LNLS Laboratório Nacional de Luz Síncrotron
sirius

CNPEM

Introduction to Vacuum Technology

Rafael M. Seraphim (rafael.seraphim@lnls.br)
LNLS Vacuum Group

ISWA 2016, July, 3-8, Campinas

Contents

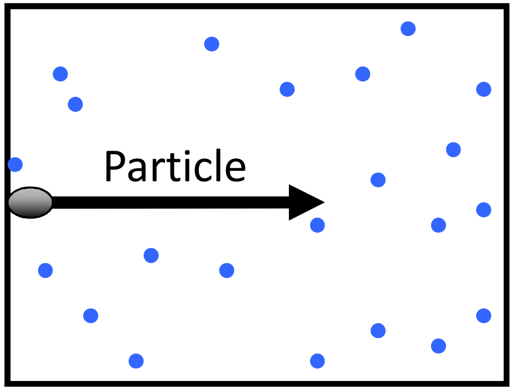
- Vacuum basics
- Vacuum system:
  - Valves
  - Pumps
  - Gauges
- Examples of vacuum systems
- Final remarks

Vacuum basics

Why vacuum?

Vacuum basics

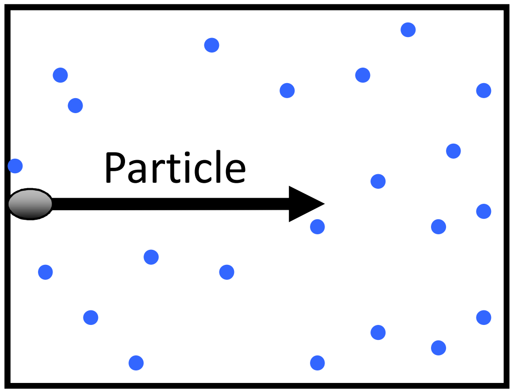
Why vacuum?



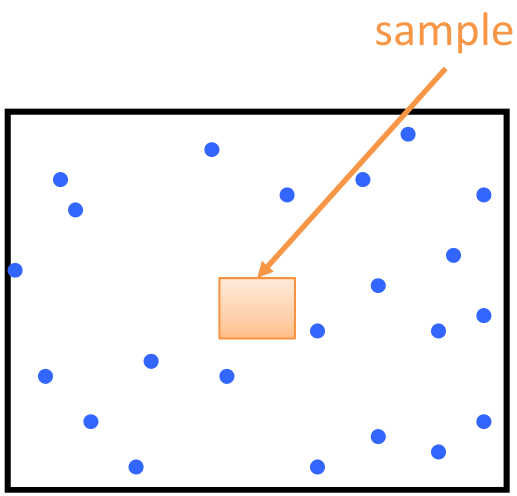
Free path to minimize collisions

Vacuum basics

Why vacuum?



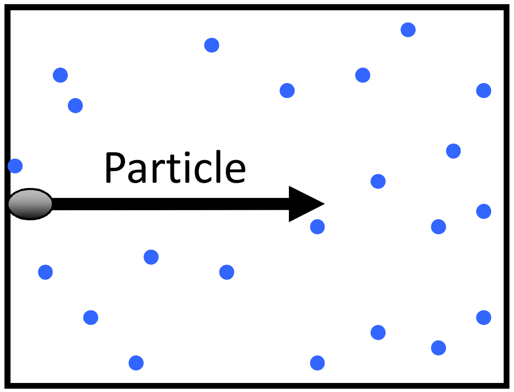
Free path to minimize collisions



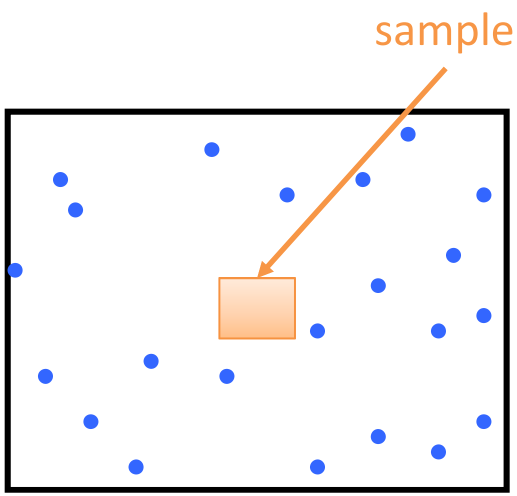
Clean environment to run an experiment
or
simulate a specific environment

Vacuum basics

Why vacuum?



Free path to minimize collisions



Clean environment to run an experiment
or
simulate a specific environment

What is the target pressure (P) or tolerable molecular density (n)?

Vacuum basics

According to Ideal Gas Law → $P = n\,K\,T$

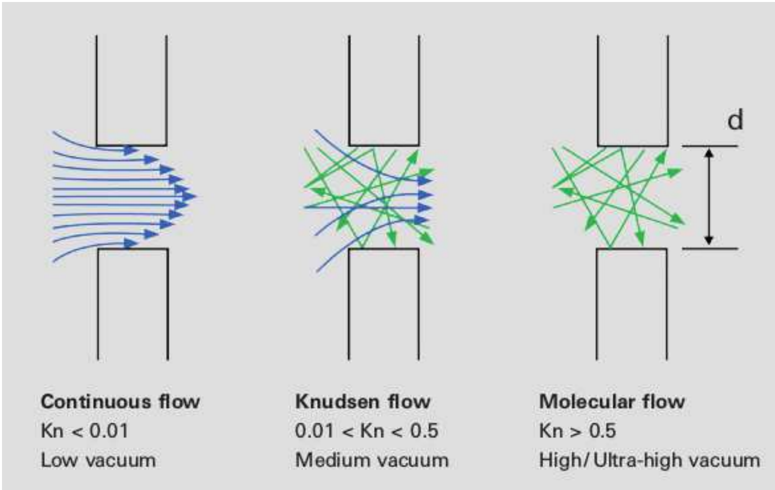
Pressure P [Pa]
Gas density n [molecules/m^3]
Boltzman constant k [J/K] = 1.38 10^{-23}
Temperature T [K]

Classification of vacuum ranges

	Pressure range [mbar]	Molecular Density n at 293 K [cm^{-3}]
Low Vacuum LV	10^3-1	10^{19}-10^{16}
Medium Vacuum MV	1-10^{-3}	10^{16}-10^{13}
High Vacuum HV	10^{-3}-10^{-9}	10^{13}-10^7
Ultra High vacuum UHV	10^{-9}-10^{-12}	10^7-10^4
Extreme High Vacuum XHV	<10^{-12}	<10^4

Vacuum basics:
Flow regimes in vacuum

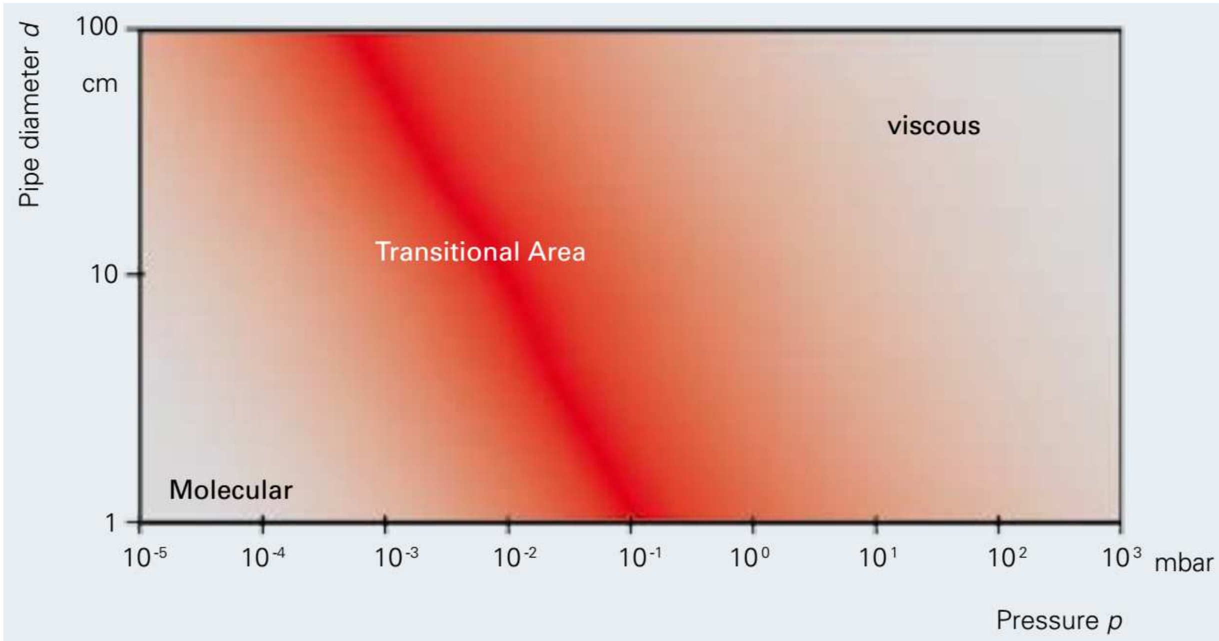
Knudsen number: $K_n = \frac{\lambda}{d}$



Mean free path: $\lambda_{air}[cm] = \frac{7\ 10^{-3}}{P[mbar]}$

d is vacuum chamber diameter

Pressure rabge [mbar]	Mean free path λ [cm]
10^3-1	$<10^{-2}$
1-10^{-3}	10^{-2}-10
10^{-3}-10^{-9}	10-10^6
10^{-9}-10^{-12}	10^6-10^8
$<10^{-12}$	$>10^8$



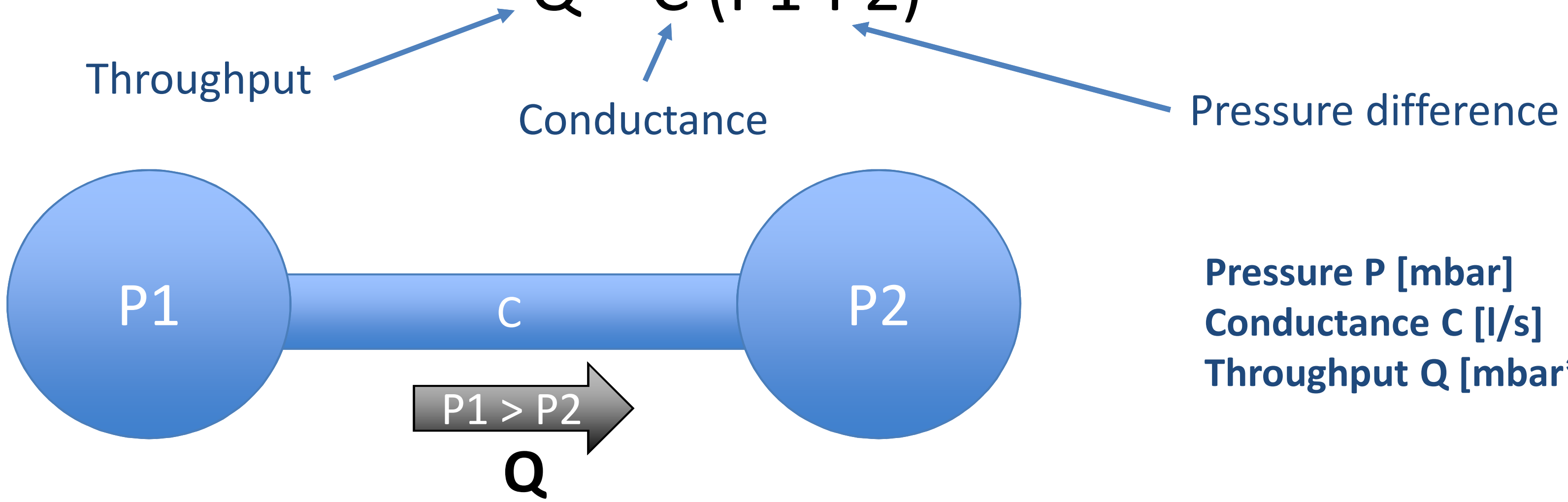
Vacuum Technology Know How. Pfeiffer book

Vacuum basics:

Gas Flow

Gas flow in vacuum can be described by the simple equation:

$$Q = C\,(P1-P2)$$



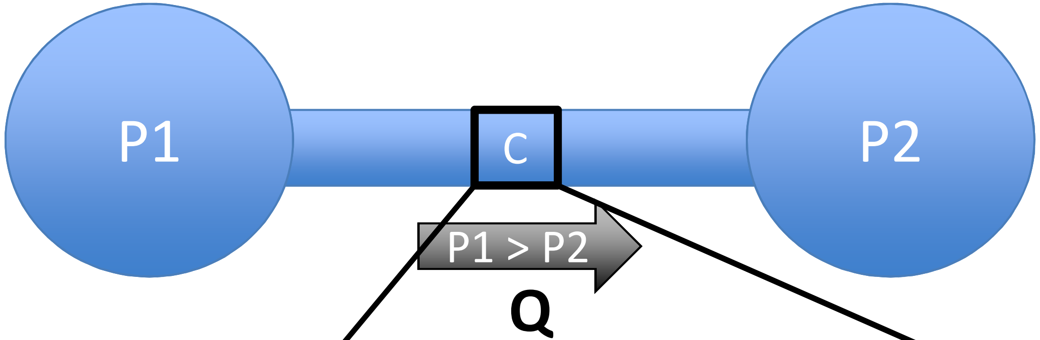
Pressure P [mbar]
Conductance C [l/s]
Throughput Q [mbar*l/s]

Vacuum basics:
Gas Flow

Gas flow in vacuum can be described by the simple equation:

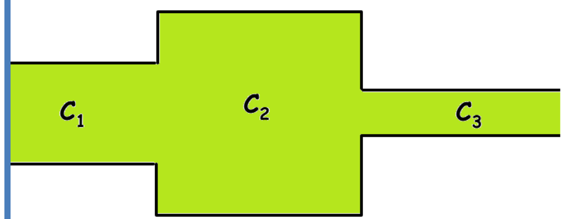
$$Q = C\,(P1-P2)$$

Throughput → Q; Conductance → C; Pressure difference → (P1-P2)



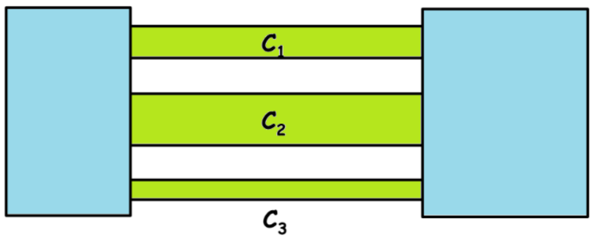
Pressure P [mbar]
Conductance C [l/s]
Throughput Q [mbar*l/s]

Series



$$\frac{1}{C_{Total}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Parallel



$$C_{Total} = C_1 + C_2 + C_3$$

Vacuum basics:

Conductance calculation in molecular regime

For simple geometry the conductance can be calculated by simple eqs.:

For an orifice: $C_{air,20°C} = 11.6\ A$

Conductance C [l/s]
Orifice area A [cm^2]

For exemple, the conductance of an orifice of 4 cm is: **146 l/s**

For a tube: $C_{air,20°C} = 12.1 \frac{d^3}{L}$

Conductance C [l/s]
Tube diameter d [cm]
Tube length L [cm]

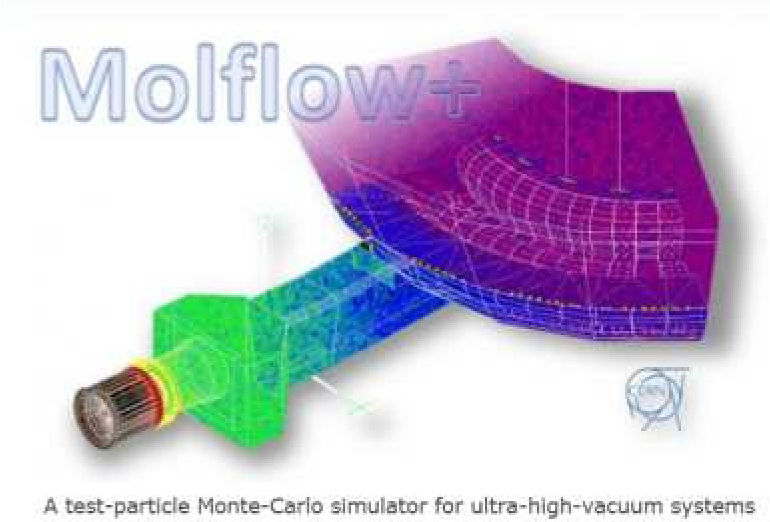
For exemple, the conductance of a tube with diameter of 4 cm and length of 10 cm is: **77.5 l/s**

Vacuum basics:

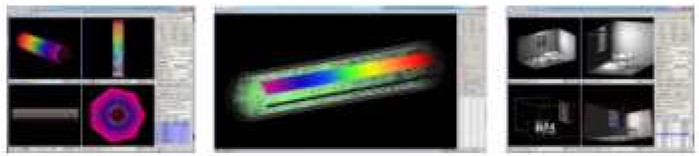
Conductance calculation in molecular regime

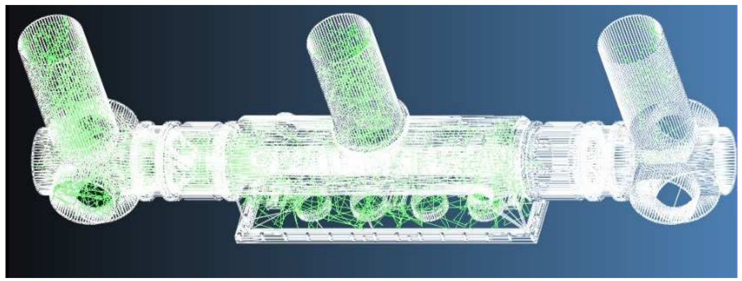
For complex geometry the conductance can be calculated by:

Based on Test-Particle Monte Carlo method (TPMC), which calculates a large number of molecular trajectories to have a picture of a rarefied gas flow.



http://cern.ch/test-molflow



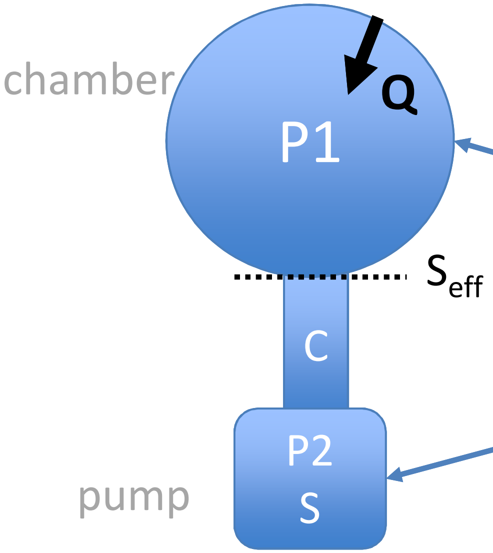


R. Kersevan and J.-L. Pons, JVST A 27(4) 2009, p1017

Vacuum basics:

Calculating the pressure in vacuum chambers

The pressure in a vacuum chamber can be described by using the following equations:



$$\begin{cases} Q = C\,(P1 - P2) \\ Q = S_{eff}\,P1 \\ Q = S\,P2 \end{cases}$$

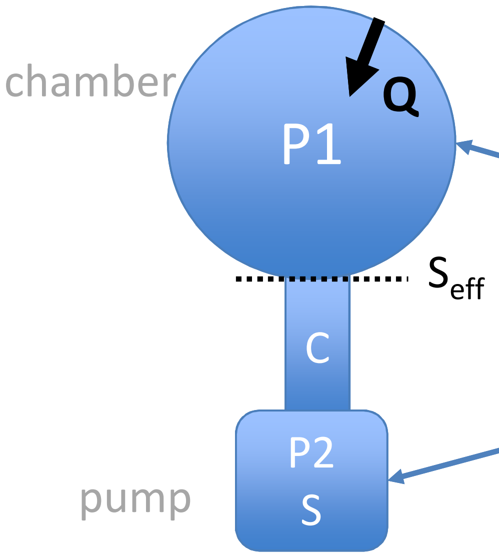
$$\frac{1}{S_{eff}} = \frac{1}{S} + \frac{1}{C}$$

Pressure in the chamber P1 [mbar]
Pressure in the pump P2 [mbar]
Conductance C [ls]
Gas load/throughput Q [mbar*l/s]
Pump nominal pumping speed S [l/s]
Pump effective pumping speed S_{eff} [l/s]

Vacuum basics:

Calculating the pressure in vacuum chambers

The pressure in a vacuum chamber can be described by using the following equations:



$$\begin{cases} Q = C\,(P1-P2) \\ Q = S_{eff}\,P1 \\ Q = S\,P2 \end{cases}$$

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

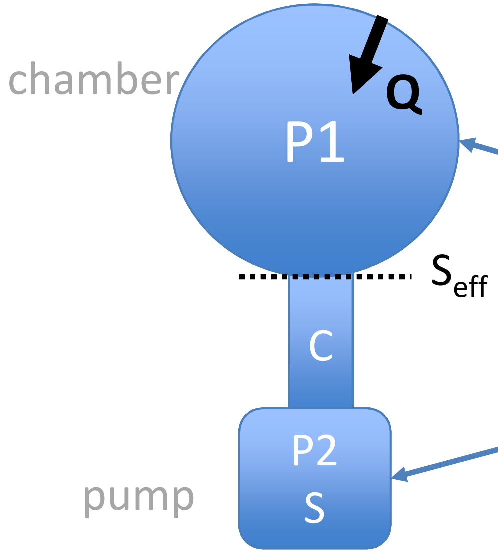
To lower the pressure in the chamber there are only two approaches:

Pressure in the chamber P1 [mbar]
Pressure in the pump P2 [mbar]
Conductance C [ls]
Gas load/throughput Q [mbar*l/s]
Pump nominal pumping speed S [l/s]
Pump effective pumping speed S_{eff} [l/s]

Vacuum basics:

Calculating the pressure in vacuum chambers

The pressure in a vacuum chamber can be described by using the following equations:



$$\begin{cases} Q = C\,(P1-P2) \\ Q = S_{eff}\,P1 \\ Q = S\,P2 \end{cases}$$

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

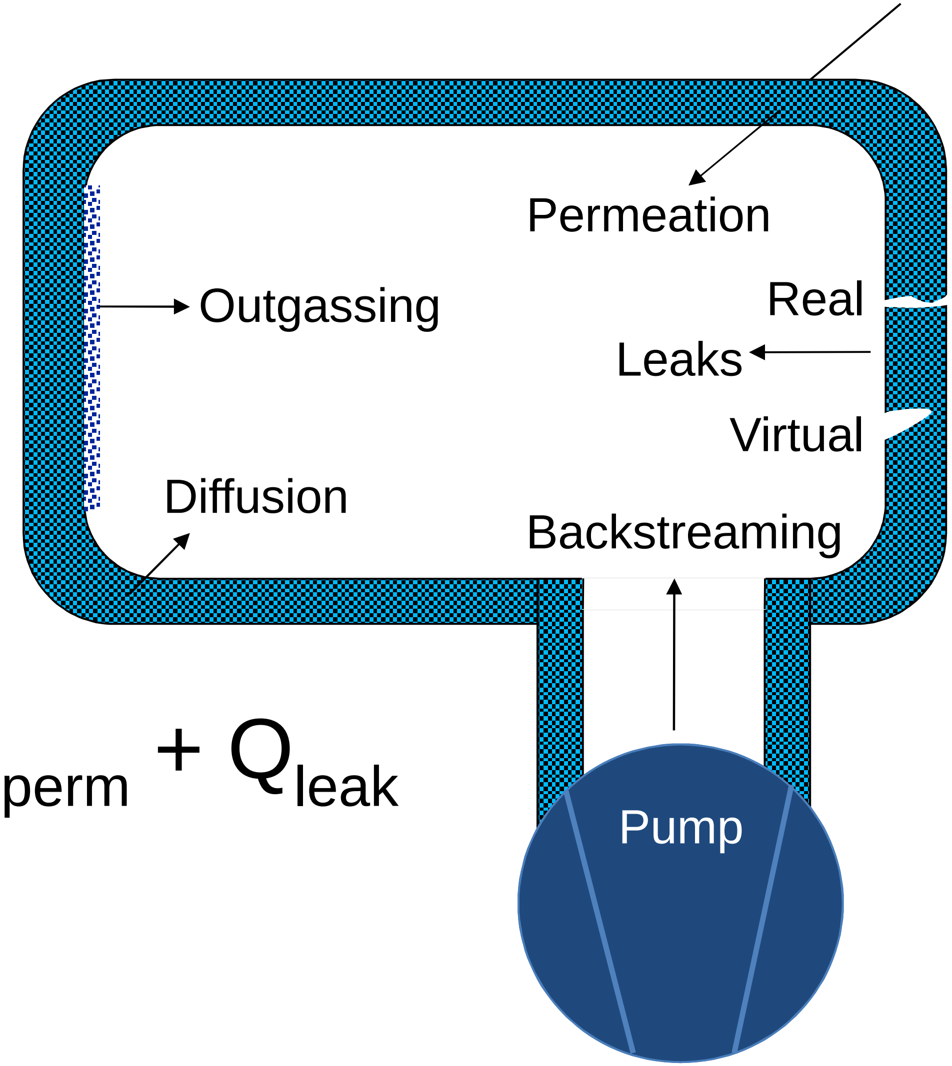
To lower the pressure in the chamber there are only two approaches:

↓ Q

Pressure in the chamber P1 [mbar]
Pressure in the pump P2 [mbar]
Conductance C [ls]
Gas load/throughput Q [mbar*l/s]
Pump nominal pumping speed S [l/s]
Pump effective pumping speed S_{eff} [l/s]

Vacuum basics:

Gas load



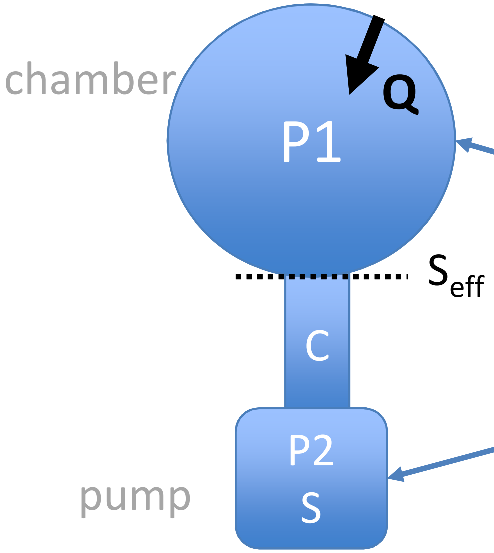
$$Q_T = Q_{out} + Q_{diff} + Q_{perm} + Q_{leak}$$

[mbar l/s)]

Vacuum basics:

Calculating the pressure in vacuum chambers

The pressure in a vacuum chamber can be described by using the following equations:



$$\begin{cases} Q = C\,(P1-P2) \\ Q = S_{eff}\,P1 \\ Q = S\,P2 \end{cases}$$

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

To lower the pressure in the chamber there are only two approaches:

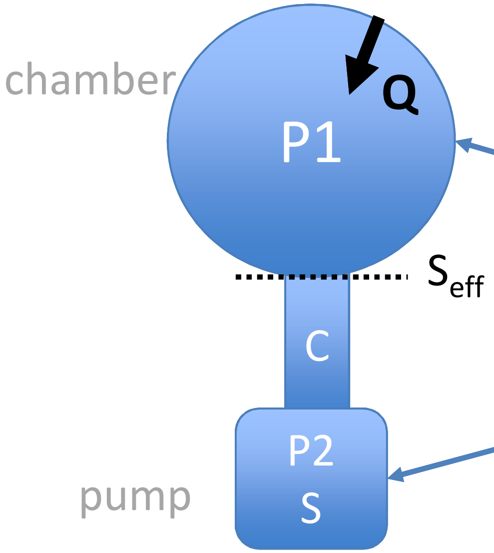
or ↓ **Q**

Pressure in the chamber P1 [mbar]
Pressure in the pump P2 [mbar]
Conductance C [ls]
Gas load/throughput Q [mbar*l/s]
Pump nominal pumping speed S [l/s]
Pump effective pumping speed S_{eff} [l/s]

Vacuum basics:

Calculating the pressure in vacuum chambers

The pressure in a vacuum chamber can be described by using the following equations:



$$\begin{cases} Q = C\,(P1-P2) \\ Q = S_{eff}\,P1 \\ Q = S\,P2 \end{cases}$$

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

To lower the pressure in the chamber there are only two approaches:

↓ Q

or

↑ S_{eff}

Pressure in the chamber P1 [mbar]
Pressure in the pump P2 [mbar]
Conductance C [ls]
Gas load/throughput Q [mbar*l/s]
Pump nominal pumping speed S [l/s]
Pump effective pumping speed S_{eff} [l/s]

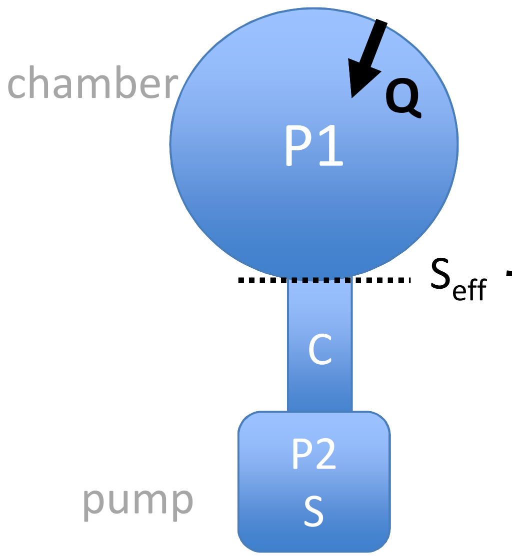
Vacuum basics:

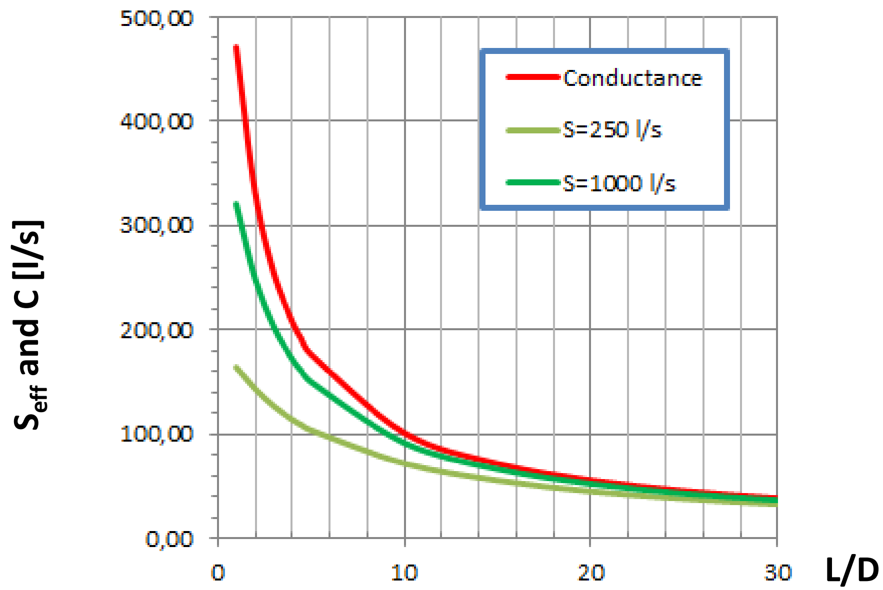
Conductance between the pump and the chamber

The design of the chamber, how the pumps will be connected and the size of pumps are a compromise that must be analyzed.

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

$$\begin{cases} \text{if } C \gg S: S_{eff} \approx S \\ \text{if } C \ll S: S_{eff} \approx C \end{cases}$$





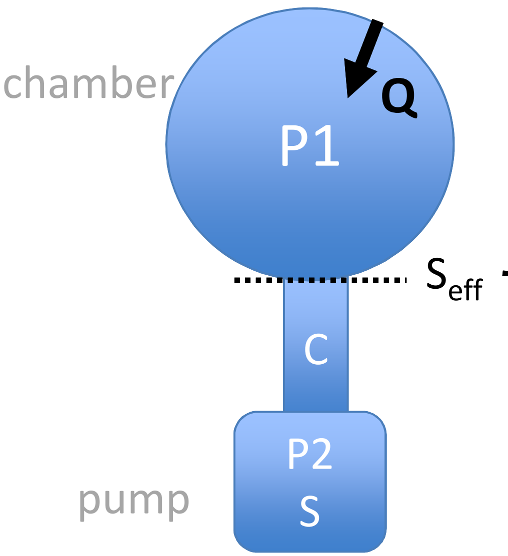
Example: Vessel and pump connected by a 100 mm diameter tube; $\mathbf{N_2}$, S=250 l/s and 1000 l/s.

Adapted from Chiaggiato; CAS-CERN, Vacuum Techniques for Superconducting Devices, 2013.

Vacuum basics:

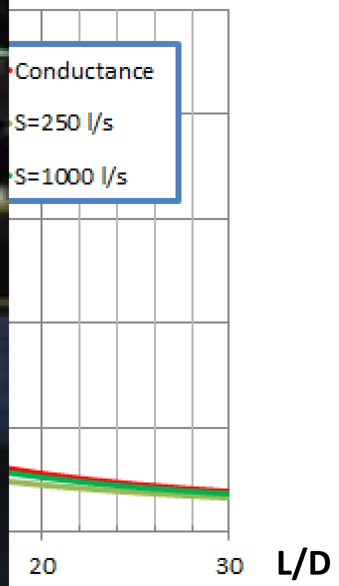
Conductance between the pump and the chamber

The design of the chamber, … e size of pumps are a compromise that must be a…



S

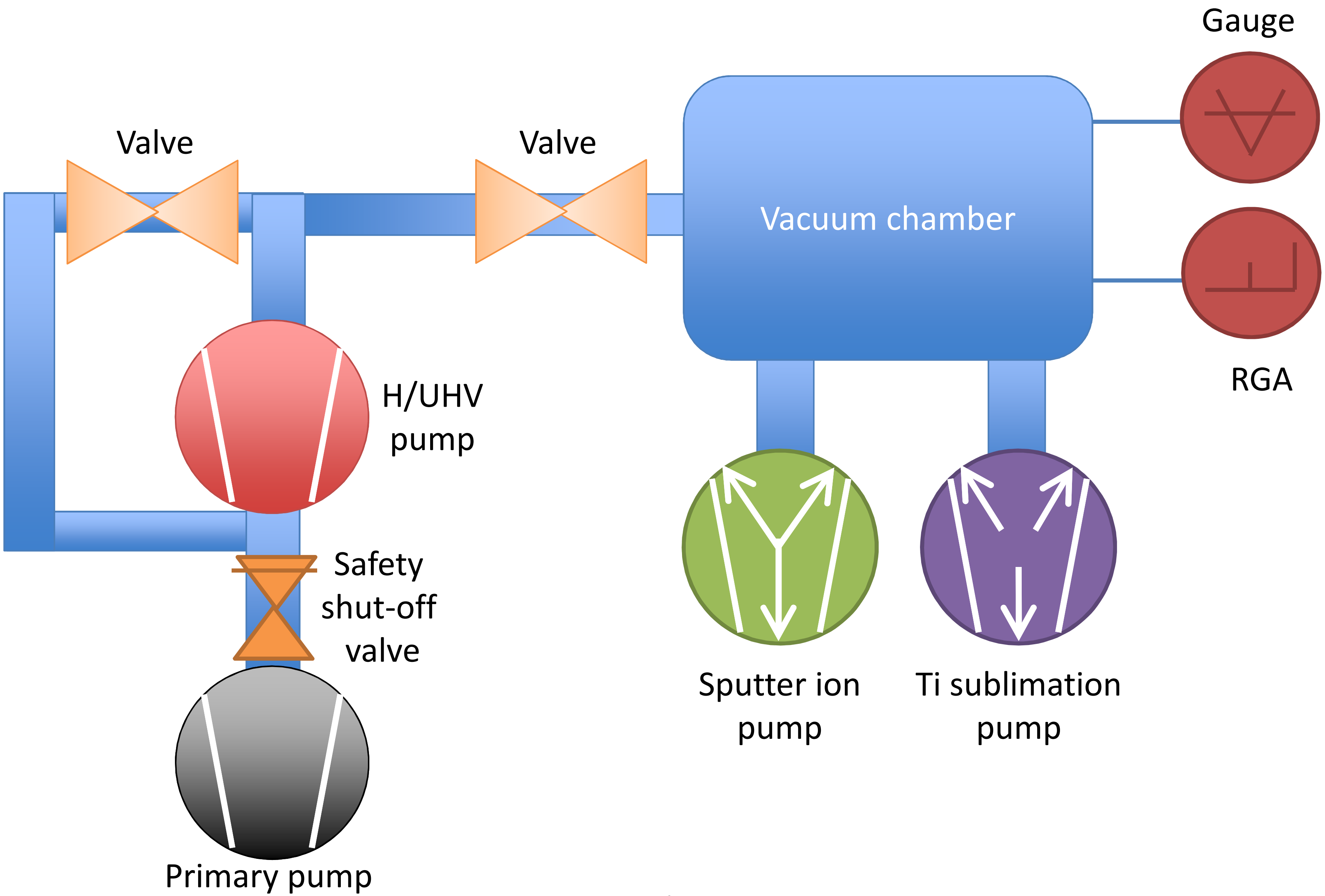
C



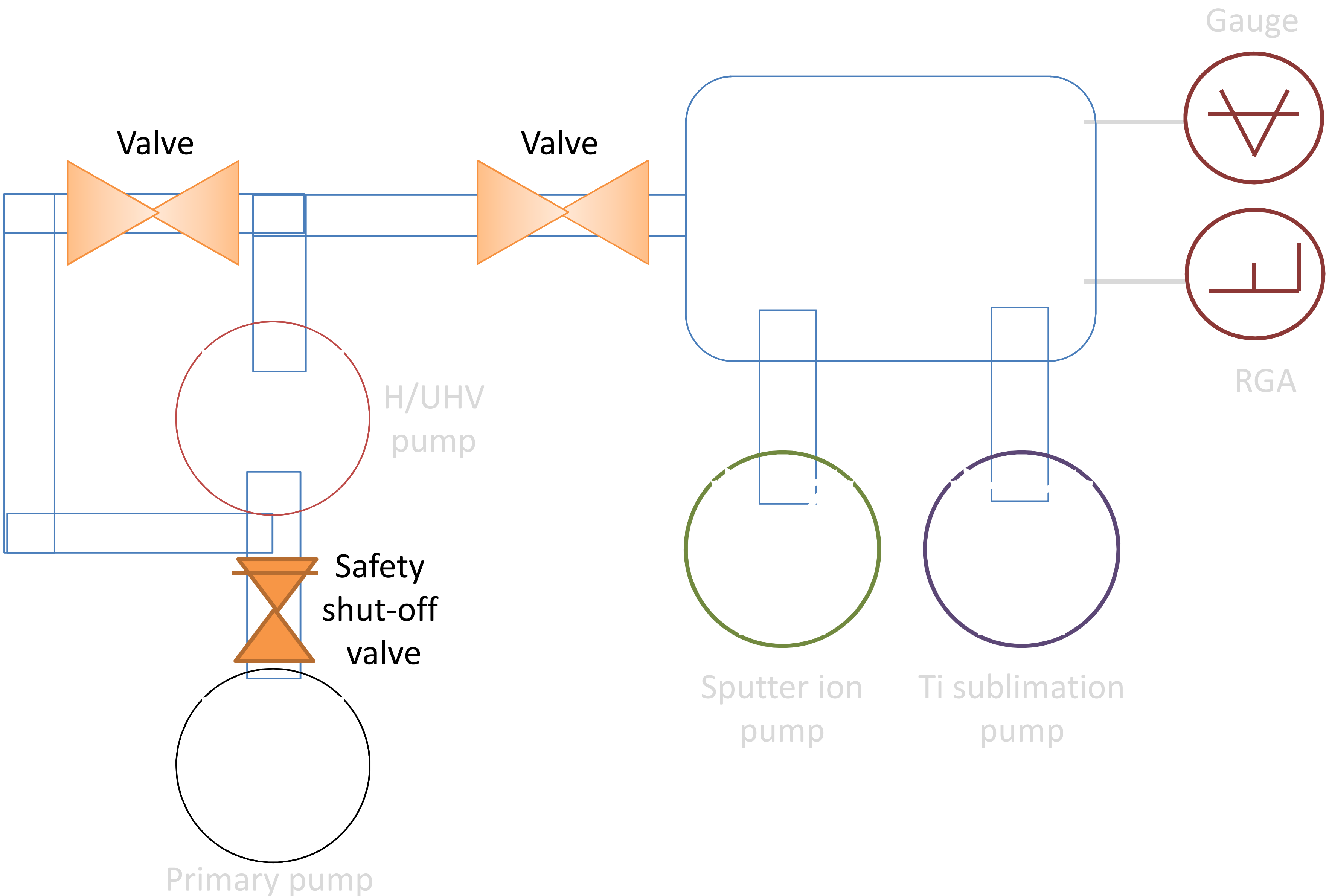
…100 mm diameter tube; N_2 ,
…l/s.

…s for Superconducting Devices, 2013.

Vacuum system



Vacuum system

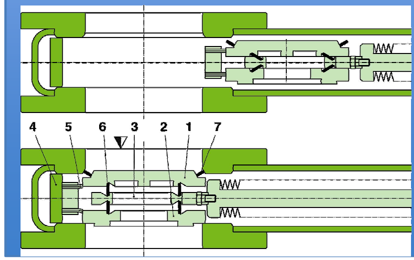


Laboratório Nacional de Luz Síncrotron

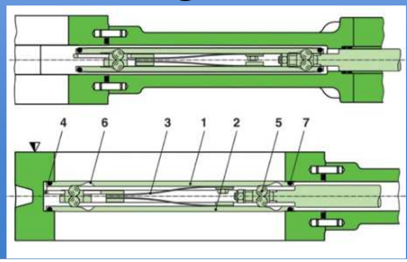
Vacuum system: valves

Gate valves:

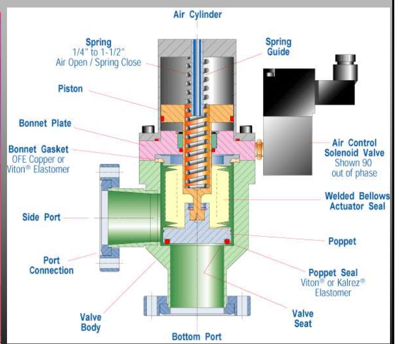
Metal sealed



O-ring sealed

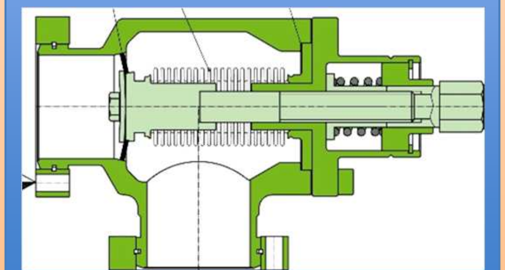


Safety shut-off valves:

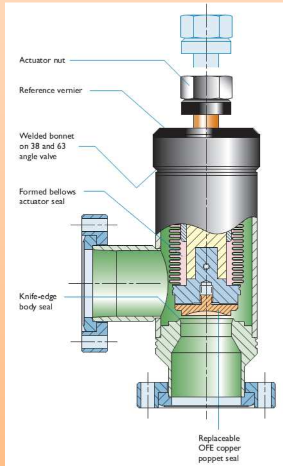


All metal right angle valves:

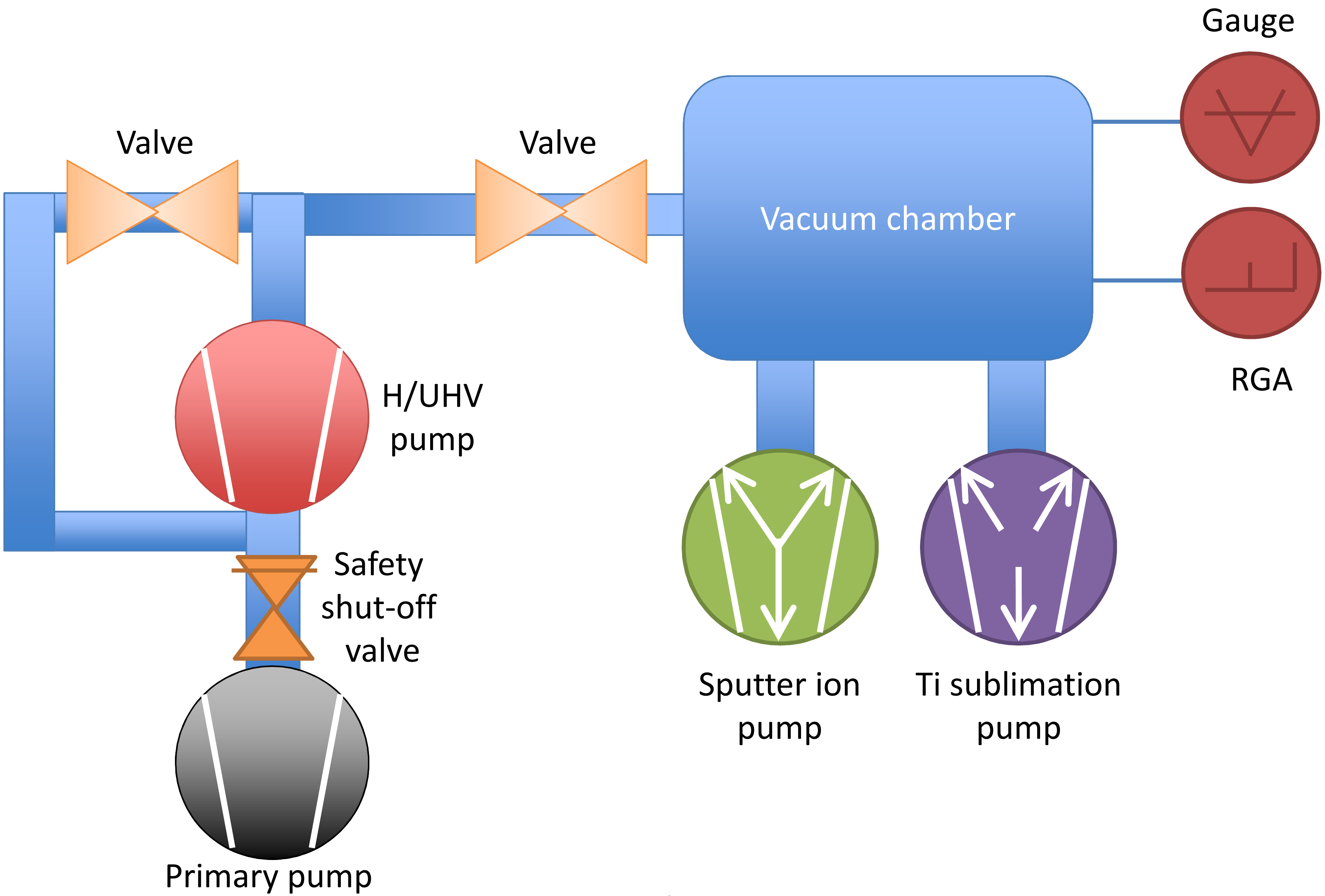
Sealing concept: hard-hard



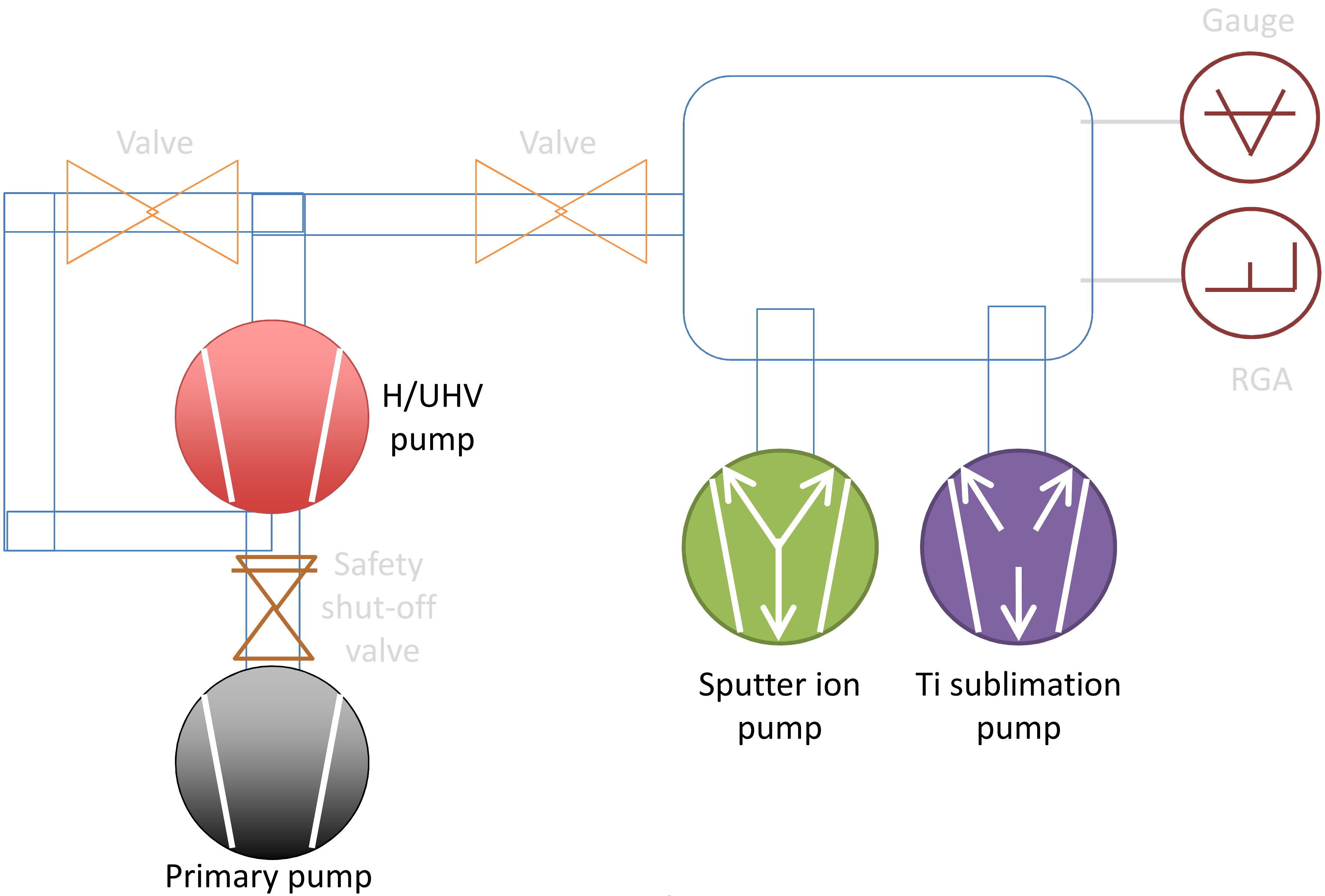
Sealing concept: hard-soft



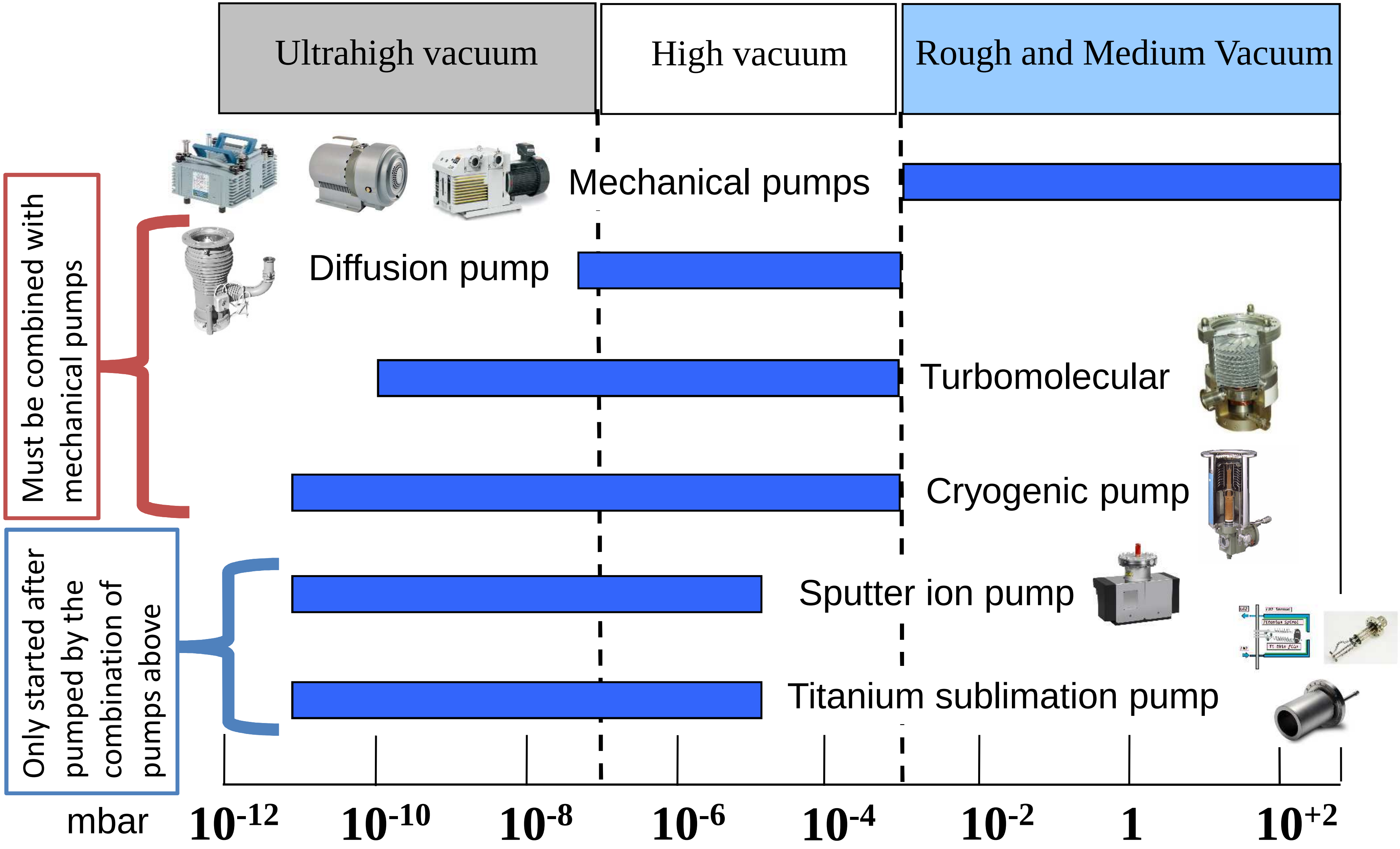
Vacuum system



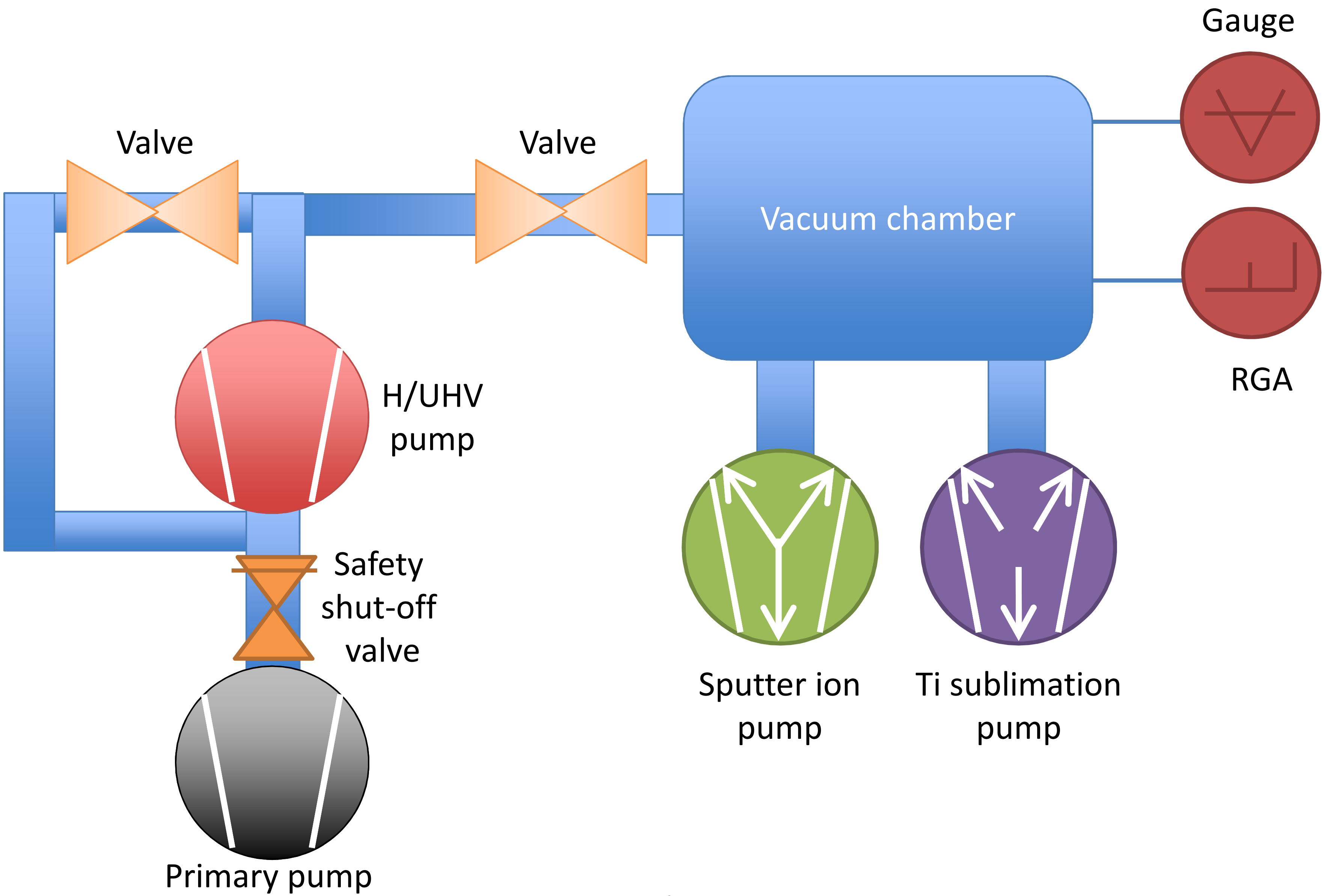
Vacuum system



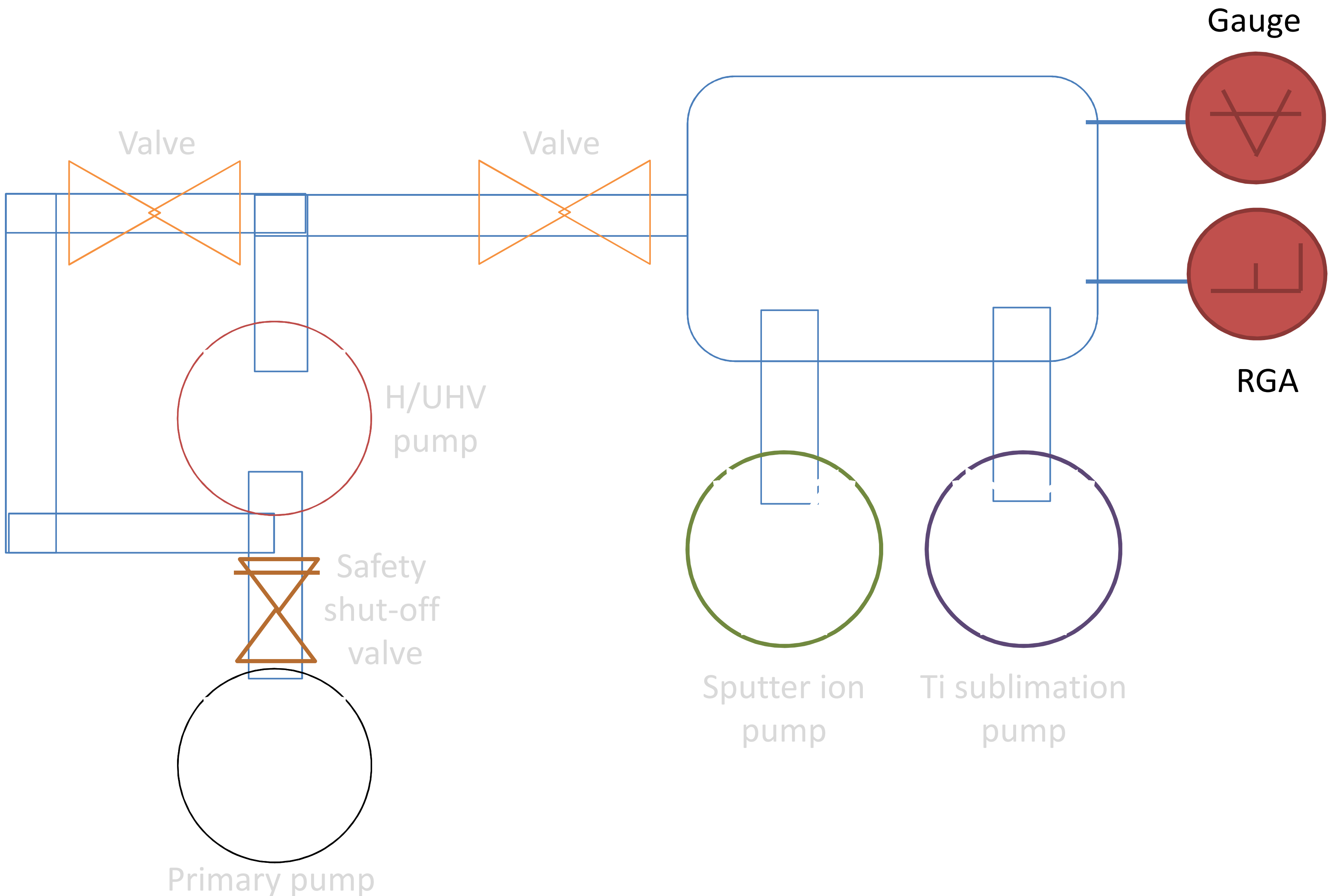
Vacuum system: pumps



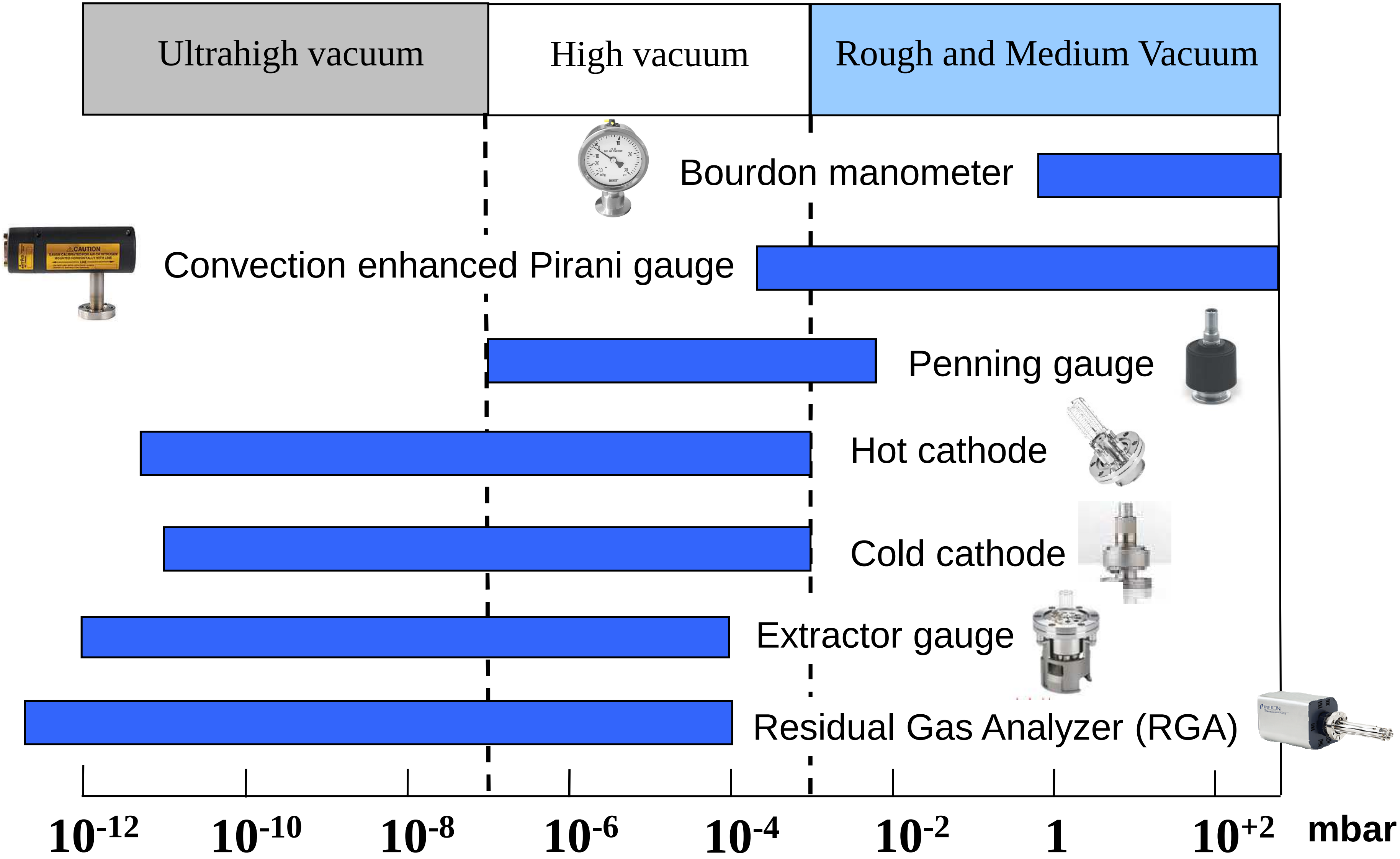
Vacuum system



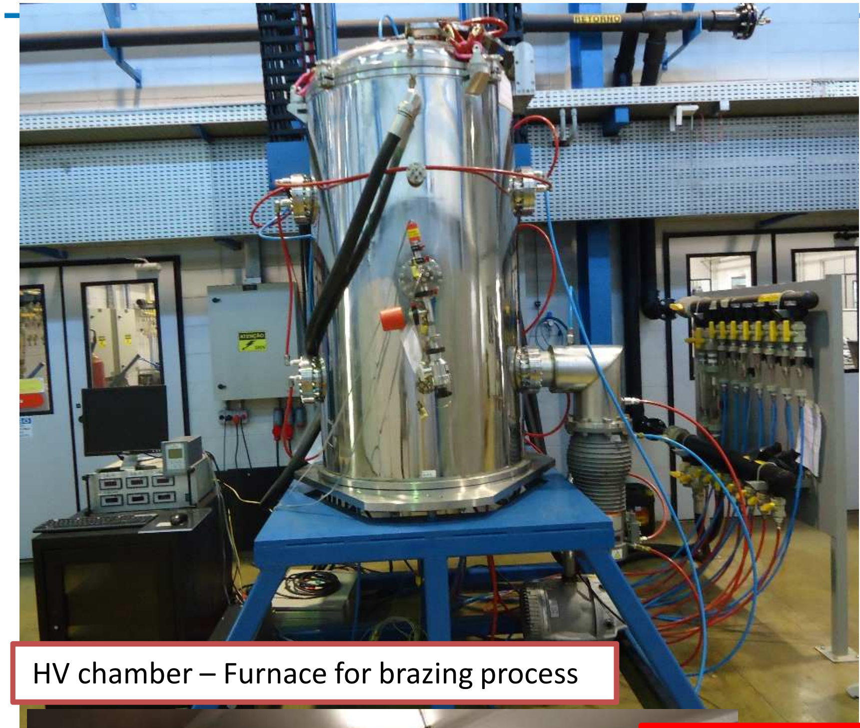
Vacuum system

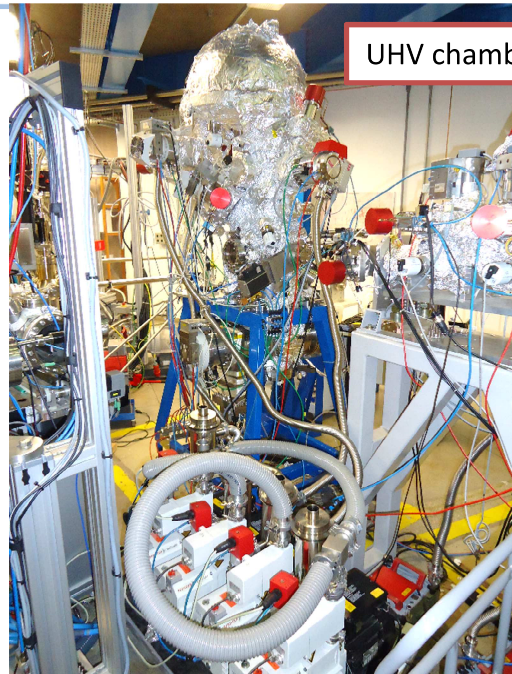


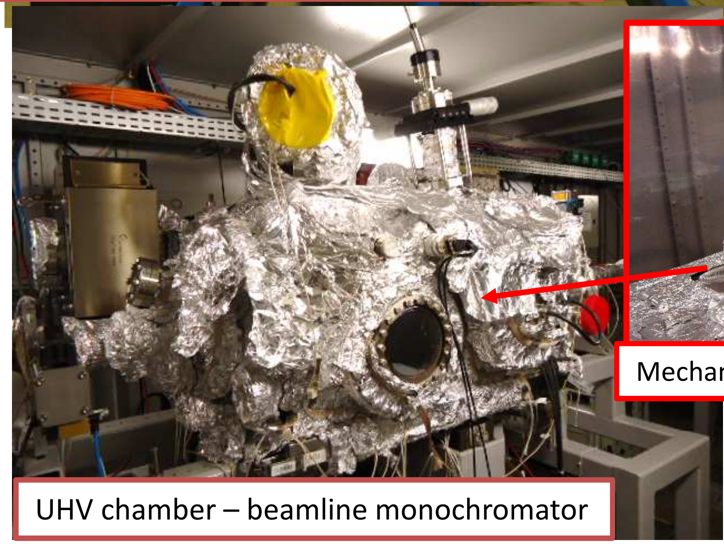
Vacuum system: gauges

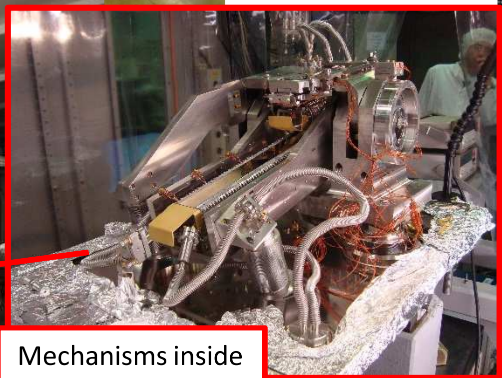


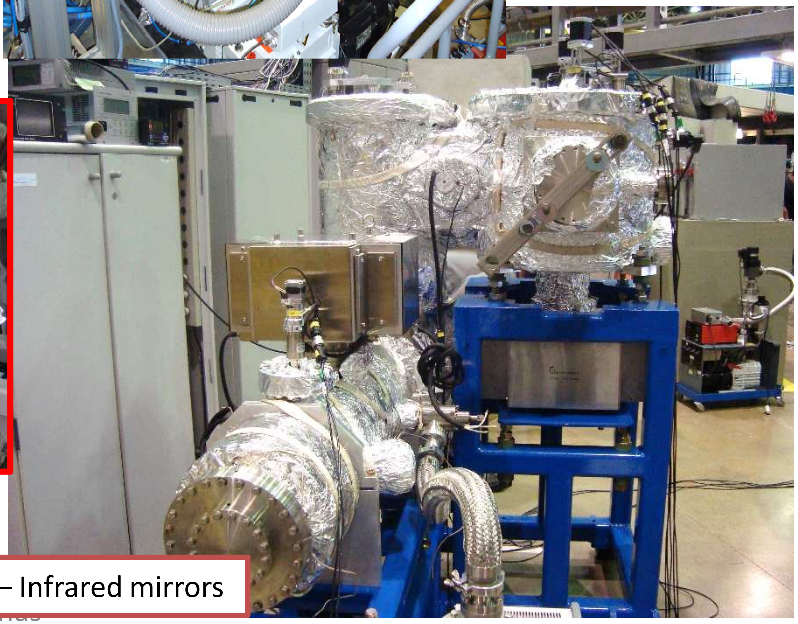
Examples of vacuum systems


HV chamber – Furnace for brazing process


UHV chamber – surface analysis

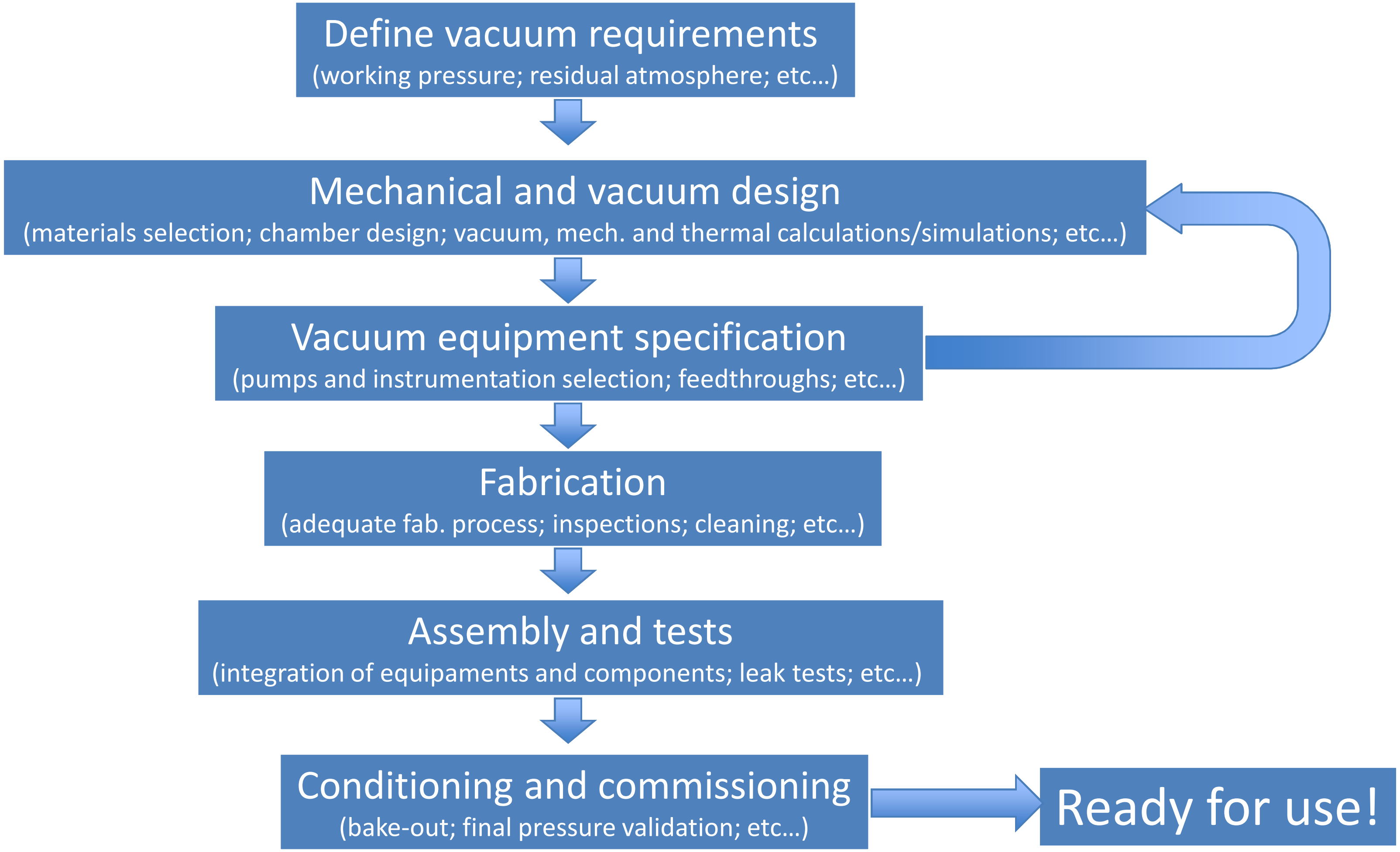

UHV chamber – beamline monochromator


Mechanisms inside


UHV chamber – Infrared mirrors

Final remarks

- **Vacuum technology** is interdisciplinary and correlates with other areas;
- A vacuum system must fabricated following a well defined flow:



Thank you for your attention!

Questions???