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# Development of High Data Readout Rate Pixel Module and Detector Hybridization at Fermilab

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# Outline

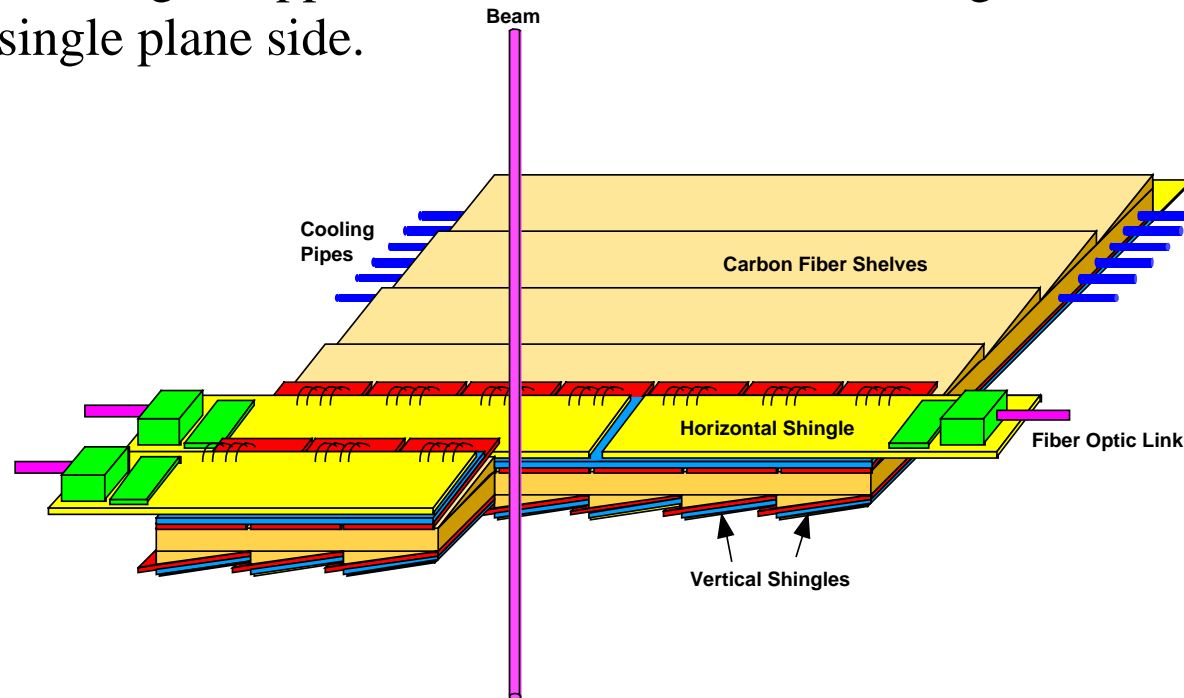
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- Introduction
- Proposed Pixel Detector MCM
  - » Constraint: data rate
  - » Block diagram and MCM
  - » Data readout variation
  - » Characteristics of the flex circuit technology
  - » Prototype and experimental results
- Hybridization studies
  - » Vendor search
  - » Indium bumps
  - » Solder bumps
- Conclusions

# Introduction: BTeV Pixel Detector

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- Pixel half plane: approximately  $5 \times 10$  cm.
- 868 pixel modules
- Position: 6 mm from the beam.
- “Shingle” approach allows for 100% coverage in a single plane side.



## Constraint: Data Rate

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- The Pixel detector will be used for the lowest level trigger      all pixel hit data needs to be readout
  - Simulation: assume
    - » Luminosity of  $2 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$  ( $\Leftrightarrow$  an average of two interactions per crossing)
    - » Threshold: 2000  $e^-$
    - » Magnetic field: 1.6 T
    - » Does not use the angle required for “shingling”
  - Chip data rate depends on:
    - » Chip active area
    - » Distance from the beam
    - » Number of pulse height ADC bits; assume 3 bits
    - » The way the data is arranged, etc.
-

# Constraint: Data Rate

Example:

Data Format

11		0	
Chip	ID	BCO #	Status
Row		Column	
PH	PH	PH	PH
PH	PH	PH	PH

Column with more hits

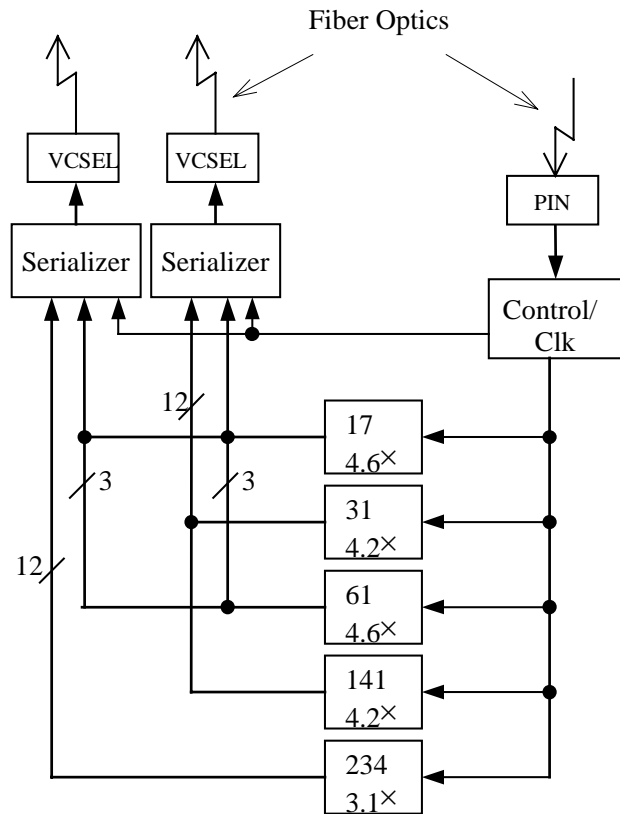
Data Rate, in MBits/sec

11	13	17	17	20	18	16	13	8
11	18	26	31	39	33	25	18	12
16	20	37	61	76	59	39	26	18
17	35	63	141	234	130	65	36	16
23	35	74	234	●				

Chip with more hits

Beam

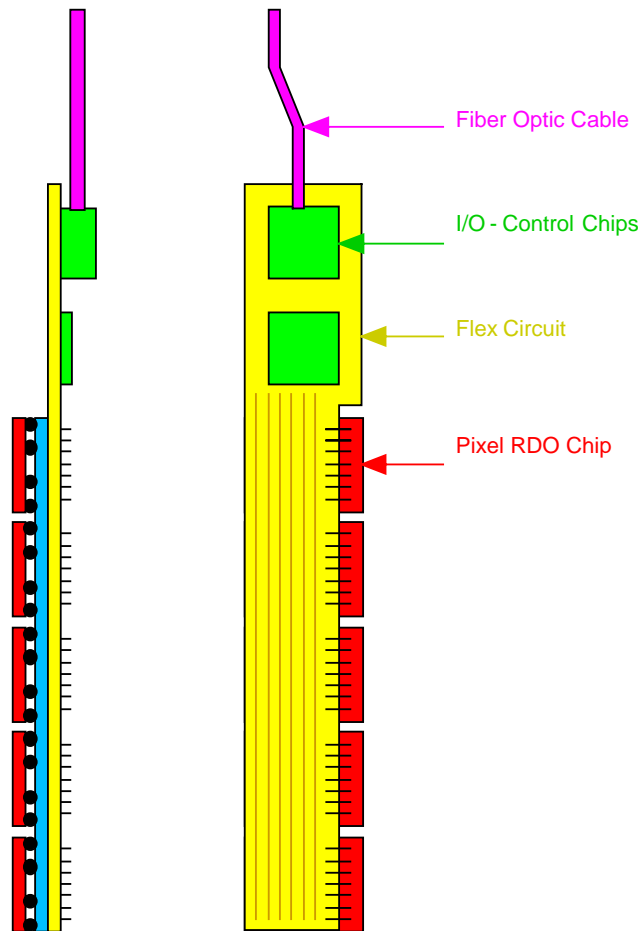
# Block diagram and MCM



- Readout through the Serializer chip.
- Serializer input: 17 bits at 60 MHz.
- Two 12 bits readout busses.
- One 6 bits readout bus.
- Remaining bits used to readout control.
- Safety margin: range from 3.1× to 4.6× from average data rate of this example.

# Block diagram and MCM

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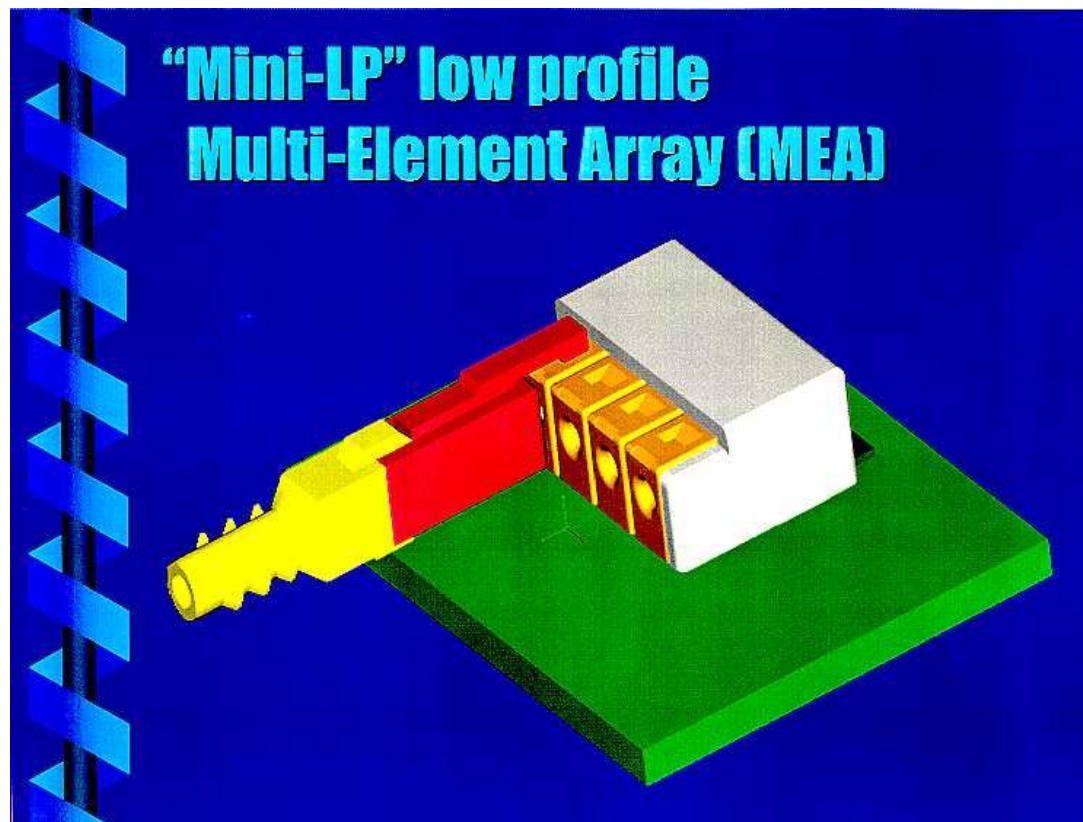
## PIXEL MODULE

- “Sandwich” of flex cable, pixel sensor and readout chips.
- Control and readout through fiber optics.

# Multi-Chip Module •

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VCSEL and Pin diode assemblies  
Methode Electronics, Inc.





# Data Readout Variation

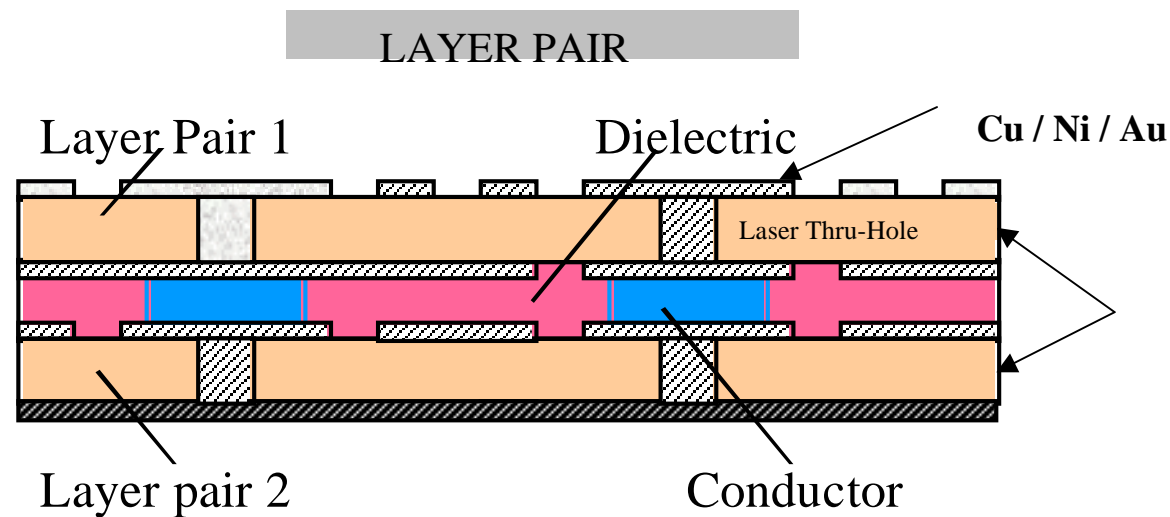
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- This proposed solution has some drawbacks:
  - » Requires the design of one more integrated circuit
  - » The area for the three chips and connectors is significant
  - » To assemble the modules we need all three rad-hard chips
- A variation is differential readout:
  - » Use differential copper wires for a point-to-point connection to the side of the beam pipe.
  - » The radiation in this area is  $<10$  Krads (hopefully) allowing the use of commercial parts.
  - » From the side, fiber optics readout.
  - » Preliminary studies show that the mass of the copper cables (power and data/control transmission) would increase by less than 15%.

# Characteristics of the Flex Circuit Technology

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Fujitsu Computer Packaging Technologies, Inc. (FCPT)

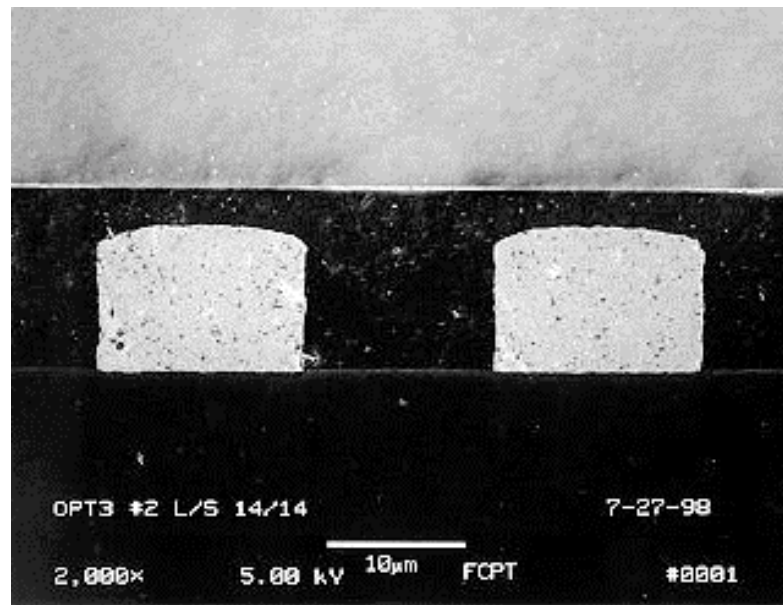


- Four layers is standard, six layers is doable.
- Dielectric base film: Upilex or Kapton.

# Characteristics of the Flex Circuit Technology

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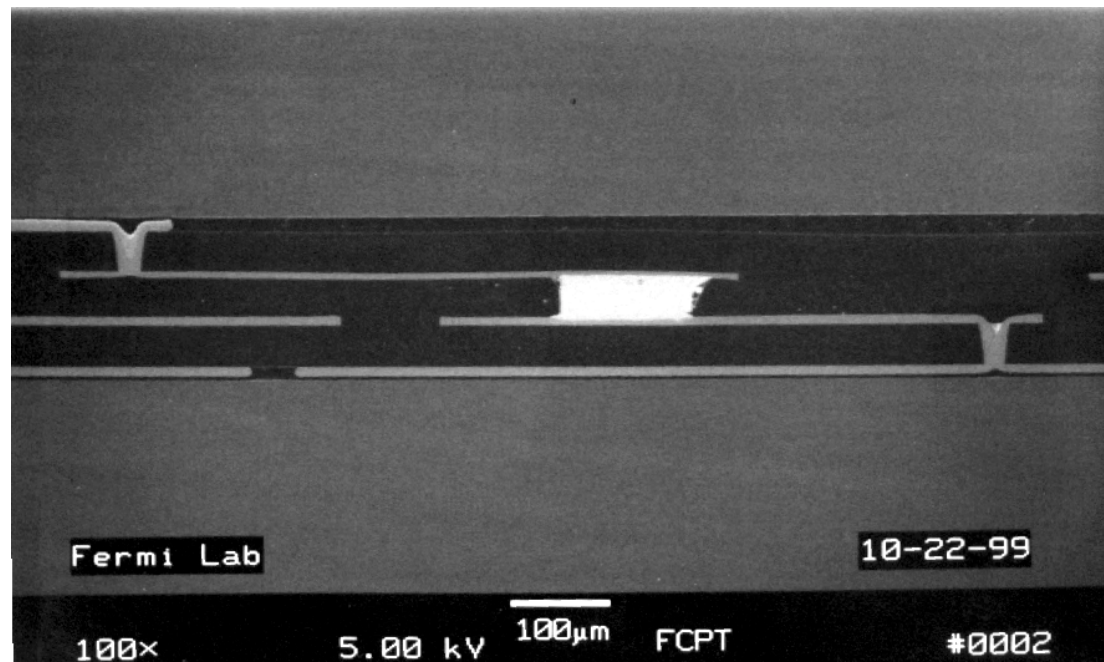
- Line width: standard, 20  $\mu\text{m}$
- Line to line clearance: standard, 20  $\mu\text{m}$
- Line thickness: standard, 5  $\mu\text{m}$



# Characteristics of the Flex Circuit Technology

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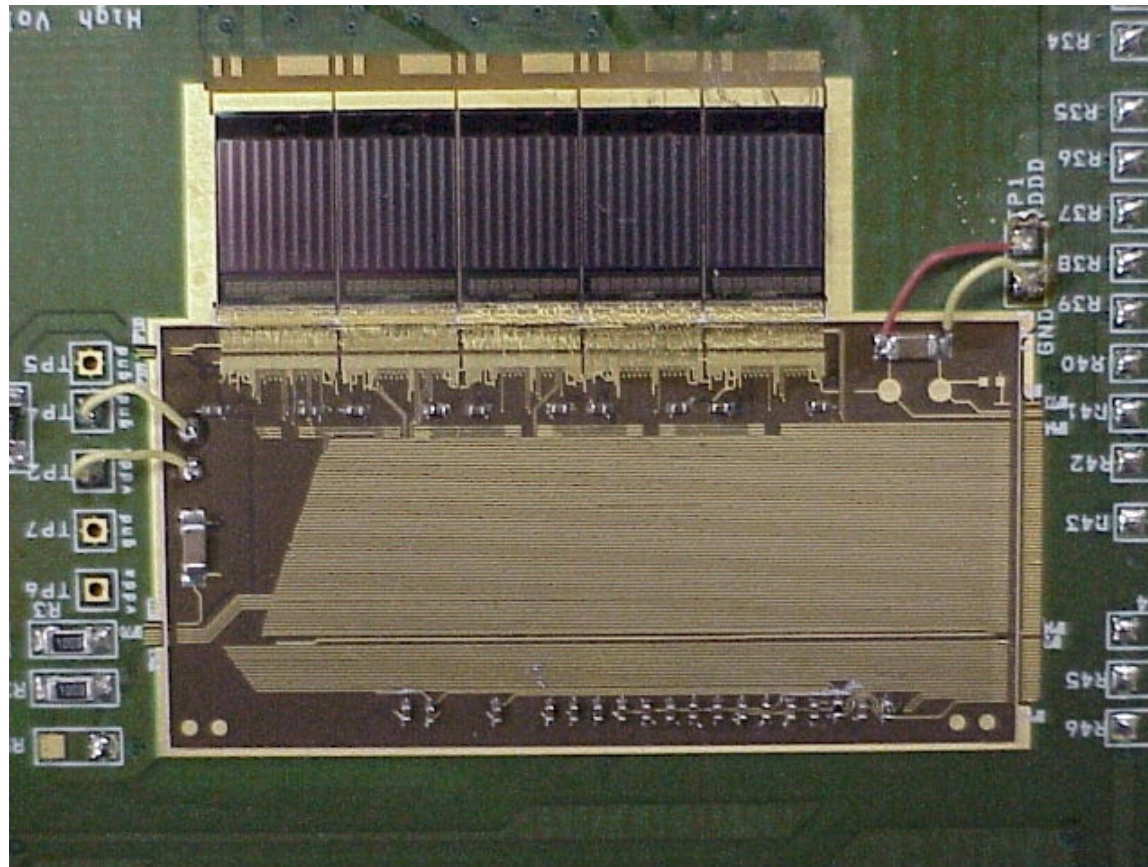
- Z Via
- Via cover pad diameter:  $108\text{ }\mu\text{m}$
- Through via hole diameter:  $35\text{ }\mu\text{m}$  top,  $18\text{ }\mu\text{m}$  bottom
- Via center spacing:  $208\text{ }\mu\text{m}$



# Prototype and Experimental Results

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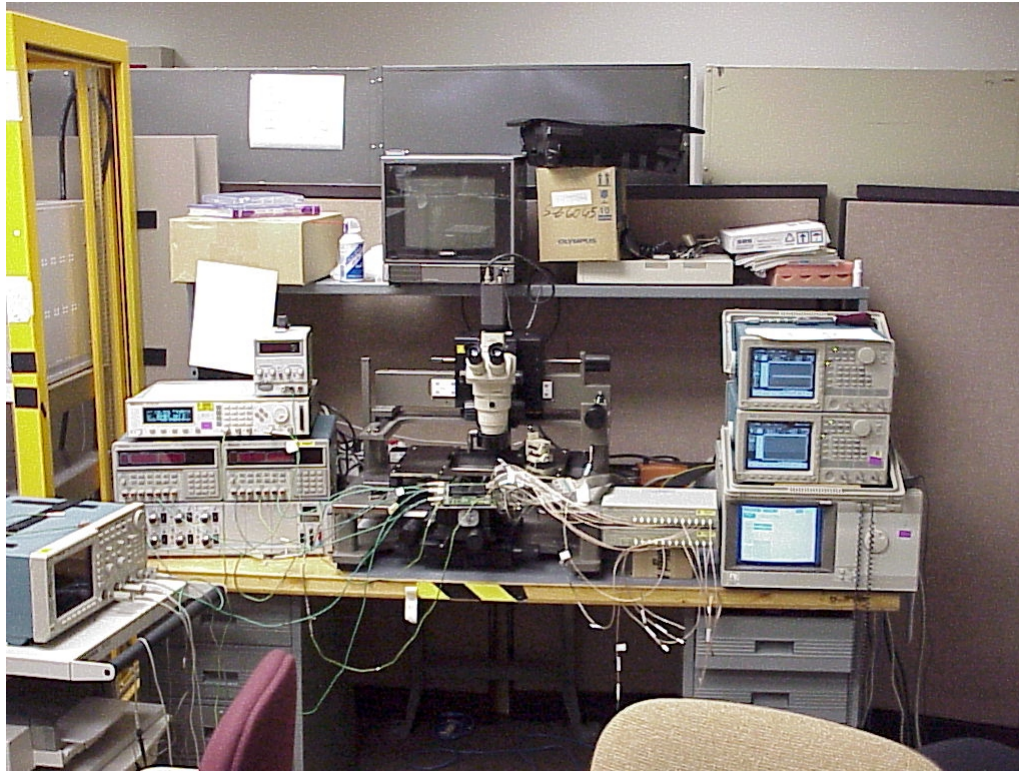
Five FPIX1's bonded to a FCPT flex circuit





# Prototype and Experimental Results

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- Test stand based on standard instrumentation.
- PC running LabView
- Control by GPIB
- Readout by Ethernet

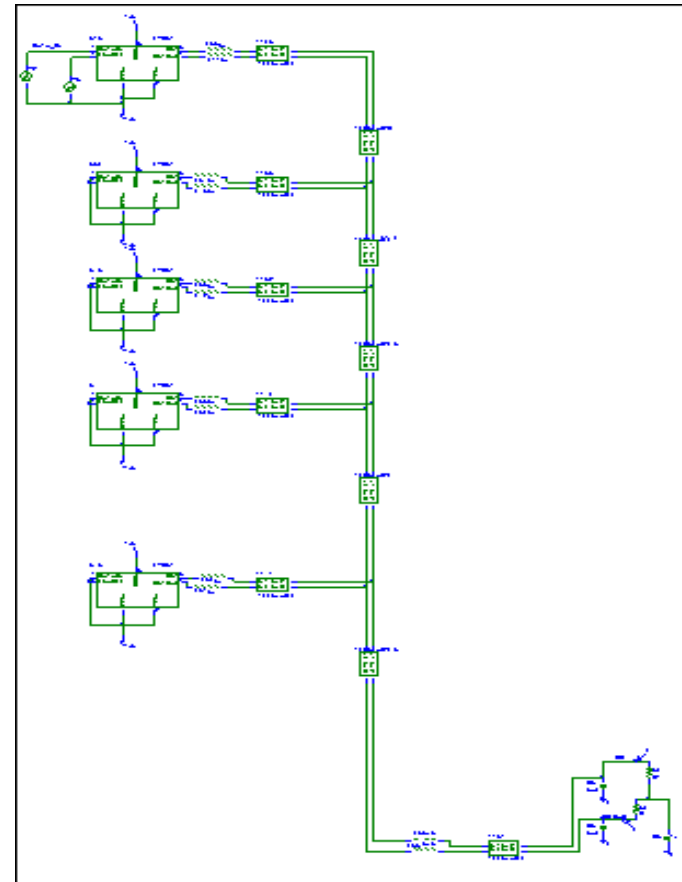
# Prototype and Experimental Results •

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Five FPIX1's bonded to a FCPT flex circuit

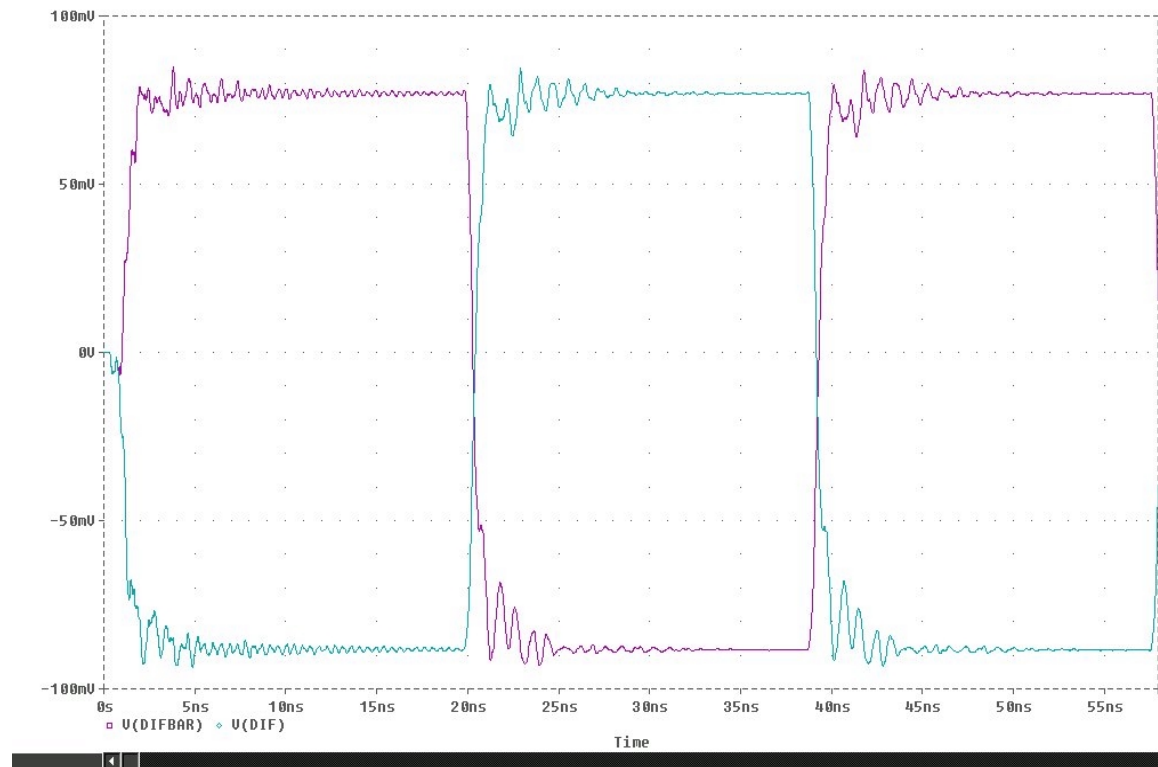
## Data Transmission

- Parameters of transmission lines
- Simulation : PSpice



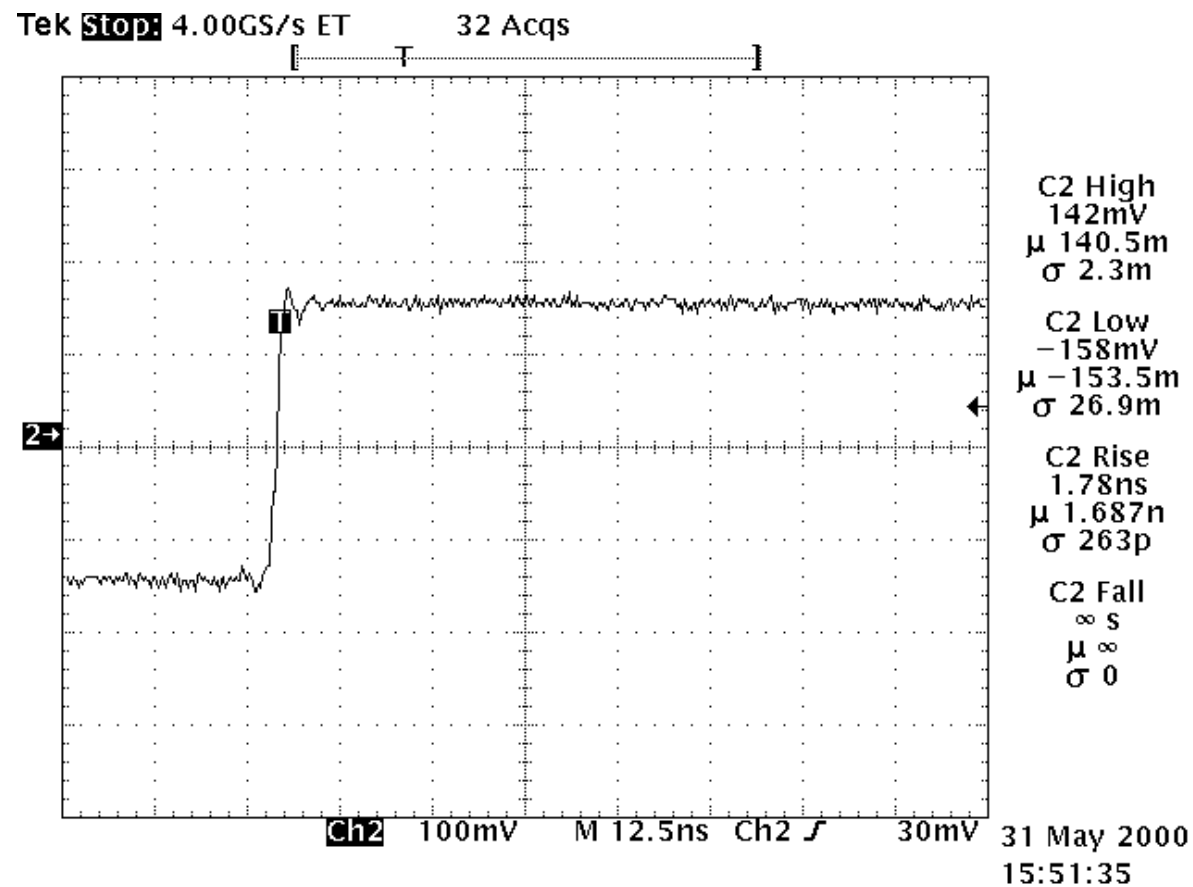
# Prototype and Experimental Results •

## Data Transmission (Simulation)





# Prototype and Experimental Results •



# Prototype and Experimental Results

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Performance of five FPIX1's bonded (no sensor) to a FCPT flex circuit

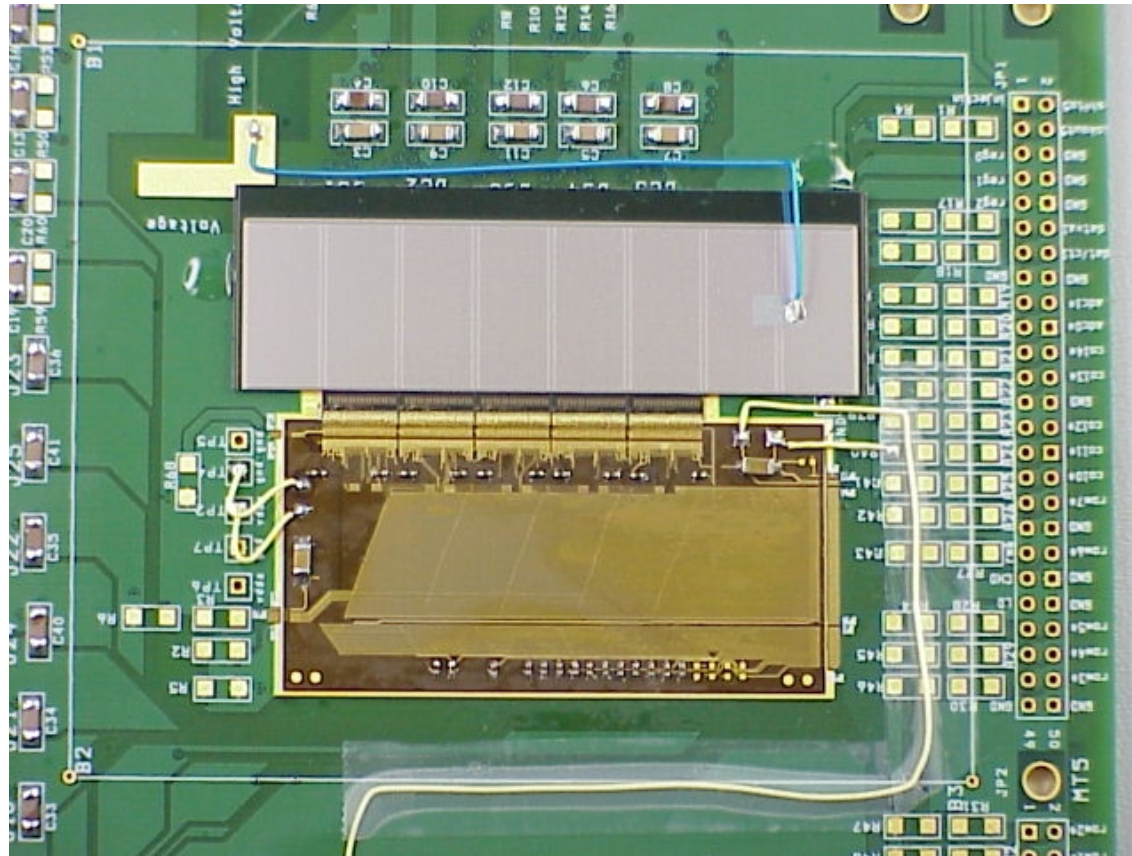
Chip	Threshold	Threshold Dispersion	Noise	Noise Dispersion
1	1672.8	257.2	38.8	8.8
2	1755.3	185.0	35.8	5.4
3	1611.8	189.4	38.5	7.1
4	1795.9	211.8	39.4	6.8
5	1596.6	217.0	42.9	8.6

All results given in  $e^-$

# First Prototype and Experimental Results •

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Hybridized sensor assembled on the prototype board



# Hybridization Studies

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- Prototype detectors
  - » Readout chip mated to sensor
  - » Experiences with both single dies and 4" and 6" wafers using Indium
  - » 2 5-chip modules mated at AIT
- Dummies
  - » Large scale studies using daisy-chained patterns
  - » Process characterization, yield determination, working with industry to find out the problems and establish quality control procedure
  - » Indium, Eutectic Pb/Sn solder treated with flux or PADS(Plasma assisted fluxless soldering)

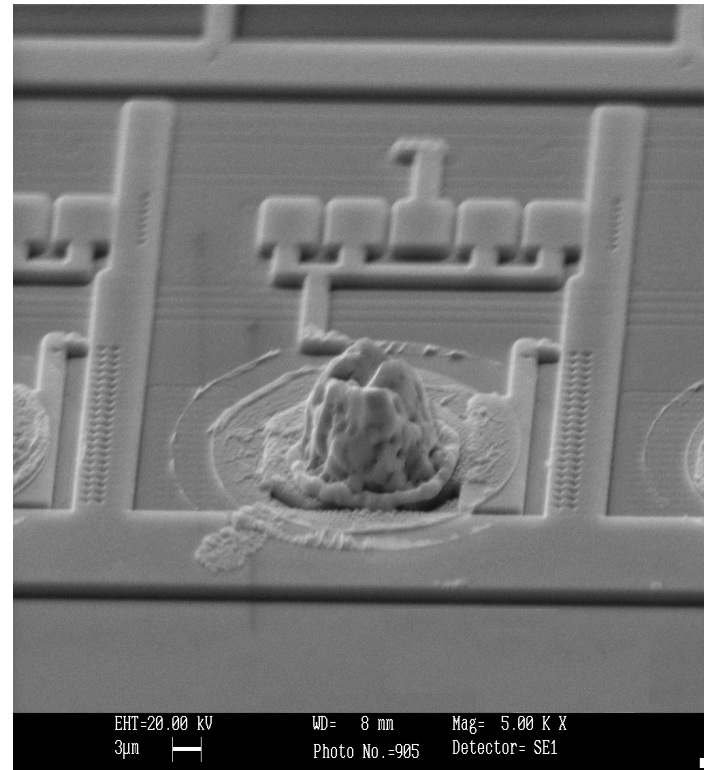
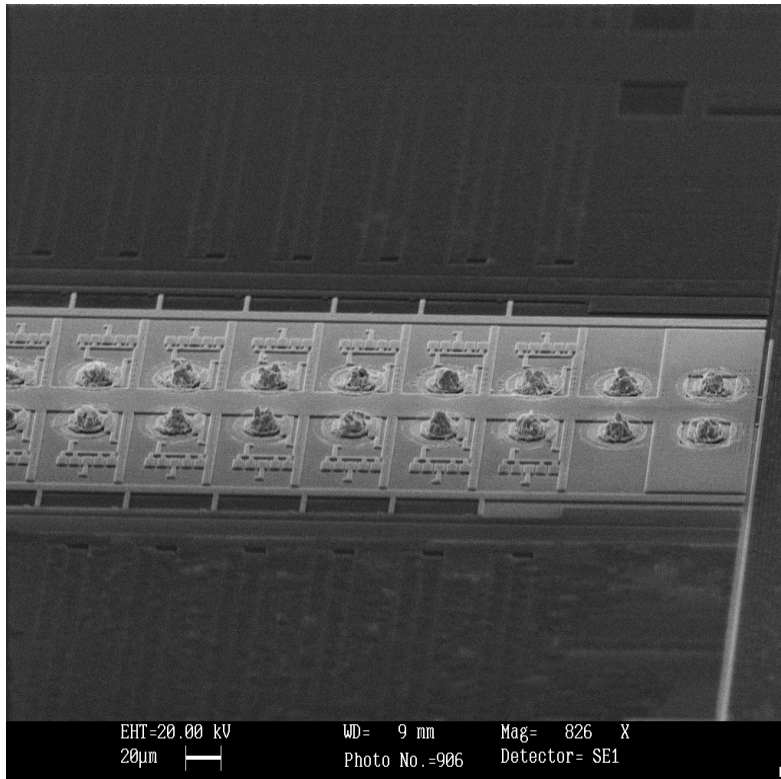
## Vendor search

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- A lot of enquiries/contacts but most companies are not interested or consider the job too challenging
- Prototyping – BOEING, AIT (both used indium and could do wafer or single dies)
- Dummies
  - » AIT (indium at 30  $\mu\text{m}$  pitch)
  - » AIT also tested wafer bumping with 200  $\mu\text{m}$  thick wafers
  - » MCNC/Unitive (solder both flux and fluxless); only 6” wafers (needs modification for 4”).

# Indium Bumps •

Indium bumps on readout chip done at AIT

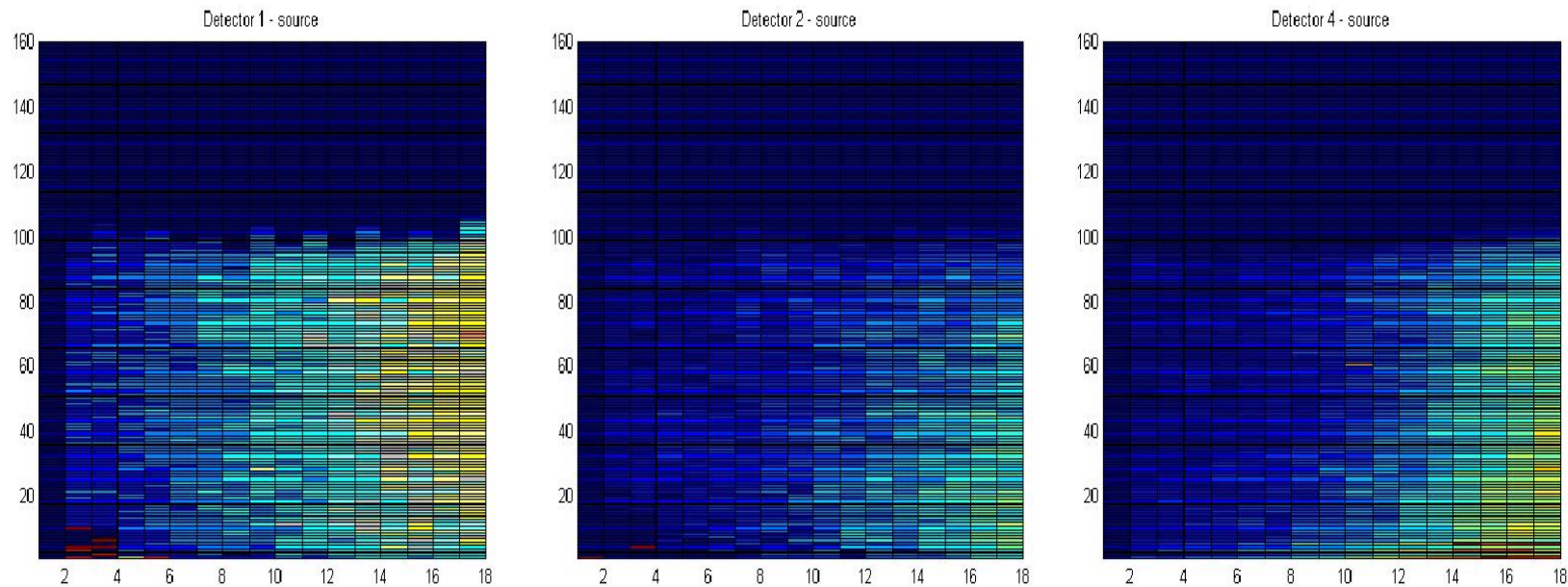




# Indium Bumps

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Results on Indium-bumped (AIT) prototype detectors:  
Hit-map for three FPIX1-implemented detectors using  
radioactive source



# Solder Bumps

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- Tests on dummies from MCNC/Unitive
  - » Structures with 50  $\mu\text{m}$  pitch (BTeV) and 150  $\mu\text{m}$  pitch(CMS) on same wafer
  - » 80 PADS single-chip assemblies and 38 fluxed single-chip assemblies (BTeV)
  - » US-CMS also tested 5 double-chip assemblies and 1 5-chip assembly (using flux-less solder)
  - » Check connectivity between matched pair of pads using a semi-automatic probe station
  - » Sometimes, need to apply a low voltage to break through
  - » Also look for shorts between neighbors



# Solder Bumps

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- Results on connectivity
  - » Much better results in the PADS assemblies than the ones using flux. The latter ones have a lot of visible residues
  - » Concentrate only on PADS assemblies
  - » 6 out of 71 assemblies (size of a  $7.2 \times 8$  mm chip) have a lot of opens due to operator error. Assembly yield is 65/71 or 91.5%
  - » 190 traces per assembly. 52 opens. Trace yield =99.58%
  - » 26 bonds per trace. Bump yield =99.98%
  - » Preliminary results from CMS module assemblies are comparable.

## Solder Bumps •

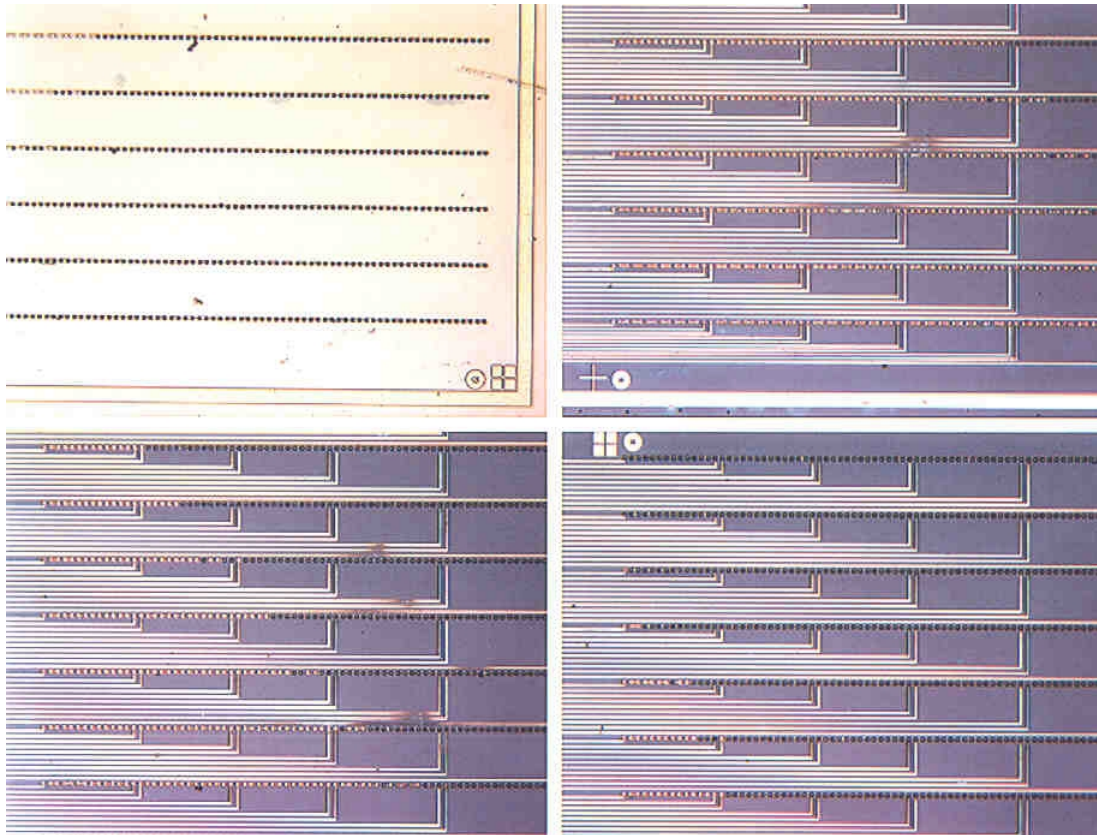
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- Problems
  - » Operator error – gross misalignment by one column
  - » Channels need voltage to break through –thought to be due to incomplete removal of oxide on Al before UBM was put on
  - » Bridges (see X ray picture)
  - » Irregular reflow
  - » Lab vs cleanroom condition
  - » Module assembly –PADS process needs modification

# Solder Bumps •

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## Defect joint



## Conclusions: MCM

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- Option for data readout needs to be studied in details.
- The prototype of the Pixel module with the sandwich of readout chip, detector, and circuit interconnect must be assembled and characterized.
- Good agreement between circuit simulation and real measurements.
- The present prototype shows good performance characteristics.

## Conclusions: Bump Bonds

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- Satisfactory results on real detectors using Indium
- Dummy tests on 30 $\mu$ m ongoing
- Fluxless solder by MCNC has good bond yield
- Whole chip losses need to be better understood and controlled
- Module assembly – non-industrial standard (closely abutted to one another); MCNC needs to learn how to do this
- Next round – real detectors will be bumped and bonded at MCNC