# 光センサーの性能劣化が MEG II 実験液体キセノン検出器の 性能に与える影響の評価

# Effect of the photo sensor deterioration to the MEG II Liquid Xe detector performance

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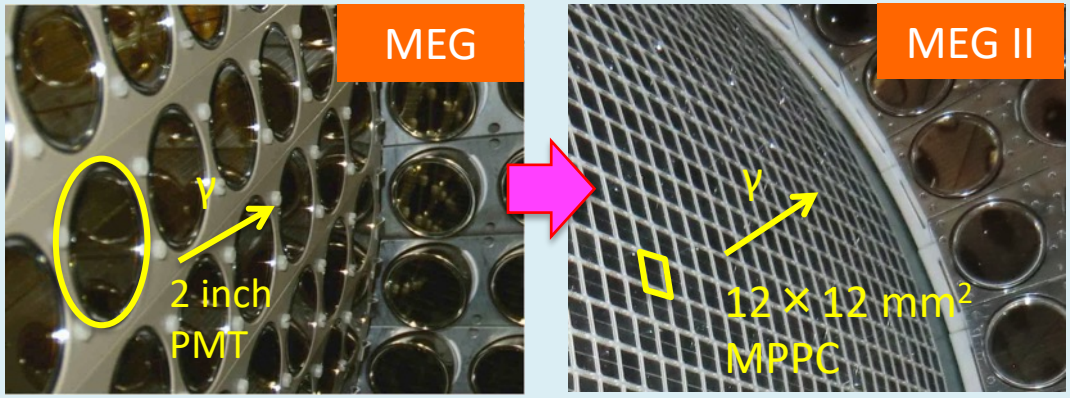
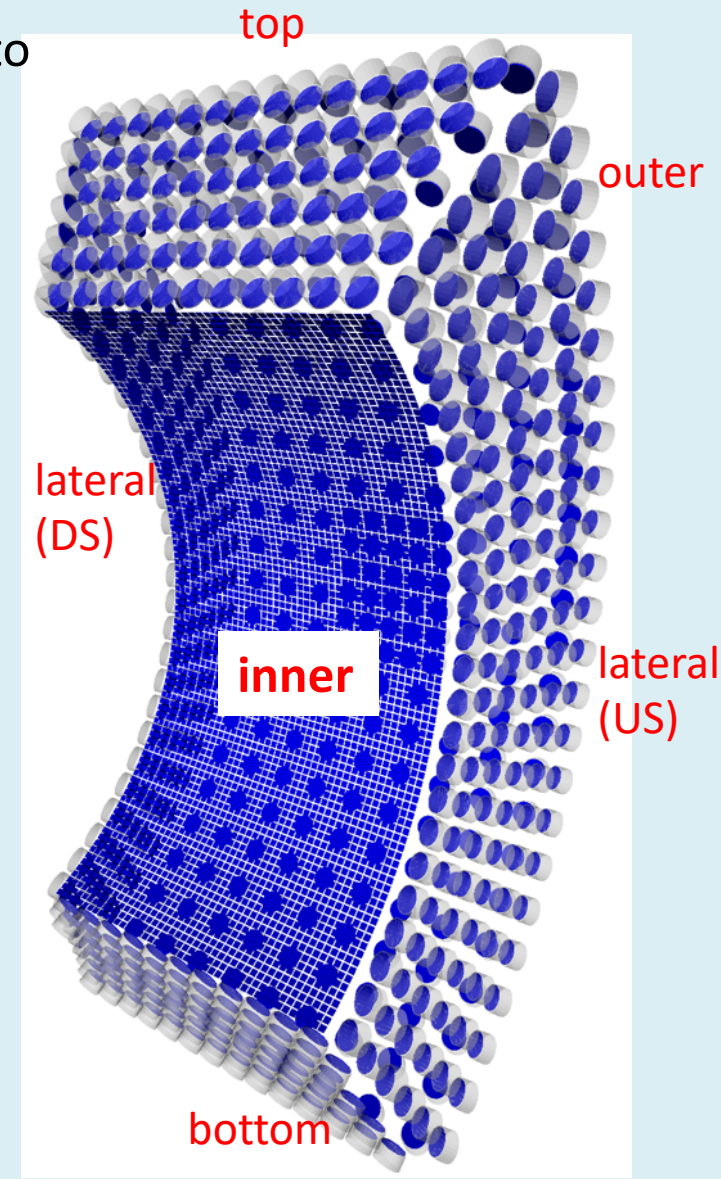
# LXe detector in MEG II

- LXe γ-ray detector has been upgraded for MEG II to significantly improve the performance.
  - measure energy, hit position, and timing of 52.8MeV γ from $\mu \rightarrow e\gamma$.




**216 2-inch PMTs** **4092 12 × 12 mm² MPPCs**

- Detector commissioning on going.
- On 2018 Dec., Pre-Engineering run 2018 was conducted.
  - Monochromatic γ-source for calibration.
  - BG γ-ray from muon beam.



# Effect of smaller MPPC PDE

- MPPC PDE for VUV is found to be decreasing under MEG II beam. (16pG22-11)
- Annealing will recover its degradation. (16pG22-12)

↓

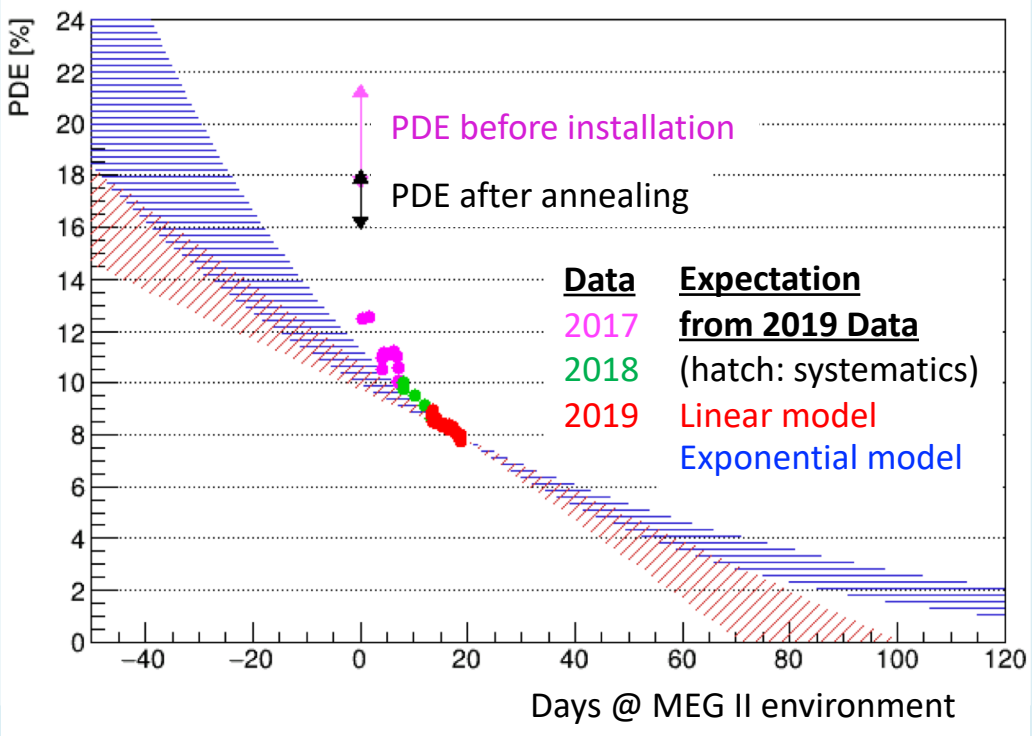
Can we carry out MEG II experiment with this degradation?

- Smaller MPPC PDE may affect sensor calibration precision, online resolution of γ, and offline resolution of γ.
- This talk will focus on offline γ resolution.
  - Smaller MPPC PDE
    → Larger statistical fluctuation, Worse S/N ratio.
    → Worse resolution of γ energy, hit position and hit timing.
    → Degradation of significance of Signal to BG.
    → Degradation of MEG II physics sensitivity.
  - Effect to physics sensitivity is estimated from
    - Degradation speed of MPPC PDE.
    - Detector resolution in MC simulation at smaller MPPC PDE.

# Degradation speed of MPPC PDE

- Still many uncertainties on the PDE in the future.
  - We do not know the shape on degradation.
  - Degradation speed in 2017-2018 is faster than that in 2019.
  - PDE before irradiation is worse than PDE after recovery by annealing, and PDE measured before installation.
- In the best case, degradation of PDE will saturate at some point.
  - Saturation of degradation observed at another VUV irradiation test at room temperature. (Ref: 17aG22-7)
- In the worst case, PDE goes to 0% after 70 days from annealing.

History of MPPC VUV PDE
(Measured data & expectation in the future)



# Possible scenarios

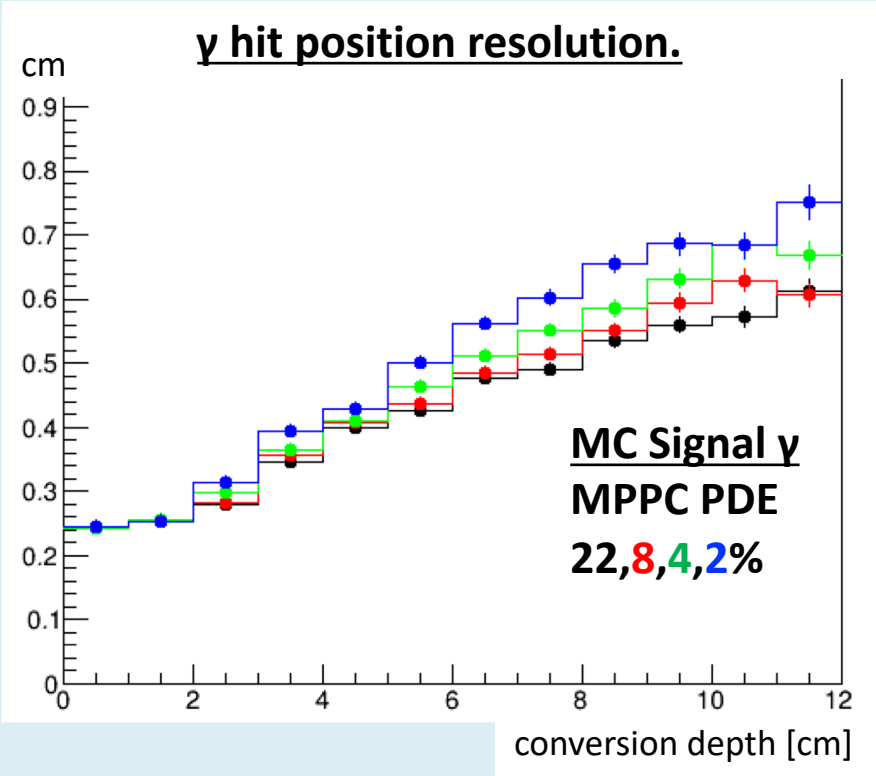
- Planned MEG II run : 140 days / year (summer - winter) x 3 years.

- There are several possibilities depending on the number of annealing process needed to keep PDE at a “reasonable” level.
  - Scenario A. (no need for annealing)
    - Degradation of PDE saturated at some point.
  - Scenario B. (annealing once / year)
    - Annealing can be performed during the shutdown period every year.
      → No effect on the statistics of physics run.
  - Scenario C. (annealing more than once /year)
    - Annealing has to be performed also during data taking period.
      → One cycle of annealing will take 1-2 month.
      This will reduce the statistics of physics run.

# Position resolution

- Hit position of γ is reconstructed from the # of p.e. distribution on MPPCs.
- Worse MPPC PDE will increase statistical fluctuation of observed distribution, and leads to worse position resolution.

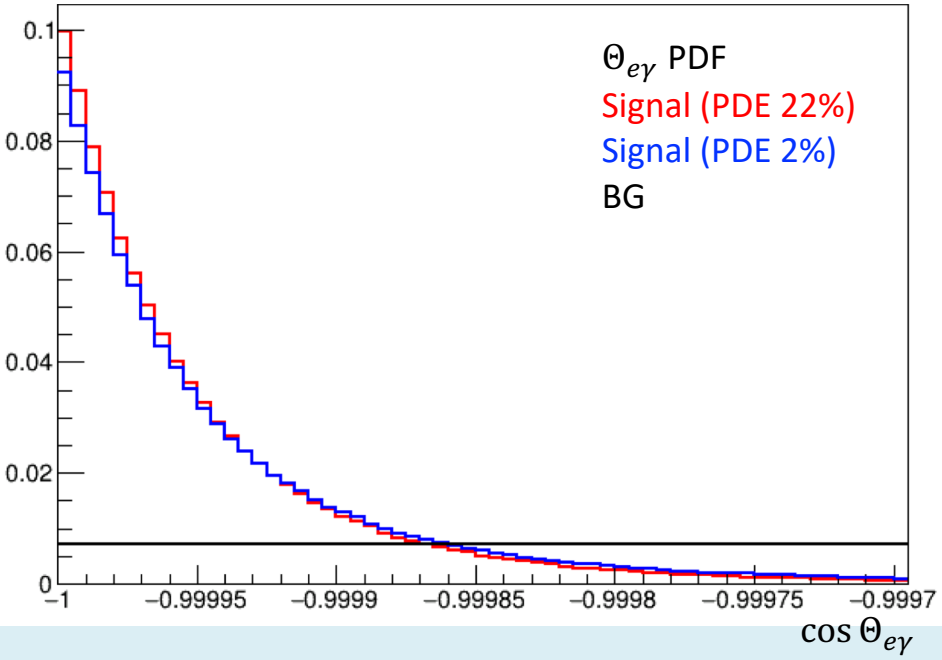
- Slight resolution degradation expected at smaller MPPC PDE down to 2%
  - more obvious at deep event due to their small # of p.e. statistics on inner face.



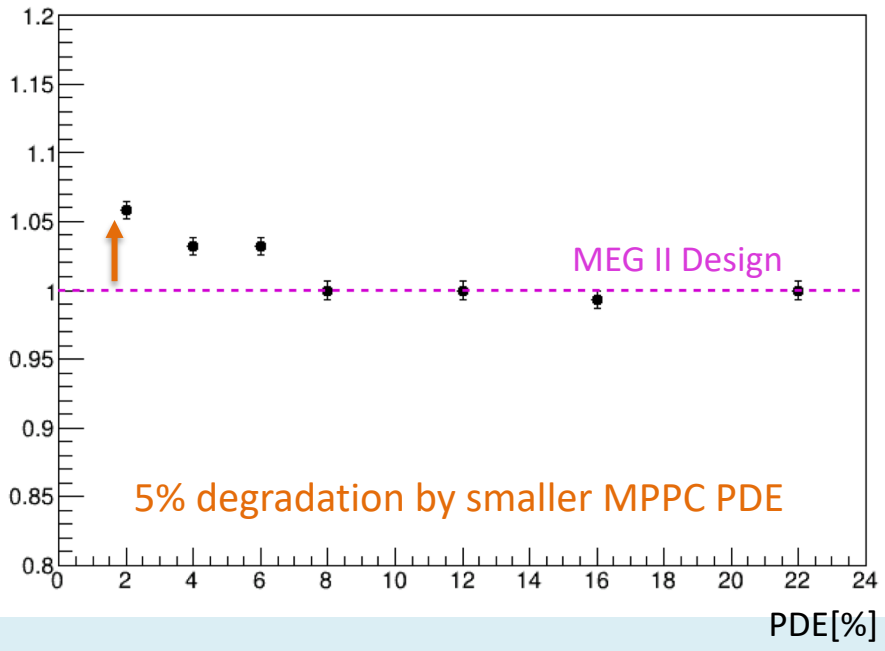
# Position resolution

- Worse position resolution leads to worse signal to BG significance on opening angle of e-γ ($\Theta_{e\gamma}$).
- Degradation of MEG II sensitivity is estimated based on Signal and BG PDF.
  - For simplicity, only considering the significance of PDFs, and neglecting single event sensitivity.
- Sensitivity degradation of 5% by MPCP PDE 22->2%.

Signal & BG PDF of opening angle between e-γ



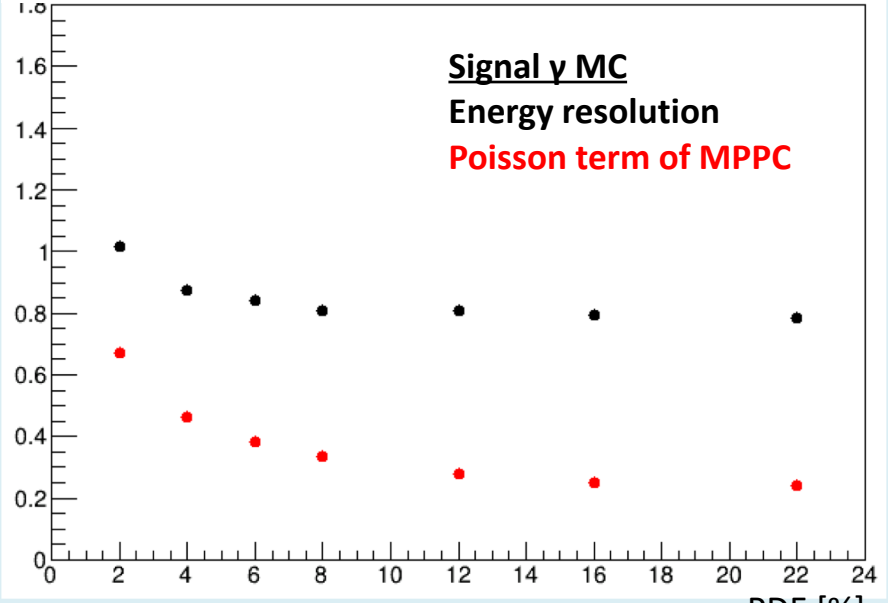

MEG II sensitivity by γ position vs MPPC PDE



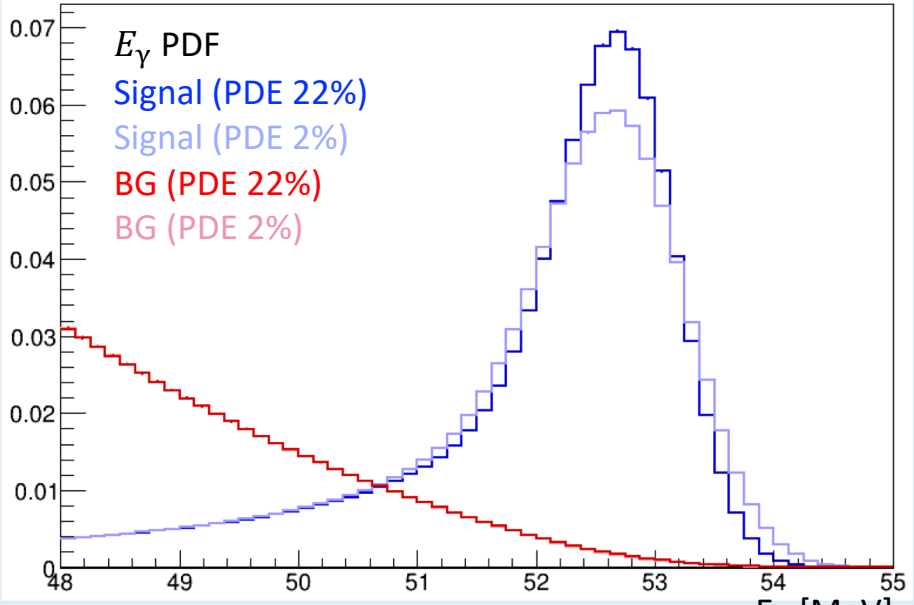
# Energy resolution

- Energy is reconstructed from sum of # of p.e. of all MPPC/ PMT.
- If we have smaller MPPC PDE, Poisson statistics contribution will become larger.
- Poisson statistics term of MPPC is not dominant contribution, thus effect is limited.

Energy resolution (%) vs MPPC PDE (%)

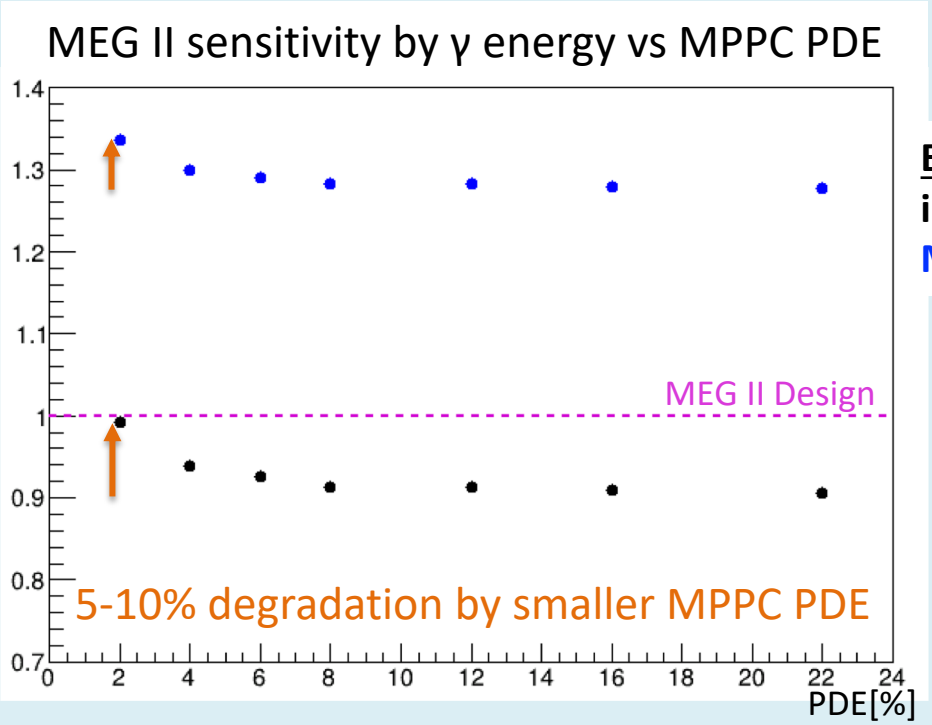



Signal & BG PDF of γ energy



# Energy resolution

- In addition to that, we have not yet achieved energy resolution in MC.
  - Energy resolution (Data) = Energy resolution (MC) + 1.4% (for 52MeV gamma)
  - Known from MEG I, and seems to be existing also in MEG II.
- Effect of PDE degradation will be further smaller.
- 5-10 % degradation by MPPC PDE 22->2%.

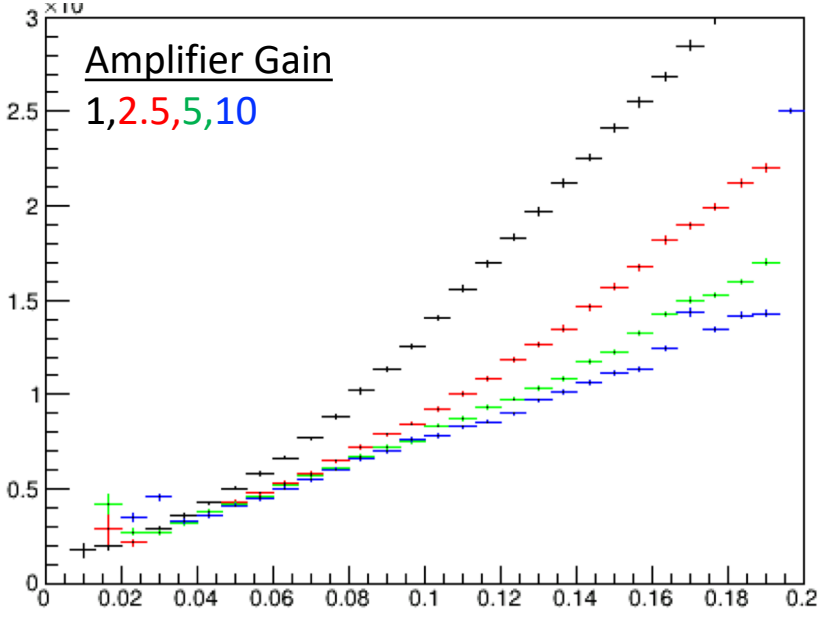



**Eγ resolution in MC**
**MC ⊕ 1.4%**

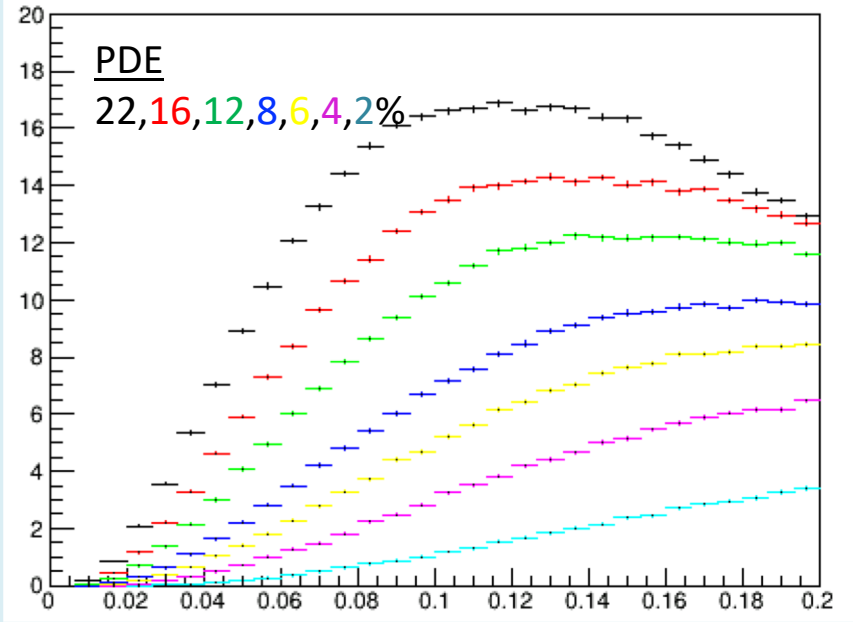
# Timing reconstruction

- Timing is reconstructed by the weighted average of hit timing of all MPPC/PMTs.
- Dominant contribution to timing resolution is the sum of timing precision of all channel.
  - Total Precision = Σ “Precision of a MPPC/PMT” x “number of MPPC /PMT in a event”.
- If we have smaller MPPC PDE, total precision of MPPC will get worse.
  - Part of the degradation can be recovered by increasing S/N ratio by larger amplifier gain, as long as signal amplitude will not exceed dynamic range of the readout.

Timing precision of a MPPC



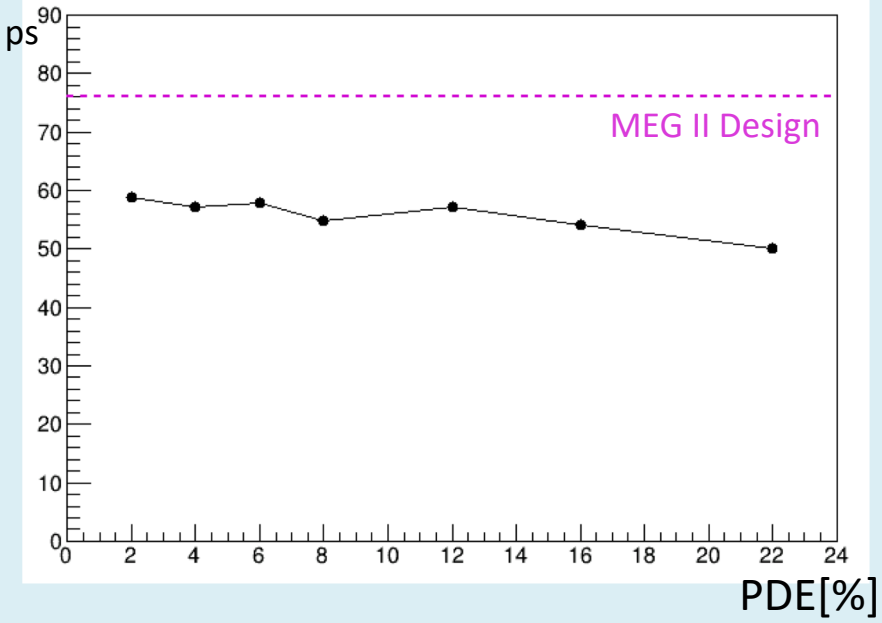

# of MPPC (avg.) in a Signal event



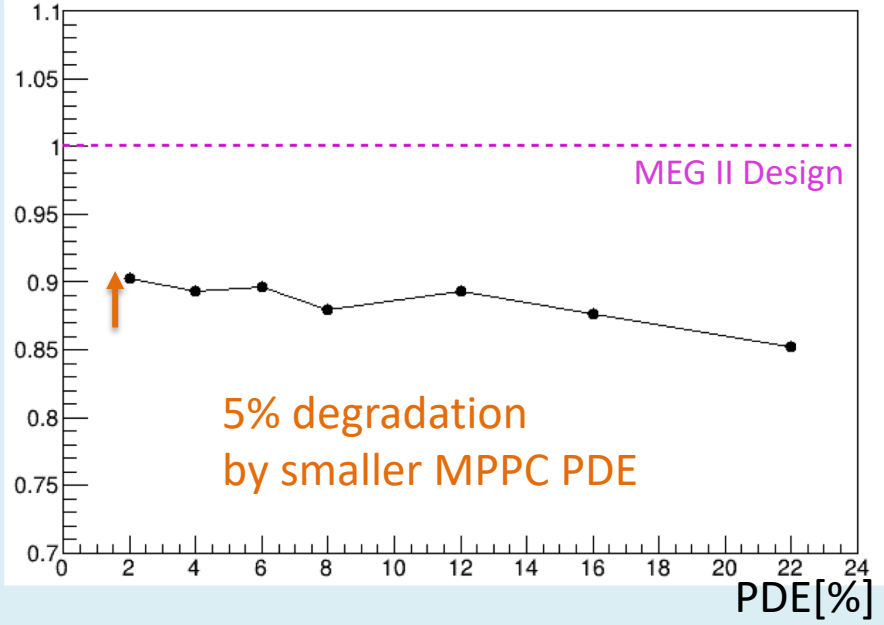
# Timing resolution

- Precision of MPPC timing will become larger at small PDE, and precision of PMT timing will define detector timing resolution.
- 5 % sensitivity degradation by MPPC PDE 22->2%.
- Still better than design resolution thanks to improvement of the offline analysis.
  (Ref: JPS 2016s 22pAN-4)

XEC timing resolution vs MPPC PDE




MEG II sensitivity by γ timing vs MPPC PDE

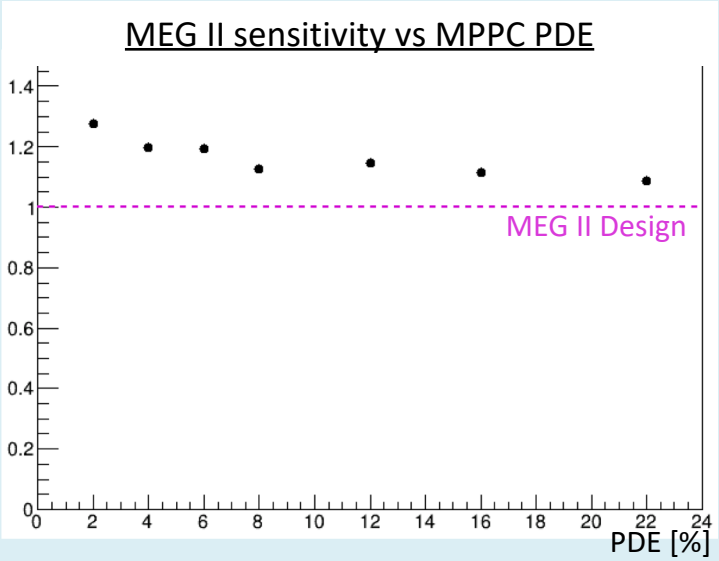


# Summary

- MEG II LXe detector will improve its performance by installing newly developed VUV MPPC. Degradation of VUV PDE under MEG II beam and recovery of degradation by annealing is observed.

- Effect of this degradation to the MEG II experiment has been discussed.

- Some degradation of γ –ray resolutions are expected at very small MPPC PDE of 2%, but its effect to the MEG II physics sensitivity is found to be limited (+20%).



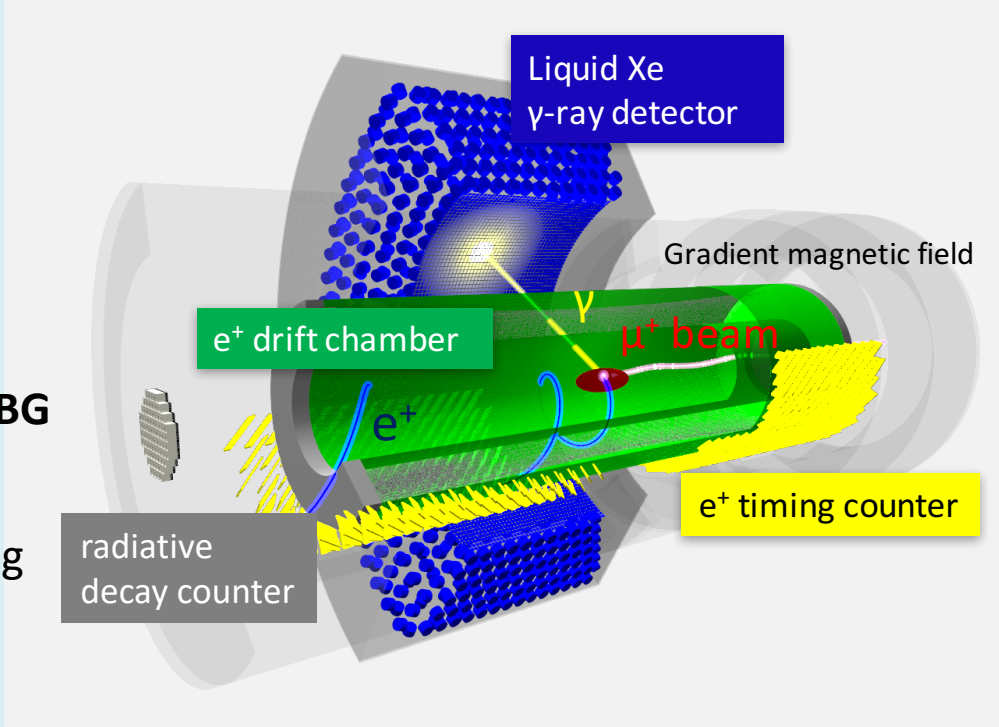

- If the degradation will saturate at PDE above ~6%, we may not need annealing.
- Even in the worst case (PDE goes to 0% in 70 days), we can operate our detector by keeping PDE above 2%.
  (This will reduce DAQ day from 140 days/year → 80 -110 days/year)

# BACKUP

# MEG II experiment

## Upgrade of MEG experiment

- Searches for $\mu \to e\gamma$.
- Dominant BG : accidental BG
- **More statistics**
  - x2.3 muon beam rate
  - x2 positron efficiency
- **Better separation of signal event from BG**
  - x2 for all detector resolutions
  - New detector for background tagging will be introduced




## Expected sensitivity: $6 \times 10^{-14}$

- One order of magnitude better than MEG

## Engineering run from 2020

- Followed by physics data taking.

Reference :
"The design of the MEG II experiment",
Eur. Phys. J. C (2018) 78:38

# MEG II Sensitivity vs DAQ time