

HL-LHC Project

O. Brüning
On behalf of the
HL-LHC Project



LHC in the Geneva Basin and its Experiments



Features proton-proton and Lead-Lead and Lead-proton collisions!

22km arcs with Super Conducting Magnets

LHC ring:
27 km circumference

LHC (Large Hadron Collider): Magnet Technology

14 TeV proton-proton accelerator-collider built in the LEP tunnel → requires ca. 9T magnets!!!

→ 200000 times the earth magnetic field!!

→ Requires Superconducting magnet technology

- 1983 : First studies for the LHC project
- 1988 : First magnet model (feasibility)
- 1994 : Approval by the CERN Council
- 1996-1999: Series production industrialisation
- 1998 : Declaration of Public Utility & Start of civil engineering
- 1998-2000: Placement of main production contracts
- 2004 : Start of the LHC installation
- 2005-2007: Magnets Installation in the tunnel
- 2006-2008: Hardware commissioning
- 2008-2009: Beam commissioning and repair

As of 2010: Physics exploitation



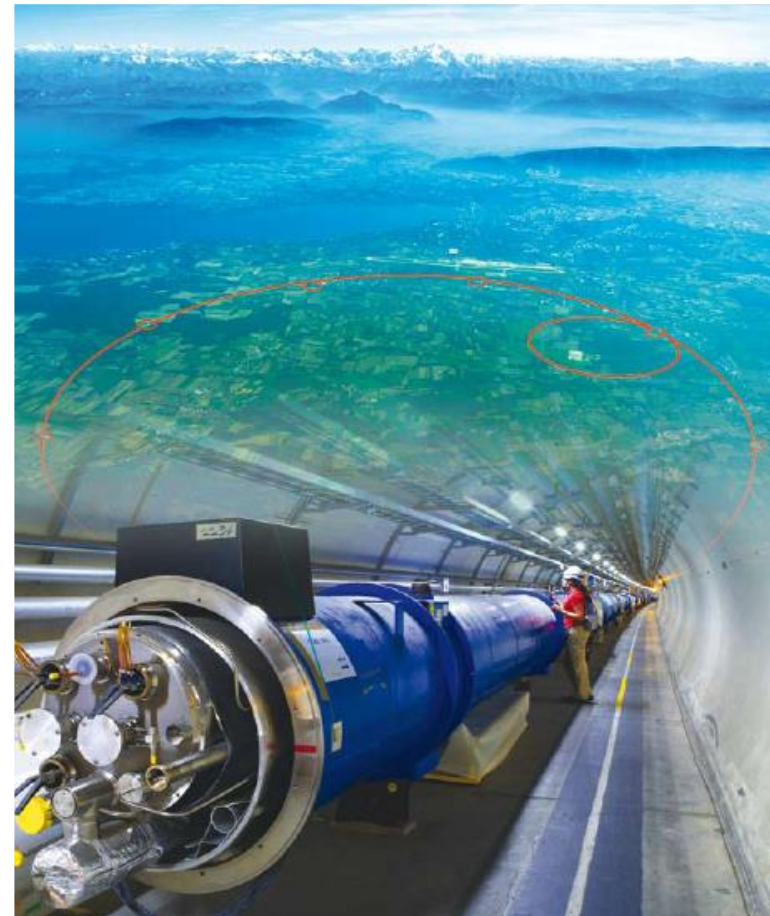
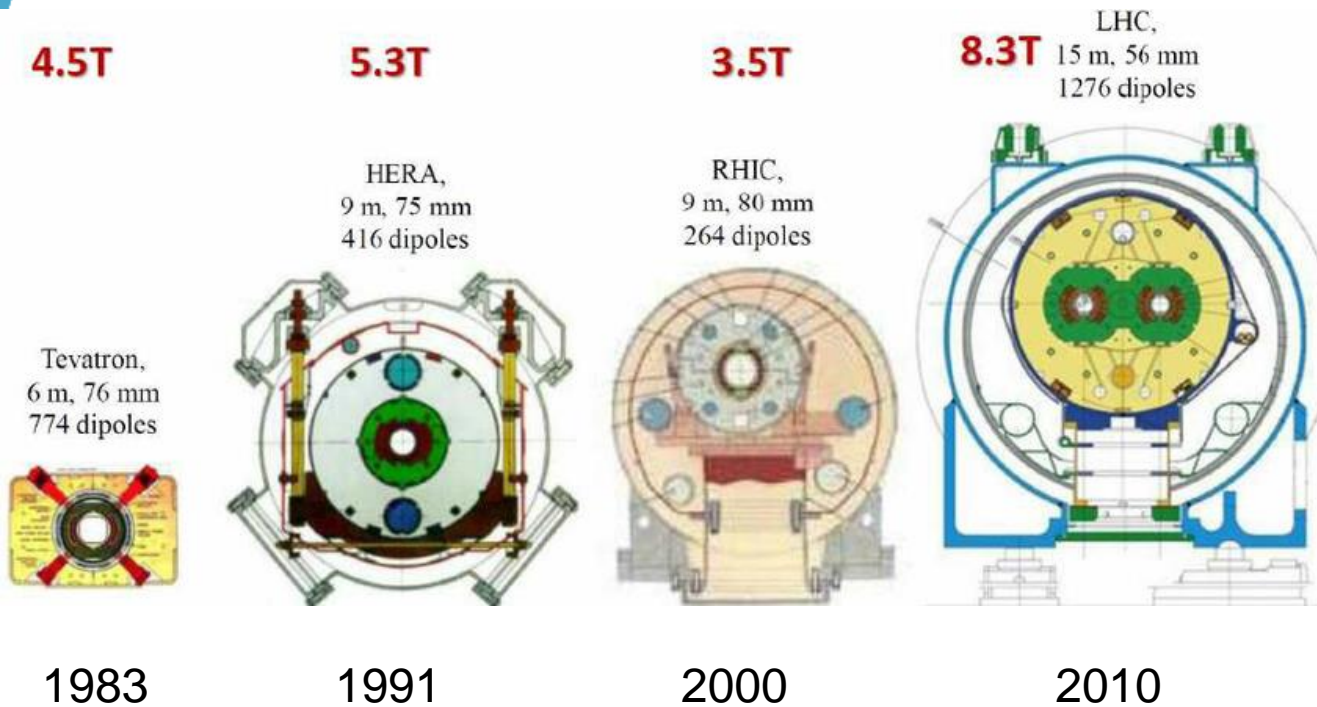
Ca. 20 years magnet development!!!



Ca. 30 years machine development!!!

→ Significant Time scale extending well beyond that of a physicist career!!!

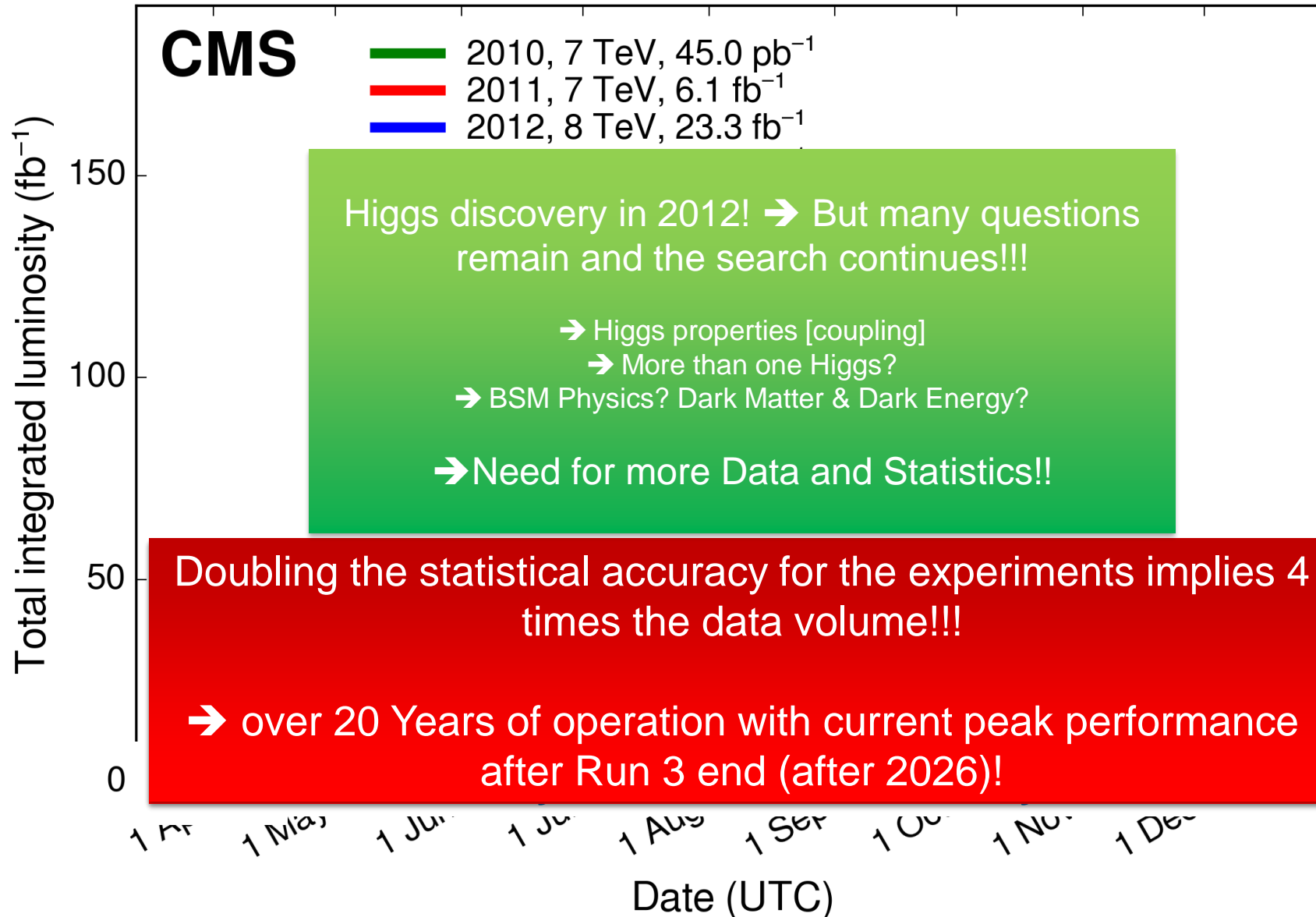
LHC (Large Hadron Collider): Magnet Technology



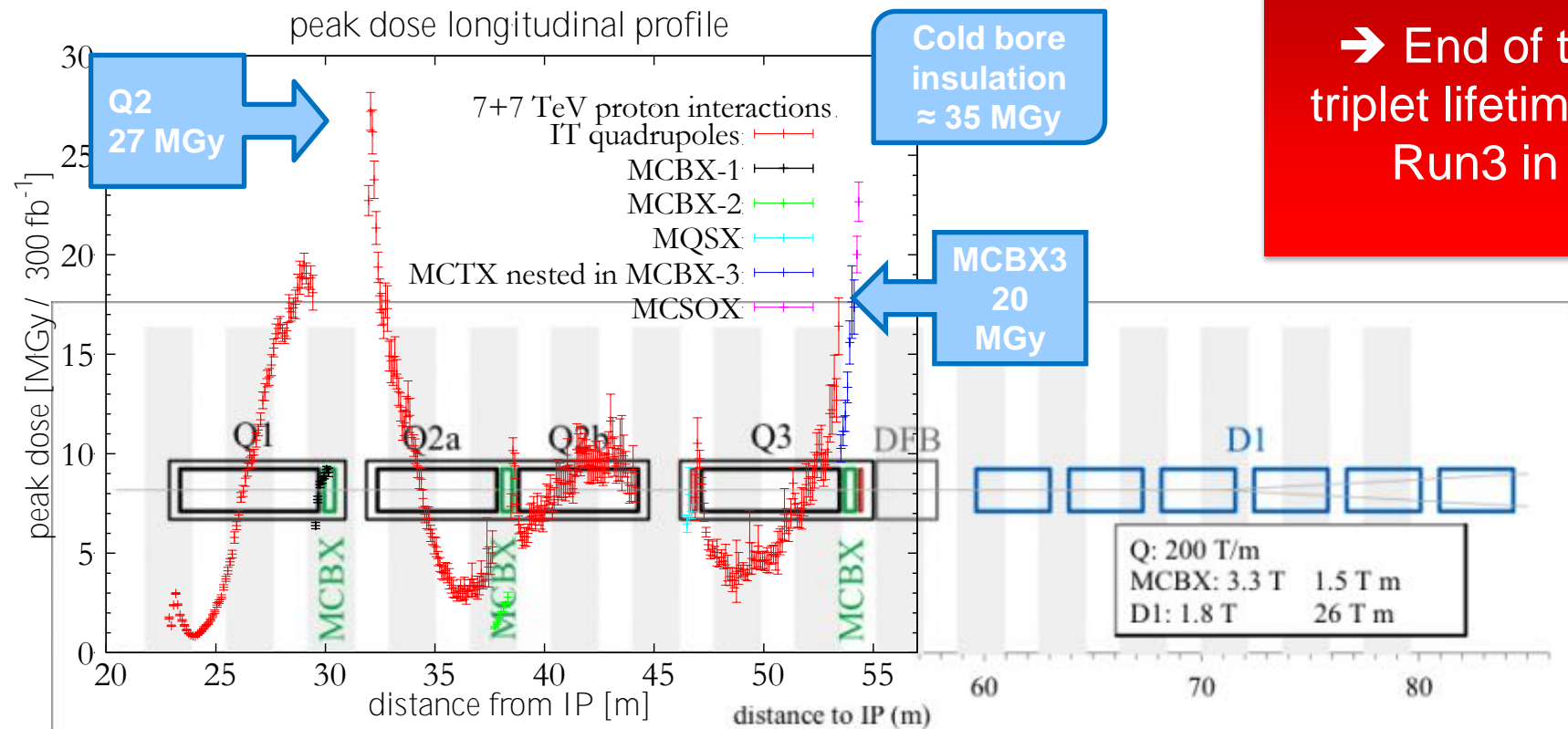
→ The LHC dipole magnets mark the culmination of 30 years of superconducting magnet technology development!

→ Requiring 1.9K [-271 degrees Celsius] operating temperature

LHC Performance



LHC Lifetime Limitation: Debris from the IP & Radiation damage to magnets!



→ End of the LHC triplet lifetime by End Run3 in 2026

→ HL-LHC goal: 10 times the LHC data Volume within 10 years of operation

HL-LHC technical bottleneck: Radiation damage to triplet magnets

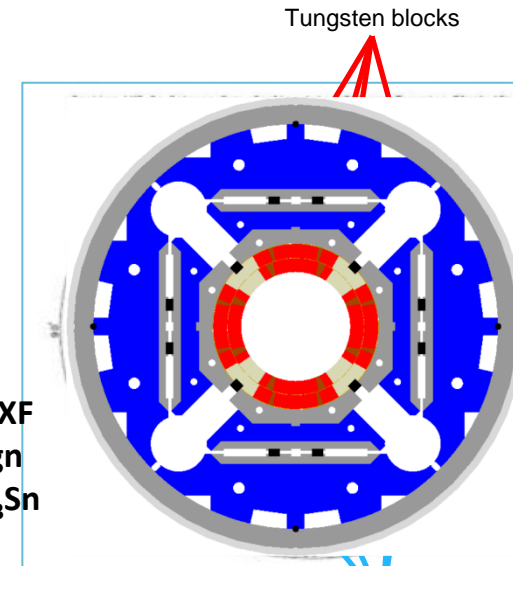
Need to replace existing triplet magnets with radiation hard system such that the new magnet coils receive a similar radiation dose @ 10 times higher integrated luminosity!!!!

→ Shielding!

- Requires larger aperture!
- New magnet technology!

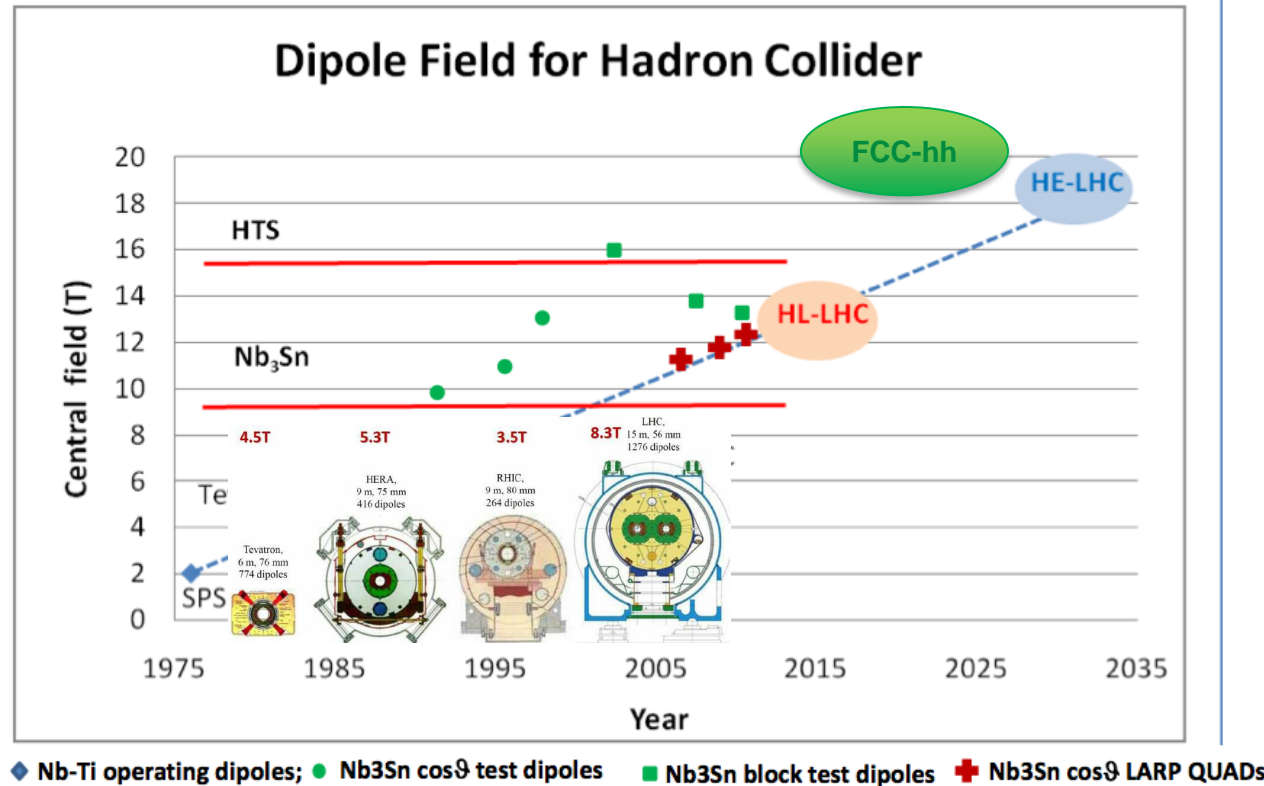
- 70mm at 210 T/m → 150mm diameter 140 T/m → Longer magnets
8T peak field at coils → 12T field at coils (Nb₃Sn)!!! → New Superconductor

US-LARP MQXF magnet design
Based on Nb₃Sn technology



High Field SC Magnets

Magnet development requires substantial R&D effort!!!



Ca. 30 years of NbTi magnet R&D leading up to the LHC dipole magnets!

Transition from NbTi to Nb₃Sn: required similar length of R&D!

HL-LHC led the R&D for 11-15T magnets based on Nb₃Sn technology:

- Started in early 2000
- 15-20 years R&D program
- Ready for installation by 2025
- Ready for operation by 2029
- ca. 30 years of development!!!

Technology Landmarks

NEW TECHNOLOGIES FOR THE HIGH-LUMINOSITY LHC



CIVIL ENGINEERING
2 new 300-metre service tunnels and 2 shafts near ATLAS and CMS.

“CRAB” CAVITIES
16 superconducting “crab” cavities for the ATLAS and CMS experiments to tilt the beams before collisions.

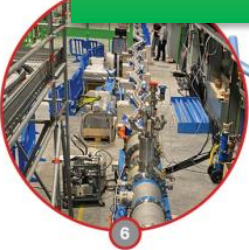
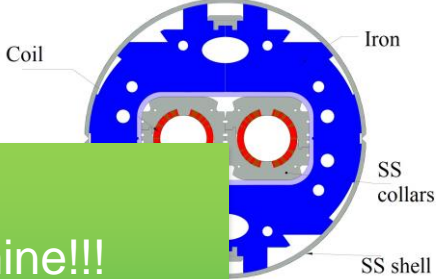


Separation / Recombination dipole magnets: D1 & D2



Need to overcome several limitations in the existing LHC machine!!!

Ca. 1BCHF CtC Project



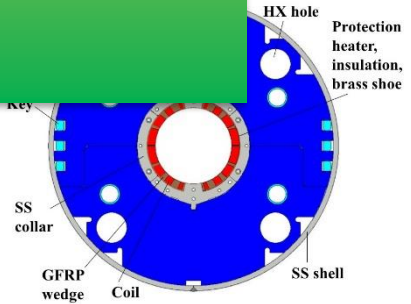
SUPERCONDUCTING LINKS
Electrical transmission lines based on a high-temperature superconductor to carry the very high DC currents to the magnets from the powering systems installed in the new service tunnels near ATLAS and CMS.



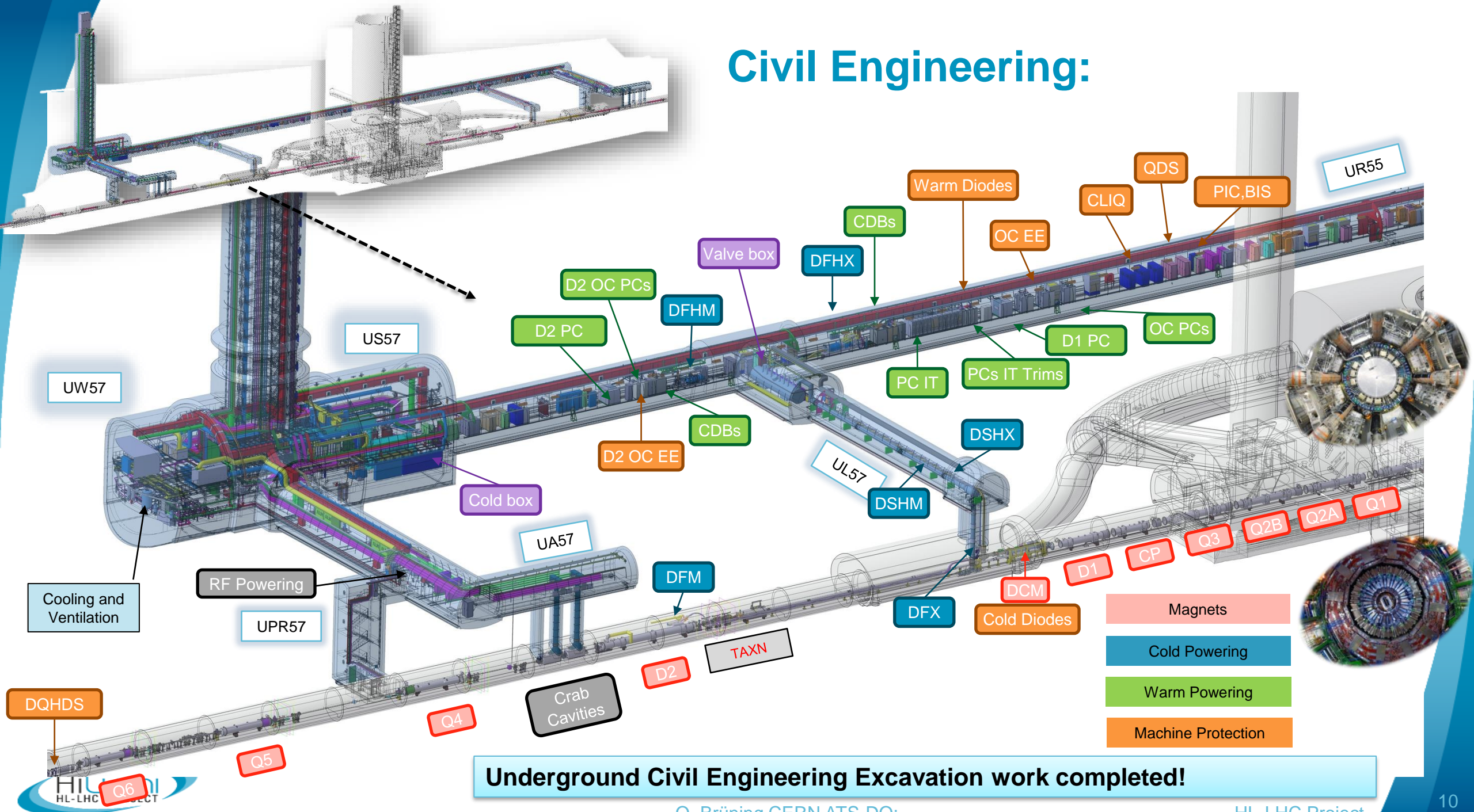
COLLIMATORS
15 to 20 additional collimators and replacement of 60 collimators with improved performance to reinforce machine protection.



CRYSTAL COLLIMATORS
New crystal collimators in the IR7 cleaning insertion to improve cleaning efficiency during operation with ion beams.

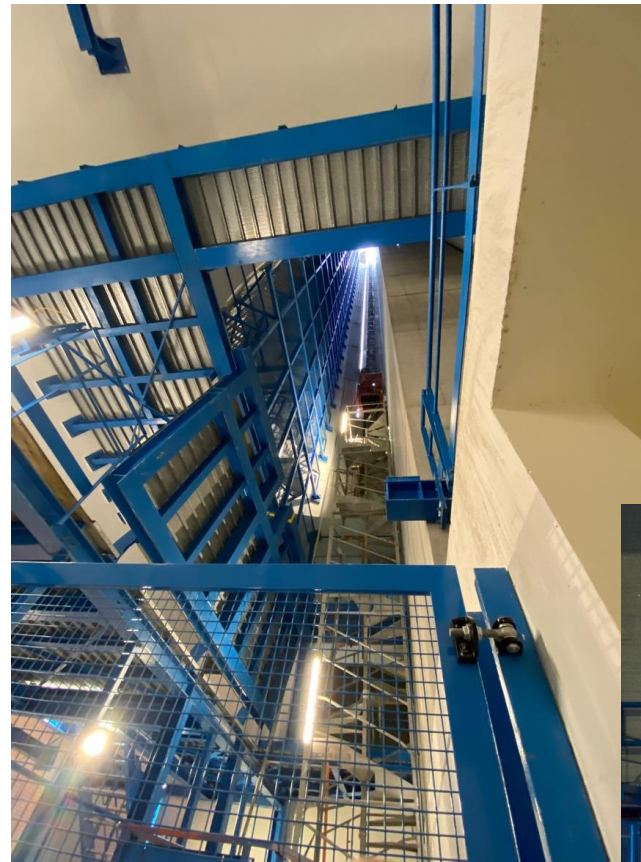


Civil Engineering:



Underground Civil Engineering Excavation work completed!

Completion of CE on January 20th 2023

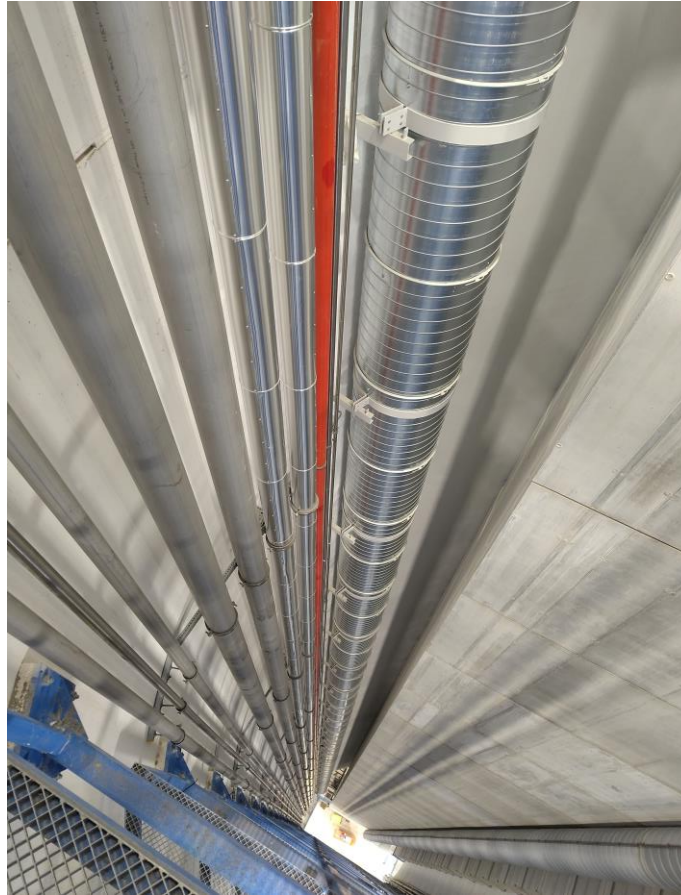


Completion of the civil engineering works: Surface Buildings finished in 2023

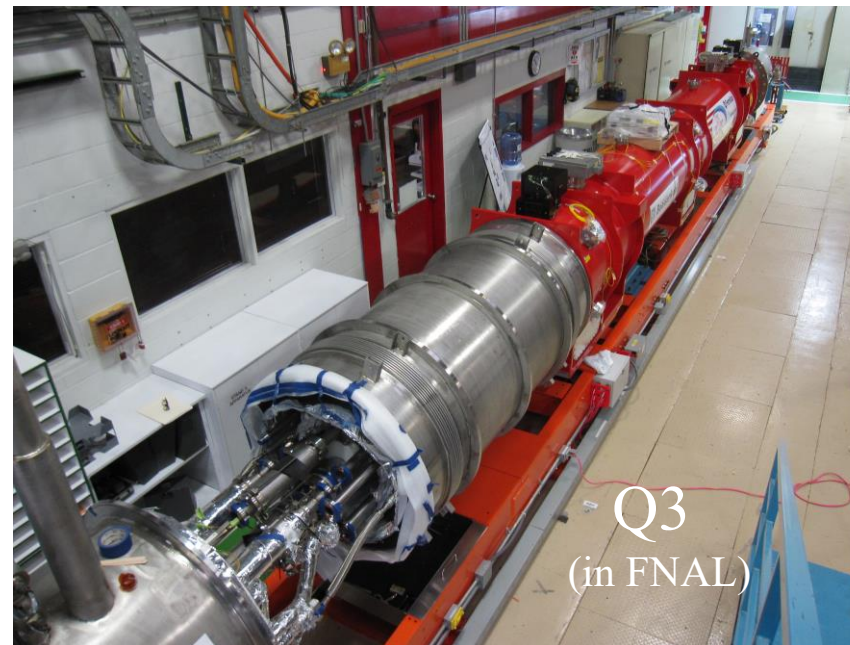
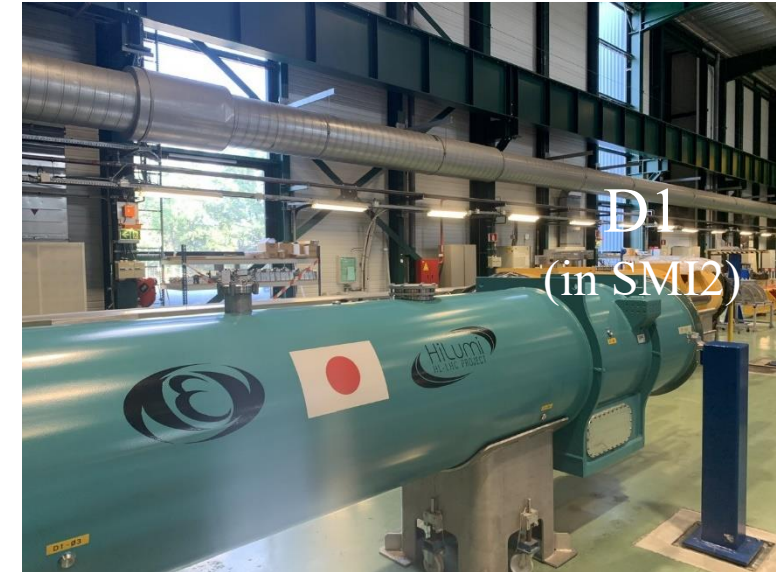


Example Point 1

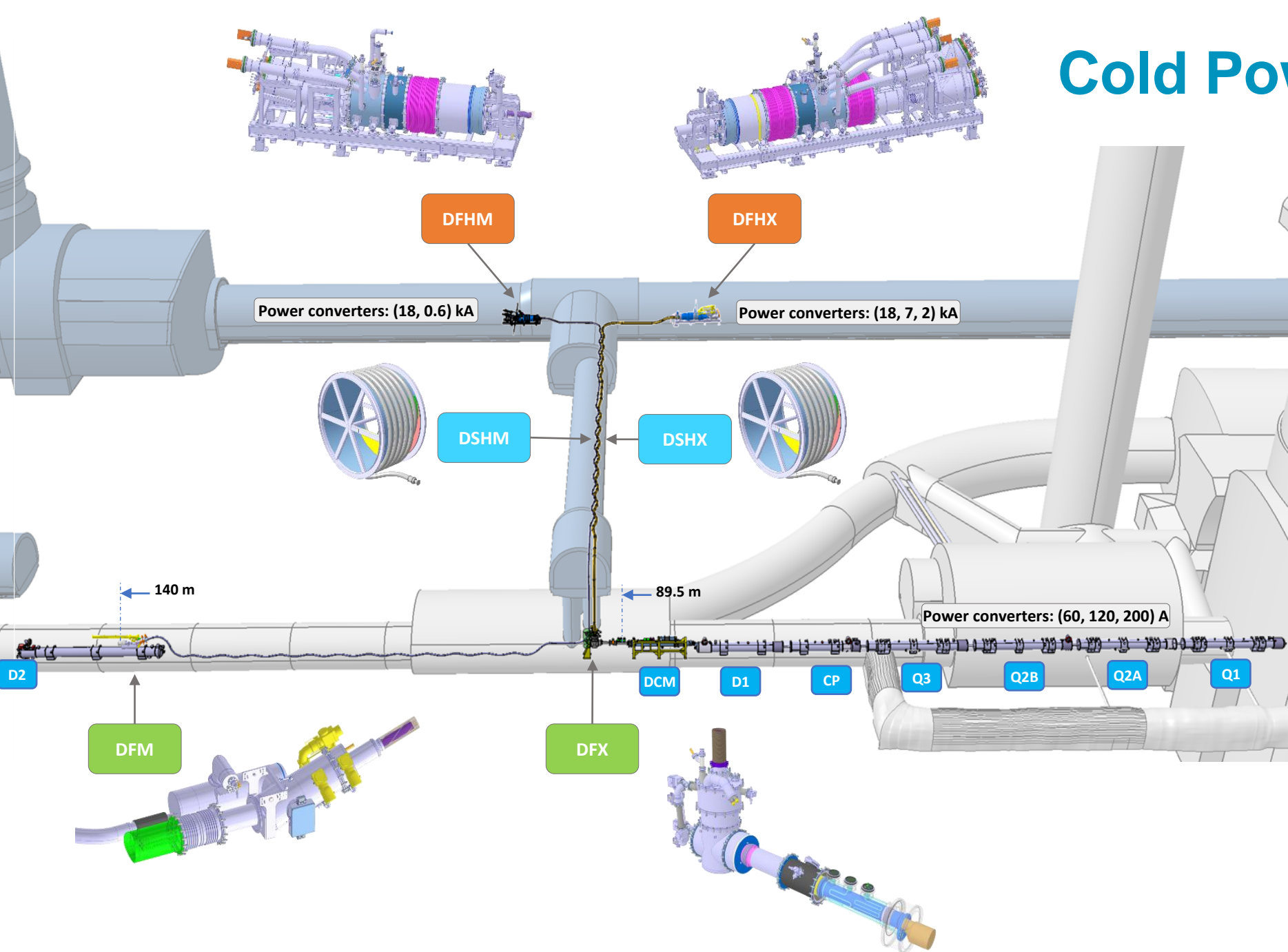
Status of infrastructure installations at P5



NEW MAGNETS ARE GETTING READY: Fully in Series Production

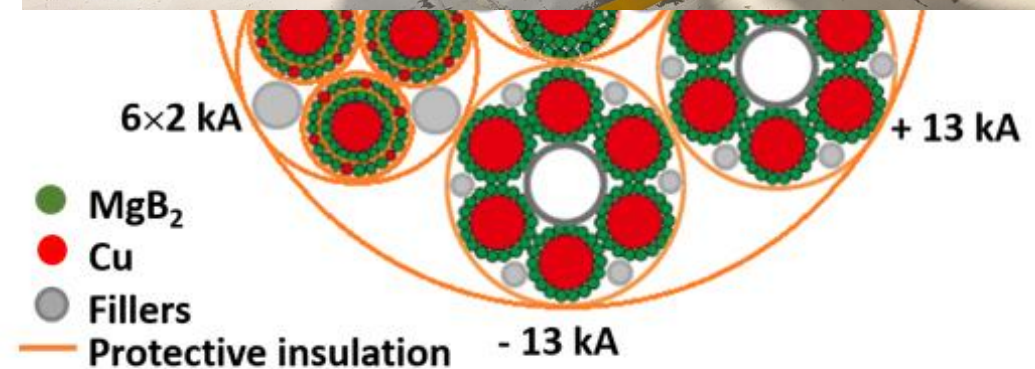


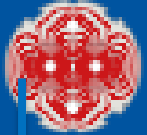
Cold Powering System



MgB₂ Superconductor and

The flexible, double-wall, corrugated cryostat comprises 19 superconducting cables twisted together to form a compact bundle. These 19 superconducting cables carry a current of about 120 kA at ~20 K.





LHC / HL-LHC Plan

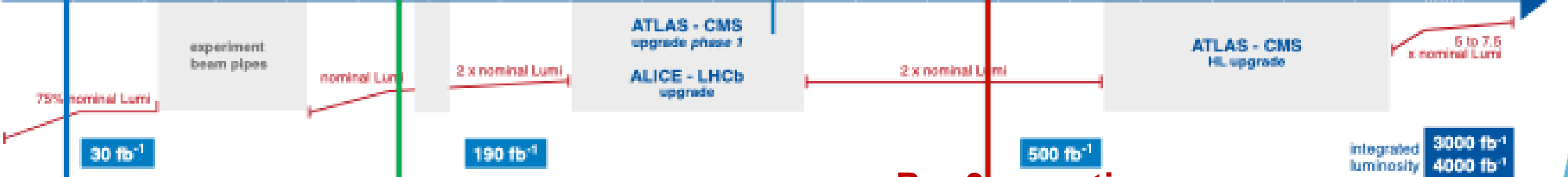
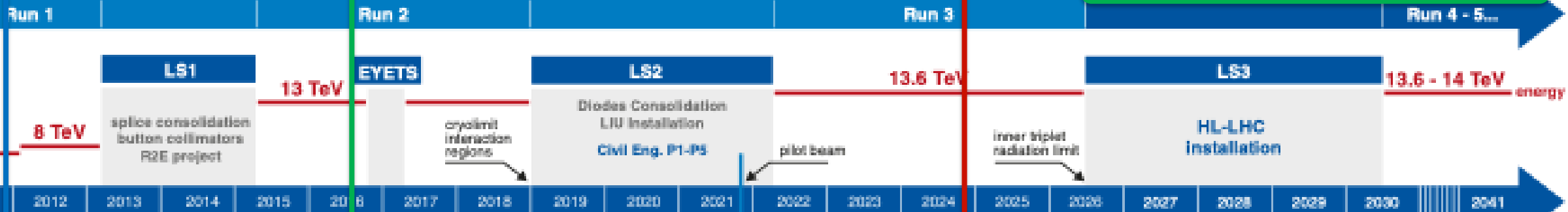


EU funded HiLumi Design Study

Approval of HL-LHC Project

LHC

HL-LHC

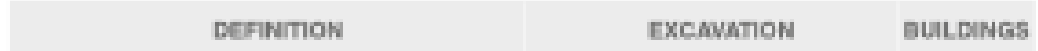


Run3 operation

HL-LHC TECHNICAL EQUIPMENT:



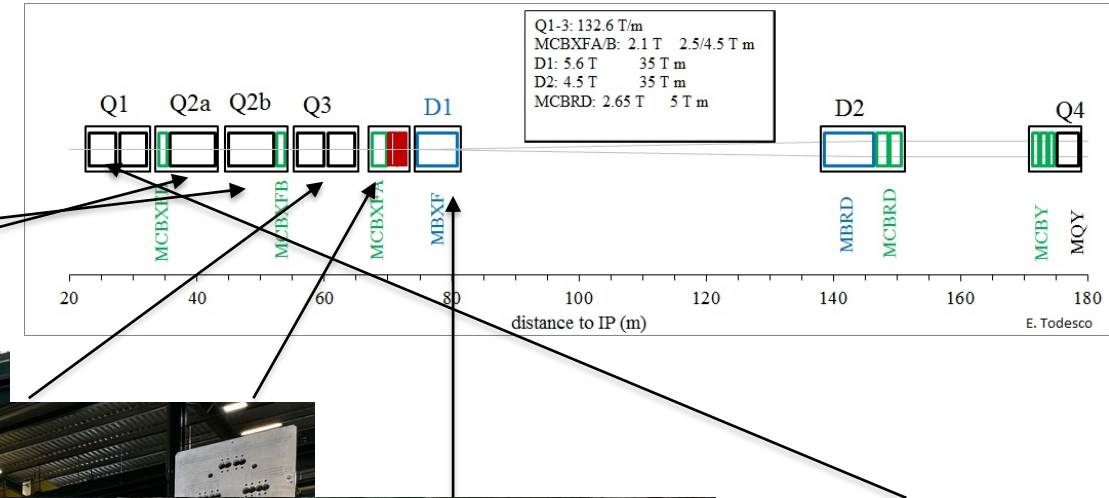
HL-LHC CIVIL ENGINEERING:



LHC Operation ends in 2026
 → HL-LHC upgrade to take over as of 2030 after LS3



Magnet Validation for IT-String



Completed testing at FNAL;
Expected @ CERN by January 2025

Q2a cold mass installation



Sc Link INSTALLATION IN THE IT STRING



ISSN 1793-1339

Advanced Series on
Directions in High Energy Physics — Vol. 31

THE HIGH LUMINOSITY LARGE HADRON COLLIDER

New Machine for Illuminating the Mysteries of the Universe

Second Edition

Editors

Oliver Brüning and Lucio Rossi



 World Scientific

LHC Summary

CERN COURIER

January/February 2024 cerncourier.com

Reporting on international high-energy physics

Published in 2024 and available
as

Open Access Publication

<https://doi.org/10.1142/13487>

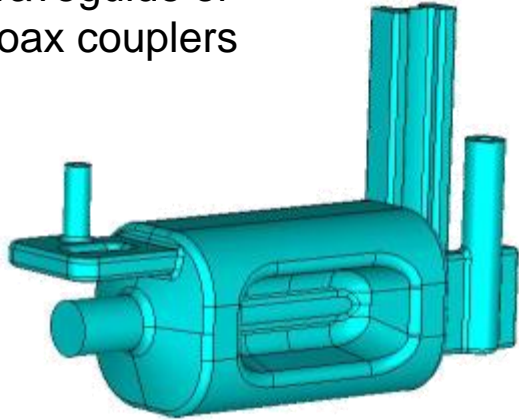
ISBN: 978-981-127-894-5

HIGH-LUMINOSITY LHC ON TRACK

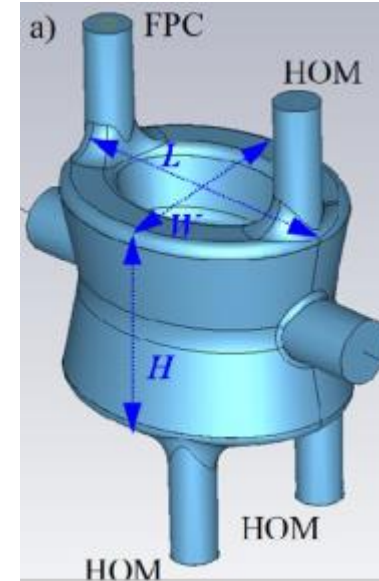


HL-LHC cavity designs

RF Dipole: Waveguide or waveguide-coax couplers



2 Designs with Different Coupler concepts and for crossings in the vertical and horizontal planes



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

Present baseline: 4 cavities / IP / side → 16 total

Present baseline: 2 cavities within one common cryostat

HiLumi HL-LHC PROJECT

RFD CAVITY ASSEMBLY

- FBI system (2x 8 heads) For CAVITY POSITION MEASUREMENT
- ALIGNMENT SYSTEM SUPPORT & ALIGNMENT OF CAVITIES
- Upper Cryogenic line LHCACF0449 (EDMS: 1833682)
- RFD Cavity assembly *See detailed view
- Cryogenic safety valve and pressure measurement in bottom guard
- Radio Frequency wave guide for RF power supply
- Tuner Actuation LHCACFTU
- V-HOM filter LHCACFVW
- Beam screen LHCACFVS
- RFD Cavity LHCACFCA
- Cold magnetic shield Cryoply 8 - LHCACFCM
- FPC LHCACFPC
- H-HOM filter LHCACFHH
- Relaxation Tank LHCACFR
- Tuner Frame LHCACFTF
- Pick Up Antenna LHCACFPA
- Vacuum Vessel LHCACFVV
- HOM extraction lines (x4) Coaxial line 25/50 ohms
- Beam vacuum gate valves (x4) with RF insert
- Cold/Warm Transition LHCACFVW See EDMS: 1758698 & 1758697
- Lower cryogenic line LHCACFCO
- Alignment jacks (x3) LHCACFAJ PSB design: SPS tandem only
- Warm magnetic shield LHCACFWS
- FBI system (2x 8 heads) For CAVITY POSITION MEASUREMENT
- Thermal screen box LHCACFTS
- MLI "watts" (50K) LHCACFMS (preliminary design for illustration)

Information about RFD cryomodule

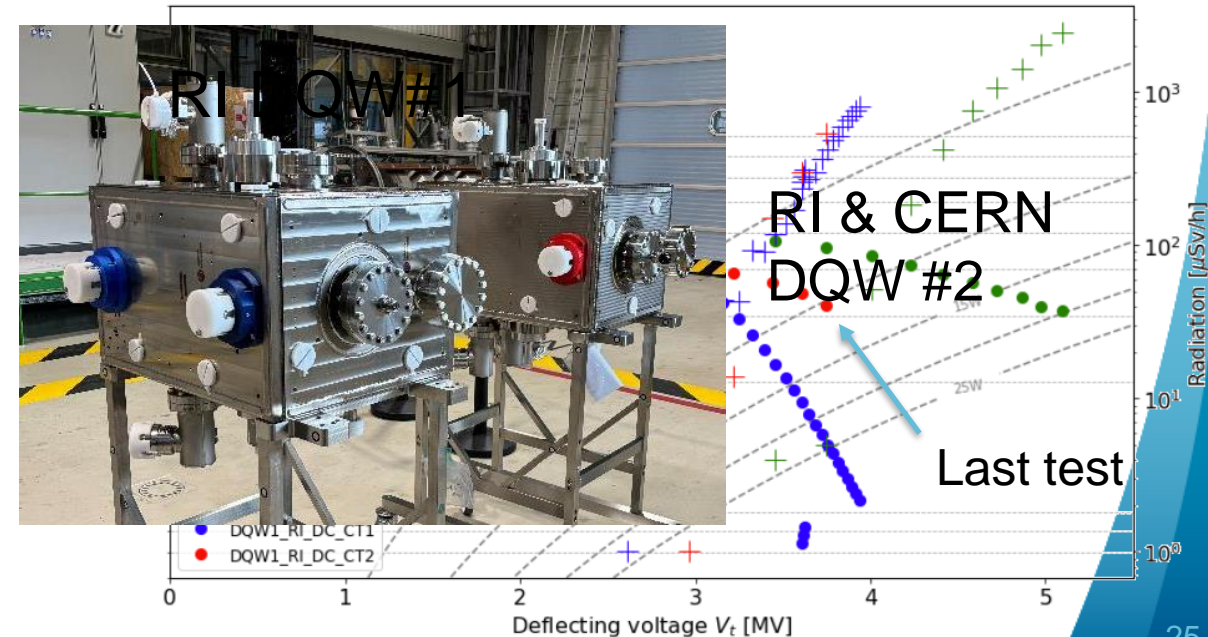
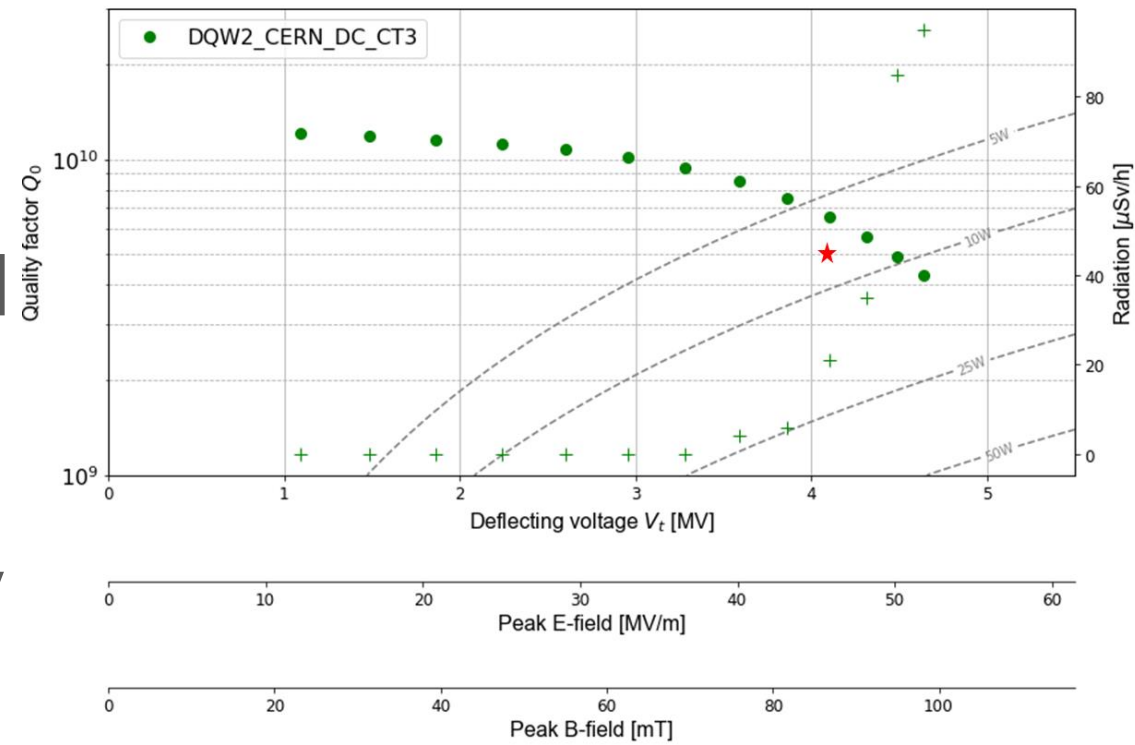
- Overall dimensions (L/l/h): 3350/950/1900mm
- Mass: ~3900kg (estimation 05-2019)
- Cavities: RFD (2x)
- HOM filters: 4 pces (2 per cavity)
- Pick Up Antenna: 2 pces (1 per cavity)
- Tuner: 2 unit (1 per cavity)
- RF Gate valves: 4 pces
- FBI Heads: 16 ports (8 per cavity)

EDMS n° 1833682 31-03-2019

HL-LHC-WP04—CRAB CAVITIES RFD CRYOMODULE FOR SPS TESTS

Industrial DQW Series Cavities

- CERN #2 & RI #2 cavities qualified (~4.7 MV)
 - Will be used for next string assembly and are already in the UK for assembly
- The RI #1 re-tested, but limited to 3.75 MV (NCR)
- The RI #3 required repair, testing @ CERN still planned for 2024



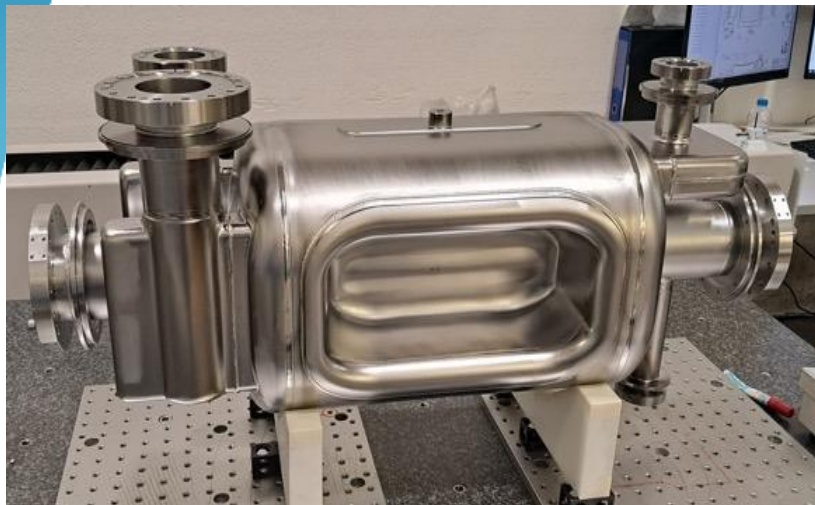
See Rama Calaga on Monday for more details



RFD cryomodule assembled in UK and being tested in M7 bunker (SM18-CERN) in 2024 before installation in SPS in YETS 2024 / 2025

O. Brüning CERN ATS-DO

Crab Cavity series production well underway



RF

One of the two
suffered from fi



See Leonardo Risoni on Monday for more details

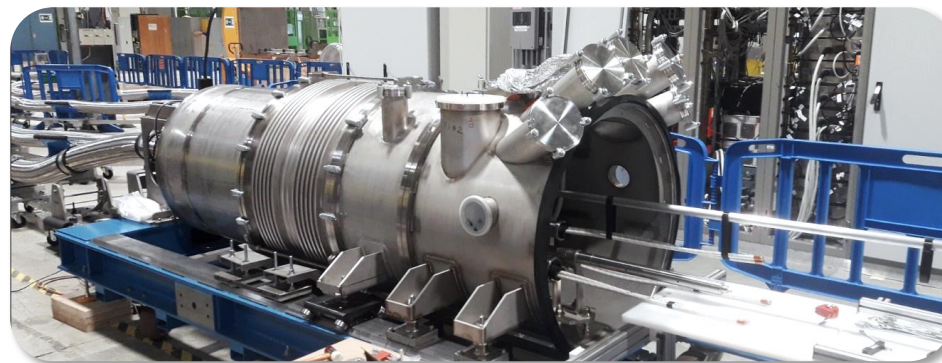
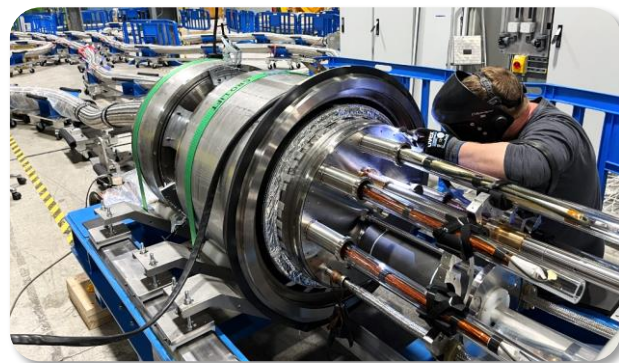
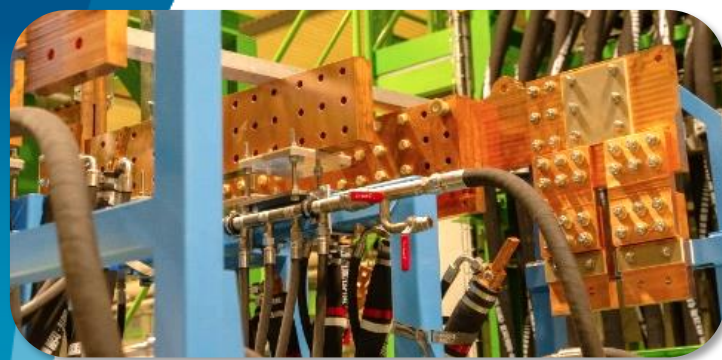
FIRST TWO PRODUCTION RFD CRAB CAVITIES WELDED!

Nov 27, 2023 | News



O. Brüning CERN ATS-DO:

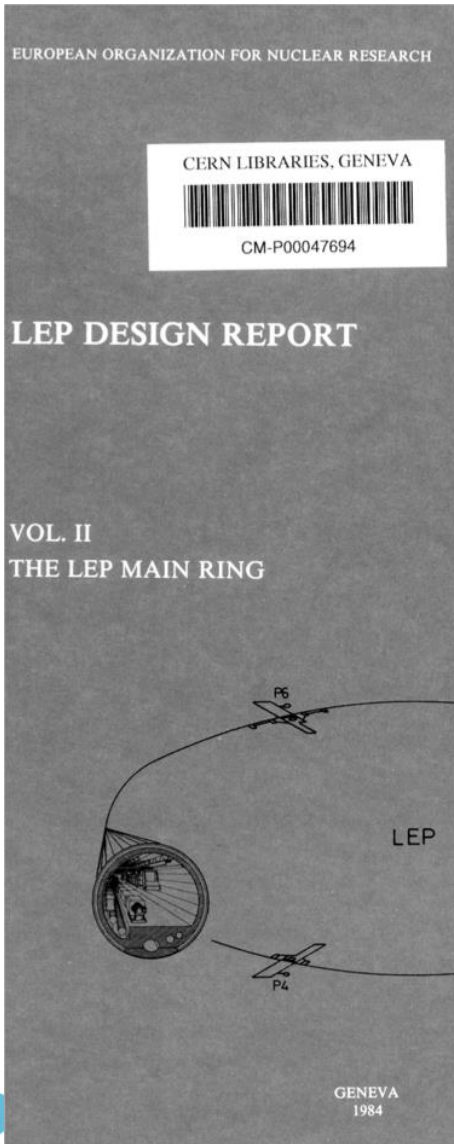
HL-LHC Introduction



SC-Link-DFHX assembly in pictures

LHC: was already

LEP
Design
Report
1984



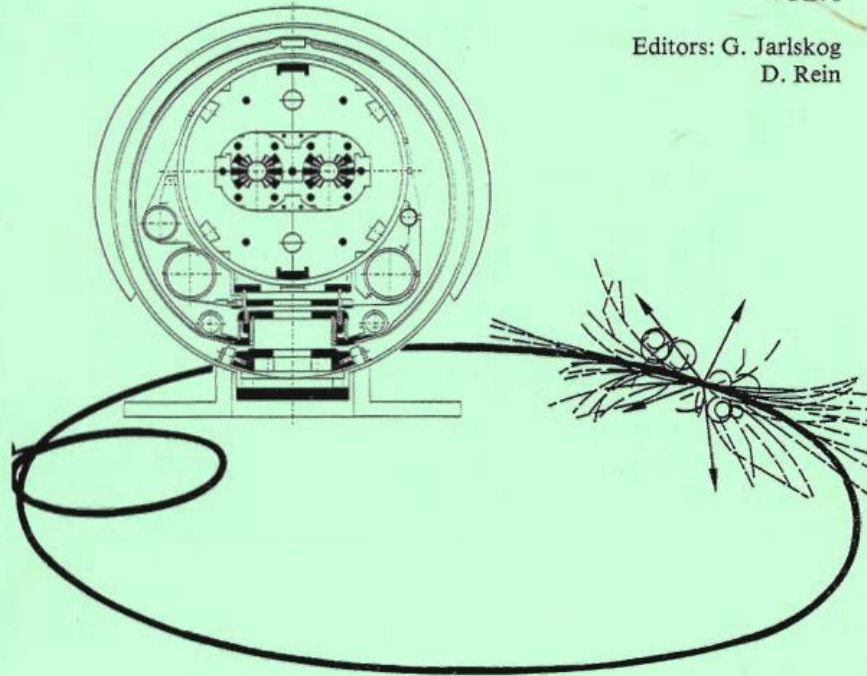
CERN 90-10
ECFA 90-133
Volume I
3 December 1990

EUROPEAN COMMITTEE FOR FUTURE ACCELERATORS

Large Hadron Collider Workshop

PROCEEDINGS
VOL. I

Editors: G. Jarlskog
D. Rein

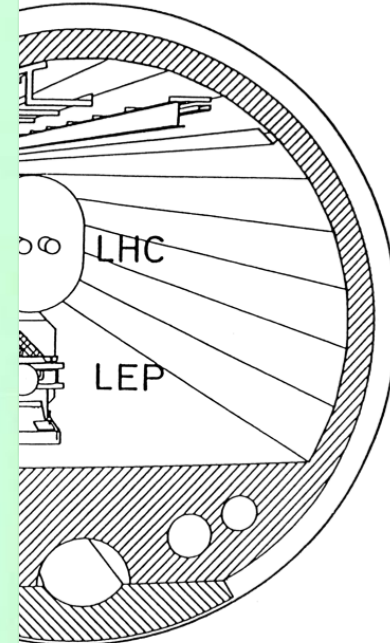


Aachen, 4-9 October 1990

Start of LEP

ECFA 84/85
CERN 84-10
5 September 1984

Lausanne
ECFA-CERN
Workshop
1984



LARGE HADRON COLLIDER
AND LEP TUNNEL

Vol. I

THE ECFA-CERN WORKSHOP

at Lausanne and Geneva,
21-27 March 1984