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Spiegel . Stancari . Sukhanov
CDF Silicon Annealing

The Basics

- RADIATION DAMAGE: High energy particles dislocate atoms from the silicon crystal lattice.
  - Bias currents increase
  - Depletion Voltage changes
  - S/N decreases (S decreases and N increases)
- ANNEALING: Some of these dislocated atoms find their original home again
  - Rate is effectively 0 below -5 C, and increases rapidly with temperature.

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Limits the lifetime of most HEP silicon detectors

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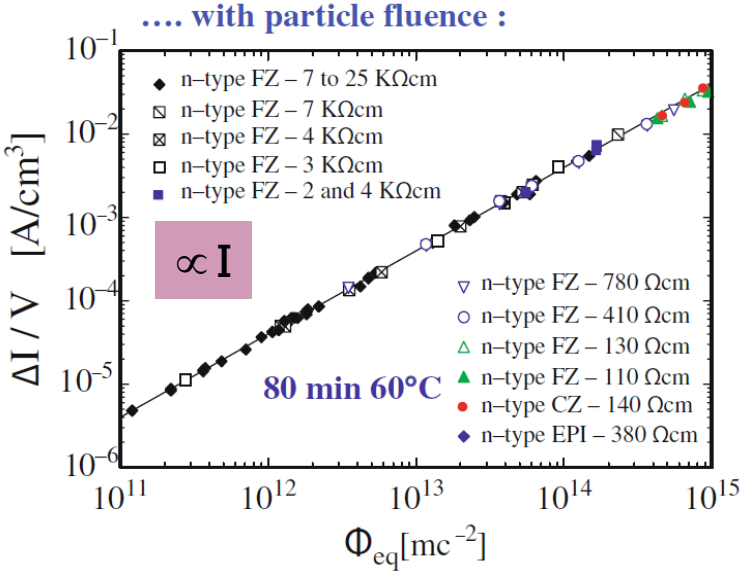
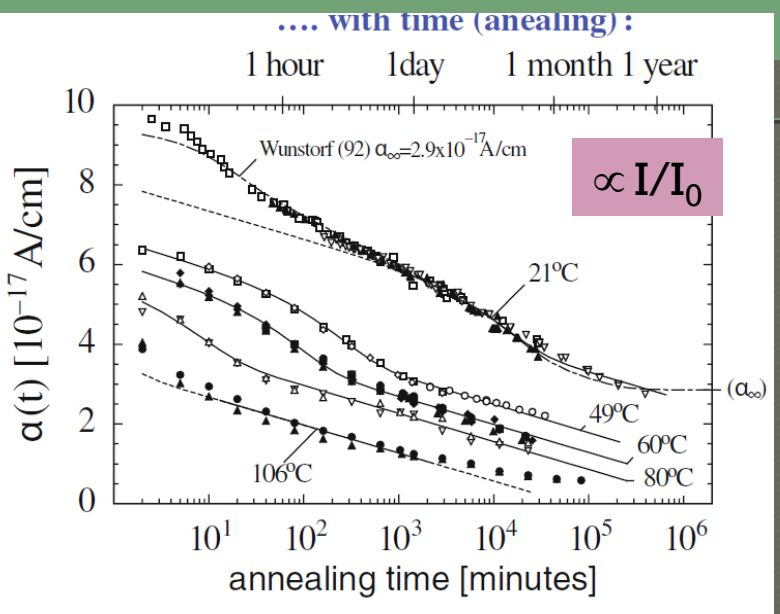
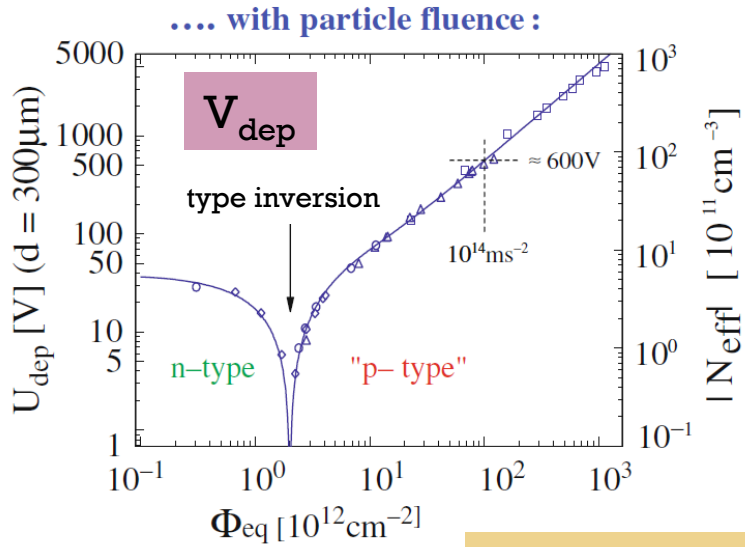
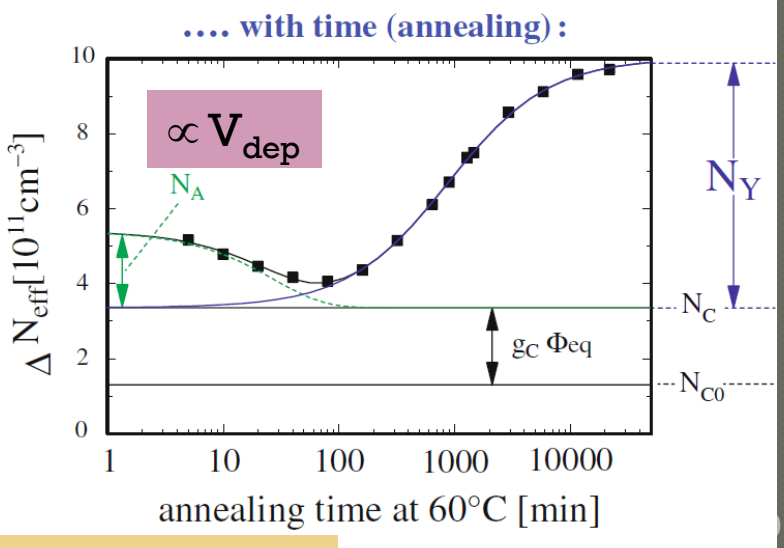
  - Rate is effectively 0 below -5 C, and increases rapidly with temperature.

What happens in a nutshell





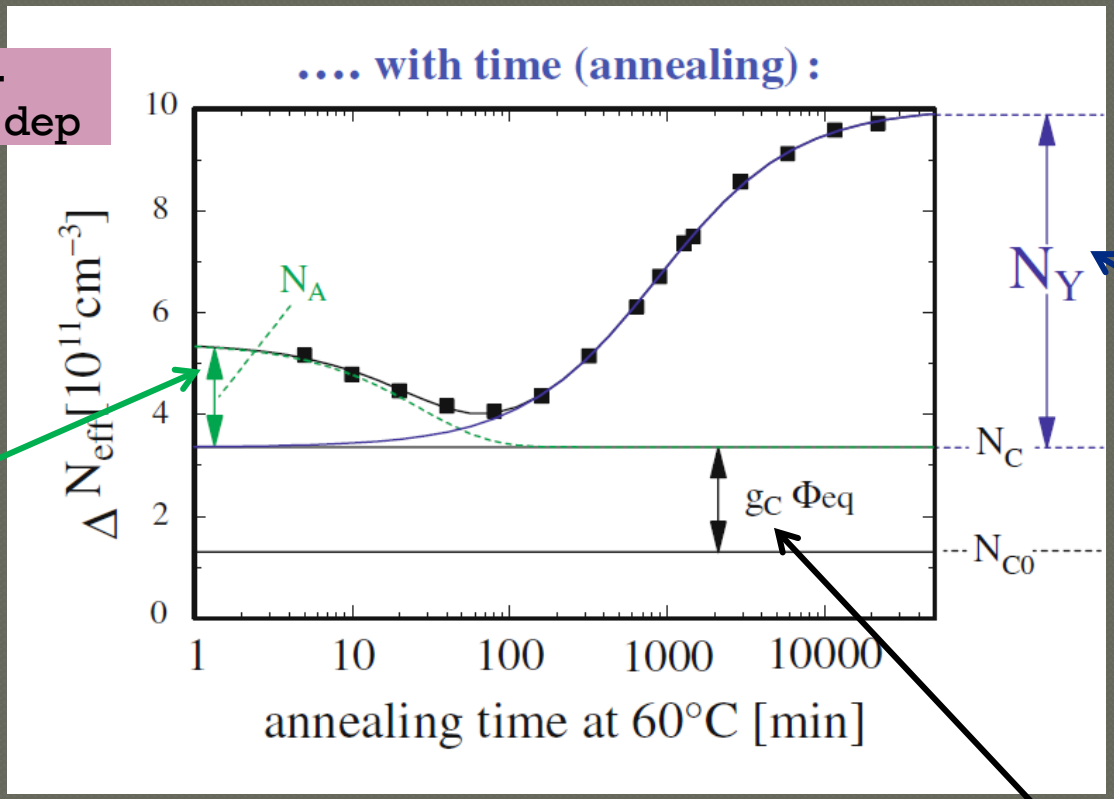




From M. Moll and R. Wunstorf and others

Annealing Model

$\propto V_{dep}$



"Good" annealing component

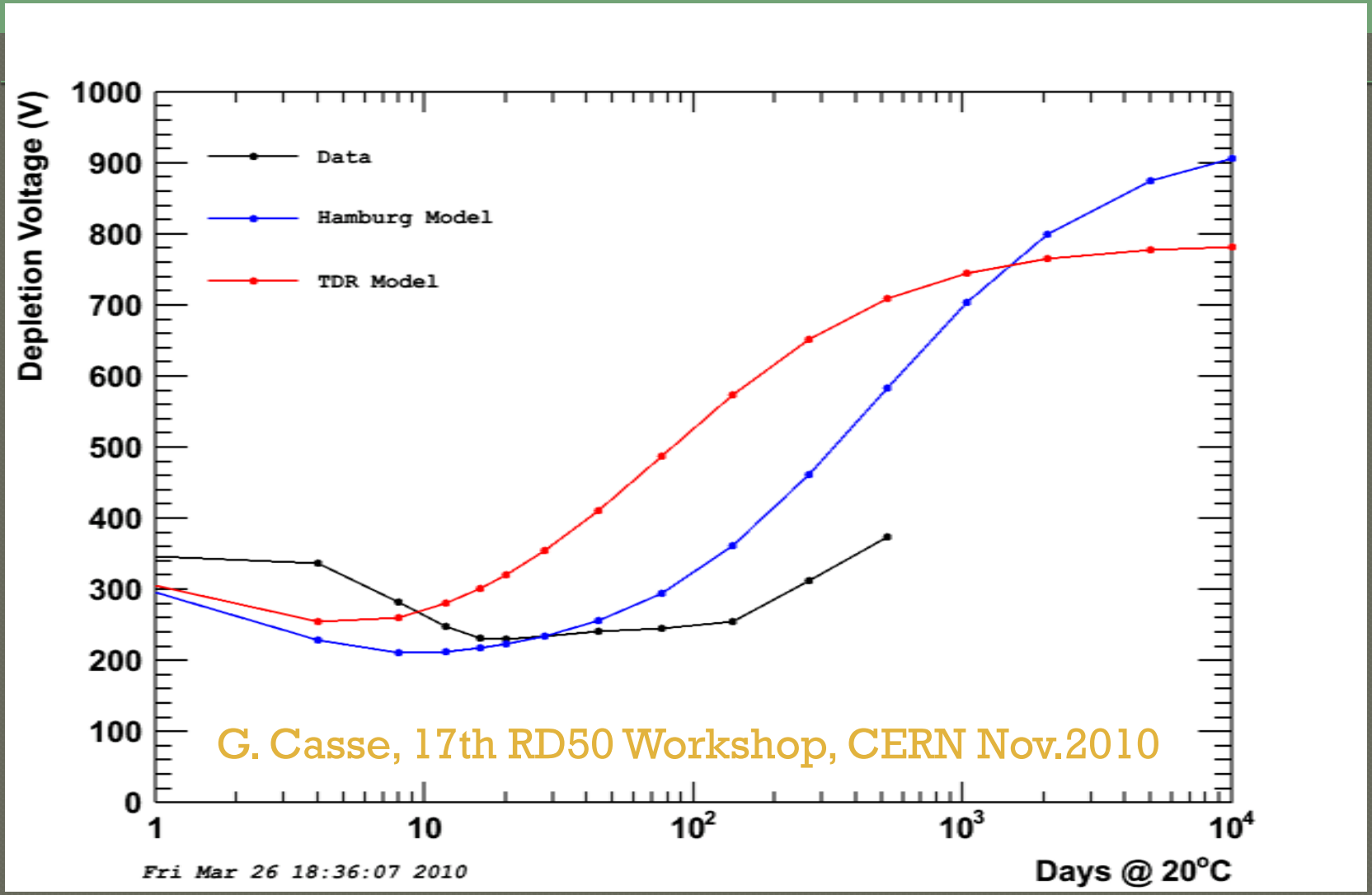
"Bad" or reverse annealing component

Stable damage component

Why study annealing?

- To understand the radiation damage in the CDF silicon detectors
  - Is low irradiation over a long period of time the same as intense irradiation over a short period of time ???????
  - Some annealing happened during run 2. Final measurements of radiation damage need to account for this
- LHC experiments warm up their detectors periodically, using the beneficial component of annealing to extend the lifetime of their detector

Test Beam Data and Annealing Models

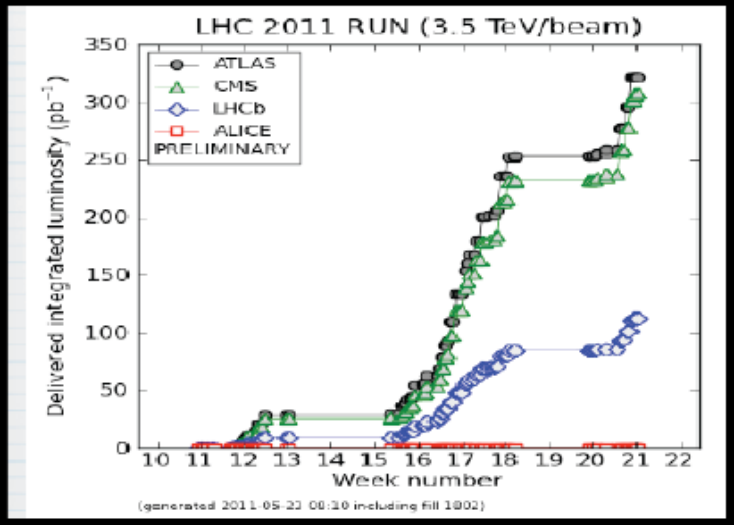


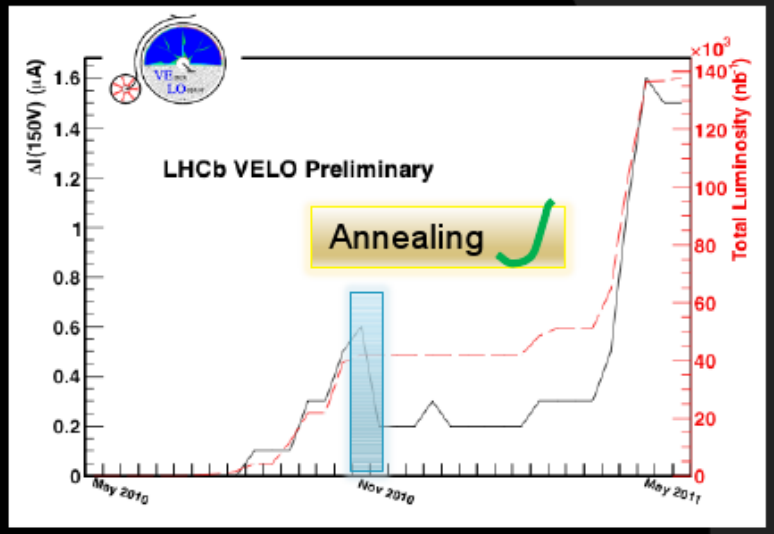
Test Beam Data and Annealing Models

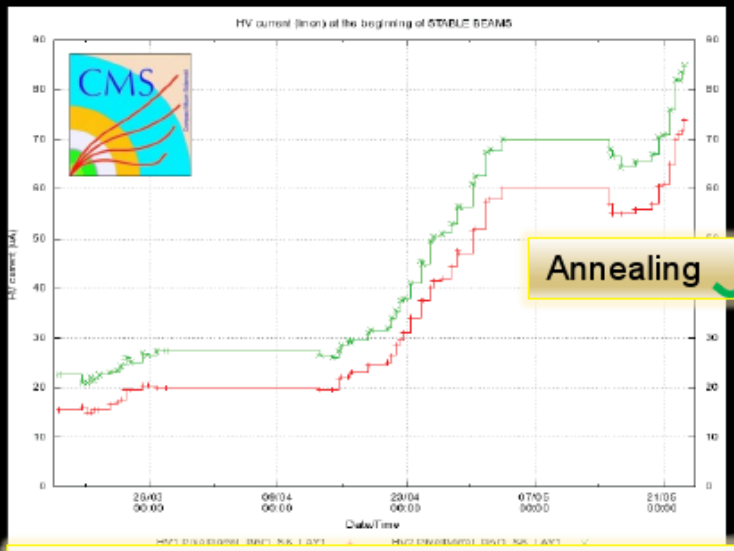
" . . . the p-in-n sensor was compared to the Hamburg model. The annealing was accelerated at 40-80 C. The comparison of the depletion voltages show there is a time mis-match which might be due to a scaling error on the temperature acceleration factor. Here's where your (CDF) measurement would help. "

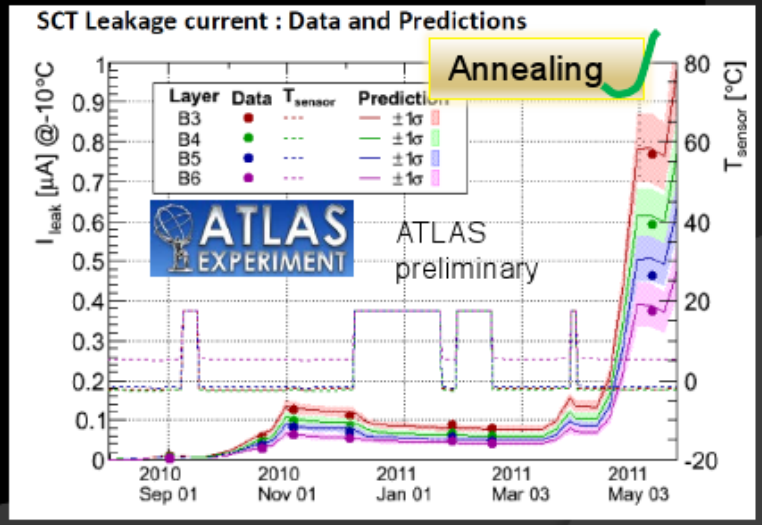
(from authors of plot on previous slide . . .)

Evolution of Sensor Currents



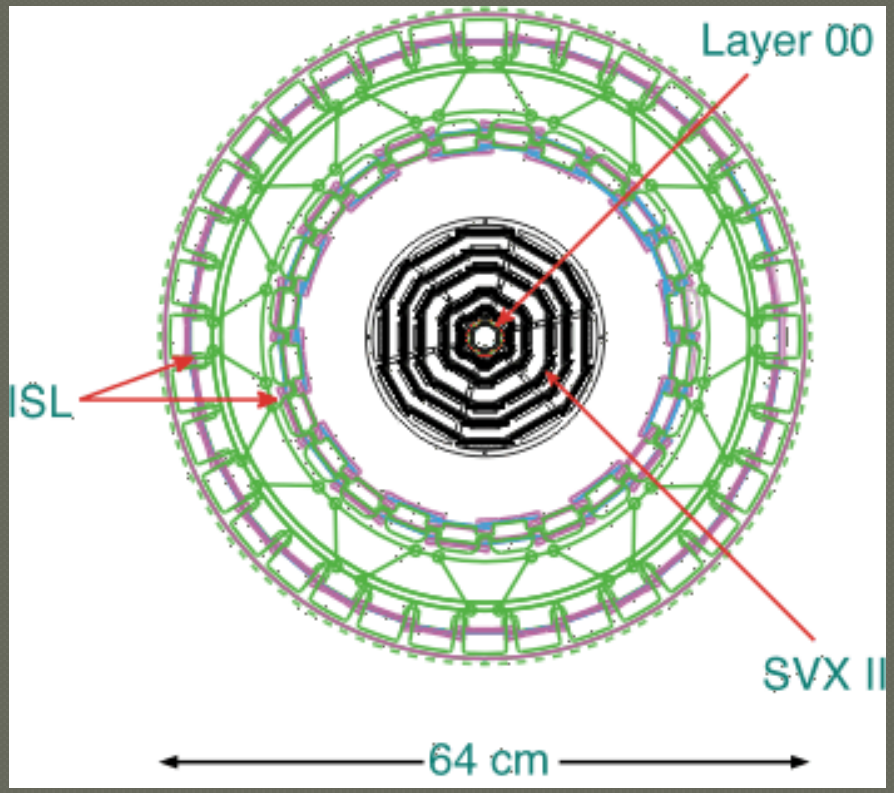


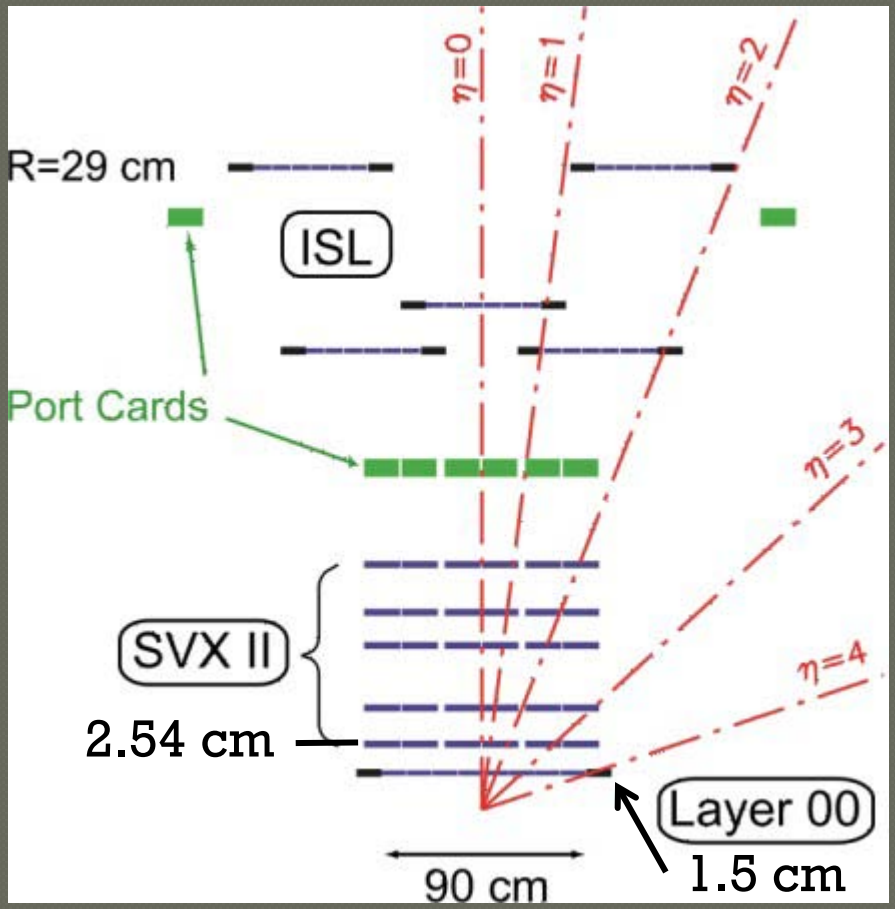




Yes, current changes and at least it qualitatively follow the delivered luminosity

CDF silicon basics





CDF history

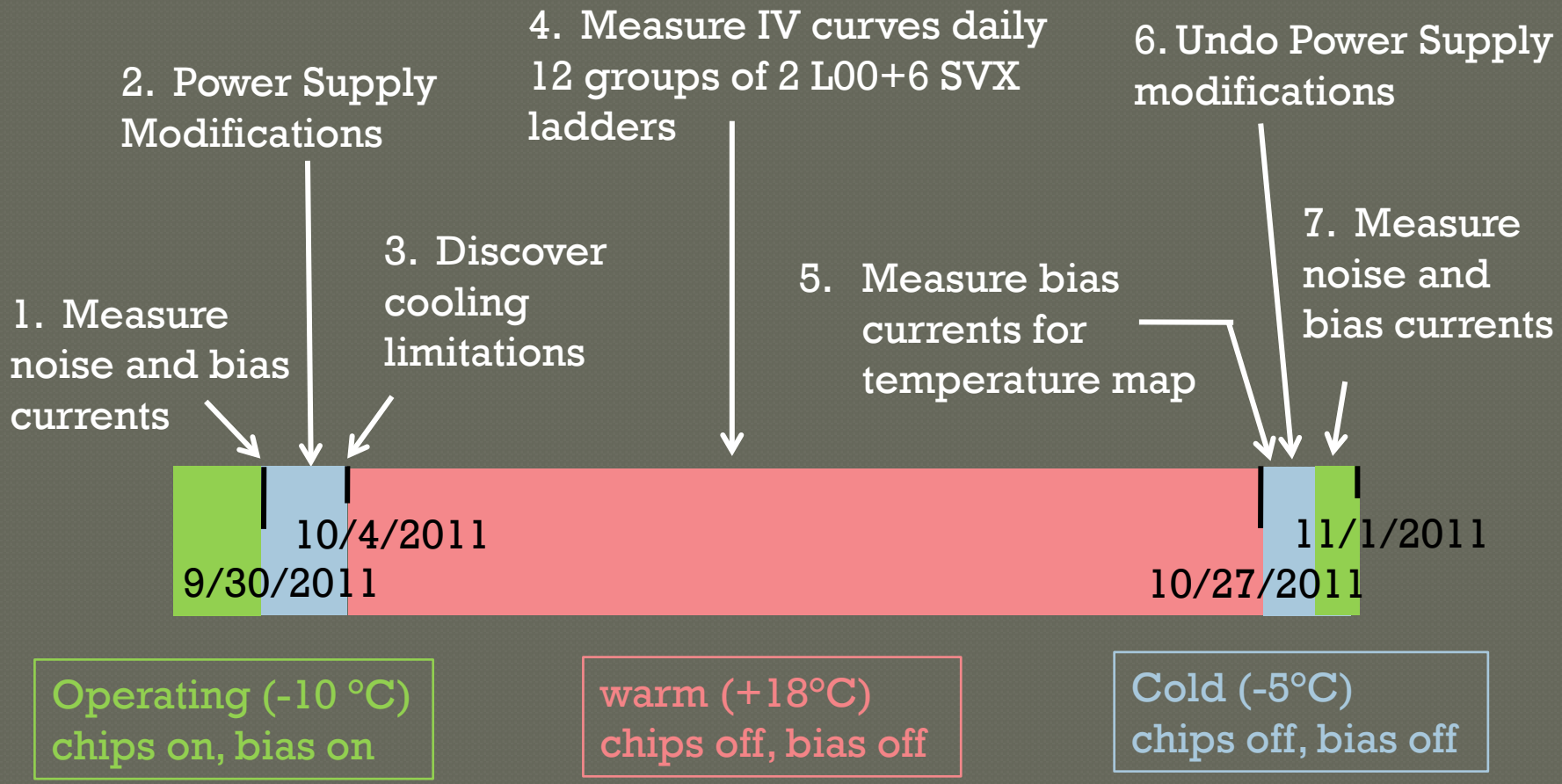
- CDF never intentionally warmed up its silicon to benefit from annealing
  - History of chip failures after thermal cycles
  - Small benefit and risk of reverse annealing damage
- Annealing measurement focuses on L00
  - SVX sensors are warmer (10°C) while irradiating, annealing calculations are more difficult
  - SVX sensor temperatures are poorly known

CDF measurement – what?

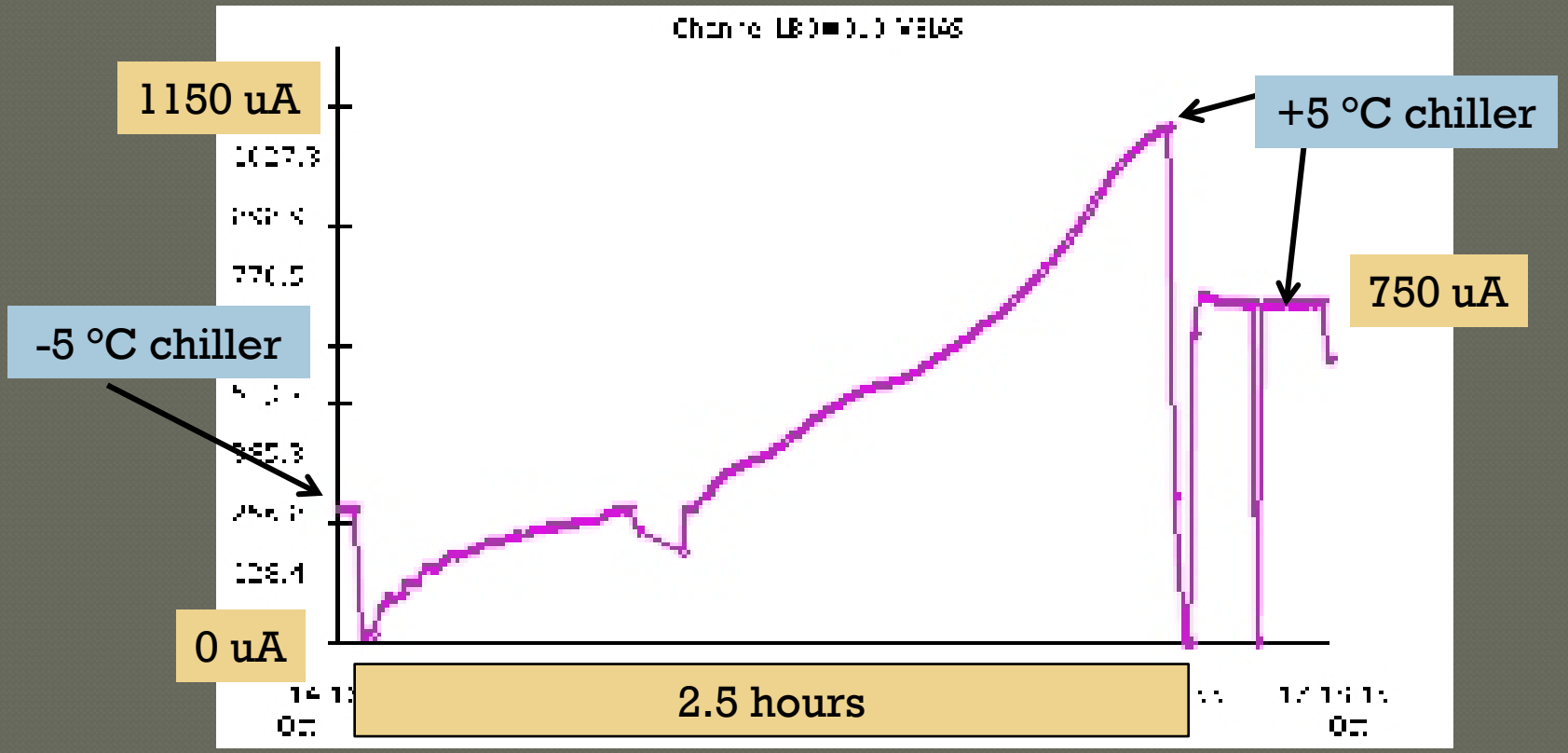
Unique annealing measurement – many sensors with 5 different radiation doses. Two oxygenated sensors.

- Measure current before and after annealing (expect 40% decrease in 30 days at 20°C IF no prior annealing)
- Measure noise before and after annealing
- Daily measure IV curves which give information about the depletion voltage

CDF measurement – how?



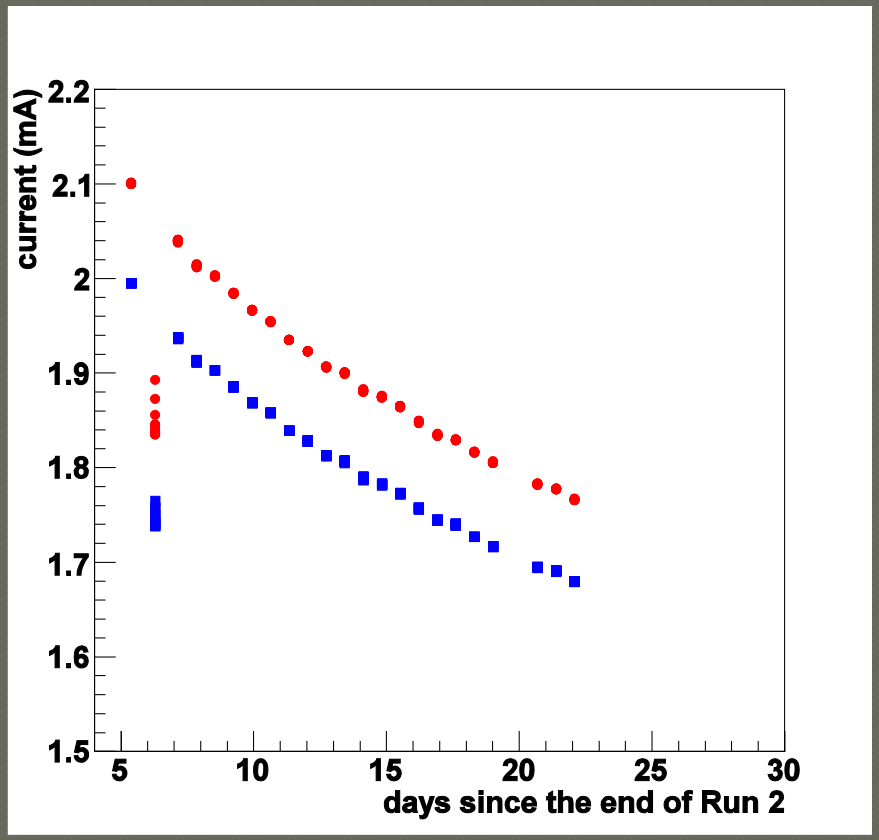
Extraordinary thermometers



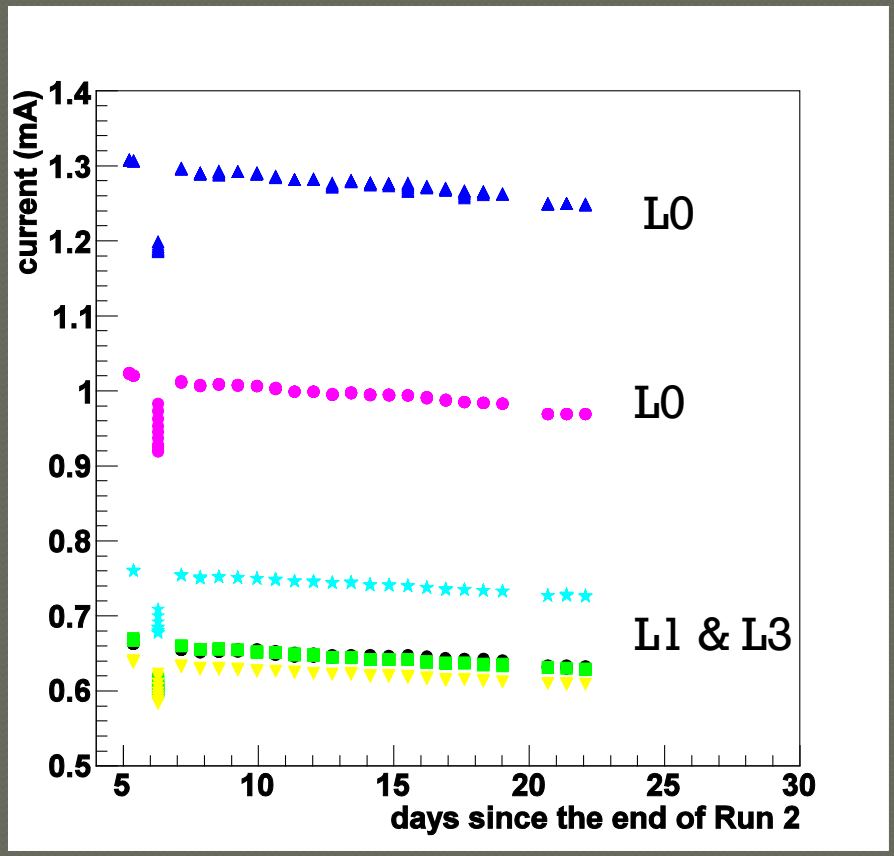
Current vs time for single L00 ladder. The rising curve is the current while warming up from -5°C to +5°C with all sensors biased, flat plateau is with only this one biased at constant temperature.

Annealing Currents – single ladders

L00: ~20% drop in 20 days



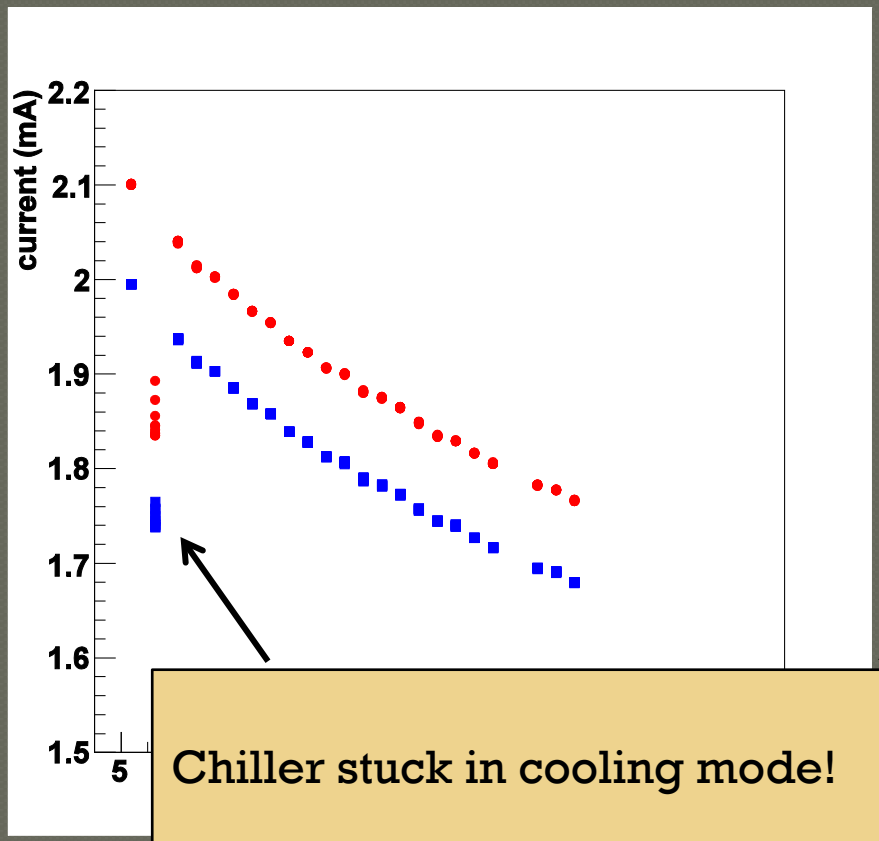
SVX: <5% drop in 20 days

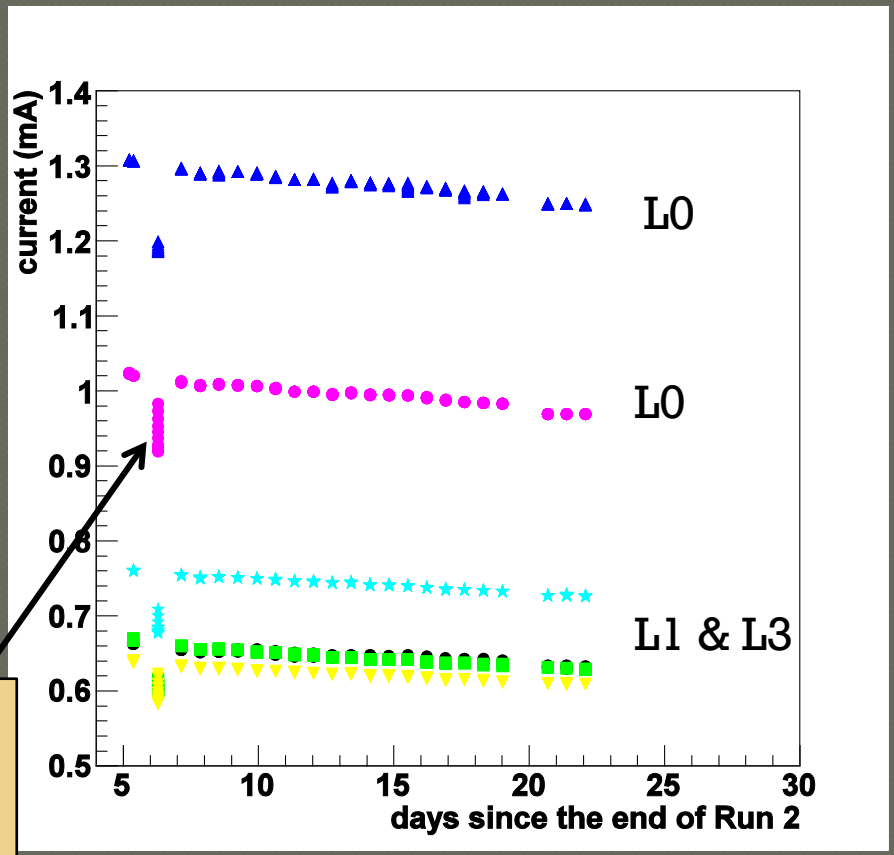


Annealing Currents – single ladders

L00 - 17% drop in 20 days

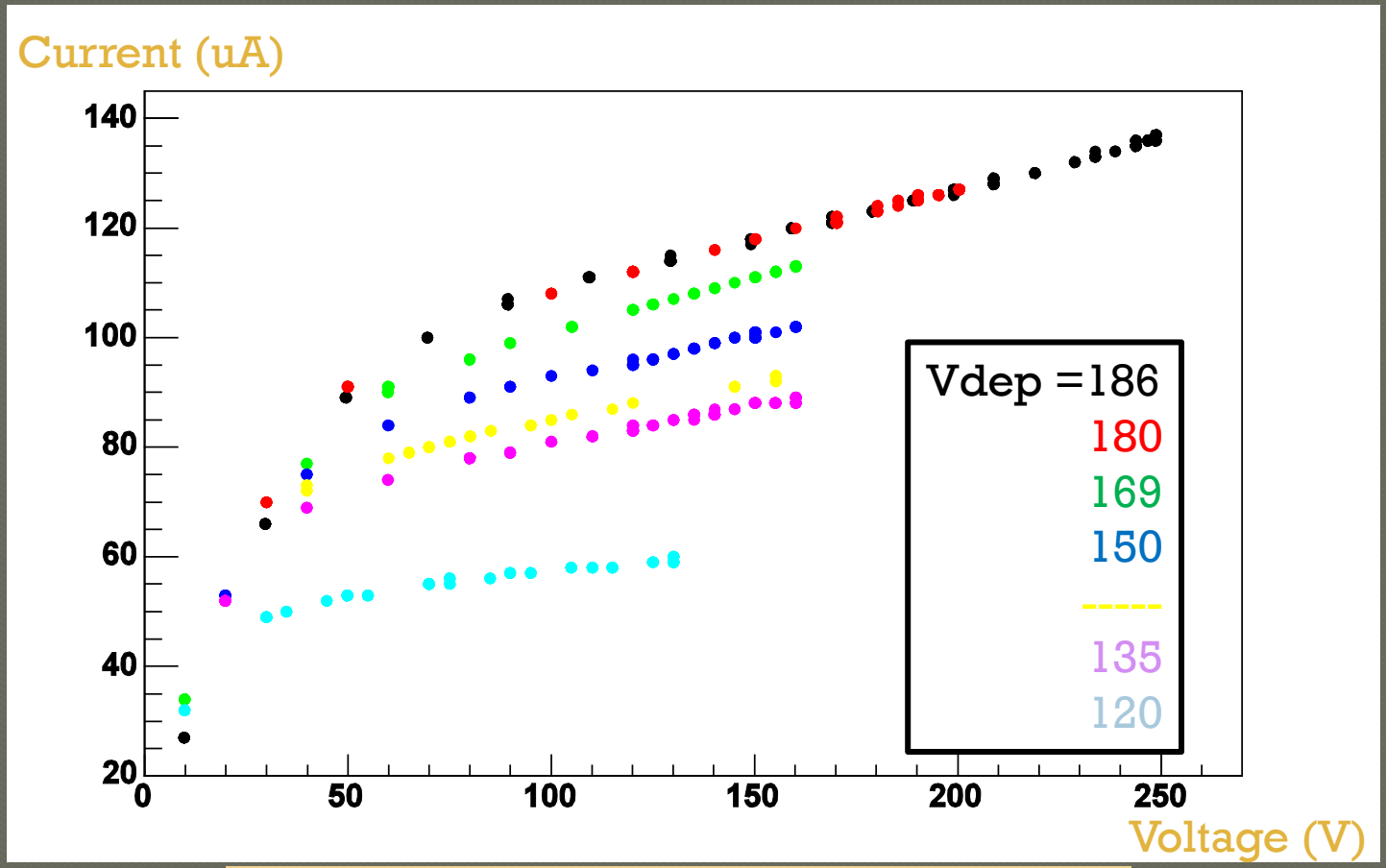
SVX - <5% drop in 20 days





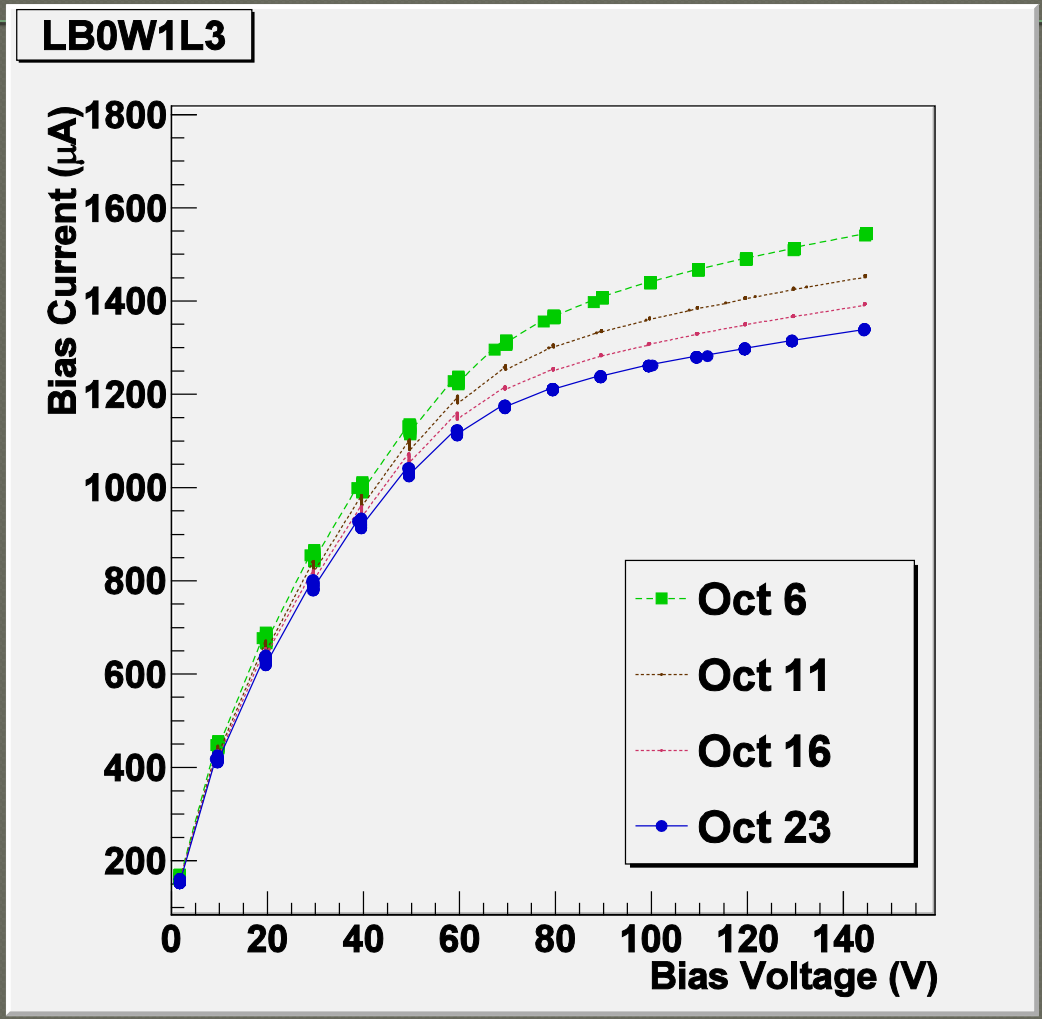
Chiller stuck in cooling mode!

IV curves and V_{DEP} (cold)



From signal scans 2010 & 2011, LB0W1L3

IV curves during annealing

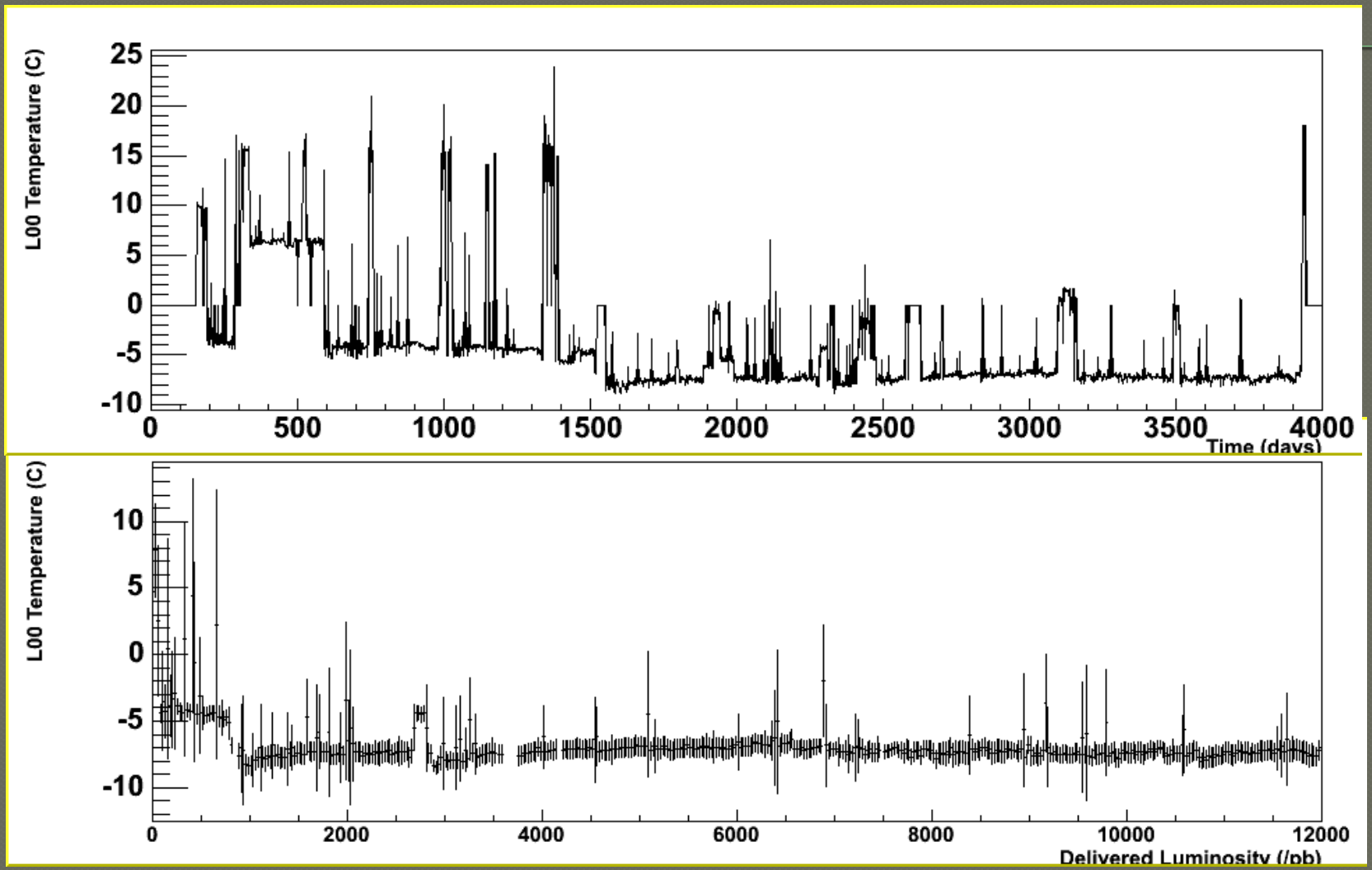


Summary

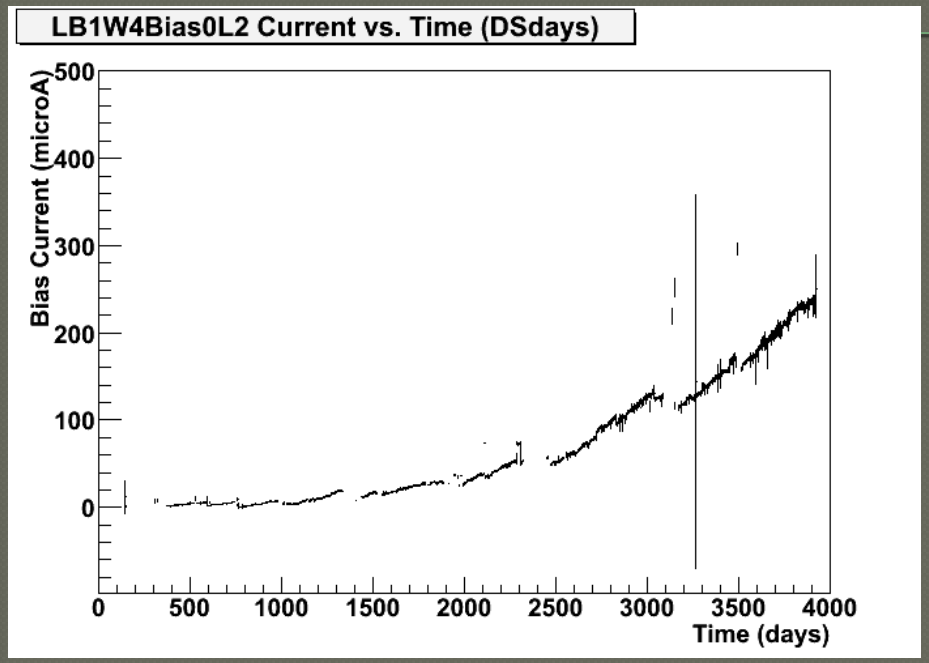
- Studies of radiation damage in the Tevatron silicon detectors are unique and relevant for designing future detectors.
- Annealing effects play an important role in understanding damage in our silicon and LHC detector lifetime estimates.
- Real detectors are messy, correcting for real life effects is important.

Backup Slides

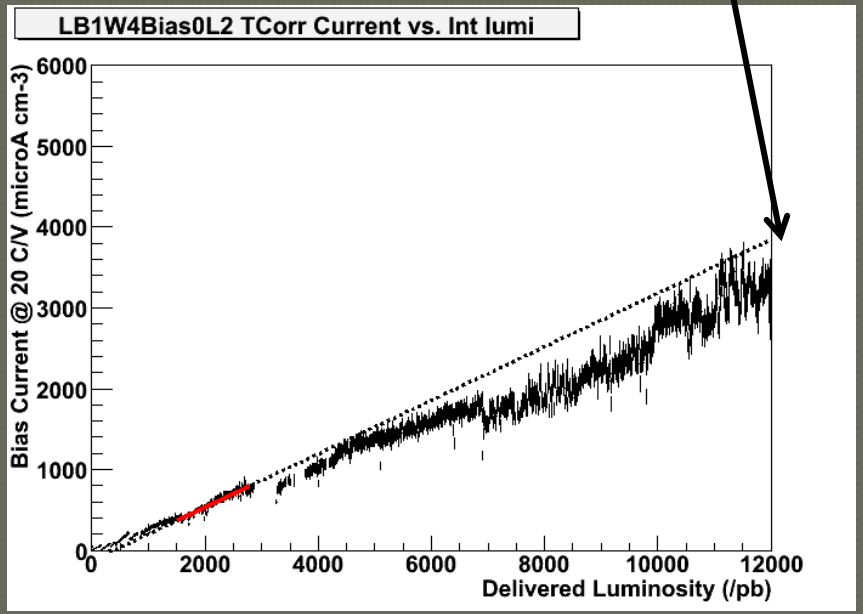
L00 cooling line temp in RunII



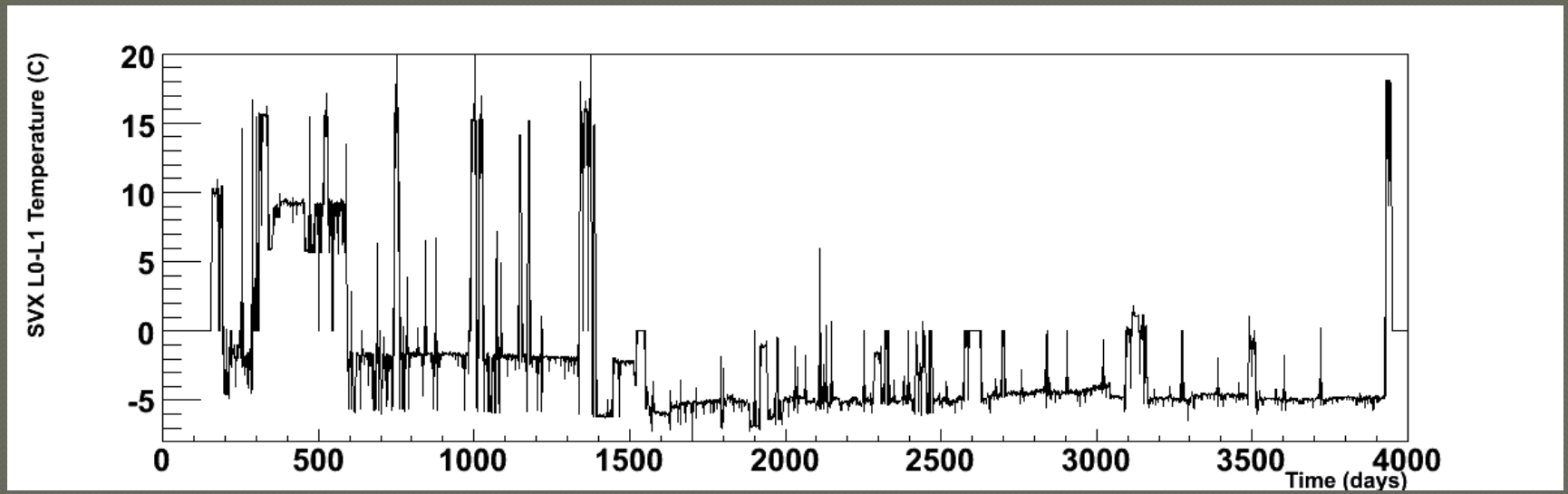
L00 annealing during shutdowns



~15% low

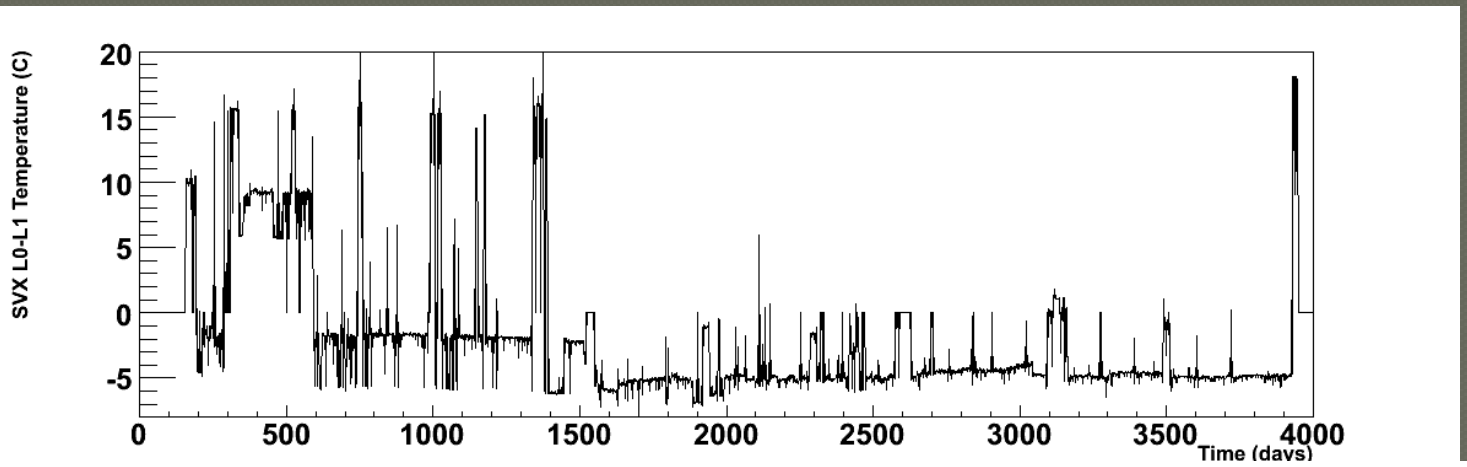


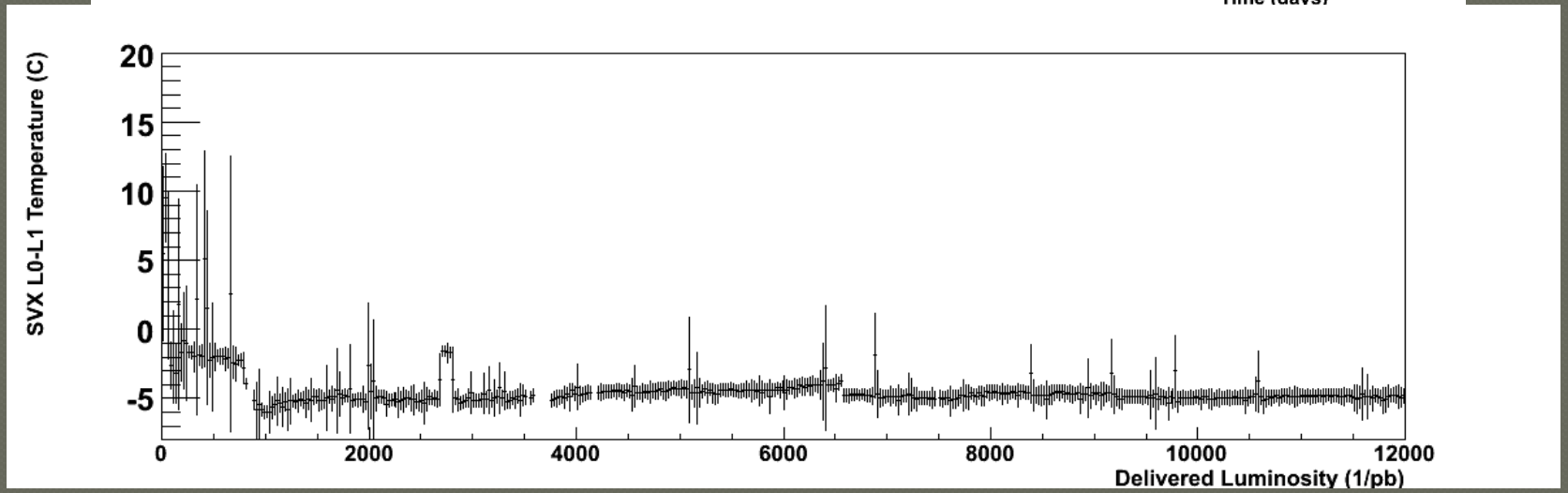
SVX Bulkhead temp in RunII



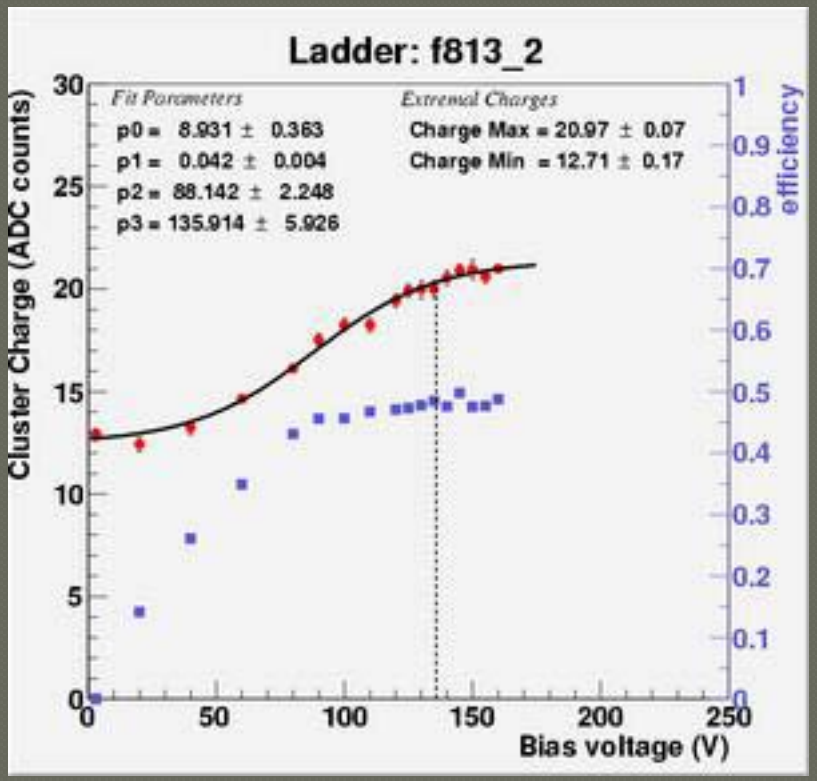
- Thermal model says that SVX sensors are +10-12°C during operation. Chips and nitrogen flow warms the sensors.

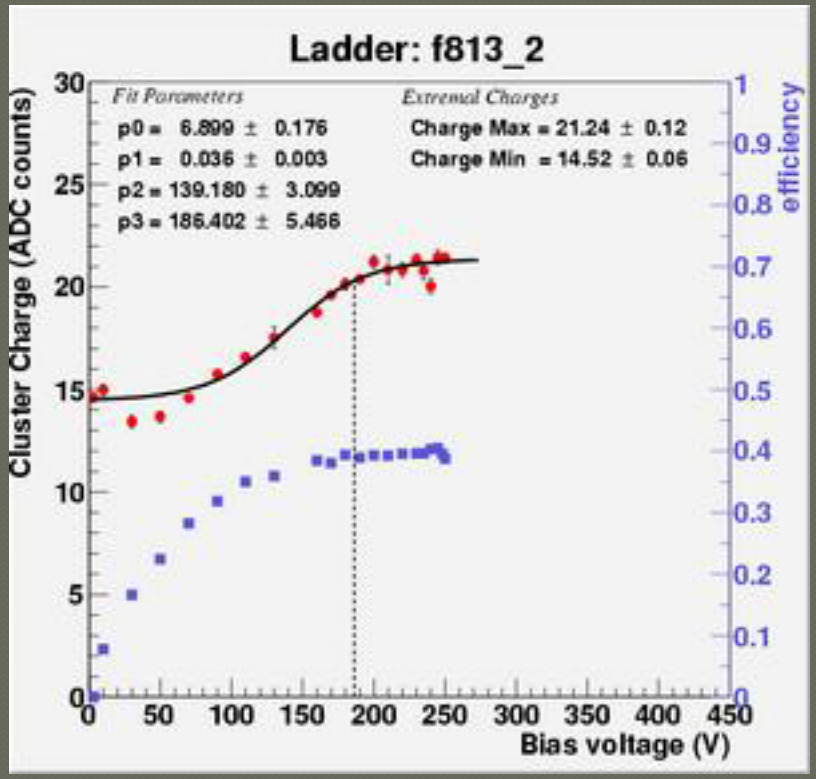
SVX Bulkhead temp in RunII



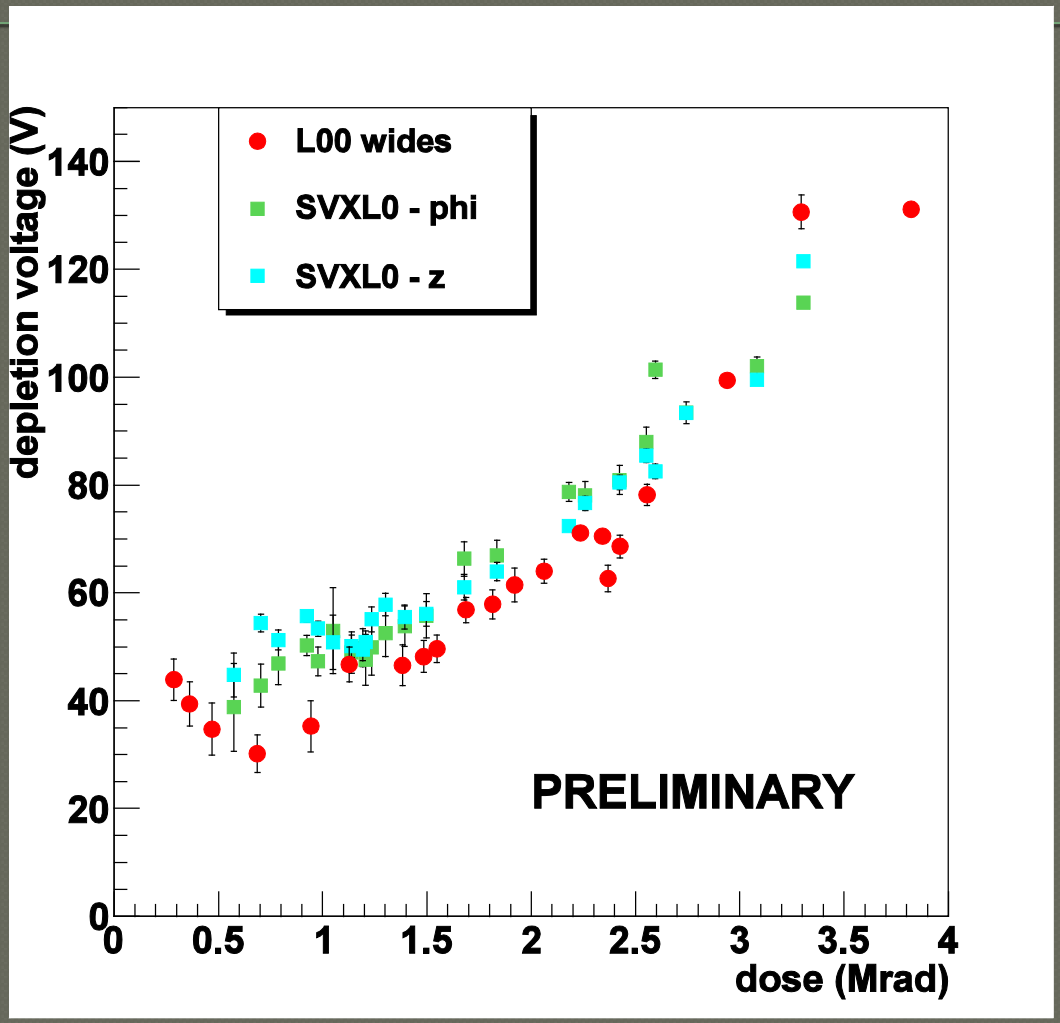


Depletion Voltage measurement

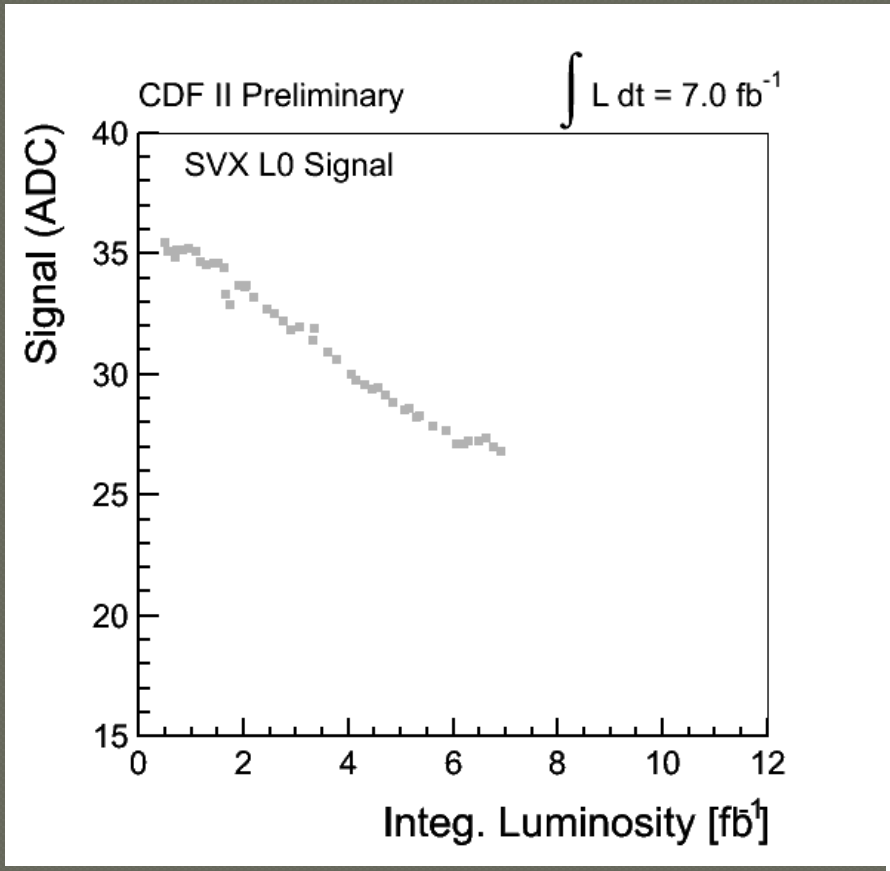


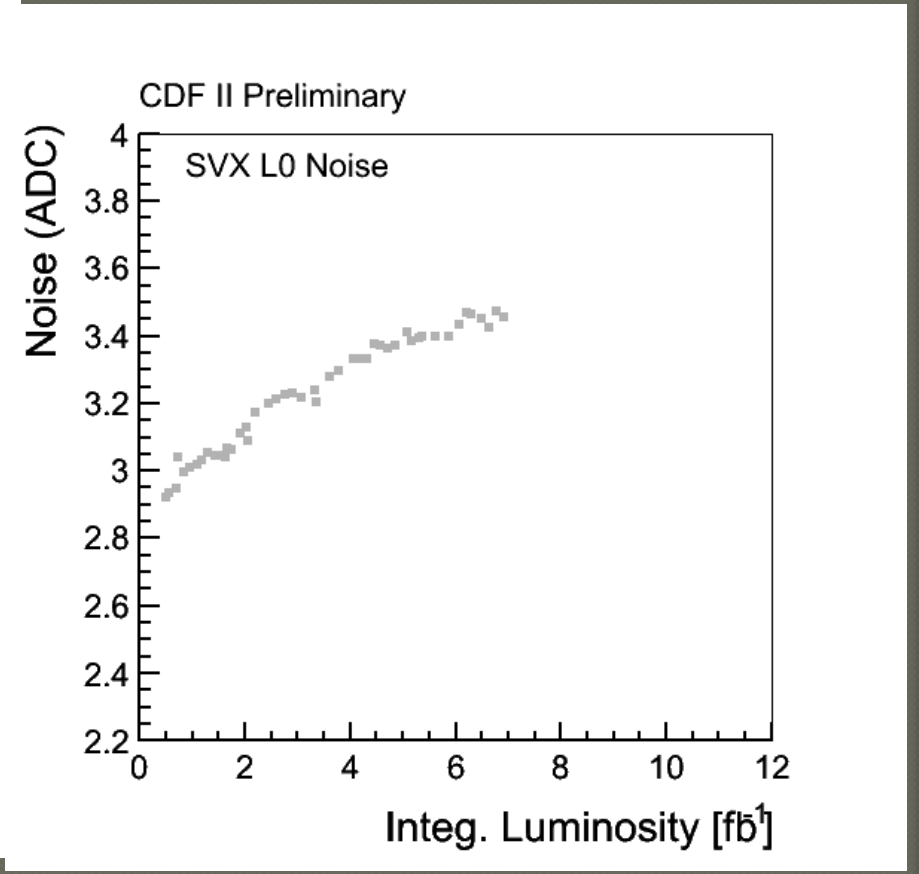


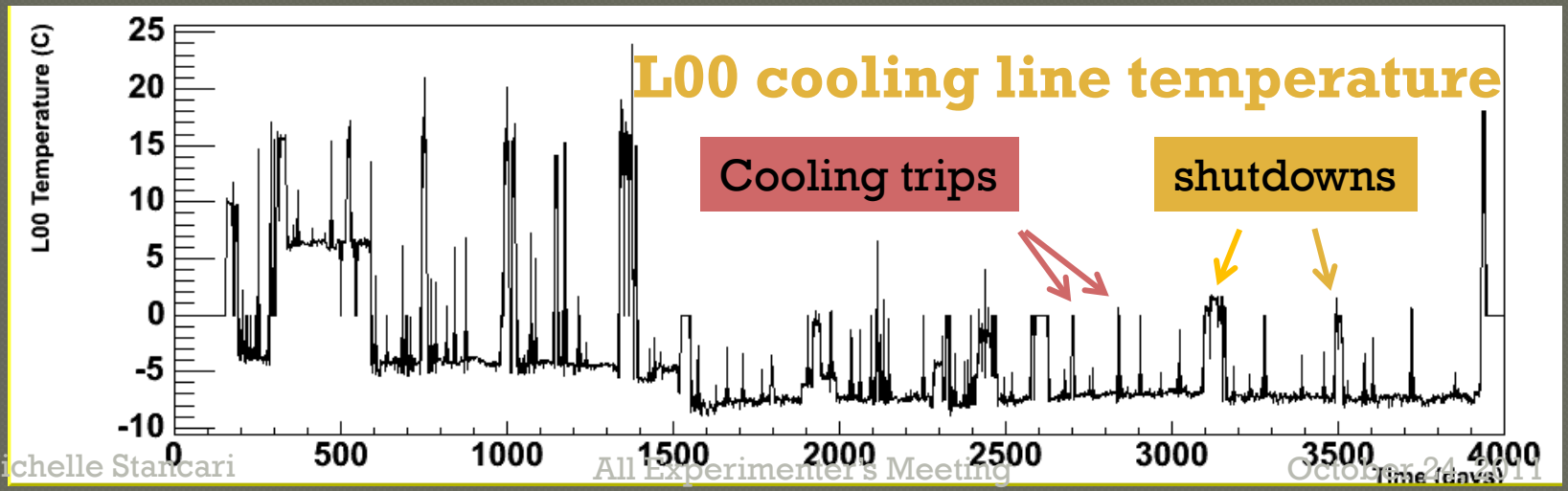
Radiation Damage at CDF



Signal and Noise






L00 cooling line temperature
Cooling trips
shutdowns
L00 Temperature (C)
25
20
15
10
5
0
-5
-10
0
500
1000
1500
2000
2500
3000
3500
4000