- Beam Gas Scattering
- Classification of Vacuum Systems
- Desorption
- UHV Pumps
- Pressure Distribution
- Chamber Design
- Conditioning
- Bibliography

Why is Vacuum Important for Synchrotron Light Sources

Residual gas contributes mainly by elastic and inelastic scattering on nuclei to beam losses.

Elastic Scattering

$$\frac{1}{\tau_{Elast}} \sim \frac{Z^2}{\gamma^2} \cdot \frac{\bar{\beta} \cdot \hat{\beta}}{H^2} \cdot P$$

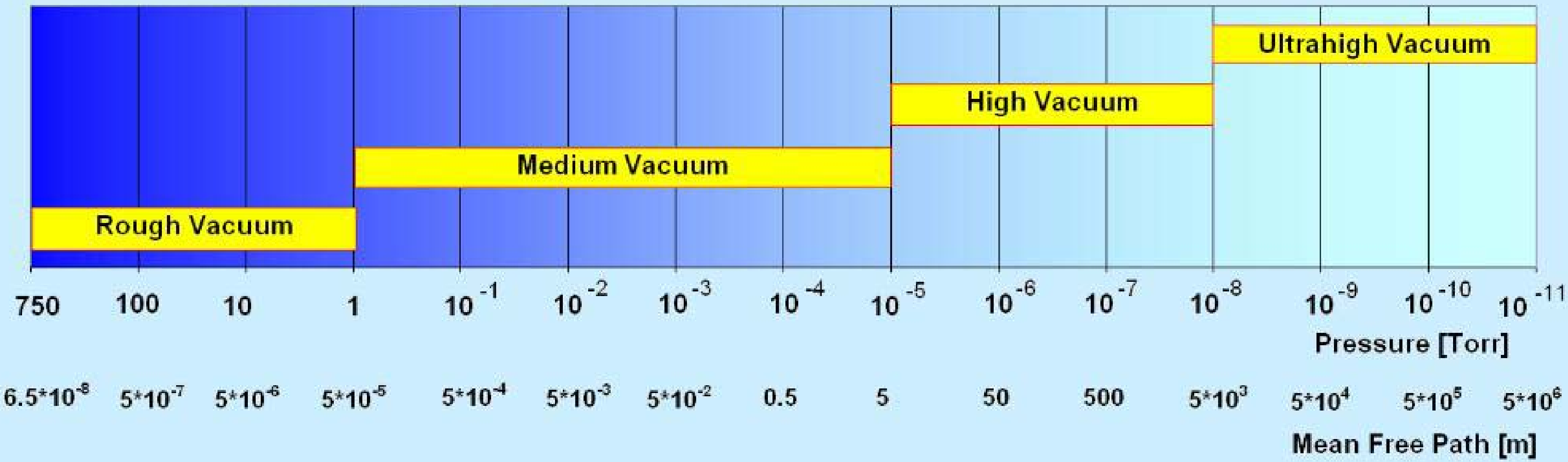
Inelastic Scattering

$$\frac{1}{\tau_{Inel}} \sim Z^2 \cdot \ln \frac{1}{\Delta p / p} \cdot P$$

P	=	Residual gas pressure
Z	=	Residual gas atomic number
γ	=	Lorentz factor
H	=	Vertical half aperture
$\bar{\beta}$	=	Average beta function
$\hat{\beta}$	=	Beta function at aperture
$\Delta p / p$	=	Momentum acceptance

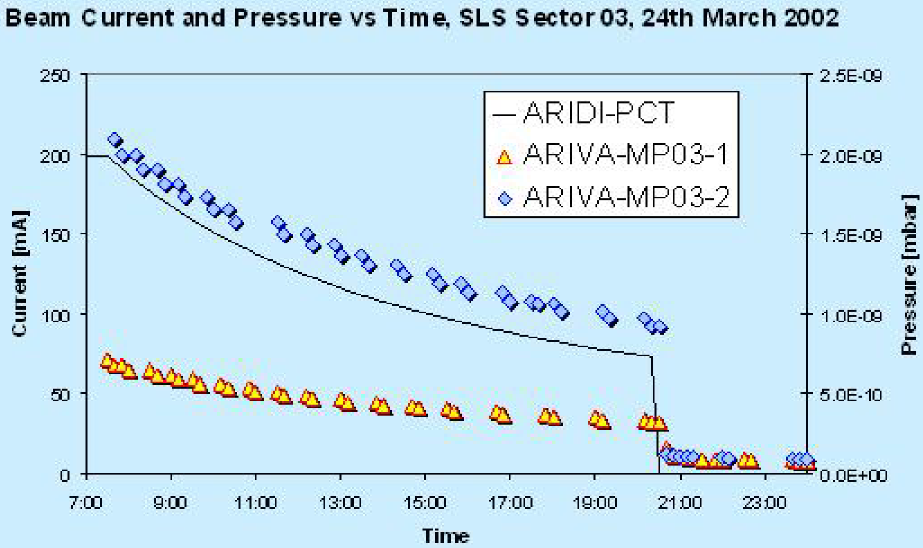
To achieve beam lifetimes in the range of 10 hours a residual gas pressure in the level of 1 nTorr is required.

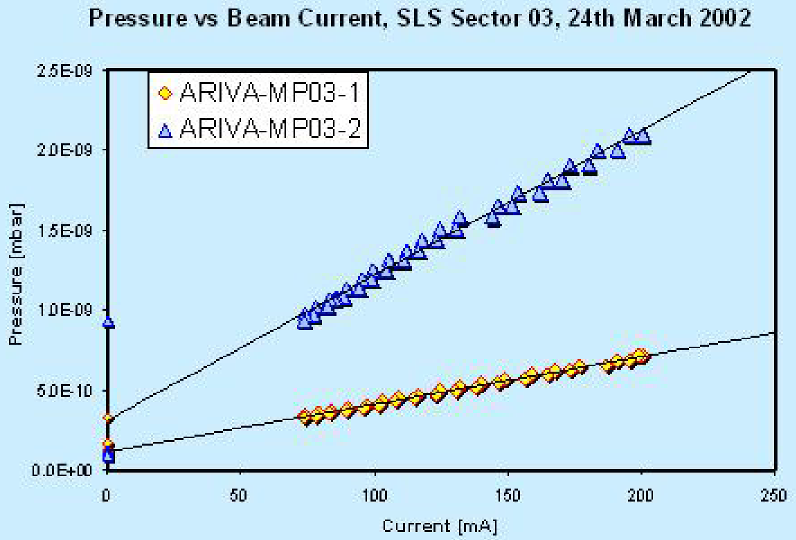
Classification of Vacuum Systems



- The main gas sources of vacuum systems are desorption, permeation, vaporization and leaks.
- In the UHV regime special designs for the vacuum chambers are required (all metal techniques) to avoid permeation, vaporization and leaks.
- In a well designed UHV system the pressure is determined by residual gas molecules which are desorbed from all inner parts of the vacuum chamber.

Thermal and Photon Induced Desorption





- The gas pressure in a synchrotron light source is dominated by the synchrotron radiation induced desorption.
- The photons of the synchrotron radiation hit the vacuum chamber walls and create photoelectrons.
- These photoelectrons can desorb residual gas molecules twice, once when leaving the chamber surface and once when striking the vacuum chamber again.

Thermal Desorption

- The surfaces of the vacuum chambers are covered with several layers of molecules of different gas species which are chemically or physically adsorbed.

$$Q_{TH} = q \cdot A$$

q	=	Specific desorption rate
A	=	Vacuum chamber surface area

- The thermal desorption rates are depending on the chamber material, his history, and how the surfaces are cleaned.
- For clean stainless steel chambers specific outgassing rates of $q=1 \cdot 10^{-12}$ Torr l s^{-1} cm^{-2} are achieved after bake-out at 250°C. (In unbaked systems the rate is 5 to 10 times higher).

Desorption

Photon Induced Desorption

$$Q_\gamma = kT\eta_\gamma\Gamma$$

η_γ	=	Photon stimulated desorption yield
Γ	=	Photon flux
k	=	Boltzmann constant
T	=	Temperature

Total Photon Flux from all Dipole Magnets

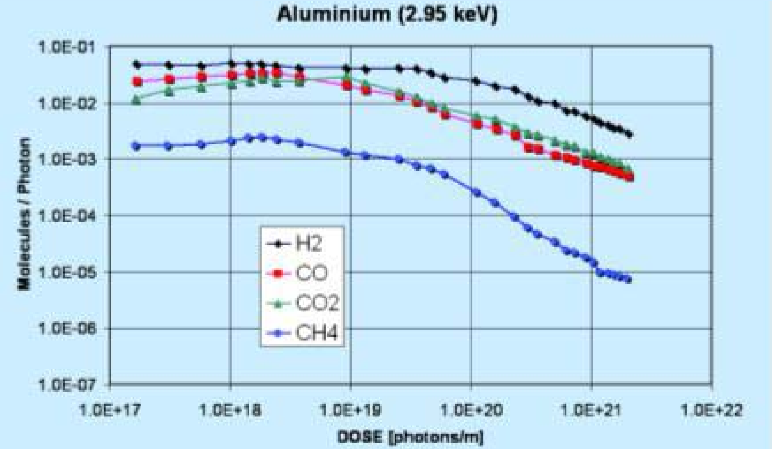
$$\Gamma[photons/s] = 8.06 \cdot 10^{20} \cdot E[GeV] \cdot I[A]$$

Linear Photon Flux Density

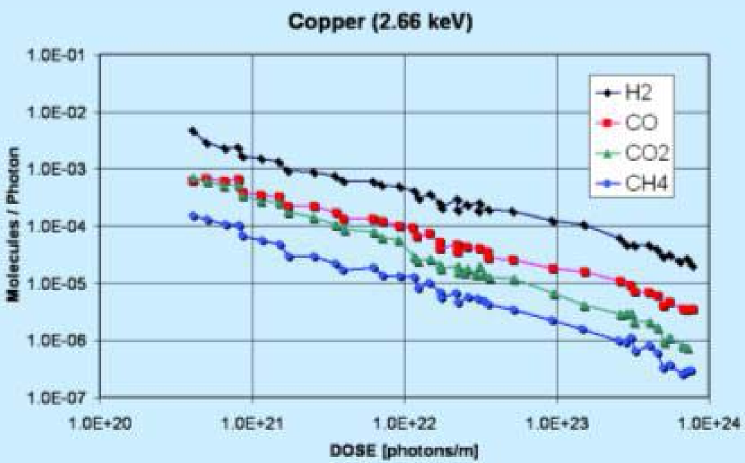
$$\Gamma_{Lin} = \frac{d\Gamma}{d\theta} \cdot \frac{\Delta\theta}{\Delta L}$$

E	=	Beam energy
I	=	Beam current
$\Delta\theta$	=	Horizontal opening angle
ΔL	=	Length of SR illuminated vacuum chamber

Photon Desorption Yield Measurements



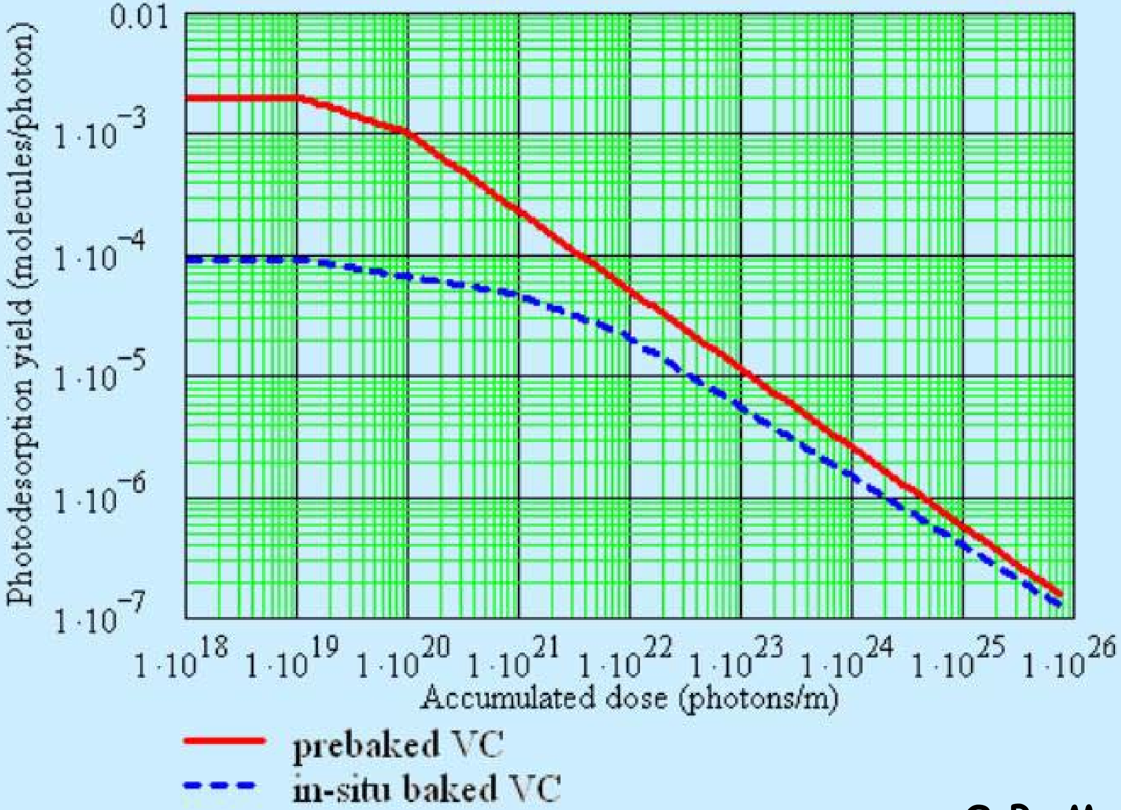
Oswald Gröbner, *"Dynamic Outgassing"* CAS, 1999-Denmark



V. Anashin, et al, Proc. EPAC-98, Stockholm, 1998

- PSD yields for different materials have bee measured in dedicated beam line experiments in several research centers.
- AL shows at the beginning a higher desorption.
- At higher doses all the values of material came more or less to the same results.

PSD Yield Model for CO



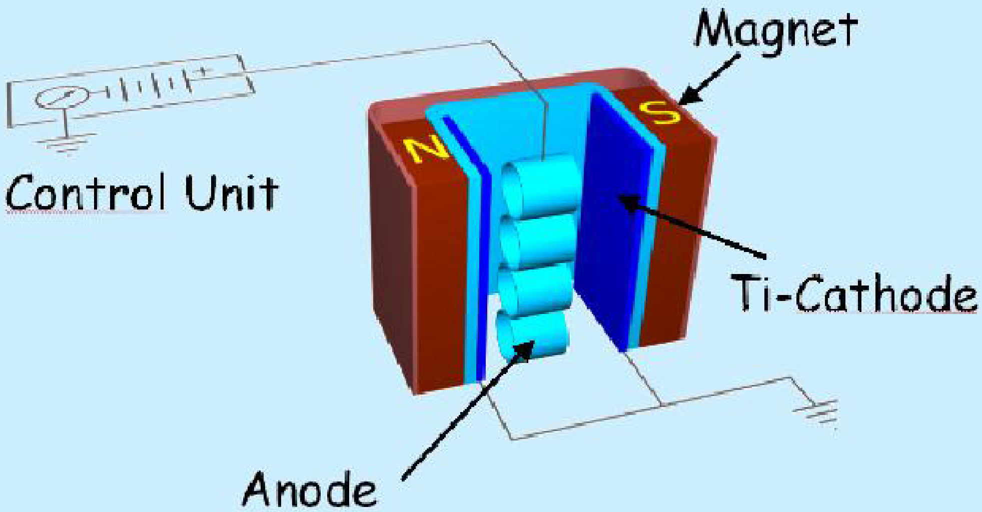
- Pre-baked VC: Pre-baked at 200°C for 24 h (but not baked in-situ).
- In-situ baked: Baked in-situ at 200°C for 48 h.
- Yields for doses higher than 10^{23} photons/m are extrapolated.

O.B. Malyshev, et al, Pressure Distribution for Diamond Storage Ring, EPAC 2002

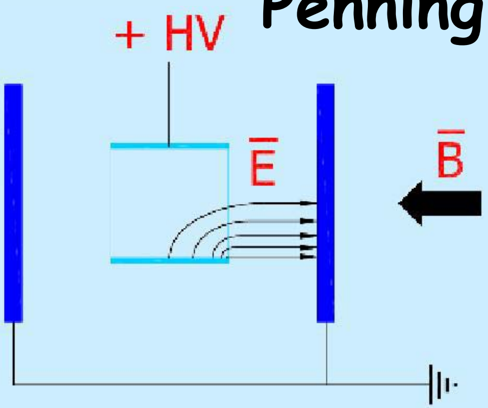
UHV Pumps for Synchrotron Light Sources

- Capture pumps dominate the UHV and HV region of accelerator vacuum systems.
- Principal pumping mechanism based on chemical transformation.
- Physisorption or gettering produce pumping action.
- Titanium is the most used evaporable getter.
- Zr and Zr alloys are the most used non-evaporable getters (NEG).

Sputter Ion Pumps

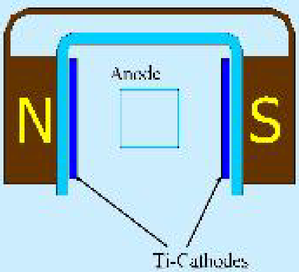


Penning Cell



- Sputter-ion pumps use chemical and ionization pumping effects.
- Common designs based on a Penning cell.
- On the cathode impacting ions sputter away cathode material.
- Sputtered titanium flies away from the cathode onto the neighboring surfaces and forms there a getter film.
- Stable chemical compound between getter film and reactive gas particles (CO, CO2, H2, N2, O2).
- The current from the control unit is proportional to the pressure.

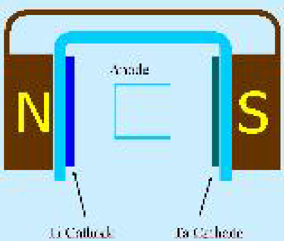
Sputter Ion Pumps



Standard Diode

Highest pumping speed per unit volume.

Low pumping speed for noble gases (<5% for Ar).

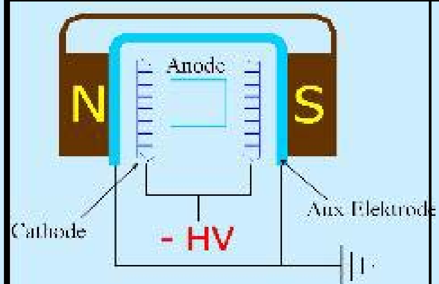


Noble Diode

A part of the cathode material is replaced with Tantalum to achieve a higher pumping speed for noble gases.

Noble gas ions are neutralized and "bounced back" on the cathode and buried in other parts of the pump.

Energetic neutrals have far greater penetrating depth.



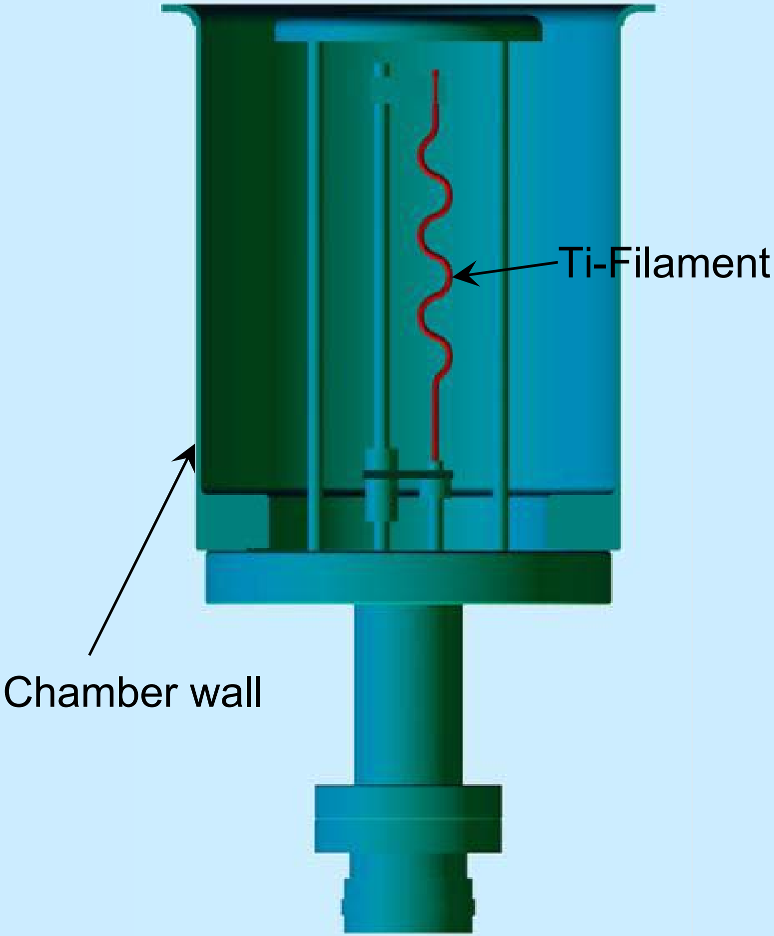
Triode

Cathode plates are replaced with grids of Ti-strips

Number of neutrals due to glancing incidence is increased.

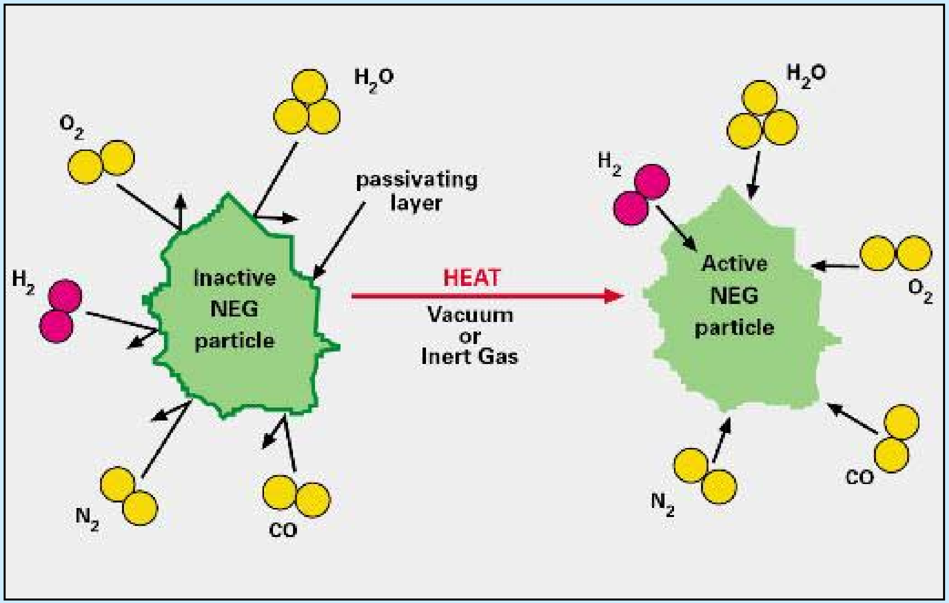
Pumping speed for noble gases of 20-25%.

Titanium Sublimation Pump



- Ti-filament periodically heated with high currents.
- Ti evaporates and generate a getter film on the chamber wall or cooled screen.
- Active gas molecules react with the getter film.
- Progressive saturation and reduction of pumping speed with time.

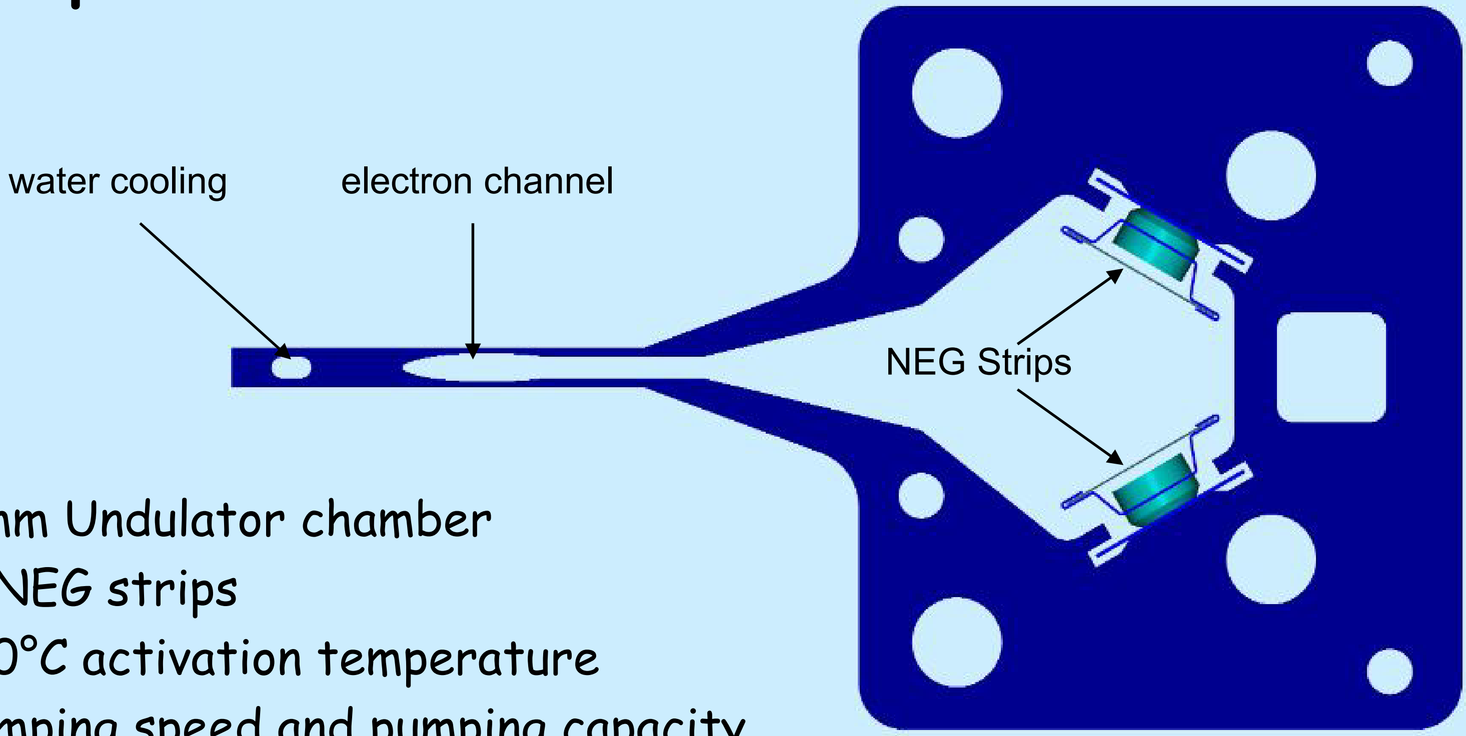
Non Evaporable Getter Pumps



SAES Getters

- Gas molecules can be sorbed by a chemical reaction when they impinge on the clean metal surface of the getter material.
- To achieve a clean metal surface the oxide layer must be removed in an activation process.
- For that the getter must be heated to a certain temperature.
- During activation the passivating layer diffuses into the bulk material.
- The metal surface saturates with cumulative sorption of gas molecules and a new oxide layer will be created.
- To achieve the full pumping speed the NEG must be reactivated.

NEG Strips

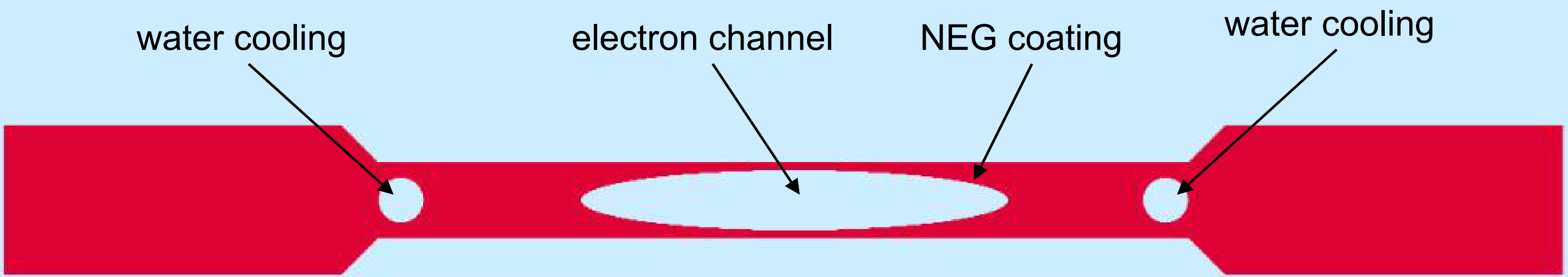


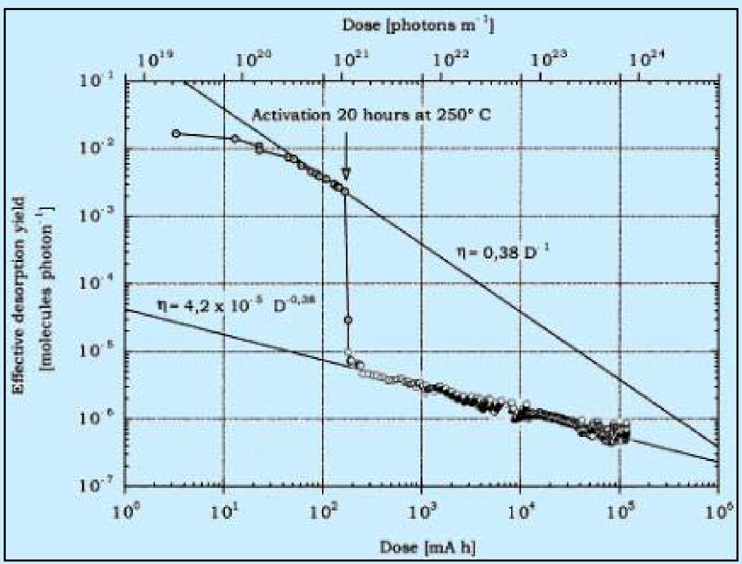
- APS 5 mm Undulator chamber
- ST707 NEG strips
- 350-450°C activation temperature
- High pumping speed and pumping capacity

E. Trakhtenberg, priv. communication

NEG Coating

- Extruded vacuum chamber (AL)
- NEG coating of electron channel

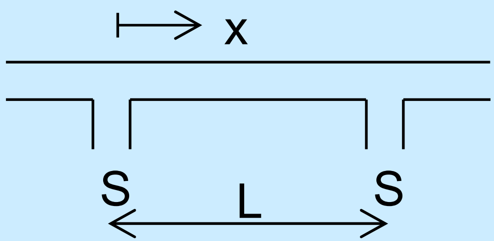




- NEG Coating, Ti-Zr-V, 2µm
- Activation temperature 200 °C
- High pumping speed and low desorption rate.

P. Chiggiato, R. Kersevan, Synchrotron radiation-induced desorption from a NEG-coated vacuum chamber
Vacuum 60, (2001) pp 62 - 72

Linear Pump Distribution



Linear gas load Q [Torr l/s], with specific molecular conductance w [m l/s], specific gas load q [Torr l/s m^{-2}], and specific surface area A [m] .

$$Q(x) = -w\frac{dP}{dx} \qquad \frac{dQ}{dx} = Aq$$

combination of both formulas   boundary conditions

$$w\frac{d^2P}{dx^2} = -Aq \qquad \left.\frac{dP}{dx}\right|_{x=L/2} = 0 \quad P\big|_{x=0} = \frac{AqL}{S}$$

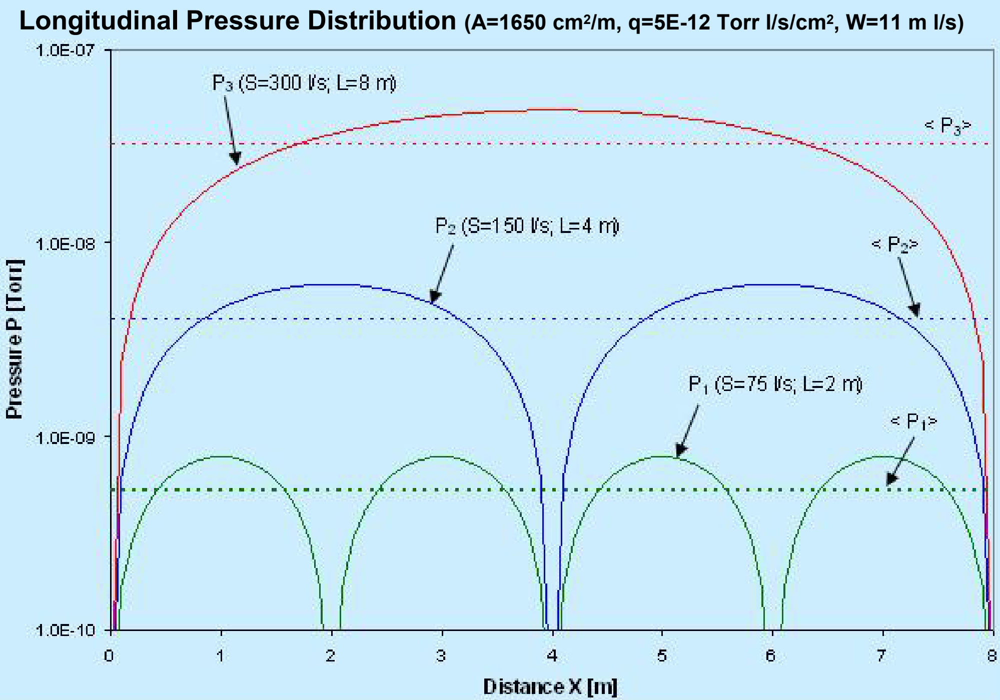
with L[m]=distance of pumps, S[l/s]=pumping speed

Pressure distribution

$$P(x) = Aq\left(\frac{Lx - x^2}{2w} + \frac{L}{S}\right)$$

Average pressure

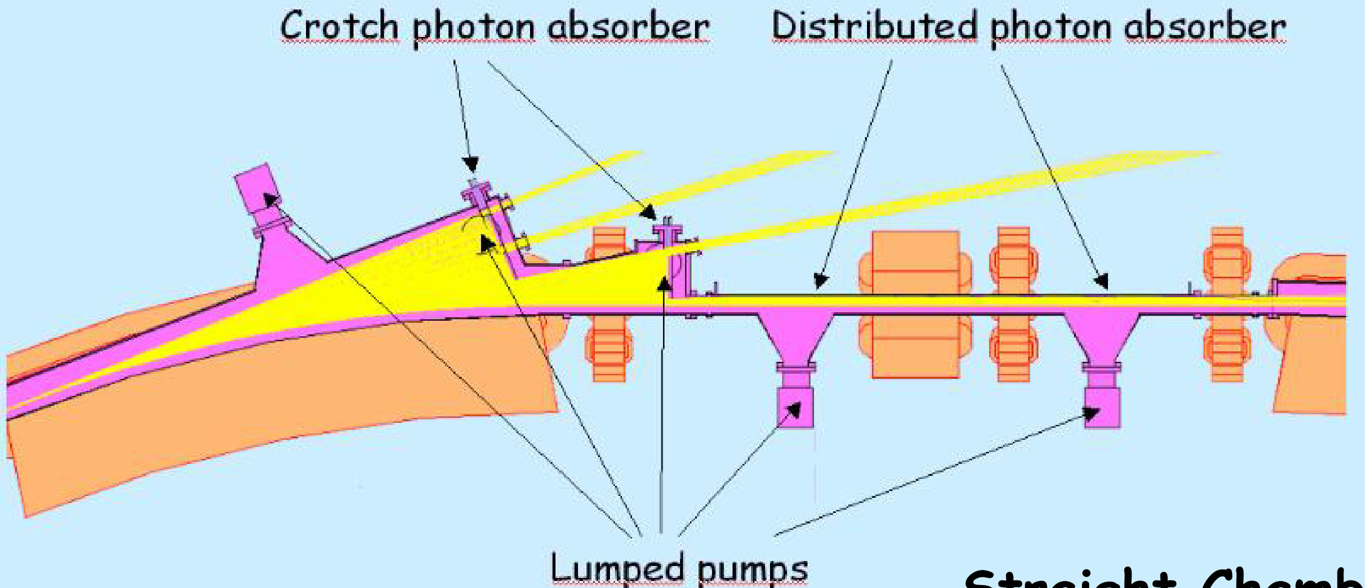
$$< P >= Aq\left(\frac{L^2}{12w} + \frac{L}{S}\right)$$



Materials

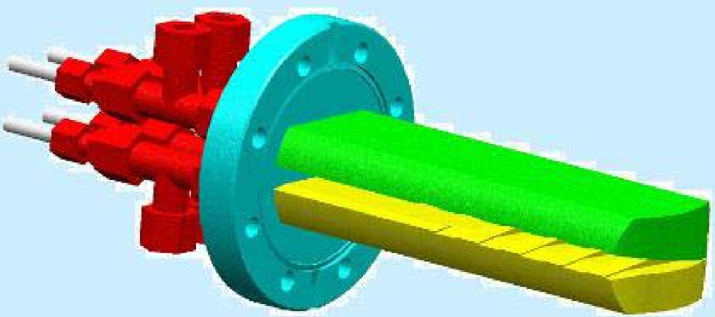
	Stainless Steel 316 LN	**Aluminum** Al Mg 4.5 Mn	**Copper** OFHC/Glidcop™
Yield stress [MNm^{-2}] 20°C/250°C	315 / 200	215	63 / 55 332 / 255
Therm. Cond. [$Wm^{-1}K^{-1}$] 20°C	15	109	391 / 345
Electr. Cond. [$10^{-6}\Omega m$] 20°C	1.4	36	58/54
Modulus of Elast. [GNm^{-2}] 20°C	200	71	117/126
Chamber fabrication	deep drawn edge bending	extrusions solid blocks	(extrusions)
Joining technique	TIG welding e- beam welding very easy	TIG welding	brazing e- beam welding

Combined Chamber Design

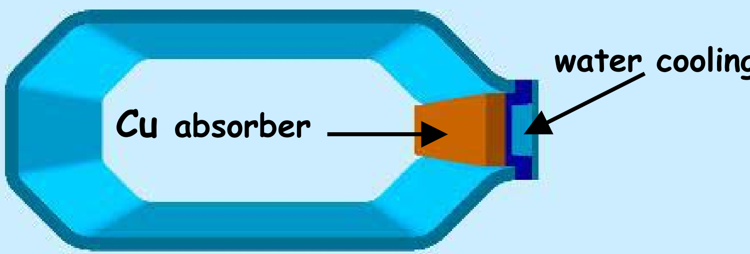


- Ante chamber in the bending magnet.
- Distributed photon absorber in the straights.

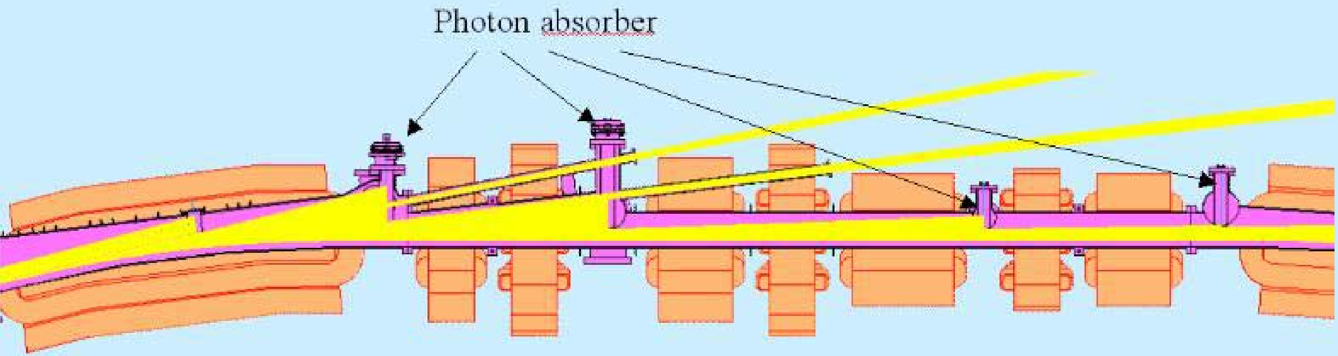
Crotch Absorber



Straight Chamber with Longitudinal Photon Absorber

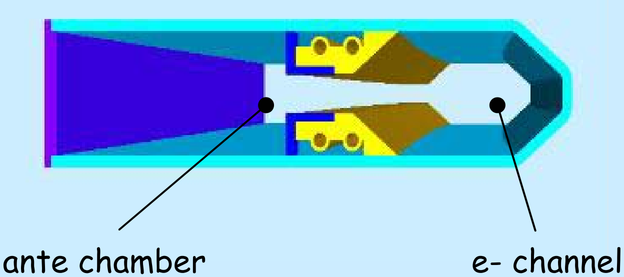


Full Ante Chamber Design

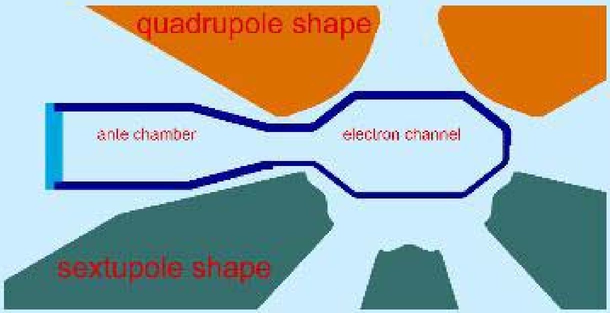


- Photon flux is concentrated on lumped absorbers.
- Pumps can be installed close to photon absorbers (the main source of the gas load).

Dipole Chamber with Cu-shield



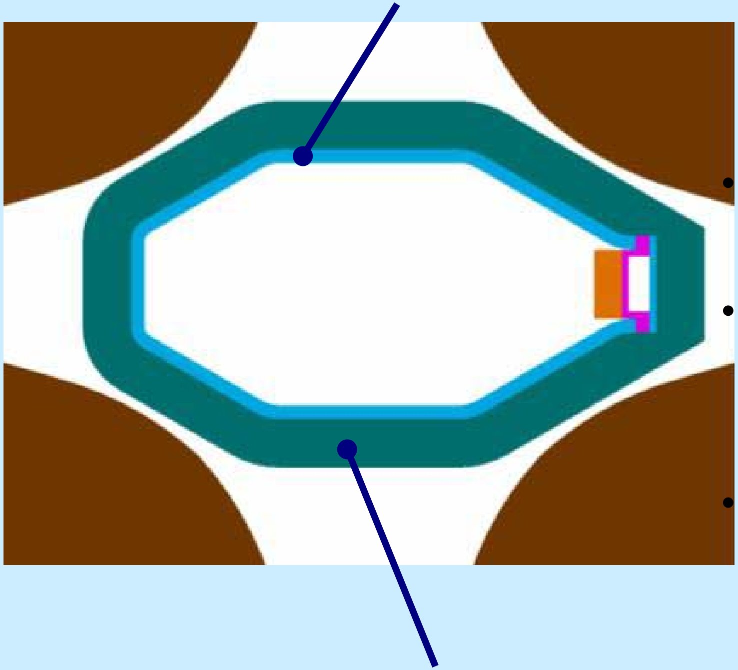
Straight Chamber



Cleaning Steps for Stainless Steel Vacuum Chambers

- Wash with a high pressure hot water (approx. 80°C) jet using a detergent.
- Ultrasonically agitated bath of clean hot solvent.
- Vapor wash in solvent vapor.
- Cleaning of the chambers in an hot (60°C) ultrasonic bath with detergent.
- Vacuum firing at 950 °C at $p \leq 1 \cdot 10^{-5}$ Torr
- Bake-out at 200 °C for a minimum of 24 hours.

In-Situ Bake-Out or Pre-Bake?



- A classical in-situ bake-out system consists of resistive heaters and thermal insulation.
- Larger magnet gaps are required.
- High costs for in-situ bake-out system and magnets.
- Improvements mostly in the start up phase of a light source.
- Special pre-bake system at SLS, and CLS.

SLS Bake-Out Procedure

- Vacuum sections assembled outside the storage ring in a clean room and baked at 250 °C in an oven.
- At room temperature each vacuum section typically reached within one day a base pressure in the low 10^{-10} mbar range.
- Installation of complete vacuum sections into the ring under vacuum.
- The straight sections are pumped down in the tunnel and baked-out with a modular oven

Bibliography

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CAS CERN ACCELERATOR SCHOOL

VACUUM TECHNOLOGY

Scanticon Conference Centre, Snekersten, Denmark
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PROCEEDINGS

Editors: S. Turner

AMERICAN INSTITUTE OF PHYSICS
CONFERENCE PROCEEDINGS NO. **171**
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