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 (The detailed characterization of VUV-MPPCs for the MEG II liquid xenon gamma-ray detector)

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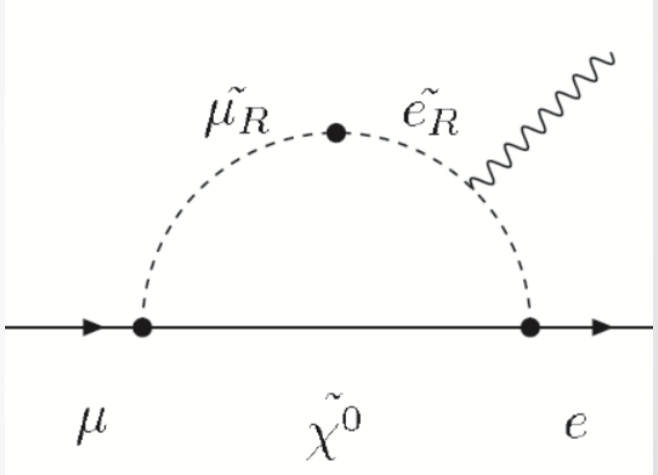
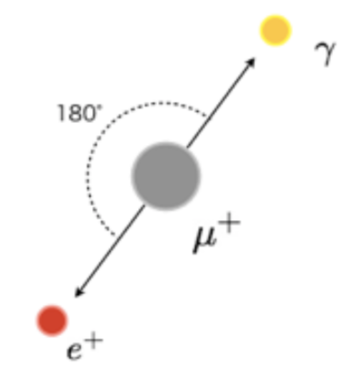
Search for $\mu \rightarrow e\gamma$ Decay

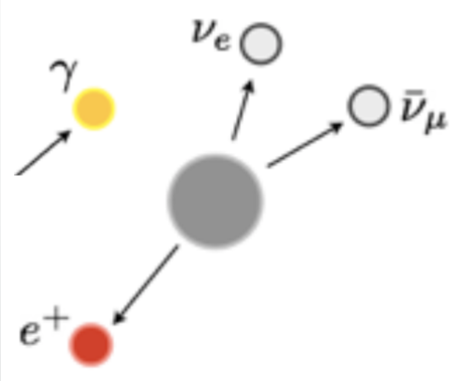
- Charged lepton flavor violation (cLFV) is strongly limited in standard model (SM) with υ oscillation ($\sim 10^{-50}$)
- However, cLFV reaction at detectable probability is predicted in beyond SM ($\sim 10^{-14}$) → not yet observed



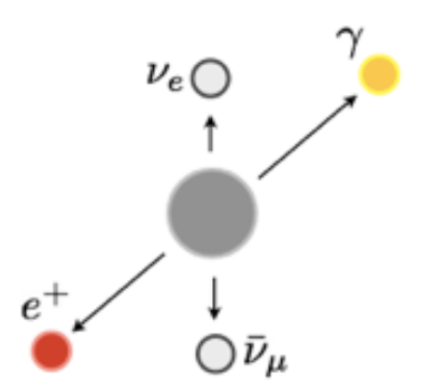
decay



background1



background2



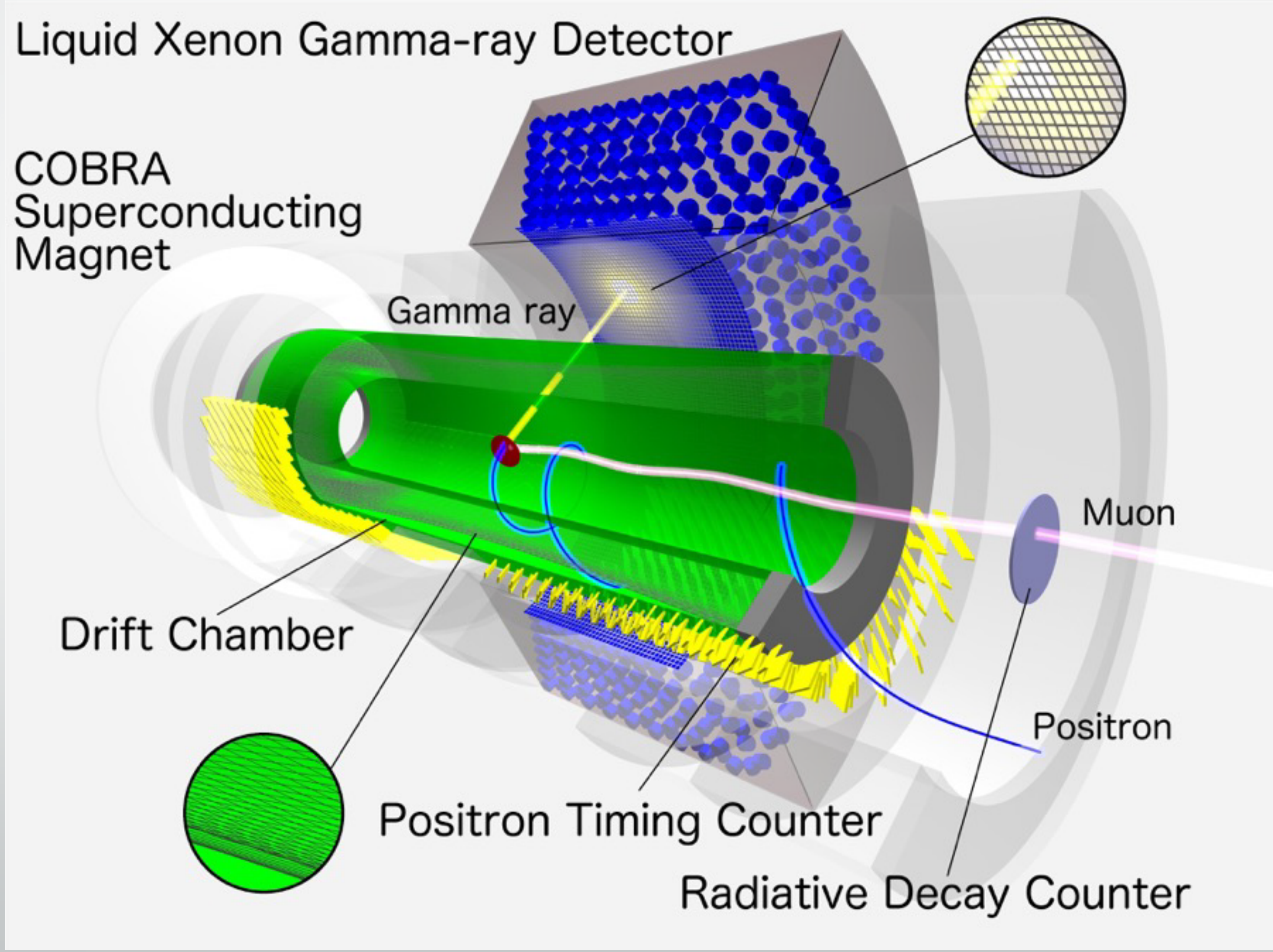
1. $E_\gamma = E_e = \frac{m_\mu}{2} (52.8MeV)$
2. Back to back
3. coincident

1. $E_\gamma < 52.8MeV$
2. Not back to back

→ Gamma ray precise measurement is very important

MEG II Experiment

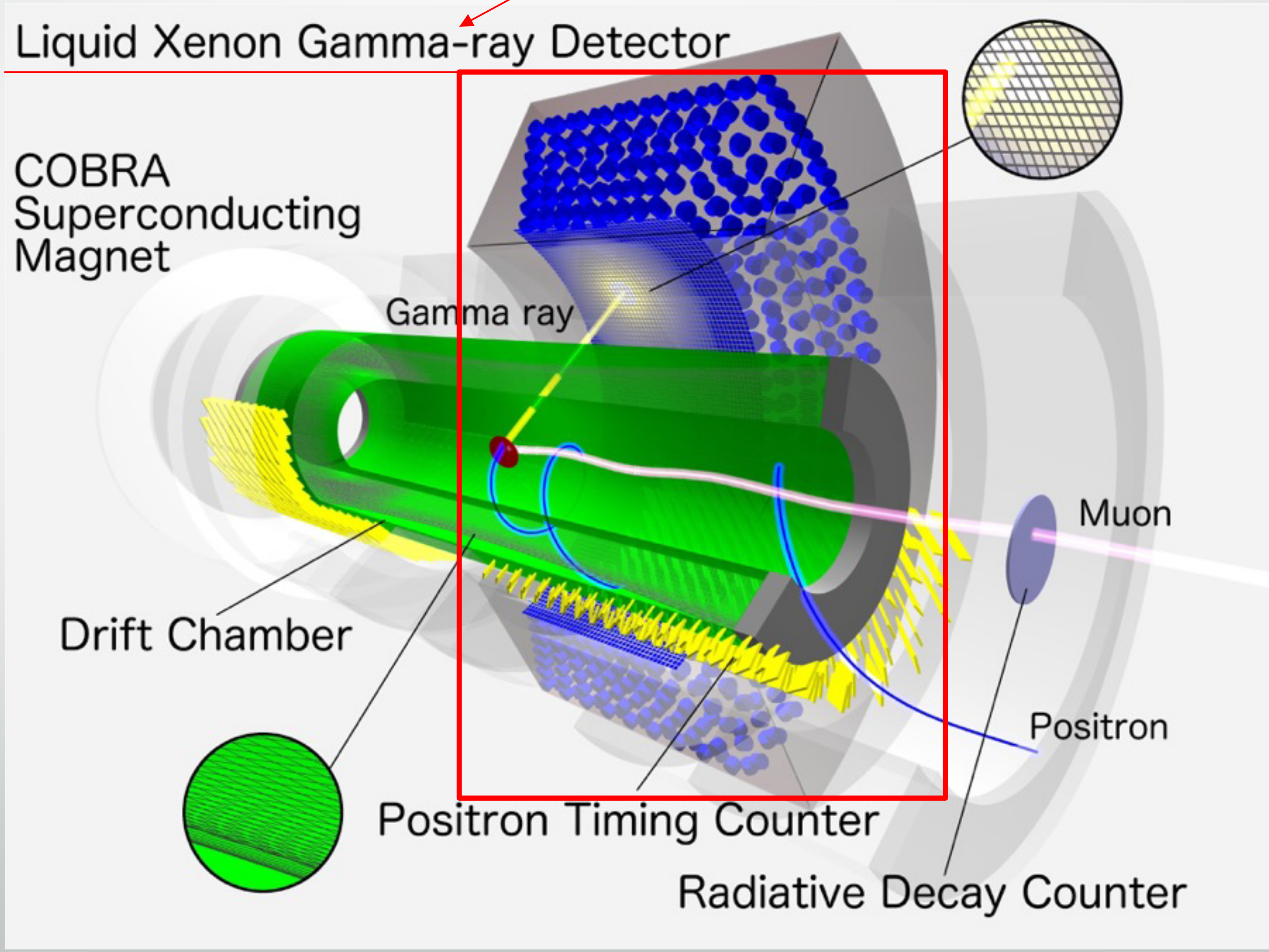
- Experiment for finding $\mu \to e\gamma$ rare decay
- Achieve the sensitivity 4×10^{-14} (10 times better than MEG I)



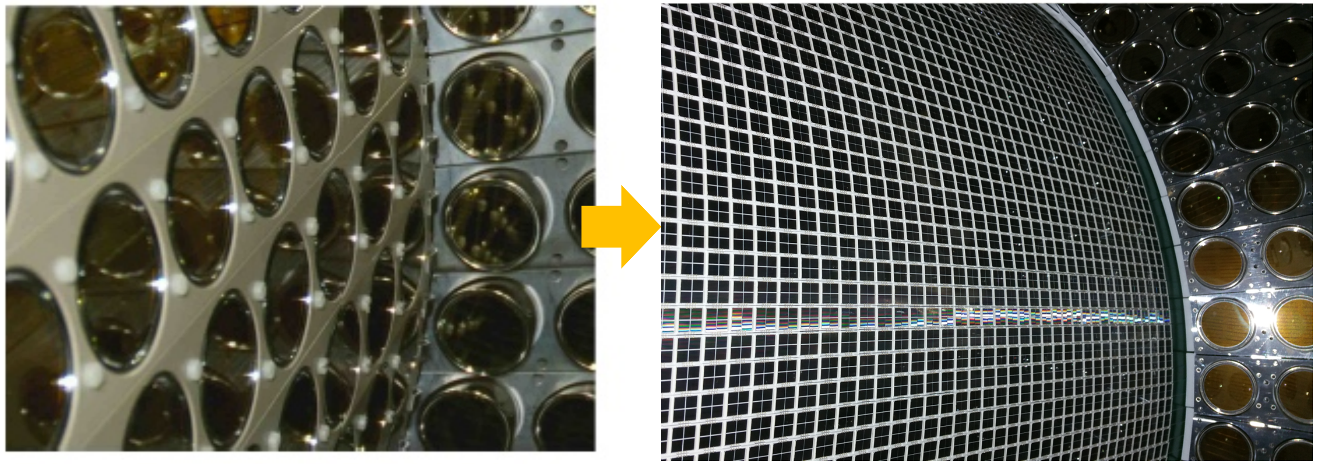
MEG II Experiment

topic for this presentation

- Experiment for finding $\mu \to e\gamma$ rare decay
- Achieve the sensitivity 4×10^{-14} (10 times better than MEG I)

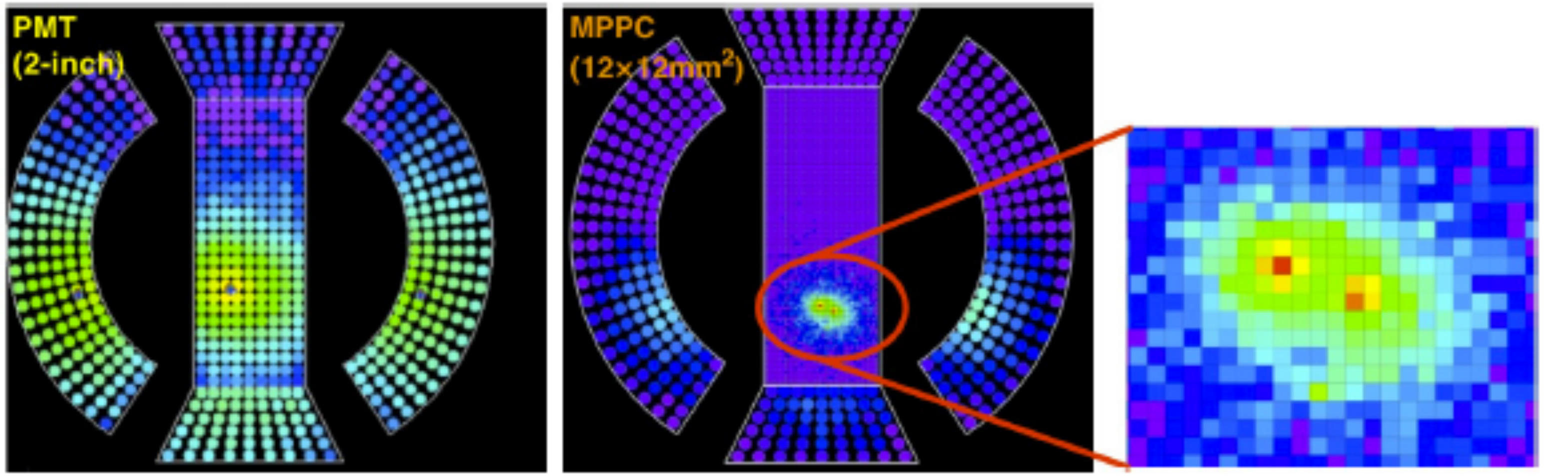


Liquid Xenon Gamma-ray Detector



previous detector

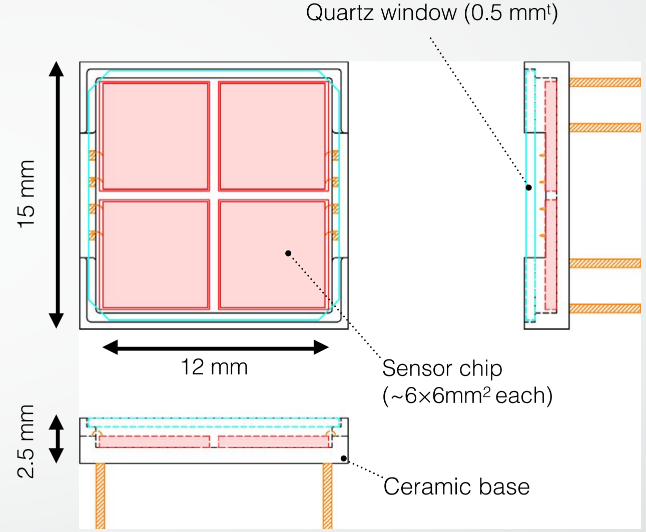
upgraded detector



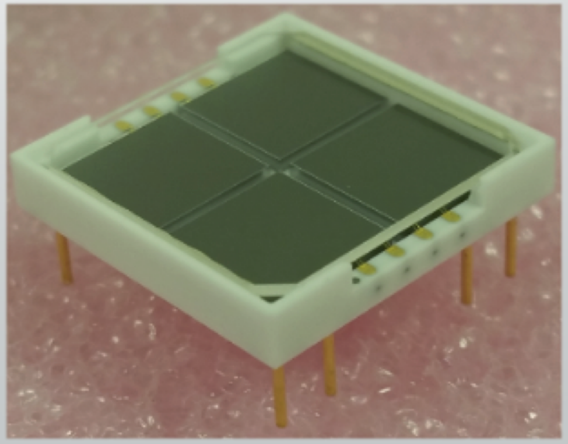
- 216 PMT on the incident face have been replaced with 4092 MPPCs
- High granularity & better uniformity for scintillation readout → resolution for position and energy of gamma ray is improved by **a factor of 2**

Large VUV-sensitive MPPC in MEG II

- We have developed MPPCs with large sensitive area in collaboration with Hamamatsu Photonics
- Size: 12*12mm² with four 6*6mm² chips in the series connection
- Sensitive for Xe scintillation VUV photon (λ=175nm)

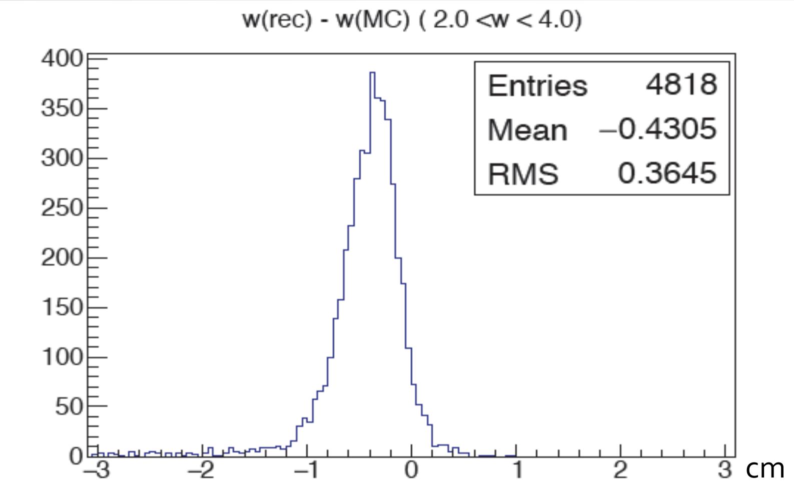


Hamamatsu S10943-4372

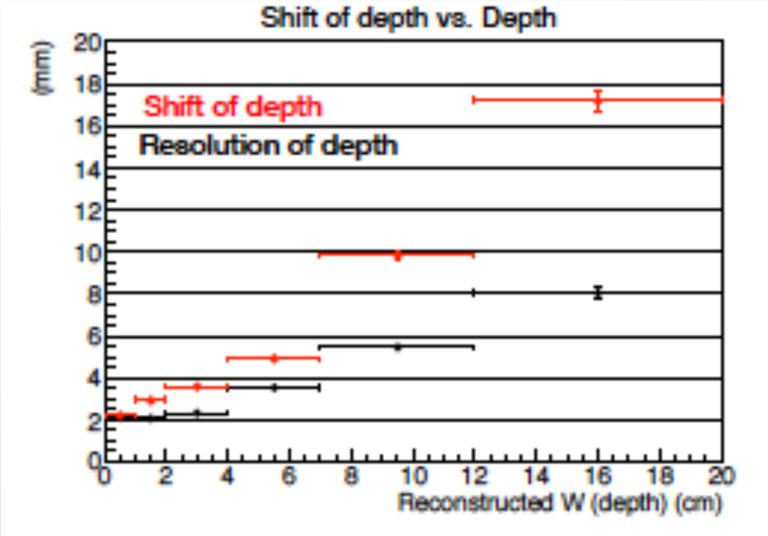


The Bias Caused by The Angular Dependence of Photon Detection Efficiency (PDE)

- By understanding angular dependence of PDE, the bias on reconstructed depth can be corrected
- **Energy and timing reconstruction are not affected by PDE dependence so much**



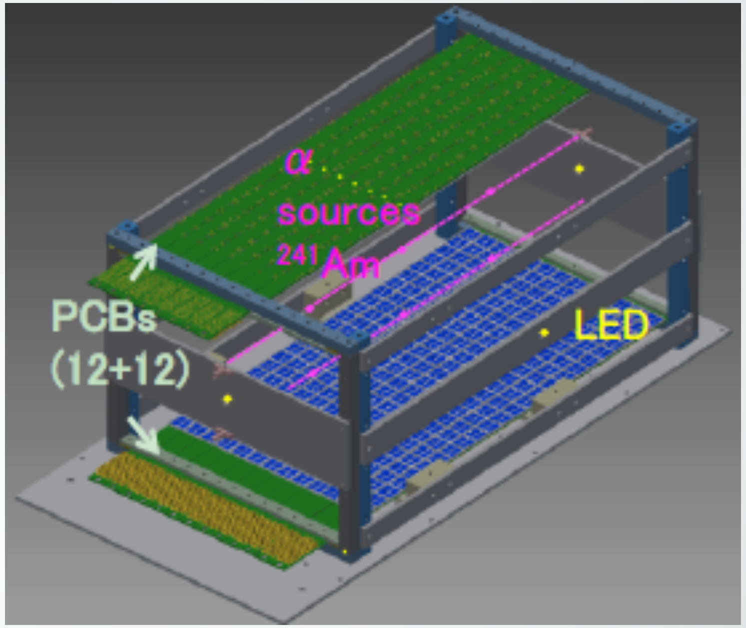
the difference between MC simulation and data

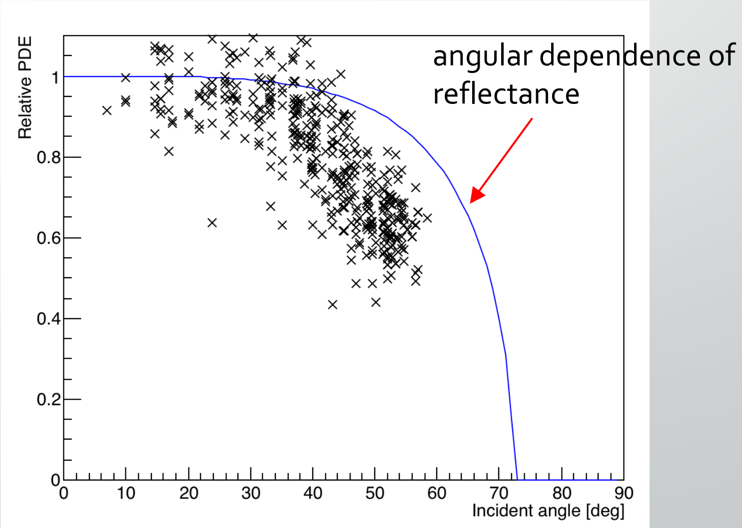


The measurement of PDE angular dependence in liquid Xe

- The result and the expectation from reflection did not match
- Many systematics exist for the measurement; sensor-by-sensor difference, reflection from MPPCs on opposite side, surrounding aluminum wall (not written in this figure)…

  → measurement in gaseous Xe is done to eliminate such systematics

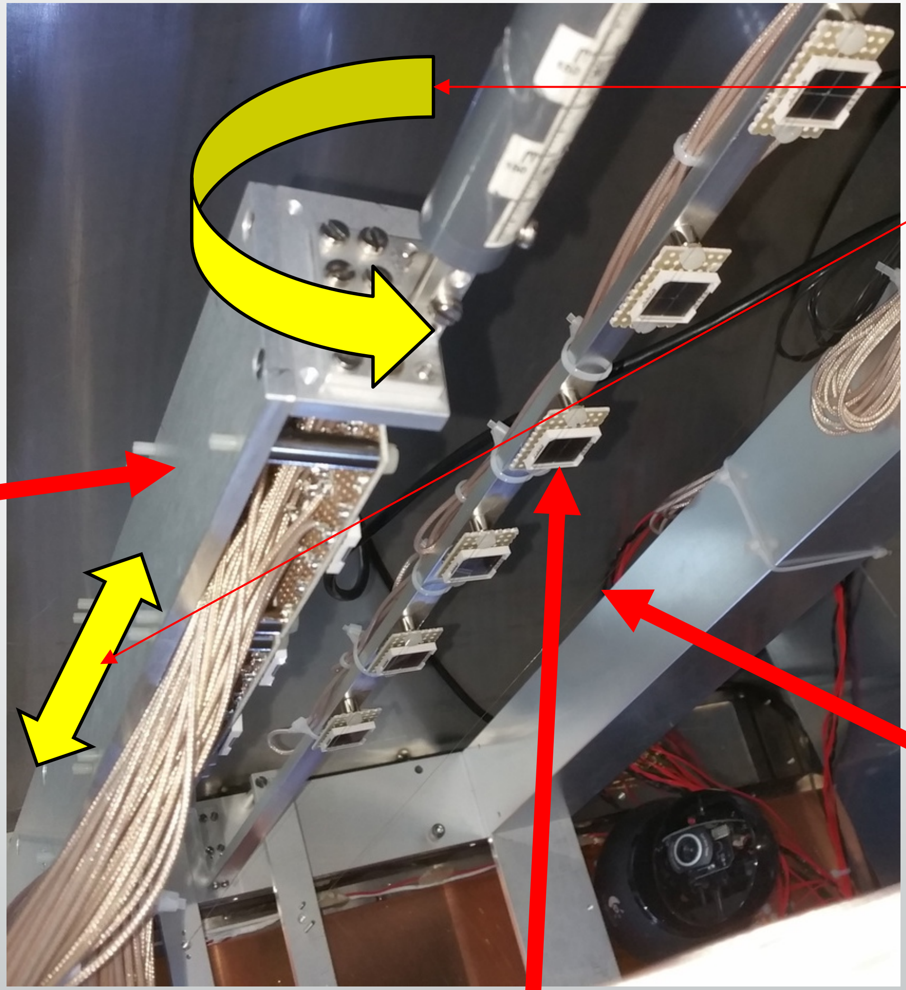




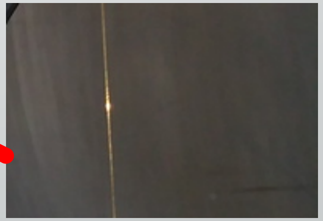
Ref: JPS2015秋季大会「MEG II実験液体キセノンガンマ線検出器に向けた再構成法の研究」,小川他

Setup for measurement in gas

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



rod can move along the axis and rotate on the axis

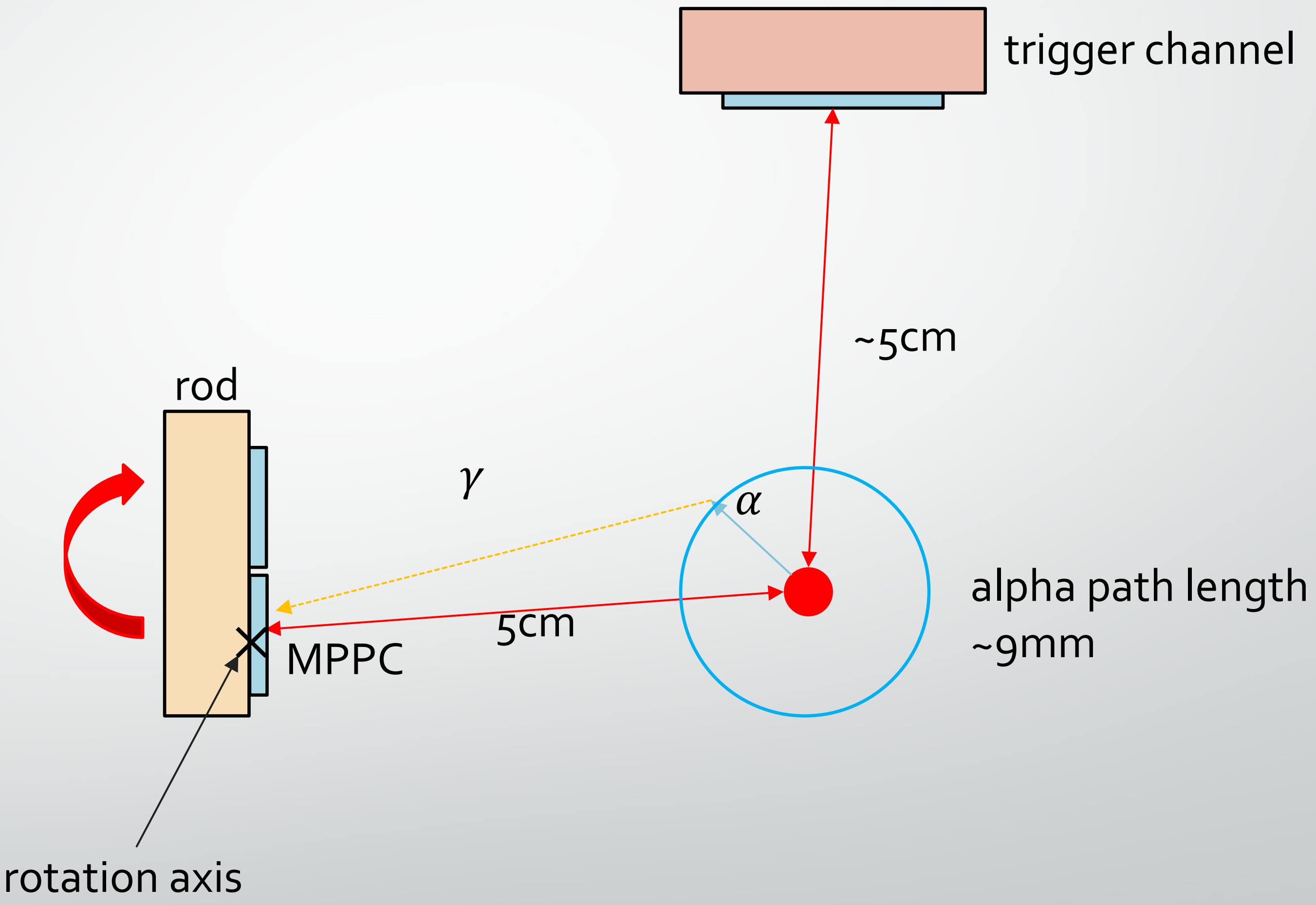


wire with alpha ray source (Americium)

trigger channel

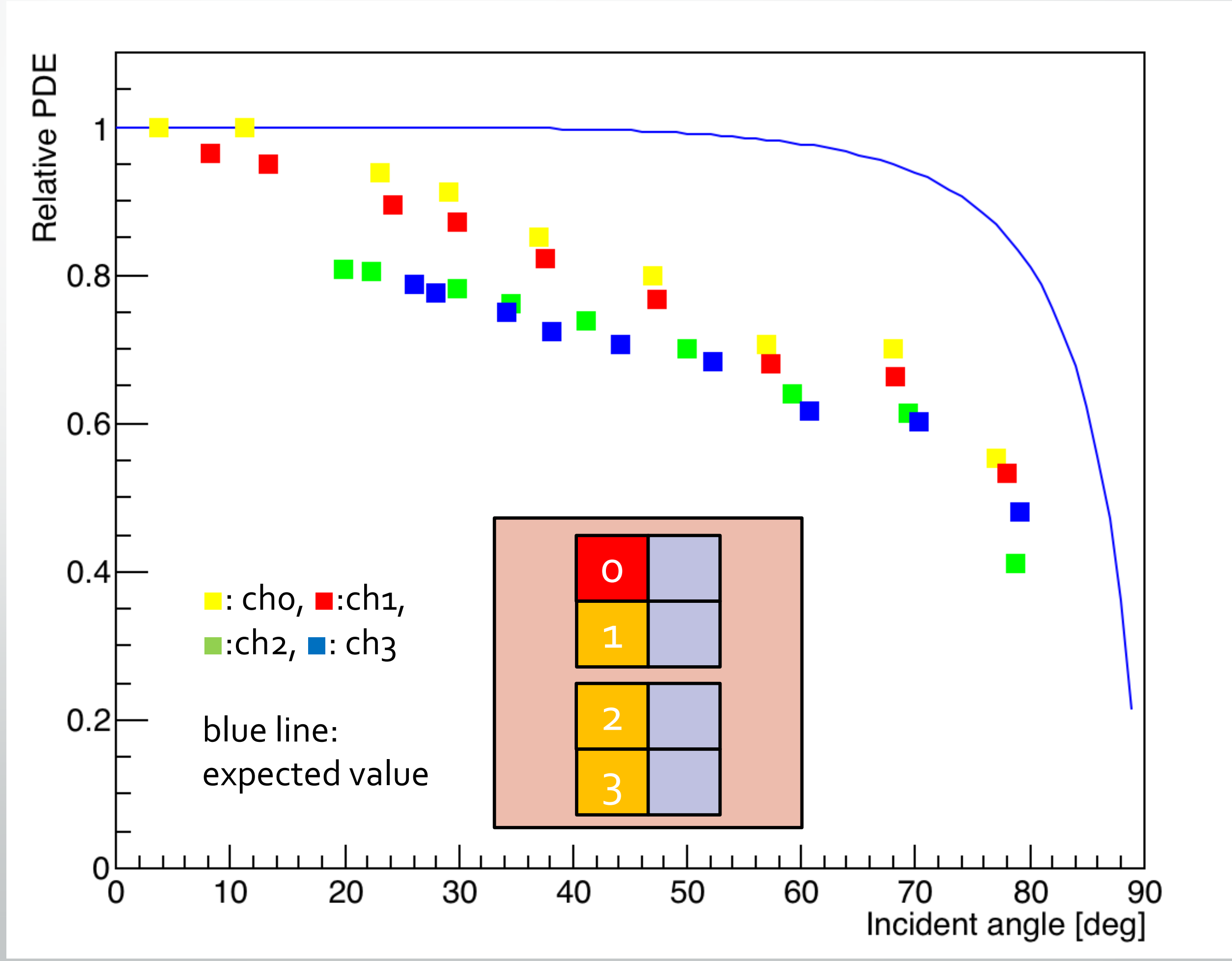
Setup for measurement in gas : Seen from Above

- Measurement in the cryostat **filled with gaseous xenon with 2.6 atm**
- By rotating the rod, incident angle can be adjusted to any degree
- operation voltage = Vhama (~Vbd+5V)



Previous measurement in gaseous Xe

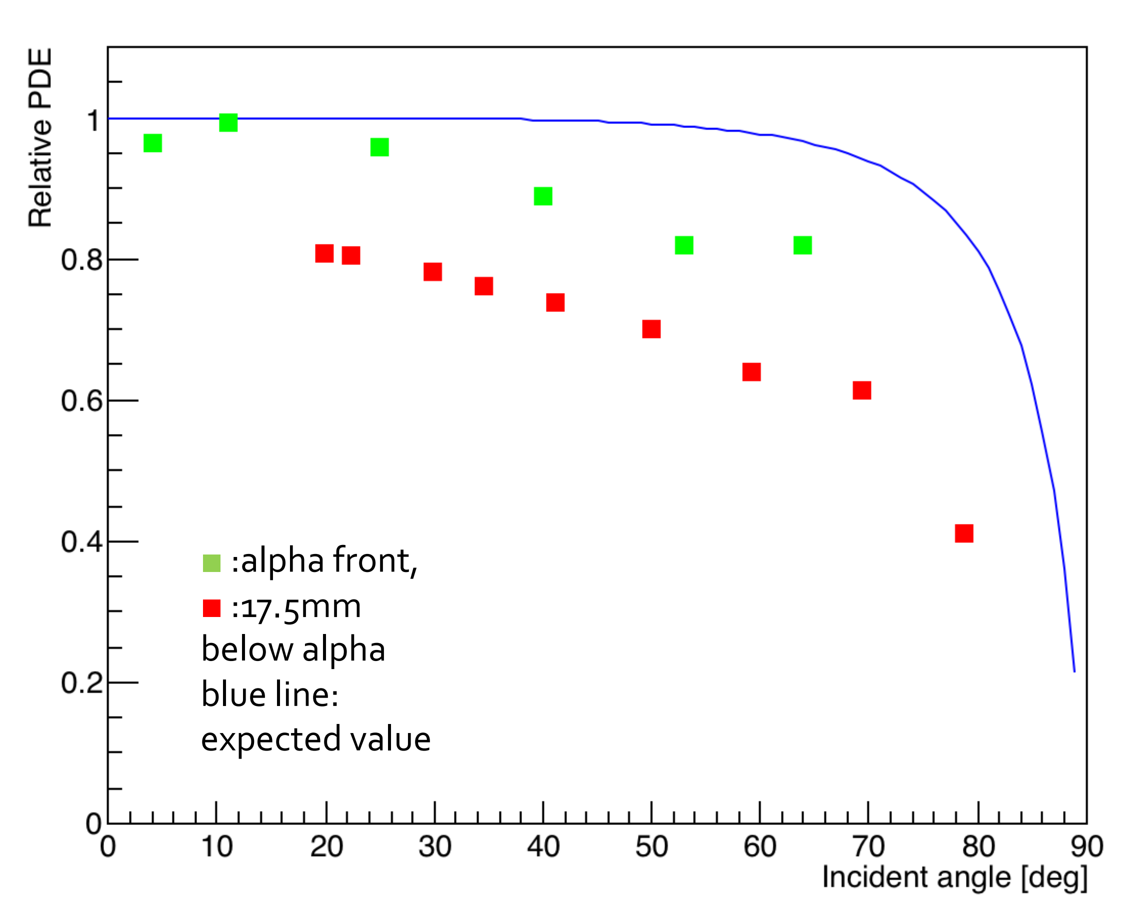
- Measurement of PDE with channel 0 in front of alpha source
- Measured PDE had stronger angular dependence than Fresnel equation
- Geometrical effect was seen for channels far from alpha source
- Relative PDE = (measured photons)/(expected number of impinging photons)÷(PDE when $\theta = 0°$ for alpha-centered ch)



Previous measurement in gaseous Xe

- By changing the position against alpha source, PDE of same channel changes
- Due to systematics such as geometrical factor, or calculation of expected number of photons is incorrect?

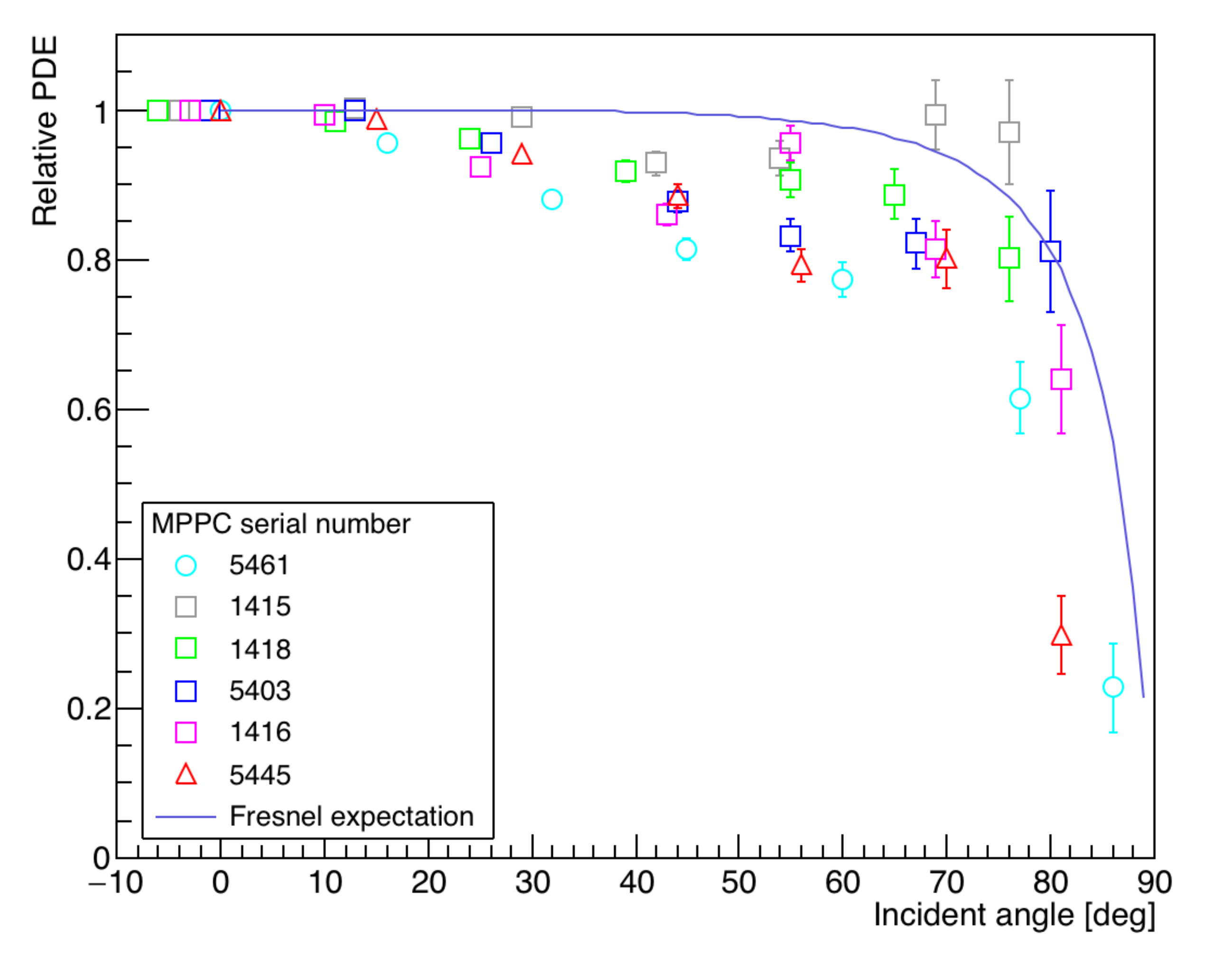
→For new measurement, MPPC chip is set in front of alpha source to reduce systematics



Result for individual channel PDE change

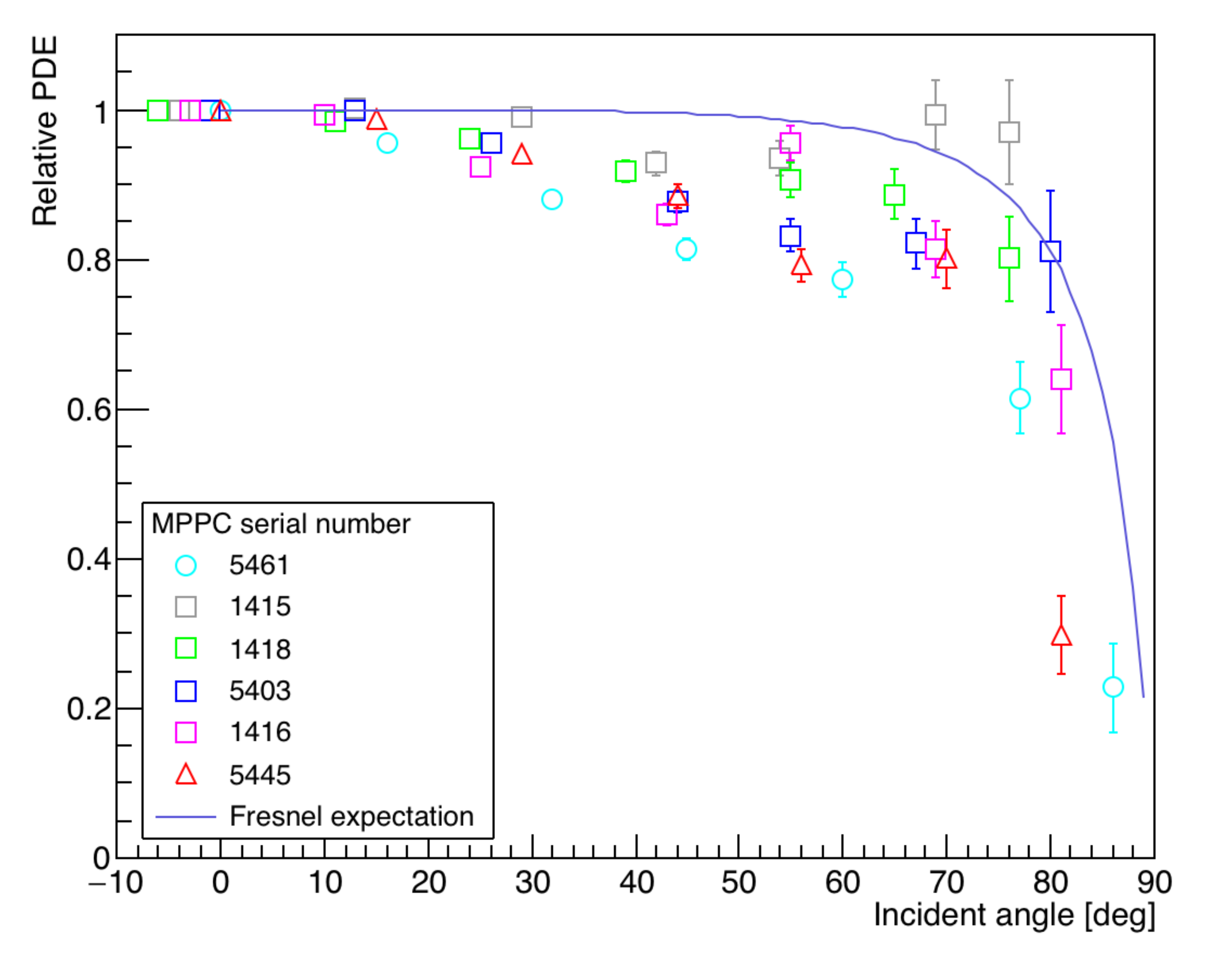
- New data were taken for 6chips
- **Senor-by-sensor variation of angular dependence between each channel is seen**

→ due to structural difference for each channels (ex. thickness of layers)?

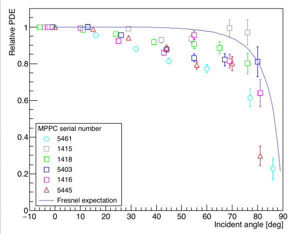


Result for individual channel PDE change

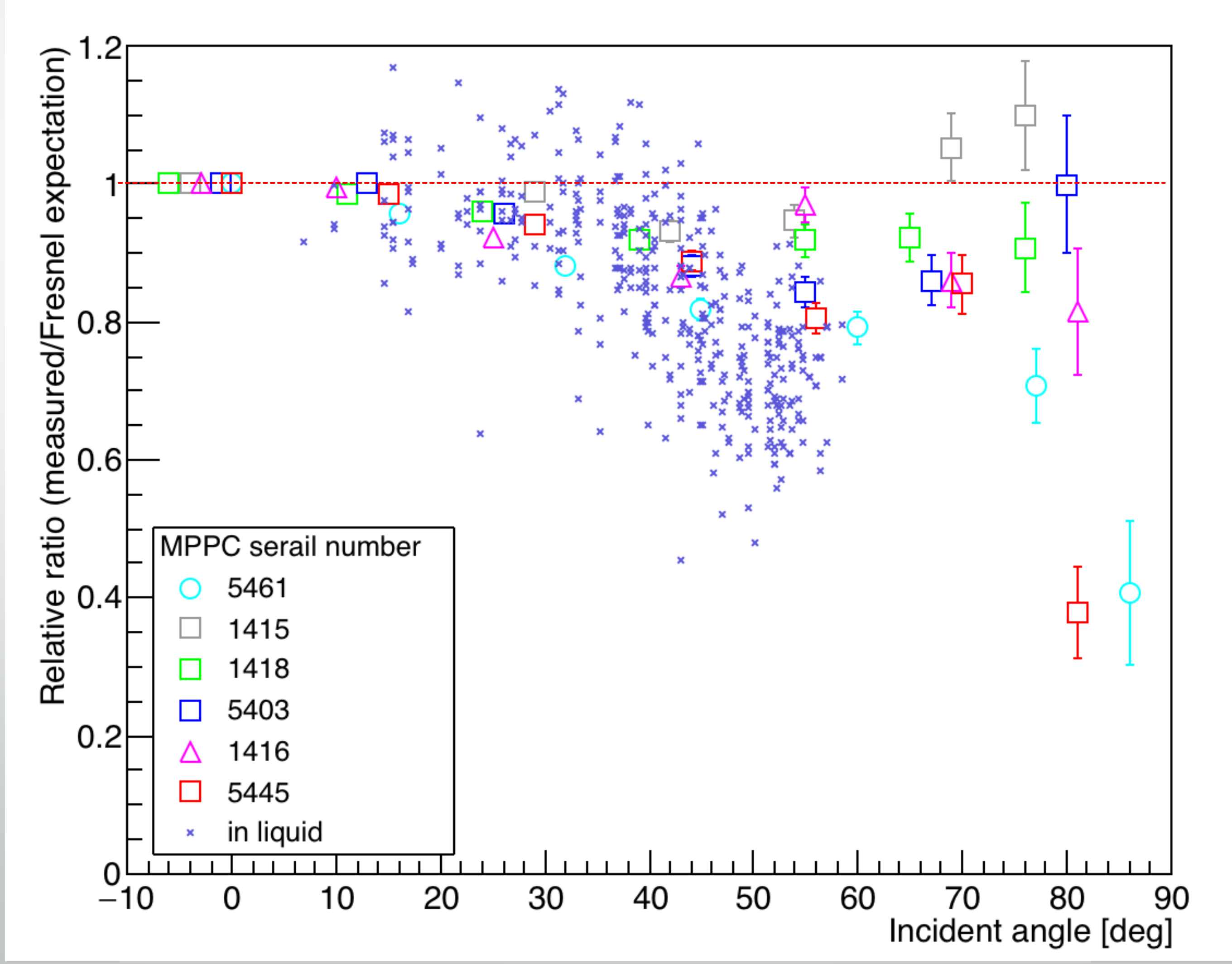
- Measured value has bigger angular dependence than the Fresnel expectation; same as previous measurement
- Model of refraction (the layers of MPPCs) might not be correct → reconstruct the model (ex. add another layer)



Comparison between in liquid and in gas

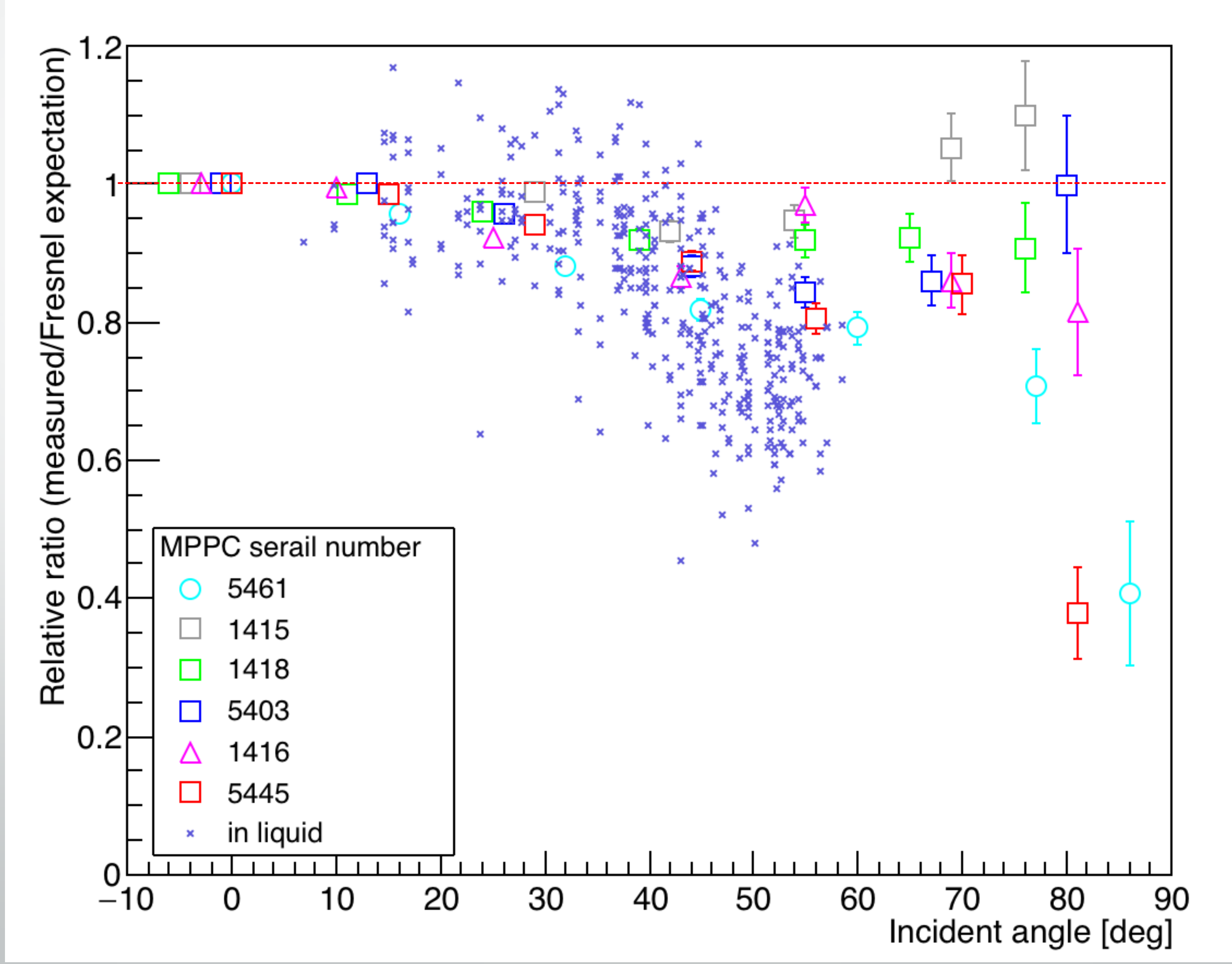


- Ratio between data and Fresnel expectation is taken **to compare in gas and in liquid**



Comparison between in liquid and in gas

- Angular dependence of in liquid and in gas is different
- In liquid measurement, many systematics affect the result
- In gas measurement, the effect of systematics are smaller than in liquid → probably more accurate PDE dependence



Summary & Prospects

- PDE angular dependence of MPPCs are checked in gaseous xenon with improvements on systematics
- Still, individual difference and the distinction from theoretical expectation exists
- Because of less systematics, in-gas measurement seems to be more accurate than in-liquid measurement

- Understand the systematics in gas Xe precisely
- Check more MPPCs to study angular dependence of PDE

Summary & Prospects

- Estimate function shape of angular dependence of PDE from in-gas measurement
- Start taking data in the MEG II liquid Xe detector this summer, and compare the result to measurements in gas
- Study how this angular dependence affect the performance of MEG II liquid Xe detector when assuming both the angular dependence and the sensor-by-sensor variation

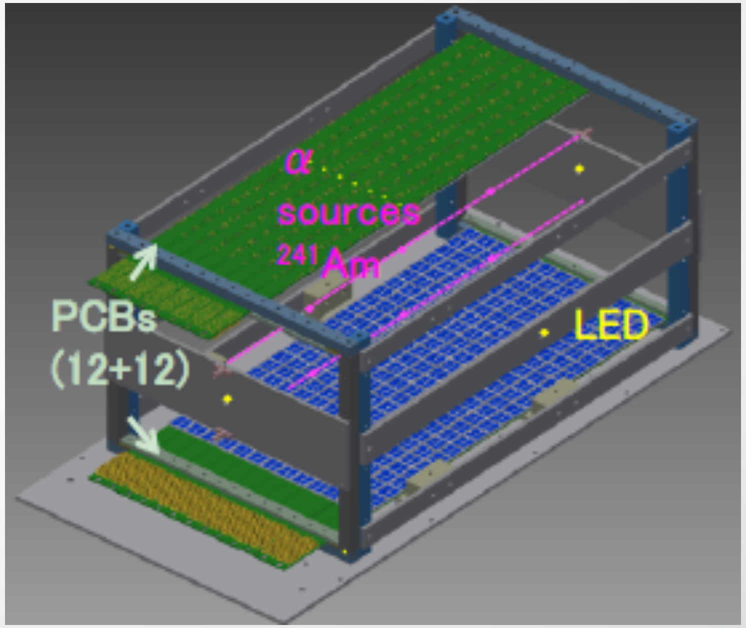
Back up

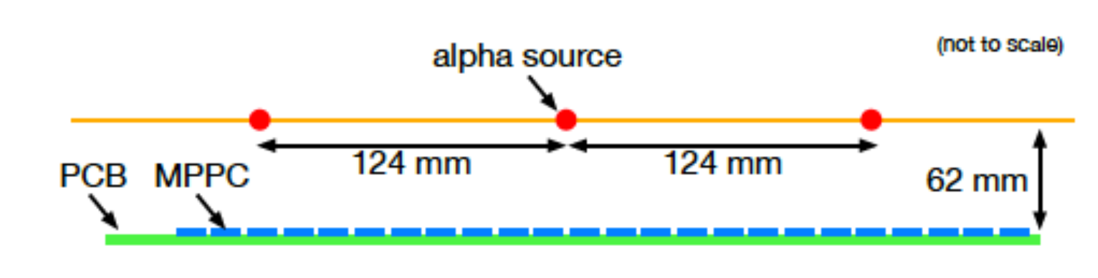
Summary

- Newly, angular dependence of MPPCs are checked in gaseous xenon
- Still, individual difference and the distinction from theoretical expectation exists
- Because of systematics, in-liquid measurement is not as accurate as in-gas measurement
- To check the effect for MEG II experiment is needed through in gas measurement

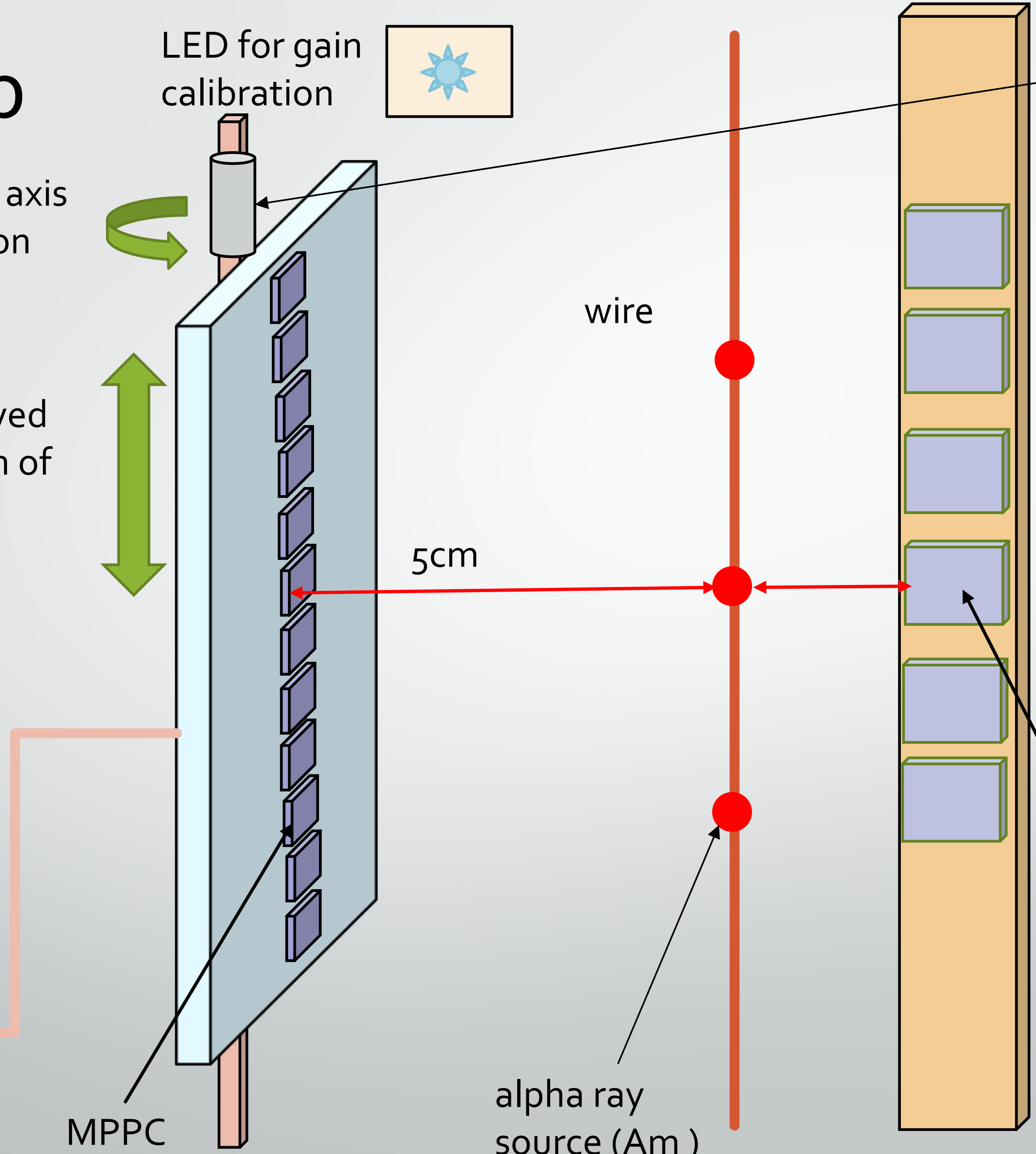
past experiment

- 600 MPPCs are put into liquid xenon: on the top and the bottom
- LED calibration and alpha ray photons measuring is done





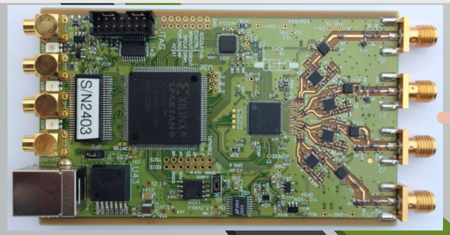
Setup



the rod can be moved so that the position of MPPC can change

height and angle can be checked by the scale on the axis by cameras

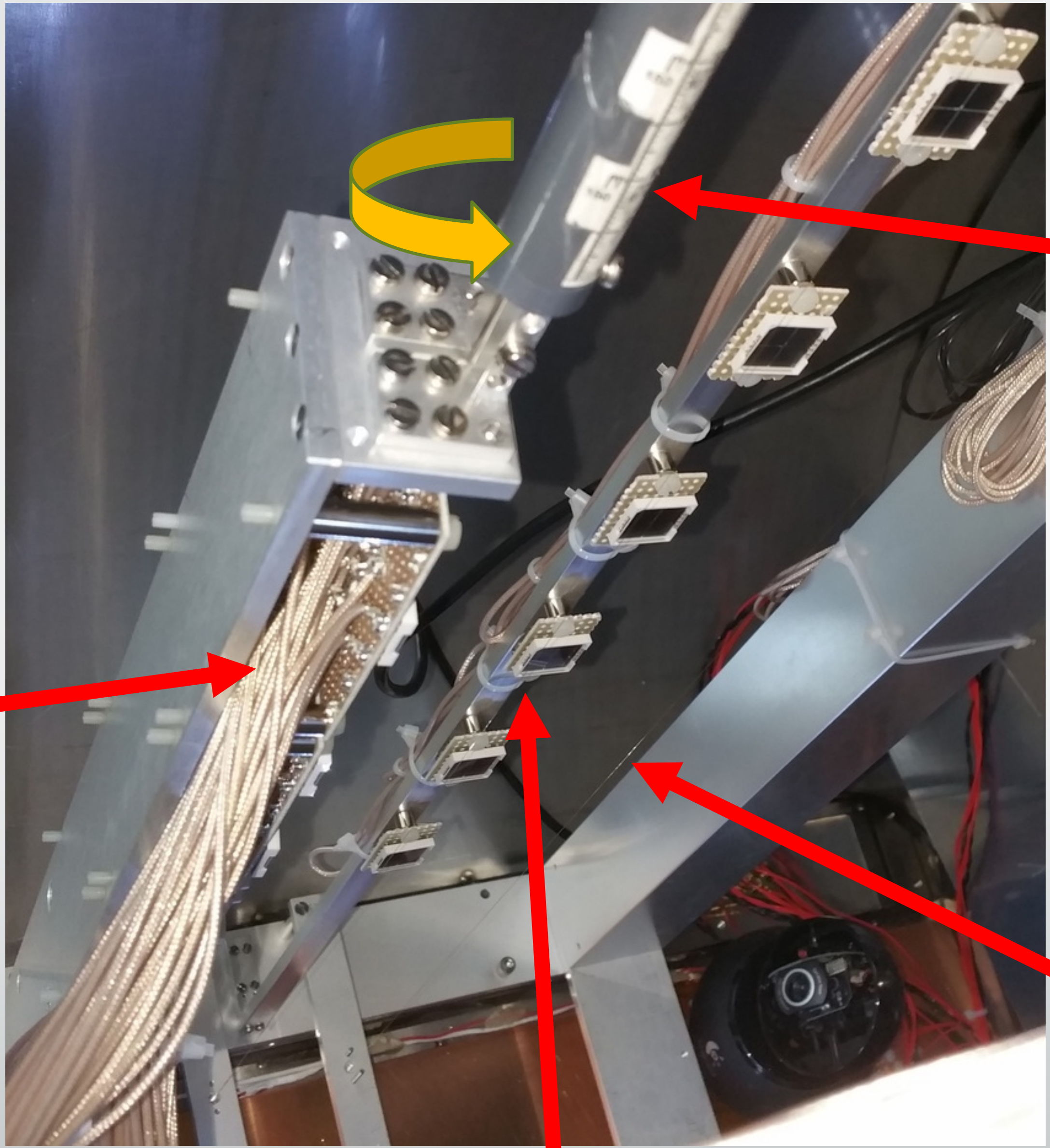
DRS (Domino Ring Sampling chips): the wave digitizer developed in PSI (Paul Scherrer Institut)



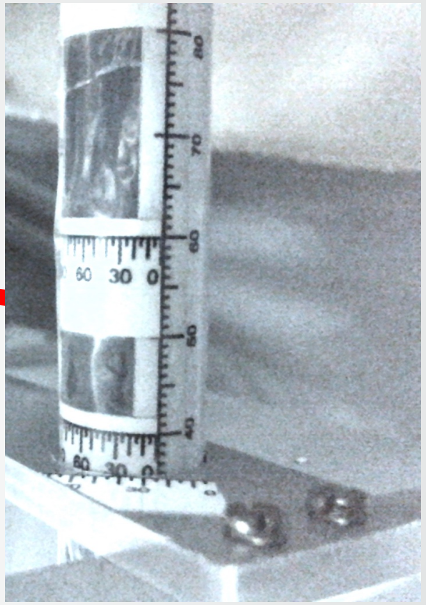
in the cryostat filled with gaseous xenon

Setup

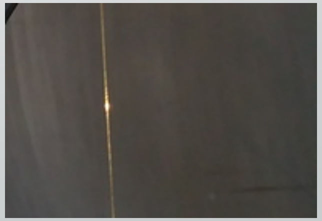
rod with MPPCs, signal is read by each chip



trigger channel

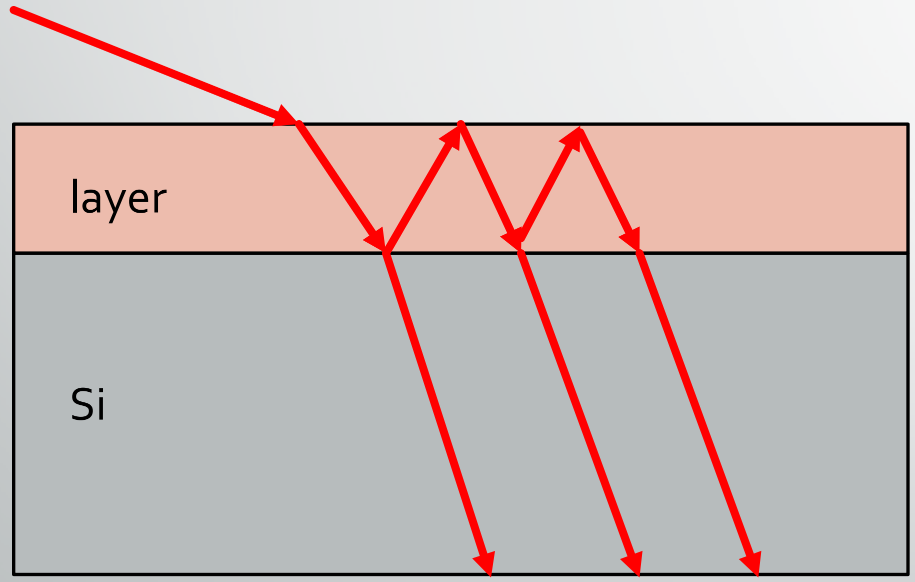


a pipe to check the angle (precision:~1°) and height of the rod, scale can be checked with a camera



wire with alpha ray source (Americium)

The model of expectation



- The refraction model shown in the figure is used
- Reflection rate and transmission rate are calculated from Fresnel equation

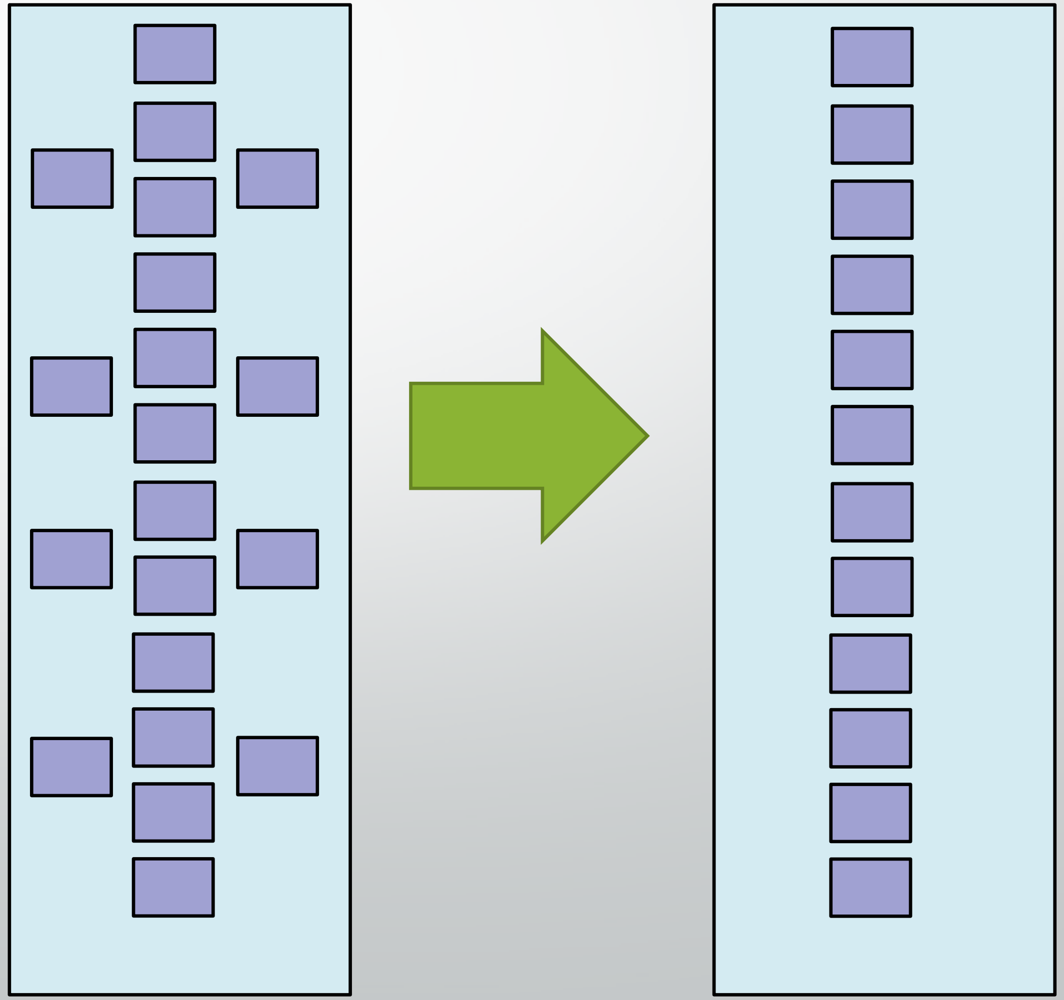
$$r_p = \frac{n_2^2 cos\theta - n_1\sqrt{n_2^2 - n_1^2 \sin^2\theta}}{n_2^2 cos\theta + n_1\sqrt{n_2^2 - n_1^2 \sin^2\theta}}$$

$$r_s = \frac{n_1 cos\theta - \sqrt{n_2^2 - n_1^2 \sin^2\theta}}{n_1 cos\theta + \sqrt{n_2^2 - n_1^2 \sin^2\theta}}$$

$$t = 1 - \frac{r_p + r_s}{2}$$

The problem with previous measurement

- Too many cables on the rod, which causes the inconsistency for the angle change -> the cables and channels were reduced
- Geometrical effect from the difference of the distance from alpha source may exist -> for every measurement, main channel is set in front of alpha source



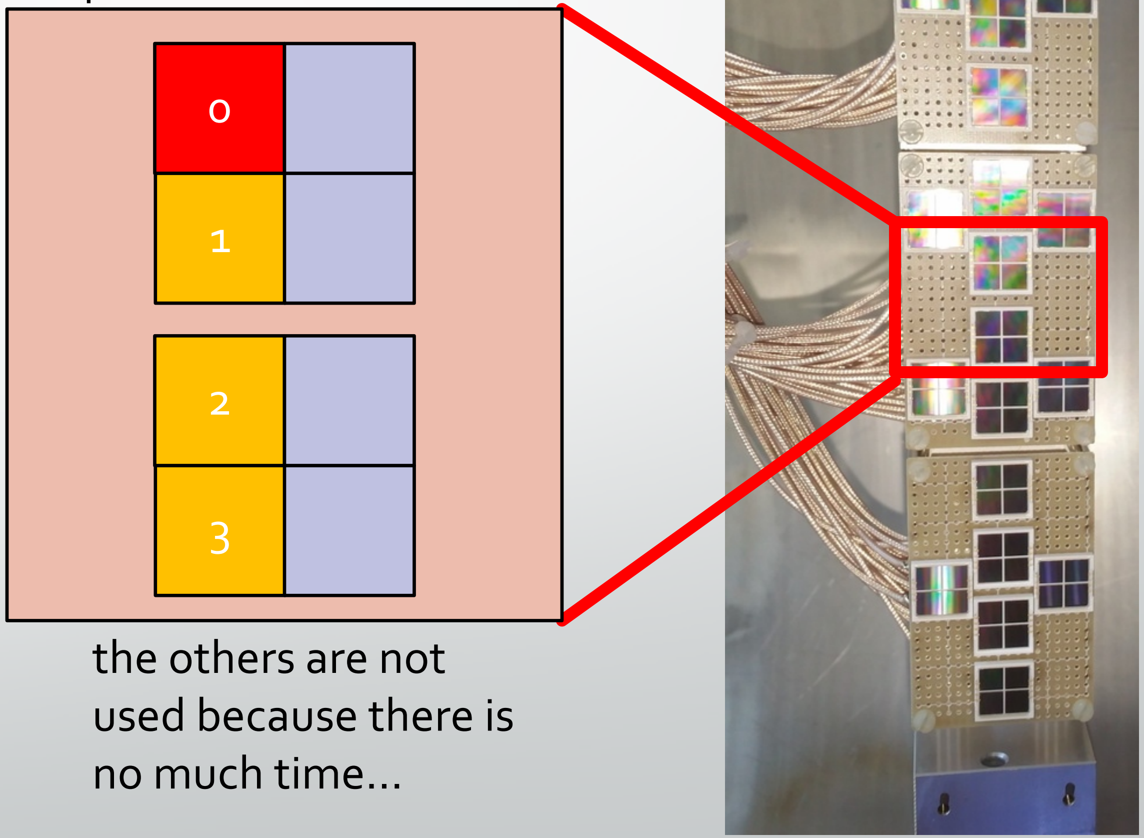
Improvement for the new measurement

- For each measurement, aimed MPPC is set in front of alpha source to avoid geometrical effect
- Newly error bars are added
- Individual difference of PDE is checked

Previous measurement

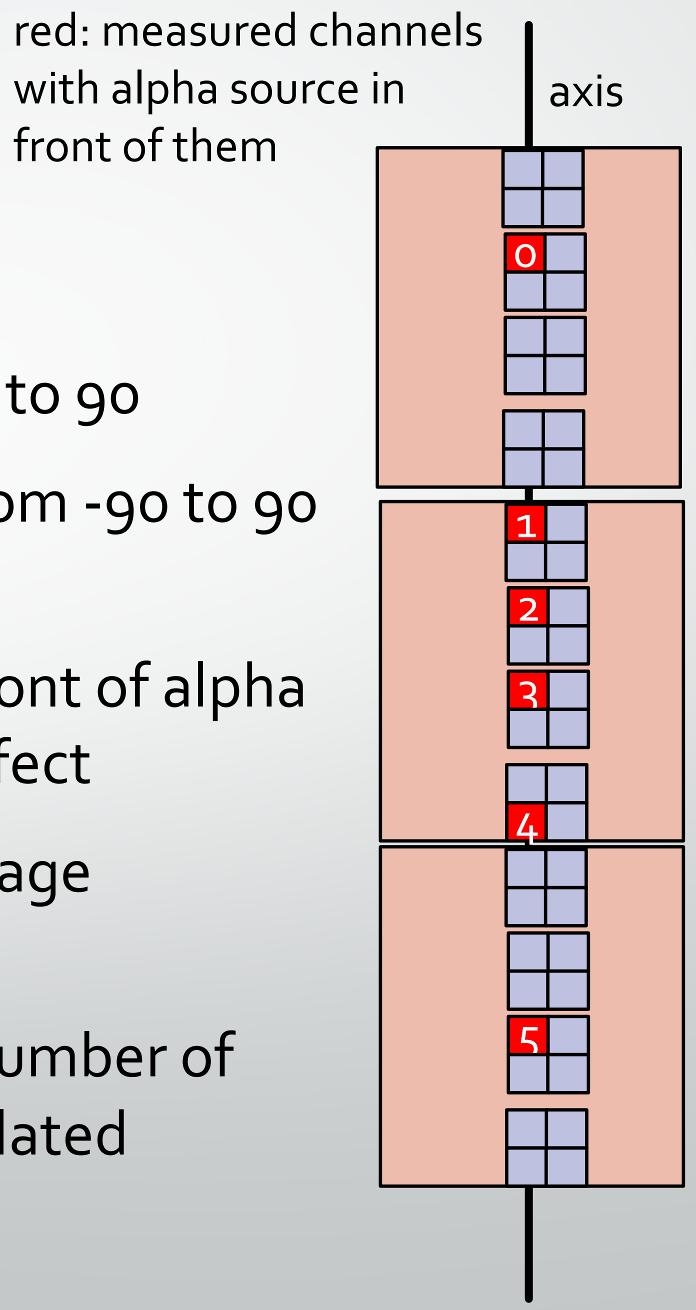
- The MPPCs are rotated every 10 degrees, from 0 to 90
- Voltage is set as Hamamatsu recommended voltage (~Vbd+4.3V)
- Alpha ray source is set in front of trigger channel and ch 0
- The number of photoelectrons were counted from alpha ray in gaseous xenon

orange: used channels
red: used & in front of alpha source



the others are not used because there is no much time…

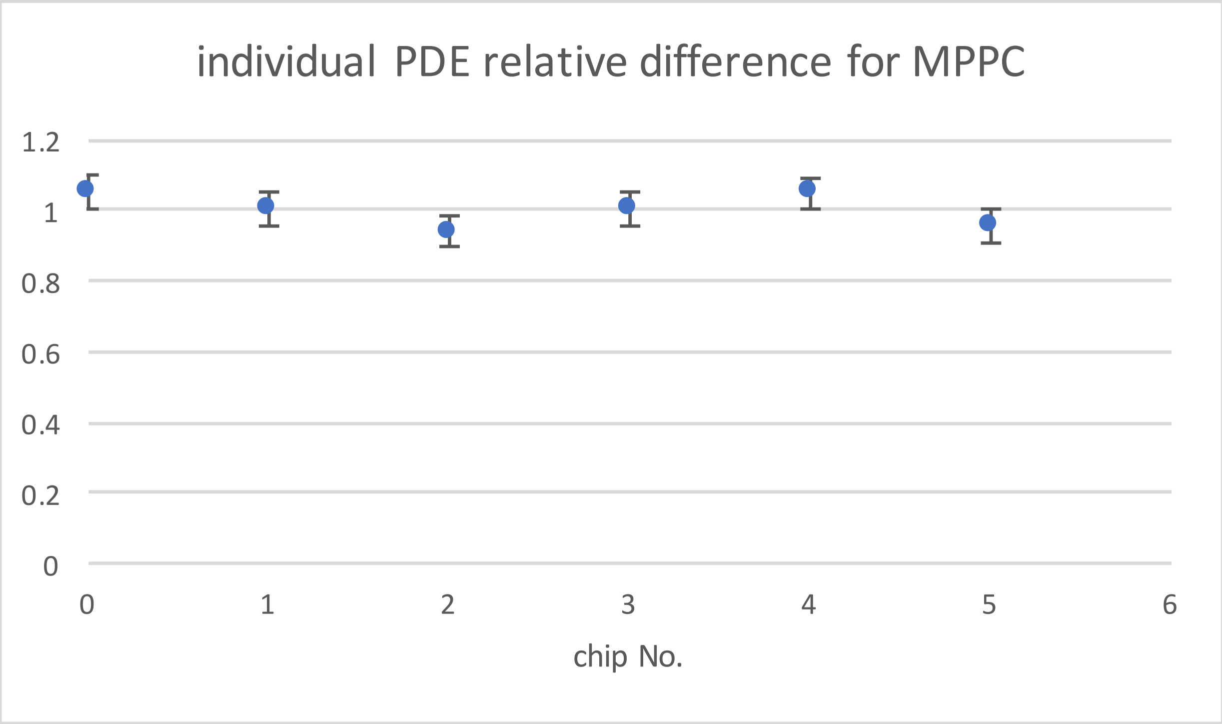
Measurement



- The MPPCs are rotated every 15 degrees, from 0 to 90
- For channel 2, angular dependence is checked from -90 to 90 degree with every 15 degree changes
- In total, 6 channels on rotation axis were set in front of alpha source for measurement to avoid geometrical effect
- Voltage is set as Hamamatsu recommended voltage (~Vbd+5V)
- Relative PDE = (measured photons)/(expected number of impinging photons)÷(PDE when $\theta = 0°$) is calculated

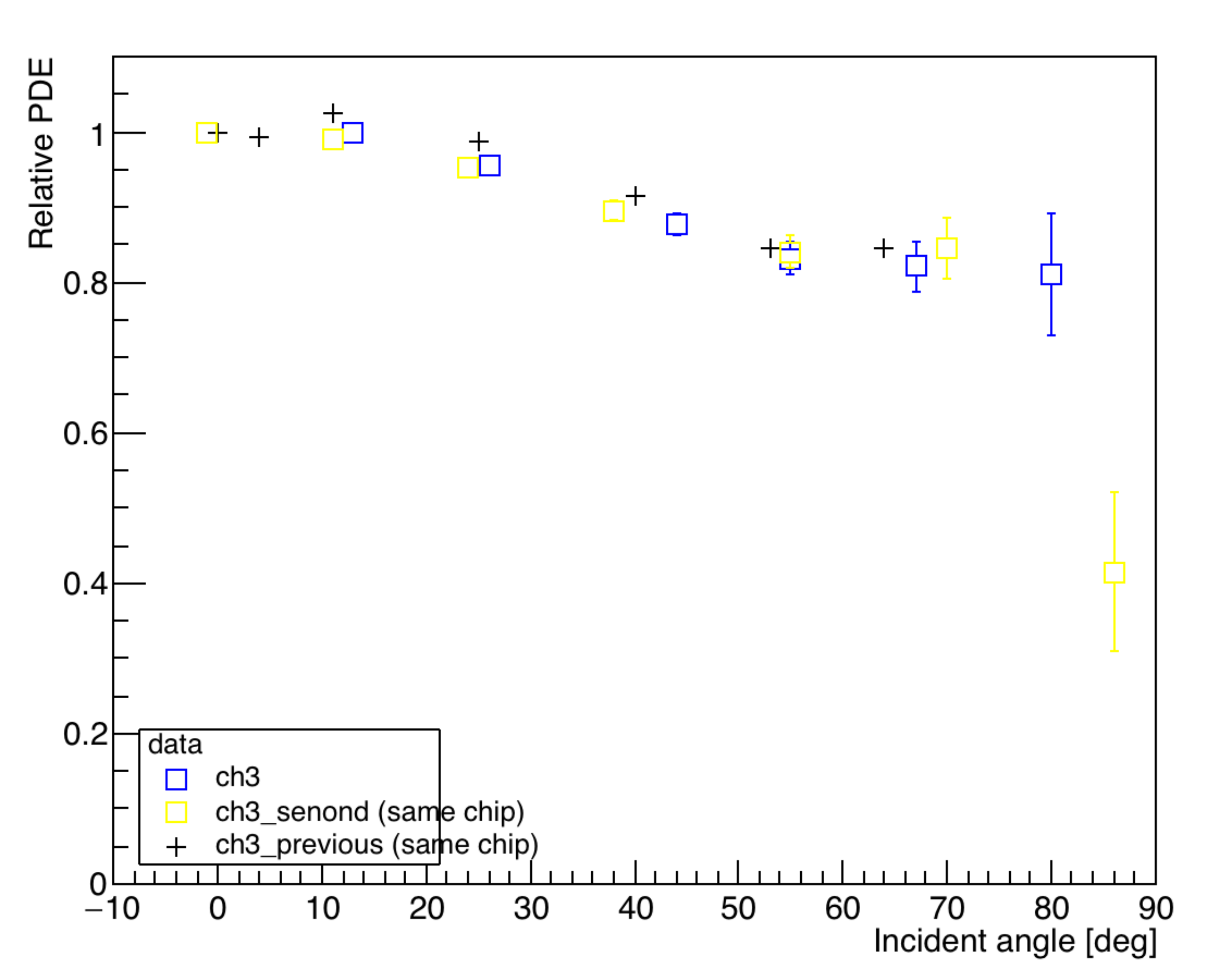
PDE difference for each channel

- PDE for each channels was compared when incident angle is ~0 degree
- At most 4.7% RMS
- Only relative difference can be discussed because the effect of cross talk and after pulse is not considered



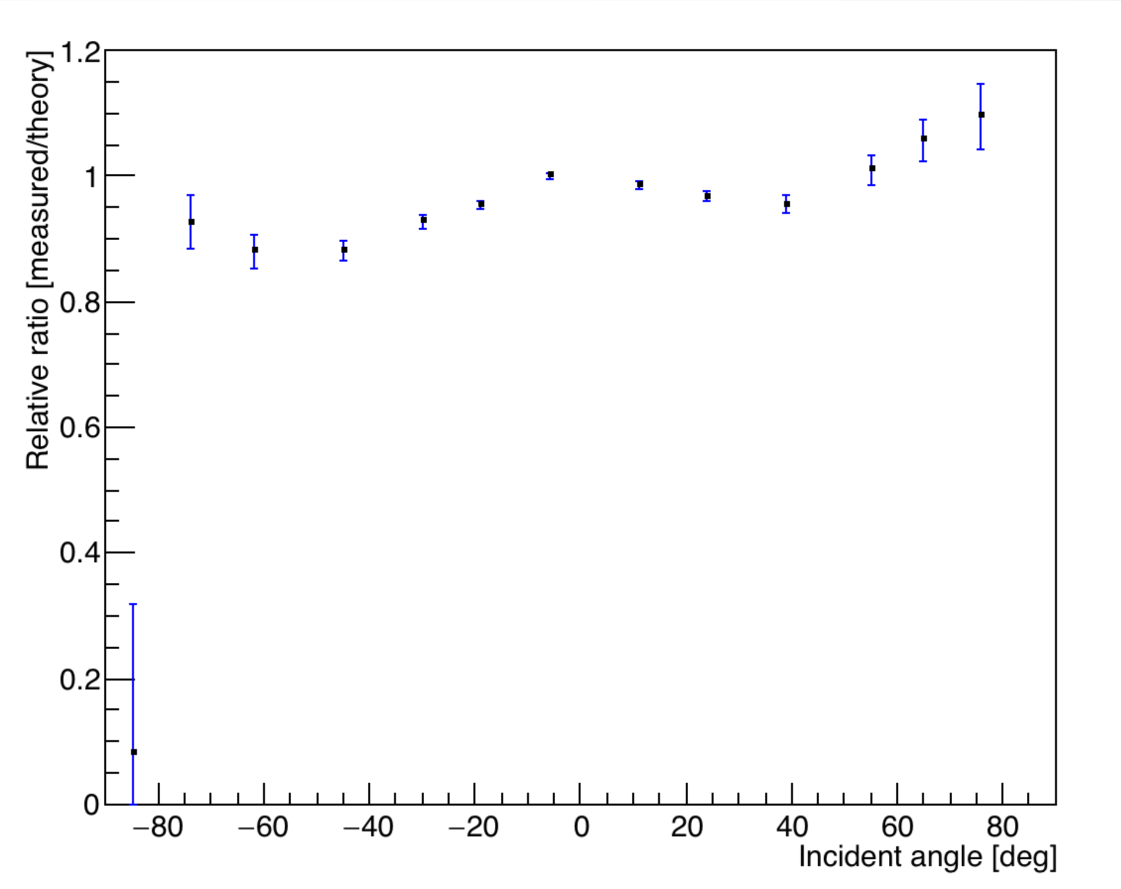
Reproductivity

- For channel 3,reproductivity is seen between previous measurement and present measurement



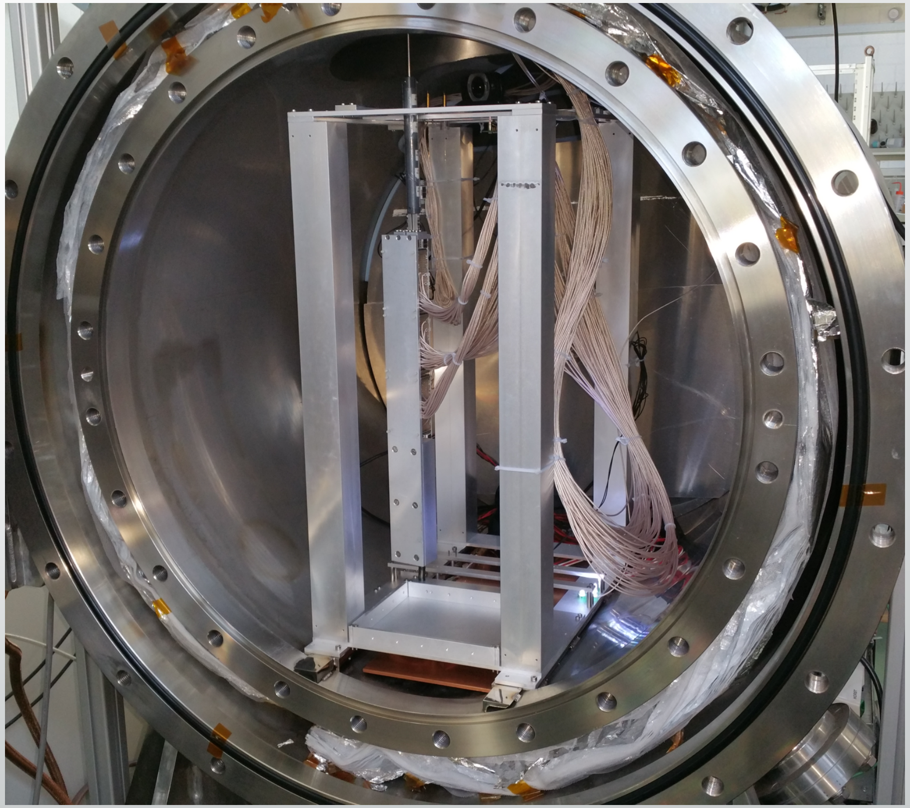
PDE dependence of photon incident angle for channel 2

- The MPPC rotation was done for both plus rotation and minus rotation to check the difference and zero-point
- For minus rotation, ratio between data and expectation get smaller than plus rotation



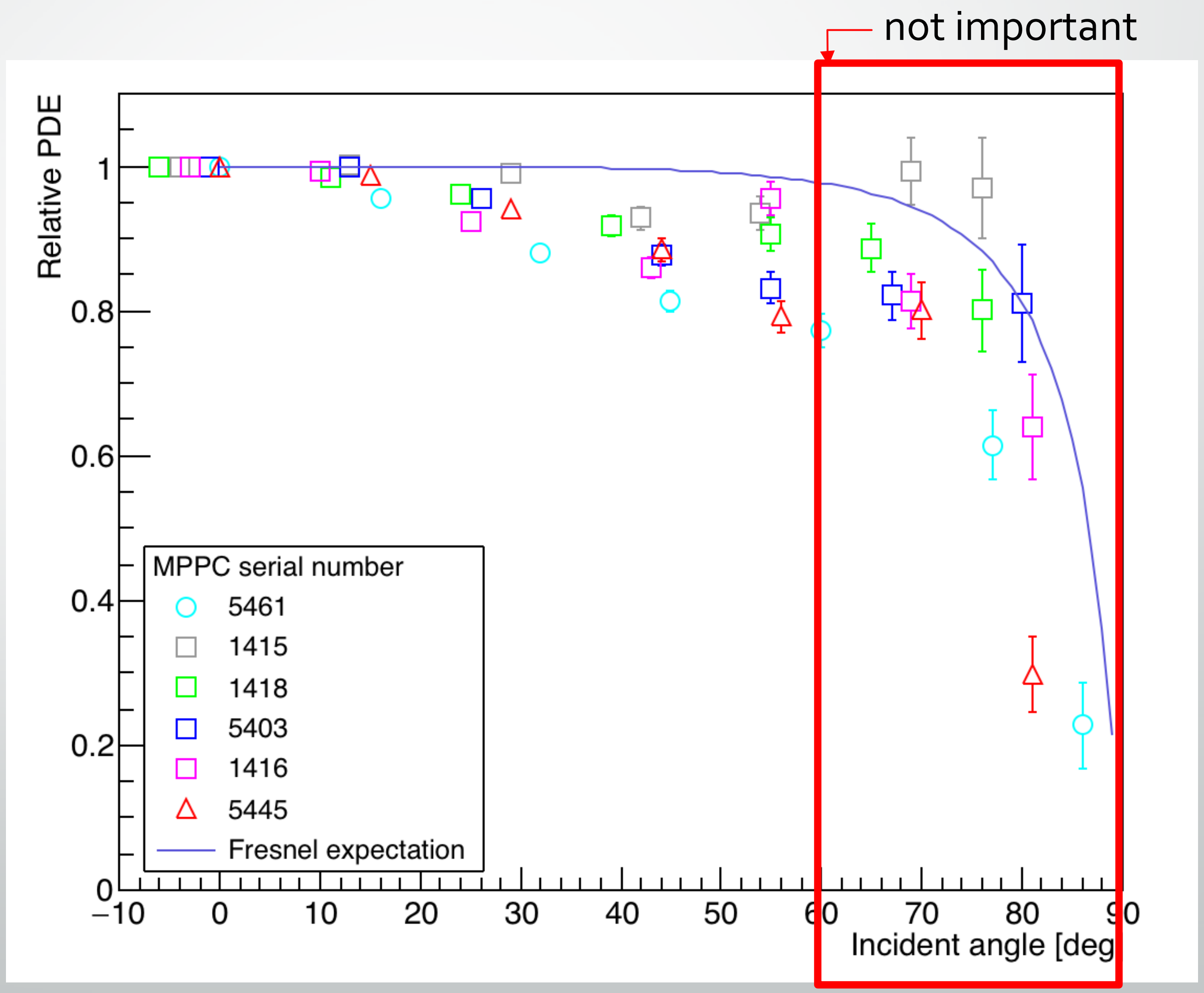
Difference between Plus &Minus rotation

1. The reflection from cryostat wall make PDE higher ← need compensation considering the distance from walls and the attenuation length of photons
2. At present, alpha source is treated as the point light source ← assumption of non-point (sphere) source needed for correct solid angle calculation



Result for individual channel PDE change

- For bigger angle area, PDEs of different channels are not consistent
- systematics like reflection from cryostat wall is too big, → **bigger angle area is not reliable**



Study

- The reason for falling faster at lower degree:

1. Model of refraction (the layers of MPPCs) is not correct → reconstruct the model again (ex. add another layer)
2. The effect of reflection on walls in the cryostat (more captured photons at smaller angle)
3. The difference between the scale and the rod → check the consistency

Study

- The individuality of MPPCs

1. The existence of insensitive layer; thickness is different
2. The alpha ray energy changes depending on the alpha source, or the effect of reflection is not same

Discussion

- The reason for falling faster at lower degree

1. Model of refraction (the layers of MPPCs) is not correct → reconstruct the model again (ex. add another layer)

- The inconsistency of different channels for bigger angle

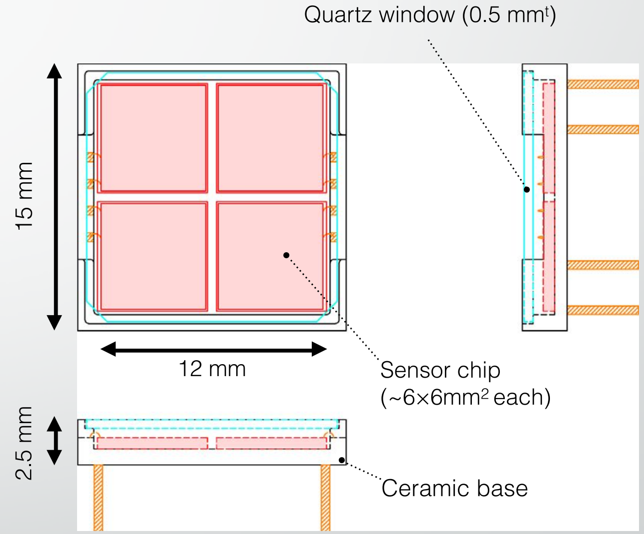
1. The effect of reflection is not same for each channel due to the position difference

   → For bigger angle, PDE measurement is unreliable

Study

- The reason of the different tendency between in liquid and in gas

1. The difference of instruments; for the experiment in liquid, the reflection effect get bigger
2. The effect of ceramic wall of MPPCs changes; in liquid, the wall effect get bigger and more area will be hidden
3. In liquid, photons are scattered and less photons get into the MPPC



Next Plan

- See the effect of insensitive layer of MPPCs (ex. correlation between angular dependence and PDE)
- Check if the measurement and modeling for analysis is correct
- If the individuality exists for each MPPC, check more MPPCs to increase statistics
- See the absolute PDE of MPPCs by eliminating the effect of cross talk, after pulse and impurity of xenon
- Confirm how this angular dependence affect the precision for measurement on MEG II experiment