Upgrades of the CMS Detector

Ivan K. Furić, University of Florida for the CMS collaboration
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LHC Timeline

LHC Phase 1

- LHC revisions necessary to run at 14 TeV
- Install collimation for \( \mathcal{L} \) beyond design (\( 10^{34} \text{ cm}^{-2}\text{s}^{-1} \))

7 TeV collisions
- Gather 1 fb\(^{-1}\)

14 TeV, peak \( \mathcal{L} \)
- \( \sim 10^{33} \text{ cm}^{-2}\text{s}^{-1} \)

\( \mathcal{L} \sim 1-2 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1} \)
- BX spacing 25 or 50 ns

Now 2012 2015-16 2020(+)

LHC Phase 2

ICHEP 2010 I.K. Furić, UF, Upgrades of the CMS detector
CMS Phase 1 Upgrades

- **Pixel Tracking System**: replace: radiation damage, data loss at full trigger rate
- **Muon System**: add redundancy in forward region, improve trig. primitives
- **Hadron Calorimeter**: depth segmentation, 1 ns timing, new, high gain photodetectors
- **Trigger**: cal. trigger - finer clustering & isolation, μ trigger - more coverage, meas. inputs
- **Data Acquisition System**: increase bandwidth \( \times 2-5 \)
CMS Muon System

Drift Tube (DT) chambers in central (barrel) region

Cathode Strip (CSC) chambers in forward region

Resistive Plate (RPC) chambers in both regions

outer ring, endcap station 4 currently not instrumented
Muon System Upgrades

- **RPC**: complete coverage
- **DT**: improve electronics, move trig. prim. syst. out of cavern
- **CSC**: complete coverage, improve trigger primitives
Hadron Calorimeter System

| Device                             | $|\eta|\text{ range}$ | absorber       | active material | photo-detector |
|------------------------------------|--------------------|----------------|-----------------|----------------|
| Barrel Hadron Calorimeter (HB)     | 0.0 - 1.5          | brass          | scintillator    | HPD            |
| Endcap Hadron Calorimeter (HE)     | 1.5 - 3.0          | brass          | scintillator    | HPD            |
| Outer Hadron Calorimeter (HO)      | 0.0 - 1.5          | brass + cryostat| scintillator    | HPD            |
| Forward Hadron Calorimeter (HF)    | 3.0 - 5.0          | steel          | quartz fiber    | PMT            |
| CASTOR                             | 5.2-6.6            | tungsten       | quartz plate    | PMT            |
| Zero Degree Calorimeter            | $|\eta| > 8.3$        | tungsten       | quartz fiber    | PMT            |

ZDC: $\sim$140 m

T1: $3.1 < \eta < 4.7$

T2: $5.3 < \eta < 6.5$

Symmetric experiment: all detectors on both sides!
Barrel, Endcap HCAL Upgrades

- replace photodetector - eliminate anomalous signals
- scintillator TDC - nanosecond timing to reject non-collision bg
- longitud. segmentation - reduce performance loss due to pile-up
Forward HCAL Upgrades

HF calorimeter - $\mu$ hitting PMT window fake high energy deposits

- replace PMT - thinner window, better shielding (metal envelope), four-way segmented anodes to reject muons hitting the PMT window

- CASTOR - replace PMTs with more radiation hard devices, replace light guides
Pixel Tracker Upgrade

• current pixel tracker designed to withstand ~200-300 fb⁻¹ of L

• not meant for L > 10^{34} cm⁻²s⁻¹:
  1st layer - 16% inefficient @ 2x10^{34}

• current system: 3 barrel layers, 2 disks

• upgrade: 4 barrel layers, 3 forward disks

• will provide 4 hit coverage up to |η|< 2.5

• less material than current system - ultra-light mechanics, CO₂ cooling
Pixel Tracker, cont’d

material: cooling, PCB flange, cabling..

smaller material budget, reduce innermost layer radius to 3.4 cm
L1 Trigger: Calorimeter

- increase granularity of calorimeter trigger internal processing
- exploit higher granularity - more sophisticated cluster algorithms & precise isolation
- state of the art Telecom technology to support required bandwidth
- prepare for matching with Level-1 Tracking trigger in Phase 2 LHC
L1 Trigger: Muon Trigger

- CSC muon finder - increased occupancy at high luminosities - redesign muon finding logic (cut based → pattern based)

- DT muon finder has complex internal connections - take advantage of new FPGAs, simplify system, maintenance

- RPC trigger - handle new RPC η coverage, new high η muon chambers
Phase 2: Tracker @ L1

- at \( \sim 10^{35} \text{ cm}^{-2}\text{s}^{-1} \), tracker information necessary to control trigger rate
- tracking in L1 trigger difficult - lots of combinations, little time (<4 \( \mu \text{s} \))
- a proposed solution: stacked Si layers
  proximity of stacks - reduced combinations
- deduce track \( p_T \) from tracklet direction, cut away soft tracks (do not point back to I.P.)
Conclusions

• LHC has started colliding; luminosity will keep increasing - detector upgrades maximize physics output

• CMS upgrade program staggered, track luminosity increase

• current focus: LHC Phase 1 upgrades

• fraction of upgrades shown target 2012 technical stop

• pixel upgrade target: 2015/16 technical stop

• all upgrades aligned to also prepare for Phase 2 (major new element - tracking at first level of the trigger)
Supporting Material
Why Upgrade?

- This decade will see the initial operation of the LHC and the increase of energy and luminosity towards design values.

- Goal of extended running in the second half of the decade is to collect ~100s/fb.

- This is the first phase of the LHC operation. Any upgrades during this phase are Phase I upgrades.

- Their motivation may be based on required performance for higher luminosity, better physics performance, better reliability of operation.
L1 Calorimeter Trigger

![Graphs showing efficiency as a function of E_{T} threshold for SLHC and LHC, with separate plots for isolated electrons and taus.](image-url)
Calorimeter Timing

HB Dataframe: Simulated jet, Noise [fC] from CRUZET3

threshold > 5 GeV in Total Energy

threshold > 30 GeV in total Energy

threshold > 60 GeV in total Energy
Isolated Electron EM fraction
Muon System Layout