High Luminosity LHC

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.

LHC vacuum system overview
&
Outlook for HL-LHC

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Outline:

- ✓ LHC Vacuum system requirements
  - ▪ Cryogenic vacuum
    - Heat load, dynamic effects, BS temperature oscillations
  - ▪ Room temperature vacuum
    - Vacuum dynamic effects
- ✓ NEG Performances: “Feedback” from operation
- ✓ RP Dose considerations during LS1
- ✓ Conclusions & Outlook for HL-LHC

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LHC Vacuum System Requirements
Cryogenic System

Cold vacuum was dimensioned as a function of the beam-induced power

1. ***Synchrotron radiation***: Intercepted by the beam screen 5K-20K

2. ***Image current from the beam:*** Intercepted by the beam screen 5K-20K

3. ***Photoelectron and multipacting:*** Intercepted by the beam screen 5K-20K

4. ***Nuclear scattering:*** Intercepted by the cold bore at 1.9K

- Nuclear scattering allowance of ≈0.2W m^{-1} for the two beams.
- Additionally beam lifetime of ≈100 h
- Average gas density must satisfy the "lifetime limit" **$<1\cdot10^{15}$ H_2 molecules m^{-3} ≈ 10^{-8} mbar**

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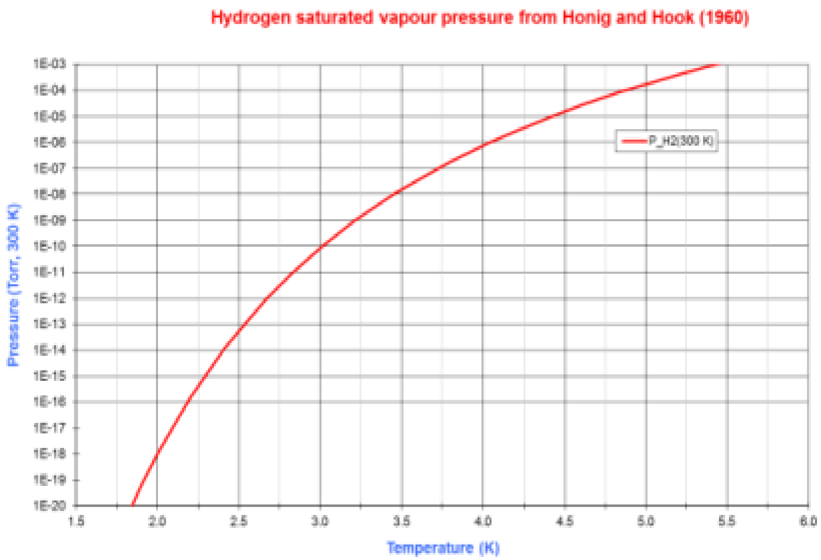
Pressure in the cryogenic LHC Vacuum



Without beam

Static pressure is in the UHV-XHV range

- In principle, inside a leak tight cryogenic vacuum system operating at 1.9 K, the pressure level is defined by the hydrogen vapour pressure (<< 10^{-19} Torr)

With circulating beam

Dynamic pressure is dominated by 3 sources :

- Ion stimulated molecular desorption
- SR stimulated molecular desorption
- Electron stimulated molecular desorption

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Ion Induced Desorption: Vacuum Stability

- Ion bombardment of the beam pipe walls desorbs gas: Feedback effect.
- When the beam current approach the **critical current**, the pressure increases to infinity.

- **Perforated beam screen:** Pumping speed for different gases

$$(\eta_i I)_{\text{crit}} = \frac{e}{\sigma} S_{\text{eff}}$$

	H_2	CH_4	CO	CO_2
$(\eta I)_{crit}$ [A]	1300	80	70	35

- Perforated beam screen offers **room for LHC upgrades** …..

Courtesy N. Kos CERN TE/VSC

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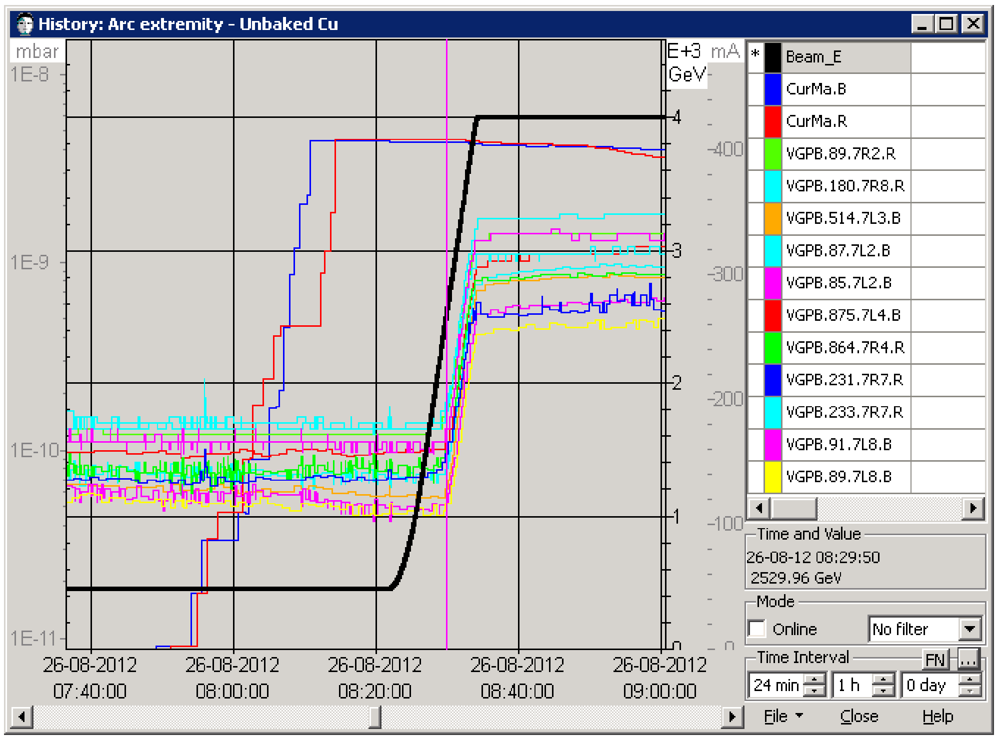
Synchrotron Radiation: Variation with E

- Example of fill 3005 – 26/8/2012 : unbaked Cu surface
- With ~ 400 mA stored current, the pressure increases at the arcs extremity during the energy ramp.
- A threshold is observed at ~ 2.5 TeV

- SR stimulate molecular desorption :

$$\eta = \frac{Number\ of\ desorbed\ molecules}{number\ of\ photons}$$



- The photodesorption yields scales with the beam energy like :

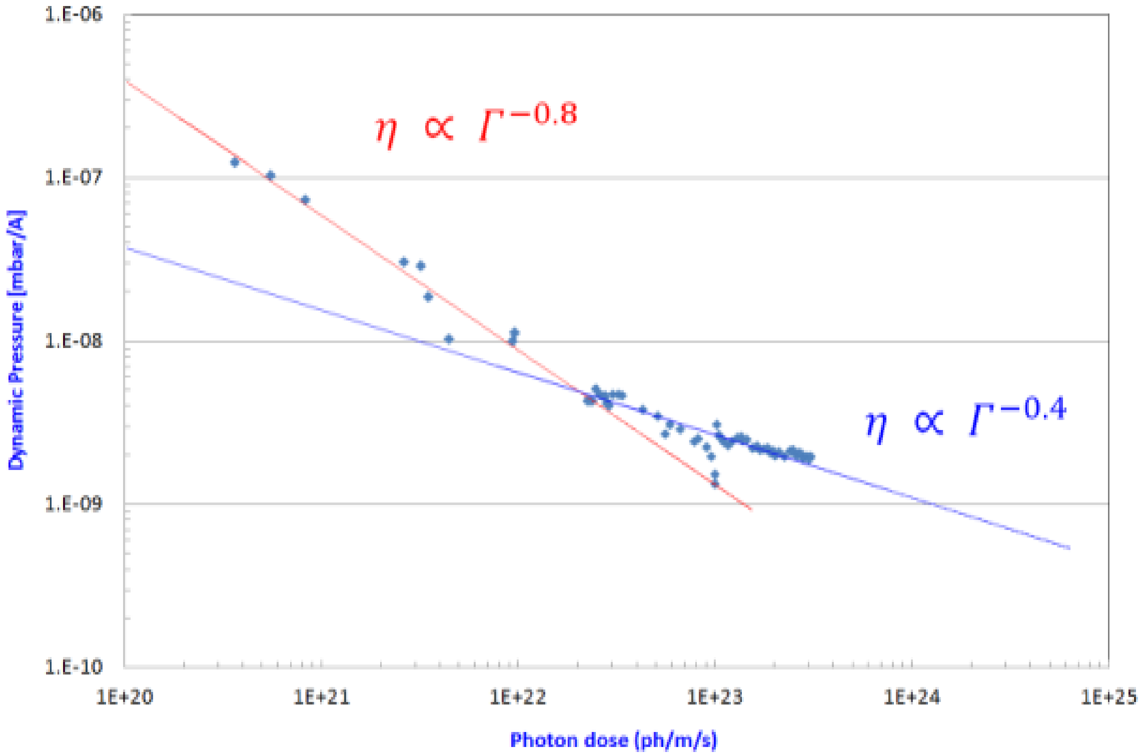
$$\eta \sim \frac{\Delta P}{I\ E} \sim E^{\alpha}$$

- **Expect a factor 50 increase when operating with 7 TeV beams**

- $P_{7TeV} \sim 5\ 10^{-8}$ mbar

Cleaning Effect Under SR

- Arc extremity's vacuum gauges : unbaked Cu and cryogenic beam screen
- Reduction by **2 orders of magnitude** since October 2010

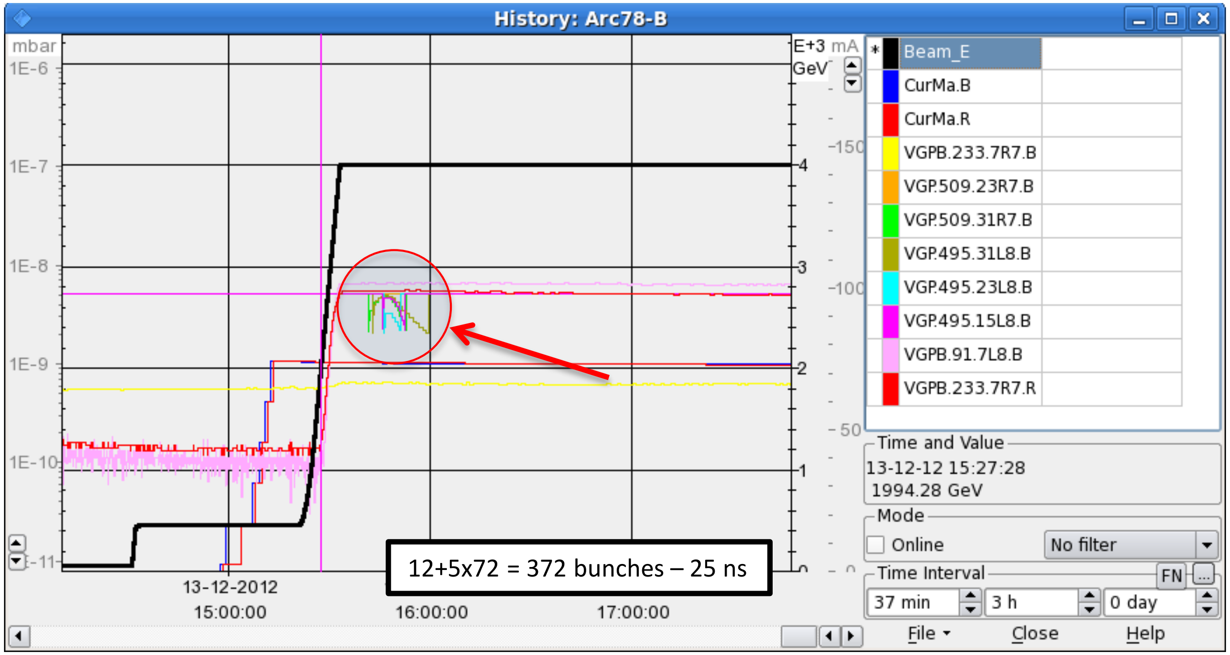


- 2 trends :
  - Room temperature
  - Cryogenic temperature

- Inside the arc, at 5-20 K, $\Delta P < 10^{-10}$ mbar (i.e. **below detection limit**)

- The photodesorption yield at **cryogenic temperature** is estimated to be $< 10^{-4}$ molecules/photon

Electron multipacting effects in the ARCs



- Limited pressure reading of the gauges in the ARC: P< $1{\cdot}10^{-9}$ mbar ≈ Under range
- No pressure rise does not means no electron cloud
- At this time, the cryogenic system observed a larger heat load due to photoelectrons induced multipacting: need scrubbing

LS1 Consolidation: Installation of vacuum gauges in Q12-13 for pressure reading down to $1{\cdot}10^{-11}$ mbar

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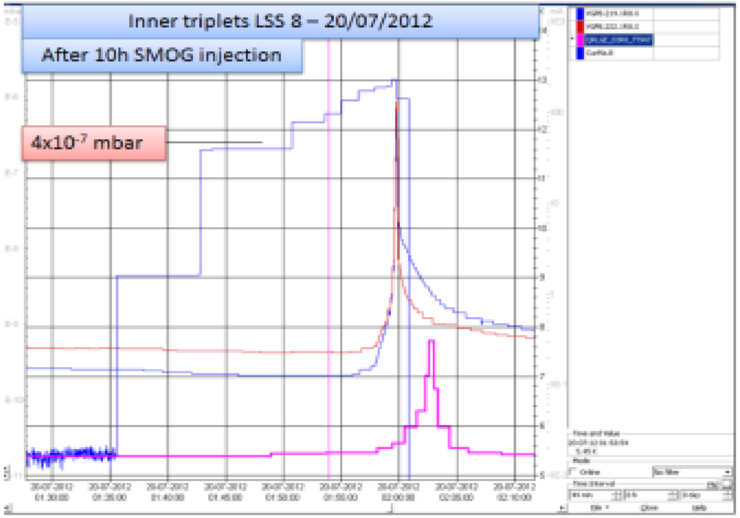
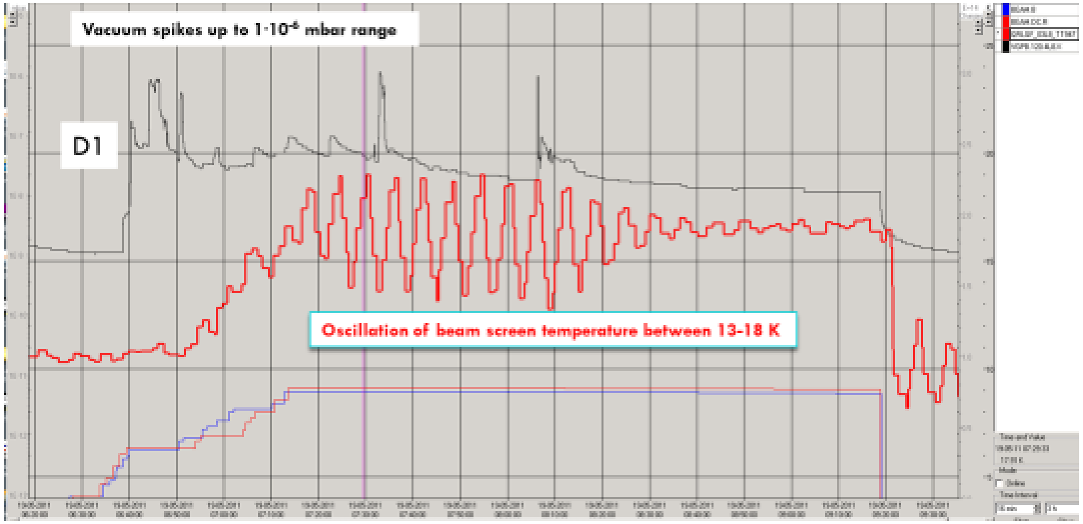
Dealing with beam screens : Example of ITs

During beam injection, the heat load onto the BS increases : as expected, gas transients appeared





G.Lanza – Evian 2012

1) Cool down sequence: CB 1st, BS 2nd
=> Keep **a bare surface on the BS**

2) Optimisation of ITs cooling loops to keep temperature increase below 25 K
=> avoid crossing adsorption isotherms

3) Flushing the gas from the BS towards the cold bore by appropriate warm up to > 90 K
=> when a lot of gas is accumulated (scrubbing run): **BS heaters updated and functional**

4) Evacuation of condensed gas during TS/Xmas-break while ITs cooling is stopped
=> definitive removal of gas from the vacuum system

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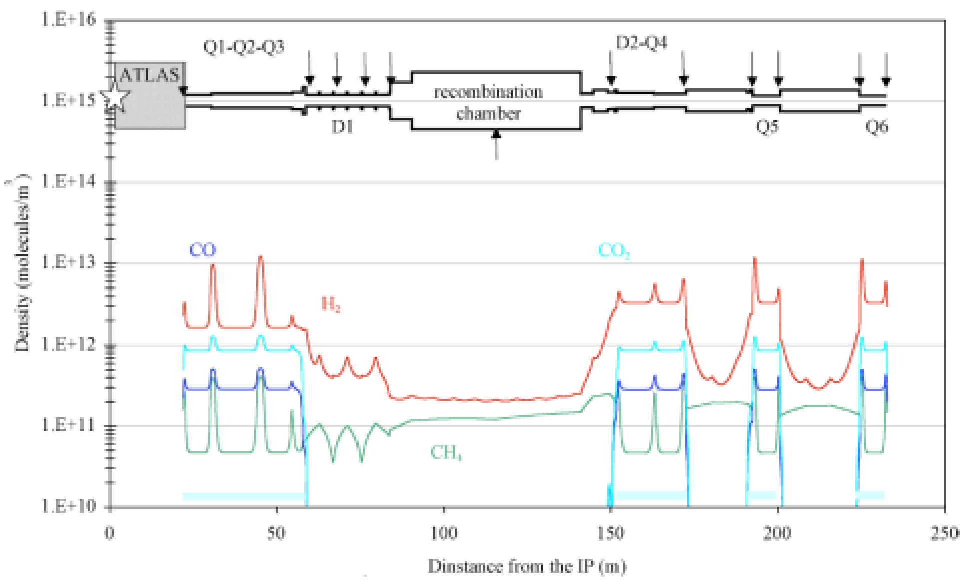
Room Temperature Vacuum System
Long Straight Sections

LSS design value: a challenge with circulating beams

- **Life time limit** due to nuclear scattering ~ **100 h**
  - n ~ 10^{15} H_2/m^3
  - $<P_{arc}>$ < **10^{-8} mbar H_2 equivalent**
  - ~ 80 mW/m heat load in the cold mass due to proton scattering
- **Minimise background** to the LHC experiments



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

A. Rossi, CERN LHC PR 674, 2003.
A. Rossi, CERN LHC PR 783, 2004.

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LSS Ion Induced Desorption: Vacuum Stability

1. The current at which a pressure run-away occurs is directly proportional to the ion induced desorption yield for a given vacuum system

2. An *in-situ* bake-out significantly reduced the ion induced desorption yields:
   - The **most critical gases** are **CH_4**, **CO** and **CO_2** due to the combined relatively large desorption yield and inferior molecular conductance.

   - For a given vacuum chambers diameter the **distance between lumped pumps** may be increased.

ID [mm]	Lmax for CH_4 stability [m]	Lmax for CO and CH_4 stability [m]	Lmax for CO_2, CO and CH_4 stability [m]
80	93	15.7	15

In the LHC:

- **Fixed distance for Ion Pumps ≈ 28 m - room for LHC upgrades but…**
- **Relaying in the NEG pumping speed for CO and CO_2**

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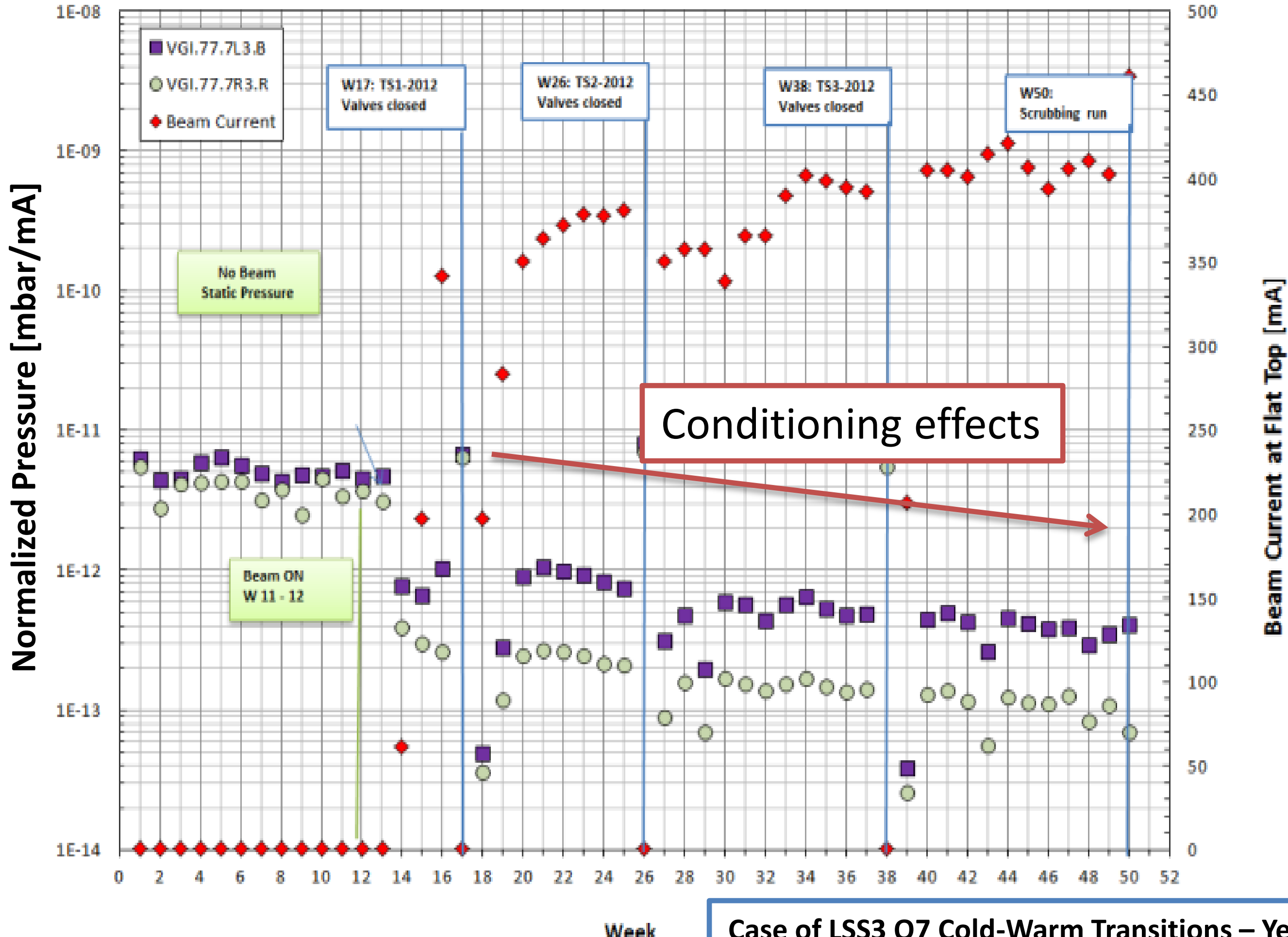
Electron multipacting in the uncoated area of the LSS

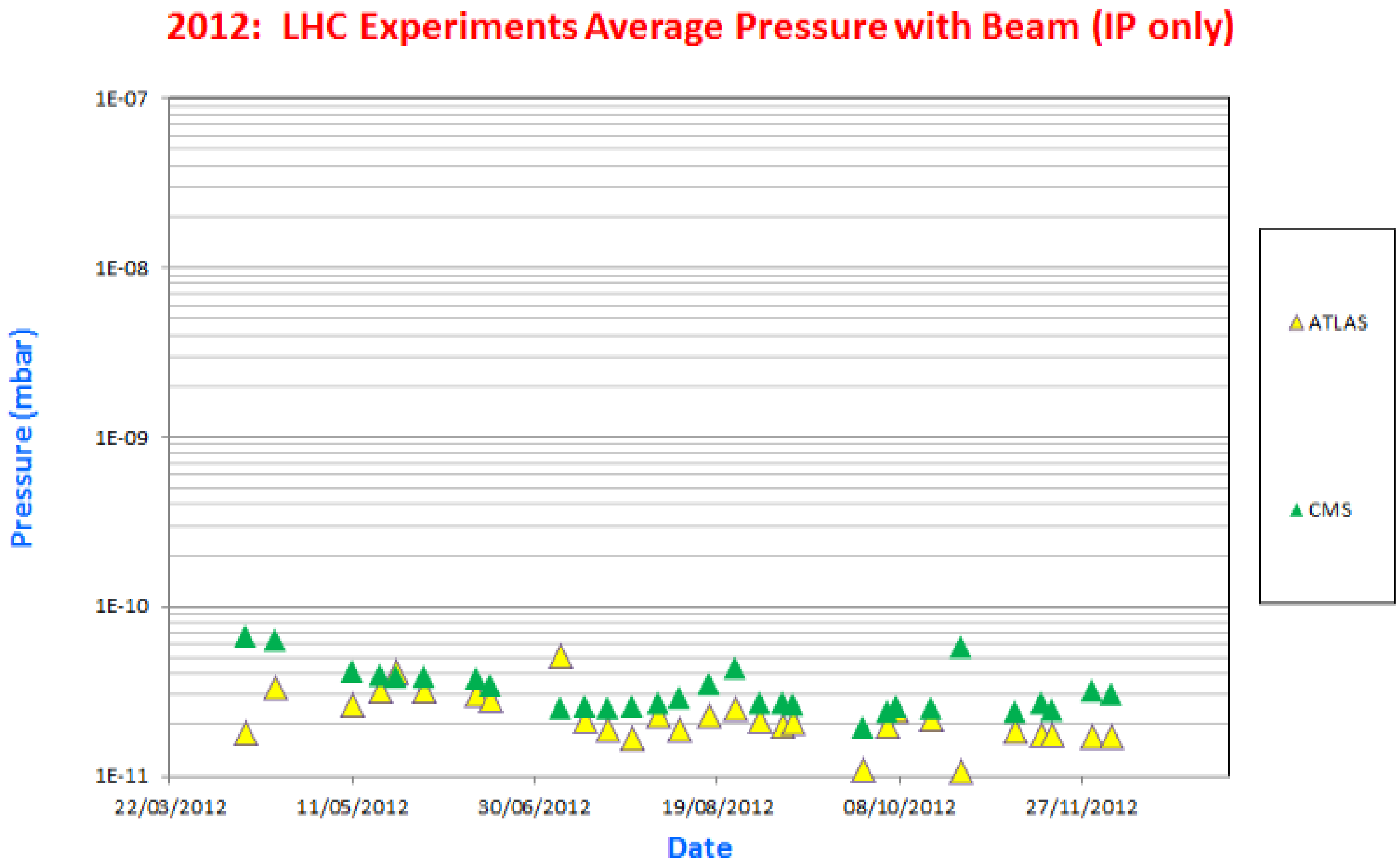
- Constant conditioning over the year on all the cold-warm transition
- <$P_{LHC\ LSS}$> ~ $5{\cdot}10^{-11}$-$5{\cdot}10^{-10}$ mbar function of the effective pumping speed at the vacuum gauge location



Case of LSS3 Q7 Cold-Warm Transitions – Year 2012

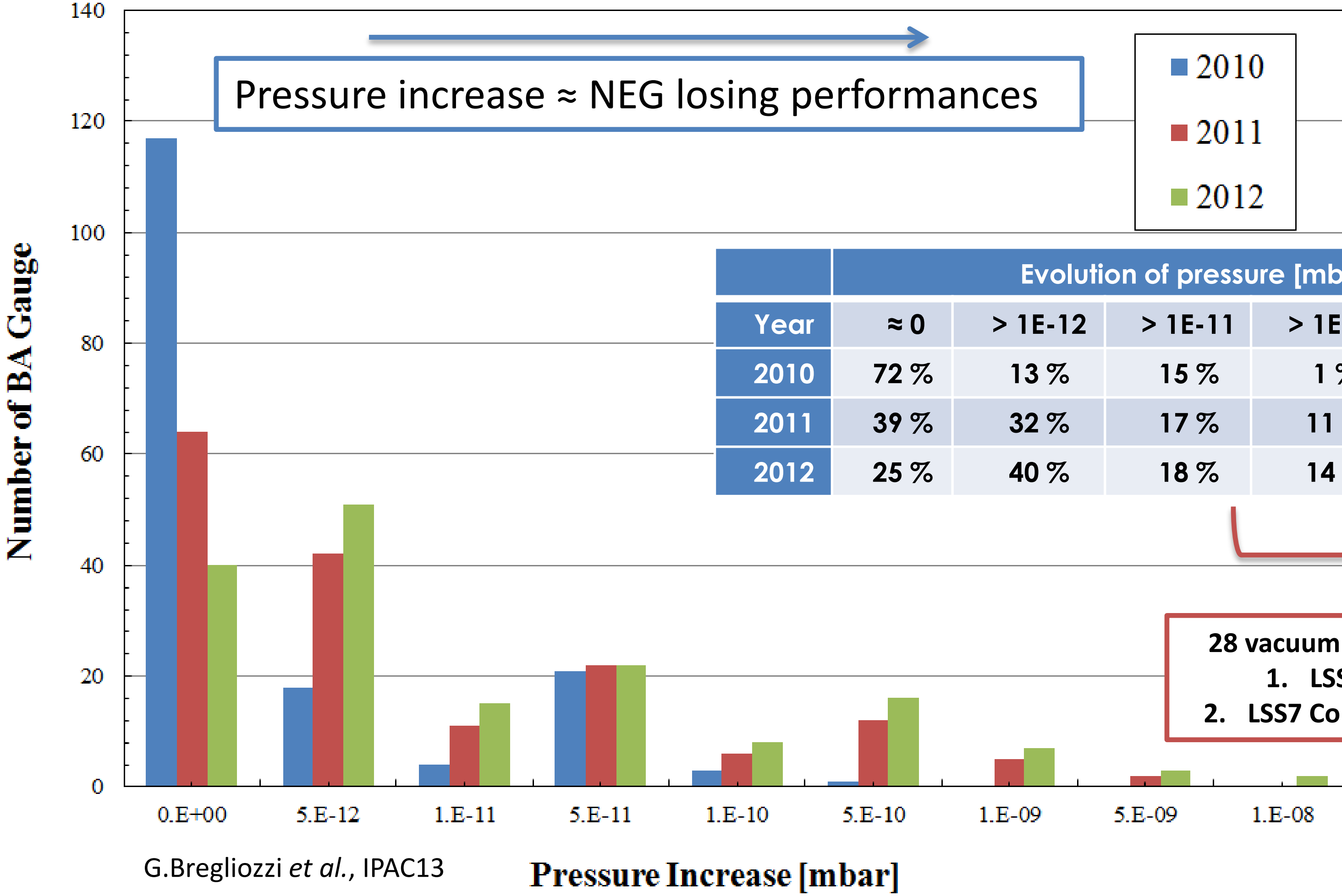
Electron multipacting in the LHC experiments NEG coating everywhere as a baseline

- Almost constant pressure during the year
- $\langle P_{\text{LHC Experiments}} \rangle \approx 3 \cdot 10^{-11}$ mbar



NEG Coating preservation in the LHC
LS2 & LS3 Outlook

Consequences from LHC operation
NEG Performances



	Evolution of pressure [mbar]				
Year	≈ 0	> 1E-12	> 1E-11	> 1E-10	> 1E-9
2010	72 %	13 %	15 %	1 %	0 %
2011	39 %	32 %	17 %	11 %	1 %
2012	25 %	40 %	18 %	14 %	3 %

28 vacuum sectors mainly in:
1. **LSS4 RF Heating**
2. **LSS7 Collimator Degassing**

G.Bregliozzi *et al.*, IPAC13

LSS NEG Performances Preservation Vacuum requirements for LS2 & LS3

Materials that will be installed in the LHC vacuum system at room temperature shall:

a) Qualified regarding their outgassing: **$< 10^{-12}$ mbar·l/s·cm^2**

b) The total outgassing flux of each devices should not exceed **≈ $1 \cdot 10^{-7}$ mbar·l/s**

c) The gas composition must be dominated by H_2 and no contaminants should be detected after bake-out of the device

d) All trapped volumes shall be avoided as well as contact between large surfaces

Any deviation from the total admissible outgassing flux or from the operating temperature imply an **additional pumping speed** to ensure the required gas density profile and the **vacuum stability and preserve the NEG performance on a long run**

a) In case of air internal leak on a vacuum components the maximum allowed leak rate $< 5 \cdot 10^{-9}$ mbar l s^{-1} - **NEW**

b) All surfaces “facing” the beam must have a low SEY - **NEW**

c) In case dumping materials like ferrite inserted on a new equipment a dedicated cooling system must be foresee - **NEW**

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RP Outlook: LS1 Activities

The LS1 is the "Splice consolidation shutdown"

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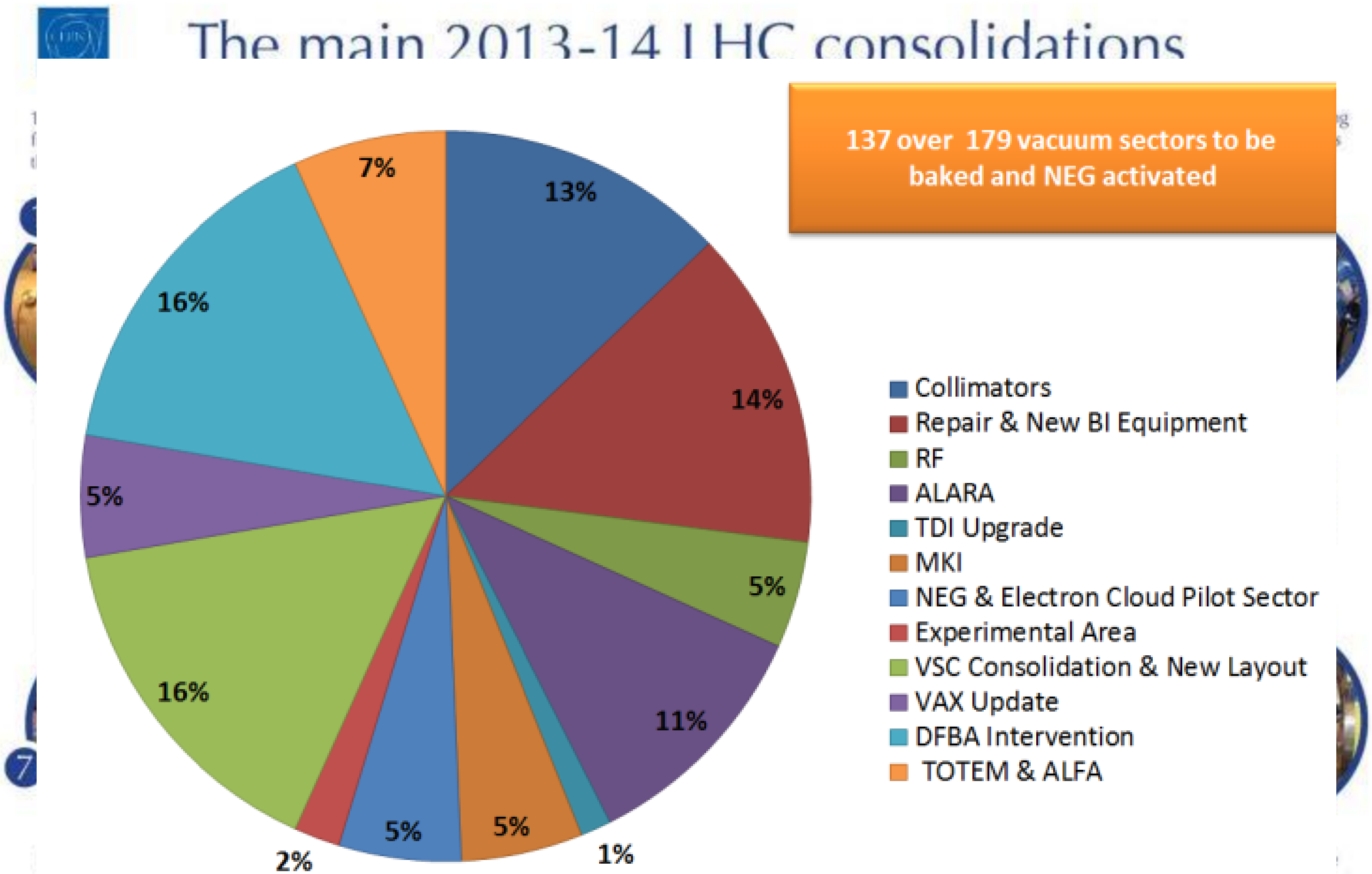
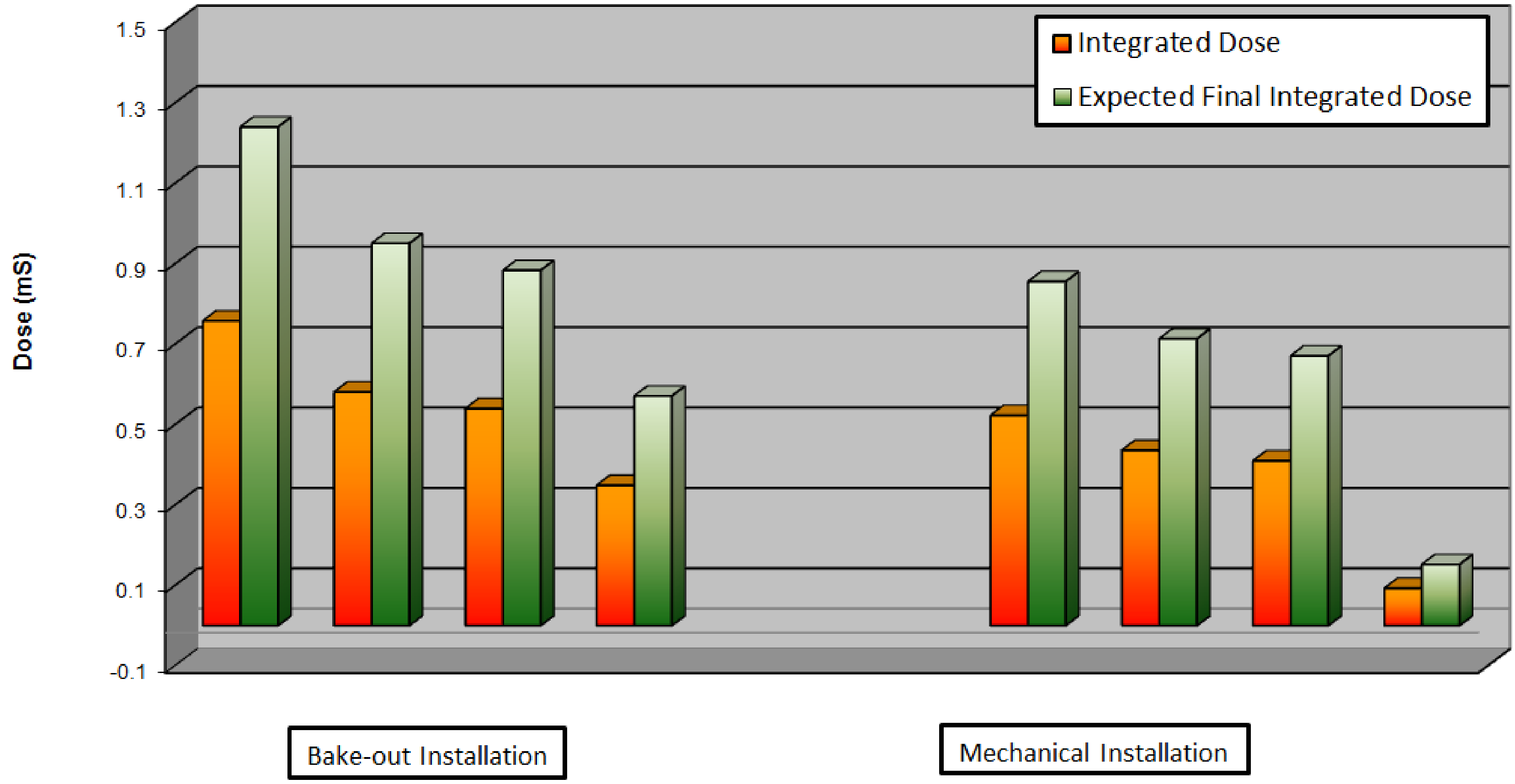


Radiation dose to the personnel already important in the LSS7

RP Outlook: LS1 Activities
Integrated dose per person 04/2013-02/2014



Data for AI4030 personnel

Conclusions from LHC operation

- NO DESIGN ISSUE: pumping layout and instrumentation behaved as expected
  - Dynamic vacuum effects were enhanced by the fast increase of luminosity
  - Non NEG coated areas dominates by far the pressure rises: all devices concerned.
- Operation with 50 ns beams has no impact for the beam vacuum after a dedicated scrubbing run even if the bunch population is increased up to $\approx 1.6 \cdot 10^{+11}$ p/b.
- Operation with ions was “transparent” for the beam vacuum

Outlook for HL-LHC

- **Ion Induced desorption:**
  - Actual ARC and LSS: NO DESIGN ISSUE.
  - New devices & layout must be validated with operation parameters
- **Synchrotron radiation:**
  - Expected heat loads and photon: photon & photon-electron stimulated desorption.
  - Some additional information will be gained by the COLDEX experiment on the possibility of implementing carbon coating
- **Electron cloud build:**
  - Upgrade of the LSS by lowering the electron cloud build up of surfaces facing the beam: **all groups are concerned**
- **More strict vacuum acceptance test of new devices:**
  - Avoid "bad" surprise in the machine
  - Must preserve the "NEG performance" to avoid any issue with background for the experiments
  - Increase pumping speed on localized area

Thank you

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