WP12: Progress on the vacuum system design

V. Baglin on behalf of WP12

6th HL-LHC Collaboration Meeting, Paris, 14-16th November 2016

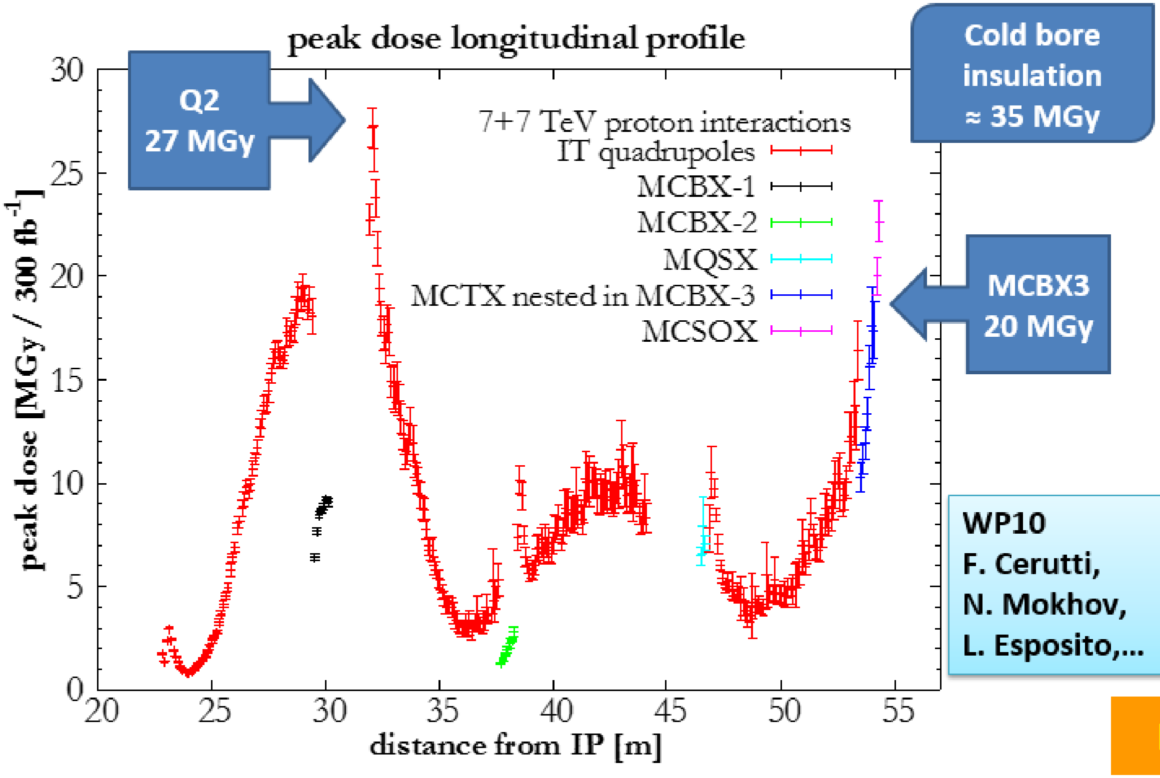
OUTLINE

1. HL-LHC beam screens
2. HL-LHC Layout
3. LS2
4. Summary

1. HL-LHC Beam Screen

1.1 Design Studies

The technical trigger of the upgrade: Radiation damage in low-beta triplet region



Q2
27 MGy

Cold bore insulation
≈ 35 MGy

MCBX3
20 MGy

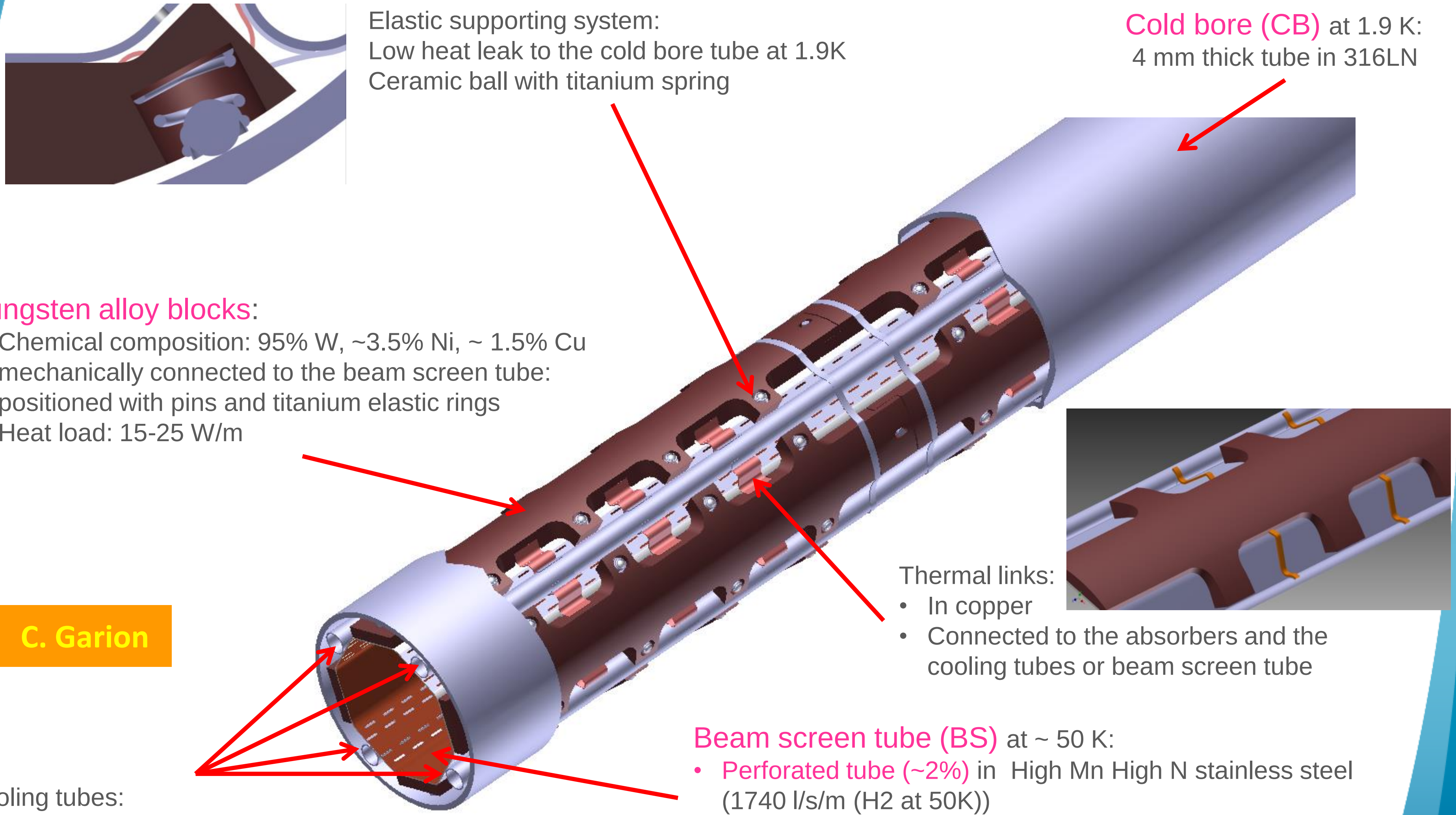
WP10
F. Cerutti,
N. Mokhov,
L. Esposito,…

L. Rossi

The Shielded Beam Screens (BS) are key devices of the HL-LHC project

Shielded Beam Screen Concept

Assembly of the beam screen



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

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

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

C. Garion

Beam screen tube (BS) at ~ 50 K:
- Perforated tube (~2%) in High Mn High N stainless steel (1740 l/s/m (H2 at 50K))
- Internal copper layer (80 μm) for impedance
- a-C coating (as a baseline) for e- cloud mitigation

Cooling tubes:
- Outer Diameter: 10 or 16 mm
- Laser welded on the beam screen tube

Progress & next Milestones

- Thermal and quench models of the beam screen/ cold bore assembly are developed
  - ➔ Under validation against experimental investigations (mid 2017)
- Beam screen and cold bore mechanical design completed
  - ➔ CB prototypes produced, tolerances to be fixed by end 2016
  - ➔ Beam screen prototypes to be produced, tolerances to be frozen by end 2017
- Interconnection baseline with deformable RF bridge
- Beam Screen Finishing Facility ready by mid 2107

10 m long CB prototype

Reception test of the gantry crane

More details by C. Garion in parallel session

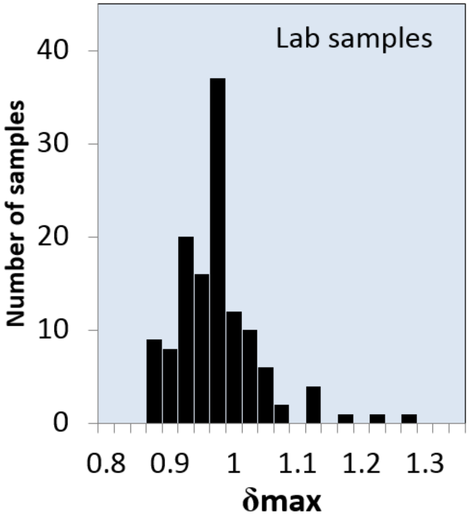
1.2 a-C Coating Performances Studies

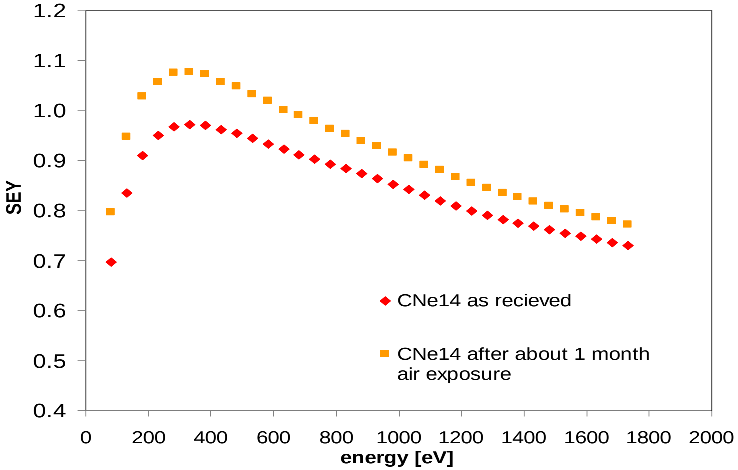
a-C Coating for Electron Cloud Mitigation

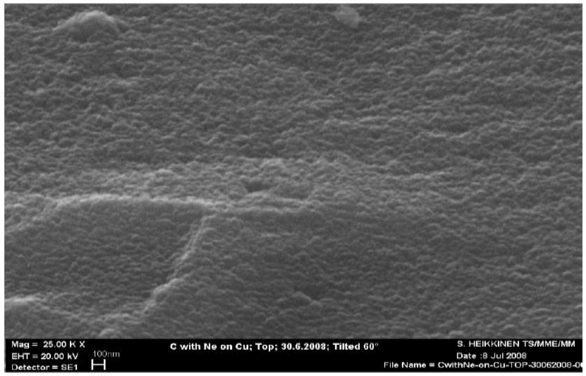
- a-C coating is proposed to mitigate electron multipacting to reduce the heat load on the beam screen and the background to the experiments.

- It has a maximum SEY of 1 +/- 0.1 ==> no or little multipacting is expected

- The coating is currently under evaluation at cryogenic temperature in the laboratory and with LHC type protons beams in COLDEX.







M. Taborelli

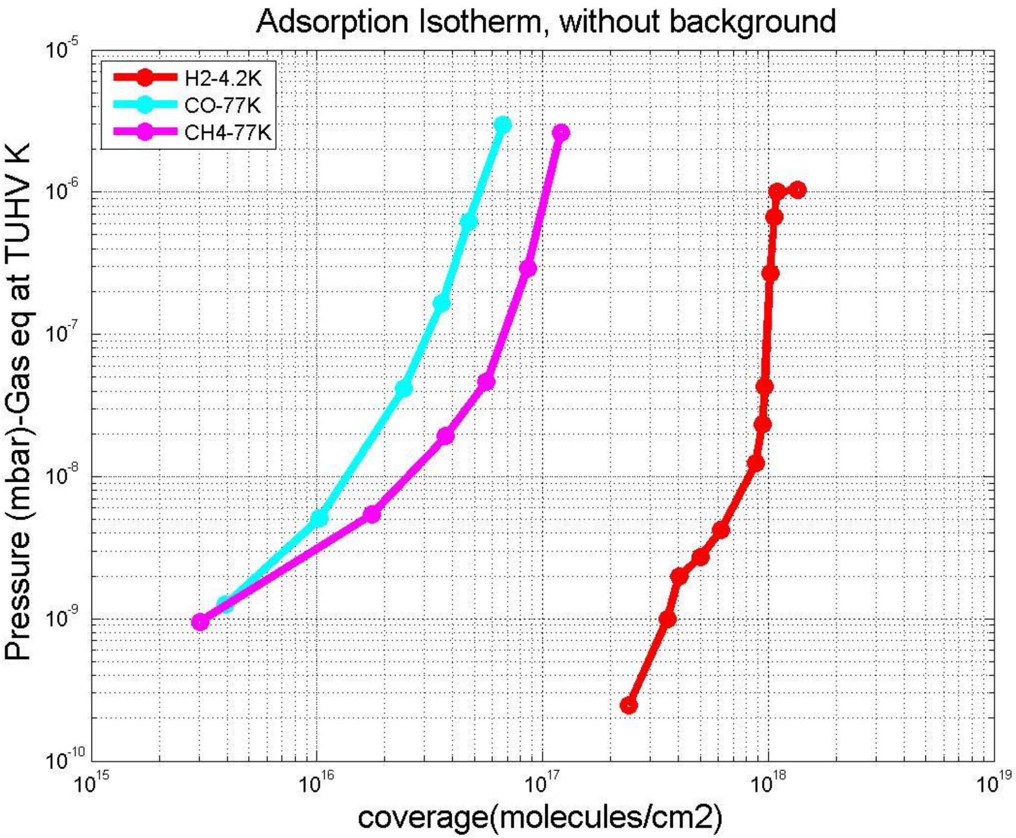
Adsorption Isotherms at 4.2 and 77 K

- ~ 500 nm thick coating

- H_2, CO and CH_4

- At 4.2 K, the capacity is much more than one monolayer (10^{15} H_2/cm^2)

- The capacity decrease with increasing temperature



- The coating is porous
- Capacity ~ 100 x Cu

A-L. Lamure

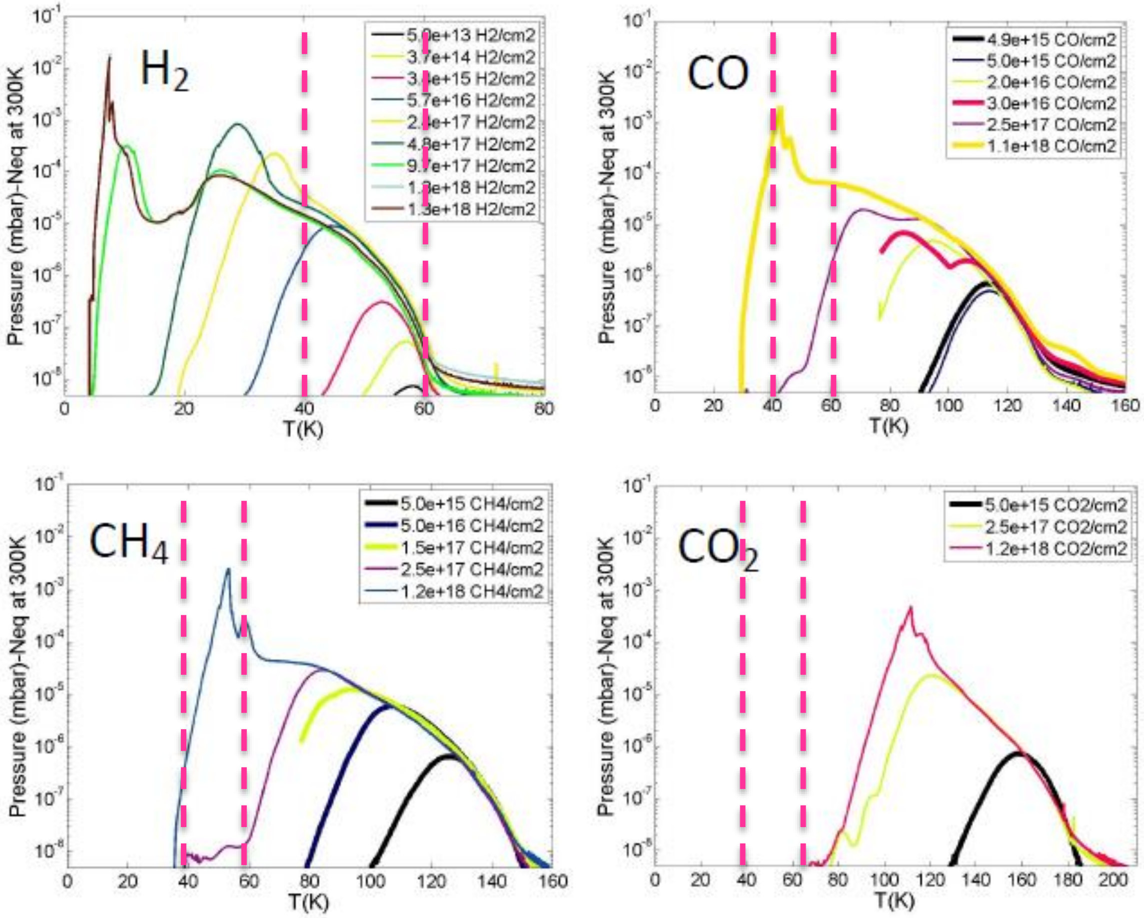
- Next steps:
  Pumping speed & adsorption isotherms and isosteres in the 20-100 K range, set-up available by spring 2017

a-C Coating Thermal Desorption Spectroscopy

- The larger the coverage, the lower the desorption temperature.

- Binding energies are in the range 100-500 meV and decrease with surface coverage

A-L. Lamure



	H2	CH4	CO	CO2
Peak in 40-60 K	Any coverage	For coverage > 10^{17} CH_4/cm^2	For coverage > 2 10^{16} CO/cm^2	For coverage > 10^{18} CO_2/cm^2

Potential modification of the proposed BS operating temperature

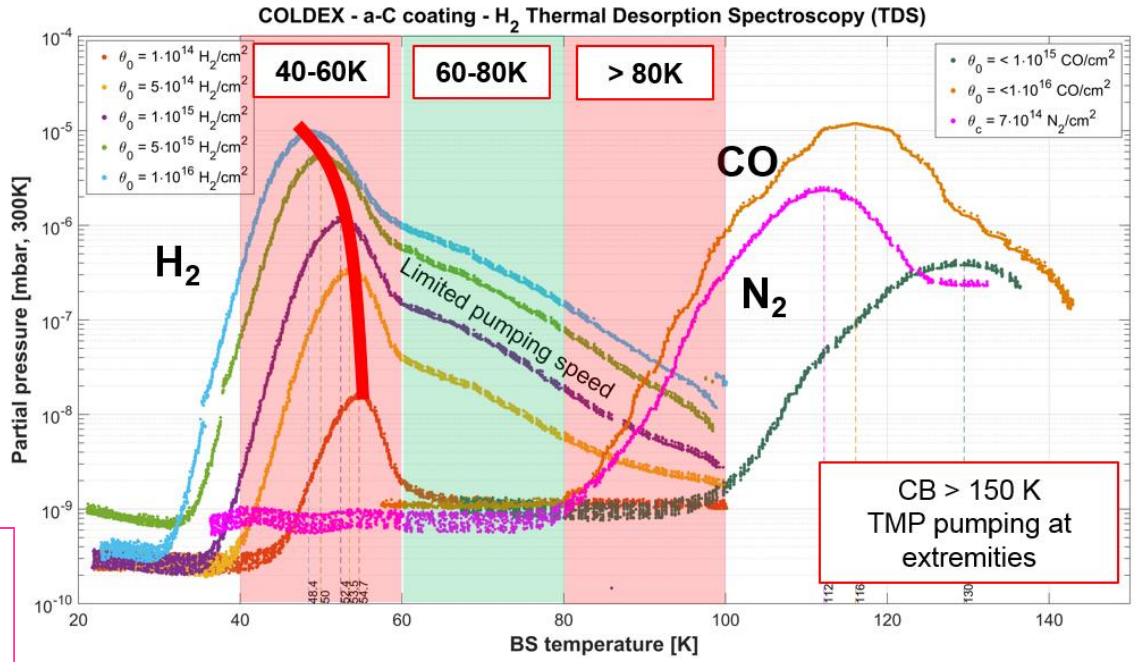
a-C Coating Studies with COLDEX

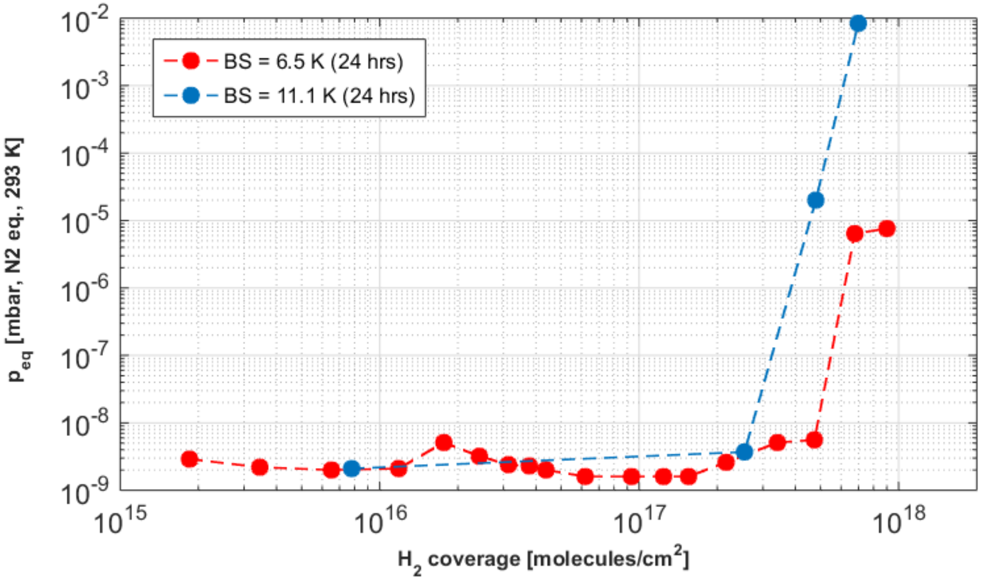
- H_2 is desorbed in the range 40-60 K
- N_2 and CO are desorbed above 80 K
- The activation energy (temperature) for desorption (release) is dependent on the coverage

A possible new operating temperature window for the beam screen could be ~ 60-80 K

- The cryosorption capacity for H_2 is ≥ $2·10^{17}$ H_2/cm^2 below 10 K
- It is intermediate between metallic surfaces and common cryosorbers

R. Salemme

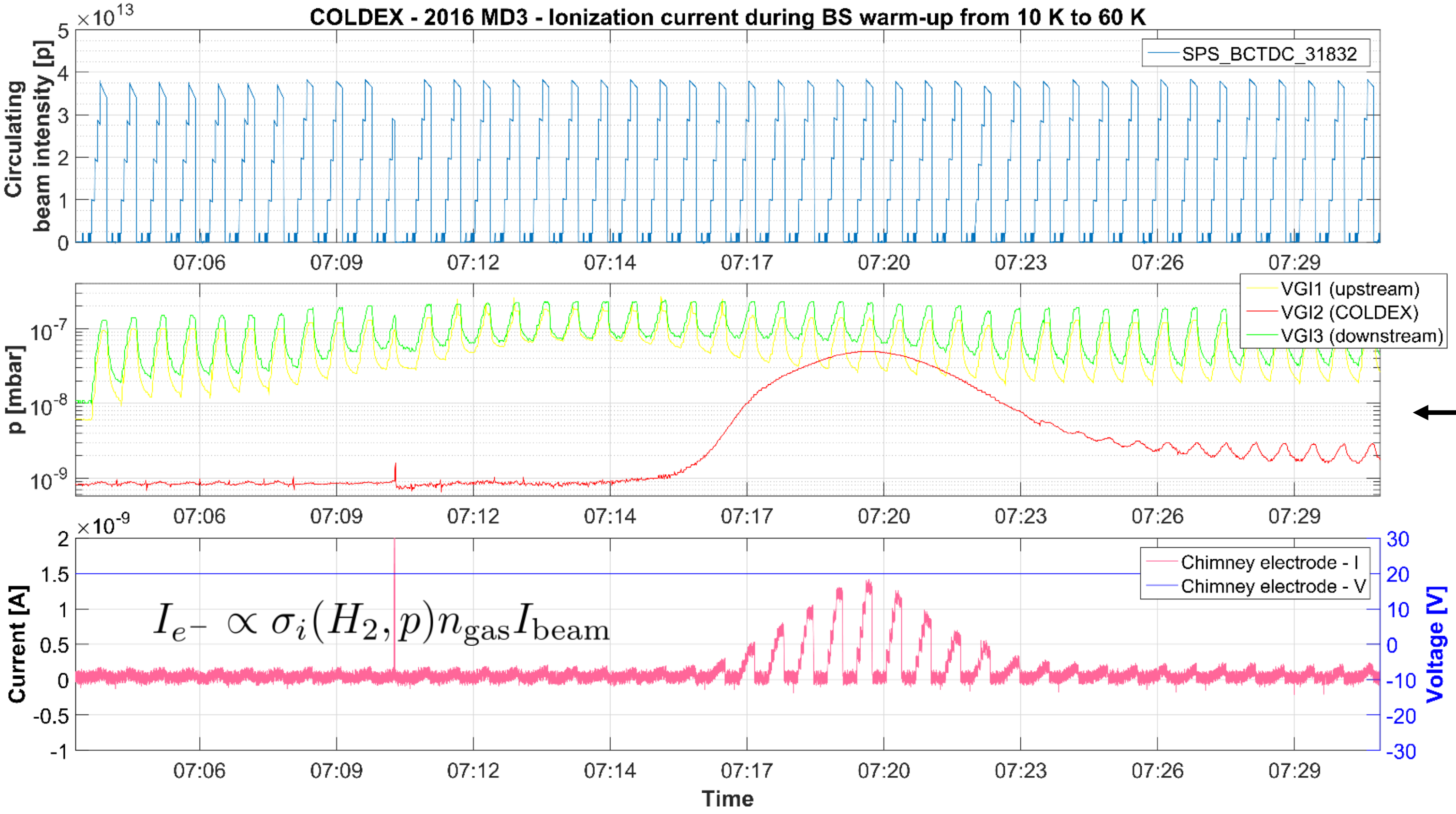




Observation of Beam-Gas Ionisation with COLDEX

- COLDEX's electrode is sensitive enough to measure beam gas ionisation!
- Sensitivity ~ 0.1 nA i.e. ~$4 \cdot 10^6$ $e^-/(mm^2\ s)$

$$\boxed{I_{e^-} \propto \sigma_i(H_2, p) n_{\text{gas}} I_{\text{beam}}}$$



Beam circulating intensity

← P at extremities

← a-C, pressure bump

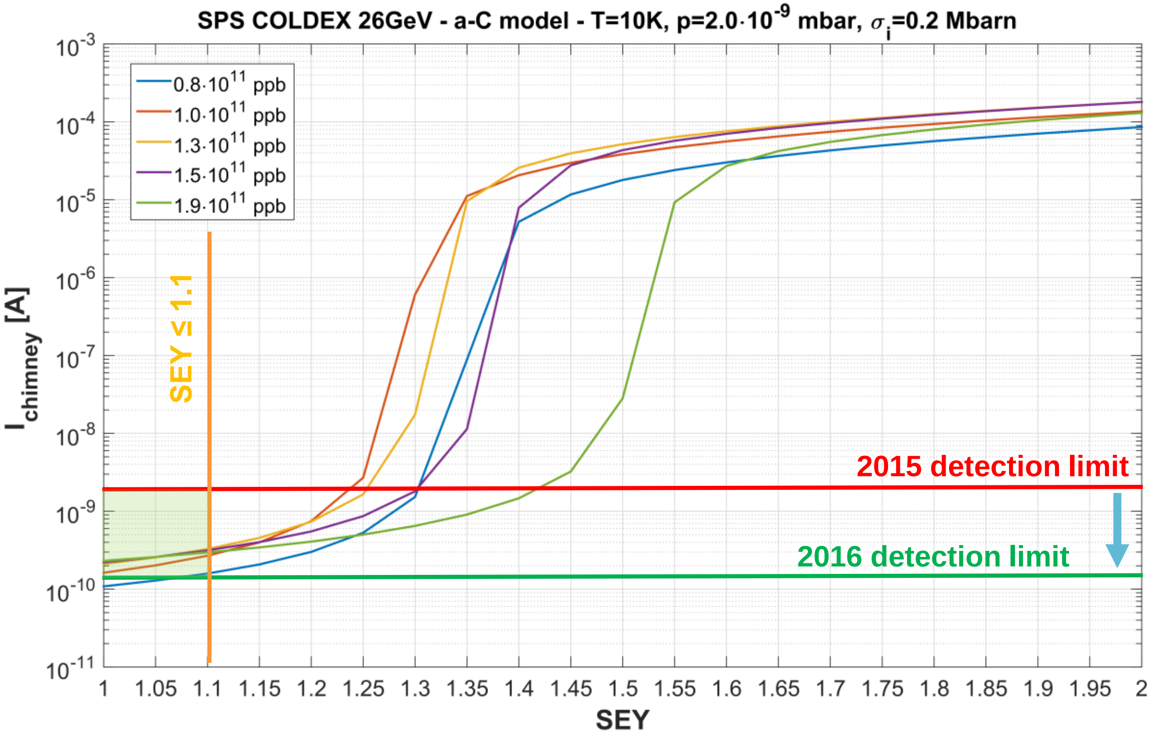
Electron/ion current

R. Salemme, PhD Thesis

a-C Coating Performances Studies with COLDEX

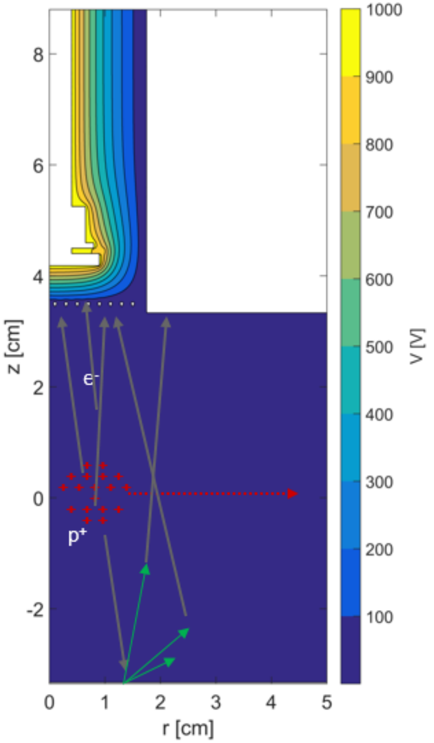
- No dynamic pressure larger than 10^{-9} mbar due to ESD is observed for:
  - bare surface
  - surface coverages of:
    - ~3 10^{16} H_2/cm^2 , ~2 10^{16} CO/cm^2, ~3 10^{16} CO_2/cm^2
- Measured dynamic heat load are within:
  - 0.2 +/- 0.1 W/m for all studied cases
- No multipacting electron activity is measured above 0.1 nA

$\delta_{max} < 1.1$



R. Salemme, PhD Thesis

Electron pick-up inserted through RT chimney
Shielded by a grid
Circular, D = 18 mm

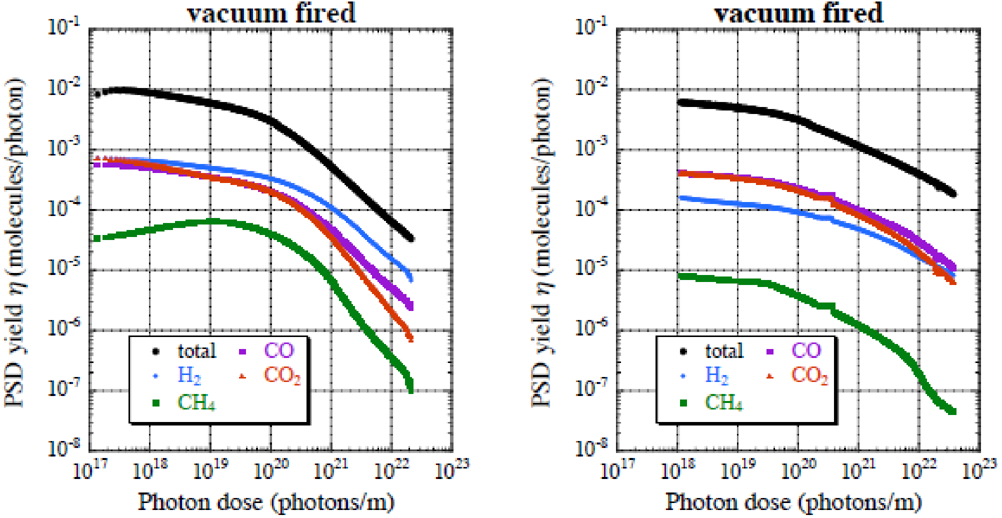


a-C coating and Synchrotron Radiation

- KEK Collaboration:
  - 4 KeV critical energy (x100 LHC)
  - Desorption yields of a-C coating larger than stainless steel
  - Conditioning with beam

M. Ady

In-situ bakeout at 120 deg

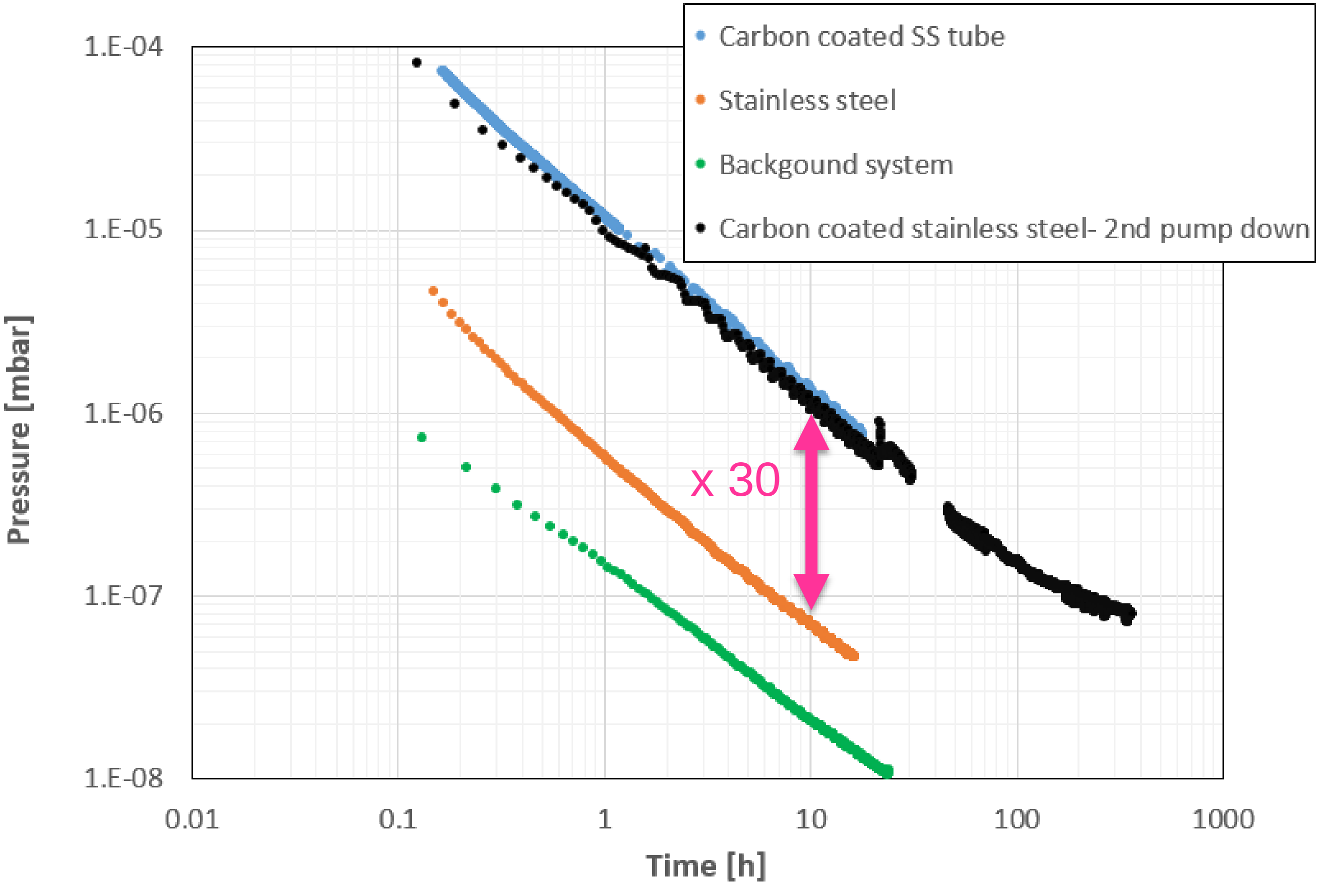


- BINP Collaboration:
  - Set-up under construction
  - Unbaked sample at room and cryogenic temperature
  - ~ 50 eV critical energy
  - Results expected by ~ mid-end 2017

V. Baglin,
A. Krasnov (BINP)

a-C Coating and Thermal Outgassing

- Unbaked a-C coated stainless steel tube, 450-500 nm thick:
  - Mass spectrum is water dominated
  - ~ x 30 unbaked stainless steel
  - 2nd pump down very similar to 1st one
- After 10h pumping:
  - Stainless steel = 2 10^{-10} mbar.l/s/cm^2
  - a-C coating = 6 10^{-9} mbar.l/s/cm^2



I. Wevers

2. HL-LHC Layout

Vacuum Chambers Apertures

- Input beam aperture table from WP2
- New vacuum chambers and vacuum modules to be designed / produced for D1-Q4 region
- Additional inner diameters standards: 91 and 248.1 mm

	HL-LHC beam aperture [mm]	Vacuum chamber aperture [mm]
D1	0 - 130	
D1 - TAXN	130 - 233	VCT - 212.7 - VCT - 248.1
TAXN	85	VCTY
TAXN - D2	85	91
D2	87	
D2 - Q4	85	91
Q4	72.41	
Q4 - Q5	72.41	80
Q5	57.8	
Q5 - Q6	57.8	80
Q6	45.1	
Q6 - Q7	45.1	80

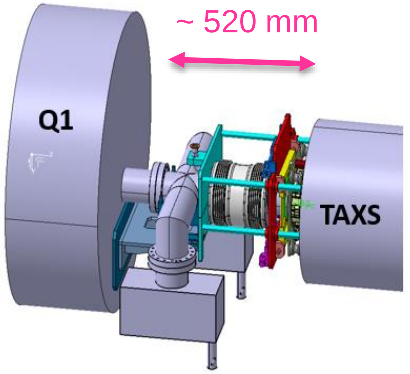
P. Santos Diaz

New VAX area in IR1 and 5

- Move the instrumentation in front of Q1 to the experiment's cavern to reduce radiation to the personnel: robustness, remote handling and tooling are required
- Installation in LS3 during TAS exchange, the impact on the experimental vacuum chamber beam pipe is under study
- TAXS-Experiments & Q1-TAXS areas studies are coordinated by WP8
- Unbaked a-C coated TAXS

Pumping and bellow to decouple room temperature TAXS from cryogenic temperature triplet

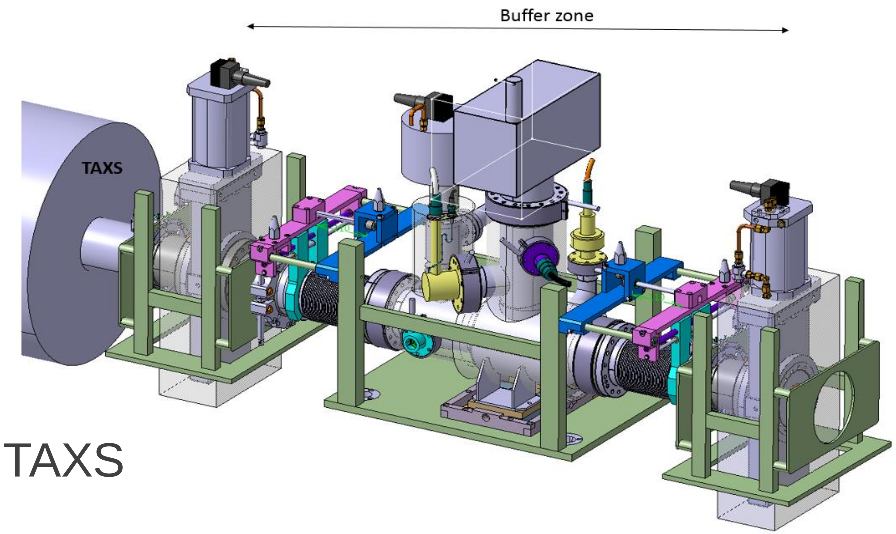
Sectorisation to decouple experiment's vacuum from machine vacuum



Q1

TAXS

Courtesy L. Krzempek



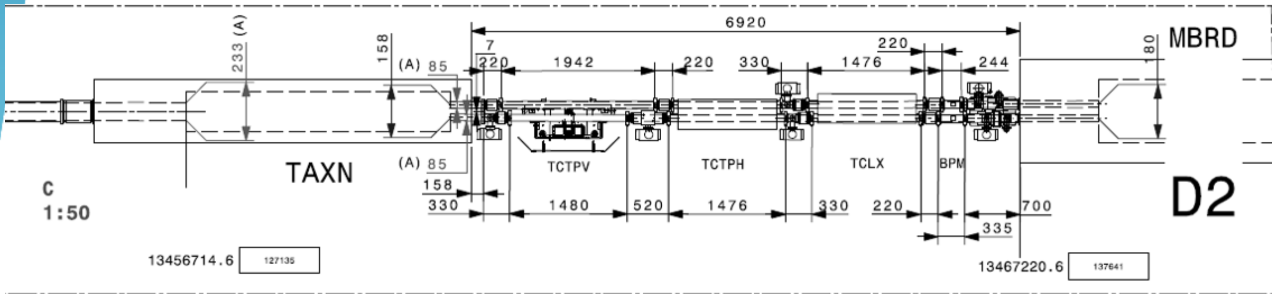
TAXS

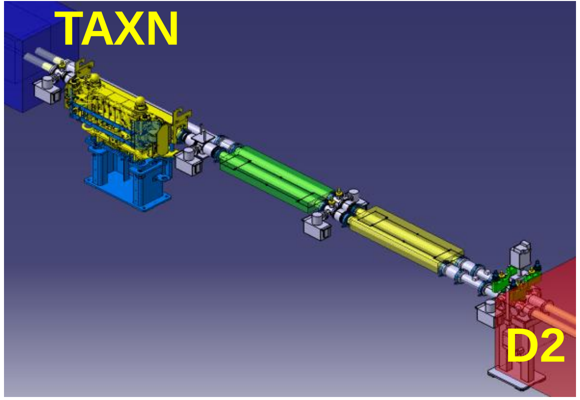
~ 16 m

J. Perez. Espinos, WP8

TAXN – D2 area

- Tertiary collimation to protect IT from incoming beams
- Longitudinal layout defined but without 5th axis for collimation (except TCTPV)



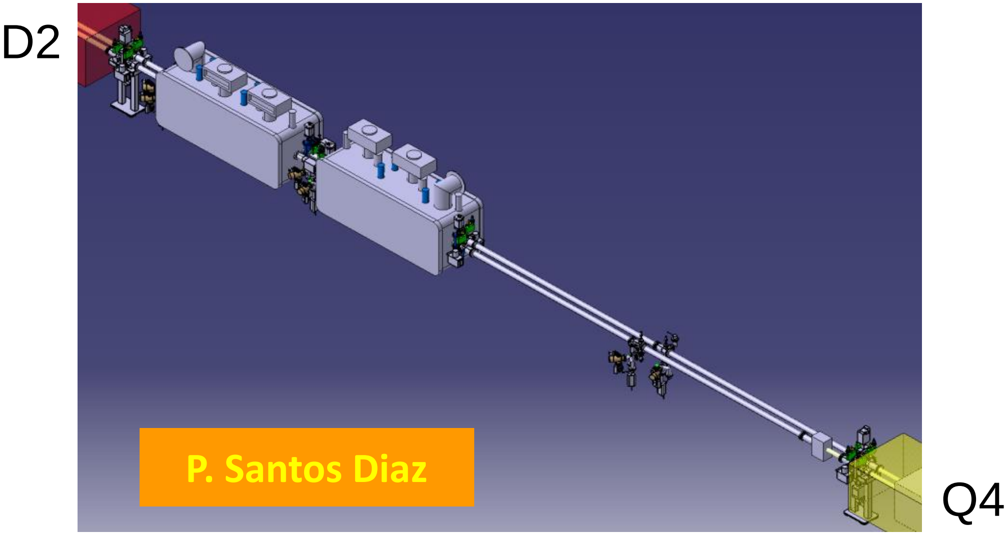


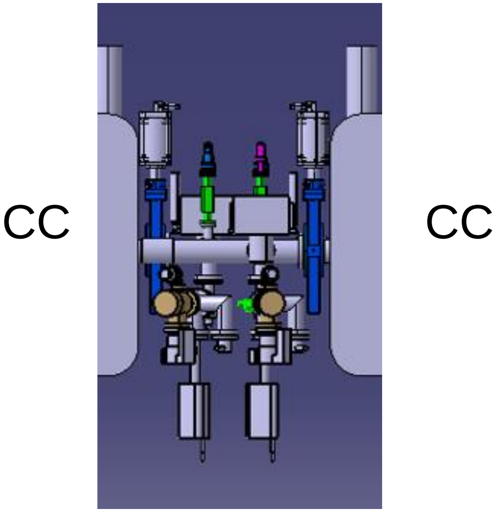
P. Santos Diaz

- New designs:
  - 2 beam in one vessel for TCL and TCTH (responsibility of the collimation project, WP5).
  - New bellows and RF transitions.
  - New chambers, supports etc.

- Base line (in collaboration with survey): minimise radiation to the personnel during intervention
  - Supports of vacuum equipment are aligned by survey during installation.
  - Vacuum components are exchangeable without re-alignment of the supports+ chamber system
  - Smoothing, when needed, during LS

Layout D2-Q4: crab cavities area





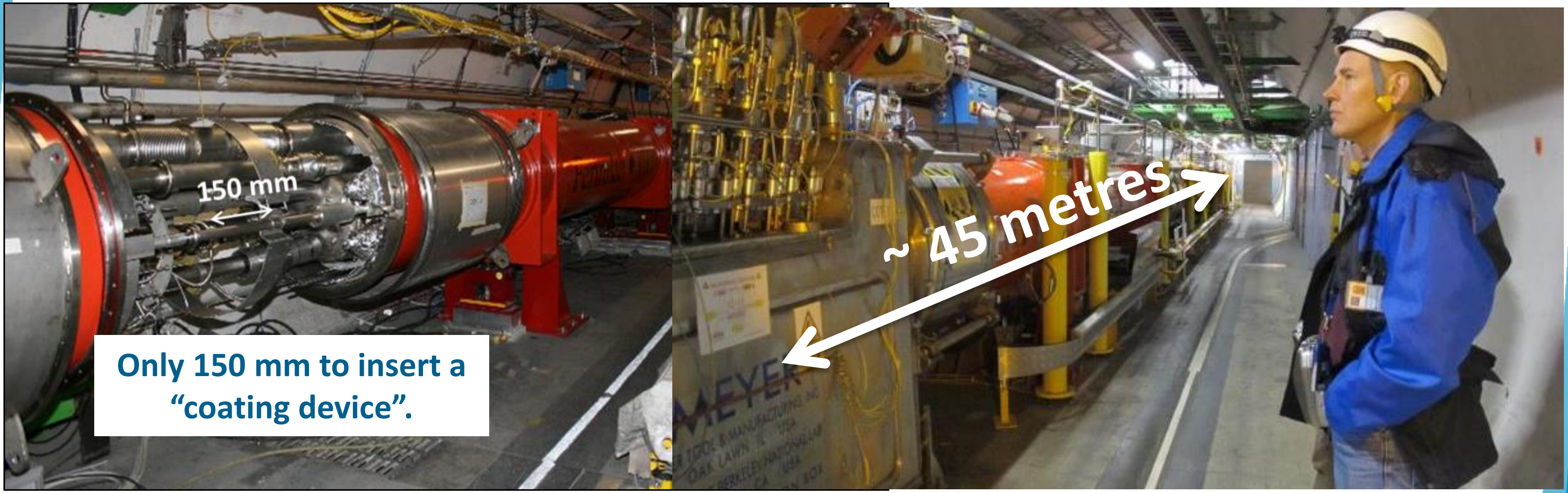
- Room temperature sectors (except CC modules): bakeable and NEG coated
- 2 sectorised CC modules: unbaked, operating at cryogenic temperature (2K)
- 3 types of sector valves assemblies (VAB)
- Non-crabbed vacuum chamber, operating at 2 K, needs to be designed with a beam screen type system

More details in WP4 parallel session

3. LS2

a-C coating: *In-Situ* Implementation

- Length to be *in-situ* coated: ~45 meters per “string” (Q1, Q2, Q3, DFBX & D1) of LSS2 and LSS8



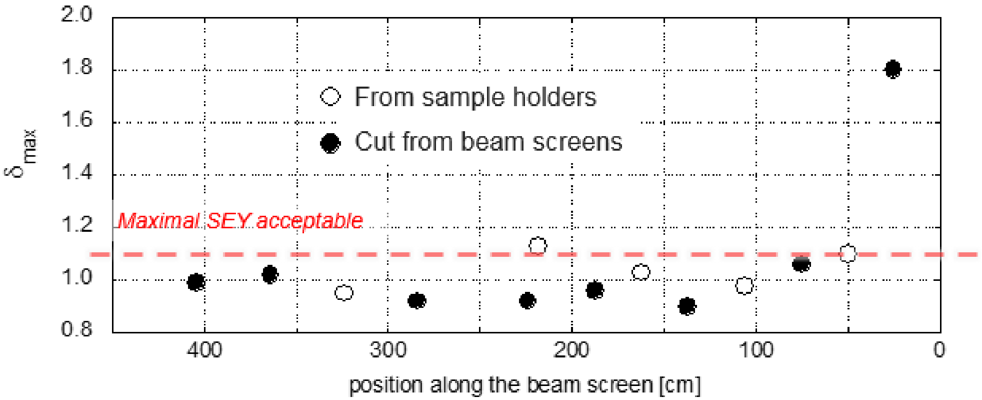
Only 150 mm to insert a “coating device”.

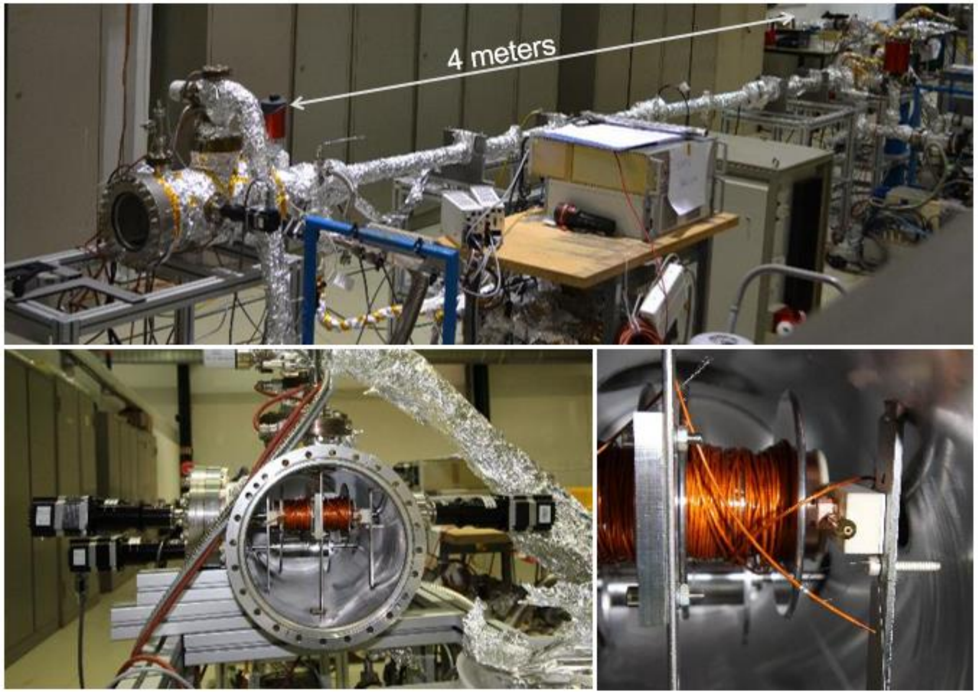
- Development of a “modular sputtering source” that can be inserted in a 150 mm slot and pulled by cables along D1 and the triplets

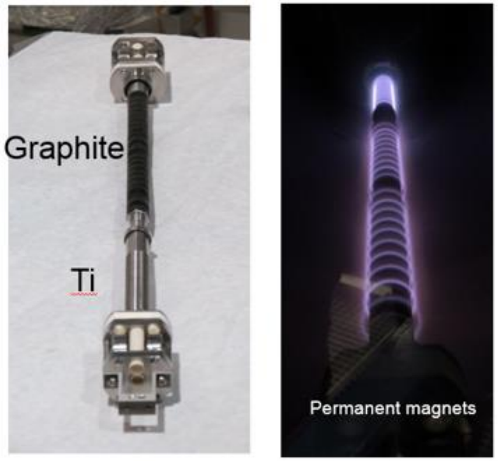
Status

- Magnetron sputtering of a graphite cathode using permanent magnets with Ti underlayer + molecular dragging (@ 1W/cm; p_{Ar}= 0.1 mbar).
- δ_{max}< 1.1 along 4 m!

More details by P. Costa Pinto in parallel session







P. Costa Pinto
P. Demolon

5. Summary

Summary

- The design of the HL-LHC vacuum system baseline is progressing very well.

- In the past year, many progresses have been done in all areas of the project:

  - Cold bores & beam screens:
    ➔design to be frozen by 2017 for a production to start by 2018

  - Baseline design for interconnects and conceptual design for cold to warm transitions.
    ➔ production to start by 2019

  - Performance evaluation of the a-C coating at cryogenic temperature.
    ➔ a performance evaluation in the LHC ring would be a real asset.

  - Definition vacuum layout.
    ➔ studies to be continued during 2017.

  - Production of *in-situ* a-C coating.
    ➔ on good track for implementation during LS2.

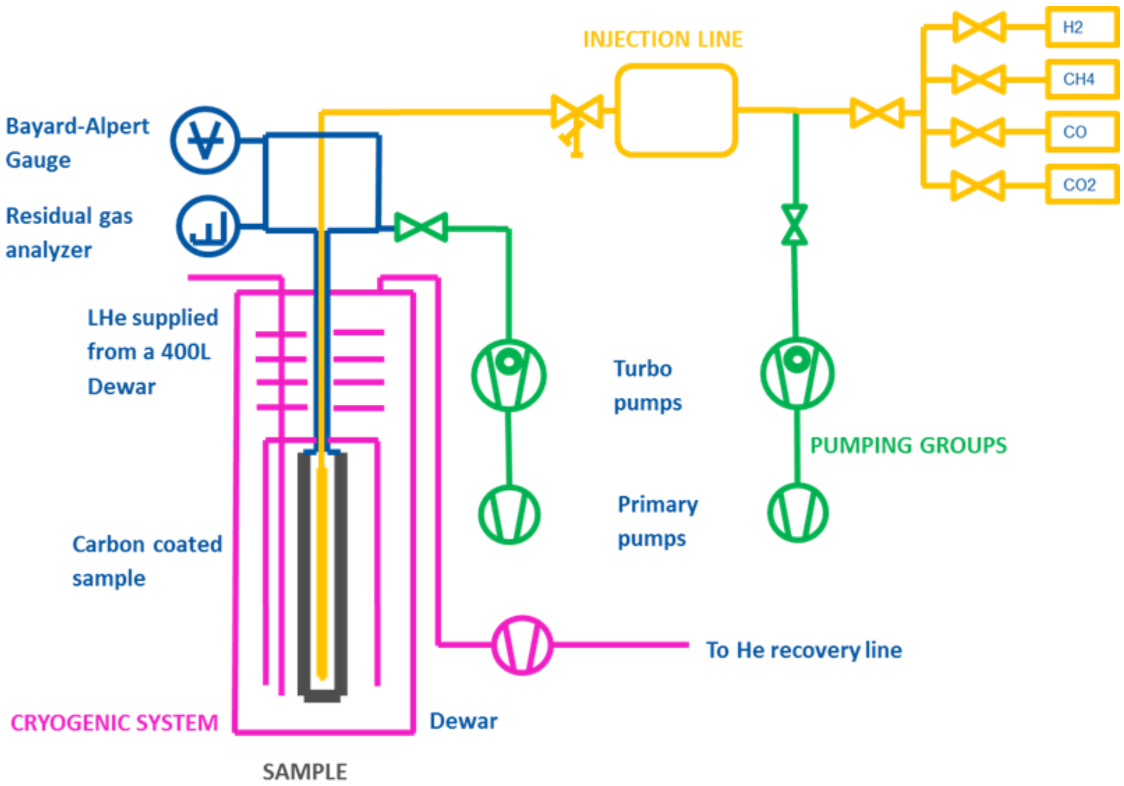
HiLumi
HL-LHC PROJECT

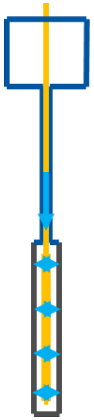
Thank you for your attention

CERN

Back-up slides

Adsorption Isotherm & Thermal Desorption Spectroscopy (TDS) Setup

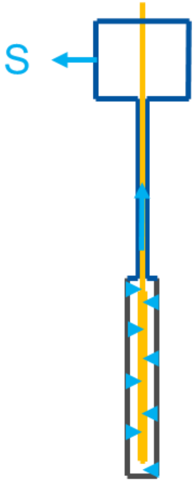




- **Adsorption isotherm**

T = constant

Gas injection



- **TDS**

T ↗

External pumping

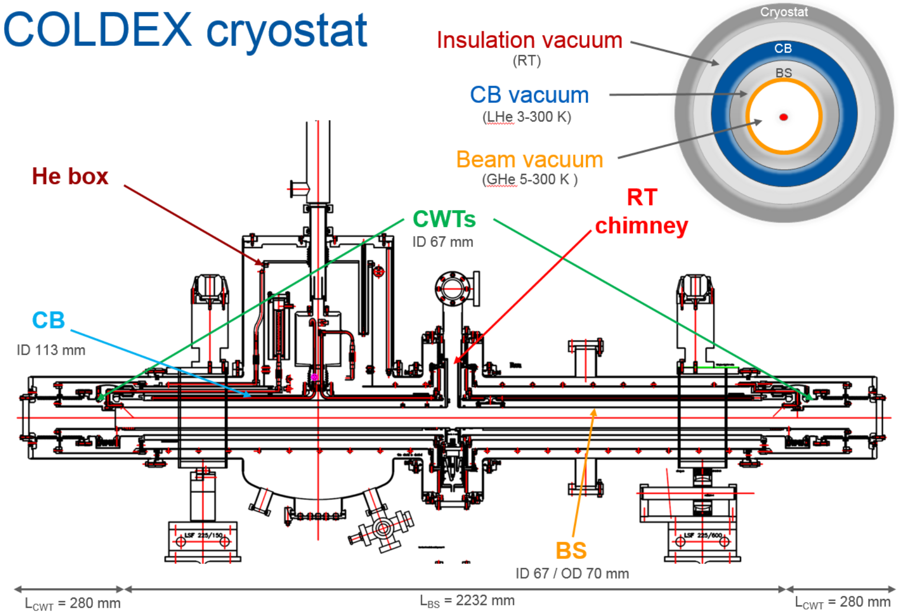
A-L. Lamure

a-C coating at Studies with COLDEX

- COLDEX Studies with SPS beams:
  - A 2 m long LHC type cryogenic beam vacuum system
  - A beam screen temperature from 10 to 80 K and a cold bore temperature from 3 to 4.5 K
- Measure of pressure, heat load and electron activity without and with gas condensates

R. Salemme

COLDEX cryostat



~2.2 m, ID 67 beam screen

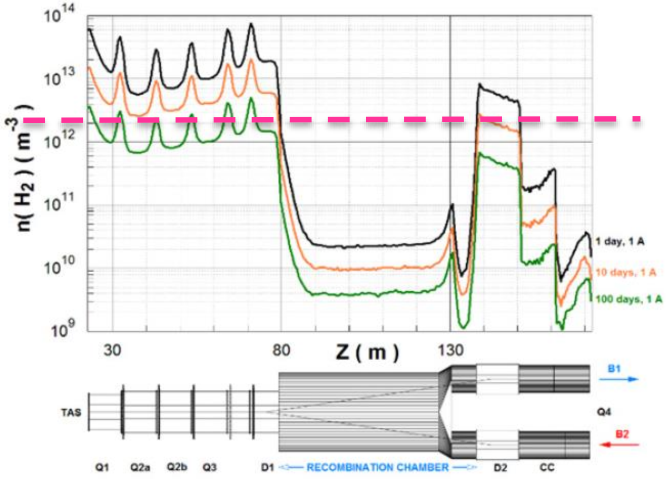
Internally coated with amorphous carbon

HL-LHC Baseline

- Applicable to new and upgraded components: LSS1 , LSS5 and part of LSS2, 4, 8
  ➔ arcs excluded !

- Room temperature vacuum system:
  ➔ same as LHC base line

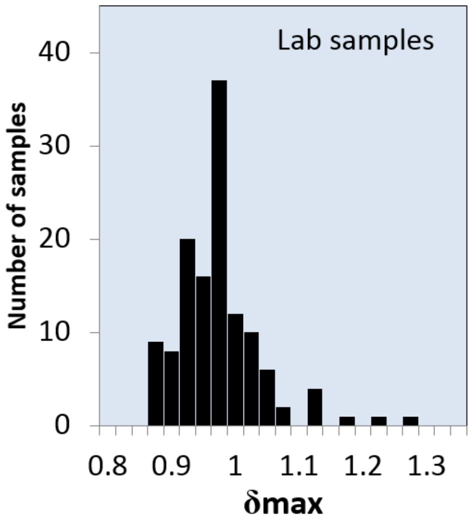
- Cryogenic temperature vacuum system:
  ➔ a-C coated beam screens when needed to mitigate multipacting in order to reduce:
    1) Background to the experiments
    2) Heat load on the beam screens *e.g.* IT in all LSSS !
  ➔ a-C performances must be validated at cryogenic temperature



10^{-10} mbar

Figure 3: H_2 density profiles for 24, 240, and 2400 A·h.

R. Kersevan. IPAC 2015

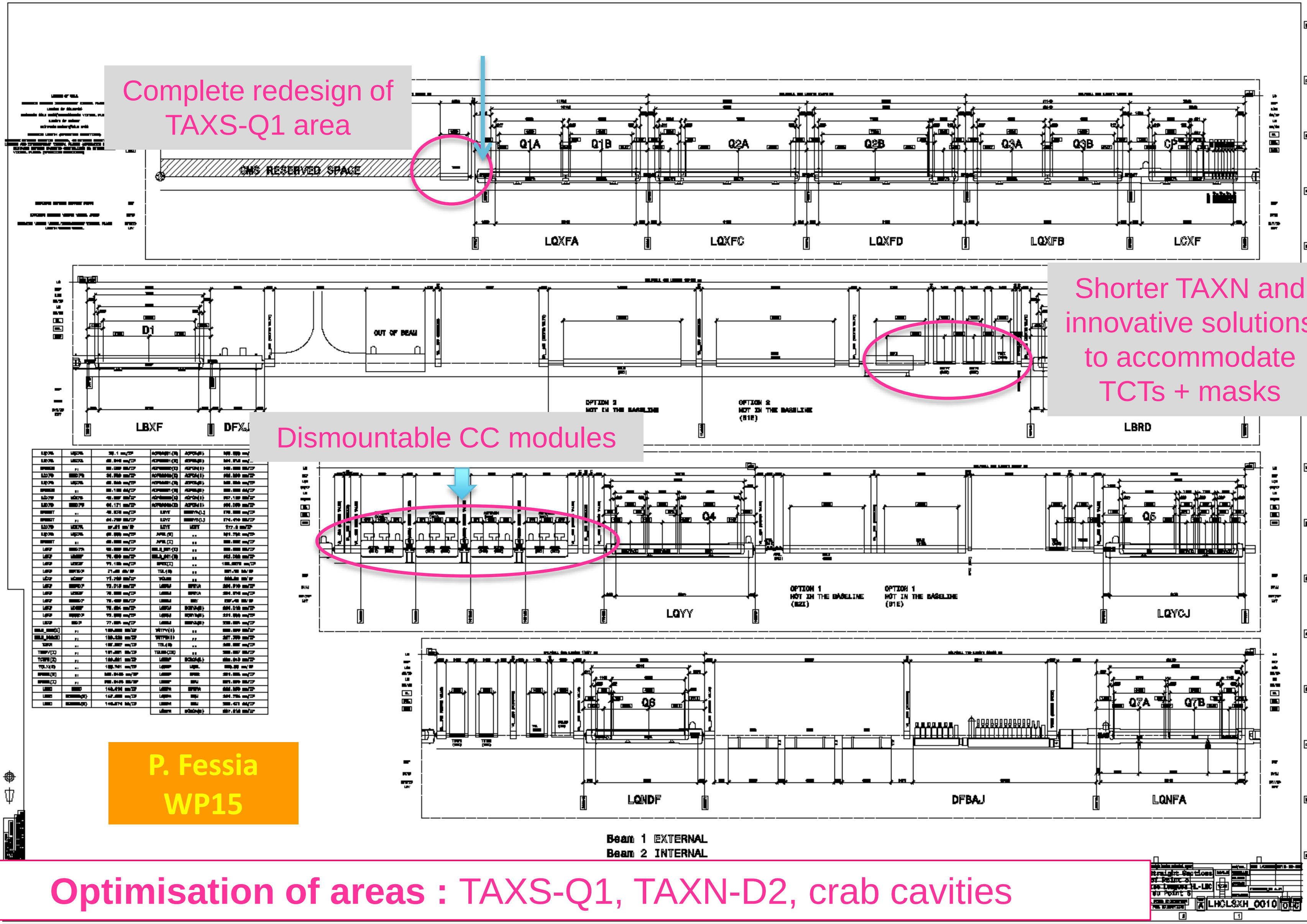


R. Kersevan

M. Taborelli

Current Layout LSS5R

- LHCLSXH__0010 and LHCLSXHT__0010
-



Complete redesign of TAXS-Q1 area

Shorter TAXN and innovative solutions to accommodate TCTs + masks

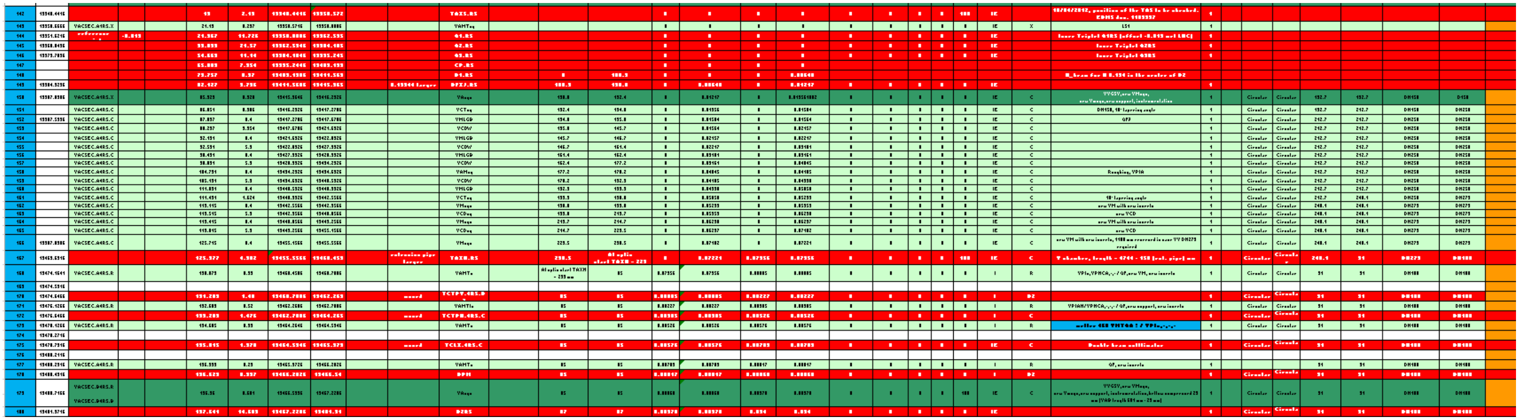
Dismountable CC modules

P. Fessia
WP15

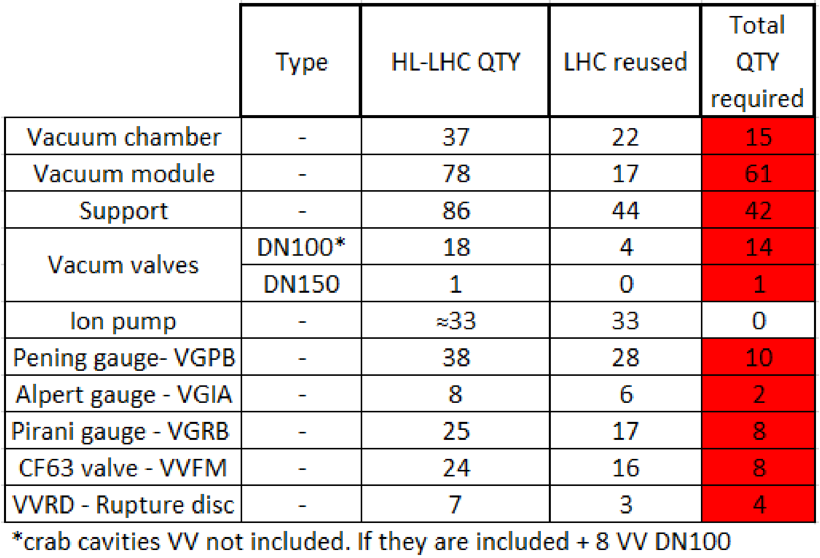
Optimisation of areas : TAXS-Q1, TAXN-D2, crab cavities

Excel Overall Vacuum Layout

- Hand made !
- No official HL-LHC data base yet



- Identification of new vacuum equipment needed: allowed to reduced WP12 CtC!



	Type	HL-LHC QTY	LHC reused	Total QTY required
Vacuum chamber	-	37	22	15
Vacuum module	-	78	17	61
Support	-	86	44	42
Vacum valves	DN100*	18	4	14
	DN150	1	0	1
Ion pump	-	≈33	33	0
Pening gauge- VGPB	-	38	28	10
Alpert gauge - VGIA	-	8	6	2
Pirani gauge - VGRB	-	25	17	8
CF63 valve - VVFM	-	24	16	8
VVRD - Rupture disc	-	7	3	4

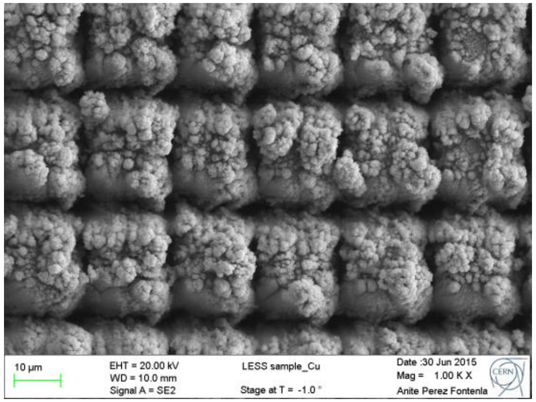
*crab cavities VV not included. If they are included + 8 VV DN100

P. Santos Diaz

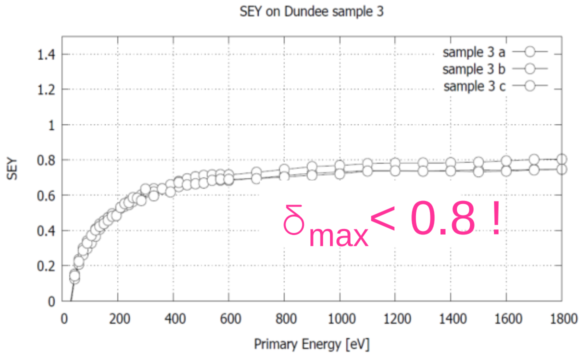
Laser Engineered Surface Structures: LESS

- A studied alternative to a-C coating. Principle: laser treatment of a tube at atmospheric pressure
- Collaboration with university of Dundee and ASTEC
- Challenges: validate vacuum performances by mid-2017:
  - Outgassing thermal and stimulated
  - Produce a tube and realise implementation on the field

- Test liners installed in SPS BA5 and in COLDEX (EYETS 2016-17)



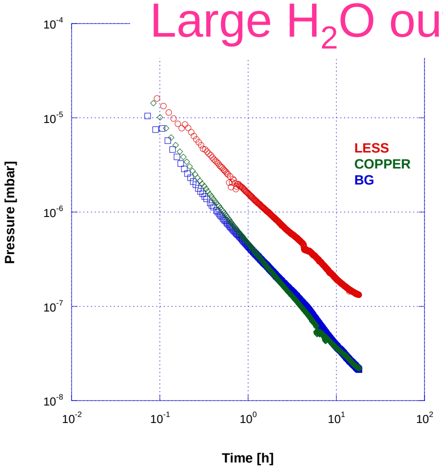
A. Abdolvand *et al.*,
Dundee University' s samples



$\delta_{max} < 0.8$!

CERN data

Large H_2O outgassing



CERN data

S. Calatroni