



ECFA HL-LHC expts workshop: 1-3 Oct

objectives



ECFA High Luminosity LHC Experiments Workshop
Physics and technology challenges
1st – 3rd October
Aix-les-Bains
France

<https://indico.cern.ch/conferenceDisplay.py?confid=252045>

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Logos at the bottom: aix-les-bains centre des congrès, ECFA, High Luminosity LHC, ALICE, ATLAS, CMS, LHCb, LHCf, CERN

From Opening talk:

Help define the upgraded HL-LHC detectors and physics program for many years to come at the LHC.

In particular:

- Develop a common approach to the HL-LHC program; identify synergies and possible common efforts.
- Provide a consistent presentation of physics goals, detector requirements and technology R&D needed, also accelerator interfaces, long shutdown constraints, and costing methods.
- Identify areas for further joint HL-LHC workshops.
- Provide a summary report to ECFA.



EFCA HL-LHC expts workshop: 1-3 Oct

Motivation: ESPP document adopted by Council in May

c) The discovery of the Higgs boson is the start of a major programme of work to measure this particle's properties with the highest possible precision for testing the validity of the Standard Model and to search for further new physics at the energy frontier. The LHC is in a unique position to pursue this programme. *Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.*

Strategy explicitly recommends 3 ab⁻¹ target

DG → we should consider this tacit approval for the HL-LHC programme and proceed.

Further evaluation of:

- physics reach
- technical feasibility for expts and machine
- timeline & cost estimates

needed for formal approval by Research Board, Council, Funding Agencies

.....the workshop in Aix was a step along this road



3 Days, 10 sessions (prep group for each)

<https://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=252045>

Opening*: European strategy, HL-LHC, Expt upgrade programmes, CERN perspective

Physics Goals, Theoretical Developments & Performance Reach:

Theory Overview, Higgs physics, Physics beyond SM,
Input to upgrade spec, Heavy Flavours, Heavy Ions

Accelerator & Experiments Interface *:

Special requests, pile-up, instrumentation, protection systems

LS constraints, radiation & activation including infrastructure changes *:

Electronics & Readout: IC's, power, modular electronics, high speed links:

Tracking systems: Overview, sensors, electronics, thermal management *, summary

Calorimetry systems: Overview, electronics, detector, summary

Muon systems: Challenges, longevity, detector/trigger upgrades, new gaseous detectors

Trigger/DAQ/offline/Computing: technologies, trigger/DAQ, computing, software

Closing*: Machine interface & LS constraints, Physics goals & detector requirements
Technology and R & D, Conclusion.



This talk



Not at all a summary talk. These highlights are my selection of topics possibly relevant to RLIUP & include recollections (possibly flawed) of some of the discussions provoked.

The “physics landscape” 30fb-1 \rightarrow 300fb-1 \rightarrow 3000fb-1 and thus the physics potential of the HL-LHC will be covered by **Fabiola**.

The need to upgrade certain key detector elements of ATLAS and CMS for ANY programme beyond 300fb-1 will be addressed by Beniamino

The role of the upgrade changes in mitigating the high rate, high pile-up conditions of HL-LHC needed to reach the 3000fb-1 target in a reasonable timescale will be discussed by **Didier**. Prospects for pile-up mitigation by tuning the luminous region will also be discussed.

Richard will cover physics motivation & realisation of the LHCb upgrade, plus the forward physics and ALICE p-p programmes.

Which leaves **Mike** as the victim trying to fit the disparate requirements for operation and upgrade into a workable schedule for the LHC and injectors, taking into account accelerator consolidation and upgrade options



ATLAS & CMS ongoing upgrades

Both ATLAS and CMS have approved and funded pre HL-LHC upgrades (Phase 0 &/or 1) underway in LS1, continuing in tech stops and in parallel with Run2, concluding in LS2.

Objectives : - reach target 300fb⁻¹ with some margin; coping with pile-up > design
- start making provision for another 20 years operation after that

Complete the detectors as originally conceived for 10³⁴ (mostly muon systems)

Correct faults, oversights or vulnerabilities exposed during Run 1 (incl cooling, power, etc)

Improve capability to match LHC conditions in Runs 2 & 3 (bp + 4-lyr pix, calorimeters, trigger)

Start consolidation for an active lifetime 10 years → 30 years (eg magnet cryo)

The LS1 programmes of both experiments are proceeding approximately on schedule

After LS1:

ATLAS

Final Phase I upgrades: LS2

New muon small wheels

Revise calorimeter R/O electronics

Improved Trigger

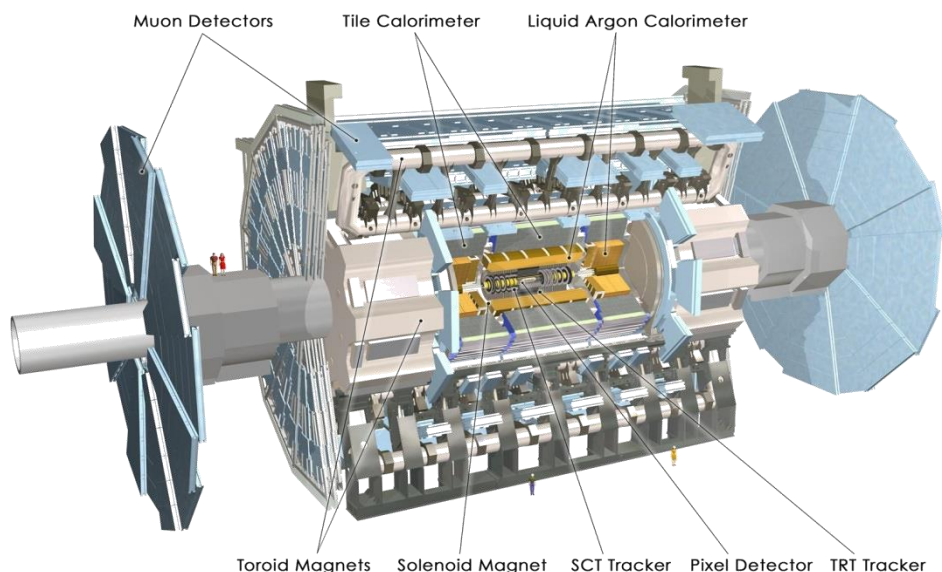
CMS

Final Phase I upgrades: 2015-LS2.

- 4-layer pixel tracker : YETS 2016-17
- Forward HCAL PMT readout : YETS 16/17
- Improved L1-Trigger – started, complete in Run2
- New readout in HCAL barrel & endcap: LS2



ATLAS Phase 2 upgrade in 1 slide



Study Standard Model in detail, including
Higgs couplings and self-coupling
Continue search for Physics beyond the SM

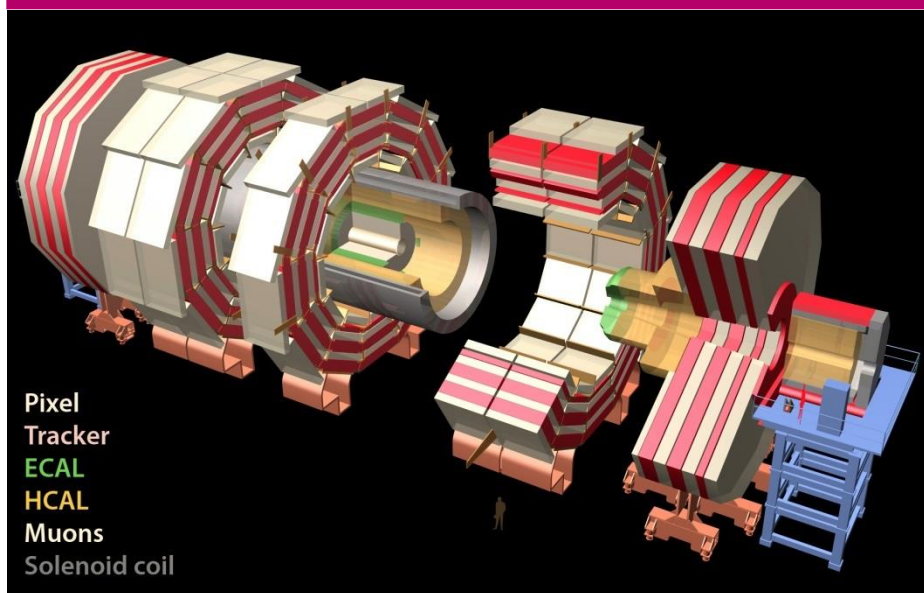
Requires x10 in statistics beyond design 300fb⁻¹
Key components of present detectors will not
survive radiation load beyond 500fb⁻¹.

Equip for 3000fb⁻¹ p-p in 10 years
LHC → HL LHC : <pileup> (23 → 140)

- Replace Pixel Tracker
- New all Silicon Tracker, probably with high η extension
- New Trigger architecture
- New readout for most components
- TAS, Shielding & infrastructure for HL-LHC
- Under investigation – Hadron Endcap & Forward Calorimeter longevity?



CMS Phase 2 upgrade in 1 slide



Study Standard Model in detail, including
Higgs couplings and self-coupling
Continue search for Physics beyond the SM

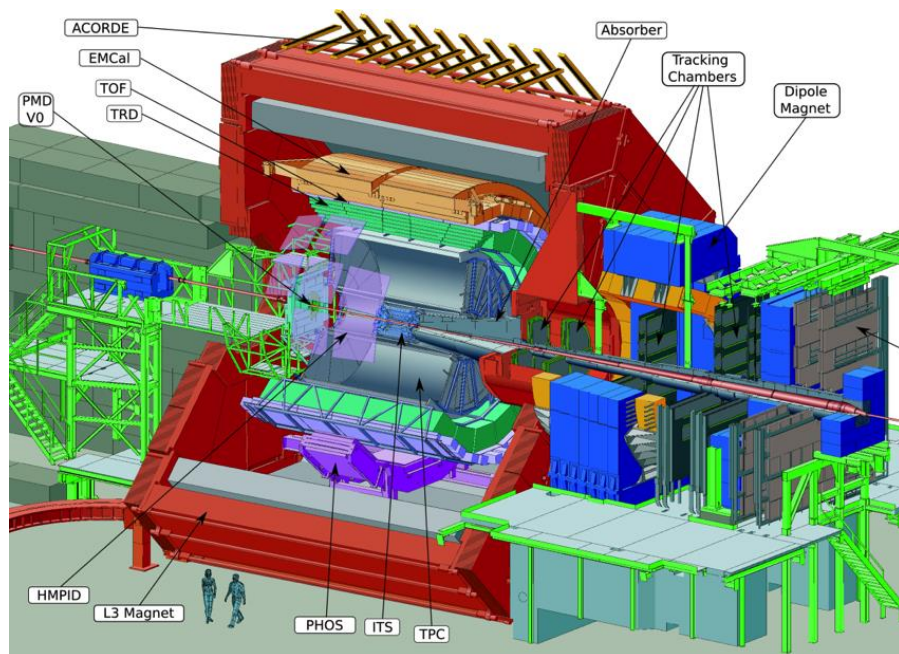
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Equip for 3000fb⁻¹ p-p in 10 years
LHC → HL LHC : pileup (23 → 140)

- Replace Pixel tracker
- Replace all-Si Tracker, probably with high η extension
- New/ revised Endcap Calorimeter system (em & had)
- New L1 trigger (longer latency, higher rate)
implies refit of entire Barrel em calorimeter → time driver
- Install new muon stations at high η (RPC & GEM) and refit barrel muon readout
- TAS, Shielding & infrastructure for HL-LHC, including magnet consolidation



ALICE upgrade in one slide



High statistics measurements using rare probe particles at low pT.

cannot be selected by trigger

Aim for 10nb-1
(factor of 100 x ongoing programme)

All readout : 500Hz → 50kHz with min bias trigger
new beampipe, ITS & 4-GEM endplates for TPC

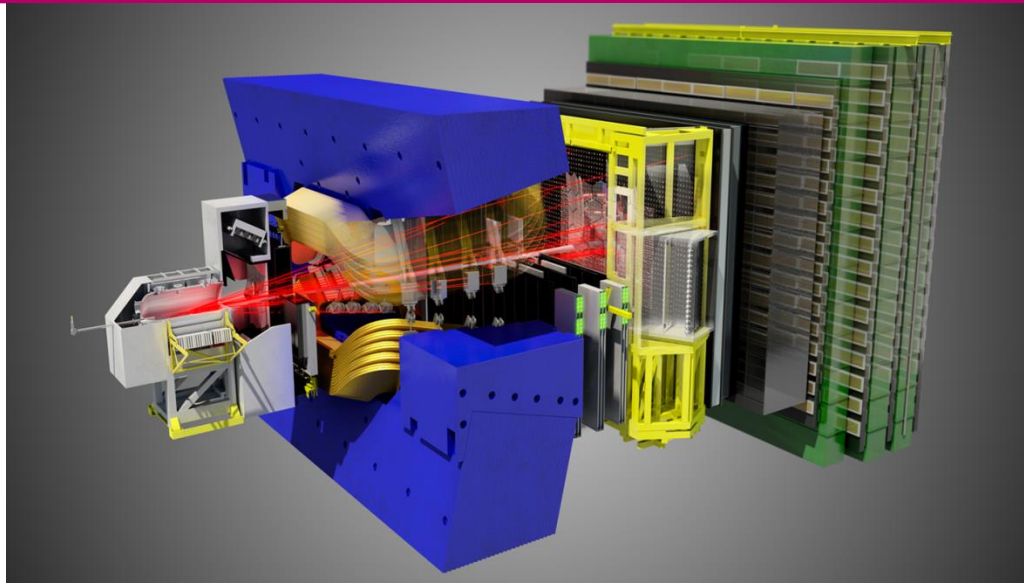
This is a single phase upgrade targeted for LS2

Physics potential at the existing event rate will by then be ~ exhausted

Requires LHC upgrade to ion source, RFQ, LINAC3, SPS kickers, DS collimators



LHCb upgrade in one slide



Record very high statistics to search for effect of possible new physics on flavour structure.

Aim for 50fb⁻¹ to match theoretical uncertainties
(factor of 5 x ongoing programme)

Replacement of VELO

Major upgrade of RICH optics,

Major upgrade of tracking system (technology decisions by end of this year)

Upgrade all existing detector FE electronics 1 MHz → 40MHz

This is a single Phase upgrade targeted for LS2

Doubling time with present detector will by then, be ~ 10 years

LHC can deliver 2×10^{33} to LHC b as soon as the upgrade is ready



Schedule: timing of shutdowns

	ATLAS		ALICE		CMS		LHCb	
YETS 2016-17 duration	Min needed by LHC		Min needed by LHC		4.5 mo	Pixel upgrade	Min needed by LHC	
Preferred LS2 start	end 2017	Trigger upgrade	end 2017	ITS,TPC & readout upgrade	end 2018.	HCAL upgrade, advanced Phase 2	end 2018	Readout upgrade
Required LS2 duration	14 mo	Trigger upgrade μ Small wheels	18 mo	ITS, TPC 4GEM, MFT	14 mo	HCAL upgrade & Phase 2 start .	18 mo	VELO, RICH, Tracking, 40MHz readout.
Preferred LS3 start	end 2021	Tracker replace- ment ready	3 y after LS2 end		end 2022 < 500fb-1		3 y after LS2 end	
Preferred LS3 duration	27-35 mo		Min needed by LHC		30-35 mo	Tracker, EE and HE repl.	Min needed by LHC	

Schedule: timing of shutdowns

LS2 : possible compromise:

Run 2 continues for part (1/2?) of 2018;

Run 3 starts early in 2020

- ATLAS gets trigger upgrade within 6 months of target
 - 18 months shutdown, but substantial physics in both 2018 and 2020
 - LS2 goes on late enough to allow some Phase 2 infrastructure work to be advanced
 - 1 year shift in LS3 start (to 2023) eases funding profile for Phase 2 upgrades
- value (or not) of this may become clear at Resources Review Boards this week

to be discussed once LHC constraints and options are understood.

LS3: best to minimise # sequential calendar years without any physics (continuity, headlines)

BUT highly ineffective to stage the detector upgrades for Phase 2 over >1 shutdown

- hybrid systems**: limited by the non-upgraded parts
 - requiring special operating conditions/ trigger/software
- have to train & retain specialised upgrade teams** > 6 years instead of ~4 —> costs
- activation constraints** become x 2-3 more severe in LS4 —> ALARA, costs.

save time by advancing some activities (machine interface, infrastructure) to LS2 ??



Pileup and luminous region

Both ATLAS and CMS:

- are designing detectors to cope with a mean pile-up of 140 ($\langle 140 \rangle$) (25ns, 5×10^{34}) which means the capability to cope with “tails” up to 200 events per crossing.

[Degradation above this is not sudden, but tends to be dominated by the effect of tails (eg on event processing times). The effect is detector and physics channel dependent.]

- are very interested in methods (eg crab kissing) allowing the extent of the luminous region in time and space to be tuned, so as to reduce the pileup density in either z or t dimensions.

Crab kissing: halving of the mean pileup density from 1.2 to 0.6 events/mm ,
= halving high end tail from near 2.0 to near 1.0 events/mm

obviously of great interest considering 2 vertex resolution of tracking systems ≥ 0.5 mm

but :not easy to evaluate gains since depends on accurate simulation of optimised detector.

:does not open up a door to accepting 2x the inst lumi (mean pile-up also has bad effects)

The potential to exploit fast timing ($\sigma \sim 10$ ps) to mitigate pile-up still requires substantial R & D, but there is a dedicated community pursuing this.



Patterns of LHC operation



Run length:

Recall : experiments originally designed around 7- mo run, 4-5 mo shutdown

Consolidations & upgrades underway will help equip them for 3-4 year operations runs with minimal ~ 3 mo year end stop, followed by LS of 1-2 years.

Single point failures (eg to magnet system, major detector or auxiliary system), requiring immediate action to restore effectiveness for physics, will always remain a risk.:

Particularly until Phase 2 upgrades in LS3, the underlying designs will still be vulnerable to:

- accumulating or debilitating faults requiring several months to fix (extended year end stops)
- premature radiation damage or other ageing phenomena, requiring 1+ years shutdown to fix

Annual pattern:

Experiments will still need around 4 short technical stops (each ~ 4 days) every year to fix minor faults, perform regenerations, minor servicing, calibration etc

HI community is assuming the same pattern of heavy ion running (1 mo per year)
+ special p-p runs as seen up to now (see also later)



Operation: special requests



Apart from usual programme of p-p and Pb-Pb at top energy

p-p reference data: 5.5TeV: ALICE 10pb-1 (takes about 1 month @ 200kHz)
ATLAS/CMS 300pb-1

p-Pb proven to be very interesting : requested for Run 2 : 50nb-1 @ 5.1 or 8 TeV
after LS2 : ~1pb-1

p-Ar and Ar-Ar possible requests

- TOTEM standalone programme (high β^*) to be finished in Run 2
 - Joint AFP & CMS-TOTEM forward physics programme at low β^* in Runs 2,3
 - under definition & resource evaluation...new or moved forward detectors at ~ 200m
- programme will be complete by LS3: no high β^* running anticipated thereafter
(ATLAS and CMS beampipes bore to be kept at ~45mm despite TAS at ~60mm)

As previously :

LHCb will need to switch dipole polarity every ~2 weeks to control systematics

ALICE will need to switch solenoid polarity occasionally

Other factors affecting LS2/LS3

Activation and application of ALARA

LS3 et seq

- LS3 activation x 10 wrt LS1, thereafter x 30 (long-lived isotopes increasing)
- **requires shielding or remote handling or both.**
- contamination precautions would substantially extend some task lengths
- several proposed upgrades (trackers, calorimeters) include replaceable inner sections, implying replacement in LS4 or 5.

Training (including 1:1 models), monitoring, access control & traceability have to meet evolving needs.

1-2 months running, other than high lumi p-p, contiguous with year end lab closure at the start of LS2 and LS3, would give a useful cooling period .

Strong ALARA case for advancing TAS replacement to end of LS2

(proposal to design with replaceable inner bore with special replacement tooling)

Forward beampipes & shielding re-build (if needed) to be considered concurrently

(required outer diameter of TAS is critical parameter)



Other factors affecting LS2 and LS3

resources

LS2

[ALICE & LHCb] single-phase upgrade + end [ATLAS & CMS] Phase 1 + early Phase2

-very substantial lab-wide programme

-resource availability to be included in planning as for LS1.

LS3

[ATLAS + CMS] Phase 2 + infrastructure

I **-massive programme** (comparable with original construction but trickier)

~30 mo estimated now does not take account of major maintenance
or end-of life replacement of infra equip in LS3

-resource loading of the planning necessary from the outset

substantial surge in resources will be needed from Collaborations & CERN

New models to be developed for:

Best use of collaboration resources for technical support on-site in an epoch where technical capabilities within institutes are generally reducing inexorably.

CERN specialist technical support for experiments (presently also in steady decline).



Other factors affecting LS2 and LS3

Strong case for advancing *some* infrastructure end-of-lifetime replacement to LS2

- avoid interference with expt upgrades, (already 2.5 calendar years with no physics)
- mitigate peak resource load at start of LS3
- 20 year service life should suffice to conclude Phase 2 programme.

Possible examples: main elevators
cranes
access system
ventilation system
alarm 3 systems

all these replacements could stop or severely hinder underground upgrade work on the experiments for substantial amounts of time.

even in LS2, mitigation measures will be needed so that work can continue



Support & co-operation

Experiments need office, laboratory, workshop & temp RP infrastructure on their sites
major refitting likely to take place on site (as already seen in LS1)
core M & O teams spend their lives on the remote sites (if they are to be efficient)

Estimates & discussions needed of :

activated material for temporary (during LS's) and permanent storage on main sites
activities requiring radioactive workshop facilities on- and off- expt sites.

R & D over the next 5-6 years will provide the foundation of the experiment upgrades

assumes:

- test beams
- irradiation facilities
- laboratory & office space, including for visitors

Coord/Cooperation between machine and experiments essential to an unprecedented level

- technical group support vital to experiments as well as machine
- many interfaces (planning, access, R2E, activation, ALARA, beam induced effects, and radiation simulations, infra systems longevity, TAS, beampipes & vac, shielding)

HL-LHC coordination group + existing joint groups (LBS etc) exist.

A project office, reporting to coord group could be helpful to acquire/direct common resources.



Conclusion

..it won't be the last such workshop!!



320 people registered ..probably 250 participated: a great success in communication and cooperation in the common interest : the preparatory groups will likely continue to play a role

Selection of (possibly) RLIUP relevant bullets from the concluding talk: (Phil Allport)

3-4 years of R&D and prototyping, followed by 5-6 years of construction, are needed to complete the largest upgrades. R & D needs proper resources as of now.

Long shutdown durations and schedule need further definition and consensus, *especially to define clear profiles of resource needs vs time.*



Conclusion

Experience & expertise from building and operating current experiment systems (*including power, cooling, gas, beampipes, survey, magnets & cryo, planning, coordination etc*) **must** be retained and transmitted to those developing new systems.

Modelling of radiation levels and radiation damage is clearly important, and in some cases more results are needed to identify where upgrades are required.

Many systems would benefit from more common facilities for irradiations and beam tests as well as greater coordination for use of those already available.

Tools for dealing with the very challenging environments at and after LS3 should be developed in common with the machine and realistic timescales presented for interventions that take full account of the overriding ALARA principle.

In some areas common standards & a common CERN interface with industries developing key technologies of importance to several experiments (& *LHC* ??) is beneficial to minimize development & procurement costs.

Forums exist for interaction between the machine and the experiments, but always helpful to update a larger forum, to be sure key parameters are widely understood across expts.