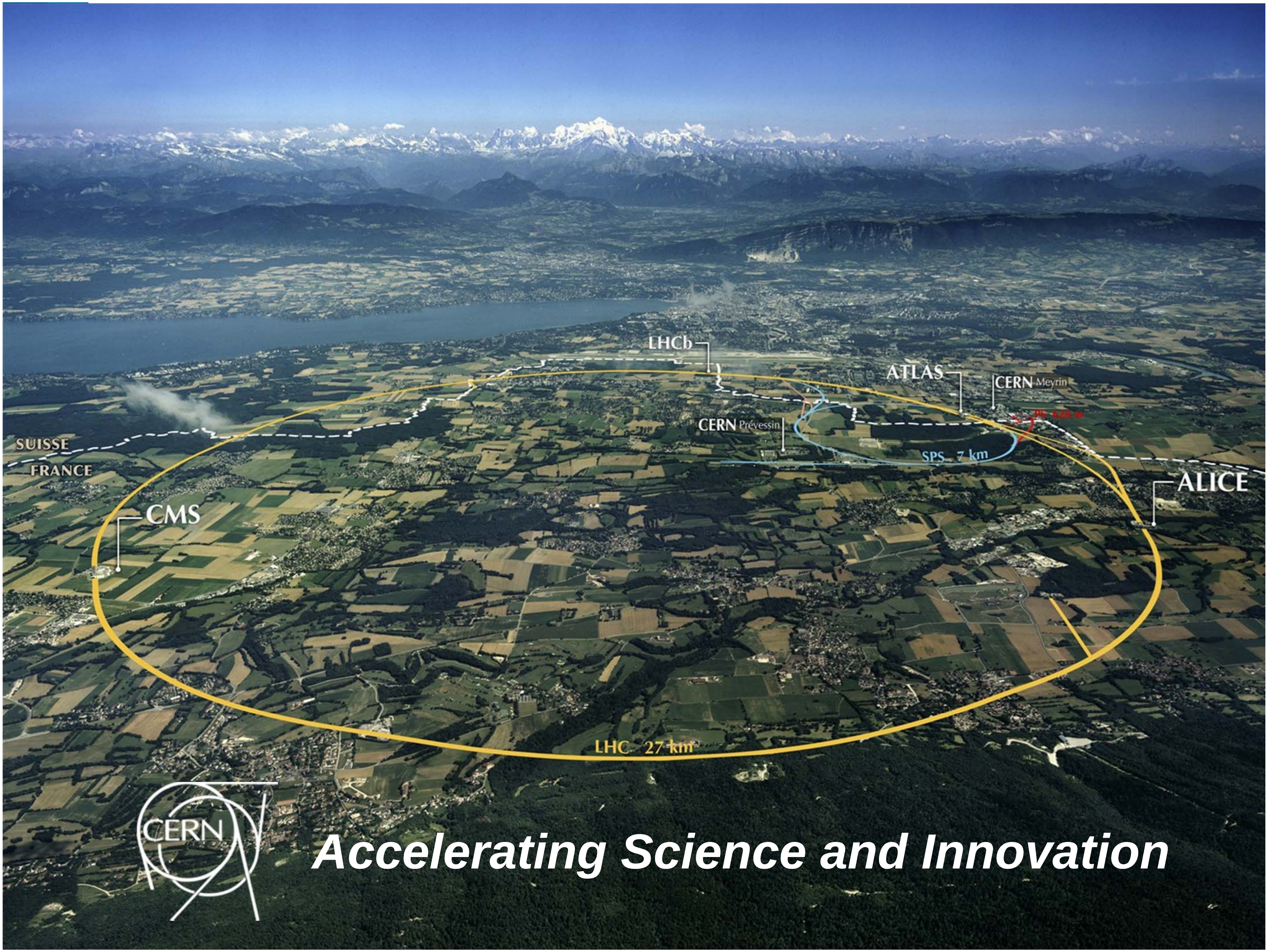
# HL-LHC (High Luminosity LHC)

# General Overview

Isabel Bejar Alonso - CERN
HL-LHC Configuration, Quality & Resources Officer
On behalf of the HL-LHC Project team

TOBB İkiz Kuleler, ANKARA, 14th April 2016


LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SPS 7 km
SUISSE
FRANCE
ALICE
CMS
LHC 27 km
CERN
Accelerating Science and Innovation

# The HL-LHC Project

## Goals, schedule and project structure

# Goal of High Luminosity LHC (HL-LHC) as fixed in November 2010

From FP7 HiLumi LHC Design Study application

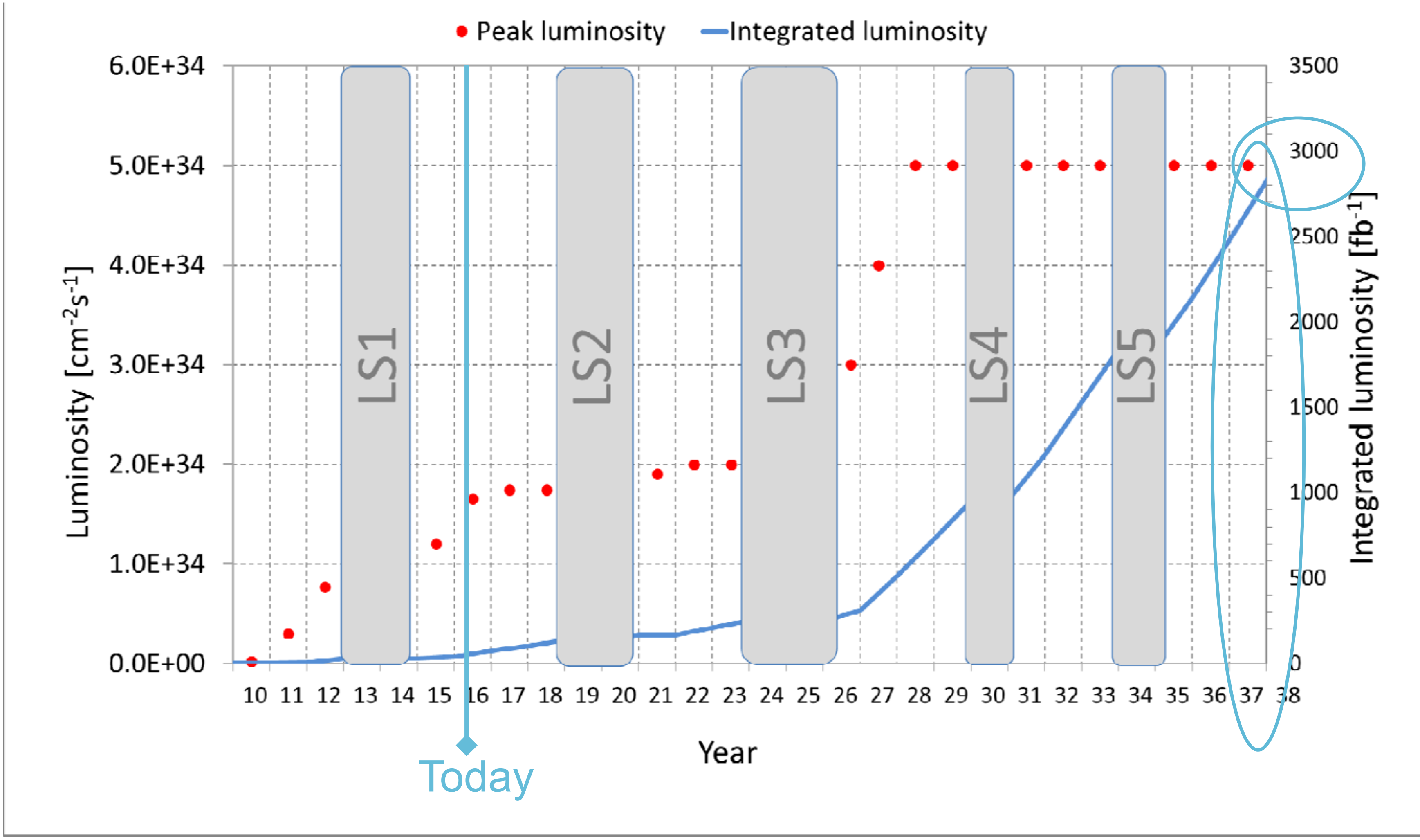
The main objective of HiLumi LHC Design Study is to determine a hardware configuration and a set of beam parameters that will allow the LHC to reach the following targets:

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

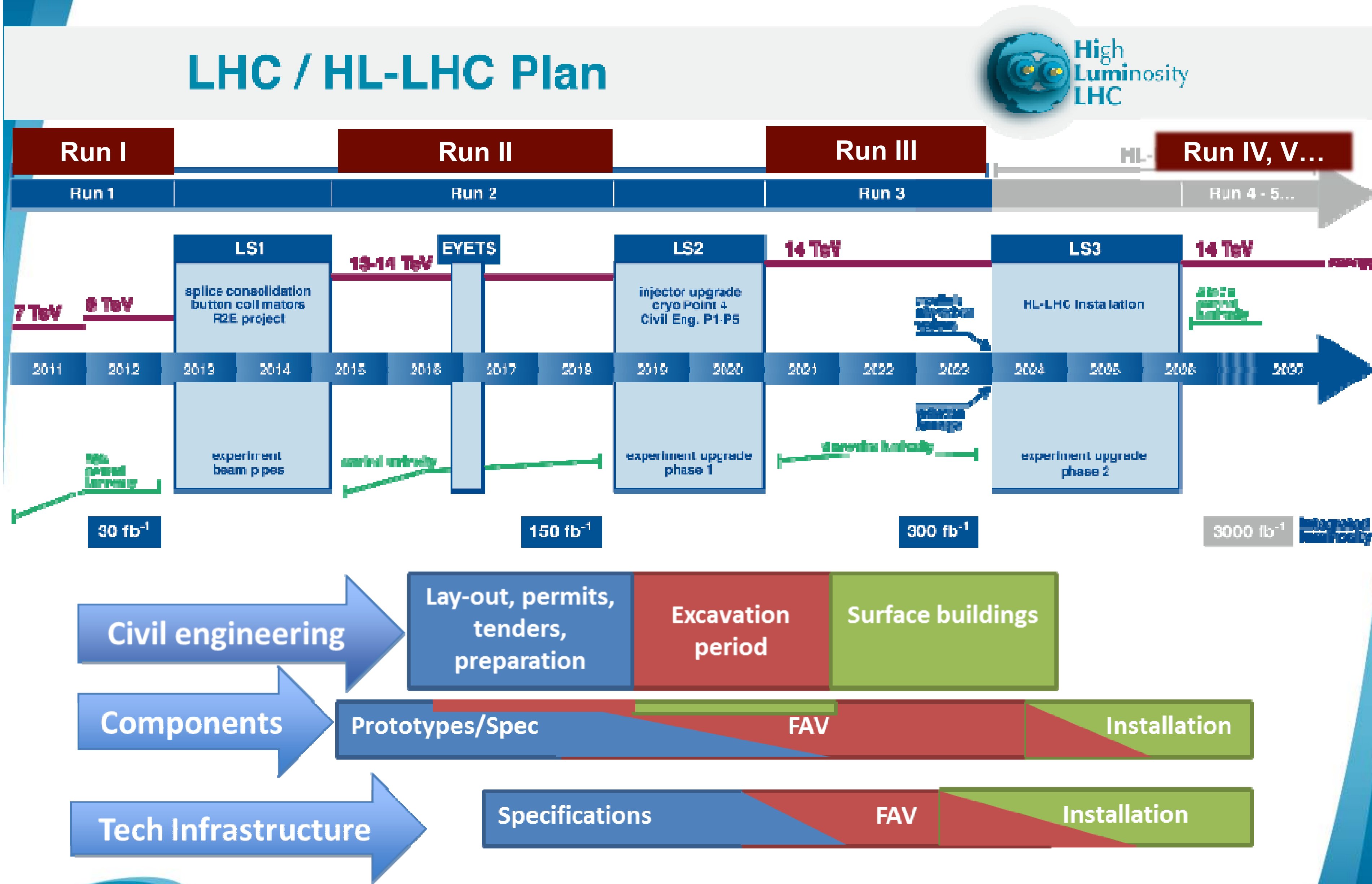
An integrated luminosity of **250 $fb^{-1}$ per year**, enabling the goal of **$L_{int}$ = 3000 $fb^{-1}$** twelve years after the upgrade.
This luminosity is more than ten times the luminosity reach of the first 10 years of the LHC lifetime.

Concept of ultimate performance recently defined:
**$L_{ult} \cong 7.5\ 10^{34}$ $cm^{-2}s^{-1}$** and **Ultimate Integrated $L_{int\ ult}$ ~ 4000 $fb^{-1}$**
LHC should not be the limit, would Physics require more…

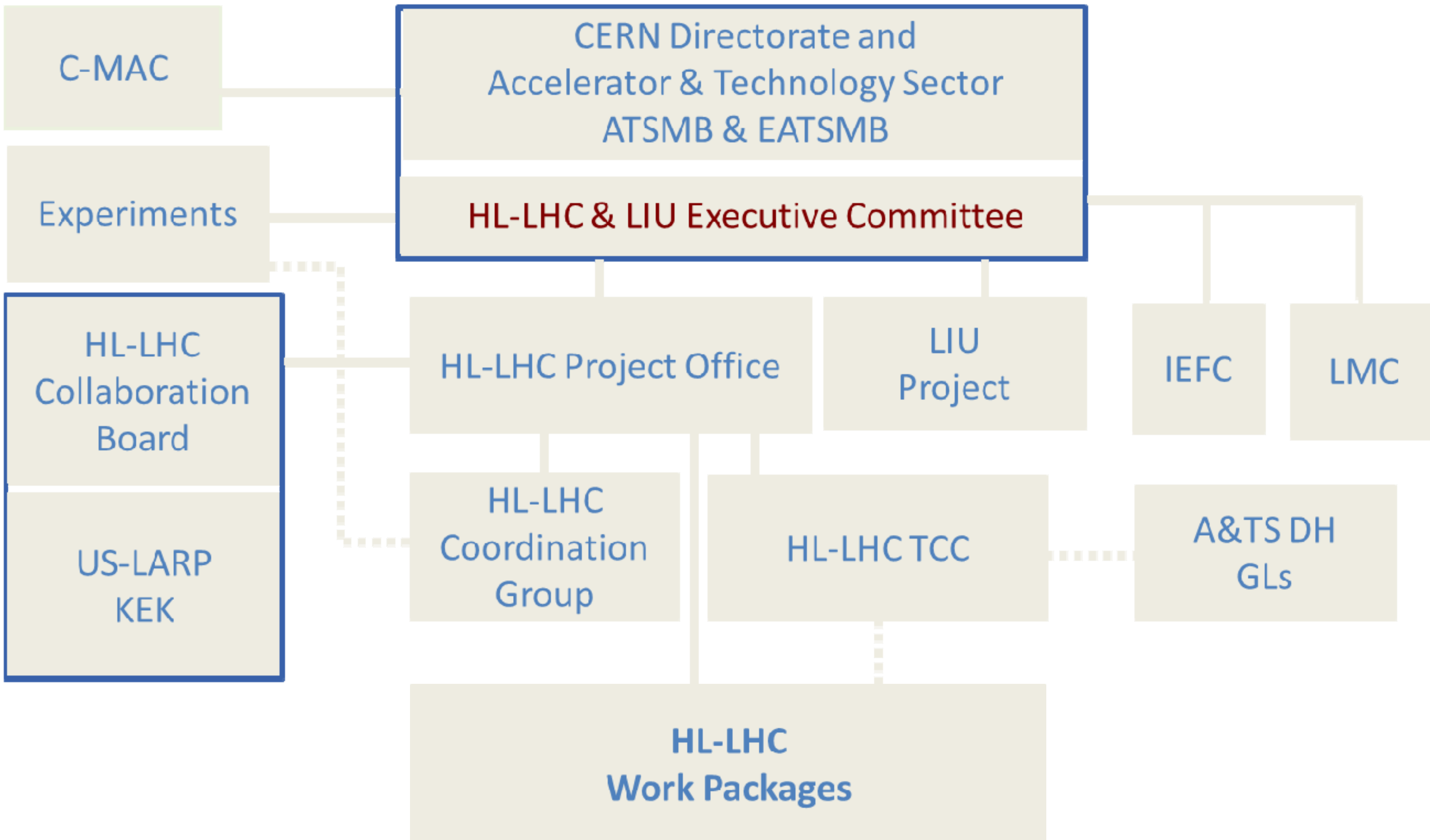
# Nominal parameters would be reached in 2037



# LHC / HL-LHC Plan



# HL-LHC Project Governance



# HL-LHC Workpackages

**MEMBER STATES COLLABORATIONS[1]**

**IR Magnets**
**CEA Saclay**: P. Védrine, J-M. Rifflet, H. Felice
**CIEMAT Madrid**: J-M. Perez, F. Toral
**INFN**: A. Zoccoli[2], G. Volpini[3], P. Fabbricatore[4]
**Uppsala University**: T. Ekelöf

**UK**: R. Appleby[5] (Spokesperson & **Collimation**), G. Burt[6] (**Crab Cavities**), S. Gibson[7] (**Beam Instr.**), Y. Yang[8] (**Cold Powering**)

**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

**NON MEMBER STATES COLLABORATIONS[1]**

**US HL-LHC AUP[9] - USA**
**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

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

**WP3 IR Magnets**
Ezio Todesco
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 Weelderen

**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

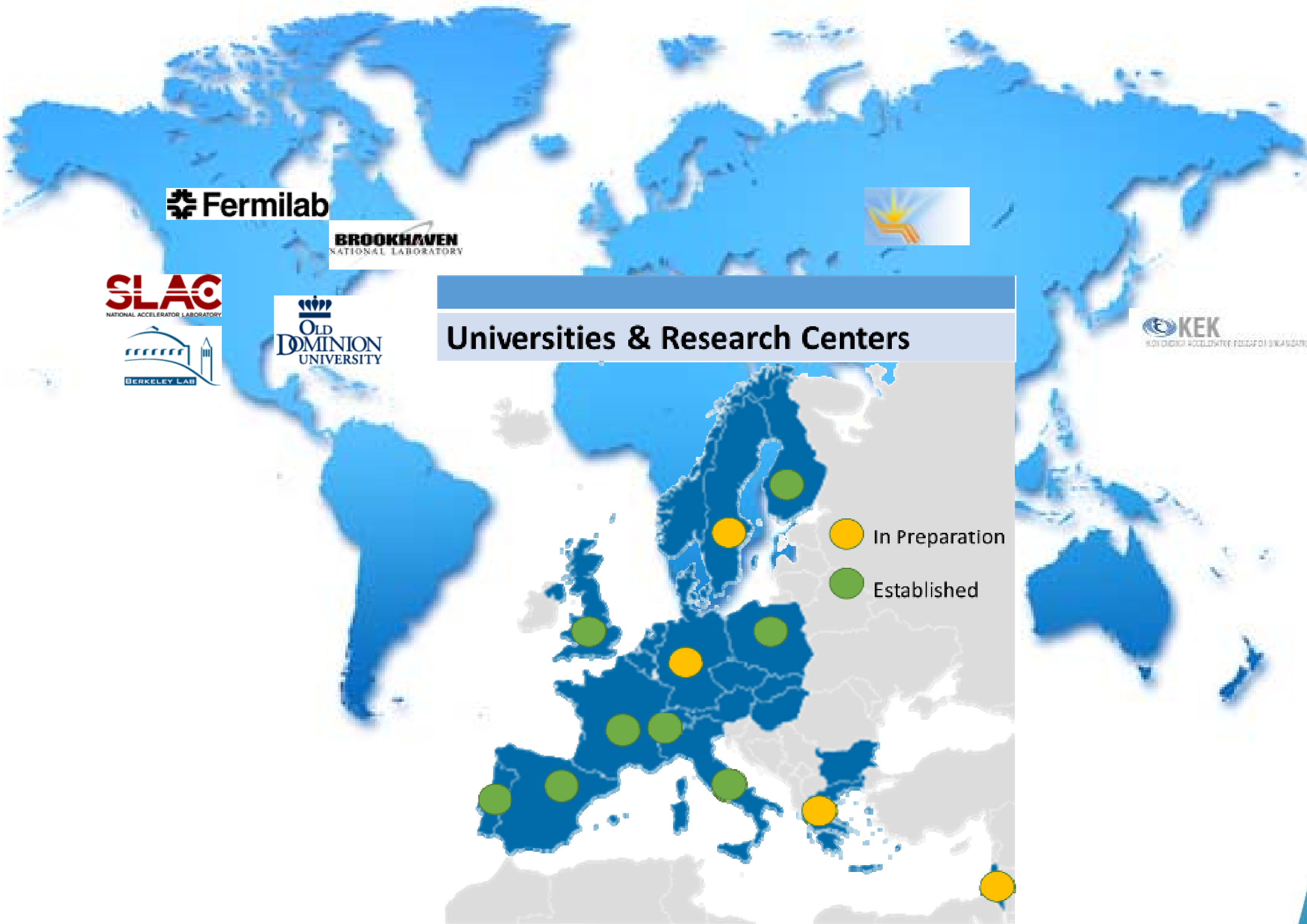
**WP14 Beam Transfer**
Chiara Bracco
Brennan Goddard

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

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

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

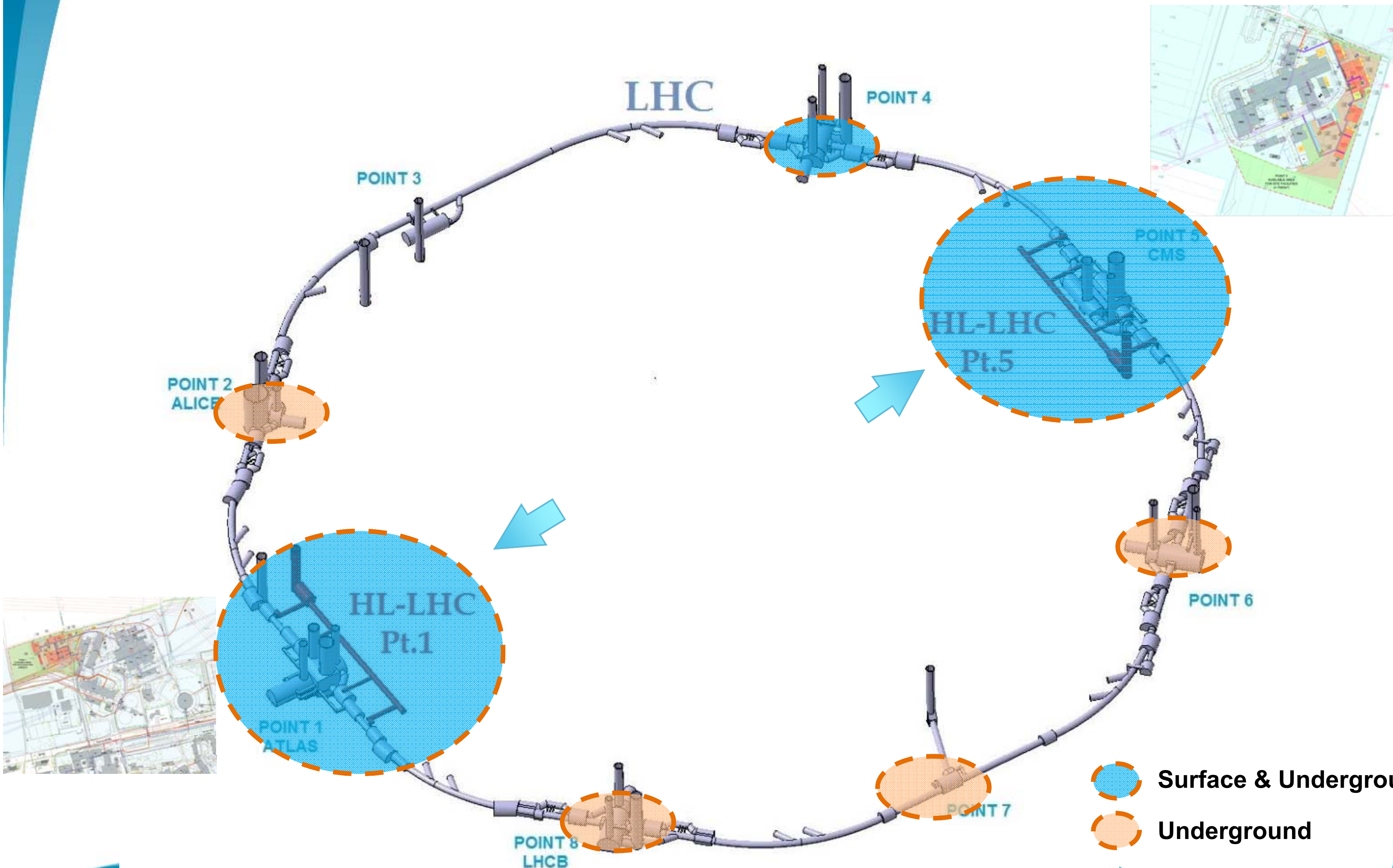
[1] In kind contributions
[2] INFN Directorate
[3] INFN Milano LASA
[4] INFN Genova
[5] University of Manchester/Cockcroft Institute
[6] Lancaster University/Cockcroft Institute
[7] Royal Holloway/John Adams Institute
[8] University of Southampton
[9] US HL-LHC Accelerator Upgrade Project


Fermilab
BROOKHAVEN
NATIONAL LABORATORY
SLAC
NATIONAL ACCELERATOR LABORATORY
BERKELEY LAB
OLD DOMINION UNIVERSITY
KEK
Universities & Research Centers
In Preparation
Established

# The HL-LHC Project

## Main components, technical services and infrastructure

# Many points around the ring

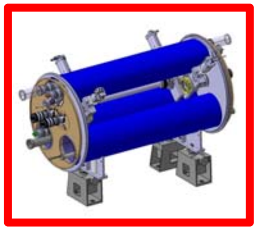


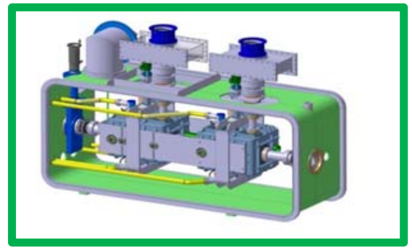

Surface & Underground

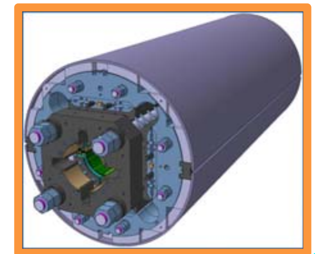
Underground

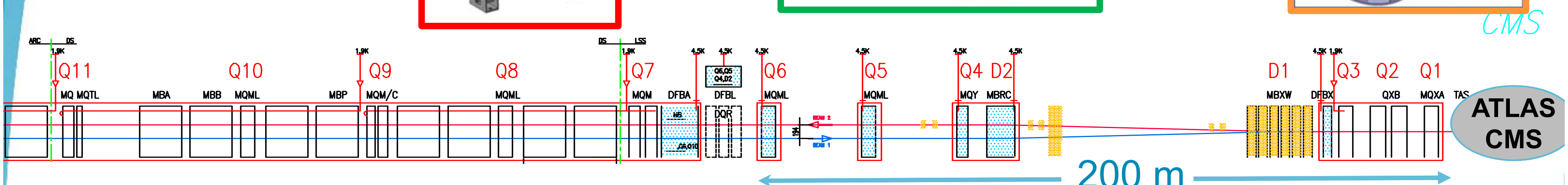
Main worksites

# 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

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

**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

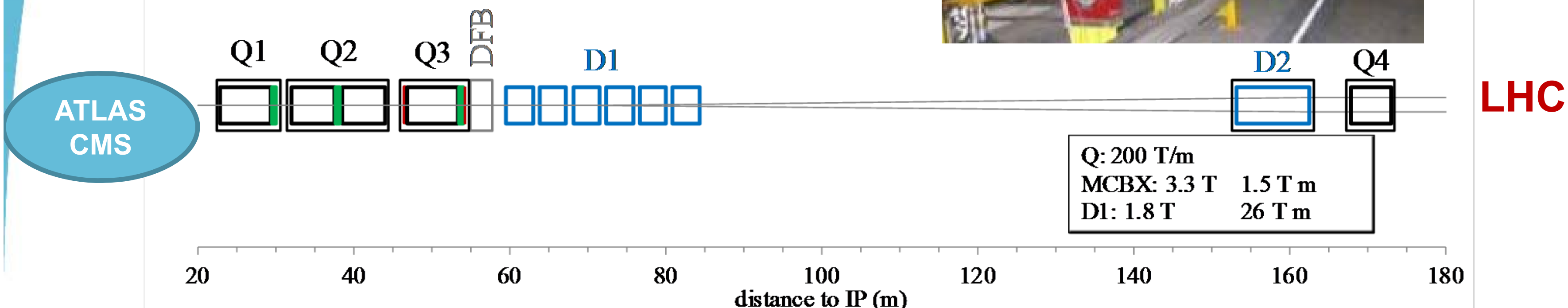
**Interaction Region (ITR)**

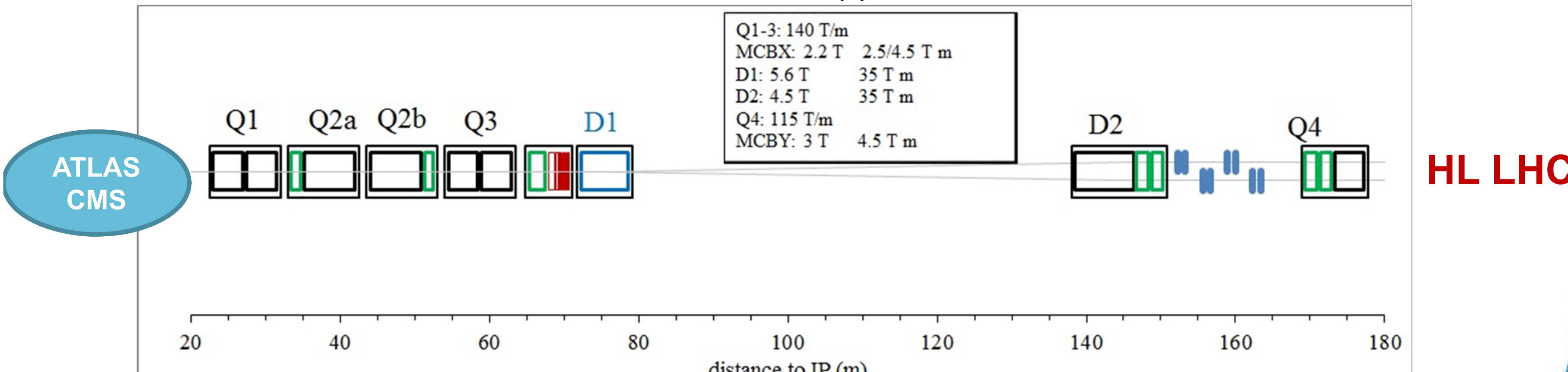
**Complete change and new lay-out**
1. TAXS
2. Q1-Q2-Q3
3. D1
4. All correctors
5. Heavy shielding (W)

**> 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**

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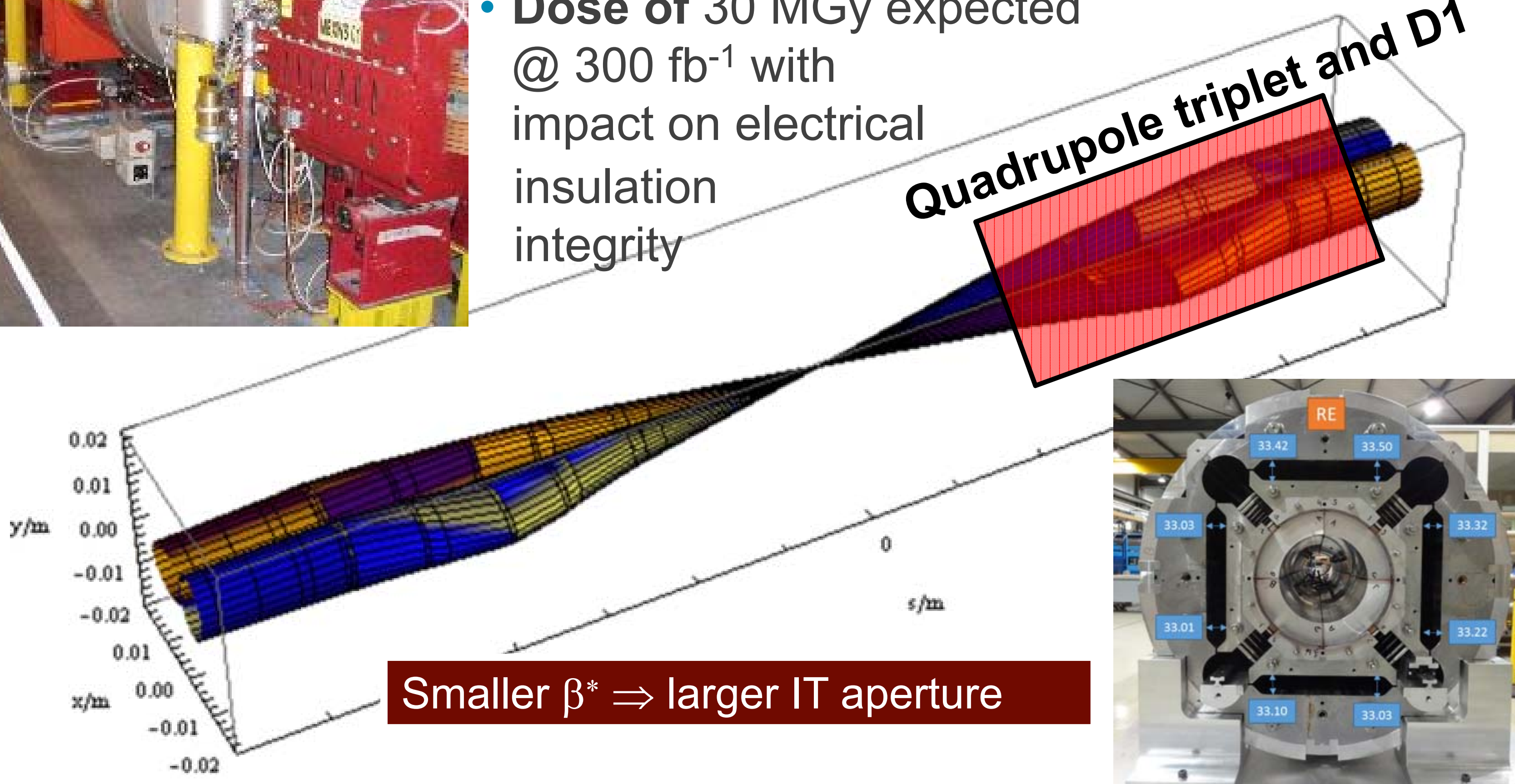
# Why changing the inner triplets

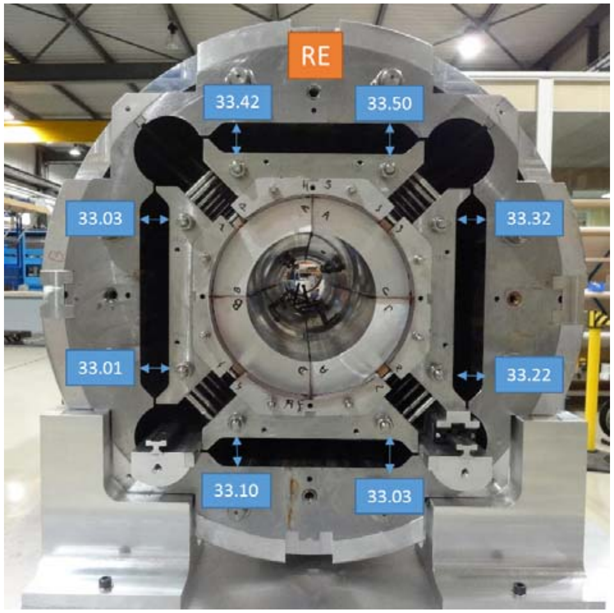
- Triggered by **radiation damage on existing equipment due to leap in performance**
- **Dose of** 30 MGy expected @ 300 $fb^{-1}$ with impact on electrical insulation integrity

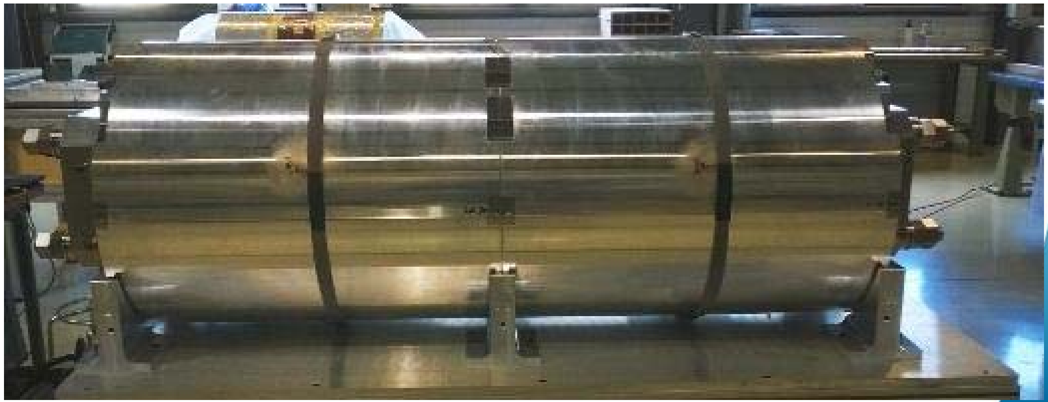



Smaller $\beta^*$ $\Rightarrow$ larger IT aperture

LHC has better aperture than anticipated and all margin can now be used. However seems very difficult to have $\beta^*$ < 35-40 cm (55 cm being the nominal)

# Working on the Inner triplet magnets

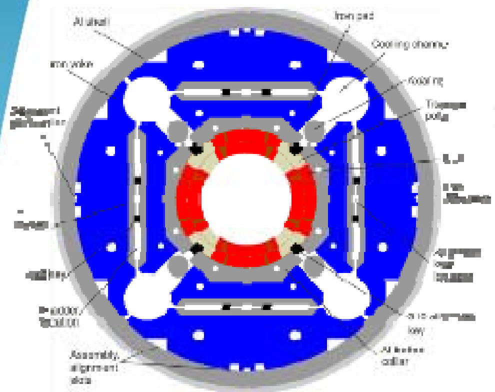


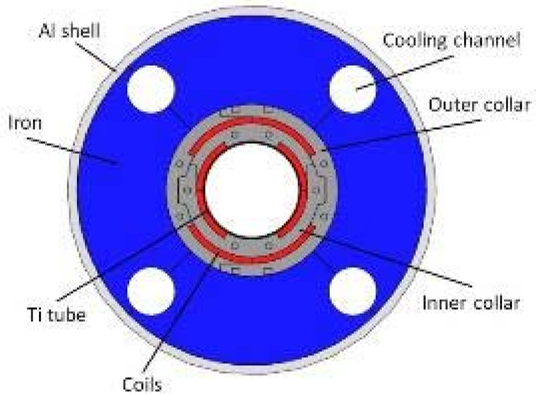
# MQXFS01 test

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

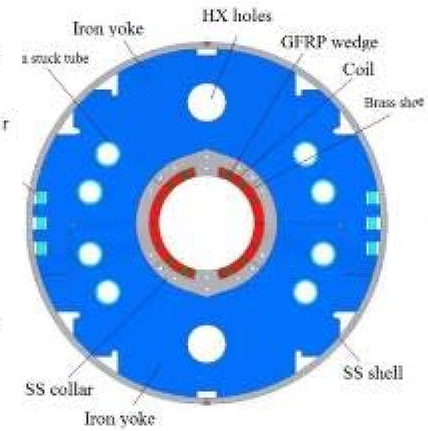
# HiLumi LHC magnet zoo



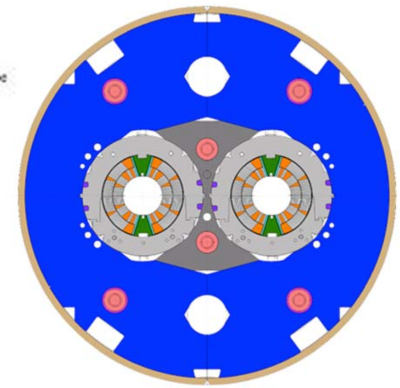

Triplet QXF (LARP and CERN)



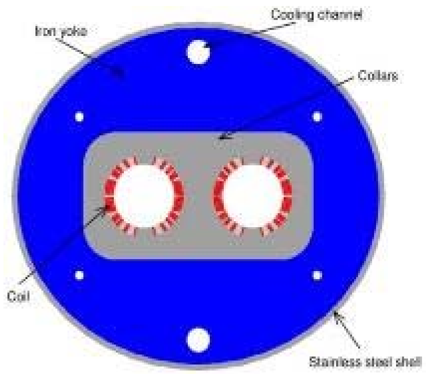

Orbit corrector (CIEMAT)



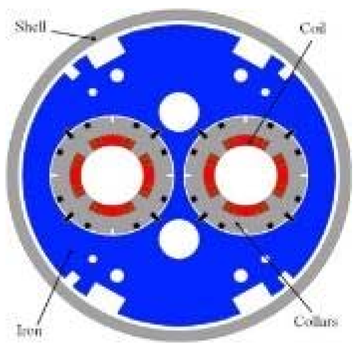

Separation dipole D1 (KEK)



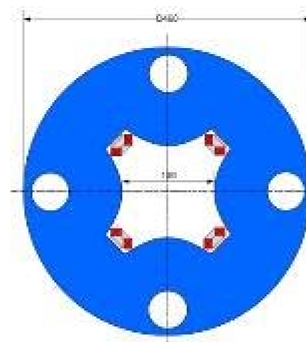
11 T dipole (CERN)



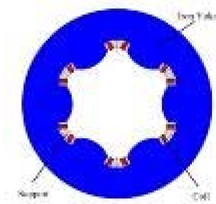

Recombination dipole D2 (INFN design)



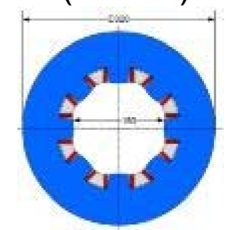

Q4 (CEA)



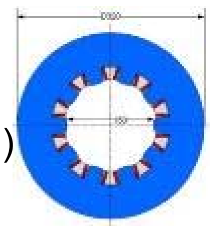
Skew quadrupole (INFN)



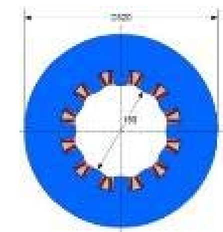
Sextupole (INFN)



Octupole (INFN)



Decapole (INFN)

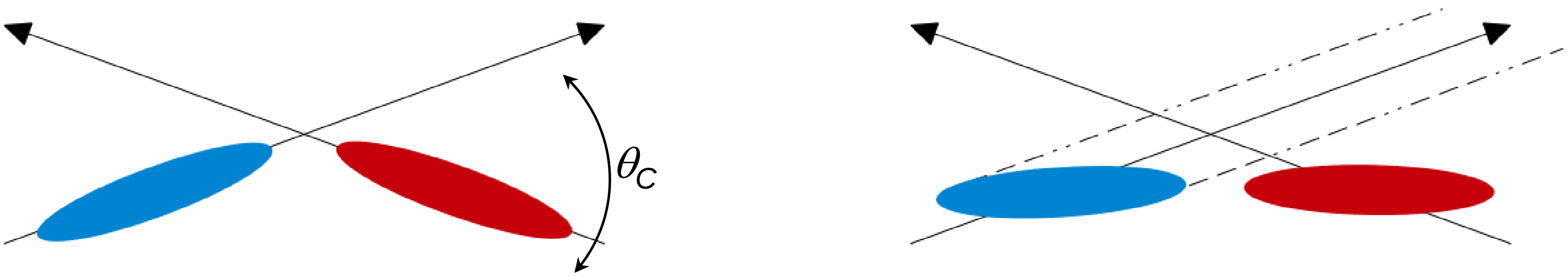


Dodecapole (INFN

**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




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

- 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

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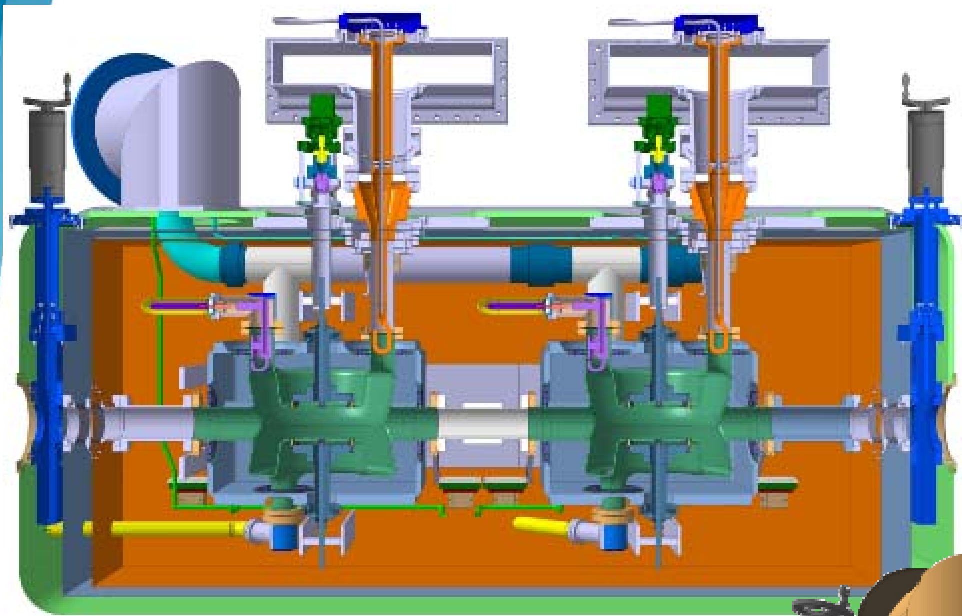
# Crab cavities

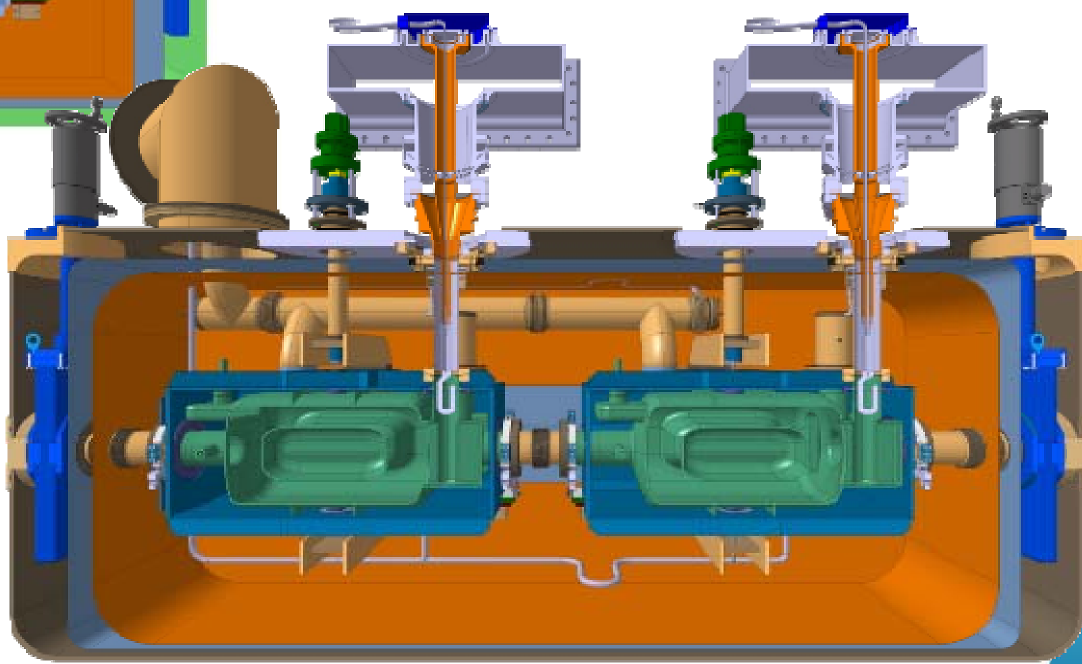


Mostly standardized interfaces and common platform

Main differences

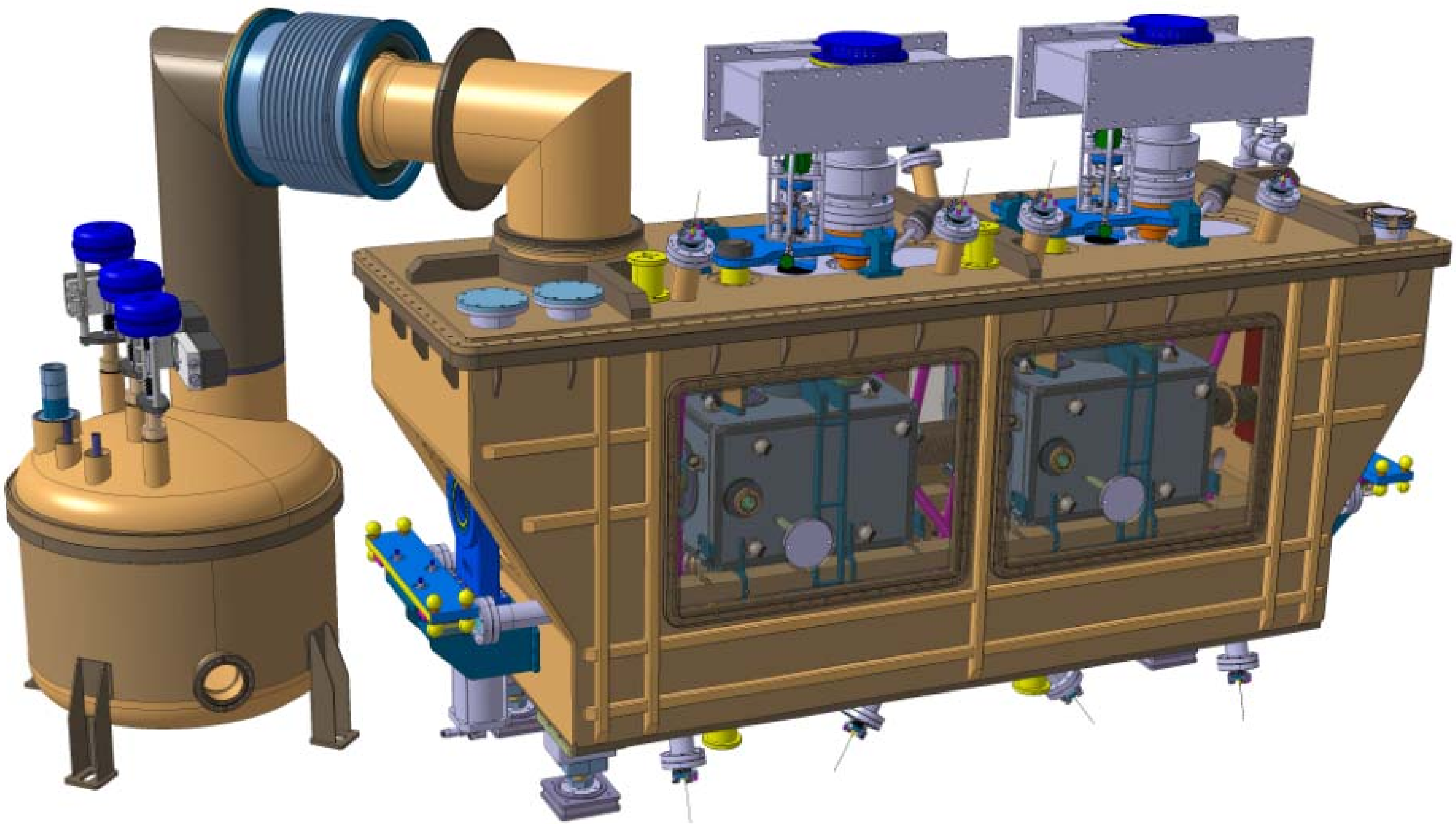
- Cavity symmetry & length
- HOM couplers

Double Quarter Wave,
Vertical Deflection



RF Dipole
Horizontal Deflection

# SPS Cryomodule:
# Include 2 identical cavities

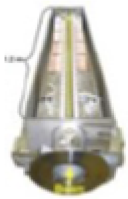


**Double Quarter Wave**

# 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

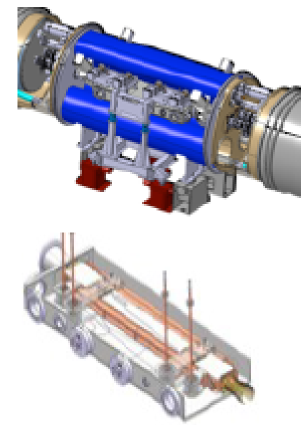


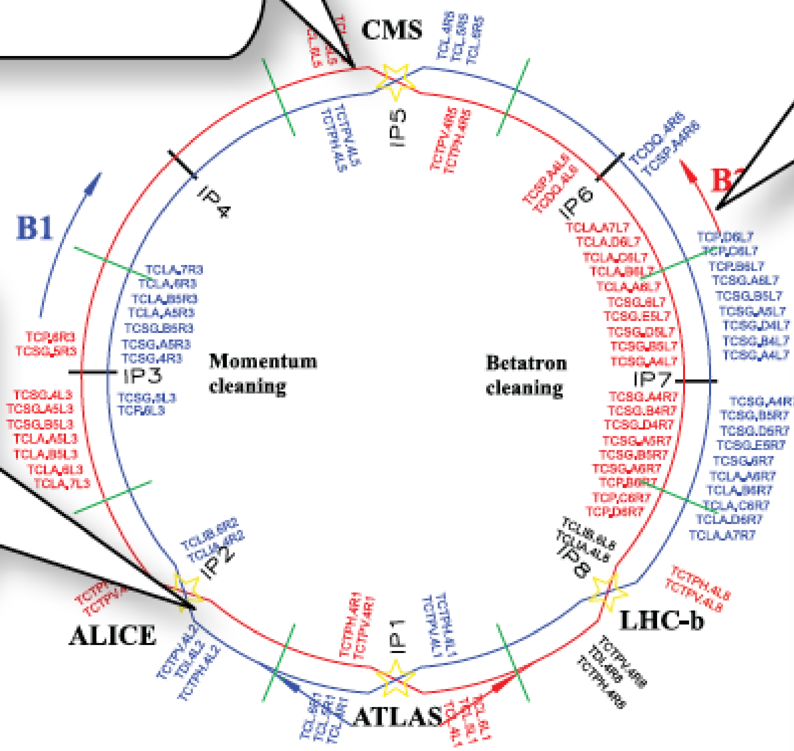
IR1+IR5, per beam:
- 4 tertiary collimators
- 3 physics debris collimators
- fixed masks

**Completely new layouts**
**Novel materials.**

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

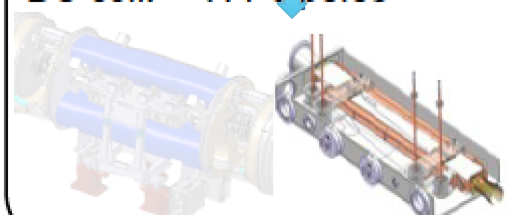
Cleaning: DS coll. + 11T dipoles, 2 units per beam





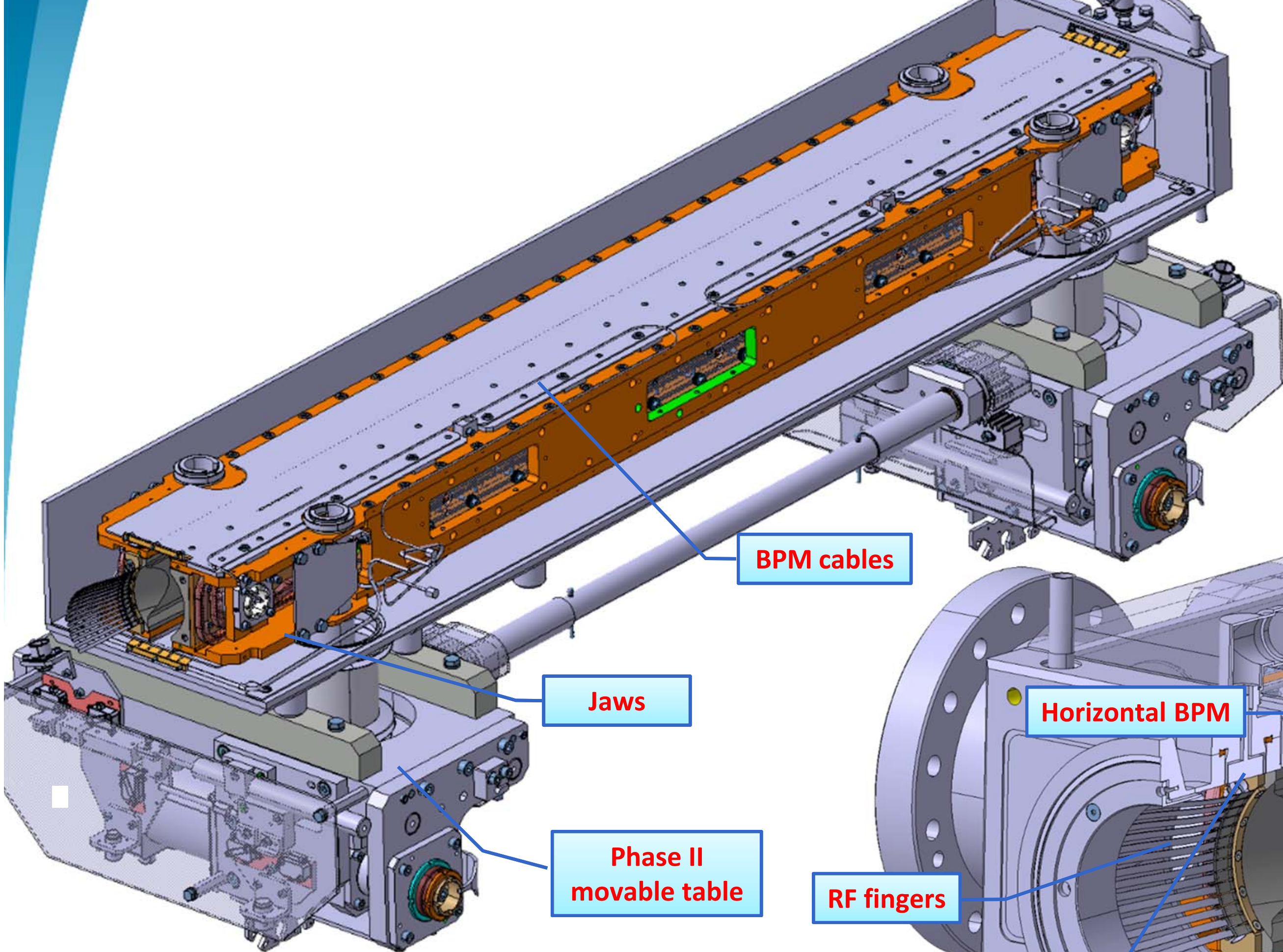


Ion physics debris: DS coll. + 11T dipoles

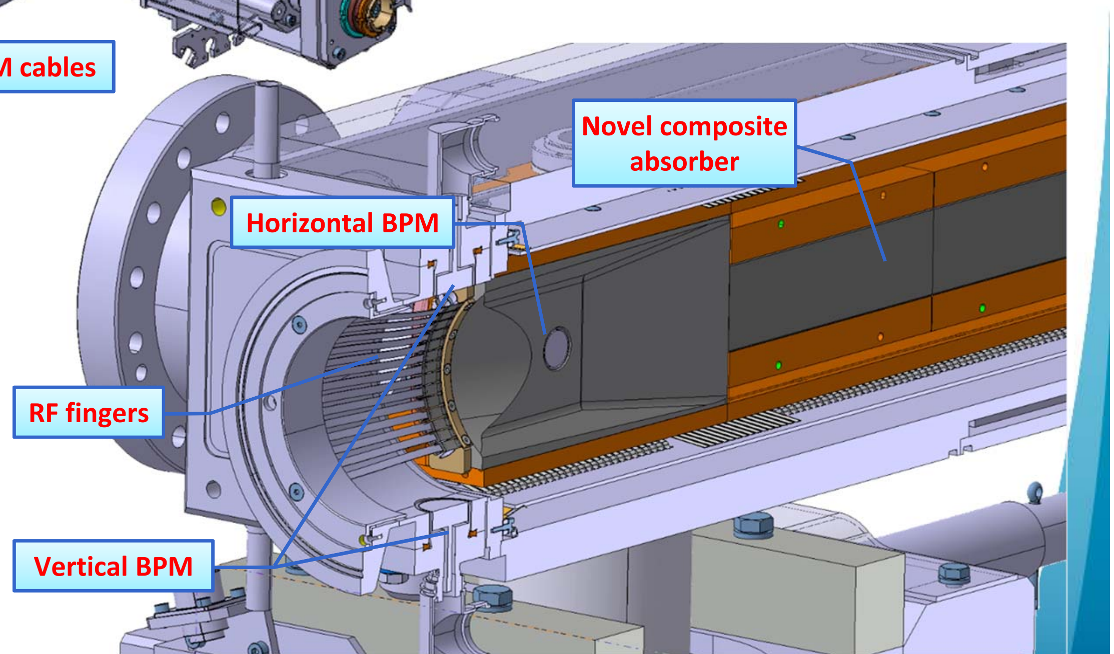


Low-impedance, high robustness secondary collimators

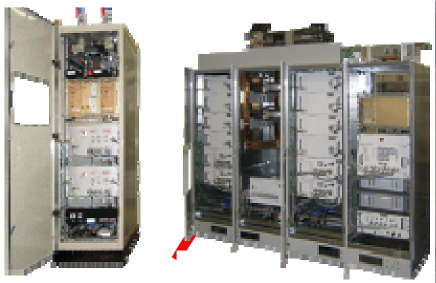
# TCSPM Overview

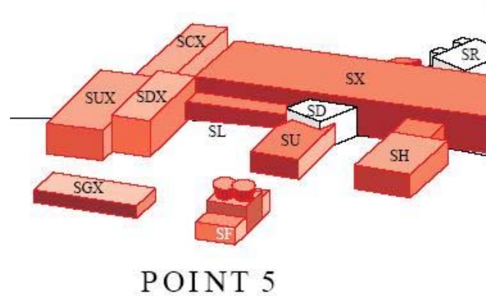



- **Longer** jaws, tapering and vacuum tank
- **Shorter** RF fingers, upstream and downstream flange collars
- **Same flange-to-flange length**
- **BPM vertical buttons** upstream, on top of the **horizontal BPMs** for jaw positioning



# Increasing availability

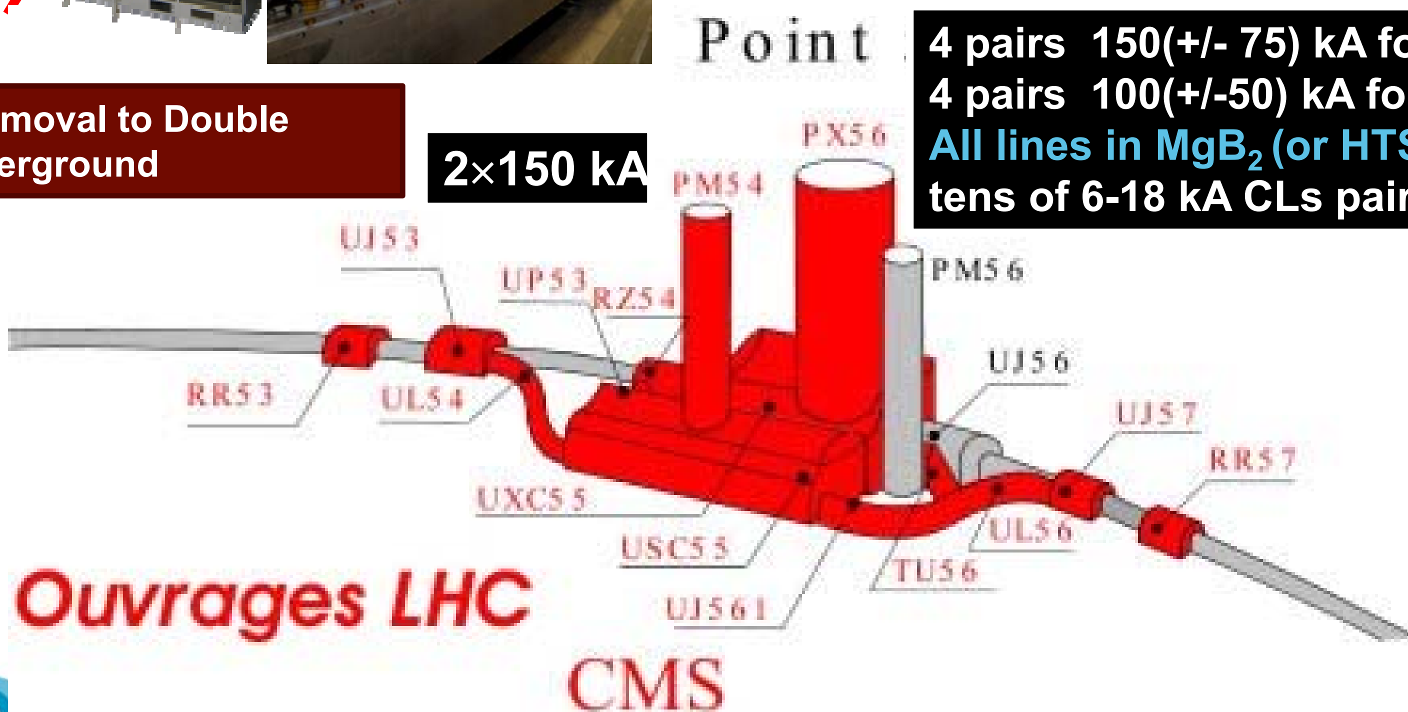




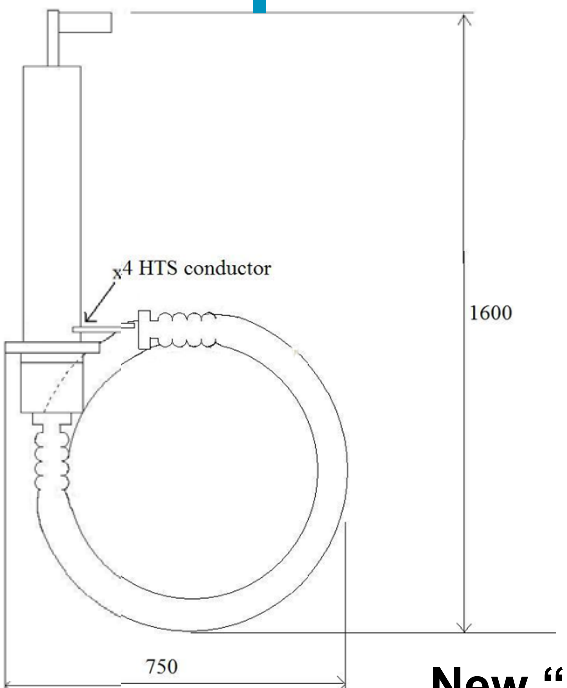

4 pairs 150(+/- 75) kA for MS– LS3
4 pairs 100(+/-50) kA for ITR – LS3
All lines in $MgB_2$ (or HTS)
tens of 6-18 kA CLs pairs in HTS

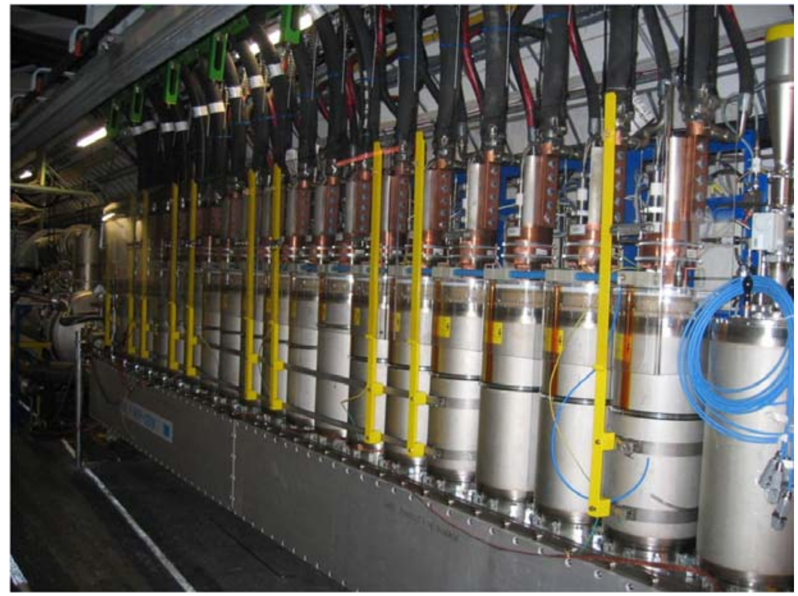
Baseline: removal to Double Decker Underground

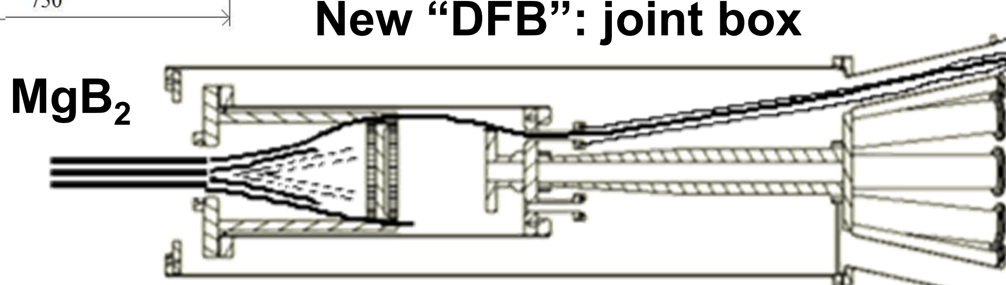
2×150 kA

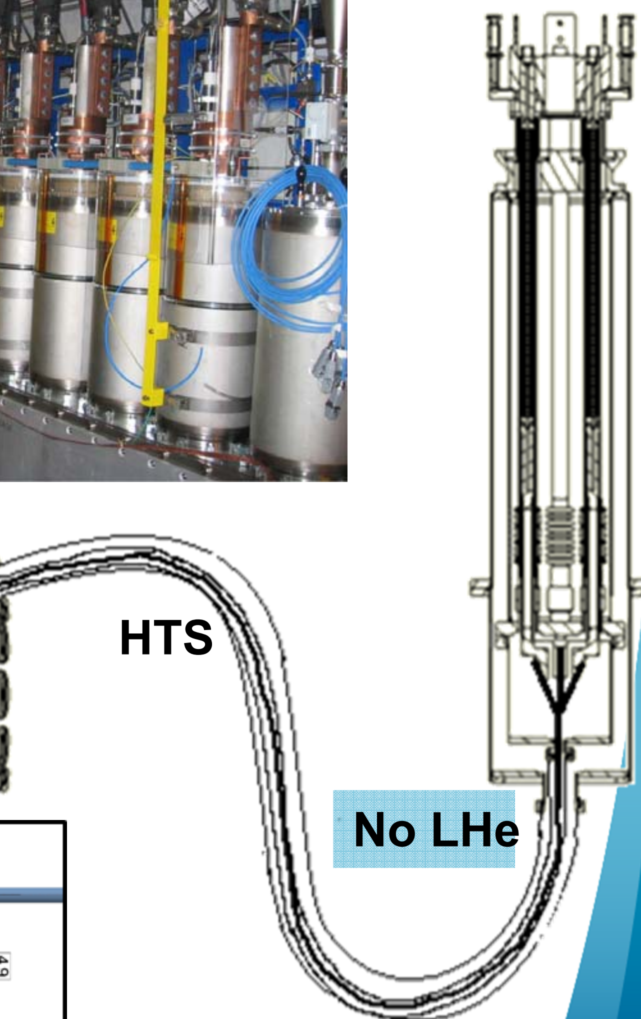


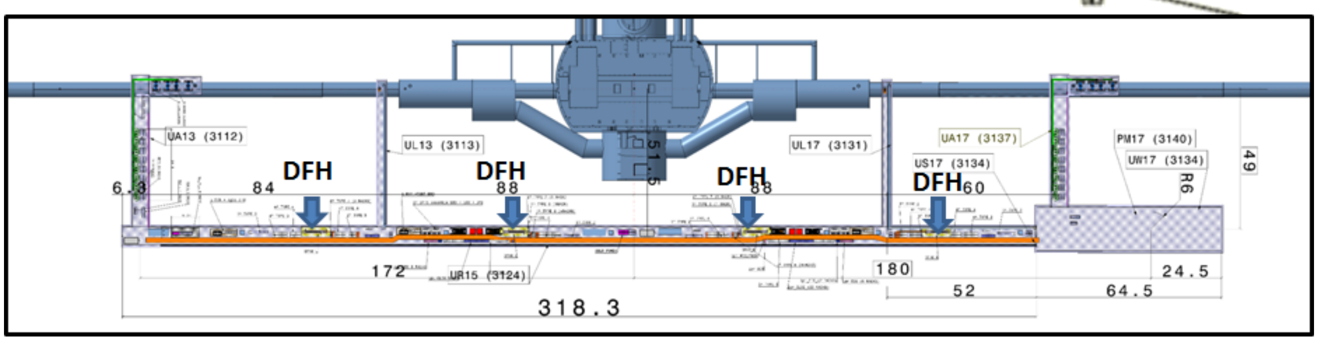
# Superconducting link concept



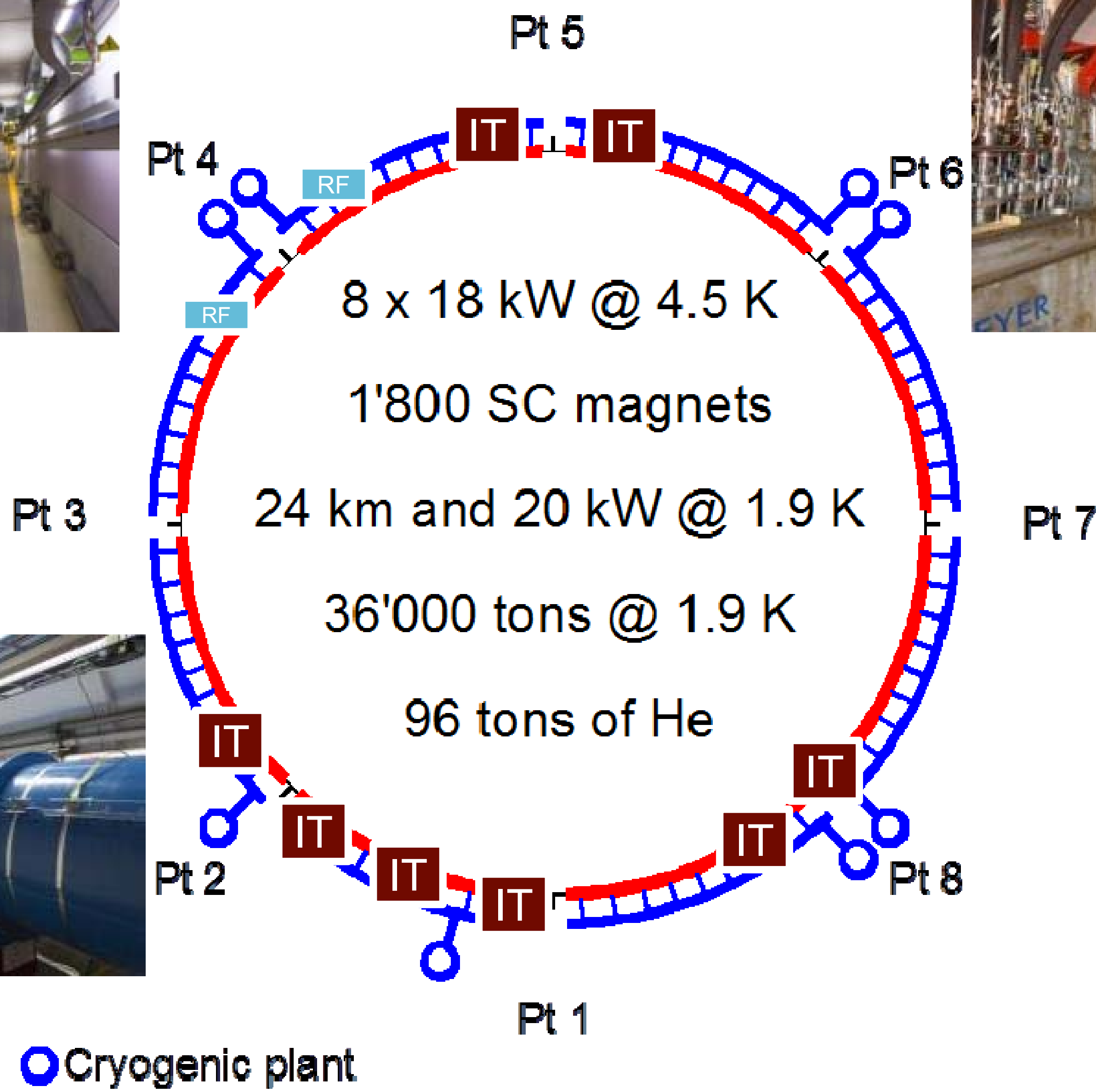





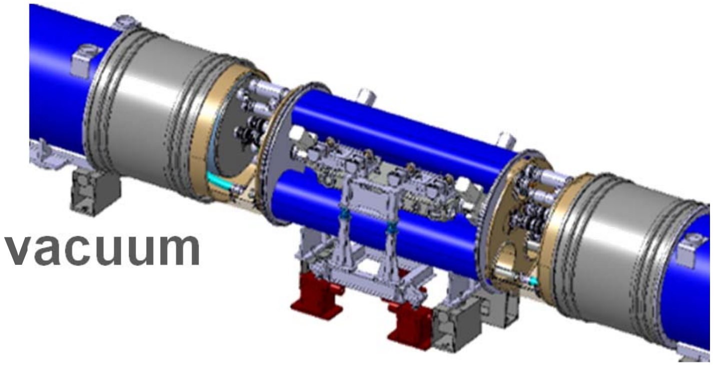



# Eliminating Technical bottlenecks

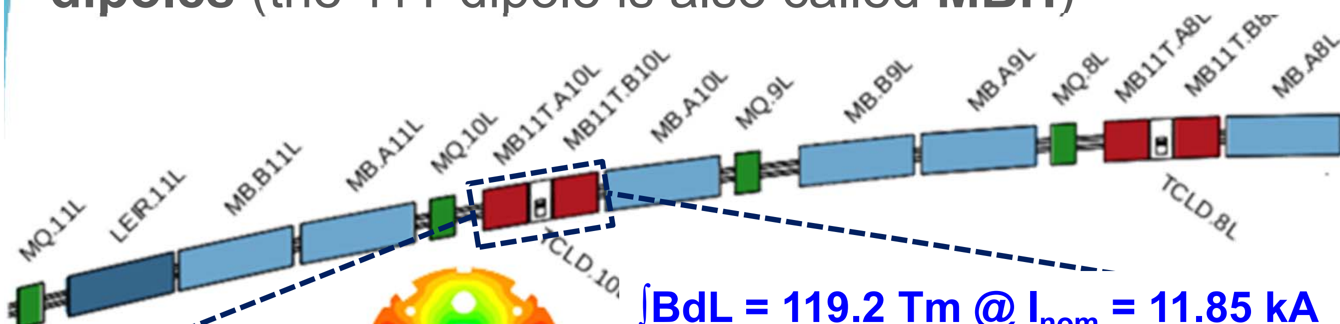


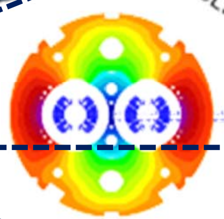
# The 11T Dipole Two-in-One for DS



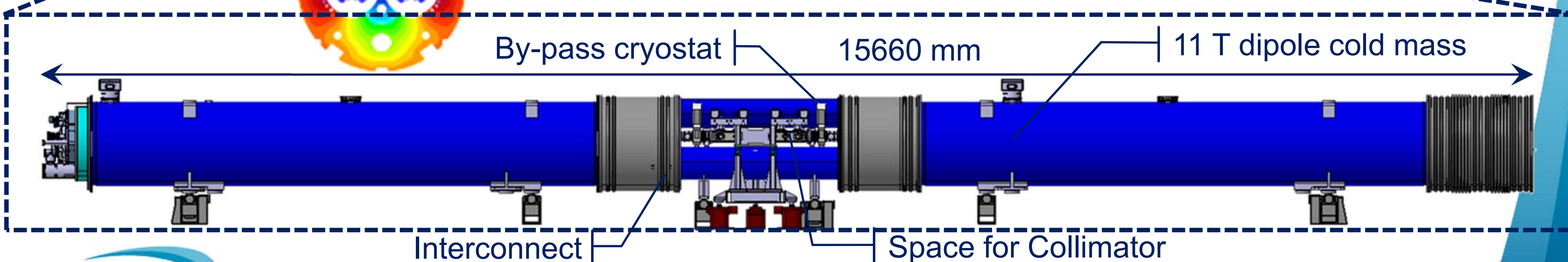
**Create space in the dispersion suppressor regions of LHC, i.e. a room temperature beam vacuum sector, to install additional collimators (TCLD)**

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



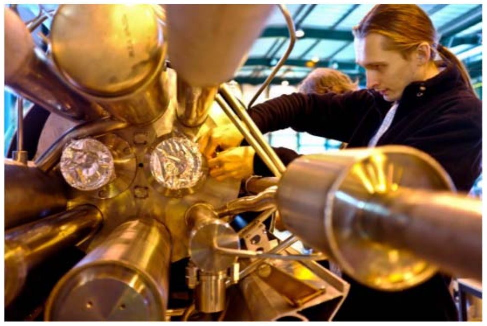



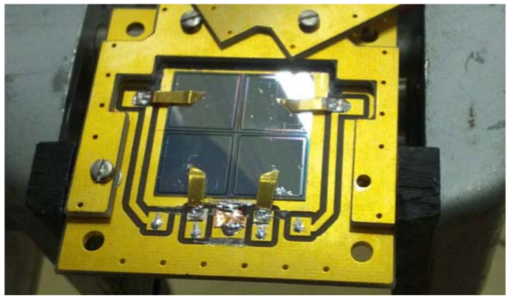
**$\int BdL$ = 119.2 Tm @ $I_{nom}$ = 11.85 kA**
**in series with MB with 20 % margin**

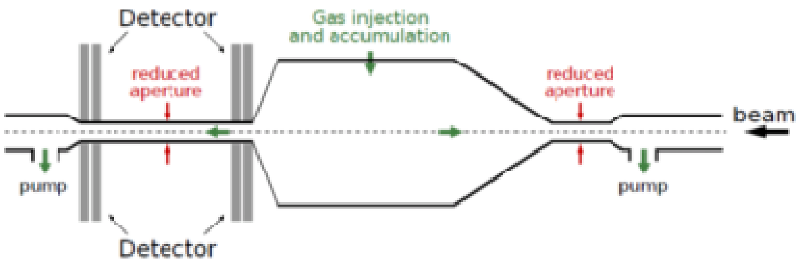


# Beam diagnostic improvement

- **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

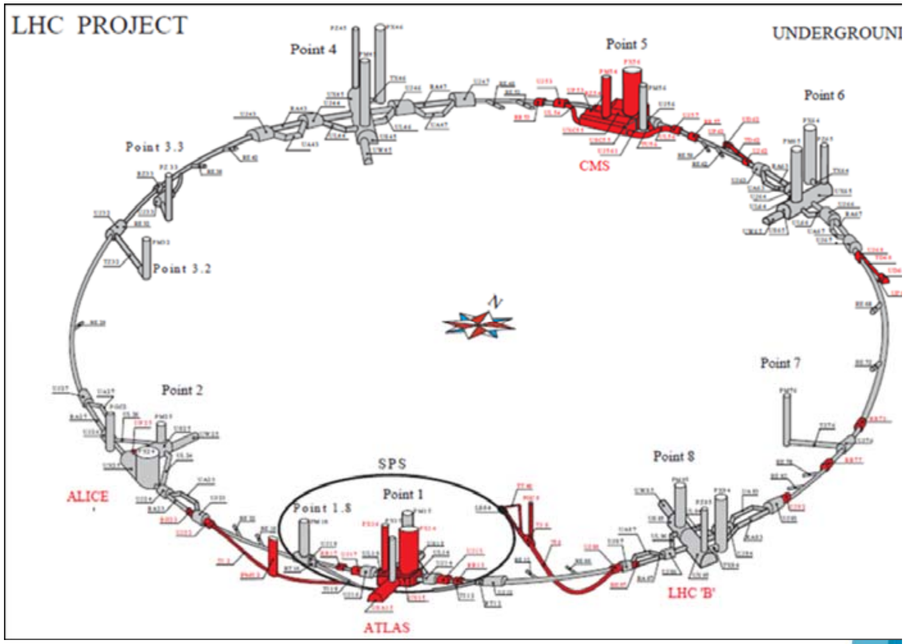






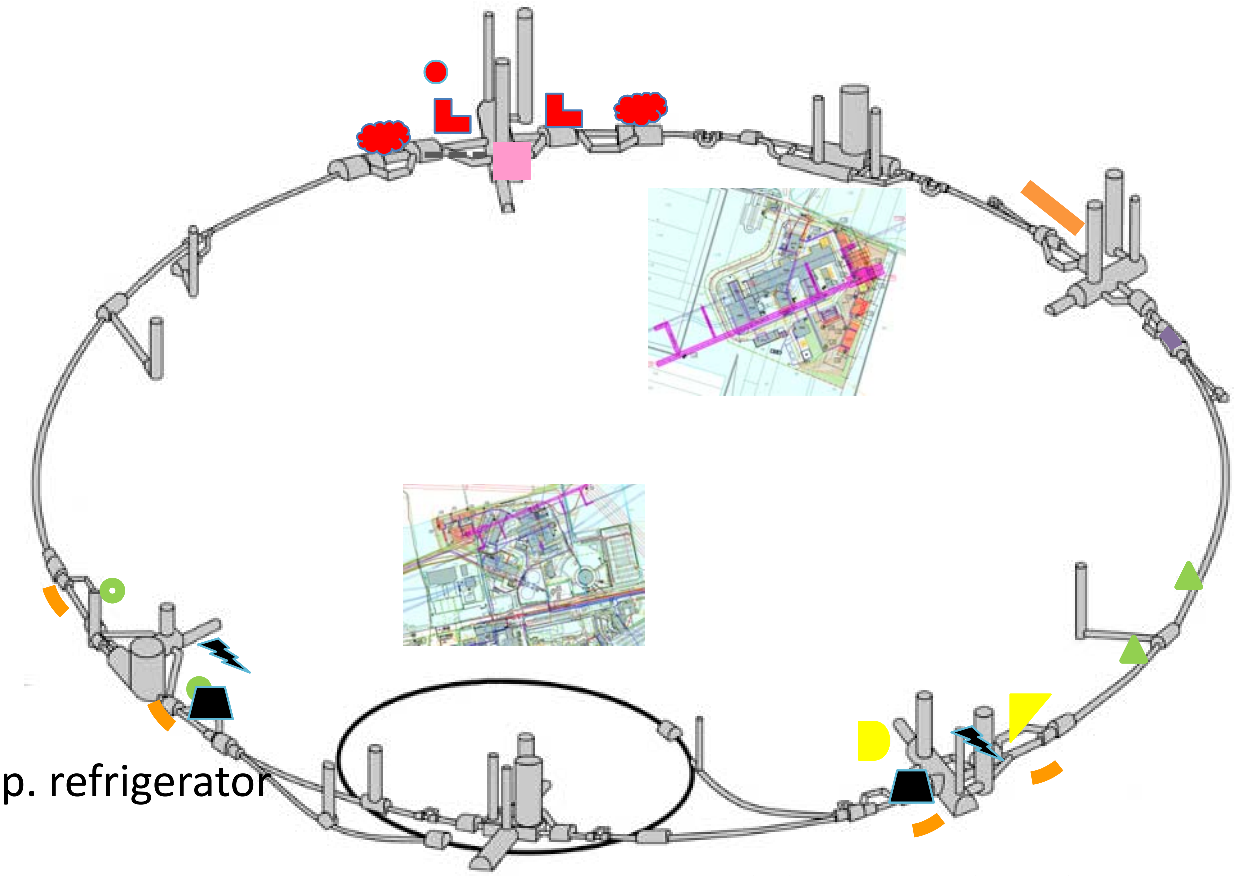
# And many other improvements

- **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** …

# 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

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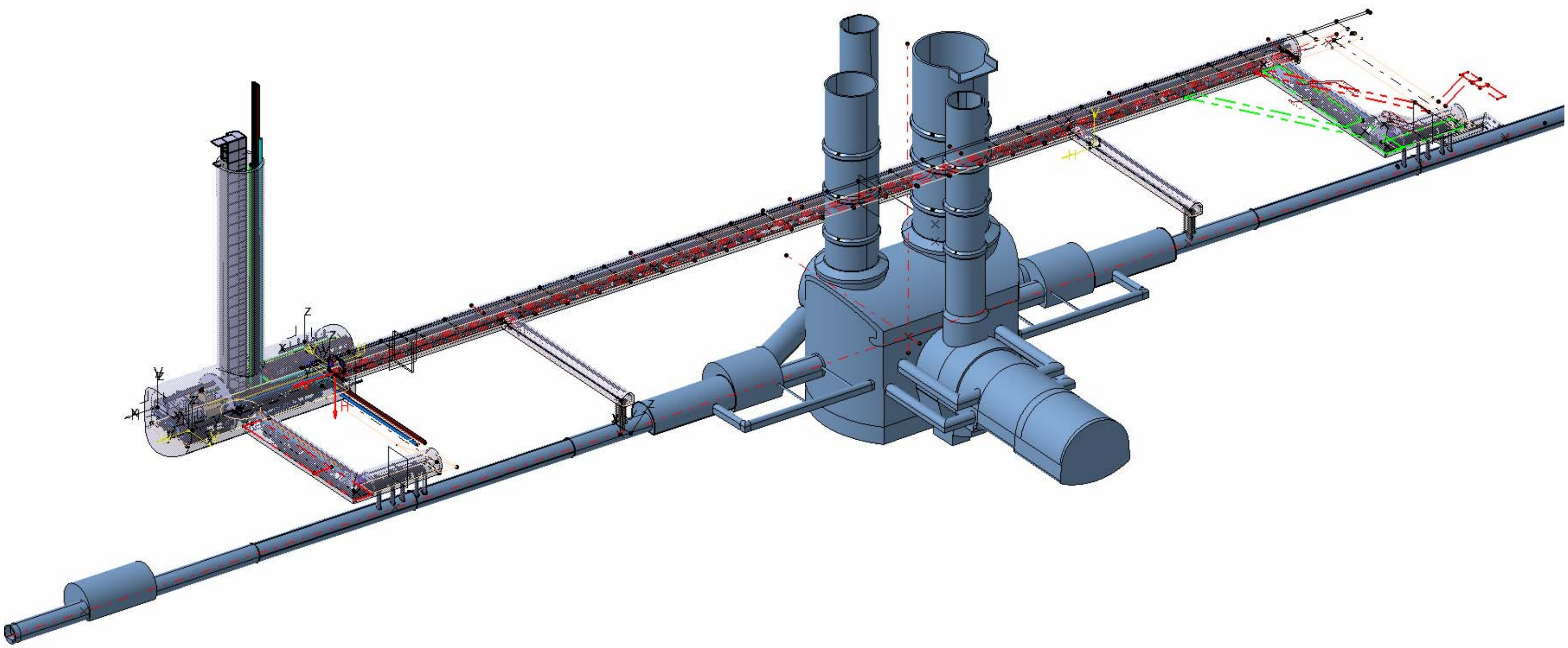
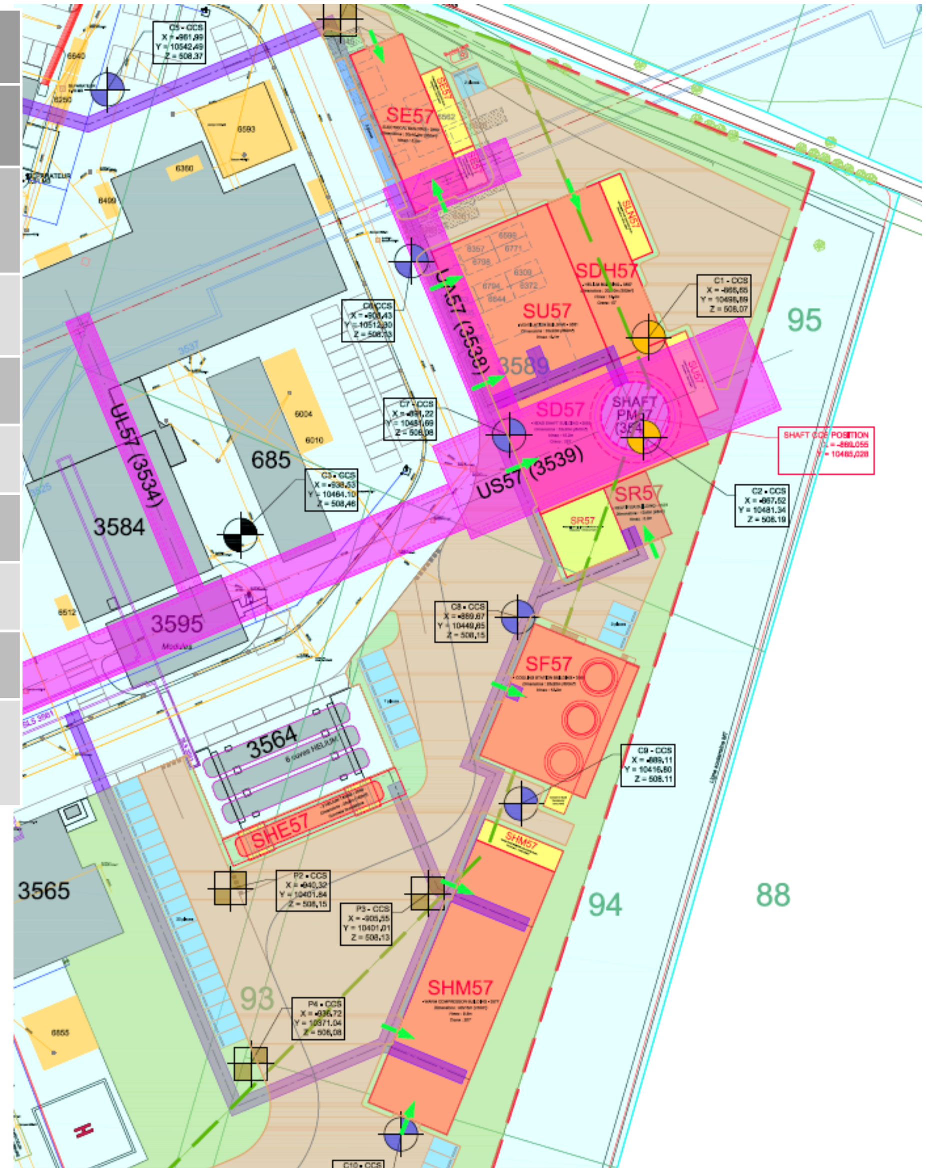
# Point 1 Civil Engineering underground



# Surface buildings

| Description | Sigle | DIMENSIONS (m) | | |
|---|---|---|---|---|
| | | H | L | W |
| Plateforme réservoirs hélium | SHE | 5 | 33 | 5 |
| Bâtiment ventilation | SU | 9 | 30 | 22 |
| Bâtiment électrique | SE | 3 | 30 | 10 |
| Bâtiment tête de puits | SD | 15 | 32 | 20 |
| Bâtiment compresseurs | SHM | 9.5 | 50 | 15 |
| Rectifier Building 3175 | SR | 7 | 12 | 8 |
| Tour de refroidissement | SF | 12 | 25 | 20 |
| Bâtiment déchargement hélium | SDH | 14.4 | 30 | 10 |

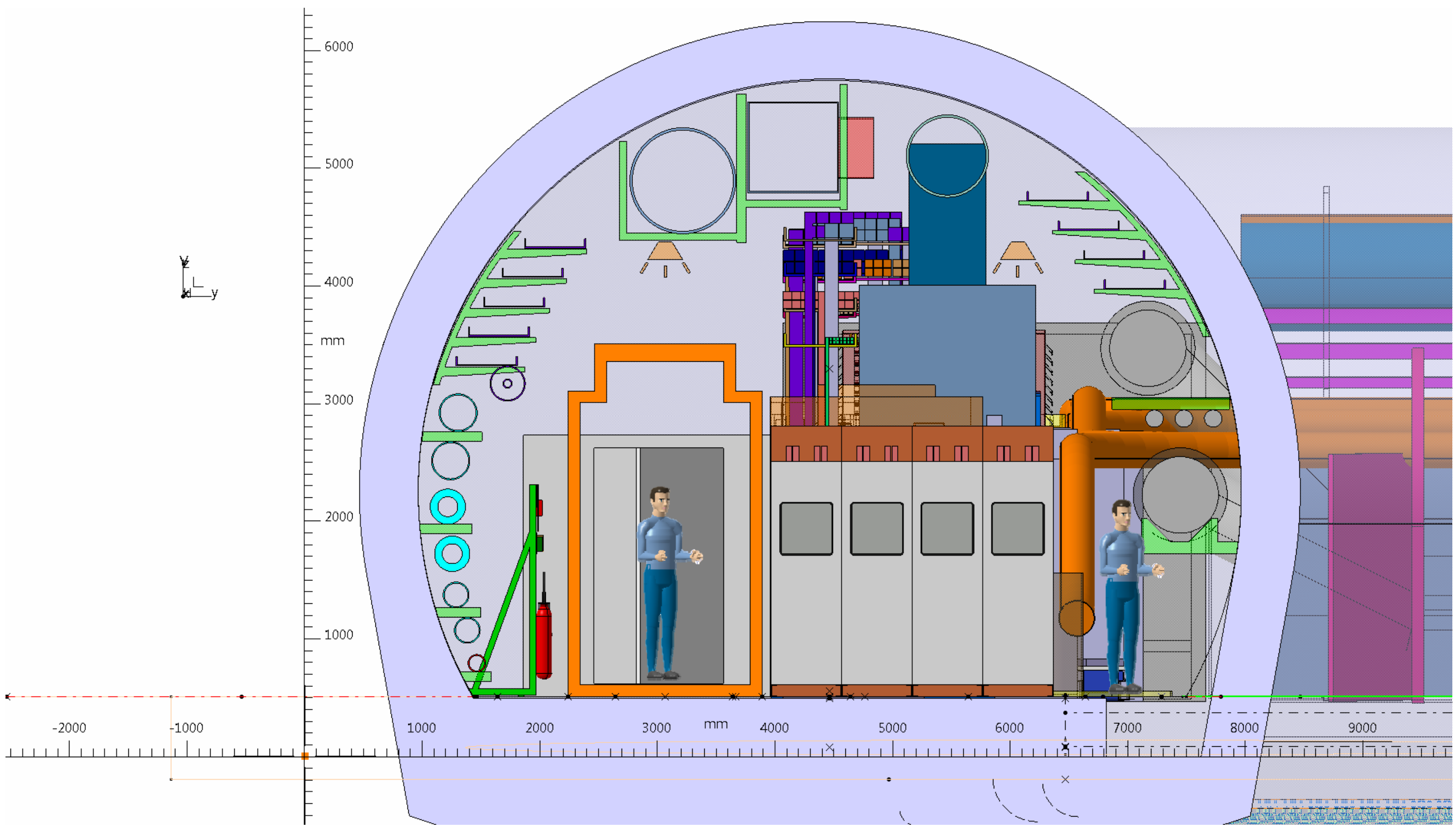



≈ 3’400 $m^2$ new buildings

P1
- Present surface≈ 75’200 $m^2$
- New surface≈ 91’200 $m^2$

P5
- Present surface≈ 42’300 $m^2$
- New surface≈ 55’300 $m^2$

# Typical view of the infrastructure needs

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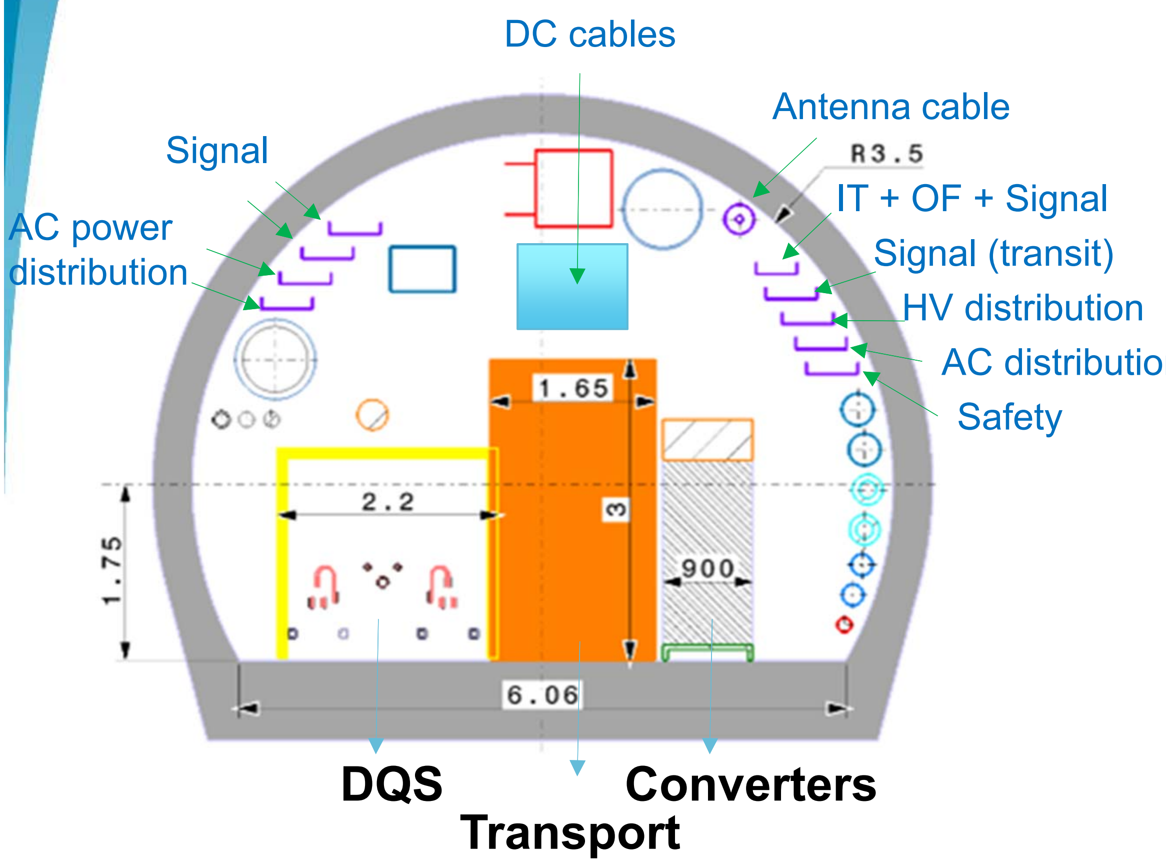
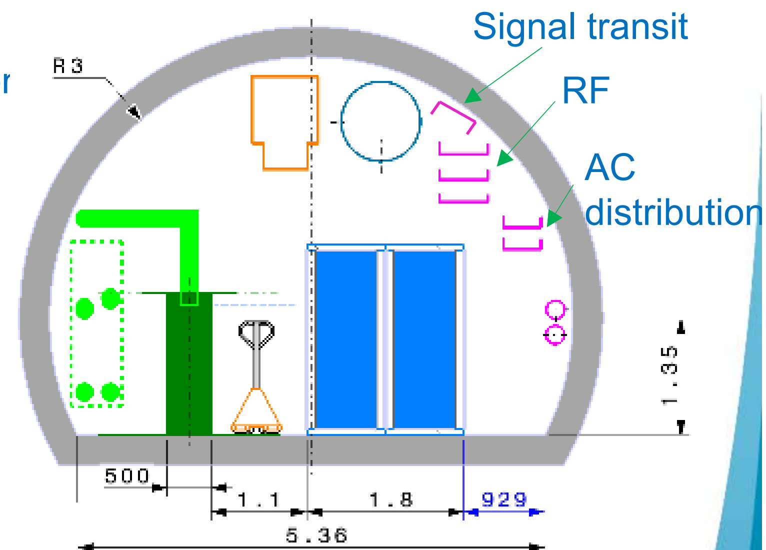
# Space needed for cable trays

UR:




UA:

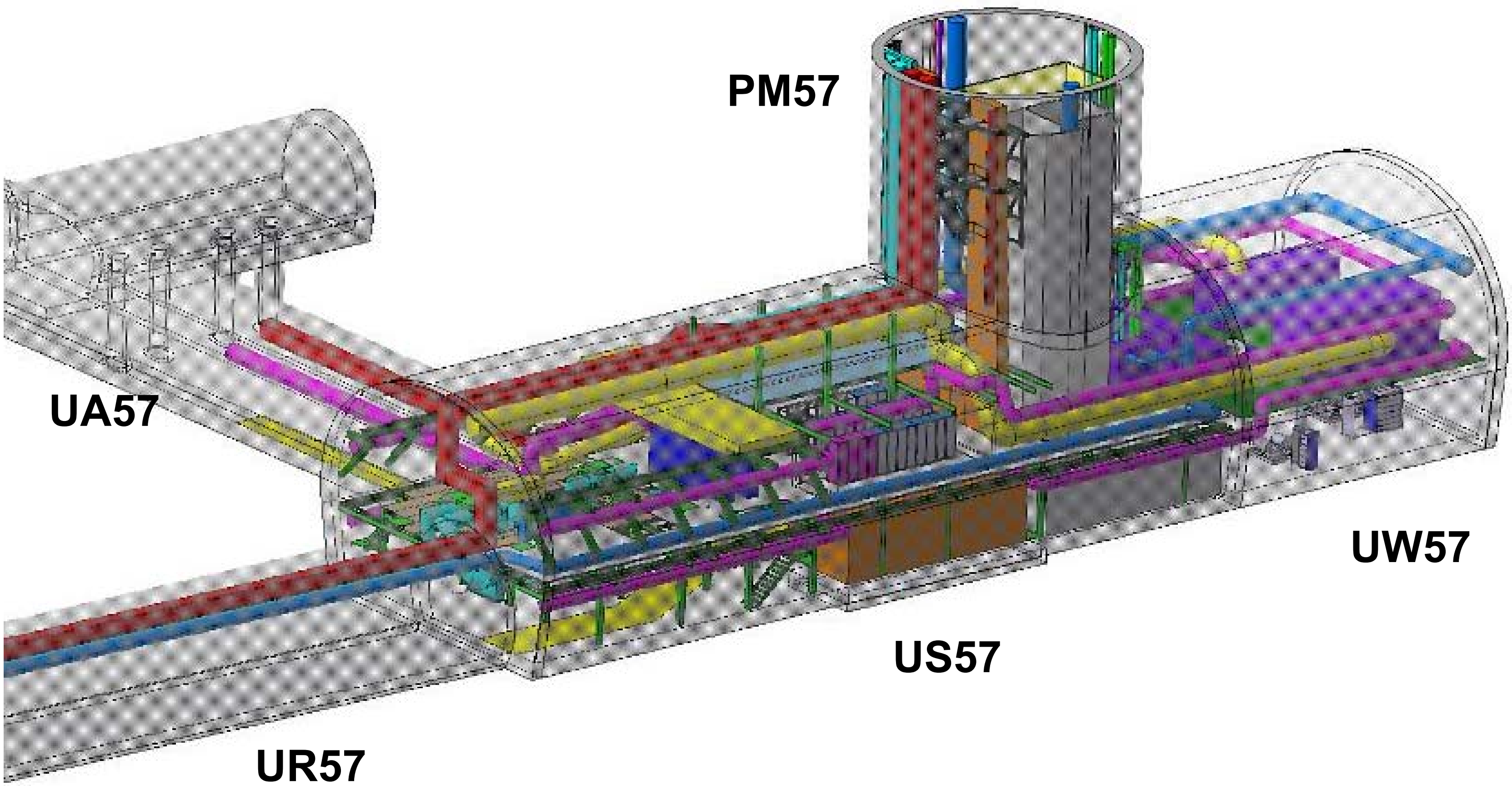



Size of cable trays (AC and signal):

600/60 mm. Distance between: 250mm

Constraints: Cable trays must be accessible for additionnal cables.

# General view



***Thank you for your attention***

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

# HL-LHC Project Office Organization

**Project Leader & Deputy**
Project Definition & Strategy
Report to CERN Management and DHs
Report to Collaboration Board
Coordination technical WPs (2-14) & Collaborations

**Safety officer**

**Budget Officer**
Budget & its follow-up
Link to RC and to DAT

KT, Outreach and Communication

**Project Office Manager**
Coordination among officers, secretariat, interface with host states, General Planning Coordination, Safety follow up

**Technical Infrastructure Officer**

Civil Engineering
Impact & Environ. Studies
Electrical Distr. & CV
Access & Alarm
Logistics & link to Test Infra.
Consolidation & Operations

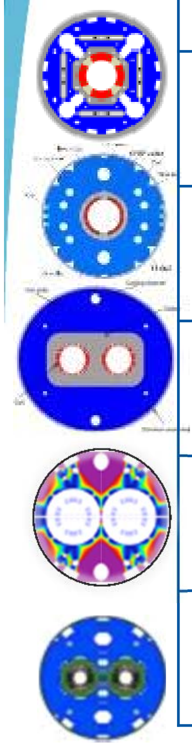
**Configuration, Quality and Resource Officer**

TDR Edition & Tech. Baseline
(PBS, interfaces, Tech. Specs, Technical documentation & ECR)
Quality and Risk management
Resource & Purchase Plan

**Integration and Installation Officer**

Integration study and layout
Lead (de-) installation
Survey

# Main HiLumi-LHC Magnet Features



| | Type | Material | Field/Gradient (T) / (T/m) | Aperture (mm) | Origin Design |
|---|---|---|---|---|---|
| Q1,Q3 Q2a, Q2b | Single aperture | $Nb_3Sn$ | 132.6 T/m | 150 | LARP CERN |
| D1 | Single aperture | Nb-Ti | 6.5 T | 150 | KEK |
| D2 | Twin aperture | Nb-Ti | 4.5 T | 105 | INFN |
| Q4 | Two-in-one aperture | Nb-Ti | 120 T/m | 90 | CEA |
| DS 11T | Two-in-one aperture | $Nb_3Sn$ | 11 T | 60 | CERN |