LHC Design and VLHC Issues

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LHC Beam-vacuum

s.r. radiation ----> photon induced desorption

ions ----> pressure stability $(\eta I)_{critical}$

electrons ----> multipacting $I_{critical}$

closed geometry!

----> recycling of gas
----> isotherm limited by SVP

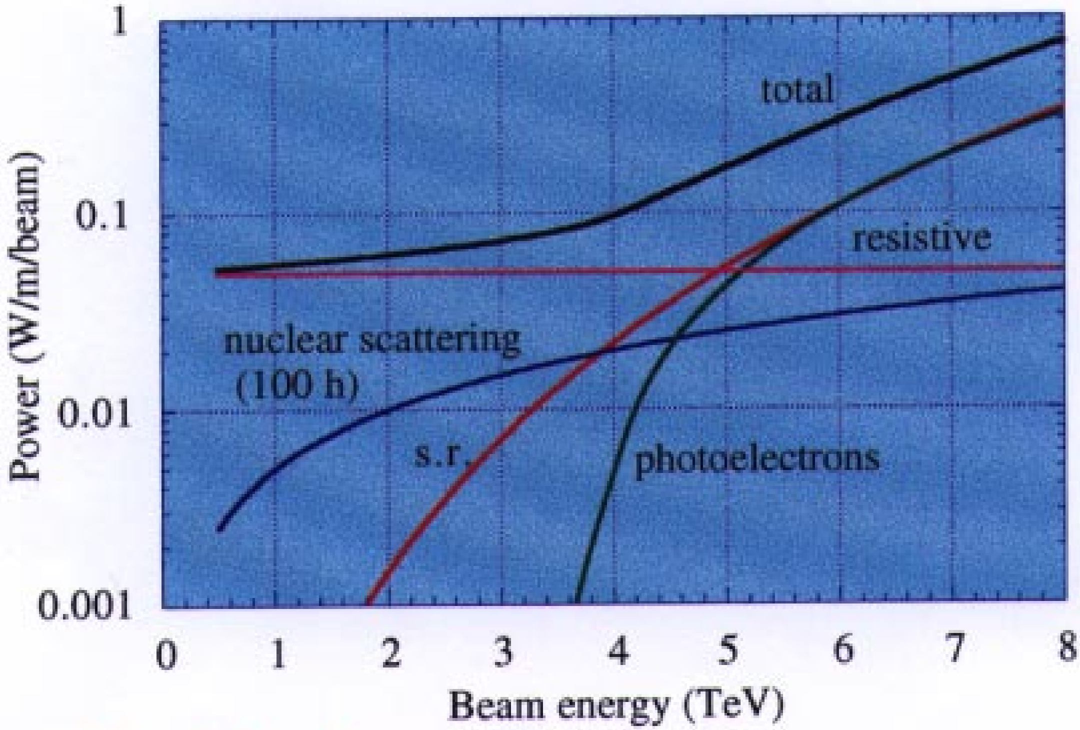
Cryogenics

----> heat load to 1.9 K

Beam dynamics

----> aperture
----> impedance limits
----> material properties

Beam induced heat load in the LHC vacuum system



1) Resistive losses

$$P \propto \rho_w I^2 \leq 0.05 (W/m)$$

2) Synchrotron radiation, (s.r.)

$$P(W/m) = 1.24 \cdot 10^3 \frac{E^4(TeV)\, I(A)}{\rho^2(m)}$$

3) Photoelectrons

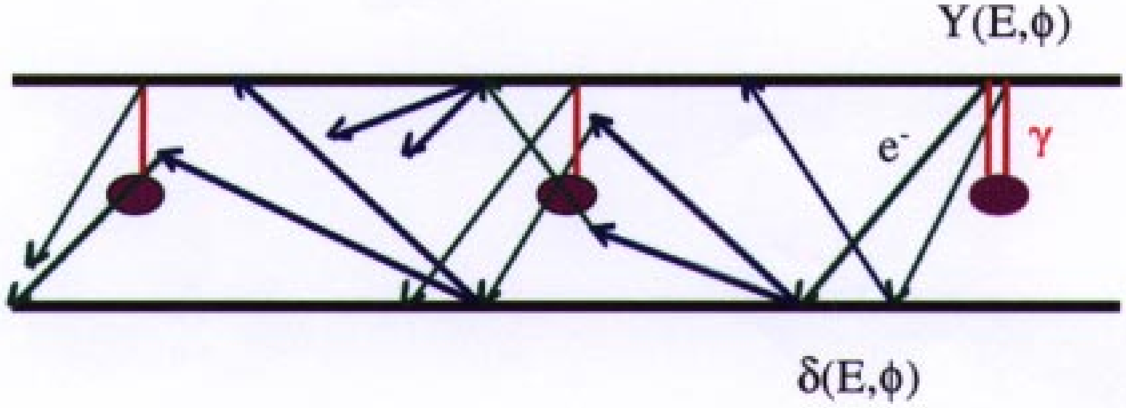
s.r. creates an electron cloud

4) Nuclear scattering

$$P(W/m) = 0.93 \frac{I(A)\, E(TeV)}{\tau(h)}$$

Beam screen removes #1, #2 and #3
#4 sets a limit for the beam lifetime

Electron cloud generated heat load in the LHC beam screen



Key parameters

Synchrotron radiation intensity, γ

$Y(E,\phi)$ photoelectric yield

$\delta(E,\phi)$ secondary electron yield, E_{max}, δ_{max}

Energy distribution of secondary electrons

Photon reflectivity (magnetic field)

Beam screen shape and diameter

Bunch intensity and spacing

External fields (magnetic, electric, space charge)

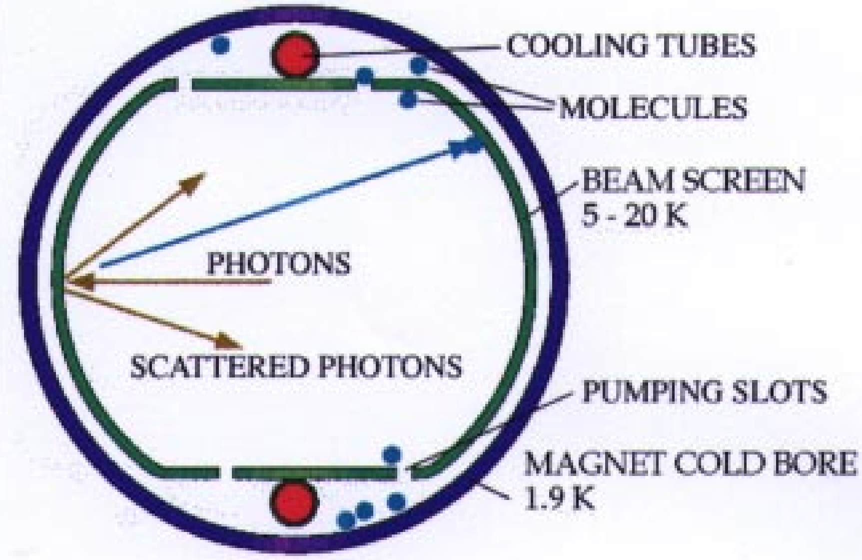
LHC vacuum with synchrotron radiation.

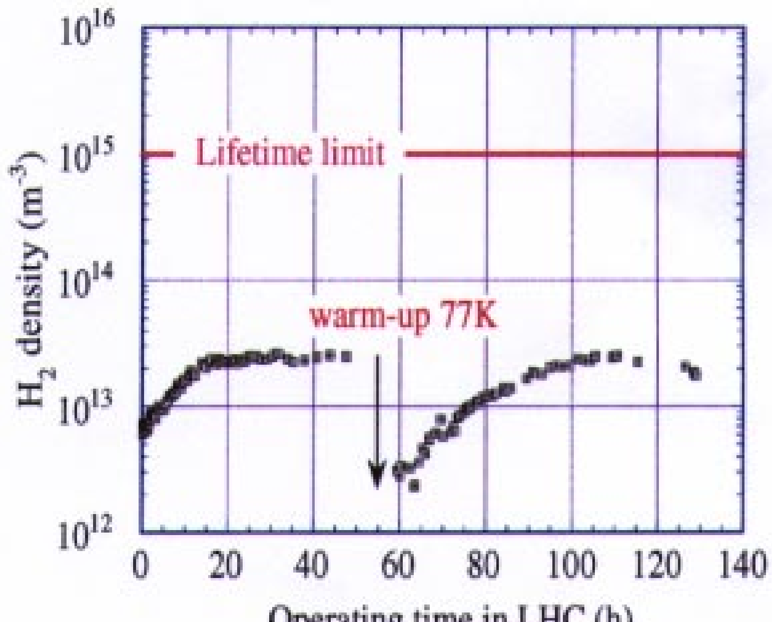
Synchrotron radiation photons desorb strongly bound gas molecules which are cryosorbed and gradually accumulate on the cold beam screen.

Scattered/reflected photons re-desorb these molecules at a rate increasing with coverage, leading in turn to an increasing gas density (pressure).

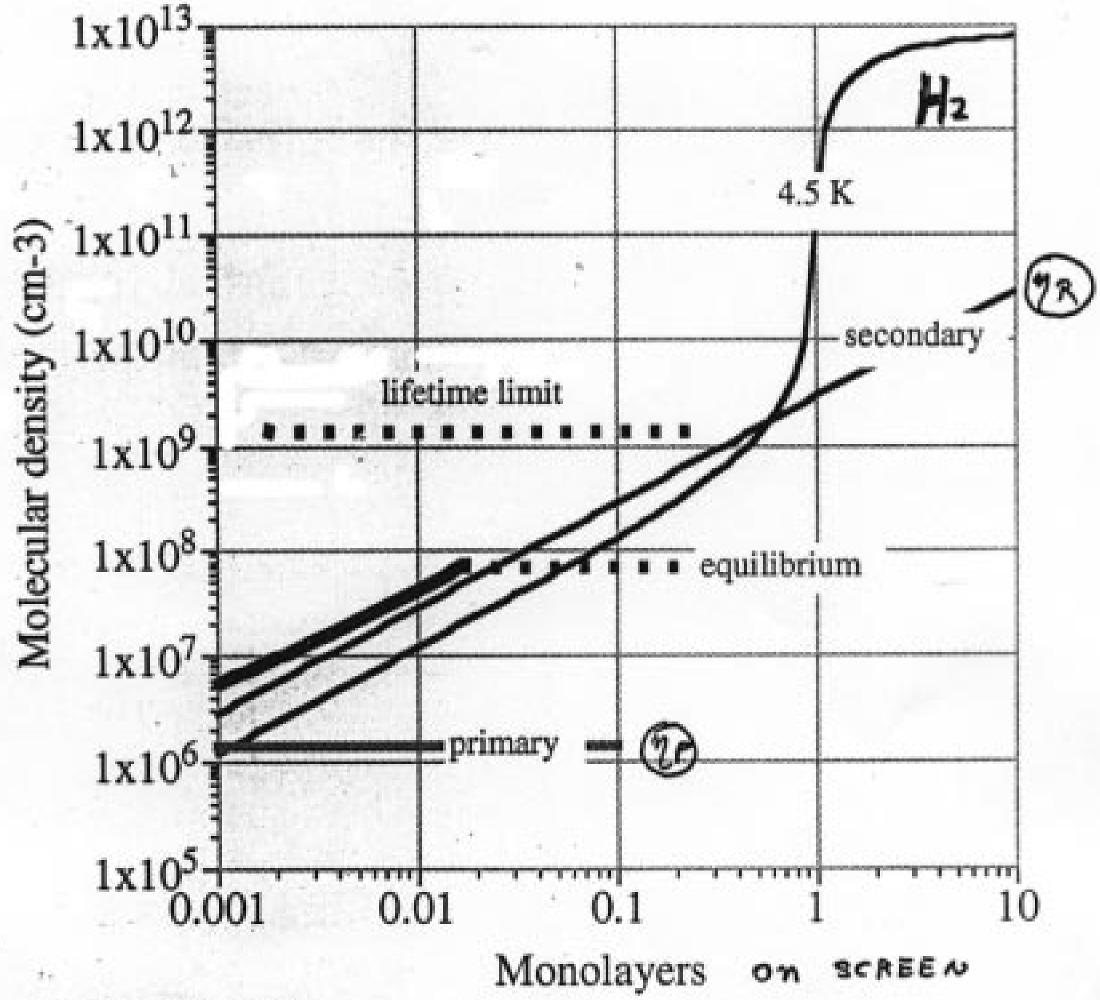
The increase in pressure due to 'recycling' of molecules increases the probability for gas to escape through the pumping slots and to be permanently cryosorbed on the 1.9K cold bore. This effect stabilises the gas density in the beam pipe to a safe value.

Without pumping slots, the beam screen would have to be warmed-up periodically to pump-out condensed gas.





Test run at INP in Novosibirsk, scaled to LHC parameters and for initial operation at ~1/10 of the nominal beam current, illustrating the effect of recycling of gas and warming-up of the beam screen.



primary density rise

$$\Delta n_p = \eta_p \frac{dN\gamma}{ds\,dt} \frac{1}{S}$$

the screen provides $S = \sqrt{\dfrac{k\,T}{2\,\pi\,m_o\,M}}\;U$

for a unit sticking probability

recycling of physisorbed gas is proportional to $\eta_r\,\Theta$

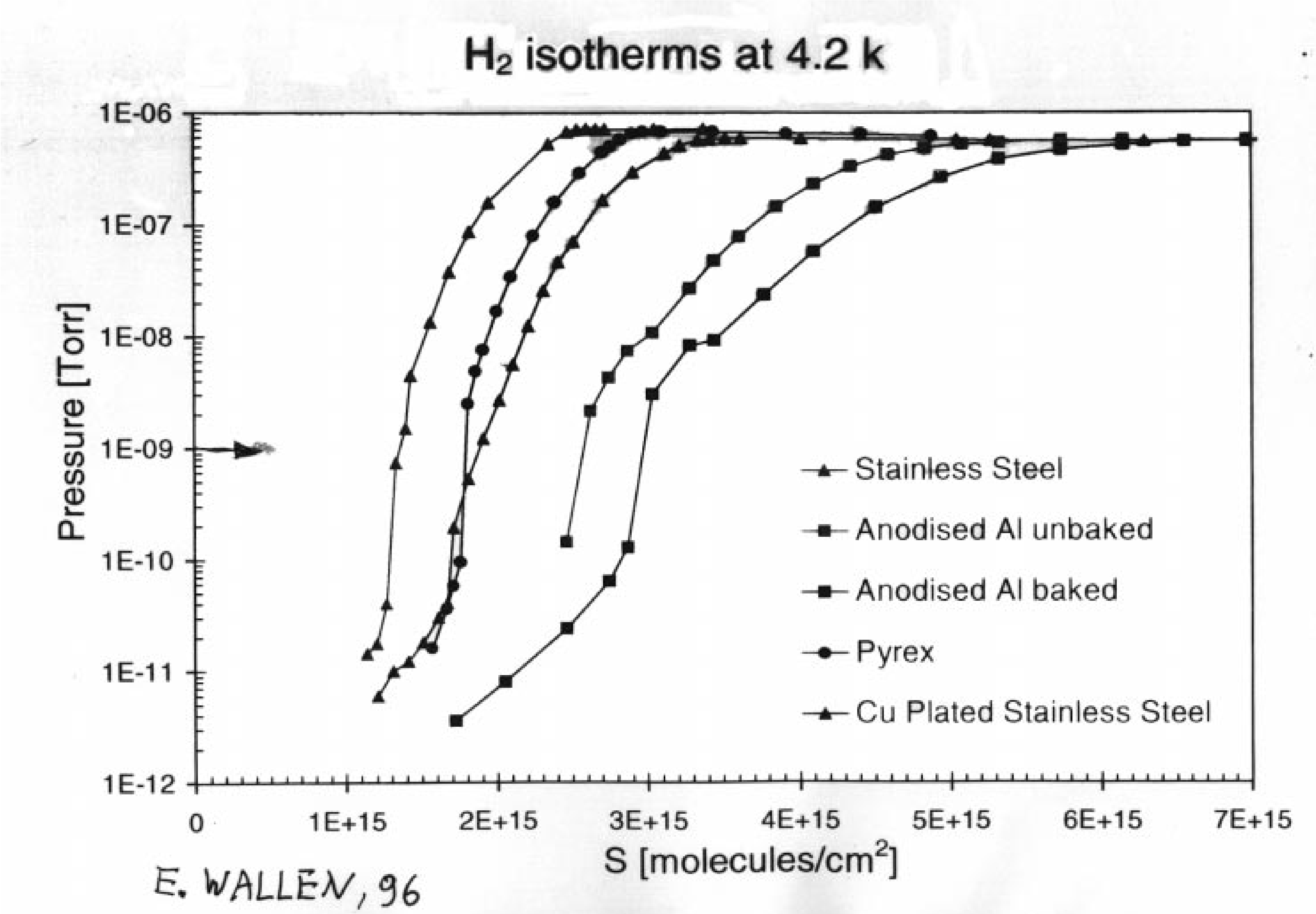
the thermal vapour pressure of condensed H_2 -> $n_T(T,\Theta)$

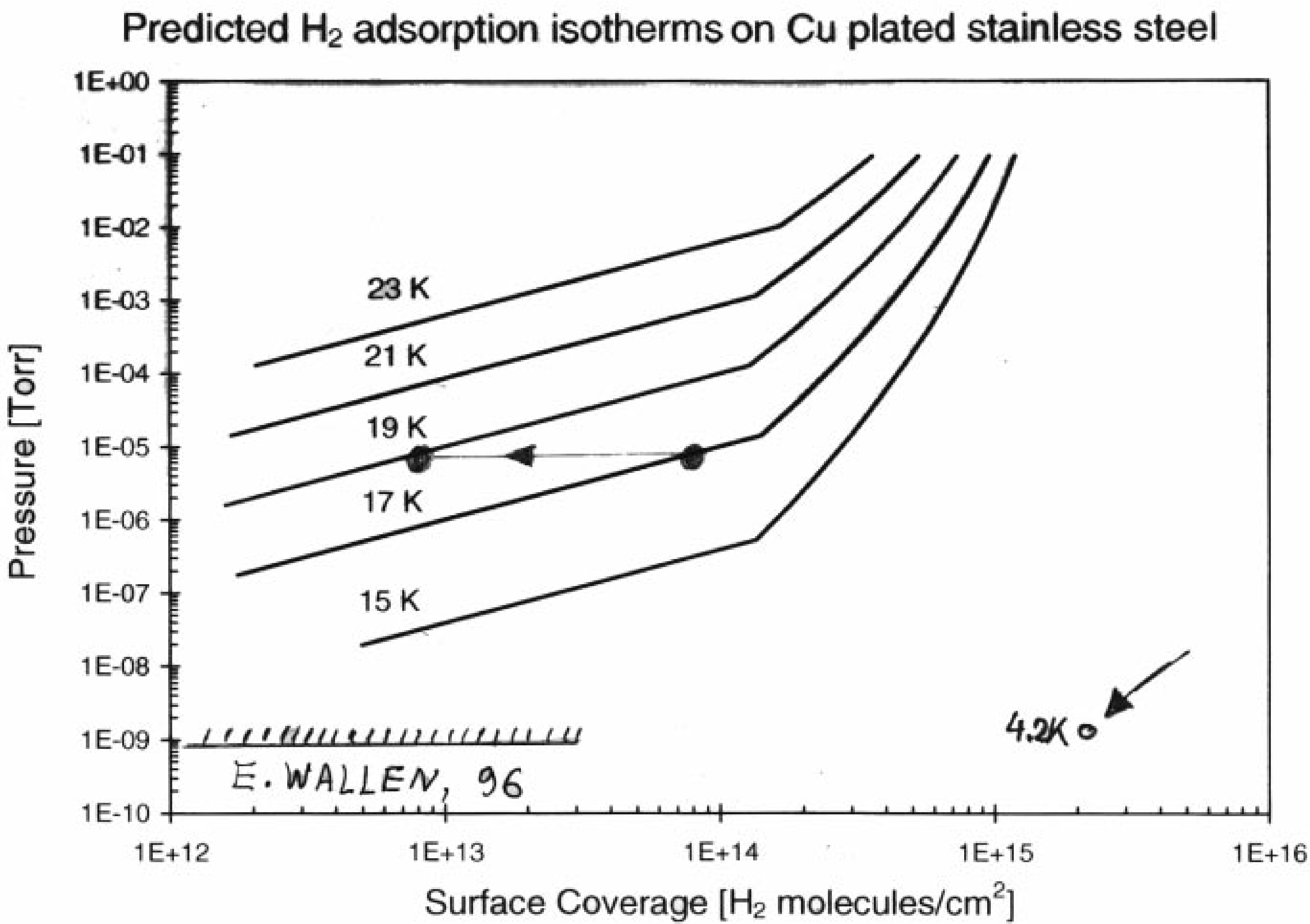
total density $n = (\eta_p + \eta_r\,\Theta)\,\dfrac{dN\gamma}{ds\,dt}\,\dfrac{1}{S} + n_T(T,\Theta)$

the steady state density is given by pumping through the holes

$n_{equ} = \eta_p\,\dfrac{dN\gamma}{ds\,dt}\,\dfrac{1}{f\,S}$

desorbed molecules ≡ pumped molecules


H2 isotherms at 4.2 k
1E-06
1E-07
1E-08
1E-09
1E-10
1E-11
1E-12
Pressure [Torr]
0
1E+15
2E+15
3E+15
4E+15
5E+15
6E+15
7E+15
S [molecules/cm2]
Stainless Steel
Anodised Al unbaked
Anodised Al baked
Pyrex
Cu Plated Stainless Steel
E. WALLEN, 96


Predicted H2 adsorption isotherms on Cu plated stainless steel
Pressure [Torr]
1E+00
1E-01
1E-02
1E-03
1E-04
1E-05
1E-06
1E-07
1E-08
1E-09
1E-10
23 K
21 K
19 K
17 K
15 K
E. WALLEN, 96
4.2K
1E+12
1E+13
1E+14
1E+15
1E+16
Surface Coverage [H2 molecules/cm2]

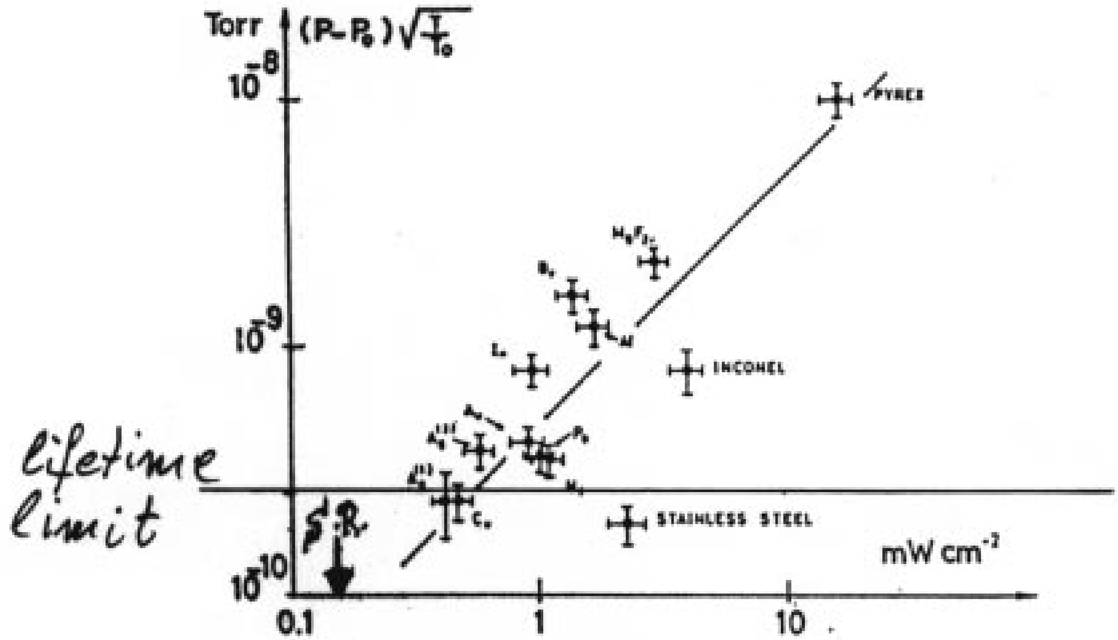


FIG. 14. Saturated vapor pressures of H_2 condensed on different cryosurfaces (at 2.3 K and fully exposed to radiation from 300 K) versus the radiation power absorbed. The line represents the best fit with slope 1 to plotted results.

J. Vac. Sci. Technol., Vol. 13, No. 6, Nov./Dec. 1976

Benvenuti, Calder, and Passardi: Influence of thermal radiation

SR in LHC = 0.14 mW/cm^2

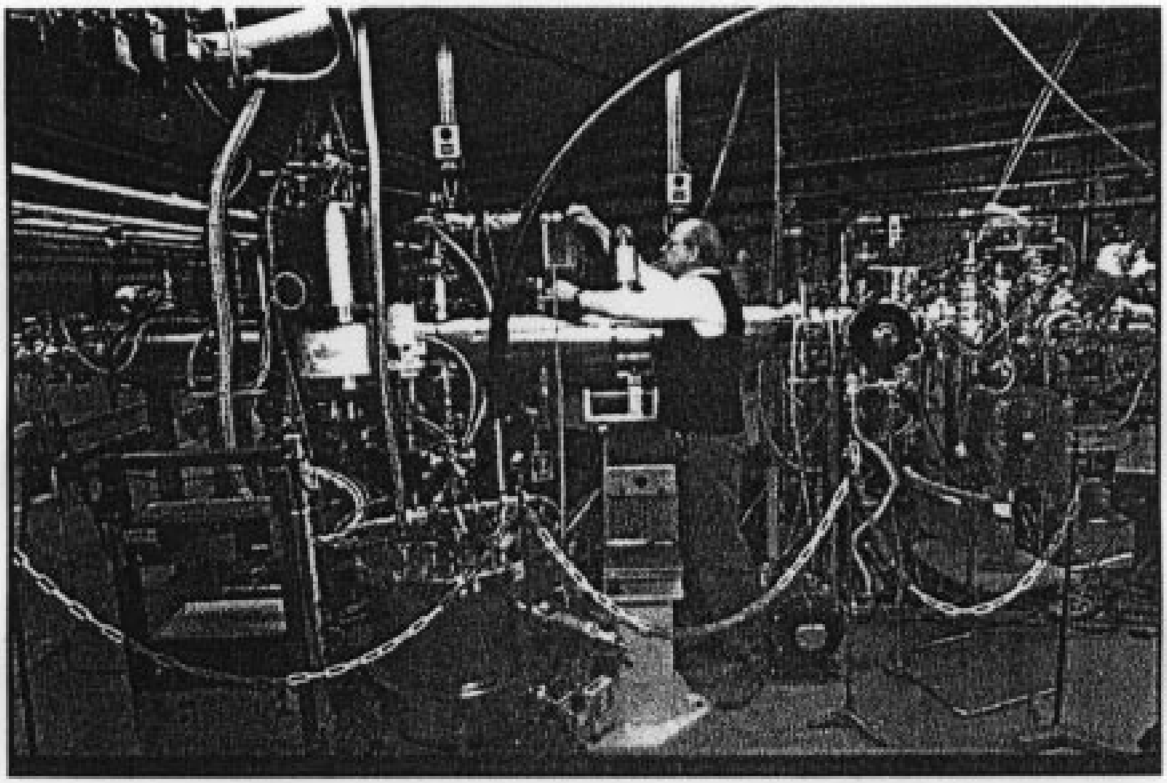
$$n[m^{-3}] = \frac{133\ P(\text{torr})}{1.38 \cdot 10^{-23}\ T(K)}$$

lifetime limit in LHC ≙ $10^{15}\ m^{-3}$

corresponding pressure at 2.3K = $2.4 \cdot 10^{-10}$ torr

COLDEX (Cold Bore Experiment)

Figure: COLDEX installed in EPA at CERN (Electron Positron Accumulator), March 1998.



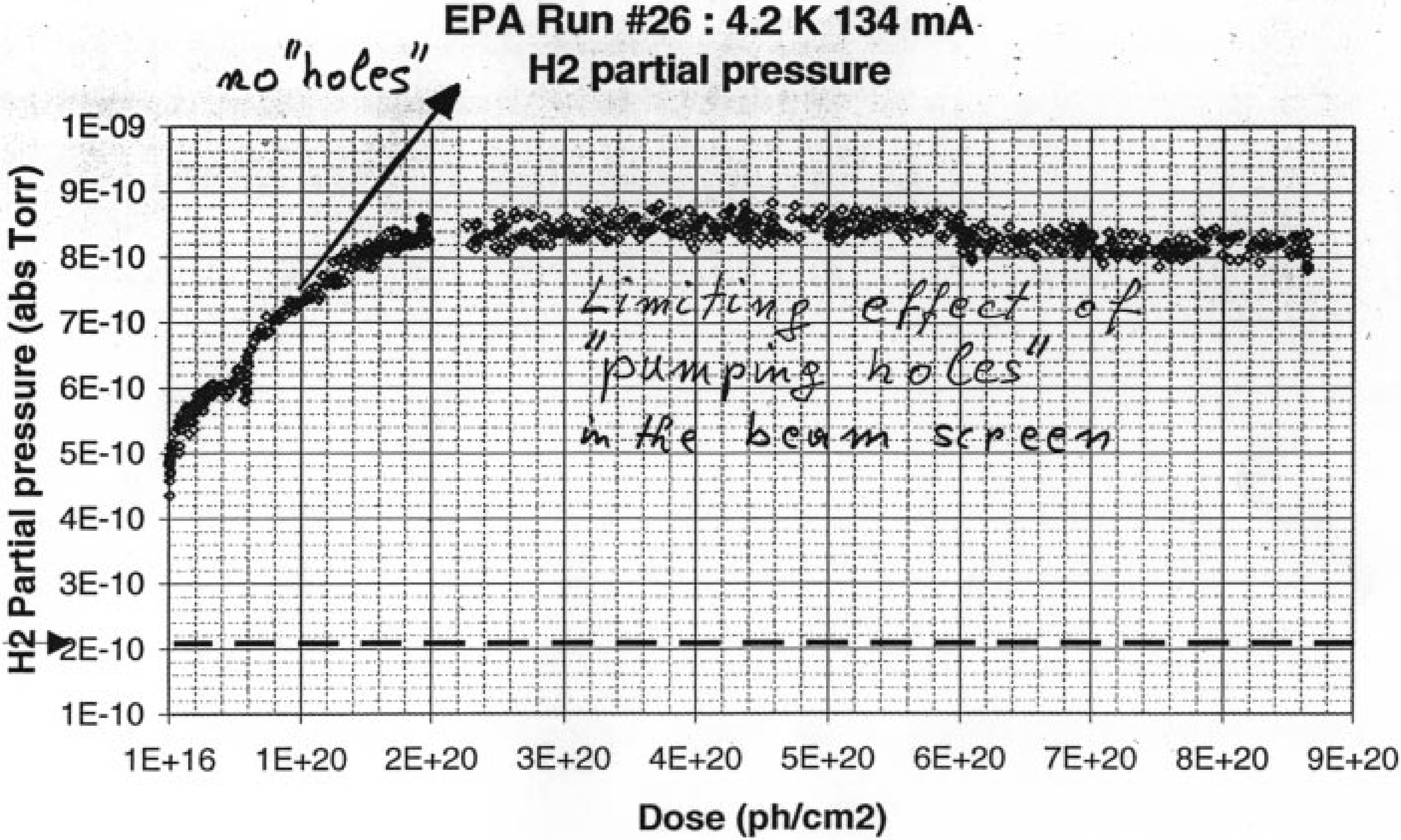
COLDEX is dedicated to study LHC vacuum conditions as close as possible to real conditions:

1. Cold Bore at 1.9 K
2. Beam screen temperature variable between 5 K and 60 K
3. Will make use of synchrotron light source in EPA (Electron Positron Accumulator) at CERN.

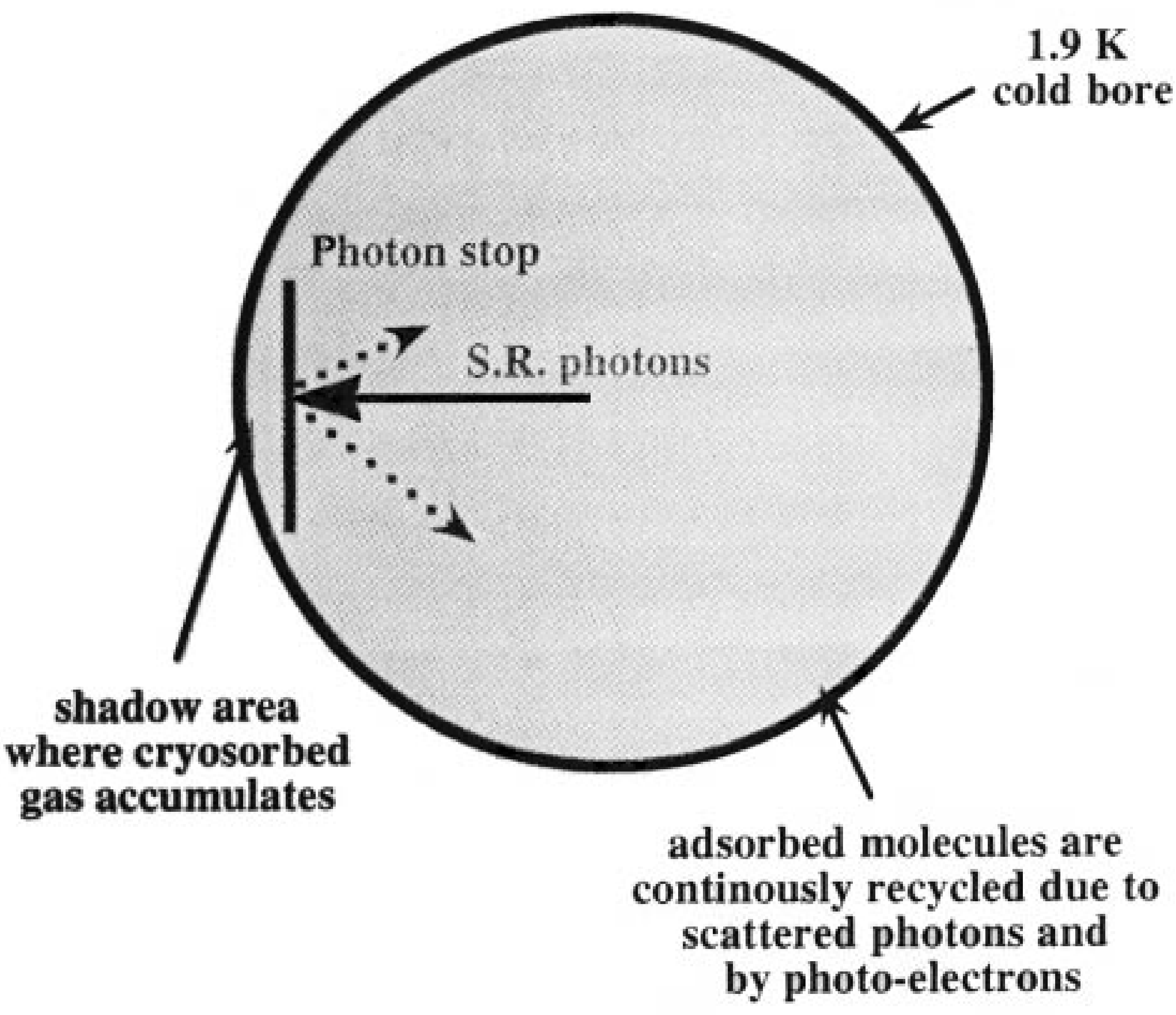
Main subjects:

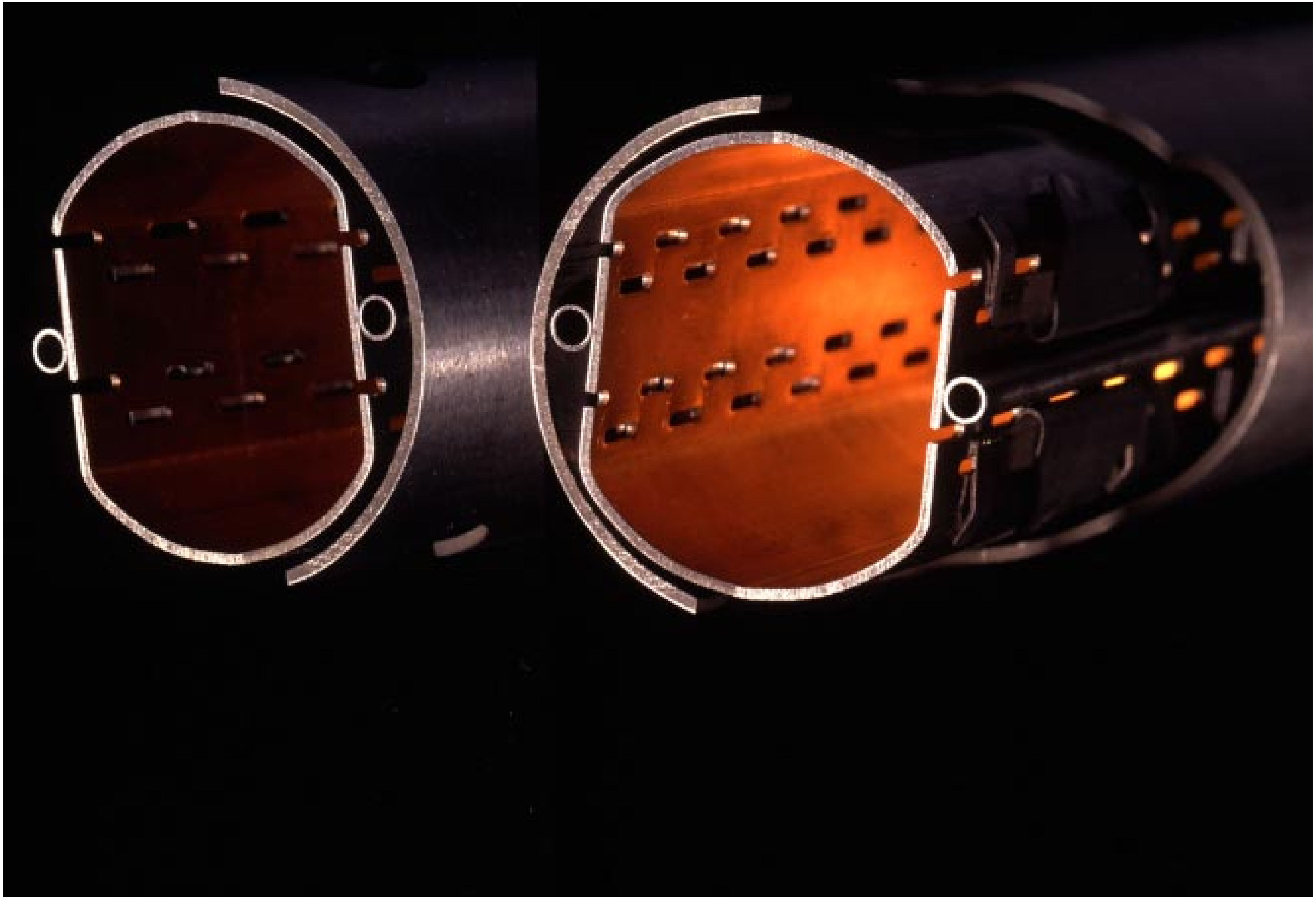
1. Synchrotron radiation induced desorption of molecules from the beam screen surface.
2. Studies on synchrotron radiation induced photoelectron cloud.

COLDEX was built in a collaboration with NIKHEF and CERN.
Delivery at CERN: November 1997

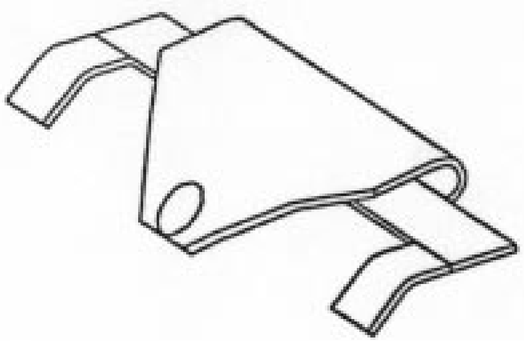

EPA Run #26 : 4.2 K 134 mA
H2 partial pressure
no "holes"
Limiting effect of "pumping holes" in the beam screen
H2 Partial pressure (abs Torr)
1E-09
9E-10
8E-10
7E-10
6E-10
5E-10
4E-10
3E-10
2E-10
1E-10
1E+16
1E+20
2E+20
3E+20
4E+20
5E+20
6E+20
7E+20
8E+20
9E+20
Dose (ph/cm2)

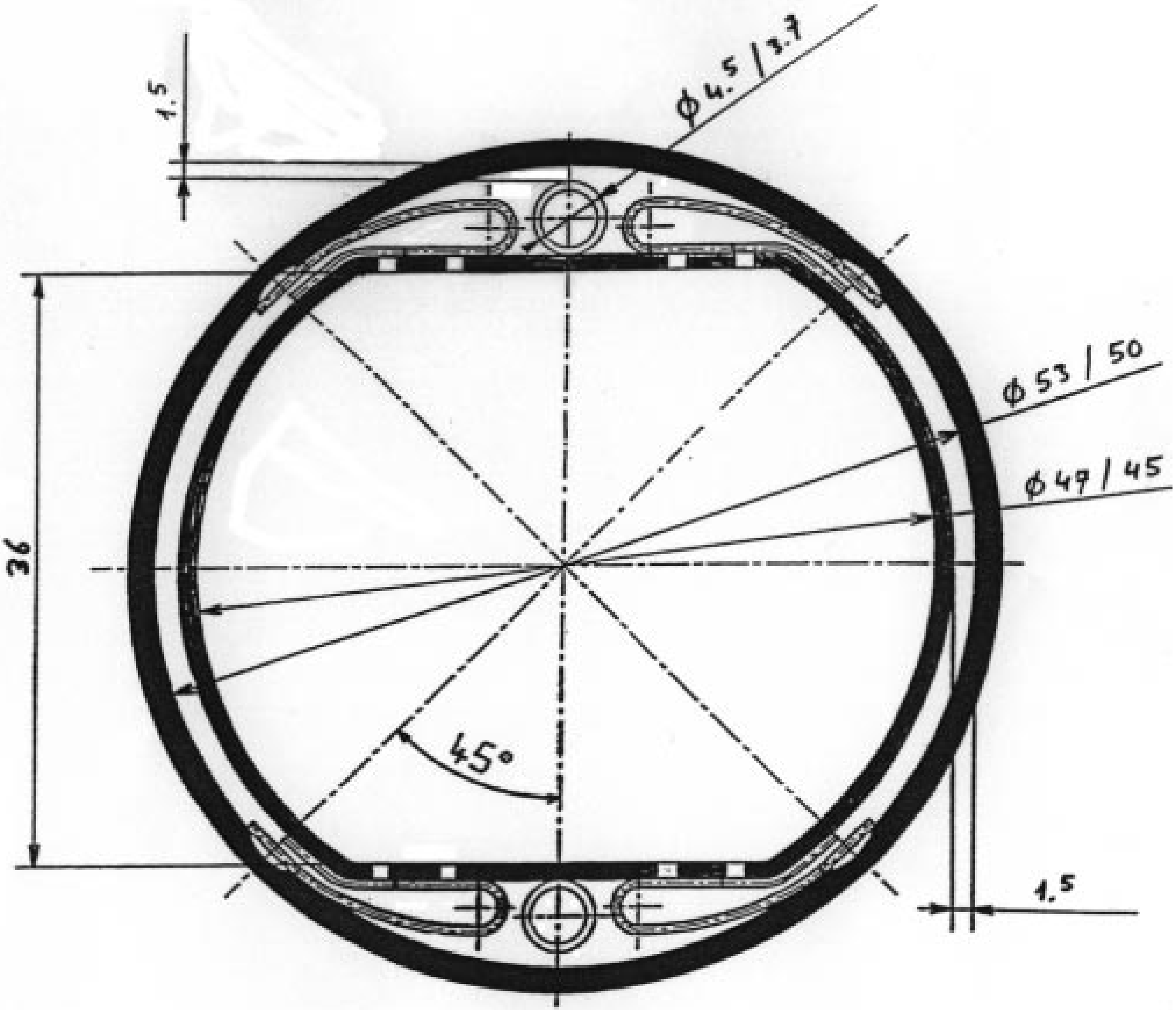
LHC Beam-Vacuum





Beam Screen Straightness	Horizontal Aperture	Vertical Aperture
0.3 mm/m	X = 21.6 mm	Y = 17.1 mm
0.5 mm/m	X = 21.4 mm	Y = 16.9 mm



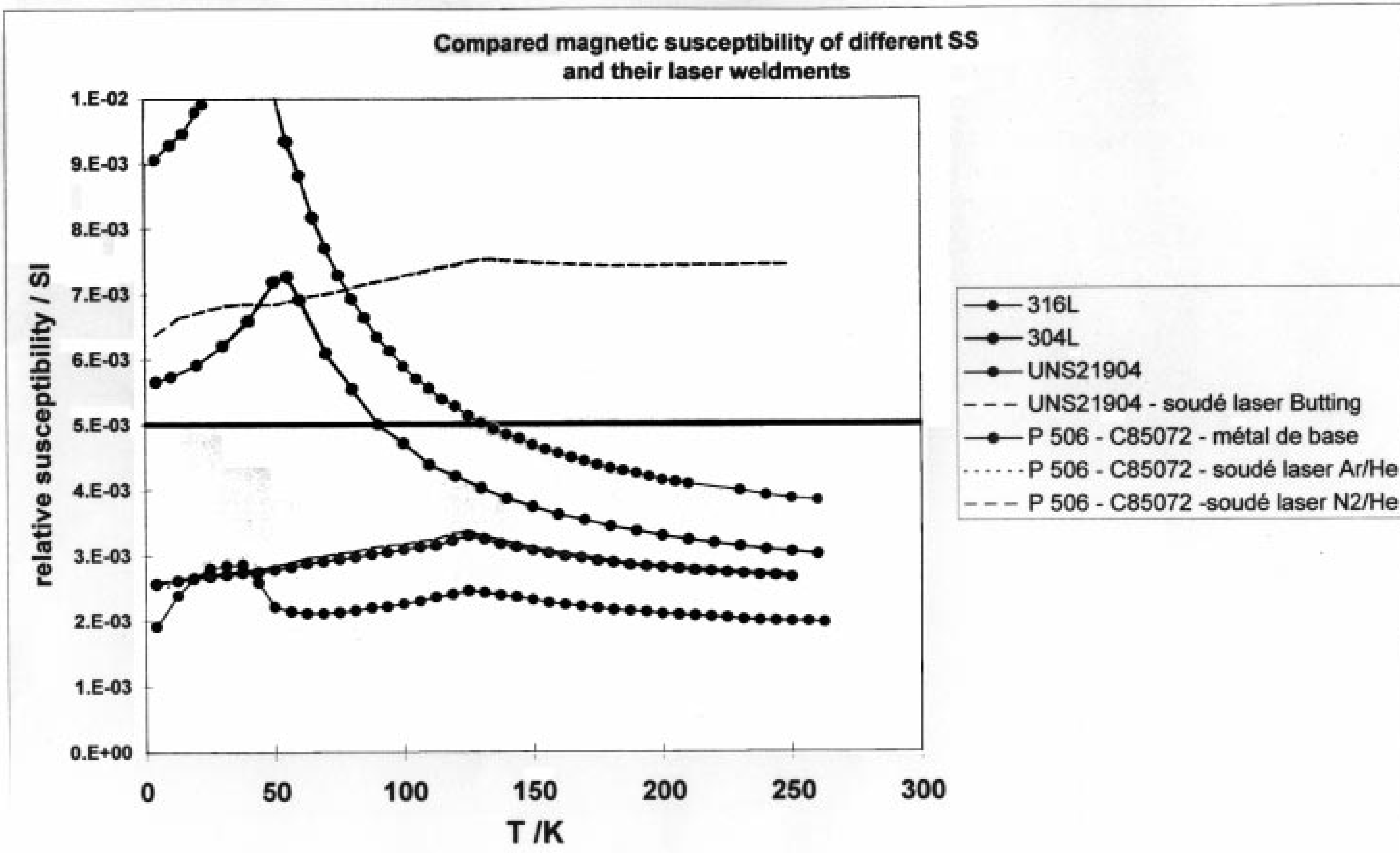


Cold Bore ID Φ 50 mm

LHC Beam Screen Parameters

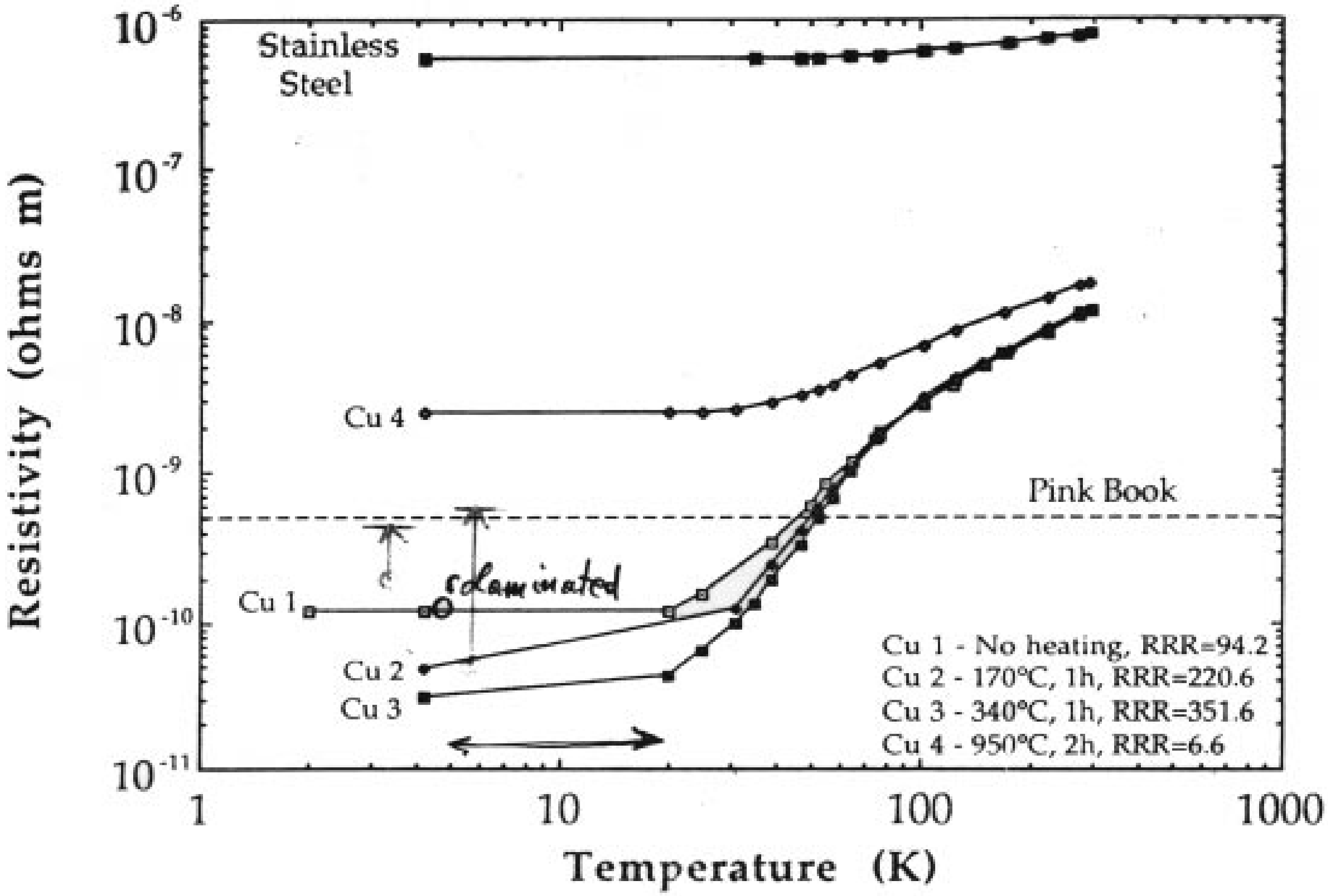
Aperture	**44/36 mm > 6 σ_{beam}**
Length	**~ 15 m**
Wall thickness	**1 mm**
Magnetic permeability	**<1.005**
Material	**Mn alloyed stainless steel**
Supports	**Ultem or Ti 4@1.7m**
Temperature	**5 - 20 K**
Heat transport	**< 1 W/m**
Cooling tubes	**2 (Φ 3.7 mm)**
Heat leak to 1.9 K	**< 0.05 W/m**
Impedance (longit.)	**< 0.5 Ohm**
transvrs, resistive	**< 10 GOhm (@ 3.3 kHz)**
Quench resistance	**> 50 Quenches**
	@B dB/dt = 300 T^2s^{-1}
Quench Stress	**< 340 MPa**
Deformation	**< 0.5 mm**
Copper coating	**50 μm (RRR = 100)**
Hole area, fraction	**~ 2% (~660 holes/m)**
Radiation resistance	**10^9 rad**

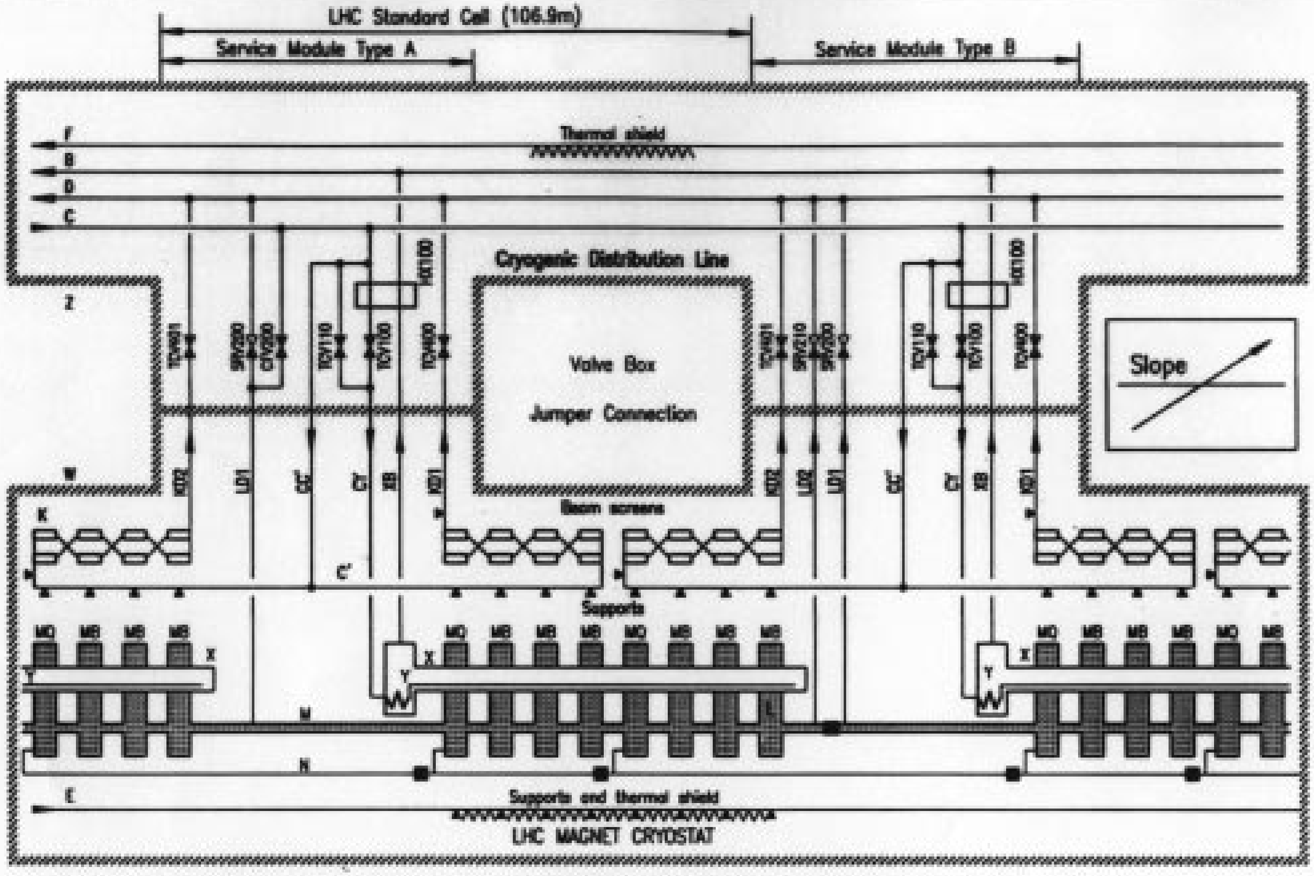
* 7P8 F. Ruggiero et al.



Ref. / S. Sgobba, proceedings du Cycle Métaux et Procédés, Cip - Tramelan (CH), 4-8 nov. 1996, vol. Journée soudage - page 8/1-10
/ S. Sgobba, G. Hochoertler, International Congress Stainless Steel 1999, to be published

The Electrical Resistivity of Cu Plated Stainless Steel as a Function of Temperature





Legend: CFV= Cooldown and Fill Valve, TCV= Temperature Control Valve, SRV= Safety Relief Valve, HX= Heat Exchanger, ■= Hydraulic plug, MQ= main Quadrupole, MB= main Dipole

Flow-scheme of LHC standard cell, service modules A and B

Schema cryogenique de la cellule standard LHC modules de service A et B

DES/DRA.	R. ASKOVIC	1998-07-03
CONTROLLED	N. VEILLET	1998-08-21
RELEASED	G. RIDDONE	1998-08-21
APPROVED	P. LEBRUN	1998-10-15

ECHELLE SCALE —

LHC\LSQR_0\LSQR_002

RELEASED BY PROJECT LEADER OFFICE — FOR INFORMATION

LHCLSQR_0002 3 A

IND.	DATE	NOM/NAME	ZONE	MODIFICATION
A	1998-08-21	J-M BIANCO		update

Long straight sections

Room temperature sections:

Cu chambers ~ 2mm wall thickness

vacuum stability with ion desorption

bakeout between 150 - 300°C

Cold parts

sofar, very preliminary studies only

limited physical aperture

reduced level of synchrotron radiation

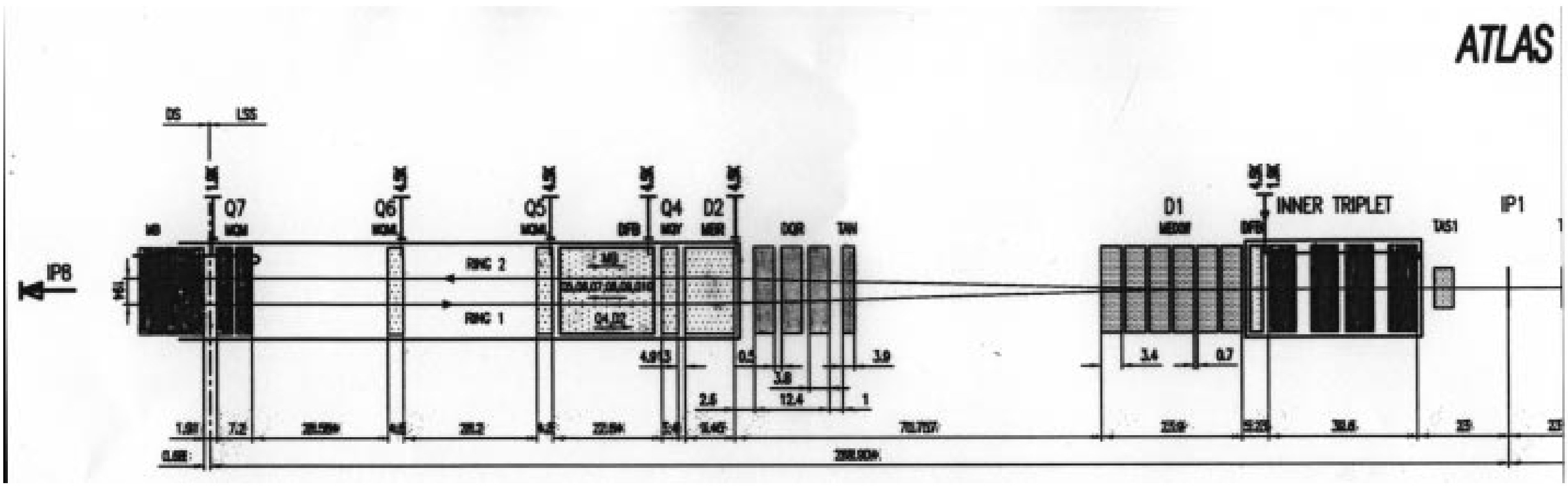
remains -> desorption by electrons and ions

Cryopumping at 1.9 K -> 'dummy' beam screen

(see buffles used in commercial cryopumps)

Sections with 4.5 K -> H_2 vapour pressure

requires special Cryosorbers


ATLAS
DS
LSS
Q7
Q6
Q5
Q4
D2
D1
INNER TRIPLET
IP1
IP8
RING 2
RING 1
TAN
TAS1
3.4
0.7
3.9
2.6
12.4
1
7.2

I. Collins, O. Gröbner, MAC, 2nd Nov. 1998

Vacuum choices

Below ~25 K all gases apart from H_2 and He (Ne) will be cryosorbed in large quantities and at negligible vapour pressure. These surfaces must be protected from s.r. photons + photoelectrons to avoid 'recycling' of gas

Option 1: (not in present base line design)

Extension of the existing design in the arcs:

-> dummy cold bore (DCB) with < 3K and a special beam screen
(note: no magnetic field, larger aperture, copper beam screen with end cooling)

sections without beam screen -> pressure bumps due to 'recycling' of H_2, -> may require a small fraction of the DCB surface to be shadowed

Option 2:

DCB at 5 K< T < 25 K
-> implies use of cryosorbing material to pump H_2 including a special beam screen (to shield the cryosorber)
-> provisions for the conditioning of the cryosorber (specifically the temperature to be defined)

I. Collins, O. Gröbner, MAC, 2nd Nov. 1998

Present work

Study of cryosorbing materials:
Isotherm measurements
pumping speed,
pumping capacity
temperature for operation and conditioning
radiation resistance, microparticles (charcoal !)
lifetime and total capacity
effect of thermal radiation (low energy part of s.r.) on the vapour pressure

How to incorporate cryosorbing materials in the design (combined with supports of the beam screen?).

Quantify the synchrotron radiation and gas desorption including from quadrupole magnets (since the beam will be off–axis at certain places).

Compatibility with requirements for cryogenics and beam impedance

Potential use of getter coatings

Primary interest:

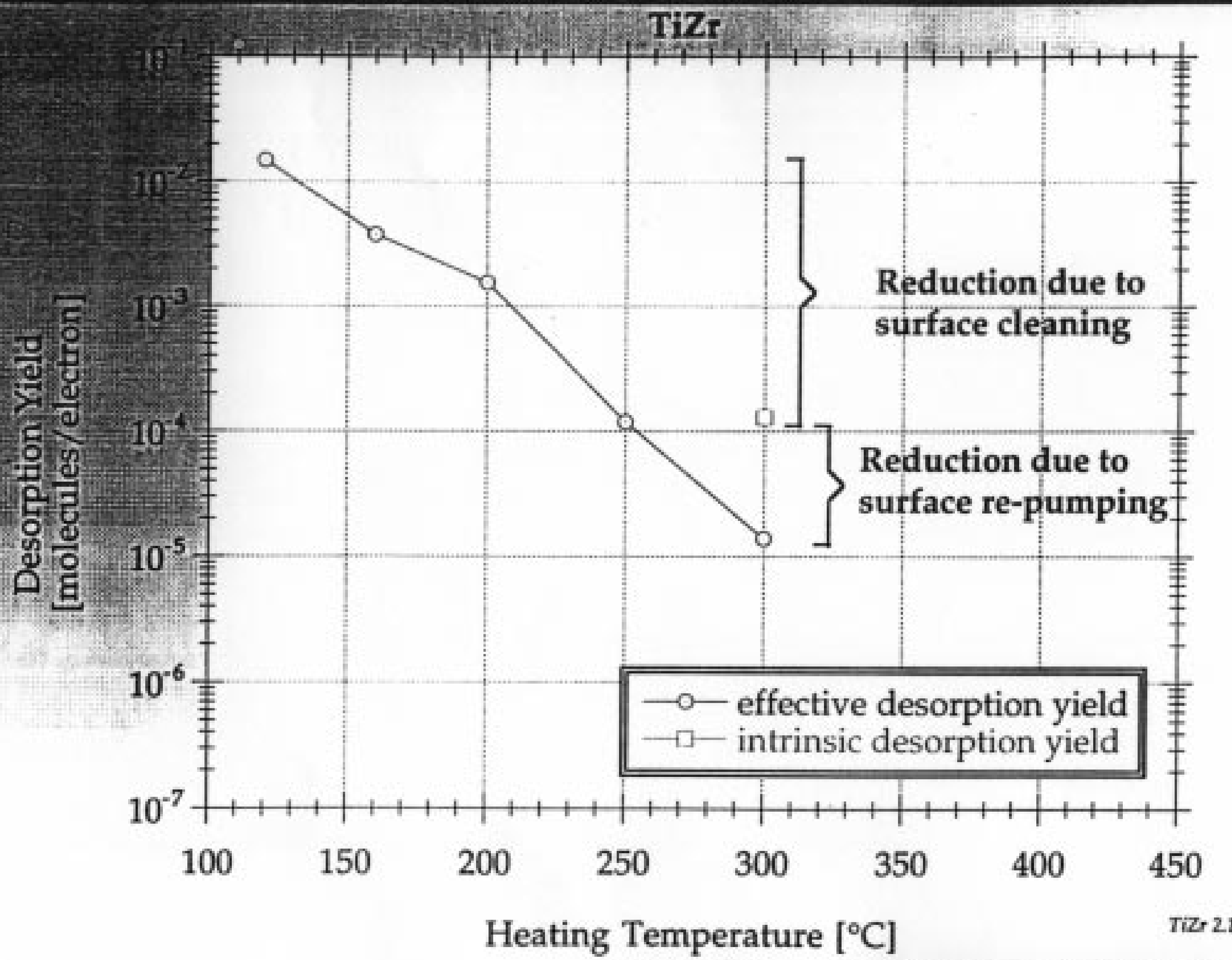
Where the base-line design cannot be applied

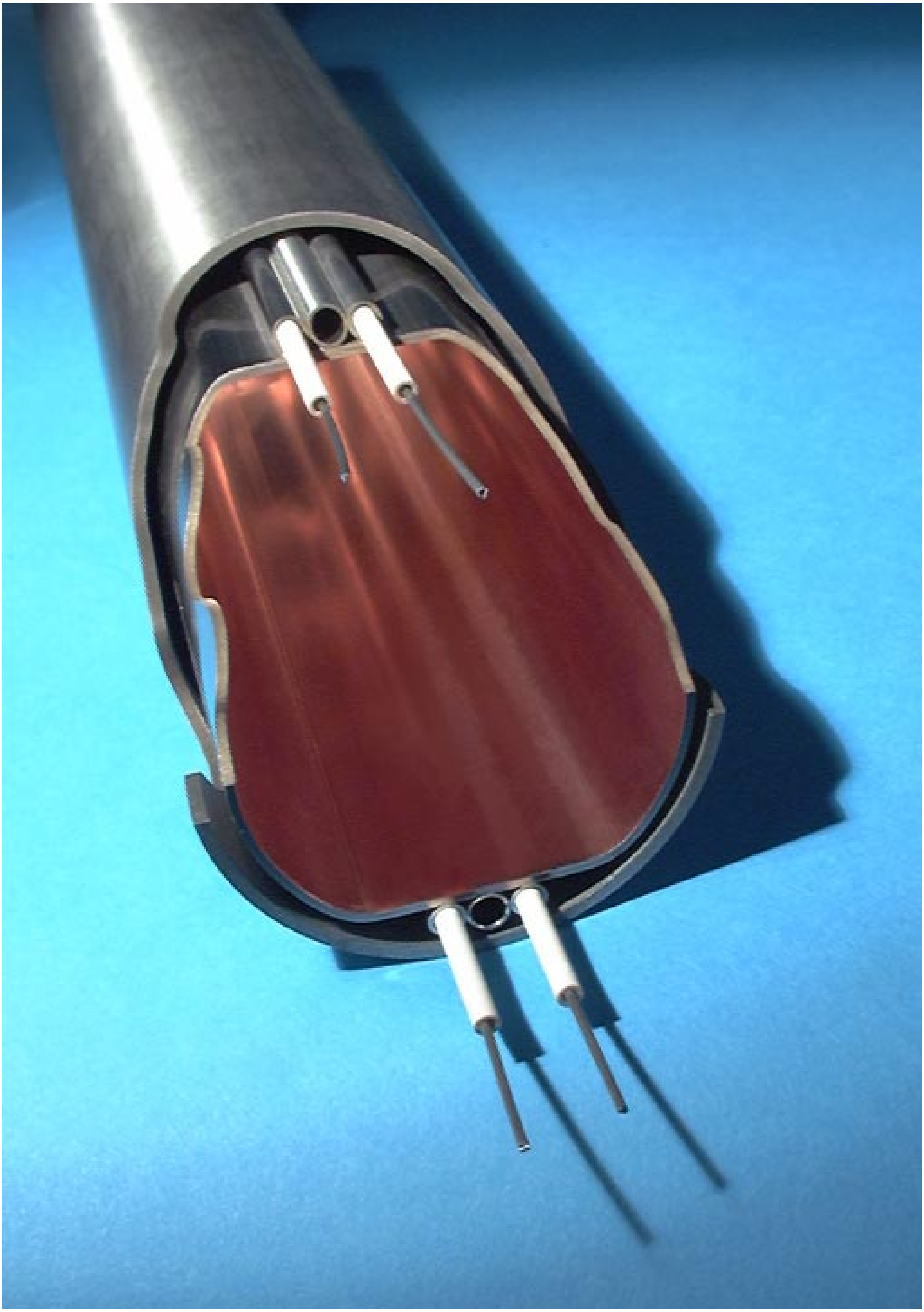
Experimental vacuum chambers

- in-situ bakeout,
- high transparency vacuum chambers,
- distributed pumping speed required

Long straight sections

- regions without a cold bore at 1.9 K which require a 'dummy beam screen'

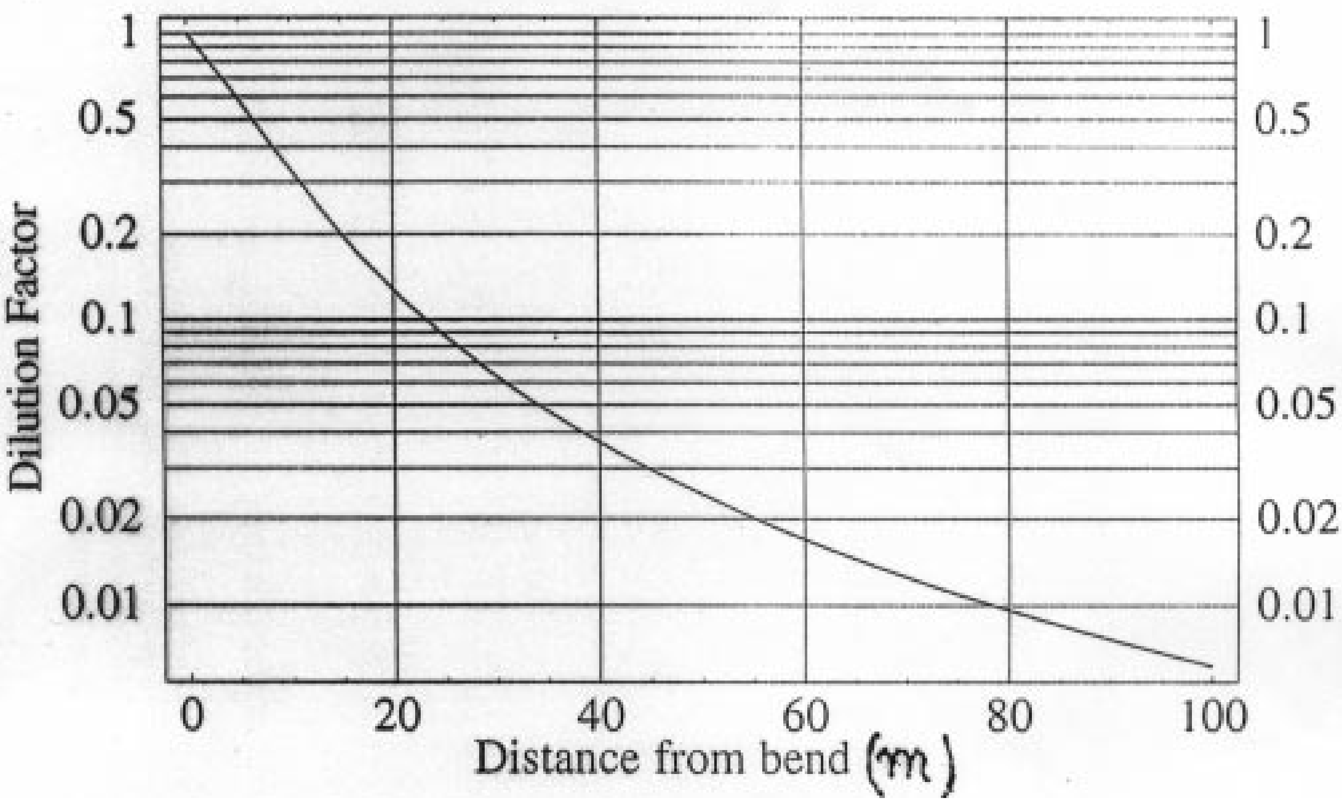

TiZr
Desorption Yield
[molecules/electron]
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
100
150
200
250
300
350
400
450
Heating Temperature [°C]
Reduction due to surface cleaning
Reduction due to surface re-pumping
effective desorption yield
intrinsic desorption yield
TiZr 2.1



Unknowns for the beam screen coating:

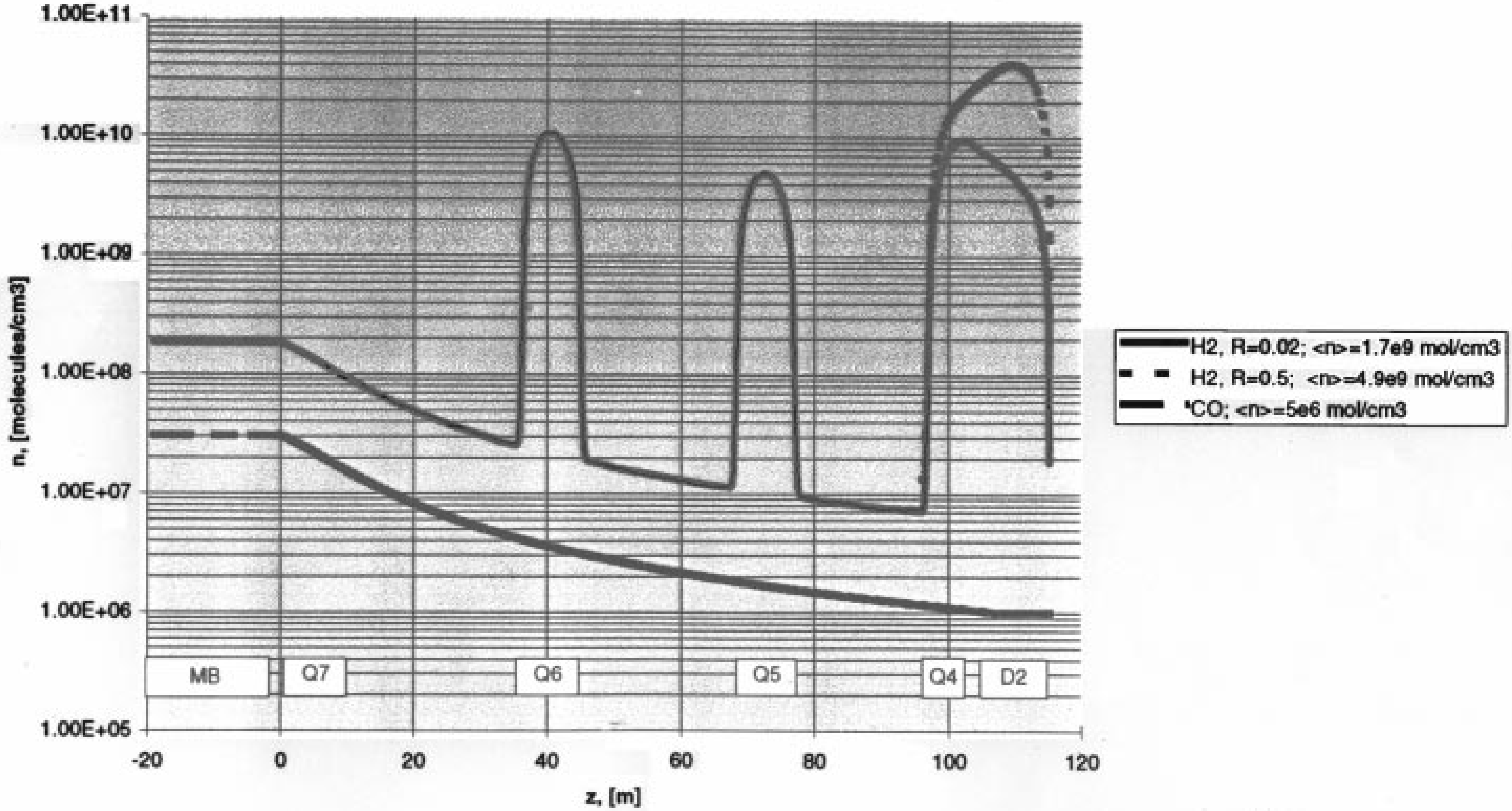
* Performance at cryogenic temperatures
* Intrinsic (primary) desorption rate due to
  - -> S.R. photons at grazing incidence
  - -> Photoelectrons
  - -> Ion bombardment
* Pumping characteristics for:

  H_2, CH_4, N_2, CO, CO_2, Ar and for gas mixtures
* Total pumping capacity
* Lifetime (ventings)

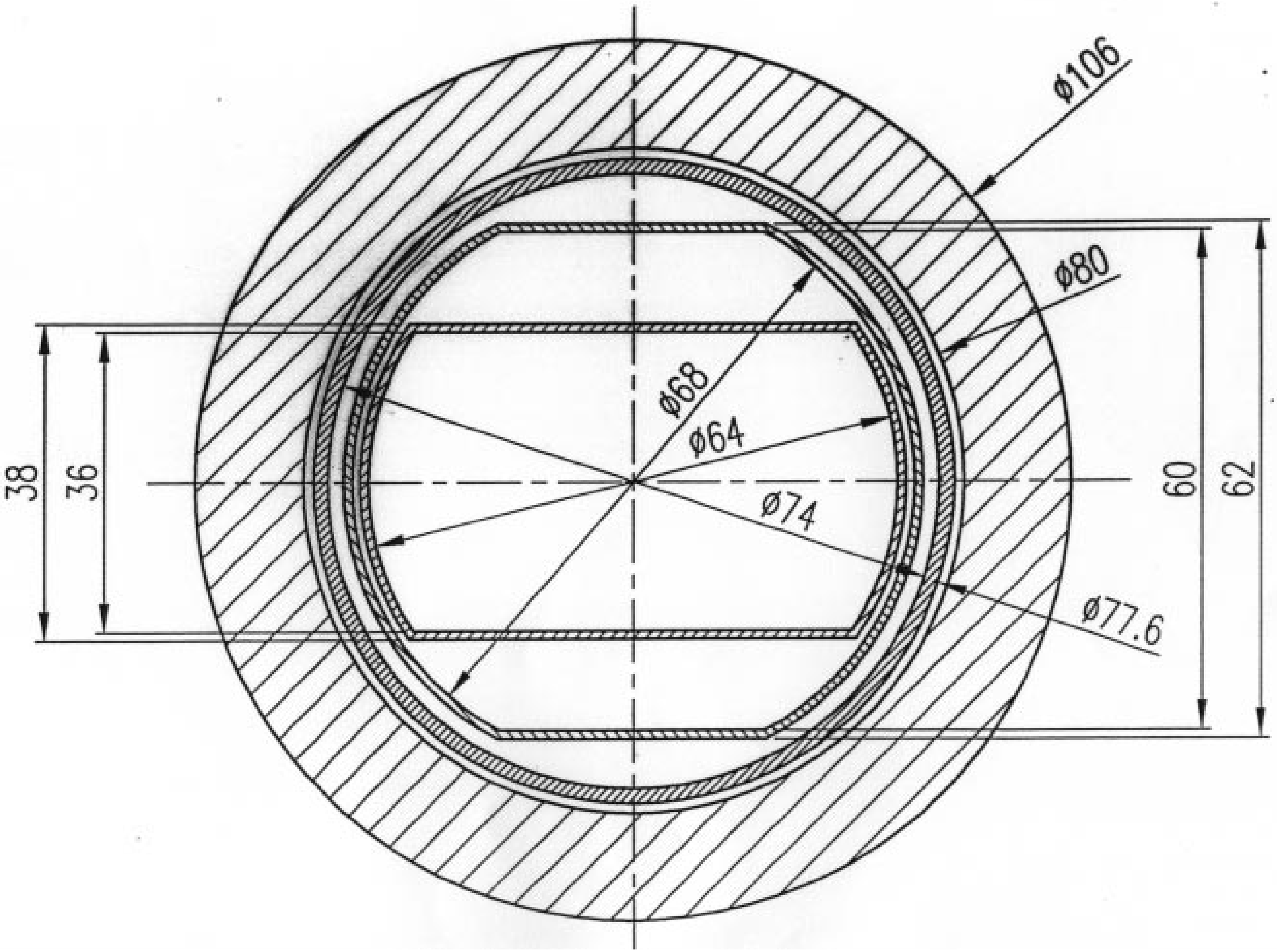


Dilution Factor
1
0.5
0.2
0.1
0.05
0.02
0.01
0
20
40
60
80
100
Distance from bend (m)

The gas density profile in Ring1 for baseline design

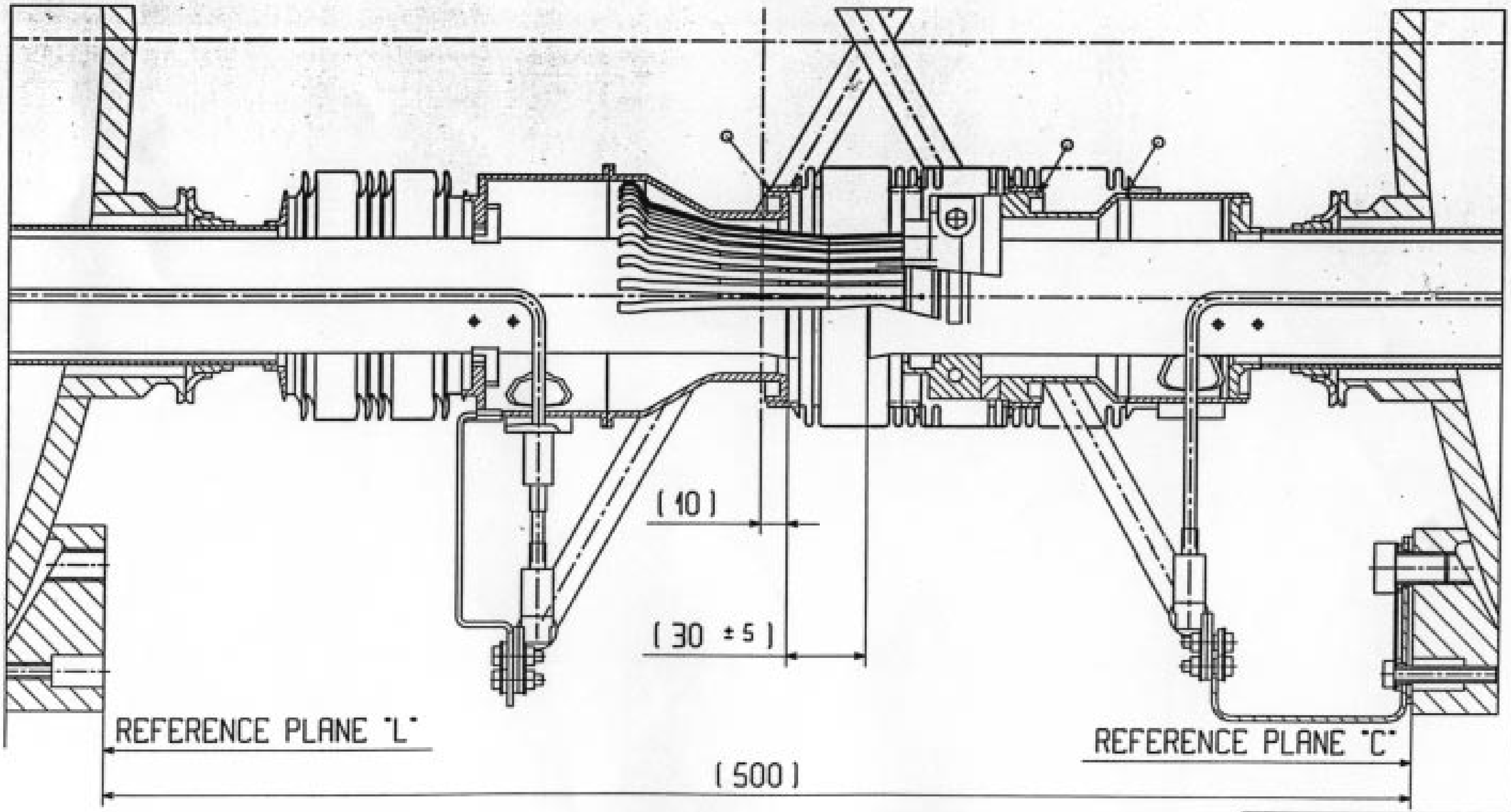


O. Malyshev / INP



ø106
ø80
ø68
ø64
ø74
ø77.6
38
36
60
62

DIPOLE - DIPOLE
V - LINE



KLEIMENOV Victor
14.05.1998