# *How e-cloud effect affects the ILC DR Vacuum System*

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# Vacuum studies vs e-cloud modelling

**Vacuum science:**

- Photon distribution, diffused and forward scattered reflection
- Photon induced electron production
- Secondary electron production
- Conditioning effects

- Photon, electron and ion stimulated desorption

- Gas density calculations

**E-cloud modelling**

- $q(e^-/m^3)$
- …
- …

- Electron flux to the vacuum chamber walls

# Photon reflectivity and azimuthal distribution

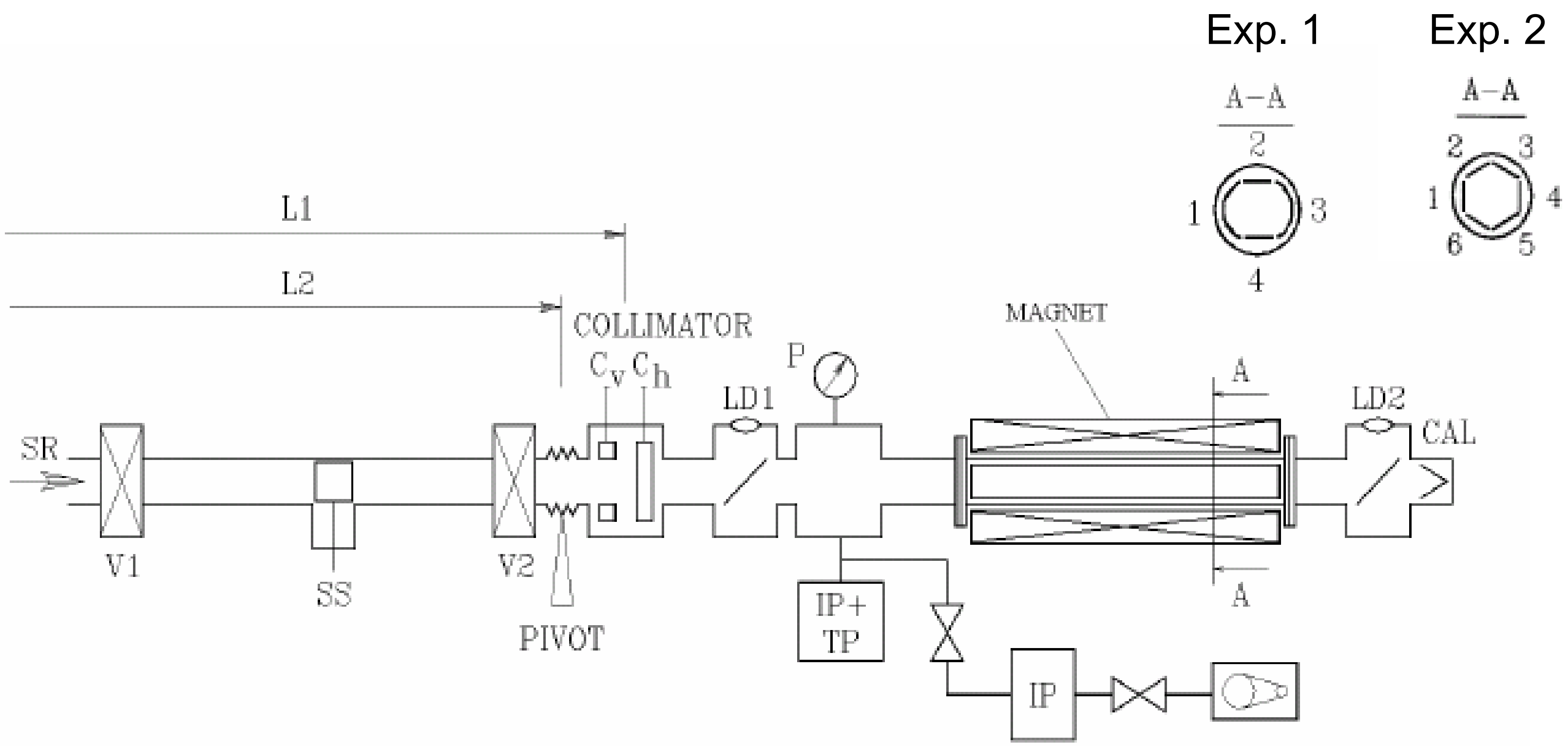



Figure 1. Set-up for measurements of the azimuthal photoelectron distribution in magnetic field and of the photon reflectivity

# Forward scattered reflectivity at 20 mrad grazing incidence

| | Sample Reflectivity (power) (%) | Reflectivity (photons) (%) |
|---|---|---|
| Stainless steel as-received | **2** | **22** |
| Cu co-laminated as-received | **50** | **95** |
| Cu co-laminated oxidised | **20** | **65** |

**I.e. the reflected photons are mainly low energy photons**

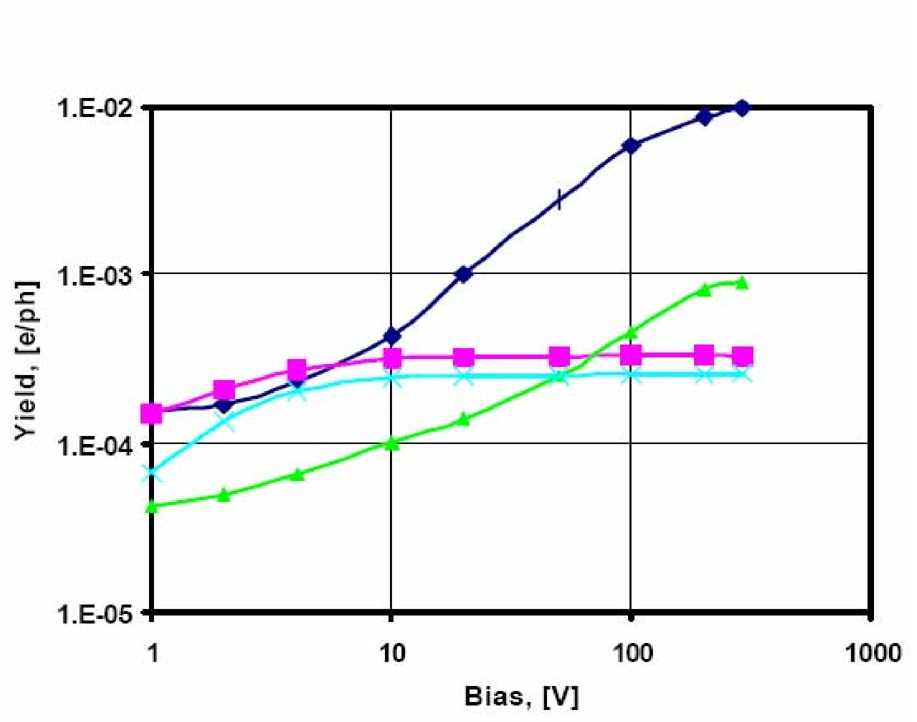
*V.V. Anashin et al. / Nuclear Instruments and Methods in Physics Research A 448 (2000) 76-80.*

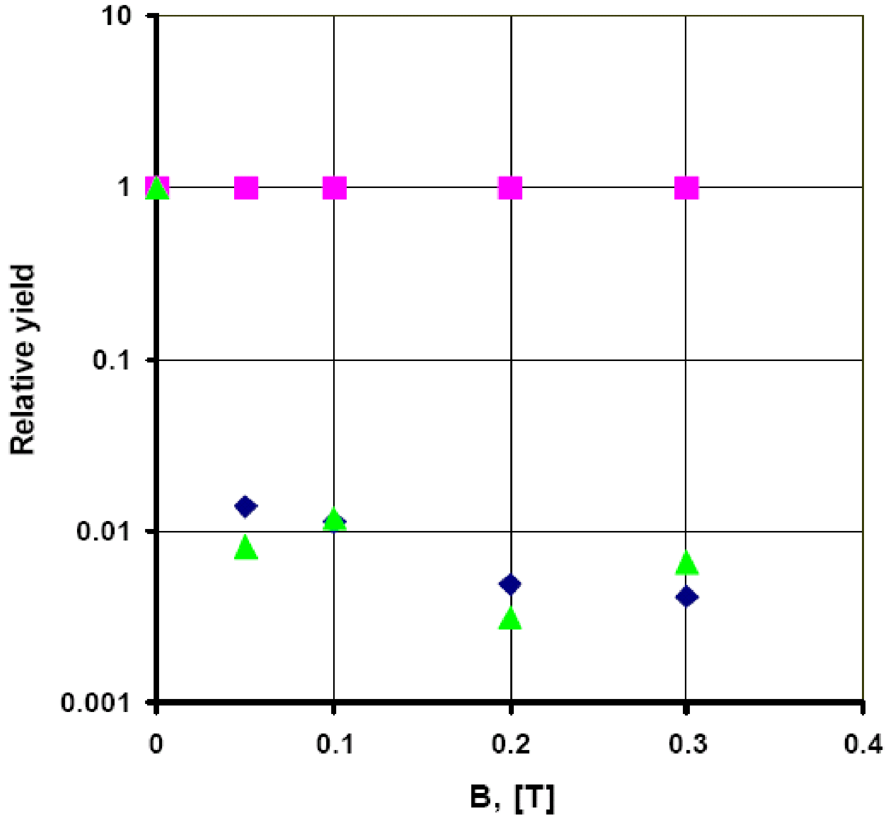
*See also: V. Baglin, I.R. Collins, O. Grobner, EPAC'98, Stockholm, June 1998.*

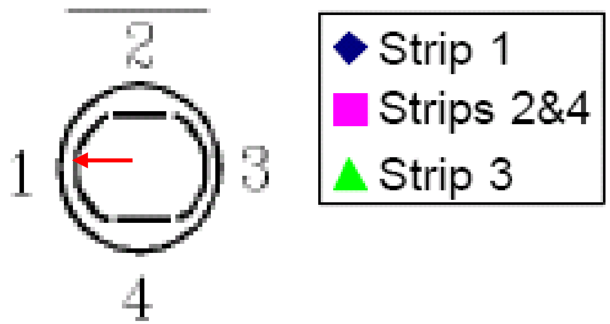
# Photon azimuthal distribution – 6 strips experiment

| Sample | $\varepsilon_c$ (eV) | Strip 1 | Strip 2 or Strip 3 | Strip 4 or Strip5 | Strip 6 |
|---|---|---|---|---|---|
| $I_i \Big/ \sum_{i=1}^{6} I_i$ | | | | | |
| Stainless steel | **243** | **74** | **3.8** | **8** | **2.5** |
| Bright Cu | **245** | **90** | **1.9** | **2** | **1.8** |
| Oxidised Cu | **205** | **95** | **1** | **1.1** | **1** |
| $I_i(1-R) \Big/ \sum_{i=1}^{6} I_i$ | | | | | |
| Stainless steel | **243** | **60** | **2.5** | **6.0** | **1.5** |
| Bright Cu | **245** | **4.5** | **0.1** | **0.1** | **0.1** |
| Oxidised Cu | **205** | **30** | **0.3** | **0.4** | **0.3** |

# Photon azimuthal distribution – 4 strips experiment

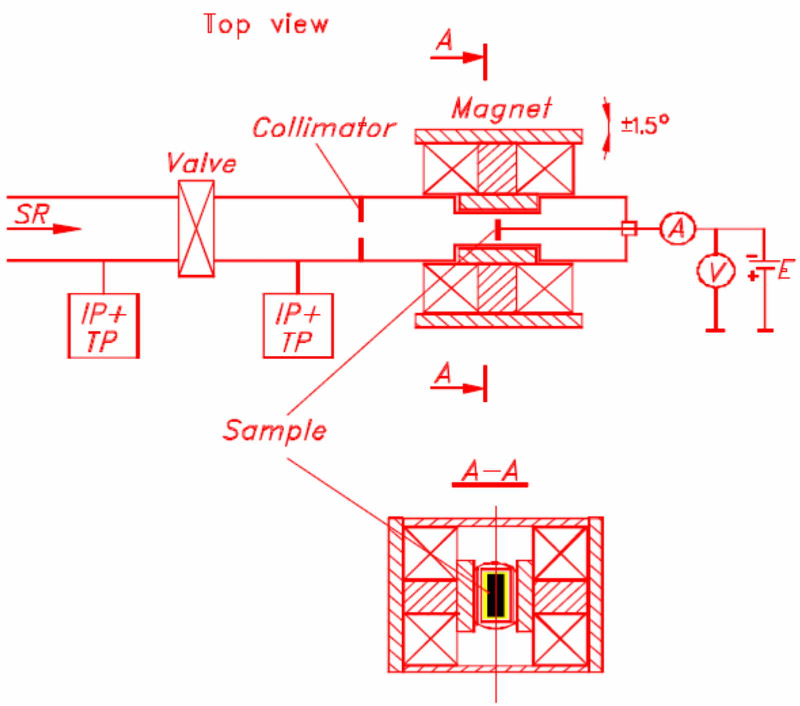



*V.V. Anashin, O.B. Malyshev, N.V. Fedorov and A.A. Krasnov.* Azimuthal distribution of photoelectrons for an LHC beam screen prototype in a magnetic field. Vacuum Technical Note 99-06. LHC-VAC, CERN April 1999.

# Photoelectron current in magnetic field




*V.V. Anashin, O.B. Malyshev, N.V. Fedorov and A.A. Krasnov. Photoelectron current in magnetic field. Vacuum Technical Note 99-03. LHC-VAC, CERN April 1999*.

- Sample SS. The stainless steel sample made from a rolled sheet.
- Sample Cu/SS-1 (=). The copper laminated stainless steel made from a sheet; the rolling lines are across the sample.
- Sample Cu/SS-2 (|||). The copper laminated stainless steel made from a sheet; the rolling lines are along the sample.
- Sample Cu/SS-3 (||| ox). The copper laminated stainless steel made from a sheet; the rolling lines are along the sample. Oxidation.
- Sample Cu/SS-4 (__/). The copper laminated stainless steel made from a sheet with turned-in, long edges, i.e. 5-mm wide strips at the long edges were turned to 10–15° towards the SR; the rolling lines are along the sample.
- Sample OFHC (⊥⊥⊥). The copper sample machined from a bulk OFHC with ribs along the sample. No special treatment. The ribs are 1 mm in height and
- 0.2 mm in width. The distance between the ribs is 3 mm.
- Sample Au/SS. The stainless steel sample electro-deposited with 6-μm Au.

# Results

1) The photoelectron yield is different for studied samples at zero potential, but the same at the accelerating potential of 300V,

***k* = (1.5 ± 0.3)×10$^{-2}$ e-/γ.** The photoelectron yield from the layer of gold is about two times higher.

2) The magnetic field suppress the photoelectron yield up to **30–100 times** when the surface is parallel to the magnetic field, but this effect is much less at

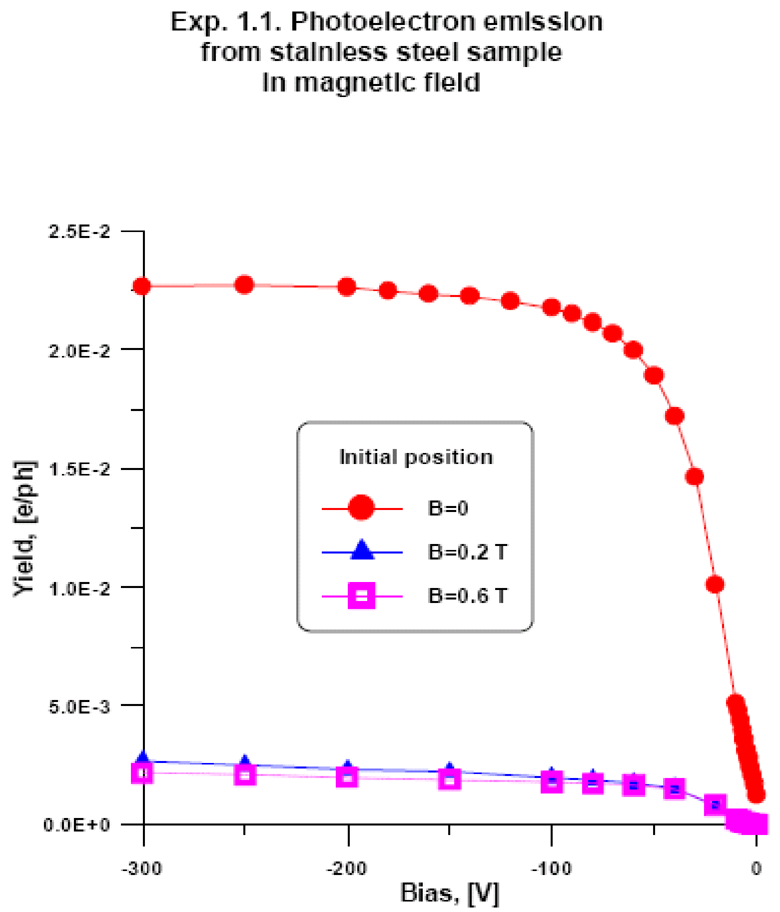
the angle of 1.5° (5–10 times).

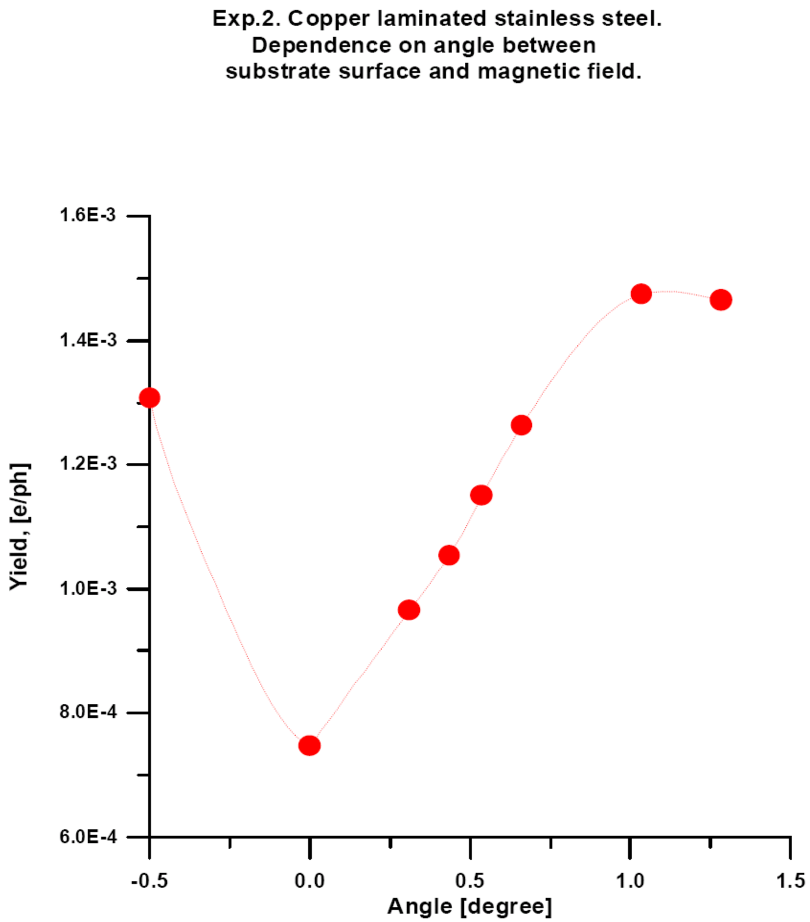
3) The photoelectron yield decreases with the accumulated photon dose: the photoelectron yield reduced 2–3 times at the accumulated photon dose of about

10$^{22}$ photons/cm$^2$.

| Experiment No. and | Beams | | Measurements without magnetic field | | | Magnetic field efficiency: | |
|---|---|---|---|---|---|---|---|
| Sample | $E_{e-e+}$, [MeV] | $E_c$, [eV]) | κ; [e⁻/γ] U=-300V | $\frac{\kappa(0V)}{\kappa(-300V)}$ | Reflectivity $\frac{\kappa(+300V)}{\kappa(-300V)}$ | U = 0 $\frac{\kappa(0.6T)}{\kappa(0T)}$ | U = -300V $\frac{\kappa(0.6T)}{\kappa(0T)}$ |
| Exp. 1, SS | 518 | 259 | 0.016 | 0.036 | 0.024 | 0.023 | 0.028 |
| Exp. 2, Cu/SS-1 (≡) | 514 | 253 | 0.015 | 0.15 | 0.044 | 0.010 | 0.029 |
| Exp. 3, Cu/SS-2 (‖‖) | 470 | 194 | 0.014 | 0.11 | 0.015 | 0.021 | 0.030 |
| Exp. 4, Cu/SS-3 (‖‖ ox) | 392 | 112 | 0.014 | 0.052 | 0.033 | 0.018 | 0.015 |
| Exp. 5, OFHC (⊥⊥⊥) | 380 | 102 | 0.0084 | 0.055 | 0.023 | 0.024 | 0.013 |
| Exp. 6, Cu/SS-4 (_/) | 220 | 20 | 0.014 | 0.07 | — | 0.02 | 0.06 |
| Exp. 7, Cu/SS-4 (_/) | 560 | 319 | 0.018 | 0.05 | 0.180 | 0.01 | 0.08 |
| Exp. 8, Au/SS | 580 | 356 | 0.027 | 0.06 | 0.045 | 0.028 | 0.042 |

# Examples of measurement results




PEY (and SEY) depends on potential gradient at the surface!

Grooves alignment in respect to magnetic field

# Input parameters in e-cloud models

- Photon distribution, diffused and forward scattered reflection
- Photon induced electron production
- Secondary electron production
- Conditioning effects

- Effect of magnetic field

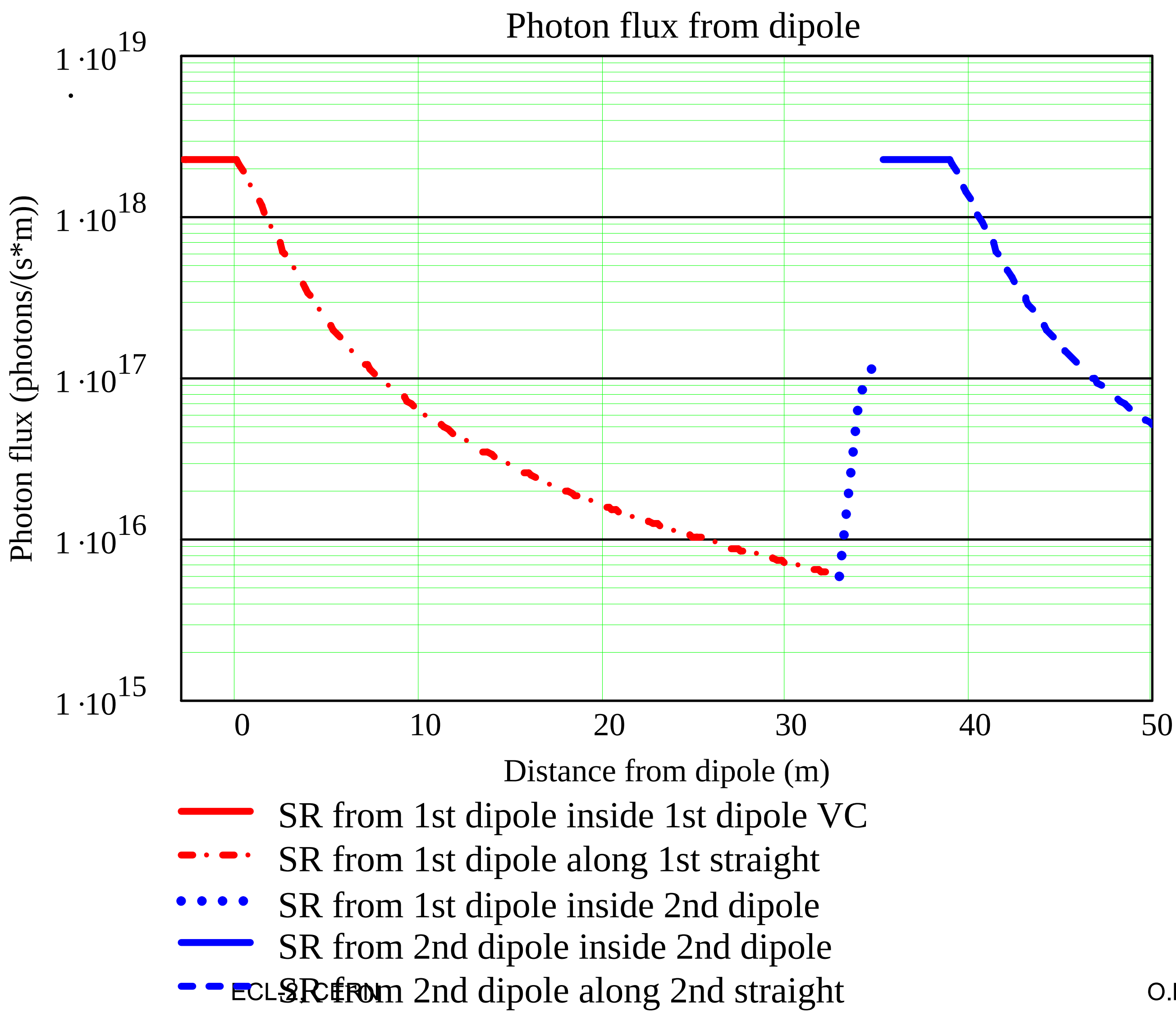
# Required vacuum for ILC DRs

- The need to avoid fast ion instability leads to very demanding specifications for the vacuum in the electron damping ring [Lanfa Wang, private communication]:

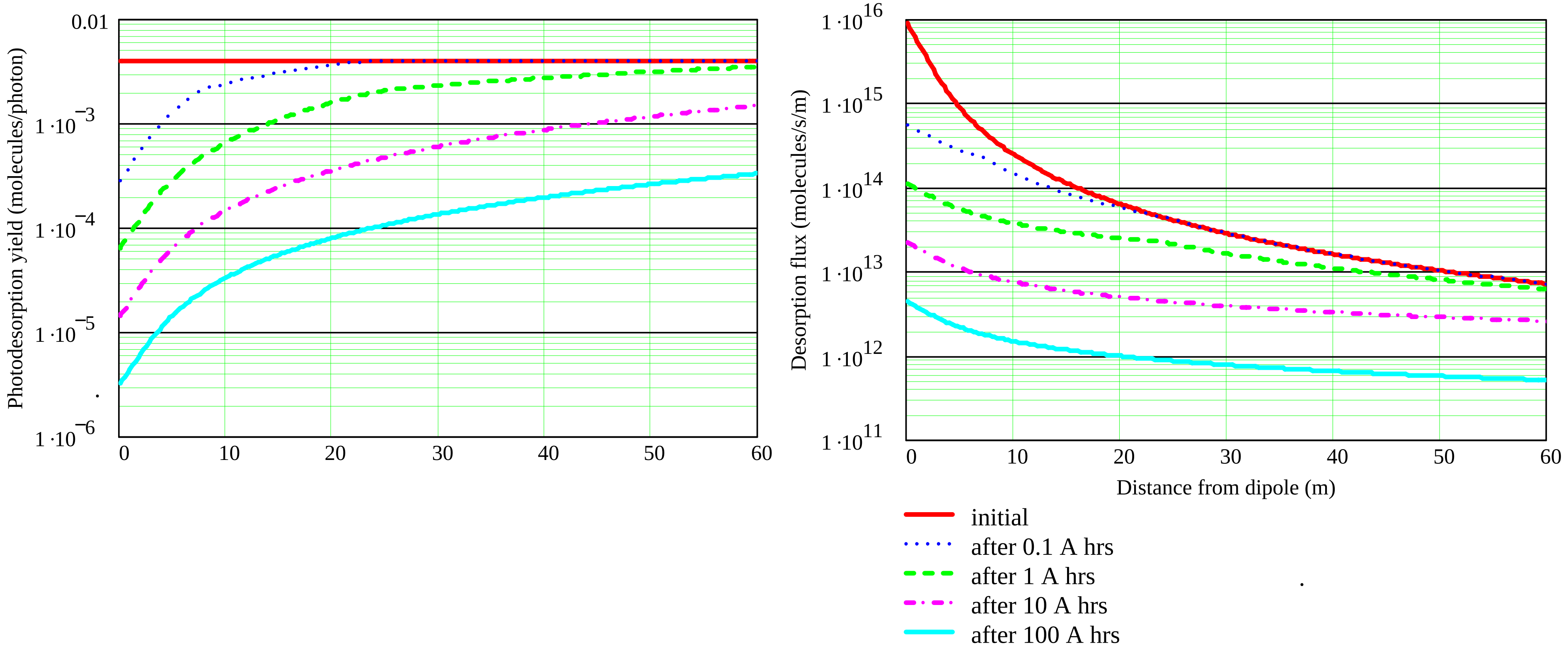
  - < 0.5 nTorr CO in the arc cell,
  - < 2 nTorr CO in the wiggler cell and
  - < 0.1 nTorr CO in the straight section

- In the positron damping ring required vacuum level was not specified and assumed as 1 nTorr (common figure for storage rings)

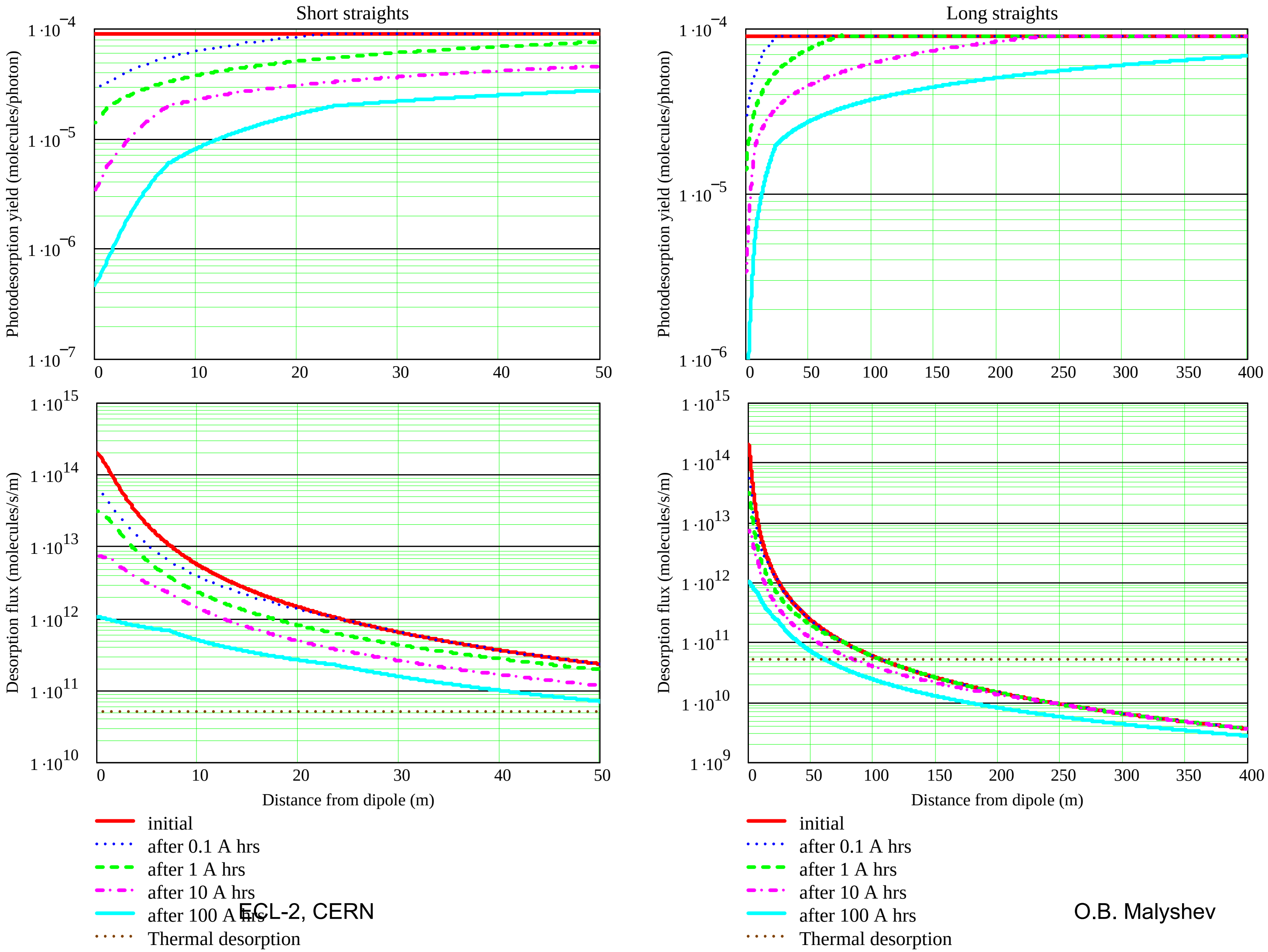
# Photon flux onto the 50-mm diameter vacuum chamber walls inside the ILC DR dipoles and along the short straights



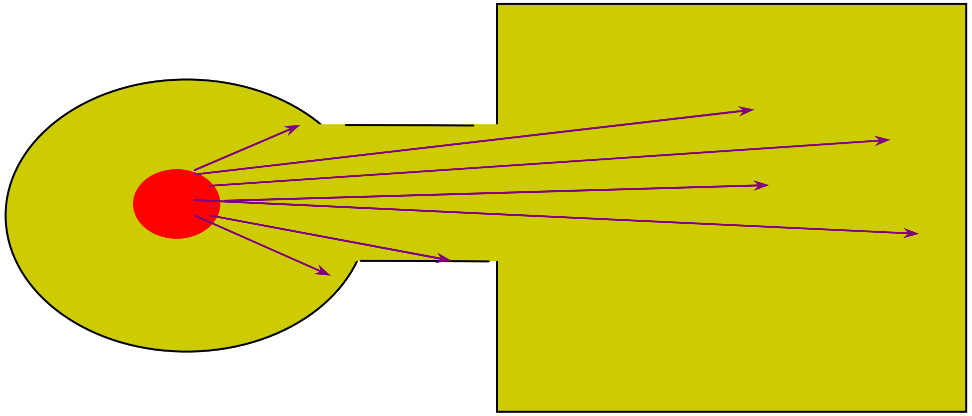
# Photodesorption yield and flux during conditioning

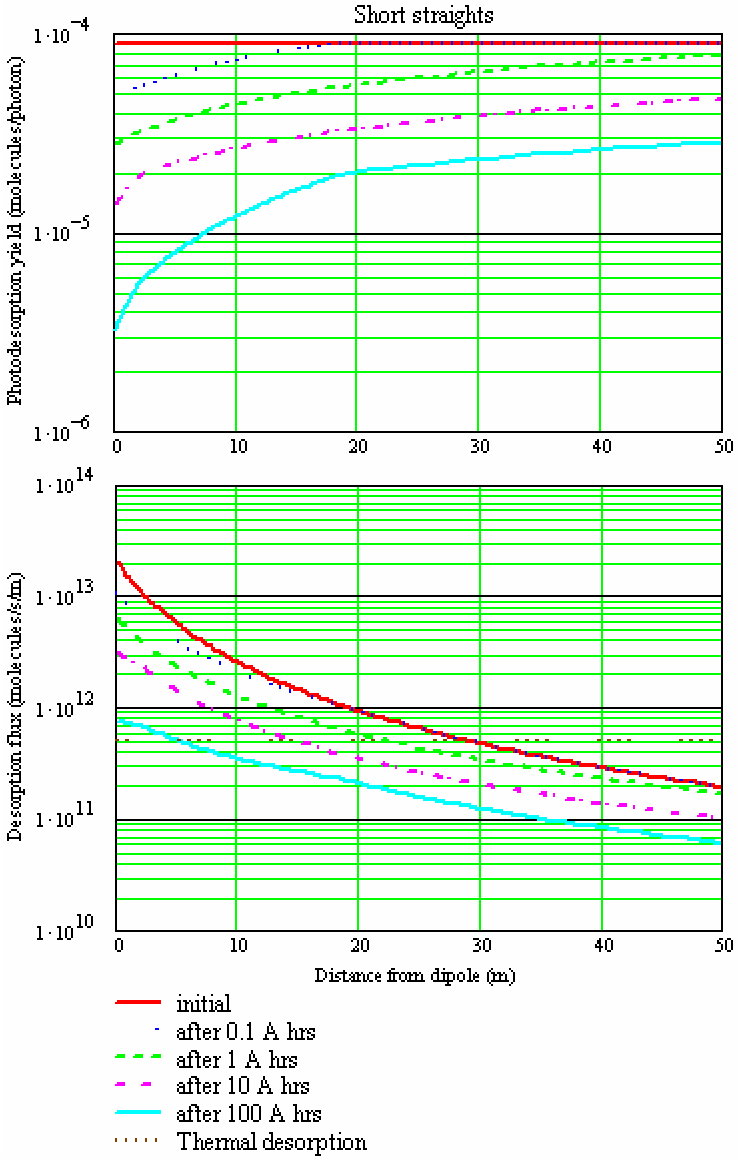


# Photodesorption yield and flux along the damping ring straights made of stainless steel *tubular vacuum chamber* and baked in-situ at 300°C for 24 hrs.



# 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.





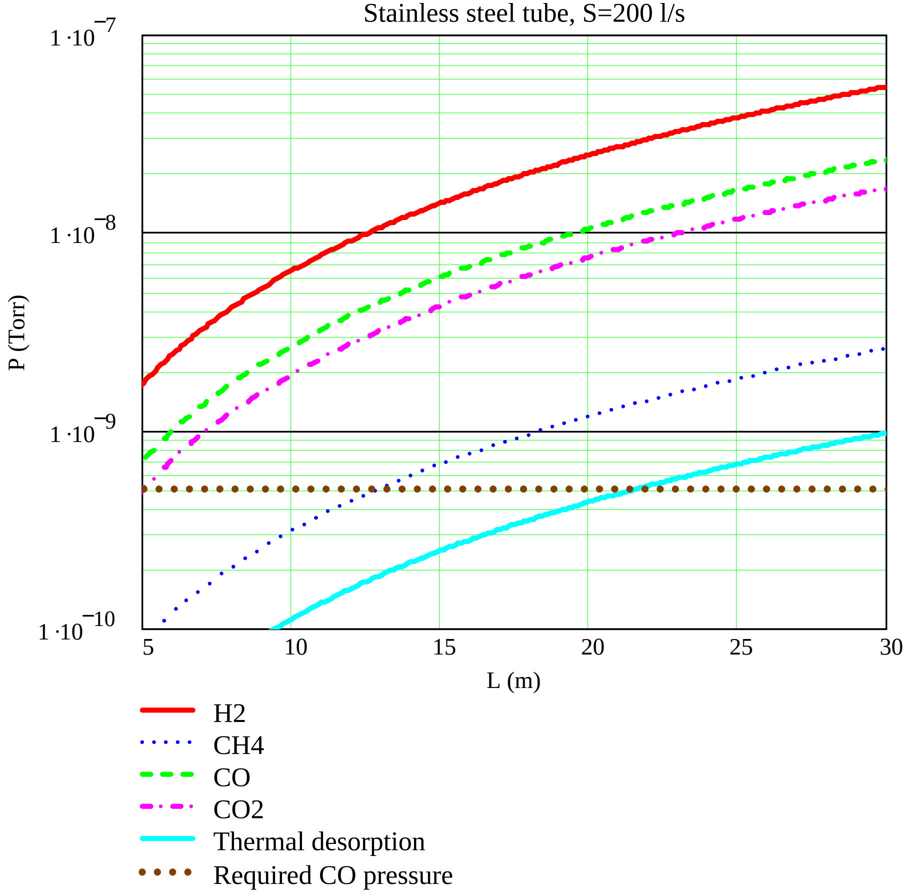

If ~10% of photons hit a beam vacuum chamber, photon stimulated desorption after 100 Ahr is almost the same as without antechamber, but thermal induced desorption is much larger.

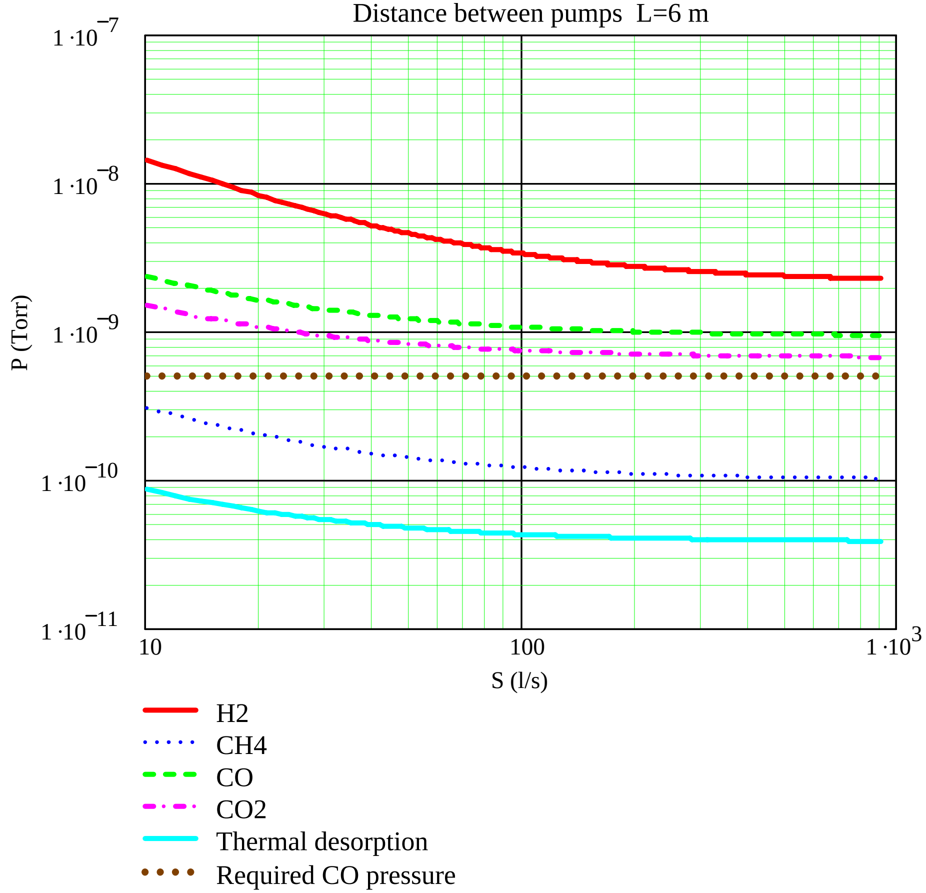
# Tubular chamber vs a vacuum chamber with antechamber

- 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.

# Pressure along the arc: inside a stainless steel tube

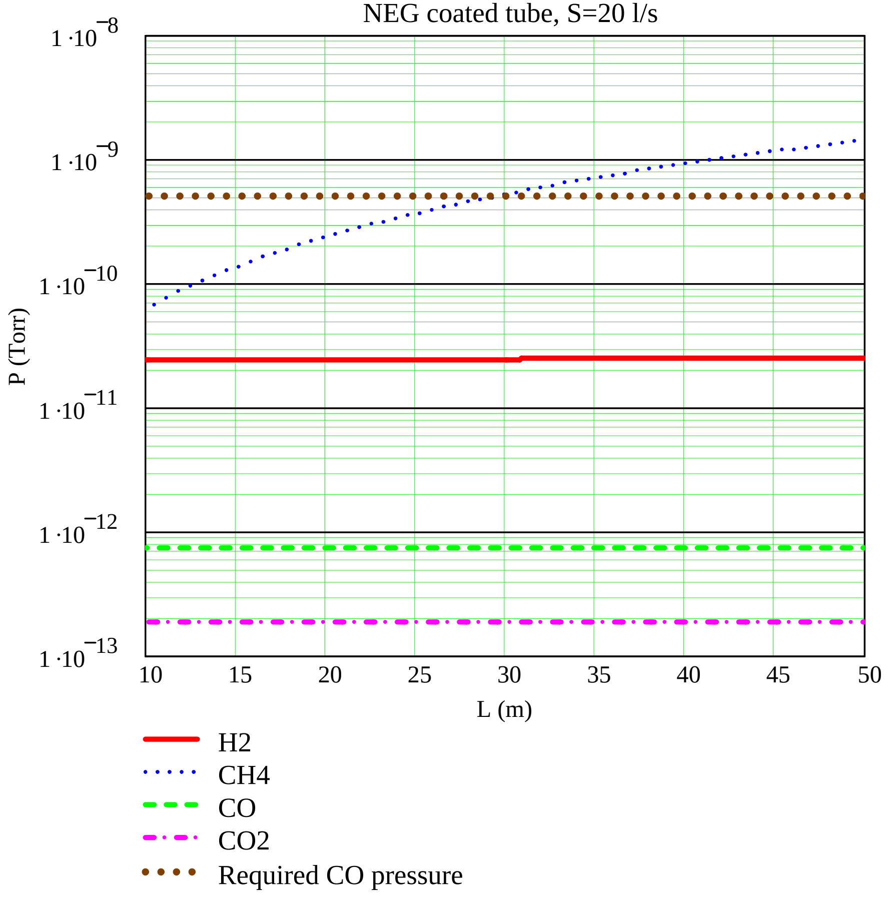
after 100 Ahr beam conditioning: $S_{eff}$ = 200 l/s every 5 m

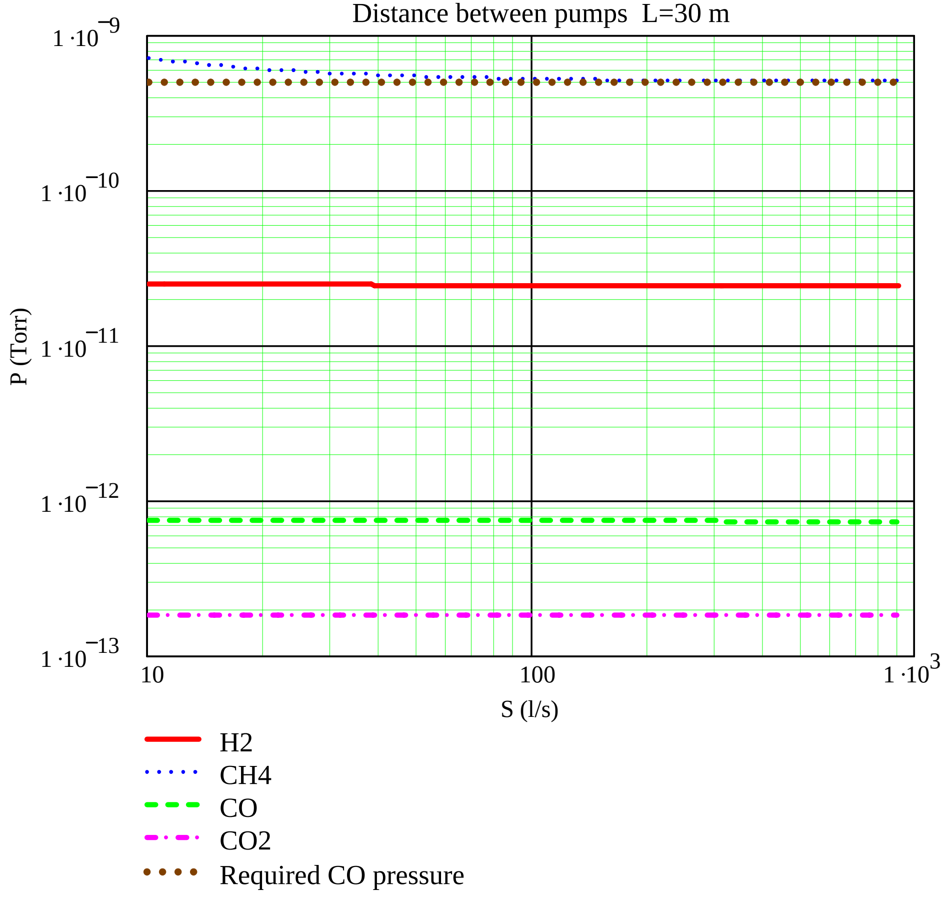


# Pressure along the arc: inside a NEG coated tube

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



# Main result 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

## Ideal vacuum chamber for vacuum design:

- Round or elliptical tube
  - Cheapest from technological point of view
- No antechamber
  - Beam conditioning is most efficient
  - Easy geometry for TiZrV coating
- 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 $CO_2$)

*O. Malyshev. Vacuum Systems for the ILC Damping Rings. EUROTeV Report-2006-094.*

# How the e-cloud affect vacuum

- The electron flux ~$10^{16}$ $e^-/(s\cdot m)$ with $E \approx 200$ eV will desorb approximately the same gas flux as the photon flux of ~$10^{18}$ $\gamma/(s\cdot m)$.
- If the electron stimulated desorption if larger than photon stimulated desorption, that should be considered in vacuum design and conditioning scenario.

- Gas density will increase => gas ionisation will also increase =>
  - Electrons are added to e-cloud
  - Ions are accelerated and hit the wall of vacuum chamber => ion induced gas desorption and secondary electron production
- Gas density increase may change e-cloud density.

# How the e-cloud affect vacuum

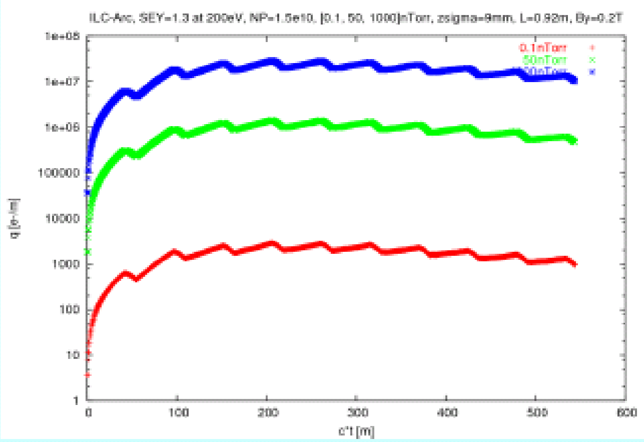
- The electron flux [$e^-$/(s·m)] and average energy [eV] and total power [W] of electrons are required for gas density calculations and vacuum design.
- Groves and antechamber will increase the necessary conditioning time and complicate the TiZrV coating. It is more expensive than NEG coated tube.
- Electrodes and insulating materials may dramatically increase das density in a vacuum chamber due to thermal, photon, electron and ion induced gas desorption.
  - Choice of material and design must be UHV compatible.
  - The NEG coating might be difficult, impossible or inefficient, which will lead to much more expensive vacuum design.
  - If the 'e-cloud killer' requires a vertical space – it will require larger magnet gap and more expensive dipoles.

# If e-cloud in too large in a round tube

- What is the main source of electrons:
  - Photo-electrons
    - Geometrical: reduction or localisation of direct and reflected photons
    - Surface treatment, conditioning, coating
  - Secondary electrons
    - All possible solution discussed during this workshop
  - Gas ionisation
    - Surface treatment and conditioning
    - Low outgasing coating
    - Better pumping
- Good solution against Photo-electrons or Secondary electrons might led to higher gas density and higher gas ionisation, and vice versa.

# Example 1: W. Bruns's results

Fixed SEY, varying Gaspressure and Bunchpopulation, no PEY



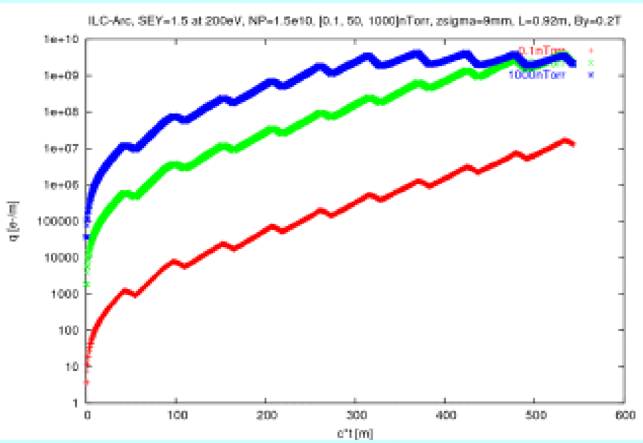

SEY=1.3, [0.1,50,1000] nTorr, nP=1.5e10

SEY=1.3 $q_{sat} \propto P$,

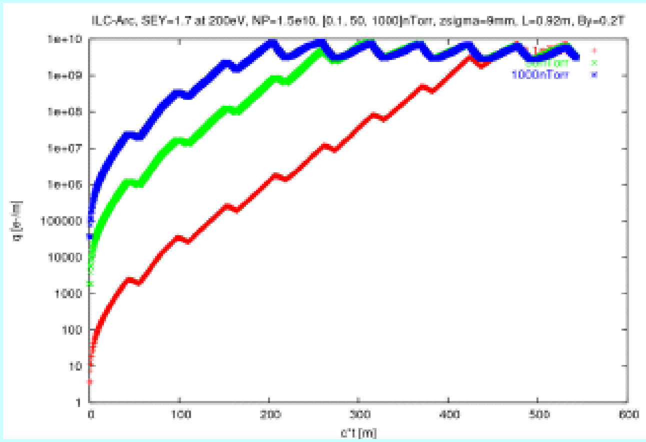
here gas ionisation is the main source of electrons but $q_{sa}t < q_{max}$ for ILC DR

SEY≥1.5 qsat>qmax for ILC DR,

here SEY is the main source of electrons



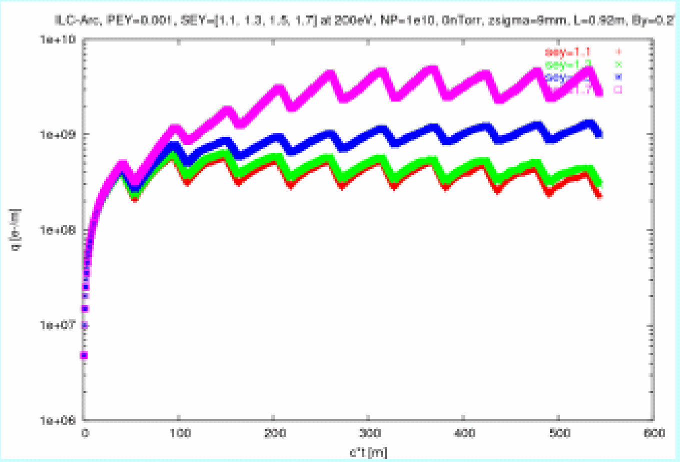

SEY=1.5, [0.1, 50, 1000]nTorr, nP=1.5e10



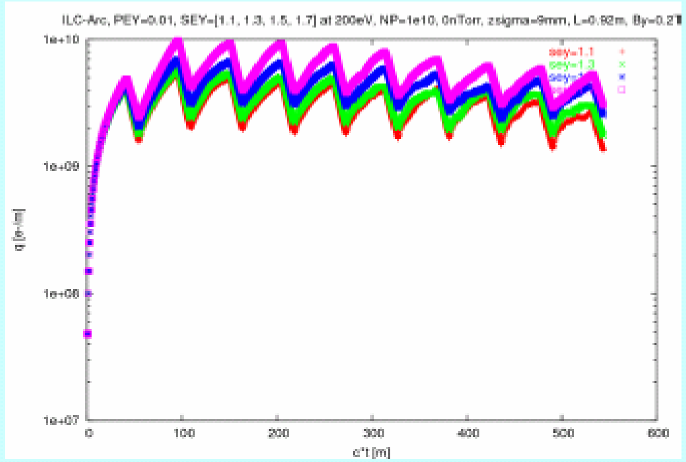

SEY=1.7, [0.1, 50, 1000]nTorr, nP=1.5e10

# Example 1: W. Bruns's results

Fixed PEY, varying SEY and Bunchpopulation, no Gaspressure




PEY=0.001, SEY=[1.3,1.5,1.7], nP=1e10




PEY=0.01, SEY=[1.3,1.5,1.7], nP=1e10

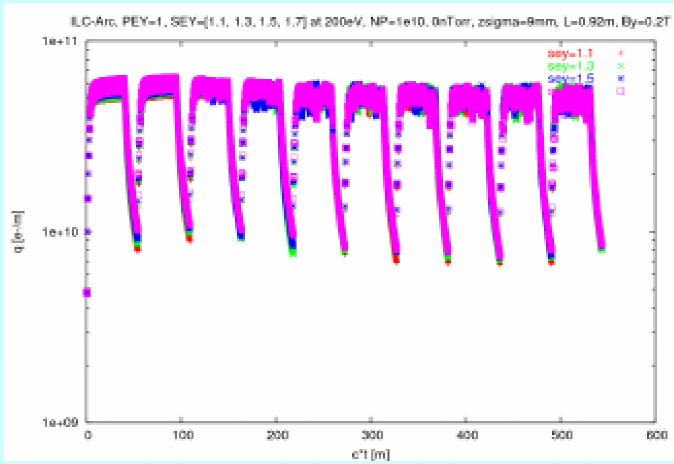
PEY=0.001 $q_{sat}$=f(SEY) for SEY>1.3, hence

the main source of electrons are

photoelectrons for SEY≤1.3,

secondary electrons for SEY >1.3.

PEY≥0.01 is the main source of electrons are photoelectrons




PEY=1, SEY=[1.3,1.5,1.7], nP=1e10