

Silicon Tracking at the Tevatron: Status Report and Lessons for the Future

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(For the D0 and CDF Collaborations)



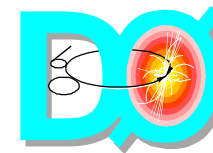
Talk Outline



- o Status report from D0, CDF
 - Current state of detectors, accelerator
 - Silicon performance optimization; charge correlation, alignment, resolution, etc
 - Some of the first physics
- o Lessons from the Tevatron
 - Radiation studies and silicon performance
 - Measurements of the radiation field
 - Surface/Noise problems
- o Observations for Run I I b
- o Conclusions



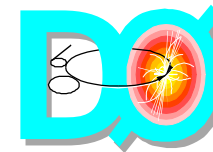
Tevatron/LHC Comparison



- o CDF and D0 *can* provide lessons for the LHC collider detectors
 - Comparable detector layout in a collider environment
 - Hadronic interaction and backgrounds from pp-bar
 - Silicon will undergo type inversion and 'die' from radiation
- o Not a perfect example because...
 - We use double-sided silicon, with voltage over the caps
 - Designed for only $\sim 6 \times 10^{13}$ (1 MeV n)
 - Last (and largest?) of the 'garage' style projects
 - Problem modules and sensors were fixed/reworked
- o Analogous, and currently one of the closest in scale



The Fermilab Tevatron Collider



1992-1995

Run 1: 100 pb^{-1} , 1.8 TeV
Luminosity $\sim 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$

1996-2001

Major accelerator & detector upgrades
bunch spacing $3.5 \mu\text{s} \rightarrow 396 \text{ ns}$

2001-2003

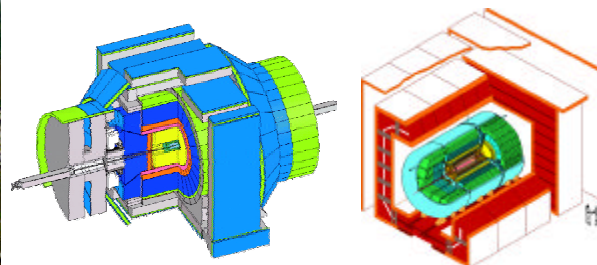
Run 2a: $2\text{-}3 \text{ fb}^{-1}$, 1.96 TeV
Luminosity $\sim 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$

2004?

Silicon tracking replacement
132 ns bunch spacing, crossing angle

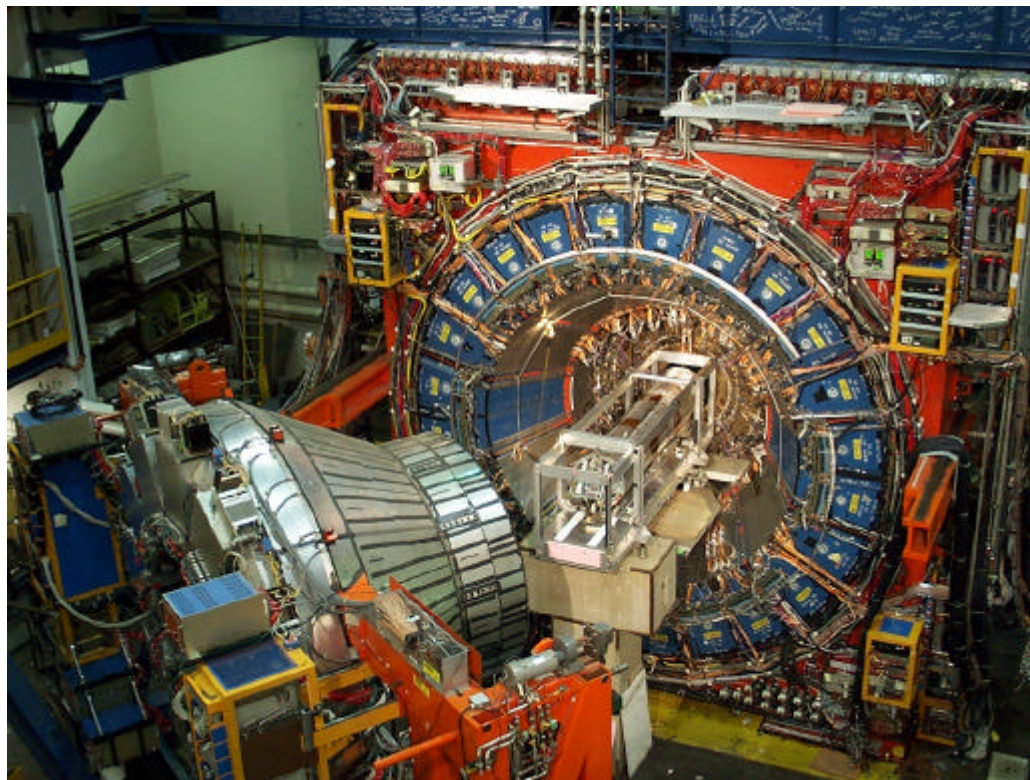
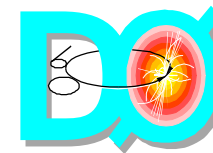
2004-2008

Run 2b: $\sim 12 \text{ fb}^{-1}$
Luminosity $\sim 5 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$





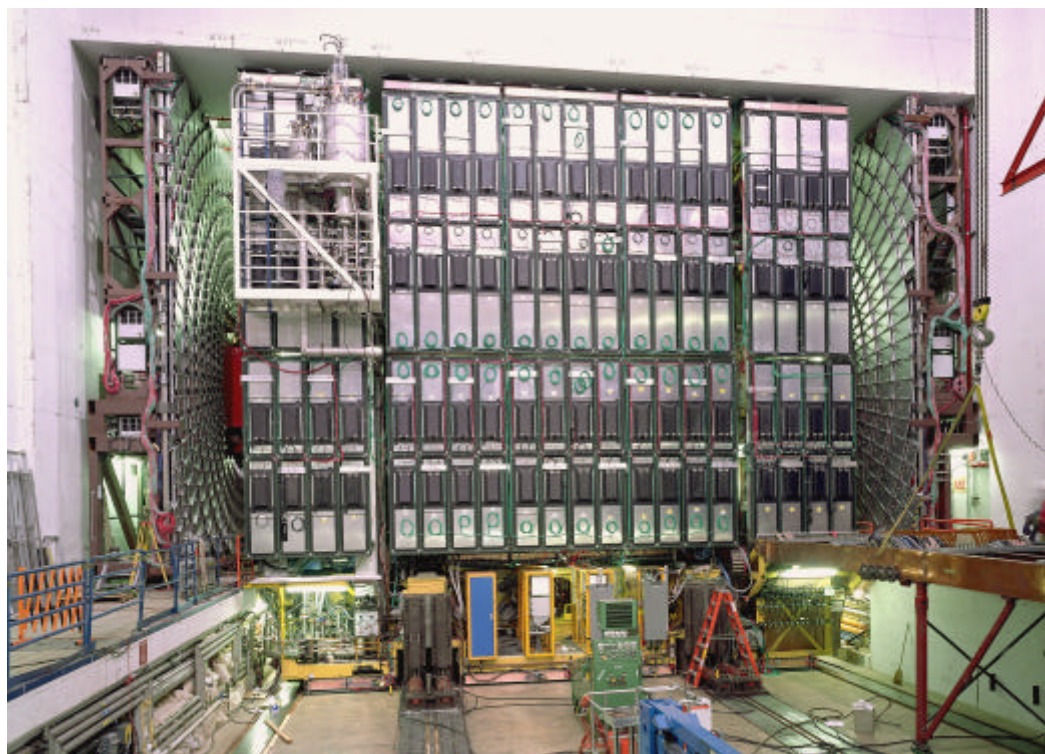
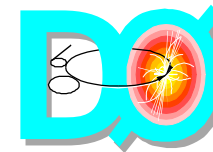
CDF Detector



installing silicon tracker, prior to detector roll-in



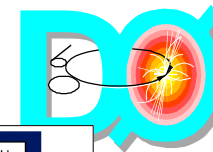
The D0 Detector



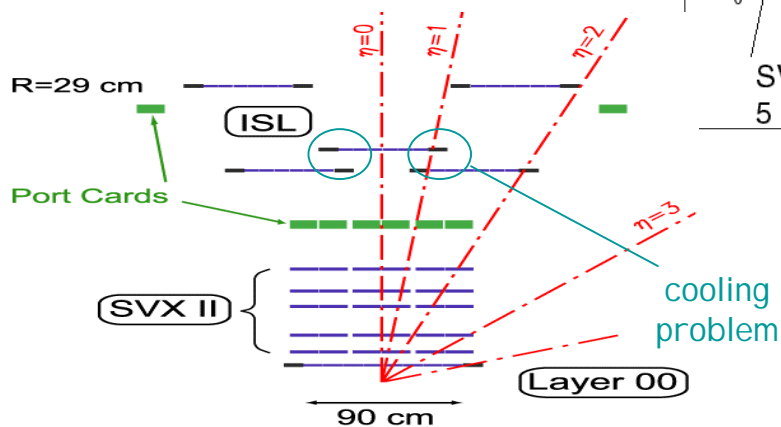
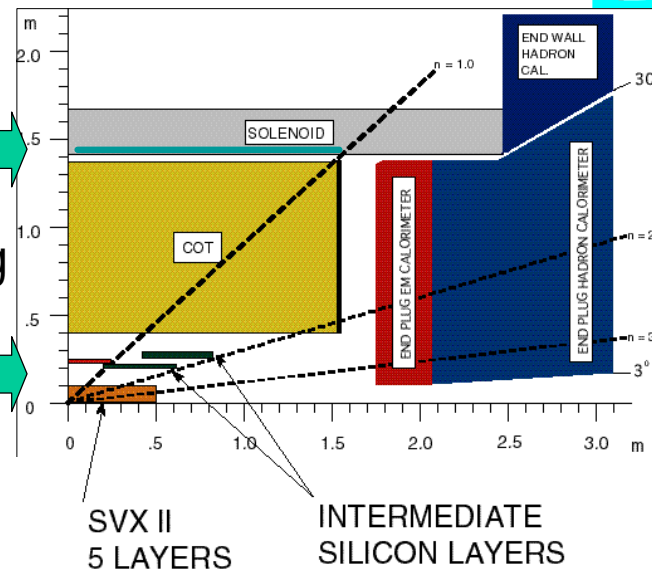
in the collision hall - Jan 2001



The CDF Detector

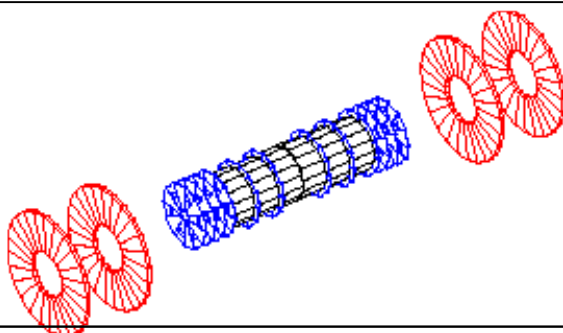
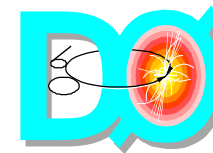


TOF
 COT: Central outer Tracking
 Silicon System



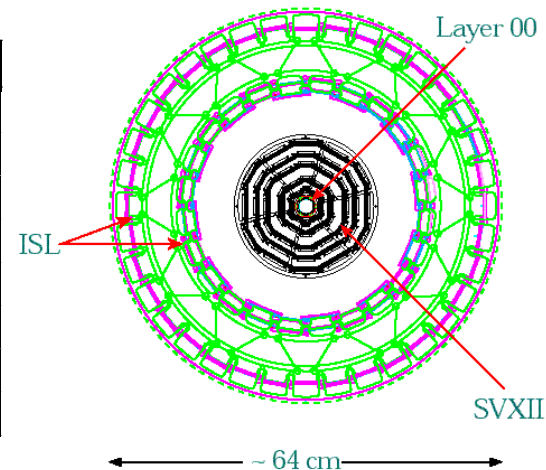


Fermilab Run II Silicon



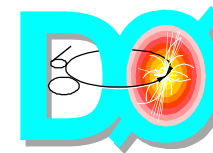
DØ	6 Barrels	F Disks	H Disks	Totals
Layers/planes	4	12	4	
Δz	77 cm	48 cm	10 cm	
Channels	387120	258000	147456	792576
Modules	432	144	192	768
Readout Length	12 cm	7.5 cm	14.9 cm	
Inner Radius	2.7 cm	2.6 cm	9.5 cm	2.6 cm
Outer Radius	9.4 cm	10.5 cm	26 cm	26 cm

CDF	Layer 00	SVX II	ISL	Totals
Layers	1	5	2	8
Length	0.9 m	0.9 m	1.9 m	
Channels	13824	405504	303104	722432
Modules	48 SS	360 DS	296 DS	704
Readout Length	14.8 cm	14.5 cm	21.5 cm	
Inner Radius	1.35 cm	2.5 cm	20 cm	1.35 cm
Outer Radius	1.65 cm	10.6 cm	28 cm	28 cm
Power	~100 W	1.4 kW	1.0 kW	1.5 kW





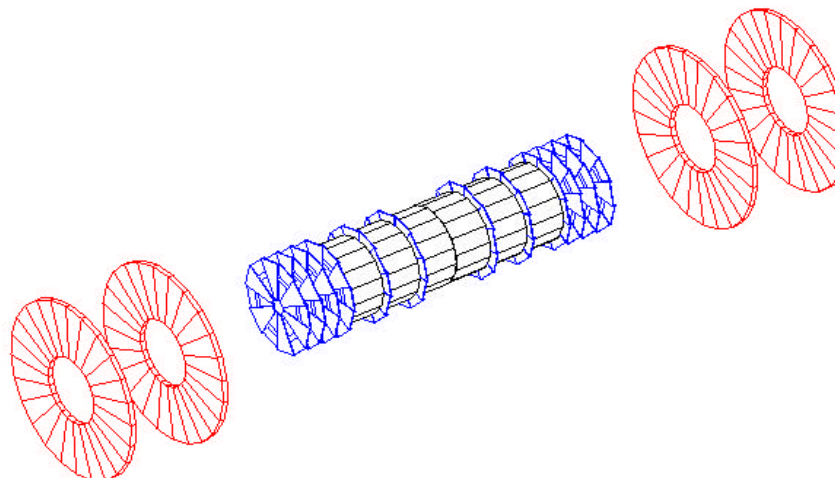
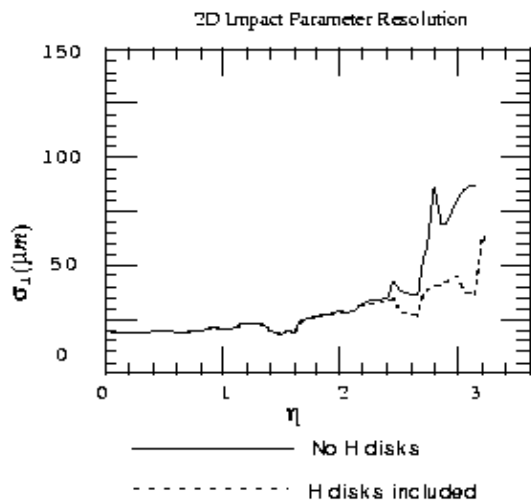
D0 Silicon: SMT



Goals and Features:

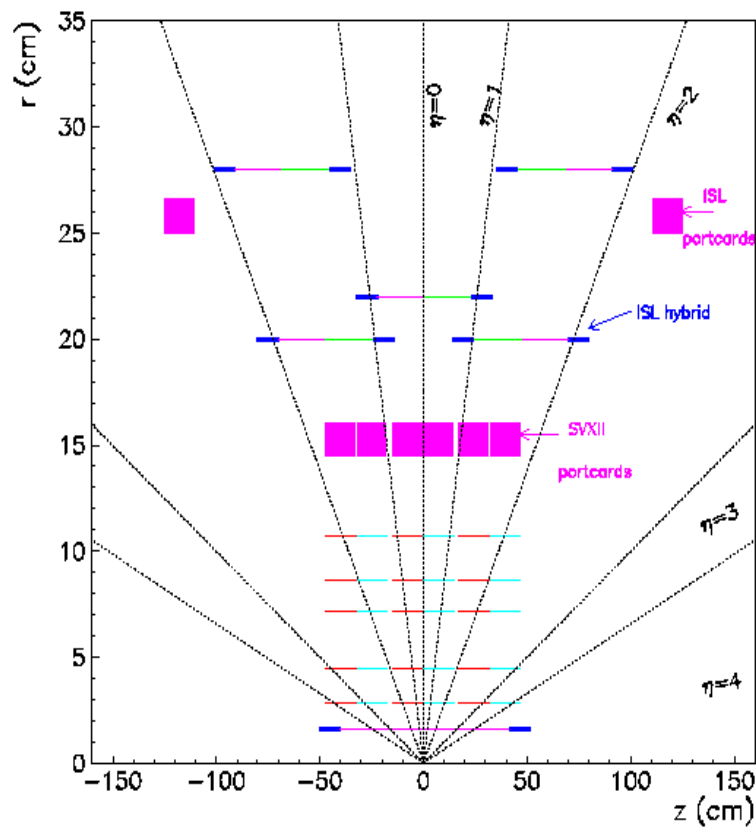
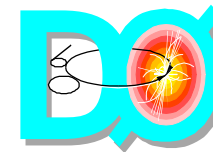
- o 800,000 readout channels
- o High efficiency tagging; for $p_T = 50$ GeV/c
 - ~50% for b-quark jets
 - ~0.5% fake tag rate for u, d, s quark jets
- o Stand-alone tracking to $\eta > 2.5$
- o Assembly to ~ 20 μm (for trigger)

	Barrels	F-Disks	H-Disks
Channels	387072	258048	147456
Modules	432	144	96
Si Area	1.3 m ²	0.4 m ²	1.3 m ²
Inner R	2.7 cm	2.6 cm	9.5 cm
Outer R	9.4 cm	10.5 cm	26 cm





CDF Silicon: L00+SVXII+ISL



Goals and Features:

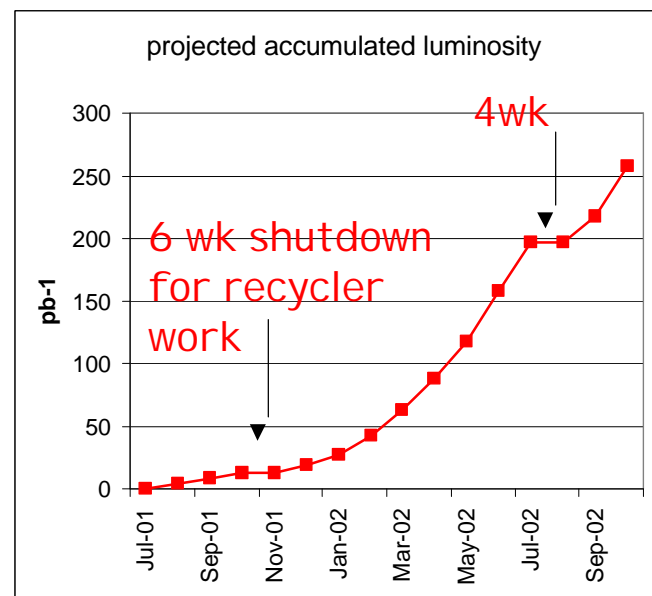
- o Precise 3D track impact parameters
 - B tagging: top, SUSY, Higgs
 - B Physics
- o Improved forward coverage
 - $0 \leq |\eta| \leq 2$
- o Level II displaced-track trigger (SVT)
 - Hadronic B decays
 - Calibration triggers
- o Improved p_T resolution
- o High tracking efficiency with good purity



Tevatron Run II : 2001-2002



- o Commissioning begins in March 2001 for Main Injector + Tevatron, detectors
- o Early in 2001
 - Achieved $7 \times 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$
 - 10.7 pb^{-1} integrated luminosity
- o Current state
 - Shutdown for ~6 weeks (Recycler work)
 - Experiments have access to detectors
- o Goals for 2002
 - $4 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$
 - ~200 pb^{-1} by summer
- o Later in 2002
 - $8 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$
 - Commission Recycler (recover antiprotons)





Current Events



- o What have we been doing during the recent shutdown?
 - Global alignment adjustments
 - Installing remaining electronics, power supplies, etc
 - Tweaking DAQ, trying to recover dysfunctional modules
- o After the October shutdown...
 - Moved, but global position still off by several mm
 - Some tweaking left to do (CDF), but overall...
 - CDF: 95%
 - 98% L00, 94% SVX, 96% I SL (mod a cooling problem)
 - DØ: 97%
 - >97% good ladders, >93% good wedges
 - >98% good channels on readout wedges
- o Success!

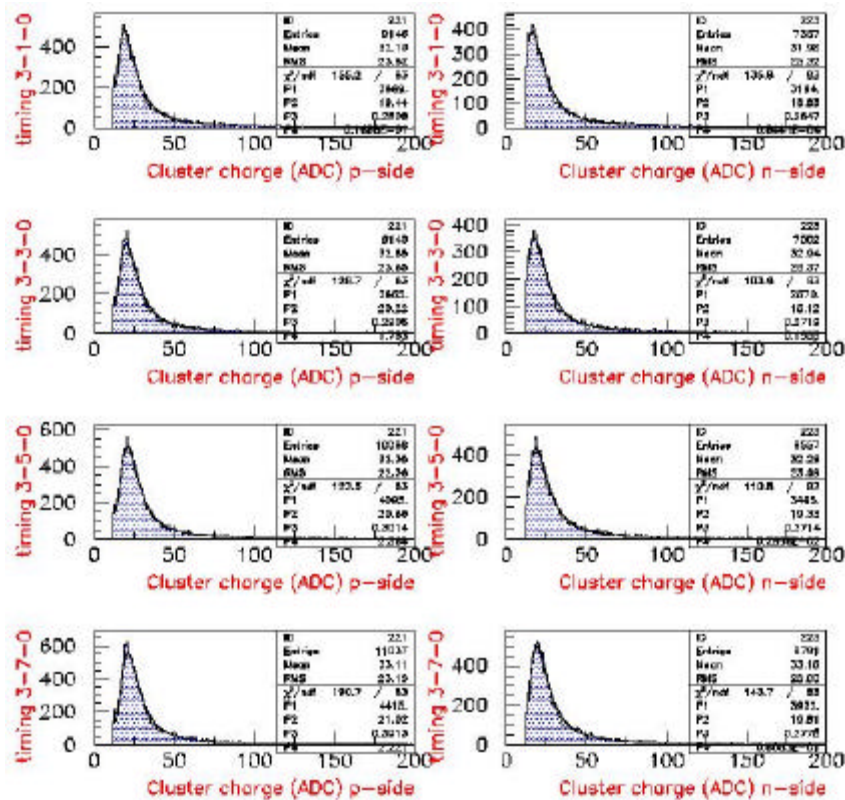
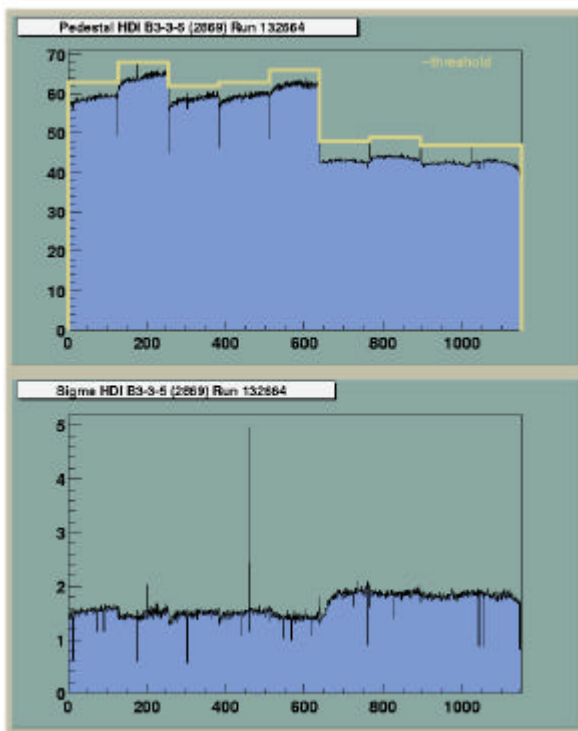


Silicon Performance (D0)



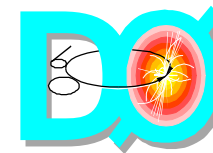
Noise, pedestals

Cluster charge: ~25 counts/MI P

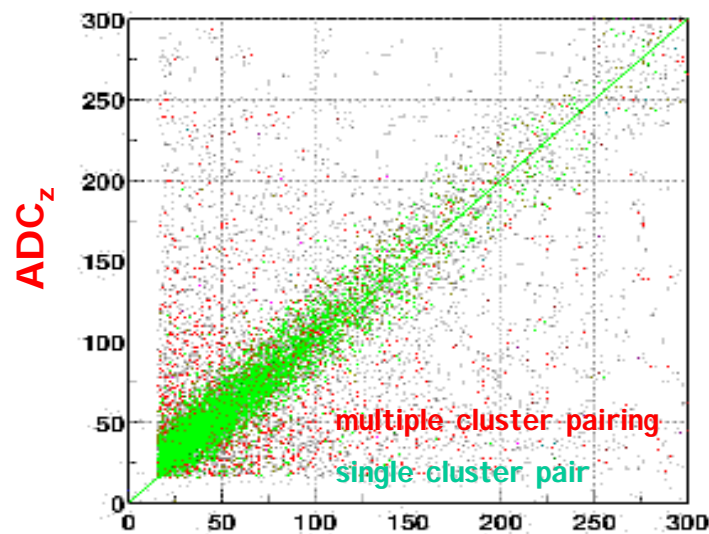
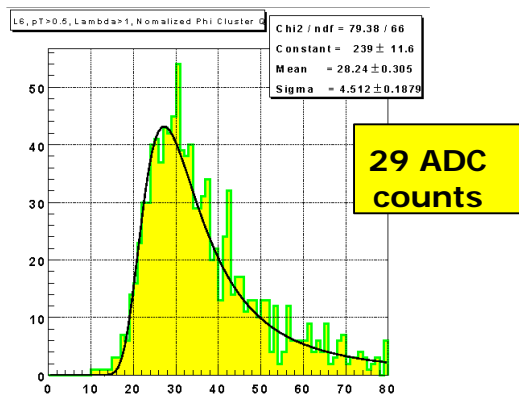




Charge Correlation (CDF-I SL)

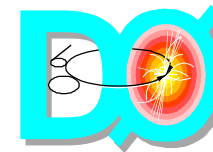


- o Optimization of the readout, clustering, and tracking is ongoing
- o Reasonable charge obtained from all layers.
- o Double-sided silicon allows for charge correlation studies.

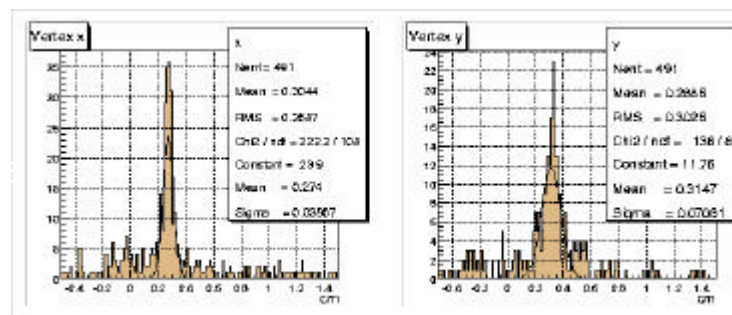
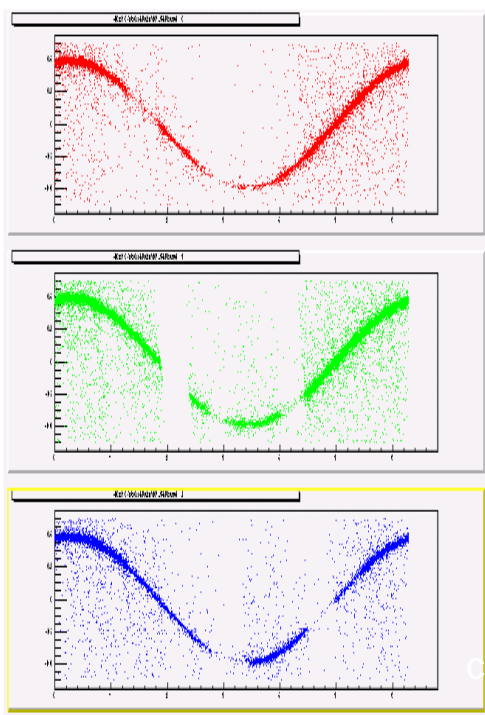




Detector Alignment (CDF & D0)

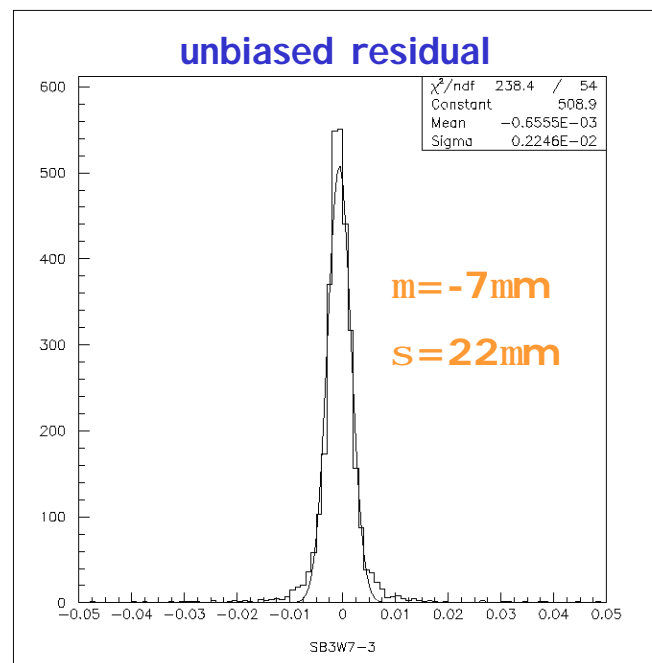
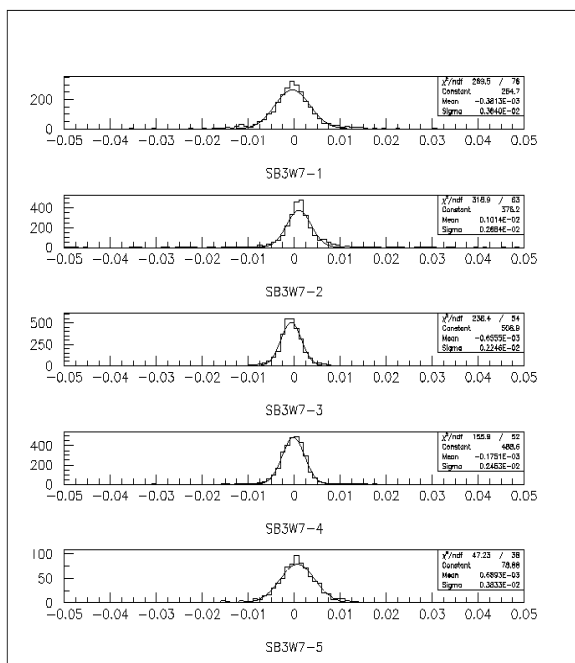
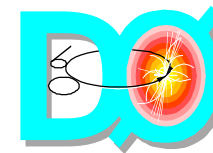


- o CDF beam spot was off by
 - $x_0 = -0.15$ cm
 - $y_0 = 0.38$ cm
- o D0 beam spot off center by
 - $x_0 = 0.27$ cm
 - $y_0 = 0.32$ cm
 - $z_0 = 7.04$ cm
- o Detectors moved during recent shutdown (for L00 and displaced track triggers).





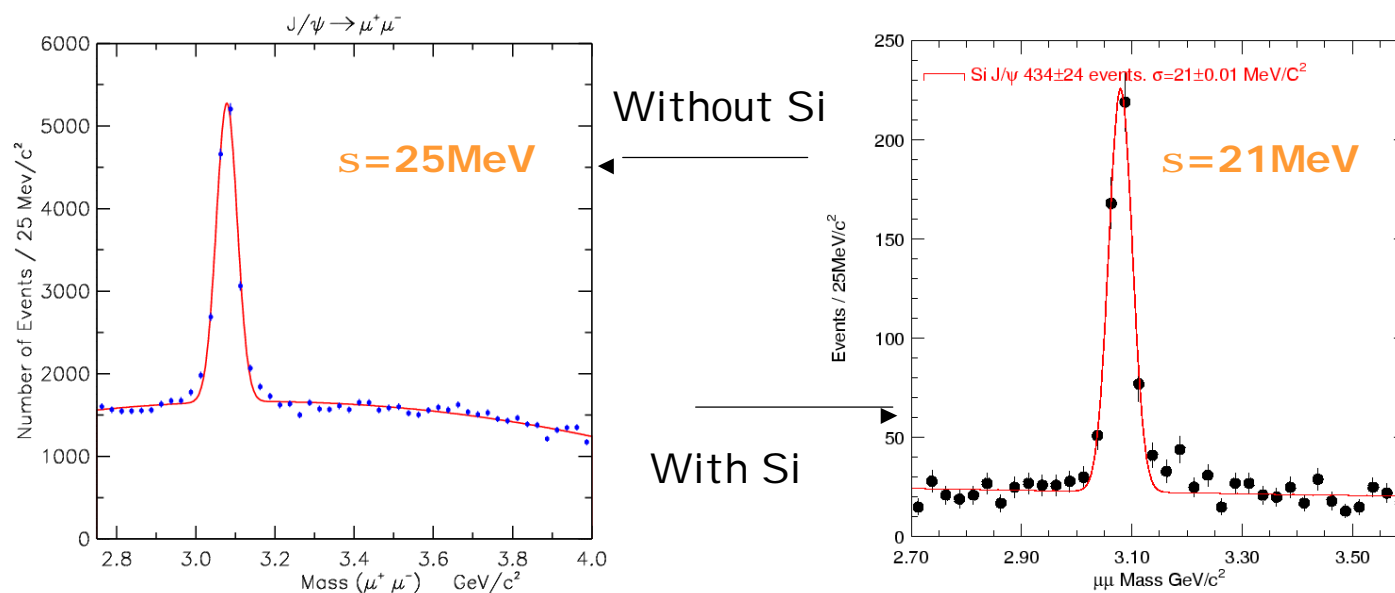
Hit Resolution



Sample well-aligned wedge. No additional alignment corrections made (yet). σ includes tracking uncertainty.



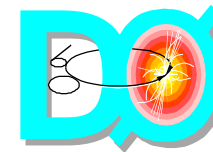
J/ ψ with and w/o Silicon (CDF)



o No alignment or energy loss corrections made for this study

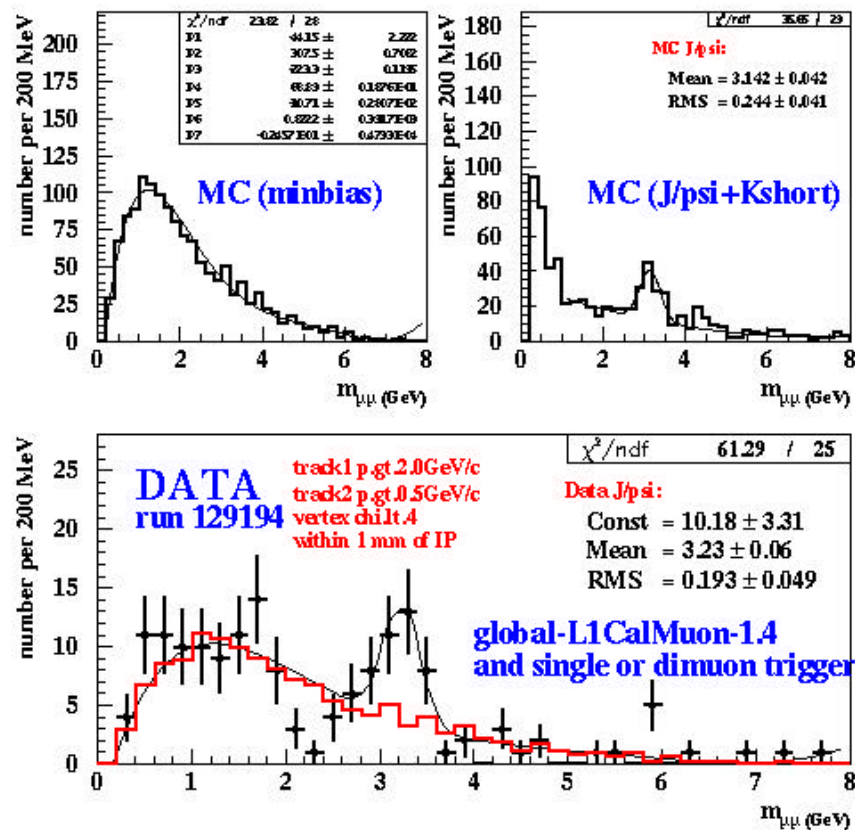


D0 Initial Data: J/ψ



SMT-only tracking for both MC (with noise) and DATA

silicon tracking
only
(one run)





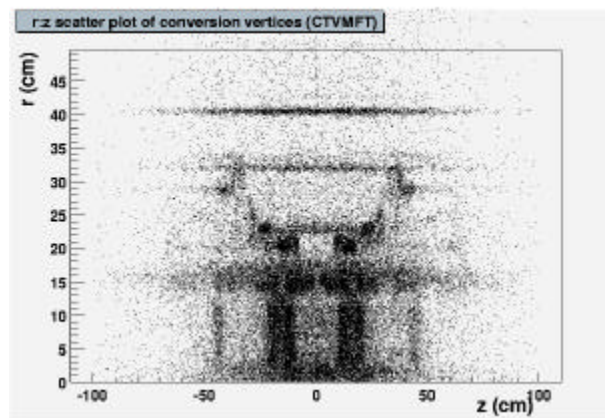
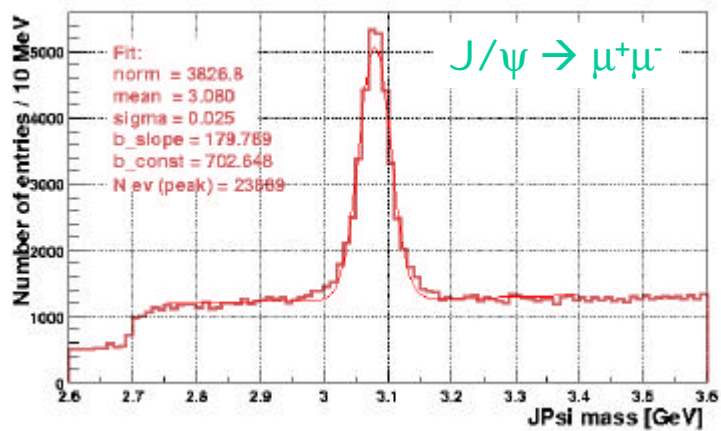
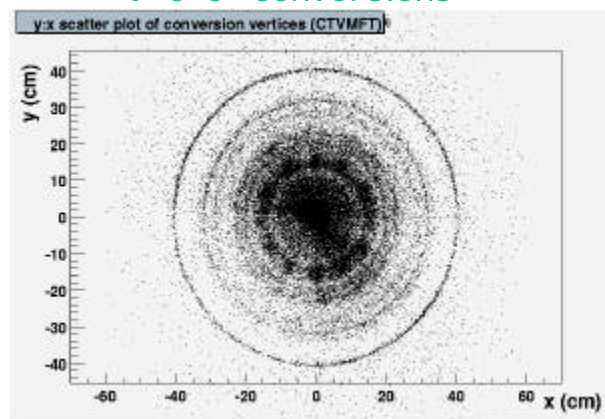
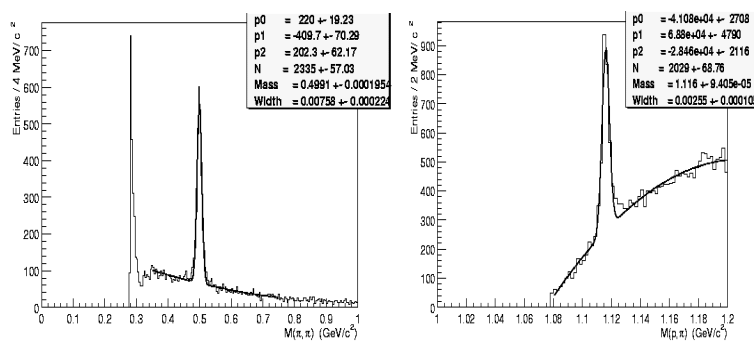
CDF "engineering samples"



$K_s \rightarrow \pi^+\pi^-$

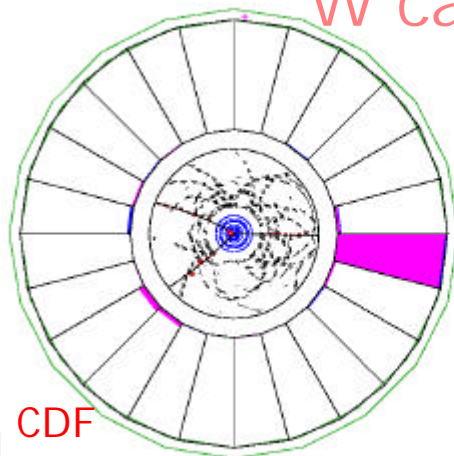
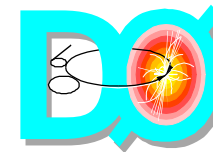
$\Lambda \rightarrow \pi\pi$

X-ray the detector with γ
 $\rightarrow e^+e^-$ conversions





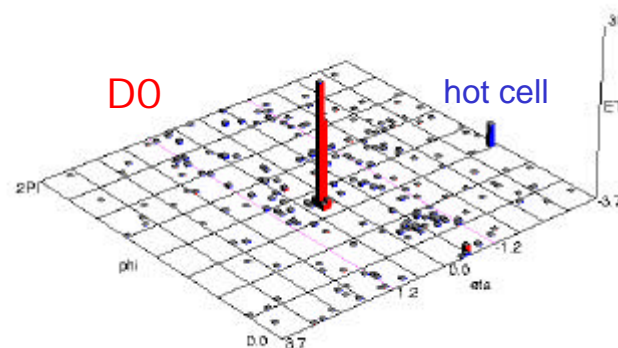
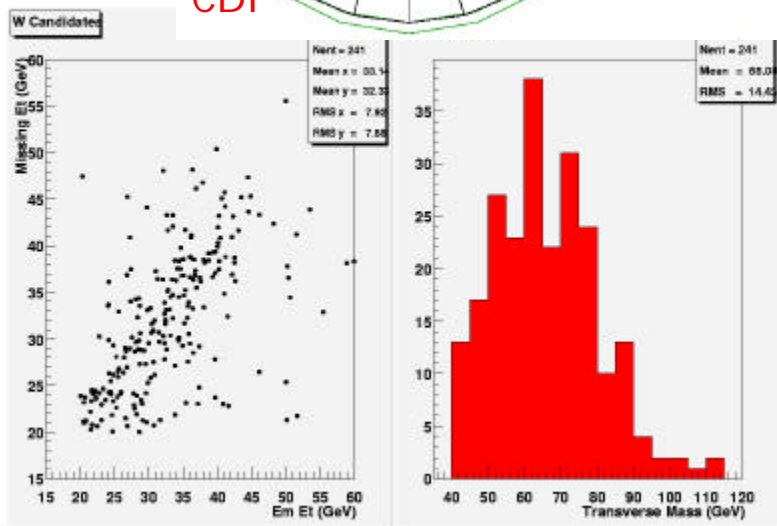
W candidates



High Pt W and Z's are very clean

$W \rightarrow e\nu$

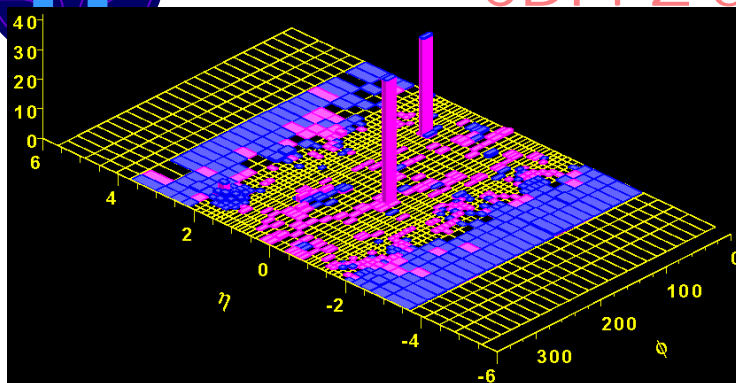
CDF



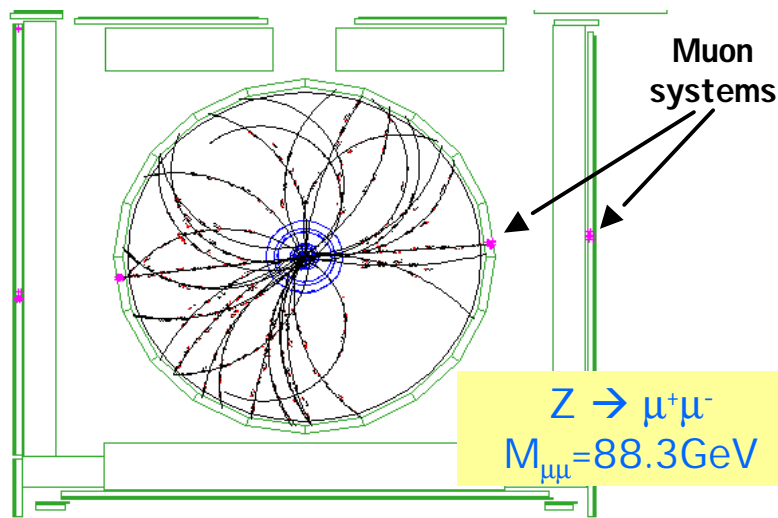
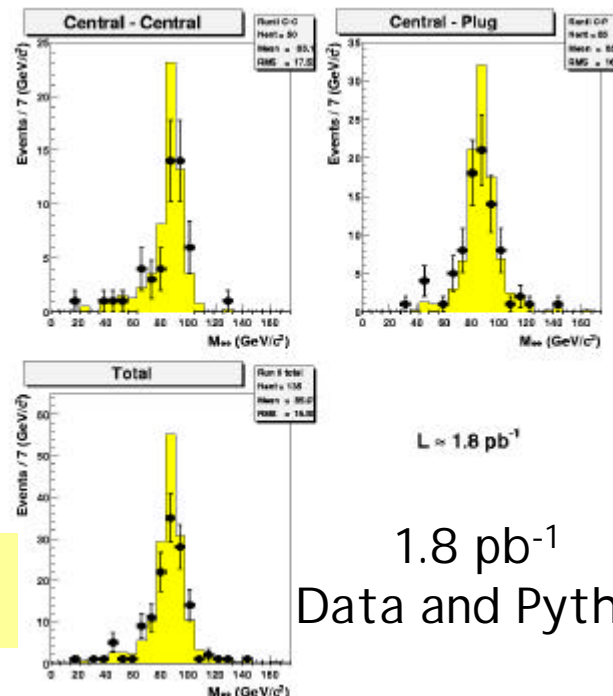
$p_T = 38 \text{ GeV}$ isolation < 0.2 EM fraction = 0.97



CDF: Z sample



$Z \rightarrow e^+e^-$



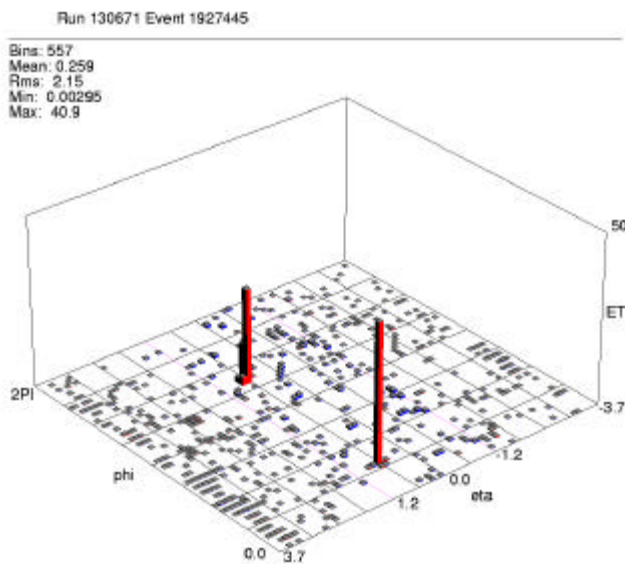
Rad hard Semiconductor Devices, CERN Nov 28-30, 2001



D0: Z's

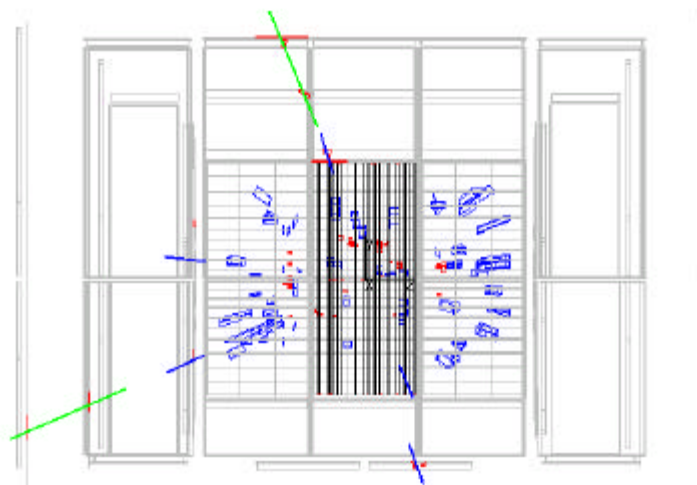


Z \rightarrow ee candidate



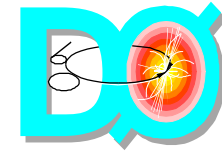
Z \rightarrow $\mu\mu$ candidate

- Two muons recoiling against a jet
- Dimuon mass = 55 GeV





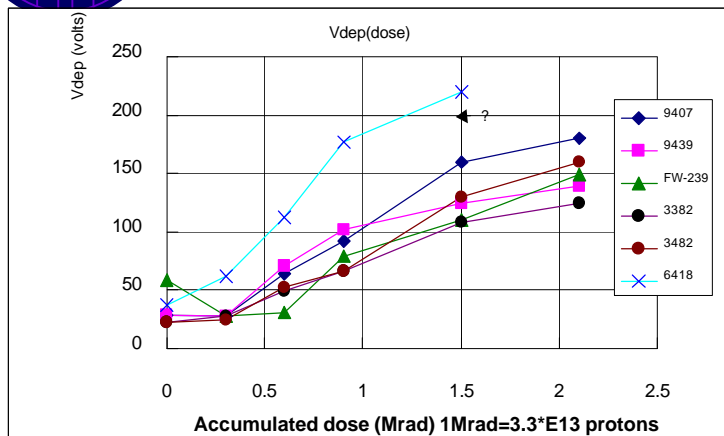
Silicon and Rad Damage Properties



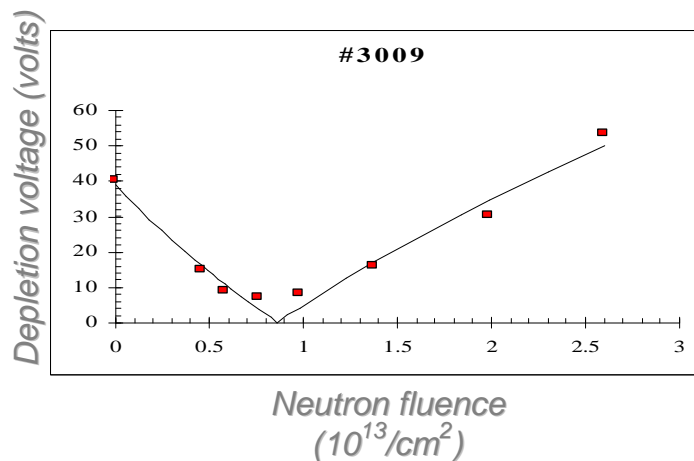
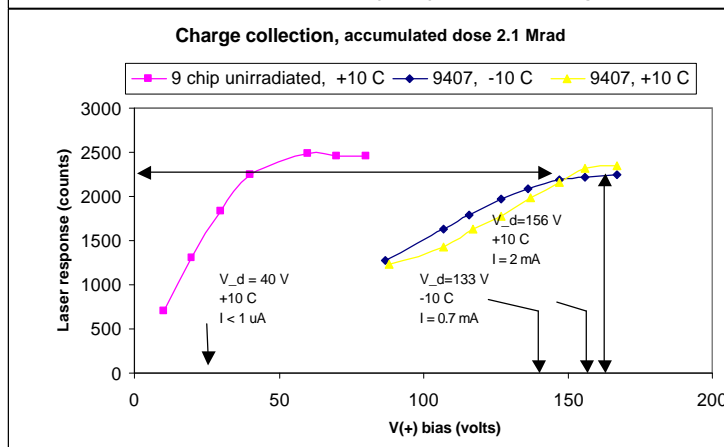
- o No appreciable radiation yet, but we will have very soon
- o Some L00 sensors are oxygenated silicon, will have in situ measure of properties
- o The radiation field and accelerator backgrounds are being studied
- o Analogous to LHC detectors, and currently one of the closest in scale



Radiation Damage (D0)



- o Modules irradiated and read out to ensure long life
- o Studies of "as built" detectors at the Fermilab booster (8 GeV protons)





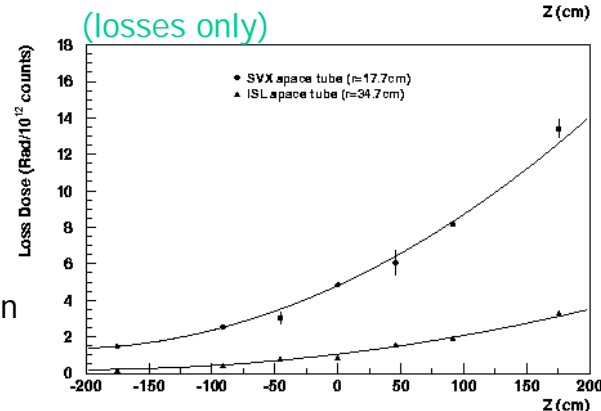
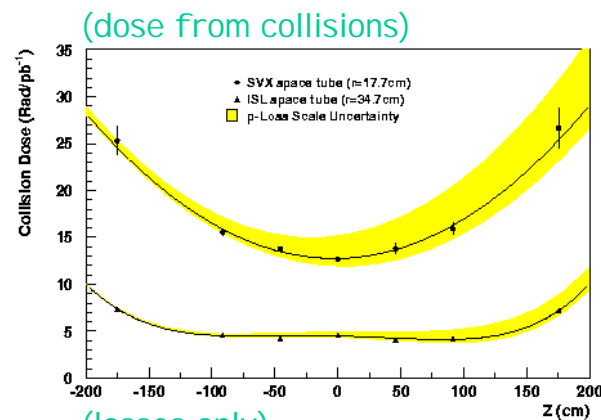
Radiation Field (CDF)



- o Thermoluminescent Dosimeters (TLD)
 - Sensitive to gammas, charged particles, thermal neutrons (^6LiF , ^7LiF)
 - Easy to place and readout
- o Dose seen from both losses and collisions
 - Dose from losses measured in early 2001
 - Collisions+losses measured May-October

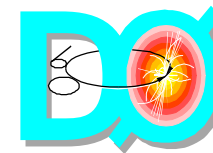
	Feb-May	May-Oct
protons	7.03 E17	1.56 E19
anit-p	0.82 E17	1.37 E18
proton loss	1.06 E12	4.08 E10
anti-p loss	0.14 E12	1.01 E10
Luminosity	41.6 nb ⁻¹	10.7 pb ⁻¹

- o Radiation vs. radius falls off as expected
 - Radial dependence varies as $\sim r^{-1.6}$ near silicon
 - Varies as $\sim r^{-2.0}$ for large z



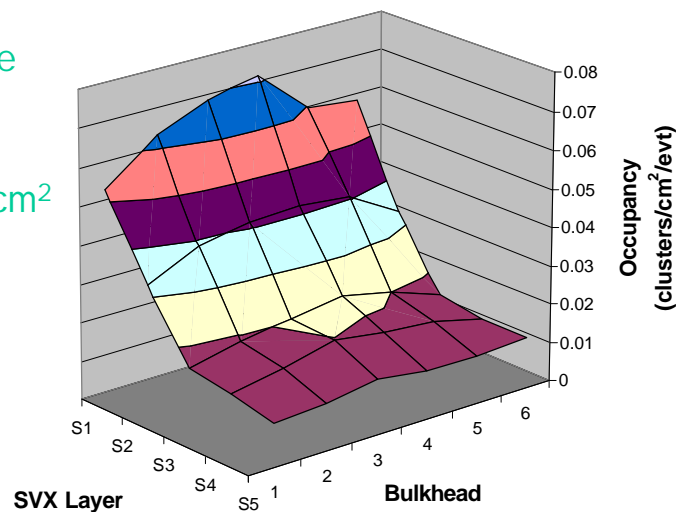
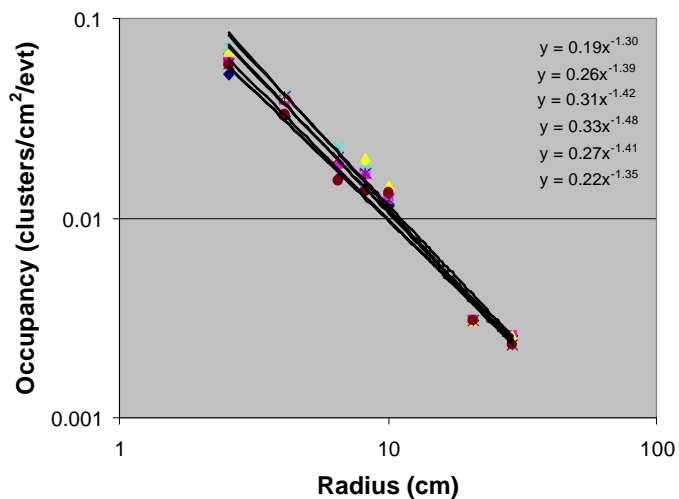


Silicon Occupancy (CDF)



High clustering thresholds and aggressive cleanup (removal of noisy devices),

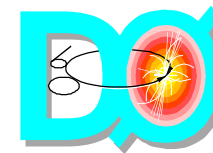
Divide by active area for occupancy per cm² per event.



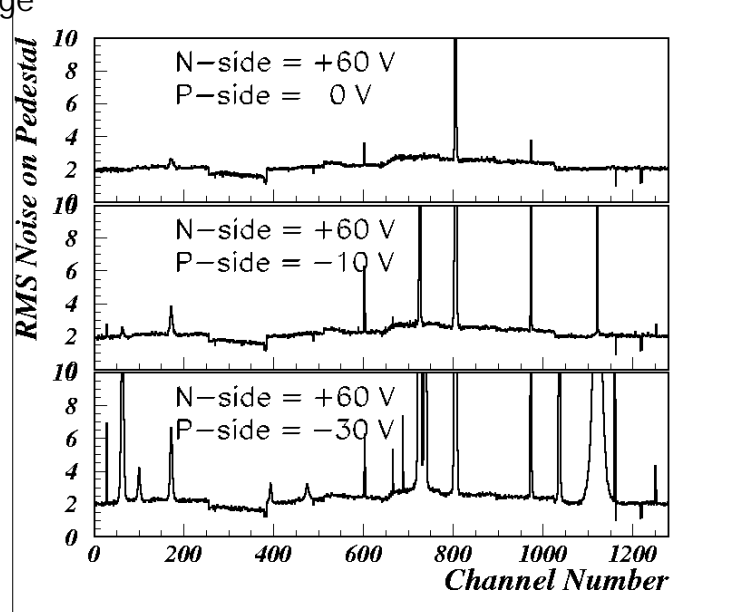
Physics occupancy also follows power law; including I SL, rate follows $\sim r^{-1.4}$.



Surface Damage (CDF/Micron)

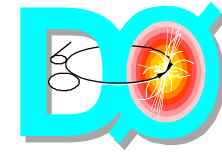


- o Oxide charges in the silicon strip sensors from Micron Semiconductor
 - Oxide charge starts out high before irradiation
 - Adversely influences operation in certain biasing configurations
- o Post-irradiation behavior of oxide-induced problems are not well known
 - Some evidence from DO indicates improved performance
 - May ultimately limit depletion voltage
- o Epoxy/SiO₂ interface not studied
- o Expected to be no surprise...
 - Hamamatsu Semiconductor sensors, despite a complicated oxide/nitride/polysilicon capacitor
 - Long-term readout chip under irradiation
 - Chips tested with ⁶⁰Co source and 63 MeV protons have performed well
 - Should withstand a very high dose (ie 4 Mrad or more)





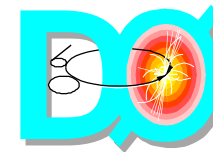
Rad Hard devices and Run I I b



- o Run I I a silicon was highly constrained mechanically (CDF from triggering, DO from space), and relied on older Si layouts, charge correlation, etc.
 - CDF silicon limited to ~170V by coupling caps and a subtle layout flaw
 - DO silicon limited to ~100V by coupling caps and old-fashioned microdischarge (implant - metal < 1 μ m).
- o Run I I b silicon must last for the duration of Tevatron data taking. There are several ways to make this possible.
 - Engineering the Properties
 - Oxygenated Silicon
 - Other tricks? Other materials?
 - Optimizing the Implementation
 - No/low voltage across the caps, guard rings to smooth transition from HV
 - Higher radius? Shorter strips?
 - Keep it cold?
- o Will likely move to single sided, and optimize implementation

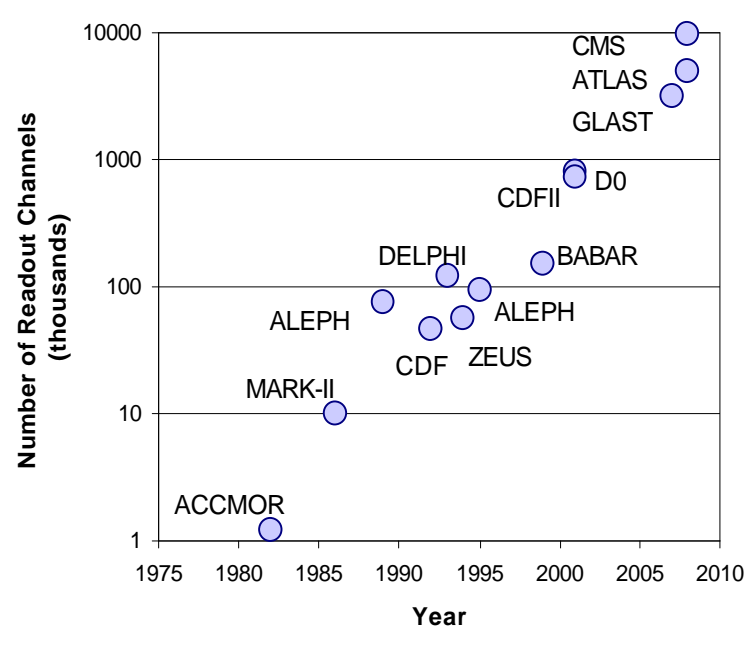


Conclusion



- o In little more than 15 years silicon has gone from an exotic to a common tracking medium.
 - "Solid-state detectors require high-technology devices built by specialists and appear as black boxes with unchangeable characteristics." -Tom Ferbel, 1987
 - CMS will have 250 m² and ~10 million channels!
- o CDF and D0 are the last stage of evolution before the LHC-scale devices
- o Dramatic advances have been made in both understanding and *reducing* the damage effects. Run I b will benefit from this work.

Each detector is ~95% operational!





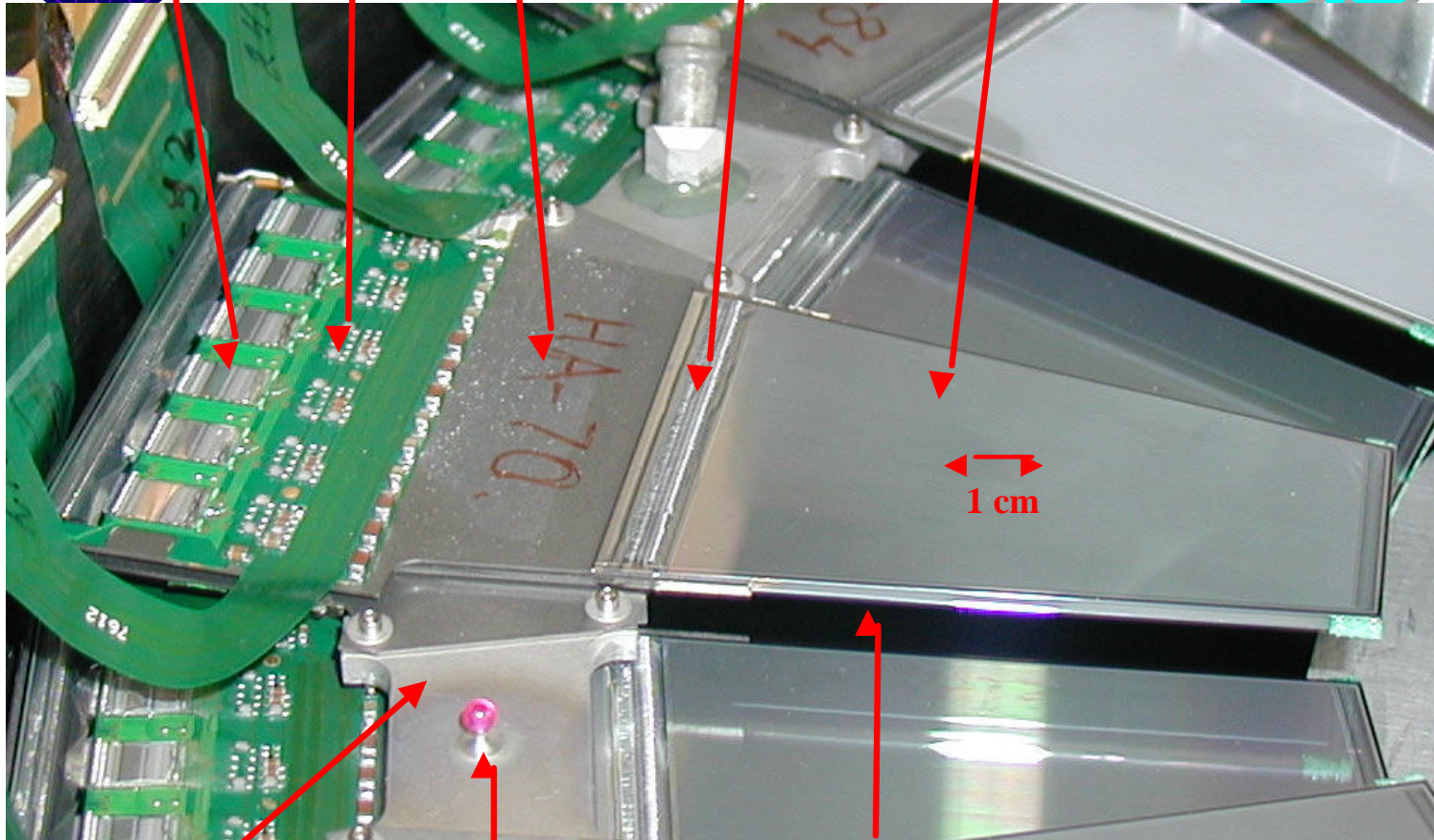
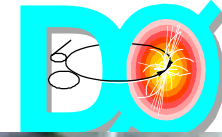
readout chips

kapton hybrid

Be hybrid substrate

wirebonds

Top detector pair



Rad hard Semiconductor Devices, CERN Nov 28-30, 2001

Be cooling channel

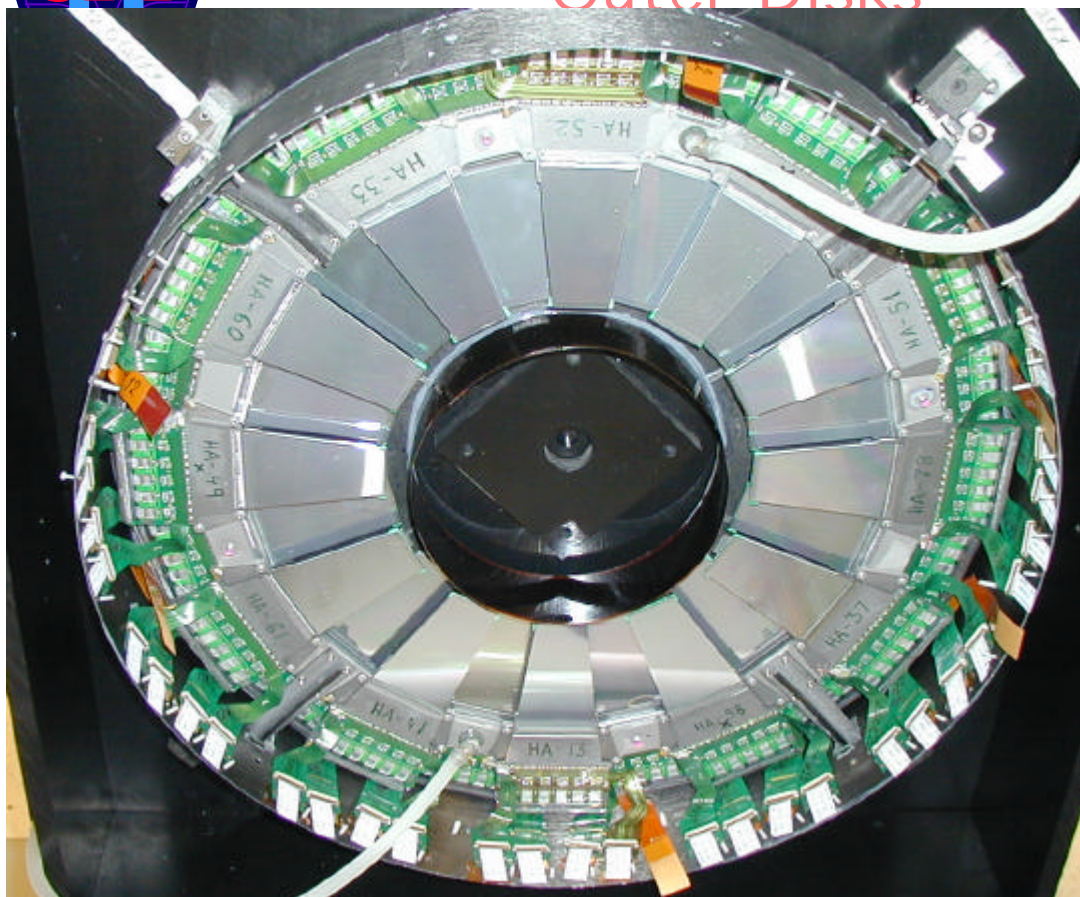
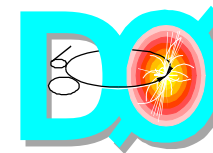
Alignment ball

bottom detector pair

Steve Worm, Rutgers 31



Outer Disks

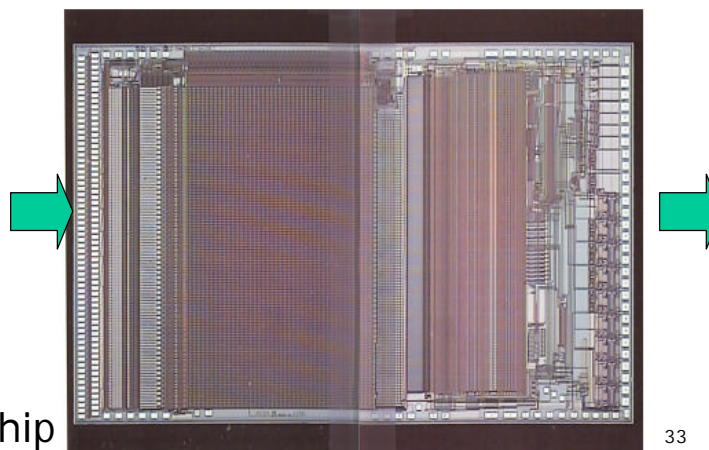
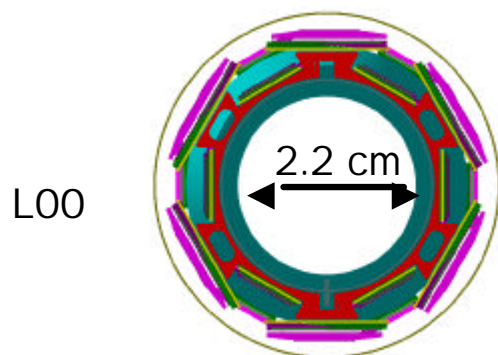
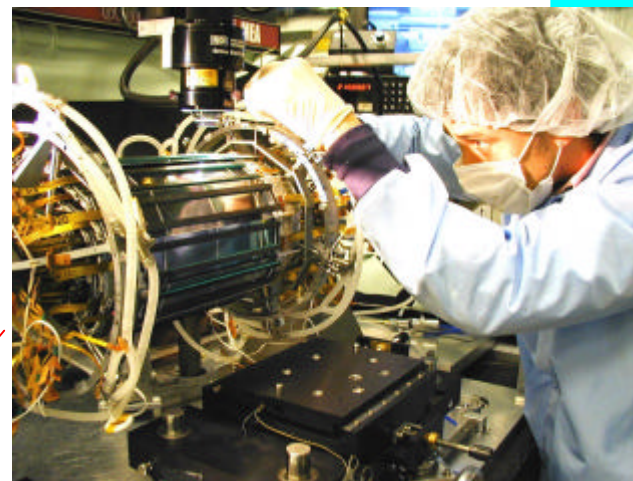
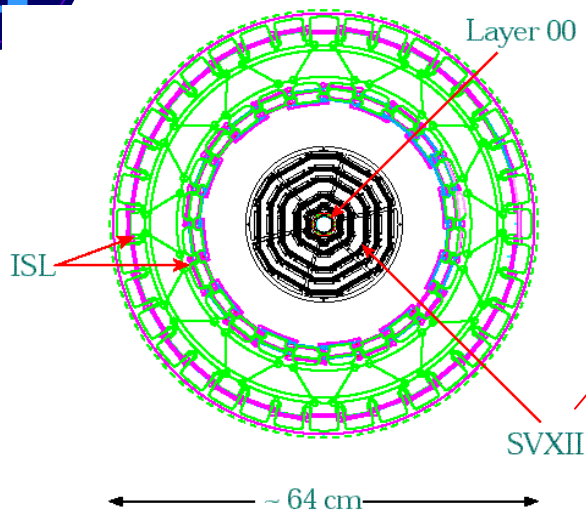


- Each Wedge consists of 4 single-sided detectors – 2 per side
- 24 wedges/plane
 - 4 planes

Rad hard Semiconductor Devices, CERN Nov 28-30, 2001 ~ 0.5 m

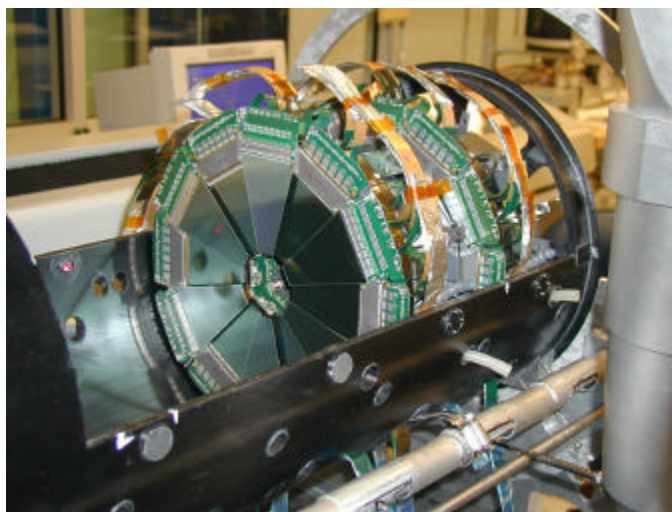


CDF Silicon Tracker

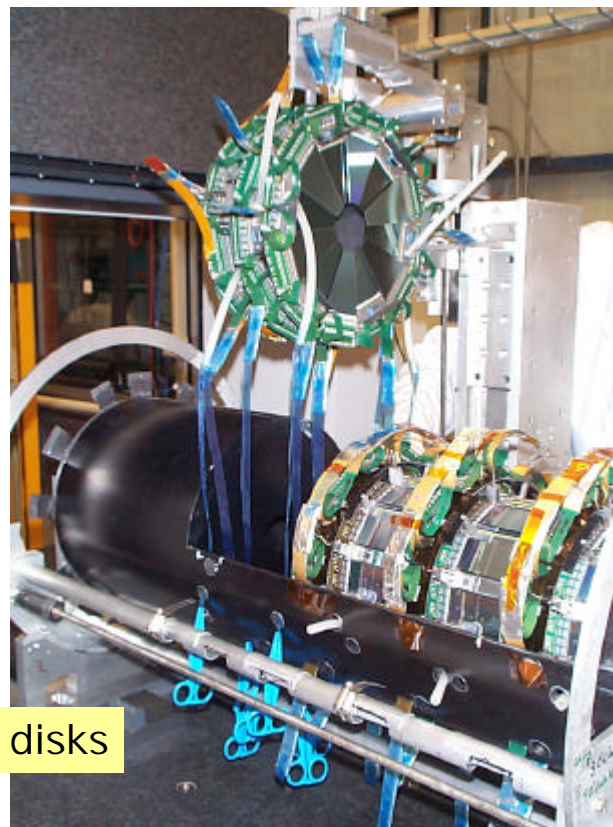




D0 Silicon Tracker: Assembly



2 of 6 barrel+disk assemblies

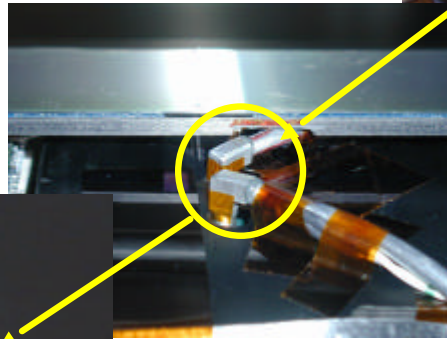
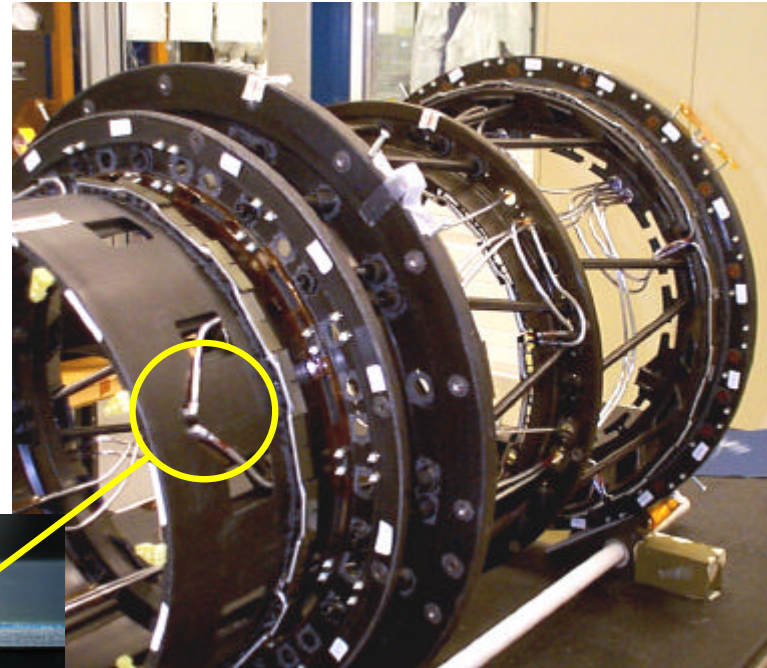


Inserting forward disks



ISL Cooling Problem

Unable to cool central part of ISL:



Solid blockage (epoxy) at Al elbows

Laser has been used to remove some of the blockages