R&D status of FPCCD vertex detector

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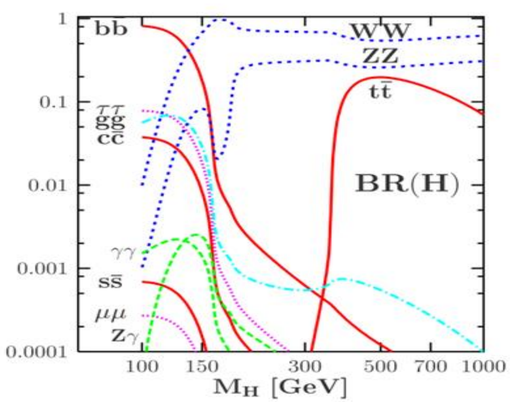
contents

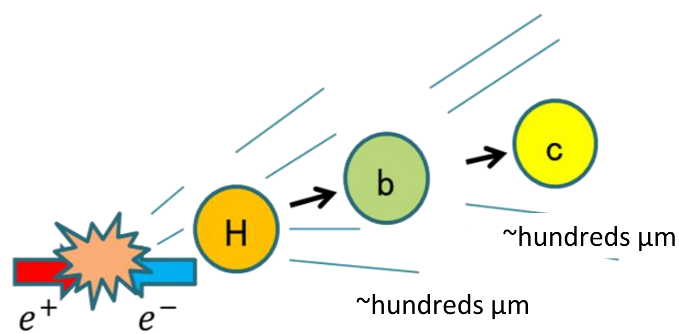
Purpose of Vertex Detector

Major targets of ILC are…

- precise measurement of Higgs
- precise measurement of Top quark
- Search for beyond the standard model

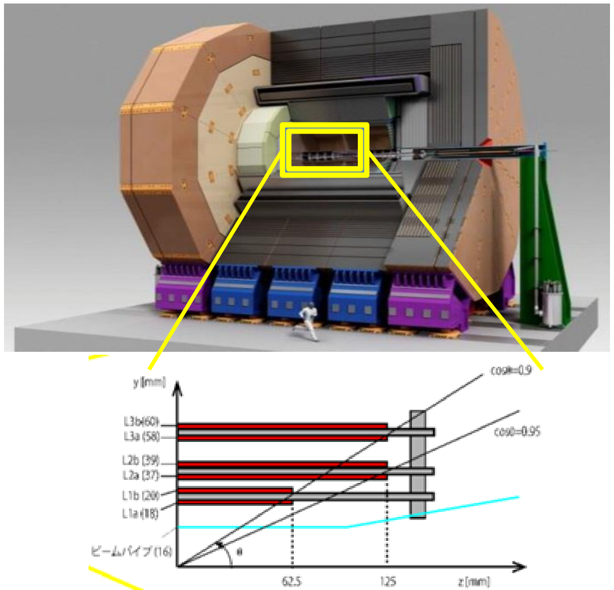
Higgs particles dominantly tend to decay bb , cc , gg.
To measure those BR, we need to identify b c g precisely





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

FPCCD Vertex Detector



FPCCD : Fine Pixel Charge Coupled Device

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

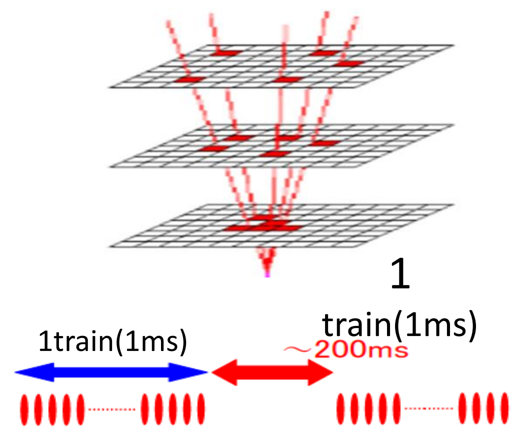
-so many pixels

☺signal is less affected by electromagnetic interference

- inter-train read-out

☺smaller gain fluctuation

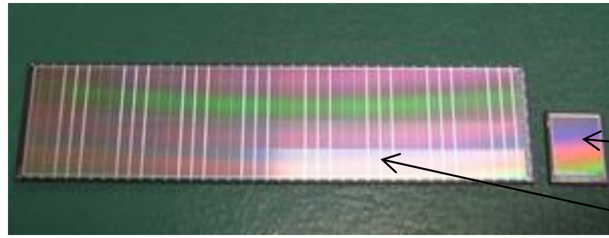
- amplify each signal after transfering



R&D status

FPCCD's Goal

pixel size : 5 × 5 μm^2
Sensitive thickness :15 µm
Total thickness :50µm



6µm pixel small prototype sensors
Working properly

Small prototype

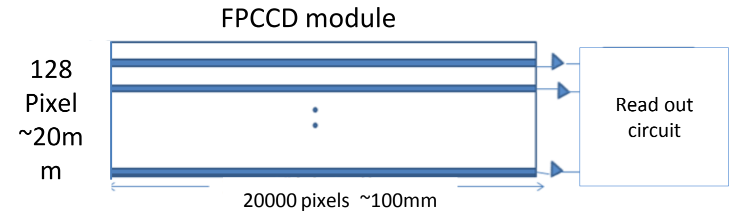
Large prototype

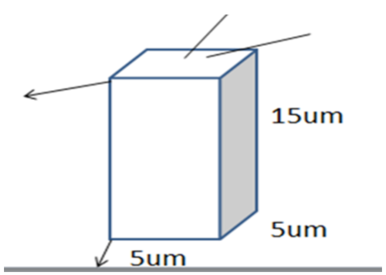
Read out circuits 's Goal

i) read-out speed > 10Mpixels / s (100MHz)
- to read out all pixel in 200ms (inter -train)

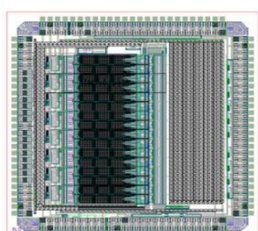
ii) noise of read-out circuits < 30 electrons
- small number of electron-hole pair produced when particles incident at shallow angle

iii) consumed power < 6mW /ch
- to keep temperature -40℃





recent prototype
read out circuit



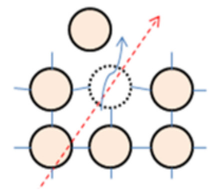
Read-out speed : 12Mpixel /s
Noise : 48 electrons
Power consumption: 5.8mW/ch

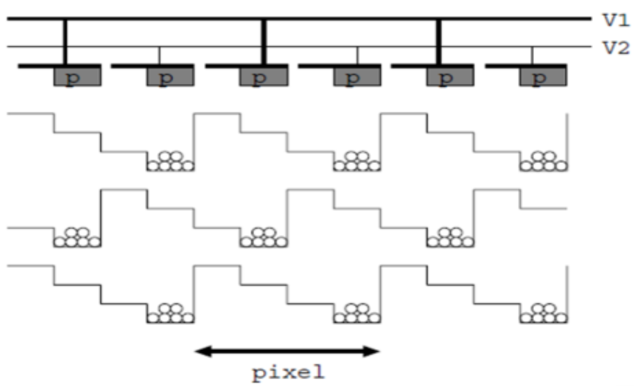
Read-out speed
Power consumption
OK!

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



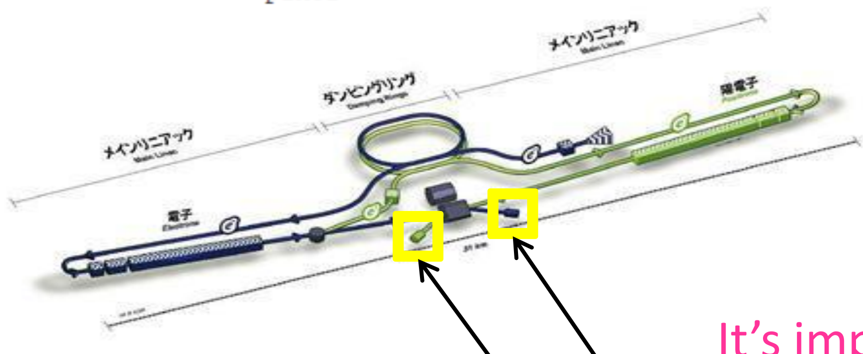


CCD transfers charge signal like bucket-brigade.

- 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



Beam dump

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.

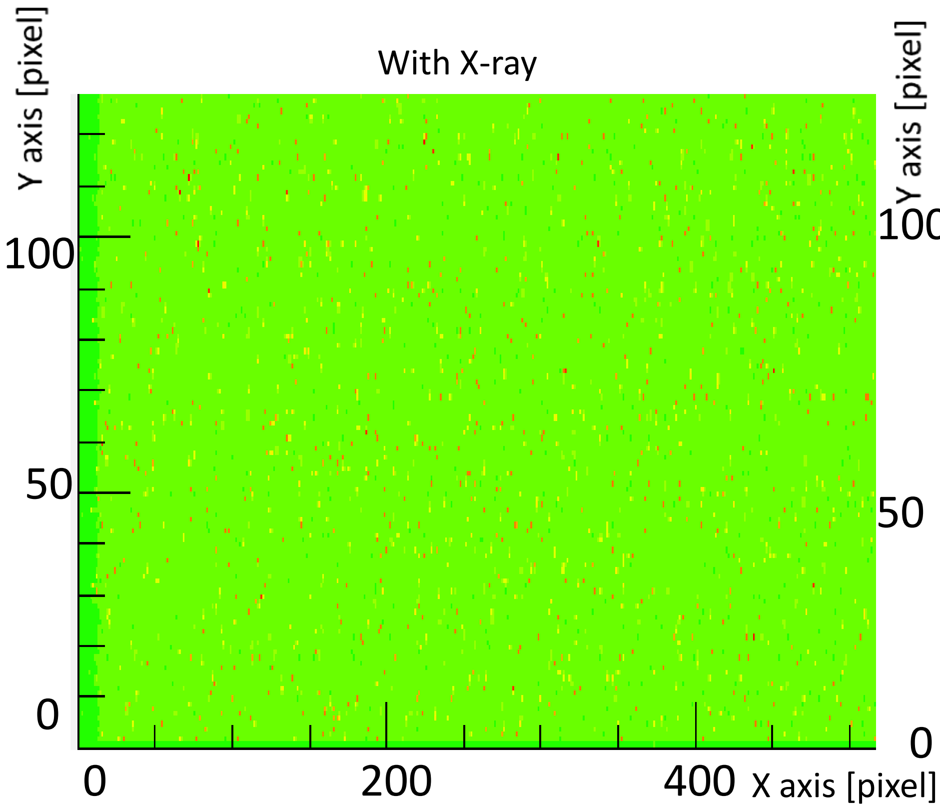
It's important to measure tolerance of detector!

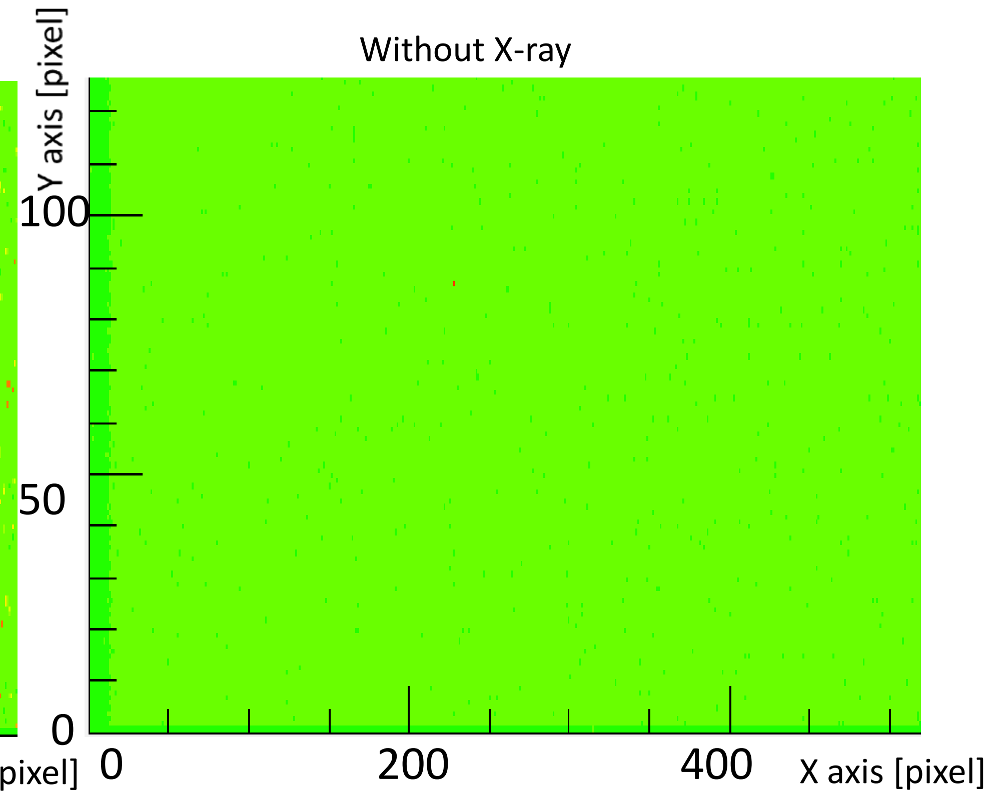
Characteristics of FPCCD

i) CTI(Charge Transfer Inefficiency)

Inefficiency in transferring charge to neighboring pixel

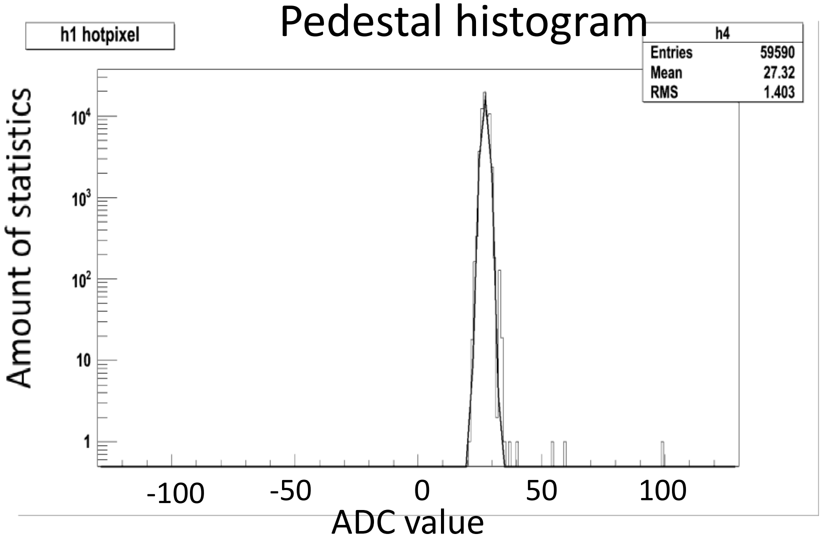
we test CTI using X-ray from Fe55.



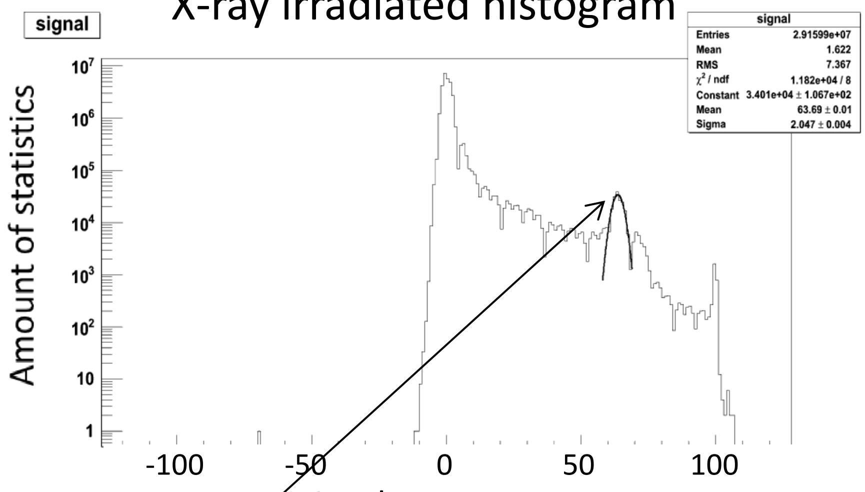


Characteristics of FPCCD

Pedestal histogram

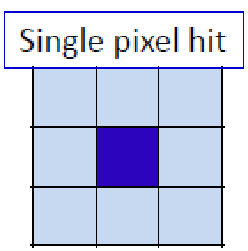


X-ray irradiated histogram



Fe55 peak (pedestal & average drift subtracted)

These figures show ADC value to amount of statistics



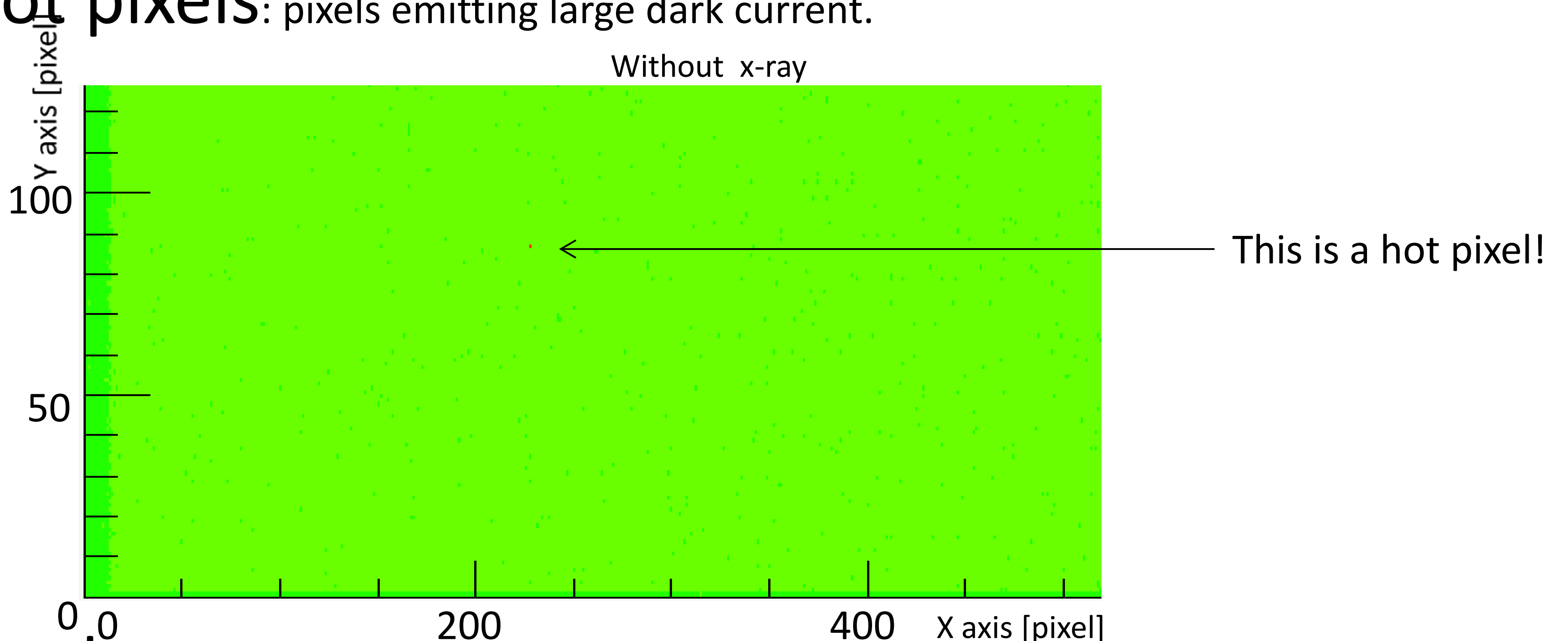
Single isolated pixel hit with ADC value consistent with X ray from Fe55.

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

- if CCD can transfer charge signal all, charge transfer efficiency is 1 …

Characteristics of FPCCD

ii)Hot pixels: pixels emitting large dark current.



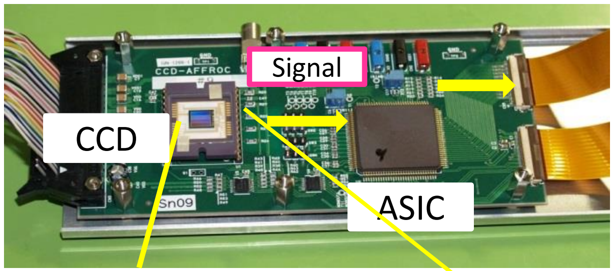
iii)Dark current: average of signal without x-ray.

At this irradiation test, we measured these 3 characteristics

Read out modules

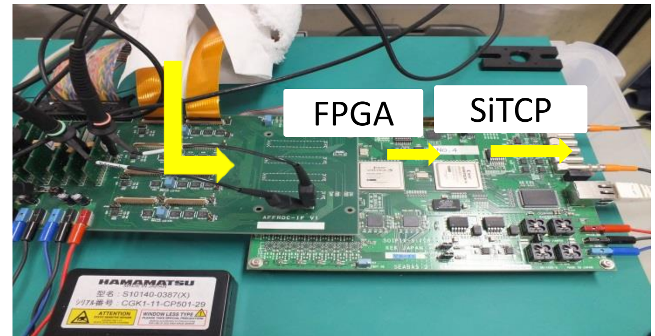
Stream of signal is …

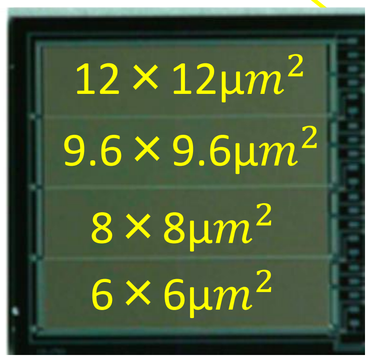
CCD --> ASIC--> FPGA --> SiTCP --> PC



ASIC out put signal

ASIC drive signal





CCD spec

Ethernet connection

PC

Sensitive thickness : 15μm

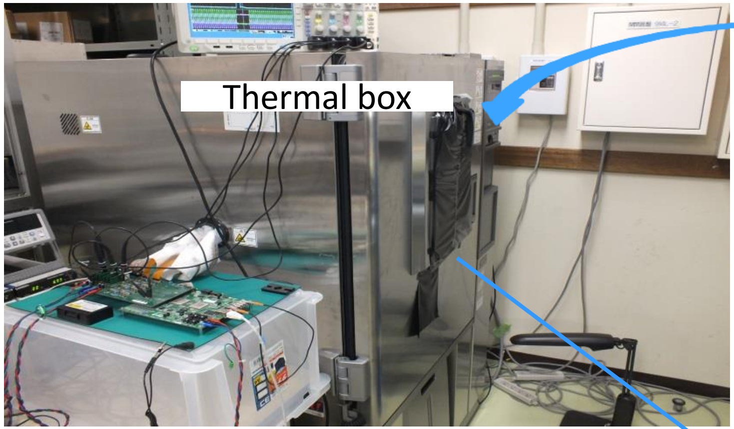
Pixel size : CCD has 4 read-out channels. Pixel sizes are …

$6 \times 6\mu m^2$, $8 \times 8\mu m^2$, $9.6 \times 9.6\mu m^2$, $12 \times 12\mu m^2$

We only measured $8 \times 8\mu m^2$, $12 \times 12\mu m^2$

Read-out modules

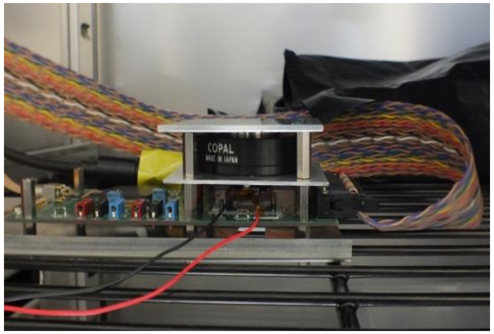
To test temperature dependence of CTI, dark current , hot pixels, CCD and read out circuit were put into thermal box

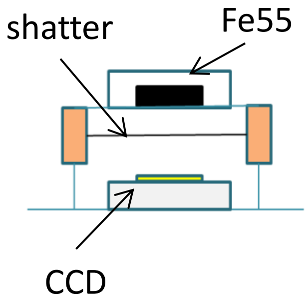


Before irradiation, we measured at
-40℃, -20℃, 0℃, +20℃
After irradiation, we measured at
-40℃, -30℃,-20℃, -10℃, 0℃, +10℃, +20℃

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

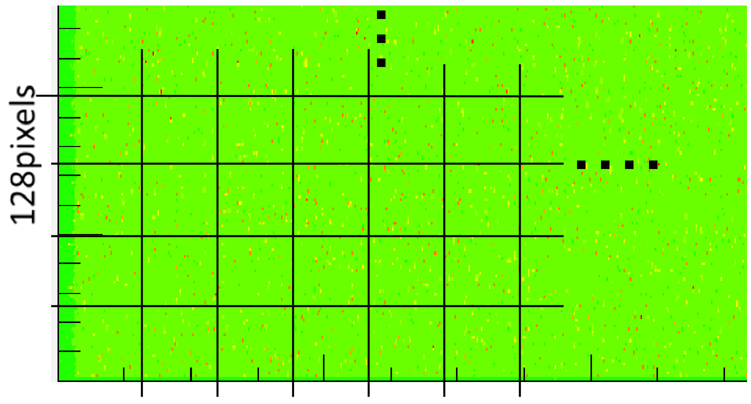




Characteristics before irradiation

i) CTI

I measured CTI of a channel of 12μm (512 x 128) pixels at -40℃



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.

I fitted this histogram with function

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

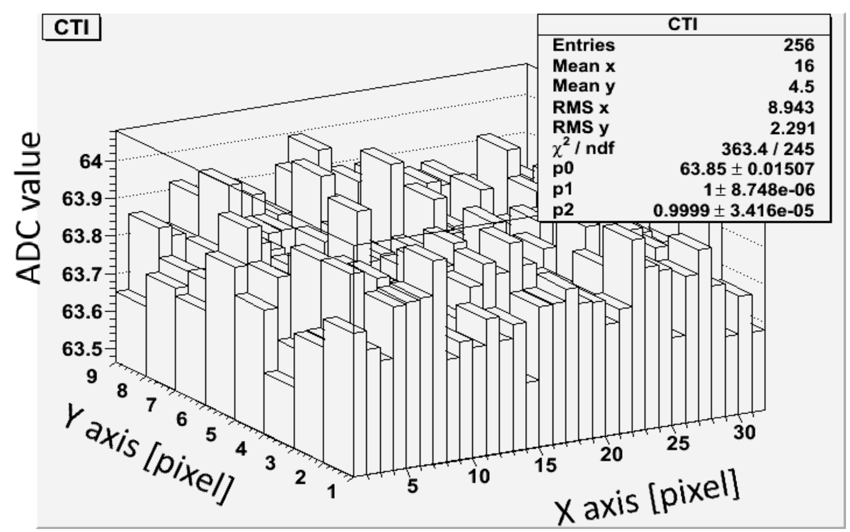
[p0] : constant number

[p1] : Horizontal CTE (x direction)

[p2] : Vertical CTE (y direction)

x : region number (x direction)

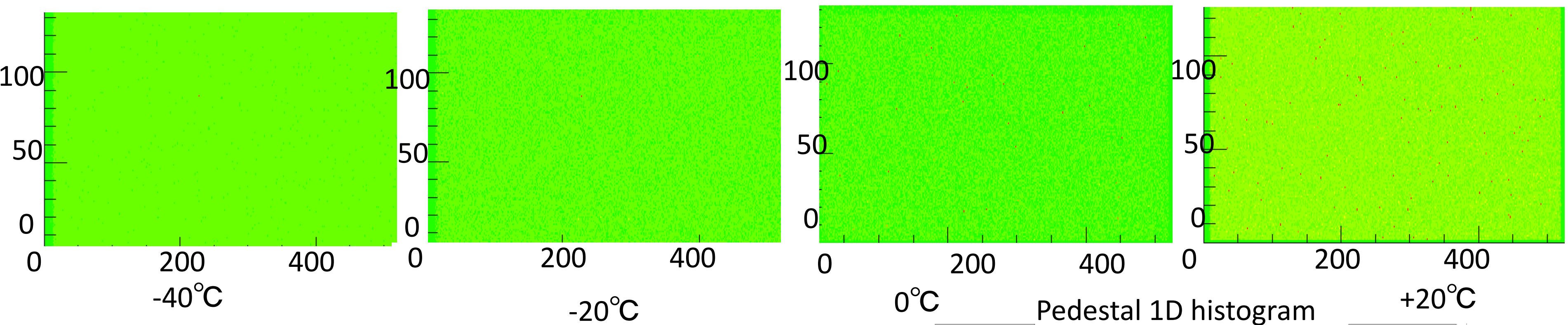
y : region number (y direction)



Characteristics before irradiation

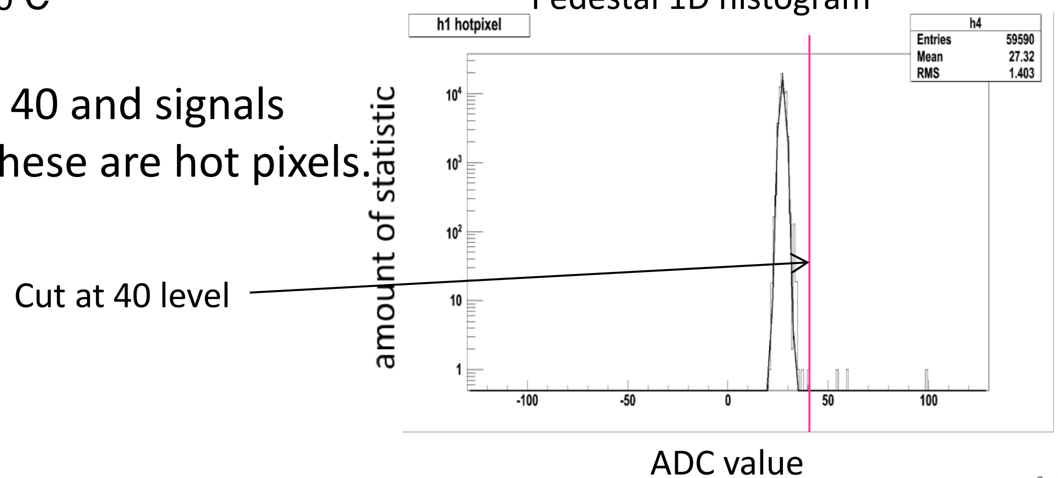
ii)Hot pixels

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



Pedestal 1D histogram

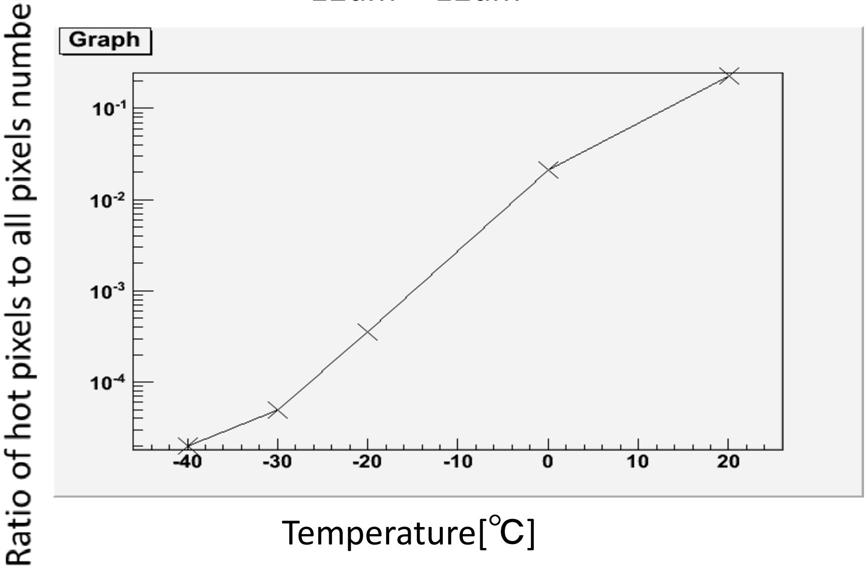
I set threshold level at ADC value of 40 and signals larger than threshold. I considered these are hot pixels.



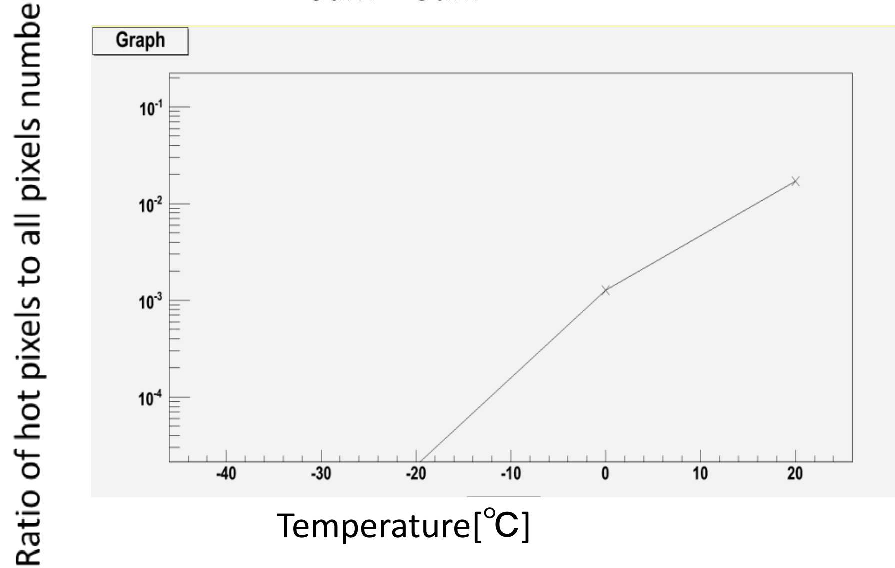
Characteristics before irradiation

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

12um × 12um



8um × 8um



Fraction of hot pixels got larger as the temperature was raised.

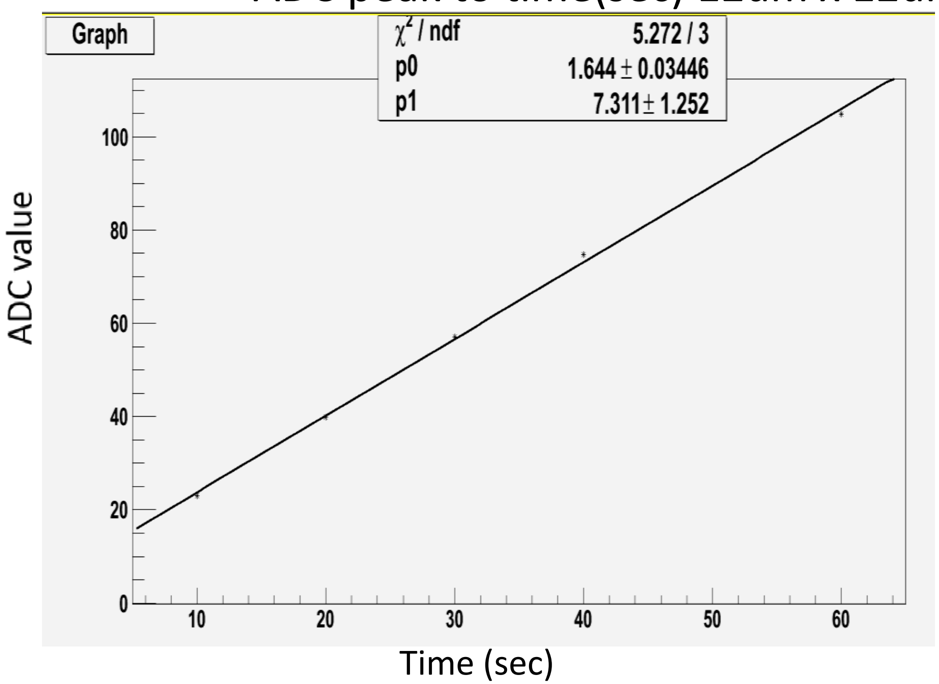
- at -40℃, fraction of hot pixels ≅ 0

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 to time(sec) 12um x 12um



Fit with linear function

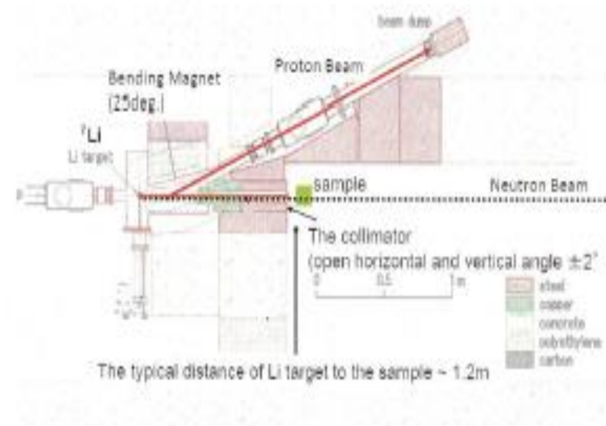
f = ax+b

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

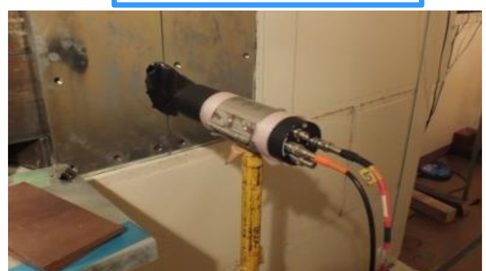
Neutron Irradiation

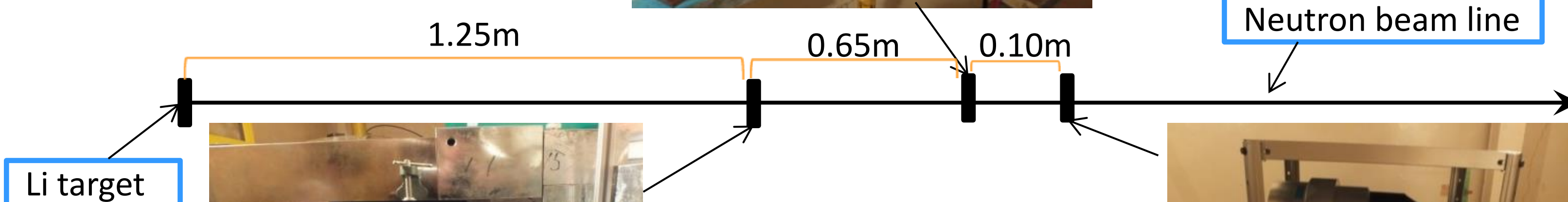
- Set up

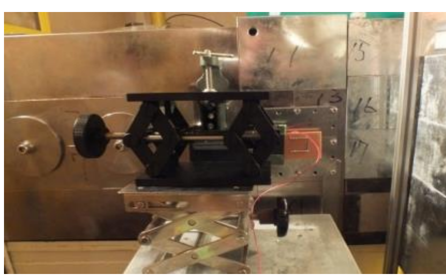
We did neutron beam irradiation at 16,17 Oct at Tohoku University CYRIC. We made neutron beam by irradiating 1μA proton beam to 7-8mm thickness Li target .
Irradiated time was
30 minutes 19 sec.



Plastic scintillator







CCD set

Liquid scintillator

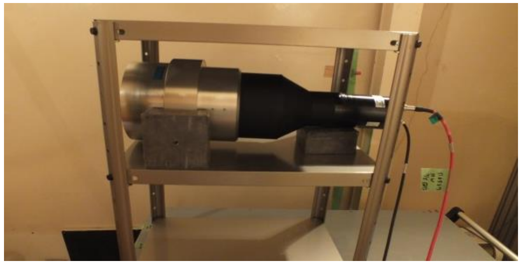
Neutron Irradiation

- Flux of neutron

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

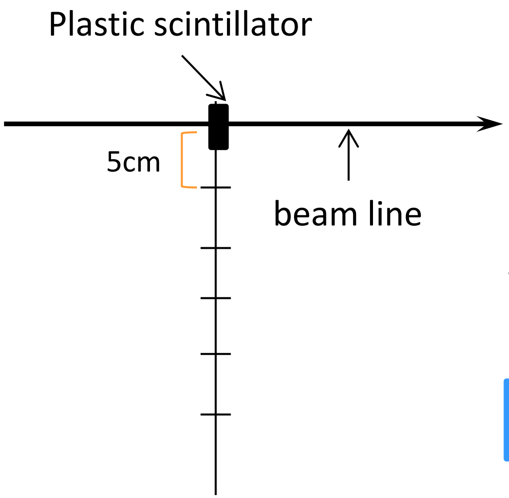
ｉ）First, we used liquid scintillator to measure total number of neutrons after collimator.

8.3×10^6neutron/sec



ⅱ）Second, we measured beam size by plastic scintillator.

And measured beam size at 6 point each 5cm from 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

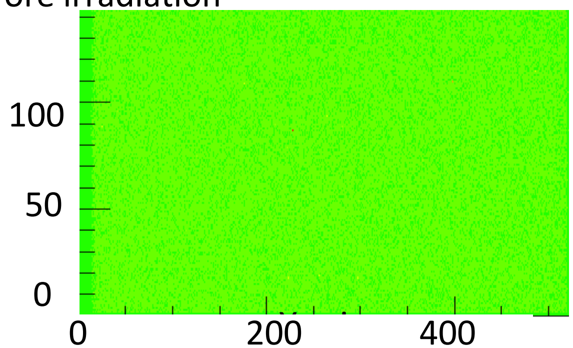
CCD set at 1.25m from Li target was irradiated 9.4×10^8neutron

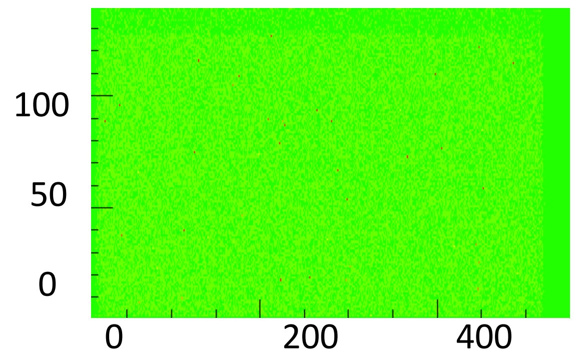
Result

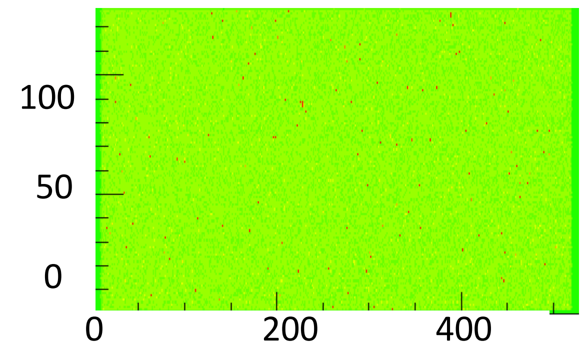
- Hot pixels

After irradiation, we saw many hot pixels.

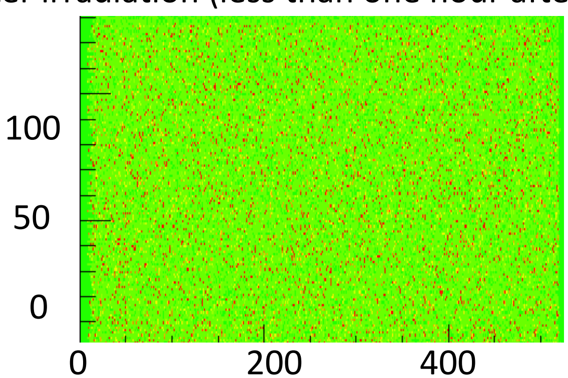
Before irradiation

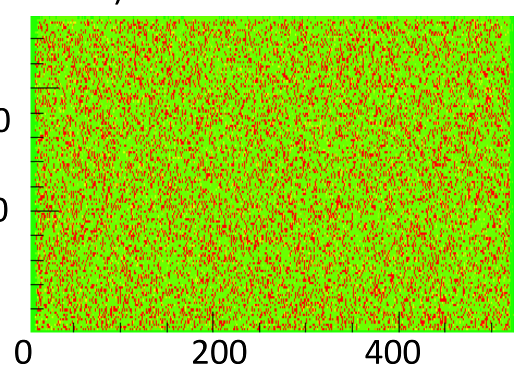


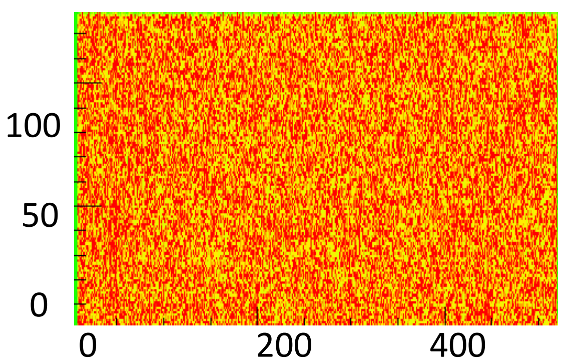




After irradiation (less than one hour after irradiation)







-20°C

0°C

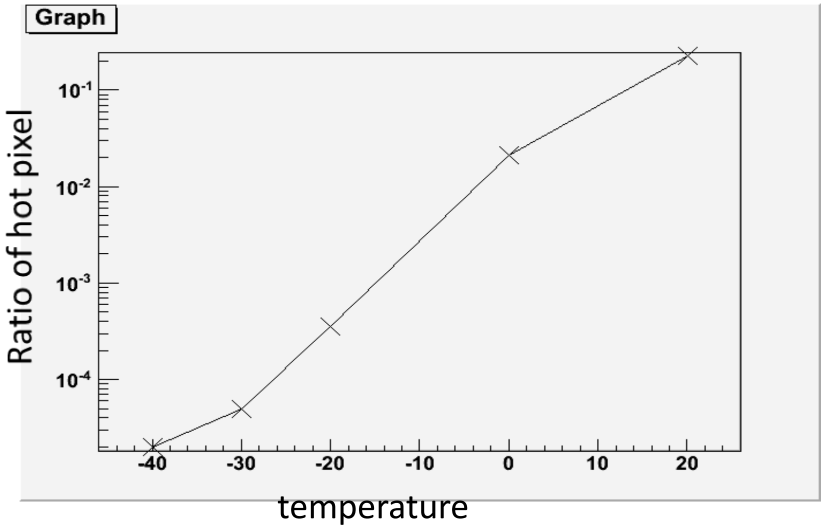
+20°C

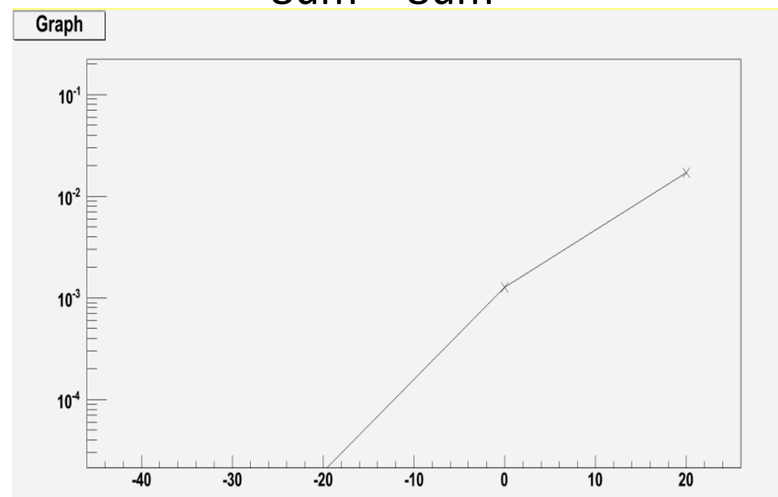
Result

12um × 12um

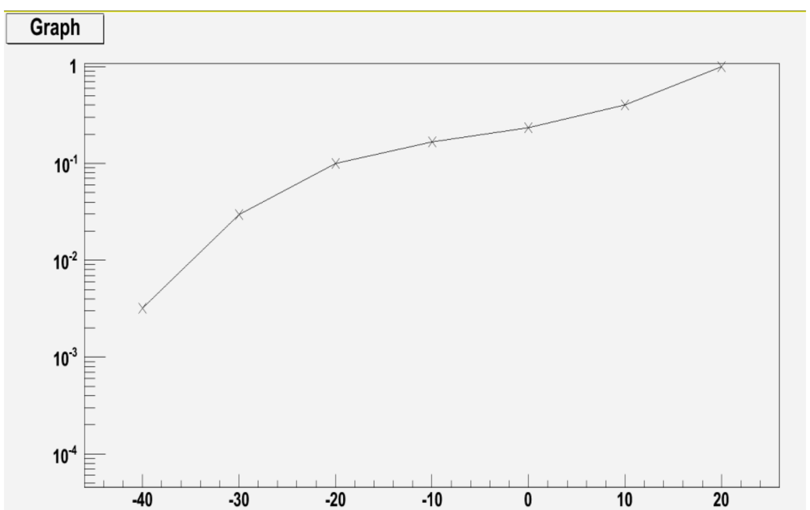
8um × 8um

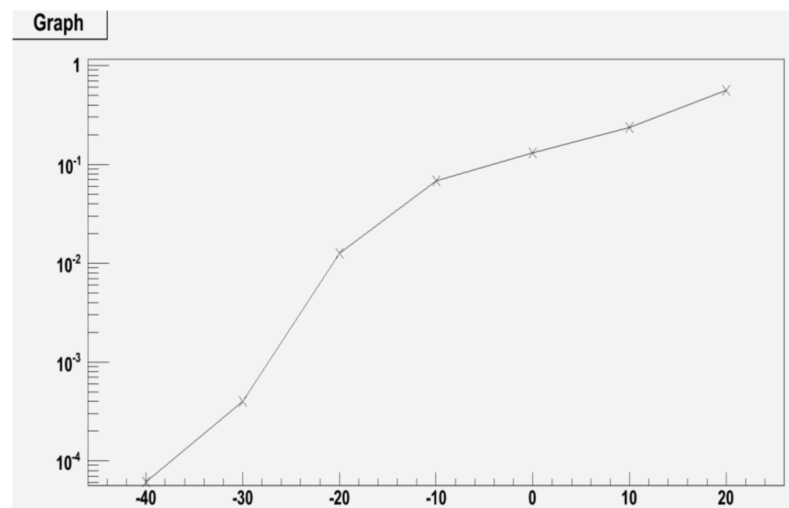
Before irradiation test





After Irradiation test

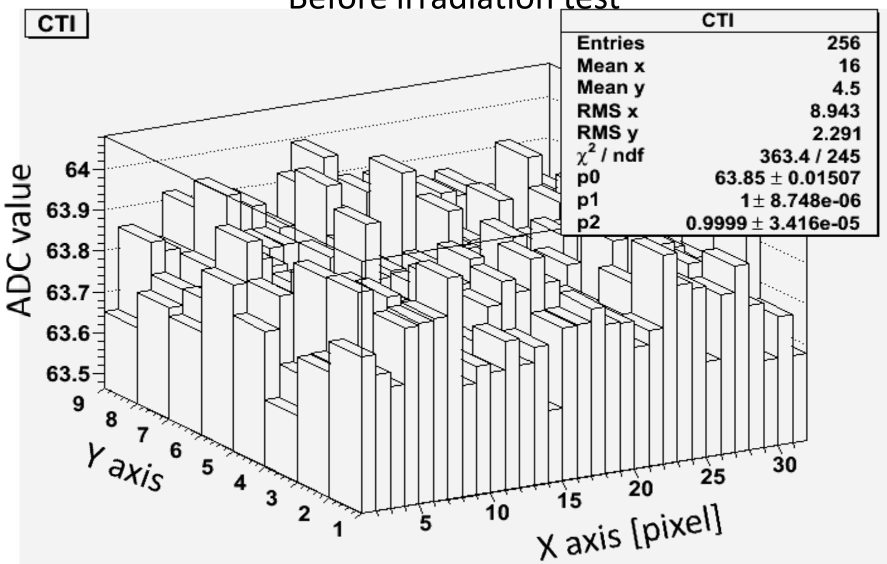




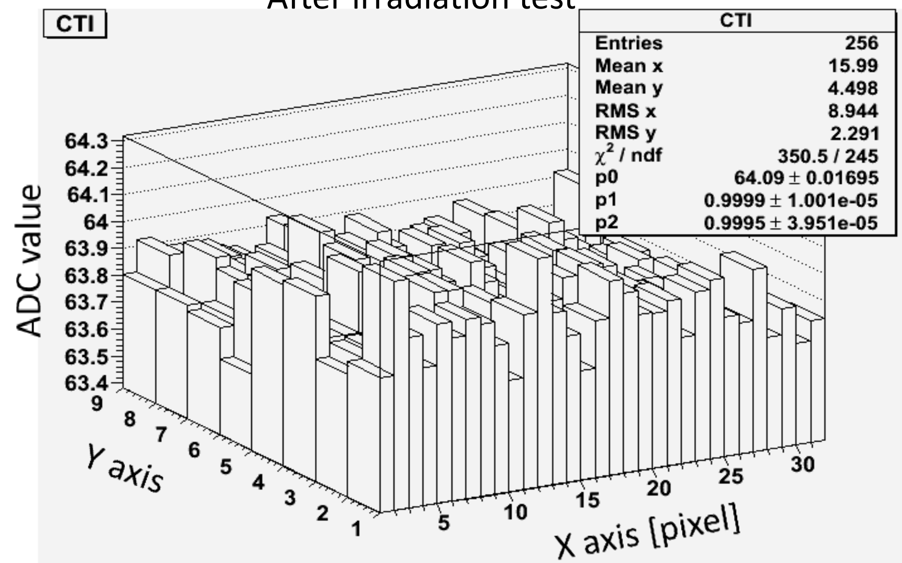
Result

- CTI

Before irradiation test



After irradiation test



CTI / pixel was …

Before irradiation test:

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

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

After irradiation test:

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

Y direction : $(2.834 \pm 0.247) \times 10^{-5}$

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