US CMS Forward Pixel Detector

Status Report on the CMS Forward Pixel Disk

M. Kubantsev (Northwestern University)
for
CMS Forward Pixel Collaboration

US CMS Forward Pixel Detector

CMS Forward Pixel Collaboration:

Colorado U.
Cornell U.
UC Davis
Fermilab
U. of Iowa
Johns Hopkins U.
Kansas S. U.
INFN Milano
U. of Mississippi
U. of Nebraska
Northwestern U.
Purdue U.
Purdue U. Calumet
Rutgers U.
Vanderbuilt U.
U. Virginia

US CMS Forward Pixel Detector

Content:

- Detector overview
- Mechanical elements of the detector:
  ½ disks, blades, panels, plaquettes
- Assembly procedures
- Test stands
- Test beam results (preliminary)
- Outlook

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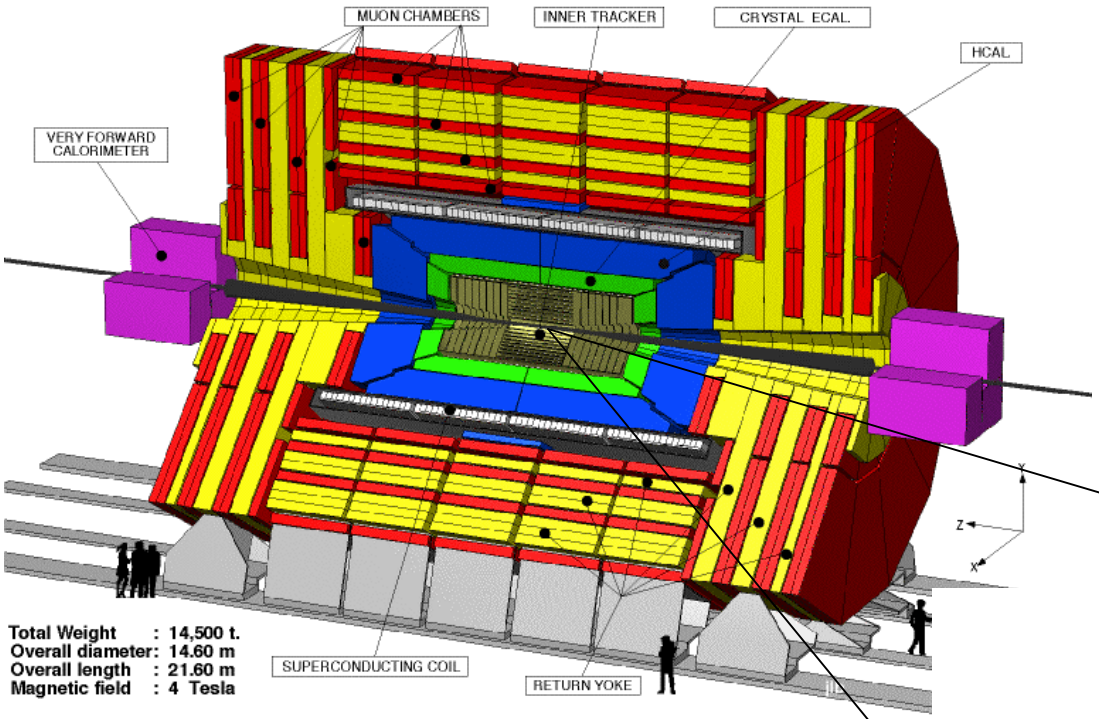
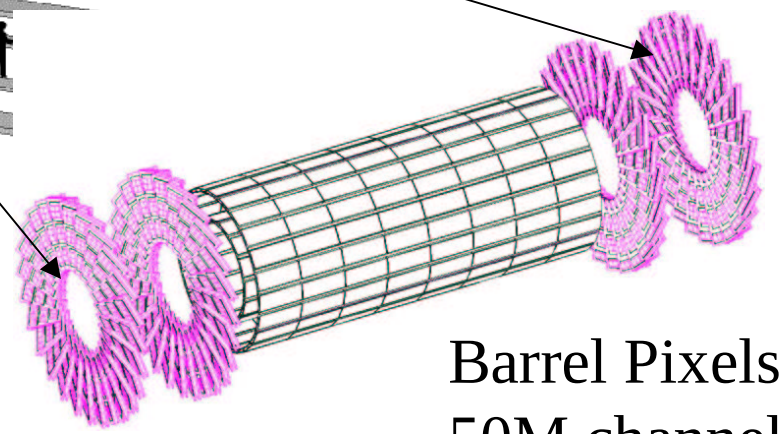


Forward Pixels
18M channels
(turbine geometry)



Barrel Pixels
50M channels

Pixel_detector inside CMS:
Barrel: Europe
Forward disks: USA

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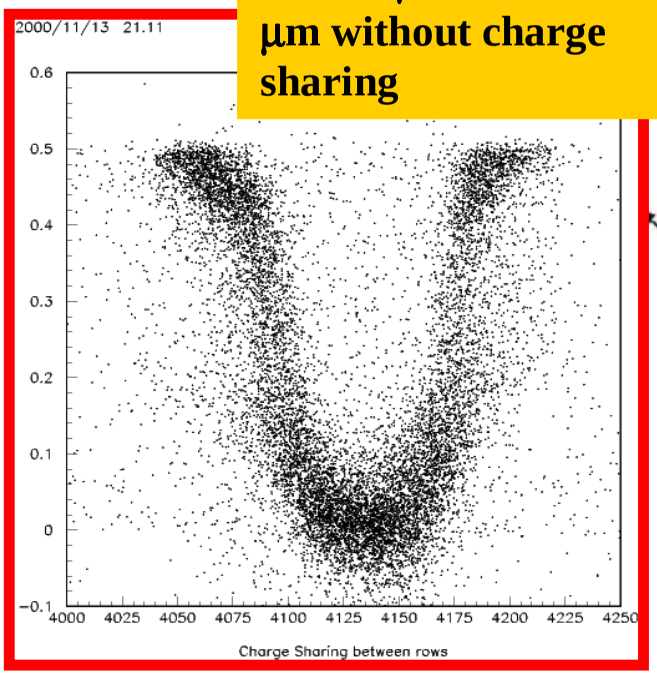
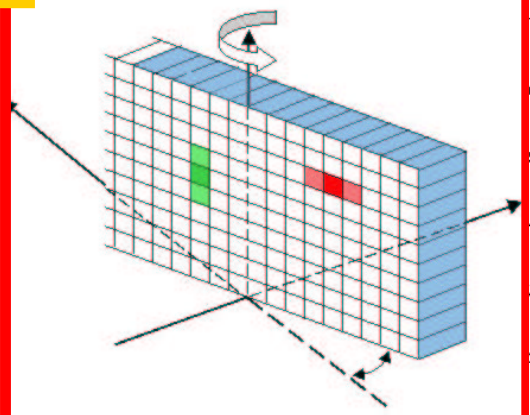
20 degrees rotation turbine blade geometry provides more charge sharing between neighbor pixels and improves precision: measurements with prototypes at CERN demonstrated this:

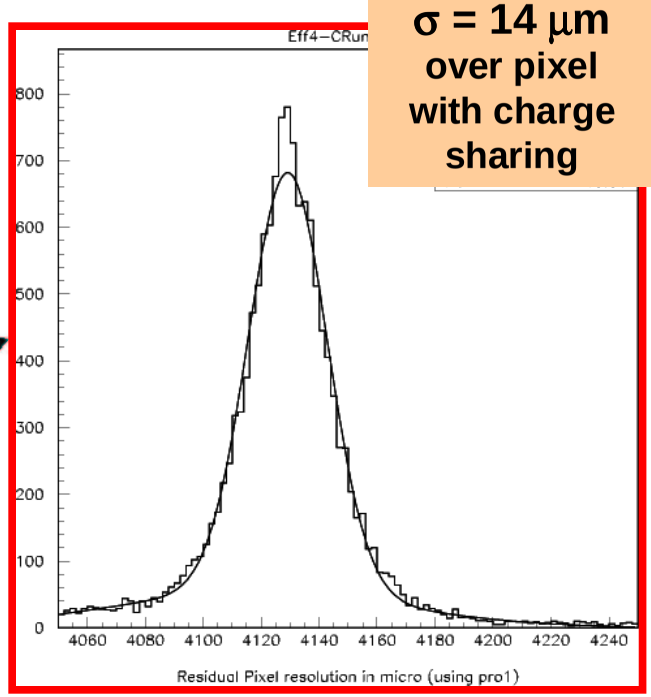
σ= 150 μm / √12 = 43 μm without charge sharing

Pixels rotated by 20 degrees to beam

σ = 14 μm over pixel with charge sharing







Forward Pixel Major Systems

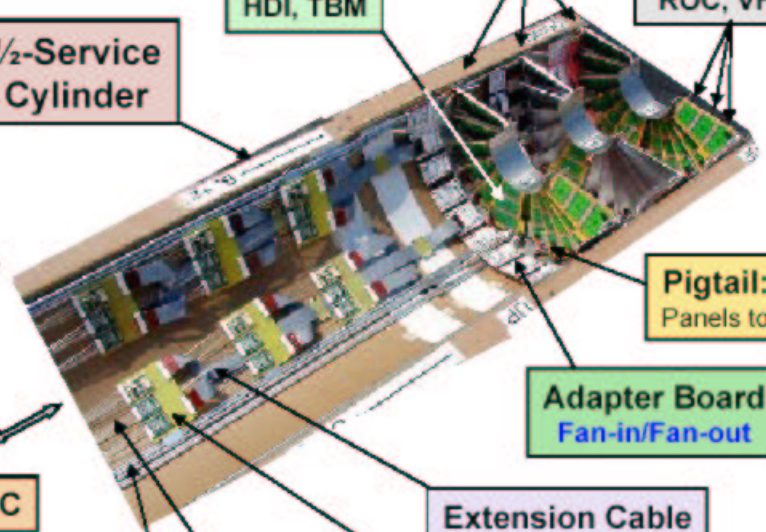
FPix (baseline):

US delivers:

4 'disks'

TBM (for CMS Pixels)

Model



- Mechanical support and cooling
- Pixel Sensors
- Assembled pixel detectors
- The required electronics (adapter board, port card) except the: ROC, FEC, FED and OL

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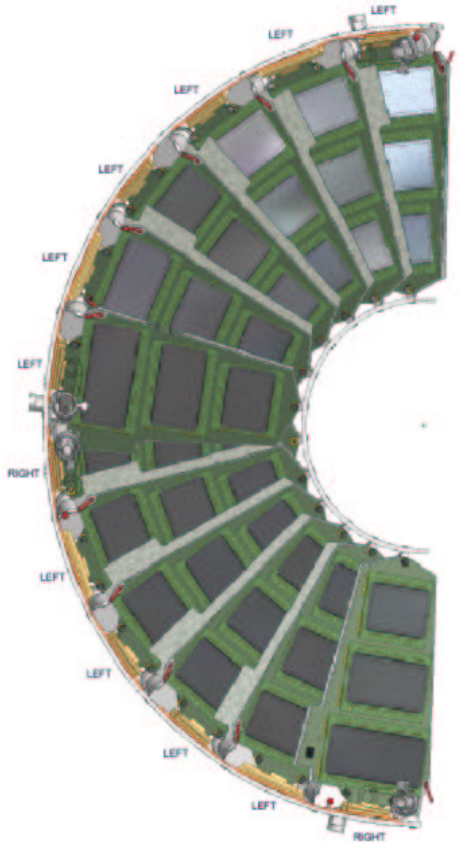
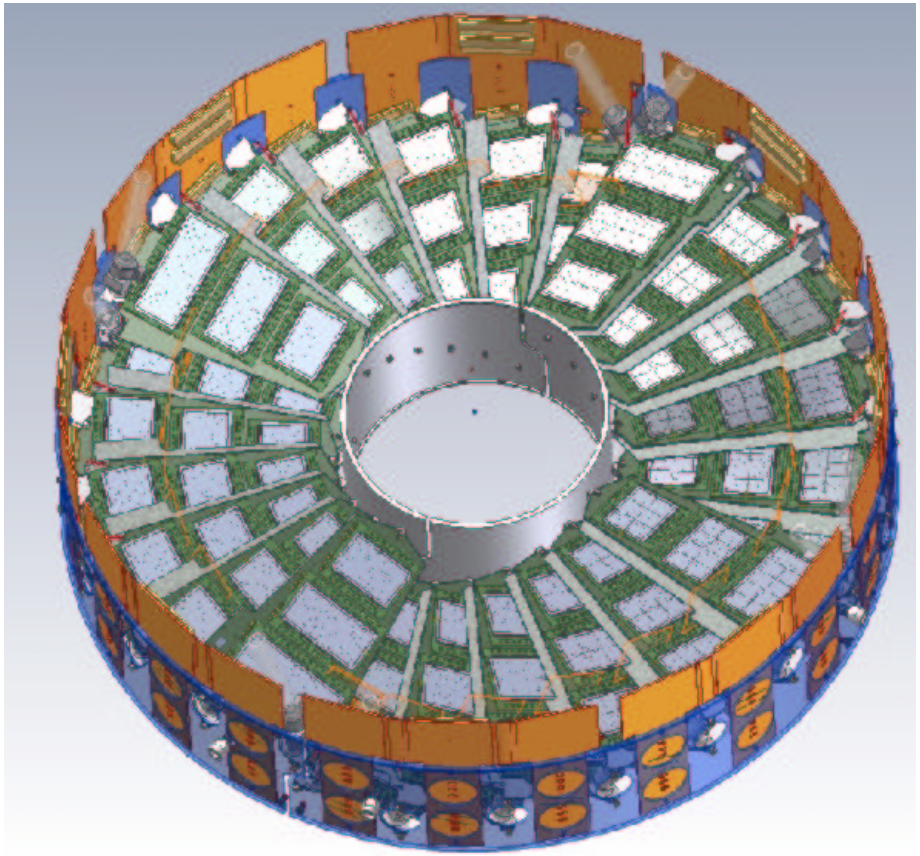
Cooling channel → **1/2 disk** → **Disk**





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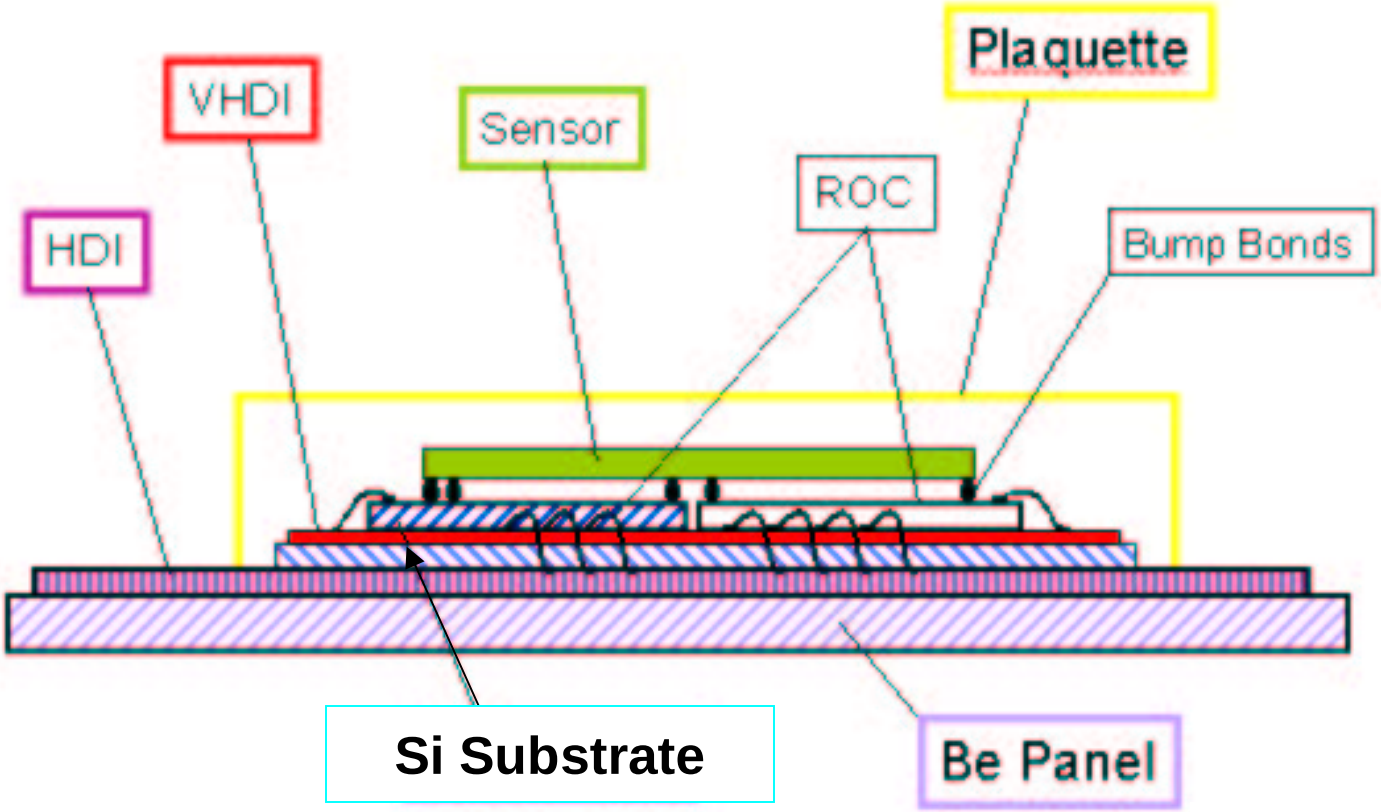
Panel major parts:



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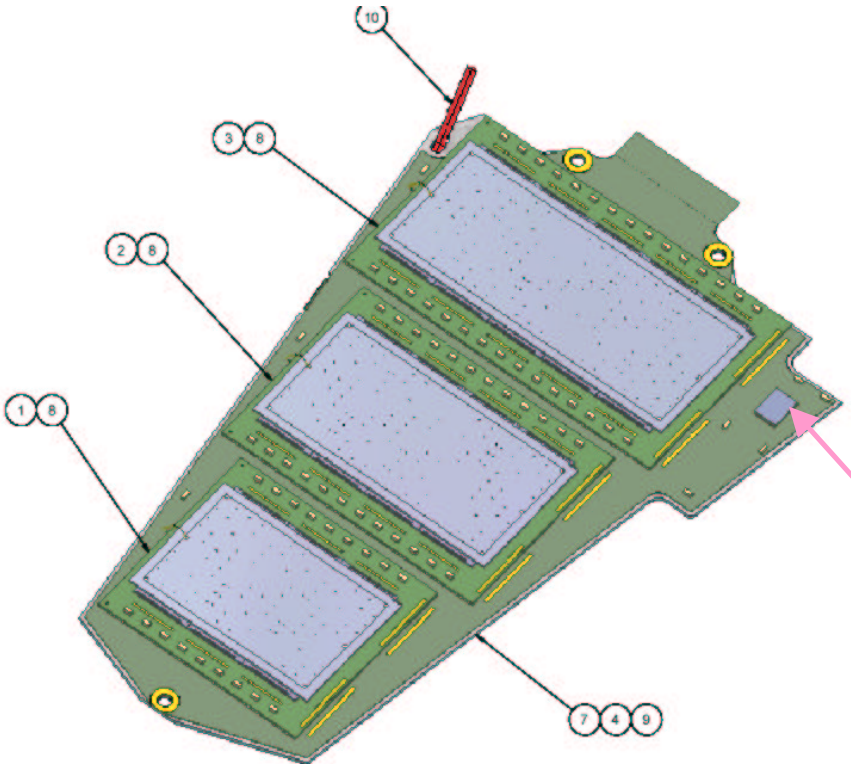
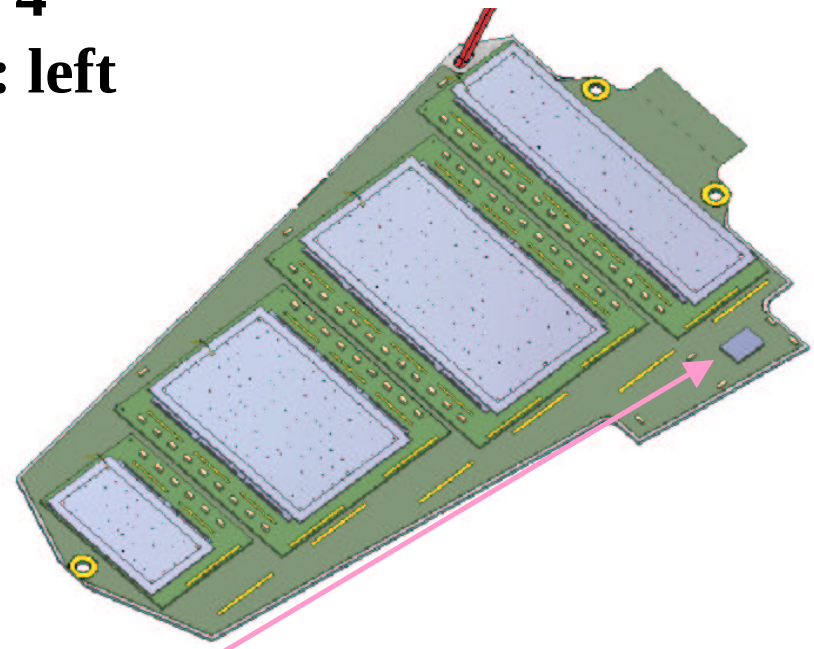
Panel with 3 plaquettes: left and right

Panel with 4 plaquettes: left and right





TBM

Parts List			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	CMSTKPFE.0019	PLAQUETTE -- 2x3
2	1	CMSTKPFE.0020	PLAQUETTE -- 2x4
3	1	CMSTKPFE.0021	PLAQUETTE -- 2x5
4	1	CMSTKPFE.0007	Be PANEL SUBSTRATE
7	3	CMSTKPFE.0054	3M-9882 FILM -- 0.002" THK
8	1	CMSTKPFE.0033	CHO-THERM 1680 FILM -- 0.007" THK
9	1	CMSTKPFE.0044	HDI -- 3-PLAQUETTE / RIGHT-HANDED
10	1	---	BIAS / GROUND WIRES

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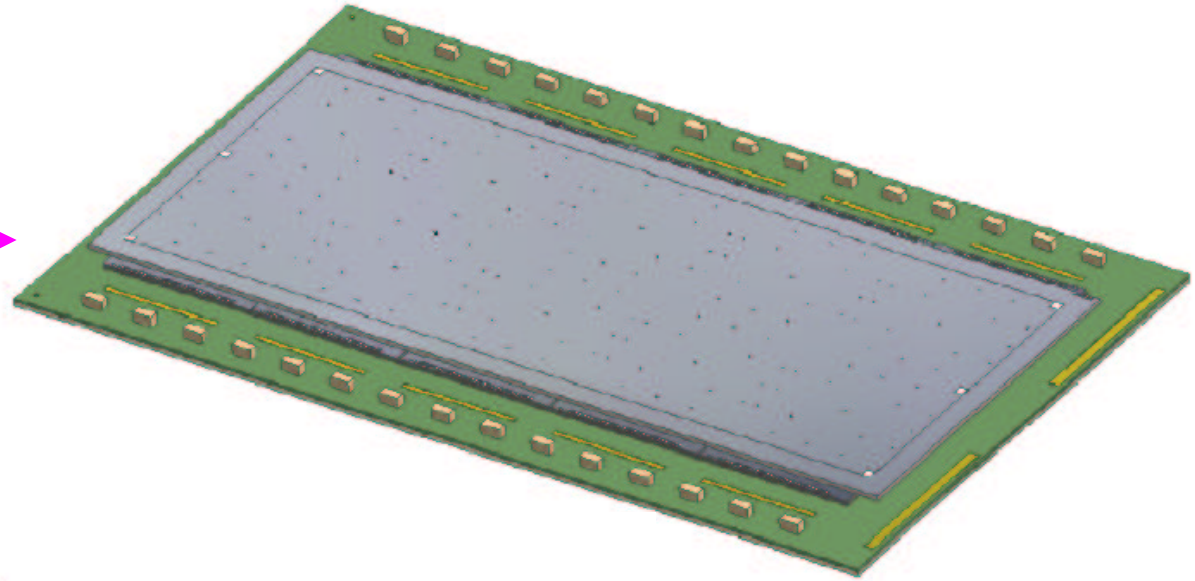
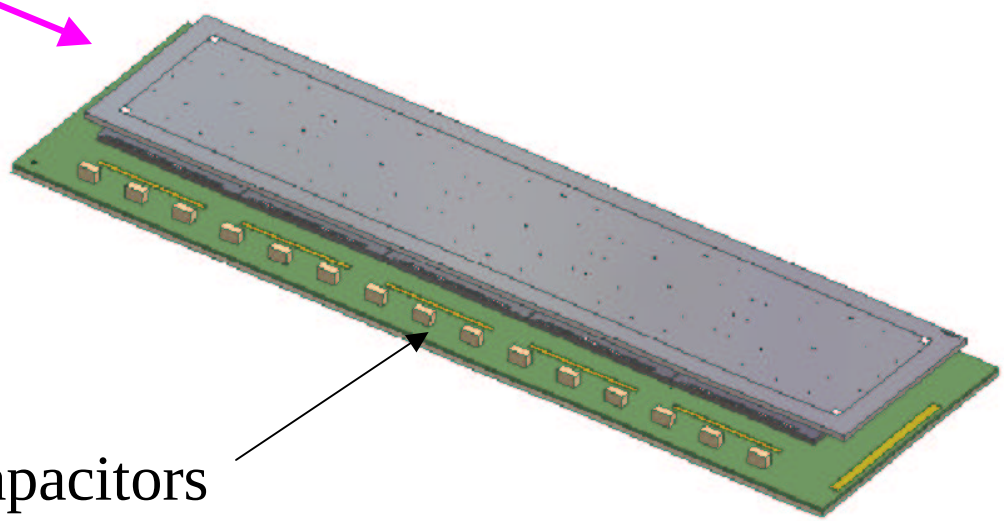
Plaquette:
7 types:
2x5 (45.7 x 27.8)
2x4
2x3
1x5R
1x5L
1x2R
1x2L





Sensor: 270μ
ROC: 200μ
Substrate: 300μ

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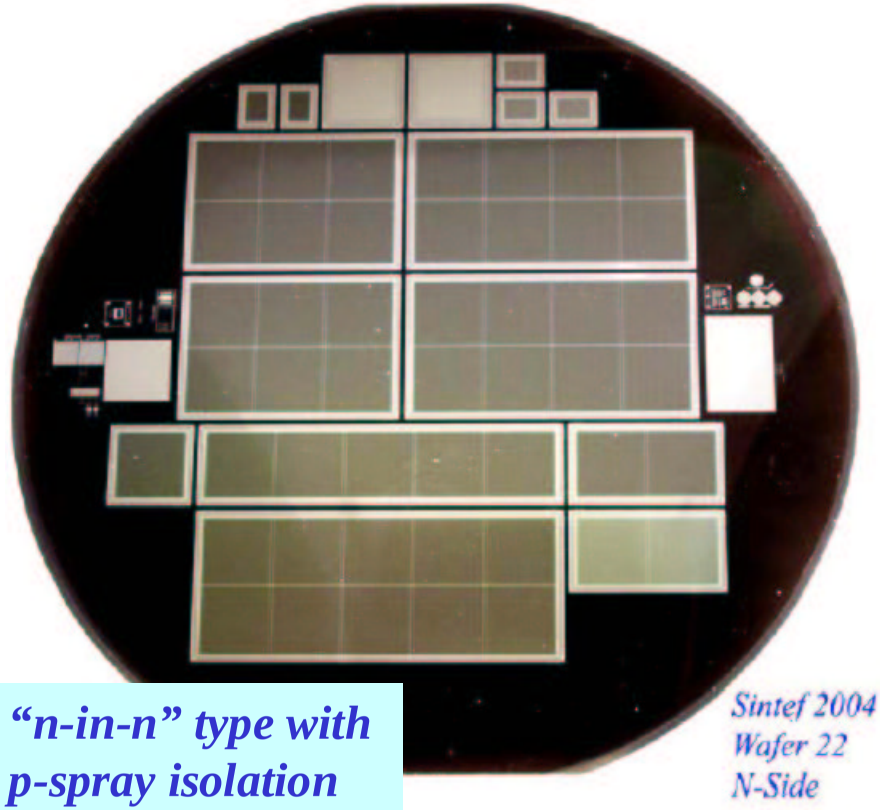
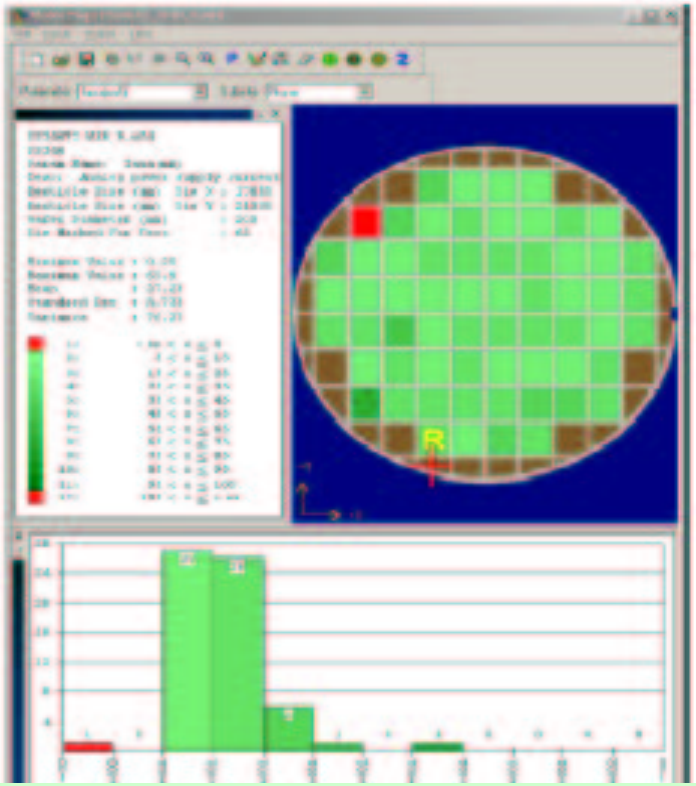
Plaquette parts:

4” sensor wafer with 5 types of sensors (plus test structures):



“n-in-n” type with p-spray isolation

PSI46v2 ROC wafer (test results sample)



PSI46v2 ROC : 52 x80 =4160 pixels of 150μx100μ

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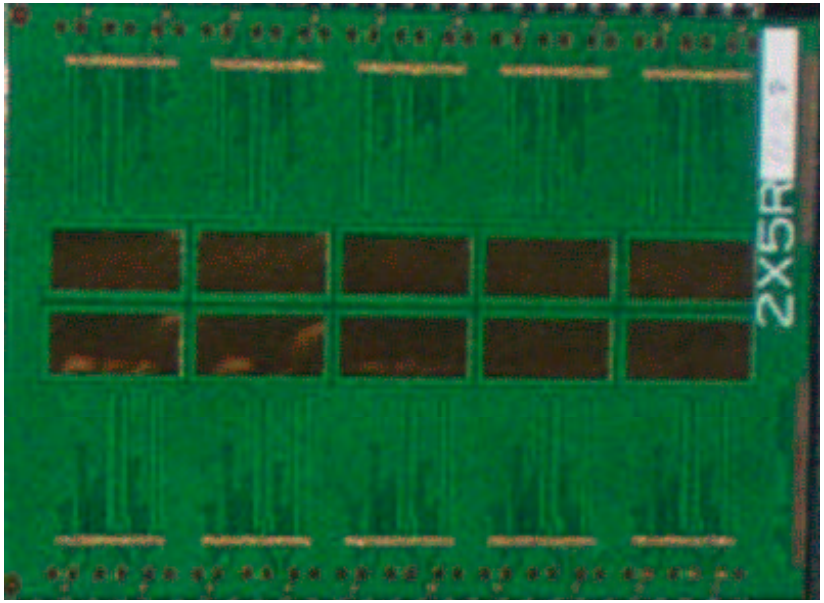
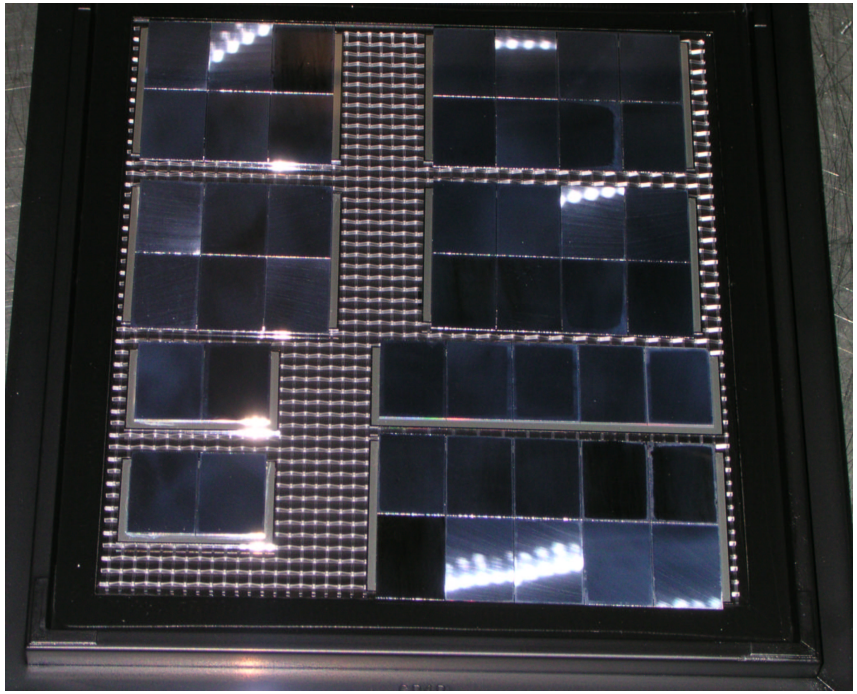
Plaquette parts:

VHDI laminated on silicon (300 micron)



5 types of bump-bonded modules (from IZM, RTI, VTT)



View with ROC's atop

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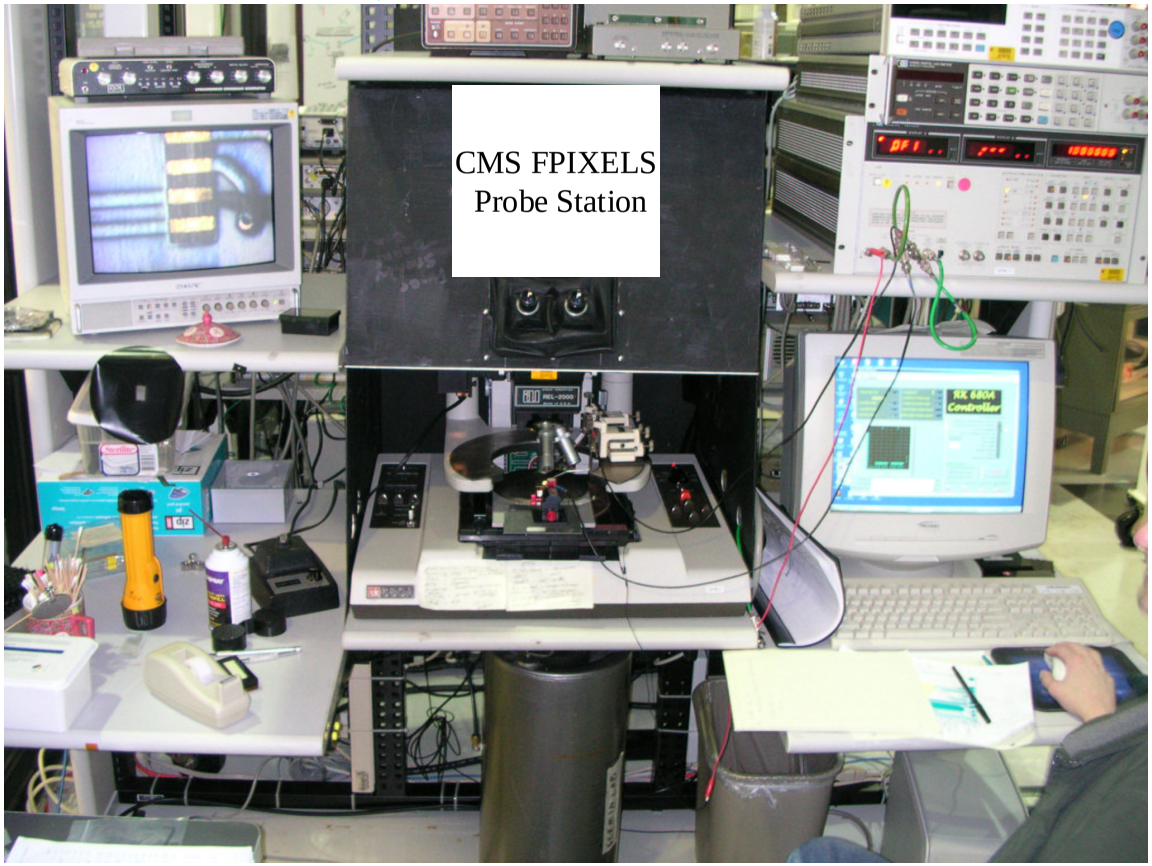
Quality assurance:

electrical testing of VHDI flex circuit with a probe station (KSU, Fermilab, NWU):



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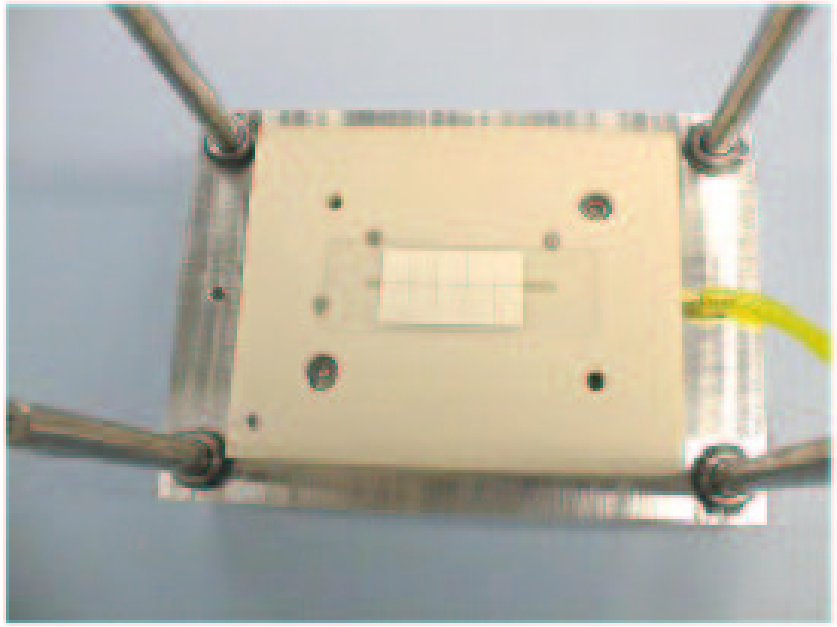
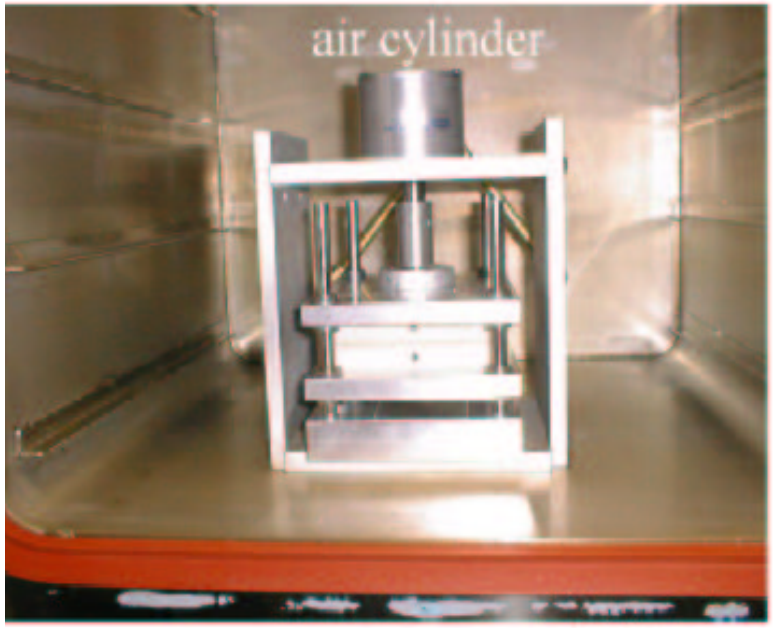
Plaquette assembly at Purdue Univ.:



Bump bonded module on the gluing fixture



Gluing plaquette in the vacuum oven

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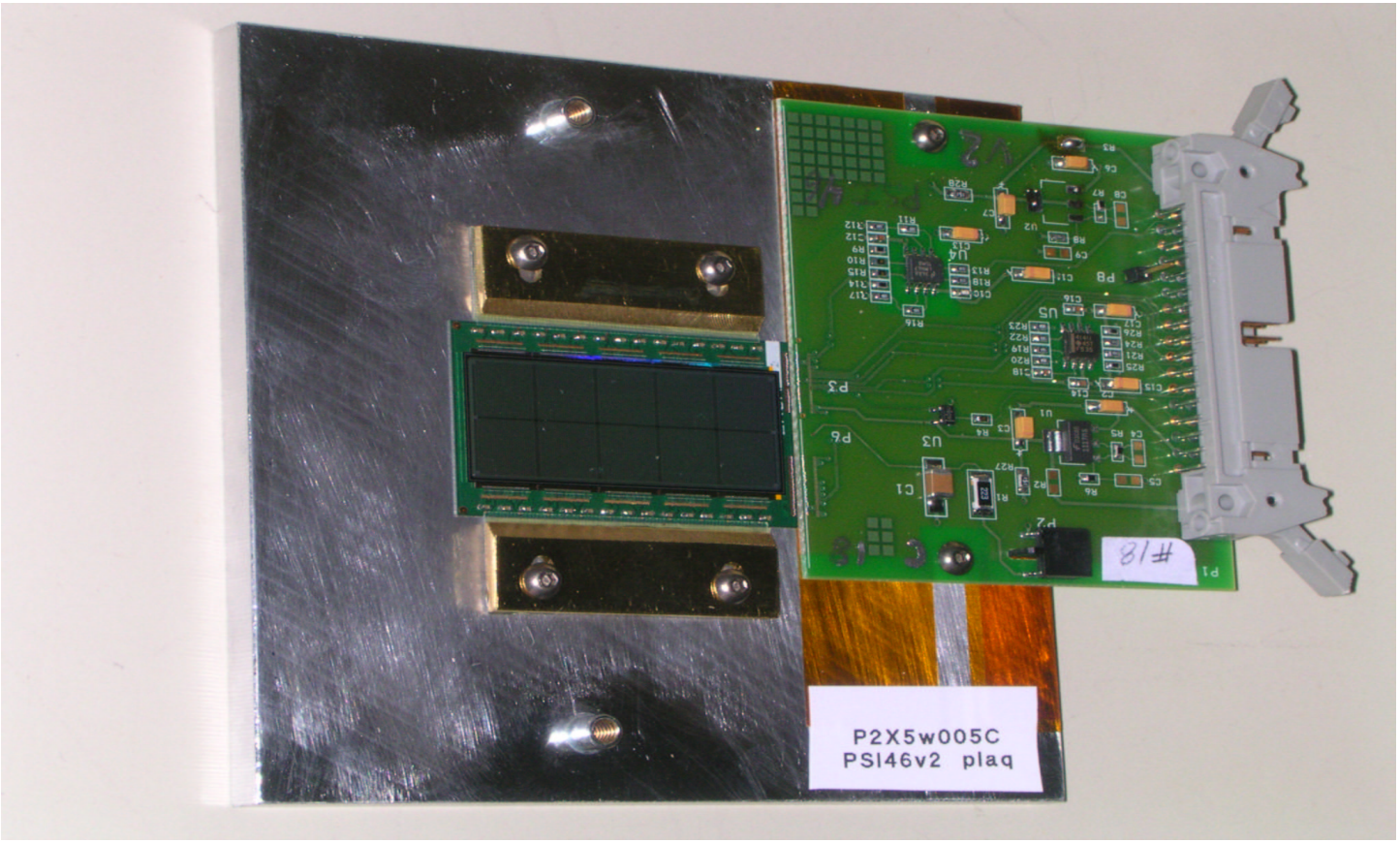
2x5 plaquette installed on the storage/test plate:



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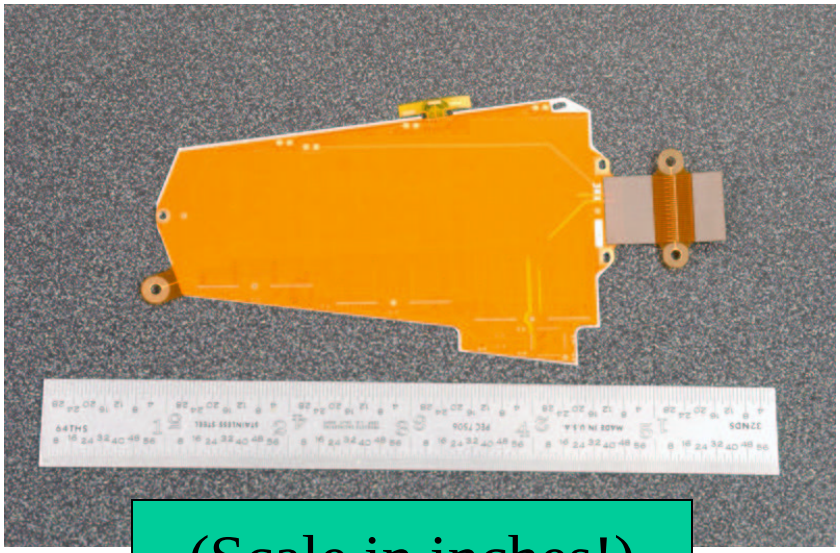
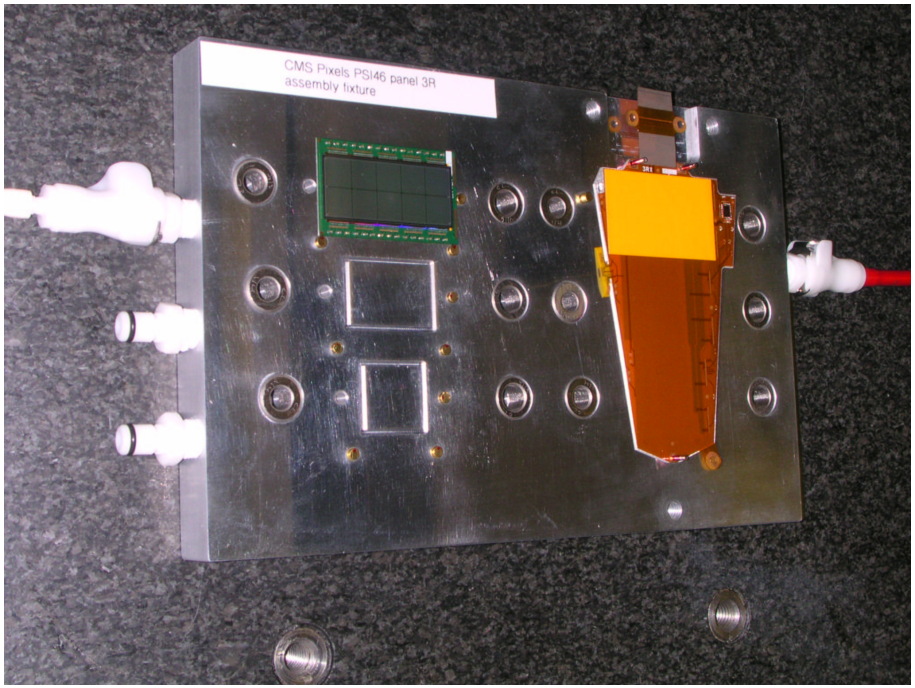
Panel assembly at Fermilab:

HDI laminated on the Be panel:



(Scale in inches!)

Plaquette installation on the panel:



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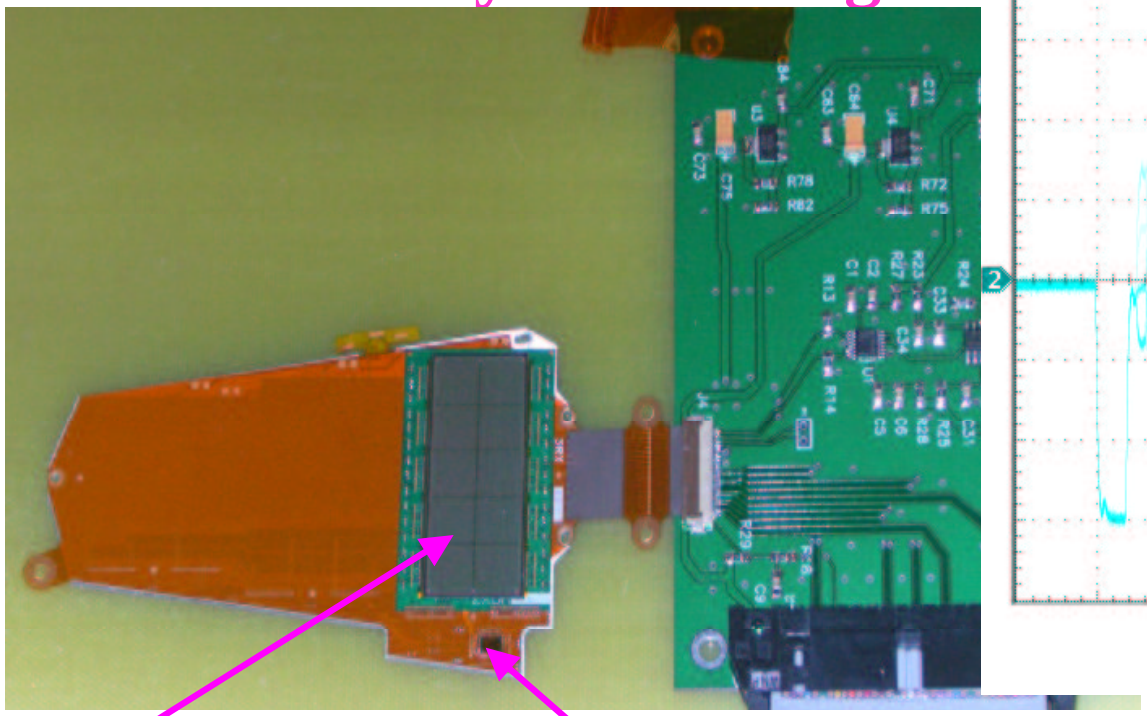
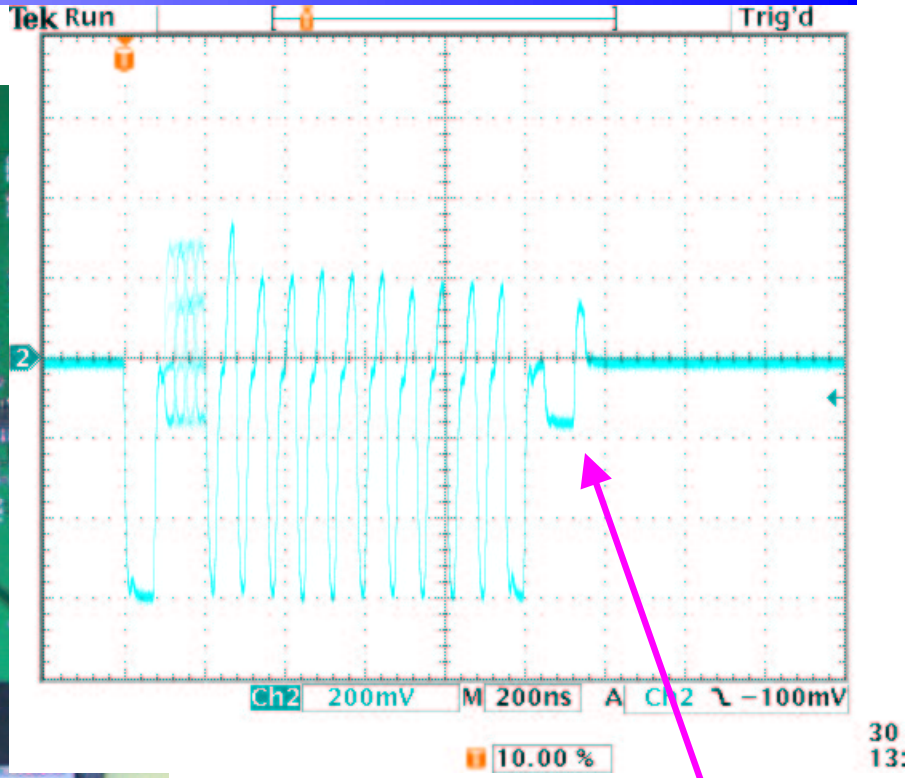
Panel assembly and testing:





2x5 plaquette and TBM installed on the panel and connected with test board

Oscilloscope trace of analog output from the TBM installed on the panel transmitting signals from 2x5 plaquette (10 ROCs) at 40 MHz frequency. Last ROC has an active pixel readout.

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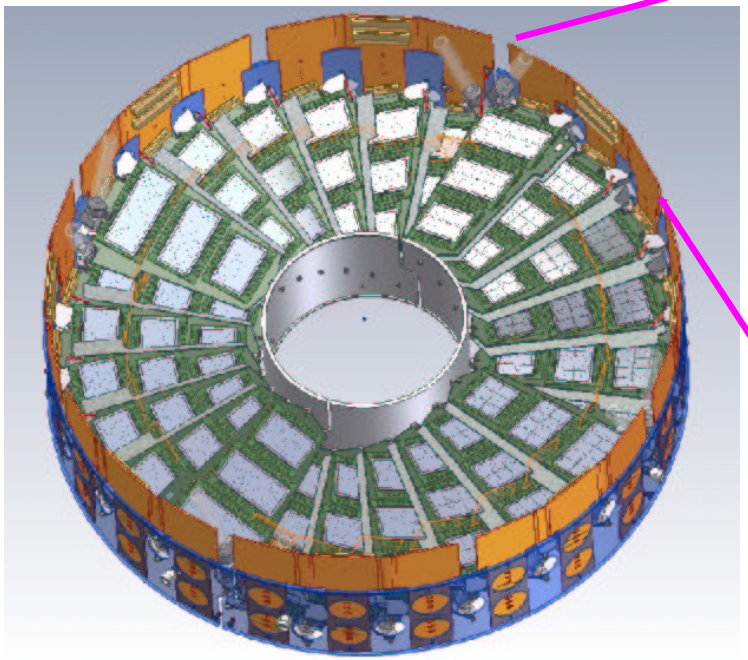
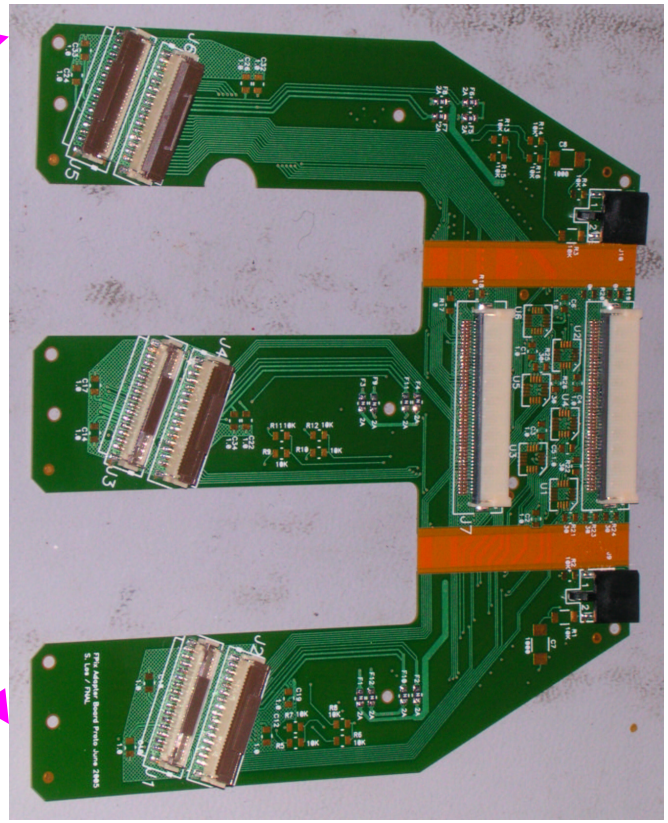
Adapter board developed:





6 panels(3 blades) are connected with the adapter board. 8 of them installed on the disc outer shell. They provide power, control signals in and data out of the panels.

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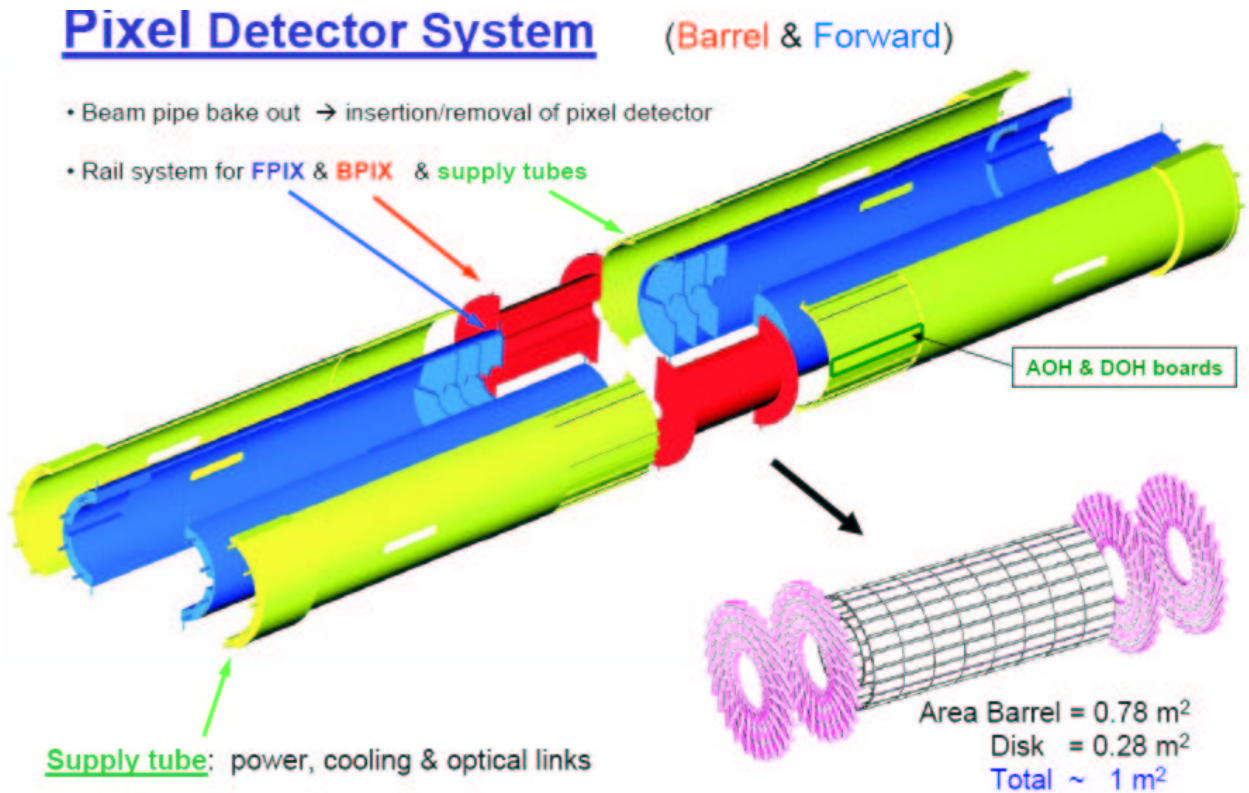
Mechanics of US-CMS Pixel includes:

½-Disk (supporting the detectors), Panels with Plaquettes
½-Service Cylinders, supporting the Disks and services (power, cooling, optical lines)



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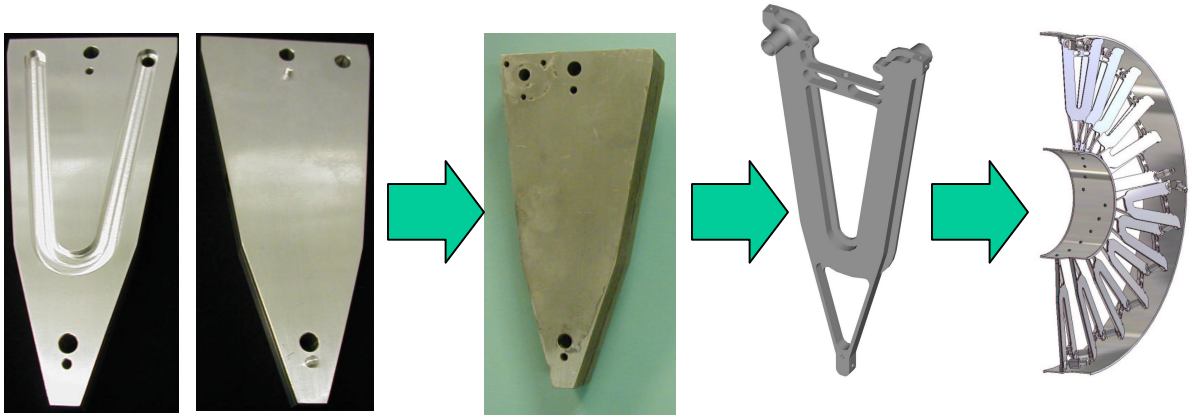
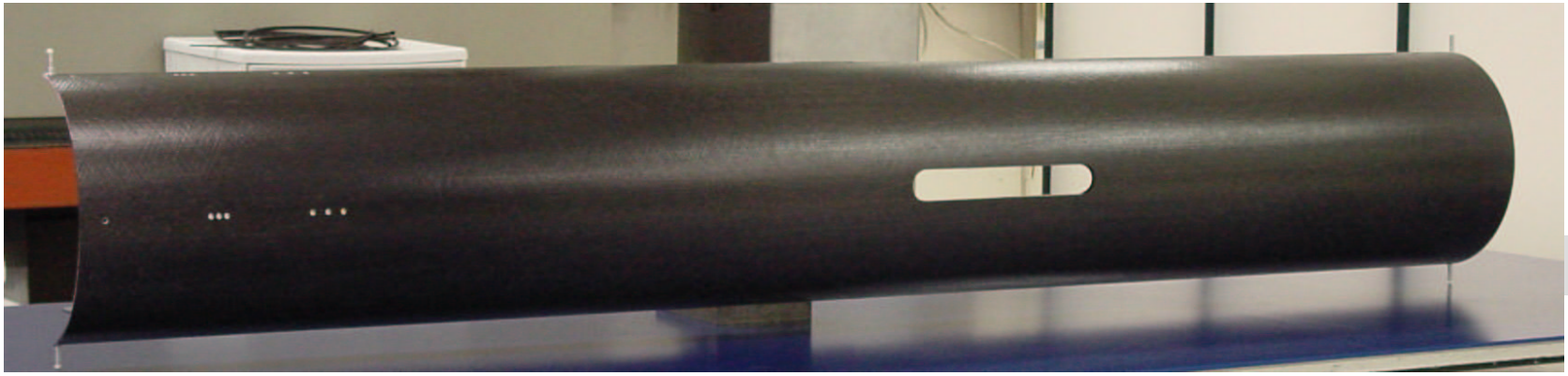
Mechanics of US-CMS Pixel, cont.

"Cooling channel" assembly made of brazed Al parts

18 cooling channels tested and passed



Service Cylinder: prototype meets specifications



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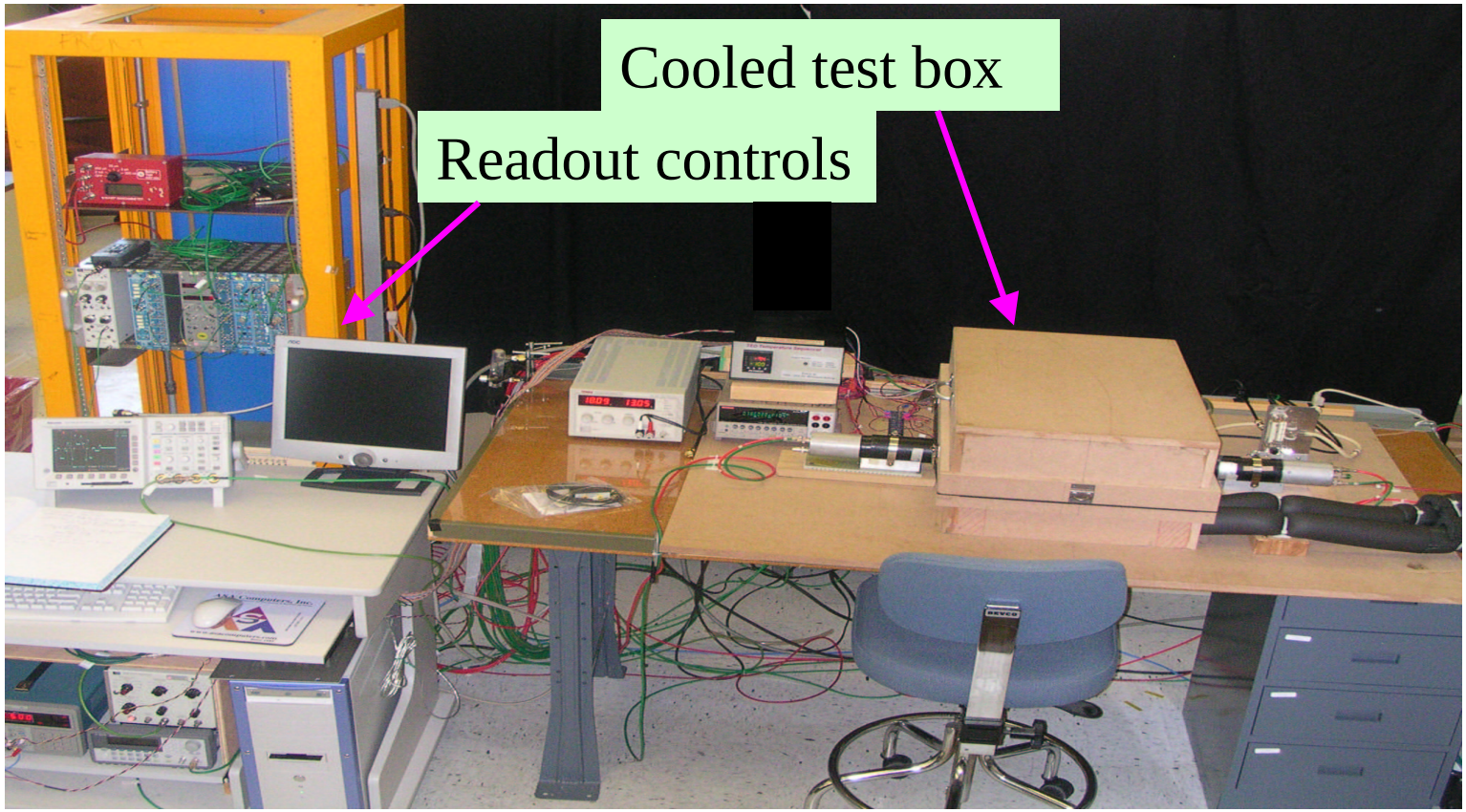
Status of testing at Fermilab:

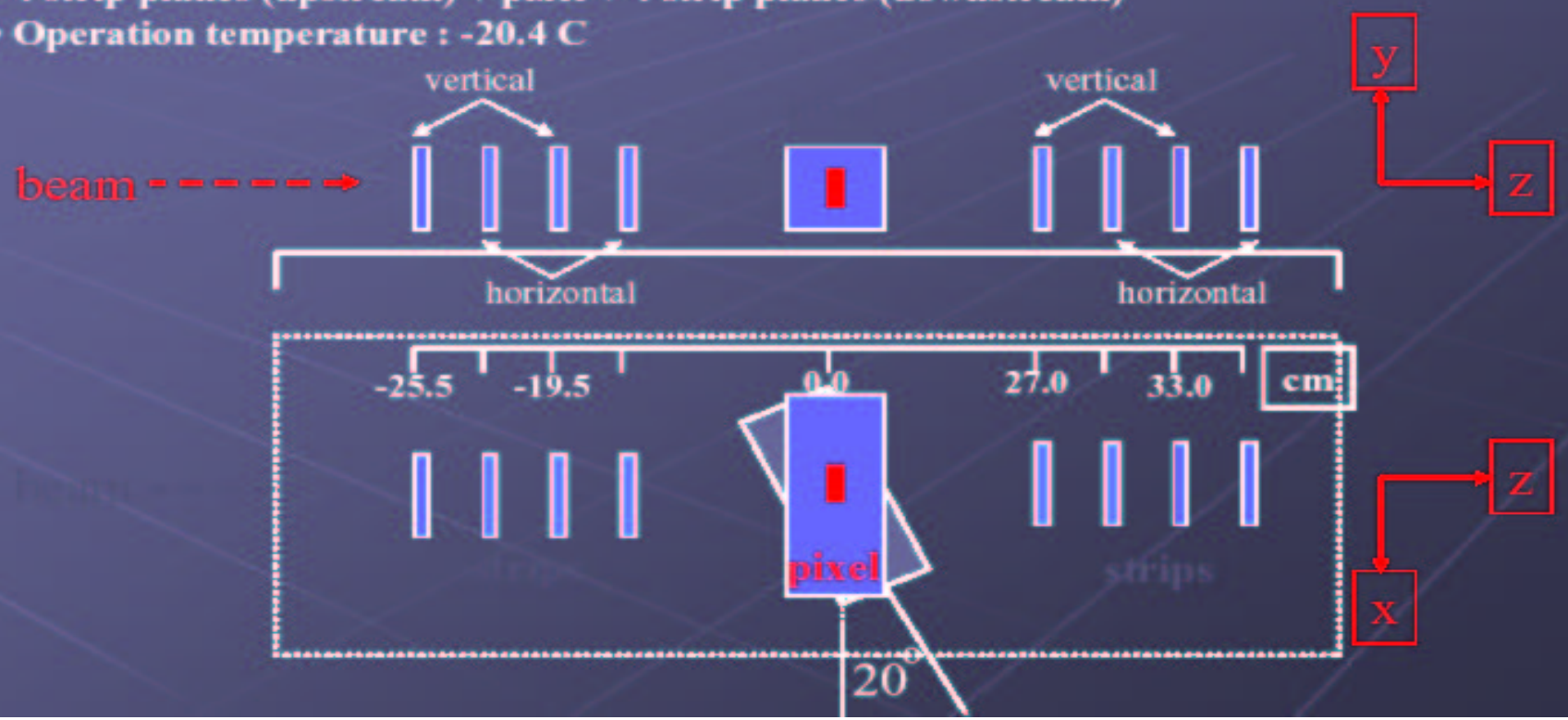
the test stand to test bump-bonded modules with source and calibrate them at room and low temperature (-25C)



US CMS Forward Pixel Detector

FNAL Test beam

- beam : 120GeV Proton,
  6-12 spills/min, few 1000 trgs/spill, 300events/spill,
- 4 strip planes (upstream) + pixel + 4 strip planes (downstream)
- Operation temperature : -20.4 C



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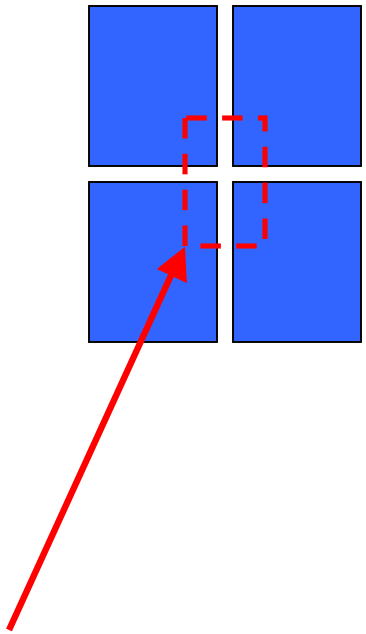
Rotation: 0° vs 20°

Bias Voltage	# of Events	Efficiency
-200	250k 250k	96.7 % 97.4 %
-250	250k 250k	99.1 % 99.2 %
-300	250k 250k	99.3 % 99.3 %
-350	1M 250k	99.3 % 99.4 %
-400	250k 250k	99.5 % 99.4 %



Measured efficiency is lower in the corners of the pixels which is consistent with laser test results

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Bump Bonding, in progress

	Wafers Received		Bump Bond.	#ROC	Tested #Plaquettes	Completed
PSI43:	3½ 6”	April ’02	IZM	38	16	complet.
DMill			RTI	34	12	complet.
PSI46V1:	2 8”	Sept. ’03	IZM	50	16	Nov/04
¼-µm			VTT	21	42	Mar/04
			VTT	180	28	Jul/05
PSI46V2:	2 8”	Sept. ’04	IZM	45	9	Jul/05
¼-µm			RTI	94	16	Jul/05
Total by Fall ’05				462	139	
Required for 4 Disks				4,320	672	

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CMS Pixel Disks Production Goals:

- **Start final assembly by spring ’06**
- **Ship instrumented ½-Service Cylinders to CERN early ’07**
- **Ship the detector to CERN in summer 2007**
- **Final check out at CERN Summer-Fall ’07**
- **Installation in the CMS detector in late 2007/early 2008**

US CMS Forward Pixel Detector

Outlook:

1. The detailed design of the Forward Pixel detector front end is completed
2. Assembly procedures are established and tested
3. The assembly fixtures are tested and final version is ready to be manufactured
4. Several dozens of plaquettes assembled with ROCs and bump-bonded modules and successfully tested
5. Panel with TBM and 2x5 plaquette assembled and tested
6. Various tests of pixel detector systems are under way

US CMS Forward Pixel Detector

Spare Slides

US CMS Forward Pixel Detector

Silicon sensors development for the CMS pixel system

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525 Northwestern Avenue, West Lafayette, IN 47907, USA

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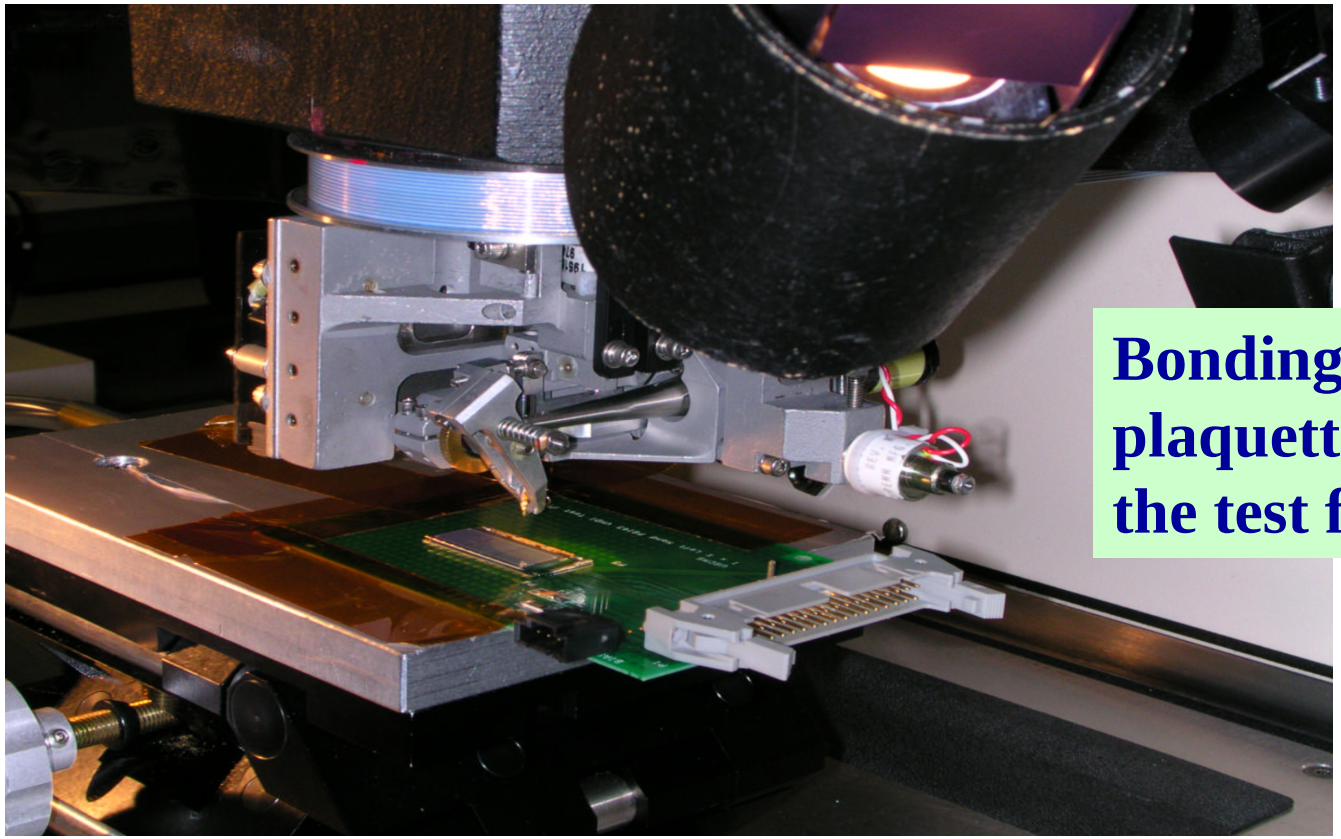
Abstract

The CMS experiment will operate at the Large Hadron Collider (LHC). A hybrid pixel detector located close to the interaction region of the colliding beams will provide high resolution tracking and vertex identification which will be crucial for b quark identification. Because of the radiation environment of the LHC, the performance of the sensors must be carefully evaluated up to a fluence of 6×10^{14} n_{eq} cm^{-2}. We expect that the sensors will be operated partially depleted during their operation at the LHC and we have implemented an n^+ on n sensor design. We have irradiated prototype sensors to a dose of 1×10^{15} n_{eq} cm^{-2}. We present the results of our testing before and after irradiation.

Nuclear Instruments and Methods in Physics Research Section A: Volume 511, Issues 1-2 , 21 September 2003, Pages 106-111

US CMS Forward Pixel Detector

Panel wire bonding between Plaquette – HDI and TBM- HDI (K&S1478 bonding machine is used):



Bonding plaquette to the test fixture

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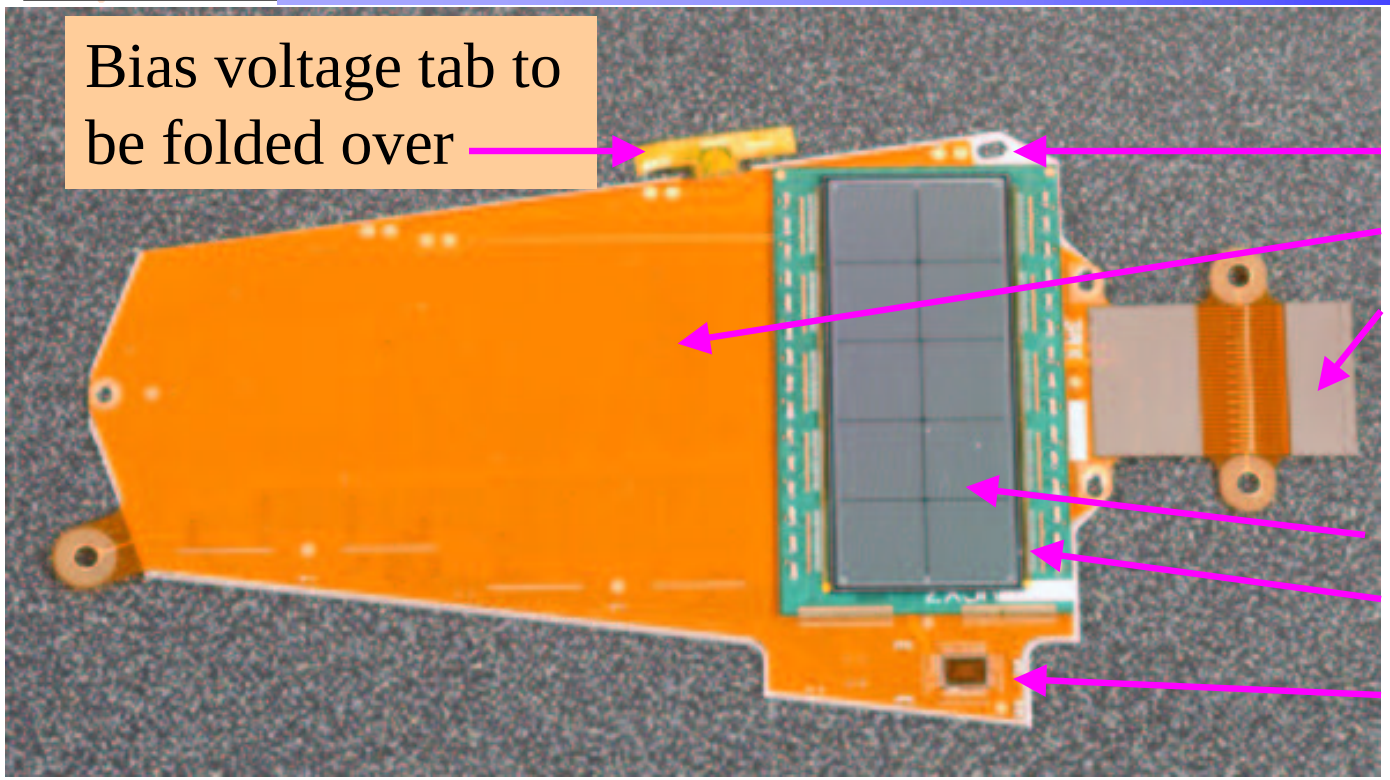

Panel parts:
Be substrate
HDI flex
Tail connector to an adapter board
Plaquette:
2x5 sensor
10 ROC's
TBM

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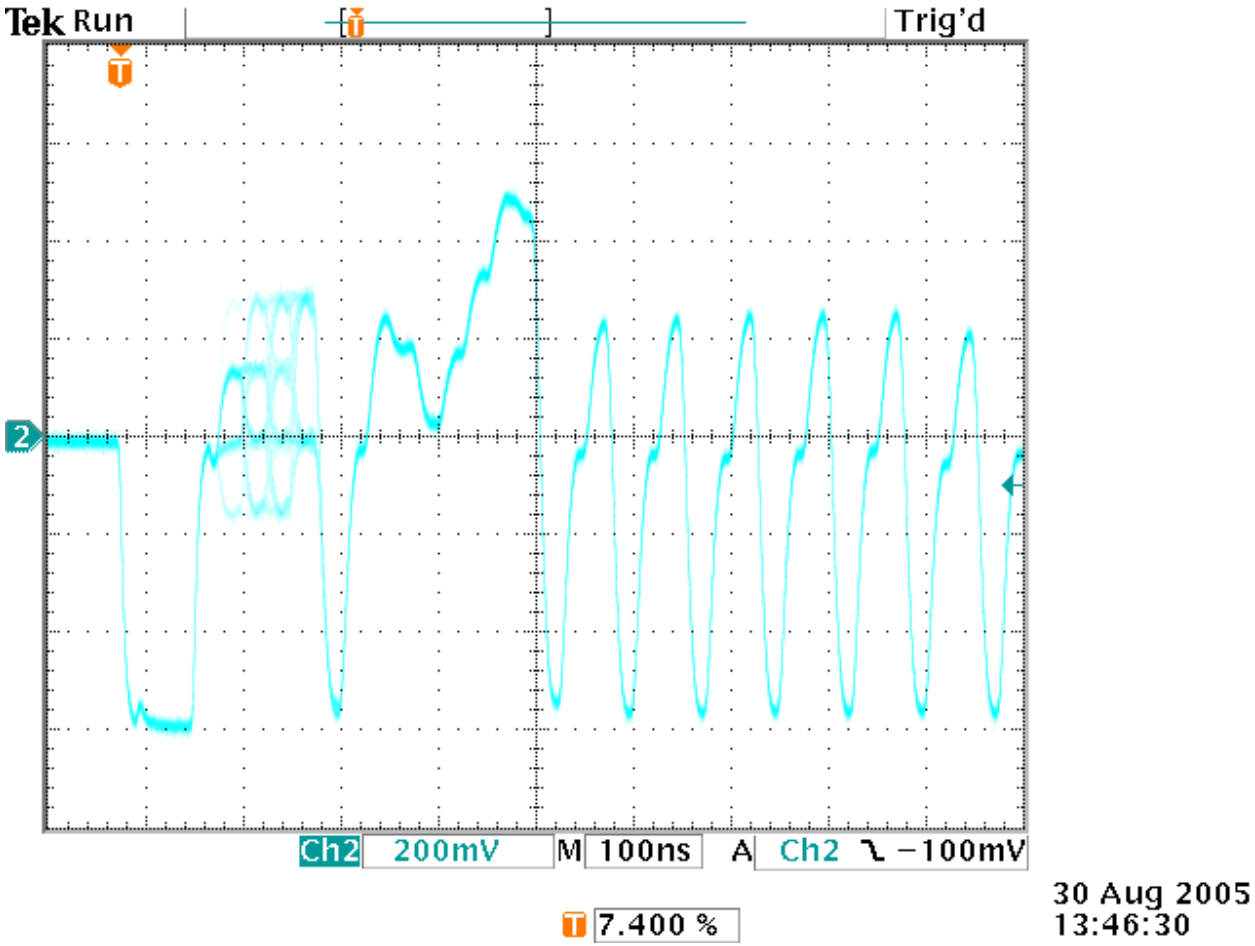
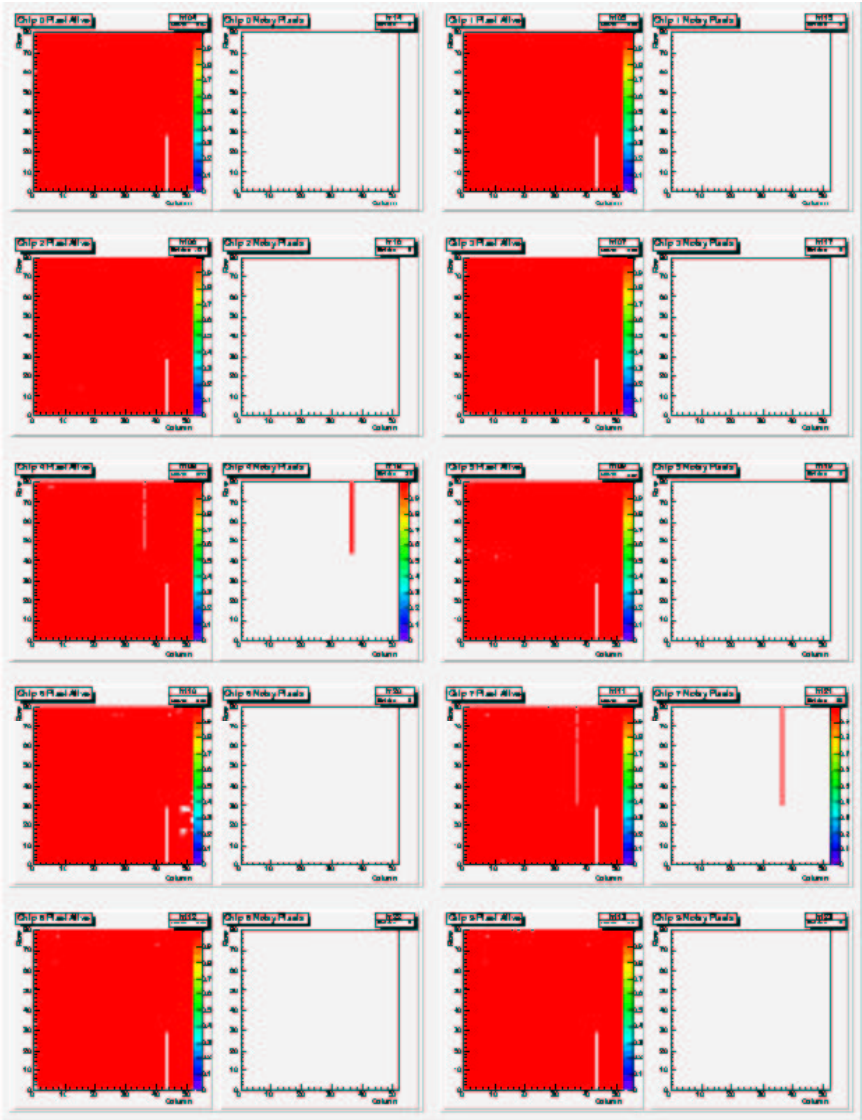


Oscilloscope trace of analog output from the TBM installed on the panel transmitting signals from 2x5 plaquette (10 ROCs) at 40 MHz frequency. First ROC has an active pixel readout.

US CMS Forward Pixel Detector



Performance of 2x5 plaquette chips mounted on the panel with TBM05 at 40 MHz:

each pair of plots presents "Alive Pixel" and "Noisy pixel" test results.

Apart some problem with column 43, raw 0-30 there are a few "non-responding" pixels and there is possible group of "noisy" pixels for several chips (possibly it is some readout problem)

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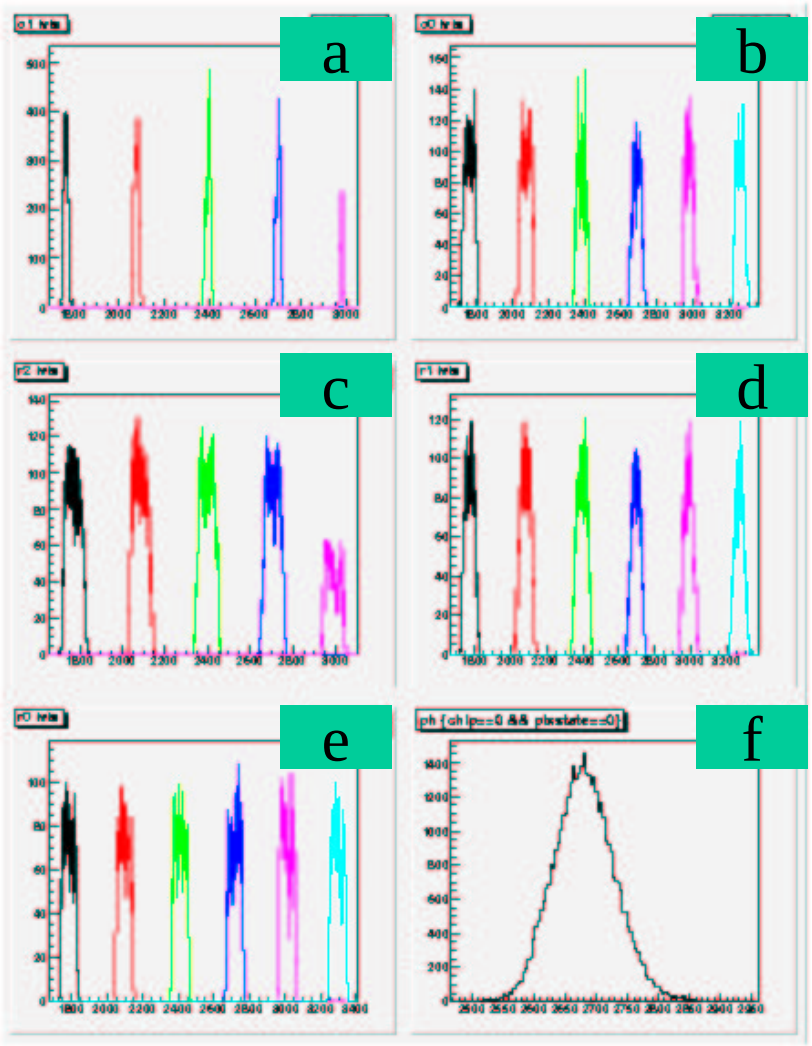

Performance of 2x5 plaquette chips mounted on the panel with TBM05 at 40 MHz:

a,b – column upper and lower address levels

c,d, e – raw upper, middle and lower address levels

f – calibration pulse height distribution
RMS/Average ~ 1.5 –2 %

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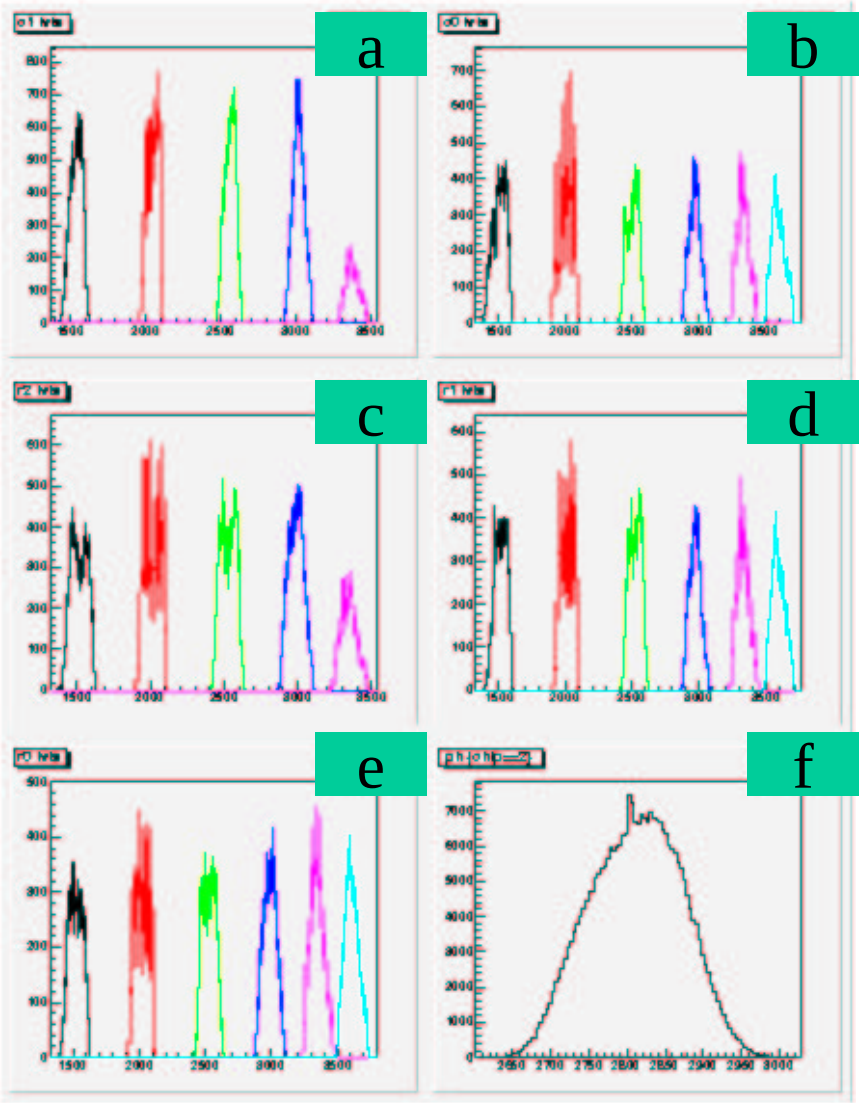

Performance of 2x2 plaquette chips mounted on the test board with TBM04:

a,b – column upper and lower address levels

c,d, e – raw upper, middle and lower address levels

f – calibration pulse height distribution
RMS/Average ~ 2 –2.5 %

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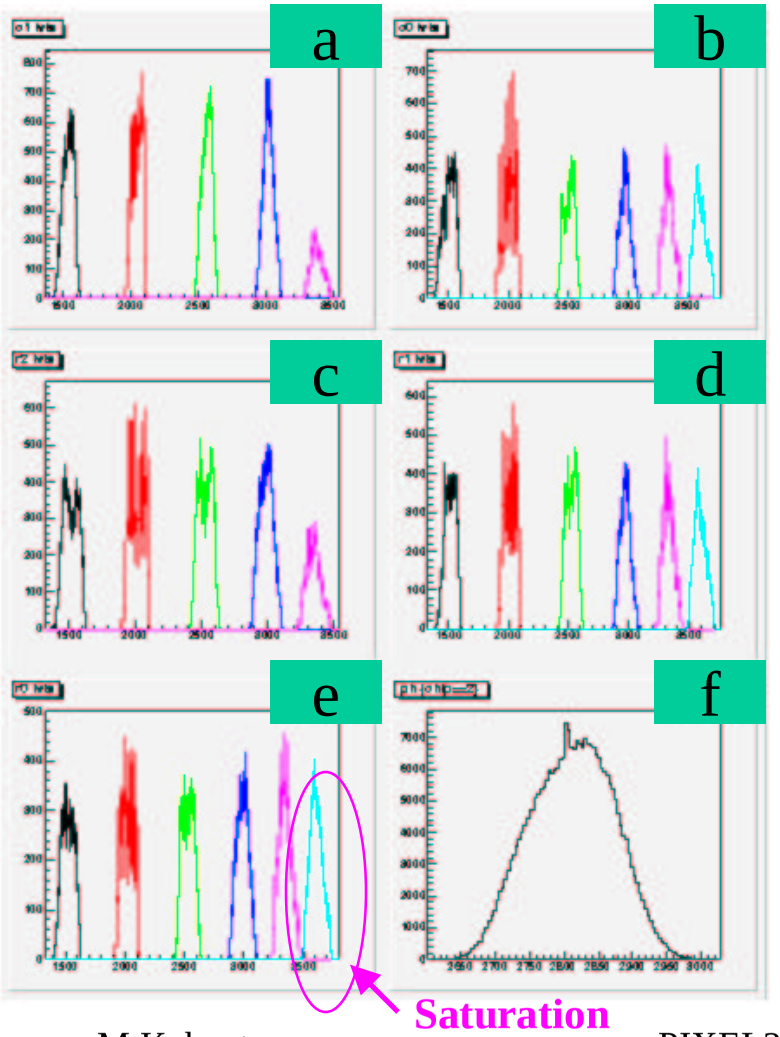
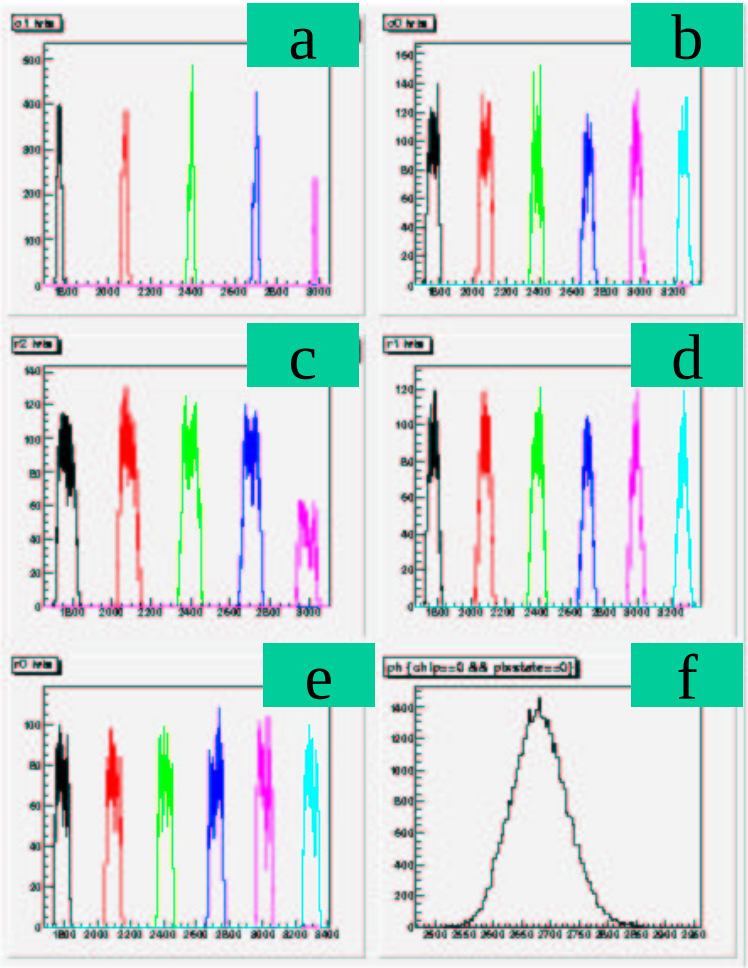
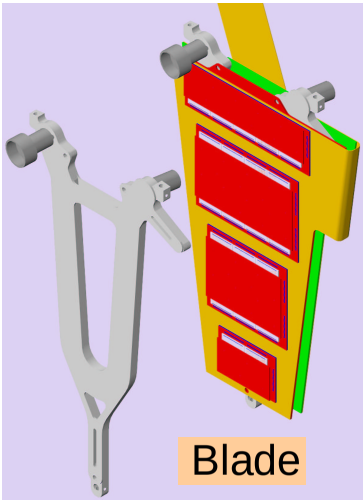
20 MHZ address levels for 2x2 plaquette on the panel with TBM04:

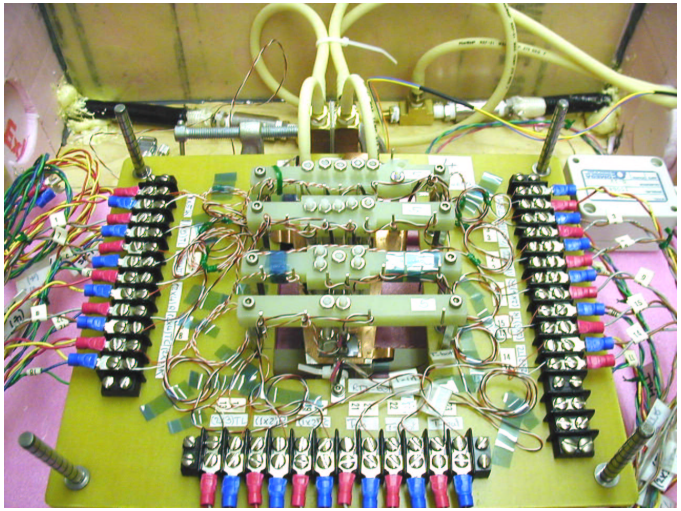


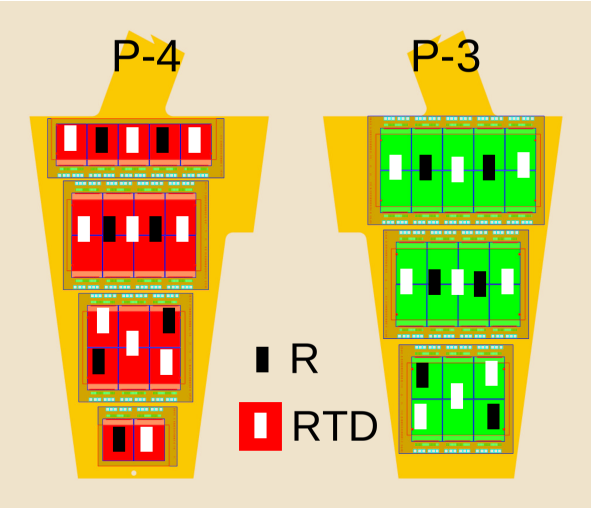
40 MHZ address levels for 2x5 plaquette on the panel with TBM05:

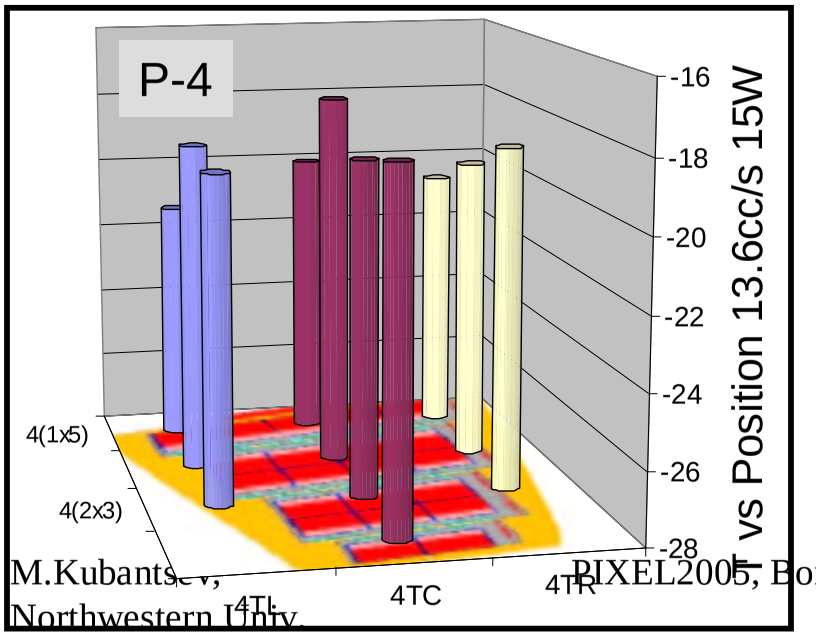


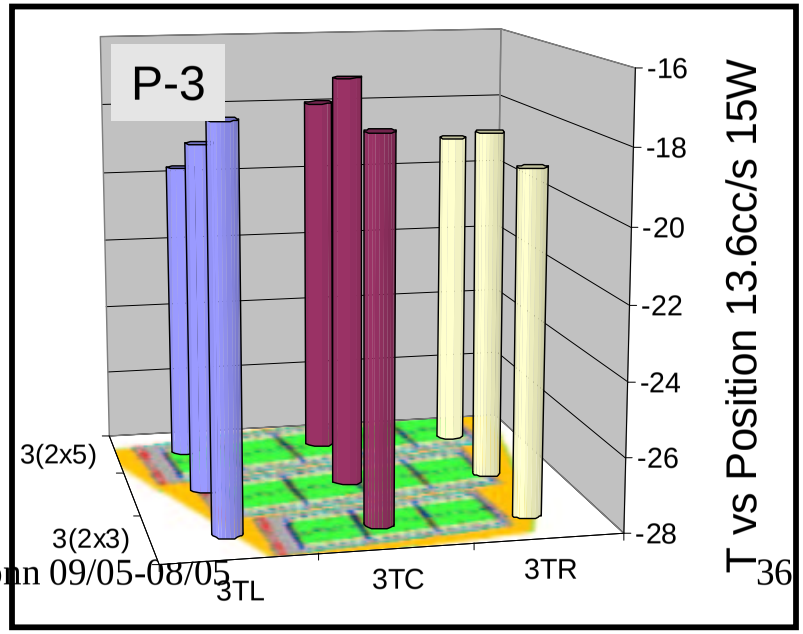
T distribution on Panels



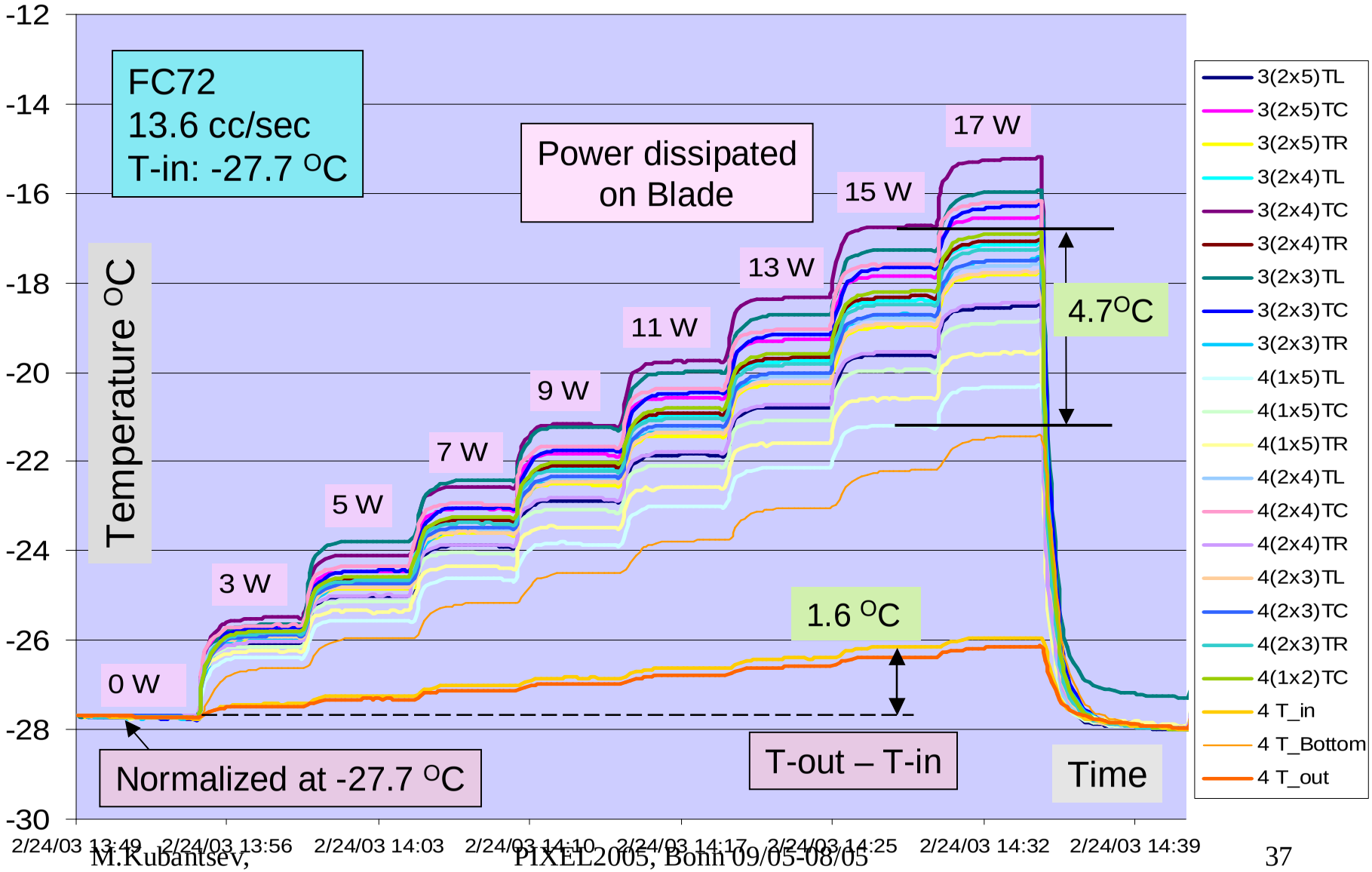








T distr. Over Panels



US CMS Forward Pixel Detector

Wire bond encapsulation is made with SYLGARD 186 by Dow Corning on an encapsulation machine equipped with two TV cameras

Bump bond test comparison

Bump Bond Testing

X-Rays:

- Pros: Definitive test for completely missing bonds.
- Cons: Time and effort intensive. Can not tell if physically present bonds are good or bad.

Charge Injection Test D:

- Pros: Simple to do, quick (~8 min), seems reliable.
- Cons: Not well understood, but we are working on it.

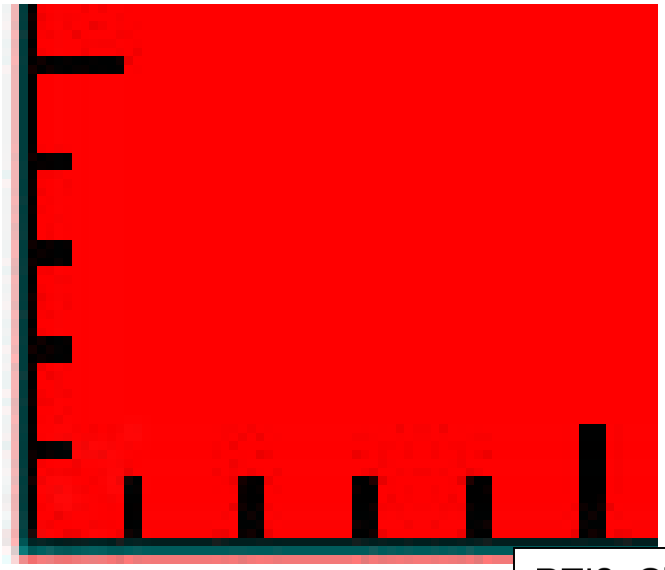
LEDs:

- Pros: Quick (~1 min/run + setup time), seems reliable.
- Cons: Difficult to setup to have entire chip/plaquette respond to 1 setting (Light intensity and pixel size not uniform). We are thinking of making a larger LED array or to mount our LEDs on XY motion stage and scan across the plaquette.

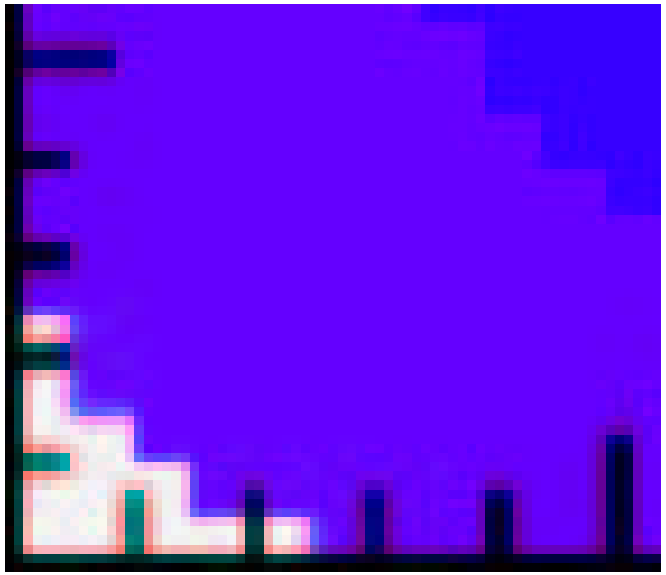
Radioactive Source:

- Pros: Understood, most conclusive test.
- Cons: Need ~2-3 hours at least to get enough statistics and can only look at 1 ROC at a time with current setup.
- Impossible with new storage boxes because of the Al base plate.

Pixel Alive: All Pixels Respond

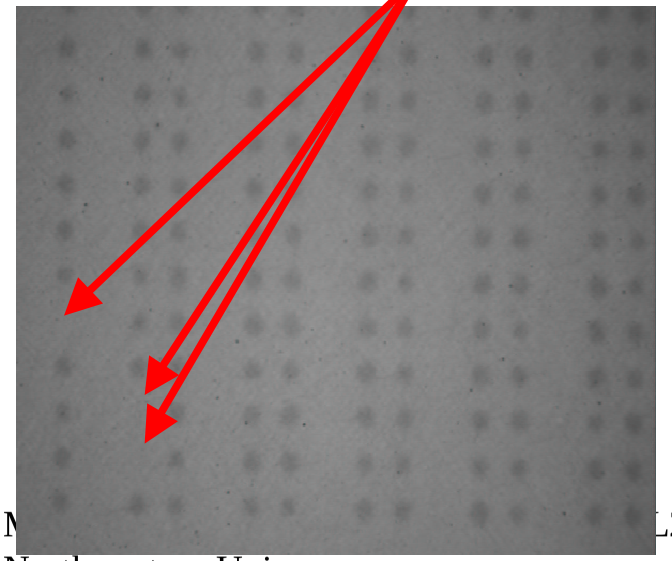


Sr90 Run (White pixels don't respond)

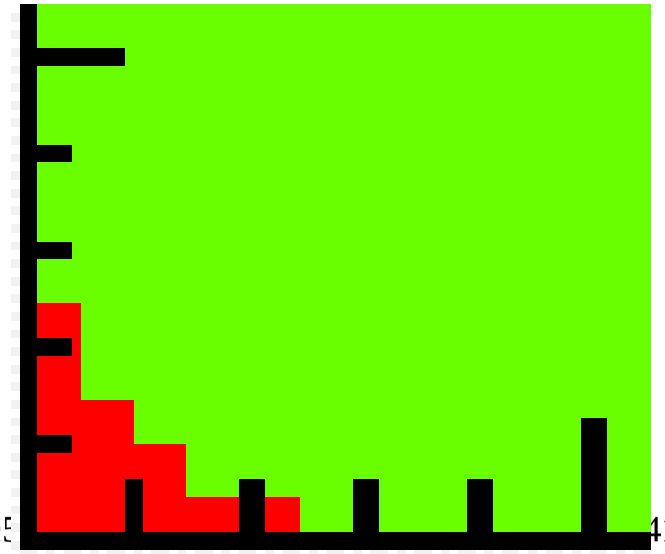


RTI2: Chip 0, 75B

X-Rays (Missing Bumps)

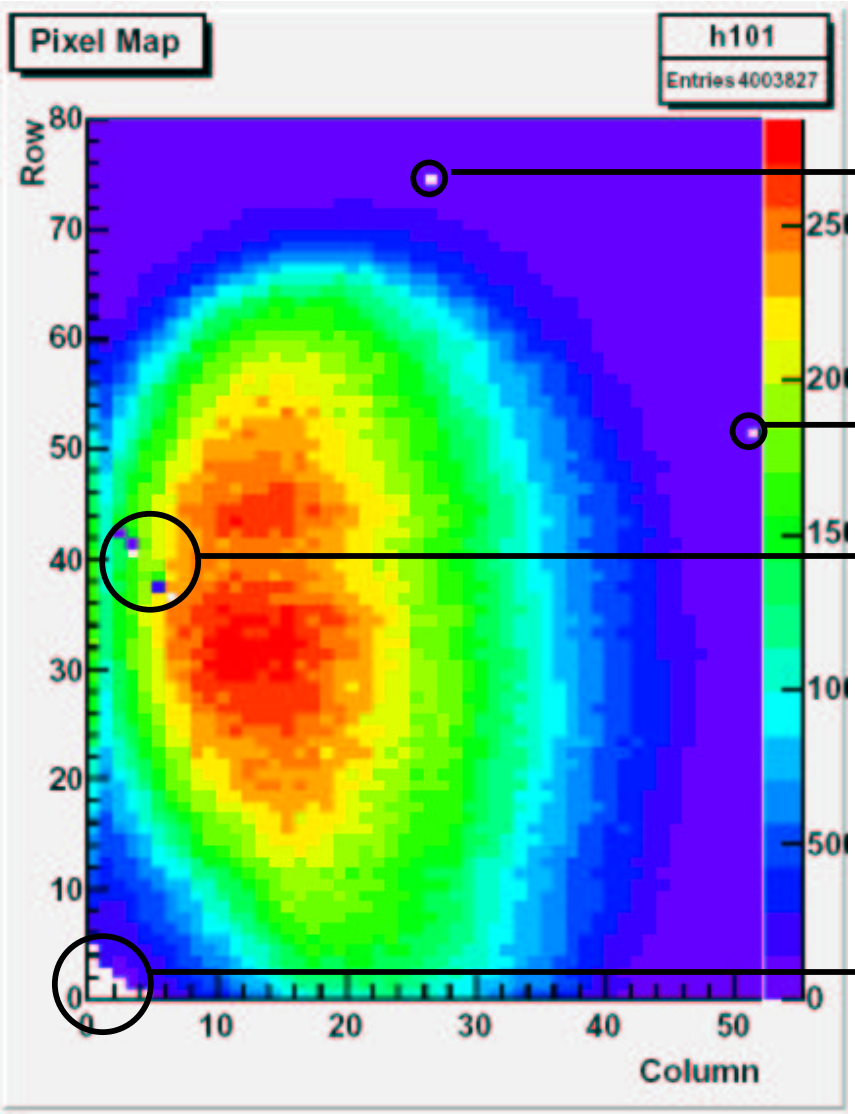


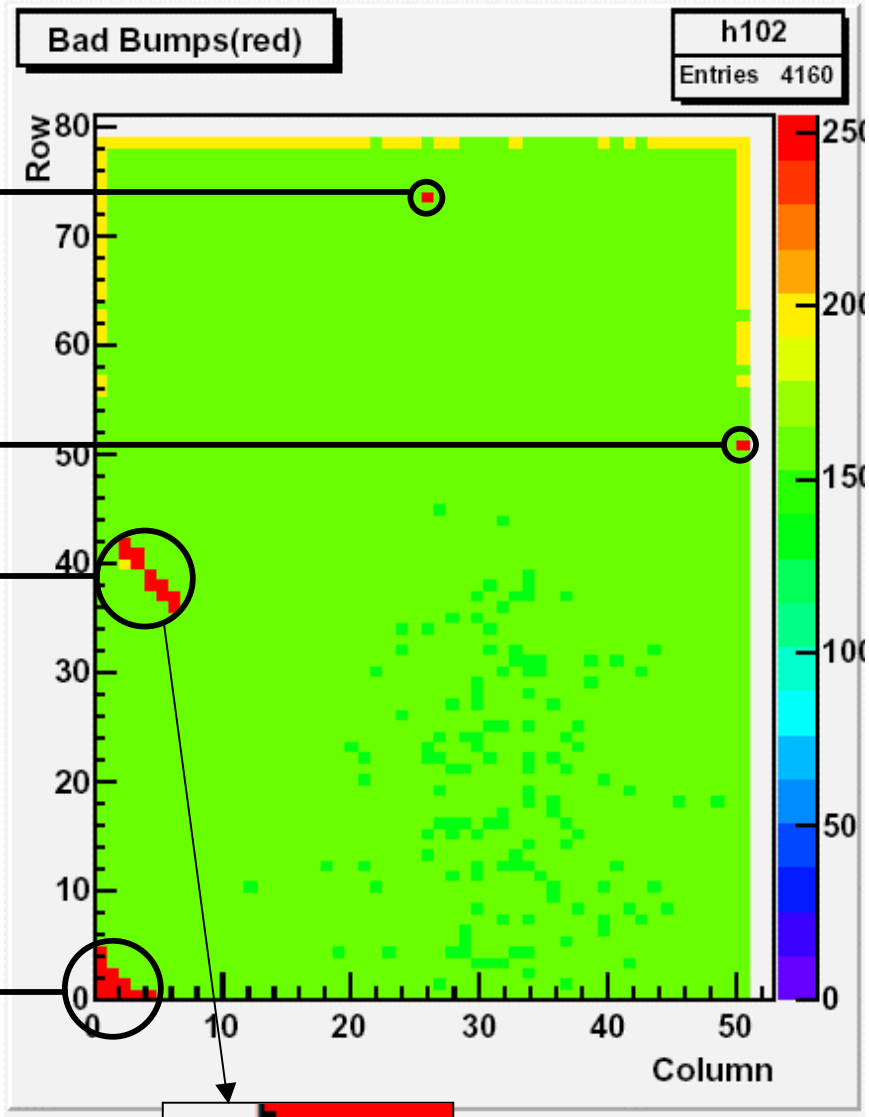
BB test D (Red pixels = Bad Bumps)

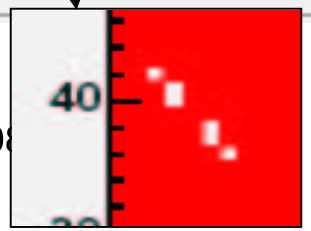


Sr90 Run (White pixels don't respond)

BB test D (Red pixels = Bad Bumps)





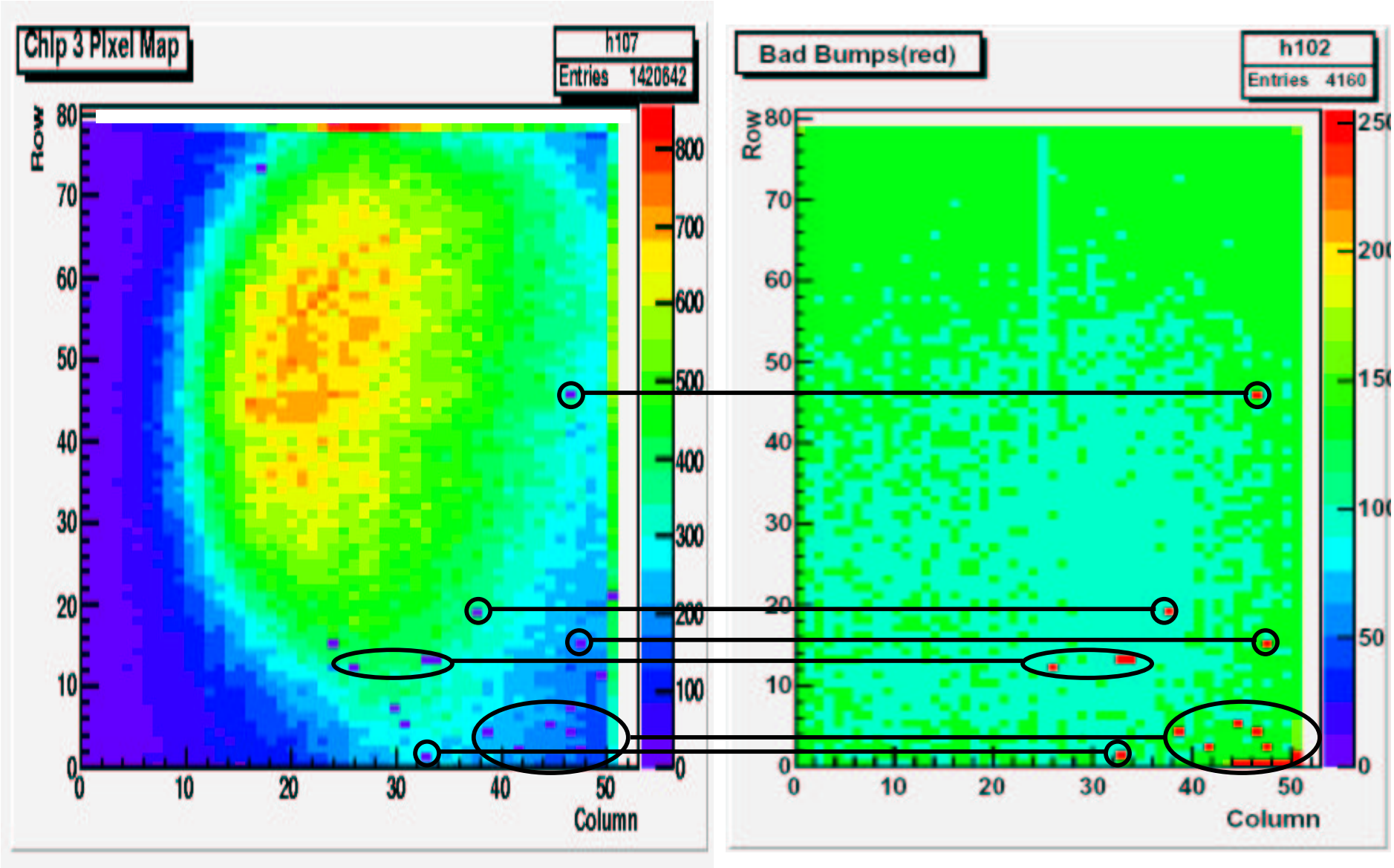


Chip 0, 75B

*Pixels don't show up on Pixel Alive Scan (may be dead pixels and not missing bumps)

Sr90 Run (White pixels don't respond)

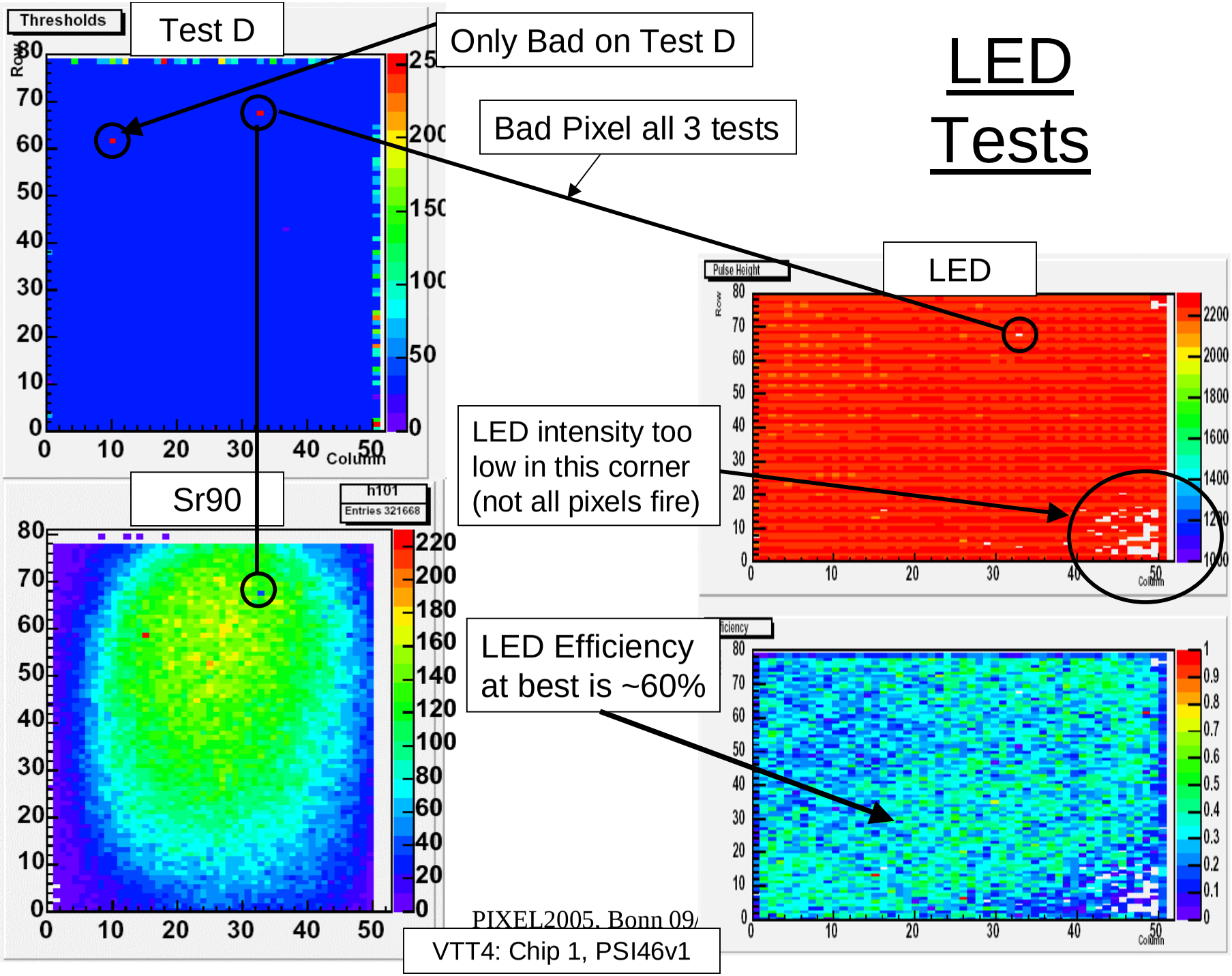
BB test D (Red pixels = Bad Bumps)



On this chip "bad bumps" from Test D still have hits with Sr90 but much fewer than their neighbors

Chip 3, 76B

LED Tests



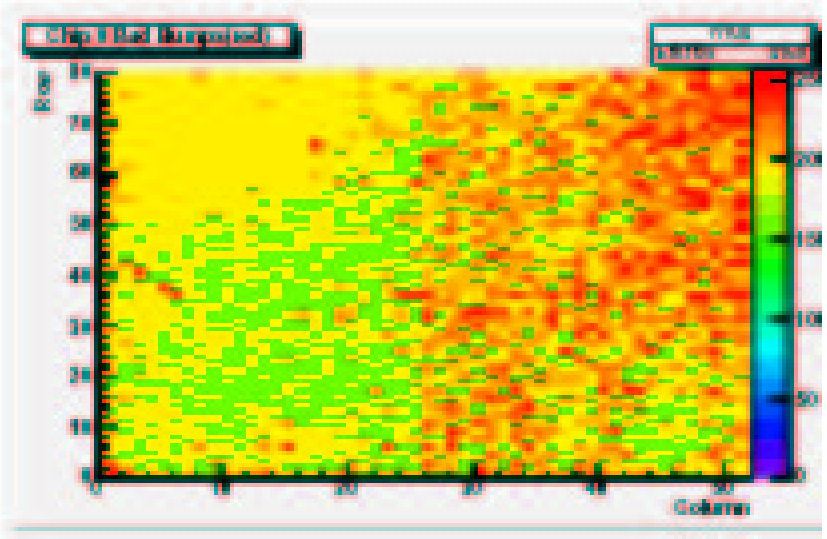
VTT4: Chip 1, PSI46v1

Conclusions

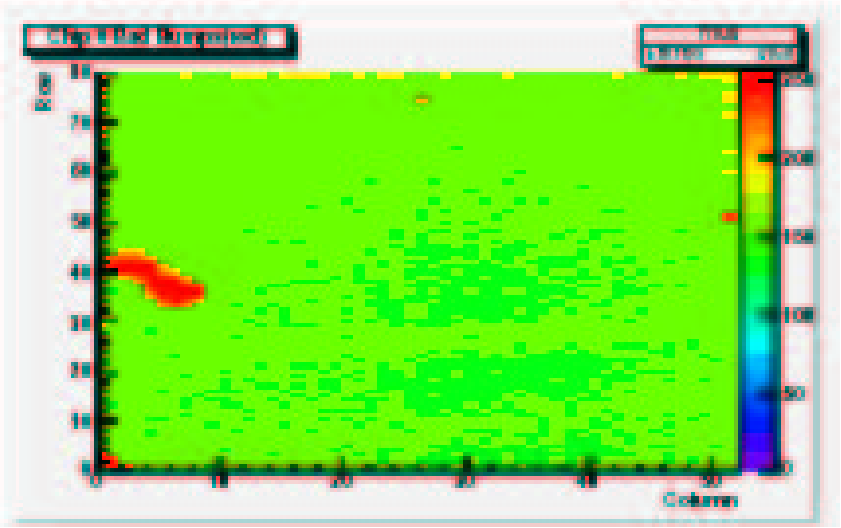
- Electrical Test D and/or LED tests would be ideal because they are quick and simple tests to do as long as we are sufficiently confident in the results.
- LED setup needs to be improved.
- Test D should be better understood.
- It is difficult/impossible to say any of the tests are 100% accurate, but they should be sufficient to compare the relative quality of bump bonds from device to device and vendor to vendor.

RTI2 Chip 0 BB Test D at Different Bias Voltages

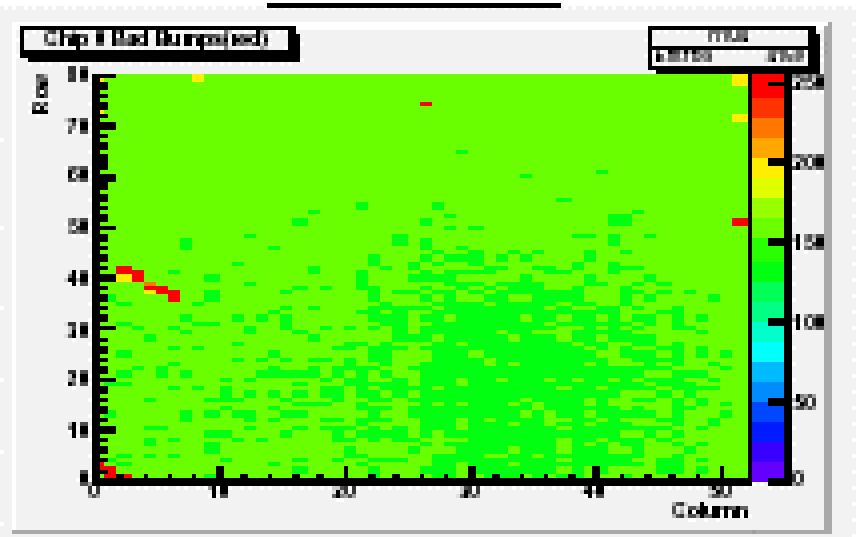
Bias V = -10V



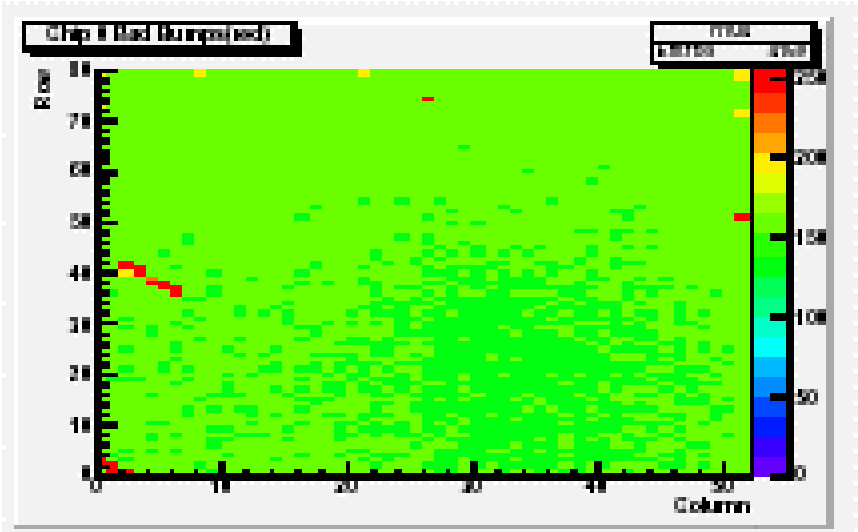
Bias V = -100V



Bias V = -200V

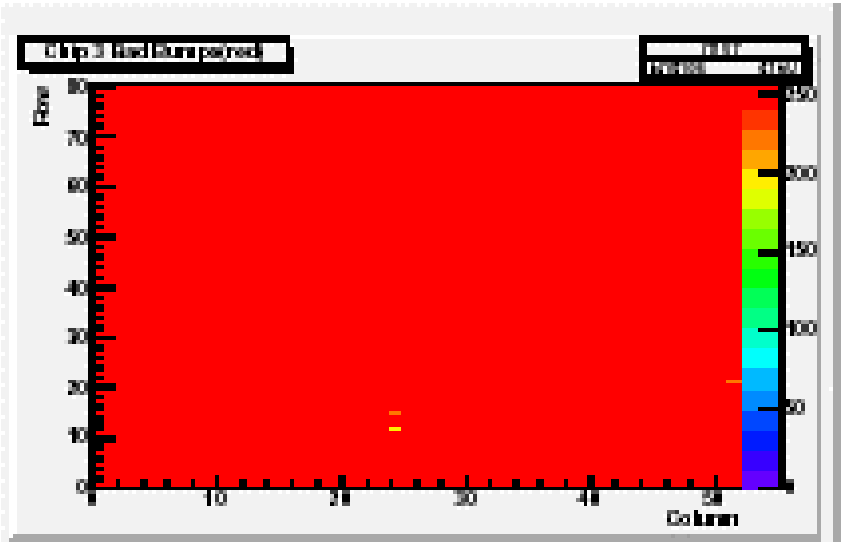


Bias V = -350V

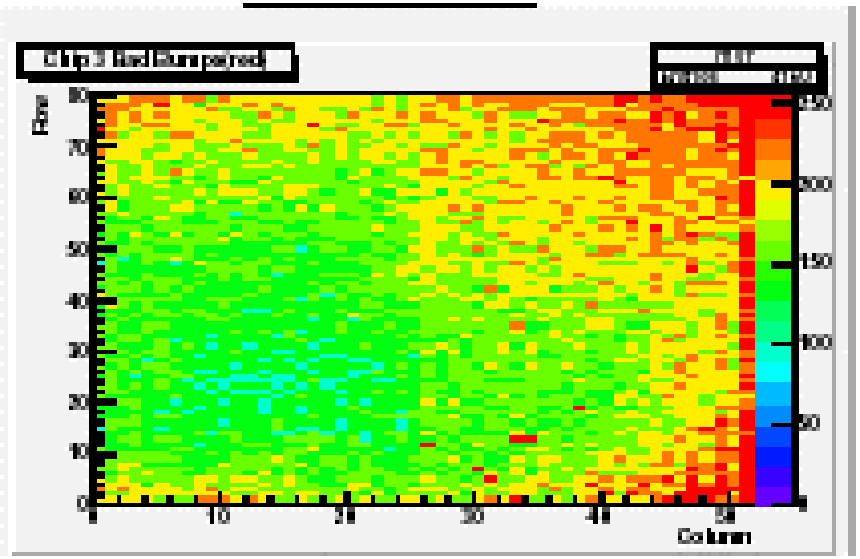


RTI2 Chip 3 BB Test D at Different Bias Voltages

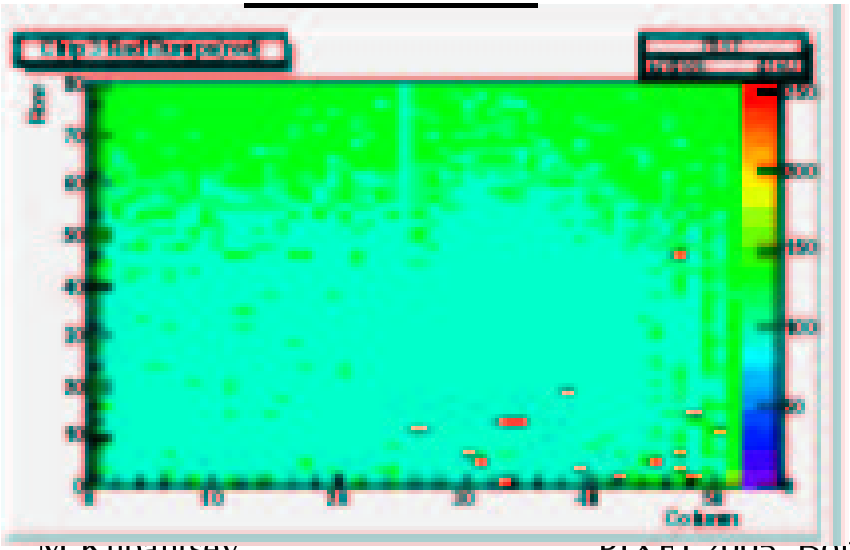
Bias V = -10V



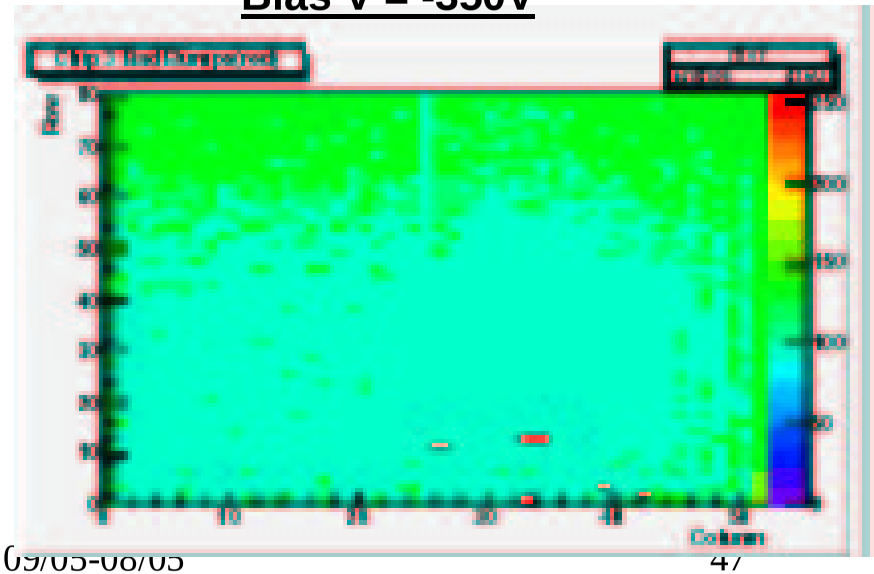
Bias V = -100V



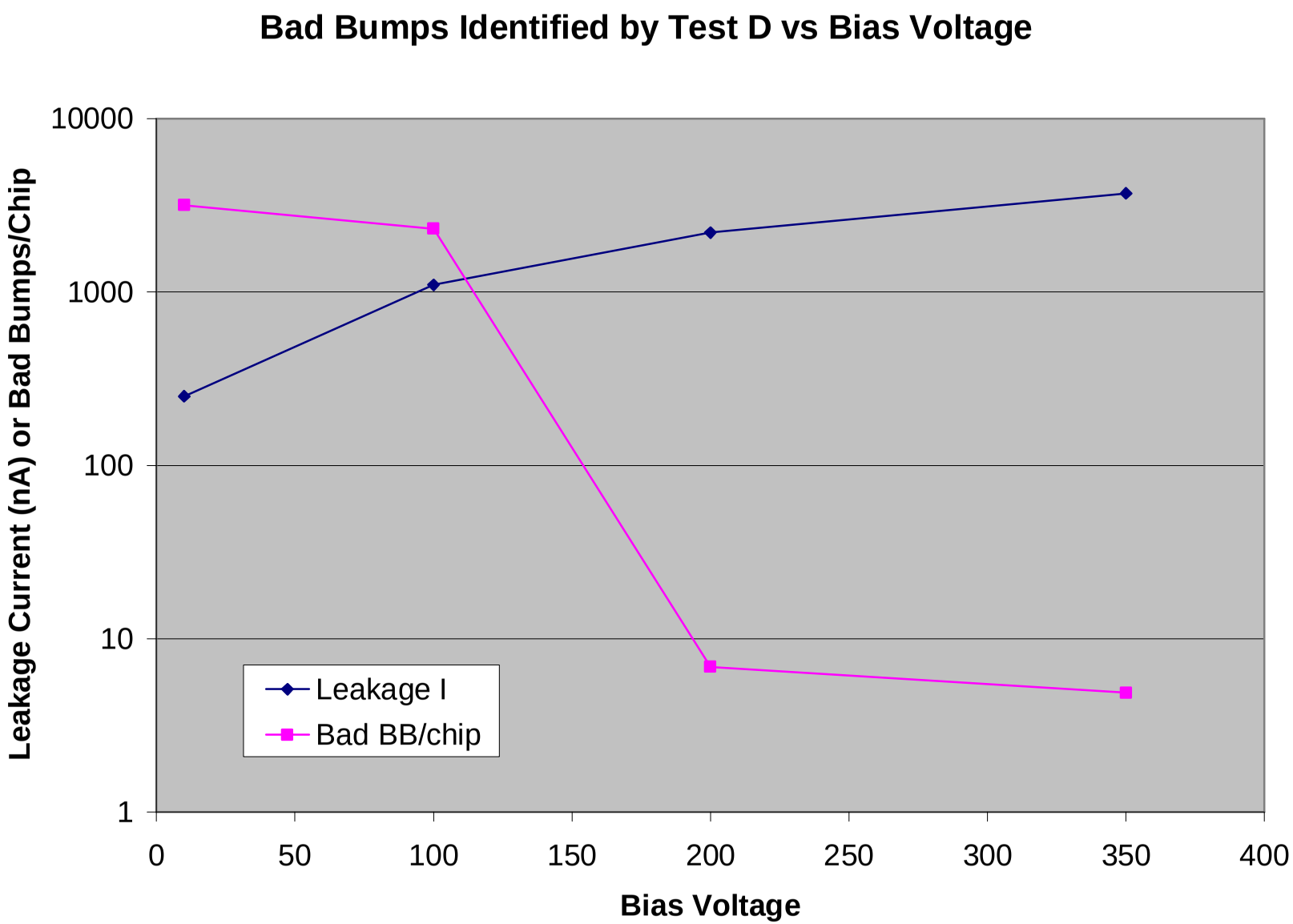
Bias V = -200V

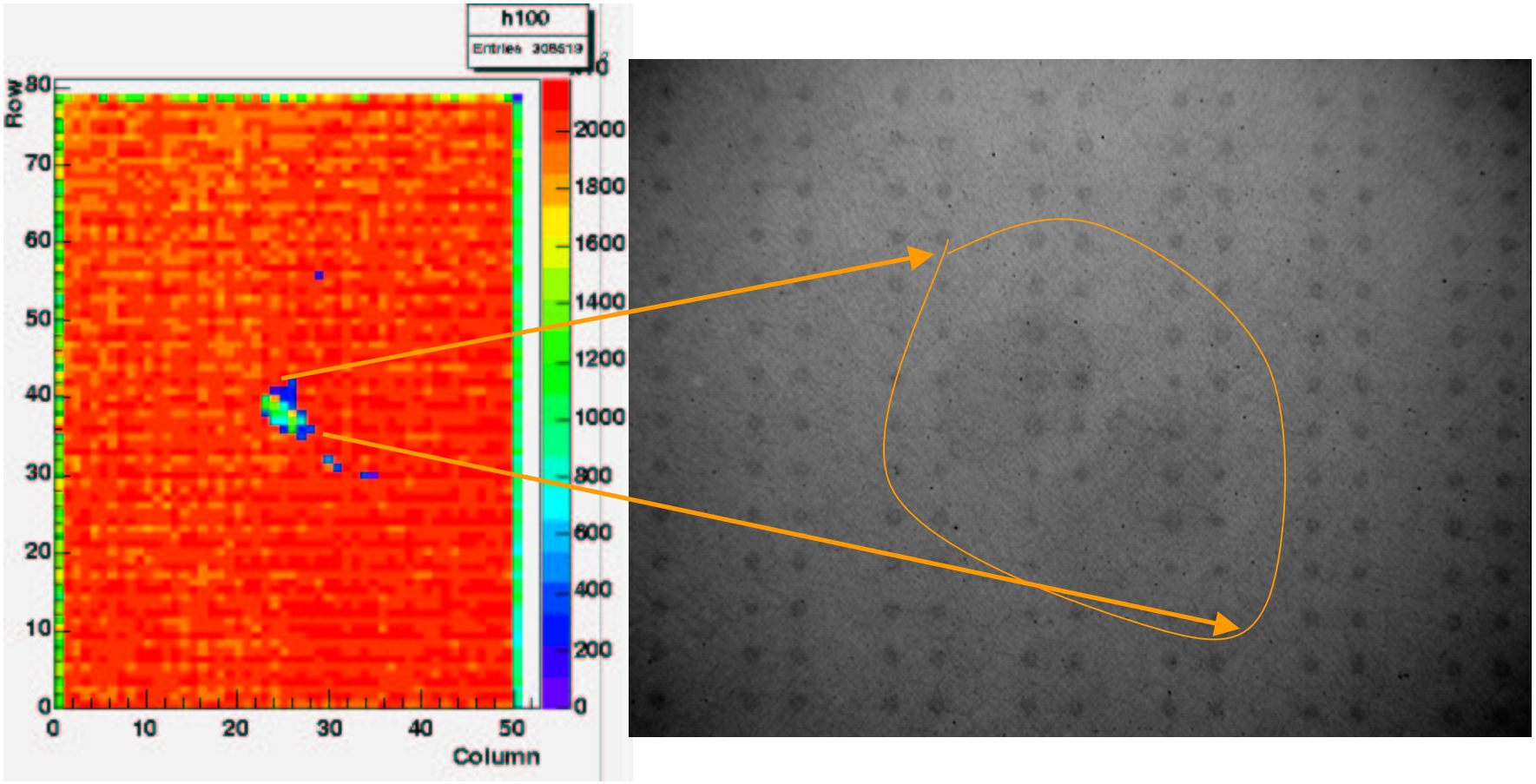


Bias V = -350V



RTI2 BB Test D at Different Bias Voltages



Reverse analysis of the “missed” bonds

The Bump bonded module 2x2 VTT#5 has a group of “missed” bump bonds in the middle of one of the chips. X-ray image shows some irregularities irregularities in the bump pattern at the same spot.