Ultra-vacuum components and systems

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(WP leader: V. Baglin)

22nd May 2017

Content

- Introduction to HL-LHC project and Plan
- Cryogenic Temperature sectors of the LSSs
- Room Temperature sectors of the LSSs
- Controls & Robotics for Vacuum
- Summary

This talk presents the general overview, extra slides are added at the end to provide additional technical details

Introduction: vacuum in accelerators

Vacuum in accelerators

vacuum to reduce interactions with residual gas molecules in the beam pipes

- maximise beam life-time (100 h: $1 \cdot 10^{-8}$ mbar)
- minimise background noise to the experiments ($1 \cdot 10^{-11}$ mbar)

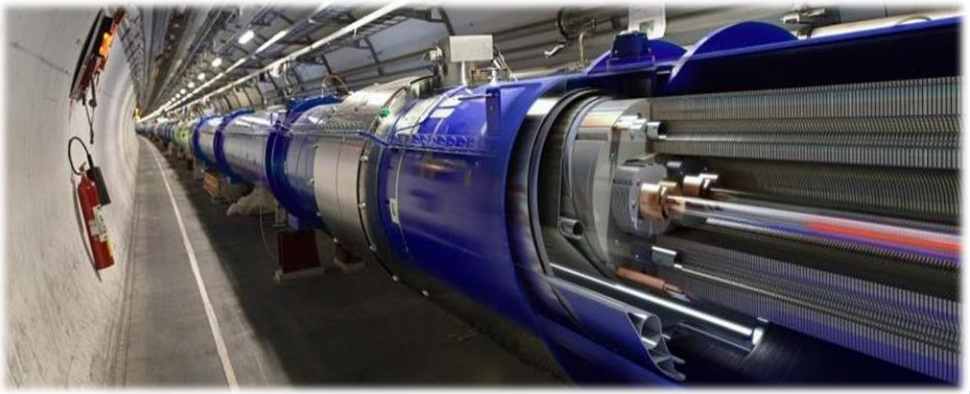
The HL-LHC vacuum system is made of:

- Cryogenic Temperature Insulation vacuum
- Room Temperature beam vacuum
- Cryogenic temperature beam vacuum
- Experimental beam vacuum

Systems under **TE-VSC group** responsibility:
→ Design, construction, installation and operation

CERN : 120 km of vacuum vessels, of which 100 km in LHC alone

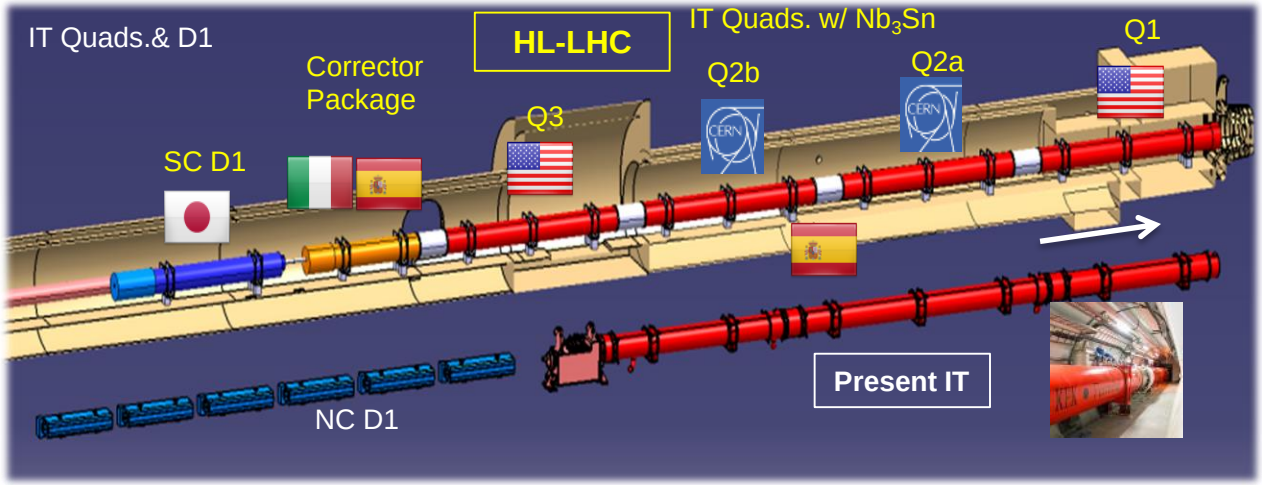
- 4x 23 km of LHC are cold (1.9 or 4.5 K): 2 beam pipes + 2 insulation volumes (magn + QRL)
- 2x 4 km of LHC are at Room Temperature (RT) : 1 or 2 beam pipes + no insulation



Introduction: HL-LHC

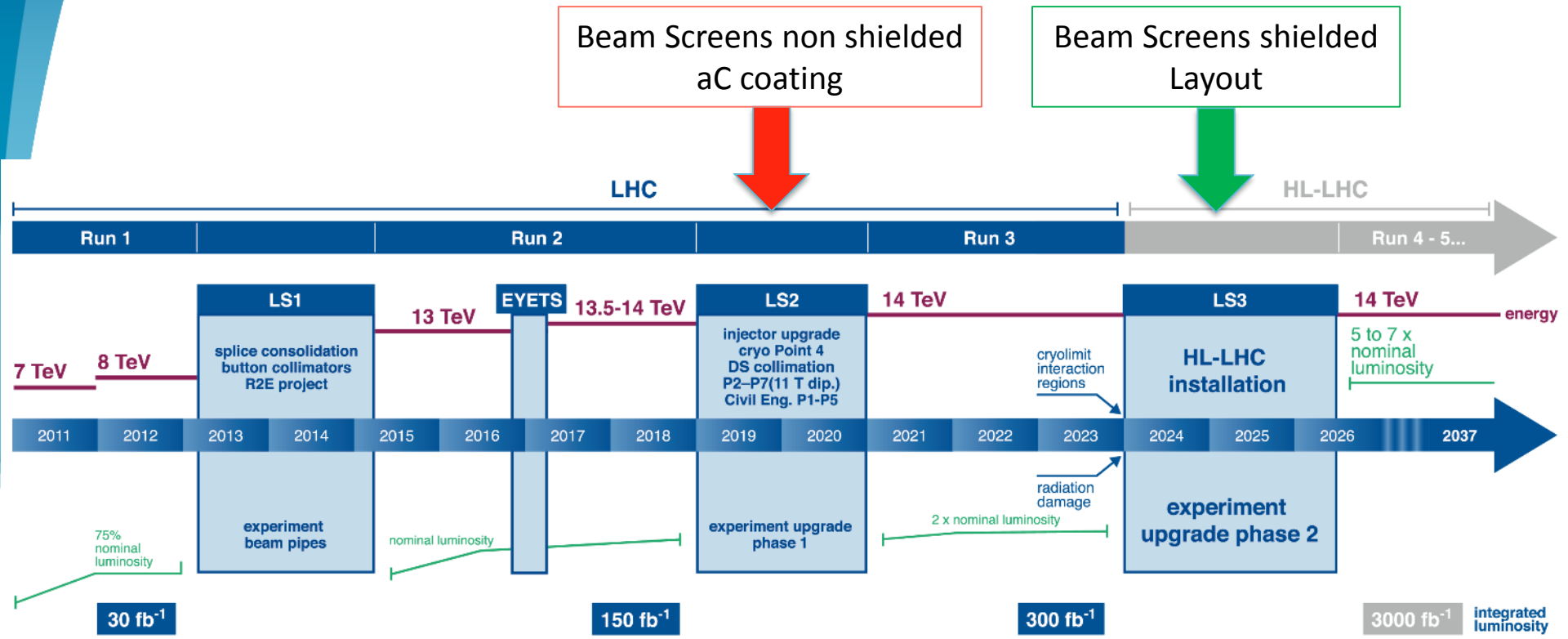
HL-LHC will need modifications / upgrades on significant portions (>1.2 km) of LHC vacuum

- New Beam Screens (shielded, non-shielded)
- New a-C coating of Beam Screens
- New layout:
  - modifications in all the 8 Long Straight Sections (LSS) /no changes in the 8 ARC sections
  - completely new accelerator layout near ATLAS & CMS (LSS1 & LSS5)
  - new interconnects & cold-warm transitions
  - increased magnet aperture (new beam pipes)



These activities will mainly occur during the 2 Long Shutdown (LS2 and LS3)

LHC HL-LHC plan



Many components need to be designed, procured and installed.

Two long shut-down periods (LS2 and LS3):

- LS2 : 2019 – 2020, preparation is NOW
- LS3 : 2024 – mid 2026, major activities

Content

- Introduction to HL-LHC project and Plan
- Cryogenic Temperature sectors of the LSSs
  - New beam screens (BS)
  - New vacuum interconnections
  - aC coating of BS

- Room Temperature sectors of the LSSs
- Controls & Robotics for Vacuum
- Summary

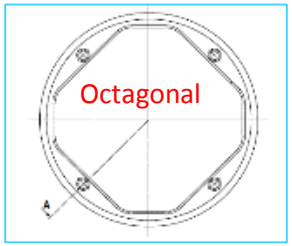
New BS for HiLumi

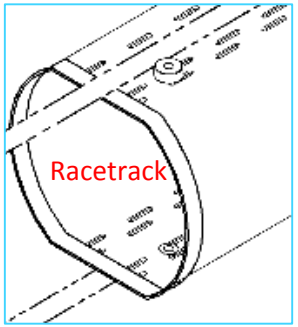
Design is under finalisation

- Different shapes and several apertures
- Tungsten allow shielding
- Stainless steel cooling tubes
- Cu colaminated, perforated P506 beam screen
- Amorphous-Carbon (a-C) coating (100 nm)

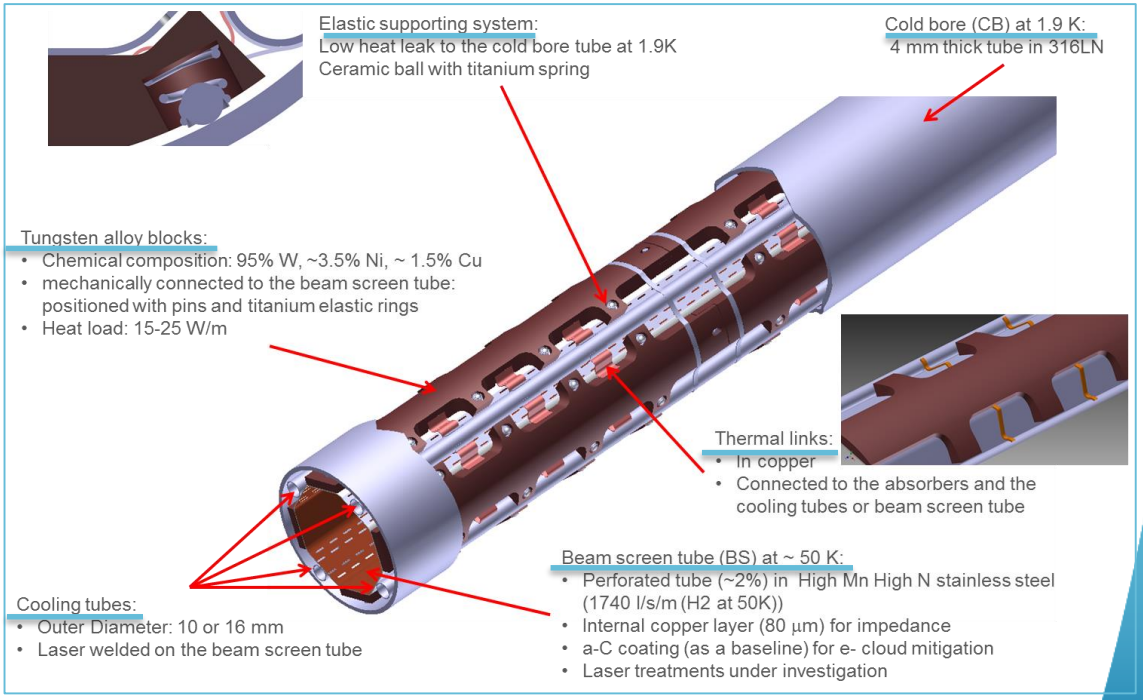
LS2 (2019-2020):
- consolidation of the beam screens in LSS2 and LSS8: production and in-situ treatment (a-C coating)

LS3 (2024-2026):
- new beam screens in LSS1 and LSS5





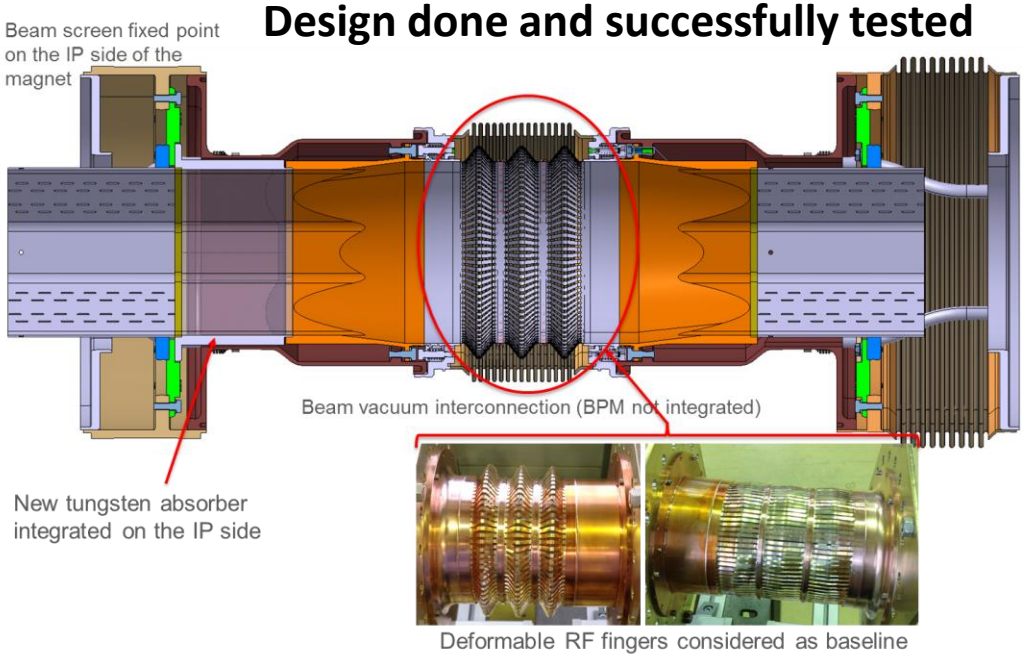
Assembly of the beam screen



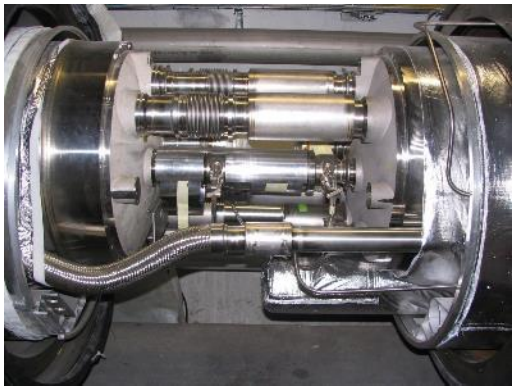
Beam pipe interconnects

- Similar or different diameter or shape (aperture matching)
- Dedicated Plug-in Modules to assure RF screening and low impedance: Cu plated stainless steel
- Connections for different temperature (Cold-Warm Transition)
- Can house BPM

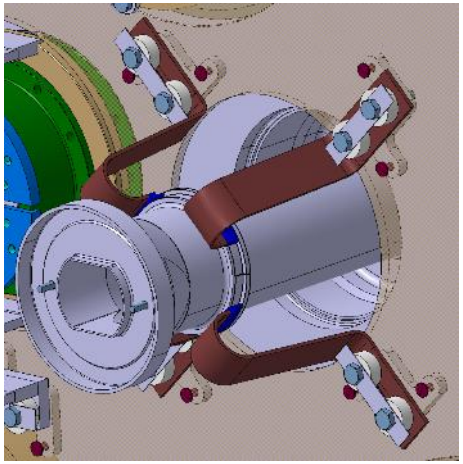
Design done and successfully tested



A typical LHC interconnection



CW transition

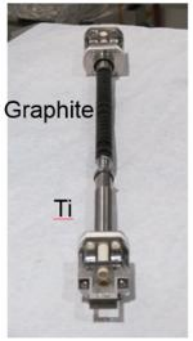


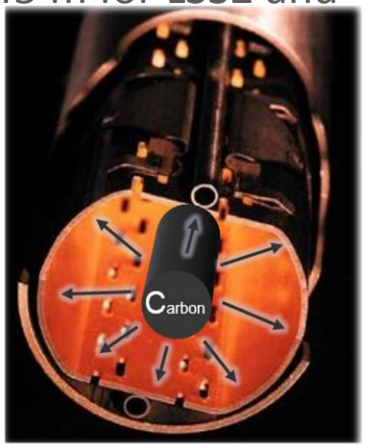
About **50** new interconnections are needed
- 20 @ LS2
- 30 @ LS3

About **60** CW transitions are needed
- 20 @ LS2
- 40 @ LS3

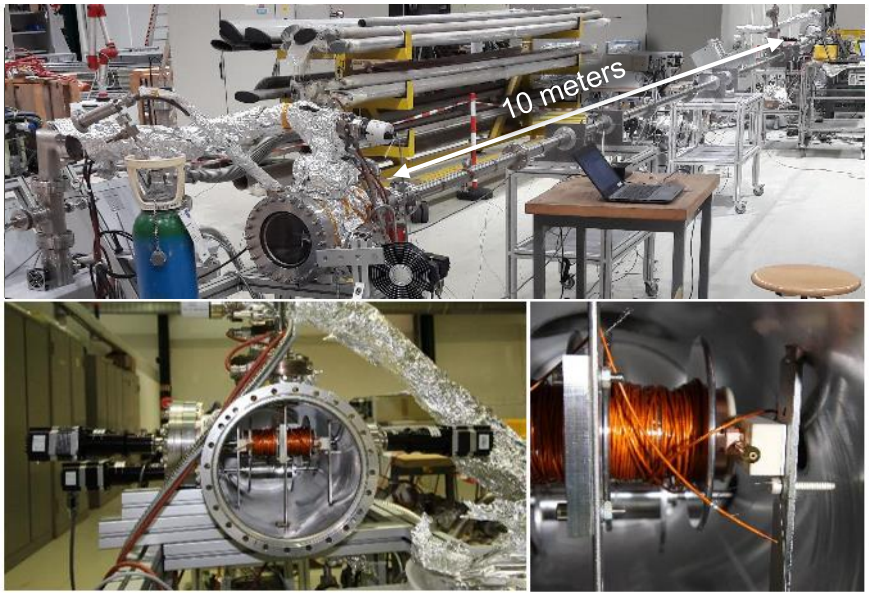
New a-C coating of BS

- to limit the development of electron clouds
- coating technology and methodology defined
- In-situ: modular sputtering source being developed: inserted in a 15 cm slot, and travel inside BS along 45 m for LSS2 and LSS8





aC-coating setup



LS2 (2019 – 2020)

in-situ a-C coating (for LSS2, LSS8) , because magnets will not be replaced

start production of Beam Screens (for LSS1, LSS5)

Content

- Introduction to HL-LHC project and Plan
- Cryogenic Temperature sectors of the LSSs
- Room Temperature sectors of the LSSs
  - Warm modules
  - Vacuum chambers
  - Instrumentation
- Controls & Robotics for Vacuum
- Summary

LS2 LS3

Room temperature vacuum system

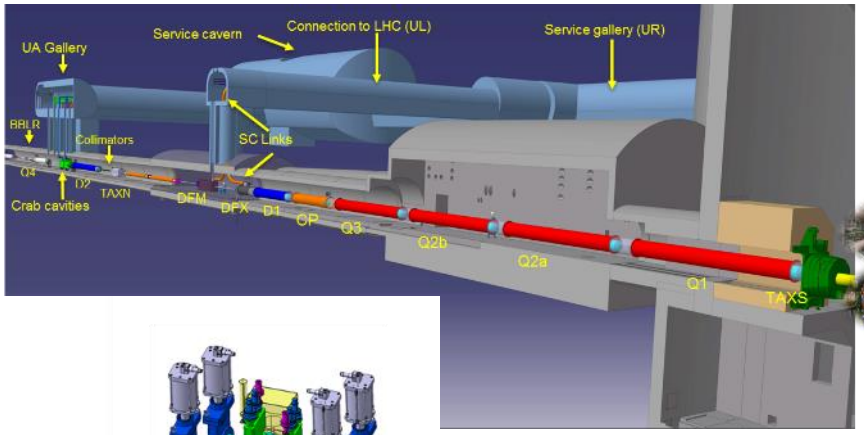
- ~ 6 km length
- Bake-able vacuum system
- Relies on TiZrV getter film pumping after activation at ~ 200°C

Item in LSS	Length (m)
SAM @ cryo T	~ 1 365
LSS @ RT baked	~ 1 000
LSS @ RT with baked NEG	~ 4 800
Total length under vacuum	7 227

"Combined" sector in both side of each experiment
Both beams circulates in the same beam pipe

"Twin" sector
Beams circulate in different beam pipes

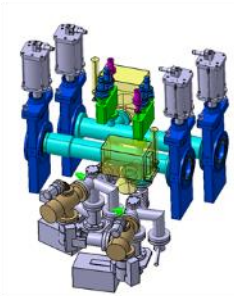
Layout modifications

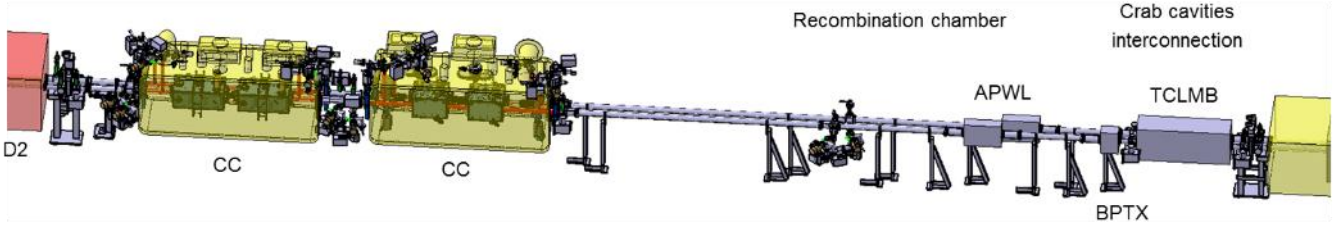


Long Straight Section 1&5 (1 km)
will be completely new

LS3

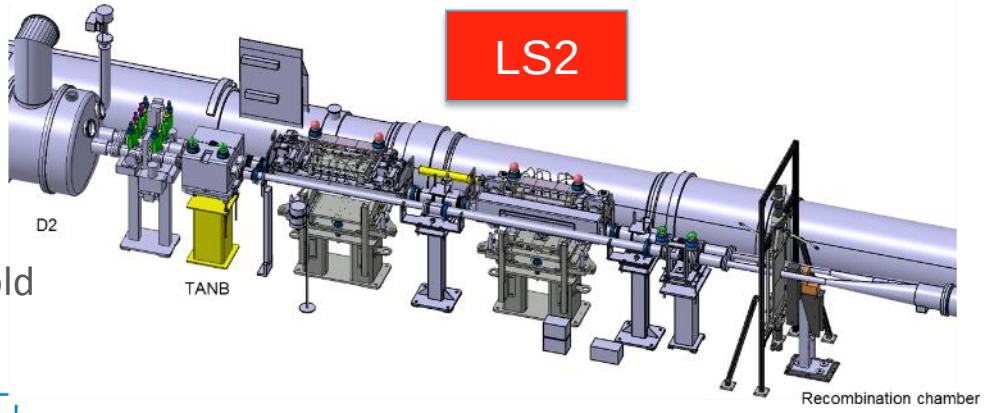

Recombination chamber


Crab cavities interconnection



Long Straight Section 8
Installation of a mask (TANB) to protect the D2 cold mass.

LS2



Needed dedicated vacuum chambers with supports, warm modules, bellows, UHV flanges, bake-out equipment,…

Quantity for cryo and RT sector components

Component	LS2	LS3	Total
Shielded Beam Screen		40	40
Non-shielded Beam Screen	30	15	45
Vacuum bellows	25	211	236
Vacuum chamber	15	65	80
Vacuum supports	30	130	160
Vacuum bakeout jackets	20	180	200
Vacuum flanges	80	600	680
Sector valves	8	52	60
Vacuum gauges		56	56
Vacuum seals	50	250	300
Vacuum pumps	10	40	50
Vacuum collars	30	120	150
Vacuum valves	10	50	60

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- Introduction to HL-LHC project and Plan
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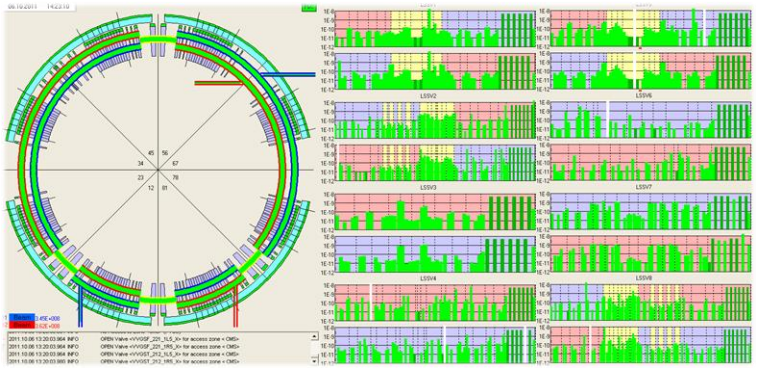
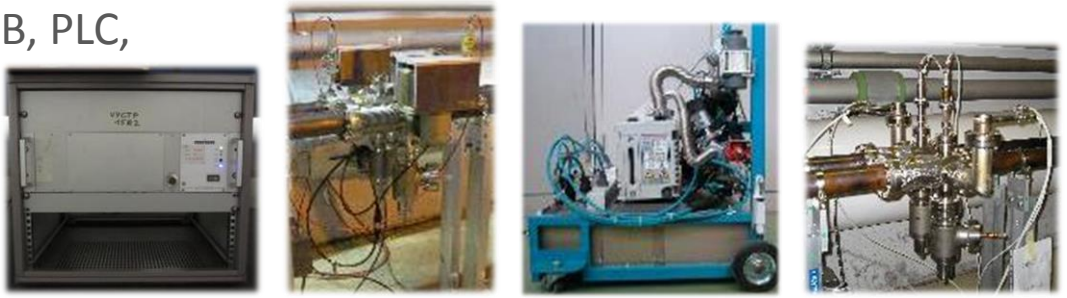
- Controls & Robotics for Vacuum LS2 LS3
- Summary

Controls

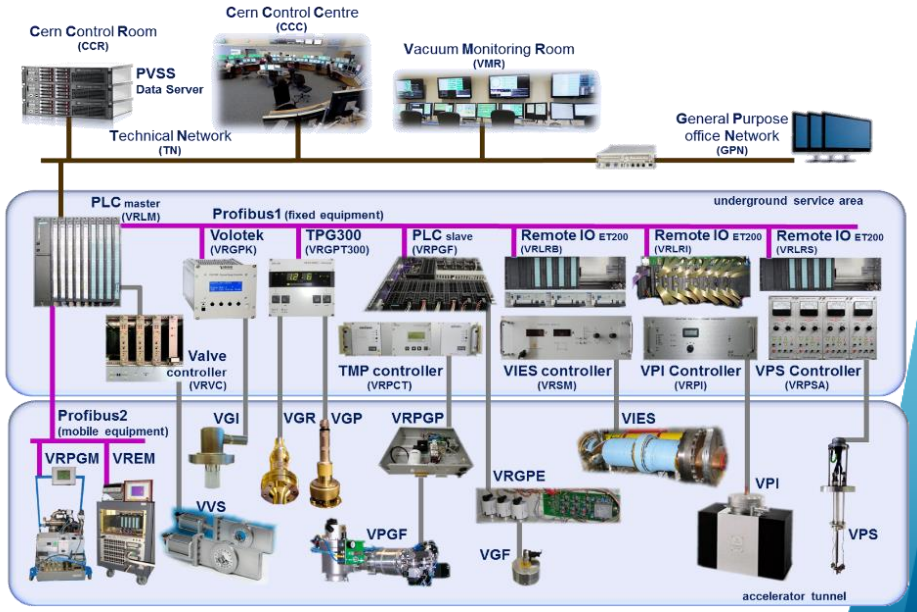
- Redesign of some electronics (front-end & controllers)
- Adding new instruments/devices (remotely controlled and interlocked)
- Evolution of software frameworks (DB, PLC, SCADA)





Preliminary estimation for HL-LHC

Component	Quantity
Sputter Ion Pump controller	60
Sector Valve controller	60
Interlock	60
Penning/Pirani gauge (LSS) controller	70
Penning/Pirani/Piezo gauge (ARC) contr.	850
Mini-racks (ARC)	130
Fixed Pumping group controller	10
Euro crates	300
PLCs	150
Long cables and connectors	280



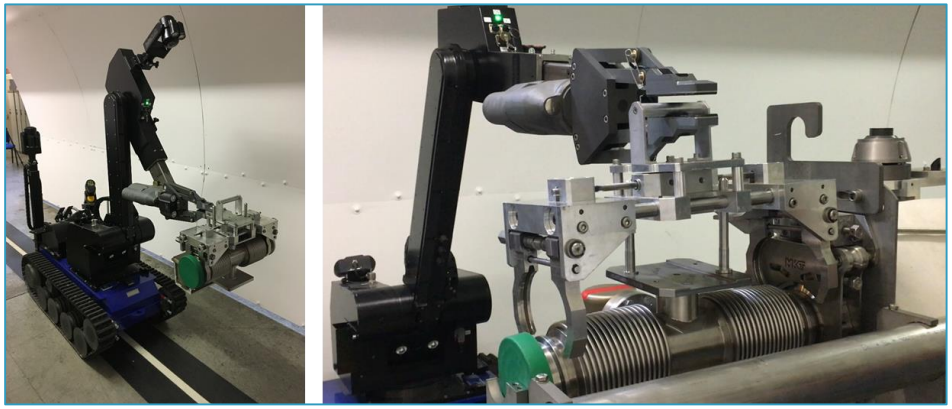
LS3

Robotics

The level of radioactivity from activated materials will require new tools for remote manipulation, enhanced reality, supervision

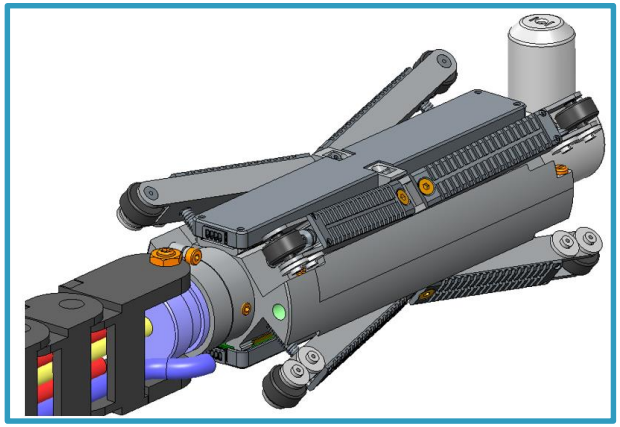
→ to minimize the radiation doses for people, during interventions, when replacing/servicing collimators, magnets, vacuum components, instruments, cables, etc,

Vacuum modules: robot for the bellows compression to remove the collimator



LS3

Laser Engineered Surface Structures (LESS) : robot for in-situ thermal treatment (CERN, STFC, Un. of Dundee Collaboration)



LS2

Content

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Summary

- *Ongoing studies*
  - a-C coating, design of beam screens, interconnects, cold warm transitions, vacuum layout

- Cryogenic temperature vacuum system
  - Design underway
  - Prototyping started
  - Procurement from 20172017

→ Shielded beam screen:
- Full scale prototype – Q3/2018
Interconnect:
- CW Transition prototype: Q1 2018

- Room temperature vacuum system
  - Design initiated
  - Procurement to start by 2018-19

→ Finalisation of layout : mid 2018

- **Will need**
  - raw materials (W alloy, Al alloy, SS, …)
  - cold bores
  - beam screen punching, forming and welding
  - bakeout systems
  - machining and assembly of UHV components
  - bellows for UHV
  - vacuum chambers and their supports
  - electronics & controllers

→ Cold bore machining from 2018

→ First beam screen tube 2018

→ **HL Make or Buy WP12 Brochure**
https://edms.cern.ch/document/1748379/1.1

Thanks for your attention

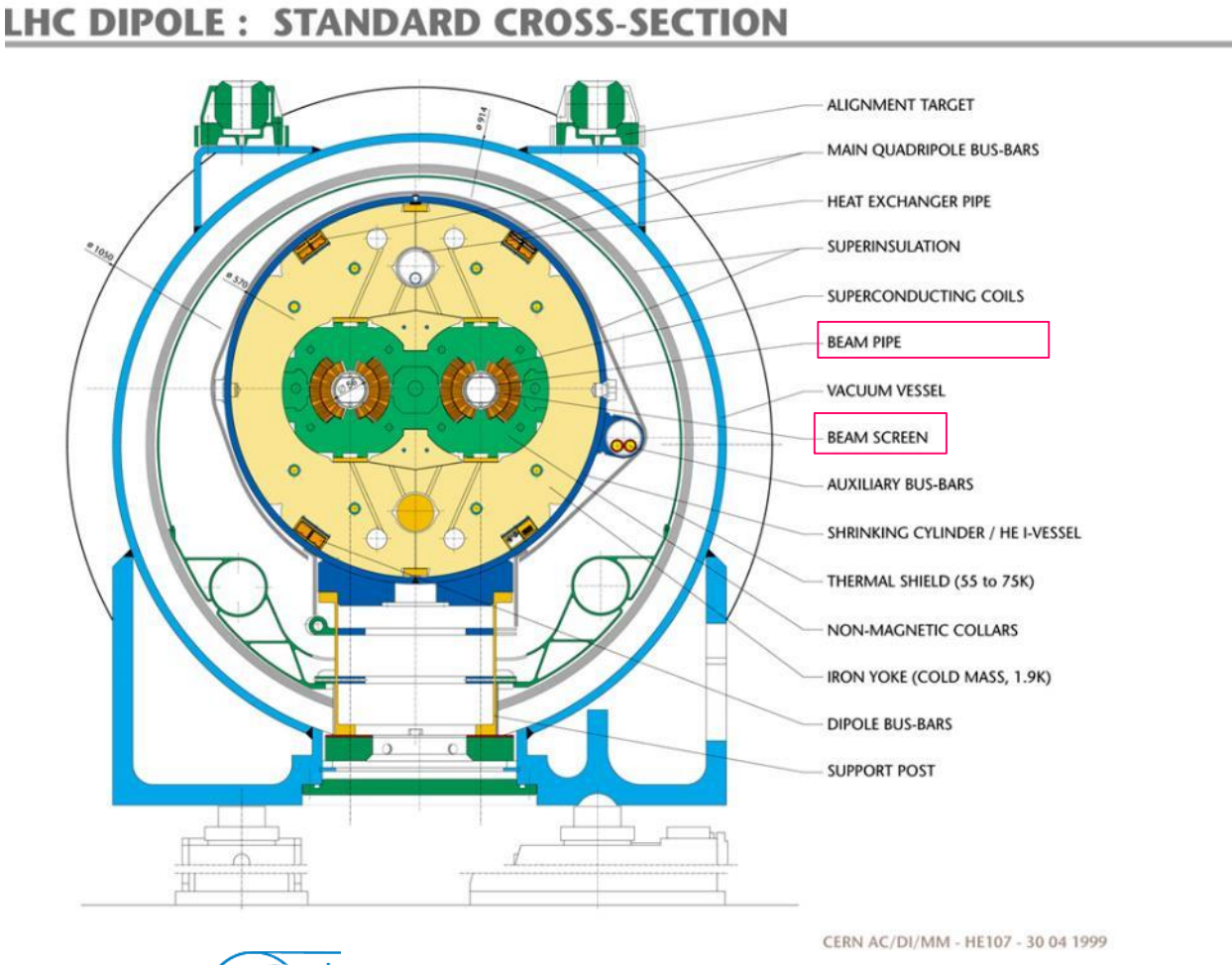
Later in the day we will be glad to:

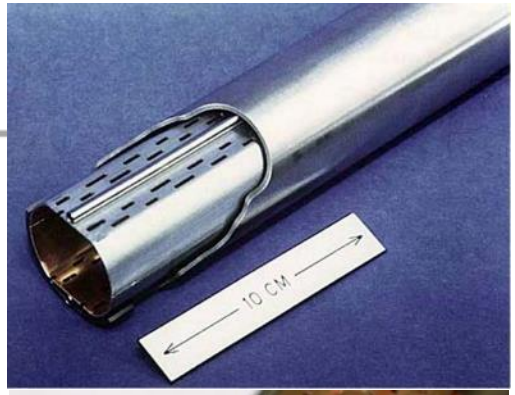
- *discuss technical details with you*
- *help you identifying common interests*

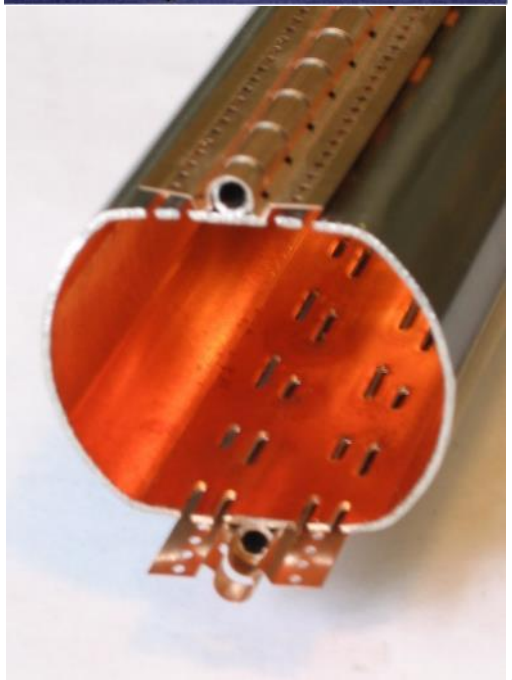
Slides with additional technical details

LHC Dipole Vacuum System

- Cold bore (CB) at 1.9 K which ensures leak tightness
- Beam screen (BS) at 5-20 K which intercepts thermal loads and acts as a screen



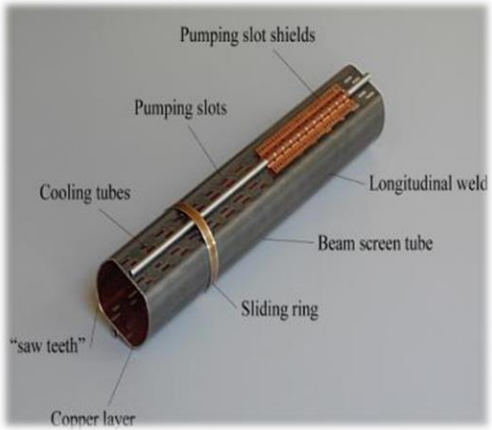


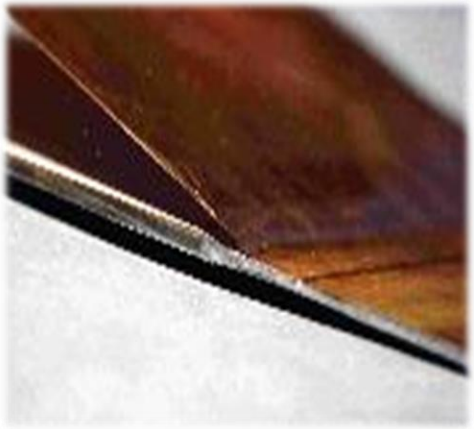


Current LHC BS

- Perforated BS at a controlled temperature of 5-20 K to:
  - intercept the heat induced by the beam (synchrotron radiation + electron cloud) before it reaches the beam pipe (@1.9 K)
  - intercept the particles produced by the beam (ions, electrons, photons etc.) before they provoke molecular desorption from the beam pipe wall
  - to allow pumping of residual molecules into the wall of the beam pipe
- racetrack shape
- made of P506 non-magnetic stainless steel
- with copper co-lamination (80 μm), on the inner surface, for reduced electrical impedance

BS are not needed in Room Temperature beam pipes; which must be bakeable



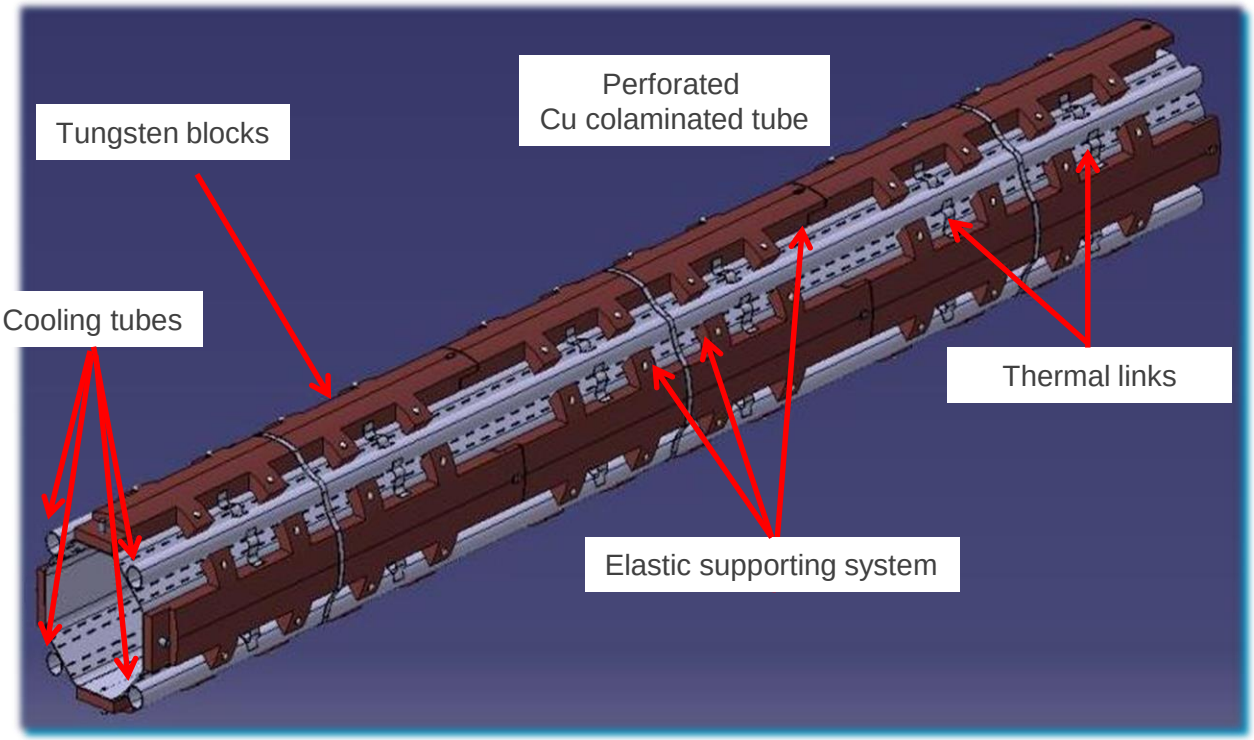


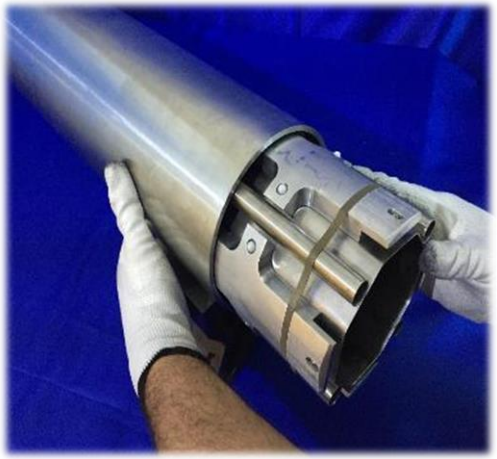
Different apertures

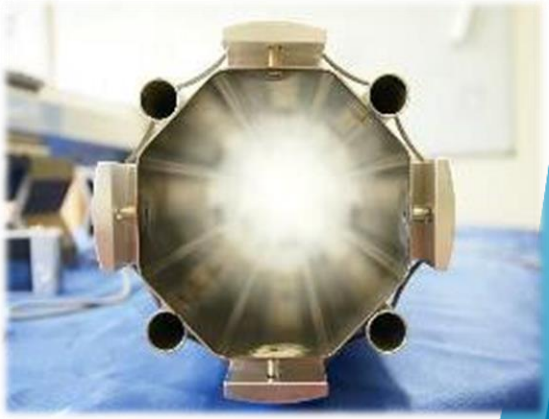
New BS design for HILUMI

- 40 cm absorber blocks of Tungsten (Inermet-180), 6 or 16 mm thick needed to shield the magnet coils, by intercepting particle debris produced by the experiments

- 4 cooling tubes stainless steel (40-60 K)
- for each quadrupole magnet : 10 m, 500 kg







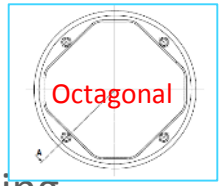
New BS for HiLumi

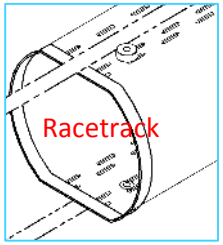
LS2 (2019-2020):
- consolidation of the beam screens in Long Straight Section (LSS) 2 and LSS8: production and in-situ treatment (a-C coating)

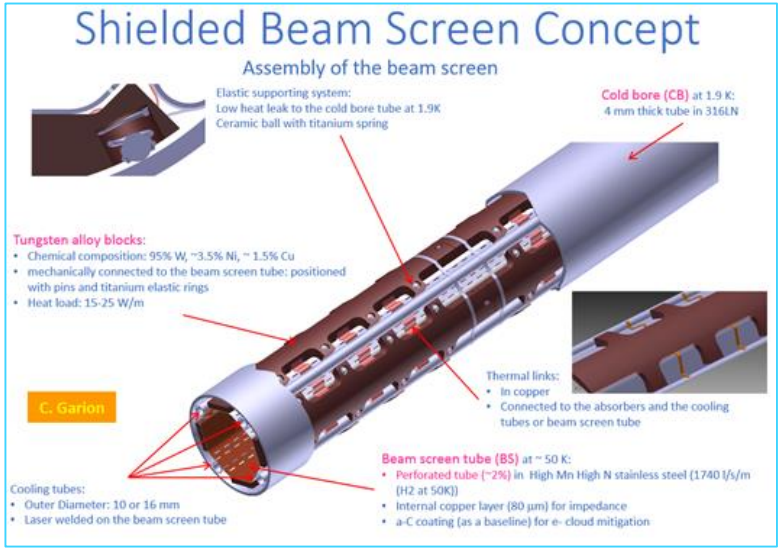
LS3 (2024-2026):
- new beam screens in LSS1 and 5

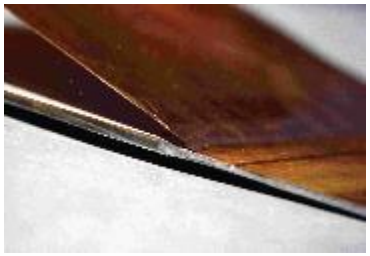
Design is under finalisation

- Octagonal or racetrack shape
- ~ 500 kg / quadrupole
- > 10 m long
- Several apertures
- Tungsten allow shielding
- Stainless steel cooling tubes (x4) at 40-60K
- Cu colaminated perforated P506 beam screen
- Amorphous-Carbon (a-C) coating (100 nm)
- Withstand cumulated radiation $1 \cdot 10^8$ Gy
- New laser welding tool at CERN








Cu colaminated

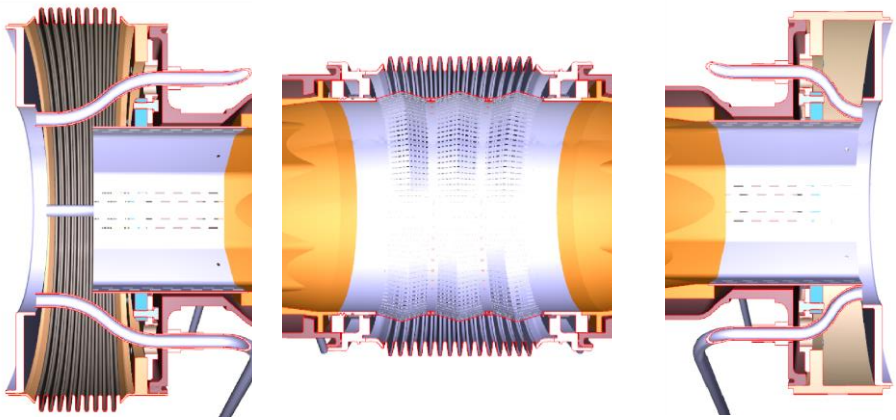

Electron shield


BS end finishing parts

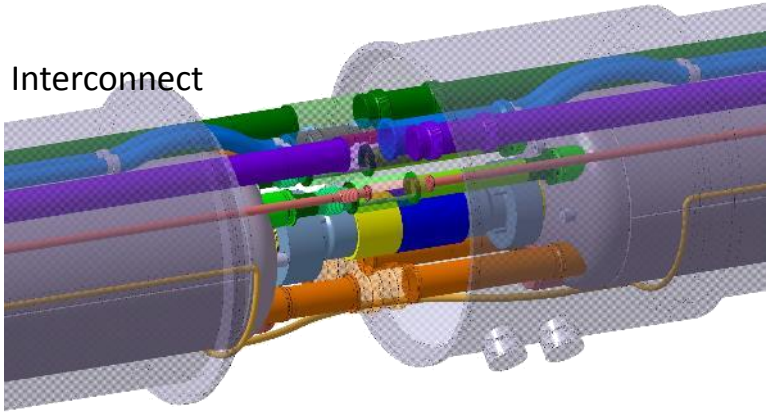

LHC BS welding

Beam pipe interconnects

- Between beam pipes of consecutive cold masses
- Similar or different diameter or shape (aperture matching)
- Dedicated Plug-in Modules to assure RF screening and low impedance: Cu plated stainless steel



Interconnect

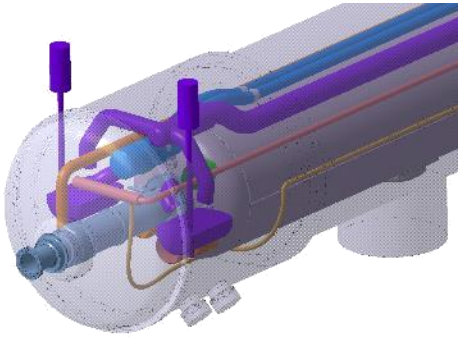


A typical LHC interconnection

About **50** new interconnections are needed

- 20 @ LS2
- 30 @ LS3

Beam pipe interconnects



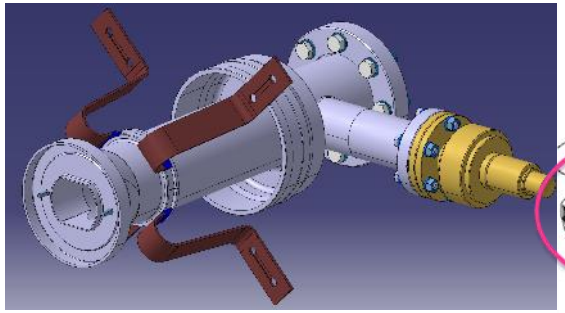
Q1 CW transition

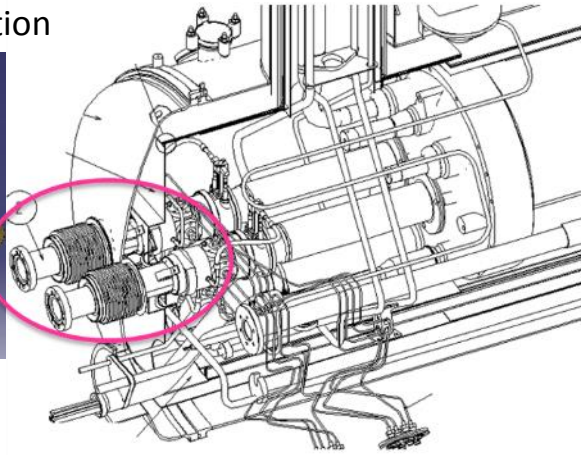
- Connections for different temperature (Cold-Warm Transition)
- Some interconnects have to house Beam-Position Monitors buttons

Many interconnects, comprising cryo-elements
(BS, plug-in modules, CW Transitions, BPM body)

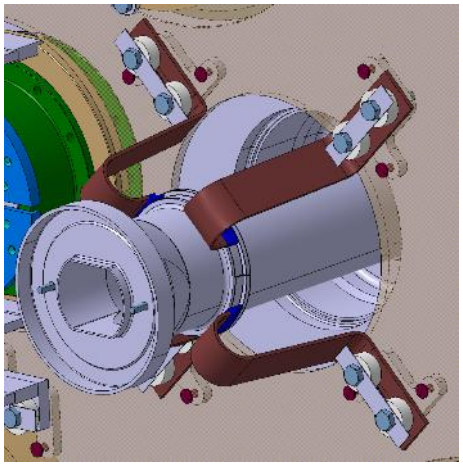
- Prototypes : 2016-17
- Procurement : 2017-19
- Assembly : 2018-22

CW transition





LHC CW transition



About 60 CW transitions are needed

- 20 @ LS2
- 40 @ LS3

Warm Modules

- Modular system: ~ 1800 in the LHC ring
- Bellow shielding to optimise beam impedance
- RF bridge with several shapes (circular/elliptical)
- Ag coated CuBe fingers
- Rh coated insert
- Allow thermal expansion during bakeout (+/- 20 mm stroke)
- Can accommodate instrumentation ports

Vacuum chambers

- Cu, Stainless steel Cu plated
- Circular, elliptical, transitions
- Specific chambers e.g. Y chamber
- Various ID diameters: 80, 91, 212.7, 250 mm
- NEG coated at CERN
- Including chambers supports

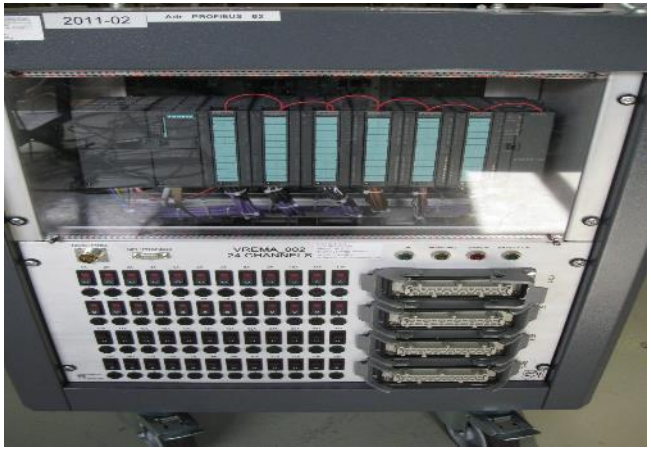
Bake-out System

Mobile and permanent system

Collars

Thermocouples

Bake-out jackets

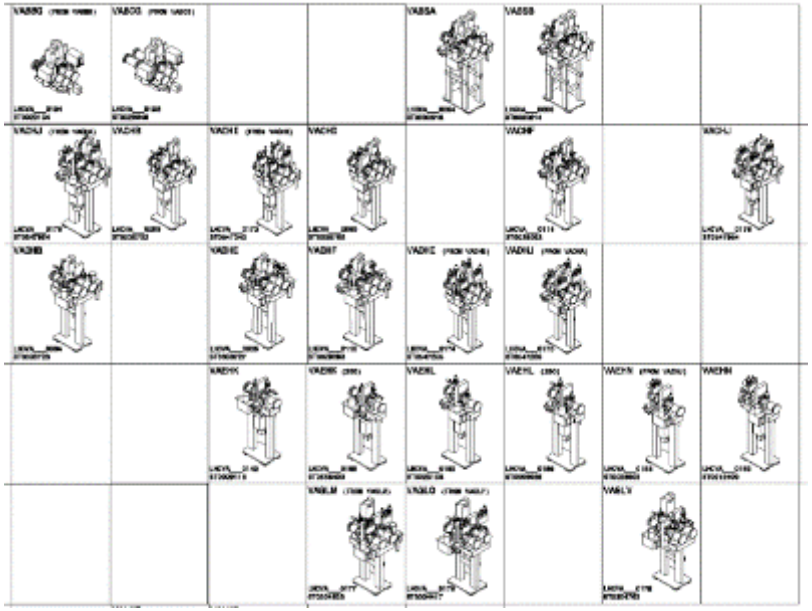


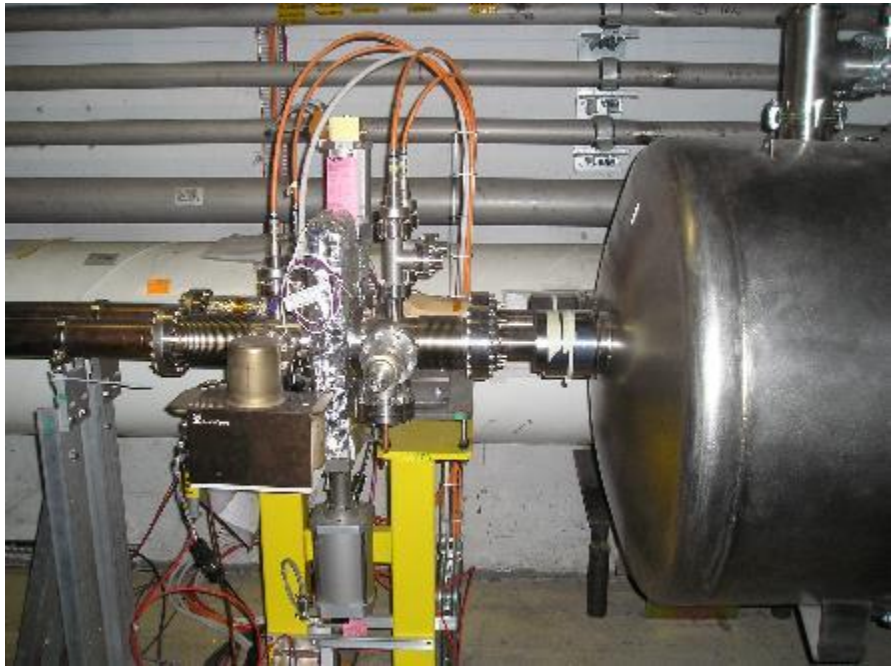
Bake-out racks

Heating tapes

Sectorisation Assembly

- Remotely controlled & interlocked sector valves
- Compact & Instrumented

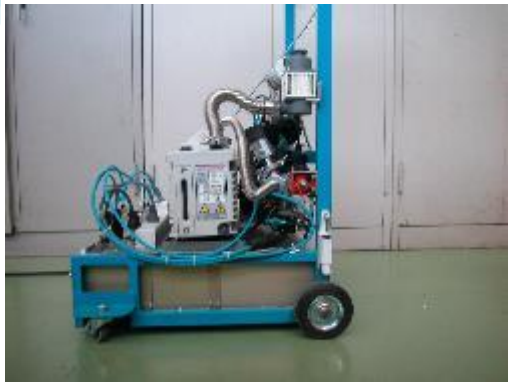




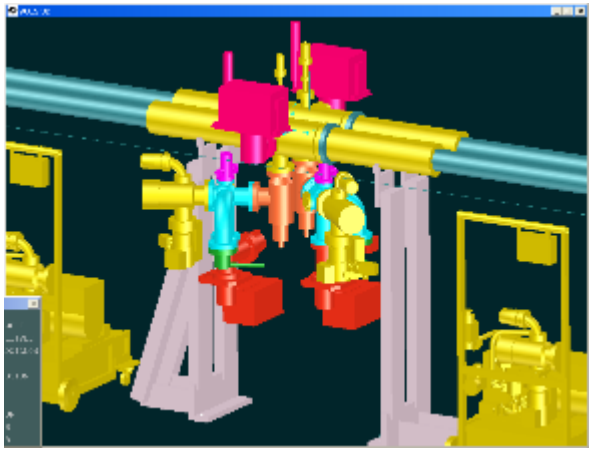
Instrumentation

- Vacuum gauges
- Turbomolecular pumps
- Ion pumps
- NEG cartridges
- “Magic Box”
- …

Component	Total
Vacuum sectors (cryogenic / RT)	88 / 174
Vacuum sector valves (all LHC)	295
Roughing valves (LSS)	309
Ion pumps (special /30 / 60 / 400 l/s)	12 / 550/ 168 / 49
Bayard Alpert gauges (LSS)	178
Penning gauges (LSS)	502
Pirani gauges (LSS)	289



Mobile Pumping Group



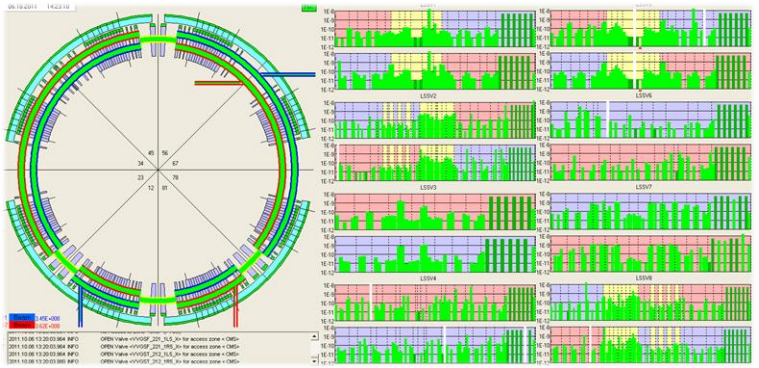
“Magic Box” for diagnostic

Ion pump modules

Instrumentation & roughing module

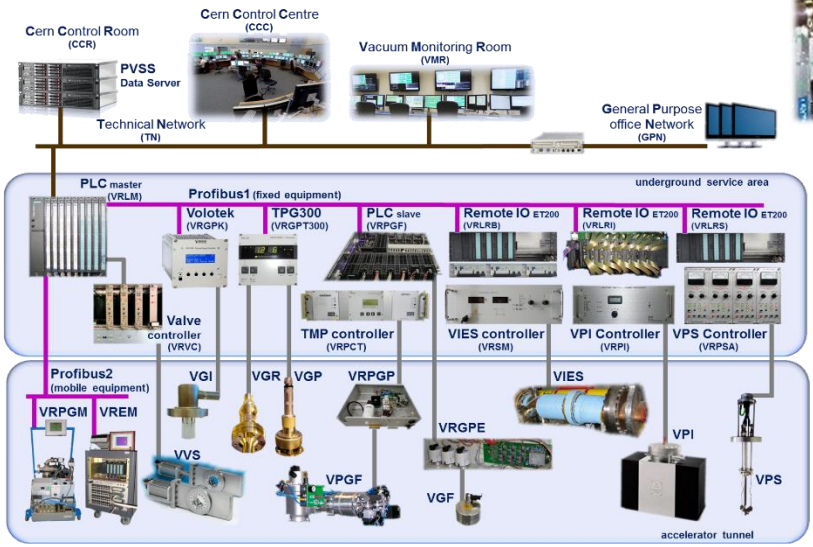
Controls

- Redesign of some electronics (front-end & controllers) for
  - Improved availability / measurement accuracy
  - Extended dynamic range
  - Radiation tolerance
  - Obsolescence
- Adding new instruments (devices) implies: more readout, control, and interlocks
- Evolution of software frameworks (DB, PLC, SCADA)
- Implementation of methods and tools: improving efficiency of intervention/repair and machine availability



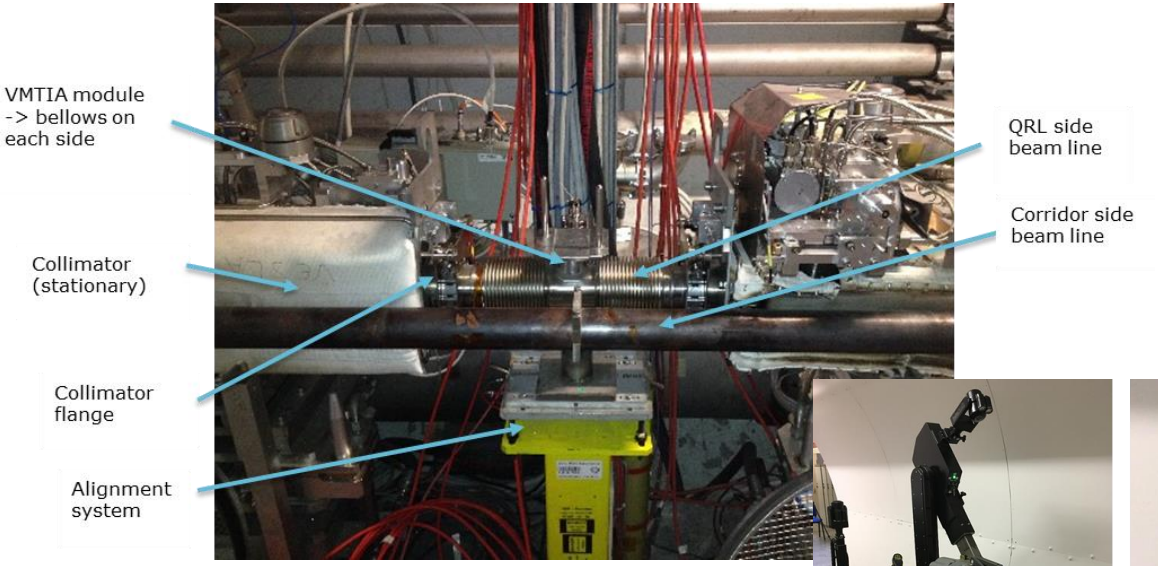
Preliminary estimation for HL-LHC

Component	Quantity
Sputter Ion Pump controller	60
Sector Valve controller	60
Interlock	60
Penning/Pirani gauge (LSS) controller	70
Penning/Pirani/Piezo gauge (ARC) contr.	850
Mini-racks (ARC)	130
Fixed Pumping group controller	10
Euro crates	300
PLCs	150
Long cables and connectors	280

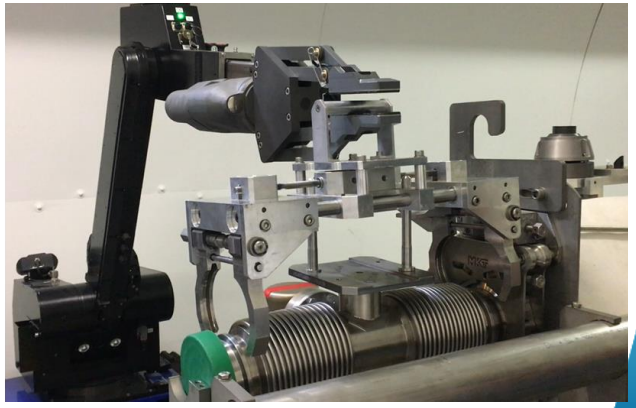


Robotics

- the level of radioactivity from activated materials, in the accelerators, will require new tools for remote manipulation, enhanced reality, supervision, in order to minimize the radiation doses for people, during interventions, when replacing/servicing collimators, magnets, vacuum components, instruments, cables, etc,
- Several developments will need R&D collaborations, manufacture, etc
  - Vacuum modules
  - Surface treatment (next slide)

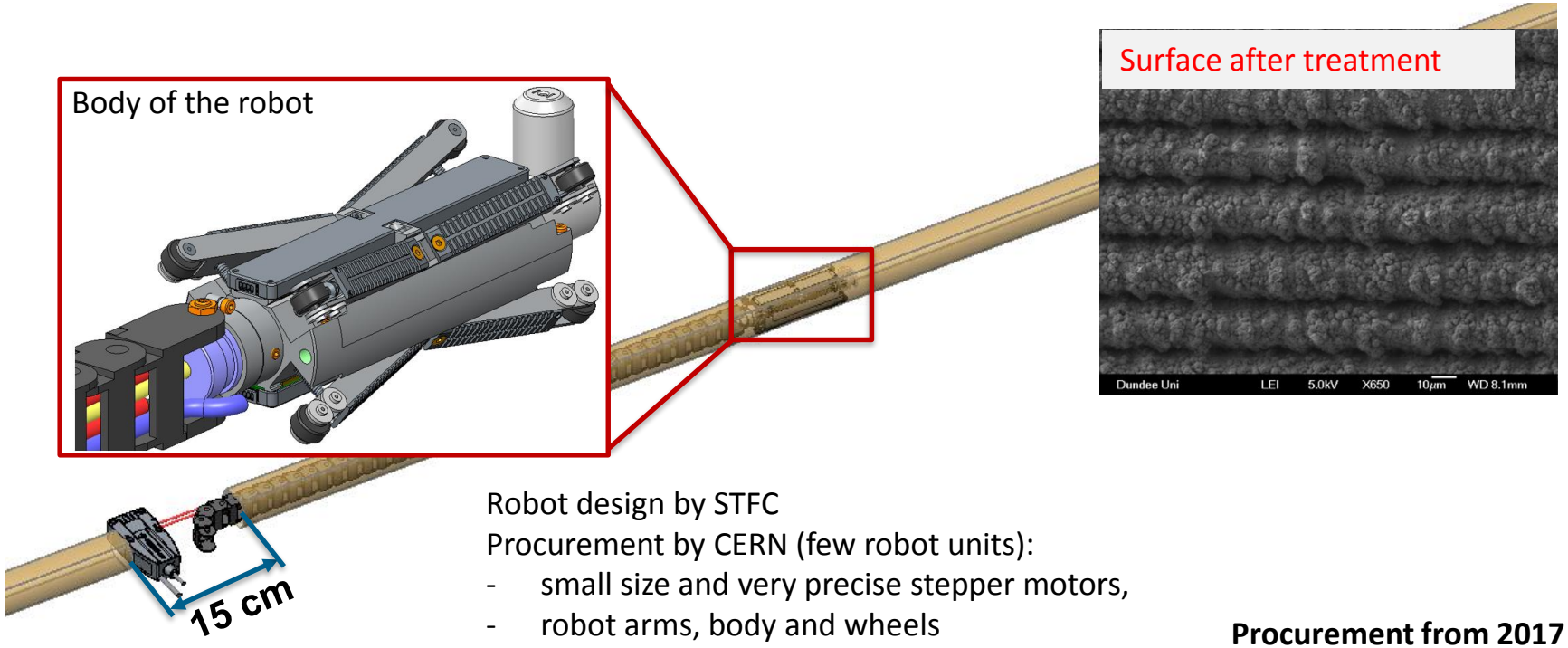


Robot allowing for the bellows compression to remove the collimator



Laser Engineered Surface Structures (LESS) for in-situ surface treatment

- **CERN** in collaboration with the **University of Dundee** and **STFC** is working on the LESS project as a solution for in-situ inner triplet beam screen treatment to mitigate electron cloud effects.
- Treatment will be done by a robot inserted in 15-cm long opening, containing a precise optical system with laser beam delivered by an optical fibre.



Robot design by STFC
Procurement by CERN (few robot units):
- small size and very precise stepper motors,
- robot arms, body and wheels
- chain to conduct the optical fibre
- interferometer for precise robot positioning

LESS treatment by Un. Dundee

Procurement from 2017

➔ Needed for LS2

G. Riddone