HiLumi HL-LHC PROJECT

Design and Construction of the Full-length Prototype of the 11T Dipole Magnet for the High Luminosity LHC Project at CERN

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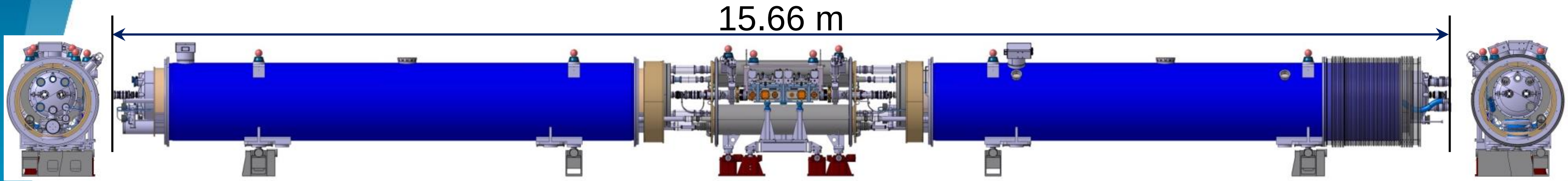
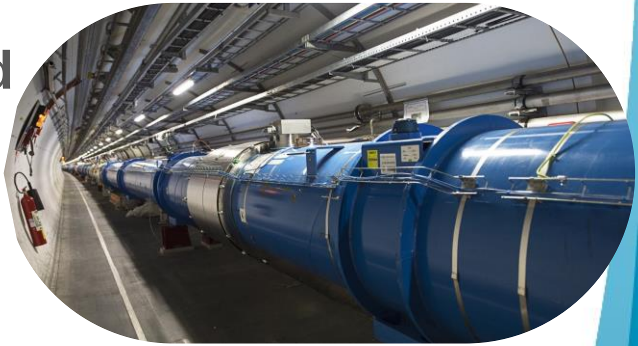
OUTLOOK

- Introduction
- Design features of the full-length prototype
- Main manufacturing steps
- Status of the prototype construction
- Quality control
- Production Plan
- Concluding remarks

Introduction

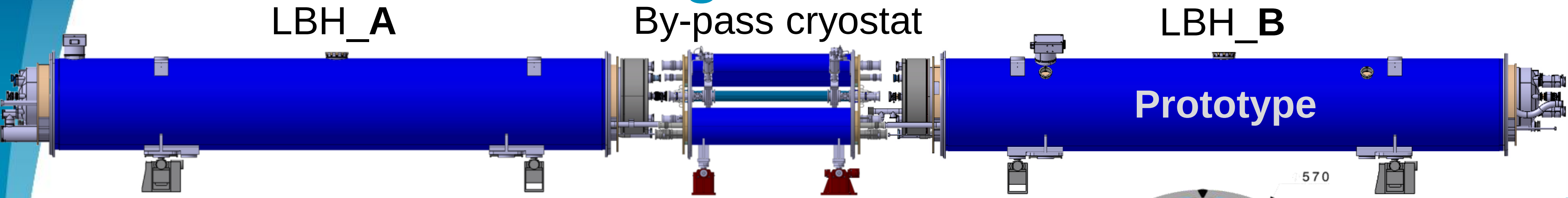


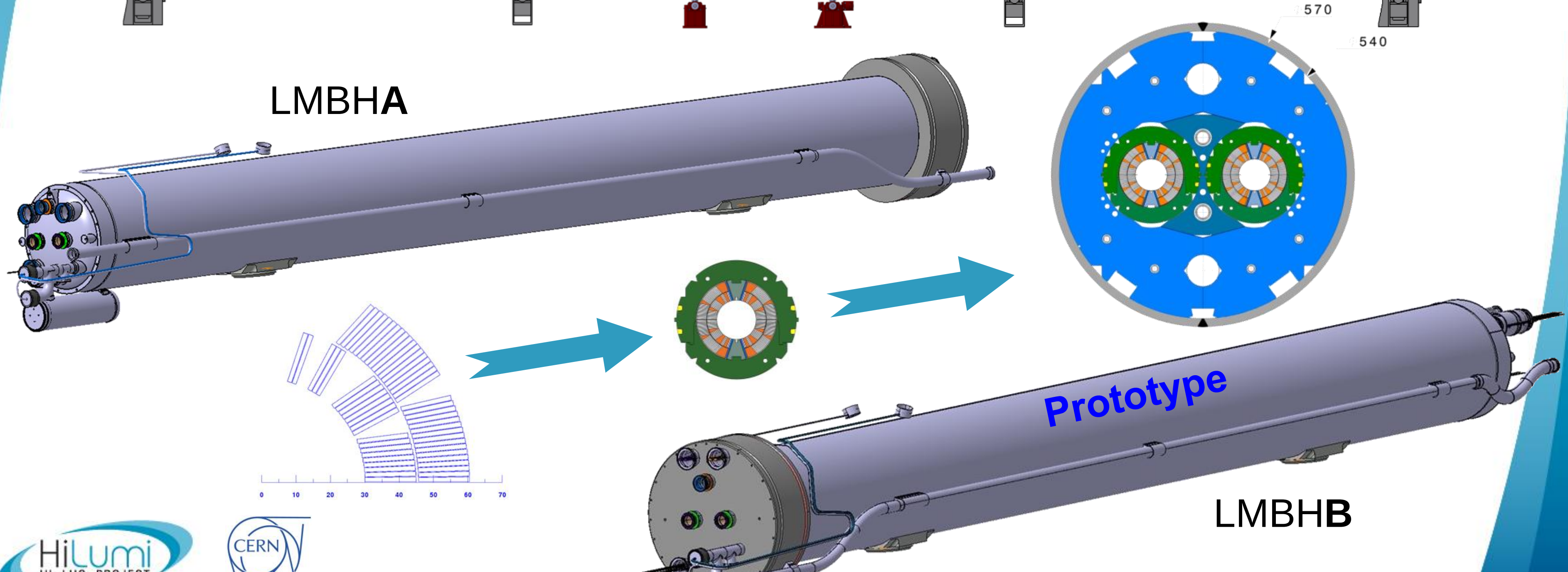
- The HL-LHC Project implies beams of larger intensity ➥ **additional collimators are needed** in order to **intercept and absorb higher beam losses** (dynamic heat loads on cryogenics and risk to quench superconducting magnets)
  - Two collimators, **one per beam, installed on either side of interaction point 7** (IP7) for both proton and heavy-ion collimation losses, in the Dispersion Suppressor region



- **Replace a standard Main Dipole by a pair of shorter 11 T Dipoles producing the same integrated field of 119 T·m at 11.85 kA**

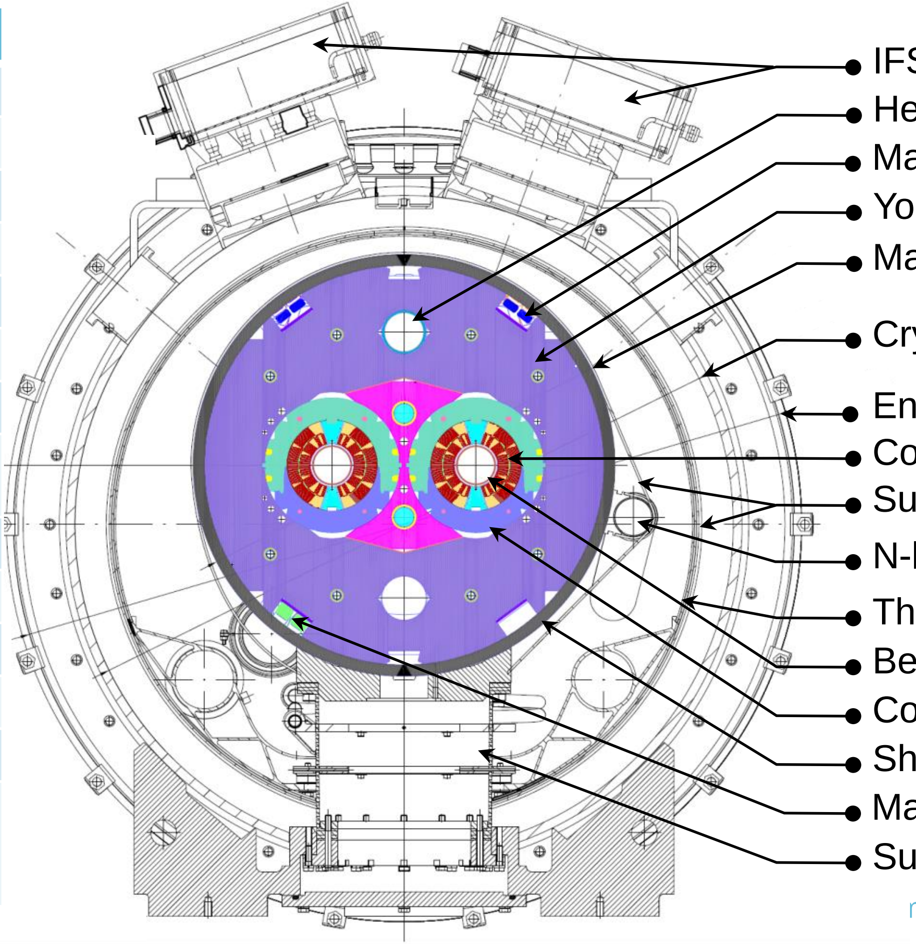
Design features





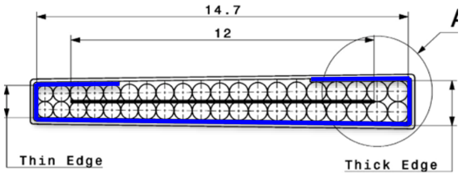
Design features of the full-length prototype

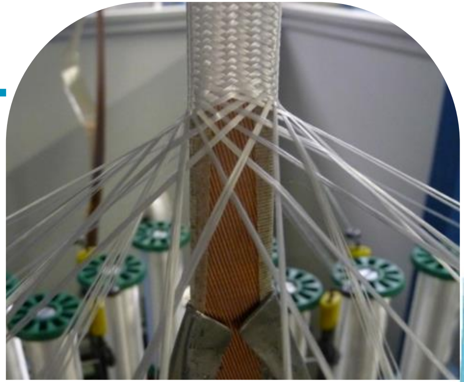
Parameter	Value
Bore field @ I_{NOM}	11.23 T
Nominal current	11.85 kA
Operating T	1.9 K
Load line margin	20 %
Magnet aperture	60 mm
# turns (inner/outer)	56 (22/34)
Cable bare width	14.7 mm
Cable bare mid-thickness	1.25 mm
Keystone angle	0.79°
Strand diameter	0.7 mm
# strands per cable	40
Cu to non Cu ratio	1.15 ± 0.1
RRR after reaction	> 150
Minimum strand critical current, Ic (12T, 4.222 K)	438 A

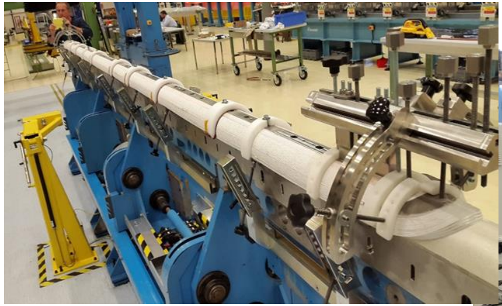


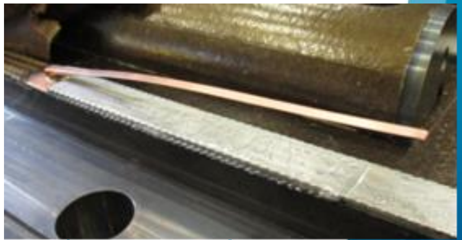
Main manufacturing steps, 1

- Cable insulation and braiding
  - 25 mm wide, and 80 μm thick Mica tape rolled around the cable in a C-shaped profile, and a 70 μm thick layer of S2-glass braided over the Mica layer
- Winding and binder curing
  - A ceramic binder is applied after winding to glue the turns together, and avoid the coil dislocation during subsequent steps
- Reaction and splicing
  - In a reaction fixture, under Ar atmosphere, 150 hours including 3 plateaus at 210, 400, and 650°C
- Impregnation
  - Resin system CTD101K, processed @ 60°C under vacuum, then pressurized to 3.5 bar before gelling @ 110 °C and curing @ 125°C



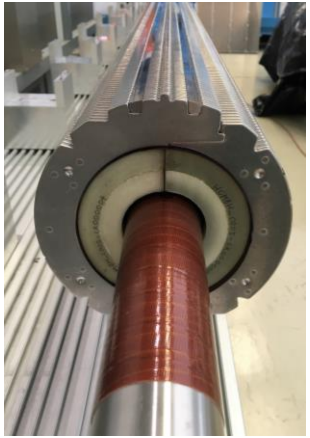






Main manufacturing steps, 2

- Coil pairing and assembly
  - With ground insulation, collaring shims, removable pole, cold bore tube, coil protection sheet, and collar packs
- Collaring
  - F = 10 MN/m (of which ~ 50 % pass in the coils / collars)
  - Stress in coils up to 180 MPa
- Yoking, and welding of the 15 mm thick shrinking cylinder made of 316LN
  - TIG welding, 13-15 passes and tensile stresses of the order of 220 MPa
- Cold mass finishing
  - Spool pieces, eletrical joints V-taps, instrumentation feed thru system, end covers, N-line, supports, …





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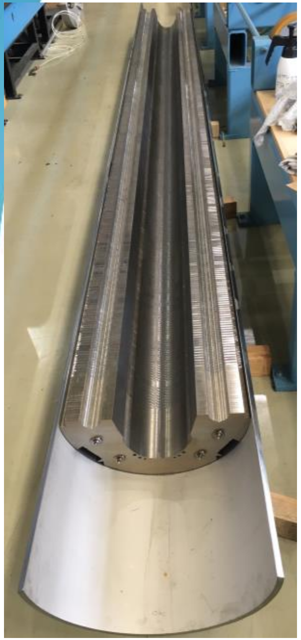
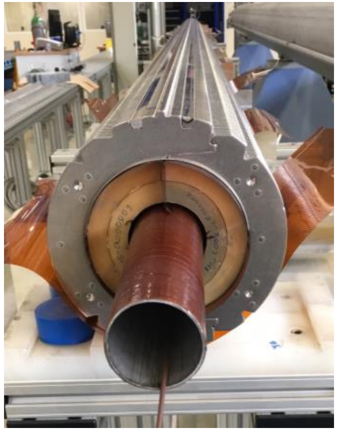
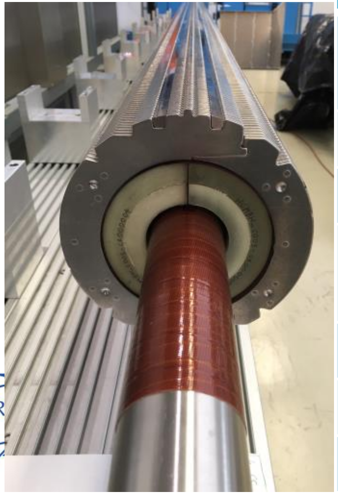
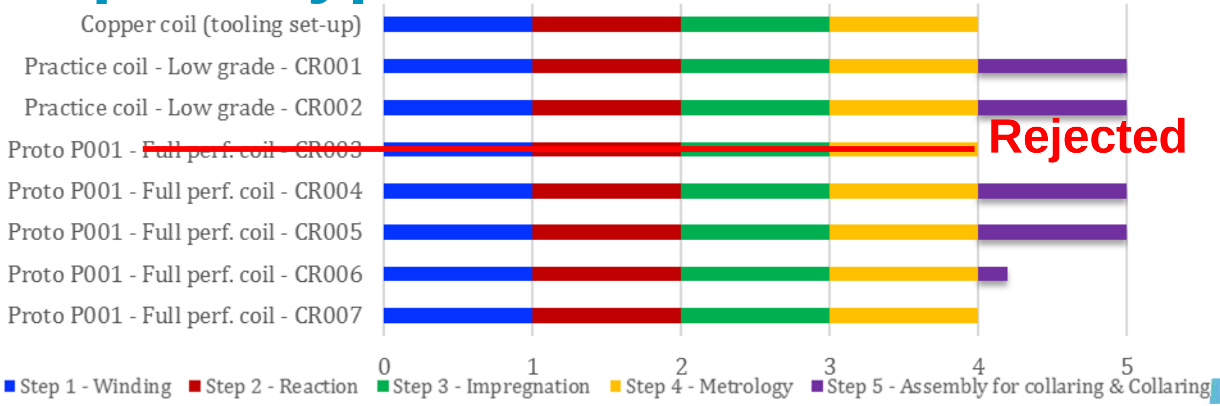
Status of the prototype construction





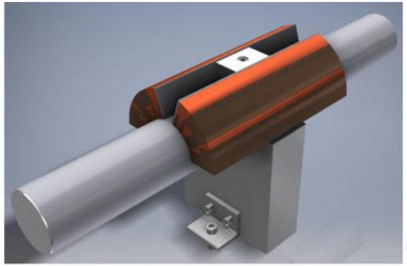


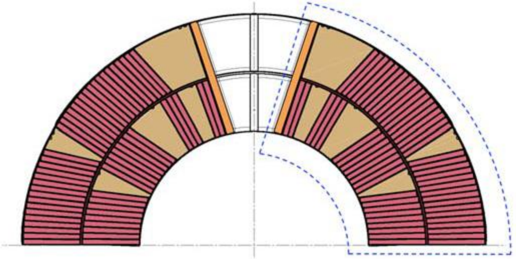


Coil ID	CR4	CR5	CR6	CR7
Strand type RRP	132/169 & 150/169	150/169 & 144/169	108/127	108/128
Cu/Sc, average	1.18	1.06	1.14	1.15
RRR, average	250.6	168.0	293.6	297.0
Critical current, I_c [A] (12 T, 4.222 K), average	404.6	451.6	449.0	460.7
Mid-thickness [mm]	1.2512	1.2486	1.2502	1.2495
Width [mm]	14.710	14.701	14.694	14.694
Keystone angle [°]	0.80	0.81	0.79	0.79

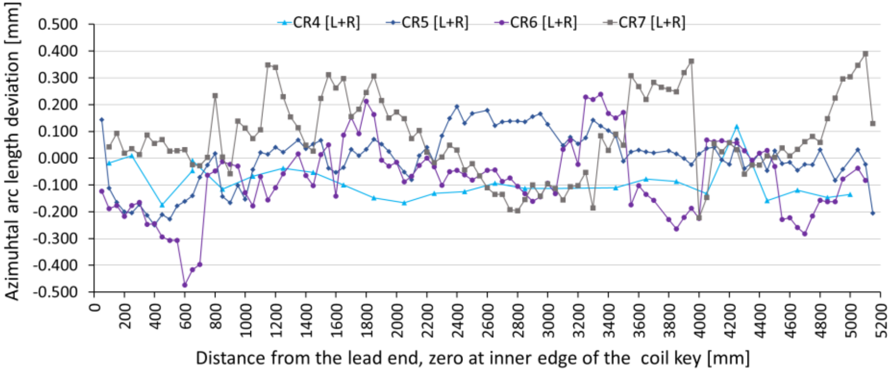
Quality control, 1 (a selection)

- A comprehensive Manufacturing and Inspection Plan (**MIP**) has been developed
- There are 15 manufacturing and assembly **procedures** (**work instructions**)
- Quality Control reports are uploaded in the CERN Manufacturing and Test Folder (**MTF**)



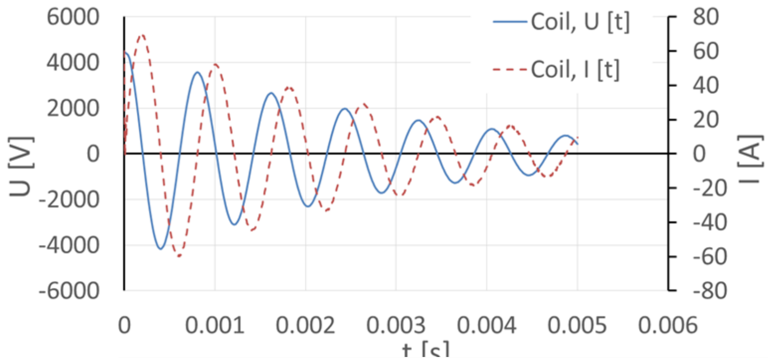


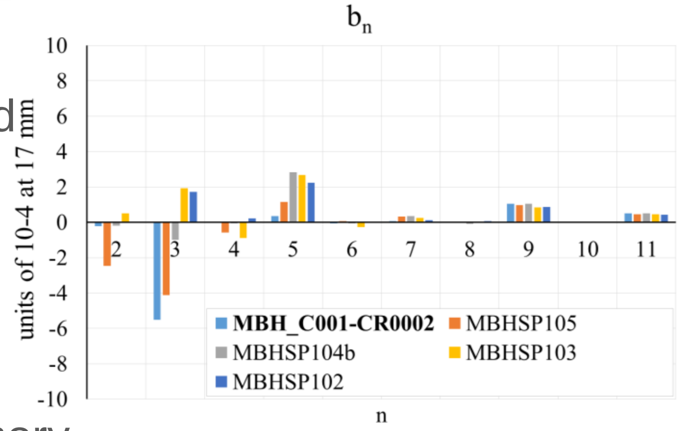
- Coil geometry (coil branch)
  - Measured after impregnation
  - Measured stress free, i.e. no compression applied on the coil
  - 3D measurements carried out with portable CMM, type FARO Arm. Coil sections can be measured independently
  - Graph shows azimuthal length, used in the FEA model to determine the shimming plan such that -150 MPa<stress<+15 MPa



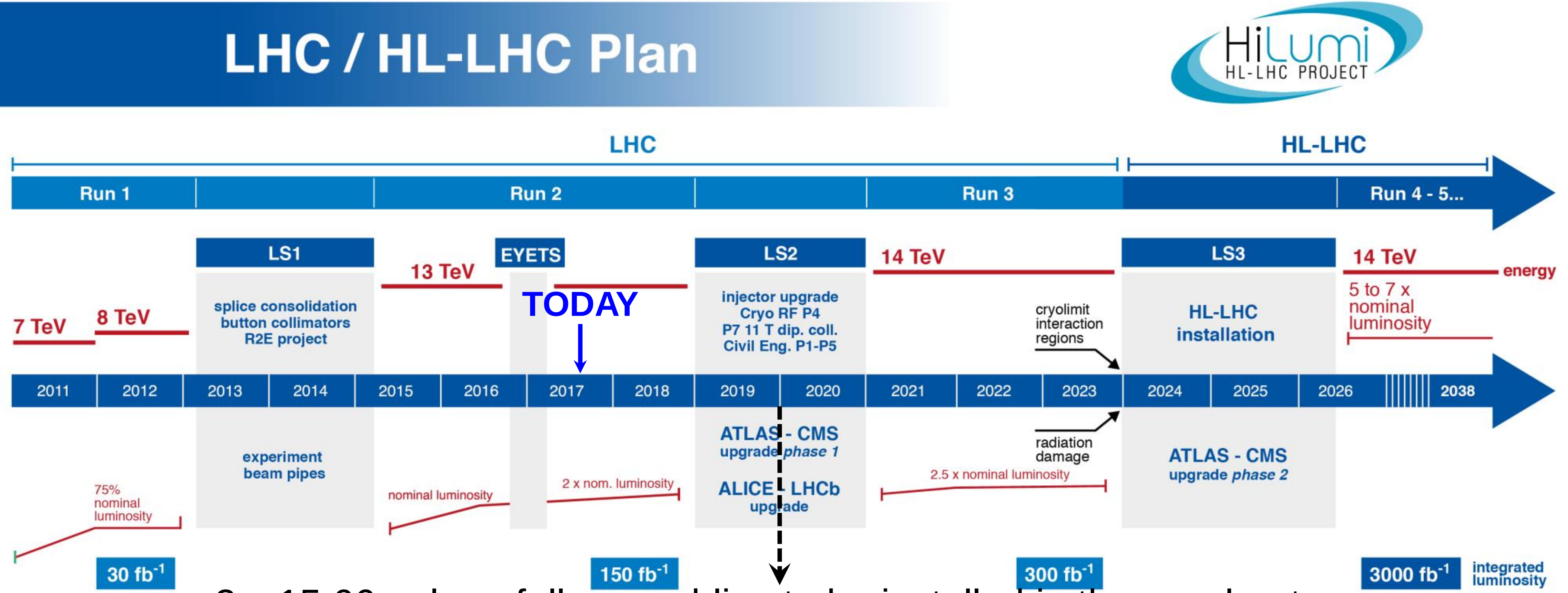
Quality control, 2 (a selection)

- Electrical tests
  - Throughout the magnet construction
  - Ensure electrical integrity of the magnet, including of the instrumentation and of the quench heaters
  - Exemple: discharge test on the coil is carried out at 4.7 kV corresponding to 85 V/turn
- Warm magnetic measurements
  - On collared coils, and on the magnet
  - Field quality, transfer function, and integral field
  - Normal multipoles of the 1st collared coils Prototype are here compared to the multipoles of the short models (SP103-SP105)
- Cold tests (in the beginning of 2018)
  - Training, quench protection studies, magnetic measurements, ramp rate dependency tests, stability under holding current, and memory





The timeline of HL-LHC



2 x 15.66 m long full assemblies to be installed in the accelerator,
i.e. 4 x 6.75 m long 11T cryo-assemblies,
and 2 x 2.16 m long by-pass cryostats

Production plan

- Production will take place at CERN, in the Large Magnet Facility (bldg.180)
- Industrial contract for the production of the collared coils
  - Procurement process ongoing
  - Start production in January 2018
- Team currently in place for the production of the cold masses, the cryostating, and the cold tests
  - Install first magnet in the LHC machine during the last quarter of 2019

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Concluding remarks

- The **construction of the LMBHB Prototype is well advanced** with the completion of the four coils, and of the first collared coils assembly
- A **complete set of manufacturing and inspection procedures is ready for the series fabrication of the collared coils**, and those regarding the construction of the cold mass assembly are in preparation
- The **cold tests of the LMBHB Prototype will be carried out in the beginning of 2018**, when the series production of the coils will start
- The production schedule is tight, as **the magnets shall be in the accelerator in less than 2.5 years from now**

Thank you for your attention

Contributions to this conference relating to the 11 T Dipole Magnet for HL-LHC:

[1] G. Willering *et al.*, “Comparison of Cold Powering Performance of 2-m long Nb_3Sn 2-m long 11T Model Magnets”, Mon-Af-Or7-02.

[2] S. Izquierdo Bermudez et al., “Quench Protection of the 11 T Nb_3Sn Di-pole for the High Luminosity LHC”, Mon-Af-Po1-01.

[3] J. Ferradas Troitino et al., “Applied metrology in the production of superconducting model magnets for particle accelerators”, Thu-Af-Po4-01.

[4] L. Fiscarelli et al., “Field quality of MBH 11-T dipoles for HL-LHC and impact on beam dynamic aperture”, Mon-Af-Po1-01.

[5] D. Pulikowski *et al.*, “Windability tests of Nb_3Sn Rutherford cables for HL-LHC and FCC”, Wed-Af-Po3-01.

[6] M. Daly *et al.*, “Multi-scale approach to the mechanical behaviour of epoxy impregnated Nb_3Sn Dipole Coils for the 11T Dipole”, Mon-Mo-Or3-03.

[7] A. Foussat *et al.*, “Frequency domain Diagnosis Methods for Quality Assessment of Nb_3Sn coil Insulation systems and impedance measurement”, Mon-Af-Po1-01.

[8] C. Scheurlein *et al.*, “Thermomechanical behavior of the HL-LHC 11 tesla Nb3Sn magnet coil constituents during reaction heat treatment”, Wed-Af-Po3.10

[9] T. Gradt *et al.*, “Friction-coefficient between the Ti6Al4V loading pole and the 316LN steel shims of the HL-LHC 11 T magnets”, Wed-Af-Po3.10