Radiation Damage and Operational Experience in the CDF-II Silicon Detector

And a few words on the D0 silicon detector Radiation Damage

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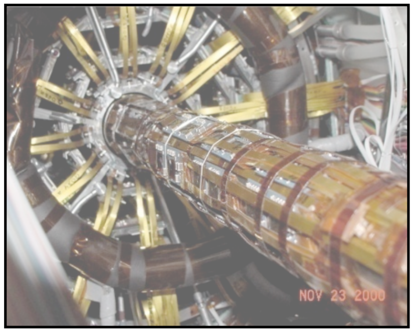
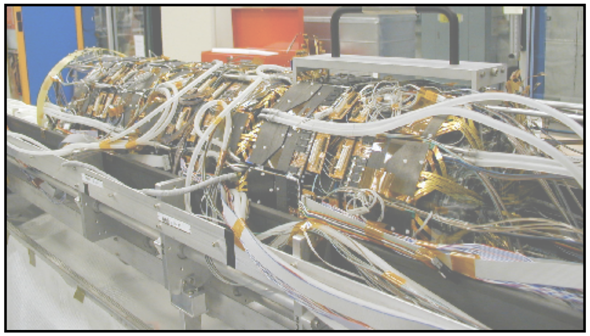
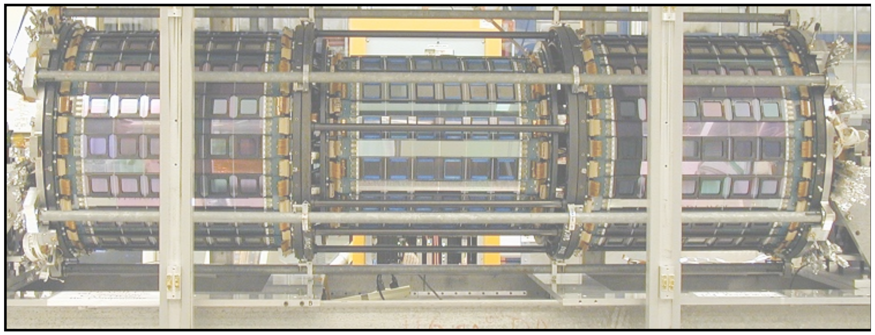
(on behalf of the CDF II Silicon group)



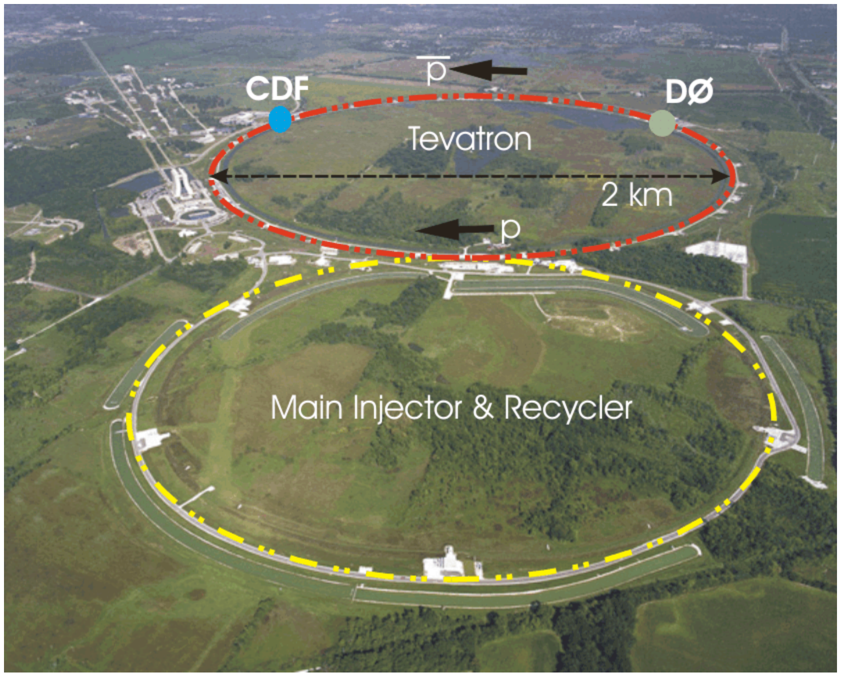




2010 VERTEX Meeting

Loch Lamond, Scotland, June. 6 - 11, 2010

HEP Detectors at the Tevatron



- **Tevatron: proton-antiproton collider at $\sqrt{s}$ = 1.96 TeV**

  Luminosity: more than 8 fb^{-1} delivered

  Expected 11 fb^{-1} delivered by 2011

  Two multi-purpose, multi-layered detectors: CDF & DØ

- **CDF II: Tracking Volume**

  Double sided, multilayered silicon strip detectors designed for ~3 fb^{-1}

  Large open-cell drift chamber

- **DØ: Tracking Volume**

  Double sided, multilayered silicon strip detector, with recent inner layer upgrade

  Scintillating fiber outer tracker

Running beyond 2011?

- The Tevatron is going strong: ~100 publications last year alone.
- The current LHC 2010/11 plan announcements is:

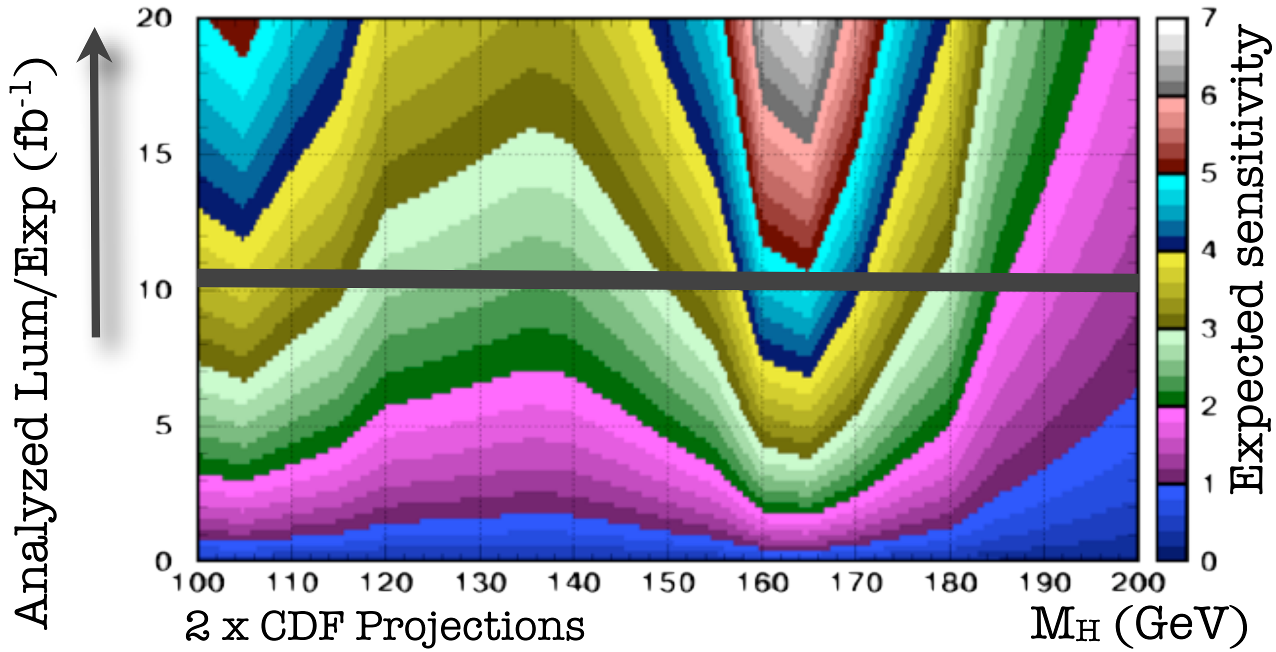
  1 fb^{-1} @ 7 TeV by end of 2011 & down in 2012 for 1-1.5 yrs

- Tevatron will remain highly competitive in a variety of physics programs, <u>especially including the low mass SM Higgs searches.</u>

- There is a **strong** physics case for running the Tevatron for 3 more years after 2011 (20 fb^{-1})

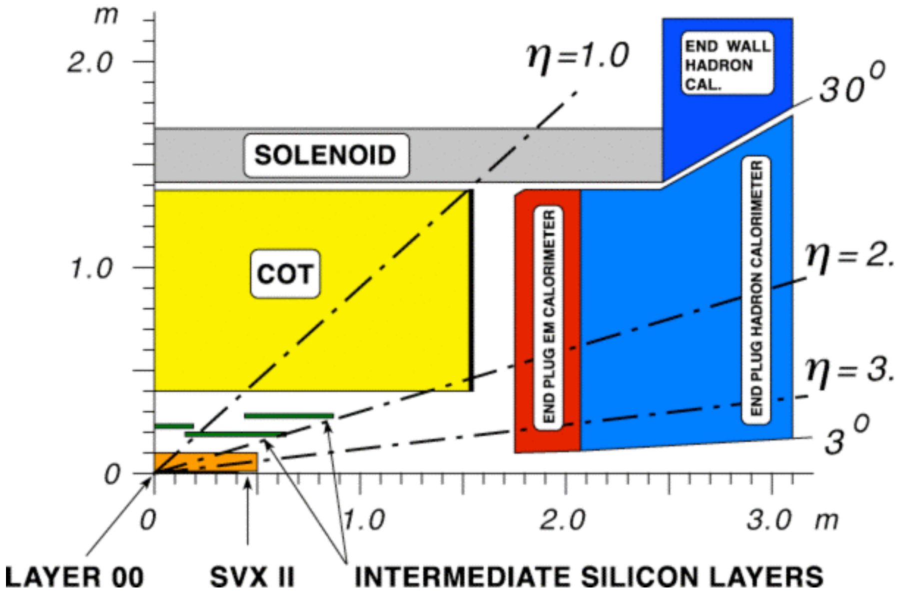
Can the silicon detectors provide efficient data that long?

HIGGS REACH



With projected improvements achieved (x1.5 in sensitivity from now)

CDF II Silicon Detectors



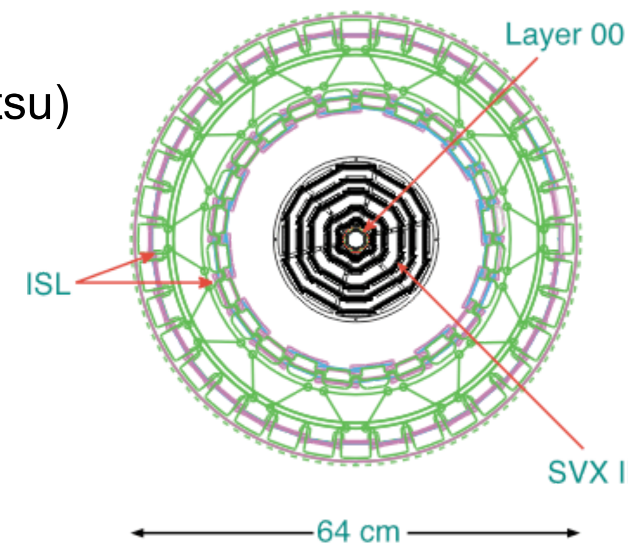
Overview:

- ✓ Three components: SVX-II, ISL, L00
- ✓ 7-8 layers, 722k readout channels
- ✓ 3D hit information
- ✓ SVX3 chips for the silicon readout

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

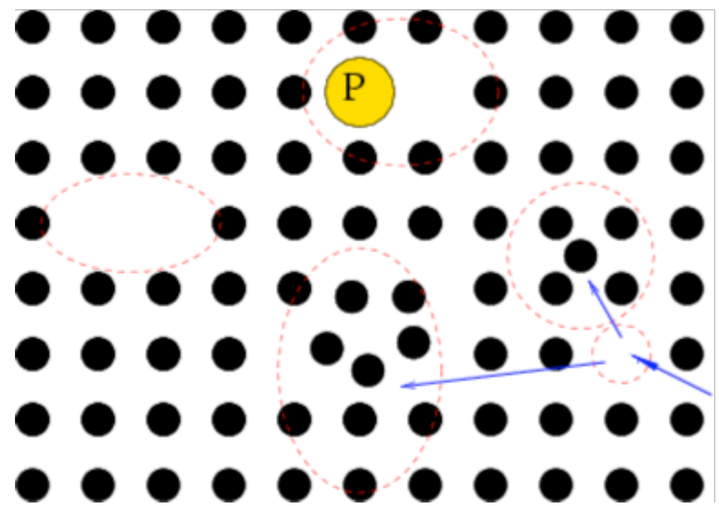
ISL: Additional layers, Hamamatsu+Micron
add forward coverage

L00: Single-sided "Narrows" (SGS Thomson
and 2 Micron) "Wides" (Hamamatsu)



Radiation Damage

- **Two general types of radiation damage to the sensors:**
  - **Crystal damage** due to Non-Ionizing Energy Loss (NIEL): displacement damage, crystal defects.
    - increase of shot noise, change of effective doping concentration, increase of charge carrier trapping.
  - **Surface damage** from Ionizing Energy Loss (IEL) causing accumulation of charge in the SiO2 and the Si/SiO2 interface.
    - Inter-strip capacitance , breakdown behavior etc.



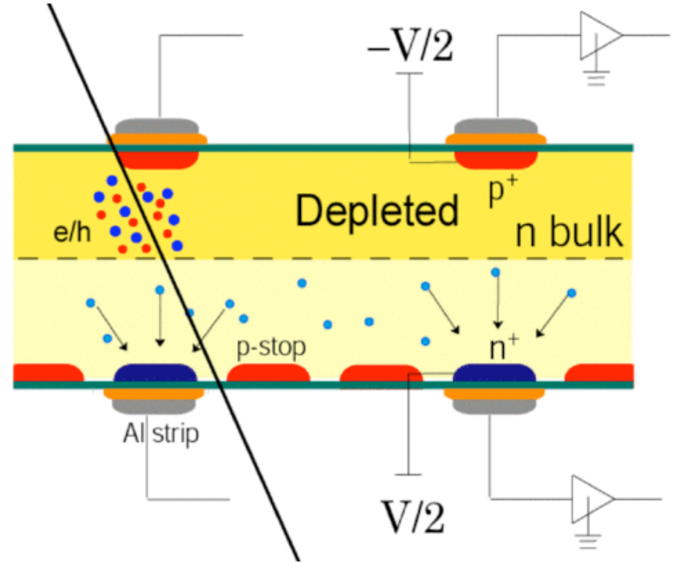
Crystal damage to the sensors is the main concern for sensor longevity

Aging Studies – Variables of Interest

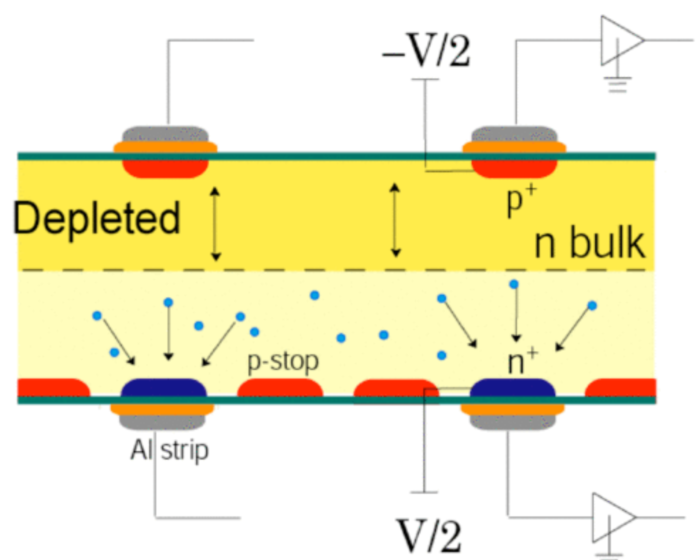
- **Information on integrated radiation dose in a sensor is obtained from:**
  - **evolution of bias current:** provides "direct" information on the crystal condition, due to increase in leakage current. Change in leakage current is linear with the absorbed dose $\Delta I_{leak} = \alpha \, \Delta\Phi_{eq}$ (α measured in 2004 to be **1.65 ± 0.12**)
  - **evolution of depletion voltage:** gives information on our ability to deplete the sensors in the future. Its extrapolation predicts the need to raise applied bias voltage and its limit.
  - **Signal-over-noise (S/N) studies:** provide estimates of usability of the detector in charged particle tracking and in turn for physics analyses.

Depletion Voltage Measurement

- **From charge (signal) collection efficiency:**
  - Charge collection is proportional to the depleted volume
  - Fully depleted sensor ➔ charge collection efficiency saturates



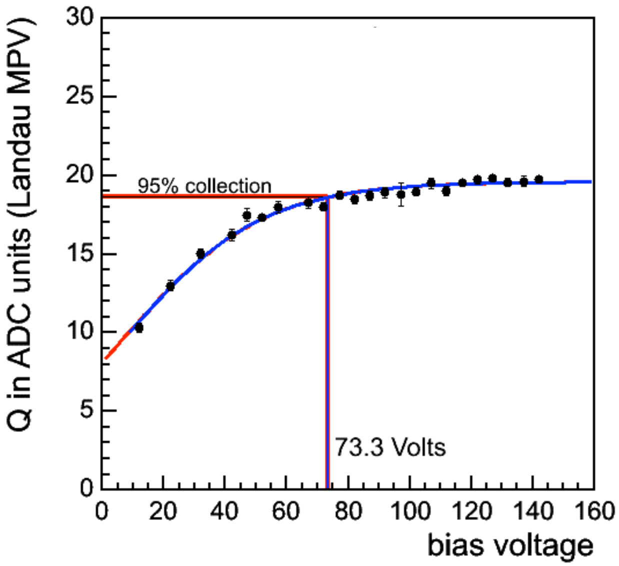
- **From noise at the n-side:**
  - Thermal noise from free carriers on the n-side is reduced with depletion (on the p-side)

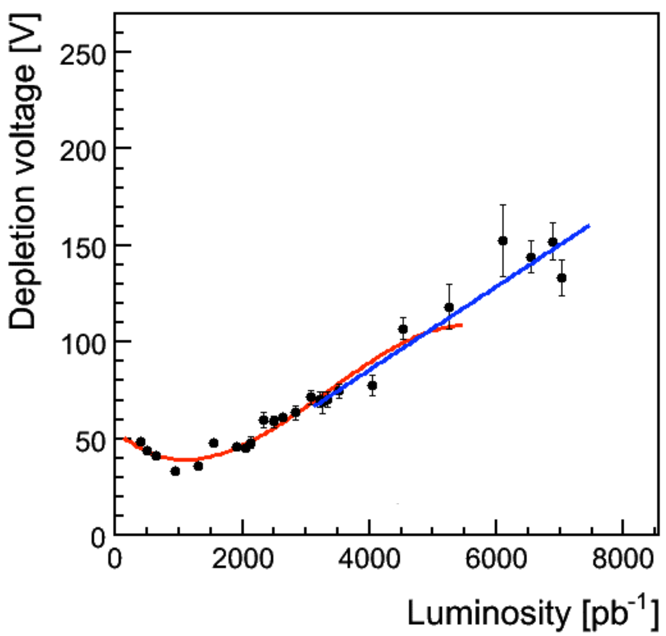


Depletion Voltage Study -- Signal Vs. Bias

- Plot charge for different bias voltages

- Define depletion voltage, V_d , as voltage that collects 95% of the charge at the plateau

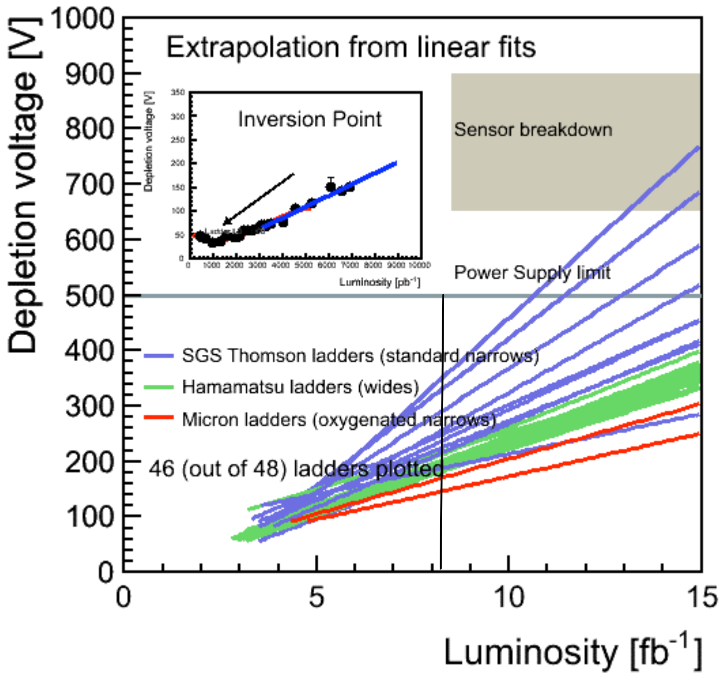




- Depletion Voltage as a function of integrated luminosity
  - 3rd order polynomial fit around the inversion point
  - Linear fit to extrapolate to the future

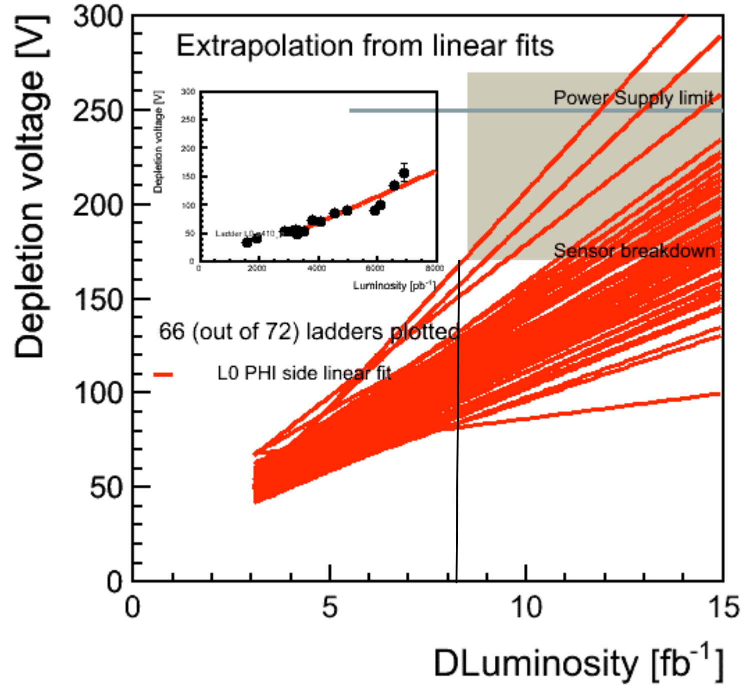
Depletion Voltage Projection L00-L0

➢ **Prediction for L00**



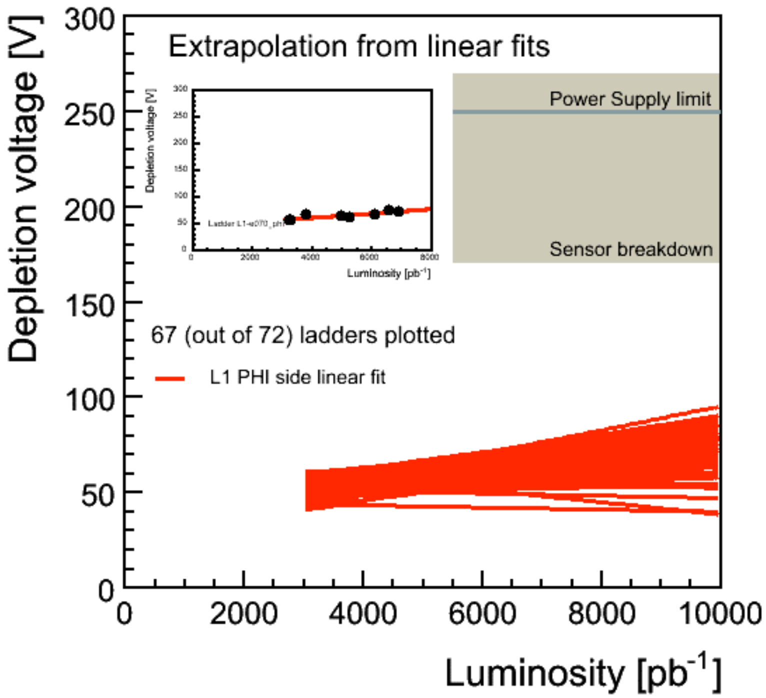
82×10^{12} 1MeV equivalent neutrons [cm^2]

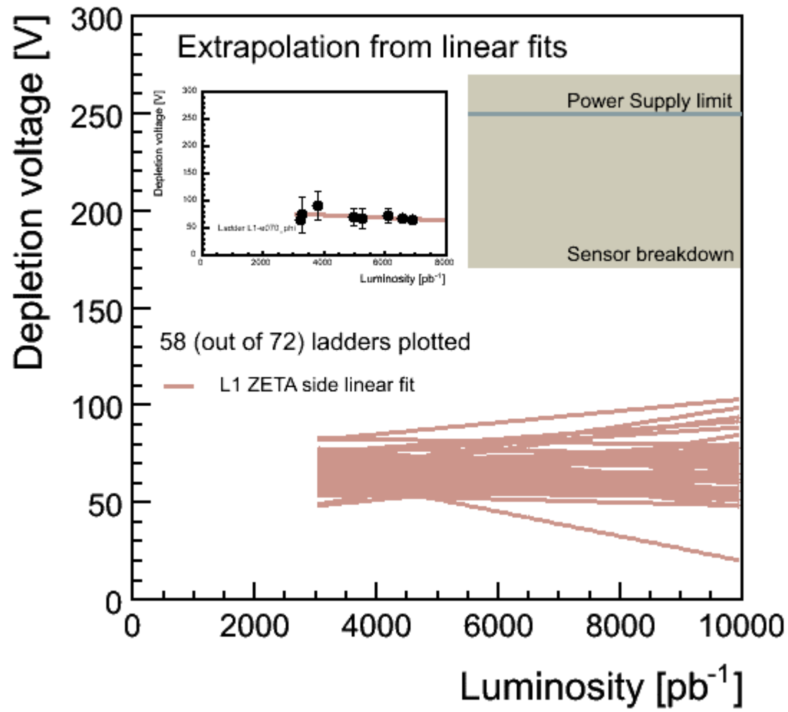
➢ **Prediction for SVX-L0**



We will be able to fully deplete most of the sensors until 11 fb^{-1}

Depletion Voltage Projection - L1





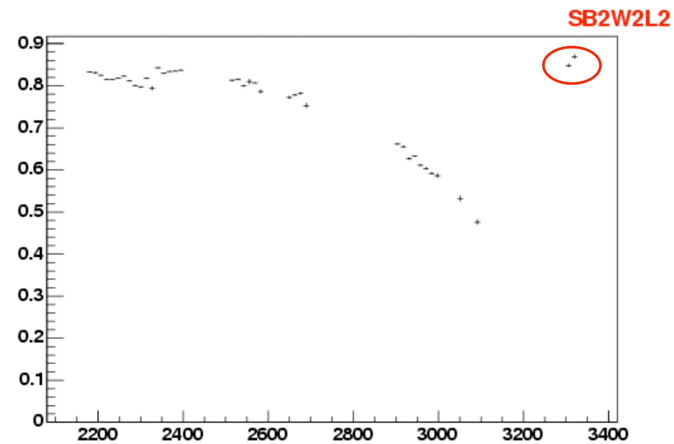
- Then, are the outer layers of no concern?

Aging in the Micron Layers (L2 & L4)

Some ladders in L2 and L4 had a recent efficiency drop (9 out of 172)

-Layers became under-depleted as they aged.

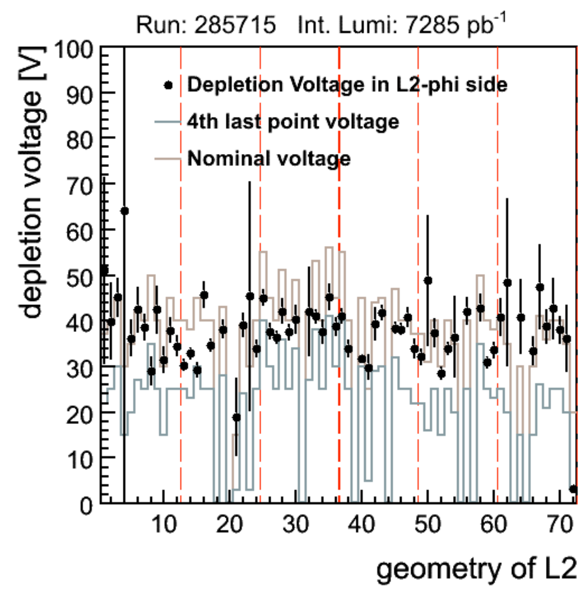
-All 9 had their bias increased with no increases in noise.



Readout Time

-Increases in noise in increases in the detector readout time, which increases the Likelihood of harmful "wire bond resonance" conditions.

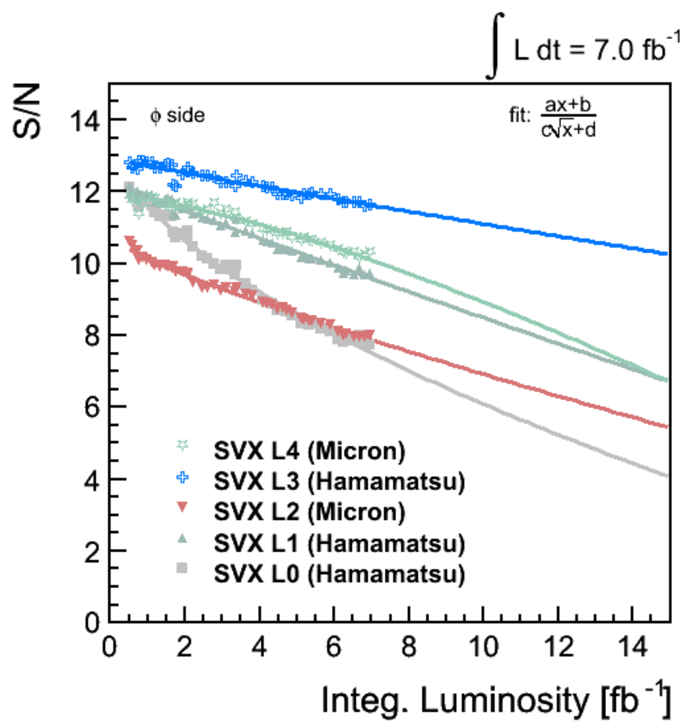
-Recent work on noisy ladders ADC thresholds has reduced our average readout time, and allowed increases the L1 trigger rate from 25kHz to 31kHz (first of our 3 level trigger system)



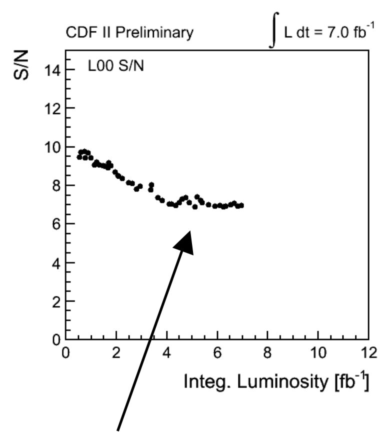
SVXII Signal / Noise Projection

Signal from J/ψ → $\mu^+\mu^-$ tracks strip cluster charge,
Noise estimation from regular calibrations

r-phi

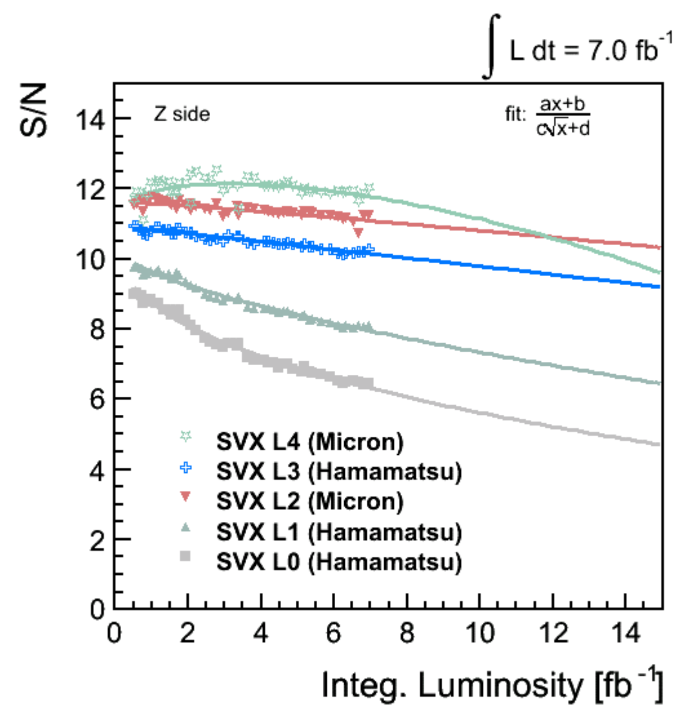


L00

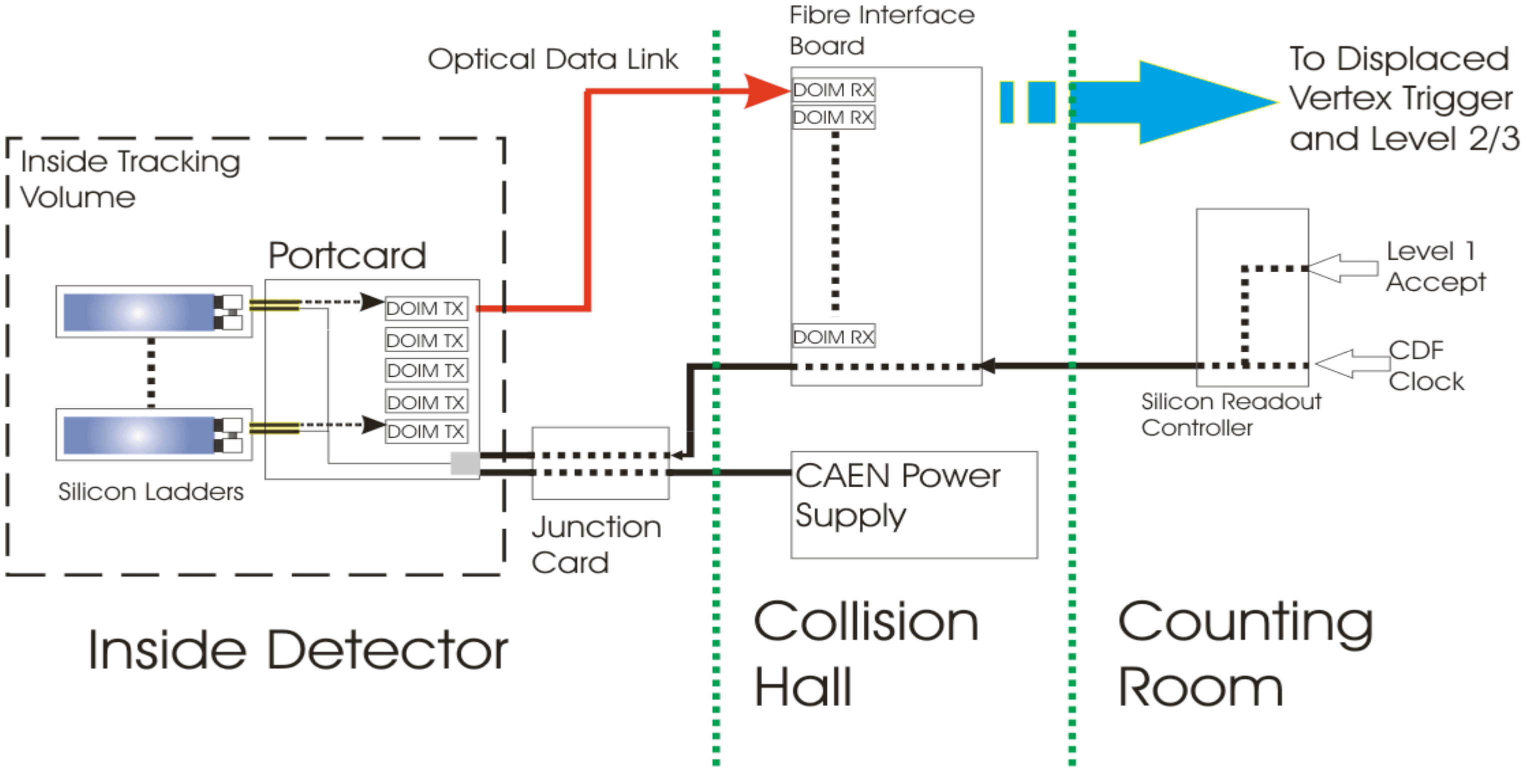


S/N has leveled off
in L00 !!

z



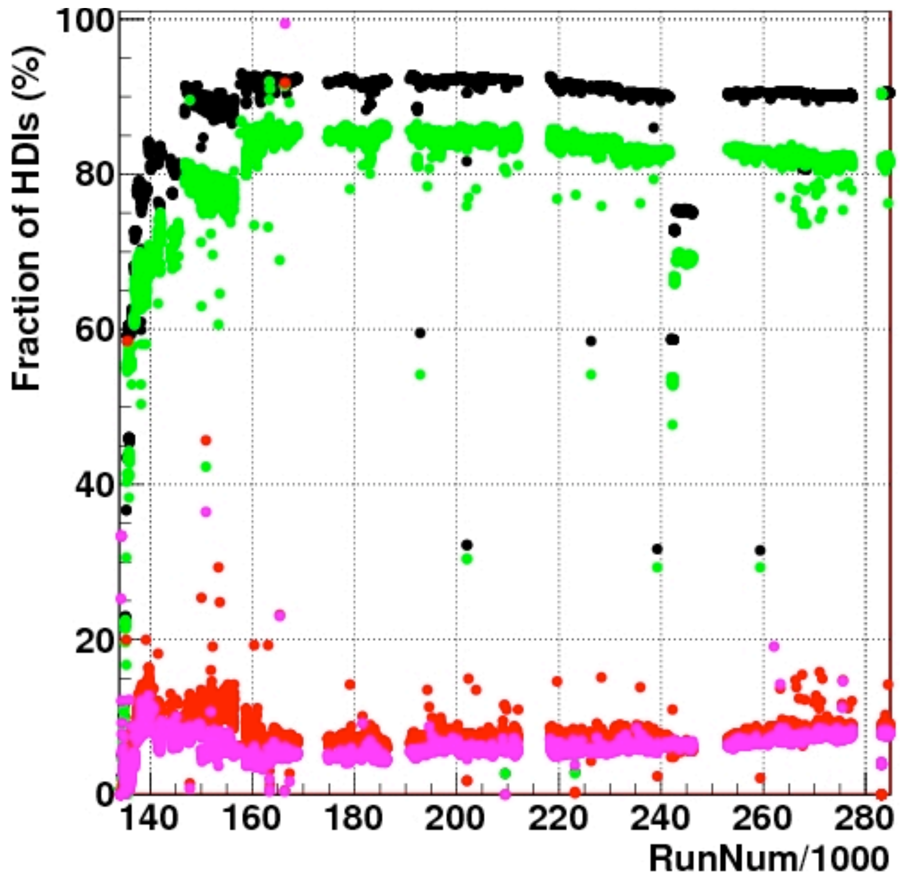
Not only the sensors are in a radiation environment



- Main components:
  - Silicon Readout Controller (SRC): “brain” of the system
  - Fiber Interface Board (FIB): control signals and optical readout
  - Portcard: chip commands and optical transmitters (DOIMs)

Leaving NO Ladder Behind

- Detector was designed for Run IIa (2-3 fb^{-1})
- Currently ~90% ladders integrated, ~80% good (< 1% error rate), ~10% bad with an average error rate of 10%
- Maintaining this level of integrity means a lot of work from the group; we use almost <u>every</u> opportunity for diagnostic and repair work



- **Great performance after 9 years of running !**

Readout Chip Accounting

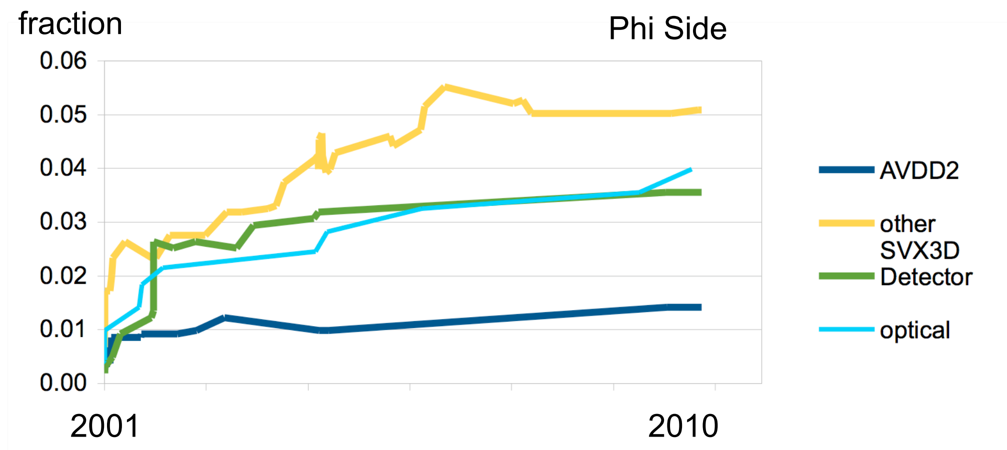
Some of the common failure modes:

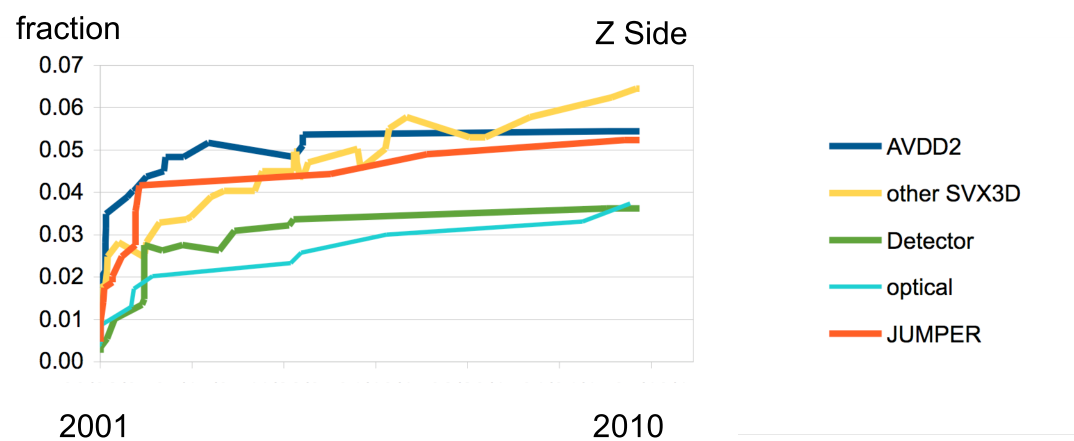
➢Detector = Port-cards, Junction Cards, cables, and sensors issues.

➢Optical = errors from the TX data transmitters in the port-cards

➢Jumper failures = chip damage due to resonances

➢AVDD2 = a SVX3D chip failure mode caused by thermal cycles



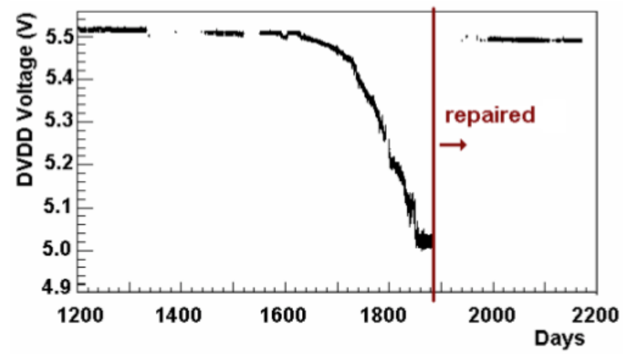


Other Operational Challenges

- **CAEN SY527 Power Supplies**

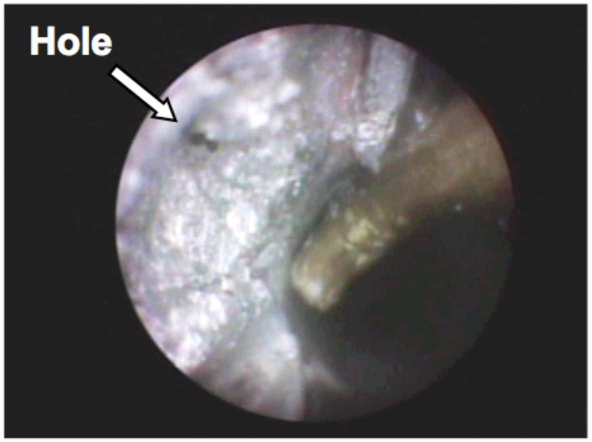
  -Communication loss, corrupted read-back, spontaneous switch off,leaking capacitors

  -A significant fraction of the supplies has been repaired



- **ISL Cooling Repairs**

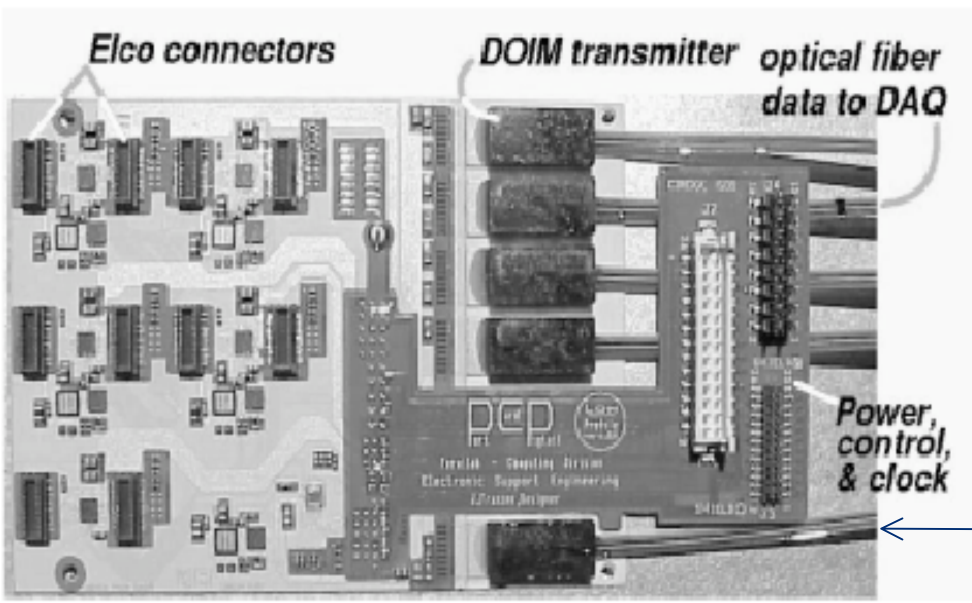
  -Glycol-water mix turned acidic causing corrosion.
  -Repairs are challenging, access is possible only from inside the cooling conduits.
  -Repairs during the 2007 and 2009 shutdowns have significantly improved the tightness of the system
  -Additional repairs to conical manifolds are planed for this summer

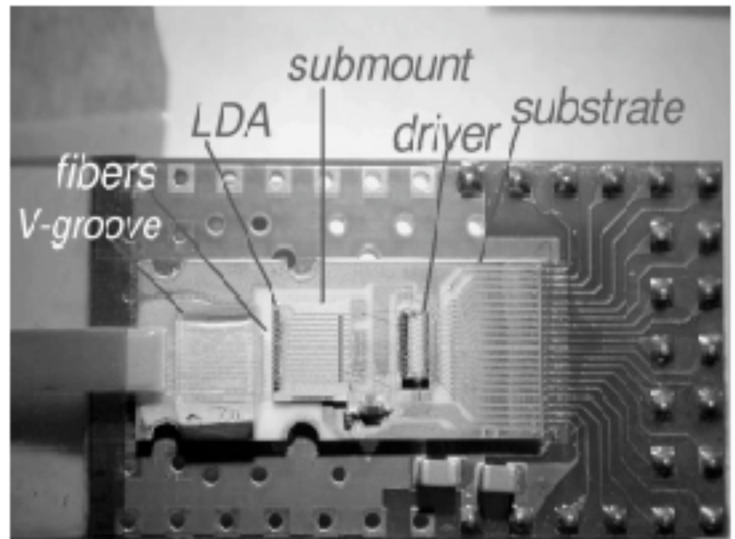


- **Maintaining spare electronic components is a challenge but we have been successful in maintaining our spare pool**

DOIM Longevity

- Dense Optical Interface Modules (DOIMs) are mounted on the Port Cards, inside the bore, 10 cm from the beam axis
- Chosen for high bandwidth data transmission with low mass optical fibers
- Array of 9 edge laser diodes





DOIM TX

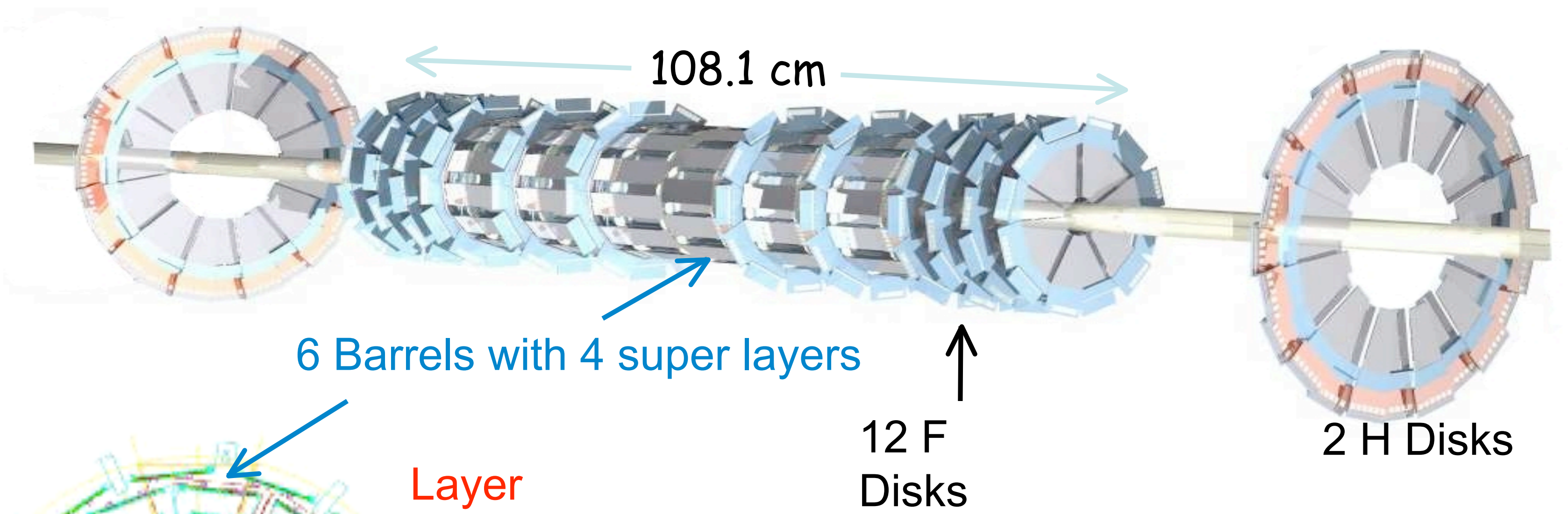
PORD CARD

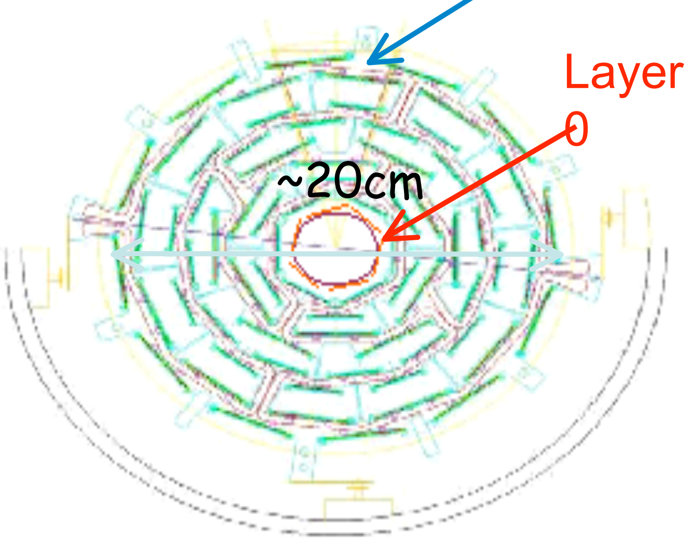
DOIM Longevity

- Solid state device that experiences the same kind of radiation damage as the silicon sensors themselves
- Beam tests which measured the decrease in output intensity linear with total dose: **80±20% for 400 krad dose**.
- Integrated luminosity of 20 fb^{-1} is about 0.5 Mrad to the most exposed DOIMs.
- No evidence so far of significant losses, but a compilation and analysis is underway to study this effect further
- Amplification nevertheless is in principle possible.

DØ Silicon Micro-strip Tracker

Provided by the DØ silicon group

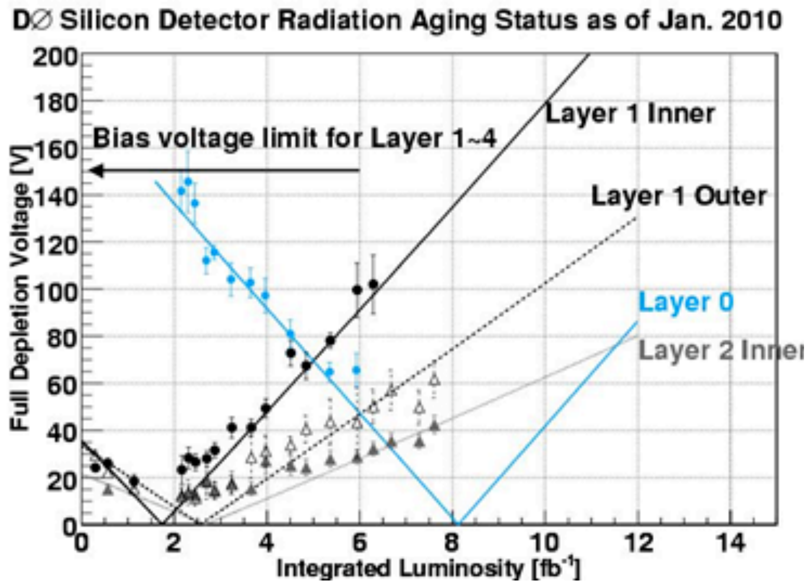




	Layer0	Barrel	F Disk	H Disk
Channels	12288	387072	258048	73728
Inner R	1.61 cm	2.7 cm	2.6 cm	9.5 cm
Outer R	1.77 cm	10.1 cm	10.5 cm	26 cm

all AC-Coupled readout

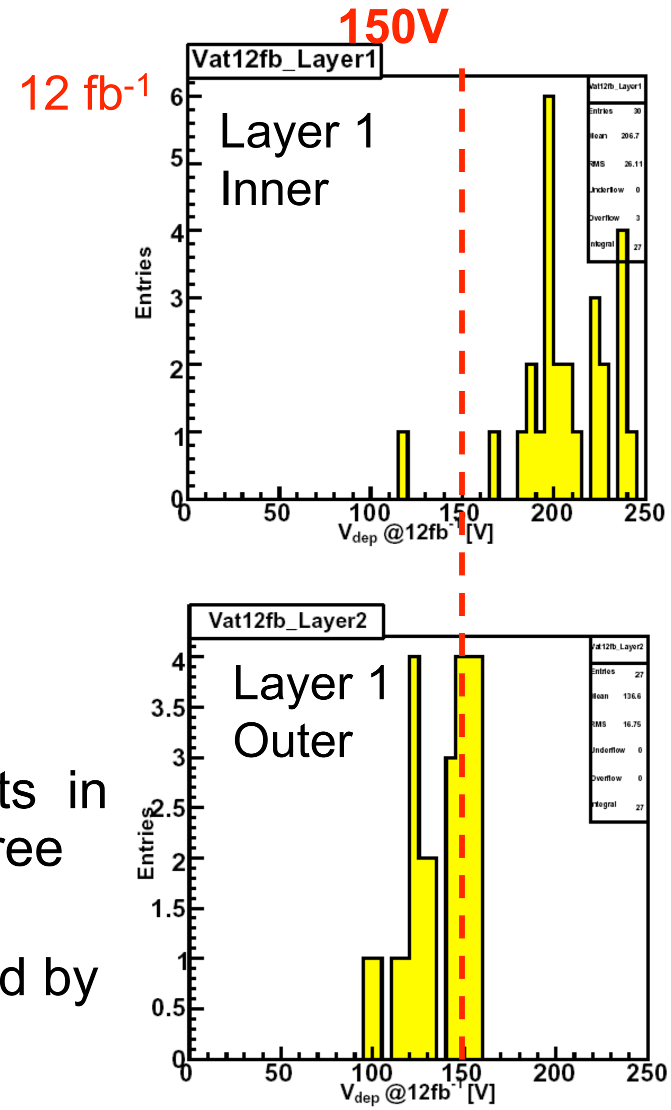
Full Depletion Voltage



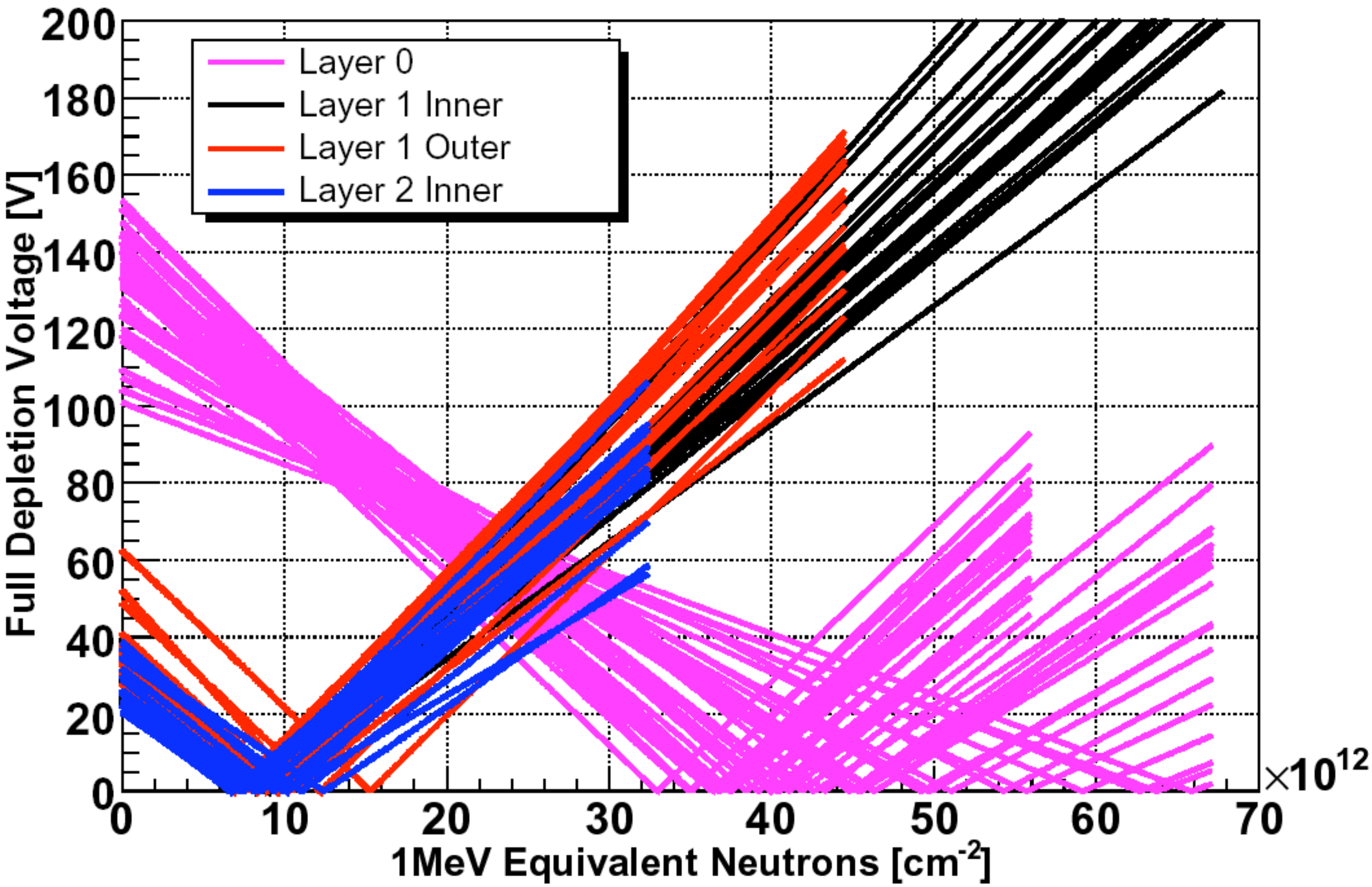
↑ Only showing data points from p-side charge collection study (We have also determined full depletion voltage by looking at noise measurements in bias scan. Measurement s using both methods agree with each other)

→Layer 1 sensors might no longer be fully depleted by the end of the Tevatron Run II

Anticipated and compensated by Layer0



Full Depletion Voltage vs Radiation



Summary

- The CDF Run II silicon detectors are in good health after 9 years of operation.
- The inner layers have long progressed through inversion and exhibit consistent post-inversion behavior.
- Most ladders in SVX-L0 and SVX-L1 layers and the rest of the detector are expected be operable with high efficiency to 11 fb^{-1}
- L0 (in DØ L1) will begin to be affected beyond that point, which does not <u>significantly</u> affect the CDF b-vertex detection (DØ might be more sensitive to loosing its inner layer)
- <u>DØ is currently performing further studies to determine their ability to run beyond 2011</u>
- For CDF, Collecting up to 20 fb^{-1} seems possible, the biggest challenges might not be the sensors themselves.

Backup Slides

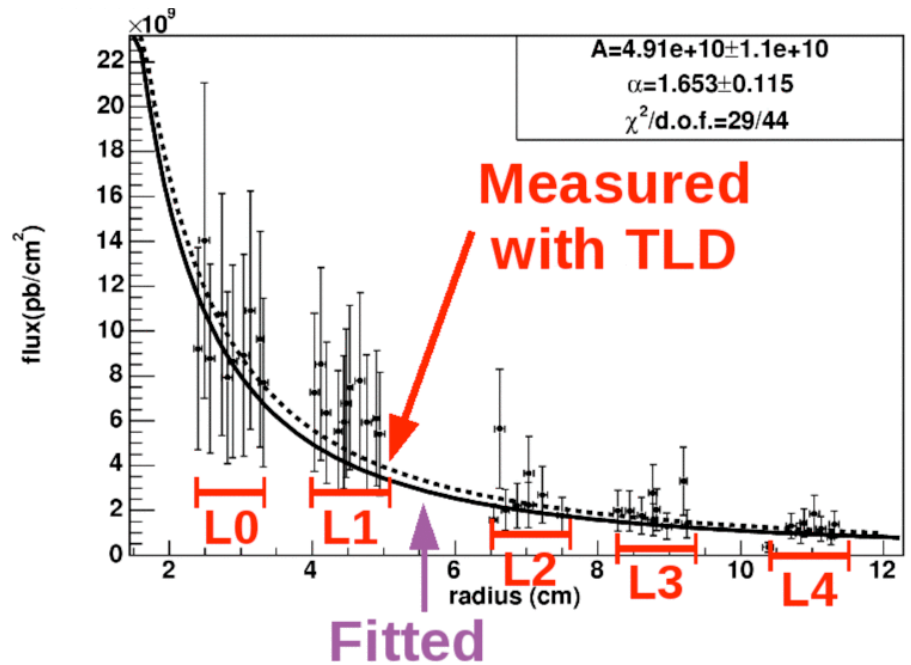
Evolution of Bias Currents

- Fluence in the CDF detector volume is **dominated by the physics collisions** - related to the delivered luminosity.

- The fluence – integrated luminosity relationship depends on distance of the sensor to the beam, and is computed by extracting the fluence from the change in bias current.

- Using a 95 pb^{-1} data sample collected in 2004, a damage factor of **1.65 ± 0.12** was extracted from bias current data (P. Dong et al. CDF/7275).

- Bias evolution and TLD measurements agree well



SVX layer	r (cm)		pitch (μm)		*stereo angle* (deg.)	N *module* [*tot.*]	$\%X_o$ avg. [*max.*]
	in	out	$r\varphi$	z			
0	1.35	1.62	25	-	-	36/36	
L00						[72]	0.6 [1.1]
1	2.5	3.0	60	141	90	36	
2	4.1	4.6	62	125.5	90	36	
3	6.5	7.0	60	60	+1.2	36	
4	8.2	8.7	60	141	90	36	
5	10.1	10.6	65	65	-1.2	36	
SVXII						[180]	7.0 [15.0]
6 C	22.6	23.1	112	112	$\mp$1.2	28	
6 F/B	19.7	20.1	112	112	$\pm$1.2	48	
7 F/B	28.6	28.9	112	112	$\mp$1.2	72	
ISL						[148]	1.0 [5.0]