Vacuum Design

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Outline

1. Dynamic vacuum due to SR
2. Vacuum-Related Electron Cloud Issues
3. Mechanical design

Vacuum required 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]:

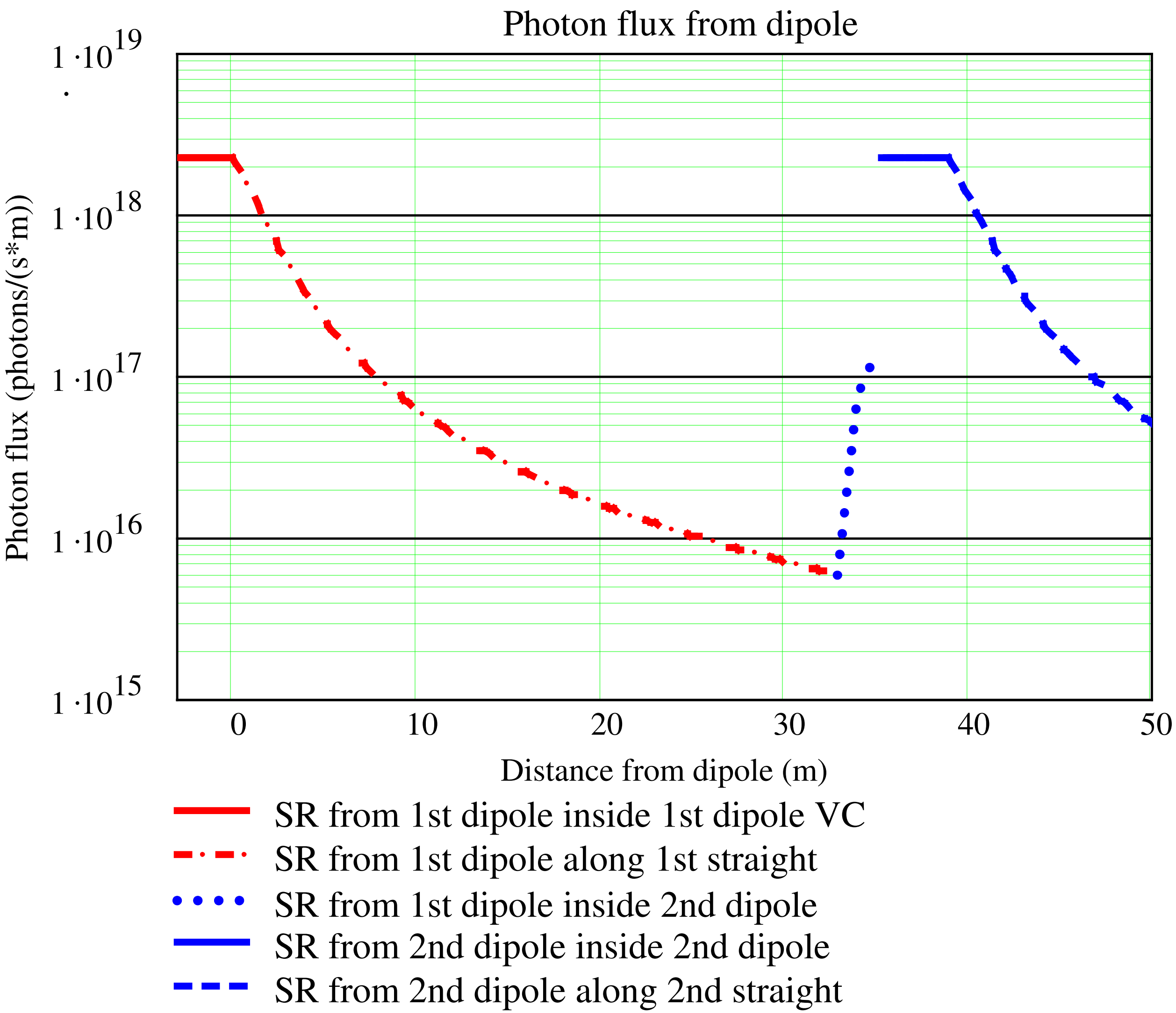
  - < 0.5 nTorr CO in the arc cell,
  - < 2 nTorr CO in the wiggler cell and
  - < 0.1 nTorr CO in the straight section

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

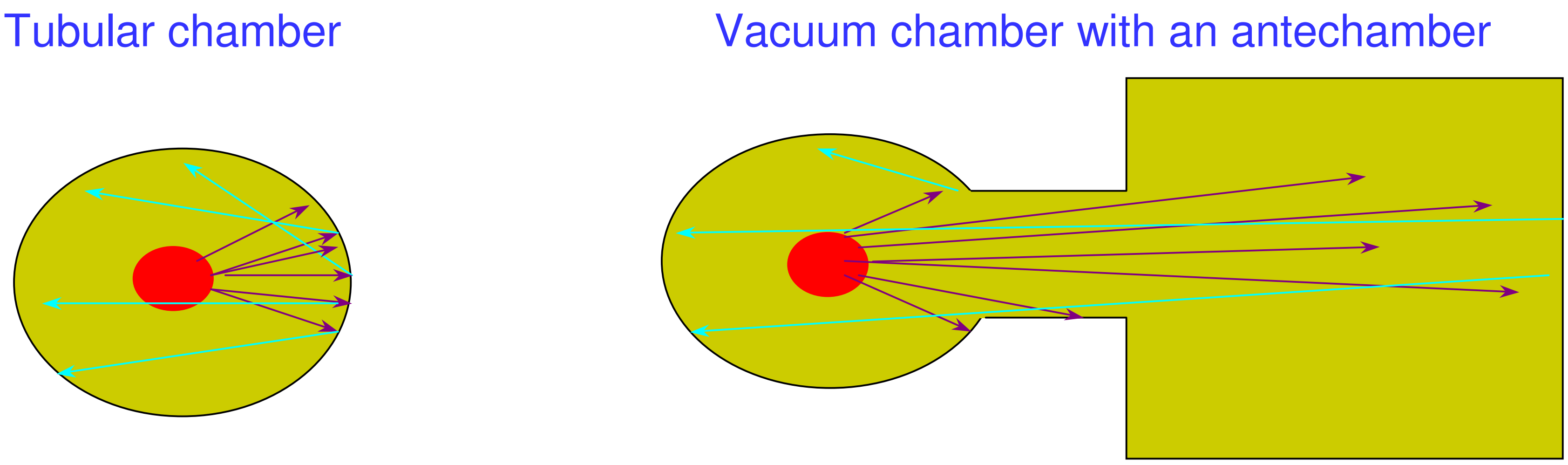
SR photon induced dynamic pressure

- SR induced gas desorption is the main source of gas defining dynamic pressure SR sources and colliders

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



Tubular chamber vs. a vacuum chamber with an antechamber



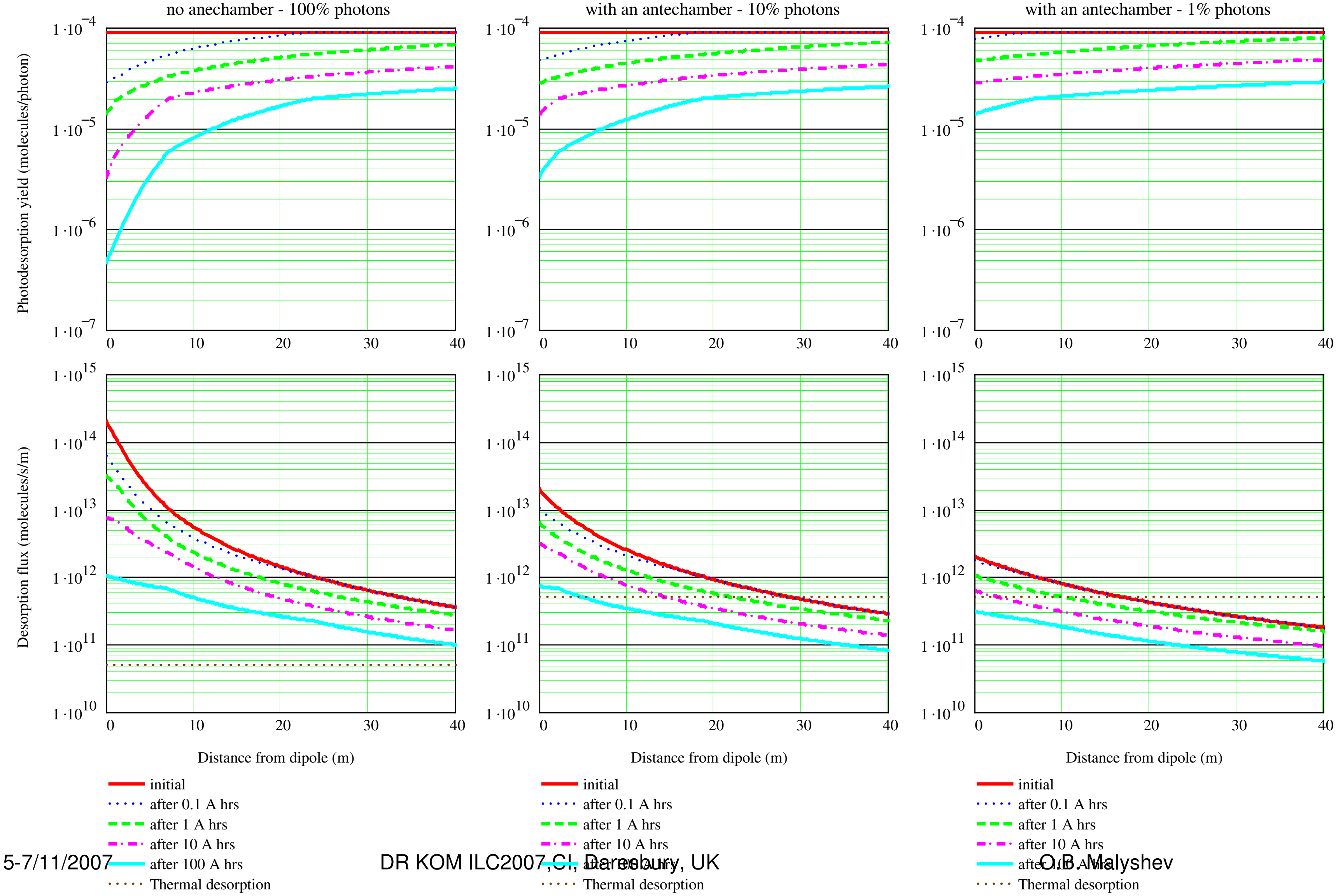
Diffuse reflected photons irradiate all surface (from **1.5% to 20%**)

Forward scattered photons from 2% to 65%

~**1-10%** of photons hit a beam vacuum chamber

- ~**99-90%** of photons enter an ante-chamber,
- thermal induced desorption is much larger (proportional to the surface area).

Outgassing from baked *in-situ* tubular chamber vs a vacuum chamber with antechamber (outgassing from an SR absorber in not included)

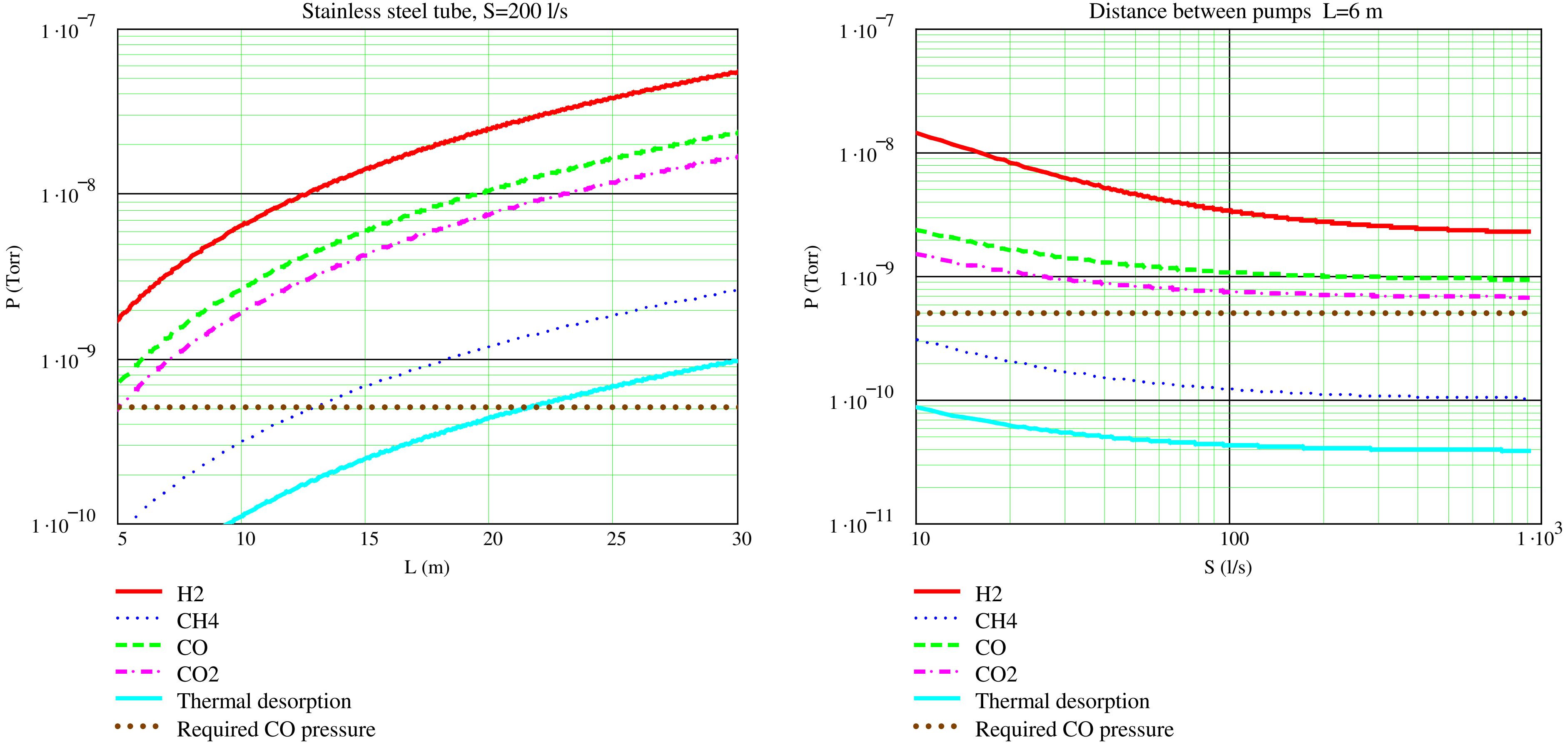


Vacuum: tubular chamber vs a vacuum chamber with an antechamber

- Results:
  - The distributed gas desorption after 100 Ahr of beam conditioning is almost the same with and without antechamber.
  - Thermal outgassing is a few times larger with an ante-chamber
  - Photon stimulated desorption from the lumped absorber in the ante-chamber.
  - => The total outgassing inside the vacuum chamber with an ante-chamber is larger.
- An ante-chamber design:
  - Does indeed increase the vacuum conductance (+)
  - Allows installing lumped SR power absorbers (+)
  - Does not help in reducing the SR induced out-gassing after 100 Ahr conditioning (–)
  - Larger thermal desorption (–)
  - Requires larger pumps (–)
  - More expensive (–)

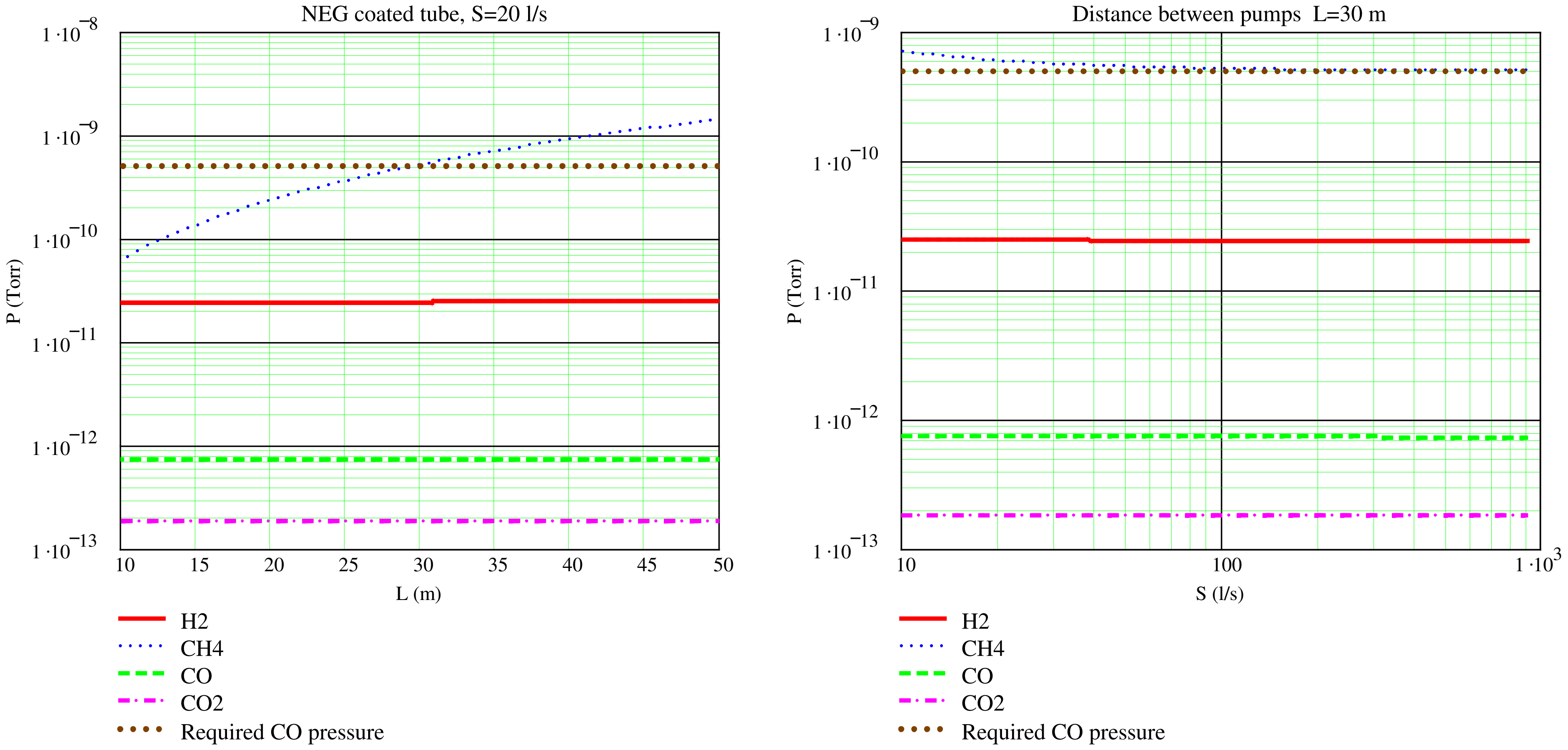
Pressure along the arc: inside a stainless steel tube

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 results of the modelling with SR only

- 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 if SR power can absorbed with vacuum chamber wall cooling
  - 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.

Ante-chamber

- An ante-chamber design is not required for vacuum to deal with photon induced desorption
- Ante-chamber is required in wigglers to deal with high SR power
- An ante-chamber might be beneficial for e-cloud suppression in the wigglers and dipoles (to reduce PEY parameter in the model)

- A vacuum chamber with an ante-chamber
  - is more expensive than a round or elliptical tube
  - beam conditioning is much less efficient
  - difficult (but possible) geometry for TiZrV coating

Optimisation of vacuum design vs e-cloud suppression

- The ideal vacuum chamber (round and NEG coated) is not necessary ideal from other points of view.
  - E-cloud suppression requires low PEY and SEY
  - Not all parts can be NEG coated
  - BPMs, Bellows, Valves

Input parameters in e-cloud models

- Photon distribution, diffused and forward scattered reflection
- Photon induced electron production
  - ***there are no data directly related to the ILC DR (i.e. measured at 3 and 30 keV),***
  - ***there are no data for NEG coated and TiN coated surfaces,***
  - ***the access to SR beamline and volunteers to perform a study are required***

Input parameters in e-cloud models

- Photon distribution, diffused and forward scattered reflection
- Photon induced electron production
- Secondary electron production
  - The uncertainties here are almost the same as with photons:
    - Secondary electron yields depend on the potential gradient near the surface (Most likely, similar to PEY, SEY increases up to 10-20 times in the presence of accelerating potential)
    - Secondary electron yields depend on the magnetic field near the surface (Most likely, similar to PEY, SEY decreases up to 2-20 times in the presence of the magnetic field parallel to the surface)
  - Choice of material: NEG coated surfaces was not well studied yet, it is still not clear what is better (i.e. lower SEY) NEG TiZrV coating or TiN coating.

Input parameters in e-cloud models

- Photon distribution, diffused and forward scattered reflection
- Photon induced electron production
- Secondary electron production
- Conditioning effects
- Effect of beam electric field
- Effect of magnetic field

All these parameters

- are not well experimentally evaluated for the ILC-DR conditions
- vary in wide range depending on material, geometry, history, etc.

Input parameters in e-cloud models

- Photon distribution, diffused and forward scattered reflection
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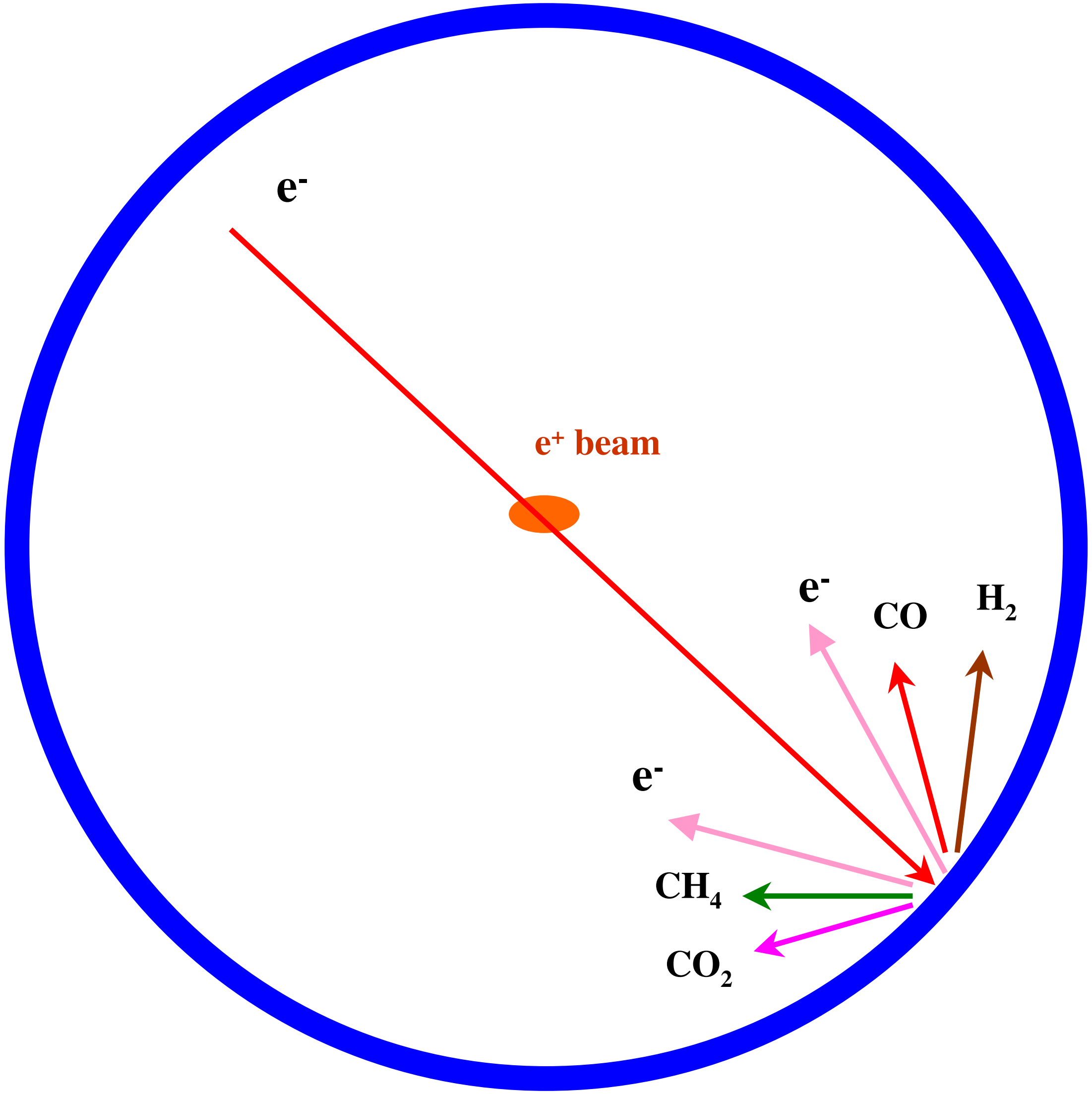
All these parameters

  - are not well experimentally evaluated for the ILC-DR conditions
  - vary in wide range depending on material, geometry, history, etc.

- Experiments with SR are planned to perform on VEPP-3 at ε_c = 4.5 keV at BINP (Novosibirsk, Russia)

How the e-cloud affect vacuum



How the e-cloud affect vacuum

- The electron flux Φ ~10^{16} $e^-/(s \cdot m)$ with E≈200 eV (0.3 W) will desorb approximately the same gas flux as the photon flux of ~10^{18} $\gamma/(s \cdot m)$ from a DR dipole.

- If the electron simulated desorption is 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

- Grooves 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 the gas 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 is too large in a round tube

- Defining 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 outgassing coating
    - Better pumping

- A complex solution for vacuum and e-cloud problem:
  - Good solution against Photo-electrons or Secondary electrons might lead to higher gas density and higher gas ionisation, and vice versa.

W. Bruns's results for the arc

SEY	q [e^-/m^3]				Power [W/m]			
	PEY [$e^-/(e^+\cdot m)$]				PEY [$e^-/(e^+\cdot m)$]			
	10^{-4}	10^{-3}	0.01	0.1	**10^{-4}**	10^{-3}	0.01	0.1
1.1	**$2\cdot10^{11}$**	$2\cdot10^{12}$	$1\cdot10^{13}$	$5\cdot10^{13}$	**0.3**	3	30	80
1.3	$3\cdot10^{12}$	$2\cdot10^{13}$	$3\cdot10^{13}$	$5\cdot10^{13}$	2	30	80	100
1.5	$3\cdot10^{12}$	$5\cdot10^{13}$	$5\cdot10^{13}$	$5\cdot10^{13}$	80	80	100	100
1.7	$5\cdot10^{12}$	$5\cdot10^{13}$	$5\cdot10^{13}$	$5\cdot10^{13}$	80	100	100	100

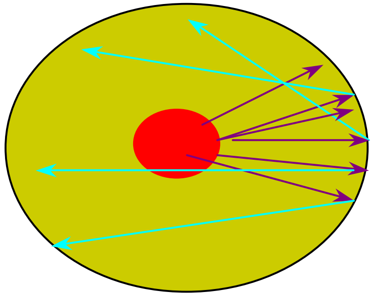
Increase of both PEY and SEY lead to multipacting,
pressure increase might also be important

PEY – the tube without a magnetic field (straights)

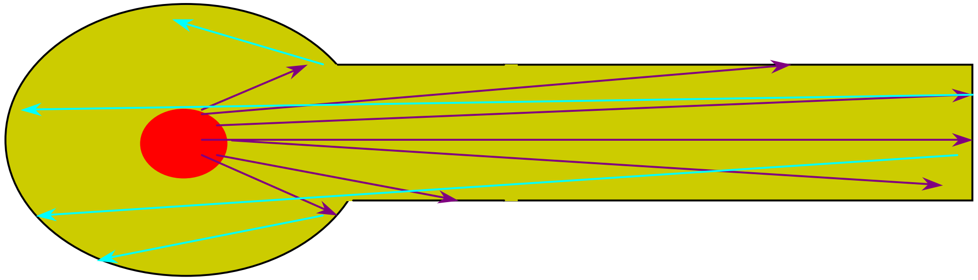
- Generated photons hitting vacuum chamber walls:
  - Γ = 0.9 γ/e^+ in the arc and shortly downstream straight
  - Γ = 10 γ/e^+ in the wiggler and shortly downstream straight
- Photo-electron emission coefficient:
  - κ = 0.01–0.1 e^-/γ depending on material, magnetic and electric field and photon energy
  - κ is unknown for NEG coating
- PEY
  - PEY_{ds} = 0.01–0.1 e^-/e^+ in a tubular chamber in the arc straight downstream a dipole
    - Required ???
  - PEY_{ws} = 0.1–1 e^-/e^+ in a tubular chamber in the straight downstream a wiggler
    - Required ???

PEY: tubular chamber vs. a vacuum chamber with an antechamber

Tubular chamber



Vacuum chamber with
a KEK type antechamber



Diffuse reflected photons irradiate all surface (from 1.5% to 20%)

Forward scattered photons from 2% to 65%

~1-10% of photons hit a beam vacuum chamber (depending on geometry + limited experimental data)

Some of photons entered an ante-chamber might be diffused or back/forward scattered to the beam chamber

PEY – tube with a magnetic field

- Generated photons hit vacuum chamber walls:
  - Γ = 0.9 γ/e^+ in the arc and shortly downstream straight
  - Γ = 10 γ/e^+ in the wiggler and shortly downstream straight
- Photons reflected/scattered after first hit with walls:
  - R = 3%–65% (material, treatment, geometry)
- Photo-electron emission coefficient:
  - κ = 0.01–0.1 e^-/γ depending on material, magnetic and electric field and photon energy
  - κ is unknown for NEG coating
- PEY
  - $PEY_d = 3 \cdot 10^{-4} - 0.065\ e^-/e^+$ in a tubular chamber in a dipole (+/-)
    - Required ~ $10^{-4}\ e^-/e^+$
  - $PEY_{ws} = 3 \cdot 10^{-3} - 0.65\ e^-/e^+$ in a tubular chamber in the straight downstream a wiggler (-)
    - Required ~ $10^{-4}\ e^-/e^+$

PEY – vac. chamber with a KEKB-type ante-chamber in a magnetic field

- Generated photons hit vacuum chamber walls:
  - $\Gamma = 0.9\ \gamma/e^+$ in the arc and shortly downstream straight
  - $\Gamma = 10\ \gamma/e^+$ in the wiggler and shortly downstream straight
- Photons absorbed in the beam chamber:
  - F = 1%–10% (material, treatment, geometry)
- Photons reflected/scattered after first hit with beam chamber walls:
  - R = 3%–65% (material, treatment, geometry)
- Photo-electron emission coefficient:
  - $\kappa = 0.01\text{–}0.1\ e^-/\gamma$ depending on material, magnetic and electric field and photon energy
  - κ is unknown for NEG coating
- PEY
  - $PEY_d = 3{\cdot}10^{-6} - 6.5{\cdot}10^{-3}\ e^-/e^+$ in a vacuum chamber in a dipole (+)
    - Required ~ $10^{-4}\ e^-/e^+$
  - $PEY_{ws} = 3{\cdot}10^{-5} - 6.5{\cdot}10^{-2}\ e^-/e^+$ in a vacuum chamber in a wiggler (+)
    - Required ~ $10^{-4}\ e^-/e^+$

PEY (e-/e+) to be used in e-cloud models for DR

	Inside magnets $B \neq 0$		Straights shortly downstream magnet $B = 0$	
Vacuum chamber	Tubular	With an antechamber	Tubular	With an antechamber
Dipole SR $\Gamma = 0.9\ \gamma/e^+$	**$3{\cdot}10^{-4}$ – 0.065**	**$3{\cdot}10^{-6}$ – $6.5{\cdot}10^{-3}$**	**0.01–0.1**	**10^{-4}–0.01**
Required max. PEY	**10^{-4}**	**10^{-4}**	**?**	**?**
Wiggler SR $\Gamma = 10\ \gamma/e^+$	**$3{\cdot}10^{-3}$ – 0.65**	**$3{\cdot}10^{-5}$ – $6.5{\cdot}10^{-2}$**	**0.1–1**	**10^{-3}–0.1**
Required max. PEY	**10^{-4}**	**10^{-4}**	**?**	**?**

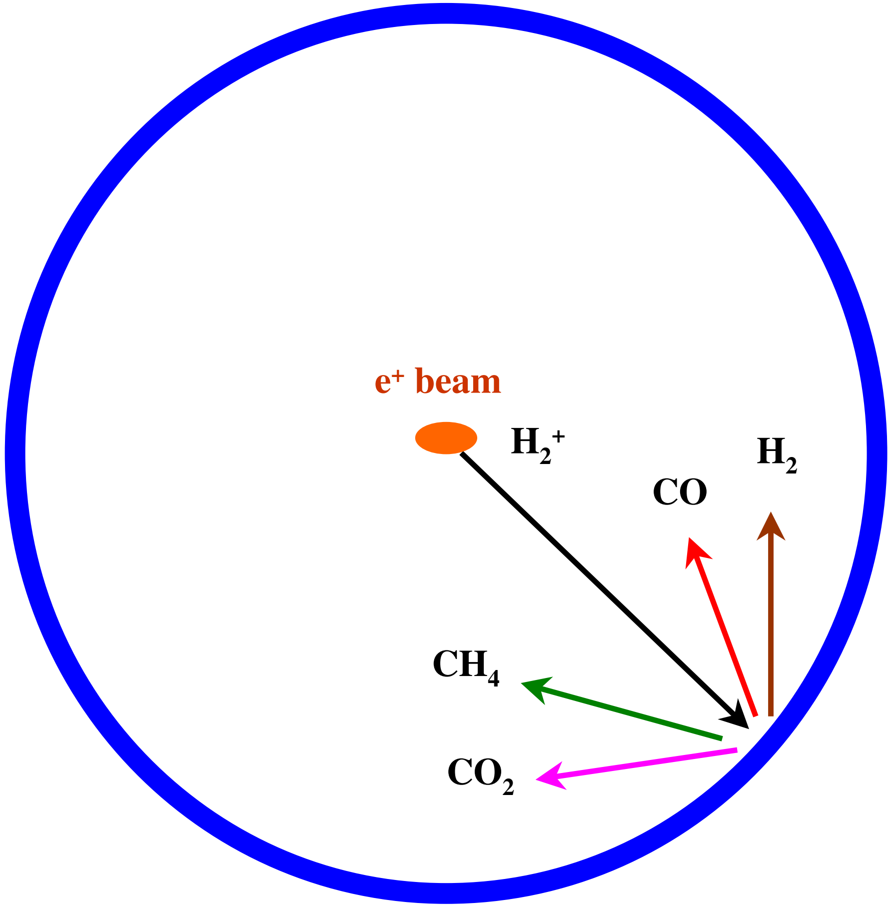
Ante-chamber vs. PEY

- To reach required value for a parameter PEY a KEKB-type antechamber
    - Is required in wigglers
    - Can help in the arc dipoles
    - Should be studied for straight for different photon fluxes, i.e. PEY can be lower 3 orders of magnitude (away downstream from the dipoles and wigglers)

SEY vs vacuum design

- SEY could be lowered by surface coating
  - TiZrV (structure, morphology, activation)
  - TiN (structure, morphology, stability to oxidation)
- Surface conditioning
  - SR – removes an oxide layer -> bare metal SEY
  - Etching – might be not good for vacuum
- Geometry of vacuum chamber
  - Grooves – difficulty for coating
  - Antechamber – more expensive than a tubular chamber (special shape, flanges, absorbers…)
- Electrodes
  - feedthroughs – more vacuum leaks,
  - insulating material - to be vacuum tested on outgassing
- Solenoid field

Ion induced pressure instability in the positron ring



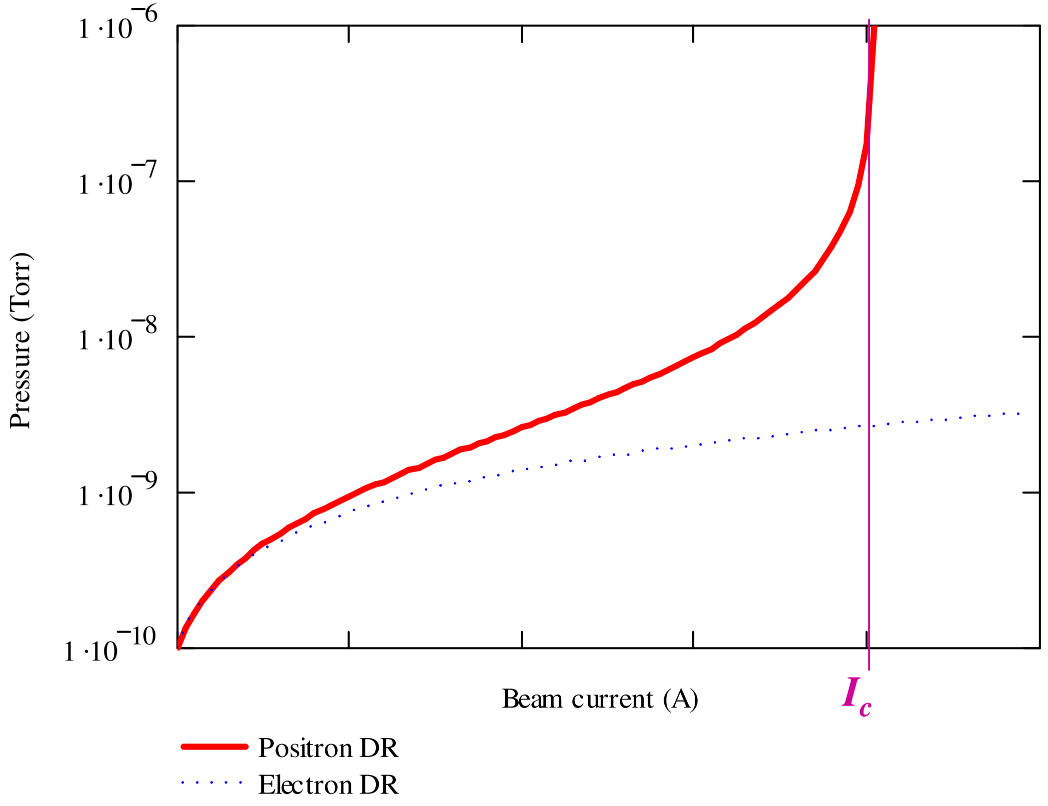
$$P = \frac{Q}{S_{eff} - \chi \frac{\sigma I}{e}}$$

where
Q = gas desorption,
S_{eff} = effective pumping speed,
χ = ion induced desorption yield
σ = ionisation cross section,
I = beam current.

$$\chi = f\left(E_{ion}, M_{ion}, material, bakeout, ...\right)$$

$$E_{ion} = f\left(N_{bunch}, \tau, T, \sigma_x, \sigma_y, ...\right)$$

Critical current



Critical current, I_c, is a current when pressure (or gas density) increases dramatically.

Mathematically, if

$$P = \frac{Q}{S_{eff} - \chi \frac{\sigma I}{e}}$$

$$\text{when } S_{eff} > \chi \frac{\sigma I}{e}$$

$$\text{Hence } I < I_c,$$

$$\text{where } I_c = \frac{S_{eff} e}{\chi \sigma I}$$

Ion energy at DR

The energy of ions reached at the end of damping cycle :

- Arcs: 220 – 270 eV
- Straights: 220 – 320 eV
- Wigglers: 320 – 340 eV

Corresponding ion induced desorption yields for Cu:

$$\chi = \begin{array}{cc} \begin{array}{cccc} \textbf{H2,} & \textbf{CH4,} & \textbf{CO,} & \textbf{CO2} \end{array} & \\ \begin{pmatrix} 0.133 & 7.5\times 10^{-3} & 0.047 & 0.015 \\ 0.433 & 0.028 & 0.233 & 0.075 \\ 0.717 & 0.05 & 0.467 & 0.15 \\ 0.867 & 0.065 & 0.65 & 0.21 \end{pmatrix} & \begin{array}{c} \textbf{H2+} \\ \textbf{CH4+} \\ \textbf{CO+} \\ \textbf{CO2+} \end{array} \end{array}$$

Pressure instability thresholds:

- I_c – critical current
  - I_c = ~0.8 A for Cu tube, pump every 6 m
  - I_c = ~2 A for NEG coated tube, pump every 40 m
- $\mathrm{L_c}$ – critical length between pumps
  - $\mathrm{L_c}$ = ~8 m for Cu tube
  - $\mathrm{L_c}$ = ~100 m for NEG coated tube
- Hence,
  - For given parameters and large uncertainties, there is a possibility of ion induced pressure increase and even ion induced pressure instability in positron damping ring if pumping is insufficient.
  - There will be no ion induced pressure instability if TiZrV coating used

Conclusions

- An ante-chamber is not needed for vacuum (electron and positron DRs)
- A KEKB-type ante-chamber is required to suppress PEY (and e-cloud) in positron DR
  - in wigglers and, possibly, dipoles
  - the straight are to be studied
- A process to suppress SEY (and e-cloud) should be cross-examined for how it might affect vacuum
- Multipacting electrons in positron DR will cause the pressure increase comparable or larger than due to photons – to be considered in vacuum design
- Ion induced pressure instability might be a problem at ILC DR
  - Large distributed pumping speed required
  - TiZrV coated vacuum chamber has a sufficient safety margin

Mechanical design of vacuum system

- Shape of vacuum chamber
  - Depends on solution for e-cloud
  - Components to be protected from SR (BPM, bellows, valves, ???)
  - Tapering angle (30 mrad?)
  - Straightness, mechanical misalignments and tolerances
- Size of vacuum chamber
  - Beam stay clear
  - Mechanical misalignments
  - Bakeout + thermal insulation
  - Gap between magnet poles
- Vacuum chamber support
  - On the same girder as magnets or special
  - Distance between support
  - BPM support?
- In situ bakeout
  - Max temperature at the magnet poles?
  - If there any non-bakable components?

Mechanical design of vacuum system

- Pump frequency
    - depends on whether or not TiZrV coating used,
    - list of components which could not be coated
- Bellow positions
    - Either side of BPM
    - At least every 25 m (?) to compensate thermal expansion during bakeout and operation.
- All metal in-line valves
    - ~30/DR in Option 1 and ~120 in Option 2 (LEP 130 valves/27 km, i.e. every 200 m)
    - RF system – will it be equipped with valves, each cavity separately or only at either side of the RF section
    - Support
- Impedance calculation may affect the design of
    - Valves, flanges, RF fingers, TiZrV coating, pumping port mesh, tapering,
    - Ion or electron clearing electrodes…

End

- Thanks!

Attachment

- Photon reflectivity
- PEY

Photon reflectivity and azimuthal distribution

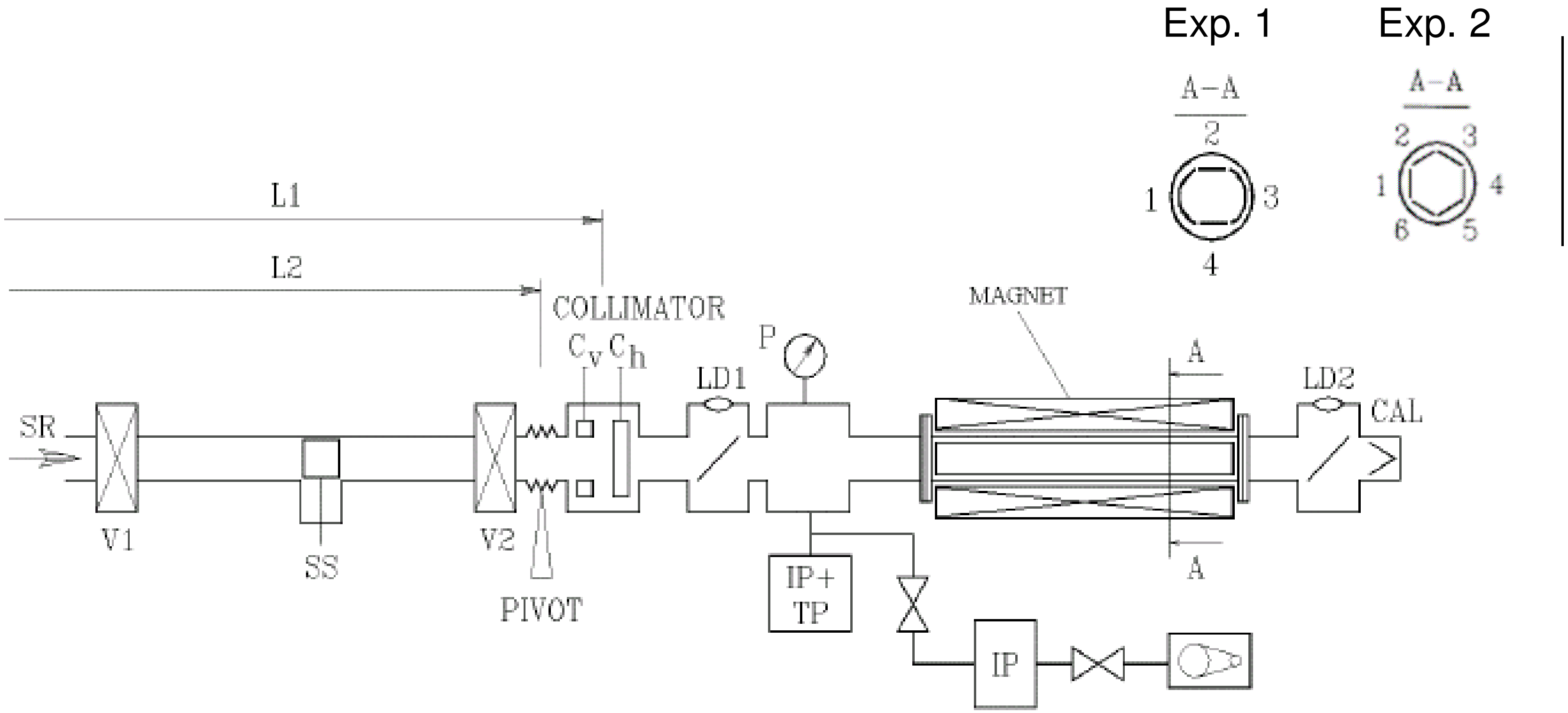


Figure 1. Set-up for measurements of the azimuthal photoelectron distribution in magnetic field and of the photon reflectivity

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

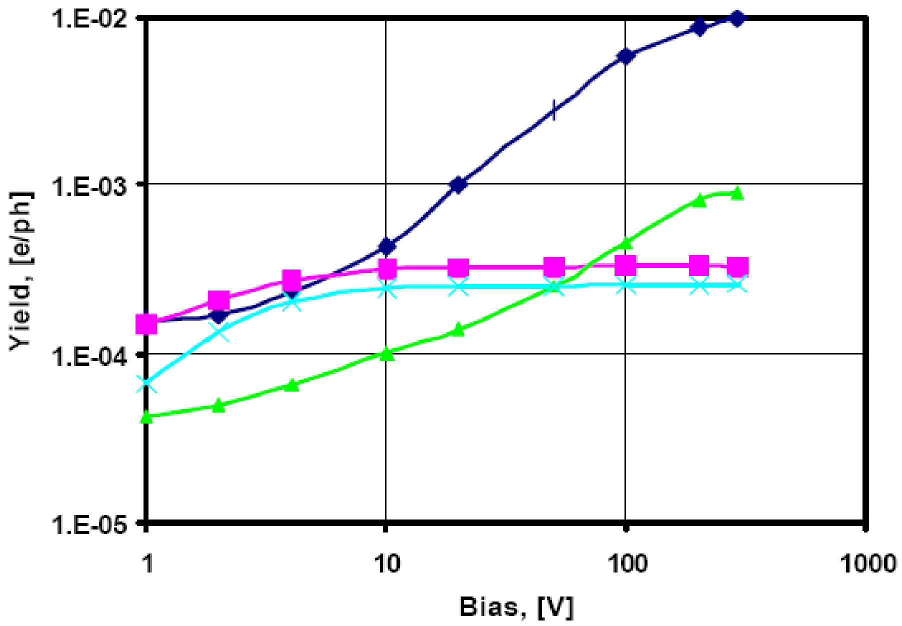
V.V. Anashin et al. / Nuclear Instruments and Methods in Physics Research A 448 (2000) 76-80.

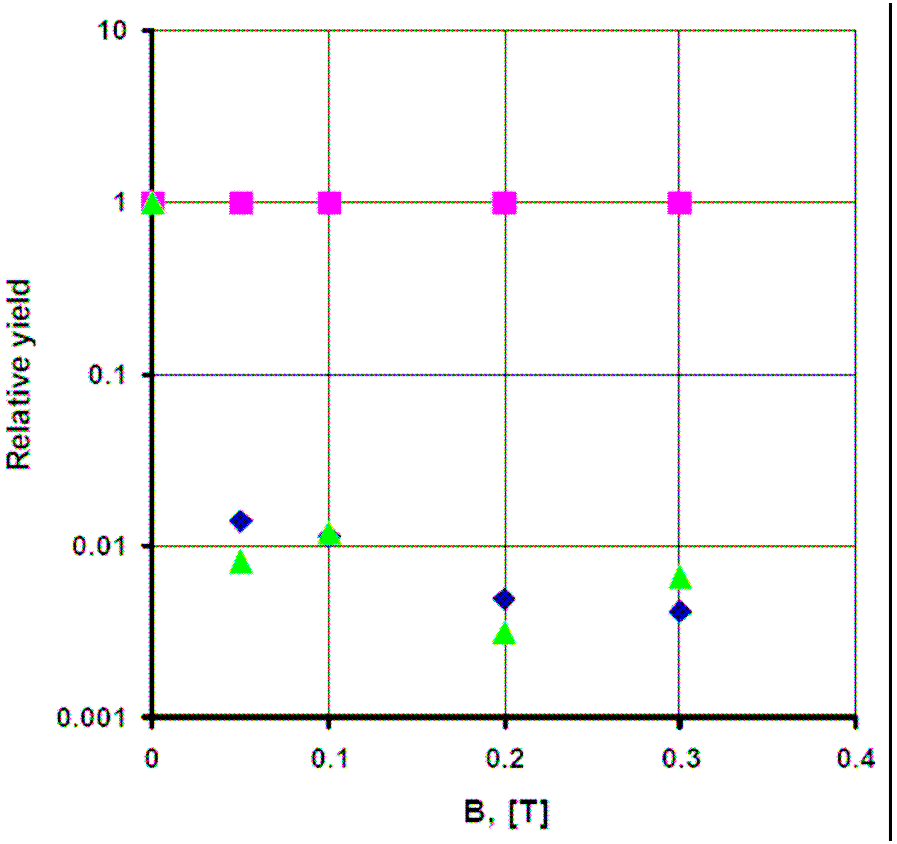
See also: V. Baglin, I.R. Collins, O. Grobner, EPAC'98, Stockholm, June 1998.

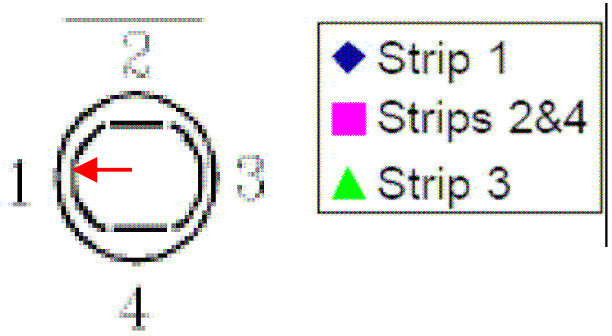
Photon azimuthal distribution – 6 strips experiment

Sample	ε_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

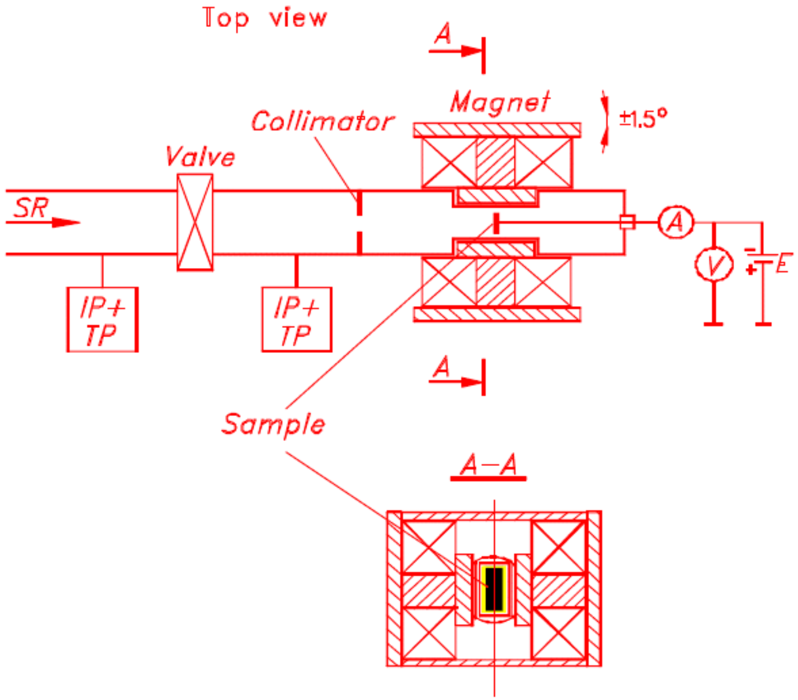






V.V. Anashin, O.B. Malyshev, N.V. Fedorov and A.A. Krasnov. Azimuthal distribution of photoelectrons for an LHC beam screen prototype in a magnetic field. Vacuum Technical Note 99-06. LHC-VAC, CERN April 1999.

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.

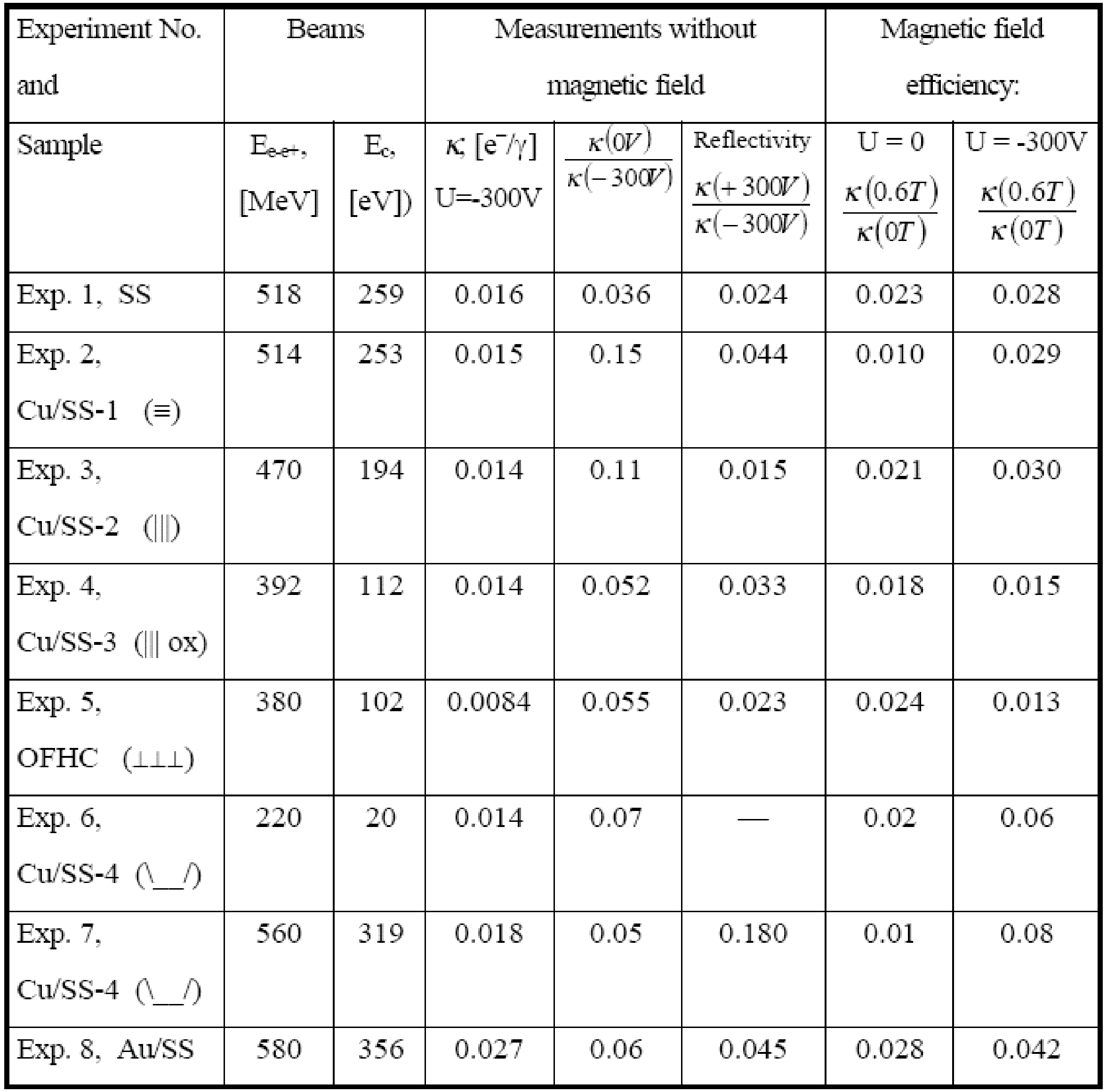
Results

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.

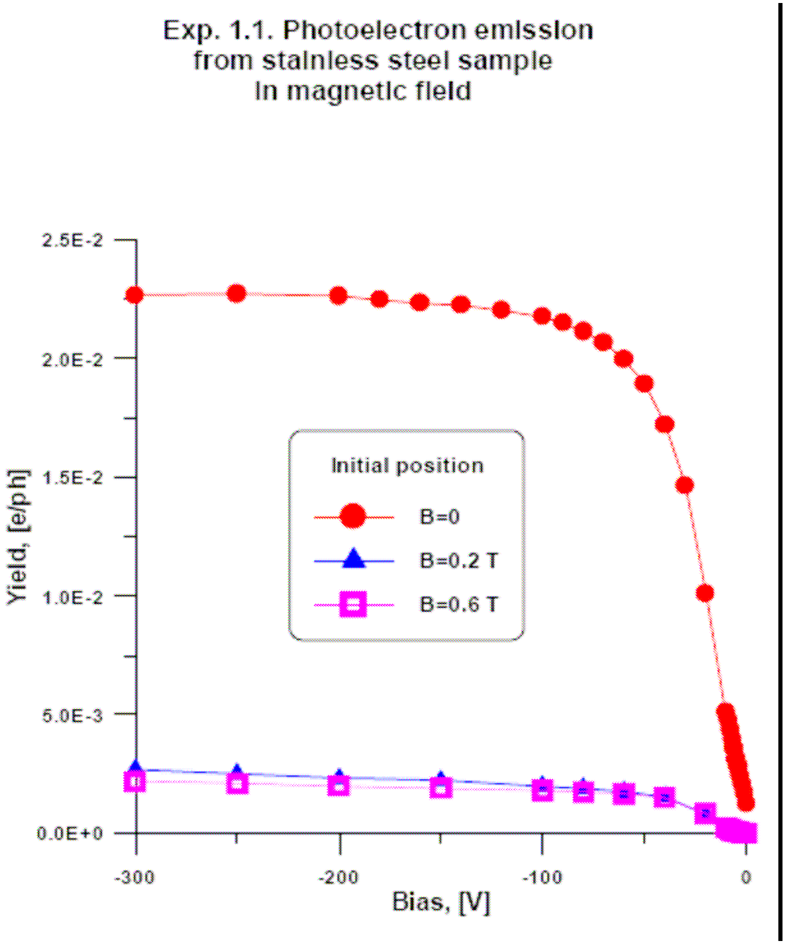
2) The magnetic field suppresses the photoelectron yield up to **30–100 times** when the surface is parallel to the magnetic field, but this effect is much less at the angle of 1.5° (5–10 times).

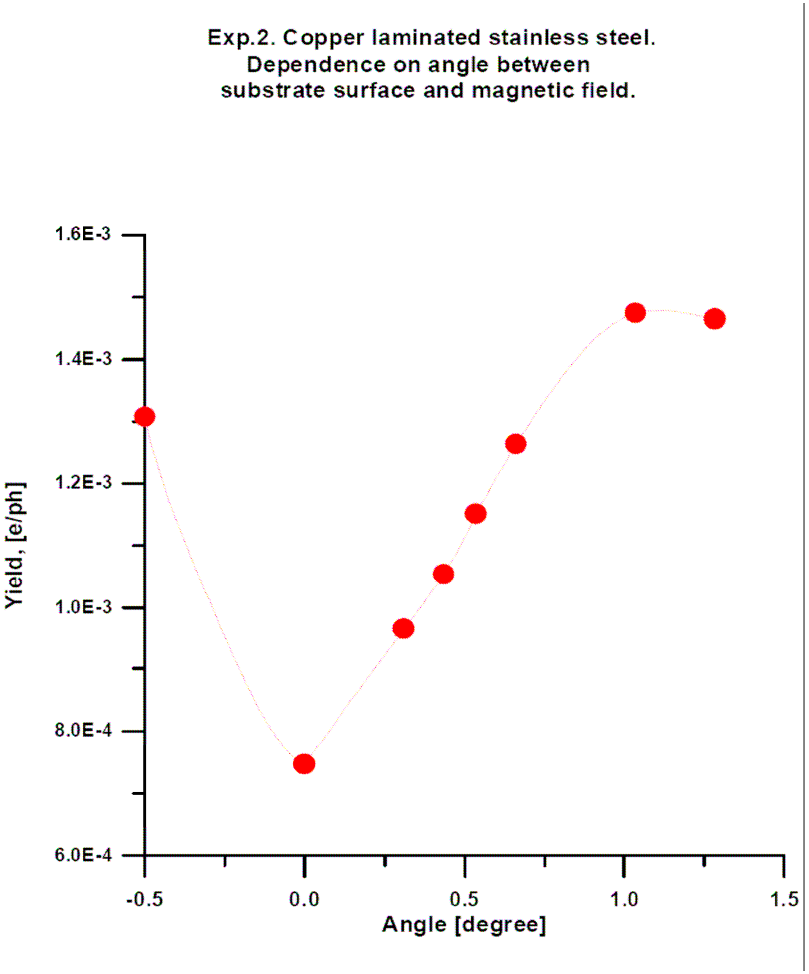
3) The photoelectron yield decreases with the accumulated photon dose: the photoelectron yield reduced 2–3 times at the accumulated photon dose of about 10^{22} photons/cm^2.



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

Examples of measurement results





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

Grooves alignment in respect to magnetic field