Prospects for the LHC detector upgrades

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Searching for long-lived particles at the LHC
4th workshop of the LHC LLP community
Amsterdam, Oct 23-25th 2018
Run 1 and 2 Legacy

- Rich harvest in Run 1 and 2, from Higgs discovery to precise measurements of top mass, $B_s \rightarrow \mu \mu$ branching ratio, etc...
- The rise of LLP searches at hadronic collider!

- Need for higher luminosity to access the next level of statistical precision.
  - More precise measurement of Higgs boson properties and SM phenomena.
  - Higher sensitivity for both direct and indirect searches for new physics.
LS, Run, Upgrade, Phase 1 and 2, HL-LHC... ???

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LHCb Upgrade 1 strategy

<table>
<thead>
<tr>
<th>$\mathcal{L}_{\text{Instantaneous}} (cm^{-2}s^{-1})$</th>
<th>LHCb</th>
<th>LHCb Upgrade 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pile-up</td>
<td>1.1</td>
<td>6</td>
</tr>
<tr>
<td>b-hadron per evt.</td>
<td>0.003</td>
<td>0.02</td>
</tr>
<tr>
<td>c-hadron per evt.</td>
<td>0.04</td>
<td>0.22</td>
</tr>
<tr>
<td>light, long-lived per evt.</td>
<td>0.51</td>
<td>2.08</td>
</tr>
</tbody>
</table>

Current LHCb: 40MHz → Hardware trigger → 1MHz → Software trigger → 0.8GB/s

Upgraded LHCb: 40MHz → Software trigger → 2-5GB/s

- Remove hardware trigger bottleneck → 40MHz readout and full software trigger.
- Adapt the detectors to maintain high physics performances (occupancy, radiation,...).
- High quality online reconstruction → Online alignment/calibration.

Physics reach bottleneck @ higher luminosity
New detector
Scintillating fibers + SiPM

New detector
Silicon strip

New detector
Silicon pixel

New photo-detectors + new optics (RICH1)

Remove first muon station, preshower and scintillating pad detectors

+Upgraded electronics, trigger and data acquisition system
40 MHz readout. Aggregate 40 Tbit/s.

Tracking, followed by high efficiency
1-, 2-displaced tracks inclusive selections
→ reduce to 1 Tbit/s

Disk buffering and online
calibration/alignment mechanisms
demonstrated in Run 2.

Full reconstruction including particle
identification + pure and efficient
exclusive selections

[arXiv:1604.05596]

Turbo stream for high rate signals
→ Analysis on trigger object, only save
what is necessary from the event

- Challenging project using modern computing methods.
  → Upgrade Software and Computing TDR [CERN-LHCC-2018-007]
LHCb Upgrade 1
The tracking system [CERN-LHCC-2013-021,CERN-LHCC-2014-001]

Planar n-in-p sensors
50x50 μm² pixels

Closest pixel @ 5.1 mm

Improved impact parameter resolution, efficiency and ghost rate.
Trigger have to select between signal and interesting signal.
- Probably need dedicated hardware for tracking.
- Timing will be crucial to minimize combinatorics and PV mis-association
ATLAS phase I upgrade - LS2

- New Small Wheel micromegas + sTGC
- LAr Calo New readout finer granularity in L1
- FastTracKer track info @ SW trigger input
- New detector (installed 2016) AFP (forward proton)

+ TDAQ modification to cope with modified detector and higher lumi than anticipated

- Consolidation of LHC ATLAS - Preparation for HL-LHC ATLAS
CMS phase I upgrade - LS2

- HCAL Upgrade HPD--->SiPM
  - End-cap done in 2017/2018
- CSC endcap muon chamber
  - New front-end
- Installation of GEM chamber
  - GE1/1
- Installation of Phase2 beam pipe

+ Trigger modification to accomodate Muon and Calo changes

Consolidation of LHC CMS / Preparation for HL-LHC CMS
Higher pile-up → Higher occupancy → Need higher detector granularity.

- Increase HW trigger latency and enhanced processing capabilities to maintain good efficiency.
- Hardware tracking to provide track information to the trigger.
- Timing and fine granularity to provide pile-up mitigation capabilities.

Major modification of the detector, trigger and DAQ system.
ATLAS Upgrade

Inner tracker
Si Pixel

New detector

RPC in inner most layer
+ new MDT readout

Outer tracker
Si Strip

New detector

Inner tracker
Si Pixel

LAr Calorimeter
higher granularity in FE and BE

Tile Calorimeter
new readout

New detector

Timing plane HGTD
$\sigma_t \sim 30$ ps

+ TDAQ modification to cope with modified detector and higher lumi (including tracking in hardware)

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New readout for Muon system
+ new stations $1.6<\eta<2.4$
+ TDAQ modification to cope with modified detector
  and higher lumi (including tracking in hardware)

ECAL Barrel readout
→ full granularity @ 40MHz

MIP timing
$\sigma_t \sim 30\text{ps}$

End-cap Calorimeter
4D showers, $\sigma_t \sim 20\text{ps}$

New detector
Outer tracker
Si macro-pixel + strip

New detector
Inner tracker
Si Pixel

+ TDAQ modification to cope with modified detector
  and higher lumi (including tracking in hardware)
- Tracking in trigger + higher granularity:
  → Maintain/improve performances of single-lepton trigger, ie. sensitivity to EW scale physics.

- Pile-up mitigation technics using tracks in the trigger:
  → Large improvement in hadronic triggers wrt. Phase I, ex. $HT < 350$ GeV instead of $HT < 700$ GeV
Reduced material budget wrt. Phase I

Extended $\eta$ coverage.

Pixel: mix of technologies, planar n-in-p, 3D, CMOS $50 \times 50$ and $25 \times 100 \mu m^2$

Strip:
- CMS: back-to-back sensors, $p_T$ measurement in the readout
- ATLAS: stereo-angle between sensors on double sided structure.

A lot of optimisation to minimize the pile-up influence (computing time, b-tagging, jet-reco, …)
**Calorimetry**

**ATLAS [ATLAS-TDR-022] / CMS [CMS-TDR-015,CMS-TDR-019]**

**ATLAS**

- New readout with increased granularity @ 40MHz
  - Better energy resolution / signal discrimination at trigger level.

**CMS**

- ECAL barrel: Full crystal granularity readout to the backend + improved shaping in VFE
  - 30 ps resolution, better trigger information

- Forward calorimeter HGCAL:
  - Very high granularity
    - “particle flow” calorimetry.
  - Silicon: 6 M channels 0.5-1cm²
  - Plastic scintillator + SiPM.
Timing

CMS
- LYSO:Ce crystals with SiPM (Barrel), $O(cm^2)$ channels
- LGAD Silicon sensors (Endcaps), $O(mm^2)$ channels
- 30-40 ps per tracks.
- Coverage $\eta < 3$

ATLAS
- LGAD Silicon sensors , $O(mm^2)$ channels
- 30 ps per tracks.
- Coverage $2.4 < \eta < 4$

Key component for pile-up mitigation techniques, in particular for jet reconstruction. Compliment calorimeter timing informations
Outlook

- Another $\sim 150 fb^{-1}$ to be collected by ATLAS CMS phase I detectors.
- LHCb Upgrade I soon to be installed, $50 fb^{-1}$ by 2029, $300 fb^{-1}$ by 2036 if Upgrade II.
- ATLAS and CMS will be fully upgraded by 2026, expect $3000 fb^{-1}$ by 2037

- The hardware modifications opens new possibilities for LLP community:
  - Tracks in the trigger $\rightarrow$ vertex in the trigger.
  - Timing information for mip / calo deposit $\rightarrow$ sensitivity to delayed vertex / calo deposit.
  - Proton tagging $\rightarrow$ low mass long-lived ?
  - RPC muon trigger provide coverage down to $\beta = 0.3$.

- But it requires time to get a new trigger line / develop new tools

$\rightarrow$ Need to think ahead!

[JINST 13, P06008 (2018)]

hadronic interactions
infered material map