Performance and Phase I Upgrade Plans for the CMS Pixel Detector

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The CMS Pixel Tracker

- The silicon pixel detector is the **innermost component** of the CMS tracking system.
- It consists of **3 layers** in the barrel (BPIX, 48M pixels) and **2+2 disks** in the forward region (FPIX, 18M pixels).
- Pixel size: $100\text{ }\mu\text{m} \times 150\text{ }\mu\text{m}$
- Plays crucial role in full tracking, triggering, primary vertex finding, e^-/γ identification, μ reconstruction, τ identification, **b -tagging**

Current Tracker Performance

- Fully operational ($\sim 96\%$)
 - Stable running, small contributions to downtime
 - Hit efficiency ($\geq 99\%$) and resolution excellent as expected
 - Radiation damage clearly visible from leakage currents which
 - rise with fluence (luminosity)
 - anneal with temperature (shutdowns/operation)
- ⇒ Layer 1 needs to be replaced in the foreseeable future (as planned)

Why upgrade?

Excellent LHC performance → increasingly challenging running conditions!

- Pixel tracker designed for and performing very well at instantaneous luminosity of up to $1 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1} \Rightarrow \text{expected 2014!}$
- At $2\times$ design luminosity (likely reached before 2018)

limitations of pixel due to:

- ▶ data loss due to limits of readout chip buffers and speed
- ▶ tracking inefficiency/higher fake rates due to difficult pattern recognition
- ▶ reduced hit resolution & detection efficiency due to radiation damage

- Goal for upgrade: maintain high efficiency and low fake rates of current pixel detector at 50 interactions per bunch-crossing (pile-up) or higher
- Schedule: planned for year-end technical stop 2016/2017
- Constrains: Need to minimize risks and downtime $\Rightarrow$ use existing services

Sensor Technology for the Upgrade

- **Keep present design:**
285 μm thick DOFZ Si
pixel size of $100 \times 150 \mu\text{m}^2$,
- n^+ -in-n: (already) radiation hard:
 - ▶ fluence of $1.5 \times 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$
expected during lifetime of Layer 1
 - ▶ for samples irradiated to
 $1.1 \times 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$
bias of 450 to 600 V sufficient
 - ▶ also gain from improvements on
thresholds (see next slide) $\Rightarrow$ Layer 1 can be efficiently operated
- p-spray (BPIX) or p-stop (FPIX) for
n-side isolation

New Readout Chip (ROC) Design

Current ROC:

- dead time free at low pixel hit rates, but
- up to 4% data loss at design luminosity
- up to 16% data loss at $2\times$ design lumi

Upgraded ROC design:

- increased readout link speed
(40 MHz analog $\rightarrow$ 160 MHz digital)
 - reduced data loss by additional buffers and increased buffer sizes
 - enhanced analog performance:
 - ▶ lower charge thresholds possible (reduced internal cross-talk)
 - ▶ reduction of time-walk effects (faster pixel cell comparator)
- $\Rightarrow$ improved performance in the presence of radiation damage

Pixel Detector Geometry: From 3 to 4 track points

- optimized detector layout for 4-hit coverage over full η range with minimal innermost layer radius
- ⇒ improves efficiency and resolution for pixel-only tracks important for:
 - ▶ High Level Triggering
 - ▶ full-track seeding ⇒ higher full track efficiency & lower fake track rate
 - ▶ vertexing: both primary (→ pile-up) and secondary (→ b -tagging)
- keep to available services:
 - ▶ DC-DC converters for increased power requirements
 - ▶ digital pixel read-out to meet bandwidth needs

Lower Material Budget

- even with additional layer ($\sim 50\%$ more modules!), reduce material budget through:
 - ▶ two-phase CO₂ cooling (low mass & small pipes possible)
 - ▶ ultra-lightweight mechanical support
 - ▶ moving passive material (electronic boards and connections) out of the tracking volume

Expected Performance: b -Tagging

- b -tagging relies on track impact parameter & primary vertex resolutions $\rightarrow$ sensitive to improvements in upgraded detector
- study performed on simulated $t\bar{t}$ sample with Combined Secondary Vertex algorithm w/o any tuning w.r.t. pile-up (PU), upgraded detector geometry or algorithm settings
- b -tagging performance significantly better for upgraded detector:
 - ▶ at zero PU: result of 4th pixel layer & smaller inner layer radius
 - ▶ at PU of 50: still better than current detector at PU of 25

Summary

- Upgrade of CMS pixel detector motivated by excellent performance of LHC as well as accumulated radiation damage
- Additional detector layer, reduced material budget and improved readout will maintain or even improve performance of current pixel detector at pile-up of 50 or higher
- Upgrade can be performed with minimal impact on other detector components (i.e. no new cables or pipes required)

New technical design report for the CMS pixel upgrade available:
<http://cdsweb.cern.ch/record/1481838>