FPCCD radiation damage test

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contents

1. Purpose of Vertex Detector
2. FPCCD Vertex Detector
3. R&D status
4. Damage from neutron
5. Characteristics of FPCCD
6. Read out modules
7. Characteristics before irradiation
   - Hot pixel
   - CTI
   - Dark current
8. Neutron Irradiation
   - set up
   - flux of neutron
9. Result of irradiation
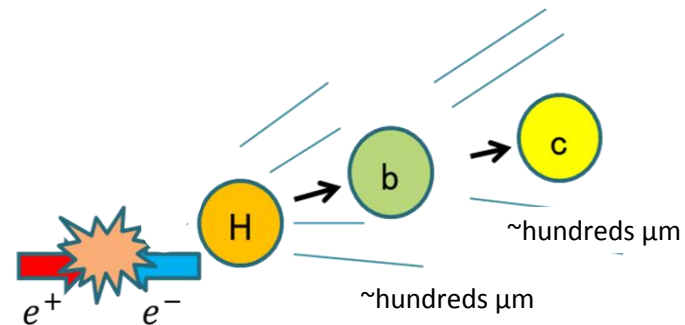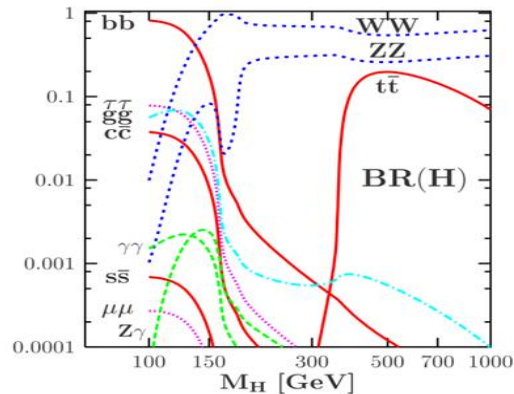   - hot pixel
   - CTI
10. Summary & plan

Purpose of Vertex Detector

Major targets of ILC are…

- precise measurement of Higgs

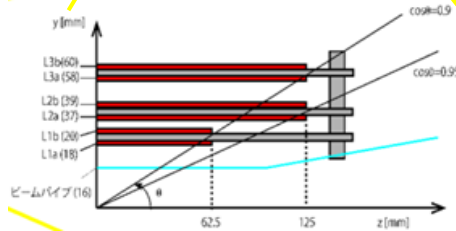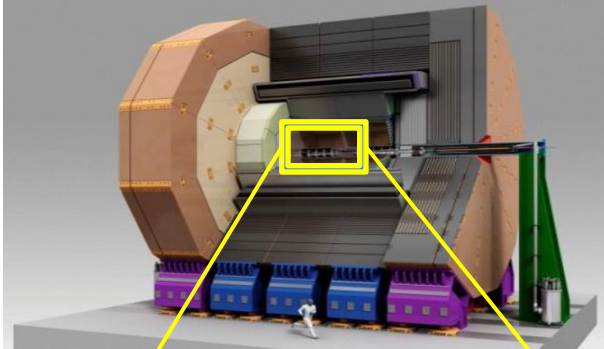- precise measurement of Top quark

- Search for beyond the standard model

Higgs particles dominantly tend to decay bb , cc , gg.
To measure those BR, we need to identify b c g precisely

~hundreds μm

~hundreds μm

To tag b, c and g from vertex position , we require less than 3μm resolution for vertex detector

FPCCD Vertex Detector

FPCCD : **F**ine **P**ixel **C**harge **C**oupled **D**evice

Vertex detector

➢ Most inner layer located 16mm from the IP
  ➢ to achieve high impact parameter resolution
➢ Thin sensor and support structure
  ➢ to reduce multiple scattering ,
➢ Three doublet-layer structure
 ➢ Better pattern recognition not to associate BG hits

Merit of FPCCD

☺Position resolution is very good (~1μm)
☺Pixel occupancy is low
        -so many pixels
☺signal is less affected by electromagnetic interference
        - inter-train read-out
☺smaller gain fluctuation
        - amplify each signal after transfering

1

1train(1ms)   train(1ms)
                   ~200ms
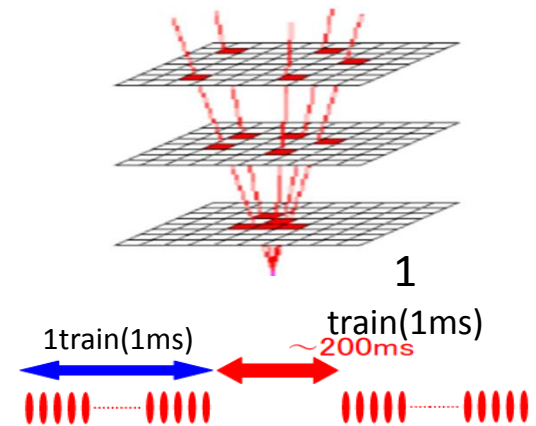
Bulk damage

High energy electron and Heavy particles like neutron sometimes make lattice defect in FPCCD. Charge signals are often trapped by lattice defect then signal will reduce…

Lattice defect
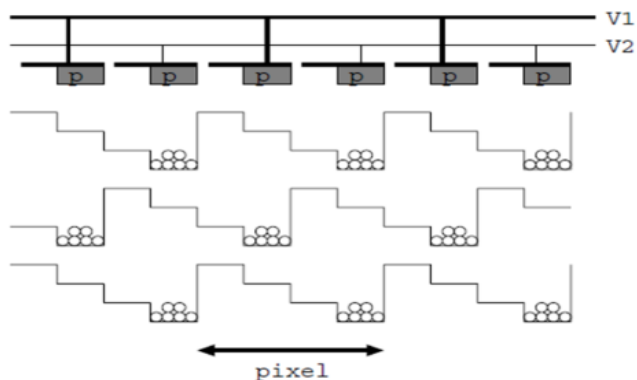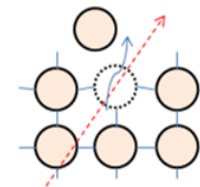
CCD transfers charge signal like bucket-brigade.
- FPCCD has so many pixels
then few lattice defect can effect on transfer
neutron equivalent flux of $O(10^{10})$ neutrons/cm^2 incident upon the vertex detector may degrade its performance

According to simulation result, neutron come from mainly beam dump.
And neutron fluence was determined to be 1.85×10^9 neutron/cm^2/year.
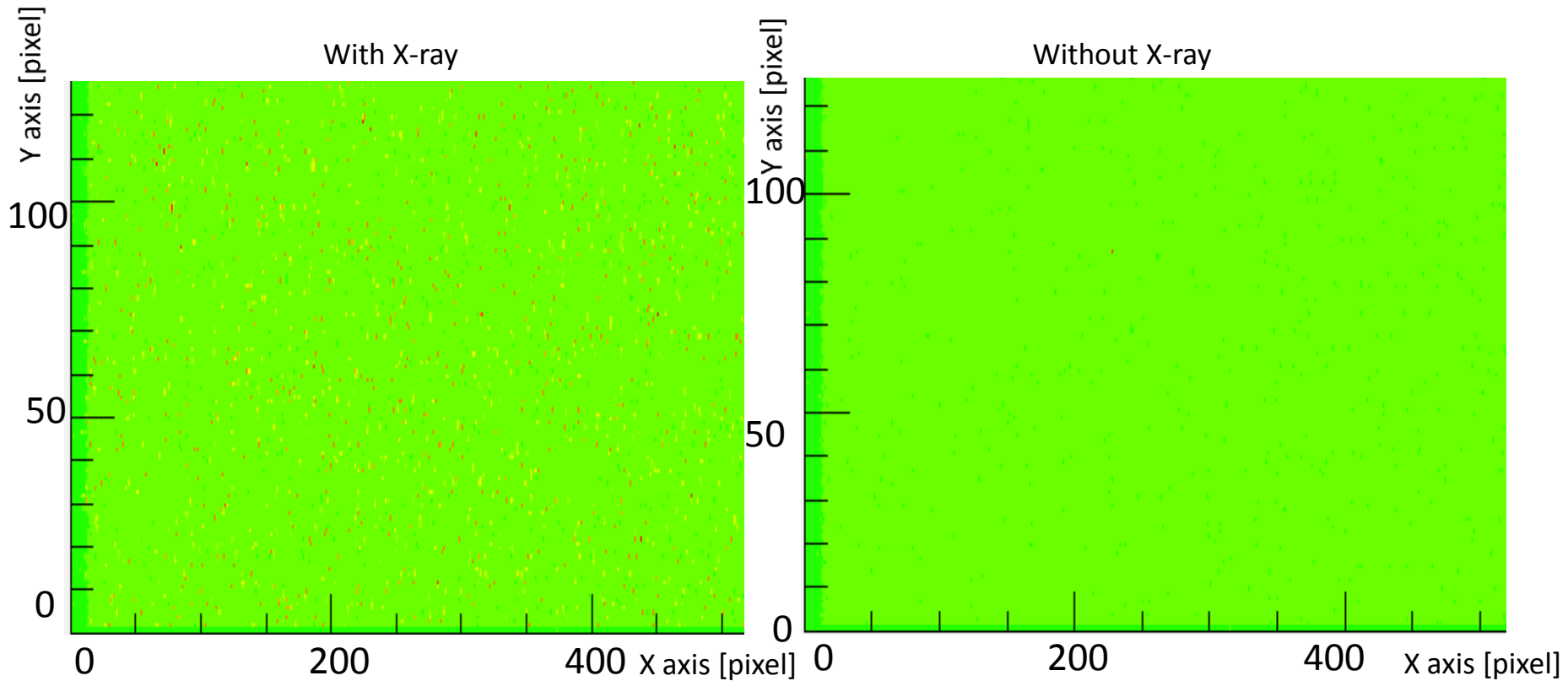
Beam dump
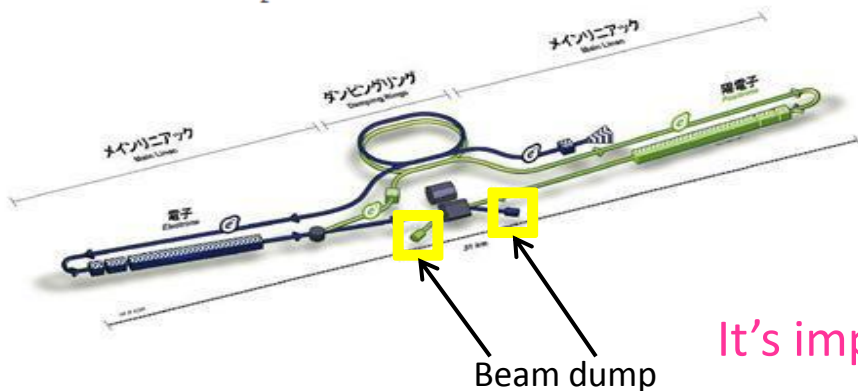
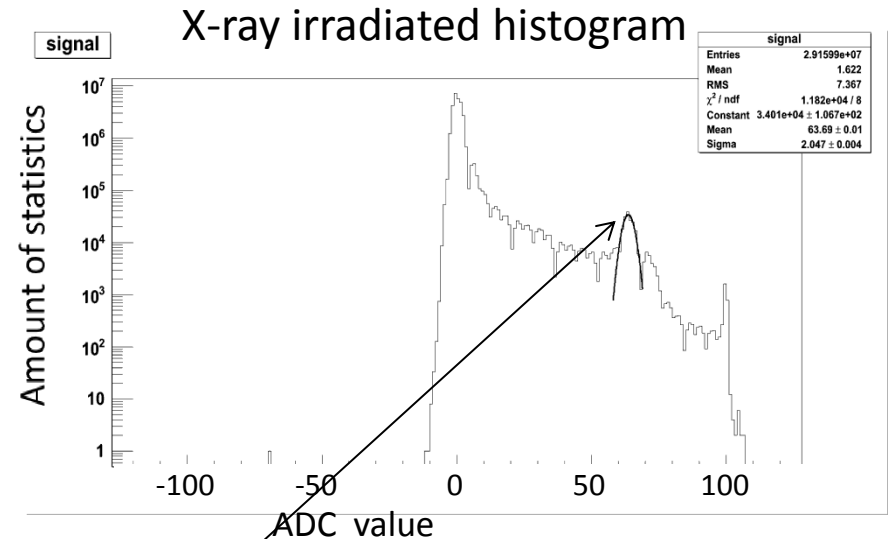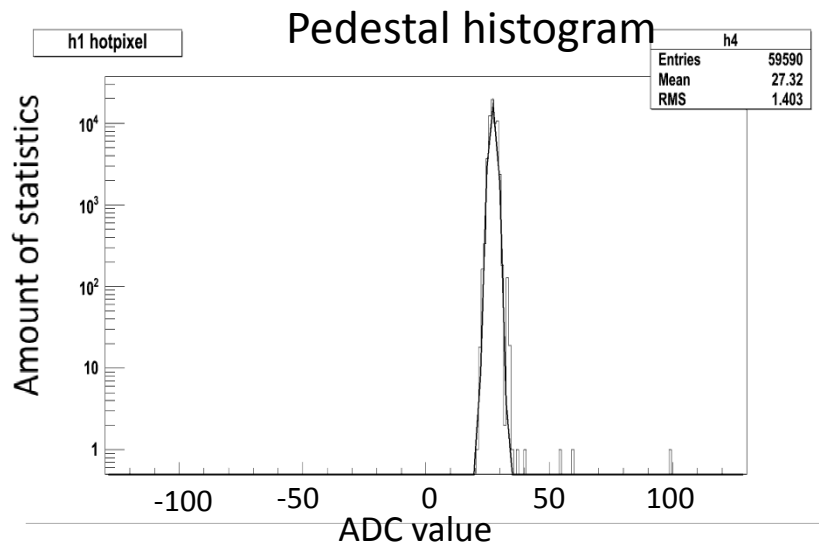It's important to measure tolerance of detector!

Characteristics of FPCCD

i) CTI(Charge Transfer Inefficiency)

Inefficiency in transferring charge to neighboring pixel

we test CTI using X-ray from Fe55.

With X-ray

Without X-ray

Characteristics of FPCCD

Pedestal histogram

h1 hotpixel		h4	
	Entries		59590
	Mean		27.32
	RMS		1.403

X-ray irradiated histogram

signal		signal	
	Entries		2.91599e+07
	Mean		1.622
	RMS		7.367
	χ^2 / ndf		1.182e+04 / 8
	Constant		3.401e+04 ± 1.067e+02
	Mean		63.69 ± 0.01
	Sigma		2.047 ± 0.004

Fe55 peak (pedestal & average drift subtracted)

These figures show ADC value vs amount of statistics

Single pixel hit
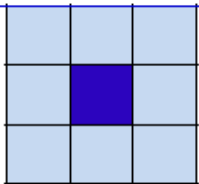
Single isolated pixel hit with ADC value consistent with X ray from Fe55.

We selected single pixel hit event to measure CTI. CTI can be measured by compering peak positions of x-ray from Fe55 .

- if CCD can transfer charge signal all, CTI will be 0

Characteristics of FPCCD

ii)Hot pixels: pixels emitting large dark current.

Without x-ray

Y axis [pixel]

100

50

0

0   200   400   X axis [pixel]

This is a hot pixel!
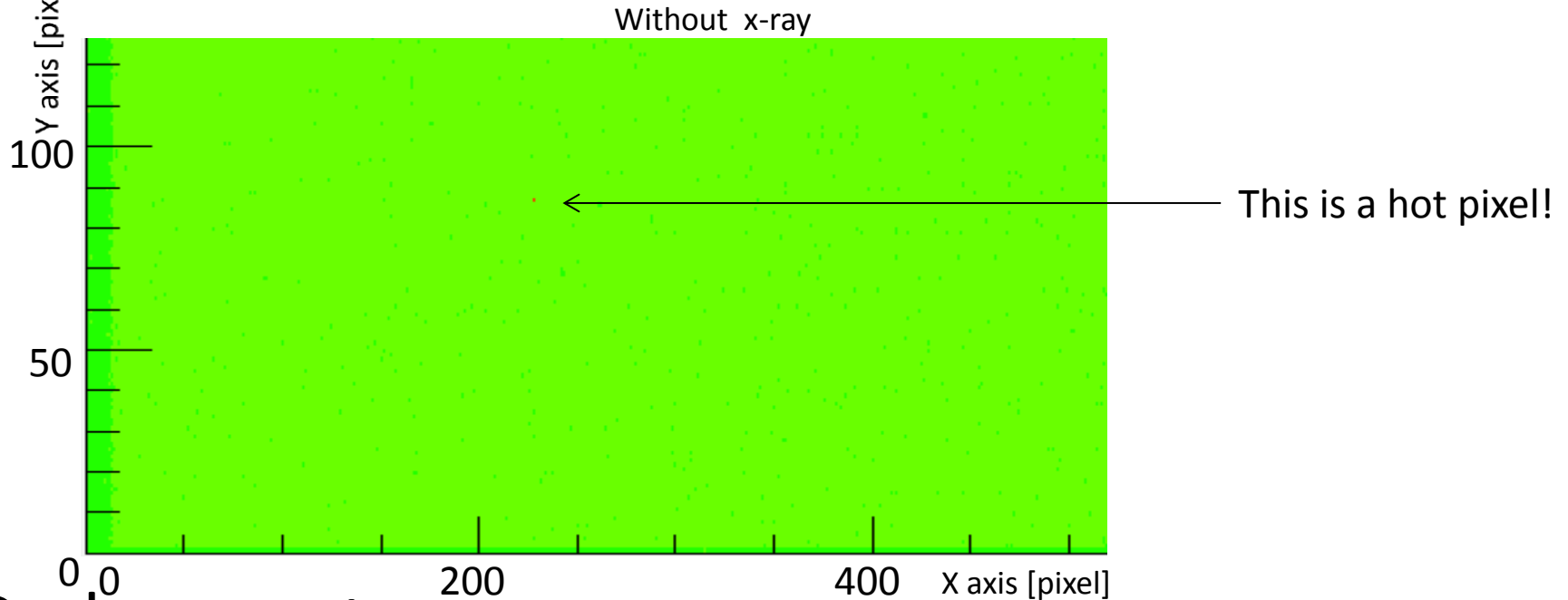
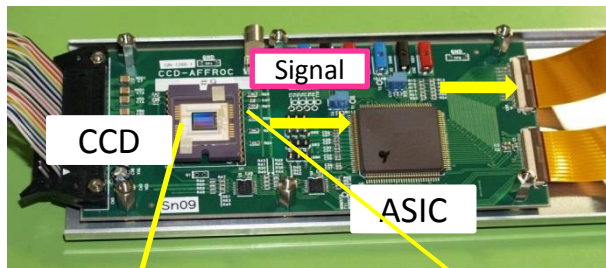## iii)Dark current: average of signal without x-ray.

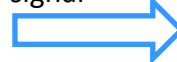At this irradiation test, we measured these 3 characteristics
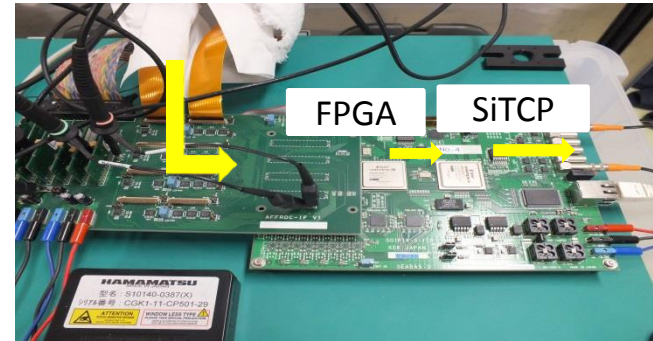
Read out modules

Stream of signal is …

CCD --> ASIC--> FPGA --> SiTCP --> PC

Signal

CCD

ASIC

ASIC out put signal

ASIC drive signal

FPGA   SiTCP

$12 \times 12 \mu m^2$

$9.6 \times 9.6 \mu m^2$

$8 \times 8 \mu m^2$

$6 \times 6 \mu m^2$

CCD spec

Ethernet connection

Sensitive thickness : 15μm
Pixel size : CCD has 4 read-out channels. Pixel sizes are …
   $6 \times 6 \mu m^2$, $8 \times 8 \mu m^2$, $9.6 \times 9.6 \mu m^2$, $12 \times 12 \mu m^2$
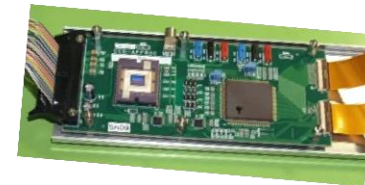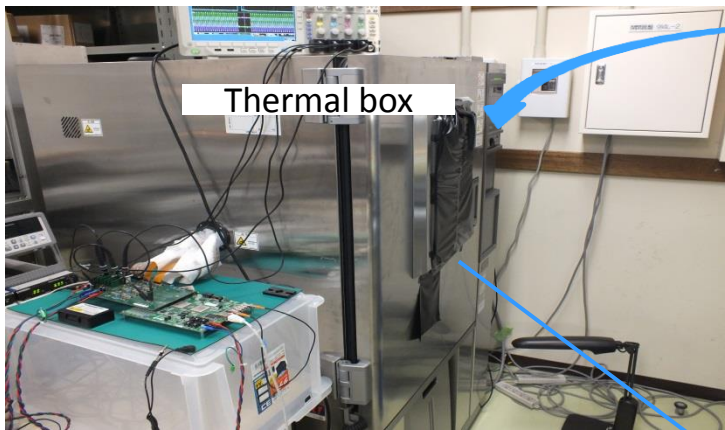We only measured $8 \times 8 \mu m^2$, $12 \times 12 \mu m^2$

PC

Read-out modules

To test temperature dependence of CTI, dark current , hot pixels,
CCD and read out circuit were put into thermal box

Thermal box

Before irradiation, we measured at
-40℃, -20℃, 0℃, +20℃
After irradiation, we measured at
-40℃, -30℃,-20℃, -10℃, 0℃, +10℃, +20℃

At each temperature, dark frame run and signal
run are taken with Fe55 by turning on/off the
shutter

shatter	open	close	close	close	close	close
Read out cycle(sec)	10	10	20	30	40	60

shatter   Fe55

CCD
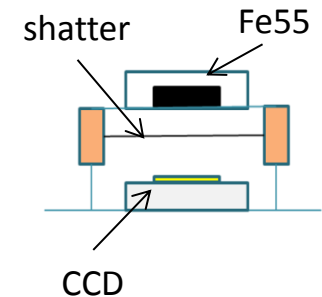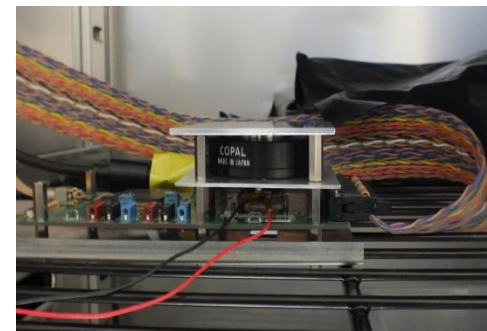
Characteristics before irradiation

i) CTI

I measured CTI of a channel of $12\mu m$ (512 x 128) pixels at -40°C

512 pixels

I fitted this histogram with function

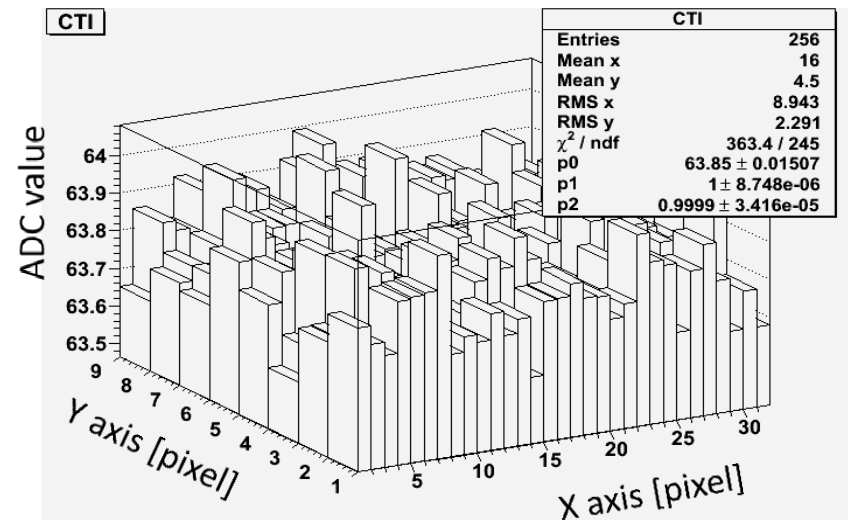Function = $[p0] \times [P1]^{x} \times [p2]^{y}$

[p0] : constant number

[p1] : Horizontal CTE (x direction)

　　(CTE : Charge Transfer Efficiency)
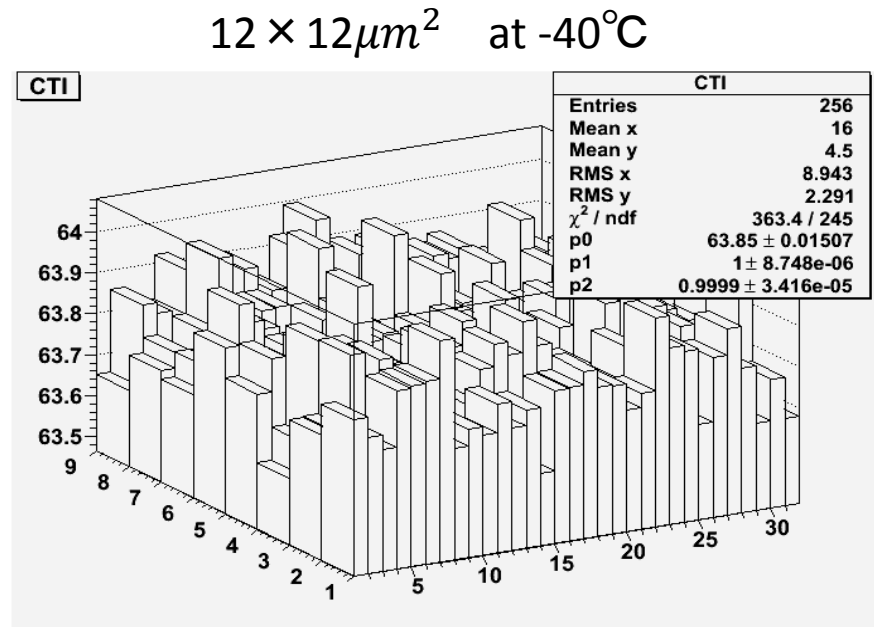
[p2] : Vertical CTE (y direction)

　x   : region number (x direction)

　y   : region number (y direction)
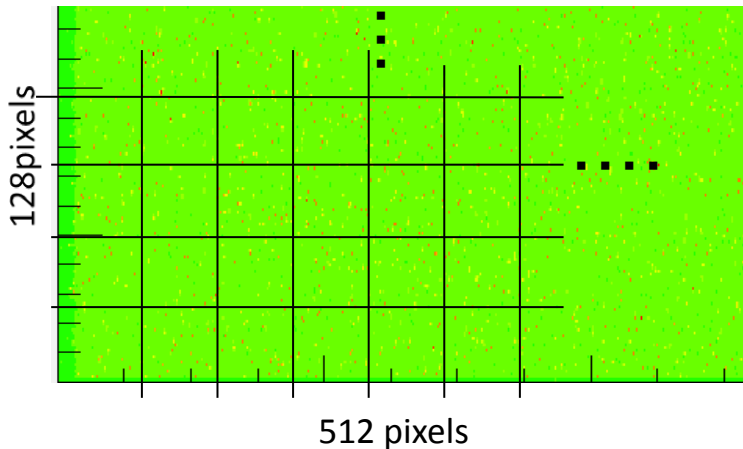
I divided 1 channel to 31 × 8 regions
1 region has 16 × 16 pixels
　　- measured ADC values for each region and
　　　fitted to extract CTI.

Characteristics before irradiation

Before irradiation result

$12 \times 12 \mu m^2$ at -40°C

CTI	
Entries	256
Mean x	16
Mean y	4.5
RMS x	8.943
RMS y	2.291
χ^2 / ndf	363.4 / 245
p0	63.85 $\pm$ 0.01507
p1	1 $\pm$ 8.748e-06
p2	0.9999 $\pm$ 3.416e-05

CTI = 1-CTE
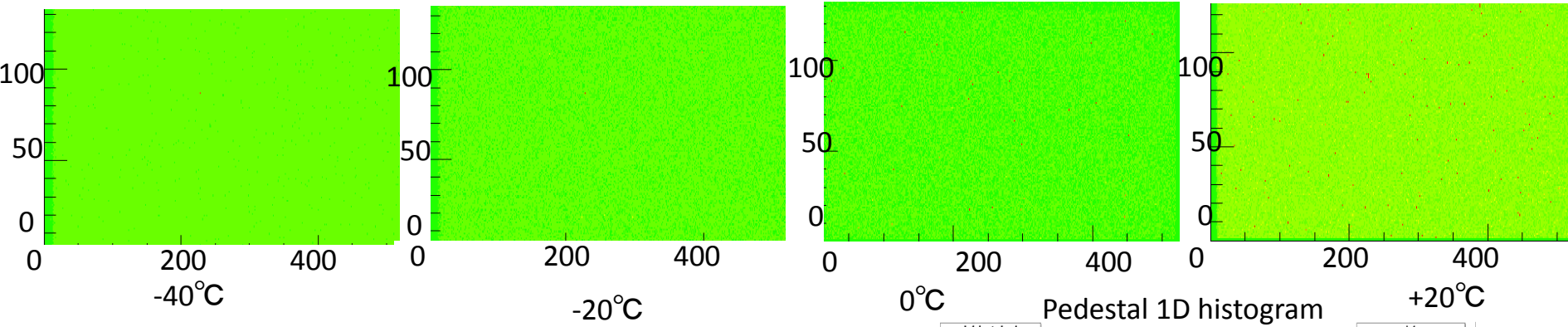
We got CTE from fitting function. Then we can calculate CTI/pixel

horizontal : $(1.844 \pm 0.547) \times 10^{-6}$
vertical : $(4.660 \pm 2.135) \times 10^{-6}$

Characteristics before irradiation

ii)Hot pixels

Number of hot pixels increase depending on temperature. These figures show temperature dependence of hot pixel for 12μm pixels channels

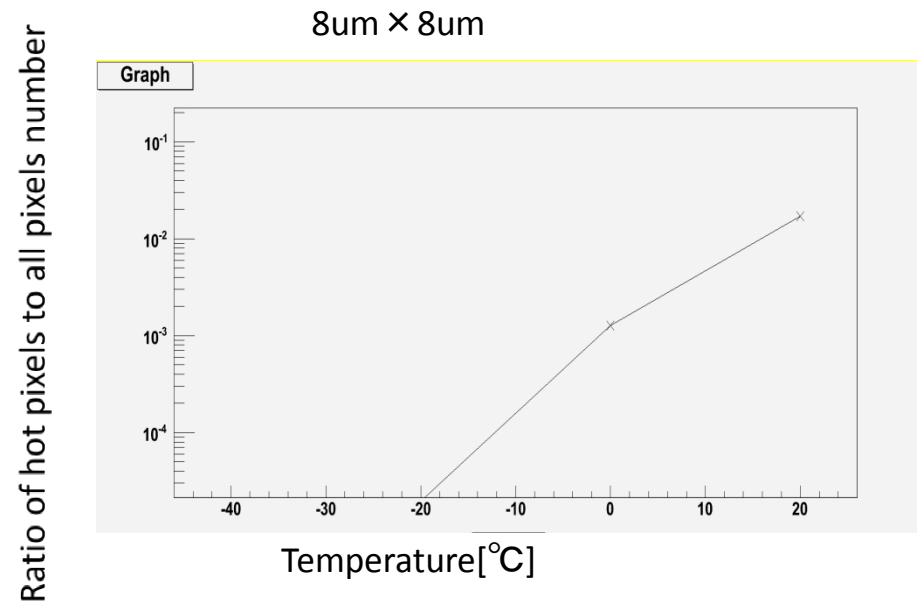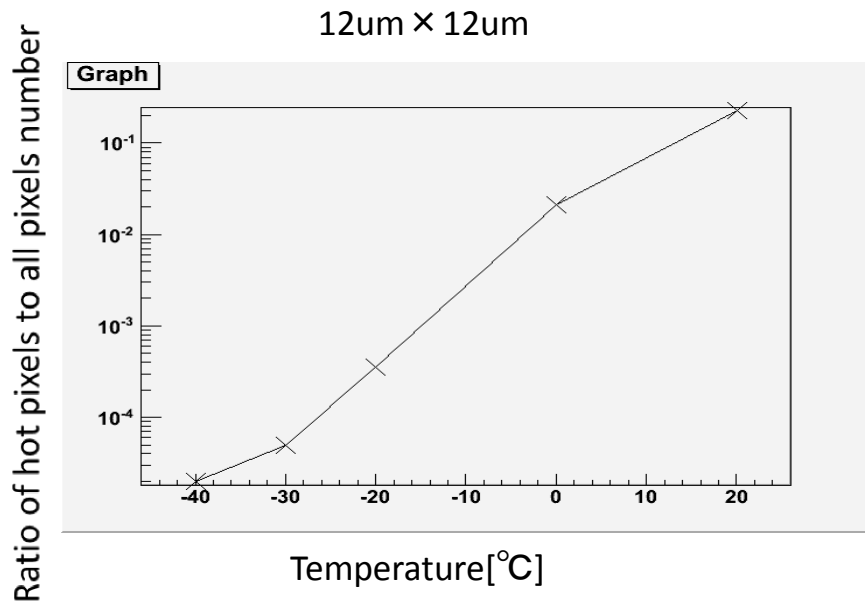-40°C
    -20°C
    0°C
    +20°C

Pedestal 1D histogram

I set threshold level at ADC value of 40 and signals larger than threshold, I considered these are hot pixels.

Cut at 40 level

amount of statistic

h4	
Entries	59590
Mean	27.32
RMS	1.403

ADC value
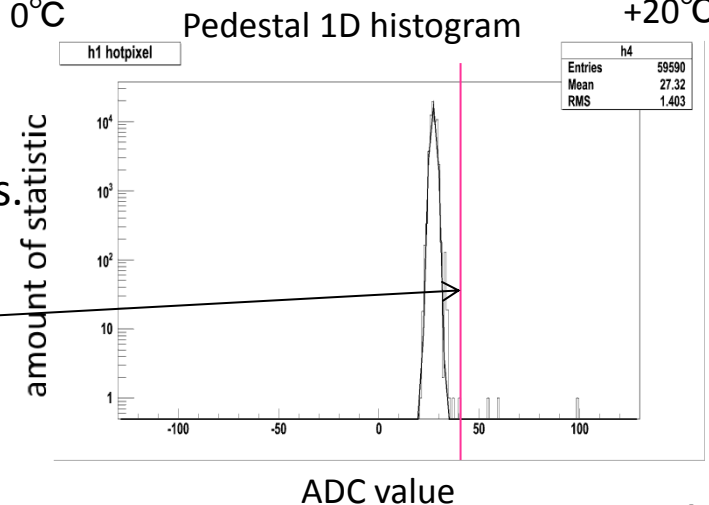
Characteristics before irradiation

Data was taken for 10sec by 10 frames for hot pixel measurements.

12um × 12um

8um × 8um

Ratio of hot pixels got larger as the temperature was raised.
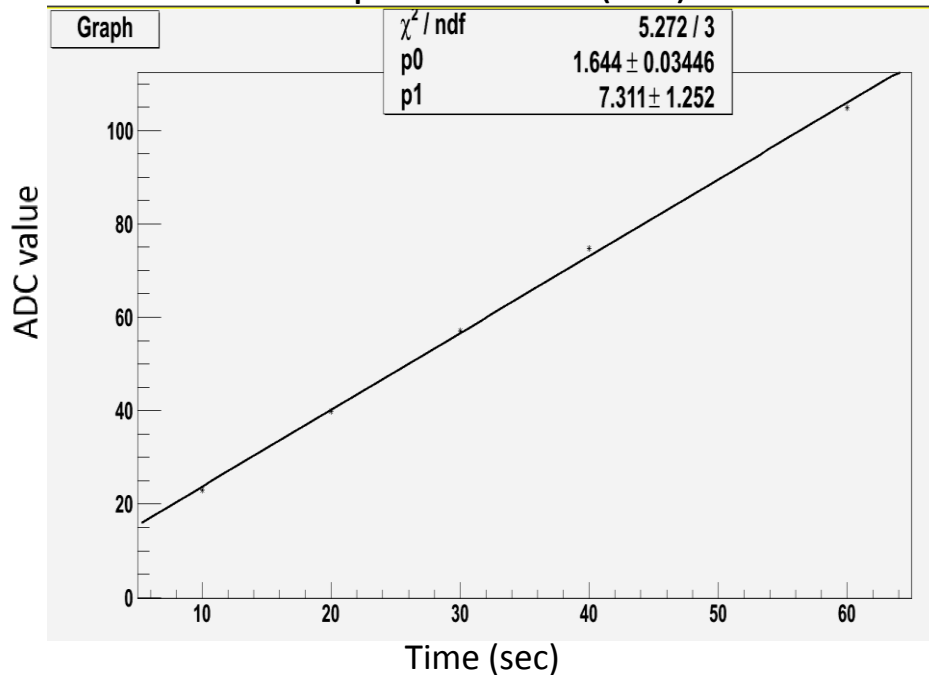- at -40°C, ratio of hot pixels ≅ 0

Characteristics before irradiation

iii)Dark current

Dark current is proportional to read out time.
We measured dark current 10sec, 20sec, 30sec, 40sec, 60sec.

ADC peak vs time(sec) 12um x 12um

Graph		
χ^2 / ndf	5.272 / 3	
p0	1.644 ± 0.03446	
p1	7.311 ± 1.252	

Before irradiation at +20°C

Fit with linear function

$$f = ax+b$$

Then we can derive pedestal level per 1 sec
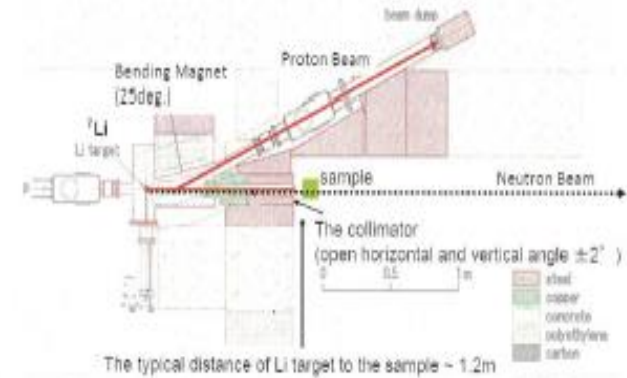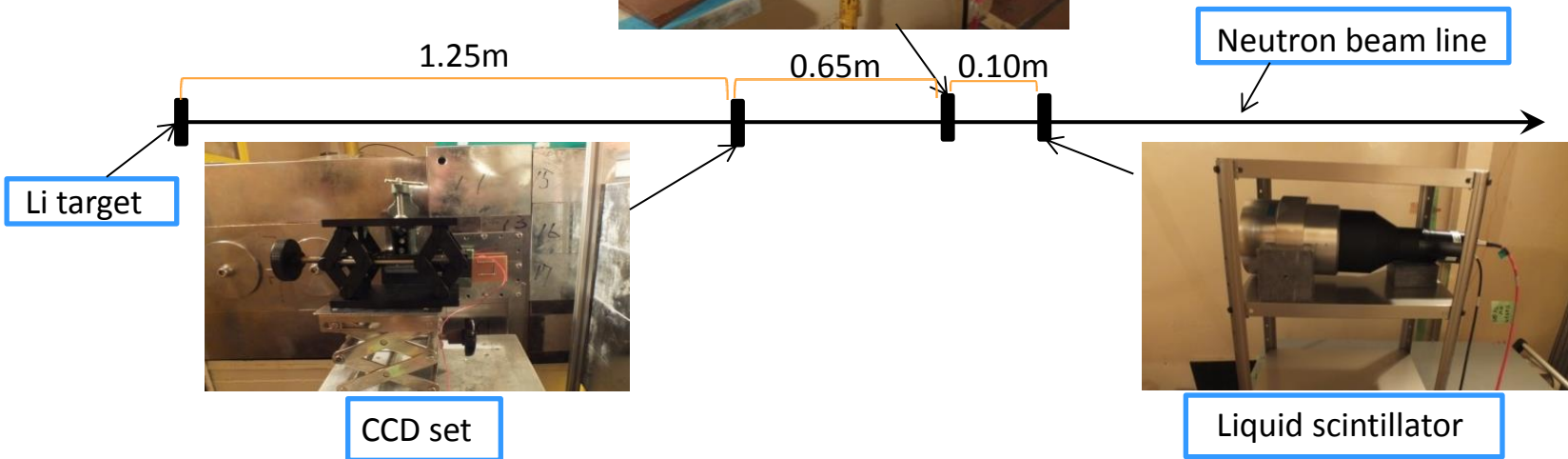- gradient means pedestal level per 1 sec

Neutron Irradiation

- Set up

We did neutron beam irradiation at 16,17 Oct at Tohoku University CYRIC. We made neutron beam by irradiating 1μA proton beam to 7-8mm thickness Li target . Irradiated time was

30 minutes 19 sec.

Plastic scintillator

Neutron beam line

1.25m   0.65m   0.10m

Li target

CCD set

Liquid scintillator

Neutron Irradiation

- Flux of neutron

To measure flux of neutron, we used plastic scintillator and liquid scintillator

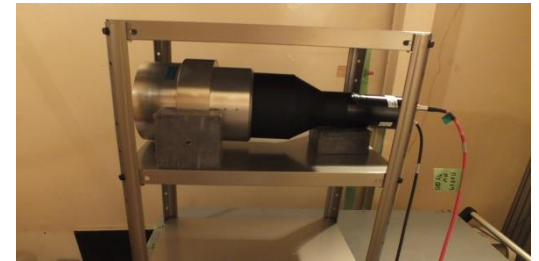ⅰ）First, we used liquid scintillator to measure

   total number of neutrons after collimator.

   8.29×10^6 neutron/sec

ⅱ）Second, we measured beam size by plastic scintillator.
   And measured beam size at 6 point
   each 5cm from beam line.

Plastic scintillator

5cm
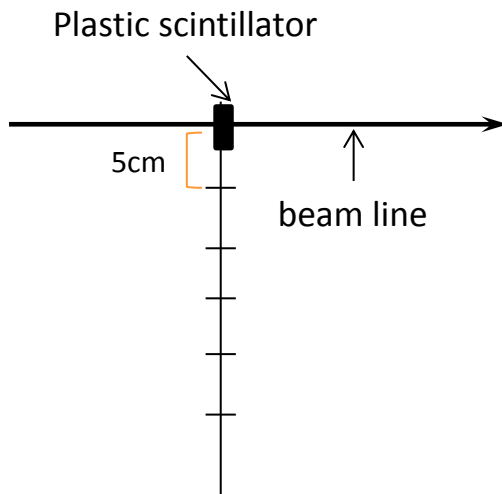
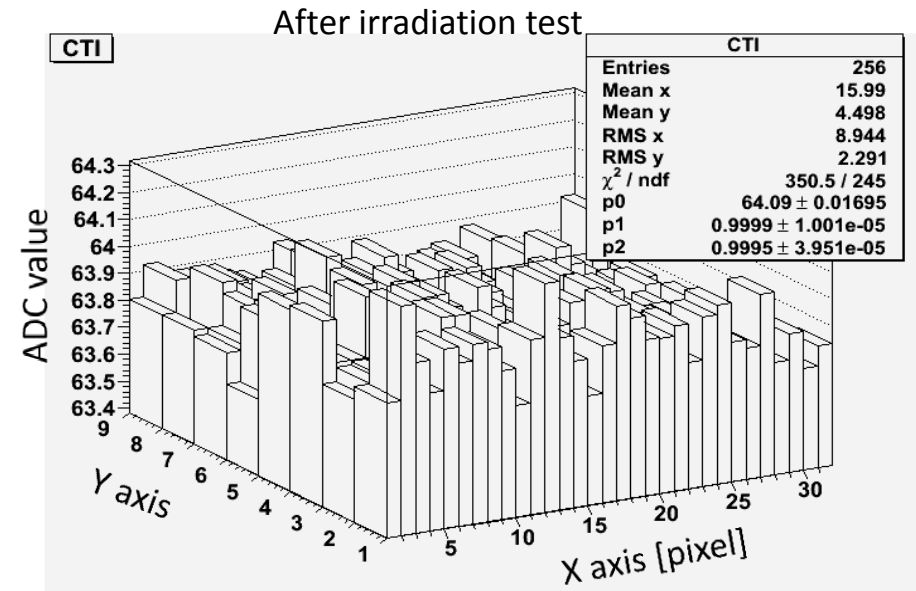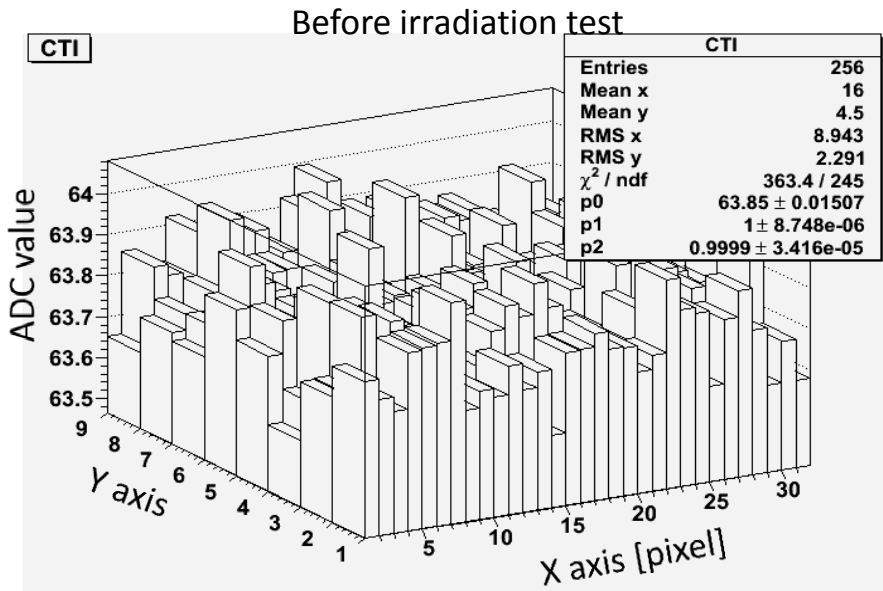beam line

- beam size was 14.7cm at 1.9m
  from Li target

We assumed neutron flux reduces linearly with respect to the distance from beam line

CCD set at 1.25m from Li target was irradiated 9.4×10^8 neutron

Result

- CTI

Before irradiation test

CTI	
Entries	256
Mean x	16
Mean y	4.5
RMS x	8.943
RMS y	2.291
χ^2 / ndf	363.4 / 245
p0	63.85 ± 0.01507
p1	1 ± 8.748e-06
p2	0.9999 ± 3.416e-05

After irradiation test

CTI	
Entries	256
Mean x	15.99
Mean y	4.498
RMS x	8.944
RMS y	2.291
χ^2 / ndf	350.5 / 245
p0	64.09 ± 0.01695
p1	0.9999 ± 1.001e-05
p2	0.9995 ± 3.951e-05

CTI / pixel was …

horizontal : $(1.844 \pm 0.547) \times 10^{-6}$

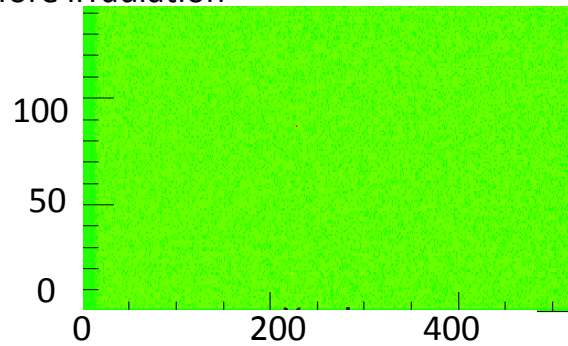vertical : $(4.660 \pm 2.135) \times 10^{-6}$

horizontal : $(6.392 \pm 0.626) \times 10^{-6}$

vertical : $(2.834 \pm 0.247) \times 10^{-5}$
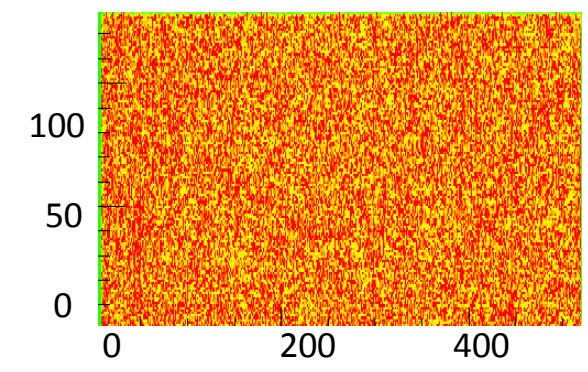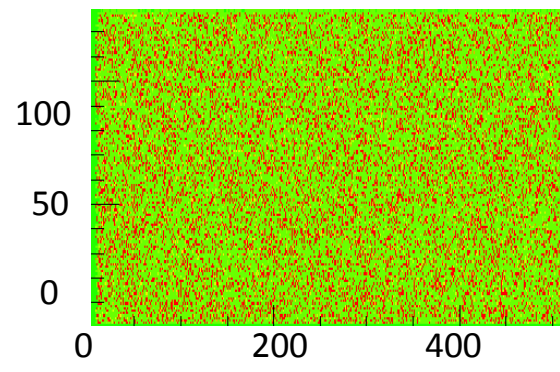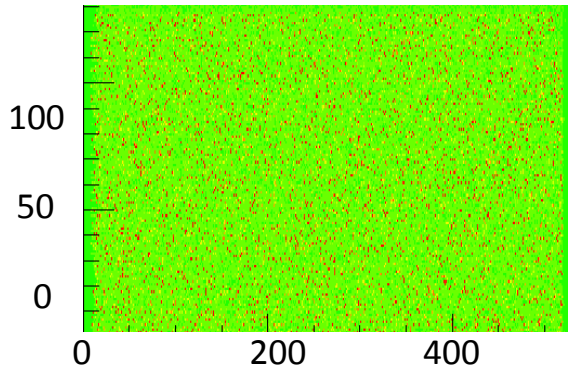
Result

- Hot pixels

After irradiation, we saw many hot pixels.

Before irradiation
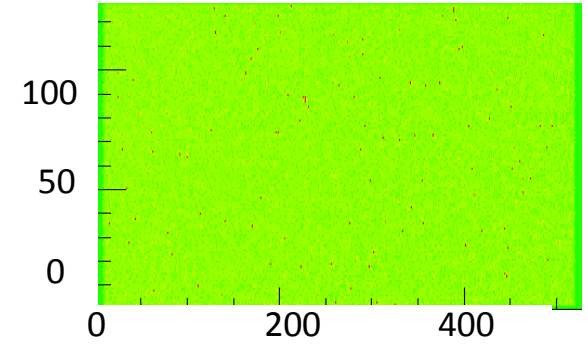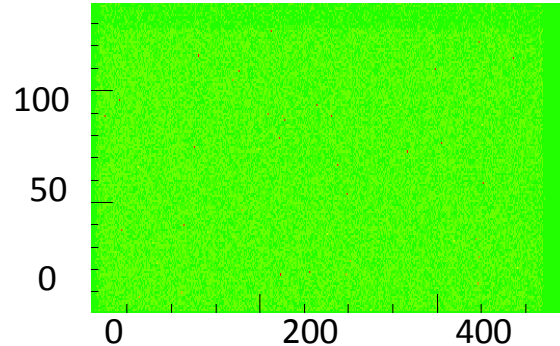
After irradiation (less than one hour after irradiation)

-20℃
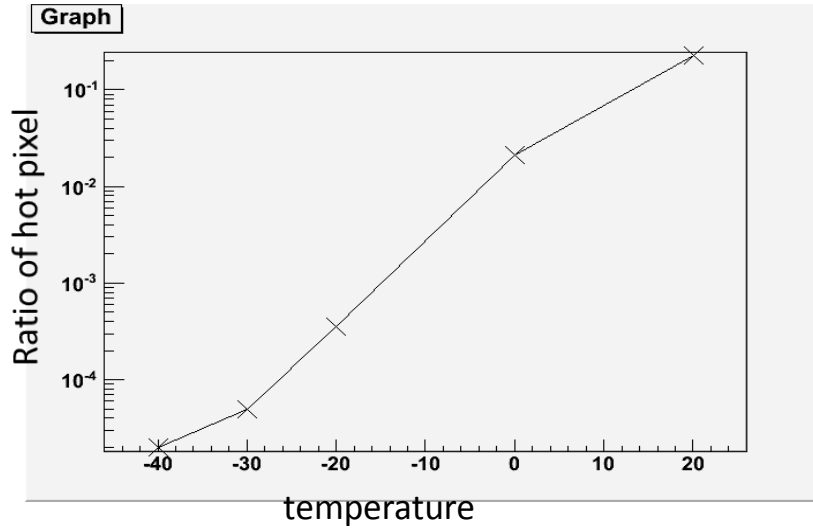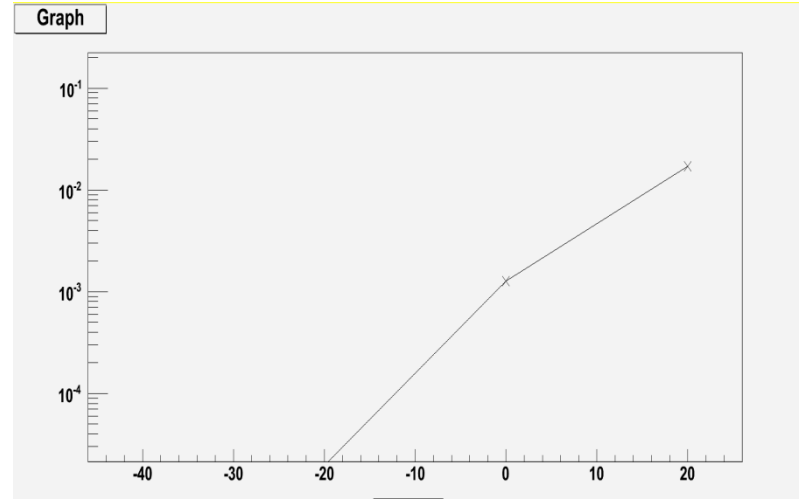
0℃

+20℃

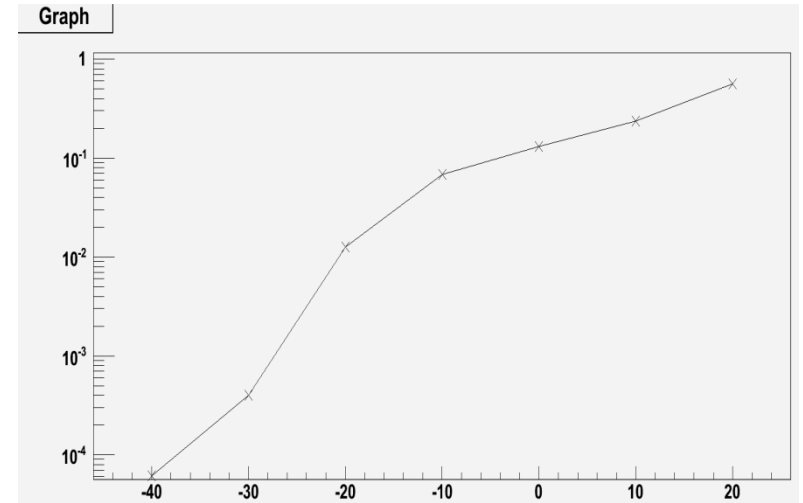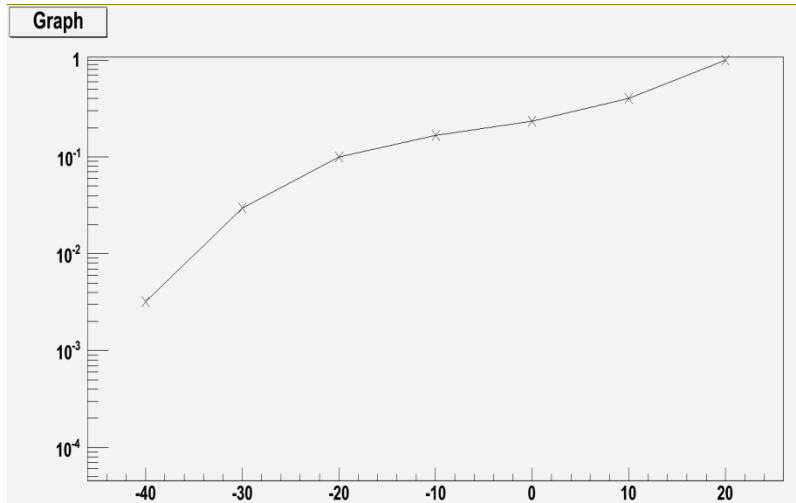# Result

12um × 12um

8um × 8um

Before
irradiation
test

After
Irradiation
test

Summary & Plan

- FPCCD is one of the candidate of vertex detector.
- We performed neutron irradiation and measured CTI, dark current and hot pixels.
- After irradiation test, we saw many hot pixels.

Plans

- To measure CTI and dark current at various temperatures.
- To measure dependence of CTI on various parameters such as clock frequency and voltage.

Back Up