ILC DR vacuum system related problems and solutions

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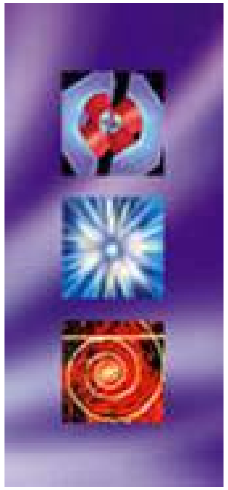

Outline

- DR Vacuum requirements
- Ion induced pressure instability in positron DR
- Vacuum vs. e-cloud

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)

Main results of the modelling with SR only

- To reach 0.5 nTorr CO in the arc cell after 100 A hrs beam conditioning it would require:
  - a pump with S_{eff} = 200 l/s every 5 m in stainless steel vacuum chamber

  or

  - a pump with S_{eff} = 20 l/s every 30 m in TiZrV NEG coated vacuum chamber
- 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

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

Main results of the modelling with SR only

Ideal vacuum chamber for vacuum design

(for the electron ring and, where possible, for the positron ring):

- 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)

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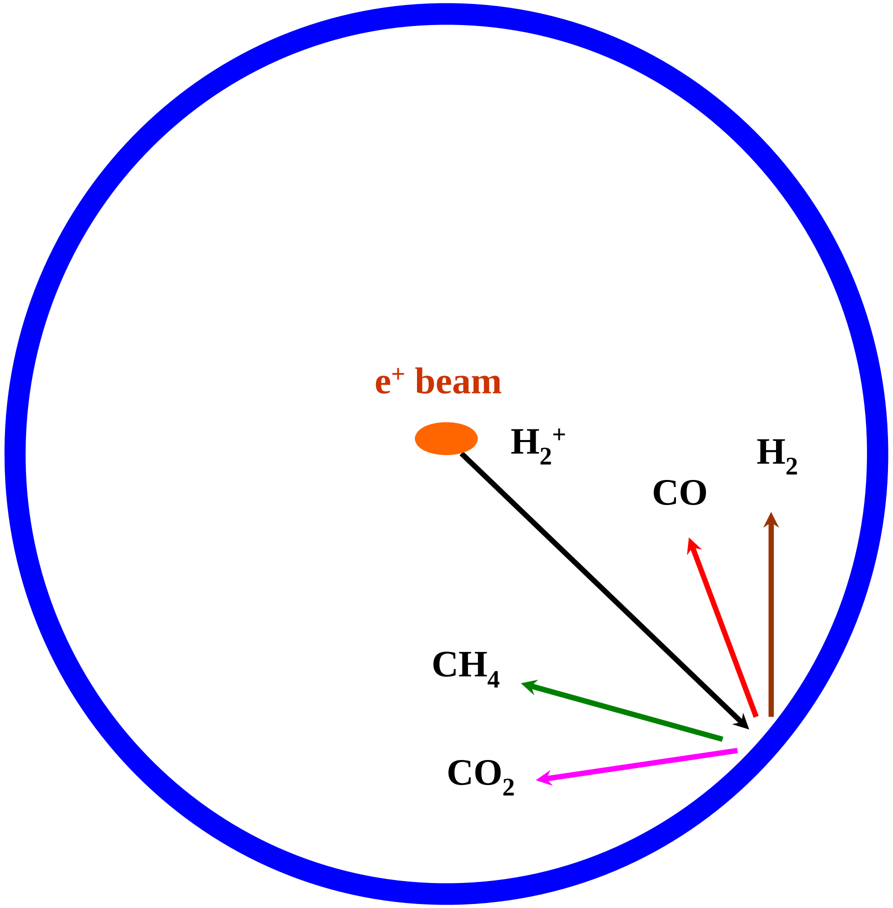
Ion induced pressure instability in the ILC positron dumping ring

What is the ion induced pressure instability



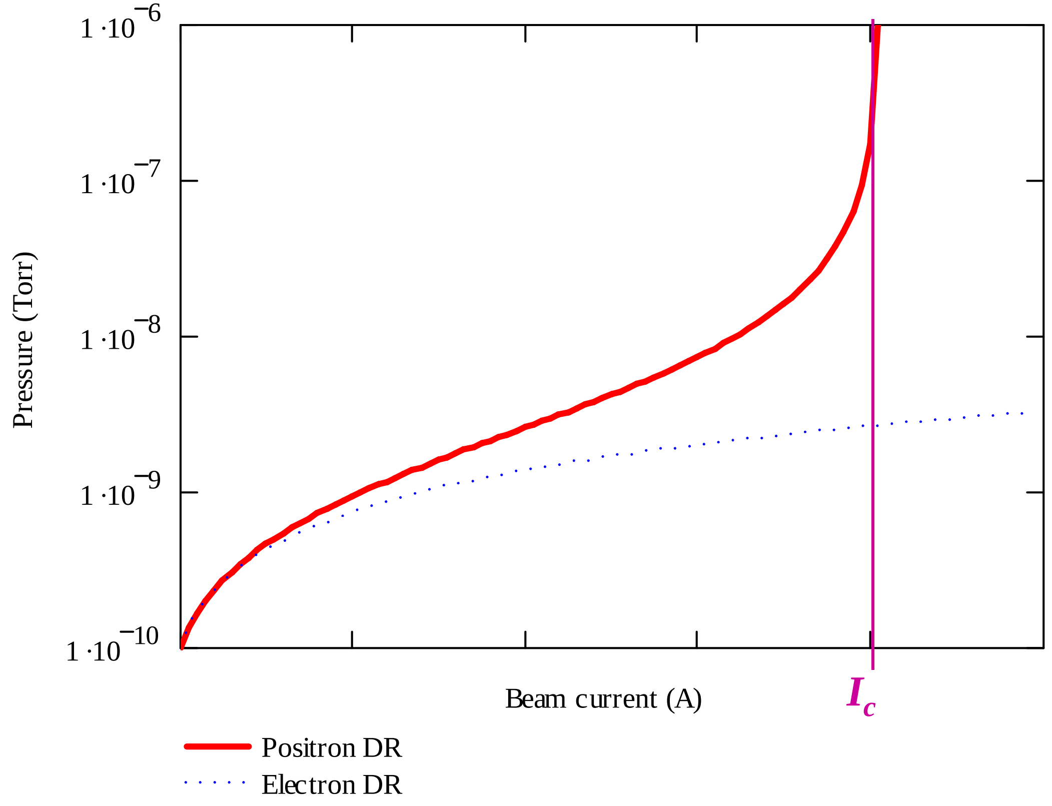
$$P = \frac{Q}{S_{eff} - \chi \frac{\sigma I}{e}}$$

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

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

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

Critical current



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

Mathematically, if

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

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

Hence $I < I_c$,

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

Ion energy at DR

		Arc	Straight	Wiggler
σ_x (m)	max	$1.3 \cdot 10^{-3}$	$1.3 \cdot 10^{-3}$	$2.7 \cdot 10^{-3}$
	min	$6.5 \cdot 10^{-4}$	$2.7 \cdot 10^{-4}$	$1.9 \cdot 10^{-4}$
σ_y (m)	max	$8.9 \cdot 10^{-6}$	$1.0 \cdot 10^{-5}$	$5.5 \cdot 10^{-6}$
	min	$5.6 \cdot 10^{-6}$	$5.6 \cdot 10^{-6}$	$3.8 \cdot 10^{-6}$
E (eV)	**max**	**265**	**320**	**340**
	min	**220**	**220**	**320**

Ion stimulated desorption yields

Impact ion	χ, (molecules/ion)			
	H_2	CH_4	CO	CO_2
316LN stainless steel				
H_2^+	0.07	0.005	0.05	0.007
CH_4^+	0.43	0.04	0.45	0.067
CO^+	0.64	0.06	0.80	0.12
CO_2^+	0.77	0.08	1.12	0.17
Pure aluminium				
H_2^+	0.18	0.008	0.07	0.022
CH_4^+	1.1	0.056	0.67	0.20
CO^+	1.6	0.088	1.2	0.36
CO_2^+	1.9	0.114	1.7	0.50
Ti alloy				
H_2^+	0.13	0.002	0.04	0.007
CH_4^+	0.80	0.015	0.38	0.067
CO^+	1.2	0.024	0.68	0.12
CO_2^+	1.4	0.031	0.95	0.17

Model

$$V\frac{dn_i}{dt}=\underbrace{\eta_i\dot{\Gamma}}_{\text{Photon stimulated desorption}}+\underbrace{\sum_{j=1}^{N}\frac{\chi_{A_i,A_j^+}I\theta_{A_j}}{e}n_i}_{\text{Ion induced desorption}}-\underbrace{C_i n_i}_{\text{Distributed pumping}}+\underbrace{u_i\frac{d^2n_i}{dz^2}}_{\text{Axial molecular diffusion}};$$

- Solving the system of N equation in quasi-static conditions, where $V\,dn/dt \approx$ 0, for gas densities $n_i(z)$ one can find gas density inside the vacuum chamber.

Solution for two-gas model

$$\begin{cases} n_1(z) = \dfrac{q_2 d_1 + c_2 q_1}{c_1 c_2 - d_1 d_2} + k_1 e^{\sqrt{\omega_1} z} + k_2 e^{-\sqrt{\omega_1} z} + k_3 e^{\sqrt{\omega_2} z} + k_4 e^{-\sqrt{\omega_2} z}; \\ n_2(z) = \dfrac{q_1 d_2 + c_1 q_2}{c_1 c_2 - d_1 d_2} + K_1 e^{\sqrt{\omega_1} z} + K_2 e^{-\sqrt{\omega_1} z} + K_3 e^{\sqrt{\omega_2} z} + K_4 e^{-\sqrt{\omega_2} z}; \end{cases}$$

where $\omega_{1,2} = \dfrac{1}{2}\left(\dfrac{c_1}{u_1} + \dfrac{c_2}{u_2} \pm \sqrt{\left(\dfrac{c_1}{u_1} - \dfrac{c_2}{u_2} \right)^2 + 4\dfrac{d_1 d_2}{u_1 u_2}} \right);$

with

$$q_1 = \eta_1 \Gamma; \quad c_1 = C_1 - \frac{\chi_{A_1, A_1^+} I \theta_{A_1}}{e}; \quad d_1 = \frac{\chi_{A_1, A_2^+} I \theta_{A_2}}{e};$$

$$q_2 = \eta_2 \Gamma; \quad c_2 = C_2 - \frac{\chi_{A_2, A_2^+} I \theta_{A_2}}{e}; \quad d_2 = \frac{\chi_{A_2, A_1^+} I \theta_{A_1}}{e}.$$

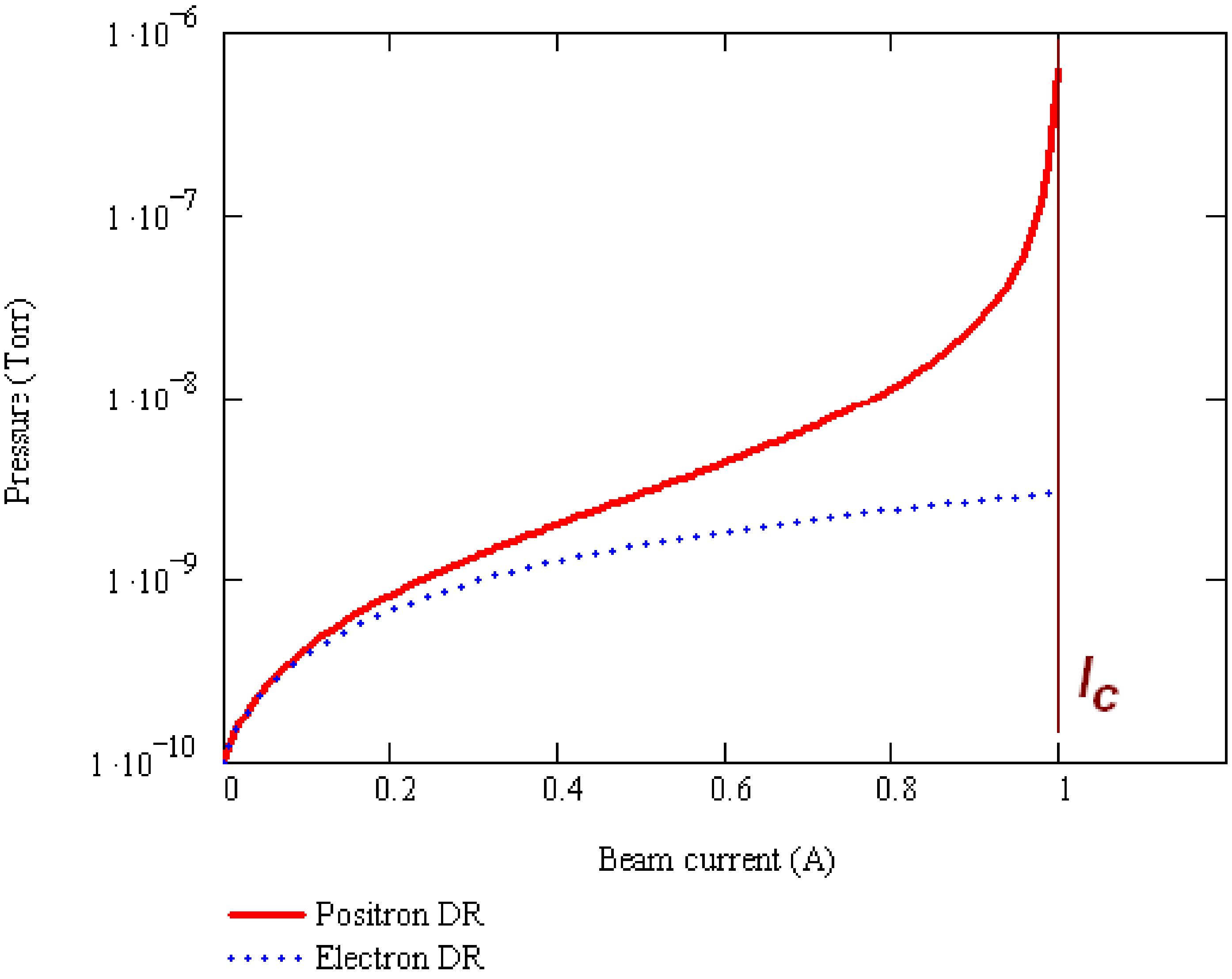
The gas densities n_1 and n_2 inspire to infinity then

$$\left(c_1 c_2 - d_1 d_2 \right) \longrightarrow 0$$

Solving this inequality for the beam current *I* one can find that the beam current must be below so-called critical beam current, ***I*_c**, which is a solution for the equation

$$c_1 c_2 - d_1 d_2 = 0$$

Critical current



The ion stability for different vacuum chamber materials, I_{max}=0.4 A

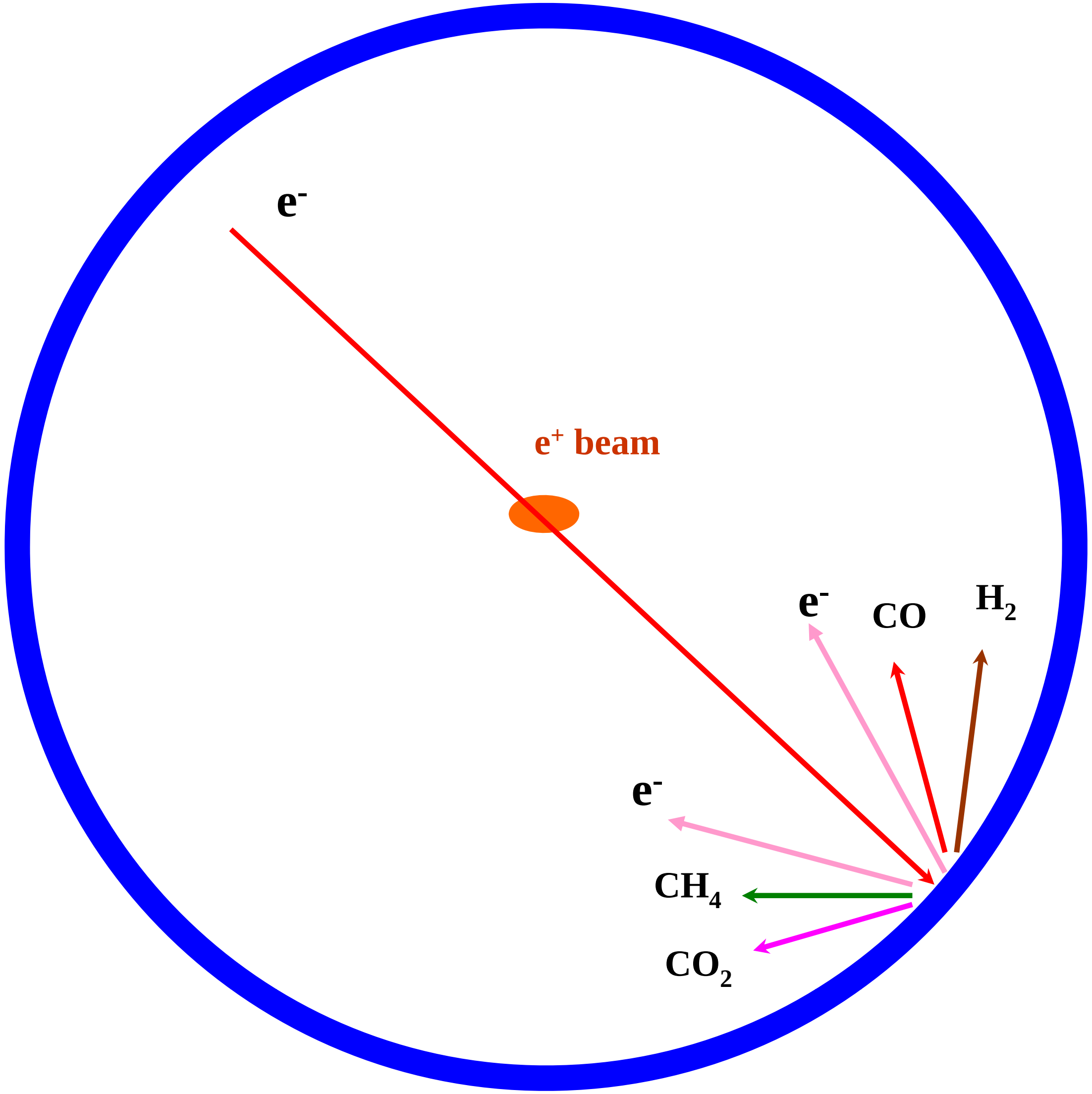
Vacuum chamber	I_c, (A)	I_c / I_{max}	Domin. gas	Stable or not
Distance between pumps L = 6 m, ID = 50 mm				
316LN	1.0	2.5	CO	Yes
Pure Al	0.5	1.25	CO	No
Ti alloy	1.1	2.8	CO	Yes
Distance between pumps L = 6 m, ID = 60 mm				
316LN	1.24	3.1	CO	Yes
Pure Al	0.64	1.6	CO	No
Ti alloy	1.4	3.5	CO	Yes
Distance between pumps L = 10 m, ID = 50 mm				
316LN	0.47	1.2	CO	No
Pure Al	0.24	0.6	CO	No
Ti alloy	0.53	1.3	CO	No
Distance between pumps L = 40 m, ID = 50 mm				
NEG coated	5	12.5	CH_4	Yes

Pressure instability conclusions:

- Ion energy = ~300 eV
- 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.
- **Use of TiZrV coating fully eliminates the probability of the ion induced pressure instability.**

Vacuum vs. e-cloud

How the e-cloud affects 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.

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 above 10^{-8} torr might also be important in e-cloud build up

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 ante-chamber	Tubular	Solenoid field	With ante-chamber
Dipole SR $\Gamma = 0.9\ \gamma/e^+$	**$3\cdot10^{-4}$ – 0.065**	**$3\cdot10^{-6}$ – $6.5\cdot10^{-3}$**	**0.01–0.1**	**0.01–0.1**	**10^{-4}–0.01**
Required max. PEY	**10^{-4}**	**10^{-4}**	**?**	**??**	**?**
Wiggler SR $\Gamma = 10\ \gamma/e^+$	**$3\cdot10^{-3}$ – 0.65**	**$3\cdot10^{-5}$ – $6.5\cdot10^{-2}$**	**0.1–1**	**0.1–1**	**10^{-3}–0.1**
Required max. PEY	**10^{-4}**	**10^{-4}**	**?**	**??**	**?**

O.B. Malyshev and W. Bruns. ILC DR vacuum design and e-cloud. Proc. of EPAC08, Genova, Italy, 2008, p. 673.

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 (see results of Mauro *at al*. for Cu – this workshop)
  - 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
  - Wires + power supply -> cost

Vacuum Priority chain for suppressing the e-cloud

- **NEG coated round (or elliptical) vacuum chamber.**

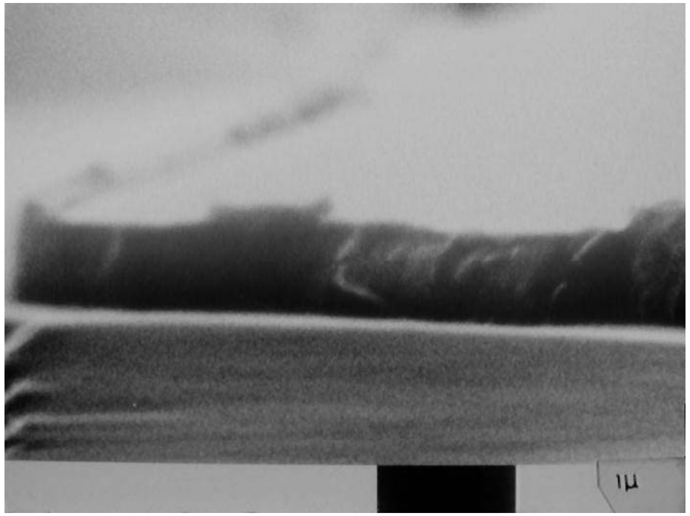
Passive anti-e-cloud tools:

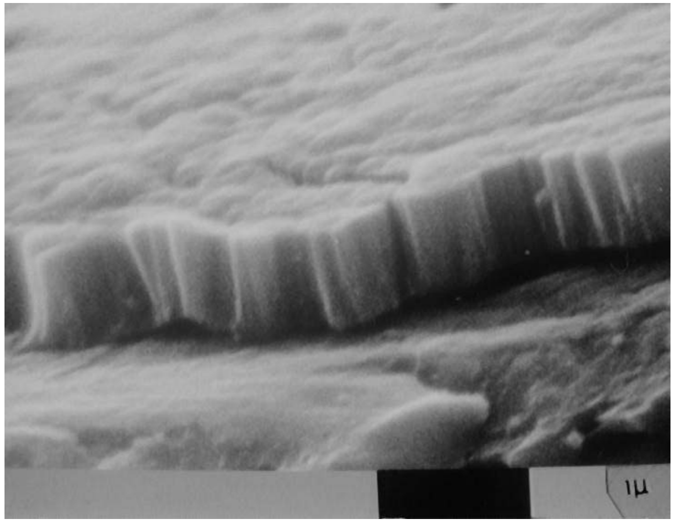
- **KEKB-type ante-chamber (to reduce PEY) with NEG coating**
- Grooves TiZrV with NEG coating (to reduce SEY).
    - TiN coated round (or elliptical) vacuum chamber.

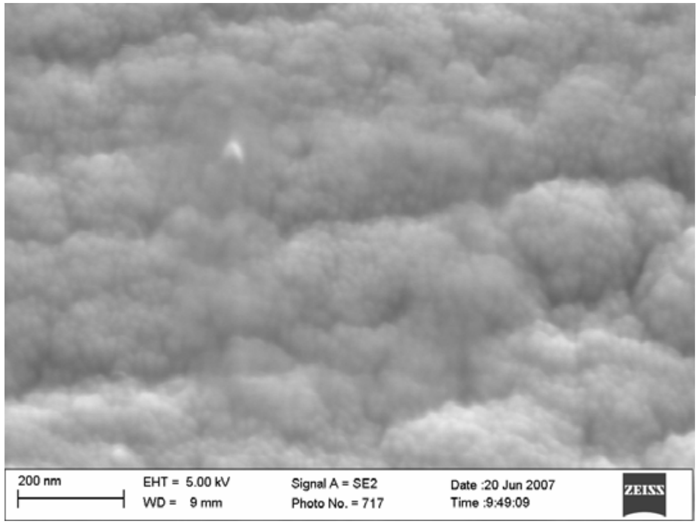
Active anti-e-cloud tools:

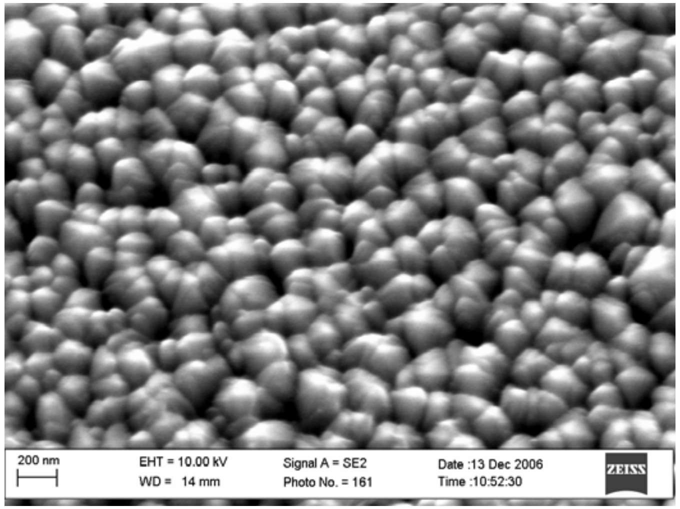
- Solenoid field along NEG coated straights
    - Solenoid field along TiN coated or uncoated straights
    - Electrodes and insulating materials

What is TiZrV and TiN coating? A few SEM examples









Conclusions for vacuum vs. e-cloud

- E-cloud modelling for field free regions are needed to specify vacuum chamber design
- What kind of TiZrV and TiN coatings is used in e-cloud test
  - surface characterisations with SEM, XPS, RBS, etc.
- Simple solutions are preferable:
  - coating, KEK-type antechamber.
- Ante-e-cloud means should not
  - compromise vacuum performance
    - **cause ion induced instability**
  - increase the cost