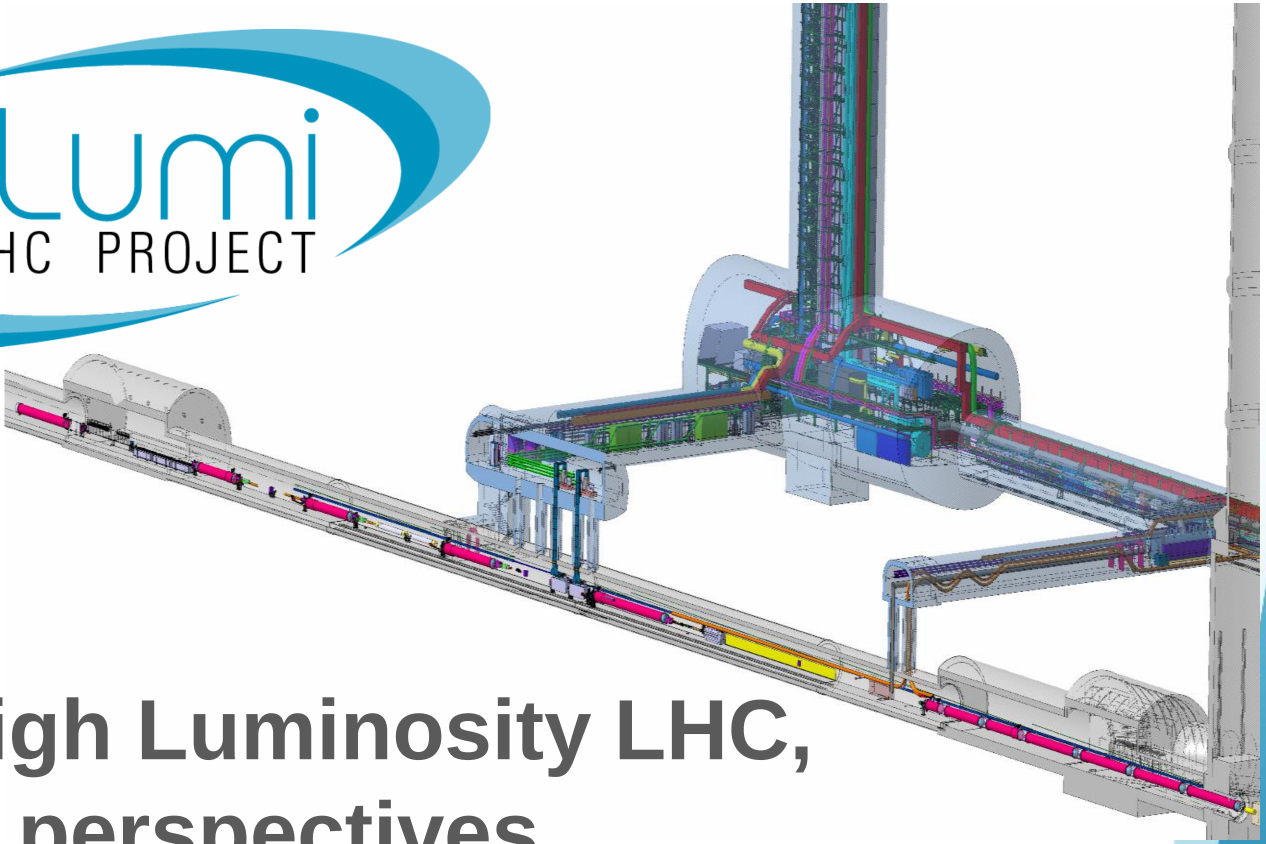
HiLumi
HL-LHC PROJECT



Le projet High Luminosity LHC, situation et perspectives

Serge Claudet – CERN
on behalf of L. Rossi, Project Leader

12e journées de cryogénie et supraconductivité, Aussois, 5-8 Juin 2018

Projet High Luminosity LHC, situation et perspectives

Serge Claudet, CERN

Depuis sa mise en service en 2008, le LHC ne cesse d'améliorer ses performances produisant ainsi chaque année de plus en plus de données en tirant le meilleur parti des infrastructures existantes.

Pour aller plus loin en compactant encore plus les faisceaux aux points de collisions, le projet High Luminosity LHC consiste à remplacer au total 1 km de machine de part et d'autre des grands détecteurs Atlas et CMS. L'augmentation des champs magnétiques passera par de nouveaux aimants de focalisation à base de Nb3Sn ainsi que tout le système d'alimentation, et bien sur la cryogénie associée.

Cette présentation fera le point sur les avancées du projet et les étapes clefs à venir.

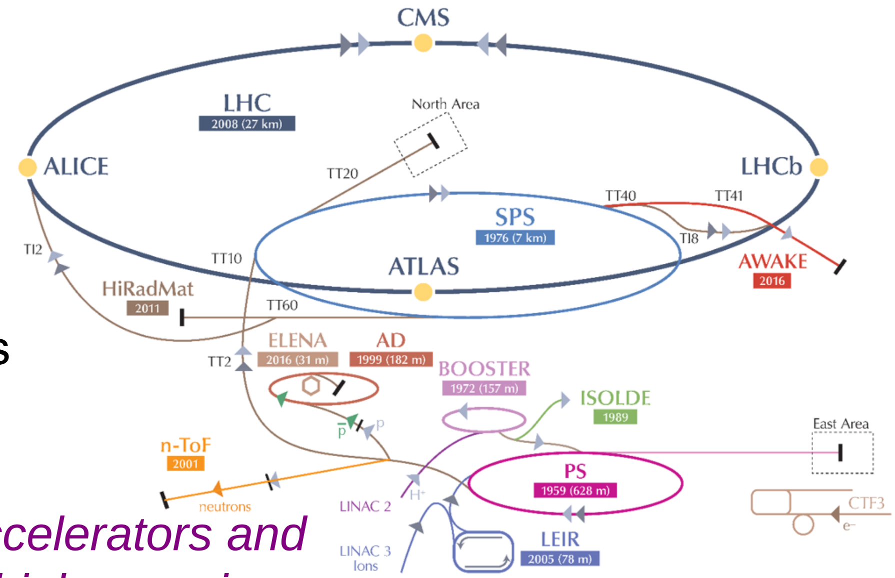
CERN in brief

Funded in 1954 as “Science for Peace”

Now with 22 member states

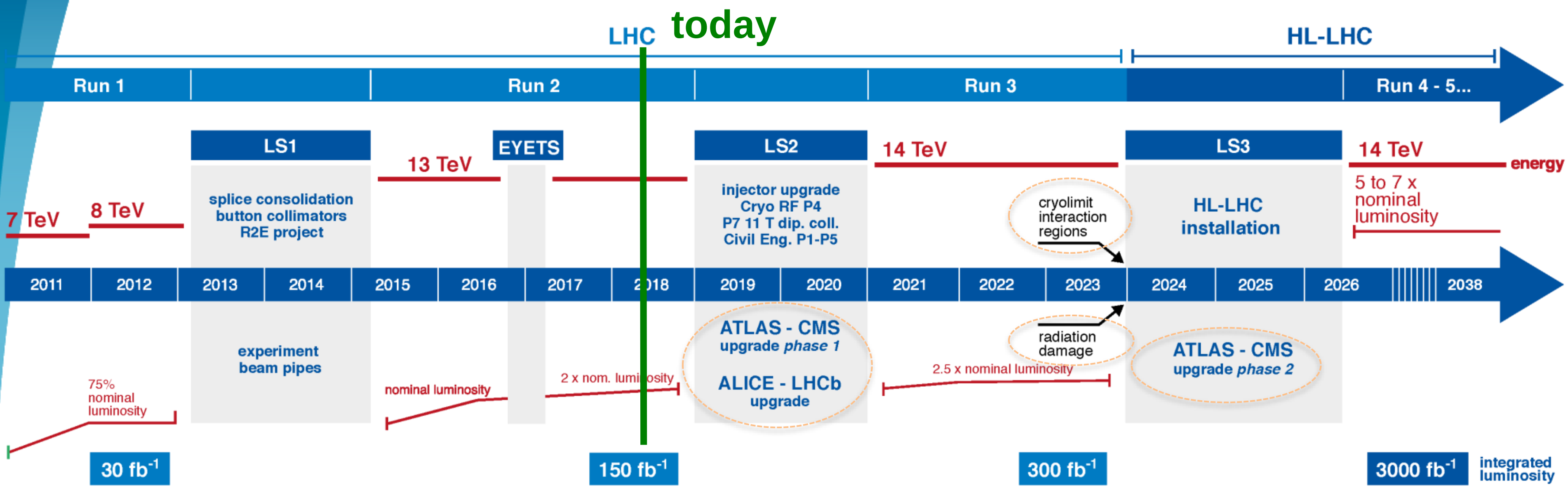
2’300 staff, 1’600 others and 10’500 users

1’100 MCHF annual budget (pro GDP)

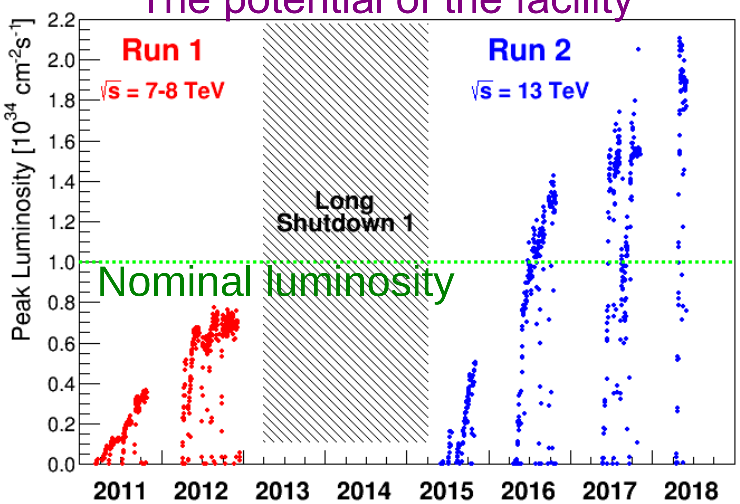


A very large technical site for a series of accelerators and detectors serving particle physics towards high energies

LHC / HL-LHC Plan

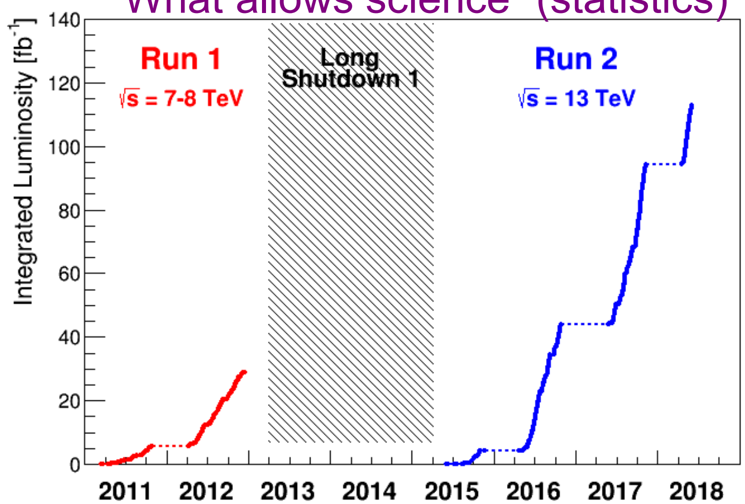


Peak Luminosity
" The potential of the facility"



Performance

Integrated Luminosity
"What allows science" (statistics)

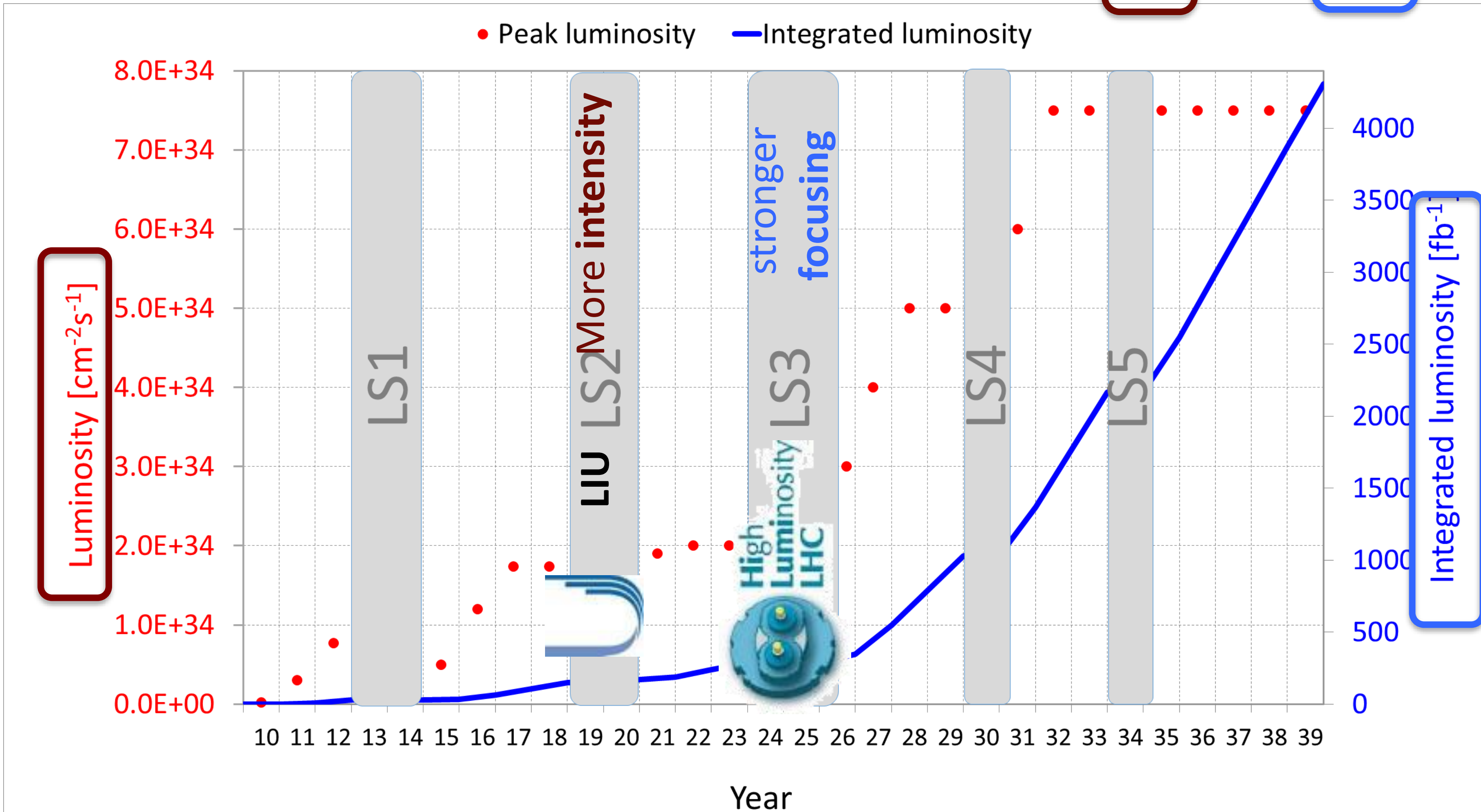


Qualification – Global availability - Time

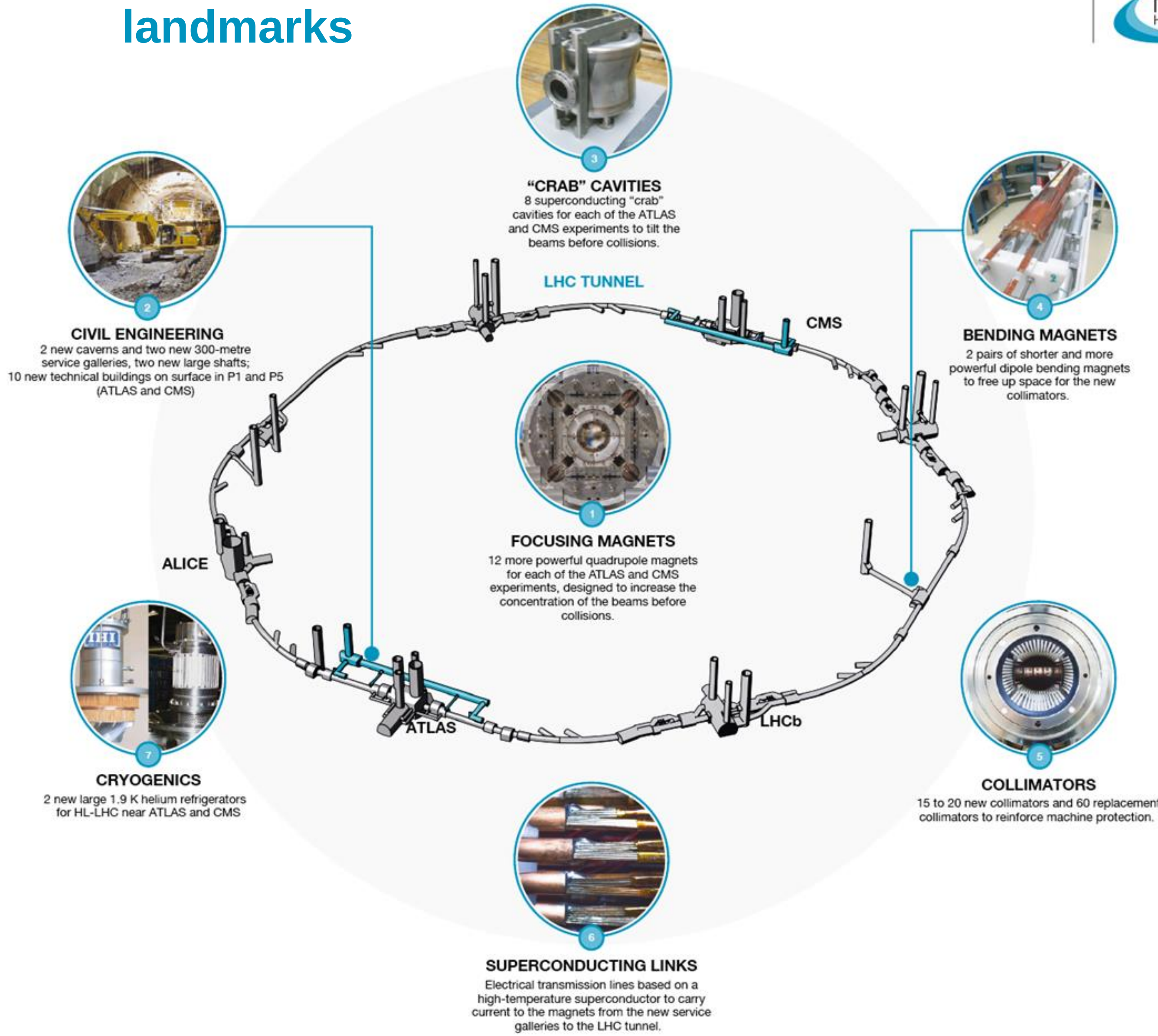
Towards higher collision rates

New discoveries or precision measurements need integrated luminosity !!!

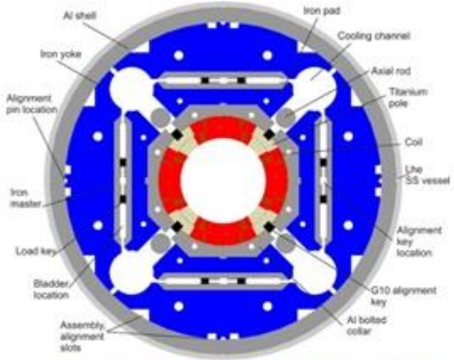
$$\text{Luminosity} = f * N^2 / 4\pi \sigma^2$$



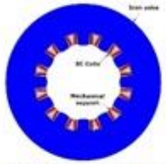
HiLumi LHC technology landmarks



THE MAGNET ZOO



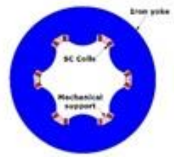
Triplet [G. Ambrosio, P. Ferracin et al.]

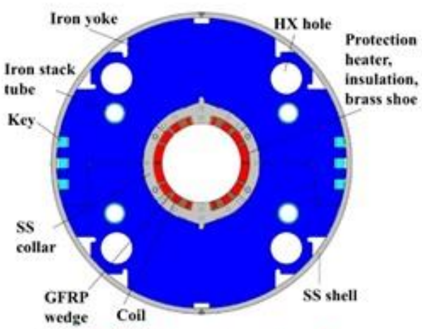


Dodecapole

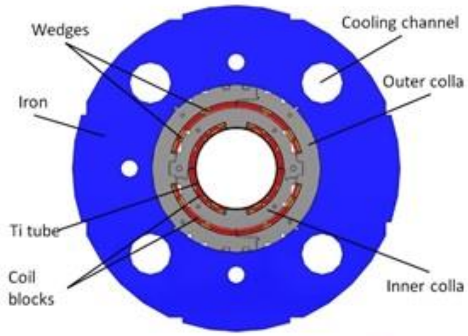
Decapole

Octupole

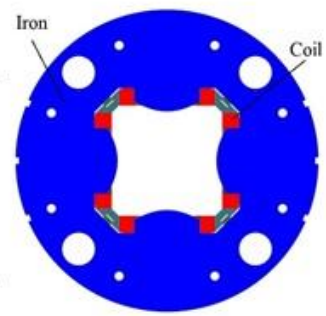




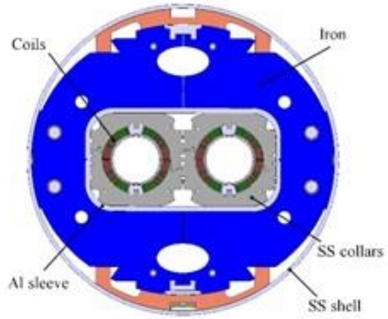
D1 [T. Nakamoto, et al.]



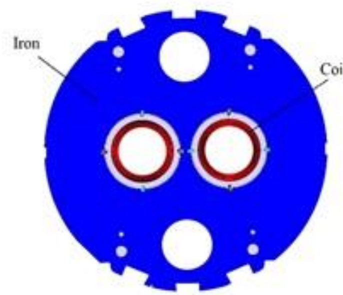
MCBXF [F. Toral, et al.]



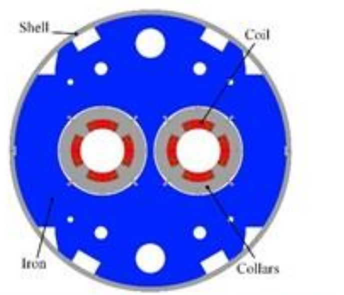
Skew quad [M. Sorbi, M. Statera, et al.]



D2 [P. Fabbricatore, S. Farinon, et al.]



D2 correctors [G. Kirby]



MQYY [H. Felice, et al.]

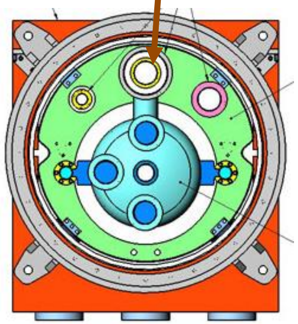
Inner Triplets Cooling (LHC vs HL-LHC)

	Beam Screen	Cold Mass	Assembly (IT.R5)

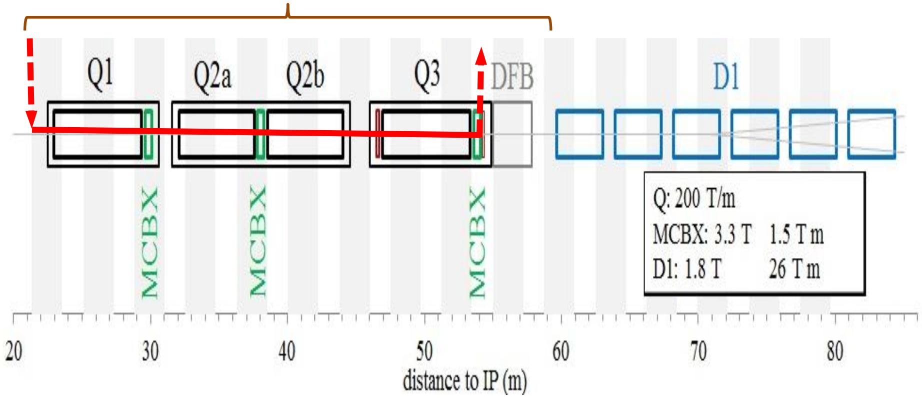
LHC


CERN

Nb-Ti, cold bore 56mm,
single cooling channel at 1.8K

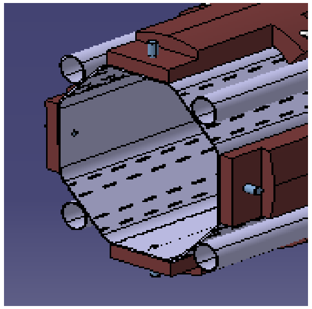

Fermilab

Cryostat + cooling loop

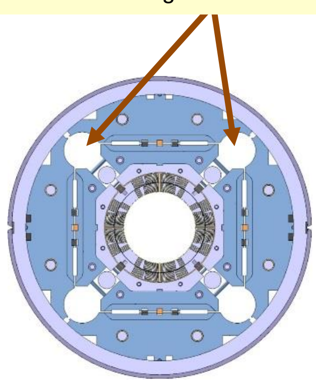


HL-LHC

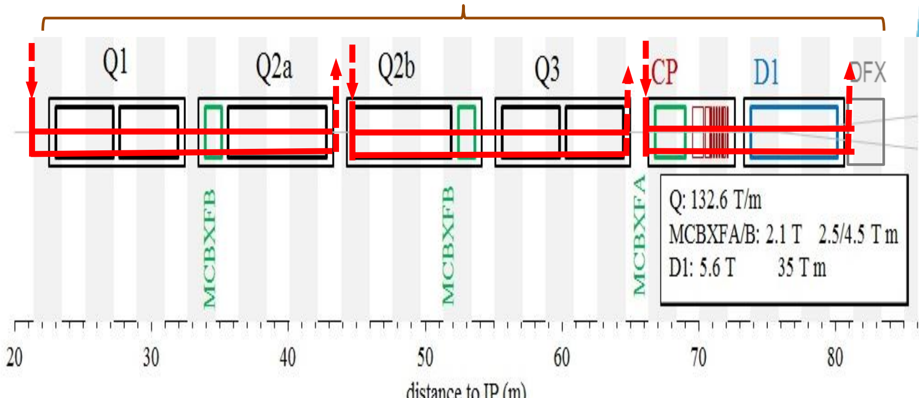
Tungsten shielding



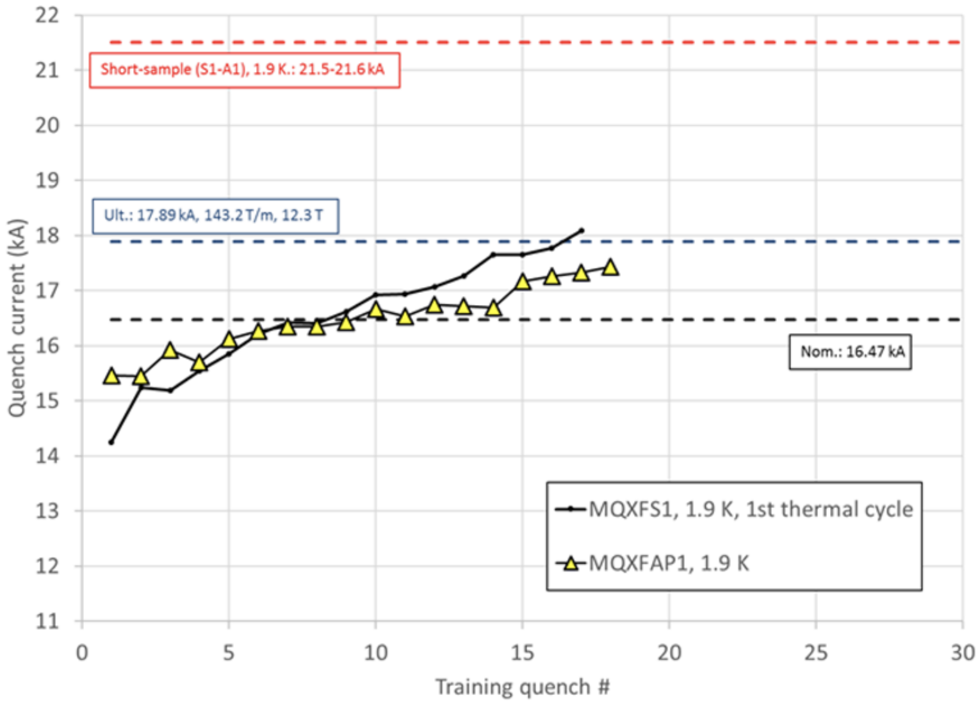
Nb-3Sn, cold bore 150mm,
double cooling channesl at 1.8K



Cryostat + cooling loops



Test of first 4 m Long Proto of IT QUAD in the USA (BNL)



Very good behaviour of the proto P1, as the short model (S1).

The only caveat: the training test has been stopped due to a short circuit (under repair).

It shows that technology is there but still vulnerable to small detail (full quality!)

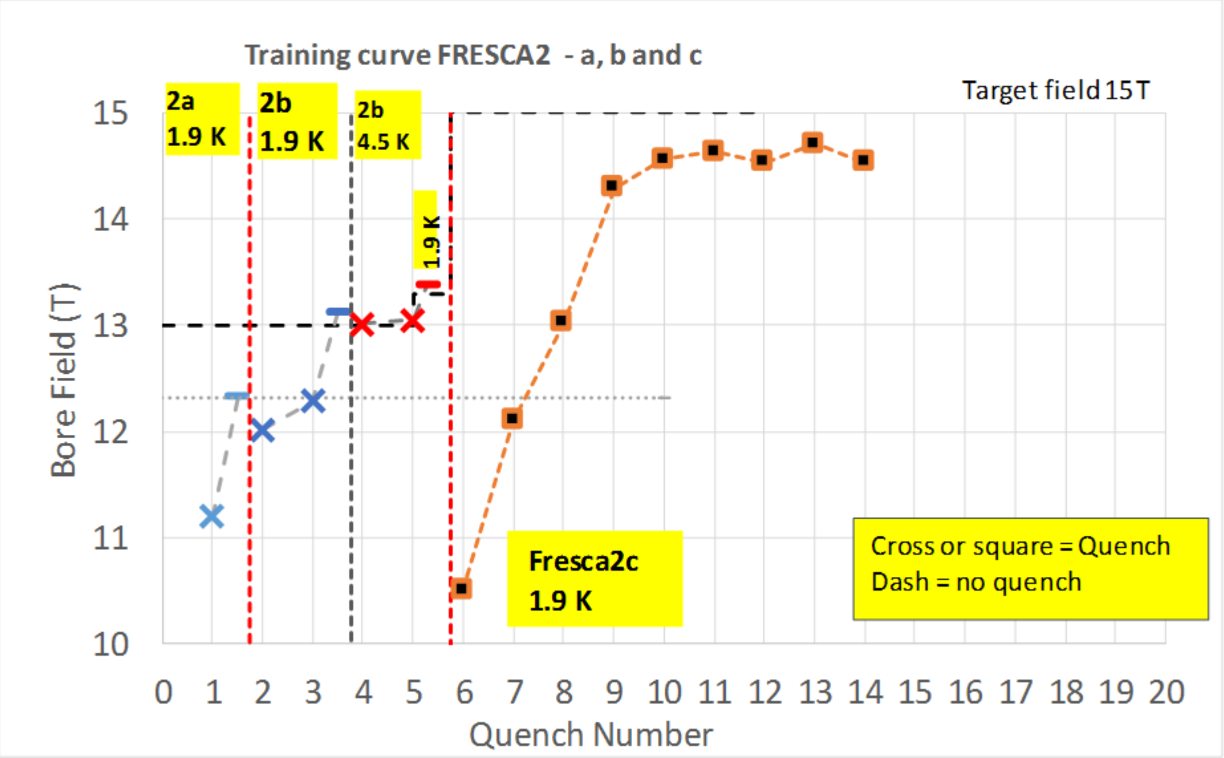
Main focussing quadrupoles (CERN)

Construction of the first 8 m long proto Nb3Sn at CERN, to be finished by 2018.

FRESCA2: the first project as R&D for Hilumi;

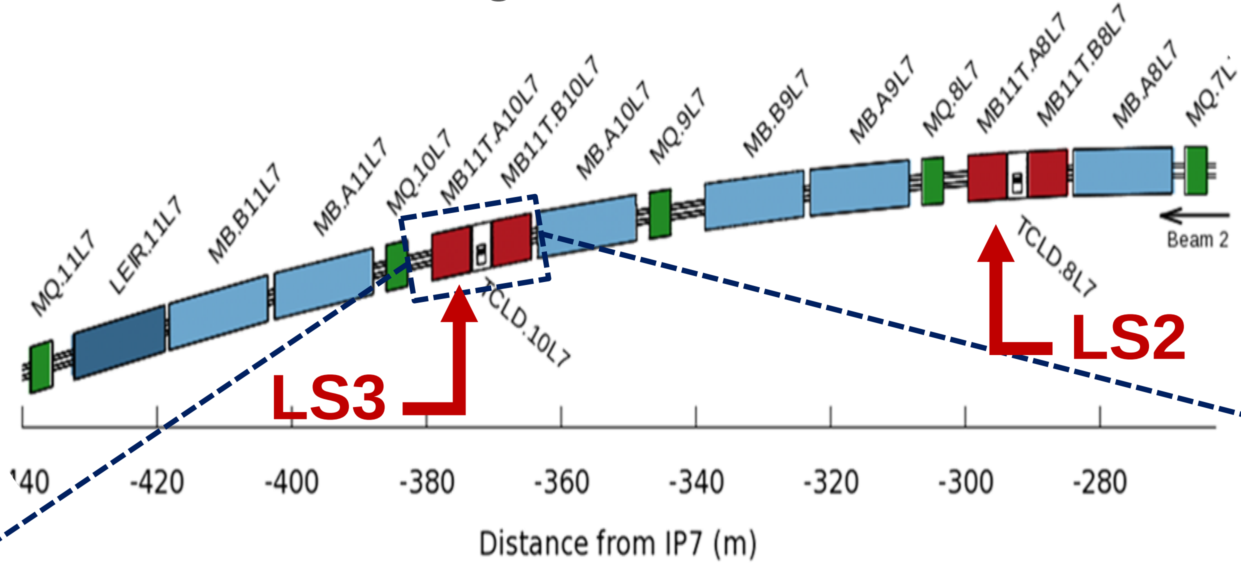
100 mm bore Nb3Sn dipole (no field quality) for cable test facility.

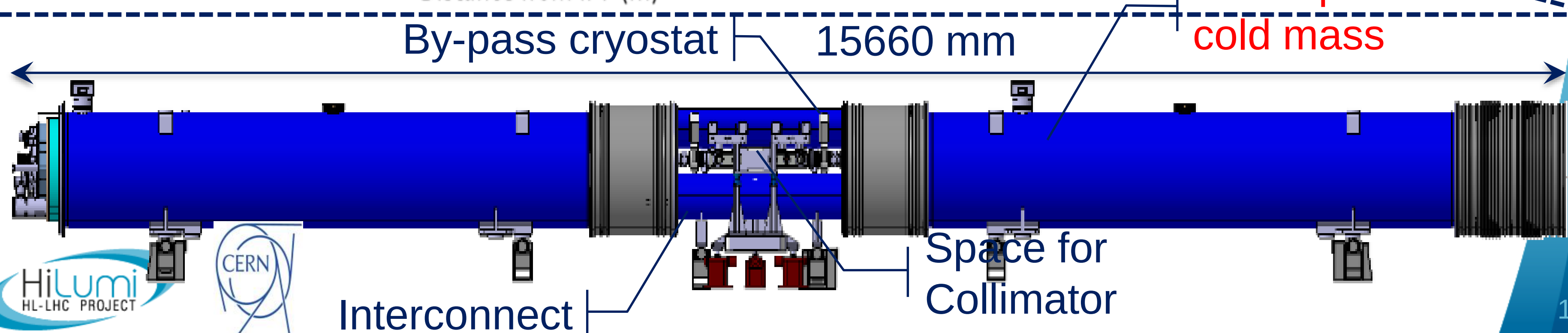
Nominal design field 13 T (ultimate 15 T): reached 14.6 T, few quenches!



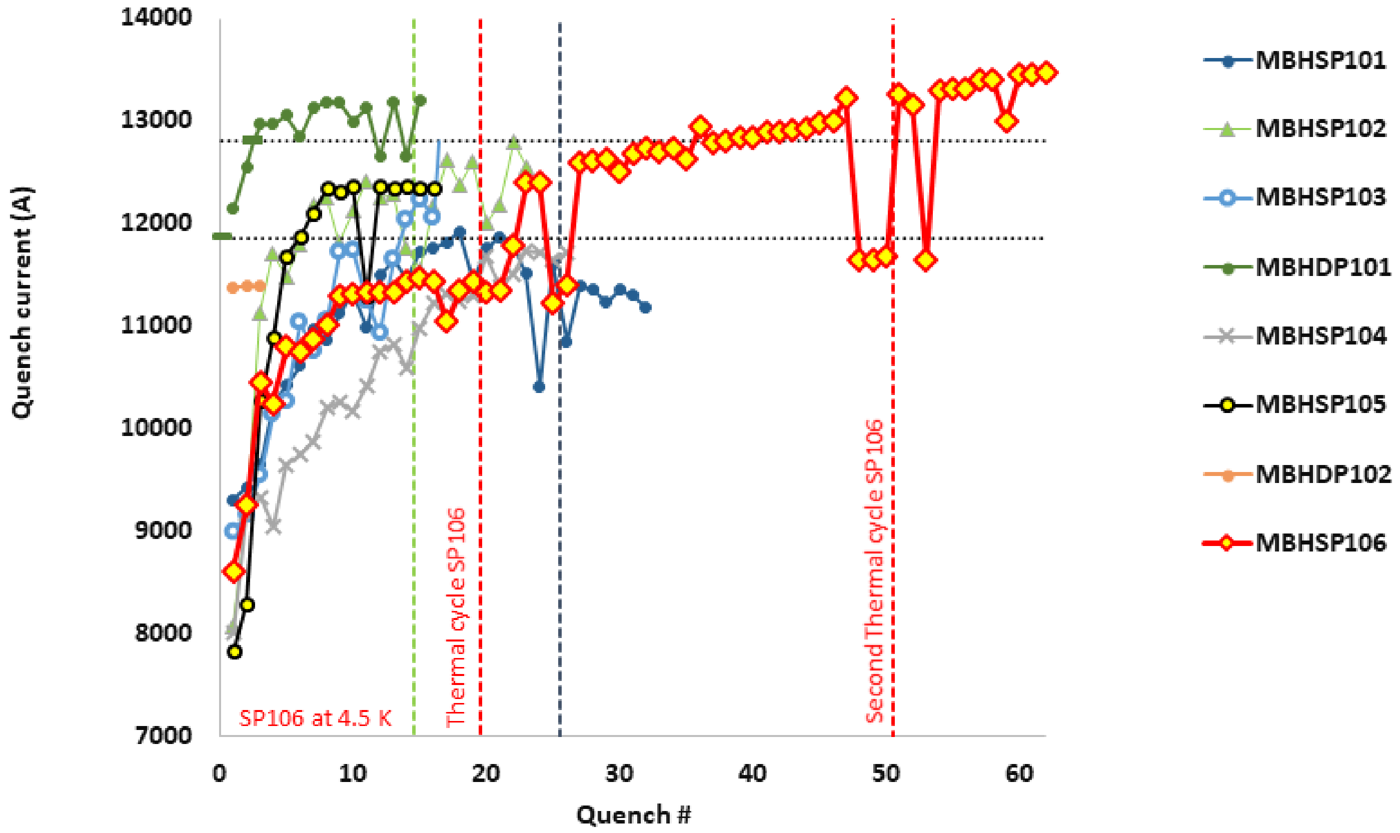
Why an 11T dipole in HL-LHC?

- **Create space in the dispersion suppressor regions of LHC**, i.e. **a RT beam vacuum sector, to install additional collimators** needed to cope with beam intensities larger than nominal
- Replace a standard Main Dipole by a **pair of 11T Dipoles producing the same integrated field of 119 T·m at 11.85 kA**





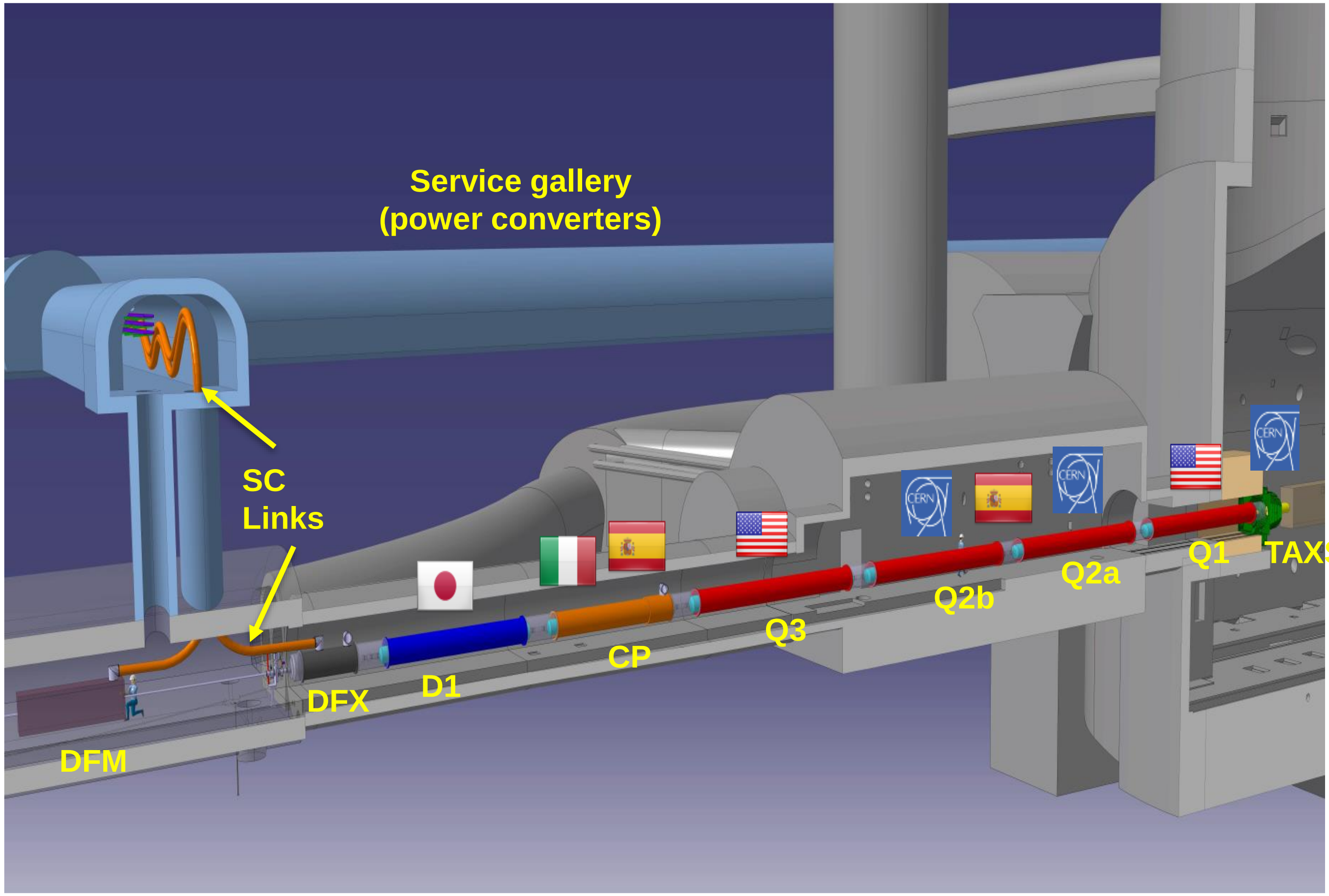
Good results on last model 11 T (>12.5 T! with some massages) but not all problems solved on 11 T & IT



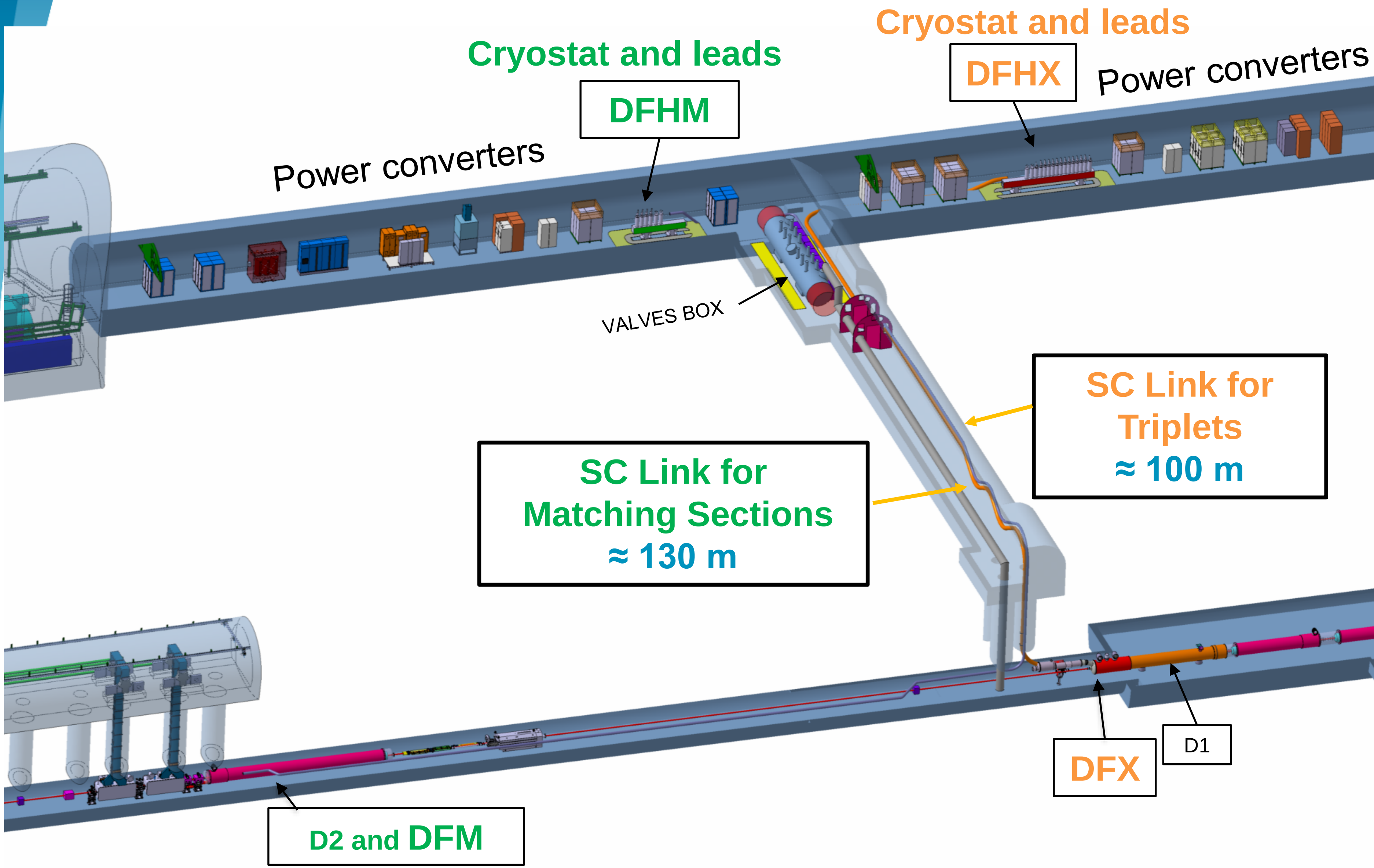
11 T prototype: ready for tests (June 2018!)

Installation foreseen in 2020, it should be the 1st Nb3Sn magnet in an accelerator

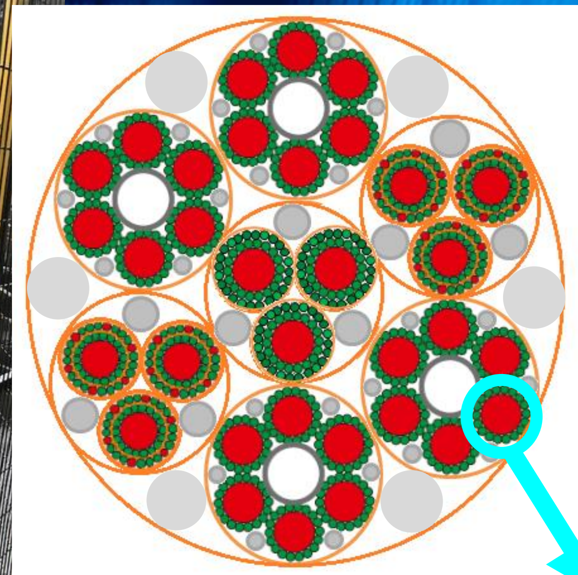
The Inner Triplet region with in-kinds
The IT QUADS are critical for performance and for installation schedule



Cold Powering System

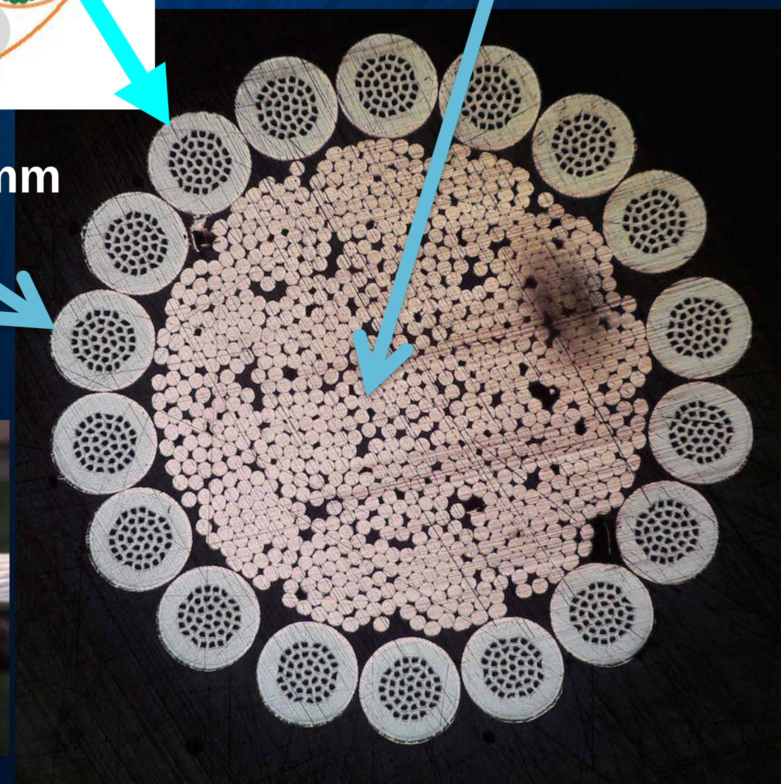


Production of CERN SC-Links MgB_2 cable



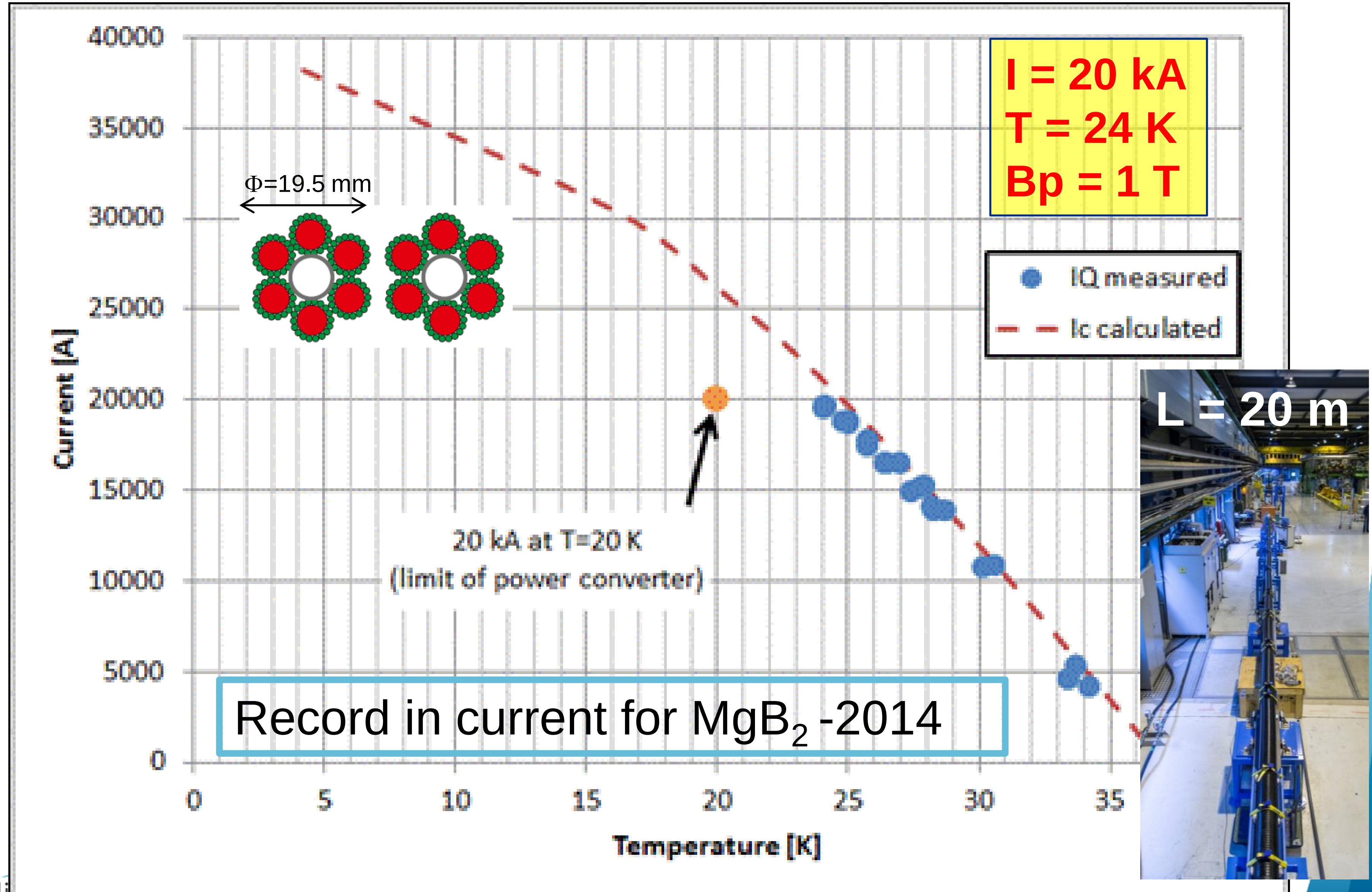
Core: 12 mm^2 Cu
Φwire=0.15 mm
46×19 wires
Tw=15/45 mm

Φcable=6.5 mm

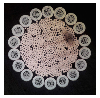


Φ=6.5 mm

Superconducting Link: MgB_2 cables



Φ=6.5 mm



Test of 60m with 18kA cable and extremities foreseen Aut’18

Effect of the crab cavities

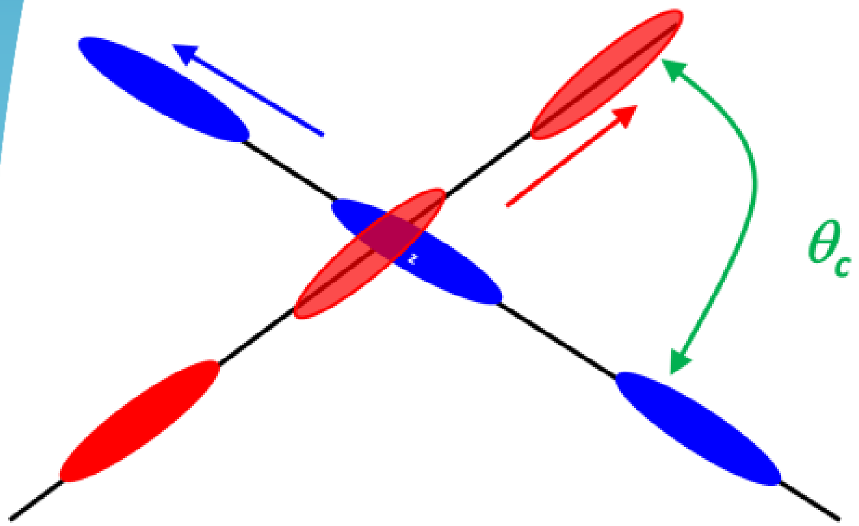
To compensate for the larger crossing angle

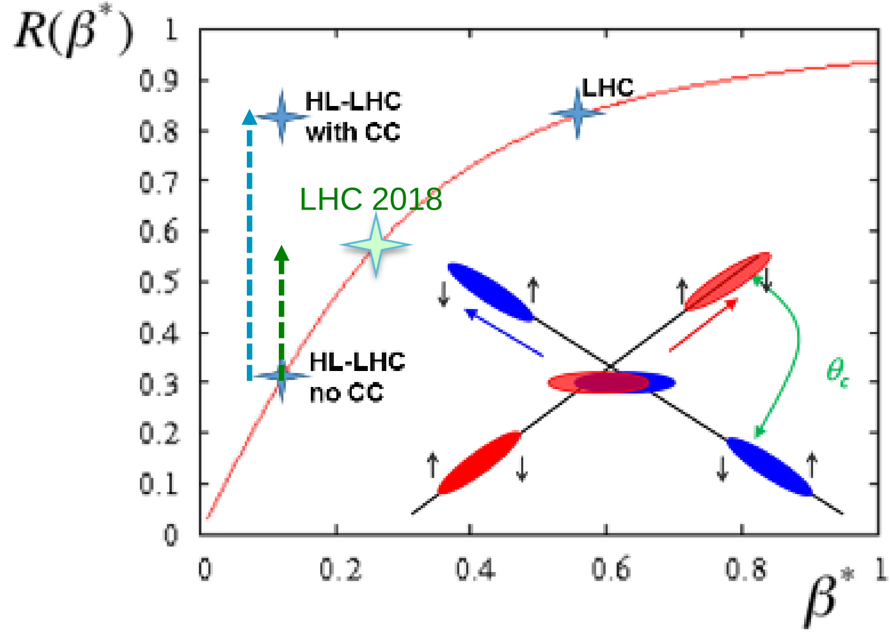
Beam current

$$L = \gamma \frac{f_{rev}\, n_b\, N_b^2}{4\pi \varepsilon_n \beta^*} R \qquad R = \frac{1}{\sqrt{1 + \left(\frac{\theta_c \sigma_s}{2\varepsilon_n \beta^*}\gamma\right)^2}}$$

energy

Beam size





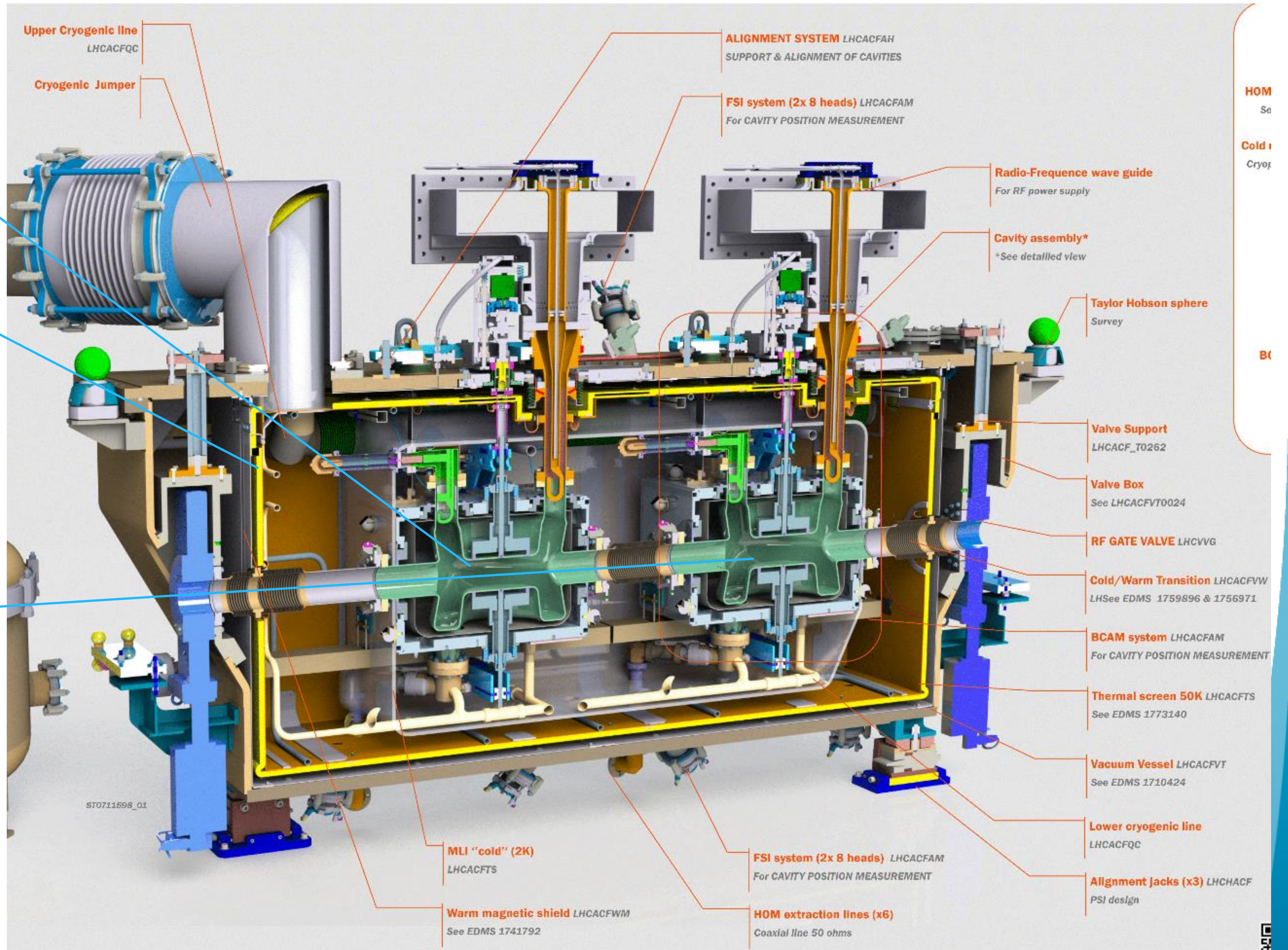
- RF crab cavity deflects head and tail in opposite direction so that collision is effectively “head on” and then luminosity is maximized
- *Crab cavity maximizes the lumi and can be used also for luminosity levelling: if the lumi is too high, initially you don’t use it, so lumi is reduced by the geometrical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

Cryomodule preview

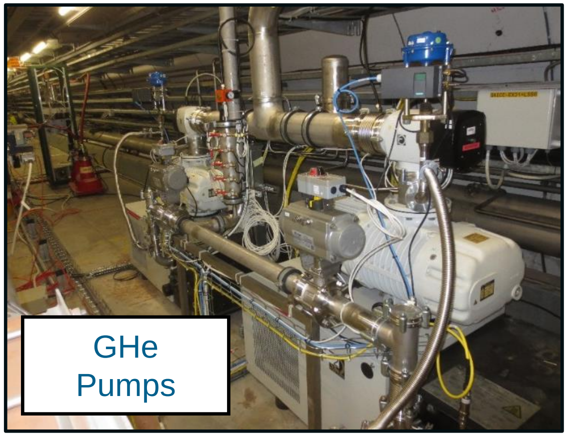
Cavity 1
«Upstream» cavity

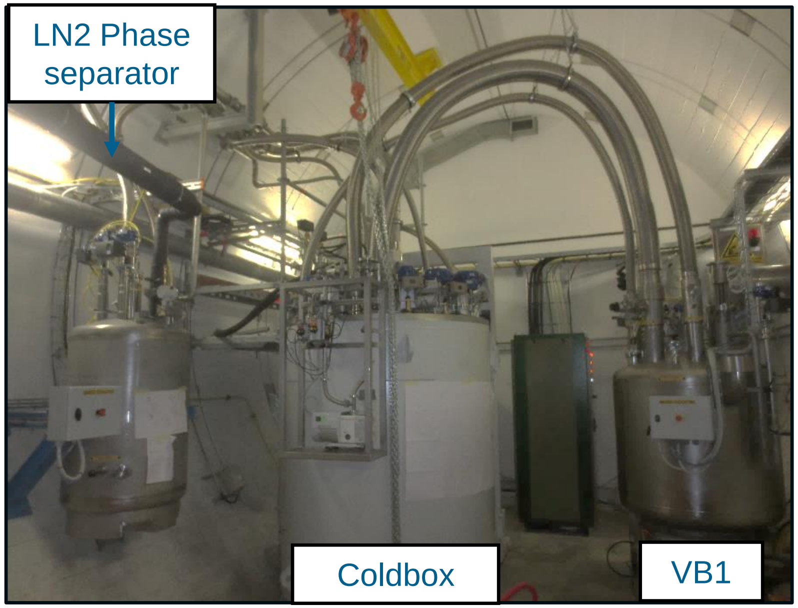
Thermal screen
Copper

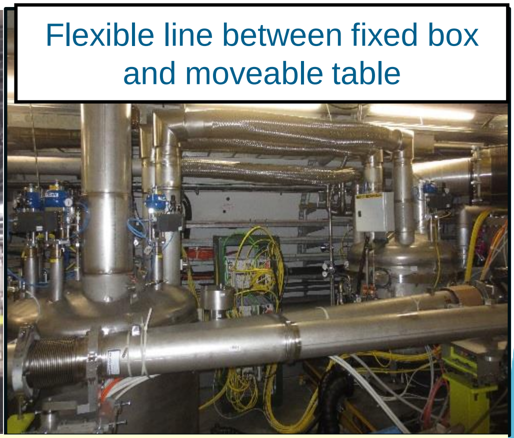
Cavity 2
«Downstream» cavity



HiLumi - SPS-BA6 – New cryo/supra RF test facility

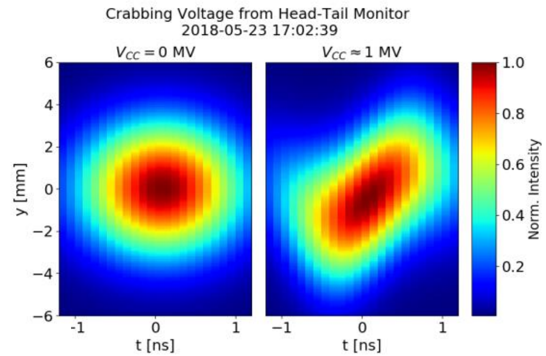


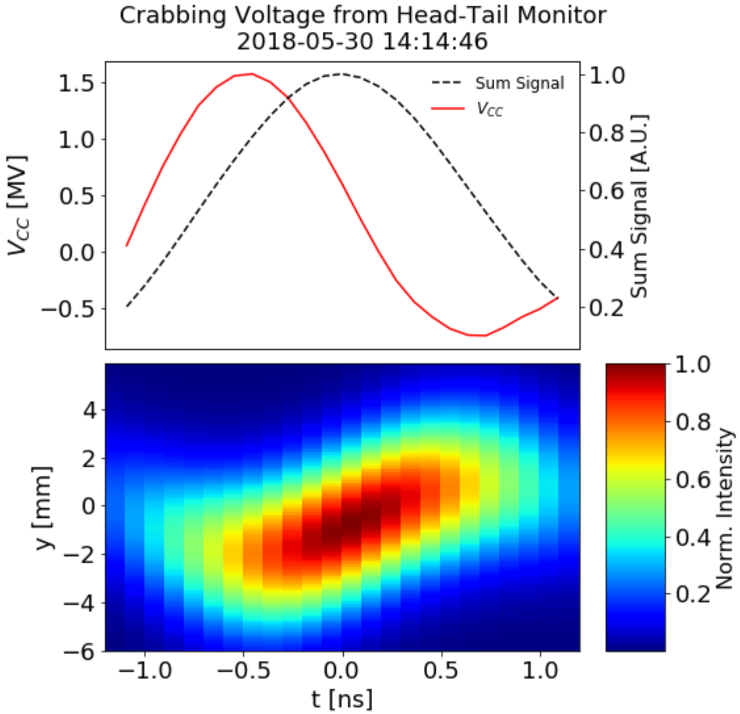




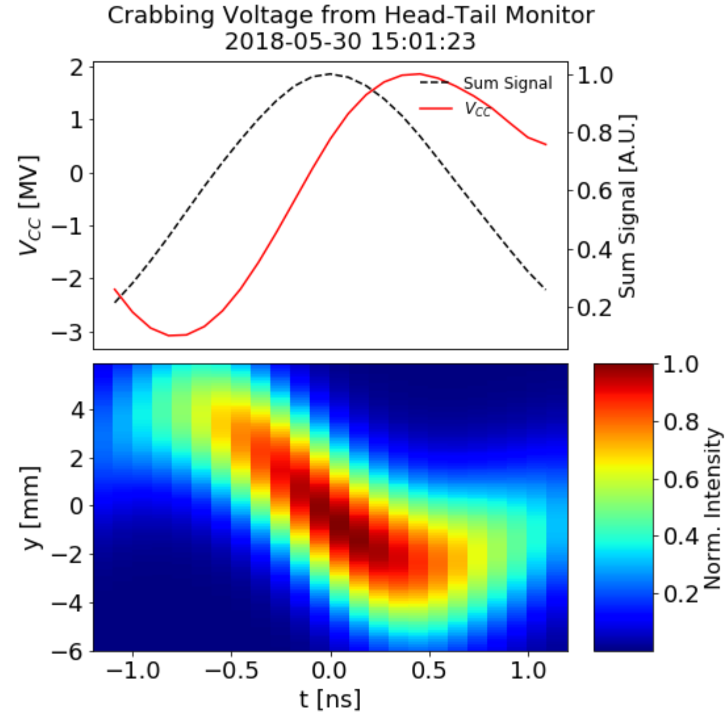
7 industrial contracts complemented with local piping, cabling, controls now installed before tunnel closure at the end of YETS

First tilting of the proton beam by a Crab Cavity!
SPS 23 May 2018 at 1 MV (3.4 MV nominal)

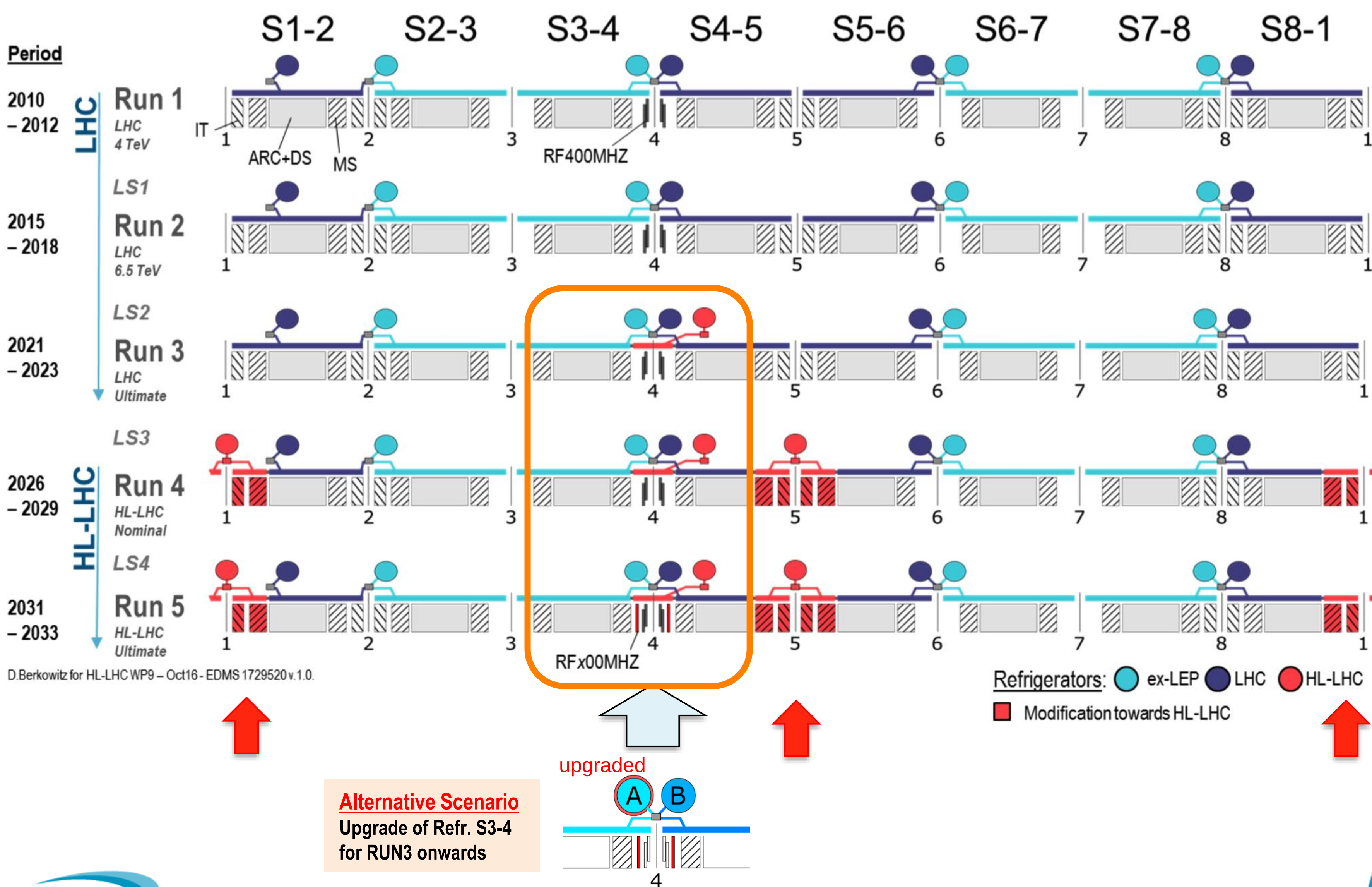




10 slots of SPS Machine Development foreseen in 2018

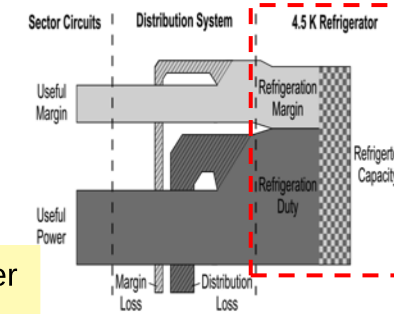


LHC Cryo-Configuration
(from Run1 to Run5)



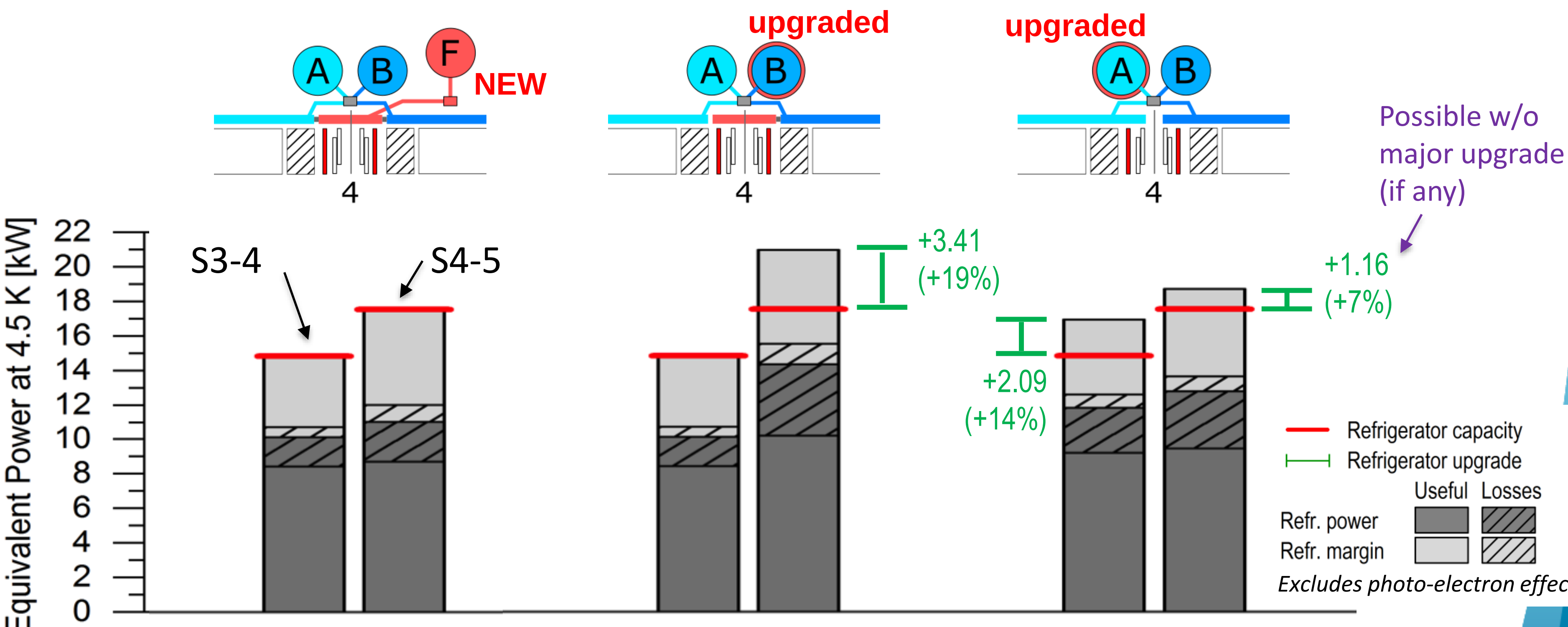
Alternative Scenario
Upgrade of Refr. S3-4
for RUN3 onwards

Alternative scenarios to cool the SRF modules at point 4



For a useful cooling capacity of 2 kW @ 4.5 K

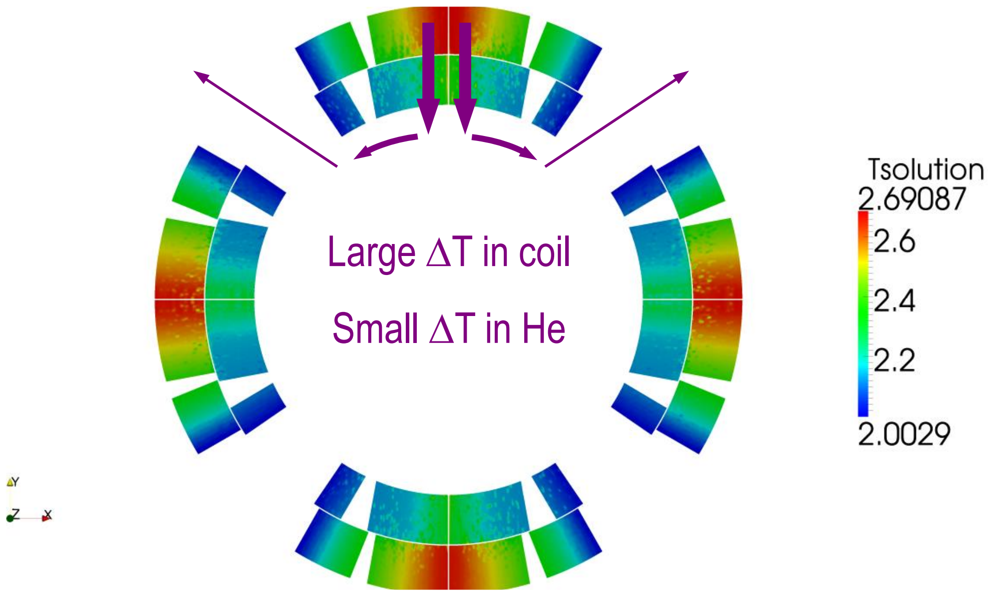
Baseline ✓	Alternative 1 ✓	Alternative 2 ✓
	Proposed with Turbo-Brayton for thermal shield loads	Proposed with higher efficiency turbines

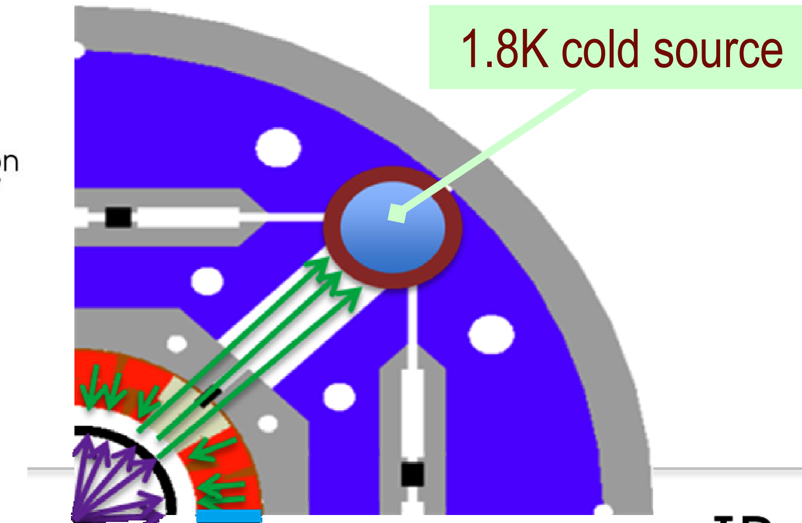


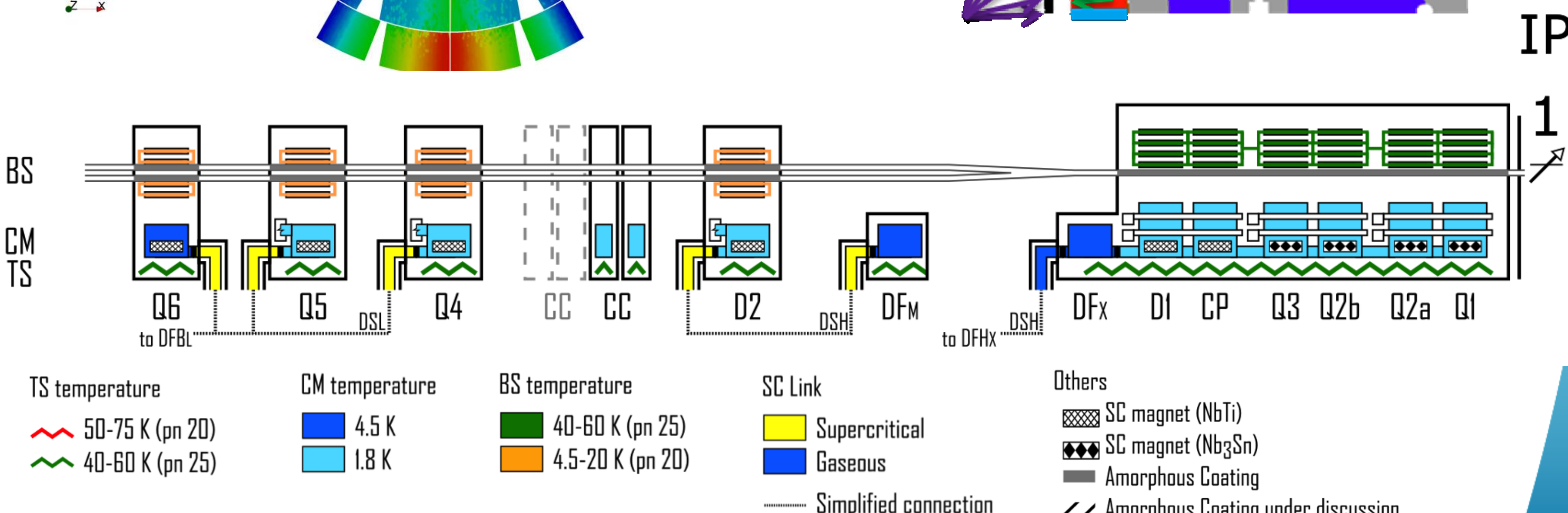
After upgrade, the refrigerator margin aligned to the other plants/sectors

HiLumi LSS overview

Clarification of needs and interfaces,
1st version of cryo-distribution being prepared







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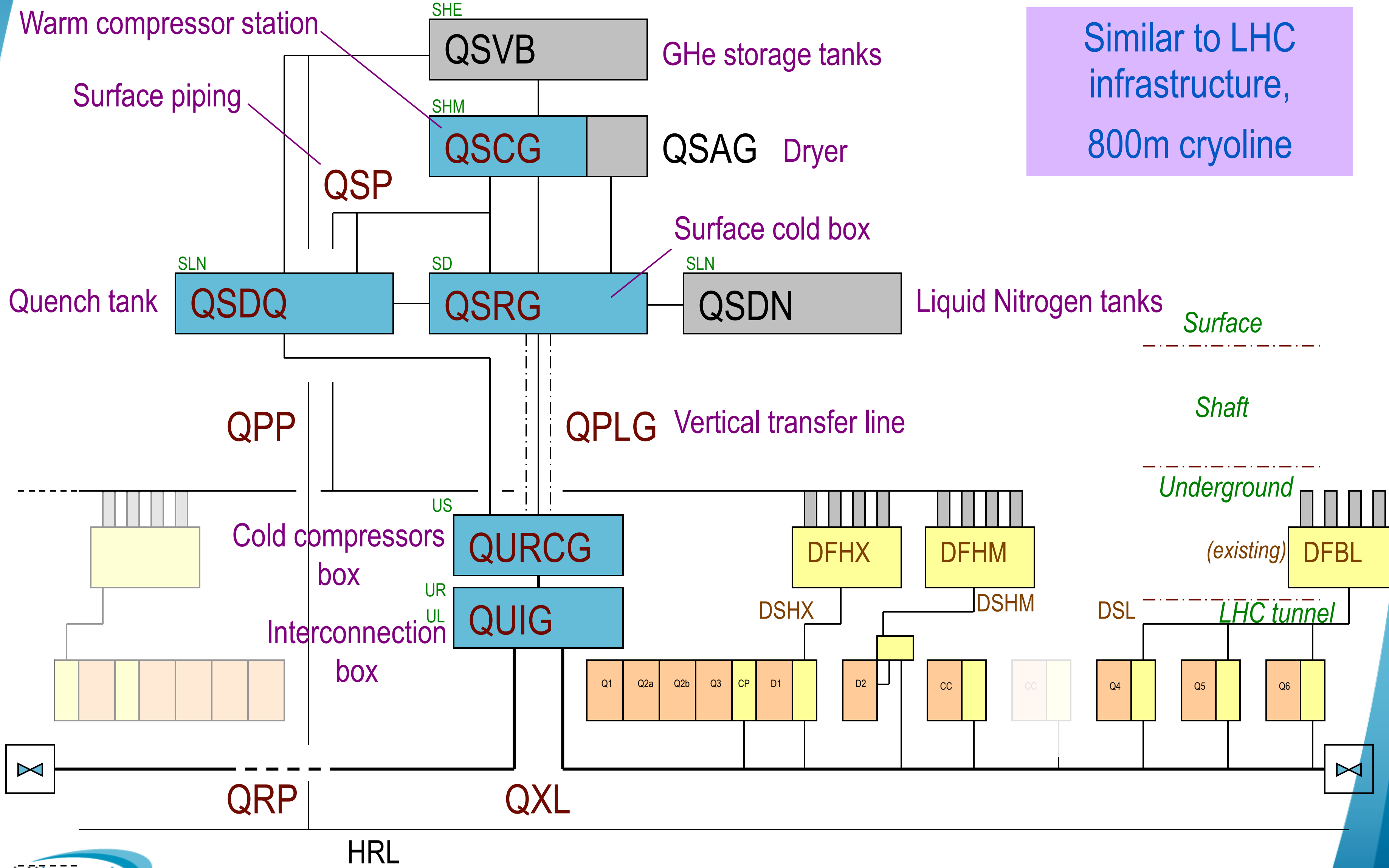
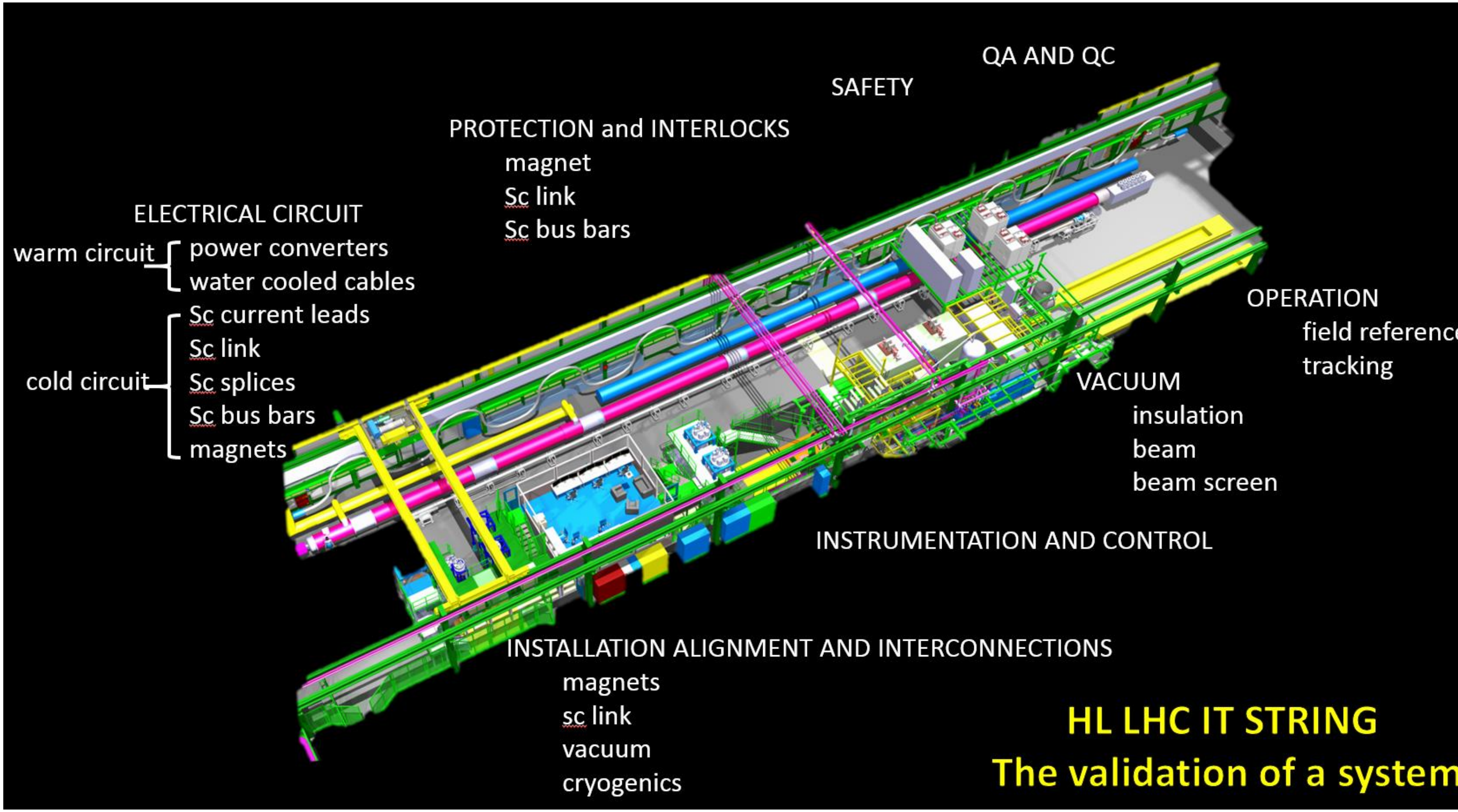
P1/P5 Cryogenic architecture

18 kW equivalent at 4.5 K, including 3 kW at 1.8 K

Similar to LHC infrastructure, 800m cryoline

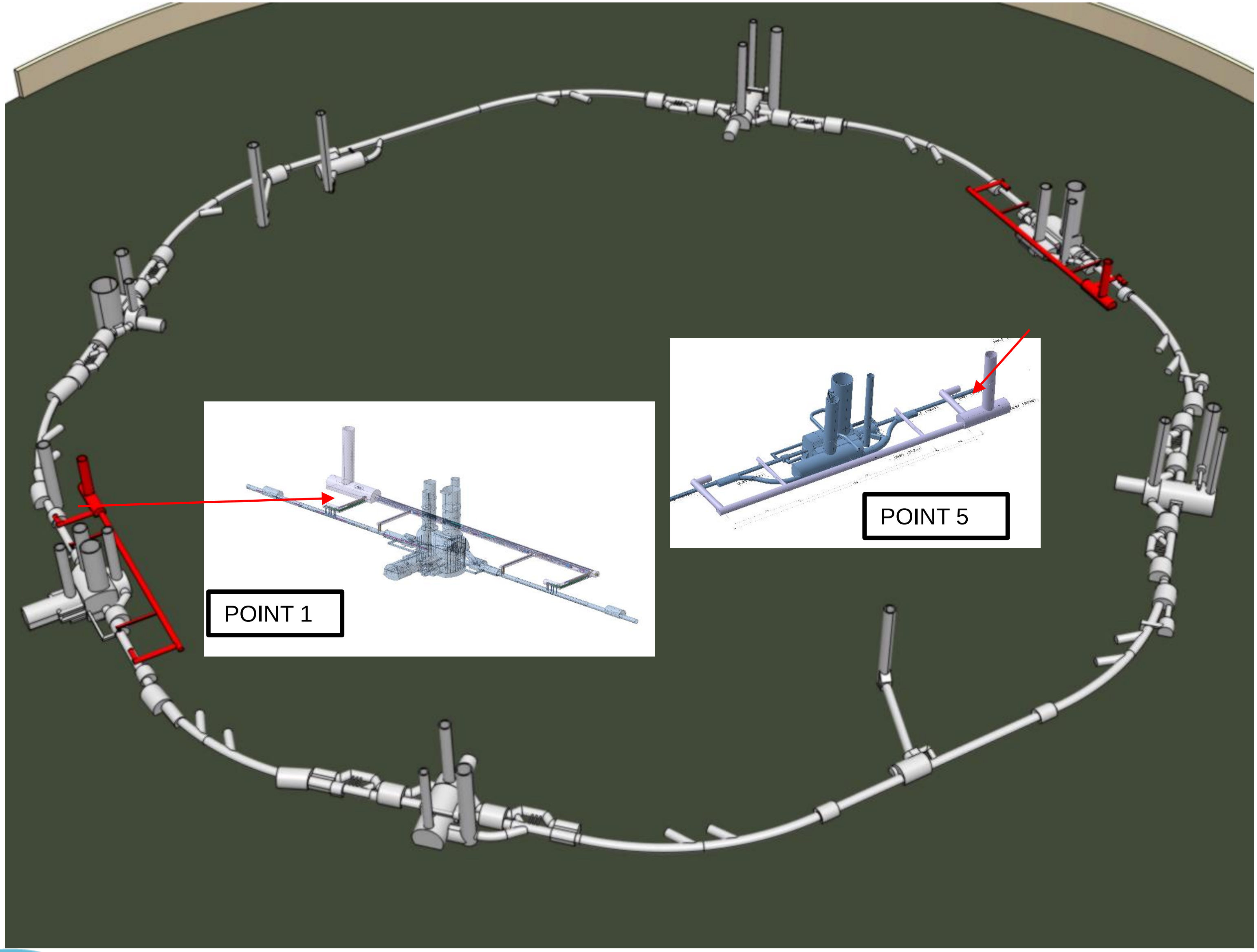


IT string integrated system test from Q1 to D1

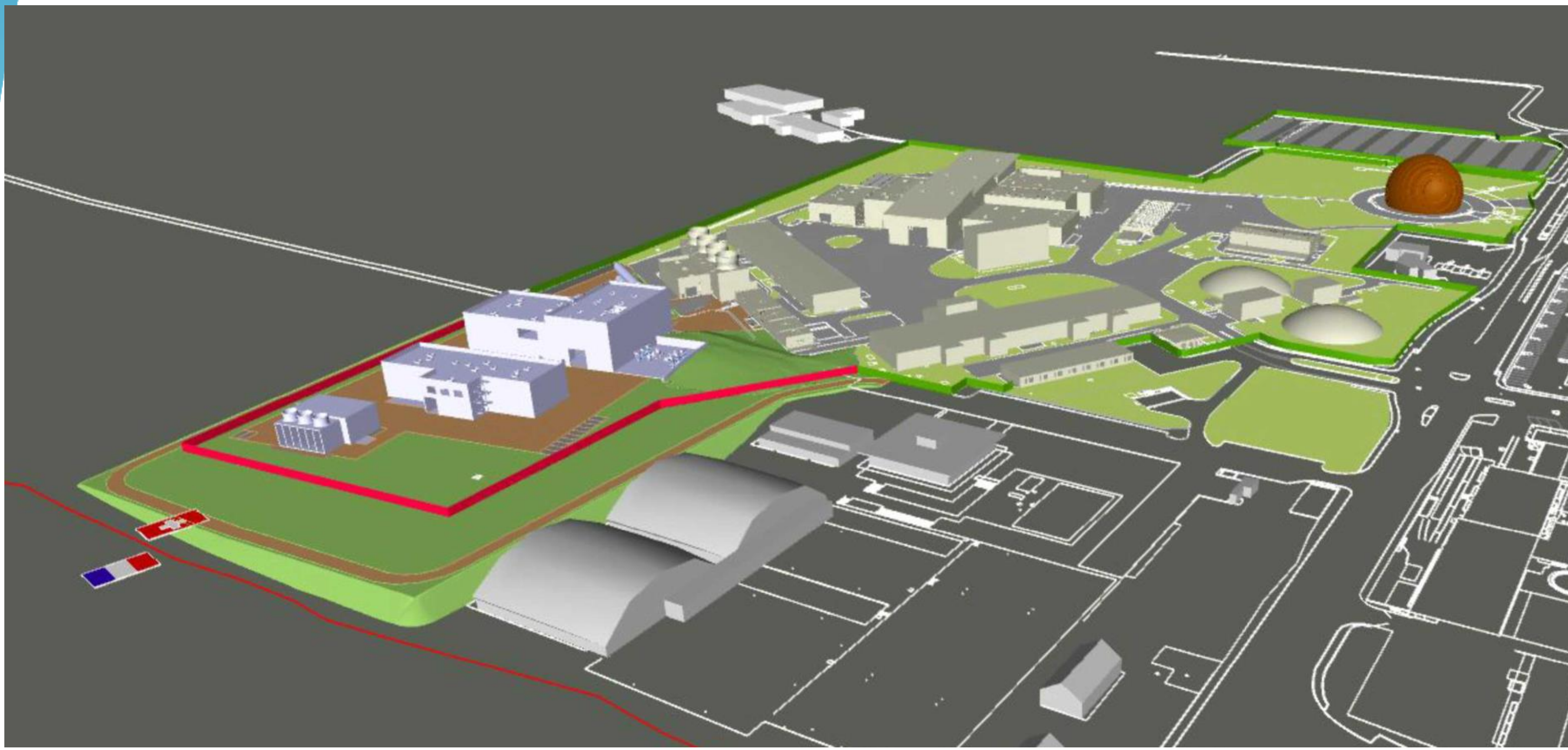


2021 - 2022

Major civil engineering required at P1-P5



Inventory of the surface works (P1, ATLAS)



Site mobilization has started

S. Claudet

Bilan

- Les principaux axes du projet (aimants haut champ et grande ouverture, dipoles 11T, ligne supraconductrice, cavités crabes) ont dépassé les phases de démonstrateur et en sont aux prototypes
- Il faudra assurer la fabrication des (relatives) petites séries (>2021) avec moins d'implication de l'industrie que pour le LHC et des accords de collaboration à finaliser
- Le génie civil devrait etre dans les temps, avec puits creusés pendant le long arret No 2 (2019-2020) pour ne pas subir les effets des vibrations pendant le fonctionnement du LHC
- Le projet est activement entré en phase de construction, avec deja des interets pour les retombées technologiques (Nb3Sn, MgB2)

Merci pour votre attention!

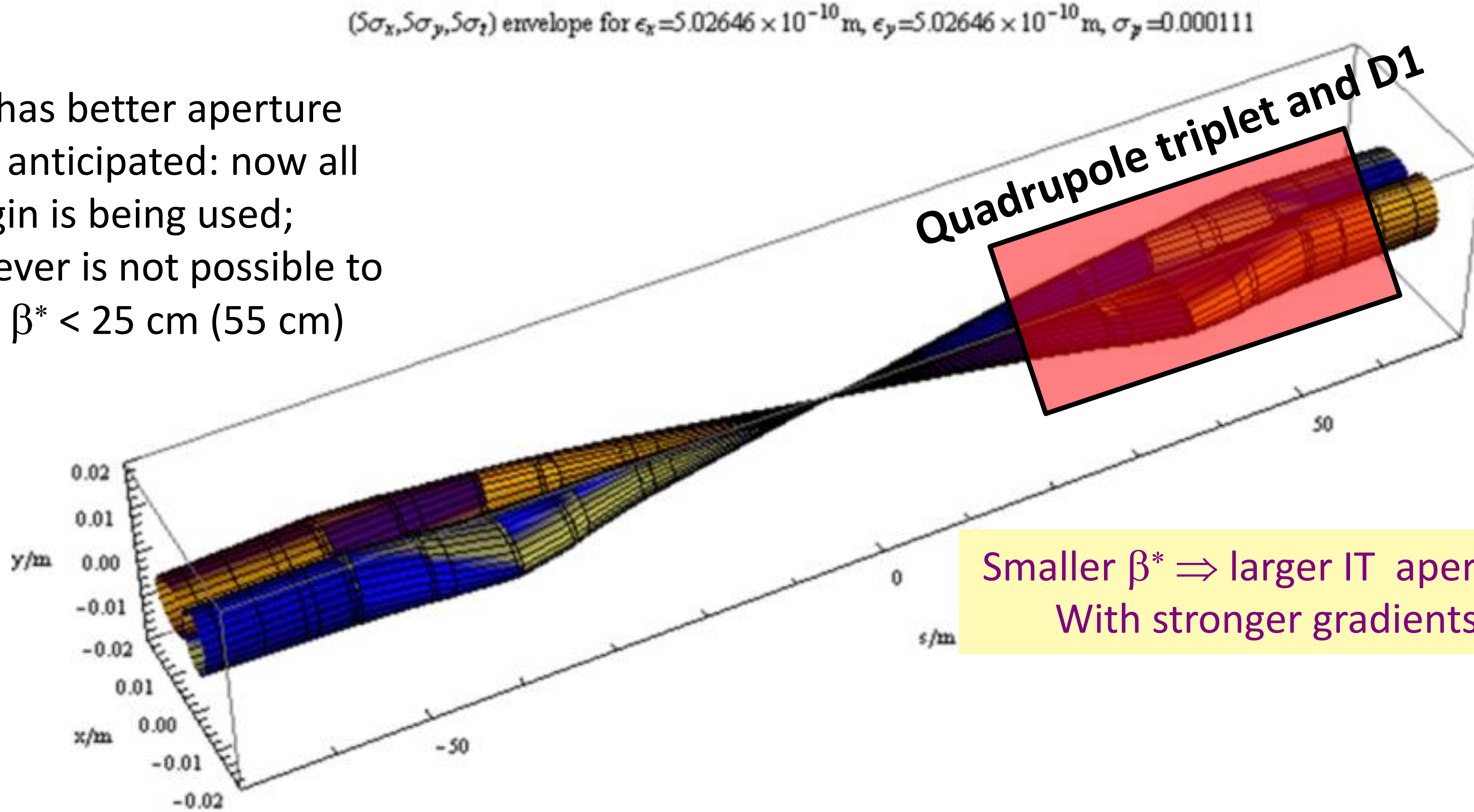
Parameters	Nominal LHC (Design report)	LHC 2017 max values	HL-LHC (standard)	HL-LHC 8b+4e[12]
Beam energy in collision [TeV]	7	6.5	7	7
N_b	1.15E+11	1.2E+11	2.2E+11	2.2E+11
n_b	2808	2556	2760	1972
Number of collisions in IP1 and IP5 [1]	2808	2544	2748	1967
N_{tot}	3.2E+14	3.1E+14	6.1E+14	4.3E+14
beam current [A]	0.58	0.56	1.1	0.79
x-ing angle [μrad]	285	300	500	470 [10]
beam separation [σ] [11]	9.4	8.6	10.5	10.5 [10]
β^* [m]	0.55	0.30	0.15	0.15
ε_n [μm]	3.75	2.30	2.50	2.20
r.m.s. bunch length [m]	7.55E-02	9.0E-02	7.61E-02	7.61E-02
Total loss factor R0 without crab-cavity			0.342	0.342
Total loss factor R1 with crab-cavity [13]			0.716	0.749
Virtual Luminosity with crab-cavity: Lpeak*R1/R0 [$cm^{-2} s^{-1}$] [13]			1.70E+35	1.44E+35
Luminosity [$cm^{-2} s^{-1}$] or Leveling luminosity for HL-LHC	1.00E+34	2.00E+34	5.0E+34 [5]	3.82E+34
Events / crossing (with leveling and crab-cavities for HL-LHC) [8]	27	55	131	140
Peak line density of events [event/mm] (max over stable beams)	0.21	0.9	1.3	1.31
Leveling time [h] (assuming no emittance growth) [8, 13]	-		7.4	7.2

Not reached at the same time

To increase Luminosity

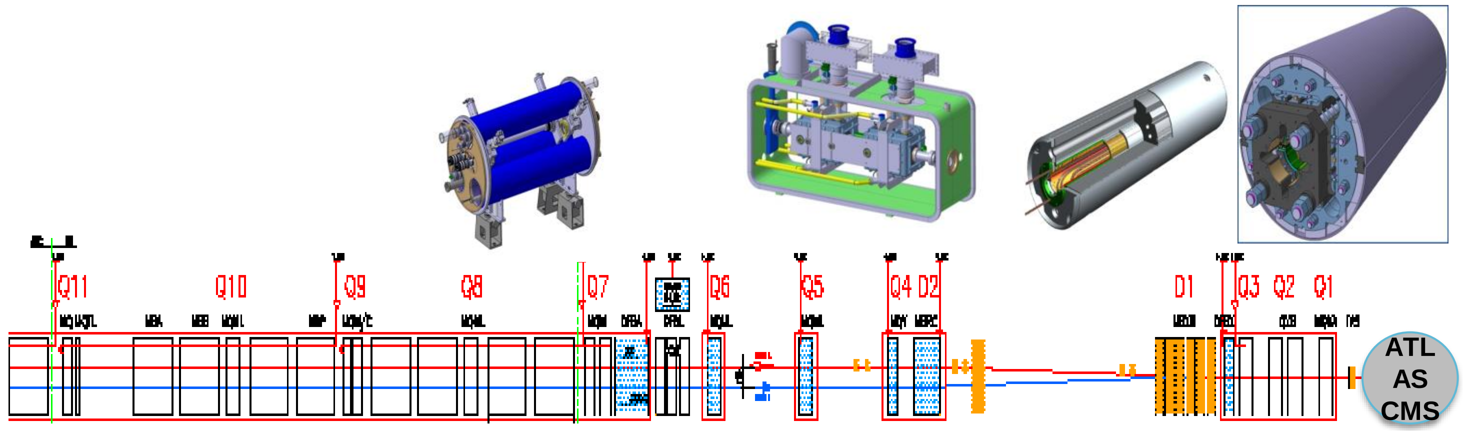
The most straight forward action: reducing beam size with a «local» action

LHC has better aperture than anticipated: now all margin is being used; however is not possible to have $\beta^* < 25$ cm (55 cm)



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

The largest HEP accelerator in construction



Dispersion Suppressor (DS) in P7

Matching Section (MS)

Interaction Region (ITR)

Modifications
1. In IP2: new DS collim. in C.Cryost.
2. In IP7 new DS collimation with

Cryogenics, Protection, Interface, Vacuum, Diagnostics, Inj/Extr, Controls, new UG and surface infrastr.

Change/new lay-out
1. TAXN
2. D2
3. CC
4. Correctors
5. Q5
6. Q5@1.9K in P6
7. New collimators

Complete change and new lay-out
1. TAXS
2. Q1-Q2a-Q2b-Q3
3. D1
4. All correctors
5. Heavy shielding (W)

> 1.2 km of LHC !!

HiLumi HL-LHC PROJECT

MgB_2 Multi-cable assembly

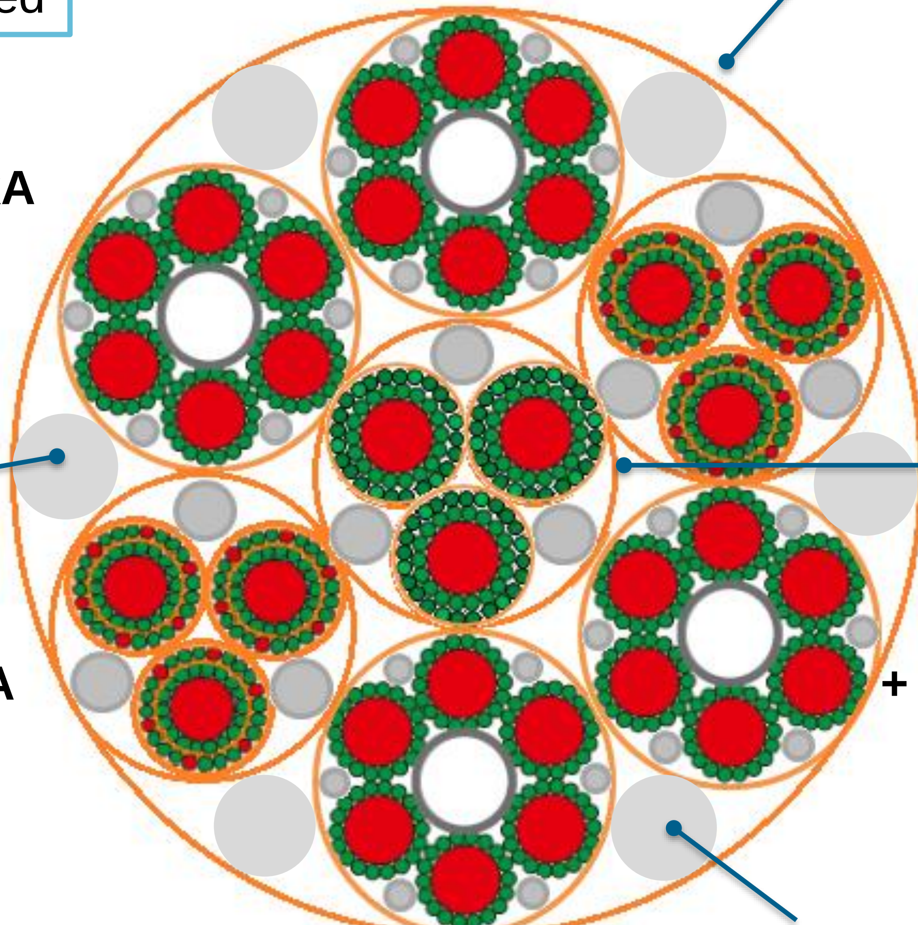
Cables and cable assemblies twisted

- 18 kA

Protective insulation (outer layer)

+ 18 kA

6×2 kA



3× 2 kA (7 kA)

120 A Leads)

6×2 kA

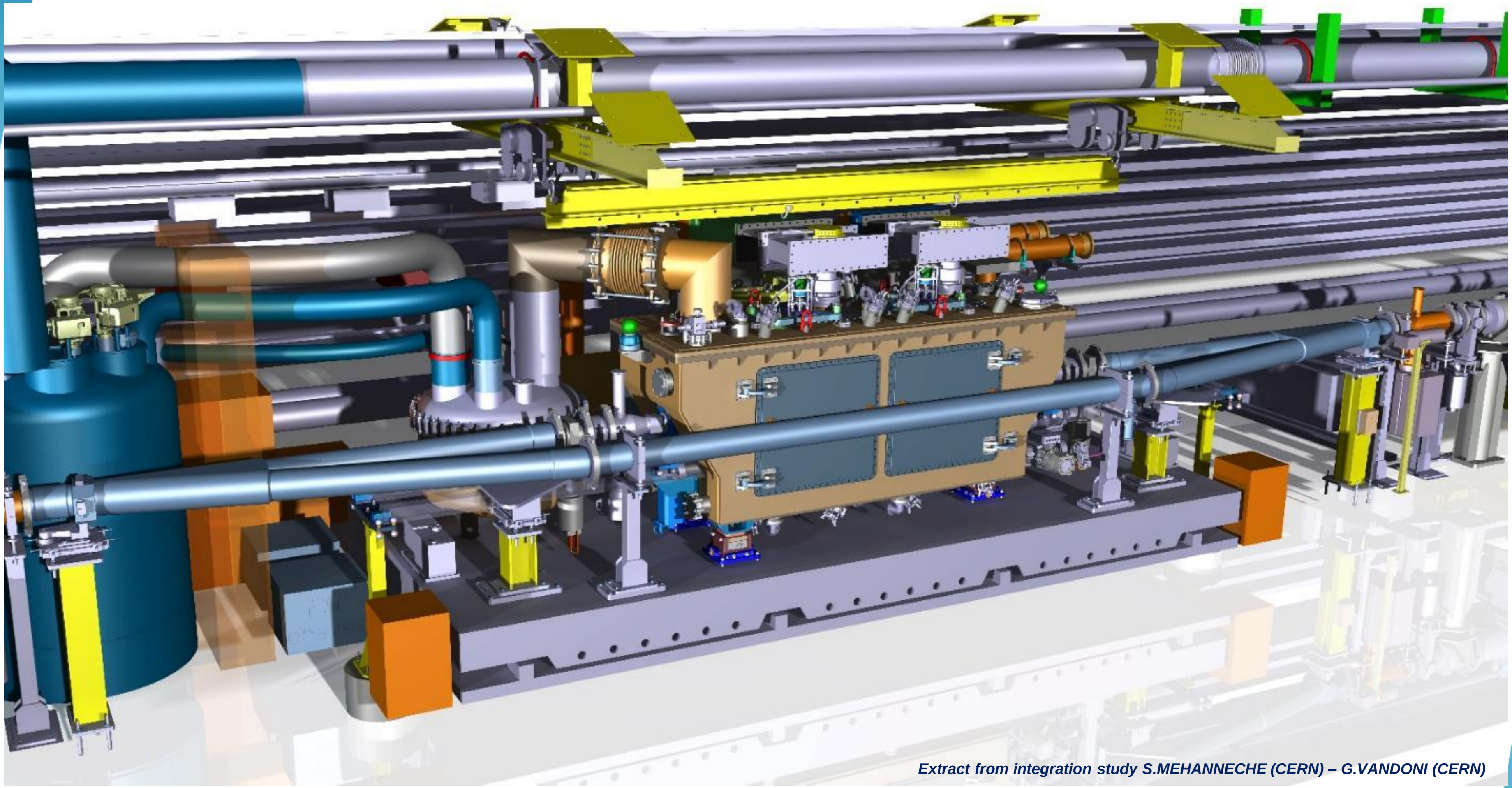
+ 13 kA

- 13 kA

Instrumentation wires (twisted and cabled)

Φ~ 75 mm → Including insulation

Cryomodule integration overview



Extract from integration study S.MEHANNECHE (CERN) – G.VANDONI (CERN)