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.
RADIATION DAMAGE: High energy particles dislocate atoms from the silicon crystal lattice.

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Limits the lifetime of most HEP silicon detectors
What happens in a nutshell

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**with particle fluence:**

\[ \Delta I / V \propto \Phi_{eq} \]

80 min 60°C

**with time (annealing):**

\[ \propto I / I_0 \]

---

**with particle fluence:**

\[ V_{dep} \]

type inversion

---

**with time (annealing):**

\[ \propto V_{dep} \]

---

From M. Moll and R. Wunstorf and others
\[ \propto V_{\text{dep}} \]

“Good” annealing component

Stable damage component

“Bad” or reverse annealing component

\[ \Delta N_{\text{eff}} \left[10^{11} \text{cm}^{-3}\right] \]

... with time (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.
Data shows a slower annealing effect than the two models presented.

**G. Casse, 17th RD50 Workshop, CERN Nov.2010**
“. . . 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 mismatch 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

- Layer 00
- ISL
- SVX II
- Port Cards
- R=29 cm
- η=0, η=1, η=2, η=3, η=4
- 2.54 cm
- 1.5 cm
- 64 cm
- 90 cm
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
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
2. Power Supply Modifications
1. Measure noise and bias currents
3. Discover cooling limitations
4. Measure IV curves daily
12 groups of 2 L00+6 SVX ladders
5. Measure bias currents for temperature map
6. Undo Power Supply modifications
7. Measure noise and bias currents

- 10/4/2011
- 10/27/2011
- 11/1/2011

- Operating (-10°C)
  chips on, bias on
- warm (+18°C)
  chips off, bias off
- Cold (-5°C)
  chips off, bias off

Michelle Stancari
All Experimenter’s Meeting
October 24, 2011
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 $V_{\text{DEP}}$ (cold)

From signal scans 2010 & 2011, LB0W1L3
IV curves during annealing
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

Michelle Stancari
All Experimenter's Meeting
October 24, 2011
Thermal model says that SVX sensors are +10-12°C during operation. Chips and nitrogen flow warms the sensors.
Thermal model says that SVX sensors are +10-12°C during operation.
Depletion Voltage measurement

Michelle Stancari
All Experimenter’s Meeting
October 24, 2011
Signal and Noise

CDF II Preliminary

$\int L \, dt = 7.0 \, fb^{-1}$

**SVX L0 Signal**

**SVX L0 Noise**
L00 cooling line temperature

Cooling trips

shutdowns