MEG II 実験に向けた液体キセノンガンマ線検出器の建設状況

The construction status of the MEG II liquid xenon gamma-ray detector

小川真治、 他MEG IIコラボレーション

@日本物理学会　2016年秋季大会

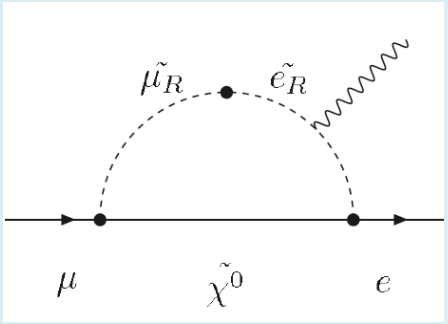
1. Introduction

2. Construction Status of LXe detector

3. Summary

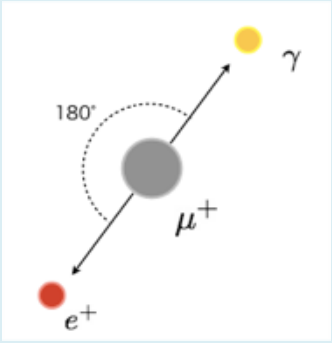
μ→eγ search

- We search for charged lepton flavor violating decay of muon, μ->e+γ.
- Prohibited in SM, detectable branching ratio in some BSM model
- Main background is the accidental background.
- Detector resolutions, **especially energy resolution of γ-ray**, are important to effectively distinguish the signal event from the accidental background



Signal

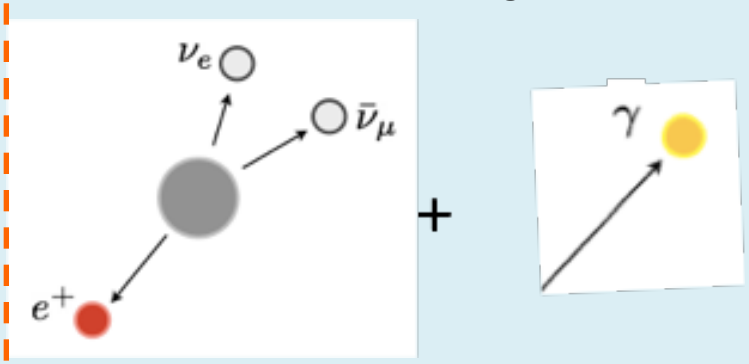
Signal decay



- E=52.8MeV
- back-to-back
- coincident

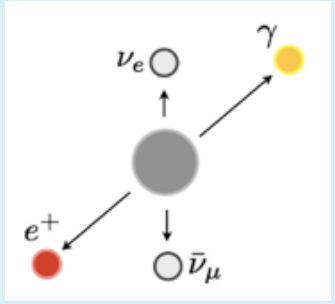
Background

Accidental background



- **Dominant background**
- E < 52.8MeV
- not back-to-back

Radiative muon decay



- E<52.8MeV
- not back-to-back
- coincident

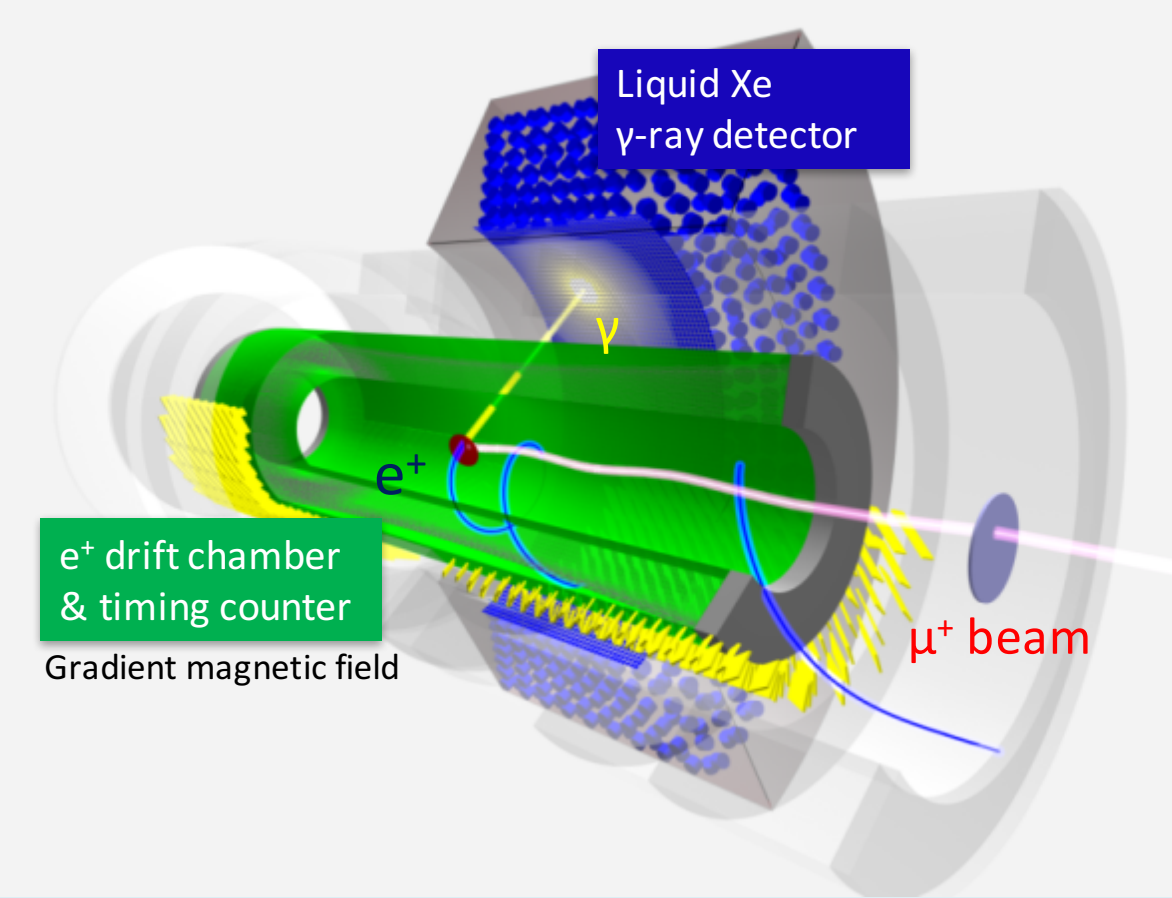
MEG II experiment

Upgrade of MEG experiment

- μ^+ stopping rate will be doubled
  - 3×10^7 μ/s → 7×10^7 μ/s
- Detection efficiency will improve.
- Resolutions of all detectors will become half.
- New detector for background tagging will be introduced

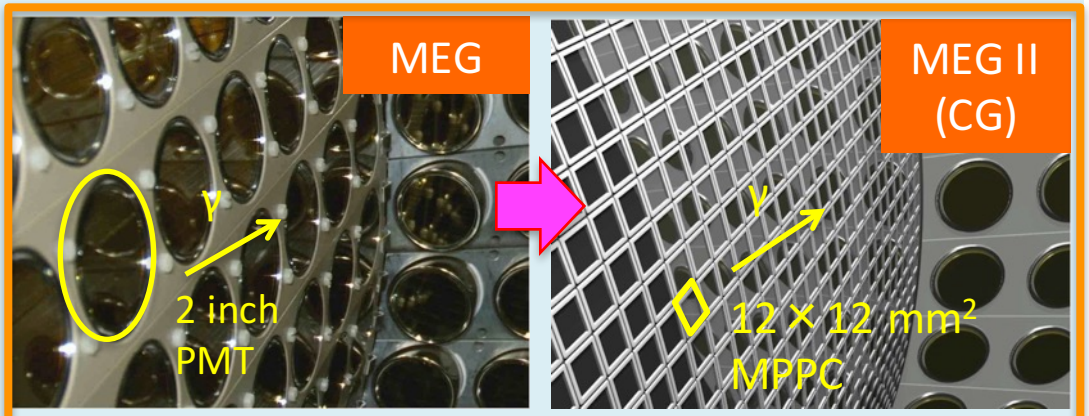
Expected sensitivity: 4×10^{-14}

- One order of magnitude better than MEG



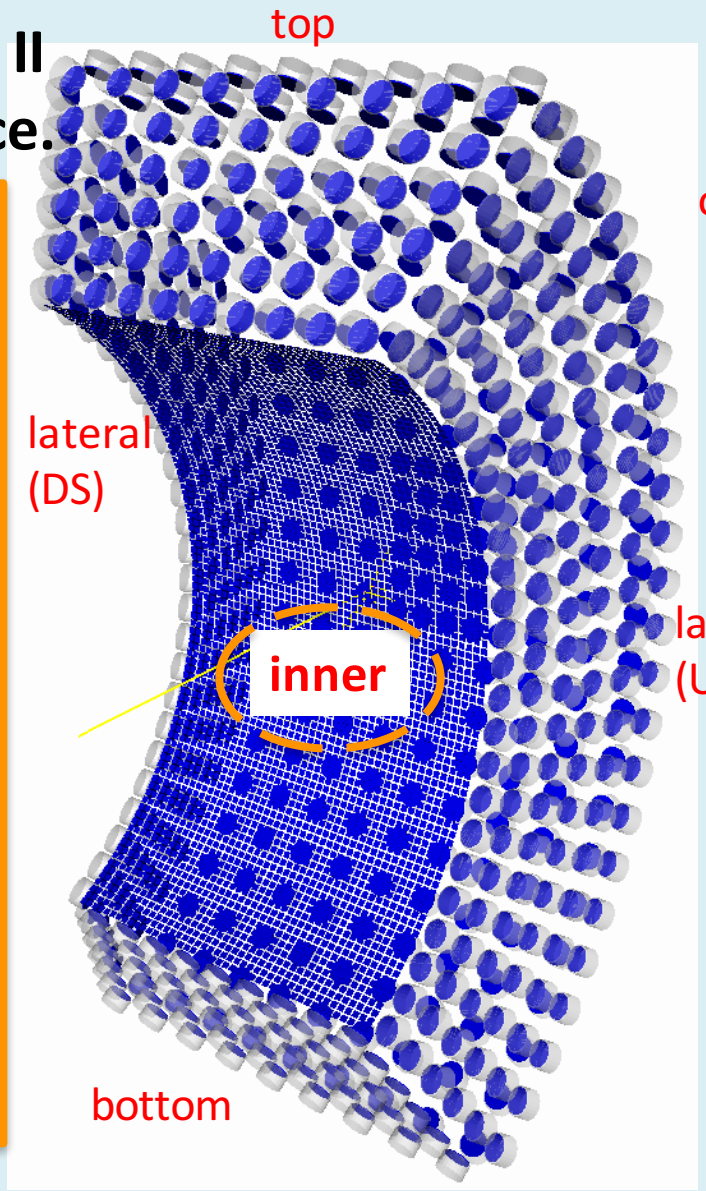
LXe detector upgrade

We are upgrading LXe detector for MEG II to significantly improve the performance.



We will replace 216 2-inch PMTs on the γ-entrance face with 4092 12 × 12 mm² MPPCs.

- Better granularity
  - Better position resolution
- Better uniformity of scintillation readout
  - Better energy resolution
- Less material of the γ-entrance face
  - Better detection efficiency



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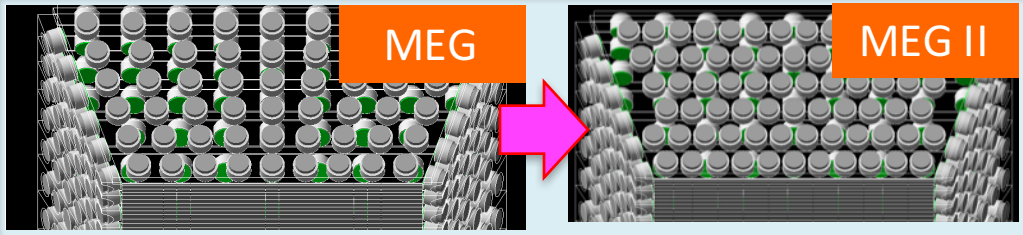
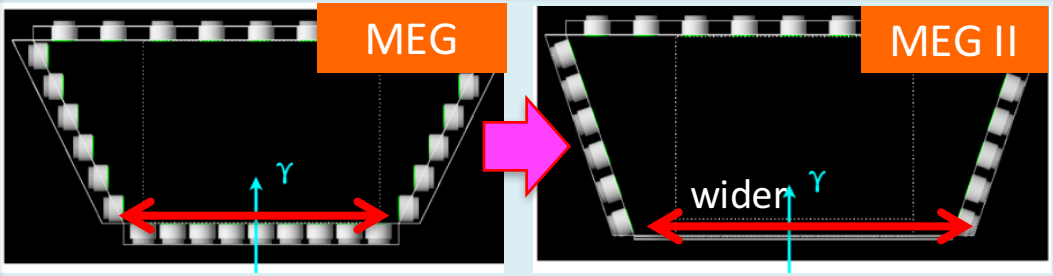


Number of PMT increases (54 → 73)
and PMT is placed staggered

- Improve the uniformity of the readout

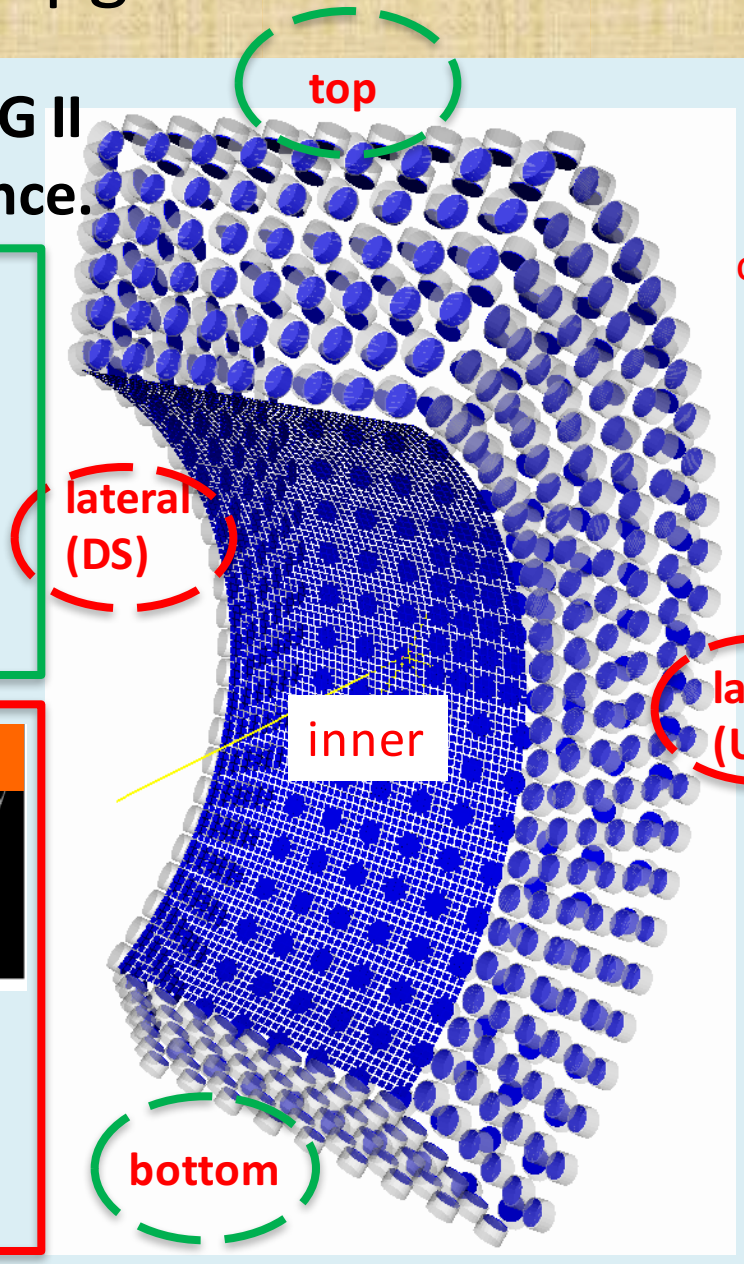


Different PMT angle of lateral face

- Improve the uniformity of the readout

Wider incident face

- Decrease energy leakage

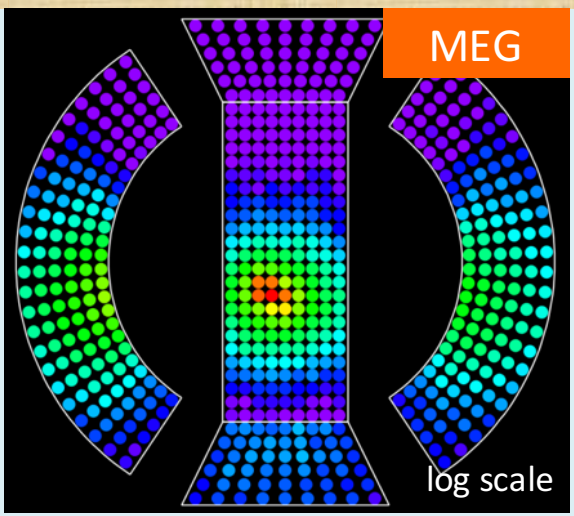


Expected performance

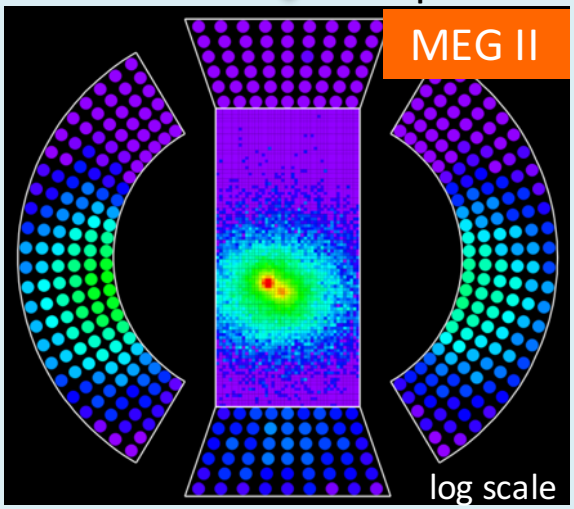
- Significant improvement of all resolutions and efficiency are expected.

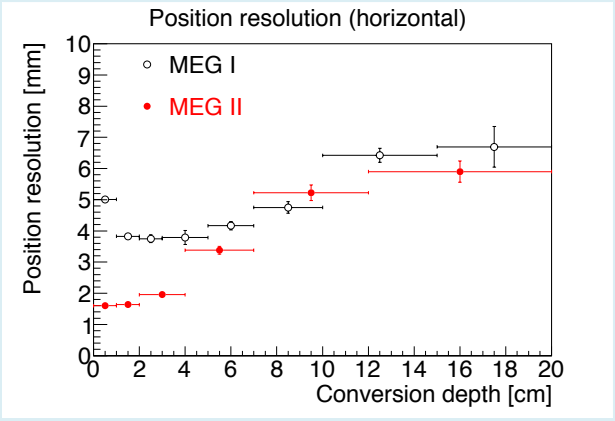
Detector performance for signal γ-ray

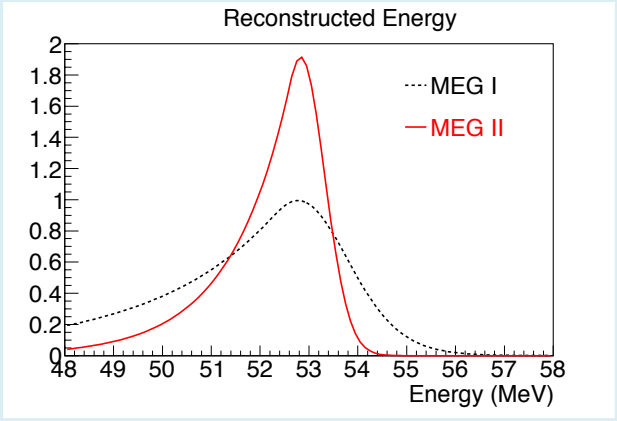
	MEG (measured)	MEG II (simulated)
Efficiency	65%	70%
Position	~5 mm	~2.5 mm
Energy	~2%	0.7 - 1.5%
Timing	67 ps	40 - 60 ps



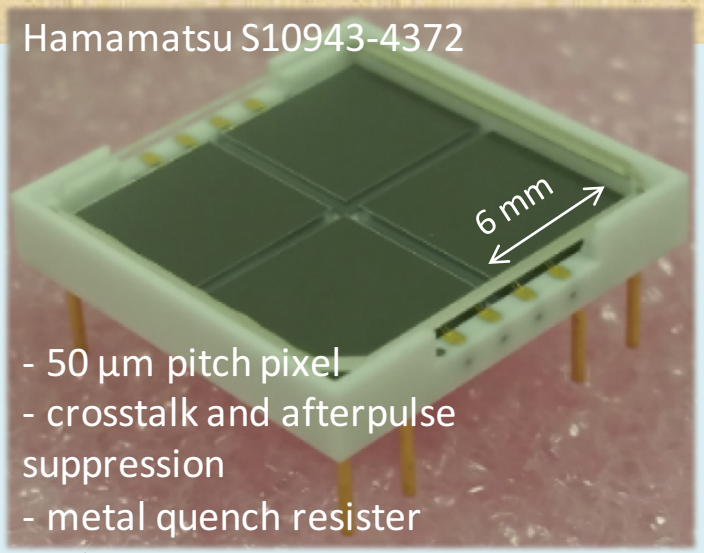
Imaging power improves



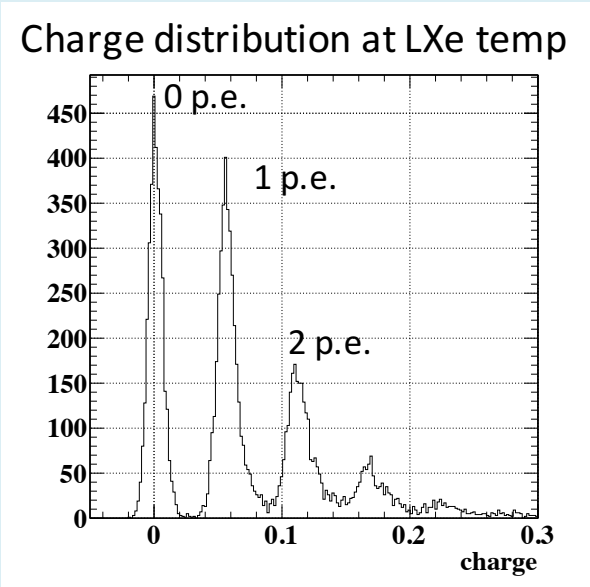


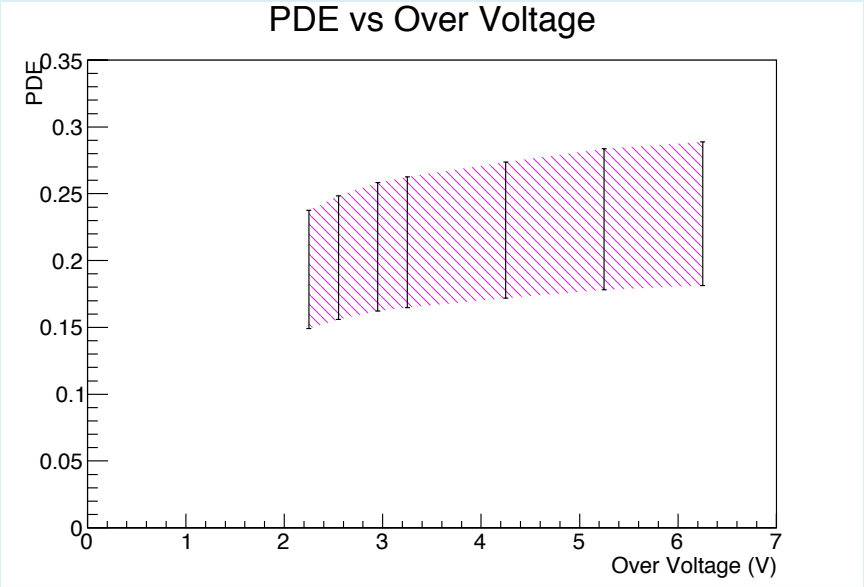


VUV-sensitive large area MPPC

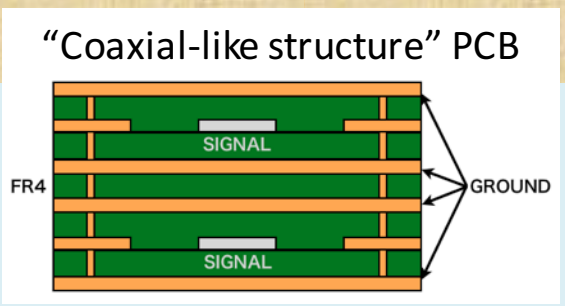


- MPPC for MEG II LXe detector has been developed in collaboration with Hamamatsu Photonics K.K.
  - VUV-sensitive (PDE (λ=175nm) > 15%)
    - Scintillation light of Xe is in VUV range
  - Large sensitive area (12 × 12 mm^2)
    - Discrete array of four 6 × 6 mm^2 chips.
    - Four chips connected in series to reduce long time constant.
- Further study is going on, to understand its performance well. (see next talk)

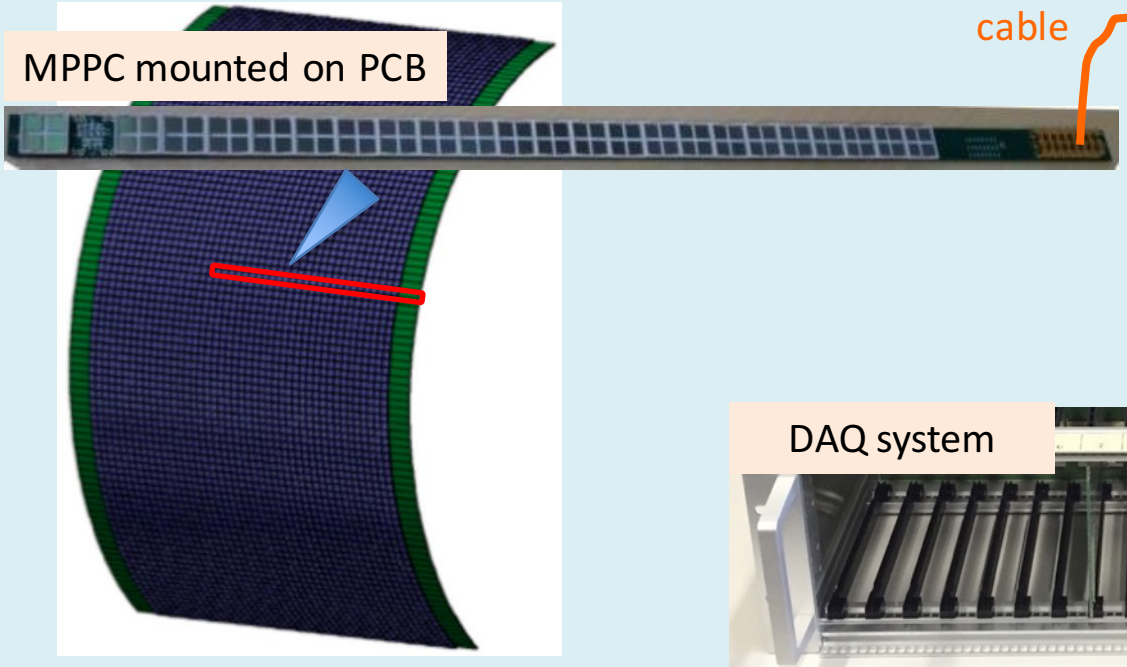




Signal transmission



- We have developed signal transmission system.
  - It can transmit ~5000 ch signals.
  - PCB has coaxial-like structure for impedance matching (50Ω) and good shielding from external noise, high bandwidth, and low crosstalk.
  - Feedthrough is based on PCB to realize high density transmission.
- New DAQ board, WaveDREAM, is being developed to cope with increased number of channels.



1. Introduction

2. Construction Status of LXe detector

3. Summary

Detector Construction Status

R&D

Production

Assembly

Commissioning

Engineering

Physics DAQ

R & D

- ✓ VUV-sensitive large area MPPC
- ✓ Signal transmission system

Production

- ✓ MPPC mass production
- ✓ MPPC mass test
- ✓ Signal transmission system
  - ✓ Cable, PCB, feedthrough
- ✓ Modified PMT holders
- ✓ Refrigerator

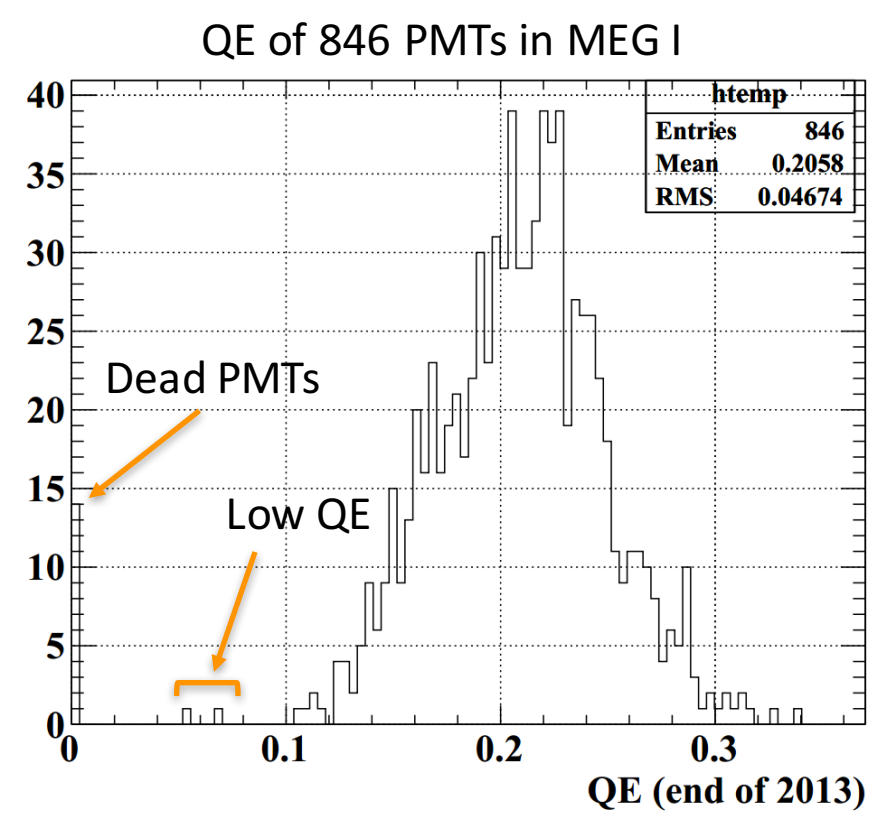
Assembly

- ✓ PMT relocation & installation
- ✓ MPPC installation
- ✓ Sensor position survey
- • Cabling & connection check
- • Calibration source installation

This talk

PMT replacement –Dead channel-

- We will reuse PMTs operated in MEG I.
  - 846 PMTs in MEG I
    → 668 PMTs in MEG II
- Based on the MEG I's history, some of the PMTs are replaced.



Bad PMTs list out of 846 PMTs in MEG I

	# of badPMTs
Dead PMTs	**15**
Low QE	**2**
Gain history is strange	29
QE history is strange	6
Short lifetime is expected	20
Total (overlap considered)	63

PMT replacement –Gain history-

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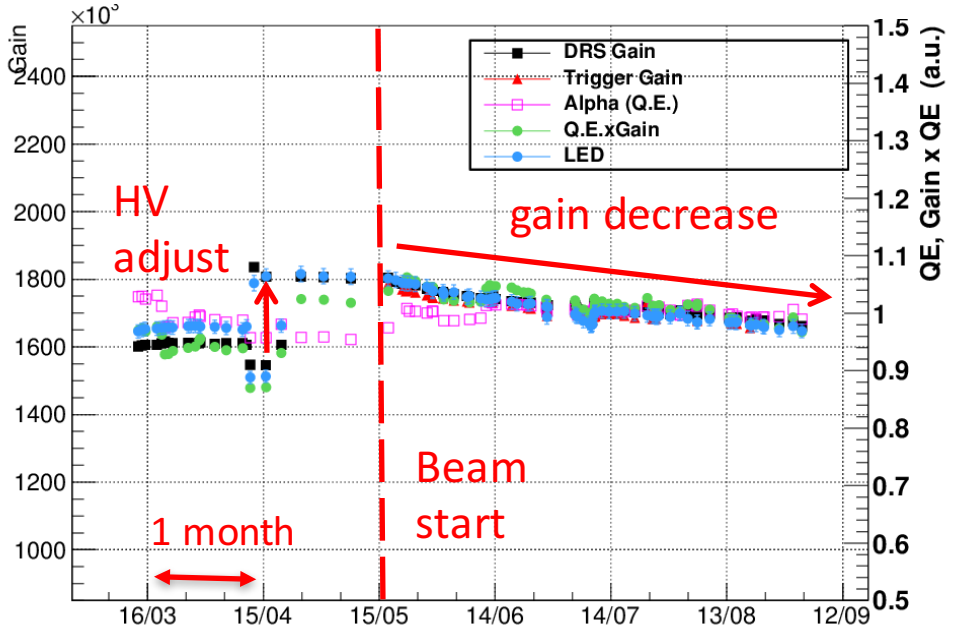
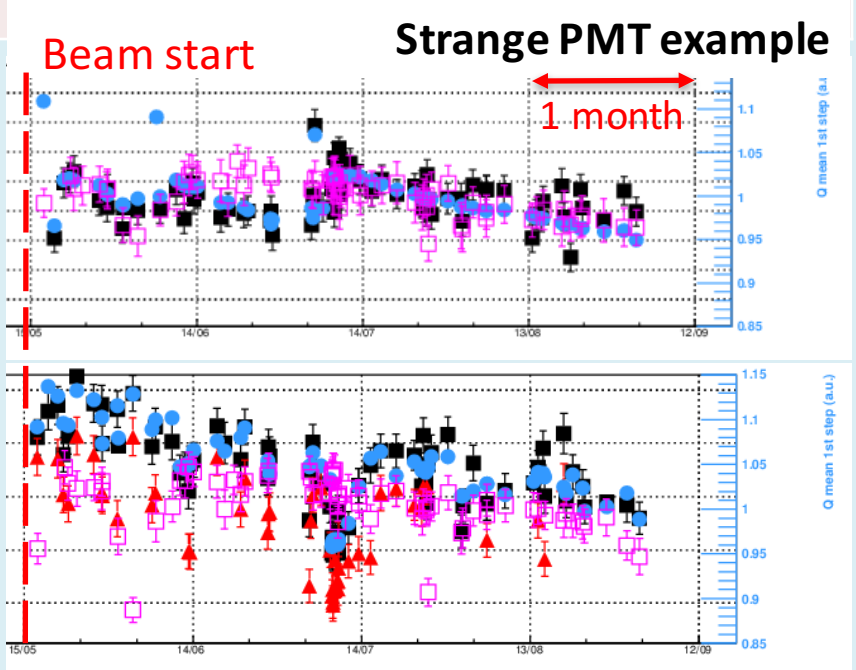
Gain history 2013

Normal PMT



Strange PMT example



PMT replacement -Lifetime-

- We will reuse PMTs operated in MEG I.
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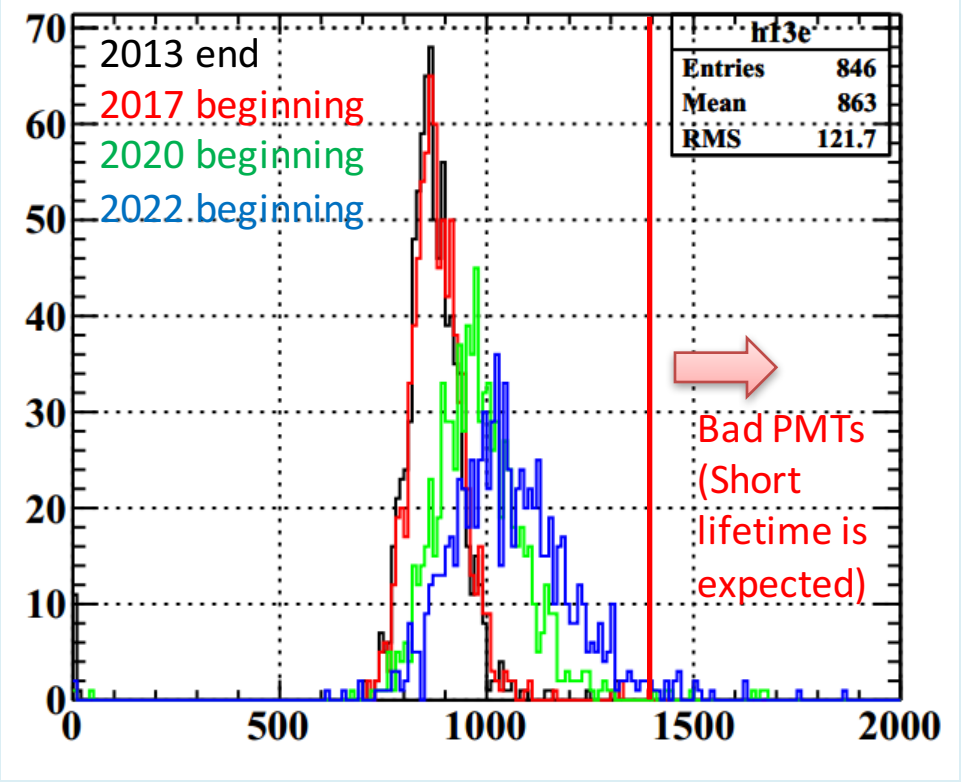

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- We will recover gain decrease coming aging effect by adjusting HV.
- We will not be able to operate it if it reaches voltage limit from electronics (1400V).

Photo sensor install

Photo sensor installation order

Top/bottom PMT install

↓

Outer PMT install

↓

MPPC install

↓

Lateral PMT install

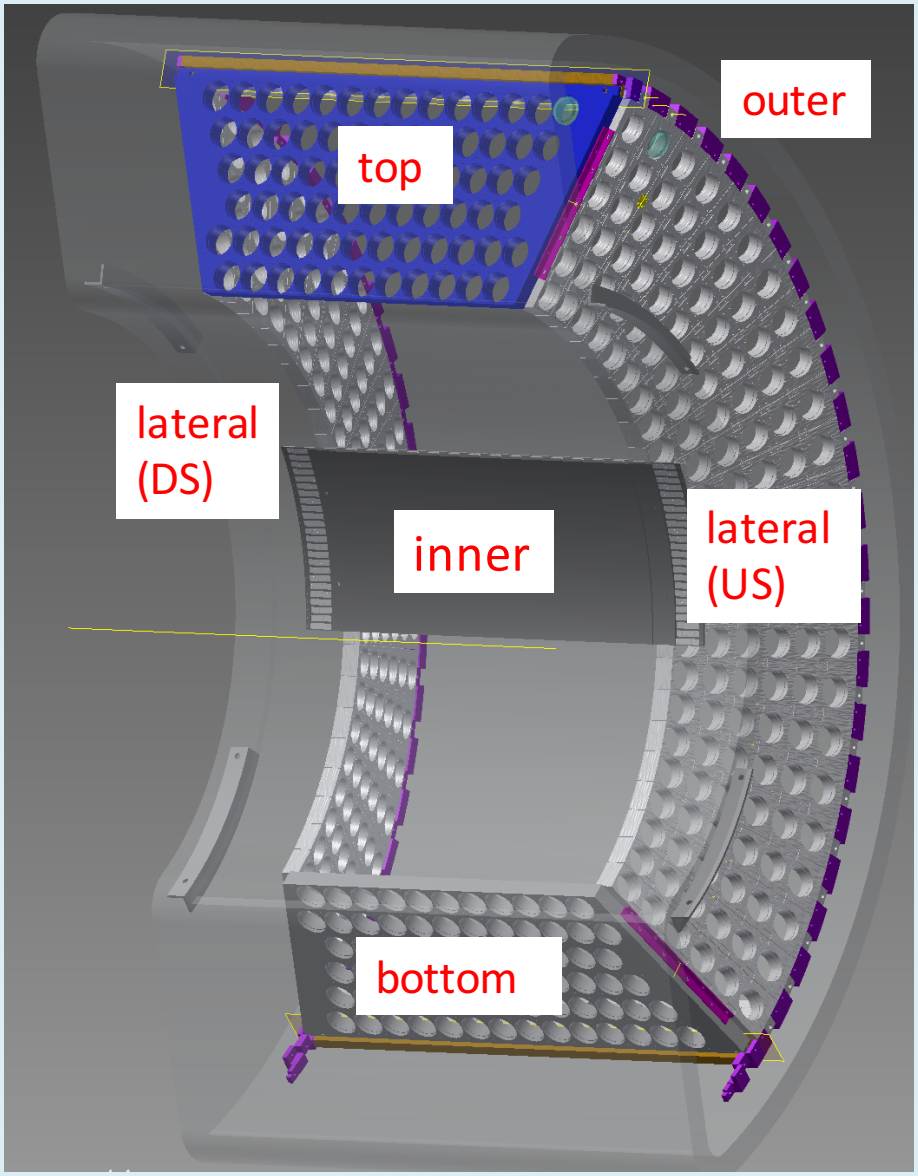
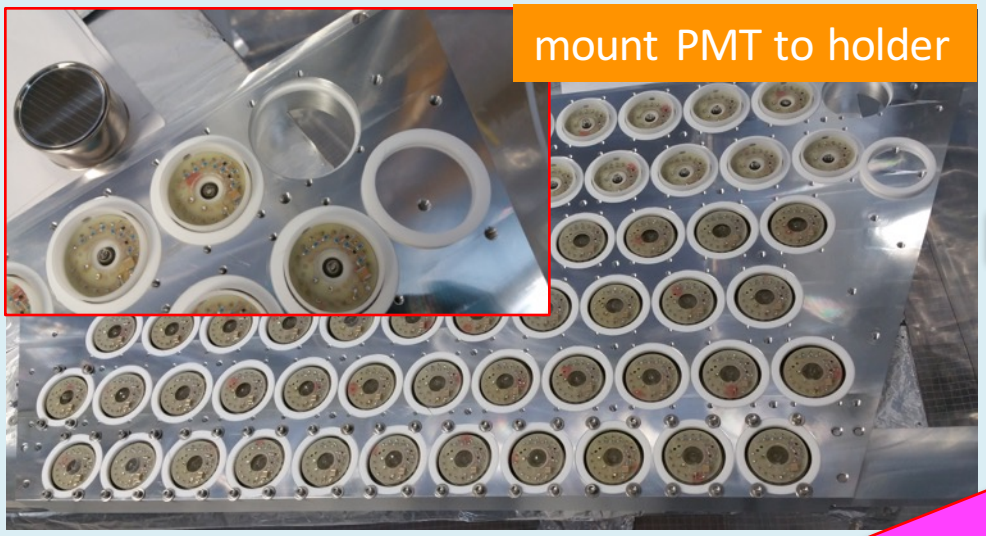
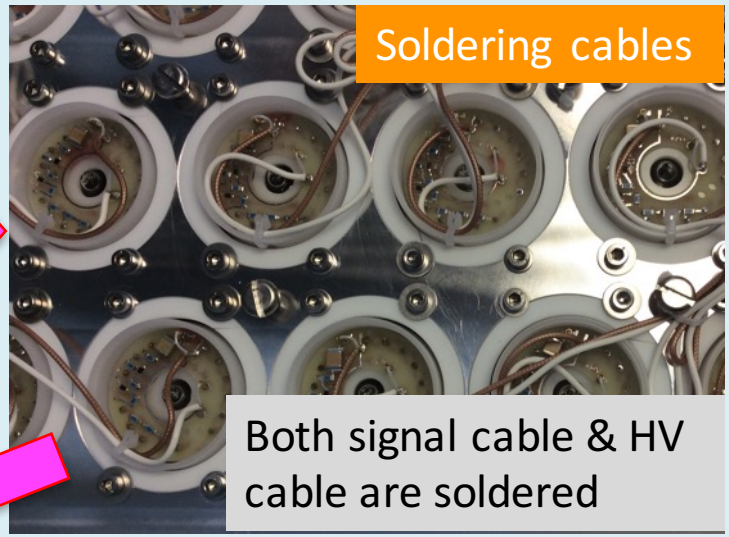


Photo sensor install –PMT-



mount PMT to holder



Soldering cables

Both signal cable & HV cable are soldered

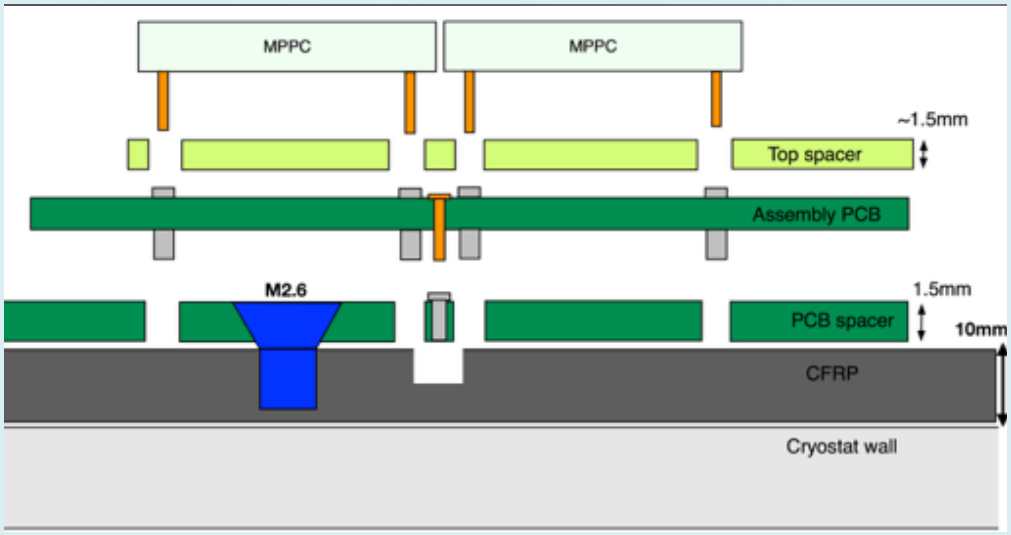
Signal check

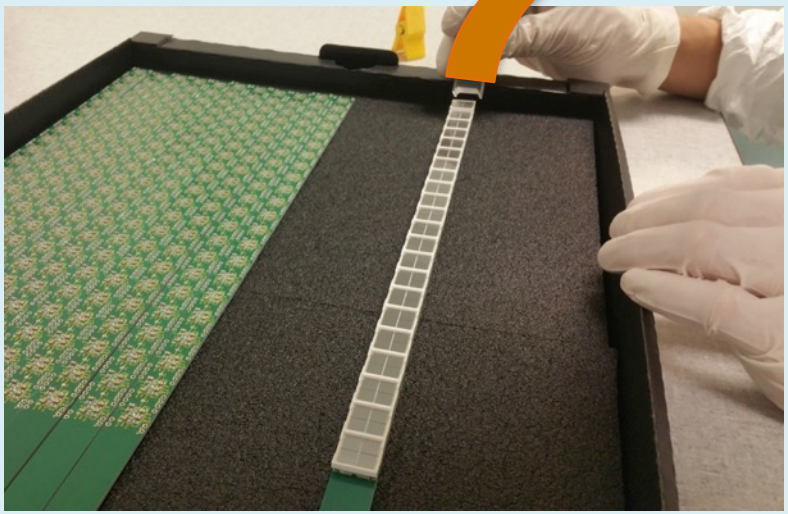
Signal check with Sr 90.
(Cherenkov light at quartz window)

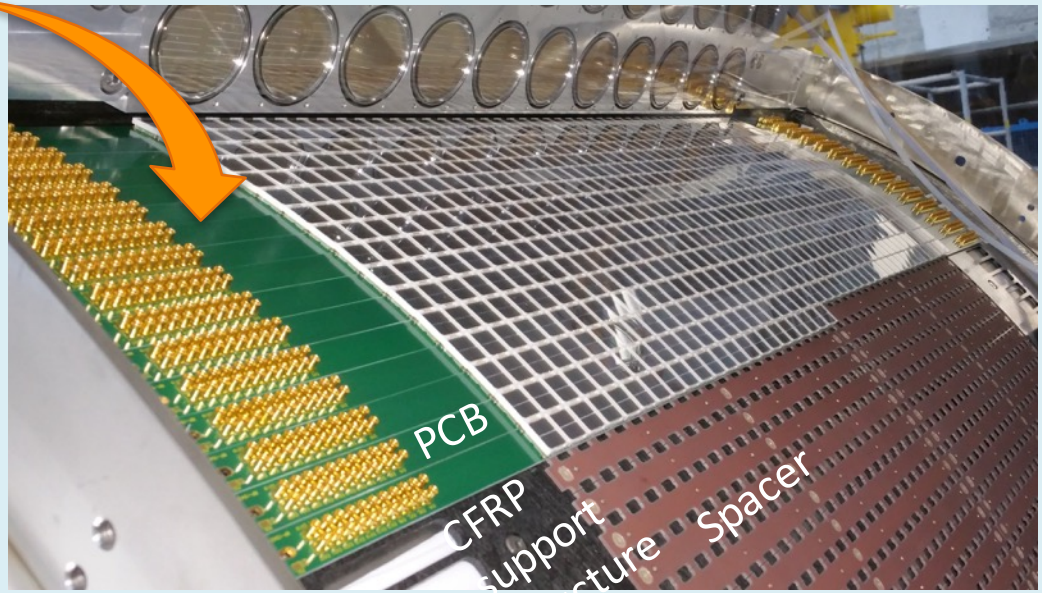
Installation to cryostat

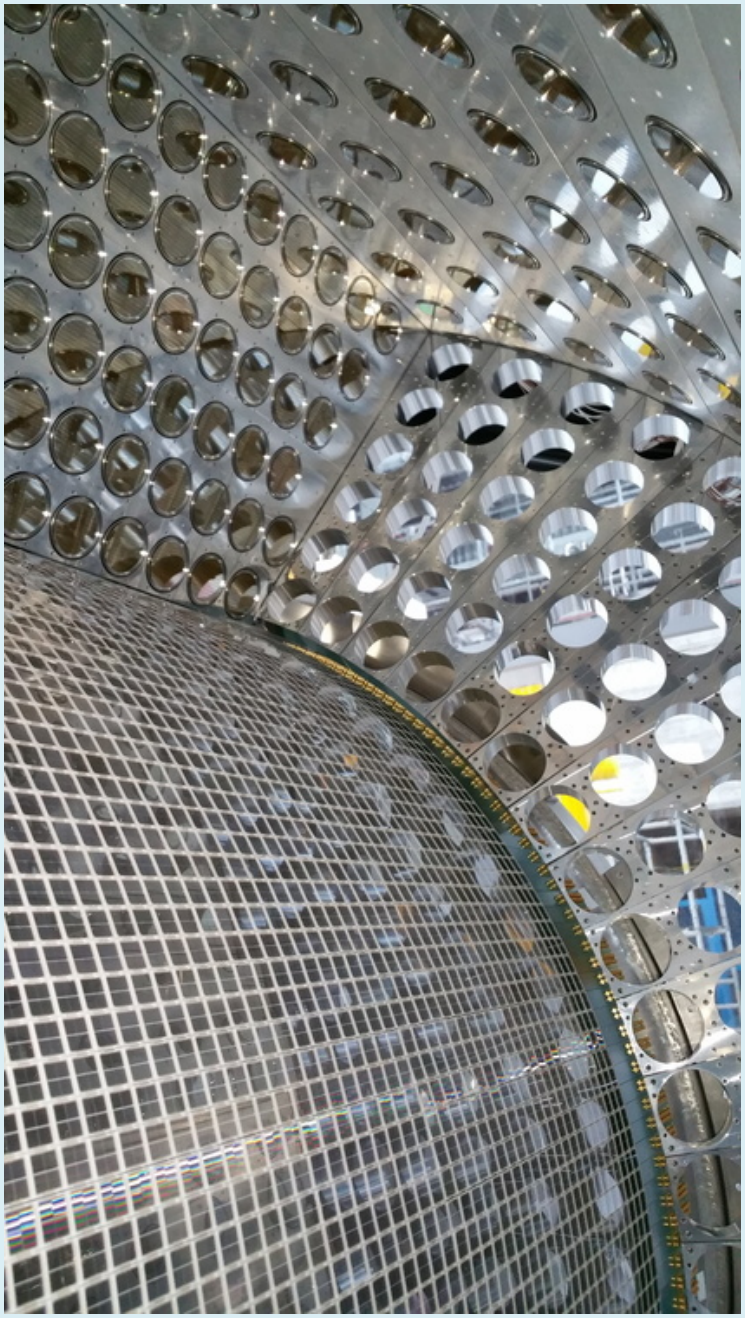
Photo sensor install -MPPC-

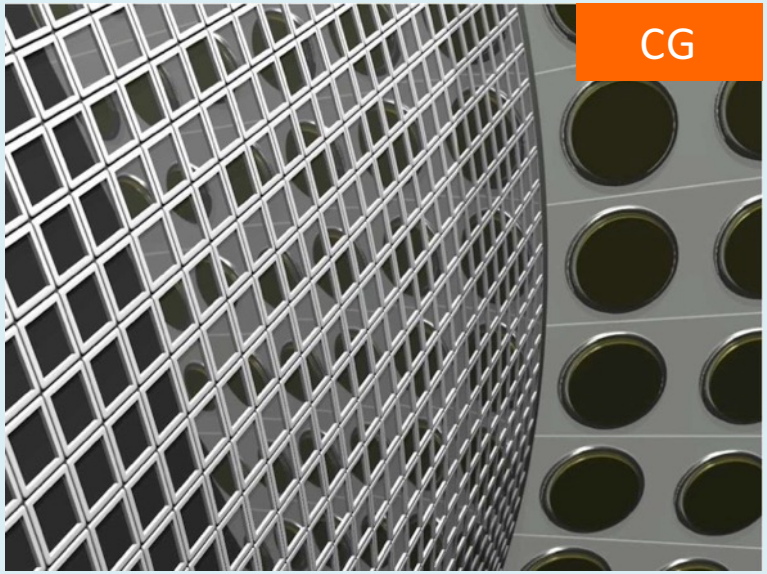
- MPPCs are mounted on PCBs for signal readout and alignment.
- PCBs are fixed on CFRP support structure which is attached on cryostat.
- Spacers are inserted to reduce the material before γ entrance face.



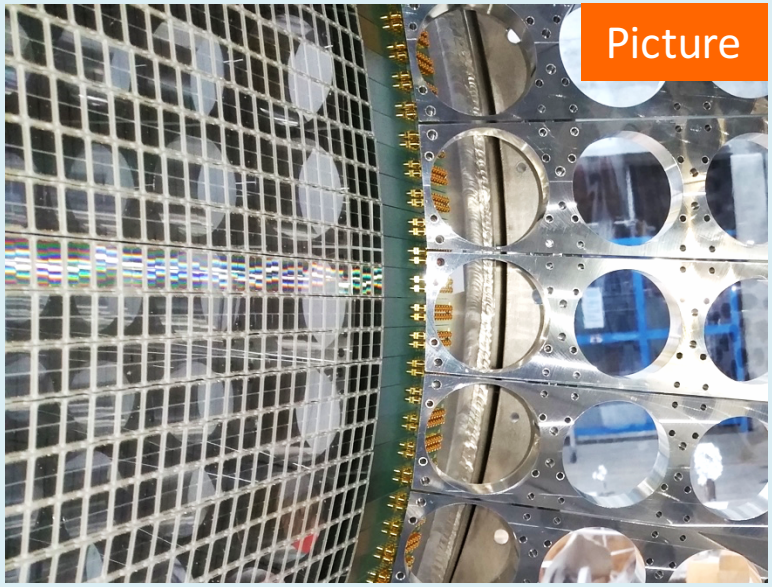








Not a CG !

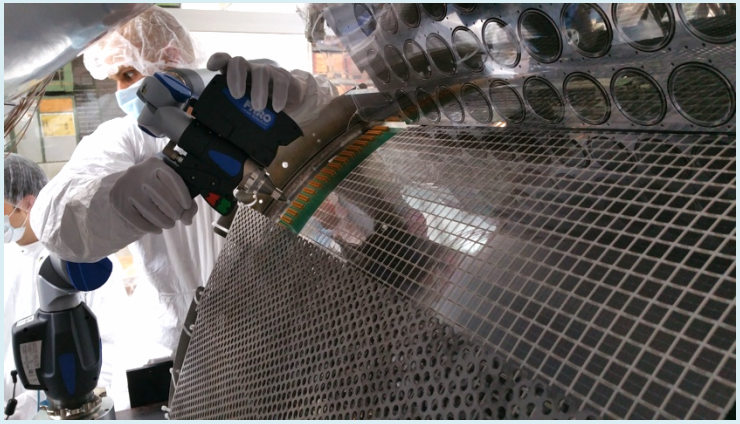


Sensor position survey

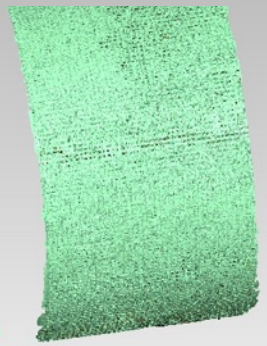
Sensor position is surveyed after installation. Measuring the position of photo sensors accurately is important for γ-ray reconstruction.

MPPC

We have scanned MPPC surface by using FARO scanner.



Measured data

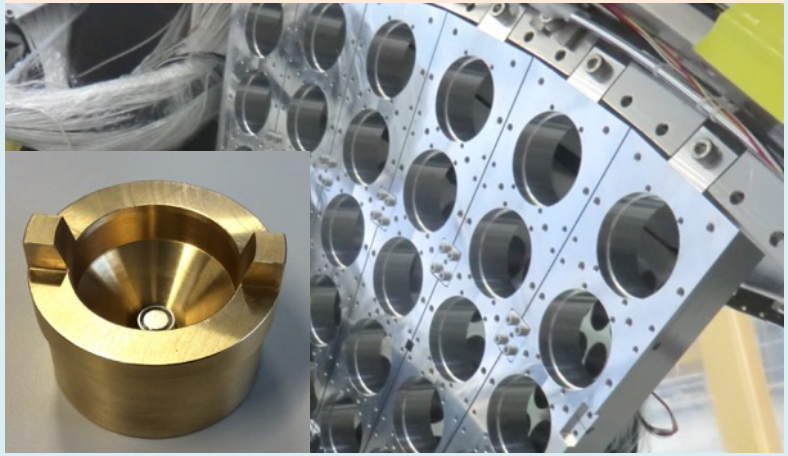


参考
中尾光孝,
「3D スキャナを用いたMEGII実験検出器の超高精度アラインメント」,
高エネルギー物理春の学校2015

PMT

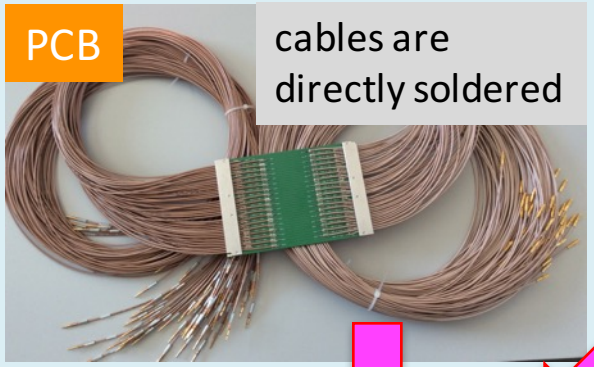
Survey is done mainly for PMT on lateral face. (Position of lateral face has some degree of freedom)
We have measured PMT position by using laser tracker and reference marker.

PMT support structure (Lateral face)



Feedthrough preparation

PCB



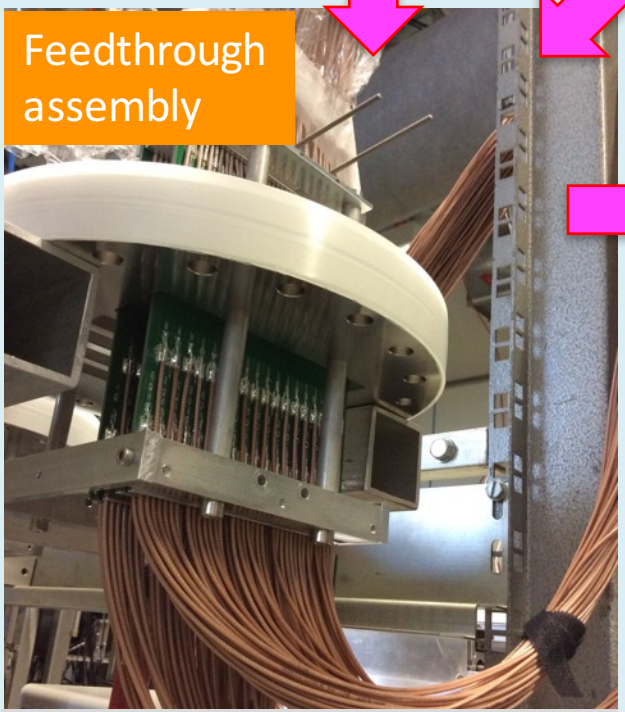
cables are directly soldered

Flange

Preparation of feedthrough has been done before its installation.

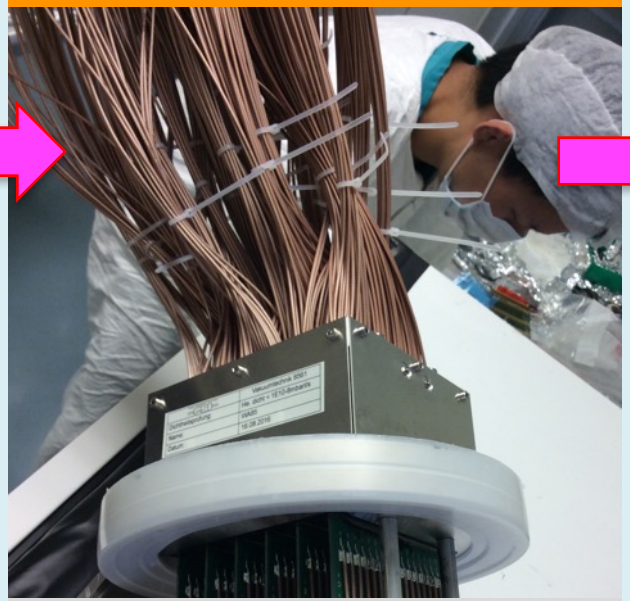
- 432 ch/flange × 12 flange = 5184 ch

Feedthrough assembly



PCBs are attached to flange by Stycast

Make bundles of cables.

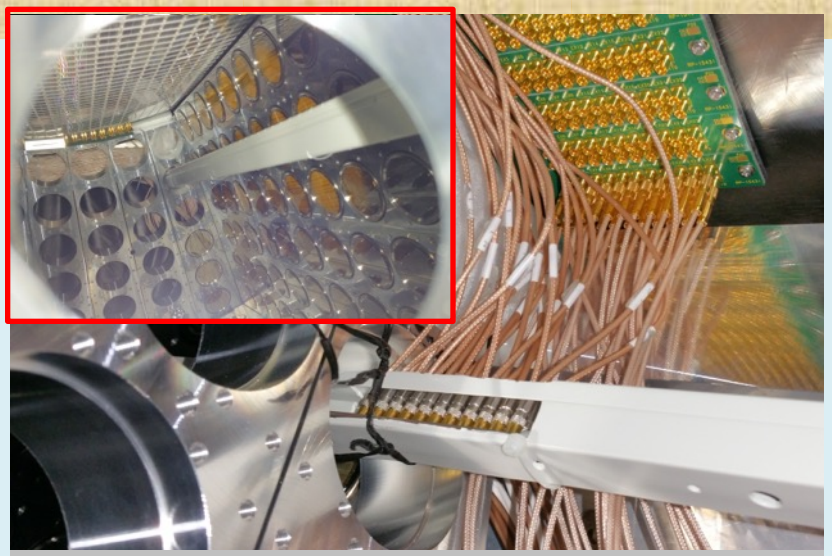


LXe side: in a unit of PCB
Air side: in a unit of readout electronics

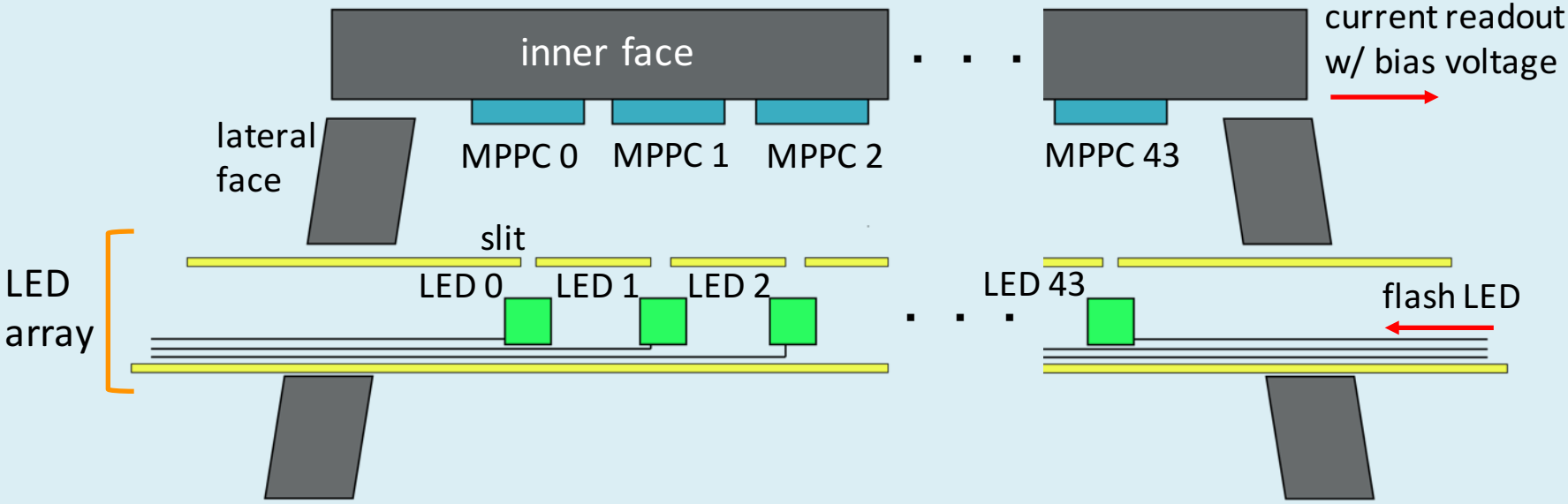
Installation to cryostat

Cabling and connection check

- Connection and channel assignment check is done in parallel with cabling.
- “connect cable -> check connection” cycle is repeated for every PCBs.
- We have prepared a “LED array” to flash the LED just in front of the each MPPC.



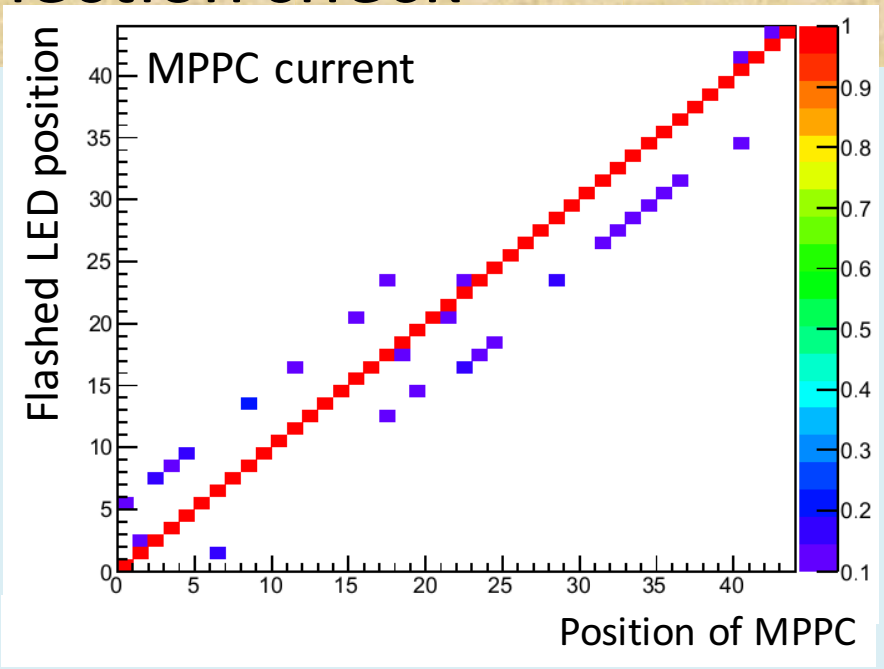
Connection check with LED array

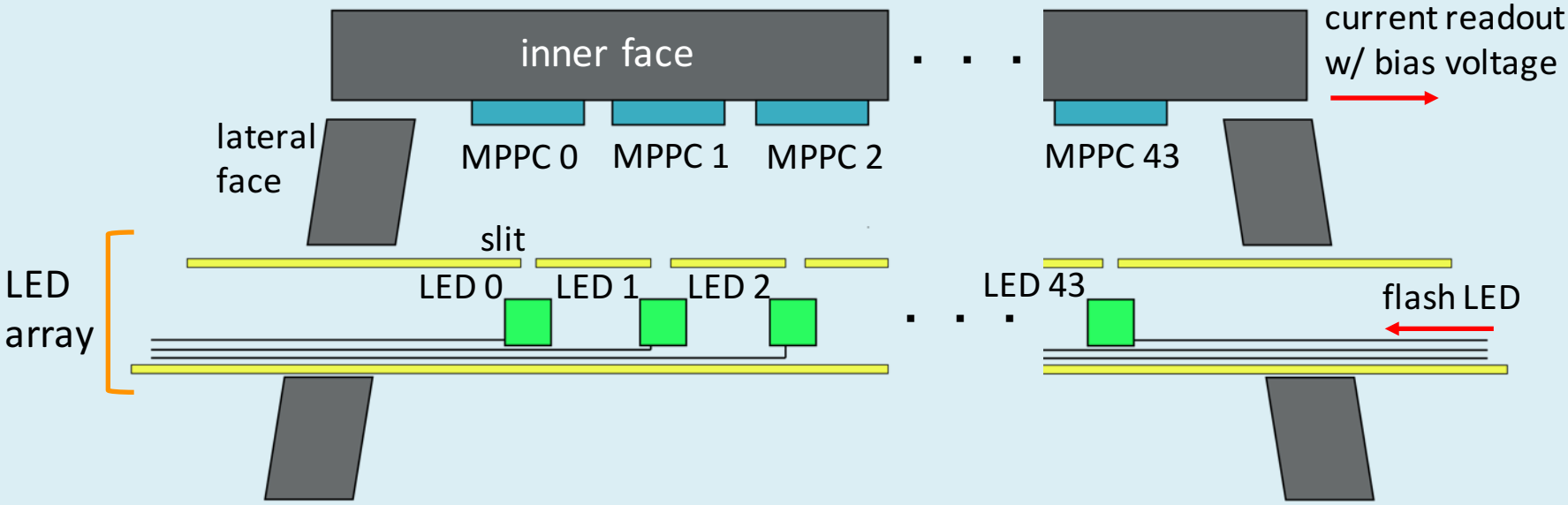


Cabling and connection check

- Each LED is flashed one by one.
- We have checked whether nearest MPPC shows larger current than others.

Cabling and connection check is on going.





Schedule

R&D

Production

Assembly

Commissioning

Engineering

Physics DAQ

Assembly

- ✓ PMT relocation & installation
- ✓ MPPC installation
- ✓ Sensor position survey
- • Cabling & connection check
- • Calibration source installation

next winter (3 months delay from last JPS)

Commissioning

- • LXe liquefaction & purification
- • Commissioning run

2017

Engineering

- • Full detector calibration
- • Performance measurement

※LXe detector construction will not limit MEG II schedule.

1. Introduction

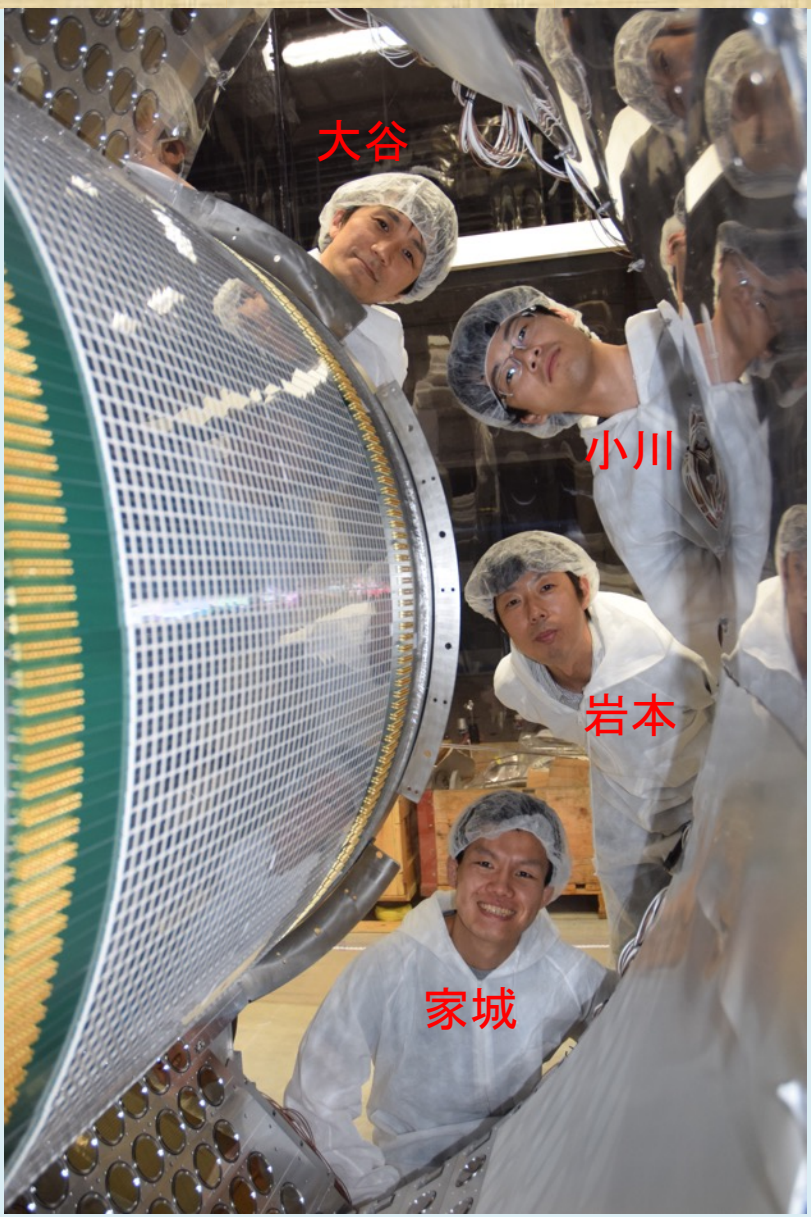
2. Construction Status of LXe detector

3. Summary

Summary

- The MEG II experiment searches for μ->e+γ decay with the sensitivity of 4×10^{-14}.
- LXe detector upgrade will play an important role to sensitivity improvement.

- Detector construction of LXe detector is on going.
  - MPPCs are successfully installed.
- Detector commissioning will be next winter.

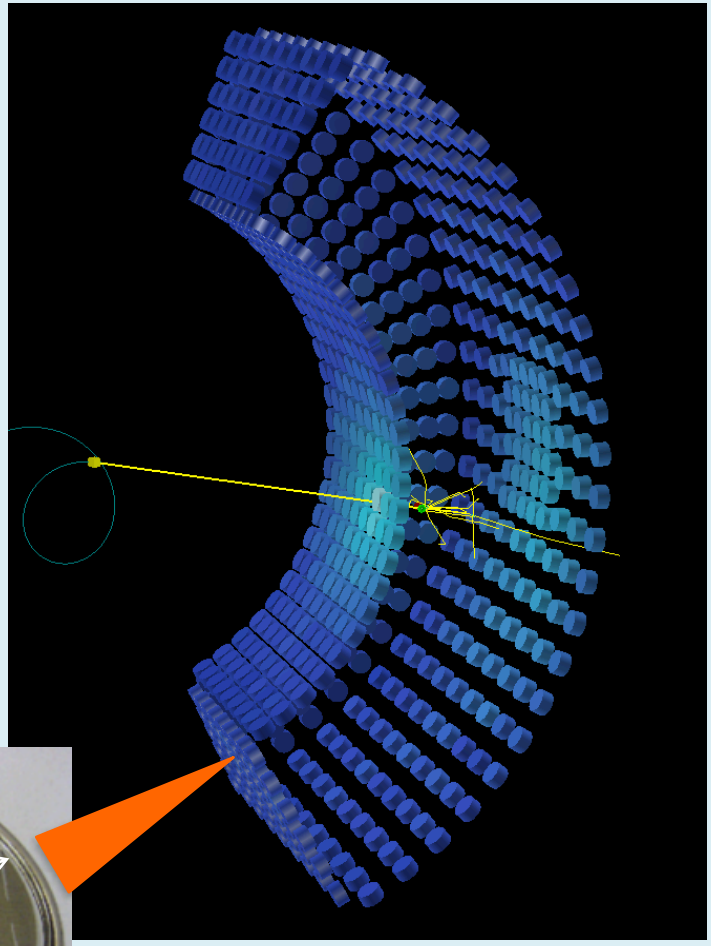


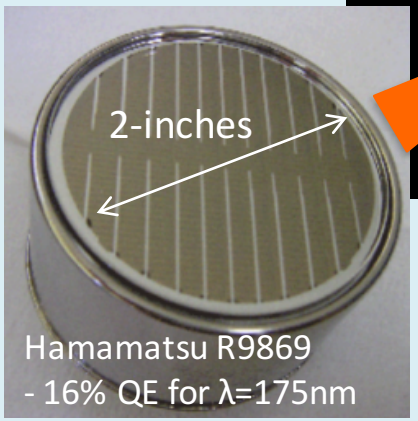
他、たずさわった方々
金子、澤田、松澤 (東大)
笠見、西口、牧、三原(KEK)
斉藤(九大)
技官の方々(PSI)

BACKUP

MEG LXe γ-ray detector

- LXe γ-ray detector was successfully operated in the MEG experiment.
  - 900 ℓ LXe detector
  - Scintillation light readout by 846 PMTs
- Advantages of LXe
  - High light yield (~75% of NaI)
  - Fast (τ_{decay} = 45ns for γ-ray)
  - High stopping power (X_0=2.8cm)
  - Uniform (liquid)
- Disadvantages of LXe
  - VUV (Vacuum Ultraviolet) scintillation light (λ=175nm)
  - High purity is needed
  - Low temperature (165K) is required





LXe refrigerator & purification

出典：家城佳, JPS 2016春

Upgraded cryogenics system is being constructed to cope with increased heat flow from 4000 MPPCs.
Sufficient power (430W @ 160K) of new GM refrigerator is confirmed.

external stage
for GM refrigerator

Additional GM refrigerator will be placed far from cryostat to prevent from noise

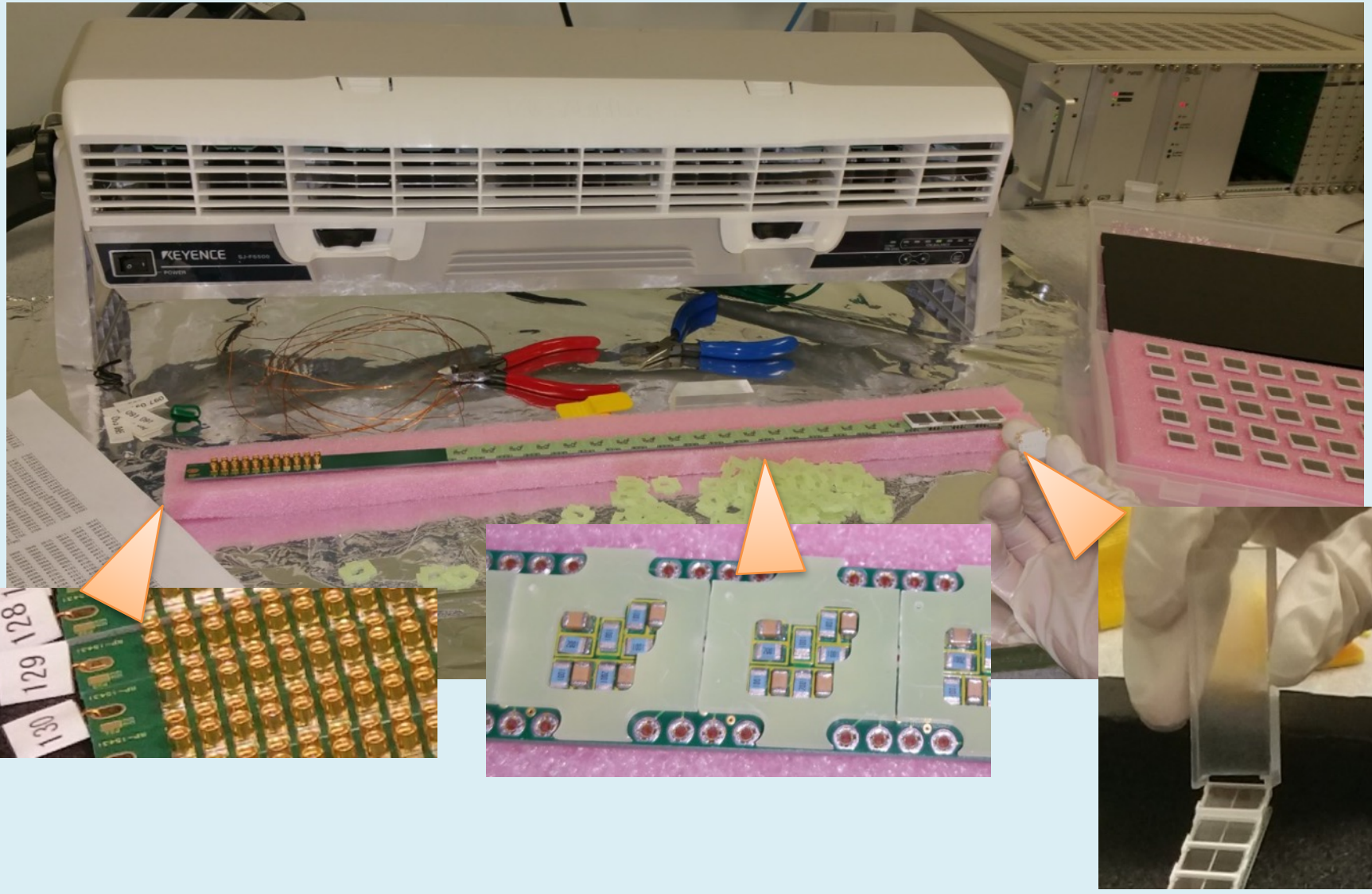
liquefaction

pulse-tube
refrigerator

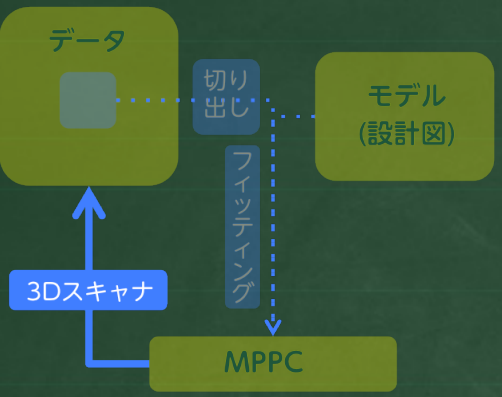
getter
(purification)

Mounting MPPCs on PCB

出典：家城佳, JPS 2016春



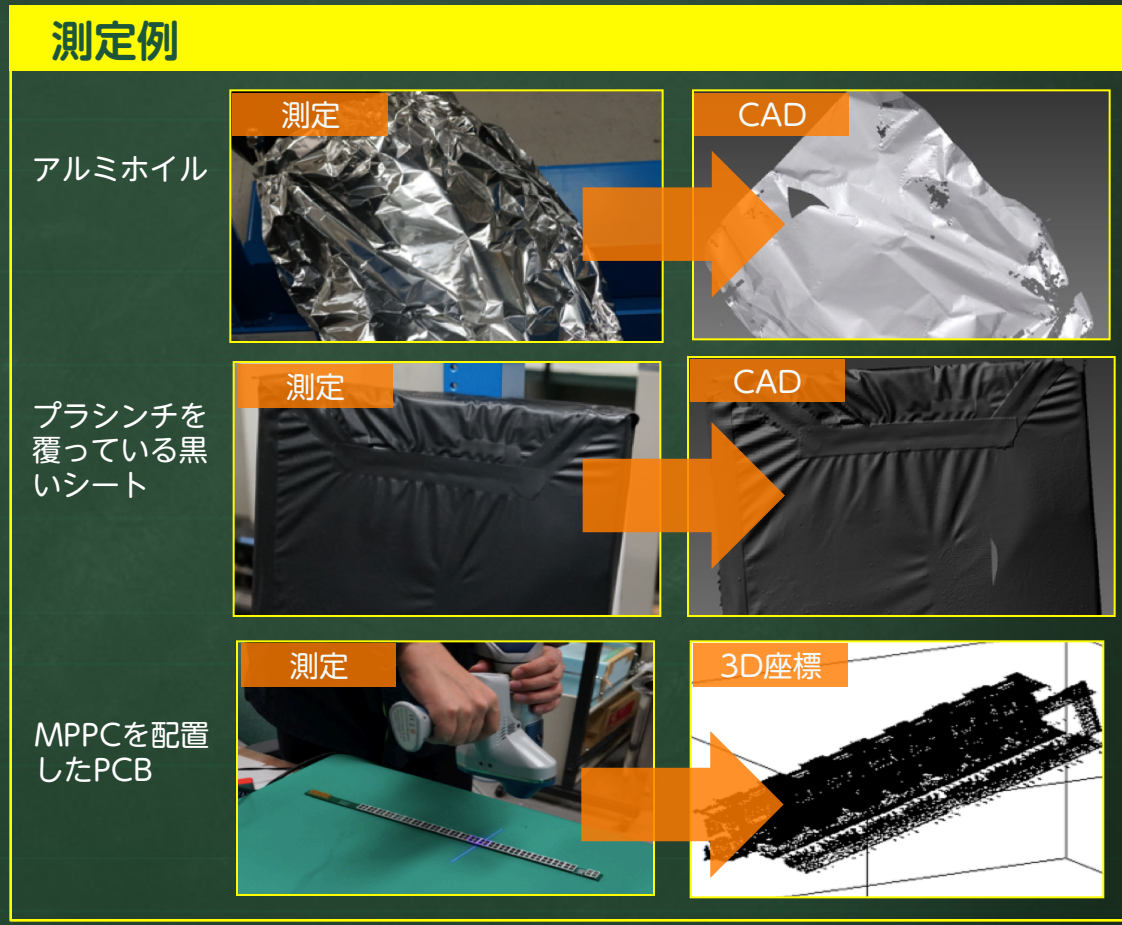
3Dスキャナ



FARO Edge ScanArm HD

- Accuracy : ±25μm
- Scan rate : 560,000 points/sec
- 基準点に対する3次元の位置を測定
- 出力はCADファイルまたは3D座標

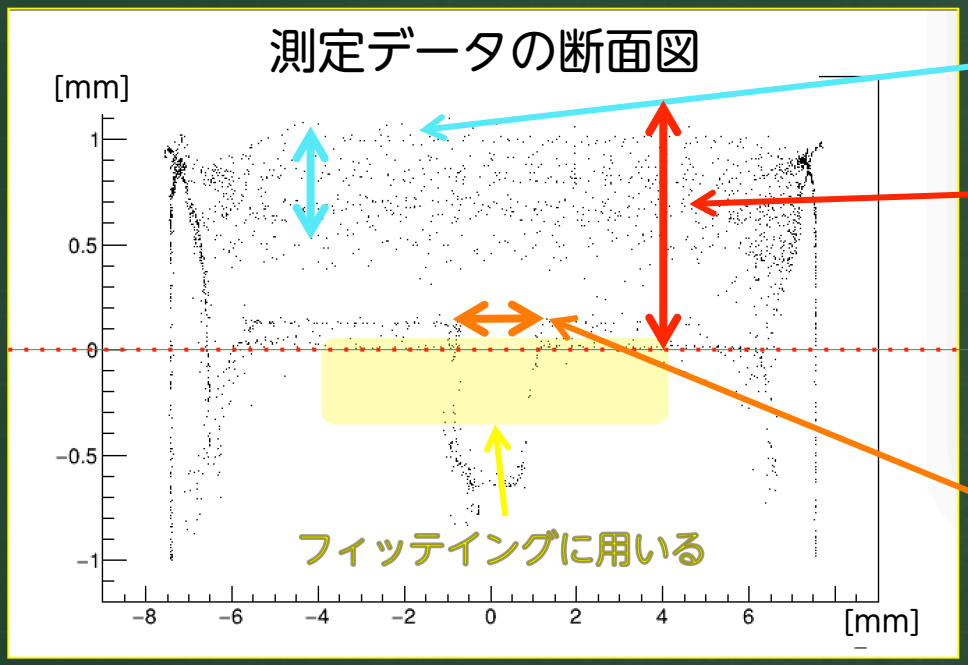
測定例



FARO社による精度:25μmをデータ点の誤差とする。

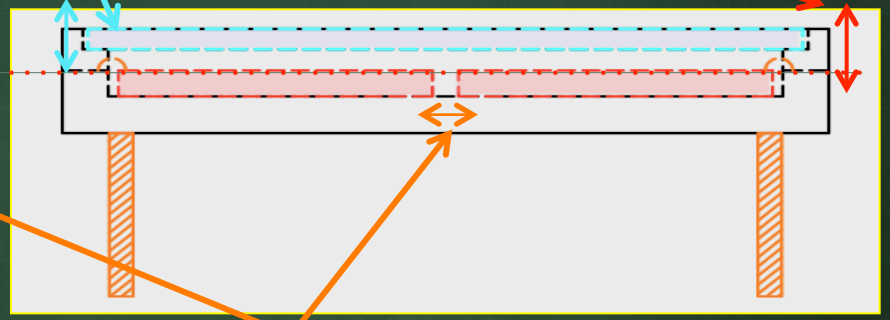
3D座標データのクォリティチェック

$\mu^+ \longrightarrow e^+\gamma$

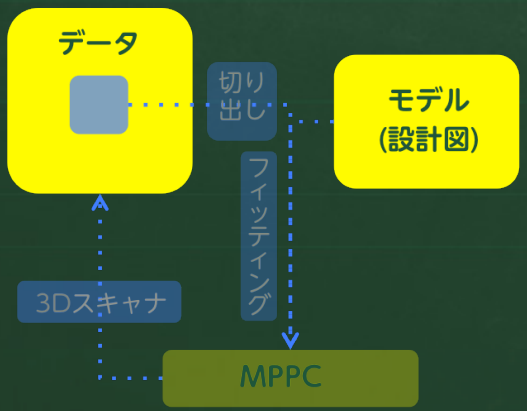


Quartz window : 0.5[mm]

MPPC受光面とセラミック枠の距離：1.2[mm]



MPPC間の溝の間隔：1.5[mm]



測定データと設計図との比較

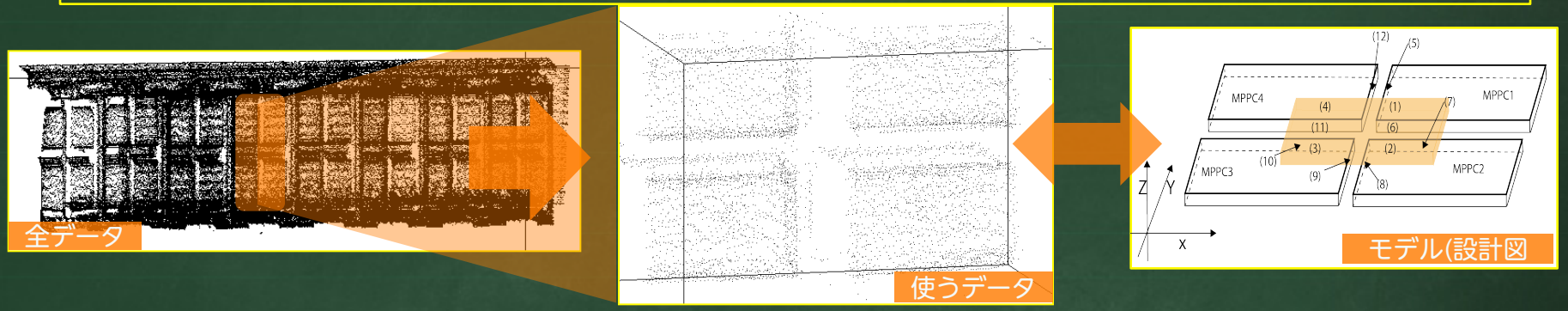
- 測定データの寸法は設計図とよく一致している。
- 場所によってはデータ点が乱雑な部分がある。
- MPPC表面上に二重構造がみえる(原因調査中)が、寸法的には下の構造がMPPC上面に対応する。
- フィッティングに用いる部分としては、4つのMPPCの中央部分で、溝に届かない範囲が適当だと考えられる(→次のスライド)。

解析手法(1) アウトライン

μ^+ → $e^+\gamma$

パラメータの数は6

3次元空間における剛体の位置は、3つの座標(x,y,z)[mm]と3つの軸周りの回転角(α,β,γ)[deg]を用いて表す。



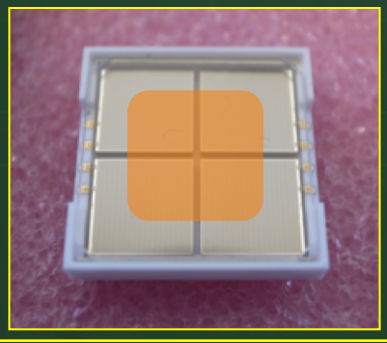
解析に用いる部分

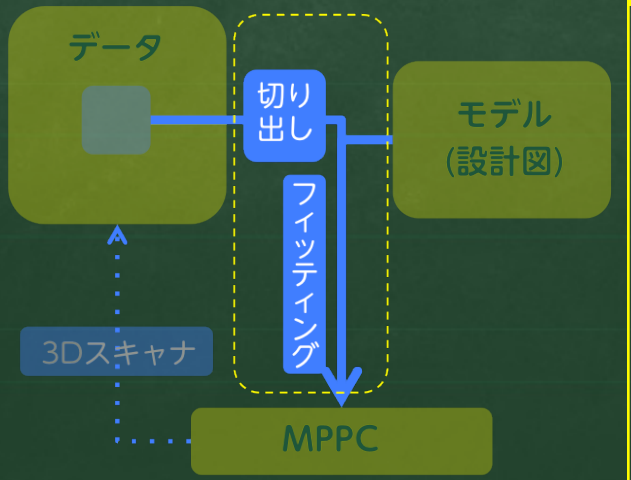
データ：

MPPCの中央部分(溝の底を除く)

モデル：

4つのチップの上面と側面(3×4面)





解析の流れ

① 切り出し

初期値=設計値としてデータを切り出す。

② フィッテイング

モデルとデータの距離の二乗和を最小化して、6つのパラメータを求める。

$$\Sigma\left(\frac{Distance}{\sigma}\right)^2$$

σ=25 μm (3Dスキャナ)

③ 再切り出し

初期値=②の結果としてデータを再び切り出す。

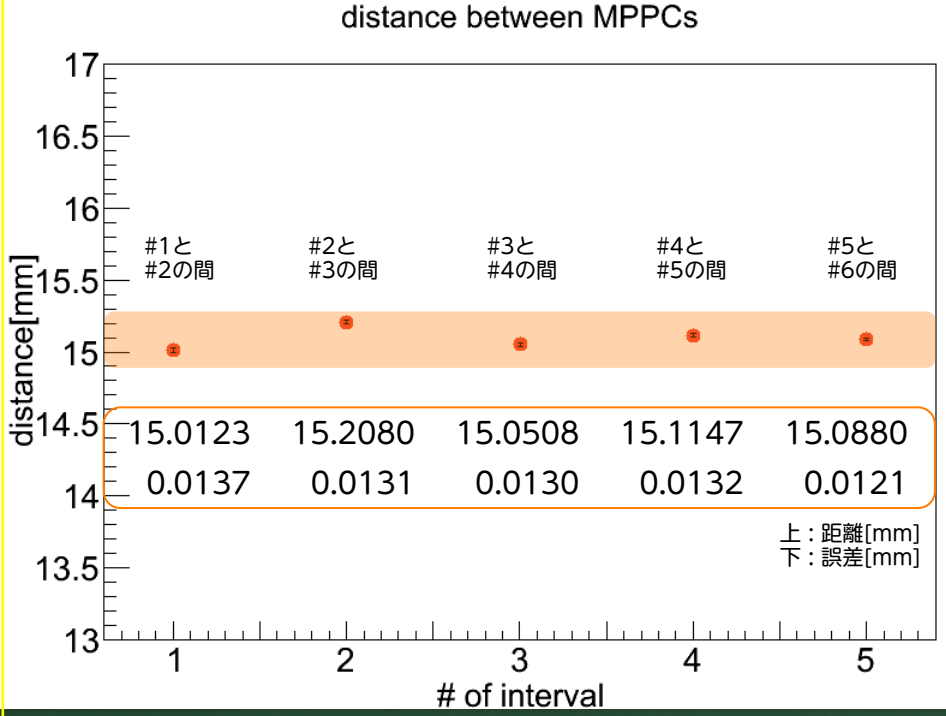
④ 再フィッテイング

6つのパラメータを求める。→ 解析結果

解析手法(4) 結果の検証

$\mu^+ \longrightarrow e^+\gamma$

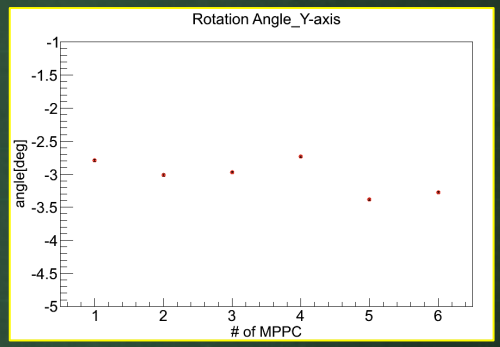
隣り合うMPPC間の距離



- MPPC間隔の設計値は、15.10±0.20[mm](オレンジバンド)
- 距離のばらつきは設計値の範囲内。
- 距離の標準偏差は66μm となり、要求精度である数100μm を下回った。

回転角について

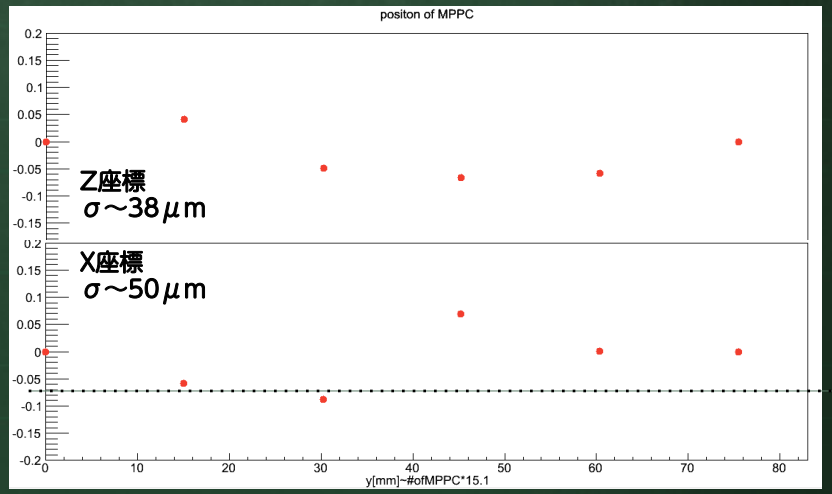
- 回転角はたとえばY軸周りについて、右図。
- 値のばらつきは最も大きかったY軸周りで、0.235[deg]～4[mrad]



仮に、長さに変換すると、30μm程度。

位置について

- #1と#6の中心を通る直線がy軸となるように変換した(下図)



隣り合うMPPC間の距離から要求精度である数100μmを達成。
回転角や位置については、MPPC設置のズレの影響を排除できない。→今後の課題