# Development of PPD Sensitive to Deep UV Scintillation Photons of Liquid Xenon

**W. Ootani**, X. Bai, T. Chiba, Y. Fujii, T. Iwamoto, D. Kaneko, T. Mori, H. Natori, R. Sawada and Y. Uchiyama
*ICEPP, University of Tokyo*

S. Mihara and H. Nishiguchi
*KEK, High Energy Accelerator Research Organization*

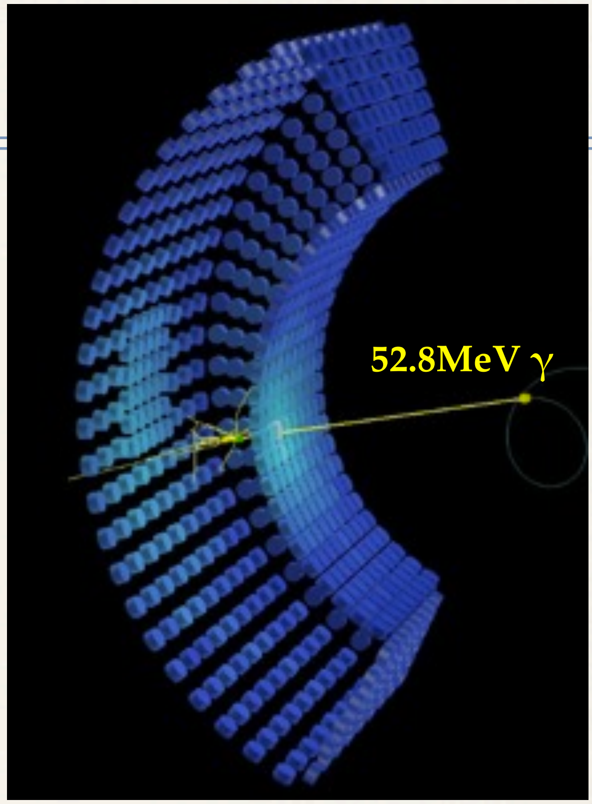
A. Stoykov
*Paul Scherrer Institut*

**International Workshop On New Photon-detectors 2012**, June 13-15, 2012, LAL Orsay

# Contents

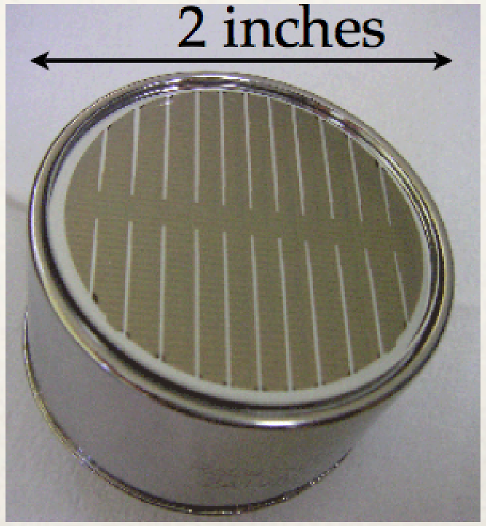
- Upgrade Plan of MEG LXe Scintillation Detector
- Characterization of Prototypes of UV-enhanced MPPC
- Other Issues (sensor size, dynamic range, radiation hardness)
- Summary

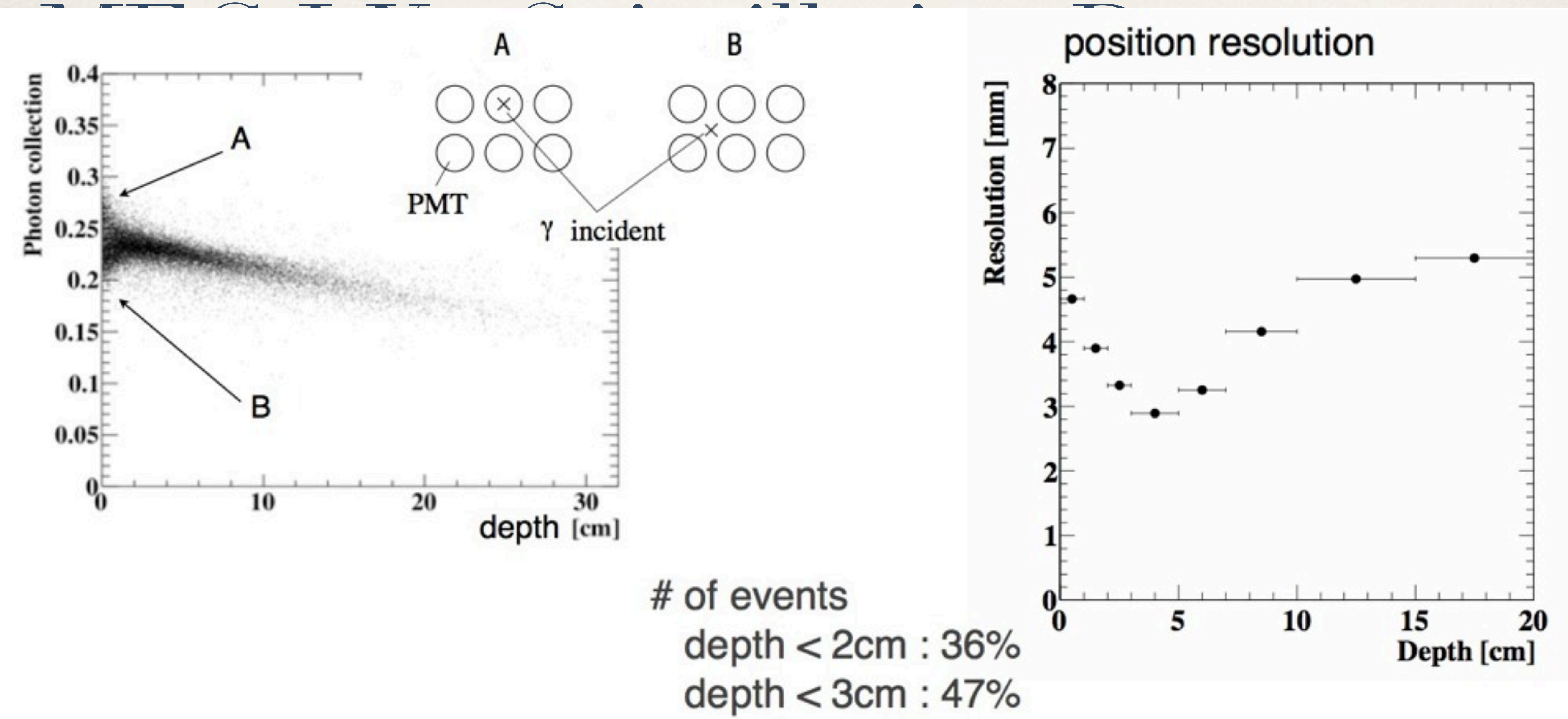
# MEG LXe Scintillation Detector



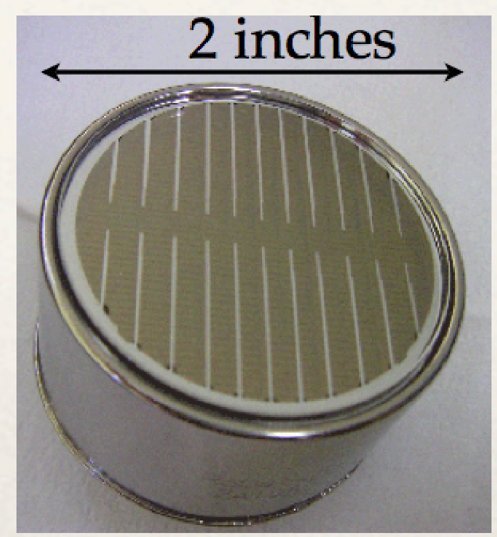

- MEG experiment searching for LFV decay, $\mu \to e\gamma$, employs 900ℓ-LXe scintillation detector to measure 52.8MeV-$\gamma$ from $\mu \to e\gamma$.
- Scintillation light (VUV $\lambda$=175±5nm) collected by 846 UV-sensitive phototubes immersed in LXe
  - Hamamatsu R9869
  - Operational in LXe (T=165K, P<3atm)
  - Synthetic quartz window
  - Photocathode: K-Cs-Sb (QE~15% at 165K)
- **Limited resolutions for shallow events due to no-uniform PMT coverage**

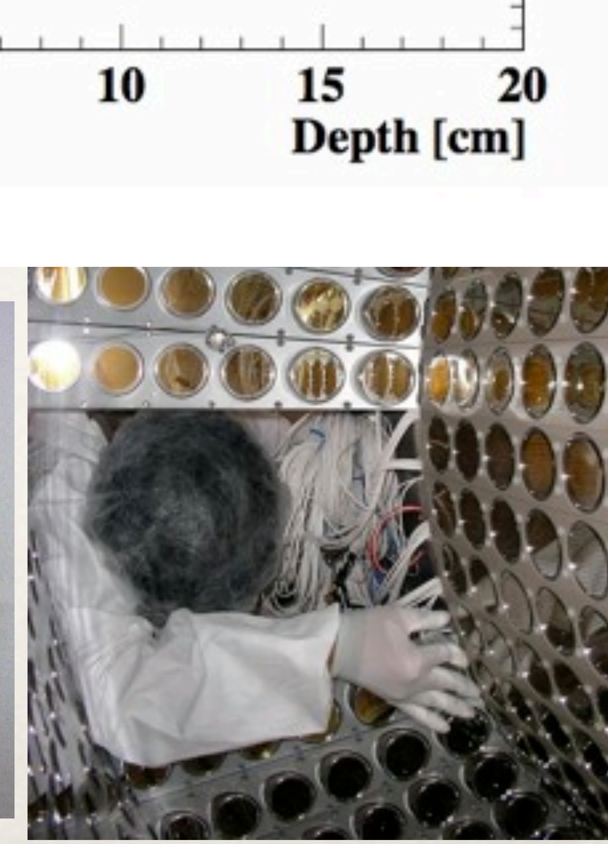
UV-sensitive PMT



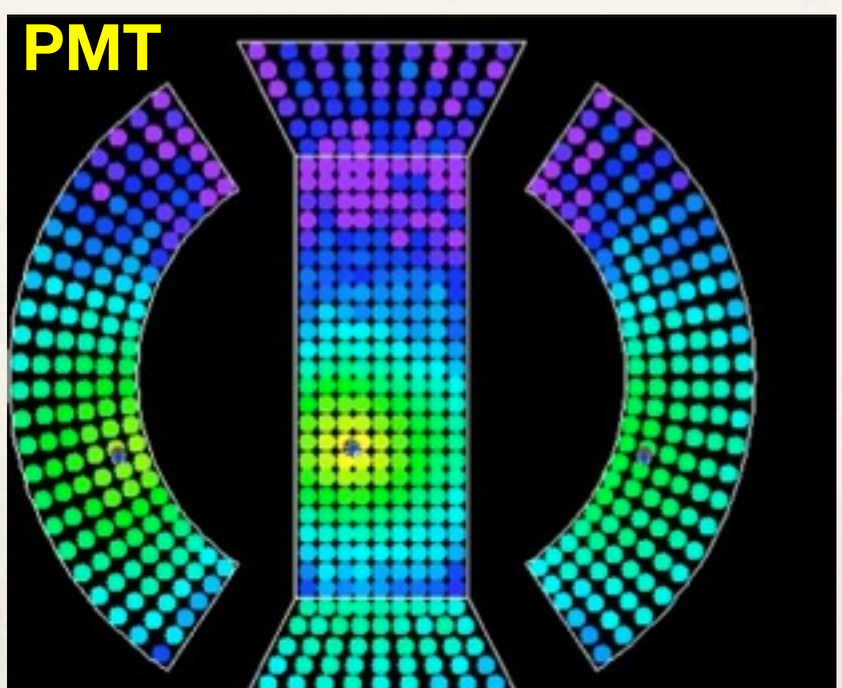

- **Limited resolutions for shallow events due to no-uniform PMT coverage**

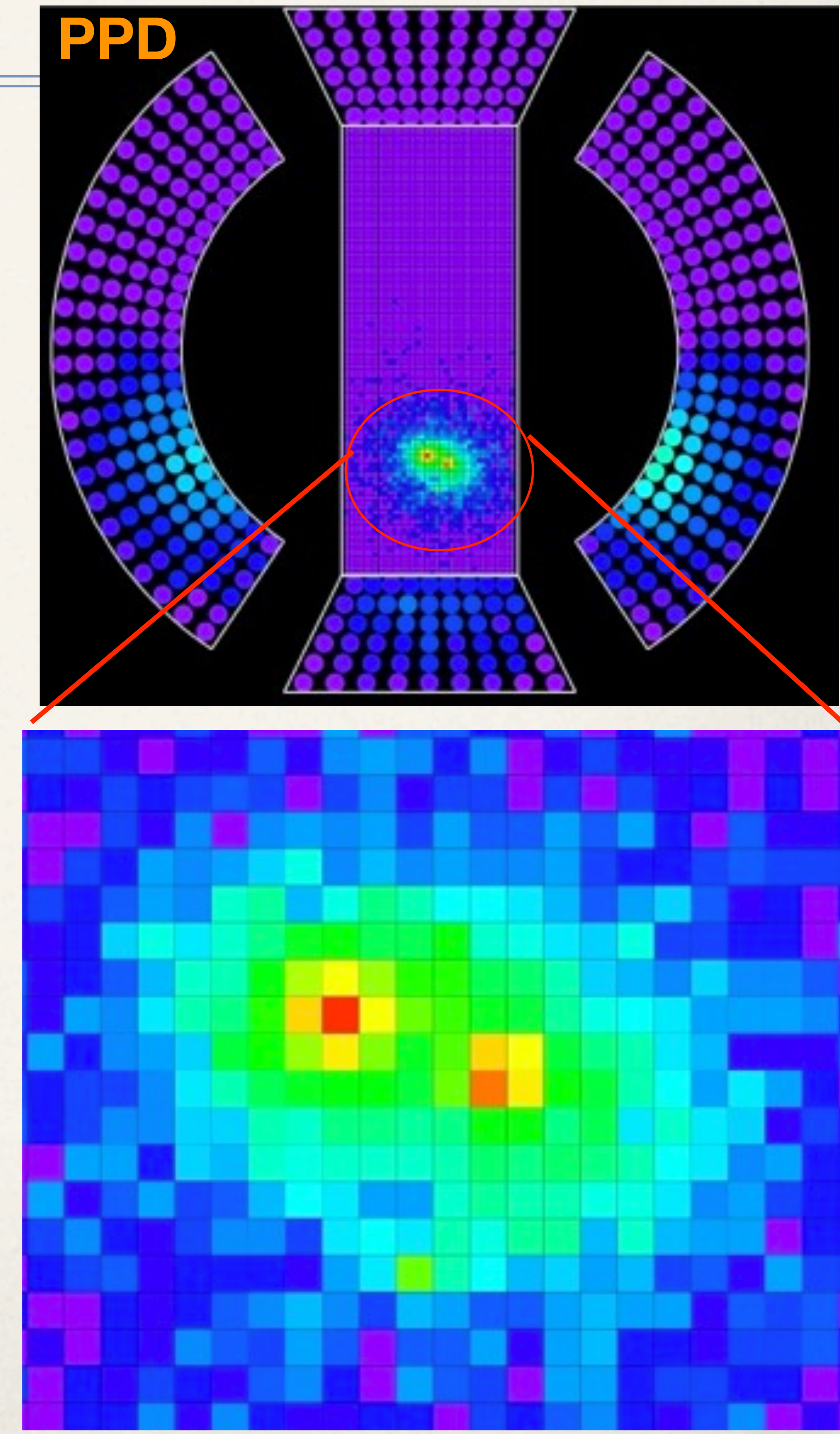


# Possible Upgrade of LXe Detector

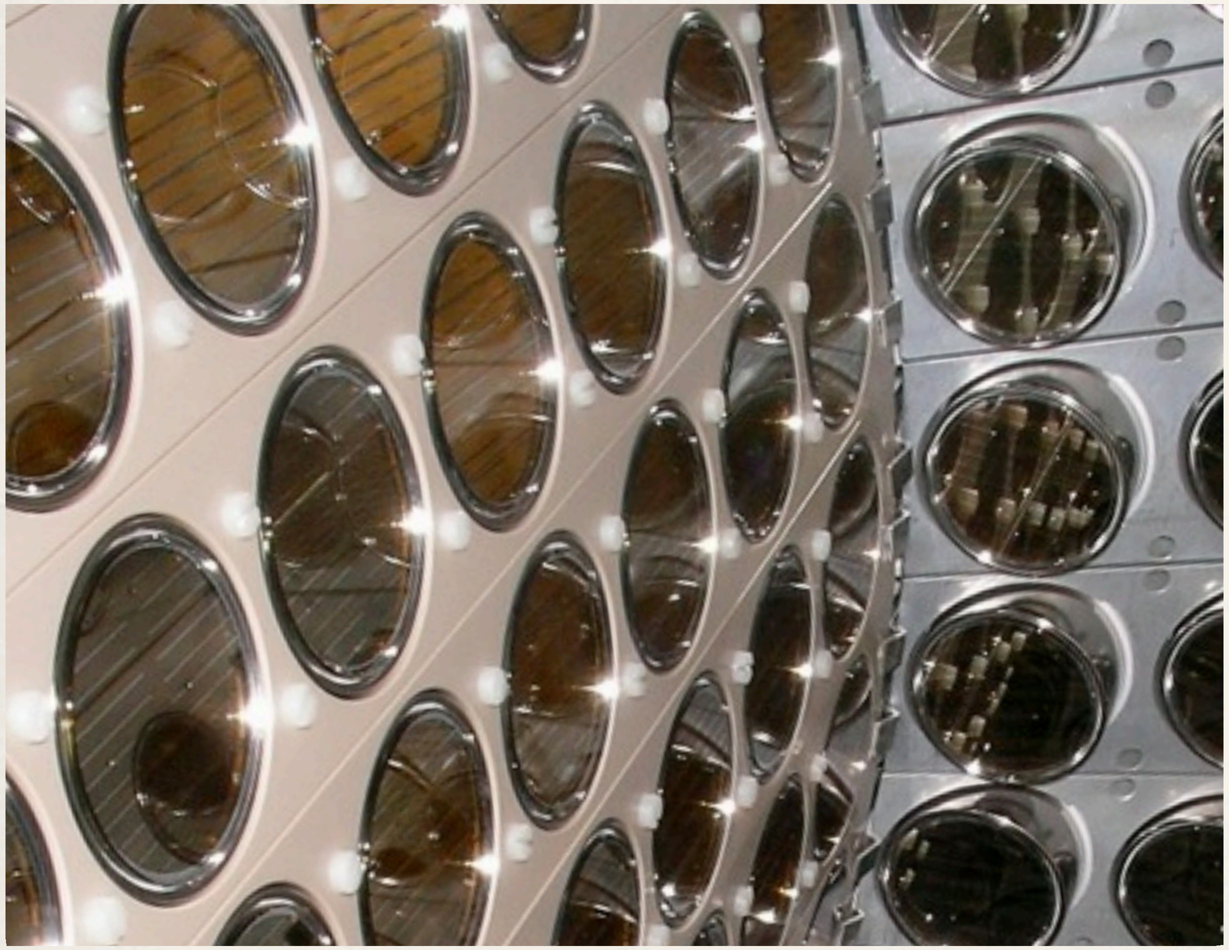
- Better imaging with smaller photo sensors
  - Replace PMTs (2″ϕ) with **small photo-sensors (~10×10mm²)** on γ entrance face
  - **Position/energy resolutions could greatly improve (factor two for shallow events).**
  - **Detection efficiency could improve by 9%.**
- **PPD is a good candidate.**



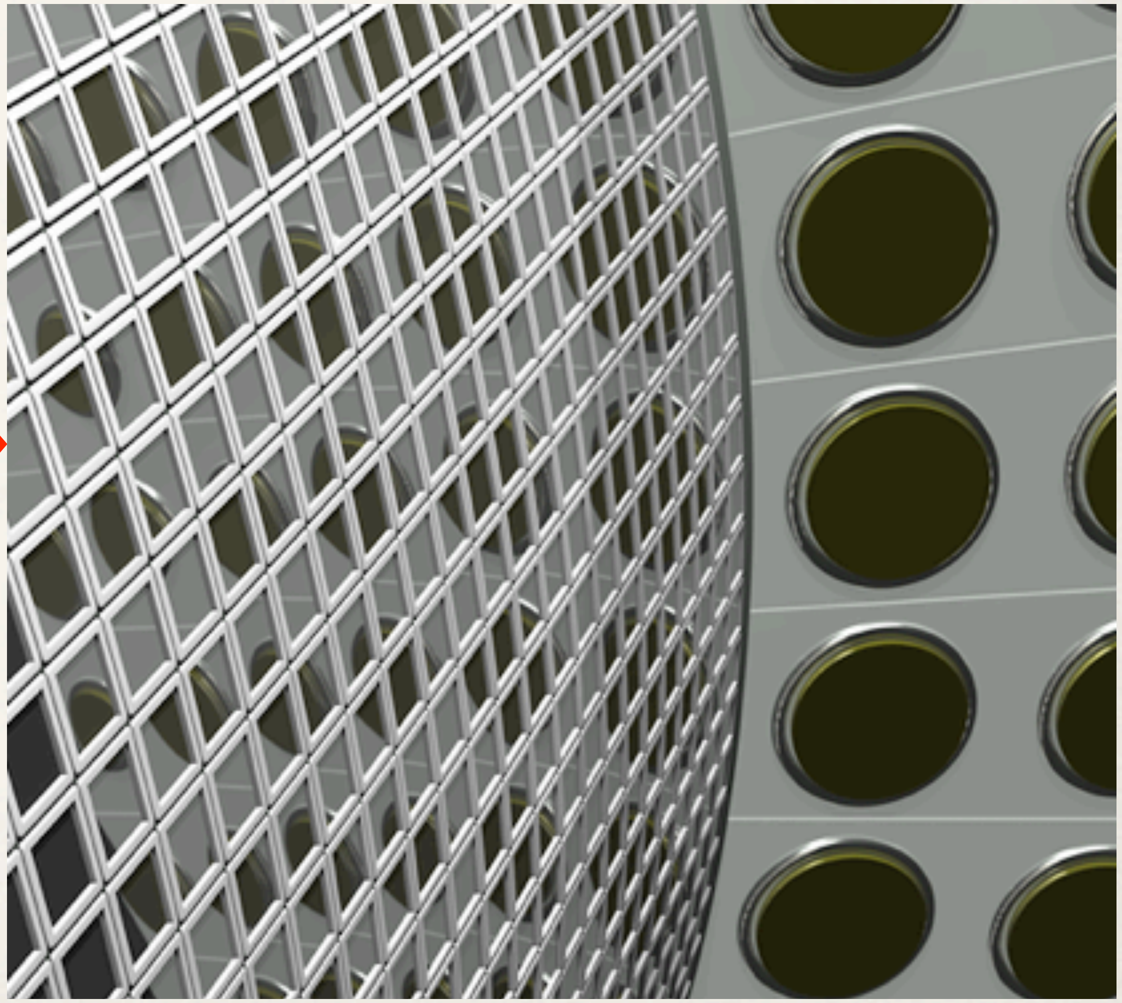



# How It Would Look Like

216 PMTs on γ entrance face



~4000 PPDs on γ entrance face



# Possible Advantages of PPD for MEG LXe Detector

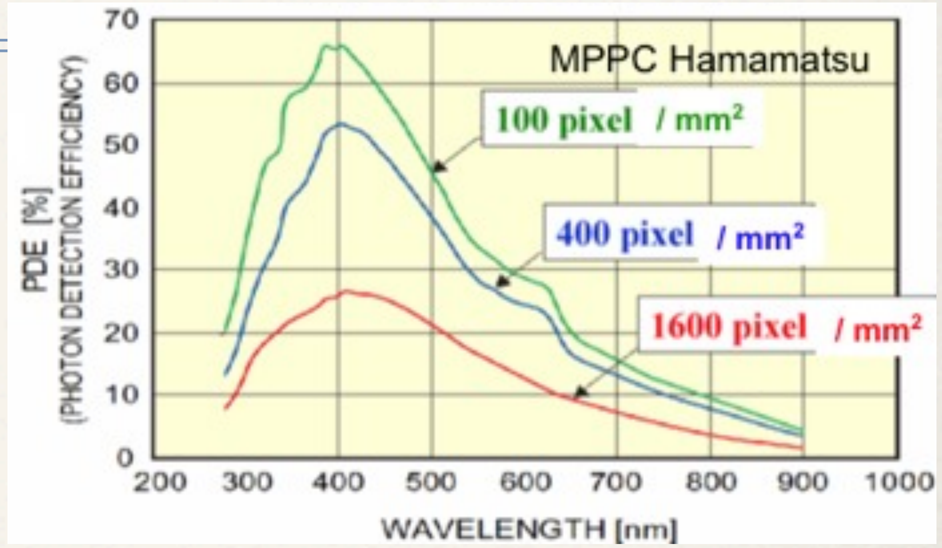
- Scintillation readout with finer granularity and higher uniformity .
- Reduction of material in $\gamma$ entrance face. (PPD is much thinner than PMT.)
- Best performance at low temperature (LXe 165K)
- Operational in magnetic field
- Easier calibration using single photoelectron signals
- Low bias voltage (~1000V for PMT ↔ <100V for MPPC)
- Low power consumption (crucial for operation at low temperature)

# Possible Issues

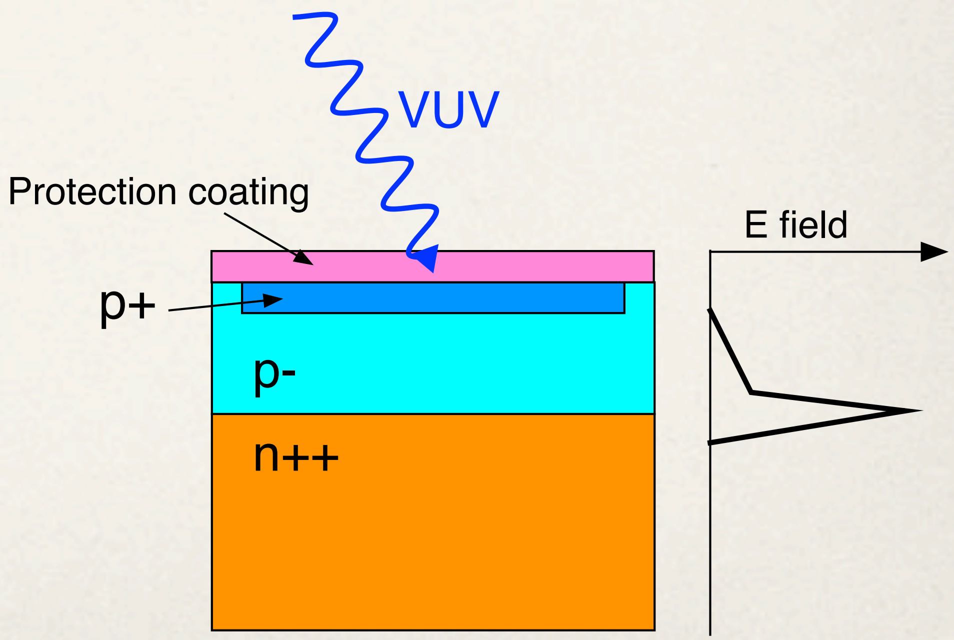
- Photon detection efficiency (PDE) for VUV light
- Dark count
- Optical crosstalk
- After-pulsing
- Sensor size
- Dynamic range
- Reflection on sensor surface
- Radiation hardness

# PDE for VUV

- PDE for VUV is nearly zero for commercial device.
- Low transmission for VUV to sensitive layer due to
  - Protection coating (epoxy resin/silicon rubber)
  - Insensitive layer (p+ contact layer with ~zero field)
    - Absorption length in Si for VUV photon: ~5nm
  - High reflectivity for VUV on Si surface

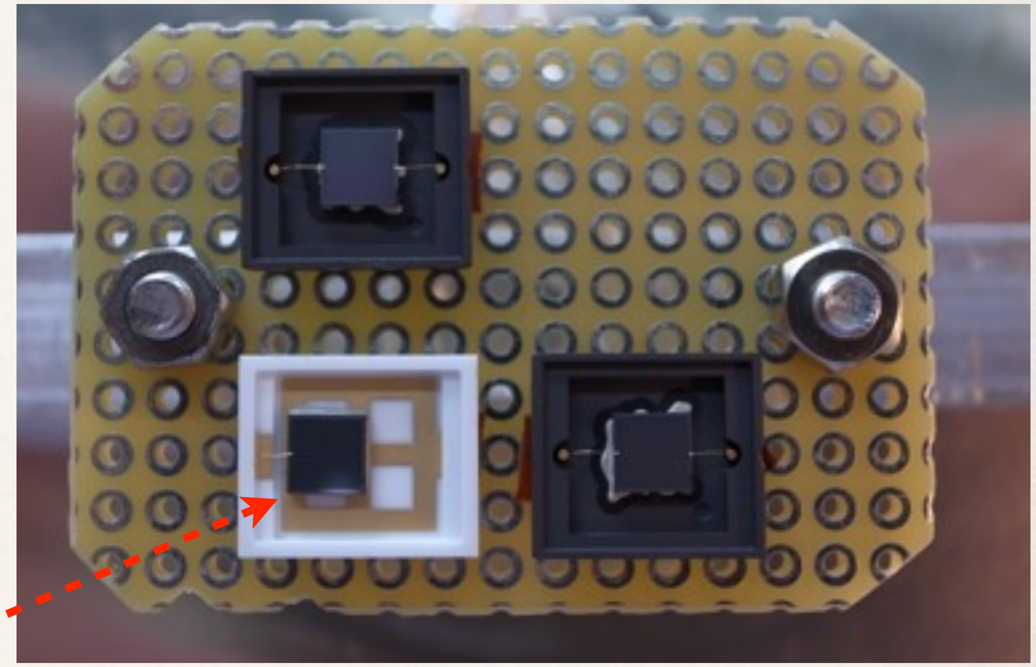



- Possible solution
  - Remove protection coating
  - Thinner p+ contact layer
  - Optimize reflection/refractive index on sensor surface



# Development of UV-Enhanced MPPC

- UV-enhanced MPPC is under develpment in collaboration with Hamamatsu.
  - Remove protection coating
  - Optimize MPPC parameters
    - Thinner $p^+$ contact layer
    - Anti-reflection coating
    - Refractive index of surface material
    - Quench resistor
    - Pixel size
    - ...
  - Currently sensor size: **3×3mm²**



# Prototypes of UV-enhanced MPPC

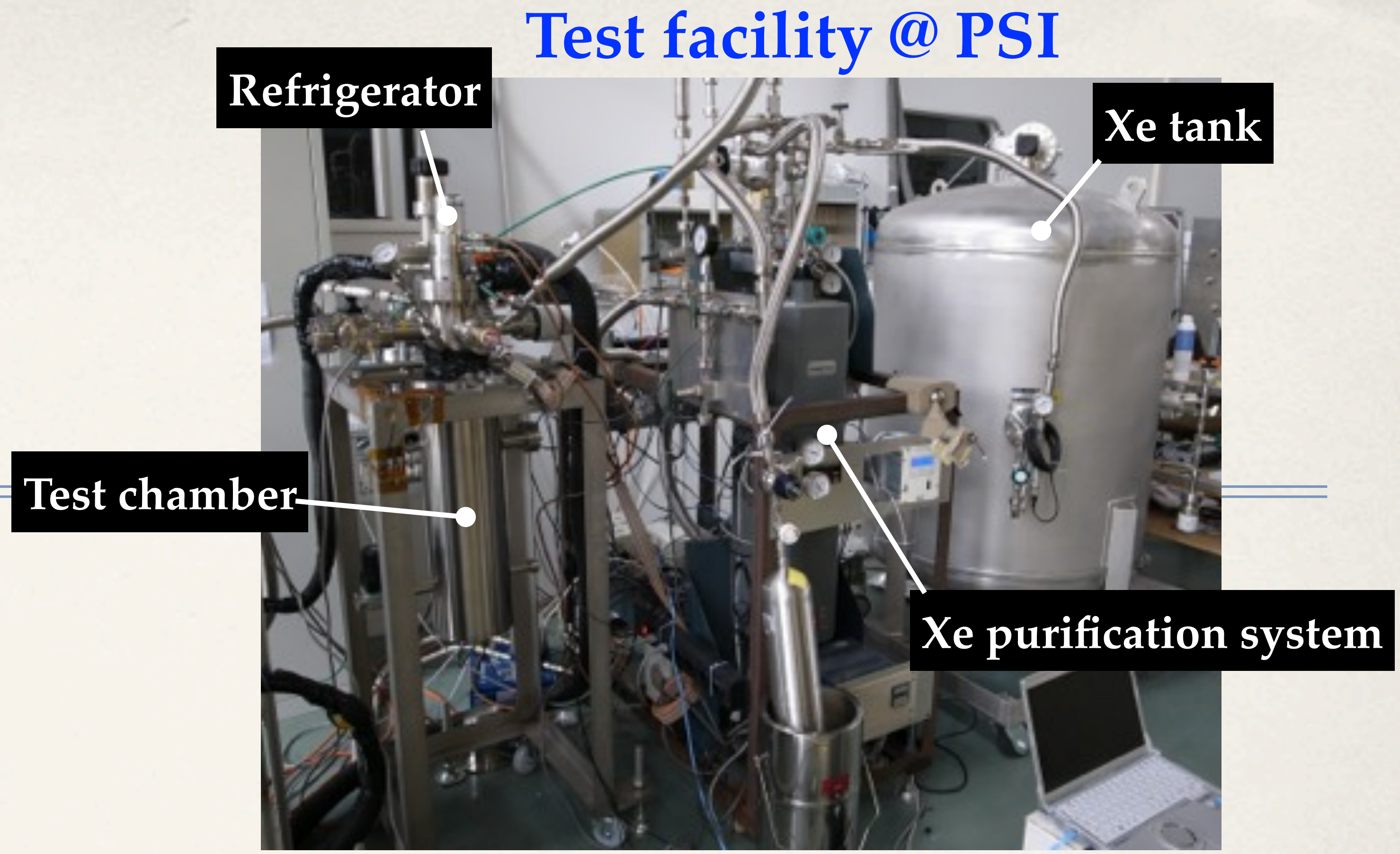
- Prototypes of UV-enhanced MPPC of various types are being tested.
- Sensor size: 3×3mm$^2$, pixel pitch: 50μm

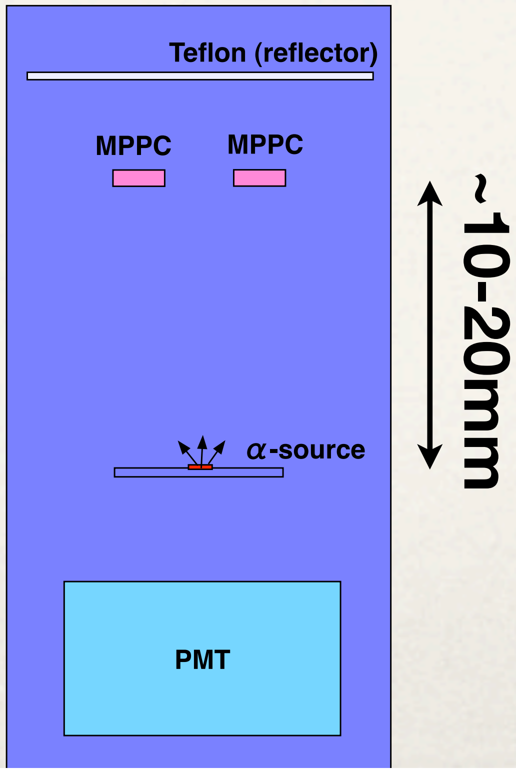
| Type | p+ contact layer | Reflection / refractive index |
|---|---|---|
| A | thinner | Anti-reflection |
| B | thinner | Anti-reflection |
| C | thinner | Anti-reflection |
| D | thinner | Anti-reflection |
| E | thinner | Anti-reflection |
| F | thinner | Anti-reflection |
| G | normal | Refractive index |
| H | normal | Refractive index |

Sorry, but we can't show details of the parameters. (we don't know either!)

# Test Setup

- Test facility at Paul Scherrer Institute (PSI).
  - 2ℓ-LXe in small cryostat
  - $\alpha$ source for absolute PDE measurement ($\alpha$ = point-like light source)
  - UV-sensitive PMT for triggering on alpha
  - LED for calibration
  - Mounted inside cylinder with VUV-“black” coating to suppress reflection
- Average number of photons from alpha event on 3×3mm$^2$ active area of MPPC ~200-900

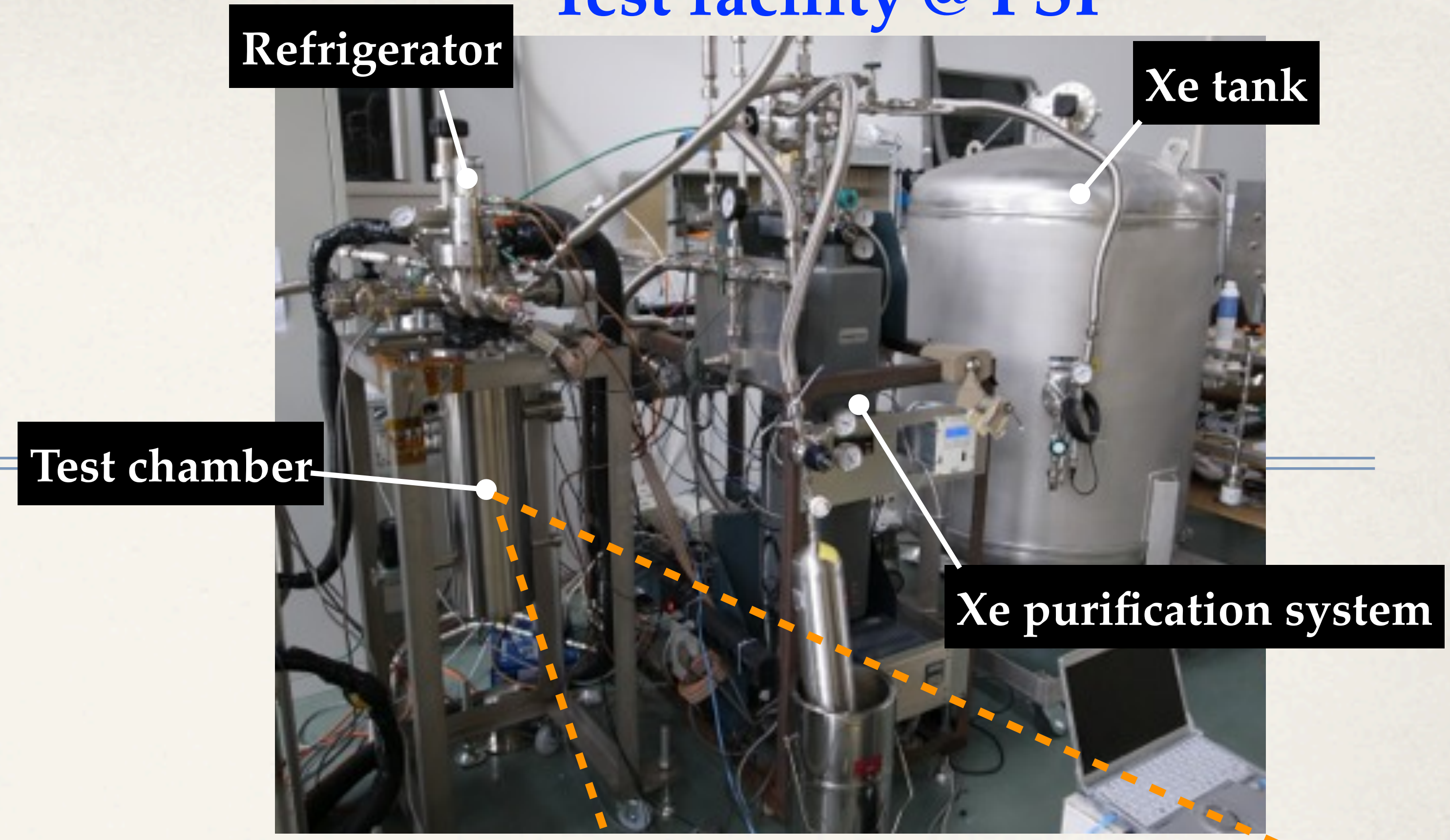


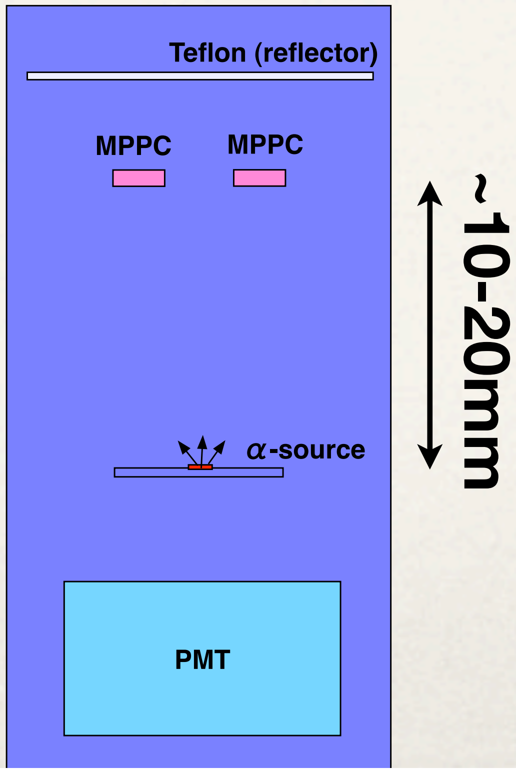



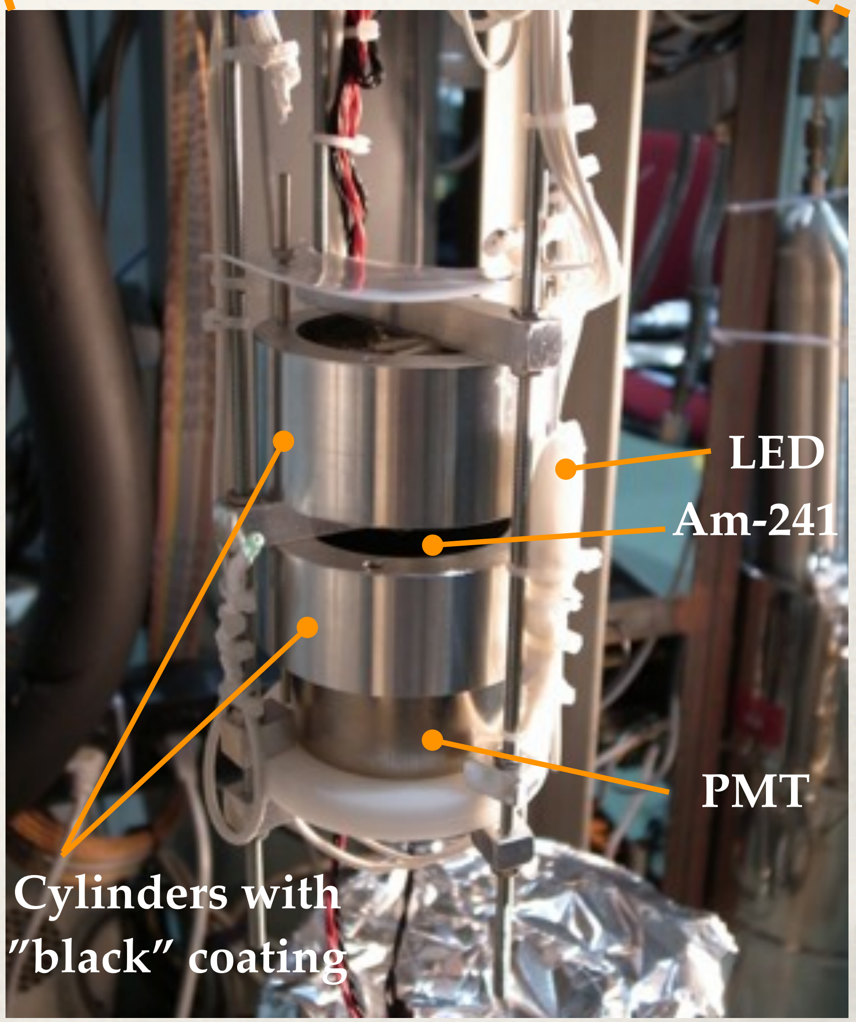
# Test Setup

- Test facility at Paul Scherrer Institute (PSI).
  - 2ℓ-LXe in small cryostat
  - $\alpha$ source for absolute PDE measurement ($\alpha$ = point-like light source)
  - UV-sensitive PMT for triggering on alpha
  - LED for calibration
  - Mounted inside cylinder with VUV-"black" coating to suppress reflection
- Average number of photons from alpha event on 3×3mm$^2$ active area of MPPC ~200-900

**Test facility @ PSI**



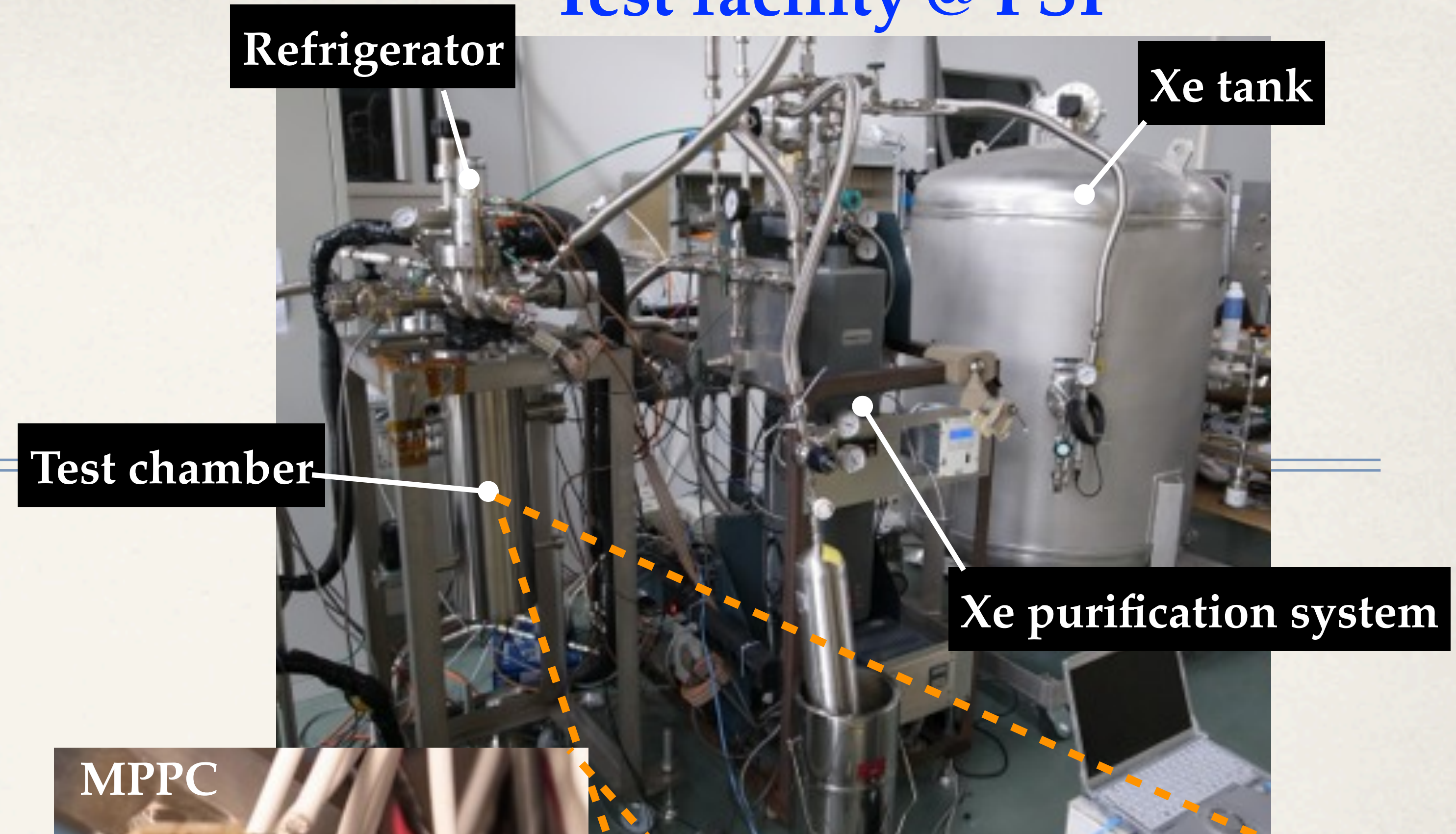



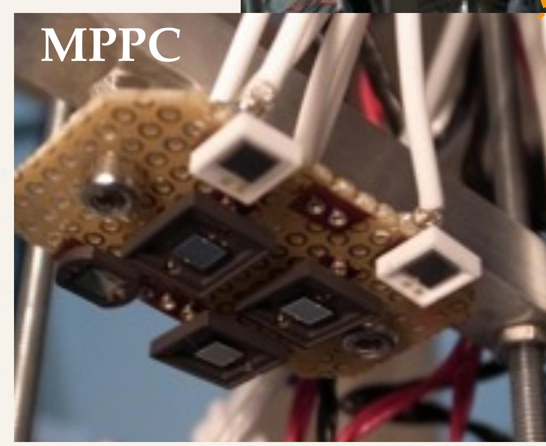



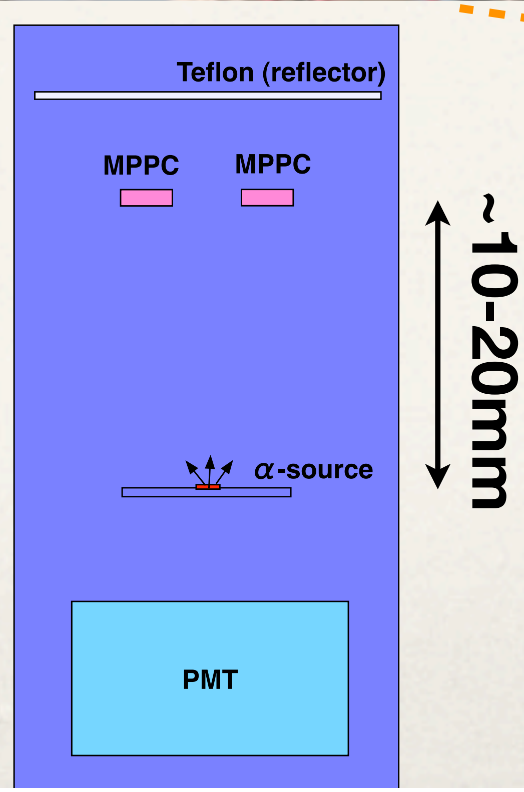
# Test Setup

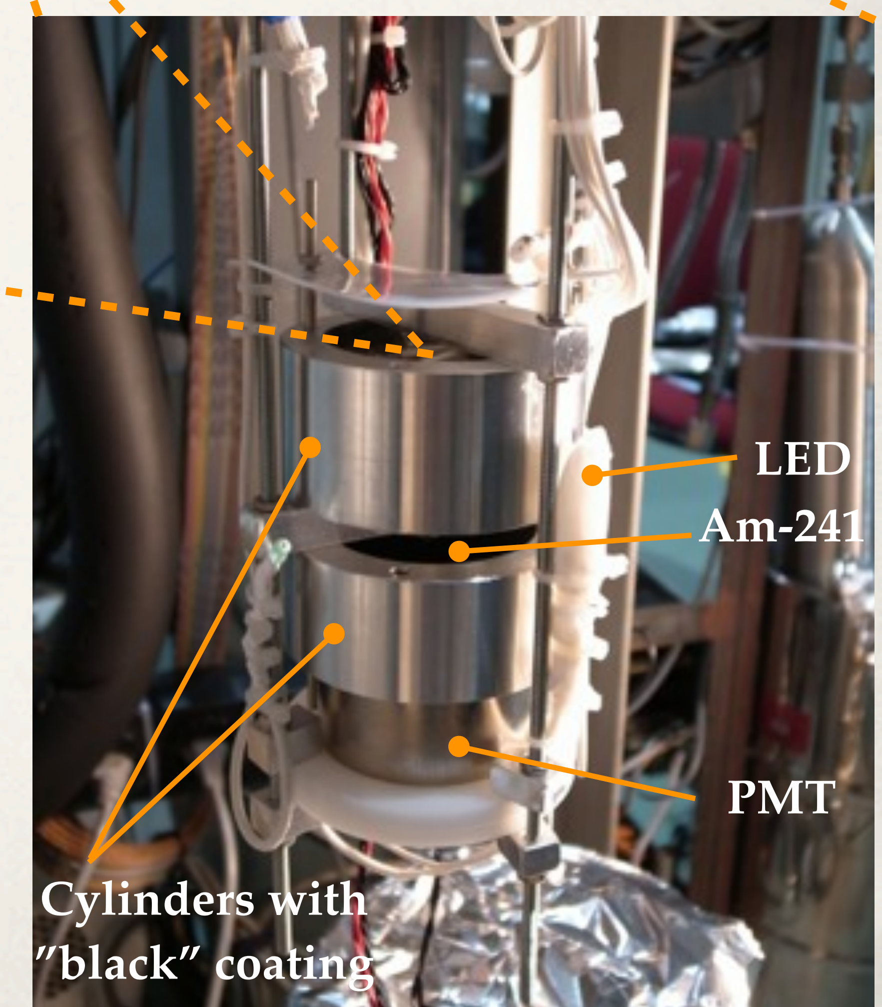
- Test facility at Paul Scherrer Institute (PSI).
  - 2ℓ-LXe in small cryostat
  - $\alpha$ source for absolute PDE measurement ($\alpha$ = point-like light source)
  - UV-sensitive PMT for triggering on alpha
  - LED for calibration
  - Mounted inside cylinder with VUV-"black" coating to suppress reflection
- Average number of photons from alpha event on 3×3mm$^2$ active area of MPPC ~200-900

Test facility @ PSI



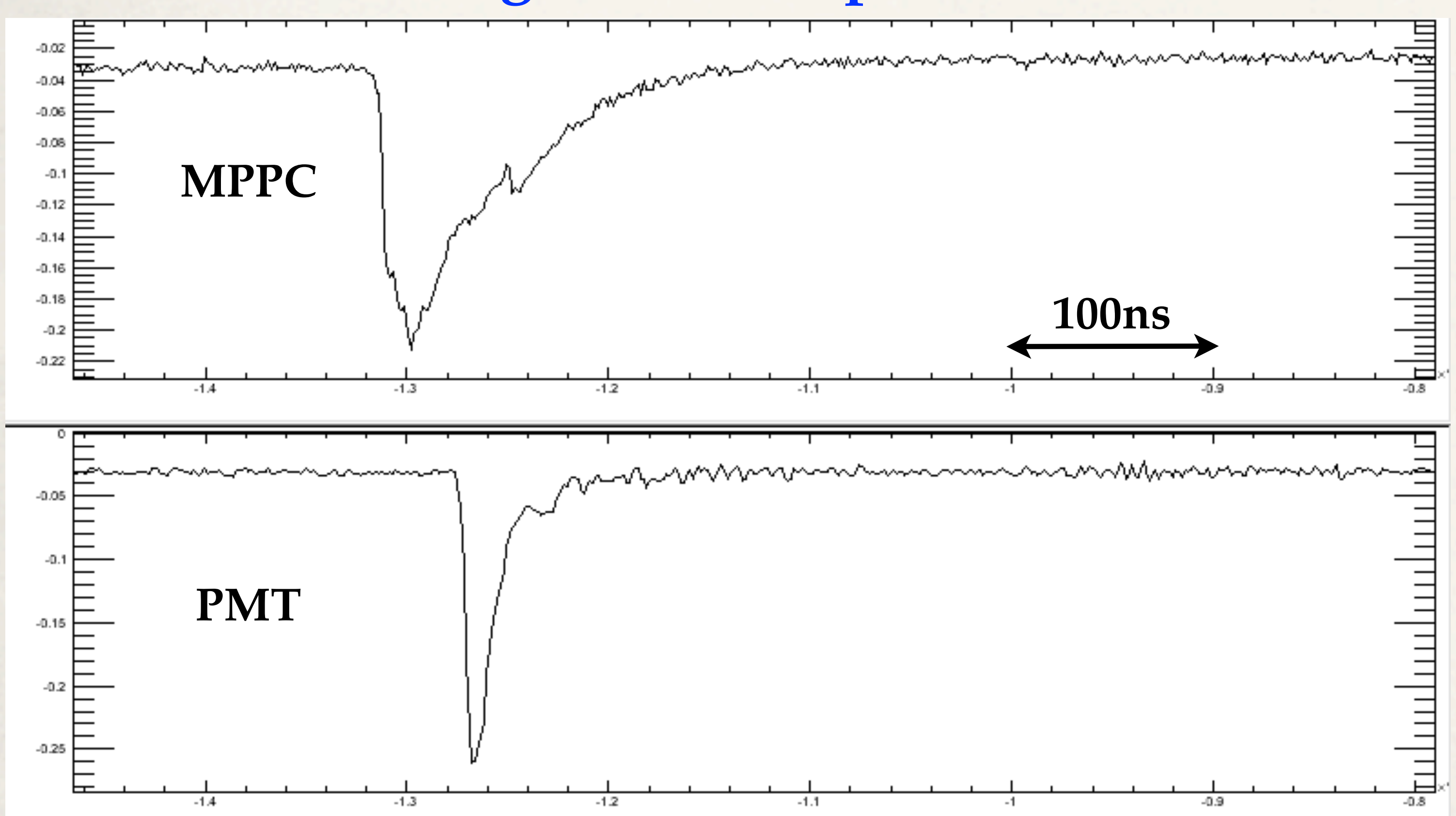



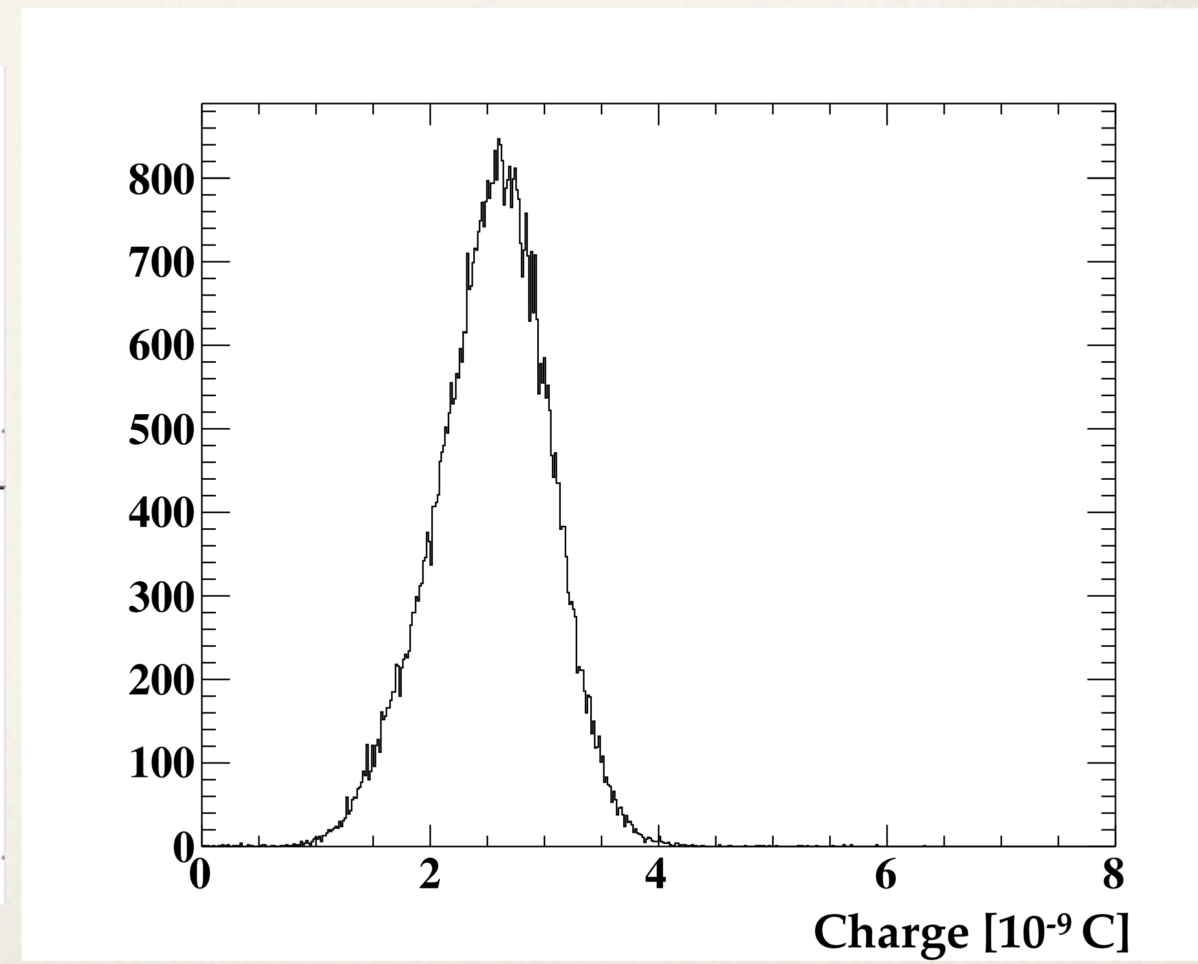
# MPPC Signal from LXe Scintillation

- We succeeded to detect LXe scintillation from alpha event with prototypes of UV-enhanced MPPC.

MPPC Signal from alpha event

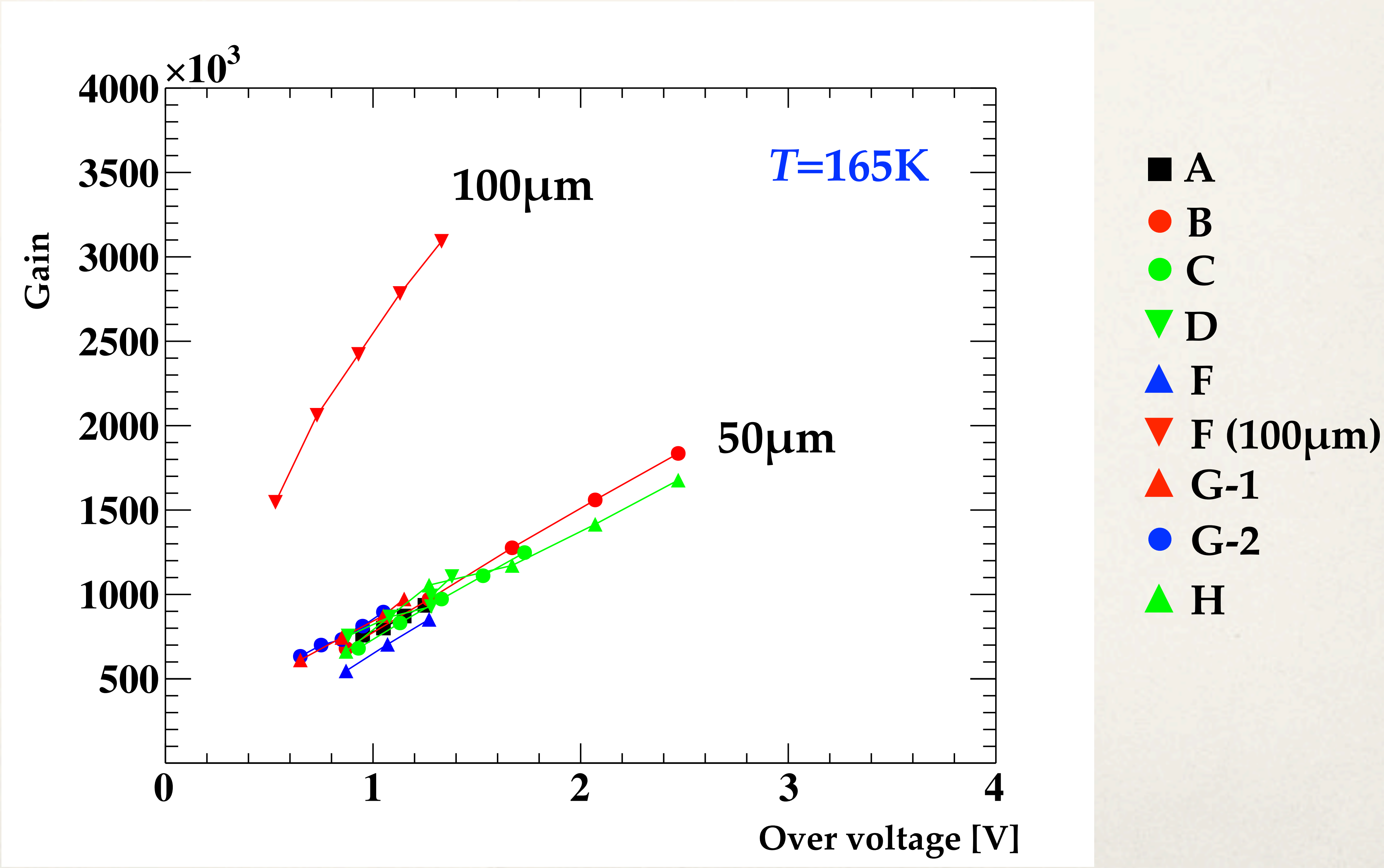



Charge spectrum for alpha events



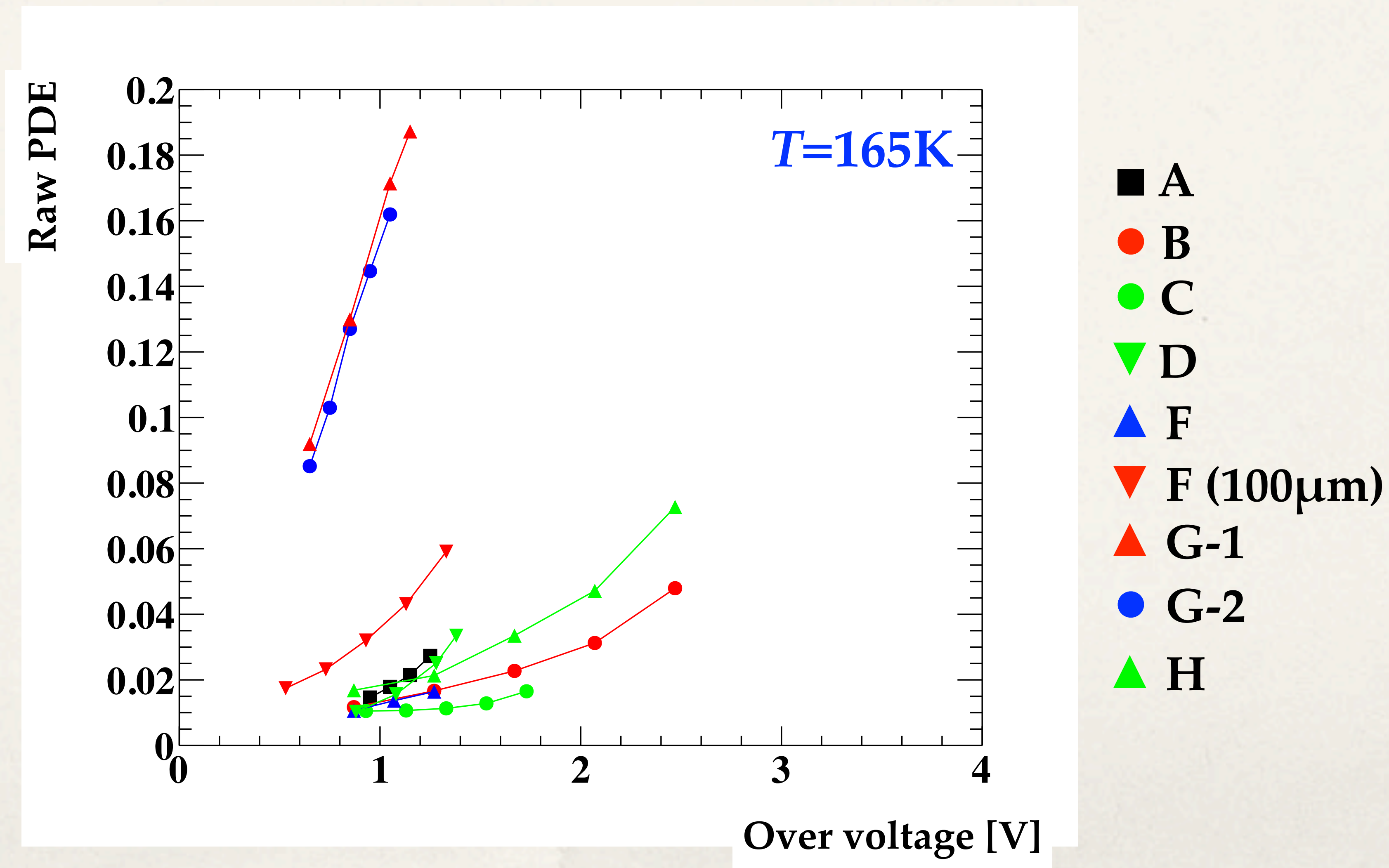
# Gain

- All samples with 50μm pixel pitch show similar gain ~$10^6$ .



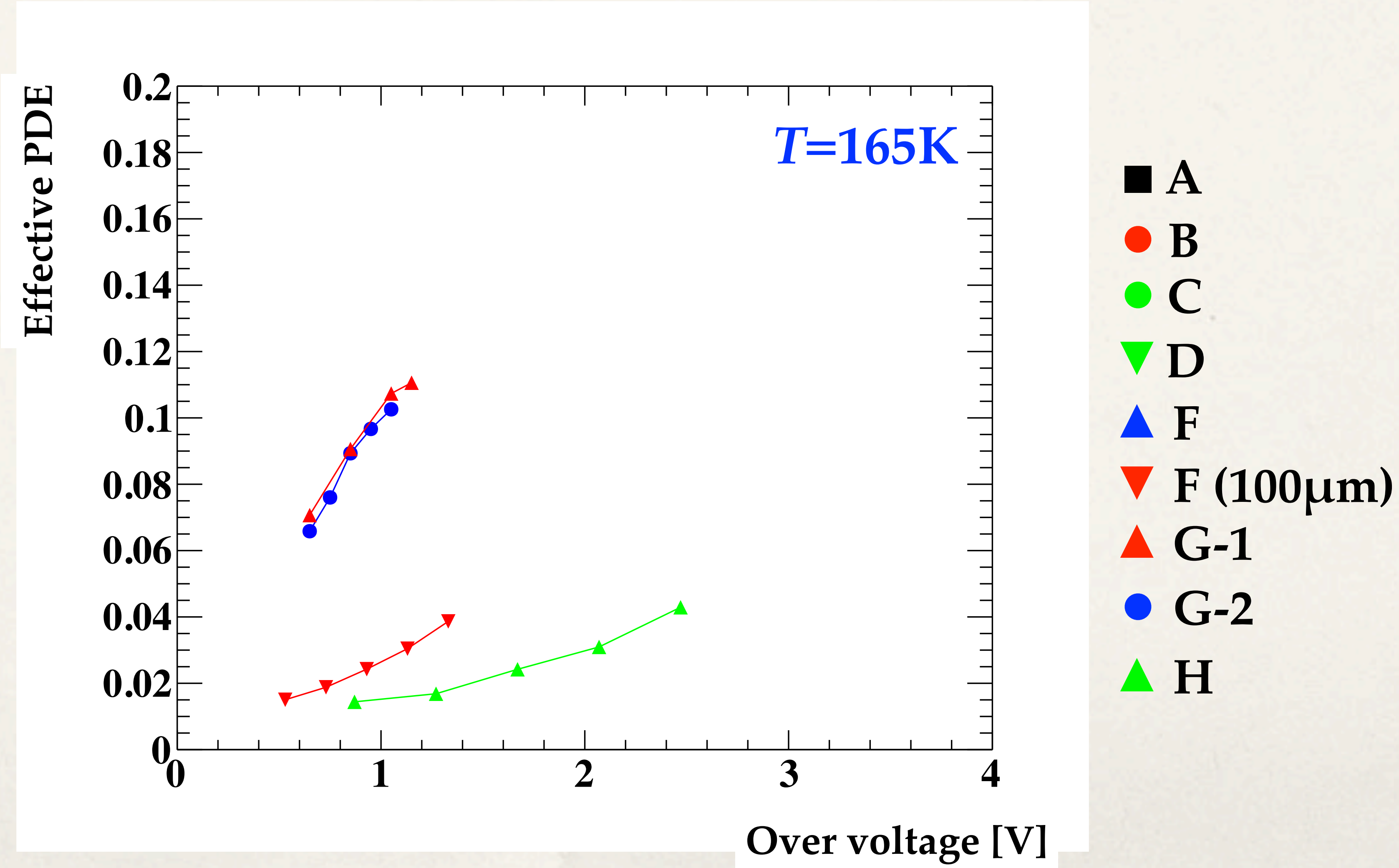
# PDE

- Estimation of absolute PDE
  - **PDE = (Observed # of p.e.) / (expected # of photons)** for alpha event
- PDE includes effects of optical crosstalk and afterpulsing.



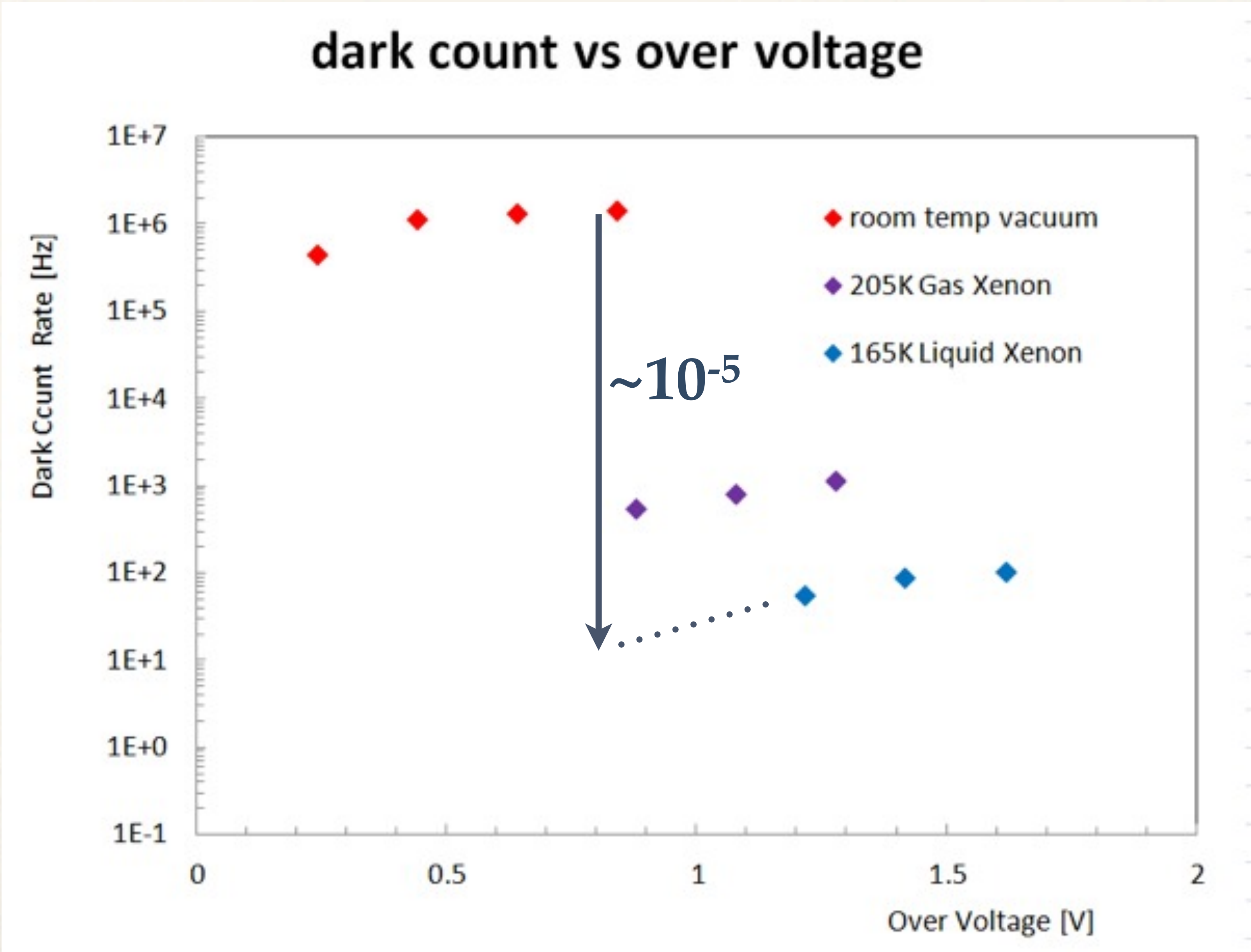
# PDE

- Effective PDE after subtracting effect of optical crosstalk (5-20% prob.) and afterpulsing (10-30% prob.)
- **Effective PDE ~10%** achieved for best samples (type G)
- Small contribution from NIR component of LXe scintillation (~1% level) included.



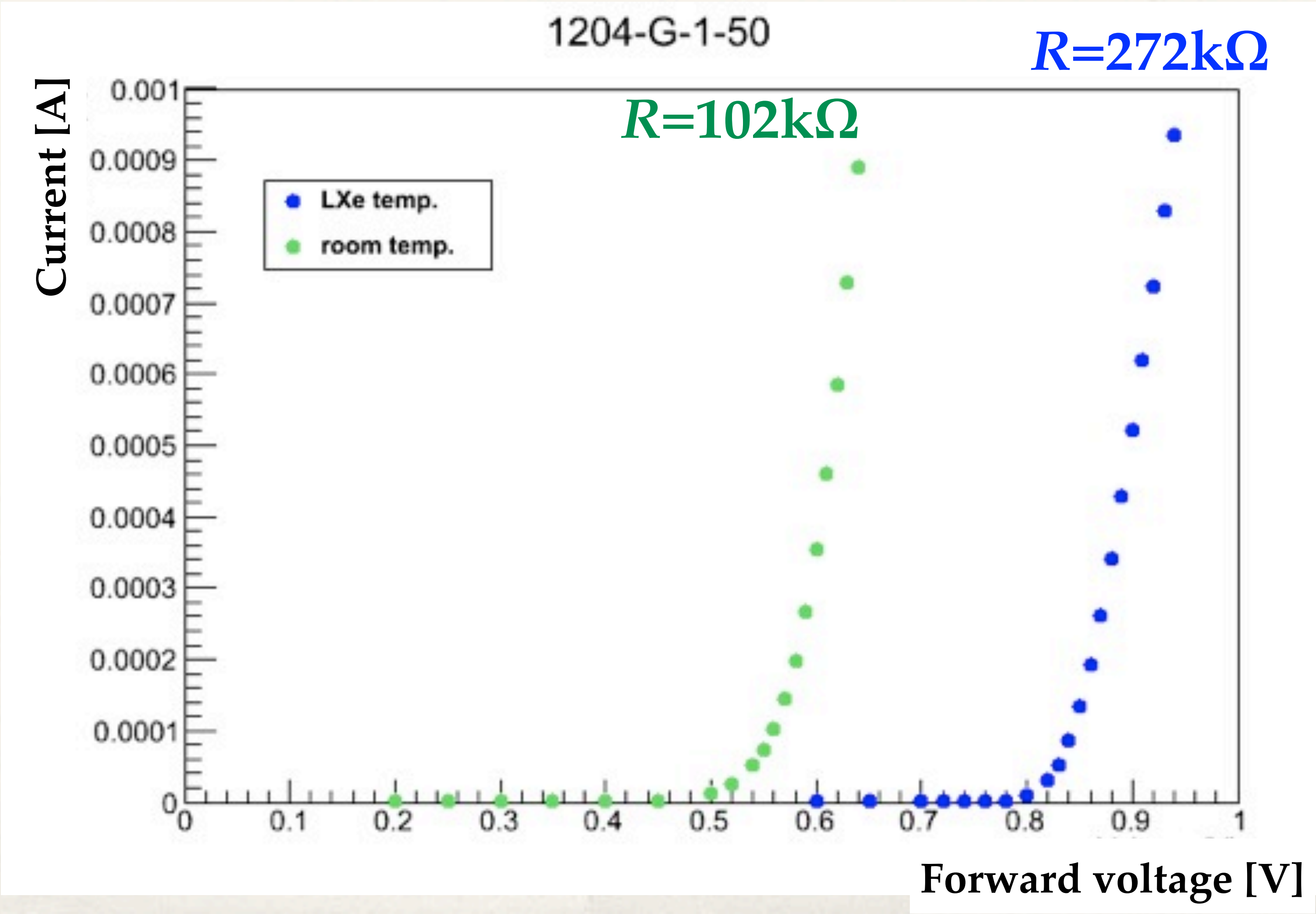
# Dark Count

- Dark count is highly suppressed at LXe temperature (165K) as expected (~$10^{-5}$).



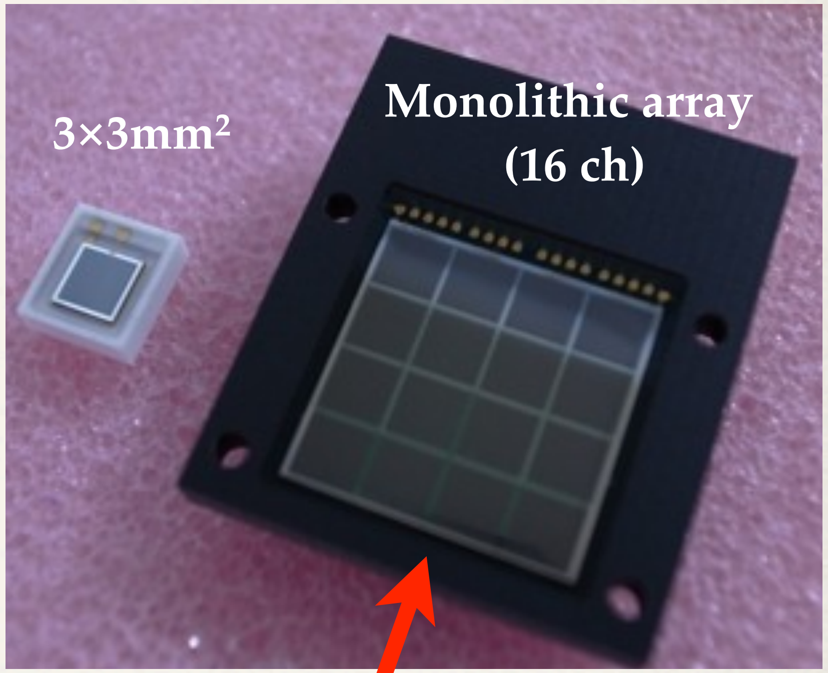
# Quench Resistor

- Resistance of quench resistor is measured by applying forward voltage.
- Quench resistor (poly silicon) shows ×2-3 higher resistivity at LXe temperature (165K).

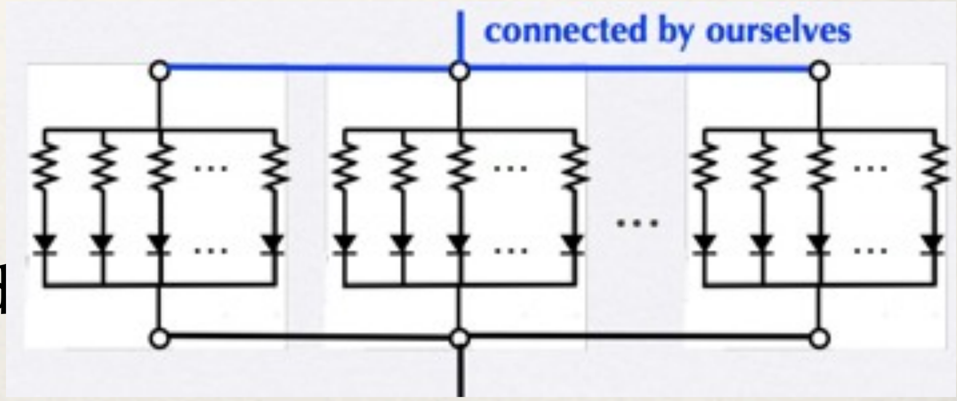


# Sensor Size

- Current largest MPPC (3×3mm²) is still too small for MEG LXe detector.
- **Need at least ~10×10mm²** to be a replacement of PMT.
- Possible issues for larger area sensor
  - Dark count rate (→ irrelevant at LXe temperature?)
  - Gain uniformity (→ single p.e. peak resolved?)
  - Large capacitance (→ long tail in waveform?, noise?)
- We tested properties of larger sensor by **connecting 3×3 or 4×4 cells in commercial monolithic array in parallel.**
  - **Effective area: 9×9mm²** for 3×3 cells connected
  - **Effective area: 12×12mm²** for 4×4 cells connected

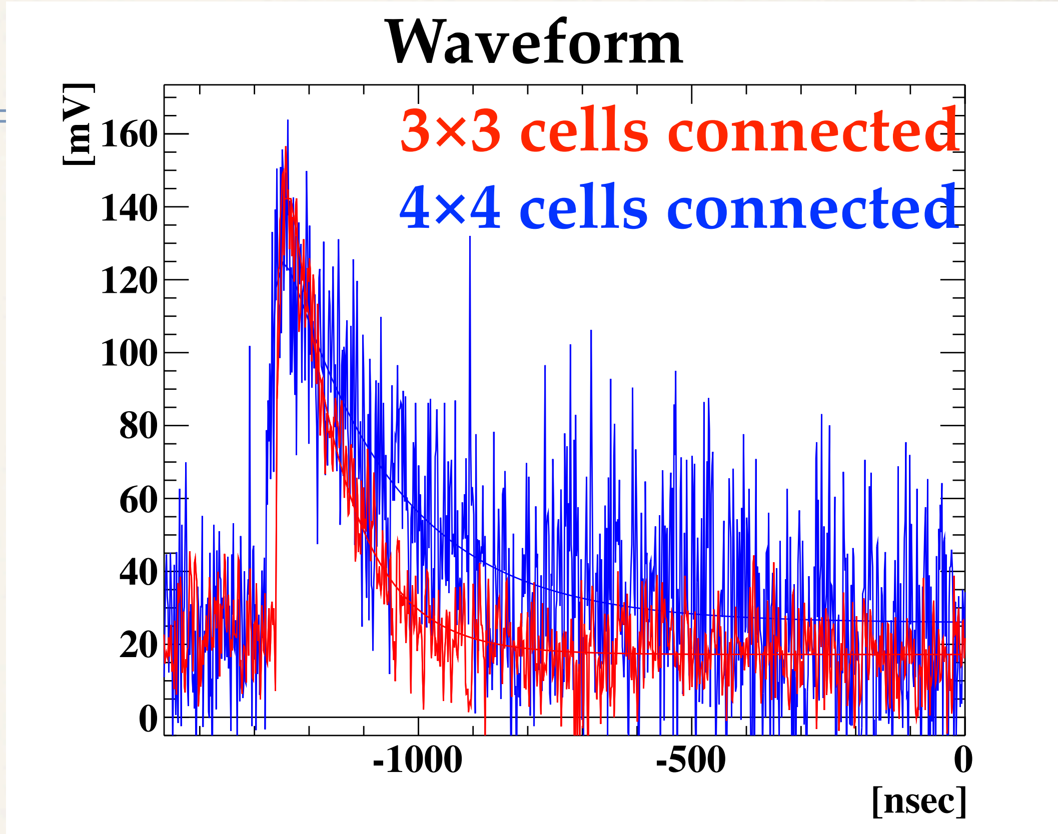


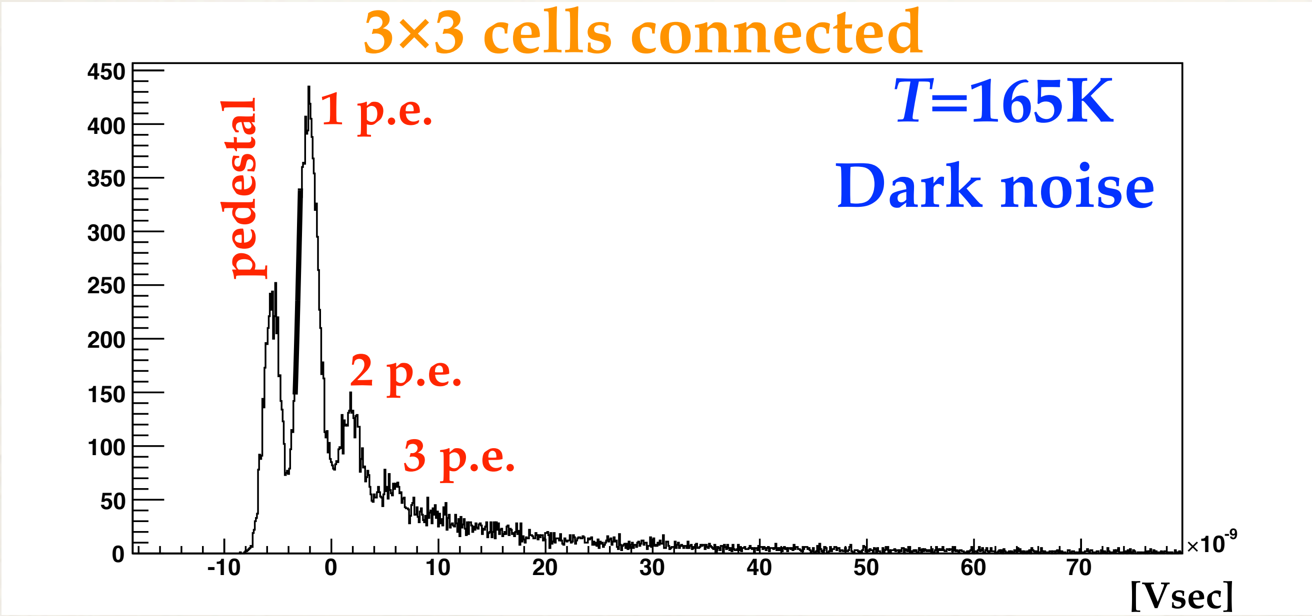

We need this size for single sensor!

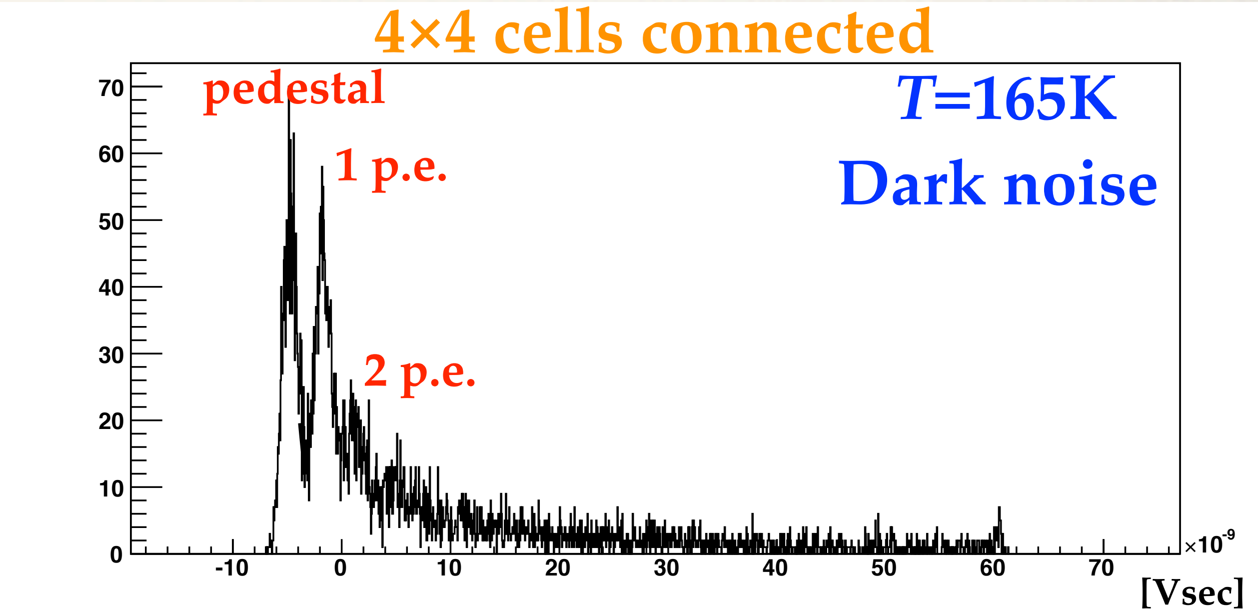


# Sensor Size

- **Single p.e. peak resolved!**
- Dark rate of 720Hz for 4×4 connection at LXe temp. → still low enough
- But there are some issues related to large sensor capacitance
  - Waveform with longer fall-time
  - Higher noise



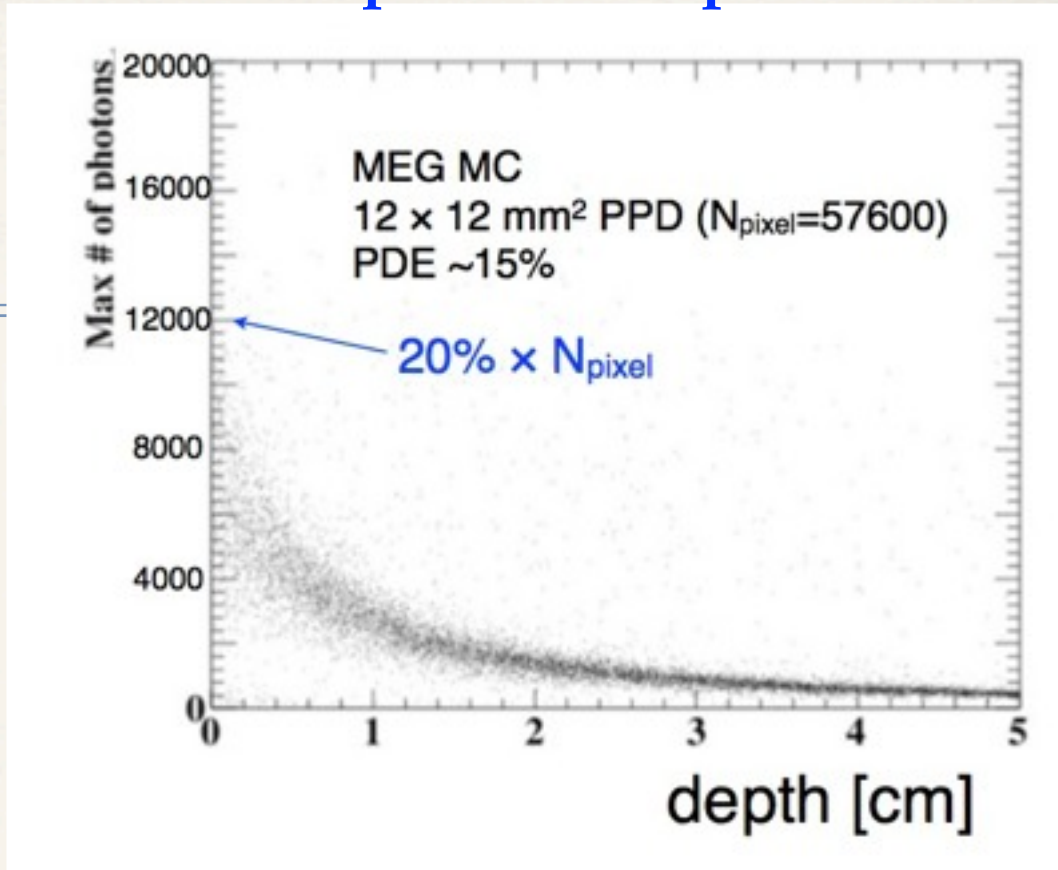



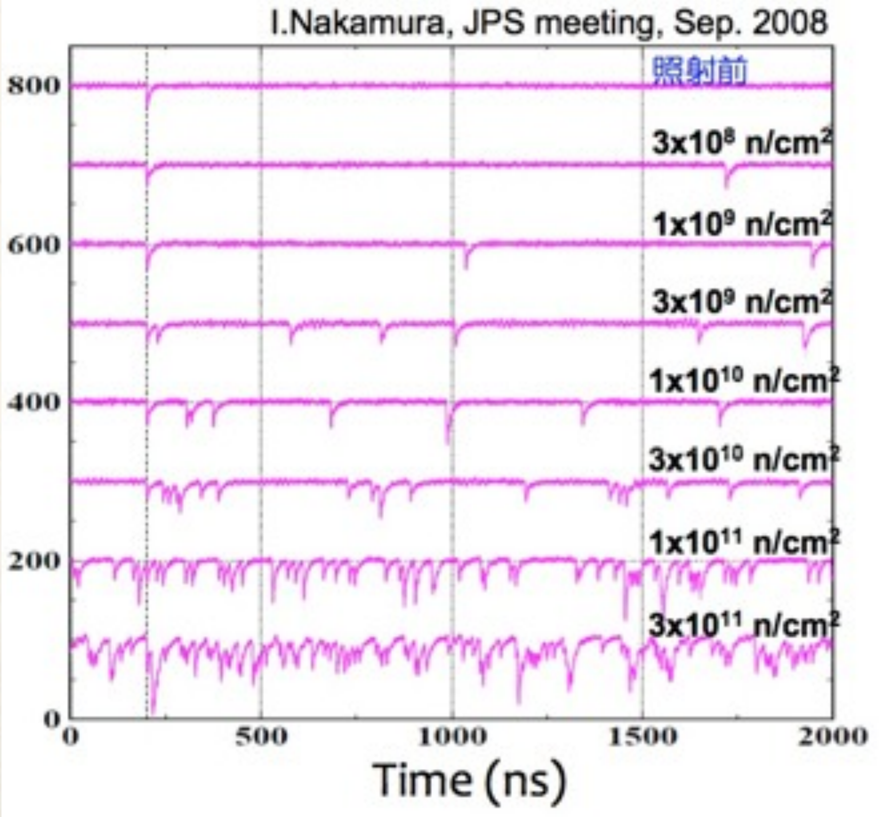
# Other Issues

- **Dynamic range**
  - # of p.e. expected in MEG LXe detector
    - 12000p.e on 12×12mm$^2$ sensor area (20% of $N_{pixel}$)
    - N.B.: time constant of scintillation emission of 45ns is comparable to cell recovery time.
  - → **OK**. Non-linearity can anyway be corrected by a careful calibration.
- **Radiation damage**
  - Irradiation foreseen at upgrade MEG
    - **Neutron: <1.6×10$^8$ *n*/cm$^2$** for 5-years operation
    - **γ: 0.6 Gy** for 5-years operation
  - → **OK.**

**Expected # of p.e.**




**Effect of neutron irradiation**



# Summary and Outlook

- MPPC sensitive to LXe scintillation photons is under development in collaboration with Hamamatsu for possible upgrade of MEG LXe $\gamma$-detector.
- Prototypes of UV-enhanced MPPC show promising performance (PDE of ~10% for best sample) although there are still some issues to be addressed.
- Next steps
  - Further improvement of performance
    - Improvement of PDE
    - Optimization of MPPC parameters such as pixel pitch and quench resistor
  - Production of large area prototype (~12×12mm$^2$)
- We plan to build LXe detector prototype with 100ℓ-LXe and ~600 large area MPPCs by spring next year and to perform a beam test.
- We aim at the construction of the final detector with ~4000 MPPCs within next year.