# 新ニュートリノ検出器WAGASCIのための新型MPPCの性能評価

細見郁直 / 東京大学

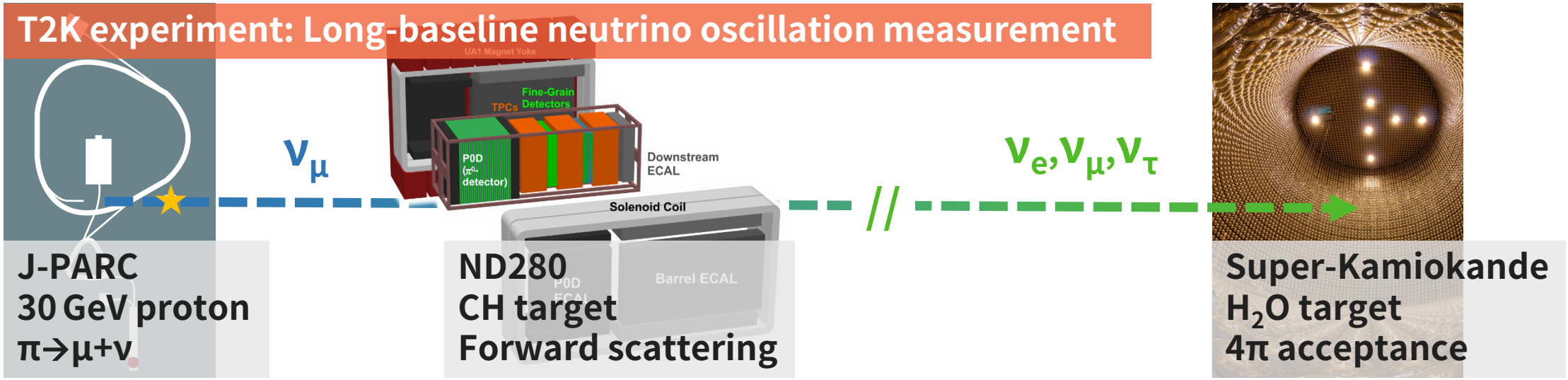
2015年 2月 8日

21st ICEPP Symposium

長野県北安曇野郡白馬村 岳美山荘

# Motivation for WAGASCI detector

**T2K experiment: Long-baseline neutrino oscillation measurement**




**J-PARC**
**30 GeV proton**
**π→μ+ν**

**ND280**
**CH target**
**Forward scattering**

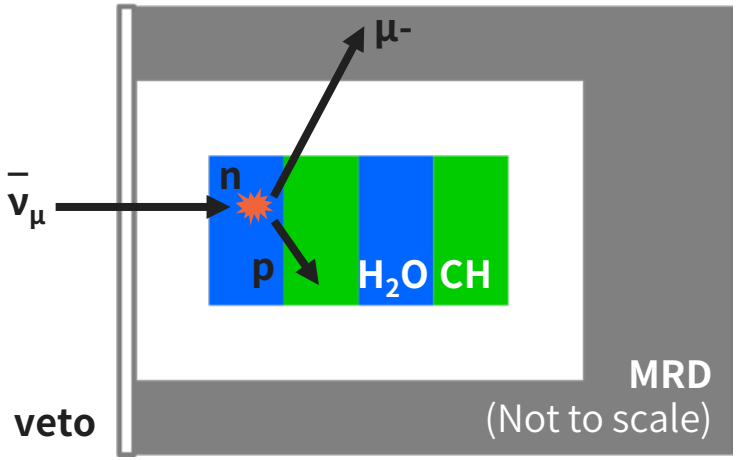
**Super-Kamiokande**
**$H_2O$ target**
**4π acceptance**

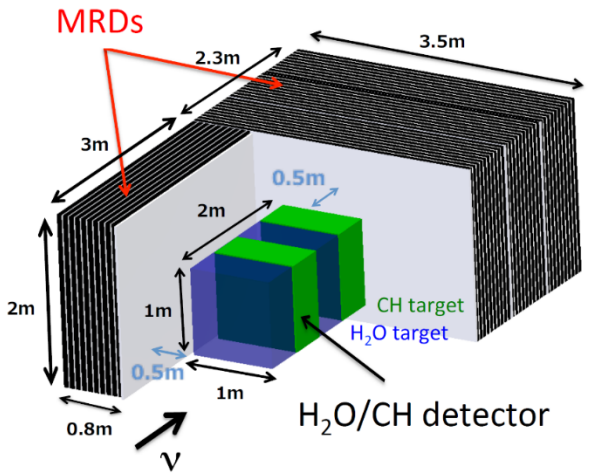
| Systematic Error sources | Error ($\nu_\mu \to \nu_e$) | Error ($\nu_\mu \to \nu_\mu$) |
|---|---|---|
| ν flux & cross section (constrained by ND280) | 2.9% | 2.7% |
| **ν flux & cross section (not constrained by ND280)** | **7.5%** | **5.0%** |
| Super-Kamiokande etc. | 3.5% | 5.6% |
| Total | 8.8% | 8.0% |

新ニュートリノ検出器WAGASCIの目的

$H_2O$/CH断面積比を広いアクセプタンスで精密測定しT2K実験の系統誤差を削減

# WAGASCI検出器の目的と構成



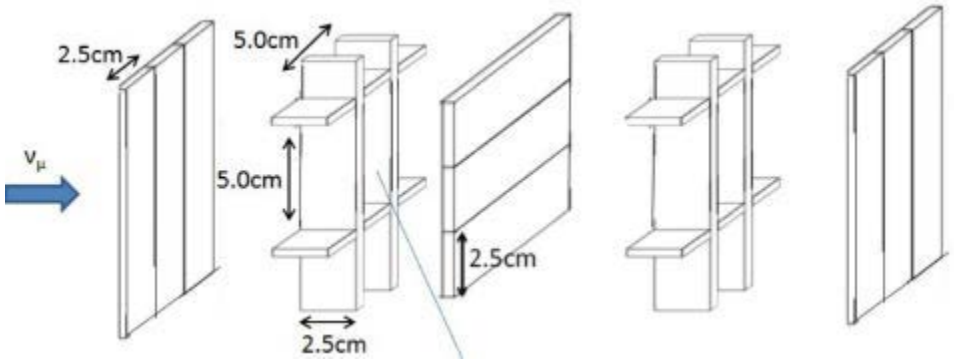

Water Grid And Scintillator

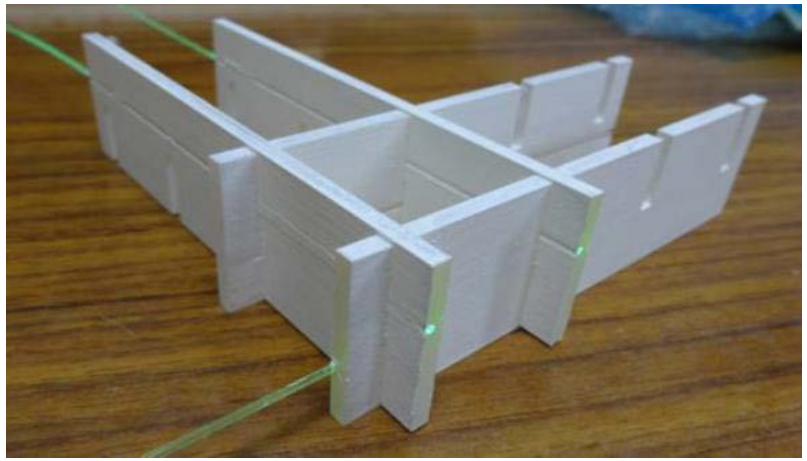
- $H_2O$/CH断面積比を3%の精度で測定
- $H_2O$断面積を10%の精度で測定

検出器の構成

- 標的部
  - $H_2O$とCHのサンドイッチ構造
  - 格子状シンチレータ
- Muon range detector (MRD)
  - 鉄とシンチレータ

# WAGASCI検出器 標的部



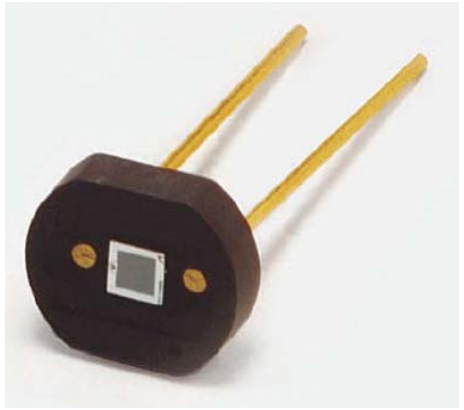



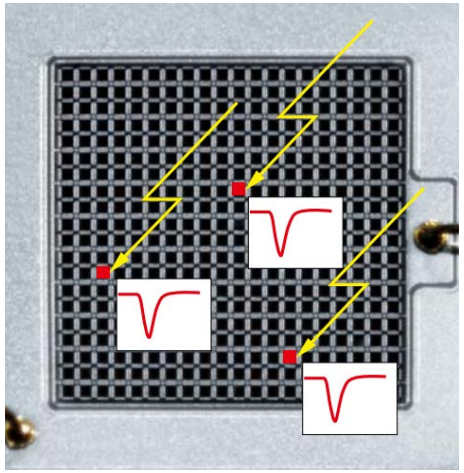
3次元格子状にシンチレータを設置

- x + grid + y + grid + … layers
- 4π angular acceptance
- 3mm厚の薄いシンチレータ
  - $H_2O$ (signal):CH (BG) = 79:21
- 波長変換ファイバとMPPCで読み出し

➔ 高い検出効率と低いノイズレートが求められる

# Multi-Pixel Photon Counter





浜松ホトニクスが開発した複数のAPDからなる光子検出器

- ガイガーモードで動作
  - Over voltage = (Bias voltage) – (Breakdown voltage)
    に対して各種性能がよい線形性をもつ
- High gain / High Photon Detection Efficiency (PDE)
- Dark noise 熱ノイズによって発生
- Afterpulse トラップされたキャリアが遅れて放出
- Crosstalk 二次光子が別のピクセルで検出される

# MPPCの研究開発

S10362 type　T2K実験で初めて大量に使用

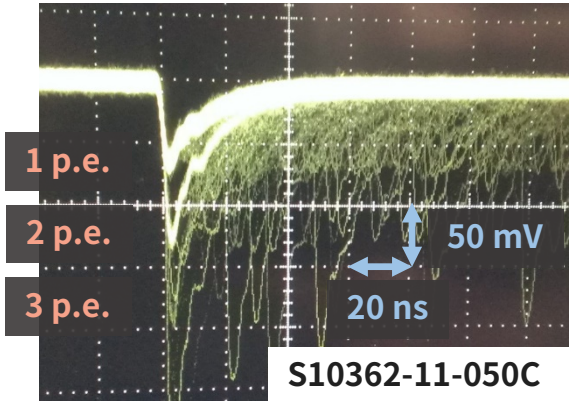
↓　Afterpulseとdark noiseを低減

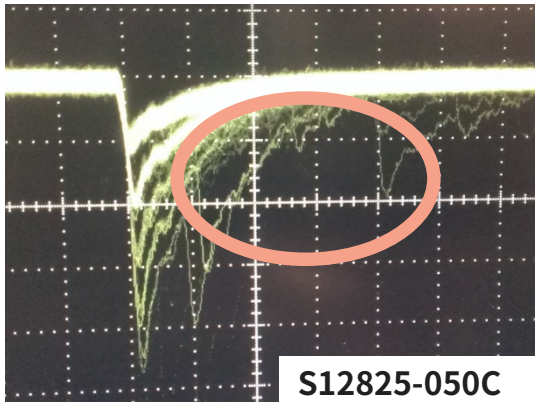
S12825 type（2013夏）

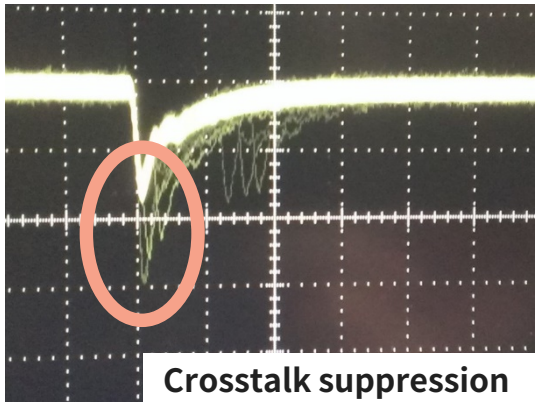
↓　Crosstalkを低減

Pre production type（2014夏）

S13081 type（2014冬）




アンプを通して100倍に増幅
Over voltage = 2.0 V
p.e. = photon equivalent

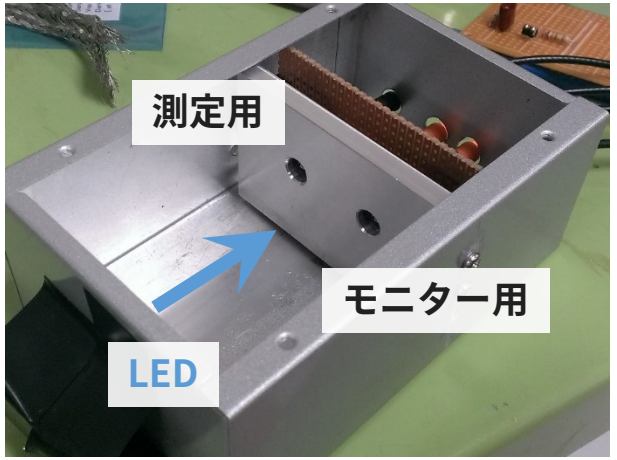
# 測定項目

Dark noiseとセルフトリガーを用いて

- Dark noise rate
- Crosstalk rate

LED光源を用いて

- Gain
- Relative PDE



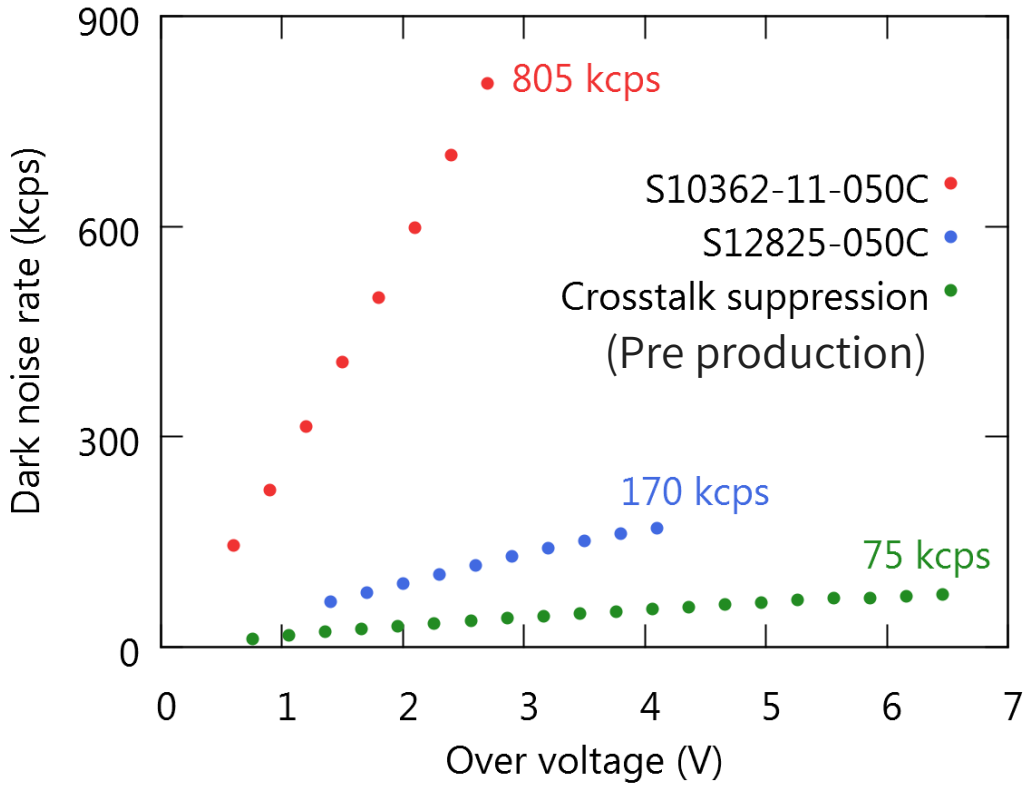

| 型番 | 特徴 | 受光面積 |
|---|---|---|
| S10362-11-050C | 旧型MPPC * | 1x1 $mm^2$ |
| S12825-050C | Afterpulse抑制型 | 1.3x1.3 $mm^2$ |
| Pre production | Crosstalk抑制型 | 1x1 $mm^2$ |
| S13081-050CS | Crosstalk抑制型 | 1.3x1.3 $mm^2$ |

50x50 $\mu m^2$のピクセルサイズ
Pre productionとS13081はほぼ同じ性能
* T2K実験では受光面積の異なる
S10362-13-050Cを使用

# Dark Noise Rate

Self trigger with 0.5 p.e. threshold

Over voltage = (Bias voltage) – (Breakdown voltage)




S10362型と比較して

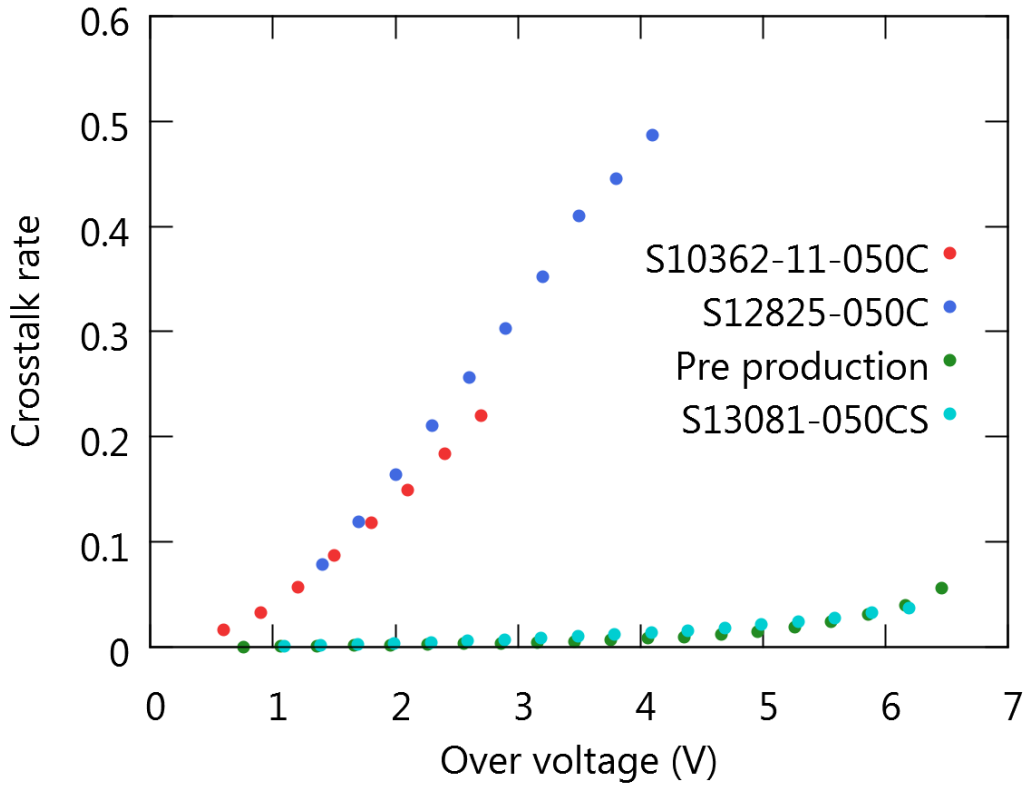
- S12825型は1/8に低減
- Crosstalk抑制型は1/10に低減

➔ Dark noise rateの大幅低減により高い電圧で動作可能に

* 1 $mm^2$の受光面積で規格化

# Crosstalk Rate

$$\text{Crosstalk rate} = \frac{\text{1.5 p.e. threshold dark noise}}{\text{0.5 p.e. threshold dark noise}}$$



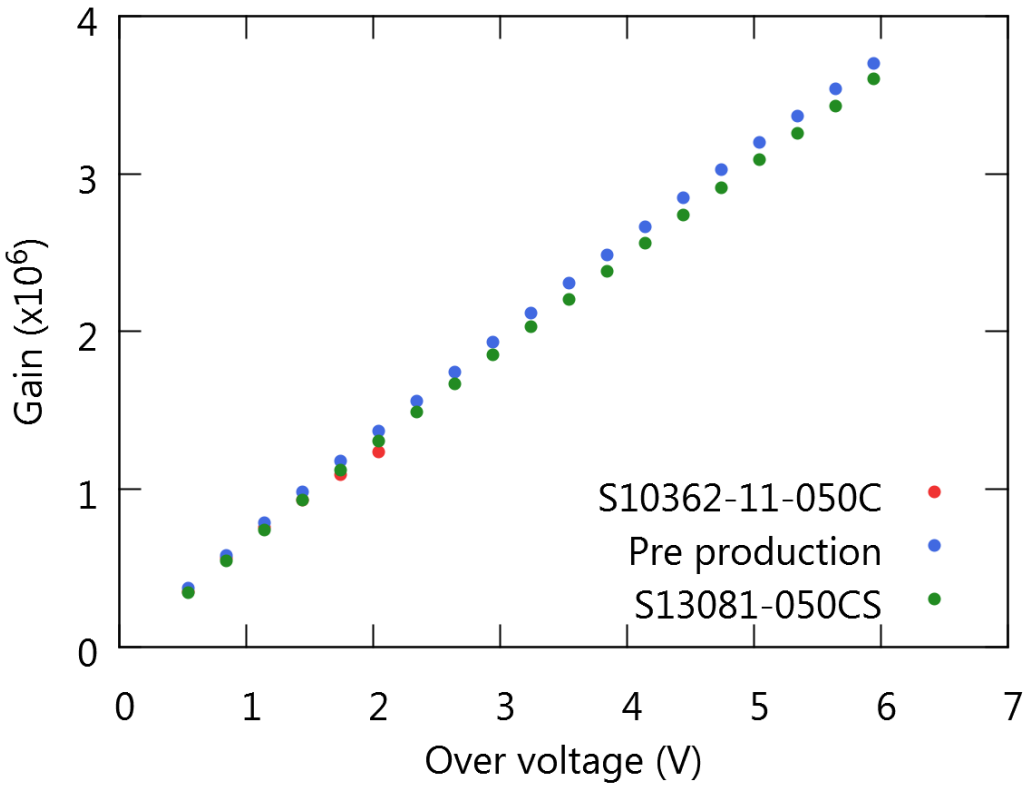

S10362型と比較して

- S12825型は同じ
- Crosstalk抑制型は1/10に低減

➔ Crosstalk rateの大幅低減により光子検出の閾値を下げることが可能に

# Gain

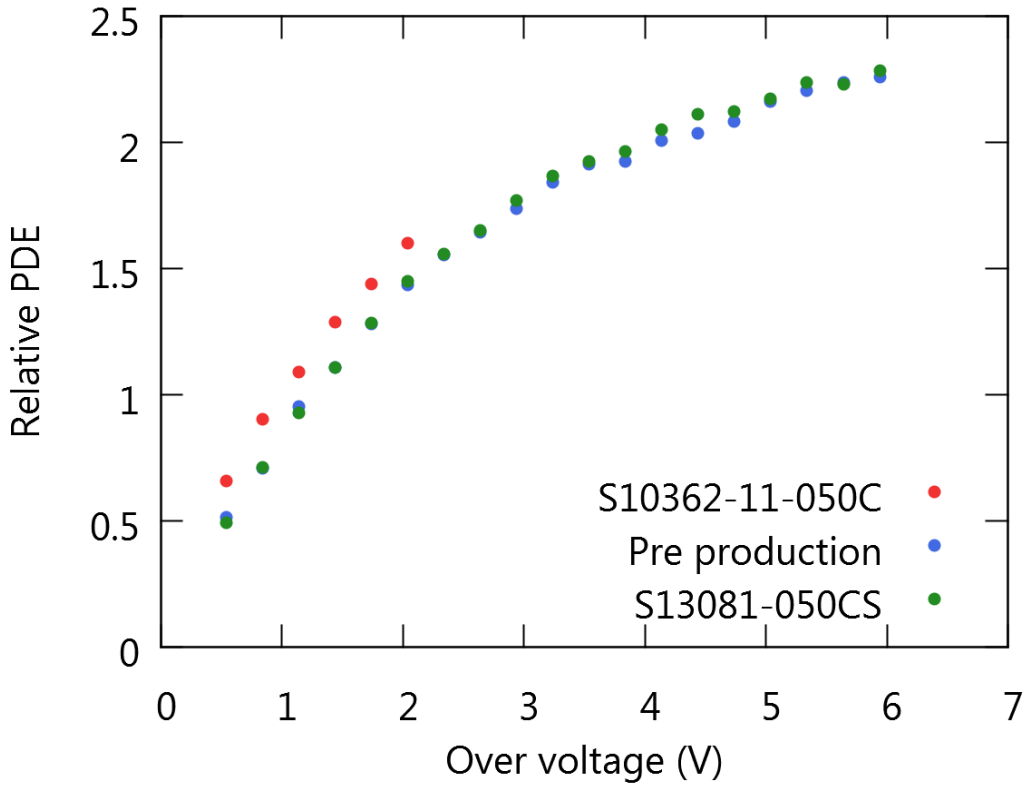
$$\text{MPPC Gain} = \frac{[(1\ \text{p.e. ADC ch}) - (\text{pedestal ADC ch})] \times (\text{ADC charge per ch})}{\text{elementary charge}}$$




- Gainは旧型と変わらないが
  より広い電圧で動作させることが
  できる
- 高い電圧で動作させることで
  高いGainを得る

# Relative PDE

$$\text{Relative PDE} = \frac{\text{各MPPCで検出した光子数}}{\text{S10362型MPPC (}\Delta V=1.0\text{ V) で検出した光子数}}$$




- 同じover voltageでは少し低いが高い電圧で動作させることで高い検出効率を得る

# 新旧MPPCの性能比較

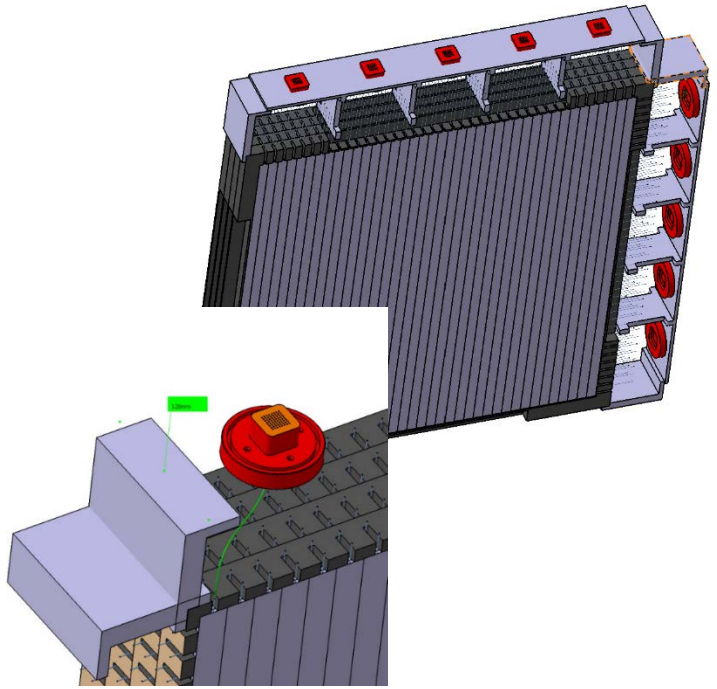
赤文字はS10362型に対する各性能の比率

| | Gain ($x10^6$) | Noise rate (kcps) | Crosstalk rate | Relative PDE |
|---|---|---|---|---|
| S10362-11-050C<br>Over voltage=1.1 V * | **0.734**<br>**1** | **284**<br>**1** | **0.0488**<br>**1** | **1.06**<br>**1** |
| Crosstalk suppression<br>Over voltage=1.1 V | **0.771**<br>**1.05** | **17.3**<br>**0.061** | **0.00091**<br>**0.019** | **0.873**<br>**0.82** |
| Crosstalk suppression<br>Over voltage=4.0 V | **2.63**<br>**3.6** | **53.3**<br>**0.19** | **0.00789**<br>**0.16** | **1.97**<br>**1.86** |

* Over voltage=1.1 VはT2Kで使われている動作電圧

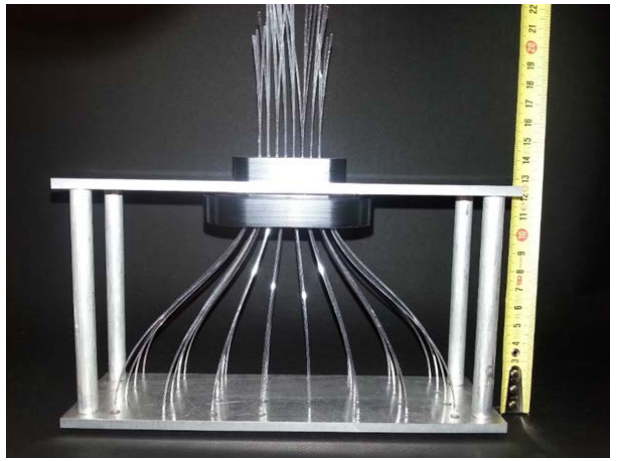
# Summary

- T2K実験の系統誤差削減のため
  新ニュートリノ検出器WAGASCIを開発中
- 新型MPPCは各種性能が向上



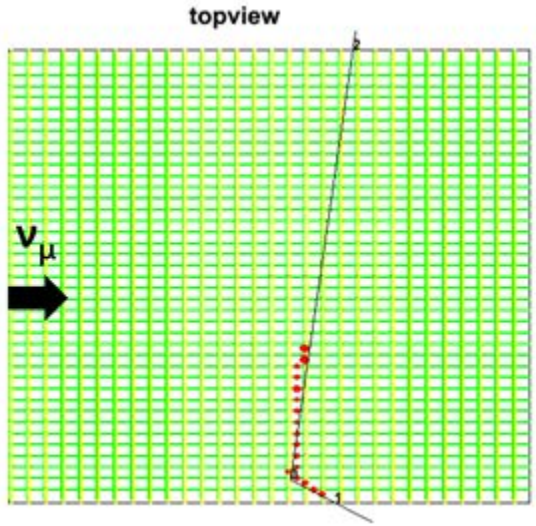
# Perspective

- およそ8000chのMPPCの大量測定
- WAGASCI標的部に用いる32ch array MPPCの
  性能評価



# Backup

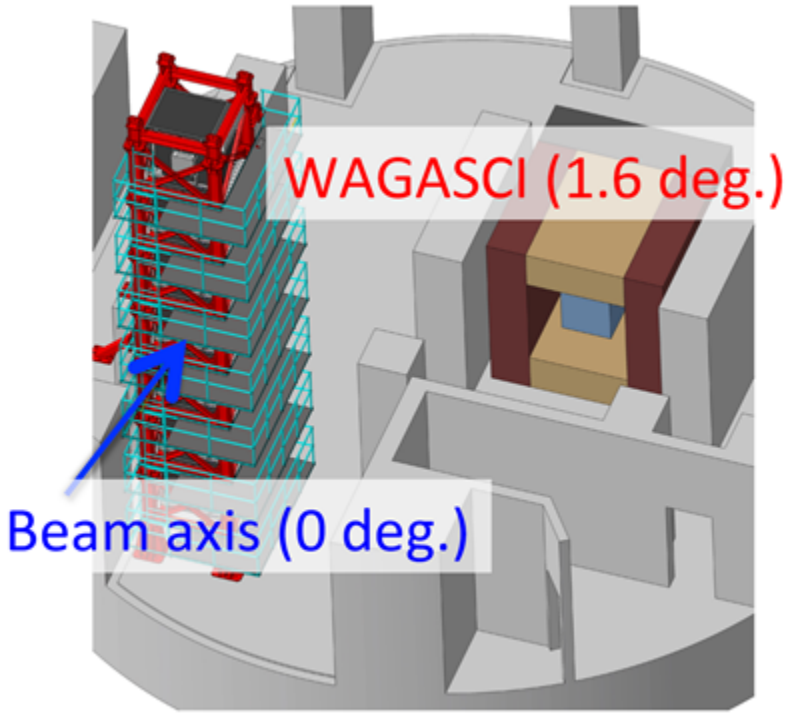
# WAter Grid And SCIntillator WAGASCI

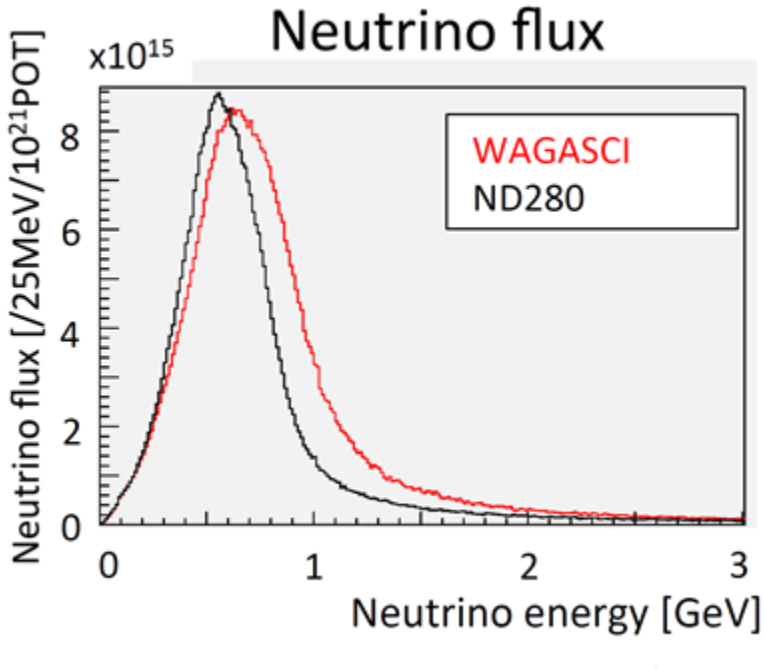


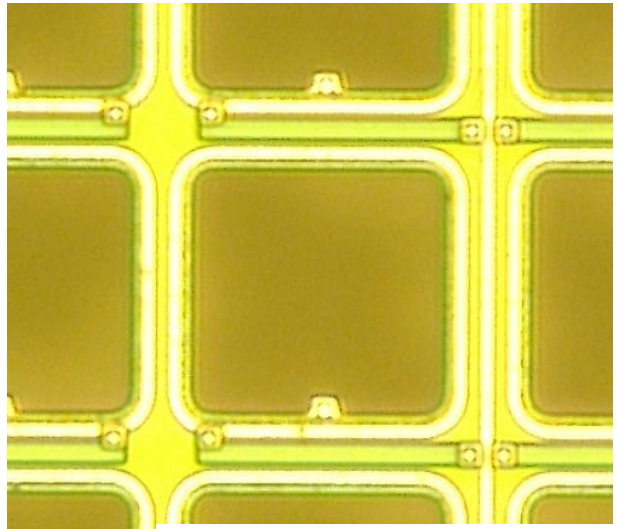

Box for Japanese sweets (Wagashi)

# Candidate Site

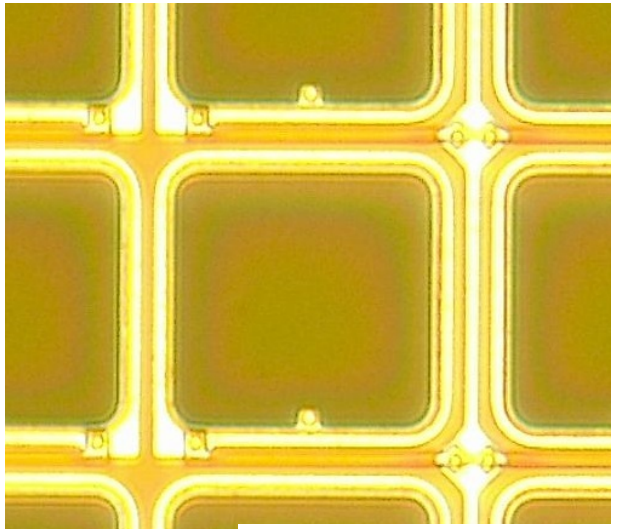
- The B2 floor of the T2K near detector hall





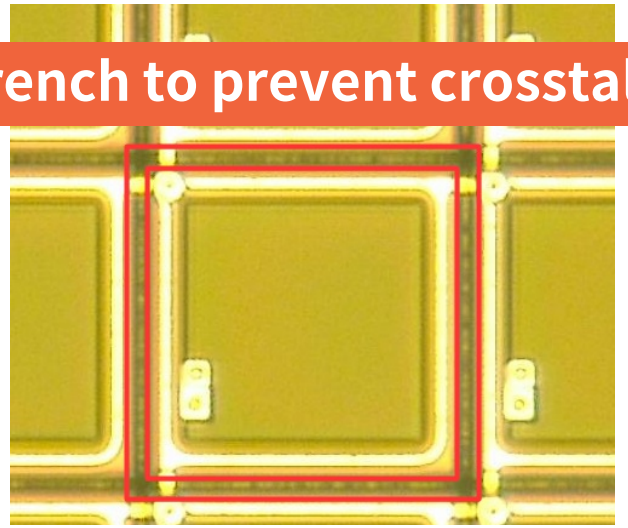
S10362-11-050C



S12825-050C

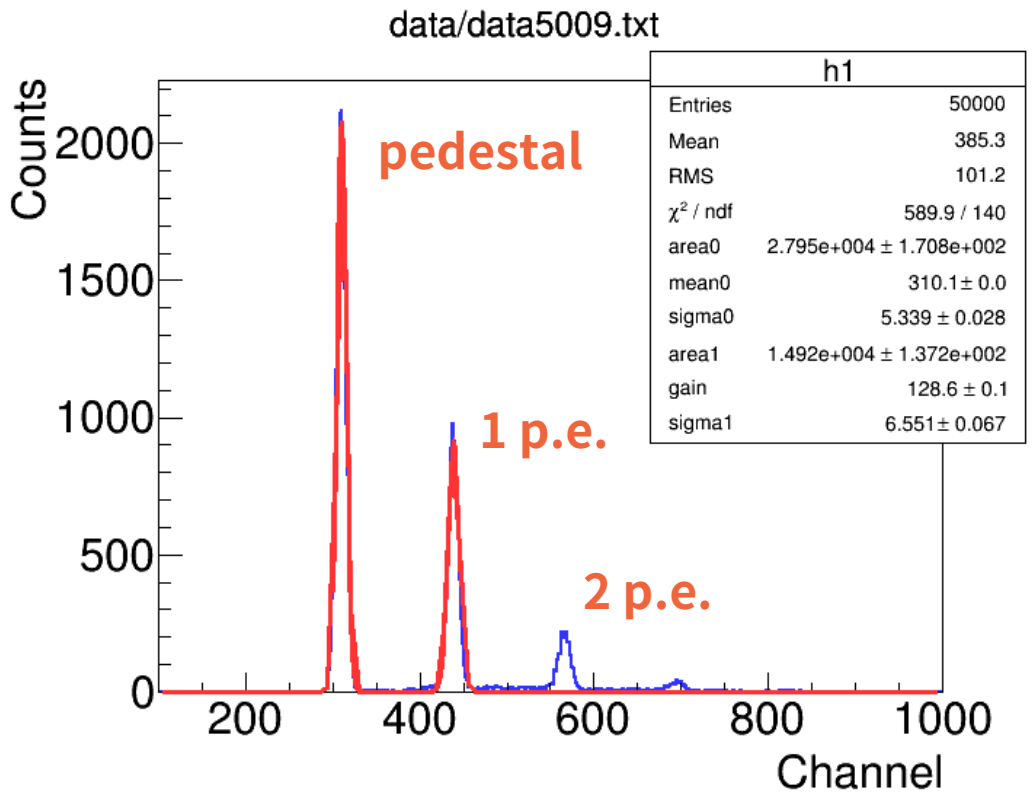
# Micrographs of MPPC

50x50 $\mu m^2$ pixel




Crosstalk suppression

# Typical Charge Distribution



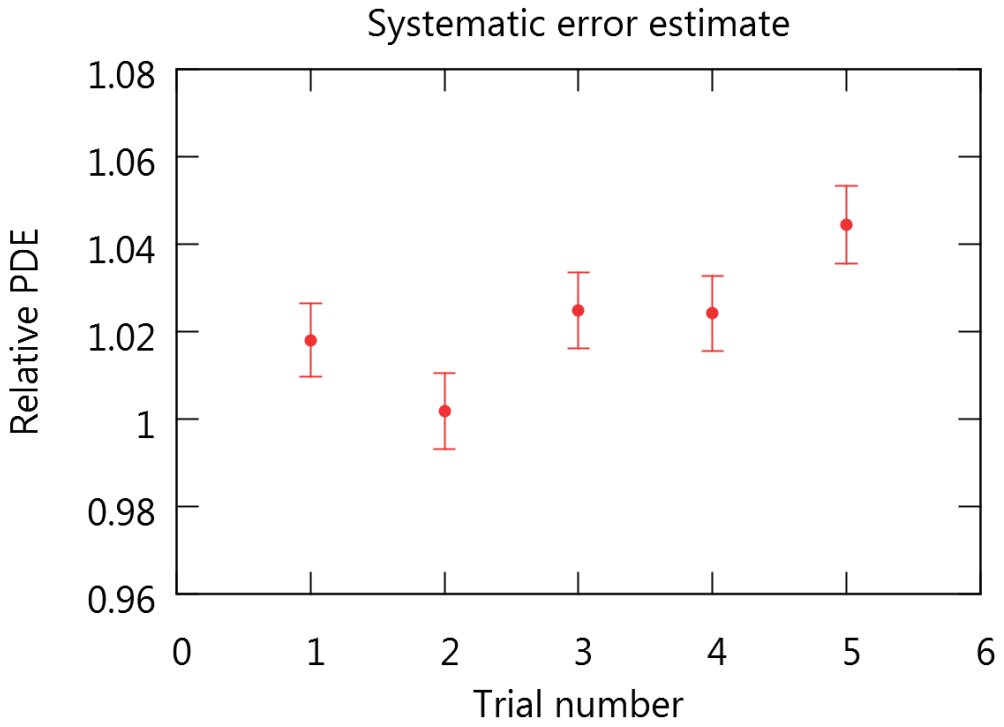

Using ADC with 0.25 pC/ch

Crosstalk suppression type: over voltage = 3.0 V

Fitting with double Gaussian

Evaluate gain and number of pedestal events

# Systematic Error Estimate

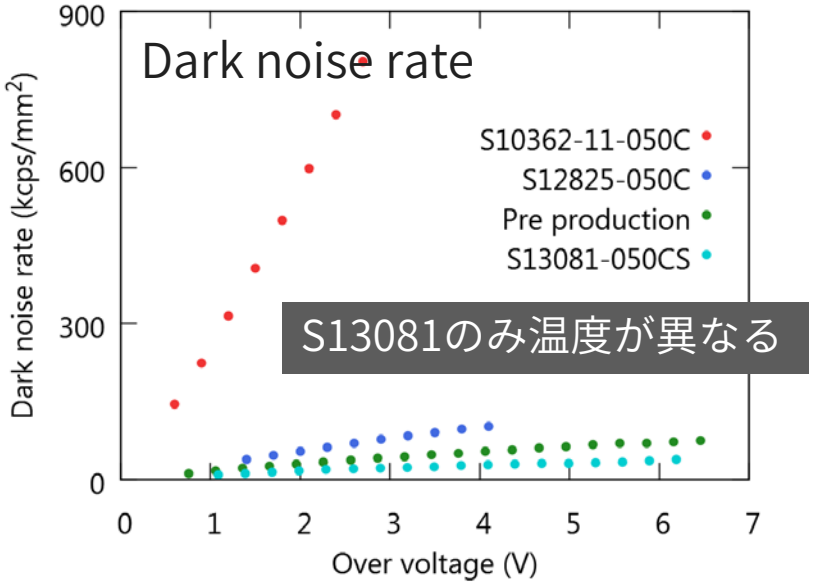


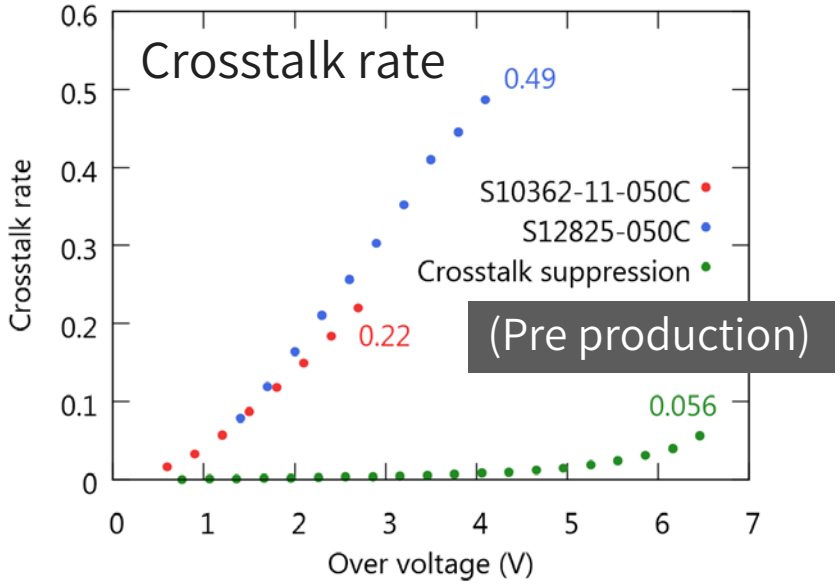

Estimate systematic error from attaching and detaching MPPC to measurement device

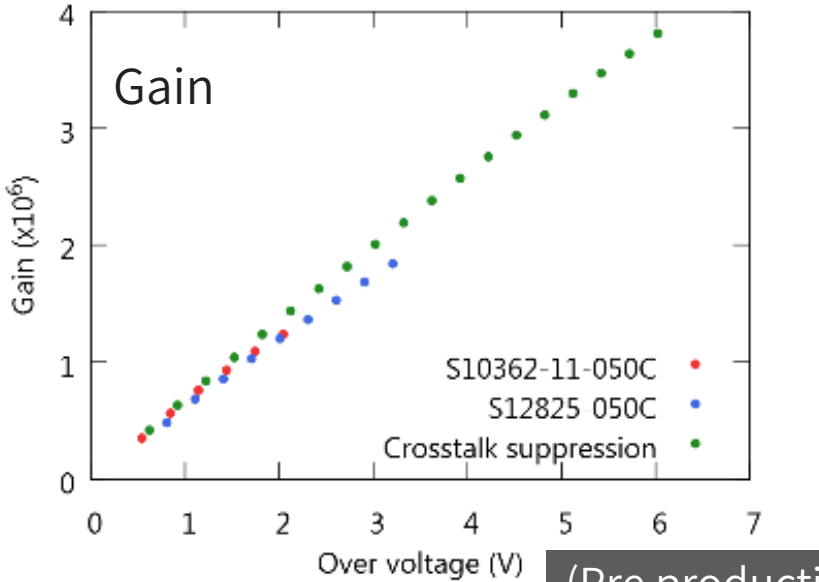
Measured five times

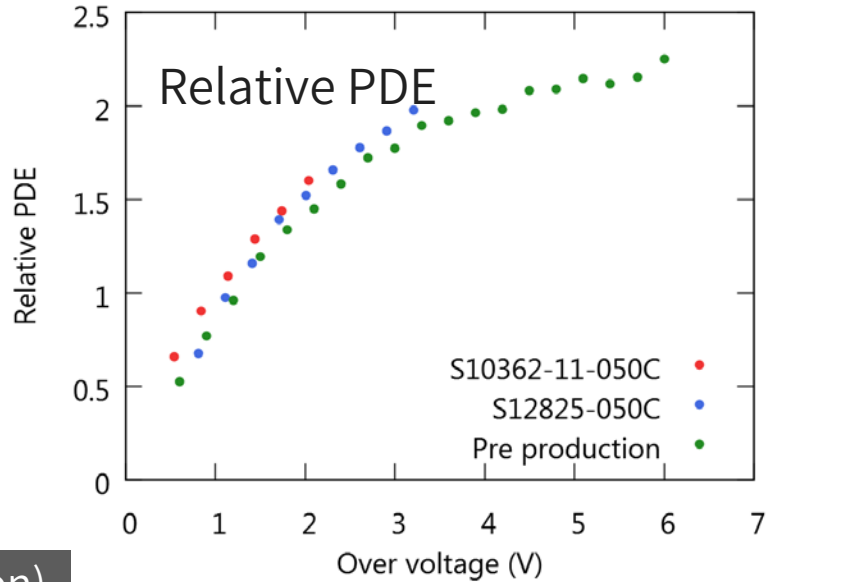
Deviation of relative PDE is about 5%

# Backup plots



# Latching Pulse

HPK specified Vmax for preproduction type.

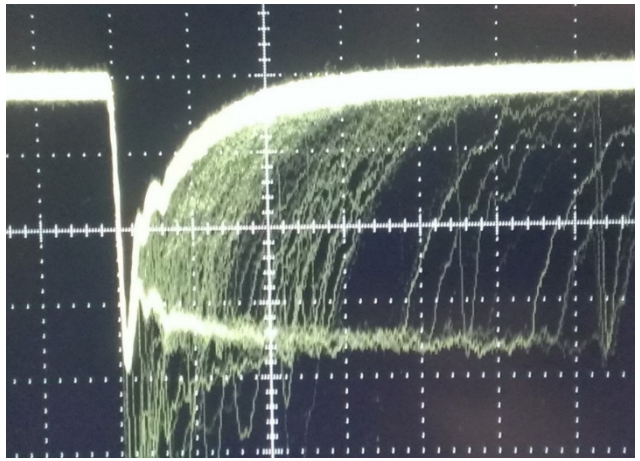
Vmax = 55.96 V

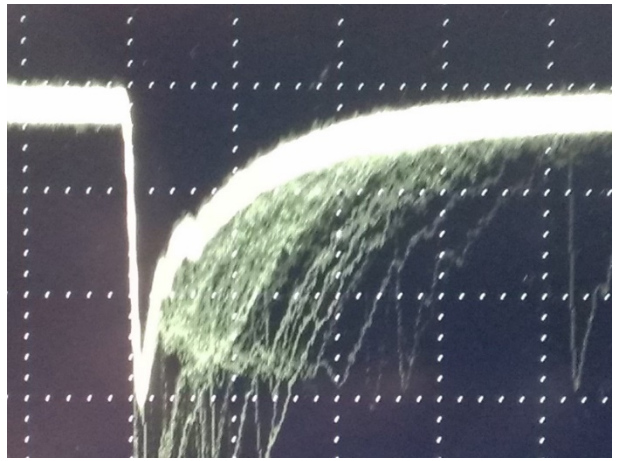
- Pre production type
- Over voltage=5.0 V

- S13081-050CS
- Over voltage=5.0 V
- Improved

Latching pulse occurred if MPPC used with bias voltage over Vmax.

It will be improved for production type.





# Relative PDE Derivation

Suppose Poisson distribution

Probability that N photons are detected:

$P(N)=\lambda^N e^{-\lambda} / N!$

$\lambda$ is mean value of detected photon.

P(0) = # of pedestal events / # of total entries

$\lambda = -\ln P(0)$

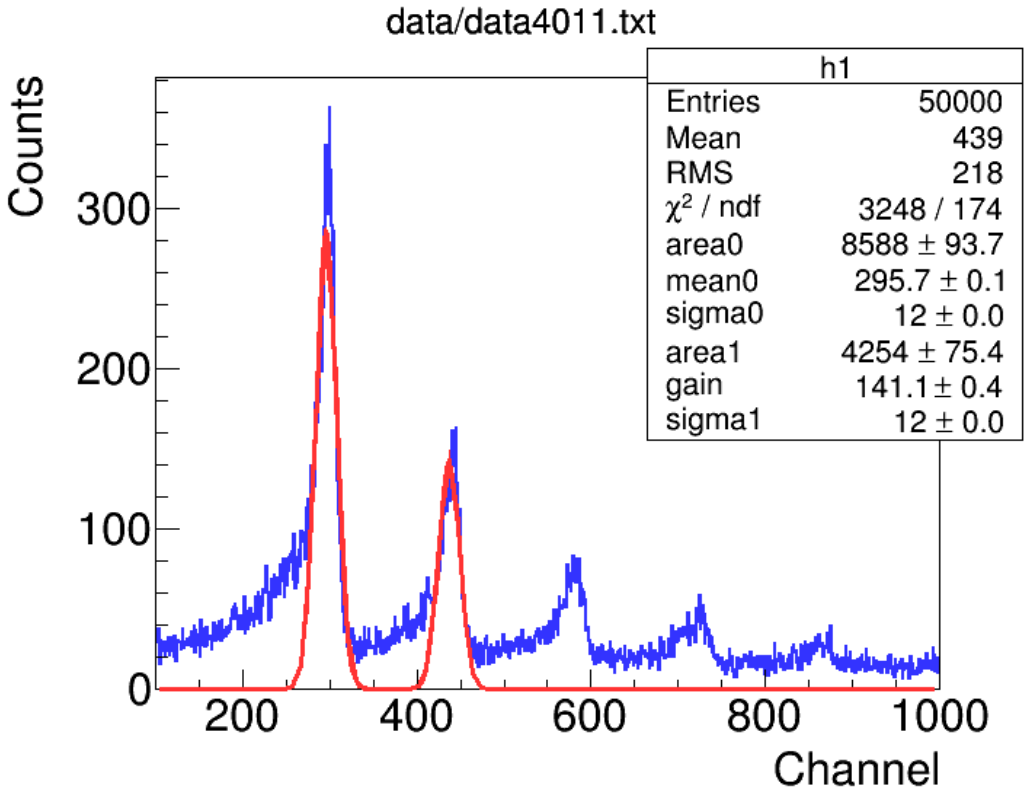
# MPPC Specification by HPK

## Measured MPPCs

| Type number | Serial number | Operation voltage (V) | Gain (x$10^6$) | Dark noise rate (kcps) | Breakdown voltage | V max | Notes |
|---|---|---|---|---|---|---|---|
| S10362-11-050C | 2660 | 71.12 | 0.750 | 396 | | | For monitor |
| S10362-11-050C | 2664 | 71.16 | 0.748 | 409 | 69.9 * | | |
| S12825-050C | 627 | 66.77 | 1.24 | 111 | 64.3 * | | |
| Crosstalk suppression | 105 | 54.96 | 1.50 | 55.1 | 51.96 | 55.96 | |

* Measured value

# Higher Over Voltage

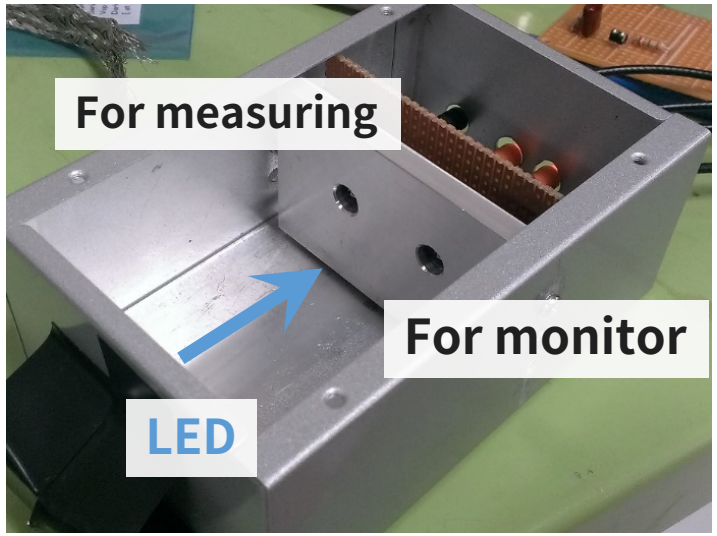



- S12825 type
  with over voltage = 4.4 V
- Charge distribution has a tail
  with lower channel

# Setup for measuring PDE

Prepare two MPPCs;
one for measuring and one for monitor

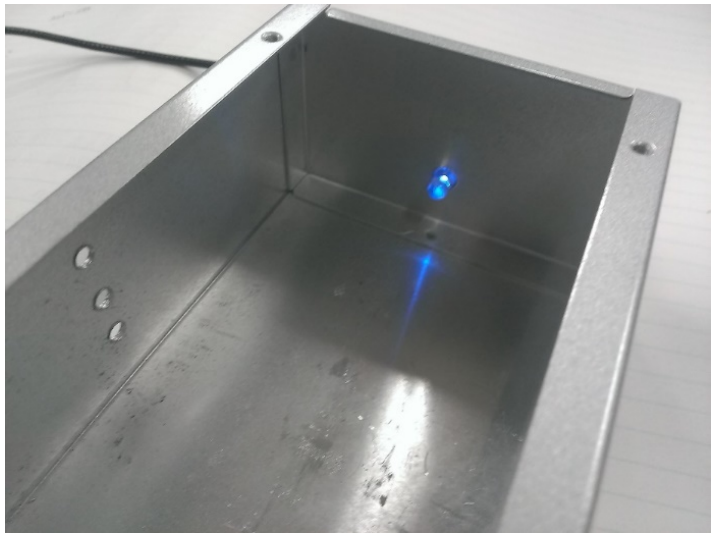
Take a ratio of these PDE and reduce LED light yield deviation




LED light source

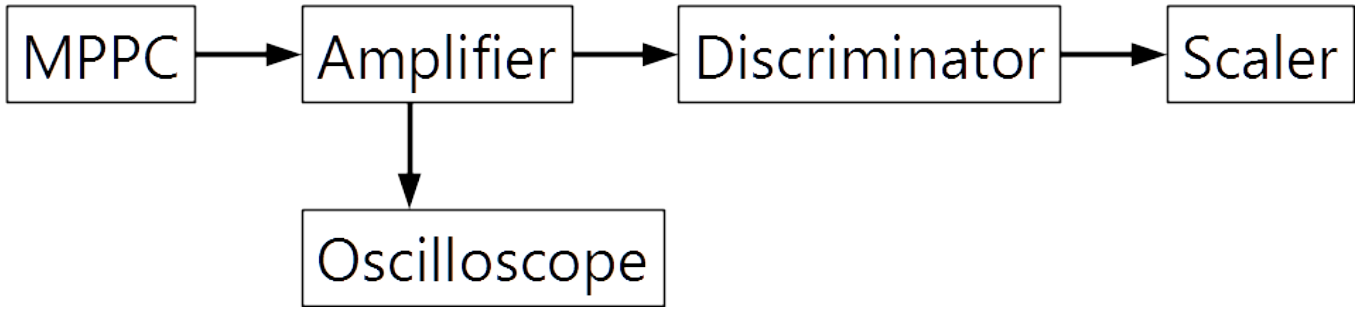
OptoSupply OSB5SA5111A-1V
λD = 465-475 nm

Attach a piece of white paper on LED to diffuse light



# Setup using self trigger

note



# Setup using LED

note