



# Triggering interesting physics events with the upgraded CMS at the HL-LHC

#### Santeri Laurila CMS experiment

Nordic Winter School, Skeikampen 5 January 2019





































CMS Experiment at the LHC, CERN Data recorded: 2016-Oct-14 09:33:30.044032 GMT Run / Event / LS: 283171 / 95092595 / 195







PU=~130

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Higher luminosity → more pileup Average pileup of ~140-200 expected at HL-LHC Physics goals require sensitivity to EW scale physics → need to maintain low trigger thresholds

#### We need a fast and radiation-hard detector with high-granularity readout ...and a smart trigger

SUPERCONDUCTING SOLENOID Niobium titanium coil carrying ~18,000A

> MUON CHAMBERS Barrel: 250 Drift Tube, 480 Resistive Plate Chambers Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

> > PRESHOWER Silicon strips ~16m<sup>2</sup> ~137,000 channels

> > > FORWARD CALORIMETER Steel + Quartz fibres ~2,000 Channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL) ~76,000 scintillating PbWO<sub>4</sub> crystals

HADRON CALORIMETER (HCAL) Brass + Plastic scintillator ~7,000 channels NSTITUTE OF PHYSICS

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New tracker: less material, extended coverage, input to L1 trigger ...and a smart trigger

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4

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Additional muon chambers with extended coverage

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#### Additional muon chambers with extended coverage and improved readout system

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Improved readout in forward calorimeter

New calorimeter readout electronics in barrel and endcaps

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Improved readout in forward calorimeter

#### Total readout rate to L1 trigger increased from ~2Tb/s to ~50 Tb/s

New calorimeter readout electronics in barrel and endcaps

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## CMS Trigger System

- Without an efficient trigger, interesting data is wasted
- Level-1 Trigger
  - Hardware algorithms for a quick first decision



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![](_page_18_Figure_5.jpeg)

# CMS Trigger System

- Without an efficient trigger,
- Without an efficient trigger interesting data is wasted
- Level-1 Trigger
  - Hardware algorithms for a quick first decision
- High Level Trigger
  - Fast software reconstruction using the full event information

![](_page_19_Figure_7.jpeg)

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![](_page_20_Picture_0.jpeg)

![](_page_21_Picture_0.jpeg)

![](_page_22_Picture_0.jpeg)

![](_page_23_Picture_0.jpeg)

Storage

![](_page_24_Picture_0.jpeg)

![](_page_25_Figure_0.jpeg)

![](_page_26_Figure_0.jpeg)

### Level-1 Trigger Upgrade

![](_page_27_Figure_1.jpeg)

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### Level-1 Trigger Upgrade

Inputs from **Trigger Primitive** Tracker Calorimeters Muon systems **Generators** (TPGs) and **track** finders are combined in a 40 MHz correlator module before the final Full event Level-1 decision by the **Global Trigger** readout Trigger <del>3 µs</del> ~10 µs <del>100 kHz</del> 750 kHz TRK EC EB HB HF DT RPC CSC GEM Data High transfer level CSC GEM EB HF BM RPC HB TPG TPG TPG TPG TPG system trigger Barrel Endcap Track Endcap -1 kHz 7.5 kHz Barrel 📈 Muon 🔨 Muon Calo Finder Calo Track Track TPG TPG Trigger Finder Finder Storage **Correlator Trigger** New algorithms are being • CTdeveloped and tested PPS possible direct links from TF Global to take advantage of this BPTX possible direct links to GT Trigger new architecture BRIL L1 Trigger Project

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Expected Performance: Muons

![](_page_29_Picture_1.jpeg)

![](_page_29_Figure_2.jpeg)

Combining tracker and muon chamber signals leads to sharper turn-on (left) and lower rates (right) w.r.t. old configuration

![](_page_30_Figure_0.jpeg)

New algorithms matching tracks and calorimeter deposits outperform the old configuration, providing lower rates for a given efficiency (left) or threshold (right) 10<sup>3</sup>

#### Groundbreaking(!) upgrade work will continue, HL-LHC results to be discussed at Winter School 2029!

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Back-up slides

- 15M Higgs bosons / year (2017: 3M)
  - More precise Higgs couplings (probe for BSM!)
  - ✤ Higgs pair production → self-coupling (120K events)
  - Differential distributions, rare decays
  - Extensive BSM Higgs searches

![](_page_34_Picture_7.jpeg)

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![](_page_35_Figure_7.jpeg)

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![](_page_36_Figure_6.jpeg)

- SM precision measurements
  - **Top quark mass** resolution of ~0.1 GeV (currently ~1 GeV)
  - Vector boson scattering, triple-gauge couplings...

![](_page_36_Figure_10.jpeg)

![](_page_36_Picture_12.jpeg)

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![](_page_37_Figure_6.jpeg)

#### BSM searches

Discoveries or further exclusion of models

![](_page_37_Figure_9.jpeg)

- SM precision measurements
  - **Top quark mass** resolution of ~0.1 GeV (currently ~1 GeV)
  - Vector boson scattering, triple-gauge couplings...

![](_page_37_Figure_13.jpeg)

![](_page_37_Picture_14.jpeg)

![](_page_38_Picture_0.jpeg)

![](_page_38_Picture_1.jpeg)

![](_page_38_Picture_2.jpeg)

![](_page_39_Picture_0.jpeg)

![](_page_39_Picture_1.jpeg)

![](_page_39_Figure_2.jpeg)

![](_page_40_Picture_0.jpeg)

![](_page_40_Figure_1.jpeg)

14

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#### MTD: MIP Timing Detector

- Thin layer between
   tracker and calorimeters,
   covering |η|<3</li>
- Time-of-arrival measurement
   with time resolution of ~30 ps

LHCC-P-009 27 November 201

Read more:

![](_page_41_Picture_5.jpeg)

![](_page_41_Figure_6.jpeg)

Physics case:

- Improved vertexing
- Better lepton/photon isolation
  - → Smaller fake backgrounds
- ◆ Enhanced pileup jet subtraction
   → Improved VBS sensitivity and jet mass resolution
- More efficient b jet tagging

![](_page_41_Picture_13.jpeg)

#### ATLAS vs. CMS upgrades for HL-LHC HELSINKI INSTITUTE OF PHYSICS Kow Muon ATLAS CMS eutral mauron (e.g. Neutron) Photon Completely new trac New inner tracker Tracker Coverage up to $|\eta|=4.0$ Coverage up **Vew** timing dete n New timing detector Timing detector eoverage n age 2.4 New FE electronics Calorimeters all readout at 40 at 40 M Muon systems FE electronics ggerfinputs, wider ni cover<u>age</u> refined Increased latency hcreased latency Hardware trigger @ 1 MHZ Hardware trigger @ 750 ron Trigger neter Hardware tracking in HLT including teacking inform Iron return yoke interspersed 7.5 with Muon chambers HLT @ 10 kHz 16 7m

4m

3m

5m

6m

**0**m

1**m** 

2m

![](_page_43_Figure_0.jpeg)

- New global electron and photon algorithms reduce the rate by a factor of ~10 (left) while the efficiency decreases only ~10% (right)
- Fine-grained calorimeter input improves performance alone