CMS PIXEL Detector
Phase I Upgrade Project

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on behalf of CMS Collaboration
Outline

• Introduction
• Detector Design and Layout
• Expected Performance
• Status of the Project
• Summary
Introduction

- The present CMS Pixel detector consists of 3 layers of Barrel PIX and 2+2 disks of Forward PIX.
- Pixel size is 100µm x 150µm with a total of 66M channels.
- Fully operational (~96%) with single hit reconstruction efficiency ≥ 99%
Introduction - cont

- Present detector:
  - proposed in 1995 for max $L = 1 \times 10^{34} \text{cm}^{-1} \text{s}^{-1}$
  - expect to replace inner most layer after exposing a total dose equivalent to 2 LHC years (fluence $6 \times 10^{14} \text{n}_{eq} \text{cm}^{-2}$) to preserve hit spatial resolution
  - Possible high dead-time ($\sim 50\% @ 2 \times 10^{34} \text{lumi} & 50\text{ns BX spacing}$)

- Upgrade detector
  - low dead-time (new ROC design)
  - Improved performance with additional layers and smaller radius of 1st layer

Extend the run and delay the LS1 to 2013 Likely to be the target of installation

LHC PLAN

<table>
<thead>
<tr>
<th>LHC machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 TeV</td>
</tr>
</tbody>
</table>

Vertice 2012

Rong-Shyang Lu / NTU

Sep. 16-21, 2012
Detector Design and Layout
Detector Layout

- Barrel from 3 to 4 layers (1216 modules, 81M pixels; 1.6x present BPIX)
- Endcap from 2 to 3 disks (672 modules, 44M pixels; 2.5x present FPIX)
- Benefits of additional hits and pixel-only tracking
Barrel PIXEL (BPIX)

- Introduction
- Detector Layout
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Two identical half shells with one type of module

<table>
<thead>
<tr>
<th>Layer</th>
<th>radius</th>
<th># faces</th>
<th># modules</th>
<th># ROCs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30mm*</td>
<td>12</td>
<td>96</td>
<td>1536</td>
</tr>
<tr>
<td>2</td>
<td>68mm</td>
<td>28</td>
<td>224</td>
<td>3584</td>
</tr>
<tr>
<td>3</td>
<td>109mm</td>
<td>44</td>
<td>352</td>
<td>5632</td>
</tr>
<tr>
<td>4</td>
<td>160mm</td>
<td>64</td>
<td>512</td>
<td>8192</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>1184</td>
</tr>
</tbody>
</table>

Total: 18944

~79M pixels

* beampipe outer diameter 45mm
New BeamPipe

- Central beam pipe from present 59.6mm down to 45mm in outer diameter.
- Allow most inner layer to 30mm radius.
- Impedance, aperture, material and construction are okay.
- Approved and ordered in 2012. Will be ready to install during LS1.
Forward PIXEL (FPIX)

- Inner and outer rings for easy repairing.
- Decided to use same module design as BPIX to fill the volume.
- 3+3 disks with 672 modules (2.5x present FPIX)
Material budget: Mechanical Optimization

Current BPIX service

- Move the service outside of $|\eta|=2$

Upgrade BPIX service

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Material Budget: Cooling

- Present BPIX uses mono-phase C\textsubscript{6}F\textsubscript{14} cooling scheme which contributes a major fraction of material budget.
- Impact Parameter resolution shows material distribution due to Cooling.
- Upgrade to two-phase CO\textsubscript{2} cooling.
- High heat transfer coefficient; more heat load per channel.
- Smaller cooling pipe (1.6/1.8 mm \(\varnothing\)) but higher pressure operation (up to 70 Bar).

Impact parameter resolution for present BPIX

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Pipes: 1.6/1.8mm \(\varnothing\) stainless steel

Weight Layer 1: 51g + 11g CO\textsubscript{2} → 40% of old first layer
Material Budget

- Significantly reduce the material budget. Factor of 2 at $|\eta|>1$
- Fewer photon conversion and fewer hadron loss

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Expected Performance
Expected Performance - Tracking

- Tracking efficiency and fake rate in MC ttbar samples with average PU of 50 and ROC data loss simulation.

![Graphs showing efficiency and fake rate vs. eta and p_t for different pixel detectors.](image)
Performance - IP resolution

- Studied the transverse and longitudinal impact parameter resolution with MC ttbar samples.
- Improvement seen in high PU and data losses scenario
Performance - b-tagging

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**B-tagging efficiency / fake rate in ttbar sample, 80<\(p_T\)<120 with combined secondary vertex tagger**

![Graph showing b jet efficiency](image)

- Light jet: Current Detector
- Light jet: Upgrade Detector
- C-jet: Current Detector
- C-jet: Upgrade Detector

2E34 cm\(^2\)s\(^{-1}\) (50 ns)
Avg. PU 100
Status of the Project
&
Detail of Components
PIXEL Sensor

- Same design with present detector. Pixel size 100x150 μm with thickness of 250 μm.
- n-in-n sensor: under-depleted operation possible
- P-spray (BPIX) or P-stop (FPIX) for N-side isolation
PIXEL Sensor

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- Assuming 250 fb\(^{-1}\), the inner most layer will receive 1.5E15 N\(_{eq}\)/cm\(^2\) fluence.
- Affect on leakage current understudy assuming max 0\(^\circ\)C; also limit is on power supply.
- For samples irradiated to 1.1E15, bias voltage up to 450-600V is sufficient.
- Capability of higher bias V will provide some room
- Lower threshold will “relax” the operation (new ROC < 2000e)

[G. Troska, TU Dortmund, PhD thesis 2012]
ReadOutChip (ROC)

- Adjustable by programmable DAC
- Modified in psi46dig

Pixel Unit Cell
ReadOutChip (ROC)

- Double column readout
- Larger L1 latency buffers to reduce trigger induced data loss
- Additional readout buffer (32→96) to reduce readout related data loss
- 160MHz Digital readout to increase bandwidth. (40MHz analog for present PIX)
ROC data format

from analog output to digital output

CLK40
TIN
TOUT
SDATA

start marker    id field    column    row    pulse height

ROC header
pixel hit (repeated)
Digital ROC

- Improved timewalk $\rightarrow$ no difference of in-time and absolute threshold.
- ROC-sensor noise $\sim 180$ electrons. Expect to operate at threshold $< 1800$ electrons.
- lower Xtalk, lower noise.
- Some problems on this submission but those have been solved for next submission.
- Will have rad-hard test with ROC irradiated to $10^{15}$ Neq/cm$^2$ at PSI.

Measurement in X-ray with fluorescence, random trigger.

Absolute threshold as low as Fe fluorescence (1.8ke$^-$).

- Ba (8.9ke$^-$)
- Sn (7.0ke$^-$)
- Ag (6.1ke$^-$)
- Mo (4.8ke$^-$)
- Cu (2.2ke$^-$)
- Fe (1.8ke$^-$)
A full module contains 2x8 pixel sensors and ROCs. Sensors are bump-bonded on ROC chips. ROC chips are wire-bonded to HDI. High Density Interconnect distributes power and control signal to ROCs and transfer data from ROC to DAQ. Token Bit Manager chip control the token signal transmitting.
Pixel Module

Barrel layers 2-4

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Pixel Module

* first prototype module made on Aug.

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Vertex 2012

Sep. 16-21, 2012
Power

- Upgrade significant increase the number of channels (demands more power) but uses present LV cables.
- Up scaling existing power system leads to high resistive power losses in cable
- Solution: DC-DC converter with conversion ratio 3-4 and place at $|\eta|=4$

Toroidal inductor:
- Plastic core
- $L = 450\text{nH}$
- $R_{DC} = 40\text{m}\Omega$

Pi-filters at in- and output

ASIC: AMIS4 by CERN
- $I_{\text{out}} < 3\text{A}$
- $V_{\text{in}} < 10\text{V}$
- $V_{\text{out}}$ configurable; $2.4V(V_{\text{ana}})$ or $3.0V(V_{\text{dig}})$
- $f_s 1.5\text{MHz}$

AC_PIX_V8 A: 2.8cm x 1.6cm; ~ 2.0g
Test beam

- Various test beam activity to understand sensor and ROC.
- Single ROC-sensor with DESY electron beam to study the ROC performance and optimization.
- 8 ROC-sensor telescope with CERN SPS proton beam to understand ROC efficiency/dead-time as a function of flux
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**Schedule**

- **Pixel construction** shared by four production centers
- **Currently 12 FAs and 45 Institutes participating the projects.**
- **Fairly short production period compare to the present detector**

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<tr>
<th>LHC Machine</th>
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</thead>
<tbody>
<tr>
<td>CMS Opening</td>
</tr>
<tr>
<td>Central Beampipe</td>
</tr>
<tr>
<td>Present detector maintenance</td>
</tr>
<tr>
<td>Upgraded pixel installation test at P5</td>
</tr>
<tr>
<td>CO2 cooling plants construction</td>
</tr>
<tr>
<td>ROC production and test</td>
</tr>
<tr>
<td>DC-DC converter production</td>
</tr>
<tr>
<td>Opto-hybrid production</td>
</tr>
<tr>
<td>Sensor production</td>
</tr>
<tr>
<td>Module production</td>
</tr>
<tr>
<td>Service tubes production</td>
</tr>
<tr>
<td>Modules integration onto mechanical support</td>
</tr>
<tr>
<td>System assembly and system test</td>
</tr>
<tr>
<td>FED firmware, software, hardware production/test</td>
</tr>
<tr>
<td>Pixel installation, commissioning, operation</td>
</tr>
</tbody>
</table>

**We are here**

Vertex 2012  Rong-Shyang Lu / NTU  Sep. 16-21, 2012
Summary

• The CMS upgrade PIXEL project aims to build a light weight detector to replace the present one.

• The upgrade detector will have one more layer with less material in all $\eta$ direction.

• The R&D is nearly finished with the production on schedule. The possible installation will be end of 2016 during the LHC extend-technical-stop period.
BACKUP SLIDES
Introduction - cont

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  • proposed in 1995 for max \( L = 1 \times 10^{34} \text{cm}^{-1} \text{s}^{-1} \)
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• Upgrade detector
  • low dead-time (new ROC design)
  • Improved performance with additional layers and smaller radius of 1st layer

20 fb\(^{-1}\) HighEnergy LHC 13/14 TeV - 500 fb\(^{-1}\) HighLumi LHC 13/14 TeV - 3000 fb\(^{-1}\)

7x10\(^{33}\) Hz/cm\(^2\) @50 ns Injection upgrade: Linac4 (H) PSB-PS 1.4\(\rightarrow\)2GeV RF upgrades PS - SPS aC coating SPS (?) LHC Interaction region upgrade: Triplets (lower \(\beta^*\)) Crab cavities (beam crossing leveling) b-b compensation (lower beam loss) \( L_{\text{peak}} \) 10\(^{35}\) Hz/cm\(^2\) \( L_{\text{leveled}} \) 5 \(10^{34}\) Hz/cm\(^2\)
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● Studied the transverse and longitudinal impact parameter performance with MC ttbar samples.

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