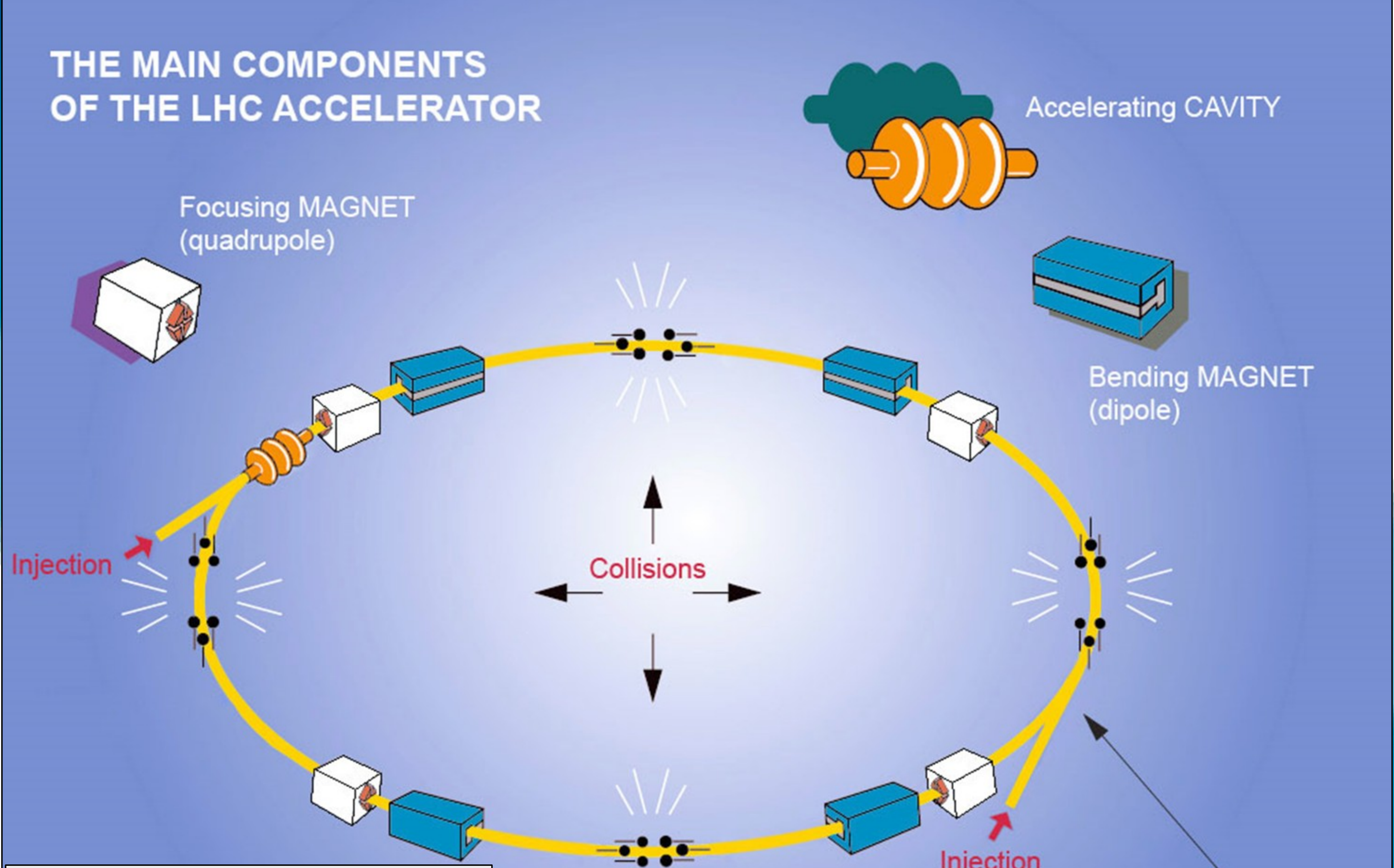
Holland:@CERN

30 May – 2 june 2016

High Luminosity LHC (HL-LHC)

Lucio Rossi – CERN
Project Leader

CERN, 2 June 2016



Each bunch is ~ 30 cm
< 1 mm radius cylinder
1-2 10^{11} protons/bunch
2600-2800 bunches per ring

LHC
the largest scientific instrument

LHC dipoles: the collider backbone

- 27 km, p-p at 7+7 TeV
  3.5+3.5 start, 4+4 in 2012
  6.5+6.5 TeV in 2015
- 1232 x 15 m Twin Dipoles
- Operational field 8.3 T @11.85 kA (9 T design)
- HEII cooling, 1.9 K with 3 km circuits (130 tonnes He inventory).

- Field homogeneity **of 10^{-4}**, bending strength uniformity better then 10^{-3}. Field quality control (geometric and SC effects) at 10^{-5}.

The dipole line inthe LHC ring

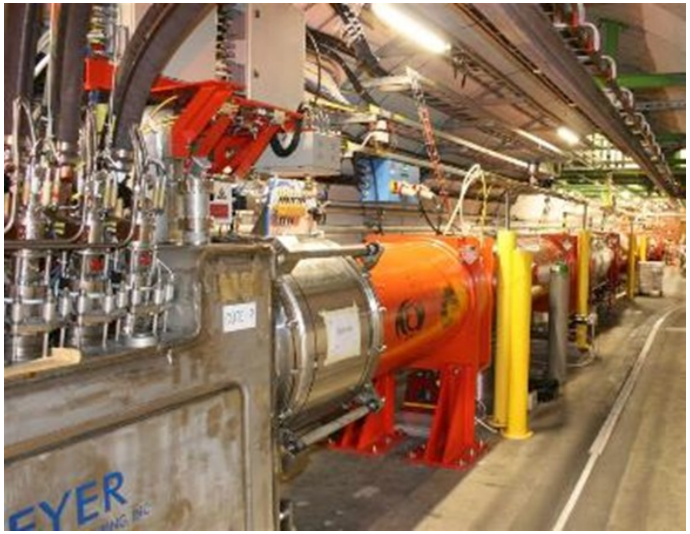
More than dipoles…

The pletora of SC magnets…

- 392 Main Quads Two-In-One rated for a peak field of 7 T.
- About 100 other Two-in-One MQs
- 32 MQX (low-β) single bore for luminosity (design $L=1\cdot10^{34}\ cm^{-2}s^{-1}$), 70 mm apertures, about 8 T peak field, high quality
- A «zoo» of 7600 «small» Sc magnets (correctors and higher order magnets
- Total: 9 MJ stored energy (at nominal)

- Large detector magnets

  ATLAS toroid – 25 m long 1.2 GJ
  CMS solenois – 12 m long 2.5 GJ



SC radiofrequency, Cryogenics,

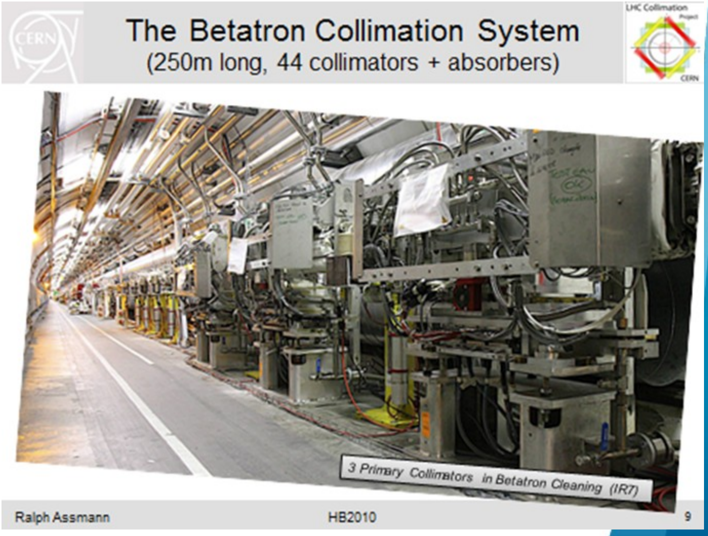
LHC: much more than magnets…

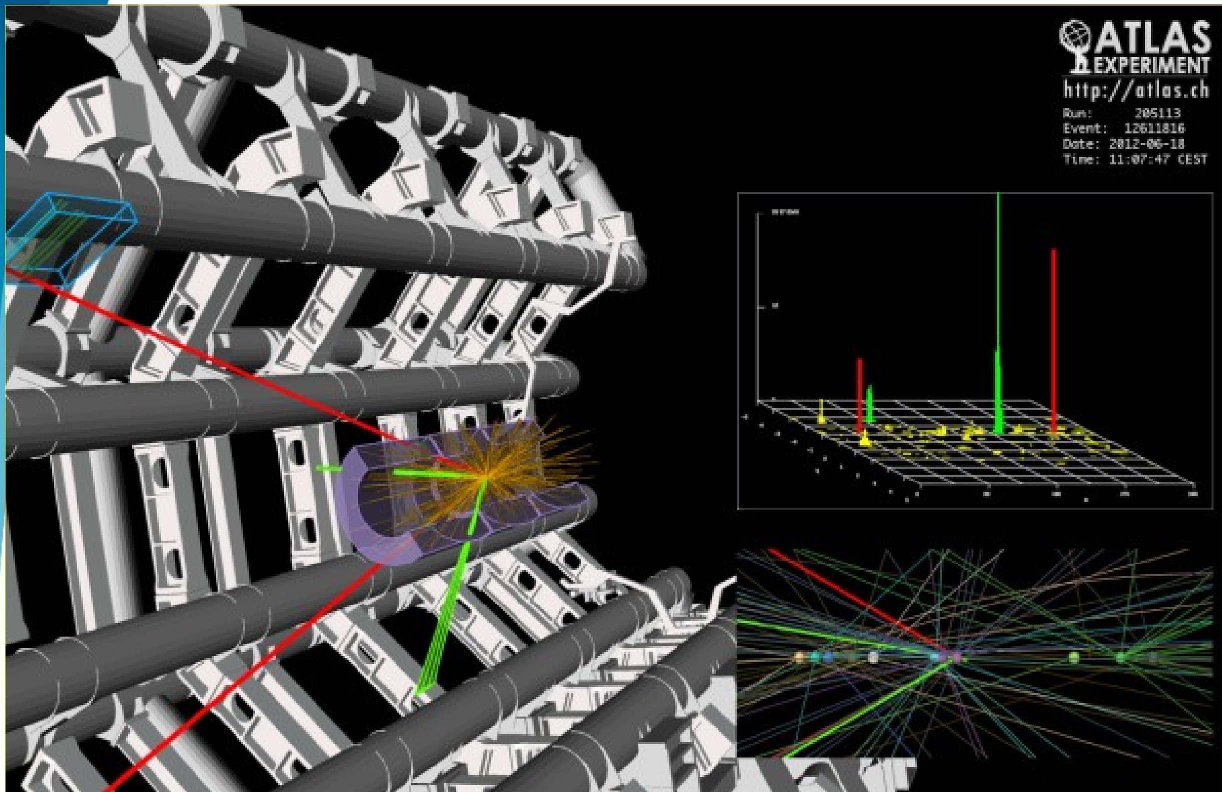
400 MHz Standing wave RF

- 4 single cell cavities in cryomodule, 2 crym per beam. Total 16 cavities.
- Sputtered niobium design (as LEP)
- Gradient 5.5 MV/m nominal (8 MV/m available)
- Nominal 2MV, up to 3 MV at 8 MV/m

Cryo : 8 x 18 kW@4.5K

Collimators: 146



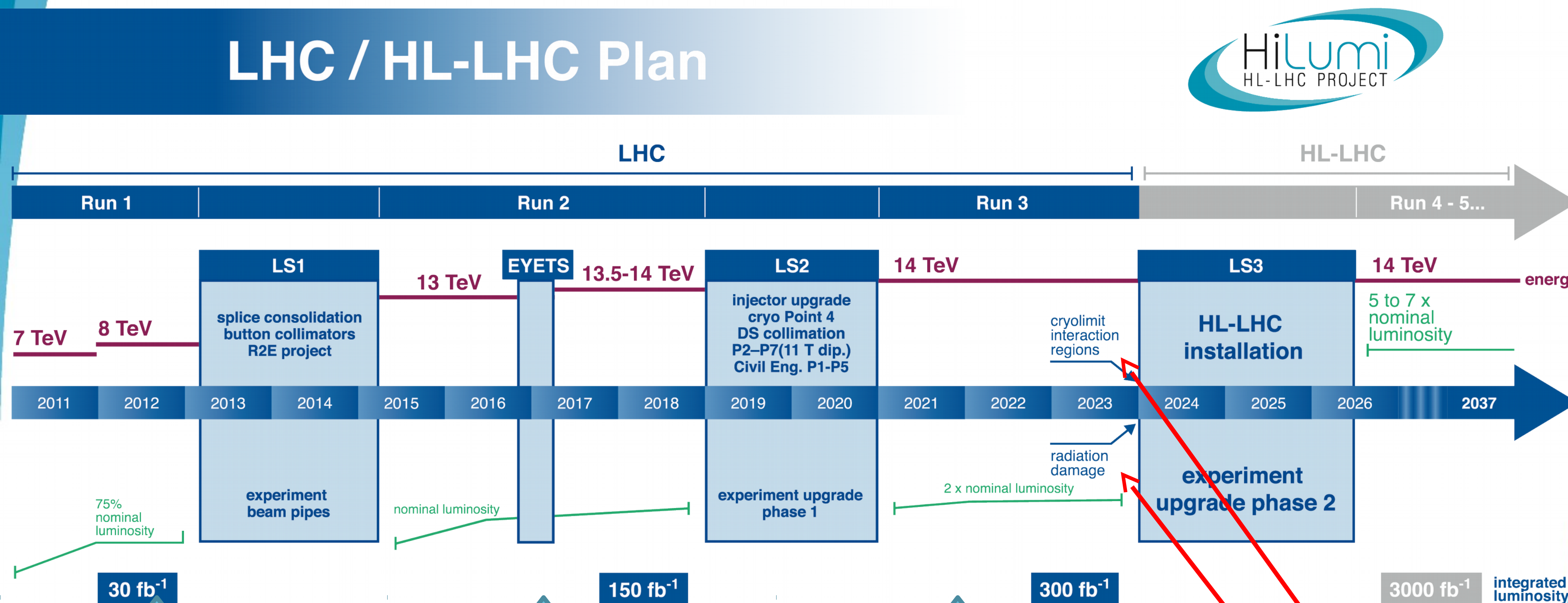


The Higgs: the needle in a haystack

luminosity: collision rate)

Z→ μμ event from 2012 data with 25 reconstructed vertices

Why upgrading the LHC?



$0.75\ 10^{34}\ cm^{-2}s^{-1}$
50 ns bunch
high pile up ~40

$1.5\ 10^{34}\ cm^{-2}s^{-1}$
25 ns bunch
pile up ~40

$1.7\text{-}2.2\ 10^{34}\ cm^{-2}s^{-1}$
25 ns bunch
pile up ~60

Technical limits to lumi increase (Machine & Experiments)

50 ⇒ 25 ns

The project started in 2010 as EC-FP7 Design Study

The HiLumi LHC Design Study (a sub-system of HL-LHC) is cofunded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404

From FP7 **HiLumi LHC** Design Study application

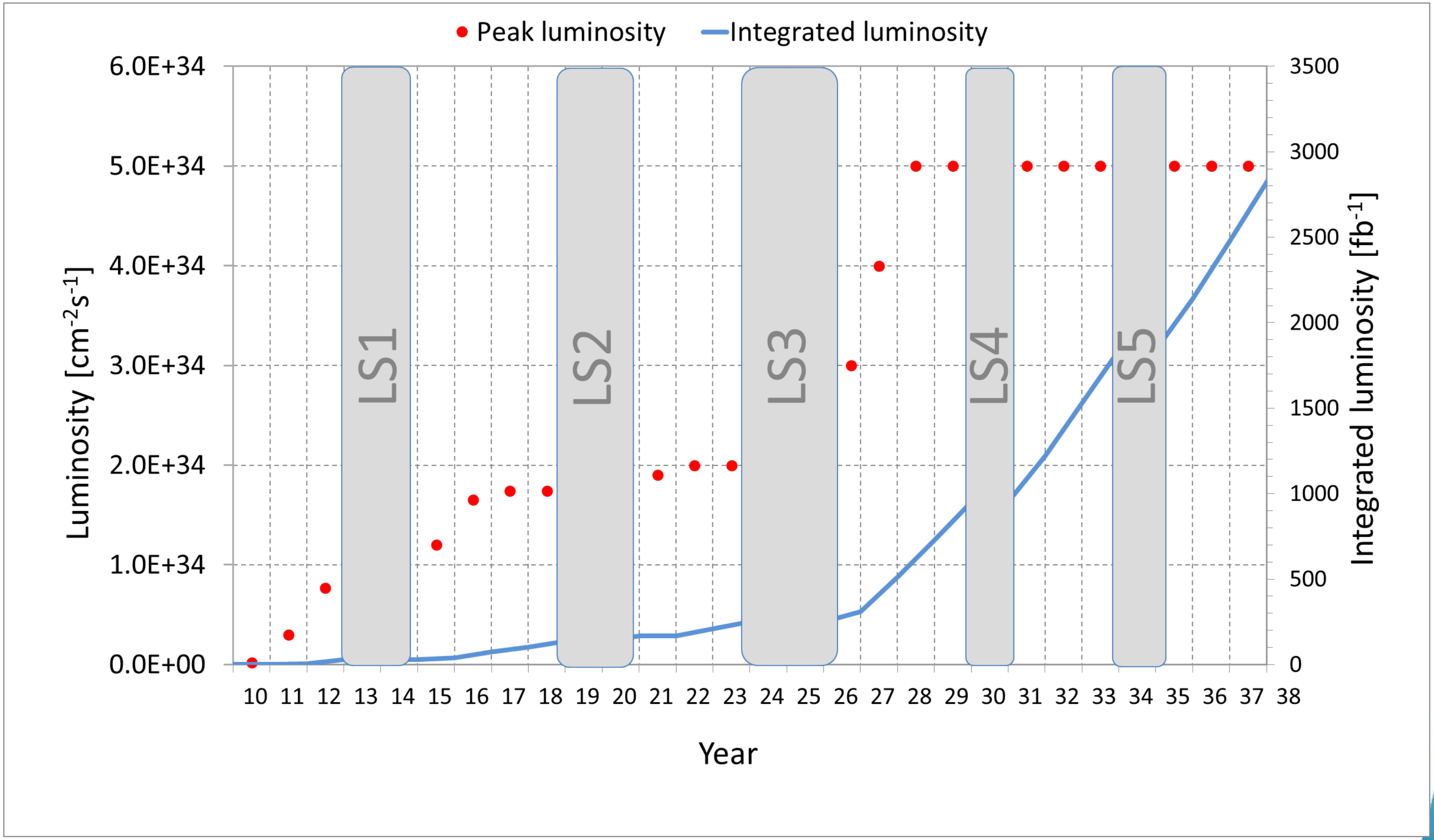
The main objective of HiLumi LHC Design Study is to determine a hardware configuration and a set of beam parameters that will allow the LHC to reach the following targets:

A peak luminosity of L_{peak} = **5×10^{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 (use of existing magin) defined:
$L_{ult} \cong 7.5\ 10^{34}$ cm^{-2}s^{-1} and **Ultimate Integrated $L_{int\ ult} \sim 4000$ fb^{-1}**
LHC should not be the limit, would Physics require more…

The bolt advance in luminosity

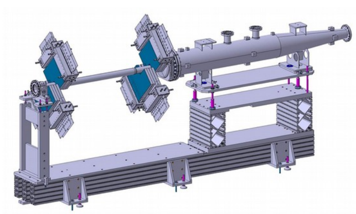


FP7-HiLumi classified as «success story» by EC

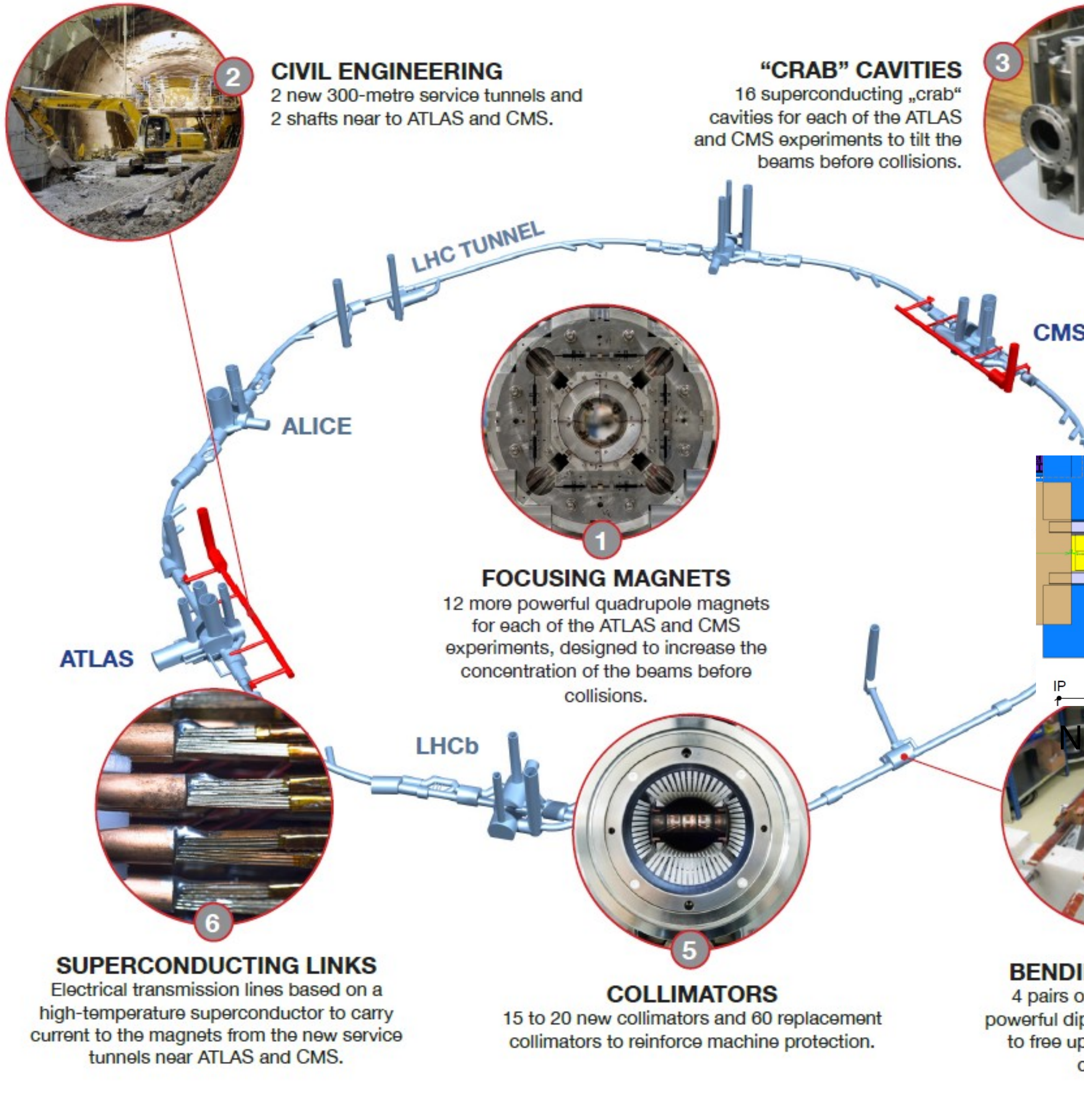
High Luminosity LHC

The HiLumi LHC Design Study (a sub-system of HL-LHC) is cofunded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404

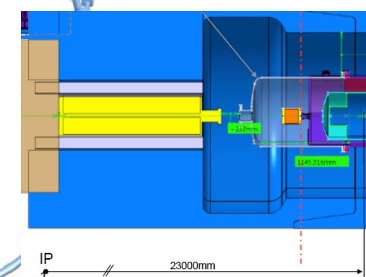
Cryo@P4



Beam diagnostics BGV



Cryo@P1-P5



New TAS and VCX

HL-LHC project breakdown structure

WP1
Project Management

WP2
Accelerator Physics & Performance

WP3
IR Magnets

WP4
Crab Cavities & RF

WP5
Collimation

WP6A
Cold Powering

WP6B
Warm Powering

WP7
Machine Protection

WP8
Collider-Experiment Interface

WP9
Cryogenics

WP10
Energy Deposition & R2E

WP11
11 T Dipole

WP12
Vacuum & Beam Screen

WP13
Beam Instrumentation

WP14
Beam Transfer & Kickers

WP15
Integration & (De-)Installation

WP16
IT String & Commissioning

WP17
Infrastructure, Logistics & Civil Engineering

High Luminosity LHC Project

MEMBER STATES COLLABORATIONS[1]

IR Magnets
France: P. Védrine, J-M. Rifflet, H. Felice (CEA)
Spain: J-M. Perez, F. Toral (CIEMAT)
Italy: A. Zoccoli, G. Volpini, P. Fabbricatore (INFN)
Sweden: T. Ekelöf (Uppsala University)

Collimation
UK: R. Appleby (UNIMAN/CI[2]), S. Gibson (RHUL)
Crab Cavities
UK: G. Burt (ULANC/CI[2])
Cold Powering
UK: Y. Yang (SOTON)

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[3] - 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

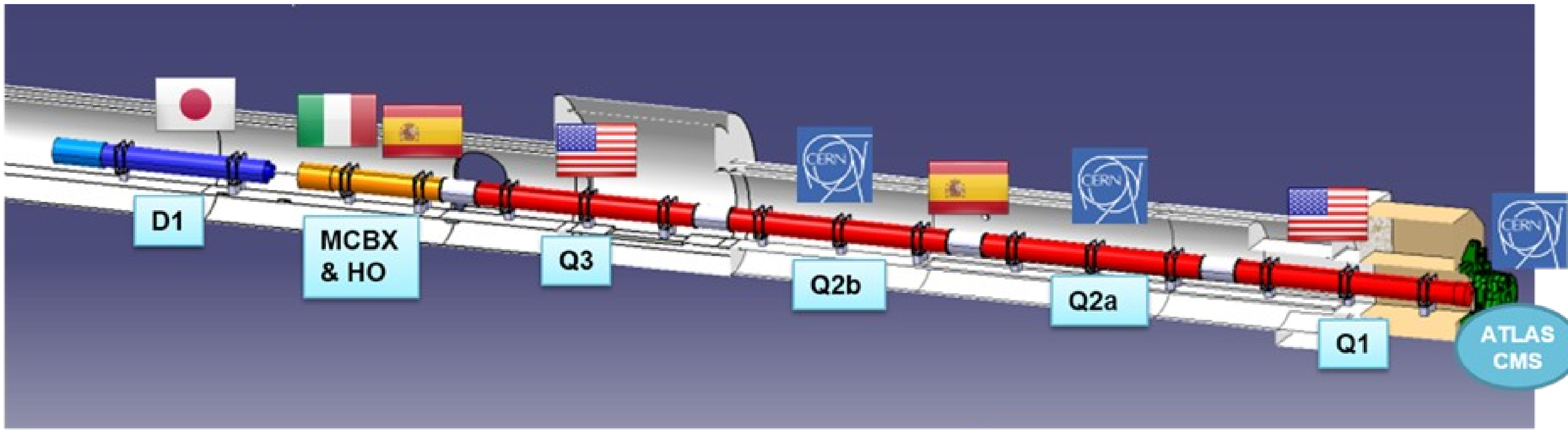
WP15 Integration & (De-)Installation
Paolo Fessia

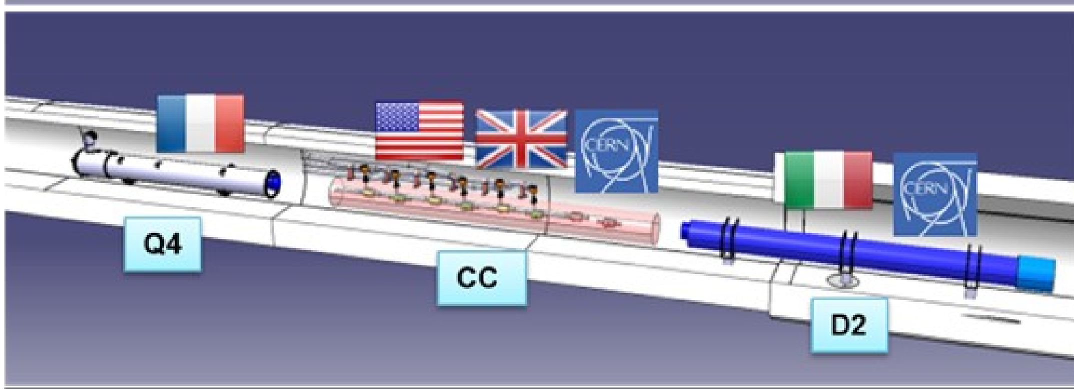
WP16 IT String & Commissioning
Marta Bajko – Mirko Pojer

WP17 Infrastructure & Logistics
Laurent Tavian
Beniamino Di Girolamo

[1] In kind contributions
[2] Cockcroft Institute
[3] US HL-LHC Accelerator Upgrade Project

Deep changes in the Inner Triplet region (around ATLAS & CMS experiments)



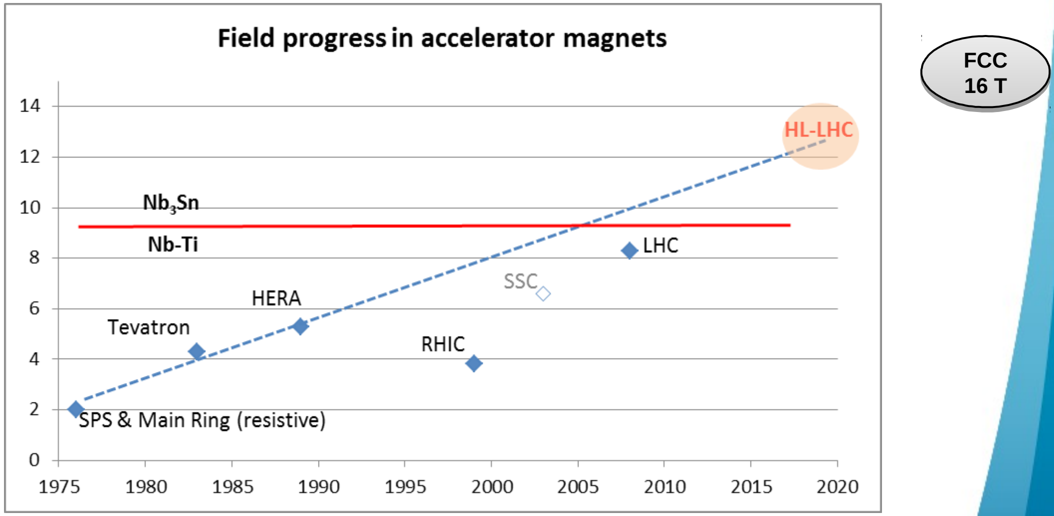


CC : R&D, Design and in-kind **USA & UK**

Q1-Q3 : R&D, Design, Prototypes and in-kind **USA**
D1 : R&D, Design, Prototypes and in-kind **JP**
MCBX : Design and Prototype **ES**
HO Correctors: Design and Prototypes **IT**
D2 Design **IT**
Q4 : Design and Prototype **FR**

Magnet the progress

- LHC dipoles features 8.3 T in 56 mm (designed for 9.3 peak field)
- LHC IT Quads features 205 T/m in 70 mm with 8 T peak field
- HL-LHC
  - **11 T dipole (designed for 12 T peak field, 60 mm)**
  - **New IT Quads features 140 T/m in 150 mm > 11 T operational field, designed for about 12.5 T).**

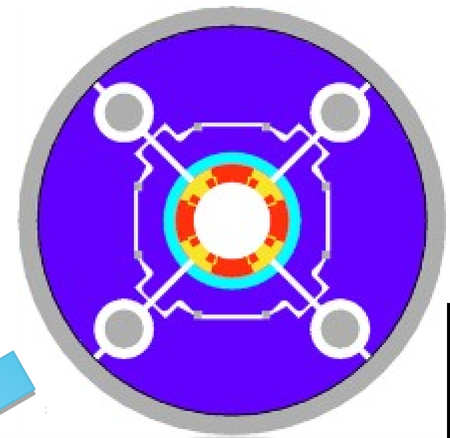


LHC low-β quads: steps in magnet technology from LHC toward HL-LHC

Fermilab KEK

LHC (USA & JP, 5-6 m)
∅70 mm, B_{peak}~ 8 T
1992-2005

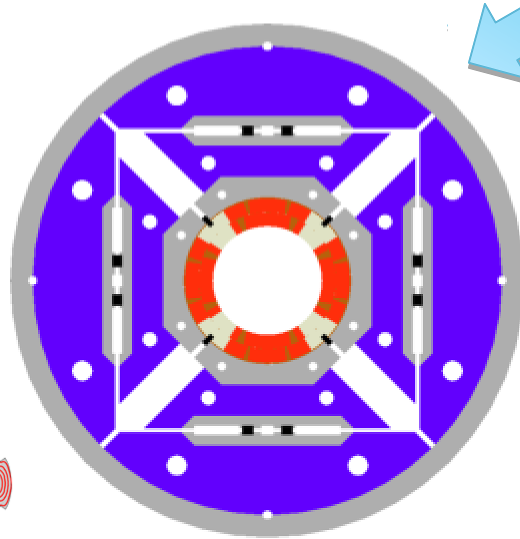
LARP TQS & LQ (4m)
∅90 mm, B_{peak}~ 11 T
2004-2010



LARP

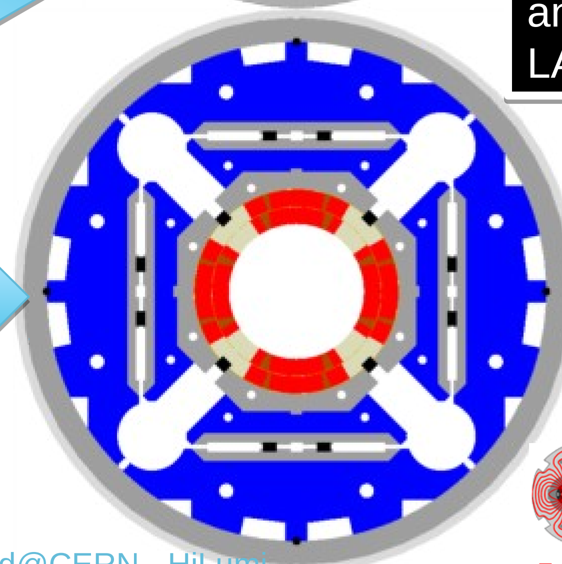
New structure based on bladders and keys (LBNL, LARP)

LARP HQ
∅120 mm,
B_{peak}~ 12 T
2008-2014



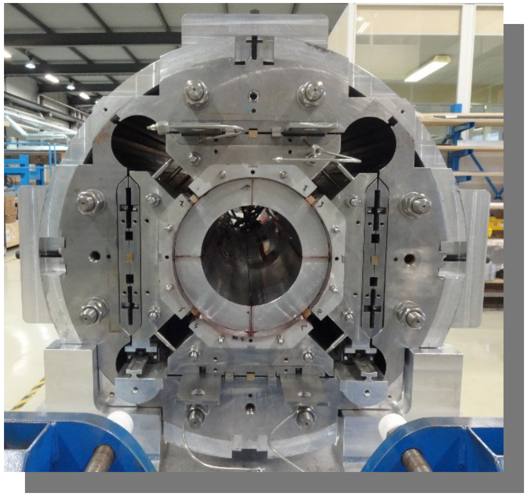
LARP

LARP & CERN MQXF
∅150 mm,
B_{peak}~ 12.1 T
2013-2020

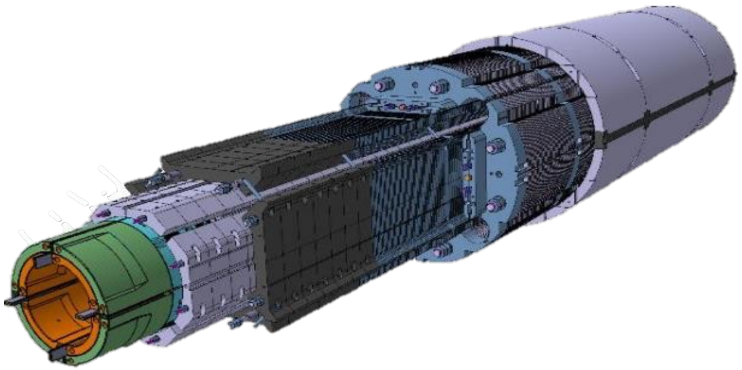


LARP

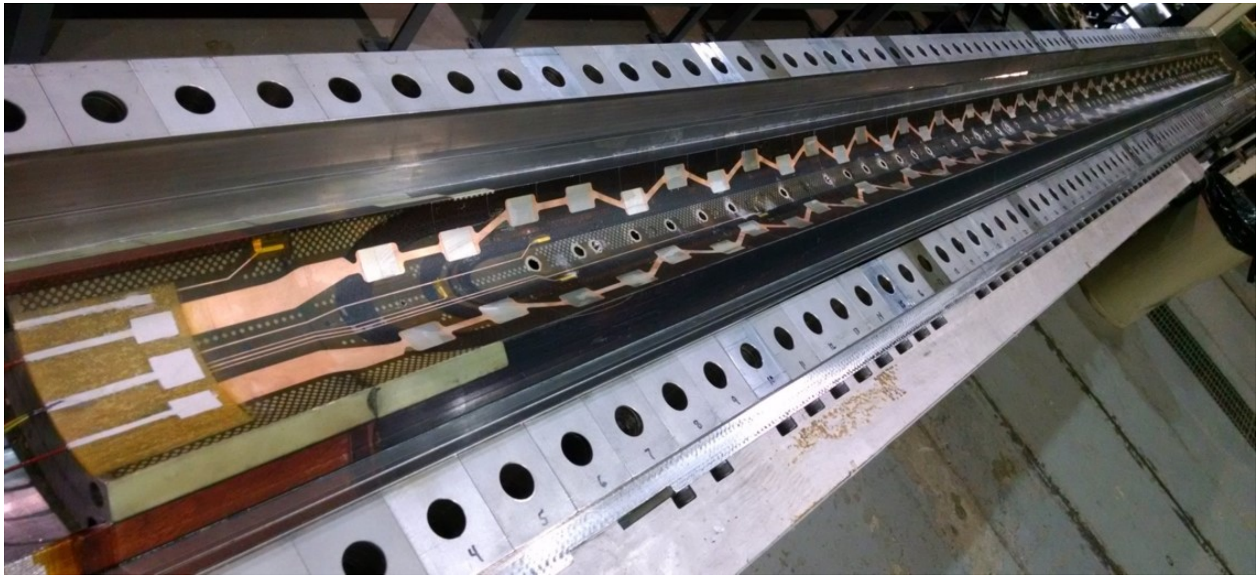
MQXF



Section of MQXF mechanical model



Laminated structure for series production



Second long (4 m) Nb3Sn coil

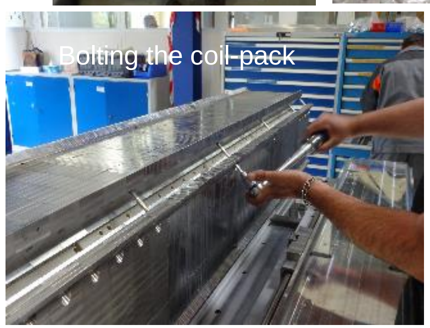
MQXF assemby test

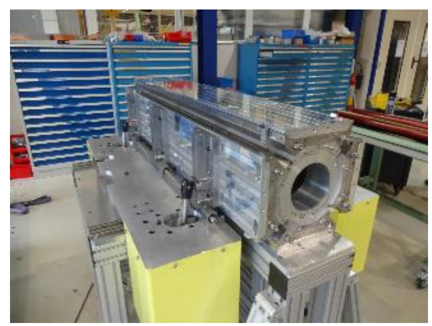

Pad assembly


Collars assembly


Coil-pack assembly table


Coil-pack assembly table

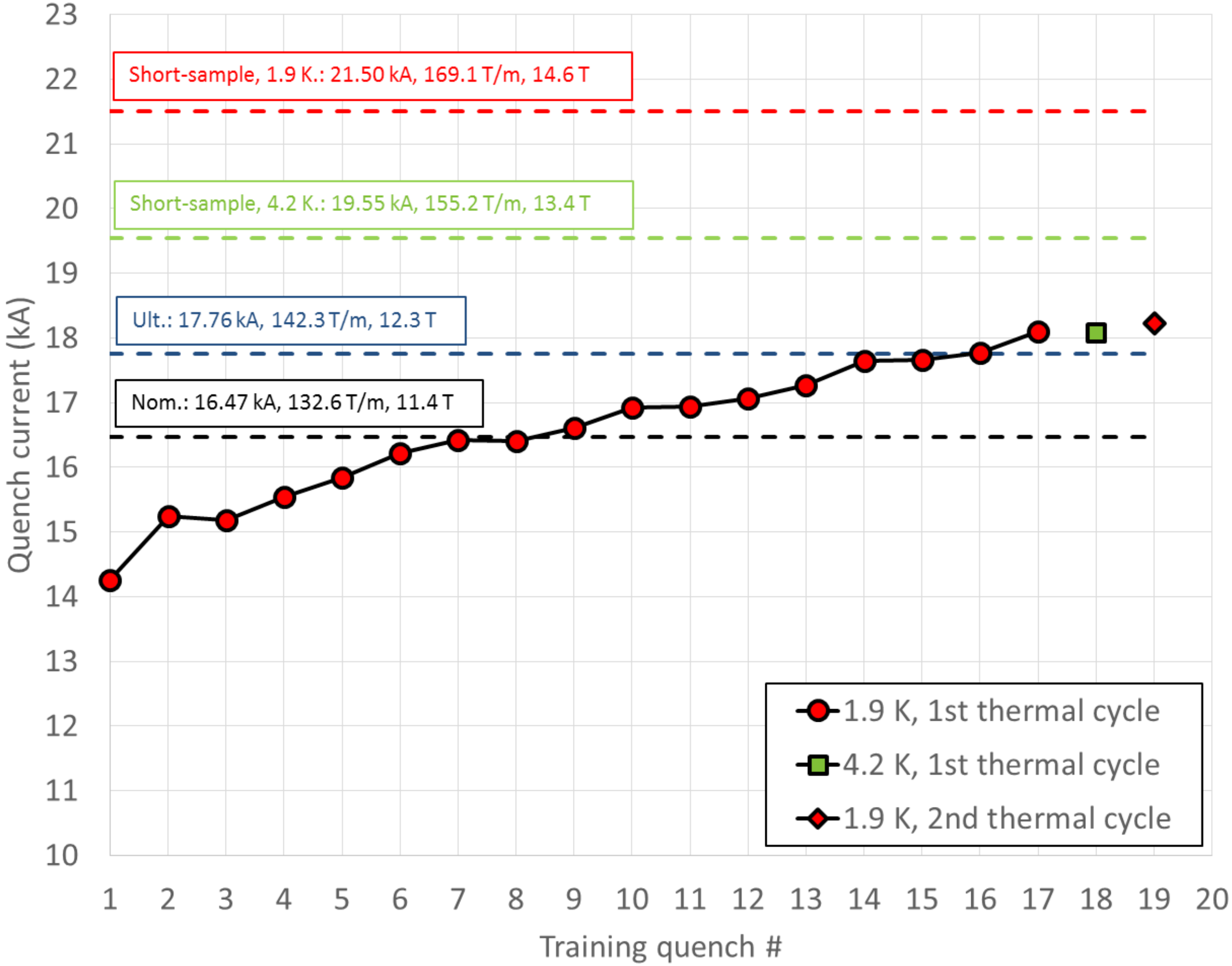

Bolting the coil-pack




Coil-pack assembled

By G. Chlachidzei

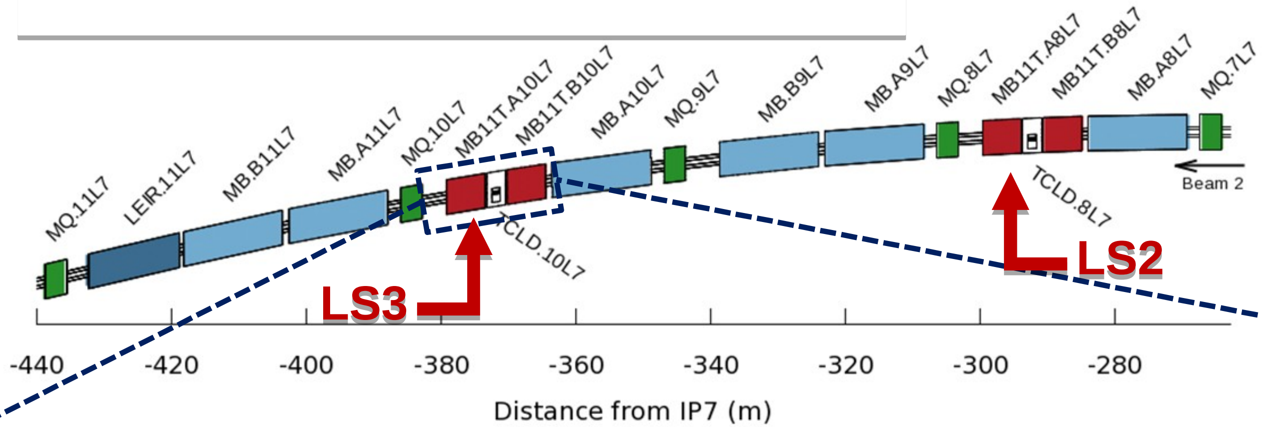
MQXFS1 test
Quench performance

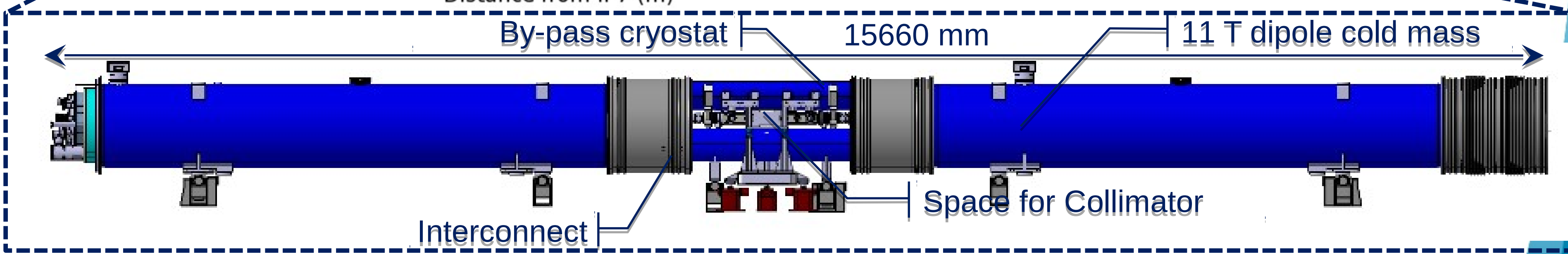


- Ultimate reached both at 1.9 K and 4.5 K
- Reached 85% of current limits at 1.9 K and 93% at 4.5 K
  - Significant margin confirmed by ramp-rate
- Full memory
- 8 hours at ultimate without quenches

11 T review : status

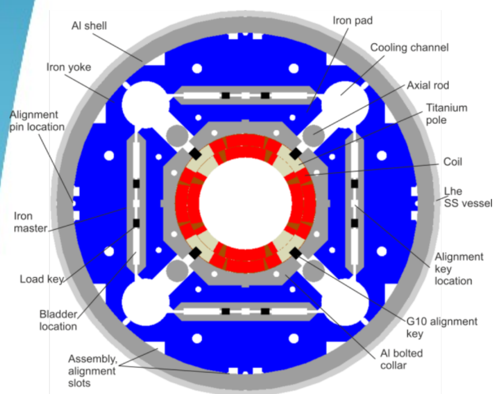
- Change! no 11 T in P2 for ions (magnetic bump + DS collimation inside Connection cryostat can make the job)
- However need to anticipate two DS collimators in LS2; the other two collimators can be installed in LS3



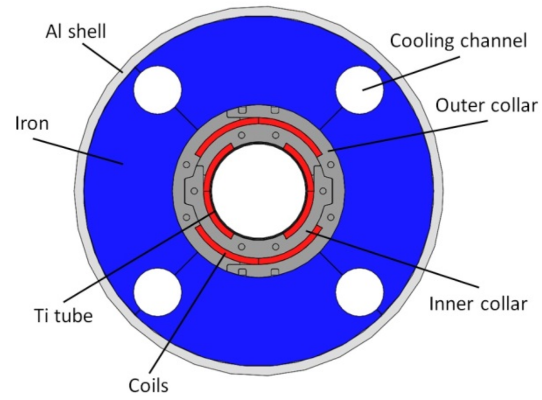


F. Savary

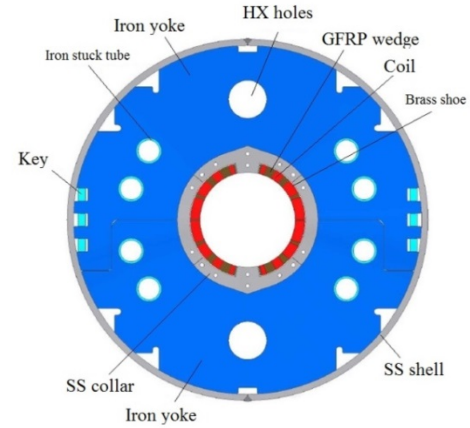
The various magnets for HiLumi



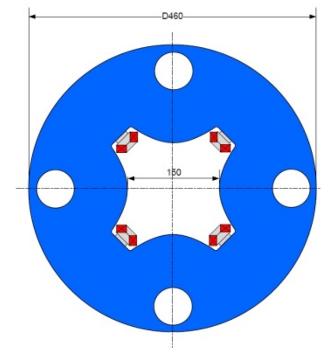
Triplet QXF (LARP and CERN)



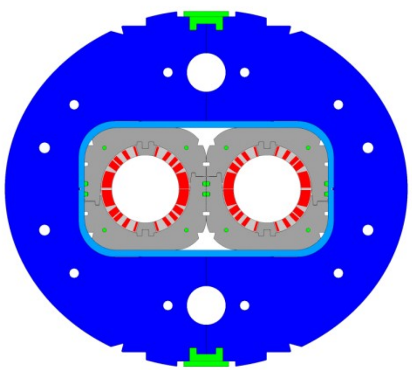
Orbit corrector (CIEMAT)



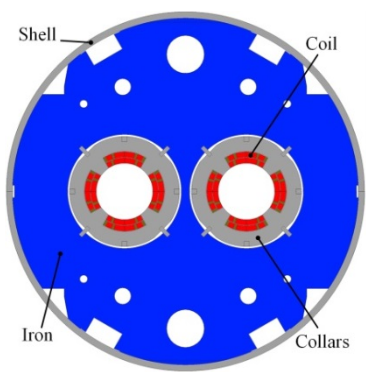
Separation dipole D1 (KEK)



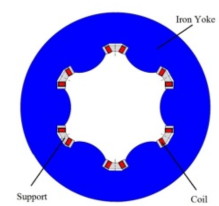
Skew corrector (INFN)



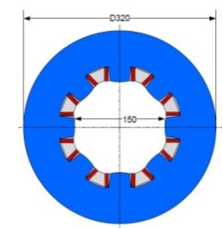
Recombination dipole D2
(INFN design)



Q4 (CEA)



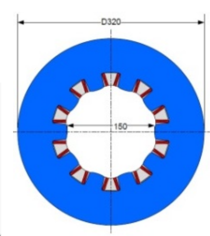
Corrector sextupole (INFN)



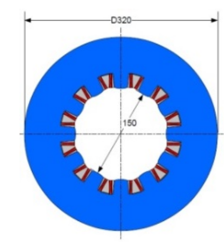
Corrector octupole (INFN)

Cross-sections in scale

E. Todesco, HL WP3 Leader @HiLumi 27.10.15



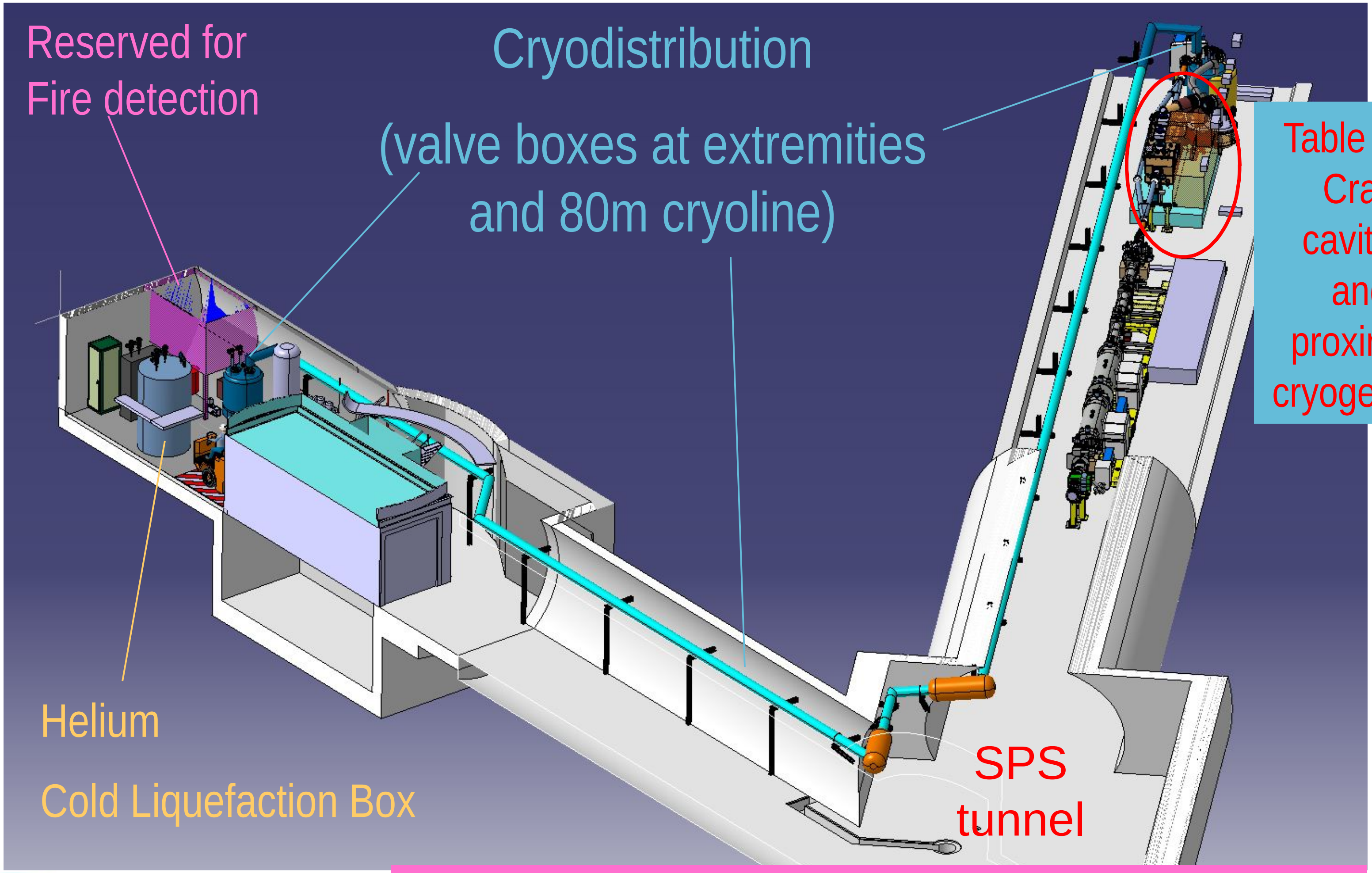
Corrector decapole (INFN)



Corrector dodecapole (INFN)

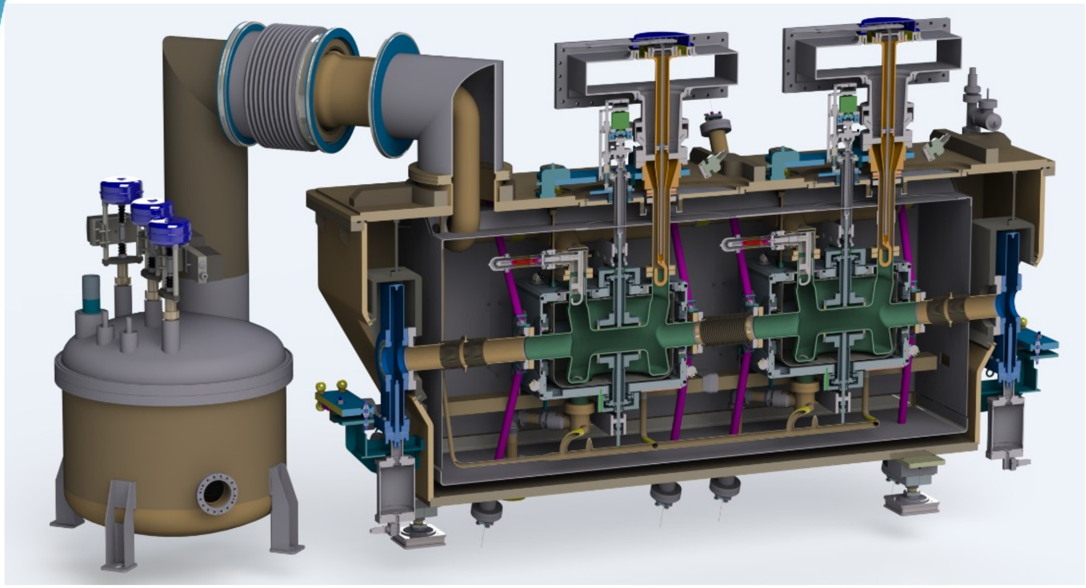
Cryogenics, SPS-BA6 Cryogenic infrastructure for superconducting RF

(HL Crab Cavities or possible future cavities)

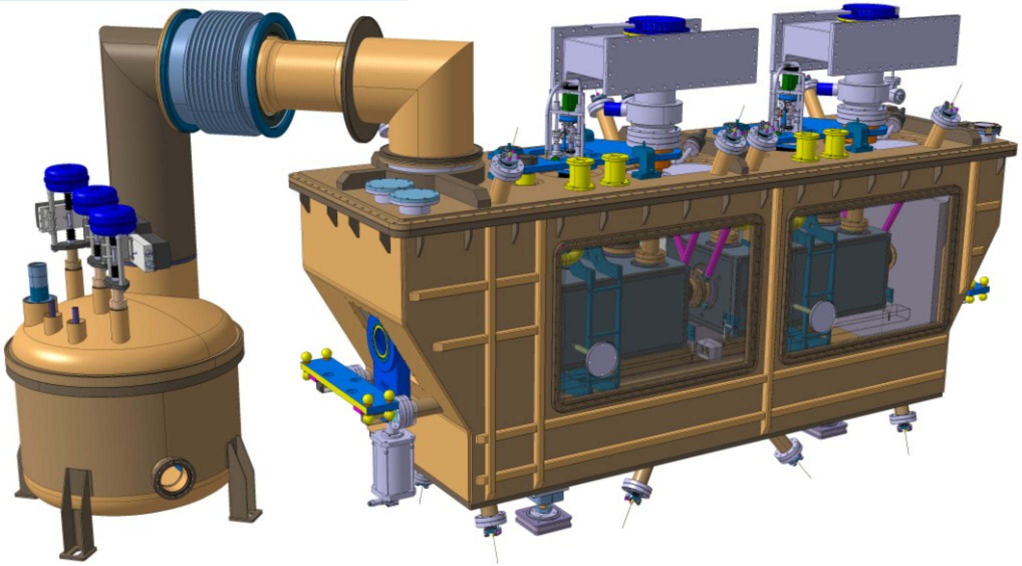


Technical infrastructure coordinated by G. Vandoni (BE-RF)

SCRF: Crab Cavities

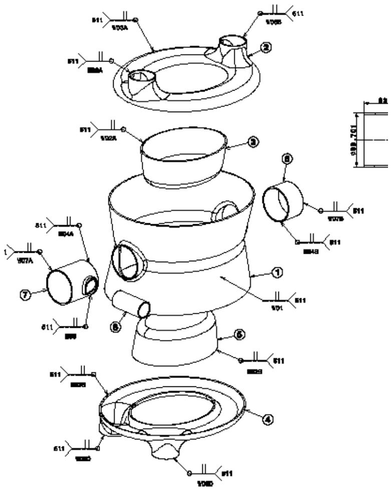


Double QW

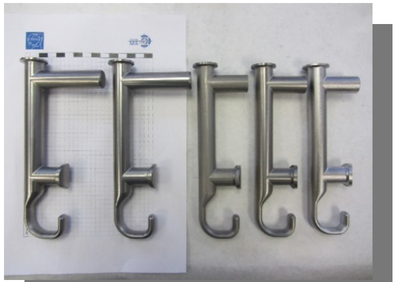


RF Dipole

CERN production for DQW for SPS: big effort

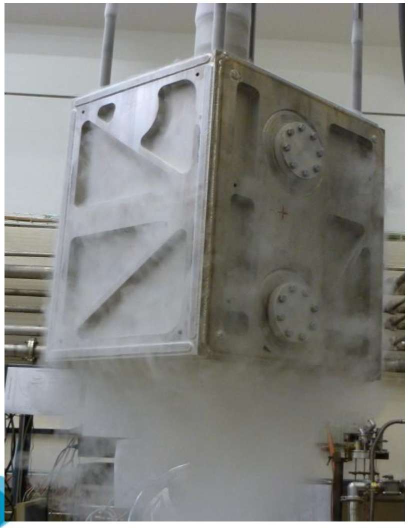


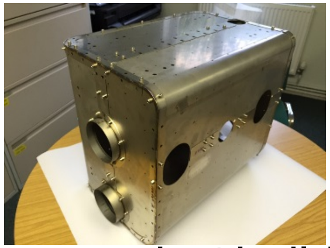
DQW Production



HOM Coupler, DQW

He-Tank Tests



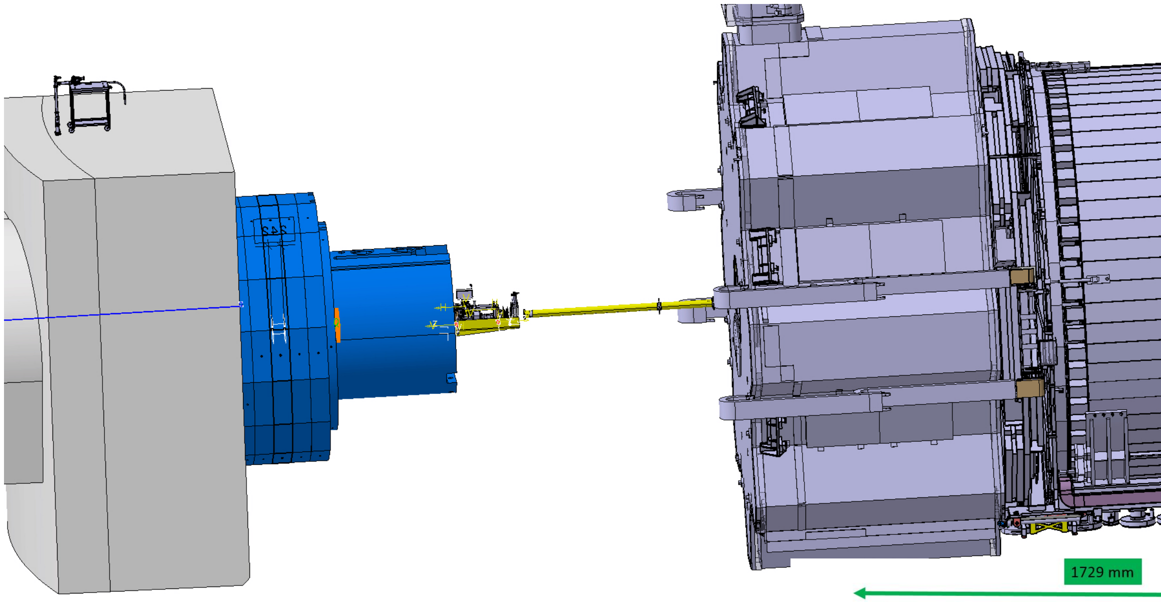


Magnetic Sheilds

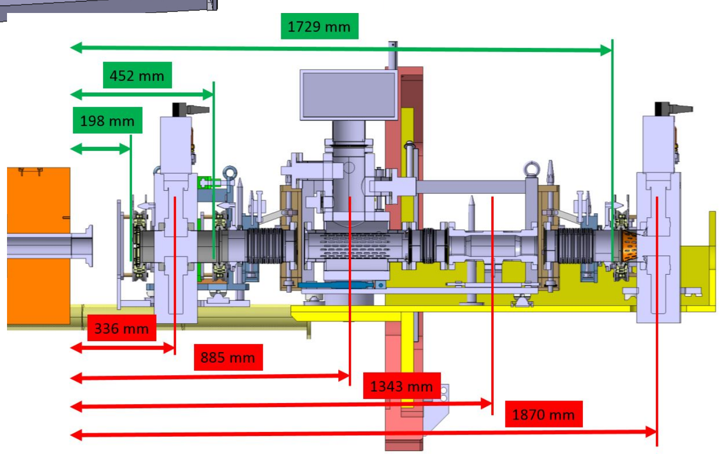
Tuning System

Thanks to the EN-MME team for the support to WP4

New TAXS
VAX relocation from machine to experiment side



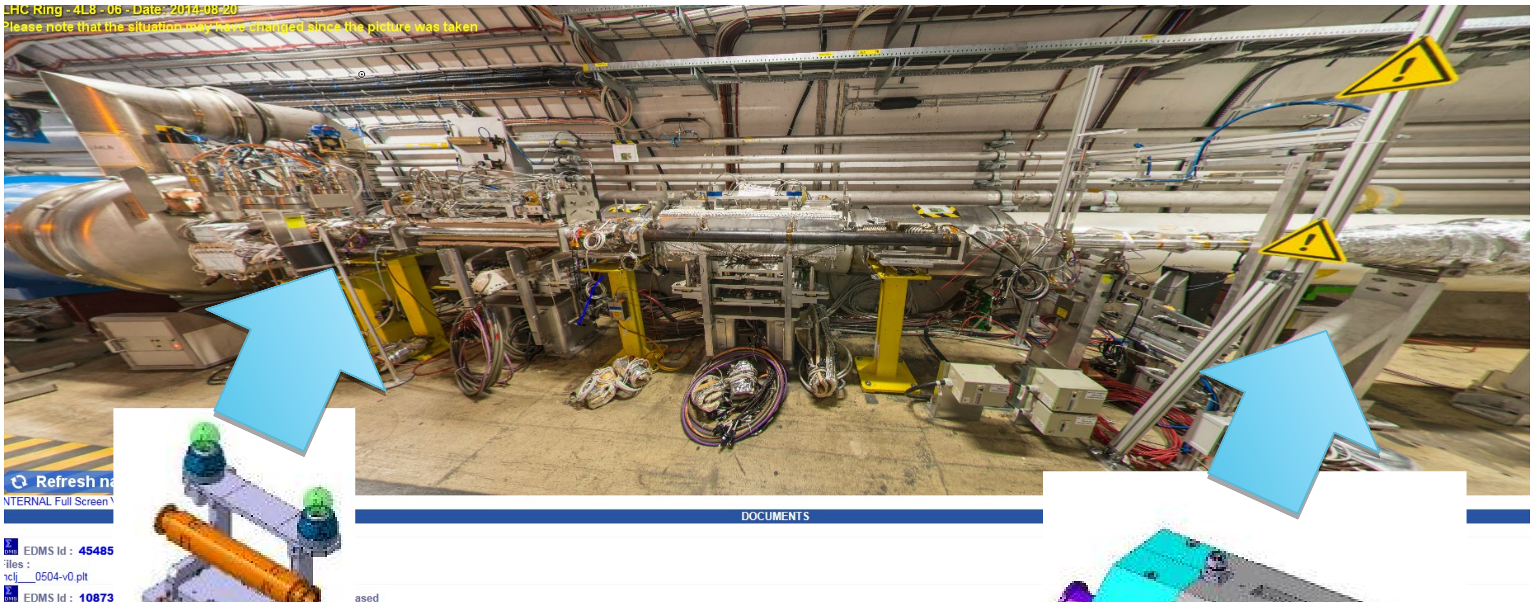
WP8- Design study, planning and coordination with experiments : choice for new TAXS, relocation of VAX modules & services.

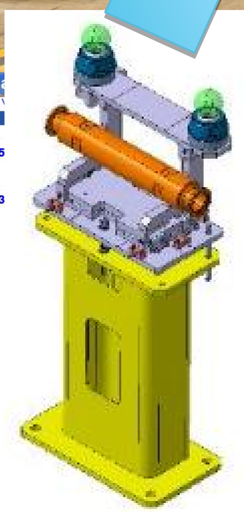


F. Sanchez Galan

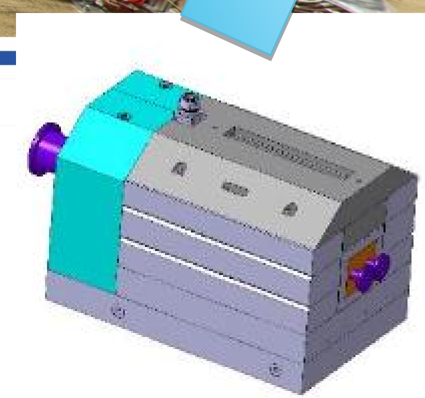
ALARA (Improve accessibility, Remote handling)

Combination of new TAXN and dedicated mask reduce the energy deposition in the superconducting dipole D2 (by absorbing collision debris), this way reducing the risk of quenches and damage for any operational scenario. (EDMS 1562627 & 1361110).



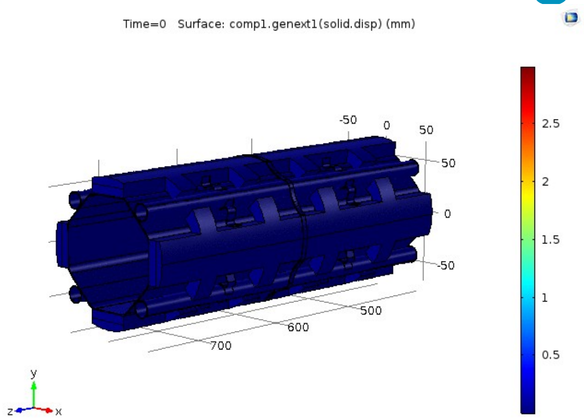


P8 → mini-TAN & protecting mask [LS2]
P1 & P5 → TAXN [LS3]

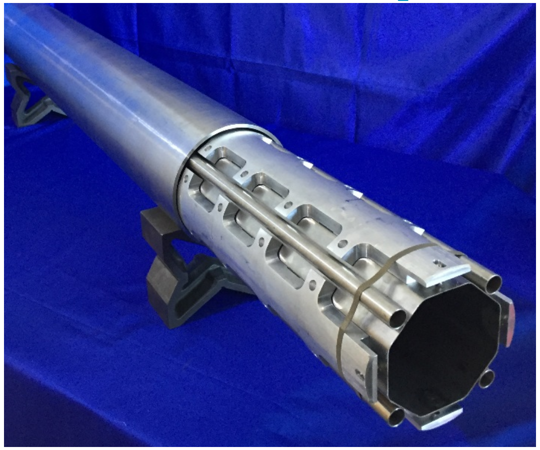
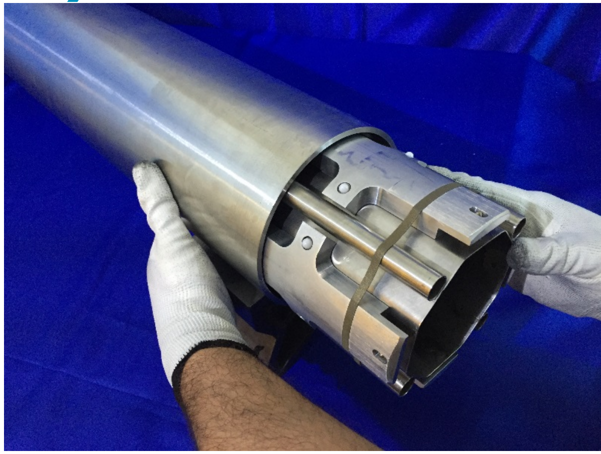


F. Sanchez Galan

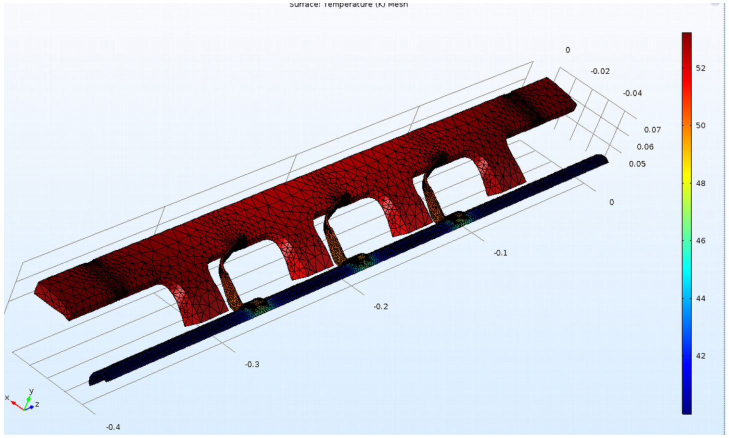
Progress Vacuum (WP12)



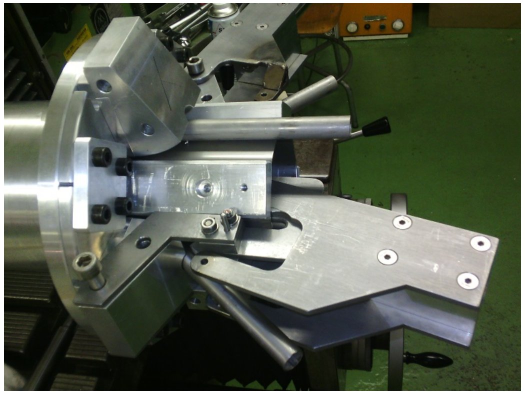
Analysis of the thermal mechanical behaviour during a quench completed. Validation test on D1 model in discussion.

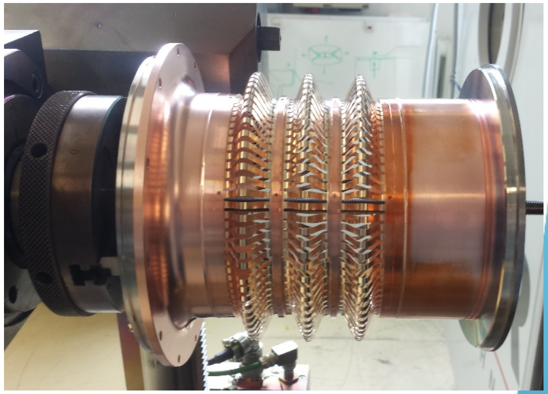
Prototype of Q1 beam screen.



Analysis of the heat transfer done. Tests at cryolab in preparation



Development of tooling for beam screen extremity preparation (cooling tube bending)

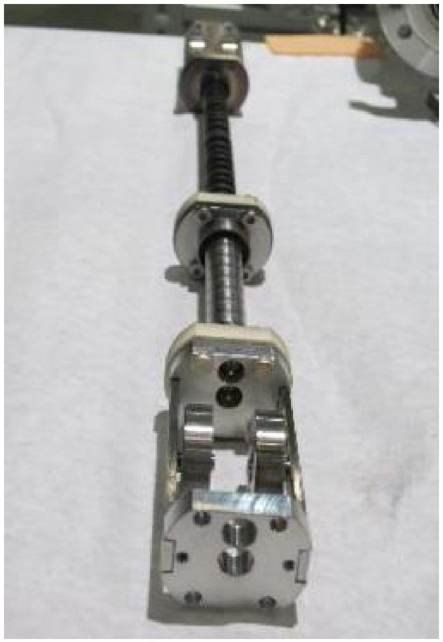


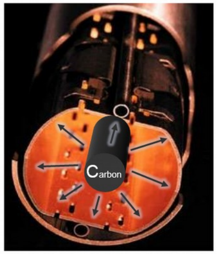
Prototype of RF fingers for the interconnections. Good results of mechanical and RF tests so far.

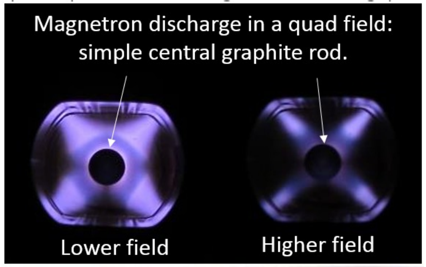
C. Garion

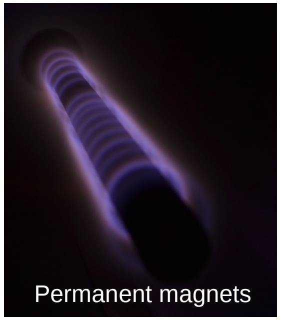
WP12-Vacuum progress in A/C coating (an alternative LESS under study)

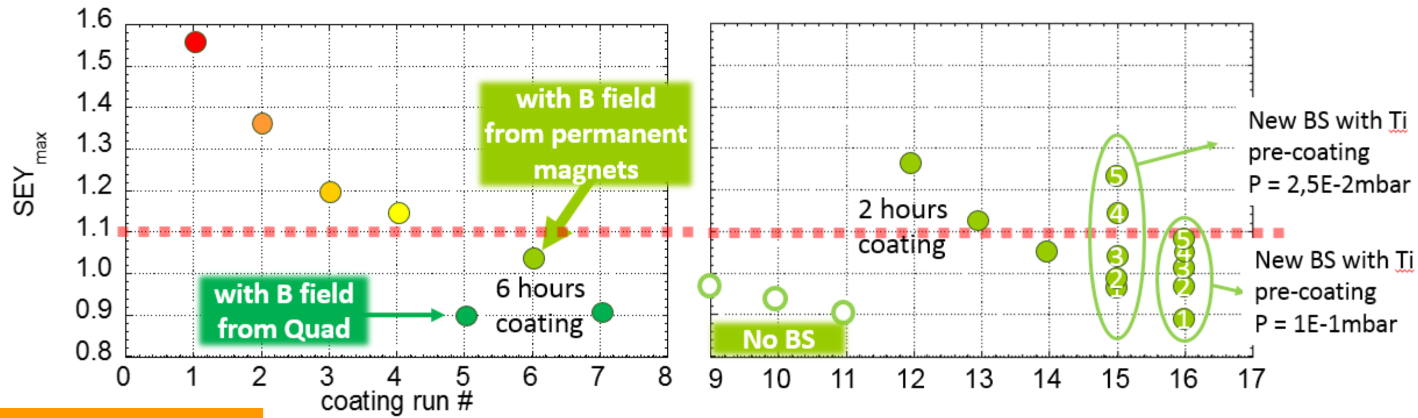
- By the end 2016, develop a "modular sputtering source" that can be inserted in a 150 mm slot and pulled by cables along D1 and the triplets
- Several coating methods investigated:
  1. DC Diode sputtering (@ 2 W/cm; p_{Ar}= 0.5 mbar)
  2. Magnetron using the magnetic field of the **quadrupoles** (@ 2 W/cm; p_{Ar}= 0.1 mbar)
  3. Magnetron using **permanent magnets** with Ti underlayer + dragging (@ 1W/cm; p_{Ar}= 0.1 mbar)
- Achieved: SEY < 1 on a 2 m long beam screen + cold bore system







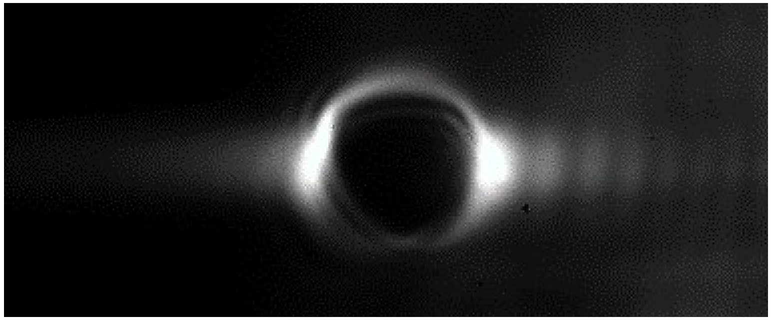




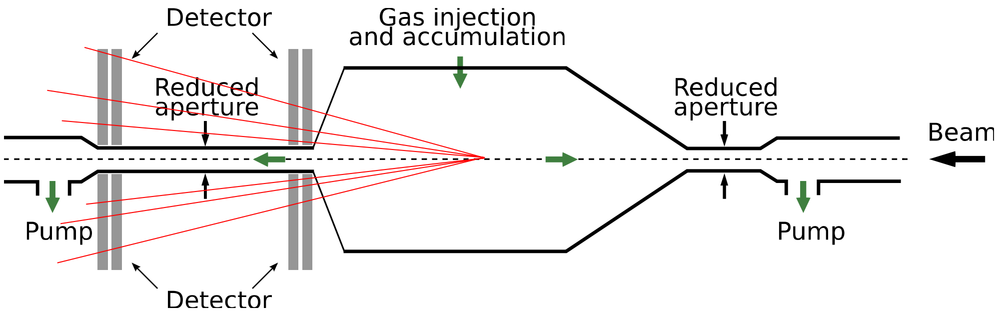
P. Costa Pinto

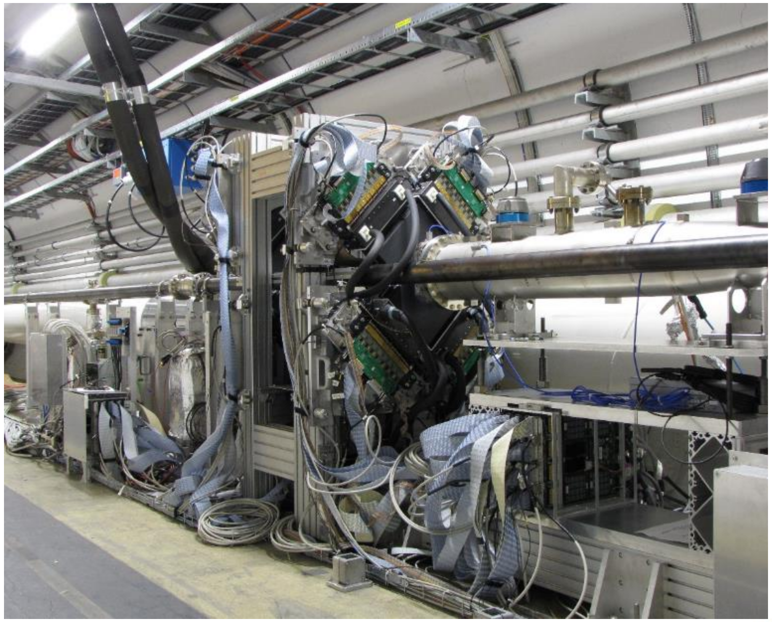
Transverse Beam Profile Measurements

- Beam Halo Coronagraph
  - Prototype installed on Beam 2
  - First images with beam acquired



- Beam Gas Vertex Detector
  - Prototype fully installed on Beam 2
  - First data acquired
  - Track reconstruction & vertex fitting ongoing

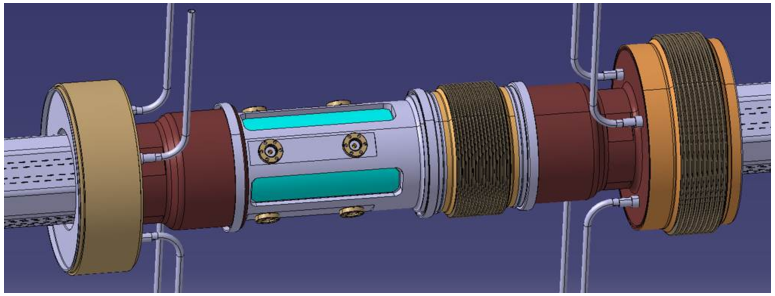




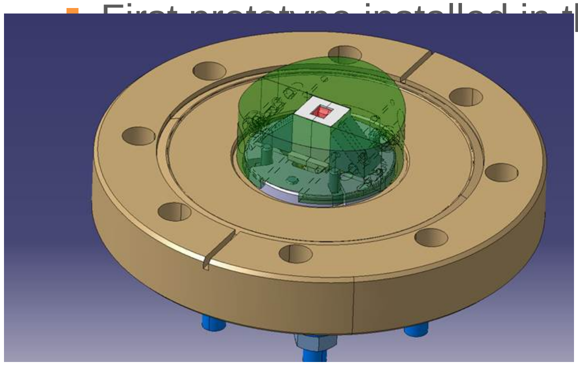
R. Jones

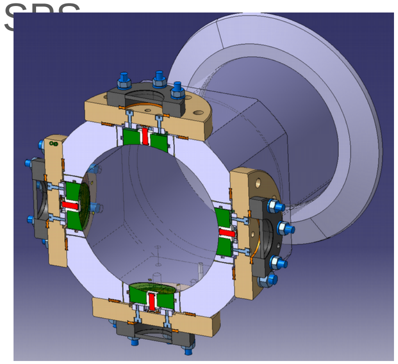
Beam Position Measurement

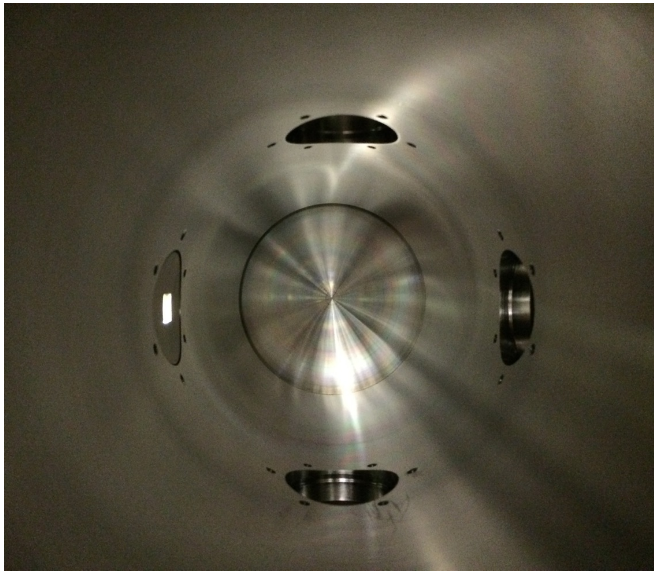
- New Stripline BPM in the triplet region
  - Layout progressing to position BPMs at locations where the two beams do not have parasitic encounters
    - Only BPM in Q2a still not at optimal position
  - RF BPM design optimised to provide highest possible directivity
  - Mechanical design & integration ongoing



- High bandwidth Electro-Optical BPM
  - For crab cavity diagnostic and measuring intra-bunch instabilities
  - First prototype installed in the SPS

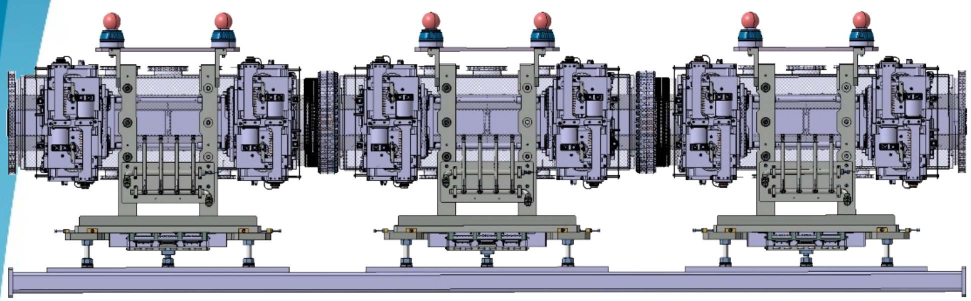




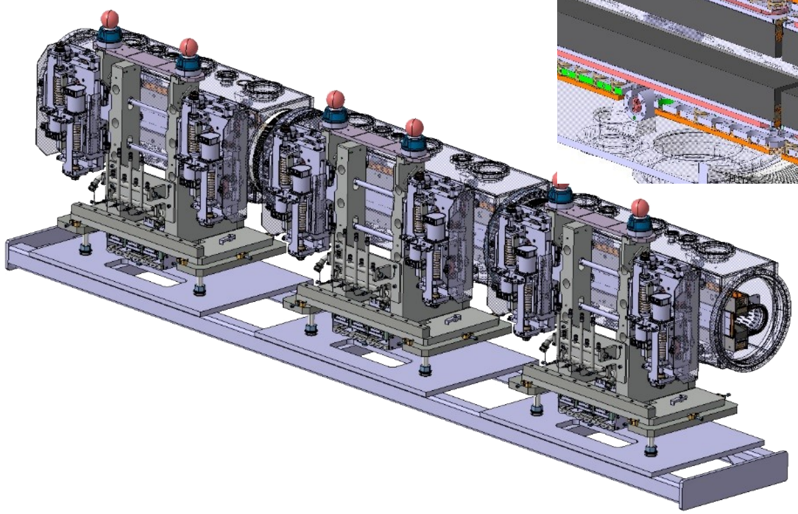


R. Jones

TDIS Progress



L. Gentini



Updates on mechanical design:

- One common support for the three modules (the modules can be aligned on surface and then installed as a single module in the tunnel)
- All modules are interchangeable
- Interconnection between modules were suppressed to improve the geometric impedance (now only 15 mm gap between modules with RF contacts)
- Total TDIS length/occupancy equal to present TDI (easier integration)

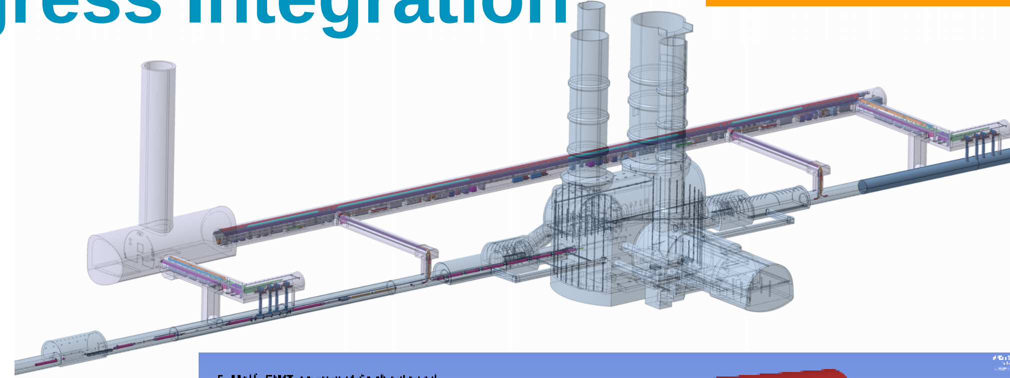
C. Bracco

2016	2017	2018	2019	2020
Final mechanical design	Prototype production	Series production	Series production	Installation

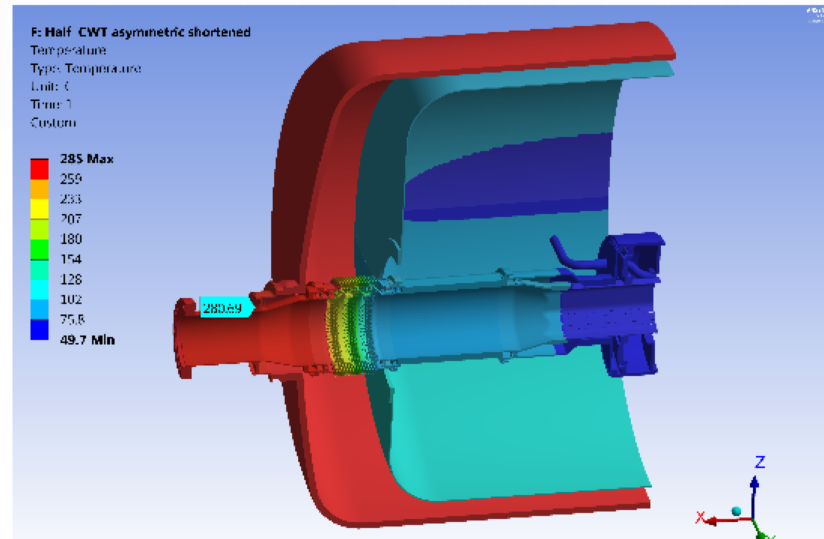
WP 15 - Progress Integration

P. Fessia

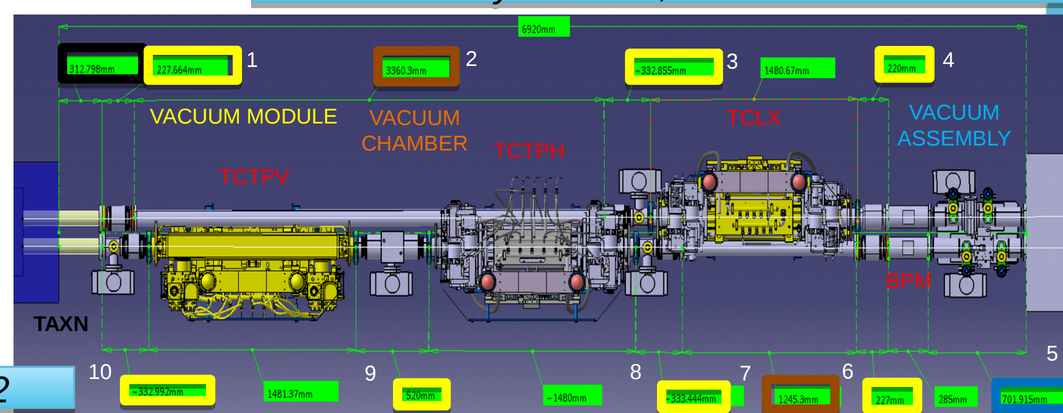
- Frozen underground integration as base for CE contract February 2016 and support to other CE activities



- In preparation of new lay- out IP 1 and IP 5
  - Conjoint work with WP 3, WP 8, WP 12, WP 13 for the integration of the BPM inside Q1
  - Conjoint work with WP 3, WP 9, WP 6 for cooling and powering of the Q6 at Point 1 and 5
  - Conjoint work with WP 5 and WP 12 for the lay-out between TAXN and D2



Courtesy M. Sitko, C. Garion WP 12



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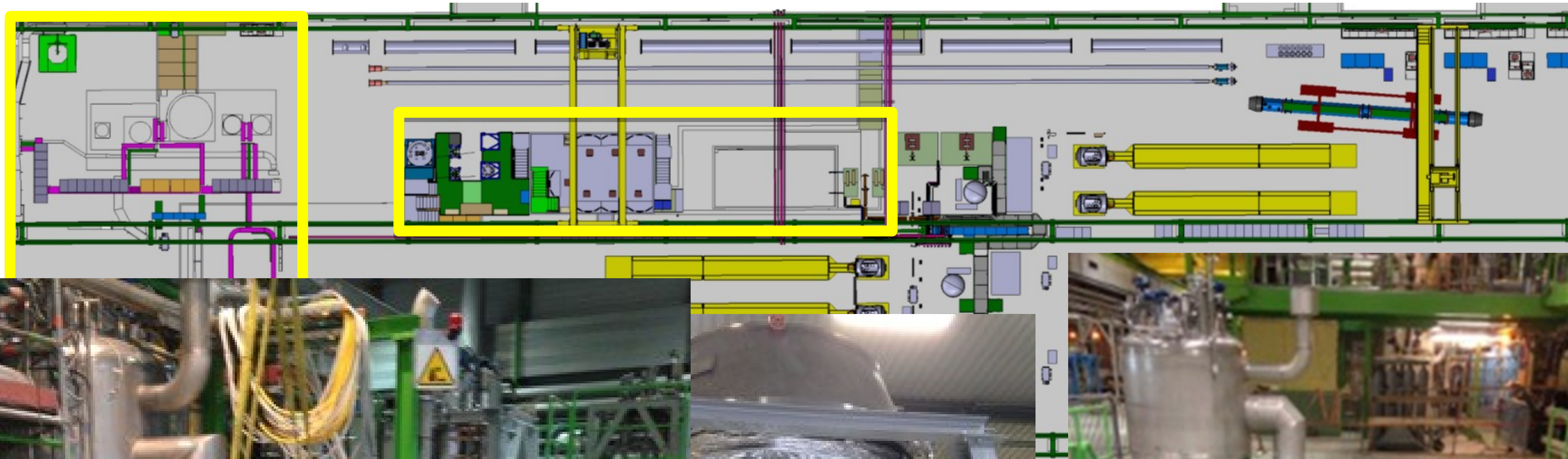
Courtesy P. Santos Díaz, V. Baglin WP 12

SM18 Test Facilitiy Upgrade
1st Magnet Test Facililty Workshop

M.Bajko

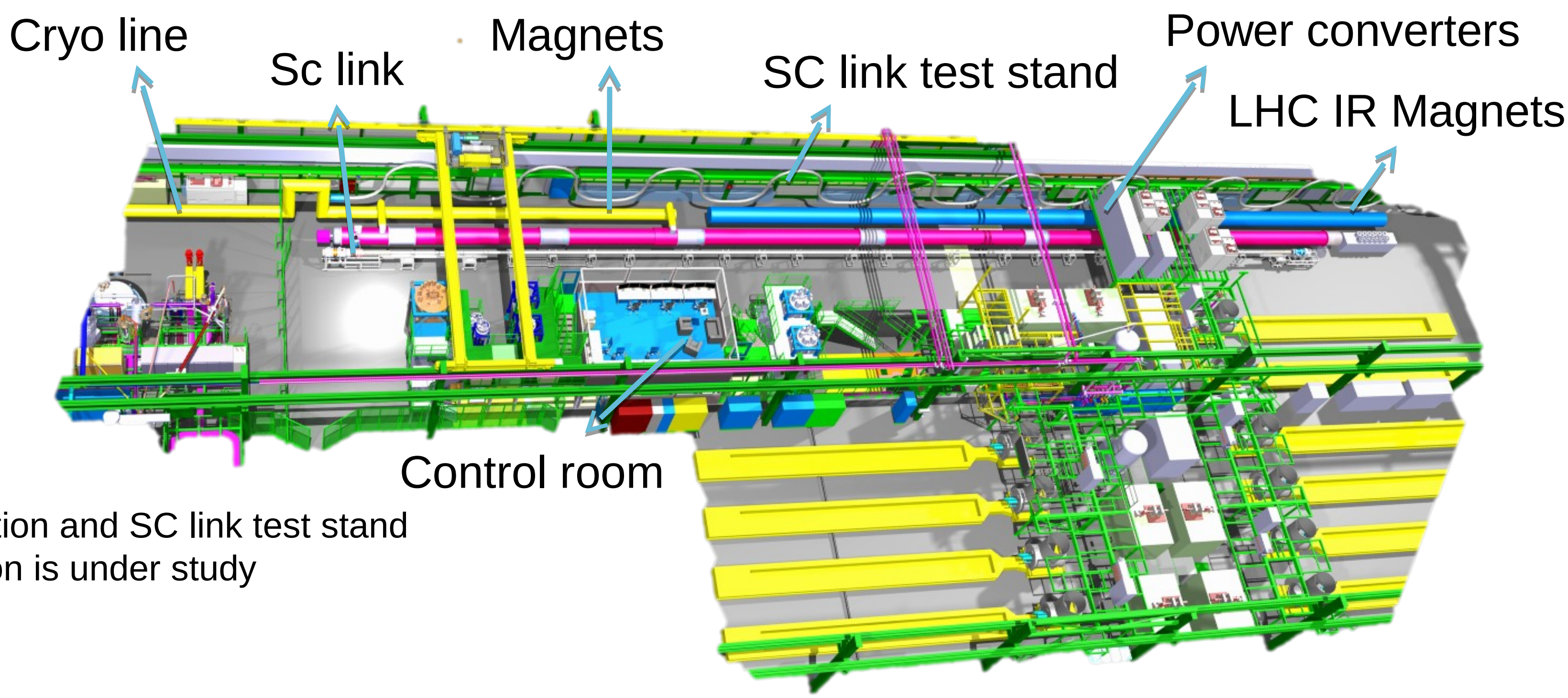
Cluster G

Cluster D



3D integration studies

M. Bajko

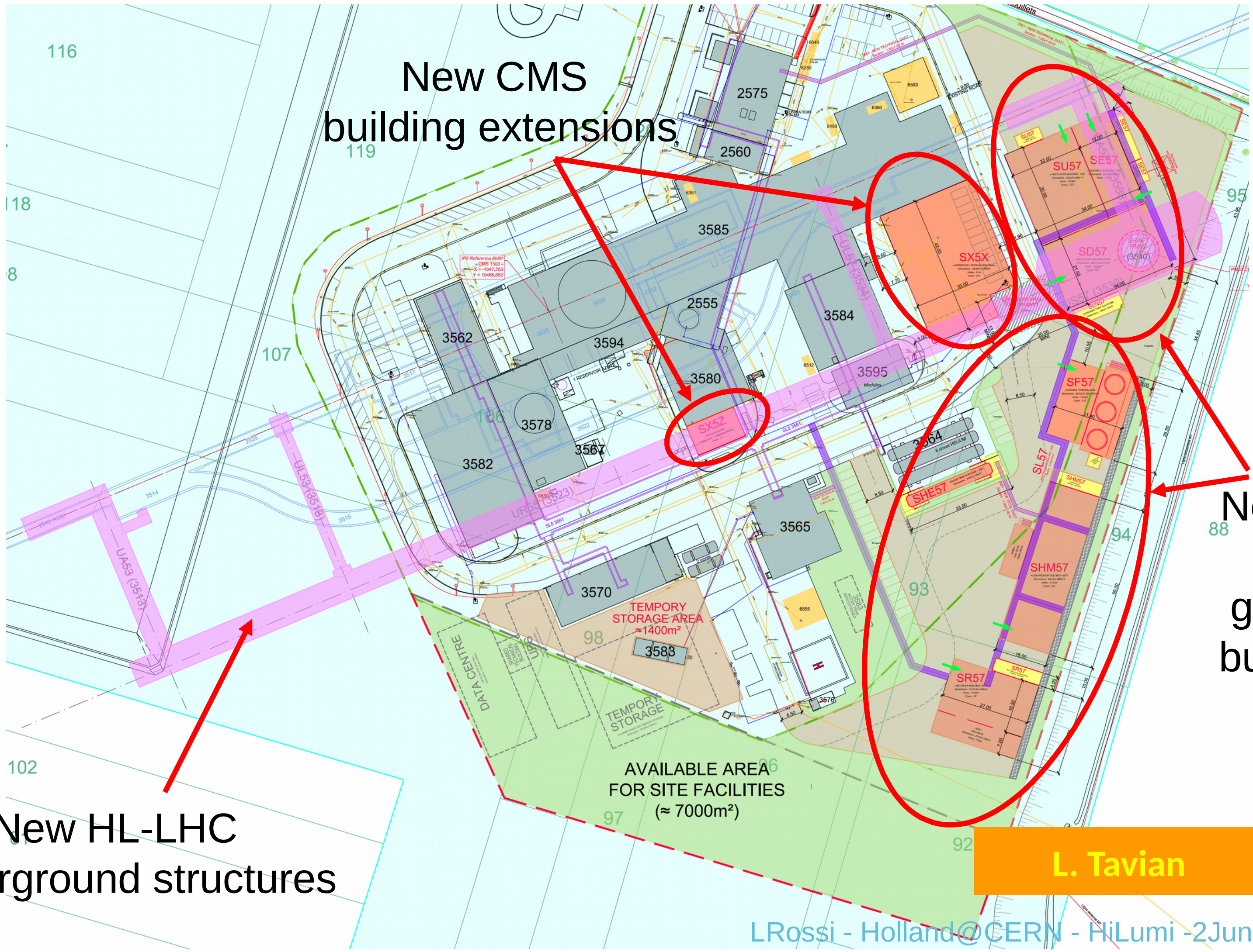


Integration and SC link test stand definition is under study

HL-LHC technical infrastructure: WP17

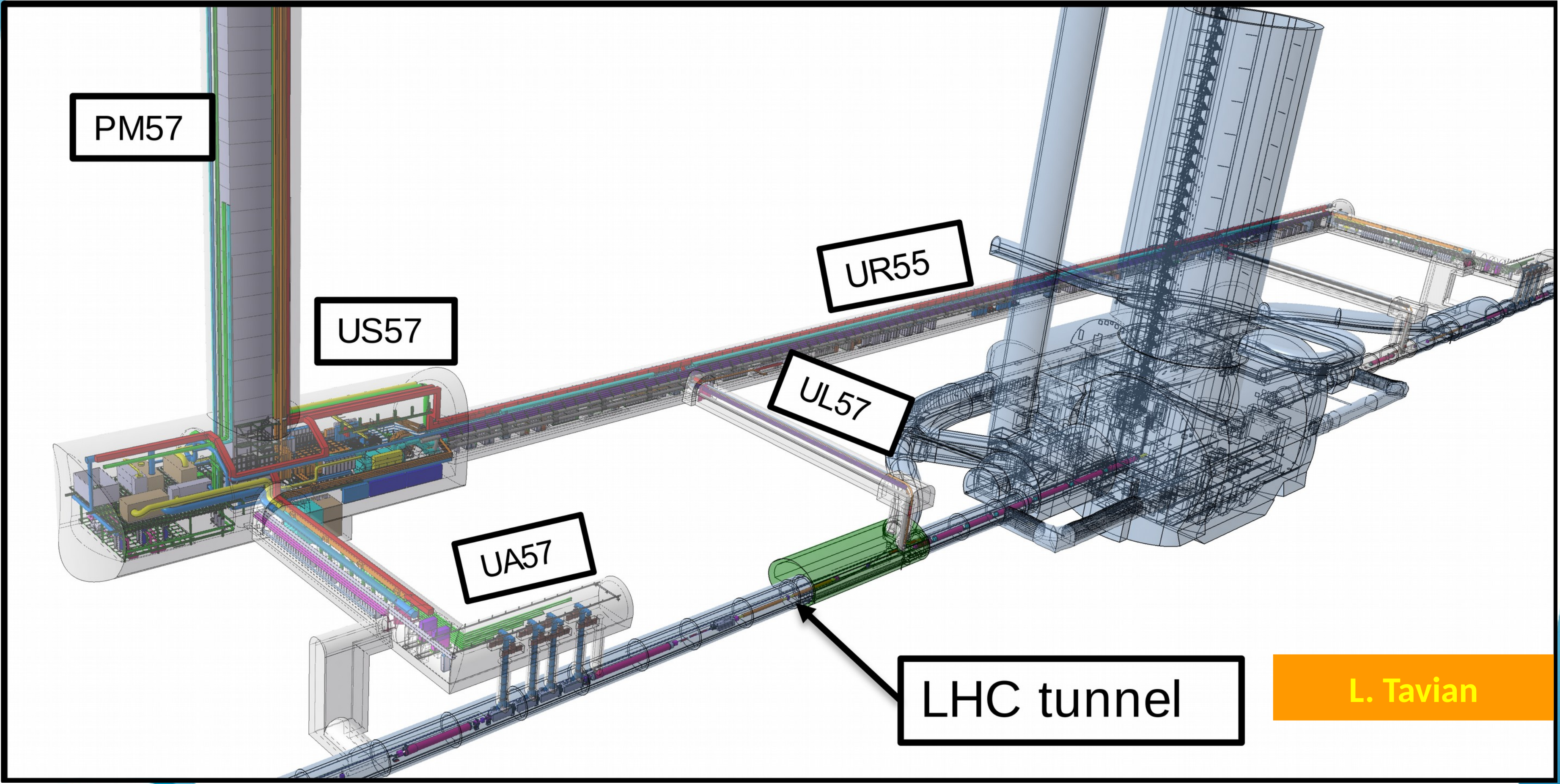
- WP17.1 Civil Engineering
- WP17.2 Electrical distribution
- WP17.3 Cooling and ventilation
- WP17.4 Access & Alarms
- WP17.5 Technical monitoring
- WP17.6 Survey & Alignment
- WP17.7 Transport
- WP17.8 Upgrad. & Cons. of Test/Assembly Facilities for HL-LHC
- WP17.9 Logistics & storage
- WP17.10 Operational Safety

New civil engineering at Point 5 (CMS, France)

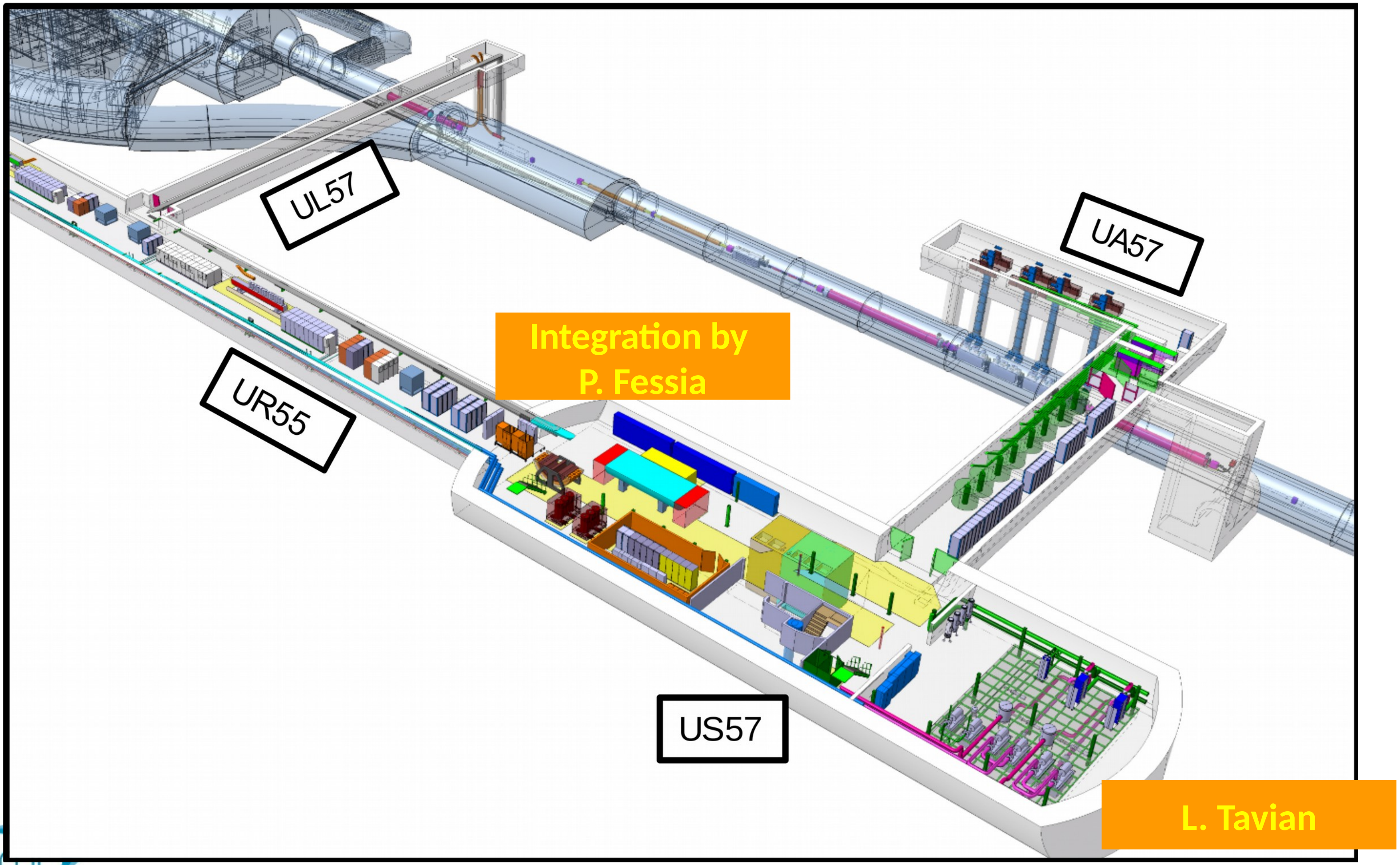


New HL-LHC ground buildings

Civil engineering underground works at Point 5



Example of service integration at Point 5



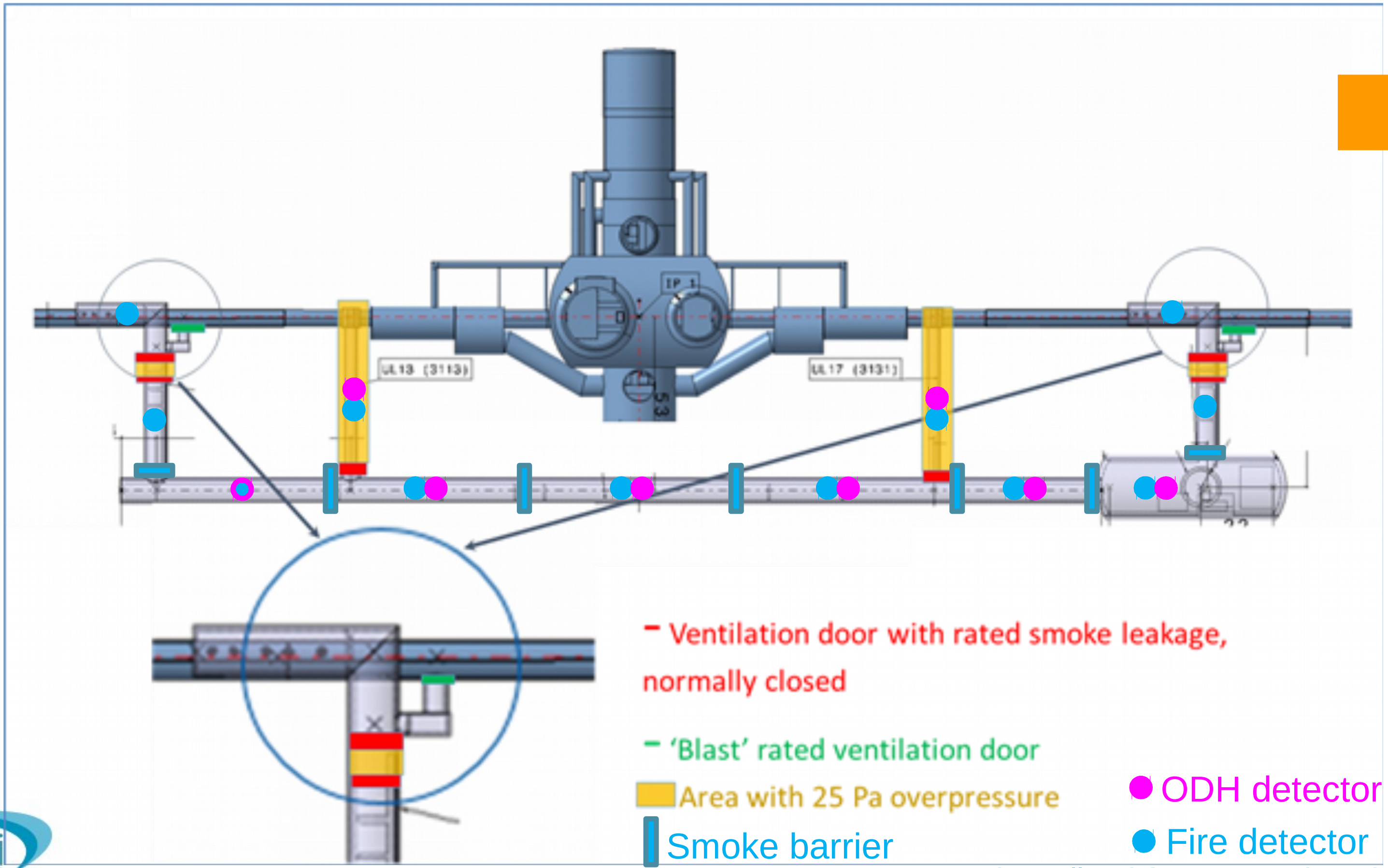
Other main technical infrastructures

- Electrical distribution:
  - ~14 MW to be distributed at Points 1 & 5
  - ~2.5 MW to be distributed at Point 4
- Cooling and ventilation:
  - ~14 MW of raw-water cooling at Points 1 & 5
  - ~1.9 MW of air cooling at Points 1 & 5
  - ~1.7 MW of chilled water cooling at Points 1 & 5
  - ~2.5 MW of raw water cooling at Point 4
- Transport:
  - 1 main 3-t lift at Points 1 & 5
  - 8 overhead cranes ranging from 3.2 to 25 t at Points 1 & 5

L. Tavian

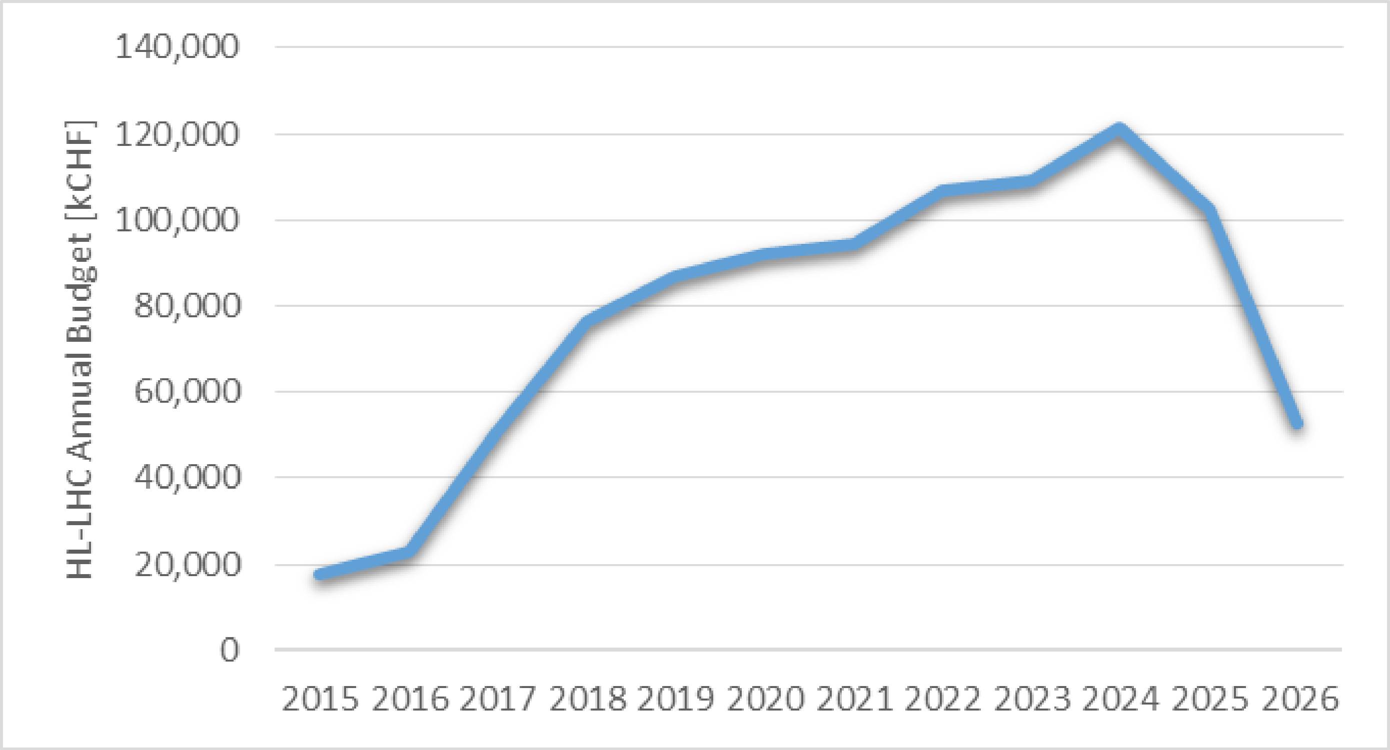
Other main technical infrastructures

- Access, alarm & technical monitoring



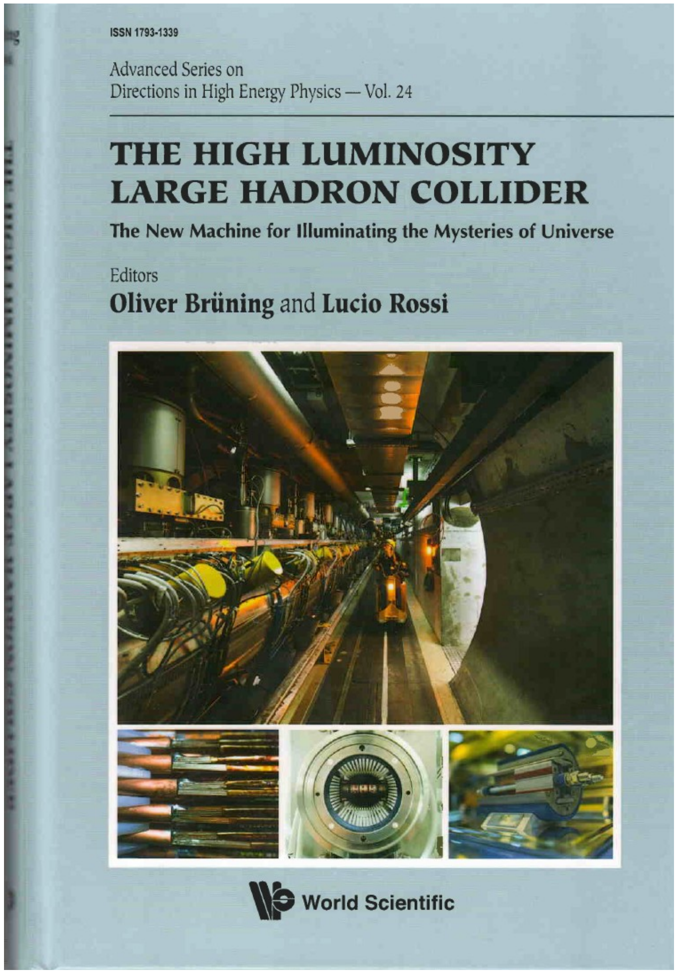
L. Tavian

Budget and approval/financing process



CERN MTP (2016-20) containing HL-LHC and with indication of the HL-LHC total CtC (till 2026) was approved by Council in 2015.
However to approve credit line, necessary to finance it, a global approval of HL-LHC is seeked next Council!

Information on the project: HiLumi book (more S&T oriented)



Chapter 6

Superconducting Magnet Technology for the Upgrade

E. Todesco[1], G. Ambrosio[2], P. Ferracin[1], J. M. Rifflet[1], G. L. Sabbi[3], M. Segreti[4], T. Nakamoto[5], R. van Weelderen[1] and Q. Xu[5]

[1]*CERN, TE Department, Genève 23, CH-1211, Switzerland*
[2]*Fermi National Accelerator Laboratory, Batavia, IL 60510, USA*
[3]*Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA*
[4]*CEA, Saclay, 91400, France*
[5]*KEK, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan*

In this section we present the magnet technology for the High Luminosity LHC. After a short review of the project targets and constraints, we discuss the main guidelines used to determine the technology, the field/gradients, the operational margins, and the choice of the current density for each type of magnet. Then we discuss the peculiar aspects of each class of magnet, with special emphasis on the triplet.

1. Targets

The HL-LHC aims at gathering 3,000 fb^{-1} over ten years. As discussed in the previous section, this ambitious target can be obtained by operating with a peak luminosity leveled at 5×10^{34} $cm^{-2}s^{-1}$. The plan is to obtain it through higher intensity/lower emittance and a larger focusing in the Interaction Point (IP). This second part is given by the magnetic lattice; the target is to be able to reduce the beam size in the IP by a factor two, and therefore one has to double the size of the quadrupoles aperture in front of the IP (triplet).

Some of the previous proposals, done during the LHC luminosity upgrade studies [1, 2, 3], aimed at a reduction of the beam size of 30%, increasing the triplet aperture 30% (see Fig. 1 for an historical view, indicating short models which have been built). The present target of reducing the beam size in the IP by a factor of two was based on theoretical studies (see for instance [4]), and was enabled by advances in magnet technology, i.e., test results from model quadrupoles of progressively larger aperture (Fig. 1).

A critical design parameter for a superconducting quadrupole is the peak field in the coil, which is a function of the aperture times the gradient. For Nb-Ti coils

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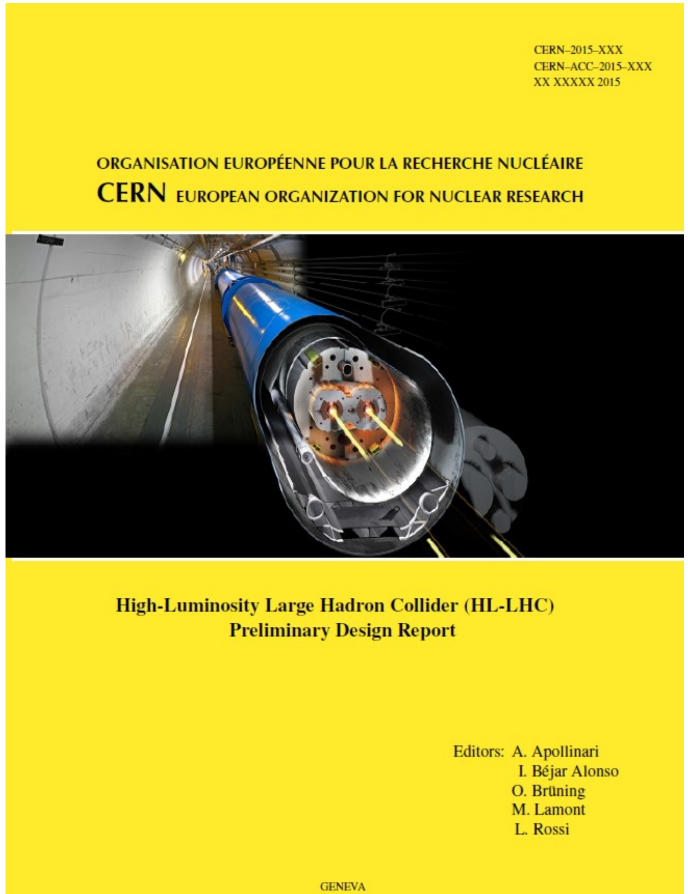
PDR (Preliminary Design Report)

Preliminary version delivered to FP7 on 30 Nov 2014

Cleaned-up version ready spring 2015 (long tedious editing for yellow paper: thanks to I. Bejar).

Published as yellow paper

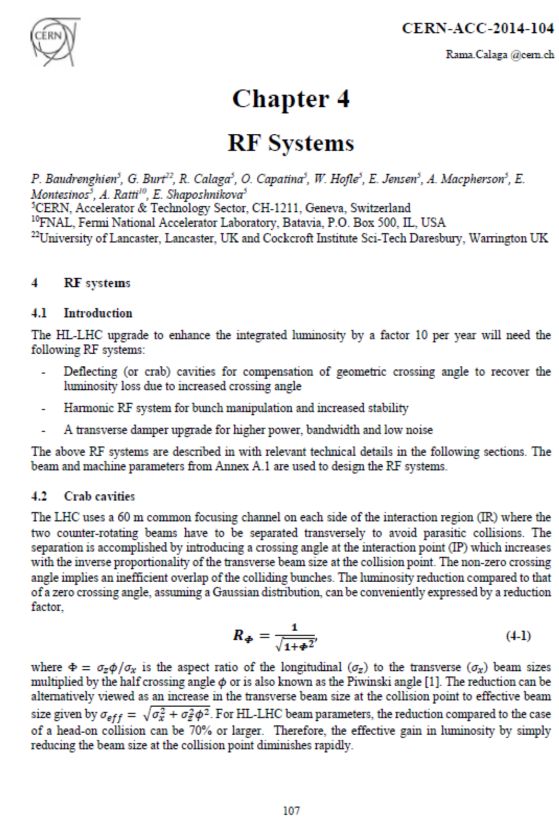

CERN–2015–XXX
CERN–ACC–2015–XXX
XX XXXXX 2015

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

High-Luminosity Large Hadron Collider (HL-LHC)
Preliminary Design Report

Editors: A. Apollinari
I. Béjar Alonso
O. Brüning
M. Lamont
L. Rossi

GENEVA


CERN-ACC-2014-104

Rama.Calaga @cern.ch

Chapter 4

RF Systems

P. Baudrenghien[5], G. Burt[22], R. Calaga[5], O. Capatina[5], W. Hofle[5], E. Jensen[5], A. Macpherson[5], E. Montesinos[5], A. Ratti[10], E. Shaposhnikova[5]
[5]CERN, Accelerator & Technology Sector, CH-1211, Geneva, Switzerland
[10]FNAL, Fermi National Accelerator Laboratory, Batavia, P.O. Box 500, IL, USA
[22]University of Lancaster, Lancaster, UK and Cockcroft Institute Sci-Tech Daresbury, Warrington UK

4 RF systems

4.1 Introduction

The HL-LHC upgrade to enhance the integrated luminosity by a factor 10 per year will need the following RF systems:

- Deflecting (or crab) cavities for compensation of geometric crossing angle to recover the luminosity loss due to increased crossing angle
- Harmonic RF system for bunch manipulation and increased stability
- A transverse damper upgrade for higher power, bandwidth and low noise

The above RF systems are described in with relevant technical details in the following sections. The beam and machine parameters from Annex A.1 are used to design the RF systems.

4.2 Crab cavities

The LHC uses a 60 m common focusing channel on each side of the interaction region (IR) where the two counter-rotating beams have to be separated transversely to avoid parasitic collisions. The separation is accomplished by introducing a crossing angle at the interaction point (IP) which increases with the inverse proportionality of the transverse beam size at the collision point. The non-zero crossing angle implies an inefficient overlap of the colliding bunches. The luminosity reduction compared to that of a zero crossing angle, assuming a Gaussian distribution, can be conveniently expressed by a reduction factor,

$$R_\Phi = \frac{1}{\sqrt{1+\Phi^2}}, \quad (4\text{-}1)$$

where $\Phi = \sigma_z\phi/\sigma_x$ is the aspect ratio of the longitudinal (σ_z) to the transverse (σ_x) beam sizes multiplied by the half crossing angle ϕ or is also known as the Piwinski angle [1]. The reduction can be alternatively viewed as an increase in the transverse beam size at the collision point to effective beam size given by $\sigma_{eff} = \sqrt{\sigma_x^2 + \sigma_z^2\phi^2}$. For HL-LHC beam parameters, the reduction compared to the case of a head-on collision can be 70% or larger. Therefore, the effective gain in luminosity by simply reducing the beam size at the collision point diminishes rapidly.

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TDR_v0 : delivered to FP7-HiLumi EU in November. It si the most updated document accessible via web.
It will included also Tech Infrastructure by summer.
TDR_v1 : completed by summer 2017, after the 2nd C&SR

HiLumi HL-LHC PROJECT

Industry Workshop : *Superconducting Technologies for Next Generation of Accelerators,* 4-5 Dec 2012 @ CERN Globe

https://indico.cern.ch/event/196164/page/972-home
101 participants, 42 from 21 companies

HiLumi LHC goes to Industry, 26 June '15: 143 attendants! https://indico.cern.ch/event/387162/

The boat is – near – full steam…
I hope you come on board
and helping to speed up!

Contact person for Industry: ISABEL BEJAR ALONSO