High Luminosity LHC

The HL-LHC project,

and associated Cryogenics

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Academia Meets Industry on Cryogenics
HEPTech
EUROPEAN CRYOGENICS DAYS
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Grenoble | FRANCE

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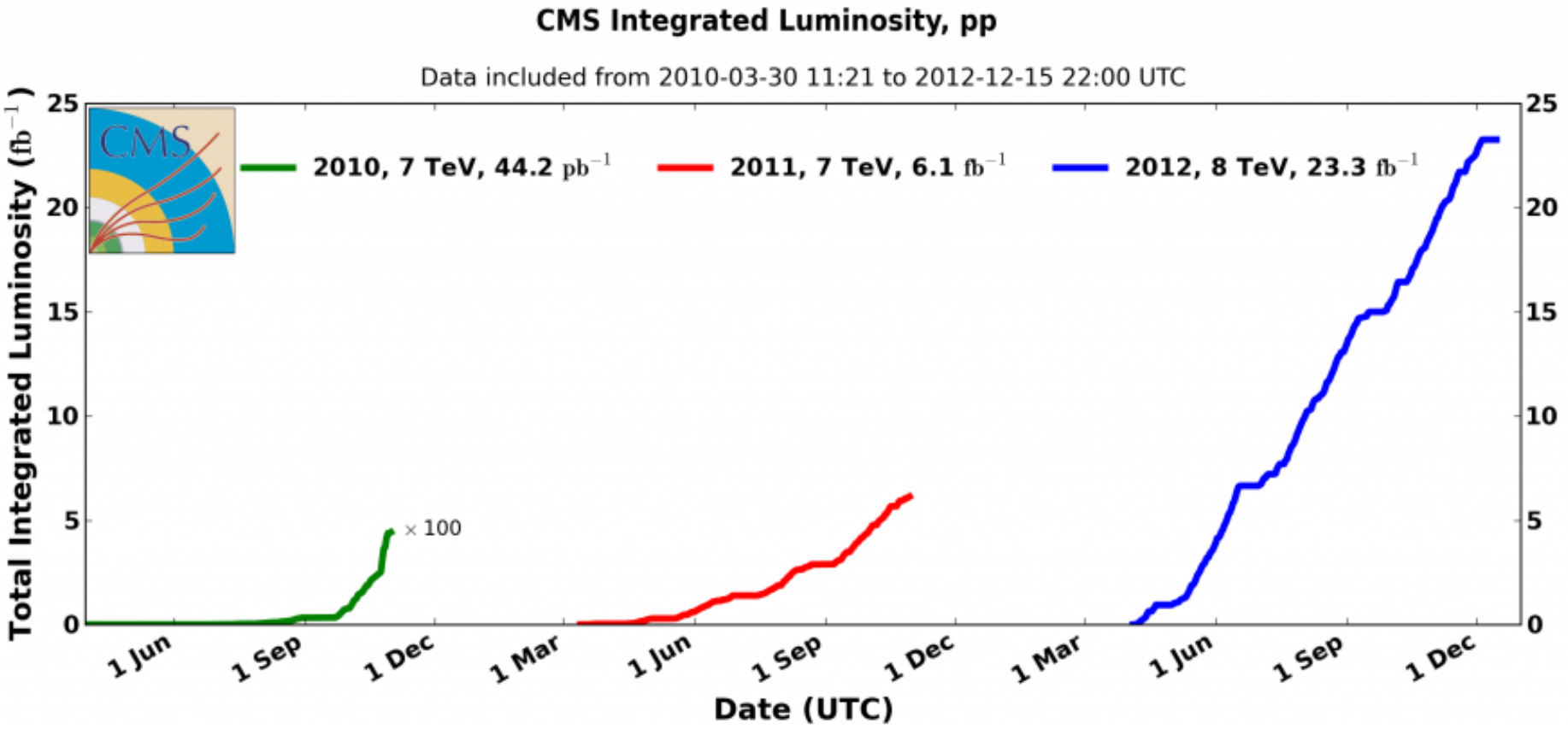
Outlook

- Introduction: LHC is fine, Why-When HL-LHC ?
- Main sub-systems concerned
- The Cryogenic part of it
- What's next & concluding remarks

LHC Run 1 - Luminosity

Luminosity # Collision rate # statistics # precision

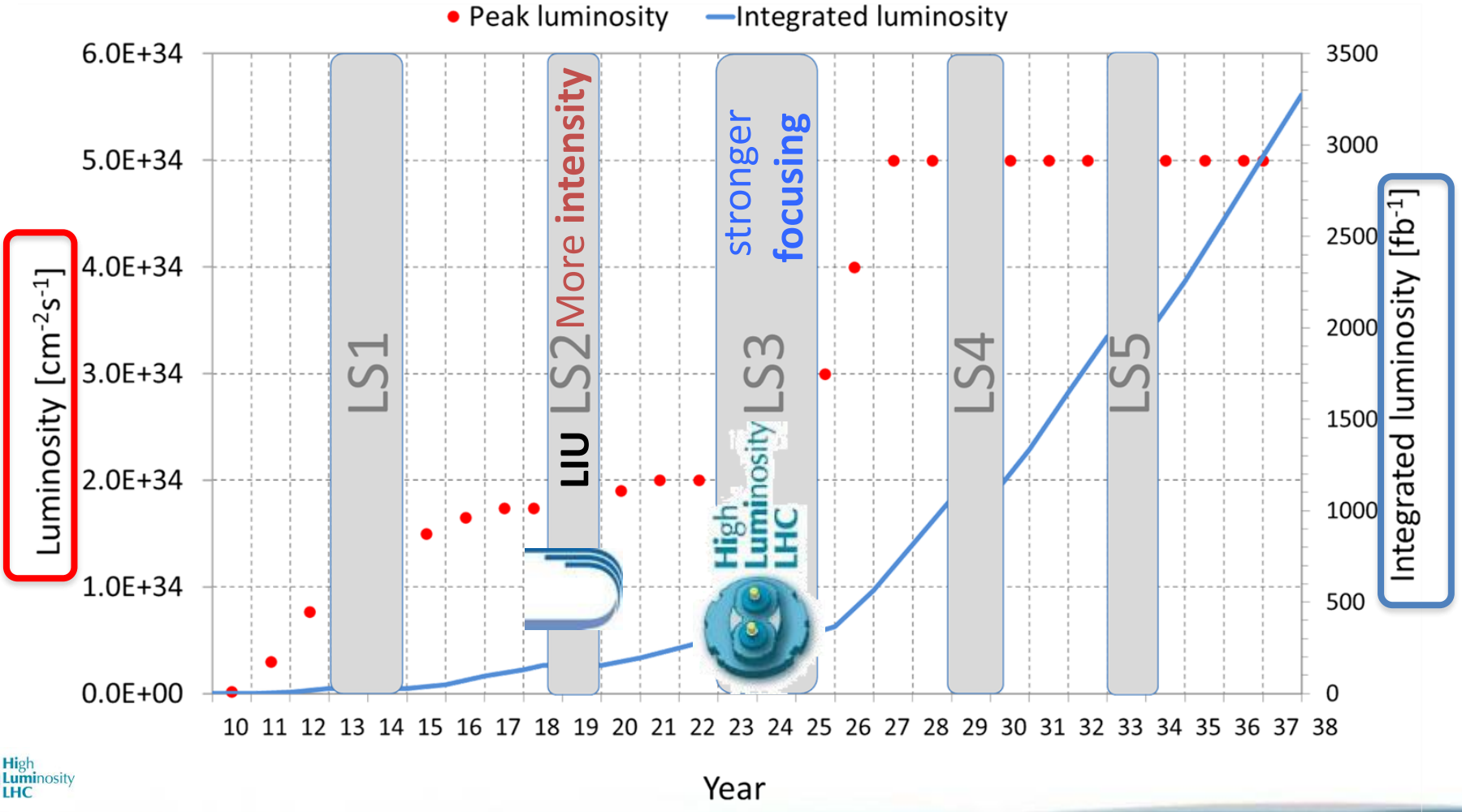


Excellent progress and performance, with outstanding physics results !

Towards higher collision rates

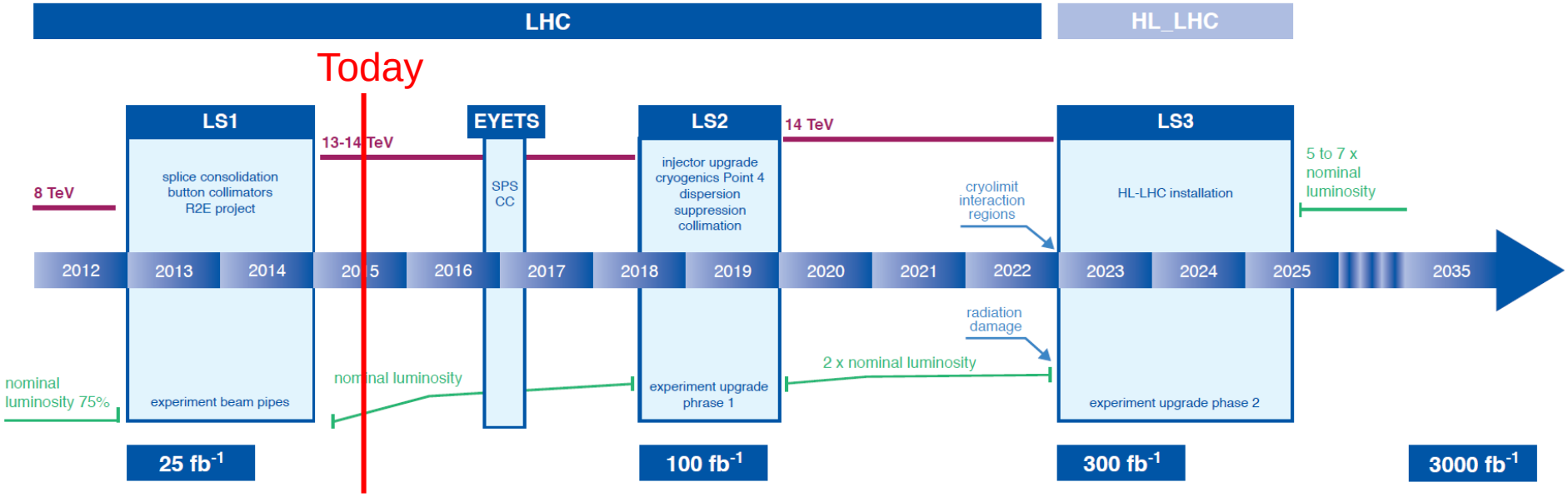
New discoveries or precision measurements need integrated luminosity !!!

$$\text{Luminosity} = f * N^2 / 4\pi\sigma^2$$



Approved & Funded

New LHC / HL-LHC Plan



LS2: Increase of the proton bunch population (~2 times the nominal)

LS3: Increase of the luminosity in ATLAS and CMS (~5 times the nominal)

→ A series of new accelerator components to allow this increased luminosity

→ Higher beam-induced heating => Major upgrade of the cryogenic system

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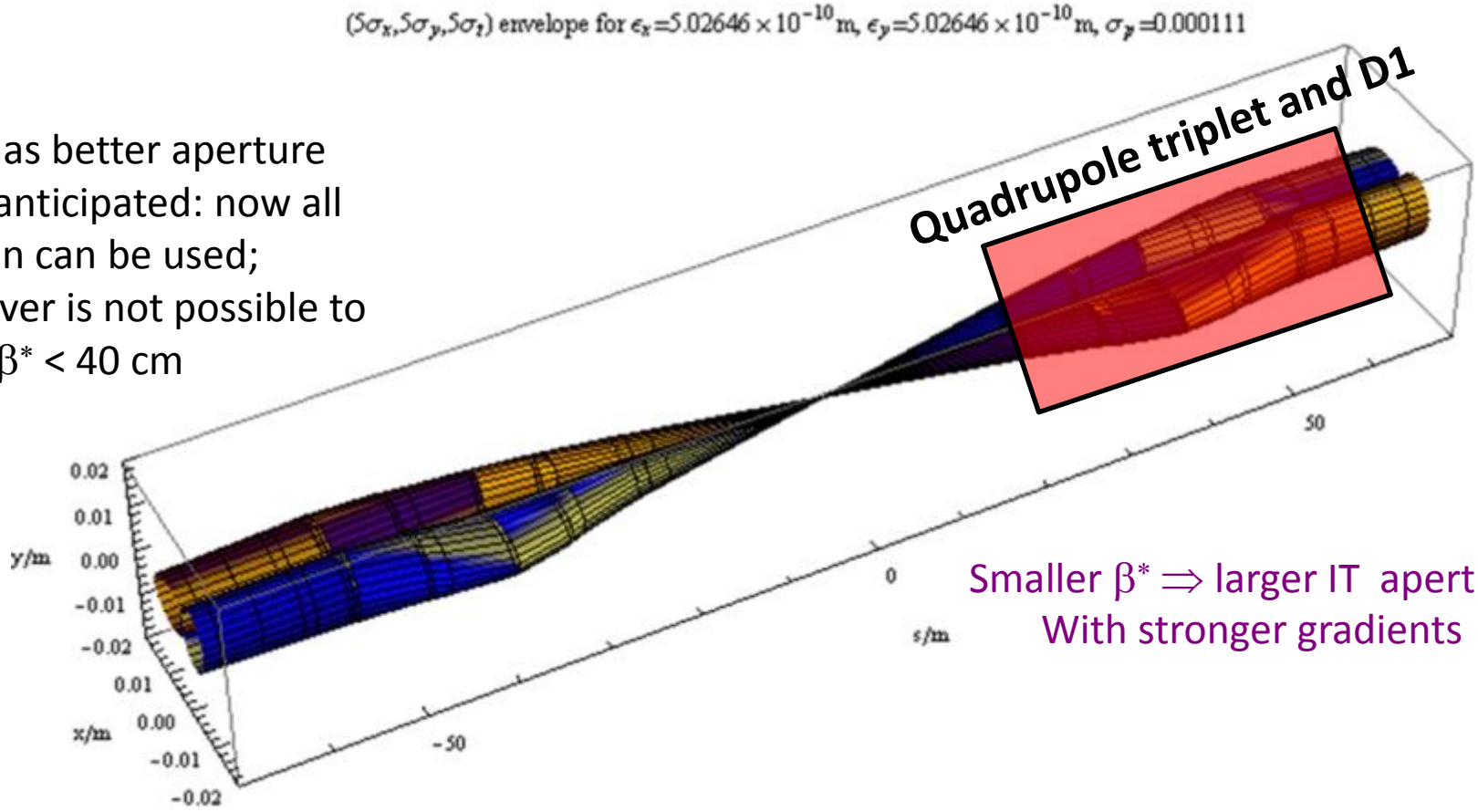
To increase Luminosity

The most straight forward action: reducing beam size with a «local» action

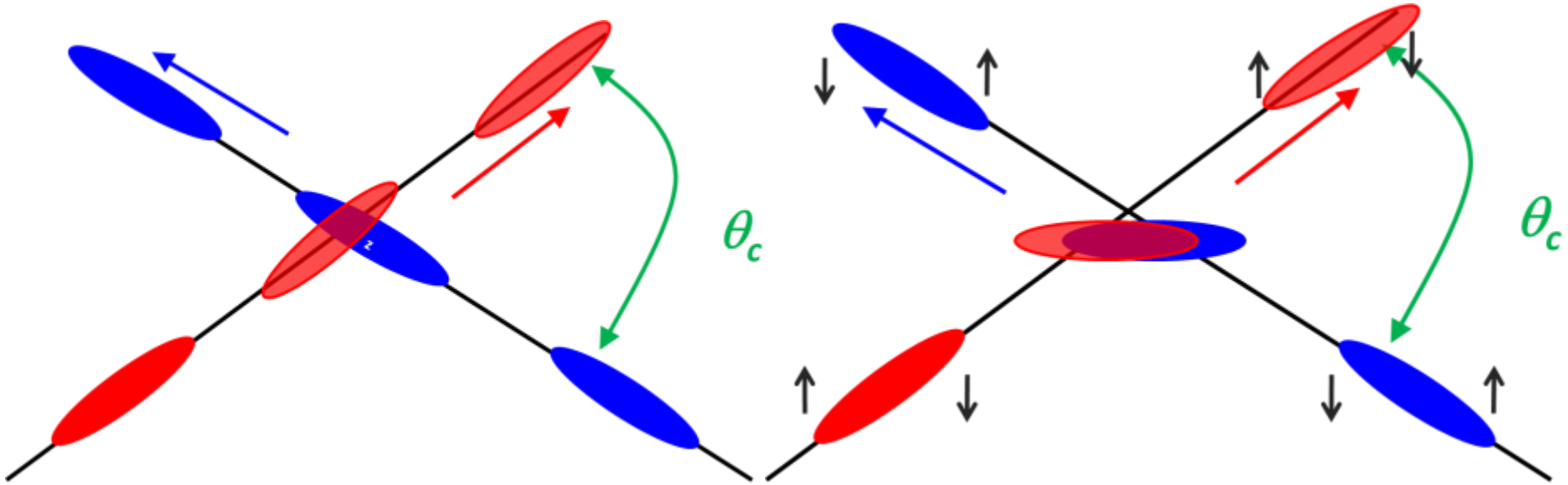
LHC has better aperture than anticipated: now all margin can be used; however is not possible to have $\beta^* < 40$ cm



Smaller $\beta^* \Rightarrow$ larger IT aperture
With stronger gradients

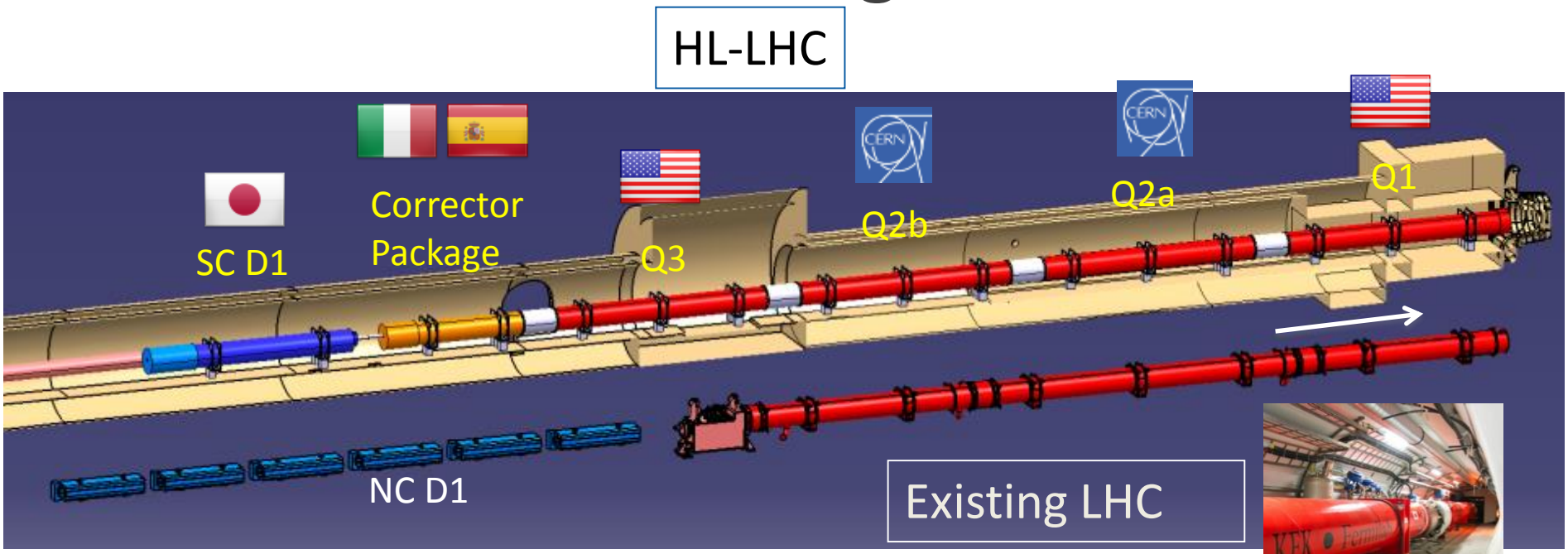
Effect of the crab cavities

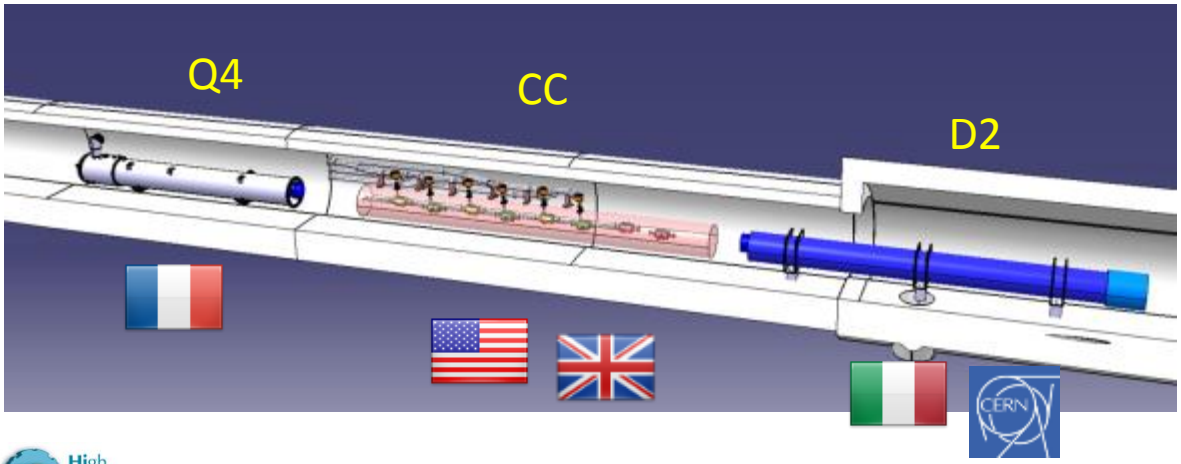
To compensate for the larger crossing angle



- RF crab cavity deflects head and tail in opposite direction so that collision is effectively “head on” and then luminosity is maximized
- *Crab cavity maximizes the lumi and can be used also for luminosity levelling: if the lumi is too high, initially you don’t use it, so lumi is reduced by the geometrical factor. Then they are slowly turned on to compensate the proton burning*

HL-LHC configuration





HL-LHC systems are entering detailed integration phase

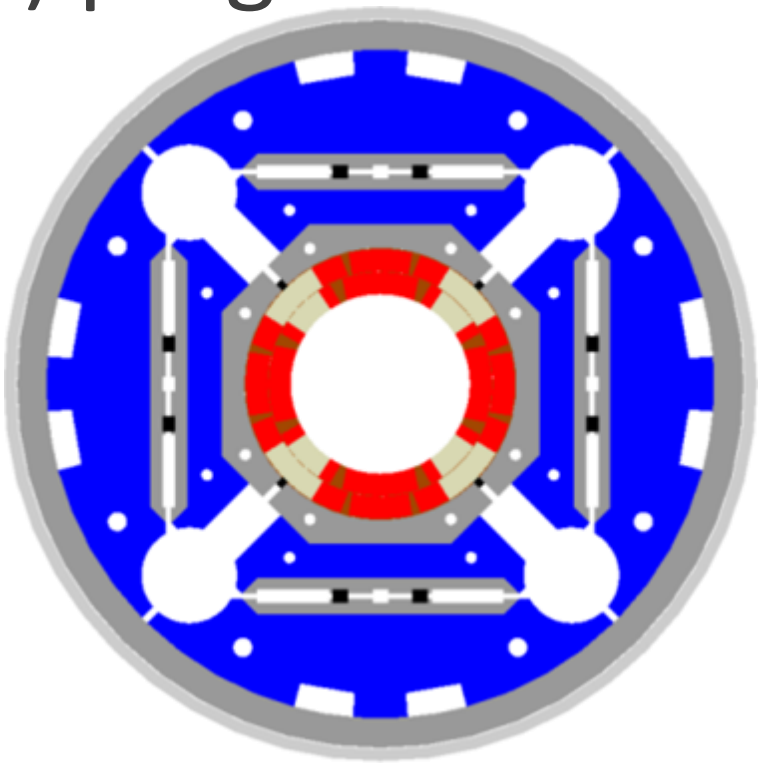
New baseline adopted to increase operating margins (Nb3Sn quadrupoles)

In-kind contribution and Collaborations for HW design and prototypes

IR-quads (QXF) program

Aperture	(mm)	150
Gradient	(T/m)	132.6
Current	(A)	16500
Temperature	(K)	1.9
Peak field	(T)	11.4

- Q1/Q3 (by US-LARP) 4.2 m long
- Q2 (by CERN), 7.2 m long
- Plan:
  - Short model program: **2014-2017**
  - Long model program: **2015-2018**
  - Series production: **2018-2022**



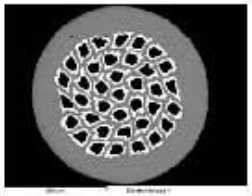
Shell-based support structure (aka *bladder-and-keys*) developed at LBNL for strain sensitive material

Cold Powering System HTS links

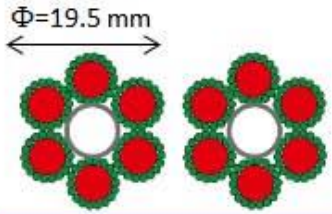
- Design and construction of test station with 20 m long SC Link cryostat (CERN)
- Development of MgB_2 round wire (CERN with Columbus – Genova)
- Development of high-current (20 kA) MgB_2 cables (CERN)
- Launched procurement of 80 km of MgB_2 round wire - which will be delivered as from April 2015

MgB_2 Wire

(Φ = 0.9 mm)



MgB_2 Cables

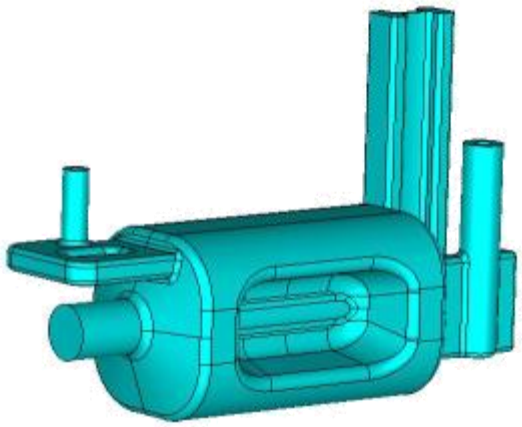


I=20 kA @ 24 K

Excellent results obtained for elementary part of the cable

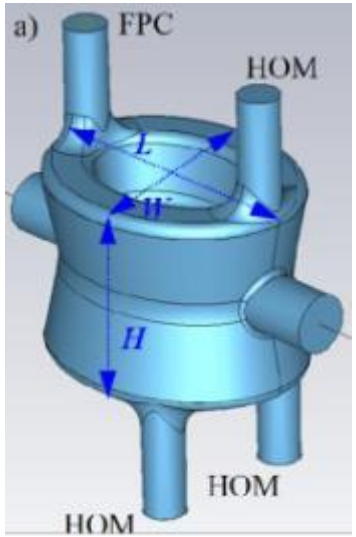
Global engineering (termination boxes, supporting) under study

Latest cavity designs toward accelerator



RF Dipole: Waveguide or waveguide-coax couplers

Dressed cavity in He tank

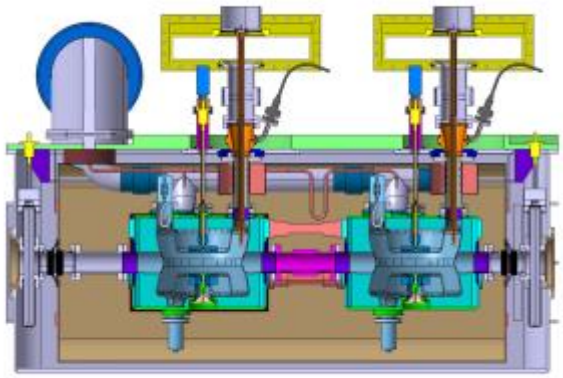


Double ¼-wave: Coaxial couplers with hook-type antenna

Prototypes validated

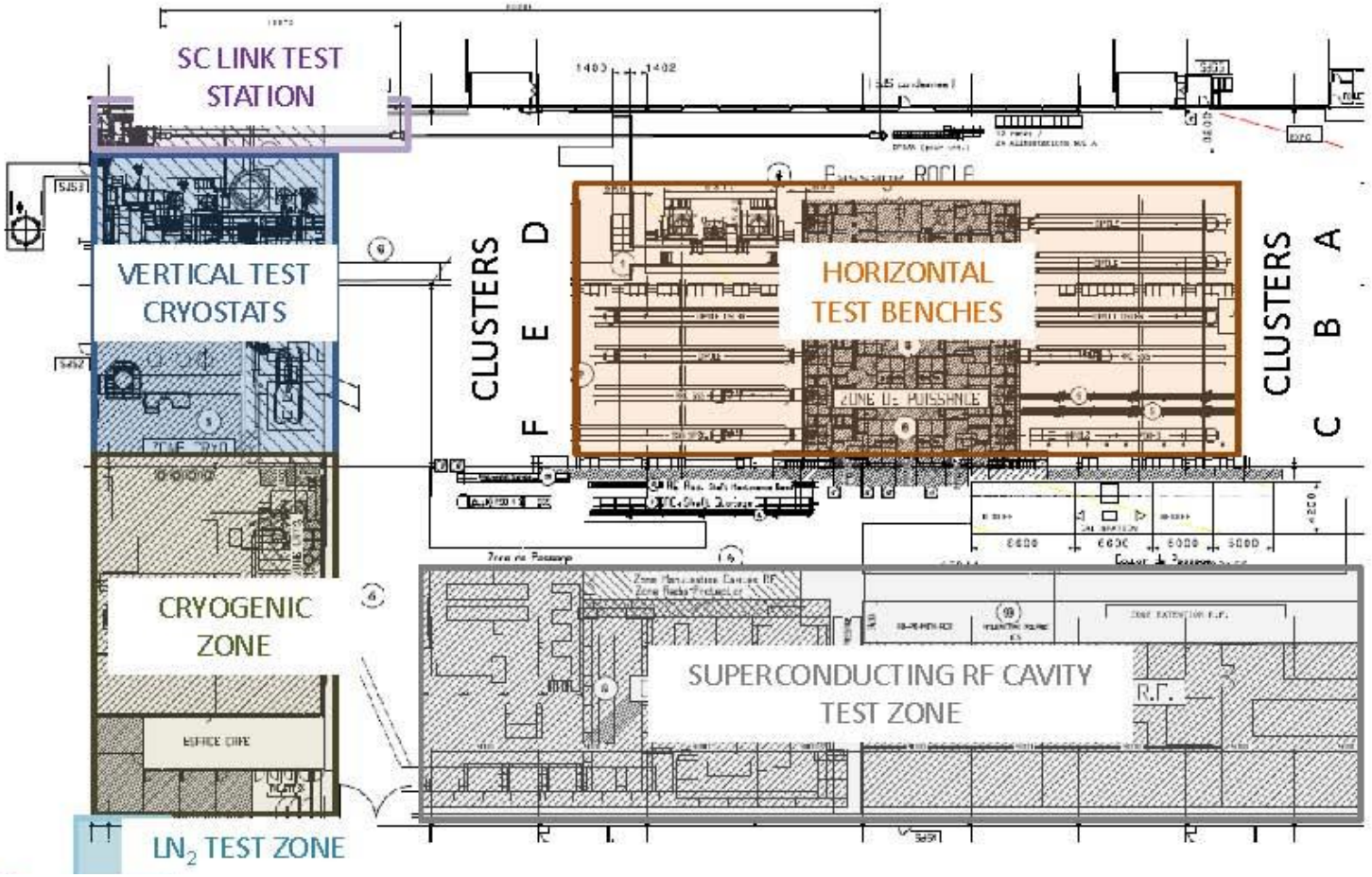
Final design of cryomodule in 2015 for construction in 2016

Complete criomodule for test in SPS during 2017



Tests & qualification

SM18 building, 100m x 80m, 6kW@4.5K



A serious transformation of this test station and cryogenic hardware has started and is to be continued to validate all the HL-LHC superconducting sub-systems

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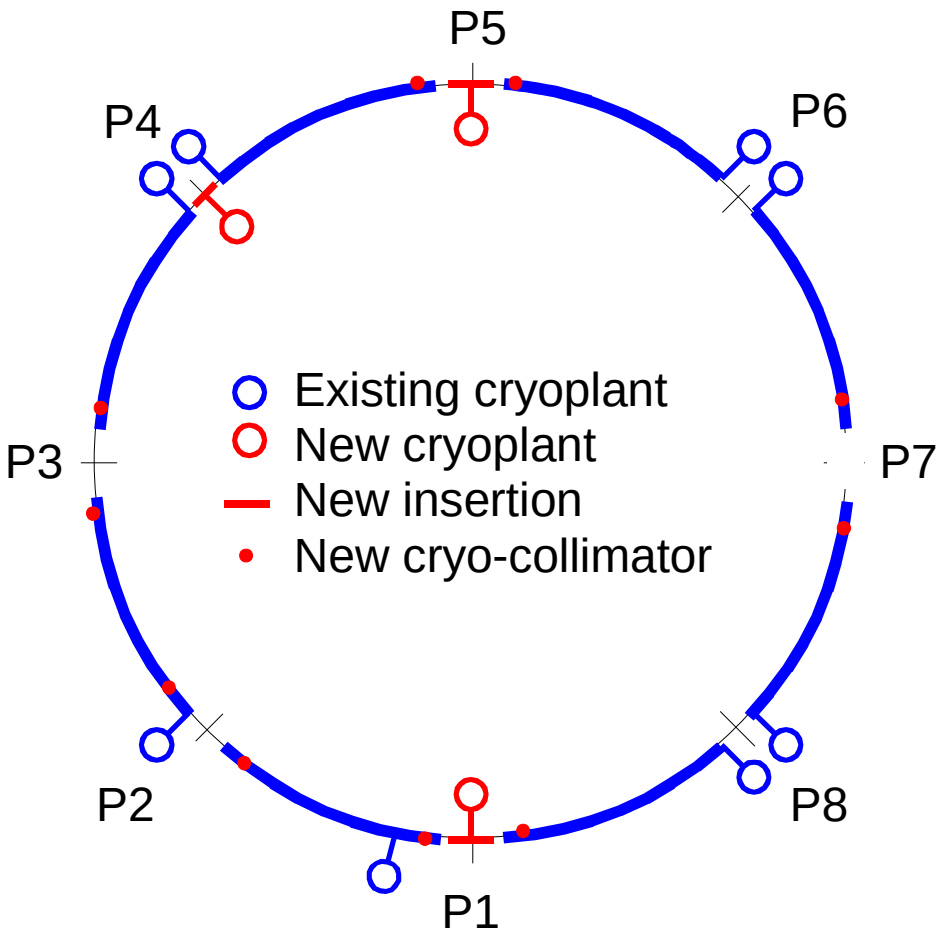
Overview



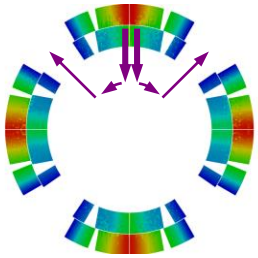
HL-LHC cryo-upgrade:

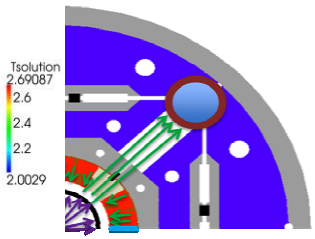
- 2 new cryoplants at P1 and P5 for high luminosity insertions
- 1 new cryoplant at P4 for SRF cryomodules
- New cooling circuits at P1, P5 for HTS links and deported current feed boxes
- New cooling circuits for cryo-collimators and 11-T dipoles at P2 and P7, and may be also at P3, P1 and P5

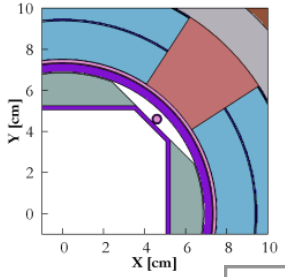
HL-LHC: heat loads on triplets & D1

Large ΔT in coil

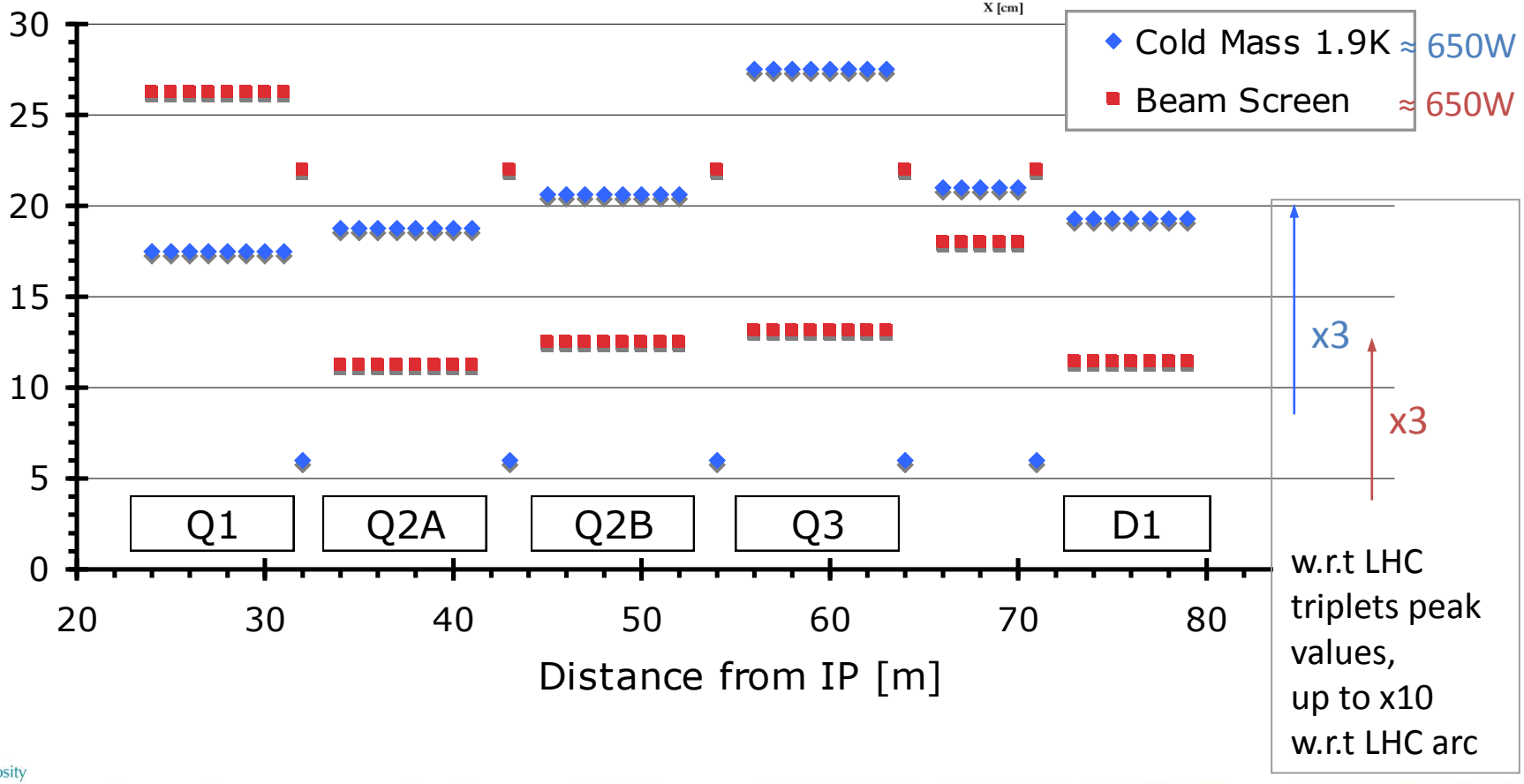
Small ΔT in He





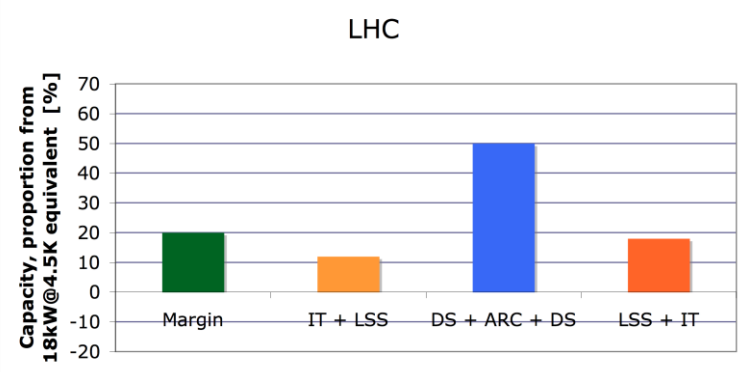


tungsten inserts on the beam screen

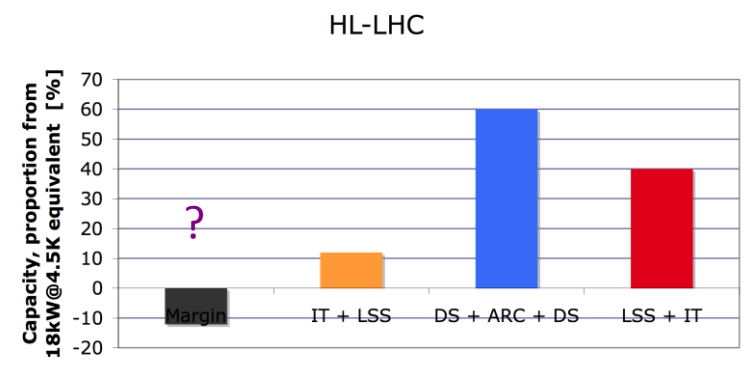


Cooling capacity requirements, basic principles

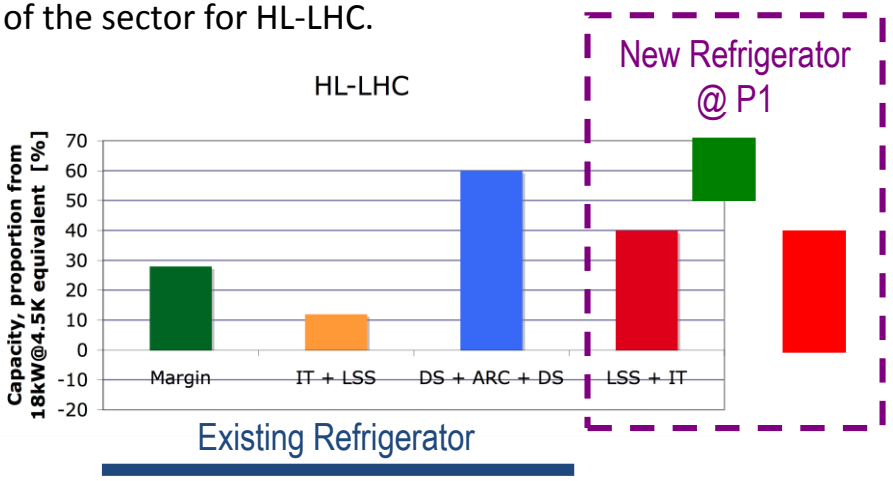
(Considered for "Nominal" beam parameters, to be confirmed by heat-load WG-2015)



Margin: required at "Nominal" to allow "Ultimate" beam parameters

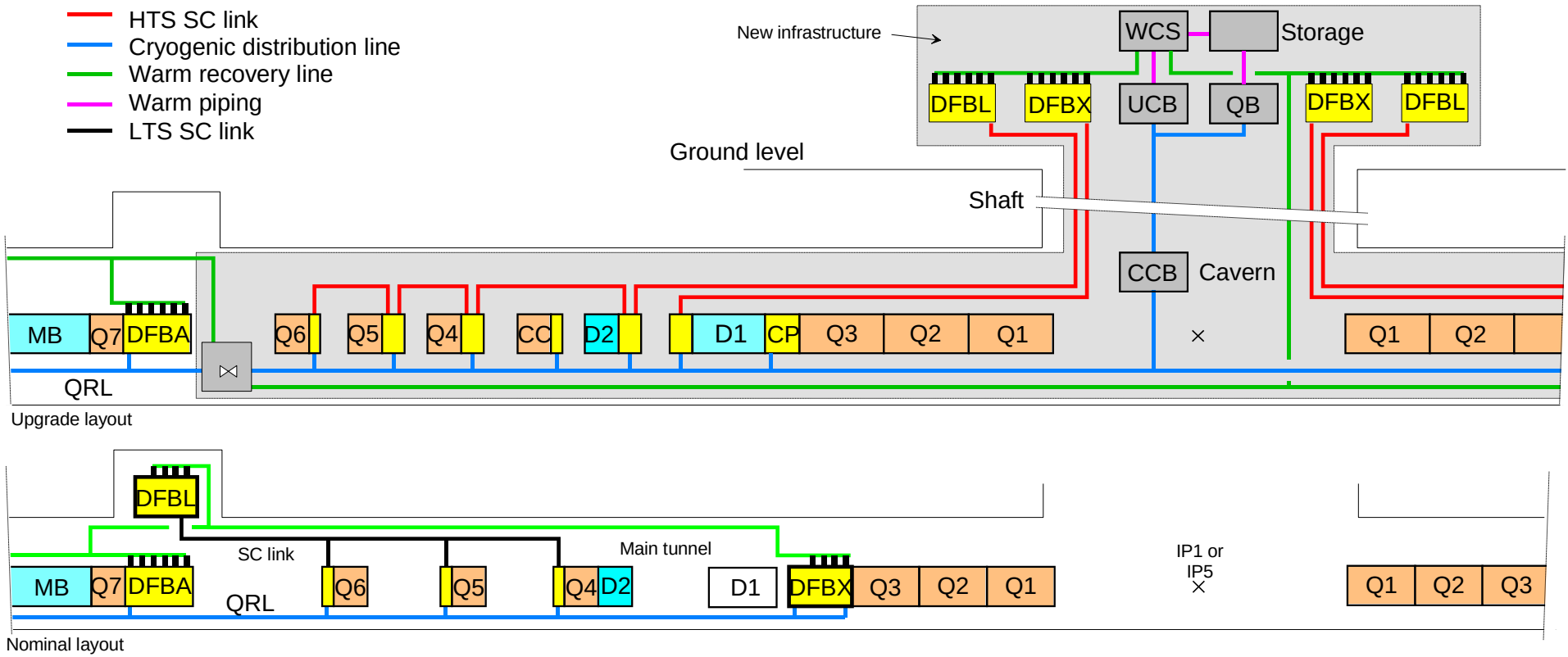


(very!) Large increase of cooling capacity at the end of the sector for HL-LHC.



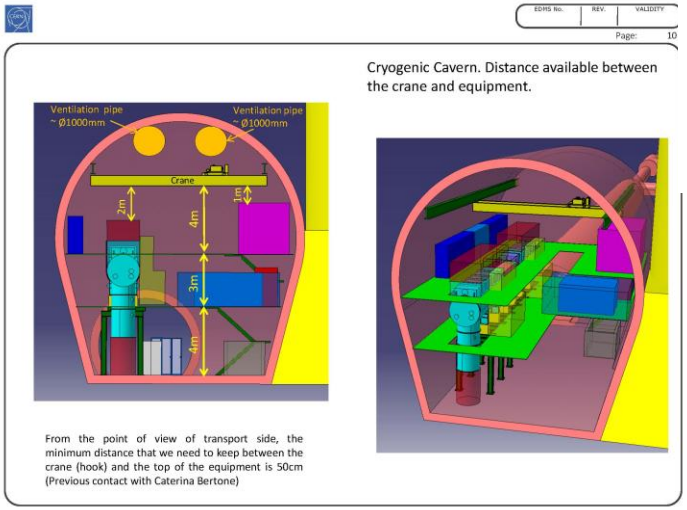
=> New refrigerator required for P1/P5, combining left & right

New insertions at P1 and P5

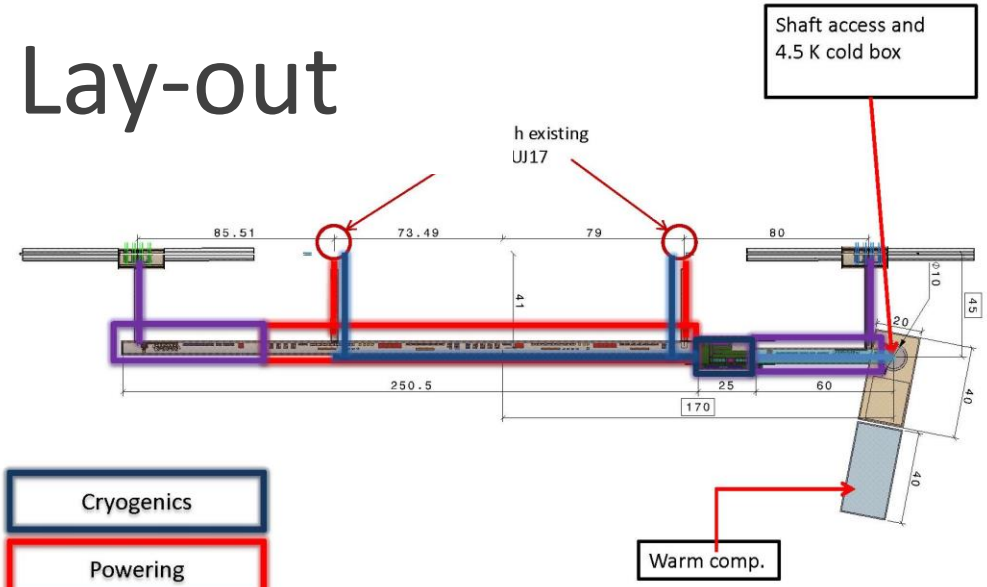


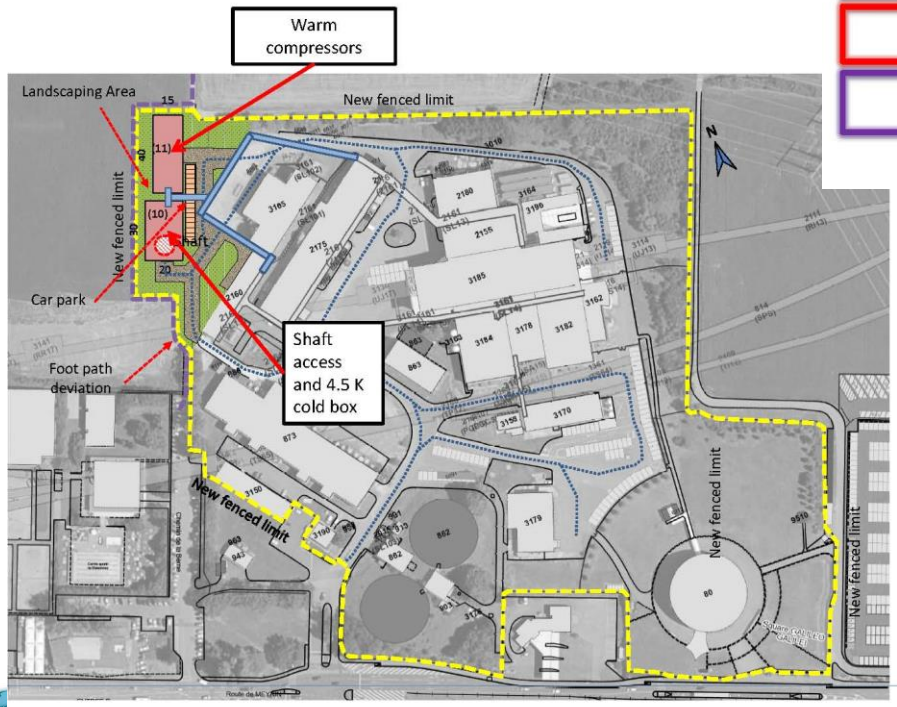
- Cryogenics for new cryo-assemblies (Crab cavities (CC), insertion cryomagnets, DFBs, HTS links…)
- 1 warm compressor station (WCS) in noise insulated surface building
- 1 upper cold box (UCB) in surface building
- 1 cold quench buffer (QV) in surface
- 1 or 2 cold compressor boxes (CCB) in underground cavern
- 2 main cryogenic distribution lines
- 2 interconnection valve boxes with existing QRL (partial redundancy with sector cryoplants)

18kW@4.5K incl. 3kW@1.8K
(integrated - mixed cycle)



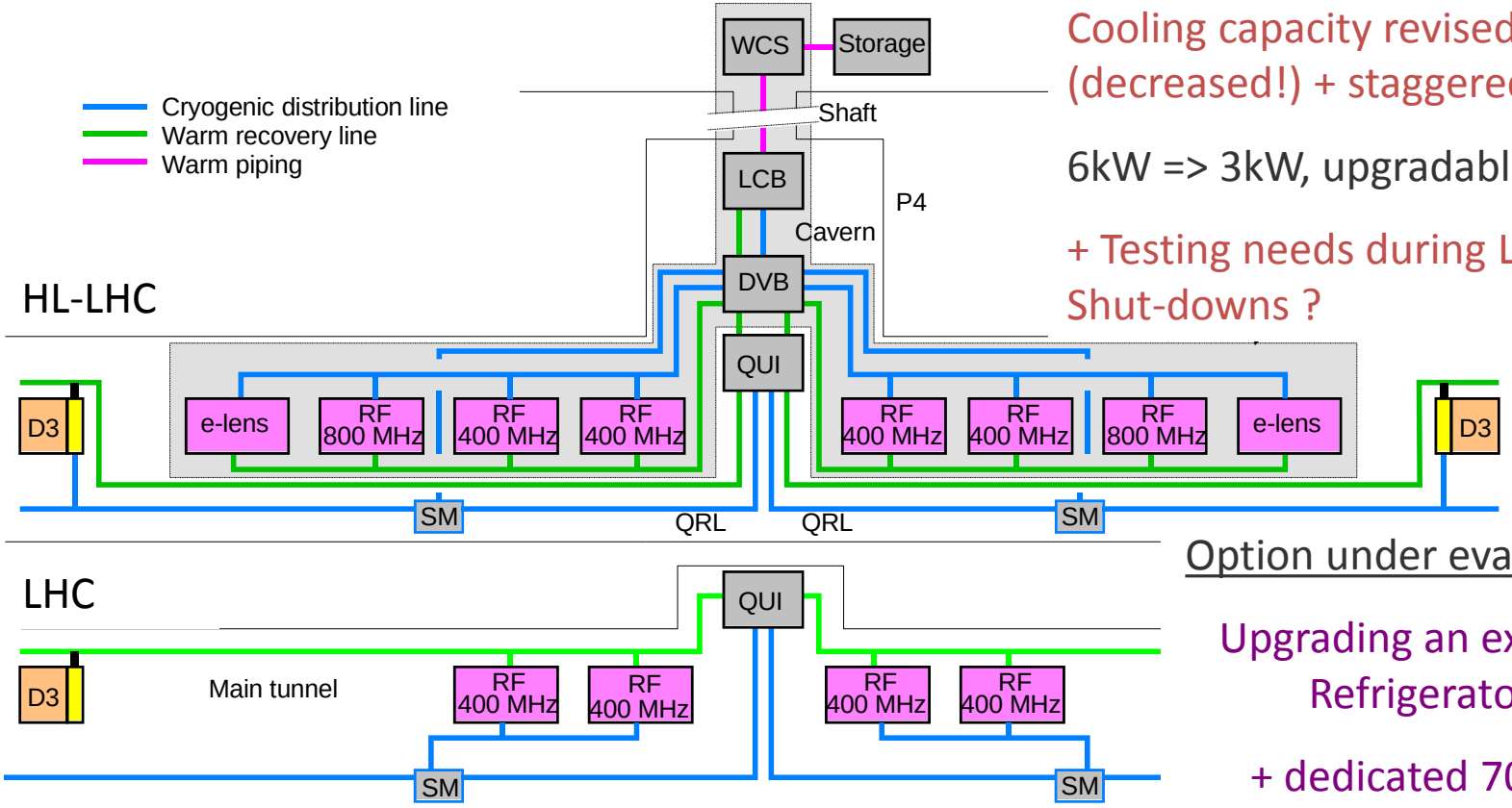
Lay-out





- No alternative to additional cavern (Cryo) and shaft (excavation material and final piping)
- Evolution of studies to match the needs at best evaluation of cost & schedule impact
- Tests done in transfer tunnels & SM18 demonstrated that vibrations from civil works would impact operation of LHC
- Close to freeze this major evolution for Hi-Lumi to allow construction works during LS2!

New insertion at P4



Cooling capacity revised (decreased!) + staggered in time

6kW => 3kW, upgradable?

+ Testing needs during Long Shut-downs ?

Option under evaluation:

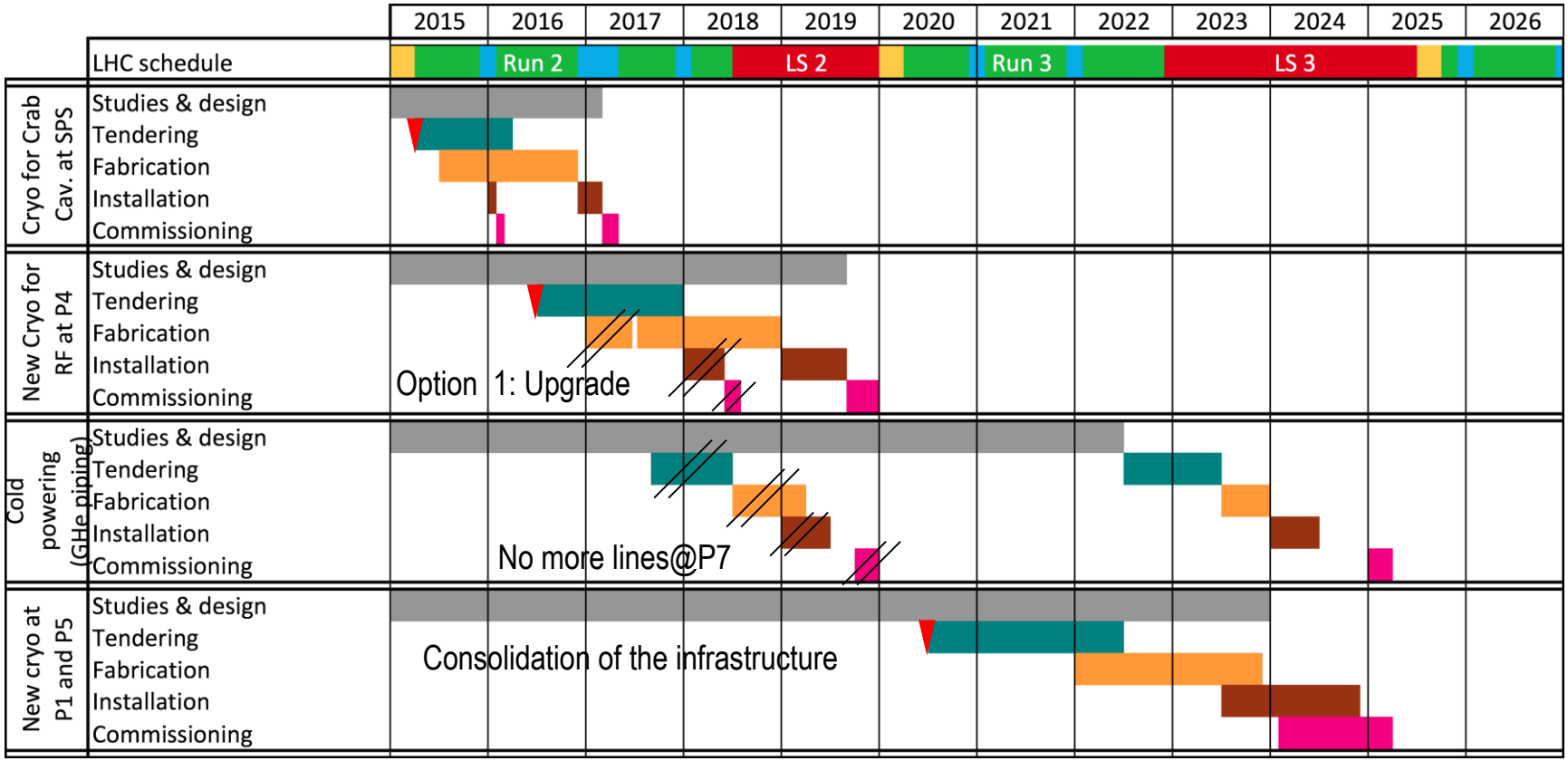
Upgrading an existing Refrigerator

+ dedicated 700W refrigerator for LS

- Cryogenics for 800 MHz SRF cryomodules and e-lenses
- 1 warm compressor station (WCS) in noise insulated surface building
- 1 lower cold box (LCB) in UX45 cavern
- 1 valve box in UX45 cavern
- 2 main cryogenic distribution lines
- 2 interconnection lines with existing QRL service modules (redundancy by sector cryoplants)

General Cryo schedule

(based on general CERN & HL_LHC schedule)



▼ *: decision/freeze of heat-loads to specify refrigerator and distribution*

HiLumi LHC goes to Industry

25-26 June 2015, CERN

https://indico.cern.ch/event/387162/

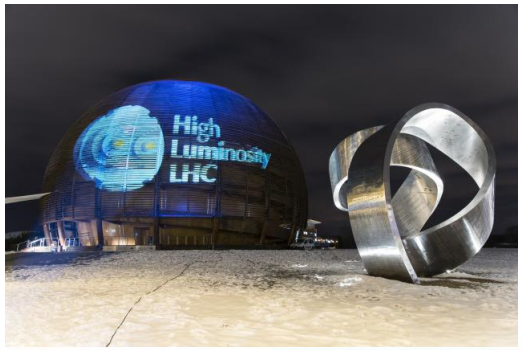
This industrial event related to the major CERN project for the next decade, the High Luminosity LHC project, will be held at CERN on 25-26 June 2015.

This event follows the previous industry oriented workshop "Superconducting Technologies for Next Generation of Accelerators" held at CERN in December 2012, and marks the end of the EU supported Design Study FP7-HiLumi LHC (grant n. 284404) and the beginning of the construction phase of the project.

Leading companies in the fields of superconductivity, cryogenics, power electronics, electrical engineering and mechanics will meet High Luminosity LHC project engineers at the IdeaSquare premises to explore the technical and commercial challenges emerging from the design and procurement of the LHC upgrade accelerator, and to match them with state-of-the-art industrial solutions.

This initiative, structured as an event connecting CERN with the potential industrial partners facing the High Luminosity LHC specific technical challenges, aims at fostering R&D collaborations and knowledge exchange, preparing the field for the deployment of the European commercial potential. The main topics of this event relevant to the manufacturing and procurement of the HiLumi LHC components will be:

- High Luminosity LHC project: technical challenges
- High Luminosity LHC project: the schedule
- Procurement and legal framework



Concluding remarks

- The High-Luminosity LHC is a worldwide funded project corresponding to a 1.2km new accelerator (advanced Nb3Sn, Crab cavities, HTS links) progressively switching to construction, with European institutes and industry heavily involved
- Series of qualification and testing of components foreseen in the coming years
- This summer, civil works and global lay-out will be decided. Precise evaluation of heat-loads and of the cryogenic architecture is underway
- And we will closely look at the LHC Run 2 performance and achievements!

Thanks for your attention!

Spares / Complements

LHC roadmap: schedule up to 2035

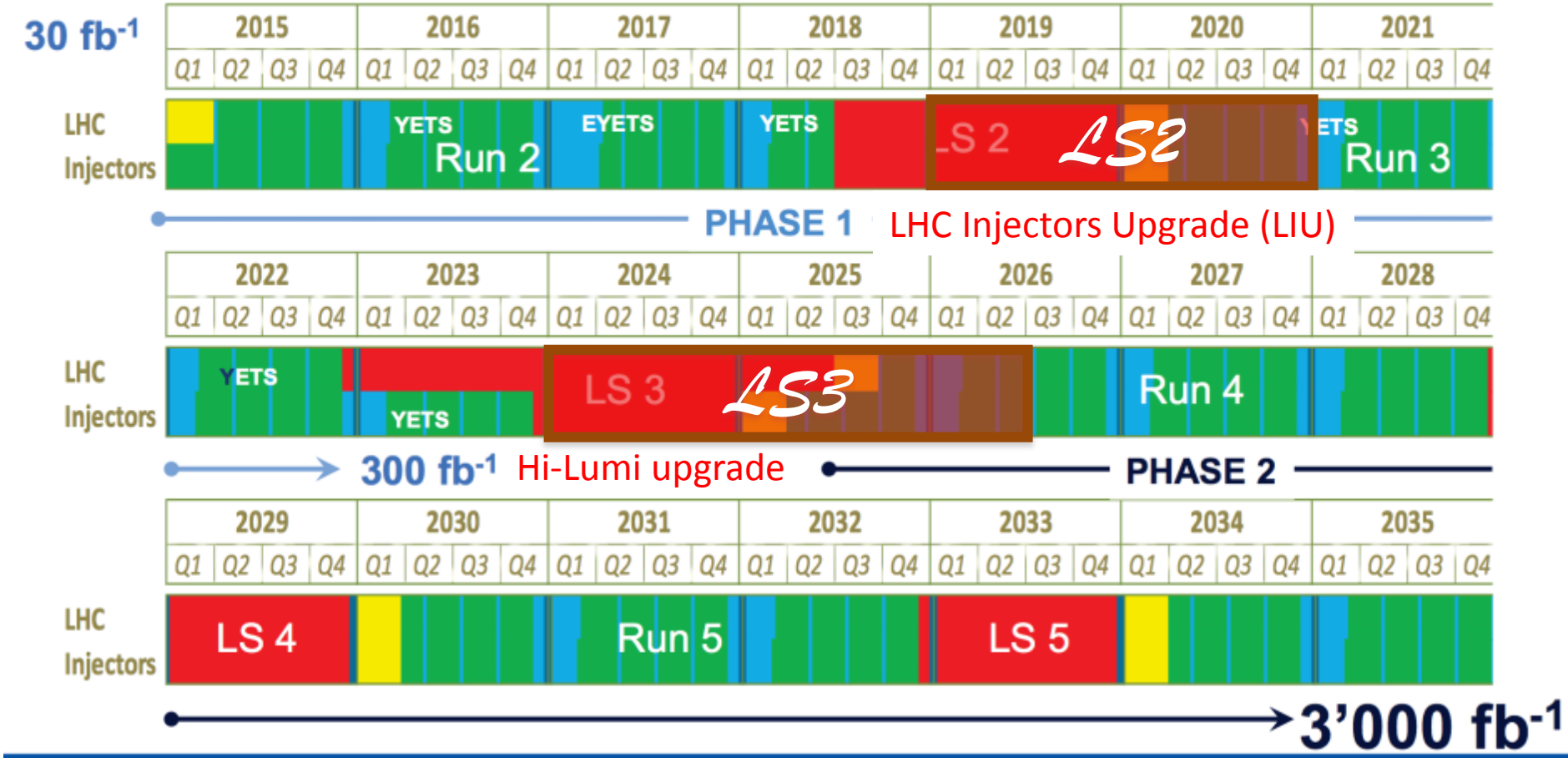
LS2 starting in ~~2018 (July)~~ 2019 => ~~18~~ 24 months + 3 months BC

LS3 LHC: starting in ~~2023~~ 2024 => 30 months + 3 months BC

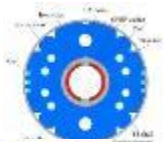
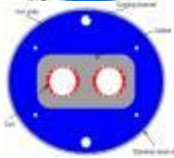
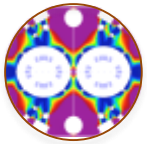
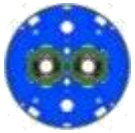
Injectors: in 2024 => 13 months + 3 months BC

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

Physics
Shutdown
Beam commissioning
Technical stop



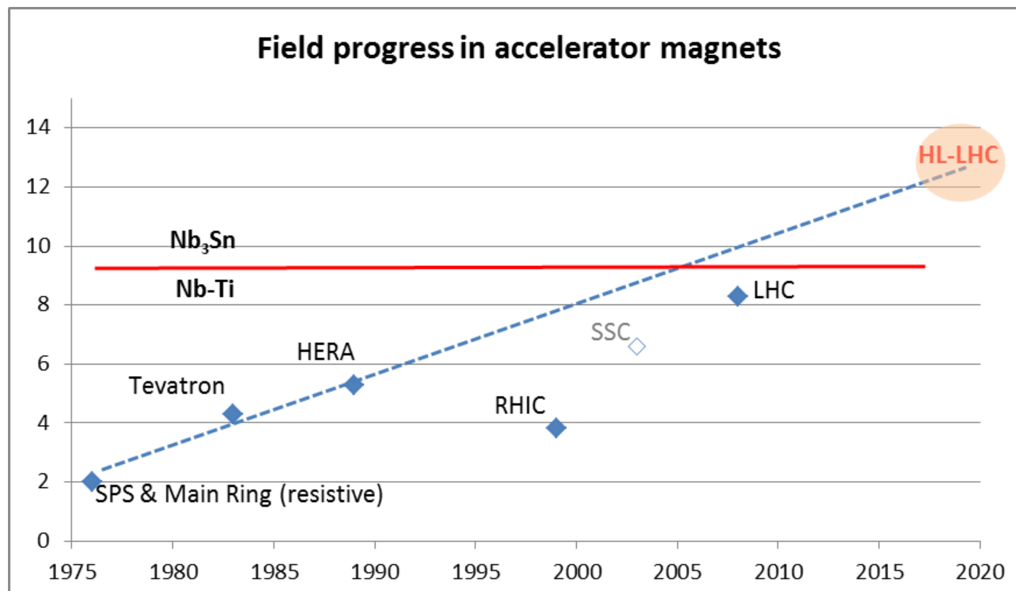
Main HL-LHC magnets

	Type	Material	Field/Gradient (T)/(T/m)	Aperture (mm)	Length (m)	Units (-)
Q1,Q3 Q2	Single aperture	Nb_3Sn	(11.4) 132.6	150	2x4.2 2x7.2	40
D1	Single aperture	Nb-Ti	6.5	150	6.3	6
D2	Twin aperture	Nb-Ti	4.5	105	7.8	6
Q4	Twin aperture	Nb-Ti	(6.0) 115	90	4.2	6
DS 11T	Twin aperture	Nb_3Sn	10.8	60	2x5.5	10 (40)

Magnet the progress

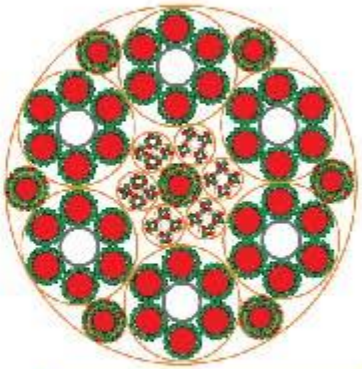
- LHC dipoles features 8.3 T in 56 mm (designed for 9.3 peak field)
- LHC IT Quads features 205 T/m in 70 mm with 8 T peak field
- HL-LHC
  - 11 T dipole (designed for 12.3 T peak field, 60 mm)
  - New IT Quads features 140 T/m in 150 mm > 12 T operational field, designed for 13.5 T).



Cold Powering System

Triplets, D1, Correctors

Room Temperature



Φext ~ 65 mm

2×72.2 kA

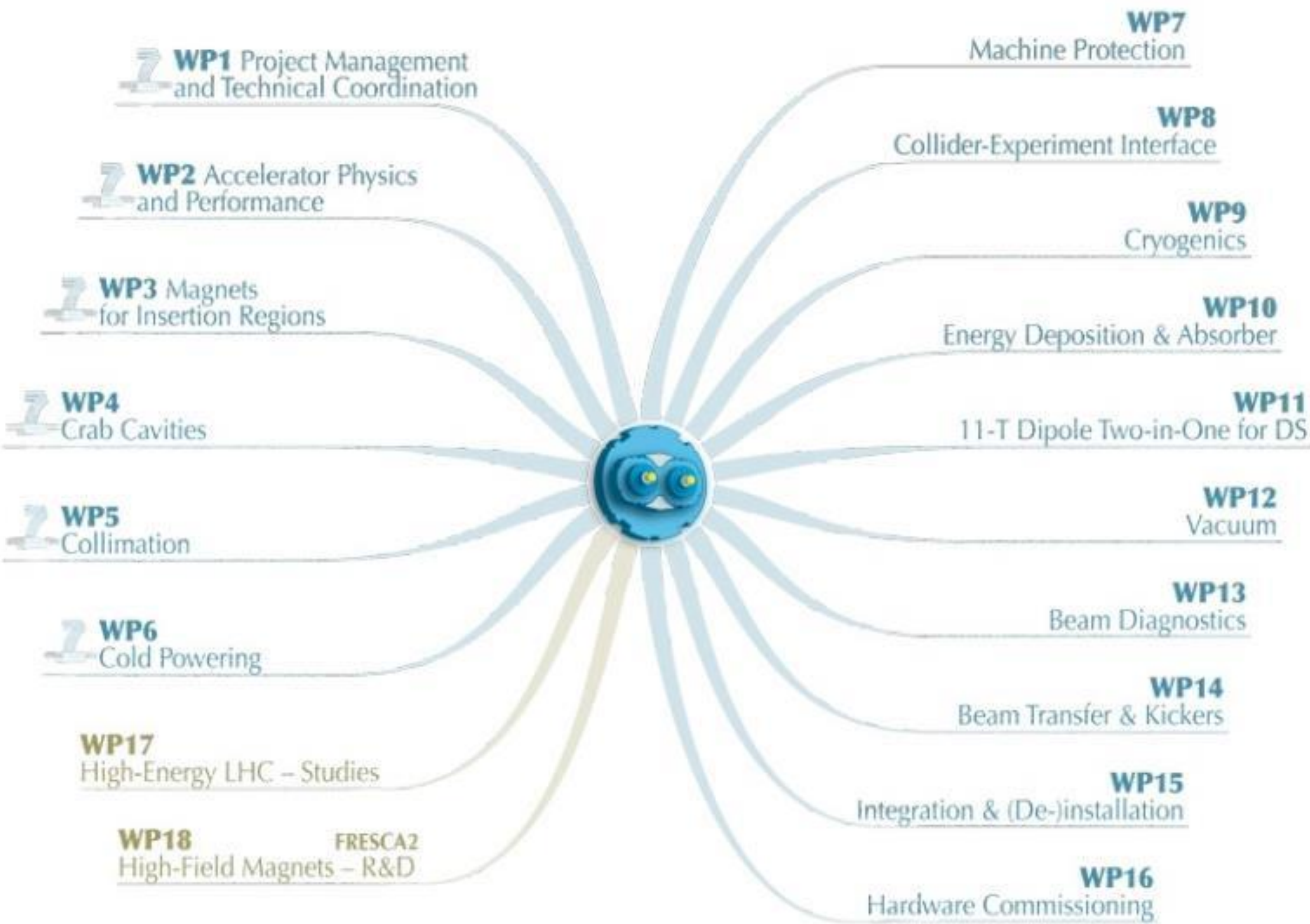
Bi-2223 or YBCO
T = 40 K- 50 K

MgB_2
$T \leq 20$ K

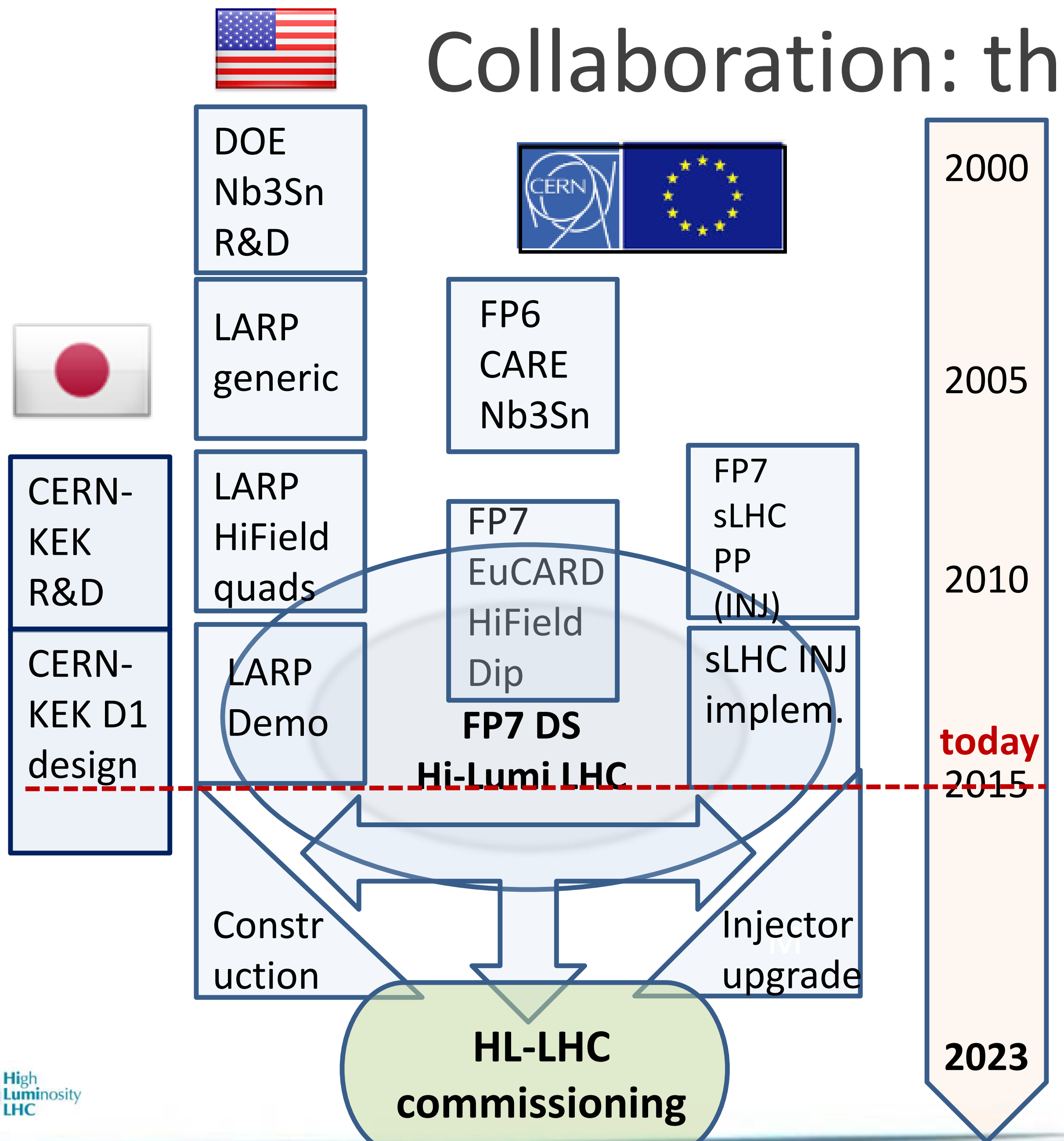
THe = 20 K

THe = 4.5 K

The core: the HiLumi WPs



Collaboration: the long way



The HL-LHC project formally started in 2010; however it is the focal point of 20 years of <u>converging</u> International Collaboration

High Luminosity LHC Participants