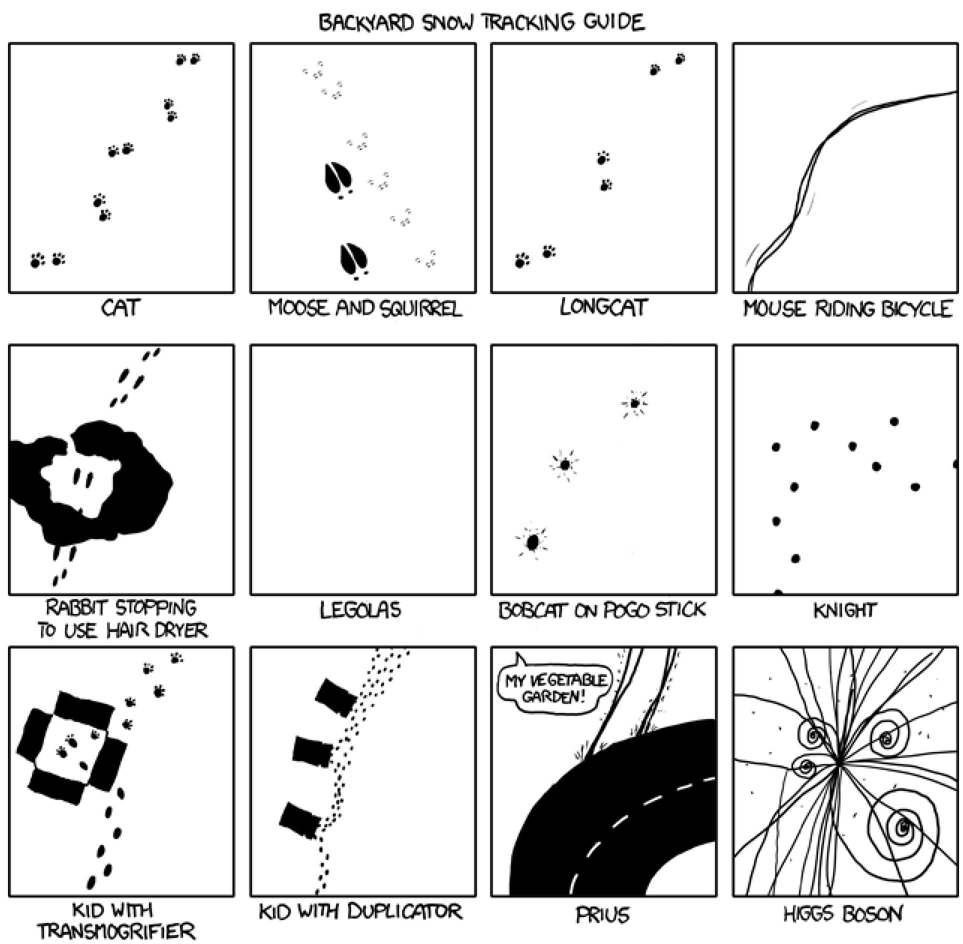
Making Tracks at DØ



Satish Desai – Fermilab

What Does a Tracker Do?

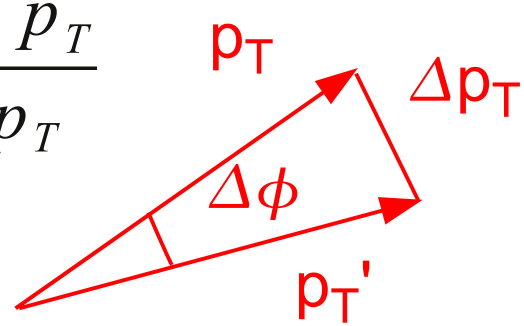
- It finds tracks (well, duh!)
  - Particle ID (e/γ separation, b-tagging...)
- Measurements of
  - Momentum
  - Electric Charge
  - Impact Parameters
  - Position and Trajectory

really measuring curvature/charge

Measuring Momentum

$$\frac{L}{R}=\Delta\phi=\frac{\Delta p_T}{p_T}$$

$$p_T=qBR$$

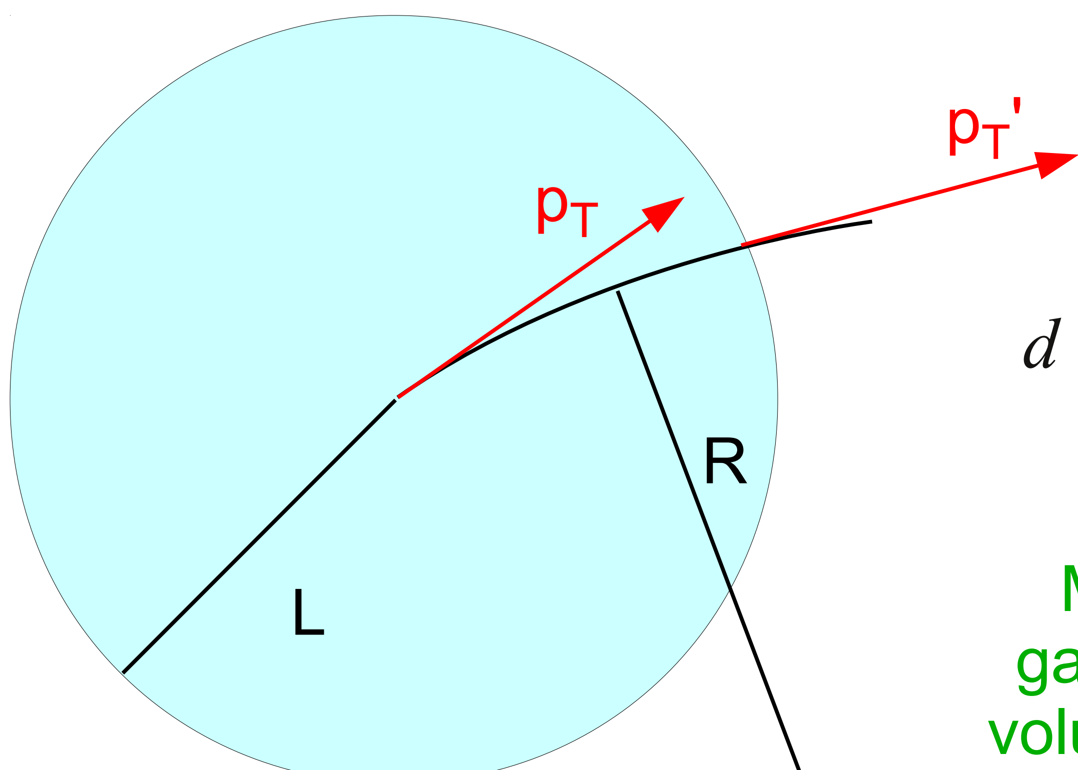


	B (Tesla)	L (cm)
DØ	2	52
CDF	1.4	140

$$\frac{1}{p_T}=\frac{\Delta\phi}{qBL}$$

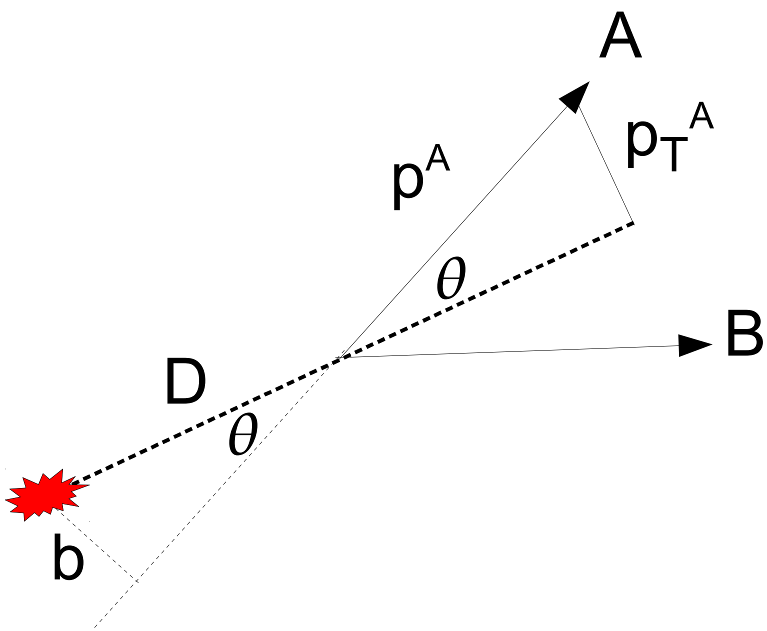
Spatial resolution of outermost tracking layer

$$d\left(\frac{1}{p_T}\right)=\frac{\Delta\phi}{qBL^2}ds$$



Momentum resolution gains more from tracking volume than magnetic field

Impact Parameters



$$b = D\sin\theta = D\frac{p_T^A}{p^A}$$

Assume massless decay products...

$$D = \gamma_D c\tau_D \qquad \sin\theta = \frac{1}{\gamma_D}$$

Impact parameter independent of boost!

- Impact parameter measurements for b-tagging, flavor physics, lepton ID...
- IP resolution driven by hit resolution
- Get hits close to original collision

	$c\tau$ (μm)
$D^\pm$	312
D^0	123
$B^\pm$	491
B^0	457

Detector Technologies

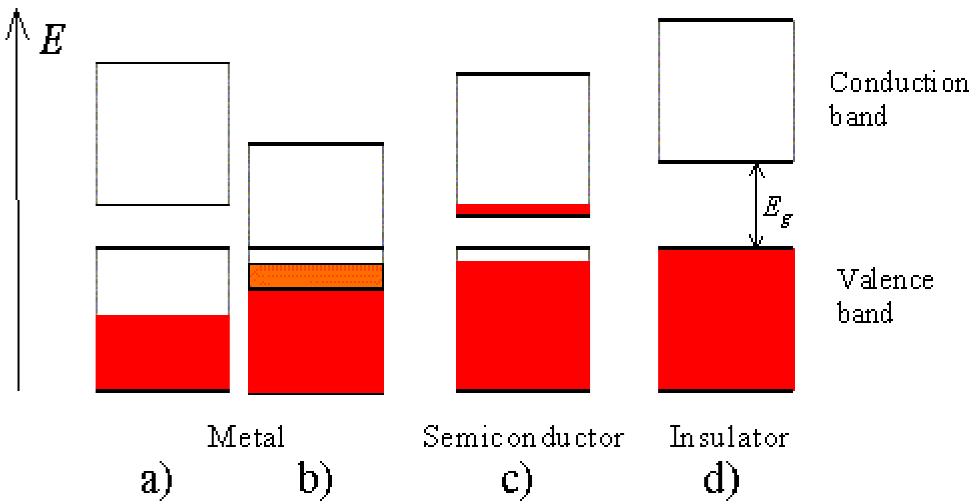
- Bubble chambers:
  - Very good resolution
  - Way too slow for colliders

- Scintillators
  - High material budget
  - Speed O(10 ns)
  - Resolution O(100 μm)

- Drift chambers/tubes
  - Low material budget
  - Speed O(100 ns)
  - Resolution > 100 μm

- Silicon
  - High material budget
  - Speed O(10 ns)
  - Resolution O(10 μm)

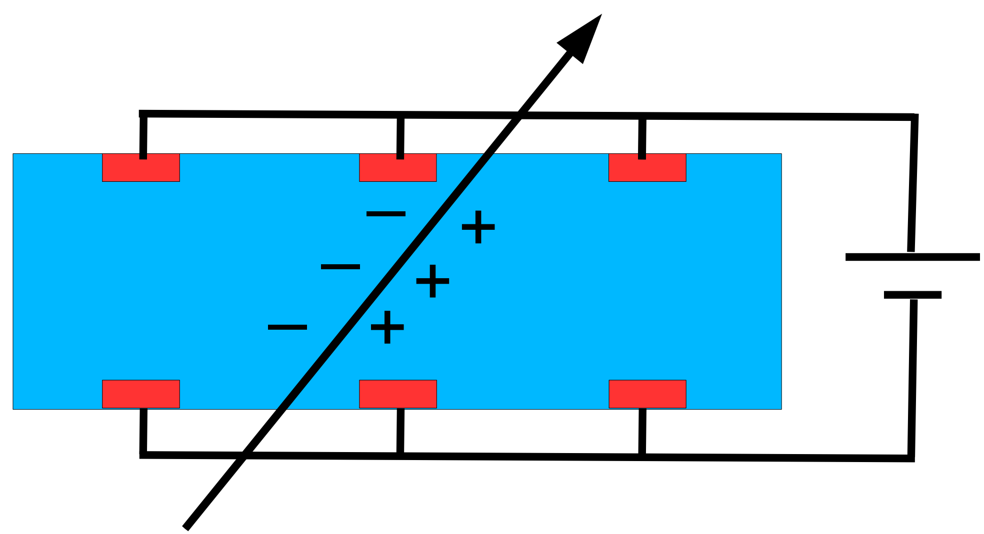
Silicon Detectors



Source: http://ecee.colorado.edu/~bart/book

- Band gap is 1.12 eV for Silicon
- Really 3.6 eV needed for ionization (heating)
- MIP deposits 79 keV
- 22k electrons, 3.5 fC

- Drift time ~7ns
- Depends on voltage and sensor thickness
- Resolution depends on strip spacing



MIP = Minimum Ionizing Particle

A Problem

- Signal size is 22k electrons
- Charge carrier density in conduction band: $10^{11}/cm^3$
- Typical sensor dimensions
  - 300 μm thick
  - 6 cm long
  - 50 μm strip spacing (more relevant than width)

A Problem

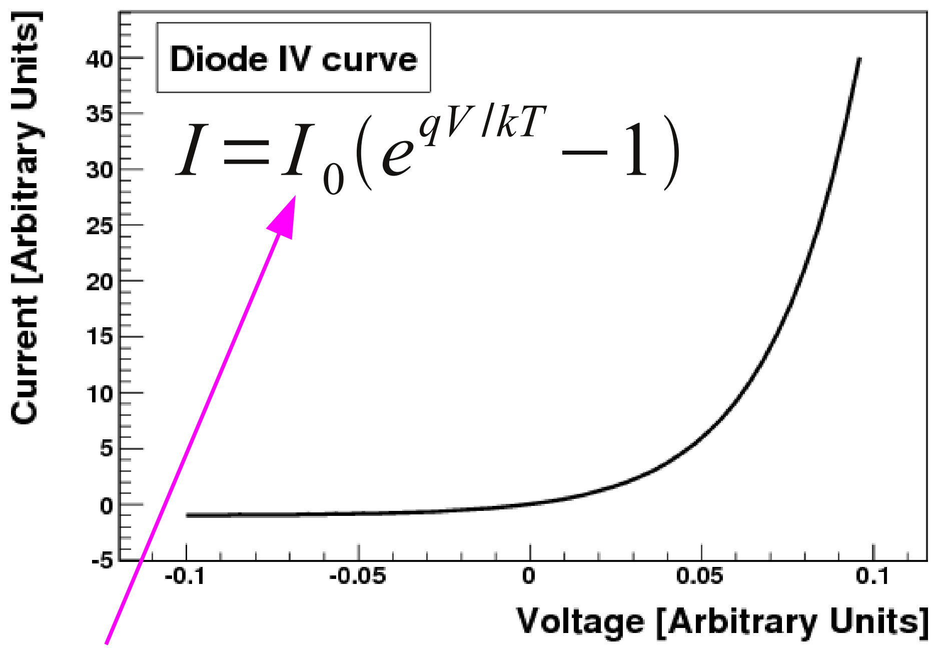
- Signal size is 32k electrons
- Charge carrier density in conduction band: $10^{11}/cm^3$
- Typical sensor dimensions
  - 300 μm thick
  - 6 cm long
  - 50 μm strip spacing (more relevant than width)
- 10^8 background charge carriers in neighborhood of signal
- Electron-hole pairs recombine easily

A Problem

- Signal size is 32k electrons
- Charge carrier density in conduction band: $10^{11}/cm^3$
- Typical sensor dimensions
  - 300 μm thick
  - 6 cm long
  - 50 μm strip spacing (more relevant than width)
- 10^8 background charge carriers in neighborhood of signal
- Electron-hole pairs recombine easily

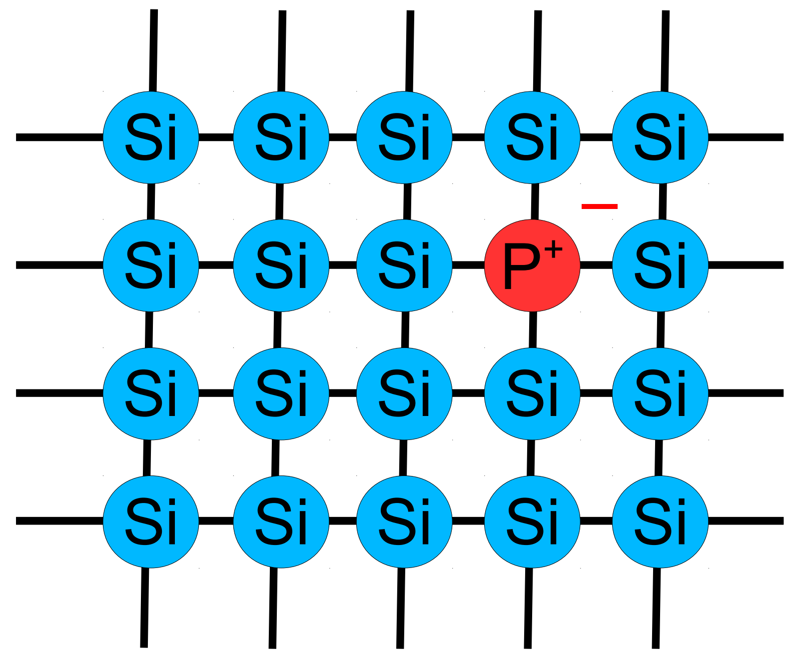
Disaster!!

Behold, the Power of Diodes

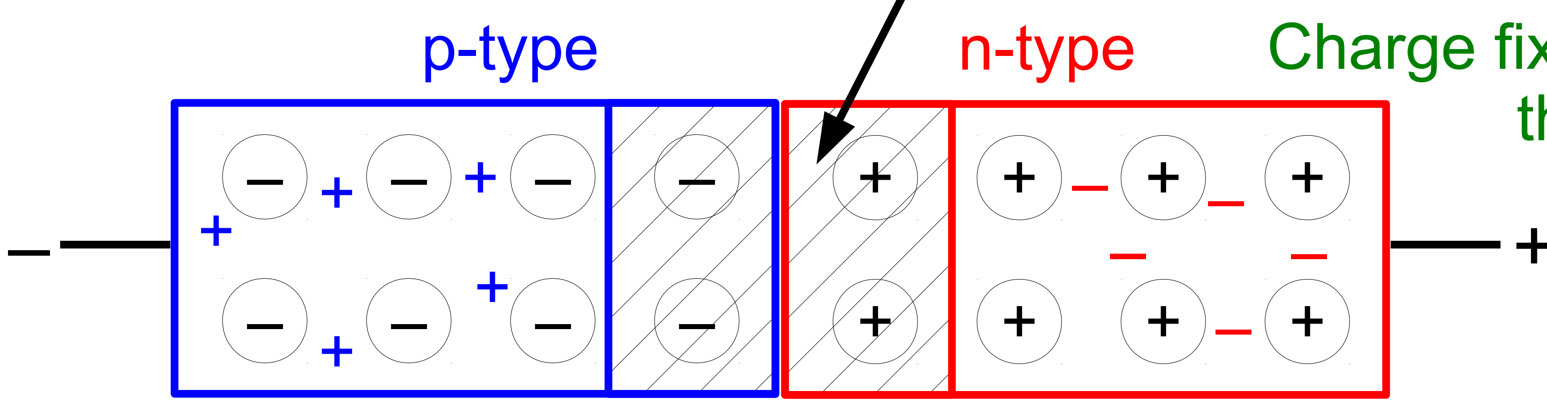


O (10 nA), depends on temperature, doping

n-type semiconductor



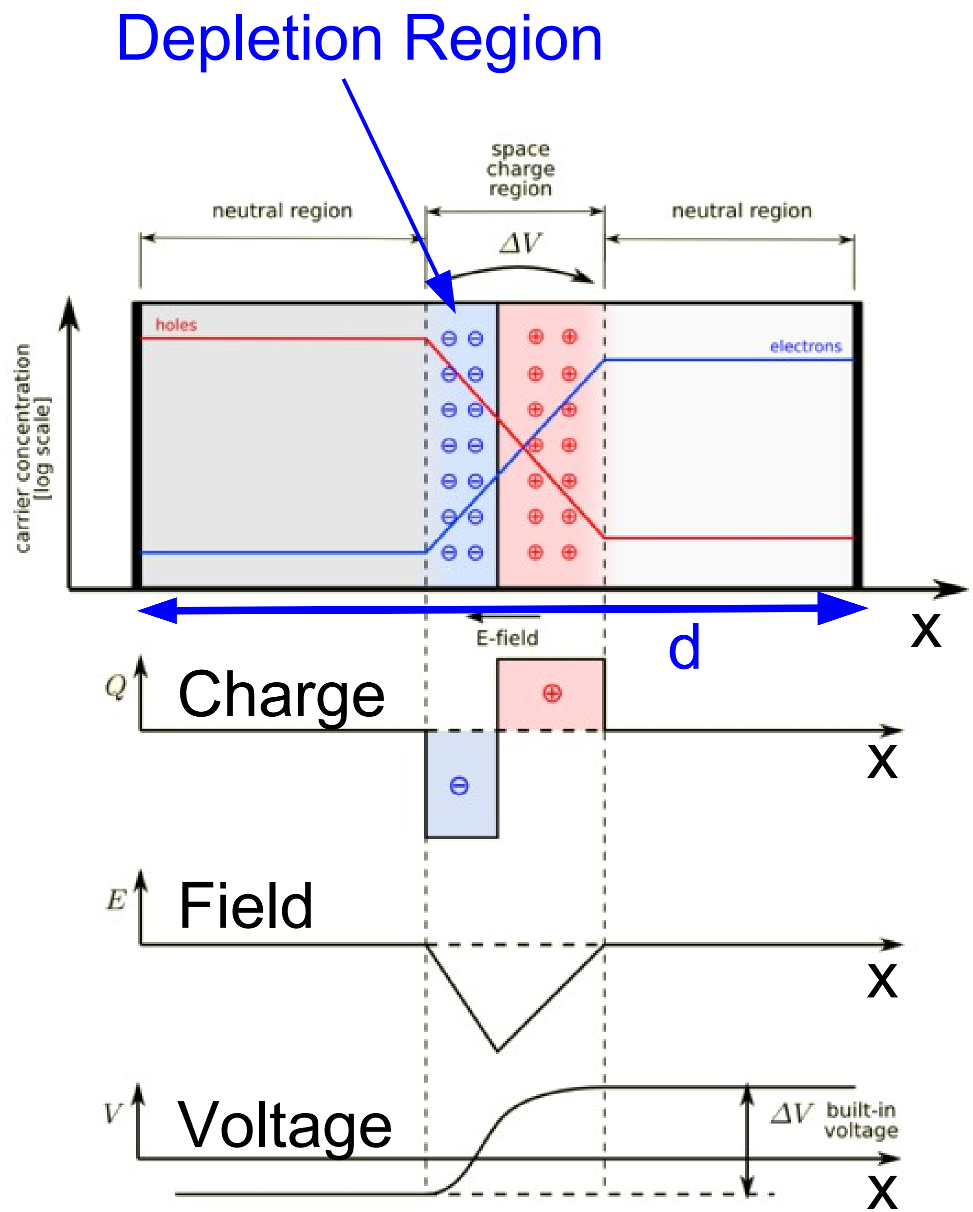
Depletion Region



Charge fixed to lattice fights the external voltage

Reverse bias

Depletion Voltage



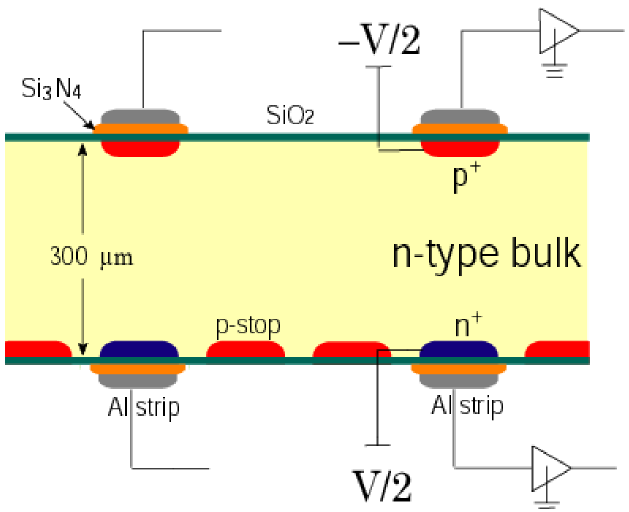
$$\frac{-d^2V}{dx^2}=\frac{dE}{dx}=\frac{q\,N_{eff}}{\epsilon\,\epsilon_0}$$

- Voltages and fields from Poisson's equation
- Charge density:
  - Set by doping concentration (N_{eff})
  - Zero outside depletion region
- p-side very thin, heavily doped
- Need full depletion for full efficiency

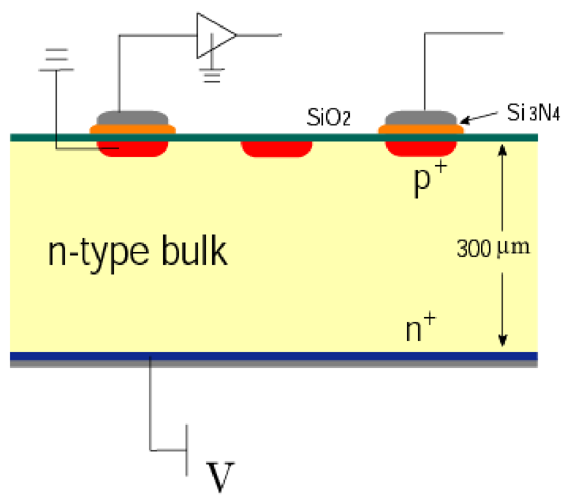
$$V_{depl}=\frac{q_0}{2\epsilon\,\epsilon_0}|N_{eff}|\,d^2$$

Closer to Reality

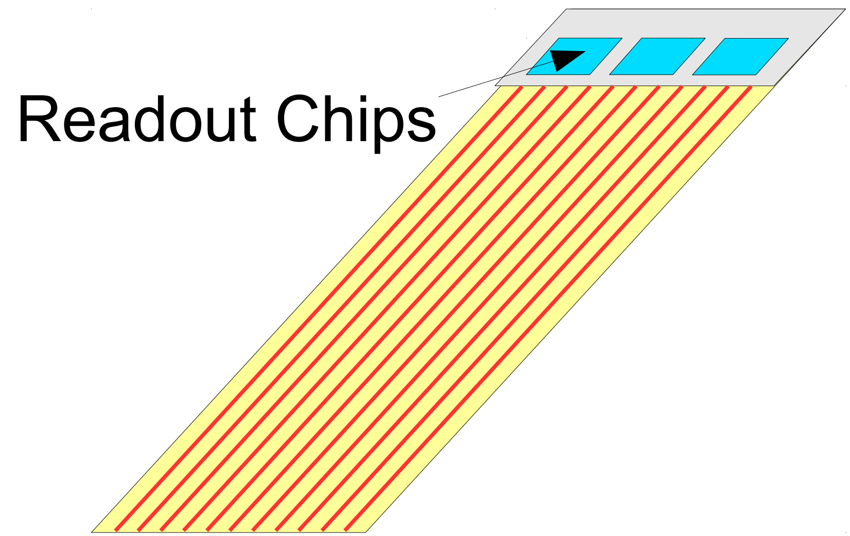
Double-Sided Sensor

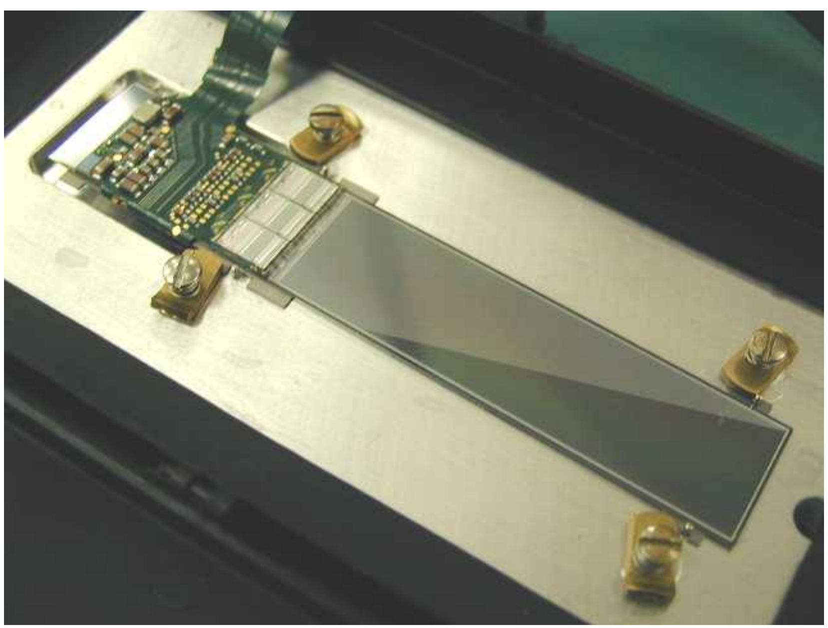


Single-Sided Sensor

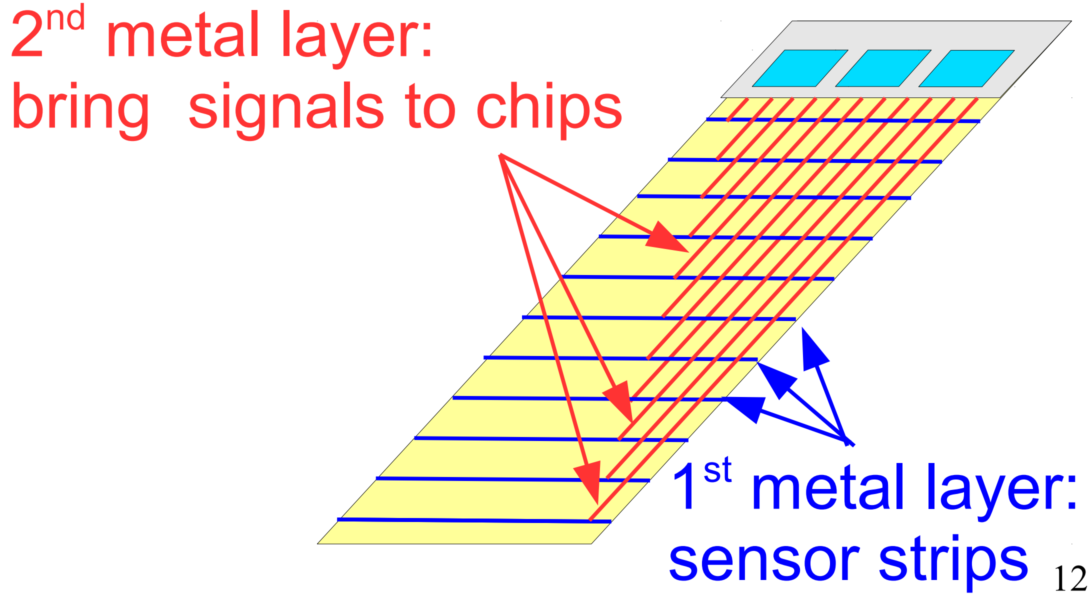


Single Sided

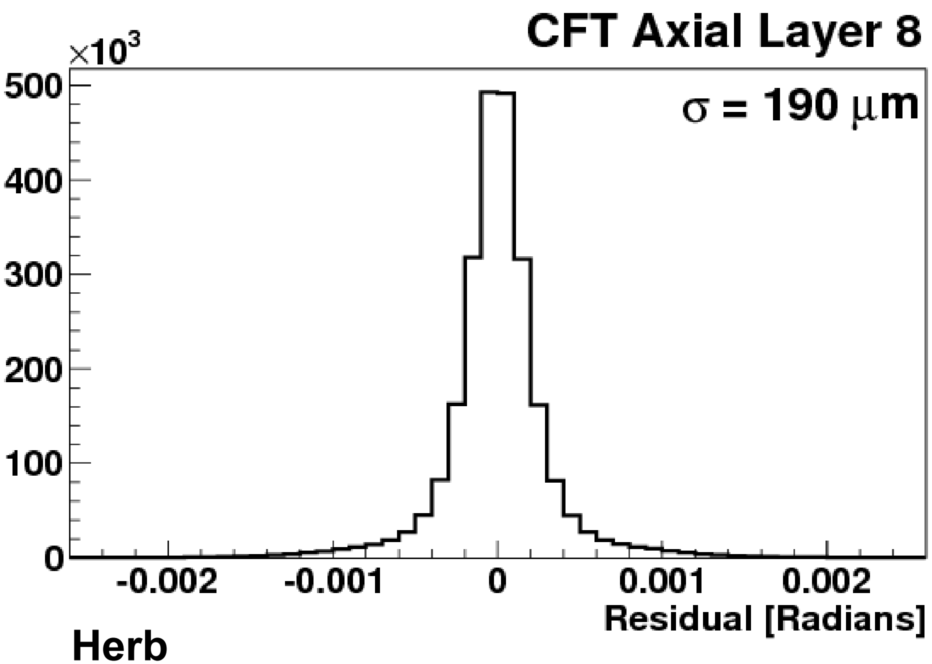




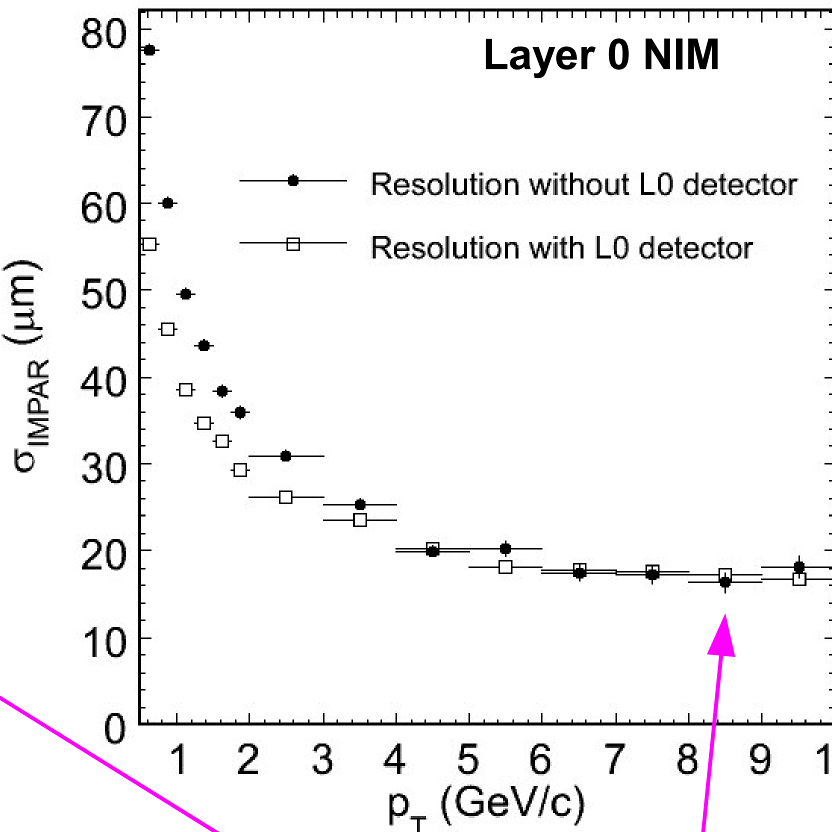
Double-sided Double-Metal

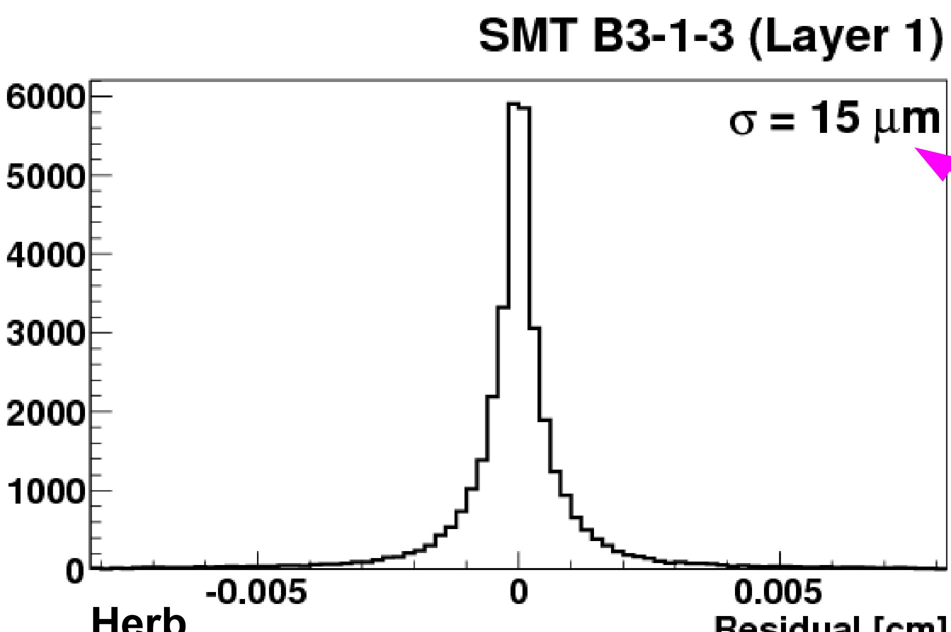


Performance



IP resolution degraded by multiple scattering





Compare to B/D $c\tau = O(100\ \mu m)$

Radiation Damage

Bulk Damage

- Ionization effects not important
- Non-ionizing: atoms knocked out of lattice
- Effectively induces p-type doping
- Changes depletion voltage

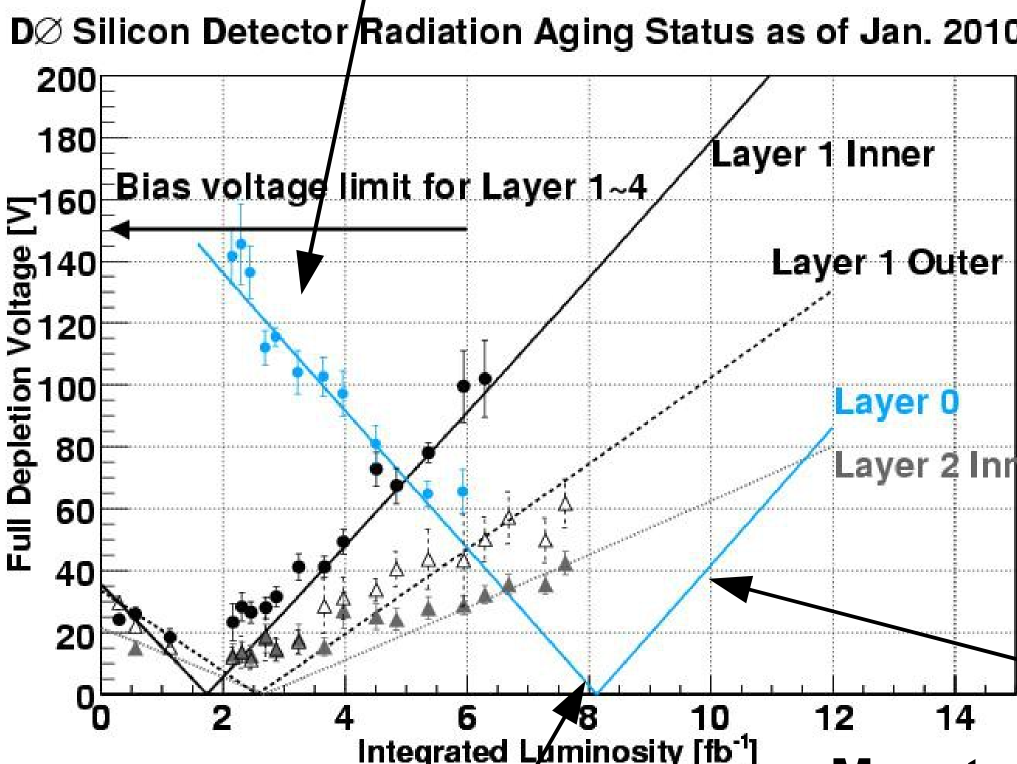
Surface Damage

- Charge trapping in insulating layer
- Increases in leakage current
- Large electric fields near surface
- Breakdowns at high voltage

Signs of Aging

n-type semiconductor
$|N_{eff}|$ decreasing

$$V_{depl} = \frac{q_0}{2\epsilon\epsilon_0} |N_{eff}| d^2$$



Masato

- If applied voltage too high (~150 V):
  - Noise increases dramatically (microdicharge)
  - Coupling capacitors breakdown (non-recoverable)

p-type semiconductor
$|N_{eff}|$ increasing

type inversion

Summary

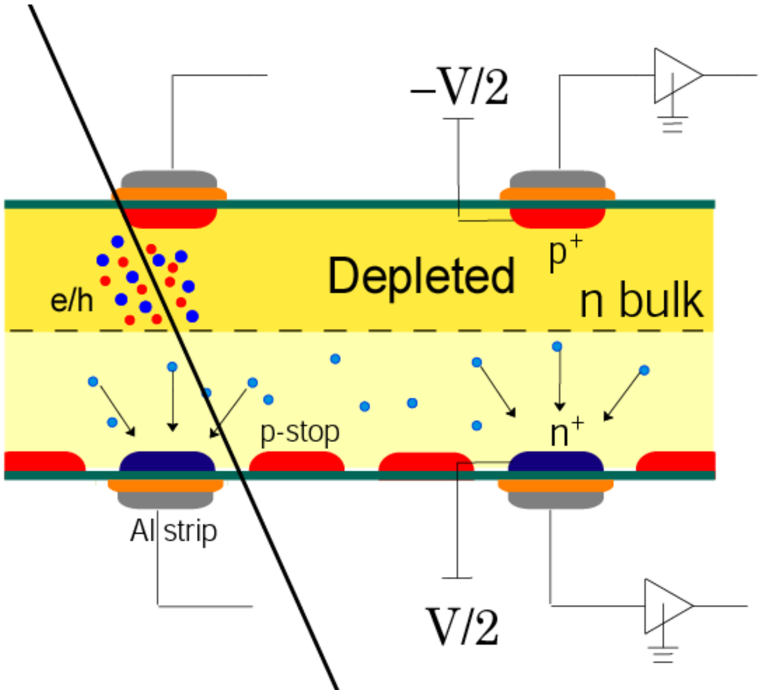
- Tracking detectors are an important component of collider experiments
- Semiconductor devices satisfy key requirements of speed and precision
- Reverse biased diode configurations make signal to noise ratio manageable
- Lifetime of silicon detectors limited by radiation induced effects
  - Microdischarge
  - Changes in depletion voltage

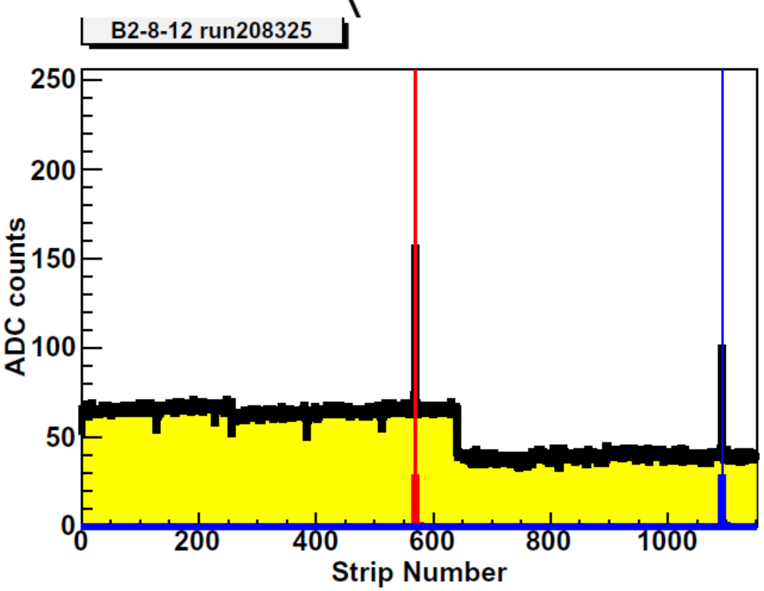
For Further Information

- *The Physics of Particle Detectors*, Dan Green
- *Semiconductor Radiation Detectors*, Gerhard Lutz
- *Silicon Particle Detectors - Why they are useful and how they work*, William Trischuk
- *Depletion Voltage for the DØ Silicon Microstrip Tracker Using the n-side Noise Method*, DØ Note 4917 (S. Burdin and S. Lager)
- *Radiation Damage in Silicon Particle Detectors*, M Moll, PhD Thesis

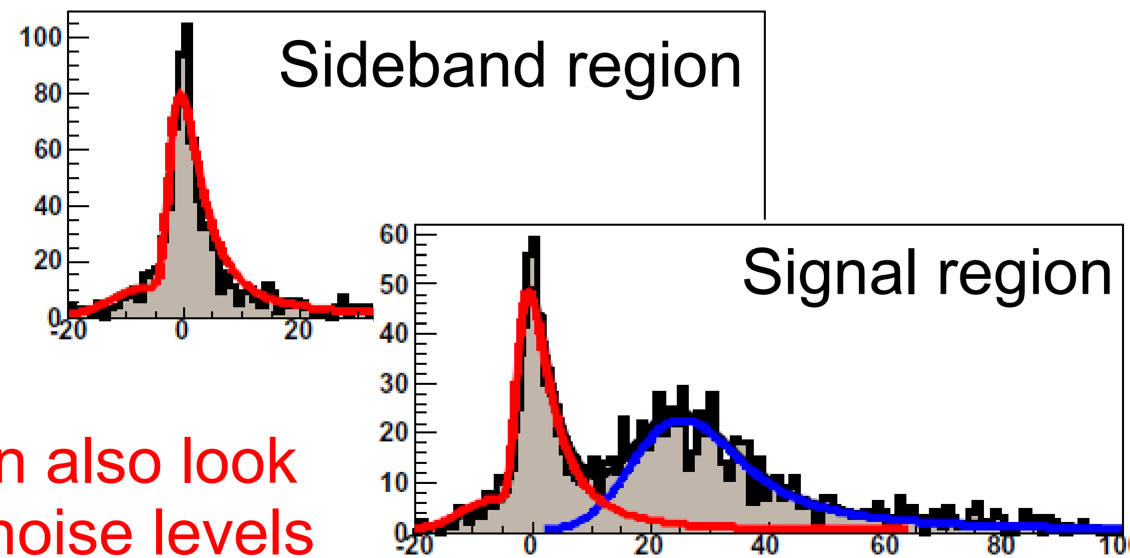
Backup Slides

Measuring Depletion Voltage

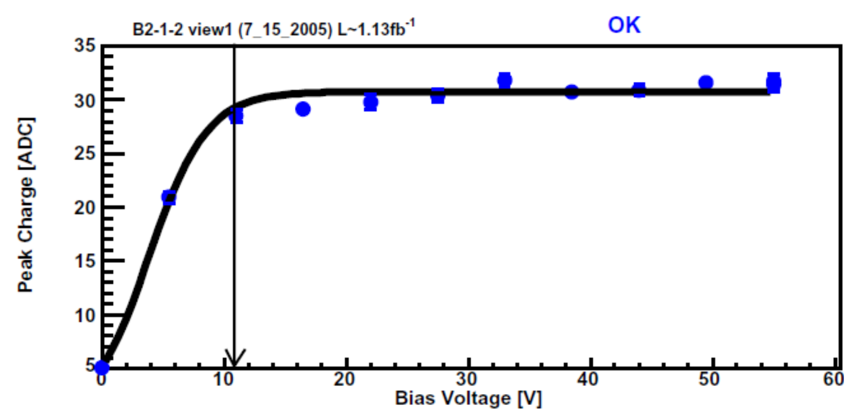




Determine depletion voltage by looking at signal size vs applied voltage



Can also look at noise levels

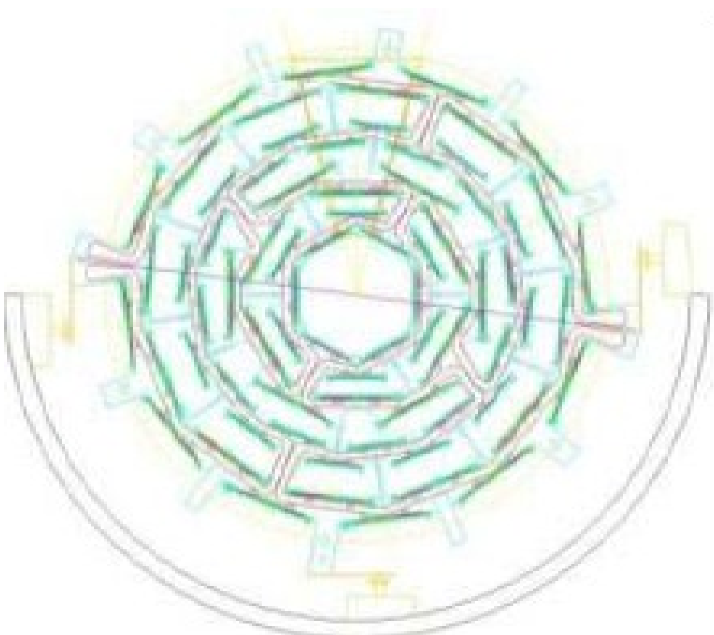


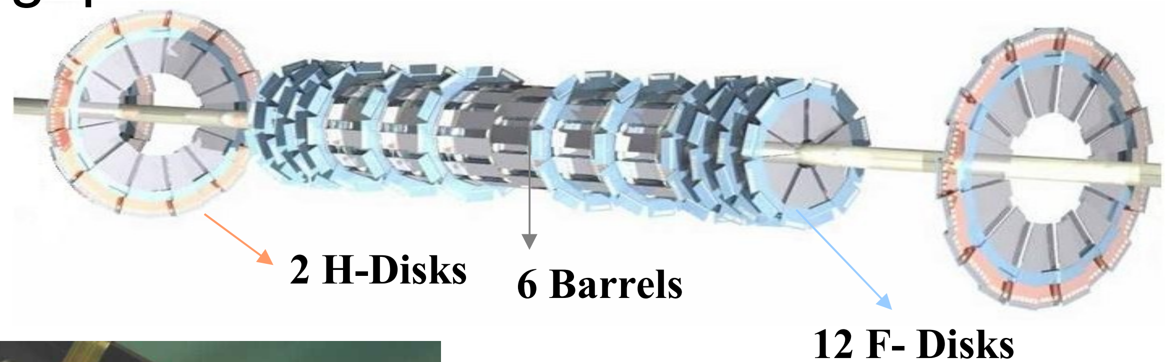
Plots stolen from Masato

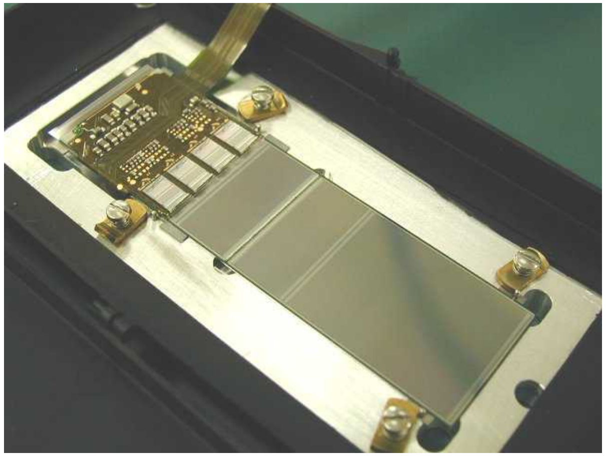
The DØ Silicon Tracker

Staggered sublayers to avoid ϕ gaps

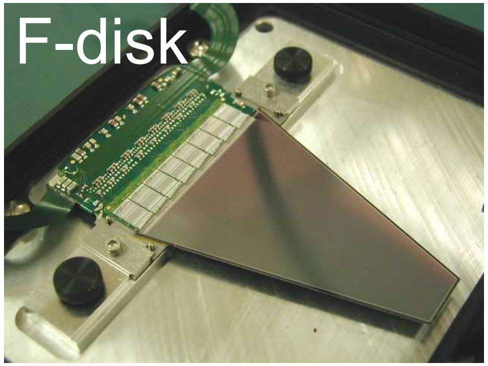
In total, 731,136 readout channels

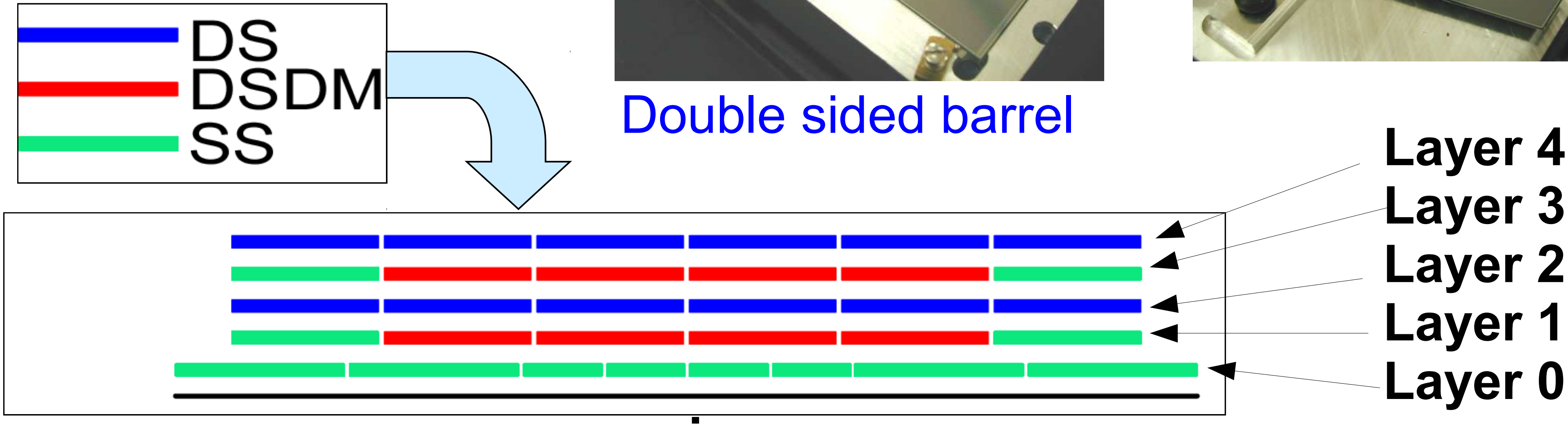






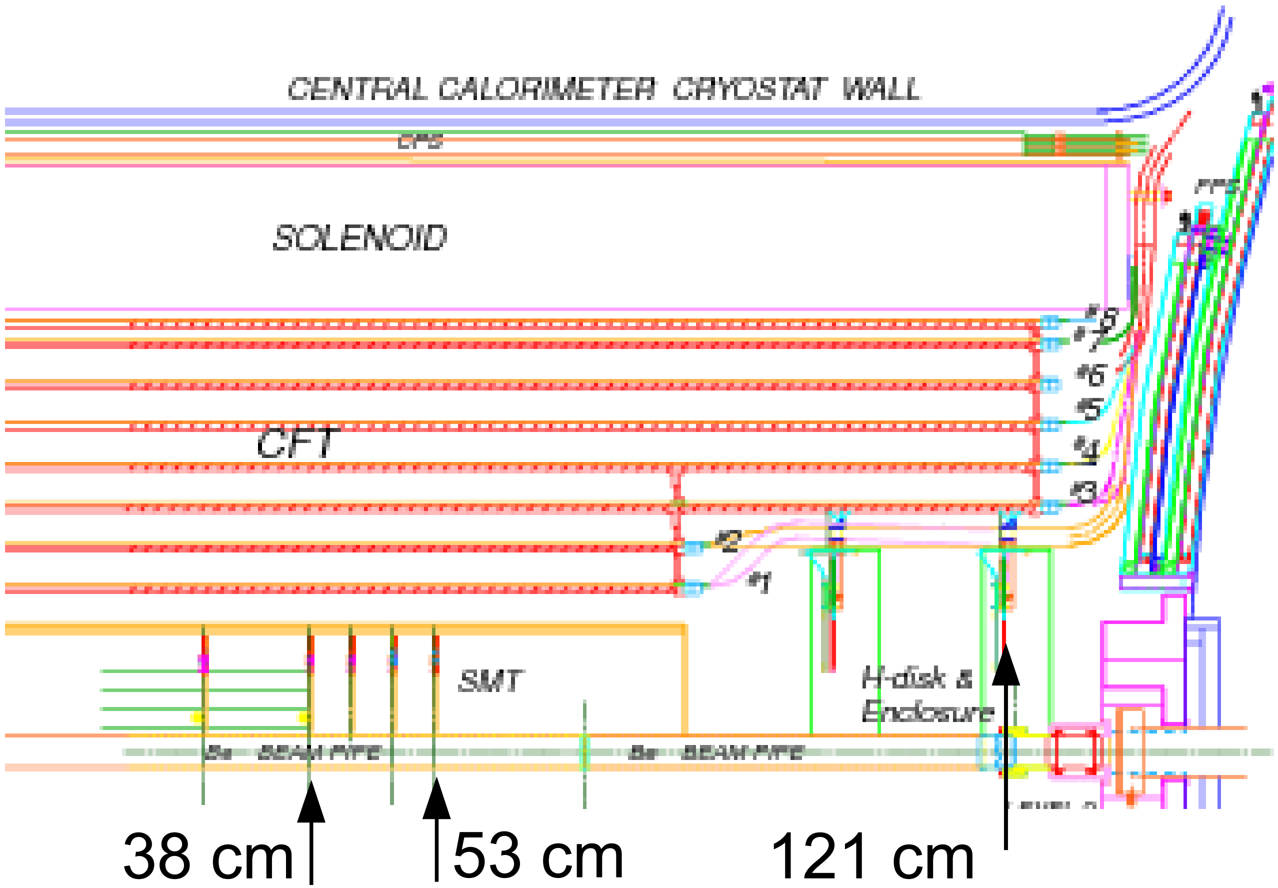
Double sided barrel





r-z view

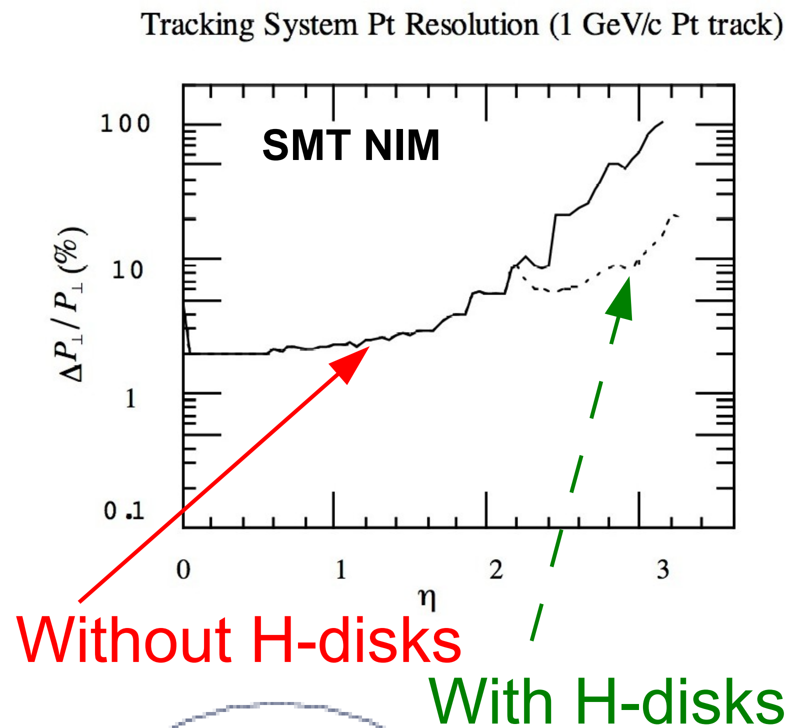
The DØ Tracking System

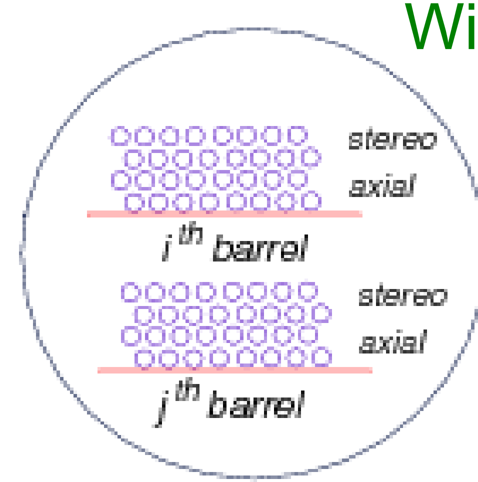


SMT	50 μm
CFT	835 μm

Strip spacing, sometimes larger

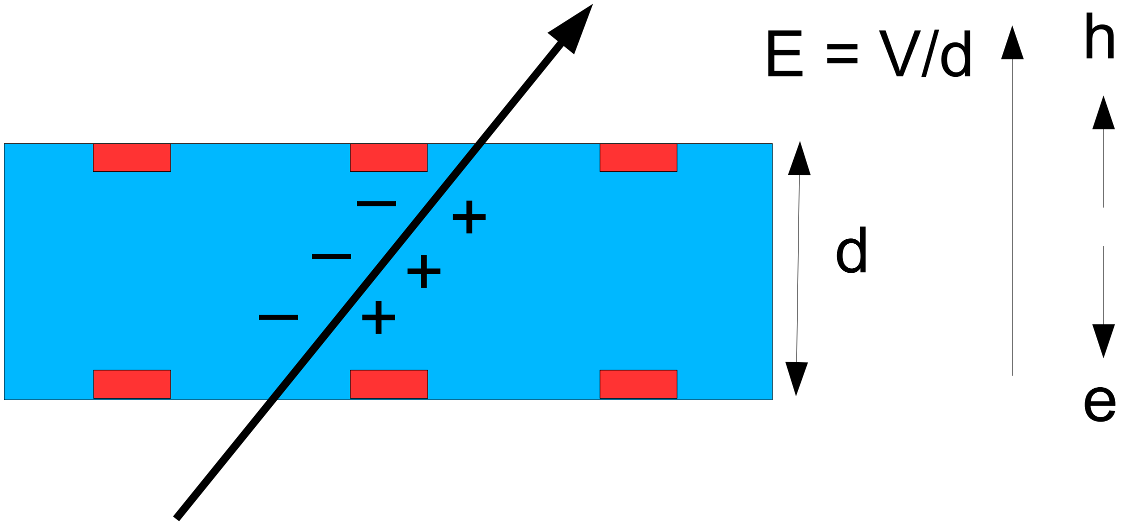
Fiber width





End View (CFT)

Lorentz Drifts

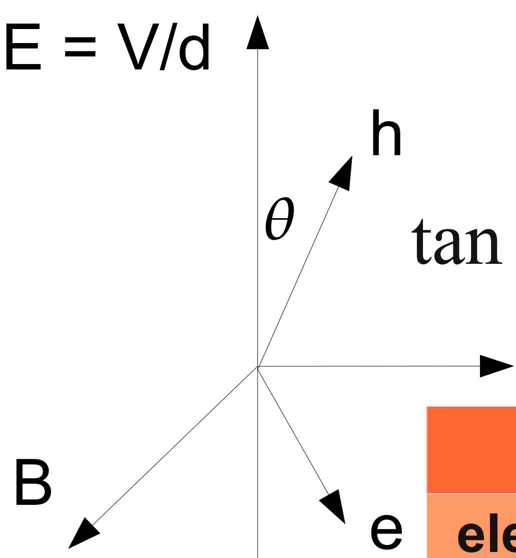


Drift velocity

$$v = \mu E = \mu \frac{V}{d}$$

	Mobility (cm²/Vs)
electrons	1400
holes	450

Lorentz drift can bias position measurement



$$\tan\theta = \mu_H B$$

Same direction for electrons and holes

	Hall Mobility (cm²/Vs)	tan θ
electrons	1670	0.33
holes	370	0.74