Radiation hardness experience in CDF/DØ silicon detectors

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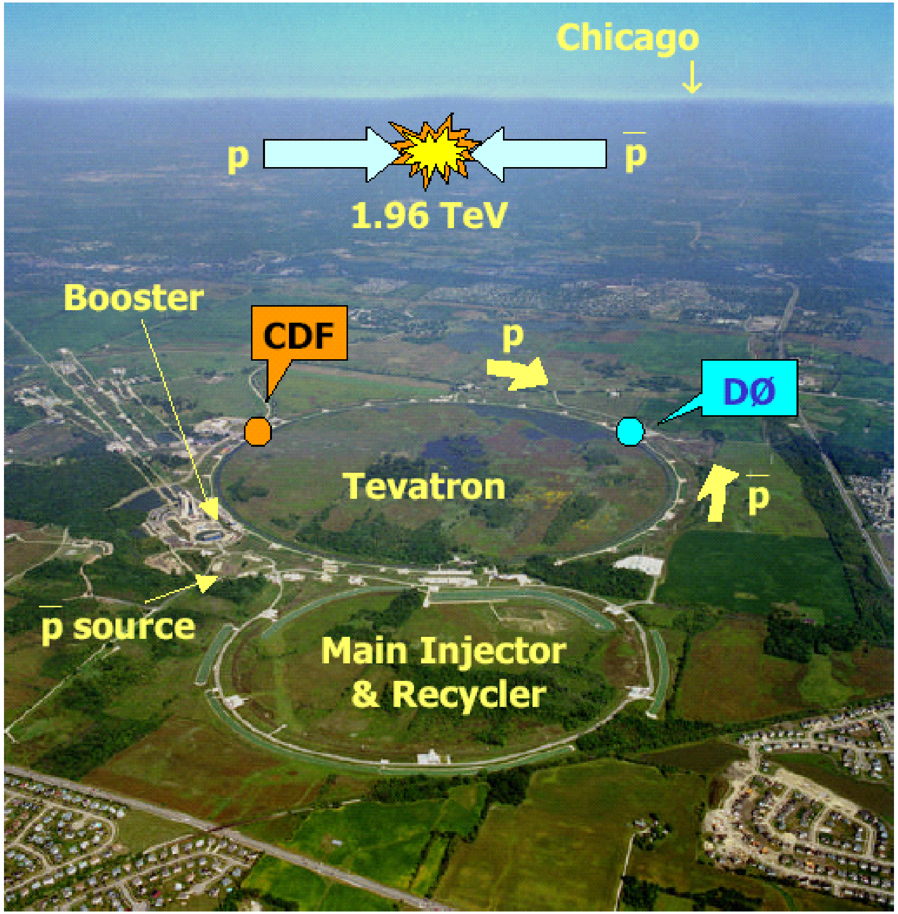
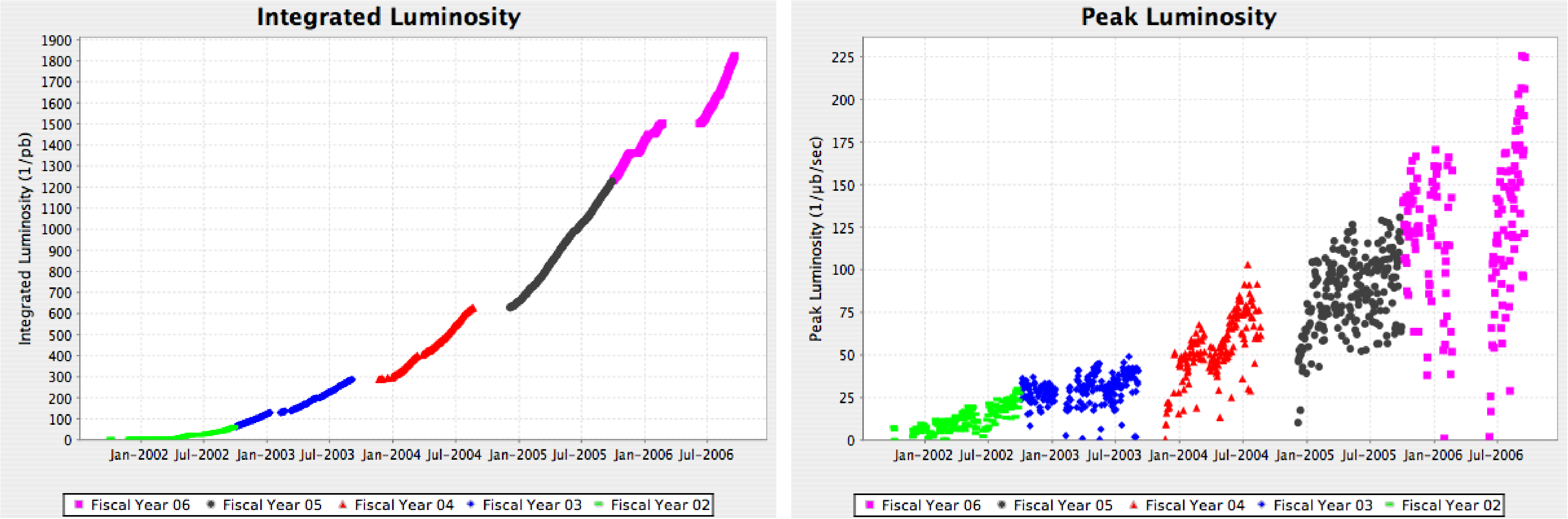
Tevatron Run-II

- Run-II energy 1.96 TeV
- Proton-Antiproton collisions
- 36 x 36 bunches
- Bunch spacing 396 ns
- Luminosity goal:
  - 8 fb^{-1}(*Design*)
  - 4 fb^{-1}(*Base*)
- Two collider experiments, **CDF** and **DØ**



Tevatron Performance



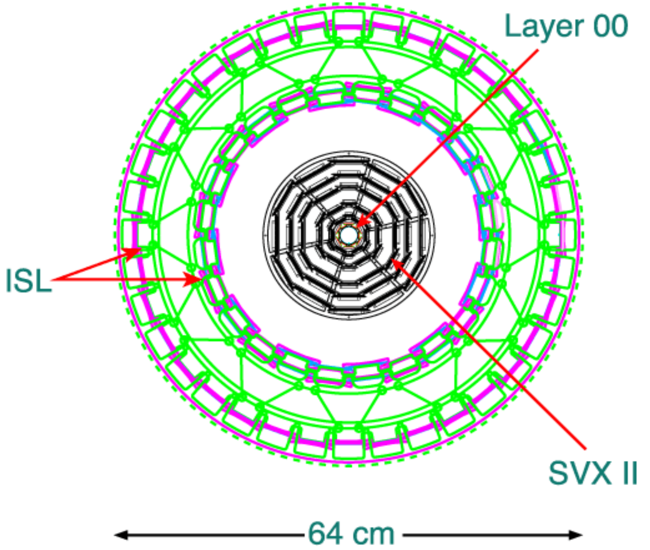
The machine is performing very well !

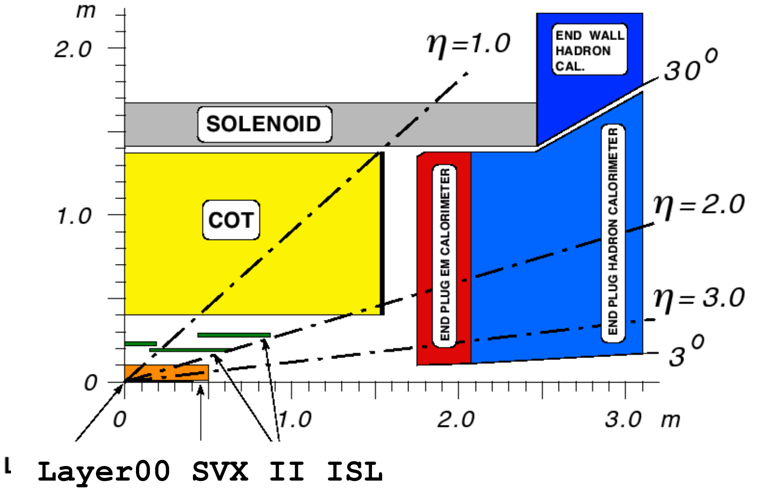
Highest instantaneous luminosity : 229 10^{30} cm^2 s^{-1}
Delivered luminosity /week : > 30 pb^{-1}
Delivered luminosity (Run-II) : 1.8 fb^{-1}
Delivered luminosity (Run-I) : ~150 pb^{-1}

Tevatron expects to deliver 5 to 8 fb^{-1} by the end of Run II

The CDF Silicon Detector

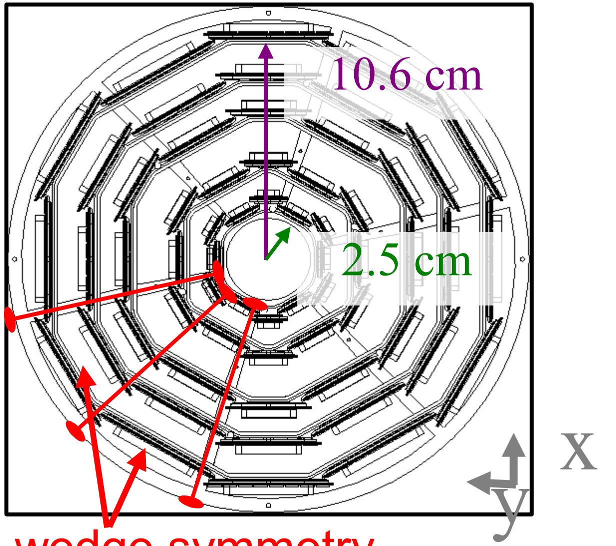
- Versatile Silicon detector
  - Three components: SVX-II, ISL, L00
  - 7-8 layers, 722432 readout channels
  - 7 m^2 of Silicon
  - 3D hit information
- Data used in L2 Trigger (SVT)
  - Deadtimeless chip (SVX3D)
  - Fast parallel readout
  - L1 Accept Rate 35-40 kHz
  - Use Dynamic Pedestal substraction



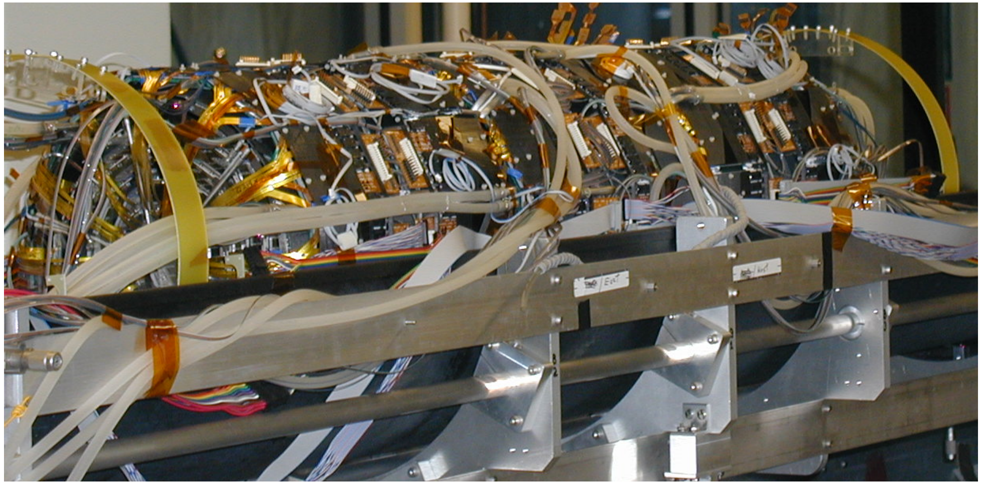


CDF SVX-II

- 6 bulkheads and 5 layers
  - 12 wedges per layer
  - Highly symmetric (for SVT)
- Double Sided Silicon
  - Layers 0,1,3 with rΦ/rZ (Hamamatsu)
  - Layer 2+4 Small Angle Stereo(SAS) (Micron)

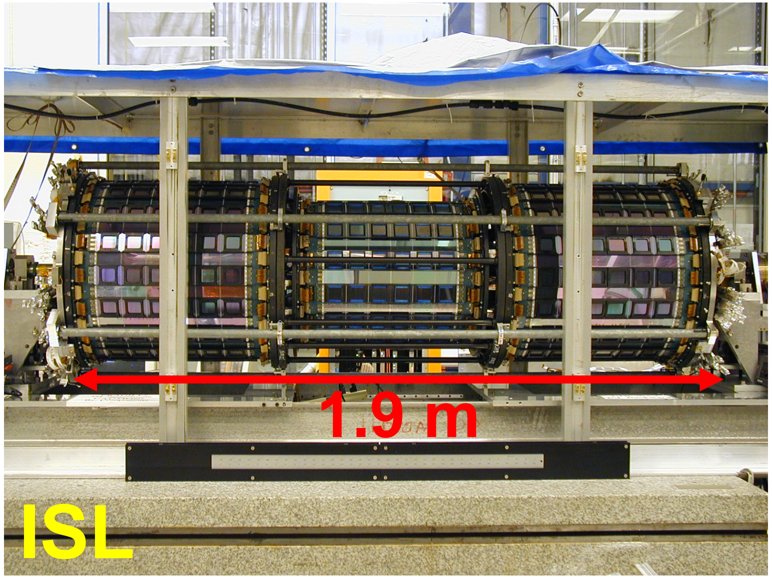


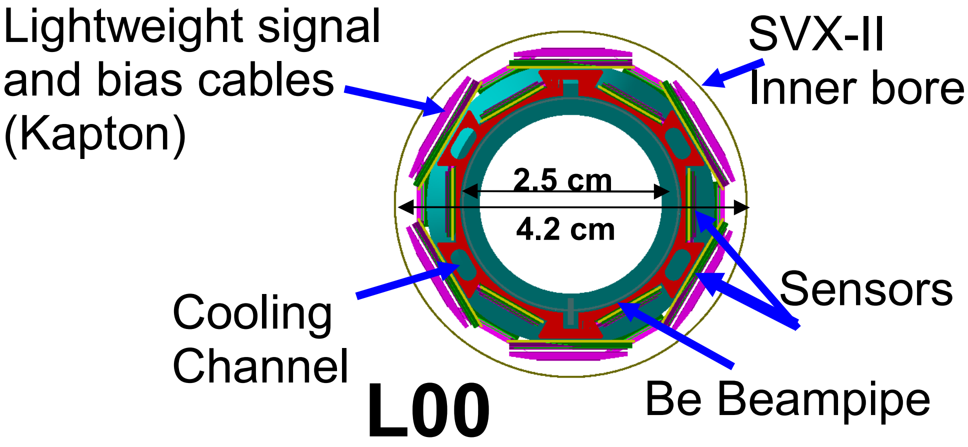
Note wedge symmetry



CDF ISL & L00

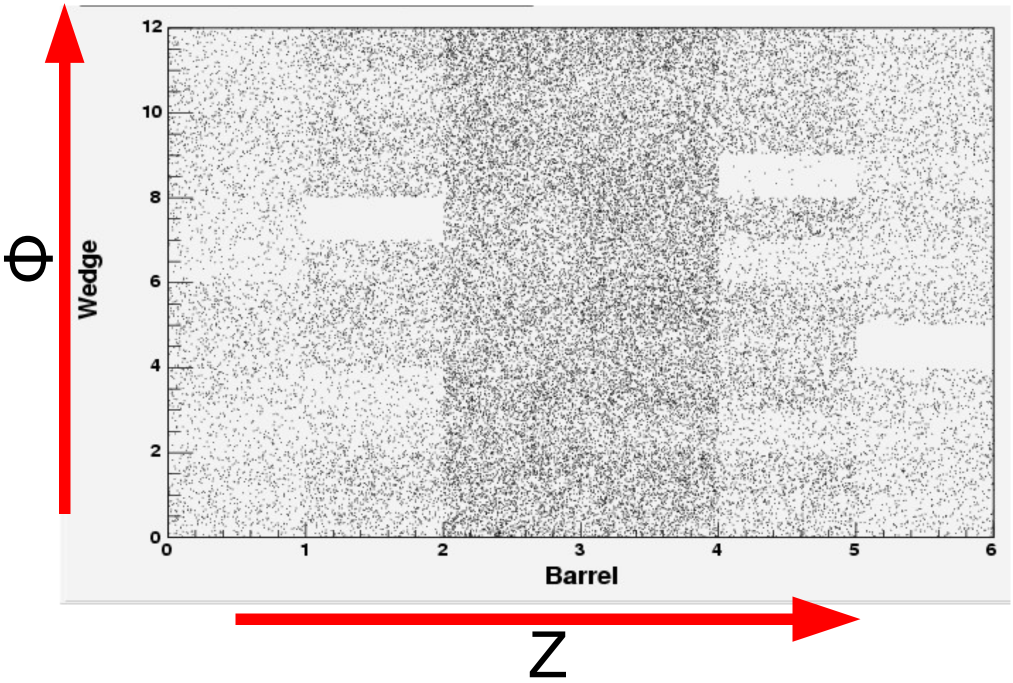
- ISL
  - 2 additional layers
  - SAS Hamamatsu+Micron
  - adds forward coverage up to |η|=2
- L00
  - LHC style Silicon
  - single-sided
  - actively cooled
- Both are not part of the trigger



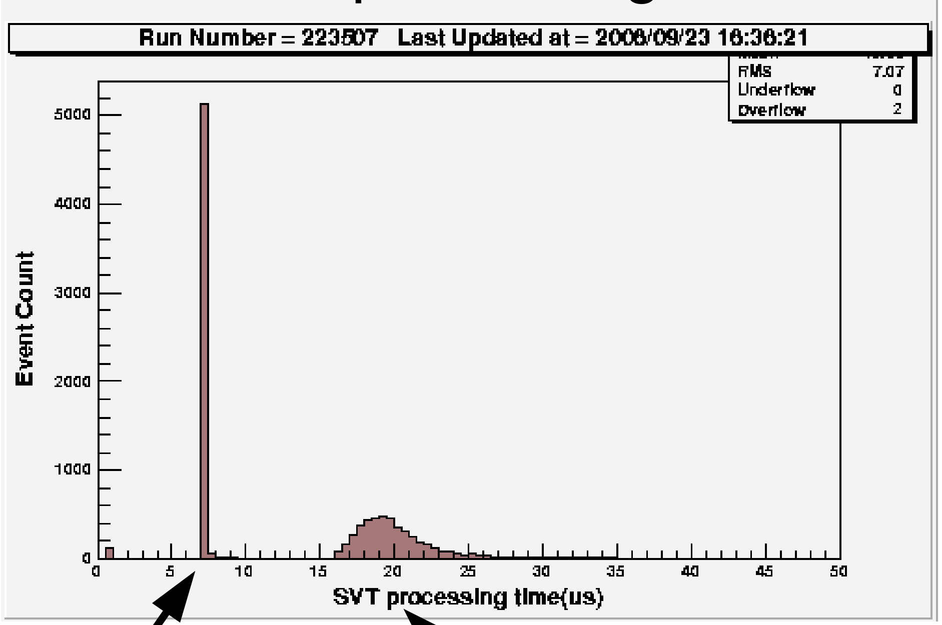


CDF: Impact of SVT

SVT coverage



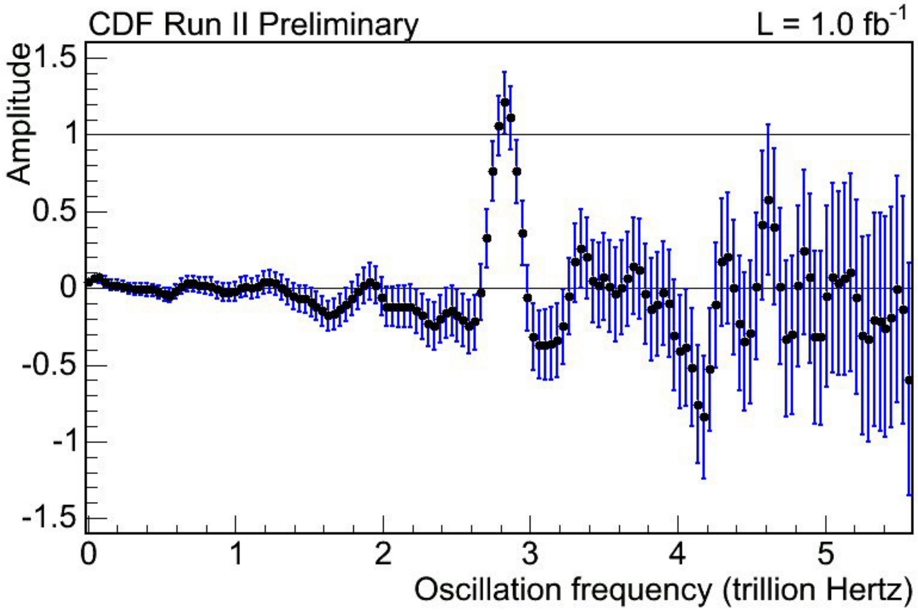
SVT processing time

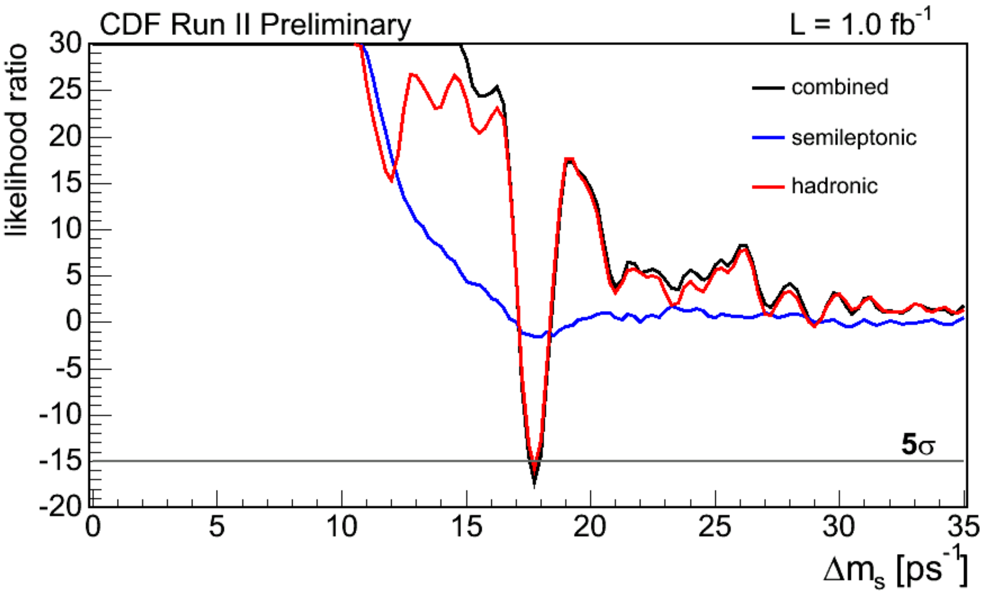


No L1 Tracks
fast abort

SVT processes
SVX-II data

CDF's latest result

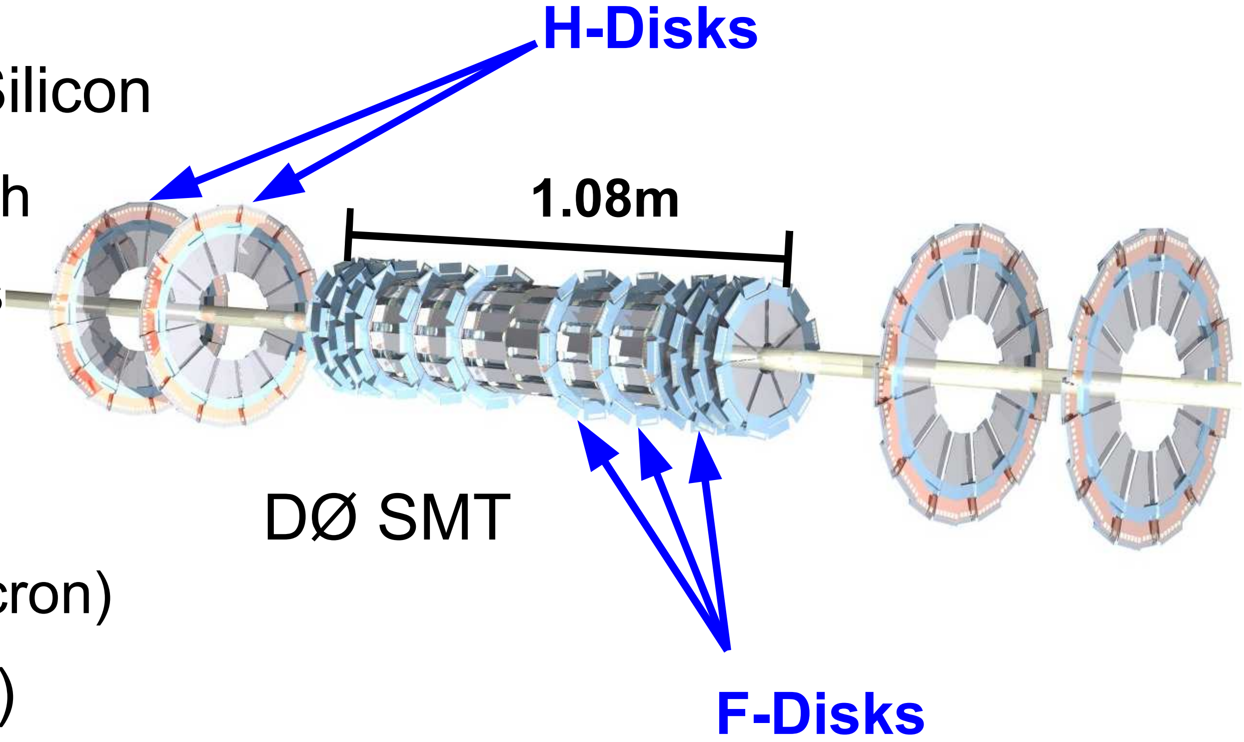




$$\Delta m_s = 17.77 \pm 0.10(\text{stat}) \pm 0.07(\text{sys})$$

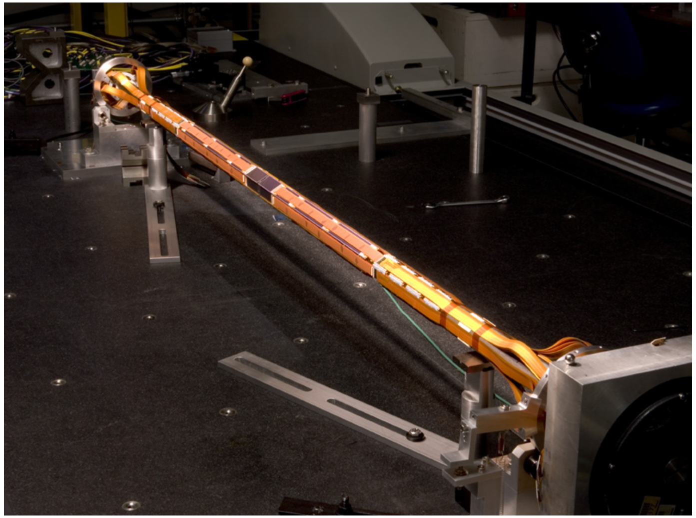
DØ Silicon Microstrip Tracker

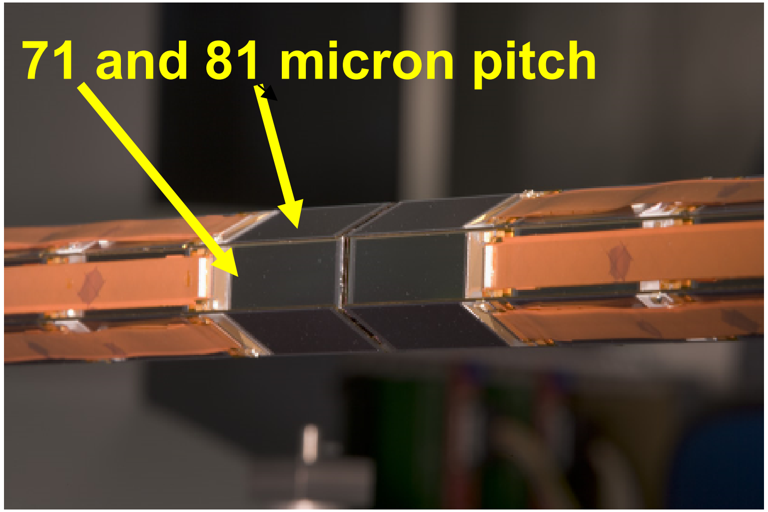
- Single system 3 m^2 of Silicon
  - 6 barrels, 4 layers each
  - 12 F-disks + 4 H-disks
- Layer 1+3
  - IN rΦ/rZ (Micron)
  - OUT Single sided (Micron)
- Layer 2+4 SAS (Micron)
- F-Disks SAS (Micron/Eurysis)
- H-Disks SAS (ELMA)
- Used in L2 Trigger ->L1 Accept rate ~ 5 kHz



DØ L0

- Most recent upgrade
- Placed inside Layer 1
- Installed during 2006 Shutdown
- The detector consists of:
  - 48 modules arranged in 6 wedges
  - Module length : 12 and 7 cm
- See D. Tsybychev's talk





71 and 81 micron pitch

Detector Longevity

For CDF and DØ, radiation damage to the sensors is the main concern for detector longevity.

Both experiments define several criteria for the lifetime

- Inability to deplete the sensors
  - The innermost layers L0 (CDF) & L1 (DØ) are most critical
  - Depletion voltage limit is sensor dependent
- S/N degradation due to radiation damage
  - There is no fixed S/N at which the hit reconstruction will be impossible, things can be recovered by smarter software
  - Impact on L2 trigger efficiency

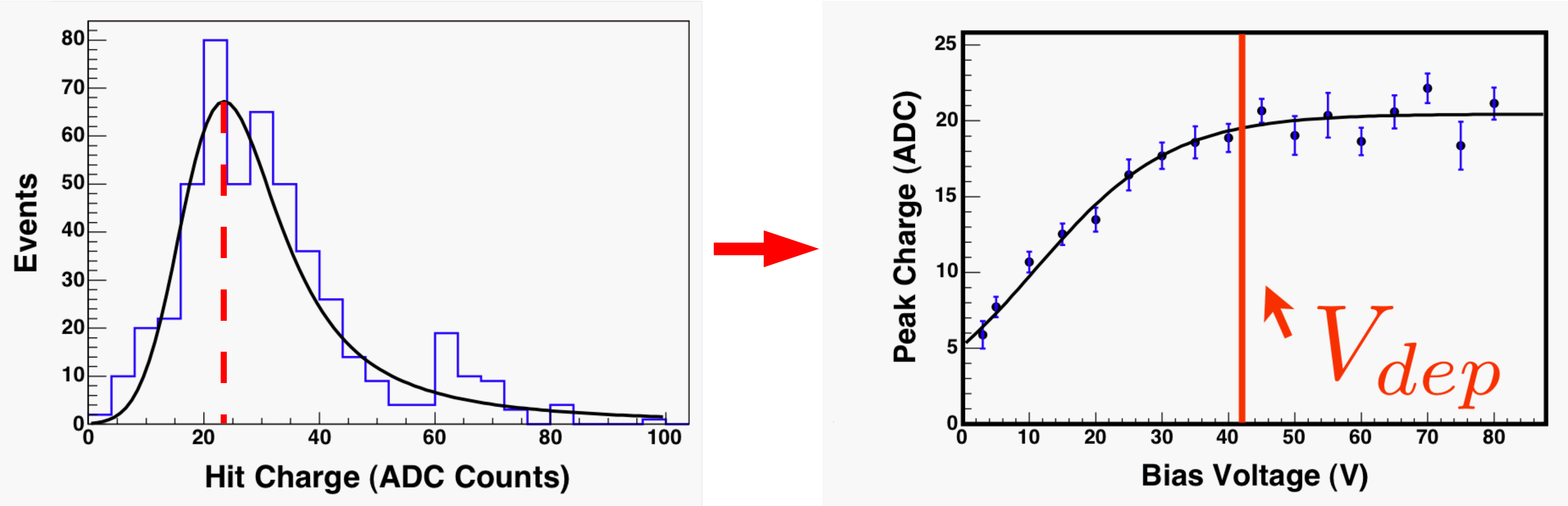
CDF & DØ Studies

- CDF
  - Depletion voltage measurements (Bias scans)
  - Bias current monitoring
  - S/N measurements using data
- DØ
  - Depletion voltage measurements (Bias scans)
  - Bias current monitoring

CDF: Depletion Voltage Scan

- Method to determine actual depletion voltage of the detector
- Signal scan
  - Requires beam time
- Noise scan
  - Can be done during no beam time
  - Works only with double-sided Silicon
- The maximum bias voltage is limited by the sensor's integrated capacitor
  - The breakdown voltage depends on the sensor type

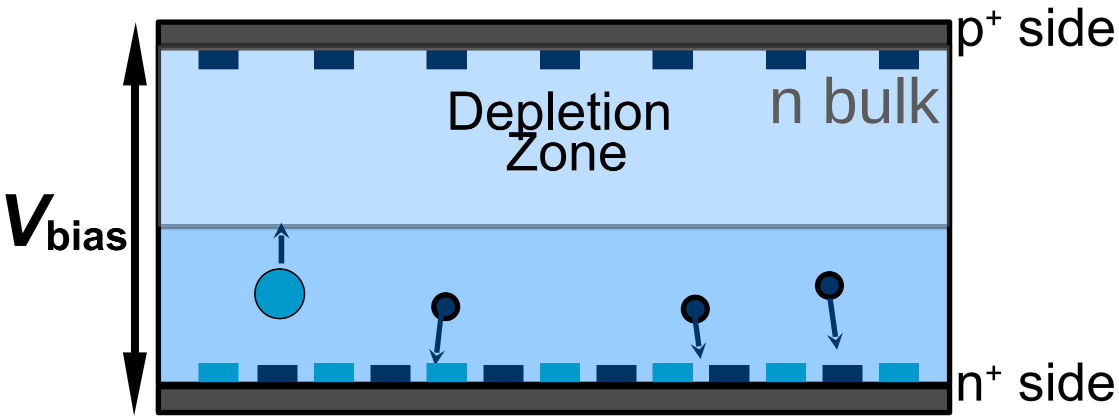
CDF Signal Scan

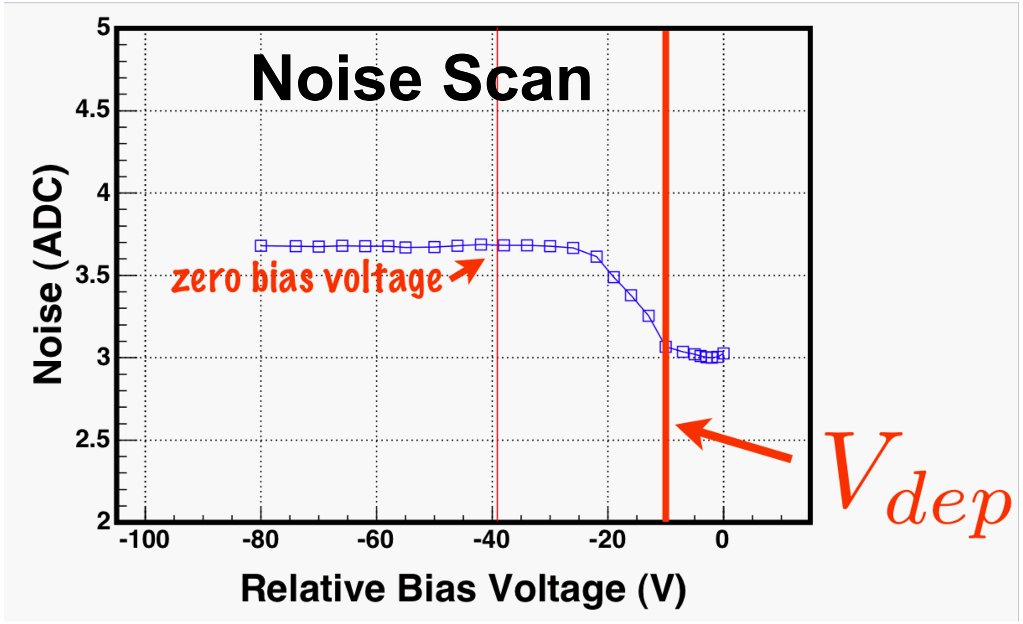


- Study collected charge of hits on tracks depending on bias voltage
- Fit Landau ⊗ Gaussian to determine the peak for each point
- Depletion voltage V_{dep} is 95 % amplitude of sigmoid fit

CDF Noise Scan

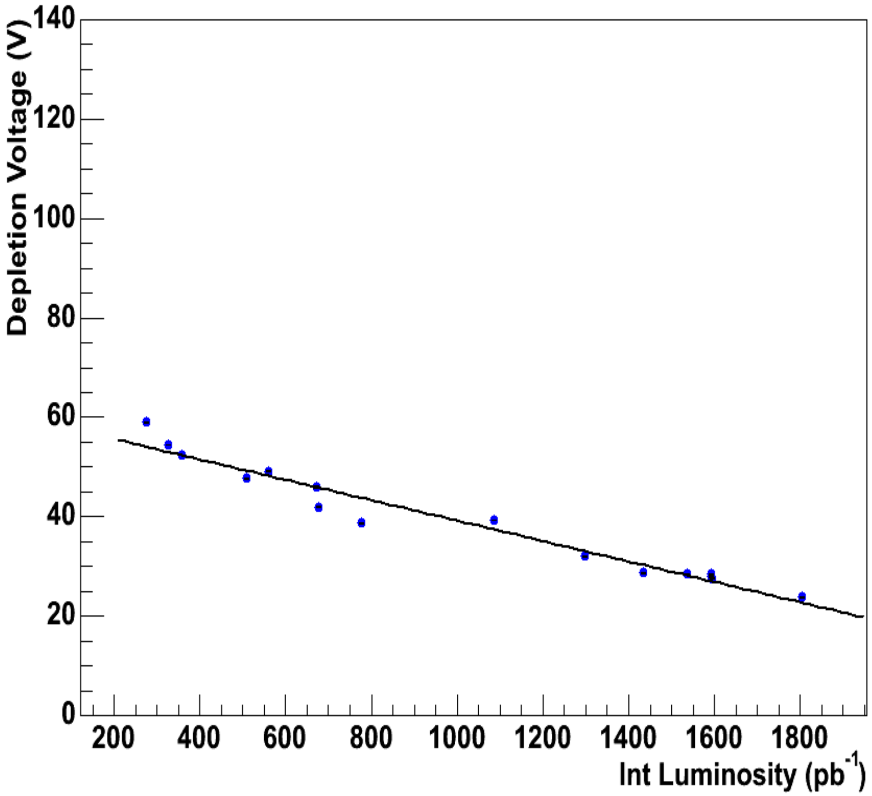
- Use dependence of the n-side noise on the bias voltage
- Depletion voltage derived from minimum in noise.
- Only works for double-sided detectors (SVX-II, ISL)
- Expected to work reliably till type inversion





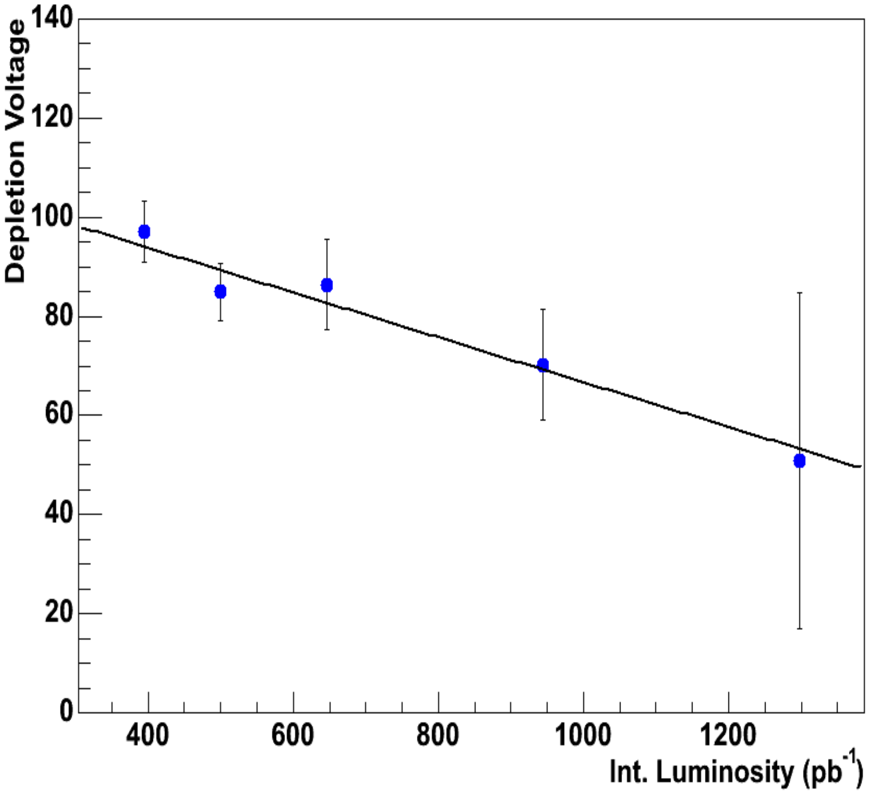
CDF Depletion Voltage Evolution

SVX Ladder From Innermost Layer



Data set 1.8 fb^{-1}

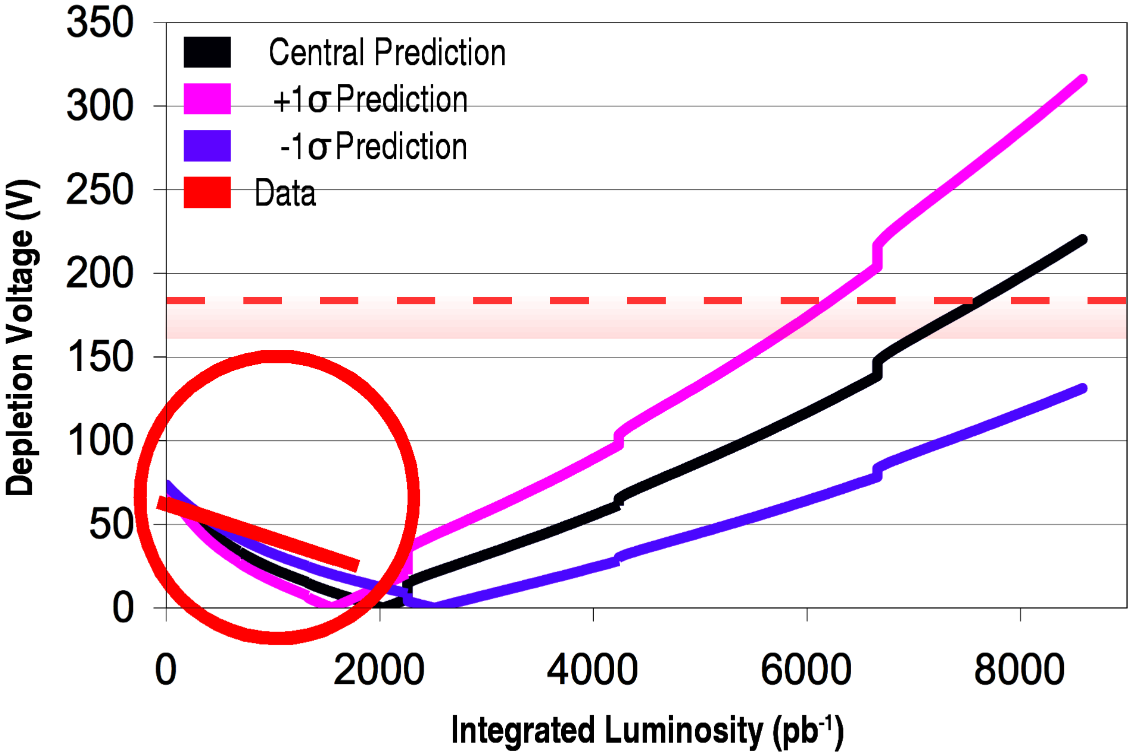
L00 Ladder from Innermost Radius



Data set 1.3 fb^{-1}

CDF Results

- Expect L0 of SVX-II to be the first layer which cannot be fully depleted
- L0 of SVX-II has not inverted yet, type inversion is expected around 2.9 fb^{-1}
- Extrapolation of current status assuming similar slopes before and after inversion: L0 of SVX will outlast Run-II



Prediction: S. Worm, "Lifetime of the CDF Run II Silicon," VERTEX 2003

CDF: Bias Currents

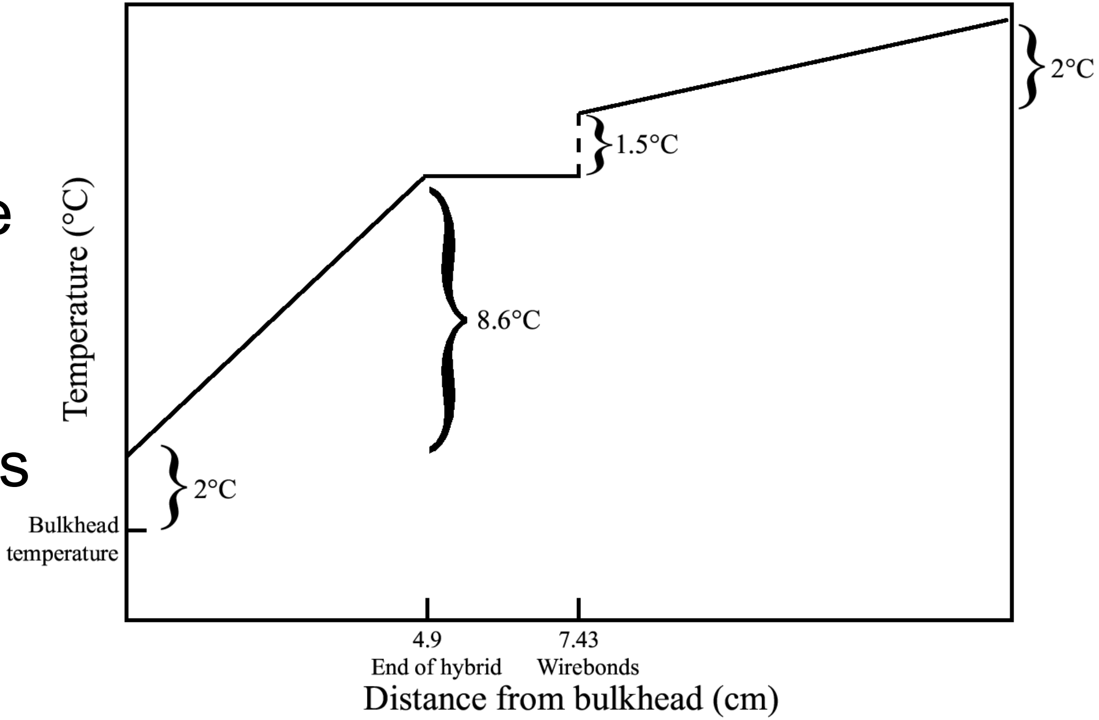
- Leakage currents are expected to evolve linearly with integrated luminosity
- Use the measured bias currents to determine
  - Leakage currents
  - Radial damage profile
- Requires knowledge of the sensor temperature
- Make a model based prediction for S/N evolution over luminosity
- Study uses data set with 95 pb^{-1} (May/June 2004)
- Takes into account the exact beam positions to correct for off-center beam position (asymmetric radiation)

CDF Temperature Modeling

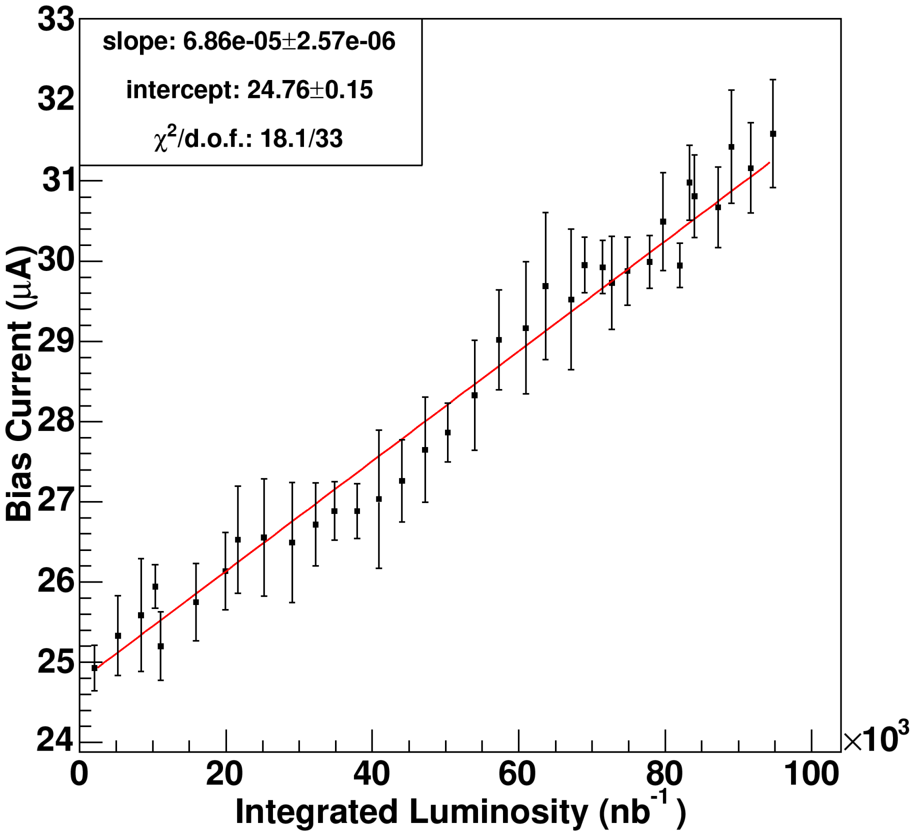
- The bias currents depend on the temperature

$$\frac{I_1}{I_2}=\left(\frac{T_2}{T_1}\right)^2\cdot e^{\frac{-E}{2k_B}\left(\frac{T_2-T_1}{T_2\cdot T_1}\right)}$$

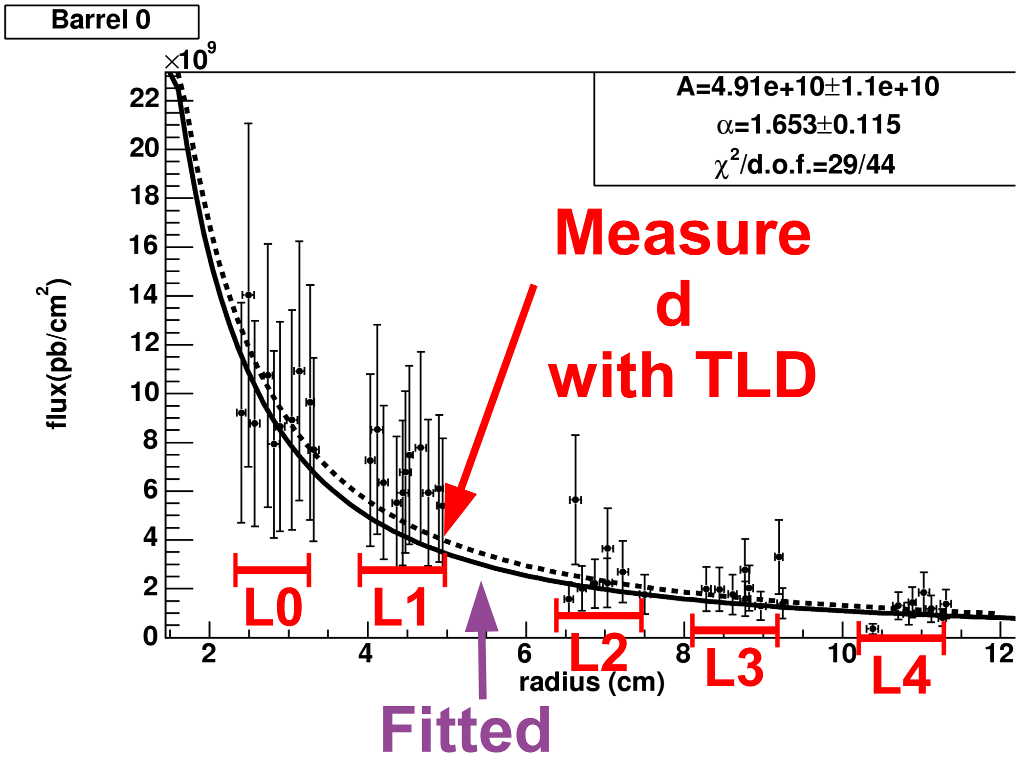
- However we cannot measure the temperature of the sensors directly
- Rely of finite element analysis modeling of the sensors, leading to large uncertainties
- This is the dominating systematic effect



CDF Results



Bias current shows expected linear dependence



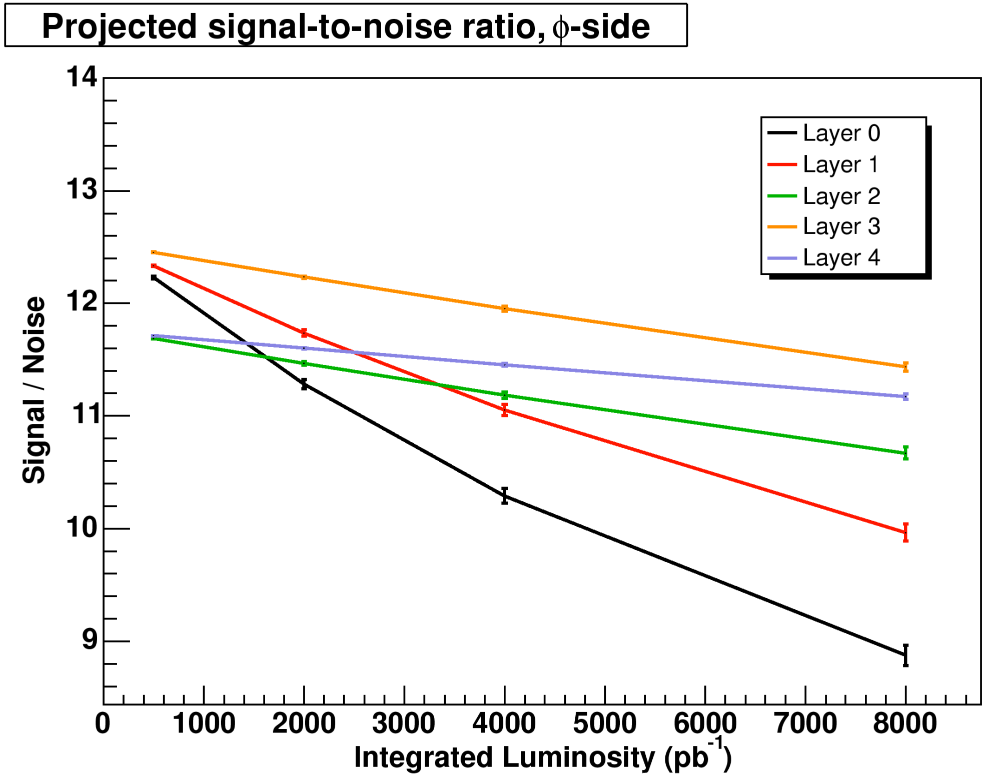
Measured with TLD

Fitted

Flux shows expected radial dependence

CDF S/N Predictions

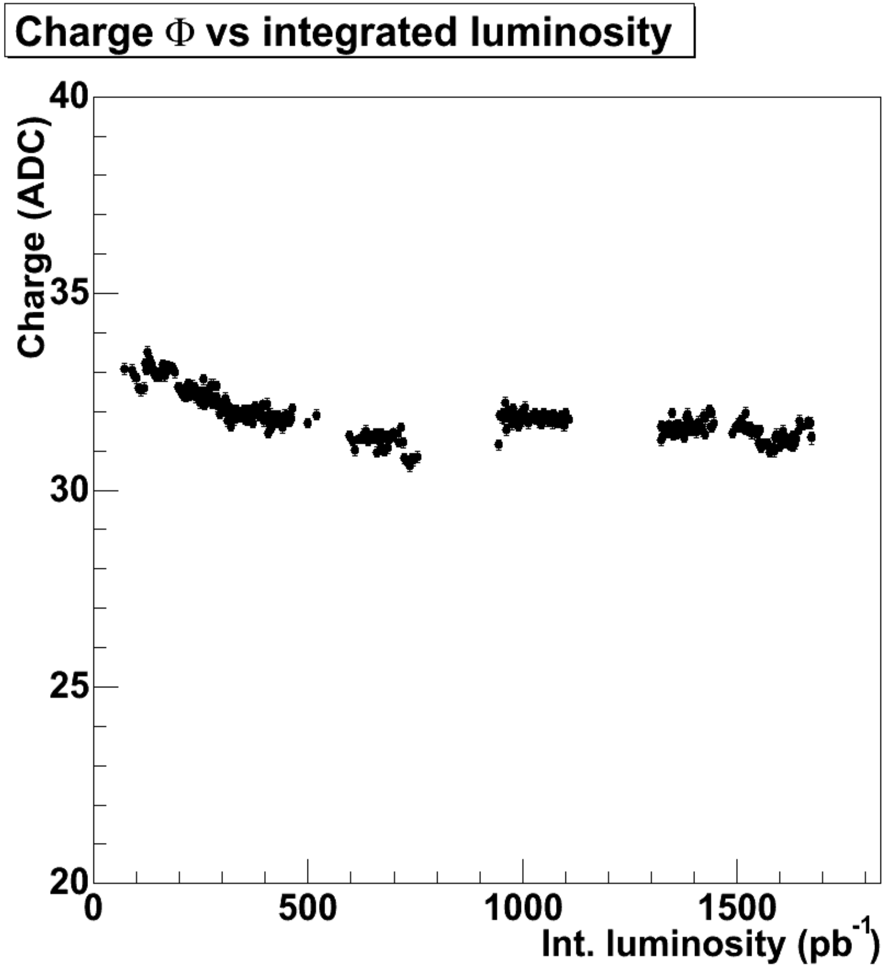
- Prediction uses
  - Shot noise (Dominant source)
  - Chip Noise
- Shot noise
  - Assume $I_{Bias} \sim I_{Leakage}$
  - $Q_{shot} = k\sqrt{I_{Leakage}}$
- Chip Noise
  - $Q_{chip} = f_1(\Phi_{Dose})C_{Chip} + f_2(\Phi_{Dose})$
  - 7 % Noise Increase per Mrad
- Model does not include signal degradation



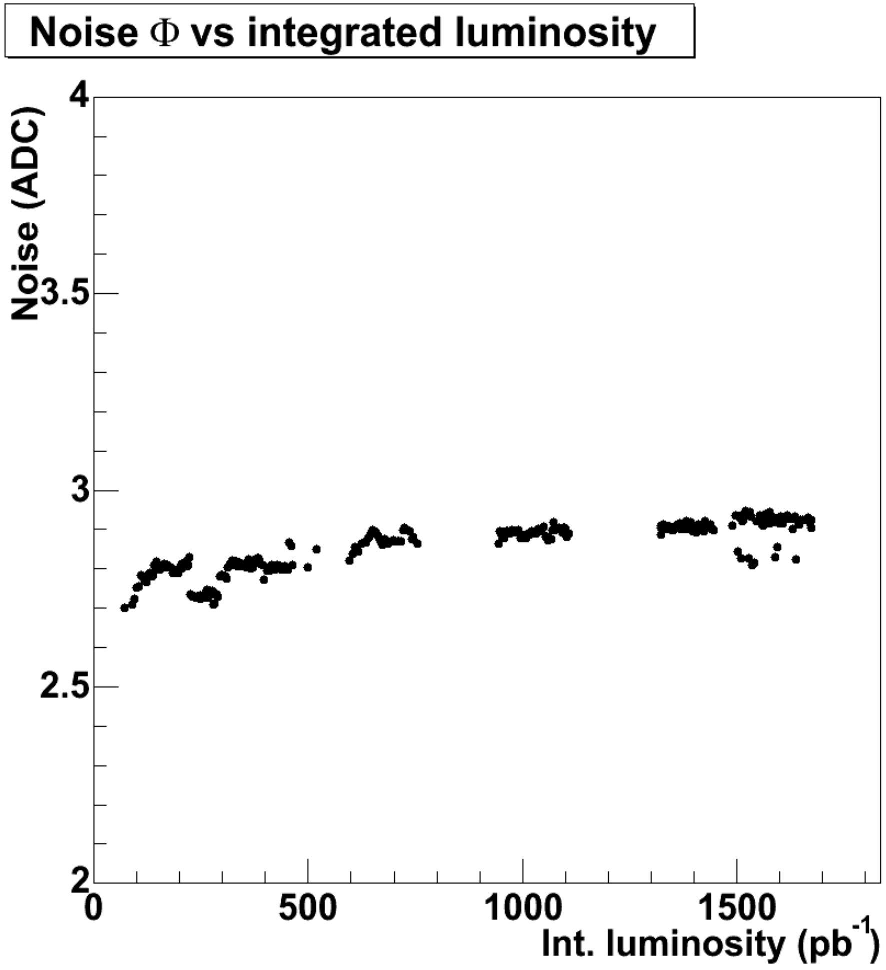
CDF S/N Measurements

- Idea : Derive S/N measurement from data.
- Using J/ψ di-muon data.
  - Signal is defined as path-corrected charge sum of cluster using hits on tracks
  - Noise is defined as the single channel noise
  - Calculate S/N from these measurements
- Use entire Run-II data set (1.7 fb^{-1} delivered)

CDF Signal & Noise

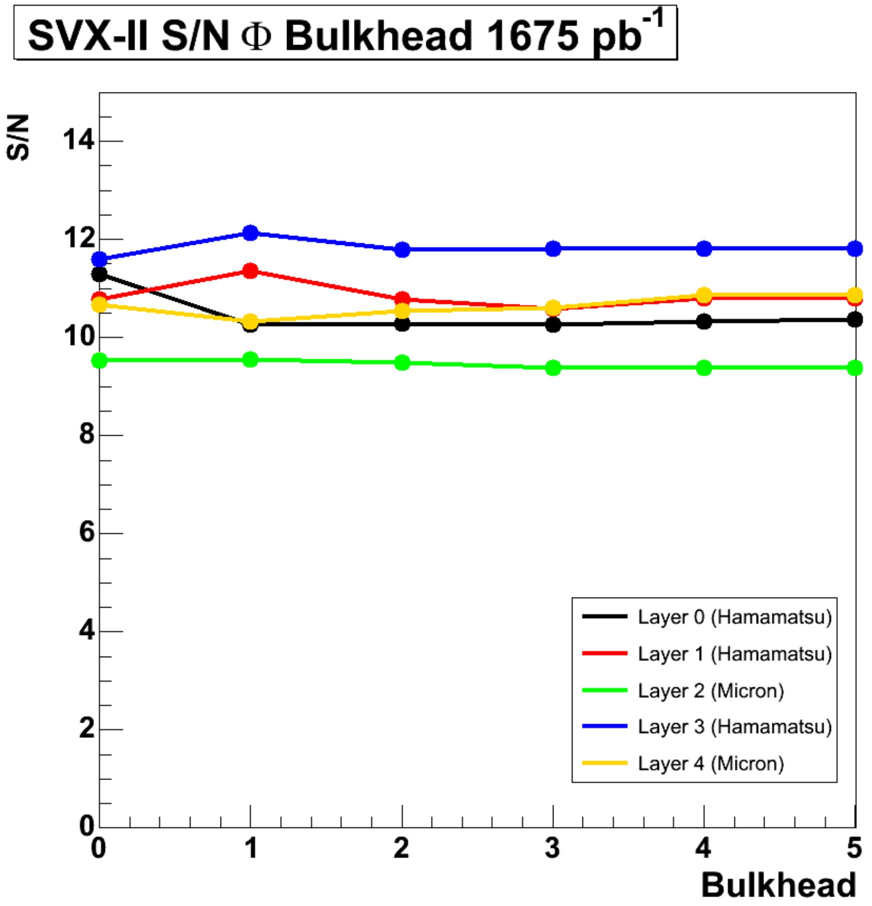

Charge Φ vs integrated luminosity

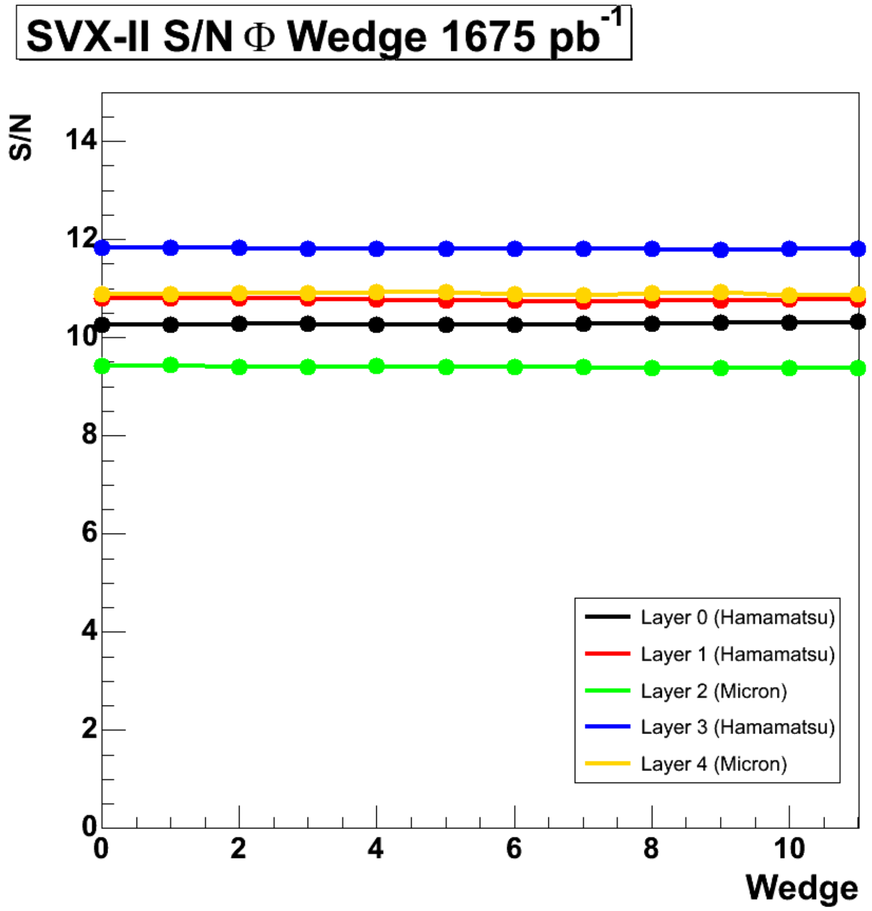
Signal in SVX-II Layer 1


Noise Φ vs integrated luminosity

Noise in SVX-II Layer 1

CDF Φ/Z Dependence



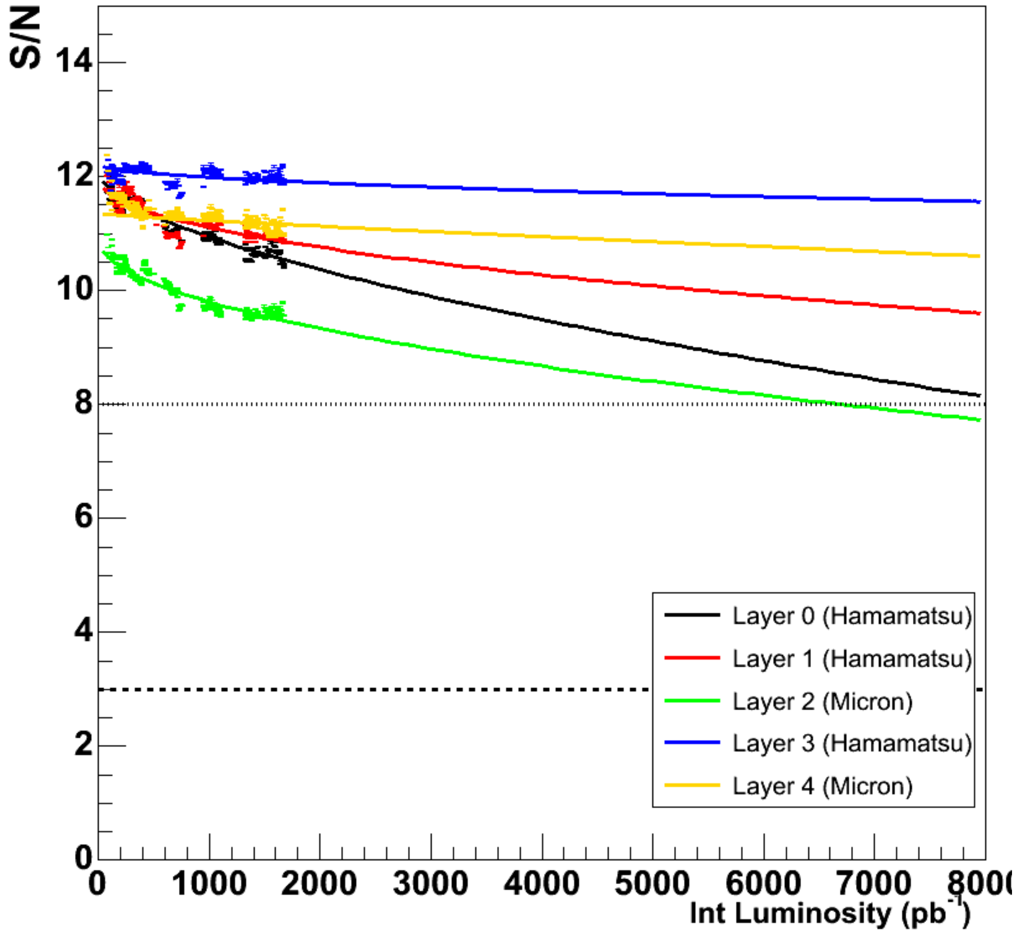


Uniform detector performance

CDF S/N Projections

- Excluded the first 164 pb^{-1} (Commissioning Phase)
- Simple model for luminosity dependence
  - Signal decreases linearly
  - Noise increase with square-root
- Use model to make projections from 1.7 fb^{-1} to 8 fb^{-1}
- Work in progress

SVX-II S/N Projection Φ



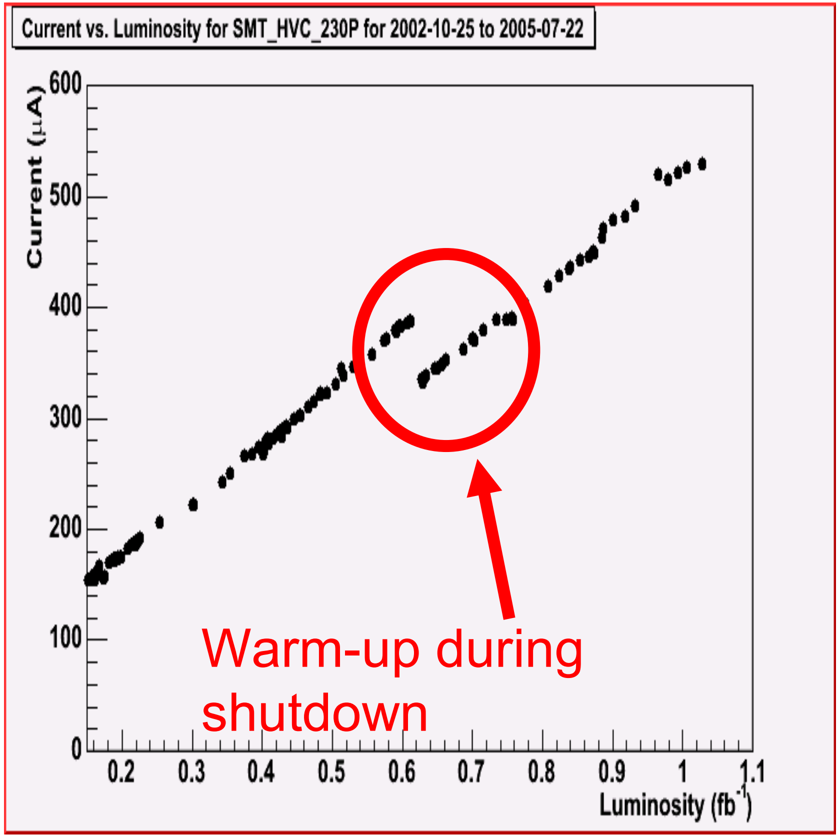
CDF Summary

Several independent measurements indicate, that the detector behaves as expected.

Assuming no changes in behavior

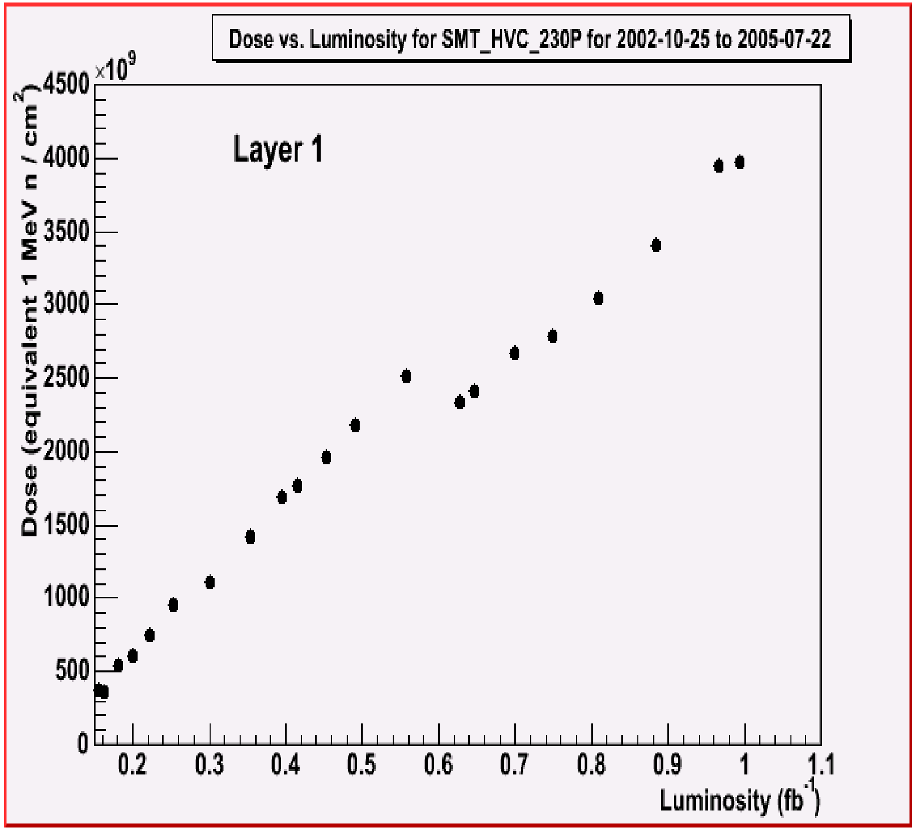
- Depletion voltage: Current projections indicate, that detector can be fully depleted throughout Run-II
- Bias current monitoring
  - Measured flux agrees with TLD measurements
  - S/N prediction indicates no problems
- S/N measurements
  - No problems expected with S/N up to 8 fb^{-1}
  - Very good agreement of predictions for Hamamatsu sensors

DØ Bias Current Studies



Warm-up during shutdown

⇒

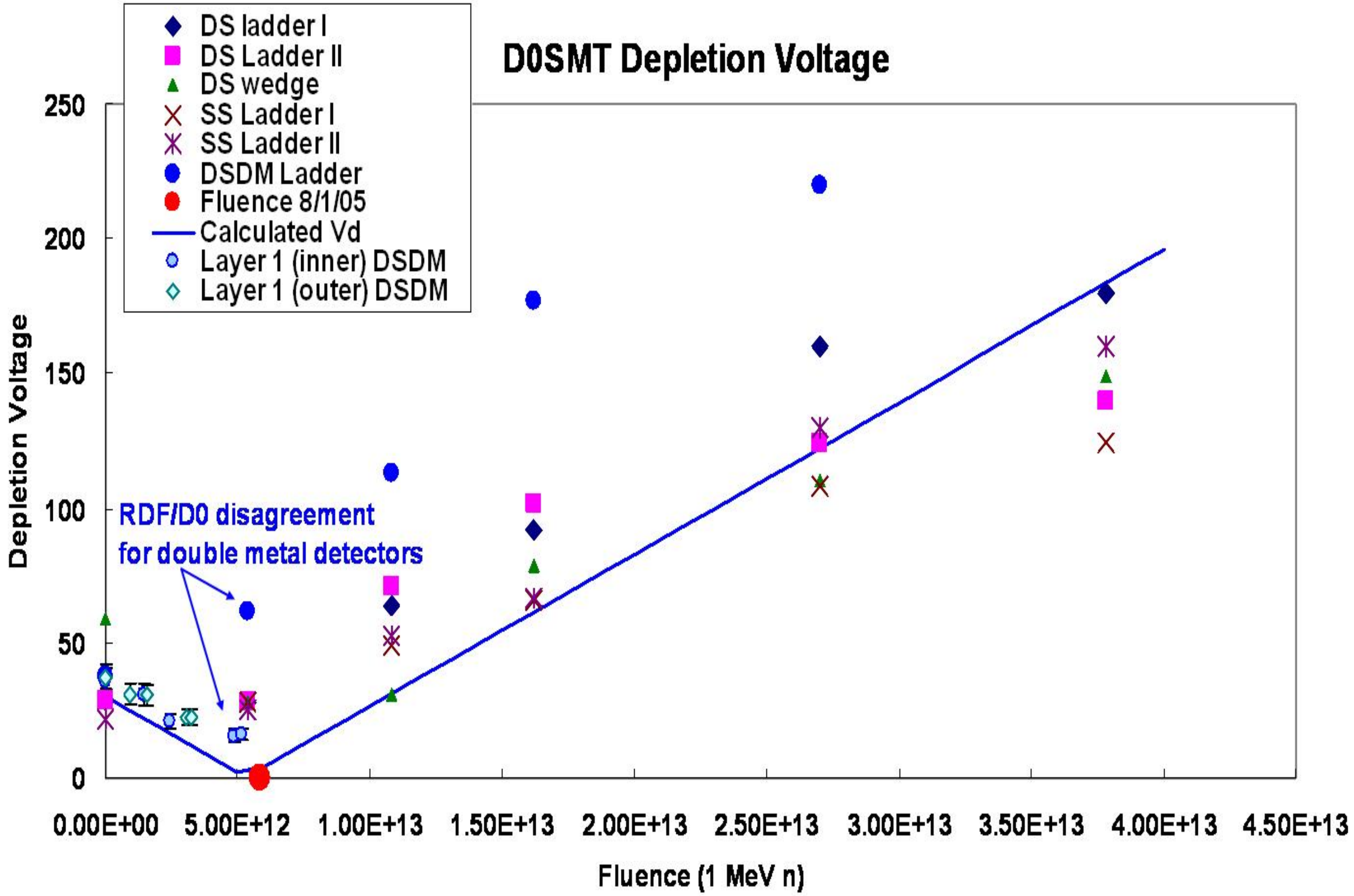


Derive the dose from the bias current measurements

DØ Dose Measurement Using The Booster

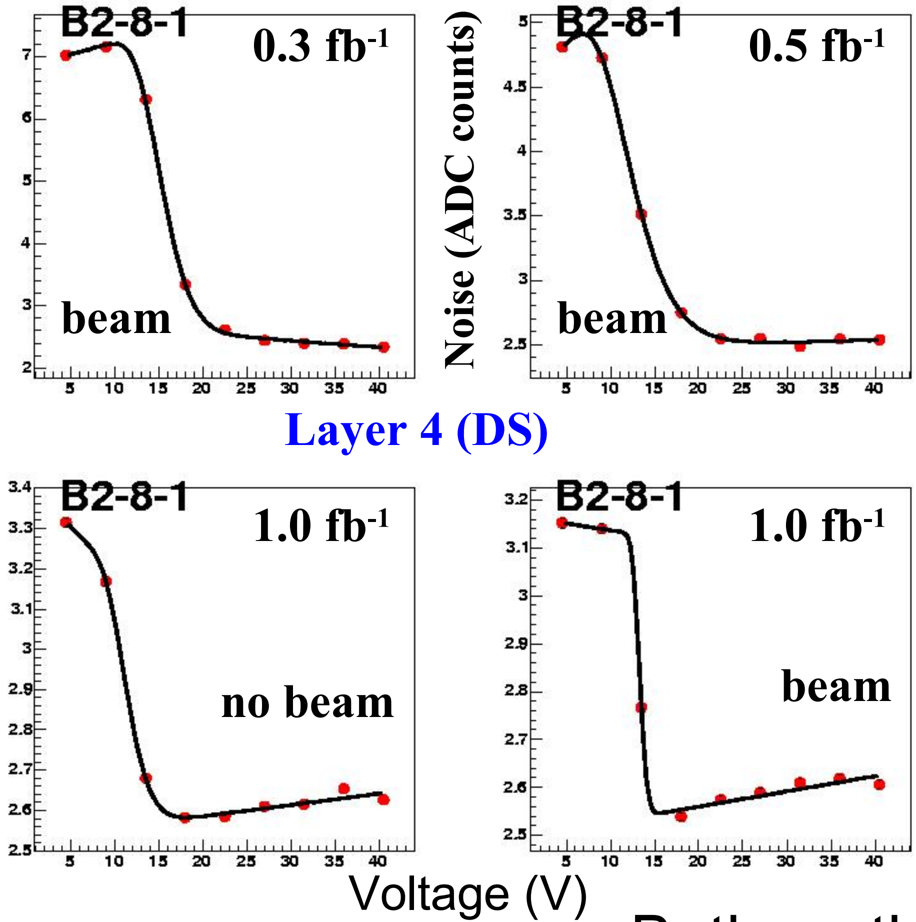
- Use Fermilab's 8 GeV “Proton Booster” to irradiate several SMT ladders
- Measure a depletion voltage as a function of the received dose
- Derive actual dose in the detector using the bias current measurement
- Compared the depletion voltage from the Booster with the depletion voltage from the bias scans

DØ Booster Measurement

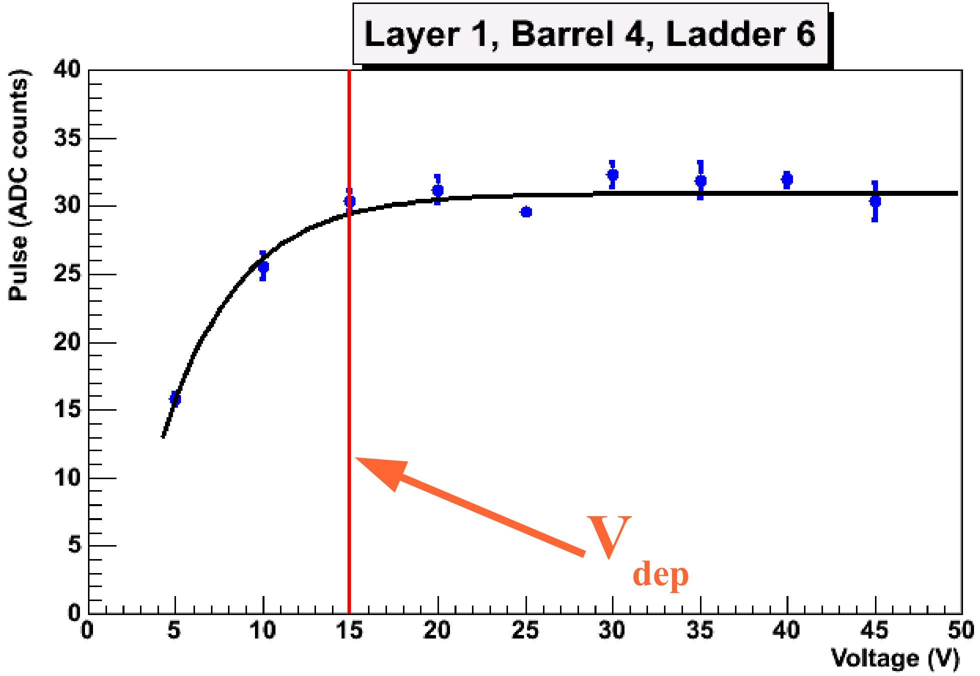


DØ Bias Scans

Noise Scan

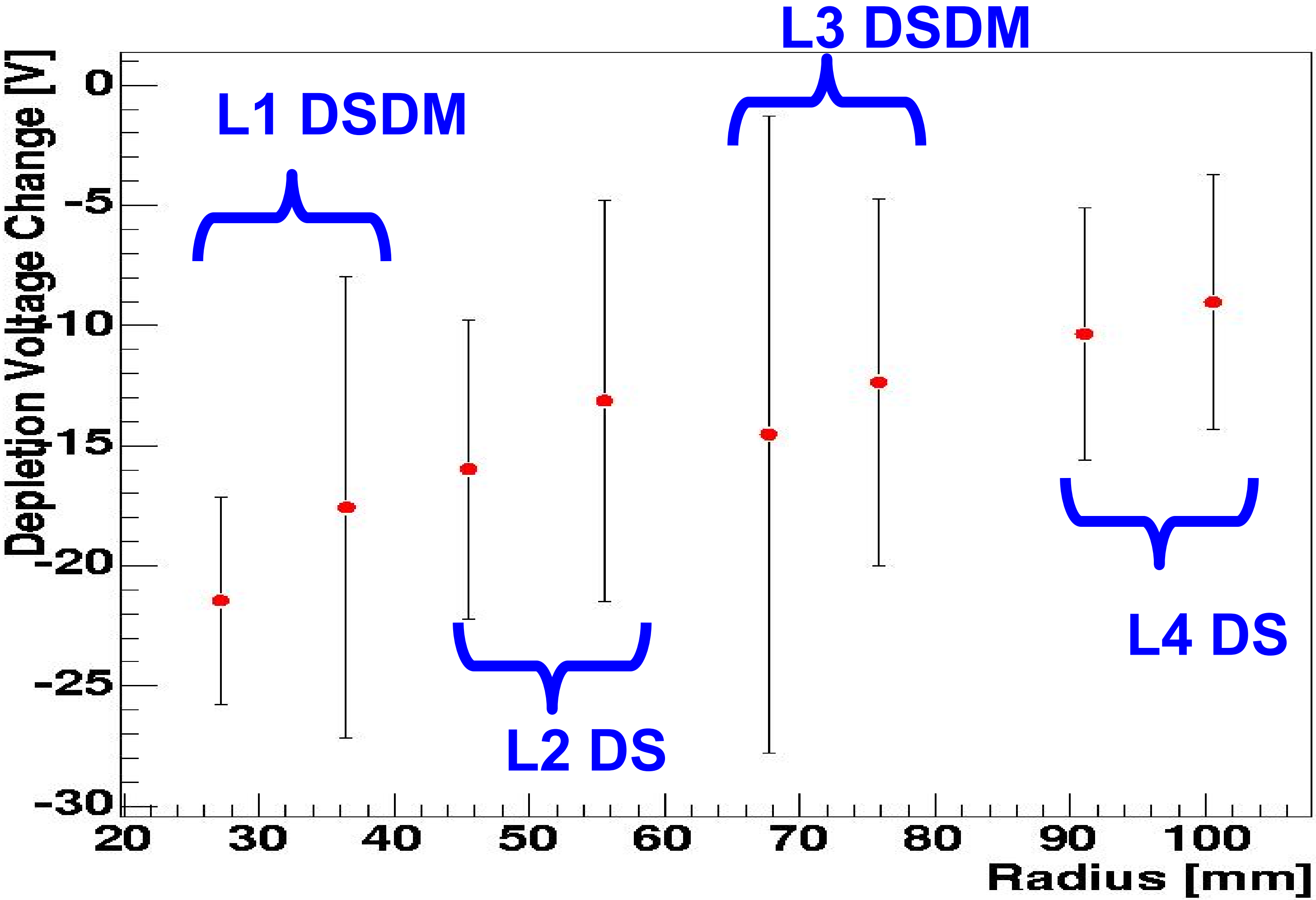


Signal Scan

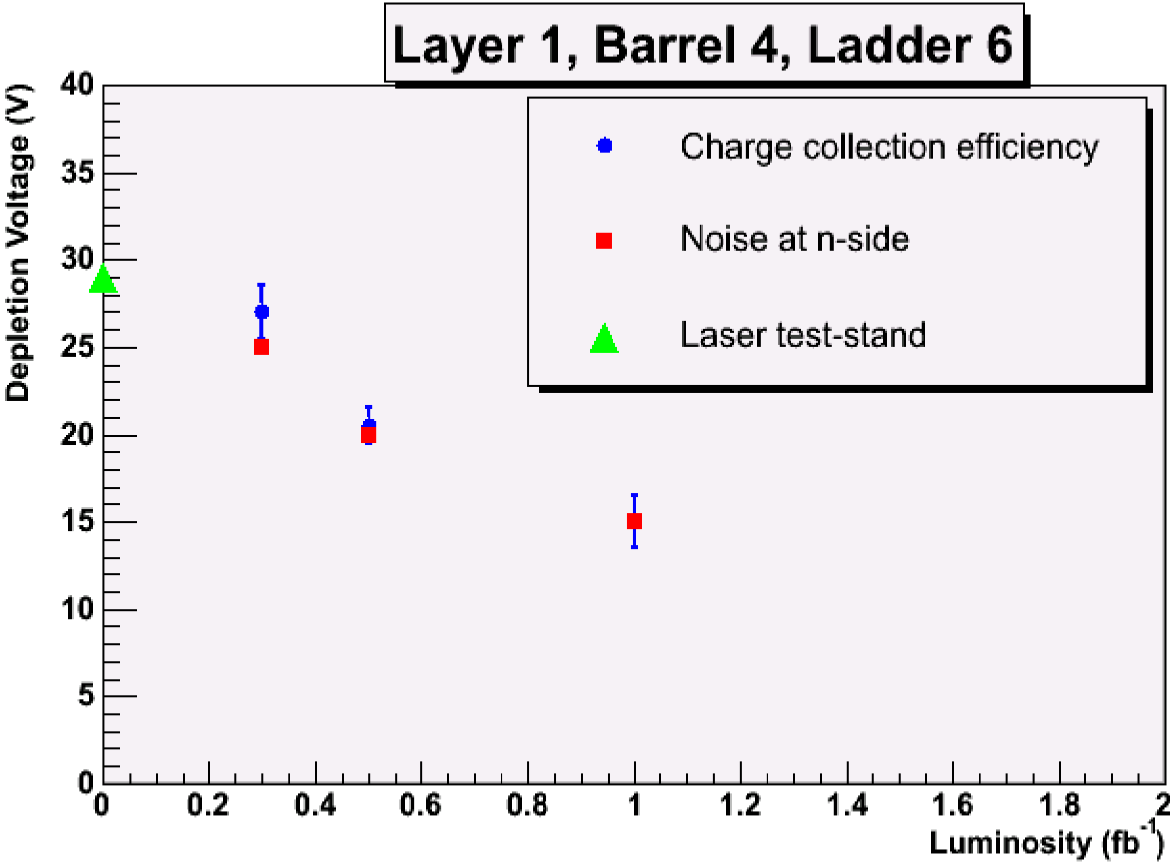


Both methods are very similar to CDF's

DØ Depletion Voltage Changes

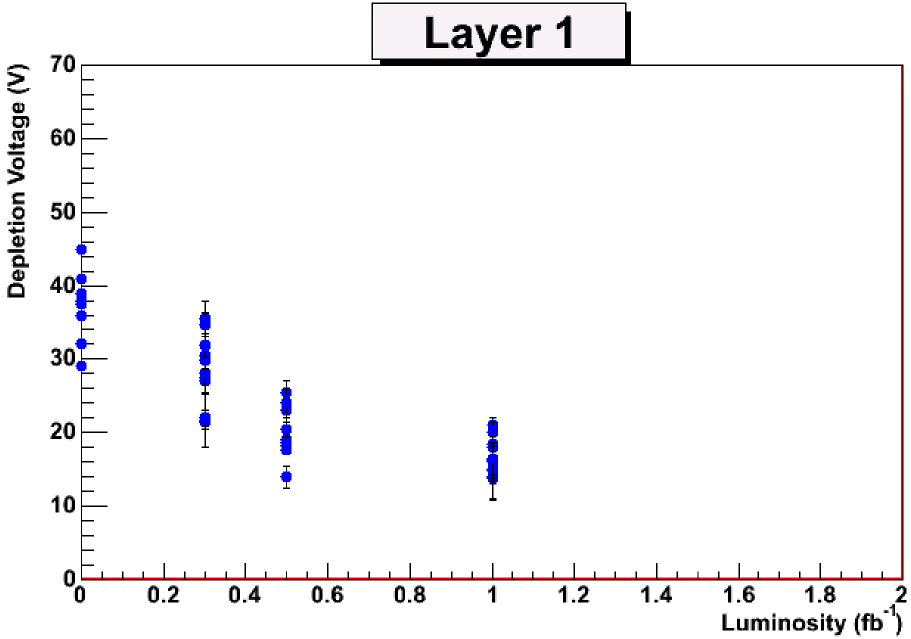


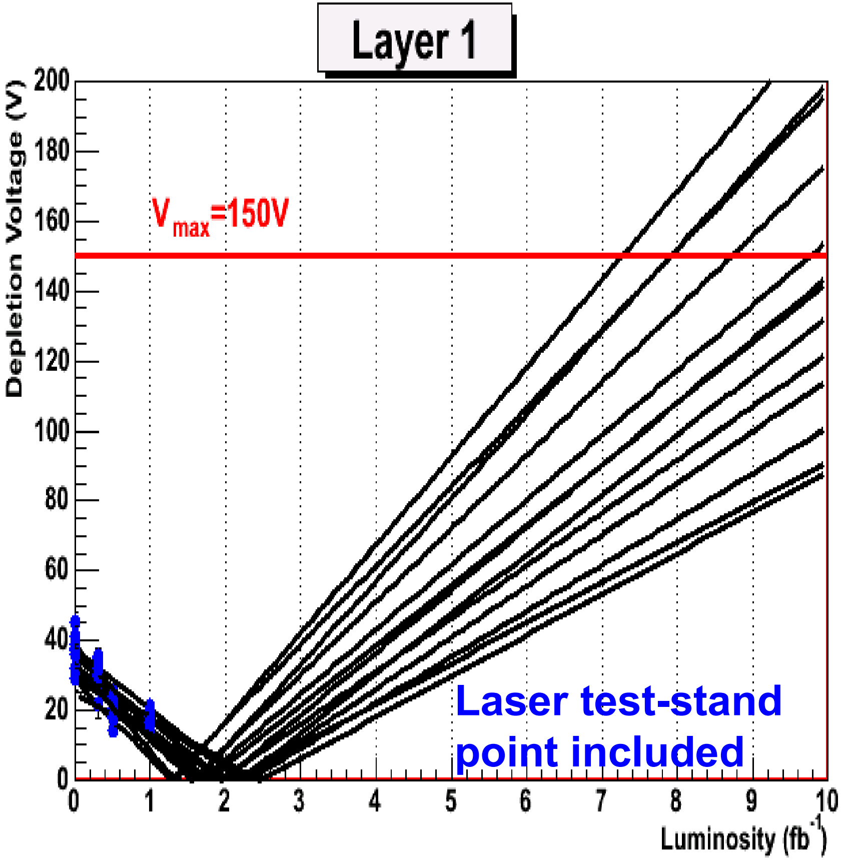
DØ Bias Scans Comparison



Both signal and noise scan are in good agreement

DØ Bias Scan Results





- Inversion point: 1.5-3 fb^{-1}
- Assuming the same magnitude slope after inversion point
  - $V_{dep} \sim V_{max}$ = 150V at delivered luminosity above 7 fb^{-1}

DØ Summary

The DØ shows the expected behavior.

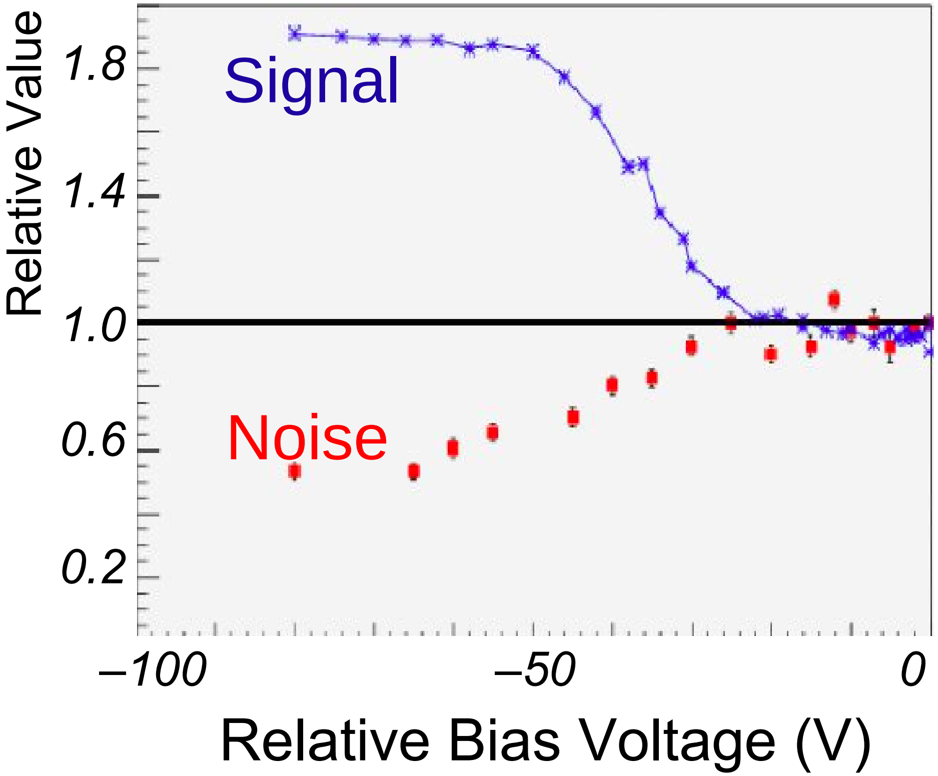
Extrapolating from this:

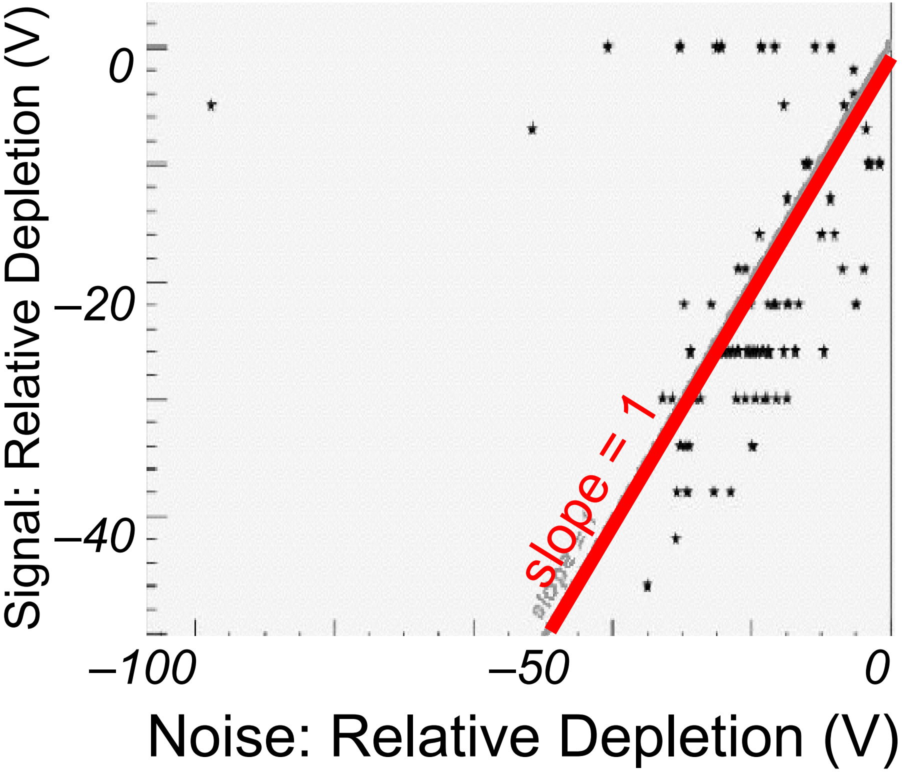
- Depletion voltage studies indicate
  - Layer 1 will last for 5-7 fb^{-1}
  - Layer 0 is designed to compensate a potential degradation of Layer 1
- Bias current measurements
  - Derive dose and comparison with results from Booster irradiation
  - Results are consistent with the bias scan results

Summary

- Both detectors are performing well
- Radiation measurements show both detector show expected behavior
- Projections indicate that the CDF silicon detector will survive up to 8 fb^{-1}
- Projections indicate that the DØ silicon detector will survive up to 8 fb^{-1} except L1, which will last for 5-7 fb^{-1}
- Both detectors are likely to invert soon
- Continuous monitoring will show if the current trend continues
- A big thanks to my CDF and DØ colleagues foe helping to prepare this talk

CDF Bias Scan Comparison





Bias current definitions

- Leakage current:
  - current measured through a PN junction when the junction is reverse biased. (can be related to materials science measurements of other diode structures).
- Bias current:
  - current measured through a semiconductor sensor when a potential difference is placed across the sensor. (includes effects of guard rings, etc).