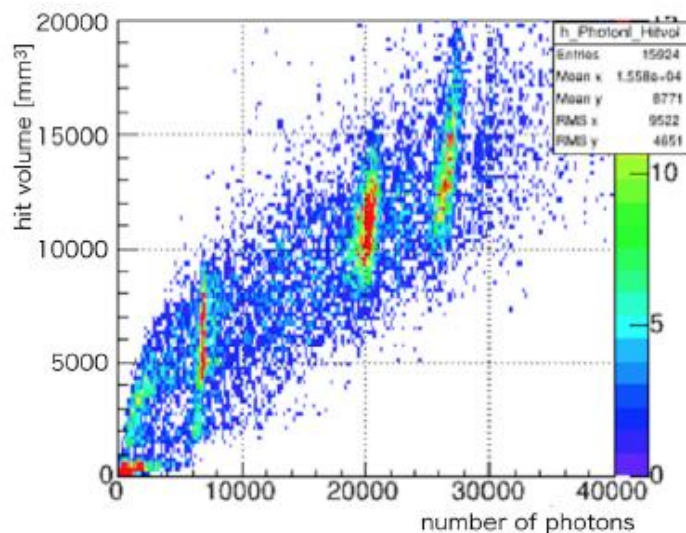


designing



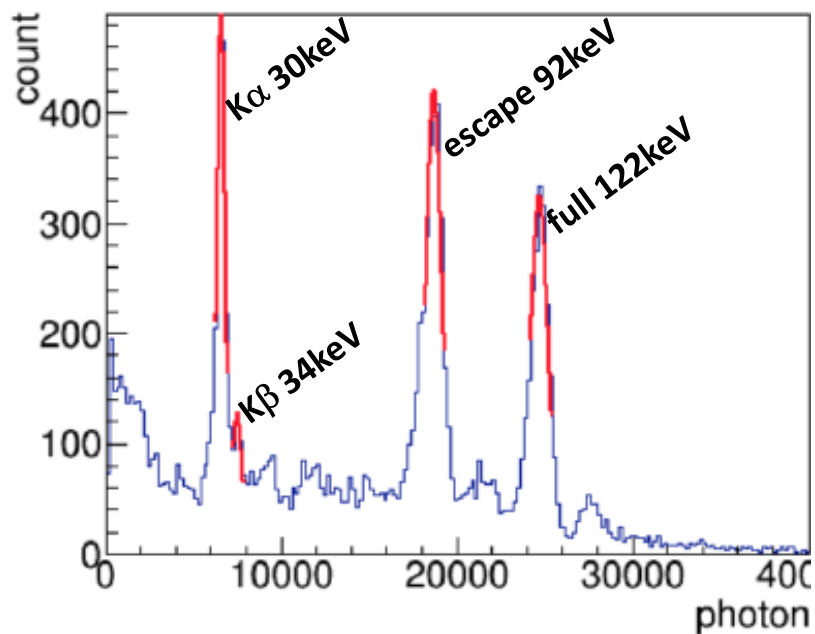
γ -ray measurement (^{57}Co 122keV)

- Hit volume correction
 - strong correlation was obtained
 - (recombination is seen ?)



Energy resolution

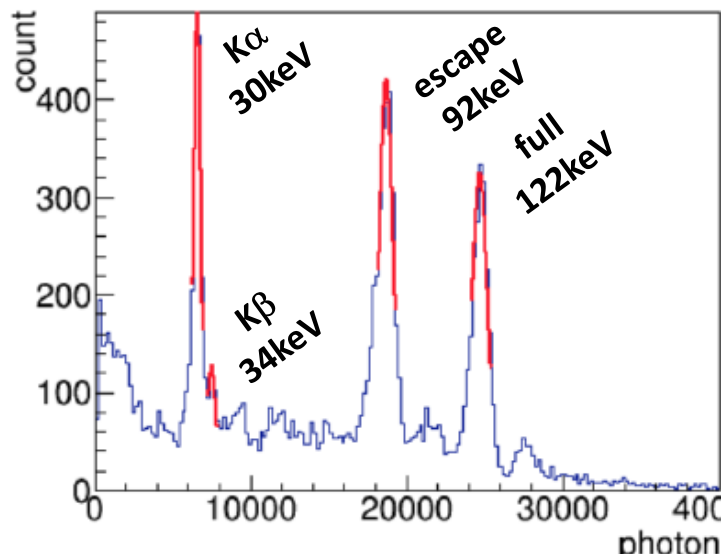
- Four peaks are observed
- FWHMs are evaluated by Gaussian fitting



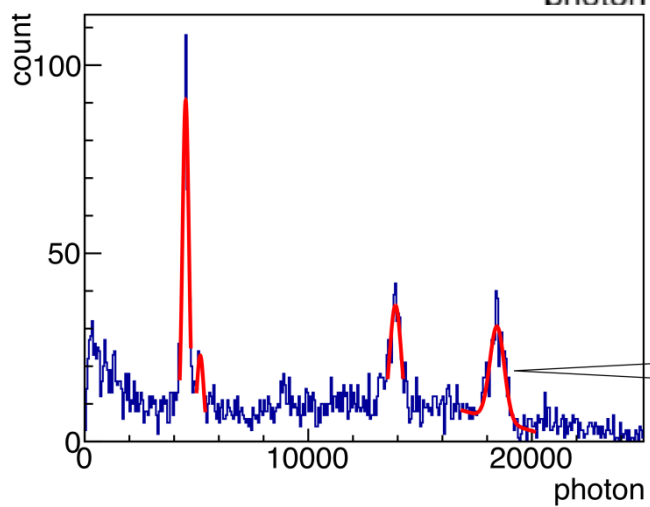
	$K\alpha$	$K\beta$	escape	full
energy	29.8keV	33.6keV	92.3keV	122keV
photon #	6605	7516	18711	24710
FWHM	7.9%	8.7%	5.6%	4.7%

Energy resolution

- 検出器サイズup、解析improveにより、少し改善



	Kα	Kβ	escape	full
energy	29.8keV	33.6keV	92.3keV	122keV
photon #	6605	7516	18711	24710
FWHM	7.9%	8.7%	5.6%	4.7%

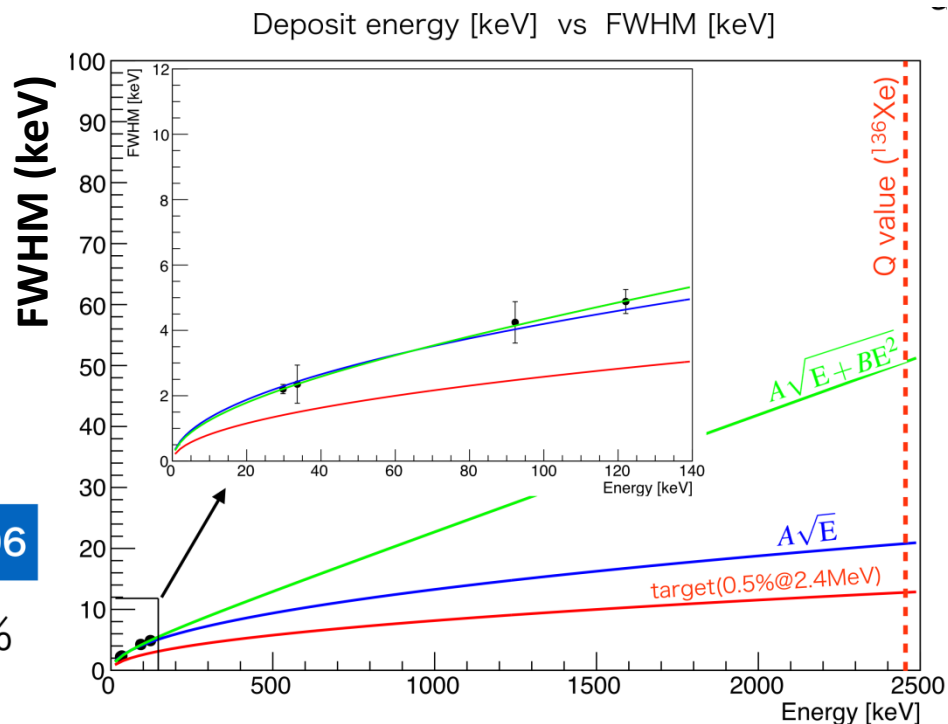


Energy [keV]	29.78	33.62	92.28	122.06
# of photon	4517.3	5169.5	13900.2	18445.0
FWHM	7.3%	7.0%	4.6%	4.0%

Energy resolution estimation at Q

- Estimated resolution is $\sim < 1\%$ (FWHM) @ 2.5 MeV
 - あとちょっと
 - 放電対策してもう少し電圧を上げる
 - 大きい検出器開発

Energy [keV]	29.78	33.62	92.28	122.06
FWHM@Q値 (converted by \sqrt{E})	0.8%	0.8%	0.9%	0.9%



Summary

- AXEL project
 - $0\nu\beta\beta$ search using high pressure xenon gas TPC with high energy resolution, large mass and tracking ability
 - New readout idea : ELCC (electric field simulation is OK)
- Prototype detector
 - Energy resolution : $\sim 1\%$ (FWHM) at Q (many improvements are ongoing)
- Future prospects
 - We started making large size detector (エレクトロニクス・設計・simulation)