Neutron damage test

Ito Shuhei(Tohoku Univ.)

A.Dubey, C.Calancha,T.Horiguchi,A.Ishikawa,J.Strube,E.Kato,S.Murai, I.Ushiki, S.Watanuki, S.Yamaguchi, A.Miyamoto, Y.Sugimoto, H. Sato,T.Suehara, H.Ikeda, H.Yamamoto

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- hot pixel
- CTI

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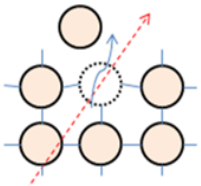
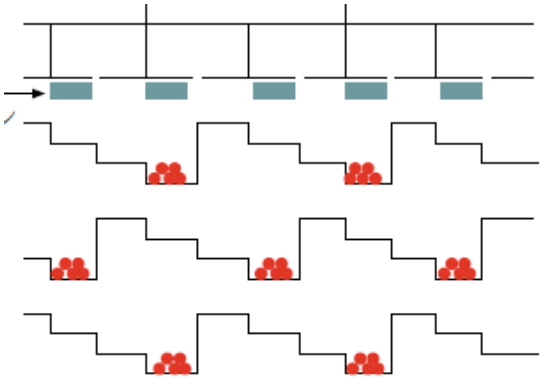
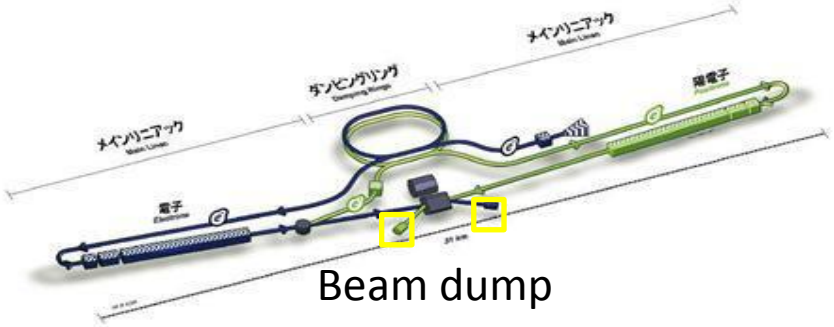
Neutron damage

Heavy particles like neutron sometimes make lattice defects in FPCCD. Lattice defect often trap charge signal and make Performance of FPCCD worse.





Mechanism of CCD



Beam dump

- CCD transfers charge signals like bucket-brigade and CCD has so many pixels(about 1 billion)
- Neutron equivalent flux of $O(10^{10})$neutrons/cm^2
- When incident upon the vertex detector may degrade its performance
- According to simulation , neutrons come mainly from beam dumps.

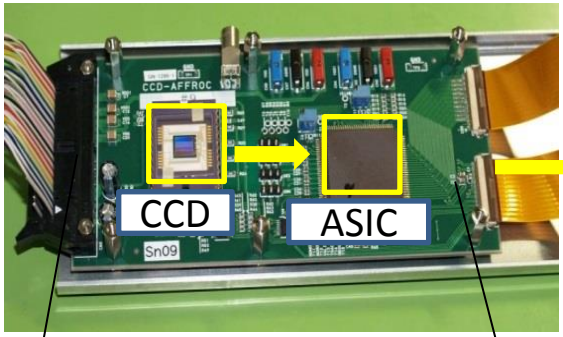
And neutron fluence to vertex detector was determined to be

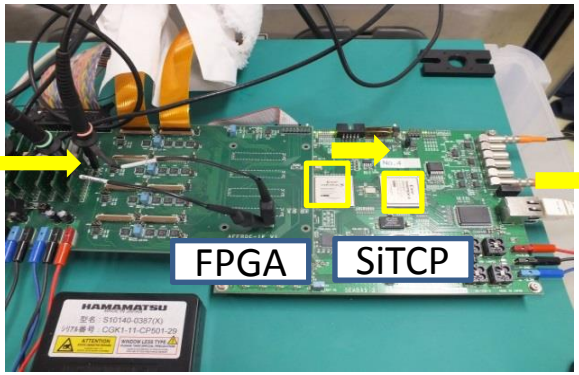
1.85×10^9neutron/cm^2/year.

Set up

Stream of signal

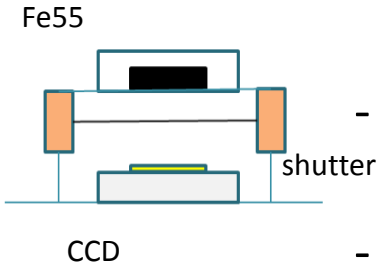
CCD --> ASIC--> FPGA --> SiTCP --> PC



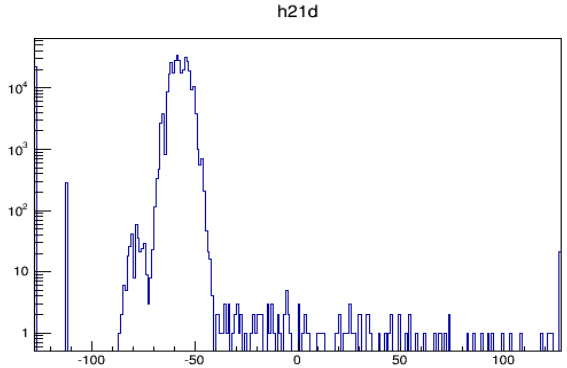


- To read out signals, we use DAQ-Middleware
  We can change CCD set up by condition file
- To measure temperature dependence of CCD, CCD and ASIC are placed in a temperature-controlled box.

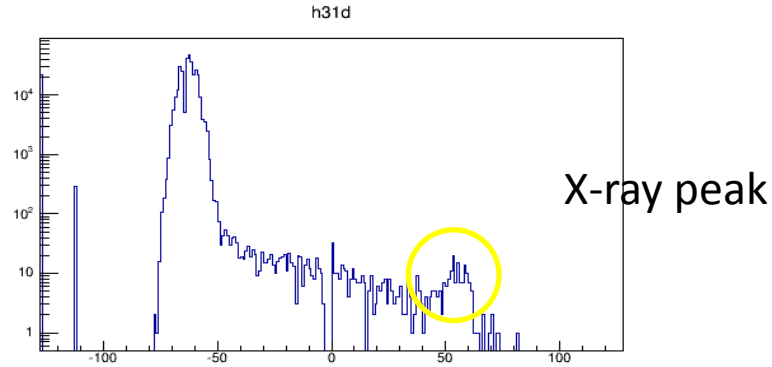
Set up



- To measure characteristics of CCD, I use Fe55
- Fe55 emits X-ray whose energy is 5.9keV
- With a shutter, I can control with X-ray or without X-ray.



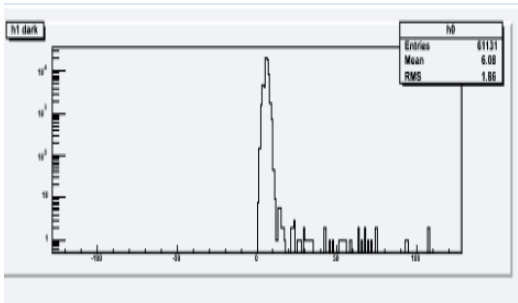
Without X-ray(close shutter)



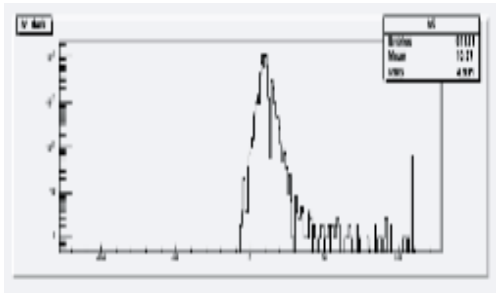
With X-ray(open shutter)

Characteristics of FPCCD

Dark current



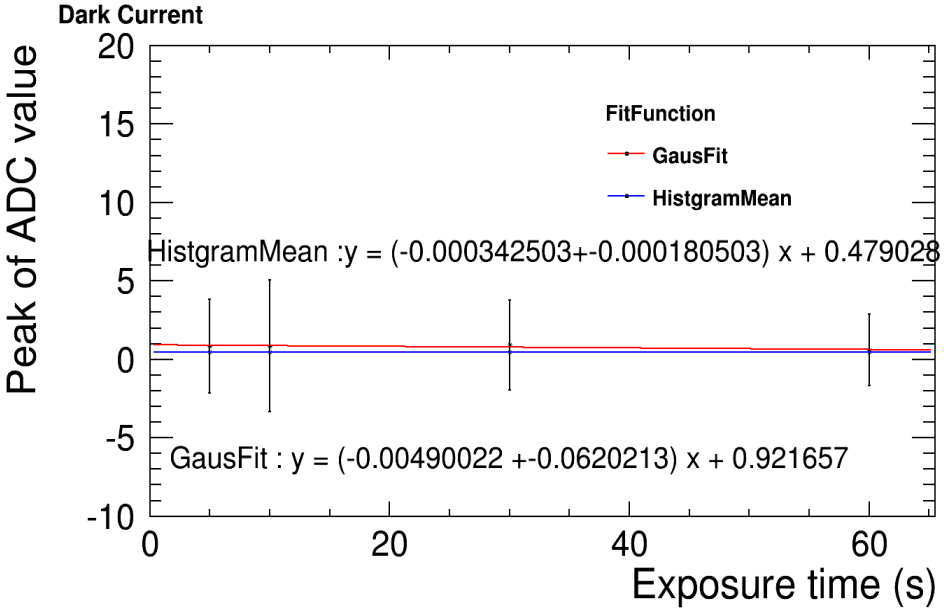
Exposure time 10 sec



Exposure time 60 sec

- The dark current becomes larger as the exposure time for measurement gets longer

5sec 10sec 20sec 40sec 60sec



Method

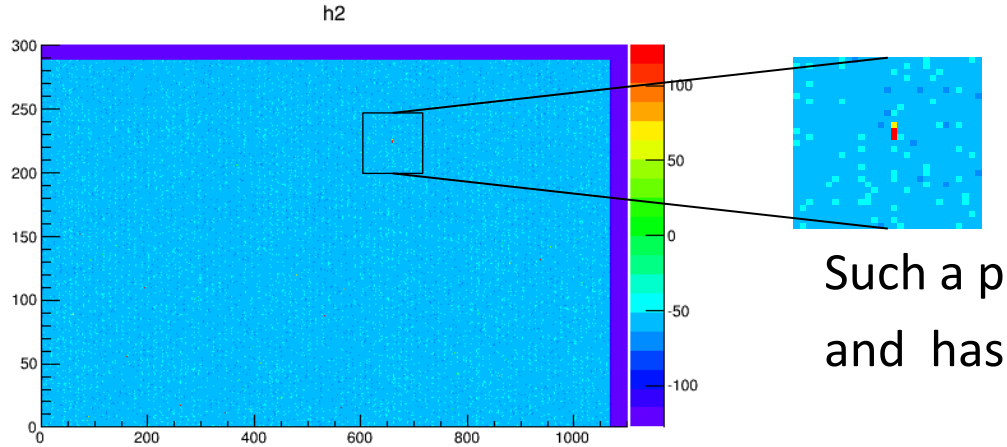
1. Fit pedestal by gausian and get mean of histogram for each exposure time
2. Prot peak ADC value vs exposure time
3. Fit by linear function

Gradient of linear function means pedestal level per 1 sec

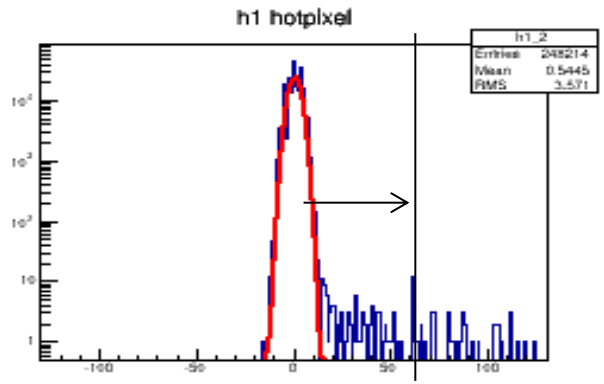
Characteristics of FPCCD

Hot pixel

Hot pixel is a pixel with large dark current even when there is no source.



Such a pixel increases pixel occupancy and has a bad influence on tracking.



Definition of hot pixel

Larger than 5σ above the pedestal position

I take 10 frames (1 frame is 5 sec exposure time) and get average of hot pixel number.

Characteristics of FPCCD

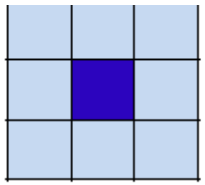
CTI(Charge Transfer Inefficiency)

CTI means inefficiency in transferring charge to neighboring pixel.

1 module of FPCCD has about 128 x 20000 pixels

method

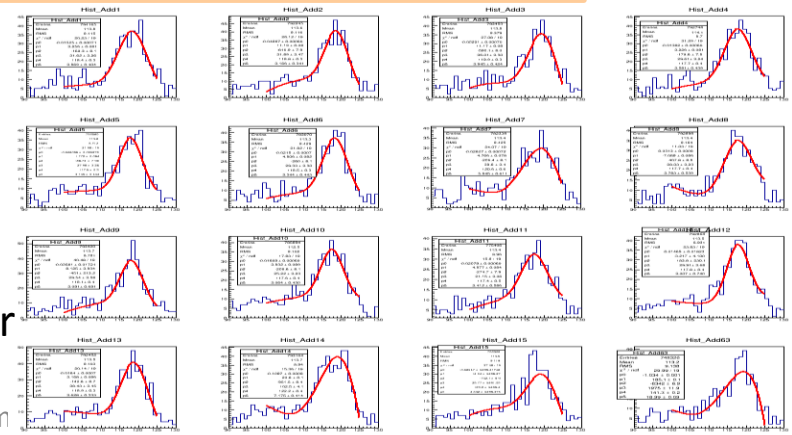
1. Divide 1 channel to 31 x 63 region. 1 region has 16 x 16 pixels
2. Choose single hit event for each region



Single hit event

- Signal level of around 8 pixels are less than 5σ of pedestal
- Signal level of center pixel is higher than 5σ of pedestal

3. Fit single hit event ADC peak by gausian for each region.

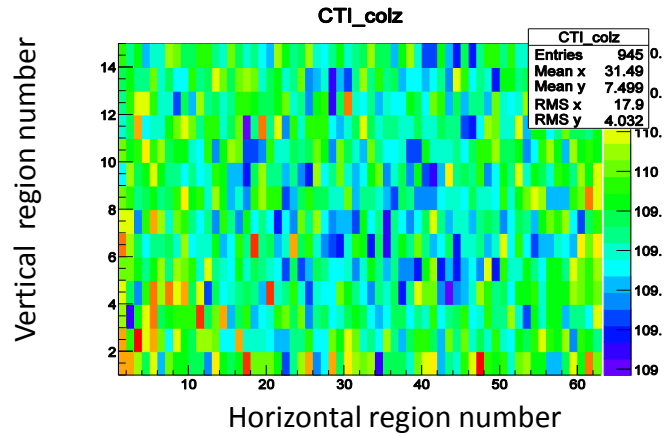


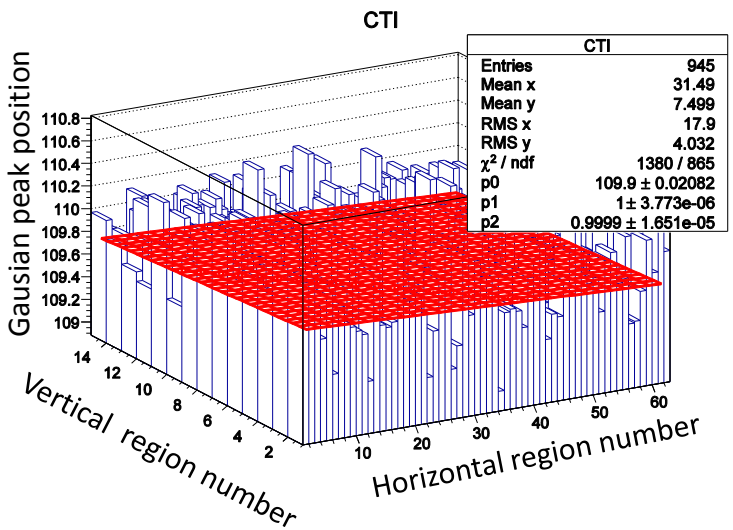
Single hit peak for 16 regions

Characteristics of FPCCD

4. Make histogram

- x axis is horizontal region number
- y axis is vertical region number
- z axis is gausian peak position





5.Fit this histogram with

$$f(x,y) = Aa^x b^y$$

a corresponds to horizontal CTE for 1 region

b corresponds to vertical CTE for 1 region

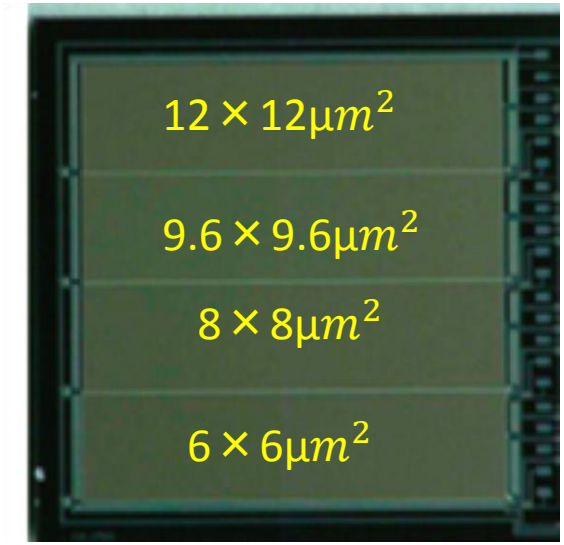
CTE : Charge Transfer Efficiency

CTI = 1 - CTE

Signals are read out from region number (0,0)

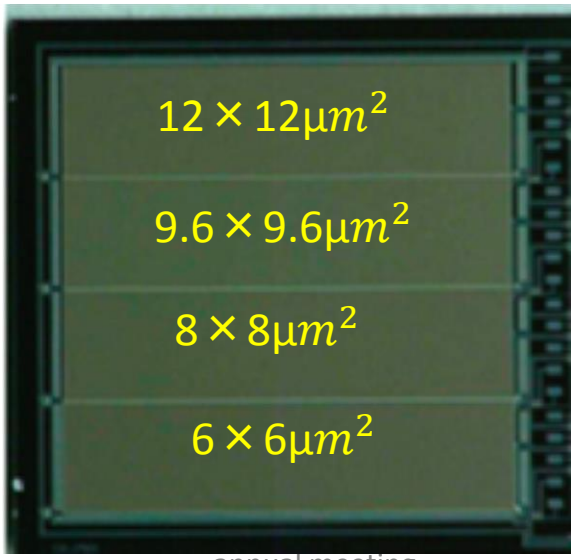
To compare how change ADC peak position of gausian

Neutron damage test



Previous neutron damage test

CCD : 4 channel different pixels size
Clock frequency : 6MHz
Irradiation time : 30 minutes

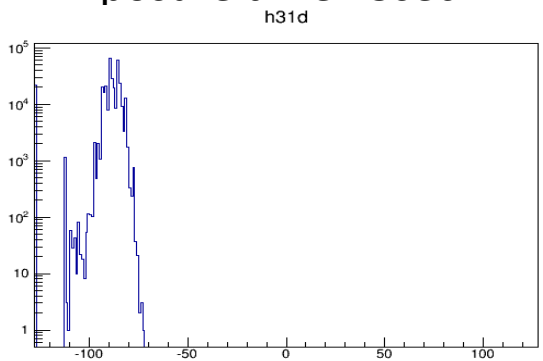


This time damage test

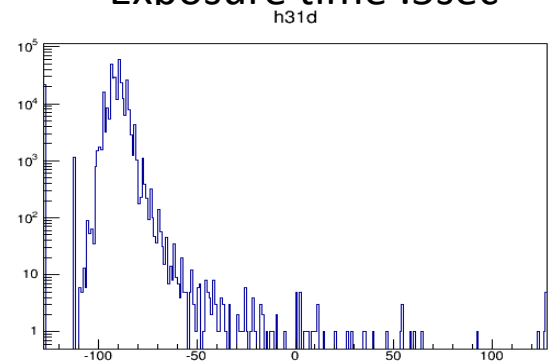
CCD : all 6um pixel size
different pixel size
Frequency : 6MHz 25MHz
Irradiation time : 2 hours
30 minutes

Dark current

Before irradiation
Exposure time : 5sec

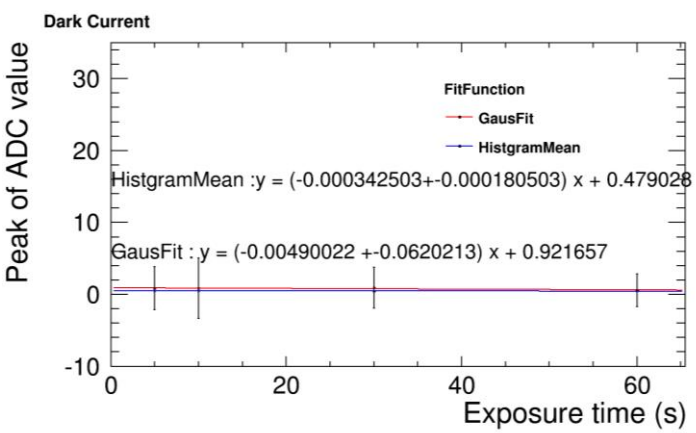


After irradiation
Exposure time :5sec

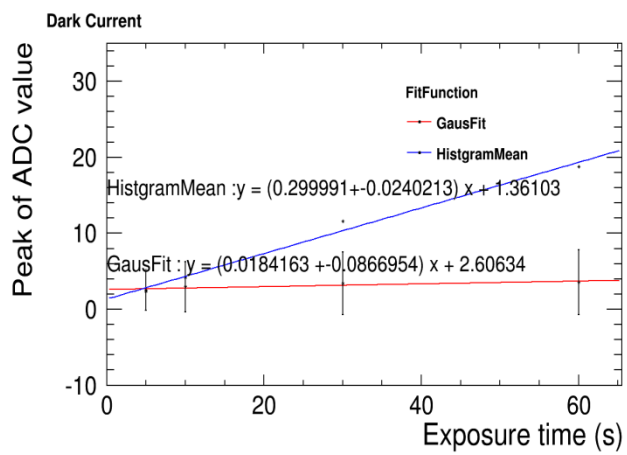


After irradiation, pedestal has tail to higher level

Before irradiation



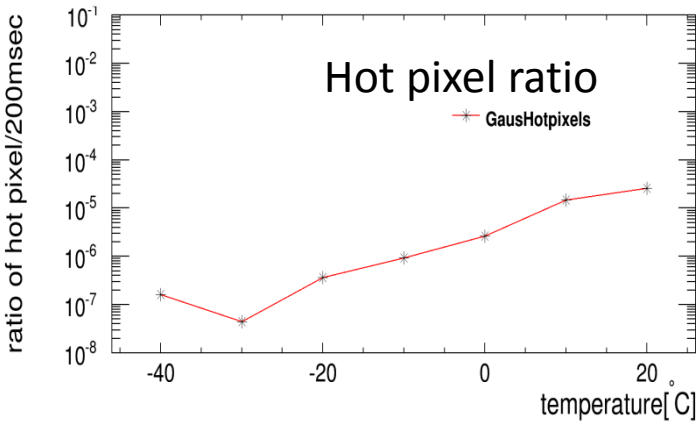
After irradiation



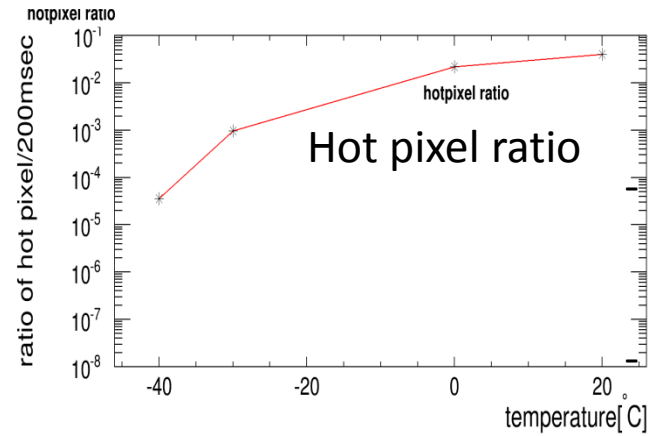
Pedestal peak position is not so different but pedestal mean get large.

Hot pixel

Temperature dependence



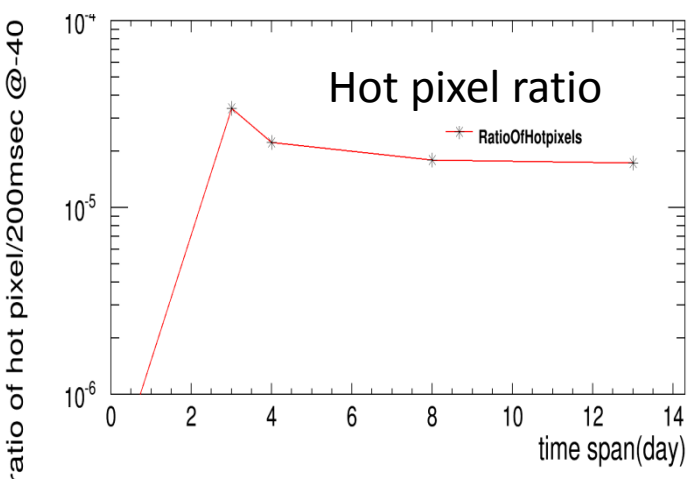
Before irradiation



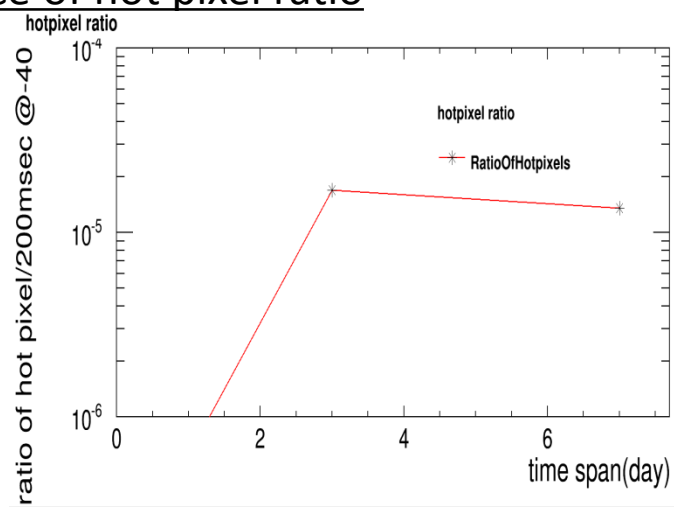
After irradiation

After irradiation, at -40℃ hot pixel ratio get worse about 100 times.
After irradiation at room temperature, there are many hot pixels

Time dependence of hot pixel ratio



25MHz @-40℃

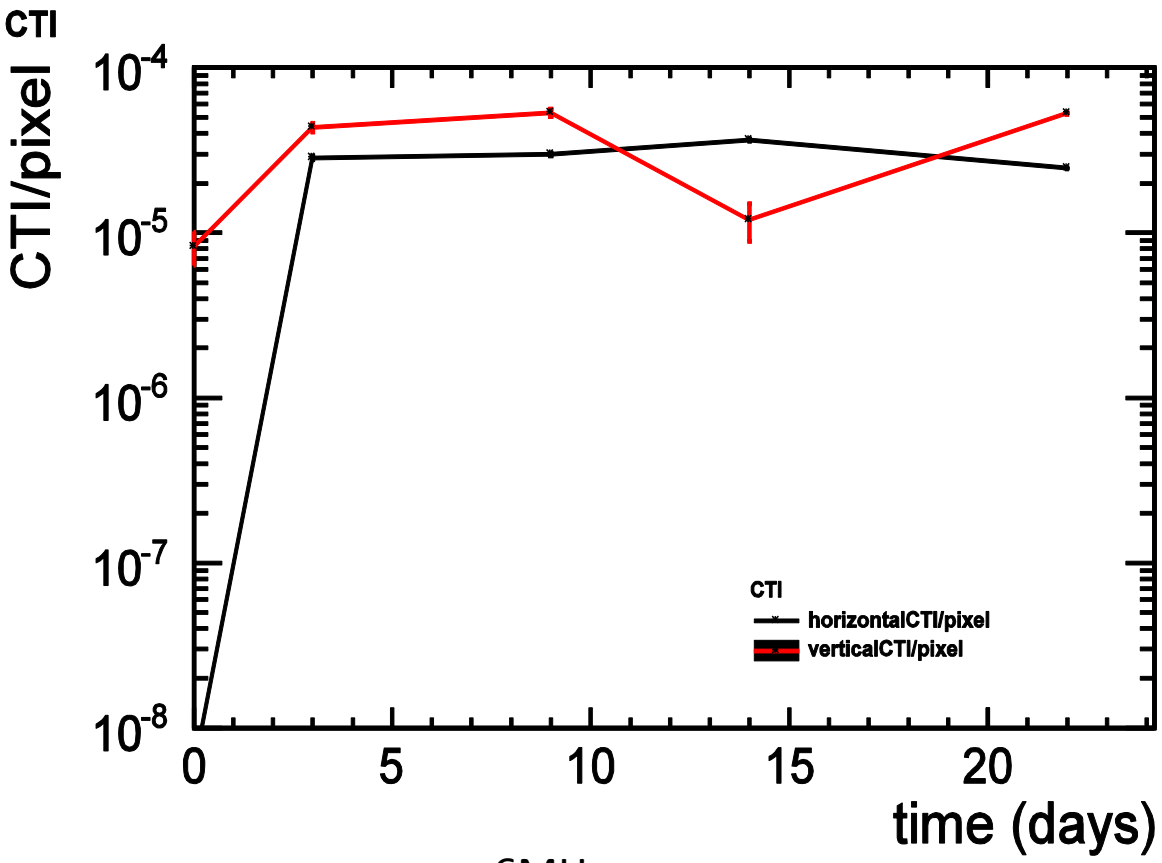


6MHz @-40℃

After irradiation, CCD recover by annealing effect.

Charge Transfer Inefficiency

CTI



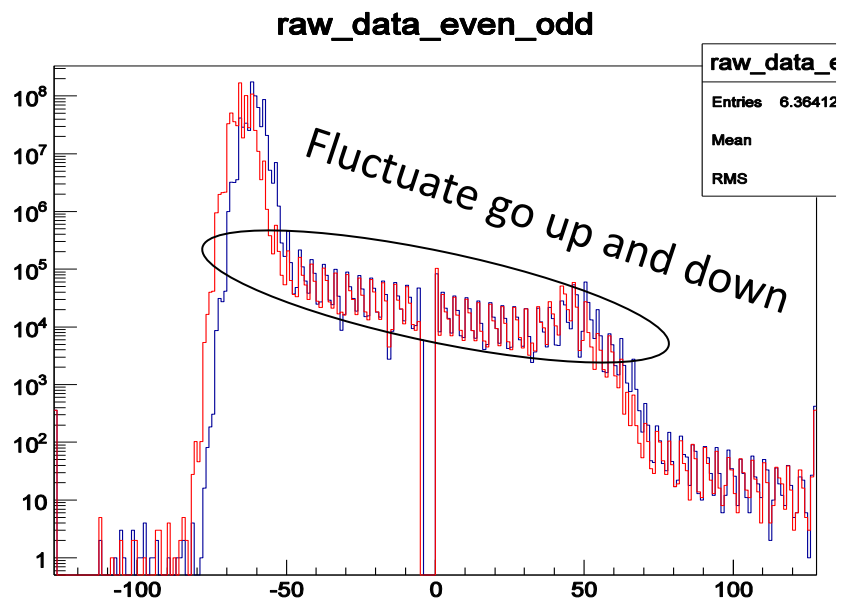
6MHz

- After irradiation, both horizontal and vertical CTI get worse.
- After irradiation, order of CTI is 10^{-5}.
- For horizontal direction, FPCCD transfer signal 20000 times and
  For vertical direction transfer signal 128 times
- Signal level of farthest pixel from read out module reduce to about 54.7%

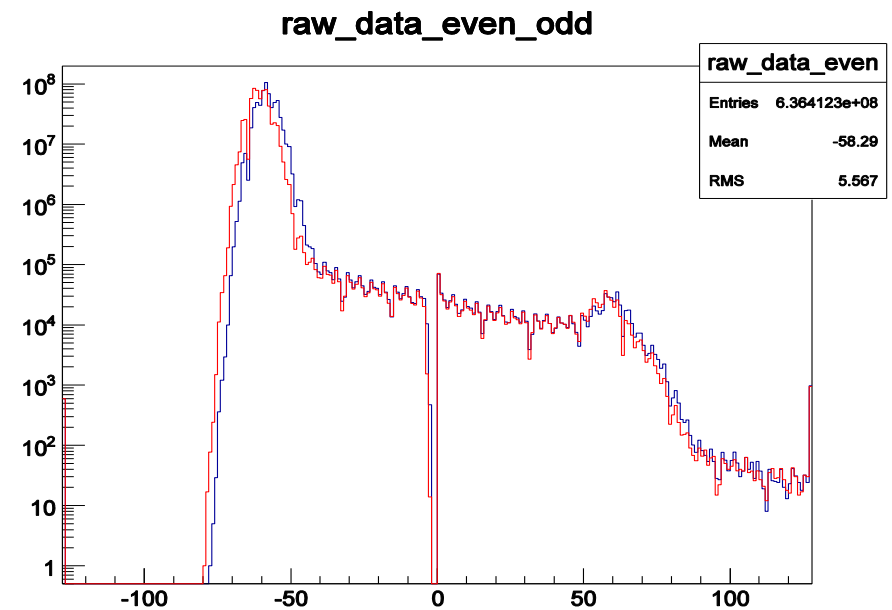
Work in progress

1. With 25MHz clock, there is structure

   Red is odd column of CCD, blue is even column of CCD



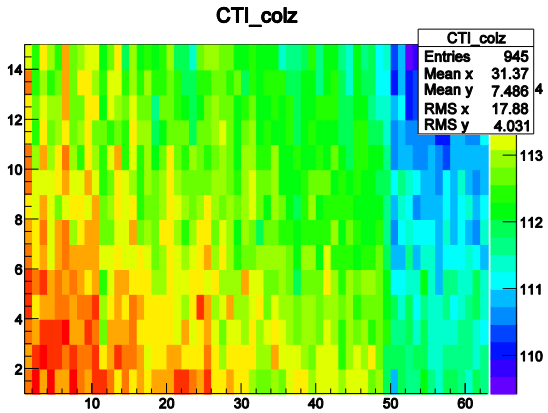
Raw data with X-ray
Frequency : 25MHz
Before irradiation



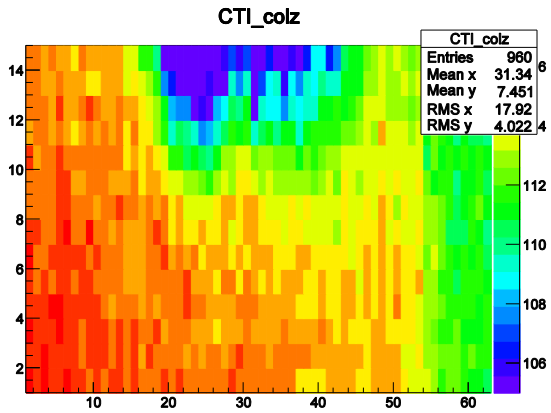
Raw data with X-ray
Frequency : 6MHz
Before irradiation

Work in progress

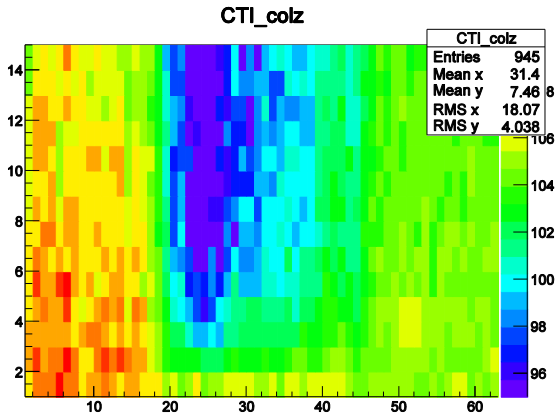
2. After irradiation, there is strange structure with 6MHz ch3 and ch2,



6MHz , ch4

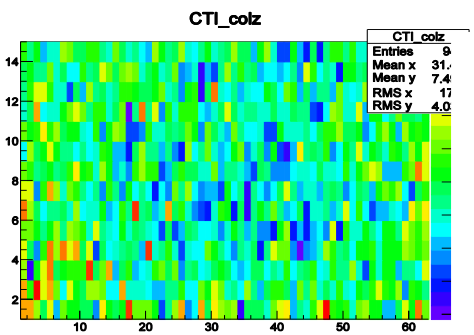


6MH, ch3

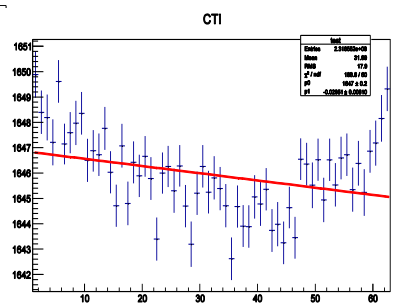


6MHz, ch2

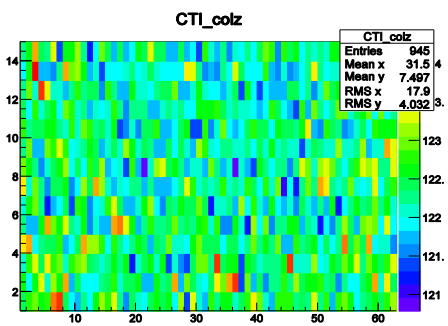
And also, before irradiation, central part of 1 channel is little bit dent.



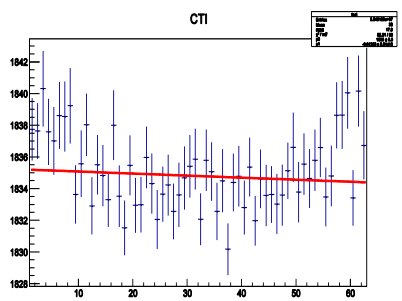
25MHz, ch4



Projection to X axis



6MHz, ch4



Projection to X axis

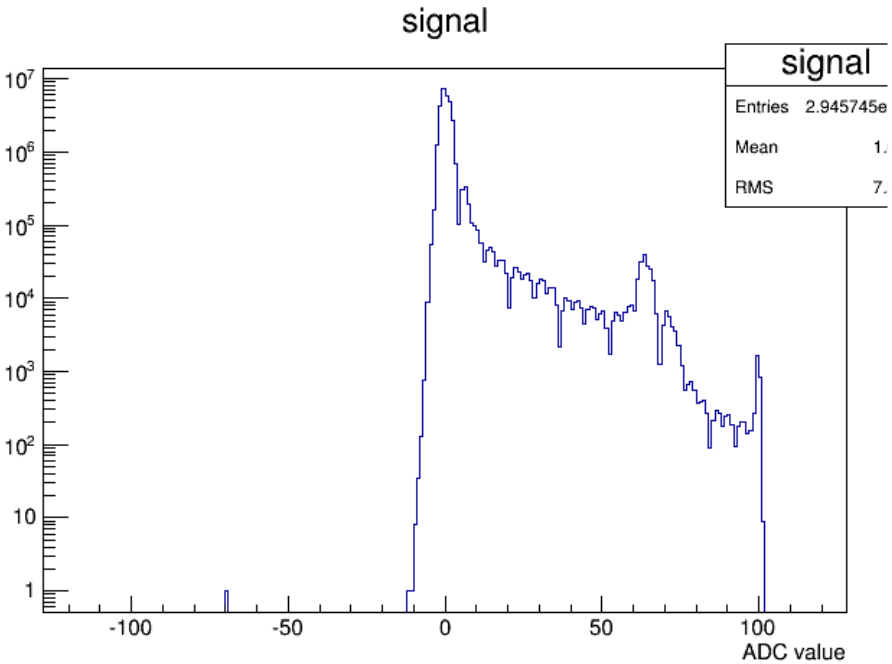
conclusion

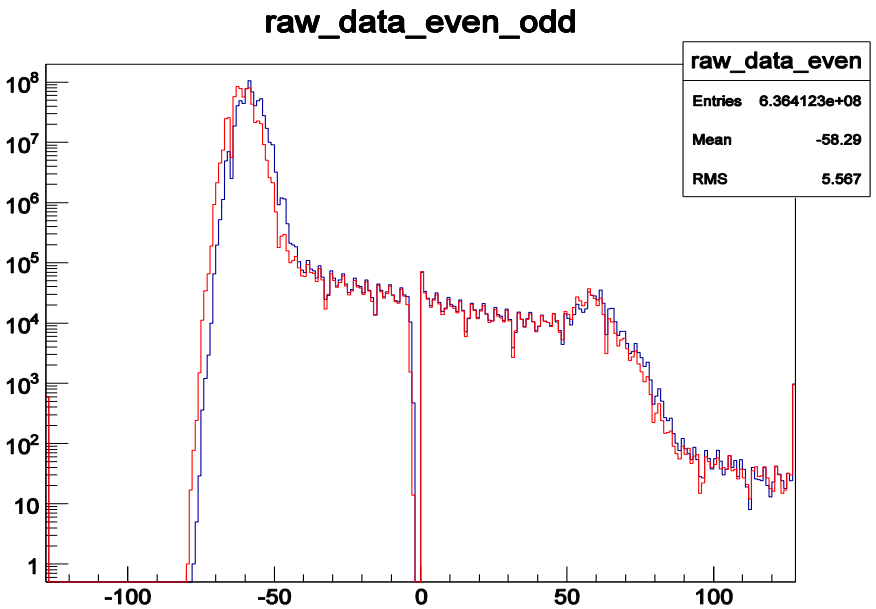
- We did neutron irradiation test with newest CCD
- After irradiation, dark current has longer tail to higher level.
- After irradiation, hot pixel ratio at -40℃ is about 10^{-5} for 200msec
- Both horizontal and vertical CTI is about 10^{-5}

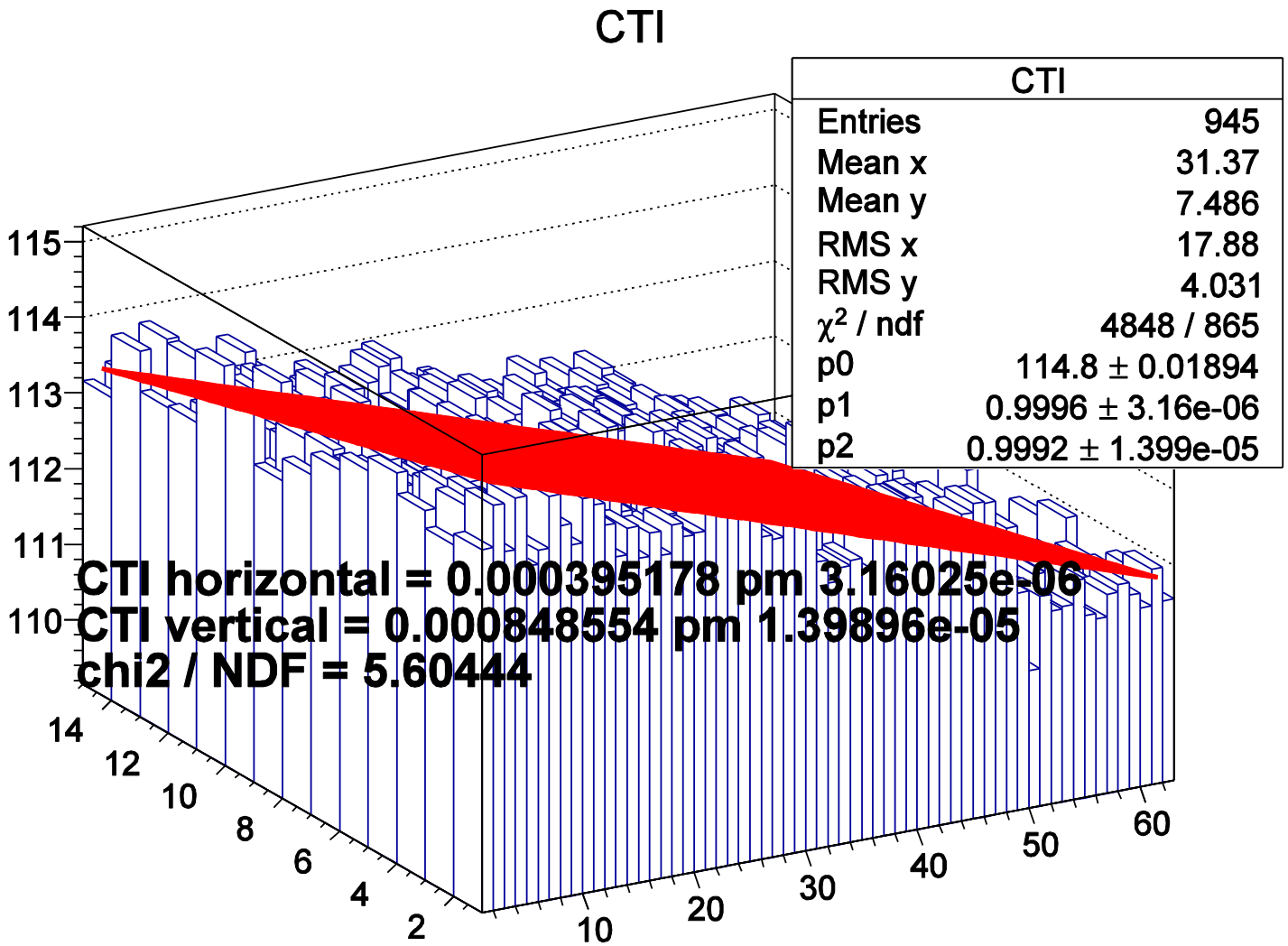
<u>Work in progress</u>

- To understand CCD characteristics more precisely, I have to remove strange structure

Back up


signal
signal
Entries 2.945745e
Mean 1.
RMS 7.
ADC value


raw_data_even_odd
raw_data_even
Entries 6.364123e+08
Mean -58.29
RMS 5.567


CTI
CTI
Entries 945
Mean x 31.37
Mean y 7.486
RMS x 17.88
RMS y 4.031
χ² / ndf 4848 / 865
p0 114.8 ± 0.01894
p1 0.9996 ± 3.16e-06
p2 0.9992 ± 1.399e-05
CTI horizontal = 0.000395178 pm 3.16025e-06
CTI vertical = 0.000848554 pm 1.39896e-05
chi2 / NDF = 5.60444
115
114
113
112
111
110
14
12
10
8
6
4
2
10
20
30
40
50
60