SiPM Characterization for CTA

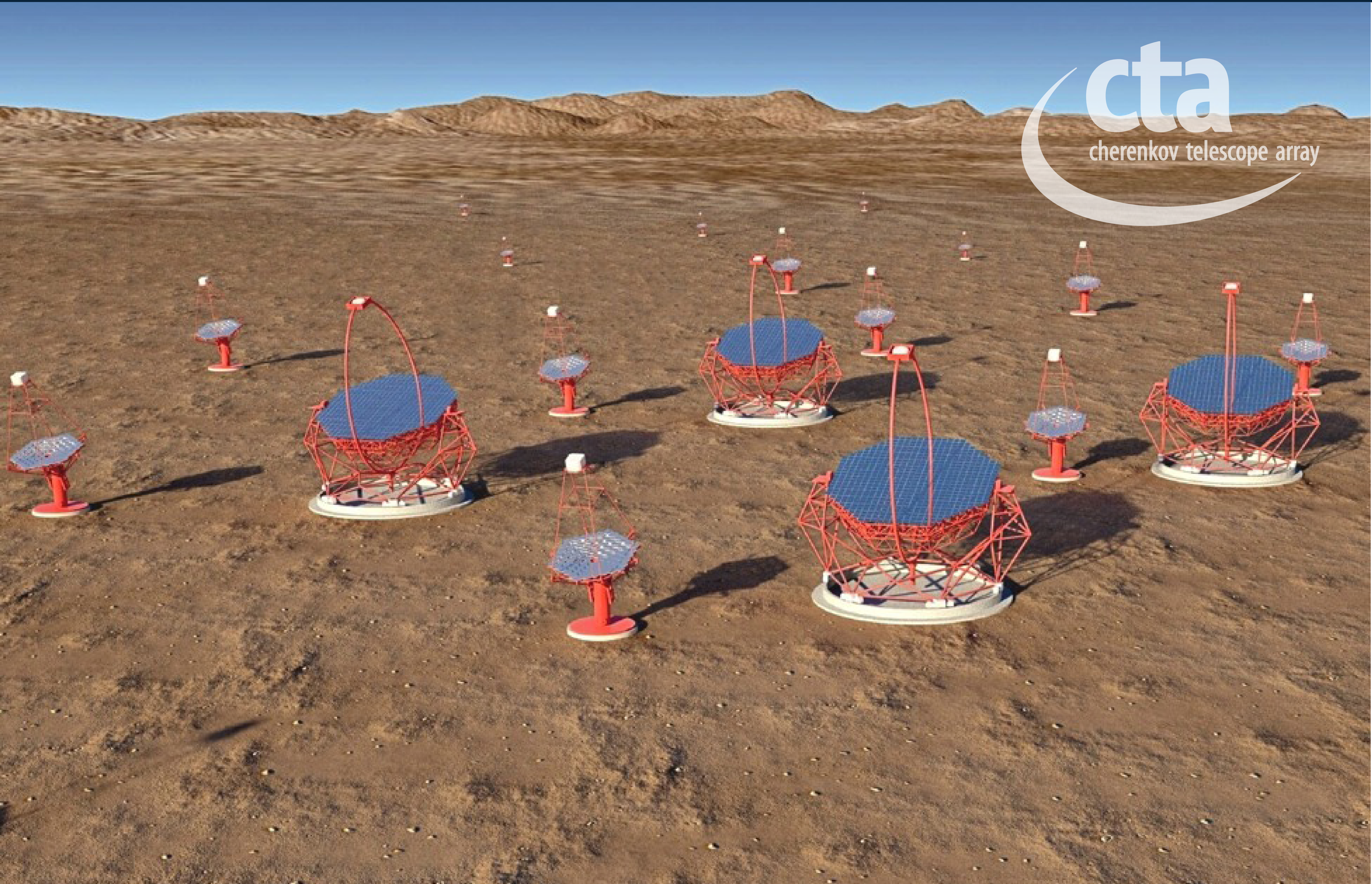
Naoya Hidaka
Nagoya University

SiPM Characterization for CTA

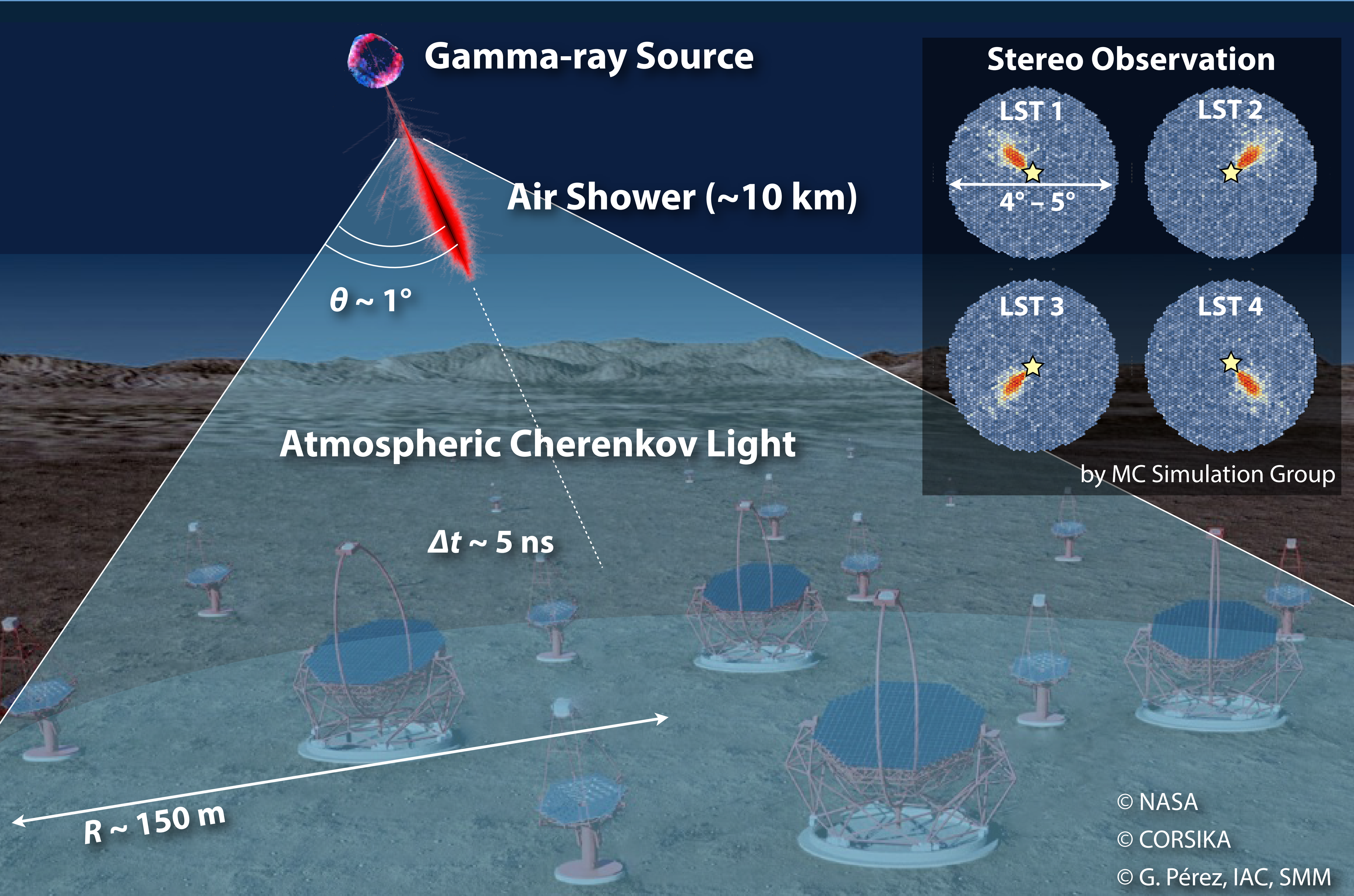
- CTA
- Cherenkov Camera
- SiPM (MPPC) Characterization

Naoya Hidaka
Nagoya University

Cherenkov Telescope Array

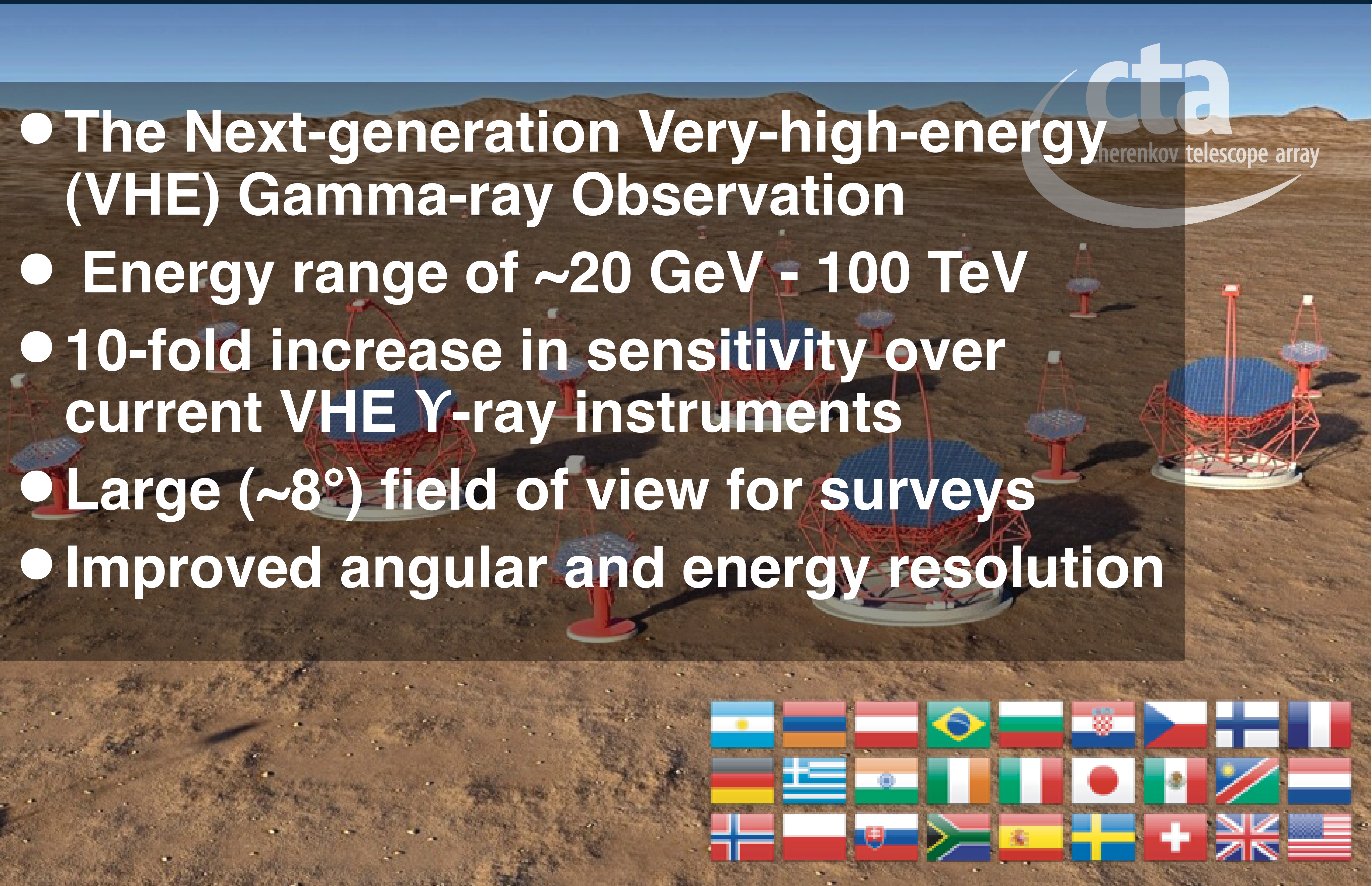


Cherenkov Telescope Array

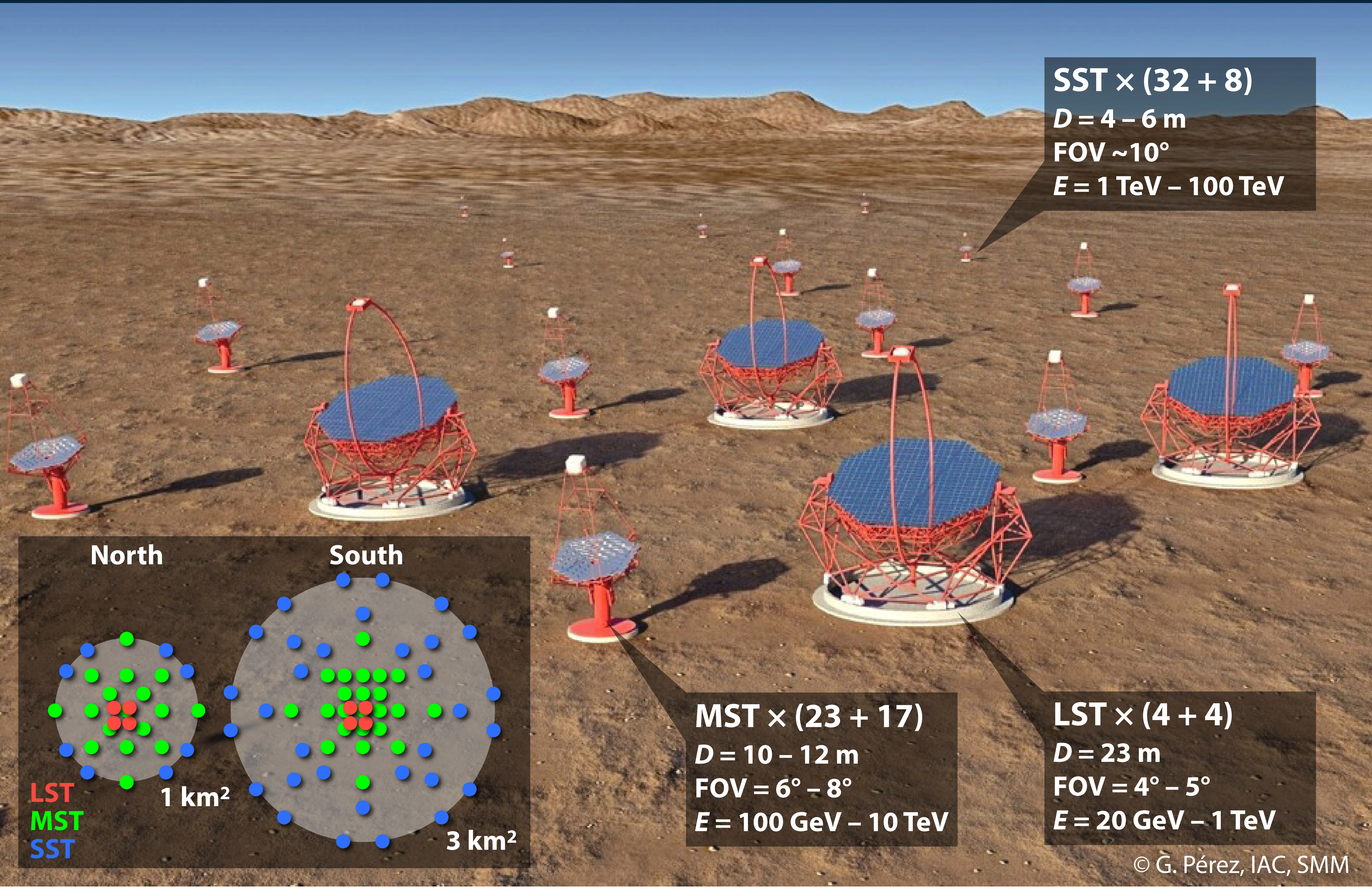


Cherenkov Telescope Array

- The Next-generation Very-high-energy (VHE) Gamma-ray Observation
- Energy range of ~20 GeV - 100 TeV
- 10-fold increase in sensitivity over current VHE γ-ray instruments
- Large (~8°) field of view for surveys
- Improved angular and energy resolution

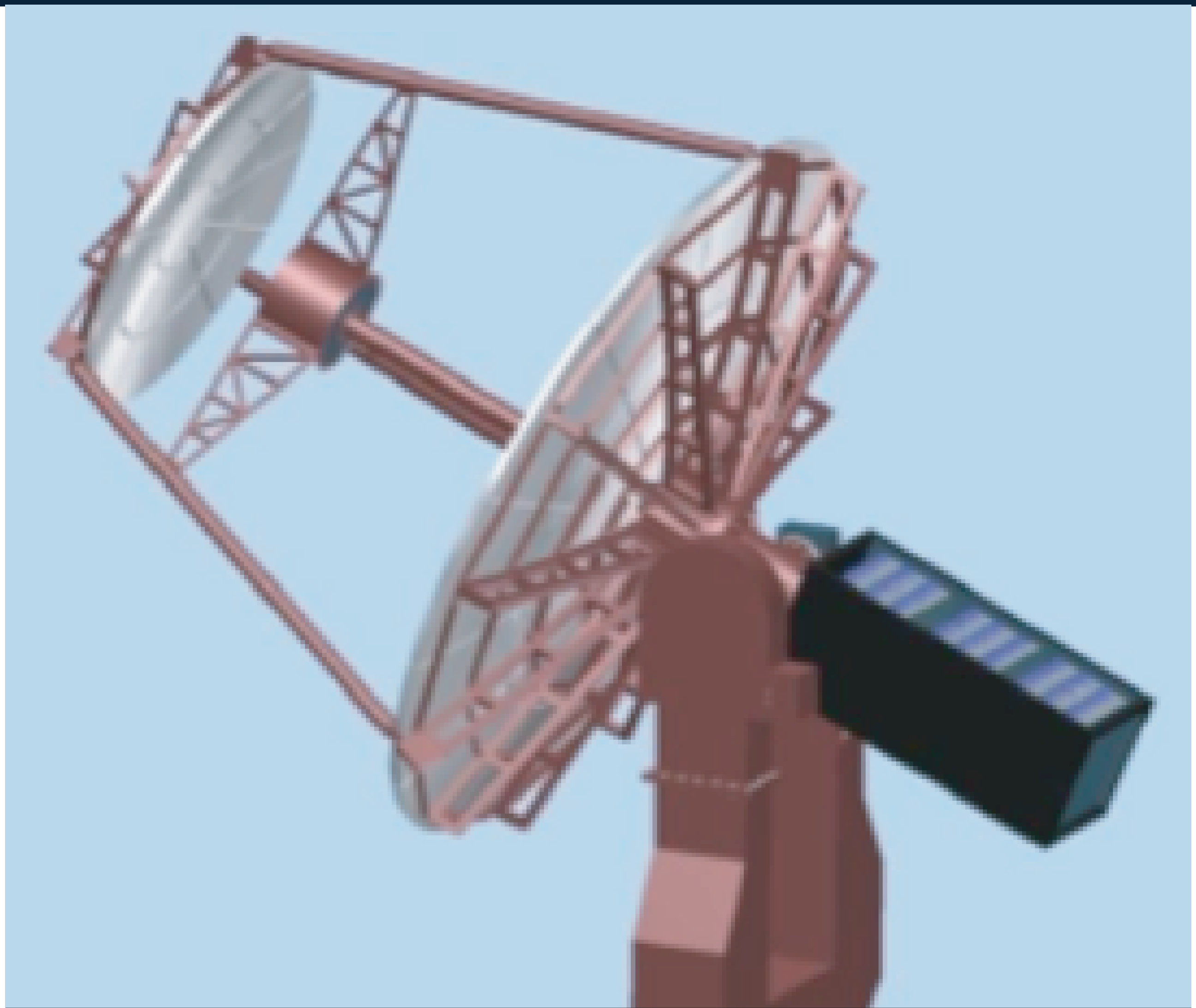


Cherenkov Telescope Array



Dual Mirror Telescope

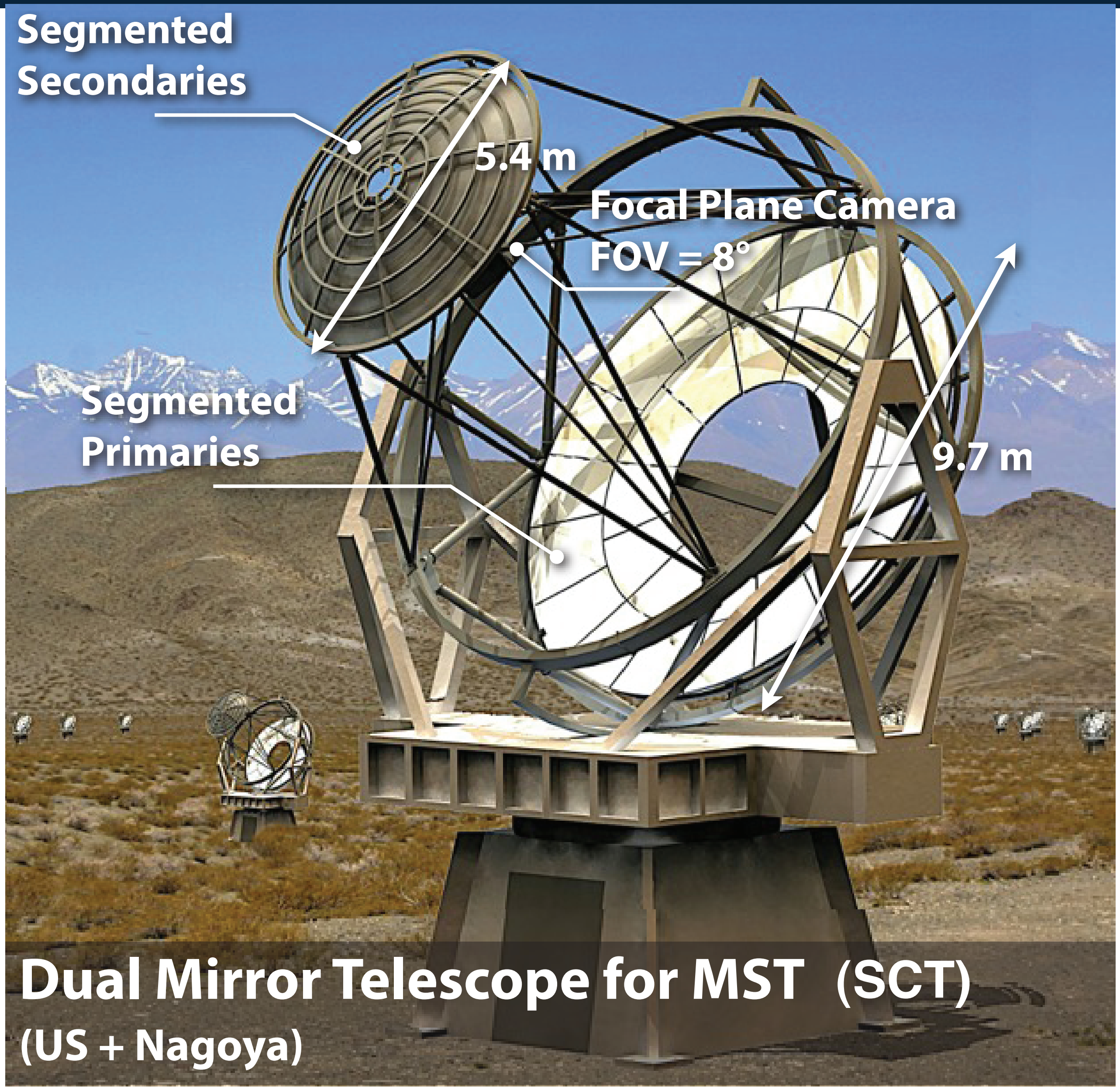
Dual Mirror Telescope for MST (SCT)
(US + Nagoya)



Dual Mirror Telescope for SST
(Europe + US + Nagoya)

- **wide FoV, high angular resolution with good off-axis response**
- **2-mirror design reduces plate scale allowing multi channel photodetectors and reducing costs**

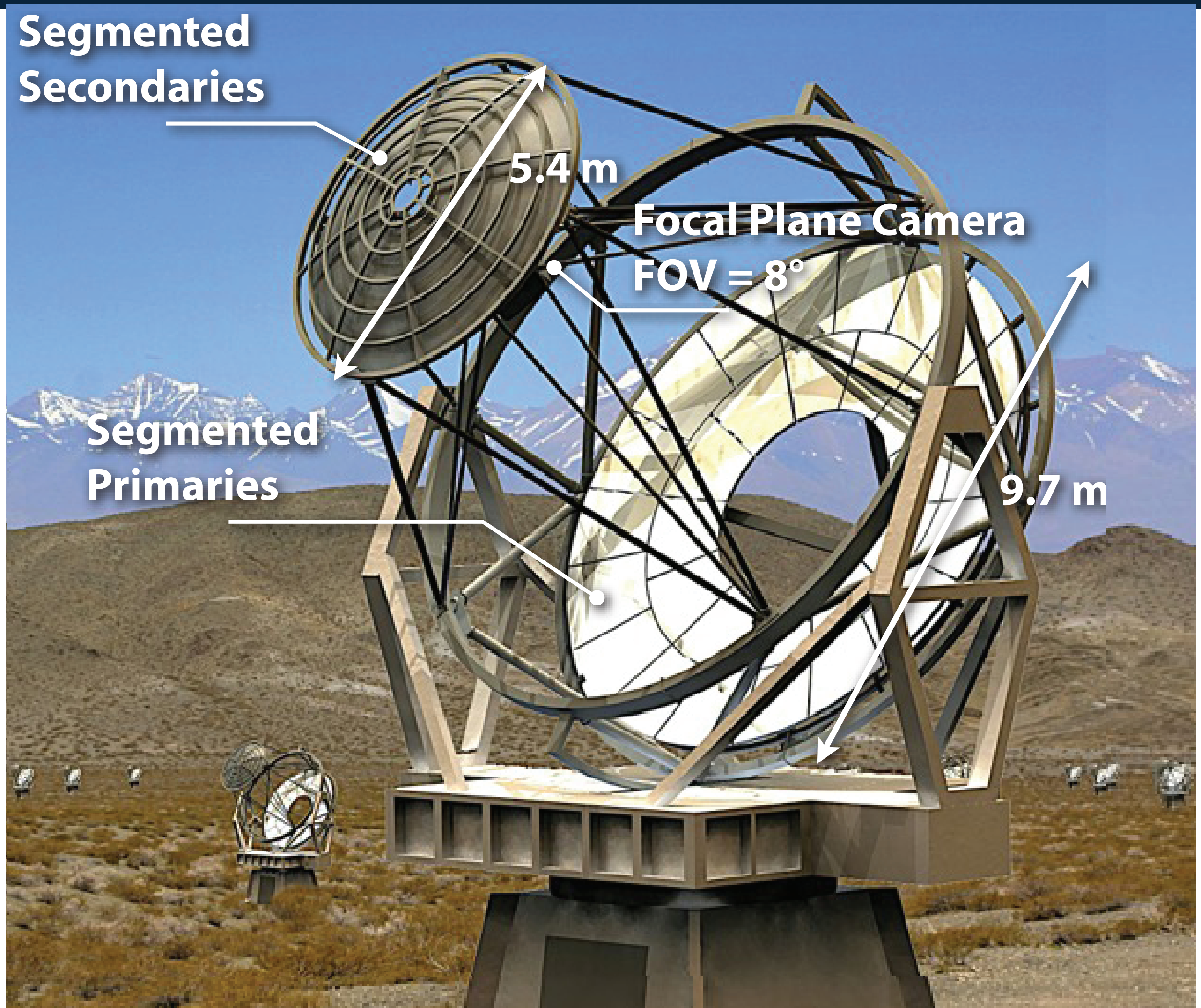
Dual Mirror Telescope



Wide FoV of 8°
Angular resolution: 4.0'

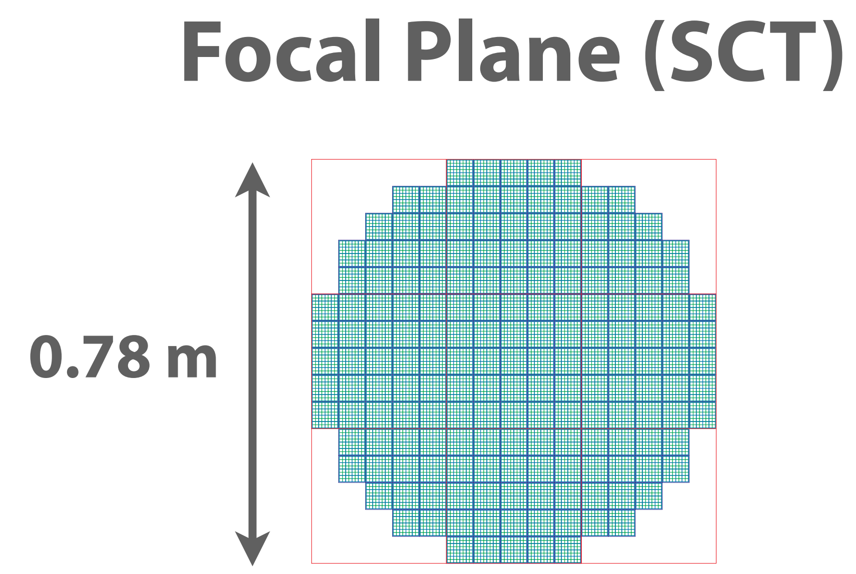
- **wide FoV, high angular resolution with good off-axis response**
- **2-mirror design reduces plate scale allowing multi channel photodetectors and reducing costs**

Dual Mirror Telescope



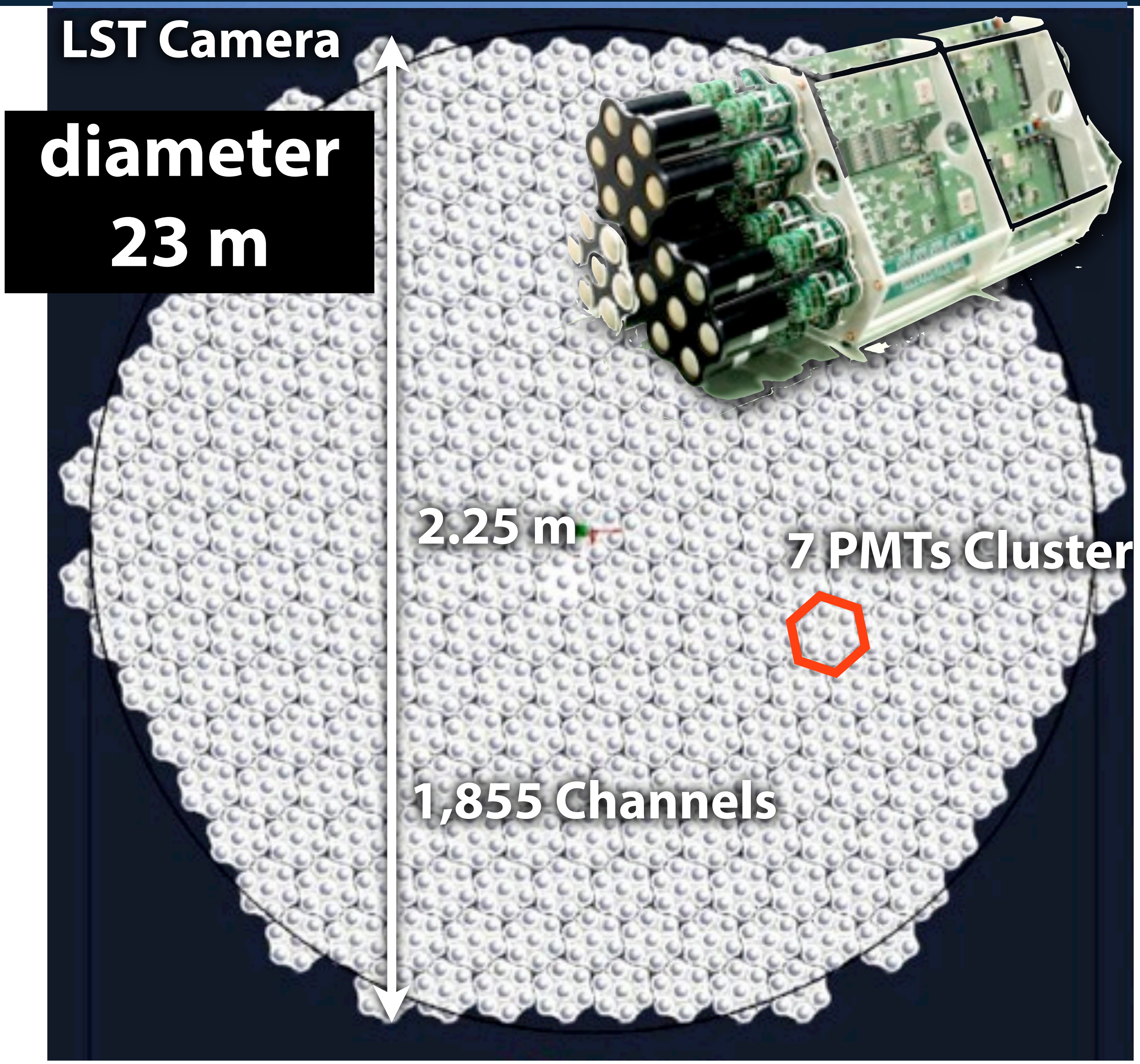
Dual Mirror Telescope for MST (SCT)
(US + Nagoya)

Wide FoV of 8°
Angular resolution: 4.0’

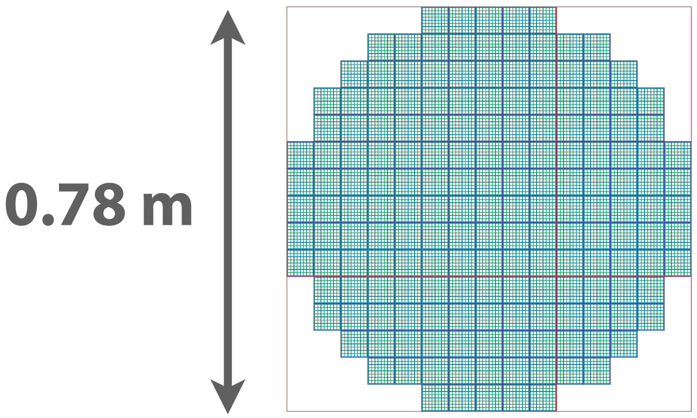


- **wide FoV, high angular resolution with good off-axis response**
- **2-mirror design reduces plate scale allowing multi channel photodetectors and reducing costs**

Dual Mirror Telescope



Wide FoV of 8°
Angular resolution: 4.0'



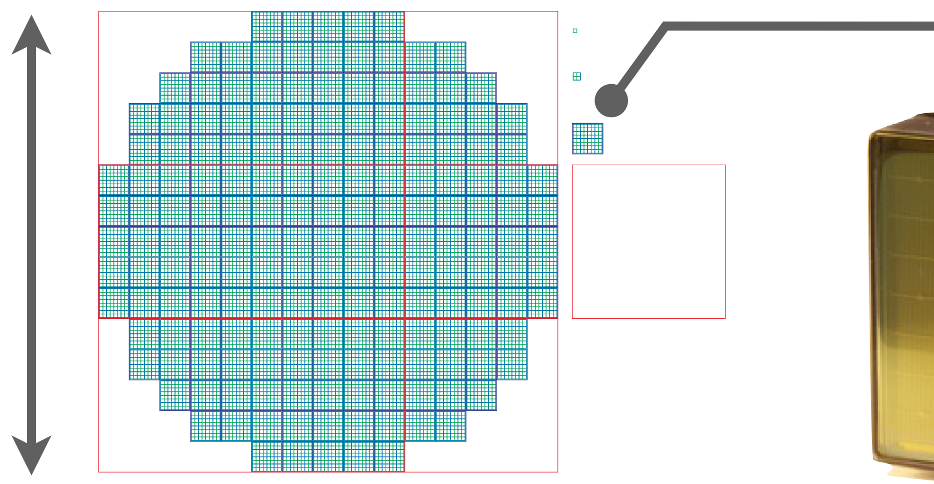
- **wide FoV, high angular resolution with good off-axis response**
- **2-mirror design reduces plate scale allowing multi channel photodetectors and reducing costs**

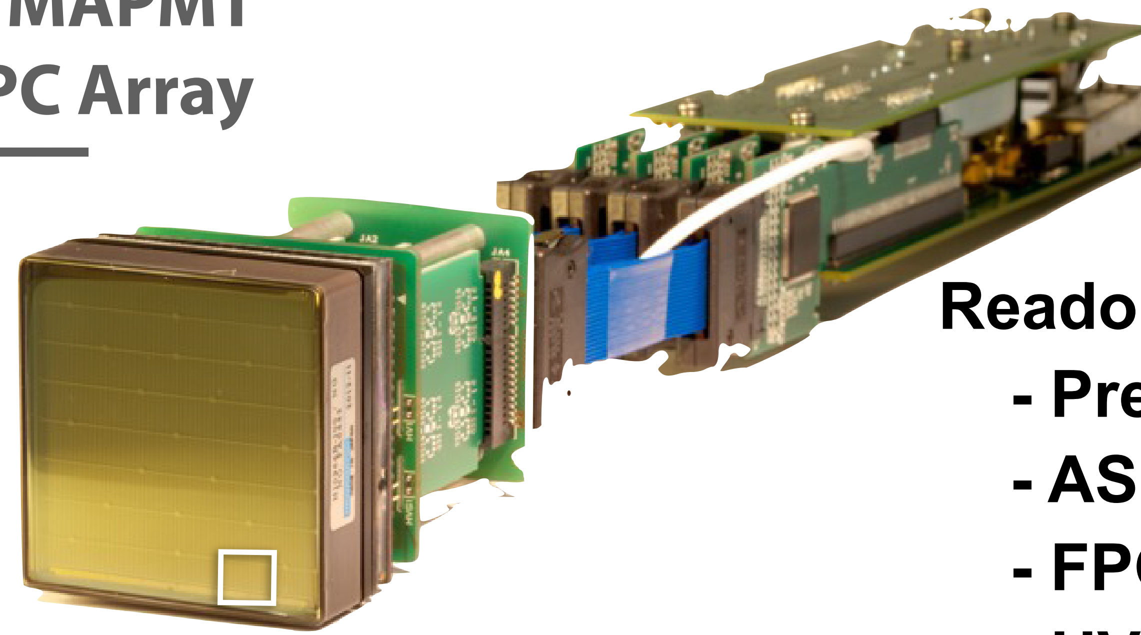
Camera Module

Focal Plane (SCT)

Single MAPMT
or MPPC Array

0.78 m

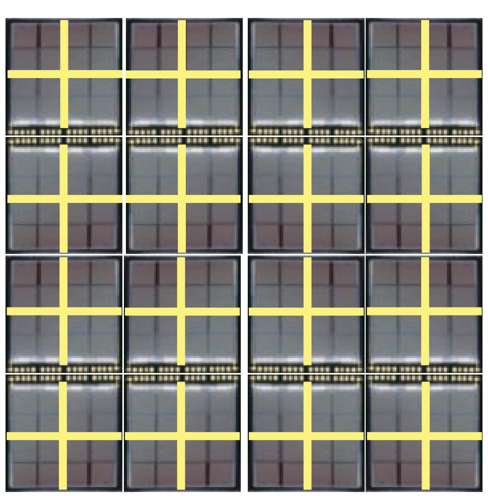




Readout module
- Preamp
- ASIC (“TARGET”)
- FPGA
- HV etc...

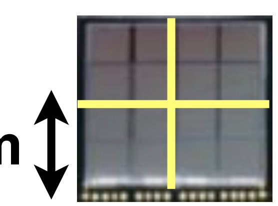
MAPMT
6.08 mm × 6.08 mm /ch
8 ch × 8 ch

11,328 Channels



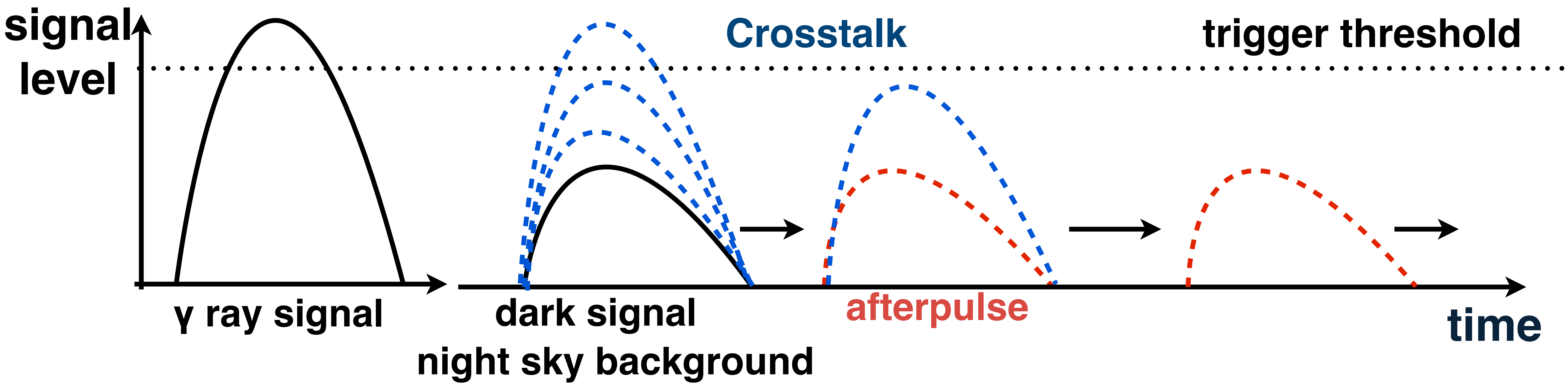
Multi Pixel Photon Counter (MPPC)
Silicone Photomultiplier device of
Hamamatsu photonics

6 mm



Higher Photon Detection Efficiency

SiPM(MPPC) Characterization



Measure ratio of photon detection efficiency (PDE) compared with MAPMT

→ ~ 60% higher light yield than MAPMT

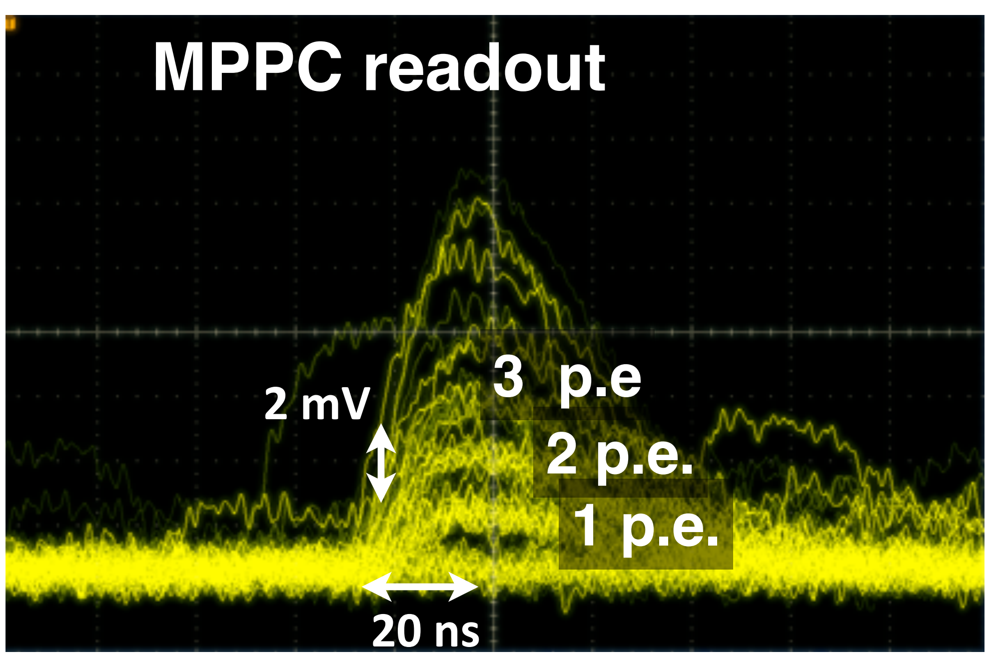
Temperature dependence of MPPC performance

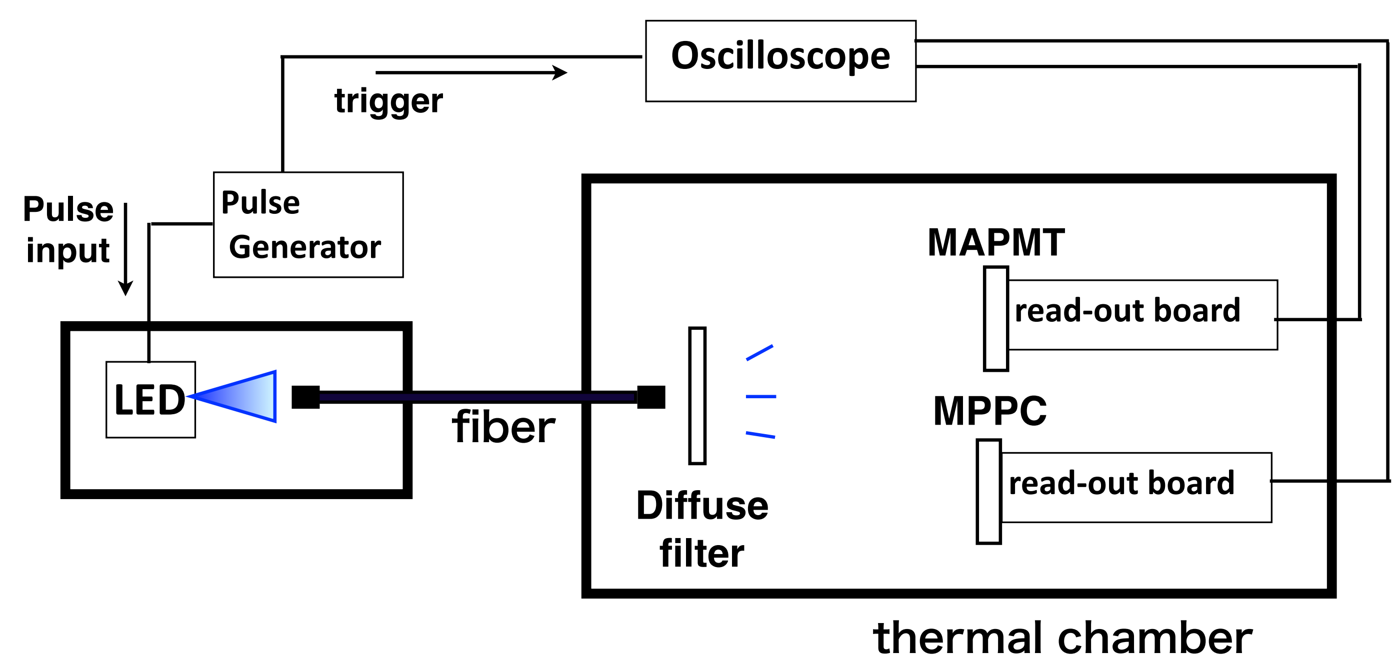
- Need to know operating temperature range of MPPCs at optimum performance conditions
- Gain, PDE
- Dark rate, Afterpulse ,Crosstalk

  →Accidental trigger rate

SiPM(MPPC) Characterization

- **Setup**
  - Waveform recording
    - Proper pile up treatments
    - Precise measurement of pulse shape (=gain)
    - Removal of accidental dark pulse
    - After pulse detection at small Δt by subtraction of primary pulse shape
- **Measurements**
  - PDE, gain, dark rate, crosstalk, after pulse rate
  - Wavelength dependence, temperature dependence



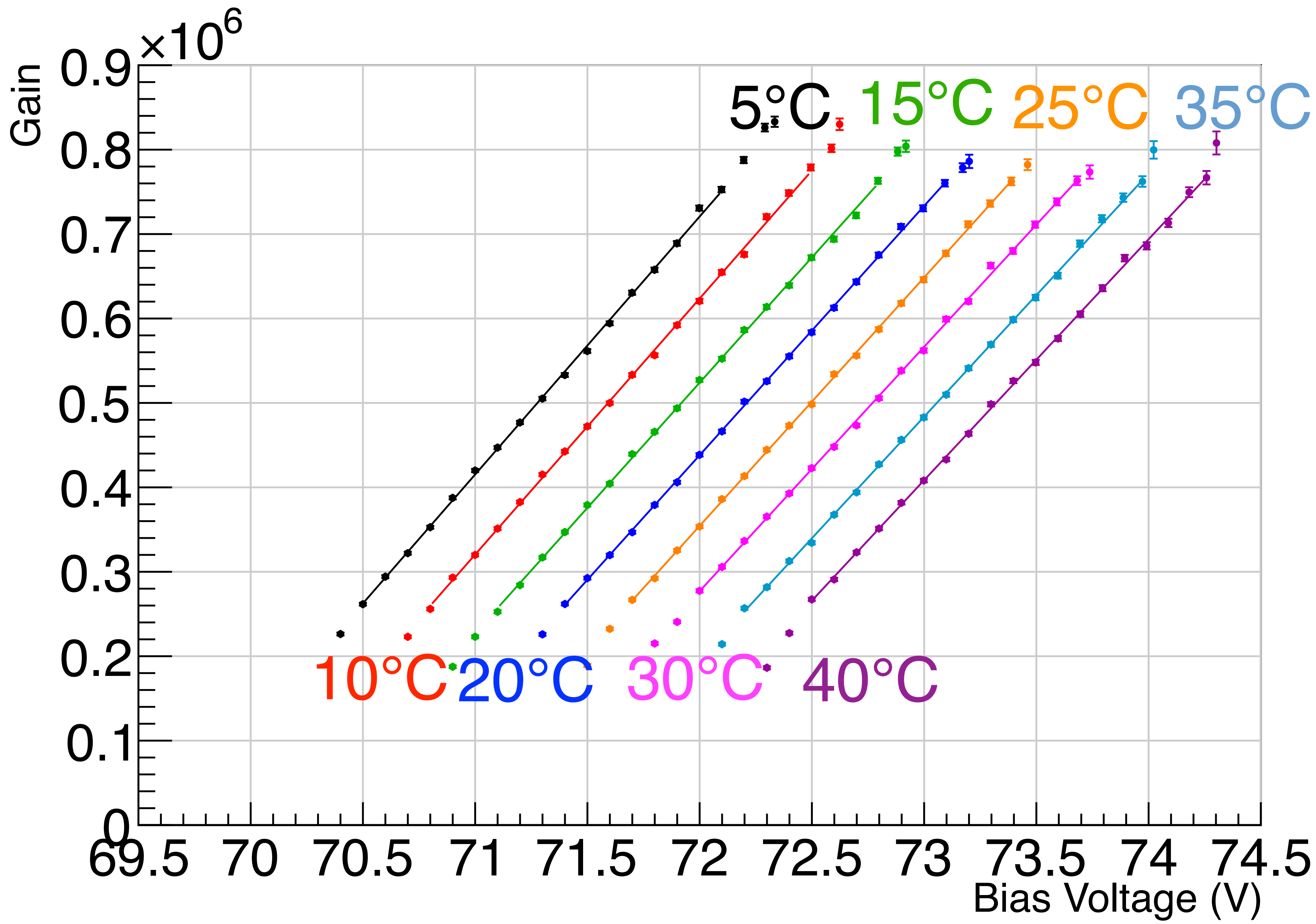


Gain

Integrate current output $V_{1\ p.e.} / R_f$

$V_{1\ p.e.}$: output voltage / p.e. (from the histogram of pulse hight)

R_f: feedback resister

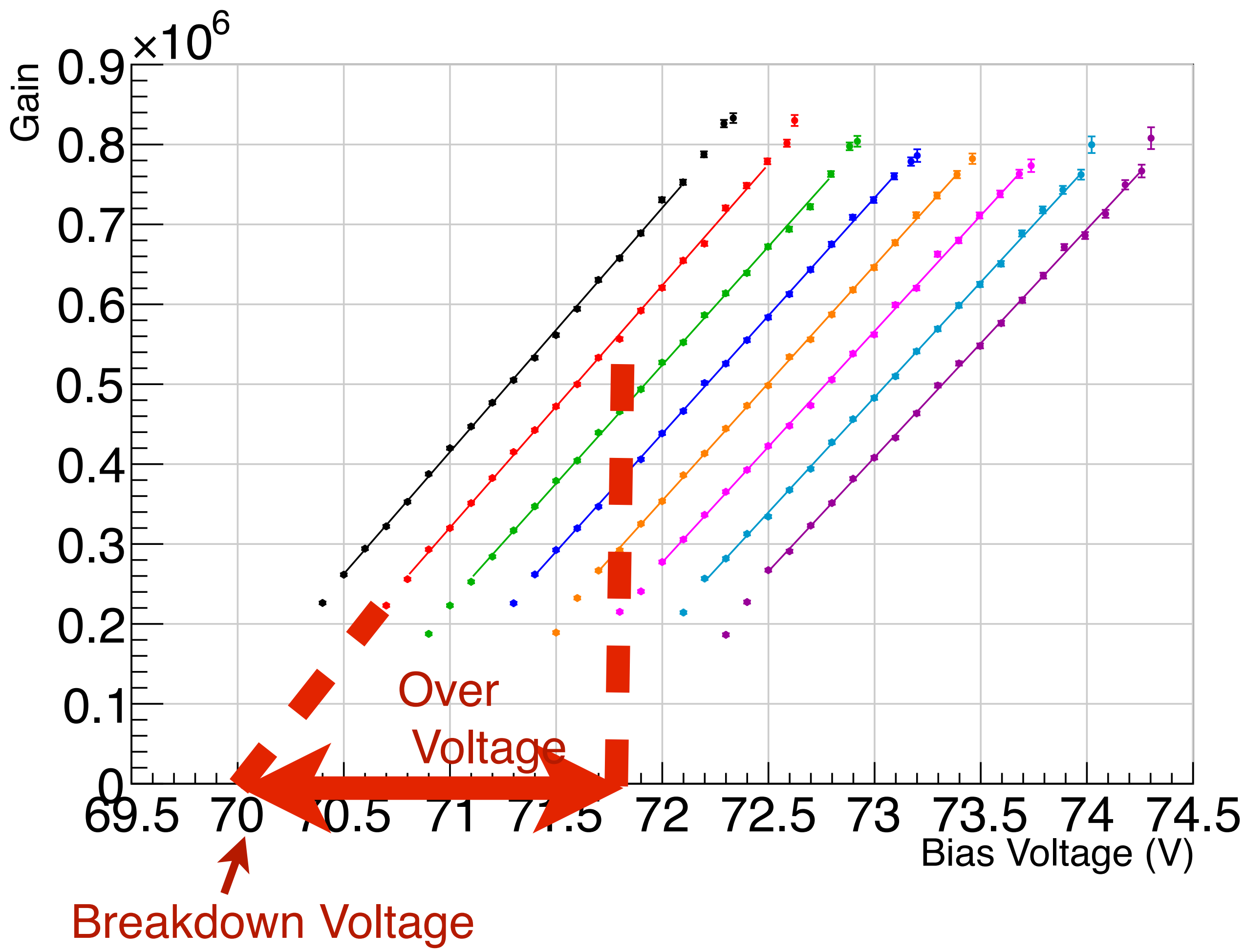


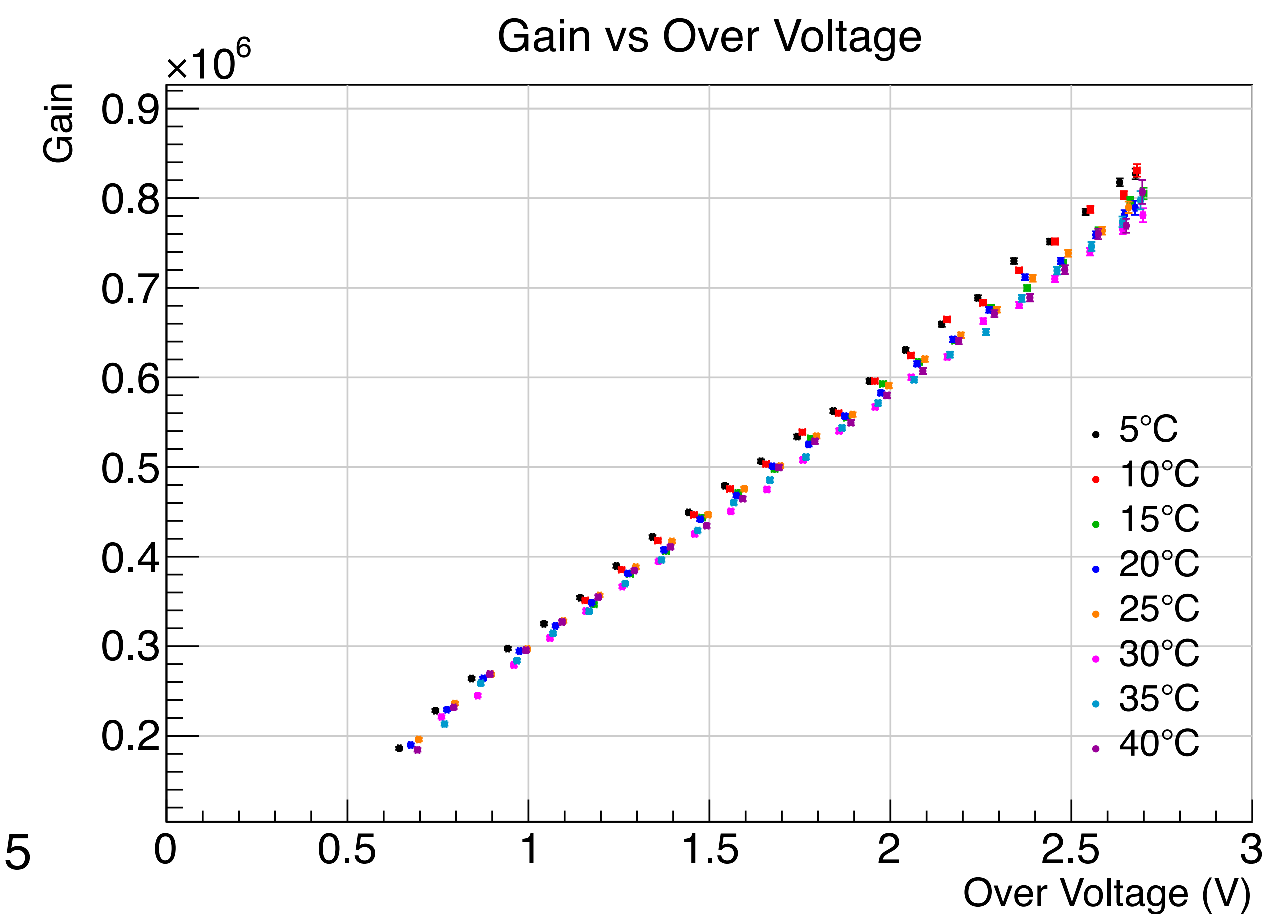
Gain

Integrate current output $V_{1\ p.e.} / R_f$

$V_{1\ p.e.}$: output voltage / p.e. (from the histogram of pulse hight)

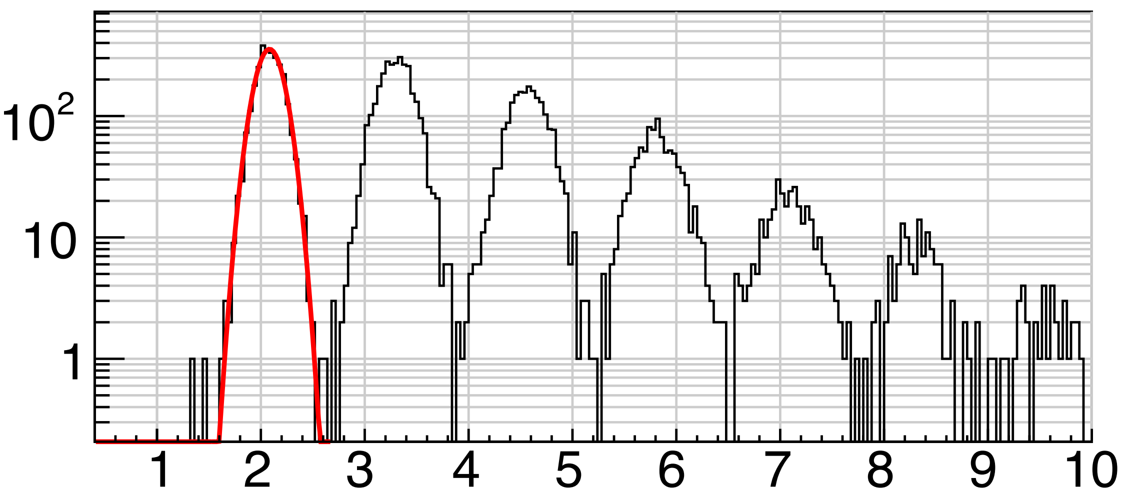
R_f: feedback resister

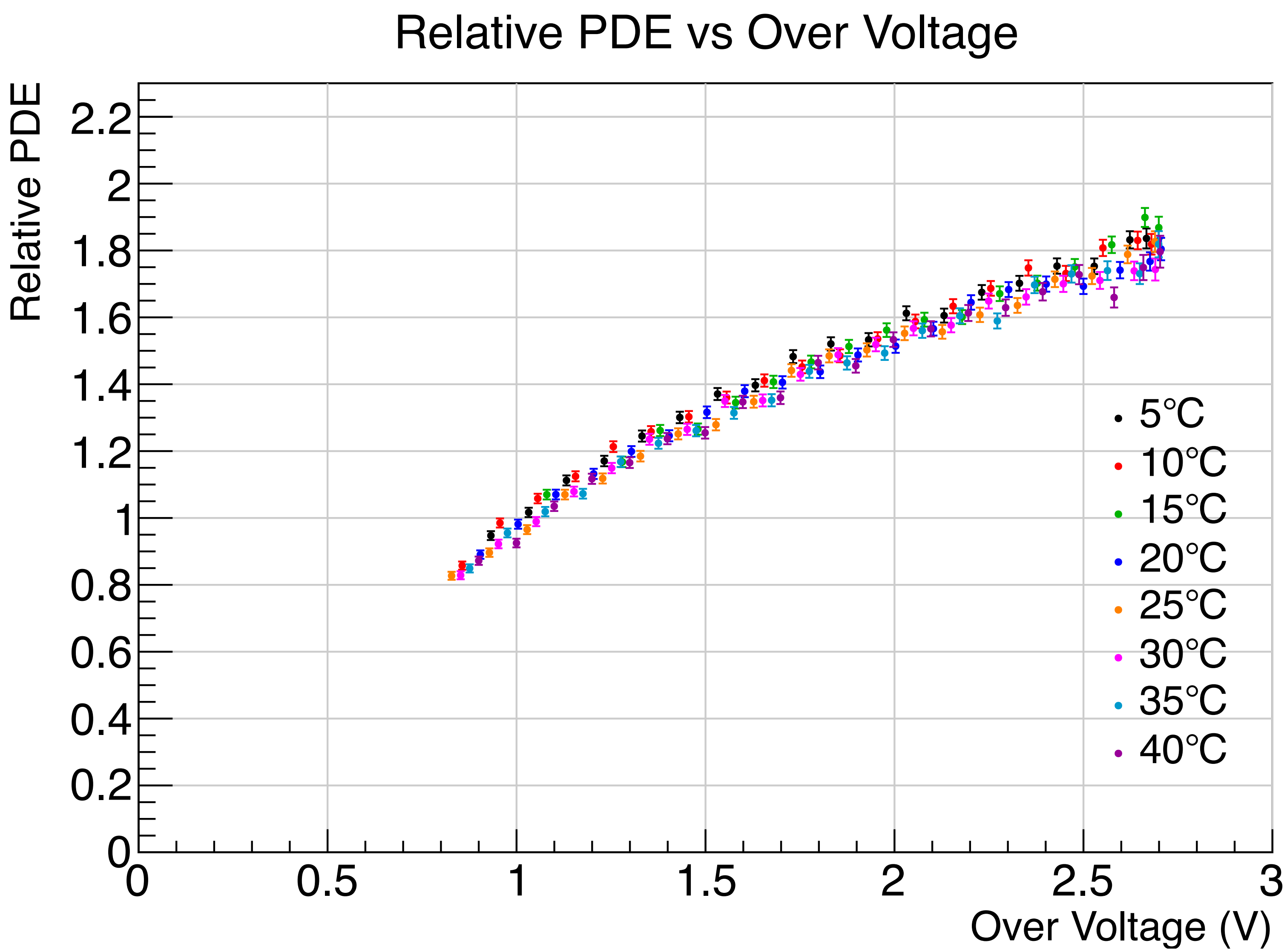




Photon Detection Efficiency

Count the number of detected photons from pulse height distribution

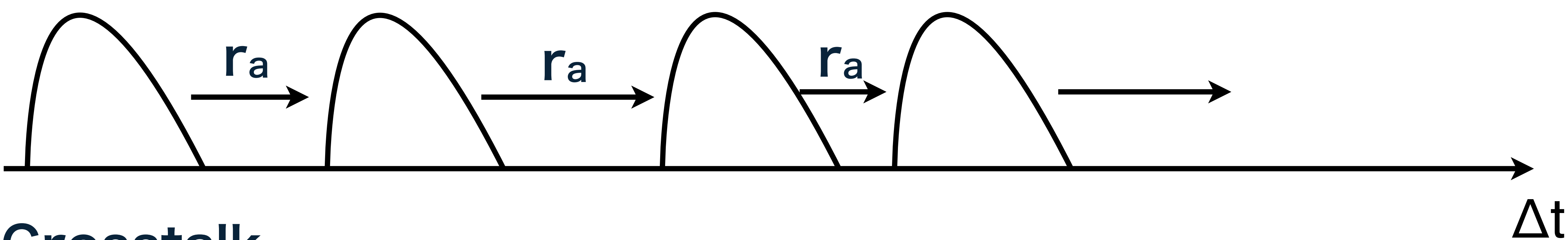




PDE have stable performance under control of bias voltage
accidental trigger rate is more important
→dark count, crosstalk rate,afterpulse rate measurement

Pixel Trigger Rate

- Dark count + Night Sky Background
- Afterpulse rate r_a
  - factor $\frac{1}{1 - r_a}$



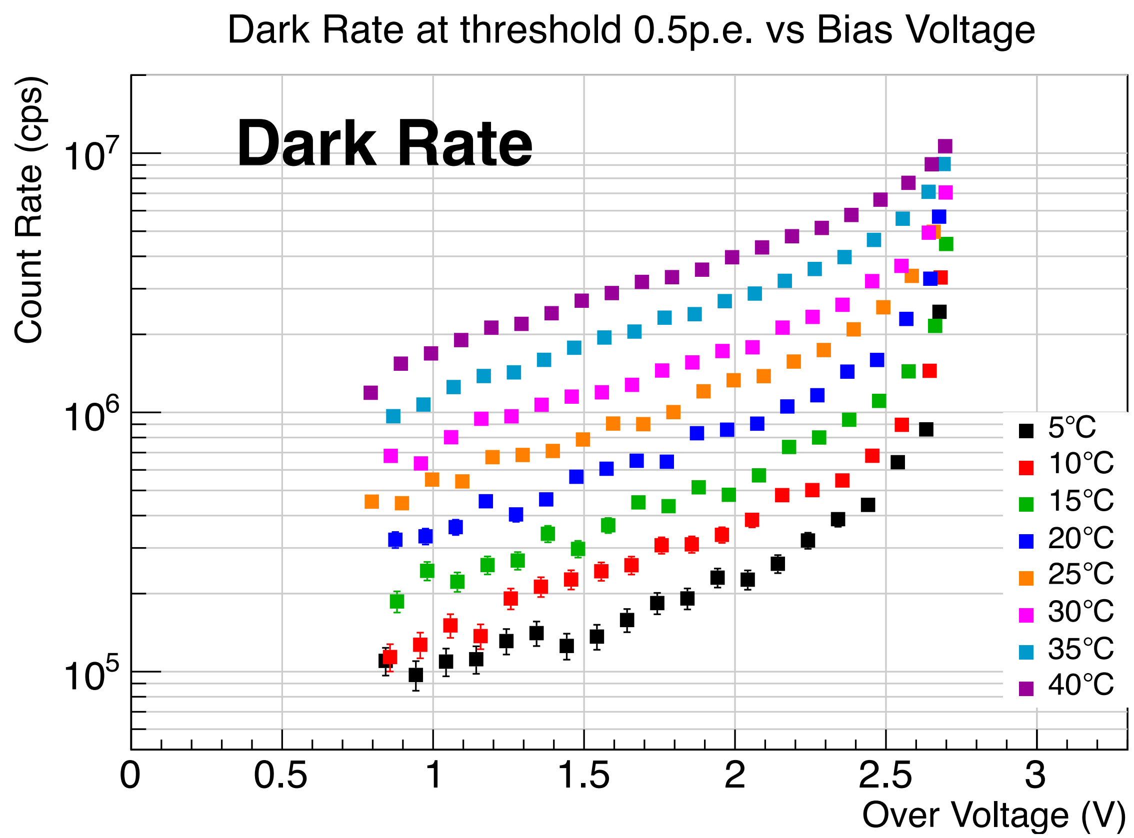
- Crosstalk

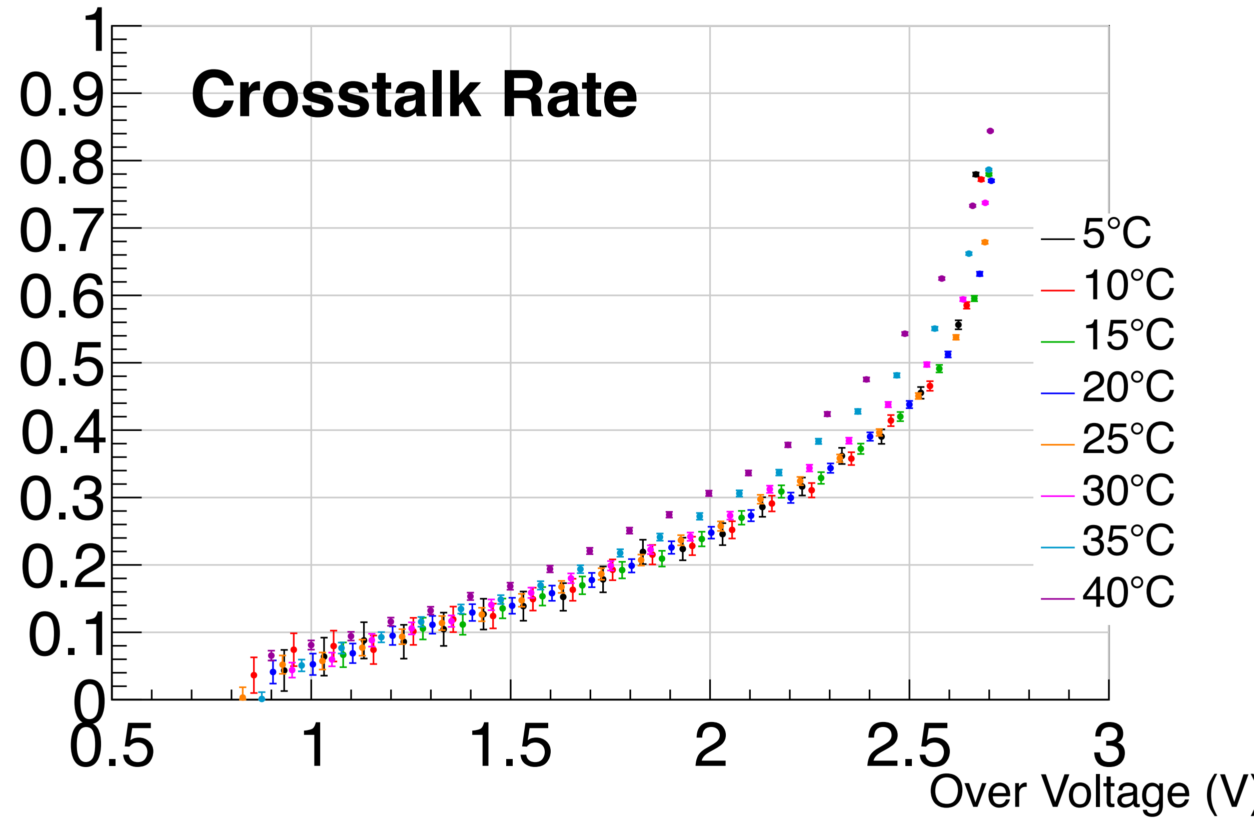
→ **4 p.e. threshold**

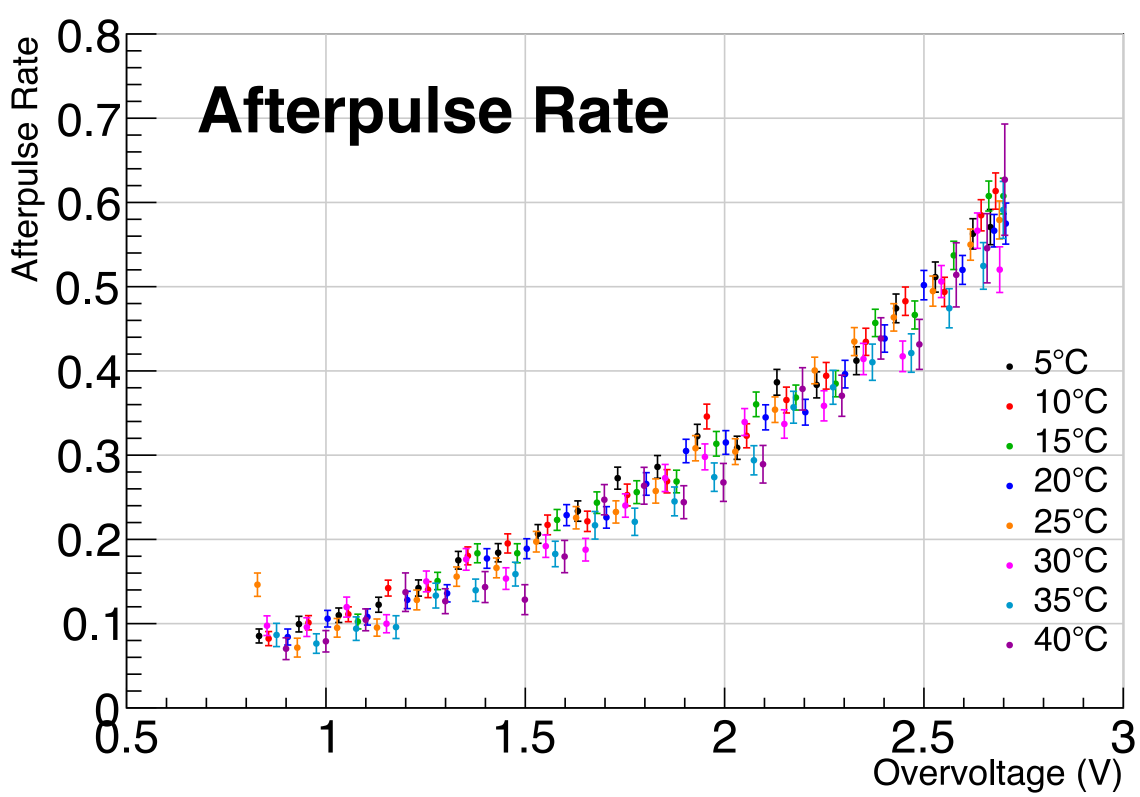
$$(f_{NSB} \cdot PDE + \underline{f_{dark}}) \times \underline{\frac{1}{1 - r_a}} \times \{\underline{1 - (P(0) + P(1) \times P(0) + P(2) \times P(0)^2 + P(1) \times P(1) \times P(0))}\}$$

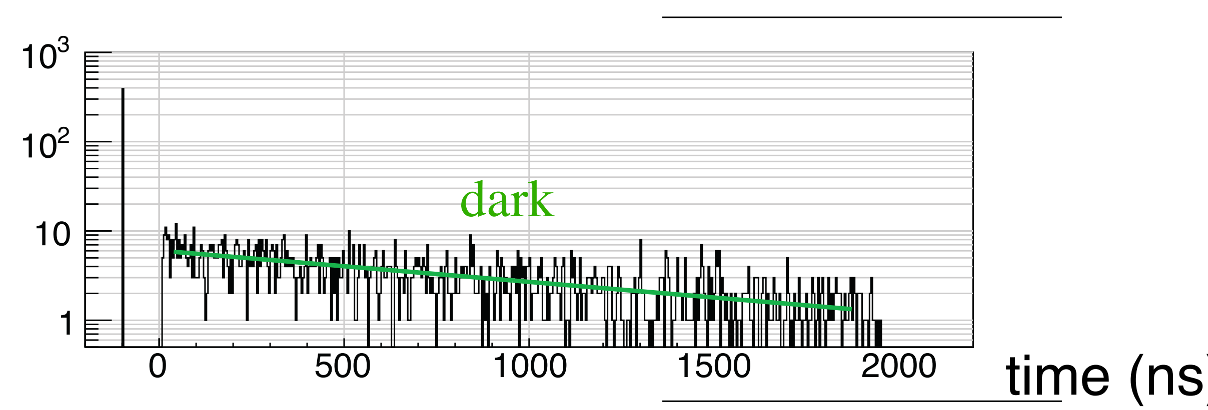
f_{NSB} : Night Sky Background rate
f_{dark} : Darkcount Rate

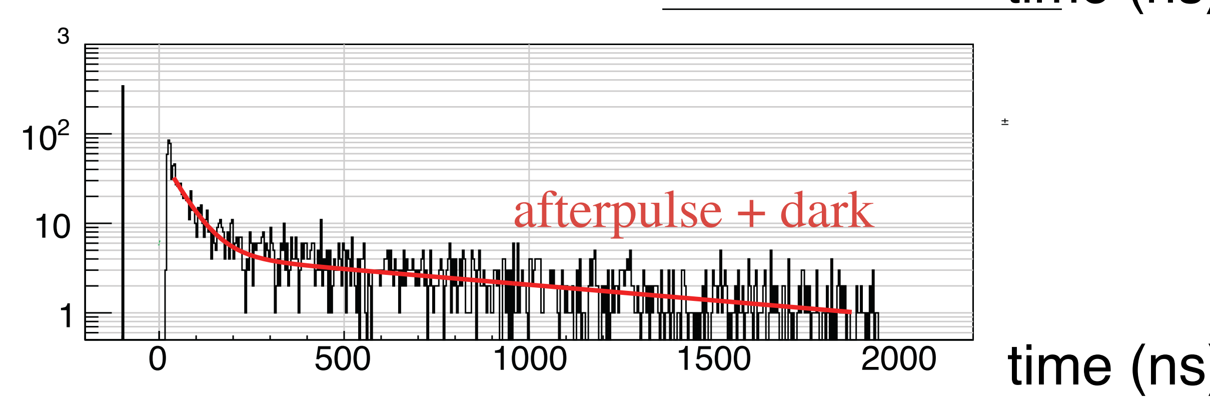
Dark rate, Afterpulse, Crosstalk





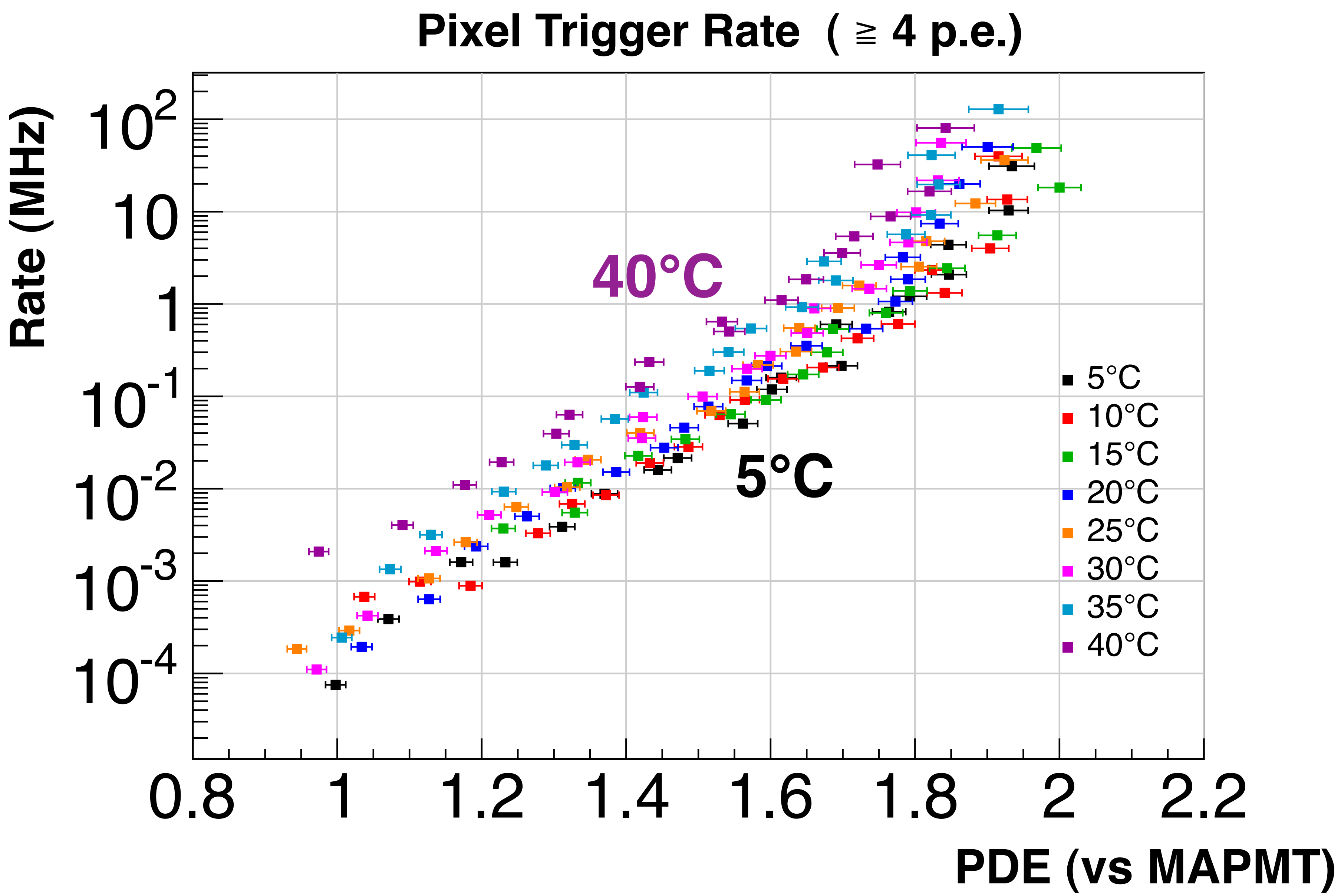






Pixel Trigger Rate

- 6mm × 6mm pixel
- NSB = 5 MHz

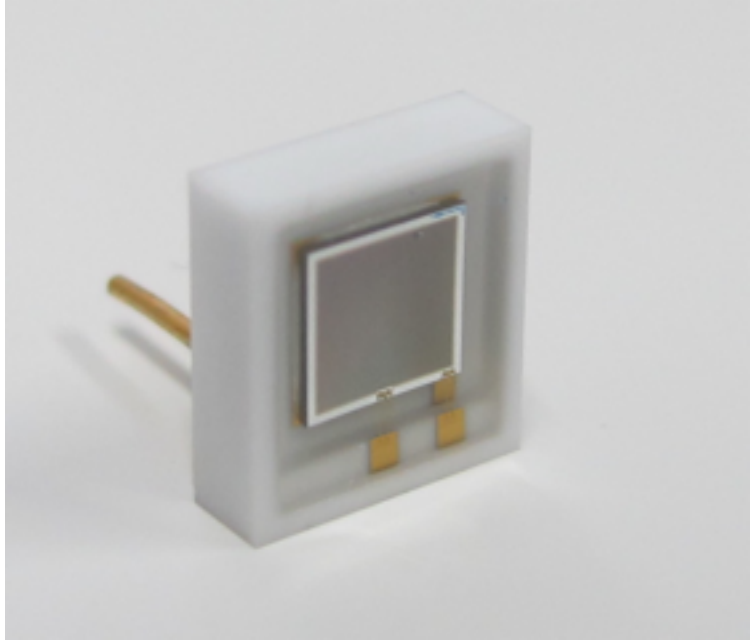


→ ～10 MHz at high PDE

increase 10 times from 5°C to 40°C

Recent Work

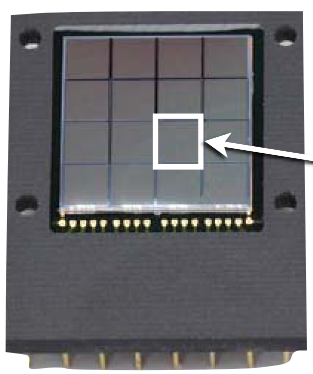
- Evaluation the accidental trigger rate
  - Simulation with trigger logic of telescope
- MPPC with trenches
  - implemented to suppress crosstalk
- evaluation of performance of “camera module”
  - MPPC array + readout



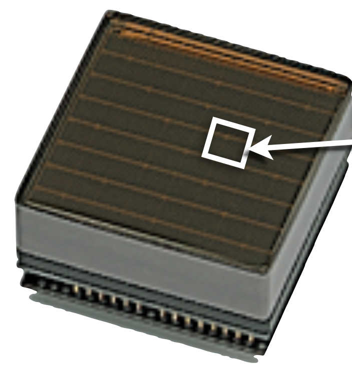
Back up

Photon Detection Efficiency Comparison

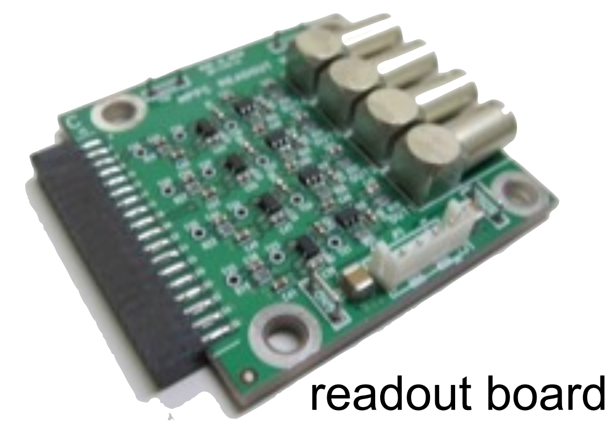
Measure ratio of MAPMT efficiency compared with MPPC efficiency

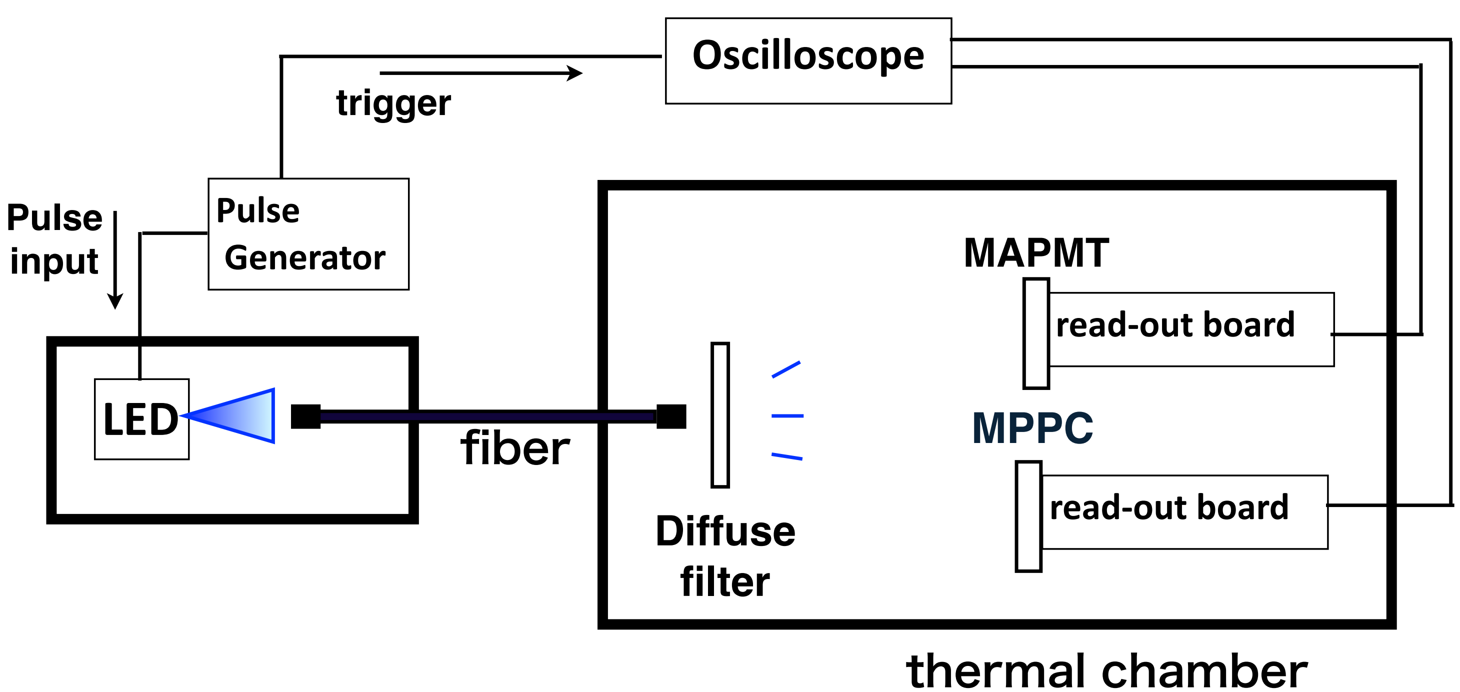


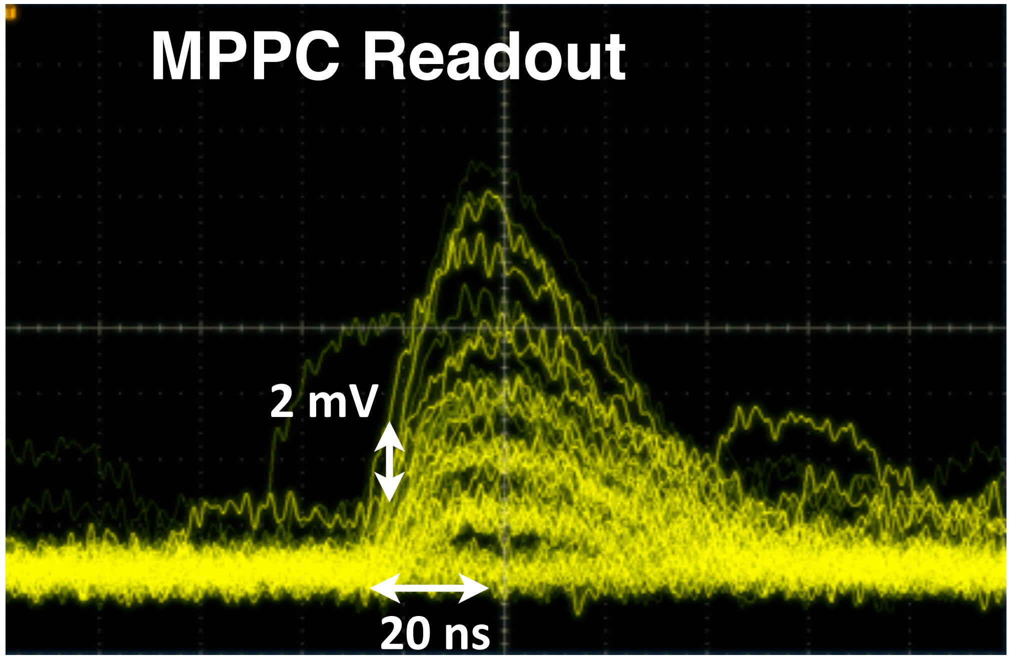
MPPC
S11827-3344MG
3 mm × 3 mm /ch
4 ch × 4 ch
50 μm GAPDs



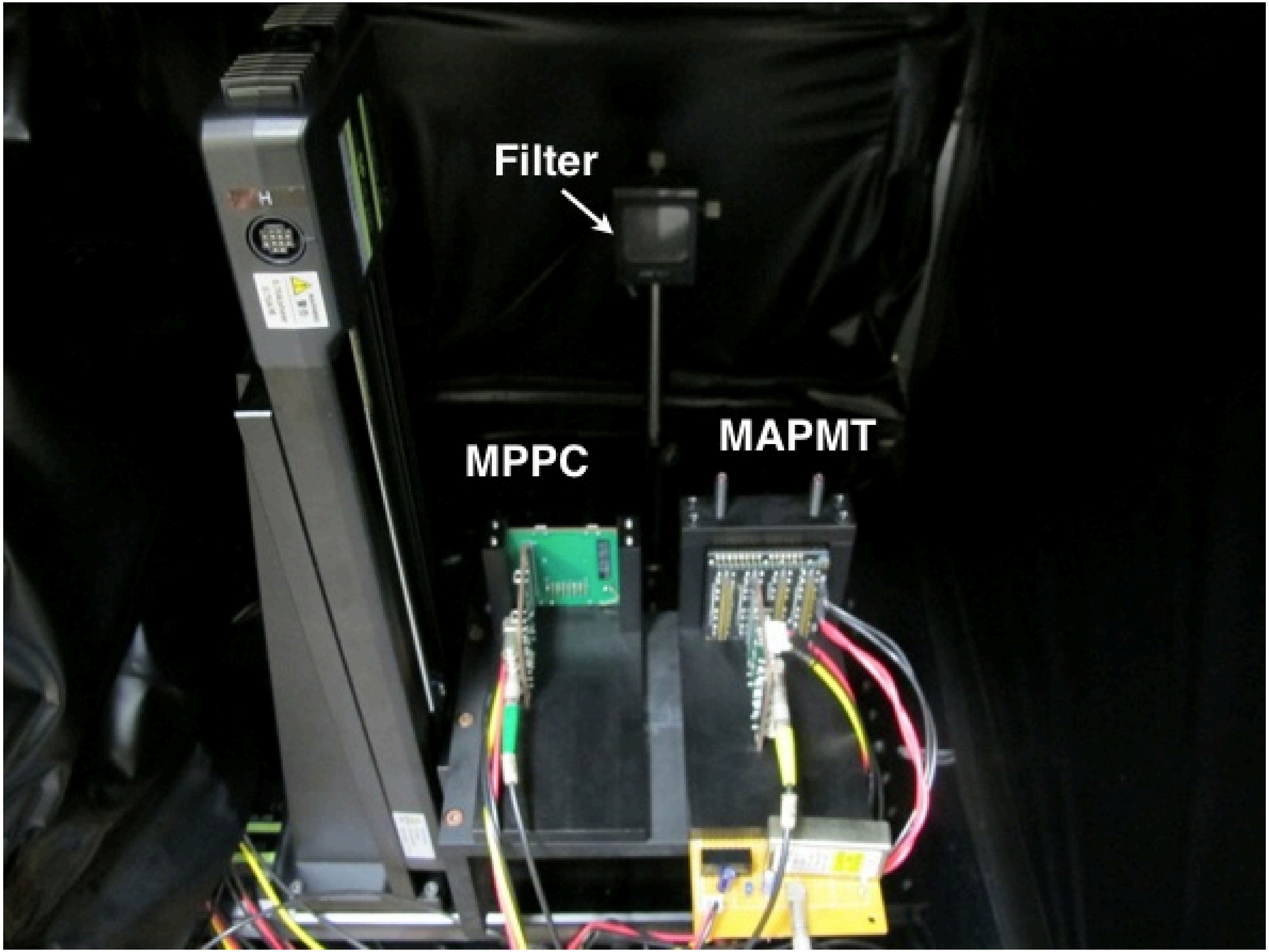
MAPMT
H8500-D
6.08 mm × 6.08 mm /ch
8 ch × 8 ch







Measurement System



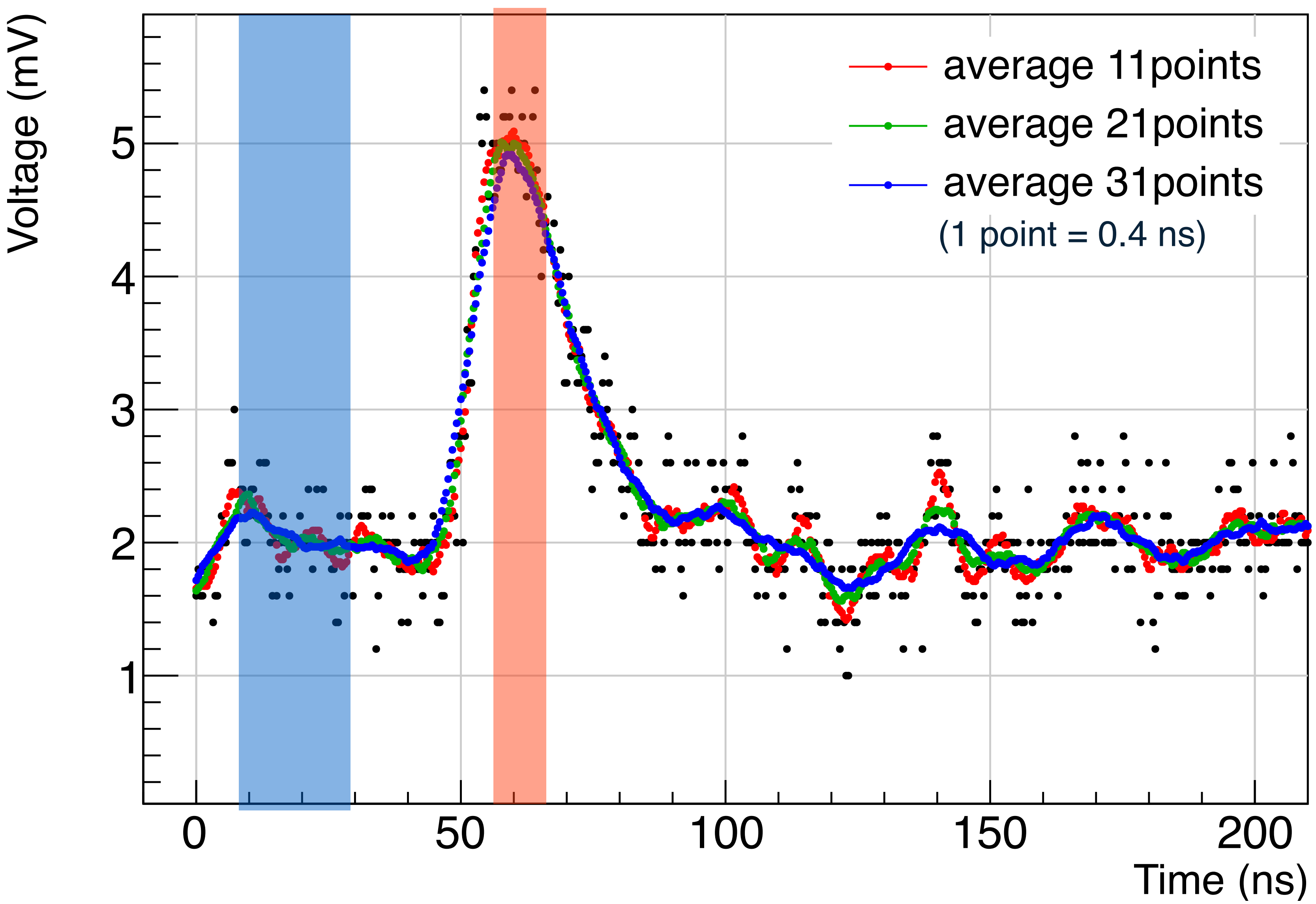
Analysis Method

Pulsehight at the time of LED emission

before average waveform around 8-ns average

Remove events if the baseline (shown in blue) is outside of nominal distribution

Remove off-timing events



Fit Method

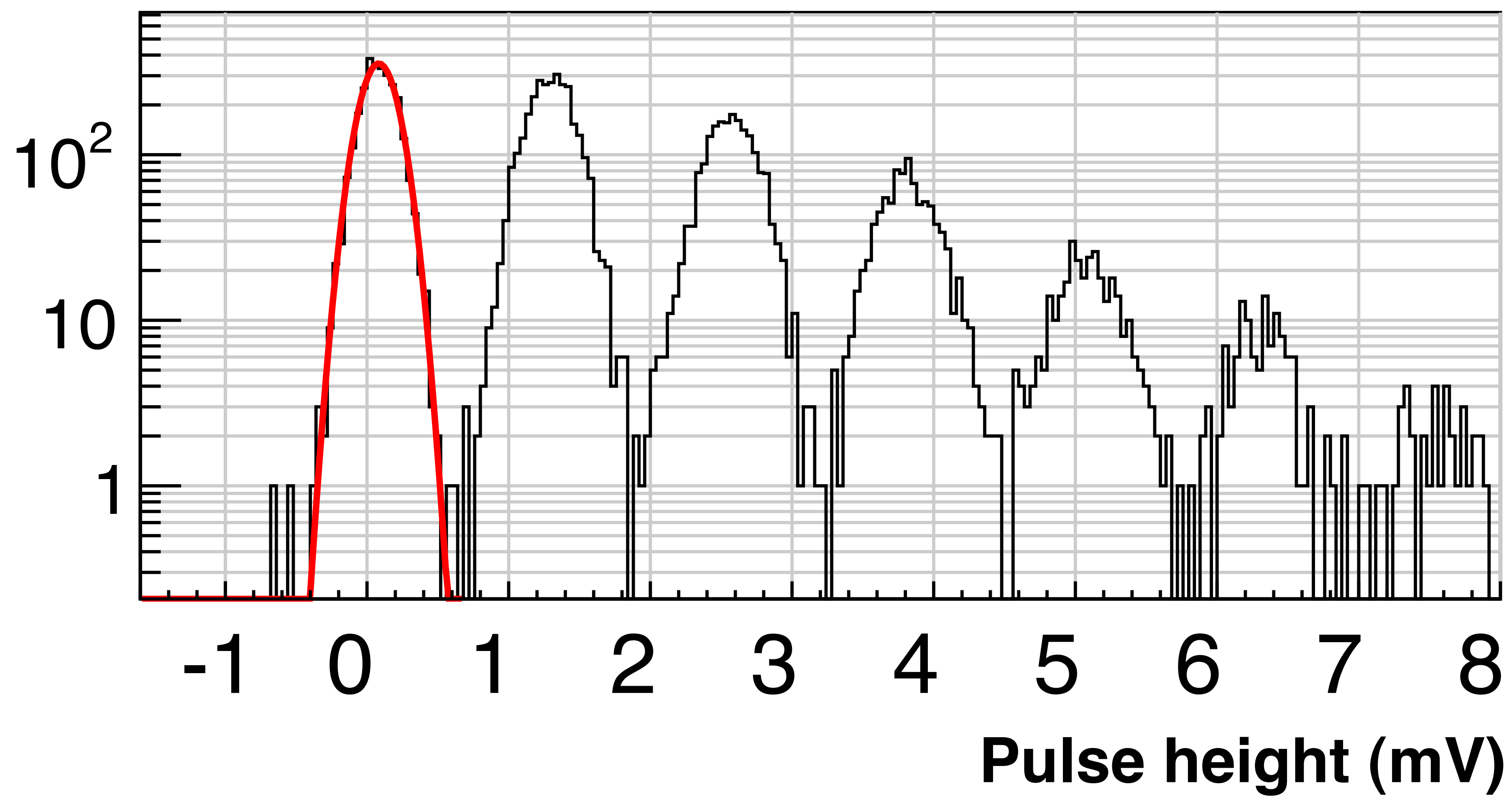
Fit to 0 p.e. distribution: P(0)

- **Avoid effect of crosstalk and after-pulse**

$$P(k) = e^{-\lambda}\frac{\lambda^k}{k!}$$

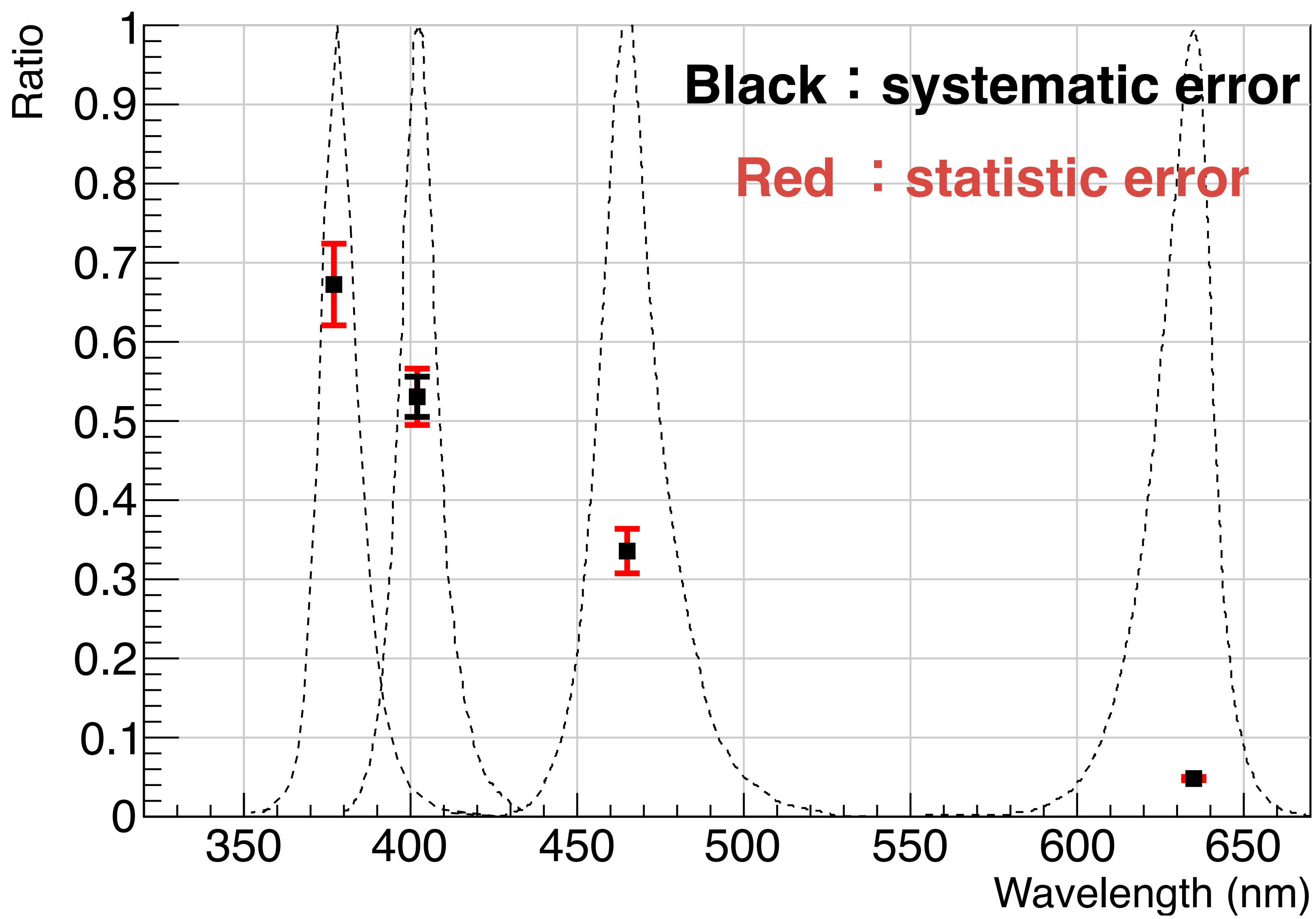
$$P(0) = e^{-\lambda}$$

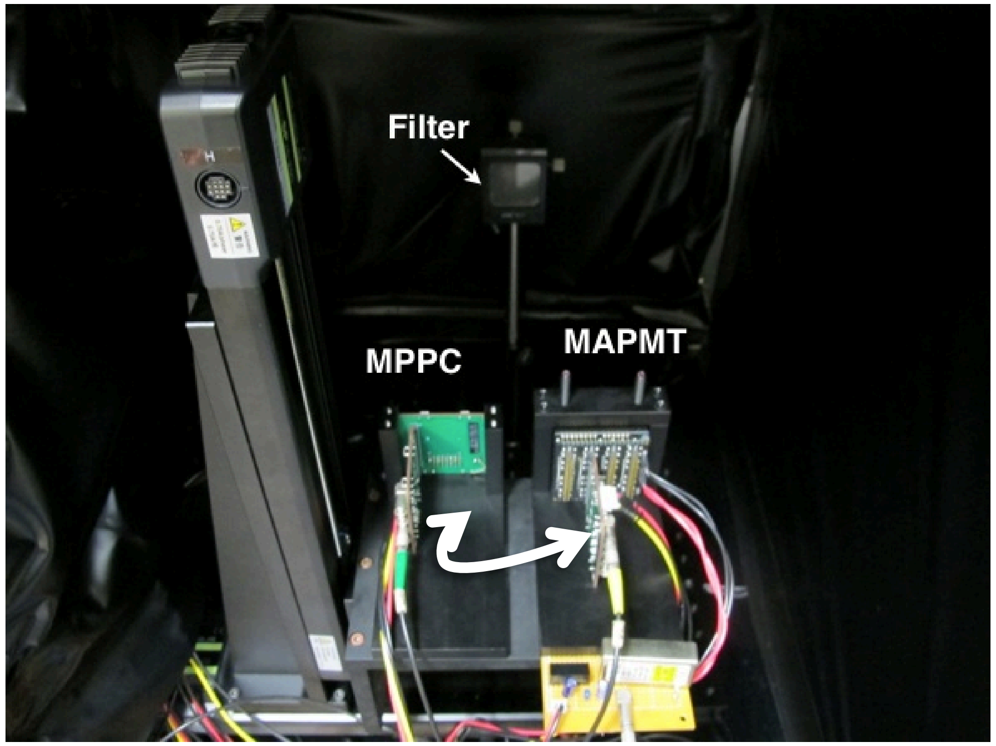
$$\lambda = \ln(P(0))$$



PDE ratio measurements

$$\text{PDE Ratio} = \frac{\lambda(\text{MAPMT})}{\lambda(\text{MPPC})} = \frac{\varepsilon(\text{MAPMT})}{\varepsilon(\text{MPPC})}$$

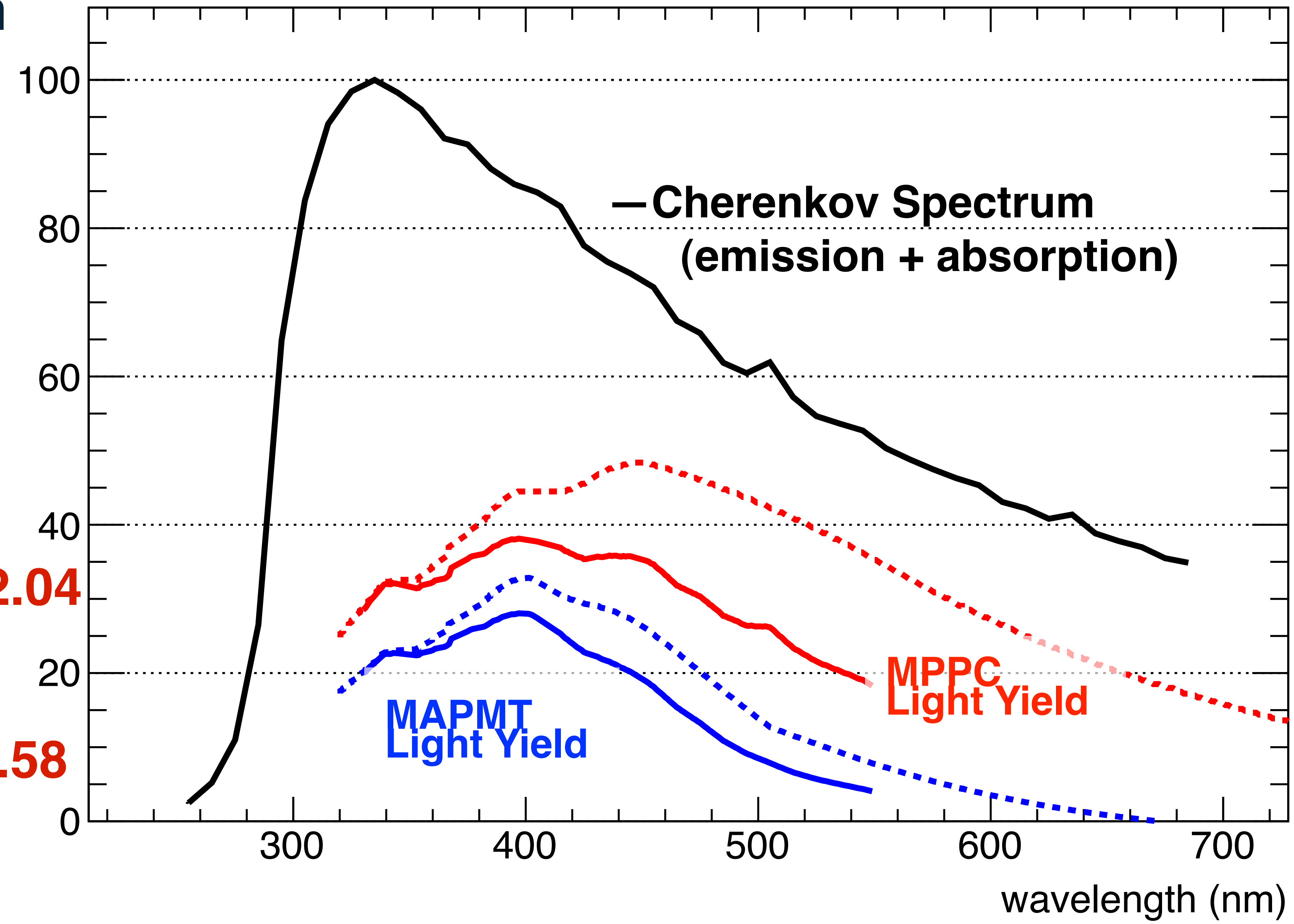




Calculation of Cherenkov Light Yield

Integrate Cherenkov light spectrum weighted by photon detection efficiency up to 550 nm

- Avoid Oxygen fluorescent line
- MPPC PDE from catalog
- MAPMT PDE from MPPC PDE and PDE ratio

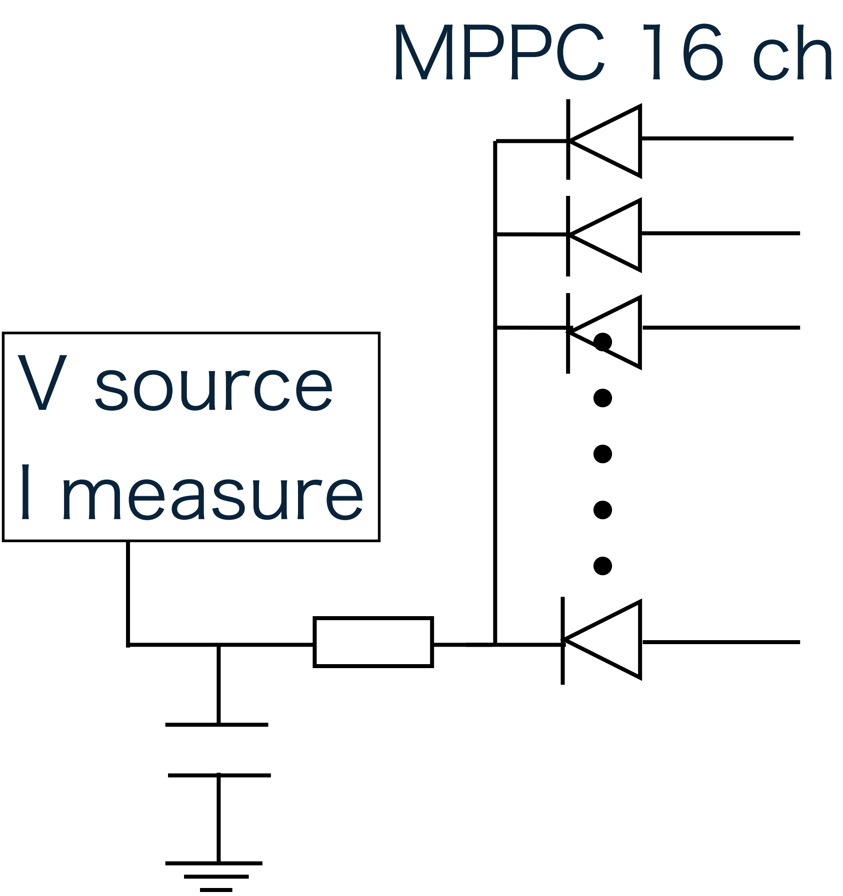


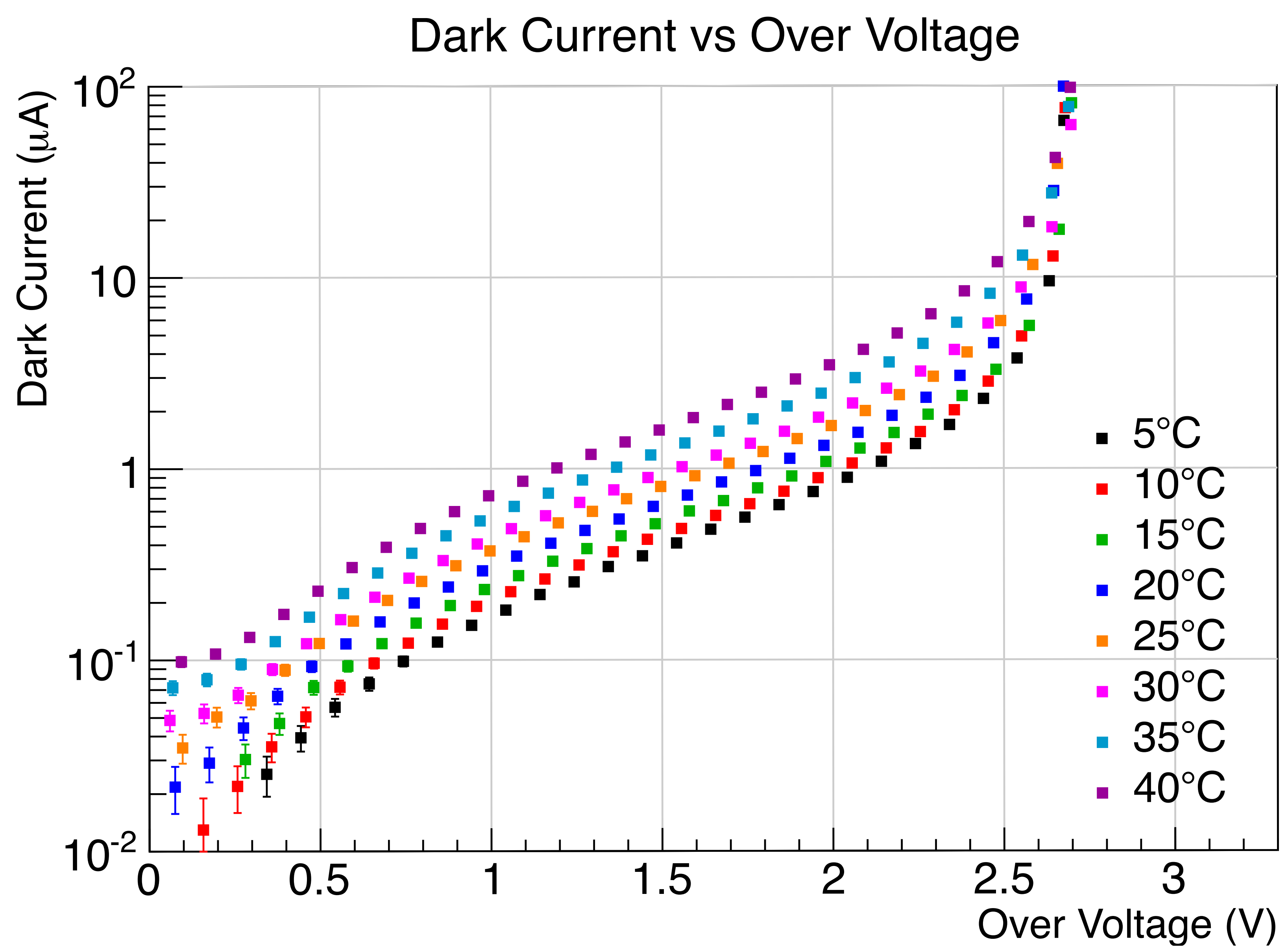
LY(MPPC)/LY(MAPMT)= 2.04
Correcting light loss at boundary of each unit
LY(MPPC)/LY(MAPMT)=1.58

ε(MAPMT)=89%
ε(MPPC)=69%
(0.5 mm gap between units)

Dark Current vs Over Voltage

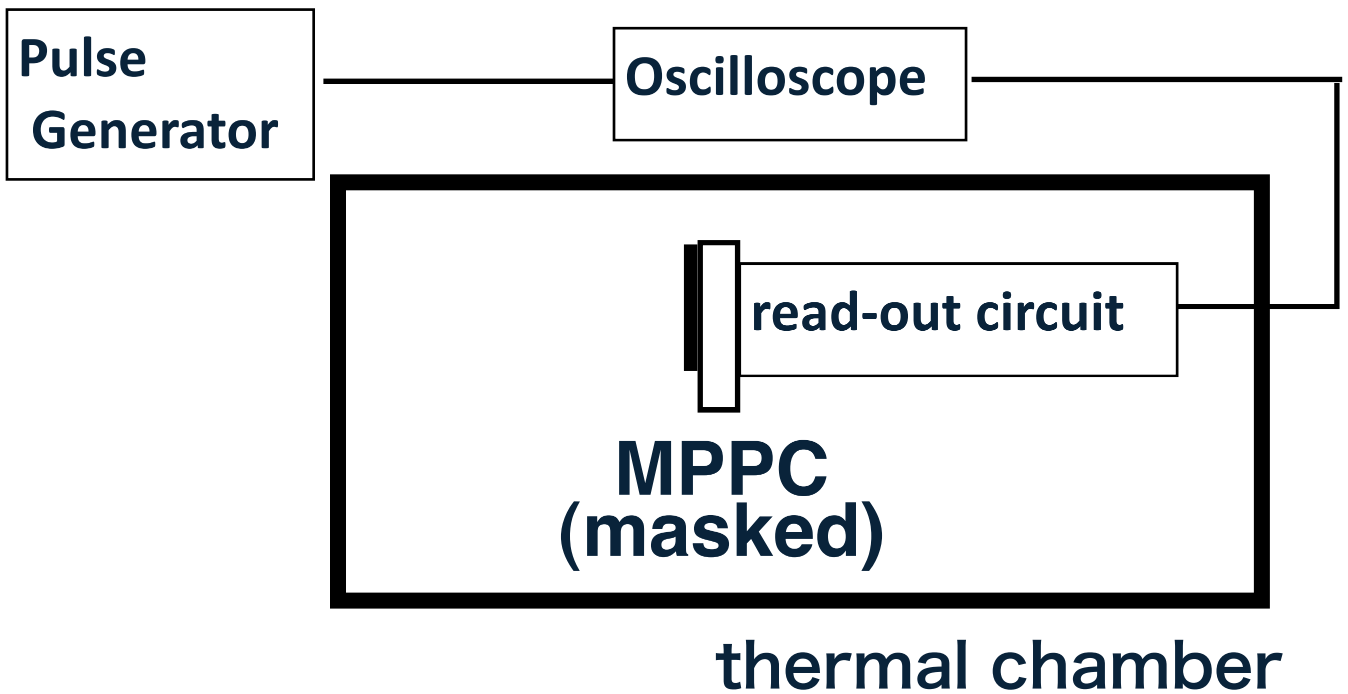
Current begins to to get higher sharply at the voltage over 2 – 3 V of the break-down voltage

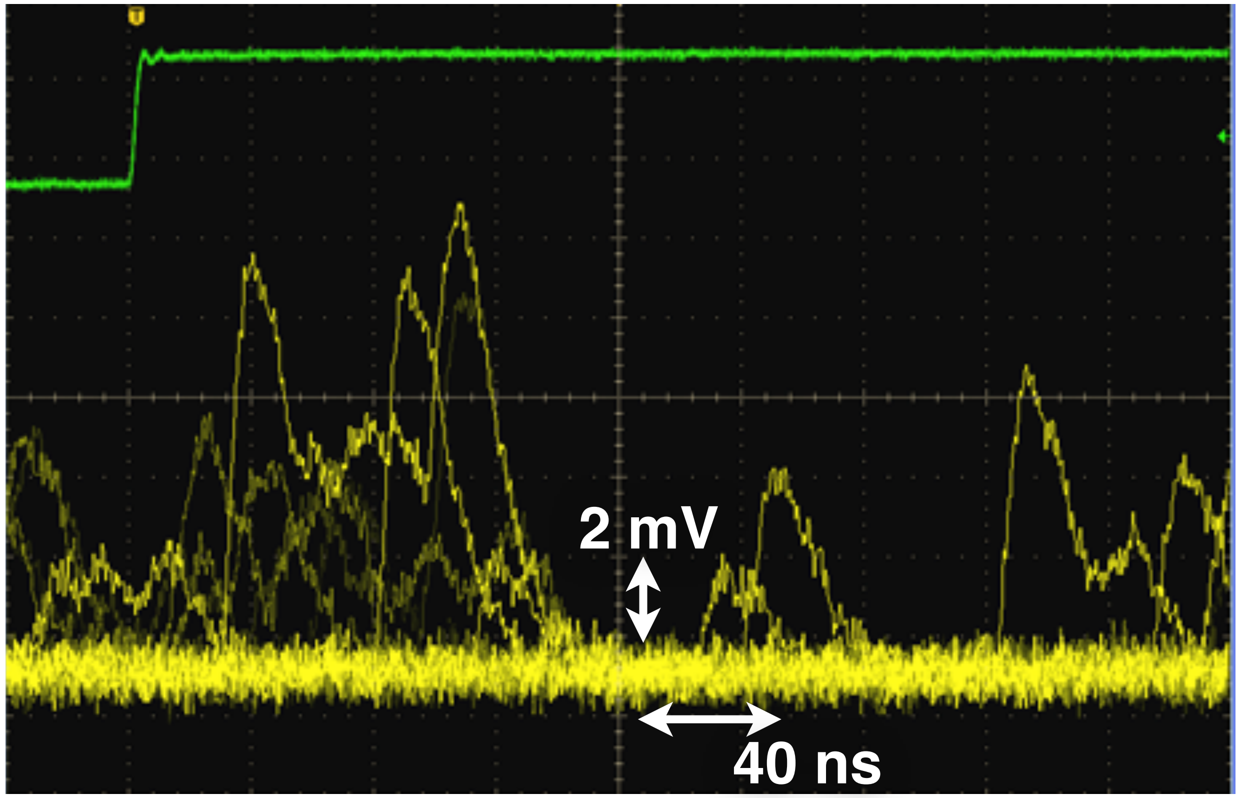




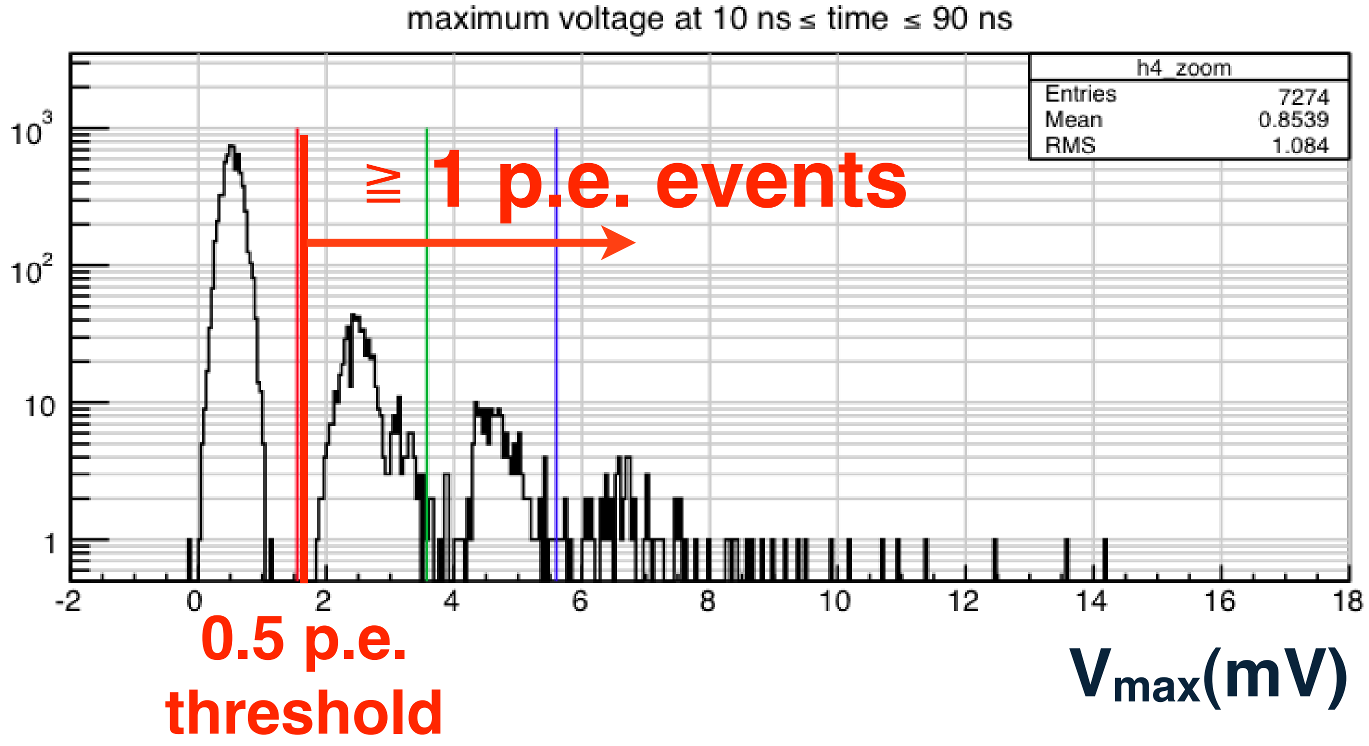
Dark Count

Take 100-ns long waveforms with random trigger
take the maximum of averaged waveform

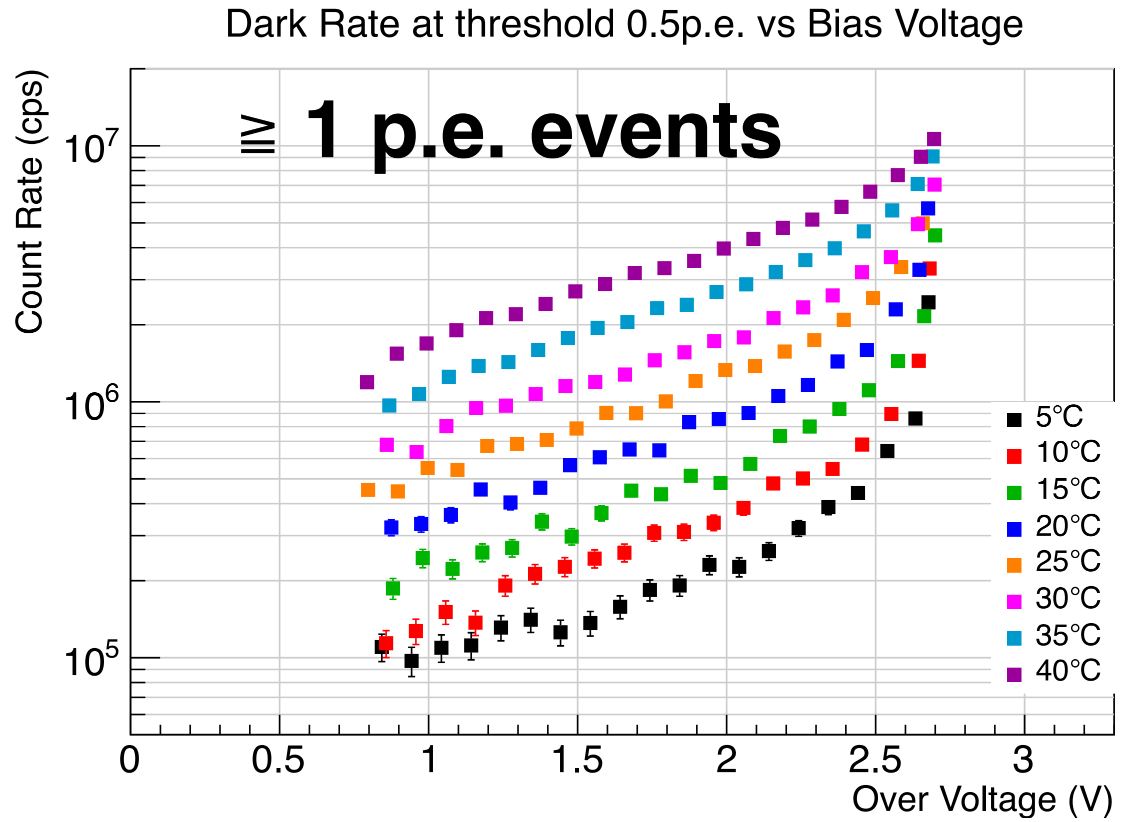




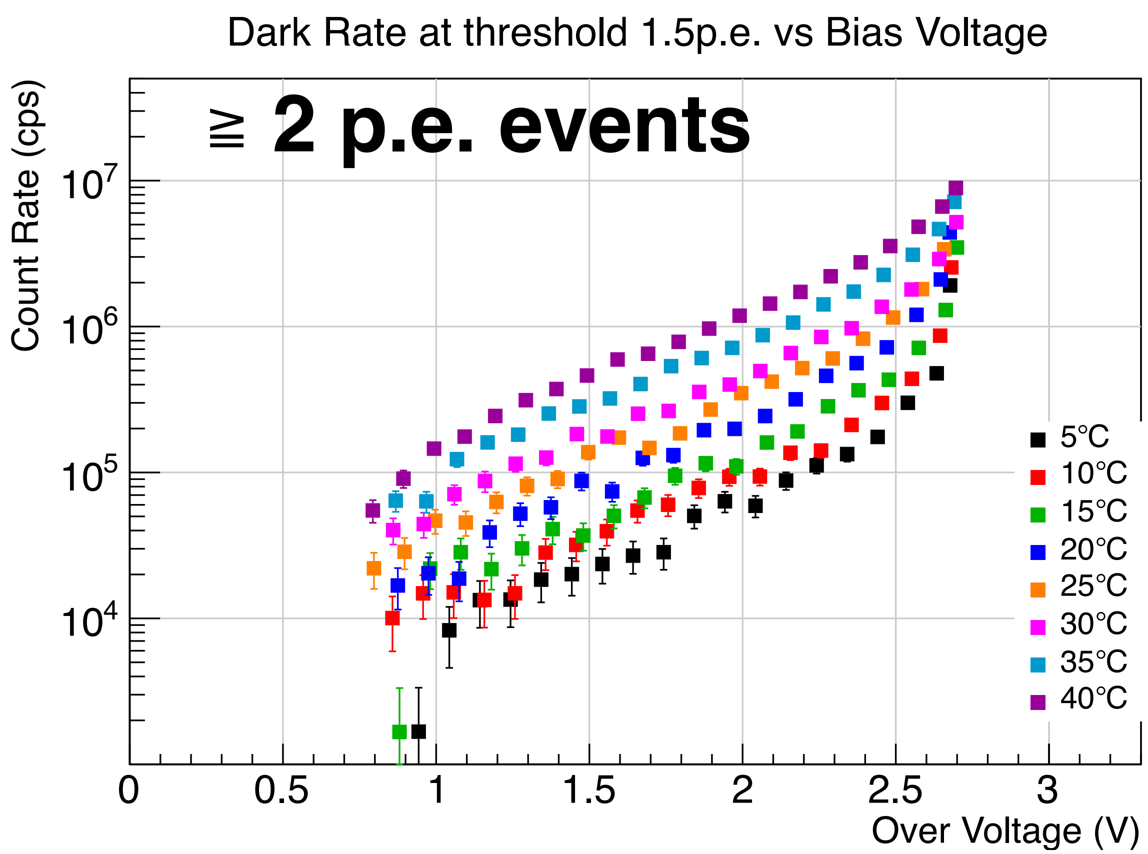
Dark Count



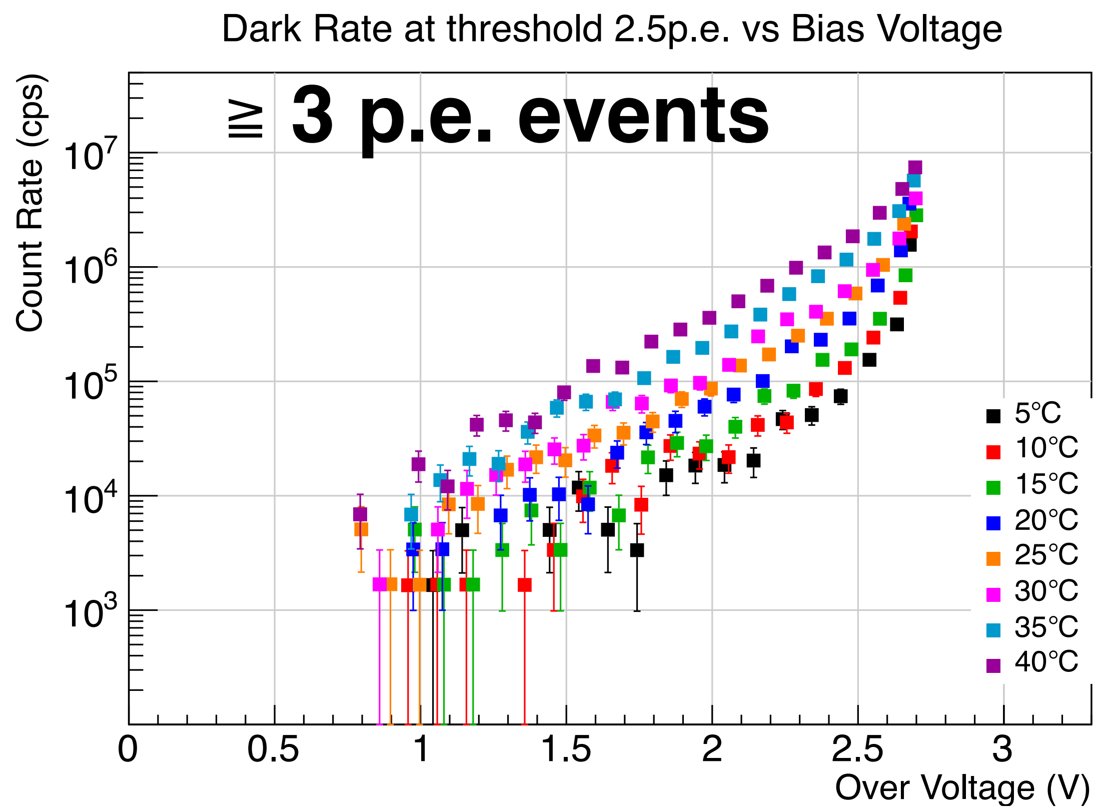
maximum voltage at 10 ns ≤ time ≤ 90 ns
h4_zoom
Entries 7274
Mean 0.8539
RMS 1.084
≧ 1 p.e. events
0.5 p.e. threshold
Vmax(mV)



Dark Rate at threshold 0.5p.e. vs Bias Voltage
≧ 1 p.e. events
Count Rate (cps)
Over Voltage (V)
5°C
10°C
15°C
20°C
25°C
30°C
35°C
40°C

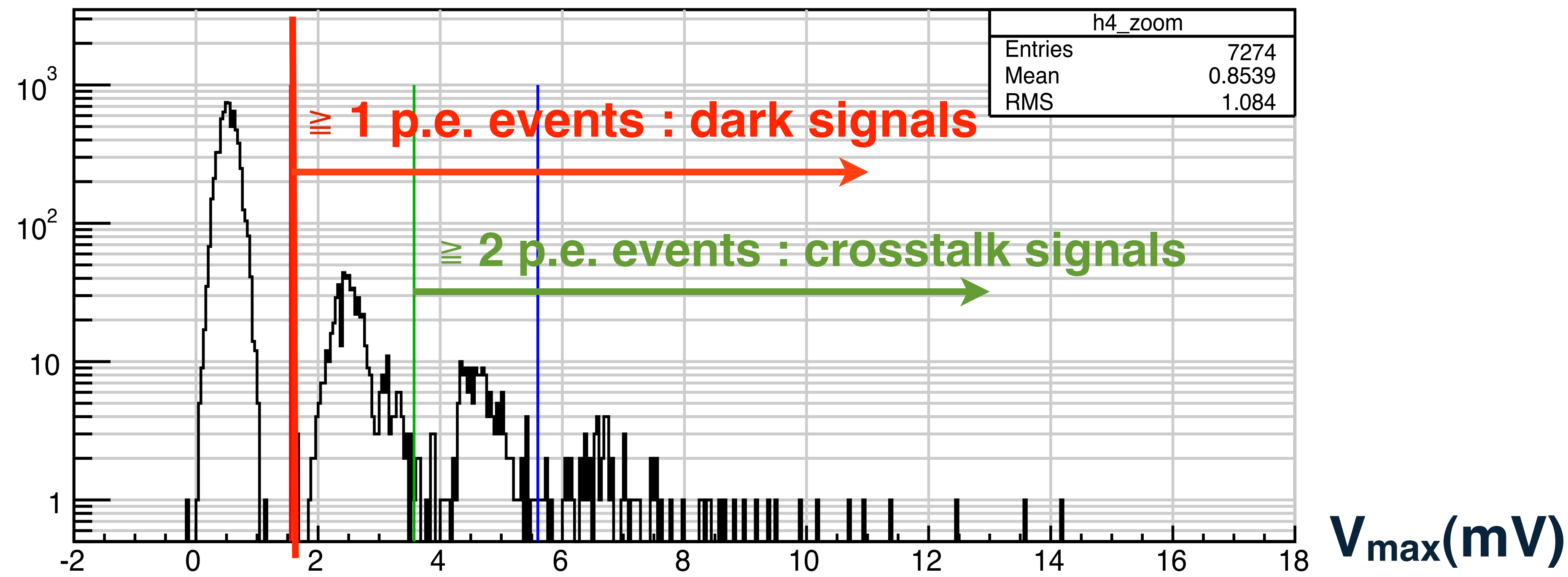


Dark Rate at threshold 1.5p.e. vs Bias Voltage
≧ 2 p.e. events
Count Rate (cps)
Over Voltage (V)
5°C
10°C
15°C
20°C
25°C
30°C
35°C
40°C



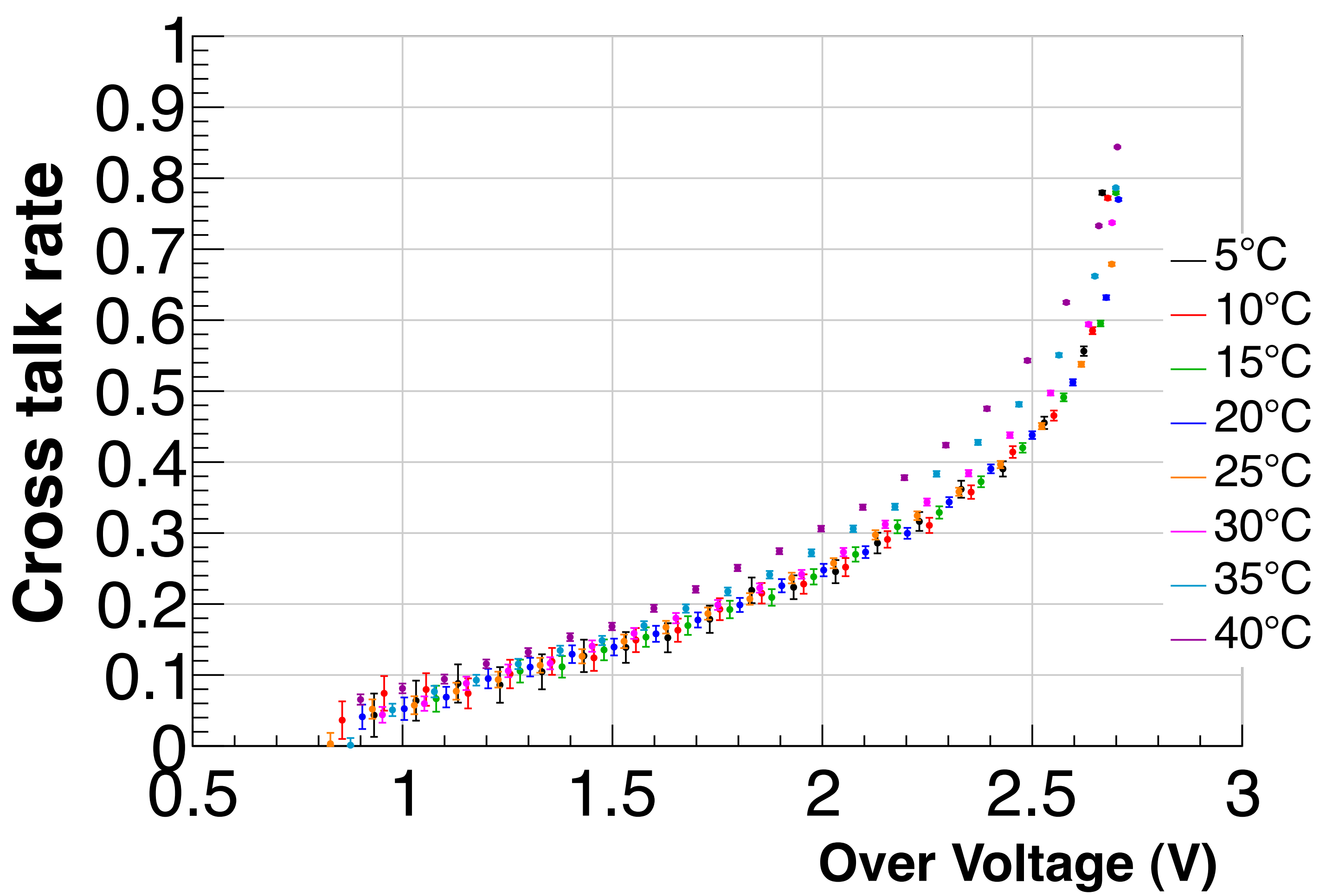
Dark Rate at threshold 2.5p.e. vs Bias Voltage
≧ 3 p.e. events
Count Rate (cps)
Over Voltage (V)
5°C
10°C
15°C
20°C
25°C
30°C
35°C
40°C

Crosstalk

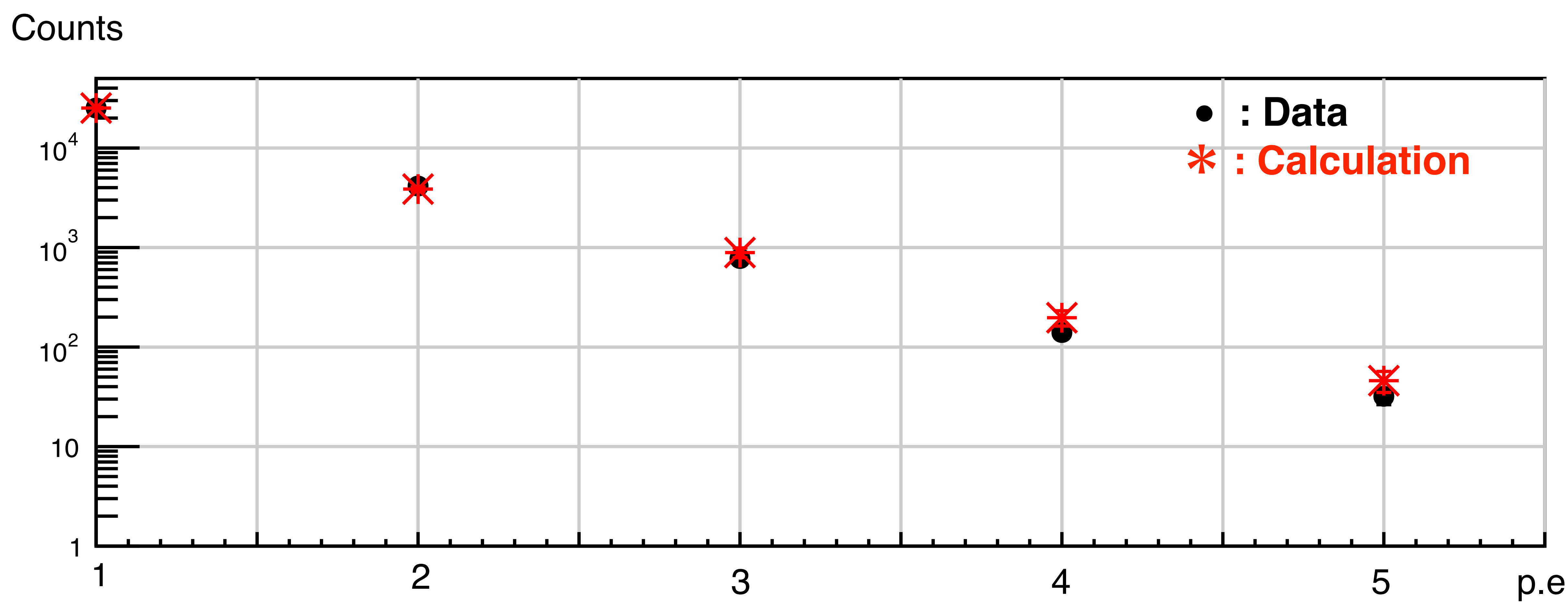


- **Cross talk rate**

  = 2 p.e. events / 1 p.e. events
- **No temperature dependence**



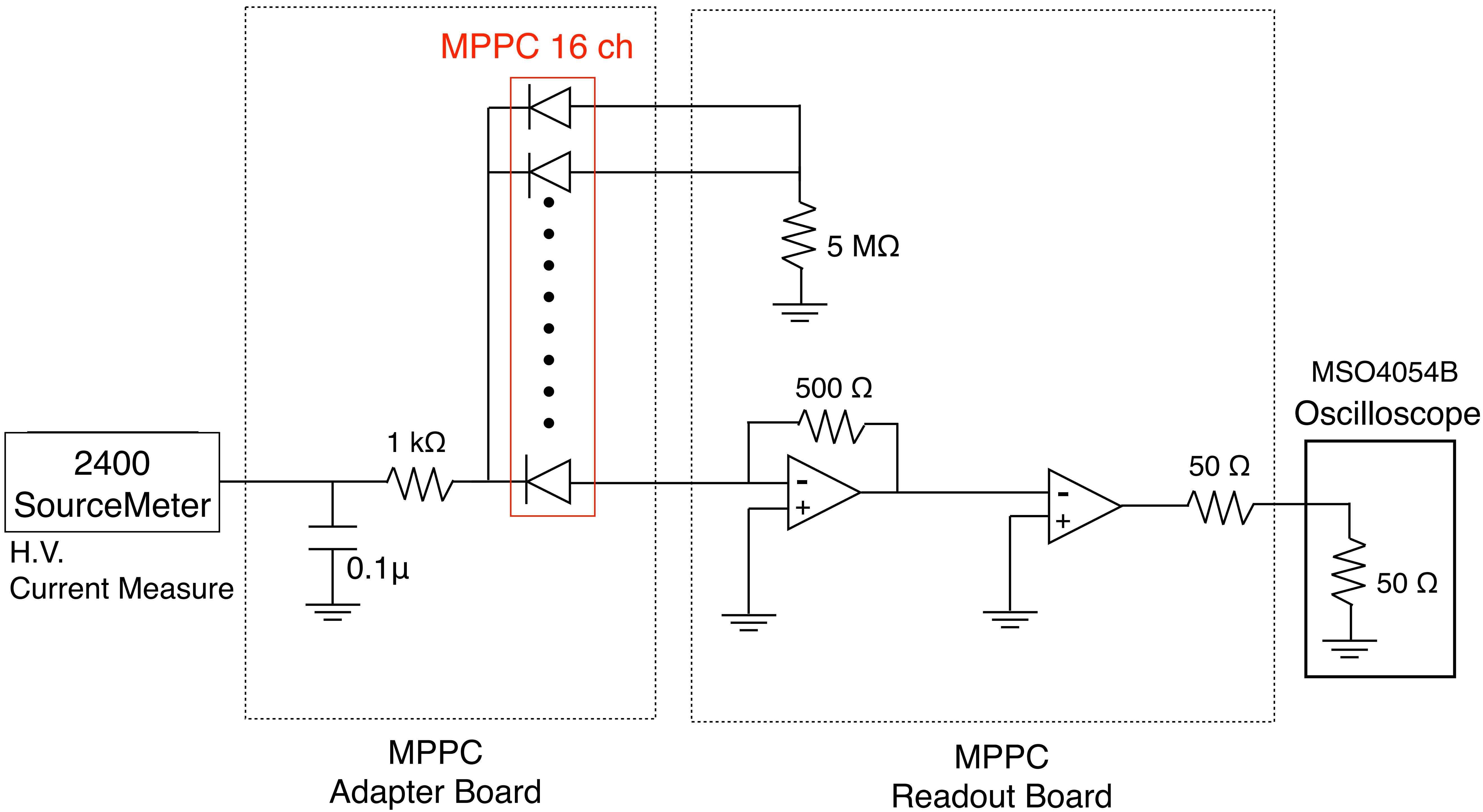
Compared with data



good agreement → pulse height distribution can be calculated

MPPC Readout

Current sensitive amp



Sensitivity of CTA