HL-LHC Beam Pipe and Forward Spectrometer

EDMS: 2366106

V. Baglin

16-17th April 2020, Forward Spectrometer Meeting
https://indico.cern.ch/event/868473/overview

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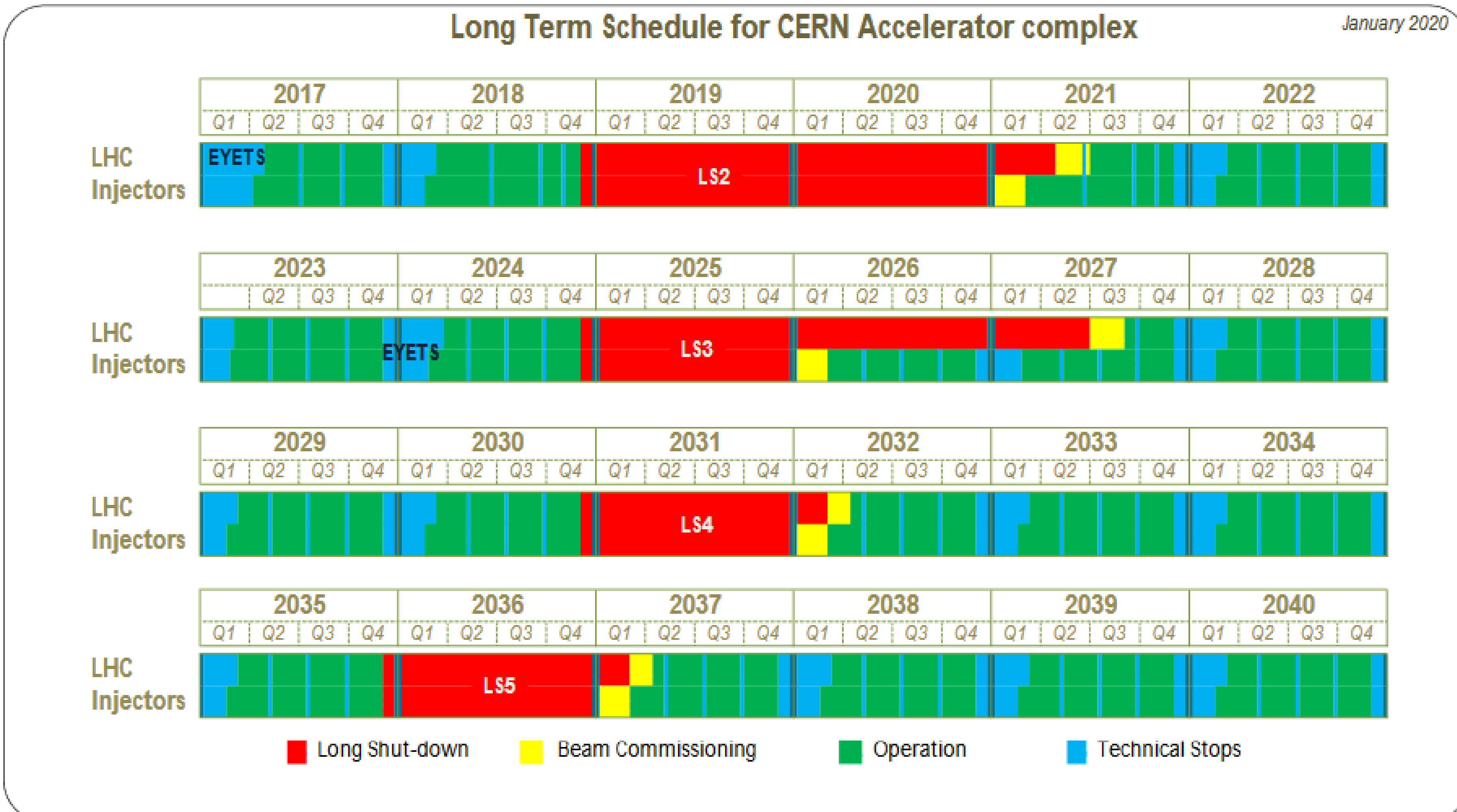
1. Machine Layout & General Design

Long Term Schedule

- LS = Long Shutdown

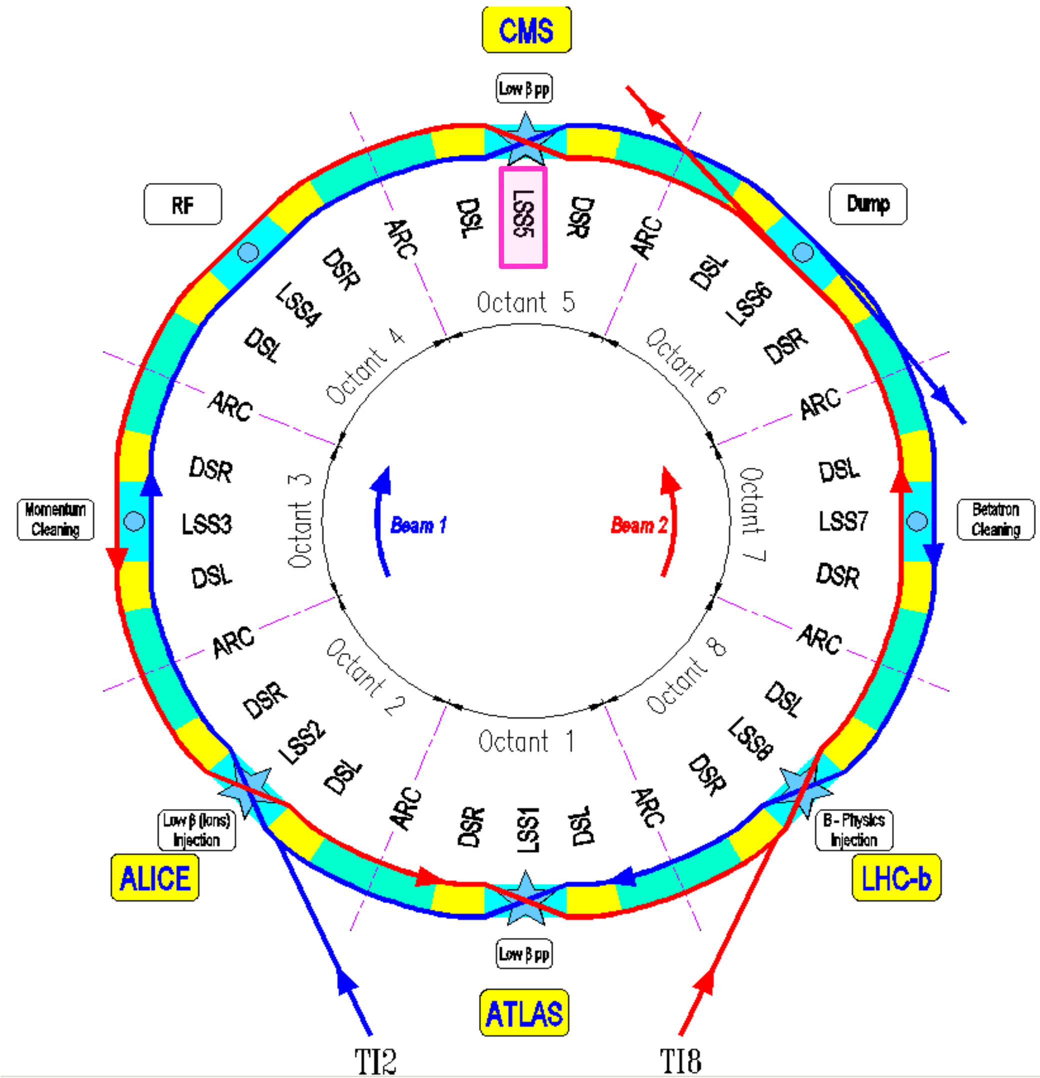
EDMS No. 2311633 | REV. 1.0 | VALIDITY RELEASED

REFERENCE ACC-PM-MS-0004



Machine Layout

- LSS5 = Long Straight Section 5

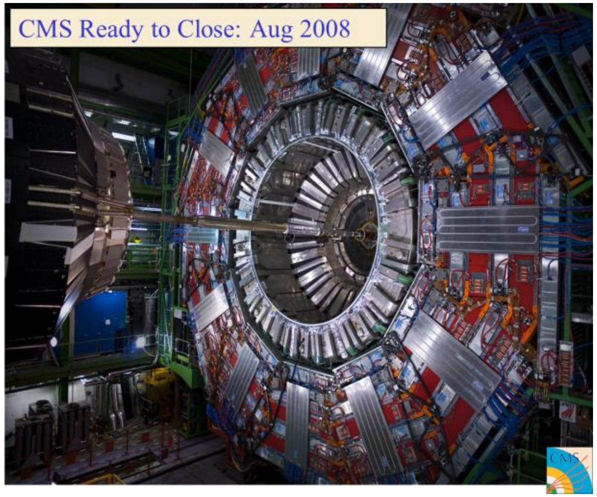


~ 5 km of RT beam vacuum in the long straight sections

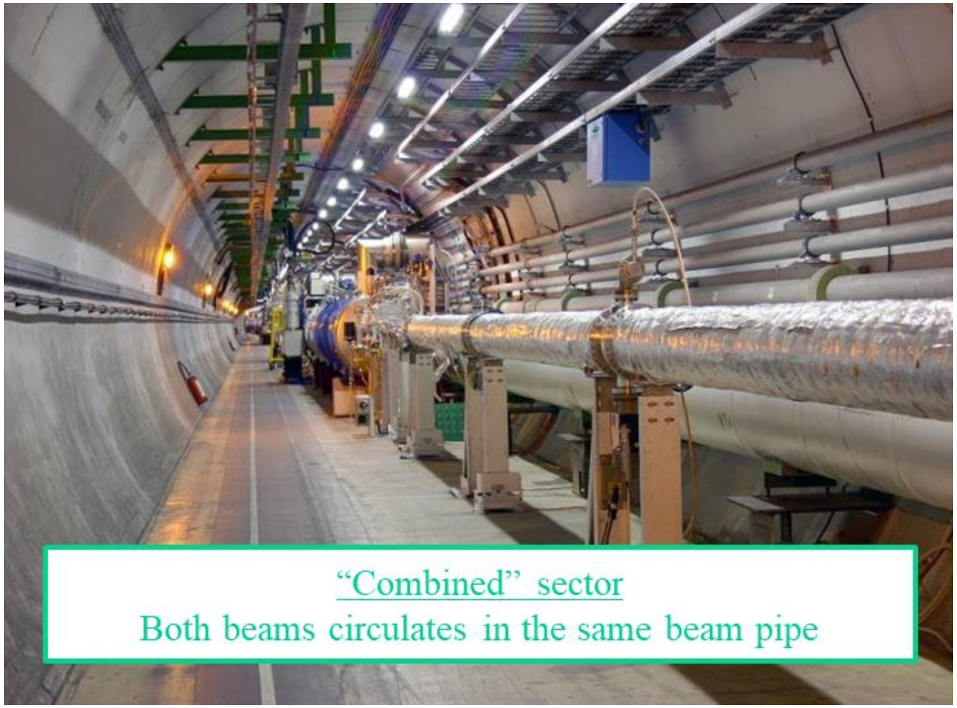
+

~ 22 km of Cryogenic beam vacuum
(2 independent beam pipes per arc: 8 arcs of 2.8 km each)

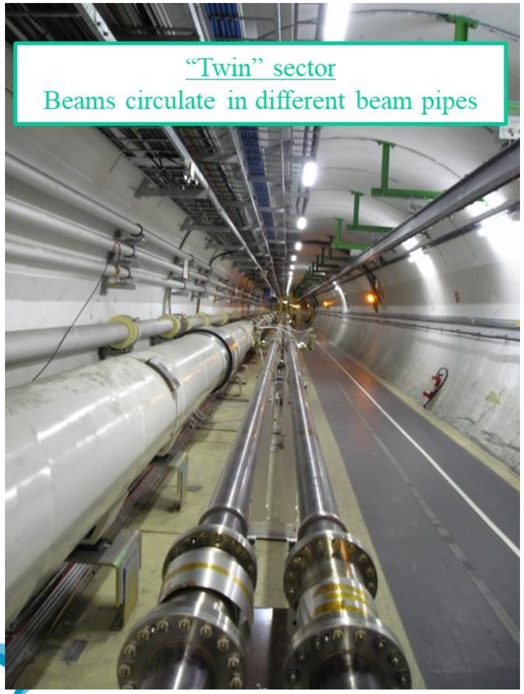
Beam Pipe Layout



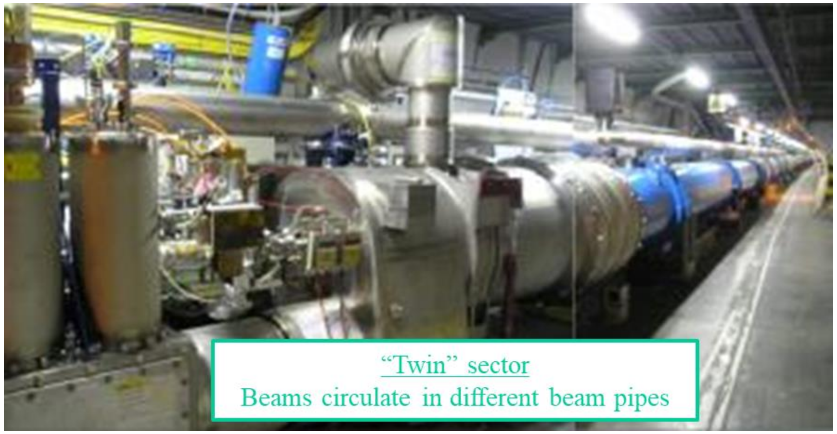
CMS Ready to Close: Aug 2008



"Combined" sector
Both beams circulates in the same beam pipe



"Twin" sector
Beams circulate in different beam pipes



"Twin" sector
Beams circulate in different beam pipes

CDR, PDR, TDR

- Conceptual specifications WP12:
  - https://edms.cern.ch/project/CERN-0000115452

- Preliminary Design Report:
  - CERN-2015-005
  - https://edms.cern.ch/document/1739481

- Technical Design Reports:
  - v.0.1
  - CERN-2017-007-M
  - https://edms.cern.ch/document/1833445

  - v.1 in progress
  - Release by mid 2020.

HL-LHC Design Performances

- The vacuum system encompass vacuum components and other equipment (magnets, collimators, crab cavities, hollow lenses, LRBB compensator etc.)
- The system must ensure vacuum performances complying the HL-LHC beam parameters and High Luminosity experiments reach
  - Ring : 200 h beam life time
  - Experiment's LSS: acceptable background, based on LHC performance and scaled to HL-LHC parameters

Table 12-1: Single gas species molecular gas density (m^{-3}) to satisfy 100 h vacuum lifetime in the LHC and 200 h vacuum lifetime in the HL-LHC assuming a single circulating beam [2].

Machine	I [A]	H_2 [m^{-3}]	CH_4 [m^{-3}]	H_2O [m^{-3}]	CO [m^{-3}]	CO_2 [m^{-3}]
LHC	0.58	1.2×10^{15}	1.8×10^{14}	1.8×10^{14}	1.2×10^{14}	7.9×10^{13}
HL-LHC	1.09	6.4×10^{14}	9.6×10^{13}	9.6×10^{13}	6.4×10^{13}	4.2×10^{13}

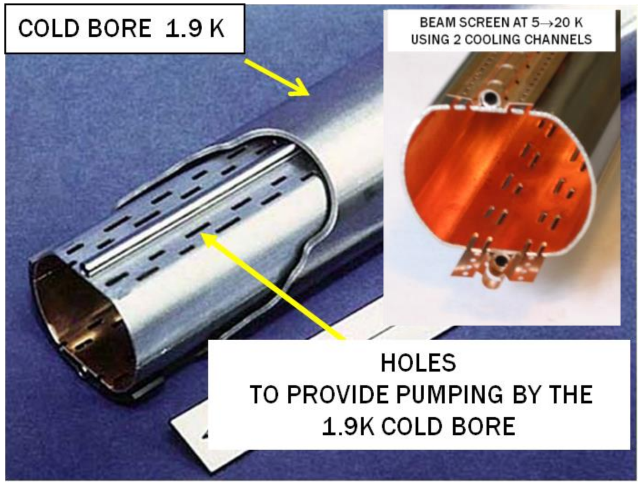
Table 12-2: H_2 equivalent gas density (H_2 equiv/m^3) design value for the LHC high luminosity experiment and IRs [2] and for the HL-LHC.

Machine	I [A]	ATLAS [H_2 equiv/m^3]	CMS [H_2 equiv/m^3]	IR1&5 [H_2 equiv/m^3]	IR2&8 [H_2 equiv/m^3]
LHC	0.58	1.5×10^{11}	3.1×10^{12}	5.3×10^{12}	6.5×10^{12}
HL-LHC	1.09	8.0×10^{10}	1.6×10^{12}	2.8×10^{12}	3.5×10^{12}

$5\ 10^{-12}$ $5\ 10^{-11}$ 10^{-10} mbar

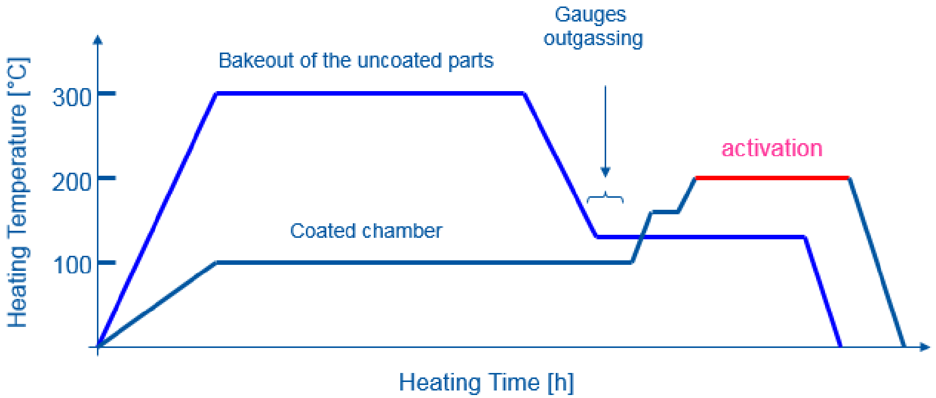
LHC / HL-LHC Base line

- Cryogenic beam vacuum system:
  - Unbaked by design
  - Perforated beam screens to provide pumping
  - Beam scrubbing to reduce to an acceptable level the gas density and the heat load on the cryogenic system
  - a-C coating in NEW HL-LHC beam screens of cryogenic equipment located around experimental areas

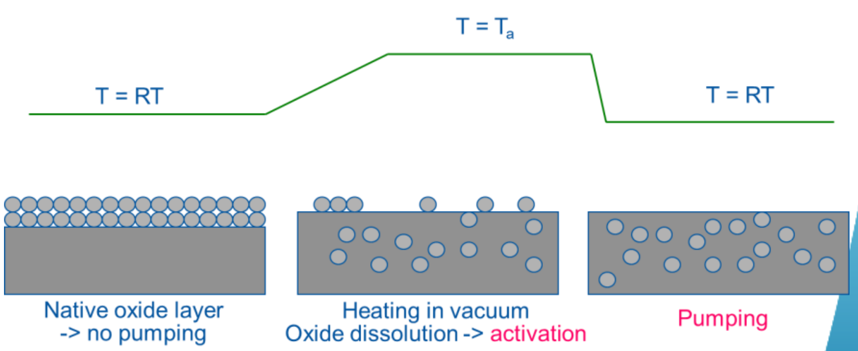


O. Gröbner, Vacuum, 60 (2001) 25-34

- Room temperature vacuum system:
  - Bake able system at 300°C ±20°C for uncoated stainless steel beam pipes (collimators, MKI, TDI etc.)
  - Vacuum activated at 230°C ±20°C of the Non Evaporable Getter (NEG), TiZrV coated, system.



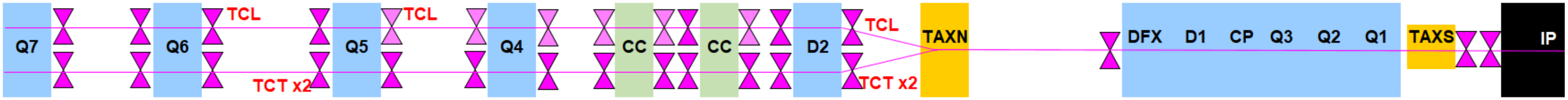
G. Bregliozzi et al, Proc. of EPAC'08, Genoa, Italy

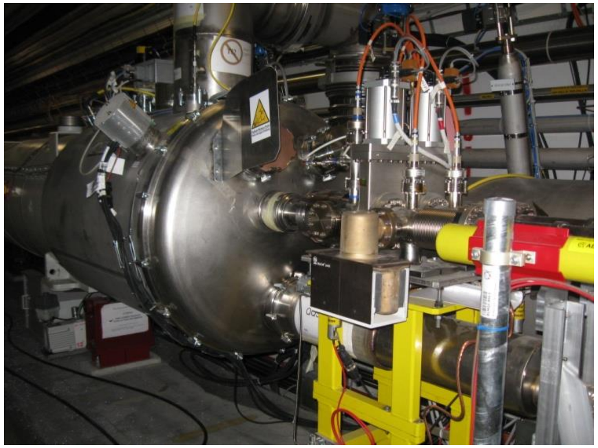


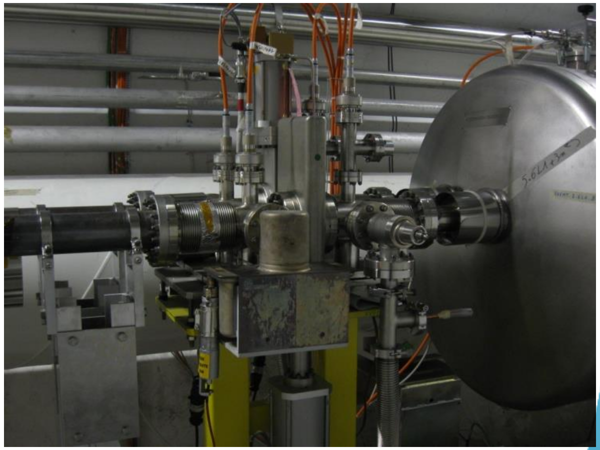
P. Chiggiato and P. Costa Pinto, Thin Solid Films, 515 (2006) 382-388

Vacuum Sectorisation

- Operating 2 types of vacuum systems requires a vacuum sectorisation, with its associated instrumentation for beam interlocking, at EACH cold to warm transition
- ~ 200 vacuum sectors in HL-LHC



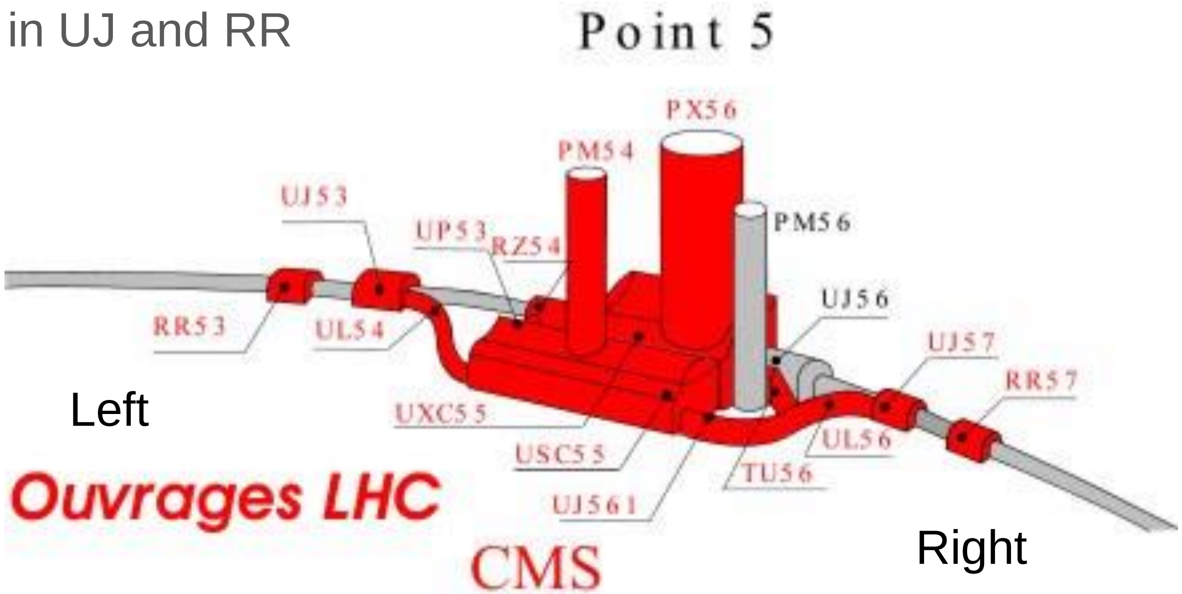




2. Long Straight Section 5 Right Layout

P5 - Buildings

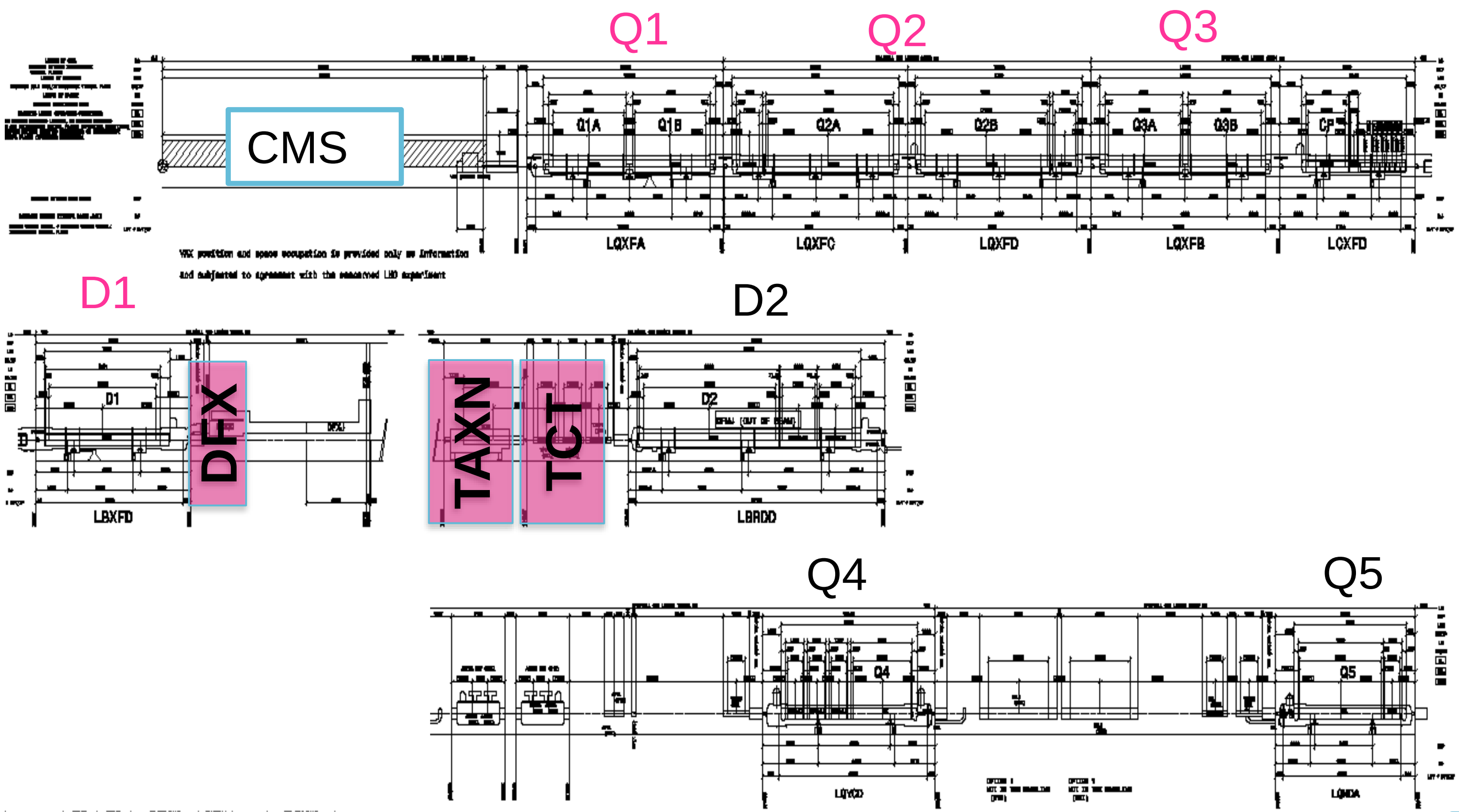
- Located in UJ and RR



LSS5R - Layout

- Objective of vacuum layout
  - Re-use LHC components, upgrade when necessary

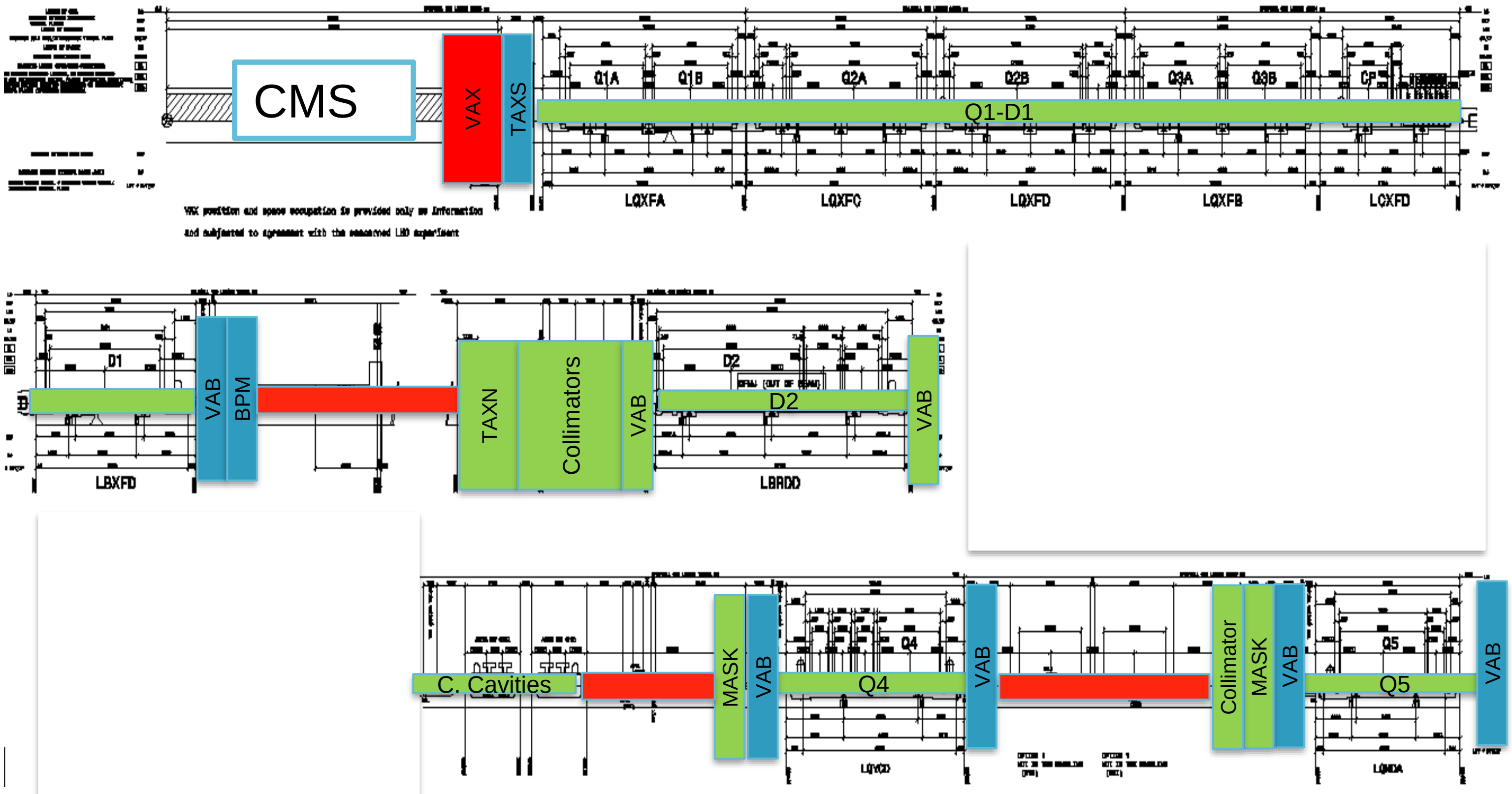
Layout :
IP5 Right



LHCLSXH_0010

Full Remote Alignment System (FRAS)

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

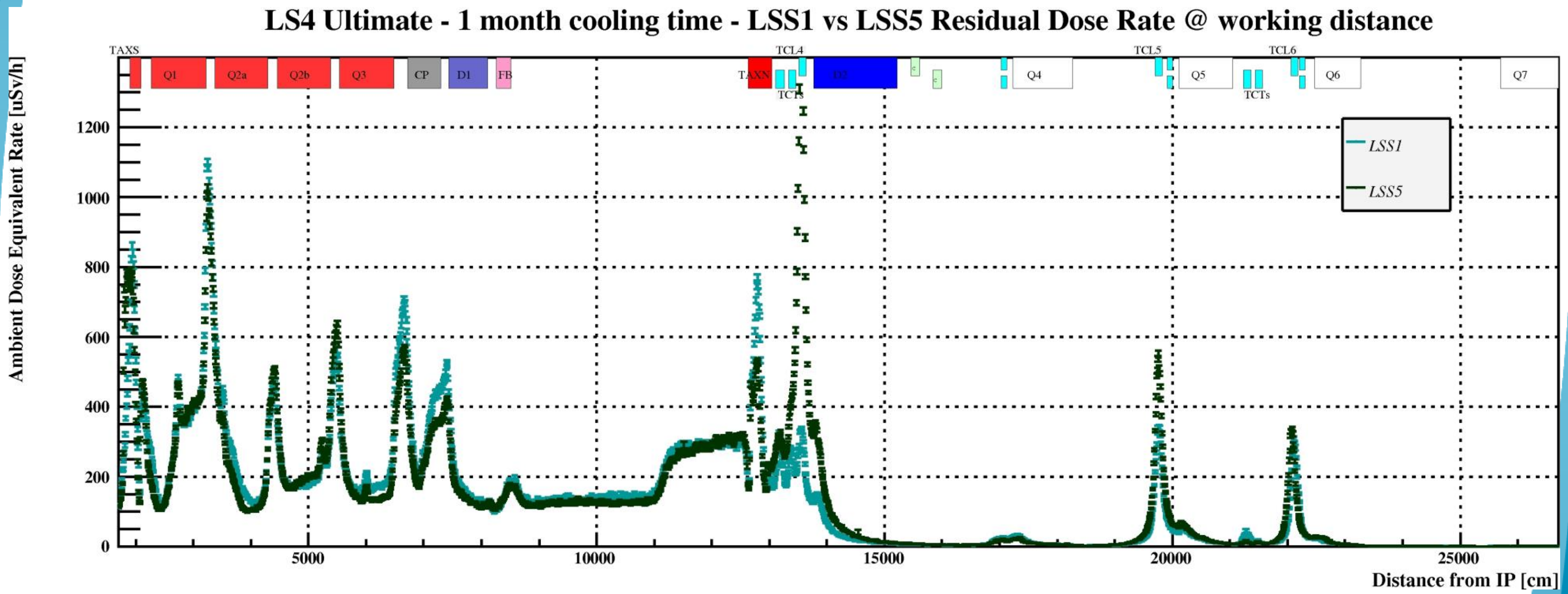


Green	Remote aligned
Blue	Manual aligned by Survey
Red	Manual aligned by TE/VSC or Survey

Residual dose rate in LSS1 and LSS5

- After 1 month cooling:
  - D1-TAXN: 150 – 300 µSv/h at working distance

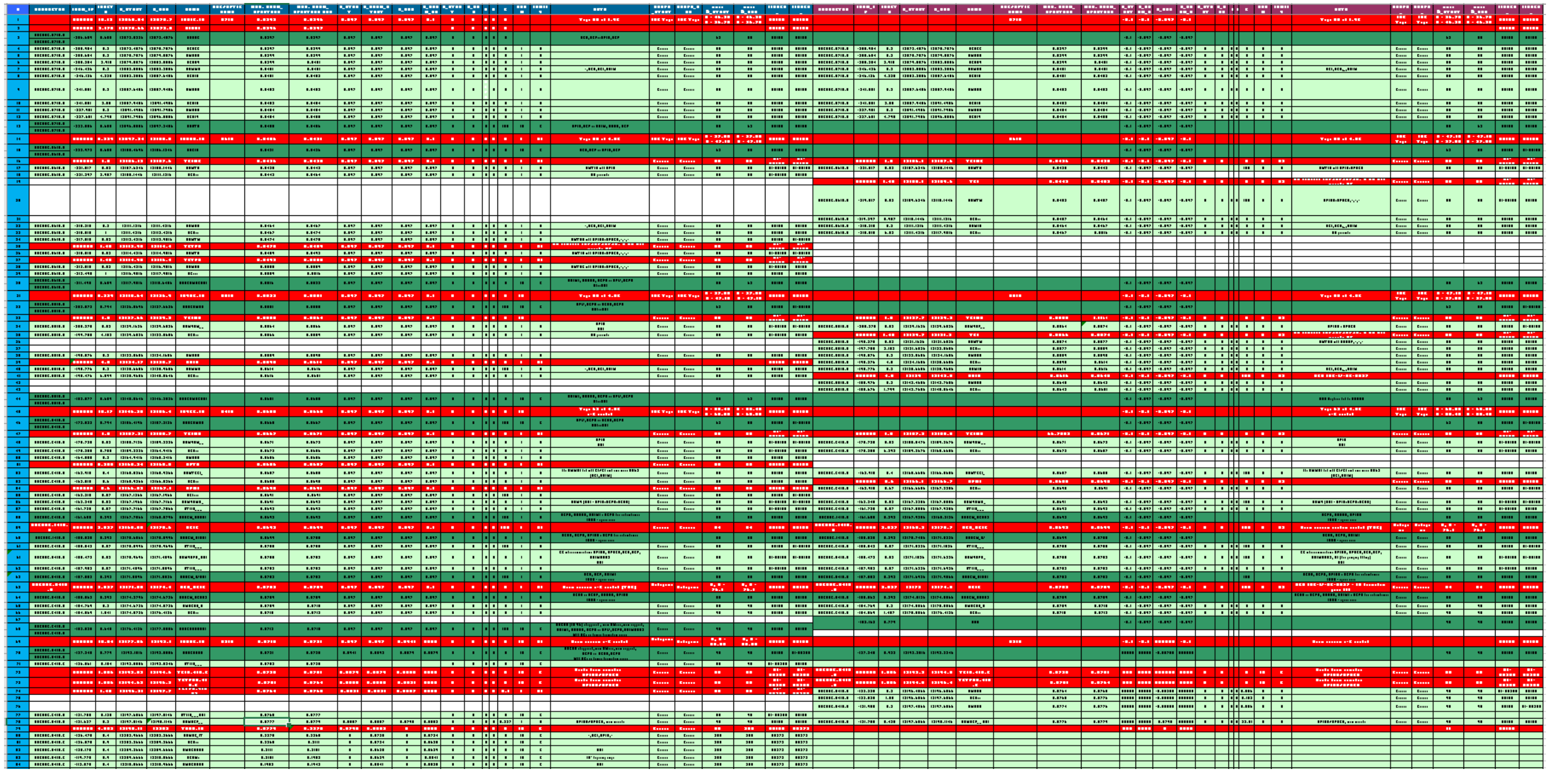
The optics and the collimator settings are the same for IR1 and IR5. Only difference is crossing angle plane.



C. Adorisio, HL-LHC - Residual Dose Rate Estimations in the LSS1 and LSS5 (from TAXS up to Q7), EDMS 1868872, CERN

VAC Layout DB

- From a (semi-private) Excel file to a real DB supported by the project:
  - Vacuum sectors
  - Vacuum instruments,
  - Pipe aperture, length, transverse dimension
  - Beam aperture ….



EDMS 1835992 for IP1 and 2045739 for IP5

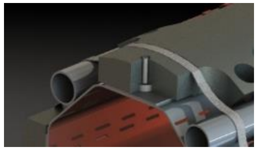
Shielded beam screen in Triplets+D1

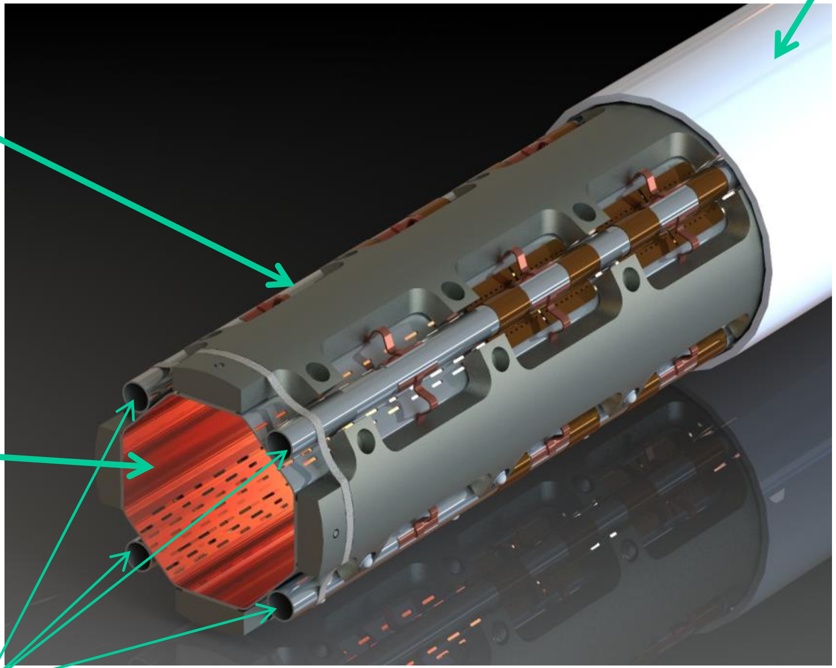
- Objective
  - Provide vacuum stability, control gas density
  - Protect the Triplet cold mass against particle collision debris

Cold bore (CB) at 1.9 K:
4 mm thick tube in 316LN

Tungsten alloy blocks:

- 16 mm thick in Q1, 6 mm elsewhere.
- 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





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:

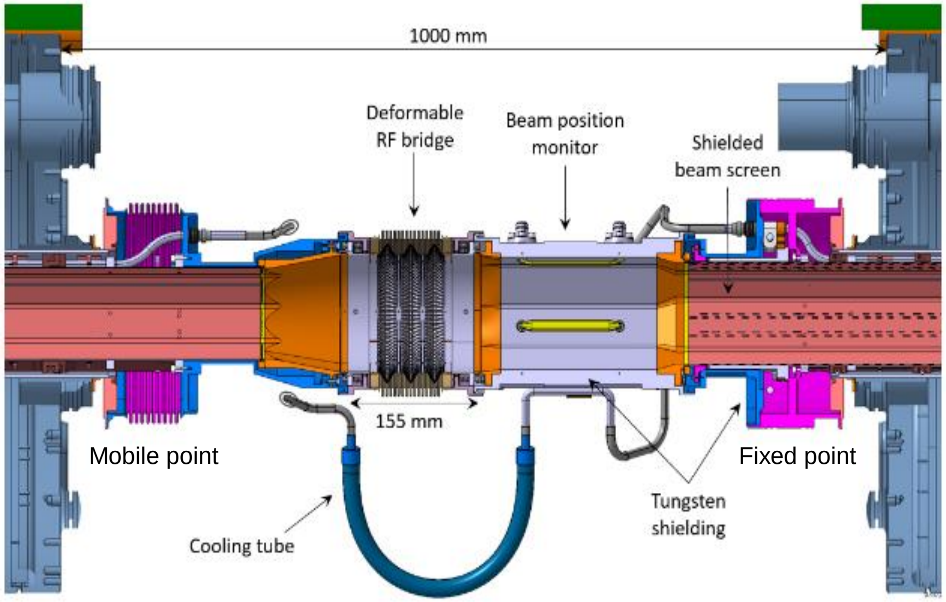
- Outer Diameter: 10 mm
- Laser welded on the beam screen tube

Design by C. Garion, CERN

Triplet interconnection

- Tungsten shielded interconnection with Deformable RF bridges
  → increased cold mass protection and mechanical robustness

- ID132 (Plug-In-Module)

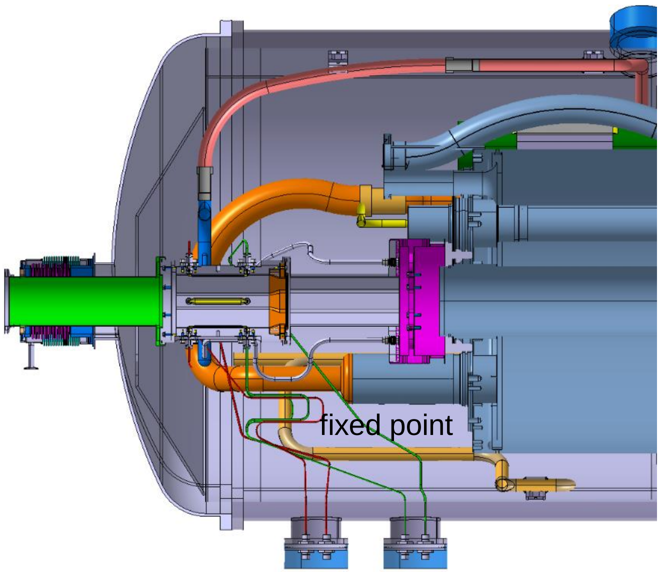


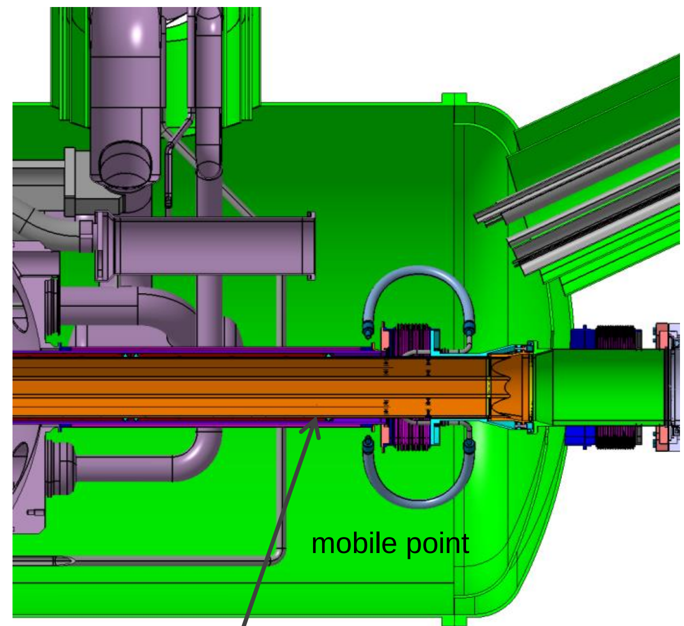
Deformable RF bridges

Design by C. Garion and J. Perez Espinos, CERN

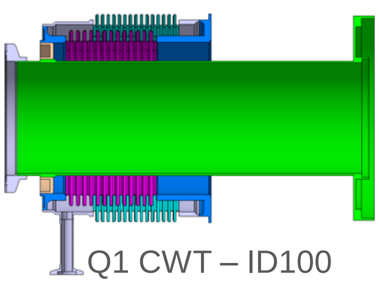
Cold to Warm Transitions

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



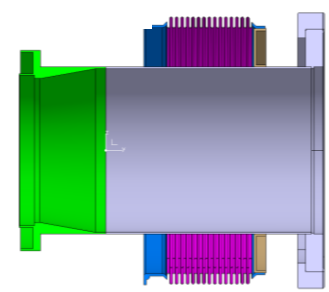


Double walls bellow



Q1 CWT – ID100

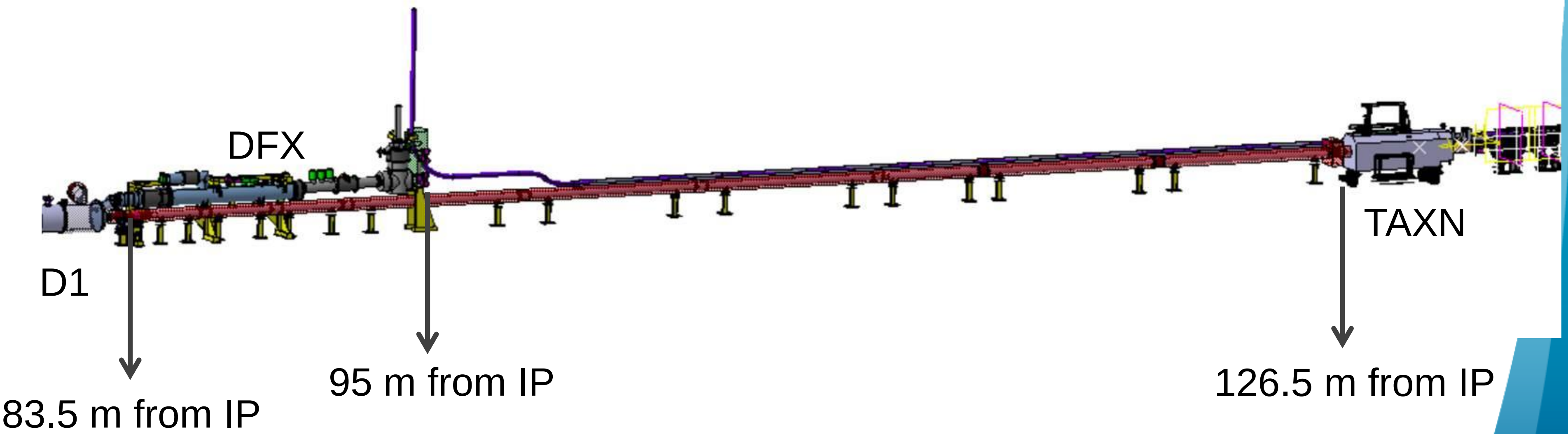
Tungsten shielded beam screen extended over the cold mass until the CWT



D1 CWT – ID130

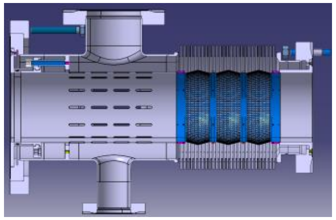
Overview of D1 - TAXN area

- Flange to flange length = 43.775 m
- Max beam size:
  - at D1 sector valve ~ 119 mm
  - at TAXN entry ~ 228 mm
- Large beam clearance (above +/- 2.5 mm) to avoid re-alignment
- Circular beam pipe aperture:
  - 150 mm over ~ 1.6 m long
  - 212 mm over ~ 23.4 m long
  - 250 mm over ~ 18.9 long

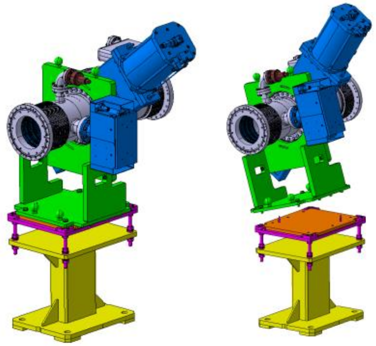


D1-DFX integration

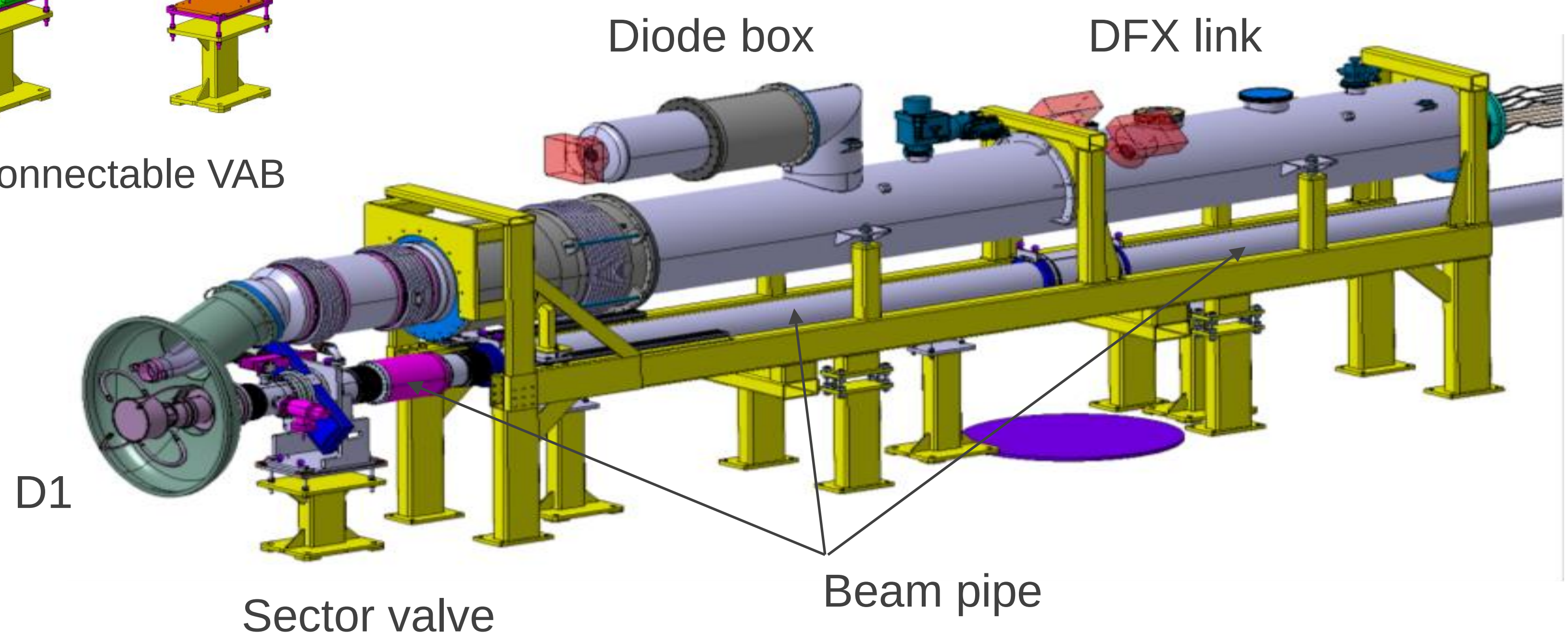
- Vacuum system designed in collaboration with WP2 & WP6A & WP15
- A dense area with D1 cryostat, superconducting link, its frame and the vacuum system!
- Beam pipe aperture 150 mm
- Instrumented sector valve (VAB)



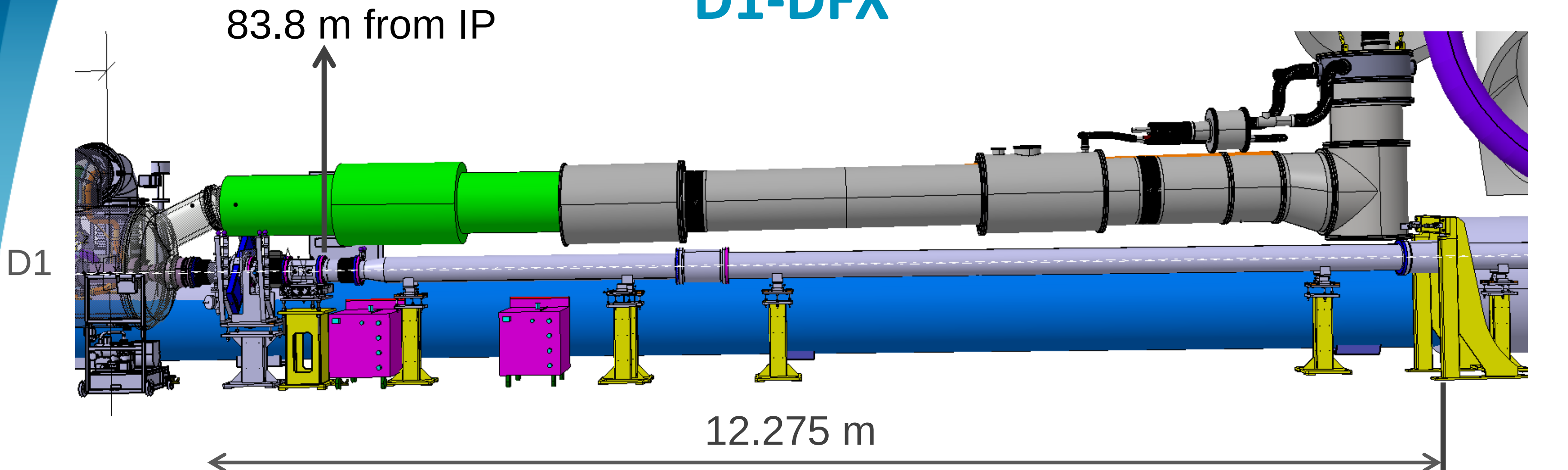
Deformable RF bridge



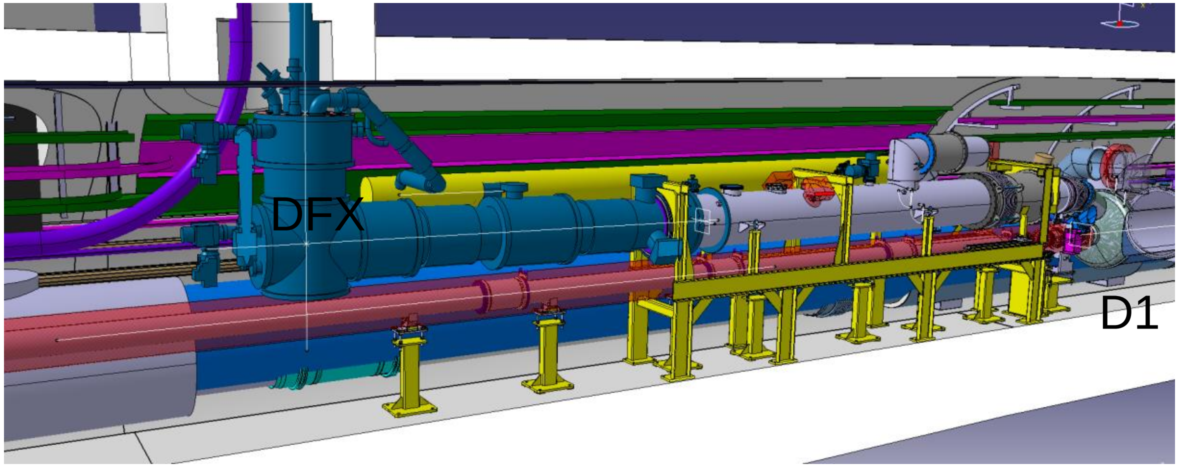
Disconnectable VAB



D1-DFX

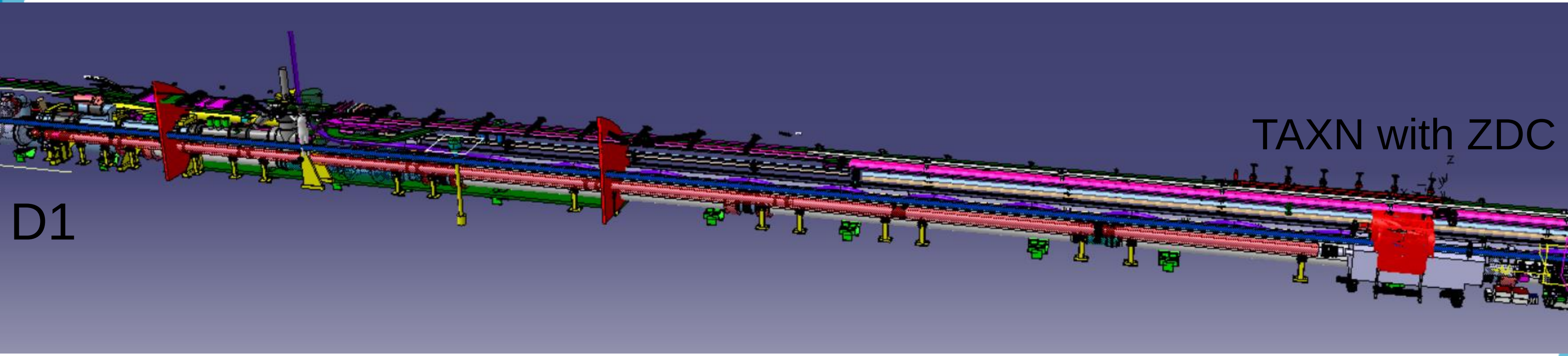


- Large aperture vacuum pipe:
  - 150 mm over 1.6 m then 212.7 mm
  - Flanges size DN200 and DN250



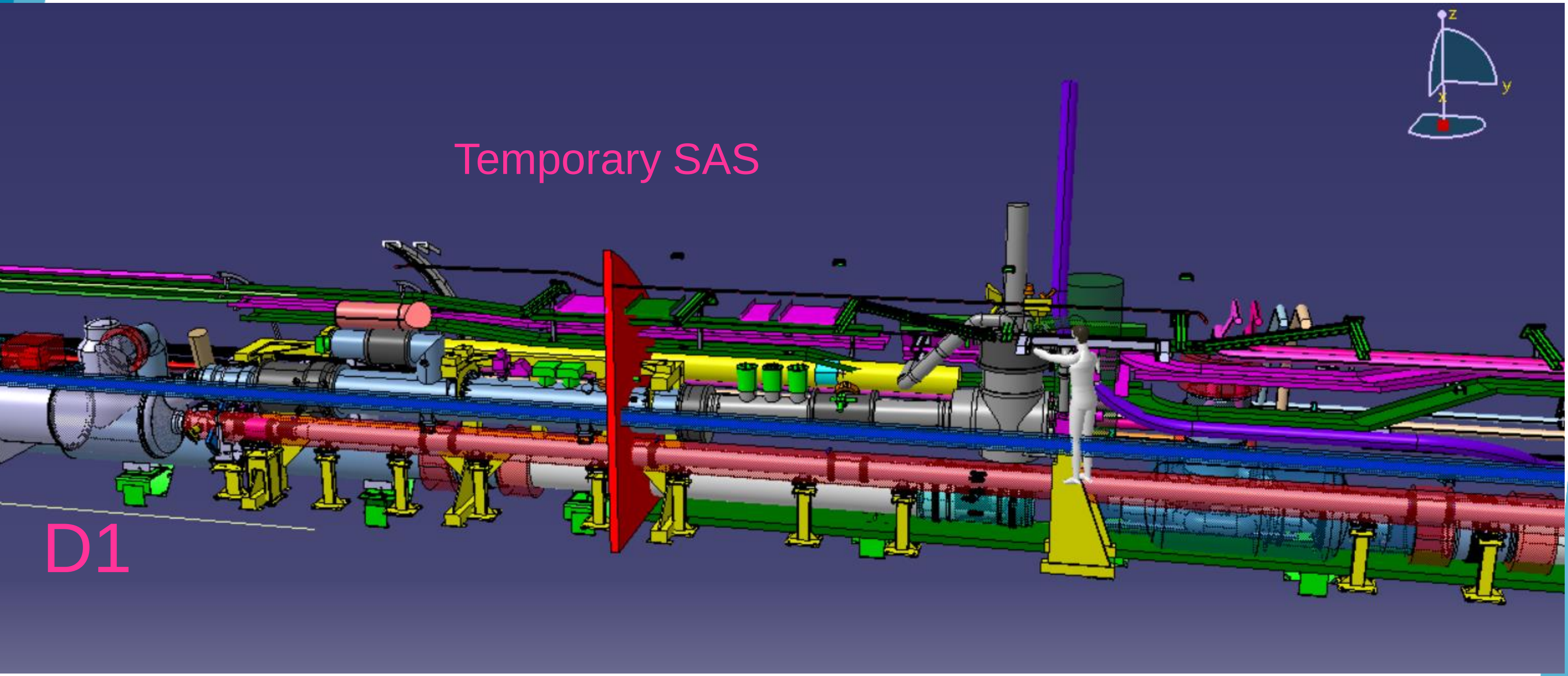
D1-TAXN

- What is presently inside the tunnel …



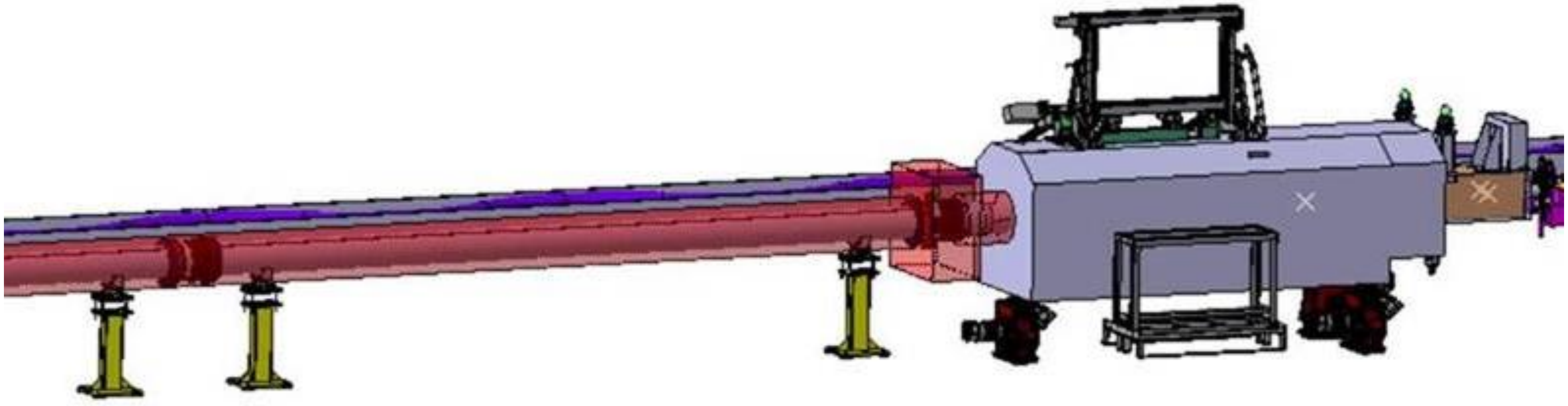
D1-DFX

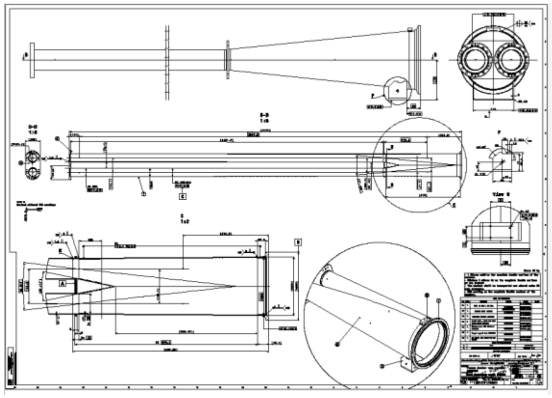
- What is presently inside the tunnel …



TAXN

- Vacuum system designed in collaboration with WP2 & WP8
- Design of the Y chamber: drawing 2282424
- Integration of bakeout, alignement, BRAN and ZDC and systems





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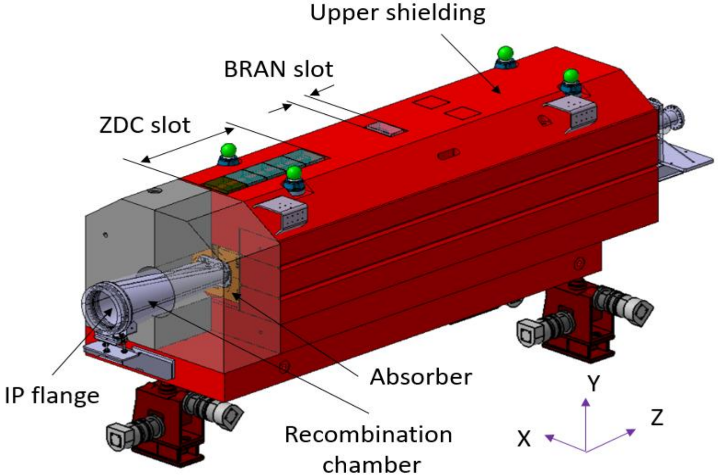
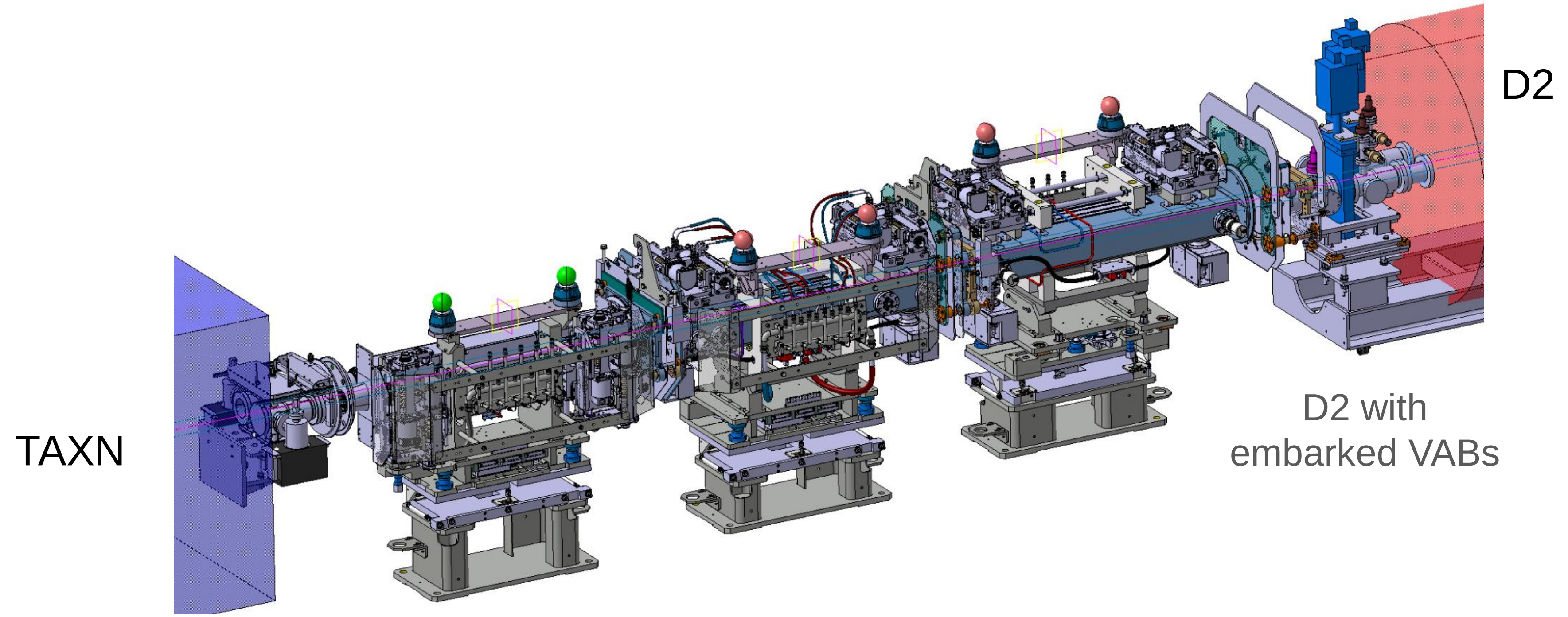


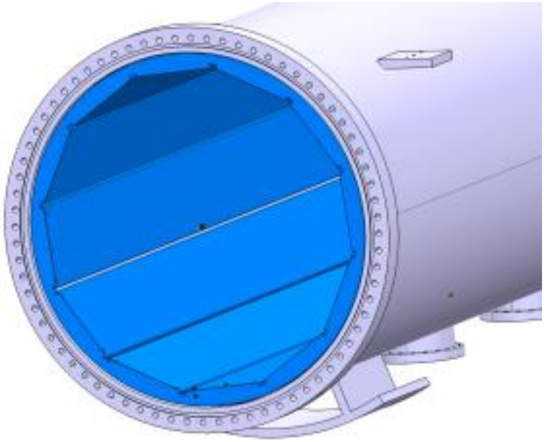
Tertiary Collimators (TCTs) between TAXN-D2

- Vacuum system designed in collaboration with WP2 & WP5 & WP15
- Space optimisation is ongoing, layout regularly updated:
  - Aperture ID80,
  - Ion pumps are integrated at the bottom of the collimator body
  - Only one quick CF DN300 flanges between collimators

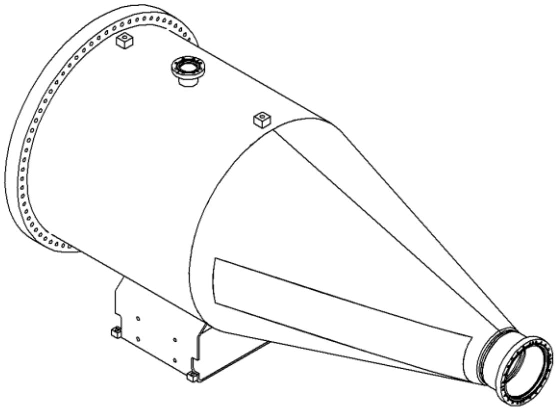


A wide aperture vacuum chamber in LHC: case of ALICE ZDC beam pipe in LSS2

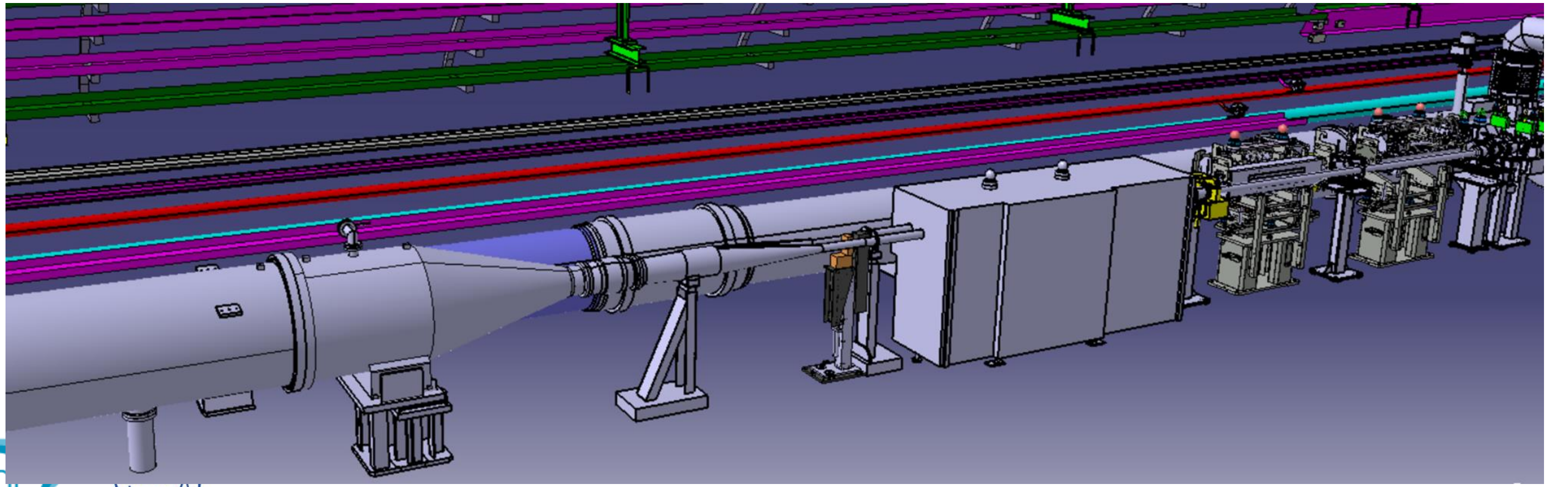
- Circular Stainless Steel beam pipe with transitions from 800 to 212.7 mm
- Length over 25.7 m
- Vacuum Transition Chambers (VCT) with 15° tapering angle (impedance)
- Frame with NEG coated liners



NEG liners



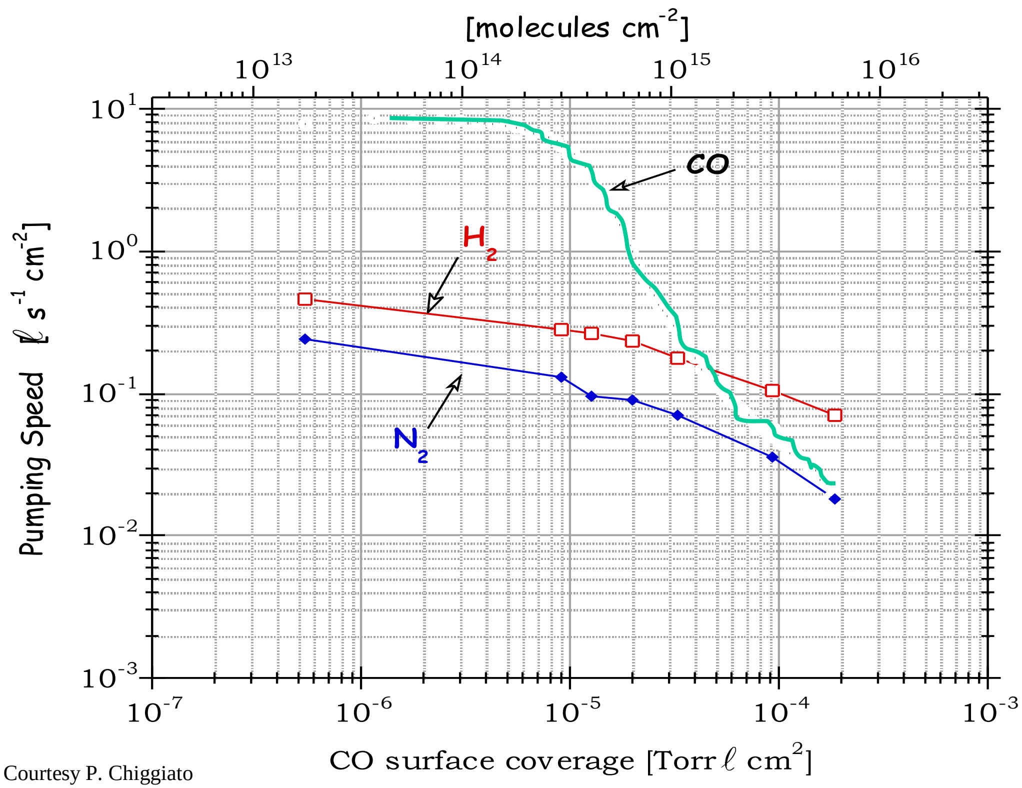
VCTCH



Thank you for your attention

TiZrV Vacuum Performance

Pumping Speed



Courtesy P. Chiggiato

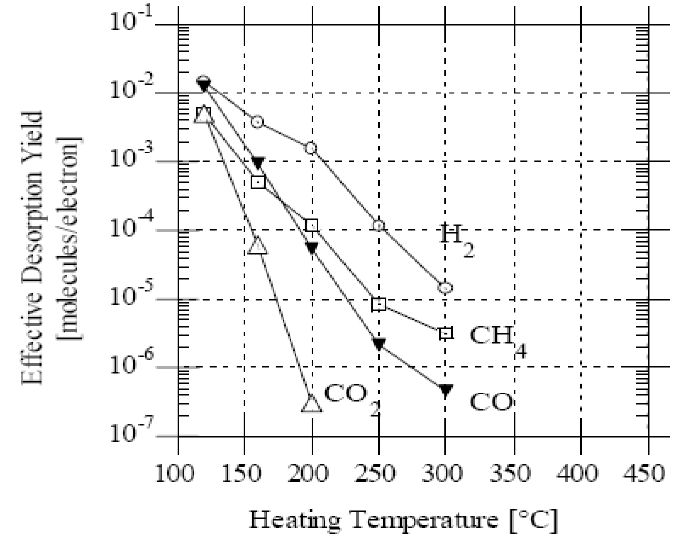
- Very large pumping speed : ~ 250 l/s/m for H_2, 20 000 l/s.m for CO
- Very low outgassing rate

- But : limited capacity and fragile coating sensitive to pollutant (hydrocarbons, Fluor …)

TiZrV Vacuum Performance

- Very low stimulated desorption yield
- SEY ~ 1.1 => very low multipacting
- But : limited capacity and fragile coating sensitive to pollutant (hydrocarbons, Fluor …)

ESD Yields



C. Benvenuti *et al.* J.Vac.Sci.Technol A 16(1) 1998

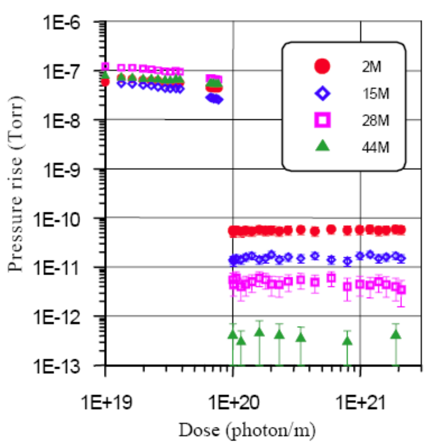


Figure 2: Pressure rise measured in the centre of the TiZrV coated test chamber before activation ($<1\cdot10^{20}$ photons/m) and after activation ($>1\cdot10^{20}$ photons/m).

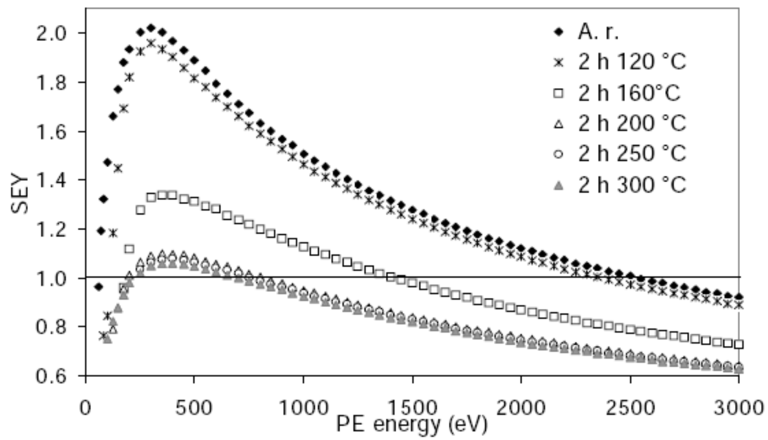
PSD Yields

Table 2: Summary of results from the activated test chamber

Gas	Sticking probability	Photodesorption yield (molecules/photon)
H_2	~0.007	$\sim 1.5\cdot10^{-5}$
CH_4	0	$2\cdot10^{-7}$
CO (28)	0.5	$<1\cdot10^{-5}$
C_xH_y(28)	0	$<3\cdot10^{-8}$
CO_2	0.5	$<2\cdot10^{-6}$

V. Anashin *et al.* EPAC 2002

Secondary Electron Yield



C. Scheuerlein *et al.* Appl.Surf.Sci 172(2001)

HiLumi HL-LHC PROJECT