Status of the vacuum technologies for HiLumi

V. Baglin on behalf of WP12

EDMS: 2253882

9th HL-LHC Collaboration Meeting, FERMILAB, 14-16th October 2019

https://indico.cern.ch/event/806637/timetable/#20191014.detailed

OUTLINE

1. Beam screens
2. Electron multipacting mitigation
3. Vacuum layout
4. Summary

1. Beam screens

Shielded beam screen

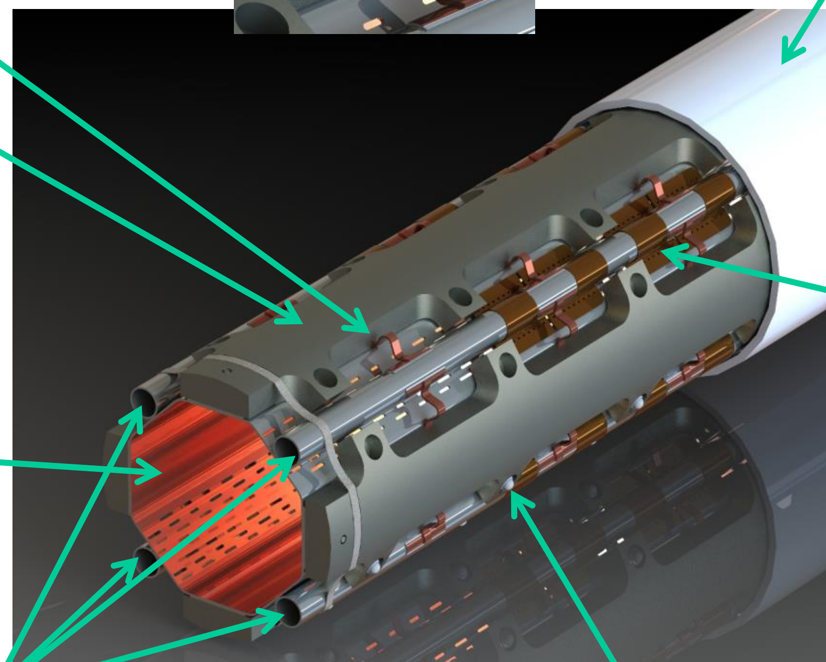
- Objective
  - Provide vacuum stability, control gas density
  - Protect the Triplet cold mass against particle collision debris

Thermal links:

- In copper
- Connected to the absorbers and the cooling tubes or beam screen tube

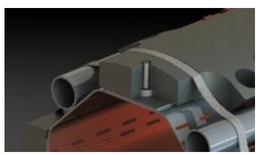
Cold bore (CB) at 1.9 K:

4 mm thick tube in 316LN



Tungsten alloy blocks:

- Chemical composition: 95% W, ~3.5% Ni, ~ 1.5% Cu
- Mechanically connected to the beam screen tube: positioned with pins and titanium elastic rings
- Heat load: 15-25 W/m
- 40 cm long



Pumping slot shield

Beam screen tube (BS) at 60-75 K:

- Perforated tube (~2%) in High Mn High N stainless steel (1600 l/s/m (H_2 at 300K))
- Internal copper layer (75 μm) for impedance
- a-C coating (as a baseline) for e- cloud mitigation

Cooling tubes:

- Outer Diameter: 10 mm
- Laser welded on the beam screen tube

Elastic supporting system:

Low heat leak to the cold bore tube at 1.9K
Ceramic ball with titanium spring

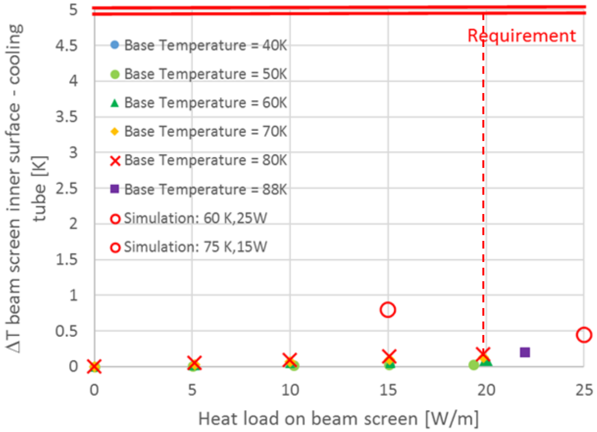
Shielded beam screen – Design Validation

- Thermal heat transfer:

Sample for heat transfer assessment

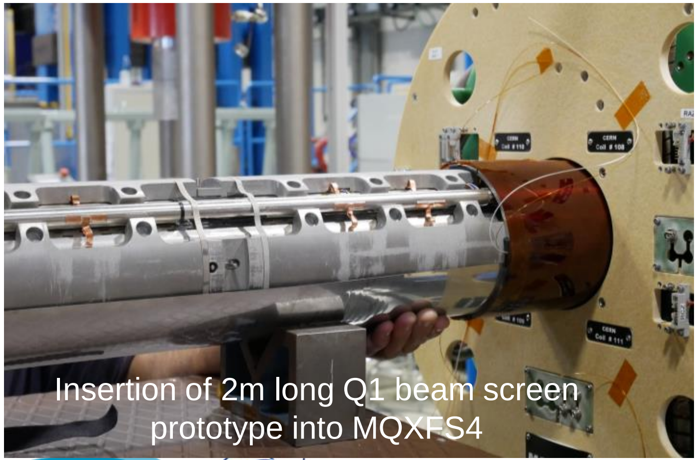
80 cm long Beam screen prototype at HL-LHC beam screen test stand

Design value = 20 W/m

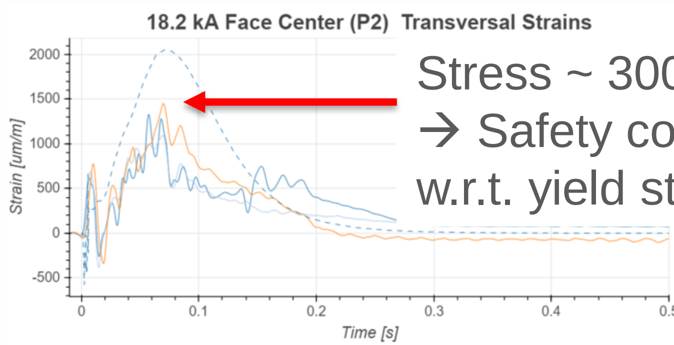


Excellent decoupling between W absorber and BS inner surface

- Mechanical integrity after magnet quenches:
  - Beam screen remains elastic after 54 quenches (10 at design current, 16.4 kA + 3 above)



Insertion of 2m long Q1 beam screen prototype into MQXFS4



Stress ~ 300 MPa
→ Safety coefficient of ~ 4 w.r.t. yield strength

No beam screen deformation above ultimate current!

Shielded beam screen – Production

- Cold bores:
  - 316LN billets sent to the firm for tubes production, 44 tubes to be delivered from Sept 2019 - Nov 2021, 8 already delivered
- Beam screen:
  - Cooling tubes and Co-laminated strips at CERN
  - After 2 market survey and 1 invitation to tender processes, the cost for the outsourcing of the beam screen tube punching-forming-welding was much higher than anticipated

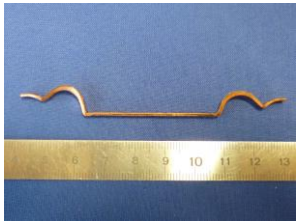
    ➔ internalisation at CERN ➔ delay by 1 year, but still in time

	Number	Start delivery	End delivery
Tungsten shielding	3’000	April 2020	May 2022
Ti alloy rings	1’600	March 2020	April 2022
Ti alloy springs	12’000	March 2020	April 2022
Thermal links	9’900	April 2020	March 2022
Pumping slot shields	25’500	Feb 2020	Jan 2022


W shielding element


Elastic ring


Spring

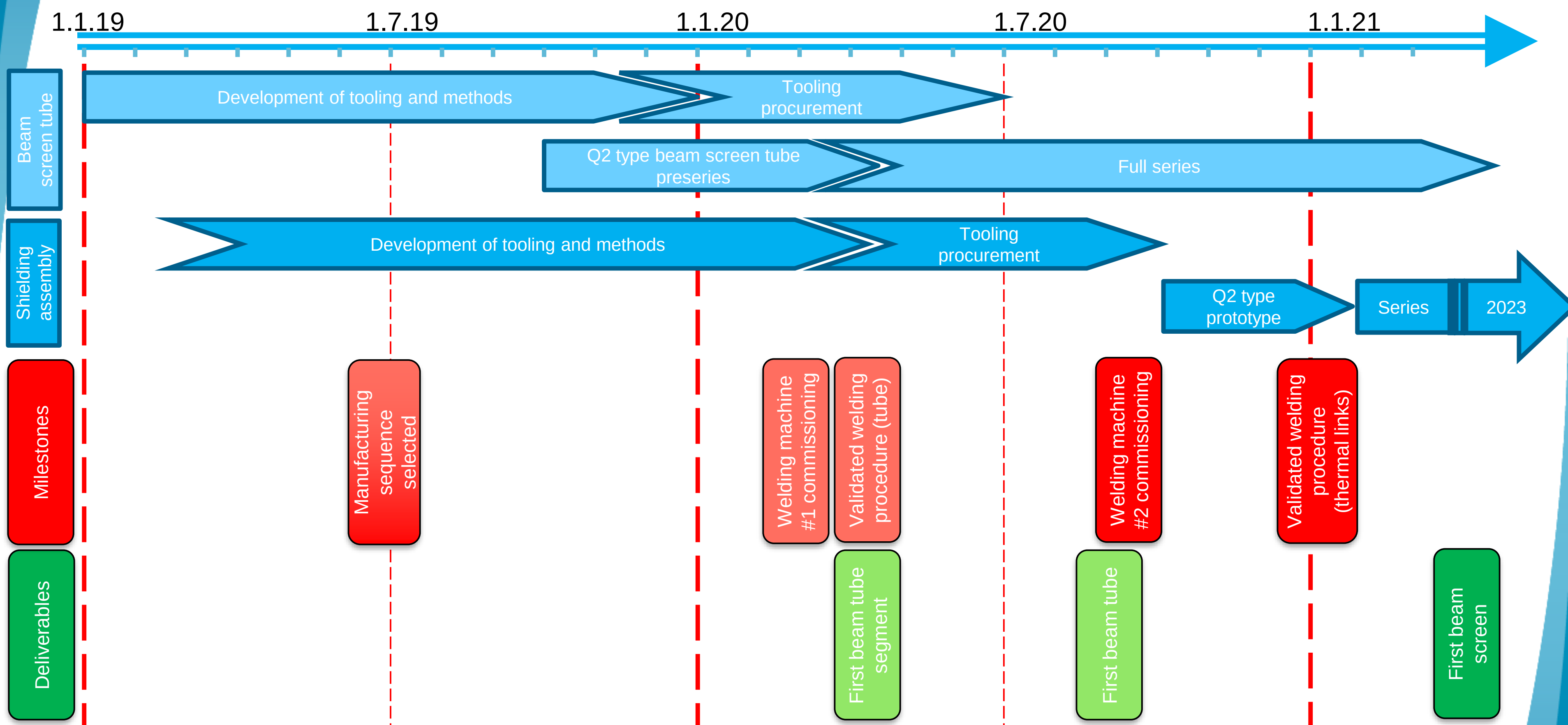

Thermal link


Pumping slot shield

Shielded beam screen – Production -

- Beam screen construction shared between CERN EN-MME and TE-VSC groups

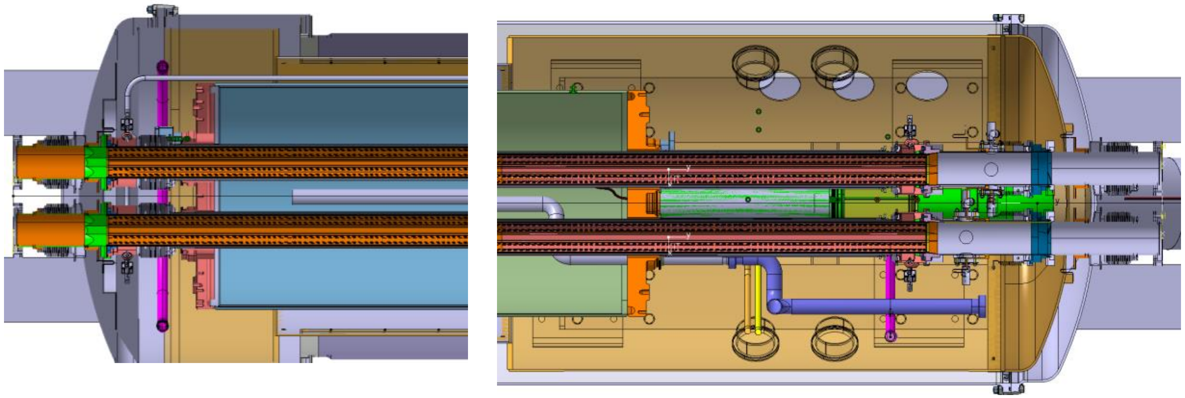
Roadmap

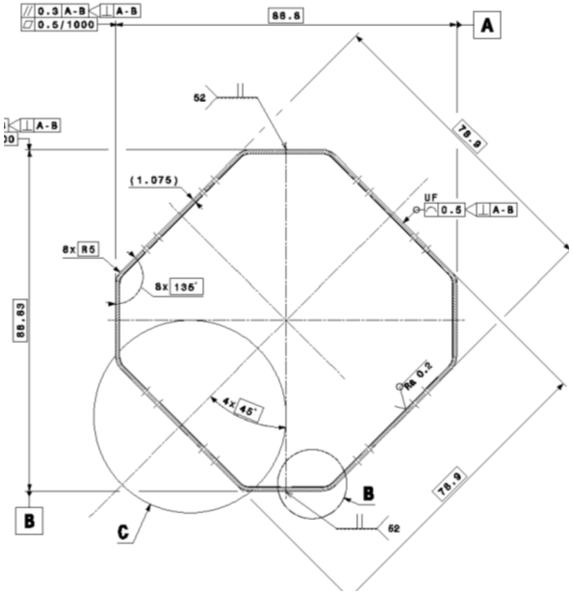


- Next steps:
  - Assembly bench to be procured by Q3-2020
  - First shielded beam screen expected by spring 2021

D2 Beam Screen

- Octagonal cross section for 94 mm ID cold bore
- Ø6 mm cooling tubes
- aC coating
- Pumping slots shields

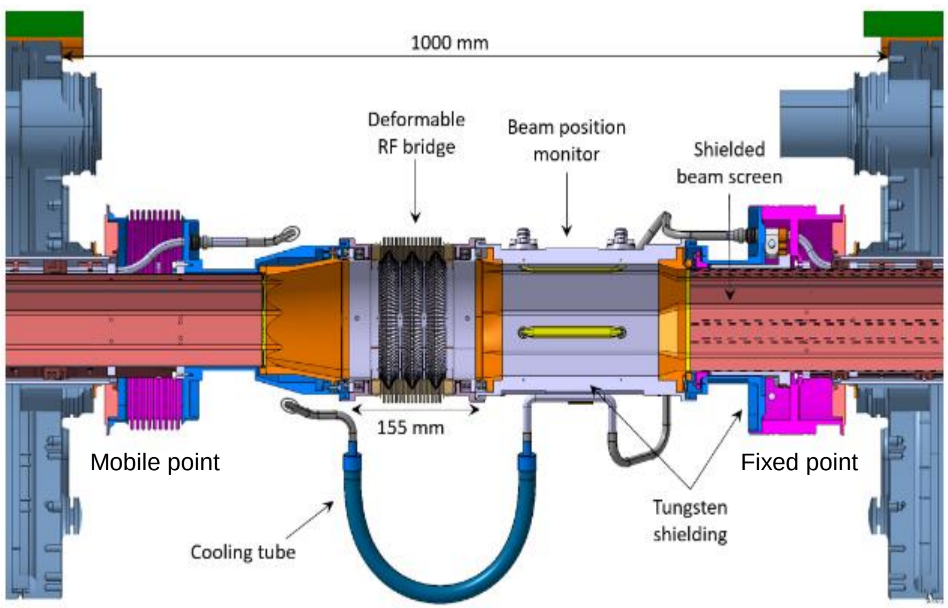




- Next step:
  - Design finalisation after cold bore delivery (Feb 2020)
  - Start production

Triplet interconnection

- Detailed design:
  - Tungsten shielded interconnection with Deformable RF bridges
    - ➔ increased cold mass protection and mechanical robustness
  - ID132 (Plug-In-Module)
  - a-C coated
  - Tooling



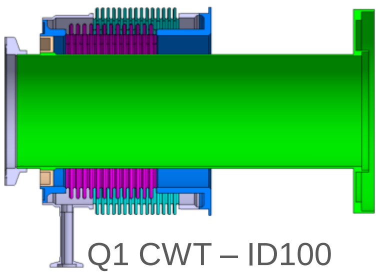
Deformable RF bridges

- Next steps:
  - Prototype by mid 2020
  - Tooling manufacturing
  - Procurement to start

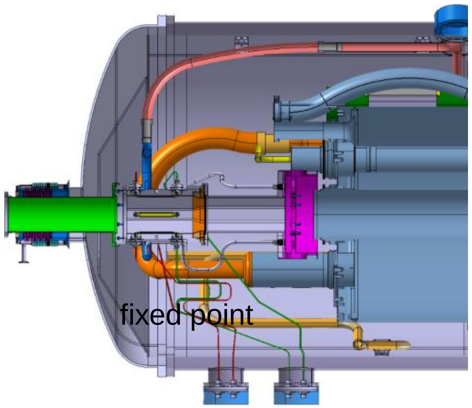
Cold to Warm Transitions

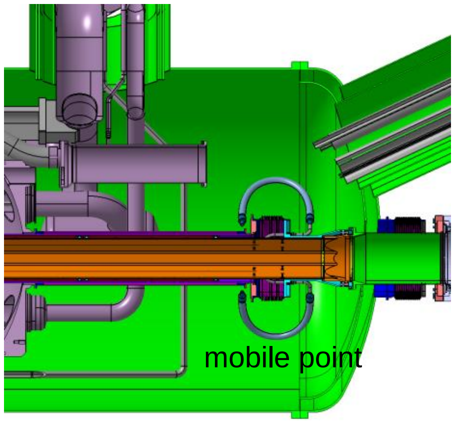
- New cold/warm transition general designs done
  - 316LN with 5 µm Cu coated + a-C coating
  - < 15º tapering angle
  - Thermal performance computed

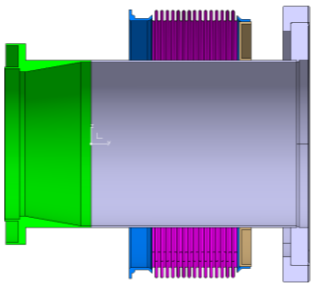
Double walls bellow



Q1 CWT – ID100

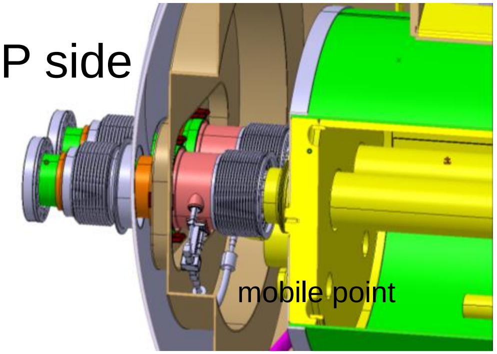


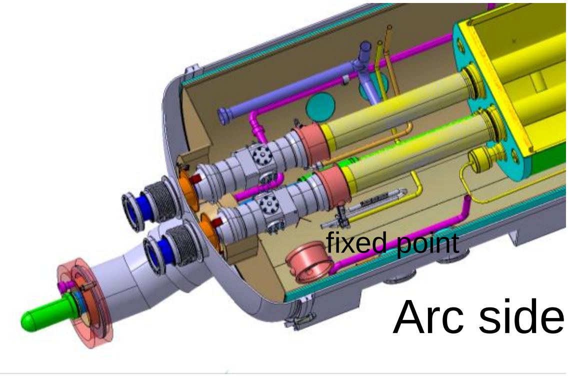




D1 CWT – ID130

D2 CWT – ID90





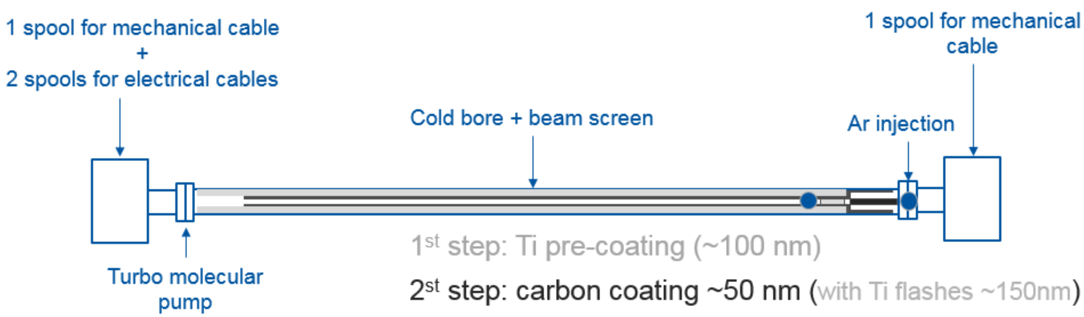
- Next step:
  - Procurement to start

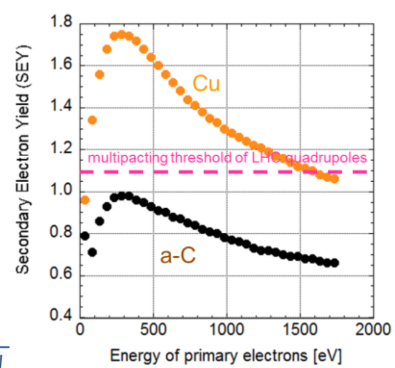
2. Electron Multipacting Mitigation

a-C Coating

- a-C coating is proposed to mitigate electron multipacting reducing electron cloud to acceptable values
- Production:
  - Improved adherence thanks to a Ti sublayer & reduced the carbon layer thickness to 50 nm thanks to H_2 pumping using Ti flashes ("Thin" coating)
  - Demonstrated in-situ coating feasibility of SSS_243: δmax = 1.02 without damage of the electrical insulation of the cold bore, no impact on BPM response and no peel-off.

➔ ready for LHC deployment during LS2

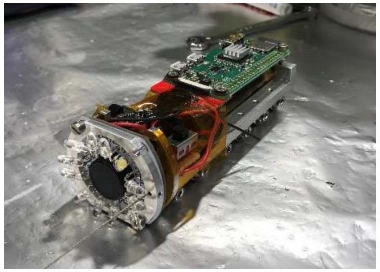




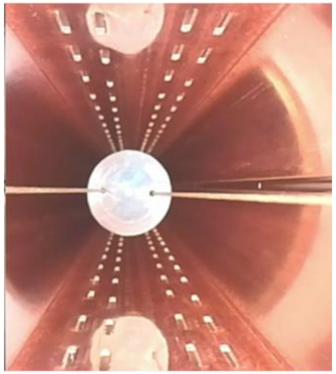
SSS_243

In-situ a-C Coating

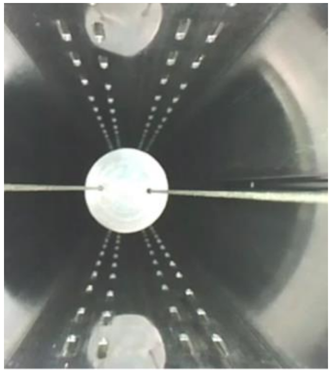
- Coating of Q5L8 (without cryosorber … a non-conformity) is ongoing!
  - ➔ First Ti layer is completed, a-C layer by this Friday!



Mole for beam screen inspection



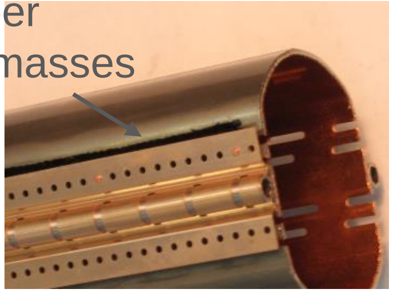
Q5L8 before coating

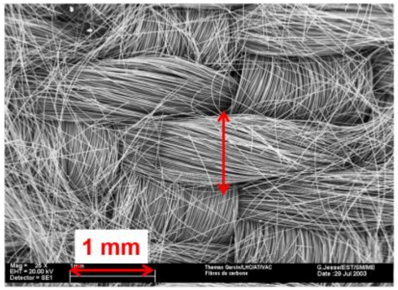


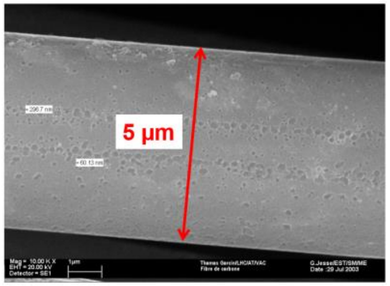
Q5L8 after Ti coating

- a-C coating of Q6L8, Q6R2 and Q5R2 is on hold due to H_2 outgassing from the cryosorber during the sputtering process

LHC cryosorber in 4.5 K cold masses





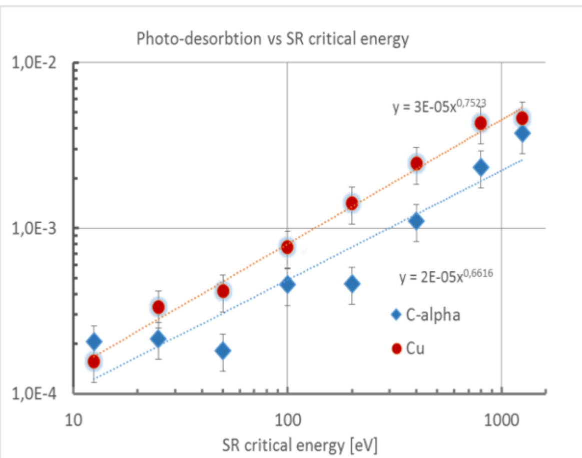


- Next step:
  - Develop and validate in the laboratory using a baking technique to degas in-situ the LHC cryosorber before the coating process.

a-C coating performance

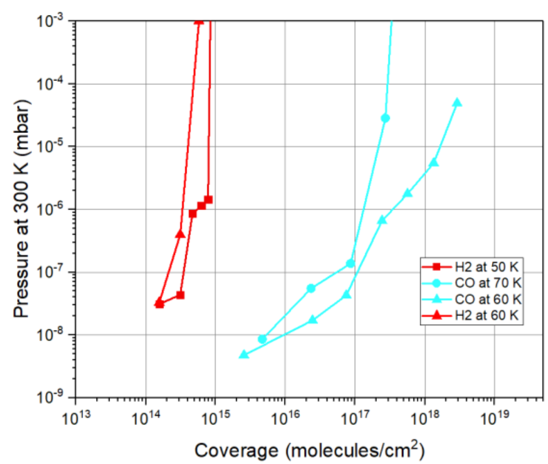
- Evaluated in the laboratory at room & cryogenic temperature
  - SEY
  - Photon stimulated molecular desorption, η
    ➔ results at 10-80 K expected by end 2020
  - Adsorption isotherm of thin coating ongoing
  - COLDEX in SPS & Vacuum Pilot Sector in LHC
    ➔ “Thin” coating evaluation with beams during RUN3

BINP Sync.Rad. beam line



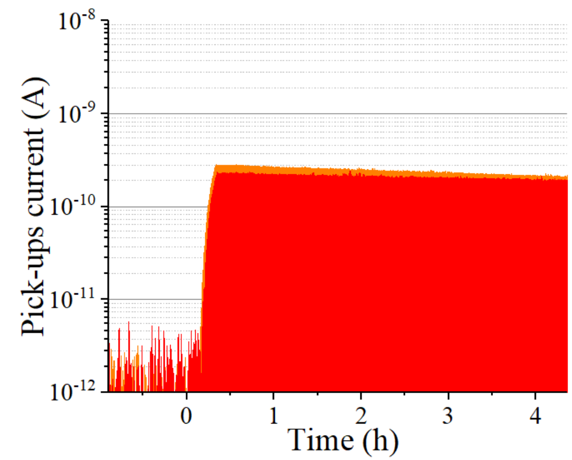
“Thick” coating
η ~ 4 10^{-5} molecules/ph
at 30 eV critical energy

Adsorption isotherms



“Thin” coating
Proposed temperature window 60-80 K

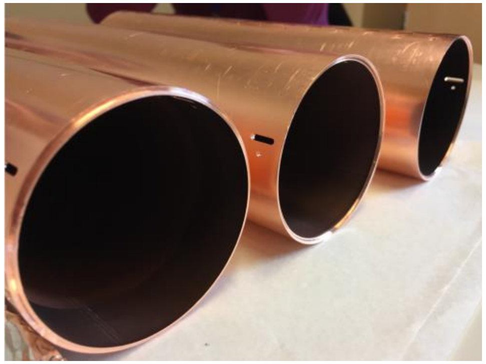
LHC VPS



“Thick” coating
Last LHC 2018 fill
(fill 7334, 2556b, 1.05 10^{11} ppb)

Laser treated surface as an alternative to aC coating

- During 2017-18, several test have been successfully performed at cryogenic temperature using COLDEX in the SPS
  - A 2.2 m long beam screen made of 9 laser treated Cu segments produced in collaboration with the University of Dundee
  - No electron multipacting was observed in the range 10–50 K even in the presence of condensed gas (CO_2) and degraded vacuum (10^{-6} mbar of H_2)



Laser treated Cu segments

COLD bore Experiment in SPS

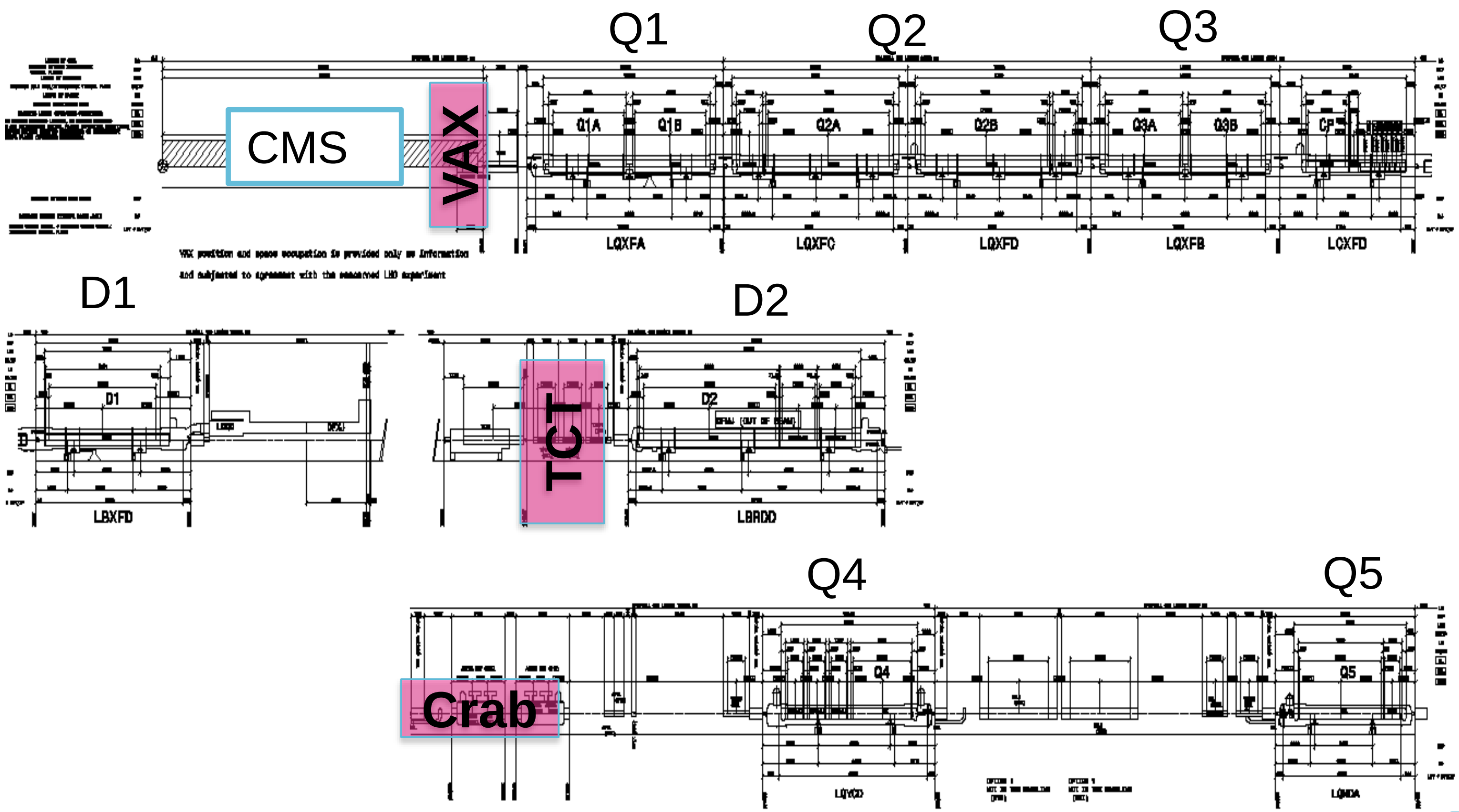
- Next steps:
  - CERN in constructing a Laser Treatment laboratory in SM18. Discussions are ongoing for the 2nd phase of collaboration with Dundee.
  - Production and laboratory evaluation of laser treated beam screen with the ultimate objective to have an alternative solution for the 4.5 K cold masses.

3. Vacuum layout

Progress on Vacuum layout definition

- Objective
  - Re-use LHC components, upgrade when necessary

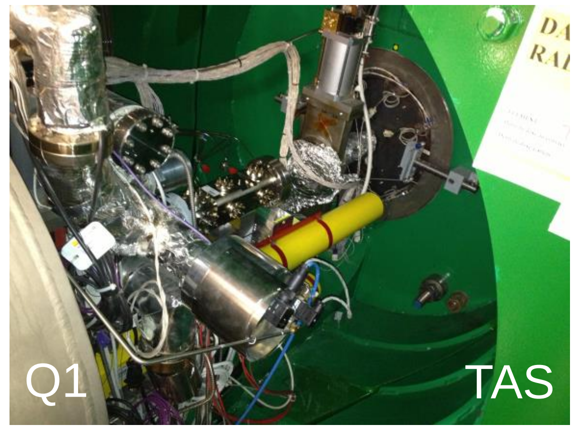
Layout :
IP5 Right



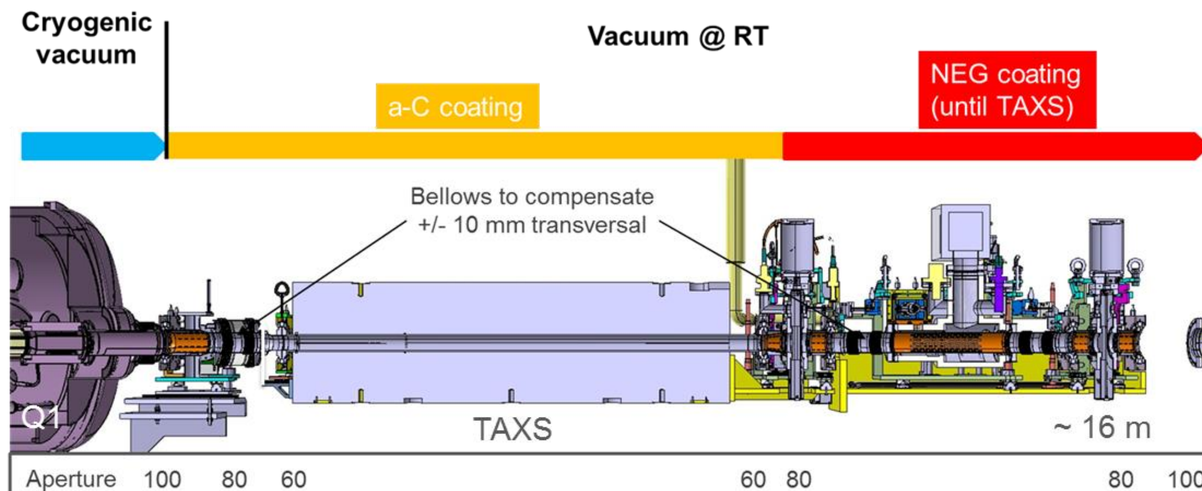
Vacuum Assembly for eXperiments (VAX)

- Objective
  - Avoid human intervention around TAXS in machine and cavern areas
  - Three modules embarking instrumentation and remote connection/disconnection of electrical connectors and vacuum flanges

Today:
a confined space in LHC



In the Future:
Remote handling for HL-LHC



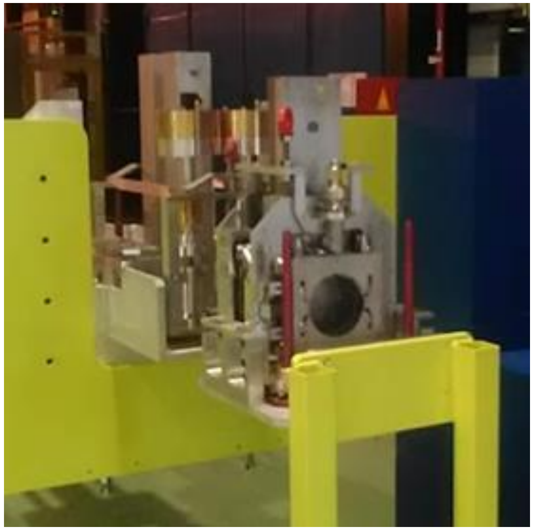
VAX - status

- Prototype build
  - Vacuum modules
  - Handling & lifting test successfully done (by WP8)

Valve module prototype

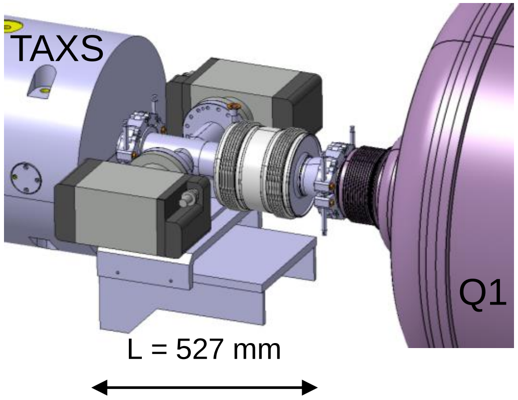
VAX module prototype

Module lifting



Assembly at CERN open days

- Concept of Q1-TAXS connection
  - Free maintenance area
  - Quick DN100 CF connection
  - Remote handling & connection
  - Both bellows with spaced double walls (with pumping port) to guarantee leak tightness



VAX – Next Steps

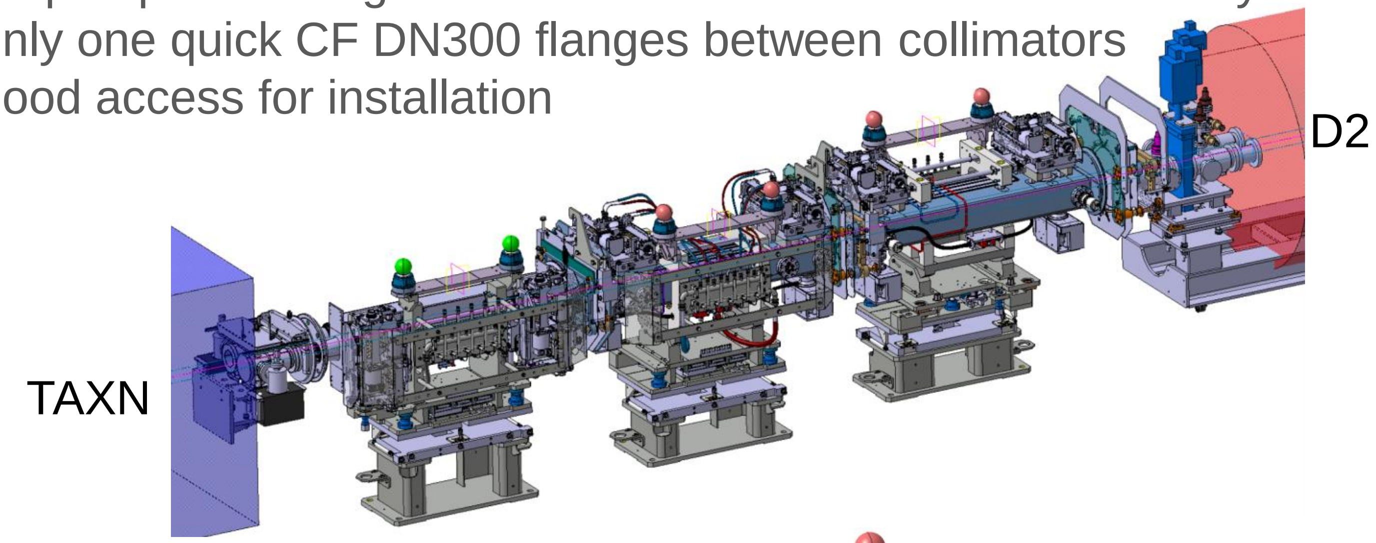
- VAX modules
  - Final validation of remote handling mechanism
  - Procurement and tests of ID80 sector valve
  - Fabrication drawings

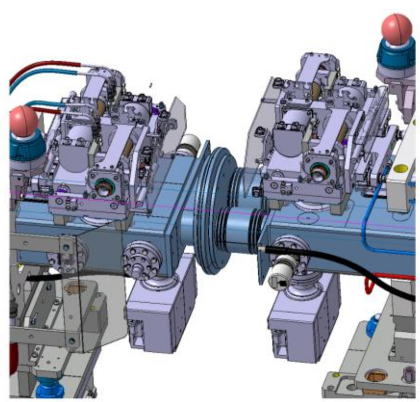
- Q1-TAXS connection
  - Remote installation / operation definition
  - Detailed design by end 2020

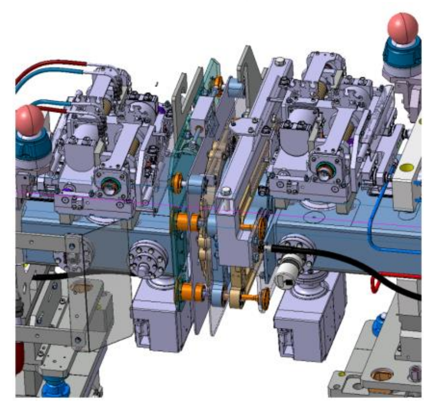
Tertiary Collimators (TCTs) between TAXN-D2

- Vacuum system designed in collaboration with WP2 & WP5

- Space optimisation is ongoing:
  - Aperture ID80
  - Ion pumps are integrated at the bottom of the collimator body
  - Only one quick CF DN300 flanges between collimators
  - Good access for installation

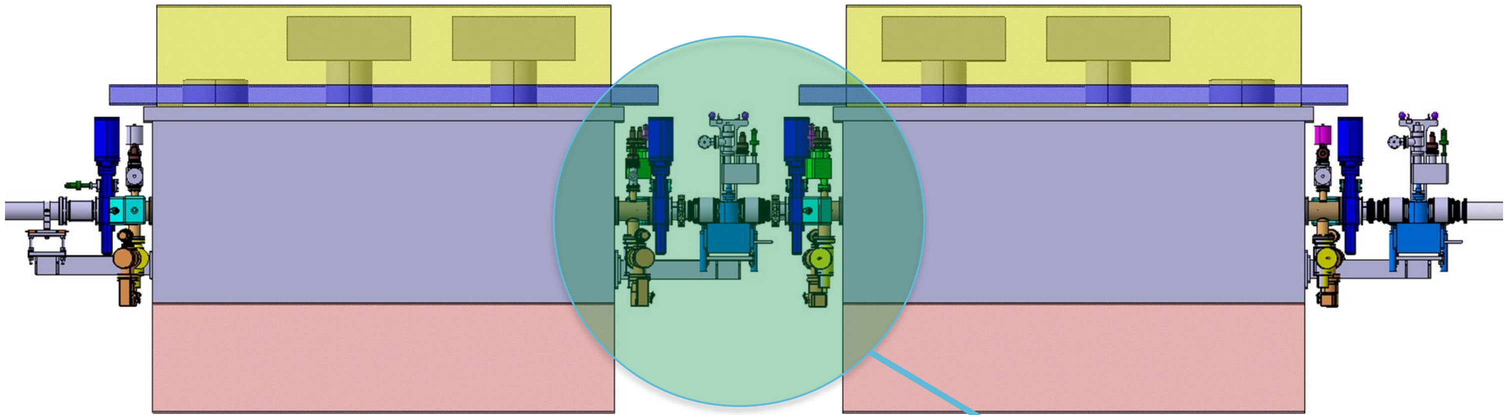


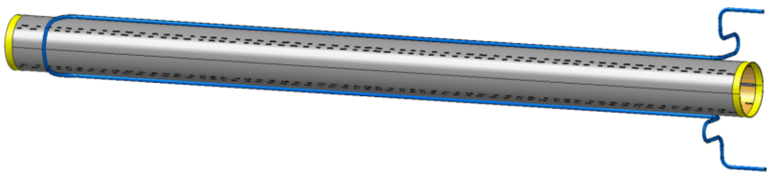




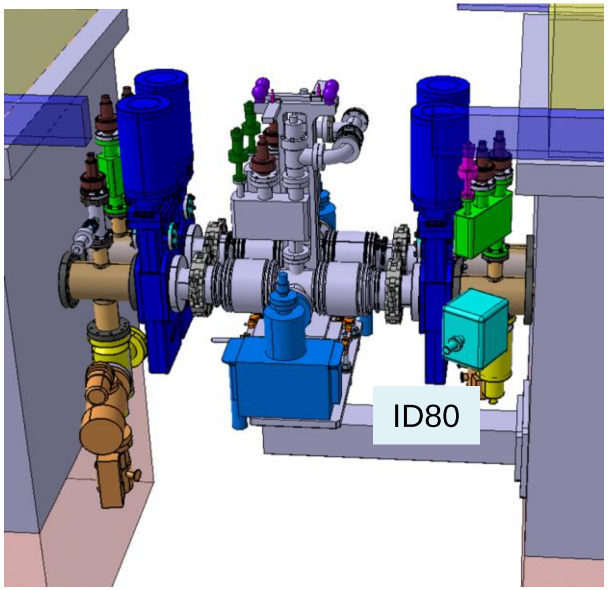
Crab cavities cryomodule

- Vacuum system designed in collaboration with WP2 & WP4
- Vacuum instruments supported by cryomodules
  - Quick connected instrumented modules





- Beam screen in non-crabbed line:
  - circular cross section for 94 mm ID cold bore
  - Standard LHC Ø4.76 mm cooling tube
  - aC coating
  - Cold bore at 2 K (no cryosorbers)

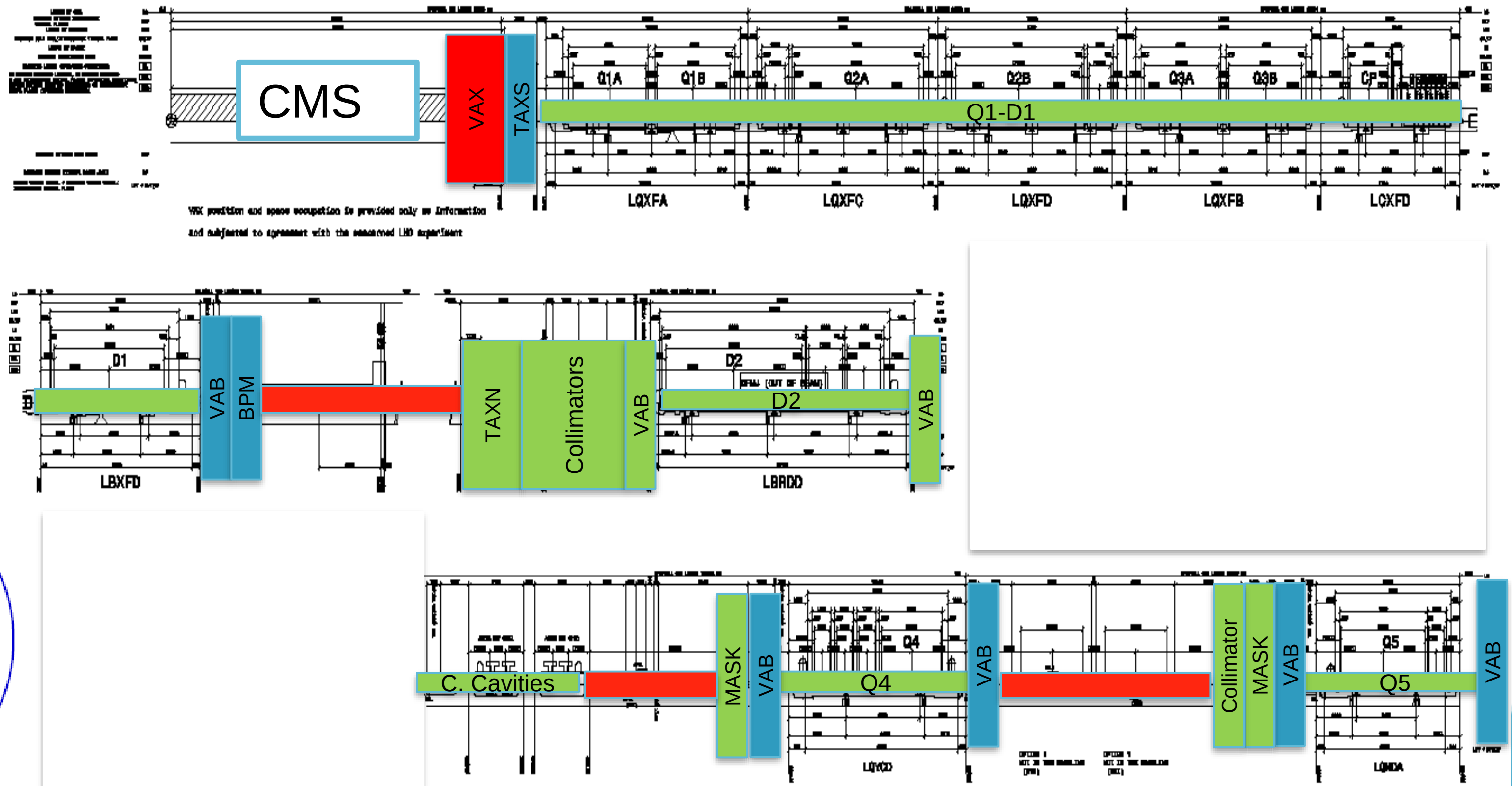


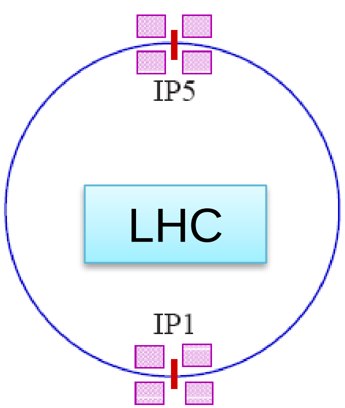
Full Remote Alignment System (FRAS)

- Objective
  - Remote alignment up to Q5 included (within ± 2.5 mm)

Layout :
IP5 Right

-IP5 left and IP1 will have the same alignment configuration

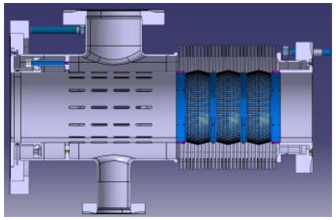




Remote aligned (green)	Manual aligned by Survey (blue)
Manual aligned by TE/VSC or Survey (red)	

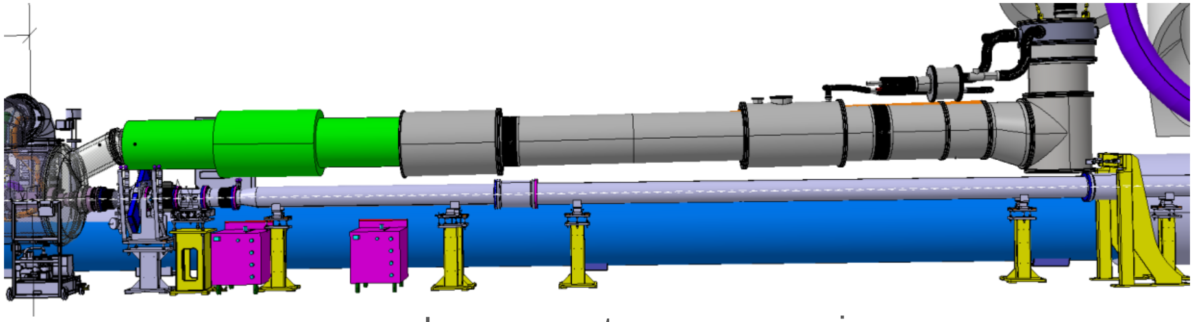
FRAS

- Vacuum system designed in collaboration with WP2 and WP15
- Based on
  - Deformable RF bridges (DRF)
  - Large aperture vacuum pipe
  - Sector valves assemblies (VAB) attached to D2 and CC cryomodule

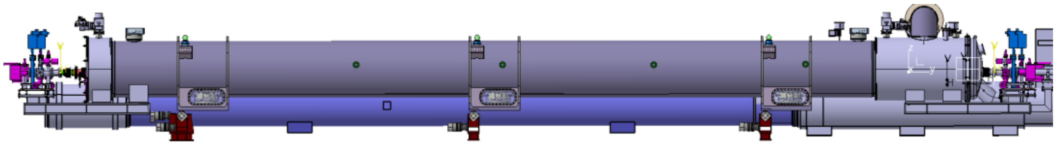


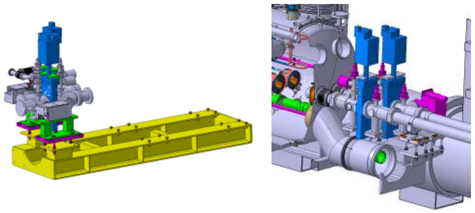
Deformable RF bridge

D1

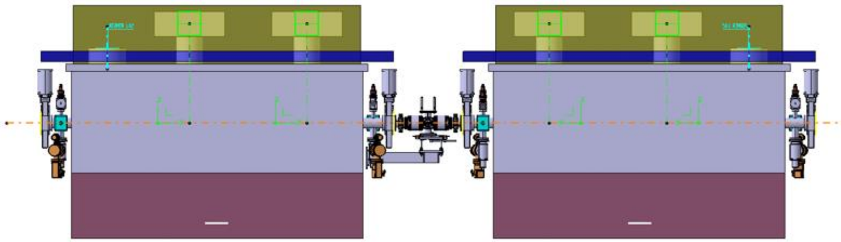


Large aperture vacuum pipe





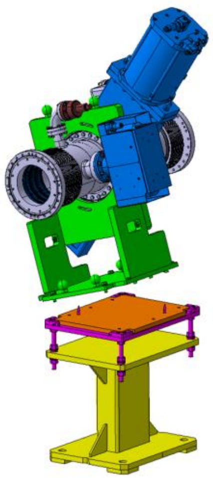
D2 with embarked VABs



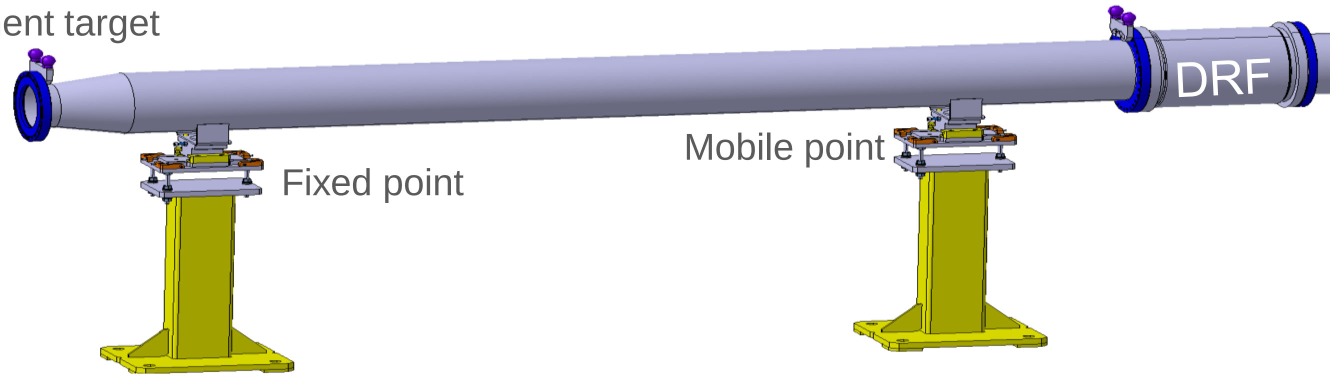
CC cryomodule with embarked VABs

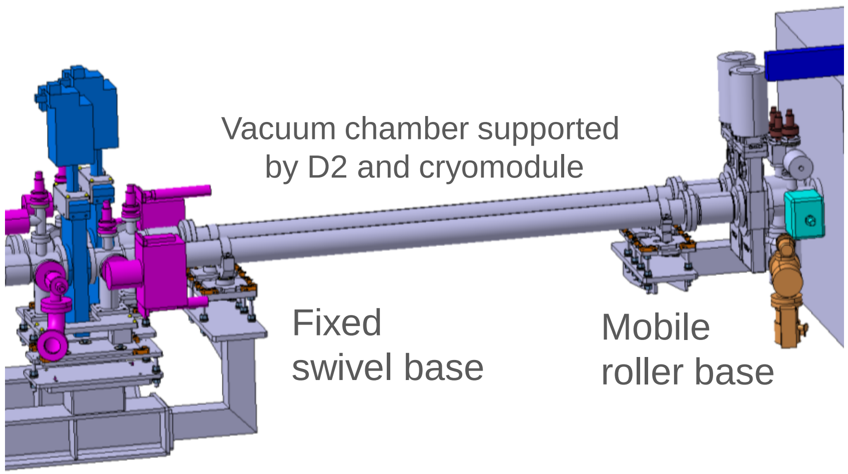
FRAS

- Next steps
  - Prototyping of new supports by 2020
  - Installation and alignment tests by 2020
  - Procurement by end 2021



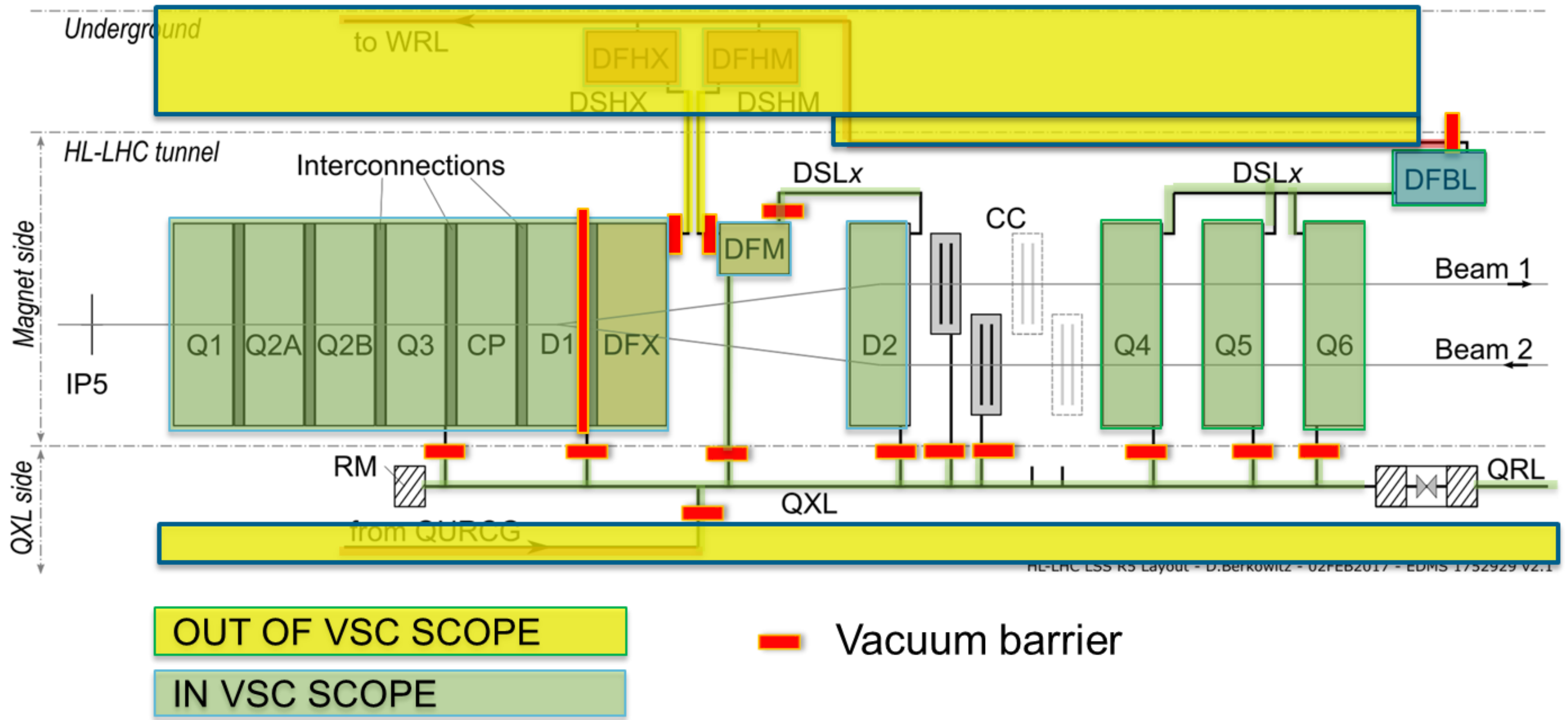
D1 VAB with plug-in interface





HL-LHC insulation vacuum layout

- Definition in coordination with WP6A and WP9 of the vacuum sectorisation and of the instrumentation layout



- Irradiation tests of O rings:
  ➔At 1 MGy leak tightness is obtained (compatible with HiLumi ultimate) but lost at 5 MGy

6. Summary

Summary

- The vacuum system for the HL-LHC project is under construction!

- The construction of the HL-LHC vacuum system is progressing very well.
  - Cold bore and beam screen designs are validated, production has started.
    - ➔ Some cold bores and beam screen components are already delivered
    - ➔ First beam screen delivery by spring 2021
  - “Thin” a-C coating is validated for installation in LHC
    - ➔ Q5L8 is already coated, others will follow
  - Vacuum layout definition is detailed including the Full Remote Alignment system
    - ➔ The Vacuum Assembly for the eXperiment prototype is built and validated

Acknowledgments

• Credits should go to all engineers, technicians, associates, students and collaborators who have (and will) participated to the design, test, construction and installation of the HL-LHC Vacuum System

THANKS to YOU ALL!

Thank you for your attention