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Testing of High Density Interconnect Circuits for the CMS Forward Pixel Detector Upgrade





Outline

- CMS Silicon Pixel Detector
- Phase 1 Upgrade

High Density Interconnect (HDI)

- Design & Function
- -Testing
- Conclusions



Compact Muon Solenoid





Silicon Pixel Detector

- Closest component to the interaction point.
- Designed to reconstruct trajectories of charged particles
- Measurements:
 - Momentum
 - Charge
- Reconstruction:
 - Primary Vertices
 - Secondary Vertices
 - Track Impact Parameter



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Changes in Pileup with 25 ns Bunch Crossings

- In-Time Pileup Decreases
- Out-Of-Time Pileup Increases

As opposed to the current
50 ns bunch crossings for the preliminary
0 Tesla data collection currently taking place at CMS.





Why Upgrade the Pixel System?



- Radiation damage to the current pixel system. Need fresh radiation-tolerant detectors.
- Good opportunity to improve performance of detector for higher pile-up, better read-out rate, increased tracking precision.

- Doubling Instantaneous Luminosity
 - 1*10³⁴ cm⁻² s⁻¹ (design luminosity)

 $\rightarrow 2^{*}10^{34} \text{ cm}^{-2} \text{ s}^{-1}$

Doubling Collision Energy

7-8 TeV \rightarrow 13-14 TeV

- Currently at 13 TeV
- Increased Integrated Luminosity

Goal of 160 fb⁻¹ before LS2

 \rightarrow 400 fb⁻¹ before LS3

Increased Pile-up

Run 1 Avg. 20 Vertices Run 2→ 50-100 Vertices



Phase 1 Pixel Upgrade

Current Detector

- 66M Pixels (18M in Forward)
- 2(3)-Hit Coverage up to pseudorapidty of 2.1
- Innermost layer at 4.4 cm
- 40 MHz Analog Readout
- Varied Pixel Plaquette Designs

Upgraded Detector

- 123M Pixels (44M in Forward)
- 4-Hit Coverage up to pseudorapidty of 2.5
- Innermost layer at 3.0 cm
- 160 MHz Digital Readout
- Uniform Pixel Plaquette Design



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Upgrade



June 8th, 2015

Phase 1 Upgrade

- 2x8 Uniform Sensors
- 4 Half Cylinders w/ 3 Half Disks Each
 - 28 Tilted "Fan" Blades per half disk (11/17 inner/outer)
 - 2 Modules per Blade
 - Total of 672 Modules
- Sensors cooled to improve radiation resistance
 - Designed to survive integrated luminosity of 500 fb⁻¹
 - Still expect to replace innermost layer midway through lifetime.
- New Power Supplies, Optical Systems and Data Acquisition (DAQ) for higher output bandwidth.

Upgraded system constructed by 50 Institutions from many countries

- Forward Systems US CMS
- Barrel Systems Europe, Taiwan









- Reduced Material Budget
 - Mass of framework holding modules reduced.
 - Readout electronics shifted out of tracking region.
 - Reduces secondary interactions.
- Resulting reduction:
 - 20% Reduction of Mass
 - > 200% Reduction in Radiation Length



Pixel Module

- Silicon Sensor segmented into 2x8 chips.
 - 52 x 80 Pixels, 100 x 150 µm Pitch
- Bump-bonded to 16 Read-Out Chips (ROC)
- High Density Interconnect (HDI) glued to opposite side of sensor, wire-bonded to ROC.
- Token Bit Manager (TBM) bonded to HDI, manages read-out of sensor information from ROC.
- Collected signal read out through connector to DAQ system.







High Density Interconnect (HDI)

HDI_revD

Layer 1 (Top)



4-Layer Copper Flexible Printed Circuit

- 200 Nets
- ~900 Pads
 - 622 VIAs
- 6.6 cm x 1.9 cm x 0.027 cm



HDI (Unpopulated)



HDI (Populated)





HDI Testing

- Weight, Thickness
 - Important for Material Budget of Detector
 - 0.56g (unpopulated), 1.42g Populated
 - ~940g over 672 Modules
- Visual Inspections
 - Performed in clean room utilizing microscopes at FNAL Silicon Detector Facility
 - Looking for "obvious" defects in chips



Visual Defects









Under-Etching



Confocal Laser Scanning Microscope

- analysis of topographical features
 to 10 nm resolution
- 30-40 microns between the gold deemed to be sufficiently safe for operation









Pilot System

- Installed in 2014 for Run 2
- 8 Modules w/ Digital ROC
- Mixture of new & old components
- Good test of modules, DAQ, before installation of full upgrade during LS3.





Conclusion

Currently Inspecting Rev D HDIs

- Testing procedures are continually being refined.
- New defects lead to updated Pass/Fail Criterion.
- Final Goal: Construction of 1000 Modules
 - 800 Production Modules, 200 Spares
 - Need: 672 for final detector.
- Time Scale:
 - August 2016 Half cylinders needed at Point 5





CMS Experiment at the LHC, CERN Data recorded: 2015-Jun-03 08:48:32.279552 GMT Run / Event / LS: 246908 / 77874559 / 86

Thank you for Listening!





- Increase in efficiency
 - Better primary, secondary vertex, impact parameter reconstruction
 - Better handling of track reconstruction w/ heavy pile-up.



High Density Interconnect (HDI)

4-Layer Copper Flexible Printed Circuit.





Combined Layers 1-3



Assembly & Future Testing Good HDIs are Assembled into modules

- Populated with components:
 - TBM, DIP Switch, Capacitors, Resistors, Connector for Voltage & DAQ, Temperature Sensors, Module end-holders
 - 50 HDIs populated so far
 - 20 Full Modules constructed at Purdue, Nebraska
- Powered & Tested for TBM functionality





Visual Inspection Results



Exposed VIAs



Missing Pad Material



Scratched Pads



Missing Gold Material



Bridged Pads



June 8th, 2015