Status of experiment upgrades

Austin Ball, CERN

ATLAS and CMS Physics programme: 2012 onwards

$30fb^{-1}$ ––> $300fb^{-1}$ ––> $3000fb^{-1}$

LHC evolution: 2012 onwards:

––> how to maintain experiment physics performance?

––>the challenge of pile-up

ATLAS and CMS upgrades, LS1, Phase 1, Phase2

v. forward detector systems

Some key technologies to be developed

Machine interface

ALICE and LHCb upgrades.

….many thanks to Rolf Lindner, Werner Riegler, Marzio Nessi

ATLAS and CMS physics : 2012 onwards

News since mid-2012 is exciting…. but also challenging:

Discovery of a Higgs-like boson:

a) low mass

b) high enough mass that many different decay modes give distinguishable signatures.

—> fruitful LHC physics :programme far into the future

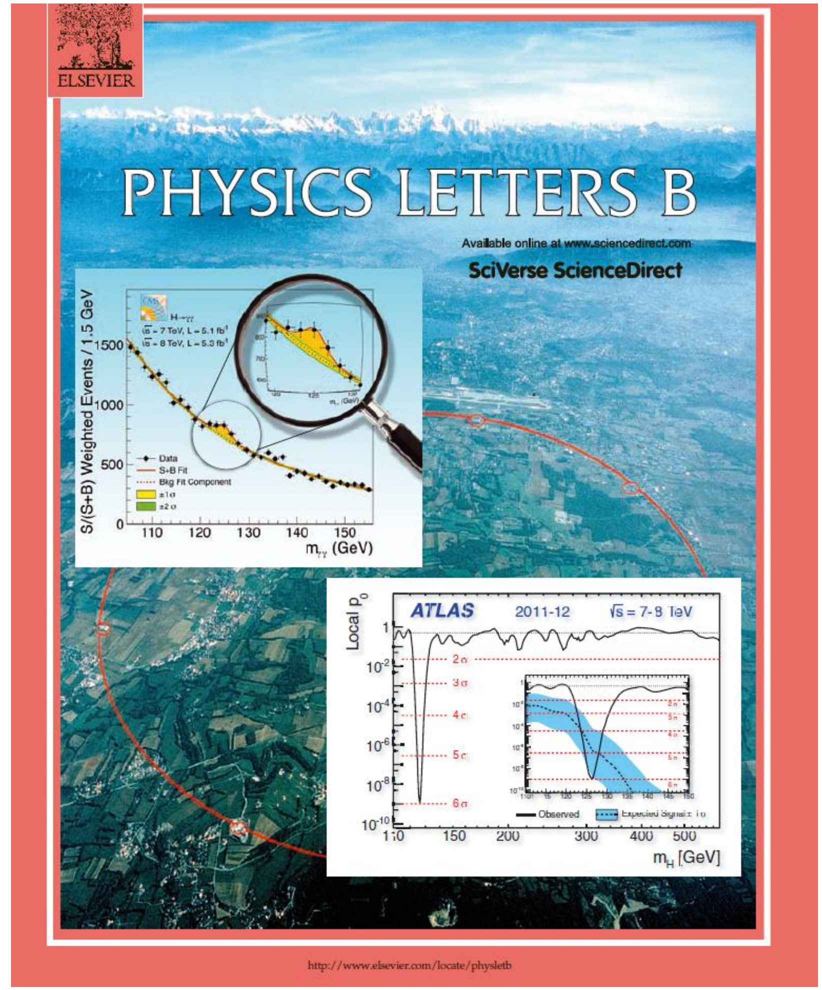
Implications for experiments ATLAS and CMS:

i)must maintain present capabilities at low momentum & low energy to extract max. physics from the discovery.

ii) must maintain capability to search for high mass, rare particles. (eg understand if something is counter-acting quantum corrections to the Higgs mass eg heavier SUSY, not seen yet, extra dimensions etc)

both at high luminosities (precision, rare processes).

generalisation: satisfying i) usually satisfies ii)



Programme of $\int L.dt$ —> $300 fb^{-1}$ —> $3000 fb^{-1}$ has an increasingly solid basis

ATLAS & CMS physics: 2012 onwards

Study of Higgs-like boson will be a high priority objective well into the next decade

With this year's data:

i) mass: expect good measurement

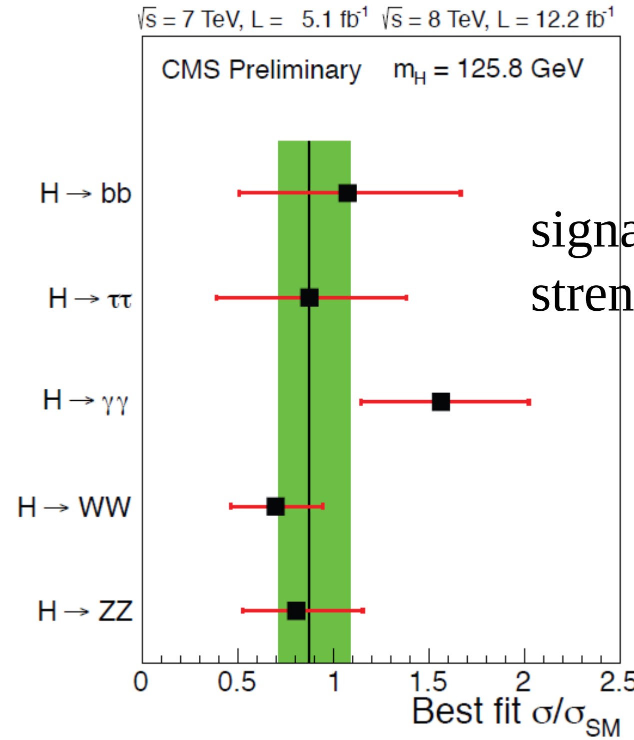
ii) spin: A+ C should achieve 4σ separation of 0 from 2
already indications that scalar is preferred (for spin 0)

iii) signal strength & couplings to fermions and bosons :
1st indications whether ~ as expected from SM

5000 physicists chewing on 2010-12 data sample in LS1
will yield more physics than we yet suspect

but

ii) and iii) probably not resolved definitively until >2015.



signal strengths

Then, with 300fb-1 and eventually 3000fb-1

iv) search for rare decay modes

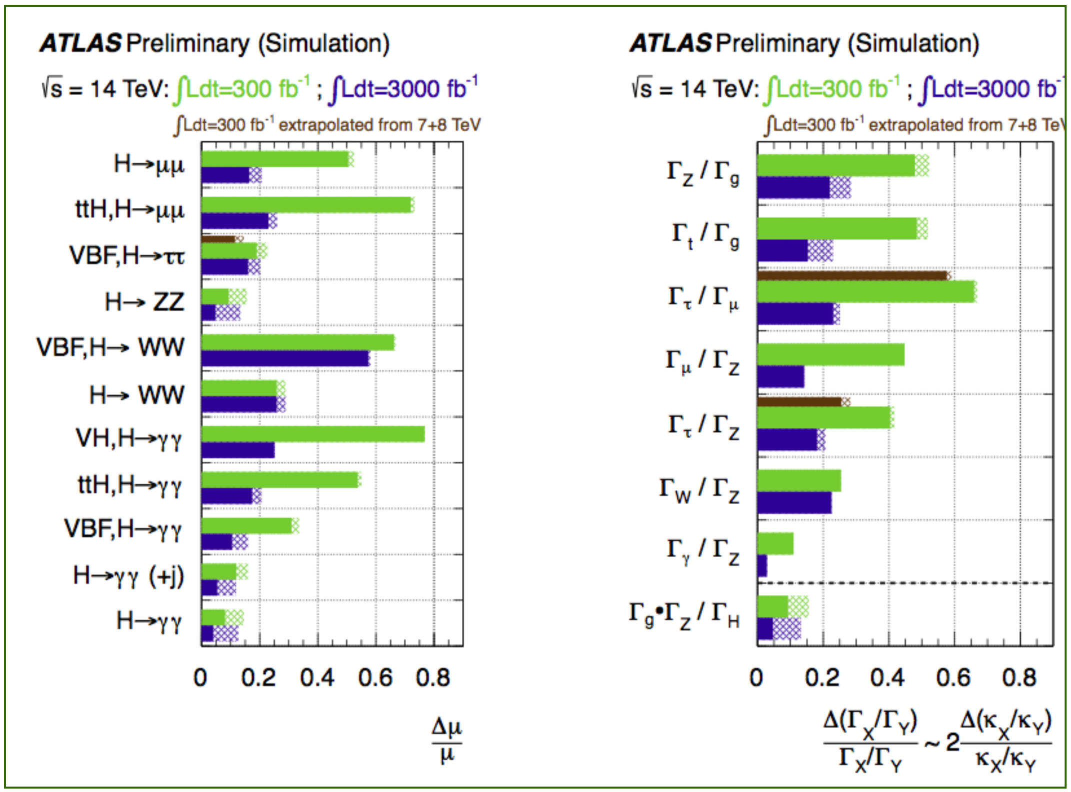
v) measurement of the self coupling (3 σ measurement per expt for 3000fb-1)
(the strength of the Higgs potential itself)

vi) very precise measurements of the relative
strength of the couplings)

Higgs $300fb^{-1}$ —> $3000fb^{-1}$

From CMS & ATLAS input to ESPP

Preliminary simulations show that the factor 10 in lumi can dramatically reduce uncertainties, leading to very precise measurements



Much depends on how the theoretical and experimental systematics evolve, but, since many systematics determined from data, 1/√lumi is not unreasonable.
Assume theory systematics can be halved

CMS (prelim)	Uncertainty (%)			
Coupling	$300\ fb^{-1}$		$3000\ fb^{-1}$	
κ_γ	6.5	5.1	5.4	1.5
κ_V	5.7	2.7	4.5	1.0
κ_g	11	5.7	7.5	2.7
κ_b	15	6.9	11	2.7
κ_t	14	8.7	8.0	3.9
κ_τ	8.5	5.1	5.4	2.0

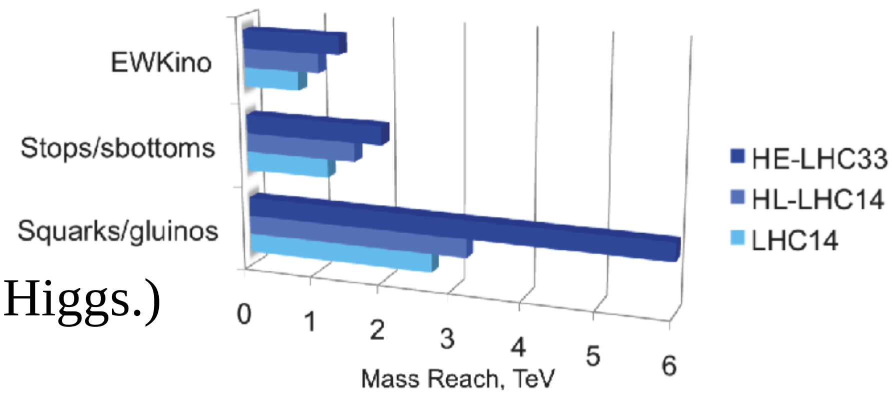
Systematics:

Unchanged   Scaled

ATLAS & CMS physics: 2012 onwards

Continuing the search for new physics: (somewhat modulated by existing discovery)

- More new particles?
    - new resonances
        - eg 2nd Higgs, Z ´, leptoquarks
    - missing E_T signatures
        - eg squarks and gluinos,
        - EWkinos
        - "light" stop and sbottom (perhaps not so light given light Higgs.)



- Top physics, exploiting LHC as a top factory, to study rare decays and measure couplings

- Precision electroweak studies (eg search for anomalous TGC's).

- Study of forward processes such as vector boson fusion and diffractive scattering

Discoveries are most likely in the first few years at 14 TeV

Assumptions about LHC: 2012 onwards

assumed performance evolution, mean pile-up <μ> are max estimates supplied

Repairs during LS1: allow LHC to operate at or near nominal E_{cm} = 14 TeV

Following LS1: *initial low lumi runs to measure cross sections (few x100 pb-1)*
possible restricted pile-up running at 50ns for quick search (few x 1fb-1)
rapidly approach operation at design luminosity & bunch spacing (25ns)

Subsequently, luminosity expected to reach :
≤ 2 x nominal before LS2, with ∫L.dt ≤ 150fb-1
≤ 2.5 times nominal before LS3, with ∫L.dt ≤ 500fb-1
} <μ> = 50-80

Following LS3: luminosity expected to reach :
~ 5 times nominal (levelled) with ∫L.dt eventually ≥ 3000fb-1, <μ> ≤ 140

In the 2030's, HE-LHC, if proven technically feasible, may deliver:
300fb-1 at E_{cm} = 33 TeV

Coherently with above, to ensure longevity and maintain existing physics performance for the increased pile-up and radiation loads resulting from luminosities up to 5x design:
ATLAS & CMS will implement a phased programme of detector consolidation & upgrade

Maintaining physics performance

Evolution of the detectors towards HL-LHC (and HE-LHC)

ATLAS & CMS were designed for 10 years of L= 10^{34} $cm^{-2}s^{-1}$ (25ns) for ∫L.dt ≤ 500fb-1

a)∫L.dt = 500-3000 fb^{-1}: enhanced radiation tolerance and simple longevity will require:

mandatory replacement of certain detectors, electronics & ancillary systems irrespective of whether lumi expected is ≤ 2 times or ≤ 5 times nominal.

b) L= 5 x 10^{34} $cm^{-2}s^{-1}$ (25ns): pileup mitigation will involve :

- tracking over extended range of η
- higher granularity and better angular measurement in the reconstruction
- use of exceptionally good timing measurements (vertex association)
- more information and more sophisticated processing in the trigger to maintain selection power with acceptable rates
  - algorithm performance degrades with pile-up:
    eg μ: increased background rates from accidental coincidences
    e/γ: at fixed efficiency, reduced QCD rejection from isolation
  - solution in general is to reconstruct more detail of the event earlier in the trigger process.

The new trackers and calorimeters required will involve a decade of R & D and construction, followed by 2-3 years of shutdown for installation. Have to assume a + b in design.

Pile-up

Commonly estimated as:

$$\text{Pile-up: } \mu = \sigma_{inel} \frac{L}{k_b\, frev}, \text{ with } \sigma_{inel} \approx 72 \text{ mbarn at 8 TeV}$$

But: what is σ *inel* ? eg is it σ *tot* – σ *el* or σ *tot* – σ *inel* – σ *diffractive ?*

—> should be x-section for processes which can give hits in detector

Sensitivity of a detector system, including online triggering, to pile-up is:

- not linear
- different for different experiments
  ..or even different detectors within the same experiment
- not well described by the mean of a pile-up Poisson distribution
  .. tails are particularly troublesome

Effect on physics efficiencies/backgrounds etc depends heavily on the process being studied.

Eg CMS uses an "effective σ *inel*" of 69.4 mbarn

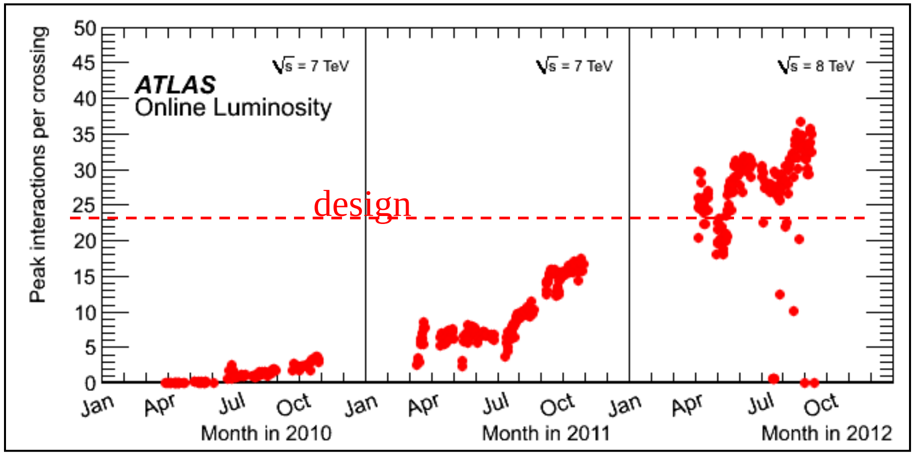
—> best agreement between simulated & observed distribution of # of vertices.

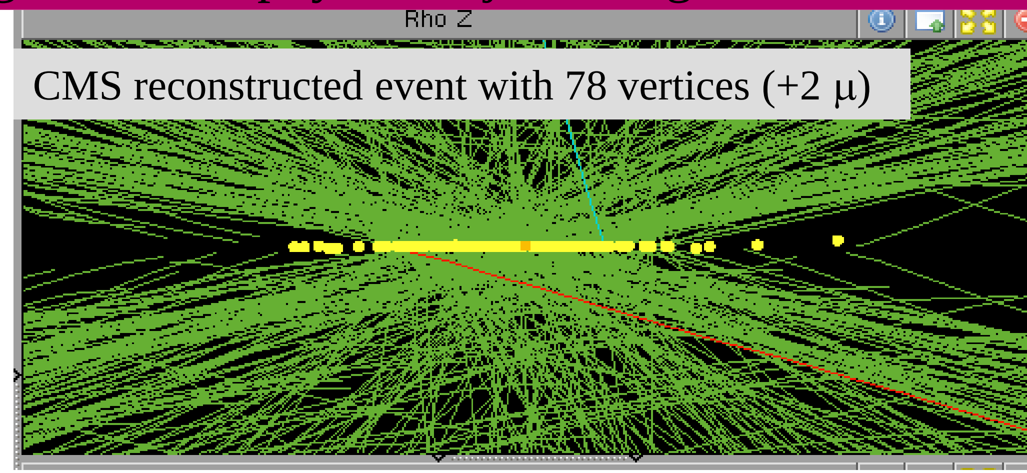
Density of event vertices in 3D space & in precise collision time is an important parameter

—> aim to associate each track/cluster to vertex with particular r,ϕ,z and t

Pile-up mitigation

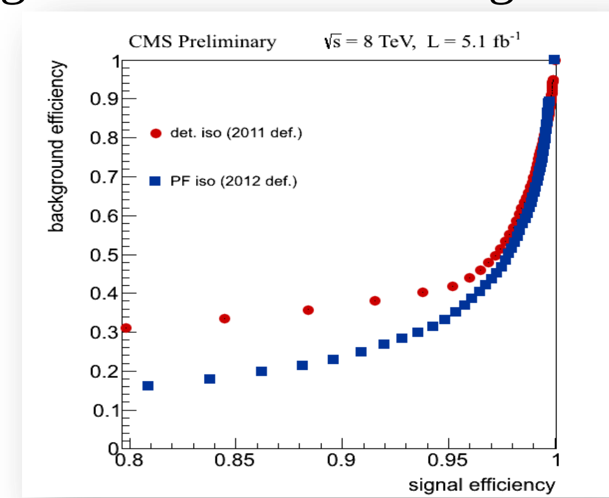
relieve stress on trigger, computing resources, physics object recognition

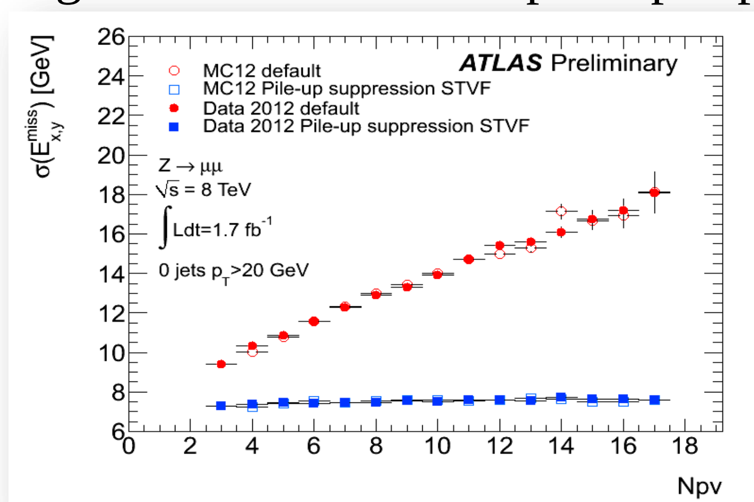




:eg CMS e isolation using P flow

eg ATLAS track based pile-up suppression



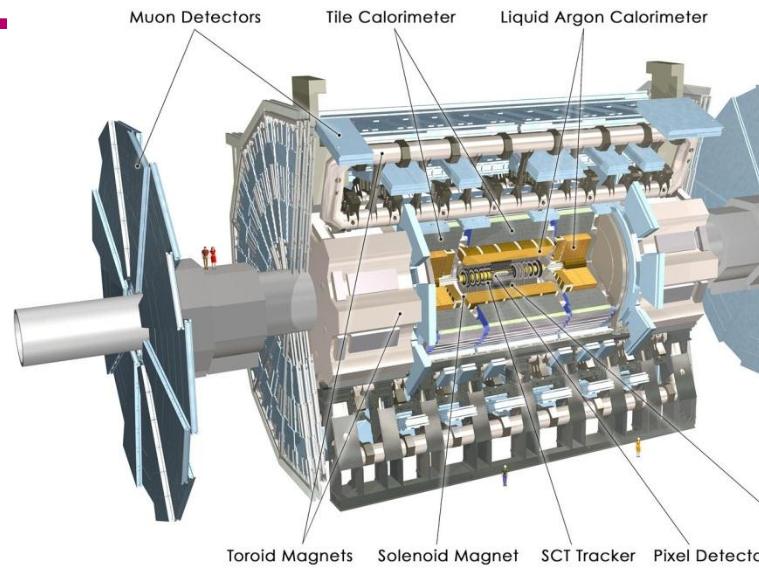


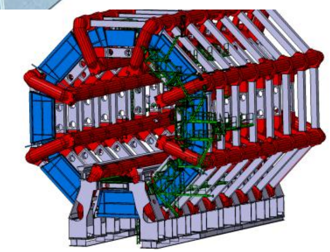
stabilises blow-up of E_T miss resolution with pile-up.

Current strategies run out of steam for <μ> > 40 —> **need 25ns and upgrades**

ATLAS detector upgrades

Phase 0: in production for LS1
3 —> 4 layer pixel (insertable B layer)
with reduced diameter Be beampipe
New Al outer beampipes
New pixel services
Complete EE muon chambers
New evaporative cooling plant





LS1 (22 mo) LS2 (12 mo) LS3 (24-36 mo)

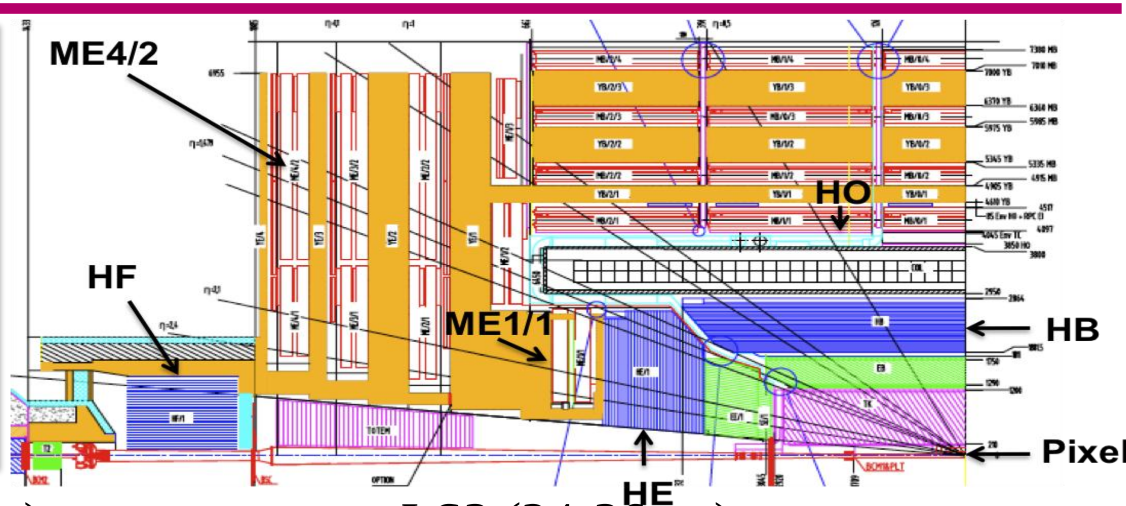
Phase 1 : up to end of LS2
LOI approved by LHCC Mar 2012
- New muon small wheels (fwd μ spectrometer)
- Fast tracking trigger (input to LVL2 trig)
- New Calorimeter Trigger tower builders (LVL1 calo trigger)
- Various trigger/DAQ upgrades

Phase 2 : for LS3 (LOI in 2013)
All new tracking detector
Possible L1 track trigger
Calorimeter electronics upgrades
Upgrade part of muon system
Possible changes to forward calorimeters

CMS detector upgrades

Phase 1: in production for LS1

- Complete muon coverage (4’th endcap layer)
- Improve muon operation (1’st endcap layer), and barrel drift tube electronics
- Replace HCAL photo-detectors in Forward (new PMTs) and Outer (HPD→SiPM)
- DAQ1 → DAQ 2
- Overhaul common systems for long-term



LS1(22mo) LS2 (12mo) LS3 (24-36mo)

Phase 1: up to end LS2 (LOI app. Sep 12)

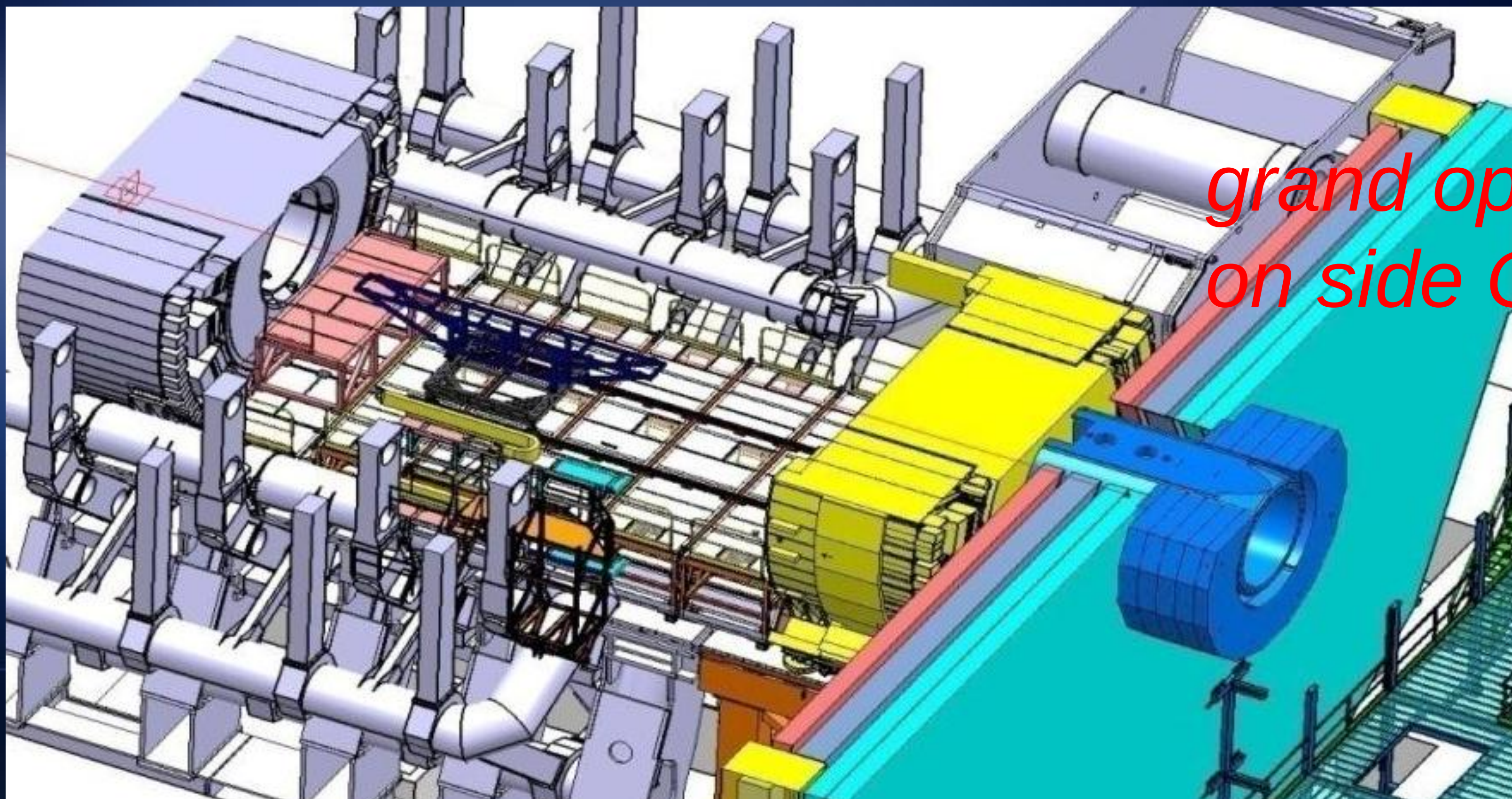
- TDR’s approved:4 layer Pixel tracker (install in YEETS 2016-17), HCAL electronics/granularity
- TDR in 2013: L1-Trigger
- Preparatory work during LS1
  - New beam pipe (for 4 layer pixel tracker)
  - Test slices: *Pixel(CO2 cooling), HCAL, L1-trig*
  - Install ECAL optical splitters
    - *L1-trigger upgrade in parallel with run.*

Phase 2 Upgrades (Tech.Proposal in 2014)

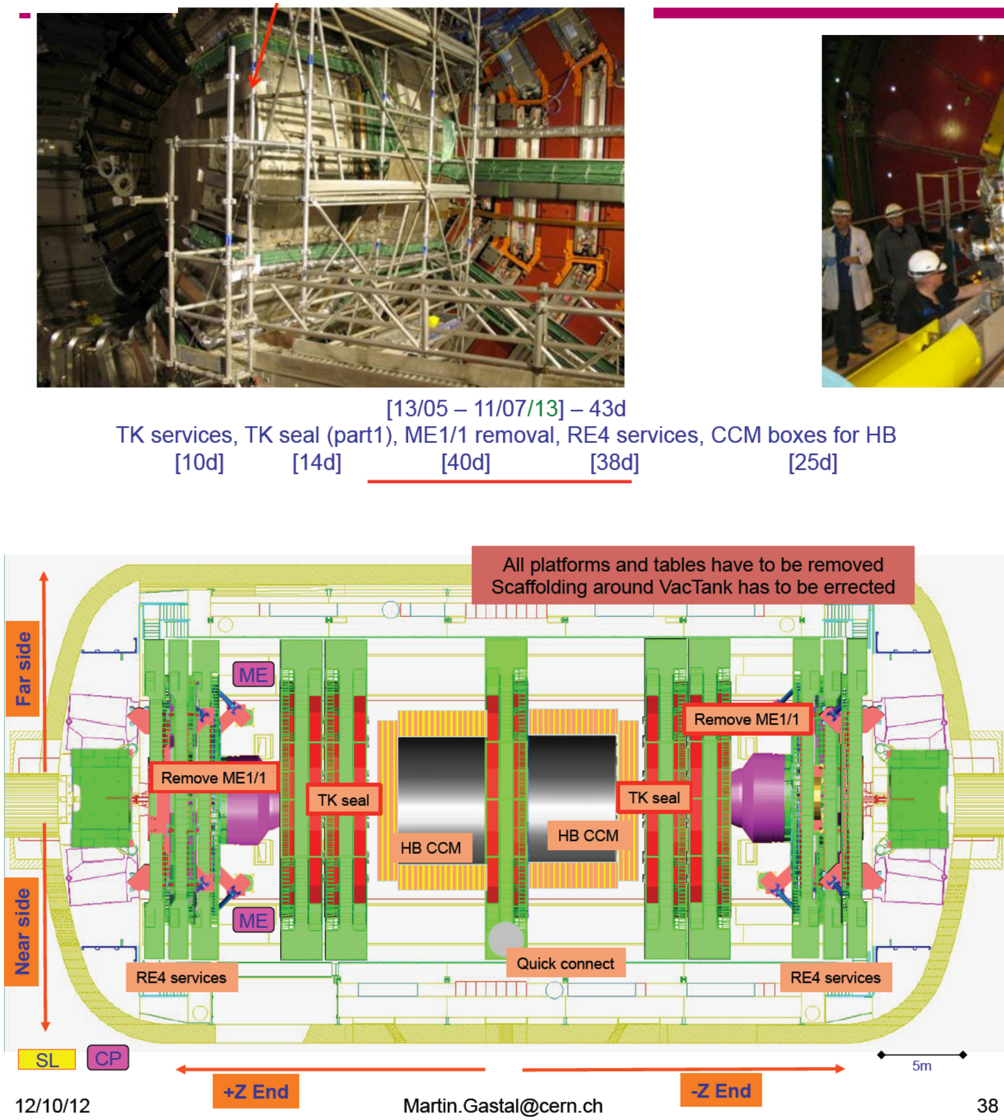
- Tracker Replacement, Track Trigger
- Endcap/Forward region improvements : Calorimetry, Muon system and tracking
- Further Trigger upgrade
- Further DAQ upgrade
- Many obsolescence/lifetime replacements
- Shielding/beampipe for higher aperture

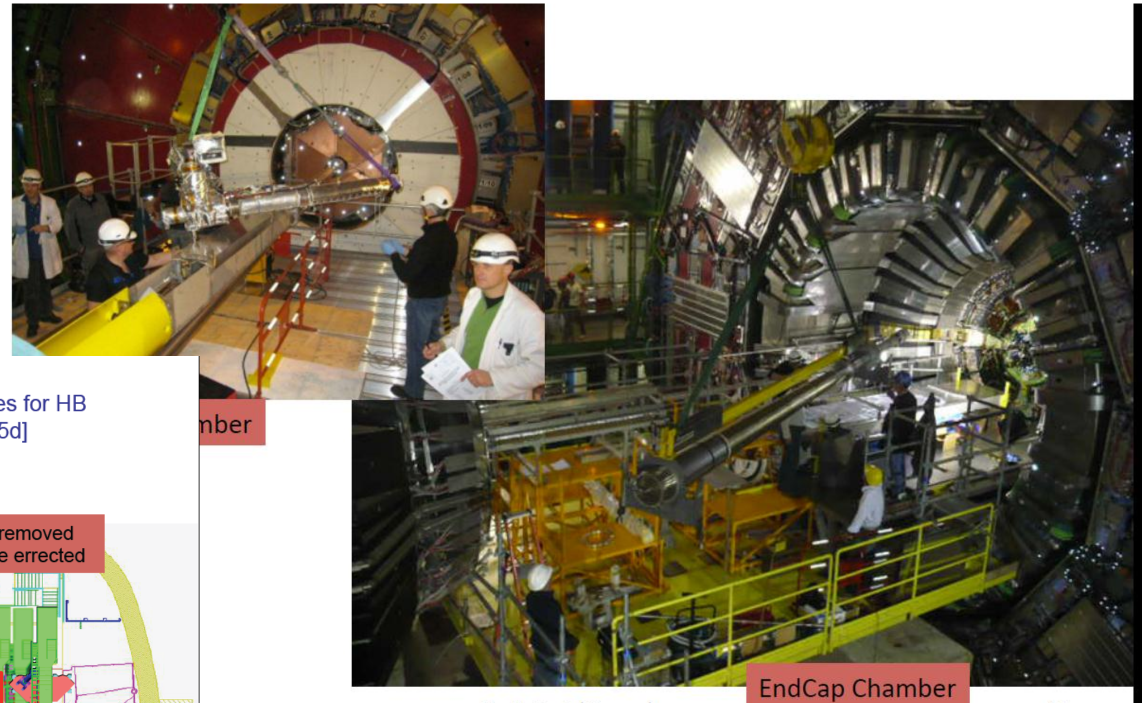
ATLAS : LS1 logistics

- The IBL installation (making a 4 layer pixel tracker) is the core activity of the ATLAS shutdown. Decide in January whether to bring pixel to surface
- Much of the shutdown is organized around the Pixel activity (e.g. large opening, small wheel de-installation, beam pipe operations)
  - LS1 work being prepared in detail (~250 work packages announced)
  - ATLAS-wide planning at https://atlasop.cern.ch/shutdown/shutdown-2013-2014.php



CMS LS1 logistics





80 major logistics operations

Complete opening of the detector and replacement of central beamipe.

Building endcap outer shielding disks in situ

Improving opening system & RP shielding

Enabling cold operation of Si tracker

LS1: ATLAS & CMS infra & common systems

Most of the work and resources will be committed to infrastructure and common systems maintenance, consolidation (for an extended, reliable operating life) and upgrade (to accommodate detector upgrades and LHC performance evolution)

ATLAS:

new ID evaporative cooling plant
magnets cryogenics consolidation
infrastructure consolidation (electricity, ventilation, radiation protection,…)
additional access structures
new UPS system
beam and luminosity monitors

CMS :

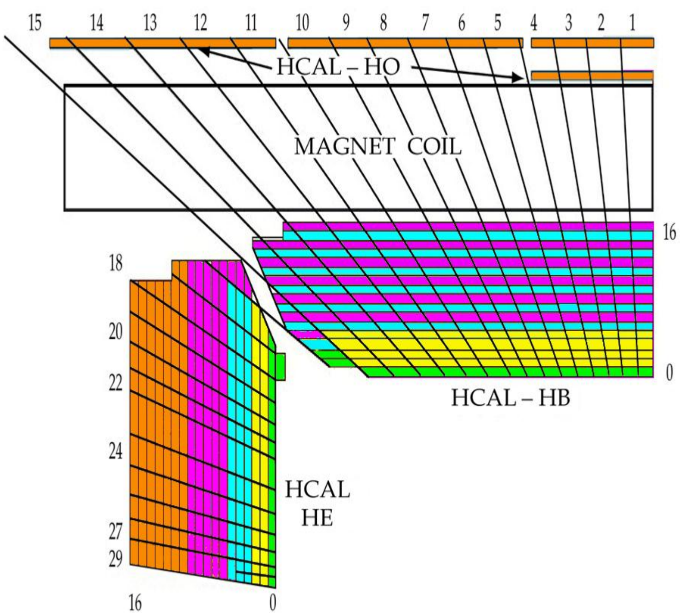
magnet cryogenics and cooling
tracker environment control
cooling systems for Phase 1 detectors
electrical system UPS extension
radiation shielding
moving and opening/closing system
beam and luminosity monitors

ATLAS & CMS P1 upgrades continue thru LS2

Finishing approved projects with more under study for approval

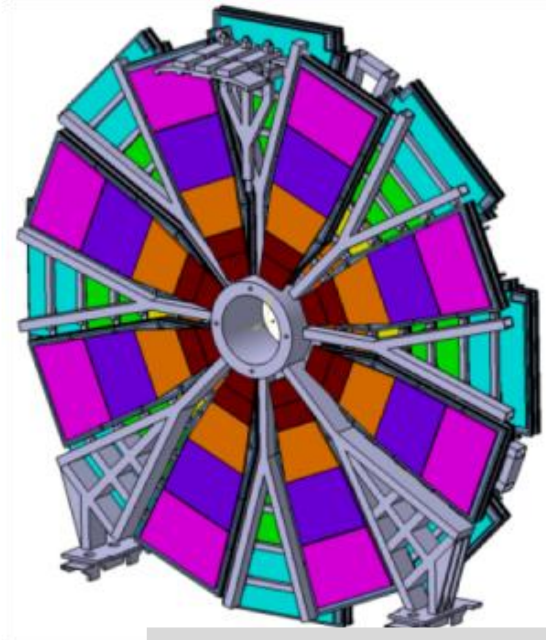
eg CMS 4 layer pixel: in YEETS 2016-17
HCAL readout in LS2

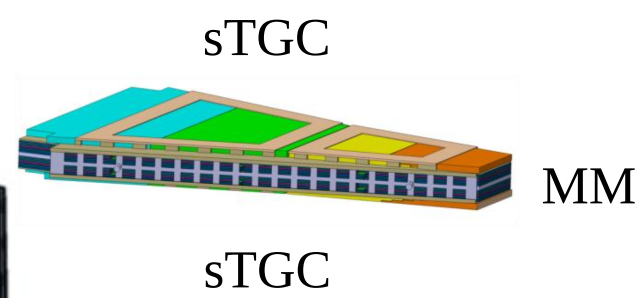
-finish phototransducer replacement
-optical switchyard reconfiguration
-new front and back end electronics
-depth segmentation & interleaving



-better performance at high lumi and pile-up

eg ATLAS small muon wheels in LS2





Baseline: sTGC (trigger & bunch id)
Micromegas (precision tracking)
—-> complementarity, redundancy, robustness
Milestone track to demonstrate feasibility
Similar GEM-based proposal to complement
CMS endcap muon layer 1 CSC's

ATLAS & CMS LS3 —> 2030+

Phase 2 upgrade: LOI's/Technical proposals in 2013-14

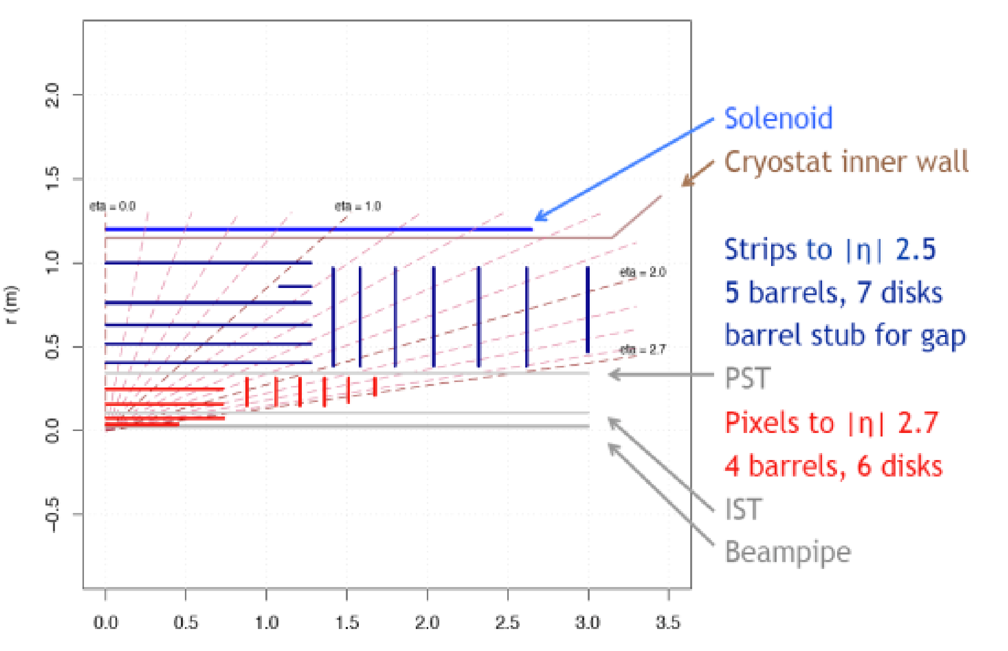
For operation beyond ~ $\int L.dt = 500\ fb^{-1}$

—> substantial changes to some detector elements become *mandatory*

In particular **-new tracking systems, radiation & rate tolerant,contributing to trigger, extending to higher η** —> compulsory, already being designed

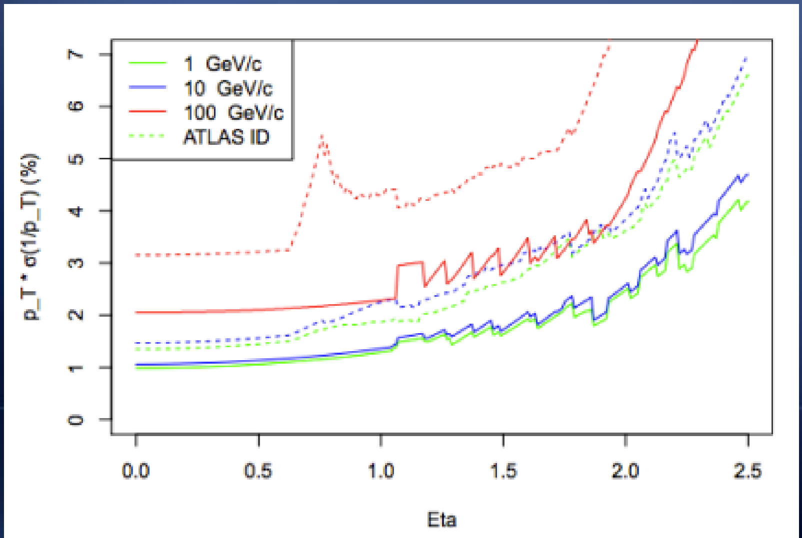
- major revision of calorimetry, at least in the endcap and forward regions where radiation damage will become severe. — v. likely
- enhancement of muon system, improving performance and robustness of trigger and reconstruction, recovering degradation due to age — possible
- major revision of forward beampipes and shielding systems to accommodate increase in quadrupole and TAS apertures — compulsory
- introduction of highly accurate time of flight detectors combined with extended calorimetry and tracking for forward physics. — v. likely
- completely revised trigger systems to maintain selection efficiency at low momentum. — compulsory
- high bandwidth DAQ replacing obsolete technologies — compulsory
- corresponding computing infrastructure — compulsory

ATLAS Phase 2: new inner detector



Stringent requirements

- *much higher integrated doses (a factor of 10 more)*
- *much higher occupancy levels (up to 200 collisions per beam crossing)*
- *14 hits per track to resolve fake tracks*
- *Up to 10m² of pixels, »190m² of strips with some layers possibly having dedicated (level-1) trigger capability*
- *Installation inside an existing 4π coverage experiment*



Detector:	Area $[m^2]$	Channels $[10^6]$
Pixel barrel	5.1	445
Pixel endcap	3.1	193
Pixel total	**8.2**	**638**
Strip barrel	122	47
Strip endcap	70	27
Strip total	**192**	**74**

~ factor 10 increase

CMS Phase 2: new tracking system

Phase 1 CMS performance good for $<\mu>=50$ with gradual degradation thereafter

Tracker requirements at HL/LHC are:

Radiation tolerant to 3000fb-1

Increased granularity and spatial resolution

- resolve up to 200 collisions per bx
- occupancy maintained at few %
- better high p_T performance

Reduced material

- better low p_T performance
- reduced secondary interactions

Input to L1 trigger : enhance event recon. at L1

-reject low pT (≤ 2GeV) charged particles locally

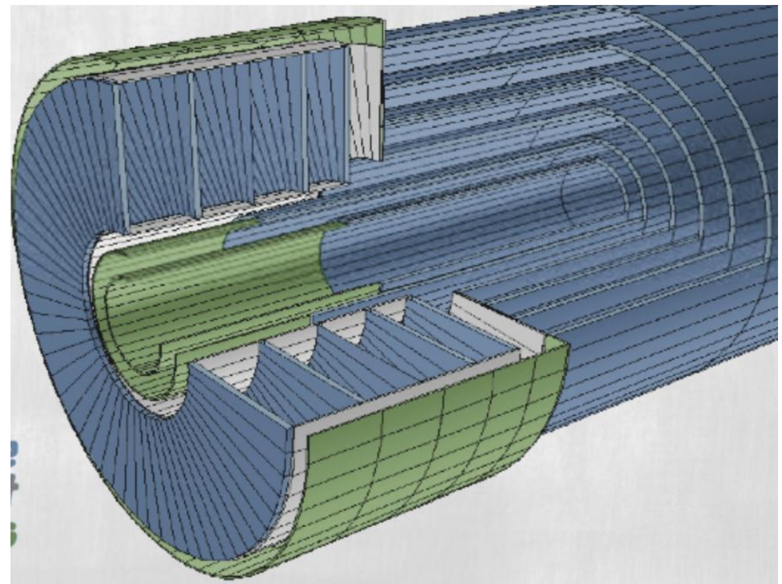
-read-out accepted signals every bx

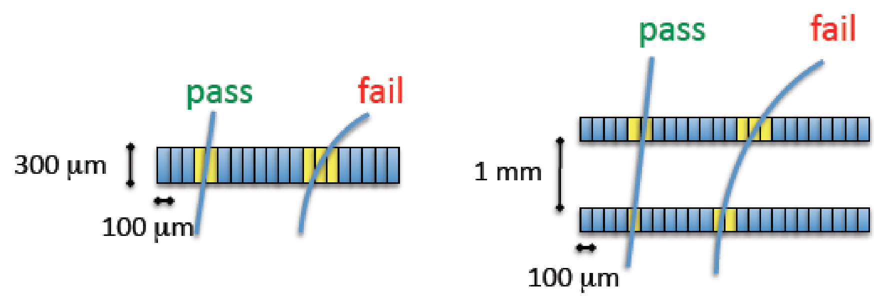
-reconstruct tracks above 2GeV @ L1

(few % pT resolution, <1mm z0 res)

- control μ,e,jet, E_T miss rates at hi lumi and pileup

Upgraded Si strip tracker (LS3), with track trigger.
At 5 x 10^{34} $cm^{-2}s^{-1}$ and 25ns bunch spacing:
expect av pile-up:120-140: limit ≤ 200.



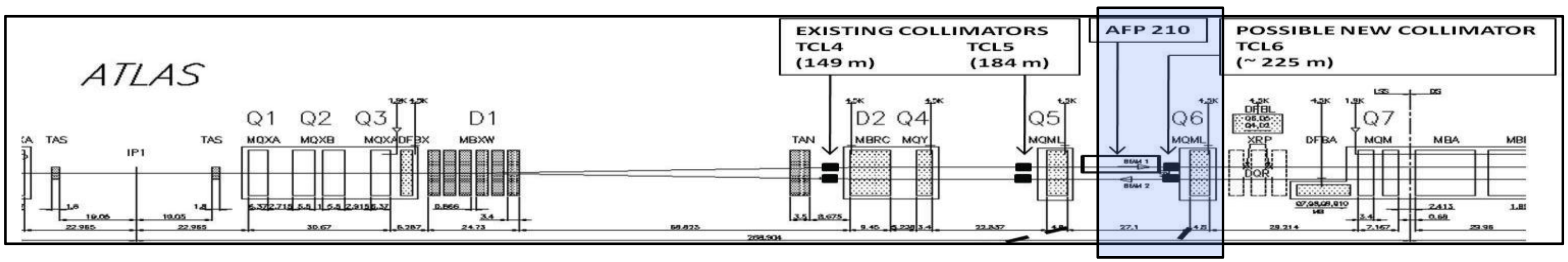


v. forward physics detectors: ≥ LS1

i)TOTEM is approved to repeat the σ_{tot} measurement at or near E_{cm} = 14 TeV, high β* will use Roman pots ~ 210m from pt 5; *if* ~147m pots not used, could be replaced by TCL4.

New proposals to operate v fwd detectors at high luminosity (access to rare processes).

ii) ATLAS (AFP) is considering installing 2 Hamburg pipe systems 200-220m from pt 1



iii) CMS (HPS) is considering installing 2 Hamburg pipe systems around 240m from pt5
iv) CMS/TOTEM are discussing installing Roman pots (from 147m) 200-220m from pt 5

ii), iii) and iv) rely on precision tracking and 10ps timing to measure diffracted protons

Internal approval of proposals if : good physics case
: technical feasibility proven
: sufficiently strong community for physics exploitation

Preparatory installations (collimators, dummy pipes etc) in LS1 will be requested.

Key technologies to develop in next 5 yrs

vigorous R&D and prototyping program + study of engineering issues

Sensor technologies with enhanced radiation tolerance(planar and 3D silicon, diamond)
Advanced ASIC technologies for front-end electronics (eg 65nm CMOS)
Highly granular, high resolution, hermetic, redundant, radiation-hard calorimetry
Large area micro-pattern gas detectors
Time of flight devices with time resolution ~ 10ps.
High bandwidth, low-power optical data links
High-density interconnects
Power management systems (eg on-detector power converters)
Advanced low mass, large scale cooling systems (eg evaporative)
High performance materials for mechanical support and thermal management in lightweight assemblies
High speed processor and computing technologies for back-end readout electronics and trigger (L1 and HLT).
Robust beam monitors with good time resolution (~1ns) and fast abort capability
Robust, cheap, environmental monitors (temp, humidity, magnetic field, strain, dose)
Remote monitoring and remote- handing techniques and equipment

HL-LHC machine interface

Can we improve estimates on when low β quads will need to be replaced?
If this drives LS3, could affect: tracker upgrade installation (eg LS3 or LS4)
pace of forward shielding & calorimetry upgrades

How active will the TAS's be (say for L= 2.5 x 10^{34}) and are the techniques to extract them available?

What are the aperture requirements along the length of the experimental beampipes once the TAS aperture is increased (assuming no change in mechanical & survey tolerances)?

What are the implication of various beam pathologies (D1 failure, crab failure etc) for beam losses in the experiment (given a particular beampipe diameter)?

What can we expect for beam-gas and beam-halo backgrounds at HL-LHC?
- any implications for vacuum, collimation?

ALICE physics: LS2 onwards

- intended for precision measurements of the Quark Gluon Plasma (QGP).
(Letter of Intent endorsed by LHCC Sept. 2012, CERN-LHCC-2012-012)

The plan is now to run at Pb-Pb Luminosities in excess of $6x10^{27}$ $cm^{-2}s^{-1}$ between LS2 and LS3 and also beyond LS3.

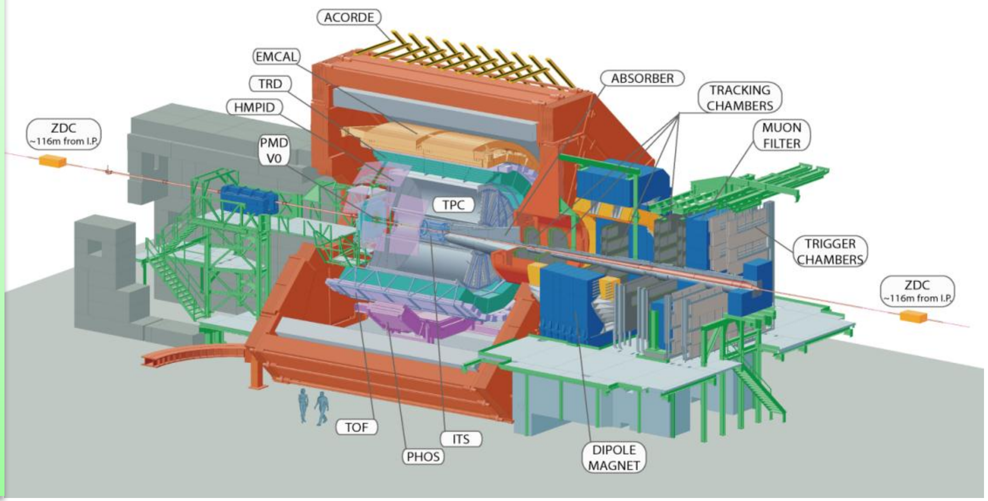
Highlights of the proposed programme are:

- **Study of the thermalization of partons in the QGP, with focus on massive c and b quarks.**
- **Study of low momentum quarkonium dissociation and, possibly, regeneration pattern --> probe of deconfinement.**
- **Study production of thermal photons and low-mass dileptons emitted by the QGP.**
- **Study of in-medium parton energy loss mechanisms through jet structure, jet-jet and photon-photon correlations and jet correlations with identified hadrons and heavy flavor.**
- **Search for heavy nuclear states.**

ALICE detector upgrade

Phase 0: in production for LS1

- Complete TRD detector (+5 Supermodules)
- Install DCal calorimeter (8 Supermodules). including support structure and support beams
- Install 1 PHOS Supermodule
- Numerous detector consolidation efforts
- UPS replacement & elec infra consolidation,
- P2 chilled water upgrade (+60% power),
- L3 magnet ventilation upgrade (+60% flow)



LS1 (22mo) LS2 (18mo) LS3

Phase 1 and 2 (LOI approved LHCC Sep 2012)

- new, ultra low mass silicon tracker & 34mm beampipe
- upgrade of the TPC with GEM detectors for continuous (un-gated) readout
- electronics upgrade of the other subdetectors
- major upgrade of the online systems to process all Pb-Pb collisions upon a (min bias) interaction trigger

Alternative: longer HI run in 2016,
no HI run in 2017.
TPC removed in YEETS (2016-17)
Upgrade complete in LS2 of 14 months

ALICE at HL-LHC

ALICE upgrade beampipe ID = 34.4mm, verified for nominal LHC running up to LS3. Needs to be done for HL-LHC optics and apertures.

Although ALICE will not operate during the entire p-p period it will turn on for a few weeks preceding the yearly HI period with a typical luminosity of 10^{31} $cm^{-2}s^{-1}$. Compatibility with HL-LHC operation to be worked out.

The vacuum pressure in the LSS around ALICE during p-p running must be at a level such that the intense HL-LHC beam does not put the ALICE detector and electronics under excessive radiation load, even if the experiment does not operate.

Preliminary:
—> For the present LHC beam current the pressure must be <$5x10^{-9}$mbar
—> The specified vacuum pressure must scale i.e. at least fact 10 lower for HL-LHC.

……more boundary conditions may arise.

LHCb physics: LS2 onwards

LHCb will collect ~ $7fb^{-1}$ by the end of 2017.

To reach the ultimate precision in flavour variables, limited by theory, requires more statistics

Current LHCb detector is limited by read-out capability (< 1 MHz) and not by luminosity

Higgs-like particle discovery, great success for LHC (…& for the Standard Model?)

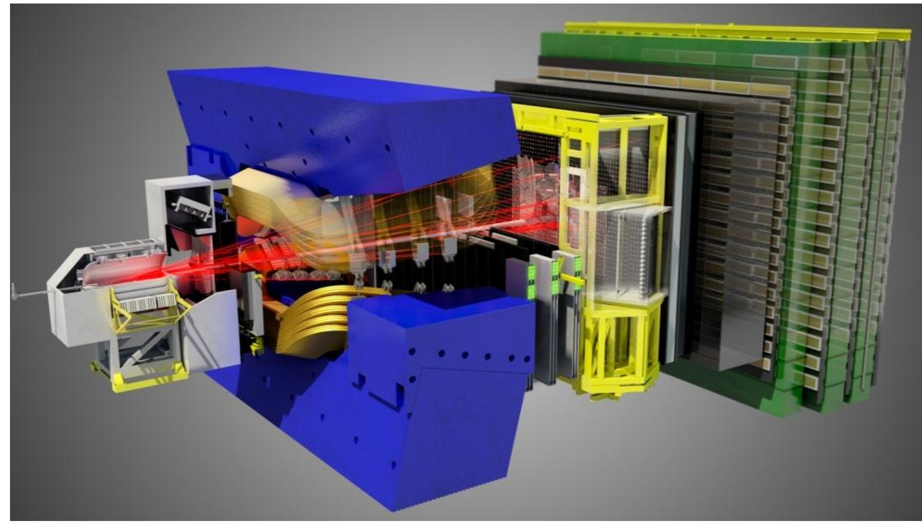
—> "New Physics" mass scale pushed higher
—> fine tuning needed to protect Higgs mass ? "Naturalness" appears problematic

Indirect searches with LHCb have the potential to see New Physics in flavor phenomena.

The LHCb Upgrade will allow operation at $L \leq 2 * 10^{33}\ cm^{-2} s^{-1}$, $\int L.dt = 50 fb^{-1}$
(for bunch spacing 25ns !!)

Increase in yields: **x10** in muonic channels **x20** in hadronic channels

LHCb: 2012 onwards



for LS1:
Pre-cabling for upgrades
Elec system revision incl UPS
Widespread consolidation work esp magnet

LS1(22mo) LS2 (18mo) LS3

Phase 1: The upgrade is "a 1-phase upgrade in LS2
LOI endorsed June 2011 & FTDR endorsed Sept 2012
New VeLO and beampipe elements
40MHz readout
Full software trigger

Profit from LS1 + YETS/YEETS before LS2 to prepare the upgrade

LHCb at HL-LHC

no show-stoppers expected for operation of LHCb at HL-LHC :

- Optics have been developed compatible with

  requirements for ATLAS&CMS (β^* 0.1m)

  requirements for the upgraded LHCb (β^*3.5m)

- **FLUKA simulations showed that for luminosities of 2 $*10^{33}$ $cm^{-2}s^{-1}$ no TAS is needed (safety-factor of ~ 3). Additional measurements at 7+7 TeV in 2015 to confirm.**
- Minimum required aperture in the LHCb VELO conservatively defined >10 years ago. To improve the physics performance,

  investigations on-going to reduce radius(?) from 5.1mm to 3.5mm.

  First conclusions indicate feasibility.

- A reduction of the beam pipe diameter for the first section is under study

Conclusions

Physics programme of LHC looks solid, but challenging for detectors, far into the future.

ATLAS & CMS collaborations are consolidating and upgrading the high luminosity experiments for a long-term programme.

The "Higgs-like" discovery at low mass means the detectors have to maintain present performance over a huge dynamic range while coping with rad damage & pile-up.

Large amounts of high quality *recorded and analysable* (integrated) luminosity are needed for precision measurements and the search for rare processes.

Pile-up mitigation was a key to early discovery in 2012, but limits will soon be reached
––> 25 ns operation must be mastered.

ALICE & LHCb have approved upgrade projects for running beyond LS3:
––> will impact the schedule and operation of LHC.

Sufficient overlapping issues in the machine interface to justify common Engineering Project Office between machine and experiments!

Additional slides

2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	...	2030
	Phase 0			LS1		Phase I,II			LS2	Phase II			LS3			

ATLAS EXPERIMENT

"Phase-0" upgrade: consolidation
$\sqrt{s}$ = 13~14 TeV, 25ns bunch spacing
$L_{inst} \simeq 1 \times 10^{34}$ cm^{-2}s^{-1} ($\mu \simeq 27.5$)
$\int L_{inst} \simeq 50$ fb^{-1}

"Phase-I" upgrades: ultimate luminosity
$L_{inst} \simeq 2\text{-}3 \times 10^{34}$ cm^{-2}s^{-1} ($\mu \simeq 55\text{-}81$)
$\int L_{inst} \gtrsim 350$ fb^{-1}

"Phase-II" upgrades:
$L_{inst} \simeq 5 \times 10^{34}$ cm^{-2}s^{-1} ($\mu \simeq 140$) w. leveling
$\simeq 6\text{-}7 \times 10^{34}$ cm^{-2}s^{-1} ($\mu \simeq 192$) no level.
$\int L_{inst} \simeq 3000$ fb^{-1}

ATLAS has devised a 3 stage upgrade program to optimize the physics reach at each Phase

- New Insertable pixel b-layer (IBL)
- New Al beam pipe
- New pixel services
- New evaporative cooling plant
- Consolidation of detector elements (e.g. calorimeter power supplies)
- Add specific neutron shielding
- Finish installation of EE muon chambers staged in 2003
- Upgrade magnet cryogenics

- New Small Wheel (nSW) for the forward muon Spectrometer
- High Precision Calorimeter Trigger at Level-1
- Fast TracKing (FTK) for the Level-2 trigger
- Topological Level-1 trigger processors
- New forward diffractive physics detectors (AFP)

- All new Tracking Detector
- Calorimeter electronics upgrades
- Upgrade part of the muon system
- Possible Level-1 track trigger
- Possible changes to the forward calorimeters

Summary of upgrades planned so far

Element	Phase1 (up to end of LS2)	Phase2 (from start of LS3)
Tracking	Pixel––> 4+3 layer, low mass, CO_2 cooled, with improved readout chip. Exchangeable/upgradable layers. Pixel and strip trackers cold operation	Pixel––> New chip & ROC. Major strip tracker re-build, trigger capable, CO_2 cooled. Possible forward trackers.
Calorimetry	HCAL Phototransducer change HB/HE Depth segmentation Front and back-end electronics	New HCAL and ECAL technology? Especially endcap & forward
Muon System	4'th endcap muon station Improved granularit at high η DT MB1 TRB, DT Sector Collector	DT minicrate revision. Rate and background mitigation, especially at high η
Trigger/DAQ	Opto SLB's. HCAL & ECAL Trigger fibres and crates.RCT/GCT to µTCA Event builder, HLT.	Major revision including track trigger.
Common systems	YE4 shielding wall, 45mm o/d beampipe, magnet cryo redundancy. Safer moving system,UPS extension. Beam monitors PLT and BSC 2.	Rebuild of forward pipes, TAS, shielding BCM system replacement V. forward detectors in LSS