The CERN Accelerator School

Vacuum Technology for Particle Accelerators

Marek Grabski (Max IV laboratory)

CERN Accelerator School: Introduction to Accelerator Physics

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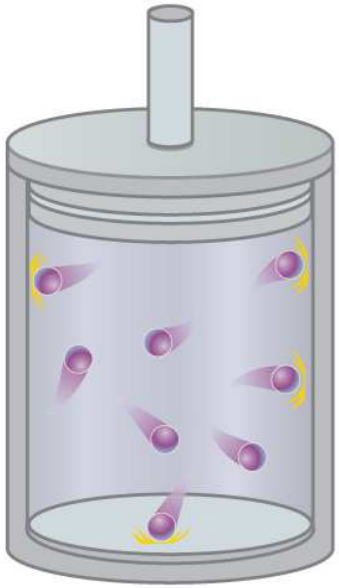
Contents

- What is vacuum and why do we need it in particle accelerators?
- Basics of vacuum technology,
- Gas sources,
- Pumping technology,
- Pressure profile evaluation,
- Outlook of accelerator vacuum systems.

What is vacuum?

Vacuum is a space with no matter inside.

Vacuum in engineering and physics is a space in which the pressure is lower than atmospheric pressure and is measured by its absolute pressure.



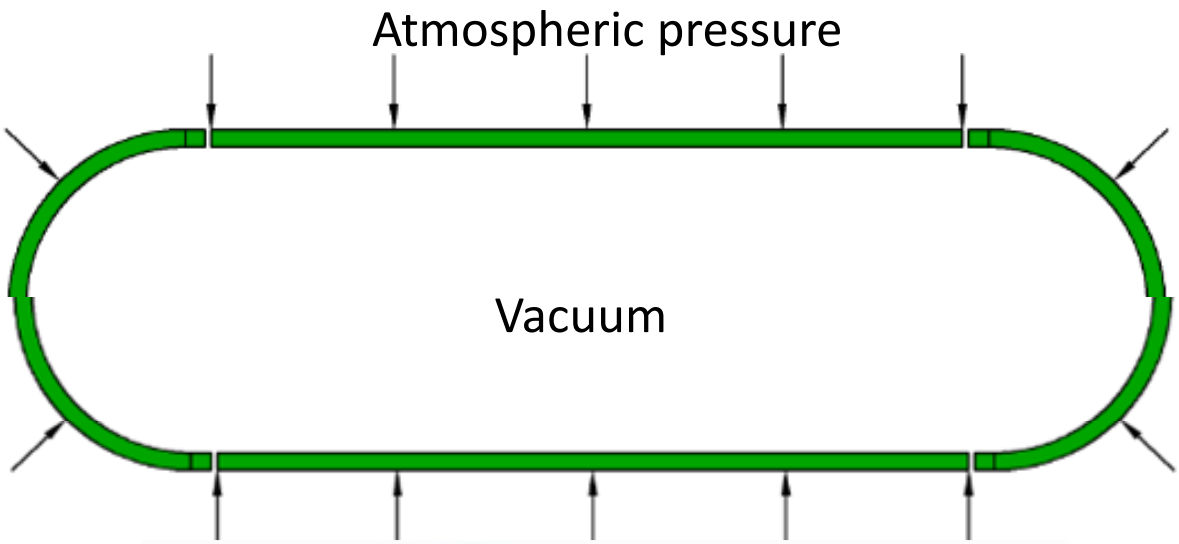
Low pressure

High pressure

Pressure is $\frac{\text{Force [N]}}{\text{Area [m}^2\text{]}}$ measured in Pascals, 1 [Pa] = 1 N/m^2

What is vacuum?

The force exerted on the walls of an evacuated vessel surrounded by atmospheric pressure is: **1 kg/cm^2**



What is vacuum?

Conversion table: units of pressure

	Pa	bar	atm	Torr
1 Pa	1	10^{-5}	$9.87\ 10^{-6}$	$7.5\ 10^{-3}$
1 bar	10^{2}	1	0.987	750.06
1 atm	$1.013\ 10^{5}$	1.013	1	760
1 Torr	133.32	$1.33\ 10^{-3}$	$1.32\ 10^{-3}$	1

In vacuum technology: mbar or Pa

Why do we need vacuum in particle accelerator?

Less beam-gas interaction:

- Increase beam lifetime,
- Prevents to increase beam size,
- Reduces radiation hazard,
- Lowers background in detectors.

The total beam lifetime in a particle accelerator is given by:

$$\frac{1}{\tau} = \frac{1}{\tau_{elastic}} + \frac{1}{\tau_{inelastic}} + \frac{1}{\tau_{Touschek}} + \frac{1}{\tau_{quantum}}$$

The interaction between beam particles and residual gas molecules consist of two main mechanisms: elastic and inelastic scattering which contribute to total beam lifetime.

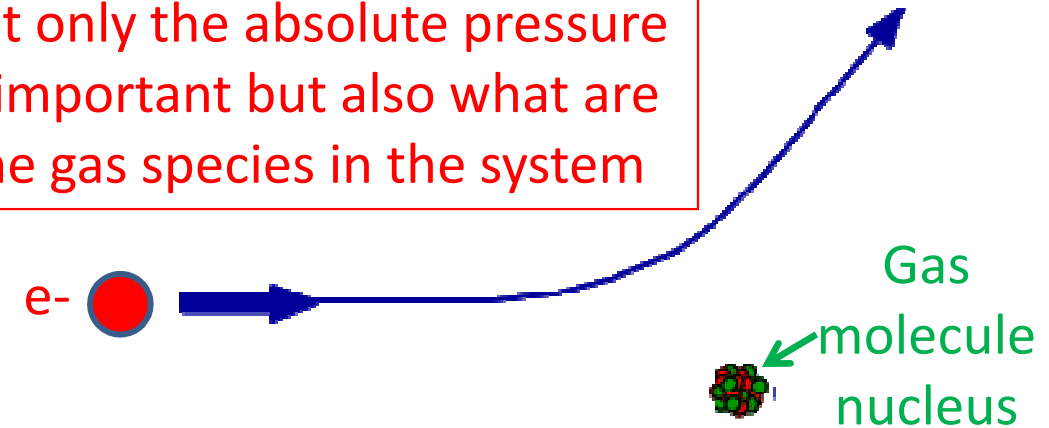
Elastic scattering

Elastic scattering with residual gas molecules alter transverse motion of particles increasing their betatron oscillations (energy of particles is conserved).

- The particles are lost when the oscillation amplitude exceeds physical acceptance aperture.

$$\frac{1}{\tau_{elastic}} \sim \frac{Z^2}{\gamma^2} \frac{\langle \beta_y \rangle \beta_y}{a_y^2} n_g$$

Not only the absolute pressure is important but also what are the gas species in the system



where:

Z	- atomic number of the residual gas (careful which gas is dominant)
$\langle \beta_y \rangle$	- average vertical beta function
β_y	- vertical beta function at the limiting vertical aperture
γ	- relativistic factor of the particles in the stored beam
a_y	- limiting vertical aperture
n_g	- residual gas density

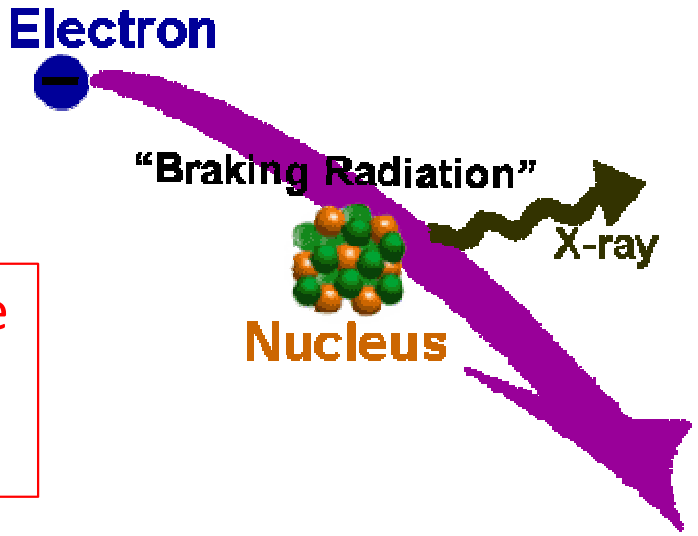
Inelastic scattering

Inelastic scattering with residual gas molecules decreases speed of particles causing photon emission called Bremsstrahlung (energy of particles is not conserved).

- The particle are lost if the energy loss exceeds the momentum acceptance of the accelerator.

$$\frac{1}{\tau_{inelastic}} \sim Z^2 \ln \frac{1}{\Delta p/p} n_g$$

Not only the absolute pressure is important but also what are the gas species in the system



where:

Z	- atomic number of the residual gas (careful which gas is dominant)
$\Delta p/p$	- momentum acceptance
n_g	- residual gas density

Vacuum ranges

1 Atm. = 1013 mbar =~ 1 bar

	Pressure range [mbar]
Low Vacuum	10^{3} - 1
Medium Vacuum	1 - 10^{-3}
High Vacuum (HV)	10^{-3} - 10^{-9}
Ultra High Vacuum (UHV)	10^{-9} - 10^{-12}
Extreme High Vacuum XHV	< 10^{-12}

Storage rings

Ideal gas law

Ideal gas equation:

$$P\,V = N_{moles}\,R\,T \quad \text{or} \quad P\,V = N_{molecules}\,k_b\,T$$

macroscopic | microscopic

1 drop of water contains: 10^{20} molecules

P	- the pressure of the gas,
V	- the volume of the gas,
N_{moles}	- the number of moles of the substance,
$N_{molecules}$	- the number of gas molecules,
R	- the universal gas constant,
T	- the absolute temperature of the gas,
k_b	- the Boltzmann constant

Each cubic centimeter of gas at room temperature contains:
~10^{19} molecules/cm^3 - at 1 atm (~1 Bar),

~10^{6} molecules/cm^3 - at 10^{-10} mbar (similar pressure as on the moon)

Maxwell-Boltzmann model

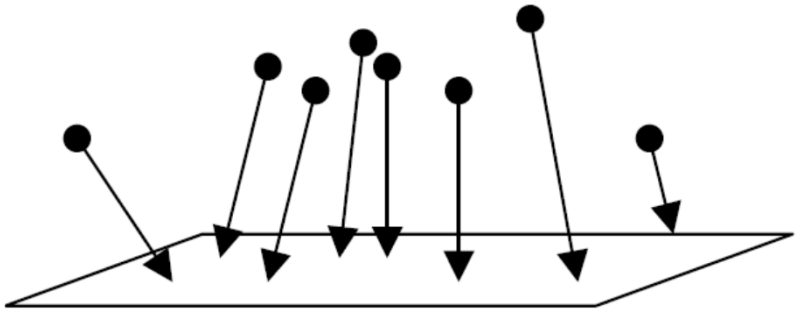
Mean speed of gas molecules:

$$\langle v \rangle = \sqrt{\frac{8k_bT}{\pi m_0}}$$

φ - impingement rate,
n - gas density (molecules/volume),
k_b - the Boltzmann constant $1.38*10^{-23}$ [J/K],
T - the absolute temperature of the gas [K],
m_0 - molecular mass [kg],
$\langle v \rangle$ - the average gas molecules speed [m/s],

Number of molecules striking unit surface in unit time (Impingement rate):

$$\varphi = \frac{1}{4} n \langle v \rangle = \frac{1}{4} n \sqrt{\frac{8k_bT}{\pi m_0}}$$



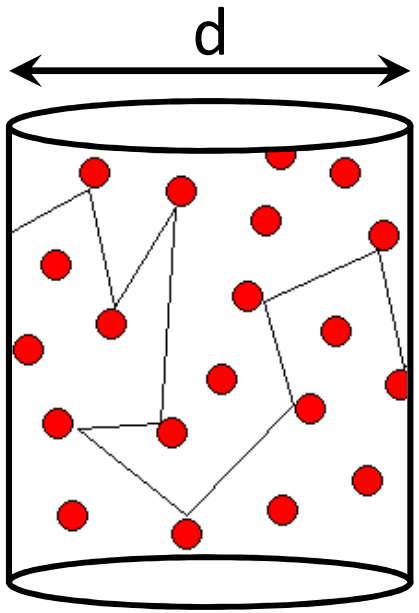
Flow regimes

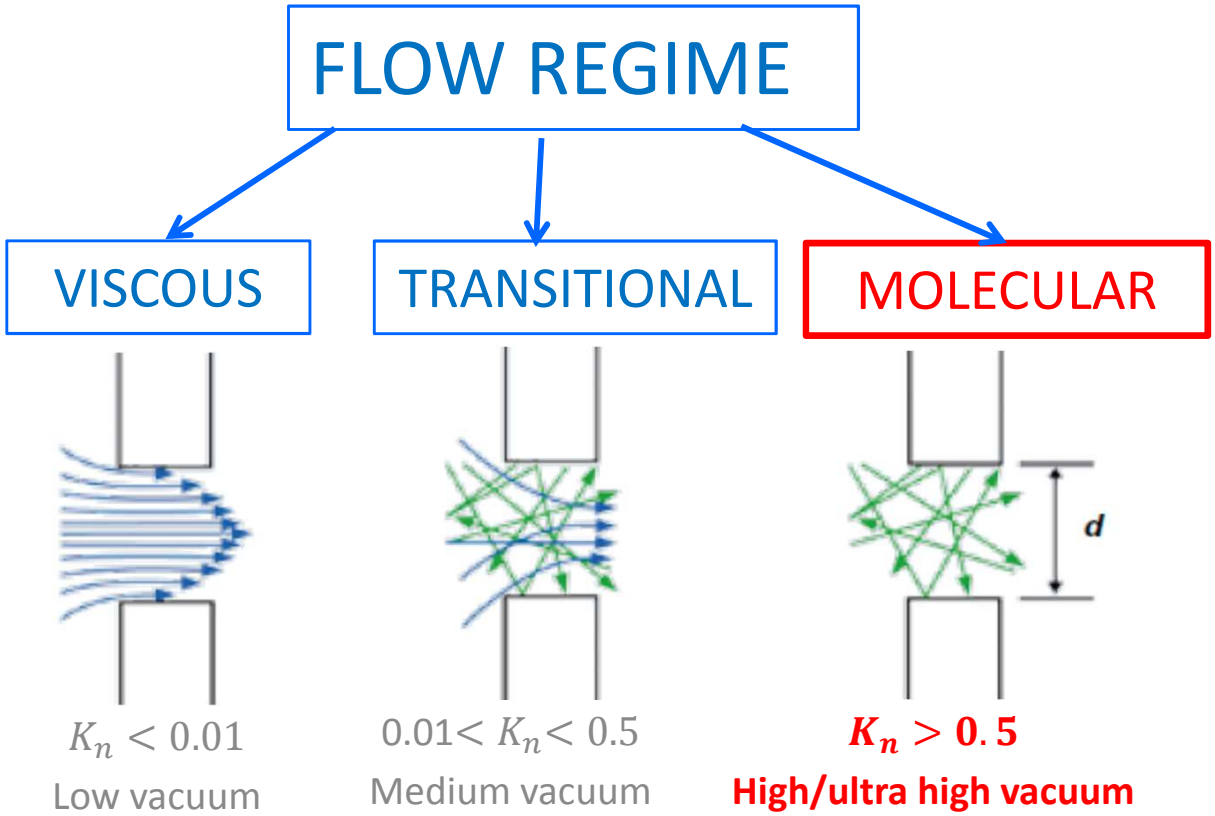
$$K_n = \frac{l}{d}$$

l - Mean free path [m]

d - Diameter of flow channel [m]

K_n - Knudsen number dimensionless

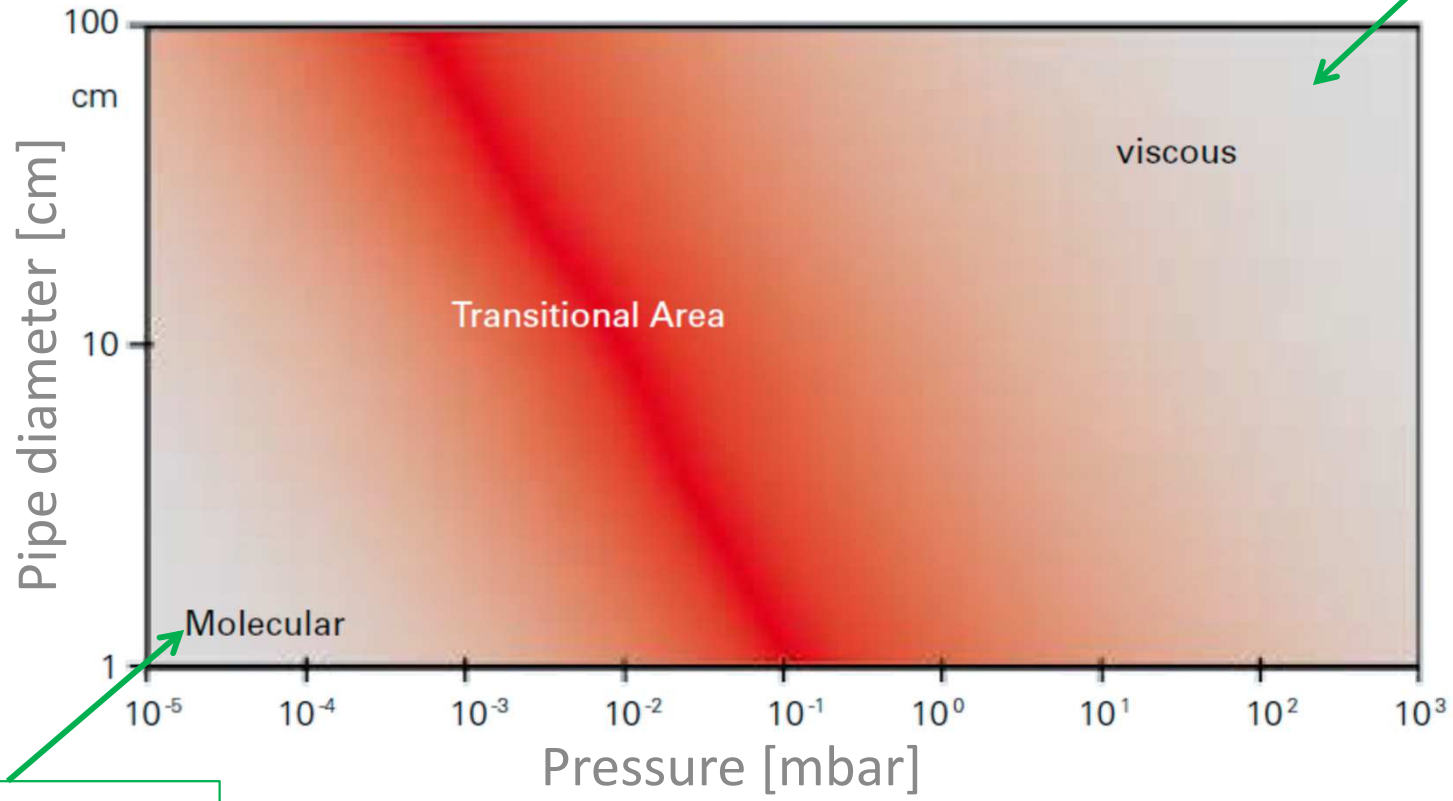




Mean free path:
At atm. Pressure = 6.5×10^{-8} m
At 10^{-9} mbar (storage ring) = 66 km

Vacuum Technology Know how by Pfeiffer Vacuum GmbH

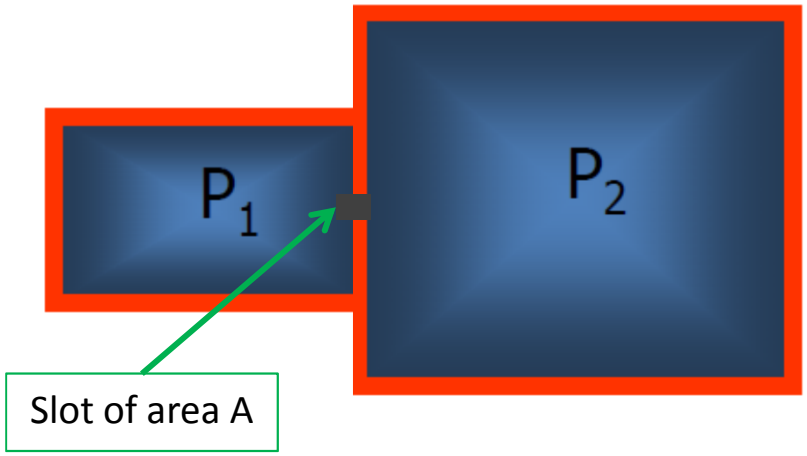
Flow regimes



Particle accelerators operate in molecular flow regime.

Vacuum Technology Know how by Pfeiffer Vacuum GmbH

Gas flow in molecular regime



In molecular flow regime the gas flow (Q) from one point to the other is proportional to the pressure drop:

Gas flow — Conductance — Pressure difference

$$Q = C(P_1 - P_2)$$

$$[Q] = \frac{mbar\ l}{s}$$

$$C = \frac{1}{4} A\langle v \rangle = C'A \left[\frac{l}{s}\right]$$

$$C' = \frac{1}{4}\langle v \rangle \left[\frac{l}{s\ cm^2}\right]$$

Conductance depends on the gas molecule velocity thus its molar mass and temperature (not on pressure).

C' - conductance of unit surface area for given gas

A – slot Area [cm^2]

$\langle v \rangle$ - the average gas molecules speed [m/s]

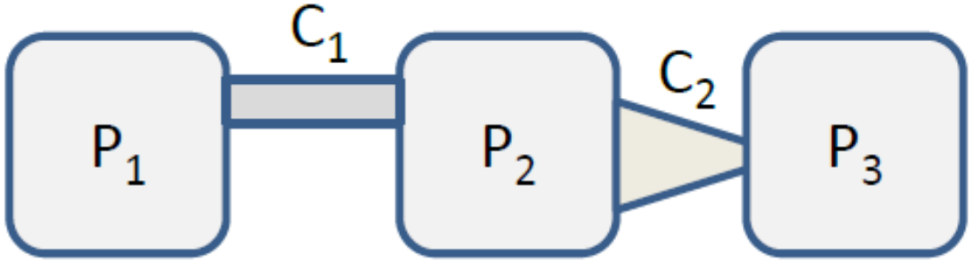
Conductance *C* at 295 K for nitrogen (N_2 - molecular mass 28):

$$C = C'A = 11.8\ A \left[\frac{l}{s\ cm^2}\right]$$

Gas flow in molecular regime

Combination of conductances:

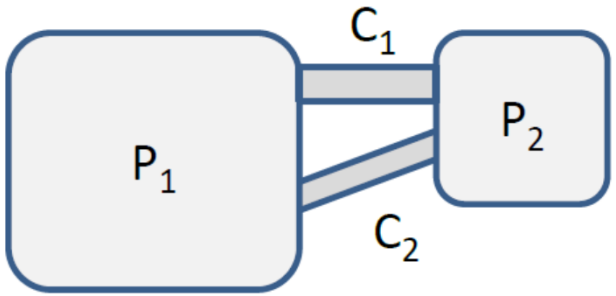
a). For components in series:



$$Q_1 = C_1(P_1 - P_2)$$
$$Q_2 = C_2(P_2 - P_3)$$
$$Q_{TOT} = C_{TOT}(P_1 - P_3)$$

In steady state $Q_1=Q_2$ -> $C_{TOT} = \frac{C_1 C_2}{C_1 + C_2}$ and $\frac{1}{C_{TOT}} = \frac{1}{C_1} + \frac{1}{C_2}$ -> $\frac{1}{C_{TOT}} = \sum_1^N \frac{1}{C_i}$

b). In parallel:



$$Q_1 = C_1(P_1 - P_2)$$
$$Q_2 = C_2(P_1 - P_2)$$
$$Q_{TOT} = C_{TOT}(P_1 - P_2)$$

$$Q_{TOT}=Q_1+Q_2 \rightarrow C_{TOT} = C_1 + C_2 \rightarrow C_{TOT} = \sum_1^N C_i$$

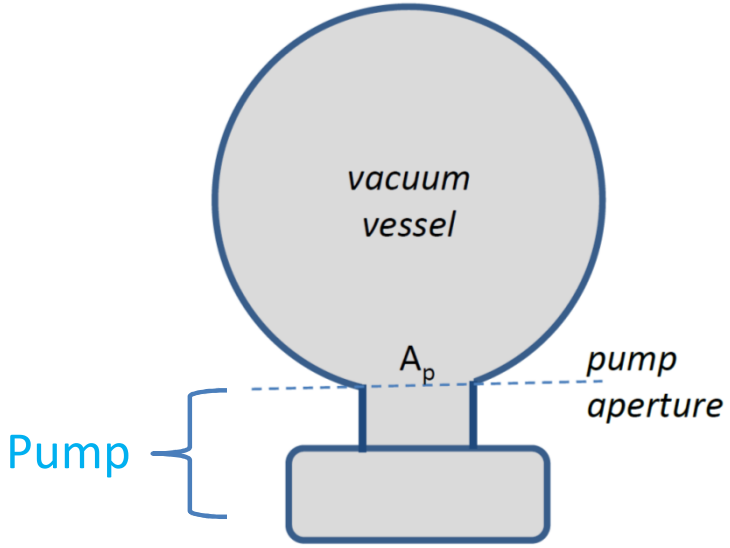
Paolo Chiggiato, Vacuum Technology for Ion Sources, CAS 2012 proceedings

Gas flow in molecular regime

In vacuum technology a pump is an object that permanently removes gas molecules from the gas phase.

Pumping speed S of a pump is defined as the ratio between the pump throughput Q_p and the pressure P at the entrance to the pump.

$$S = \frac{Q_p}{P} \quad \left[\frac{l}{s}\right]$$



Gas removal rate can be written as:

$$Q_p = \varphi A_p \alpha = \frac{1}{4} A_p n \langle v \rangle \alpha = A_p C' P \alpha$$

From the definition of pumping speed:

$$S = A_p C' \alpha$$

φ - impingment rate

A_p – is the area of the pump aperture [cm^2]

C' - is the conductance of the unit surface area for given gas

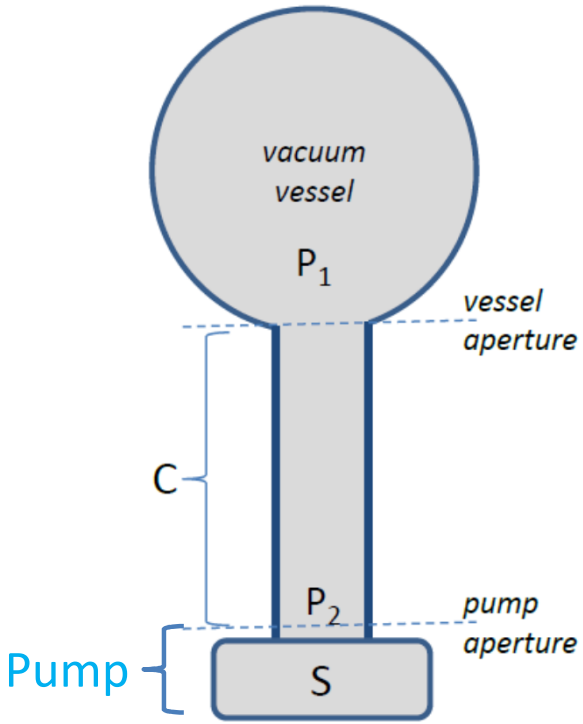
n – gas density

α – is the capture probability

Paolo Chiggiato, Vacuum Technology for Ion Sources, CAS 2012 proceedings

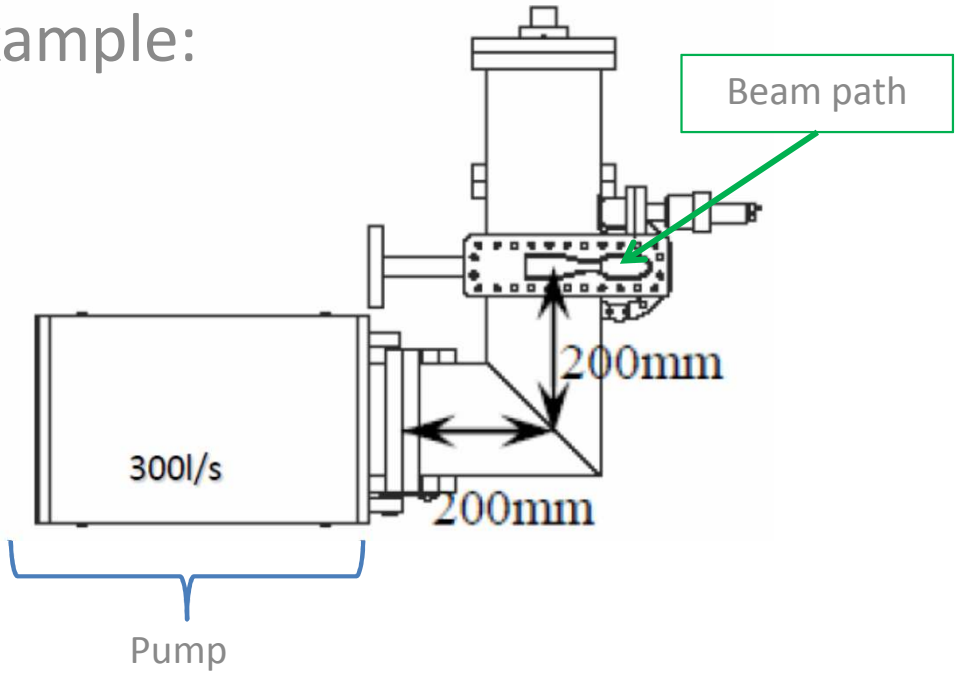
Gas flow in molecular regime

Introduced limitation between pump and pumped vacuum volume limits the nominal pumping speed of chosen pump.



$$\frac{1}{S_{eff}} = \frac{1}{S} + \frac{1}{C}$$

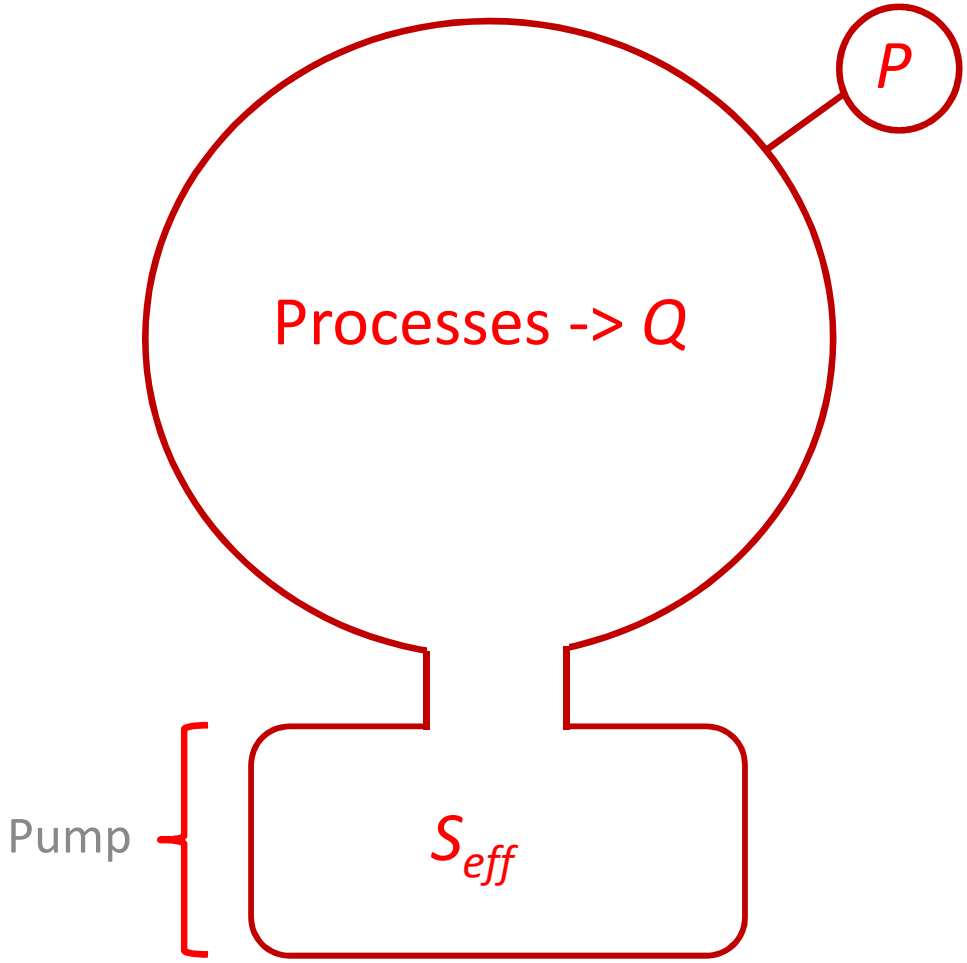
Example:



300 l/s ion pump connected to a vacuum chamber through a 90 deg elbow of given dimensions can result in ~30 % pumping speed reduction.

Paolo Chiggiato, Vacuum Technology for Ion Sources, CAS 2012 proceedings

Generic vacuum system



$$P = \frac{Q}{S_{eff}}$$

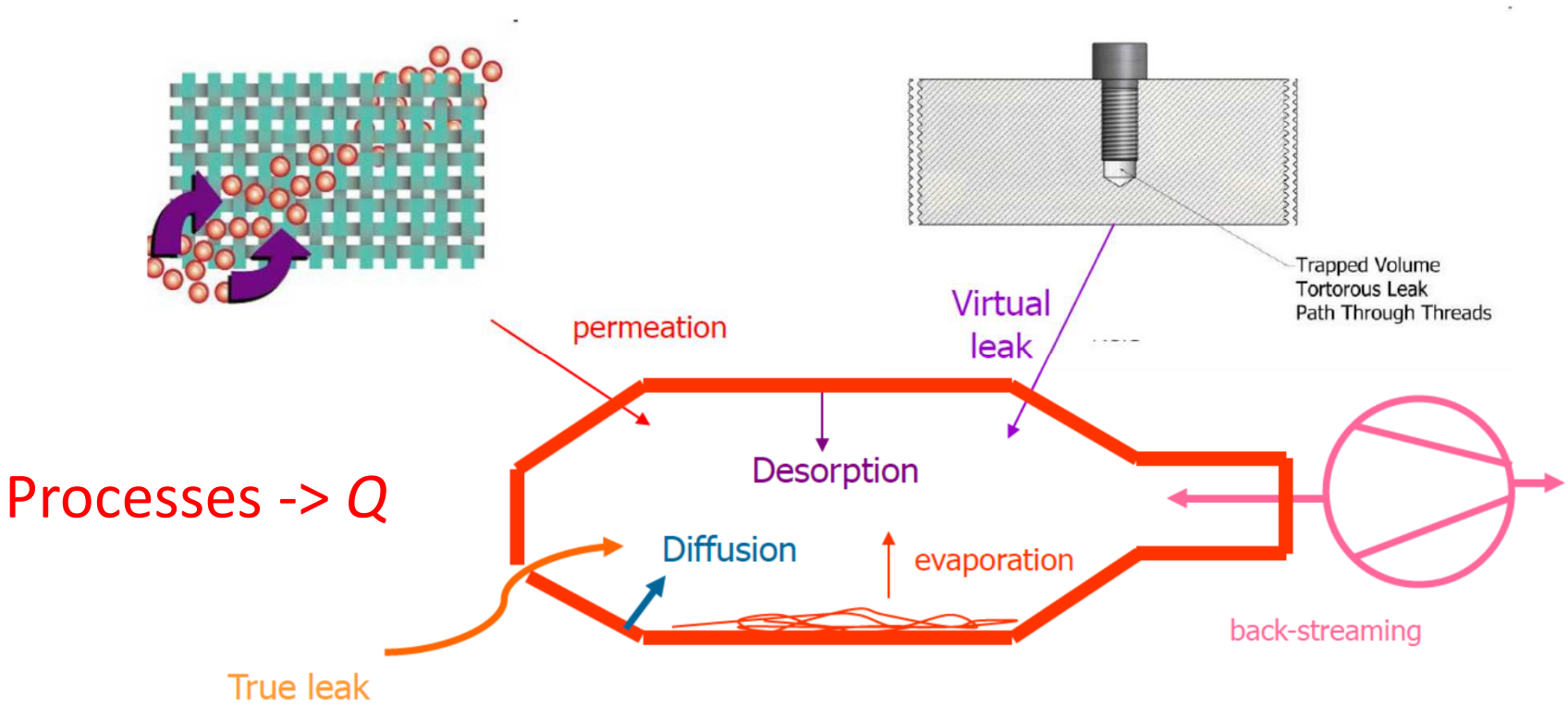
P – gas pressure,

Q – gas load (outgassing),

S_{eff} – Effective pumping speed.

Sources of gases

Sources of static gas loads in vacuum system:



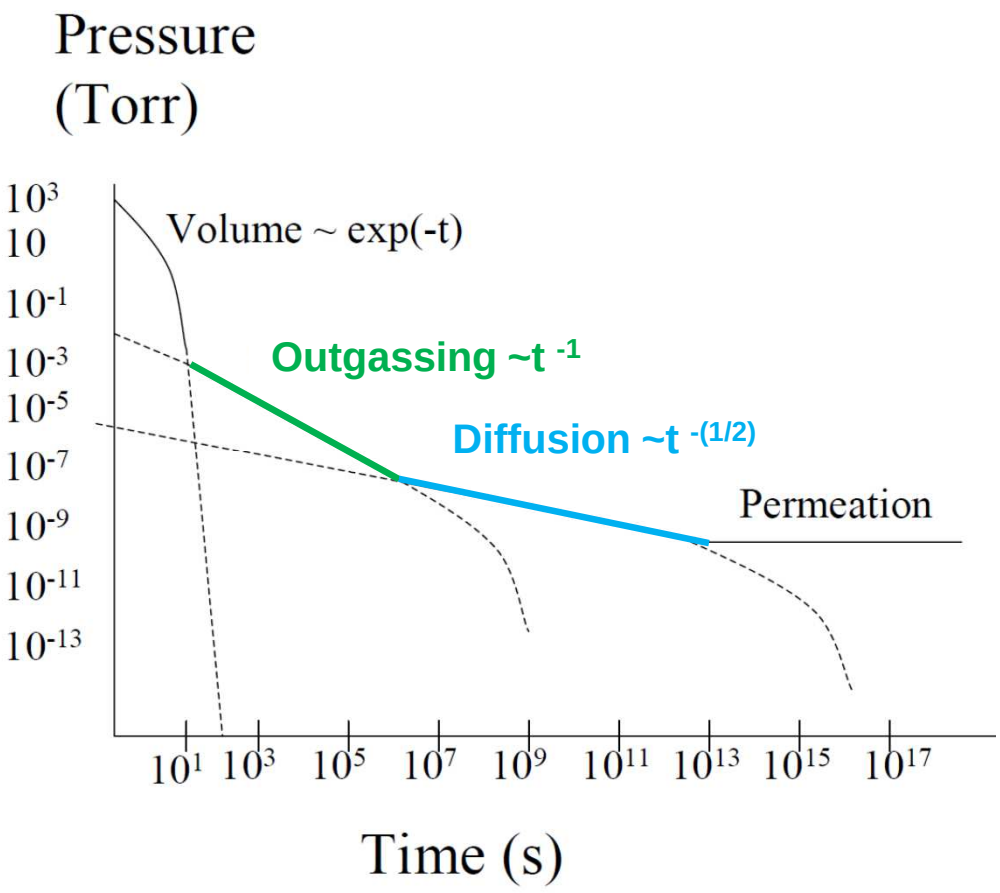
Processes -> *Q*

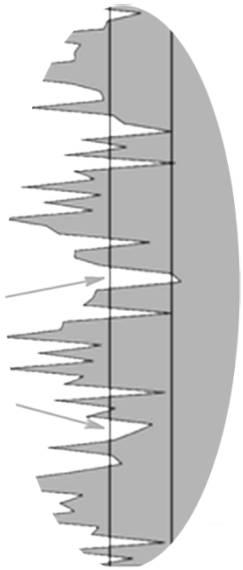
Vacuum chambers are source of gas

Courtesy of Eshraq Al-Dmour

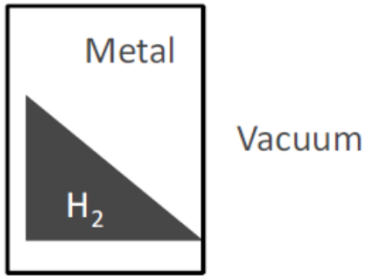
What process defines pressure

What process defines the pressure over time?





Outgassing:
Material
– Binding energy
Surface condition
– As delivered
– Machined
– Polished
– Cleaning
– Heat treatment…



Difussion:
- Material
- Heat treatment
  (Vacuum firing)
- Inner surface barrier
  (Air baking, Film deposition)

http://web.utk.edu/~prack/Thin%20films/VACUUM-3.pdf

Thermal outgassing

Thermal outgassing (static outgassing)

For metals:

- If not baked (heated to 200^{0}C) in-situ water is the dominant gas specie.

$$q_{H_2O} \approx \frac{3 \times 10^{-9}}{t[h]} \left[\frac{mbar\ l}{s\ cm^2}\right]$$

- If baked (heated to ~200^{0}C) in-situ hydrogen H_2 is the dominant gas

Outgassing rates q $\left[\frac{torr\ l}{s\ cm^2}\right]$ at 20^{0}C:

Austenitic stainless steel not baked, after 10 h pumping	3x10^{-10} (H_2O)
Austenitic stainless steel baked in-situ for 24 h at 150^{0}C	2x10^{-12} (H_2)
OFS copper baked in-situ for 24 h at 200^{0}C	~10^{-14} (H_2)

Paolo Chiggiato, Vacuum Technology for Ion Sources, CAS 2012 proceedings

Dynamic outgassing

In particle accelerators energized particles impinging on vacuum surfaces induce desorption of molecules. Usually such dynamic gas load dominate over thermal outgassing.

Beam stimulated desorption is characterised by η - the desorption yield:

$$\eta = \frac{number\ of\ desorbed\ molecules}{number\ of\ particle\ impinging\ the\ surface}$$

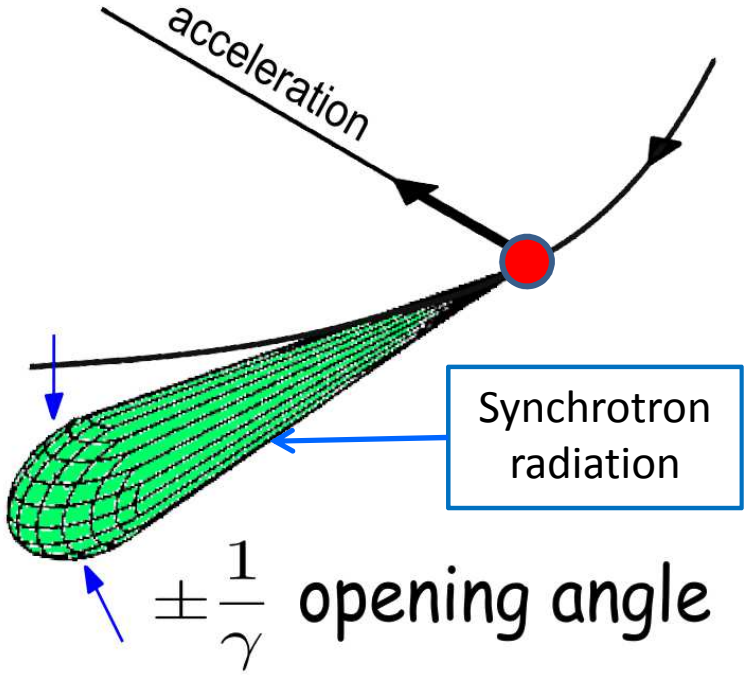
η – depends on many parameters:

- incident particle: type and energy,
- material,
- surface roughness,
- cleanliness of the surface,
- history of the material (dose),
- Particle flux.

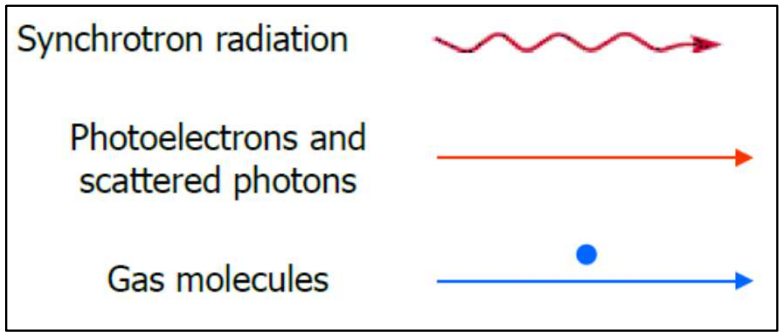
The desorption may be stimulated by:

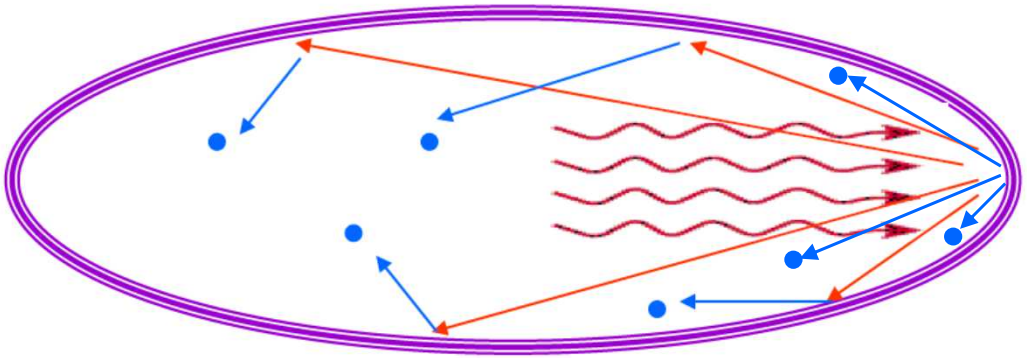
- electrons,
- ions,
- synchrotron radiation (photons).

Photon Stimulated Desorption



When charged particles (moving at relativistic speeds) are accelerated they emit synchrotron radiation in a narrow cone. This photon flux impinging on vacuum suraces produces strong outgassing thus a large dynamic pressure increase.





http://photon-science.desy.de/research/studentsteaching/primers/synchrotron_radiation/index_eng.html

Courtesy of Eshraq Al-Dmour

Photon Stimulated Desorption

Total photon flux $\dot{\Gamma}$ [photons/s] around electron storage ring:

$$\dot{\Gamma} = 8.08 \cdot 10^{17} I E \quad \text{->} \quad \frac{photons}{s}$$

I – machine current [mA]

E – energy [GeV]

Gas flow Q_{PSD} due to photon induced desorption:

$$q_{PSD} = \eta \dot{\Gamma} \quad \text{->} \quad \frac{molecules}{s}$$

$$Q_{PSD} = K \eta \dot{\Gamma} \quad \text{->} \quad \frac{mbar\ l}{s}$$

K – converts number of molecules to pressure units 4.04×10^{-20} [mbar*l/molecule]

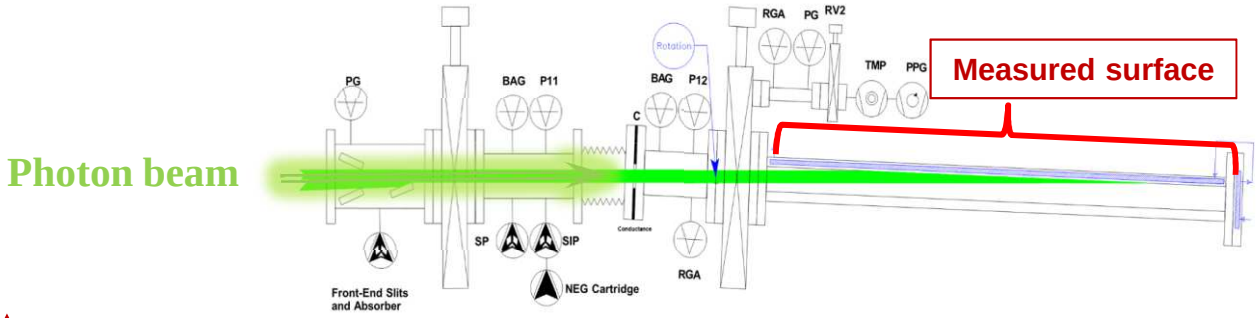
η – desorption yield

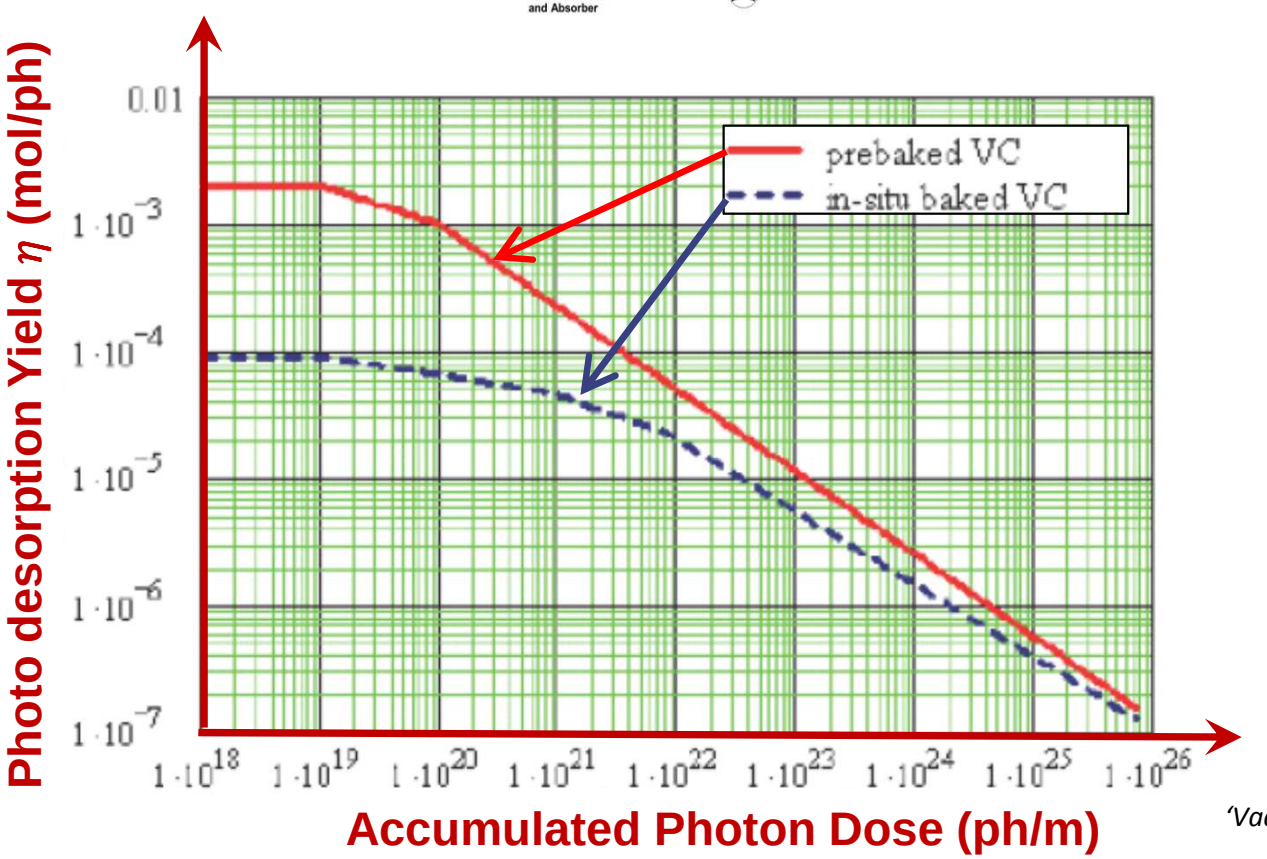
Knowing the gas load (outgassing) due to PSD (Q_{PSD}), thermal outgasing ($Q_{thermal}$) and the target pressure (P) the effective pumping speed S_{eff} can be calculated.

$$S_{eff} = \frac{Q_{PSD} + Q_{thermal}}{P}$$

Photon Stimulated Desorption

Evaluating Photon Stimulated Desorption (PSD):





PSD yield effect of the dose:

$$\eta = \eta_0 D^{-\alpha}$$

α is between 0.6 and ~1

'Vacuum aspects of synchrotron light sources', R. Reid, Vacuum in Accelerators, CAS 2006 proceedings

Vacuum scrubbing

Dynamic pressure is proportional to current:

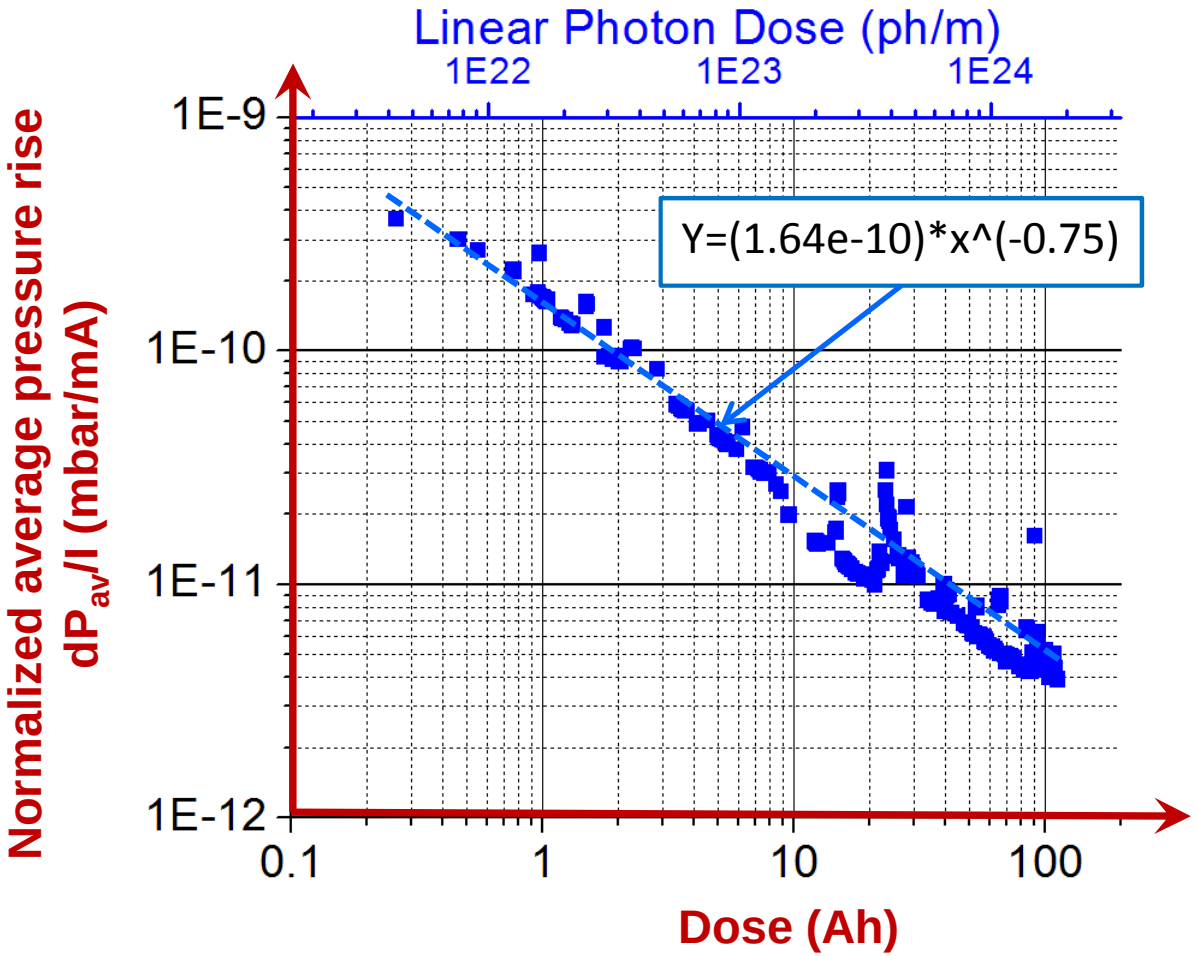
$$P \propto I$$

Dynamic pressure rise:

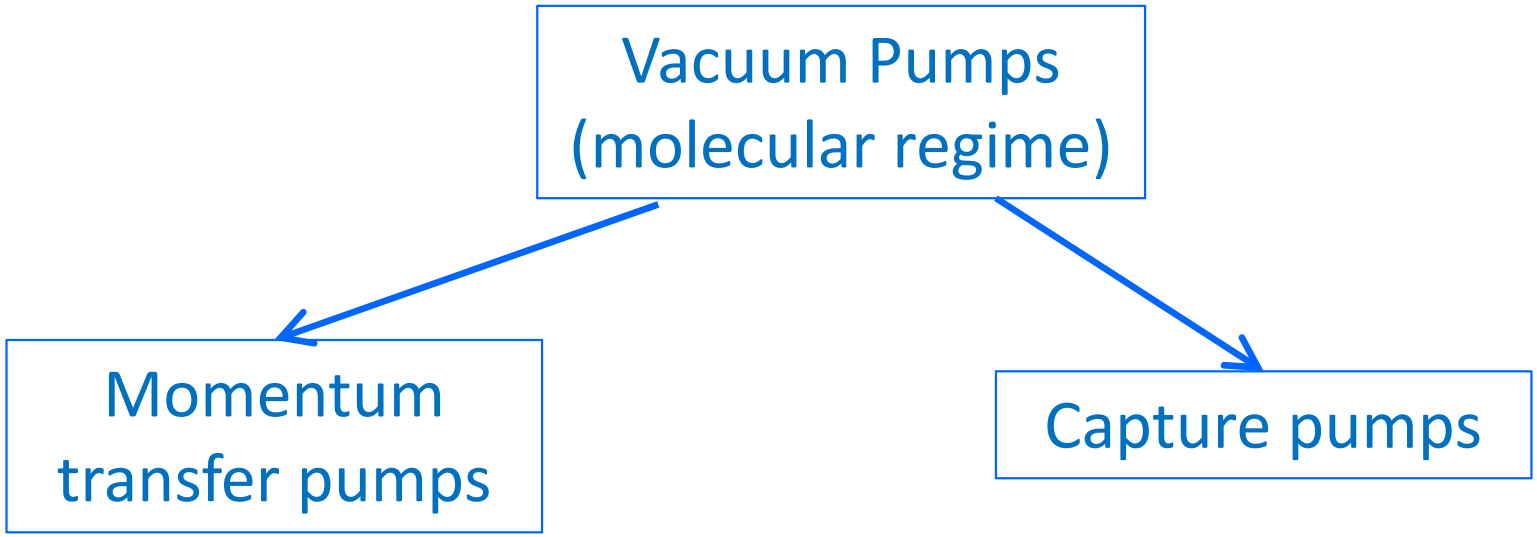
$$\frac{\Delta P}{I}$$

Vacuum conditioning:

Average pressure normalized to machine current vs accumulated beam dose (or photon dose)



Pump clasification



Example: Turbomolecular Pump

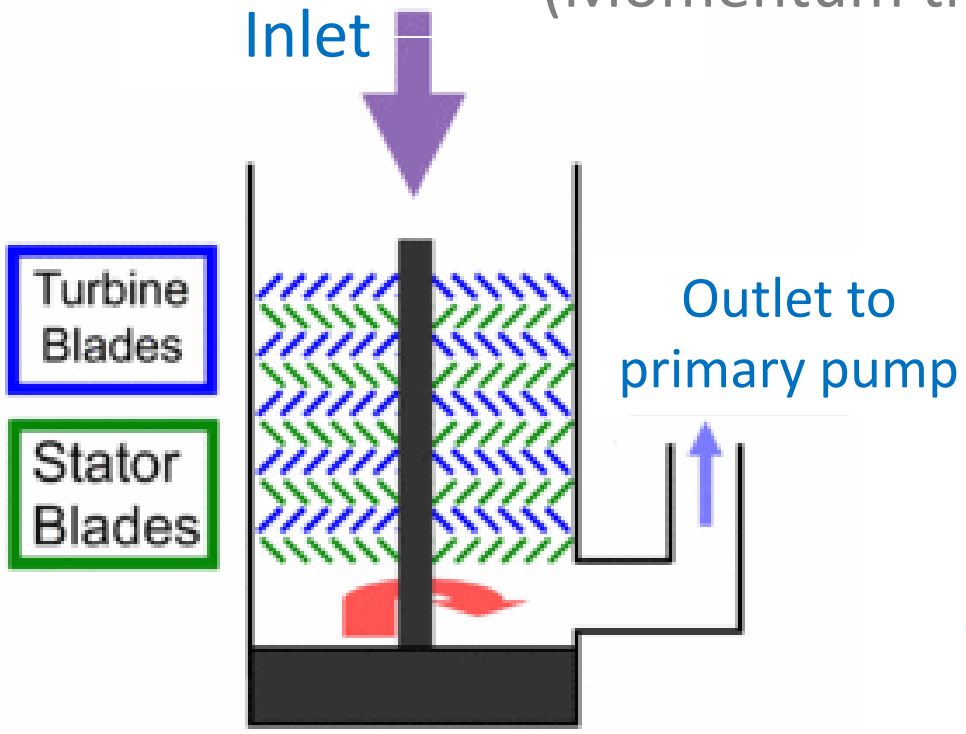
Principle: Molecules impinge on fast moving surfaces which direct them towards the pump outlet where they are evacuated by pumps operating in viscous flow. The molecules do not transfer energy to each other.

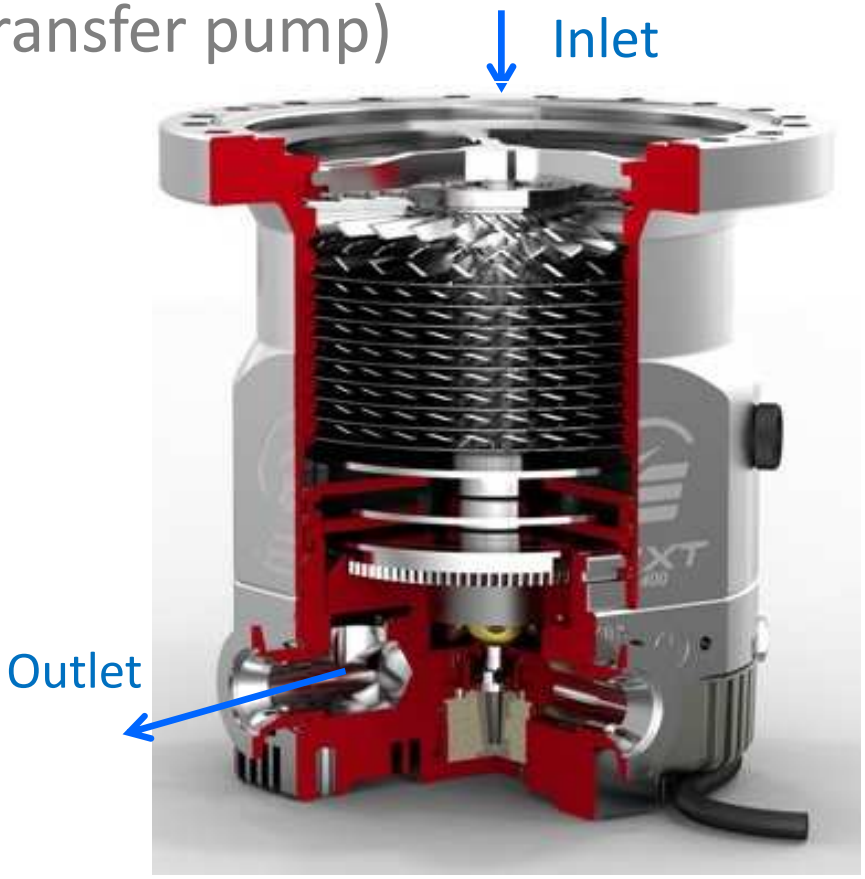
Example: Sputter Ion Pump, Getter pump, Cryo pump

Principle: gas molecules are fixed to a surface inside vacuum (pump has no moving parts).

Turbomolecular Pump

(Momentum transfer pump)





Blade rotational speed 1000 – 1500 Hz

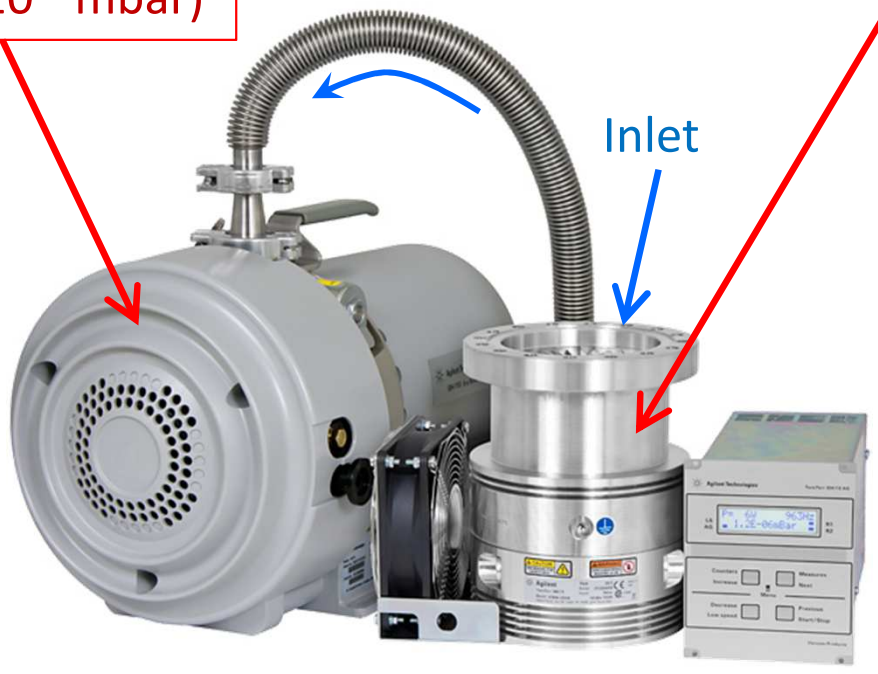
Pressure range: 10^{-1} till 10^{-10} mbar,
(with backing pump connected in series).
Usual operational pressure < 10^{-5} mbar.

S (pumping speed) does not depend significantly on the mass of the molecule.

K_o = $\frac{P_{outlet}}{P_{inlet}}$ (compression ratio) depends exponentially on the wall speed and square root of the gas molecule mass.

'Fundamentals of vacuum technology' (Leybold)

Turbomolecular Pump



Turbo molecular and roughing pump connected in series: from 1 bar (atmospheric pressure) until ~10^{-10} mbar

Turbomolecular pumping speeds: 10 l/s - 25,000 l/s.

Turbomolecular pumps are widely used in particle accelerators for:

- evacuating vacuum systems from atmospheric to ultra high vacuum,
- Testing (leak tests),
- Conditioning (bakeouts),
- High gas loads,
- For accelerator operation with beam capture pumps take over,

Usually they are not permanent part of the vacuum system (attached when needed).

'Fundamentals of vacuum technology' (Leybold)

Capture pumps: getters

Getter materials adsorb gas molecules on their surface which is contamination and native oxide layer free. Such surface can be produced in two ways:

- sublimating the reactive meta *in situ:* evaporable getters or sublimation pumps,
- dissolving the surface contamination into the bulk of the getter material by heating: non-evaporable getters (NEG); the dissolution process is called activation.

Getter surface is characterized by the sticking probability 'α':

$$\alpha = \frac{number\ of\ molecules\ captured}{number\ of\ molecules\ impinging}$$

Getter pumping speed (S):

$$S = \alpha\, A_{\text{getter}}\, C'$$

Where:

A_{getter} surface area of active getter surface,
C' conductance for given gas of unit surface area.

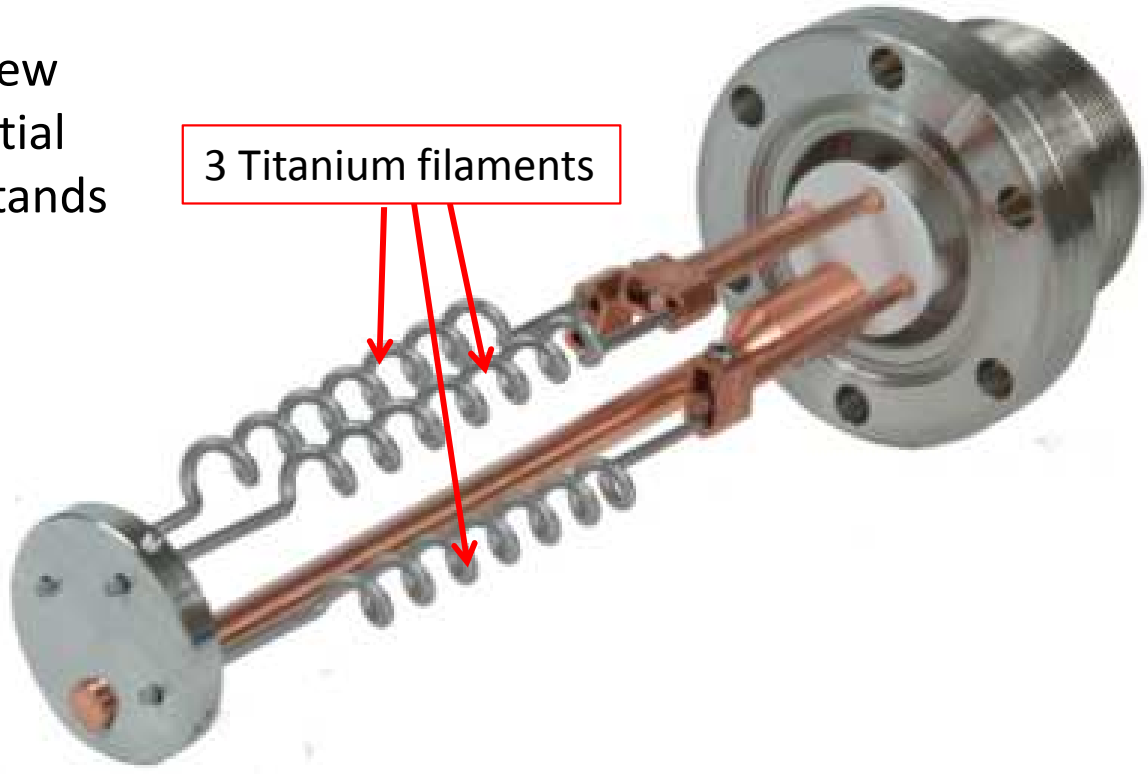
Getter materials do not pump noble gases and methane (CH_4) at room temperature. Therefore, they need auxiliary pumping to keep a stable pressure.

Evaporable Getters

Evaporable getters: TSP – Titanium Sublimation Pump

Ti is the **sublimated** metal. Ti filaments are heated up to 1500°C reaching Ti vapour pressure which is deposited on the surrounding surfaces creating a chemically active surface where gas molecules are captured.

When the deposited film is saturated, new sublimation is needed to recover the initial pumping speed. A single filament withstands hundreds of sublimation cycles



Sticking probablities:

H_2: $0.01 \leq \alpha \leq 0.1$

CO: $0.5 \leq \alpha \leq 1$

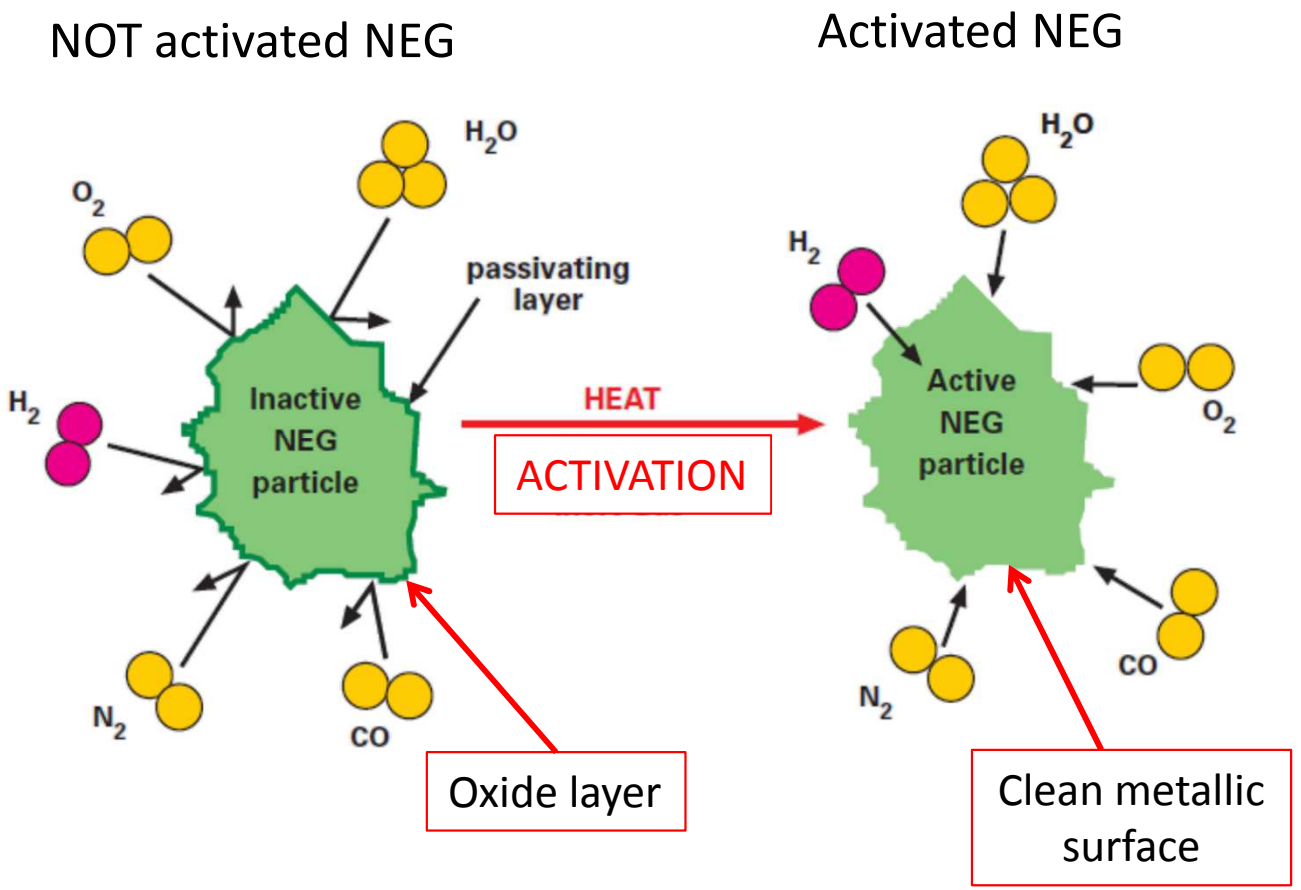
Film capacity:

- For CO, one monolayer adsorbed,
- For of O_2 several monolayers,
- For N_2 fraction of monolayer

Hydrogen diffuses in the Ti film → much higher capacity

Non-Evaporable Getters (NEG)

NEG activation:



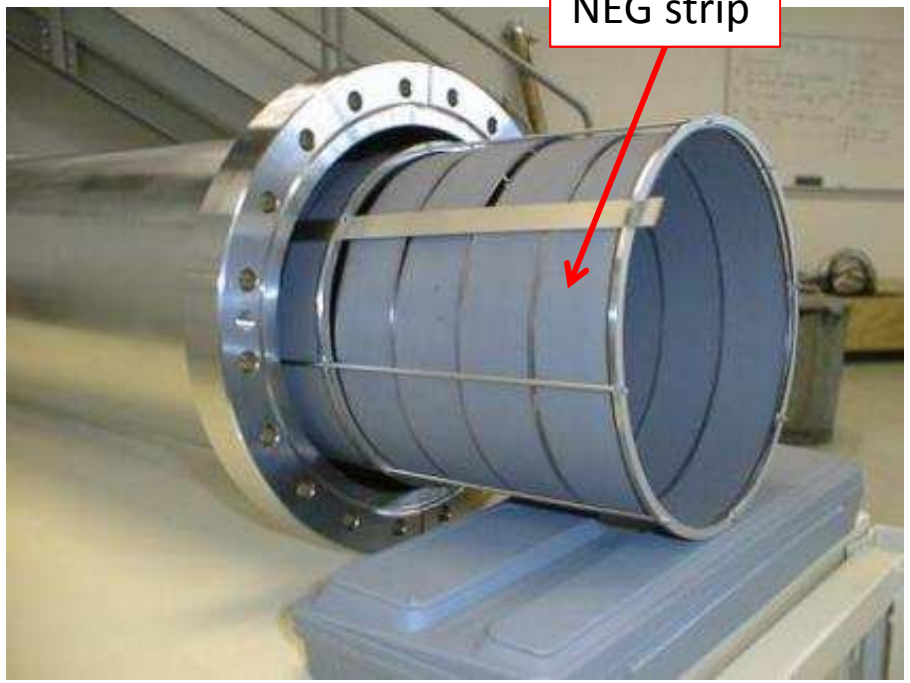
Courtesy of SAES getters

On activation the oxide layer at the surface of NEG is diffused to the bulk of the material creating clean, chemically active surface where gas molecules are captured.

Non-Evaporable Getters (NEG)

NEG materials are produced industrially by powder technology. The powder is sintered to form discs or strips.

A typical alloy produced by SAES Getter is **St707 made of Zr (70%), V (25%), Fe (5%)**.



SAES getters

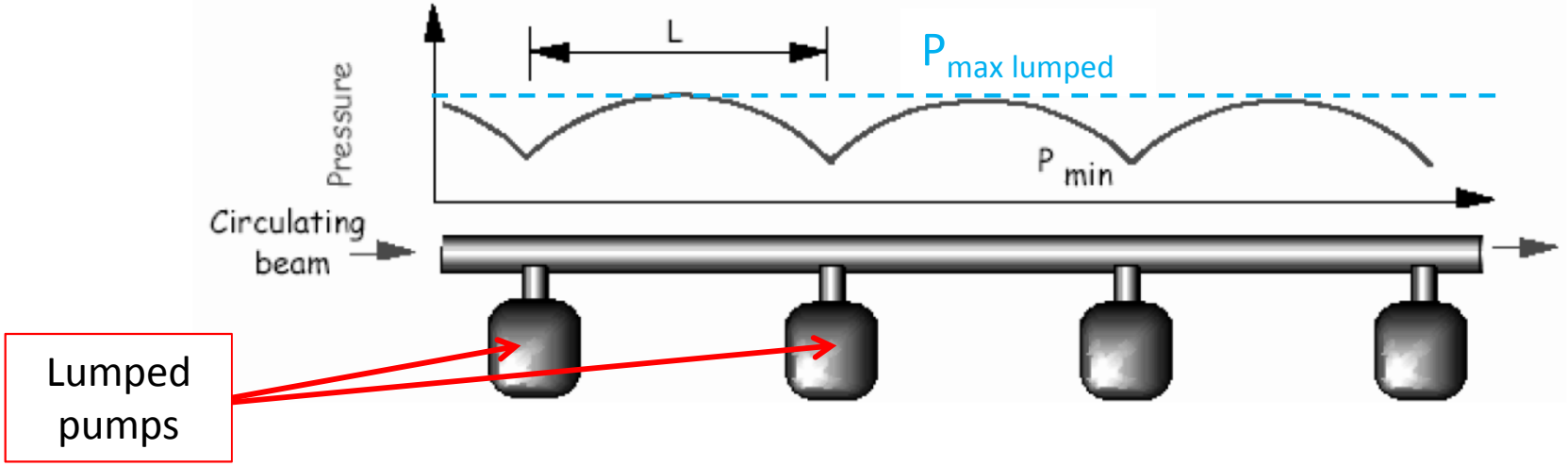
Paolo Chiggiato, Vacuum Technology for particle accelerators, 2013

Full pumping speed is obtained after heating at 450°C for 45' or 350°C for 24h

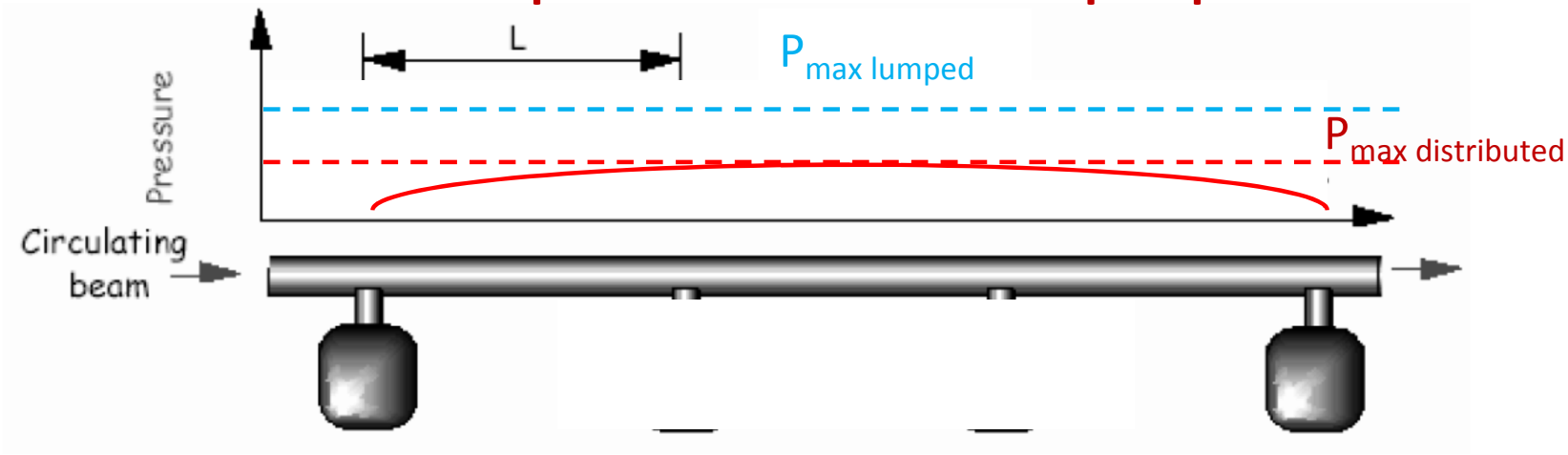
The **high porosity of NEG materials** allows pumping of relatively high quantities of gas without reactivation.

Distributed pumping

Pressure profile with lumped pumps



Pressure profile with distributed pumps

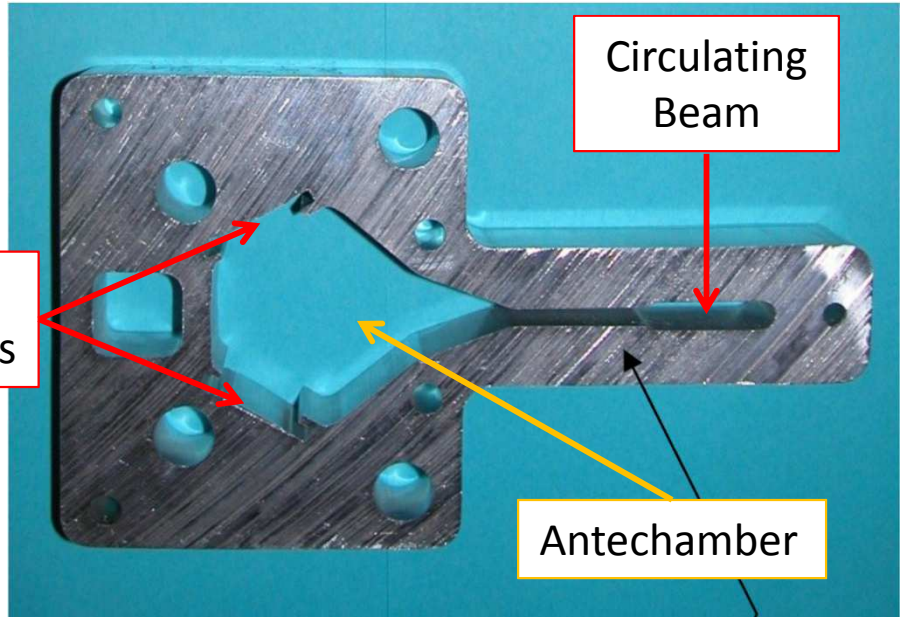


F. Mazzolini, 'The use of NEG pumps and coatings in large vacuum systems: experience and limitations', CAS 2006 Vacuum in accelerators

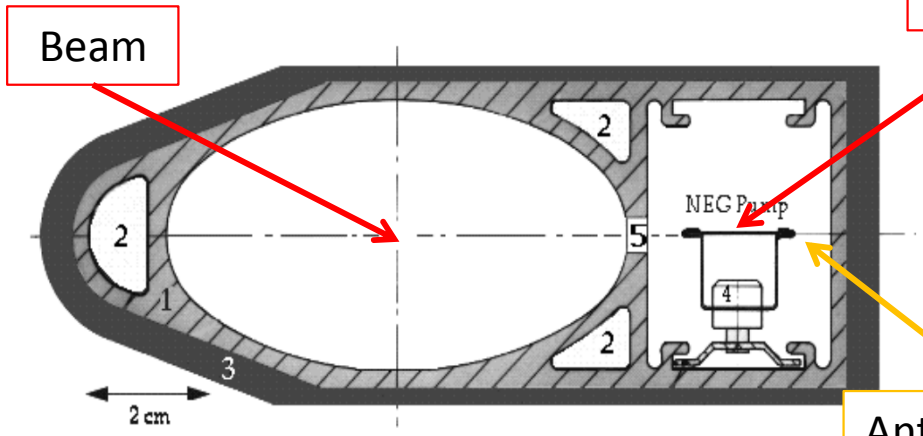
Distributed pumping

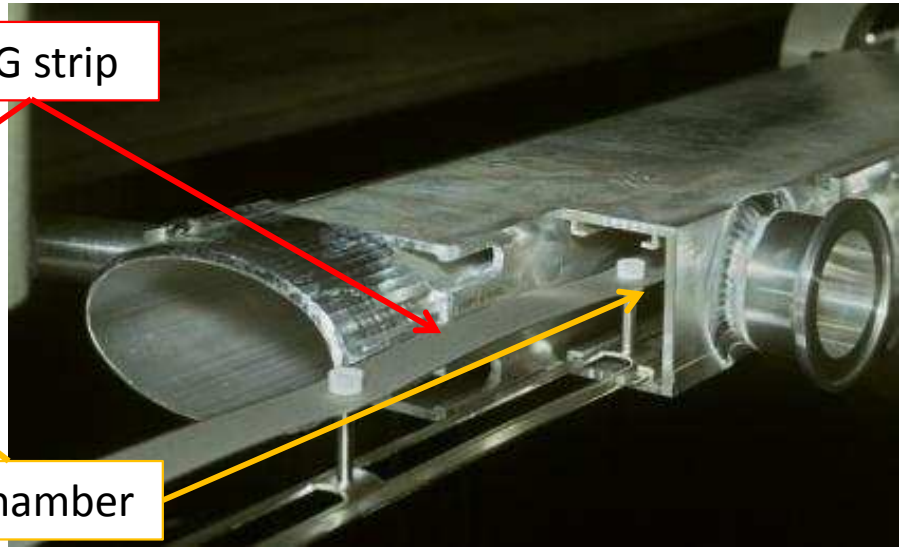
Distrubuted pumping can be obtained by installing NEG strips (antechamber needed)

Cross section of Advanced Photon Source chamber



LEP dipole vacuum chamber (first application of NEG strip for distributed pumping)

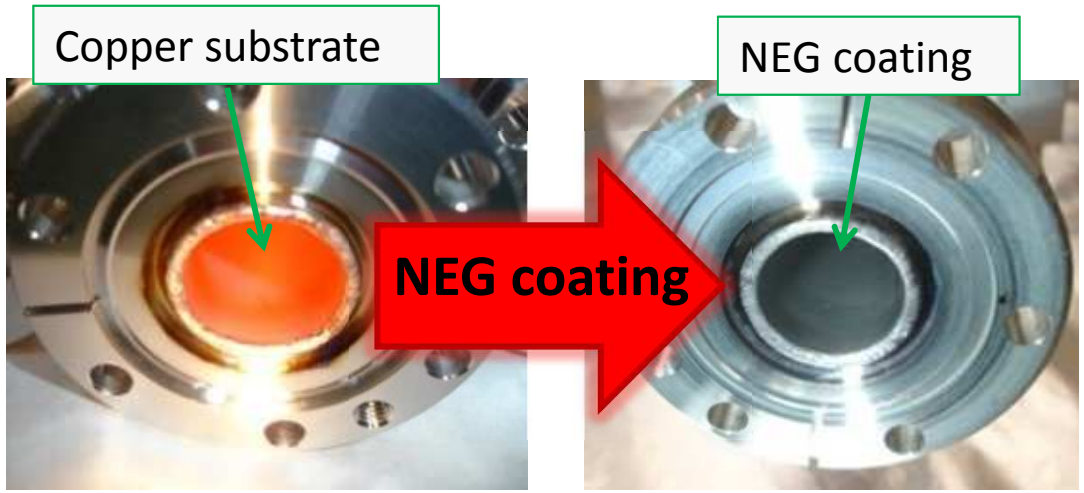




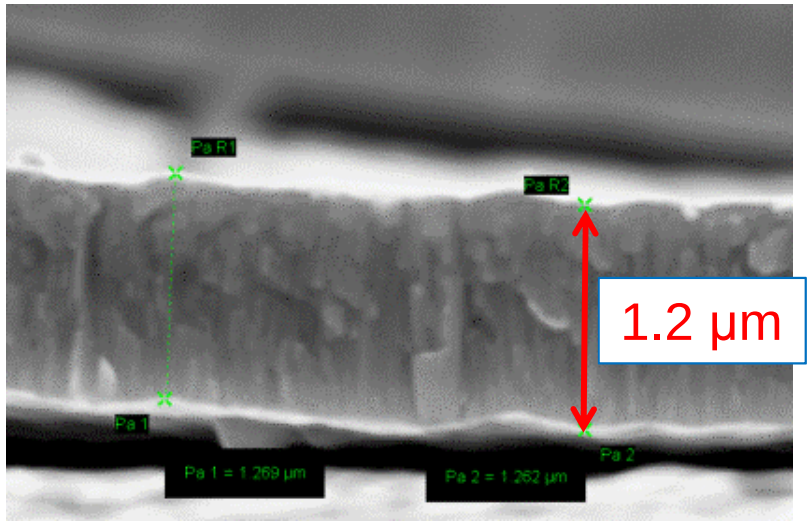
Emil Trakhtenberg et al., Extruded Aluminum Vacuum Chambers for Insertion Devices,

NEG coatings

NEG-coating transforms a vacuum chamber from a gas source to a vacuum pump.



The technology of coating vacuum chambers by magnetron sputtering was developed at CERN for the warm sections of LHC. Nowadays it is also widely applied in synchrotron radiation sources.



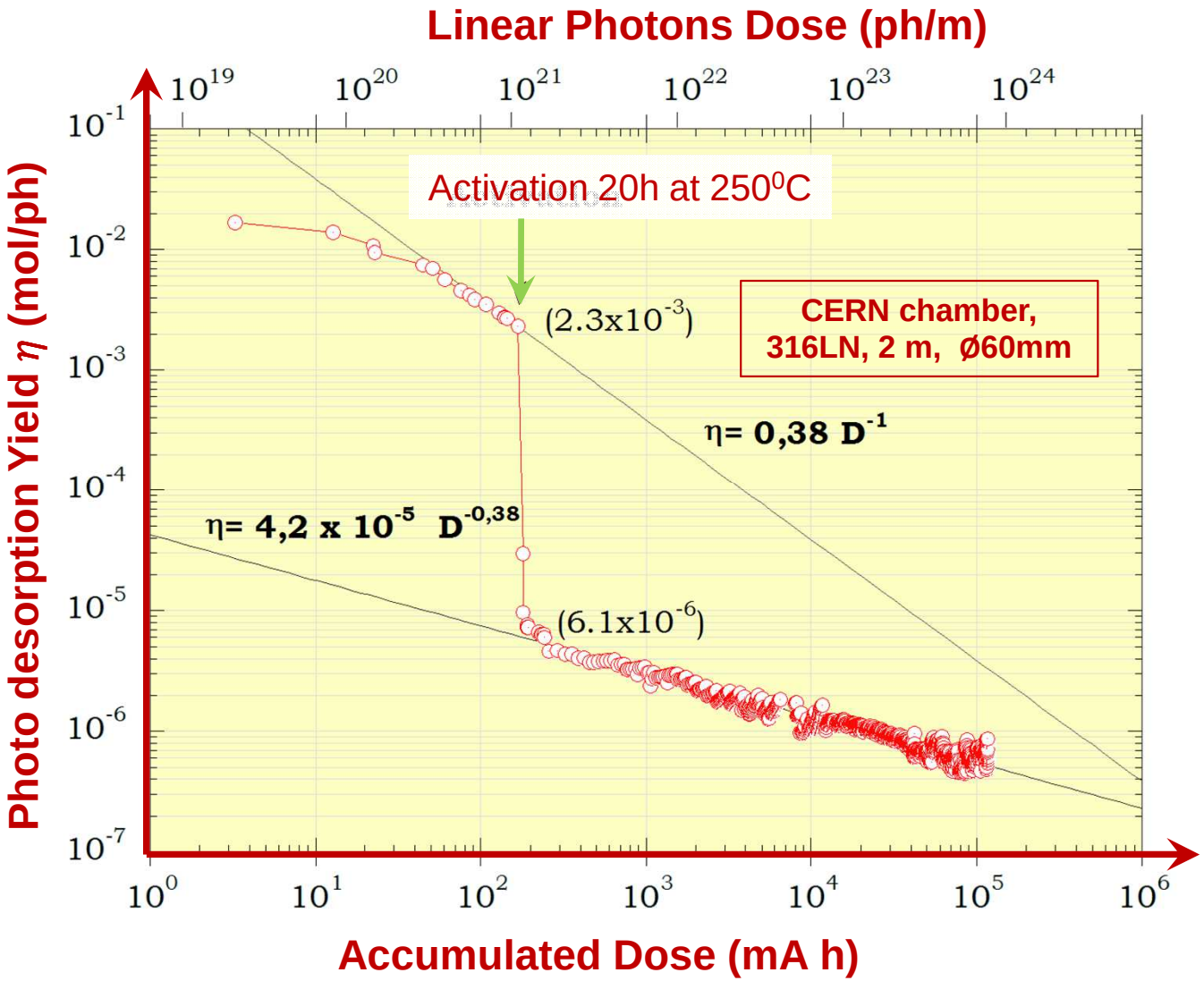
NEG film characteristics:

- Film composition: Ti (30%), Zr (40%), V (30%).
- Thickness ~1 um,
- Activation temperature 200^0C for 24 h,
- Low PSD (Photon stimulated desorption),
- Sticking probability similar to TSP.

Disadvantage of NEG: has limited capacity and activation cycles.

NEG coatings

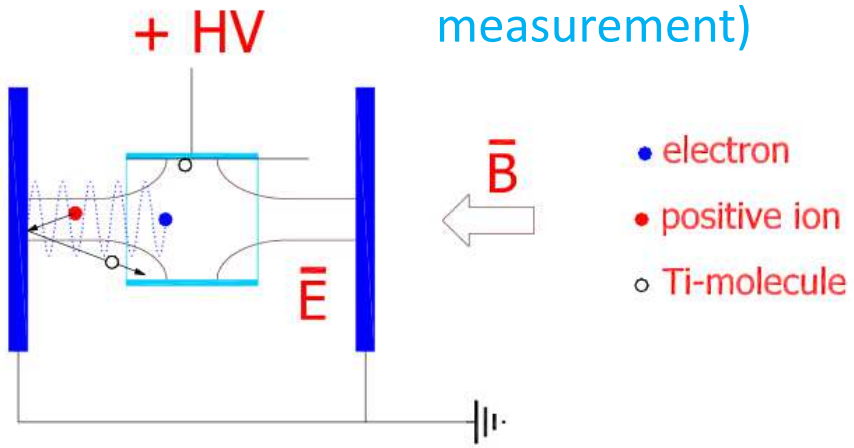
Photon stimulated desorption (PSD) measurements at ESRF (beamline D31).



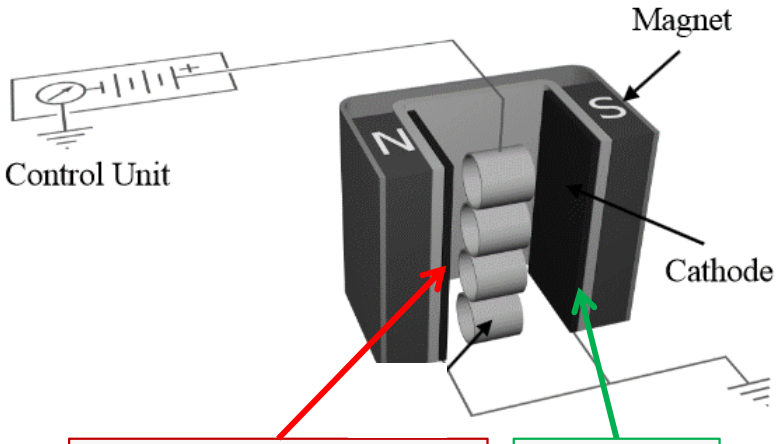
'Synchrotron Radiation-Induced Desorption from a NEG-Coated Vacuum Chamber', P. Chiggiato, R. Kersevan

Sputter ion pumps

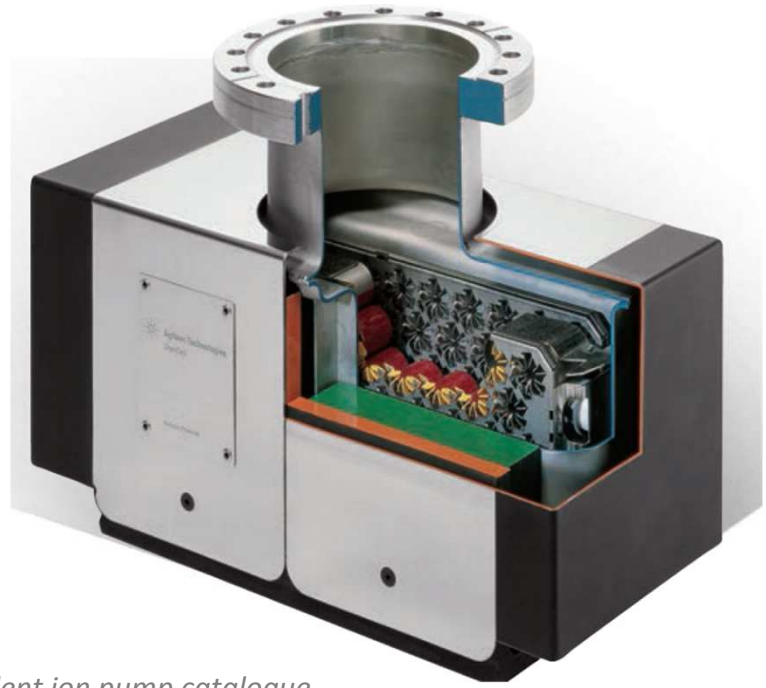
Penning cell (also used for pressure measurement)



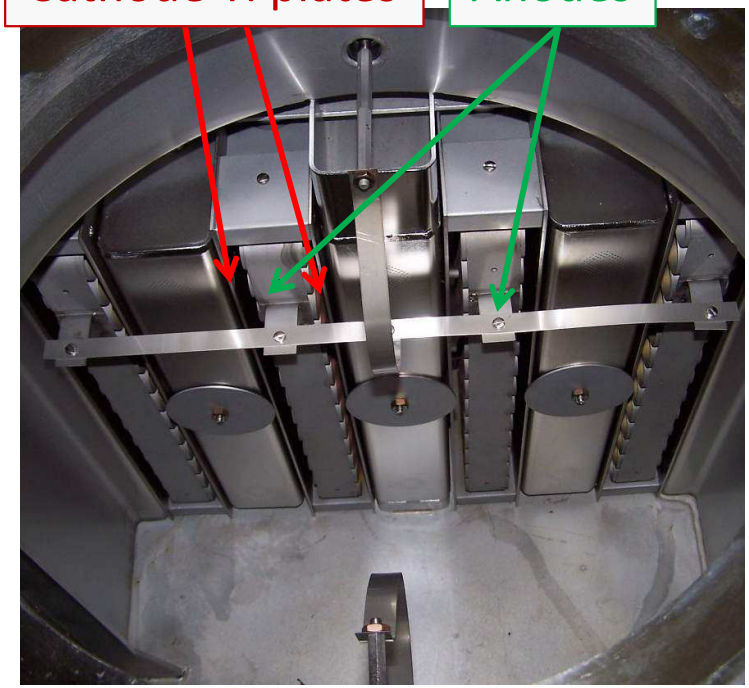
Sputter ion pump



- Voltage 3 to 7 kV,
- Cathodes are plates of Ti at ground potential,
- Magnetic field generated by external permanent magnets ~0.1 T.



Agilent ion pump catalogue

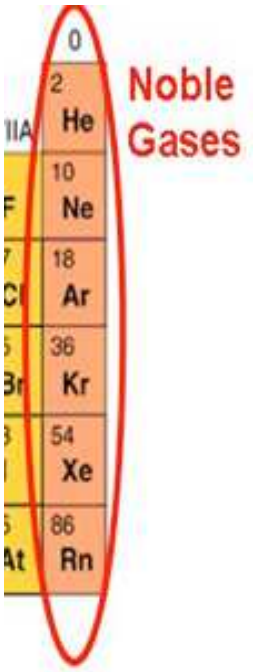


L. Schulz, Sputter ion pumps, CAS 1999 proceedings

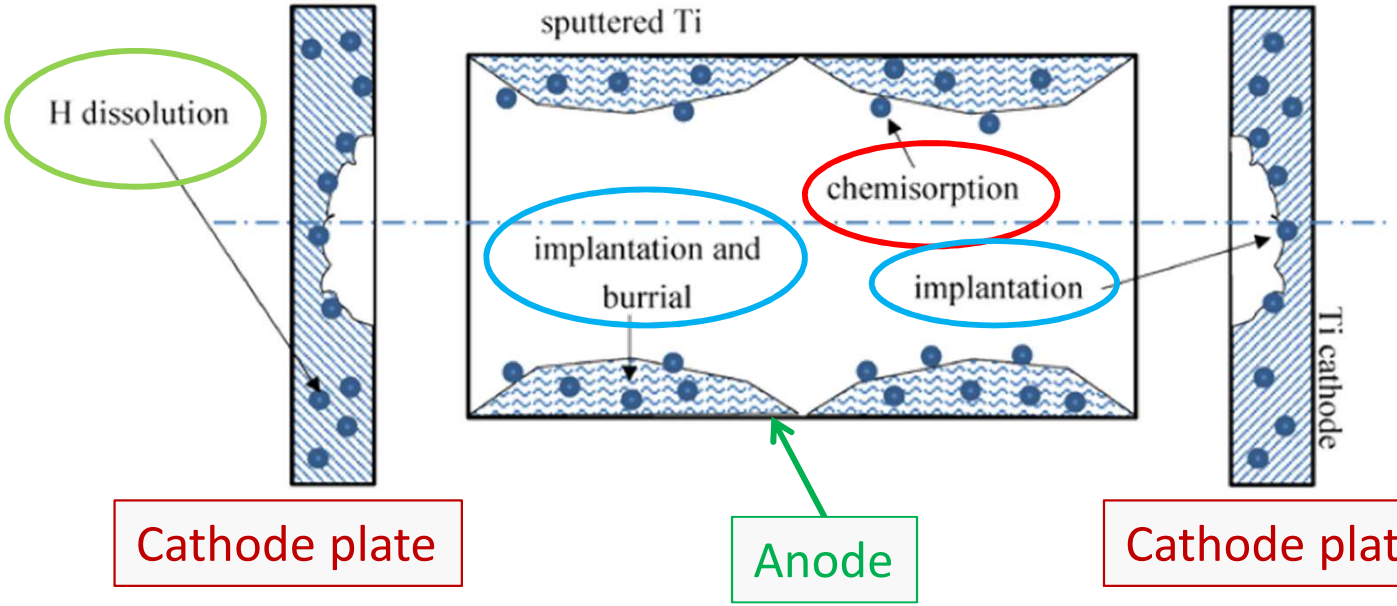
Sputter ion pumps

Sputter ion pumps pumping mechanisms:

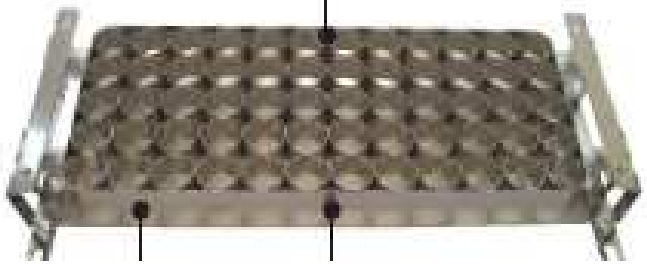
- **Chemical adsorption onto the reactive metal layer (Ti) deposited on anode** and subsequent burial by additional metallic atoms of gas molecules: all gases except rare gases,
- **Implantation of gas ions in the cathode** (not permanent), and of energetic neutrals bounced back from the cathode in **the deposited film**: only mechanism of pumping for rare (noble) gases,
- **Diffusion** into the cathode and the deposited film: only H_2



Diode configuration (cell cross-section)



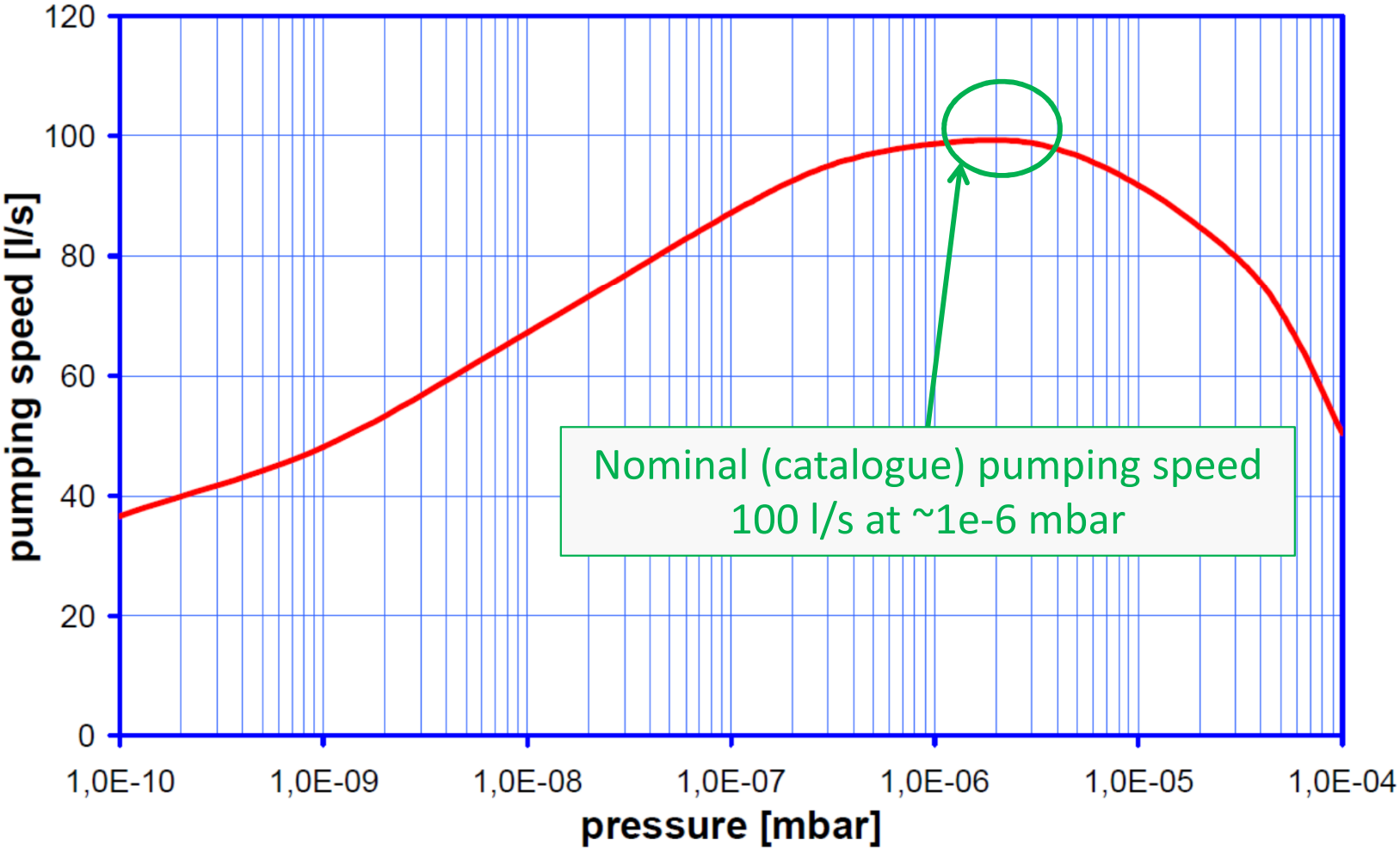
Anode assembly



Paolo Chiggiato, Vacuum Technology for Ion Sources, CAS 2012 proceedings

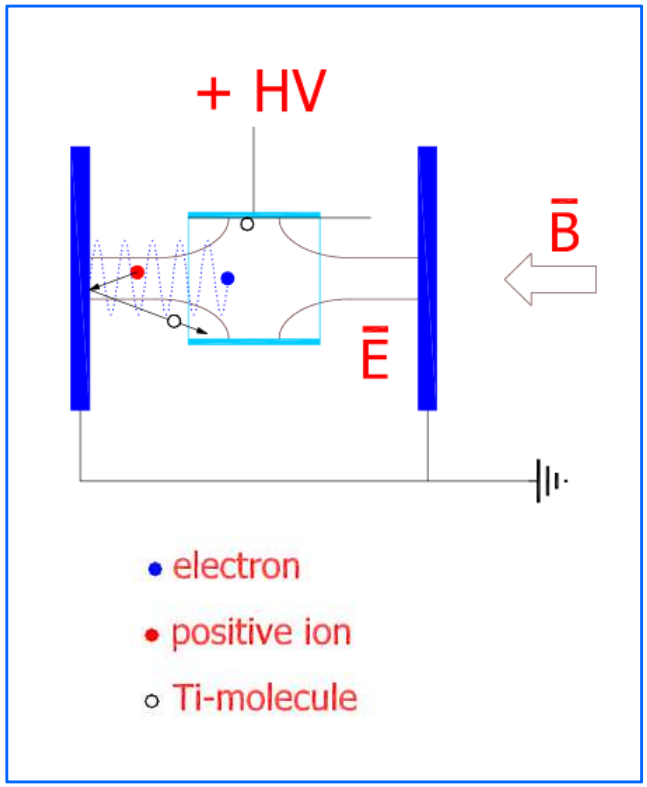
Sputter ion pumps

Effective pumping speed:
Pumping speed vs pressure
for a diode ion pump with nominal pumping speed 100 l/s (for air after saturation)

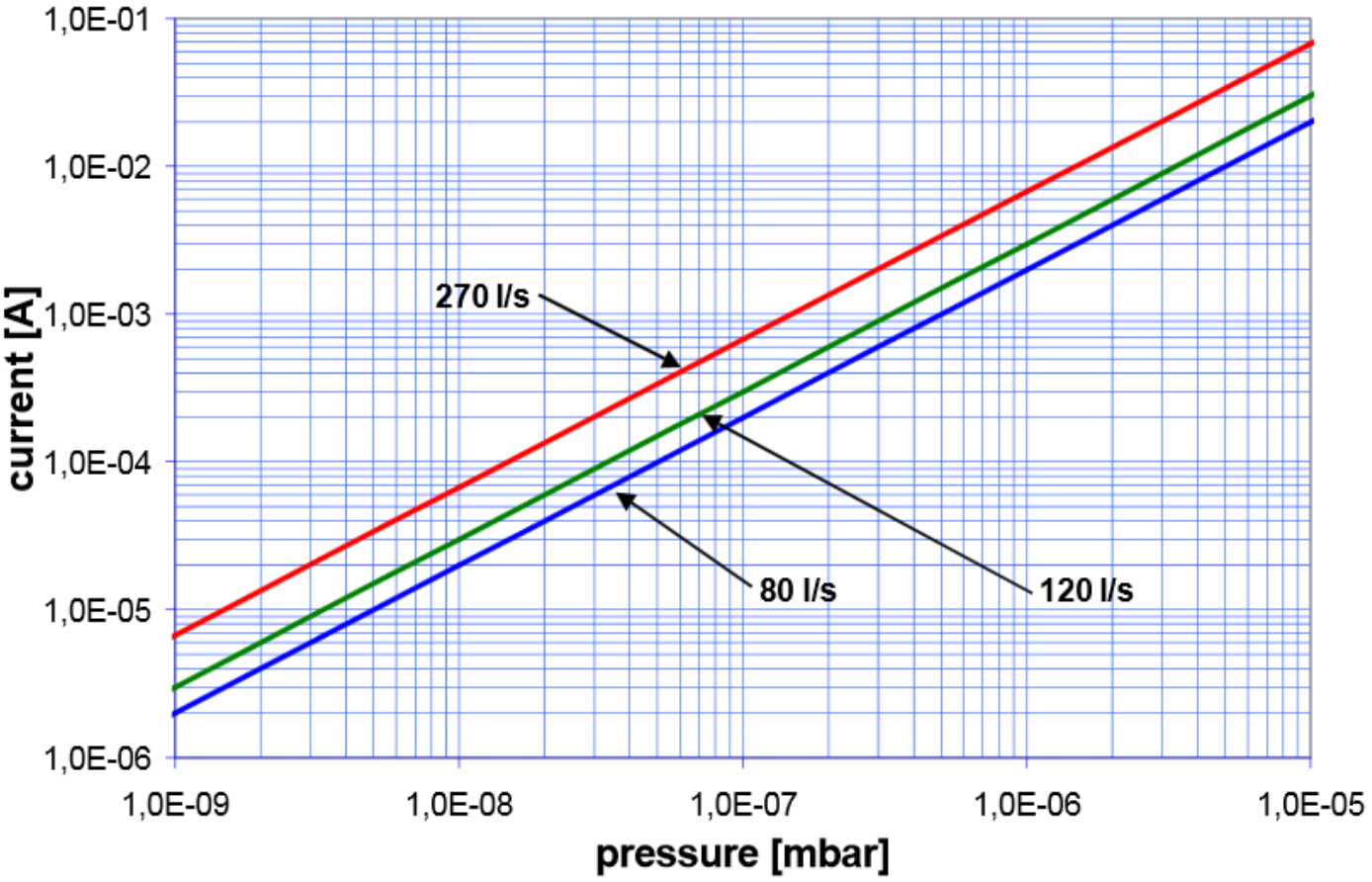


L. Schulz, Sputter ion pumps, CAS 1999 proceedings

Sputter ion pumps



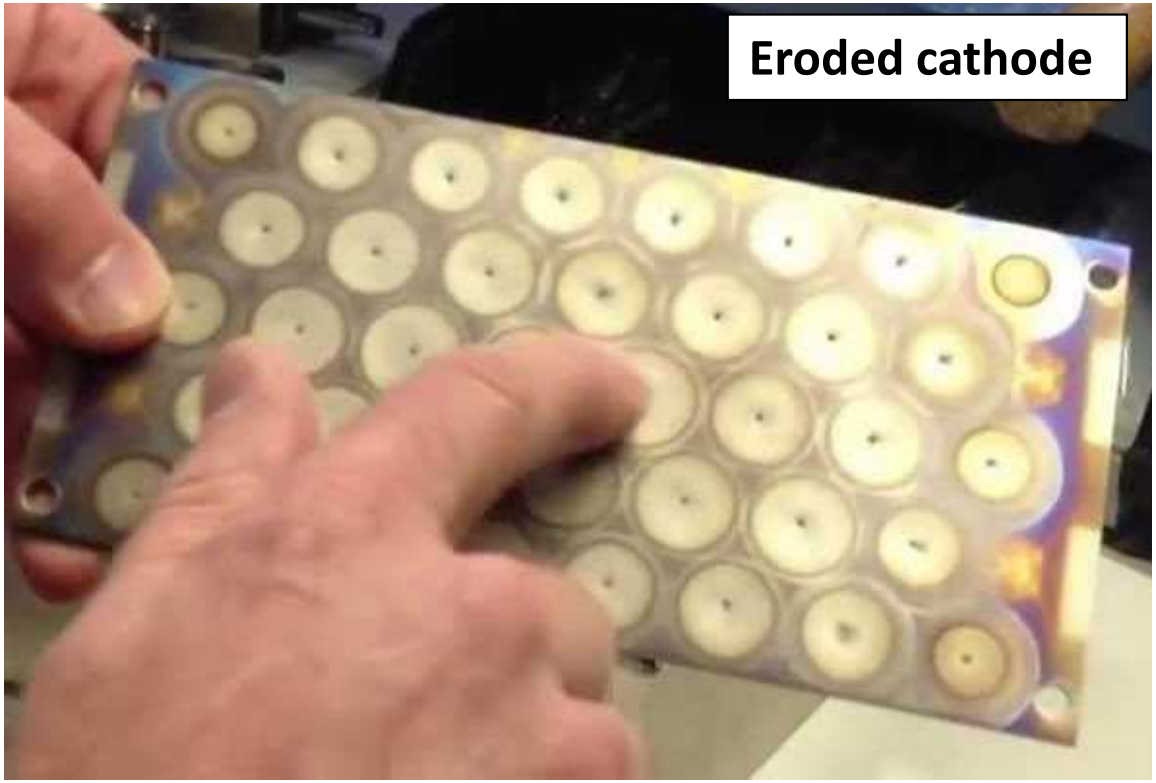
Pressure measurement:
Ion pump current vs pressure



Pressure measurement: Ion pumps can be used for pressure measurement up to 10^{-10} mbar if the voltage is reduced to 3 kV. The current is proportional to pressure.

L. Schulz, Sputter ion pumps, CAS 1999 proceedings

Sputter ion pumps



Lifetime: cathode is sputtered away (eroded) by impacting ions. If operating at high pressures (10^{-4} mbar) the pump lifetime is 400 h whereas at 10^{-6} it is 40000 h (4.5 year).

Sputter ion pumps

Agilent ion pump catalogue

Wide variety of ion pumps to choose:

- **Electrode material and configuration: Diode, noble diode, triode,**
- **Pumping speeds: from 0.2 l/s (weight 0.6 kg) till 500 l/s and more (260 kg)**

S = 500 l/s, 260 kg

S = 0.2 l/s, 0.6 kg

Nominal pumping speed normalized to that of air for diode and triode ion pump:

Gas	Air	N_2	O_2	H_2	CO	CO_2	H_2O	CH_4	Ar	He
Diode	1	1	1	1.5-2	0.9	0.9	0.8	0.6-1	0.03	0.1
Triode	1	1	1	1.5-2	0.9	0.9	0.8	0.6-1	0.25	0.3

Advantages of ion pumps: clean, bakeable, vibration free (no moving parts), continuous operation, wide operating range 10^{-4} to 10^{-11} mbar, low power consumption, long lifetime at low pressure.

Paolo Chiggiato, Vacuum Technology for Ion Sources, CAS 2012 proceedings

Pressure profile simulation

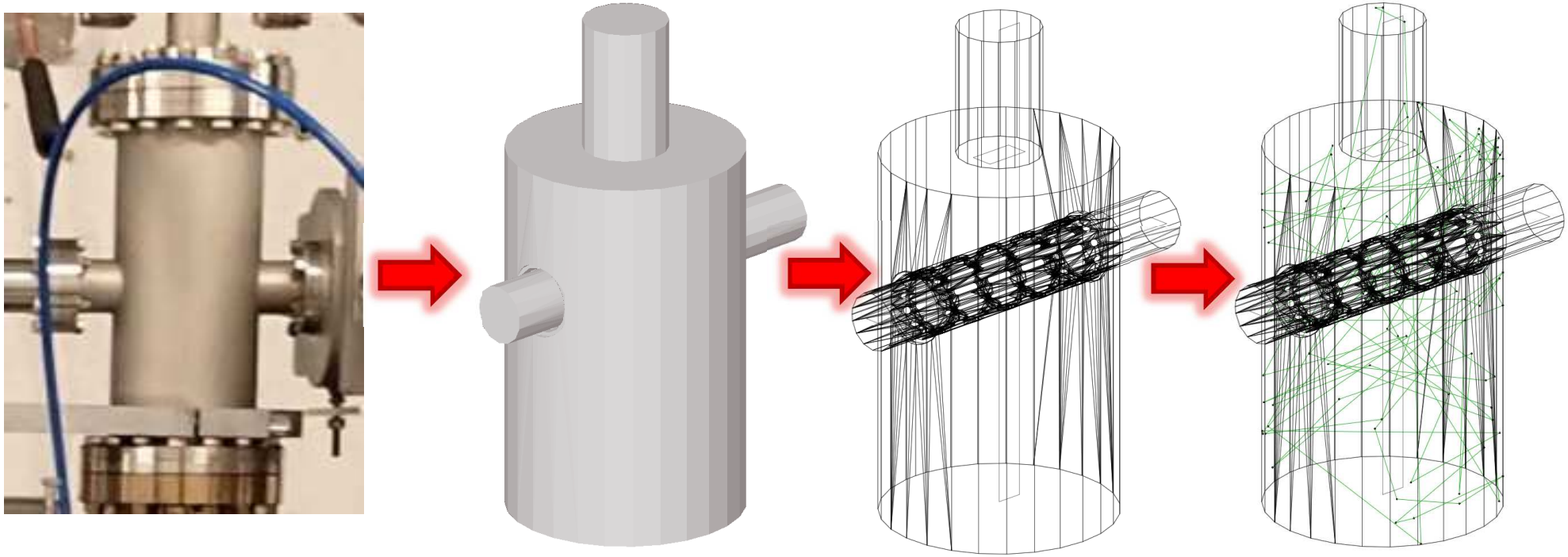
To ensure that the pressure distribution in an accelerator is satisfactory, the pressure profile must be evaluated. For this purpose simulations programs based on test particle Monte-Carlo are widely used (eg.: Molflow+).

Component

CAD model of surfaces exposed to vacuum Imported to Molfow+

Boundary conditions defined

Simulation



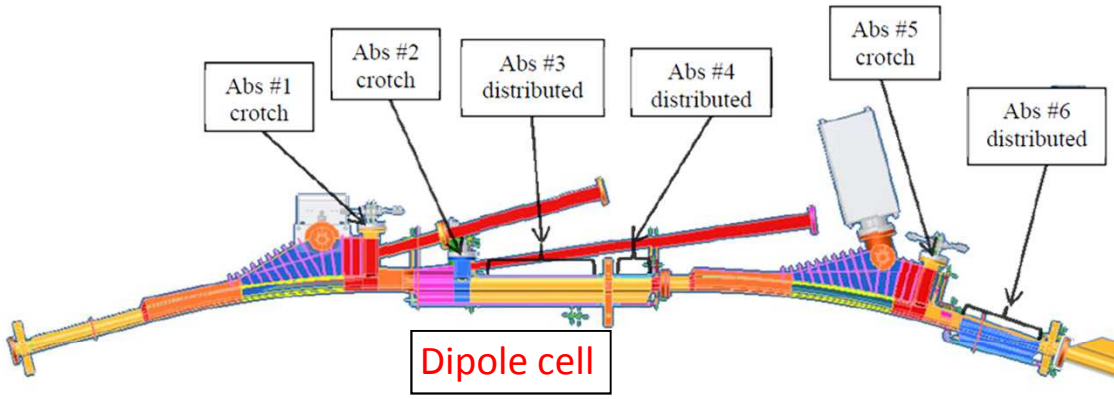
Set: desorption, pumping surfaces (sticking probability), opacity.

Particle trajectories in green.

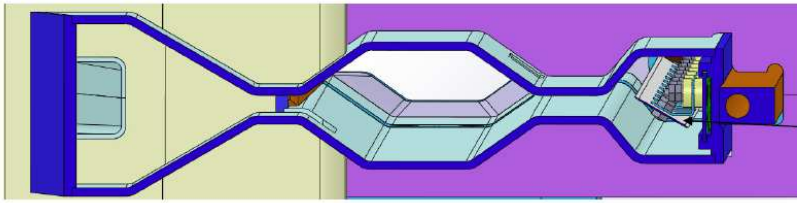
https://test-molflow.web.cern.ch/content/about-molflow

Pressure profile simulation

CAD model with highlighted absorber (Abs) locations:

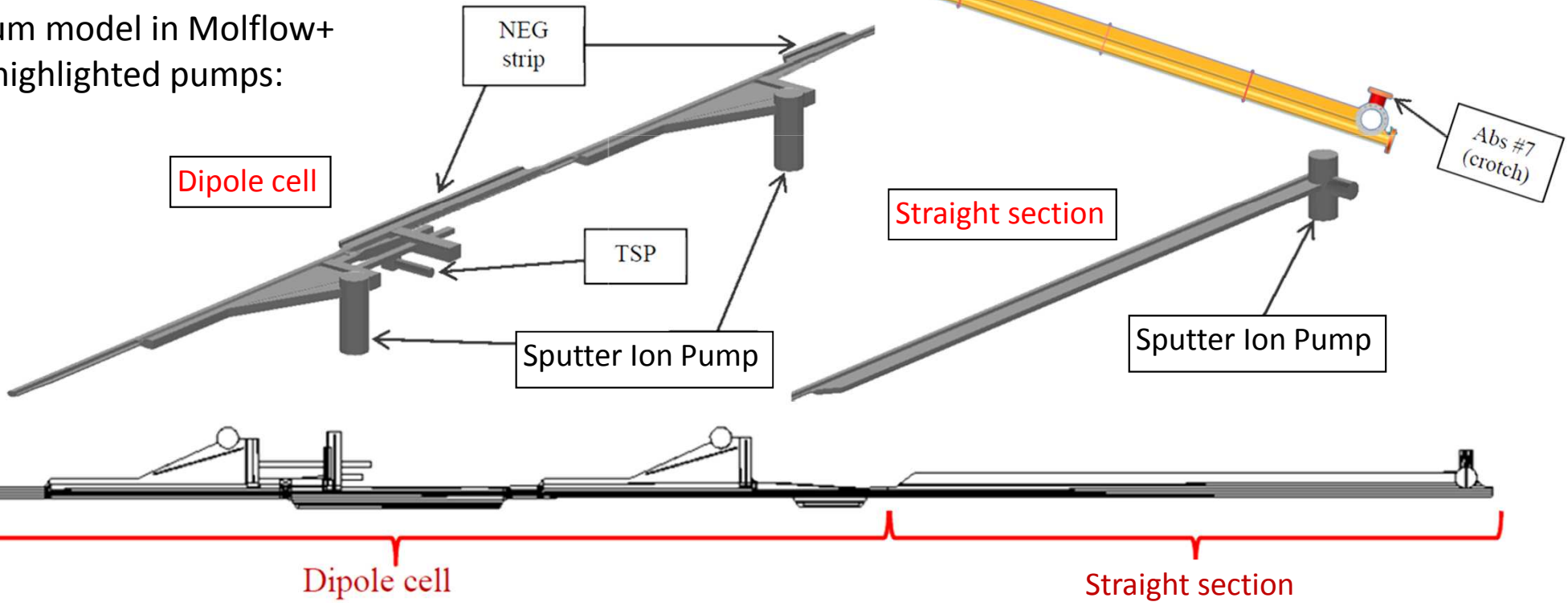


Arbitrary cross-sections can be modelled:

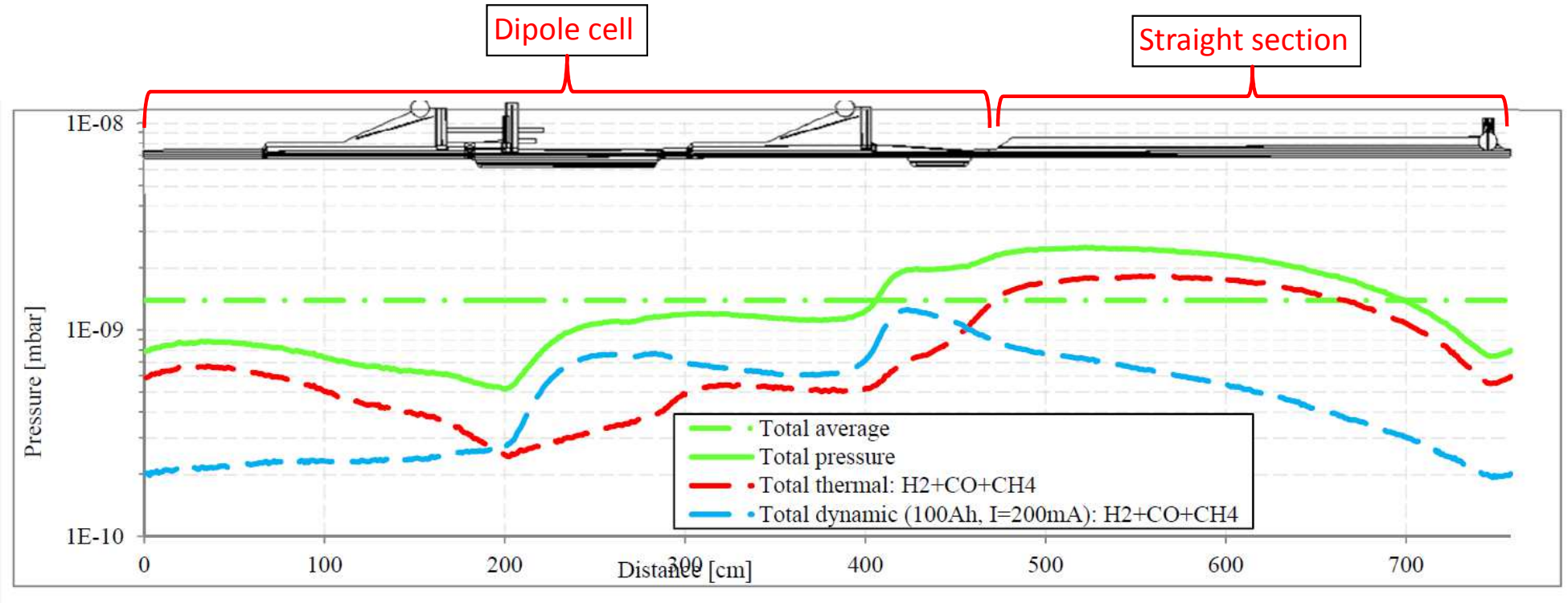


Straight section

Vacuum model in Molflow+ with highlighted pumps:



Pressure profile



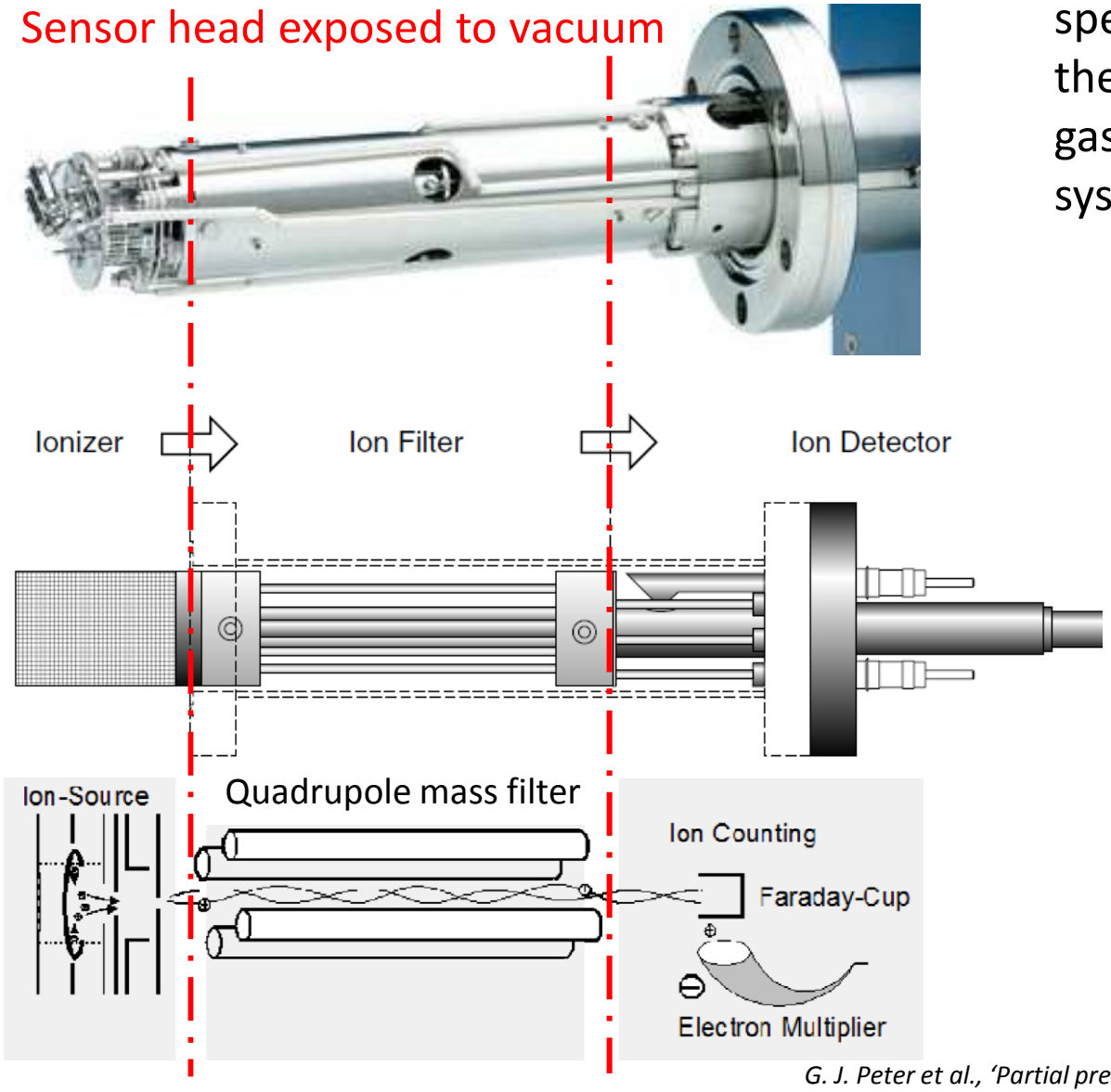
To evaluated static pressure due to thermal outgassing the total surface area is multiplied by the outgassing rate for chosen material.

To calculate dynamic pressure profile due to Photon Stimulated Desorption (PSD):

- **Photon flux** [photons/s] for each surface intercepting the beam (absorbers) is calculated,
- Photon Stimulated Desorption (PSD) **yield** [molecules/photon] for assumed accumulated dose in [Ah] or [photons/m] is estimated from published data:
- Having the **PSD yield** and **photon flux** impinging on each surface, local outgassing [mbar*l/s] can be calculated for each irradiated area that is the input to the simulation.

Partial pressure measurement

Residual gas analyzer assembly



Residual gas analyzer – (mass spectrometers) used to monitor the quality of vacuum i.e. which gas species are present in the system.

Quadrupole mas filter:

- Ions entering the quadrupole field experience potential differences deflecting them from their original trajectory.
- The extent of deflection of ions is related to its mass to charge (m/e or m/z) ratio.
- At each instance only one m/e ratio resonates with the field allowing the ion to pass along its axis.
- All other species are deflected and neutralised by impact on the quadrupole rods.

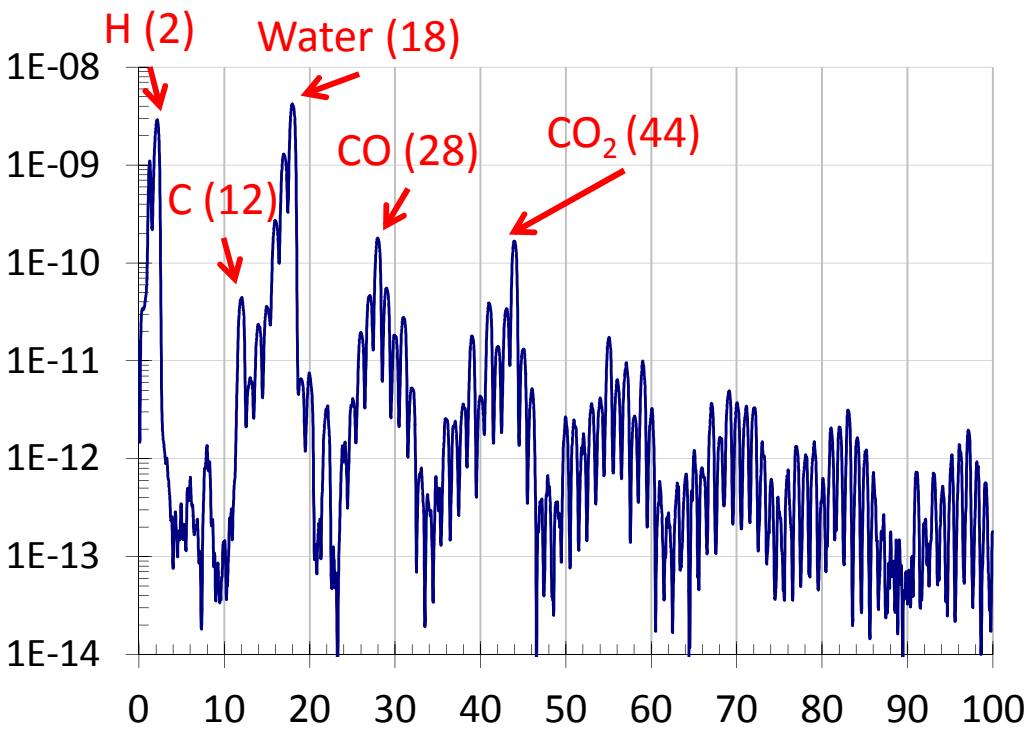
http://www.hidenanalytical.com/

G. J. Peter et al., 'Partial pressure gauges', Vacuum in Accelerators, CAS 2006 proceedings

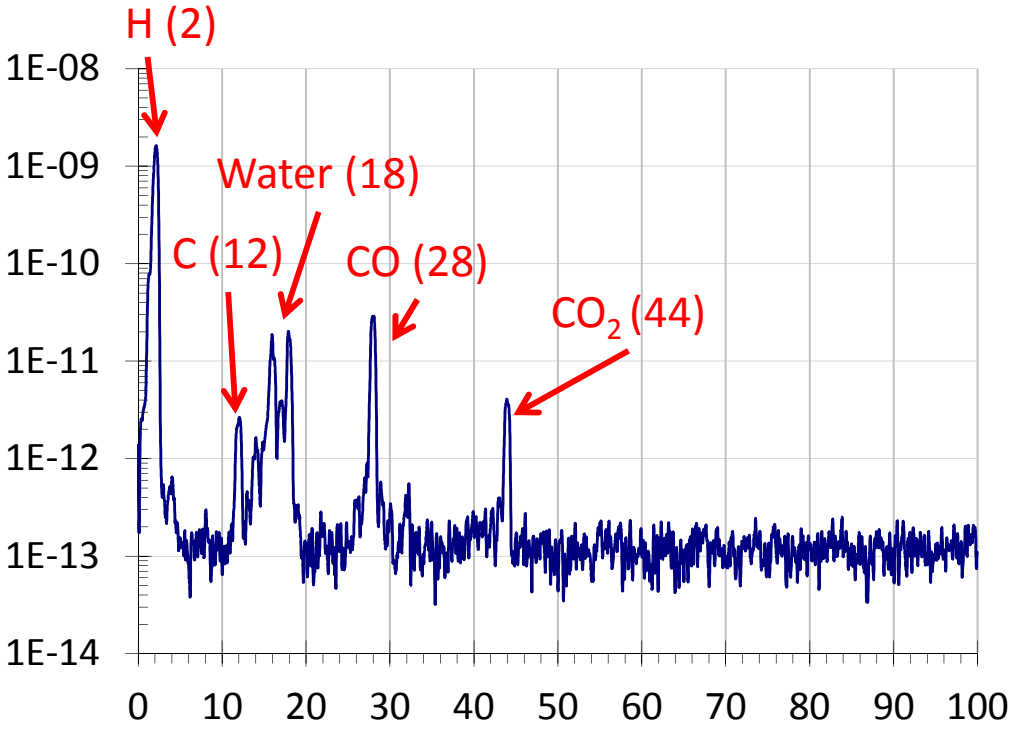
Partial pressure measurement

Residual gas spectrums of an UHV system:

at total pressure 4×10^{-9} mbar

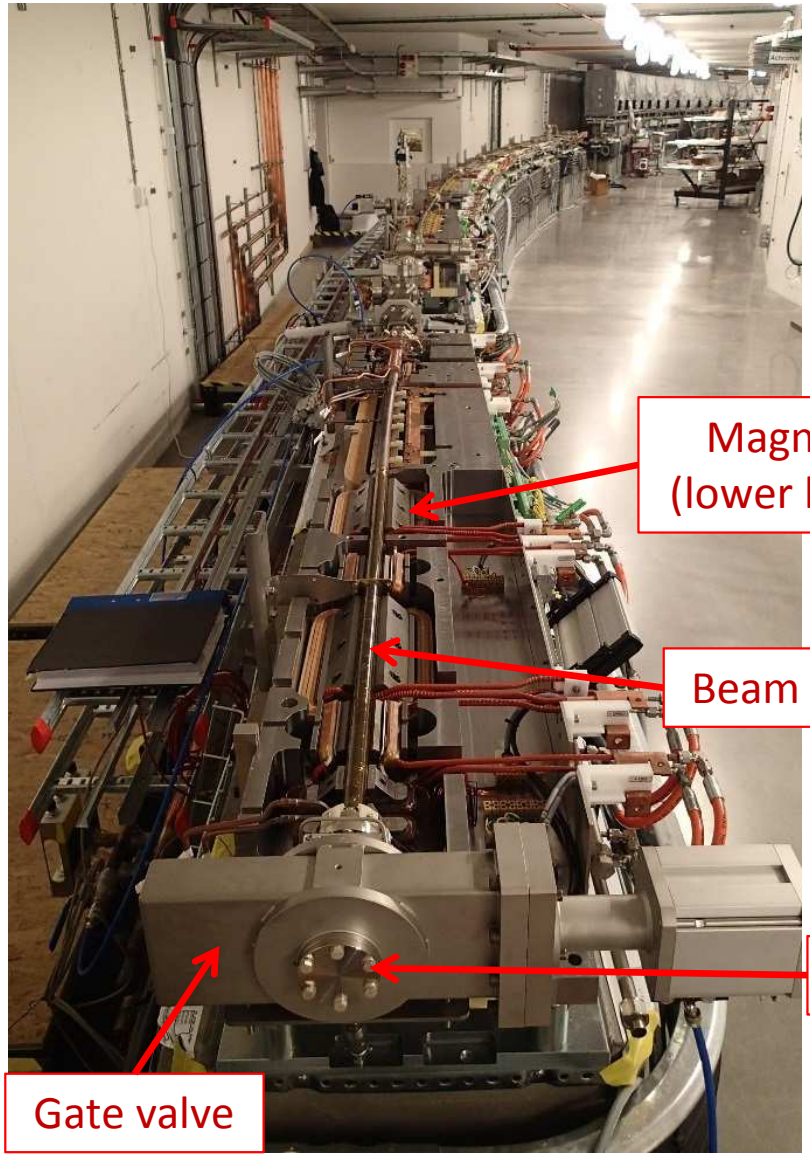


at total pressure 4×10^{-11} mbar

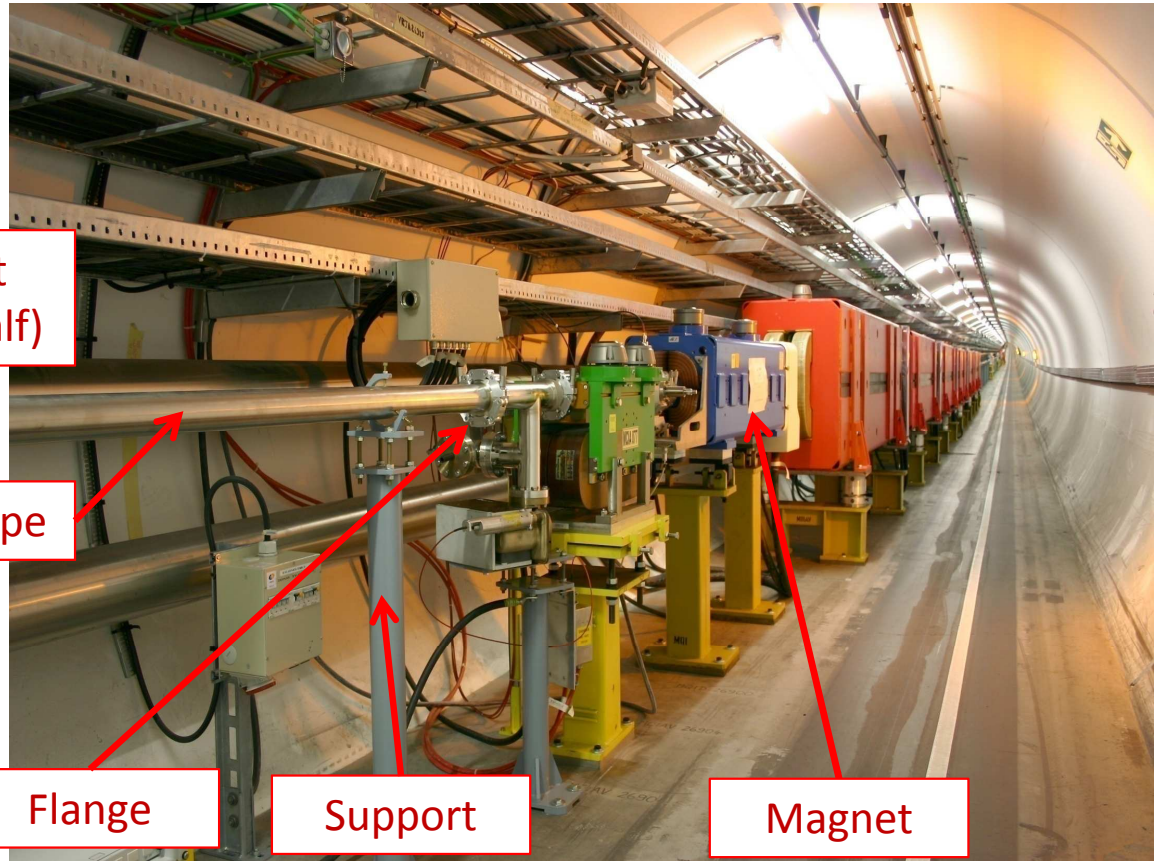


Paolo Chiggiato, Vacuum Technology for particle accelerators, 2013

Vacuum systems in accelerators

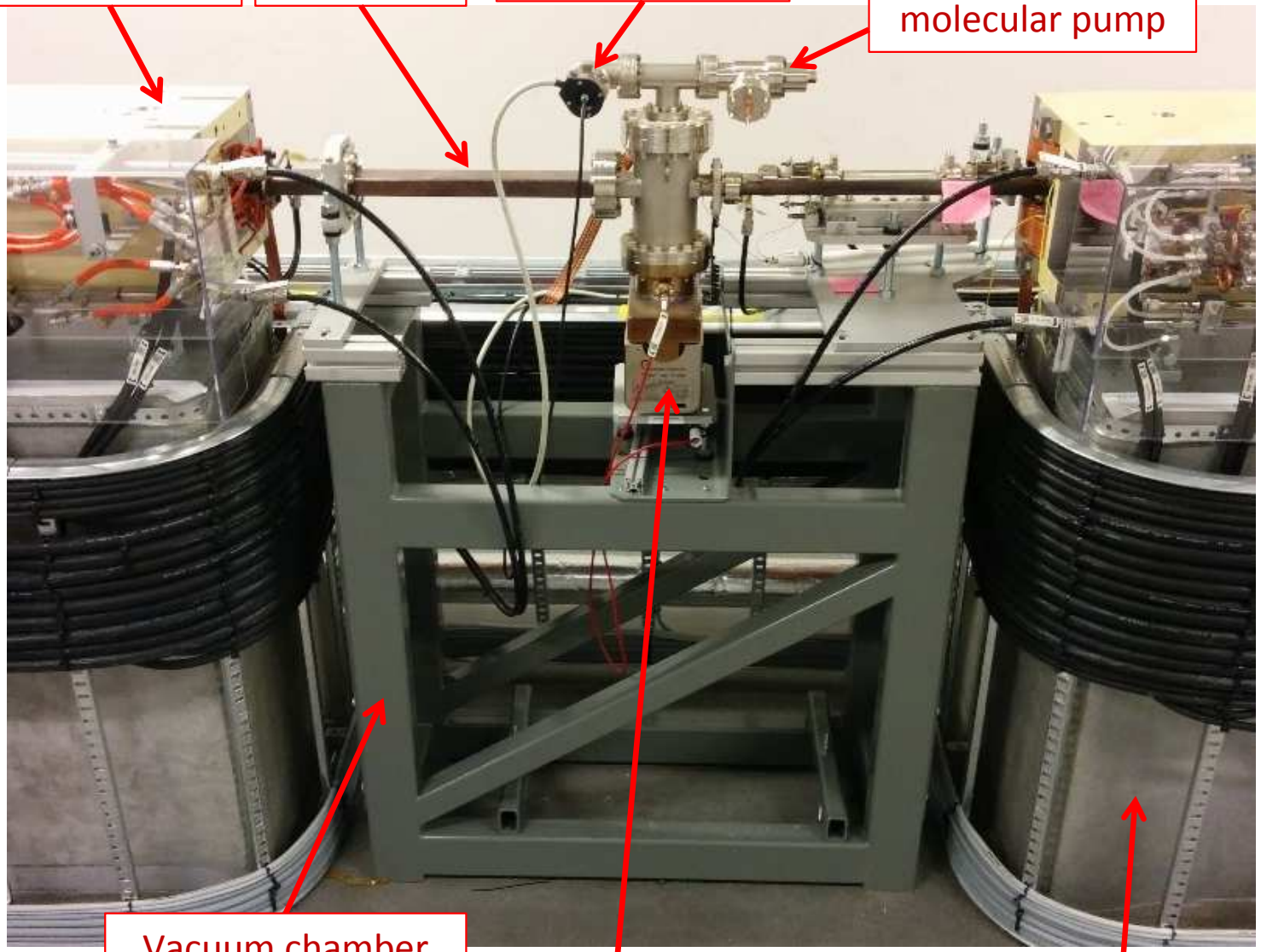


Vacuum systems are constructed of many components joined together with flanges.



Vacuum systems are divided in sectors by gate valves.

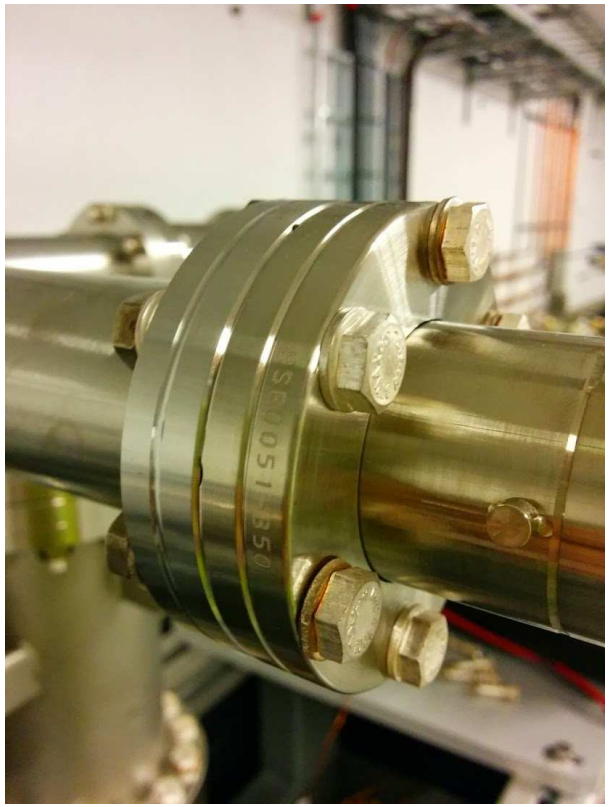
Vacuum systems in accelerators

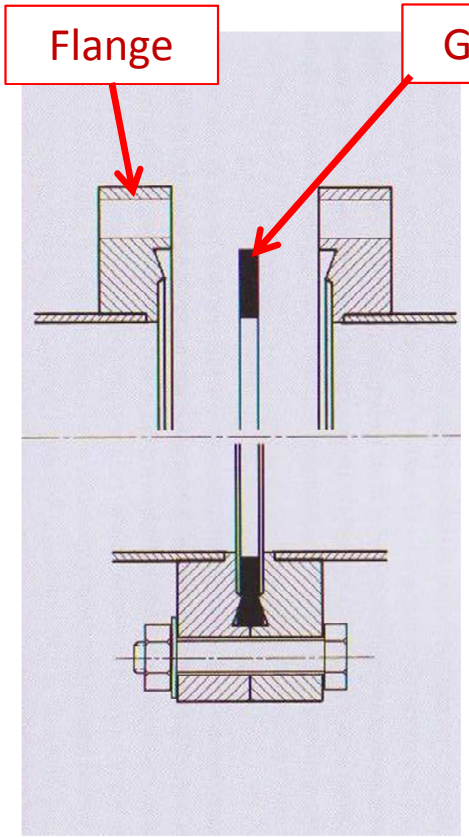


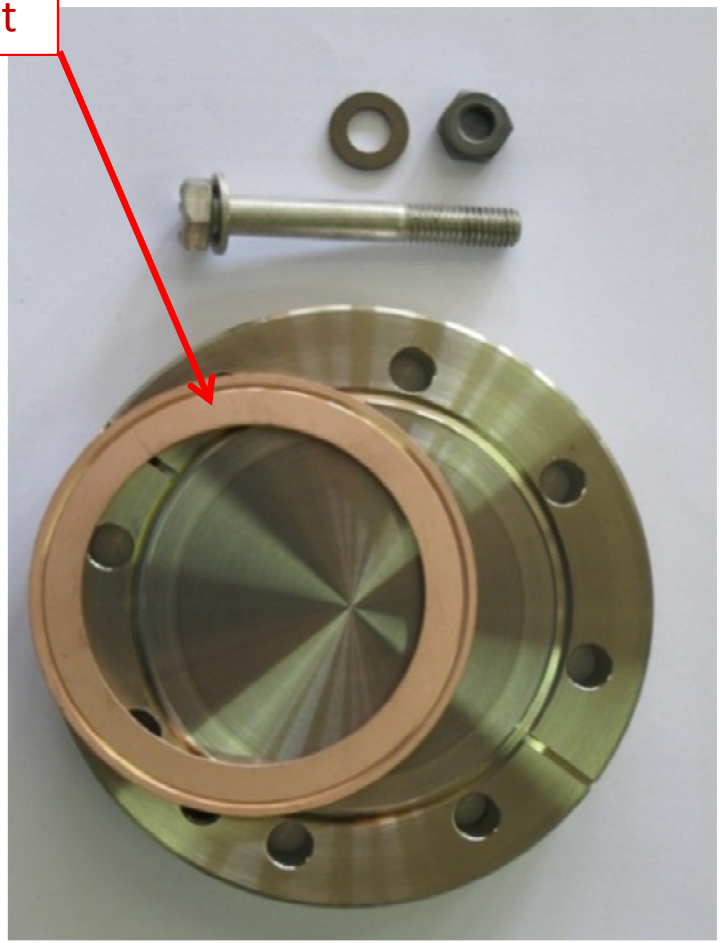
The pressure is monitored by vacuum gauges.

Bayard-Alpert hot cathode ionization gauge

Vacuum systems in accelerators



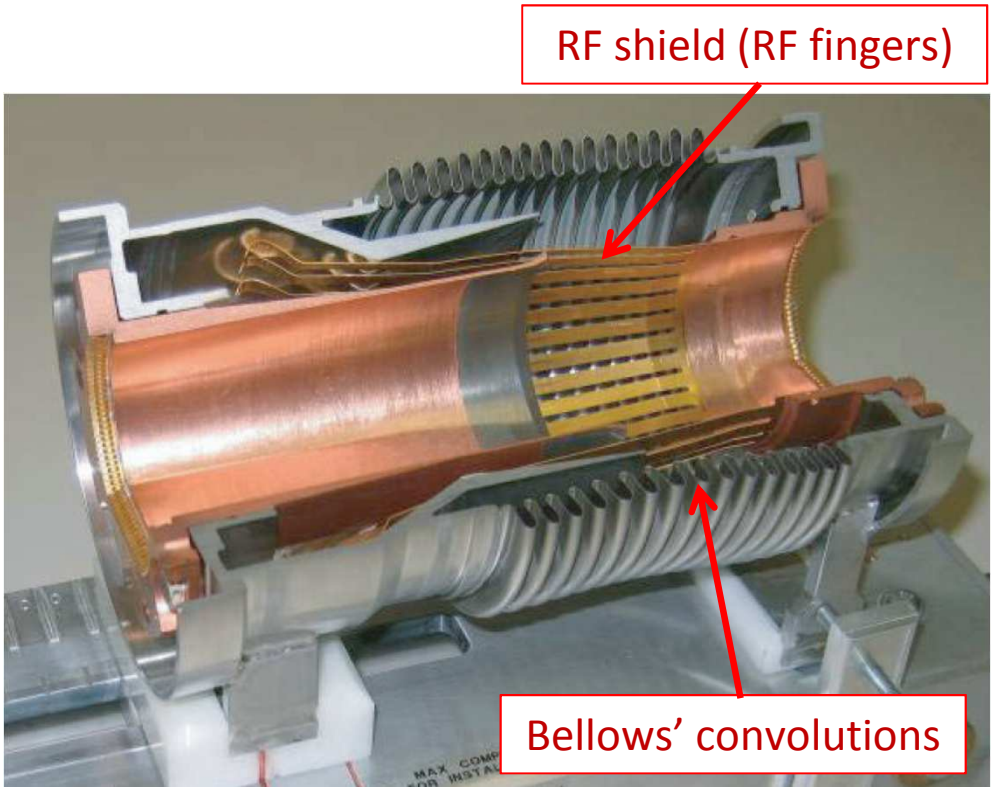




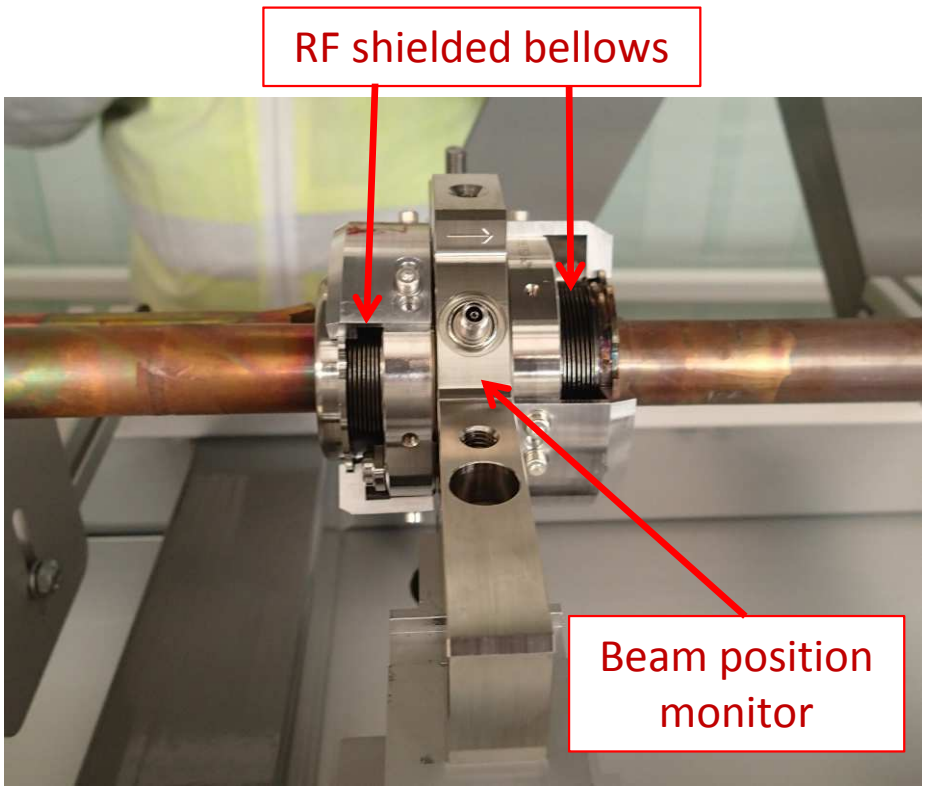
Connection between UHV components is made by copper gaskets that are squeezed between two flanges.

Paolo Chiggiato, Vacuum Technology for particle accelerators, 2013

Vacuum systems in accelerators



RF shielded bellows are essential to ensure low impedance and allow vacuum chamber compression and expansion.



Beam diagnostic devices are often integral part of vacuum system (example: beam position monitor.

Acknowledgments:

Paolo Chiggiato (CERN), Eshraq Al-Dmour (MAX IV),

Some references:

CERN Accelerator School, Vacuum in accelerators, Platja d'Aro, Spain 16 – 24 May 2006 Proceedings

CERN Accelerator School, Vacuum Technology, Snekersten, Denmark 28 May – 3 June 1999 Proceedings

The physical basis of ultra-high vacuum, P.A. Redhead, J.P. Hobson, E.V. Kornelsen. AVS.

Foundations of Vacuum Science and Technology, Edited J.M. Lafferty, John Wiley & Sons, 1998