Radiation Damage Studies of the DØ Silicon Tracking System

Satish Desai (Fermilab)
on behalf of the DØ Collaboration

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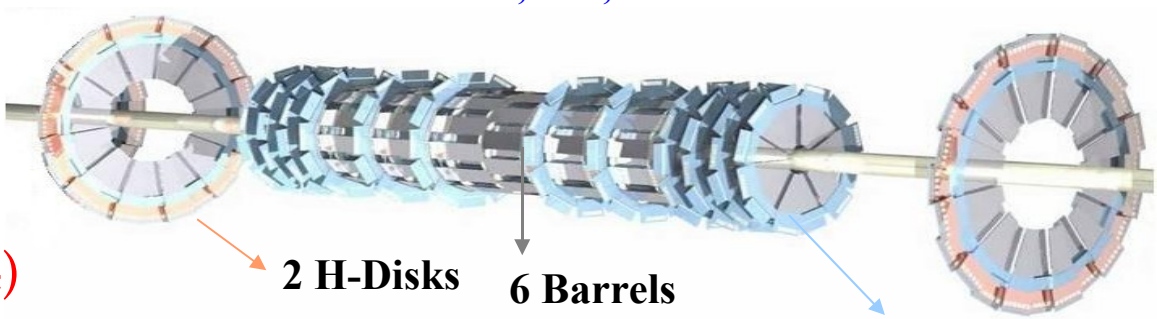
Outline

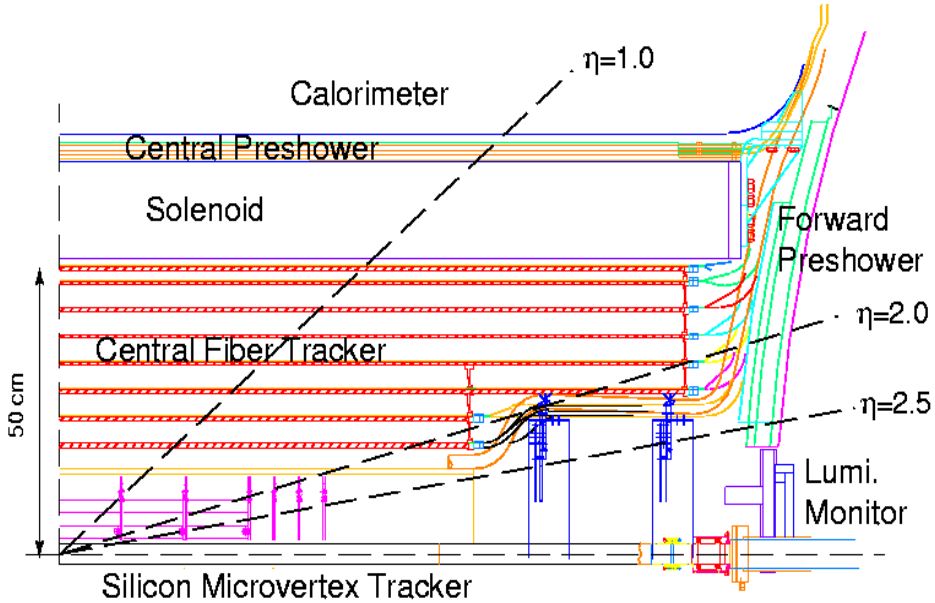
- Overview of the DØ silicon tracker
- Tevatron performance and projections
- Radiation damage studies
  - Measurements of depletion voltage
  - Fits and projections
- Conclusions

The DØ Silicon Tracking System

- Silicon Microstrip Tracker (SMT)
- Consists of
  - 6 barrels
  - 12 F-disks
  - 2 H-disks (used to be 4)
  - Layer 0 (8 barrels), installed spring 2006 for Run IIb

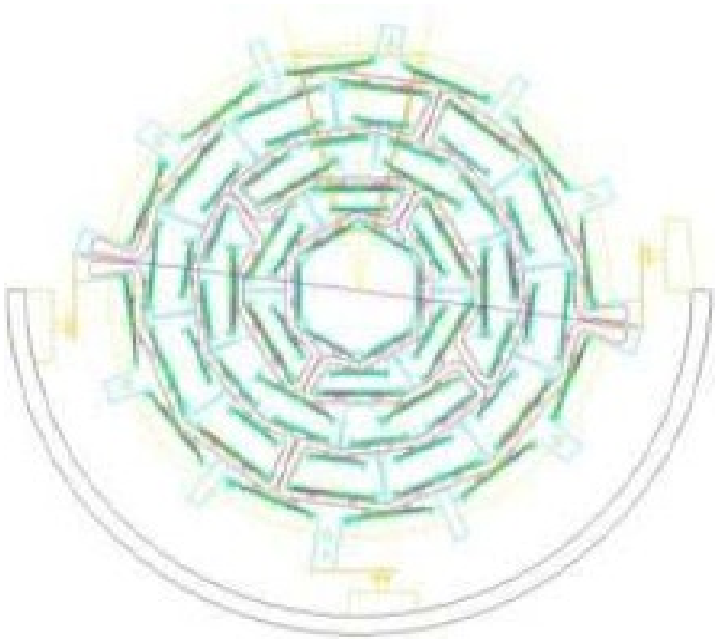
In total, 731,136 readout channels

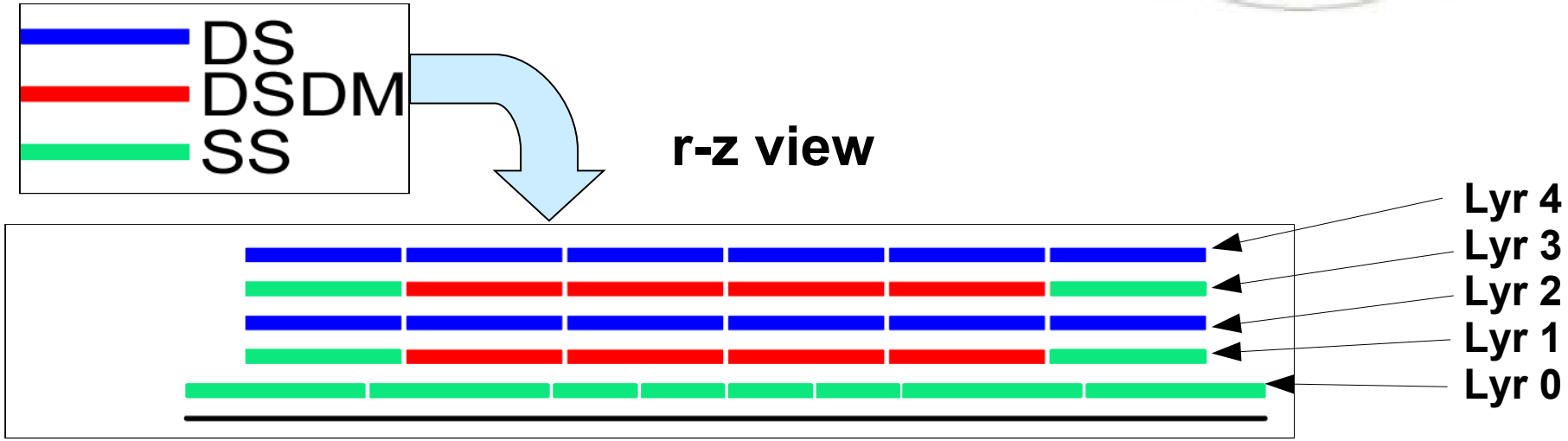




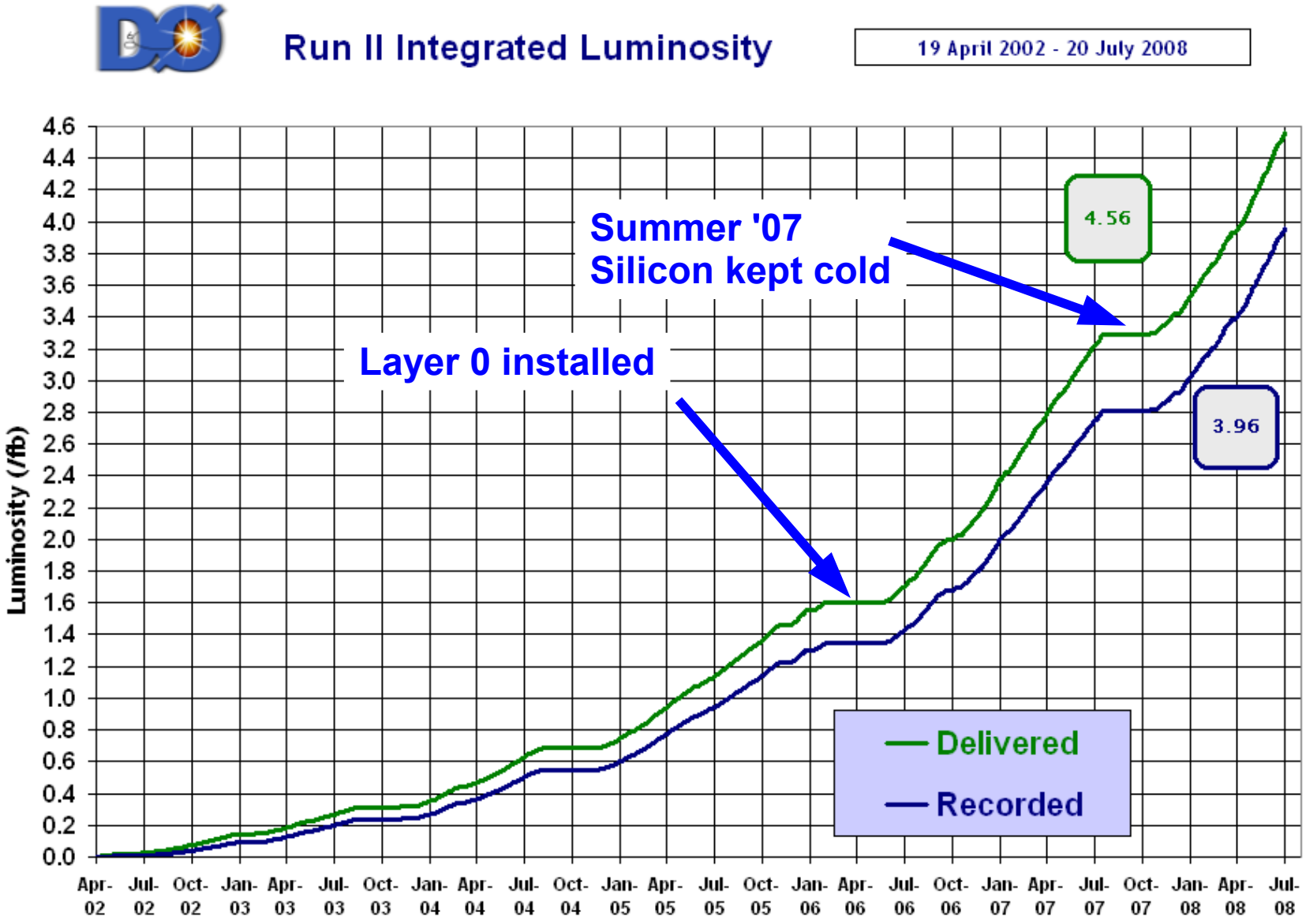
The DØ Silicon Tracking System

- Barrel sensors have 5 super-layers (including layer 0)
- Each super-layer has 2 staggered sub-layers
- Barrel radii: 1.6 cm - 10 cm
- Single-sided, double-sided, double-sided double-metal sensors

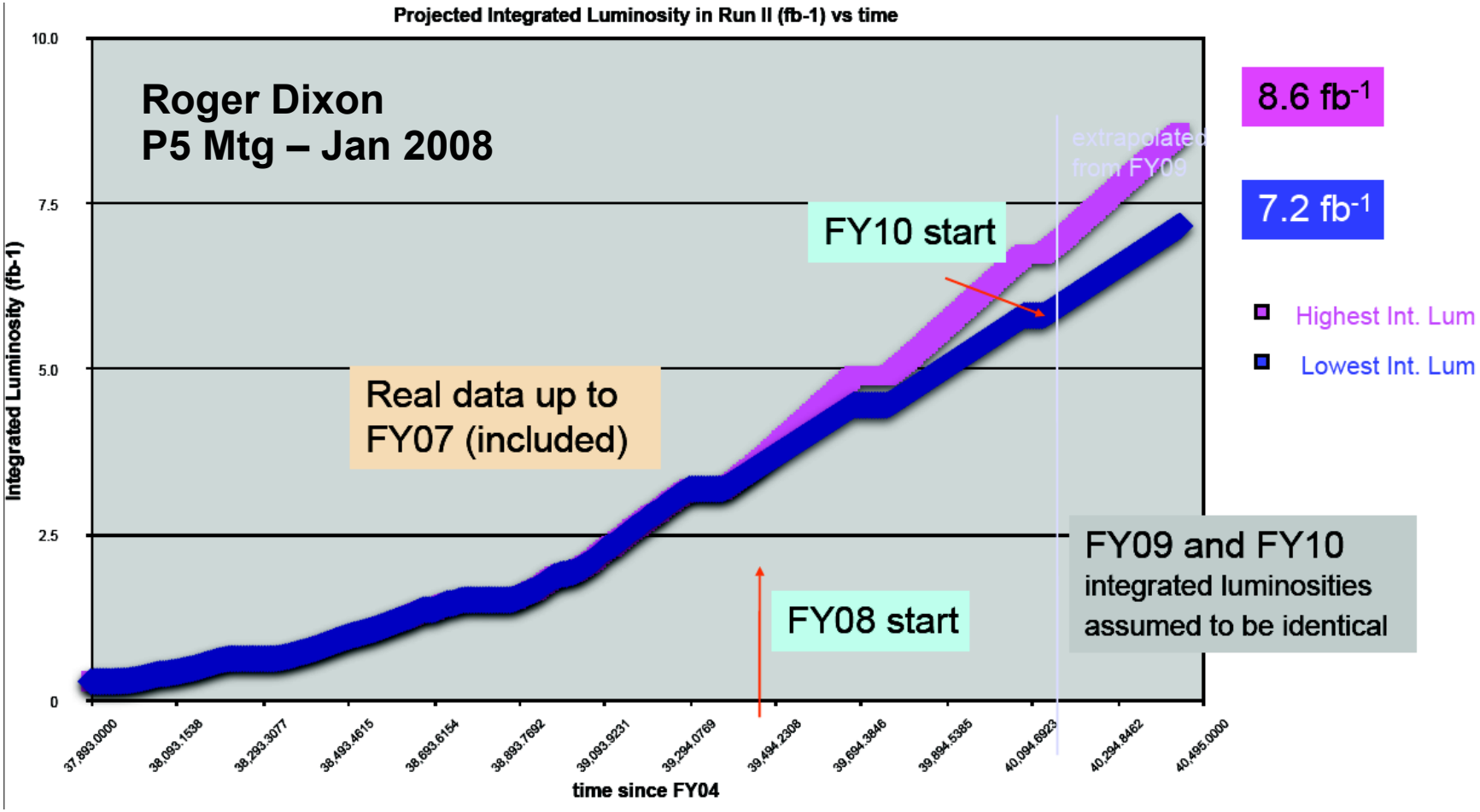




Tevatron Performance to Date



Luminosity Projections



- Will show projected aging of silicon tracker up to 8 fb^{-1}

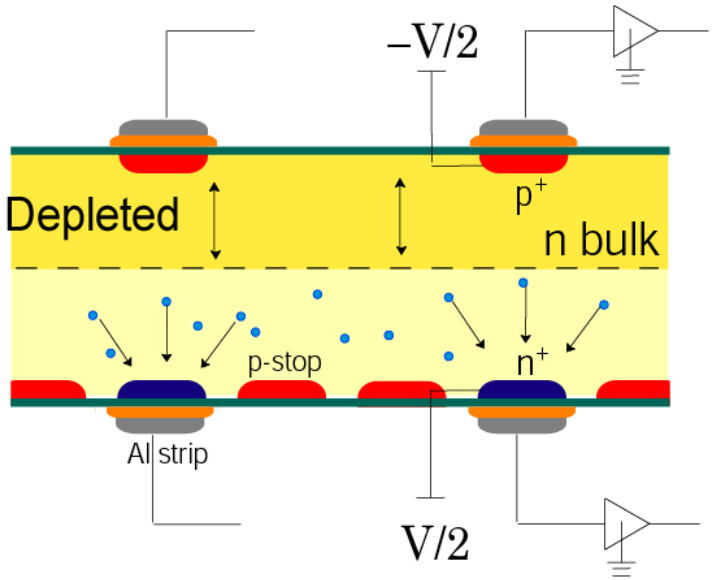
Types of Radiation Damage

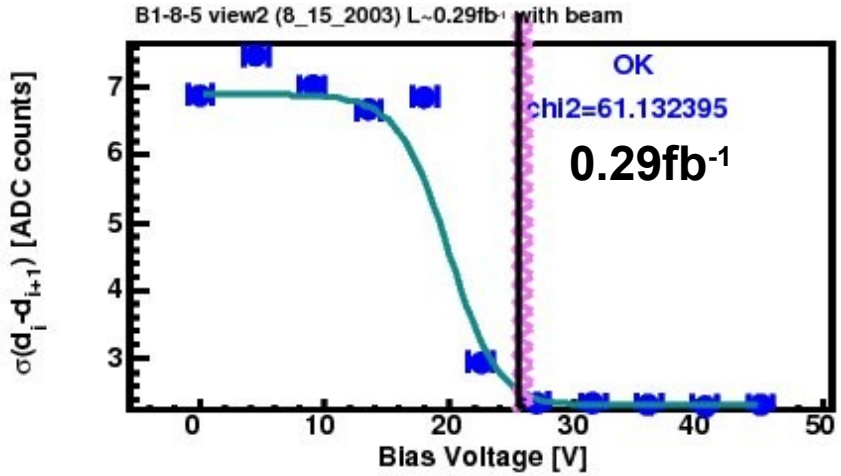
- Bulk damage to the crystal from non-ionizing energy loss
  - Changes in effective doping concentration
    - Higher depletion voltage
    - Type inversion
  - Leakage current increases (increased noise)
  - Creation of charge trapping centers (decreased efficiency)
- Surface Damage from ionizing energy loss
  - Buildup of charge in the oxide layers and at the interface with the crystal
  - Interstrip capacitance, breakdown behavior

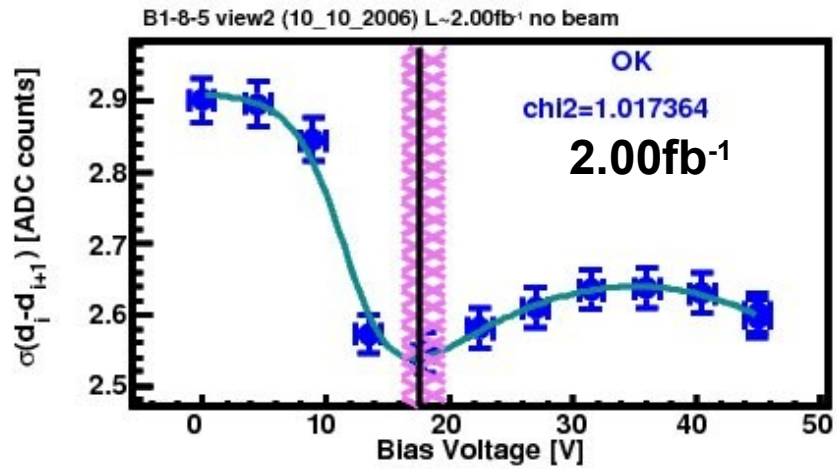
Focus of this talk

Noise on the n-side

- Look at noise on the n-side as a function of applied voltage
  - Double-sided sensors only
  - Before type inversion



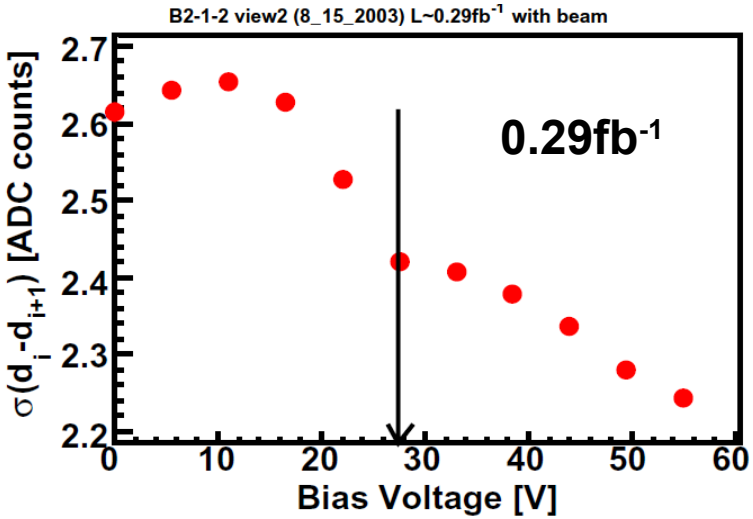




Evolution of Sensor B1-8-5

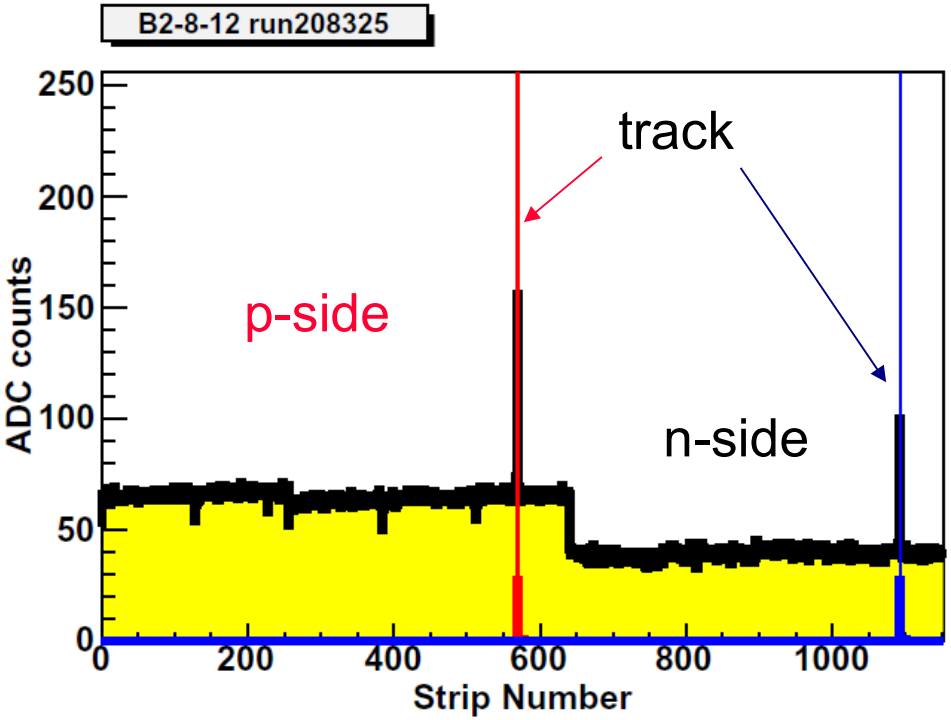
Double-sided Double-metal Noise

- Unexpected behavior for double-sided double metal sensors
- Believed to be a result of charge buildup in thin insulating layer between metal layers
- Position of kink interpreted as V_{dep}
- Kink not present in all cases



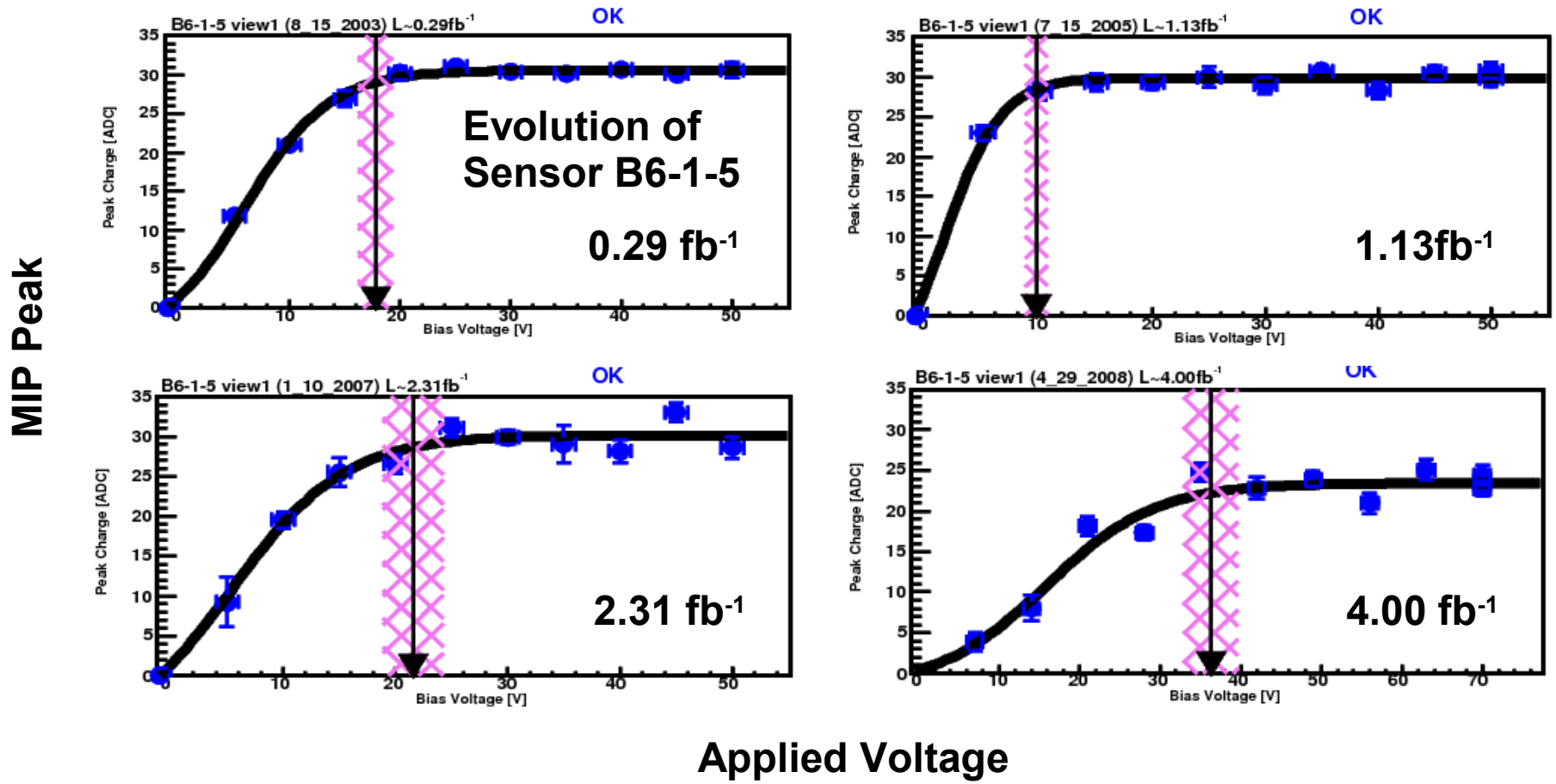
Depletion Voltage from the MIP Peak

- Take a series of runs at various bias voltages (10% steps)
  - Strategy is to measure MIP peak versus applied voltage
  - Scan each layer independently
  - Zero suppression off
- Look for tracks passing through each sensor
- Use sidebands to determine event by event pedestal
- Get the pulse height from the signal region
- Correct for incident angle of track



Extraction of Depletion Voltage

- Fit to a sigmoid plus a constant
- Define depletion voltage to be at 95% of the plateau



The Hamburg Model

- Express V_{dep} as function of time from:
  - Fluence (Φ)
  - Temperature
- Get fluence from luminosity
  - Assume CDF Run I value for α:
  - $2.2 \times 10^{13} cm^{-2} / fb^{-1}$ at 1cm
- Get radial dependence (p) and N_{eff0} from fit

$$V_{dep} = \frac{|N_{eff}| \cdot e \cdot d^2}{2 \cdot \varepsilon}$$

$$N_{eff} = N_{eff0} - (N_c + N_a + N_y)$$

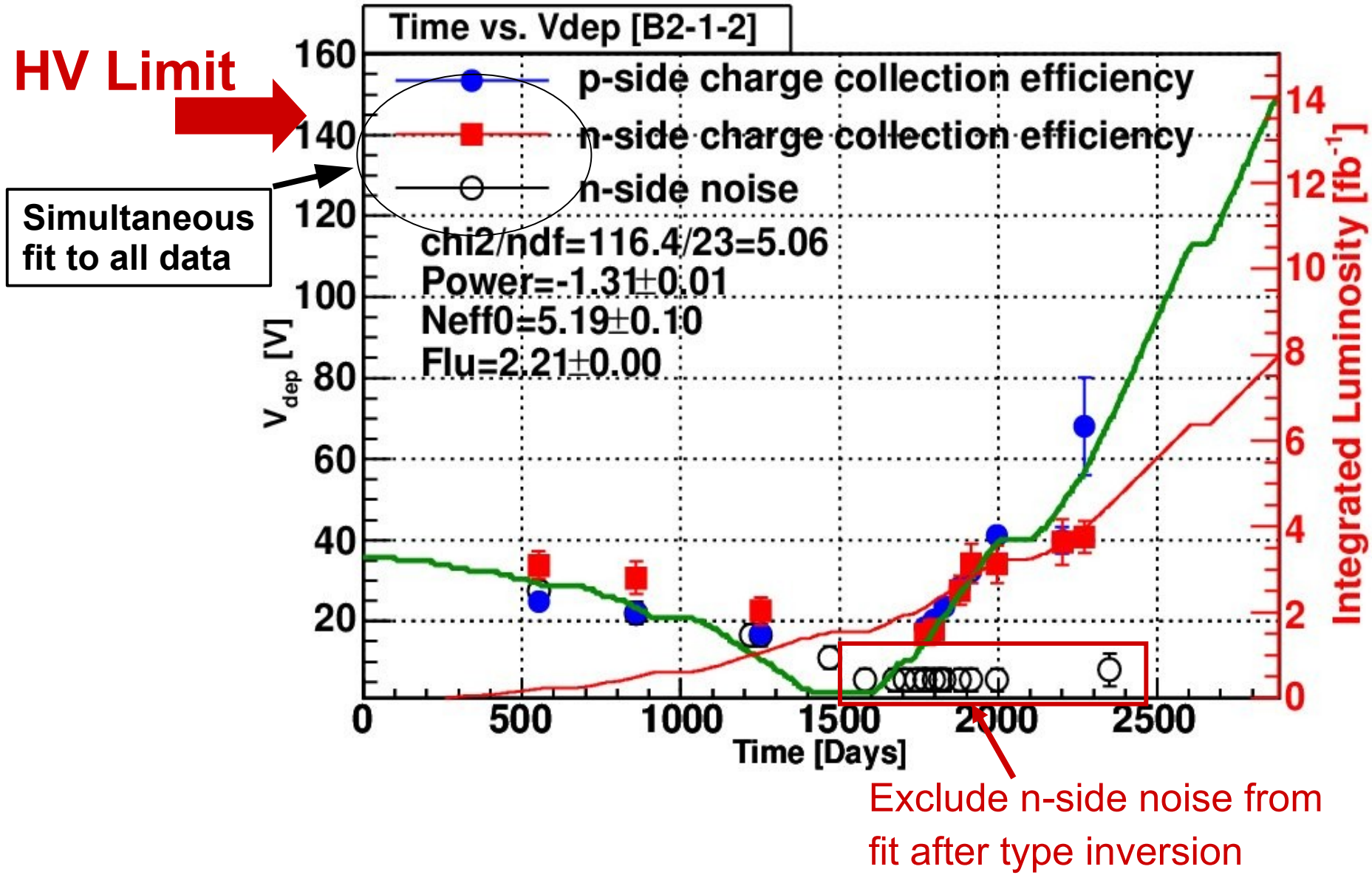
$$N_c(\Phi) = N_{c0} \cdot (1 - e^{-c \cdot \Phi}) + g_c \cdot \Phi$$

$$N_a(\Phi, t, T) = g_a \cdot \Phi \cdot e^{-k_{a0} \cdot e^{-E_{aa}/k_B T} \cdot t}$$

$$N_y(\Phi, t, T) = g \cdot \Phi \cdot \left(1 - \frac{1}{1 + k_{y10} e^{-E_{ay}/k_B T} \cdot t}\right)$$

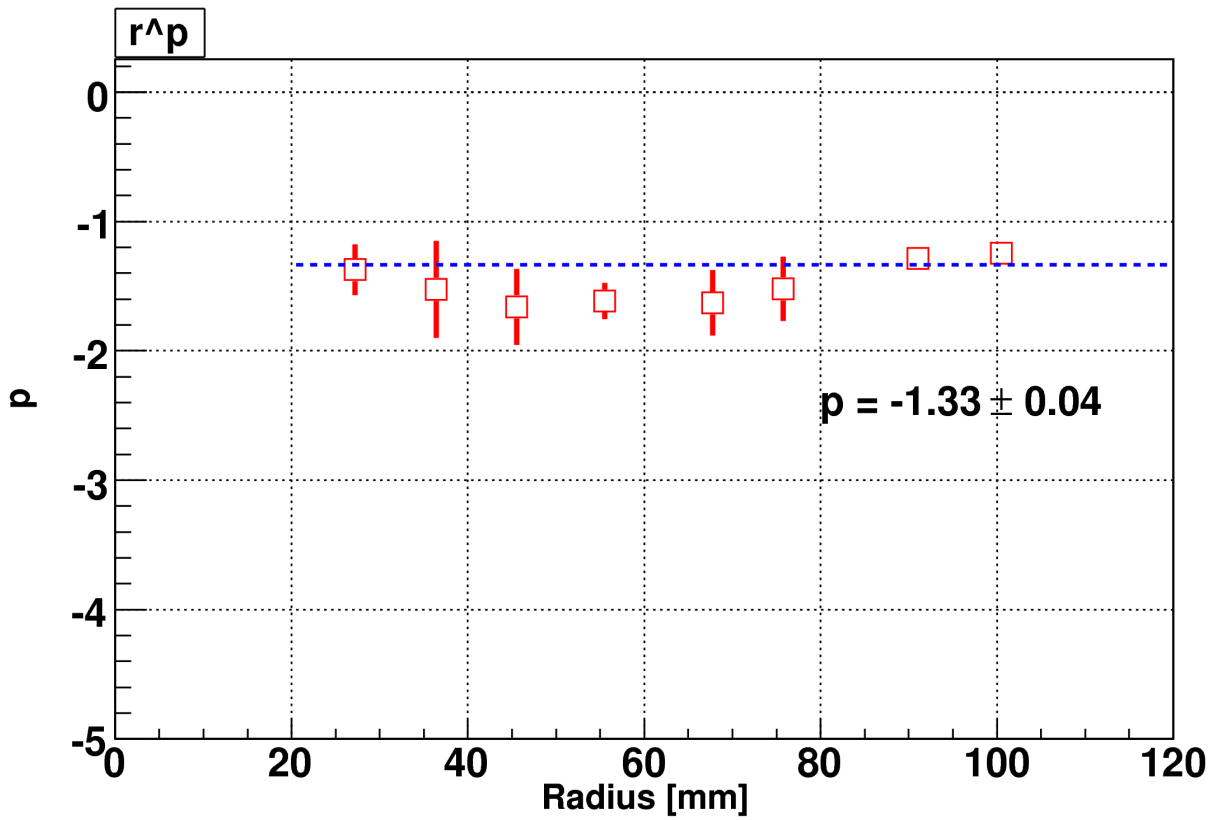
$$\Phi = \Phi_{1cm} \cdot r^p = \alpha \cdot L_{int} \cdot r^p$$

Fits to Hamburg

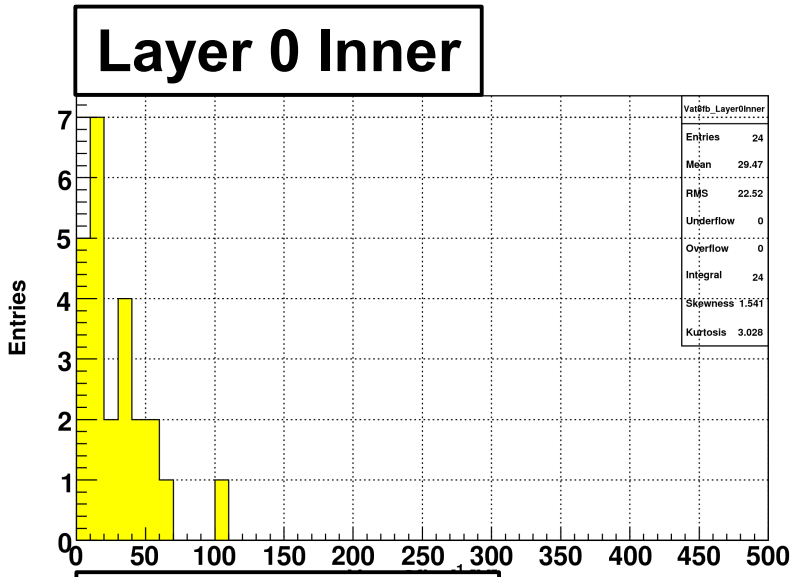


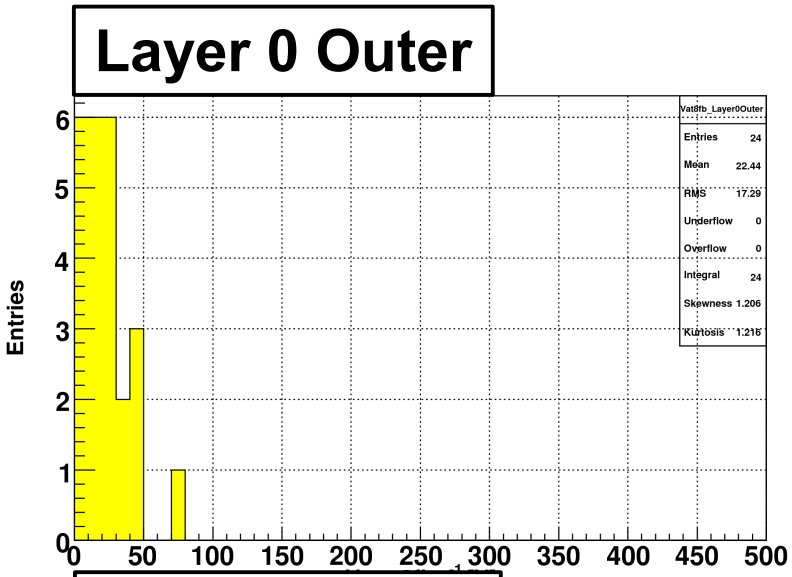
What is p?

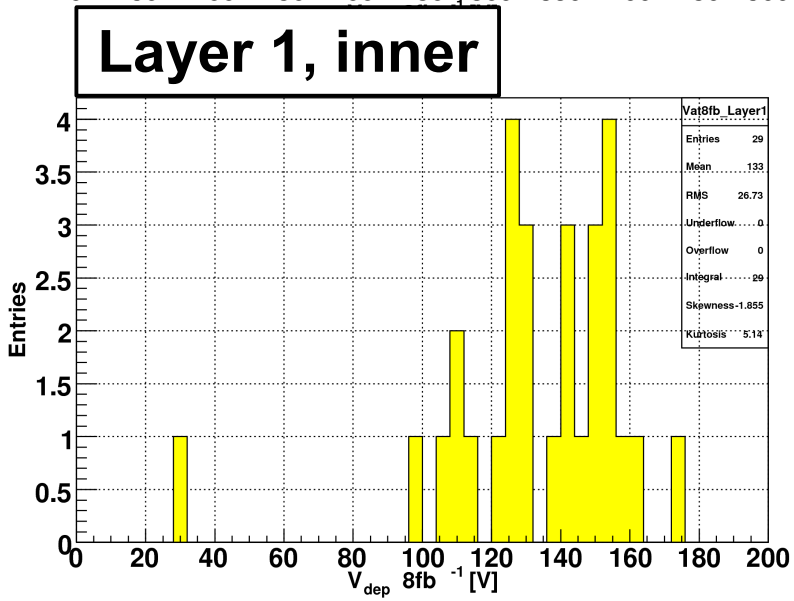
- From CDF Run I: 1.7
- Measure p to be 1.33 from fits of depletion voltage
- From leakage current measurements: 1.3

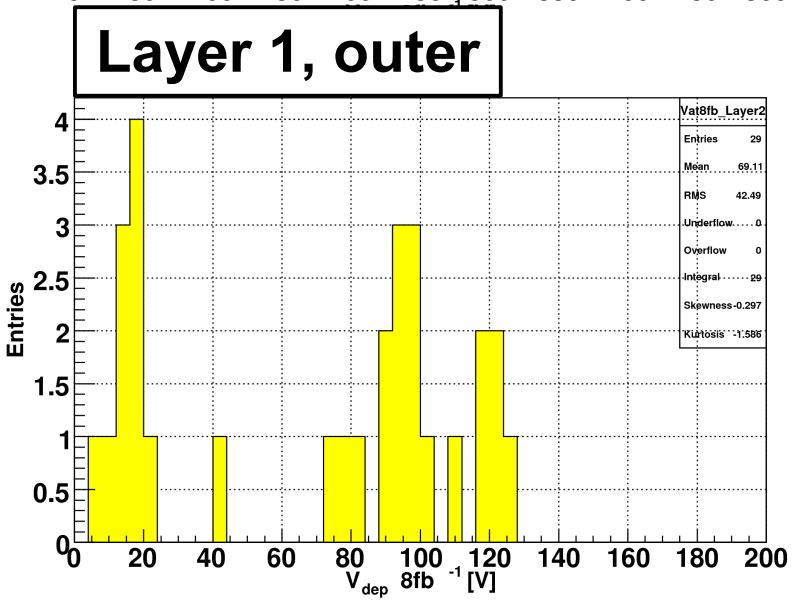


Anticipated Depletion Voltages at 8 fb^{-1}

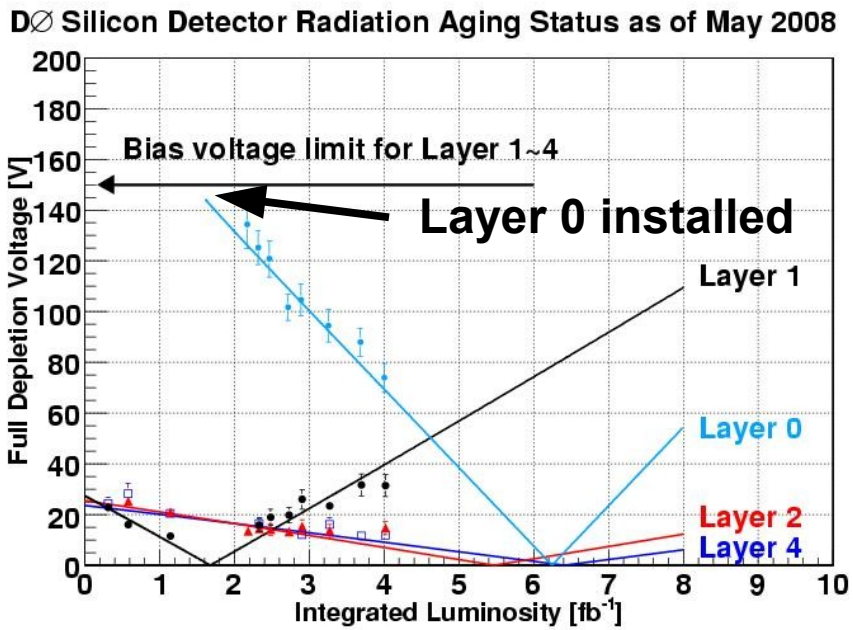








Projection Summary



Total $\mathcal{L}$ for Run II

- Bias voltage ultimately limited by
  - Breakdown of AC coupling capacitors
  - Microdischarge at the junction
  - Both set in at roughly 150 V
    - For original SMT
    - Layer 0 has higher tolerance
- At ~8 fb^{-1} may not be able to fully deplete all Layer 1sensors
- Layer 0 expected to be fine
- Other layers will reach type inversion but should also be fine

Conclusions

- Layer 1 undergoing type inversion
  - Inner layer already through it
  - Outer layer happening right now
- Currently project full depletion of some Layer 1 sensors may not be possible towards the end of Run II
- No difficulties expected for remaining layers (including Layer 0)
- Layer 0 installed to preserve tracking performance in precisely these circumstances
- DØ has an ongoing program to monitor radiation aging of the SMT