High Luminosity LHC

Vacuum System Design and Progress

V. Baglin (TE-VSC)

on behalf of WP12

5th Joint HiLumi LHC-LARP Annual Meeting

CERN – 26-30 October 2015

The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

Outline

1. LHC and HL-LHC baseline generalities
2. HL-LHC beam screens
3. Vacuum layout
4. Conclusion

1. LHC and HL-LHC Baseline Generalities

LHC Baseline

- Reduce to an acceptable level the background to the experiments:
  - Room temperature vacuum system:
    - Bakeable system (collimators, MKI, TDI etc.)
    - Vacuum activated TiZrV getter coated system
  - Cryogenic temperature vacuum system:
    - Unbaked by design
    - Perforated beam screens to provide pumping
    - Anti-multipacting solenoids when needed

➔ Low yields & pressure rise

➔ Rely on vacuum conditioning

Table 2: Summary of results from the activated test chamber

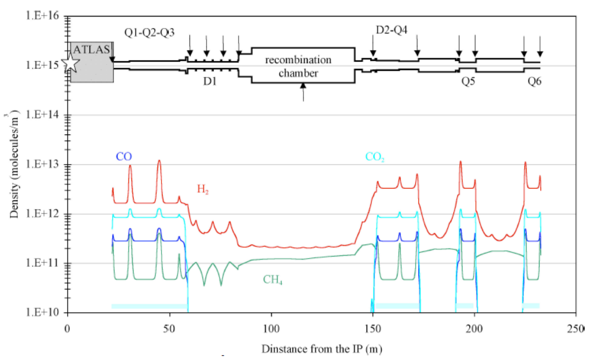
Gas	Sticking probability	Photodesorption yield (molecules/photon)
H_2	~0.007	$\sim 1.5 \cdot 10^{-5}$
CH_4	0	$2 \cdot 10^{-7}$
CO (28)	0.5	$<1 \cdot 10^{-5}$
C_xH_y(28)	0	$<3 \cdot 10^{-8}$
CO_2	0.5	$<2 \cdot 10^{-6}$

V. Anashin *et al.* EPAC 2002

Table 1 : Primary, recycling photodesorption yield measured at 10^{22} photons/m and cleaning rate

	H_2	CH_4	CO	CO_2
η	$2\ 10^{-4}$	$>6\ 10^{-6}$	$>3\ 10^{-5}$	$>2\ 10^{-5}$
$(\eta+\eta')/\sigma$	$2\ 10^{-2}$	$6\ 10^{-4}$	$3\ 10^{-3}$	$2\ 10^{-3}$
a	0.6	0.6	0.2	0.8

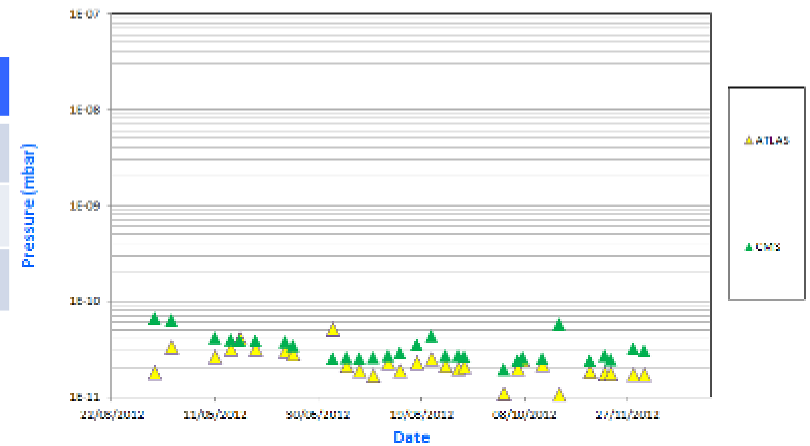
V. Baglin *et al.* EPAC 2002



A. Rossi, CERN LHC PR 783, 2004.

	H2_eq / m3	mbar
$<LSS_{1\ or\ 5}>$	~ $5\ 10^{12}$	10^{-10}
<ATLAS>	~ 10^{11}	10^{-11}
<CMS>	~ $5\ 10^{12}$	10^{-10}

2012: LHC Experiments Average Pressure with Beam (IP only)



LHC Baseline -2

- Reduce to an acceptable level the heat load on the cryogenic system:
  - ➔ Rely on beam conditioning: scrubbing

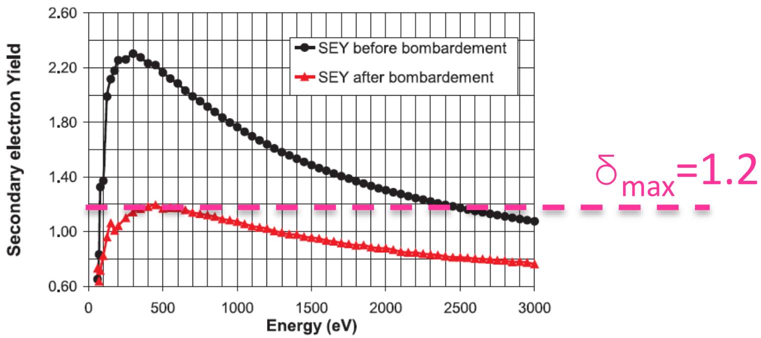
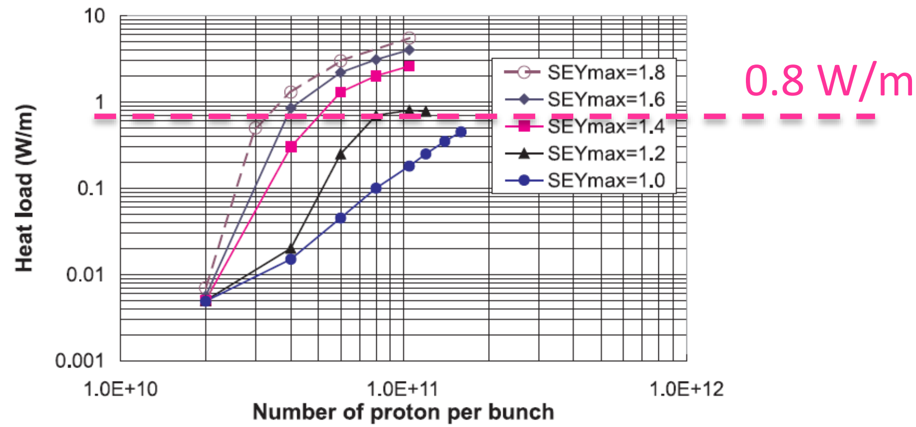
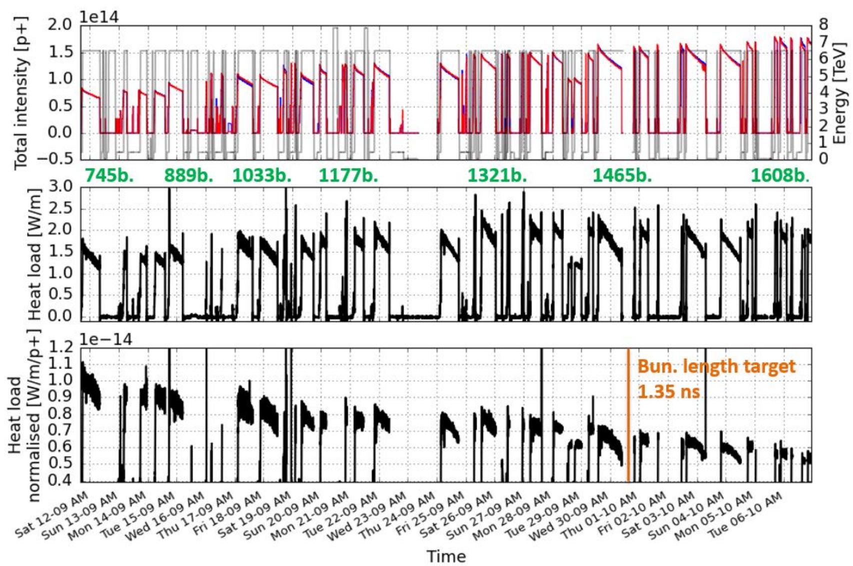


Figure 1: Variation of $\delta_{\rm SEY}$ as a function of the primary electron energy, for a sample of copper colaminated on stainless steel, before and after bombardment with 500 eV electrons, corresponding to a dose of 5×10^{-3} C/mm^2.



N. Hilleret *et al.*. PAC 1999



G. Iadarola
LMC, 7/10/15

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

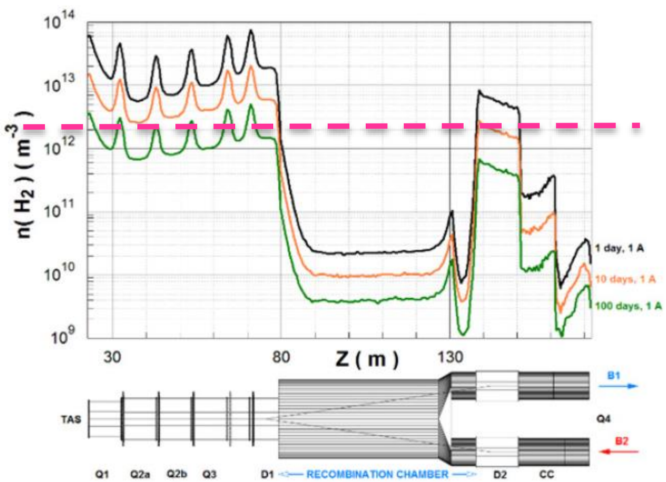
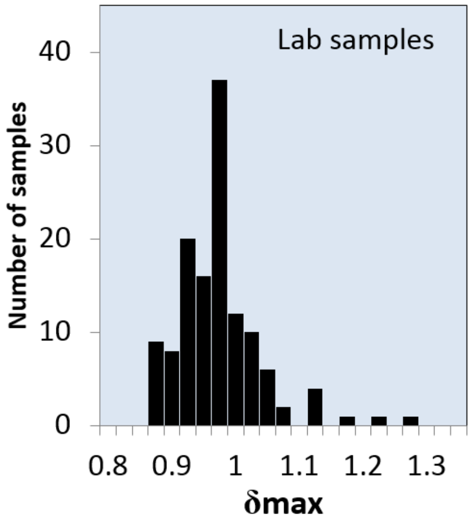


Figure 3: H_2 density profiles for 24, 240, and 2400 A·h.

R. Kersevan. IPAC 2015



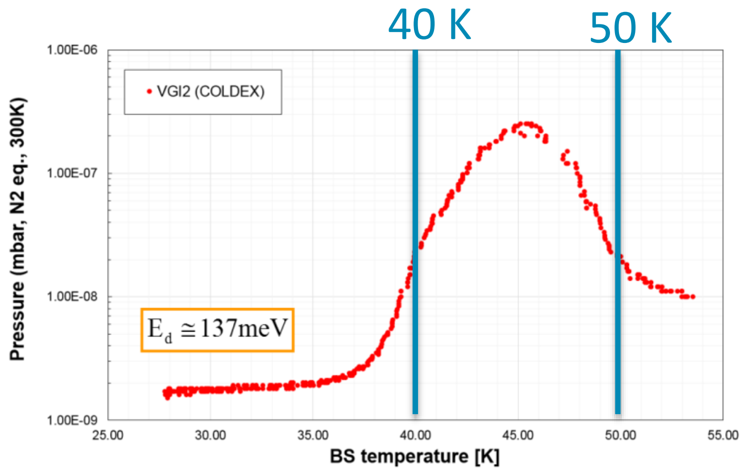
R. Kersevan

M. Taborelli

2. HL-LHC Beam Screens

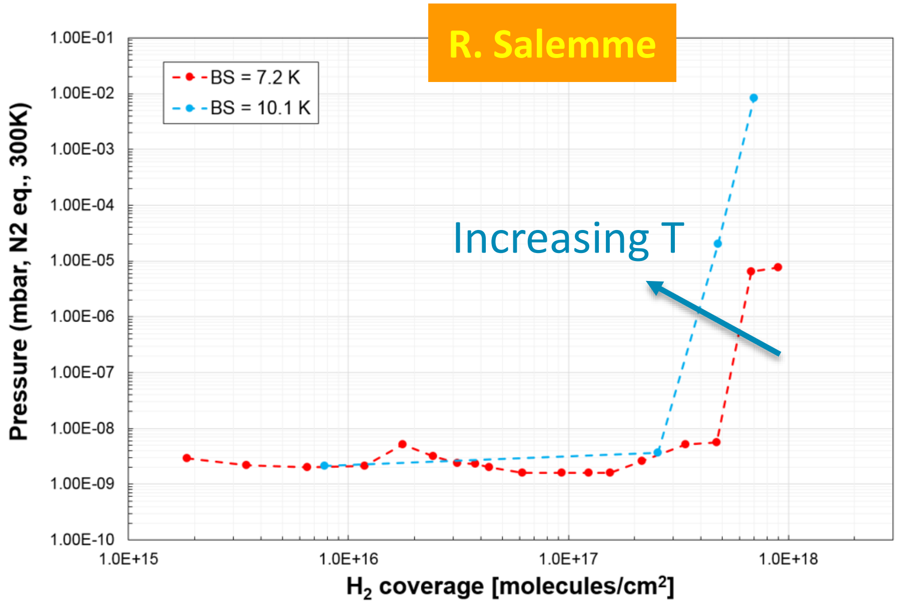
a-C coating at Cryogenic Temperature

- The COLDEX program (LSS4 of SPS) is in progress, and will continue in LSS4 after EYETS (thanks to HL-LHC and CERN managements decision) :



- Thermal desorption spectroscopy
- Physisorbed / condensed H_2 is released from 400 nm thick a-C coating in the 40-50 K temperature range !

➔ The temperature window 40-60 K is not appropriated
➔ TBC in the coming year(s) if 50–70 K is an alternative

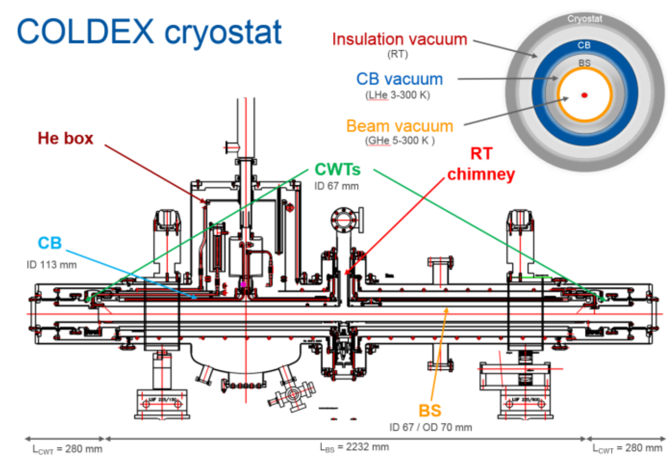


- H_2 adsorption isotherm
- a-C coating is a cryosorber !
- At 10 K:
  - capacity ~ 100 Cu
  - but 1/10 of LHC cryosorber

Characterisation with different gases and temperatures to be continued in 2016

a-C coating at Cryogenic Temperature

- 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



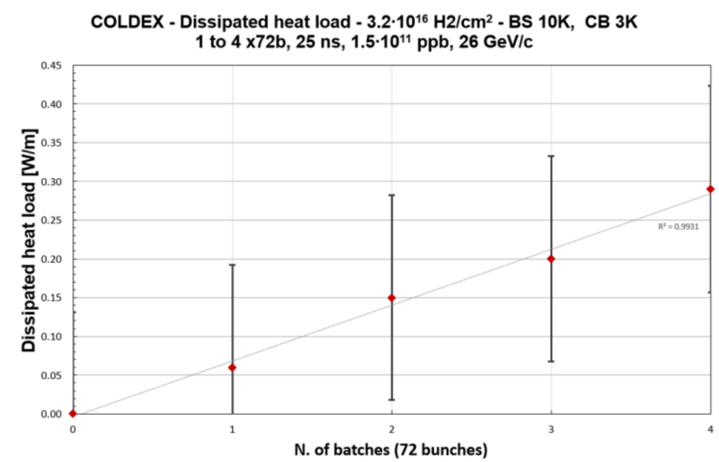
- In the 10 – 80 K range:
  - Pressure rise < 10^{-9} mbar, dominated by H_2
  - Heat load < 0.4 W/m
  - Electron cloud activity < 2 10^{-9} A/cm^2

  } **Inconsistency**

- H_2 condensation up to 3 10^{16} H_2/cm^2 do not strongly modify the behaviour

R. Salemme

- Commissioning of COLDEX is not finished:
  - Difficulties to keep the cryogenic settings
  - Helium leak in the insulation vacuum
  - Instruments to be repaired / calibrated / upgraded



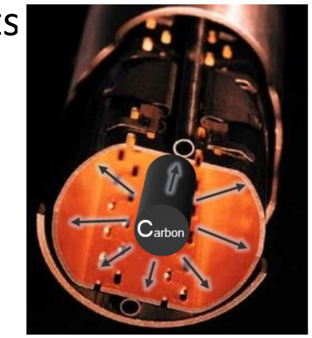
Many activities are planned during this YETS
Several MDs are needed to **consolidate** the results and to continue the **study**

In-situ a-C coating

- During LS2: *in-situ* a-C coating of D1+ IT in LSS2 and 8
- 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

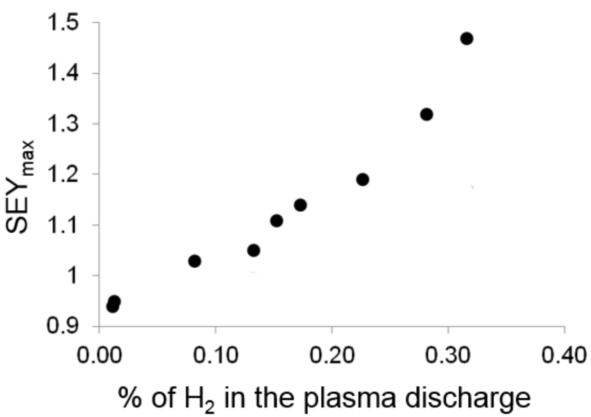
δ_{max} , unbaked	~ 1.2
δ_{max} , after baking at 100°C	~ 1.15

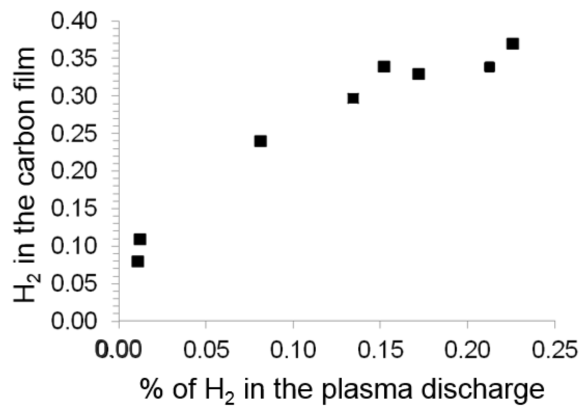
Results achieved in a 3 m long prototype using diode sputtering



P. Costa Pinto

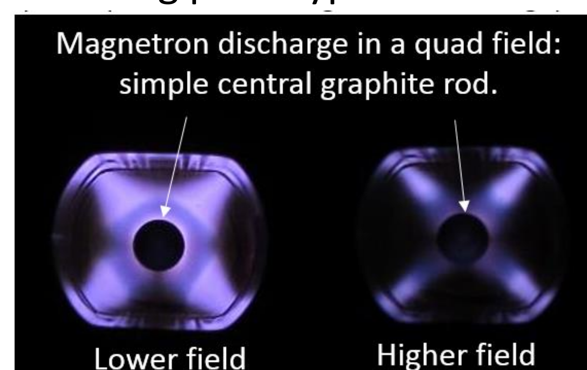
- The current challenge is to decrease the SEY in the presence of outgassing and H_2 contamination from the cod bore and beam screen





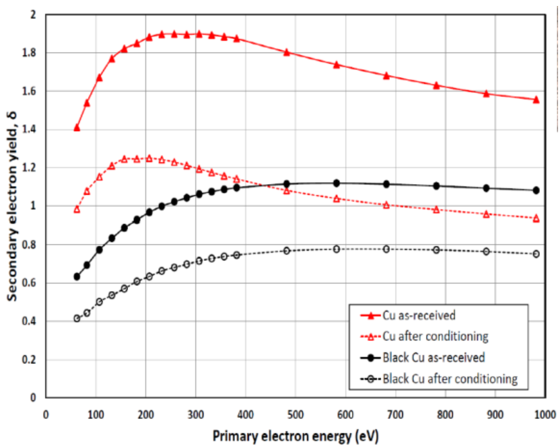
M. Taborelli
Chester Sept. 2015

- Increasing the sputtering rate with Hollow cathode with quadrupole field magnetron discharge to counteract the H_2 outgassing in a 10 m long prototype



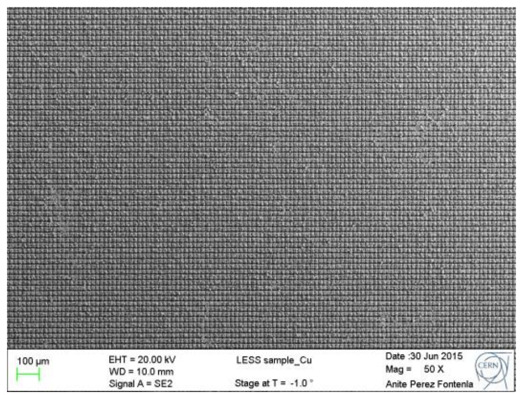
Laser Engineered Surface Structures: LESS

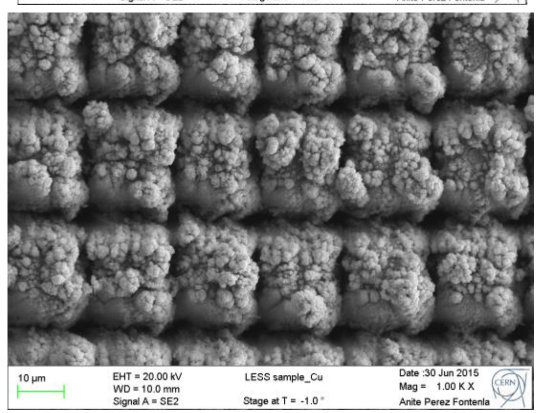
- A studied alternative to a-C coating. Principle: laser treatment of a tube at atmospheric pressure
- Collaboration with university of Dundee and ASTEC, patent deposition underway
- Challenges: validate vacuum performances by end 2016:
  - Outgassing thermal and stimulated
  - Produce a tube and realise implementation on the field
- Test liners to be installed in SPS BA5 and later in LHC VPS and COLDEX



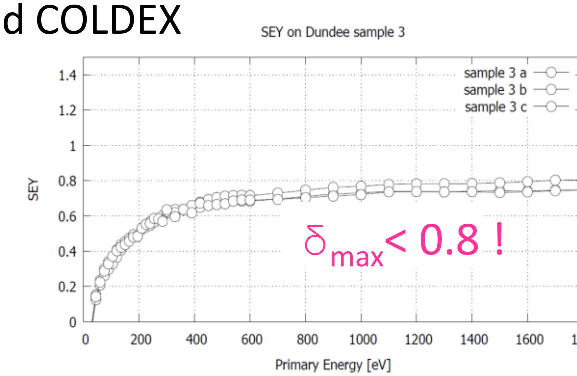
O. B. Malyshev *et al.*, Appl. Phys. Let. 105, 231605 (2014)

$\delta_{max} < 1.1$

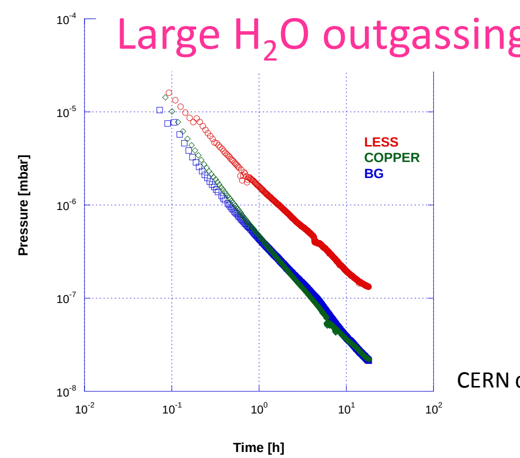




A. Abdolvand *et al.*, Dundee University' s samples



CERN data

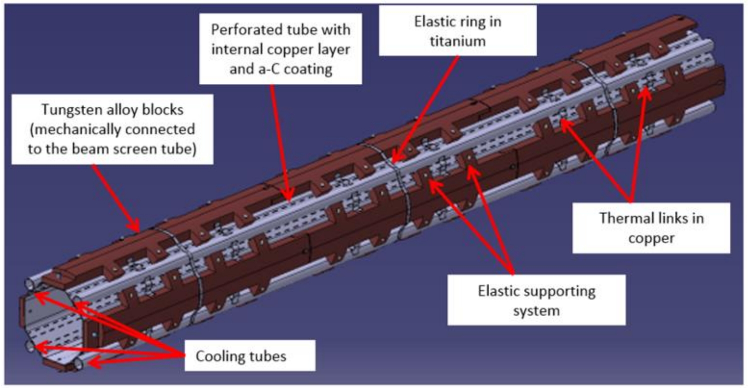


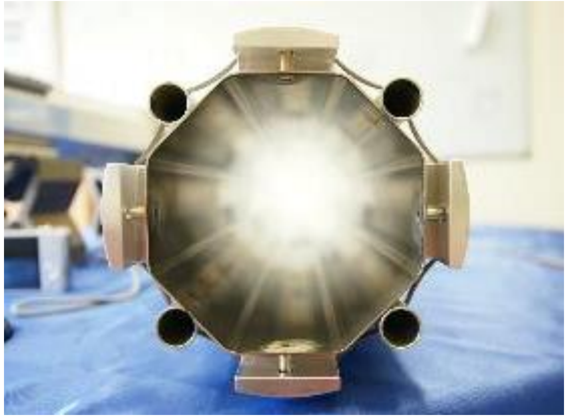
CERN data

S. Calatroni

Shielded Beam Screen

- Tungsten alloy (Inermet) to intercept the debris
- 100-200 nm thick a-C coated onto 80 μm copper co-laminated beam screen
- Operating temperature : 40 – 60 K (base line under review) with the cold bore at 1.9 K
- Length ~ 8-9 m, weight ~ 700-800 kg , transparency for pumping ~ 2 % (cannot be lower !)
- Mechanical prototyping underway





Element	Shape	W thickness [mm]
Q1	Octagonal	16
Q2-Q3-CP	Non regular octagonal	6
D1	Non regular octagonal	6
DFXJ	tbd	-

C. Garion

Deformable RF finger prototype

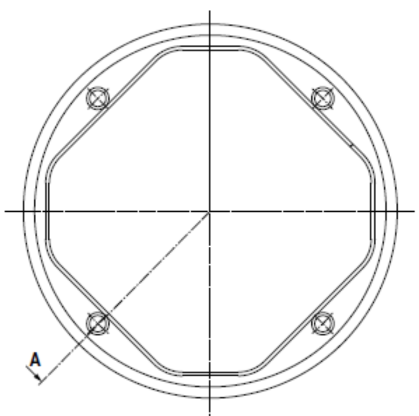
- Apertures & tolerances discussed by C. Garion in parallel session, 28/10.
- Next steps: Validate thermal and quench models against experimental tests

Non-shielded Beam Screens

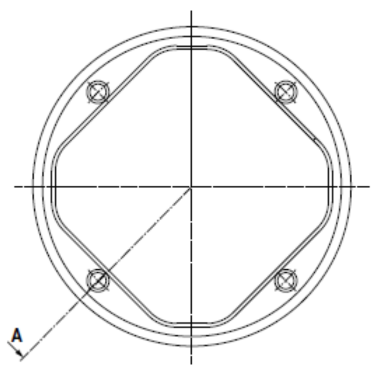
- Operating temperature : 5 – 20 K with the cold bore at 1.9 K
- a-C coated Cu co-laminated beam screen except Q5 & Q6
- Q5 is LHC Q4
- Q6 is LHC Q6

Element	Shape
D2	Non regular octagonal
Q4	Non regular octagonal
Q5	racetrack
Q6	racetrack

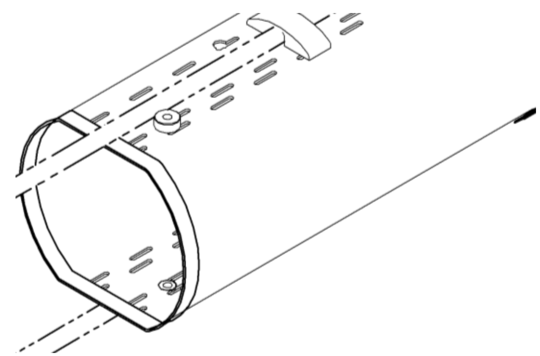
C. Garion



D2: octagonal shape,
CB ID: 94



Q4: octagonal shape,
CB ID: 79.8



Q5-6: racetrack shape,
CB ID: 63

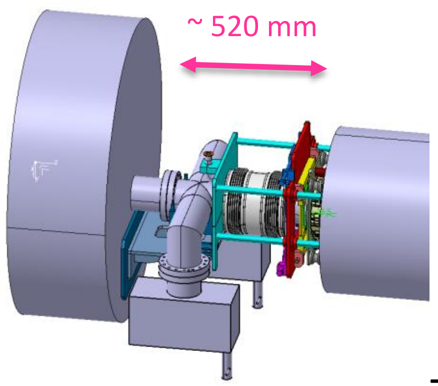
3. Vacuum Layout

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 during LS3 during TAS exchange, the impact on the experimental vacuum chamber beam pipe still needs to be defined
- TAS-Experiments & Q1-TAS areas studies are coordinated by WP8 (see I. Efthymiopoulos, 29/10)

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

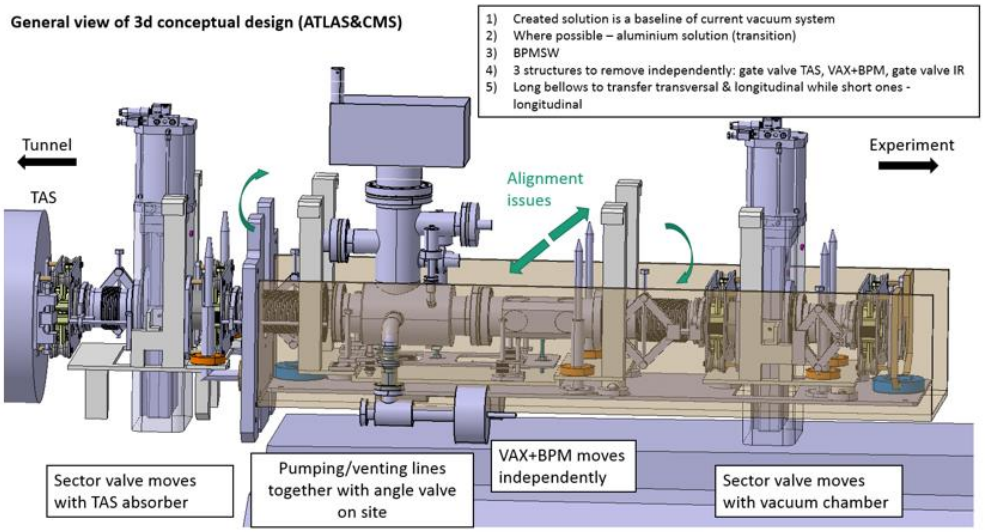
Sectorisation to decouple experiment's vacuum from machine vacuum



Q1

TAS

Courtesy L. Krzempek



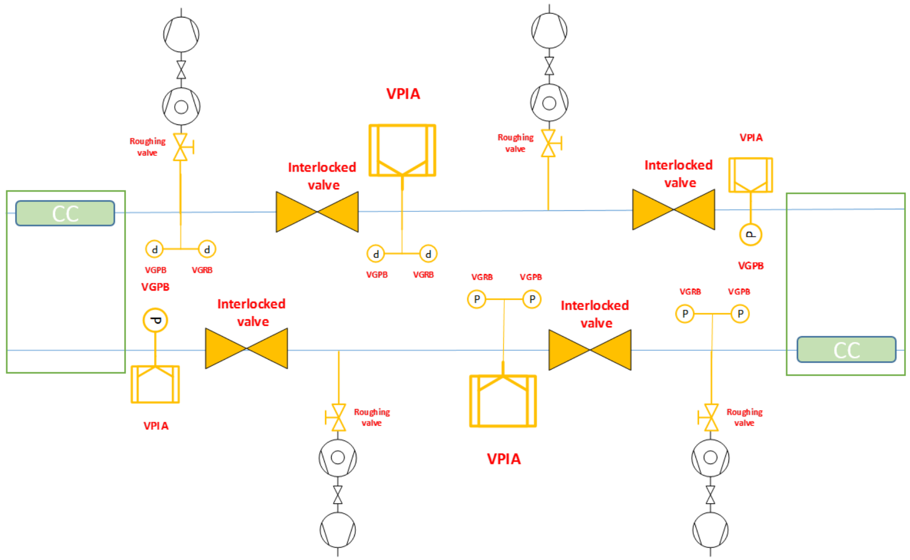
TAS

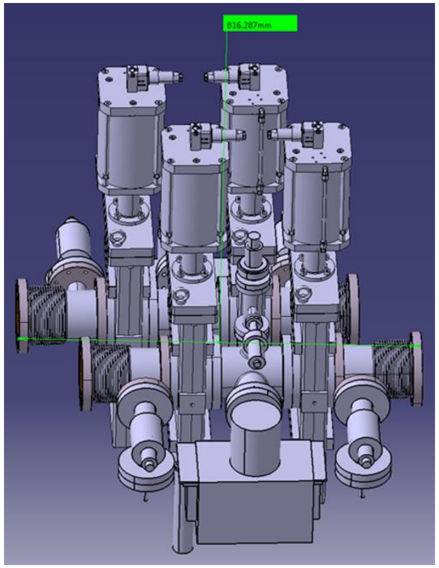
~ 16 m

J. Perez. Espinos

Crab cavity

- Progress in the definition of the inter-module: allocated length increased to 820 mm
- Integration of instrumentation from D2 to Q5 is underway





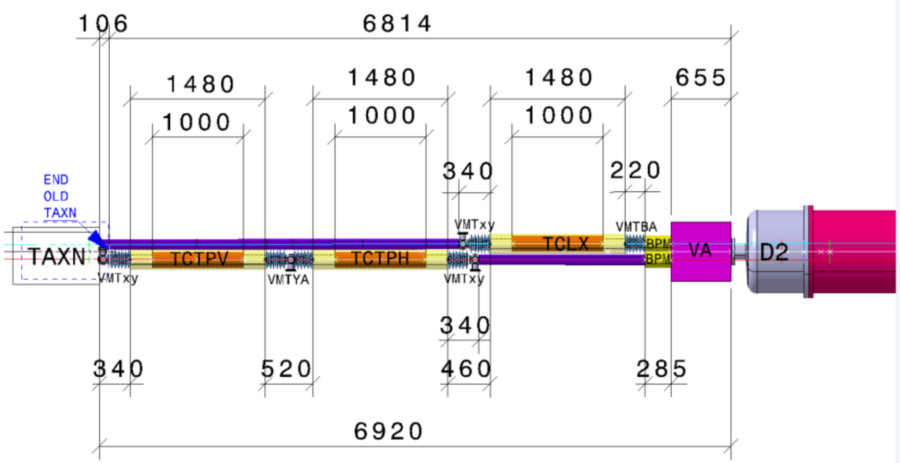
Courtesy R. F. Gomez

- Non-crabbed beam line, held at 2 K, must be designed to allow the integration of a beam screen – like vacuum system to comply with vacuum stability and pressure levels
- Impact of electron clouds on crab cavity's vacuum system to be studied

- SPS test:
  - The vacuum layout in LSS6 must be defined by end 2015 (parallel session 30/10)
  - The movable bypass system, without the CC, must be installed during EYETS 2016

TAXN – D2 area

- Longitudinal layout defined including 5th axis for collimation
- Potential issue with transverse dimensions: learn from LHC YETS 2015

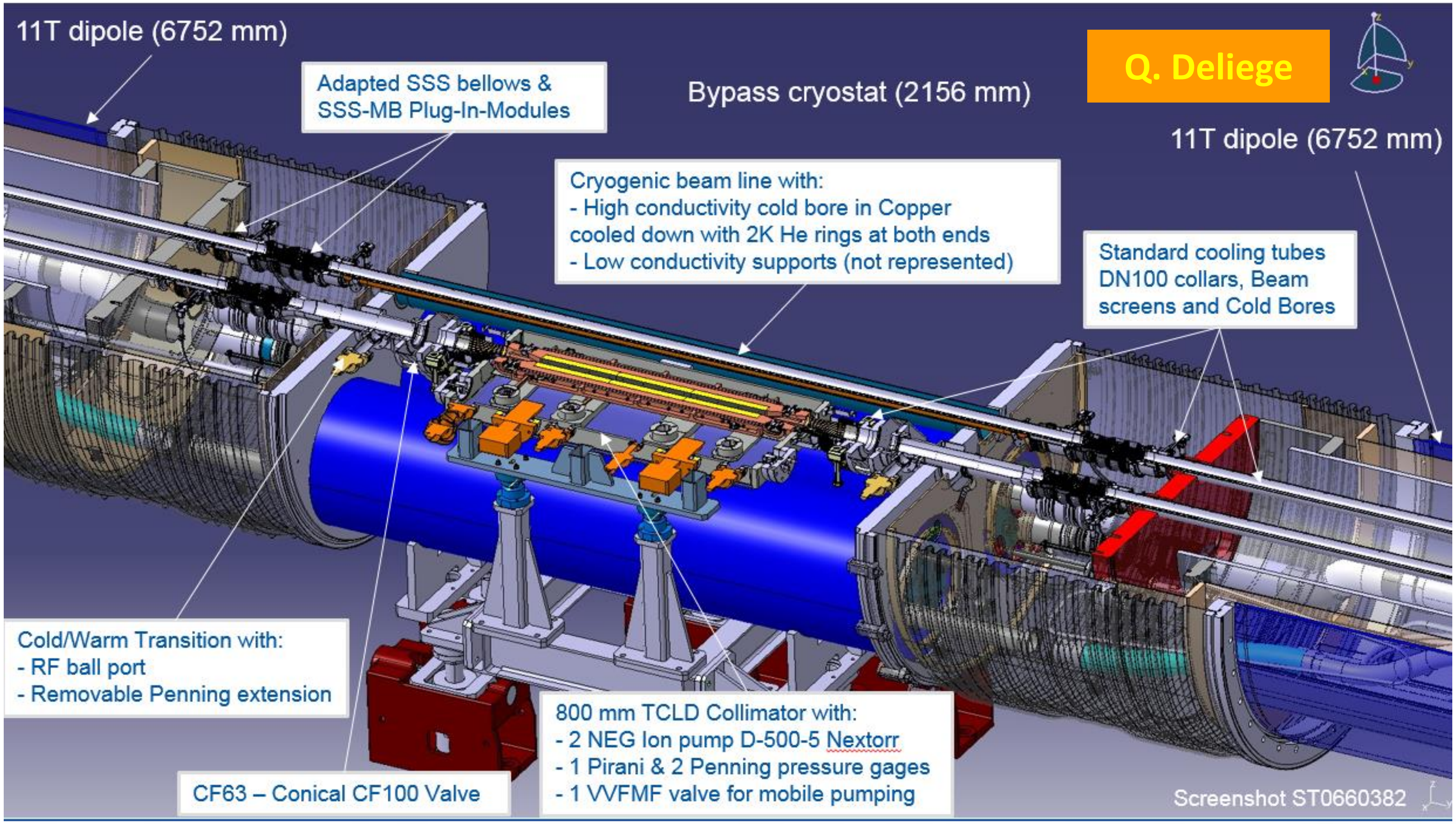


- Bakeout jacket of TCTPV removed to allow the installation of the beam pipe

➔ loss of vacuum performances

Collimation in DS

- Detailed definition of the vacuum system and bypass
  - Line 1: continuous arc beam line at cryogenic temperature
  - Line 2: cold to warm transition with a sectorised room temperature vacuum sector to allow the collimator to be *in-situ* baked.
- Prototyping for integration ongoing



HL-LHC activities during LS2 & LS3

- Presented during LS2 days (P. Alvarez Lopez, G. Bregliozzi)
  - In-situ a-C coating of IT in LSS2 and 8
  - Support to other WP

Equipment	Location
In-situ a-C coating	P2, P8
Works for other WPs[1]	P2, P4, P6, P7, P8

[1] EQUIPMENT REQUIRING VACUUM INTERVENTION

WP3	Q5	P6
WP5	By-pass collimator + TCLD	P2
WP5	Hollow e-lens	P4
WP5	TCSPM	P7
WP8	TAXN	P8
WP8	Mask for D2	
WP13	Fast wirescanners	P4
WP13	BGV	P4
WP14	TDIS	P2,P8
WP14	Mask for D1	P2, P8

P. Álvarez López
LS2 days

- Detailed list of activities during LS2 and LS3 is drafted

	LHC	LS1	HL-LHC		
	Vacuum Sectors	Vacuum Sectors	Vacuum Sectors	LS2: Length (m)	LS3: Length (m)
Cryogenic temperature	92	92	56	57	700
Baked Room temperature	185	146	141	837	2555
Unbaked Room temperature	6	2	6	400	500

* HL-LHC options are excluded

4. Conclusions

Conclusions

- The characterisation of the a-C coating at cryogenic temperature with COLDEX has started :
  - The tested coating release H_2 at ~ 45 K:

    ➔ a new temperature window 50-70 K must be studied
  - with SPS beams, there are no evidence of electron cloud induced heat load larger than 0.4 W/m and pressure rise larger than 10^{-9} mbar
  - must continue studies in 2016 and maybe 2017

- Development of *in-situ* a-C coating technology has started:
  - 3 m long prototypes have been coated
  - Current δ_{max} is believed to be limited by H2 outgassing

- Qualification of Laser Engineered Surface Structure to reduce the SEY has started

Conclusions

- Design, modelling and prototyping of the shielded beam screen / cold bore assembly is progressing:
    - Mechanical, thermal and quench tests are mandatory to validate the models

- The definition of the HL-LHC vacuum layout has progressed in many areas:
    - Q1-TAS and TAS-16 m
    - TAN-D2
    - D2-Crab-Cavities-Q4

Thank you for your attention

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Other activities

- The impact of the LHCb high luminosity is under study with WP8:
  - New layout upstream of Q1
  - TAXN to be integrated in front of D2

- The interfaces and specifications with HL-LHC options such as hollow e-lens, BBLR etc. needs to be defined

- Photon stimulated molecular desorption a-C coating is underway :
  - At room temperature with
    - ~ 4 keV critical energy SR at KEK
    - and ~ 50 eV critical energy SR at BINP.
  - Studies at cryogenic temperature are planned.