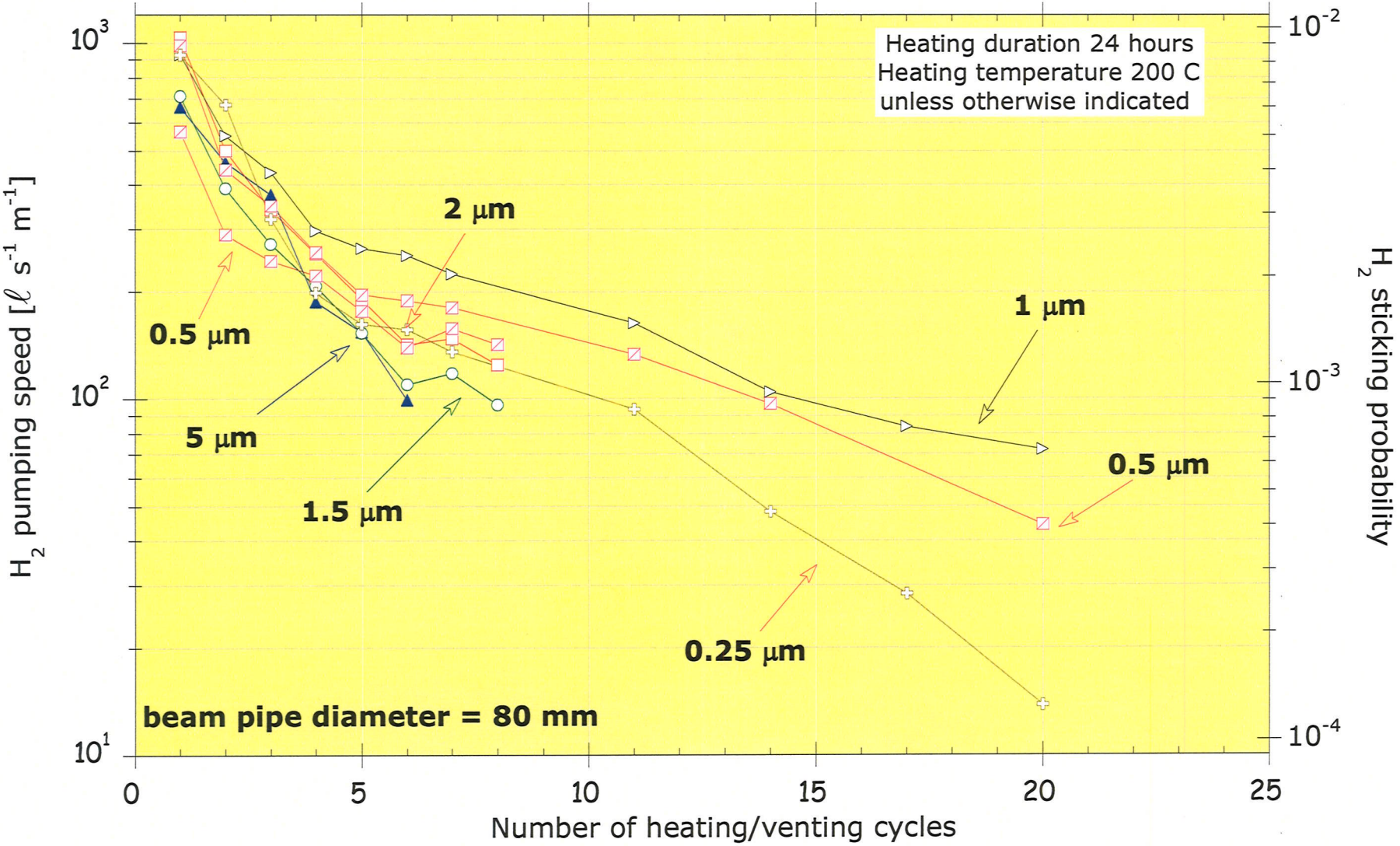
Performances deterioration: ageing



✓ Performances deterioration:

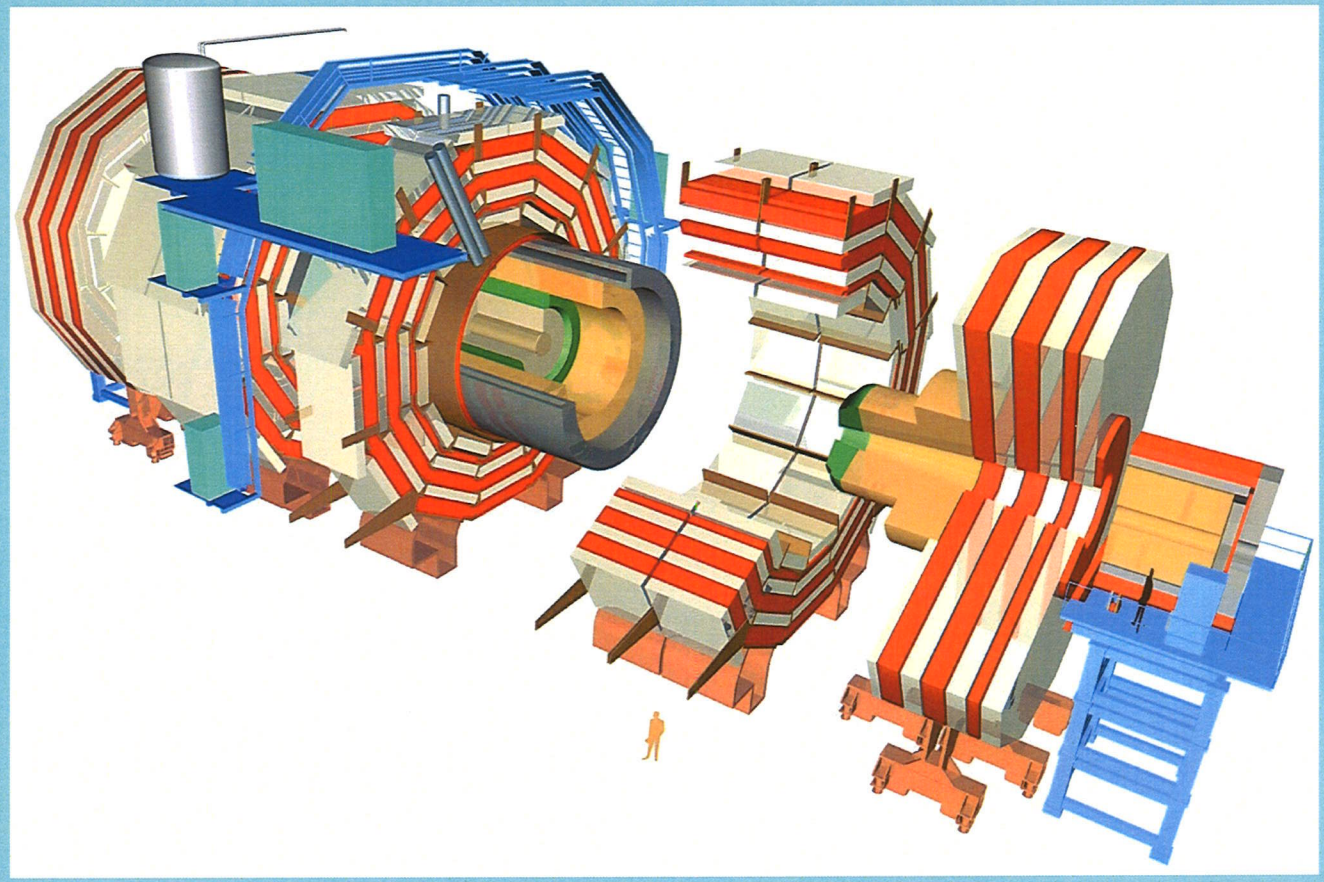
- The pumping speed shows a gradual decrease after each venting-activation cycle.
- The decrease of performance depends on the heating temperature; higher the temperature, lower the loss. For a heating cycle of 200°C x 24h, for the first 10 cycles, in the worst case:

$$S_{H2} \propto \frac{1}{n}$$

- When the activation cycle is carried out at temperatures lower than 250°C, pumping speed can be partially recovered by increasing the heating temperature.
- The loss of performance recorded along the first 10 cycles does not depend on the thickness of the film, for thickness higher than 0.25 μm.

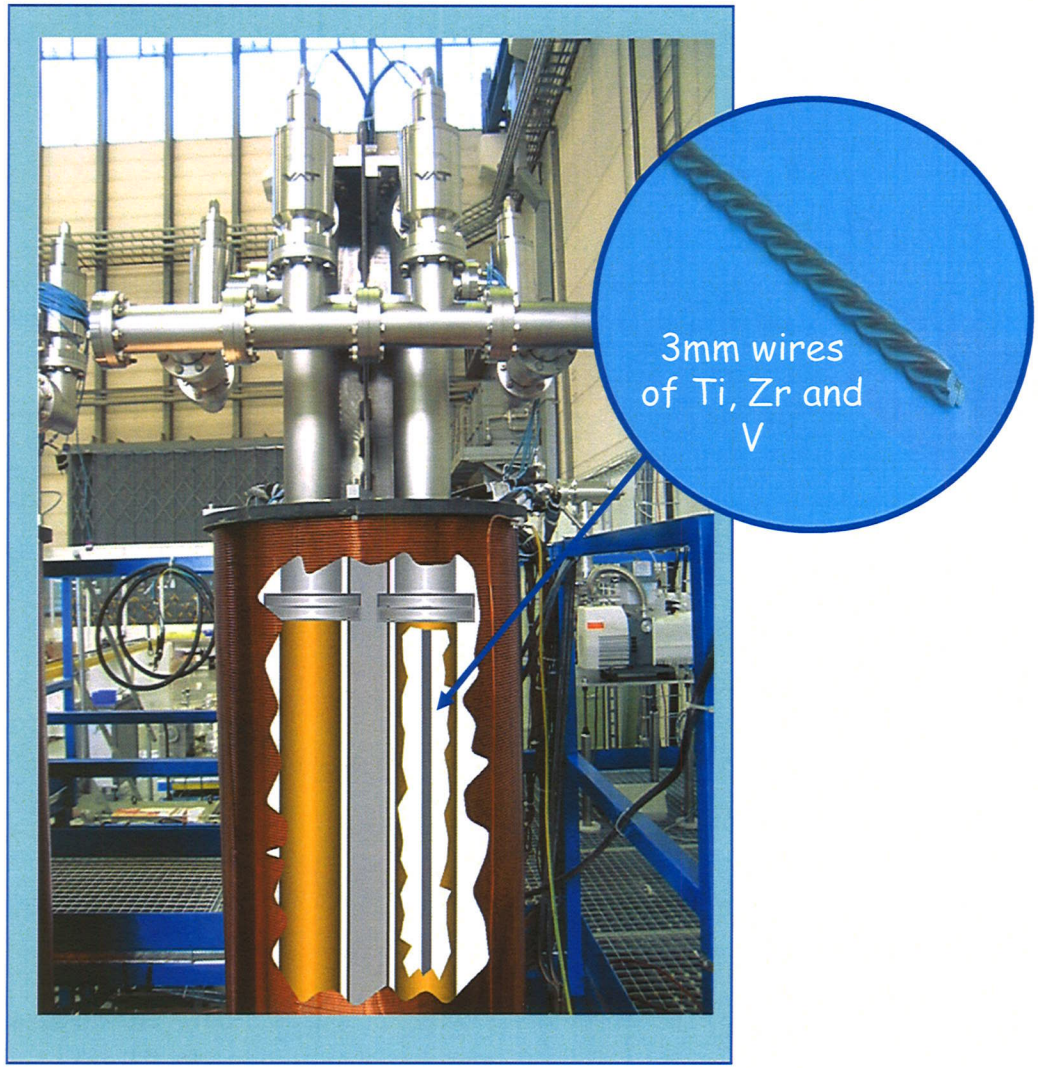
About 1 Kg of Ti-Zr-V will be spread over the LHC to coat about 1200 vacuum chambers of roughly 6 Km of long straight section beam pipe.

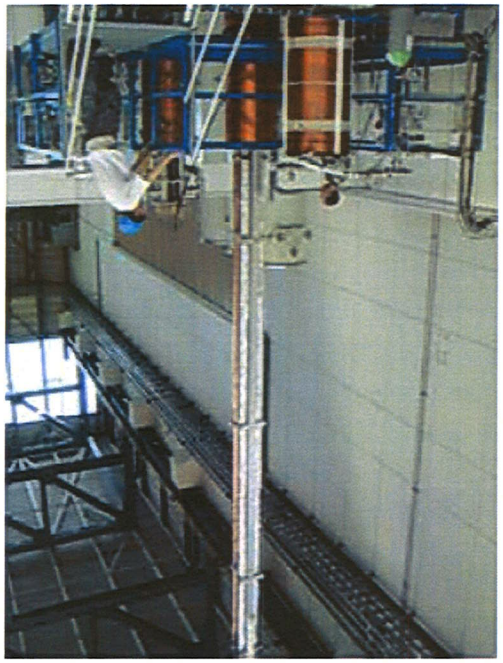
Most important vacuum chambers are in the proximity and in the centre of the 4 gigantic experiments.

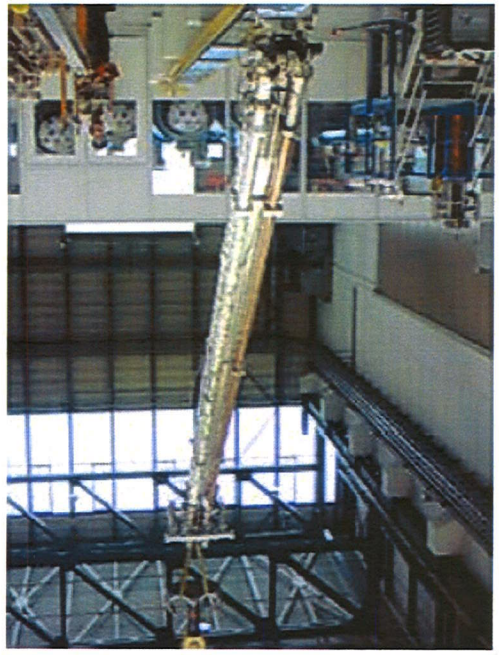


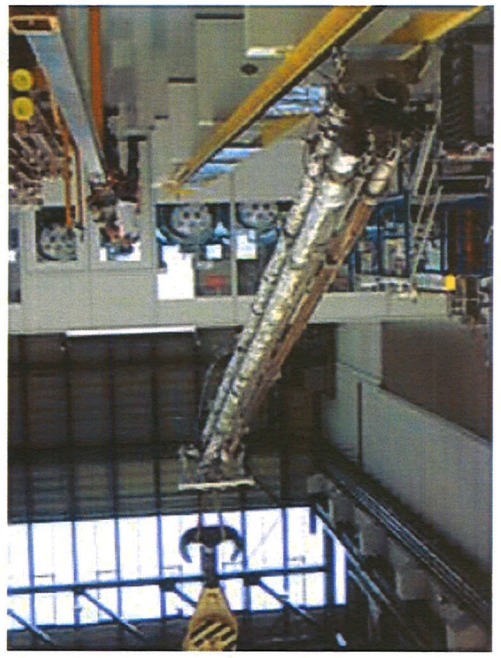
A dedicated coating facility is available at CERN since 2004:

- ✓ 3 independent magnetron sputtering systems
- ✓ maximum length: 7.5 m; maximum diameter: 60 cm
- ✓ maximum production rate: 20 chambers per week.


3mm wires
of Ti, Zr and
V

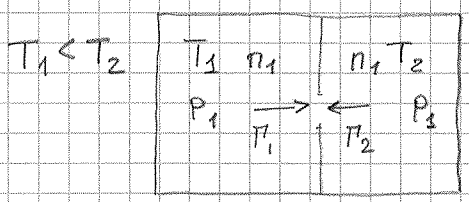






3.3.3 CRYOPUMPING

Pressures and gas density at low temperature



unit surface area

opening between the 2 volumes

$$\Gamma_1 = \frac{1}{4} n_1 v_1 \; ; \quad \Gamma_2 = \frac{1}{4} n_2 v_2$$

In equilibrium : $n_1 v_1 = n_2 v_2$

$$P_1 = n_1 k_B T_1 \qquad P_2 = n_2 k_B T_2 \Rightarrow \frac{P_1}{k_B T_1} \cdot v_1 = \frac{P_2}{k_B T_2} v_2$$

$$v \propto \sqrt{T} \Rightarrow \frac{n_1}{n_2} = \frac{v_2}{v_1} = \sqrt{\frac{T_2}{T_1}}$$

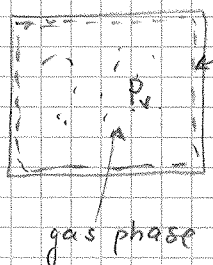
$$\Rightarrow \frac{P_1}{\sqrt{T_1}} = \frac{P_2}{\sqrt{T_2}} \Rightarrow \frac{P_1}{P_2} = \sqrt{\frac{T_1}{T_2}}$$

In the colder volume the gas density is higher, but the pressure is lower.

$\sqrt{\frac{T_1}{T_2}}$ = thermomolecular transpiration factor

Saturated vapour pressure

For a given gas and surface temperature, by progressively increasing the surface coverage a saturation equilibrium between gas adsorption and desorption is established. The corresponding gas pressure is the saturated gas pressure.



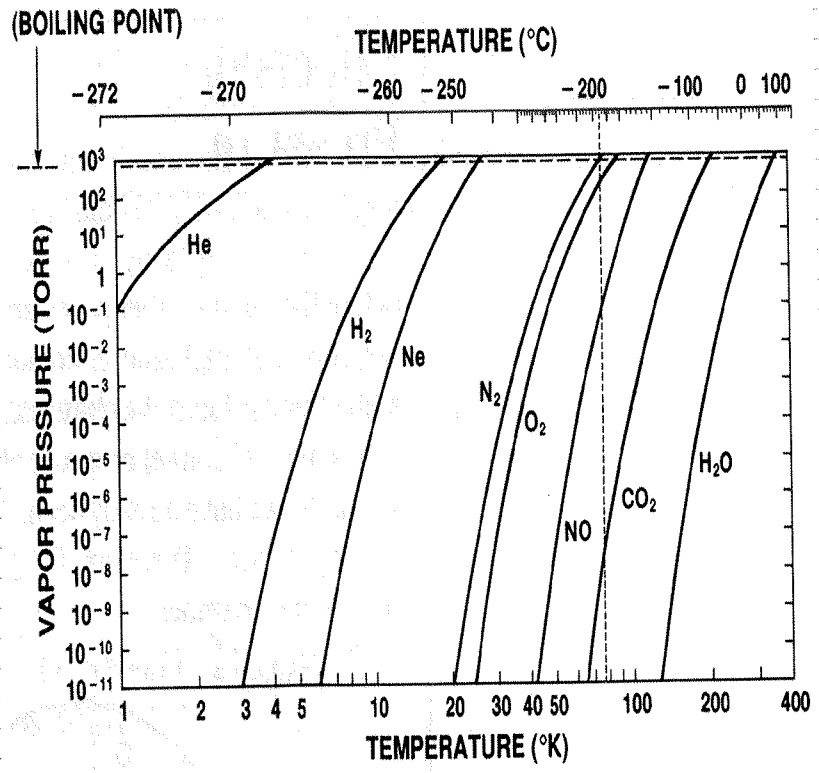
$$\text{desorption} : A \frac{N_s}{\tau_0} \cdot e^{-\frac{E_v}{k_B T}}$$

$$\text{adsorption} : \frac{1}{4} A n_1 \bar{v}_{th} \cdot \alpha$$

Most of the gases have a saturated gas pressure lower than 10^{-11} Torr at 20 K except for Ne, H_2 and He.

At the He boiling temperature (4,3 K), the vapour pressure of H_2 is in the the 10^{-7} Torr range. At 3 K the H_2 vapour pressure is in the 10^{-11} Torr range.

At the superfluid He critical temperature, $P_{H_2} < 10^{-12}$ Torr.



VAPOR PRESSURES OF COMMON GASES

(E_v) Heat of vaporisation [kcal/mol] @ Boiling temperatures [K]

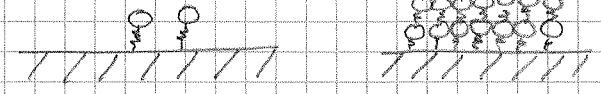
He	0.020	4,2
H_2	0,215	20,3
Ne	0.431	27,1
N_2	1,333	77,3
CO	1.444	82
Ar	1.558	87,2
CH_4	1.995	111,6
H_2O	9,7	373

$$1 \frac{eV}{molecule} = 23 \frac{kcal}{mol}$$

The CONDENSATION CRYOPUMPS are based on gas condensation on a cold surface. Once a condensation layer is formed, these pumps cannot achieve a pressure lower than the satured gas pressure:

$$P = \frac{Q}{S} + P_{sat}$$

Lower pressures than P_{sat} are obtained for submonolayer coverage. This is possible because the attractive van der Waals forces are stronger between the gas molecules and the substrate then between similar gas molecules in the condensed phase.



HIGHER BINDING ENERGY

For example:

He on porous glass at low coverage

$E_{ads} \simeq 0{,}68$ kcal/mol

$E_v = 0{,}02$ kcal/mol

H_2:

$E_{ads} \simeq 1{,}97$ kcal/mol

$E_v = 0{,}215$ kcal/mol

The important consequence is that H_2 can be significantly cryosorbed at 20 K and He at 4,2 K, up to a monolayer coverage.

Submonolayer quantities of all gases may be effectively cryosorbed at their own boiling temperature; at 77 K all gases except He, H_2 and Ne.

The pumps based on physisorption at low coverage are called CRYOSORPTION PUMPS. To increase the adsorption area, porous materials are used (charcoal and zeolites). Huge surface area can be obtained; for charcoal $\sim 1000\ m^2$ per gram are typically achieved. About 10^{-6} Torr$\cdot$l/cm^2 of He can be adsorbed before the pressure rises above 10^{-10} Torr.

Most of the commercial cryopumps used in particle accelerators rely on cryosorption. The condensation cryopumping is in general a bonus of the superconducting magnet cooling.

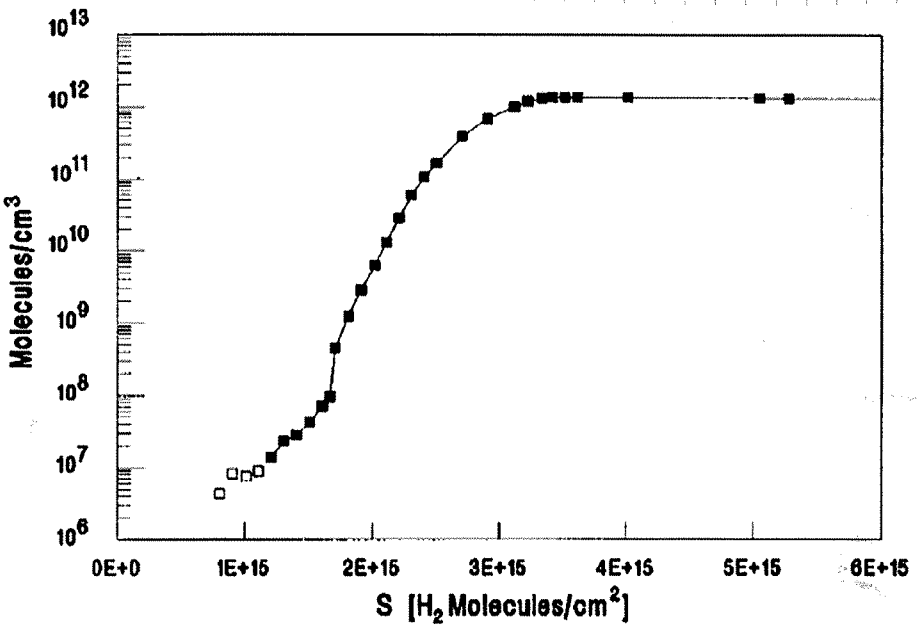


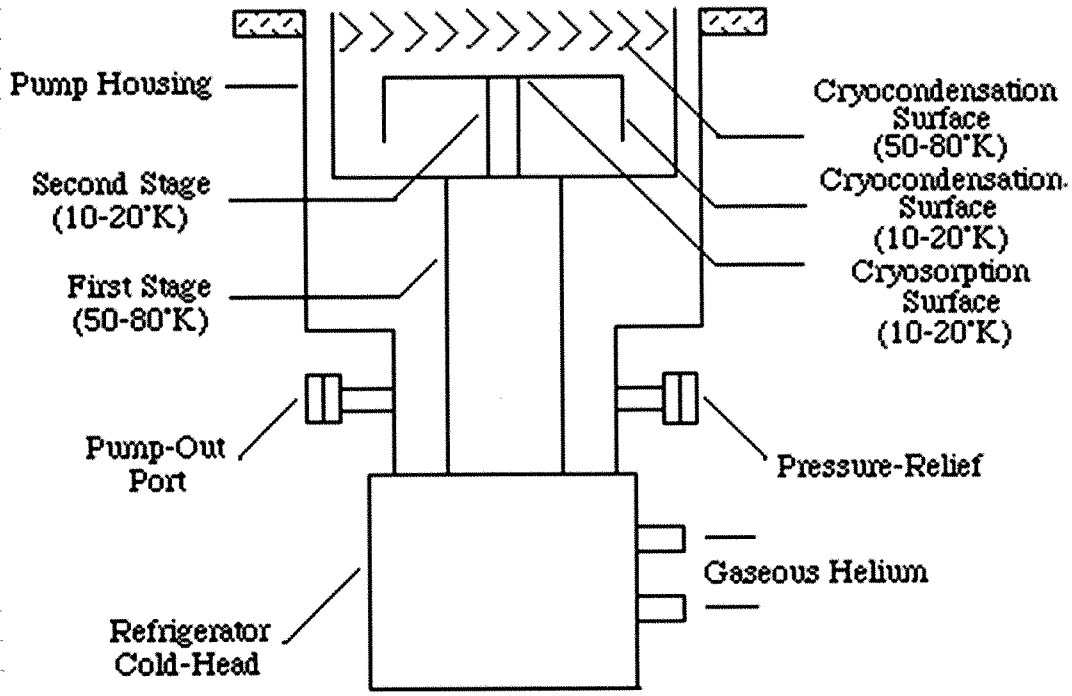
FIG. 2. Isotherm for H_2 on Cu plated stainless steel at 4.2 K plotted as a function of the surface density of H_2. The nonfilled markers represent measured points on the isotherm that are less than 10% above the background pressure of the instruments.

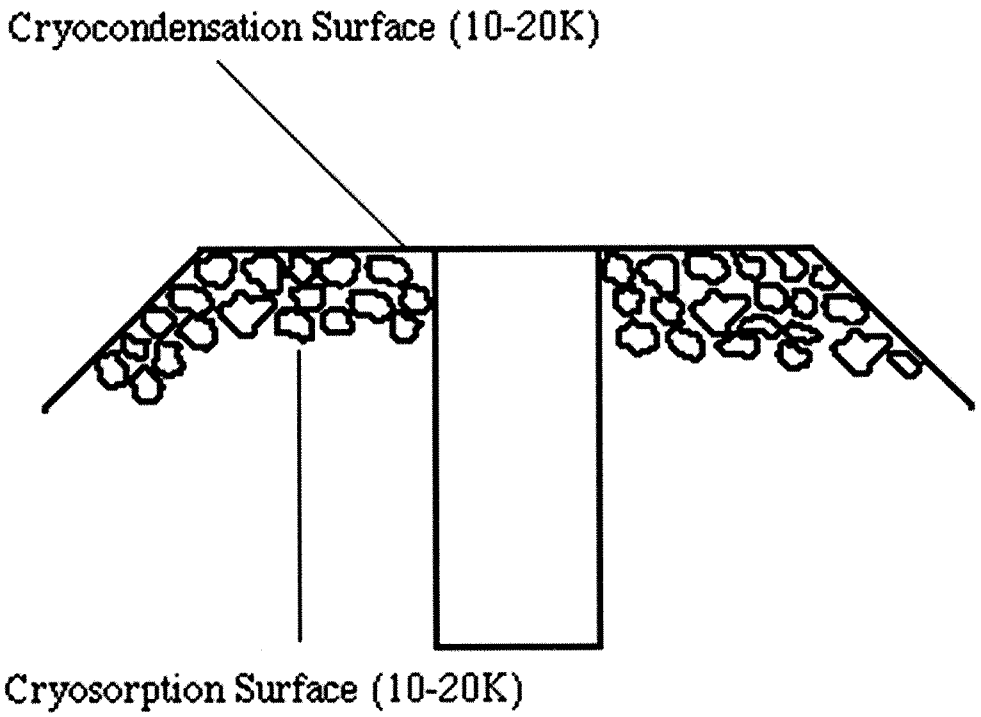
The cryogenic pumps that are commercially available take advantage of both cryosorption and cryocondensation. Cooling is usually achieved by a two stage refrigerator providing about 80 K on the first stage and 10 K on the second. A part of the coldest surface is coated with a porous material to provide a large pumping speed for H_2.

If a large load of gas heavier then H_2 is pumped on the porous material, the H_2 pumping is strongly reduced. For this reason the heavier gases are captured on 10-20 K smooth surfaces before arriving on the porous one. (see picture)

Cryogenic pumps can provide very large pumping speed ($>10^4$ l/s). They need regeneration to release the adsorbed gas after long period of pumping. This implies the need for a valve to separate them from the rest of the system and the help of a turbomolecular pump to remove the desorbed gas. Their cost is relatively high.

He gas refrigerators are used to cool cryosorption pumps.


Pump Housing
Second Stage
(10-20°K)
First Stage
(50-80°K)
Pump-Out
Port
Refrigerator
Cold-Head
Cryocondensation
Surface
(50-80°K)
Cryocondensation
Surface
(10-20°K)
Cryosorption
Surface
(10-20°K)
Pressure-Relief
Gaseous Helium


Cryocondensation Surface (10-20K)
Cryosorption Surface (10-20K)

3.3.4 CRYOPUMPING IN THE LHC

The vacuum chamber in contact with the arc magnets ("cold bore") is at about 1.9 K. At this temperature all gases have saturated vapour pressures lower than 10^{-12} Torr.

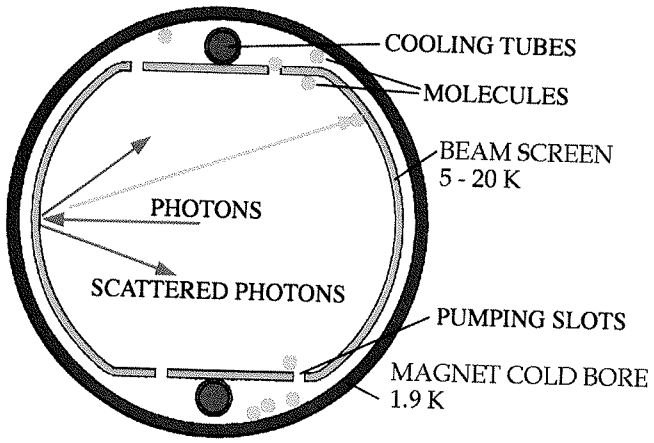
The heat load due to the beam is due to:

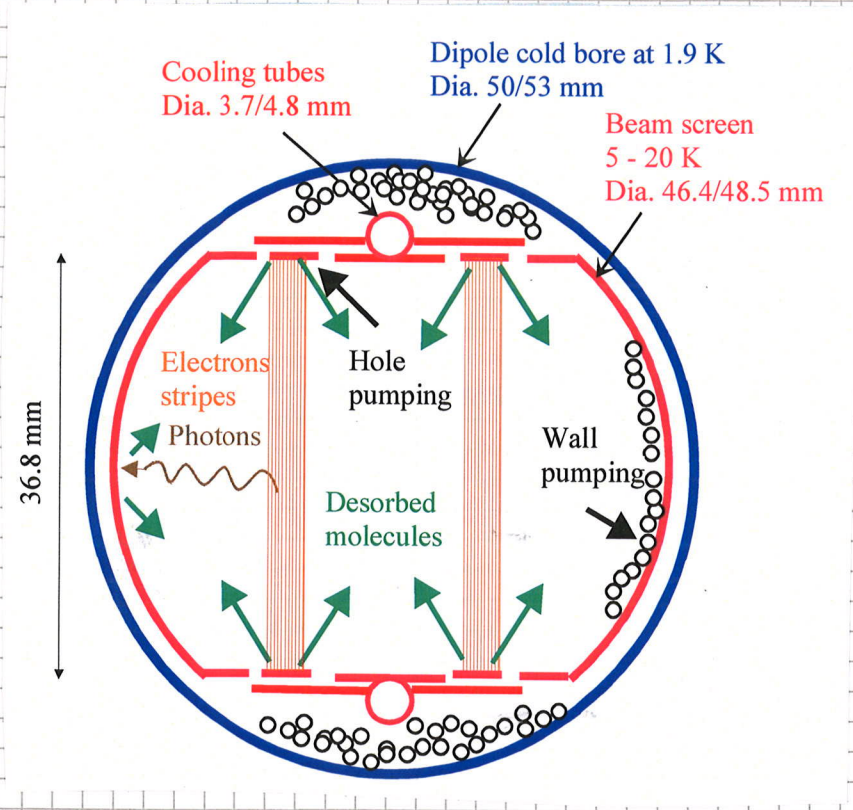
~ 1 W/m
- synchrotron radiation : 0,2 W/m per beam
- energy loss by nuclear scattering : 30 mW/m per beam
- image current 0,2 W/m per beam
- electron cloud

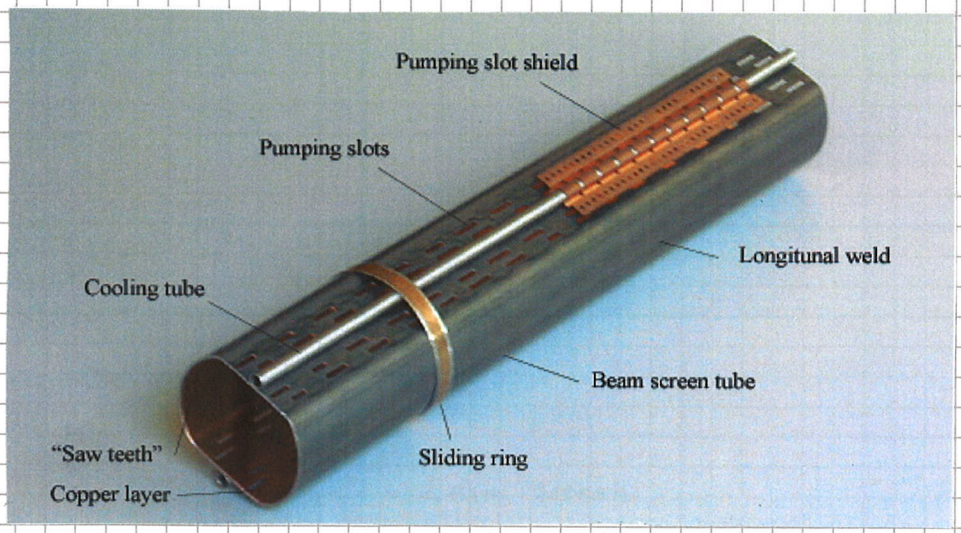
At 1,9 K a huge power is needed to transfer this thermal load at room temperature (about 1 KW per W).

To intercept the thermal load, a beam screen kept at 5 - 20 K is interposed between the beam and the cold bore.

The beam screen has pumping holes that allow the transfer of molecules to the cold bore surface.

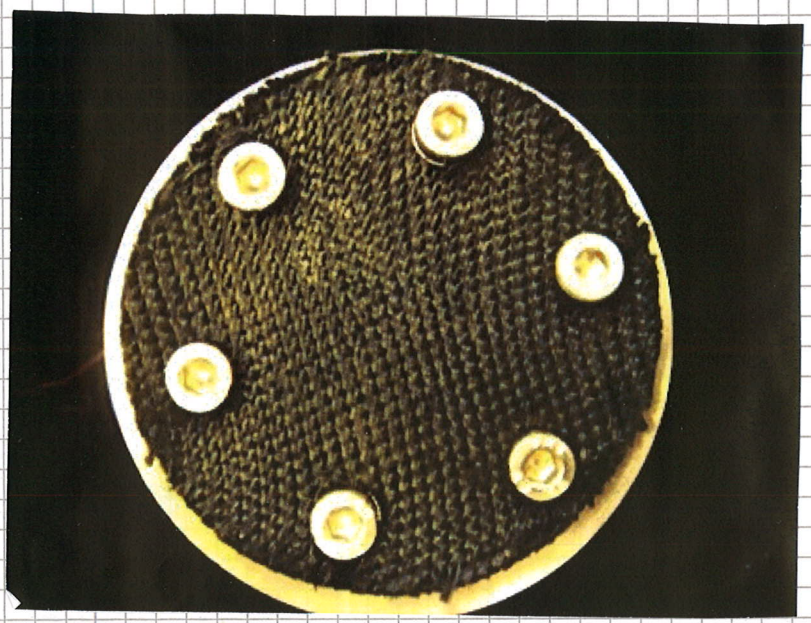



Cooling tubes
Dia. 3.7/4.8 mm
Dipole cold bore at 1.9 K
Dia. 50/53 mm
Beam screen
5 - 20 K
Dia. 46.4/48.5 mm
36.8 mm
Electrons
stripes
Photons
Hole
pumping
Wall
pumping
Desorbed
molecules

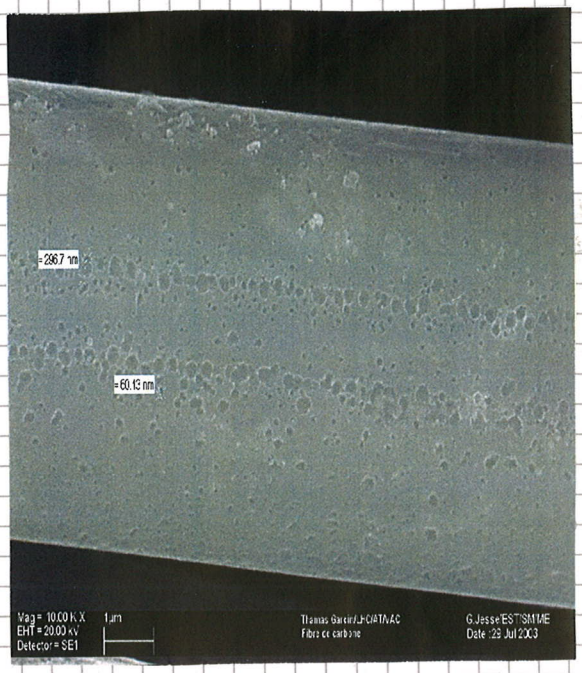

Pumping slot shield
Pumping slots
Longitunal weld
Cooling tube
Beam screen tube
"Saw teeth"
Copper layer
Sliding ring

In a few magnets the cold bores are cooled only at 4.3 K and, as a consequence, the H_2 pumping cannot rely on cryocondensation.

Cryosorbers made of woven carbon fibers (developed by BINP) are inserted between the beem screen and cold bore. At 6 K, 10^{18} H_2 molecules/geometric cm^2 are adsorbed with vapour pressure lower than 10^{-8} Torr.



X 25



x 10 000