MEG II実験液体キセノンガンマ線検出器用MPPCの検出効率の角度依存性評価

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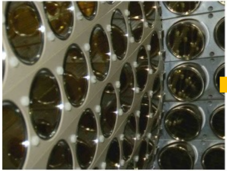
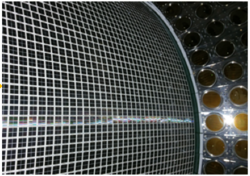
OUTLINE

- Introduction
- Measurement of Photon detection efficiency (PDE) angular dependence for MPPCs with special setup
- Measurement of PDE angular dependence for MPPCs in the MEG II gamma-ray detector
- Summary

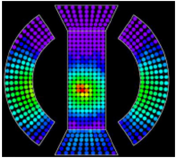
LIQUID XENON GAMMA-RAY DETECTOR FOR MEG II



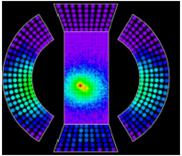
previous detector



upgraded detector



MEG



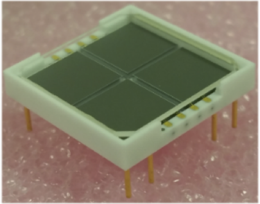
MEG II

simulation of gamma-ray event

- 216 PMTs on the incident face have been replaced with 4092 MPPCs
- High granularity & better uniformity for scintillation readout → resolution for position and energy of gamma ray is expected to improve by **a factor of 2**

VUV-SENSITIVE LARGE AREA MPPC

Hamamatsu S10943-4372

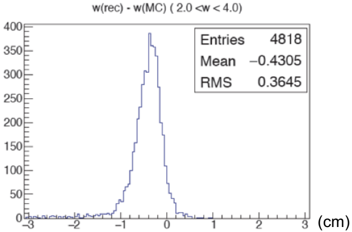


- VUV-sensitive MPPC has been developed in collaboration with Hamamatsu Photonics K.K.
- **<u>Photon detection efficiency (PDE) (λ=175nm) > 15%</u>**
  - Sufficient PDE for scintillation light of xenon
- **<u>Large sensitive area (12×12 mm^2)</u>**
  - To keep the number of readout channels manageable
  - Discrete array of four 6×6 mm^2 chips
- Quartz window for protection (VUV-transparent in liquid xenon)

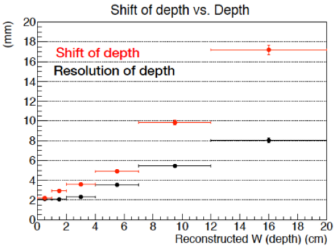
- **<u>Larger angular dependence of PDE was seen than the expected value from Fresnel reflection</u>**
  - (Ref：「MEG II実験液体キセノンガンマ線検出器のVUV有感MPPCの詳細な特性評価」松澤他、第72回年次大会)

ANGULAR DEPENDENCE OF PDE

- **Without understanding angular dependence of PDE, reconstructed gamma-ray conversion depth will be biased**
- Energy and timing reconstruction are not affected by PDE dependence so much

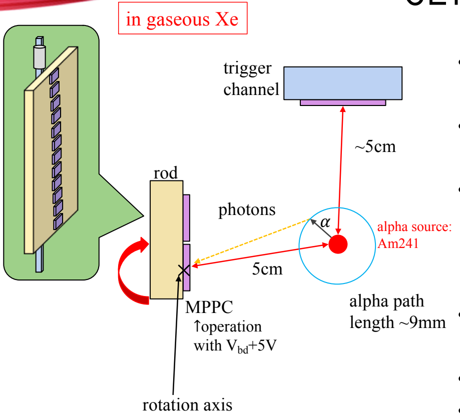


distribution of the difference between real conversion depth and reconstructed depth (simulation)



shift of depth > resolution of depth → significant bias

SETUP FOR MEASUREMENT

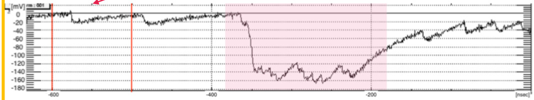


- MPPCs are mounted on a rotation stage, which can be adjusted to any degree against light source
- Dependence of PDE against any incident angle can be seen chip-by-chip
- 2.6 atm gaseous xenon is used instead of liquid xenon
  - Quartz windows are removed to prevent reflection
- **Previously, the effect by dark noise was not taken account into analysis**
- **New analysis with dark noise cut was done**
- **Channel number increase: 6→10 channels**

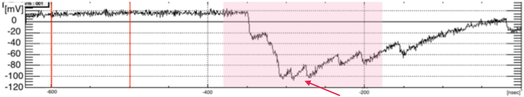
EXCLUSION OF DARK NOISE EFFECT

bad event

dark noise at baseline area

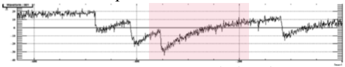


good event



charge calculation area:
alpha event + dark noise

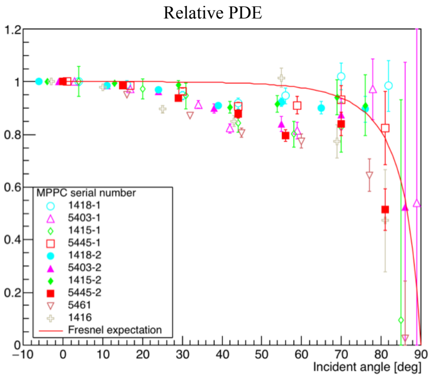
subtract



dark noise event

- The correction of charge misestimating caused by dark noise is done
  - Dark noise rate: ~MHz @ room temperature
  - maximum ~20% charge increase by dark noise when incident angle is ~40 degree
- Exclusion of the events that dark noise exists at baseline area
- Subtraction of dark noise existing in charge calculation area

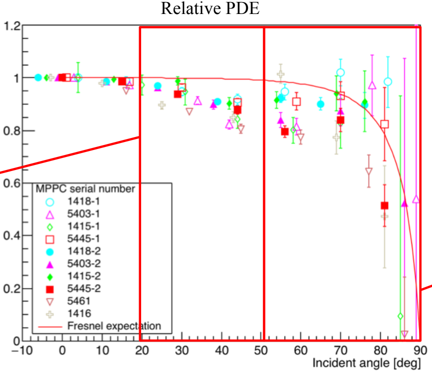
RESULT OF PDE MEASUREMENT AGAINST INCIDENT ANGLE



- In total 10 chips were measured for its PDE angular dependence
- Relative PDE = (measured photons)/(expected number of impinging photons)÷(PDE when $\theta = 0°$ for alpha-centered channel)
- Red line: the expected PDE from reflection in gaseous xenon
- **The result did not change greatly through new analysis**

- error bar: uncertainty of incident angle readout (~1°)

RESULT OF PDE MEASUREMENT AGAINST INCIDENT ANGLE



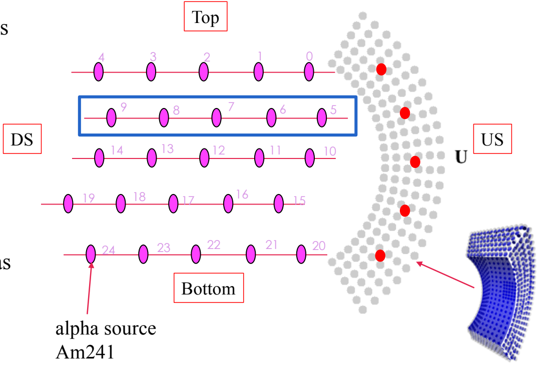
measured data is smaller than expectation from reflection

→ **unexpected angular dependence exists**

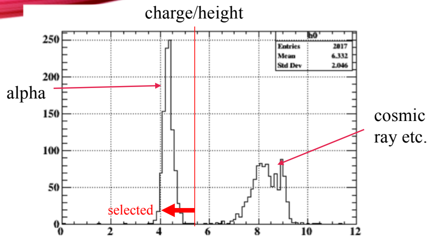
In bigger angle area, uncertainty is large due to small light detection ← anyway it is not important in gamma-ray reconstruction

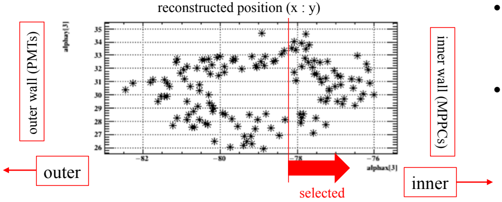
PDE ANGULAR DEPENDENCE OF MPPC IN THE DETECTOR

- Angular dependence of PDE for the MPPCs in the liquid xenon detector was observed
  - To check whether there is the consistency between previous measurement
- Light source: alpha ray from alpha-source Am241 in the detector
  - In total 25 sources (5 wire with 5 sources installed)
  - Second highest wire (5 sources) was used for PDE measurement
  - In total 862 channels (out of 4092) around wire were measured

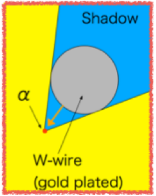


EVENT SELECTION

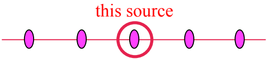


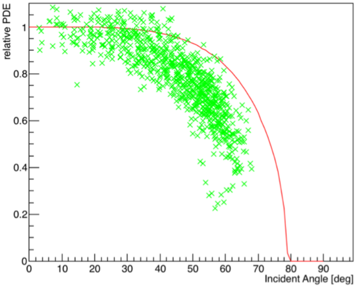


- Alpha events are selected from charge/height (pulse shape) discrimination
- Reconstructed light emission point exists surrounding the alpha source
- Only emission points at inner side of the detector are used
- Wire can be a shade for scintillation light ($L_{\alpha} \sim 40\mu m, \phi_{wire} \sim 100\mu m$)



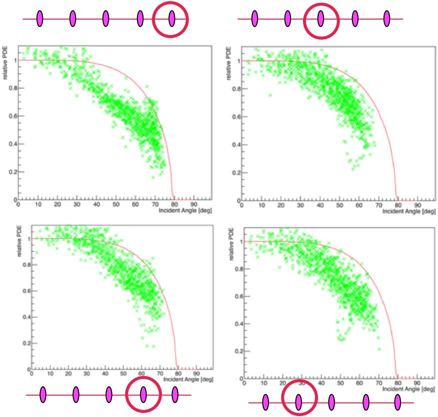
RESULT OF PDE MEASUREMENT IN THE LIQUID XENON DETECTOR

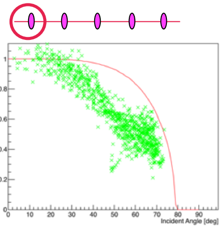




- Correction of normalization is done for each lot
- There are 4 lots of MPPCs, and same lot is cut from same silicon wafer
    - the effect of cross talk & after pulse is lot-dependent
- Red line: the expected PDE from reflection in liquid xenon
- **Larger angular dependence of PDE is seen for MPPCs compared to expected value**

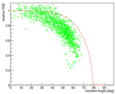
DIFFERENCE BETWEEN SOURCES

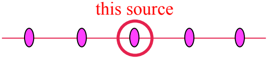




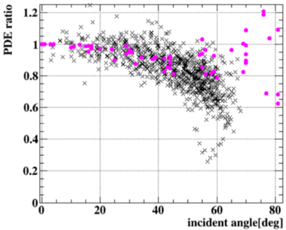
- Angular dependence is different source-by-source
- This should be because the reflection from walls is different depending on its position

COMPARISON BETWEEN PREVIOUS MEASUREMENT AND IN THE DETECTOR





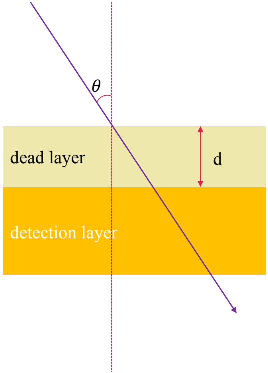
- Data of alpha-source at center position is used as representative, the farthest source from wall
- Relative ratio = (measured PDE) / (expected PDE from reflection)
  - Relative ratio is used to compare the result in gas xenon and in liquid xenon
- For the area where incident angle < 50°, tendency is roughly consistent between previous measurement in gas and measurement in the liquid xenon detector



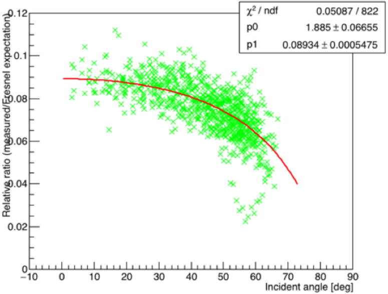
●: previous measurement in gas
×: measurement in the detector

FITTING WITH ONE MODEL

- One model that assumes the dead layer, which cannot detect and only attenuate photons
- Intensity of light signal: $I \propto \exp\left(-\frac{4\pi k}{\lambda} \cdot \frac{d}{cos\theta}\right)$
  - k: imaginary component of refractive index (2.4685 for Si)
  - λ: wavelength of photon (175nm)
  - **d: thickness of dead layer (parameter)**



FITTING



- Function parameter can be estimated from data of the MPPCs inside the liquid xenon detector

- This function can be used for charge correction of the MPPCs, by calculating the incident angle from the position relation of sensors and hit point of gamma-ray

SUMMARY & NEXT TO DO

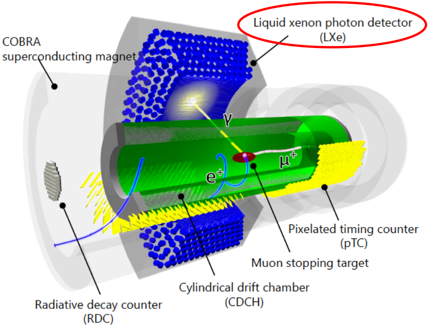
- The MPPCs are measured to have unexpected angular dependence of PDE in the important angle area for analysis using special setup
- Same tendency of PDE angular dependence was seen between result in gaseous xenon and in liquid xenon

- Estimate the effect of reflection from the wall of the detector
- Obtain the normalization factor and fitting parameter chip-by-chip for MPPCs
  - Using several light source in the detector, PDE angular dependence of a MPPC can be seen chip-by-chip

BACKUP

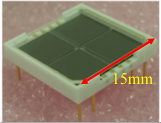
MEG II EXPERIMENT

- Search for $\mu \rightarrow e\gamma$ rare decay
- Achieve the sensitivity 6×10^{-14} (**~10 times better than MEG**)
- Main upgrade from MEG experiment
  - Doubled stopping rate of μ^+ at target (7×10^7)
  - Improvement for detector resolution: **twice for each detector**
    - Liquid xenon photon detector, Pixelated timing counter, Cylindrical drift chamber
  - Radiative decay counter: new instrument to suppress background

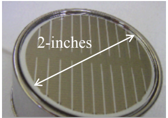


LIQUID XENON (LXE) GAMMA-RAY DETECTOR

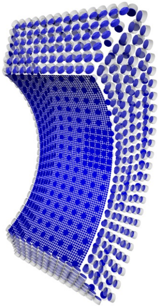
- Detecting 52.8MeV gamma-ray from $\mu \to e\gamma$ decay
- Filled with 900L liquid xenon as scintillator
  - Scintillation light is VUV-light (λ=175nm)
- 4092 MPPCs (Multi Pixel Photon Counters) on the gamma-ray incident wall
- 668 PMTs (Photo-multipliers) on the whole wall except gamma-ray incident wall
- **Upgrade from MEG: 216 PMTs on the incident wall were replaced with 4092 MPPCs**



Hamamatsu S10943-4372



Hamamatsu R9869
- 16% QE for λ=175nm



LXE DETECTOR PERFORMANCE

- Improvements with MPPC
  - Energy:

    Better uniformity for scintillation readout
  - Position:

    Higher granularity with smaller sensors
  - Time:

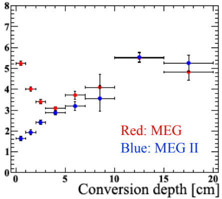
    More accurate estimation of TOF

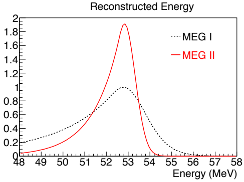
- High detection efficiency due to lower material on incident surface

	MEG (measured)	**MEG II (simulated)**
σ (position)	~5 mm	~2.5 mm
σ (energy)	~2%	0.7 - 1.5%
σ (timing)	67 ps	50 - 70 ps
Efficiency	65%	70%

twice better

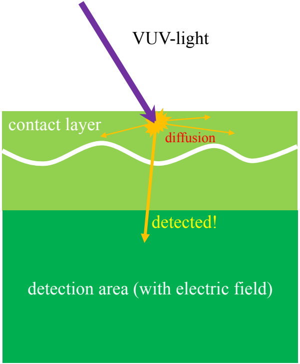
position resolution for horizontal axis[mm]





VUV SCINTILLATION LIGHT DETECTION

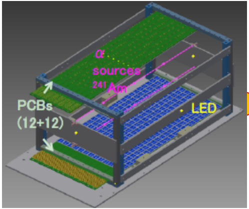
- Absorption length of VUV light is ~5nm in Si
  - Easily absorbed at insensitive layer in the surface
- Detection of VUV light is realized by removing the protection layer of resin, optimizing optical matching between LXe and sensor surface and thinning contact layer
  - With thinner surface, some carriers can reach to detection area by diffusion → VUV can be detected as a signal

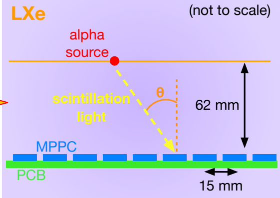


ANGULAR DEPENDENCE OF PDE

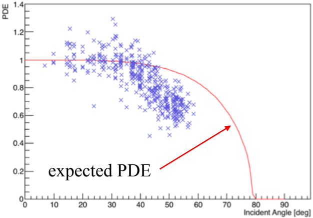
- PDE was measured to be small at large incident angle in the mass test before
  - **Inconsistent with what we expected from Fresnel reflection at Si surface**
- There might be some systematics in this setup (reflection, attenuation etc.)
- For a MPPC, position against alpha source is fixed
  - Cannot discuss the dependence of PDE from various angle

600 MPPCs mass test in LXe





relative PDE change against incident angle

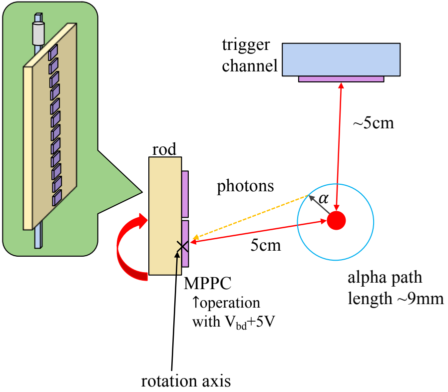


XE

	gas Xe	liquid Xe
good	• easy to be treated with in the room temperature • no attenuation of photons	• refractive index: LXe~= quartz window, window is "transparent" • low temperature = MPPC dark noise is small
bad	• refractive index: gas Xe<quartz window • bigger dark noise • source cannot be treated as a point • alpha ray flying range is too long	• difficult to be treated, because to keep ~165K is needed • liquefaction takes much time

- The angular dependence of PDE for the final version of VUV-MPPC is measured in gas xenon
- Because of the convenience for using gas, gas xenon is used for this experiment
- The pressure of gas Xe is 2.6 bar, at room temperature
- To avoid the refraction in windows, windows on MPPCs are removed

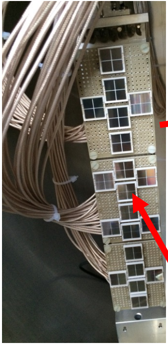
SETUP FOR MEASUREMENT

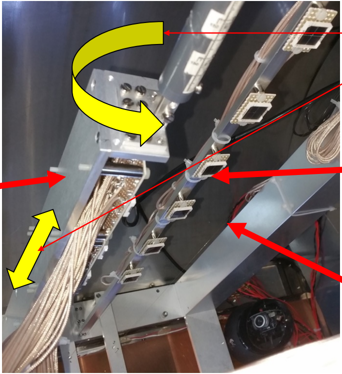


- MPPCs are mounted on a rotation stage
- By rotating the rod, incident angle can be adjusted to any degree
- Rotation stage can be moved to change the MPPC to measure
- Dependence of PDE against any incident angle can be seen chip-by-chip
- 2.6 atm gaseous xenon is used instead of liquid xenon
  - Operational at room temperature
  - Attenuation can be ignored in gaseous environment
  - Alpha path length is sufficiently small
    - can be treated as point light source

SETUP FOR MEASUREMENT

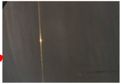
every MPPC channel on axis can be set in front of alpha source





rod can move along the axis and rotate on the axis

trigger channel



wire with alpha ray source (Americium)

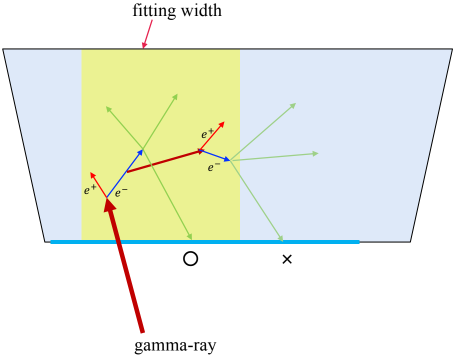
No protection windows on MPPCs to avoid refraction in gaseous xenon

THE IMPORTANT RANGE OF INCIDENT ANGLE FOR THE DETECTOR

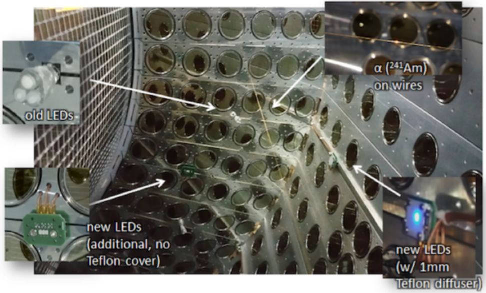
- At bigger angle area, the measurement of PDE would be inaccurate
  - The detected light yield gets smaller, and reflection from wall of chamber may appear

- In the detector, photons with bigger incident angle would make a contribution on worse resolution
- From simulation, it seems photons whose incident angle is smaller than 45° is important for depth reconstruction

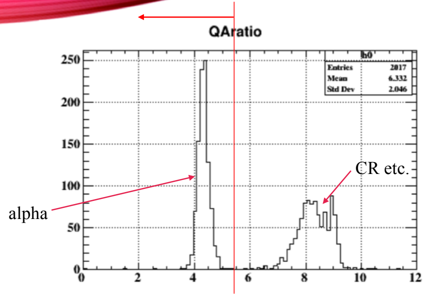
→ data whose incident angle < 45° should be used

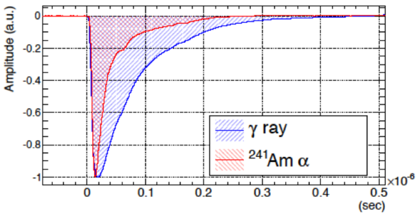


CALIBRATION SYSTEM IN THE XENON DETECTOR



EVENT SELECTION

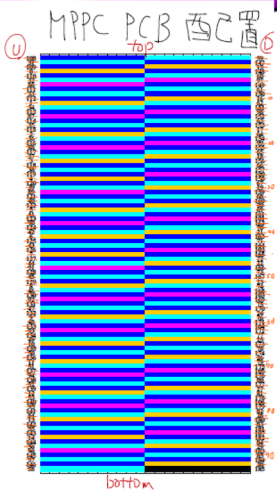




waveform obtained in MEG I

- Alpha ray events were selected from charge/height value (Q/A value)
- Alpha events have smaller Q/A value compared to other events (cosmic ray etc.)

PRODUCTION GROUP OF MPPC



- There are in total 4 groups of MPPCs
- The MPPC in the same group is cut from same silicon wafer
- On one PCB, all 22 MPPCs belong to same group
- In the left figure, different color represents different group