The CDF II Silicon Detector
Longevity and Performance

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(on behalf of the CDF Silicon group)
Radiation damage to sensors:
- Will the \textit{depletion voltage} eventually exceed the sensor breakdown voltage and/or power supply limits?
- Will the decreasing S/N ratio affect the physics analyses before underdepletion?

Radiation damage to electronics:
- Power supplies, FIB readout modules in collision hall
- DOIM data transmitters in the bore

Chip and sensor failure rates:
- No dramatic increase in failures with age

ISL cooling system:
- Stable after 2007 and 2009 repairs
**CDF II Silicon Detectors**

**Overview:**
- Three components: L00, SVX-II, ISL
- 8 layers, 722k readout channels
- 3D hit information
- SVX3D chips

**SVX:** Double sided silicon
- Layers 0,1,3 (Hamamatsu) 90° strips
- Layer 2+4 (Micron) small angled strips

**ISL:** Additional layers, Hamamatsu+Micron
- Add forward coverage

**L00:** Single-sided, radiation hard sensors
- “Narrows” (SGS Thomson and 2 Micron)
- “Wides” (Hamamatsu)
Depletion Voltage Measurements

- Measure collected charge for different bias voltages
- CDF defines depletion voltage, $V_d$, as the minimum voltage that collects 95% of the charge at the plateau

Depletion Voltage as a function of integrated luminosity

- 3rd order polynomial fit around the inversion point
- Linear fit to extrapolate to the future
Depletion Voltage Projections

Prediction for L00

Extrapolation from linear fits

- Inversion Point
- Sensor breakdown
- Power Supply limit

<table>
<thead>
<tr>
<th>Depletion voltage [V]</th>
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<tbody>
<tr>
<td>1000</td>
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<tr>
<td>900</td>
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<tr>
<td>800</td>
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<td>100</td>
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<tr>
<td>50</td>
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<td>0</td>
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Luminosity [fb⁻¹]

0
5
10
15
20

Today’s operating voltages

Predictions for SVX-L0 show no danger of underdepletion before 20 fb⁻¹.

Prediction for SVX-L0

Extrapolation from linear fits

- Power Supply limit
- Sensor breakdown

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Luminosity [fb⁻¹]

0
5
10
15
20

66 (out of 72) ladders plotted

L0 PHI side linear fit

Predictions for SVX-L1 show no danger of underdepletion before 20 fb⁻¹.
Underdepletion is not instant death, but a slow process of decreasing efficiency!

~2 years / 3.75 fb$^{-1}$

A single L00 ladder was unintentionally underdepleted in 2007-08. Its efficiency was restored after a bias voltage increase from 95 to 150 V.
Signal/Noise Measurements

- Signal from $J/\psi \rightarrow \mu^+\mu^-$ tracks strip cluster charge
- Noise estimation from regular calibrations
- Extrapolations assume fully depleted sensors
- Studies in progress to understand the effect of decrease S/N on physics analyses for run 3 (see recent CDF talk to PAC)

\[ \int L \, dt = 7.0 \text{ fb}^{-1} \]
Ladder Failures and Challenges

Radiation damage in the sensors is not the only issue!

One ladder = chain of 4-14 readout chips (128 microstrips each chip)

Currently ~90% ladders integrated, ~80% good (< 1% error rate), ~10% bad with an average error rate of 10%

Great performance after 9 years of running
Other Radiation Effects

- SEU requires FPGA and fuse replacement on FIBS (2/year)
- Power Supplies need replacement capacitors every 5 fb$^{-1}$
- DOIM TX light output decreases linearly with radiation dose
Dense Optical Interface Modules contain 9 edge-emitting laser diodes that transmit data from the bore to electronics outside the detector.

These are solid state devices, and thus experience radiation damage, similar to the sensors.

CDF note 6497 reports on beam tests which measured the decrease in output light intensity linear with total dose: \(80\pm20\%\) for 400 krad dose.

Integrated luminosity of 20 fb\(^{-1}\) \(\Rightarrow\) \(~1\) Mrad to the DOIMs.

2010 Shutdown work: measured light intensity for \(~10\%\) of detector (900 numbers!). Status is good.

Light-amplifying circuit is being built to recover a few ladders with initial light below specs that is now below the receiver threshold of 50 uW.
Light Intensity Measurements

- Measured 10% of detector at receiver input.
- Receiver threshold is 30-50 µW.
- Weakest bit in each ladder is critical.
- Predicting the future is not trivial.
Summary and Conclusions

- The CDF Run II silicon detector is in extremely good health after 9 years of operation.
- The innermost layers have long progressed through inversion and exhibit consistent post-inversion behavior.
- The measured DOIM light intensities are well above the receiver thresholds. We will monitor the loss rate in the future.
- Stable performance will continue through the end of run II.
Run 3 Considerations

- SVX-L0 will be underdepleted between 12 and 15 fb$^{-1}$ and eventually unusable.
- Some L00 sensors may be underdepleted between 15 and 20 fb$^{-1}$, but should still provide usable information.
- B-tagging should remain efficient despite decreasing S/N (see CDF presentation to PAC).
- Should the light output of DOIM transmitters decrease more dramatically than expected, light amplifiers can be implemented.
- Current SVT (displaced vertex trigger) will lose resolution and acceptance without SVX-L0. (Current SVT algorithm requires hits in 4 of 5 SVX layers).
Common failure modes:

**Detector** includes port cards, junction cards, cables, and the sensors themselves.

**Optical** is bit errors from the internal DOIM data transmitters.

**Jumper** is SVX3D chip failures due to wire bond resonances.

**AVDD2** is a SVX3D chip failure mode caused by thermal cycles.

**Other SVX3D** includes all other chip failure modes.
The Problem

- In 2007, bad vacuum in ISL indicates presence of leaks. Eventually, east side bad enough to interfere with detector operations.
- Found high acidity in coolant, $\text{pH} = 2$
- Formic acid had formed out of the glycol/water mixture (after warming up during the 2006 shutdown)
- Corrosion affected vulnerable parts (Al-alloys welding, brass e-valves)

Hole

Conductivity [\text{\Omega/cm}]}

<table>
<thead>
<tr>
<th>Month</th>
<th>AUG-06</th>
<th>MAR-06</th>
<th>APR-07</th>
<th>MAY-07</th>
<th>SEP-07</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductivity</td>
<td>3</td>
<td>16</td>
<td>700</td>
<td>8</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Time

Trips, high pressures, low flows, $\text{pH} = 2$, corroded e-valves

No flow

Manifolds

Epoxied

Drain

Contact us for more information.
The Repair

- Internal walls of pipes were probed using boroscopes and catheters (~1 m inside CDF detector)
- Port Card manifold-pipe junctions were coated with epoxy
- Brass e-valves were replaced (mounted on CDF detector)
- The ISL coolant was replaced with deionized water
- Expanded monitoring of pH and conductivity
- Frequent replacement of deionizer (DI) resin filters

**Graph:**
- **Conductivity [μS/cm]:**
  - MAR-06: 3
  - AUG-06: 16
  - JUL-06: 1200
  - AUG-06: 700
  - SEP-06: 8
  - OCT-06: 0.5

**Time:**
- JAN-07: Trips, high pressures, low flows, pH = 2, corroded e-valves
- APR-07: No flow
- MAY-07: Manifolds epoxied

**Note:**
- Details in “All Experimenters Meeting” (Nov 05, 2007)
- http://www.fnal.gov/directorate/program_planning/all_experimenter_meetings/2007/final_reports/Garcia_CDF_ISLLeakCause_11_05_07.ppt
Current status of ISL Cooling

- Running, no serious incidents
- Good and stable flows
  - ISL CCE1 is stable but lower than perfect
- Good and stable sub-atmospheric pressures
- pH measured weekly from coolant samples
- Low conductivity <2 $\mu$S/cm
- Maintenance during each shutdown to improve hermeticity
- Chillers running well,
- New air-cooled backup chiller for power outages
- No jumper failures for ISL because readout happens only after L2 accept
- No AVDD2 failures because of warmer temperature than SVX
- Sensor recovery after JC pushes (disconnected cables)
- Long history of cooling problems
  - 2003 – unblocked cooling lines
  - 2007 – major leak repaired
• Radiation field measured with TLDs outside the silicon volume in 2002-2003.
• NIM A514 188 (2003)
• Bias current evolution 2002-2004 consistent with this radiation dose
Depletion Voltage Projections

Prediction for L1 – phi side

Extrapolation from linear fits

Power Supply limit

Sensor breakdown

67 (out of 72) ladders plotted

L1 PHI side linear fit

Prediction for L1 – z side

Extrapolation from linear fits

Power Supply limit

Sensor breakdown

58 (out of 72) ladders plotted

L1 ZETA side linear fit