The D0 Silicon Microstrip Tracker

Cecilia Gerber - Fermilab

Outline

- The D0 detector for Run II
- Introduction to Silicon Detectors
- Building the D0 Silicon Tracker
- Conclusions and Outlook

D0 @ Run II

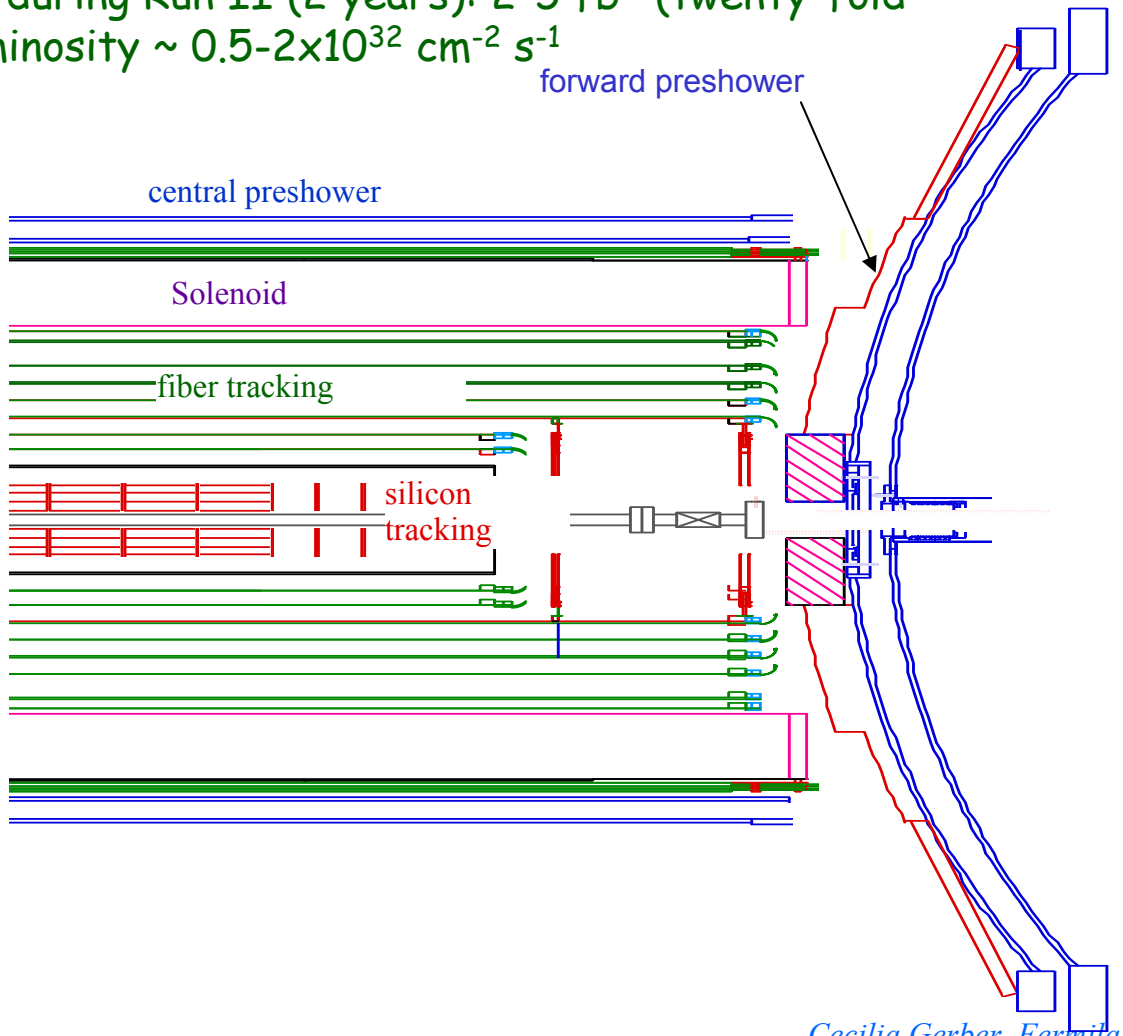
- Run II will start March 1st 2001
- Center-of-mass energy increased to 2 TeV
- Bunch crossing reduced from 3.5 μs in Run I to 396 ns (132 ns)
- Expected integrated luminosity during Run II (2 years): 2-5 fb^{-1} (twenty-fold increase over Run I), typical luminosity ~ $0.5\text{-}2\times10^{32}$ cm^{-2} s^{-1}

New inner tracking system with

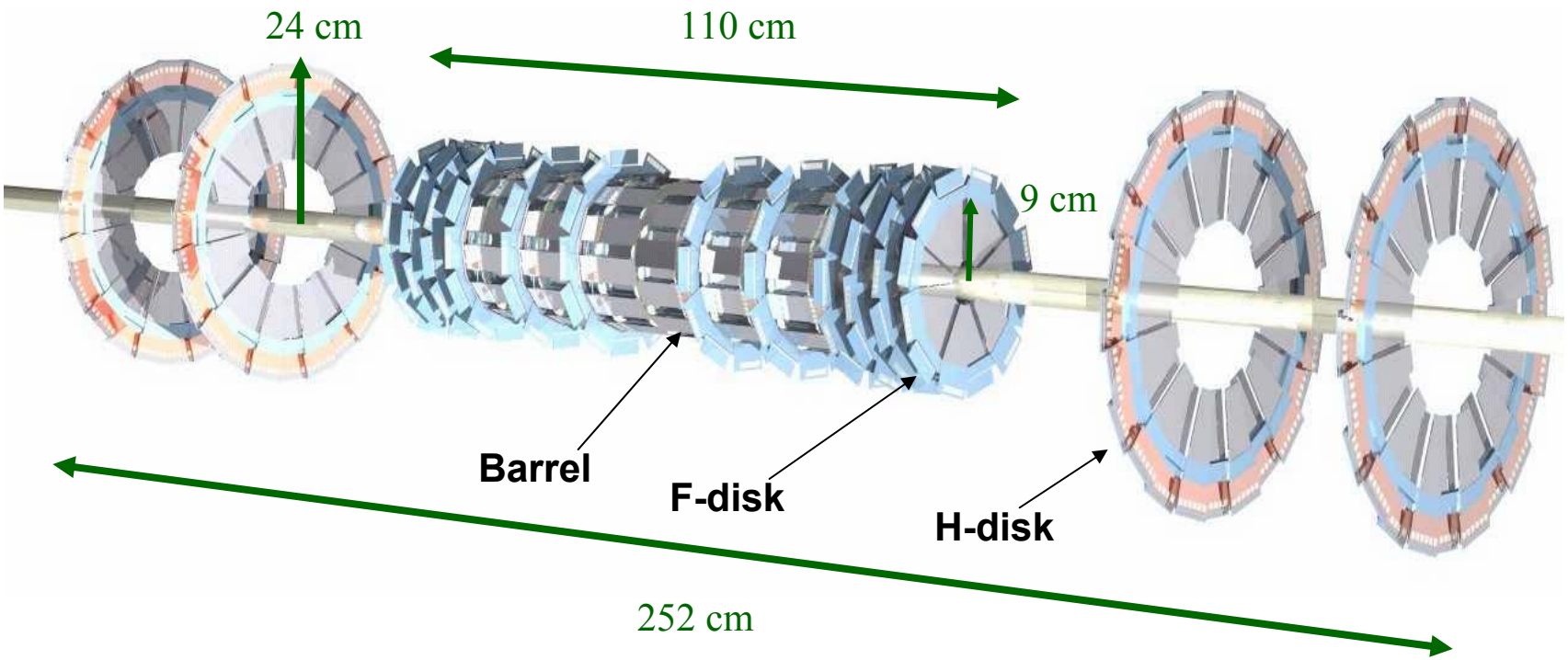
- 2T superconducting solenoid
- Silicon Microstrip Tracker
- Scintillator Fiber Tracker
- Preshowers

Faster Readout, Trigger and DAQ systems

Extended Muon Coverage and Shielding

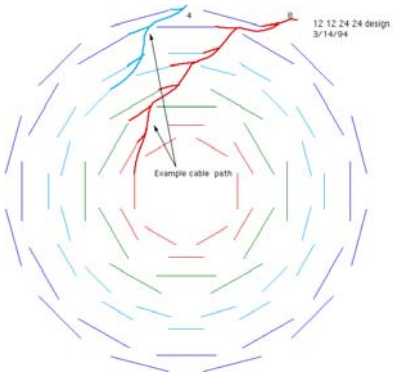


D0 Silicon Microstrip Tracker



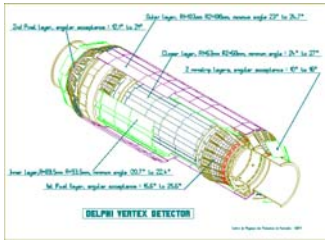
- Innermost system in D0 Run 2 detector
- Silicon tracking up to $|\eta| < 3$
- ~ 800,000 channels read out by SVX-IIe
- Interspersed Barrel-Disk design

- 6 Barrels
- 12 F-Disks
- 4 H-Disks



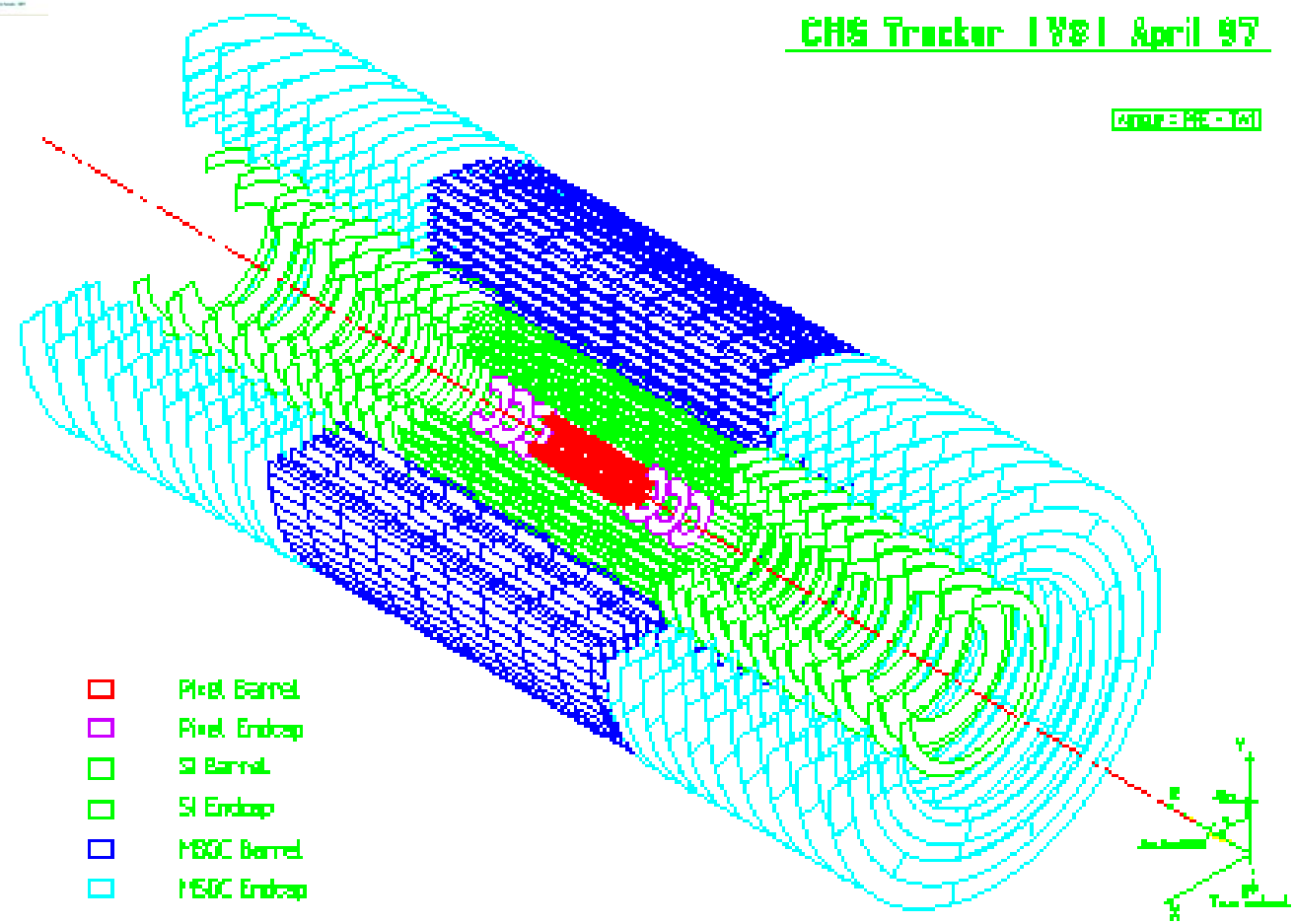
Cecilia Gerber, Fermilab

Silicon Trackers in HEP



Delphi

D0



D0 Silicon Tracker Design

- Extended luminous region in z (σ_z = 22 cm) makes it difficult to deploy detectors such that the tracks are perpendicular to detector surfaces for all $\eta \Rightarrow$ motivates the barrel/disk design

barrel detectors measure vertices for low η tracks and disk detectors measure vertices for high η tracks

- disk separation must be kept small to minimize extrapolation errors

vertex resolution at high $\eta \sim 1/$(disk spacing)

- each plane of disk is a dead region for barrels

this lowers the efficiency at small η

☞ Need to compromise

Inboard mounting of electronics, inboard routing of cables and thin disk modules help keep the gap between barrel sections to a minimum.

Physics Requirements

- Momentum Resolution

determined by the magnetic field, the measurement of the helix and the multiple scattering. Depends mostly on CFT and H-disks (η>2)

- Pattern Recognition

performed mostly in the outer layers of the Fiber Tracker (η<2) and extrapolated to the silicon barrels. Disks used for forward tracks.

- Impact Parameter Resolution

$$\sigma_{ip} = \sigma_{meas} \sqrt{1+(\frac{R_1}{R_2})^2} \Big/ (1-\frac{R_1}{R_2})$$

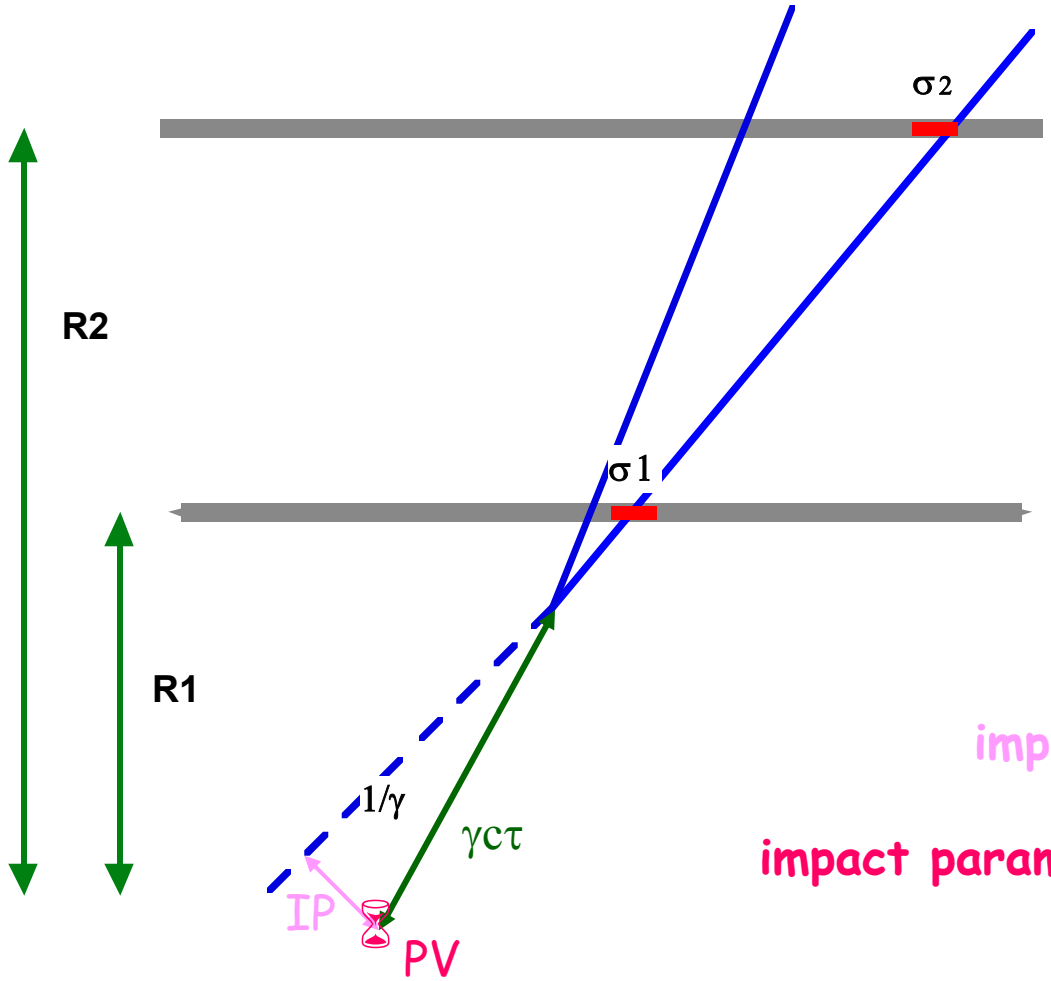
depends on detector resolution and the ratio of inner to outer radii of the tracker (cost depends strongly on the outer radius).

Secondary vertices IP~100μm, Multiple vertices IP~mm-1cm

Decided on inner layer as close to the beam pipe as possible (~3cm) and outer layer consistent with deploying four layers of silicon (~10cm).

Cecilia Gerber, Fermilab

Physics Requirements - Position resolution



$$\sigma_{ip} = \sigma_{meas}\left(\frac{\sqrt{1+(\frac{R_1}{R_2})^2}}{(1-\frac{R_1}{R_2})}\right)$$

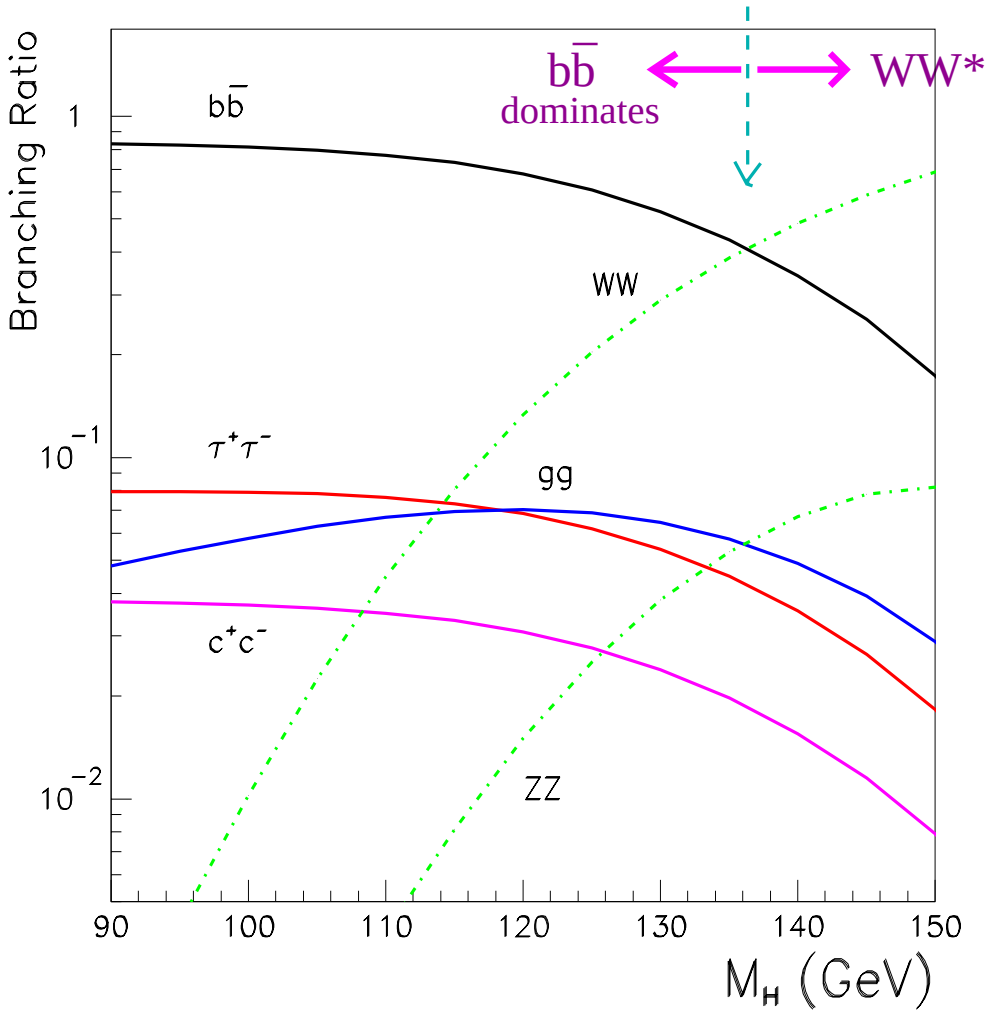
decay length $\gamma c\tau \sim 3\text{mm}$

impact parameter ~ 100μm

impact parameter resolution ~ 15μm

Cecilia Gerber, Fermilab

Why do we care about b-tagging?



Requiring double b-tagging reduces the QCD background by a factor of 1,000.

Even after double b-tagging the S/√(N) ratio for SM Higgs is 0.9-0.3 (for m_H 100-130 GeV)

Cecilia Gerber, Fermilab

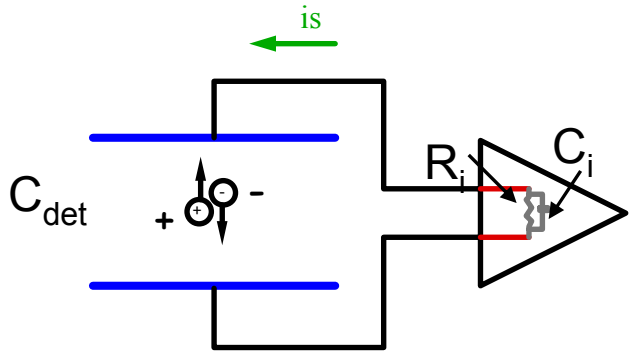
Why Silicon?

Silicon has properties which make it especially desirable as a detector material:

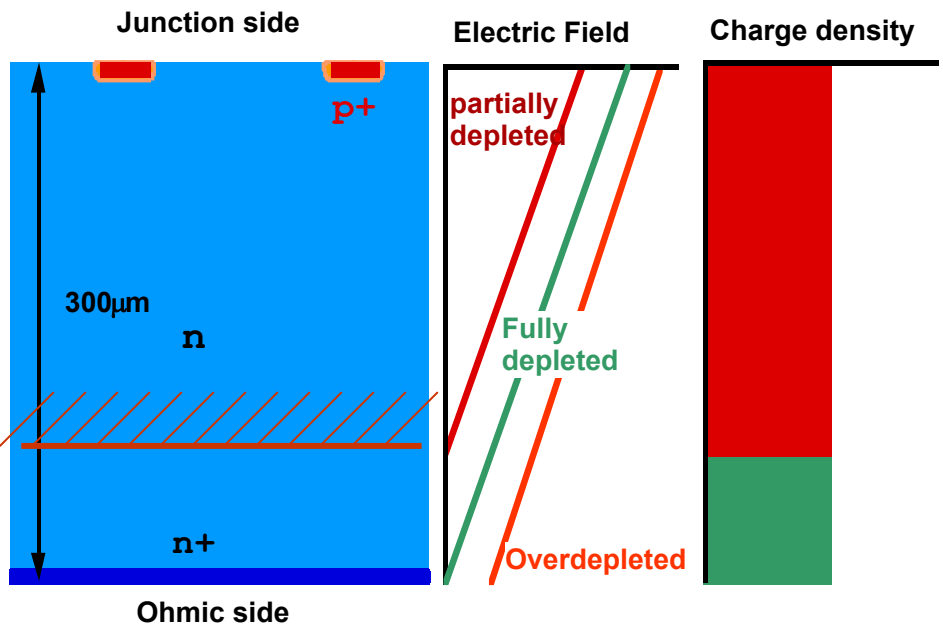
- low ionization energy (1 e-h pair/3.6eV) ➔ Good energy resolution.
- high density of medium reduces the range for secondary electrons ➔ Good spatial resolution
- long mean free path ➔ good charge collection efficiency
- high mobility ➔ fast charge collection (~10ns)
- Very thin detectors (~300μm) ➔ low multiple scattering
- Low voltage operation

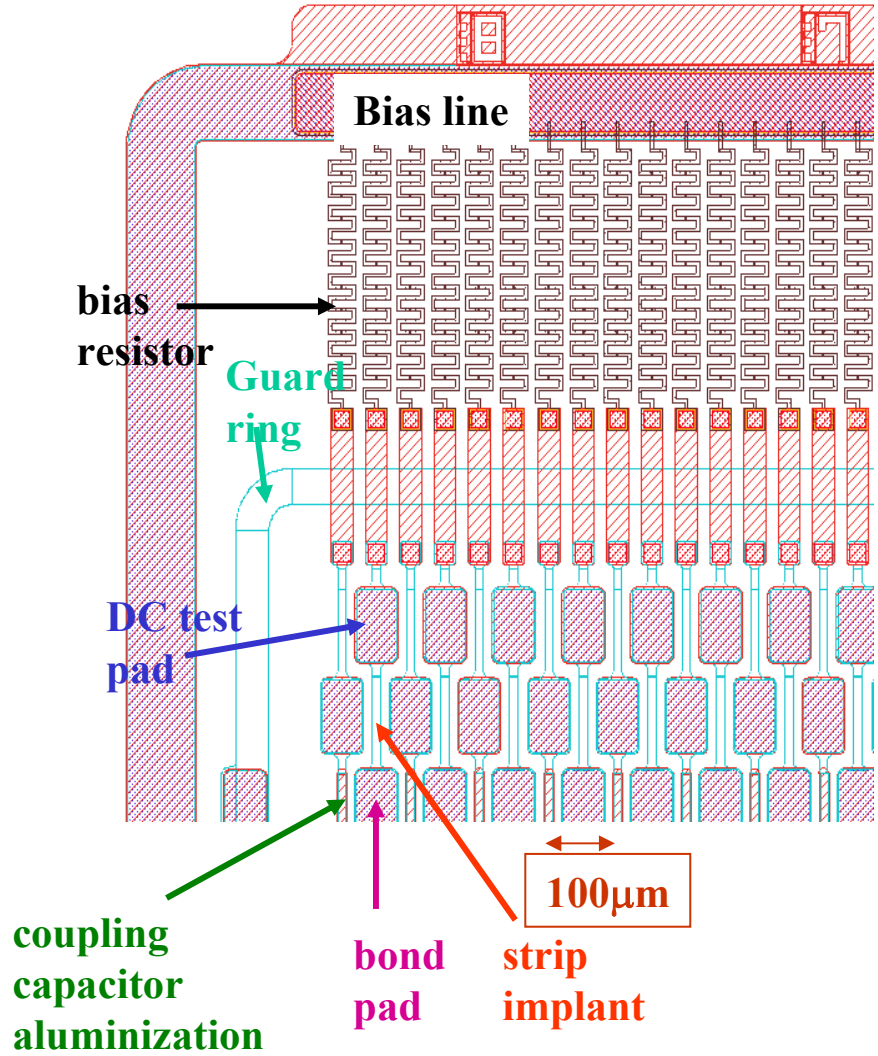
- Very well developed technology

Single Sided Silicon Microstrip Detectors

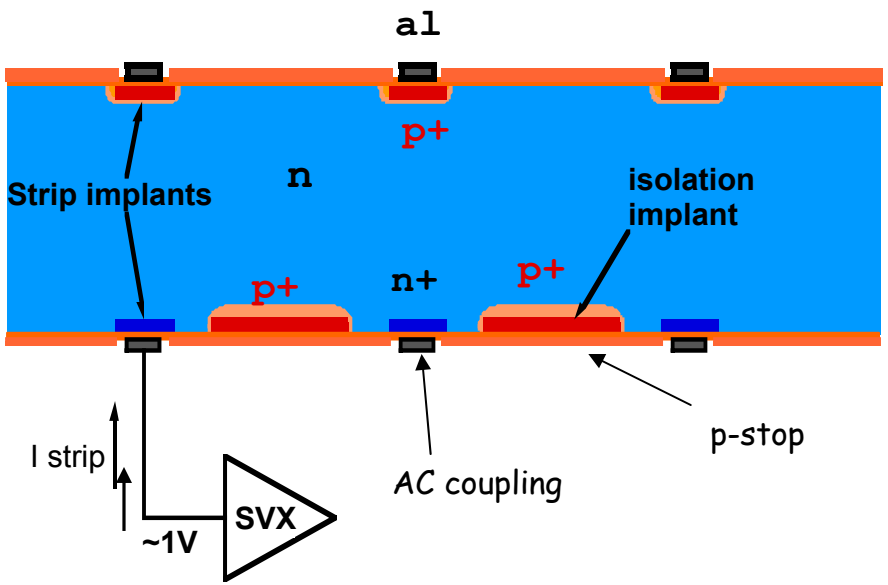


Solid state detectors are ionization chambers:



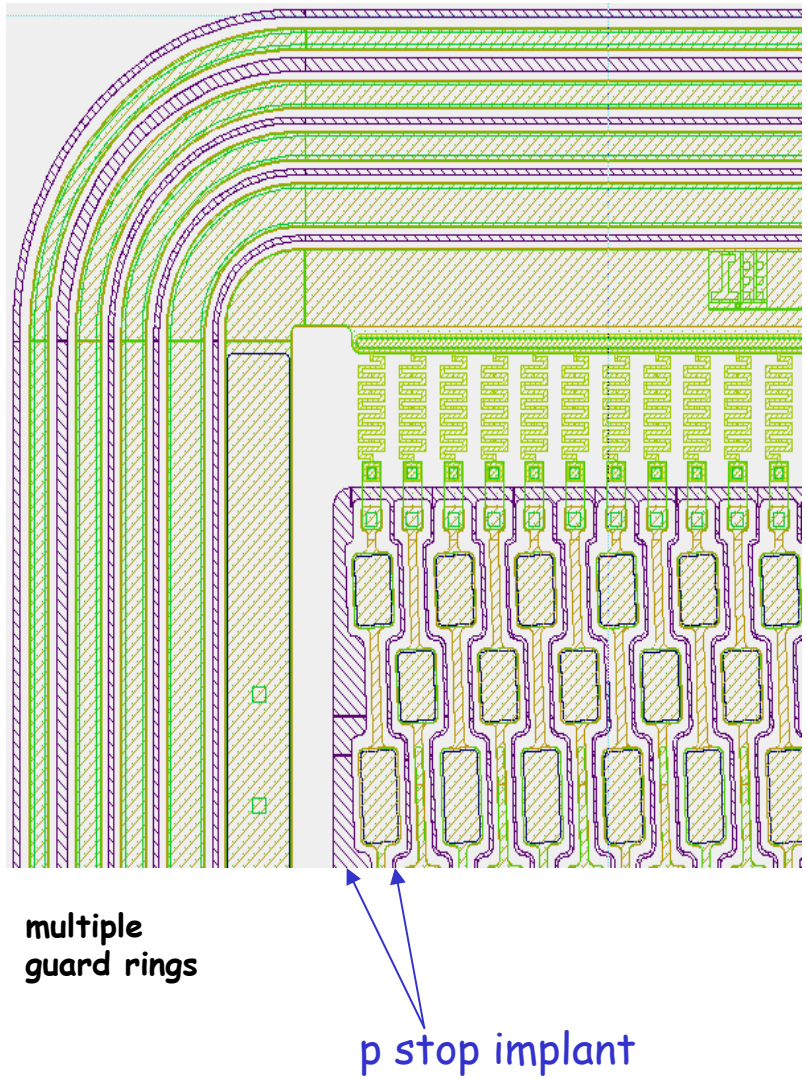


Double Sided Silicon Microstrip Detectors

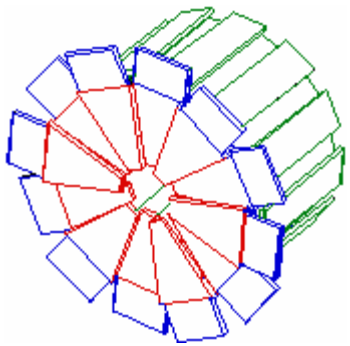


AC-coupling: add a thin (2000A) SiO_2 layer between readout implant and Al (integrated capacitor). Capacitors must withstand bias voltage.

p-stop: add blocking p+ strips on n-side to ensure strip isolation at full depletion



D0 Silicon Microstrip Tracker



5 different detector types...

Barrel

- 72 SS (3-Chip)
- 144 DS90deg (6-Chip)
- 216 DS2deg (9-Chip)

Disks

- 144 DS 15deg (6+8-Chip)
- 96x2 SS (6-Chip)

D0	Barrels	F-Disks	H-Disks
Layers/planes	4	12	4
Channels	387120	258000	147456
Modules	432	144	192
Readout Length	12 cm	7.5 cm	14.6 cm
Inner Radius	2.7 cm	2.6 cm	9.5 cm
Outer Radius	9.4 cm	10.5 cm	26 cm

~ 793,000 readout channels

Barrel Detectors

Single sided ladders (72)

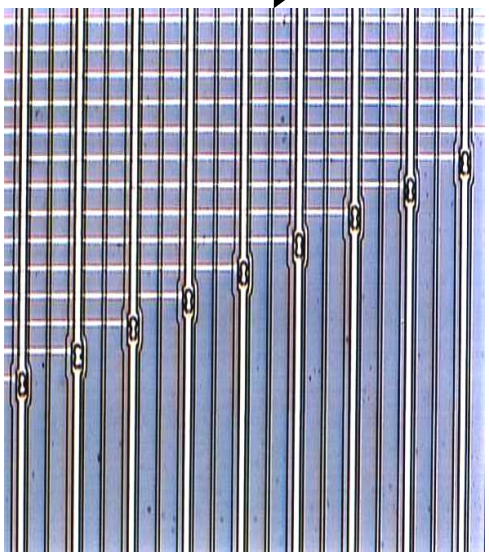
- 3 chip readout
- 50 μm (p-side) pitch
- Layers 1 and 3 of two outer barrels
- 12cm long (2 sensors), 2.12cm wide

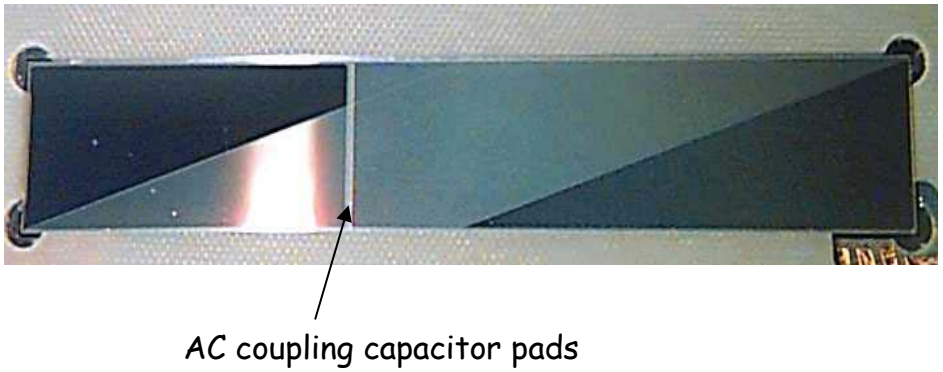
Double sided ladders 2^0 stereo (216)

- 9 chip readout
- 50 μm (p-side), 62.5 μm (n-side) pitch
- Layers 2 and 4 of all barrels
- 12 cm long (2 sensors), 3.4 cm wide

Double sided ladders 90^0 stereo (144)

- 6 chip readout
- 50 μm (p-side), 153 μm (n-side) pitch
- Double metal in 6" technology
- Two non-adjacent strips are read out by the same channel (ghost hits)
- Layers 1 and 3 of four inner barrels
- 12 cm long (1 sensor), 2.12cm wide

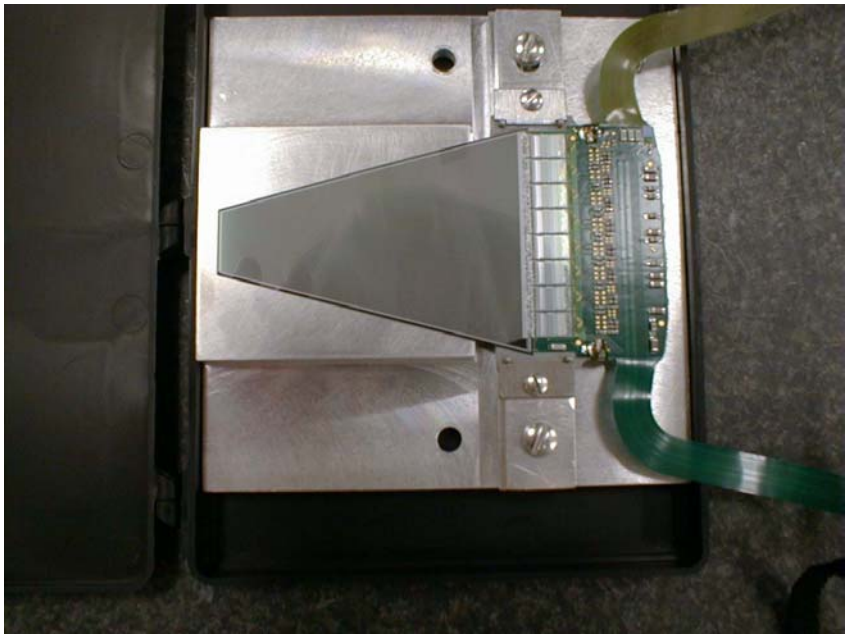


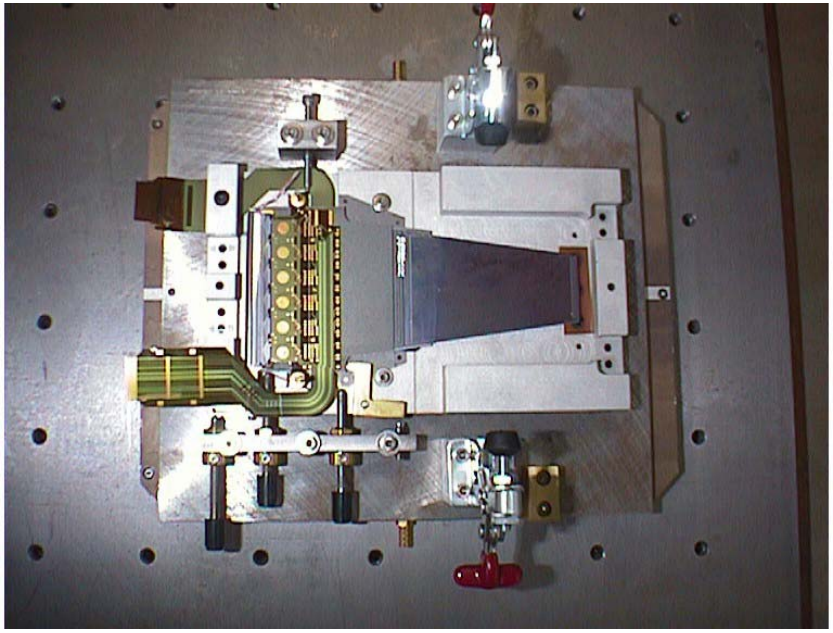


Disk Detectors

F-Wedge Detectors (144)

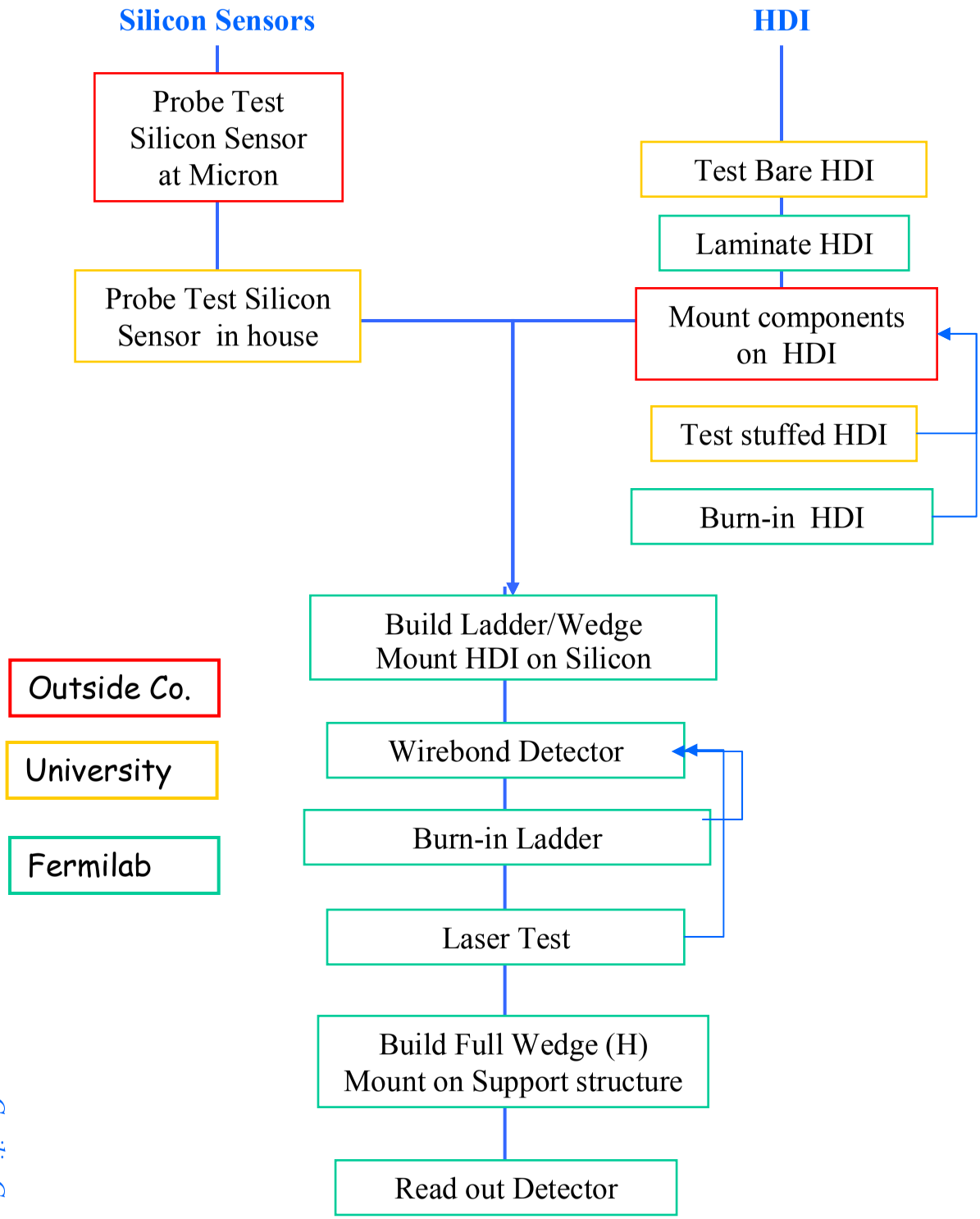
- 8+6 chip readout
- 2.6 cm < r < 10 cm
- Double sided wedges with $\pm 15^0$
- 50 μm (p-side), 62.5 μm (n-side)
- Variable strip length





H-Wedge Detectors (384)

- 6+6 chip readout
- 9.6 cm < r < 23.6 cm
- Single sided glued back-to-back with $\pm 7.5^0$
- 40 μm (p-side) strip pitch
- 80 μm readout pitch
- Variable strip length

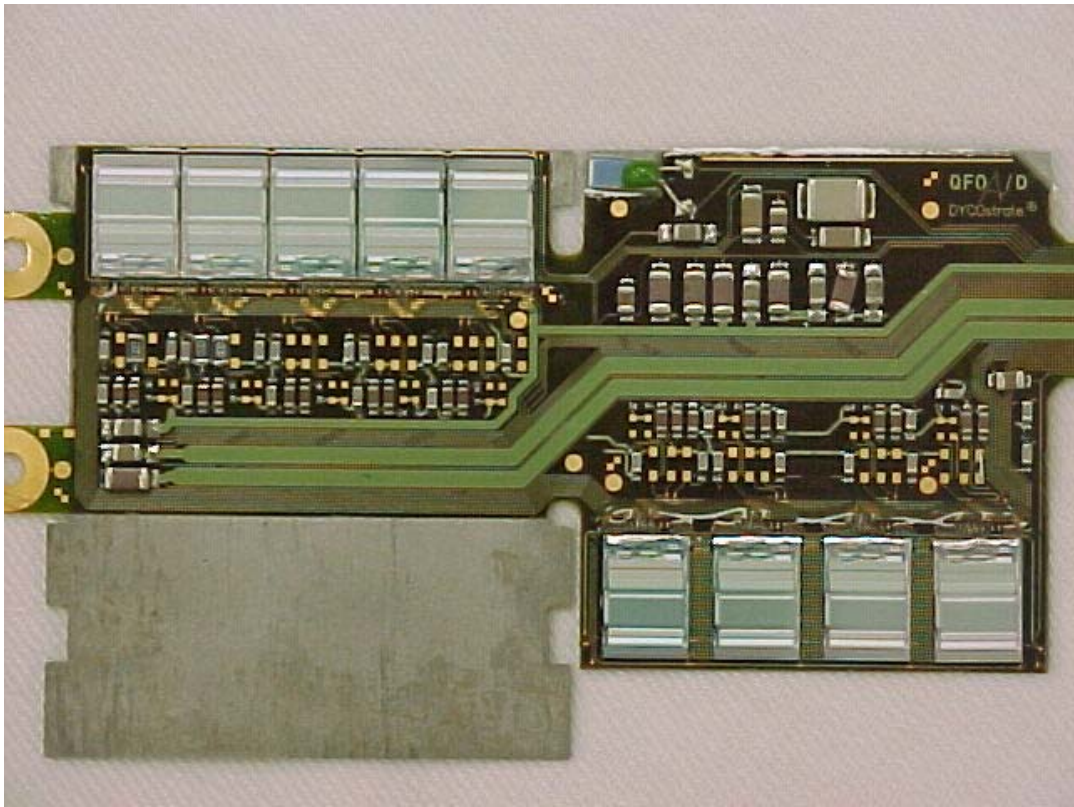

Silicon Sensors
HDI
Probe Test Silicon Sensor at Micron
Test Bare HDI
Laminate HDI
Probe Test Silicon Sensor in house
Mount components on HDI
Test stuffed HDI
Burn-in HDI
Build Ladder/Wedge Mount HDI on Silicon
Outside Co.
University
Fermilab
Wirebond Detector
Burn-in Ladder
Laser Test
Build Full Wedge (H) Mount on Support structure
Read out Detector

What is an HDI?

- High Density Interconnect
- 0.005 inch thick flex circuit (Kapton & Cu layer) with integrated "pigtail" cable
- Laminated to Be substrate & glued directly on Si sensors.
- Carries SVX chips & passive components
- 9 Types (3 differ only in tail length) and 4 different vendors

HDI Fabrication

- Bare HDI tested at University
- Laminated to Be at FNAL
- Stuffed at PROMEX
- Functionality test at Universities
- ~70 hours burn-in at FNAL (testing shifts)

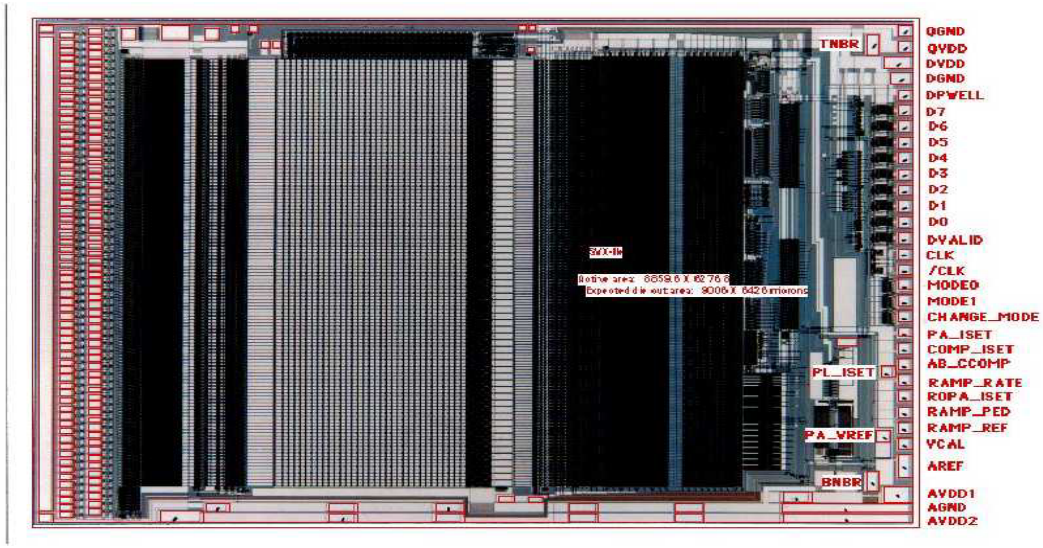


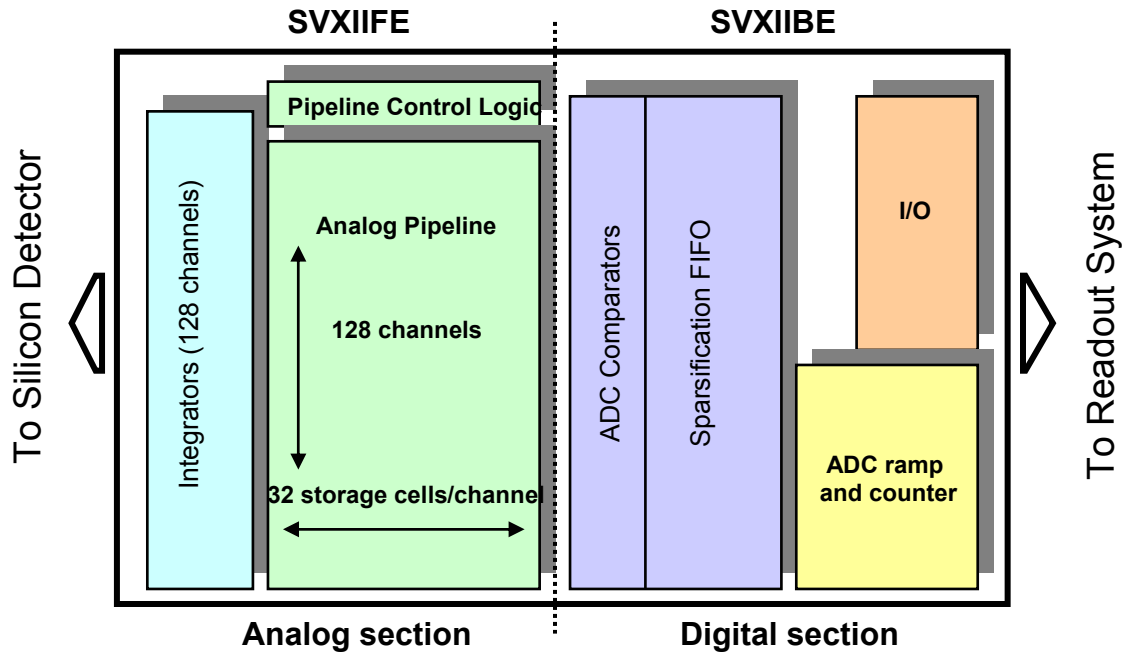
SVXIIE chip

- 1.2 mm CMOS amplifier/analog delay/ADC chip fabricated in the UTMC rad hard process
- LBL/Fermilab group (Milgrome/Yarema)

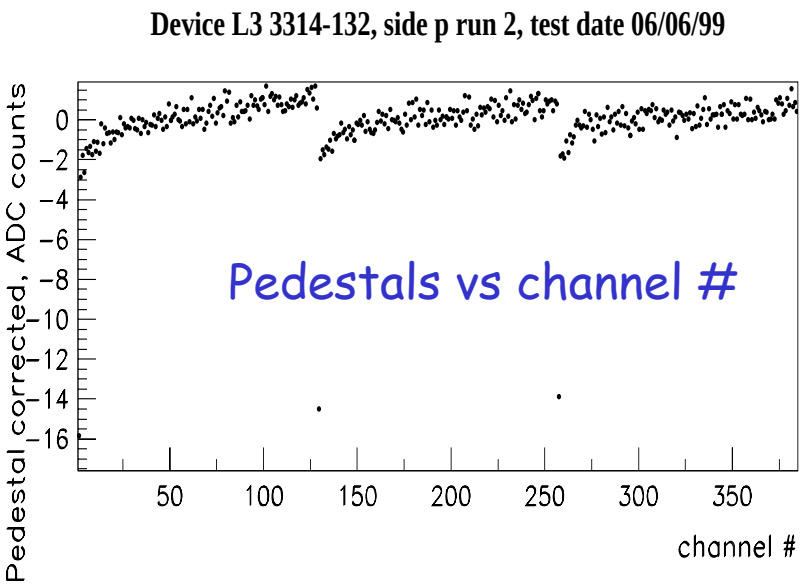
Features:

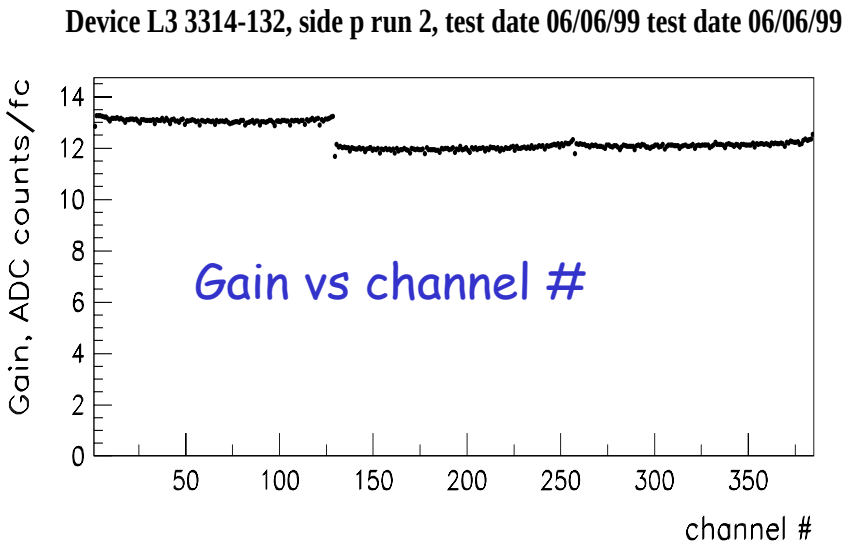
- 128 channels (5 mW/channel)
- 32 cell pipeline /channel
- 8-bit Wilkenson ADC with sparsification /channel
- Programmable test pattern, ADC ramp+pedestal, preamp bandwidth, calibration, polarity…
- 53 MHz readout
- 106 MHz digitization
- Dimensions: ~ 6.4 x 9.7 mm^2
- ~ 85,000 transistors

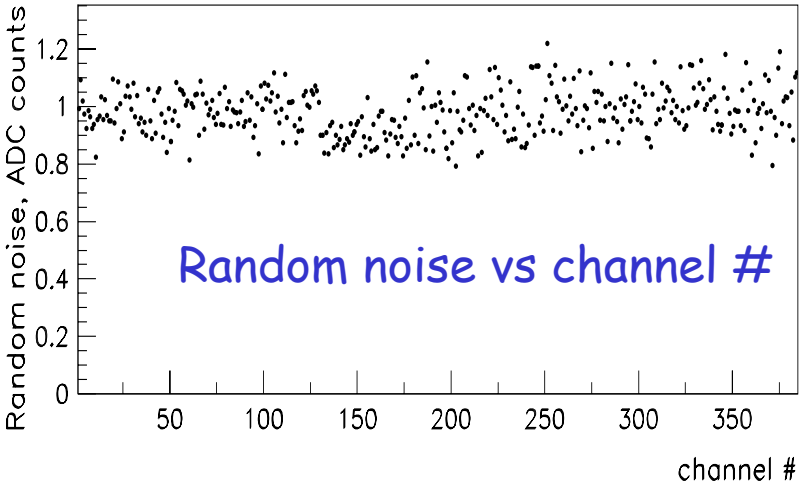


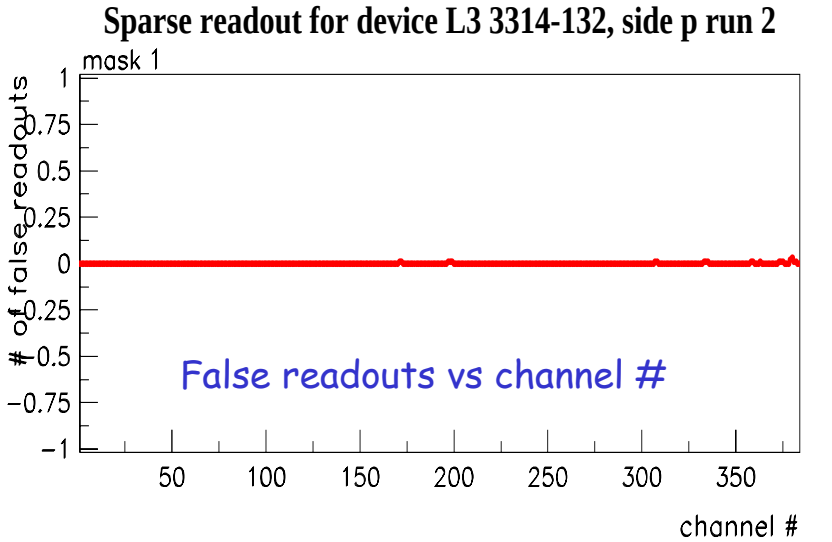


HDI burn-in results

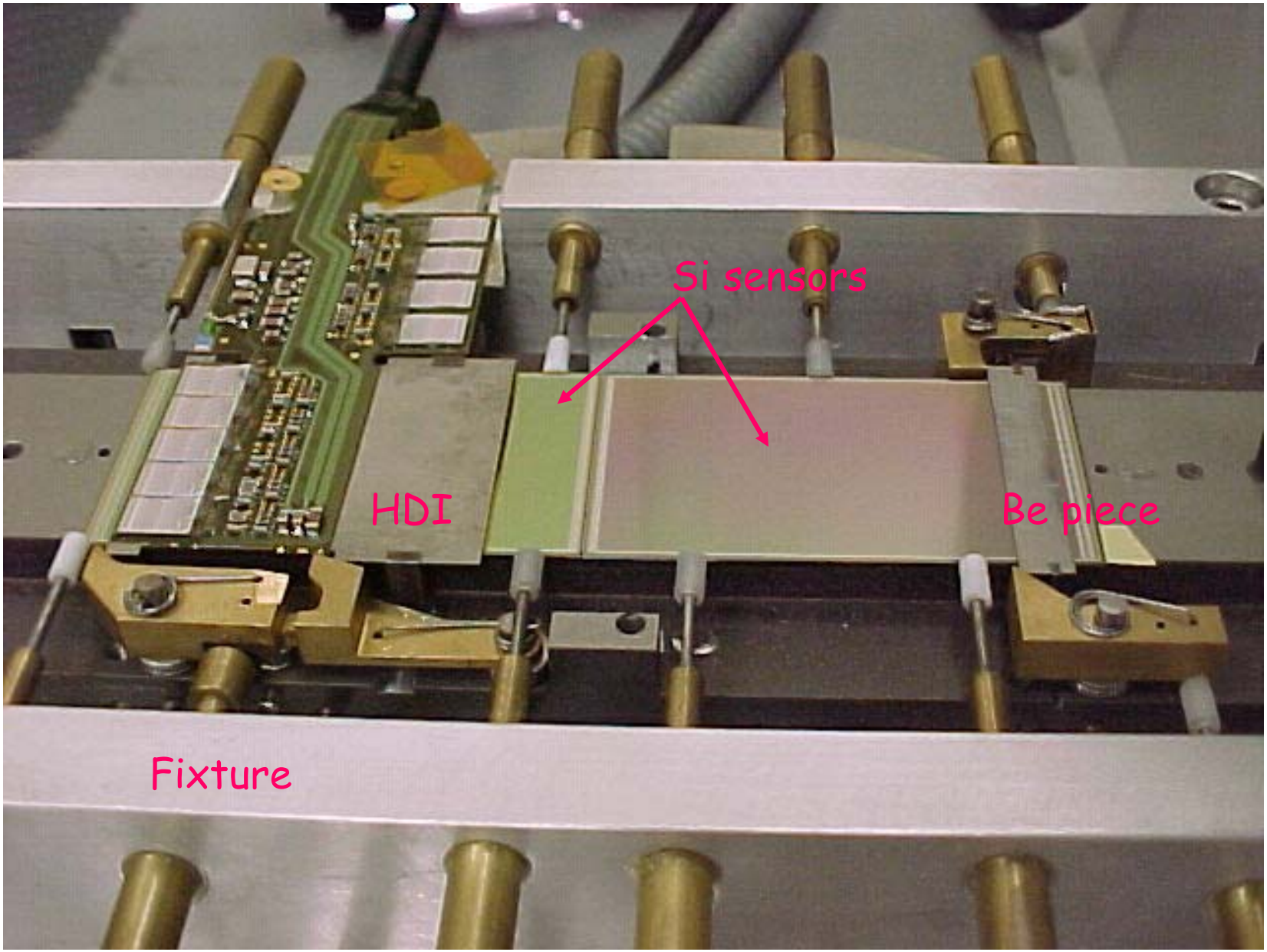




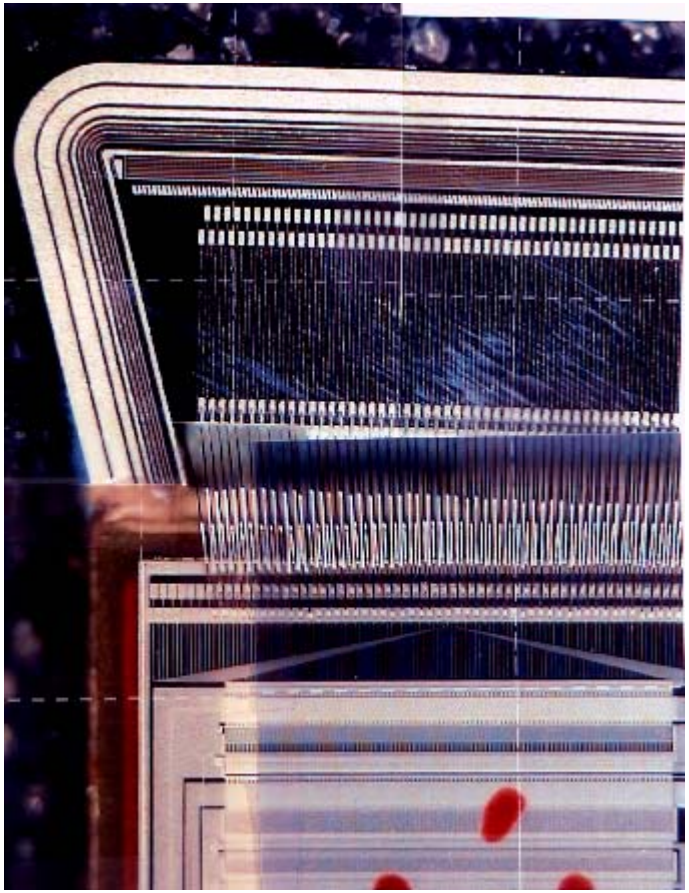


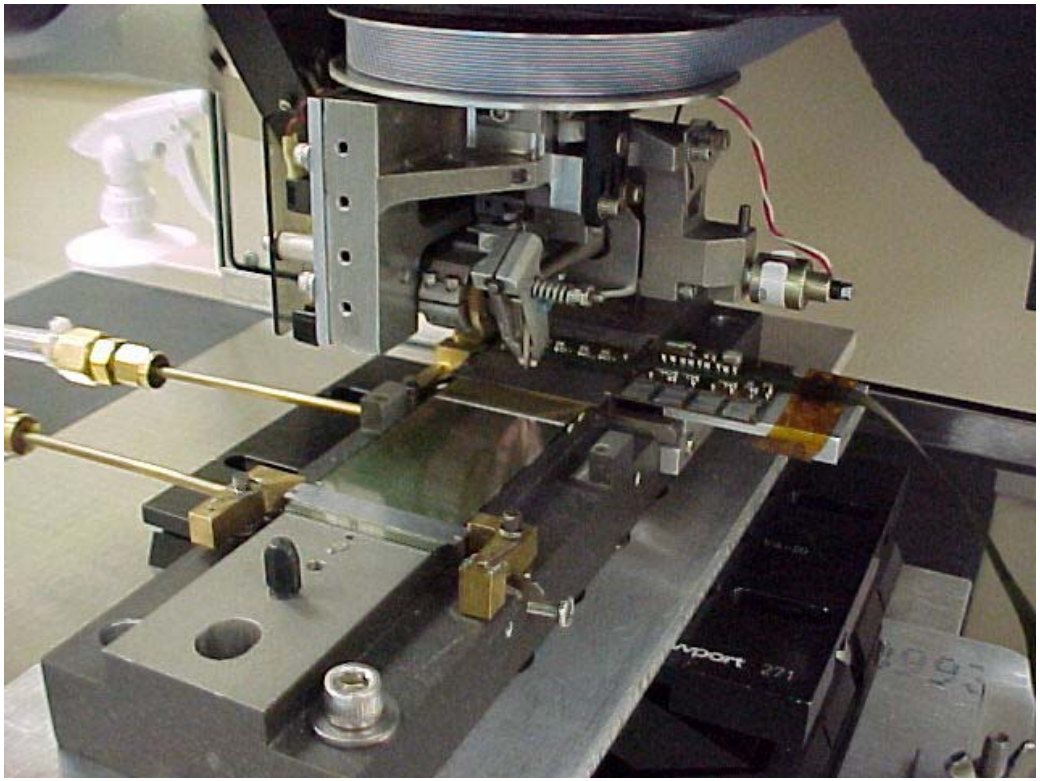


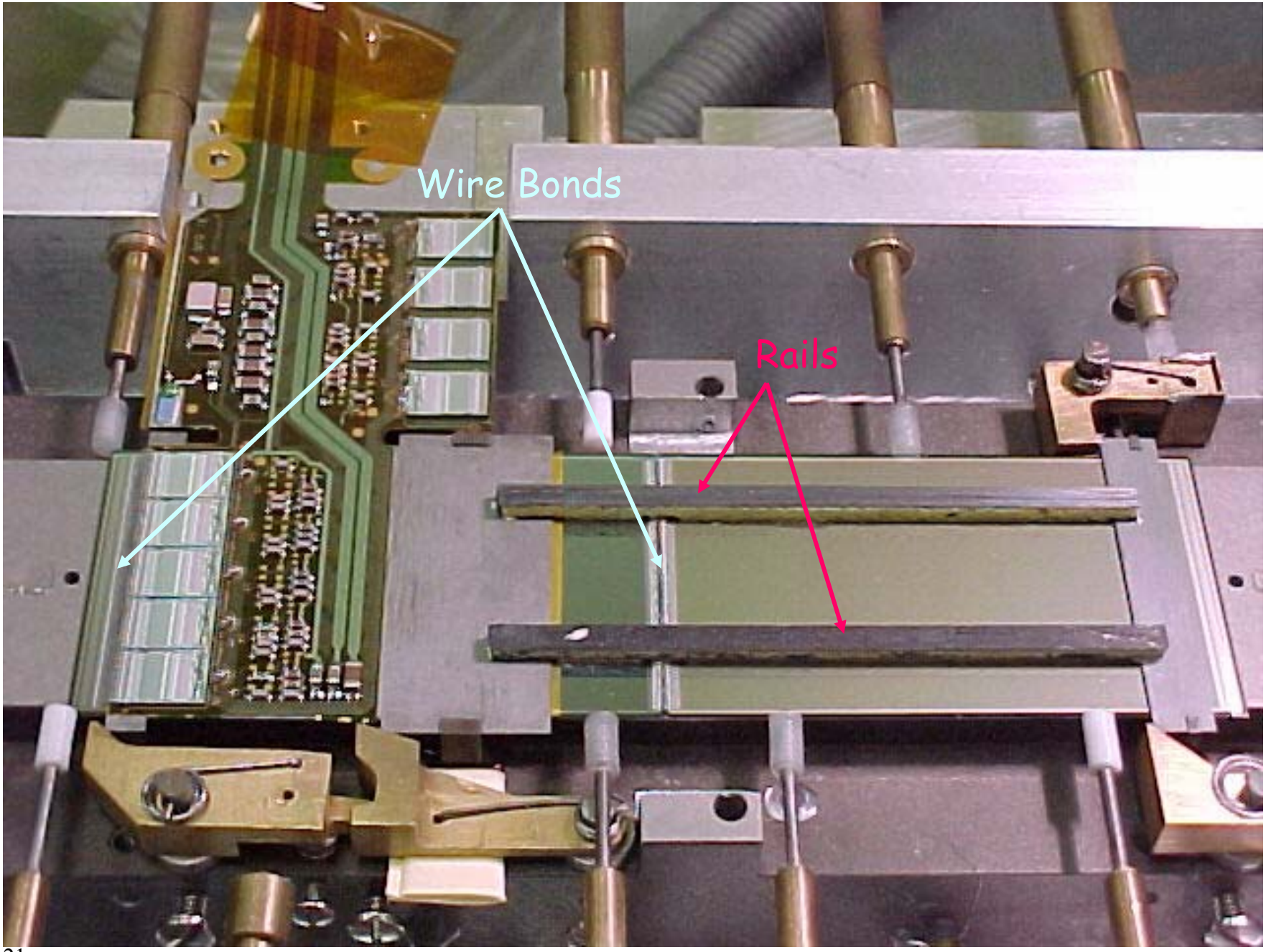
Detector Assembly



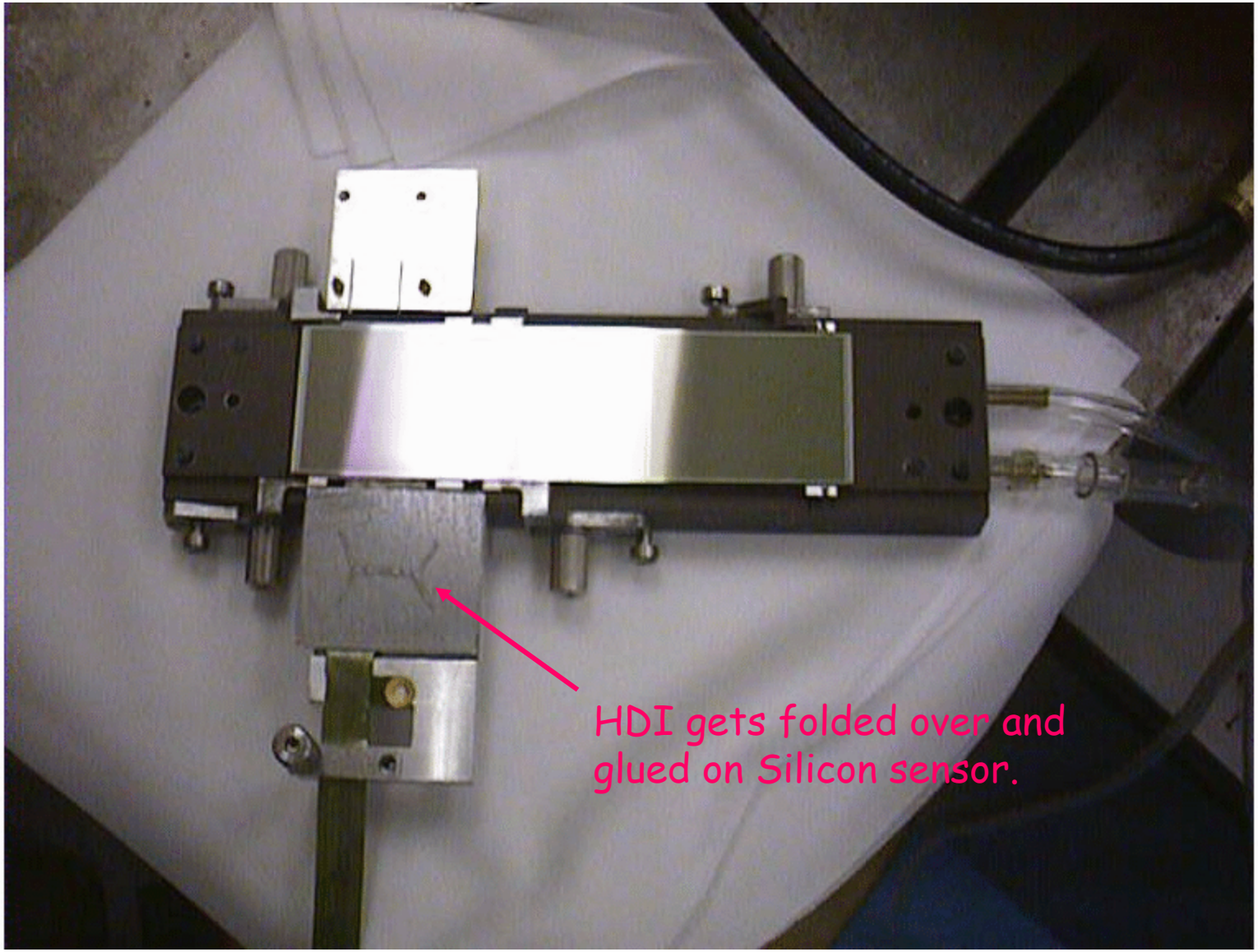
Wirebonding

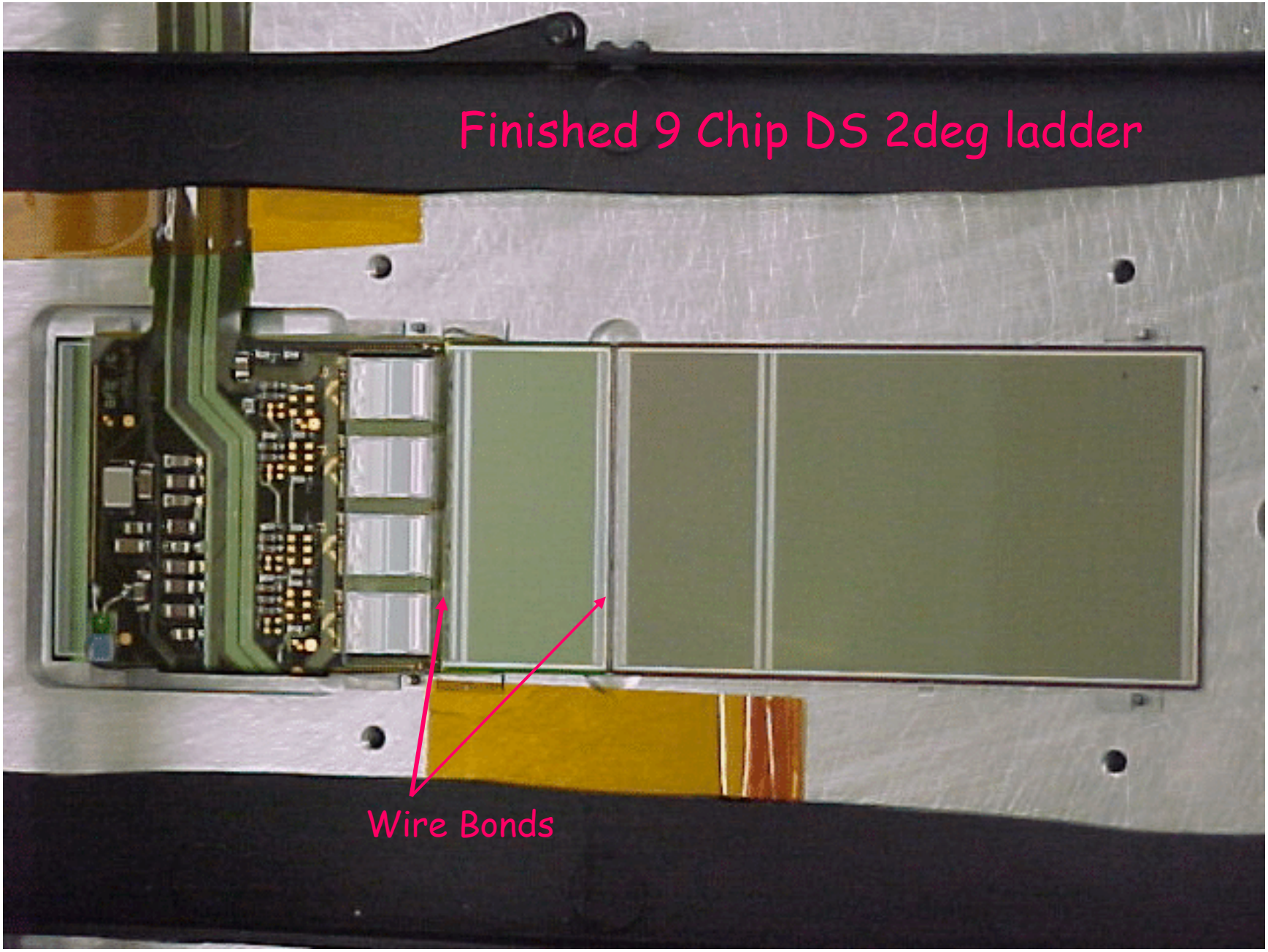




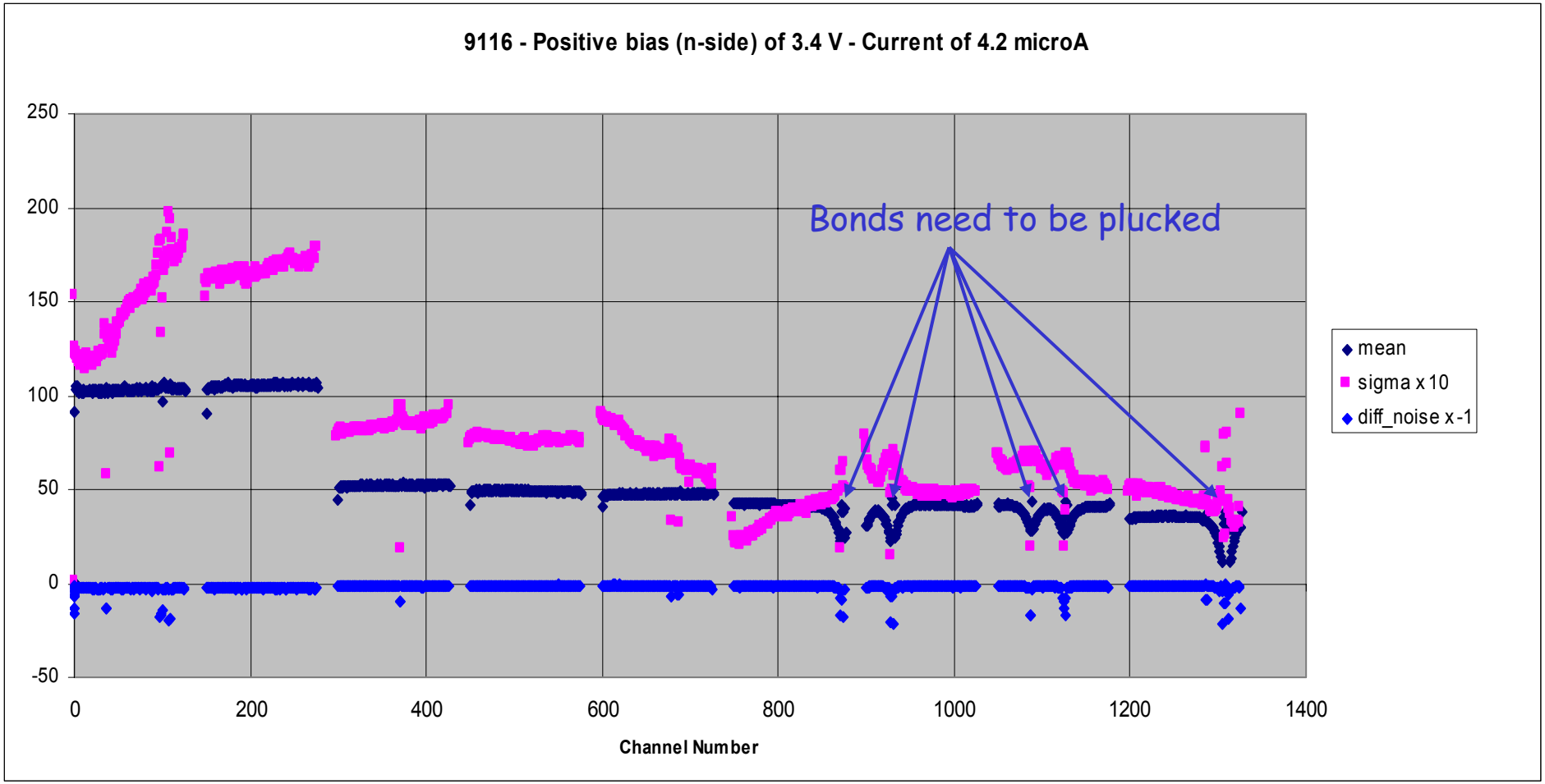

Wire Bonds
Rails

After flipping the ladder over




Finished 9 Chip DS 2deg ladder
Wire Bonds

First look at finished ladder



Cecilia Gerber, Fermilab

Detector Debugging and Repair

- Pluck bonds corresponding to noisy strips
- Be piece has good connection to ground
- Add/change components
- Fix electrical or mechanical problems
- ……

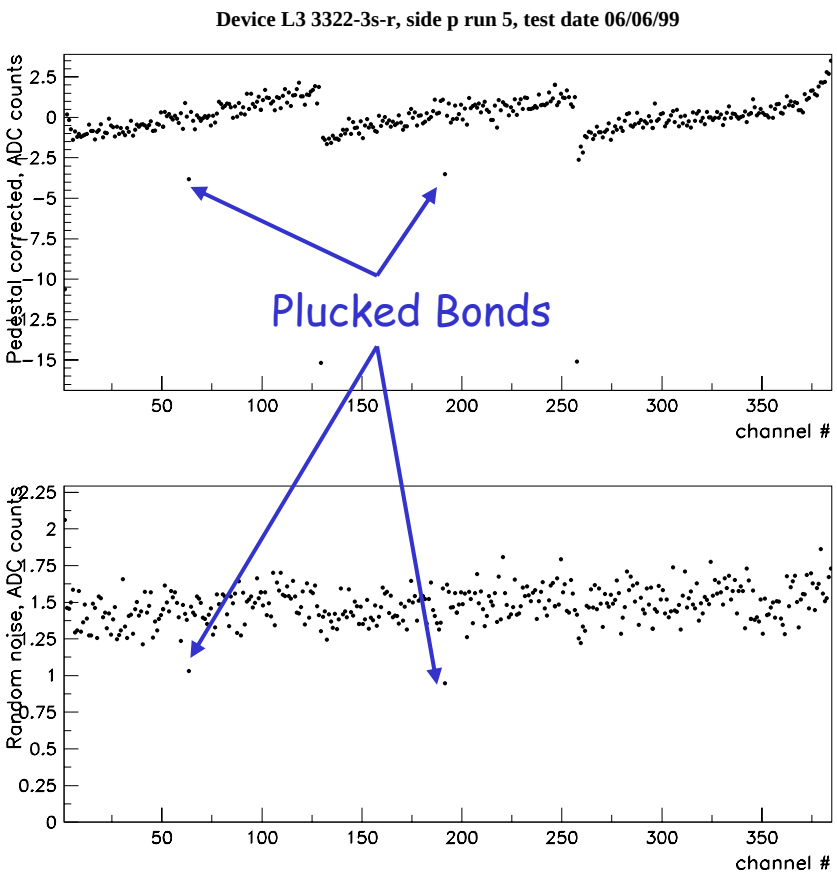
Time consuming, share the same resources (techs and test stands) as production, need dedicated experts to decide what needs to be done for each detector in particular.

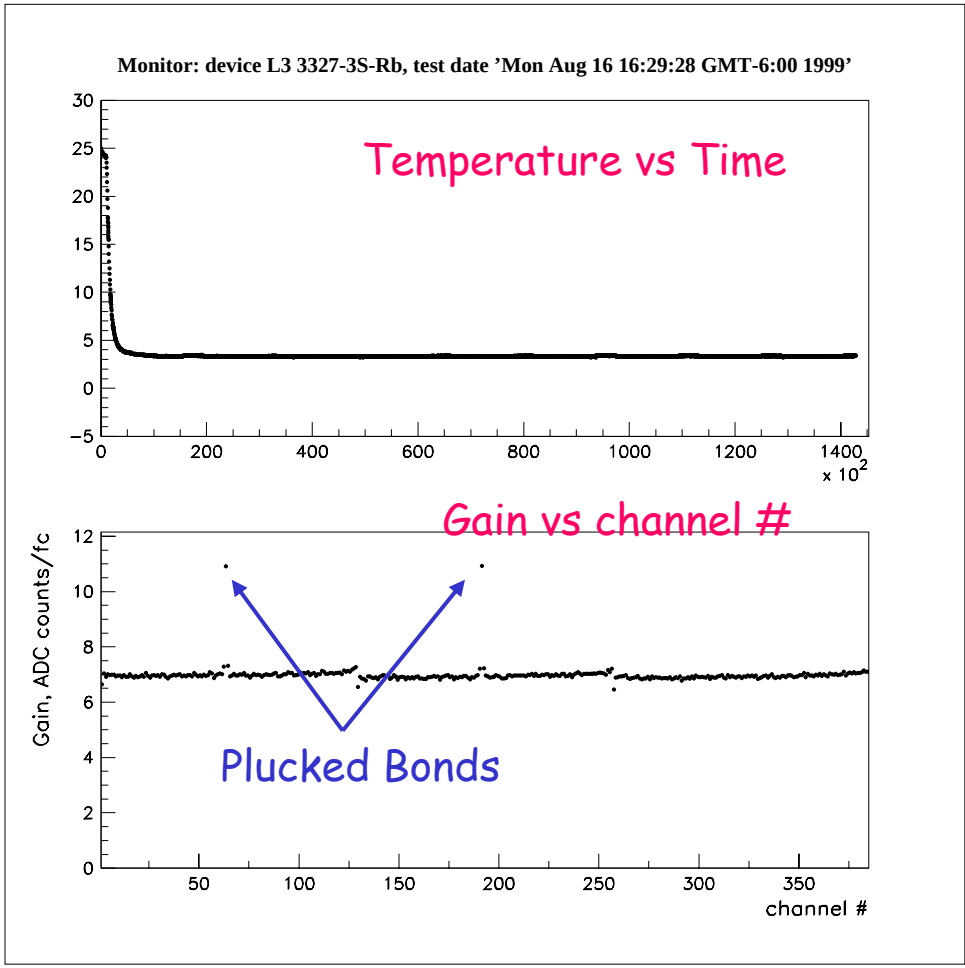
Detector Low Temperature burn-in (testing shifts)

- 70 hours at 5° C with detector biased.
- Measure Pedestal, Noise, Gain, Sparse Readout.
- Monitor temperature, depletion voltage and currents.

Ladder burn-in results

Pedestals & Random Noise vs channel

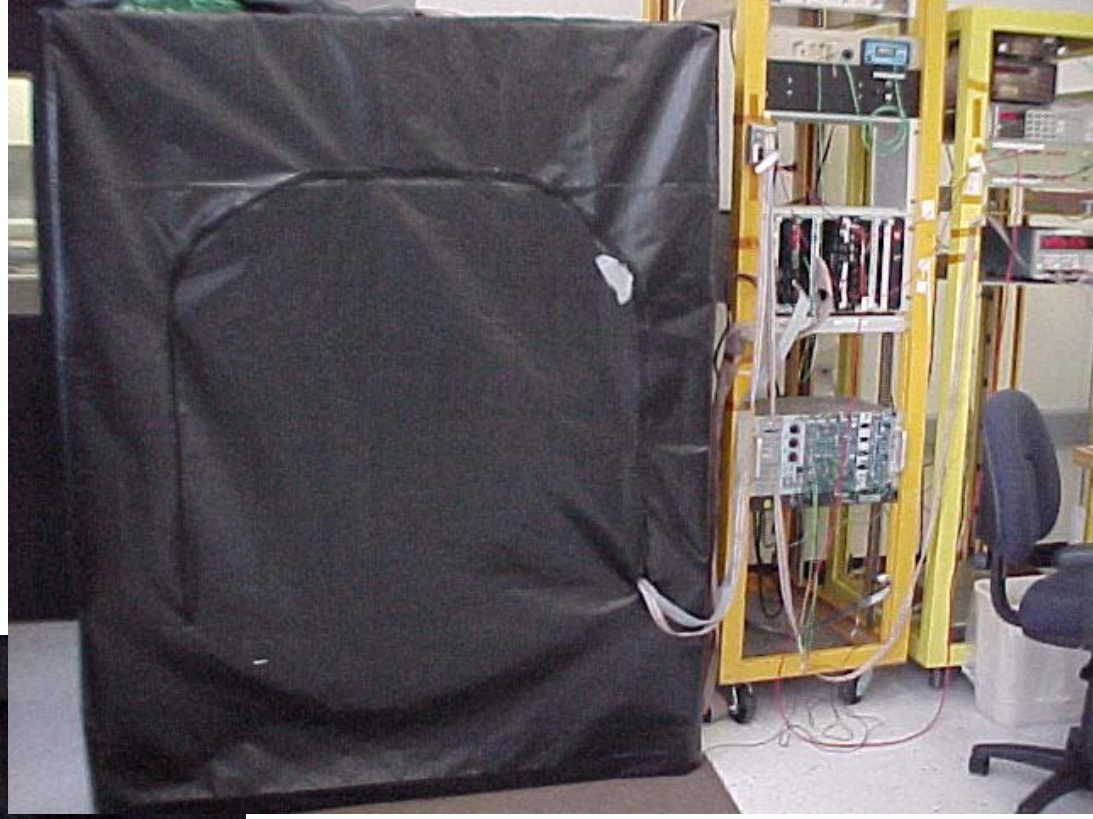


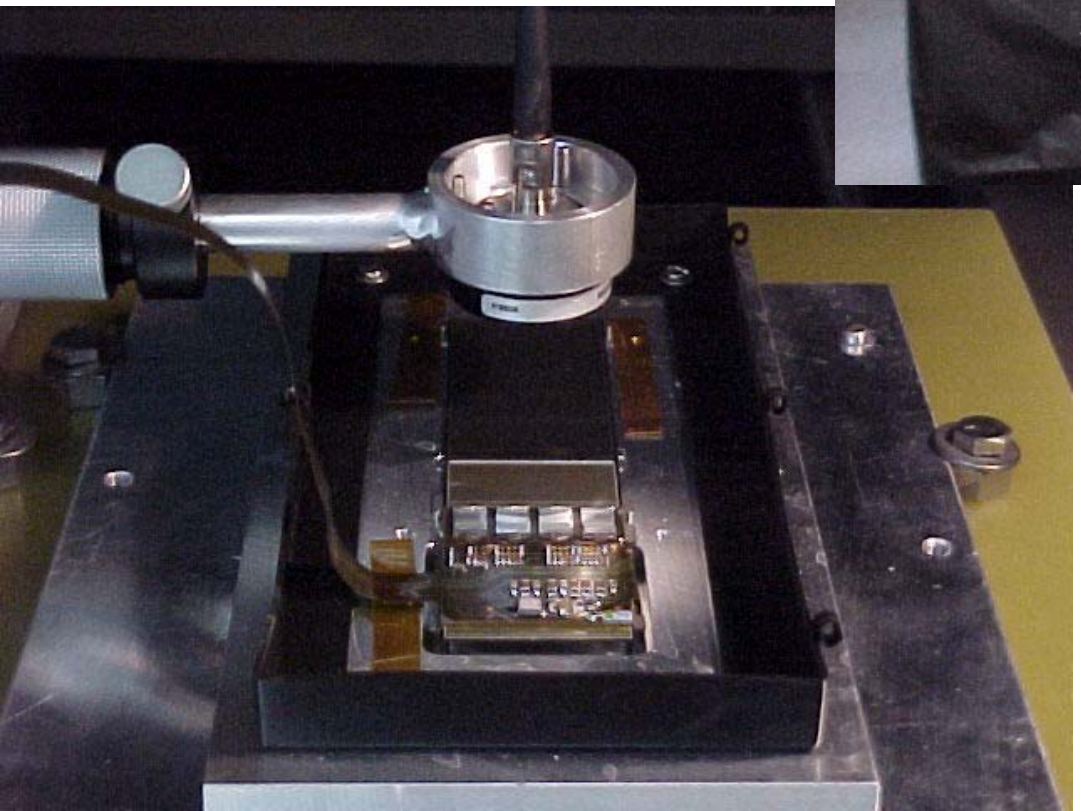


Cecilia Gerber, Fermilab

Laser Test Stand

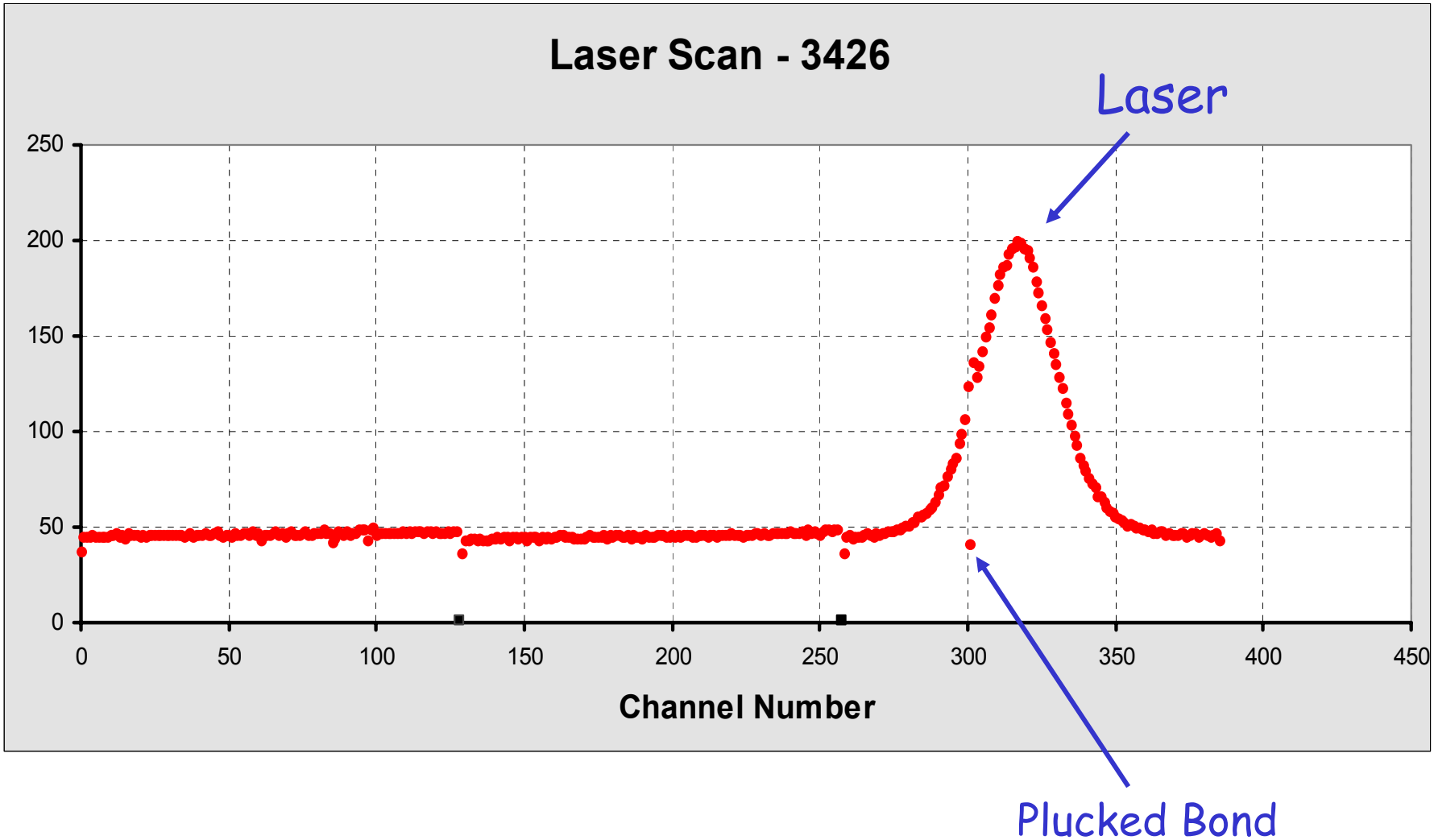
(testing shifts)





- Scan for dead channels
- Measure depletion voltage and leakage current
- Find mistakes during wire-bonding

Laser Test Results



Cecilia Gerber, Fermilab

Electrical Grading

- Bad channels:

  Response to laser < 40 ct (average is 100 ct) **DEAD**

  Random Noise in data mode > 6 ct (average is 1.5 ct) **NOISY**

- # of noisy + # of dead channels

  < 2.6% (10 bad channels for every 3 chips) **A GRADE**

  < 5.2% (20 bad channels for every 3 chips) **B GRADE**

  > 5.2% of bad channels **C GRADE**

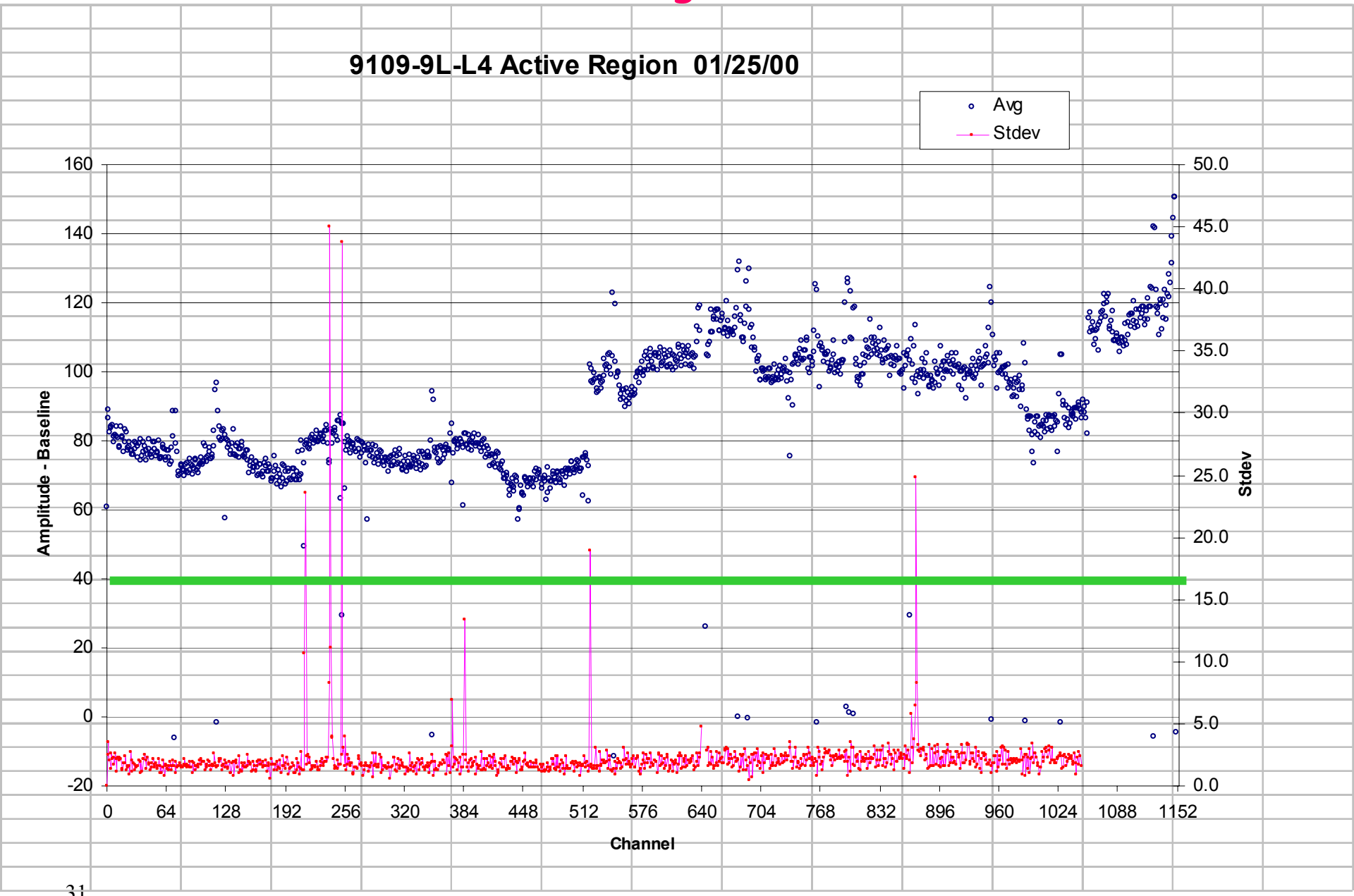
- Other considerations:

  Leakage current < 50 μA @ Operating Voltage

  Proper functioning of cal-inject mode

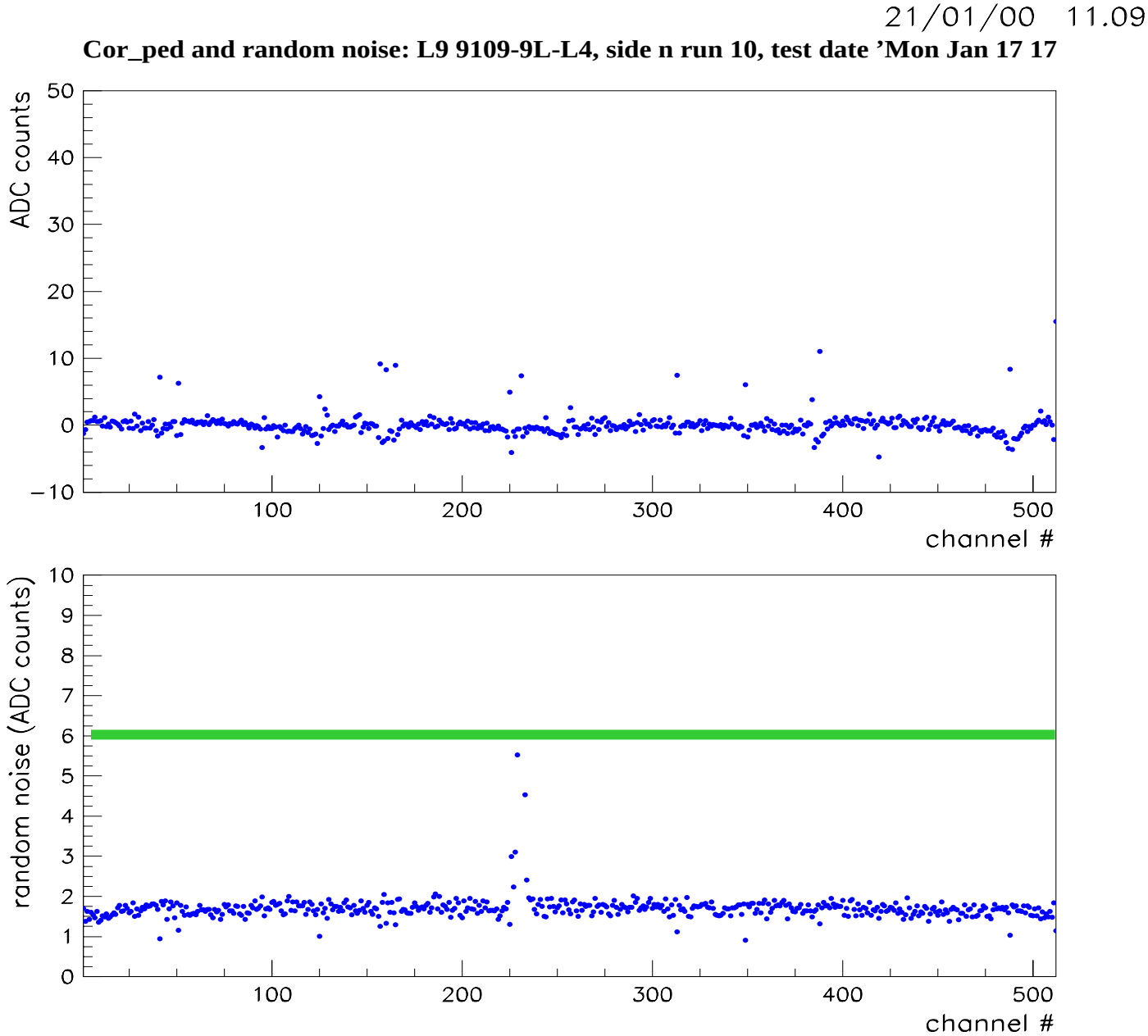
  Proper functioning of sparse mode

Laser Test: finding DEAD channels



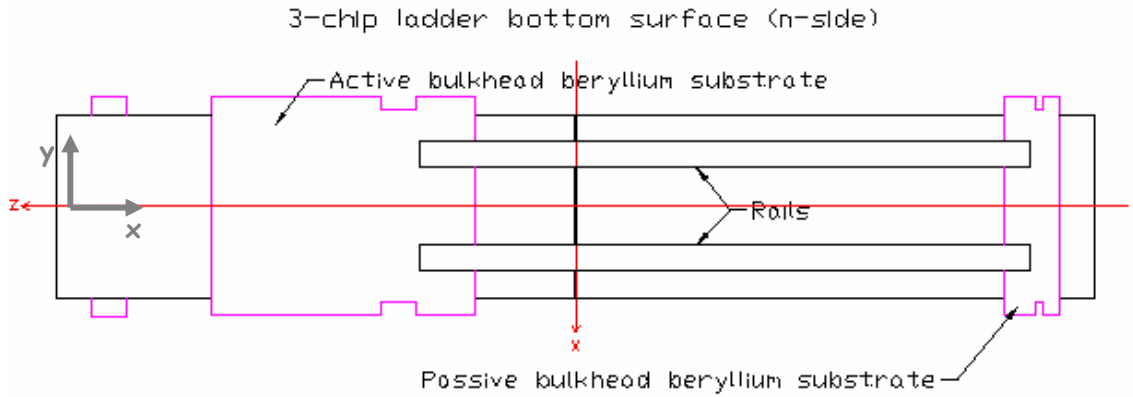
Cecilia Gerber, Fermilab

Burn-in: finding NOISY channels



Cecilia Gerber, Fermilab

Mechanical Grading



- active-to-passive notch (with any of 4 possible push directions)
  - <10 microns - A1 grade
  - <20 microns - B1 grade
  - >20 microns - C1 grade, to be repaired.

- ladder flatness:

layer 1&2 Zmax-Zmin
- < 60 microns - A2 grade
- < 120 microns - B2 grade
- > 120 microns - C2 grade, for repairs.

layer 3&4 Zmax-Zmin
- < 120 microns - A2 grade
- < 240 microns - B2 grade
- > 240 microns - C2 grade, for repairs.

A1 & A2 -> A

A1 & B2 -> B
B1 & A1 -> B

B1 & B2 \
A1 & C2 |
C1 & A2 |-> C
B1 & C2 |
C1 & B2 |
C1 & C2/

Cecilia Gerber, Fermilab

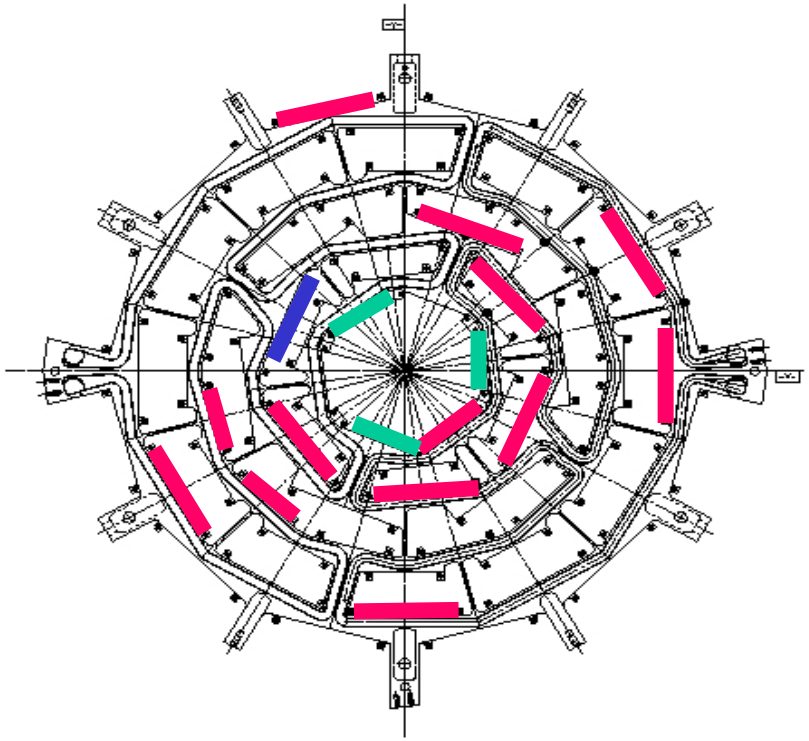
Barrel 1

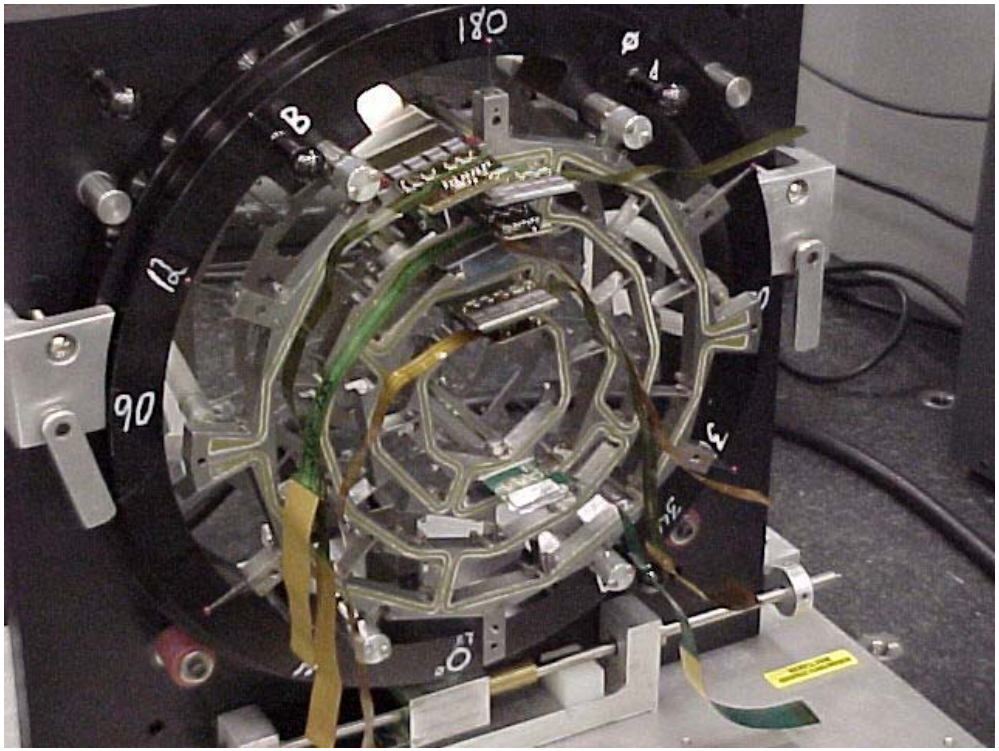
Electrical grade

B

C

Unassigned





Cecilia Gerber, Fermilab

Schedule: August 1 (half cylinder), November 2 (complete)

Week	B1	B2	B3	B4	B5	B6	F0	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	H1	H2	H3	H4	3-chip M	3-chip P	3-chip T	6-chip M	6-chip P	6-chip T	9-chip M	9-chip P	9-chip T	F M	F P	F T	H M	H P	H T
																									55	30		38	2		77	7		33	0	0	0	0
06-Mar-00							I																															
13-Mar-00	I						RO																			38						38						
20-Mar-00	AA																																					
27-Mar-00								I												I															12			24
03-Apr-00	RO																			AA																		
10-Apr-00																																						
17-Apr-00									I																										24			
24-Apr-00																																						
01-May-00		I								I																			36			72			36			
08-May-00		AA																			I																48	
15-May-00											I										AA														48			
22-May-00		RO																																				
29-May-00																				RO	RO																	
05-Jun-00								RO																														
12-Jun-00			I						RO																				72			108						
19-Jun-00			AA							RO		I																							60			
26-Jun-00												RO	I																						72			
03-Jul-00			RO																			I																72
10-Jul-00													RO									AA																
17-Jul-00				I										I								RO				72						144			84			
24-Jul-00				AA										RO	I																				96			
31-Jul-00															RO																							
07-Aug-00				RO																																		
14-Aug-00																I																			108			
21-Aug-00					I											RO													108			180						
28-Aug-00					AA												I																		120			
04-Sep-00																	RO																					
11-Sep-00					RO													I					I												132			96
18-Sep-00																		RO					AA															
25-Sep-00								I															RO						144			216						
02-Oct-00								AA													I														144			
09-Oct-00																					RO																	
16-Oct-00								RO																														
23-Oct-00																																						
30-Oct-00																																						
06-Nov-00																																						
13-Nov-00																																						
20-Nov-00																																						
27-Nov-00																																						
04-Dec-00																																						

I = Detector Installation
AA = Alignment
= Contingency
RO = Read-out

Current Status (http://martureo.fnal.gov/d0smtproduction/)

Barrel	# HDIs	# Chips	# Detect.	# Built	# Ready
3-C SS	72	216	72	63	37 (18)
6-C DS	144	864	144	71	38 (22)
9-C DS	216	1944	216	131	62 (53)
Sub-total	**432**	3024	**432**		
F-Disks					
8-Chip	144	1152			
6-Chip	144	864			
Sub-total	**288**	2016	**144**	63	4 (32)
H-Disks					
6-Chip	**192**	1152	**96**	166	18 (125)
Total	**912**	6192	**672**	494	158 (251)

Deterioration of Detector Performance due to Rad Damage (NIM A 426 (1999))

Increased Noise

- leakage current in an irradiated silicon detector will increase linearly with dose
- an increase in I_{leak} leads to an increase in noise, and a deterioration of S/N ratio

Increased Depletion Voltage

- effective doping concentration α V_{dep}. Lower doses cause type inversion (n⊠p). After type inversion, V_{dep} increases with dose, I_{leak} increases with V_{dep}
- eventually device breaks down due to the high depletion voltage, or cannot be fully depleted, reducing the charge collection efficiency.

Decrease in charge collection efficiency

- radiation induces additional trap centers leading to a linear decrease of carrier mobility and lifetime with dose

➔ run and KEEP the detector at low temperature , use n-bulk devices with high initial depletion voltage, operate with split bias, multiple guard rings...

Reverse annealing

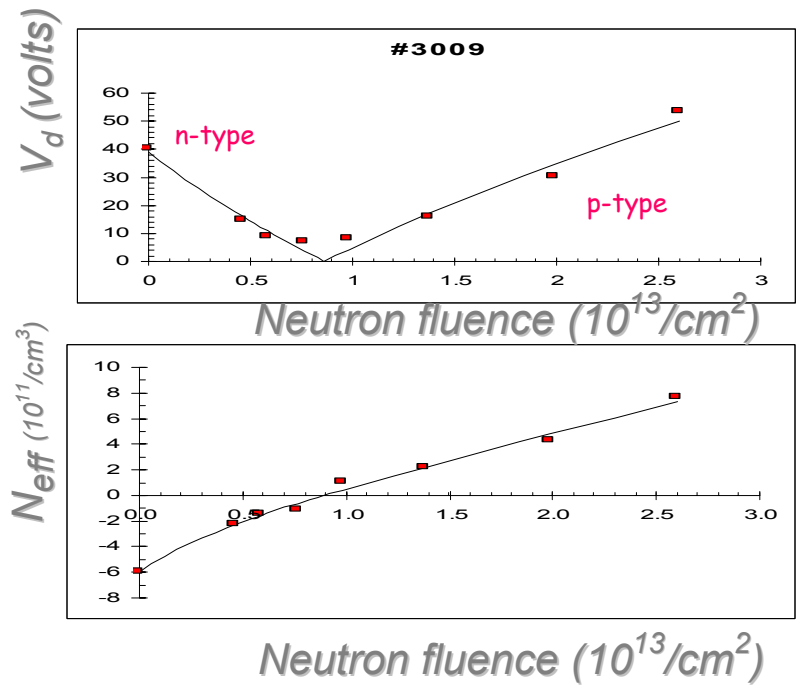
SSC studies found a complex radiation induced "acceptor generation" effect. Sensitive to time and temperature

$$Neff = -N_0 e^{-c\Phi} + g_c(\Phi) + g_s \Phi e^{-t/\tau(T)} - N_y(\phi,\tau,T)$$

Effective doping concentration ∝ V_{dep}

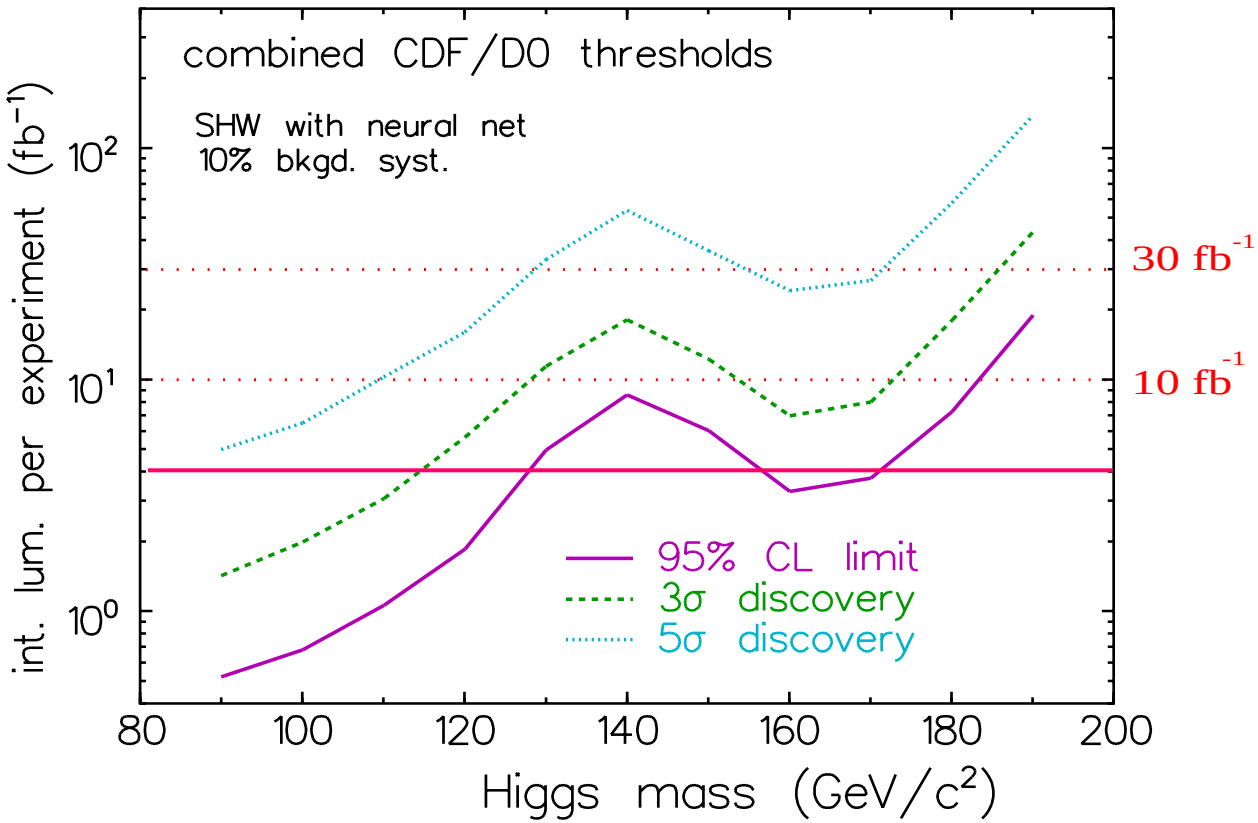
Donor removal | Acceptor creation | Beneficial annealing | Reverse annealing

- First two terms lead to type inversion ("stable damage part")
- Third term cancels out between the low temp running and the room temp maintenance
- Last term can be frozen if detector is kept at ~-10C



Cecilia Gerber, Fermilab

Expected Reach for SM Higgs



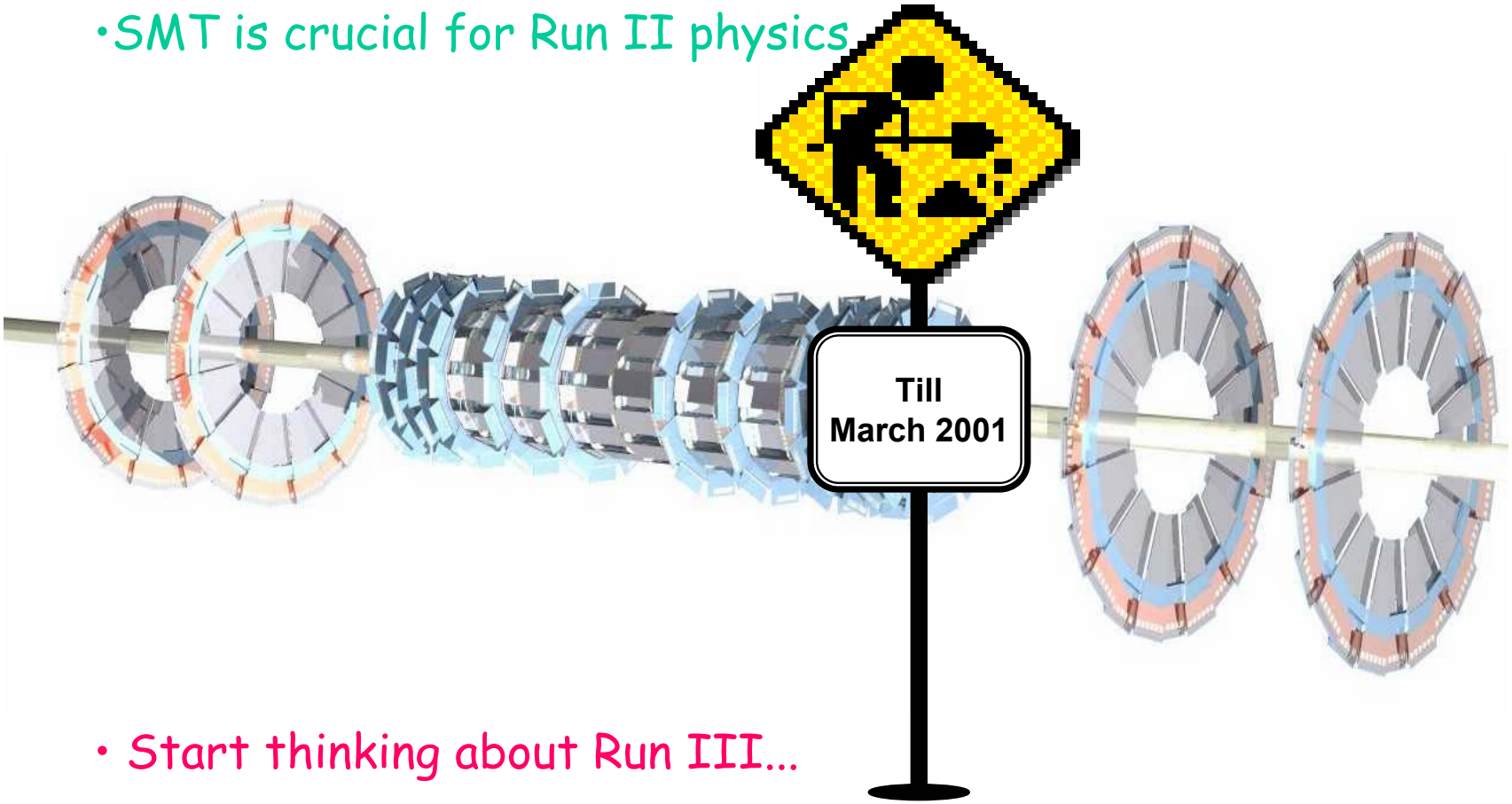
- Radiation damage for Luminosity ~ 0.5-2 x10^{32} cm^{-2} s^{-1}, 0.5 MRad/fb^{-1} layer 1

Inner layer will die after 2MRad, ~ 4fb^{-1}, ~2-3 years of running.

Cecilia Gerber, Fermilab

Conclusions

- Schedule is very tight
- SMT is crucial for Run II physics



- Start thinking about Run III...