Experience from the LEP Vacuum System

O. Gröbner

CERN, LHC-VAC

Workshop on an e^+e^- Ring at VLHC

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References

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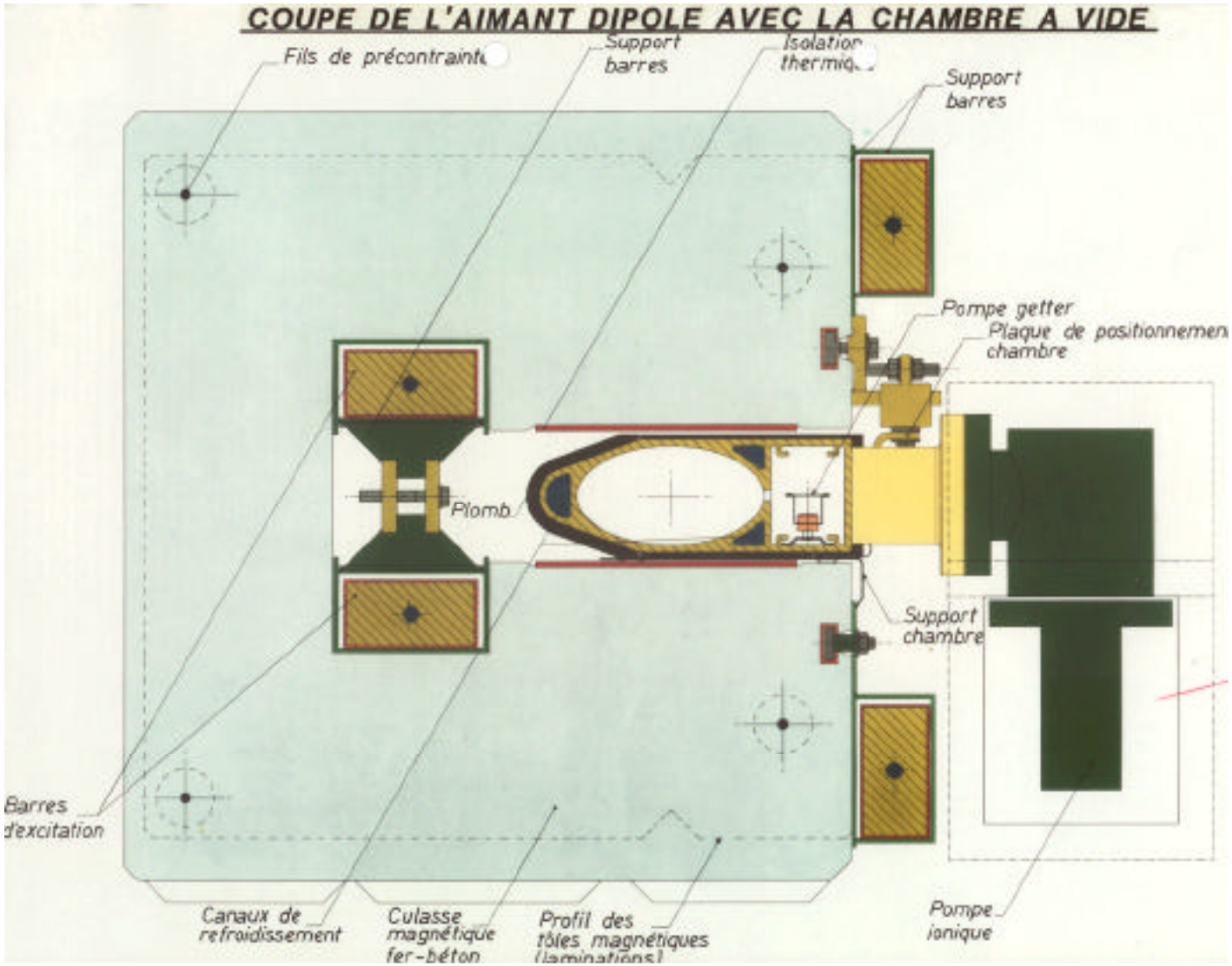
LEP Parameters (initial design phase)

Bending radius	m	3096		
Energy	GeV	20	46	90
Nominal beam current for 4+4 bunches	mA	3+3	3+3	6+6
SR power	$W\ m^{-1}\ mA^{-1}$	0.235	6.56	96.2
Critical photon energy	keV	5.72	69.6	522
Linear photon flux	$m^{-1}\ s^{-1}\ mA^{-1}$	$8.3\ 10^{14}$	$1.9\ 10^{15}$	$3.7\ 10^{15}$
Dose equivalent	photons m^{-1}/Ah	$3\ 10^{21}$	$6.8\ 10^{21}$	1.310^{22}

Vacuum characteristics

Pumping speed					
NEG max./min	500 ($l\ s^{-1}\ m^{-1}$)	30			
Ion pumps approx.	3 ($l\ s^{-1}\ m^{-1}$)				
Base pressure (baked 150°C)	$2 – 5\ 10^{-11}$Torr				
Beam-gas lifetimes	H_2	CH_4	CO	CO_2	A
(nTorr/h)	460	55	28	17.5	9.5


COUPE DE L'AIMANT DIPOLE AVEC LA CHAMBRE A VIDE
Fils de précontrainte
Support barres
Isolation thermiq
Support barres
Pompe getter
Plaque de positionnemen
chambre
Plomb
Support chambre
Barres d'excitation
Canaux de refroidissement
Culasse magnétique fer-béton
Profil des tôles magnétiques (laminations)
Pompe ionique

LEP vacuum chamber section

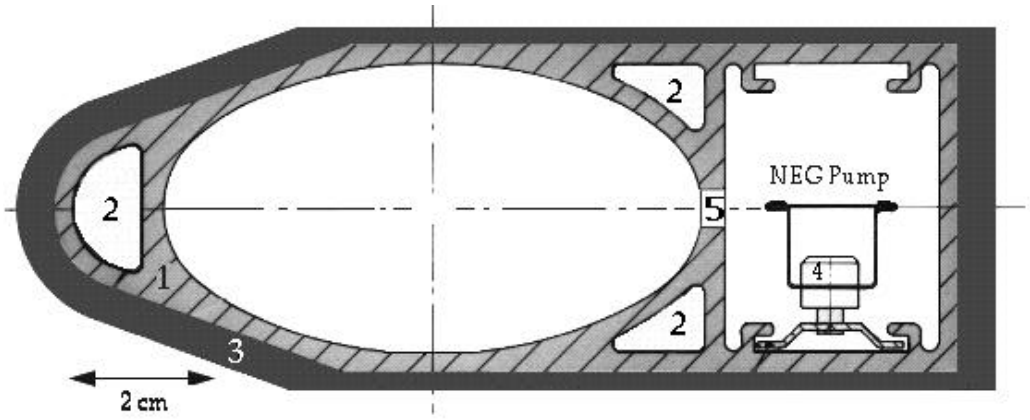


Fig. 2 : Vacuum chamber section made of (1) extruded aluminium profile with the elliptic beam channel, three cooling water ducts (2) and surrounded by 3 to 8 mm thick lead shield (3). The NEG pump (4) is housed in a separate pump channel connected to the beam channel by a row of longitudinal slots (5).

LEP-type bakeable vacuum flange Al to st.st.

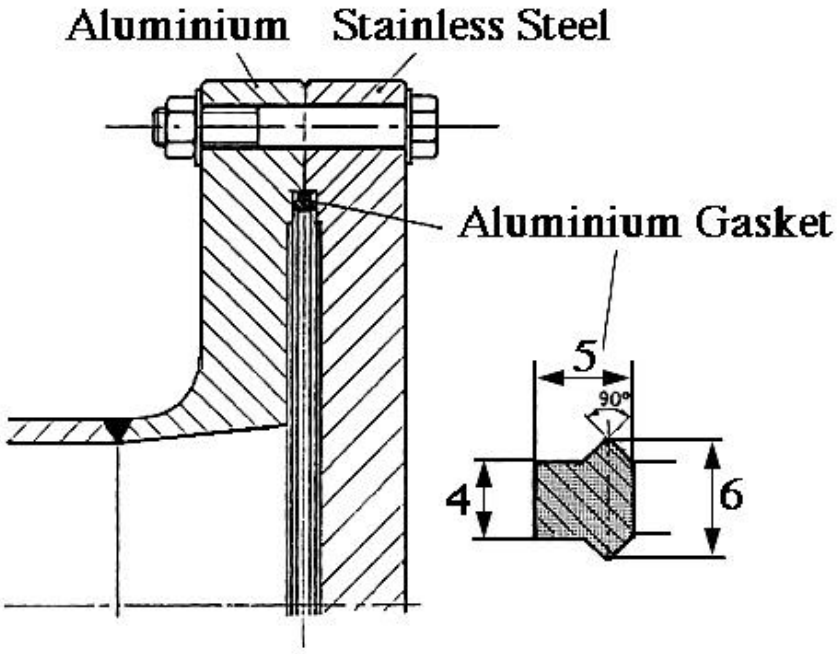
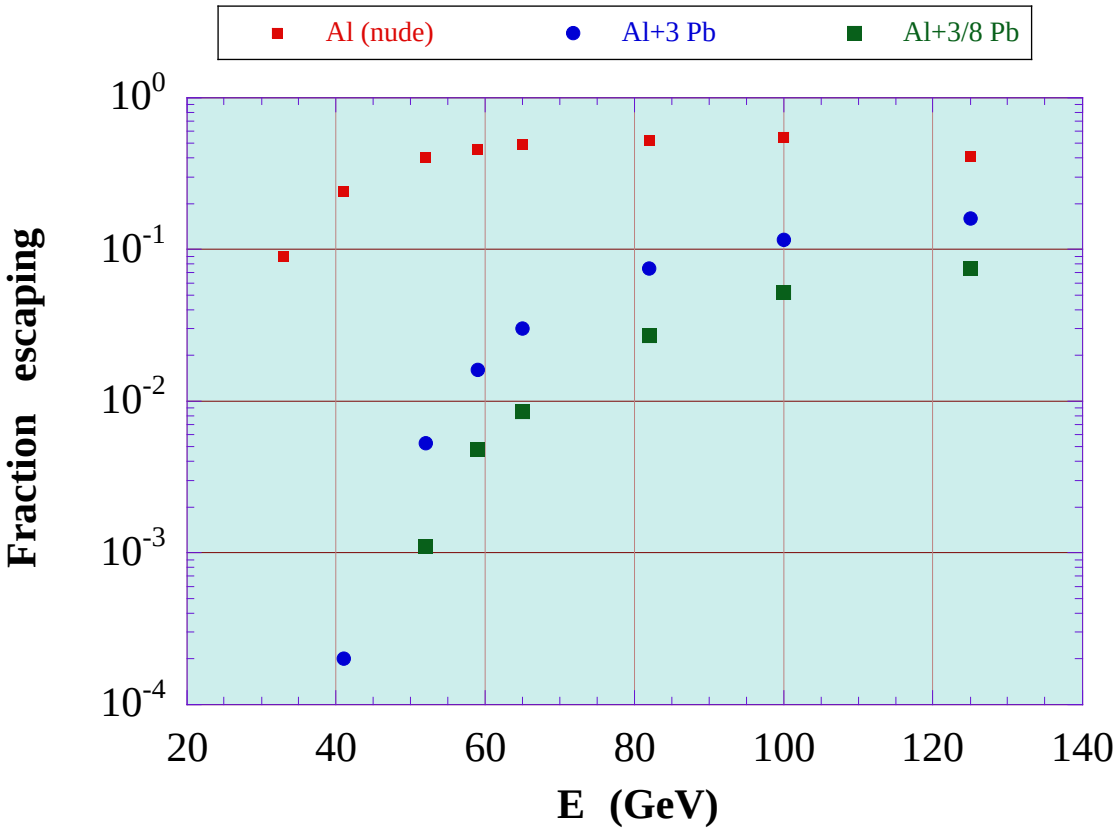


Fig. 3 : Flange pair of dissimilar materials which has been developed to join the aluminium vacuum chamber to the stainless steel expansion bellows in LEP. The gasket uses pure aluminium.



Fraction of s.r. escaping from LEP aluminium vacuum chamber as a function of the energy.

Cases studied:
Nude chamber
3 mm uniform lead coating
3 mm on top and bottom between dipole magnet gap and
8 mm on lateral parts

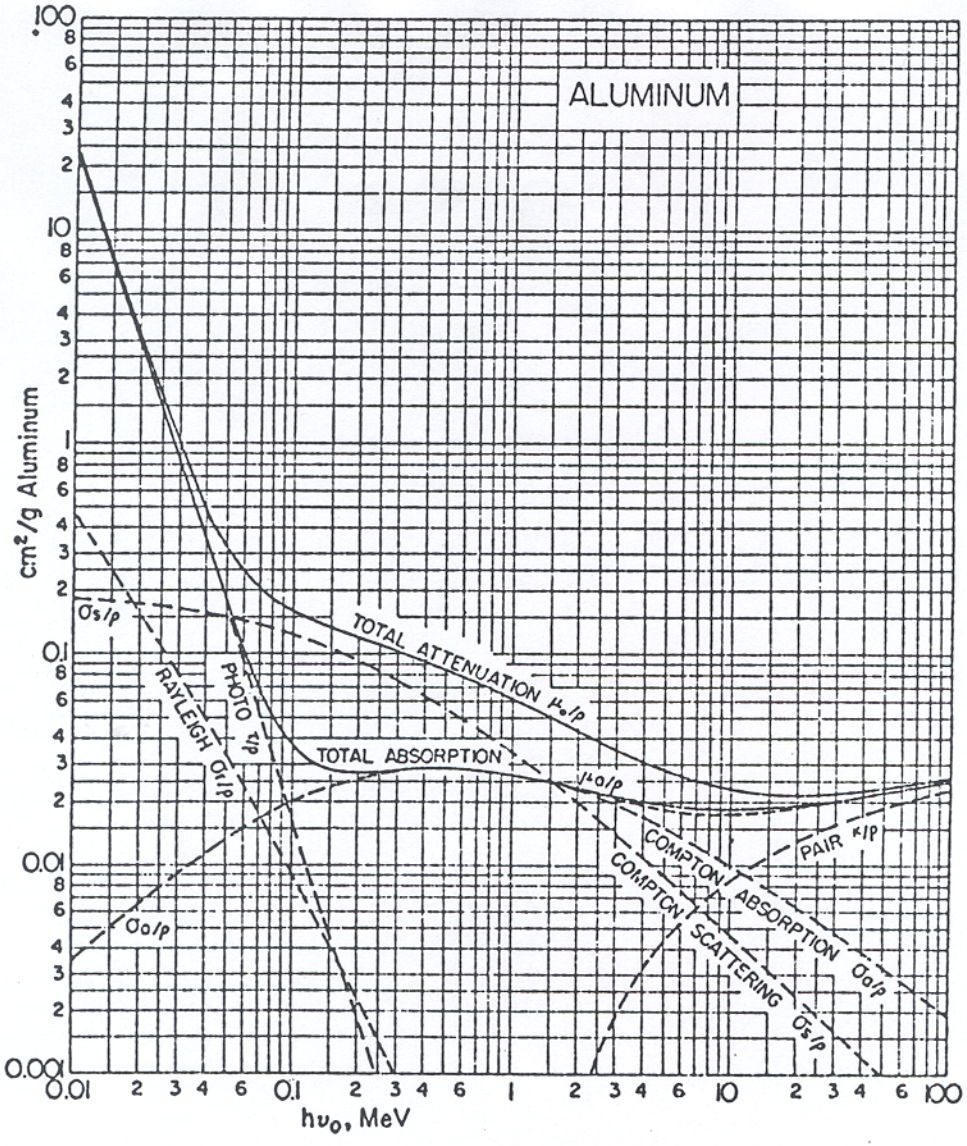


FIG. 8e-8. Mass attenuation coefficients for photons in aluminum ($Z = 13$). The dashed branch on the μ_a/ρ curve shows the effect of excluding annihilation photons [Eq. (8e-47)]. The corresponding linear coefficients for aluminum may be obtained by multiplying all curves by $\rho = 2.70$ g/cm³ Al. [*From Evans* (E1).]

Photon absorption in aluminium

Aluminium becomes “transparent” to hard part of the s.r. spectrum.

In LEP: Photons are incident at grazing incidence :

about 50% of incident power is absorbed in the wall of the chamber

remaining 50% are Compton scattered, penetrate the aluminium wall and leave the vacuum chamber as diffuse radiation. Absorbed by the lead coating around the chamber.

Dynamic Pressure Rise by Synchrotron Radiation

In e^+e^- storage rings the pressure increases due to photon induced desorption from the walls of the vacuum chamber

Radiated power (W) : $P_\gamma = 88.6 \frac{E^4 I}{\rho}$

E, beam energy of electrons (GeV)

I, beam current (mA)

ρ, bending radius (m),

Critical energy of the S.R. spectrum (eV) $\varepsilon_c = 2.2 \ 10^3 \frac{E^3}{\rho}$

Photon flux (s^{-1}) $\dot{\Gamma} = 8.08 \ 10^{17} I E$

Linear photon flux ($m^{-1} s^{-1}$) $\frac{d\dot{\Gamma}}{ds} = 1.28 \ 10^{17} \frac{I E}{\rho}$

Molecular desorption occurs in two steps :

-> photons -> produce photo-electrons, secondary electrons

-> photo-electrons -> excite molecules which subsequently desorb thermally

-> meta-stable molecules accumulate and recombine on the surface to produce new species e.g. H_2O and O_2

Close correlation between photo-electrons and the gas flow:

Gas flow : $Q = \eta \dot{\Gamma}$

$Q = K \eta I E + Q_o$ with Q_o, the static, thermal desorption.

η, molecular desorption yield (molecules per photon).

Dynamic pressure : $P_{dyn} = \frac{Q}{S}$.

The dynamic pressure increases approx. proportionally with the beam intensity : $\frac{\Delta P}{I}$ (Pa/mA).

'**Beam cleaning**' (scrubbing) of the vacuum system to reduce the molecular desorption yield.

-> Conditioning period for vacuum systems requires a 'beam dose' D(mA h)

$$\eta = \eta_o D^{-a}$$

High energy photons penetrate deeper into the surface which leads to a reduced escape probability for secondary-electrons

-> desorption yield increases with critical photon energy.

LEP2: Compton scattering (photons + electrons) are important

Molecules desorb not only from the directly illuminated region but from the **entire surface**

-> scattered and reflected photons

-> secondary electrons

molecules re-adsorb on the walls before leaving the system -> effective, net-yield is measured

strong **wall pumping** effect is observed after prolonged photon exposure

Molecular desorption can be separated in a

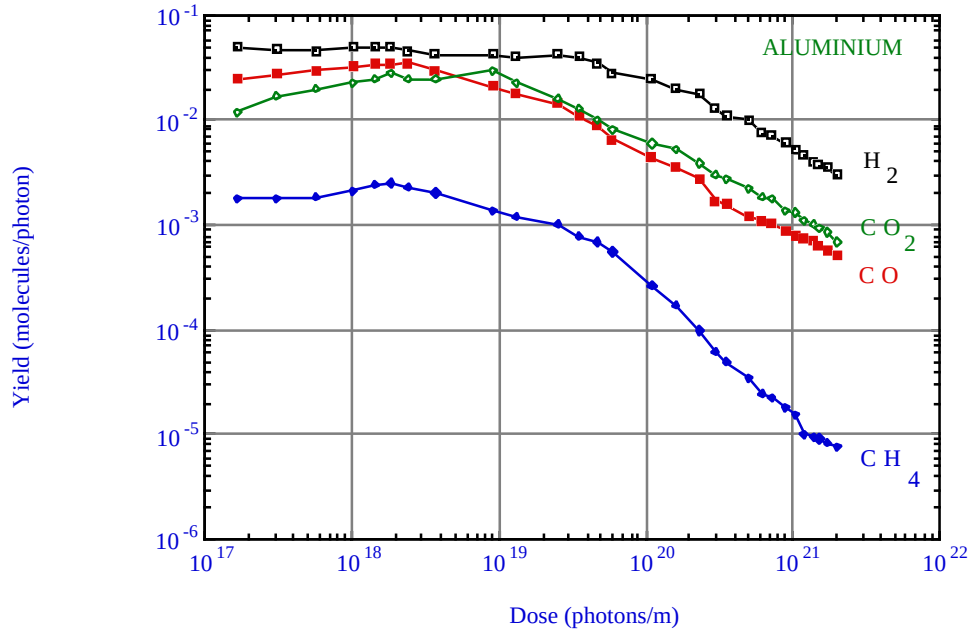
-> **promt component**, desorption stops as soon as photon irradiation is interrupted

-> **delayed component**, increased thermal desorption persisting long after the photon irradiation and with the formation of 'new' molecular species

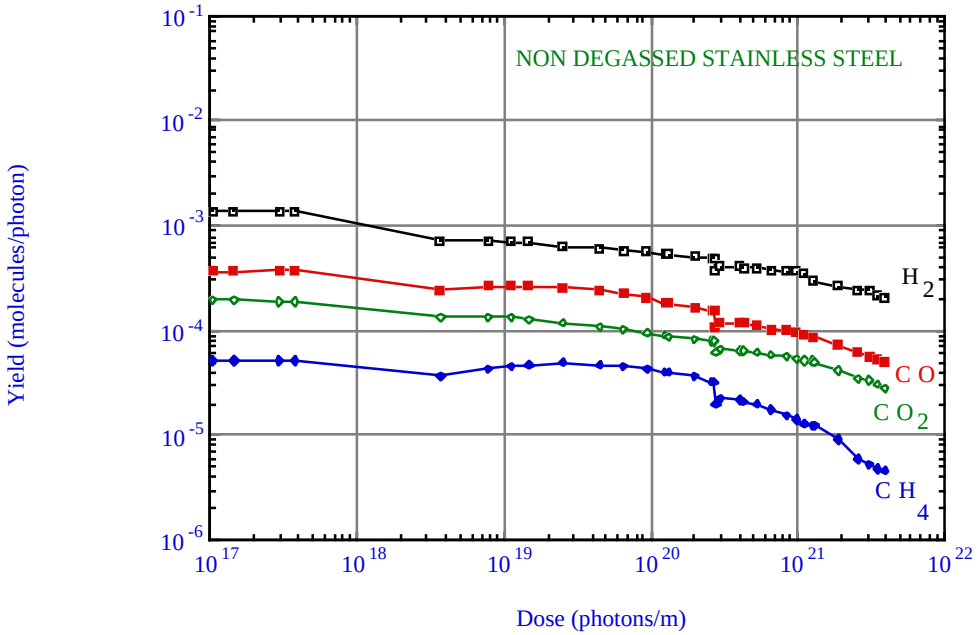
Comparison of aluminium, stainless steel and copper

3.75 keV critical photon energy

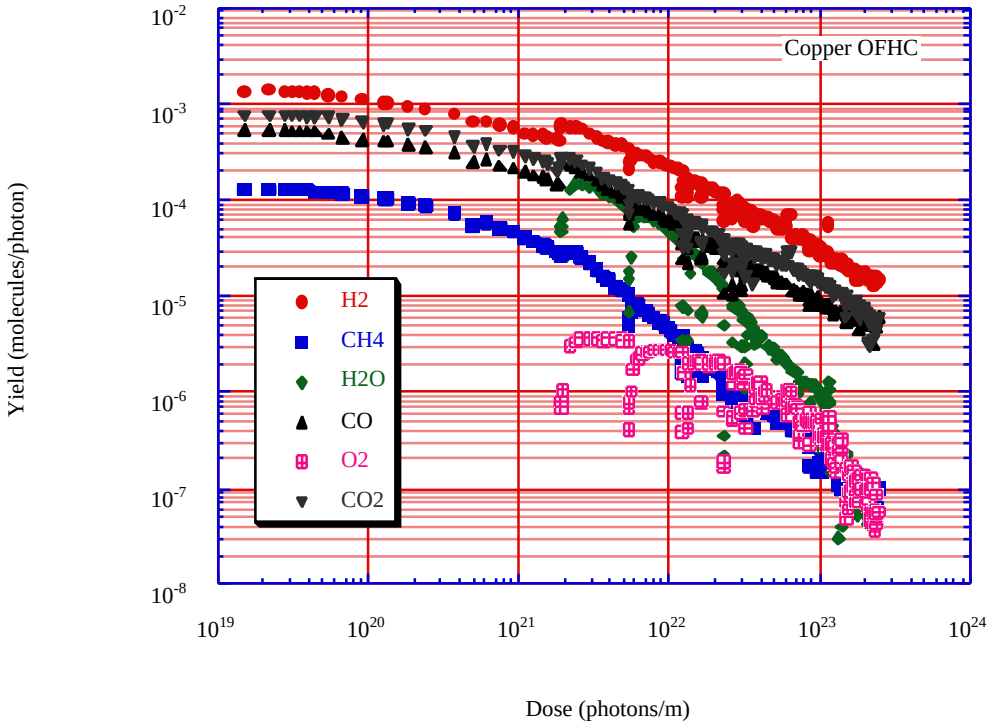
Aluminium, in-situ baked to 150 °C

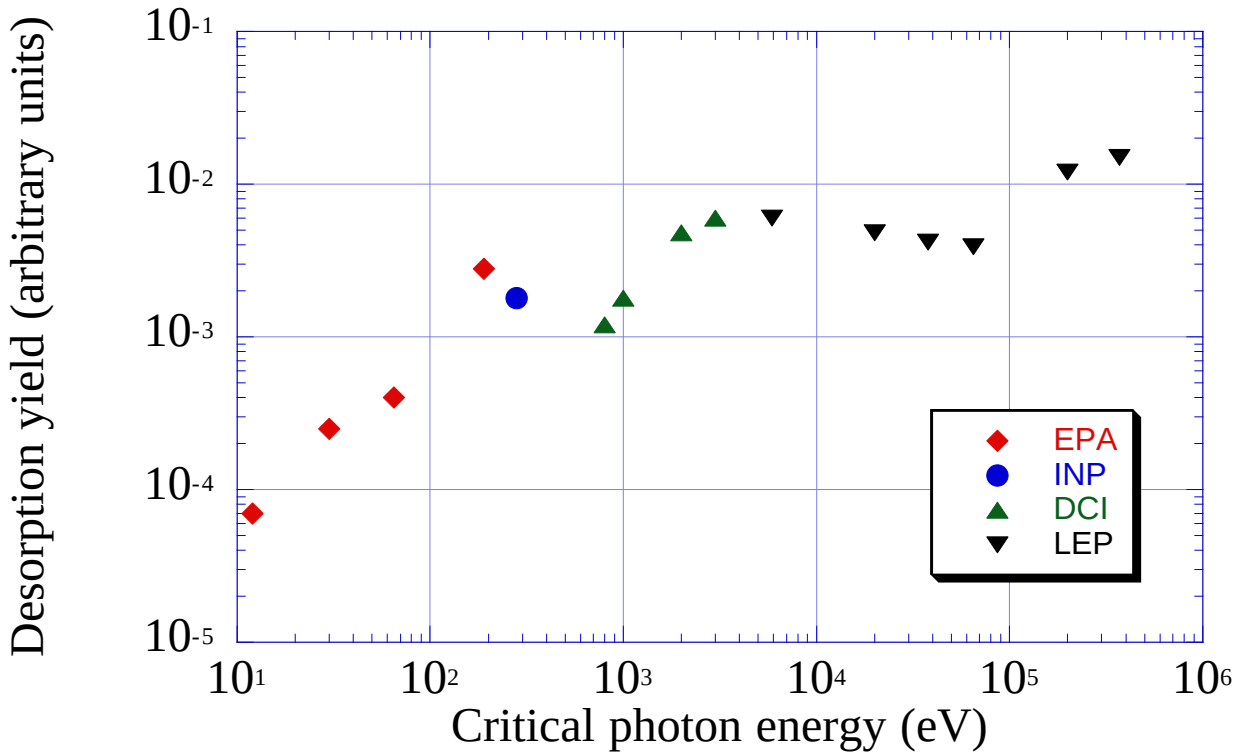


Stainless steel in-situ baked 150-300°C



OFHC-copper, in-situ baked to 150°C




Desorption yield (arbitrary units)
10-1
10-2
10-3
10-4
10-5
101
102
103
104
105
106
Critical photon energy (eV)
EPA
INP
DCI
LEP

Surface Pumping

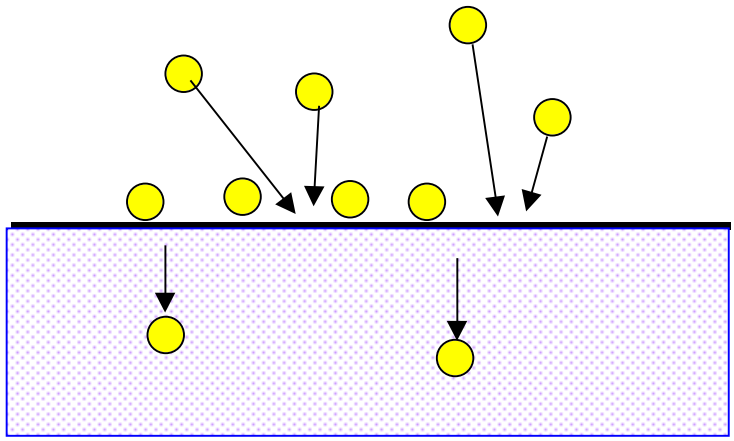
Getters (chemisorption E~eV)

Evaporable getter pumps (Ti sublimators)

Non Evaporable Getters (NEG)

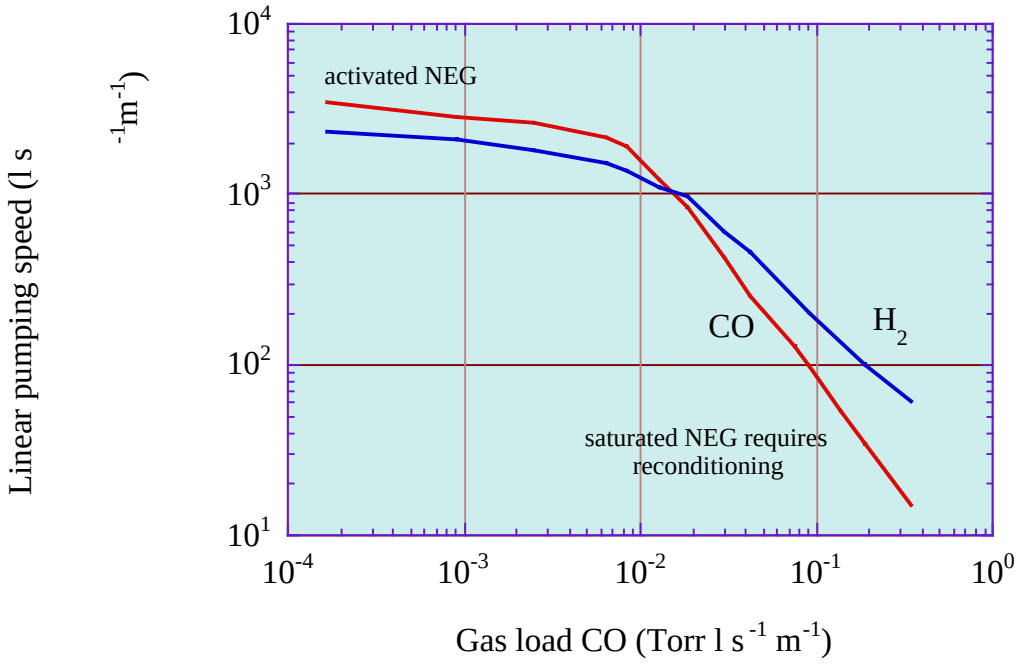
bulk getters: Ti, Zr, V

Surface pumping -> $S \quad \frac{1}{4}\bar{v}\ nF$



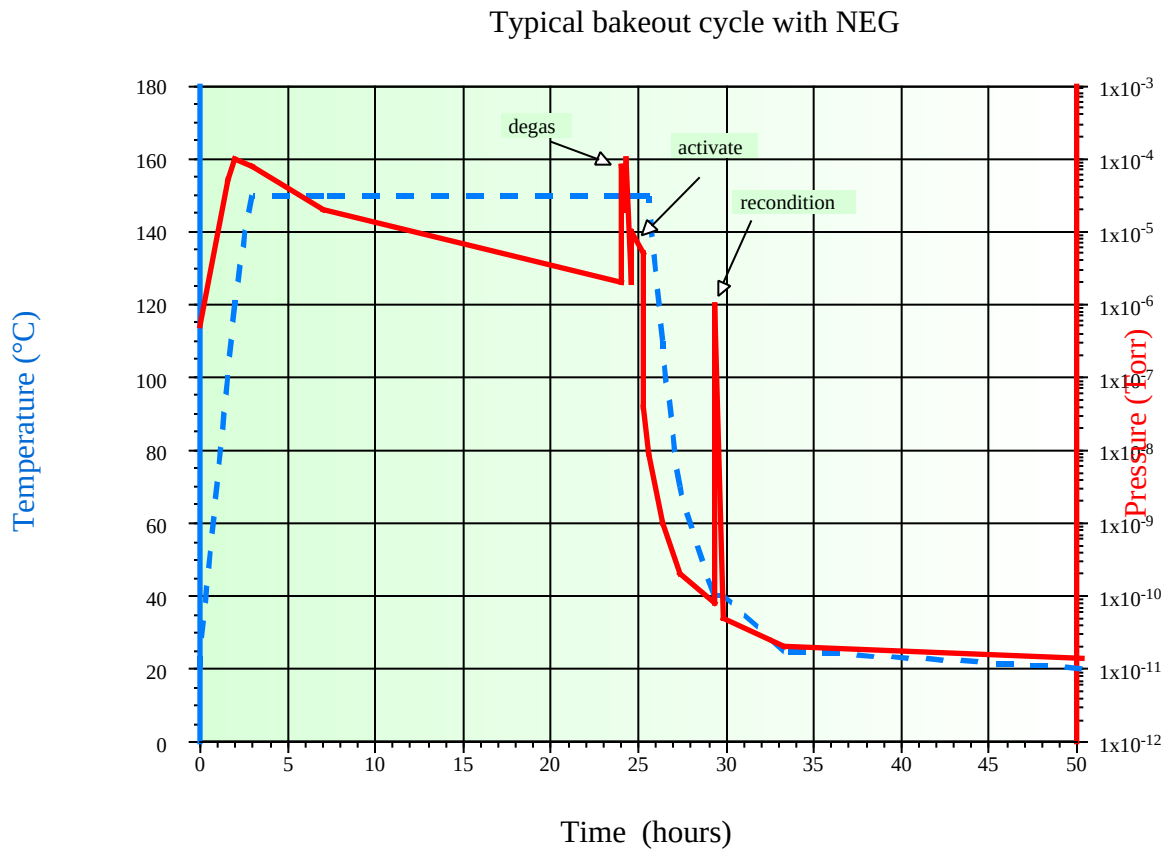
Gettering surface achieved by sublimation (Ti-filament) by surface activation (heating -> reduction of surface oxide layer and diffusion into the getter (bulk getters). Gas covered, saturated surface looses its pumping action and has to be reconditioned.

NEG pumping speed



Pumping speed as a function of the gas load for LEP-type St101 getter ribbon.
30 mm wide, representing 600 cm^2 /m active surface per m of vacuum chamber

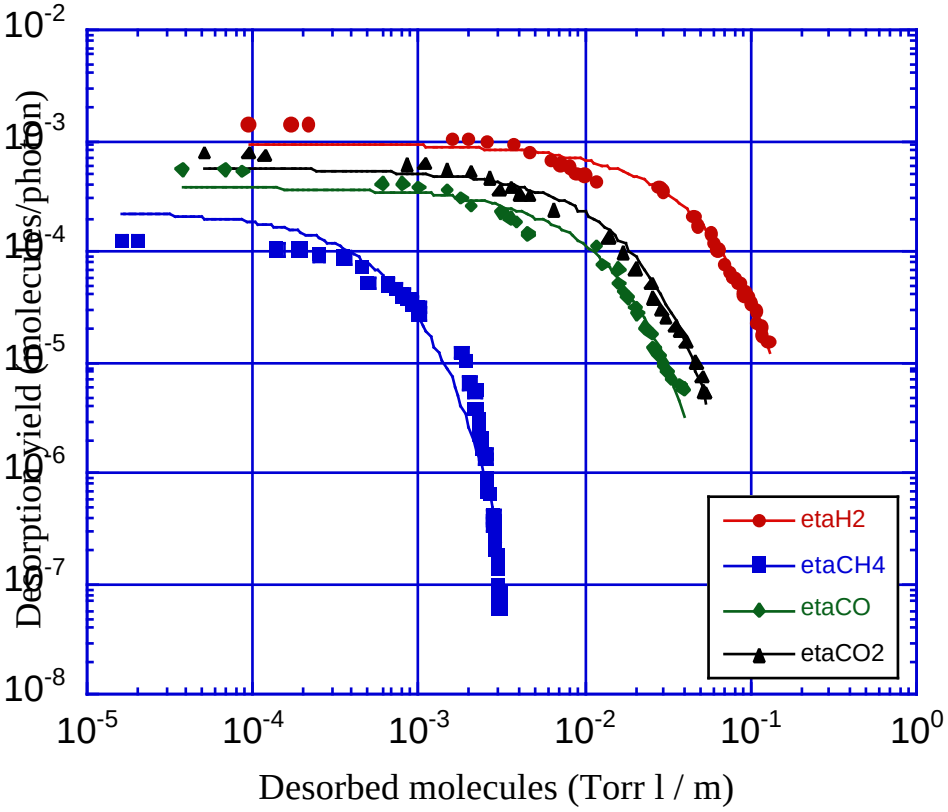
Experience with LEP vacuum system



Molecular desorption yield for a baked OFHC copper chamber exposed to 3.75 keV critical energy synchrotron radiation

The desorption yield as function of the gas load may be described by the exponential expression:

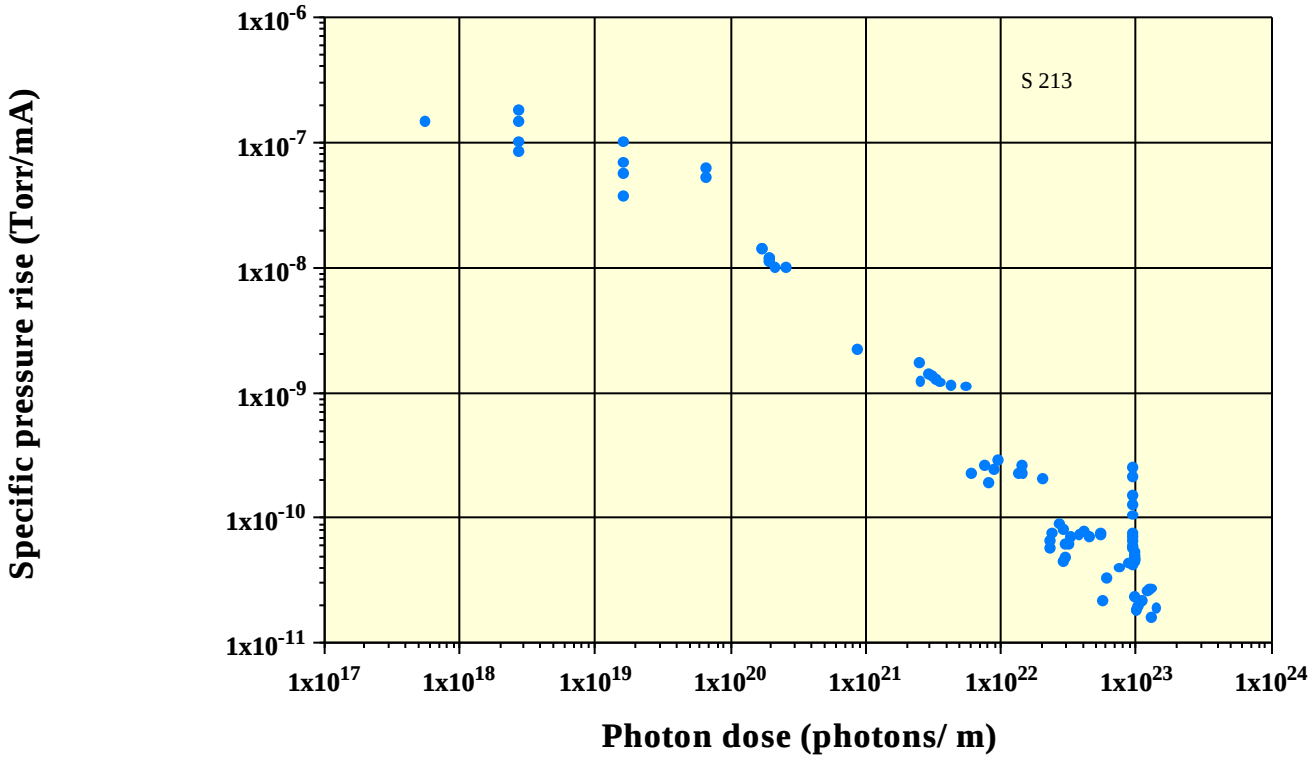
$$\eta = \eta_o \exp[-Q/Q_o]$$



Parameters for the different gas species:

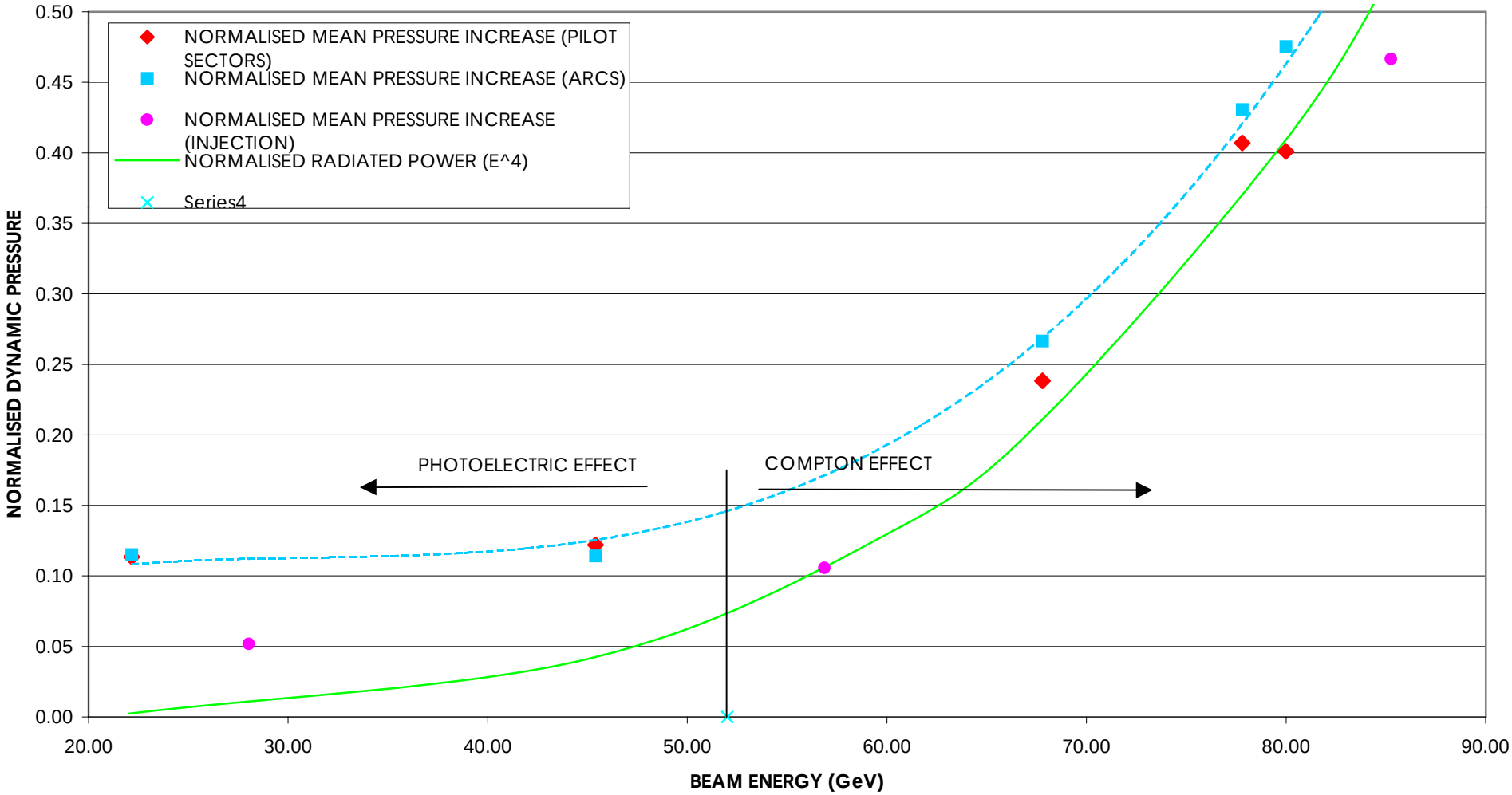
	H_2	CH_4	CO	CO_2
Molecules / monolayer	$1.8 10^{15}$	$1.2\ 10^{15}$	$1.0 10^{15}$	$9.6 10^{14}$
η_o	$9.2 10^{-4}$	$2.3 10^{-4}$	$3.7 10^{-4}$	$5.5 10^{-4}$
Q_o (Torr l/m)	$3.0 10^{-2}$	$4.5 10^{-4}$	$8.4 10^{-3}$	$1.1 10^{-2}$

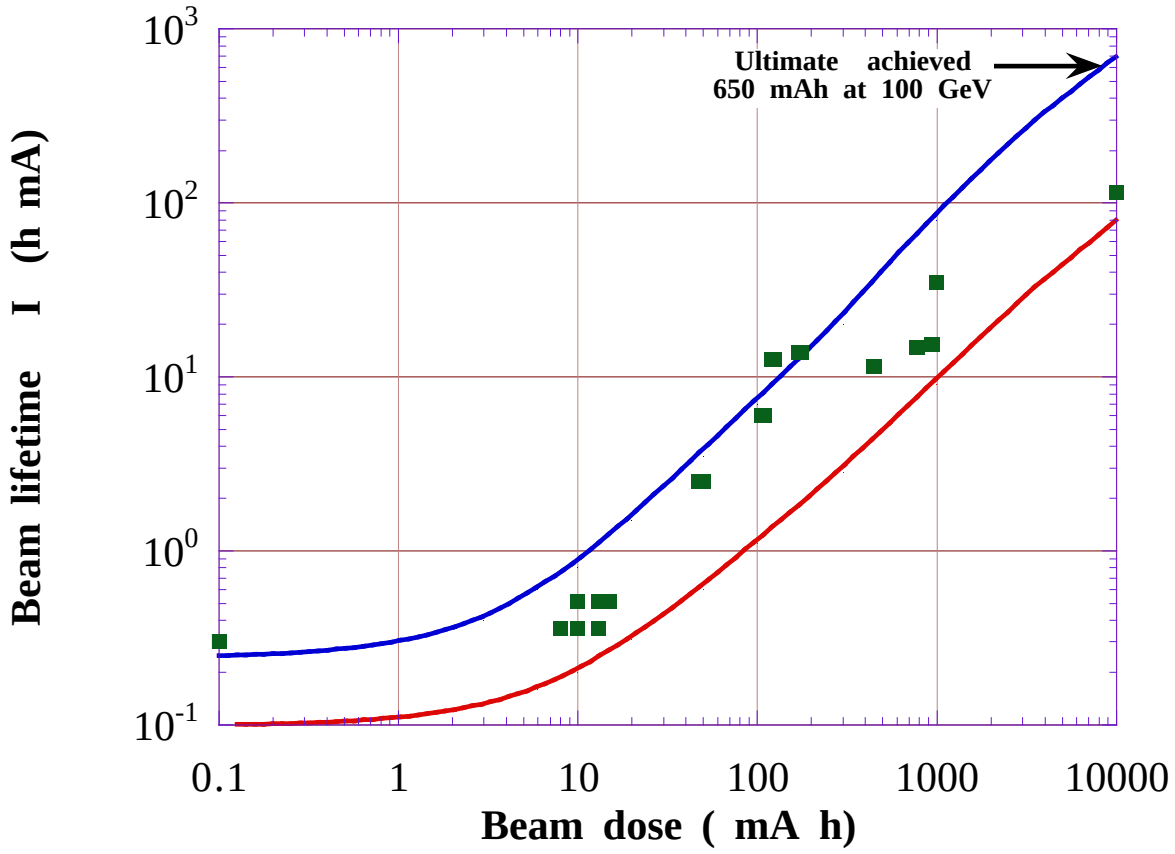
Dynamic vacuum



Discontinuities correspond to NEG activation/reconditioning
Data at 45 GeV during initial running of LEP

NORMALISED PRESSURE INCREASE
(measured in LEP arcs 1999)





Product of Beam current I and beam lifetime tau
as a function of the beam dose (mAh) for the
running-in phase of LEP.

Upper and lower curves correspond to
maximum and minimum values of the NEG pumping speed respectively.

LEP and VLLC

	LEP	VLLC
ρ (m)	3096	25411
Ax (m)	0.065	0.053
ψ (mrad)	3.9	3.6
W (m)	0.1	0.35
Vacuum chamber (m)	0.23	0.46

Here it has been assumed that the distance between absorbers is given by the length of a bending magnet.

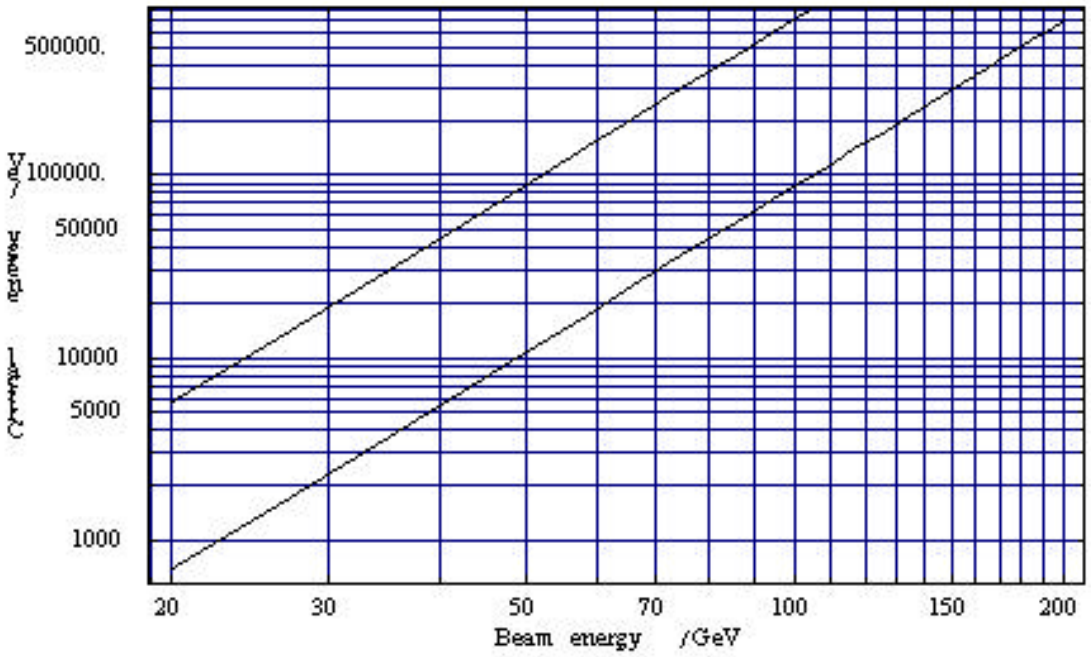
The total width of the vacuum chamber is : W+2Ax

Synchrotron radiation stimulated desorption

Linear photon flux(s^{-1}, m^{-1}) $\frac{dN_\gamma}{ds} = 1.28\ 10^{20}\frac{E\,I}{\rho}$ (GeV, A, m)

VLLC/LEP100 ~ 3 (two beams in same vacuum chamber)

Critical energy of S.R. spectrum also similar with LEP.



Linear power (W m^{-1}) $\frac{dP_\gamma}{ds} = 1.4\ 10^{4}\frac{E^4\,I}{\rho^2}$ (GeV, A, m)

VLLC/LEP100 ~ 0.8 (two beams in same vacuum chamber)

->> The LEP vacuum system could be used as is

Static, dynamic vacuum performance can be estimated from LEP

Issues : Bakeout (initial outgassing of H_2O)

Cooling

Shielding (radiation damage to cables and components)

NEG activation, conditioning

Average Pressure

Periodically pumped system :
Pump distance L, pumping speed S, pressure at the pumps P_{pump}
Conductance of vacuum chamber between pumps C, perimeter of the chamber H and q the specific outgassing rate.

$$P_{av} = P_{pump} + qHL\left(\frac{1}{S} + \frac{1}{12C}\right)$$

The conductance $C = \frac{4}{3}\frac{\bar{v}}{\int_0^L \frac{H}{A^2} dl}$ with A the vacuum chamber section and the mean molecular velocity $\bar{v} \sim 146\sqrt{\frac{T}{M}}$.

For a rectangular duct (w, h) $C = \frac{2}{3}\bar{v}\frac{h^2 w^2}{L(h+w)}$

For a round chamber (r) $C = \frac{4}{3}\bar{v}\left(\frac{r}{L}\right)^3 \sim 306\left(\frac{r}{L}\right)^3\sqrt{\frac{T}{M}}$

Lumped S.R. absorbers outside of the vacuum system

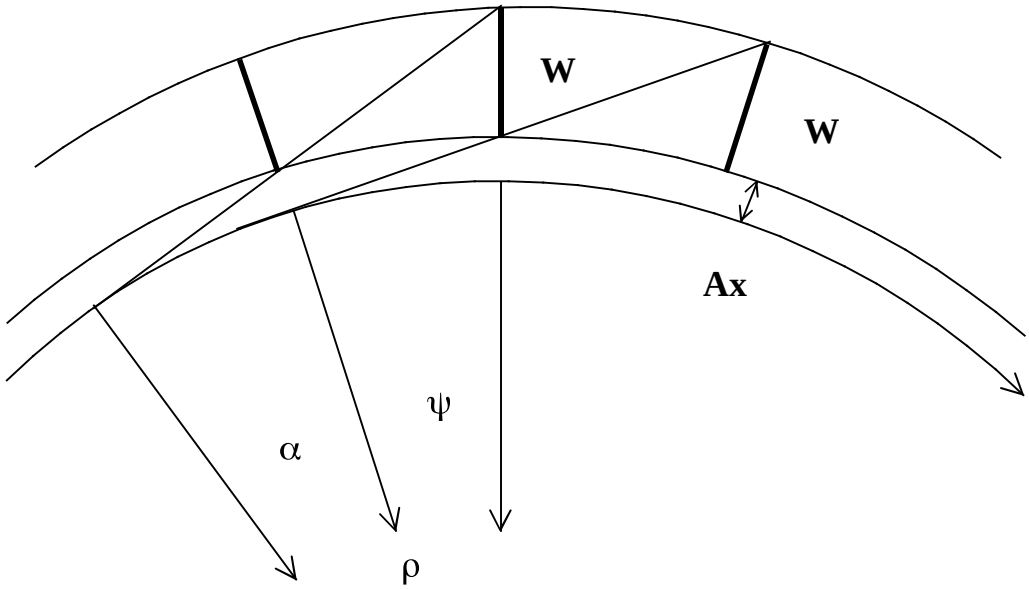
Basic concept :

S.R. passes through the antechamber of the beam pipe and irradiates the end face at perpendicular incidence. Since most of the power is in hard photons, this part of the spectrum escapes through the wall of the vacuum chamber. The absorption in an aluminium wall of a few mm can be tolerated. (Proof of principle : positive experience with the LEP polarimeter vacuum chamber).

Advantages :

* Photon absorbers are outside the vacuum system and need not meet stringent uhv requirements.
* These photons do not desorb gas, hence the design of the pumping system can be simplified. (Requirement of large lumped pumps near the absorbers is relaxed)
* Easily accessible and replaceable if required.
* Can be designed to optimise the radiation shielding and thus to limit the scattered photons to adjacent machine components.
* Cooling of these absorbers is independent of the vacuum system : temperature rise, water flow, vibrations, corrosion and vacuum leaks are no longer an issue.

Arrangement of absorbers with antechamber



ρ bending radius

ψ bending angle between absorbers

α angle from beam orbit to the horizontal aperture, Ax

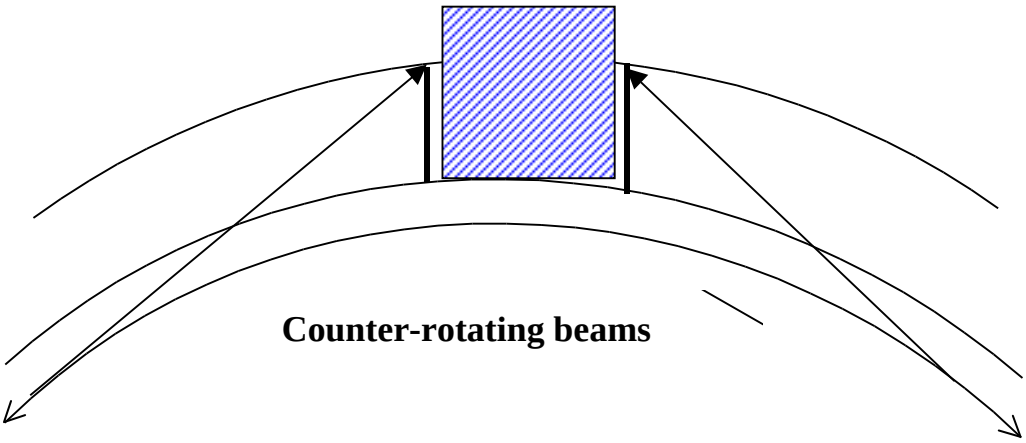
W width of antechamber and of absorbers

Since ρ is very large $\alpha \approx \sqrt{\frac{2Ax}{\rho}}$ and

$$W \approx \frac{1}{2}\left(\sqrt{\frac{2Ax}{\rho}} + \psi\right)^2 \rho - Ax$$

Absorber configuration

Outside of the vacuum system :



Absorber requires the equivalent of few cm of copper.

Synchrotron radiation load :

$$\frac{dP_\gamma}{d\psi} = 1.4\ 10^4 \frac{E^4 I_b}{\rho} \quad \text{(W, GeV, A, m)}$$

Single beam only :

	LEP	VLLC
ρ (m)	3096	25411
I (A)	0.00275	0.0125
E (GeV)	100	184
ψ (mrad)	3.9	3.6
$\psi \frac{dP_\gamma}{d\psi}$ (kW)	4.9	28.8

Practical experience has been gained with the windows of the LEP polarimeter vacuum chamber. (about 2 mm Al wall)

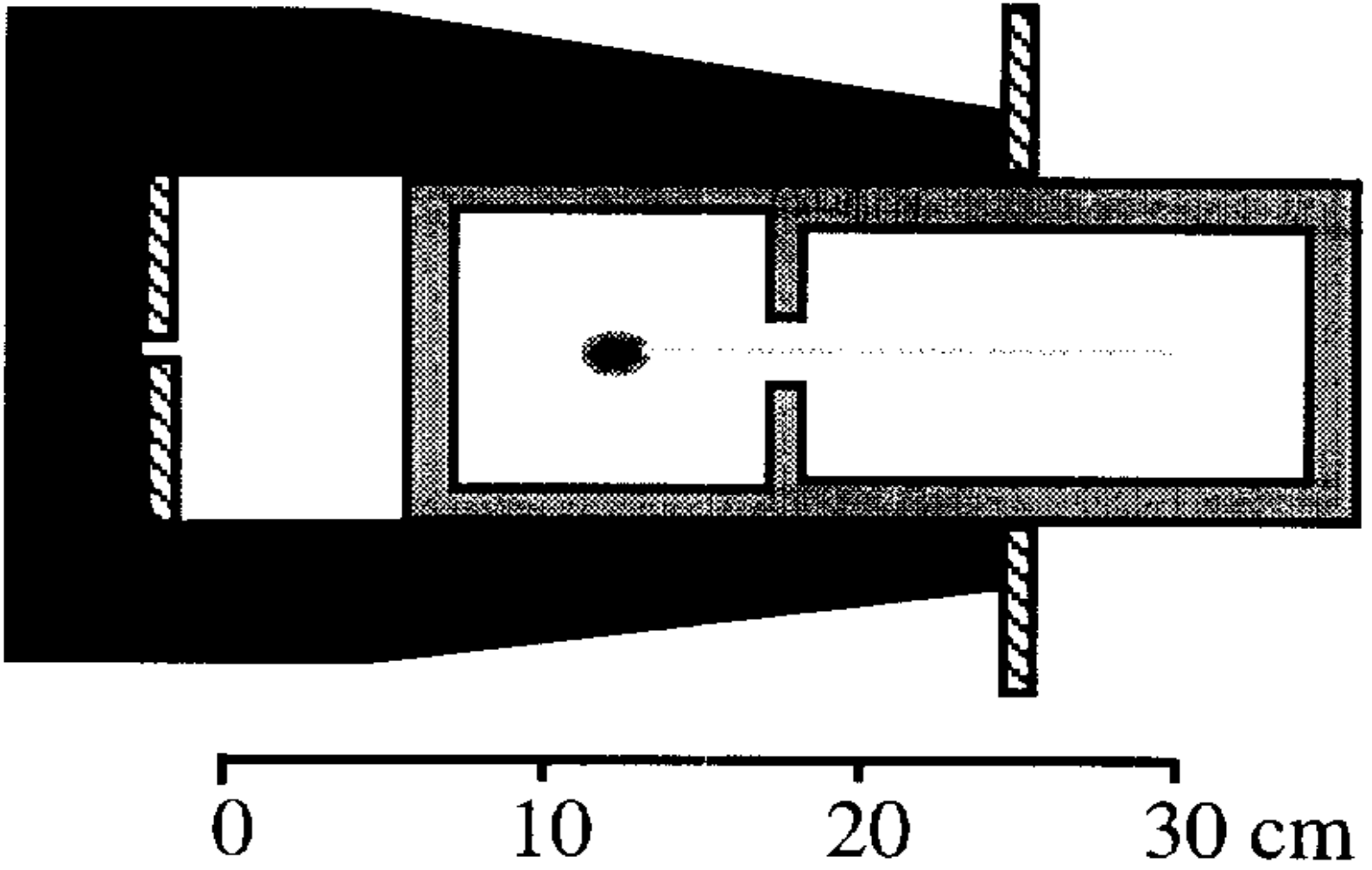


Fig 2. Dipole yoke, 4 conductors and vacuum chamber