

Characteristic studies of silicon sensor for ILD ECAL

Shusuke Takada

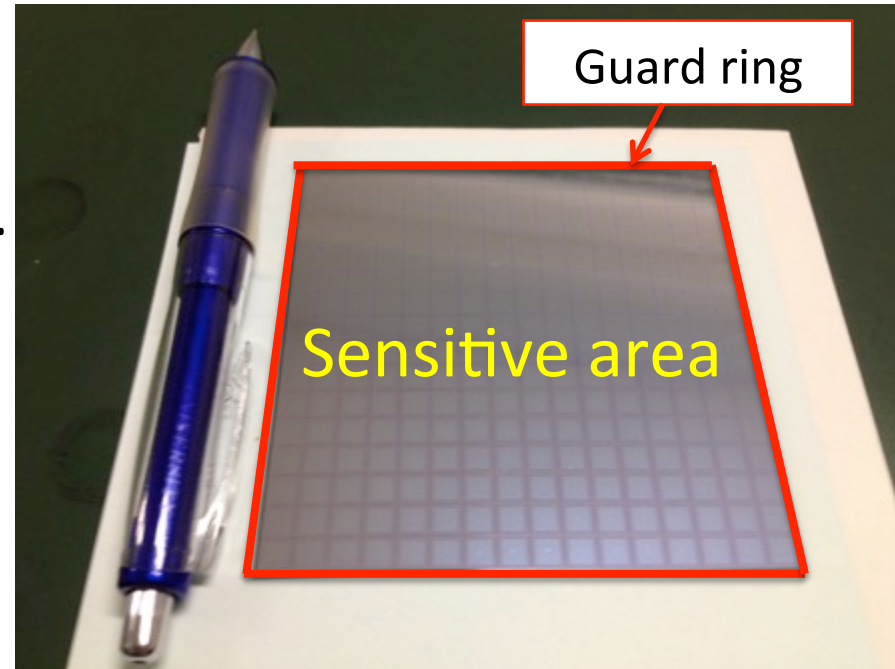
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Kyushu Univ., CALICE Asia group

1. Pixelized silicon detector

Pixelized silicon detector(Si-pad)

- Produced by Hamamatsu Photonics.
- Pixel size : 5.5 mm x 5.5 mm
- Thickness : 320 μm
- 16 x 16 pixels

✂ Some chips have **guard-ring(s)**.



Advantage : Collect surface current, Decrease dark current, etc.

Disadvantage: Decrease sensitive area, Arise crosstalk, etc.

Motivation

Studying characteristics of silicon sensors for optimization

- Comparing effect of guard ring
- Measuring cross-talk between pixels

2. Measurement

We performed two measurements.

(Guard-ring is not grounded.)

3-1 Temperature dependence

Measurement of temperature dependence on dark current of Si-pad.

3-2 Laser injection

Measurement of laser injection for Si-pad.

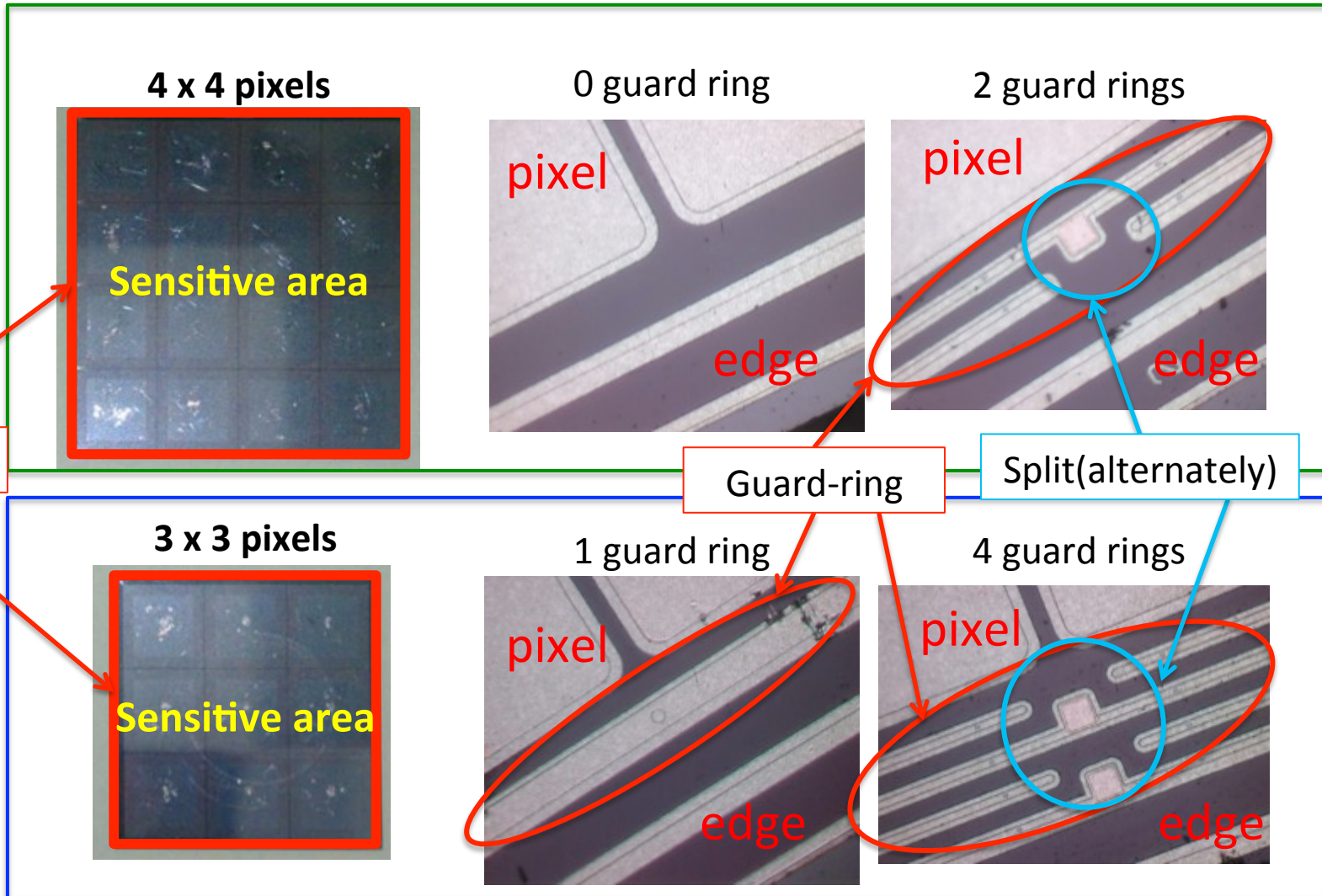
- Inside pixels (to see inter-pixel cross-talk)

Baby chip(to compare guard rings)

These chips are made to compare the effect of different guard ring structures.

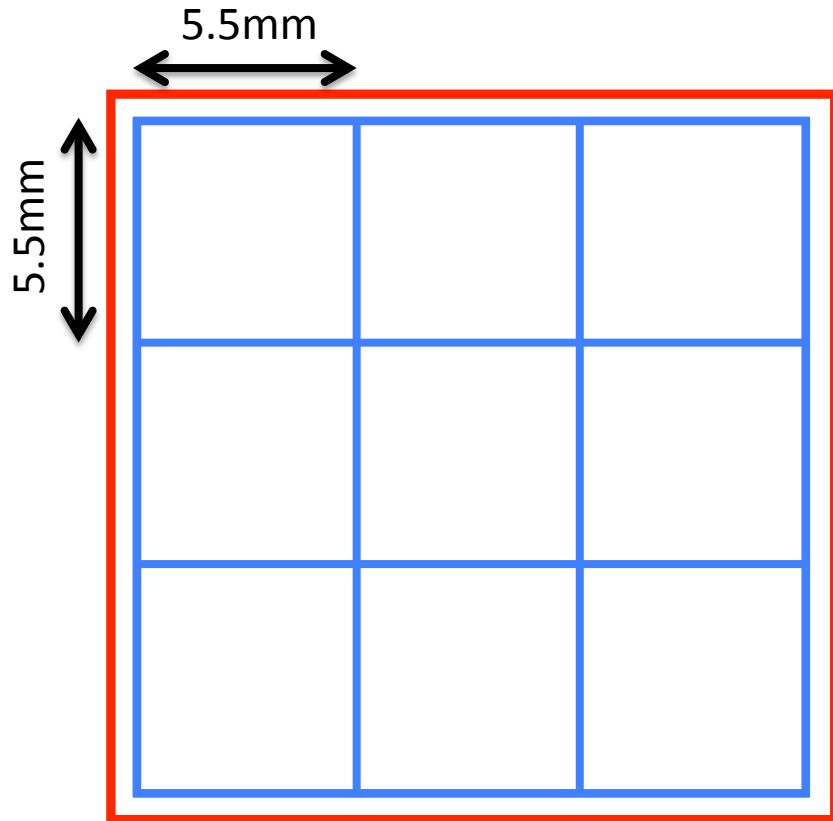
Pixel size : 5.5 mm x 5.5 mm

Thickness: 320μm

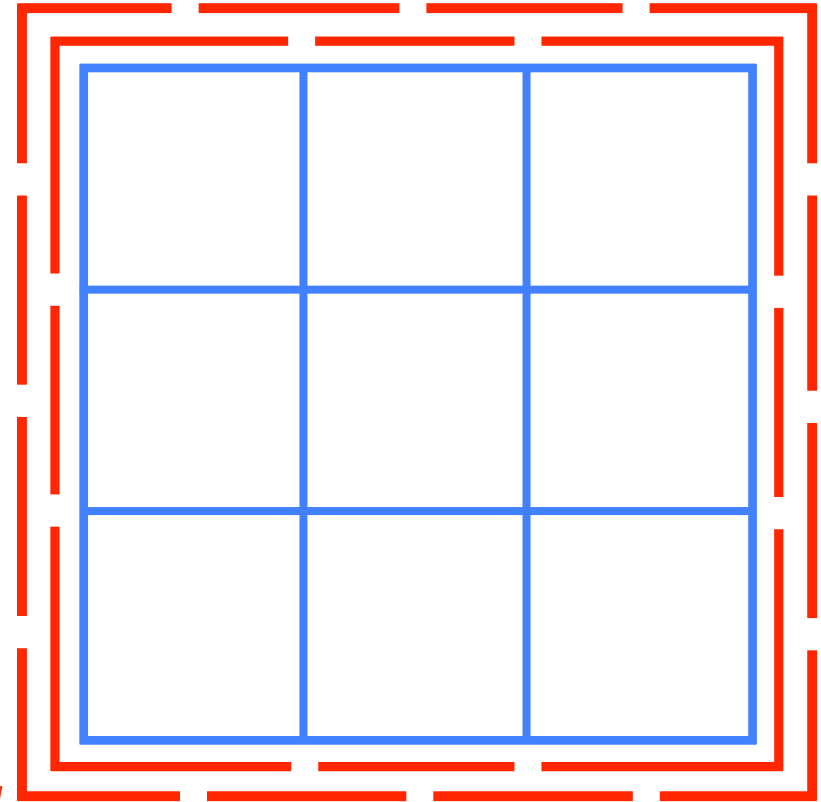


Structure of guard ring (Outline)

1 guard ring



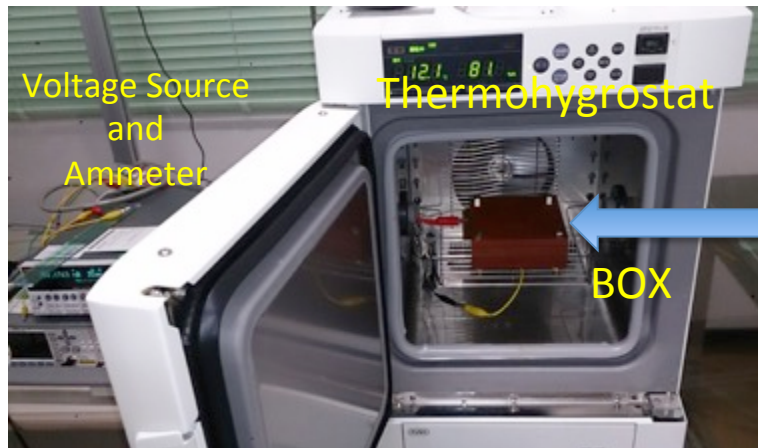
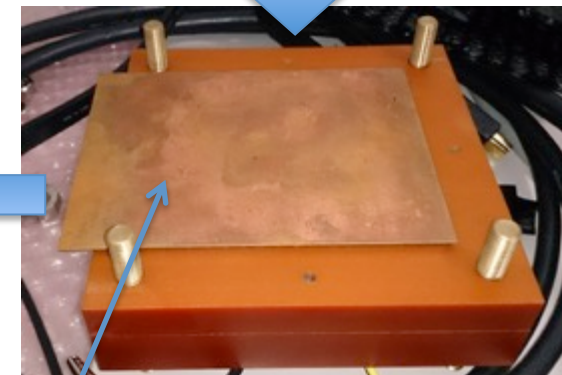
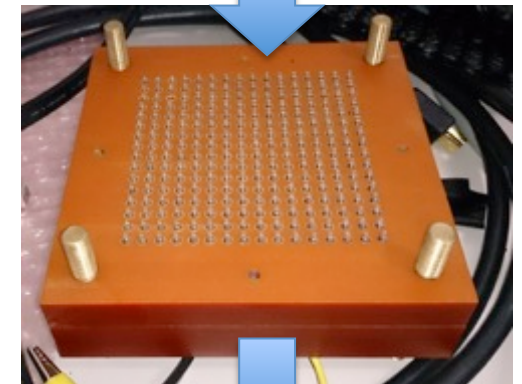
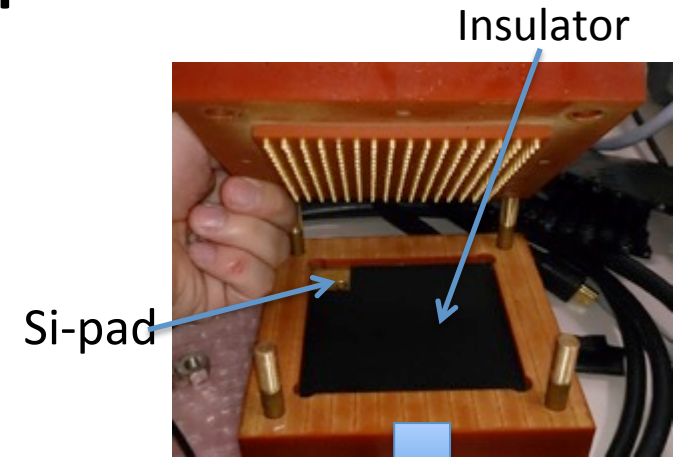
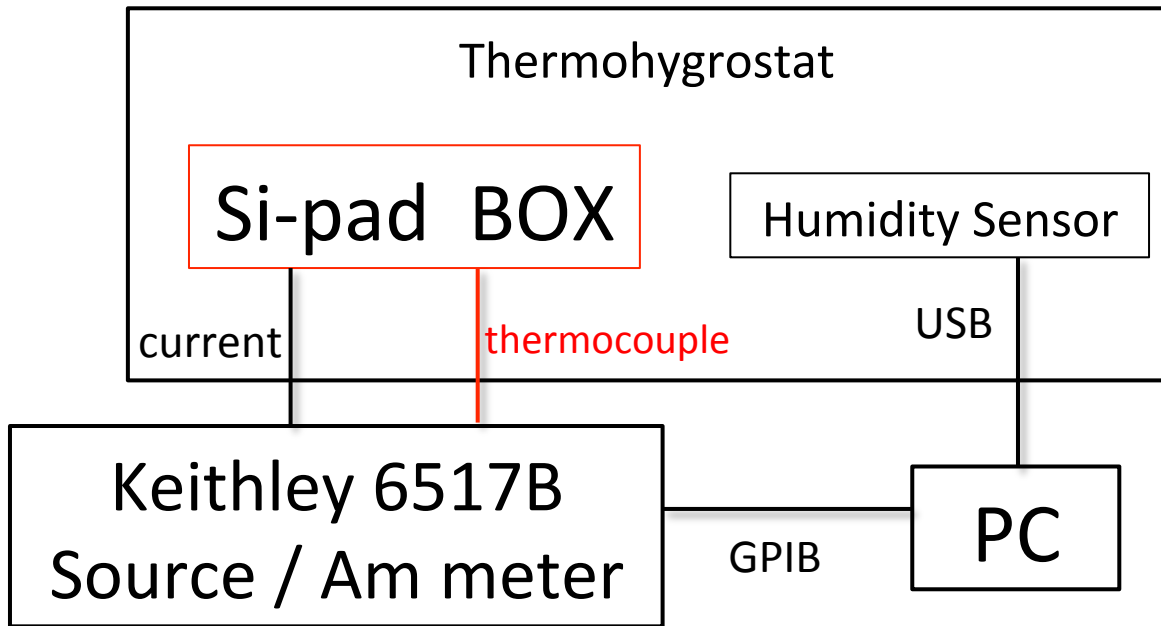
2 guard ring



Guard ring

※Structure of 4 guard ring is the same as this type.

2-1 Temperature dependence Setup

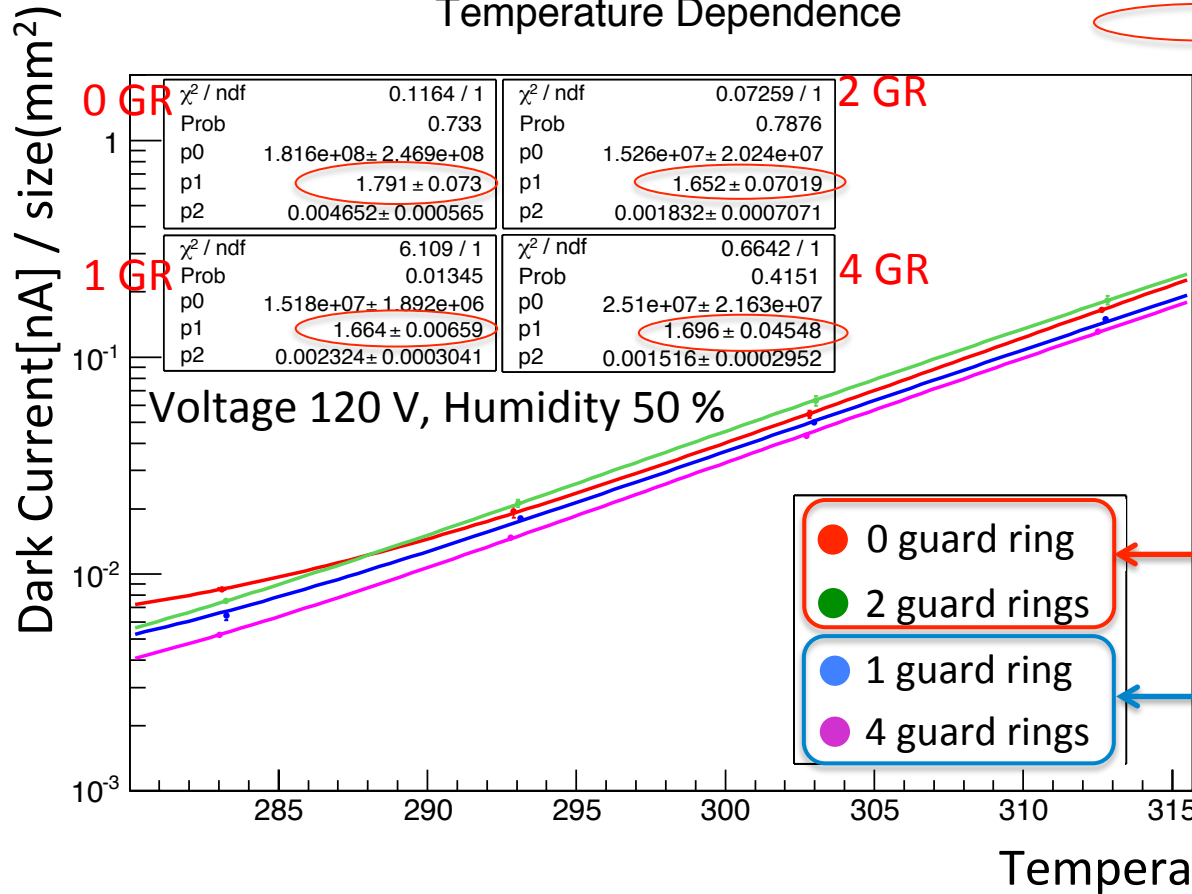


Copper sheet

Result

Temperature Dependence

band-gap energy



Fitting function

$$I(T) = AT^2 \exp\left(-\frac{E_g(T)}{2k_B T}\right) + Bkg.$$

$$E_g(T) = E_g(0) - \frac{\alpha T^2}{\beta + T}$$

- Significant difference was seen. (max 0.1 nA/sensitive area)
- Lower dark current for pads with 1 and 4 guard rings. (especially 4 guard ring)
- May be due to the difference of chip size.
- Silicon's band-gap energy $E_g(0)$ is 1.166 eV, but this result is not consistent. (Fitting parameter $p1 \approx 1.7$)

2-2 Laser injection Setup

Specification of laser

CRYLAS GmbH

DSS1064-Q2 (Class 3B)

Wave length : 1064 nm

Pulse width : ~ 1.5 ns

Pulse energy : $> 20 \mu\text{J}/\text{pulse}$
 $\sim 10^{14}$ photons/pulse

Peak power : $> 13\text{kW}$ -> use ND filter

Repetition rate : 1 kHz

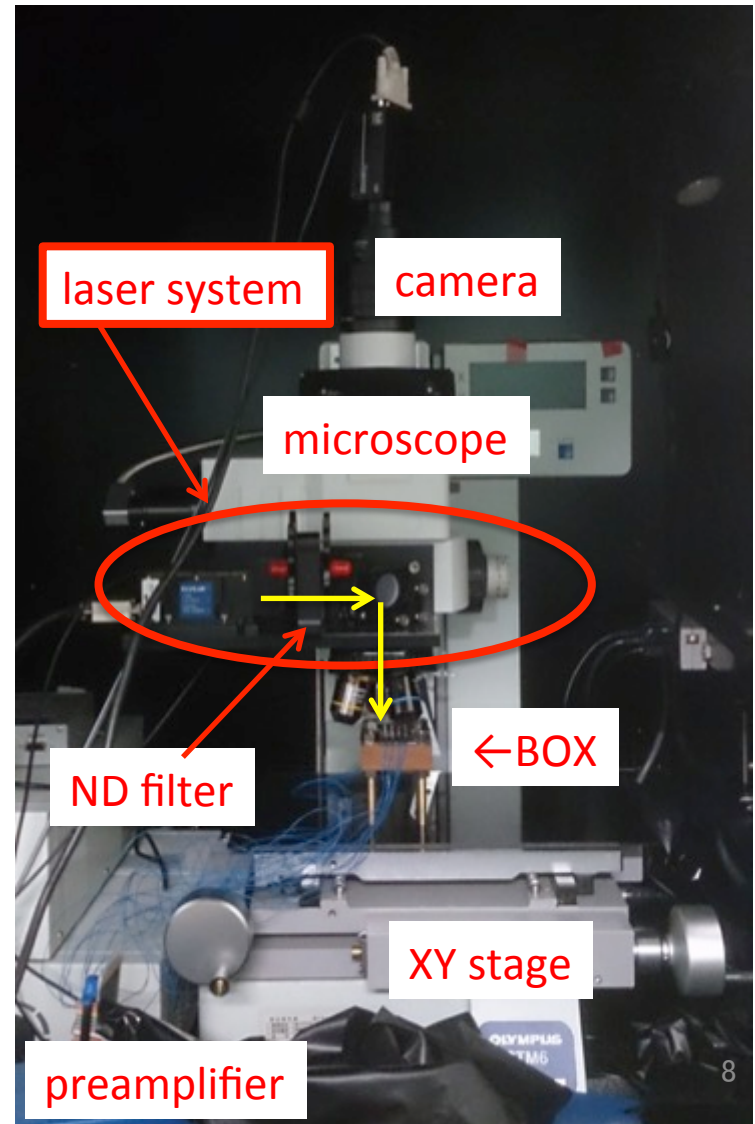
Laser spot size : $< 20 \mu\text{m}$

1064nm = 1.16 eV

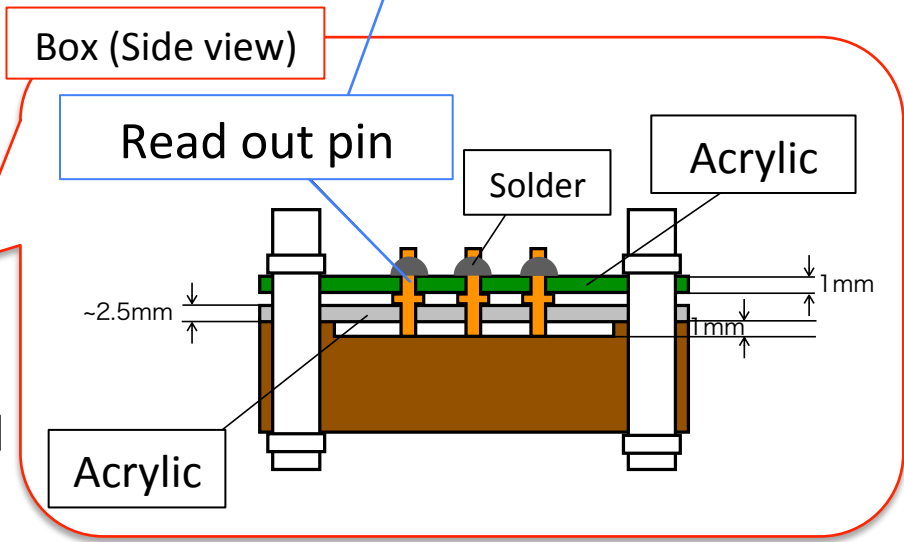
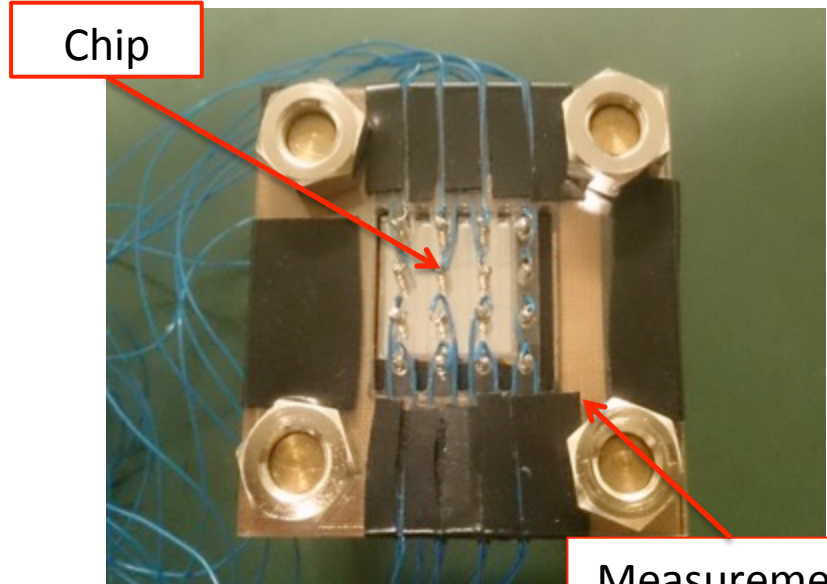
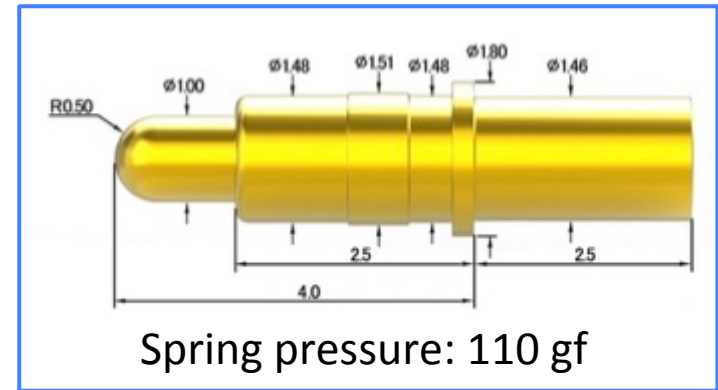
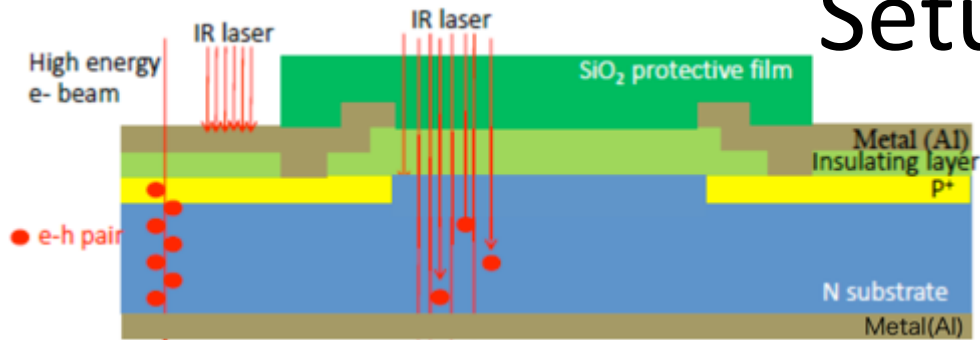
(※Silicon 's band-gap energy is 1.12 eV)



A photon can product an electron-hole pair.

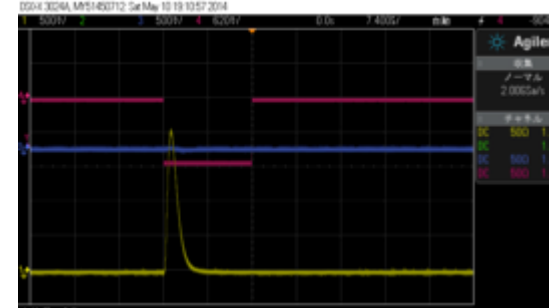


2-2 Laser injection Setup



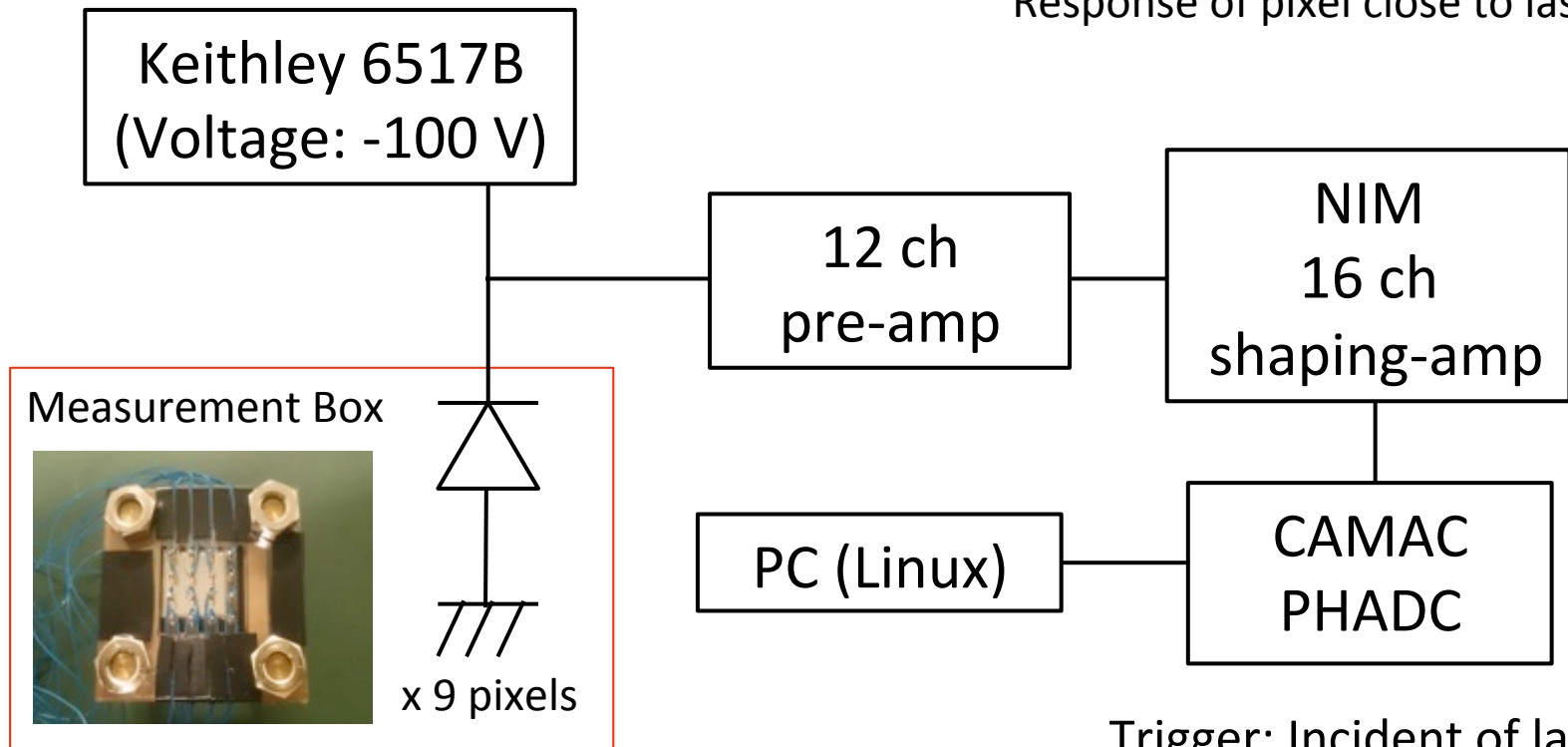
• This box can individually read out each pixel

2-2 Laser injection Setup



Response of pixel close to laser point

Data taking circuit

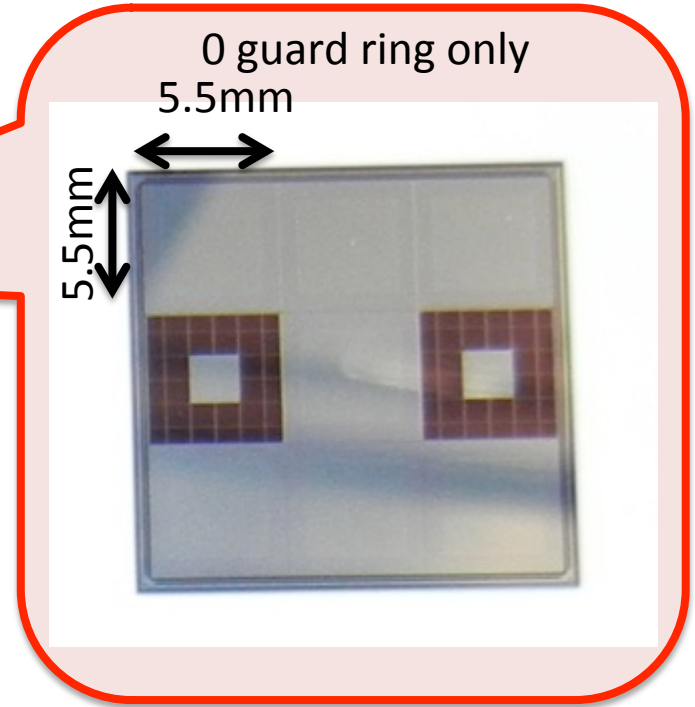
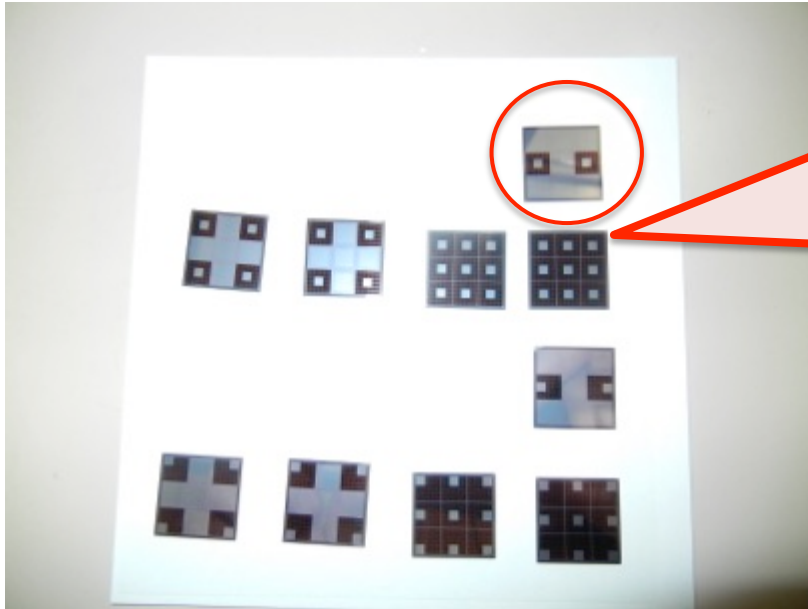


2-2 Laser Injection (inside pixels)

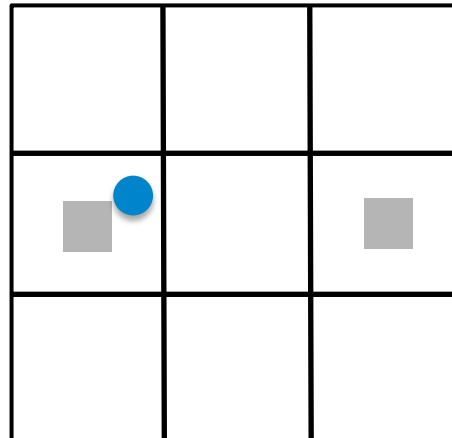
Baby chip (for laser injection inside pixels)

Pixel size : 5.5 mm x 5.5 mm

Thickness: 320 μ m



Schematic diagram



✘ Except for the light-injected pixel, Si-pad was masked by black sheet.

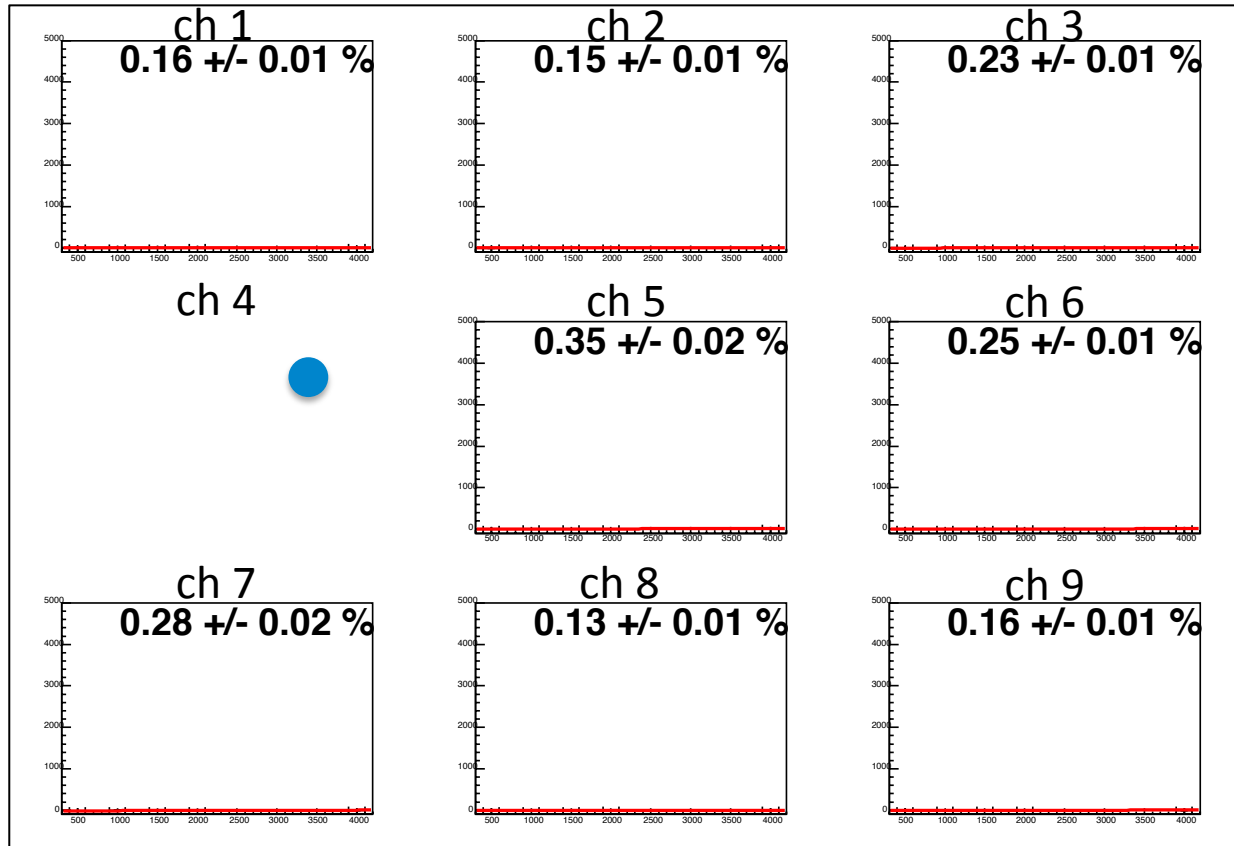


● Laser point

Result

Horizontal axis : Response of ch 4 [mV] (\sim Laser Power)

Vertical axis : Response of each pixel



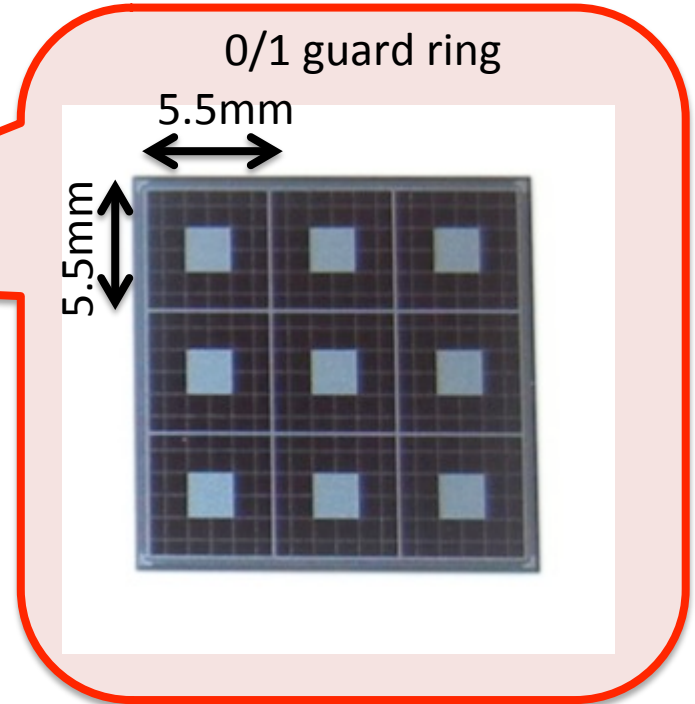
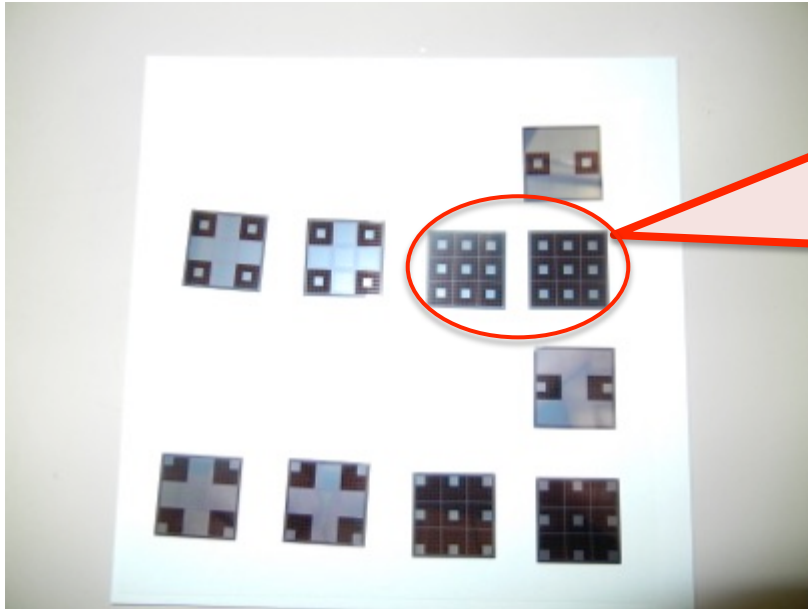
- All channels, cross-talk < about 0.5%
- We are able to get reproducible results.

2-2 Laser Injection (inside pixels)

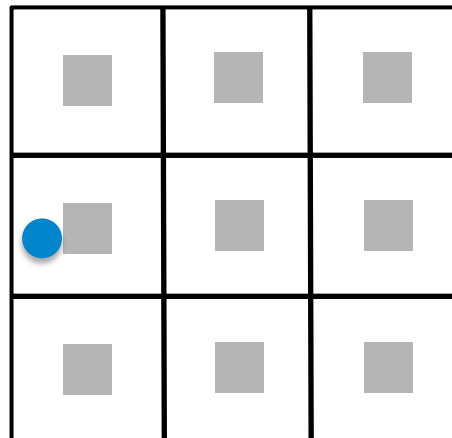
Baby chip (for laser injection inside pixels)

Pixel size : 5.5 mm x 5.5 mm

Thickness: 320 μ m



Schematic diagram



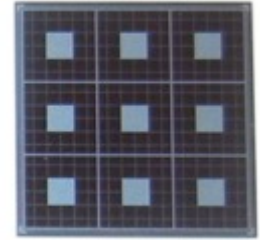
⌘ Except for injected pixel,
Si-pad was masked by black sheet.



Laser point

● Laser point

Result

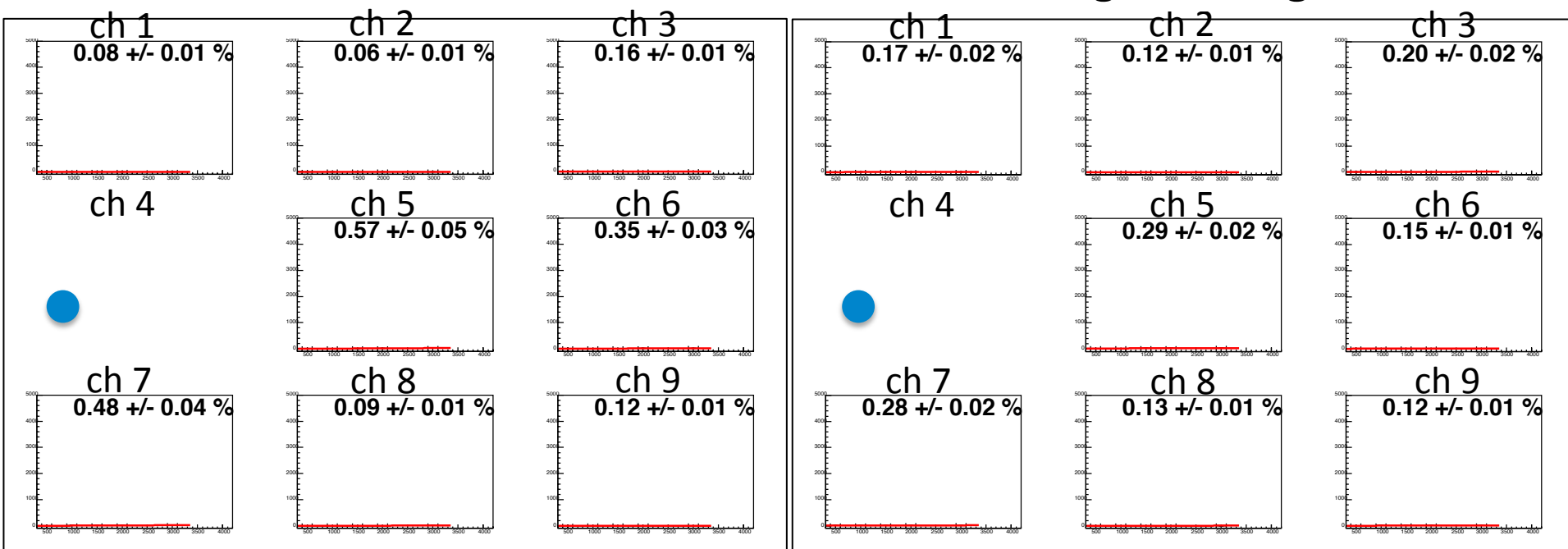


Horizontal axis : Response of ch 4 [mV] (\sim Laser Power)

Vertical axis : Response of each pixel

0 guard ring

1 guard ring



▪ No big difference was seen.

3. Summary & Conclusion

Summary

- At most 0.1 nA / sensitive area was seen as the difference of dark current among guard ring types.
- For the type of 1/4 guard ring, dark current was decreased.
- May be the difference of chip size.
- No big difference was seen for study of cross-talks between pixels, and it was less than 0.5% level.

Conclusion

- Currently we do not see any disadvantages in 0 guard ring sensors.

4. Plan

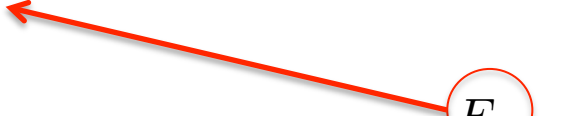
Plan

- Temperature dependence (continue)
 - Edge current, systematic error, etc...
 - Individually read out each pixel
- Meshed electrode chip (continue)
 - Inject to different type of meshed chip
 - Inject into a gap between pixels
- (- Grounded guard ring)

backup

Band-gap energy is also depend on temperature.

$$E_g(T) = E_g(0) - \frac{\alpha T^2}{T + \beta}$$

$$I(T) = AT^2 \exp\left(-\frac{E_g}{2k_B T}\right)$$


Silicon

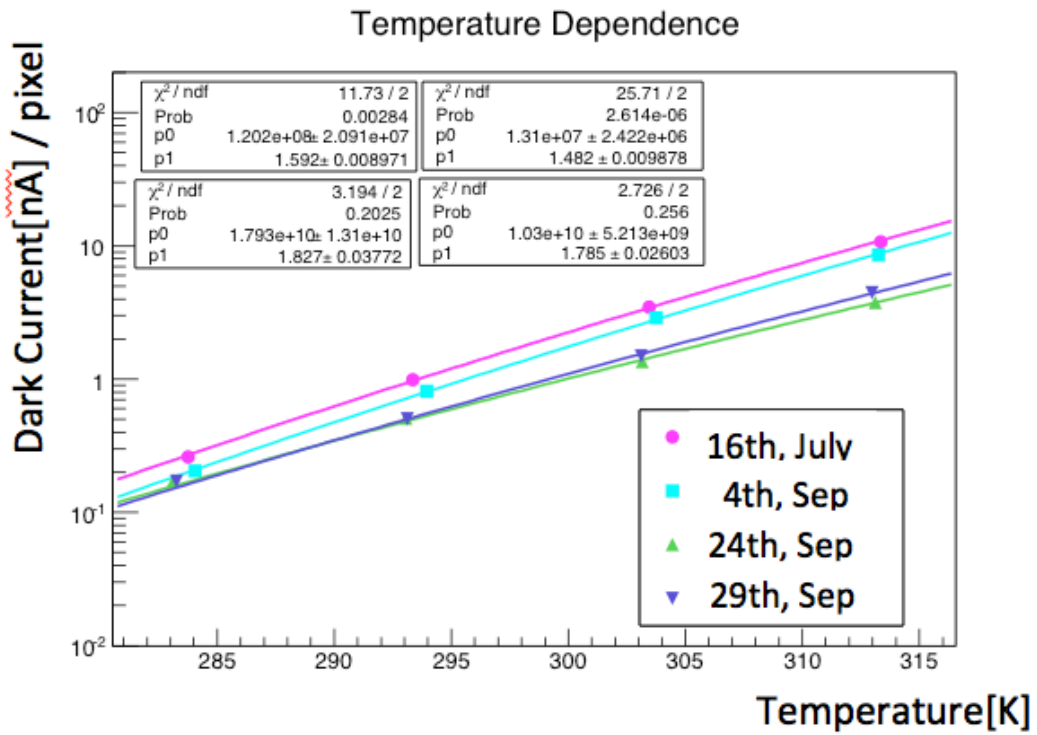
$E_g(0)$	1.166 eV
α	4.73×10^{-4} eV/K
β	636 K

✘ If $T=293.15$ K (20°C), $E_g(T)$ is 1.122252312....

backup

Problem

Example : result of 1 guard ring
(Temperature dependence)

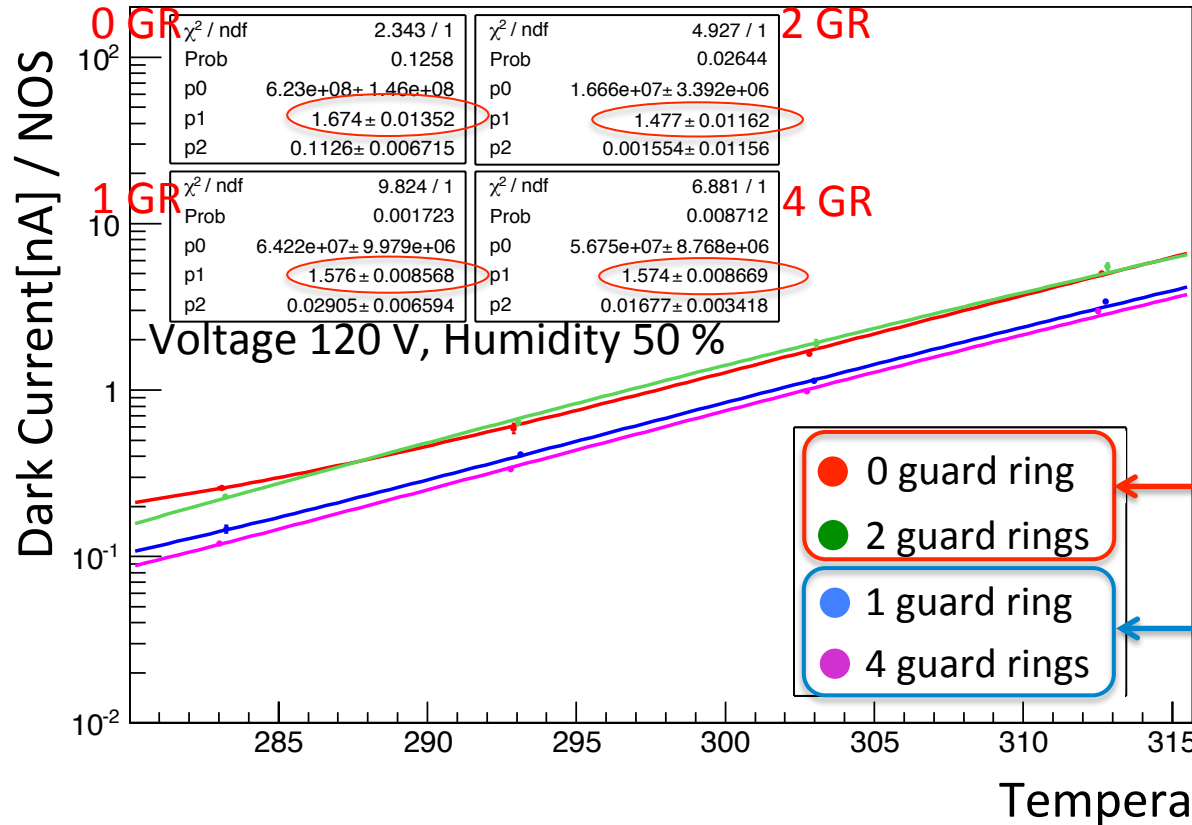


- Poor reproducibility seen by taking out and in the sensor from the measurement box. (should be fixed)
- This shift may be occurred by surface resistance of copper sheet. (condition is not good)

Result

Temperature Dependence

band-gap energy



Fitting function

$$I(T) = AT^2 \exp\left(-\frac{E_g(T)}{2k_B T}\right) + Bkg.$$

$$E_g(T) = E_g(0) - \frac{\alpha T^2}{\beta + T}$$

- Normalized by the number of sides(NOS).
 - To take account of edge current.
- Silicon's band-gap energy $E_g(0)$ is 1.166 eV, but this result is not consistent. (Fitting parameter $p1 \approx 1.5$)

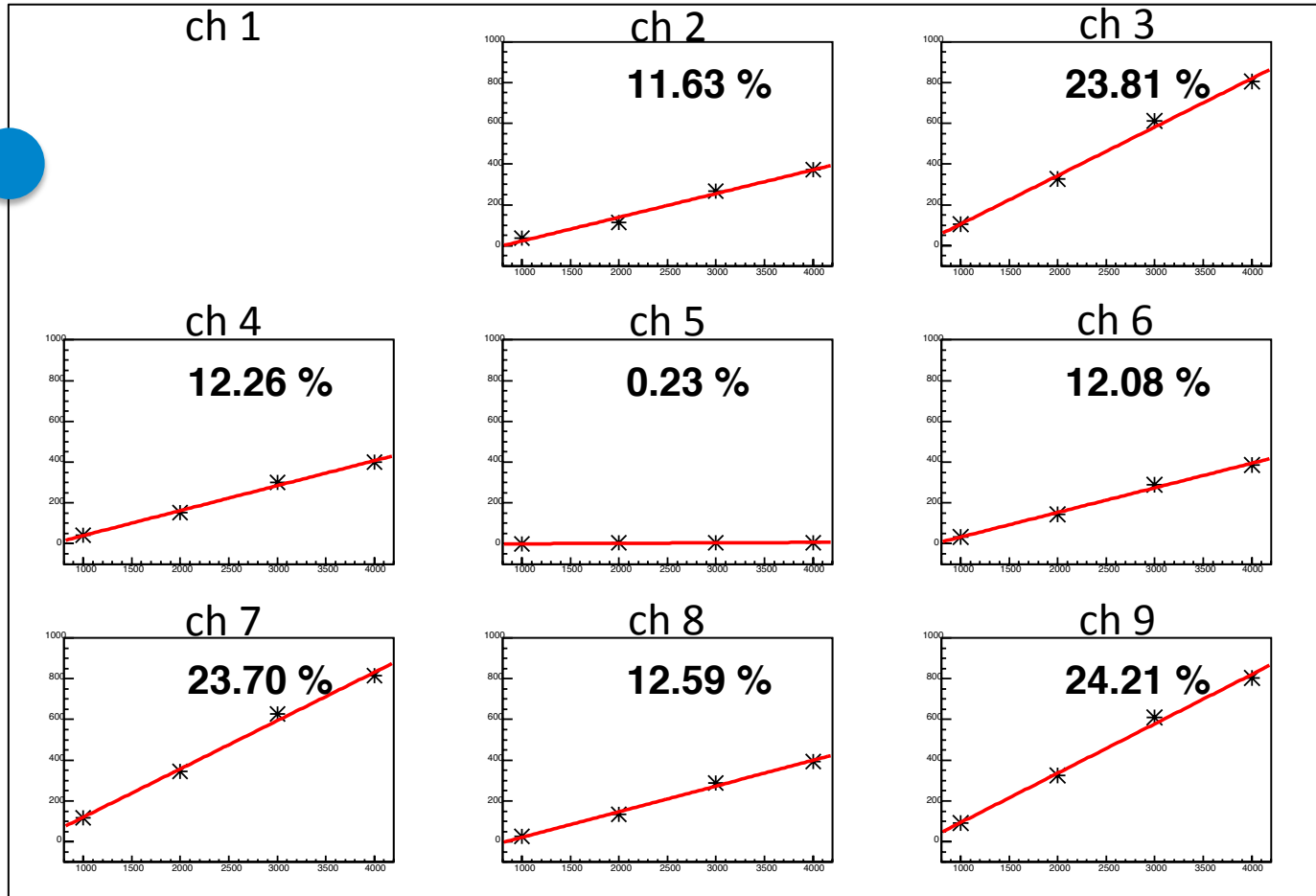


Laser point

Horizontal axis : Response of ch 1 [mV] (\sim Laser Power)

Vertical axis : Response of each pixel

Results of 1 GR



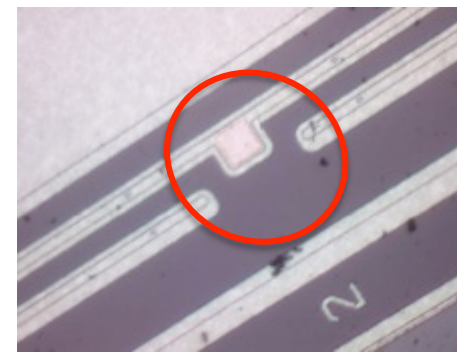
- Cross-talk was seen along the guard ring as expected.
- We are able to get reproducible results.

● Laser point

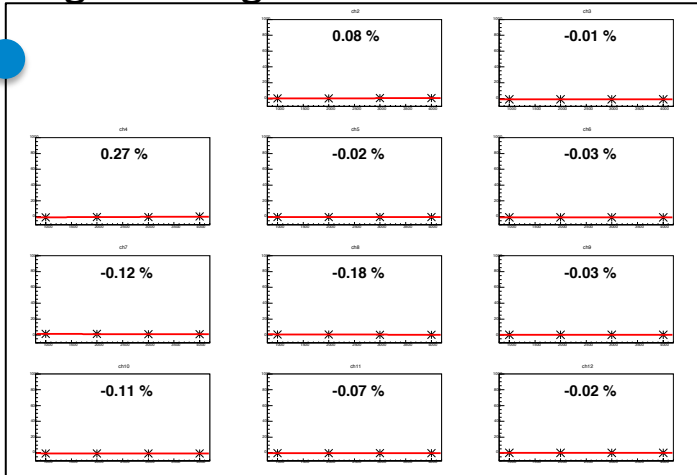
Results of Others

Horizontal axis : Response of ch 1 [mV] (~Laser Power)

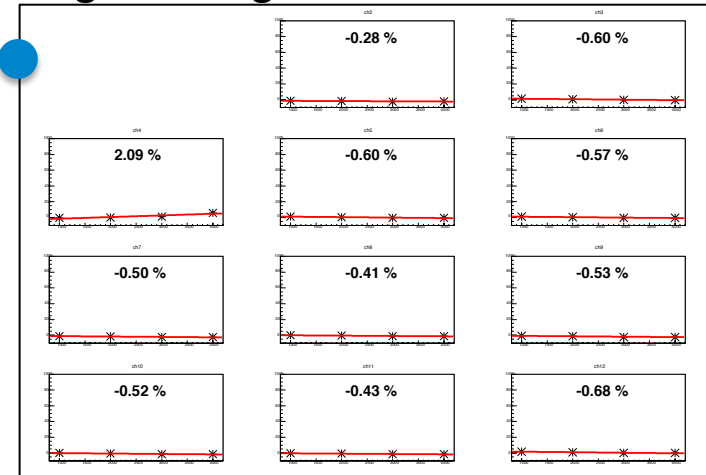
Vertical axis : Response of each pixel



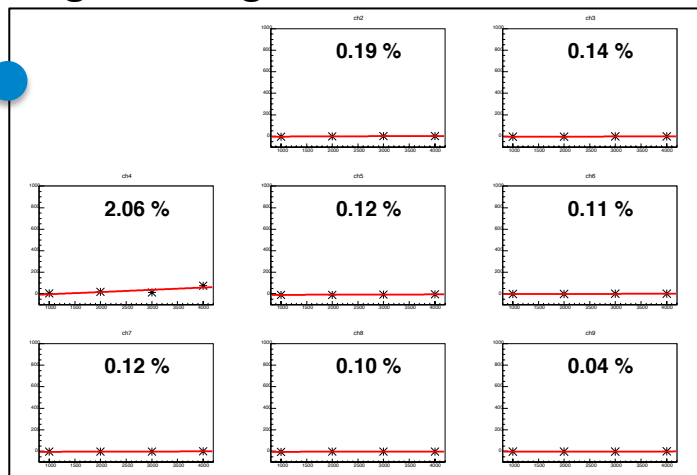
0 guard ring



2 guard rings



4 guard rings



- Significant cross-talks were not seen because of the following:
 - Si-pad doesn't have guard ring.(no GR)
 - Guard rings are separated.(2,4 GR)

● Laser point

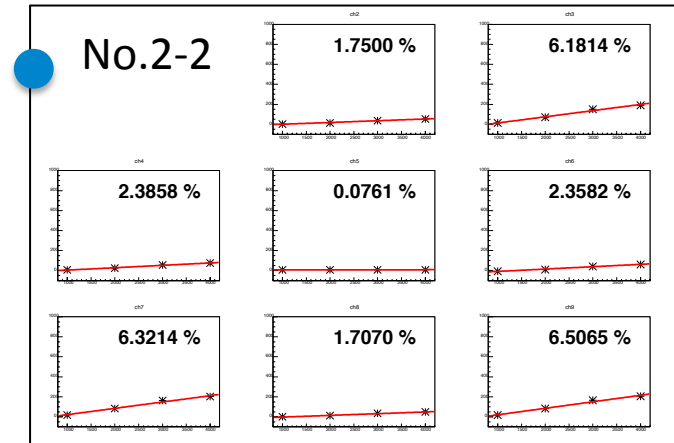
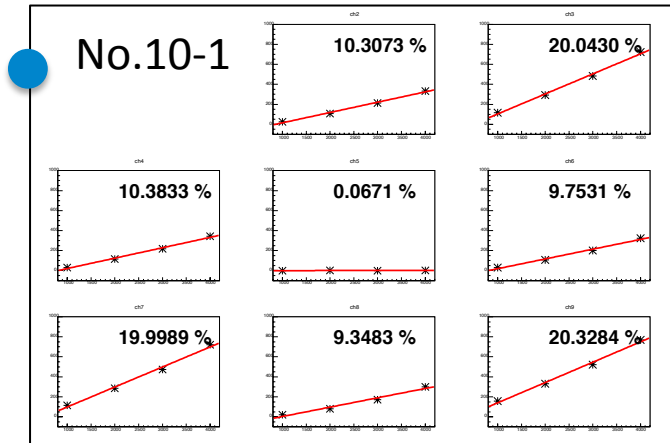
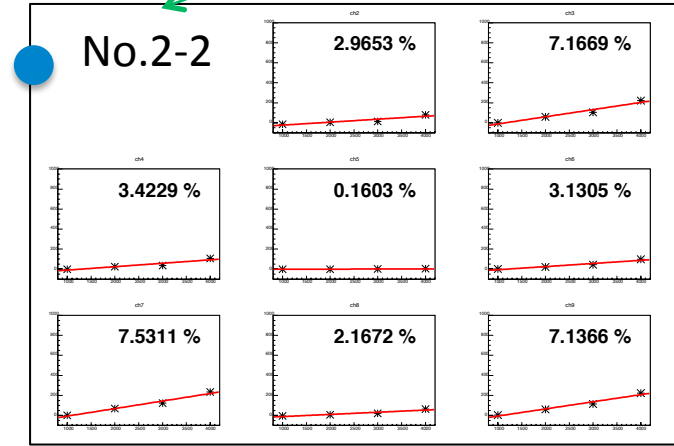
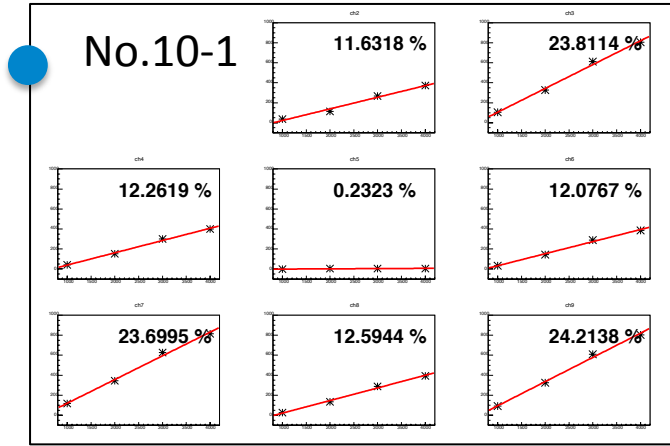
Horizontal line : Response of pixel close to laser point[mV]

Vertical line : Response of each pixel[mV]

backup

Serial Number of Si-pad

All 1 guard ring



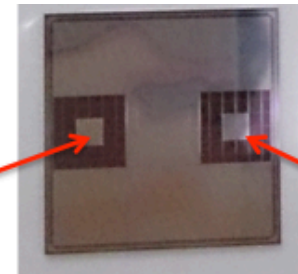
- Si-pad was not masked by black sheet.

From my slide@LCWS14

backup

3-2-2 Injection inside pixels

Results

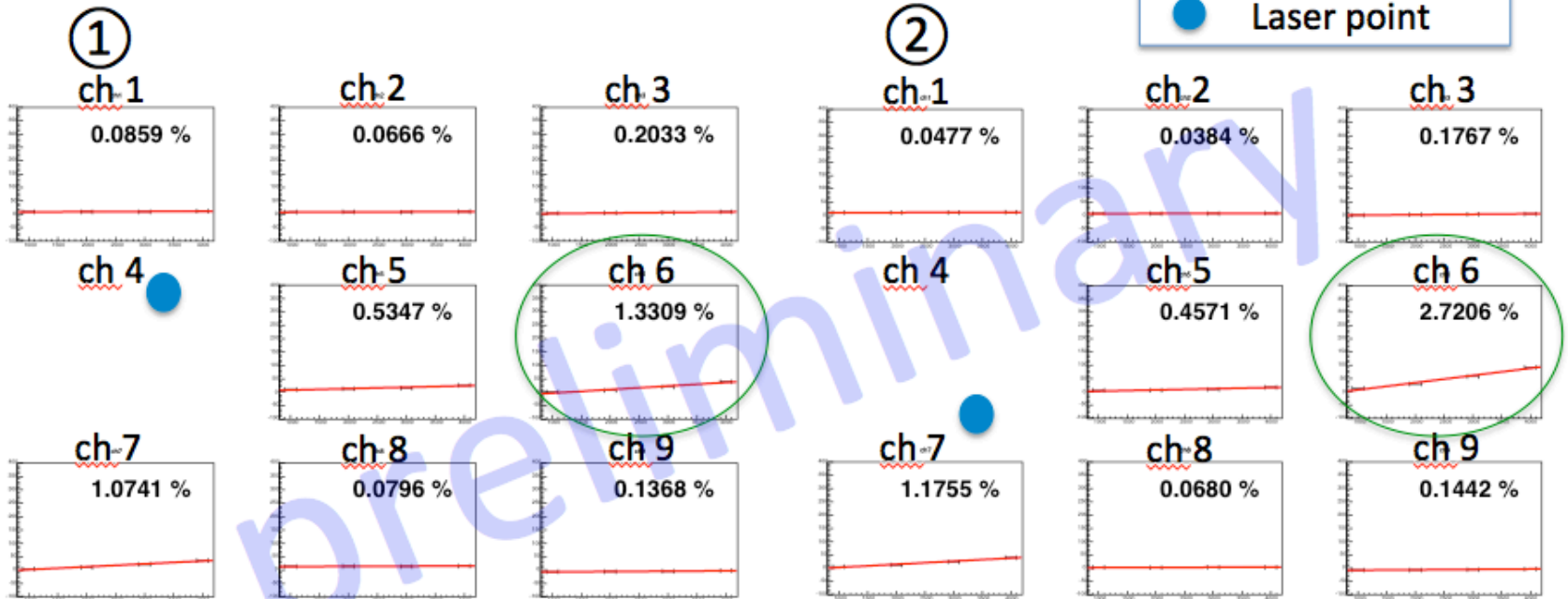


Horizontal axis: Response of ch 4 [mV] (~Laser Power)

Vertical axis: Response of each pixel [mV]

ch 4 ch 6

● Laser point



- Almost all channels, crosstalk < about 1%
- Optical crosstalk seen at ch 6 -> to be fixed

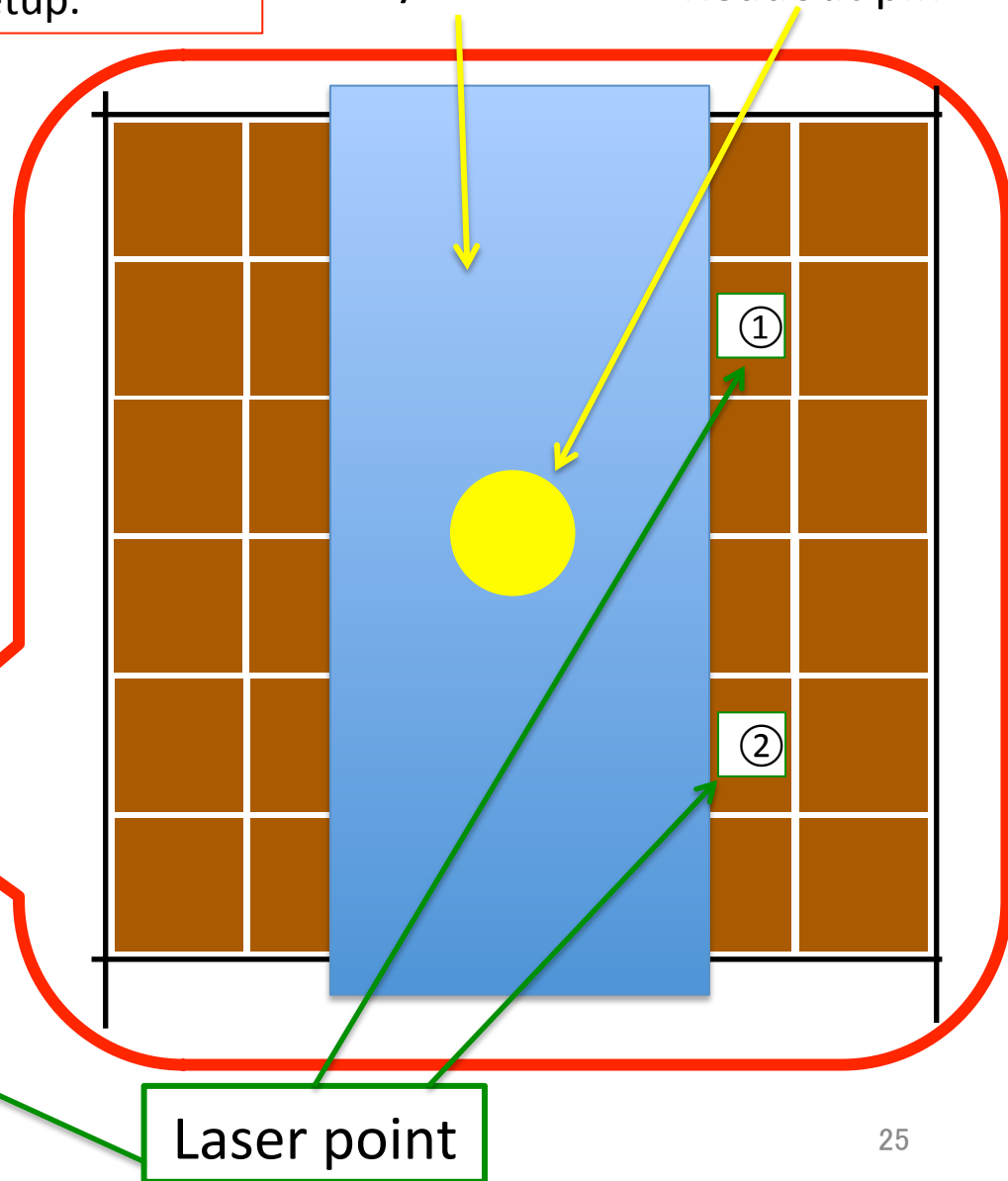
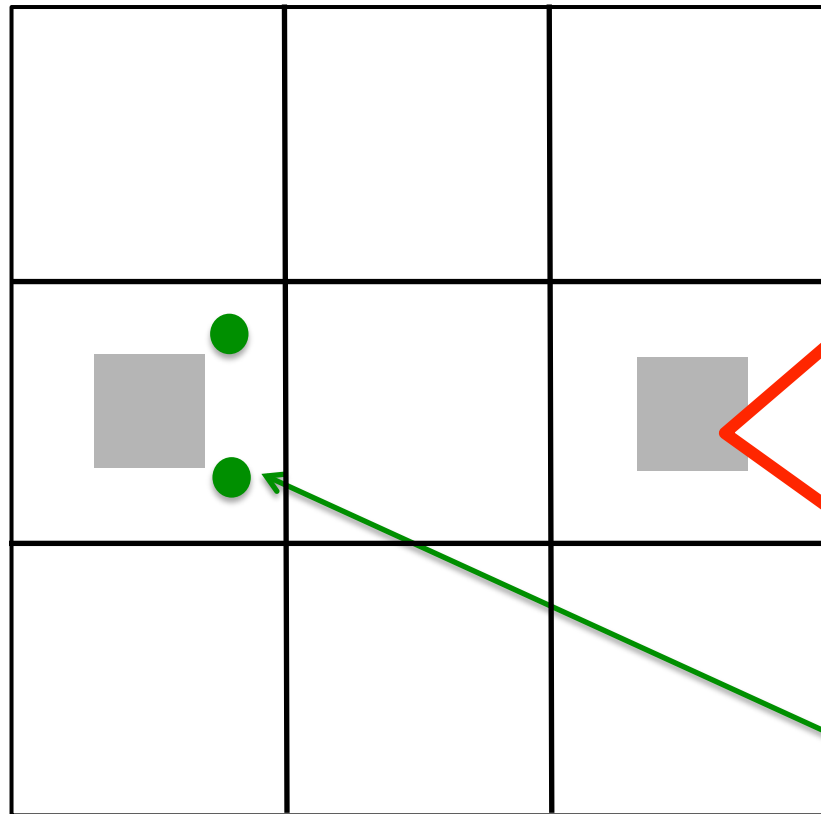
backup

Laser system is the same setup.

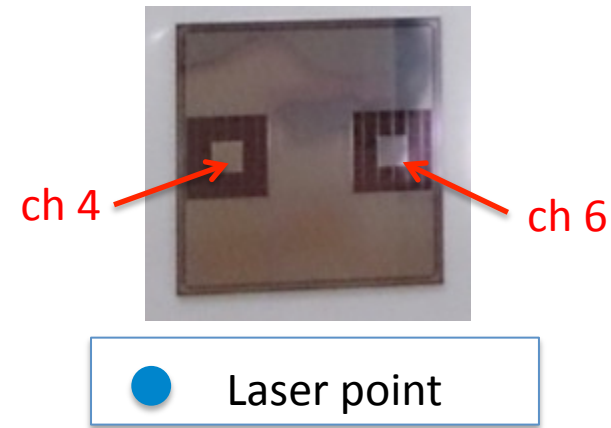
Only 0 guard ring

Acrylic sheet

Readout pin



backup



Horizontal axis : Response of ch 4 [mV] (~Laser Power)

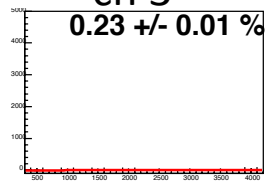
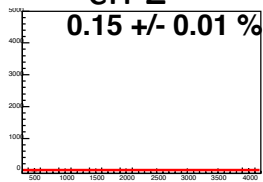
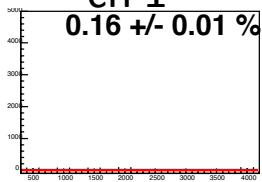
Vertical axis : Response of each pixel

①

ch 1
0.16 +/- 0.01 %

ch 2
0.15 +/- 0.01 %

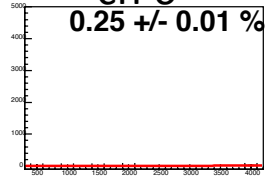
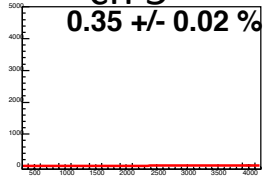
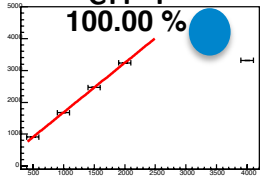
ch 3
0.23 +/- 0.01 %



ch 4
100.00 %

ch 5
0.35 +/- 0.02 %

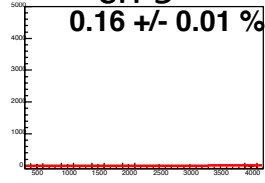
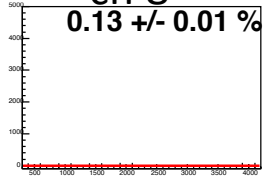
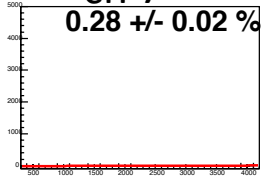
ch 6
0.25 +/- 0.01 %



ch 7
0.28 +/- 0.02 %

ch 8
0.13 +/- 0.01 %

ch 9
0.16 +/- 0.01 %

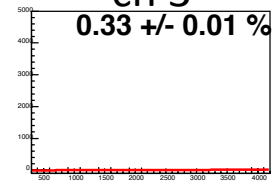
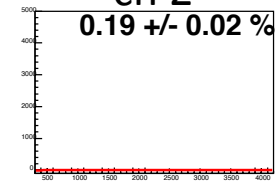
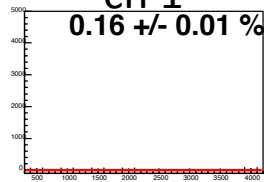


②

ch 1
0.16 +/- 0.01 %

ch 2
0.19 +/- 0.02 %

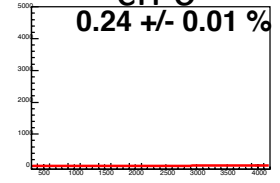
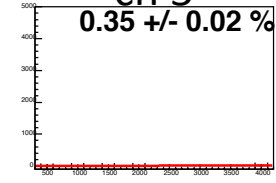
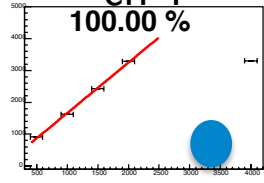
ch 3
0.33 +/- 0.01 %



ch 4
100.00 %

ch 5
0.35 +/- 0.02 %

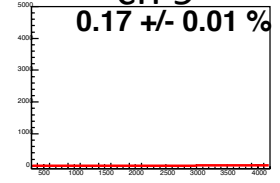
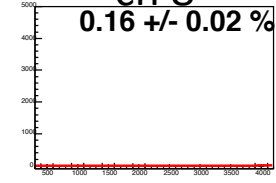
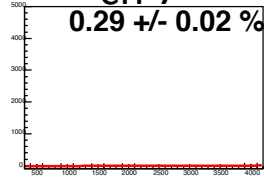
ch 6
0.24 +/- 0.01 %



ch 7
0.29 +/- 0.02 %

ch 8
0.16 +/- 0.02 %

ch 9
0.17 +/- 0.01 %

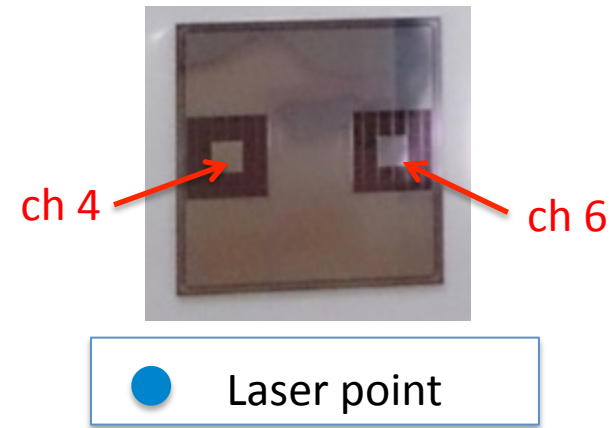


- All channels, crosstalk < about 0.5%
- We are able to get reproducible results.

backup

Horizontal axis : Response of ch 4 [mV] (\sim Laser Power)

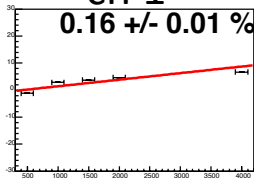
Vertical axis : Response of each pixel



①

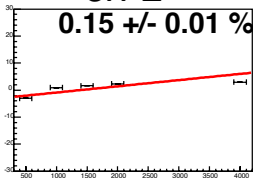
ch 1

0.16 \pm 0.01 %



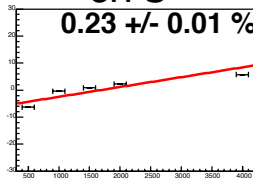
ch 2

0.15 \pm 0.01 %



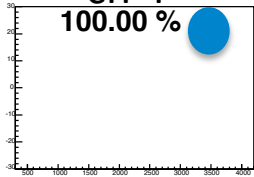
ch 3

0.23 \pm 0.01 %



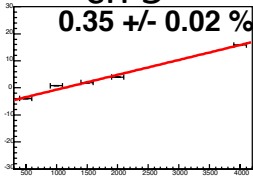
ch 4

100.00 %



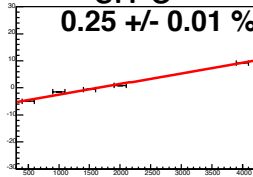
ch 5

0.35 \pm 0.02 %



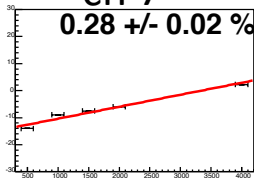
ch 6

0.25 \pm 0.01 %



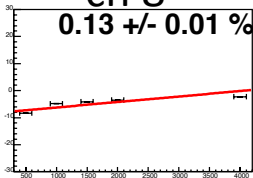
ch 7

0.28 \pm 0.02 %



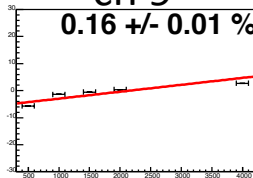
ch 8

0.13 \pm 0.01 %



ch 9

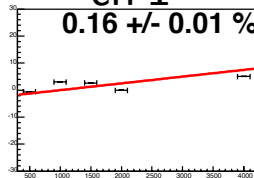
0.16 \pm 0.01 %



②

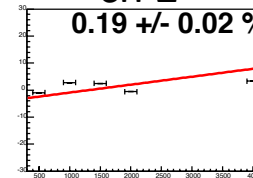
ch 1

0.16 \pm 0.01 %



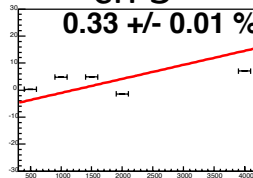
ch 2

0.19 \pm 0.02 %



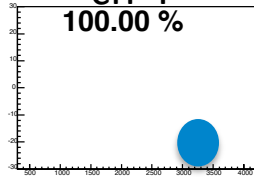
ch 3

0.33 \pm 0.01 %



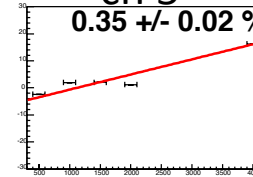
ch 4

100.00 %



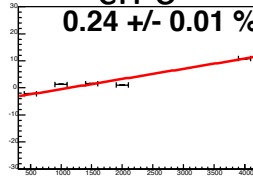
ch 5

0.35 \pm 0.02 %



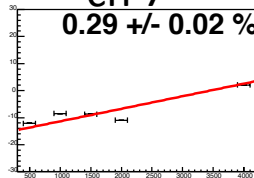
ch 6

0.24 \pm 0.01 %



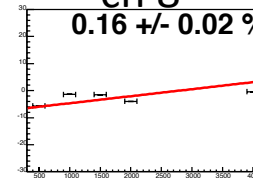
ch 7

0.29 \pm 0.02 %



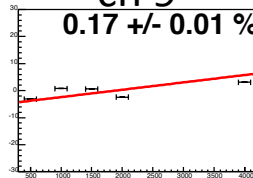
ch 8

0.16 \pm 0.02 %



ch 9

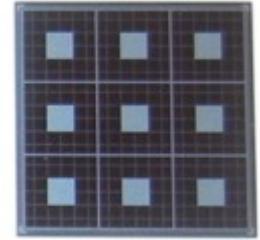
0.17 \pm 0.01 %



- Expanded for Y axis
- All channels, crosstalk < about 0.5%
- We are able to get reproducible results.

● Laser point

Result

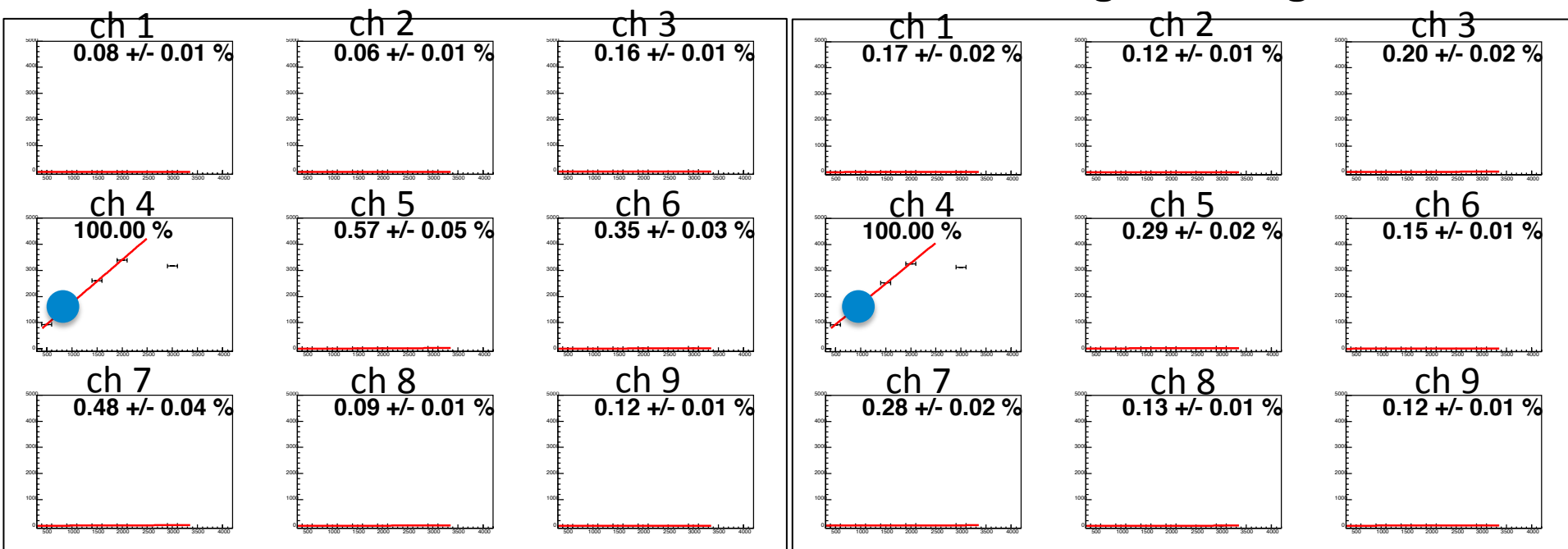


Horizontal axis : Response of ch 4 [mV] (\sim Laser Power)

Vertical axis : Response of each pixel

0 guard ring

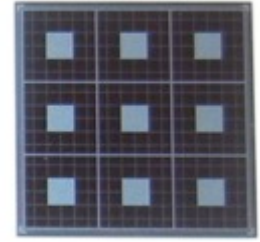
1 guard ring



▪ No big difference was seen.

● Laser point

Result

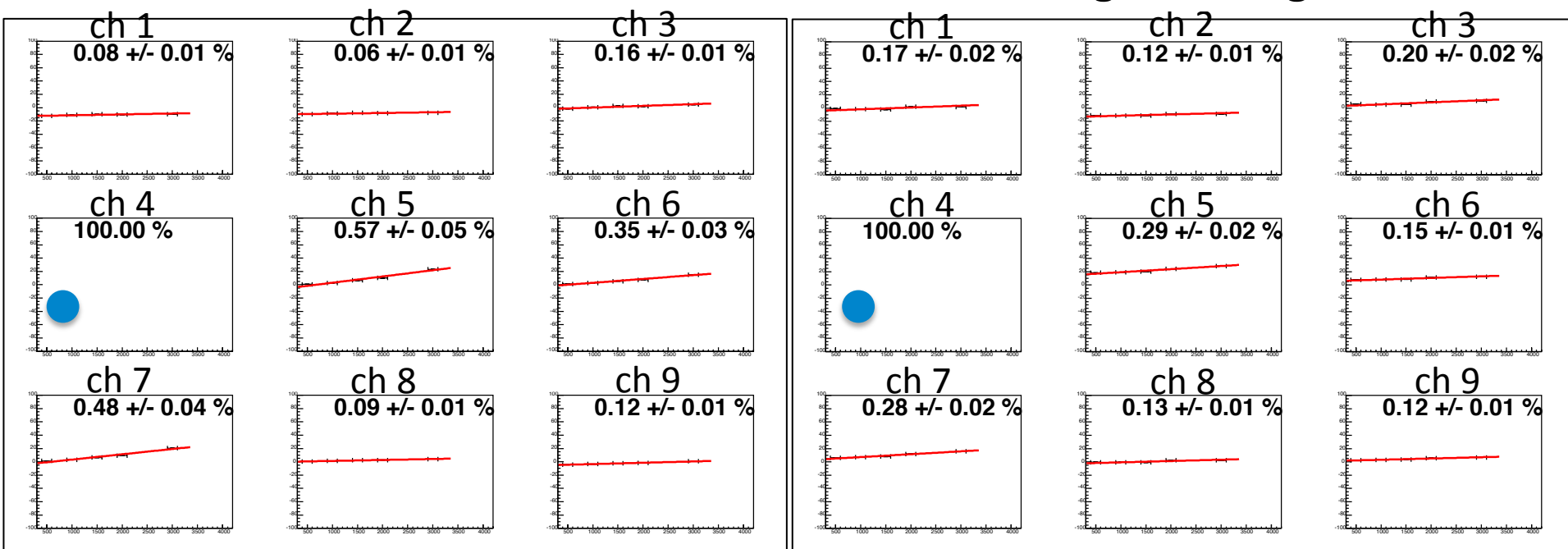


Horizontal axis : Response of ch 4 [mV] (~Laser Power)

Vertical axis : Response of each pixel

0 guard ring

1 guard ring



- Expanded for Y axis
- No big difference was seen.