HL-LHC (High Luminosity LHC)

Technical challenges

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HL-LHC Configuration, Quality & Resources Officer
On behalf of the HL-LHC Project team

Accelerators Revealing the QCD Secrets, Greece, 3rd September 2016
The HL-LHC Project

Goals, schedule and project structure
The main objective of HiLumi LHC Design Study is to determine a hardware configuration and a set of beam parameters that will allow the LHC to reach the following targets:

A peak luminosity of $L_{\text{peak}} = 5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ with levelling, allowing:

An integrated luminosity of 250 fb$^{-1}$ per year, enabling the goal of $L_{\text{int}} = 3000$ fb$^{-1}$ twelve years after the upgrade. This luminosity is more than ten times the luminosity reach of the first 10 years of the LHC lifetime.

Concept of ultimate performance recently defined:

$L_{\text{ult}} \approx 7.5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ and Ultimate Integrated $L_{\text{int, ult}} \sim 4000$ fb$^{-1}$

LHC should not be the limit, would Physics require more…
Nominal parameters would be reached in 2037

Logarithmic graph showing the progression of luminosity and integrated luminosity from today (2010) to 2038. The graph indicates a steady increase in luminosity across different years, with peaks and integrated luminosities marked for each year until 2038.
HL-LHC Project Governance

CERN Directorate and Accelerator & Technology Sector
ATSMB & EATSMB

HL-LHC & LIU Executive Committee

HL-LHC Project Office

LIU Project

HL-LHC TCC

HL-LHC Work Packages

C-MAC
Experiments

HL-LHC Collaboration Board
US-LARP KEK

IEFC
LMC

A&TS DH GLs
HL-LHC Workpackages

**HL-LHC Project Management**
- **Project Leader:** Lucio Rossi, CERN
- **Deputy Project Leader:** Oliver Brüning, CERN
- **Project Office Manager:** Laurent Tavian, CERN
- **Configuration, QA, Resource Manager:** Isabel Bejar Alonso, CERN
- **Integration:** Paolo Fessia, CERN
- **Collaborations & Consolidation:** Beniamino Di Girolamo, CERN
- **Budget Officer:** Benoit Delille, CERN
- **Safety Officer:** Thomas Otto, CERN
- **Secretariat:** Cécile Noels & Julia Cachet, CERN

**Member States Collaborations**
- **IR Magnets**
  - CEA Saclay: P. Vedrine, J-M. Riflet, H. Felice
  - CERN: J-M. Perez, F. Toral
  - INFN: A. Zoccoli, G. Volpini, P. Fabbricatore
  - Uppsala University: T. Ekelöf
  - UK: R. Appleby (Spokesperson & Collimation), G. Burt (Crab Cavity), S. Gibson (Beam Instr.), Y. Yang (Cold Powering)

**Non Member States Collaborations**
- **US HL-LHC AUP**
  - Project Manager: G. Apollinari, FNAL
  - Deputy Project Manager: R. Carcagno, FNAL
  - Magnet Systems: G. Ambrosio, FNAL
  - Crab Cavities System: A. Ratti, LBNL, L. Ristori, FNAL
  - KEK - Japan
    - LHC Upgrade Coordinator: K. Tokushuku
    - SC D1 Magnet: T. Nakamoto

**Workpackages**
- **WP2 Accelerator Physics**
  - Gianluigi Arduini
  - Rogelio Tomas Garcia

- **WP3 IR Magnets**
  - Elio Todisco
  - Paolo Ferracin

- **WP4 Crab Cavities & RF**
  - Rama Calaga
  - Ofelia Capatina

- **WP5 Collimation**
  - Stefano Redaelli
  - Roderik Bruce

- **WP6A Cold Powering**
  - Amalia Ballarino
  - Vittorio Parma

- **WP6B Warm Powering**
  - Jean-Paul Burnet
  - Michele Martino

- **WP7 Machine Protection**
  - Daniel Wollman
  - Reiner Denz

- **WP8 Collider-Experiment Interface**
  - Helmut Burkhardt
  - Francisco Sanchez Galan

- **WP9 Cryogenics**
  - Serge Claudet
  - Rob Van Weerden

- **WP10 Energy Deposition & R2E**
  - Markus Brugger
  - Francesco Cerutti

- **WP11 11 T Dipole**
  - Frédéric Savary
  - Hervé Prin

- **WP12 Vacuum**
  - Vincent Baglin
  - Roberto Kersevan

- **WP13 Beam Instrumentation**
  - Rhodri Jones
  - Hermann Schmickler

- **WP14 Beam Transfer**
  - Chiara Bracco
  - Brennan Goddard

- **WP15 Integration & (De-)Installation**
  - Paolo Fessia

- **WP16 IT String & Commissioning**
  - Marta Bajko
  - Mirko Pojer

- **WP17 Infrastructure & Logistics**
  - Laurent Tavian
  - Beniamino Di Girolamo

1. In-kind contributions
2. INFN Directorate
3. INFN Milano IASA
4. INFN Genova
5. University of Manchester/Cockcroft Institute
6. Lancaster University/Cockcroft Institute
7. Royal Holloway/John Adams Institute
8. University of Southampton
9. US HL-LHC Accelerator Upgrade Project
The HL-LHC Project

Main components, technical services and infrastructure
Many points around the ring

Luminosity
Availability
Reliability
HL-LHC project breakdown structure

- **WP1**
  - Project Management
- **WP2**
  - Accelerator Physics & Performance
- **WP3**
  - IR Magnets
- **WP4**
  - Crab Cavities & RF
- **WP5**
  - Collimation
- **WP6A**
  - Cold Powering
- **WP6B**
  - Warm Powering
- **WP7**
  - Machine Protection
- **WP8**
  - Collider-Experiment Interface
- **WP9**
  - Cryogenics
- **WP10**
  - Energy Deposition & R2E
- **WP11**
  - 11 T Dipole
- **WP12**
  - Vacuum & Beam Screen
- **WP13**
  - Beam Instrumentation
- **WP14**
  - Beam Transfer & Kickers
- **WP15**
  - Integration & (De-)Installation
- **WP16**
  - IT String & Commissioning
- **WP17**
  - Infrastructure, Logistics & Civil Engineering
The largest HEP accelerator in construction

DispersIon Suppressor (DS)
Modifications
1. In IP2: new DS collimation in c. Cryostat
2. In IP7 new DS collimation with 11 T

Matching Section (MS)
Complete change and new lay-out
1. TAN
2. D2
3. CC
4. Q4
5. All correctors
6. Q5
7. New MQ in P6
8. New collimators

Interaction Region (ITR)
Complete change and new lay-out
1. TAXS
2. Q1-Q2-Q3
3. D1
4. All correctors
5. Heavy shielding (W)

Cryogenics, Protection, Interface, Vacuum, Diagnostics, Inj/Extr… extension of infrastructure

> 1.2 km of LHC
New Insertion Region lay out

Longer Quads; Shorter D1 (thanks to SC)
Interaction region length is unchanged

Thick boxes are magnetic lengths -- Thin boxes are cryostats
Why changing the inner triplets

- Triggered by radiation damage on existing equipment due to leap in performance
- **Dose of** 30 MGy expected @ 300 fb$^{-1}$ with impact on electrical insulation integrity

LHC has better aperture than anticipated and all margin can now be used. However, seems very difficult to have $\beta^* < 35\text{-}40\text{ cm}$ (55 cm being the nominal)
Working on the Inner triplet magnets
MQXFS01 test

Test at FNAL in progress. The magnet tested at Fermilab consists of two coils manufactured at CERN and two others manufactured by the LARP (LHC Accelerator Research Program) consortium.
HiLumi LHC magnet zoo

- Triplet QXF (LARP and CERN)
- Orbit corrector (CIEMAT)
- Separation dipole D1 (KEK)
- 11 T dipole (CERN)
- Recombination dipole D2 (INFN design)
- Q4 (CEA)
- Sextupole (INFN) Octupole (INFN)
- Skew quadrupole (INFN)
- Decapole (INFN) Dodecapole (INFN)

Overall, about 150 magnets are needed
Superconducting crab cavities – Why?

- Deflecting (or crab) cavities will be needed for compensation of the effective geometric crossing angle \( \theta_c \) at the Interaction Points (IP) to recover the luminosity loss due to increased crossing angle.

- The cavities generate a transverse electric field that rotates each bunch by \( \theta_c /2 \). The time dependent transverse kick from an RF deflecting cavity is used to perform a bunch rotation, in the \( x-z \) plane or \( y-z \) plane depending on the crossing angle orientation, about the barycentre of the bunch.

- The kick is transformed to a relative displacement of the head and the tail of the bunch at the IP to impose a head-on collision while maintaining the required beam separation to minimize parasitic collisions.

Bunches colliding with a crossing angle without (left) and with (right) the crab crossing.
Crab cavities

Mostly standardized interfaces and common platform

Main differences
- Cavity symmetry & length
- HOM couplers

Double Quarter Wave, Vertical Deflection

RF Dipole, Horizontal Deflection
SPS Cryomodule:
Include 2 identical cavities

Double Quarter Wave
Why upgrading the Collimation system

- Because of a high stored energy, above 700 MJ, the beams in LHC are highly destructive. **Even a local beam loss of a tiny fraction of the full beam in a superconducting magnet could cause a quench**, and large beam losses could cause damage to accelerator components.

- In the LHC, a multistage **collimation system** has been installed to safely dispose of beam losses.

- The **HiLumi LHC** imposes increased challenges to the collimation system. The **factor ~2 increase in total stored beam energy** requires a corresponding improvement of cleaning performance to achieve the same losses in the superconducting magnets.
Collimation system evolving with the Run

- IR1+IR5, per beam:
  - 4 tertiary collimators
  - 3 physics debris collimators
  - fixed masks
- Completely new layouts
- Novel materials.

Final decision on installation to be taken based on Run 2 experience

Cleaning: DS coll. + 11T dipoles, 2 units per beam

Ion physics debris:
- DS coll. + 11T dipoles

Low-impedance, high robustness secondary collimators
TCSPM Overview

- Longer jaws, tapering and vacuum tank
- Shorter RF fingers, upstream and downstream flange collars
- Same flange-to-flange length
- BPM vertical buttons upstream, on top of the horizontal BPMs for jaw positioning
Increasing availability

Baseline: removal to Double Decker Underground

4 pairs 150(+/− 75) kA for MS−LS3
4 pairs 100(+/−50) kA for ITR−LS3
All lines in MgB$_2$ (or HTS)
tens of 6-18 kA CLs pairs in HTS
Superconducting link concept

New “DFB”: joint box

MgB$_2$

HTS

No LHe
Eliminating Technical bottlenecks

8 x 18 kW @ 4.5 K
1'800 SC magnets
24 km and 20 kW @ 1.9 K
36'000 tons @ 1.9 K
96 tons of He
The 11T Dipole Two-in-One for DS

Create space in the dispersion suppressor regions of LHC, i.e. a room temperature beam vacuum sector, to install additional collimators (TCLD)

Replace a standard Main Bending dipole by a pair of 11T dipoles (the 11T dipole is also called MBH)

\[ \int B dL = 119.2 \text{ Tm} @ I_{\text{nom}} = 11.85 \text{ kA} \]

in series with MB with 20% margin

By-pass cryostat 15660 mm 11 T dipole cold mass

Interconnect Space for Collimator
Beam diagnostic improvement

- Cryogenic BLMs & Radiation Hard Electronics
  - Cryogenic BLMs
  - Radiation hard electronics
- Fast WireScanners
- Insertion Region BPMs
  - Cold directional couplers
  - Tungsten shielded cold directional couplers
  - Warm directional couplers
  - High precision electronics for insertion region BPMs
- Luminosity Monitors
- Diagnostics for Crab Cavities
- Upgrade to Synchrotron Light Monitors
  - Upgrade to existing monitor
  - New light source
  - Halo diagnostics
- Beam Gas Vertex Detector
  - Final Implementation
- Long-Range Beam-Beam Compensator
  - Prototype
  - Final Implementation
And many other improvements

- **Machine protection:** improved robustness to mis-injected beams, to kickers sparks will be required. The kicker system, collimation and TDI, is the main shield against severe beam induced damage.

- **Quench Protection System** of SC magnets to remake a 20 years old design.

- **Remote manipulation:** the level of activation around 2020 requires development of special equipment to allow replacing/servicing collimators, magnets, vacuum components etc., according to ALARA principle. Remote manipulation, enhanced reality and supervision is the key to minimizing the radiation doses sustained during interventions.

- **Vacuum …**
A glimpse to the future

http://plabdev.ramk.fi/cern/
How it could look like in point 5 (Before)
How it could look like in point 5 (after)
Over the LHC Tunnel
On the new HL-LHC infrastructures
On the new HL-LHC infrastructures
On the new HL-LHC infrastructures
Challenges

Technical
Industrial
Human
Political
Thank you for your attention

Special Thanks to all HL-LHC WP Leaders for their contribution
# Surface buildings

<table>
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≈ 3’400 m² new buildings

Present surface≈ 75’200 m²
New surface≈ 91’200 m²

Present surface≈ 42’300 m²
New surface≈ 55’300 m²
Space needed for cable trays

UR:

Size of cable trays (AC and signal):
600/60 mm. Distance between: 250mm

Constraints: Cable trays must be accessible for additional cables.

UA:
General view
Installation Overview for LS2 (2019-2020)

- New transp. refrigerator
- New Q5
- TCSPM
- Cryo-bypass+TCLD
- In-situ a-C coating
- Mask for D2
- TAXN
- High bandwidth pick-ups
- Fast wire scanners
- BGV
- Prep. works
- halo diagnostic systems
- TDIS
- TCDD Mask for D1
Typical view of the infrastructure needs