Prospects for the LHC detector upgrades

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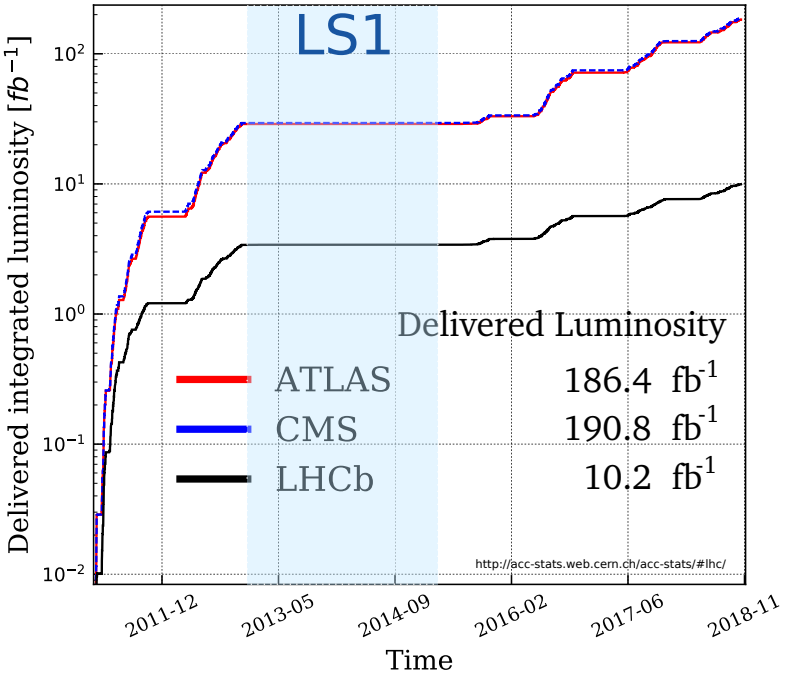
CERN

October 23, 2018

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

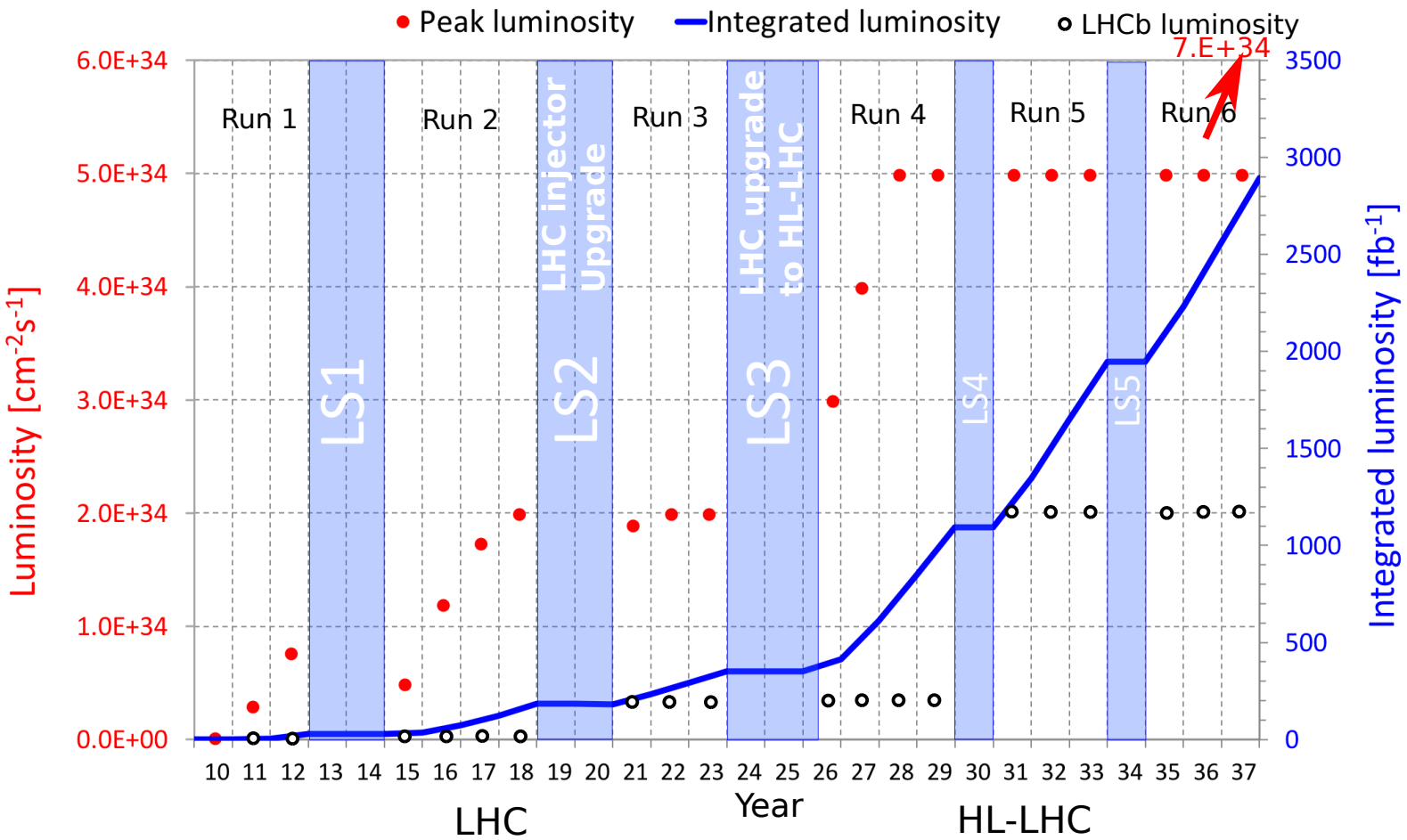
Run 1 and 2 Legacy



- Rich harvest in Run 1 and 2, from Higgs discovery to precise measurements of top mass, $B_s \to \mu\mu$ 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... ???

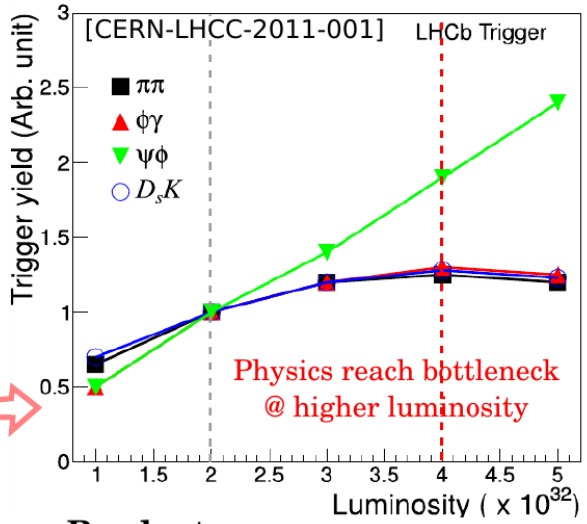


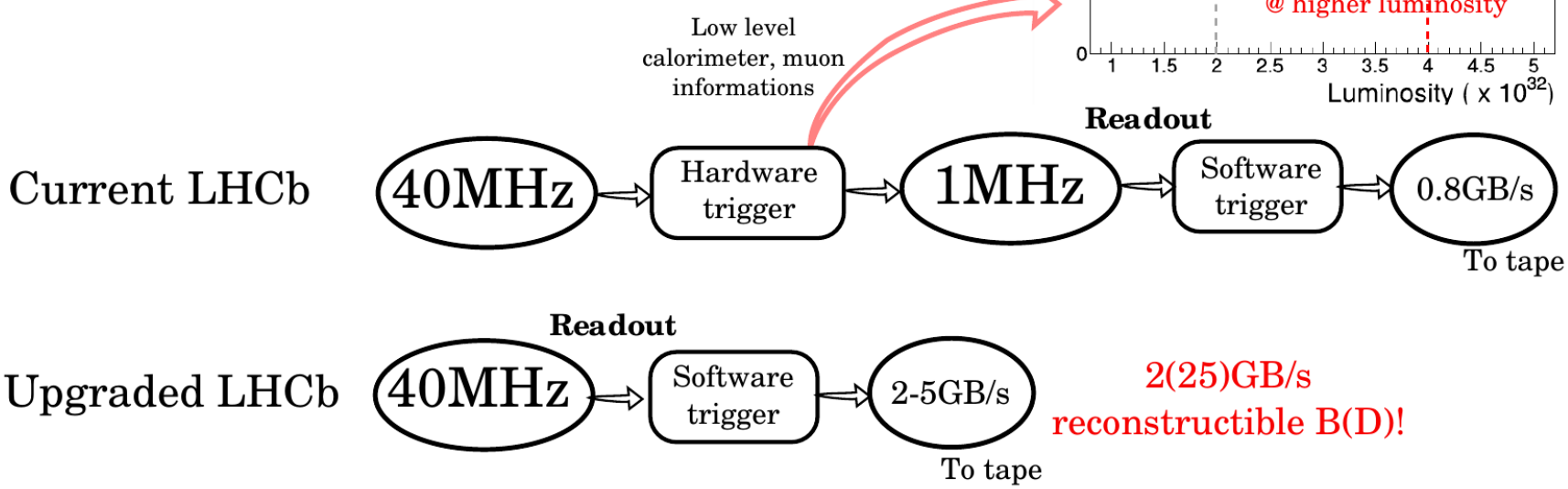
	Phase I		Phase II
LHCb	Upgrade I	Upgrade I consolidation	Upgrade II
ATLAS	consolidation /preparation	Upgrade	
CMS	consolidation /preparation	Upgrade	

LHCb Upgrade 1 strategy

	LHCb	**LHCb Upgrade I**
$\mathcal{L}_{Instantaneous}$ $(cm^{-2}s^{-1})$	4×10^{32}	$\mathbf{2\times10^{33}}$
Pile-up	1.1	**6**
b-hadron per evt.	0.003	**0.02**
c-hadron per evt.	0.04	**0.22**
light,long-lived per evt.	0.51	**2.08**

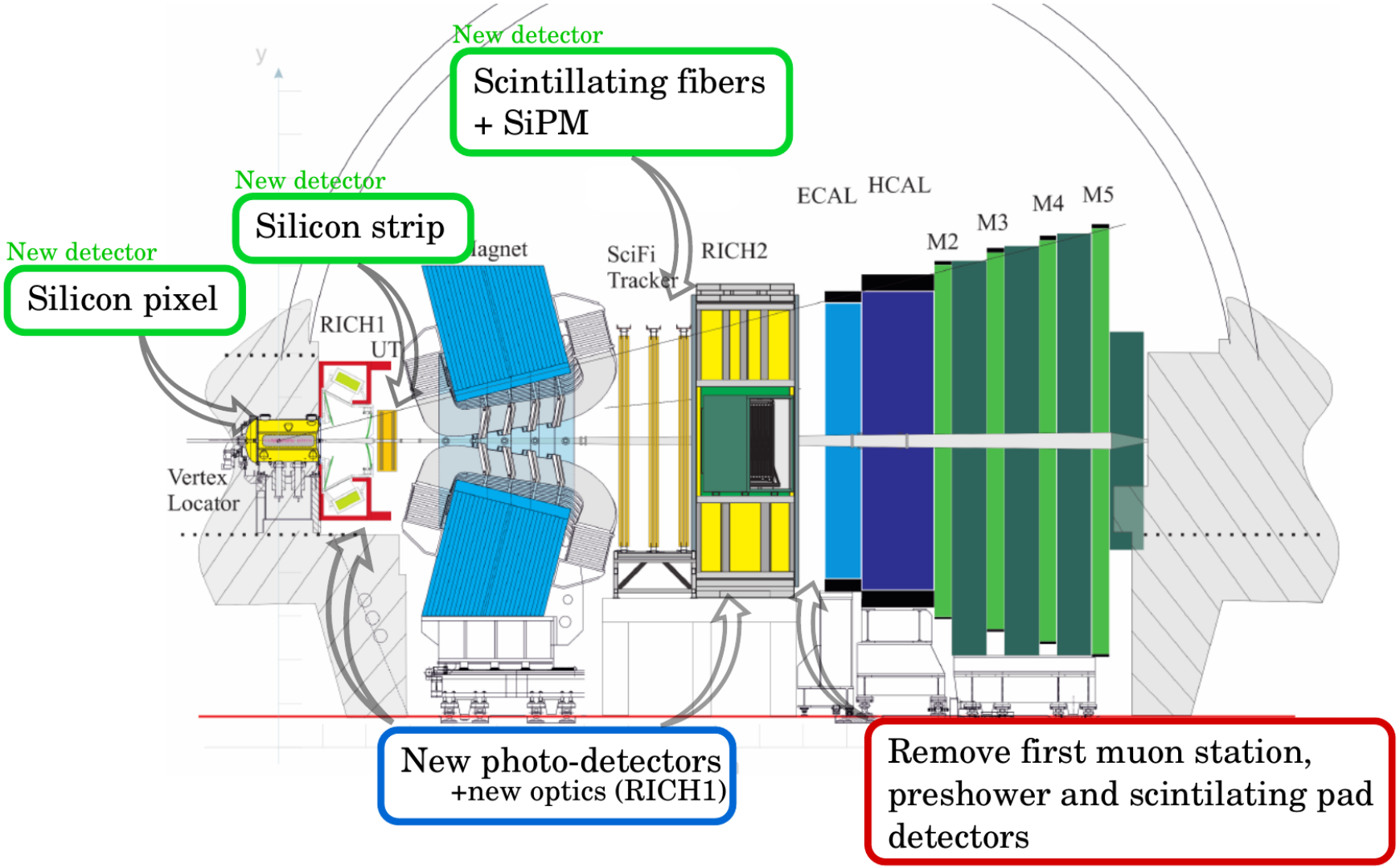
[LHCb-PUB-2014-027]





- 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 alignement/calibration**.

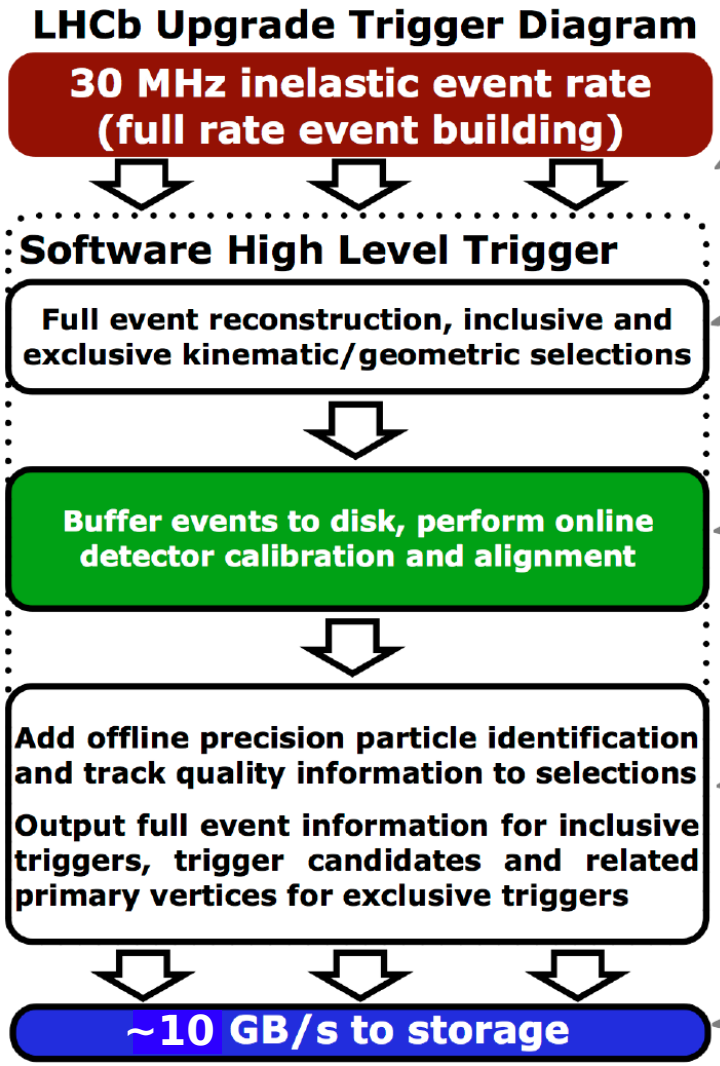
LHCb Upgrade 1



+Upgraded electronics, trigger and data acquisition system

LHCb Upgrade 1

The trigger: the upgrade workhorse



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/alignement mechanisms demonstrated in Run 2.

Full reconstruction including particle identification + pure and efficient exclusive selections

[arXiv:1604.05596]

Turbo stream for high rate signals

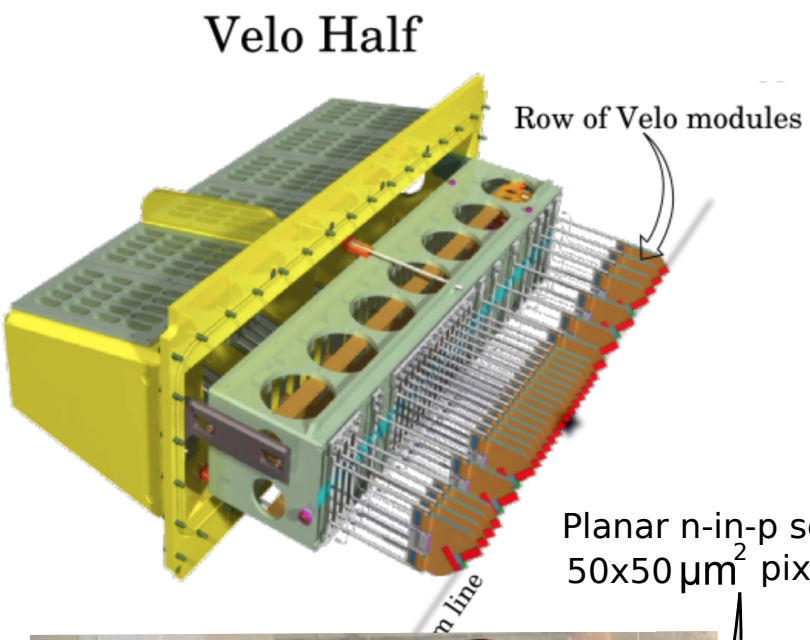
→ Analysis on trigger object, only save what is necessary from the event

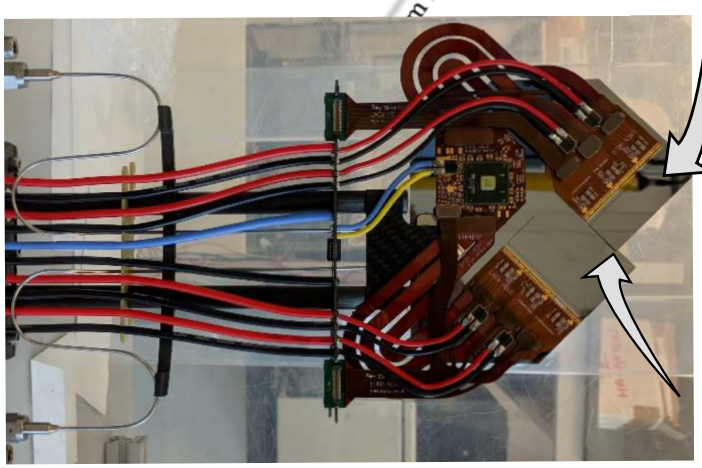
- Challenging project using modern computing methods.

  → Upgrade Software and Computing TDR [CERN-LHCC-2018-007]

LHCb Upgrade 1

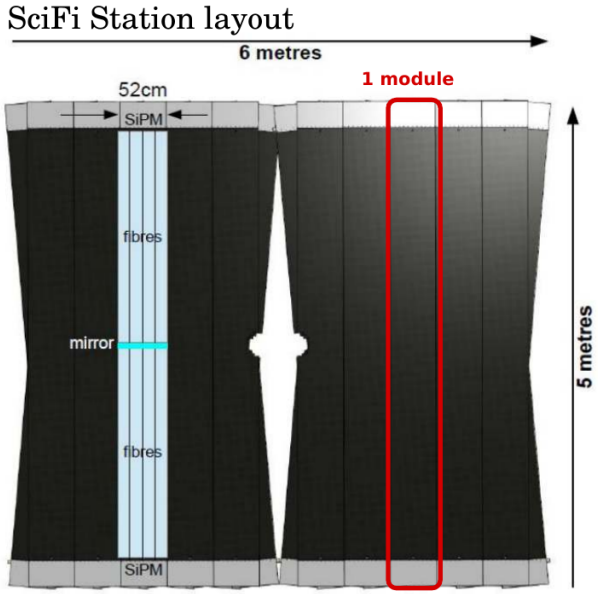
The tracking system [CERN-LHCC-2013-021,CERN-LHCC-2014-001]

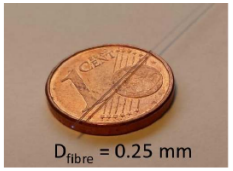




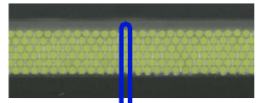
Planar n-in-p sensors
50x50 μm^2 pixels

Closest pixel
@5.1 mm

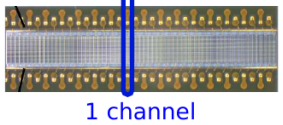




Fiber



Fiber Mat



Silicon PM

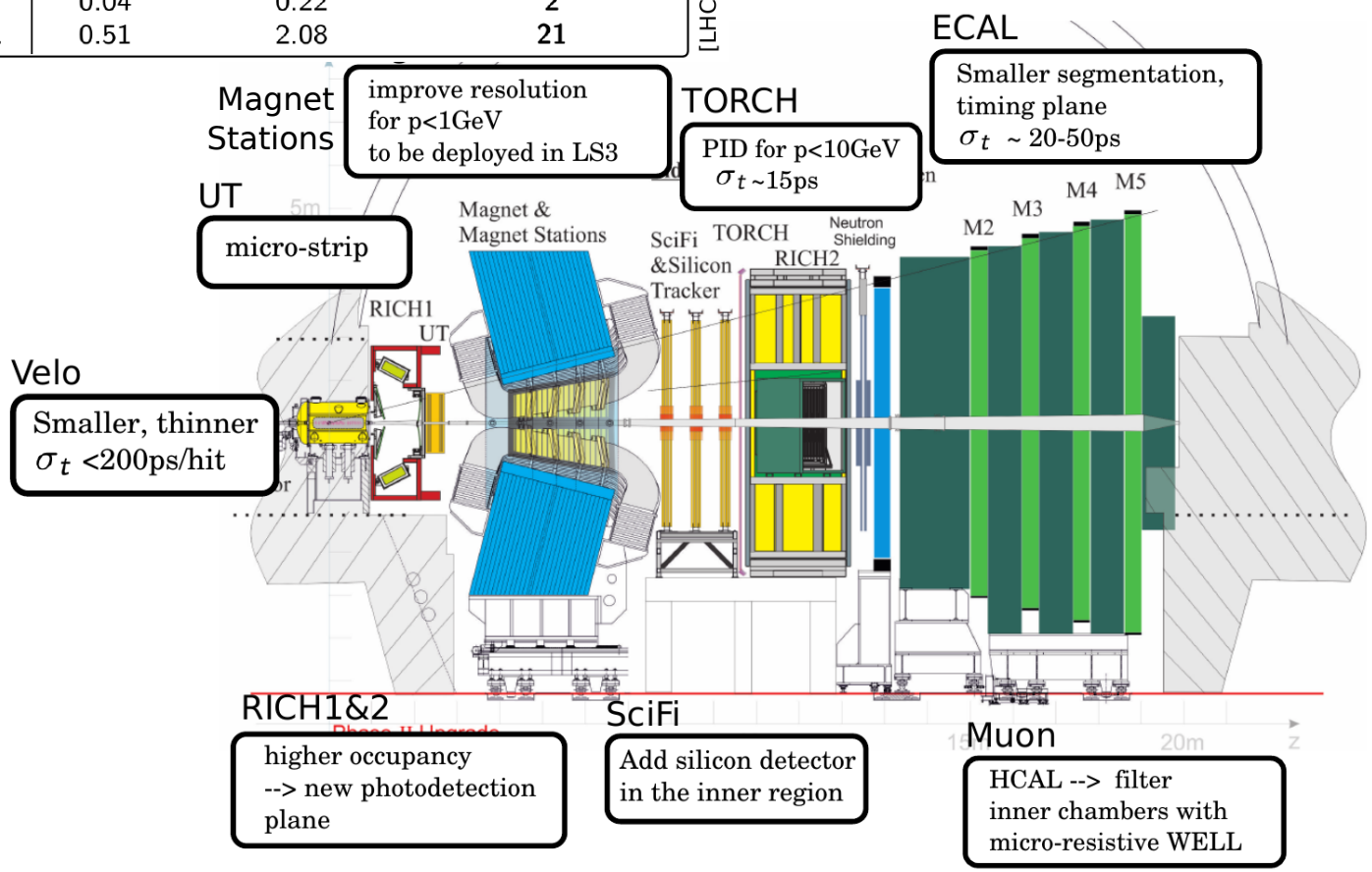
Improved impact parameter resolution, efficiency and ghost rate.

LHCb Upgrade 2

EOI [CERN-LHCC-2017-003] and Physics case [CERN-LHCC-2018-027]

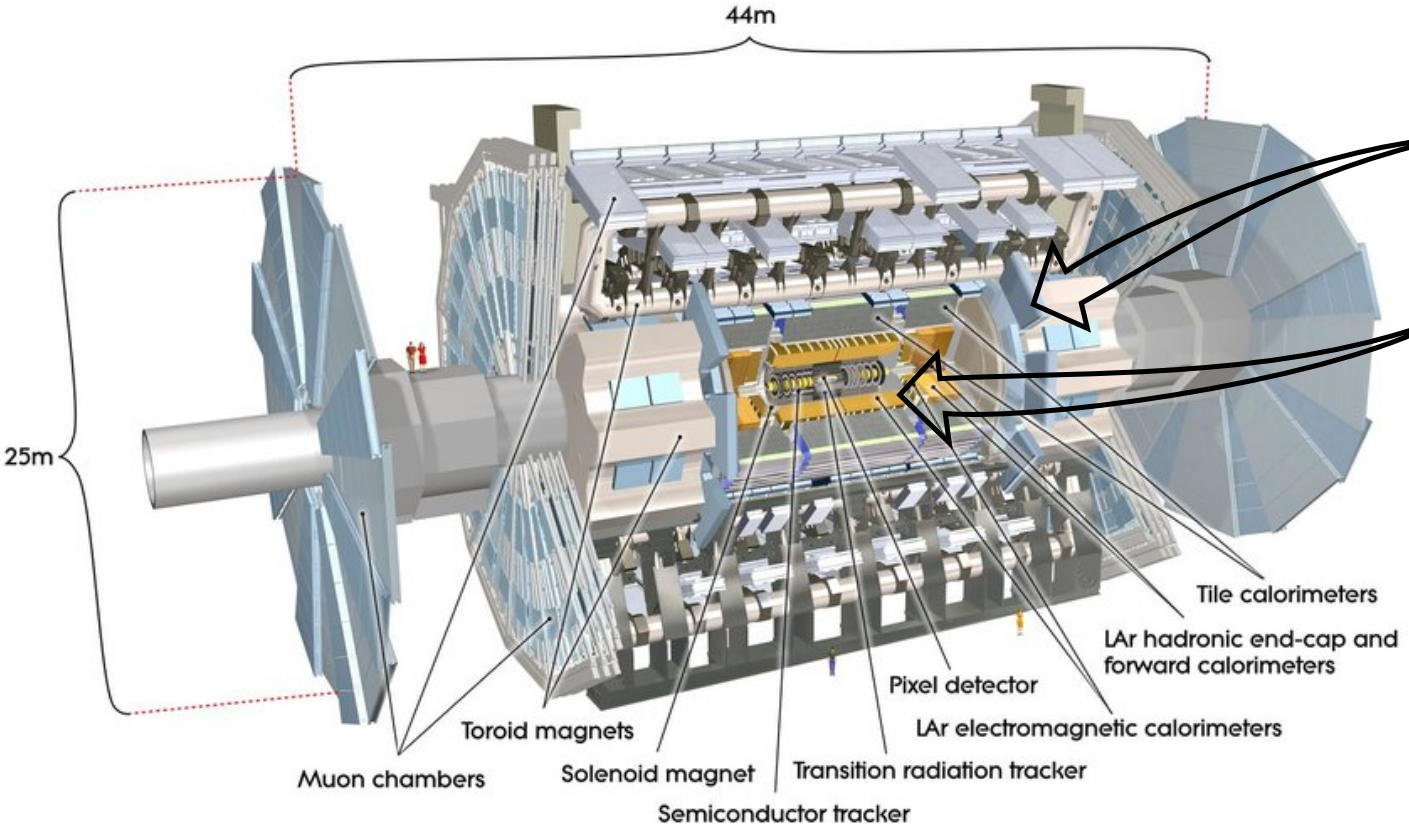
	LHCb	LHCb Upgrade I	LHCb Upgrade II
$\mathcal{L}_{instantaneous}$ $(cm^{-2}s^{-1})$	4×10^{32}	2×10^{33}	$\mathbf{2 \times 10^{34}}$
Pile-up	1	6	**60**
b-hadron per evt.	0.003	0.02	**0.2**
c-hadron per evt.	0.04	0.22	**2**
light,long-lived per evt.	0.51	2.08	**21**

[LHCb-PUB-2014-027]



- 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 detector

New Small Wheel
micromegas + sTGC

LAr Calo New readout
finer granularity in L1

FastTracKer
track info @ SW trigger input

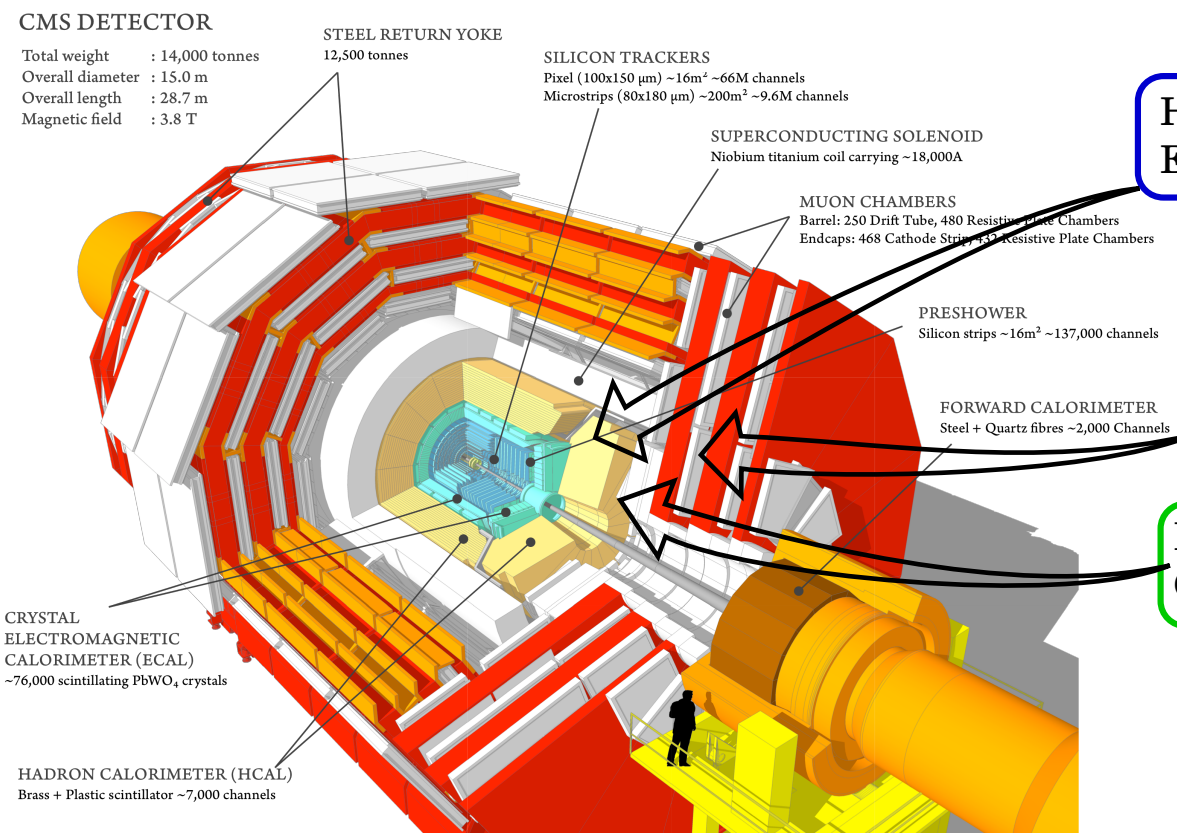
New detector (installed 2016)

AFP (foward 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

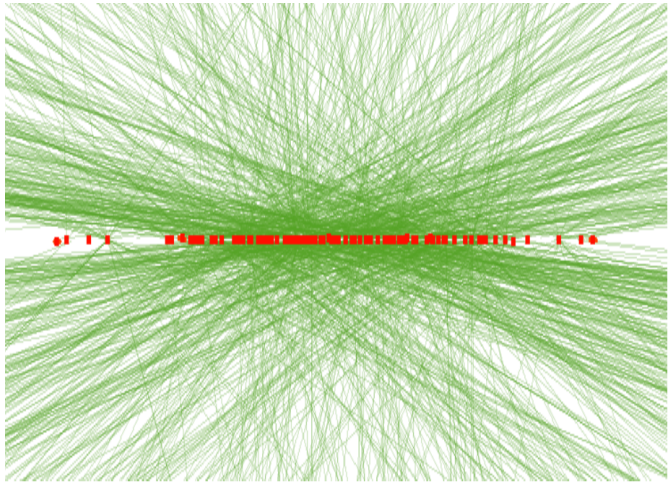
+ Trigger modification to accomodate Muon and Calo changes

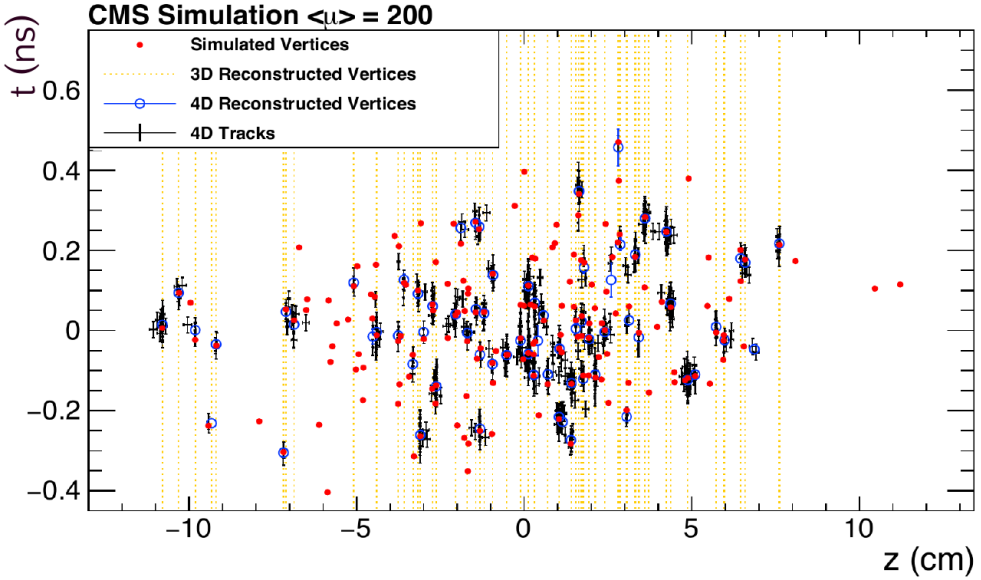
- Consolidation of LHC CMS / Preparation for HL-LHC CMS

Phase II upgrade stategy

	Phase I (LHC)	Phase II (HL-LHC)
$\mathcal{L}_{instantaneous}$ $(cm^{-2}s^{-1})$	2×10^{34}	$5 - 7.5 \times 10^{34}$
Pile-up	55	140-200

Fluences up to $10^{16} n_{eq}.cm^{-2}$

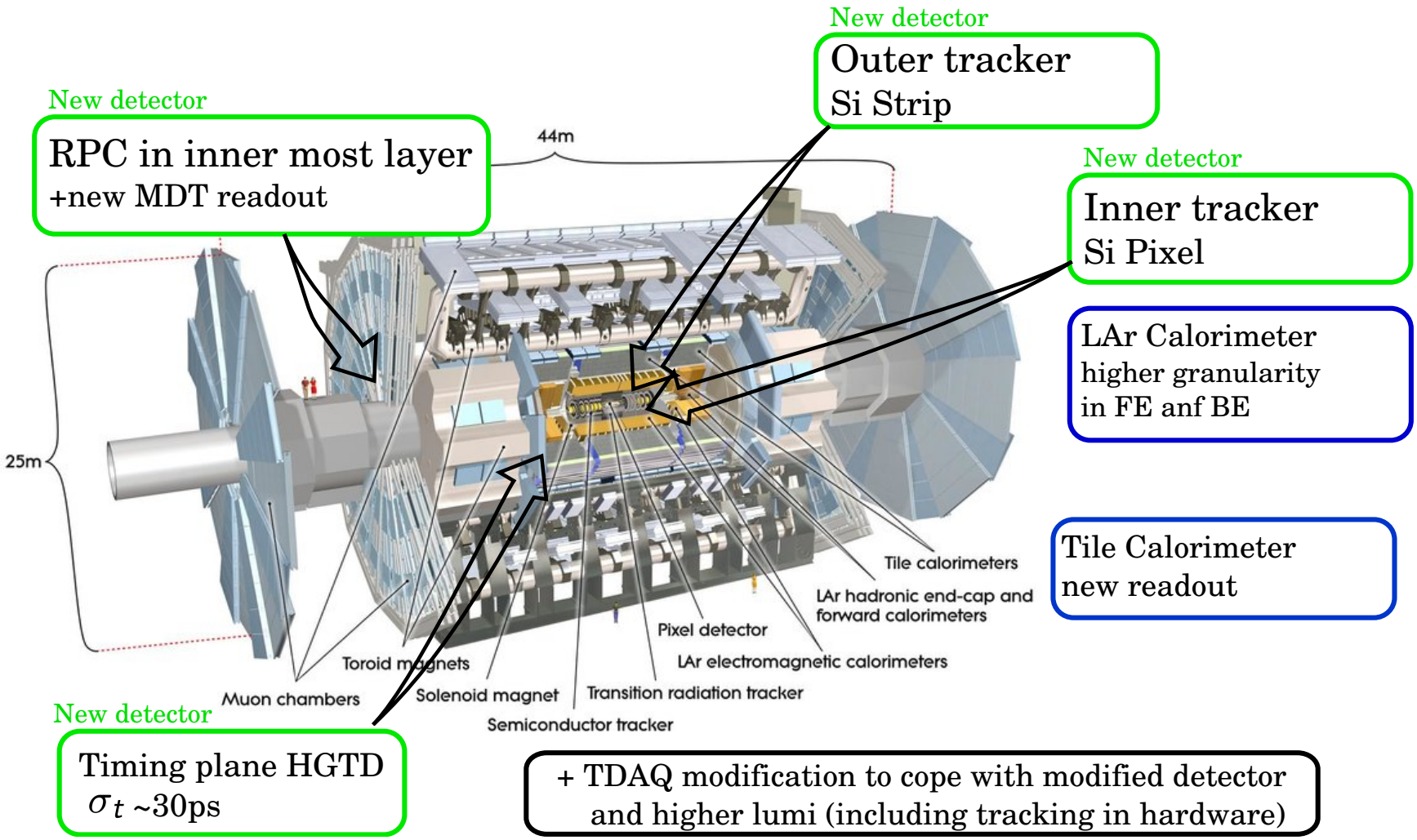




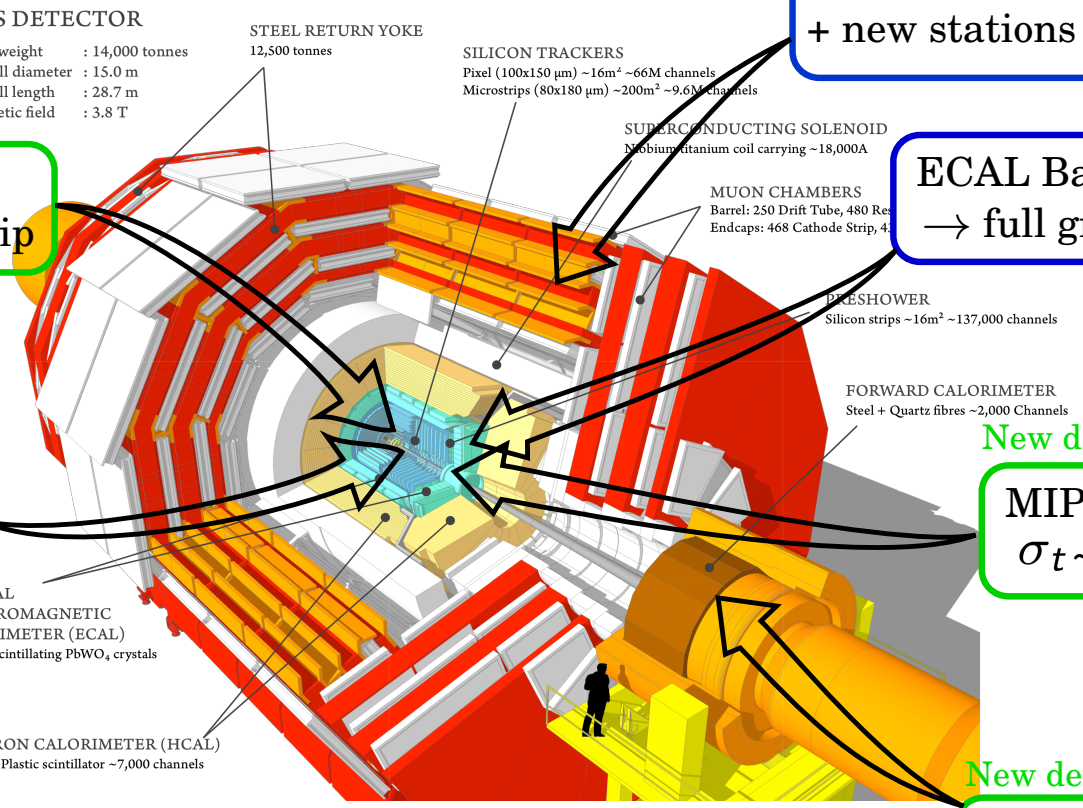
- Higher pile-up → Higher occupancy → Need higher detector granularity.
- Increase HW trigger latency and enhanced processing capabilities to maintain good efficiency.
- Hardware tracking to provide track information to the trigger.
- Timing and fine granularity to provide pile-up mitigation capabilities.

Major modification of the detector, trigger and DAQ system.

ATLAS Upgrade



CMS Upgrade



New detector

Outer tracker
Si macro-pixel + strip

New detector

Inner tracker
Si Pixel

New readout for Muon system
+ new stations $1.6<\eta<2.4$

ECAL Barrel readout
$\rightarrow$ full granularity @ 40MHz

New detector

MIP timing
σ_t~30ps

New detector

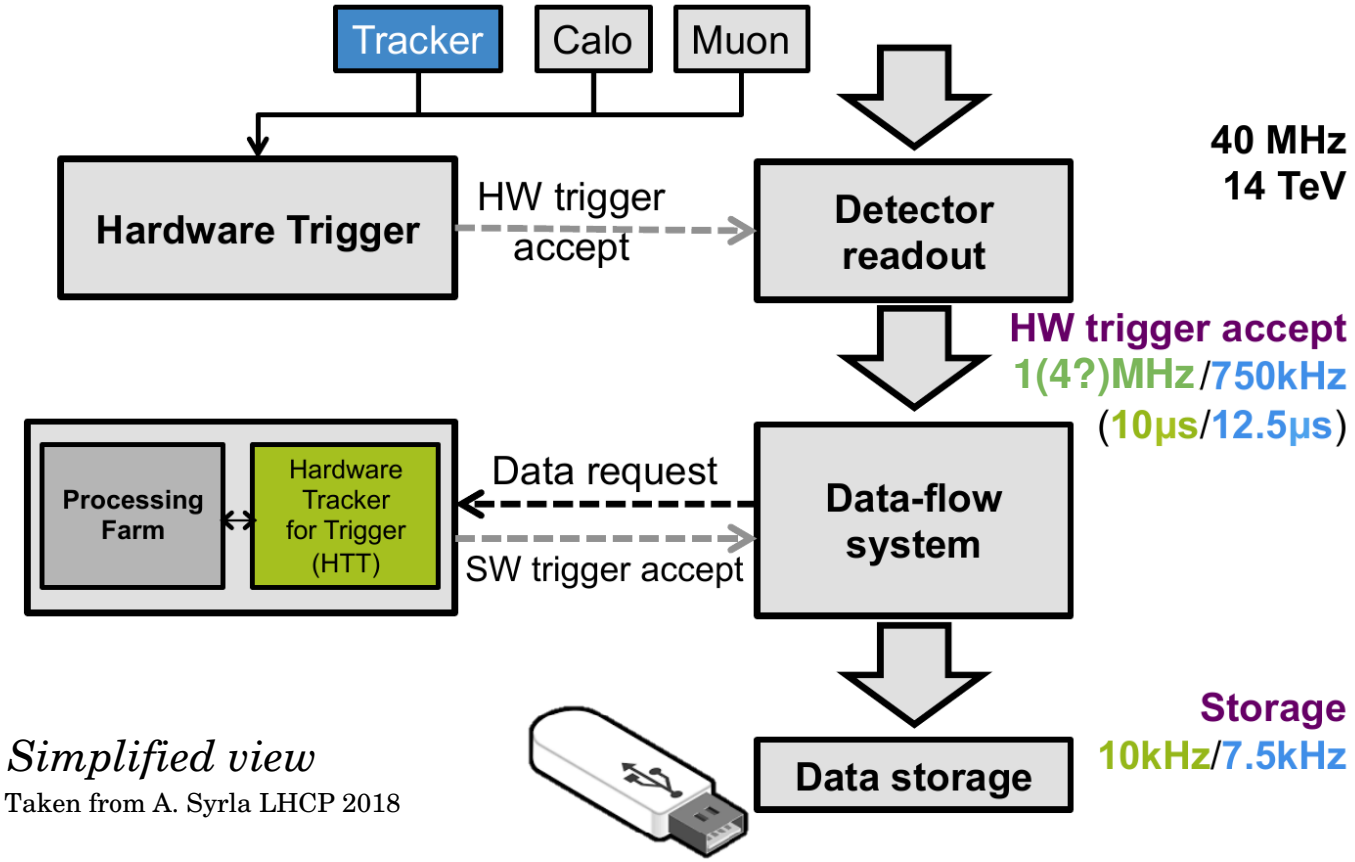
End-cap Calorimeter
4D showers, σ_t~20ps

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

Trigger

ATLAS [CERN-LHCC-2017-020] / CMS [CERN-LHCC-2017-013,014]

ATLAS/CMS



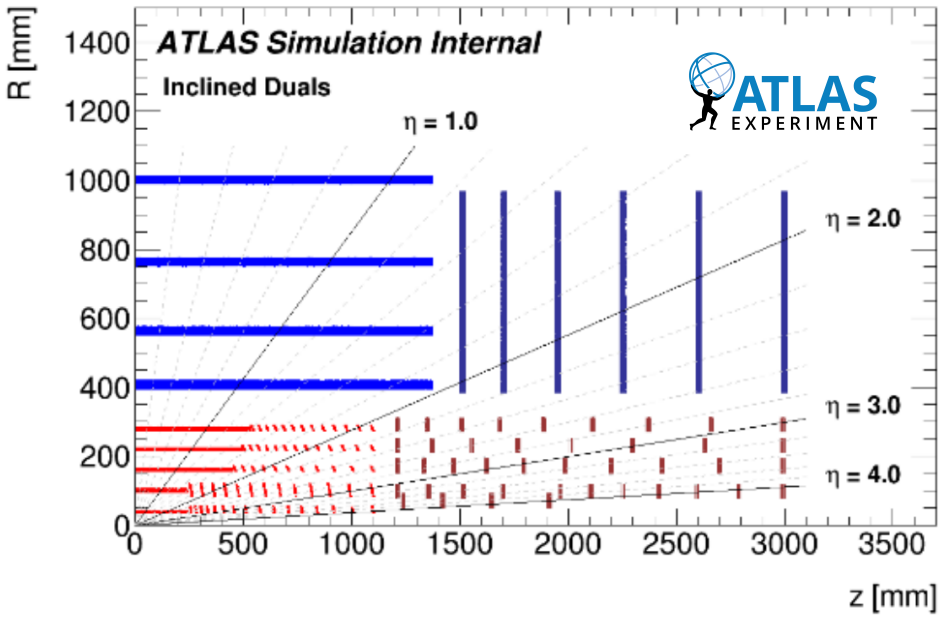
Simplified view

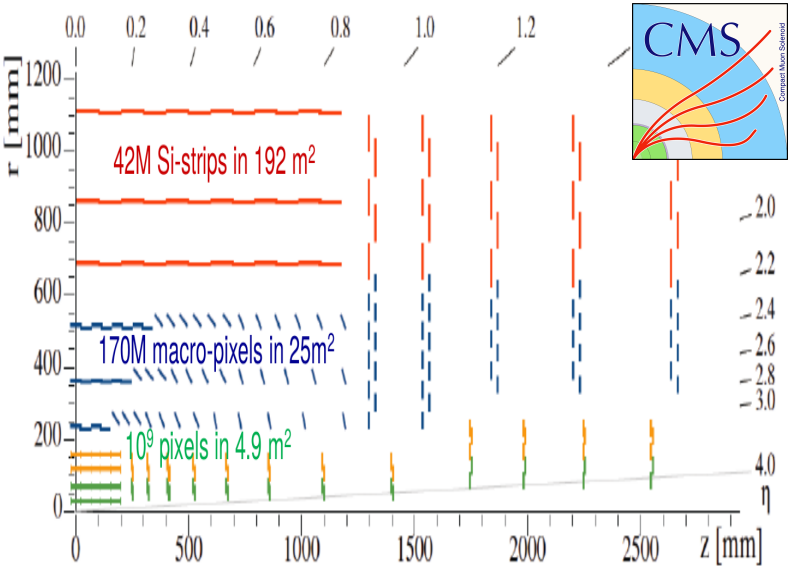
Taken from A. Syrla LHCP 2018

- 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 $HT < 700\ GeV$

Tracking

CMS [CERN-LHCC-2017-009] / ATLAS [CERN-LHCC-2017-005,CERN-LHCC-2017-021]





- Reduced material budget wrt. Phase I
- Extended η coverage.
- Pixel: mix of technologies, planar n-in-p, 3D, CMOS 50×50 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.

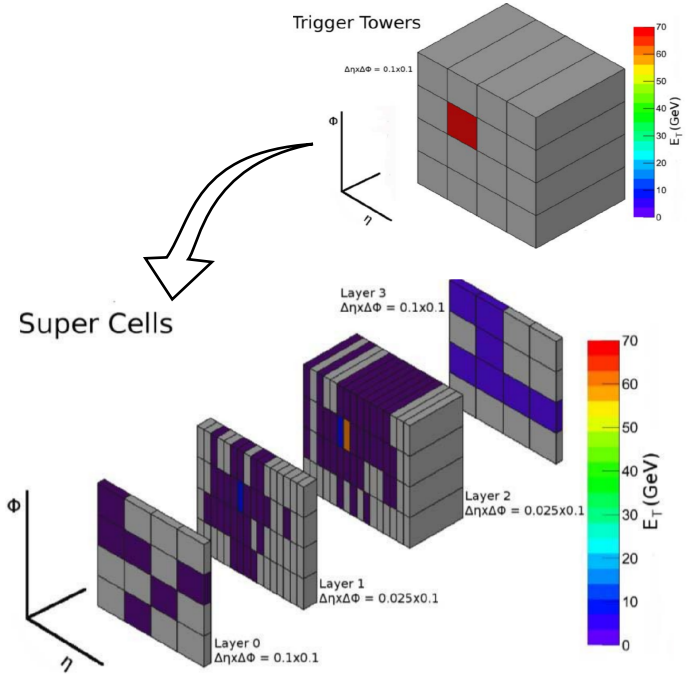
CMS

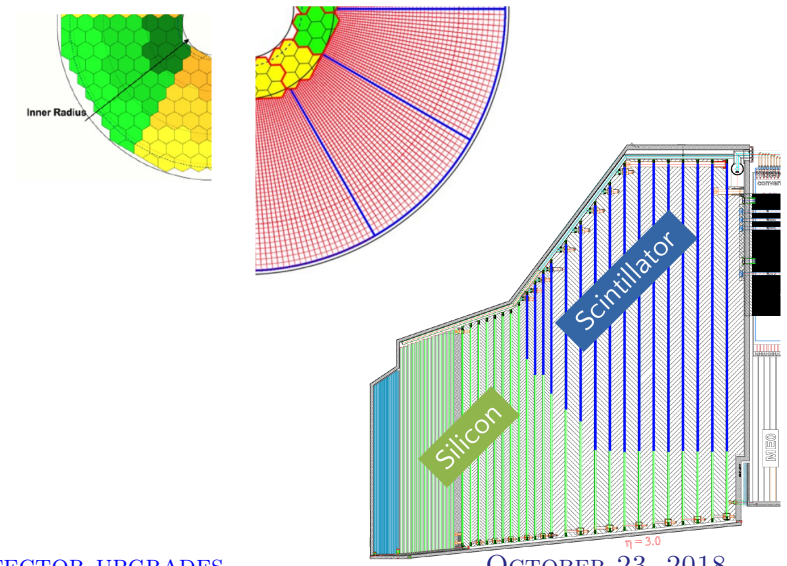
- ECAL barrel: Full crystal granularity readout to the backend + improved shaping in VFE

  → 30 ps resolution, better trigger information

- Forward calorimeter HGCAL:
  - Very high granularity

    → "particle flow" calorimetry.
  - Silicon: 6 M channels 0.5-1cm^2
  - Plastic scintillator + SiPM.





Timing

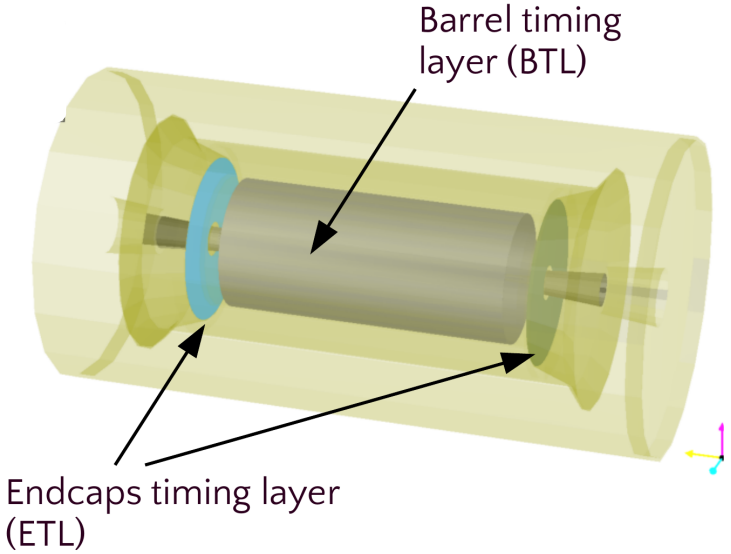
CMS

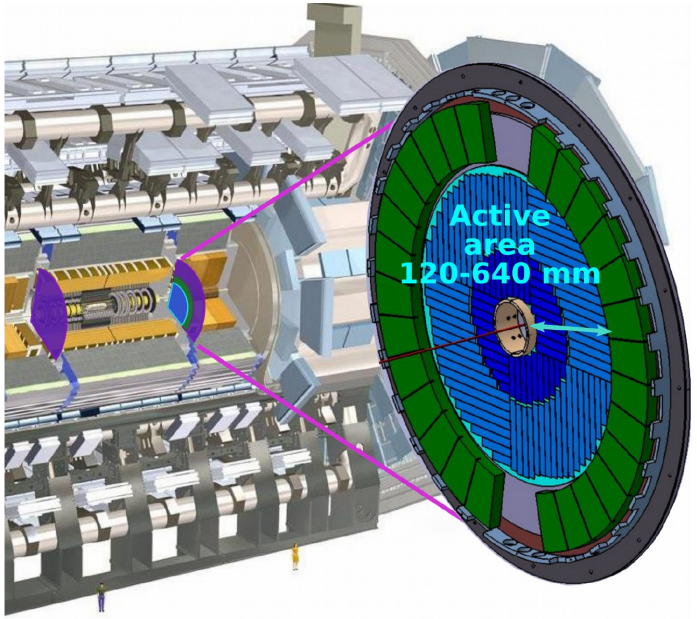
- LYSO:Ce crystals with SiPM (Barrel), $O(cm^2)$ channels
- LGAD Silicon sensors (Endcaps), $O(mm^2)$ channels
- 30-40 ps per tracks.
- Coverage $\eta < 3$

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





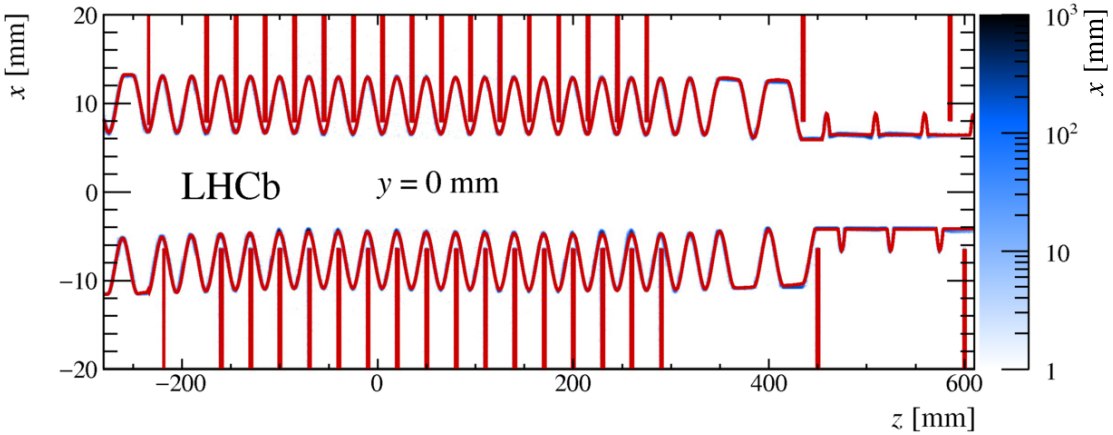
Outlook

- 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