

CCD Radiation Damage Studies

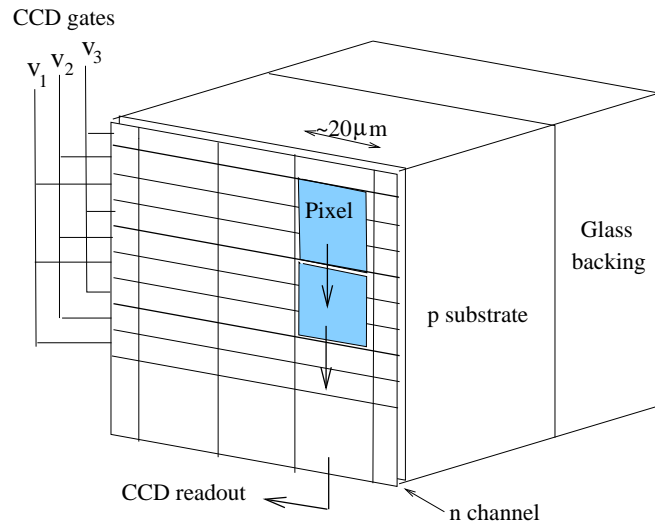


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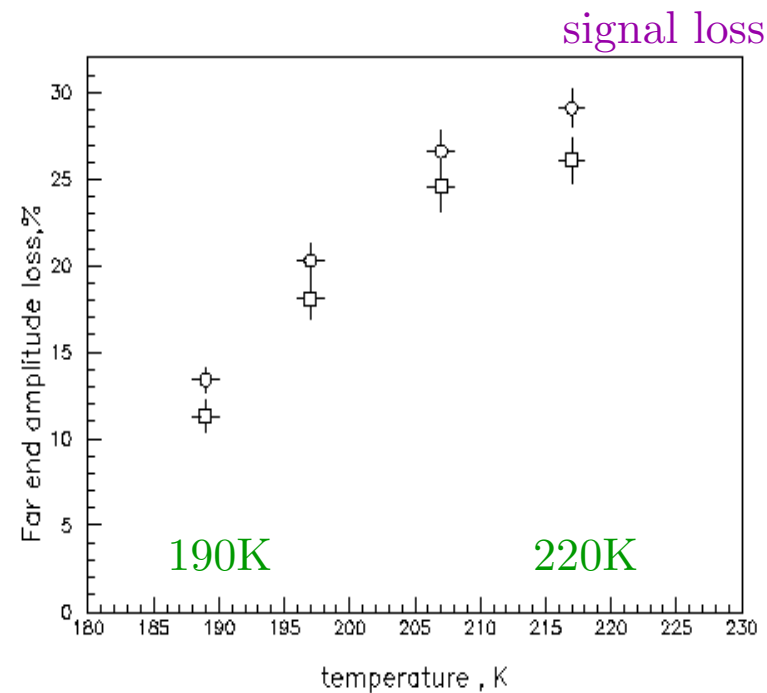
Outline:

- Introduction
- Repeating 1999 year study
- Irradiation of CCD with electrons
- Measurement of CTI and trap/pixel distribution
- Conclusions
- Plans



CCD is proposed as vertex detector for next linear collider. It has excellent space resolution ($\sim 4\mu\text{m}$) and is very thin ($0.4\text{-}0.1\%X_0$).

The CCD at SLD has shown an outstanding performance, but it also saw the **radiation damage** when undamped beam run through the detector.





- to predict the radiation damage of a CCD in the environment of linear collider
- to verify background conditions (source of radiation) at linear collider by studying **SLD VXD3** CCD
- to minimize impact of radiation damage on the detector operation

It is very important to understand (quantitatively and qualitatively) the effects from radiation by different type of particles (neutrons, electrons).

- to understand what kind of traps are created :
 - cluster of traps or single traps per pixel
 - nature of trap (VO, V₂O, V₂, etc; acceptors or donors)
 - charge retention time by traps (depends on trap sort)
- to measure the charge transfer inefficiency (CTI) due to damage
- to find out if can traps be annealed



Analysis of the different CCDs:
irradiated with neutrons, irradiated with electrons, CCD from SLD VXD3

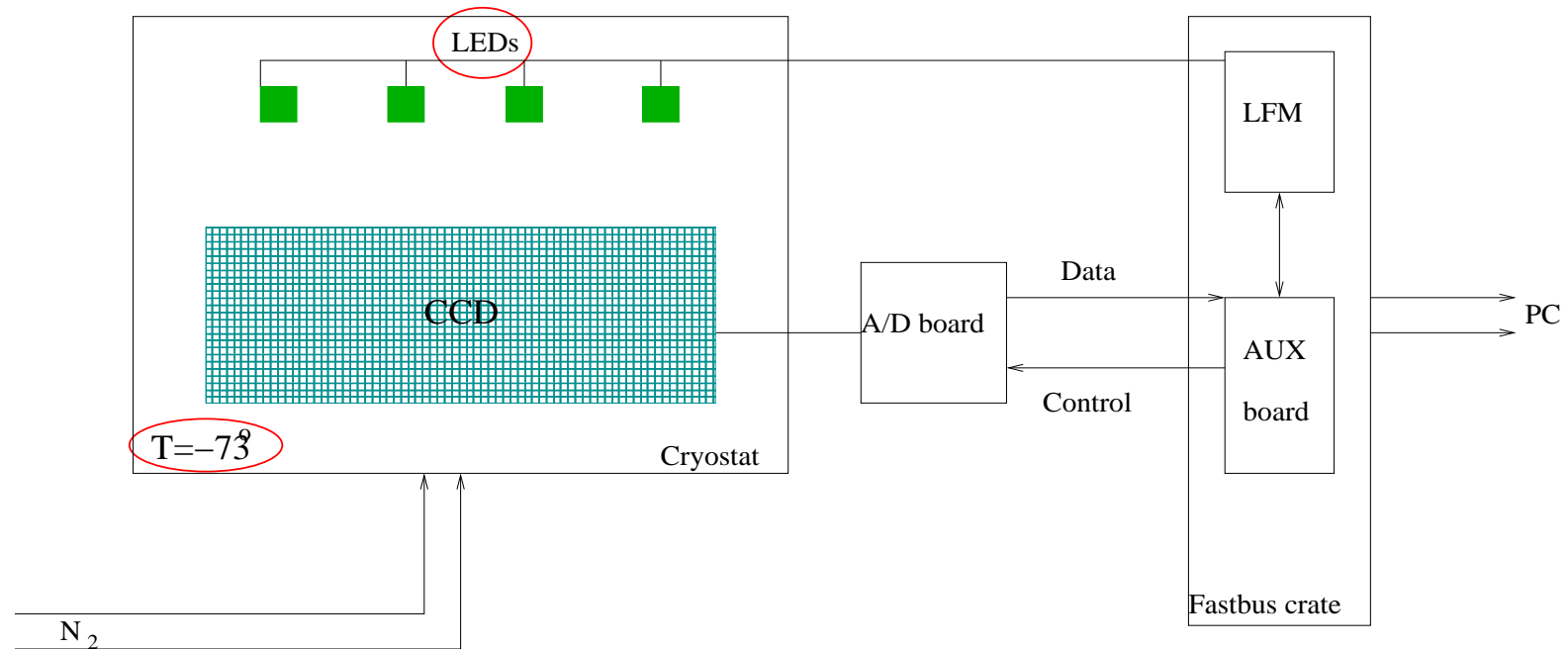
- the distribution of number of traps per pixel
- the space distribution of damaged pixel (to study background conditions at SLD)
- the charge transfer inefficiency
- the charge retention time by traps and its temperature dependence
- the temperature and speed of damage annealing

See IEEE Trans. Nucl. Sci NS-47 (2000) 1898

for results on radiation damage by $5 \cdot 10^9$ neutrons/cm².

This talk is concentrated on the work on radiation damage by 10^{12} electrons/cm².

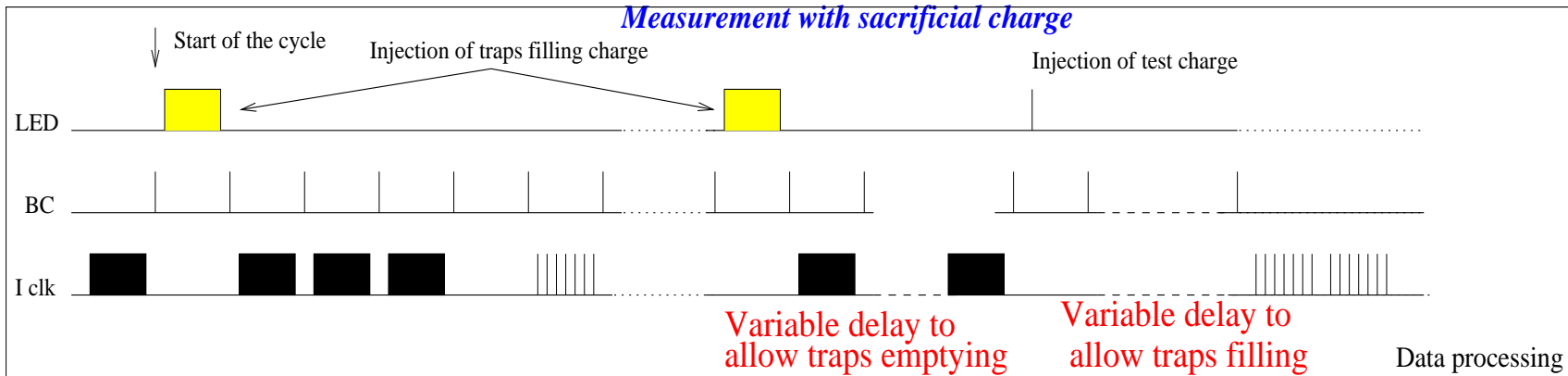
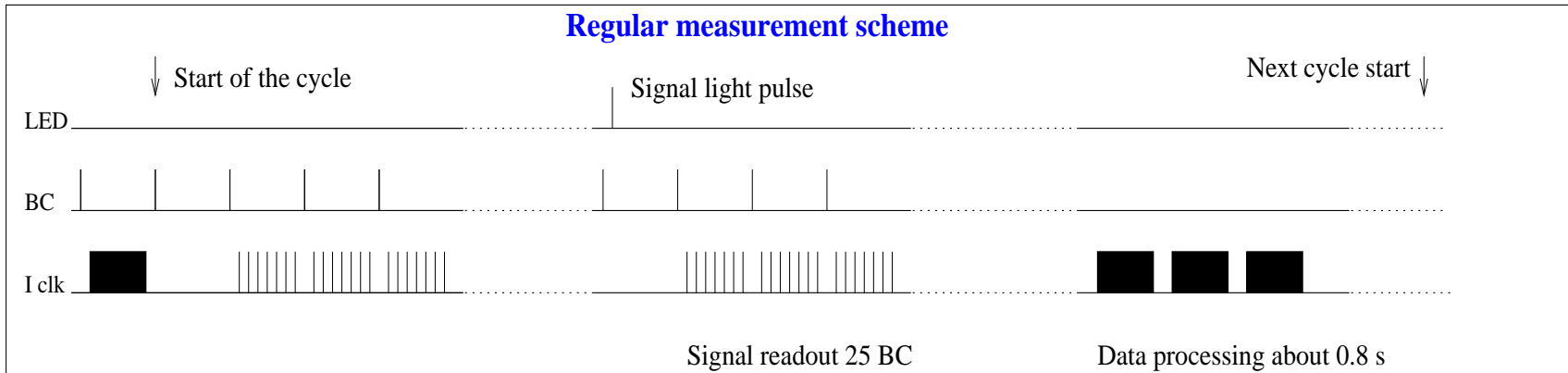
Next workshop - analysis of the SLD VXD3



Two types of LED were used :

- “Uniform” light source which flashes the complete CCD surface uniformly. The average signal intensity is about 25-30 electrons/pixel
- “Narrow line” source which flashes only few pixels per column. The average signal intensity is 100 times larger.

Timing Diagram of the test

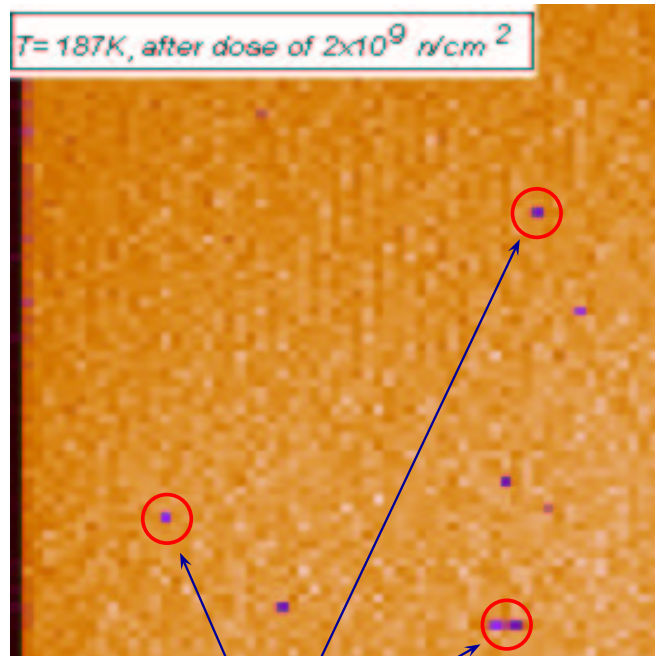


Example: CCD Image with Uniform Light

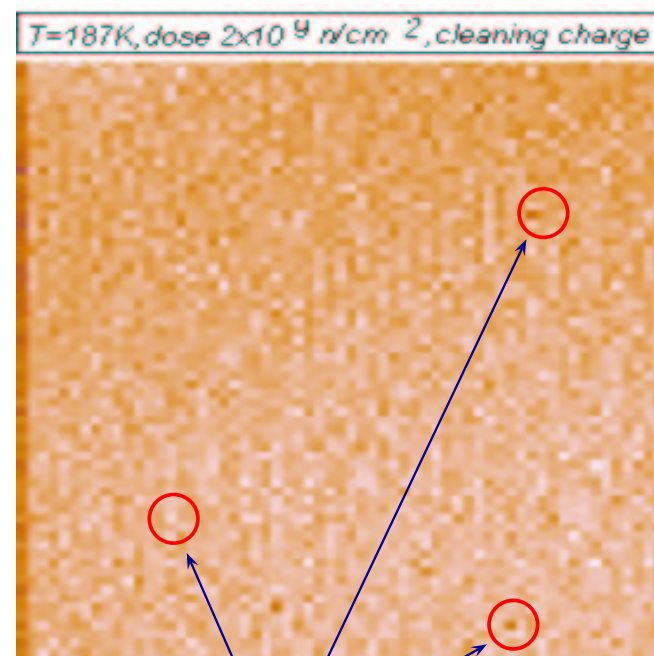


Each pixel is clearly identified

Varying delay between sacrificial light and signal one could have all traps filled or empty



traps



traps are filled - no signal lost

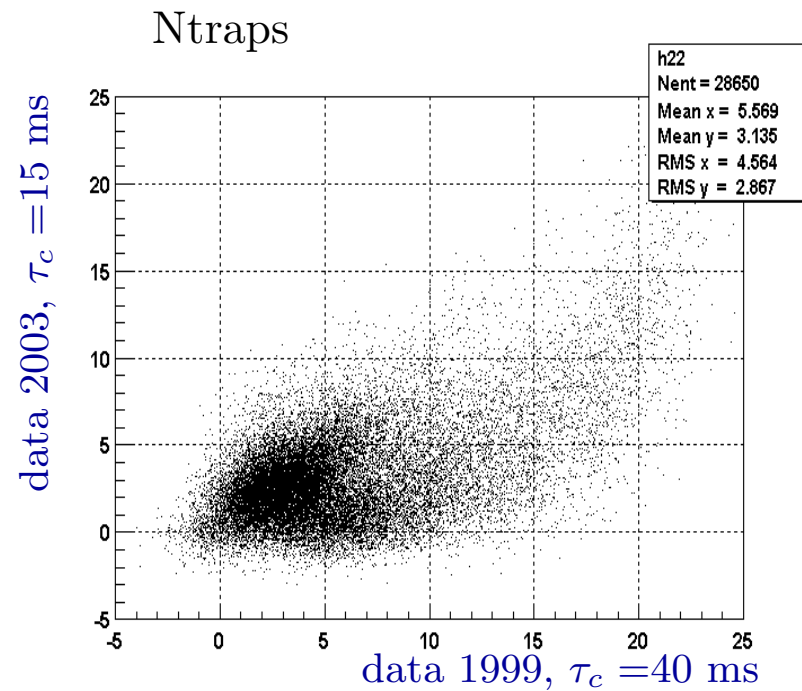
shown in 1999 year studies



Changing the delay between signal injection and start of read out from 40 ms to 15 ms showed that the

filling time τ_c is of the order of tens ms!

which contradicts to the expectation that τ_c is of the order of ns (C. Damerrel, RAL-P-95-008)



First comparison 2003 vs 1999 - looks like the traps have annealed.

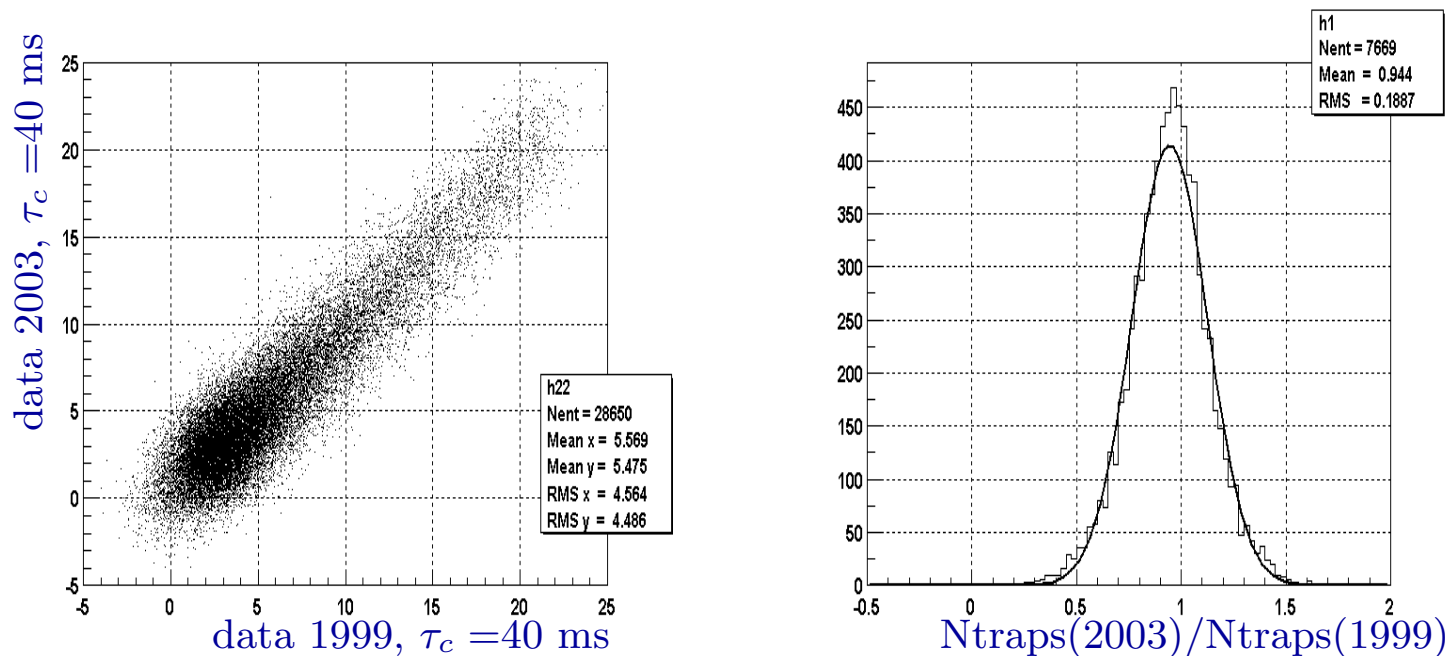
but data 2003 with $\tau_c = 40$ ms showed
that just more time is needed to trap electrons





Comparison of the 1999 and 2003 data before irradiation with electrons (collected under exactly the same conditions) shows same amount of traps in the same pixels.

The expectation that traps will anneal during 1 year at room temperature is not confirmed.





During last month we have

irradiated the CCD with about $10^{12}e^-/\text{cm}^2$ of 60 MeV energy

at NLCTA test beam (SLAC) and continued the analysis of the traps :

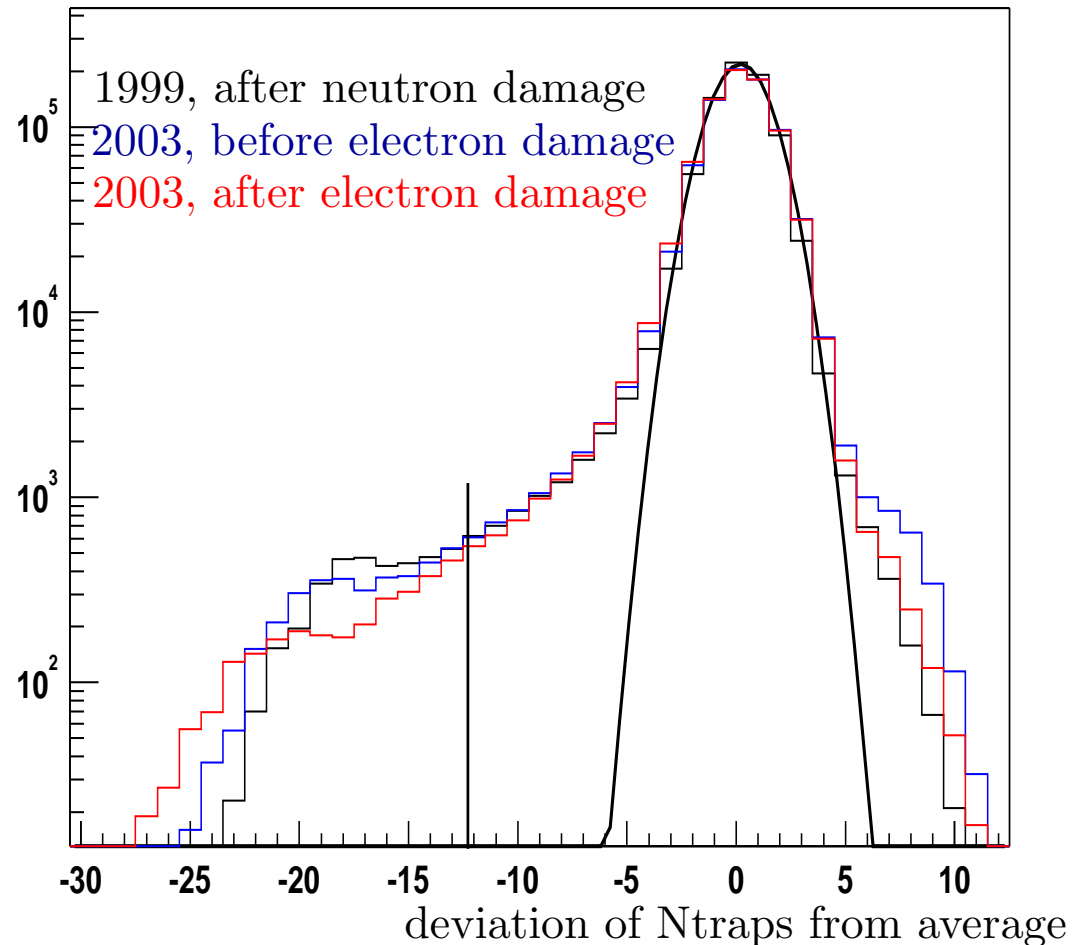
- using the “flat” uniform light source compare **number of traps** per pixel before and after irradiation
- using the “narrow line” light source compare the **charge transfer inefficiency** before and after irradiation

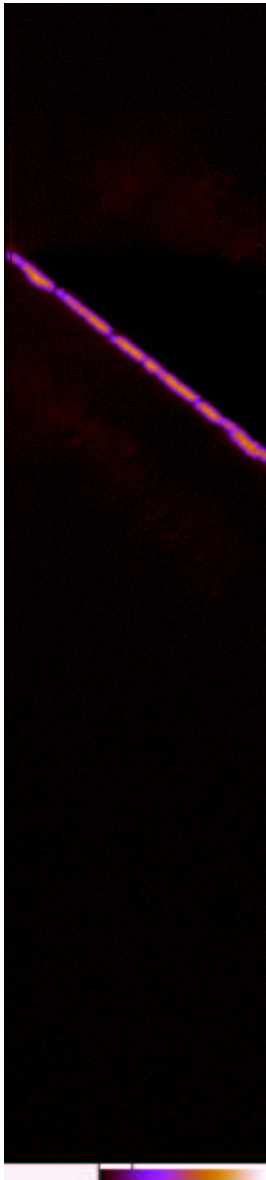


n traps/ pixel

However, **no** new pixel with a lot of **new traps** are observed - electron damage does not cause trap clusters (as expected). Some old clusters of traps were annealed during irradiation of CCD by electrons.

Ntrap - Average < - 12.6	
year 1999	3552
2003 before irr.	3503
2003 after irr.	2754





The **CTI** is measured with the **narrow line light**. The signal has large intensity, but travels through about 1500 pixels during read-out.

The amplitudes of the CCD output at 2 different conditions are compared :

- a* with minimum delay between “sacrificial” charge and signal light pulse (almost all traps are filled - no signal loss)
- b* with large (~ 1 s) delay between “sacrificial” charge and signal light pulse (almost all traps are empty - cause signal loss)

Average CTI = $1 - b/a$

Before irradiation with electrons $CTI_{before} = 14.4\%$;

After irradiation with electrons $CTI_{after} = 52.9\%$

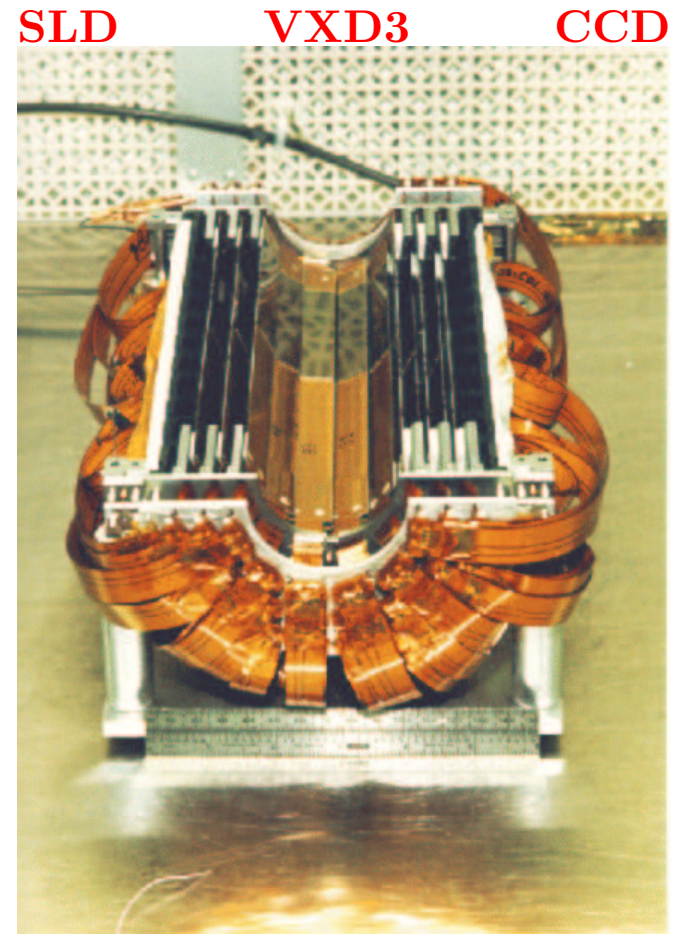
Irradiation with $10^{12}e^-/\text{cm}^2$ results in large CTI

The dose is to be estimated more precise



The radiation damage by $5 \cdot 10^9$ neutrons /cm² resulted in clusters of traps. The traps created during irradiation with electrons ($\sim 10^{12} e^- / \text{cm}^2$) distributed uniformly over the surface of the CCD but cause large charge transfer inefficiency.

That should help us to distinguish between 2 types of the radiation in analysis of SLD VXD3 and verify the background condition at the linear collider.





- After 4 years the CCD still had the same traps - **no significant annealing at room temperature** is observed.
- **Traps filling** with signal charge takes **noticeable time** - much larger than the time signal spend in each pixel. We expect that the increased readout speed will lead to decrease of charge transfer inefficiency. One could, however, start to see CTI from shallow traps at very high readout speed (see http://www.hep.lancs.ac.uk/lcfi/talk_Aachen.pdf)
- The **large CTI** is observed **after electron irradiation** damage. The new traps, however, are distributed uniformly over CCD and do not combine clusters. This suggests that we should be able to distinguish the radiation damage by neutrons and electrons analyzing the SLD VXD3 CCD and to understand damage observed there



- Finish the analysis of the electron radiation damage. We still have spare CCD (not damaged yet) to be irradiated with electron beam at NLCTA (SLAC).
- Understand more accurately the dependence of the charge transfer inefficiency on the measurement parameters (temperature, delay between signal and sacrificial light, readout speed)
- Application of presented technique to SLD VXD3 should show the origin of the its radiation damage and clarify the background conditions at SLD. This in turn will allow to predict the radiation damage at future linear collider.
- Develop the technique to minimize the impact of the radiation on the detector operation.