# HL-LHC Project – Procurement of high-precision machined components

**Hector Garcia Gavela**
**on behalf of the HL-LHC Project**

# Outline

1. HL-LHC upgrade
2. Procurement – High Precision Machining
3. Return of experience
4. Conclusions

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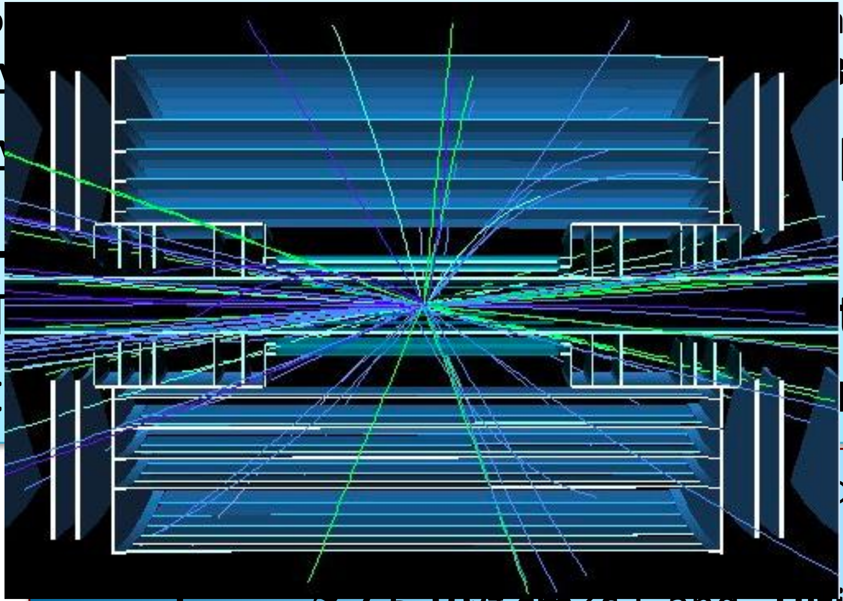
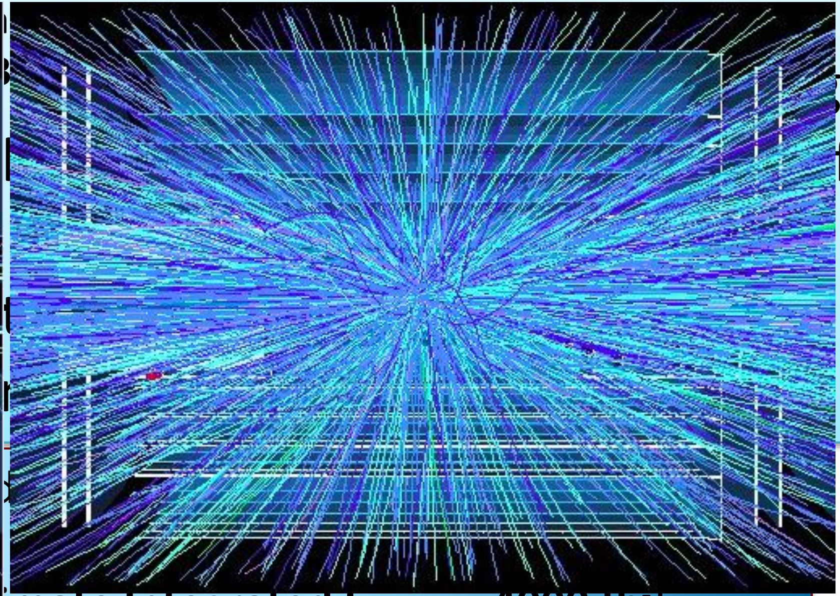
1. **HL-LHC upgrade**
2. **Procurement – High Precision Machining**
3. **Return of experience**
4. **Conclusions**

# Goal of HL-LHC

From EC-FP7 HiLumi LHC Design Study application of 2010

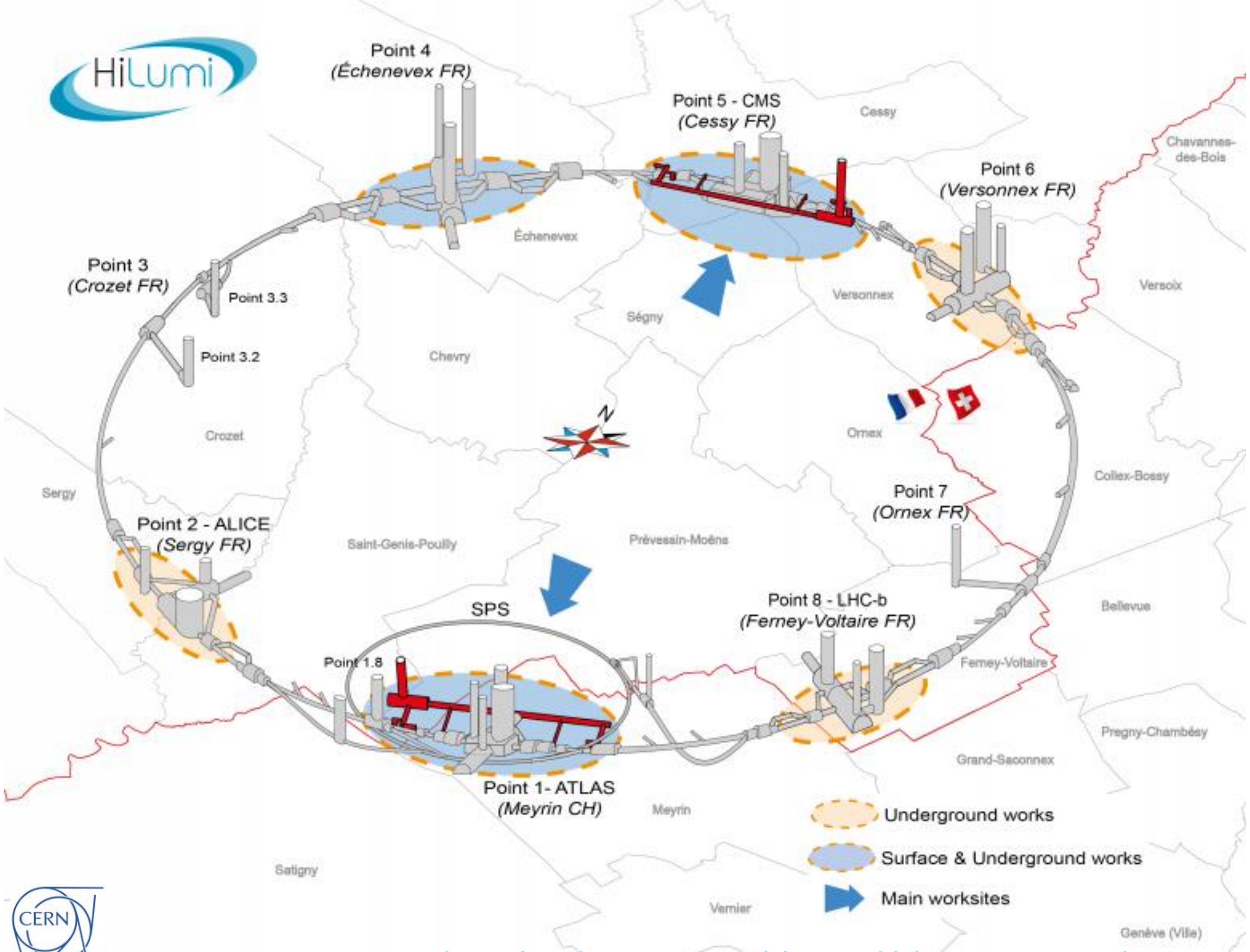
The main objective of HiLumi LHC Design Study is to determine a hardware configuration and a set



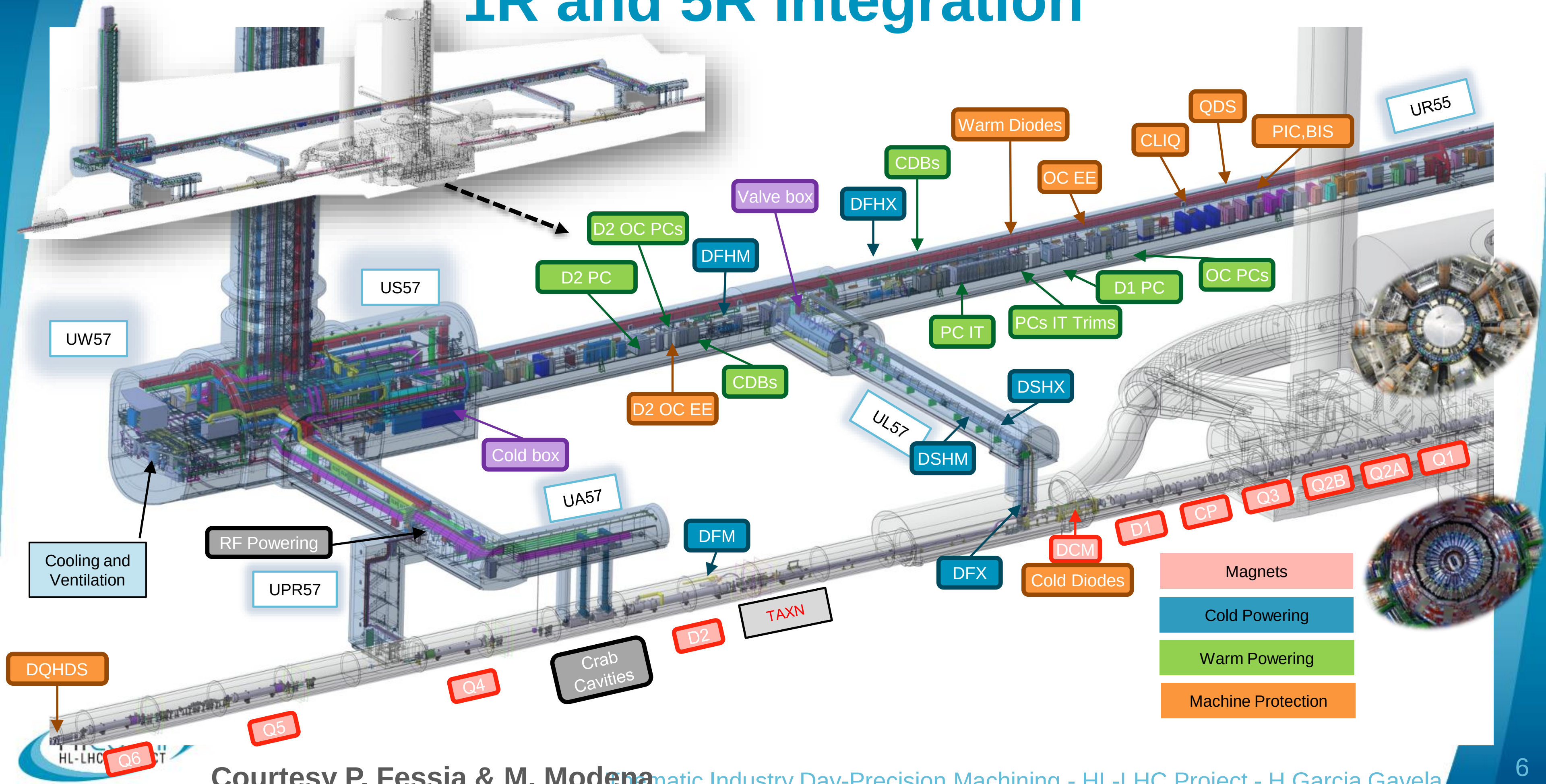


$L_{peak\ ult} \cong 7.5\ 10^{34}\ cm^{-2}s^{-1}$ and Ultimate Integrated $L_{int\ ult} \sim 4000\ fb^{-1}$

LHC should not be the limit, would Physics require more…


Point 4
(Échenevex FR)
Point 5 - CMS
(Cessy FR)
Cessy
Chavannes-des-Bois
Point 6
(Versonnex FR)
Échenevex
Point 3
(Crozet FR)
Point 3.3
Point 3.2
Ségny
Versonnex
Versoix
Chevry
Crozet
Ornex
Sergy
Collex-Bossy
Point 7
(Ornex FR)
Point 2 - ALICE
(Sergy FR)
Saint-Genis-Pouilly
Prévessin-Moëns
SPS
Point 8 - LHC-b
(Ferney-Voltaire FR)
Bellevue
Point 1.8
Ferney-Voltaire
Pregny-Chambésy
Grand-Saconnex
Point 1- ATLAS
(Meyrin CH)
Meyrin
Underground works
Surface & Underground works
Main worksites
Satigny
Vernier
Genève (Ville)

# 1R and 5R Integration



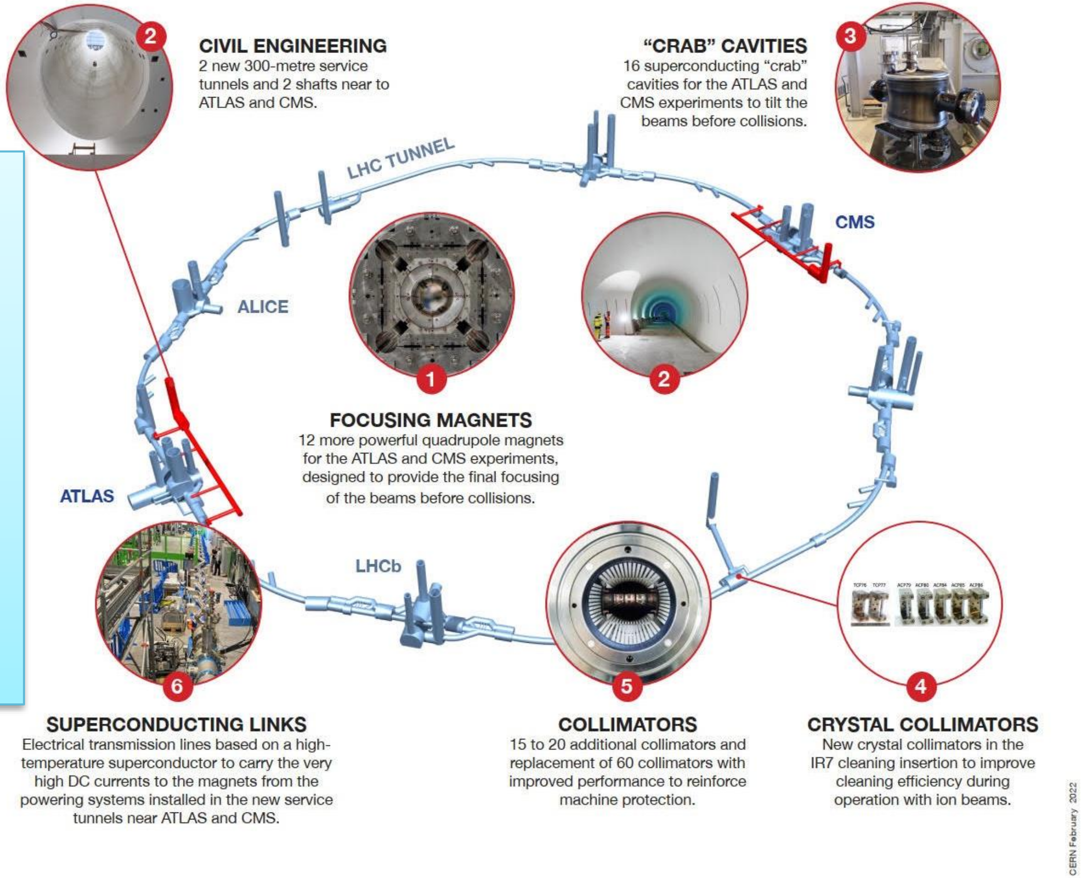

Courtesy P. Fessia & M. Modena

# HL-LHC technology landmarks

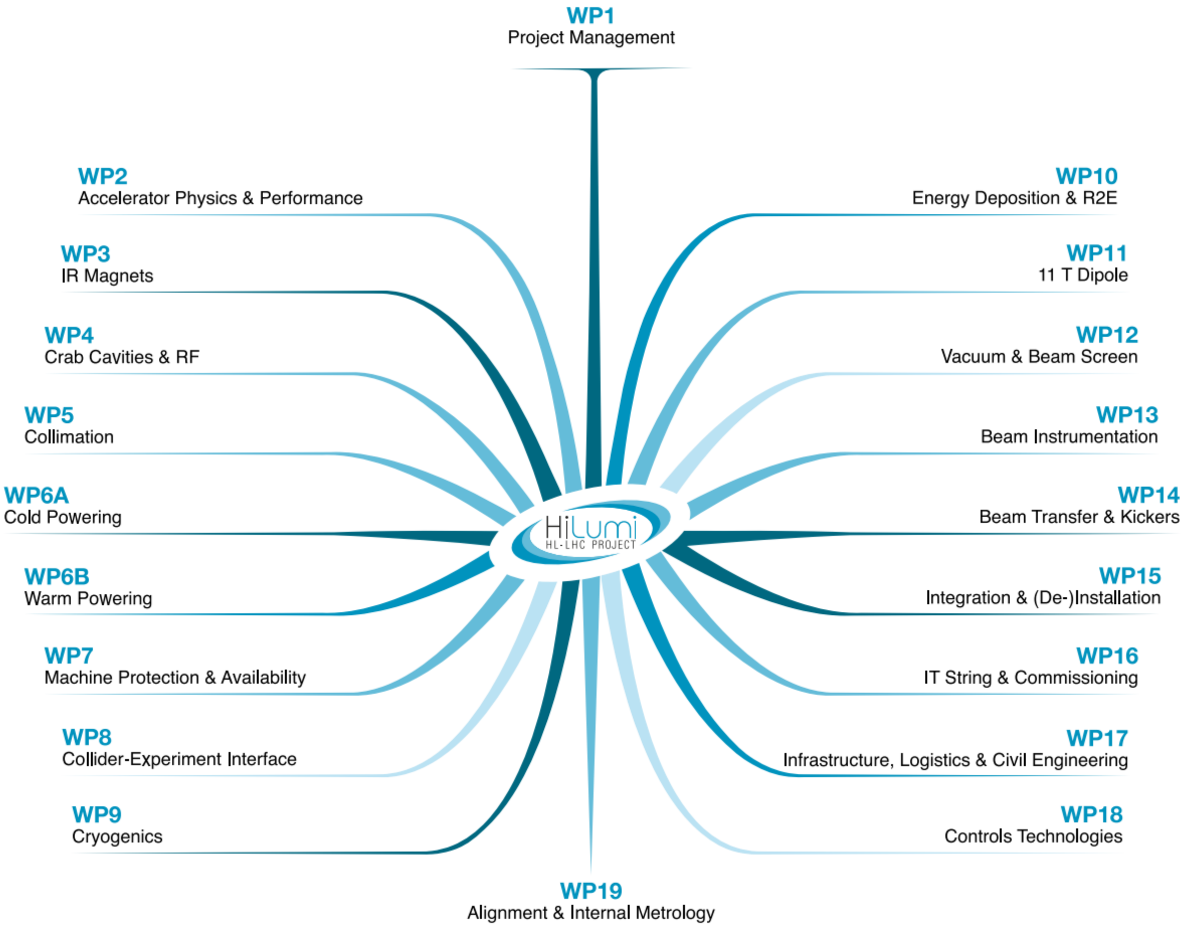
No accelerator upgrade project has so many challenging novelties covering such a broad technology spectrum

*Technology intensive project!*

*Major upgrades in P1 and P5, large fraction of LHC will remain unchanged*

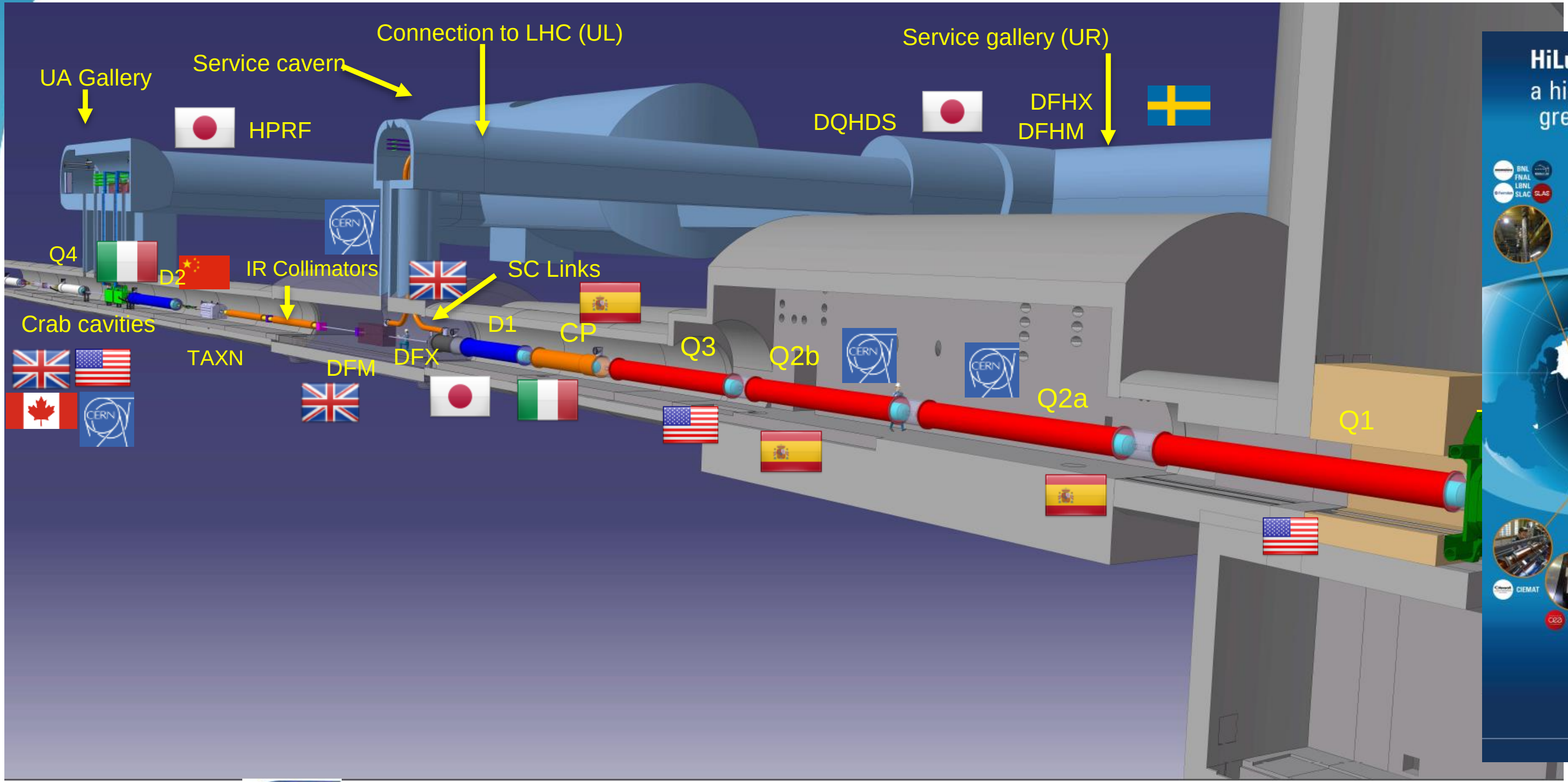


# HL Project Management and Organsiation

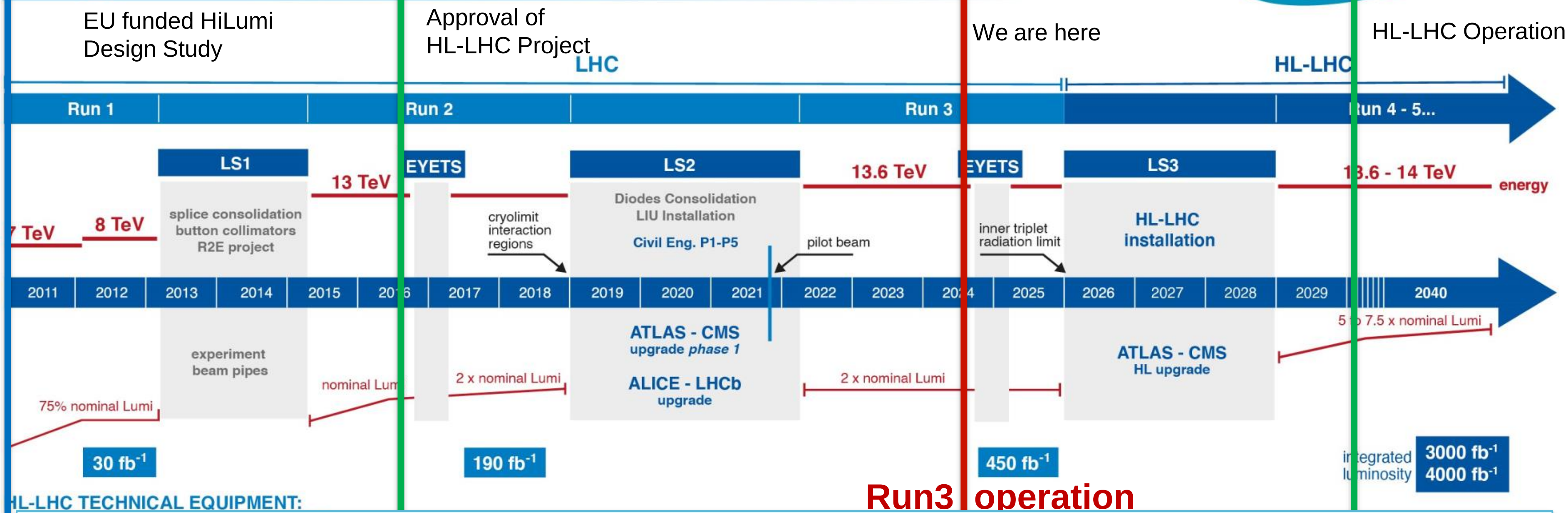



- Major upgrade of the iconic LHC machine (mainly but not only at P1 and P5)
- All core technologies and CERN expertises are well represented within the Project
- Industry is heavily involved in the construction of the hardware (60% of the total budget spent in Supply Contracts)

# HL-LHC - A truly international collaboration




# LHC / HL-LHC Plan




➔ ~1.5 years until start of Long Shutdown 3 (Jul-26) – New dates announced by CERN management in September (starting date Jul-26 and beam back to the machine in mid -2030)

➔ 80% of the project budget of ~1.1 BCHF already committed (10% out of the 20% is workforce)

➔ Optimization of the present LS3 installation schedule on-going

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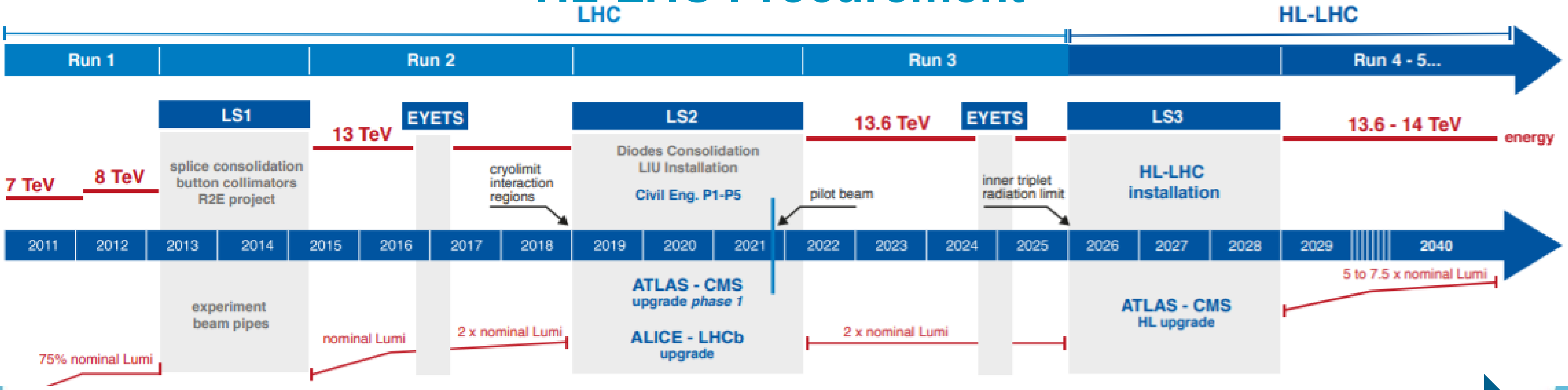
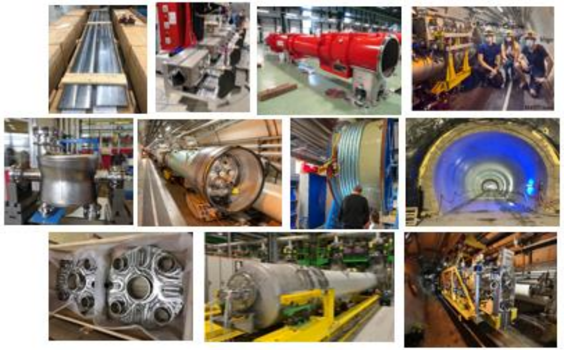
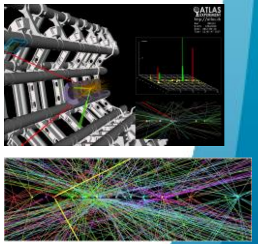
# HL-LHC Procurement

New schedule under preparation




**MOCK-UPS / SHORT MODELS/ PROTOTYPES** | **LS2 / CE / LONG LEAD ITEMS RAW MATERIALS / MECHANICS** | **LS3 / ELECTROMECHANICS SERVICES / IT STRING** | **ELECTRONICS TRANSPORT**





Acknowledgement: Susana Izquierdo Bermudez

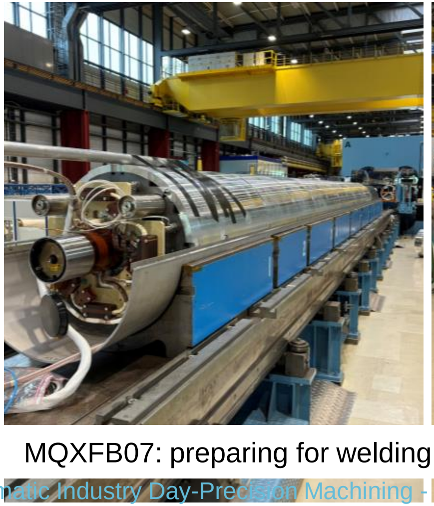
MQXFBP2: being prepared for the HL-LHC string

MQXFBP3: in the HL-LHC string

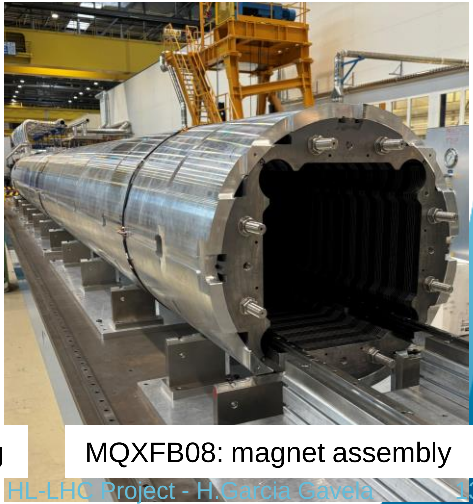
MQXFB03: ready to be tested in Q2 conf.
MQXFB05: fully qualified for HL-LHC ✓

MQXFB04: fully qualified for HL-LHC ✓

MQXFB06: cold mas finishing



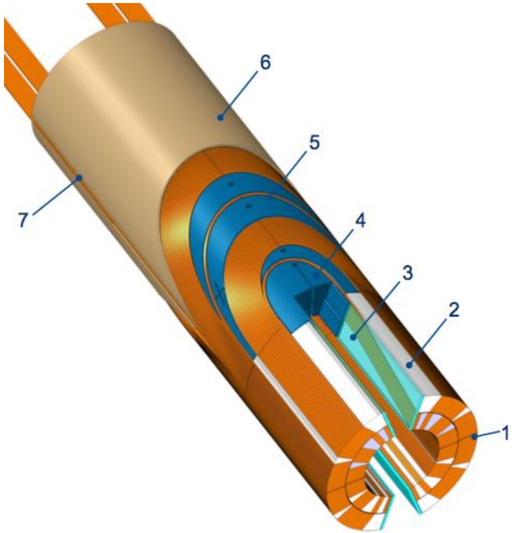
MQXFB07: preparing for welding

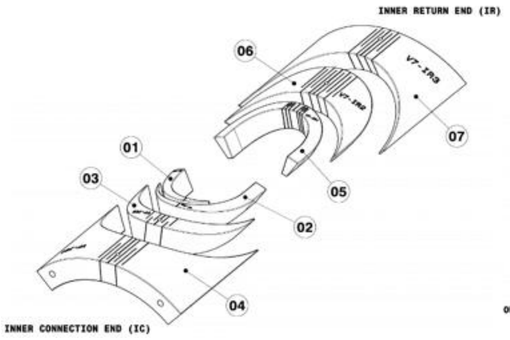


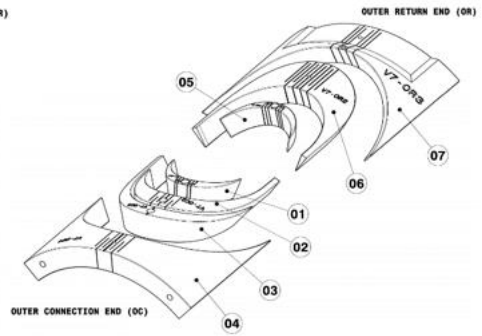
MQXFB08: magnet assembly

# Coil keys – end spacers – saddles

- Can be produced from STP files
- Item 4: coil key, AISI 316 L
- Item 5: Selective Laser Sintering (SLS) end spacer, AISI 316 L, with flex. legs
- Item 6: Saddle, EP-GC22, base material woven glass cloth, matrix epoxy resin
- 5 axes milling machine or multitasking machine

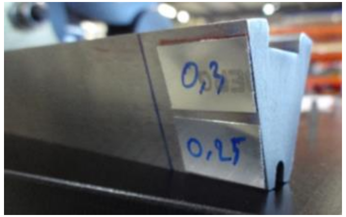


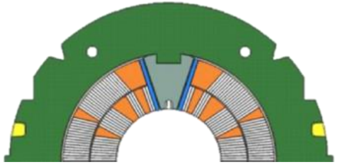



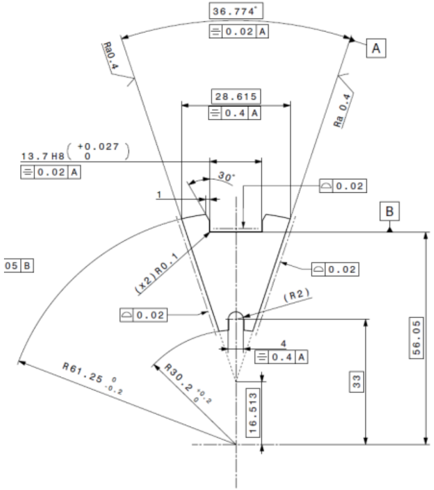



# Loading pole – ODS Wedge

- Loading pole, made of titanium (Ti6Al4V), 240 mm long

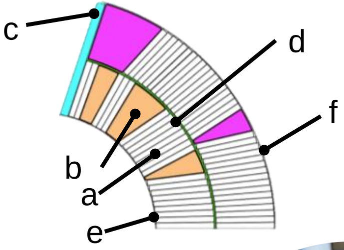


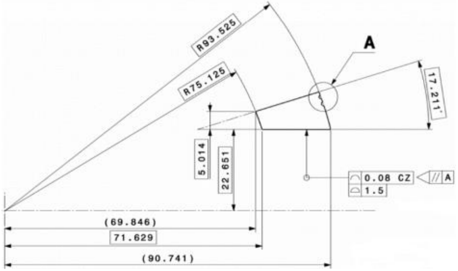



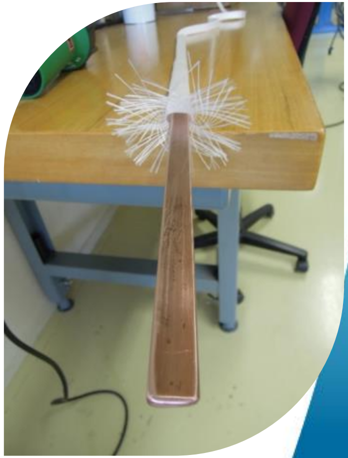



- Wedges, made of aluminum oxide dispersion strengthened copper, cold drawn in length of 2.6 m

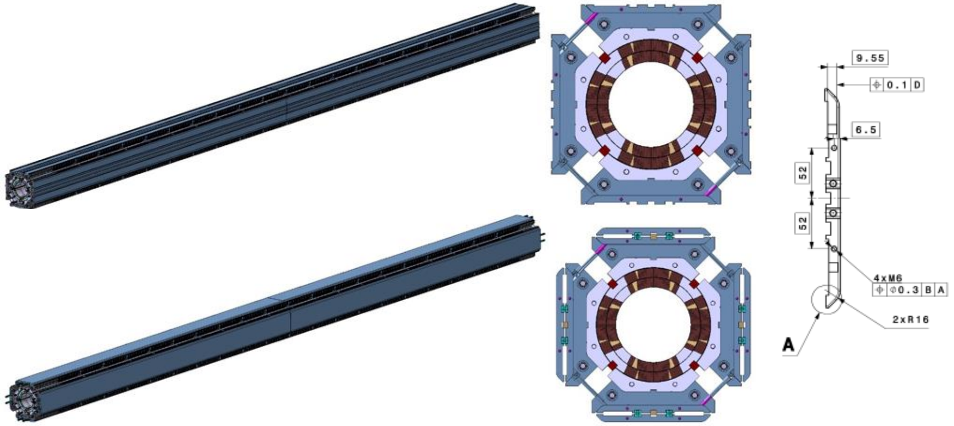
a. Insulated cable
b. Filler Wedge
c. Loading plate
d. Inter-layer
e. Inner ground wrap
f. Outer ground wrap



# Mechanical structure




- Aluminium shells (material provided by CERN)
- High-Precision CNC Lathe or Multi-Tasking Machinery

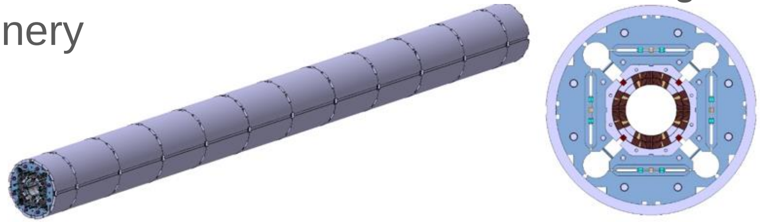
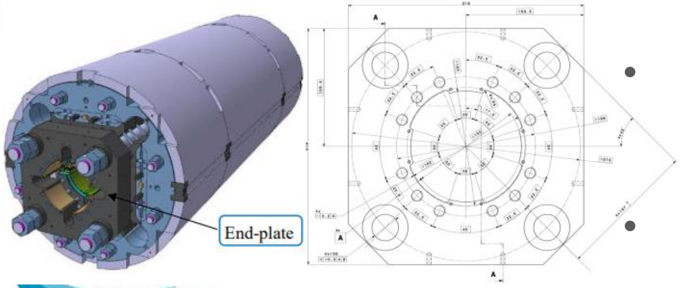
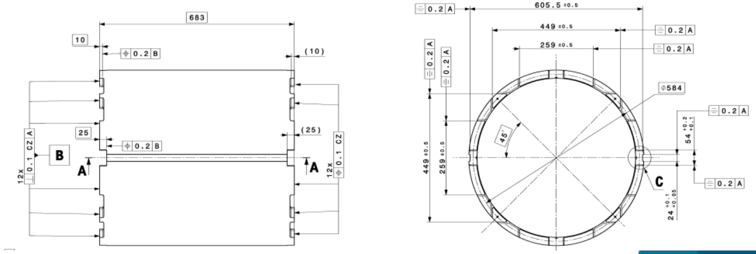


Figure 14: Al shells assembly in the MQXFB cold mass


- Internal and external master structure made of ARMCO (provided by CERN)
- CNC Milling Machine



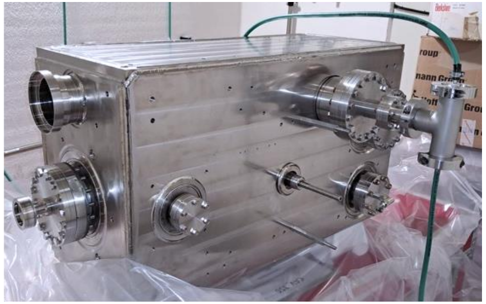

- End Plates made of NITRONIC (provided by CERN)
- CNC Milling Machine

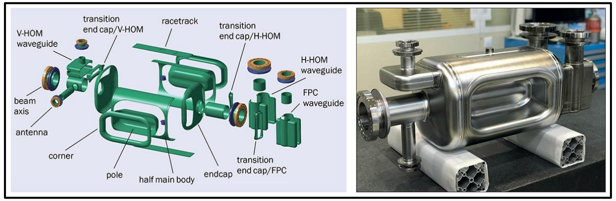


# Vacuum vessels

- First two units (Q1/3,Q2) produced as prototypes
- Design change on the lateral and bottom covers to allow helicoflex seals
- Contract for series production: Build to print supply of 38 vessels, contract signed August 2019
- Cylinders made out of tubes for lower production cost
- End flange welding procedure developped for low distorsion
- Machining of support post interfaces after welding
- Epoxy painted outside, sand blasted and degreased inside (no coating)
- QC at the supplier (all units)
  - Full metrology
  - Leak testing
- QC at CERN
  - Metrology of selected features (alignment of post  interfaces, flanges, FSI ports)
  - Leak testing
  - Currently being performed on all units at reception, but the goal is to test only a sample from each batch delivery

# Crab Cavities

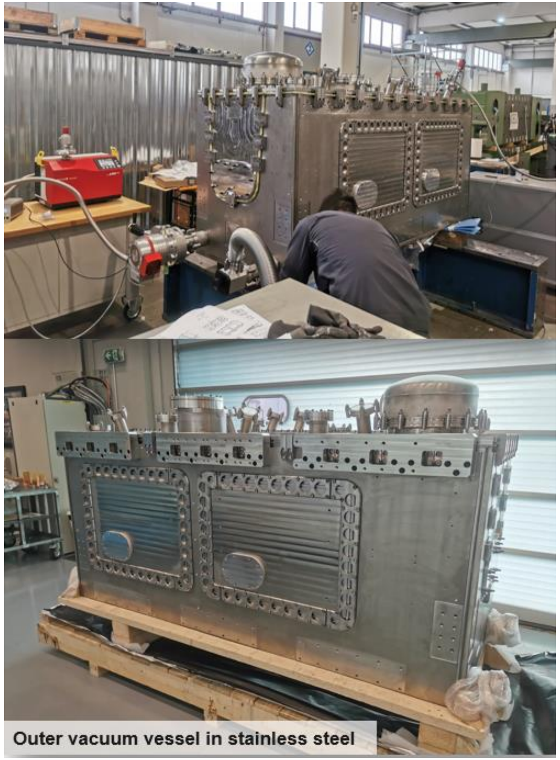




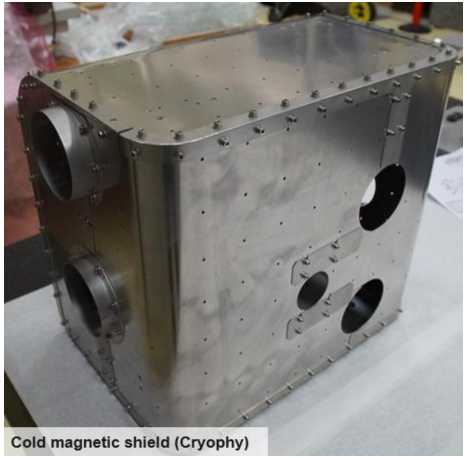

- Novel concept of SRF cavities to compensate the geometric loss in luminosity due to the non-zero crossing angle and the extreme focusing of the bunches in the HL-LHC
- Complex geometry involving exotic materials (Nb, NbTi), very tight tolerances and high-quality RF surface (and a non-negligible amount of brazed and E-B welded joints)
- PED compliance

# Crab Cavities

Warm magnetic shield made of Mu-metal

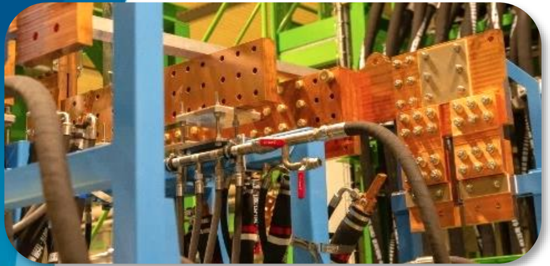


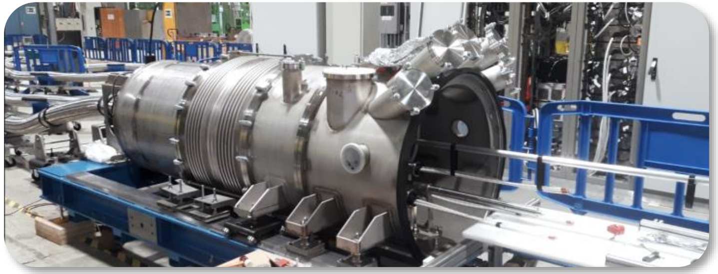
Outer vacuum vessel in stainless steel



Cold magnetic shield (Cryophy)

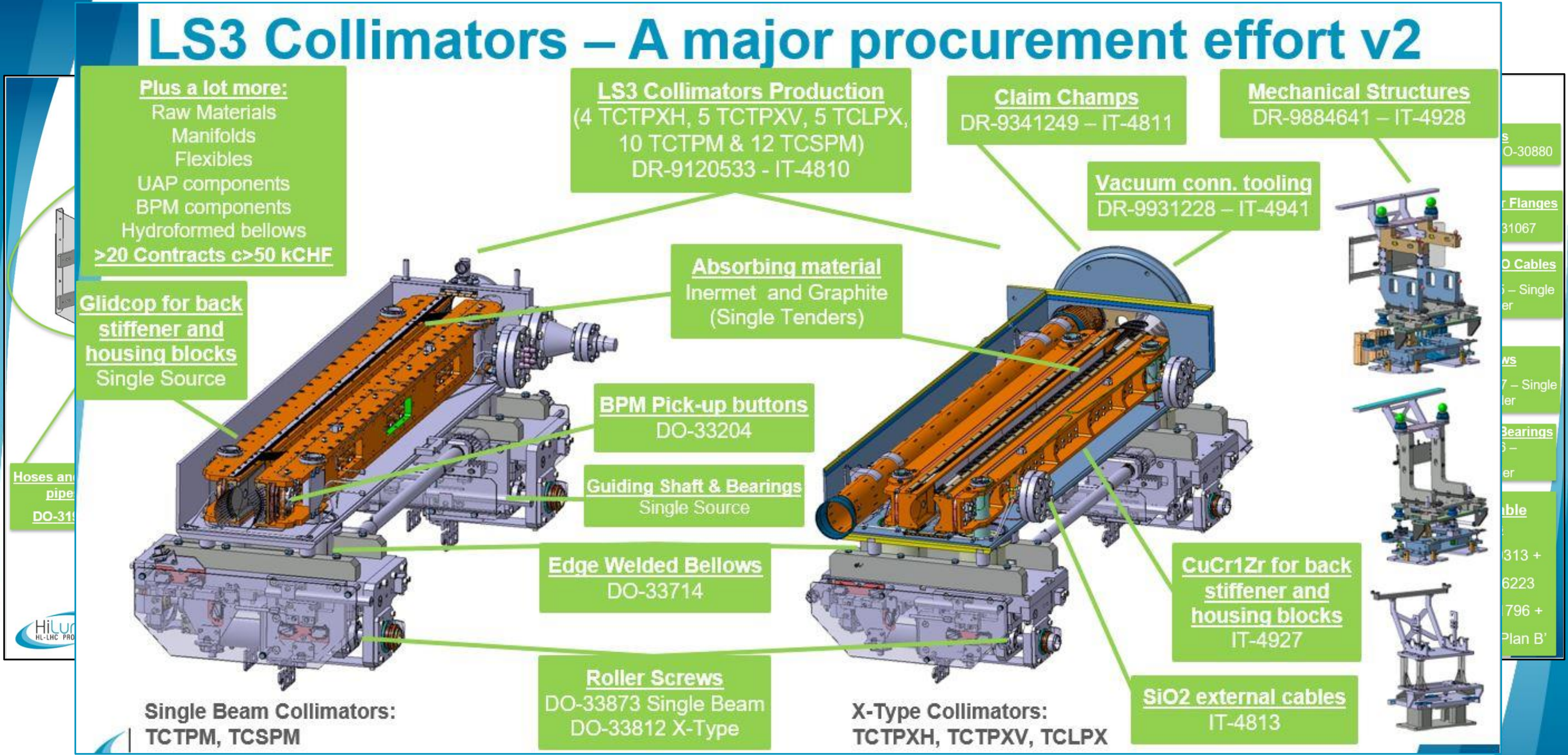
Titanium helium vessel



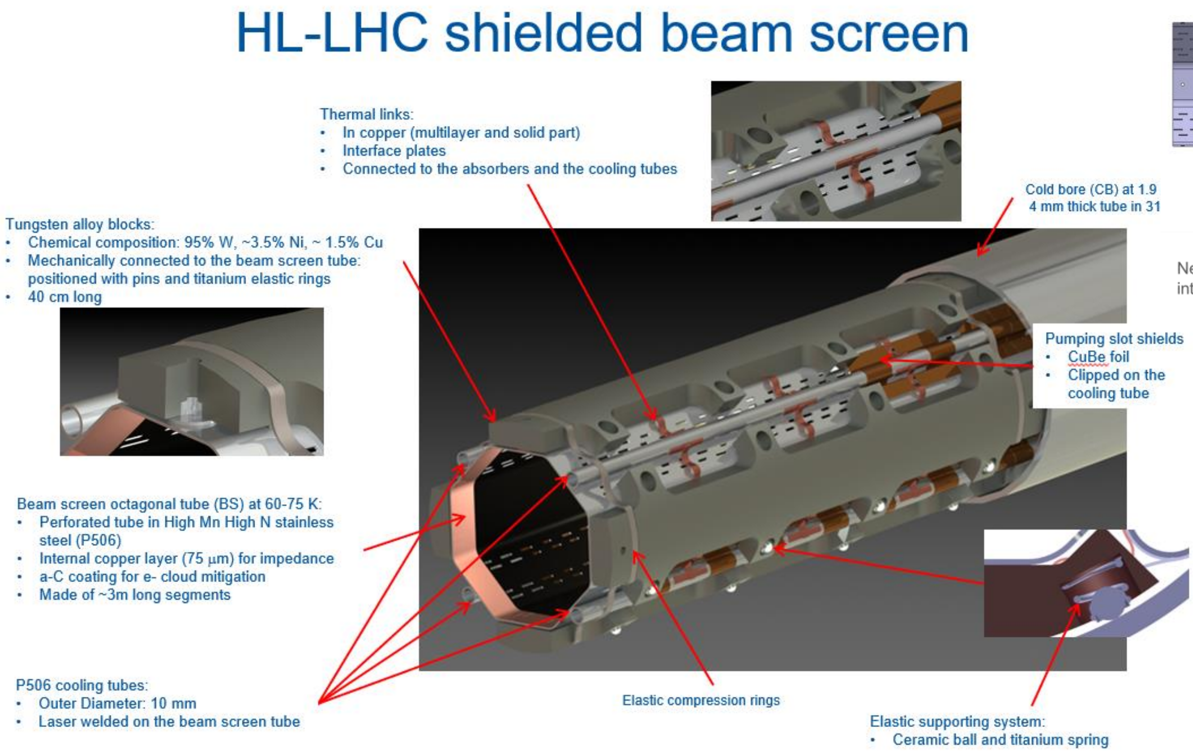
Multi-technological challenge involving a broad number of different mechanical components (and different requirements)

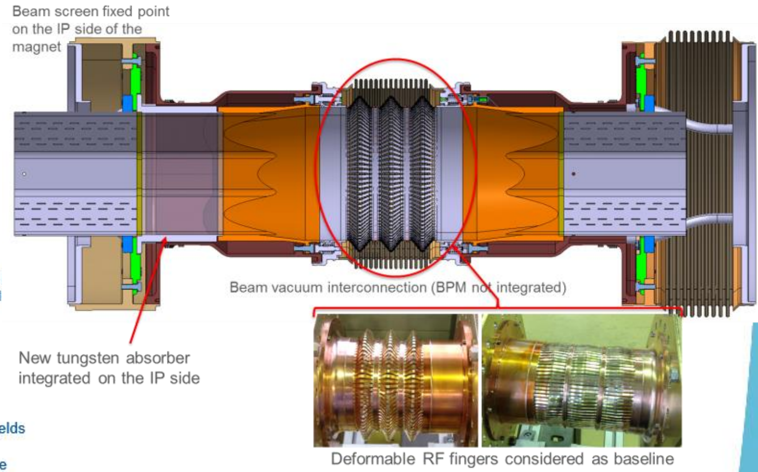
HL-LHC PROJECT

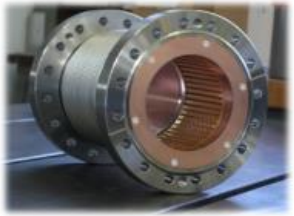



See presentation from **A. Perillo & M. Calviani** for BID (**Beam Intercepting Devices – Targets, Collimators and Dumps**) – Some of the r**emaining needs for HL-LHC also covered here**

# UH Vacuum Components



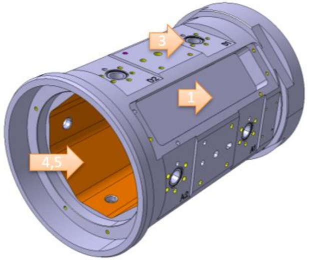



# Beam Instrumentation

## BPM Body Manufacturing Process Overview

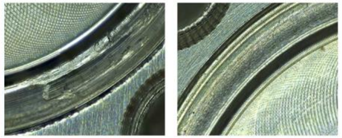
Machining → Cleaning → Leak check → Dimensional control → Gold/Copper coating → Dimensional Control → Leak check → Welding of cooling tubes → Welding quality control → Dimensiona l control → Leak check → Assembly

1. Material: CERN material spec. 1001 for 1.4429 round, forged blanks
2. Strict tolerances
3. Machined ConFlat interfaces
4. Octagonal shape (electroerosion wire cutting)
5. Copper electroplating 0.1 mm (with gold flash for adhesion)

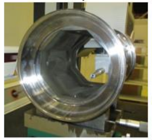



BPM Proto, ACC

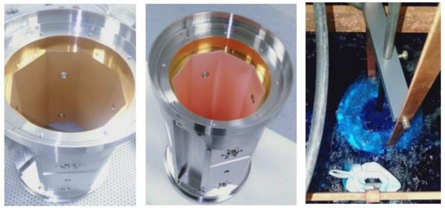
CF – machining results (best – ball mill 0.6 mm)

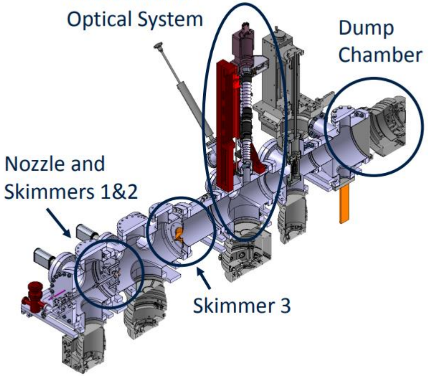


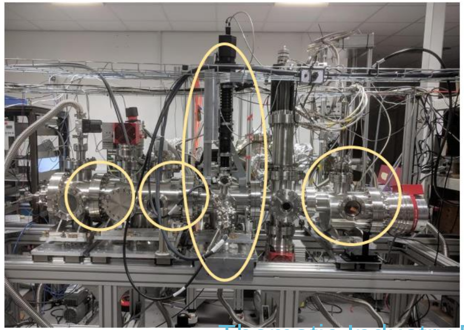
EE-wire cut, Ra3.2



Gold strike and Copper plating

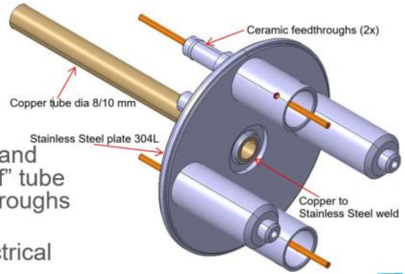




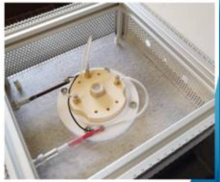
## BLM IC Critical Part Endplate

- Endplate Production Competencies (LHCBLM__0002):
  - High Precision machining
  - UHV cleaning
  - UHV-compatible assembly and welding of copper “pinch-off” tube (SS/Cu) and electric feedthroughs (SS/SS)
  - Dimensional and basic electrical checks
  - Leak check



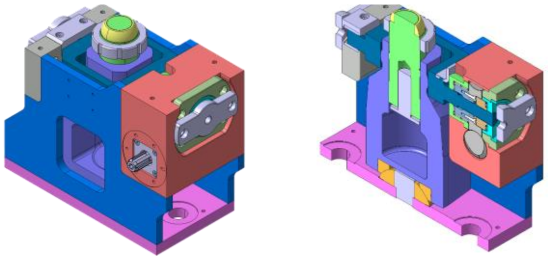

## BLM IC Critical Part Ceramic Insulator

- Ceramic Insulator Production Competencies (LHCBLM__0005):
  - High Precision ceramic $Al_2O_3$
  - Ultra-high resistance:
    - < 1 pA when 1.5 kV applied
  - Resistivity checks in a controlled environment to guarantee consistent measurements
  - UHV-clean delivery

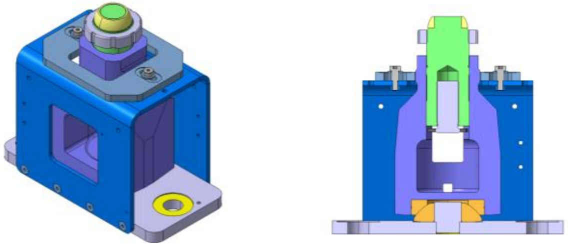


# HL-LHC Jacks

## 114 Radial/Longitudinal Jacks

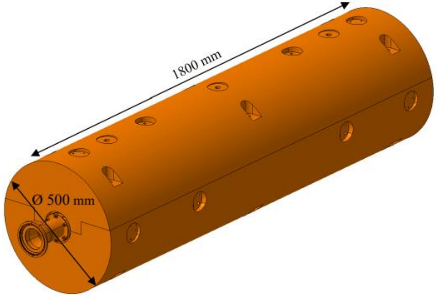


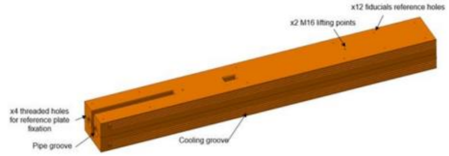
## 26 Central Jacks

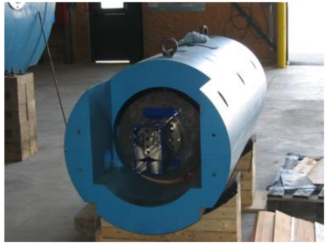


- Designed to **support cryo magnets up to 30 tonne** in weight with the capability to **align**, and **maintain the alignment** in **operating conditions** throughout the whole lifetime
- For **standardization** & **cost optimization**, the **design** was also **adopted** for **Crab Cavities** and **TAXN**
- **Smooth control** of the **displacements**, requiring **tight manufacturing tolerances** and **low friction**
- Motorization, instrumentation and controls are to be integrated as part of the **Full Remote Alignment**
- **Mechano-welded structures with tight tolerances on individual components due to the functional requirements**

# TAXN/S Cu Absorbers

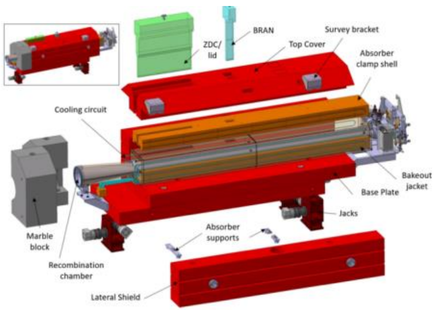



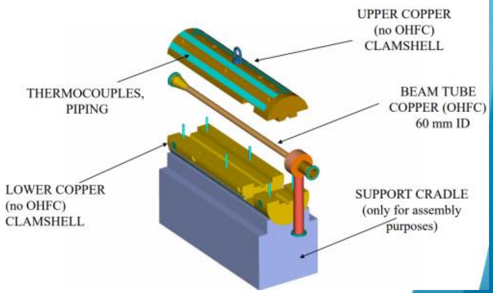



- **TAXN** and **TAXS Cu absorbers** (made of **casted Cu, which is part of the scope of the Contractor**)

- **~1.5 tonne/piece** with **tight dimensions/tolerances** as they will **clamp the vacuum chambers inside**

- **Forward detectors (BRAN & ZDC) inserted in the absorber slots**



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# Return of Experience and tips – High Precision Machining

- High Precision Machining components are a recurrent need for Projects/Programs/Operations at CERN
- Orders from a few kCHF to MCHF – However, there are no medium/large size projects at all times…
- Wide broad of materials used at CERN (sometimes provided by CERN but they can also be in the scope of the Contractor)
- Wide broad of geometries, sizes, weights and functionalities involving different machining methodologies – Case-by-case
- However, some components are (will be) recurrently needed in present and future Projects
- We all must follow the CERN Procurement Rules (see presentation from A. Lacinana) – Market Survey to qualify companies (sometimes via qualification samples) and Price Enquiries/Invitation to Tender for bidding (only companies qualified and selected)

# Return of Experience and tips – High Precision Machining

- Orders/Contracts managed directly by the equipment owners (Work Packages) or via EN-MME-FS (vast experience in this domain) – Collaborations manage their own procurement
- For high precision machining, we look for companies that can provide references of similar works and level of complexity of the required work
- Metrology in-house is usually required (efficiency in the production workflow)
- Quality and Planning of utmost importance
- Requirements are usually high, but they are specified due to a well assessed need (we work in a unique environment and a failures can bring downtime in operation)

HiLumi HL-LHC PROJECT

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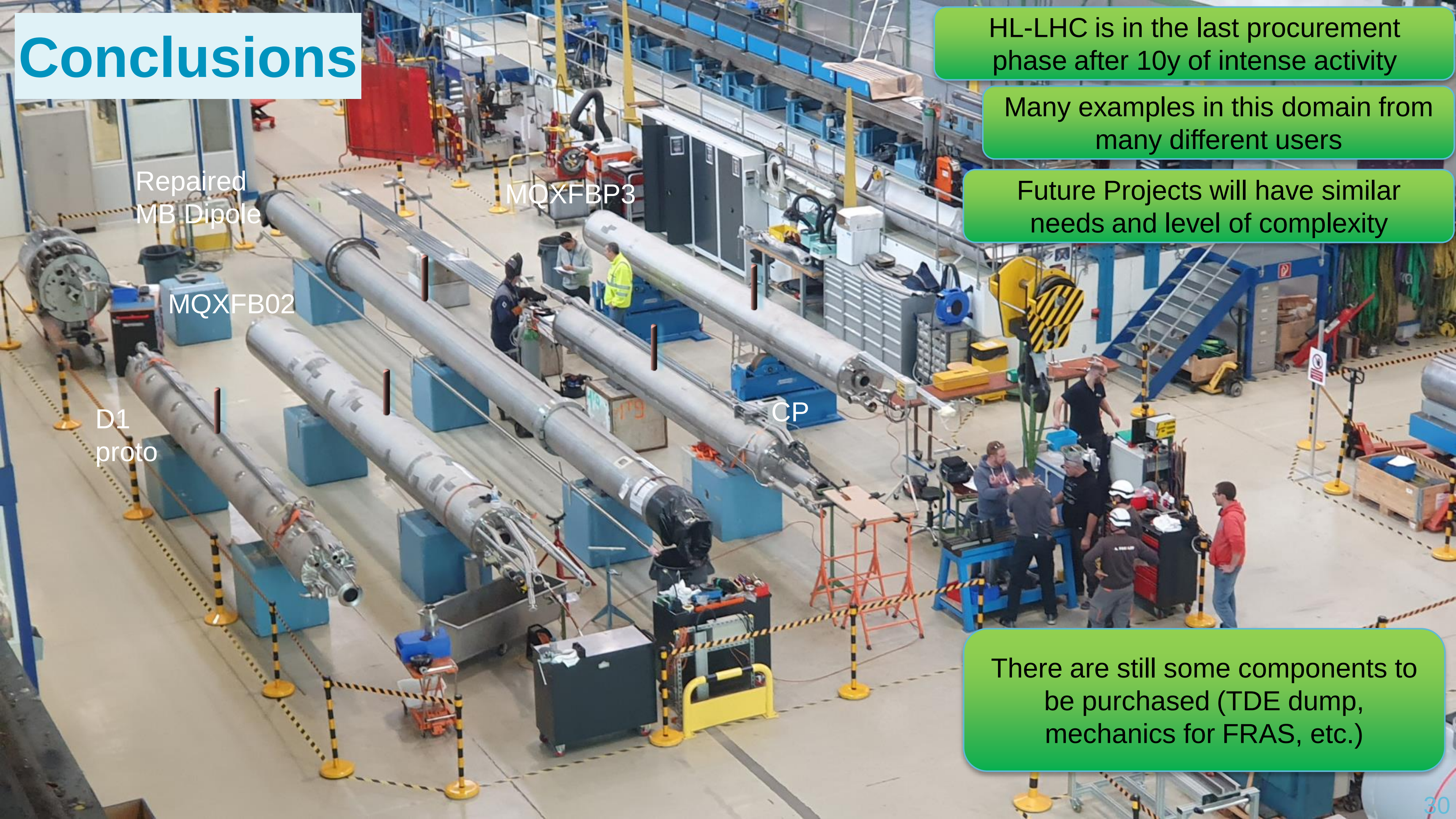
3. Return of experience
4. Conclusions

# Conclusions




HL-LHC is in the last procurement phase after 10y of intense activity

Many examples in this domain from many different users

Future Projects will have similar needs and level of complexity

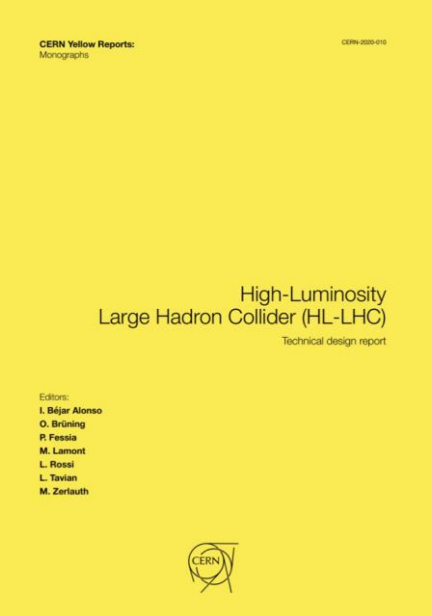
There are still some components to be purchased (TDE dump, mechanics for FRAS, etc.)

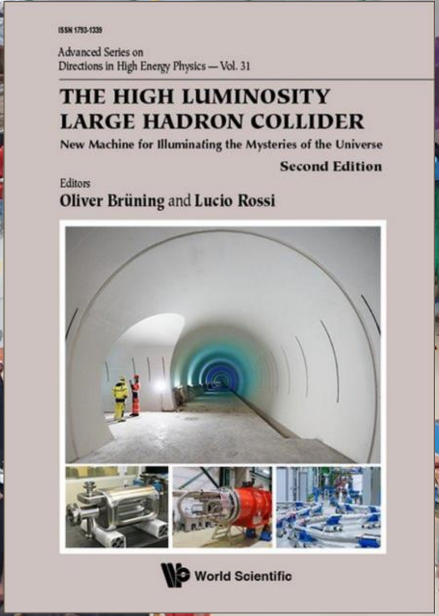
# Outline

1. HL-LHC upgrade goals
2. (Main) Technical challenges of the HL-LHC upgrade
3. Inner Triplet String
4. Conclusions

# Many Thanks!


MQXFBP3




**V0.1 Published in electronic version for the October 2016 Cost & Schedule review**
EDMS: 1723851
and as CERN Yellow Book in October 2017

**Updated Version V 1.0 published as**
**CERN Yellow Book in December 2020**
https://e-publishing.cern.ch/index.php/CYRM/issue/view/127

**Hi-lumi Book 2nd edition**
https://www.worldscientific.com/worldscibooks/10.1142/13487#t=aboutBook

# Spare Slides

# HL-LHC Design Parameters

| Parameter | Nominal LHC (design report) | HL-LHC 25ns (standard) |
|---|---|---|
| Beam energy in collision [TeV] | 7 | 7 |
| $N_b$ | 1,15E+11 | 2,2E+11 |
| $n_b$ [12] | 2808 | 2760 |
| $N_{tot}$ | 3,2E+14 | 6,1E+14 |
| Beam current [A] | 0,58 | 1,1 |
| Half Crossing angle [μrad] | 142,5 | 250 |
| Minimum $\beta^*$ [m] | 0,55 | 0,15 |
| $\varepsilon_n$ [μm] | 3,75 | 2,50 |
| $\varepsilon_L$ [eVs] | 2,5 | 3,03 |
| Piwinski parameter | 0,65 | 2,66 |
| Peak Luminosity without crab-cavity [$cm^{-2}\ s^{-1}$] | 1,00E+34 | 8,1E+34 |
| Virtual Luminosity with crab-cavity: Lpeak*R1/R0 [$cm^{-2}\ s^{-1}$] | - | 1,70E+35 |
| Events / crossing without levelling and without crab-cavity | 27 | 212 |
| Levelled Luminosity [$cm^{-2}\ s^{-1}$] | - | 5,0E+34 [4] |
| Events / crossing (with leveling and crab-cavities for HL-LHC) [7] | 27 | 131 |
| Leveling time [h] (assuming no emittance growth) [7] | - | 7,2 |
| $n_b$ / injection | 288 | 288 |
| $\varepsilon_n$ at SPS extraction [μm] [3] | 3,5 | 2,1 |

LHC Magnet system

LHC injector complex

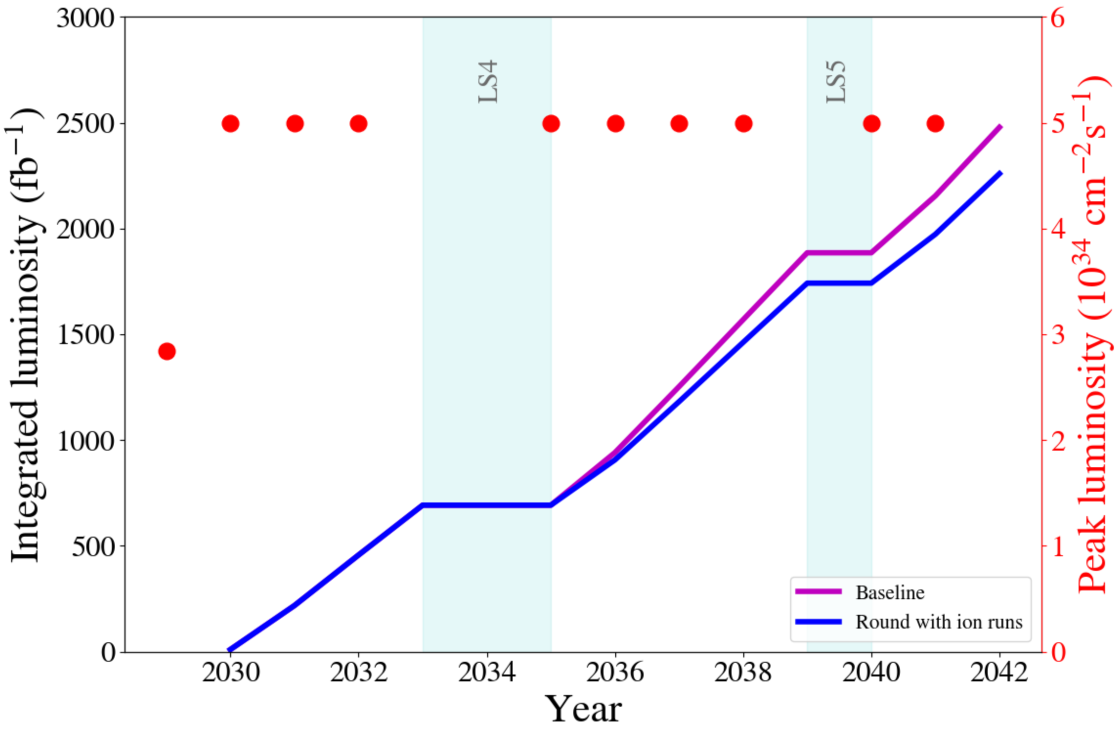
HL-LHC triplet magnets

HL-LHC crab cavities

Machine operation & availability

LHC injector complex

# Luminosity performance




**Courtesy N. Mounet**

(Note that **~460 $fb^{-1}$** should be added for the **LHC runs)**

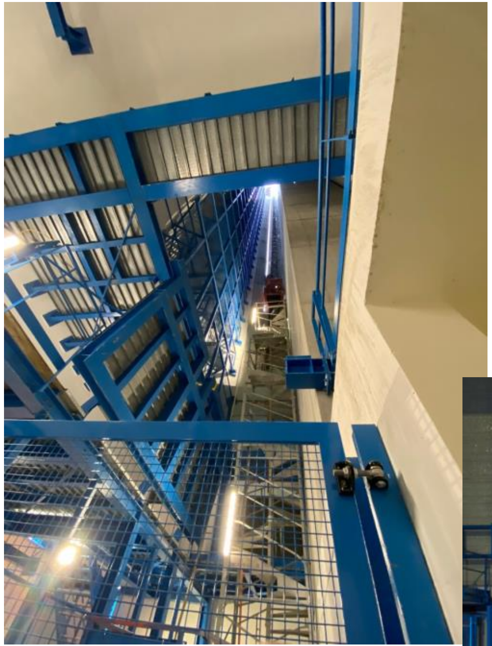
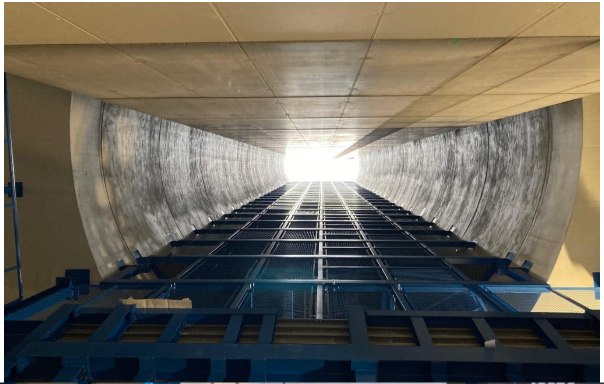
Extension of the ALICE run beyond LS4 and the planned LHCb upgrade in LS4, both will have an impact on LHC operation and on the performance reach of HL-LHC

# IR1/5 underground civil engineering completed in 2022

Construction Finished End 2022

vork was conducted during LS2 ➔ vibration impact

# Ceremony for completion of CE on January 20th 2023

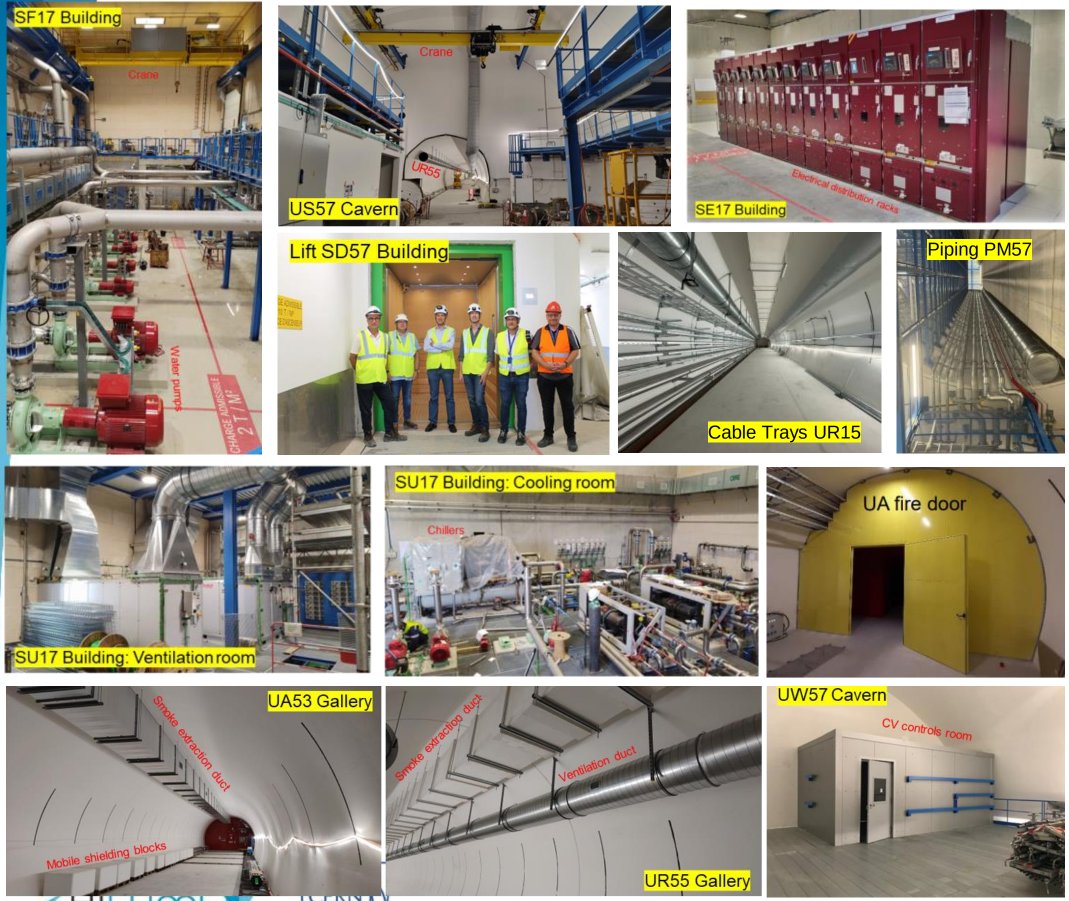
# Completion of Surface buildings in 2023

Work Ended Spring 2023

Point 1


Point 5

# Technical Infrastructure – Installation Services

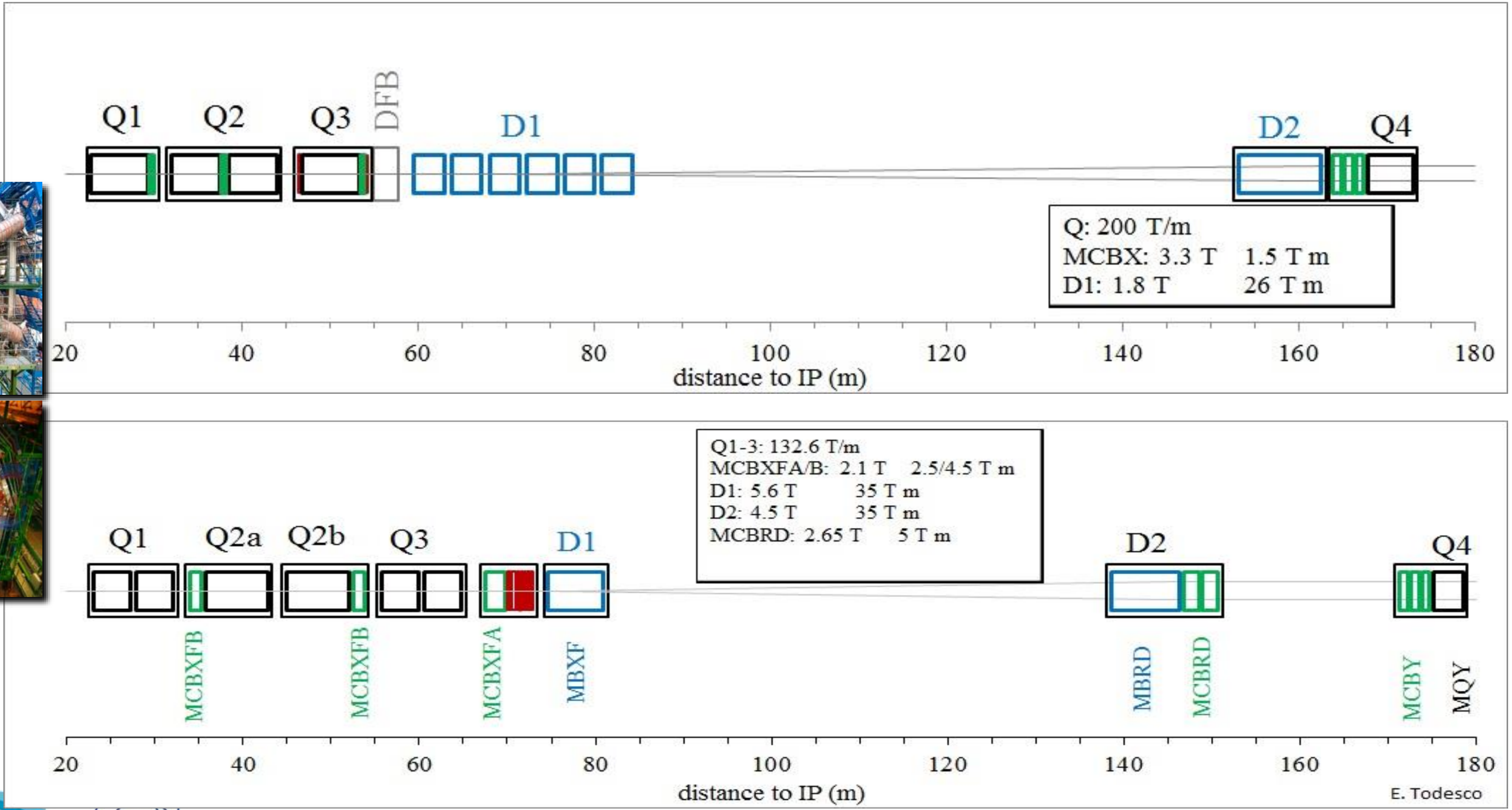



**Technical Services** in full swing for installation:

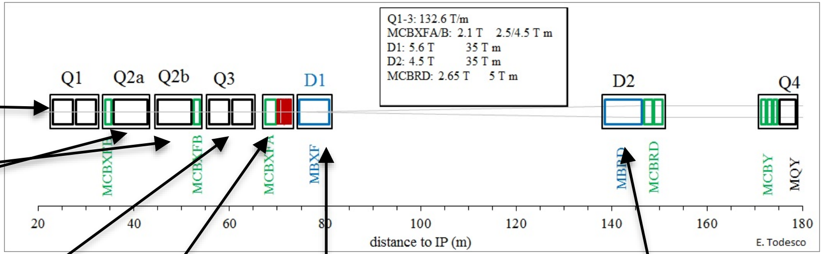
- ✓ **Sectional doors**
- ✓ **Lifts**
- ✓ **Overhead Cranes**
- ✓ **Fire safety**
- ✓ **Cable trays & cabling**
- ✓ **Lighting**
- ✓ **Switchboards**
- ✓ **Racks**
- ✓ **Power Transformers**
- ✓ **Ventilation system**
- ✓ **Cooling system**

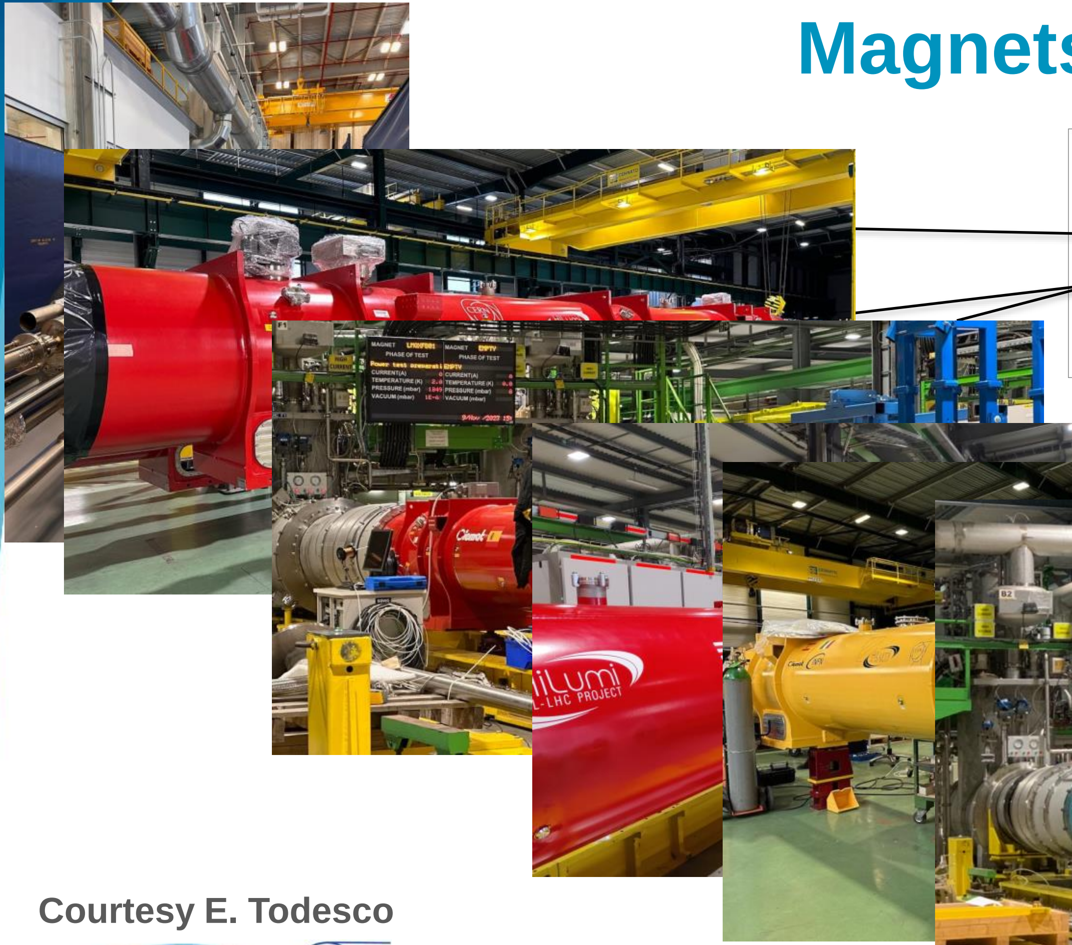
# New HL-LHC Triplet Layout

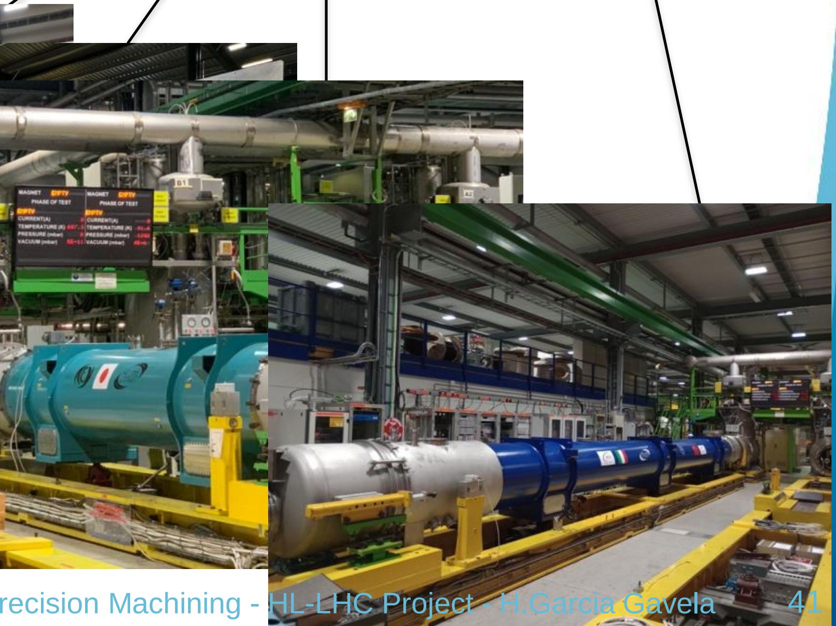




# Magnets

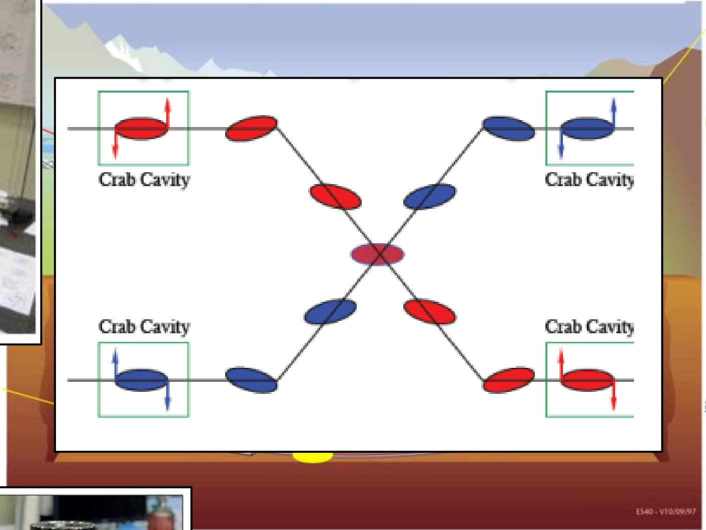


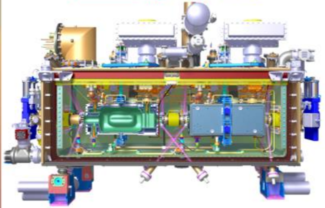


Courtesy E. Todesco

# Crab Cavities *See R. Calaga's presentation*

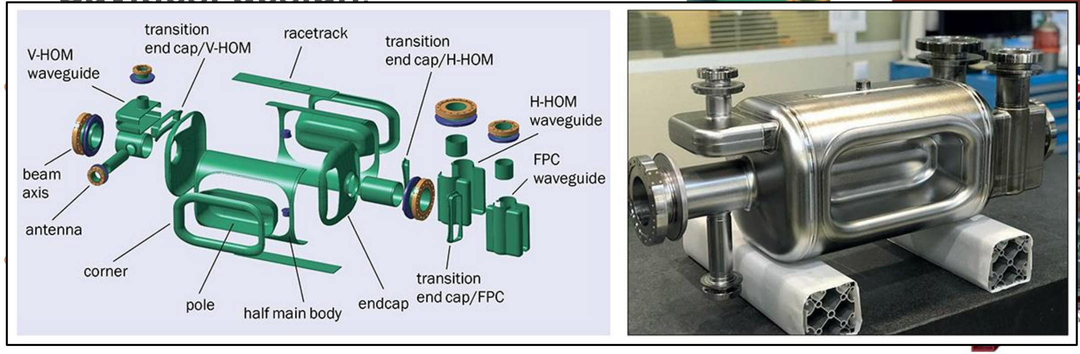


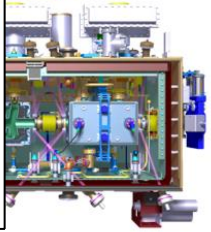

4+1 RF Dipole cryomodules
US-AUP, Canada, CERN



cavities emerged **in ~2006**. Since then, many years of **R&D, Proof of Principle Cavities, design**.

4+1 DQW Cryomodules
UK, CERN



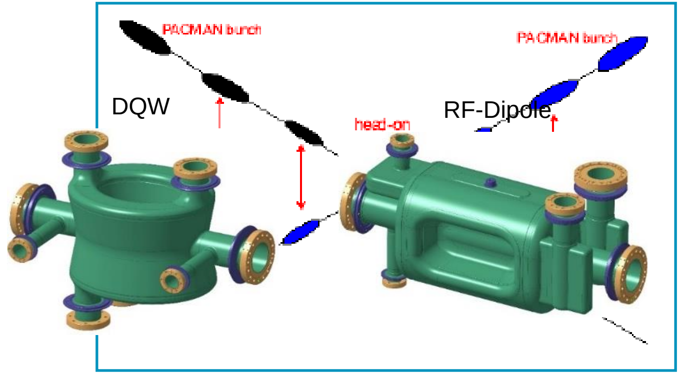



RF powering & control

# HL-LHC Technical Challenges: Crab Cavities

## Crab Cavities:

## Geometric Luminosity Reduction Factor:

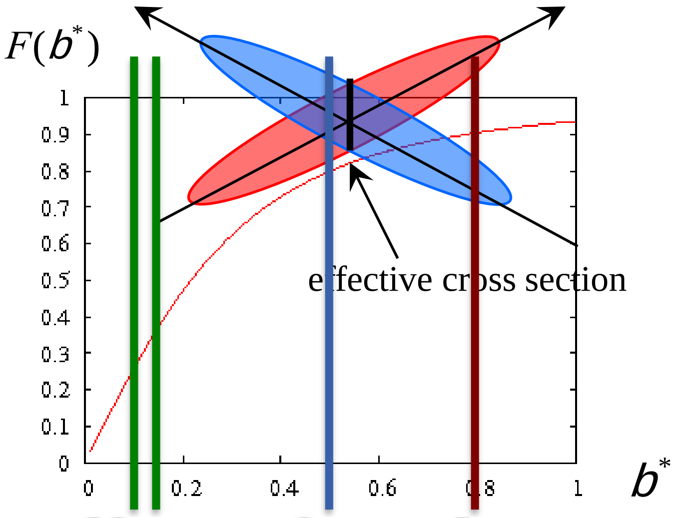


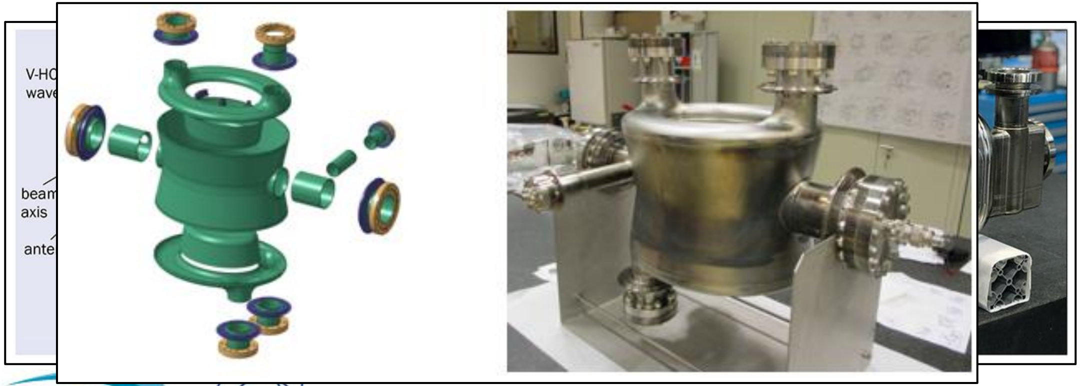

Full Crossing angle:

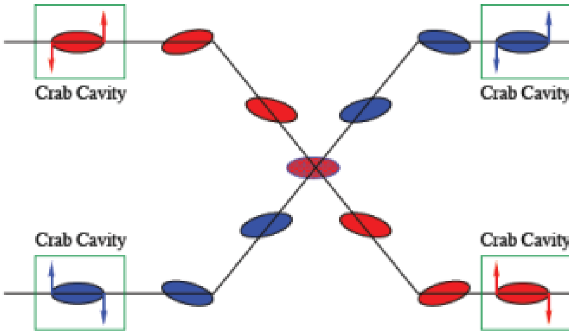
285 mrad LHC TDR

-> 329 mrad in LHC op

-> 500 mrad HL TDR



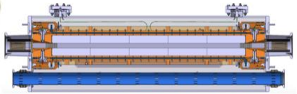


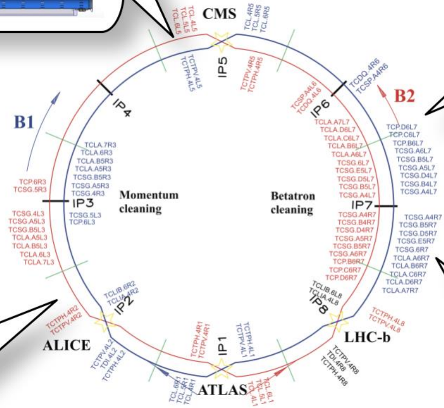
# Collimation

*See S. Redaelli's presentation*

**LS3**

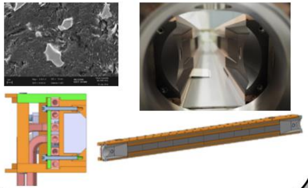
**IR collimation:** Completely new layouts and collimator designs: IR1+IR5: incoming and outgoing. Full remote alignment system (FRAS)

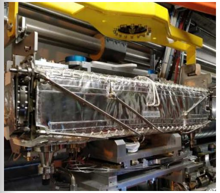





**LS2+LS3**

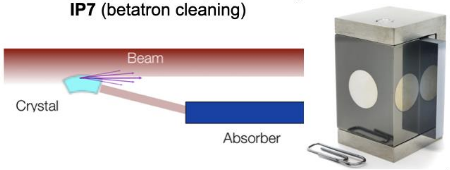
**Impedance reduction:** low-impedance, high robustness secondary collimators: coated MoGr
Un-coated MoGr primary collimators.





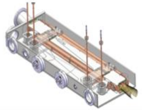

**LS2+YETS**

**Crystal-assisted collimation (Pb ions)**
4-8 bent crystals, 50 µrad bending
**IP7** (betatron cleaning)




**LS2**

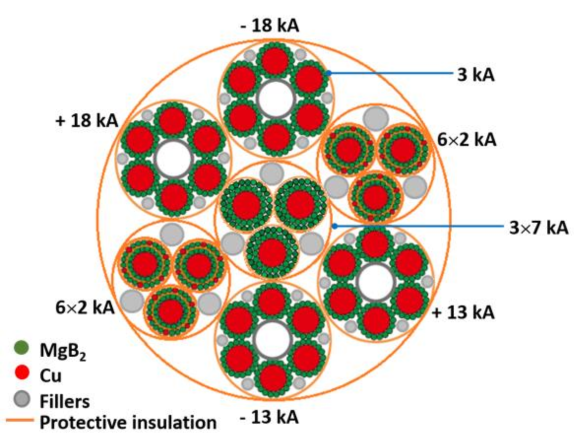

**Dispersion suppressor collimation:** Secondary beams from ion physics



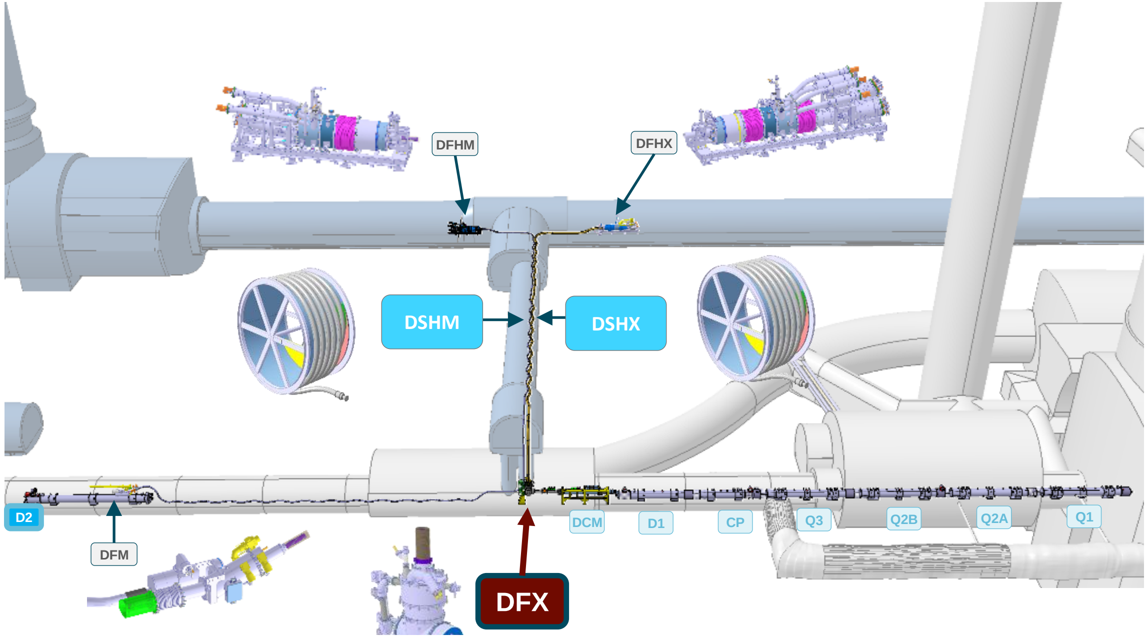
**Consolidation (not HL):** low-impedance primaries (material from WP5), renew controls, maintain / replace rest of system

***Crucial upgrades took place in LS2: the LHC is already profiting from! Moving now towards LS3 production***

# Cold powering systems - SC link using $MgB_2$ superconductor




Diam ca. 90mm
> 100kA @ 25K




- **Successful PoP validation** via **system demonstrators (DEMO)**
- **MgB2 wire production complete**
- **MgB2 cable** production at **80%**
- **DFX cryostats** delivered by **UK Collaboration**; **DFM** in production
- **DFHX cryostats** delivered by **Swedish Collaboration**; **DFHM** in production
- All **flexible cryostats at CERN**
- **Rebco Tape** in production
- **Assembly of the first complete system and successful validation test**

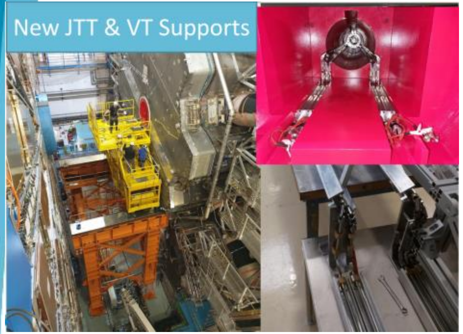
# Successful test of the 1st SC Link System

- Cryogenic performance and operation
- Powering and EMC among circuits
- HV Tests including ELQA validation
- Instrumentation
- Thermal cycling and contraction of the system
- Mechanical integrity




# Other major achievements


TANB absorber installed in LS2



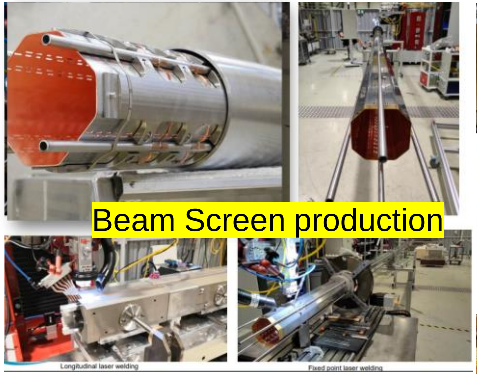


MKI installed in *EYETS'23


TDIS installed in LS2

BGC installed in EYETS'23


Warm Helium Storage Tanks at P1 & P5

Beam Screen production


EE Systems pre-series

Power Converters production



BPM production

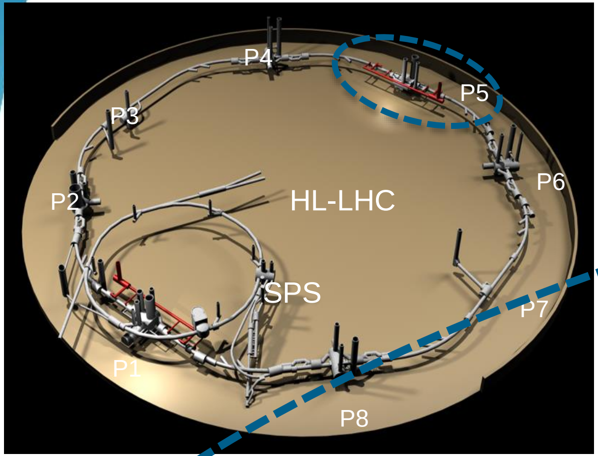

CLIQ pre-series

TDE material HiRadMat

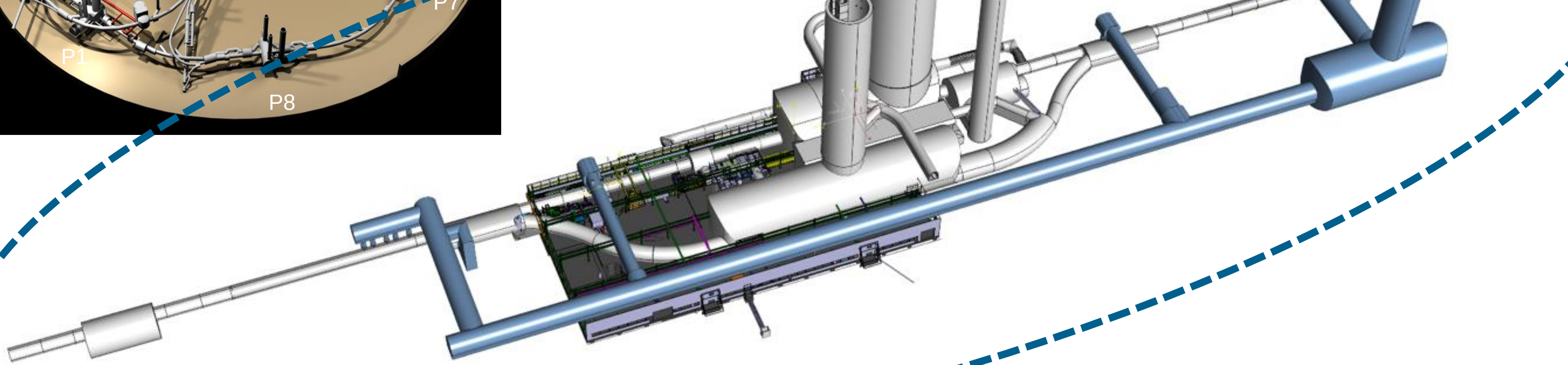

EYETS - Extended Year-End Technical Stop
MKI – Magnet Kicker at Injection
BGC – Beam Gas Curtain
TDIS - Target Dump Injection Segmented

CLIQ - Coupling-Loss-Induced-Quench
BPM – Beam Position Monitors
TDE – External Beam Du

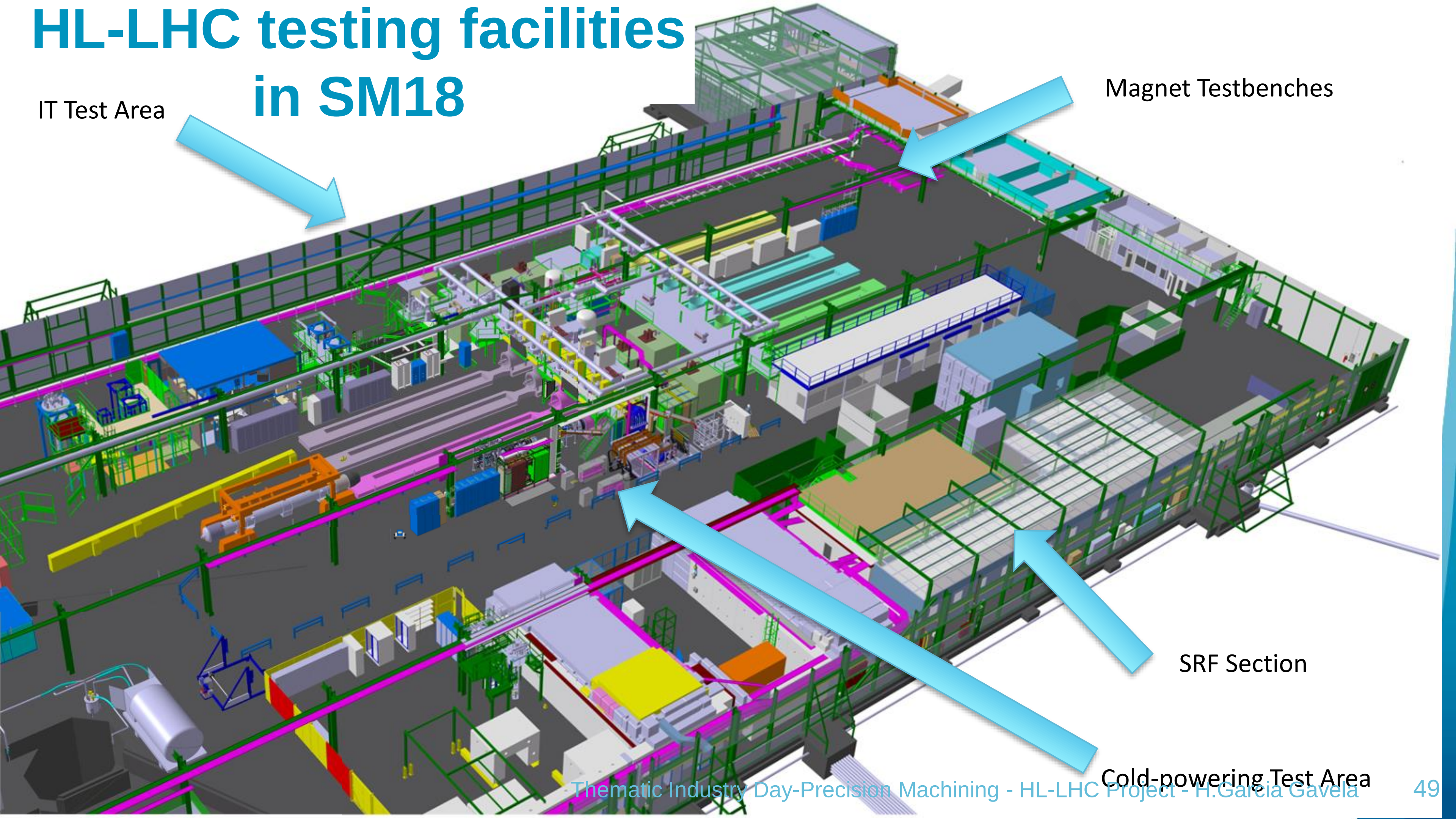
# Next Milestone: HL-LHC IT STRING: P5L



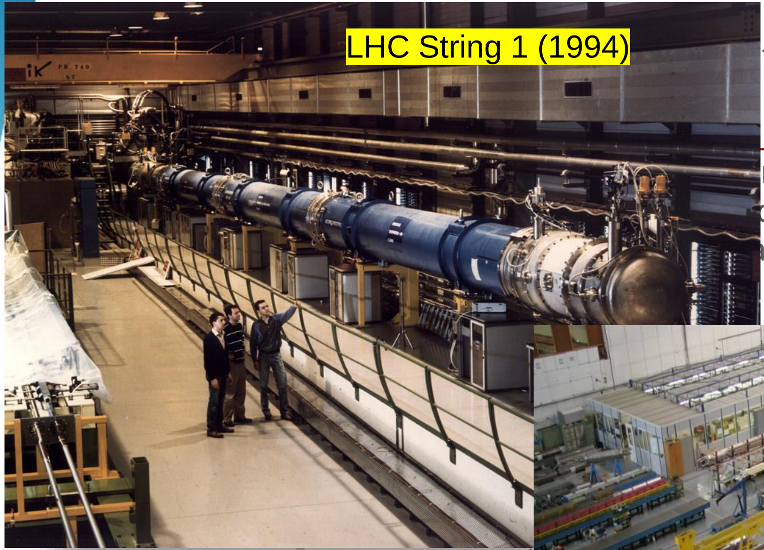

P5



# HL-LHC testing facilities in SM18



# The IT STRING Scope

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magnet prot
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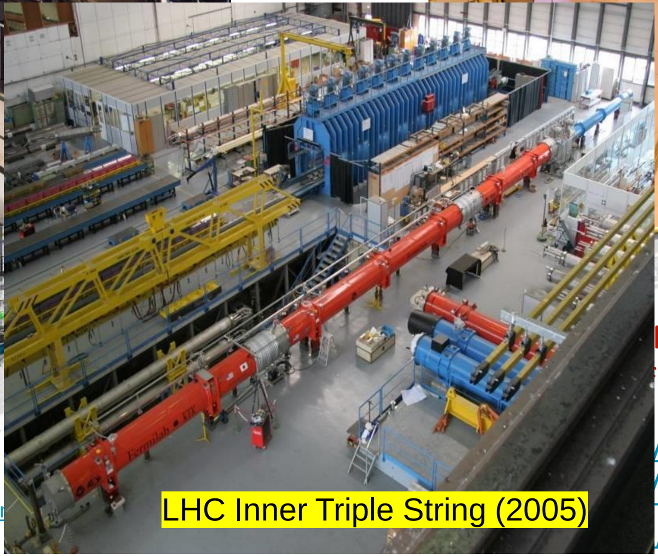


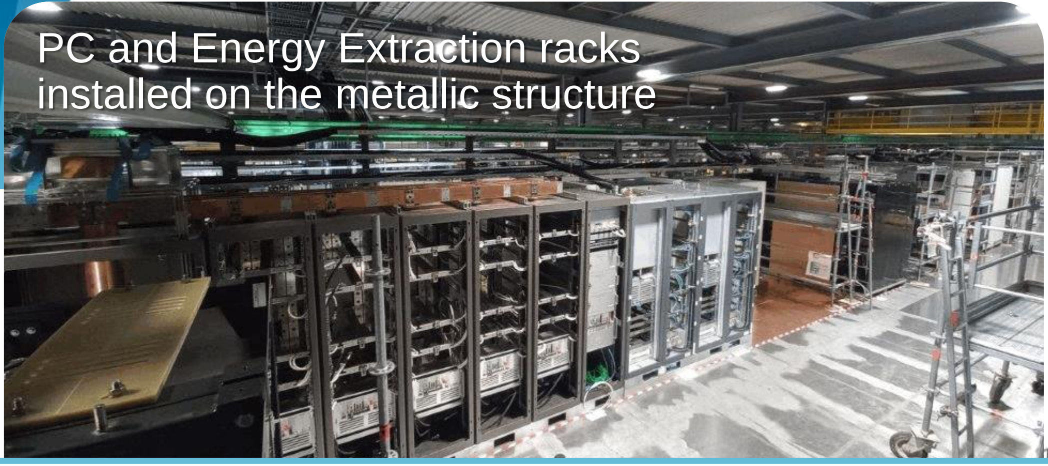

Ref. HL-LHC IT STRING Scope https://edms.cern.ch/documer

NG will deliver **the first complete experience**
installing and operating the IT zone

/indico.cern.ch/event/741801/ - Oct’18
//indico.cern.ch/event/1183794/ - Sep’22
//indico.cern.ch/event/1298459/ - Sep’23
IT String Day IV - https://indico.cern.ch/event/1408524/ - Sep’24

HiLumi HL-LHC PROJECT
CERN

# IT String Status in pictures




IST (Individual System Tests) and SCT (Short Circuit Tests already carried out this year.