Status & prospects LHC accelerator and HL-LHC plans

High Energy Physics Advisory Panel
Frédérick Bordry
10th December 2015

- Prepare the LHC for Operation at Nominal Energy
- Consolidate and Upgrade the LHC and Injector performance
- Major Maintenance Programme

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Over 1 Million Hours Worked in the LHC Tunnel

Safety First, Quality Second, Schedule Third.
The main 2013-14 LHC consolidations

1. 1695 Openings and final reclosures of the interconnections
2. Complete reconstruction of 3000 of these splices
3. Consolidation of the 10170 13kA splices, installing 27 000 shunts
4. Installation of 5000 consolidated electrical insulation systems
5. 300 000 electrical resistance measurements
6. 10170 orbital welding of stainless steel lines
7. 18 000 electrical Quality Assurance tests
8. 10170 leak tightness tests
9. 3 quadrupole magnets to be replaced
10. 15 dipole magnets to be replaced
11. Installation of 612 pressure relief devices to bring the total to 1344
12. Consolidation of the 13 kA circuits in the 16 main electrical feedboxes
The CSCM is a test to **fully qualify** if the main dipole bypass can take over the current if the superconducting circuit quenches. A kind of dry-run of the bypass (very low energy 200 kJ and low time constant 0.2s)

**Basic idea**
- Stabilize the entire sector at around 20 K, so the magnets and bus are not superconducting. Keep the DFB at 4.5 K.
- Connect the two 6 kA/200 V power converters in series ($\Rightarrow$ 400V)
- Apply several steps of current pulse, up to 11.1 kA (6.5 TeV), $\tau$=100 s
Since September 15th 2014:

1566 superconducting circuits commissioned through execution and analysis of more than 10,000 test steps (~13,800 test steps including re-execution)
Dipole Training Campaign

Each Sector Trained to 6.55 TeV (11080A) (100 A above the operational field)

Large variation in number of training quenches per sector

---

**Sector** | **# Training quench** | **Flattop quenches**
---|---|---
S12 | 7 | 0
S23 | 17 | 0
S34 | 15 | 1
S45 | 51 | 0
S56 | 18 | 3
S67 | 22 | 1
S78 | 19 | 3
S81 | 29 | 0
Total | 171 | 8

Detailed Analysis in Progress!
First circulating beams in LHC on Easter Sunday
5th April 2015
First beam at 6.5 TeV! (10th April)
First beams at 6.5 TeV! (12th April)
LHC experiments are back in business at a new record energy 13 TeV
3rd June 2015
A lot of lessons learnt and experience from Run 1

- Excellent and improved system performance (LS1)
  - Beam Instrumentation
  - Transverse feedback
  - RF
  - Collimation
  - Injection and beam dump systems
  - Vacuum
  - Machine protection
- Improved software & analysis tools (LS1)
- Magnetically reproducibility
- Optically good, corrected to excellent
- Behaving well at 6.5 TeV
  - One additional training quench so far
- Operationally well under control
  - Injection, ramp, squeeze, de-squeeze

Beam commissioning in two months 😊

13 TeV
1. **Low intensity commissioning** – 8 weeks
2. **First physics** – low number of bunches, LHCf run
3. **Electron cloud scrubbing for 50 ns (e-cloud)**
4. **Physics - intensity ramp-up with 50 ns**
   - Characterize high intensity operation (≈ repeat 4 TeV @ 6.5 TeV)
5. **Electron cloud scrubbing for 25 ns (e-cloud)**
6. **Physics - ramp-up intensity for 25 ns operation**
Resume of the intensity ramp up after TS2
  - First driven by machine protection validation
  - Then driven by cryo system operation (> 1600 bunches)

Special physics run (90 m optics)
  - back to lower beam intensity for commissioning and production
  - step down for 25 ns physics run

Ions run to conclude the year:
  - Including intermediate energy run with proton at 2,51 TeV

End of 2015: 25 ns physics run
2015 LHC Luminosity

**ATLAS**

**Peak**

- Peak: $5 \times 10^{33} \text{ cm}^{-1} \text{ s}^{-1}$
- Design: $10^{34} \text{ cm}^{-1} \text{ s}^{-1}$

**Integrated**

**CMS**

- CMS Peak Luminosity Per Day, pp, 2015, $\sqrt{s} = 13 \text{ TeV}$
  - Max. Inst. Lumi.: 4900 fb$^{-1}$

- CMS Integrated Luminosity, pp, 2015, $\sqrt{s} = 13 \text{ TeV}$
  - LHC Delivered: 4087.52 fb$^{-1}$
  - CMS Recorded: 3667.75 fb$^{-1}$
The initial projections of integrated luminosity for 2015 were ~ 8-10 fb\(^{-1}\).
Achieved ~ 4.3 fb\(^{-1}\).
Slope at the end of the run better than in 2011, and close to 2012 slope (last week of operation > 1 fb\(^{-1}\))

- Start-up delays (~ 4 weeks),
- Availability issues (radiation failures on the quench protection tunnel electronics; solved after TS2),
- Electron clouds mitigation
UFOs

There are with us, they are many of them, they are large!

- UFO events observed quite often during operation at 6.5 TeV

LHC FILL NUMBER: 4378 CYCLING

PROTON PHYSICS

Beam | Intens
--- | ---
1 | 0.00E
2 | 0.00E

Inj. scheme: 25ns_1033b_1021_878_885_144bpi10inj

2015-09-16 15:47:40 precycle... next: physics 1033b / 144bpi

Beam intensity and Energy

1033 x 1033

UFO
UFOs

There are with us, they are many of them, they are large!

- UFO events observed quite often during operation at 6.5 TeV
- Conditioning is observed on the UFO rate in spite of the increasing number of bunches
- BLM thresholds being optimize to find a good compromise between availability and quench protection

25ns scrubbing

![Graph showing UFO events over fill number]

2015

![Image of a particle track]
Aperture restriction:
✧ A position with anomalous beam losses was located on beam 2 in the arc between LHCb and ATLAS only few days after commissioning.
✧ Measured at injection and 6.5 TeV
✧ An aperture restriction due to an was found by scanning the beam position.
✧ Reference orbit is bumped by +1mm in V and -3mm in H at 15R8.
✧ 2015 not a limiting aperture for operation

Objects found in the past in the LHC vacuum chambers
Aperture restriction:
✧ A position with anomalous beam losses was located on beam 2 in the arc between LHCb and ATLAS only few days after commissioning.
✧ Measured at injection and 6.5 TeV
✧ An aperture restriction due to an was found by scanning the beam position.
✧ Reference orbit is bumped by +1mm in V and -3mm in H at 15R8.
✧ 2015 not a limiting aperture for operation

✧ Opening the magnet to remove this object would take 2-3 months!
✧ => Not planned for YETS (Year End Technical Stop)
Some issues:

- Higher Order Modes heating of the injection collimator and kickers
- Number of injections limited by same components
- Injection speed in general limited by time response of the cryogenic system
Heat Load Evolution – E cloud

Scrubbing observed with physics fills at 6.5 TeV

→ Hopefully gaining margin to further increase the number of bunches
→ Scrubbing “memory” kept while running with 25 ns beams - deconditioning was observed after few weeks of low e-cloud operation
2015 LHC Machine availability

Statistics for 25 ns run from September 7 to November 3
• In 2004, during commissioning of the system at the surface, about 2 litres of Breox were “spilled” in the cold box (wrong manipulation). The system was cleaned with isopropyl alcohol. It was afterwards very difficult to get the cleaning solvent out.

• During commissioning of compressor station, an under-dimensioning of the oil separator system has been identified.

• At that moment the oil separator system was not upgraded, but a 4th coalescer added to the system.

• The refrigerator system operated through Run 1 (≈10 years), with only minor problems.
CMS Cold-Box Contamination: *Summary of events*

- CMS refrigerator has been re-started in November 2014 after the LS1 maintenance;
- Mid March first sign of contamination, at that moment blamed on air / water-pollution. *Procedures applied: sub-system regenerated.*
- Beginning of May contamination identified at three different points. *Procedures applied: System stopped, samples taken and complete regeneration.*
- After re-start of system almost *immediate contamination measured* at same points. Confirmed by result analysis of samples. *Procedures applied: System stopped.*
- Analyse shows compressor oil (Breox®) milligram (mg) traces.
• Breox® (compressor oil) was found on  
  1. Outlet filter 80K and 20 K adsorbers  
  2. Inlet filter T1  
  3. Inlet filter T2  
  4. Turbine gas bearing inlet filters  

• Breox® is thought to diminish the heat exchange surface of the first heat-exchanger.

Normally a cold-box having suffered such a Breox® pollution is stopped to be cleaned. This was however impossible in the CMS case, and the installation was kept alive with regular 80K adsorber and turbine inlet filters regenerations. When judged necessary the turbine filters were exchanged for new ones.

Of the integrated (p-p) luminosity delivered to CMS in 2015, about 73% of the data is taken under nominal field conditions;
CMS cryogenic issue: 
**YETS** (Year End Technical Stop) consolidations

- Cleaning of the cold box circuits: procedure and cleaning medium compatible with cavern environment.
- Installation of a new high-pressure line in CMS pit.
- Consolidation of the oil removal system:
  - New high-pressure primary oil separator
  - New coalescers for the final oil removal system
- Repair of a bended cryo-valve on the 6000-l LHe buffer in the UX cavern (damaged during LS1)
- Repair of the leaky LN2 pre-cooler
- Additional boosting of the cryoplant with the connection of a 11’000-l LHe mobile reservoir (feasibility under study).
• Change the 80 K and 20 K adsorbers (remove polluted equipment which cannot be cleaned)

• Clean cold-box equipment from Breox®: which solvent to use?
  1. Solvent shall adsorb Breox compressor oil, but not attack cold-box equipment
  2. It shall be possible to remove the solvent from the cleaned volumes
  3. Solvent shall be used in underground area

Adequate solvent has been selected, machinery to circulate the solvent though the cold-box equipment has been ordered, safety measures have been implemented;
A first review took place on the proposed measures discussed above, and a second one of the risks which these interventions could bring to the system. Both reviews supported the proposed measures.

A preliminary planning was established, but has to be finalized after the completion of the cleaning procedure of the first sub-system.
LHC goal for Run 2 and 3

Integrated luminosity goal:
Run2: \(\sim 100-120 \, \text{fb}^{-1}\)

\(\sim 300 \, \text{fb}^{-1}\) before LS3
- After TS3, restart for ions physics run
- Intermediate energy run with protons at 2.51 TeV:
  - Full cycle commissioning: combined ramp and squeeze, optics, Machine protection validation....
  - Intensity ramp up: up to 1800 bunches per beam
- 3 weeks of Pb-Pb collisions:
  - Again full validation of a new cycle at 6.37 ZTeV: Alice pre-squeeze, squeeze, ALICE crossing reversal + IP shift....
  - Now operating with 518 bunches per beam
11 Nov – First Pb-Pb STABLE BEAMS

First Pb-Pb Stable Beams at 5.02 A TeV = 1.045 PeV

ALICE event with TPC and muon spectrometer

- Design peak lumi: $1 \times 10^{27} \text{ cm}^{-2}\text{s}^{-1}$:
  - ALICE already leveled at design lumi
  - ATLAS/CMS already beyond

- Delivered lumi so far (2.5 weeks of physics):
  - ALICE 280 $\mu$b$^{-1}$; ATLAS/CMS 410 $\mu$b$^{-1}$
  - Target for 2015 ions run: 300 - 500 $\mu$b$^{-1}$
ALICE levelled at saturation value $L = 1 \times 10^{27}$ cm$^{-2}$s$^{-1}$ (design)

Design luminosity

Source refill

Van der Meer scans

Crystal coll. MD

ALICE polarity reversal

LHCb should have about 2% of ATLAS

13 days

Integrated luminosity in each fill
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.

HL-LHC from a study to a PROJECT
300 fb\(^{-1}\) → 3000 fb\(^{-1}\)
including LHC injectors upgrade LIU
(Linac 4, Booster 2GeV, PS and SPS upgrade)
Near-term & Mid-term High-energy Colliders

LARGE HADRON COLLIDER

- The HL-LHC is strongly supported and is the first high-priority large-category project in our recommended program. It should move forward without significant delay to ensure that accelerator and experiments can continue to function effectively beyond the end of this decade and meet the project schedule.

- Recommendation 10: Complete the LHC phase-1 upgrades, and continue the strong collaboration in the LHC with the phase-2 (HL-LHC) upgrades of the accelerator and both general-purpose experiments (ATLAS and CMS). The LHC upgrades constitute our highest-priority near-term large project.
Increase intensity/brightness in the injectors to match HL-LHC requirements

⇒ Enable Linac4/PSB/PS/SPS to accelerate and manipulate higher intensity beams (efficient production, space charge & electron cloud mitigation, impedance reduction, feedbacks, etc.)
⇒ Upgrade the injectors of the ion chain (Linac3, LEIR, PS, SPS) to produce beam parameters at the LHC injection that can meet the luminosity goal

Increase injector reliability and lifetime to cover HL-LHC run (until ~2035) closely related to consolidation program

⇒ Upgrade/replace ageing equipment (power supplies, magnets, RF…)
⇒ Improve radioprotection measures (shielding, ventilation…)
LS2 : (2019-2020), LHC Injector Upgrades (LIU)

LINAC4 – PS Booster:
- $^1H$ injection and increase of PSB injection energy from 50 MeV to 160 MeV, to increase PSB space charge threshold
- New RF cavity system, new main power converters
- Increase of extraction energy from 1.4 GeV to 2 GeV

PS:
- Increase of injection energy from 1.4 GeV to 2 GeV to increase PS space charge threshold
- Transverse resonance compensation
- New RF Longitudinal feedback system
- New RF beam manipulation scheme to increase beam brightness

SPS
- Electron Cloud mitigation – strong feedback system, or coating of the vacuum system
- Impedance reduction, improved feedbacks
- Large-scale modification to the main RF system

These are only the main modifications and this list is far from exhaustive
Goal of High Luminosity LHC (HL-LHC):

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:

Prepare machine for operation **beyond 2025 and up to 2035-37**

Devise beam parameters and operation scenarios for:

# enabling a total integrated luminosity of **3000 fb\(^{-1}\)**

# implying an integrated luminosity of **250-300 fb\(^{-1}\) per year**,  
# design for \(\mu \sim 140 (\sim 200)\) (⇒ peak luminosity of \(5 (7) \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}\))

# design equipment for ‘ultimate’ performance of \(7.5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}\) and **4000 fb\(^{-1}\)**

⇒ **Ten times the luminosity reach of first 10 years of LHC operation**
Luminosity recipe:

\[
L = \frac{n_b \cdot N_1 \cdot N_2 \cdot \gamma \cdot f_{rev}}{4\pi \cdot \beta^* \cdot \varepsilon_n} \cdot F(\phi, \beta^*, \varepsilon, \sigma_s)
\]

1) maximize bunch intensities  ➨ Injector complex
2) minimize the beam emittance  ➨ LIU ⇔ IBS
3) minimize beam size (constant beam power); ➨ triplet aperture
4) maximize number of bunches (beam power); ➨ 25ns
5) compensate for ‘F’; ➨ Crab Cavities
6) Improve machine ‘Efficiency’ ➨ minimize number of unscheduled beam aborts
The HL-LHC Project

- New IR-quads Nb$_3$Sn (inner triplets)
- New 11 T Nb$_3$Sn (short) dipoles
- Collimation upgrade
- Cryogenics upgrade
- Crab Cavities
- Cold powering
- Machine protection
- ...

Major intervention on more than 1.2 km of the LHC
Squeezing the beams: High Field SC Magnets

Quads for the inner triplet
Decision 2012 for low-β quads
Aperture $\varnothing$ 150 mm – 140 T/m
($B_{\text{peak}} \approx 12.3$ T)
operational field, designed for 13.5 T
=> $\text{Nb}_3\text{Sn}$ technology

$LHC$: 8 T, 70 mm

<table>
<thead>
<tr>
<th></th>
<th>$\beta_\text{triplet}$</th>
<th>$\Sigma_\text{triplet}$</th>
<th>$\beta^*$</th>
<th>$\Sigma^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal</td>
<td>$\sim 4.5$ km</td>
<td>1.5 mm</td>
<td>55 cm</td>
<td>17 um</td>
</tr>
<tr>
<td>HL-LHC</td>
<td>$\sim 20$ km</td>
<td>2.6 mm</td>
<td>15 cm</td>
<td>7 um</td>
</tr>
</tbody>
</table>
Target: 200 T/m gradient at 1.9 K

LQS01a: 202 T/m at 1.9 K
LQS01b: 222 T/m at 4.6 K
         227 T/m at 1.9 K

LQS02: 198 T/m at 4.6 K 150 A/s
         208 T/m at 1.9 K 150 A/s
limited by one coil

LQS03: 208 T/m at 4.6 K
         210 T/m at 1.9 K
1st quench: 86% s.s. limit

3.3 m coils
90 mm aperture

Quadrupoles of LARP

Courtesy: G. Ambrosio FNAL and G. Sabbi, LBNL

LARP
LS2: collimators and 11T Dipole

- LS2 2017-18: Point-X, 7 & IR-2
- LS3 2020+: IR1, 5 as part of HL-LHC

\[ J_{BrL} = 119.2 \, \text{Tm} \quad @ \quad I_{\text{nom}} = 11.85 \, \text{kA} \]

in series with MB with 20% margin

<table>
<thead>
<tr>
<th>LS2</th>
<th>LS3</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 coldmass + 2 spares = 14 CM</td>
<td>8 coldmass + 2 spares = 10 CM</td>
</tr>
<tr>
<td>Total = 24 CM</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LS2</th>
<th>LS3</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 coldmass + 4 spares = 28 CM</td>
<td>16 coldmass + 4 spares = 20 CM</td>
</tr>
<tr>
<td>Total = 48 CM</td>
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</tr>
</tbody>
</table>
11 T Magnet – Nb3Sn technology
Status on recent developments & tests at CERN

MBHSP0001-102 training

- Test target, 7.6 TeV, 12 T
- Nominal current, 7 TeV

Quench current (A)

- MBHSP101
- ▲ coil 106 inner
- ◈ coil 106 outer
- ▼ coil 108 inner
- ▼ coil 108 outer
- ○ undefined
- ✗ No quench

Quench number

0 10 20 30 40

13000
12000
11000
10000
9000
8000
In-kind contributions and collaborations for design, prototypes, production and tests

Discussions are ongoing with other countries, e.g. Canada,…

Q1-Q3 : R&D, Design, Prototypes and in-kind USA
D1 : R&D, Design, Prototypes and in-kind JP
MCBX : Design and Prototype ES
HO Correctors: Design and Prototypes IT
Q4 : Design and Prototype FR

CC : R&D, Design and in-kind USA
CC : R&D and Design UK
Cost & Schedule review of LIU and HL-LHC (March 2015)
### CMAC Members:
- Brinkmann, Reinhard
- Fischer, Wolfram
- Gourlay, Stephen
- **Holtkamp, Norbert (Chair)**
- Oide, Katsunobu
- Qin, Qing
- Roser, Thomas
- Seeman, John
- Shiltsev, Vladimir

### DESY (Deutsches Elektronen-Synchrotron)
- BNL (Brookhaven National Laboratory)
- LBNL (Lawrence Berkeley National Laboratory)
- **SLAC (SLAC National Accelerator Laboratory)**
- KEK (高エネルギー加速器研究機構)
- IHEP (Institute of High Energy Physics)
- BNL (Brookhaven National Laboratory)
- SLAC (SLAC National Accelerator Laboratory)
- FNAL (Fermi National Accelerator Laboratory)

### Reviewers:
- Neumeyer, Charles L.
- Petersen, Bernd
- Seidel, Mike
- Vedrine, Pierre
- Yamamoto, Akira

### PPPL (Princeton Plasma Physics Lab)
- DESY (Deutsches Elektronen-Synchrotron)
- PSI (Paul Scherrer Institute)
- CEA-Saclay (Commissariat à l'énergie atomique et aux énergies alternatives)
- KEK (Kō Enerugī Kasokuki Kenkyū Kikō)
Conclusion

C&S review committee side
Executive Summary - The first sentence of the 4 first paragraphs

Executive Summary
The review committee is very impressed with the enormous amount of work that was presented.

A very competent, engaged and effective management team is in place to manage both projects.

The Project Management tools used at CERN are state of the art, well utilized and well understood by the management team as well as all the personnel the review committee talked to.

The QA and QC programs are well established, flexible and effective.
LIU : Cost Summary

- Budgets are correctly assembled and adequate
- Schedule is generally well defined and realistic
- Some options for savings, deferrals or deletion (<15 MCHF)
- Scope on IONS is not well enough defined which leaves uncertainty in the design
- Significant ramp up of effort in the next 2 years requires close tracking of resources
- General concern about retiring expertise/ expertise availability

<table>
<thead>
<tr>
<th>Total cost / MCHF</th>
<th>186*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncertainty / %</td>
<td>-10 / +15</td>
</tr>
<tr>
<td>Uncertainty / MCHF</td>
<td>167 - 214</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>Class 2</td>
</tr>
<tr>
<td>% complete</td>
<td>17% (31 MCHF)</td>
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<tr>
<td>Total FTE / CERN</td>
<td>691</td>
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<tr>
<td>Total FTE / MPA</td>
<td>194</td>
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</tbody>
</table>

*Does not include LINAC4
Total cost / MCHF (original estimate 2011) | 833
---|---
Total cost / MCHF (new estimate) | 949
  | Construction phase 27
  | R&D phase
Uncertainty / % | -15 / +22
Uncertainty / MCHF | -142 / +208
Uncertainty | On average Class 3
% complete | R&D phase
Total FTE / CERN | 1660
Total FTE / MPA | 946

- Budgets are correctly assembled and adequate, but uncertainty varies between class 1 and 5
- Schedule is generally well defined and realistic
- Some options for savings, deferrals or deletion (see table later)
- More expensive workpackages have generally less uncertainty (apart from Civil Engineering).
- Unlikely that uncertainty on the negative site will materialize to the degree assumed.
- General concern expertise availability (new contract policy should help)
- Late information on cost / risk of Civil Engineering creates major risk that needs to be retired asap
MTP – HL-LHC revised cost profile

HL-LHC revised cost profile

R&D phase: 27 MCHF

Construction phase: 950 MCHF

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### LHC roadmap: schedule beyond LS1

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<tr>
<td>LHC</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
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<tr>
<td>Injectors</td>
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<tr>
<td></td>
<td>YETS</td>
<td>Run 2</td>
<td>EYETS</td>
<td>YETS</td>
<td>LS 2</td>
<td>YETS</td>
<td>Run 3</td>
</tr>
</tbody>
</table>

#### PHASE 1

- LS2 starting in **2018 (July)** => 18 months + 3 months BC
- LS3 LHC: starting in **2023** => 30 months + 3 months BC
- Injectors: in **2024** => 13 months + 3 months BC

**Extended Year End Technical Stop: (E)YETS**

<table>
<thead>
<tr>
<th>300 fb⁻¹</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
<th>2025</th>
<th>2026</th>
<th>2027</th>
<th>2028</th>
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<tr>
<td>LHC</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
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<tr>
<td>Injectors</td>
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<tr>
<td></td>
<td>YETS</td>
<td>YETS</td>
<td>LS 3</td>
<td>YETS</td>
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<td></td>
<td>Run 4</td>
</tr>
</tbody>
</table>

#### PHASE 2

**Goal of 3’000 fb⁻¹ by mid 2030ies**

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10th December 2015
LHC roadmap: according to MTP 2016-2020

LS2 starting in 2019 => 24 months + 3 months BC
LS3 LHC: starting in 2024 => 30 months + 3 months BC
Injectors: in 2025 => 13 months + 3 months BC

2015
Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4

2016
Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4

2017
Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4

2018
Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4

2019
Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4

2020
Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4

2021
Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4

LHC Inverters
Run 2

HL-LHC Civil engineering
LS 2
LIU installation

PHASE 1

LHC Inverters
Run 3

LS 3
Run 4

PHASE 2

LHC Inverters
LS 4
Run 5

LS 5

CERN
Status & prospects LHC accelerator and HL-LHC plans
High Energy Physics Advisory Panel
Frédéric Bordry
10th December 2015
Integration: vibration, machine integration, double decker and more

Vibration studies and measurements

Machine lay-out

Double Decker: lay-out and service integration (for WP17)

Courtesy of P. Fessia
Conclusions

LHC is operational at 13 TeV c.m. and with 25ns beams (2x2244 nominal bunches)

From 2016 in production mode
- 6.5 TeV, machine scrubbed for 25 ns operation
- $\beta^* = 40$ cm in ATLAS and CMS
- Rapid intensity ramp up should be possible
- Nominal design luminosity $1 \times 10^{34}$ cm$^{-2}$ s$^{-1}$ should be reached (expectation to go up to $\sim 1.2 \times 10^{34}$ in 2016)

RUN 2 goal: 100 fb$^{-1}$ and to reach 300 fb$^{-1}$ at the end of RUN 3

LHC Injector Upgrade (LIU => LS2) and High Luminosity LHC (HL-LHC => LS3) well defined and now in construction phase

-Full exploitation of the LHC with optimised planning out to 2035.
Thanks for your attention