# AHCAL Activities in Tokyo

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*CALICE AHCAL Main Meeting*

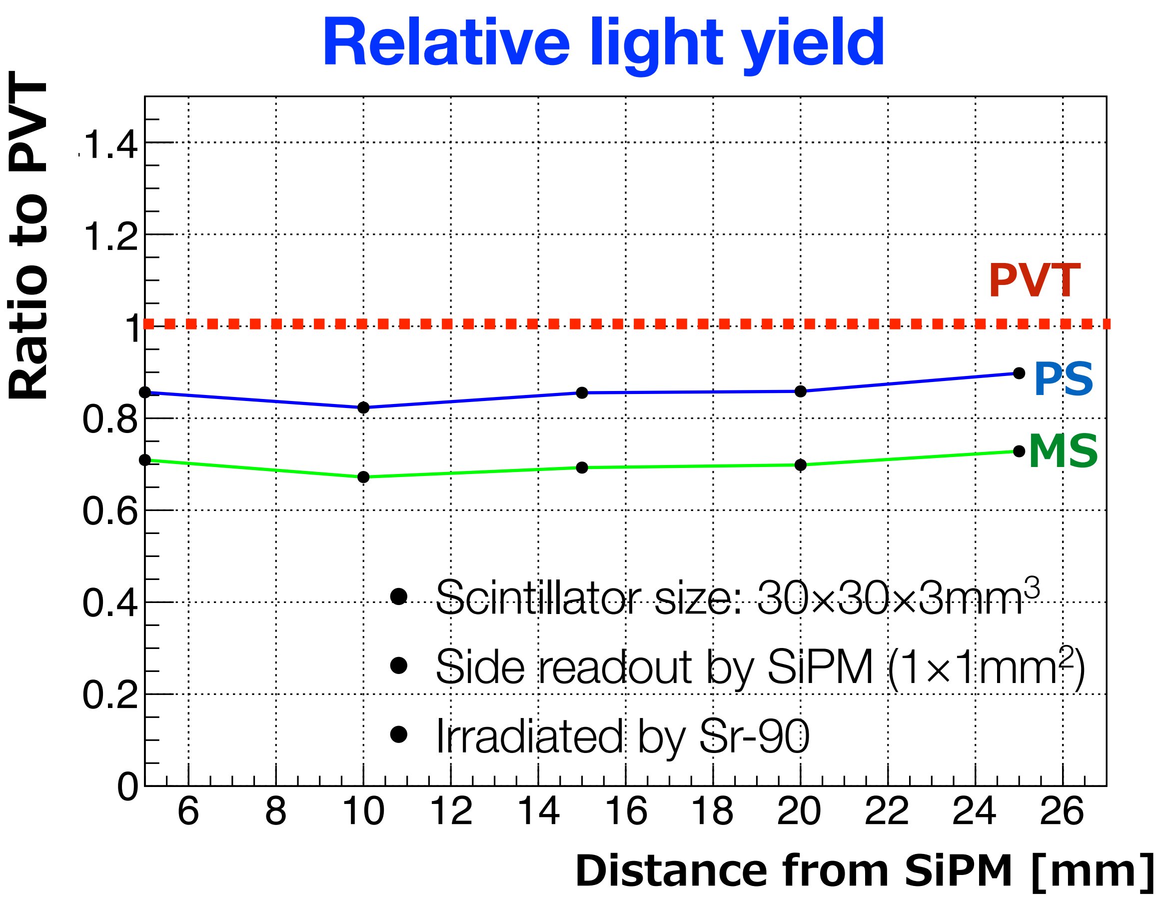
Dec. 10-11, 2015 DESY

# Current Activities @Tokyo

- Scintillator material study
- New readout scheme for AHCAL scintillator tile
- Radiation hardness test

# Scintillator Material Study: Reminder

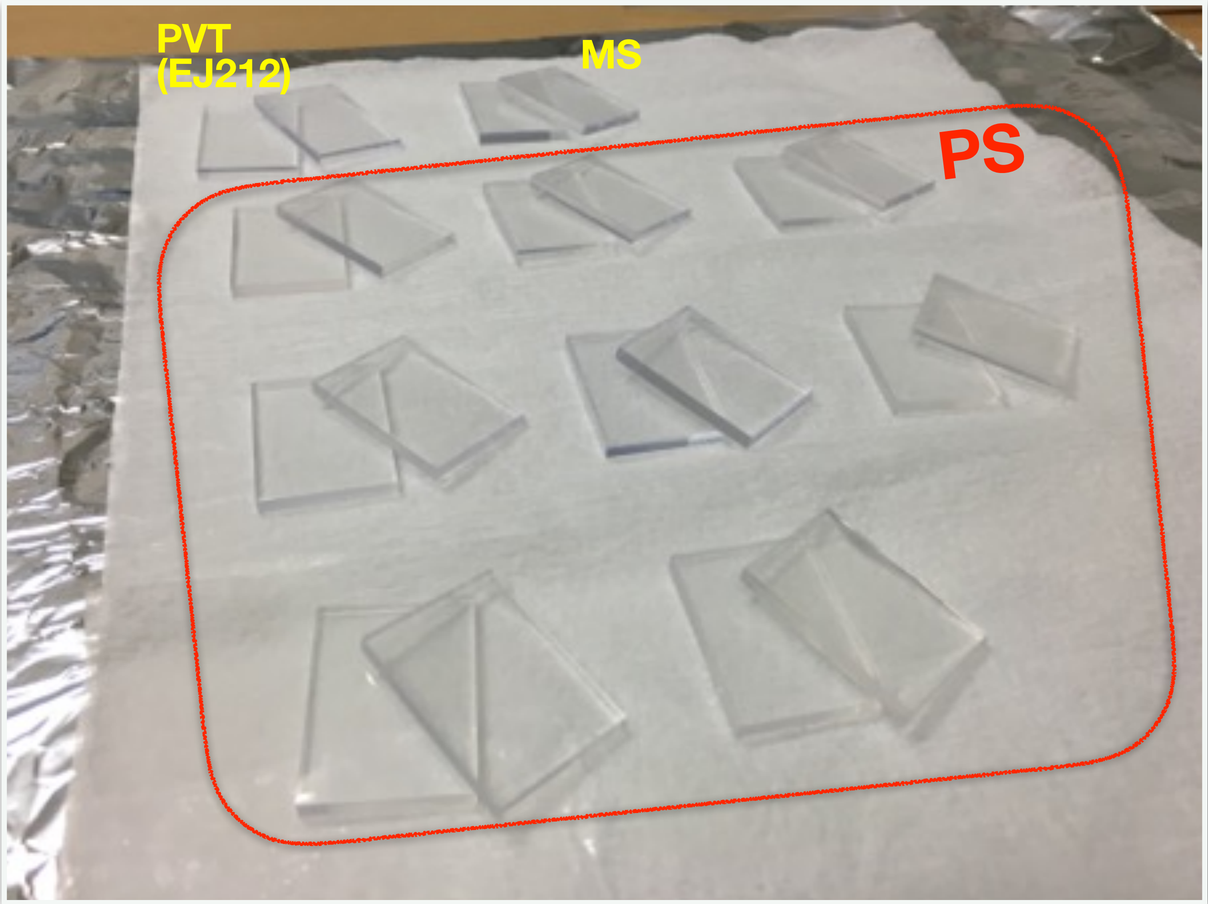
- Development of plastic scintillator material of better performance
- Base scintillator material candidates
  - Poly-vinyl toluene (PVT):
    - 😊 Higher light yield
    - 😥 Production (casting+machining) is cumbersome.
  - Polystyrene (PS), Estyrene-MS (MS)
    - 😐 Moderate light yield
    - 😊 Production (injection moulding) is easier.
- Light yield was measured with AHCAL tile configuration ($30\times30\times3mm^3$).




- PVT shows the highest light yield (as expected).
- The light yield of PS is reasonably high (80-90% of PVT).
  - PS can be a good candidate material.
- No visible difference in position dependence.
  - →No significant difference in both reflection and attenuation
- Further optimisation of scintillator materials is underway especially for PS/MS.

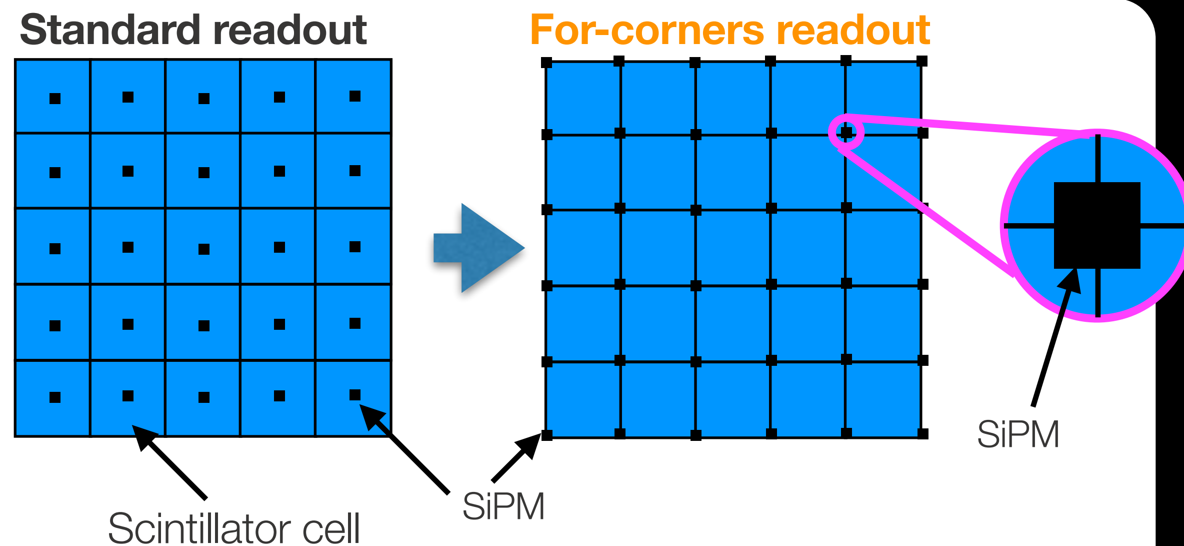
# Scintillator Material Study

- Starting with optimisation of polystyrene(PS)-base scintillator
  - Primary fluorescent:  **p-Terphenyl**
  - Secondary fluorescent: **POPOP**
- Test scintillator cells (30×22×3mm$^3$) are produced with injection molding for different combinations of fluorescent concentrations to find the best production parameters.
- Performance is being measured.

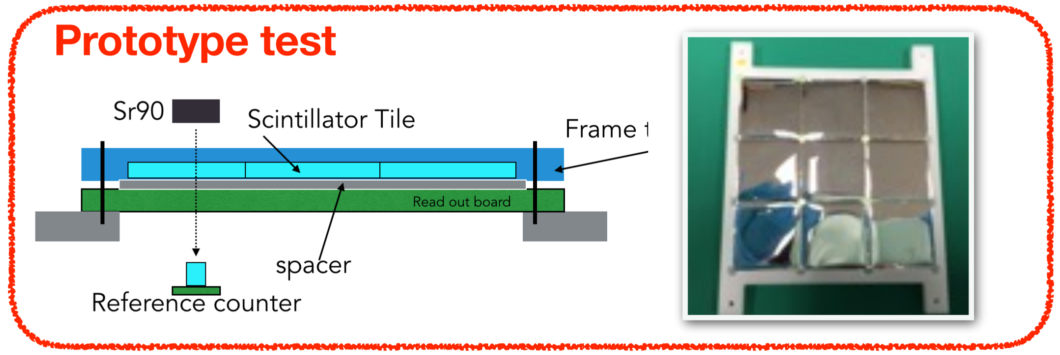


# New Scheme for AHCAL Tile Readout: Reminder

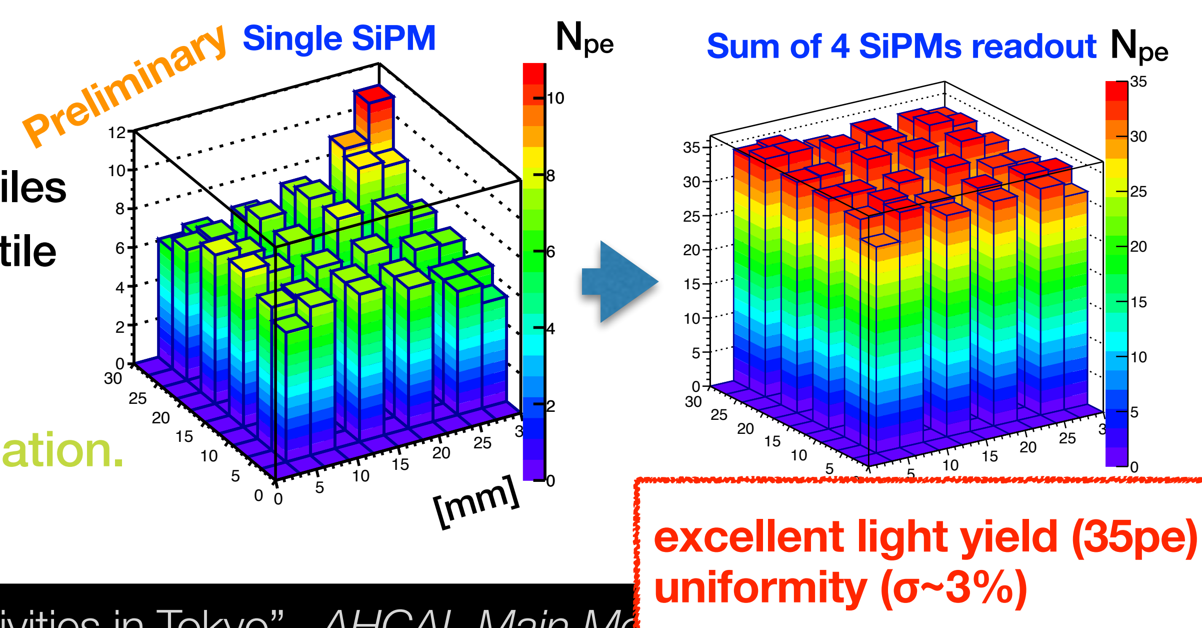
- A new AHCAL tile readout scheme, “four-corners readout”, is under study.
  - SiPMs are located at vertices of scintillator tiles and detect scintillation light from four adjacent tiles.
  - Tile hit is defined by taking a coincidence on four SiPMs belonging to the tile.
  - SiPM charge is split to hit tiles if shared by adjacent hit tiles.




- Advantages
  - **Reduced random noise by taking a coincidence over multiple SiPMs**
  - **Excellent uniformity and light yield**
  - **Still operational even with dead SiPM(s)**
  - Reduced number of calibration LEDs



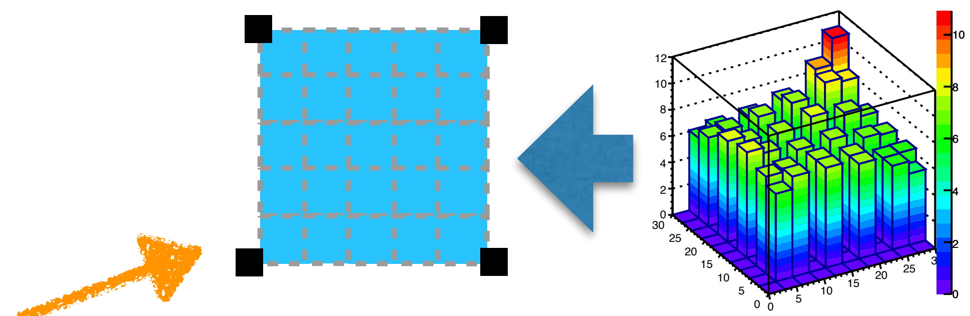

- Possible issues
  - **Cluster smearing due to fake hits**
    - Intrinsic fake hit when the tile is surrounded by true hit tiles
    - Fake hit due to light leakage from neighbouring true hit tile
  - How to split charge to adjacent hit tiles



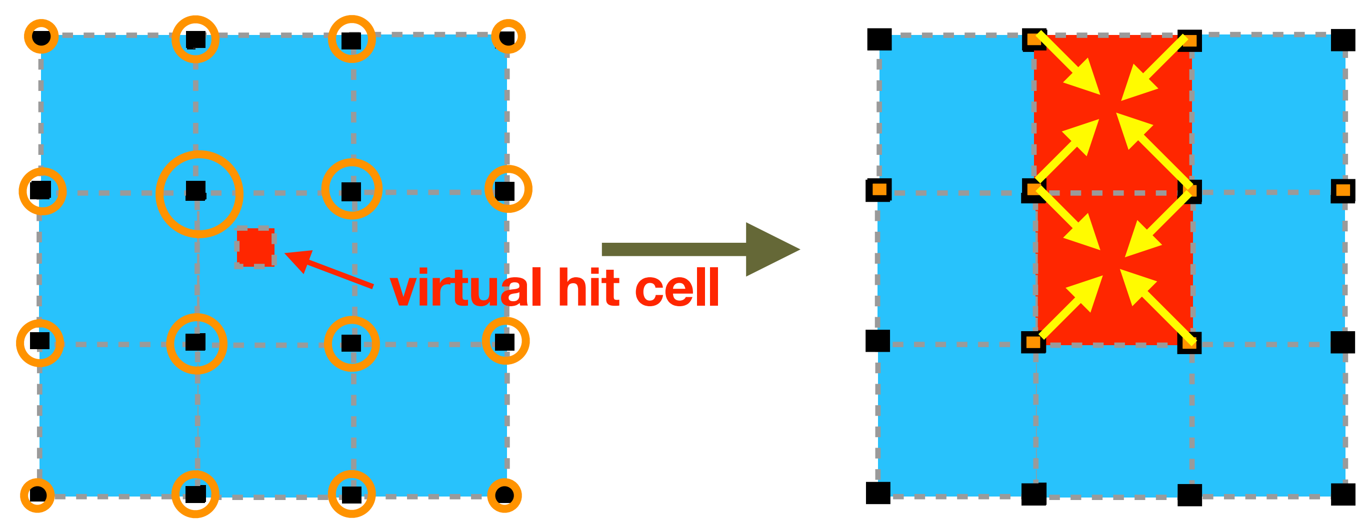

- Effect of cluster smearing is being evaluated by MC simulation.
- Optical coupling btw tile and SiPM is being optimised.

# Simulation Study with Four-corners Readout

- Simulation study on performance of AHCAL with four-corners readout
- Implementation of readout scheme
  - Implemented in digitisation task of Marlin
  - Properties of four-corners readout are implemented
    - Position dependence in inside-tile response
      - Each tile is subdivided into 25 virtual cells (6×6mm$^2$ each) to include position-dependent SiPM output at both hit tile and neighbouring tile (light leakage)
    - Taking coincidence to define tile hit
    - Each SiPM is shared by four adjacent tiles. Summed SiPM charge is split into adjacent tiles.



- Implementation completed.

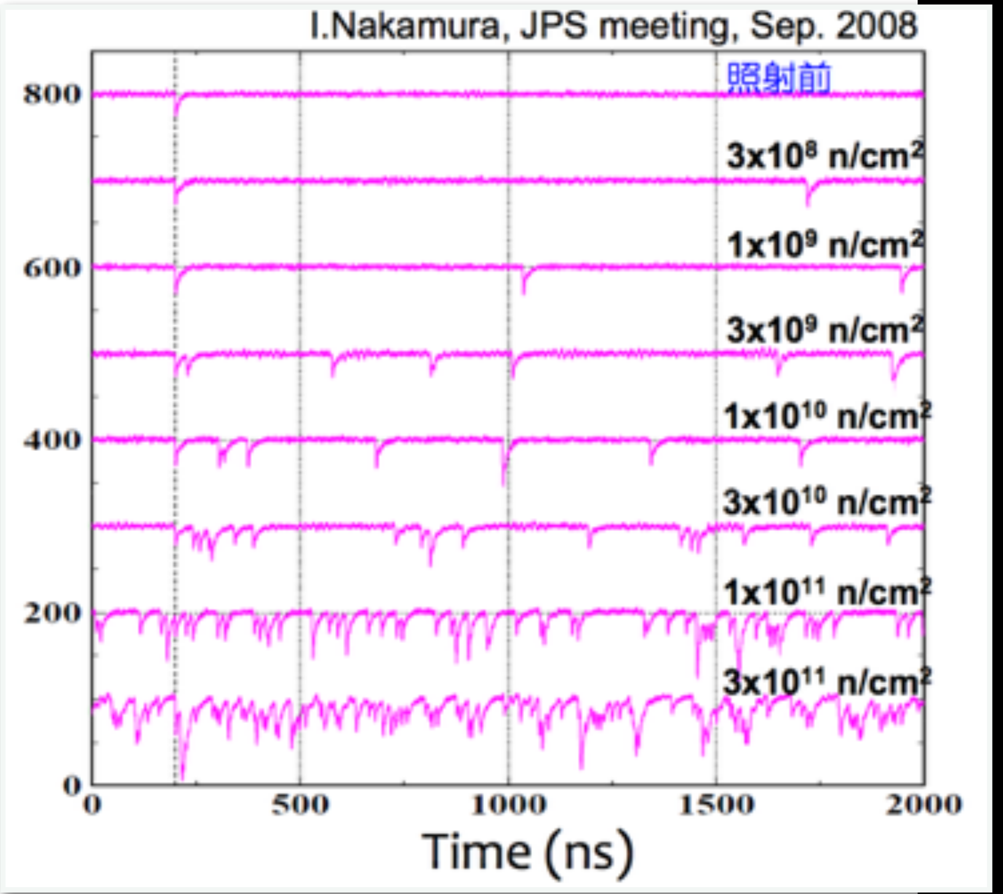



Generate charge at 16 surrounding SiPMs according to measured response and define tile hits

Split SiPM charge to neighbouring tiles

# SiPM Radiation Hardness Study

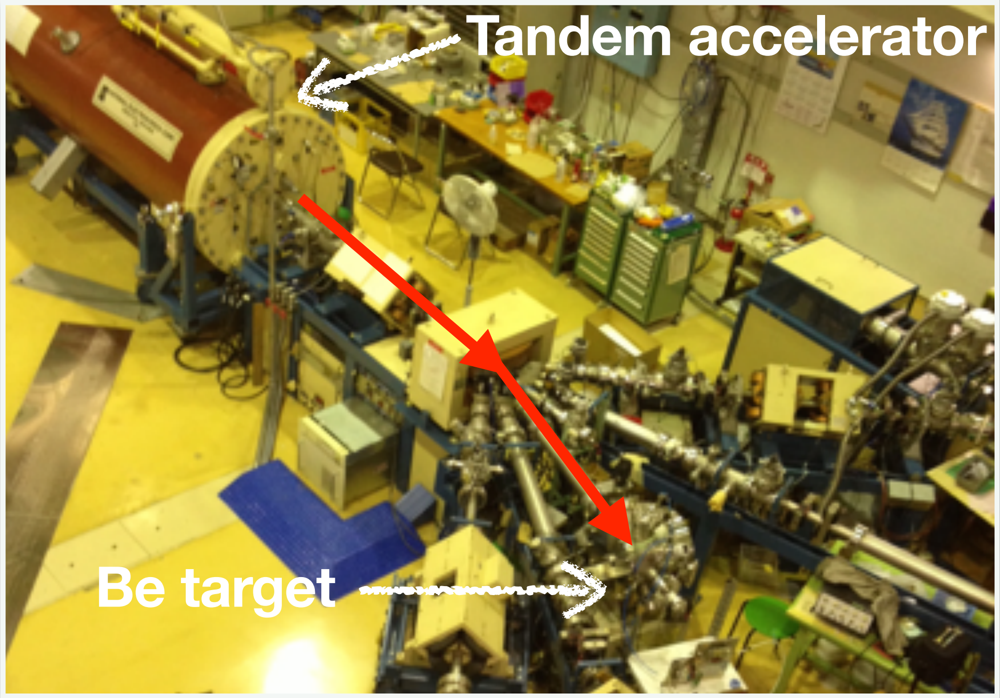
- Radiation damage of SiPM
  - **Non-ionising process**
    - Lattice defect
      →Additional energy level→increasing DCR/leak current
  - **Ionising process**
    - Damage in interface region btw insulation layer ($SiO_2$) and Si
      - Modified E-field distribution
      - Additional energy level→increasing DCR/leak current
- Radiation hardness of SiPM is not excellent as shown in previous studies.




- Expected dose @ ILC detector
  - ECAL barrel: ~$10^7$ n/$cm^2$/10years (LC-DET-2007-013)
  - ECAL endcap (CLIC): < $2\times10^{11}$ n/$cm^2$/10years (A. Sailer, CLICdp meeting on Oct. 2, 2013)
- Not crucial but might be an issue in extreme conditions

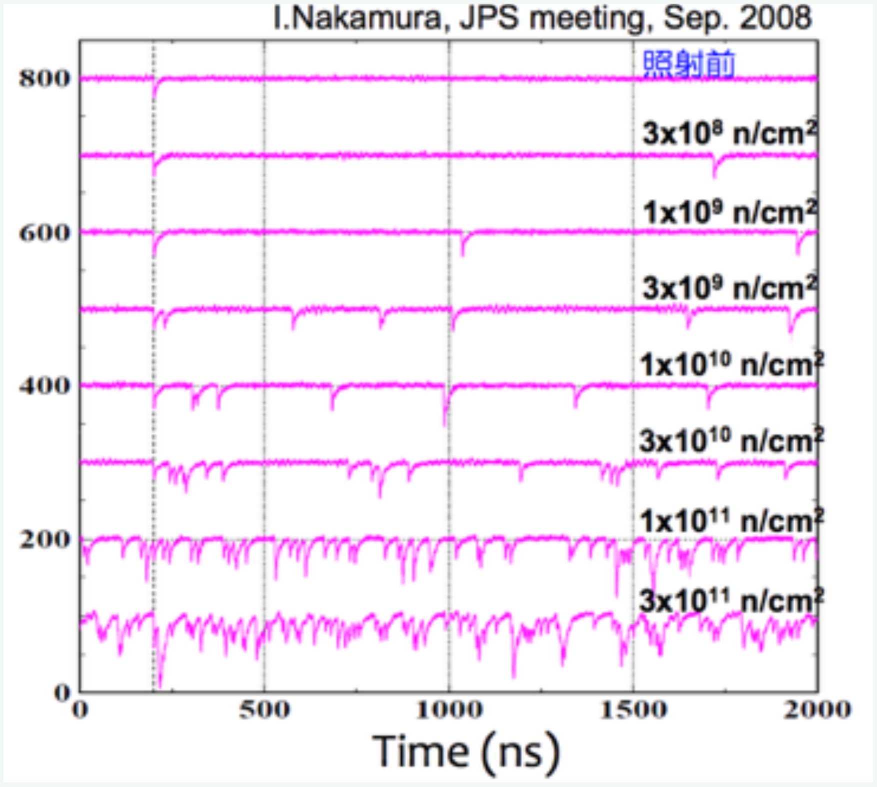
- Radiation hardness of **new generation of MPPC** might be different (hopefully better) since the layer/cell structure and material of insulation layer are modified.
- Also requested by Hamamatsu

# Neutron Irradiation Test

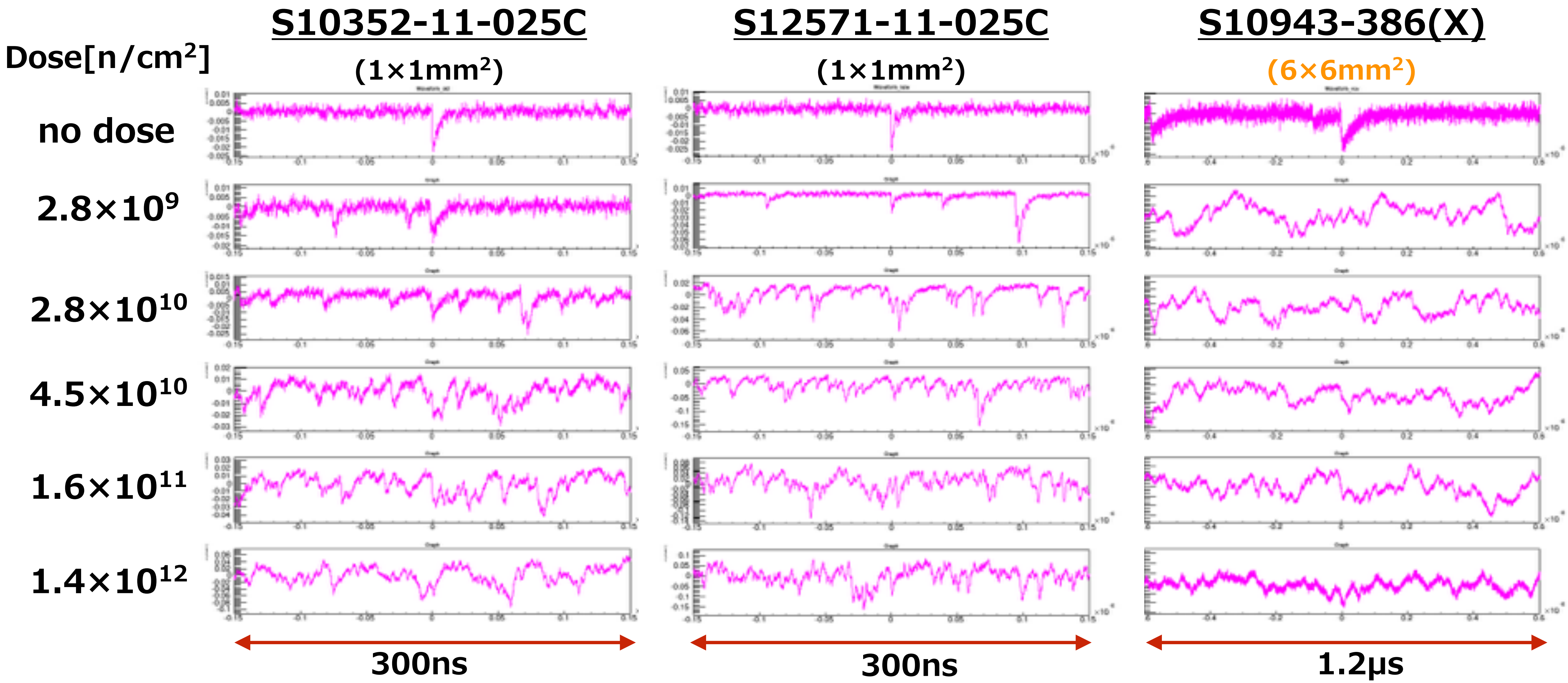



- Tandem accelerator at Kobe University
  - Neutron from nuclear reaction: $^{9}$**Be+d→**$^{10}$**Be+n**
  - Neutron yield: **$10^8$ n/sec**
- Neutron fluence was measured by calibrated silicon diode (ELMA diode)
  - Increase of leak current is calibrated by known flux.
- Irradiated samples
  - MPPC (**S10352-11-025C**)
    - $1\times1$mm$^2$, 25μm-pixel
    - **Old version,** no suppression on after-pulsing/cross-talk)
  - MPPC (**S12571-11-025C**)
    - $1\times1$mm$^2$, 25μm-pixel
    - **Suppression on after-pulsing only,** No suppression on cross-talk
  - MPPC (**S10943-3186(X)**)
    - $6\times6$mm$^2$, 50μm-pixel
    - VUV-sensitive, developed for MEG
    - **Suppression on after-pulsing only,** No suppression on cross-talk
- Total fluence [n/cm$^2$]
  - $2.8\times10^{9}$, $2.8\times10^{10}$, $4.5\times10^{10}$, $1.6\times10^{11}$, $1.4\times10^{12}$

# Increase of Dark Noise




Increase of dark noise looks consistent with previous study



# Increase of Dark Noise

- Measured dark count rate only for the minimum dose ($2.8\times10^9$ n/cm$^2$).
- Compared leakage current for higher dose

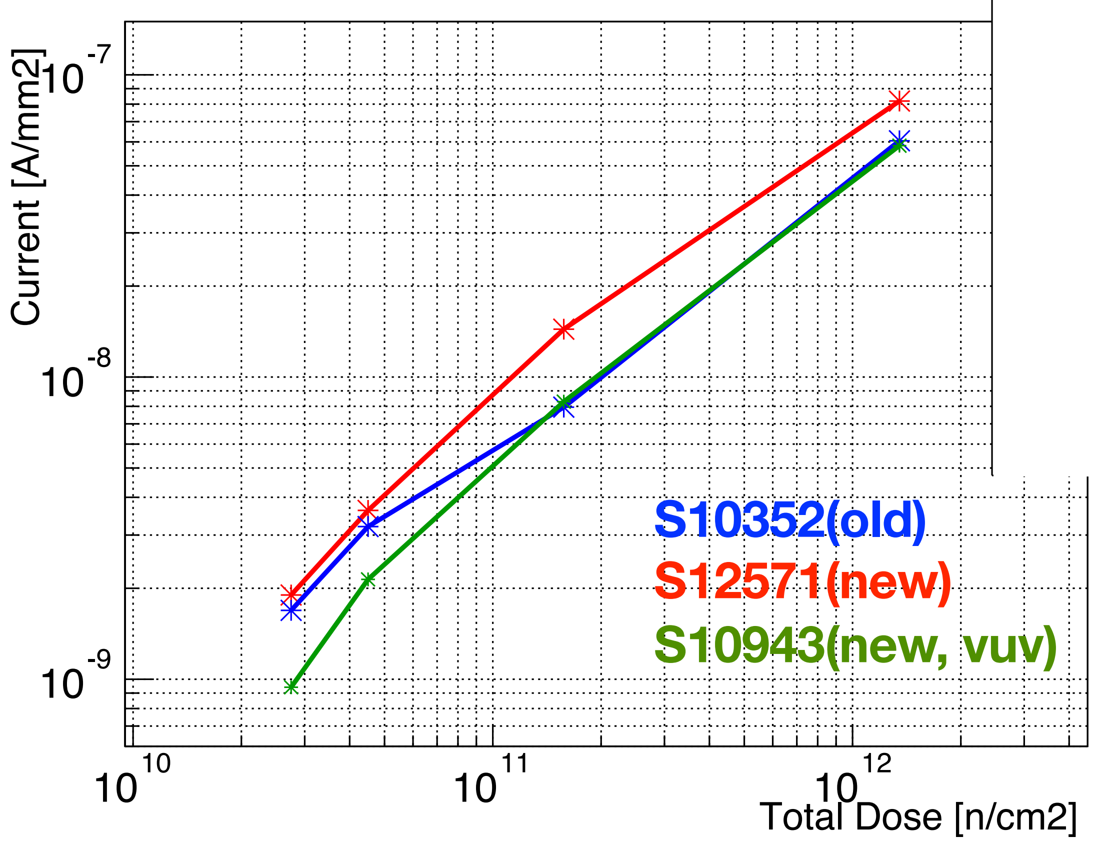
→**No significant difference of radiation hardness btw old and new versions**

**Dose @ $2.8\times10^9$ n/cm$^2$**

| | DCR **before** irradiation [Hz] | DCR **after** irradiation [Hz] |
|---|---|---|
| **sample 1 S10352 (old)** | **$3.0\times10^4$** @$V_{ov}$=2.3V | **$4.8\times10^6$** @$V_{ov}$=2.3V |
| **sample 2 S10352 (old)** | **$2.6\times10^4$** @$V_{ov}$=2.3V | **$7.7\times10^6$** @$V_{ov}$=2.3V |
| **sample 3 S12571 (new)** | **$12.7\times10^4$** @$V_{ov}$=3.5V | **$15.6\times10^6$** @$V_{ov}$=3.5V |
| **sample 4 S12571 (new)** | **$7.2\times10^4$** @$V_{ov}$=3.5V | **$14.3\times10^6$** @$V_{ov}$=3.5V |

**N.B. different $V_{ov}$ for old and new**

**Leakage current (@$V<V_{bd}$)**





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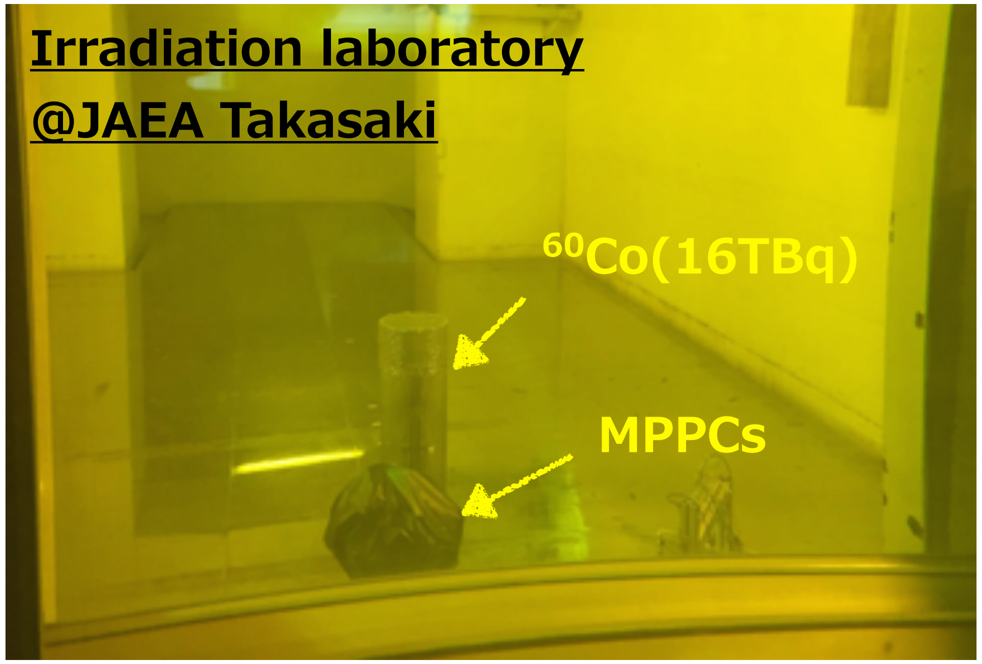
# Gamma Irradiation Test

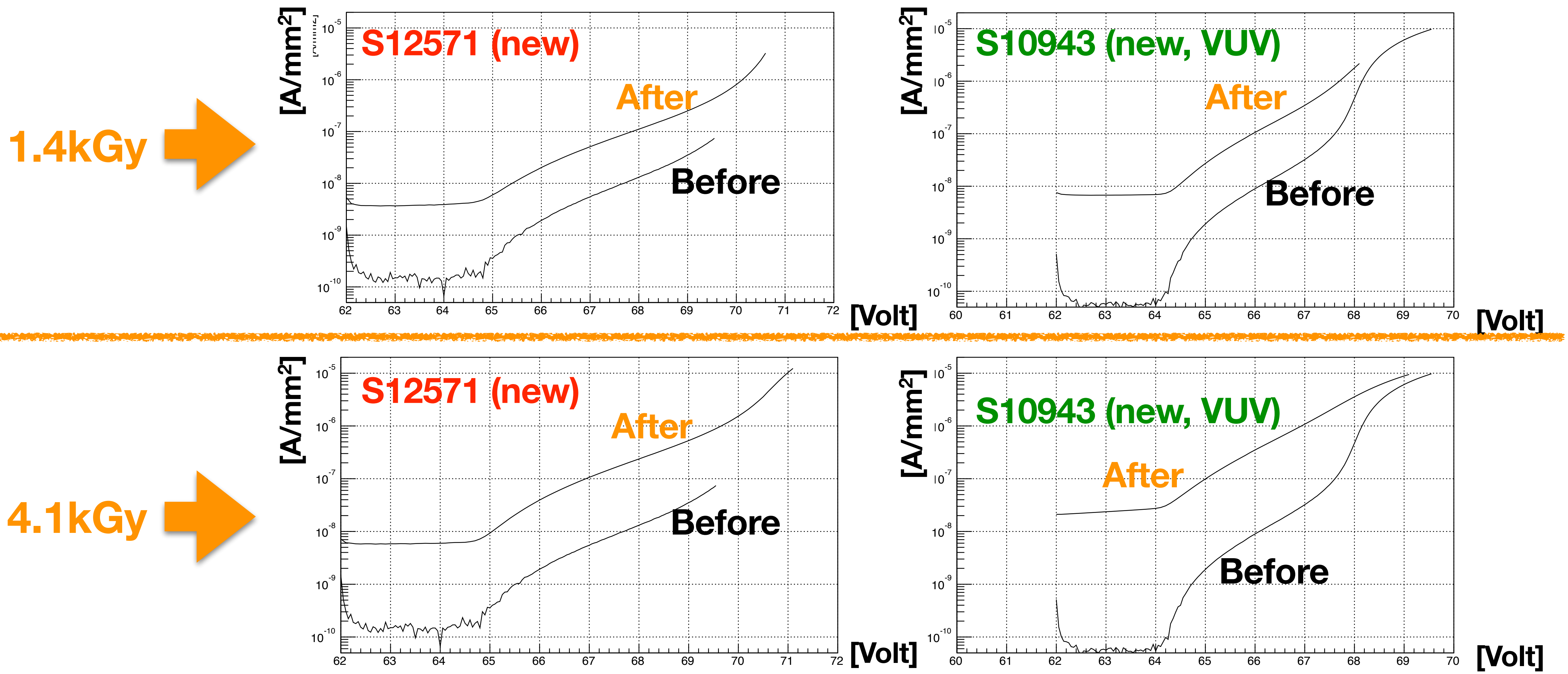
- Co-60 (16TBq) at JAEA Takasaki
- Irradiated samples
  - MPPC (**S12571-11-025C**)
    - 1×1mm$^2$, 25μm-pixel
    - **Suppression on after-pulsing only,** No suppression on cross-talk
  - MPPC (**S10943-3186(X)**)
    - 6×6mm$^2$, 50μm-pixel
    - VUV-sensitive, developed for MEG
    - **Suppression on after-pulsing only,** No suppression on cross-talk




- Compared btw only recent MPPCs (with after-pulsing suppression)
  - Material type of insulation layer is different for S10943-3186(X) (VUV-sensitive).
- Dose conditions
  - 1.4kGy, 4.1kGy

# Gamma Irradiation Test

- Compared increase of leakage current after irradiation




- Increase of leakage current ~ ×10 @ 1.4kGy
- No significance difference in increase of leakage current btw S12571 and S10943

# Next Steps for Radiation Hardness Study

- Extended test of neutron irradiation is planned.
    - Neutrons from reactor
    - Research reactor TRIGA at LENA, Pavia
- Items to be tested.
    - SiPMs
        - Most recent MPPC (with suppression on both afterpulsing and crosstalk)
        - VUV-MPPC
        - SiPM from FBK-AdvanSiD
    - Radiation hardness of candidate materials of scintillator (PVT, PS, MS)

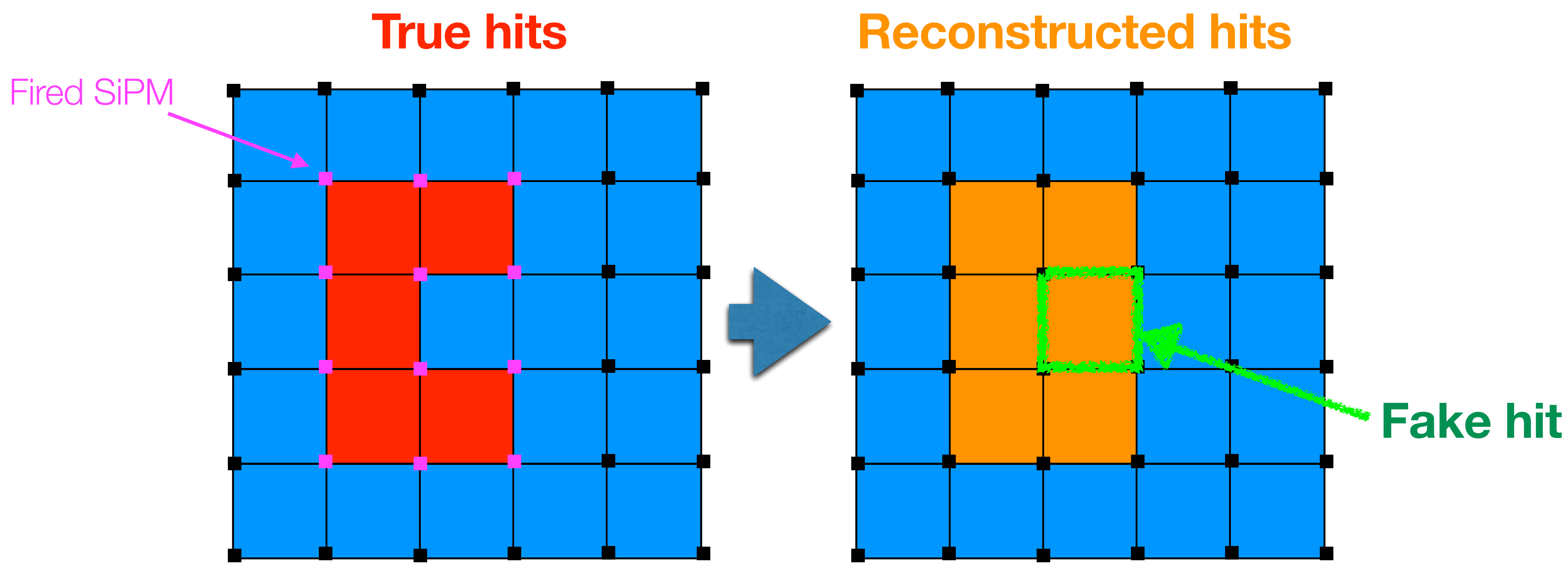
# Summary

- Scintillator material study
  - Optimisation of scintillator material especially for PS/MS which can be produced with injection molding.
  - Test production has been performed for PS-base scintillator with different fluorescent concentrations
- New AHCAL tile design
  - Simulation study to investigate effect of cluster smearing is ongoing.
    - Implementation in digitisation task is completed.
  - Optimisation of coupling btw tile and SiPM to maximise light yield and to minimise light leakage to neighbouring tile
- Radiation hardness study
  - No significant difference for recent version of MPPC (with after-pulsing suppression)
  - Further study is planned using reactor neutrons.

# Backup

# How It Works

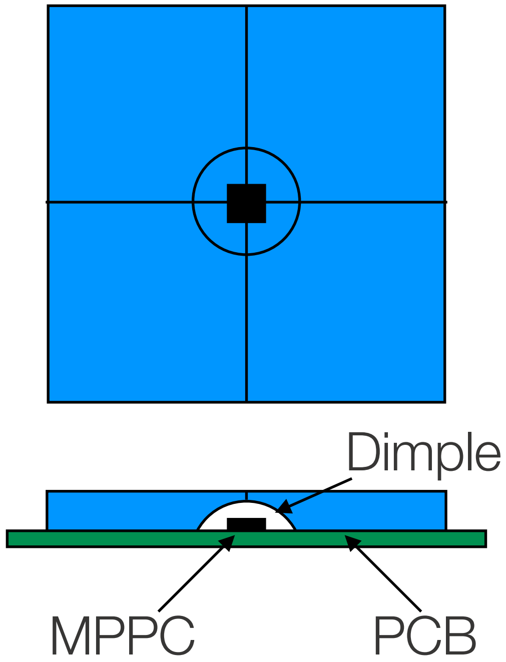
- Reconstruction of cell hit and cell charge
  - Cell hit is defined by taking a coincidence on four SiPMs belonging to the cell.
  - Cell charge is reconstructed by
    - Summing up charges for four SiPMs
    - If SiPM is shared by adjacent cell hits, SiPM charge is split to hit cells.



# Possible Implementation

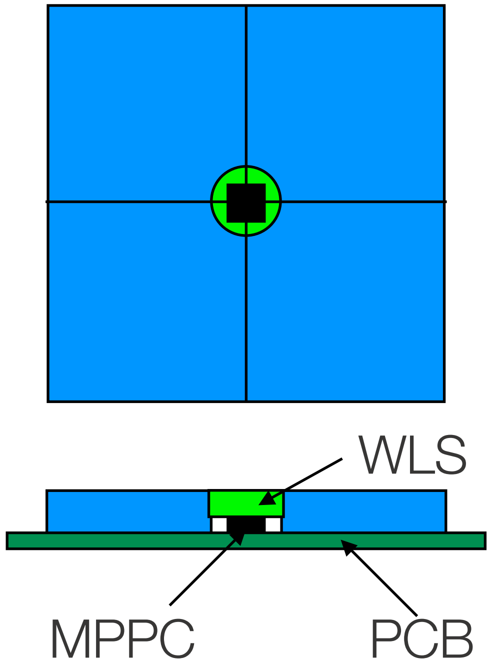
- Possible optical coupling of SiPM + Scintillator at cell vertex

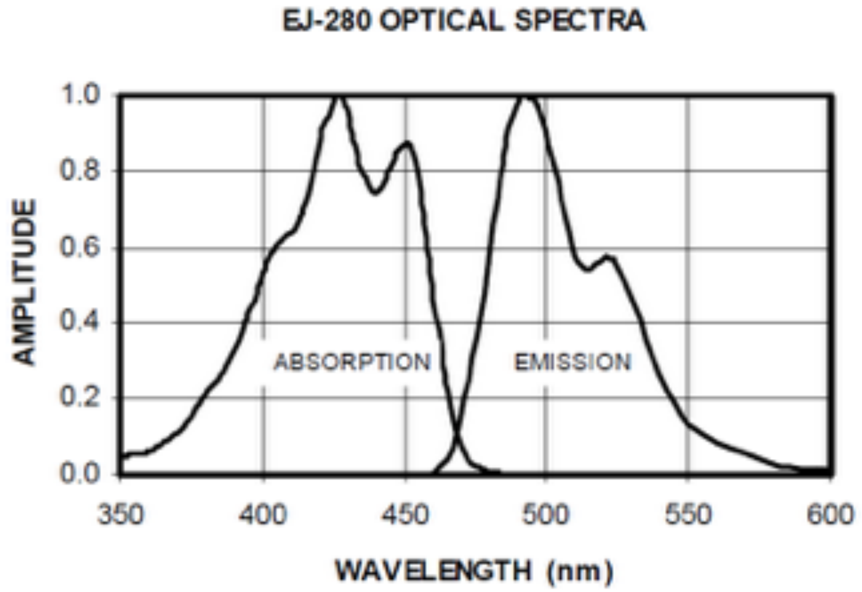
## Dimple at vertex




- Easier assembly
- Larger cross-talk?

## Wavelength shifter (WLS) at vertex




- Complicated assembly
- Less cross-talk?
- Higher light yield?
- Dead region (~1%)

no absorption (and emission) of light from WLS at neighbouring cell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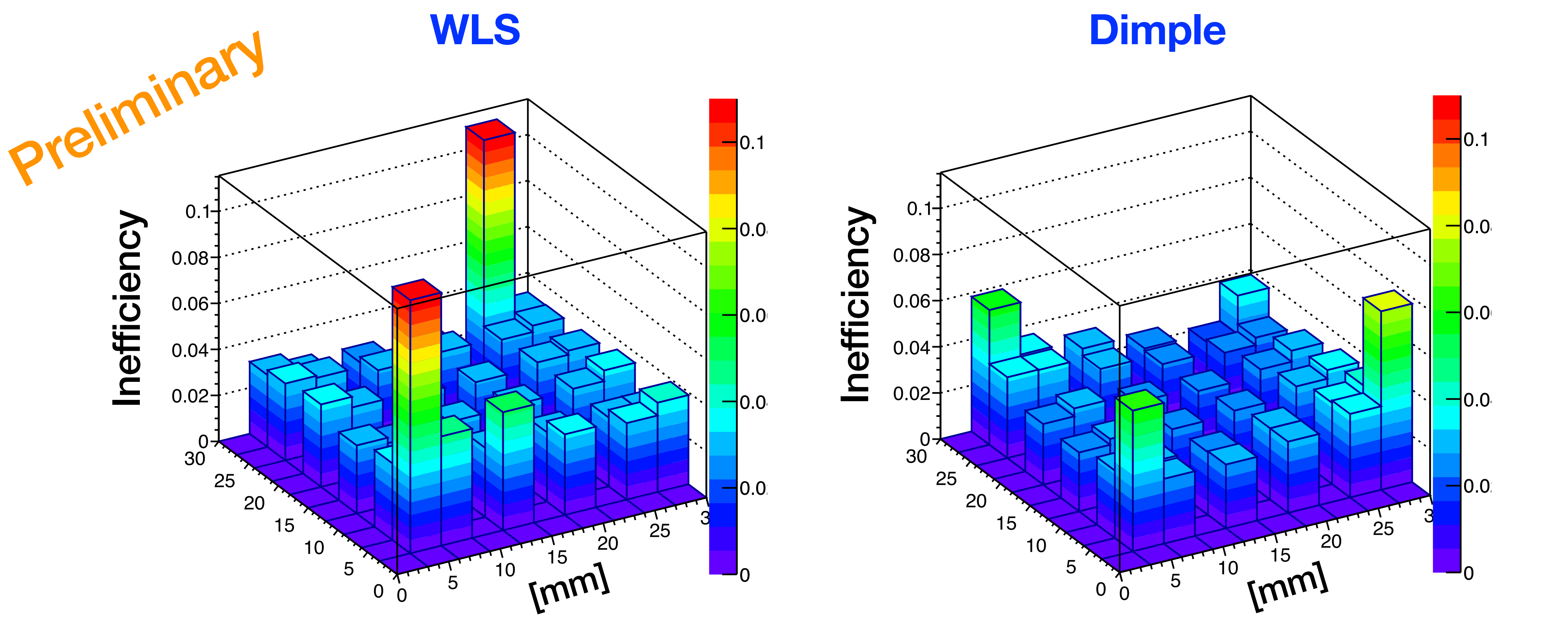
# Inefficiency

- Small chance of $N_{pe}$=0 at each SiPM if light yield is moderate. No hit is defined when taking a coincidence in this case. → inefficiency!
- Measured inefficiency ~ a few %
- Can be mitigated with improvement of light yield or higher threshold for coincidence. Note that optical coupling is not optimised yet.





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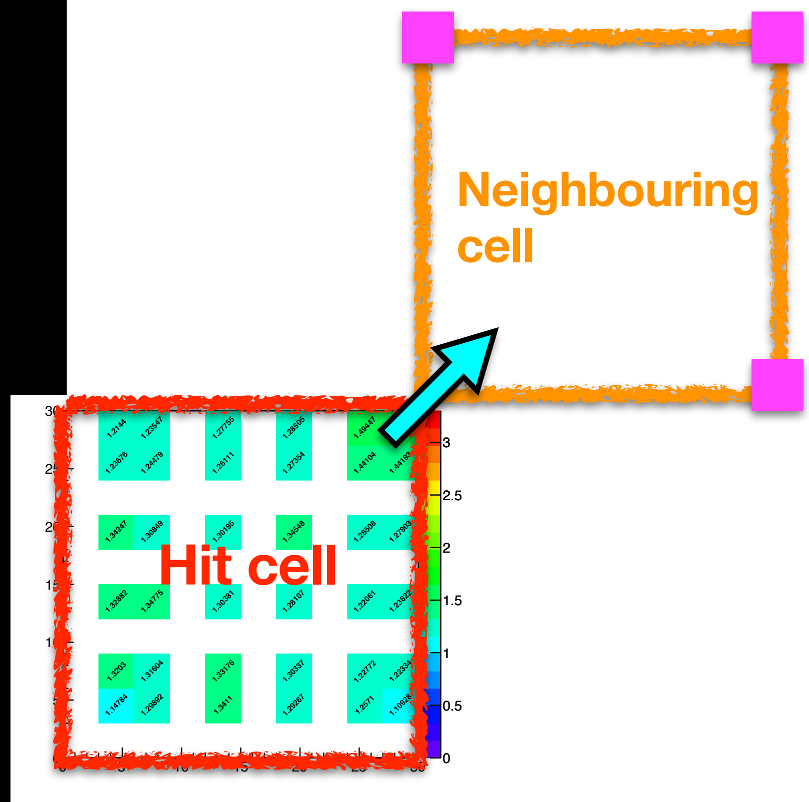
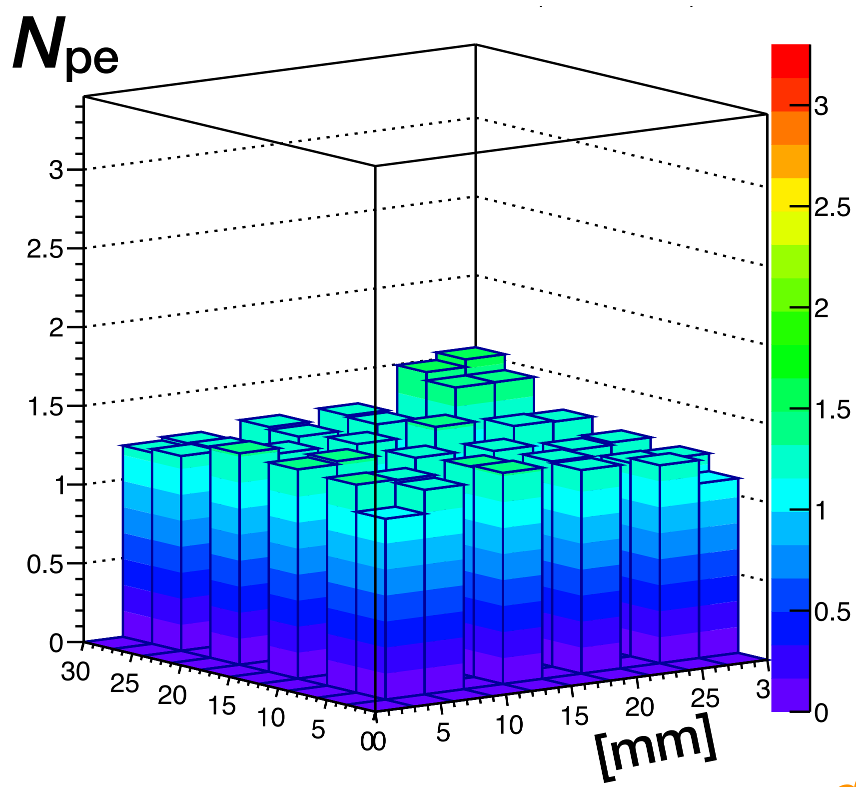
# Cross-talk (Dimple)

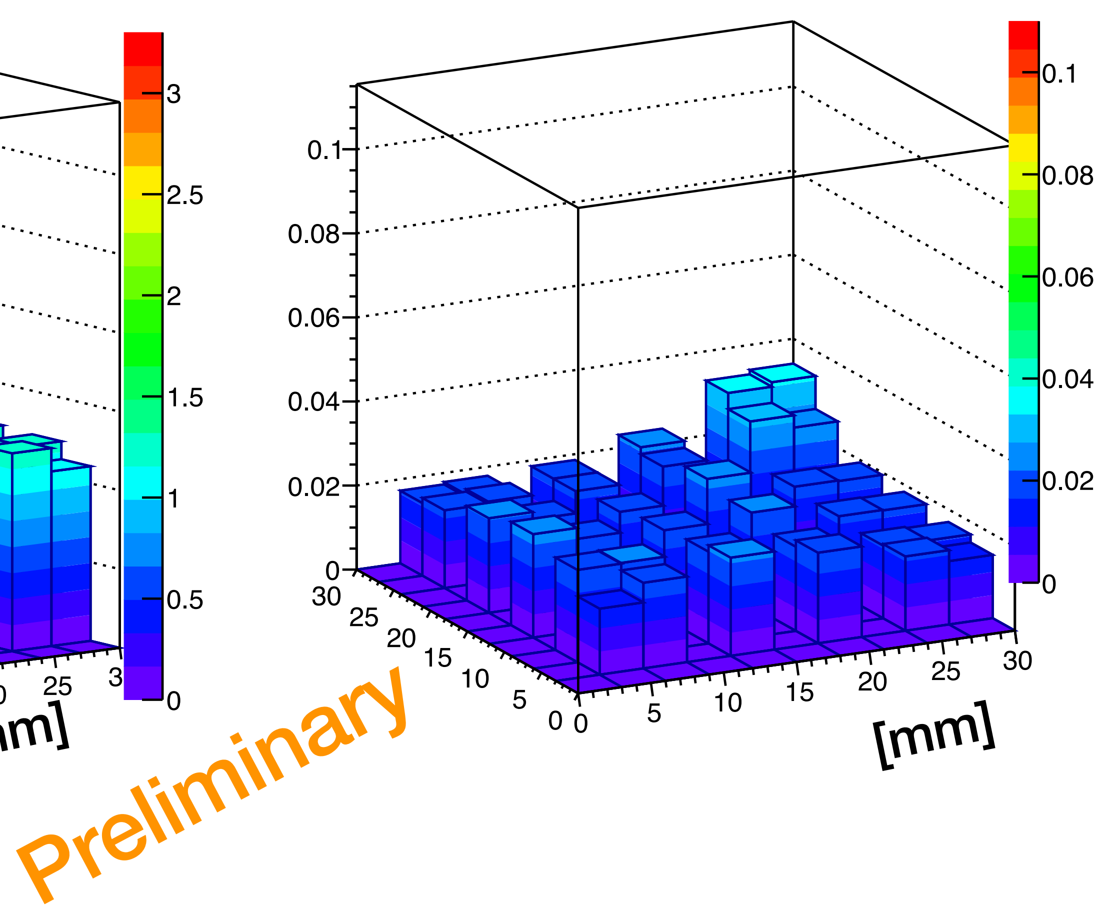
- Light leakage from hit cell to neighbouring cell was measured.
  - Sum of # of p.e. detected at three SiPMs in neighbouring cell ~1p.e.
  - Probability of fake hit at neighbouring cell triggered by light leakage (when taking quad coincidence) ~2%




Average $N_{pe}$




Prob. of fake hit



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