Status of CCD-based vertex detector R&D for a linear collider

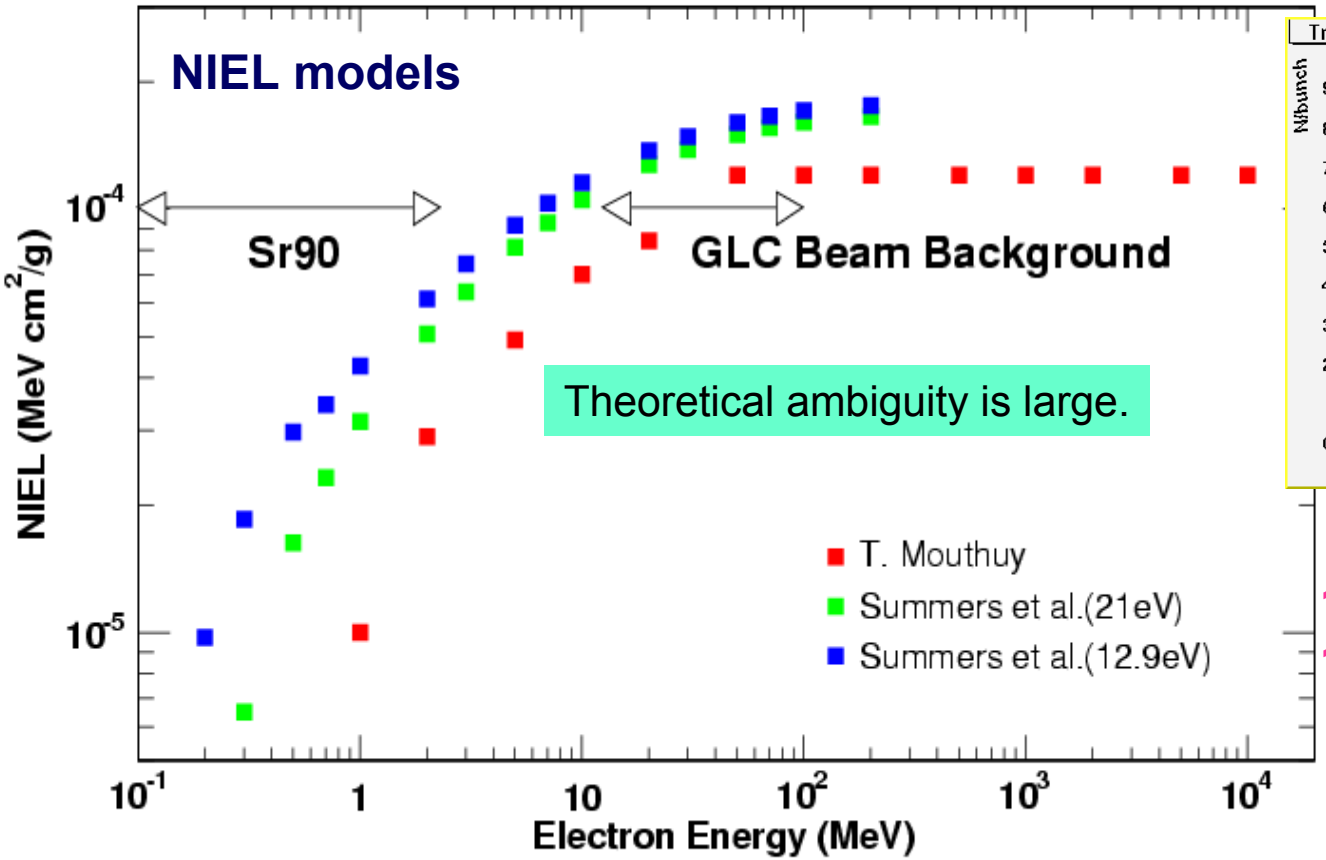
Tsukasa Aso, Toyama College of Maritime Technology
G.Iwai, H.Takayama, N.Tamura, Niigata University
Y.Sugimoto, A.Miyamoto, KEK
K.Abe, Tohoku Gakuin Univ.

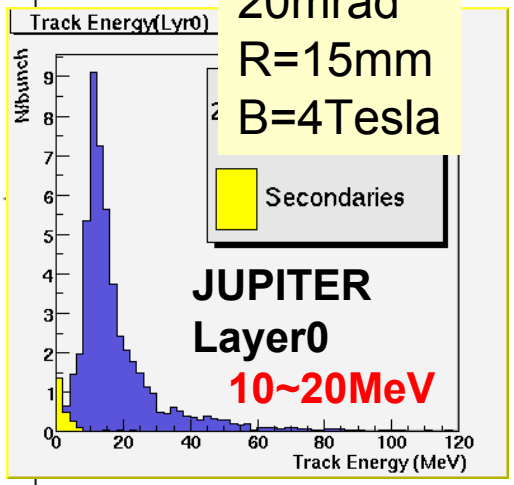
Objective

- VTX requirement needed for a linear collider
  - Excellent impact parameter resolution for b/c tagging
  - Must be
    - High resolution detector - Intrinsic resolution
    - Close to the interaction point - Small extrapolation
    - Low materials - Minimum Multiple scattering
  - CCD is a one of the candidates, but…
    - Issues
      - Radiation tolerance at realistic conditions
        - High energy charged particles
      - Spatial resolution at faster readout cycle
        - Diffusion is a key process for a excellent spatial resolution
      - Flatness of a thin detector

Radiation damage

- **Surface damage appears as increase of dark current due to interface charge.**
- **Bulk damage increases a CTI which is proportional to Non Ionizing Energy Loss (NIEL).**



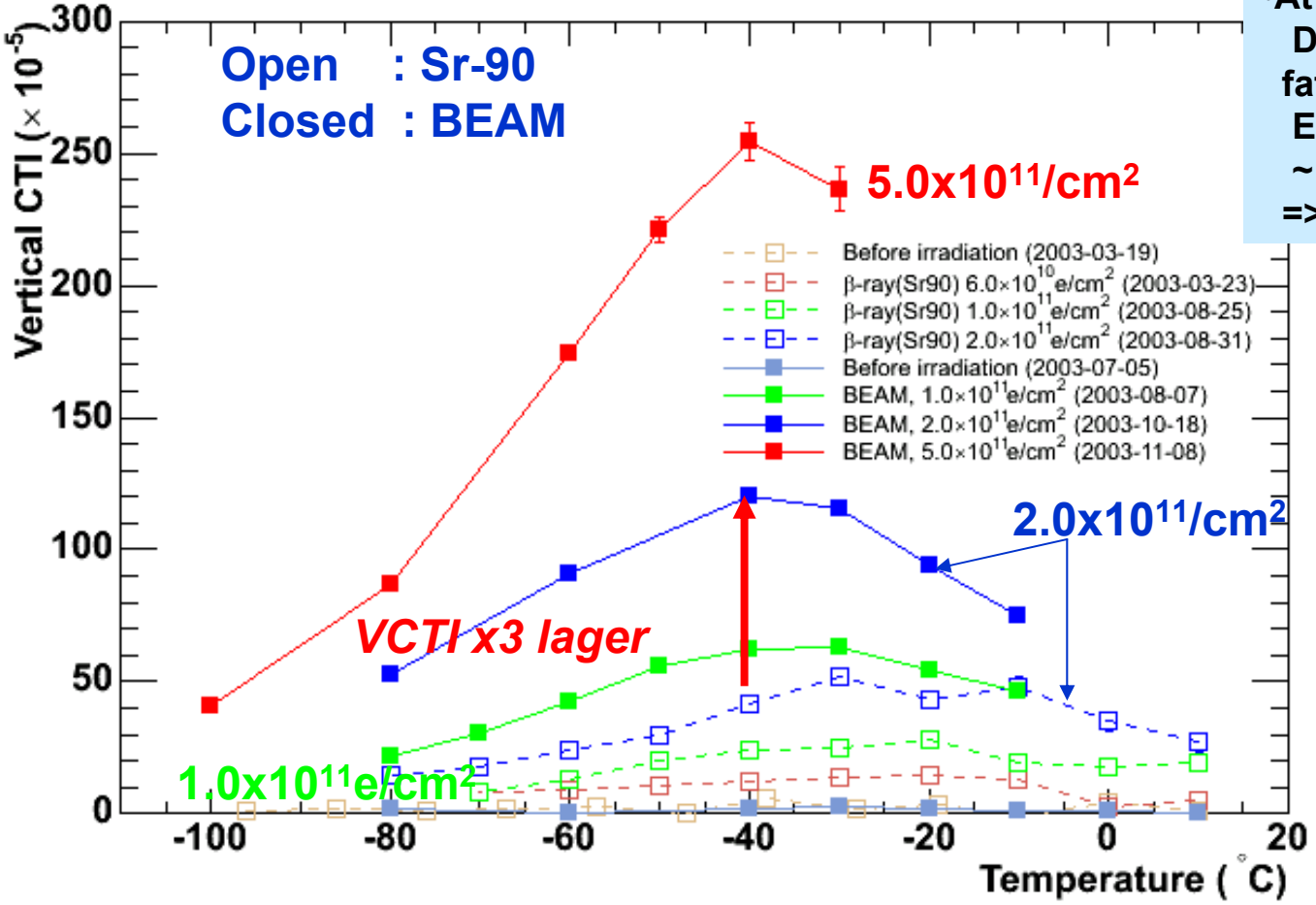


1 year operation gives $1.5 \times 10^{11}/cm^2$

CTI caused by the High Energy Electron (more than 10 MeV) should be studied.

Charge Transfer Inefficiency

S5466 HPK CCDs had been irradiated by 150MeV electrons at LNS Tohoku Univ.



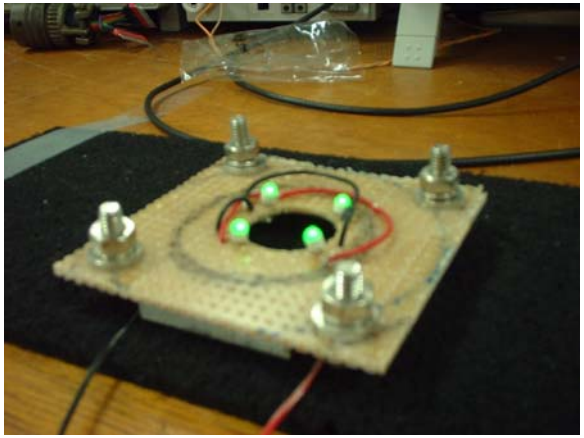
- **VCTI for beam irradiation is 3 times lager than that for Sr90 irradiation.**
- **At above -40C,**
  Dark current works as fat zero charge.
  Emission time become shorter ~ ms.
  => Suppression of CTI.

250kpix/s
R/O cycle 2s
w/o bias/clocking.
at room temp.

The effect in VCTI is not larger than the theoretical prediction.
But actually, high energy charged particle gives more damage to CCD.

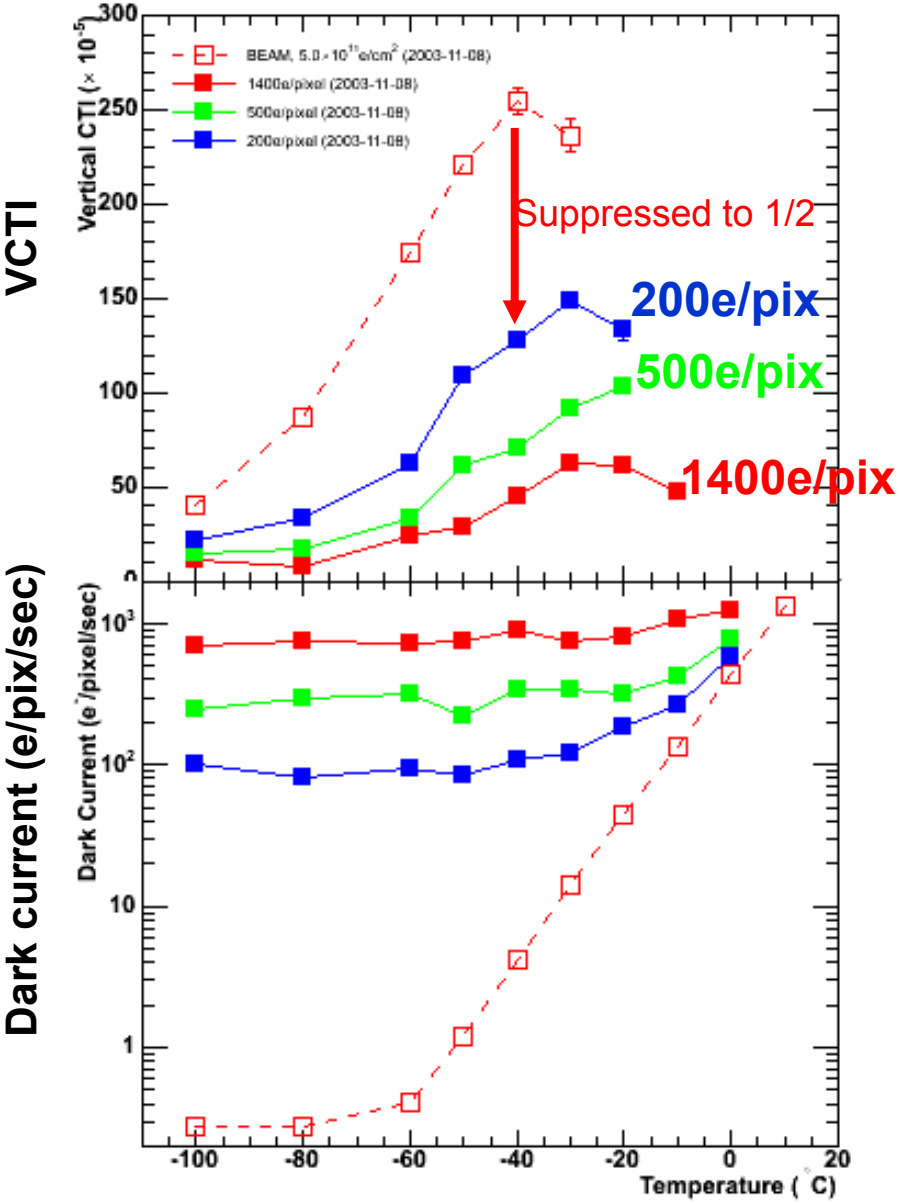
Fat zero injection

CCDs: High energy electron irradiated sample ($5x10^{11}e/cm^2$).



LED was used for injecting the fat zero charge.
LED light makes sacrificial charge in CCD.
It fills up traps and improve the CTI.

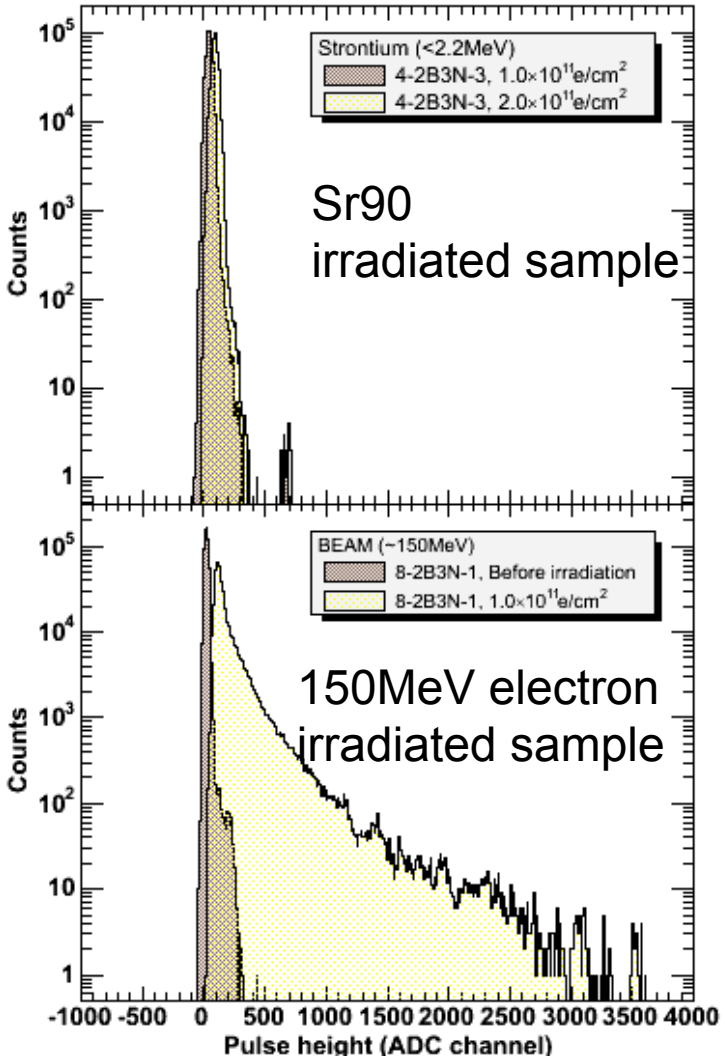
VCTI suppression by fat zero injection had been confirmed.



G.Iwai

Hot Pixels

Temp. of +10 deg,
R/O Cycle of 2 sec.



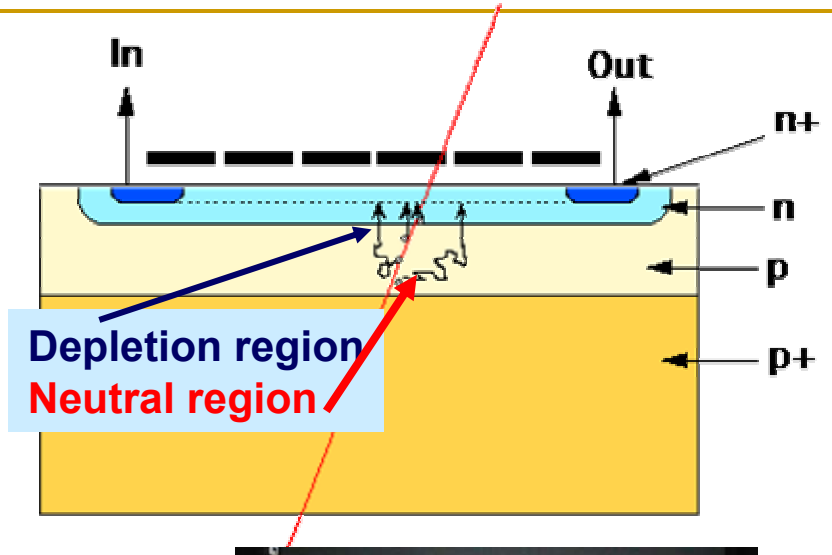
Observed only in beam irradiated CCDs.

Presumably due to cluster defects which can not be created by the low energy electrons.

G.Iwai

Diffusion study

- Diffusion of signal electrons in epitaxial layer is essential for excellent spatial resolution in CCD.
  - Charge sharing ratio improves the spatial resolution
  - Diffusion length is L~sqrt(Dt) L=20um @ t=100ns
- If accumulation time < diffusion time
  - Signal becomes an afterimage.
  - Neutral region is essential for charge sharing properies.



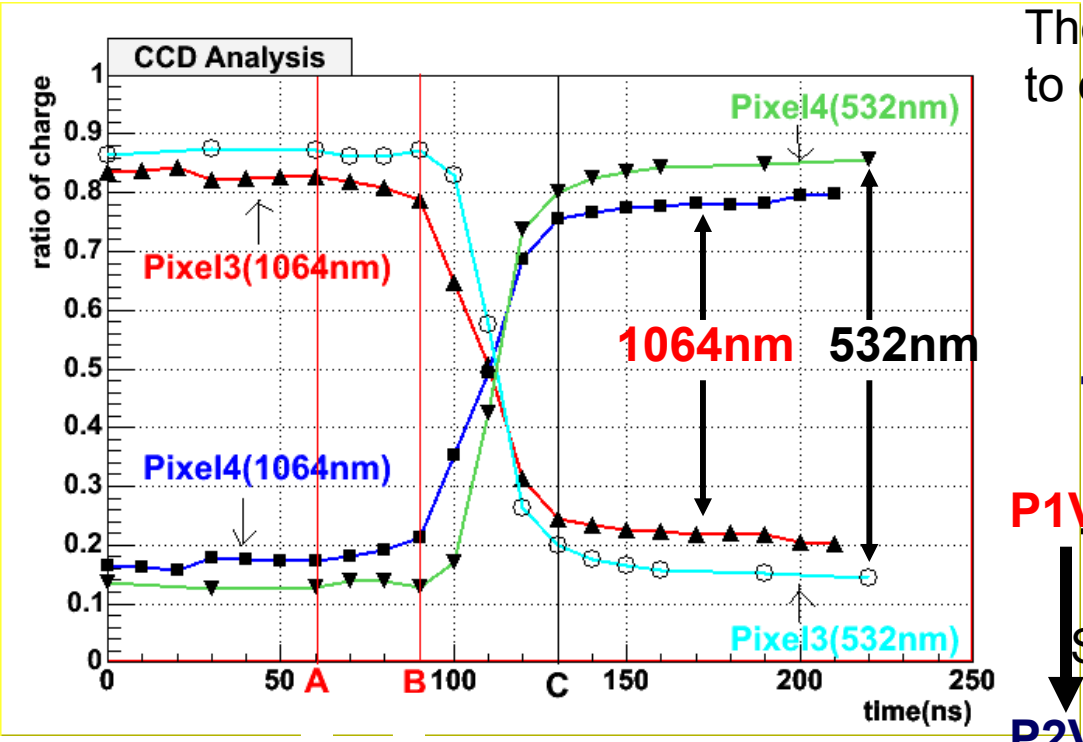
Study using Laser System

YAG Laser 1064nm/532nm
Laser fire jitter < 1ns
Laser spot at sample 4um x 4um

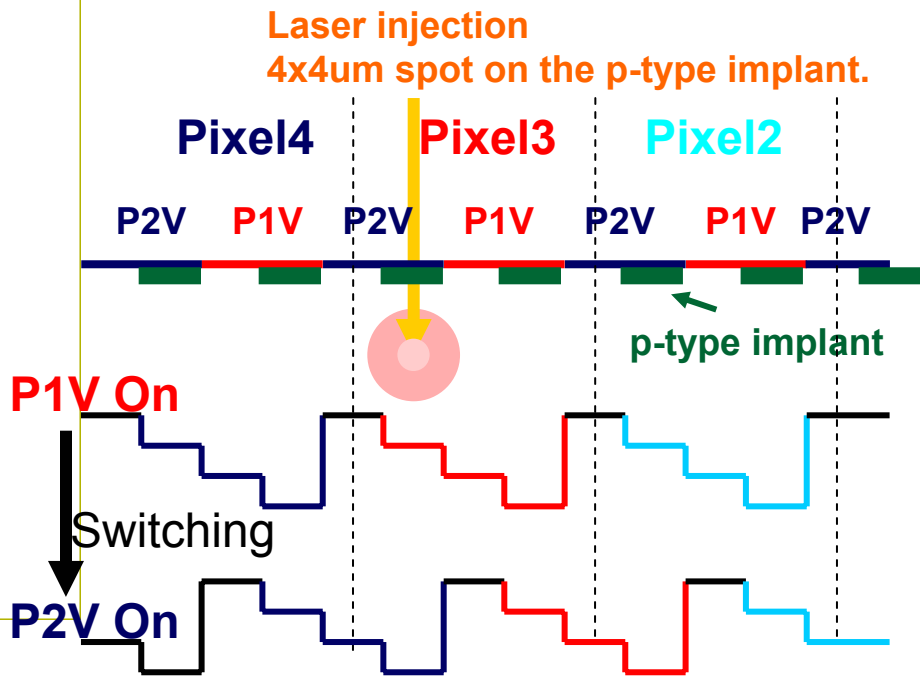
Sample CCDs
Hamamtsu S5466
Pixel pitch 24um x 24 um
Epitaxial layer 10um

Short range time scanning around pixel switching

Comparison of 1064nm with 532nm laser signal.



The timing of laser injection was delayed to estimate signal collection time.



Signal induced by 1064nm laser is more affected by the diffusion in the neutral region. It takes more time for pixel switching. It is demonstrated in the figure.

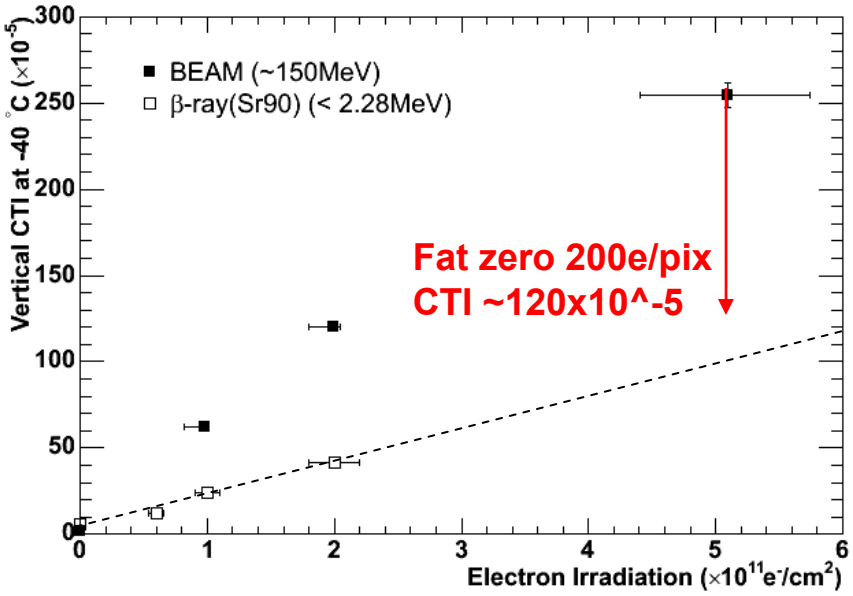
For more precise analysis, the study using the faster readout CCDs is desireble!!

H.Takayama

Summary

Radiation damage

- CTI in 150 MeV electron irradiation had been studied.
- VCTI for beam irradiated CCDs increases about 3 times than Sr-90 sample.
  At -40 C, 2×10^{11}e/cm^2, VCTI~1.2×10^{-3}
- Fat zero injection using LED was demonstrated.
  VCTI is improved to a half of normal operation,
  by 200e/pix fat zero injection.
- The other choice of improvements will be possible,
  Notch structure, Faster readout before trapping.

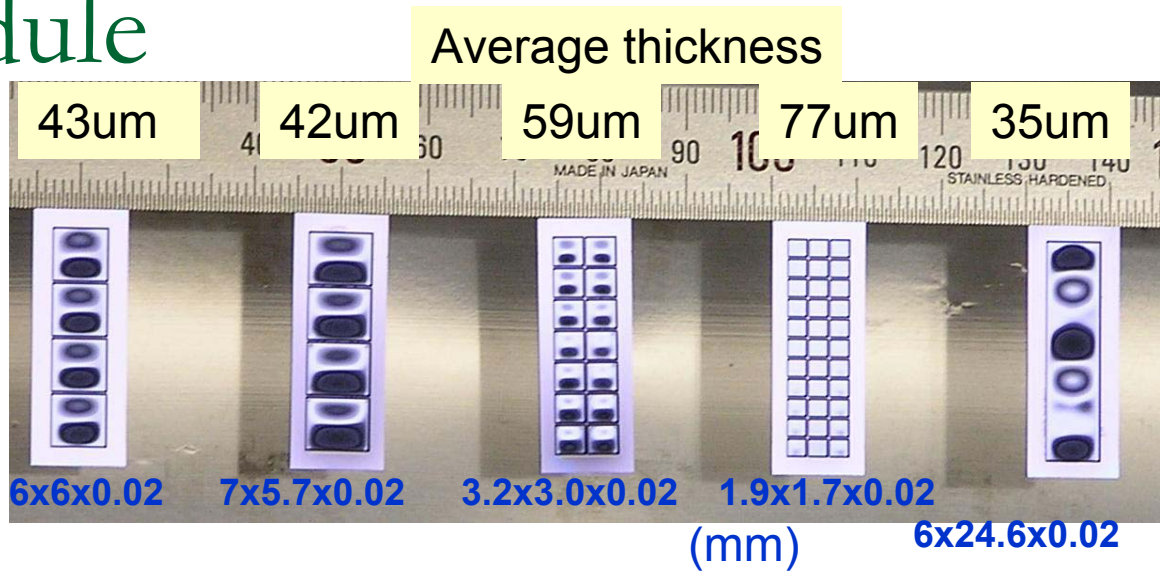


Diffusion study

- Charge diffusion study has been started using YAG-Laser system
- Delay of switching due to the signal collection time had been observed.
  This is supposed to be the effect of diffused electrons from neutral region.
- Quantitative measurement and analysis will be necessary at faster readout operating condition.

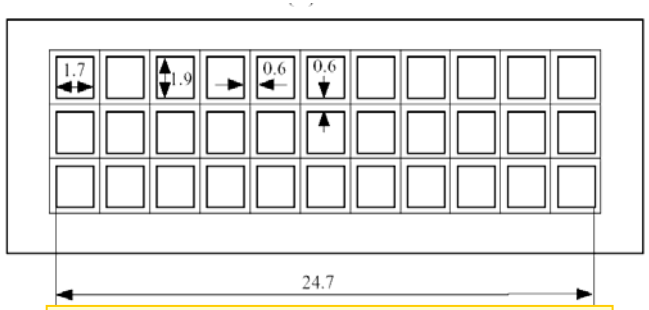
Plan and Schedule

- Thin wafer
  - Mechanical strength
  - Electrical property
  - Physics impact
- Radiation damage
  - Effect of faster readout
  - Spatial resolution (Laser)
  - Thin wafer stability (S7960)



New thin wafers based S7960 Hamamtsu K.K have been delivered. Those are partially thinned with supporting rims.

The fast readout DAQ for R&D is being developed and used for fast readout studies. (12bits-20MSPS)



Separated by 0.6mm rim thickness of 300um.

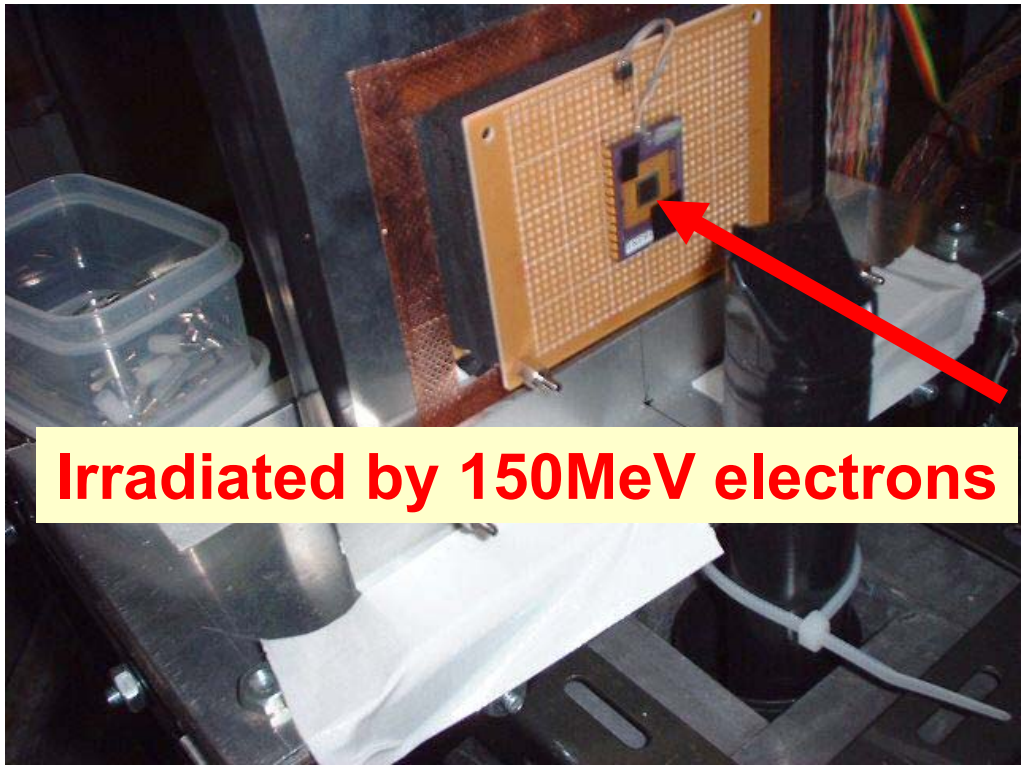
Radiation damage study (Conditions)

- Background sources
  - Incoherent e^+e^- pair – Beam beam interaction
    - At R=15mm, B=4Tesla, 1.5×10^{11}hit/cm2/yr
  - Neutron – Backscattering from beam extraction line
    - ~$10^9/cm^2/yr$
- Damage in CCDs
  - Surface damage -- Increase of dark current
    - Charged layer formed on the insulator interface by the ionization particles
  - Bulk damage – increase of CTI, Hot pixels, RTS etc.
    - Trapping centers formed in the bulk by non ionizing energy loss

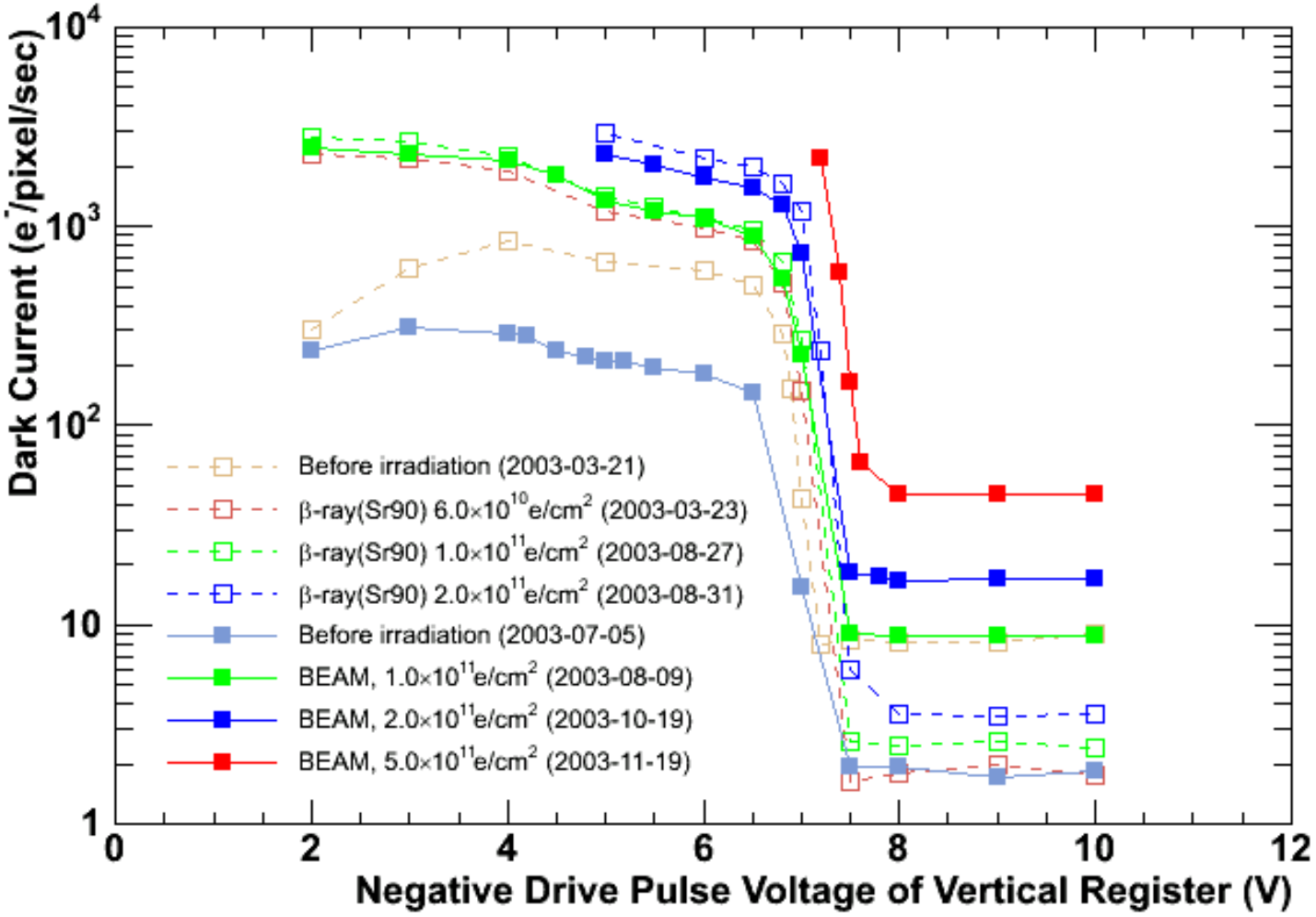
Surface damage can be treated by Flat band voltage shift, but bulk damage will be serious.

Experimental setup

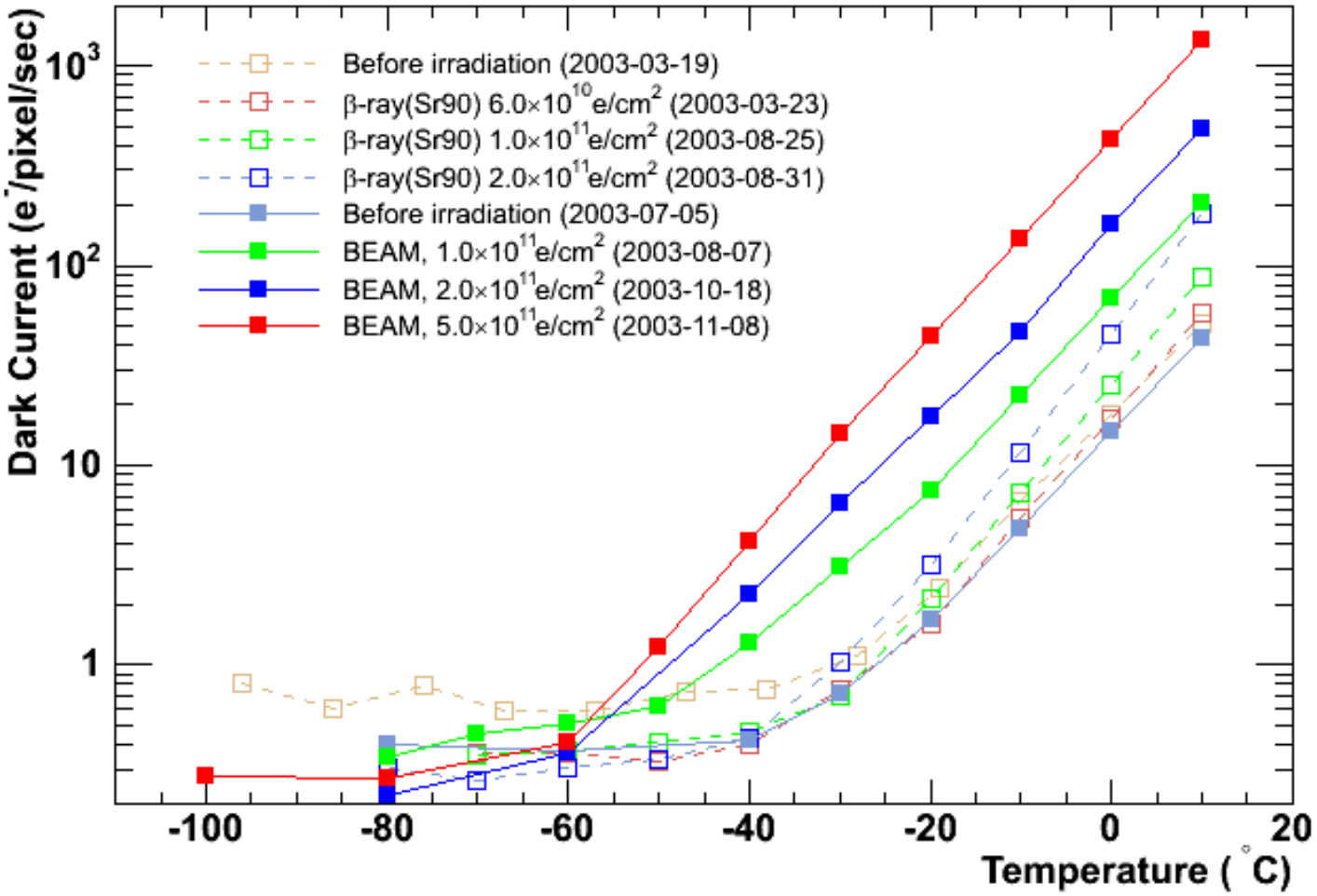
- Jul./Oct.2003:
  High energy electron irradiation test at LNS (Tohoku Univ.)
  - Hamamatsu Photonics K.K.
    - S5466
    - 2 phase CCDs
    - 256x256 pixels
    - 250kpix/s
    - R/O cycle 2sec
  - Irradiation condition
    - 150 MeV electrons
    - Room temperature
    - w/o bias/clocking
  - CTI measurement
    - Fe-55 5.9keV Mn Xray
    - using single pixel events



Flat band voltage shift

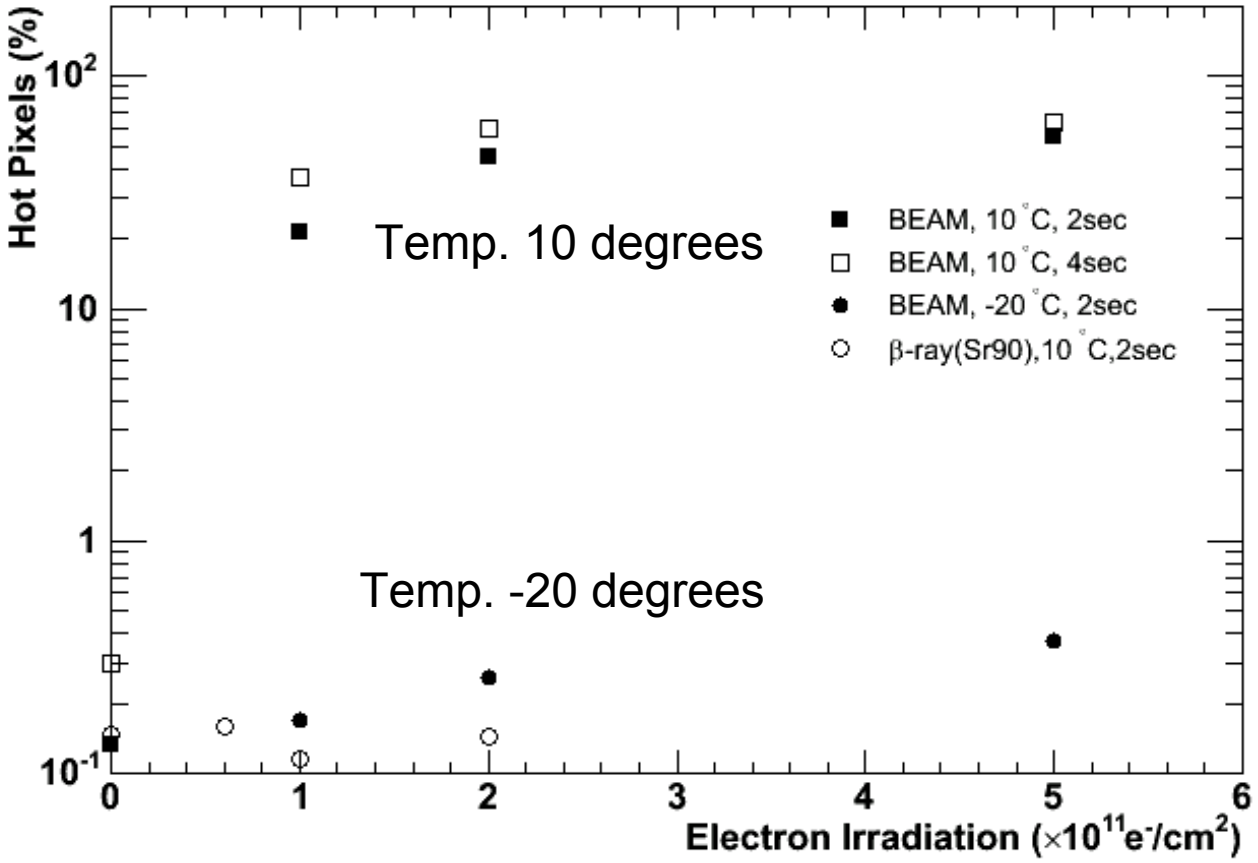


Dark current



Hot pixel

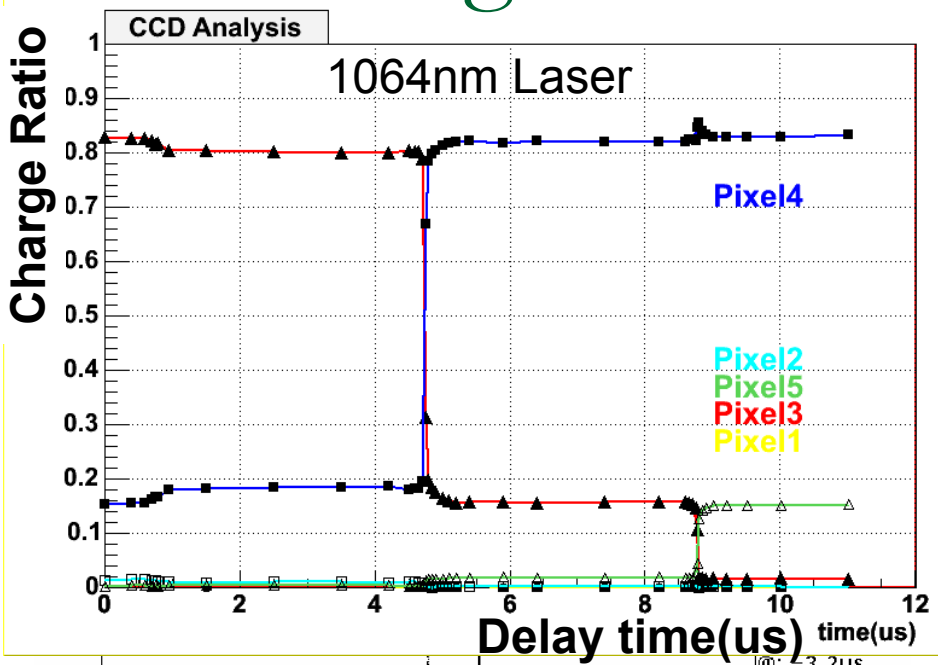
Number of hot pixels will be reduced by the cooling and the faster readout cycle.



By cooling to -20 degrees, hot pixels suppressed to < 0.5 %.

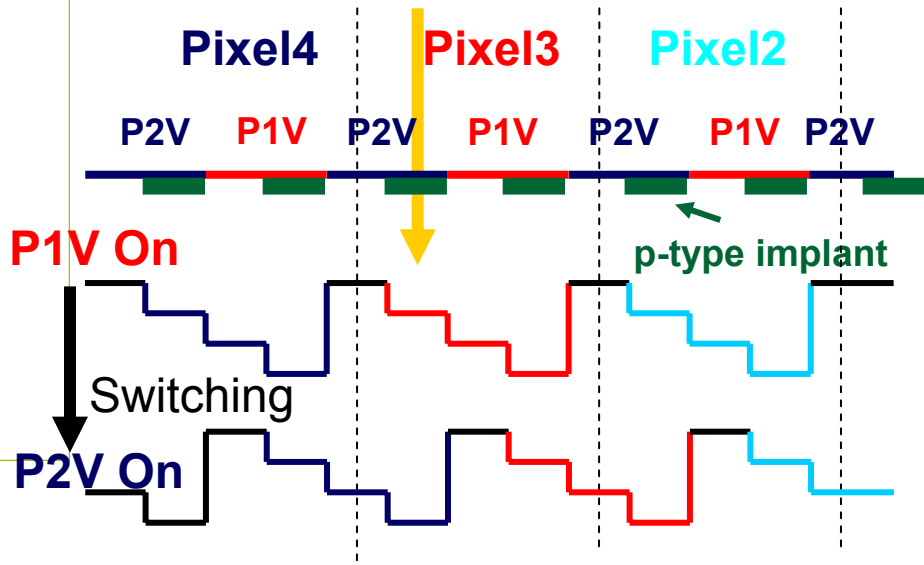
By faster readout cycle, 6.7ms, hot pixels are suppressed.

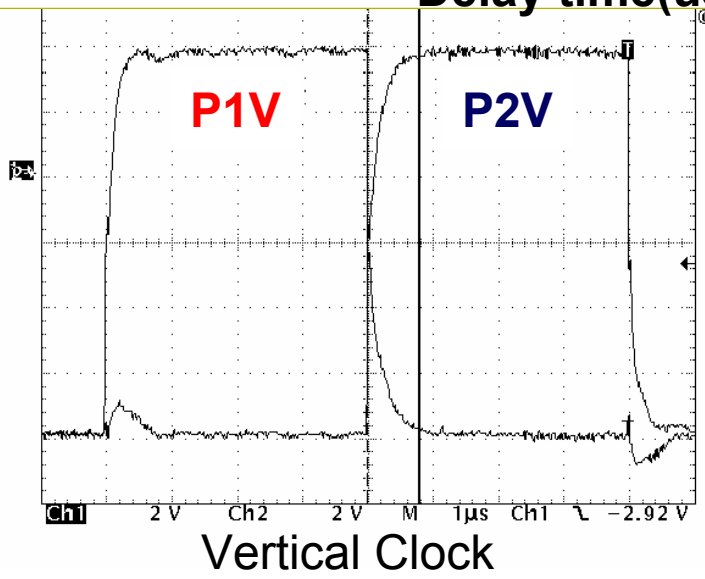
Wide range time scanning



Hamamatsu S5466
2-Phase CCD

Laser injection
4x4um spot on the p-type implant.





Vertical Clock

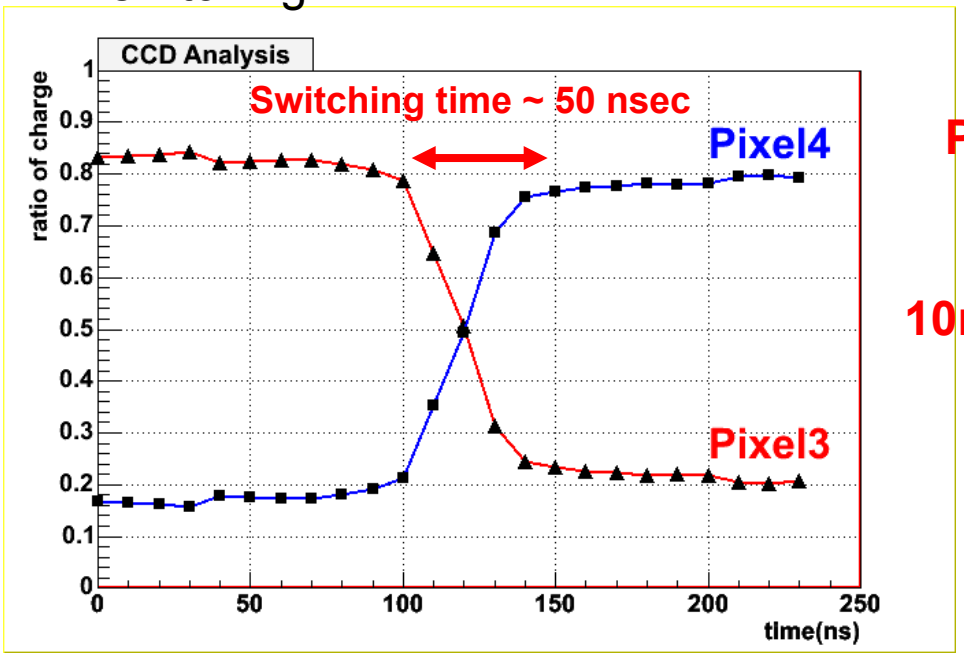
The timing of laser injection was delayed to estimate signal collection time.

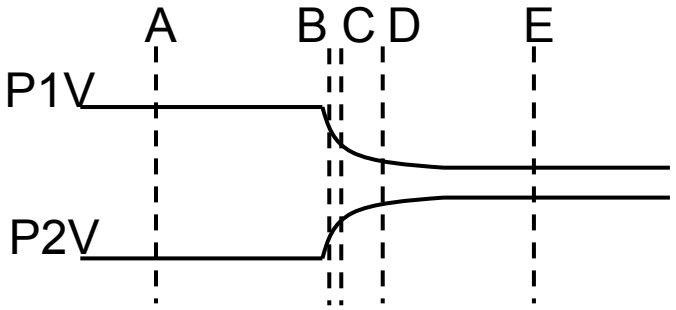
Result of wide range timing scanning follows vertical clock signatures.

H.Takayama

Short range timing

Short range scanning around P1V/P2V switching.





P1V-P2V switching done in 10ns,
but charge switching needs 50ns.
This will be explained by an afterimage.