THE PROGRESS OF SIPM-BASED CAMERA FOR LHAASO-WFCTA

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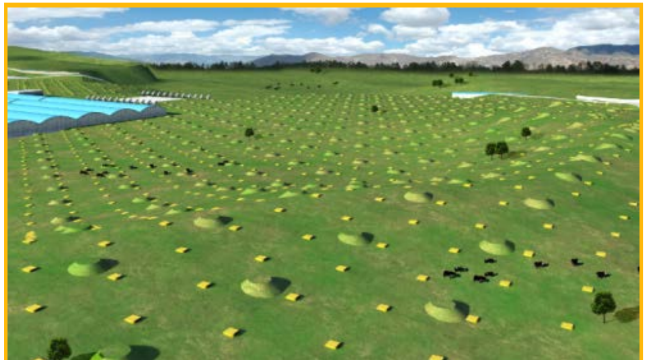
for the LHAASO Collaboration

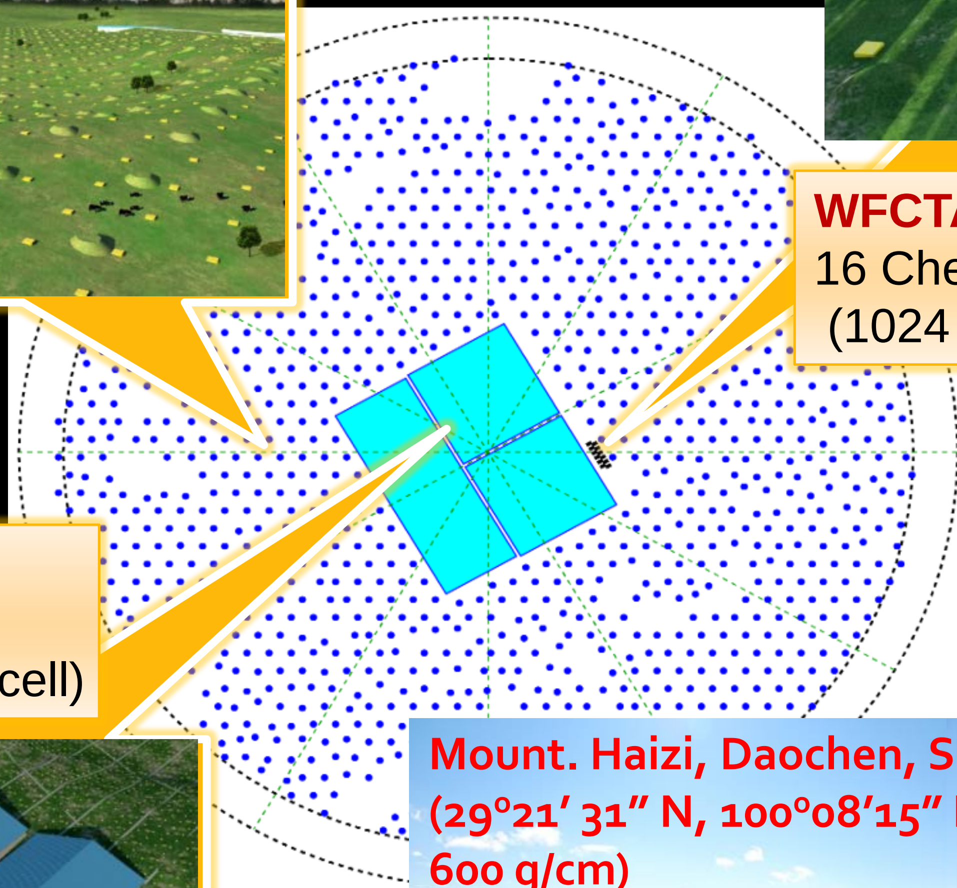
Outline

- Introduction
  - LHAASO-WFCTA
  - Why SiPM?
- Progress
  - Design of Camera/Sub-Cluster
  - Design of SiPM
  - Pre-amplifier
  - Analog & Digital Board
  - Slow Control Board
  - Winston Cone
- Summary

LHAASO



KM2A:
5195 EDs
1171 MDs

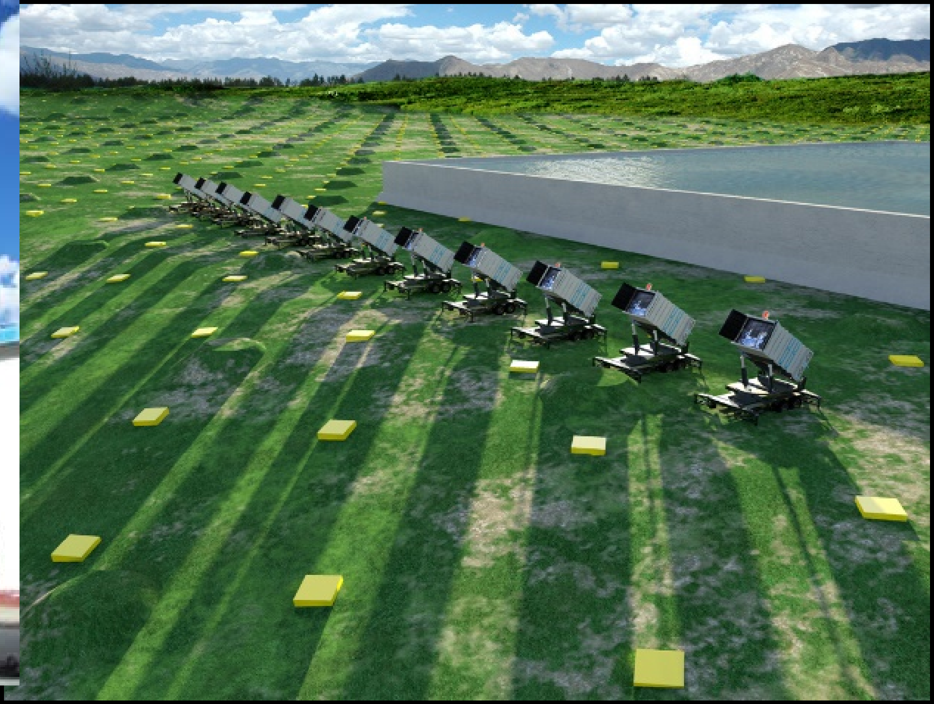


WFCTA:
16 Cherenkov telescopes
(1024 pixels/telescope)

WCDA:
78,000 m^2
3000 cells(25m^2/cell)

Mount. Haizi, Daochen, Sichuan
(29°21′ 31″ N, 100°08′15″ E, 4410 m a.s.l., 600 g/cm)

WFCTA

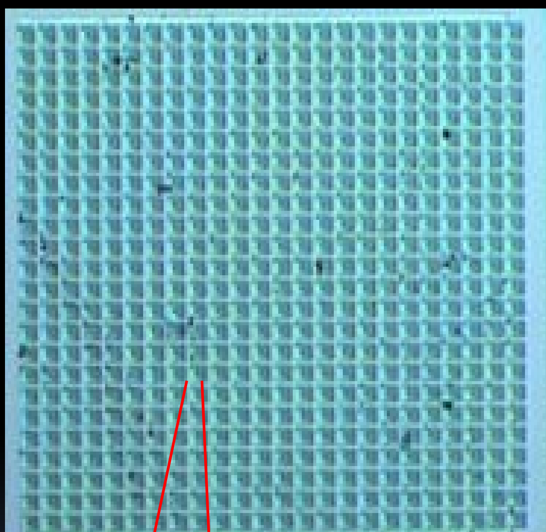


Prototype
16x16 Pixels
1° /pixel
PMT Array

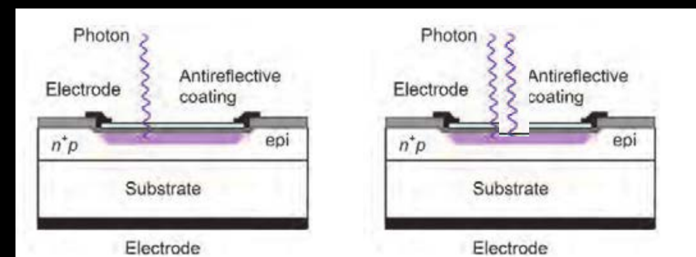
LHAASO-WFCTA
32x32 Pixels
0.5° /pixel
SiPM Array

Introduction to SiPM

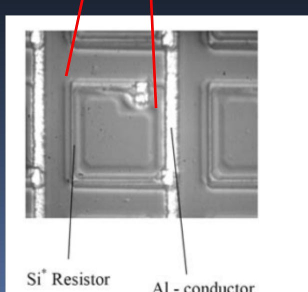
- Silicon Photomultiplier
- Geiger mode APD（binary）



SiPM
1~5mm



Same Output



APD
20~100μm

$$N_{fired} = N_{cell}\left(1 - e^{-\epsilon N_{ph}/N_{cell}}\right)$$
$$= N_{cell}\left(1 - e^{-N_{pe}/N_{cell}}\right)$$

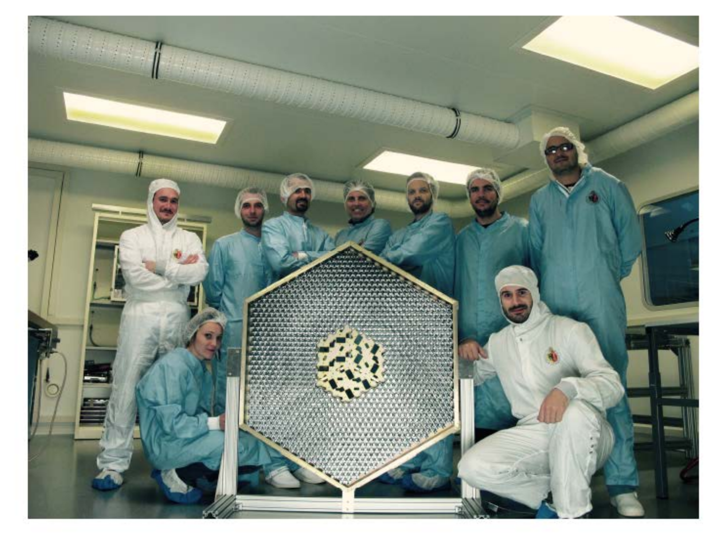
PMT vs SiPM

	PMT (WFCTA)	SiPM
Size	✓ 1 inch (25.4mm)	15mm x 15mm
Resolution	12%@100pe, 4%@1000pe	12%@100pe, 4%@1000pe
FWHM of Pulse	~6ns	✓ ~60ns
Dark count rate(Dark noise)	✓ <1kHz @ Th=0.5pe	>10kHz @ Th=0.5pe
Gain	10^6 @ >1000V	✓ 10^6 @ <100V
G-T Stability	✓ ~0.2%/℃	1.5%/℃
Magnetic field	Sensitive	✓ Not sensitive
Ageing under strong light	Yes	✓ No
Dynamic range	Depend on PMT type, HV....	Depend on number of APDs

Why SiPM?

- ✓High gain at low operating voltage
- ✓Duty cycle up to 30% (10% for PMT)
- ✓Experience of FACT & CTA

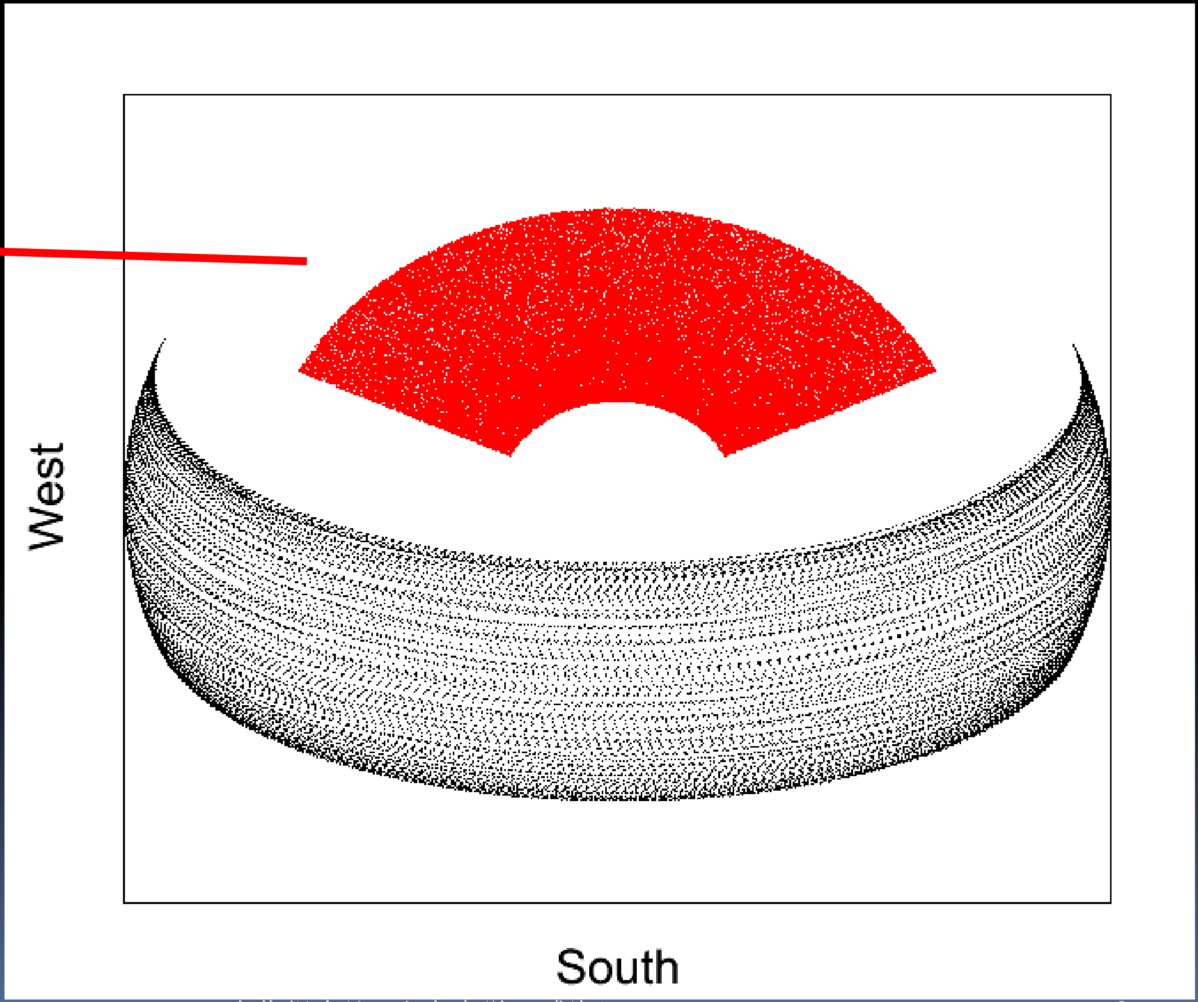
The First G-APD Cherenkov Telescope (FACT)
La Palma, Canary Islands, Spain，2011

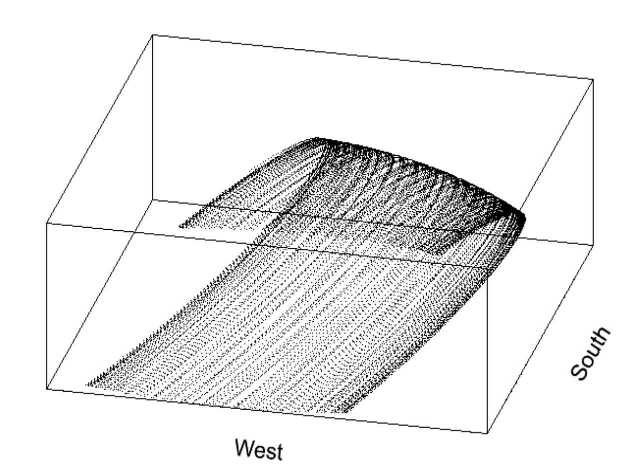


CTA: single-mirror (dual mirror)
Small Size Telescope(High Energy)

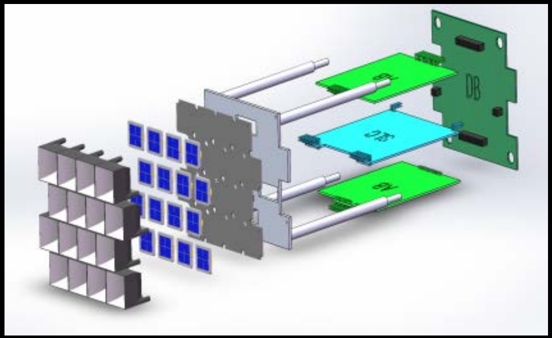
Moon trajectory

8x2 Telescopes
128° x 32°
90°±64°,30°±16°

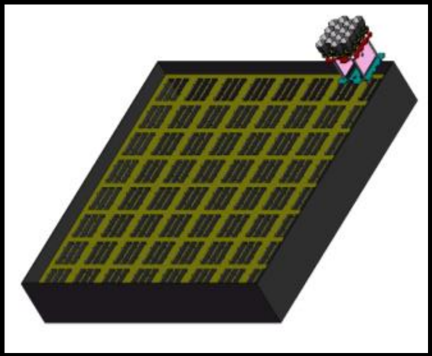




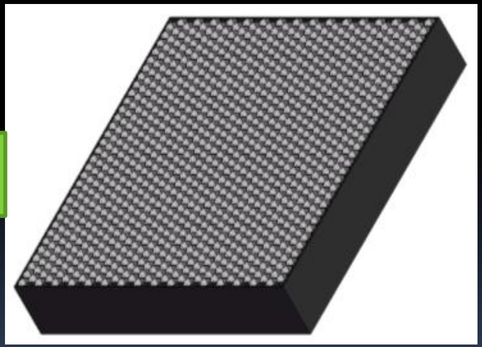
Design of Camera



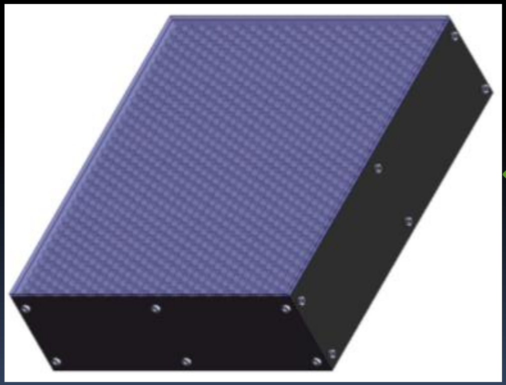
Sub-Cluster:
4x4 SiPM array



Camera
Box

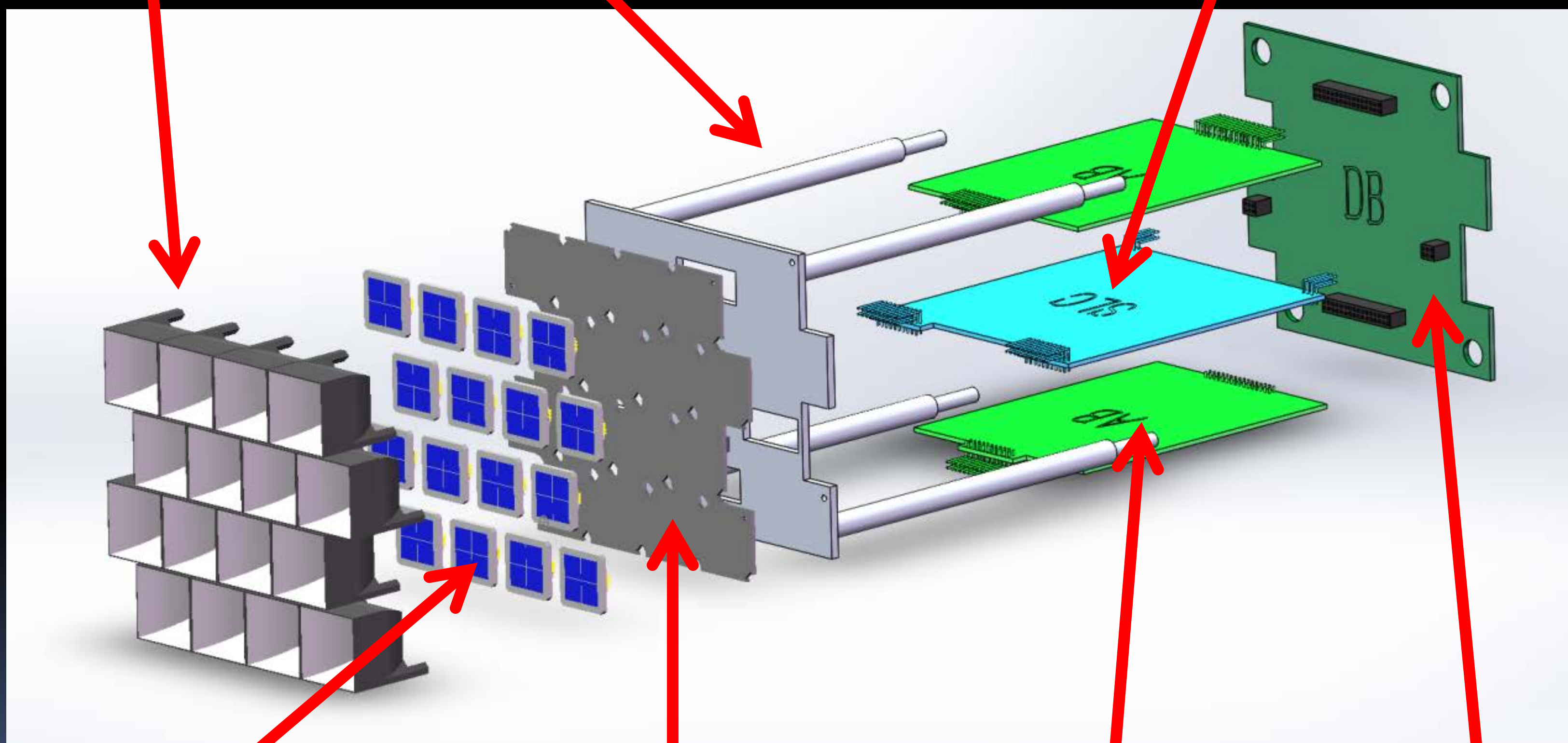


Camera:
8x8 Sub-Clusters

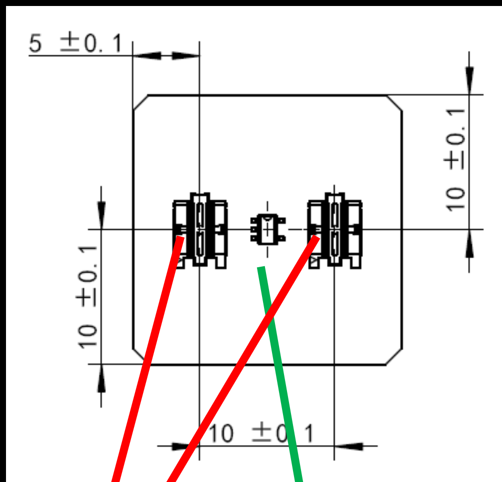


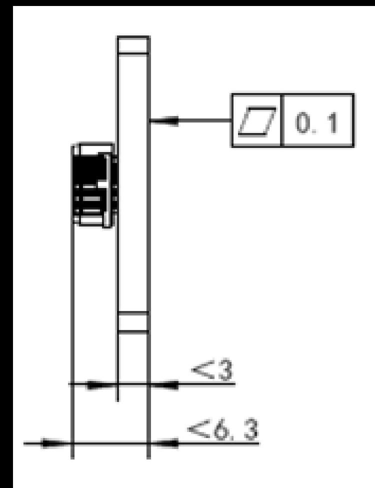
Optical Filter

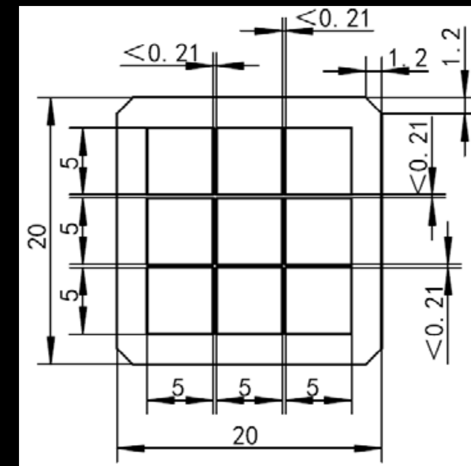
Design of Sub-Cluster



Design of SiPM







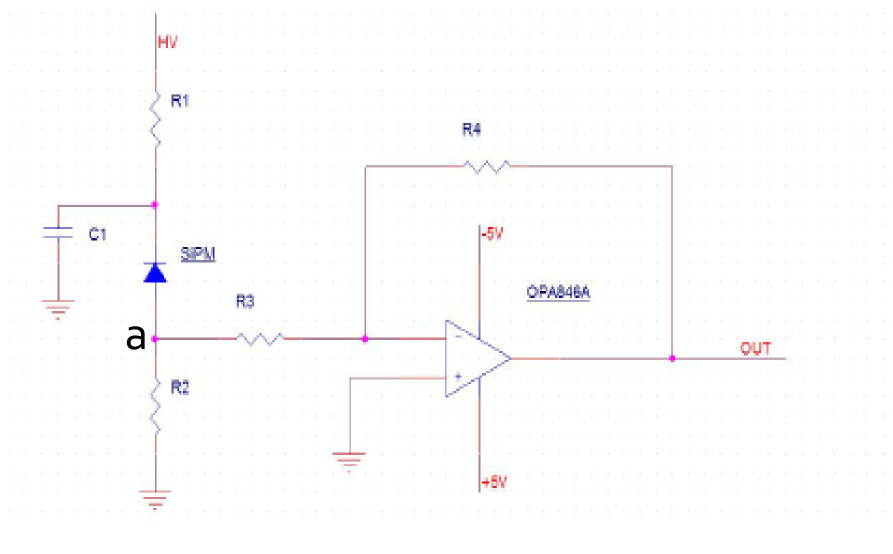
Two Terminal Strips

Temperature Sensor LM94021

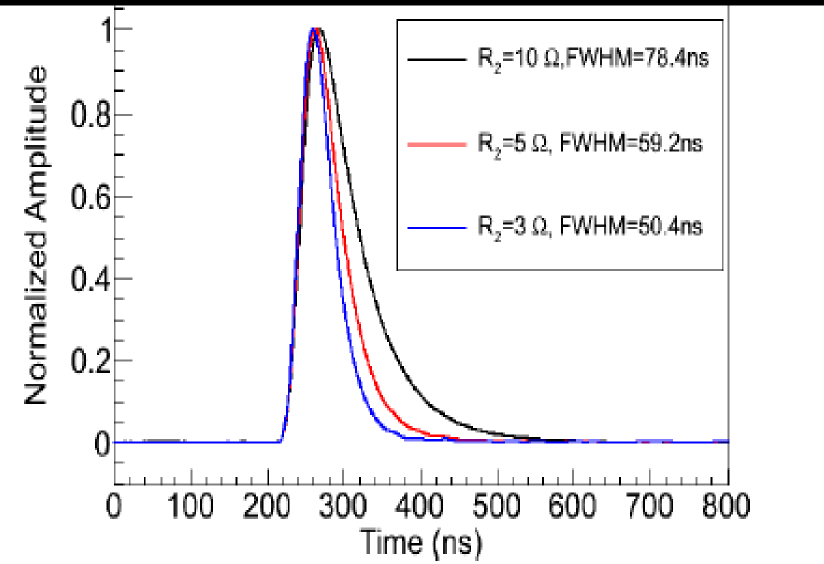
Test Sample:
Hamamatsu S13361-5488
16 (4x4) chips
3mm x 3mm per chip
Pixel Size: 25μm x 25μm

- Hamamatsu
- 9 (3x3) chips (15mm x 15mm)
- 5mm x 5mm per chip
- Pixel size: 25μm x 25μm
- Gain=1.1×10^6 @~60V
- Gain Uniformity: Typ:1.3%
- Dark Count Rate = Typ:5.4Mhz
- V-T Coefficient: 54mV/℃

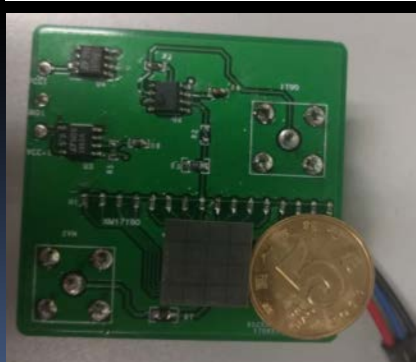
Pre-amplifier

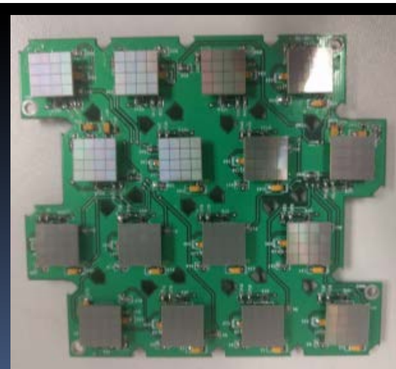


(a)



(b)





$R2 = 3\Omega$， $R3 = 100\Omega$， $R4 = 1k\Omega$

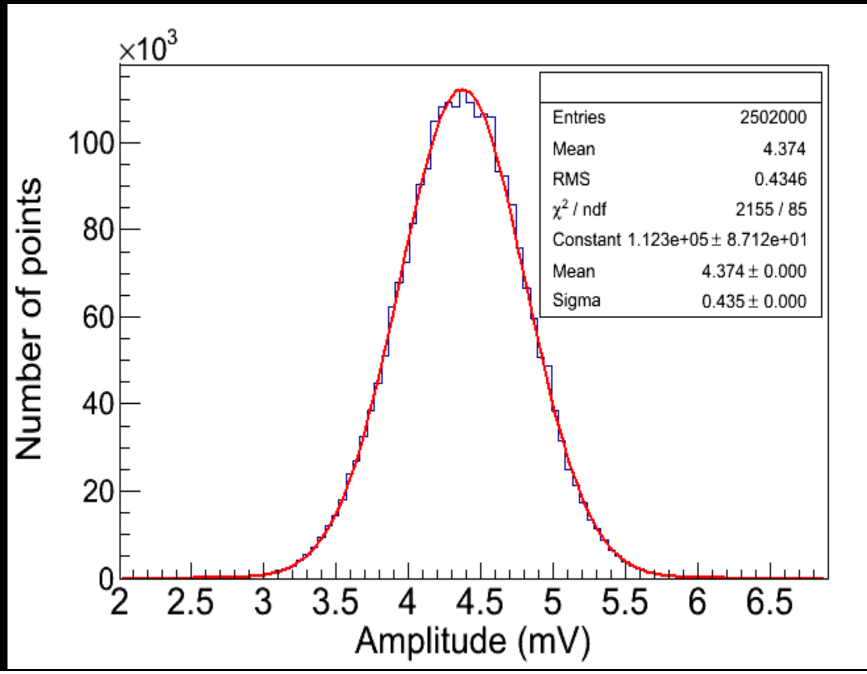
$V_a = I \times 3\Omega$

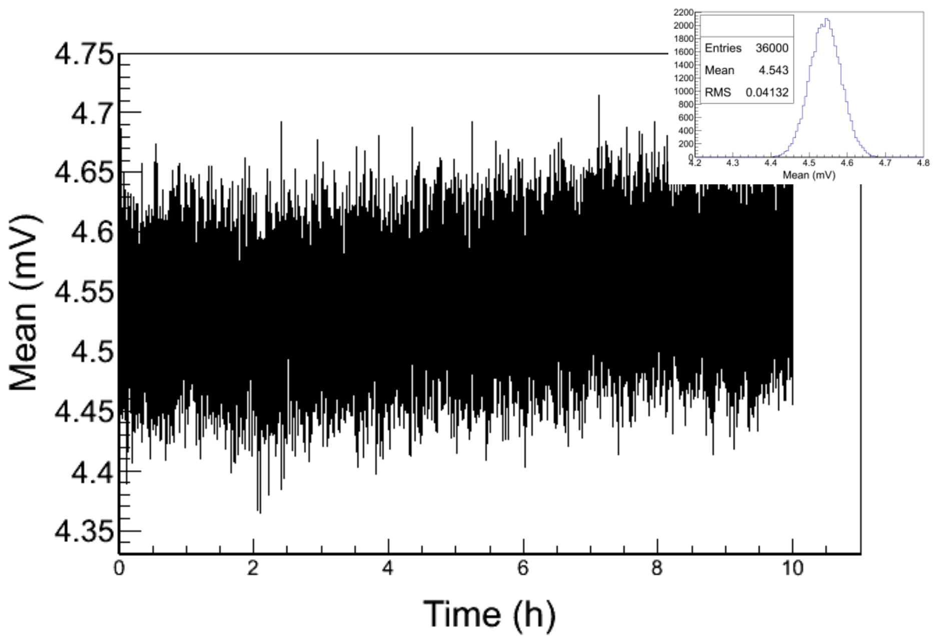
Inverting Amplifier: Gain = -10

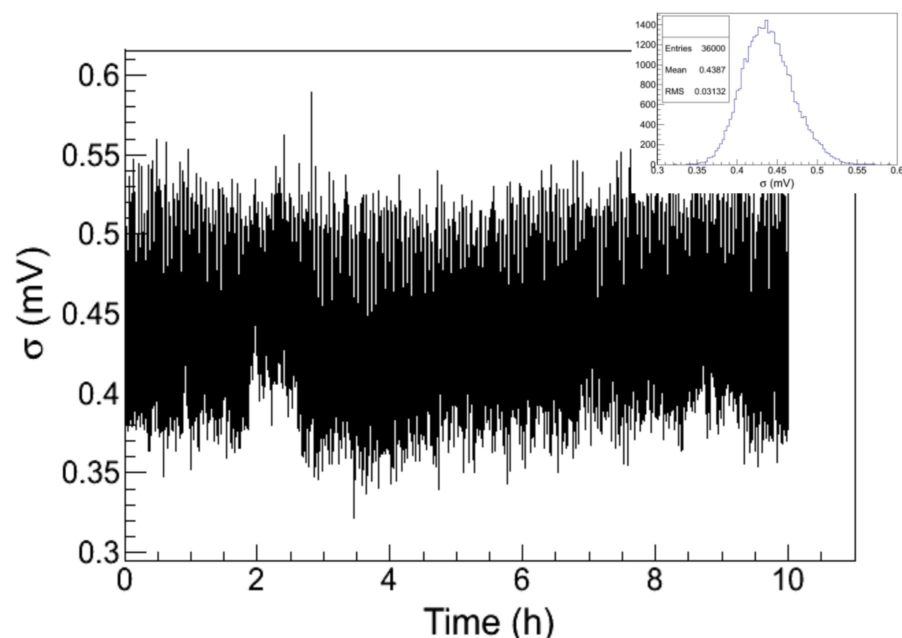
Pedestal

Ped < 5mV

σ ~ 0.43mV







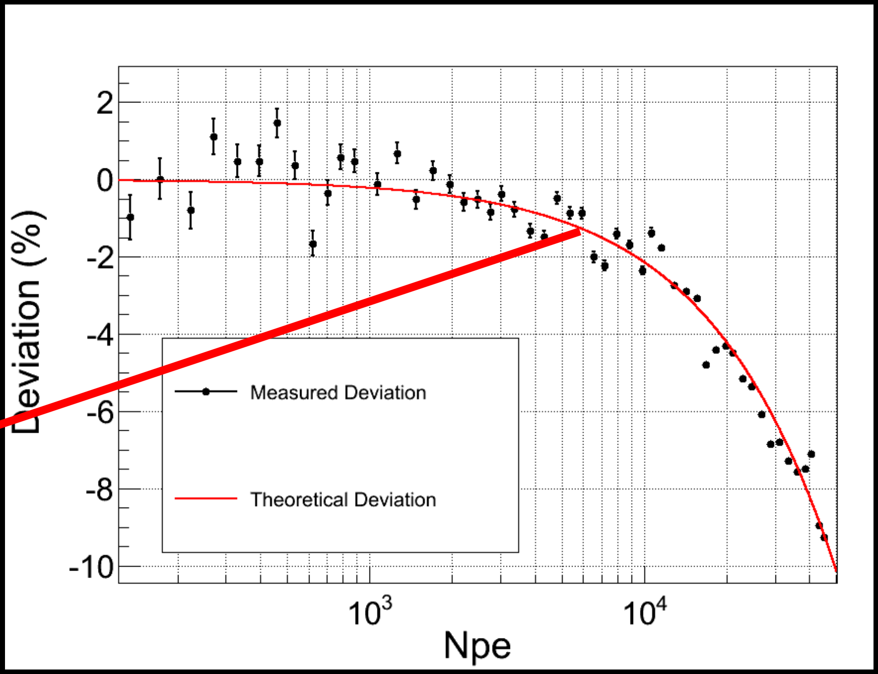
Dynamic ranges

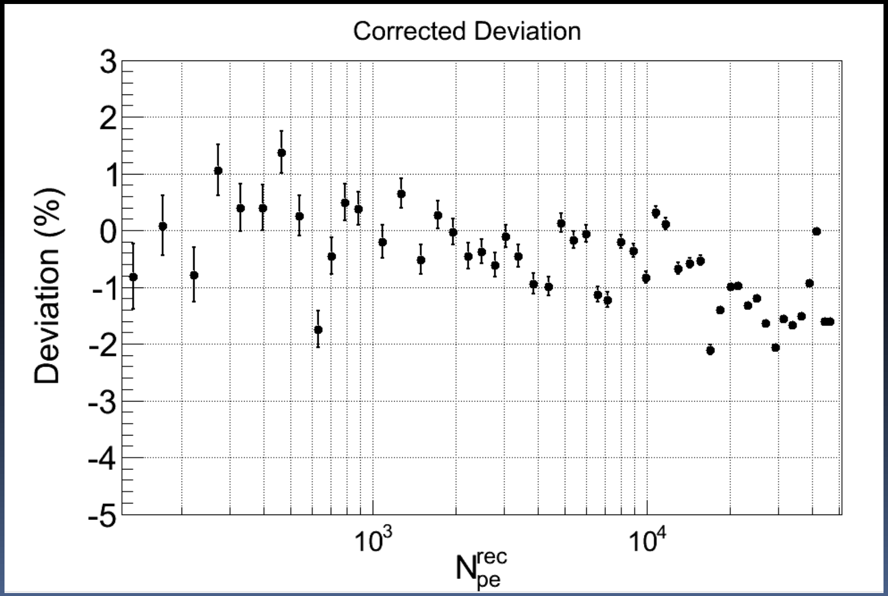
$$N_{fired} = N_{cell}\left(1 - e^{-\epsilon N_{ph}/N_{cell}}\right)$$
$$= N_{cell}\left(1 - e^{-N_{pe}/N_{cell}}\right)$$

$$N_{pe}^{rec} = N_{cell}\ln\left(\frac{1}{1 - N_{fired}/N_{cell}}\right)$$

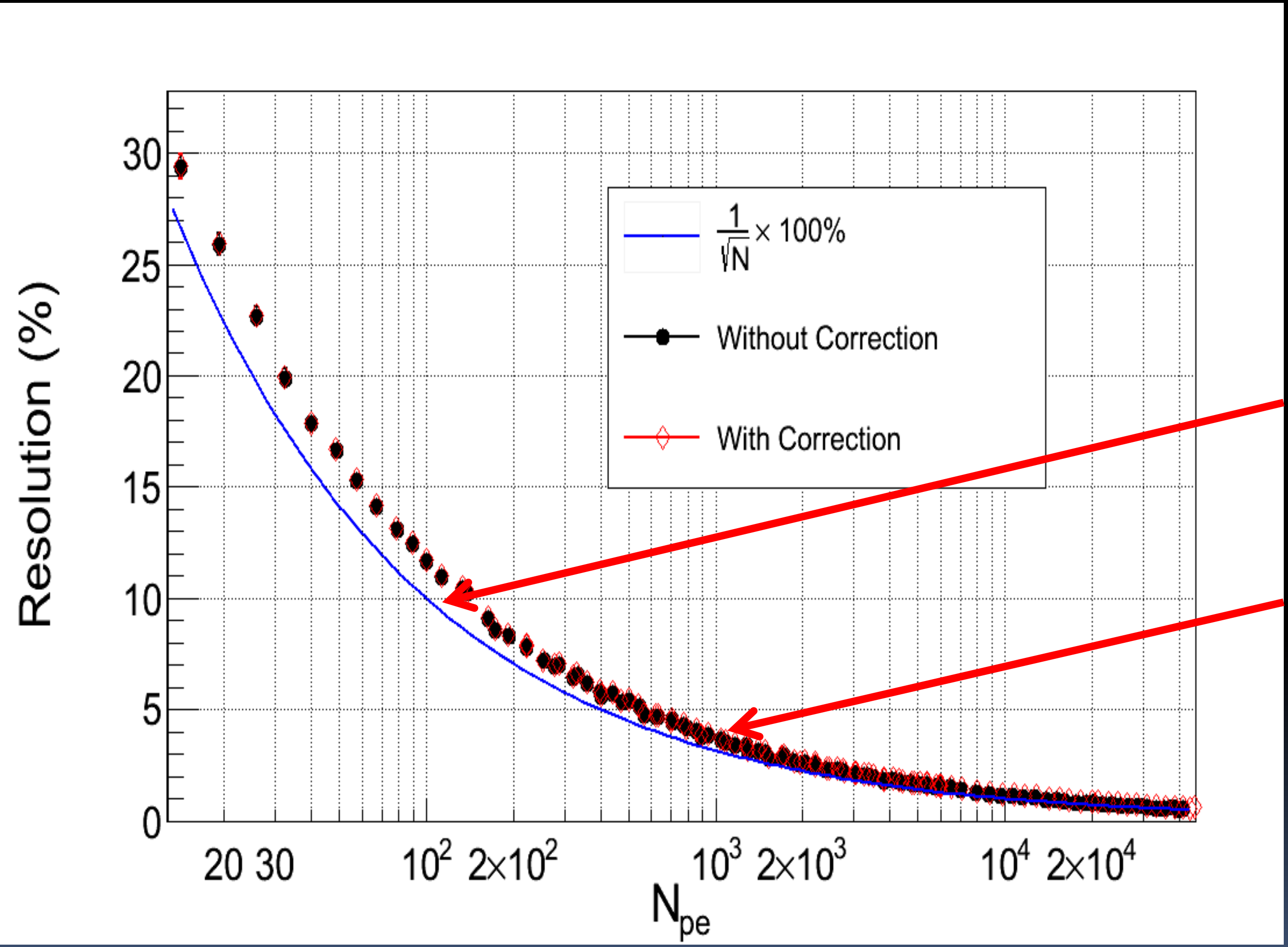
Deviation < ±2%

up to 50000 pe





Resolution

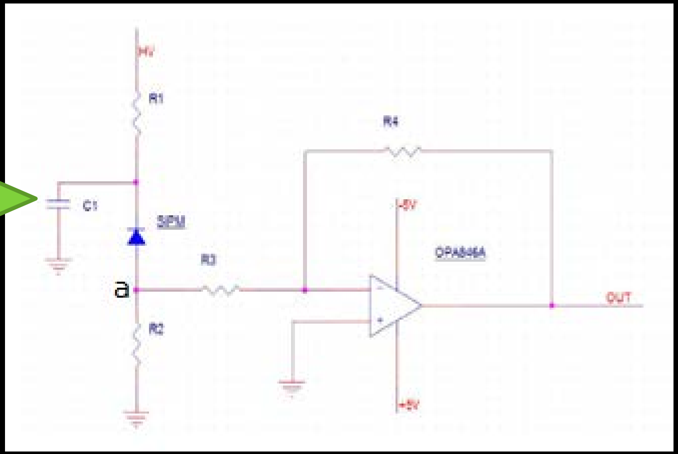


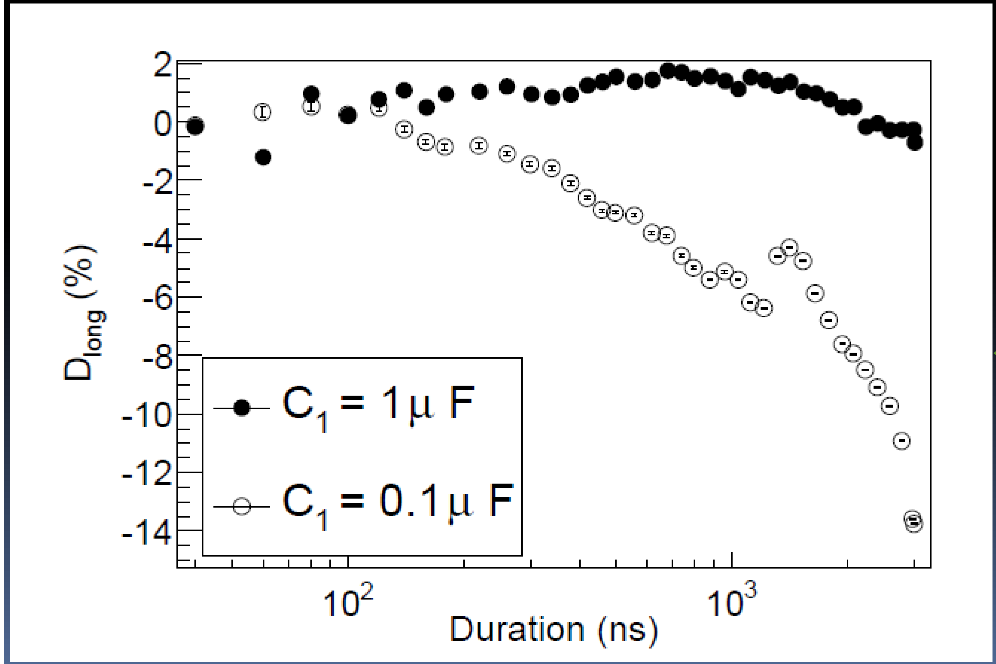
~12% @100pe

~4% @1000pe

Stability of the Gain

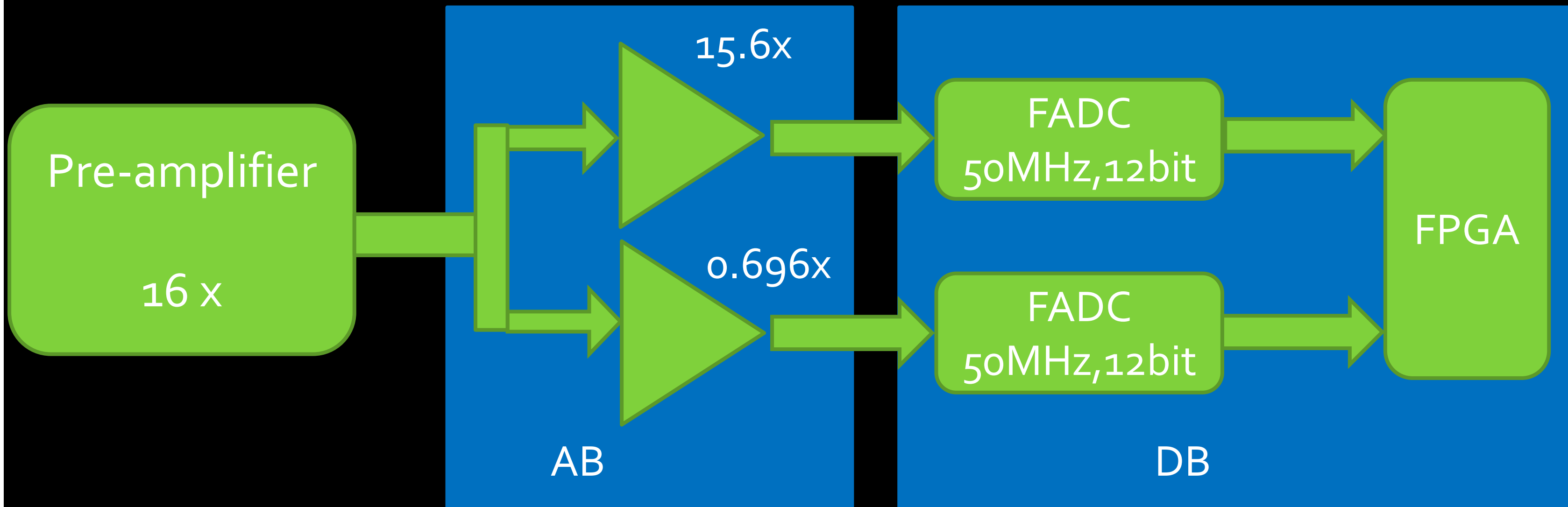
Keep operating voltage stable

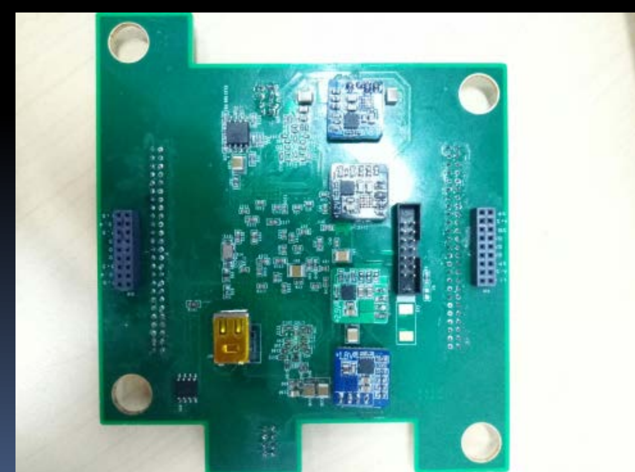




Duration of fluorescence signal could reach several μs

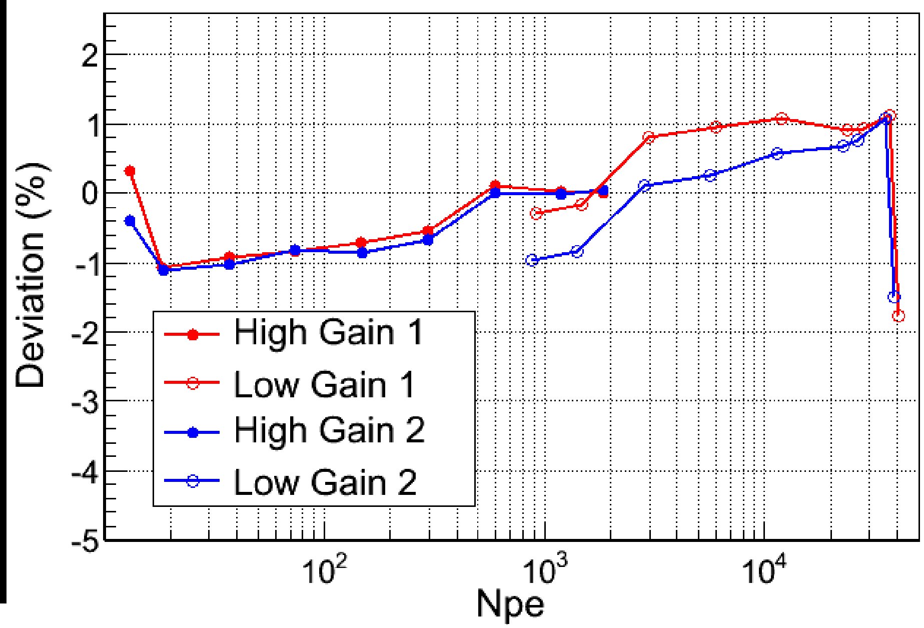
Design of Analog/Digital Board

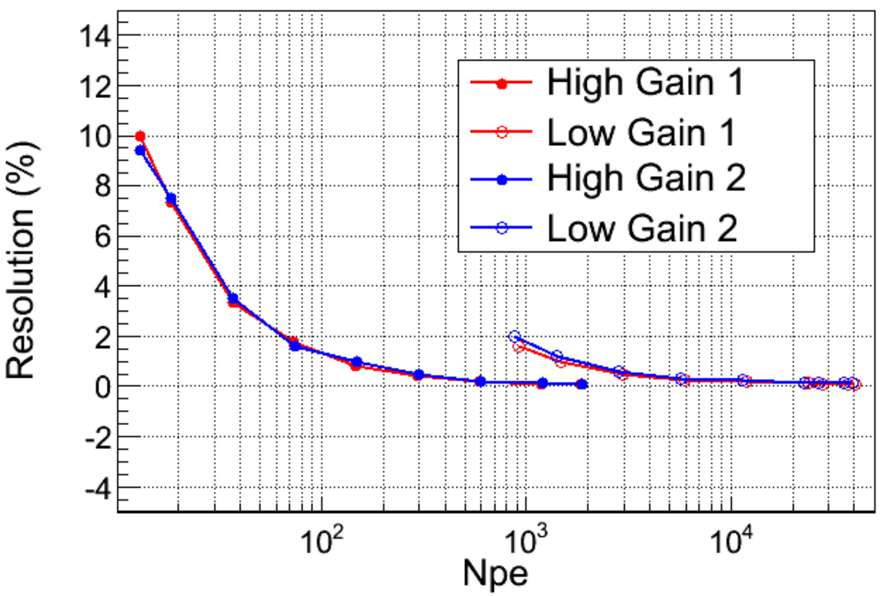




Test of AB/DB

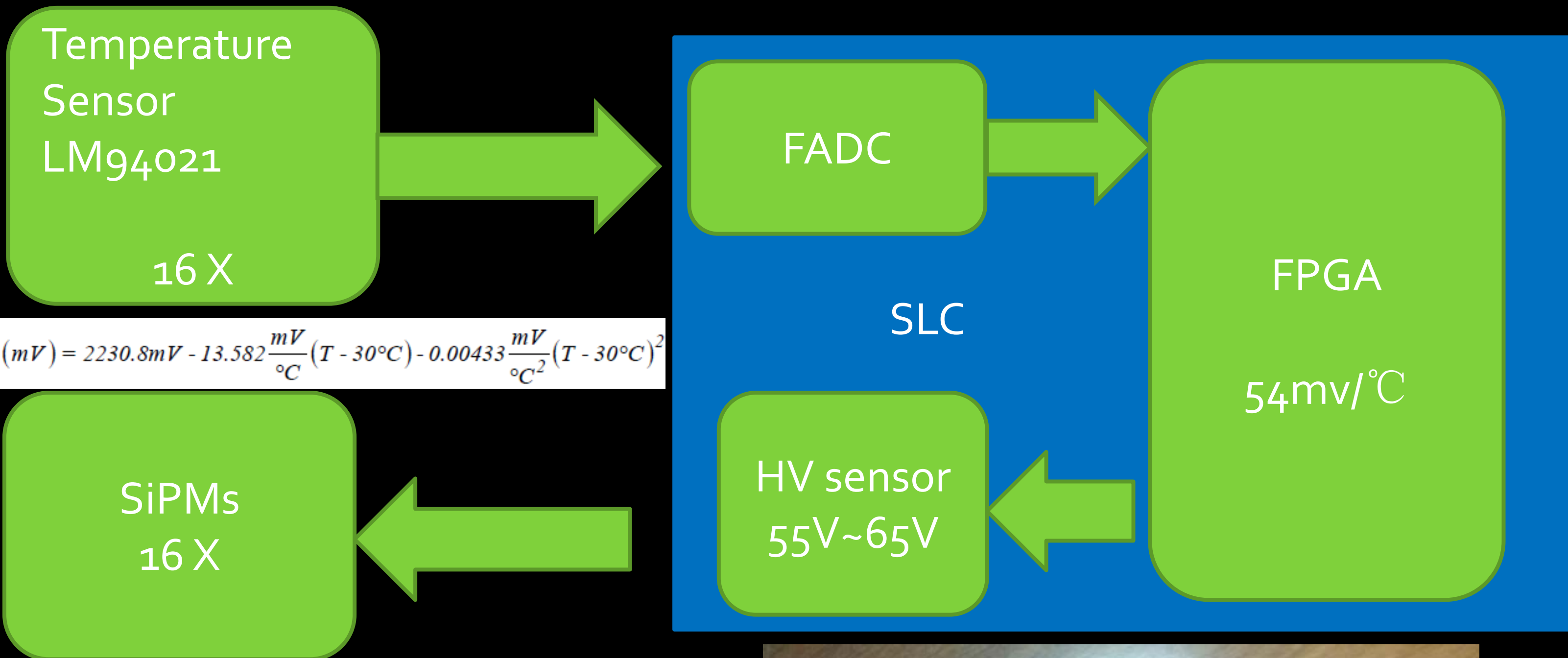
Dynamic Range:
Deviation < ±2%
10 pe ~ 32000pe



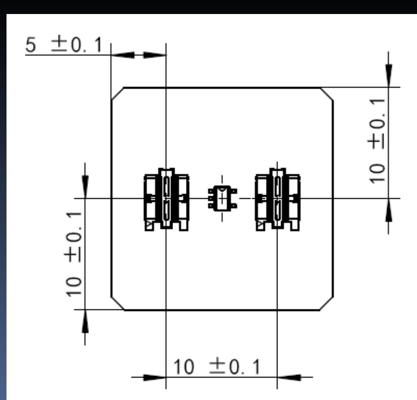


Resolution:
~10% @ 10pe
<2% @ >70pe

Design of Slow Control Board



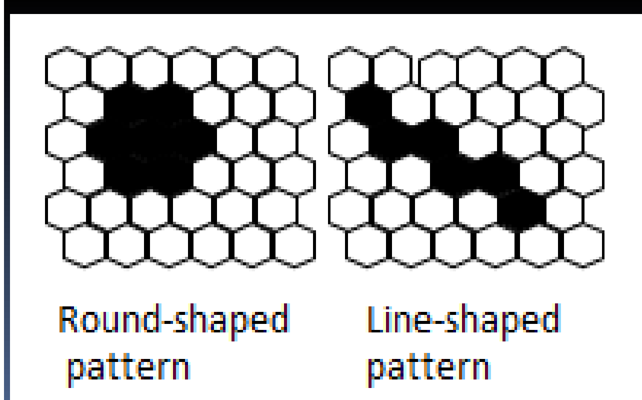
$$V_{TEMP}(mV) = 2230.8mV - 13.582\frac{mV}{°C}(T - 30°C) - 0.00433\frac{mV}{°C^2}(T - 30°C)^2$$



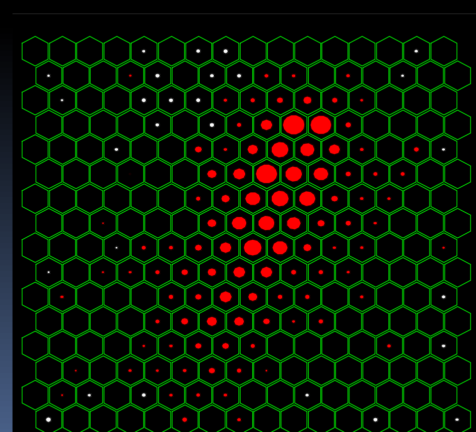
Trigger algorithm

- First level trigger： single channel trigger
  - Signal to noise ratio: S/N>n
  - Threshold varies with the intensity of the sky background light.
- Second level trigger： pattern recognition

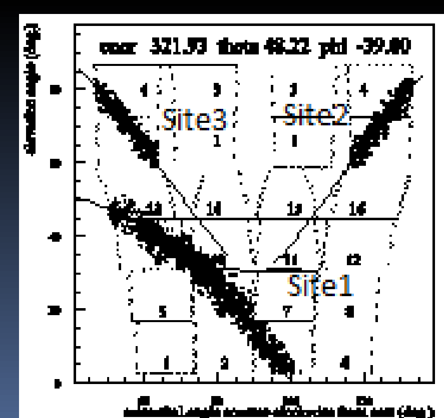
Patterns



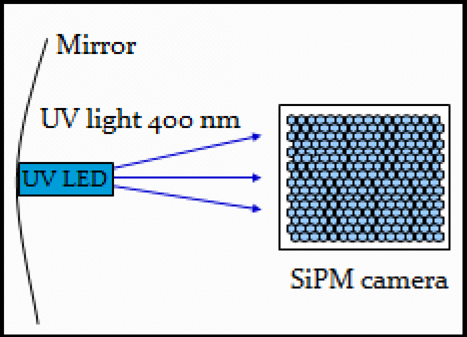
Cherenkov Event



Fluorescence Event

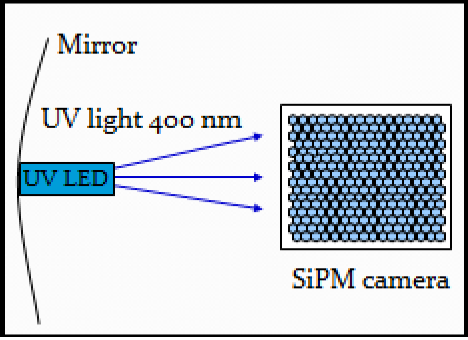


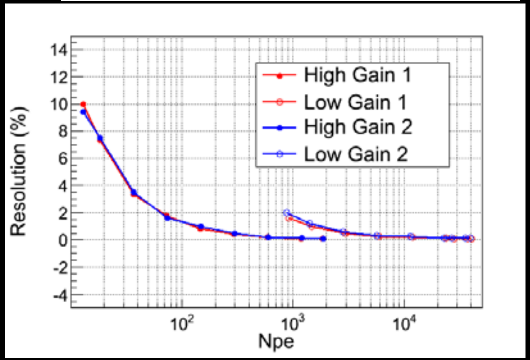
Gain monitor



- The Gain of SiPM
  - The SiPM gain (break down voltage) is sensitive to the temperature.
  - The voltage drop on the R_0 varies with the intensity of the sky background light.
- Monitor the high gain and the low gain of the electronics.
- UV-LEDs configuration
  - Low Temperature Coefficient (~ 0.2%)
  - Pulse width <20 ns

Gain monitor





- Point Light Source
  - Light source: 12mm
  - Focus distance: 2870mm
  - Camera size: 800mm
  - 3.88% lower at corner than center
  - 500pe (x 1,2,3,4,5,6)

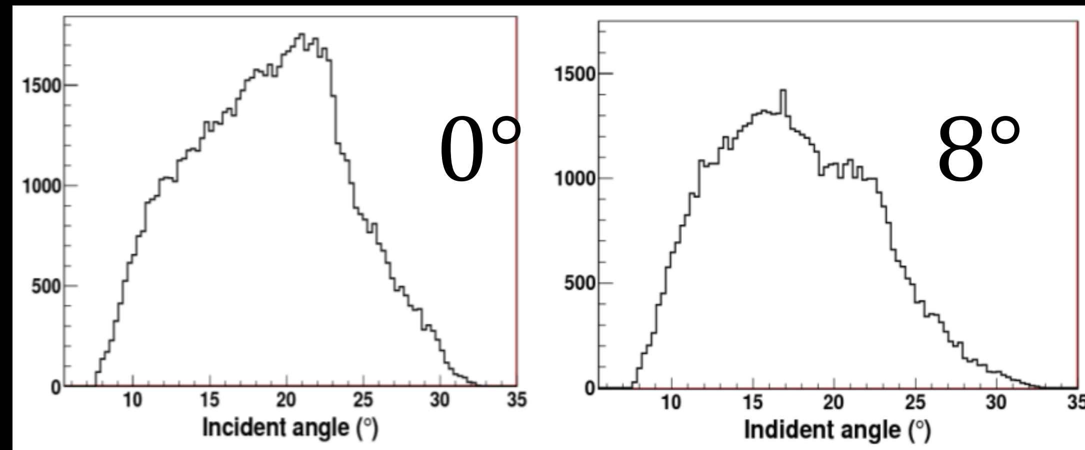
Winston Cone

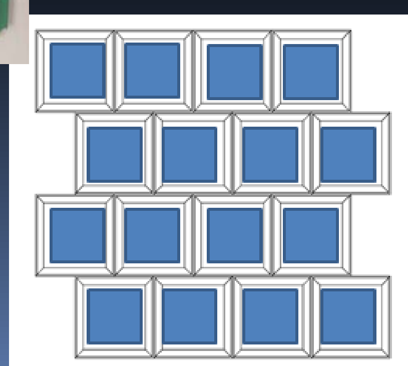
Pixel:25.4mm

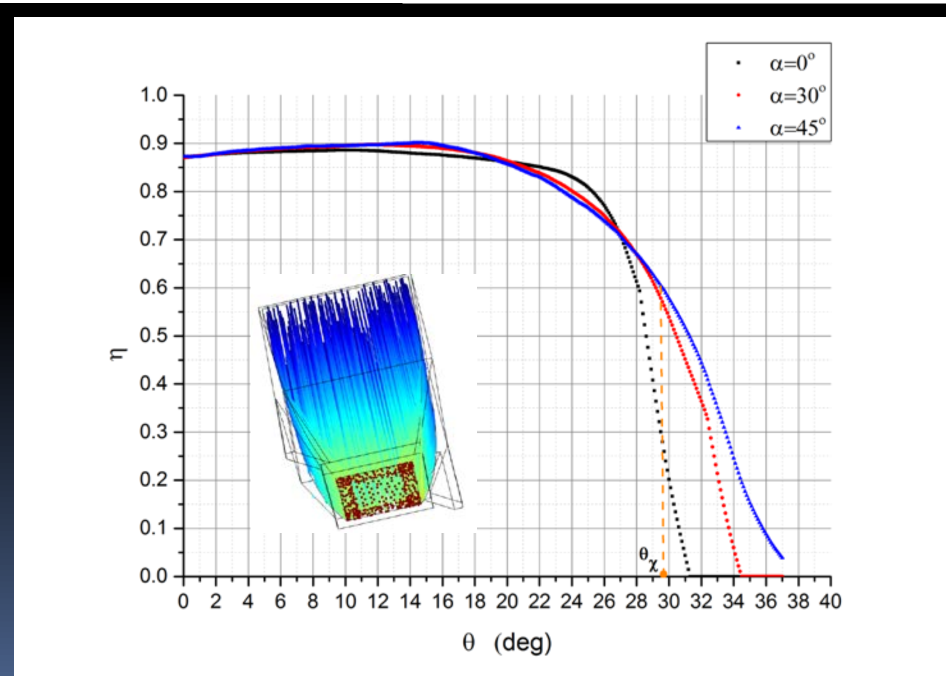
In:24.4mm

Out:15mm

Height: 25.3mm

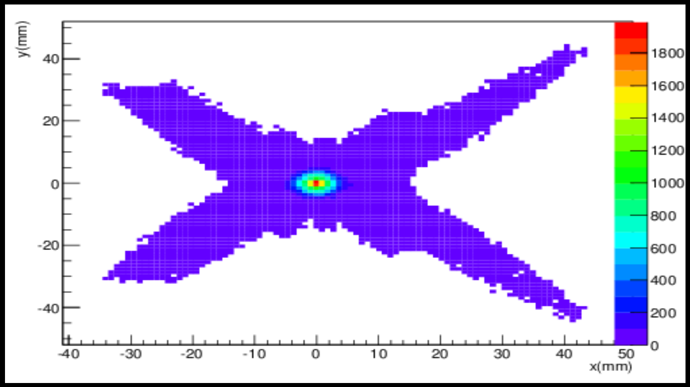




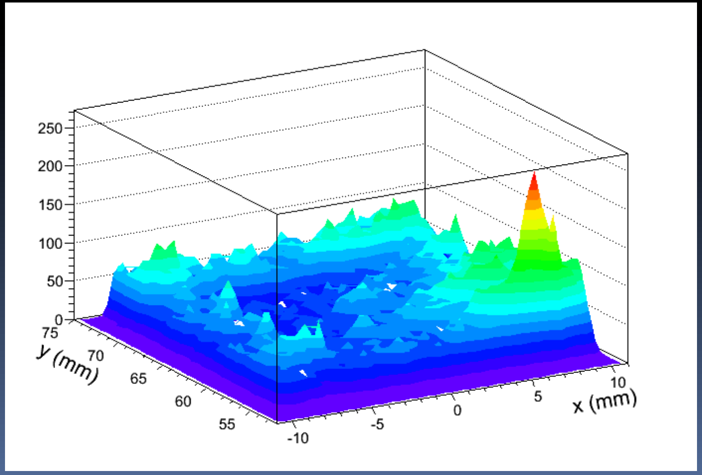


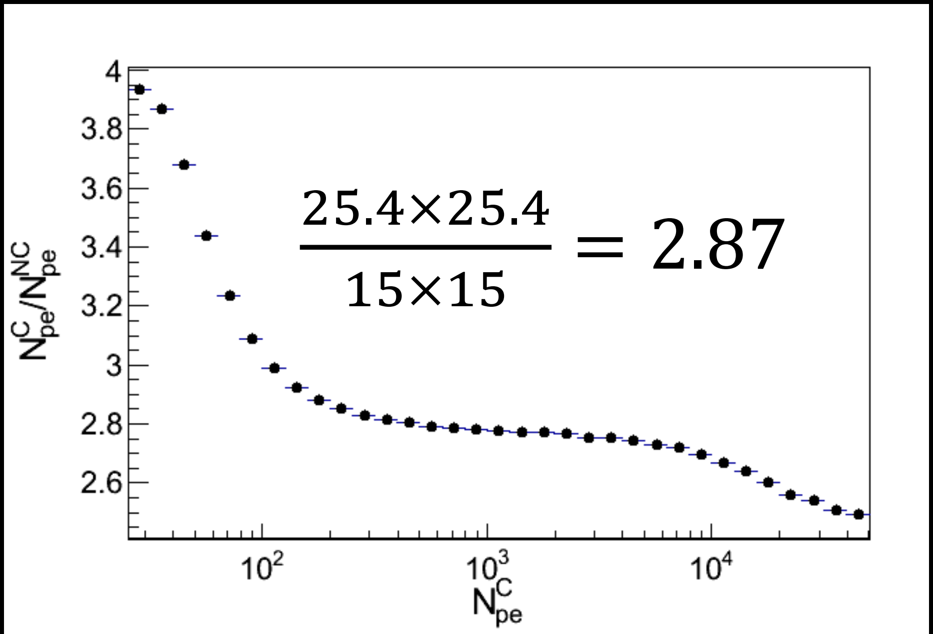
Simulation

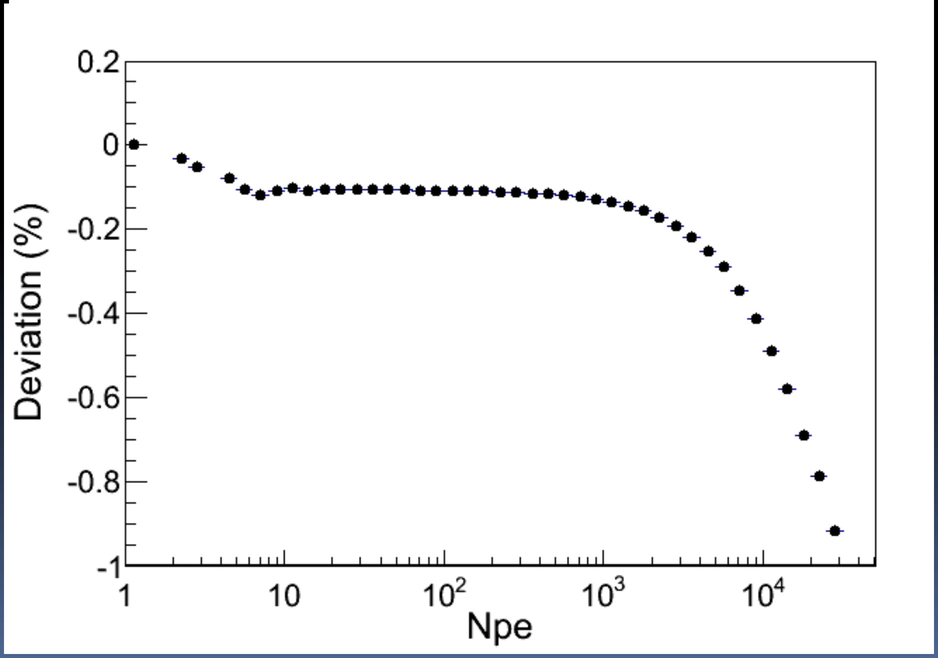
Photons on focal plane



Photons on SiPM surface







Summary

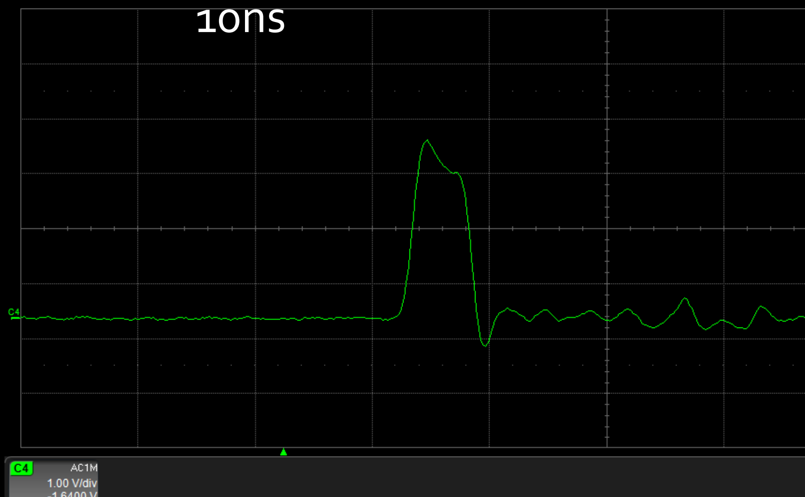
- Camera Design
  - We have designed a new SiPM
  - Pre-amplifier, AB,DB have been finished, more tests are undergoing
  - Slow Control Board is being developed
  - Winston cone is being tested
- Time schedule
  - First SiPM camera will be built before Jan. 2018;
  - 6 telescopes based on SiPM camera will be built and run before the end of 2018.
  - 16 telescopes will be run at 2020.

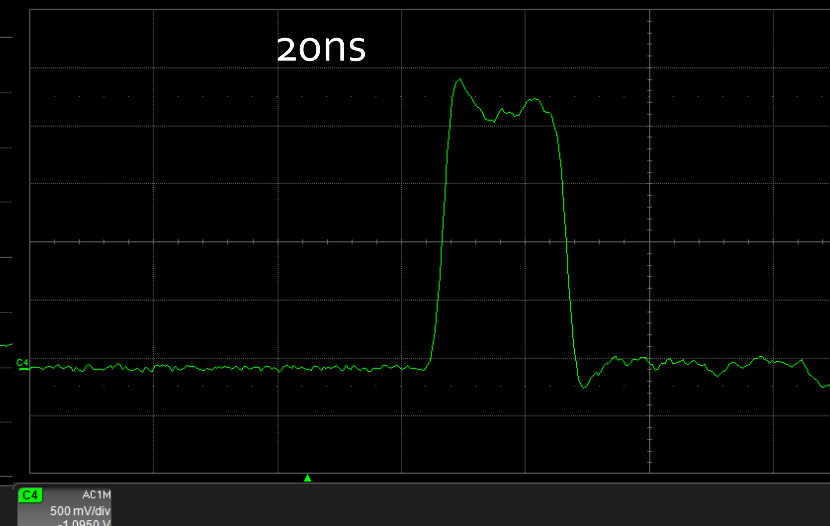
DEIC420 In/Out

10ns

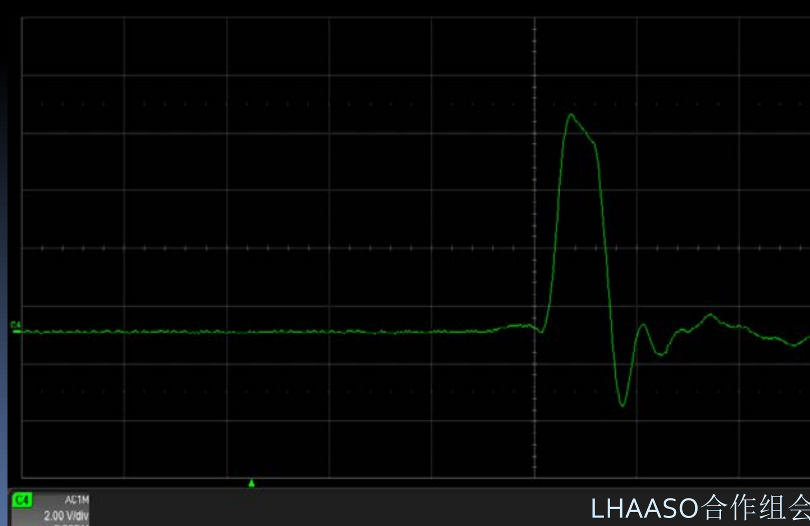
20ns

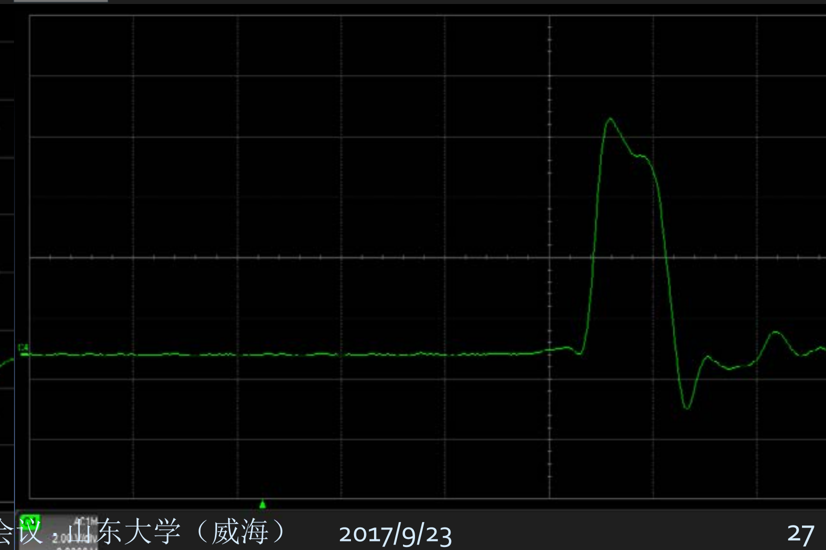
In





Out





Signal to noise ratio

	SiPM	PMT （R7899）
Relative PDE/QE	29%@400 nm	16%@400 nm
Dark count rate @ threshold=0.5pe	5.4MHz	<1kHz
Sky background noise	~37 MHz	~21MHz
S/N Ratio	0.11Ns	0.087Ns

$$\frac{S}{\sqrt{N}} = \frac{N_s^{ph} \times PDE}{\sqrt{N_{BG}^{ph} \times PDE + N_{DCR}^{pe}}} \propto \frac{N_s^{ph}}{\sqrt{N_{BG}^{ph}}} \times \sqrt{PDE}$$