ILC DR Vacuum System

Progress in ECLOUD Task (Goal 7) for the ILC DR

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Required vacuum

- The need to avoid fast ion instability leads to very demanding specifications for the vacuum in the electron damping ring [Lanfa Wang, private communication]:
  - < 0.5 nTorr CO in the arc cell,
  - < 2 nTorr CO in the wiggler cell and
  - < 0.1 nTorr CO in the straight section
- In the positron damping ring required vacuum level was not specified and assumed as 1 nTorr (common figure for storage rings)

Sources of Gas in a Vacuum System

- Thermal stimulated desorption
  - The thermal desorption rate for stainless steel, well-known as a good vacuum material, can be reduced to the level of 10^{-12} Torr·l/(s·cm^2) for CO after 24 hrs bake-out at 300ºC and weeks of pumping.
- Photon stimulated desorption
  - Depends on many parameters as
    - Choice of material and cleaning procedure
    - Bakeout temperature and duration
    - Photon/electron/ion intensity flux, energy and integral dose.

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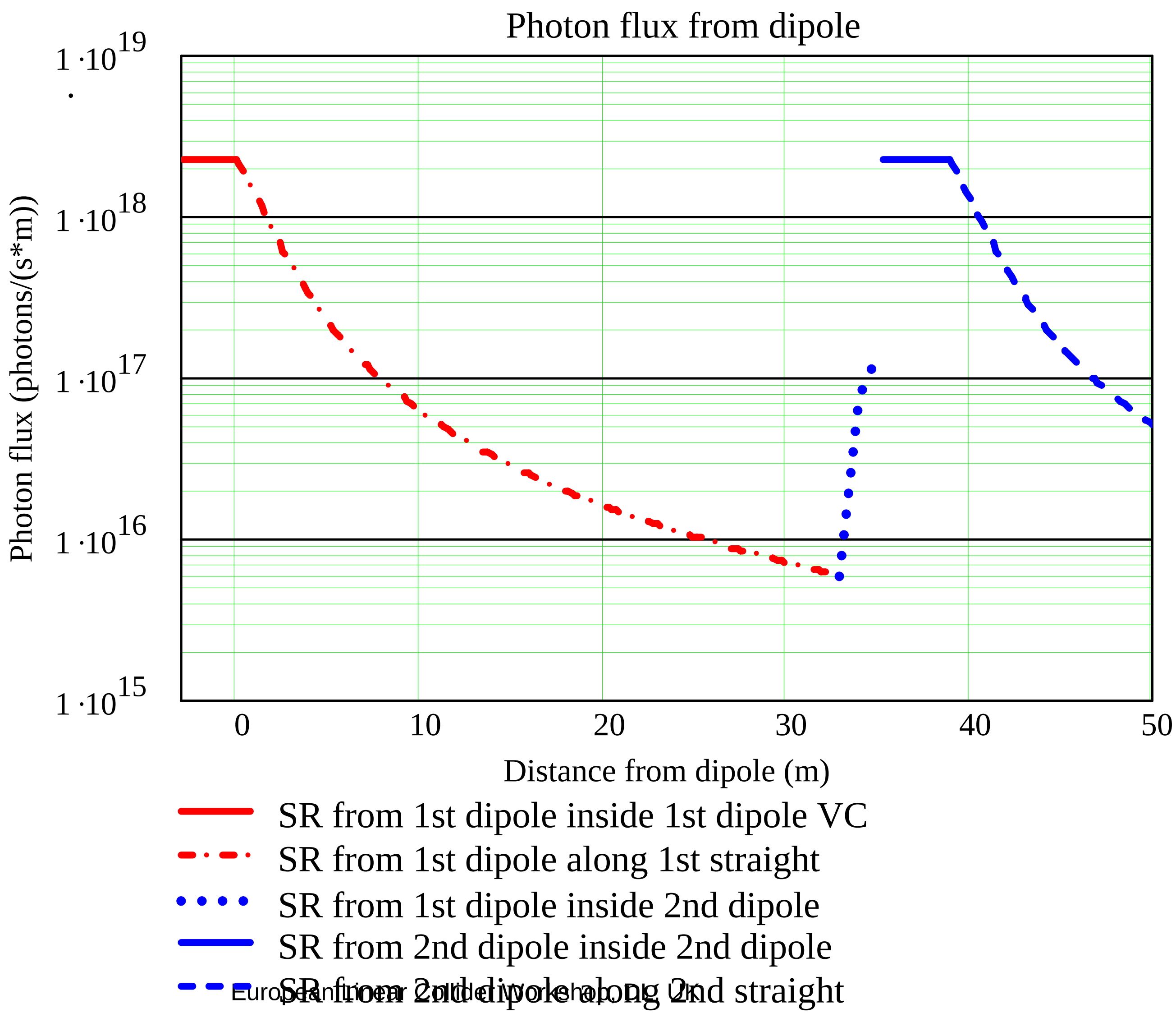
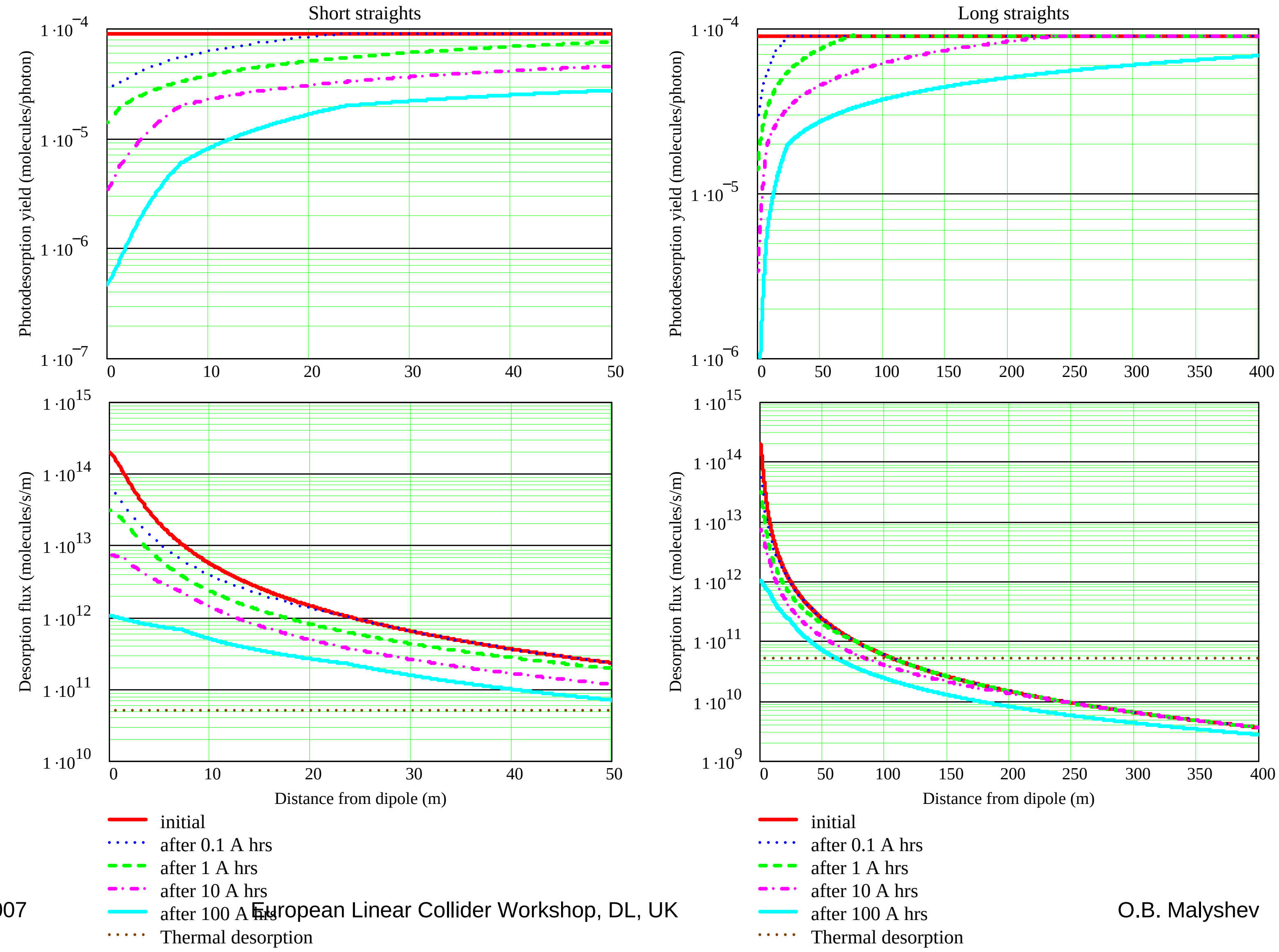
DR & Beam Parameters

	Arc cell	Wiggler cell	Straight section
Number of dipole/wiggler cells per beamline (ring)	120	40	—
Sectorisation	12 x 5 x 2	5 x 4 x 2	2 x 404.6 m + + 110 x 32.9 m + + 10 x 58.7 m + + 16 x 43.8 m
Total arc/wiggler cell length	38.9 m – most of (58.8 m x 10 times)	6.3 m (5 wigglers in row)	1775 m
Dipole/wiggler length (pole face – pole face)	6 m	2.45 m	—
Dipole field /Wiggler peak field	0.1455 T	1.58 T	—
Dipole bend angle	$2\pi/120$	—	—
Electron beam energy	5 GeV		
Electron beam average current	0.400 A		
Chamber vertical full aperture	50 mm	46 mm	50 mm
Chamber horizontal aperture	50 mm	120 mm	50 mm
Required residual gas pressure after 100 Ahr beam conditioning	< 0.5 ntorr CO	< 2 ntorr CO	< 0.1 ntorr CO
Photon critical energy	2.4 keV	26 keV	2.4 keV after arc or 26 keV after wiggler
Photon flux (maximum)	$2.23\cdot10^{18}$ photons/(m·s)	$2.43\cdot10^{19}$ photons/(m·s)	From 0 to $2.43\cdot10^{19}$ photons/(m·s)

Photon flux onto the 50-mm diameter vacuum chamber walls inside the dipoles and along the short straights

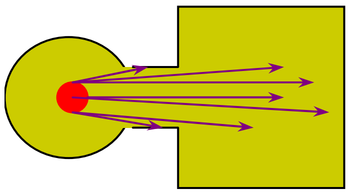


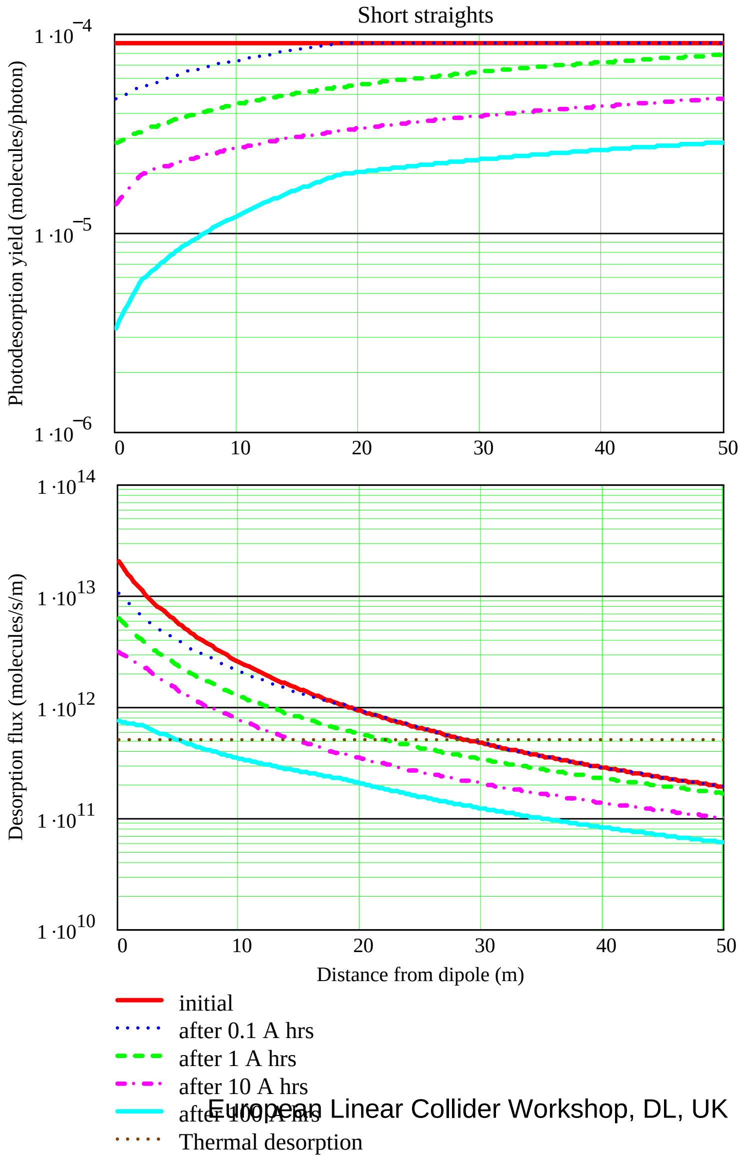
Photodesorption yield and flux along the damping ring straights made of stainless steel *tubular vacuum chamber* and baked in-situ at 300°C for 24 hrs.

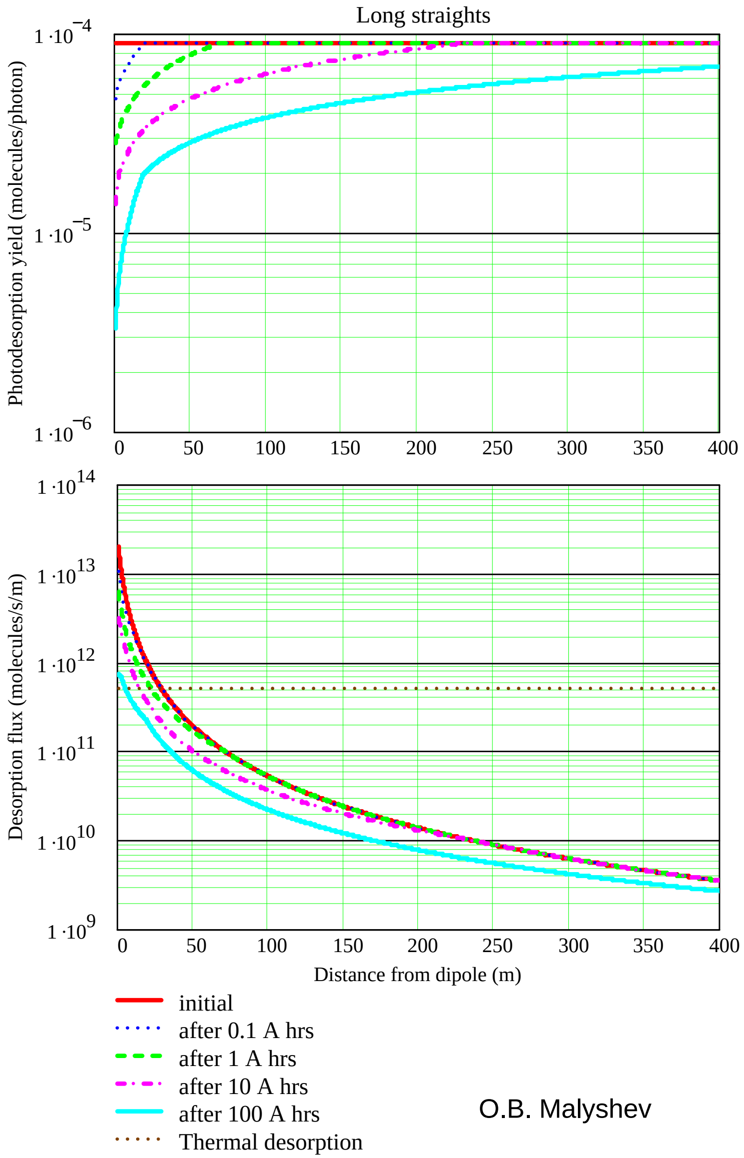


Photodesorption yield and flux along a stainless steel vacuum chamber *with an ante-chamber* in the damping ring straights baked in-situ at 300°C for 24 hrs.

10% of photons hit vacuum chamber







Tubular chamber vs a vacuum chamber with antechamber

- Assumption:
  - 90% of photons are absorbed by SR absorbers and
  - 10% of photons are distributed along the beam vacuum chamber, a gas load analysis can be performed.
- Results:
  - The distributed gas desorption due to 10% of photons is after 100 Ahr of beam conditioning the distributed photon stimulated desorption due to 10% of photons is the same for both designs: with and without antechamber.
  - Meanwhile, in addition to photon stimulated desorption from the chamber there is thermal outgassing (10 times larger with an ante-chamber) and photon stimulated desorption from the lumped absorber.
  - Therefore the total outgassing inside the vacuum chamber with an antechamber is larger. Hence, one can conclude that the thermal outgassing will be reduced much faster in a tubular vacuum chamber conditioned with photons than in a vacuum chamber with an ante-chamber.
- Therefore, the ante-chamber design:
  - does indeed increase the vacuum conductance,
  - but this does not help in reducing the outgassing.
  - After 100 Ahr of beam conditioning the total outgassing along a tubular vacuum chamber is the same or lower than that along a vacuum chamber with an antechamber, and the SR absorbers make a gas load on the pumps even larger for an antechamber design.
  - Since the antechamber design is more expensive, it worth to explore only if it is necessary to deal with other problems such as beam induced electron multipacting and electron cloud.

TiZrV NEG coating for accelerator vacuum chambers

- A new vacuum technology for accelerators developed at CERN in recent years [i], is the use of TiZrV (NEG) coating for all inner surfaces of the vacuum chamber.
- TiZrV films have been intensively studied by vacuum groups in many different laboratories [ii].
- TiZrV coated vacuum chambers:
  - are already used in accelerators:
    - for six years at the ESRF [iii] and
    - for 4 years at ELETTRA [iv];
  - many others are just beginning (RHIC, Soleil, Diamond) or will use them in future.

[i] C. Benvenuti. Non-Evaporable Getters : from Pumping Strips to Thin Film Coatings. EPAC '98 , Stockholm, Sweden , 22 - 26 Jun 1998, pp. 200-204.

[ii] 45th IUVSTA Workshop on NEG coatings for particle accelerators and vacuum systems. 5-8 April 2006. Catania, Italy. *www.iuvsta.org.*

[iii] M. Hahn and R. Kersevan. Status of NEG coating at ESRF. Proc. of 2005 Particle Accelerator Conference, Knoxville, Tennessee, pp. 422-424.

[iv] F. Mazzolini, L. Rumiz, J. Miertusova, F. Pradal. Ten years of ELETTRA vacuum system experience. Vacuum 73 (2004) 225–229.

[v] V.V. Anashin, I.R. Collins, R.V. Dostovalov, N.V. Fedorov, A.A. Krasnov, O.B. Malyshev and V.L. Ruzinov. Comparative study of photodesorption from TiZrV coated and uncoated stainless steel vacuum chambers. Vacuum 75 (2), July 2004, pp. 155-159.

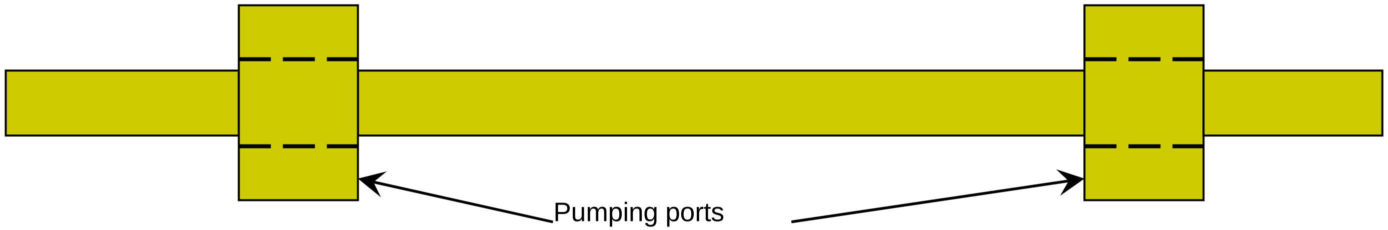
TiZrV NEG coating for accelerator vacuum chambers

- A 1-micron NEG coating used on a vacuum chamber made of stainless steel, copper or aluminium :
  - reduces the outgassing from the vacuum chamber walls (between 10 and 200 times less than *in-situ* baked stainless steel) and
  - introduces a distributed pumping speed, resulting in lower gas density in a beam vacuum chamber [v]. The only gases which are not pumped by such a coating are hydrocarbons and noble gases; these requires the use of other pumps, (for example, sputter ion pumps) but with much lower pumping speed.
  - The use of NEG coating requires activation, i.e. 24 hours bakeout at 180°C.
- In a positron DR the NEG coating also will play a role of an anti-multipacting coating due to low SEY.
- Thermal stimulated desorption from the NEG is negligible; the pressure inside the NEG coated chamber without SR is less than 10^{-13} Torr (Helmer gauge limit)

Pressure calculations

The average pressure can be calculated

- as a function of a distance between pumps L or
- as a function pumping speed S



For two cases without or with distributed pumping speed C

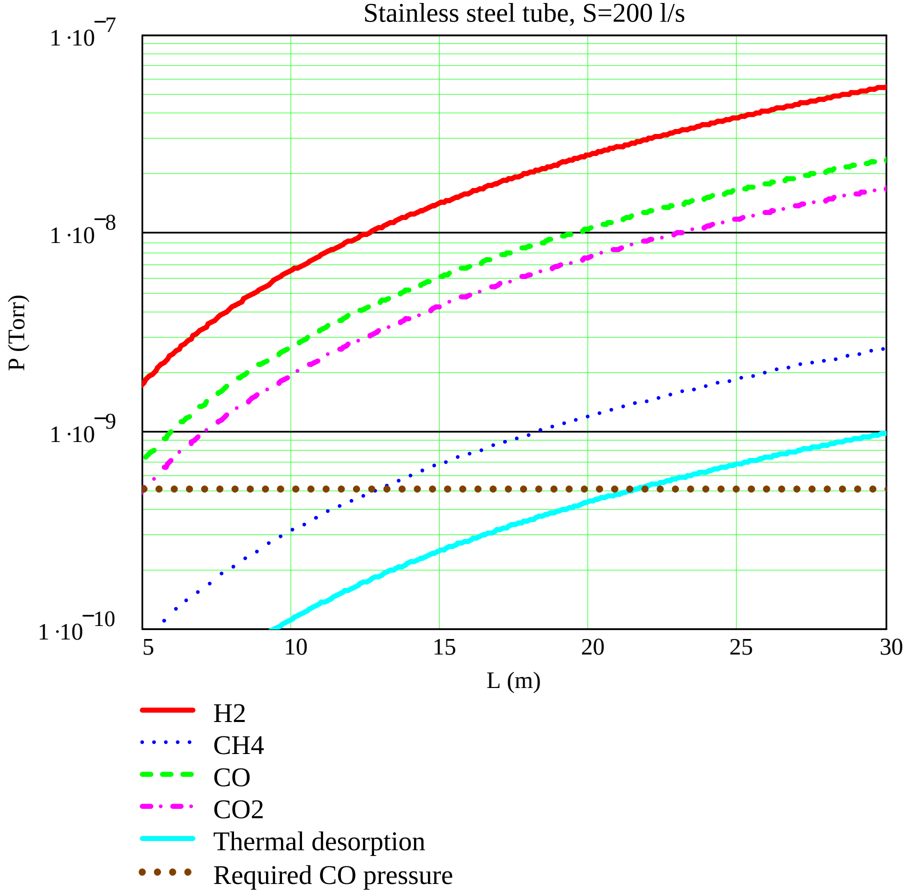
$$\langle n(L) \rangle = \eta \dot{\Gamma} \left(\frac{L}{12u} + \frac{1}{2S} \right) L$$

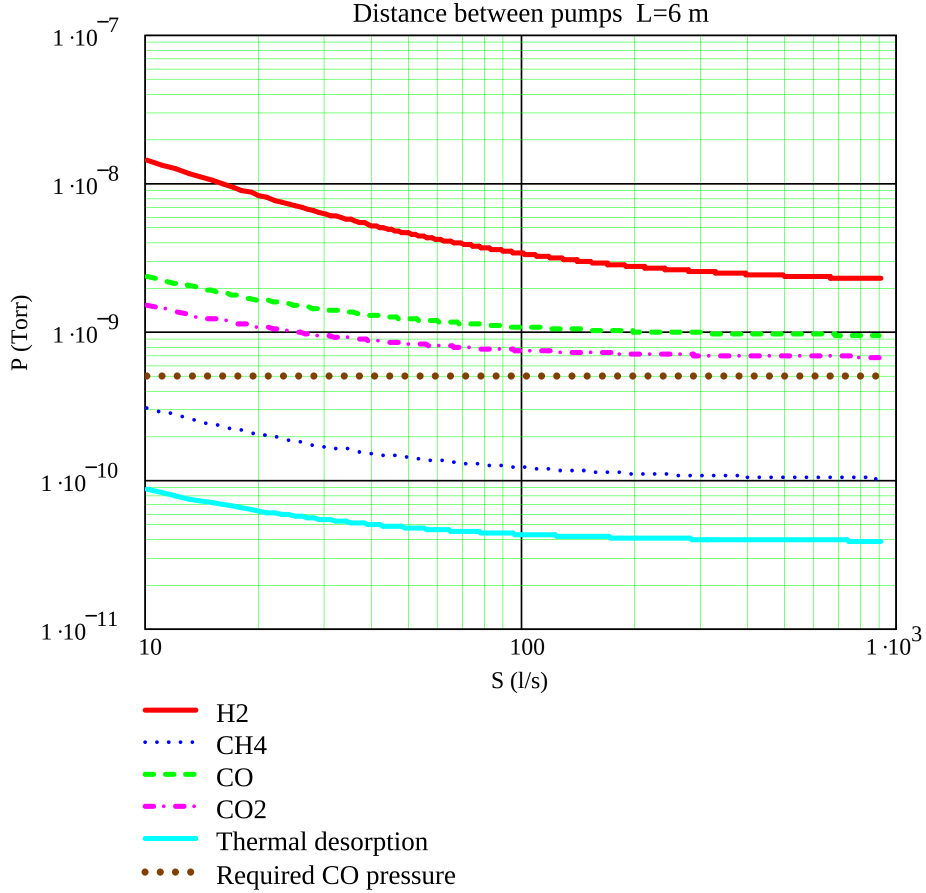
$$\langle n(L) \rangle = \frac{\eta \dot{\Gamma}}{\alpha C} \left(1 - \frac{2\tanh\left(\frac{\omega L}{2}\right)}{\omega L \left(1 + \frac{u}{S} \omega \tanh\left(\frac{\omega L}{2}\right) \right)} \right),$$

where $\omega = \sqrt{\alpha C / u}$

Pressure along the arc: inside a stainless steel tube

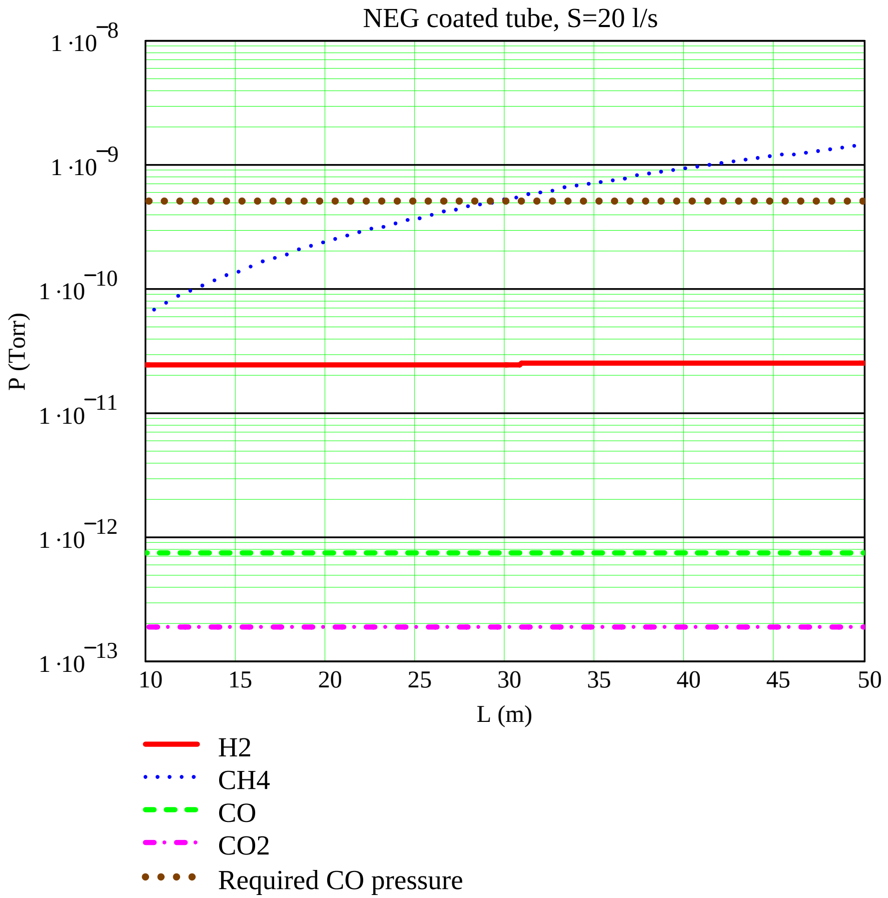
after 100 Ahr beam conditioning: S_{eff} = 200 l/s every 5 m

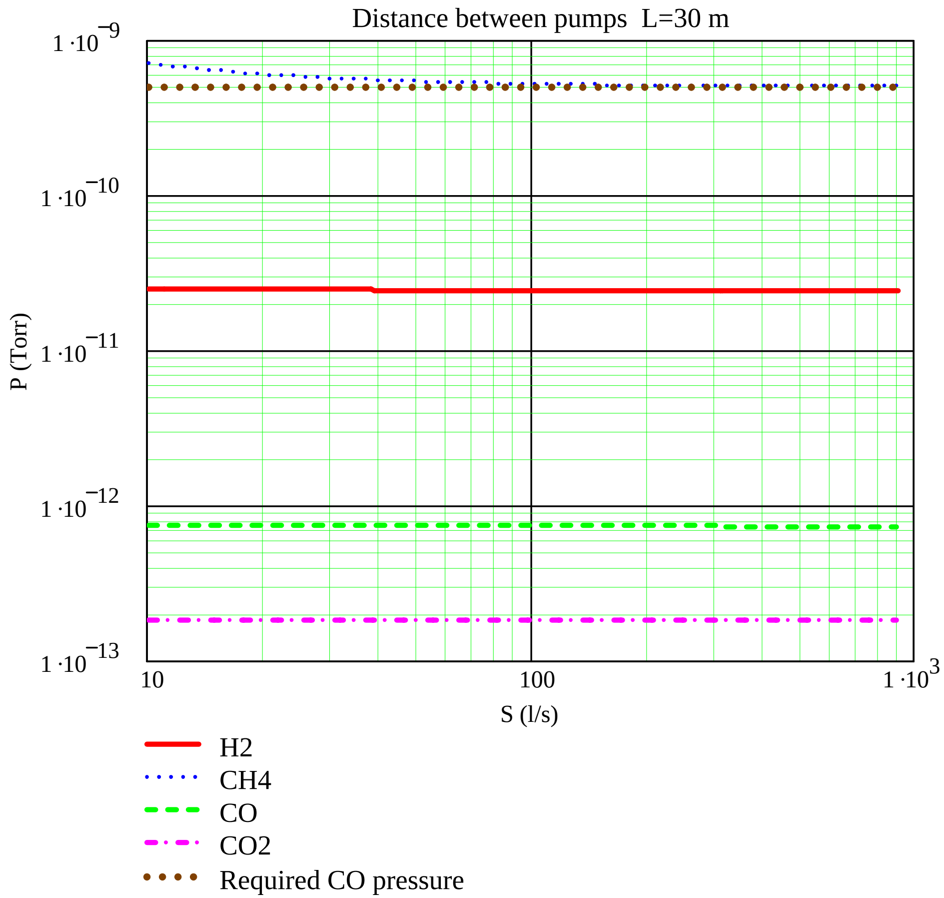




Pressure along the arc: inside a NEG coated tube

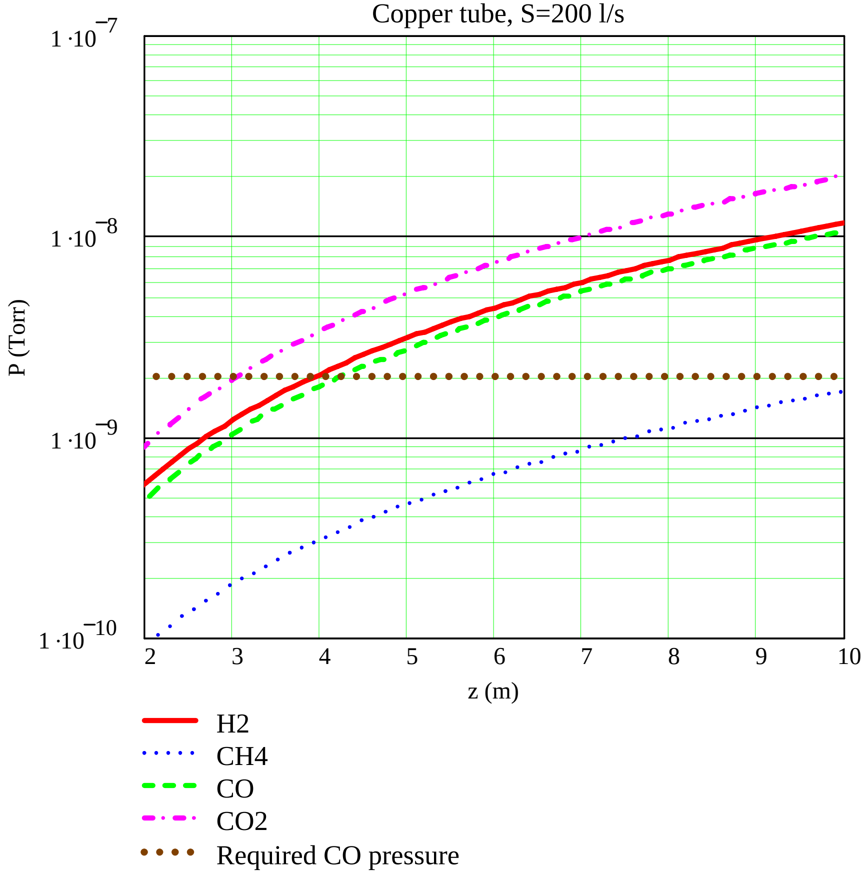
after 100 Ahr beam conditioning: S_{eff} = 20 l/s every 30 m

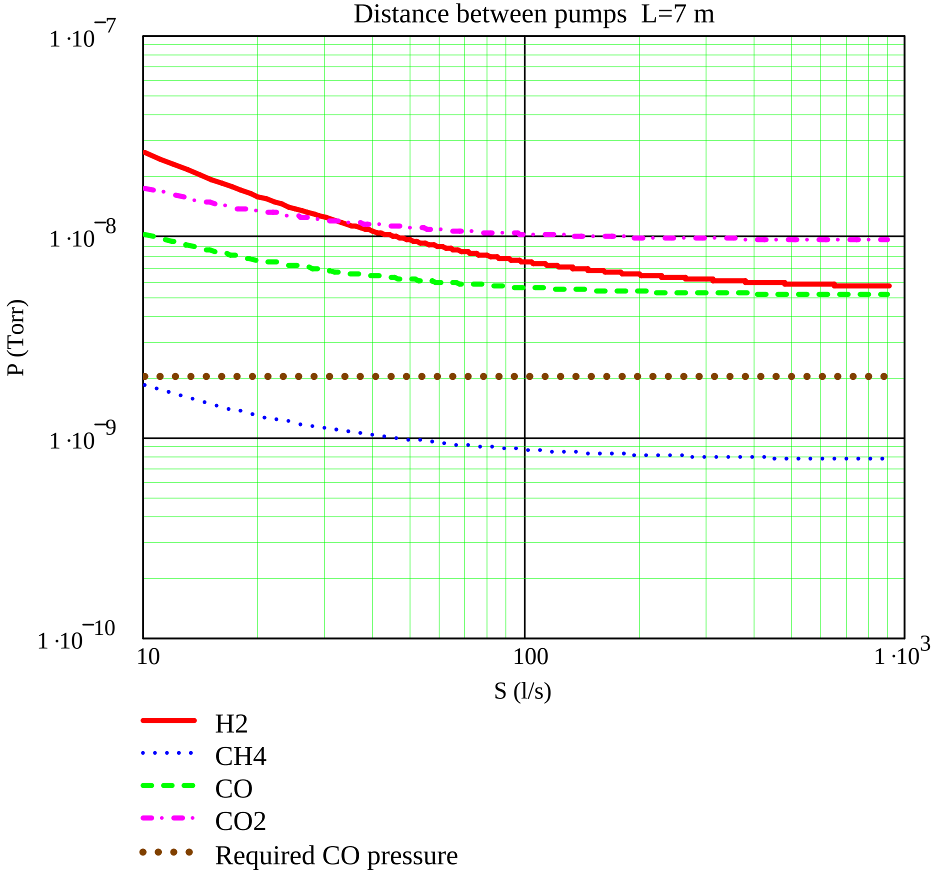




Pressure along the wiggler VC: inside a copper tube

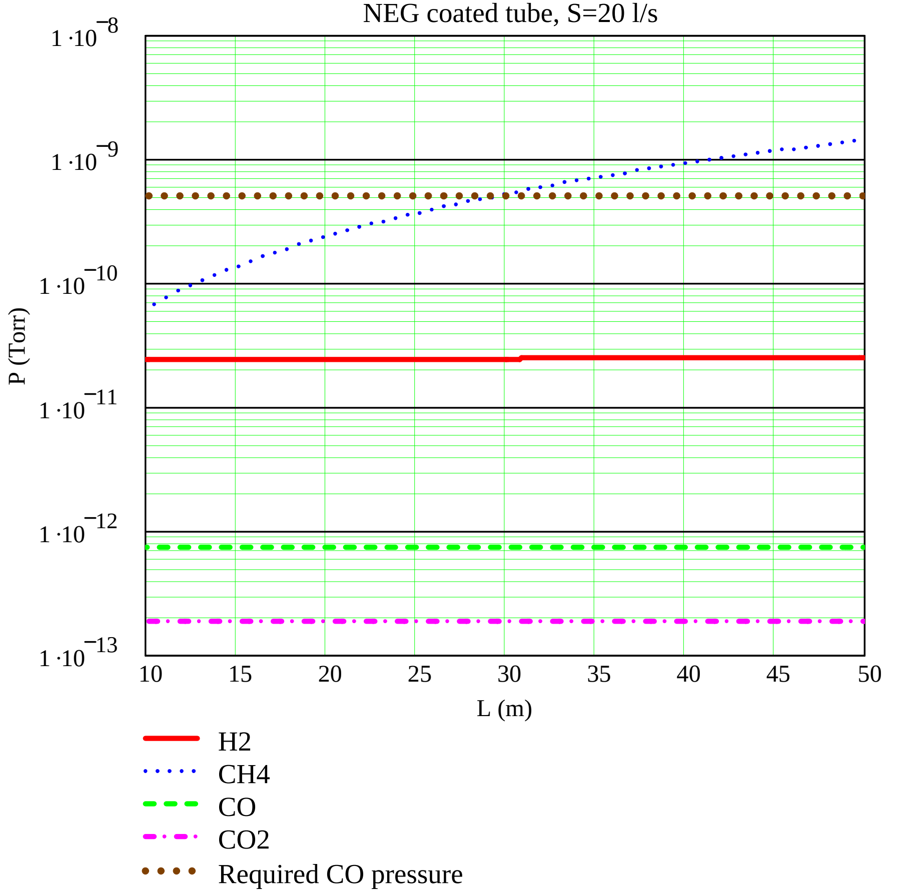
after 100 Ahr beam conditioning: S_{eff} = 200 l/s every 3 m

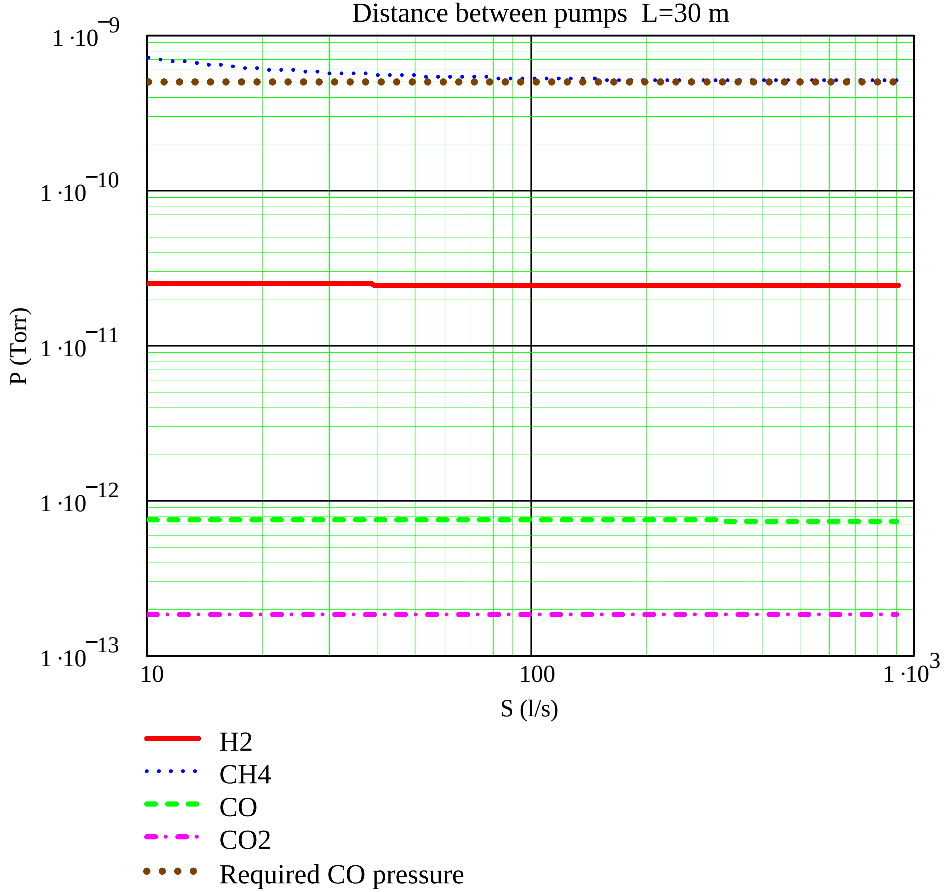




Pressure along the wiggler VC: inside a NEG coated tube

after 100 Ahr beam conditioning: S_{eff} = 20 l/s every 30 m

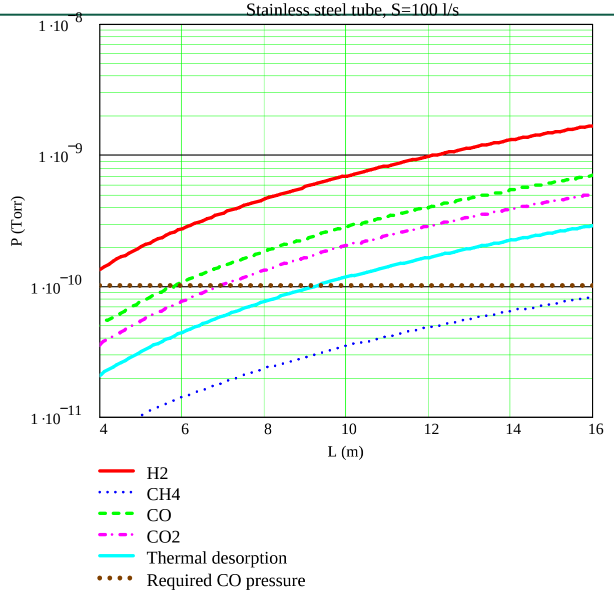


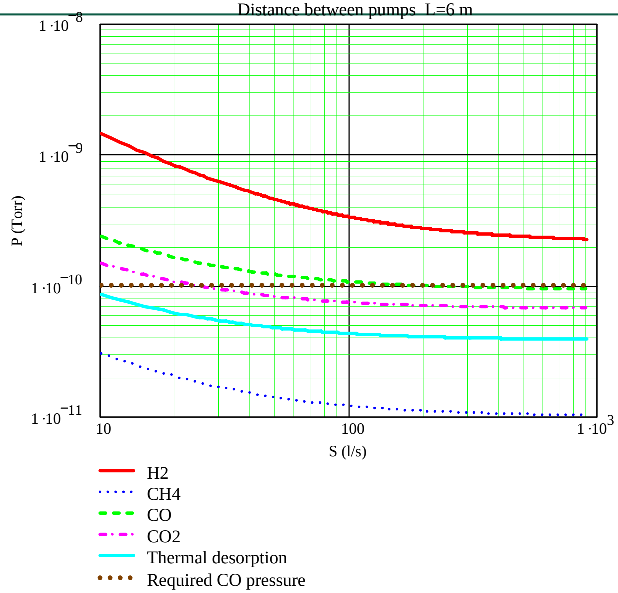


Pressure along the stainless steel Long Straight sections

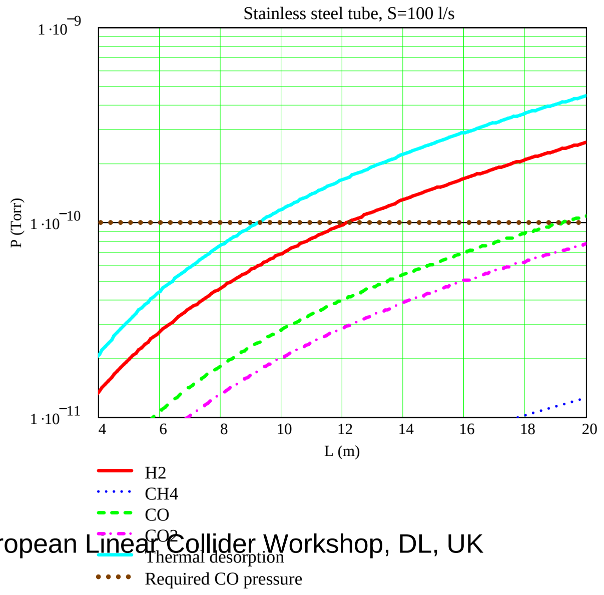
after 100 Ahr beam conditioning

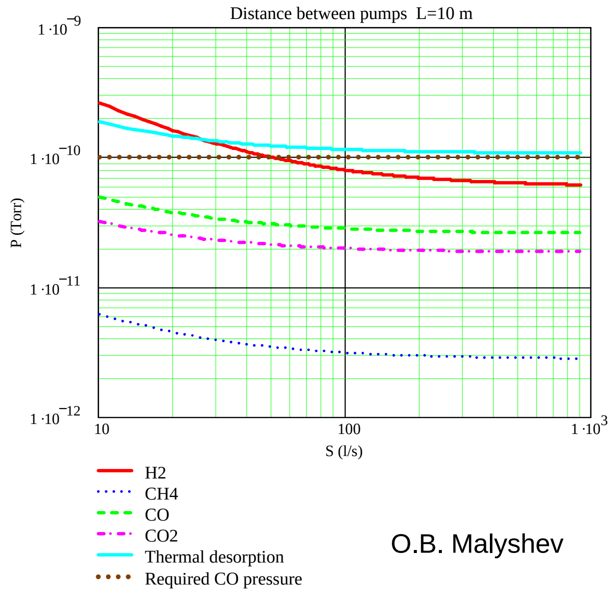
40 m downstream from a dipole
S_{eff} = 100 l/s every 6 m





170 m downstream from a dipole
S_{eff} = 100 l/s every 10 m

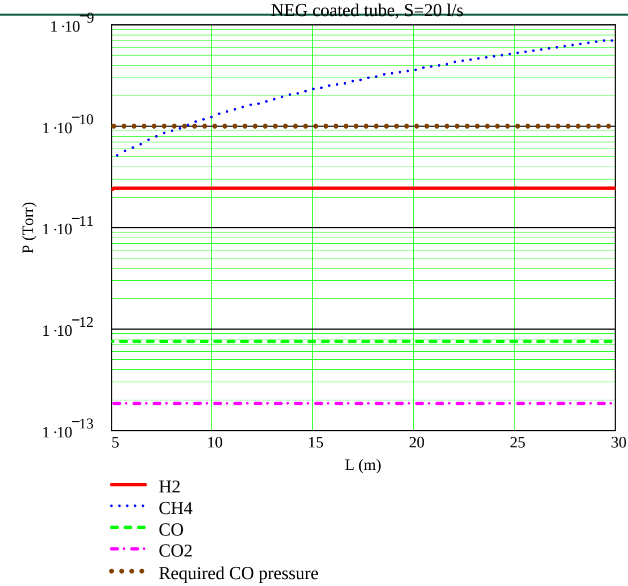


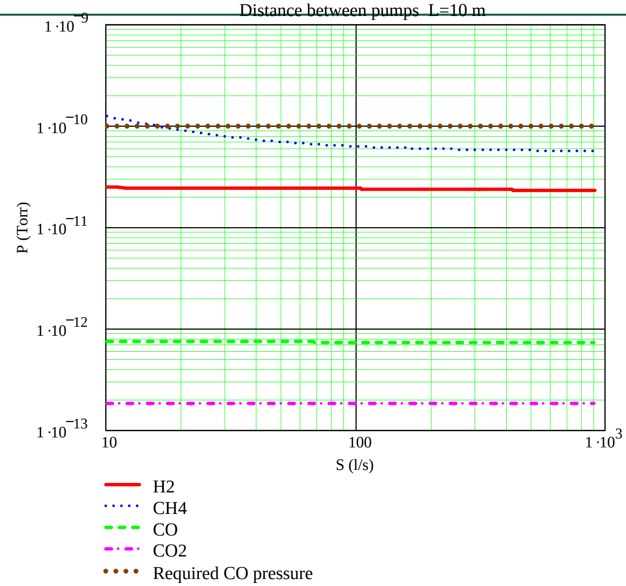


Pressure along the NEG coated Long Straight sections

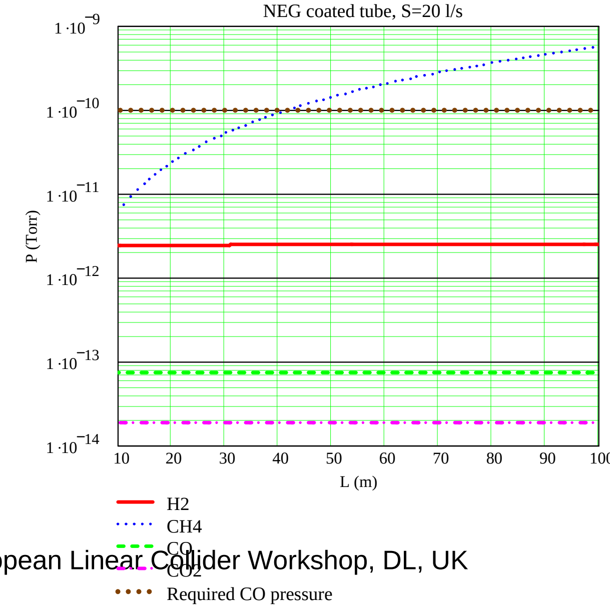
after 100 Ahr beam conditioning

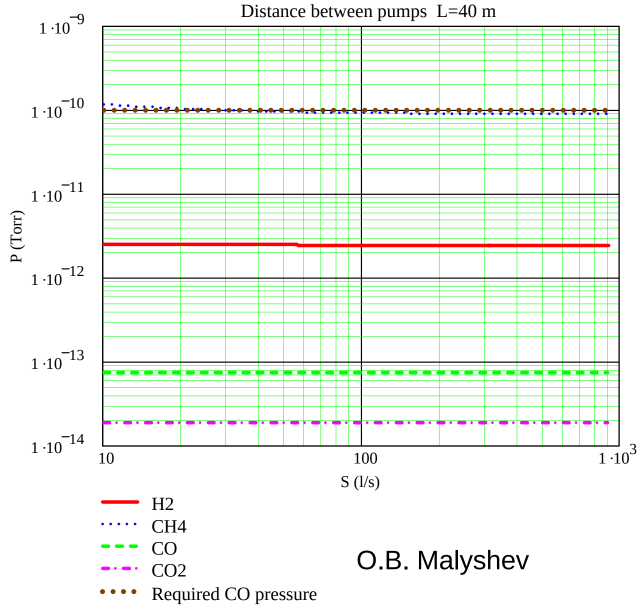
40 m downstream from a dipole
S_{eff} = 20 l/s every 10 m





170 m downstream from a dipole
S_{eff} = 20 l/s every 40 m





Electron multipacting effect on vacuum

- The photon stimulated desorption is a two-step process:
  - Photoelectron emission (E_1 =~5-10 eV and E_2 =~ E_γ, PEY=~0.1 e^-/γ)
  - Electron stimulated molecular desorption
- The electron stimulated desorption grow with electron energy and electron flux hitting the vacuum chamber.
- For example, for E_{e-}= 100 eV and Γ_{e-}= 10^{16} $e^-/(m\cdot s)$, the electron stimulated gas desorption is comparable to the photon stimulated desorption for Γ_γ= 10^{17} $\gamma/(m\cdot s)$ (~8 m downstream dipole). I.e. the electron multipacting may affect on vacuum, new results of e-cloud modelling are required for different parts of DR.
- If the electron multipacting is significant on long straights, it will badly affect the vacuum performance as no vacuum conditioning will be done there with photons.

Main results of the modelling

- NEG coating of vacuum chamber along both the arcs and the wigglers as well as a few tens meters downstream of both looks to be the only possible solution to fulfil vacuum requirement for the ILC dumping ring
- Beam induces electron Multipacting (BIEM) looks to make negligible impact inside dipoles and wigglers, but it might affect on the straights vacuum design and the beam conditioning scenario. E-cloud modelling results are needed!
- Power dissipation from SR (and BIEM if there is any) have to be considered:
  - vacuum chamber water cooling is required in wigglers, arcs and a few tenth meters downstream of both.
  - end power absorber for SR from the wiggler (at first dipole downstream a wiggler)
- NEG coated power absorber for wiggler vacuum chamber needs to be studied experimentally.

Ideal vacuum chamber for ILC DR

- Round or elliptical tube
  - Cheapest from technological point of view
- No antechamber
  - Beam conditioning is most efficient
- NEG coated
  - Requires less number of pumps with less pumping speed
  - 180°C for NEG activation instead of 250-300°C bakeout
  - Choice of vacuum chamber material (stainless steel, copper and aluminium) does not affect vacuum in this case
  - Residual gas CH_4 and H_2 (almost no CO and CO_2)
- There are experimental results that NEG coated elliptical vacuum chamber might be re-activated even without baking to 180°C, just by SR.
  - Accurate experimental study is needed