
Flex Circuits for the ATLAS Pixel Detector

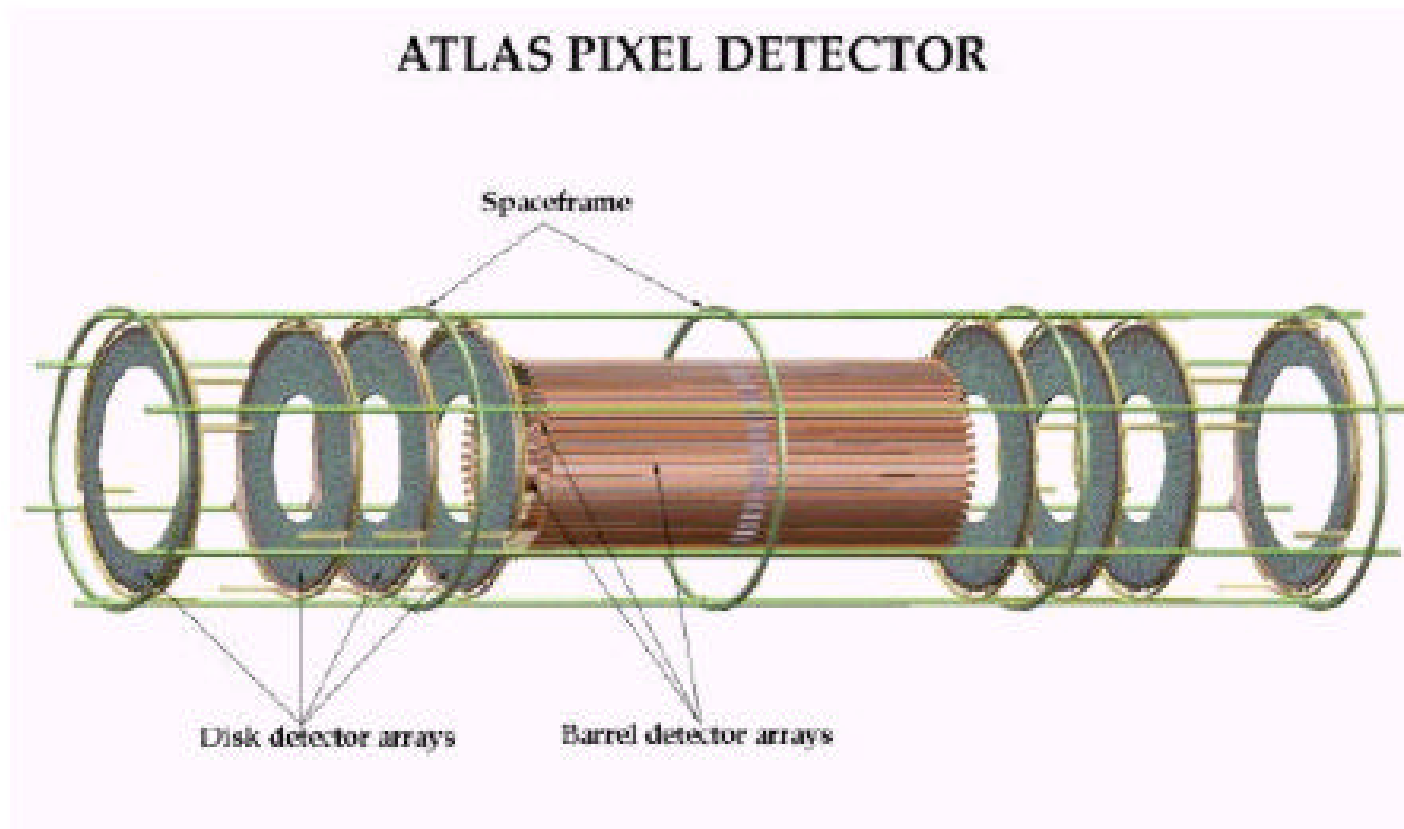
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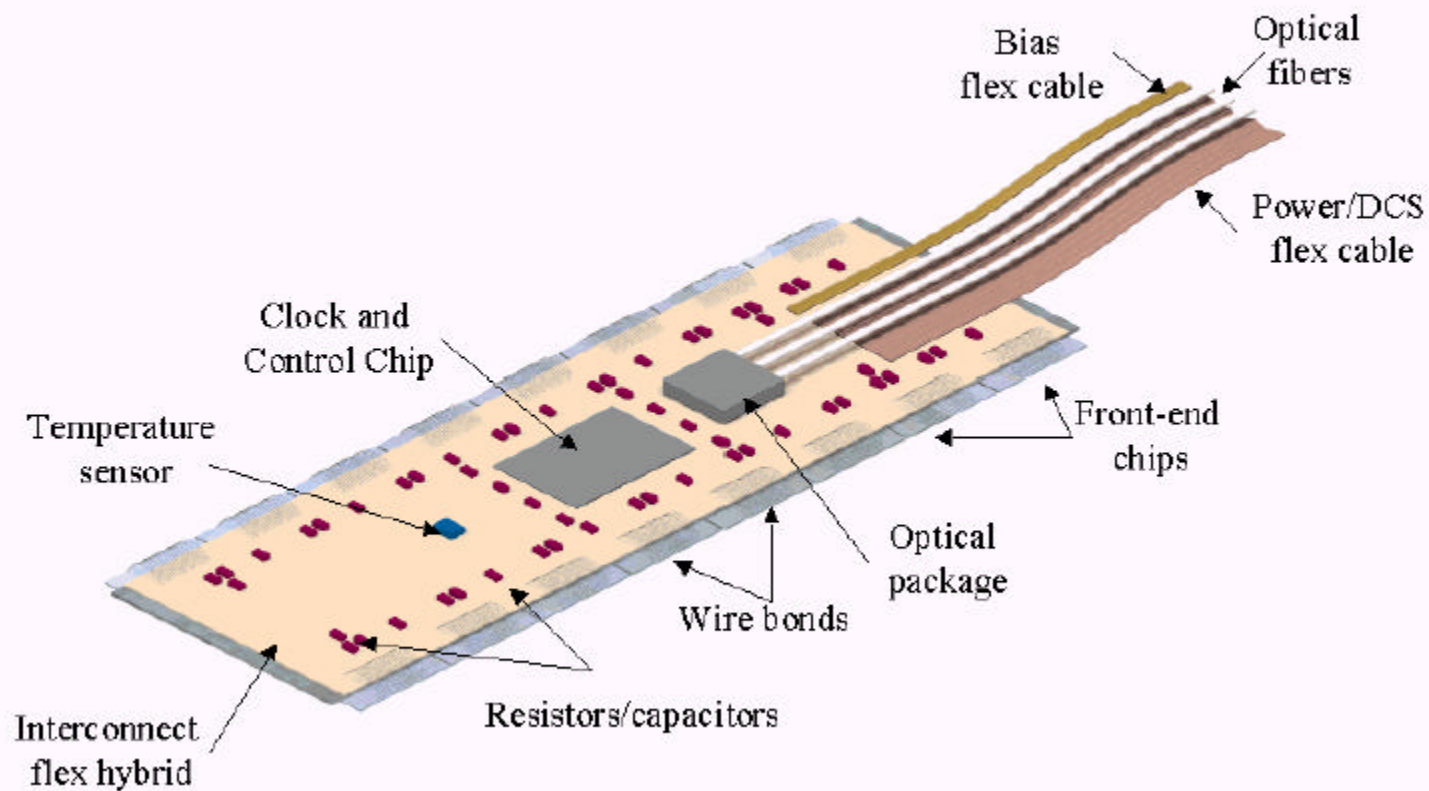
Outline

- ATLAS pixel detector
- ATLAS prototype Flex hybrid designs
- Performance simulations
- Performance measurements
- Wire bonding experience (CLEO III)
- Vendors
- Test beam results
- Conclusions

The ATLAS Pixel Detector



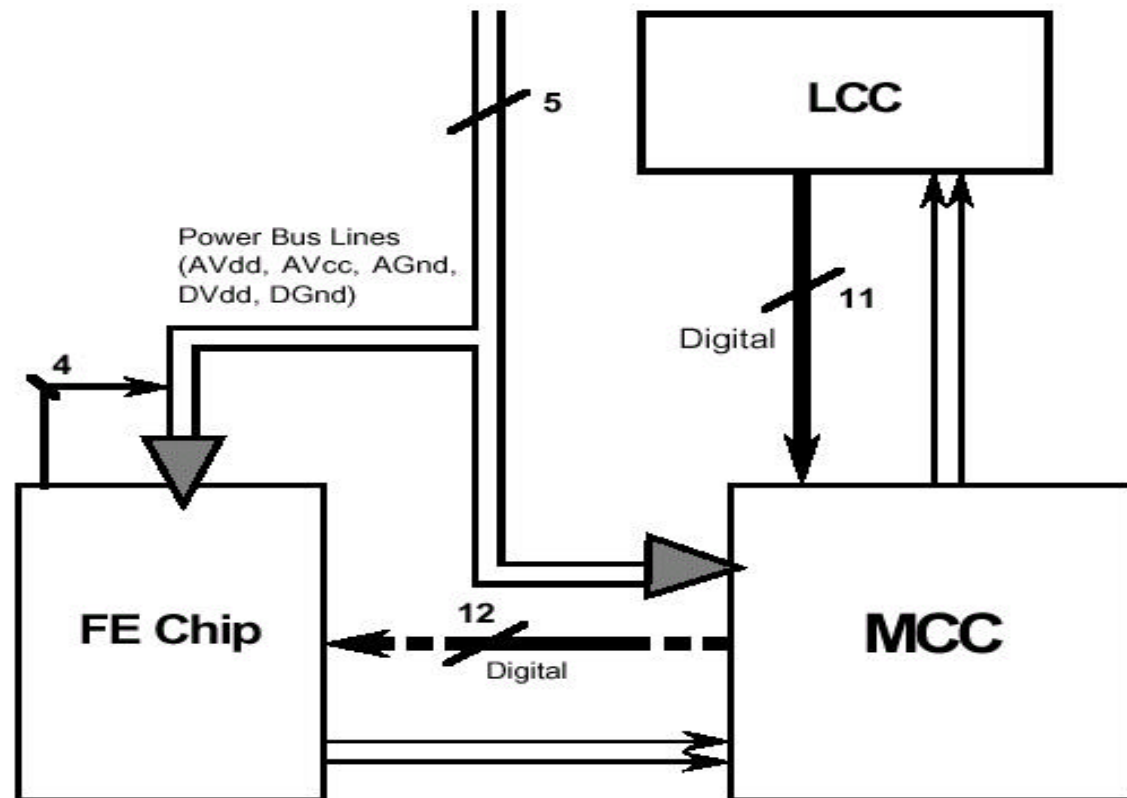
The Module Concept



Assumptions for the Design of the Flex Hybrid

- All specifications for the Front End chip and the MCC pinout, pin description, and geographical location are from Darbo, et al.; “ATLAS Module Demonstrator - Pixel Module Specifications”. (Revision 2.0)
- Current specification of the chips.
 - » FE Chip:
 - 40 mA for 3.0 V analog power
 - 50 mA for 1.5 V analog power
 - 50 mA for 3.0 V digital power
 - » MCC:
 - 200 mA for 3.0 V digital Power
- 150 mV voltage drop in the power lines over the length of the module
- Each power line can be one bus feeding different pads on the FE and MCC chips.

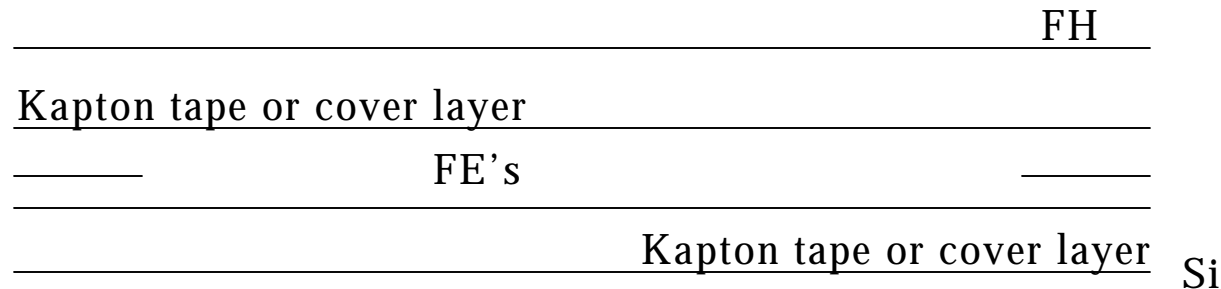
Block Diagram of Signal Connections



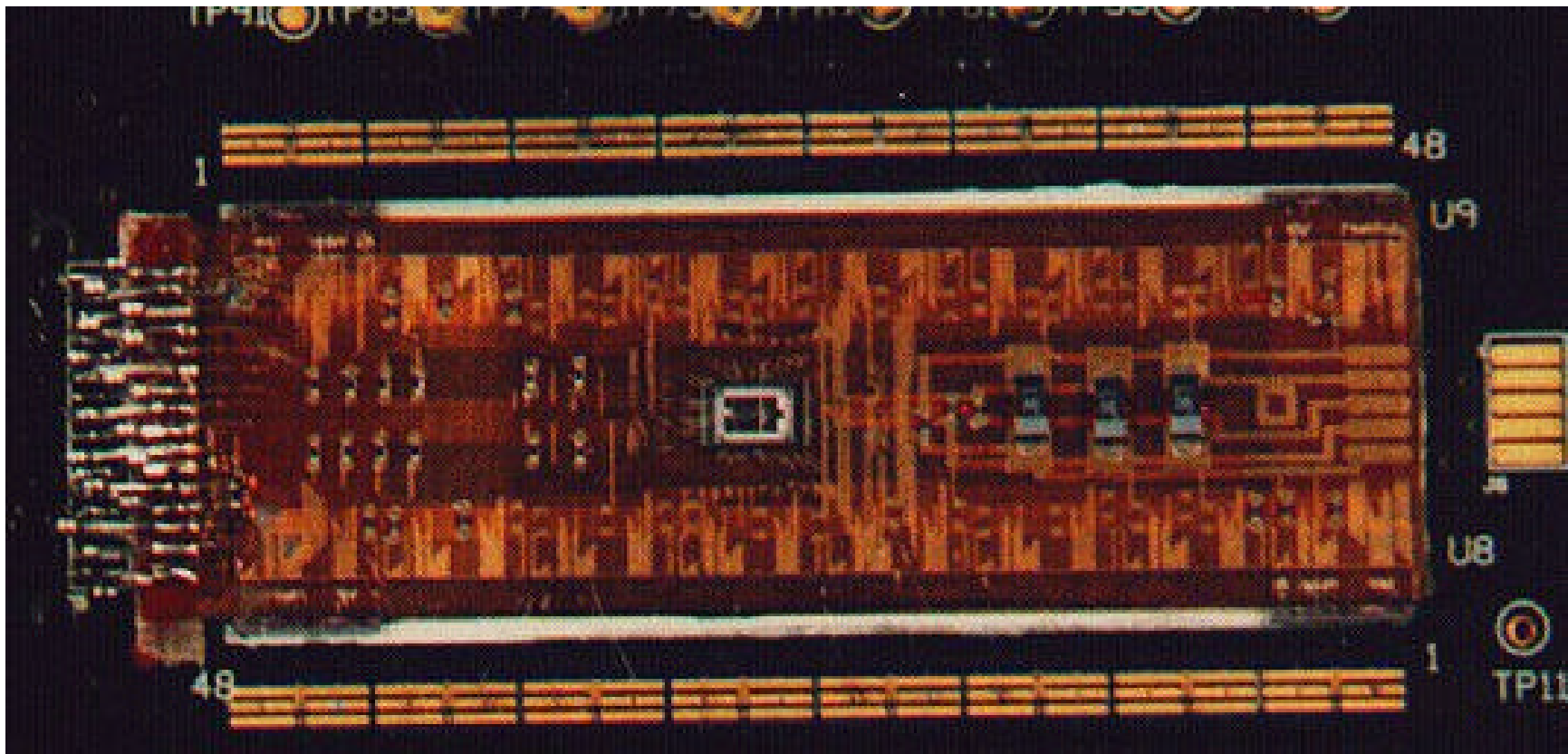
MCC : Module controller chip

Module Assembly at OU

- All modules assembled with conductive epoxy to attach SMD's
- 4 FE only flex hybrid dummy “module”



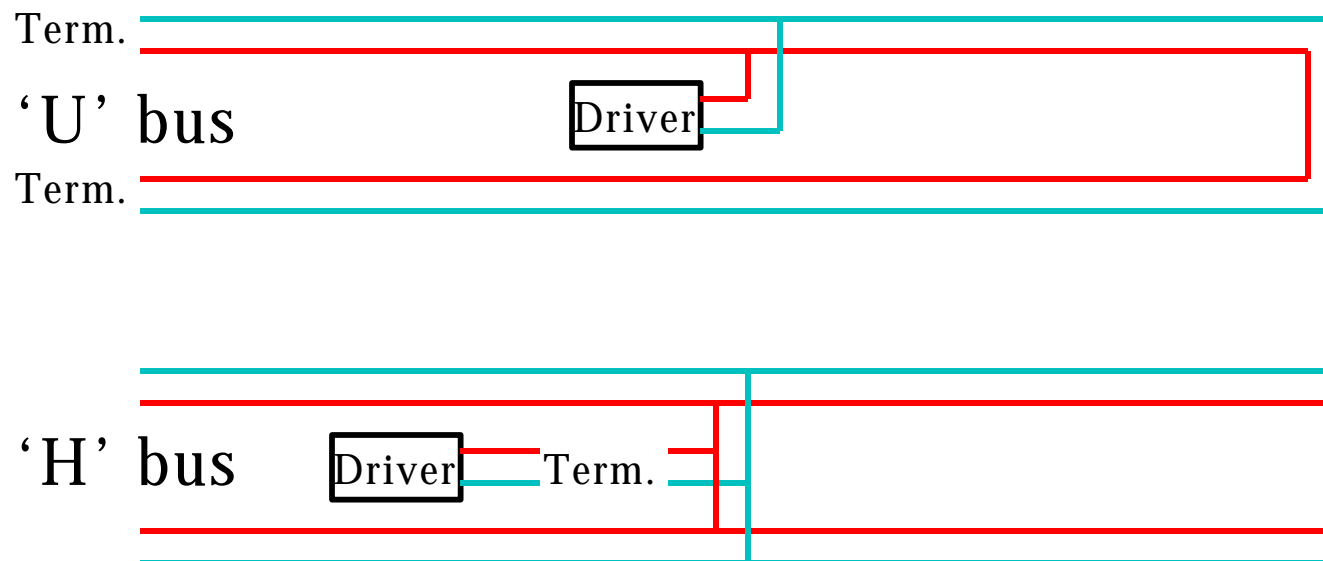
4 FE Only Module (OU)



Year	Current government (%)	Previous governments (%)
2008	45	55
2009	55	45
2010	65	35
2011	75	25
2012	85	15

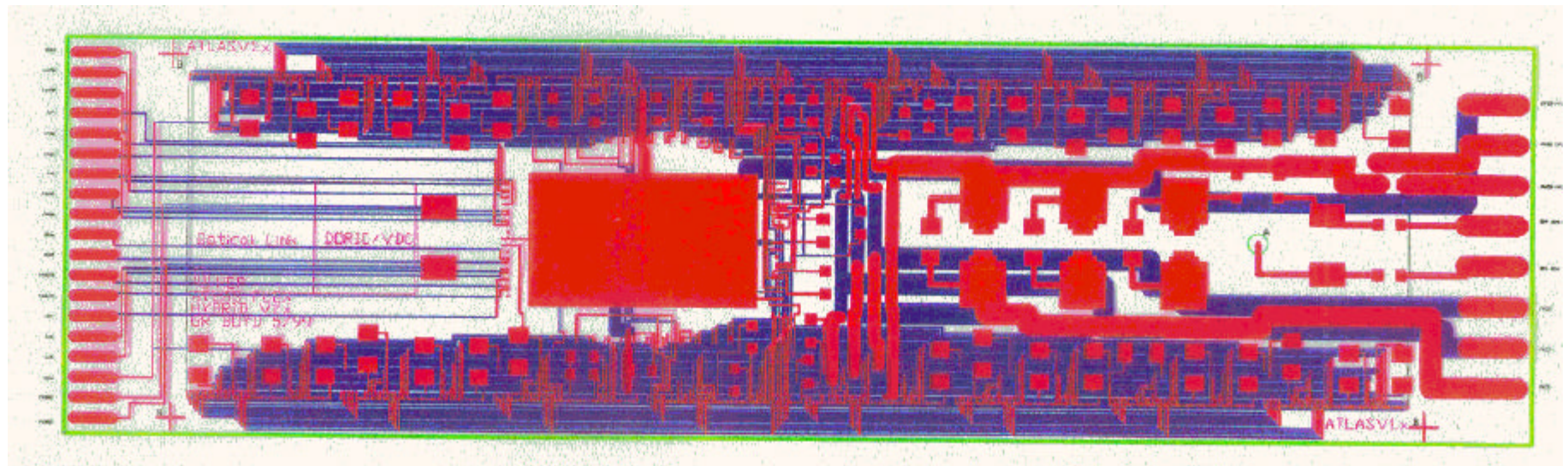


Prototype 1.1 Design

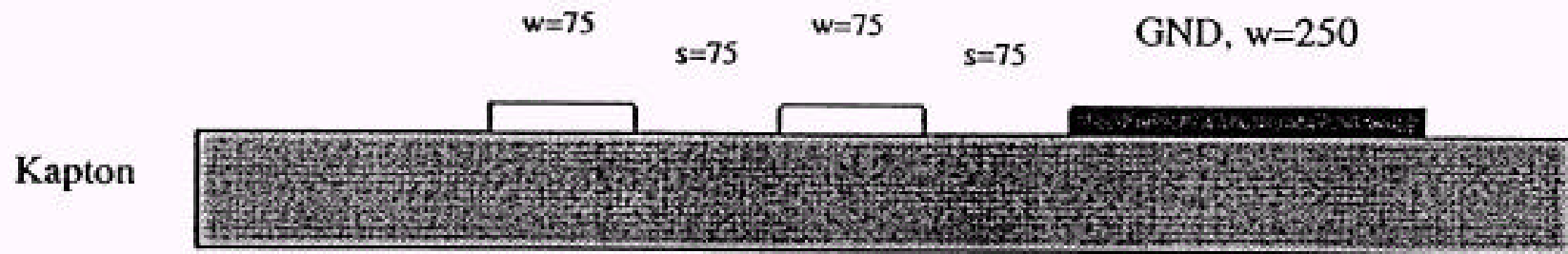


- If simulations agree with measurements → 'H' bus layout

Flex Hybrid V1.1

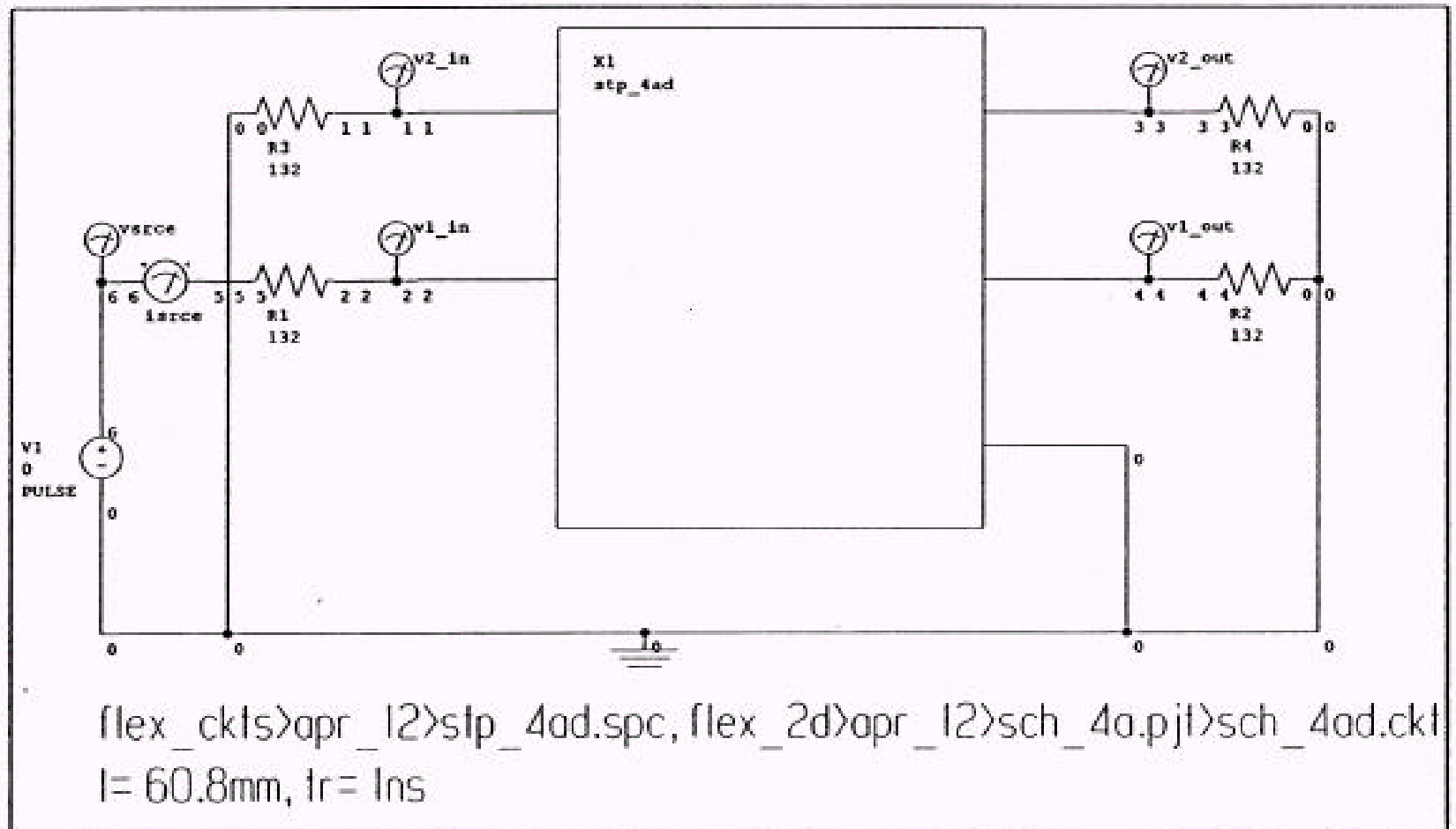


Simulations with Maxwell-Spice Link

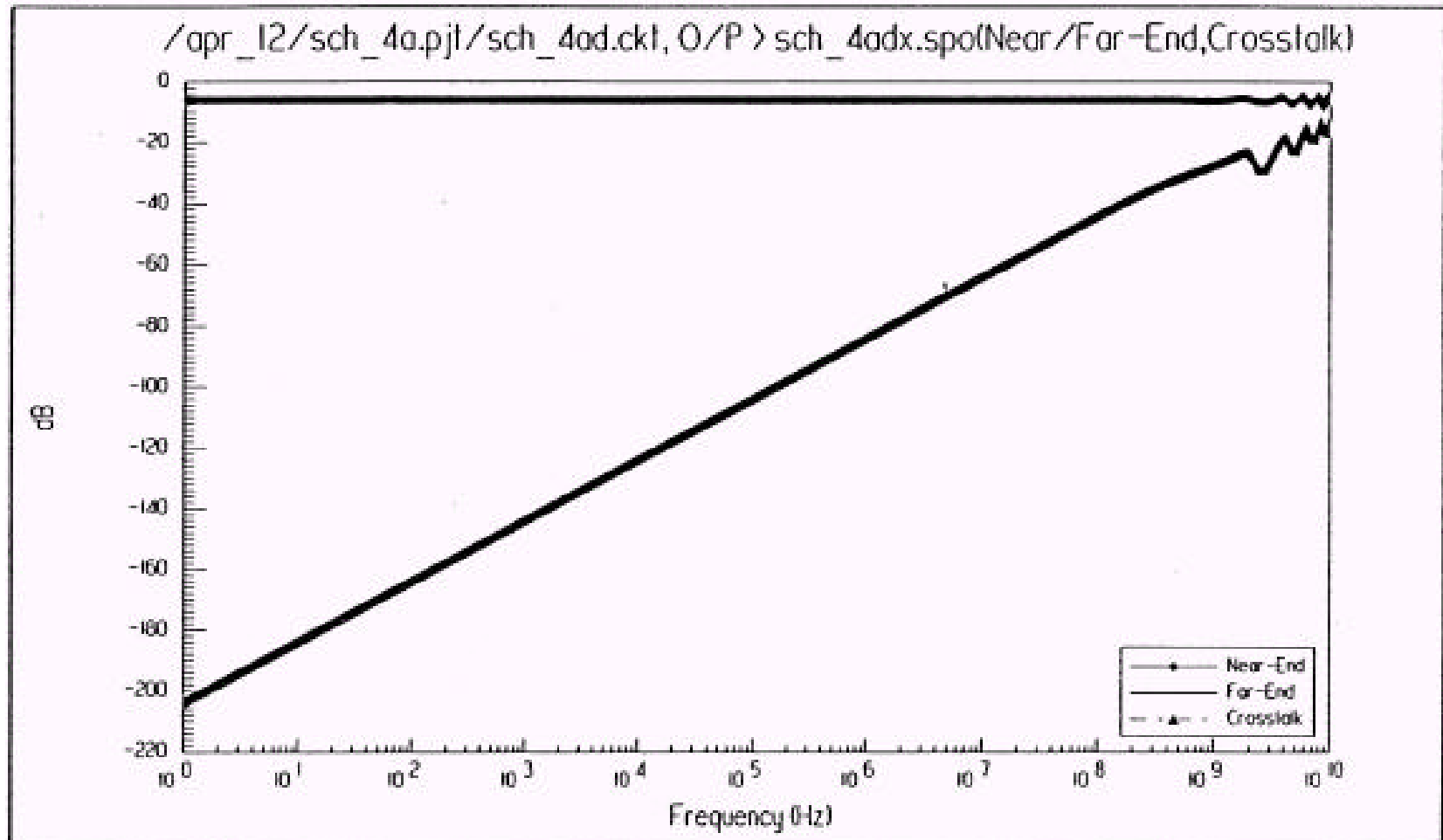


Dual Trace Model with Adjacent GND trace

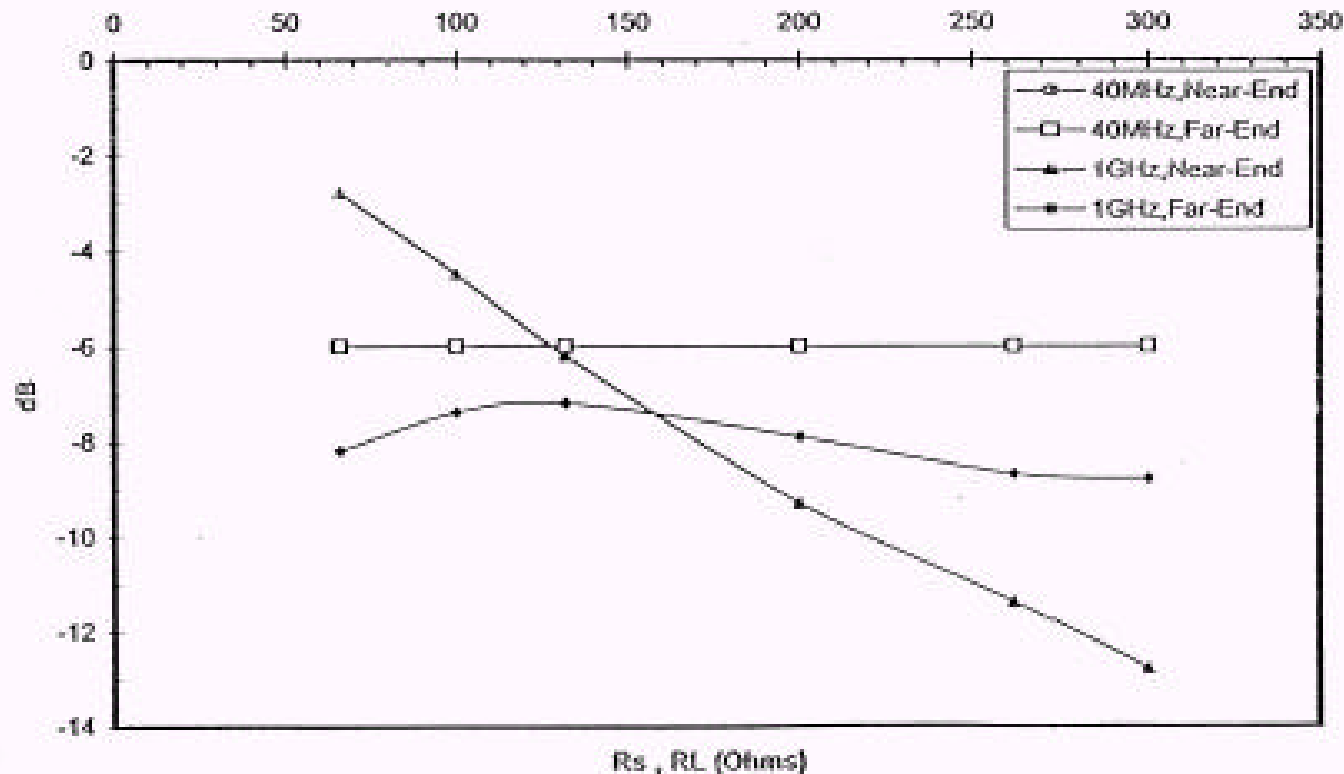
Simulation of Dual Trace Model with Adjacent GND



Simulation of Dual Trace Model with Adjacent GND

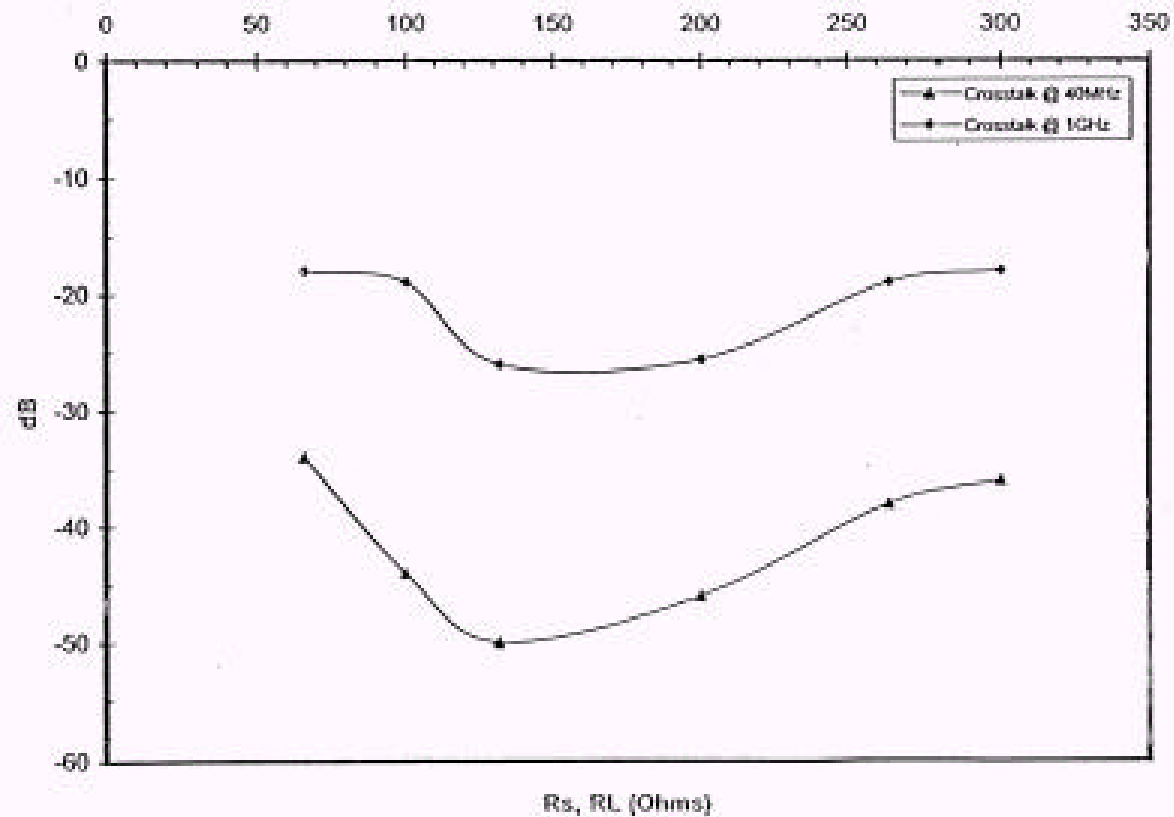


Simulation of Dual Trace Model With Adjacent GND



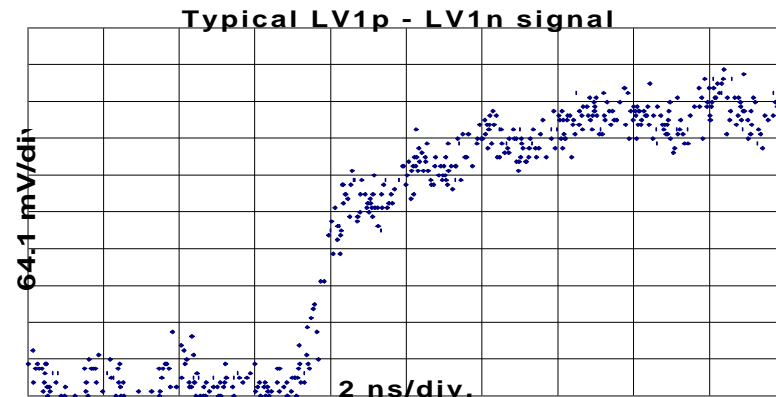
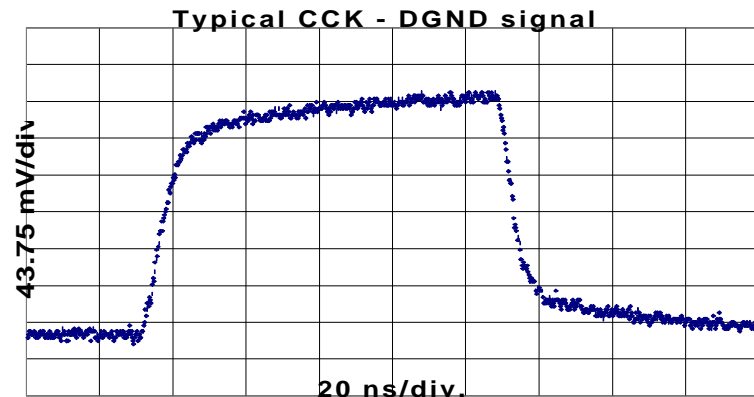
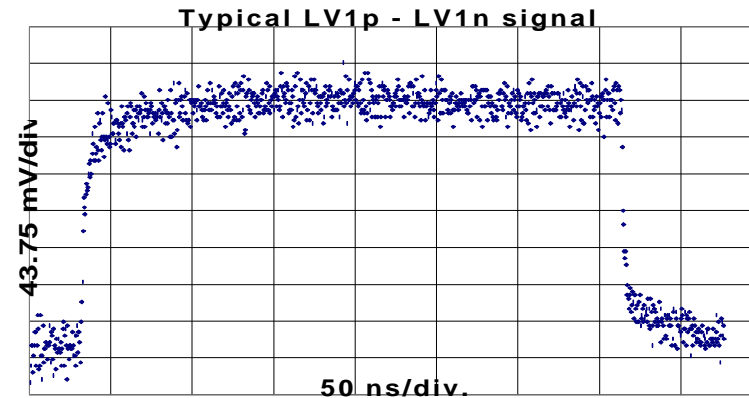
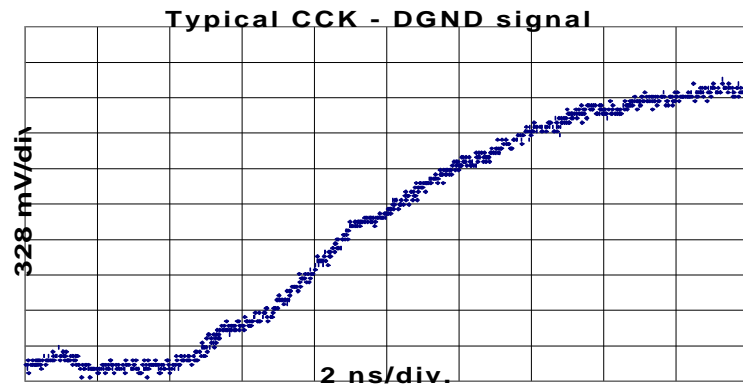
Frequency Response as a Function of Termination Values

Simulation of Dual Trace Model With Adjacent GND

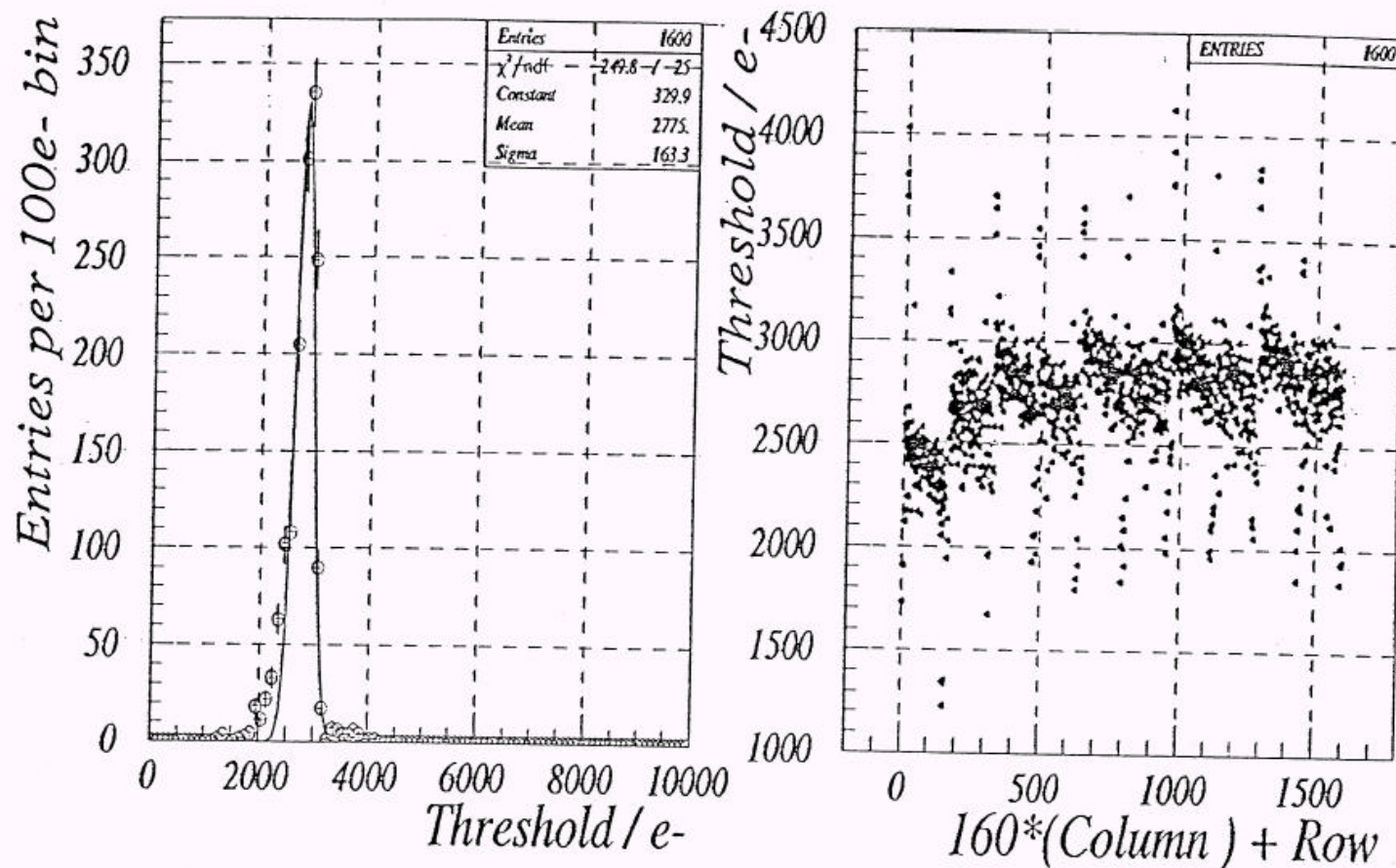


Crosstalk as a Function of Termination Values

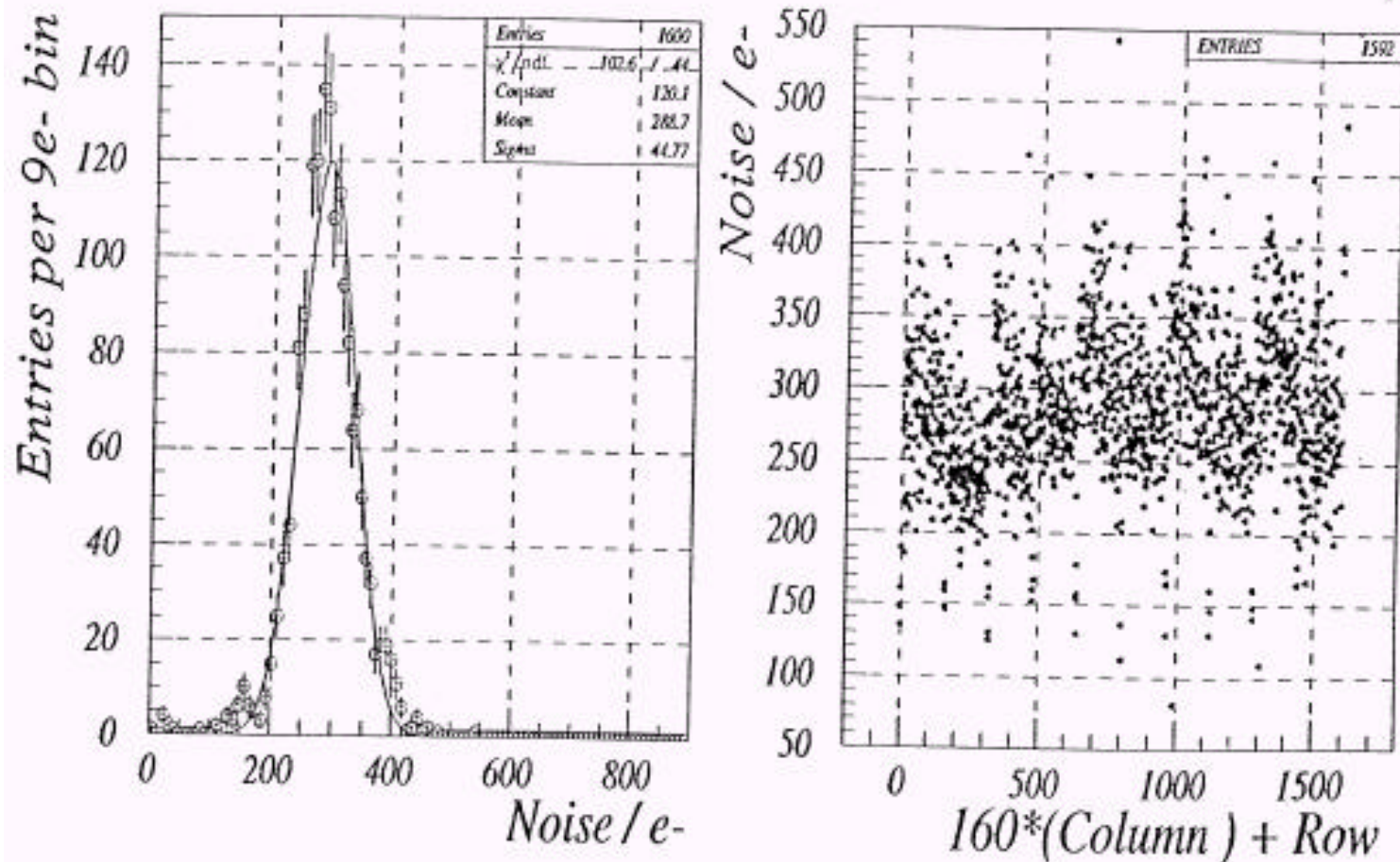
Flex Hybrid signal measurements



Thresholds for a typical FE chip on Flex module



Noise for a typical FE chip on Flex module



Vendor experience

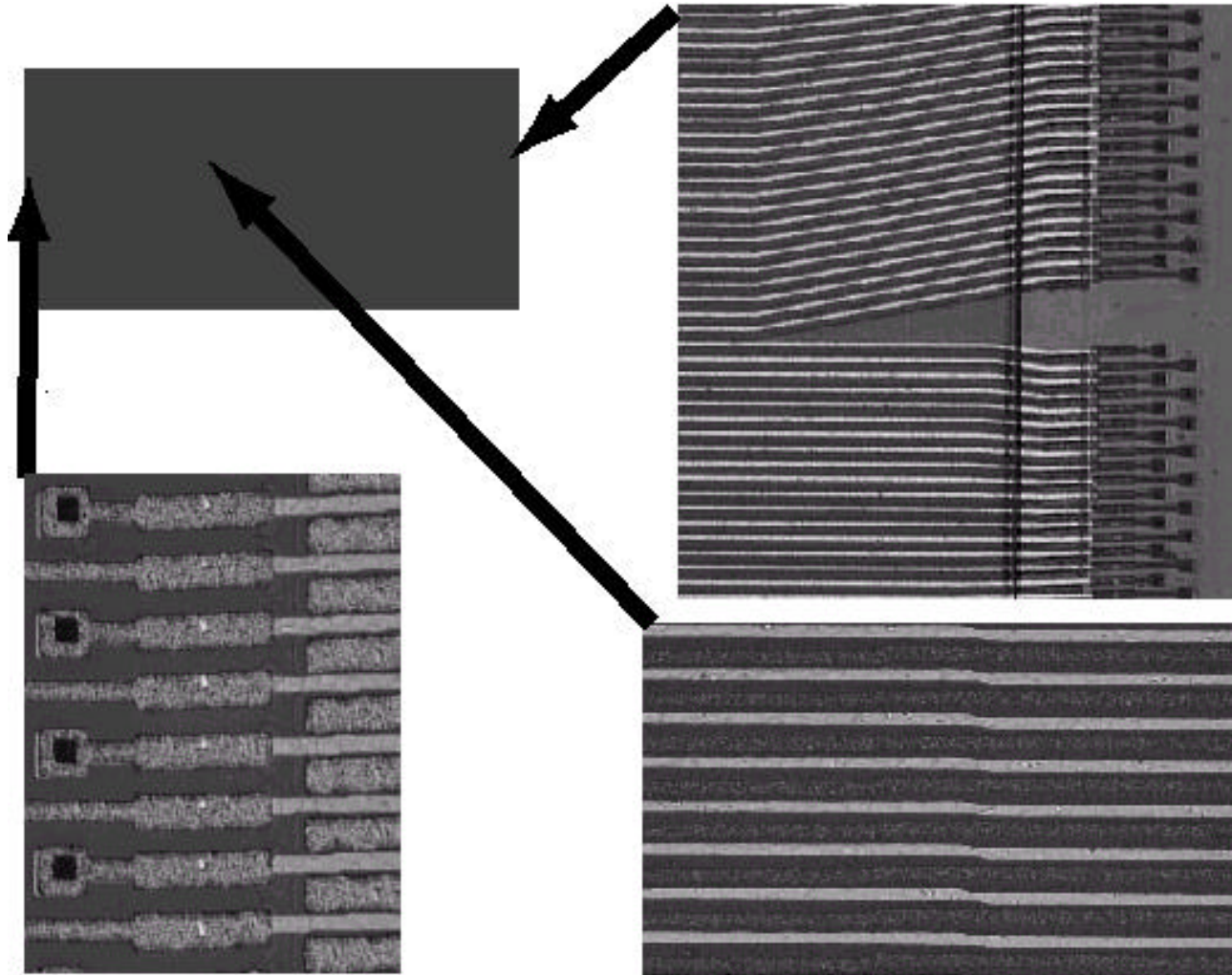
- GE (*General Electric Corporate Research and Development*), NY

Completed delivery of CLEOIII flex circuits Nov. 98

Final cost (11 & 12 flex/frame) \$175/flex

- Design rules used on CLEO III flex connector
 - 60 μm spaces and 40 μm traces
 - Via cover pad = 75 μm square; 25 μm plated hole
 - 75 μm wide bond pads on 100 μm pitch; two interleaved rows
 - Double sided
 - 512 vias

CLEO III Flex Connector

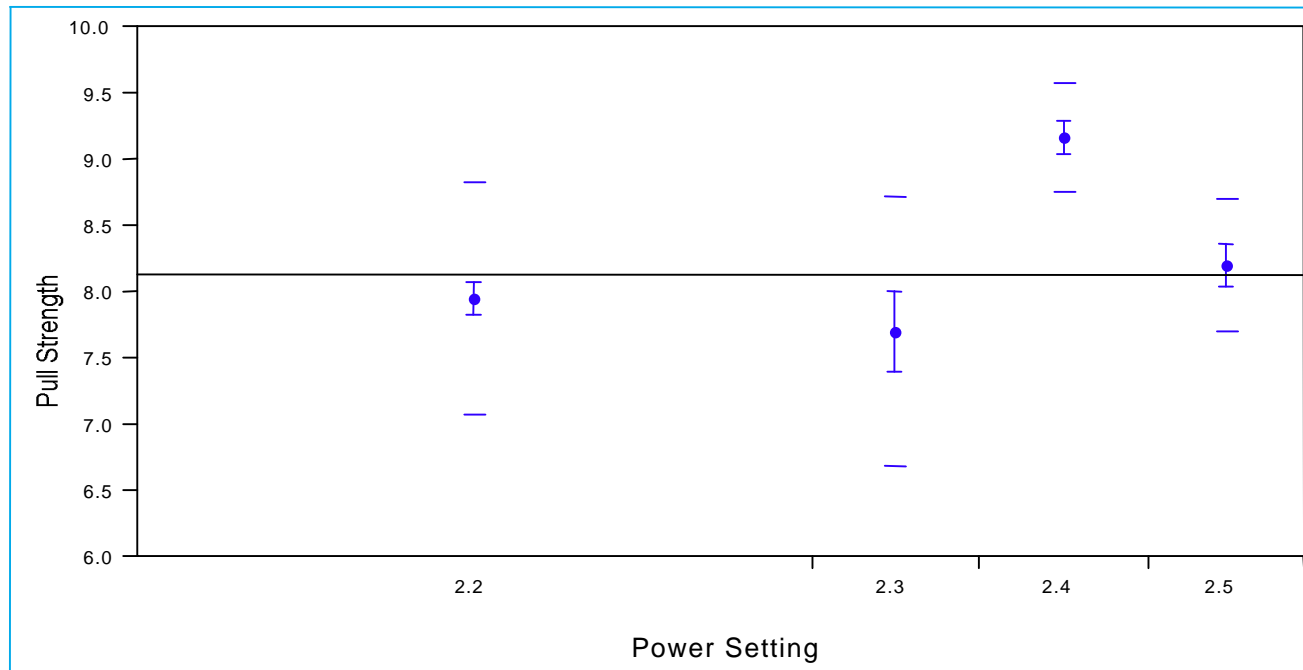


CLEOIII Wire Bonding Experience

- 1022 100 μm pitch wire bonds x 244 flex circuits ~ 250K wire bonds
- Automated wire bonder tuning
 - » 47 bonds
 - » Average pull strength 7.3, gm std. dev. 0.9 gm
 - » Min. 5.7 gm
 - » Operating parameters (*power, time, force, etc.*) optimized for consistent results on two different bonding stations of same model
 - » Support of piece being wire bonded must be consistent

CLEOIII Si3 Wire Bonding Experience (cont.)

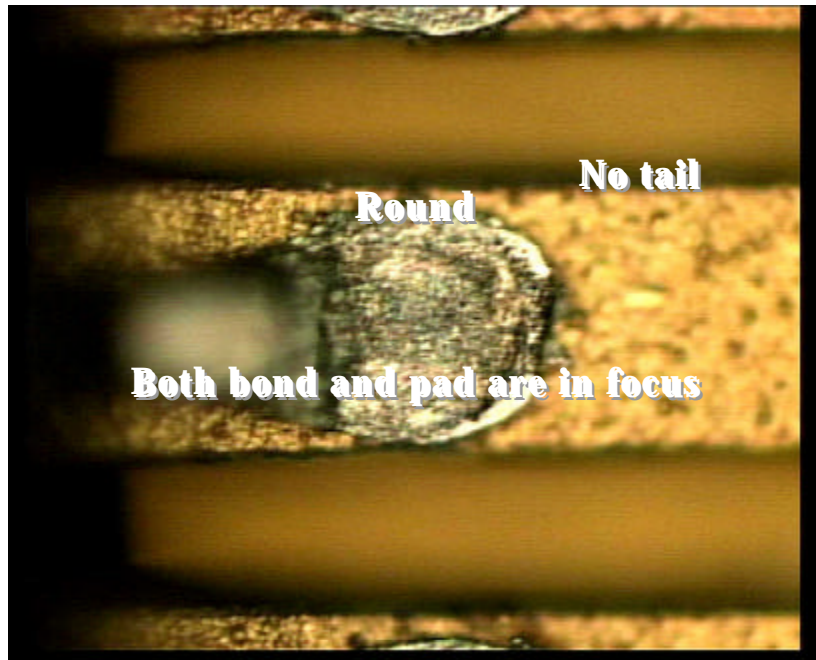
Power	Number	Mean	Std Dev	Std Err Mean
2.2	44	7.95636	0.87973	0.13262
2.3	11	7.70364	1.02165	0.30804
2.4	11	9.16545	0.42597	0.12843
2.5	10	8.20100	0.51654	0.16334



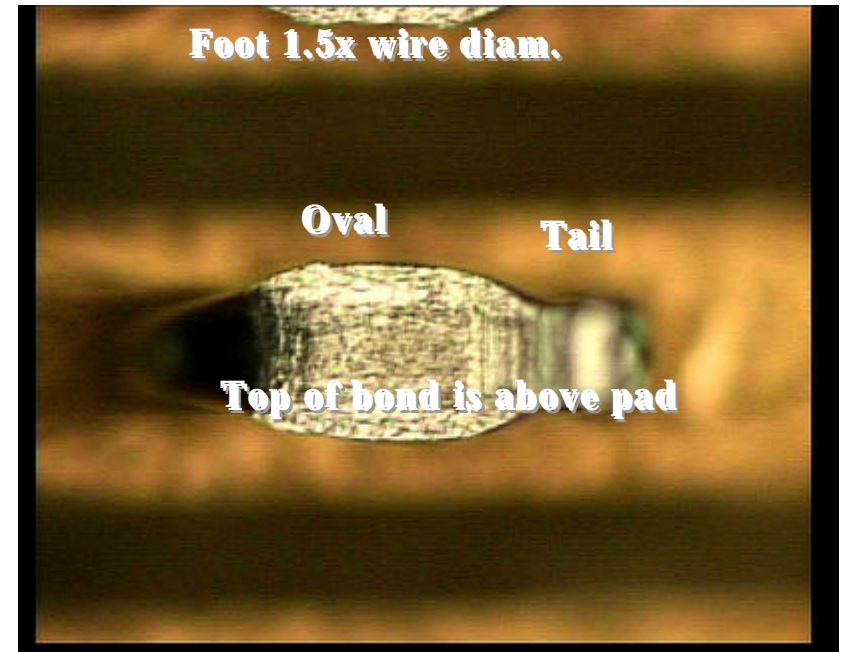
CLEOIII Si3 Wire Bonding

Experience (cont.)

- Wire bond quality can be discerned by visual inspection



Example of smashed bond on production (hybridless) starter NL2-03.



Example of a "good" wirebond on flex bond pads.

CLEOIII Wire Bonding

Experience (cont.)

- Conclusion: Uniform high pull strength bonds are made:
 - » Using parameters that form a tail on the bonds
 - » By adjusting power and/or bond-time as needed to yield bond foot deformation ~1.5x wire diameter
- 81K wire bonds to date - 3 failures (*due to pad delamination*)
- Wire bonds are encapsulated with Dow Corning Sylgard 186
- Note: *R&D Circuits claims that 15 gm wire bonds are obtained by controlling Au purity*

Vendors

- CERN: produced over 50 flex circuits
 - » Design rules: 75 μm traces and spaces
 - » Metal: 16 μm Cu, 2 μm Ni, 0.1 μm Au
 - » Via's: 130 μm cover pads, 70 μm holes
 - » Substrate: 50 μm thick Kapton
 - » Cover layers: 60 μm thick cover (Pyralux) on top and bottom
 - » Over 600 via's

Vendors (con't)

- Compunetics, Inc. (Monroeville, PA):
produced 42 flex circuits
 - » Design rules: 75 μm traces and spaces
 - » Metal: 16 μm Cu, 2 μm Ni, 0.1 μm Au on solder pads and 1.5 μm on bond pads
 - » Via's: 130 μm cover pads, 50 μm holes
 - » Substrate: 25 μm thick Upilex
 - » Cover layers: 13 μm thick (Intek) on top and bottom
 - » Over 600 via's

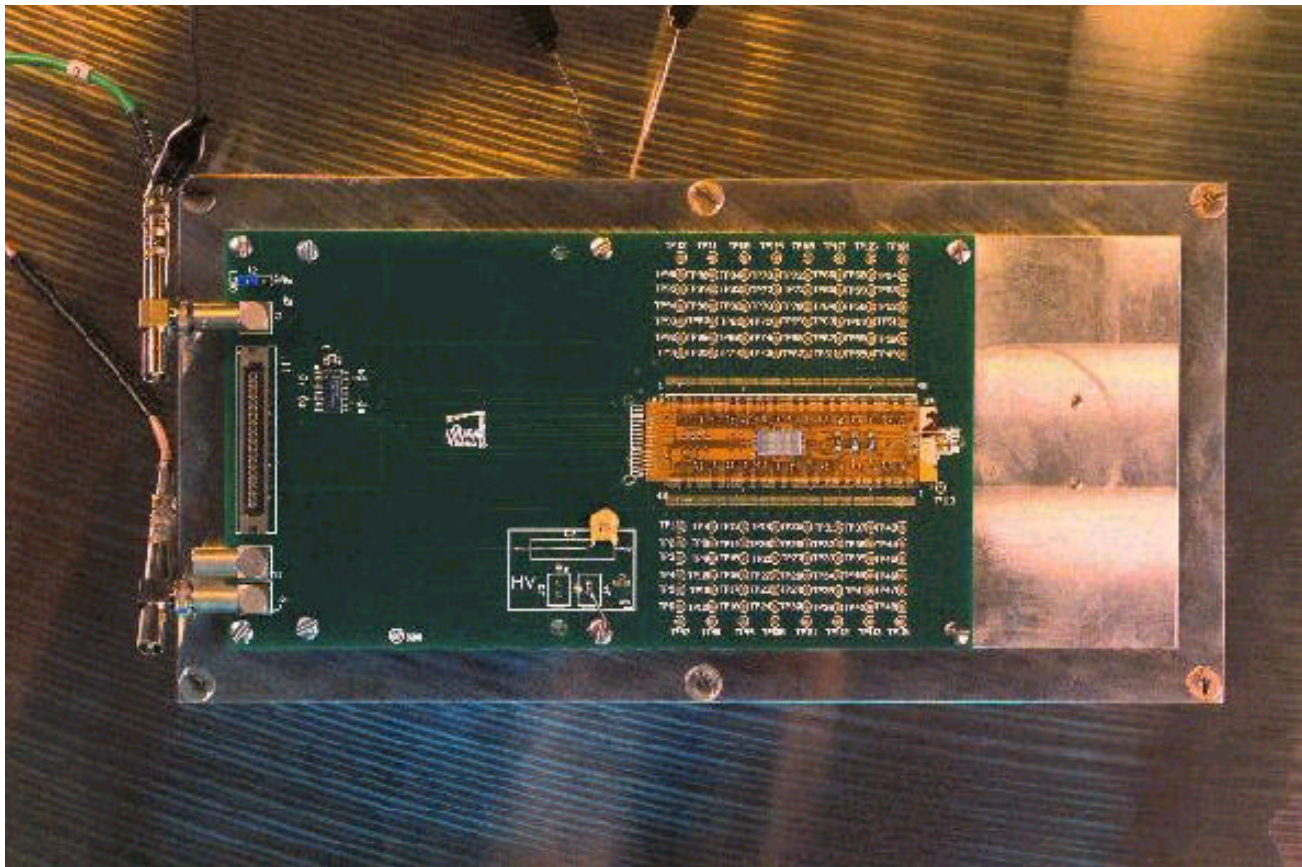
Vendors (con't)

- R&D Circuits (Edison, *N.J.*): produced several non-functional samples
 - » Design rules: 75 μm traces and spaces
 - » Metal: 16 μm Cu, 2 μm Ni, 0.1 μm Au on solder pads and 1.5 μm on bond pads
 - » Via's: 130 μm cover pads, 50 μm holes
 - » Substrate: 25 μm thick Kapton
 - » Cover layers: none on samples
 - » Over 600 via's

Vendors (cont.)

- Assembly: AMA; Sunnyvale, CA
 - » mounted SMD's on 10 flex circuits
- Testing: Microcontact; Switzerland
 - » Tested flex circuits produced by CERN before Ni and Au plating
- Test verification: SUNY- Albany
 - » Developing procedures for testing flex hybrids before and after SMD mounting

Flex Hybrid Module (LBL) in CERN test beam (May '99)



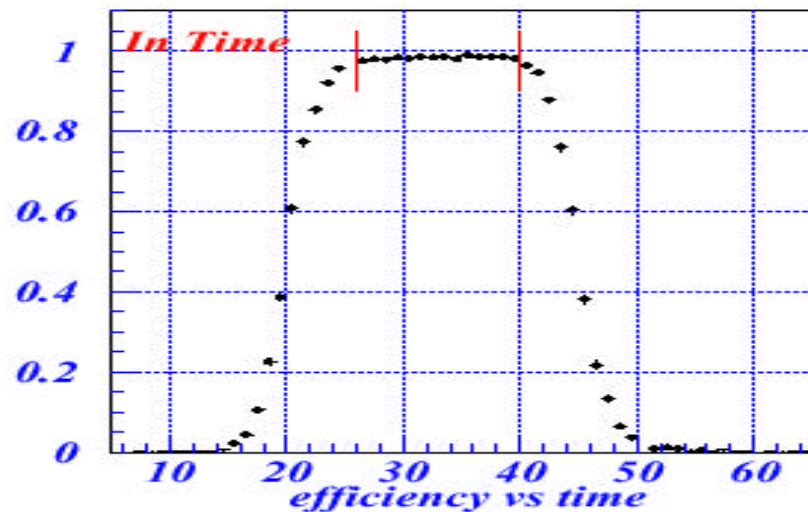
- SnPb bumps
- 200 μm thick detector
- 16 FE chips
- MCC readout

Module in test beam: Efficiency vs Time

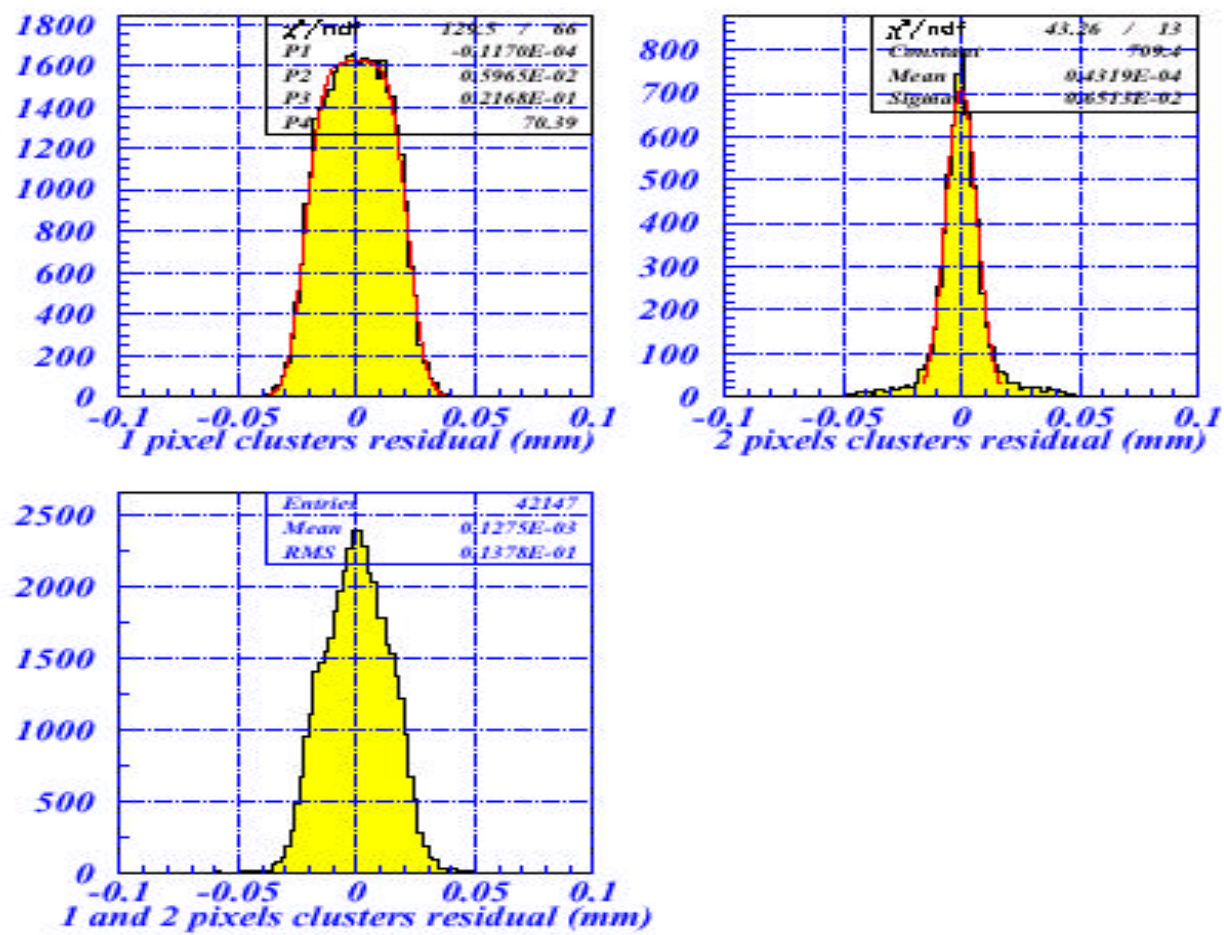
Efficiency 'In Time'

Tile 1 module - not Irradiated - Thr. 4 Ke

<i>efficiency</i>	<i>98.4</i>	<i>Losses</i>	<i>1.6</i>
<i>1 hit</i>	<i>81.2</i>	<i>0 hits</i>	<i>0.7</i>
<i>2 hits</i>	<i>15.1</i>	<i>not matched</i>	<i>0.2</i>
<i>>2 hits</i>	<i>2.1</i>	<i>not in time</i>	<i>0.7</i>



Module in test beam: Resolution



Module resolution from test beam measurements

- One pixel cluster:
 - » flat top $21.68 \times 2 = 43.4 \text{ } \mu\text{m}$
 - » $\sigma = 6.0 \text{ } \mu\text{m}$
- Two pixel clusters:
 - $\approx \sigma = 6.5 \text{ } \mu\text{m}$
- One and two pixel clusters:
 - $\approx \sigma = 13.8 \text{ } \mu\text{m}$

Charge Sharing from test beam measurements

Summary:

- *The charge sharing is confined to a region $\pm 5 \mu\text{m}$ between 2 adjacent pixels for $280 \mu\text{m}$ thick detector; the region shrinks to $\pm 4 \mu\text{m}$ for a $200 \mu\text{m}$ detector*
- *The fraction of 2 pixels clusters is $\sim 15\%$ for the Tile 2 design at 0° before irradiation with a threshold of 3 Ke*
- *The fraction of 2 pixels clusters is only $\sim 7.5\%$ after a dose of 10^{15} n/cm^2*

Conclusions

- Flex circuits have been made which provide required pixel module interconnections
 - » Material constraints favor aggressive non-standard design rules
- Measurements indicate that the designs meet signal integrity requirements
- Wire bonding to flex is not trivial, but can be understood
 - » Quality of bond can be evaluated by visual inspection
- No problems attributable to Flex Hybrid or layout have been observed to date