Gas Condensates onto a LHC Type Cryogenic Vacuum System Subjected to Electron Cloud

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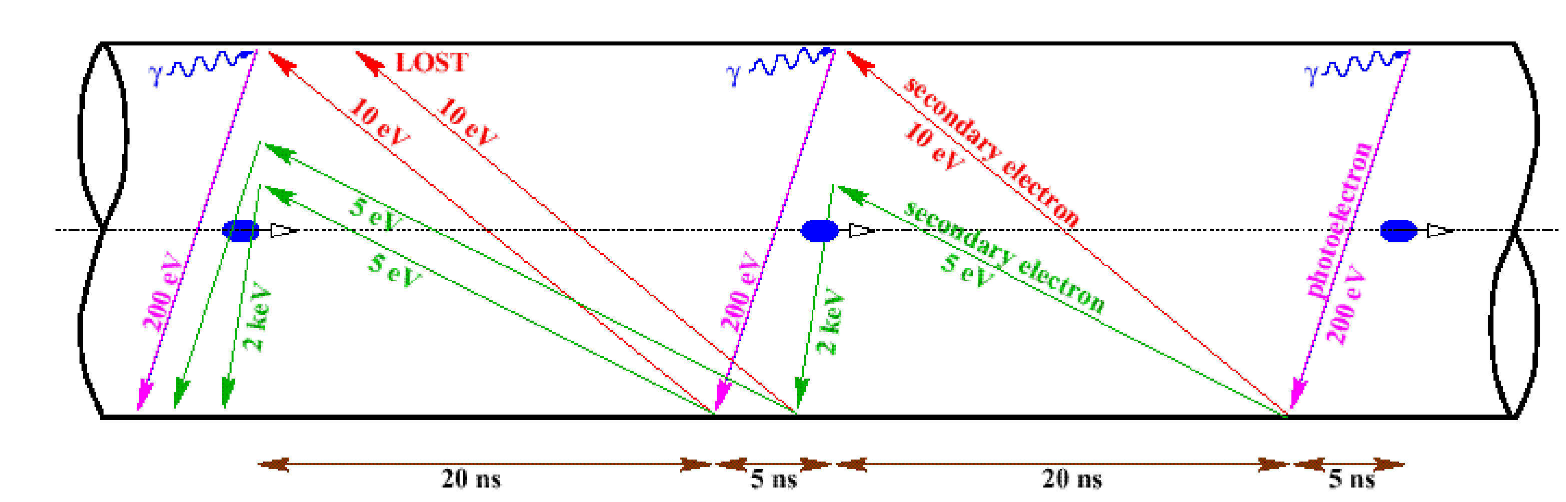
1. Introduction

1.1 Electron cloud & LHC

- Limit performances of PEP-II, KEK-B, SPS …
- In LHC, it will induce heat load and stimulated molecular desorption
- Vacuum chamber parameters : secondary electron yield, photon and electron reflectivity photoelectron yield, vacuum chamber geometry …
- Beam structure : bunch spacing, bunch density, bunch length …



Schematic of electron-cloud build up in the LHC beam pipe.

F. Ruggiero *et al*. EPAC 98

1.1 Electron cloud & LHC (2) : budgets

- Electron cloud heat load budget :

  ~ 1.5 W/m at injection (450 GeV)

  ~ 1 W/m at collision (7 TeV)

- Gas budget : (450 GeV dominated by Coulomb scattering, 7 TeV dominated by nuclear scattering)

  Scrubbing beams at injection : ~ 10^{-7} Torr H_2 eq.

  Physics beams : ~ 10^{-8} Torr H_2 eq.

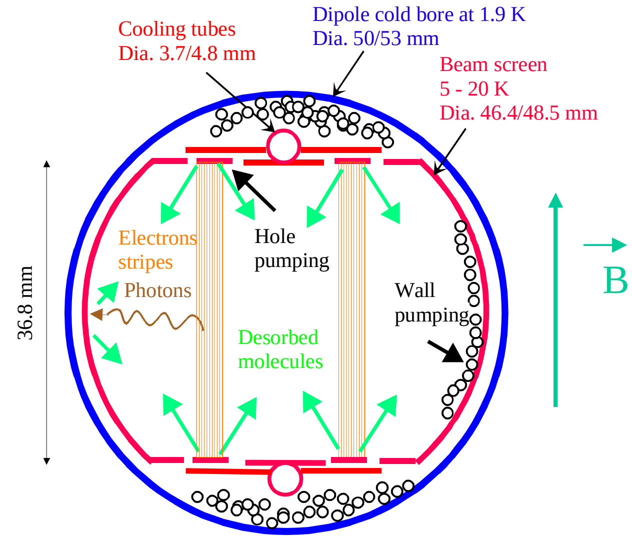
1.1 Electron cloud & LHC (3) : SPS

- An electron cloud is observed in the CERN SPS machine
- COLDEX which simulates a LHC type cryogenic vacuum chamber is installed in the SPS

Parameters	LHC	SPS	
Beam energy (GeV)	7 000	26	450
Bunch length (ns)	1	2.8	1.7
Revolution period (μs)	89	23	
Batch spacing (ns)	940	225	
Beam current (mA)	560	55 / 110 / 165 / 220	
Number of batches	10	1 / 2 / 3 / 4	
Number of bunches	2808	72 / 144 / 216 / 288	
Filling factor (%)	79	9 / 16 / 24 / 31	
Bunch current (protons/bunch)	$1.1\ 10^{11}$		
Bunch spacing (ns)	25		

1.2 LHC cryogenic vacuum system

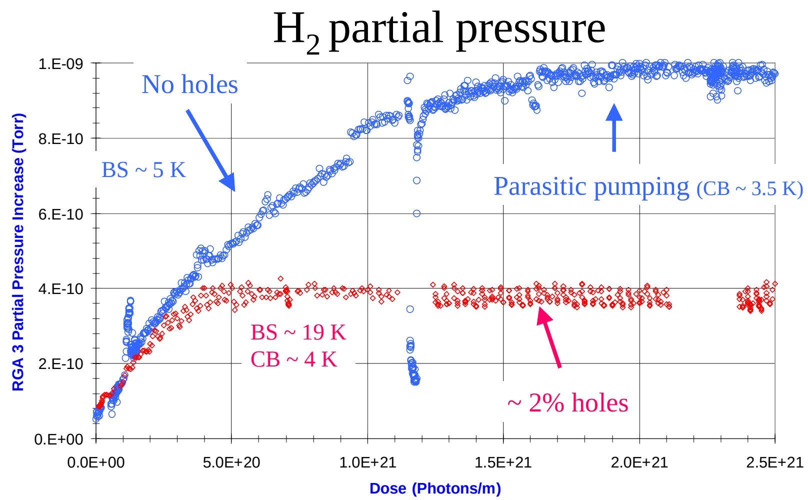
- Molecular desorption stimulated by photon, electron and ion bombardment
- Desorbed molecules are pumped on the beam vacuum chamber : **CLOSED geometry**



- Molecular physisorption onto cryogenic surfaces (weak binding energy)
- Molecules with a low recycling yield are first physisorbed onto the beam screen (BS) (CH_4, H_2O, CO, CO_2) and then onto the cold bore (CB)
- H_2 is physisorbed onto the CB

- The vacuum dynamic is defined by :
  - pumping speed of holes (C), BS (σS) and CB
  - vapor pressure
  - primary and recycling desorption yields

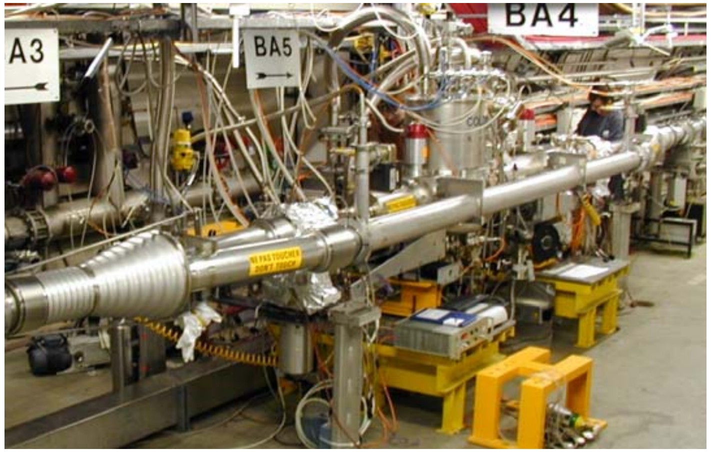
$$n \approx (\eta + \eta'(\theta)) \frac{\dot{\Gamma}}{\sigma S + C} + n_e$$



V. Baglin *et al.* EPAC 2000, COLDEX, EPA beam line SLF 92

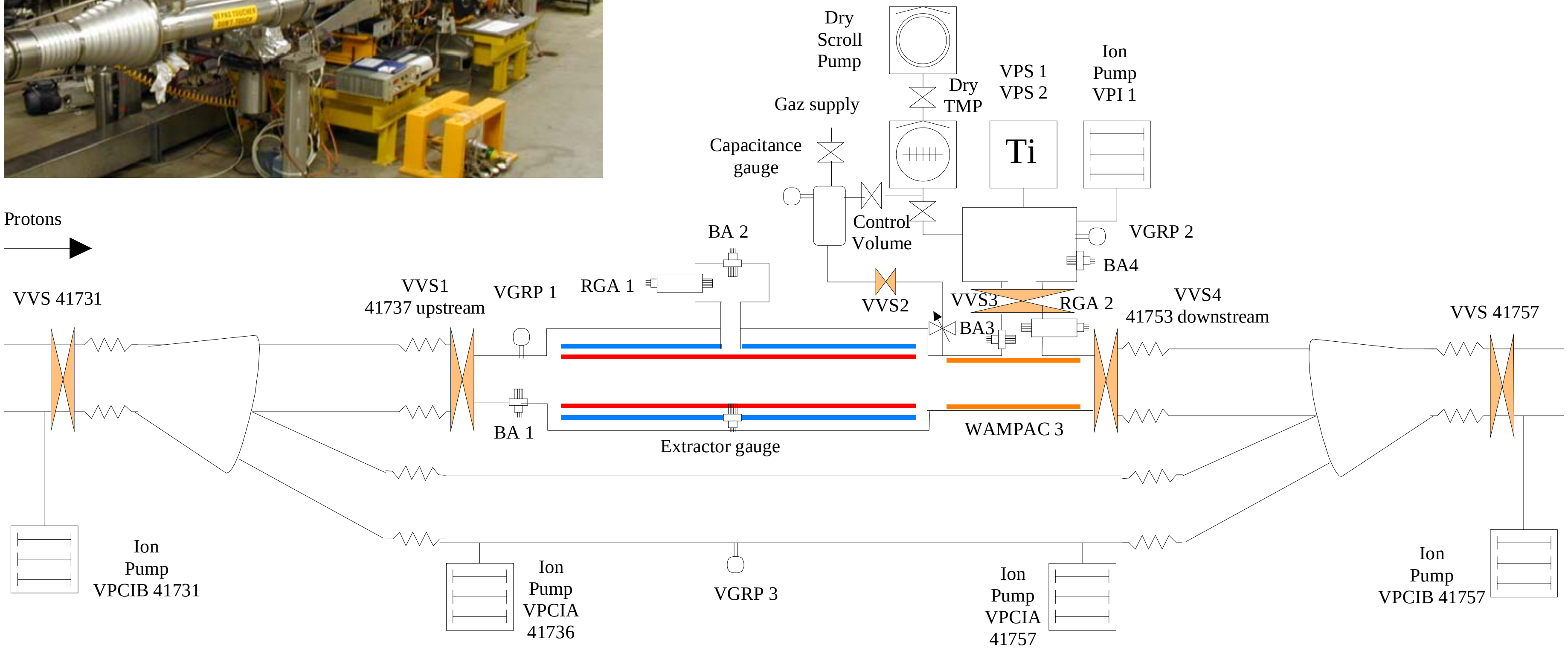
2. Experimental set-up : COLDEX

Field free region (SPS Long straight section 4), closed geometry, 2.2 m long
Pressure & gas composition measurements, heat load measurement (temperature, flow)



BS from 5 to 150 K

CB from 2 to 5 K



3. Results

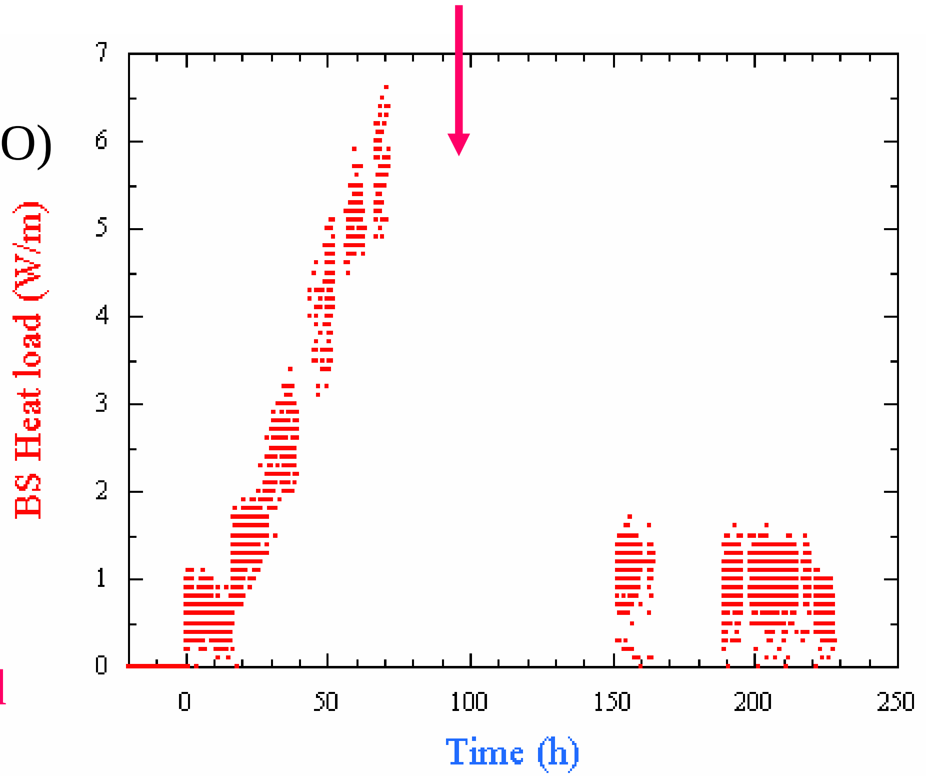
3.1 Effect of condensed gas with electron cloud

First beam into a vacuum chamber cleaned according to UHV standard

- Strong dynamic outgassing ~ 10^{-6} Torr
- Heat load up to 6 W/m
- At 80 h, warm up to 40 K (removal of H_2, CH4, CO)
- Still 6 W/m
- At 100 h, Warm up the BS to 240 K and the CB to120 K. (removal from BS of CO_2 and H_2O)
- Heat load of 1 W/m, 10^{-8} Torr
- Presence of condensed gas induces large heat load
- <u>Ex</u> : 30 monolayers of H_2O has a δ_{max} ~ 1.9 (on a baked surface)

N. Hilleret *et al.* EPAC 2000

Warm up to 240 K and beam circulation at RT for 4 h



From 50 to 100 h : BS and CB increase to 20 K
Afterwards : BS ~ 10 K, CB ~ 5 K

2 batches with ~ 1.1 10^{11} protons/bunch, 95 % duty cycle

3.2 Atmospheric gases and thermal desorption

During operation, some vacuum chambers are vented and exposed to thermal desorption

- No significant change of the achieved pressure and heat load after 220 h operation :

  - after 2 months under vacuum at room temperature

  - after air-venting and immediate pumping

  - after air-venting, 2 weeks exposure at atmospheric pressure, pumping to 10^{-4} Torr and BS cooling down

- The conditioning of the LHC vacuum system will not be significantly altered during the shutdown periods or after a venting

3.3 Injection of gas (1) : 10^{15} H_2/cm^2

H_2 vacuum transient

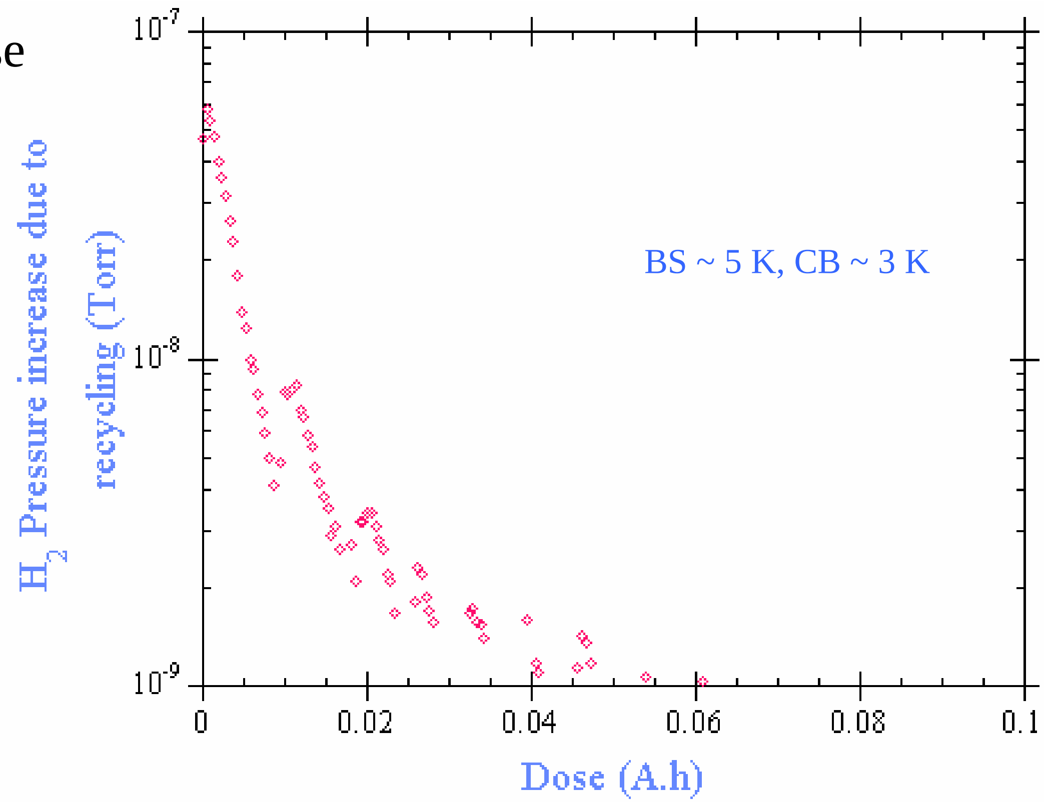
- Pressure increase due to the recycling of the condensed molecules into the gas phase (the level vary with the surface coverage and the electron flux)

- Large pressure increase : $6\ 10^{-8}$ Torr

- ~ 6 times the 100 h life time limit

- $\eta' / \sigma \sim 3\ H_2/e^-$

- Fast flushing of gas <0.01 A.h



2 batches with ~ 1.1 10^{11} protons/bunch, 95 % duty cycle

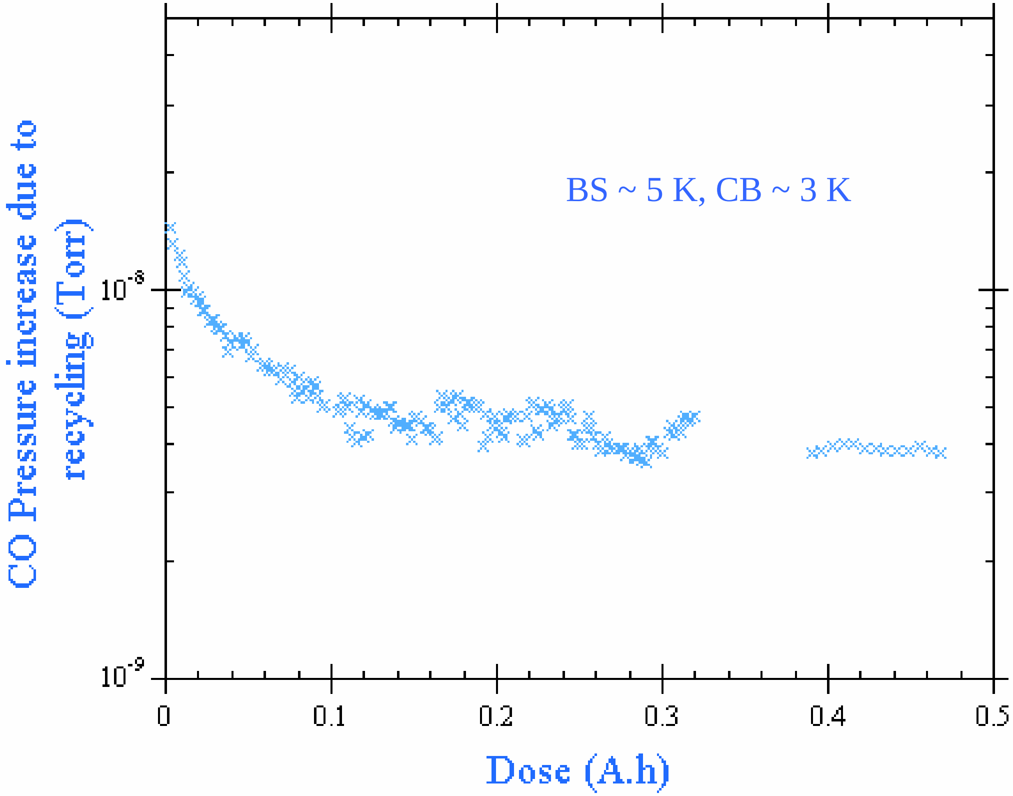
- No significant increase, as compared to a "bare surface", of the heat load due to the electron cloud

3.3 Injection of gas (2) : 5 10^{15} CO/cm^2

CO and CO_2 vacuum transients

- Recycling of the condensed molecules into the gas phase

- Pressure increase : 10^{-8} Torr
- ~ 5 times the 100 h life time limit for more than 0.5 A.h
- $\eta' / \sigma \sim 0.4$ CO/e^-
- Slow flushing of gas >0.5 A.h



2 batches with ~ 1.1 10^{11} protons/bunch, 95 % duty cycle

- No significant increase, as compared to a "bare surface", of the heat load due to the electron cloud

- Similar results for the condensation of 15 10^{15} CO_2/cm2
- But cracking of CO_2 into CO and O_2
- $\eta' / \sigma \sim 0.01$ CO_2/e^-

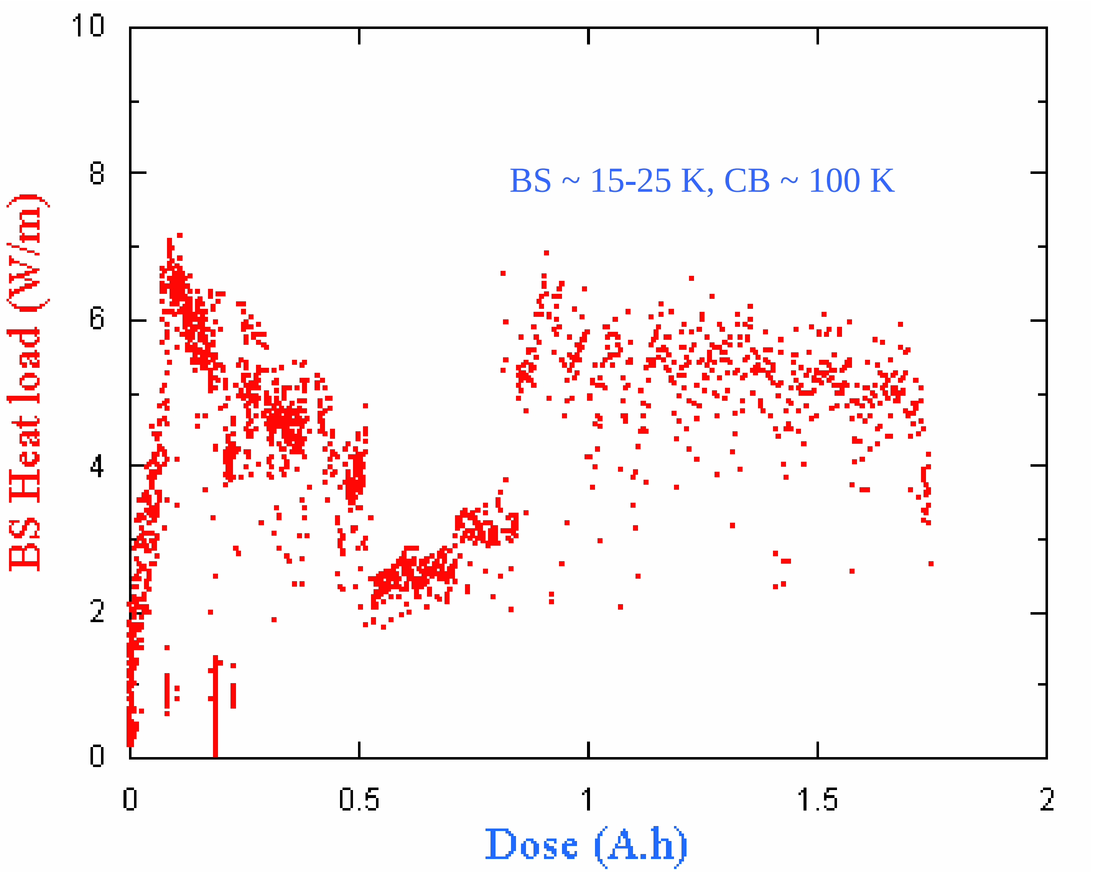
3.3 Injection of gas (3) : 60 10^{15} CO/cm^2

Heat load due to the condensation of thick layers of gas

- Large heat load due to the electron cloud up to 6 W/m

- Long period

- After a quench, the condensation of thick layers of gas induces large heat load onto the BS for more than 1.5 A.h



Before 1 A.h :
- 1 batch with ~ 1.1 10^{11} protons/bunch, 95 % duty cycle

After 1 A.h :
- 4 batches with ~ 1.1 10^{11} protons/bunch, 95 % duty cycle

4 Implications for the LHC

The local condensation of gas could hamper the LHC operation.

The amount of gas condensed onto the BS should be controlled.

- During the cool down, the BS temperature will be kept above the CB temperature

- Before venting the vacuum system, the whole sector should be at room temperature

- During the shutdown, the LHC will be warm up to 240 K and the desorbed gas will be systematically evacuated by turbomolecular pumps

- The quantity of surface having large gas load and located close to the BS should be minimised. For instance, the cold warm transition might be baked to reduce the stimulated molecular desorption

- The LHC cold vacuum system is a closed geometry : the gas remain trapped onto the BS or the CB.

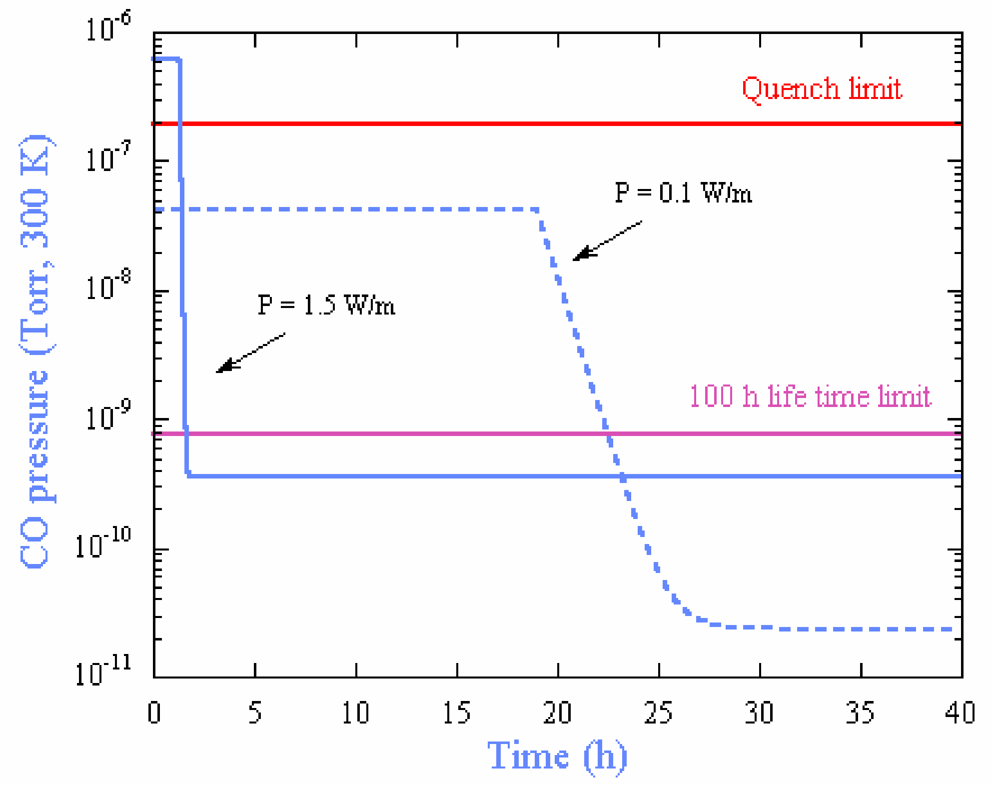
⇨ A BS heater is required to control the surface coverage.

⇨ Vacuum valves are used to decouple the room temperature vacuum chambers and the vacuum chambers operating at cryogenic temperature.

Example : consequences of a magnet quench.
Condensed CO onto the BS over 2 m, 25 10^{15} CO/cm^2,
heat load onto the BS due to electron cloud : 0.1 and 1.5 W/m, 100 eV electron energy

- Above quench limit for 1 h with 1.5 W/m
  => risk of quench
- Below quench limit for 20 h with 0.1 W/m
  => lower beam current

flushing of the CO via BS heaters will improve the situation



Computation with :
BS = 15 K
CB = 1.9 K

V. Baglin. Chamonix 2004

4. Conclusions (1)

- The electron cloud interacts in a complex manner with the LHC cold vacuum system

- Studies with condensed gases have shown that significant heat load and / or pressure rise are observed

- Thick layers of H_2O and CO induce large heat load

- Recycling desorption yields, η', could be derived from the results

- When η' is low (*e.g.* CO, CO_2), during the vacuum transient (*e.g.* after a quench), the pressure due to the recycling can be larger than the 100 h life time limit for a long period

- Vacuum transients might induce quench, activate the vacuum components and dissipate power into the cold masses

4. Conclusions (2)

- The solution is to control the amount of condensed gas onto the BS

- Appropriate cool down, venting scenari are required

- BS heaters are used to flush the gas, during dedicated period, from the BS towards the CB

- The vacuum valves are used to protect the TiZrV getter coating of the room temperature vacuum system from the cryogenic temperature vacuum system

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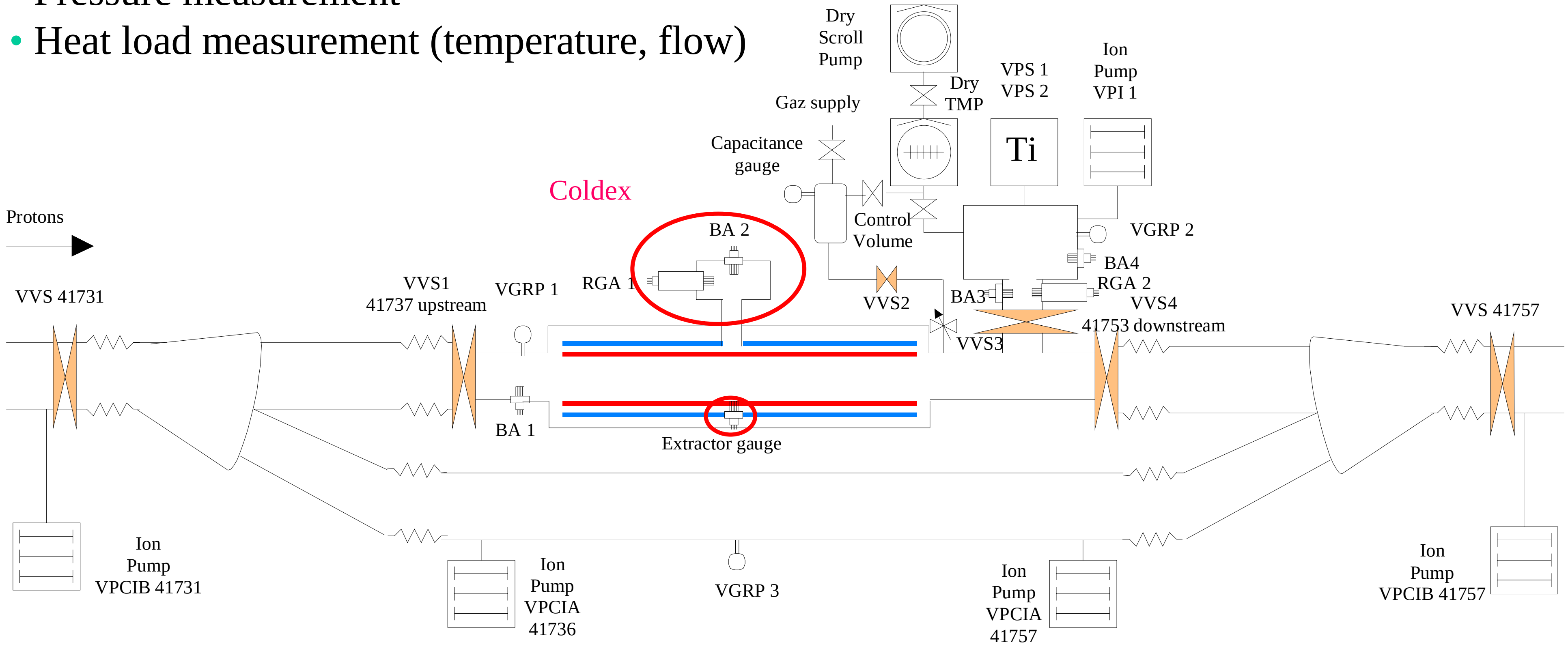
Back-up slides :

2. Experimental set-up

- Field free region (SPS Long straight section 4), closed geometry
- OFE Cu, 2.2 m long, elliptic, H = 84 mm, V = 66 mm
- Cryogenic temperature, 1 % holes, BS ~ 5 to 100 K, CB ~ 3 to 5 K
- Pressure measurement
- Heat load measurement (temperature, flow)



2.1 COLDEX set-up (2) : types of beam screens

Year 2002

(8th EVC, Berlin, June 2003 - Vacuum 73 (2004) 201-206)

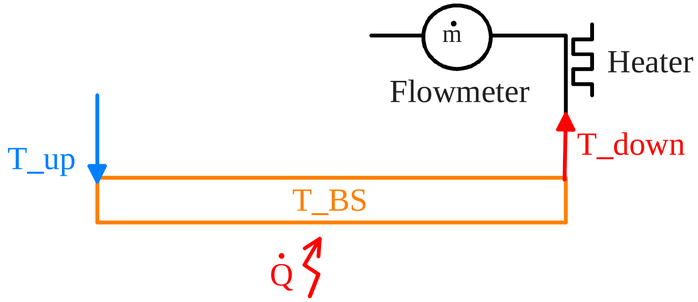
- OFE Cu, 2.2 m long, elliptic, H = 84 mm, V = 66 mm
- 1 % holes (7 mm diameter)
- Inserted cold warm transition (15 mΩ), stainless steel, 0.1 mm thick.
- Calibrated thermometer, anchoring < 0.6 K, linear flow meter
- Background : (1.5 +/- 0.4) W/m

Year 2003

- OFE Cu, 2.2 m long, circular, D = 67 mm (was in EPA ring in 1999, dose of 10^{23} ph/m)
- 1 % slots (2 x 7.5 mm)
- Electron shield behind slots (L = 17.85 cm) to protect cold bore and measure current
- Thermalised cold warm transition with RF fingers. Cu coated stainless steel, 0.1 mm thick.
- In situ heat load calibration, ~ 100 mW/m is measurable
- Calibrated thermometer, anchoring ~ 3 K, calibrated flow meter
- Background : ~ 1.4 W/m

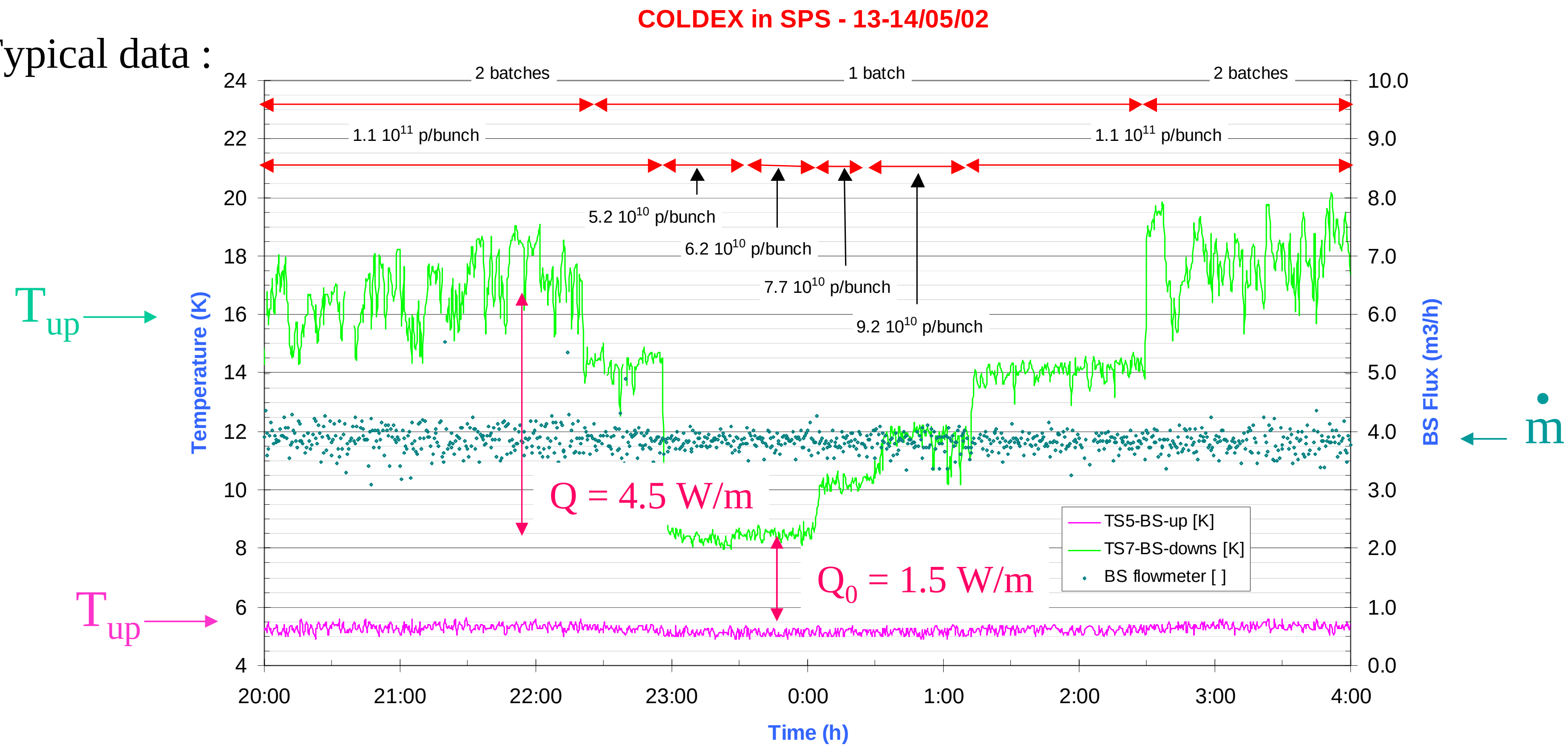
2.1 COLDEX set up (3) : heat load measurement

- Direct heat load measurement by the flow method, He at 1 bar :



$$\dot{Q} = \dot{m}\,[h_{He}(T\_down) - h_{He}(T\_up)]$$

- Typical data :



3.1 Long term circulation (2)

2 batches with ~ 1.1 10^{11} protons/bunch, 95 % duty cycle

- 2 orders of magnitude reduction of total pressure

- Heat load on BS increase with time

- Heat load on BS decreased after warming-up and beam at ~ RT

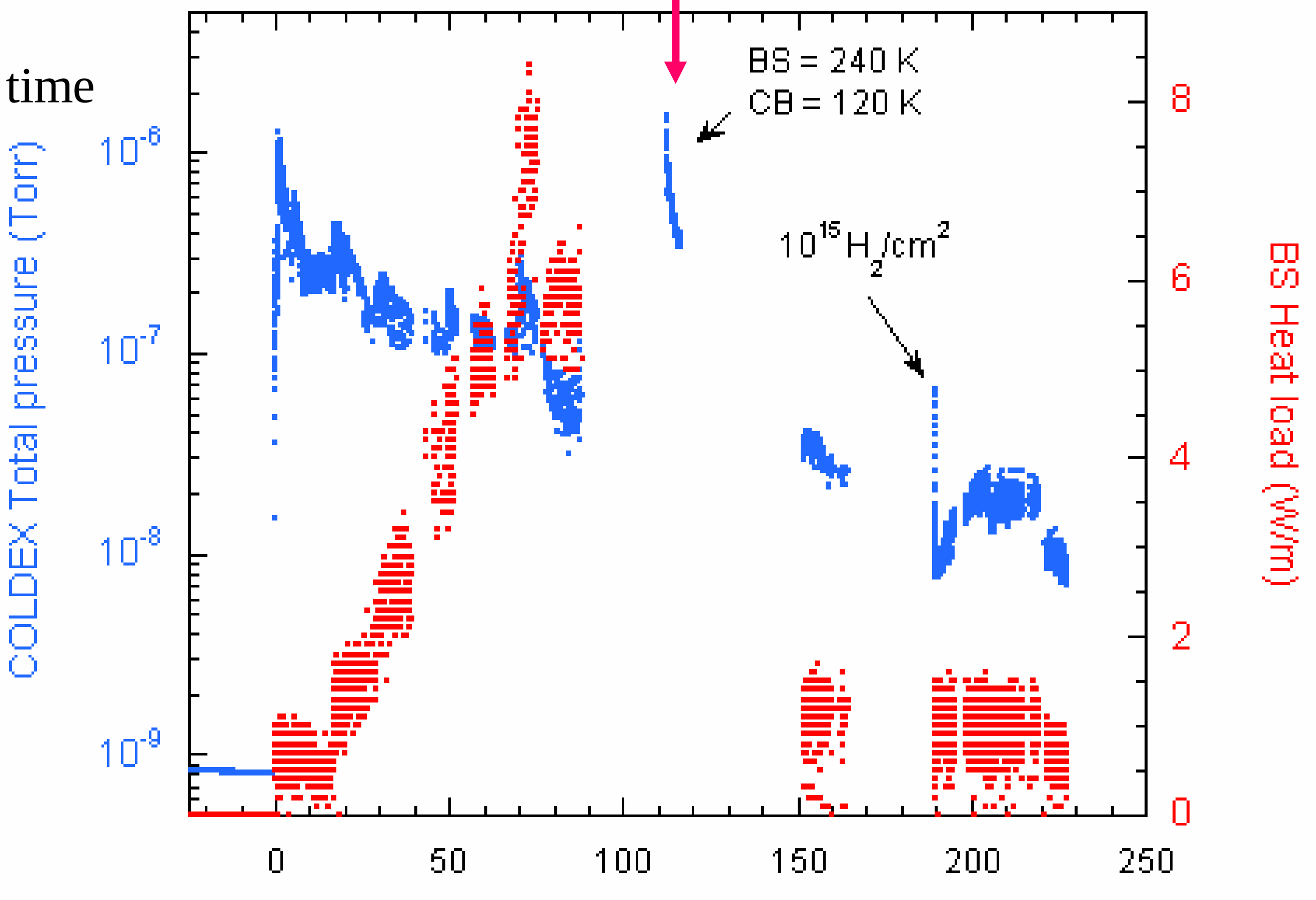
- H_2 recycling of physisorbed molecules :

  $\eta' \sim 2\ 10^{-1}\ H_2/\ e^-$

- At the end :

  10^{-8} Torr, 0.5 W/m

Warming-up and beam circulation at RT



BS and CB increase to 20 K

BS ~ 10 K, CB ~ 4.2 K

2. Vacuum transient

Definition

• An undesirable vacuum transient appears, when the BS coverage prior to switching ON the beam with a given set of parameters, is larger than the required equilibrium coverage onto the BS for these parameters. The equilibrium coverage decreases from a few to ~ 0.01 monolayers ($\theta_{eq} \sim \eta$)

Effect of ~ 1 monolayer of H_2 condensed onto the BS subjected to synchrotron radiation

100 h life time limit →