MAX IV LABORATORY

UHV Training 22-24 October 2019

Vacuum technology for synchrotron light sources

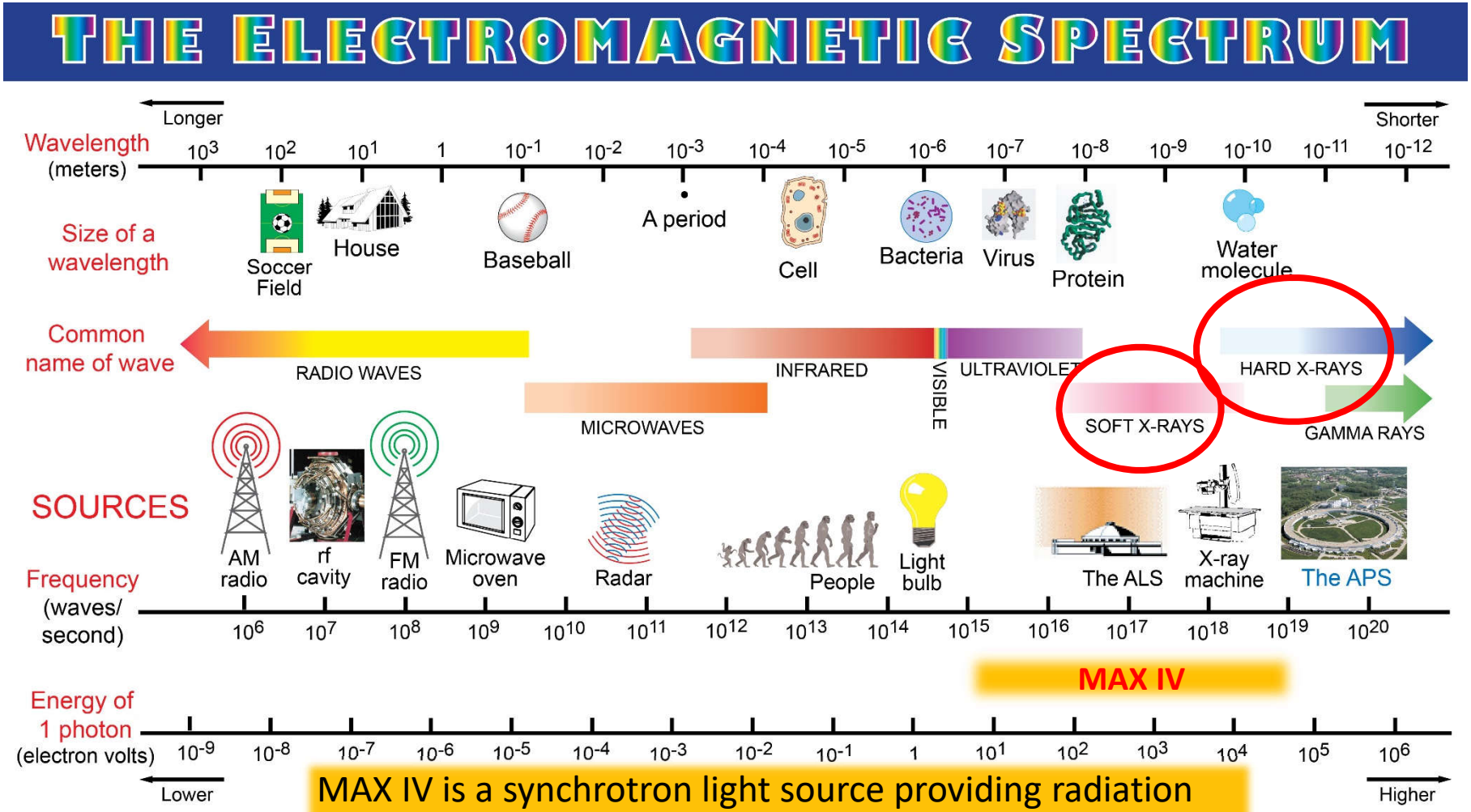
23rd October 2019, ESS, Lund

Contents

- What is a synchrotron light source?
- Why we need vacuum in particle accelerator?
- Basics of vacuum (for particle accelerators),
- Sources of gas,
- Vacuum pumps and sensors,
- MAXIV 3 GeV storage ring layout, design and installation,
- MAXIV 1.5 GeV storage ring layout and design.

What is MAX IV?

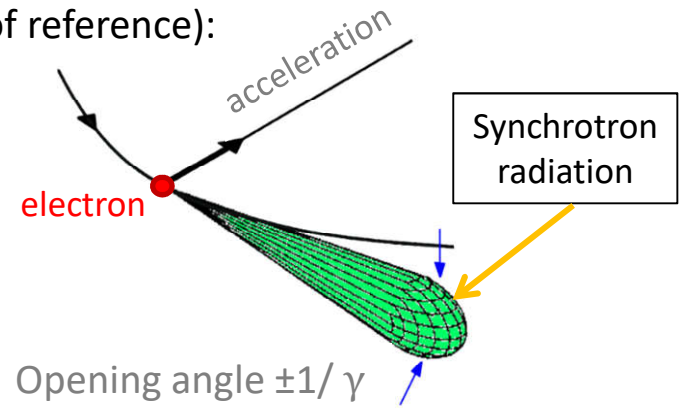
MAX IV - set of particle accelerators producing electromagnetic radiation (synchrotron light) which is used at beamlines for experiments and measurements.

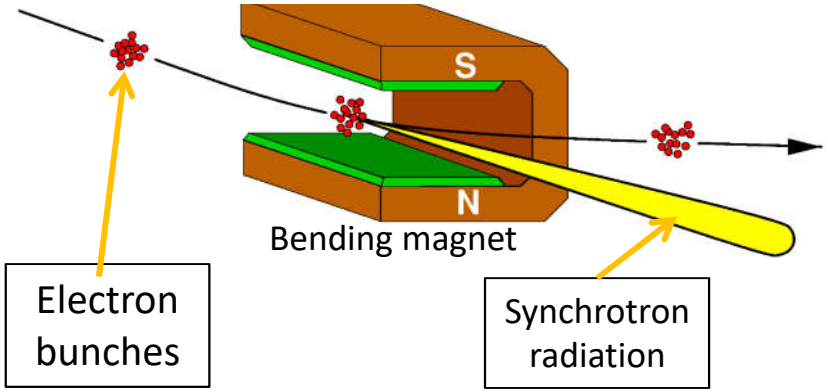


MAX IV is a synchrotron light source providing radiation from 4 eV till 40 keV to the beamlines for experiments.

How light is generated

Radiation emission of a relativistic electron (stationary lab frame of reference):

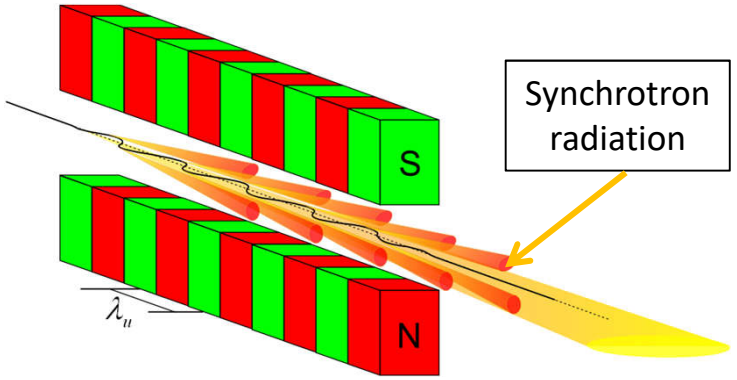




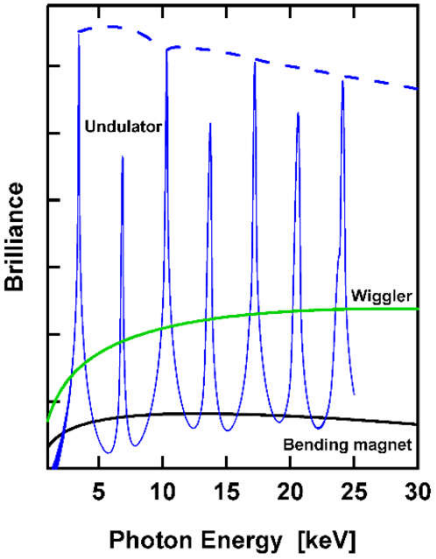
$$\textbf{brilliance} = \frac{\#p\ otons}{s \cdot mrad^2 \cdot mm^2 \cdot 0{,}1\%BW}$$

The greater the brilliance, the more photons of a given wavelength and direction are concentrated on a spot per unit of time.
Brilliance is mainly determined by the cross-section of the electron beam.

Insertion device - periodic magnetic structure (wiggler, undulator):



Brilliance of 3 radiation source types:



4th Generation light source

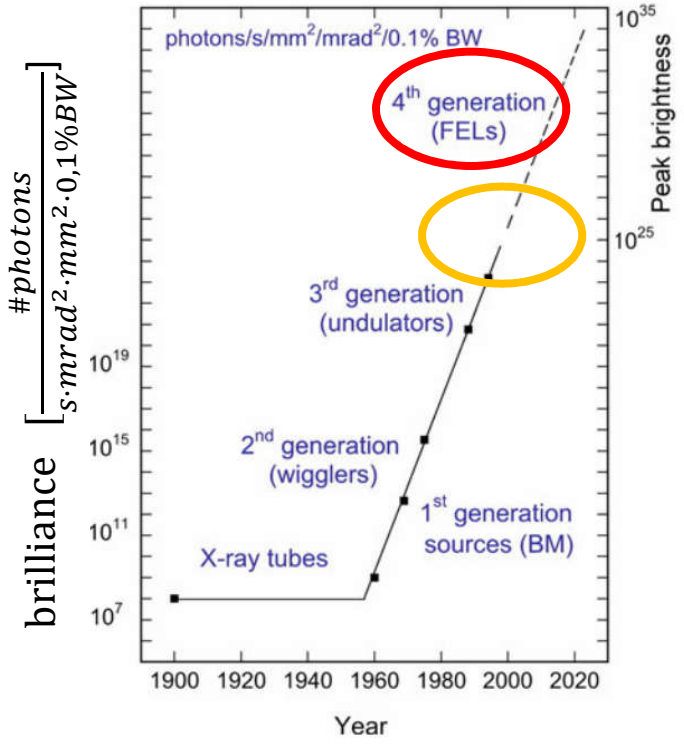
4th Generation light sources, mainly Free Electron Lasers (FELs) with brilliance higher from previous generation by many orders of magnitude.

MAX IV is **storage ring based** 4th generation light source with brilliance higher by at least one order of magnitude from 3rd generation light sources.

At MAX IV:

- Higher brilliance is achieved by lowering electron beam emittance,
- Only insertion devices are used: wigglers, undulators (no more bending magnet radiation).

X-ray source brilliance as a function of time since discovery of X-rays in 1895



4th generation light sources:
at least 1 important parameter factor of 10 better than the previous generation.

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

MAX IV layout

Synchrotron light source facility in Lund, Sweden.

3.4 GeV Linear accelerator - Linac (300 m)

Short pulse facility

Electron gun

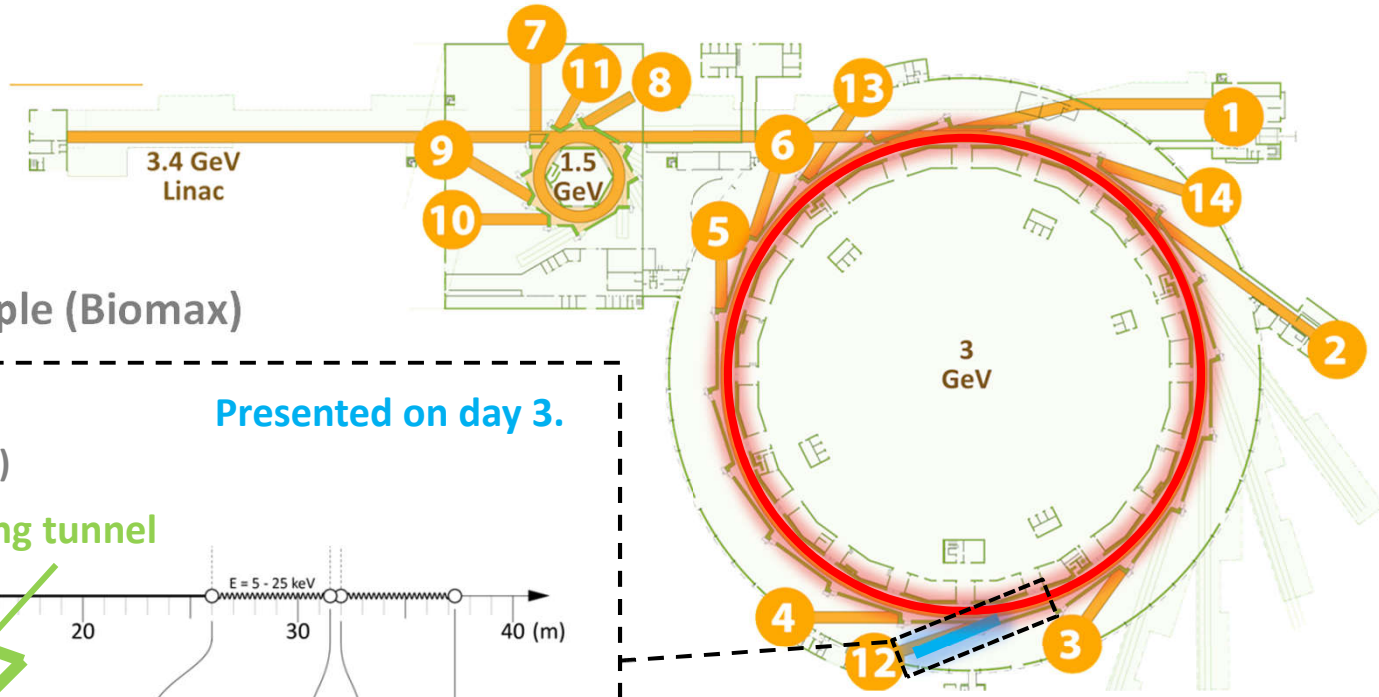
1.5 GeV storage ring for soft x-rays

3 GeV storage ring for hard x-rays

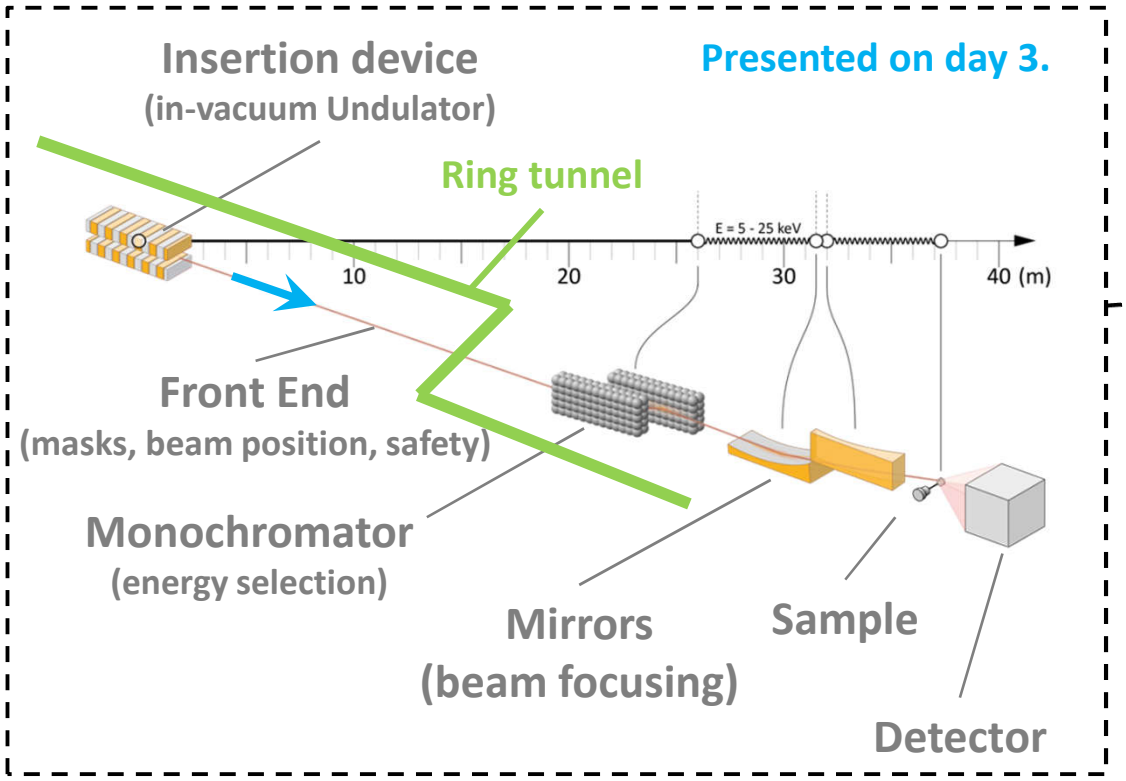
Commissioning started: September 2016

Commissioning started: August 2015

MAX IV beamline layout



Beamline layout example (Biomax)



Beamlines at MAX IV:
11 beamlines in operation/commissioning,
3 being installed,
2 under design.

Total beamline capacity: ~30 beamlines

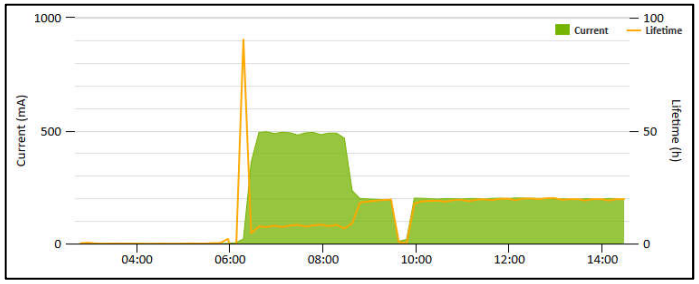
https://www.maxiv.lu.se/

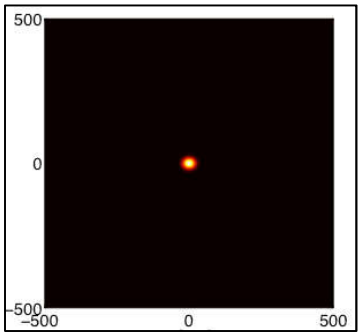
Why we need vacuum in particle accelerators?

Why do we need vacuum in particle accelerator?

Less beam-gas interaction:

- Increase beam lifetime,

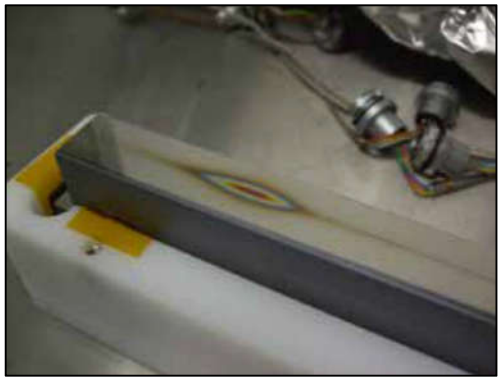




- Prevents to increase beam size,
- Reduces radiation hazard,

- Allows the synchrotorn readiation (light) reach the sample,

- Helps to protect optics…



OLAV IV 2014, Matthew Cox

Why do we need vacuum in particle accelerator?

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, inelastic beam lifetime:

$$\tau_{el,\,inel} \sim \frac{1}{Z^2}\frac{1}{n_g}$$

Z - atomic number of the residual gas (depends on gas specie),

n_g - residual gas density (pressure).

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

Basics of vacuum
(for particle accelerators)

Pressure units

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

Vacuum ranges

1 Atm. = 1013 mbar =~ 1 bar

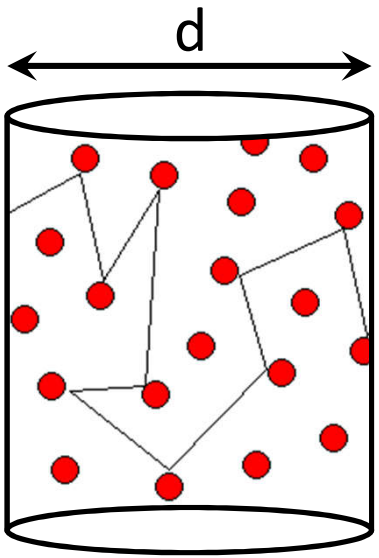
	Pressure range [mbar]
Low Vacuum	10^{3} - 1
Medium Vacuum	1 - 10^{-3}
High Vacuum (HV)	10^{-3} - 10^{-9}
Ultra High Vacuum (UHV)	10^{-9} - 10^{-12}
Extreme High Vacuum XHV	< 10^{-12}

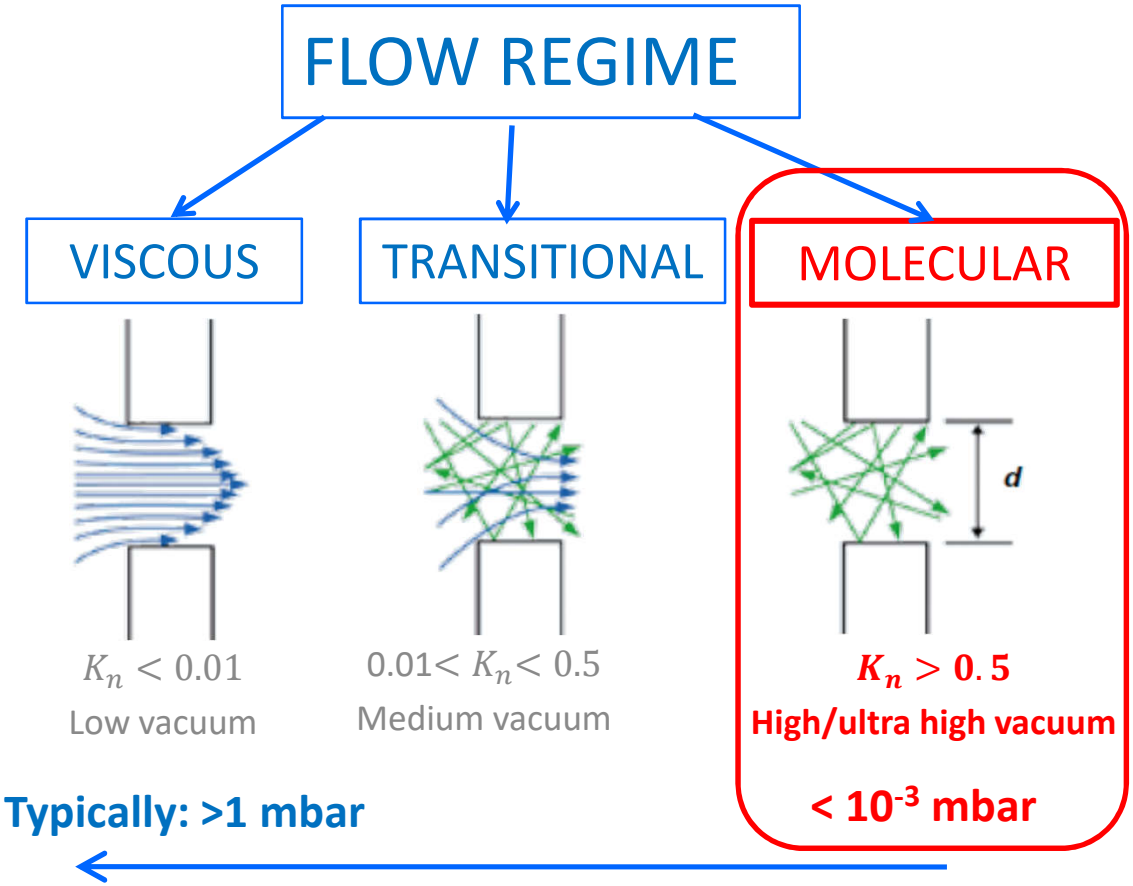
Storage rings, Beamlines

Flow regimes

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

l - Mean free path [m]
d - Diameter of flow channel [m]
K_n - Knudsen number [dimensionless]





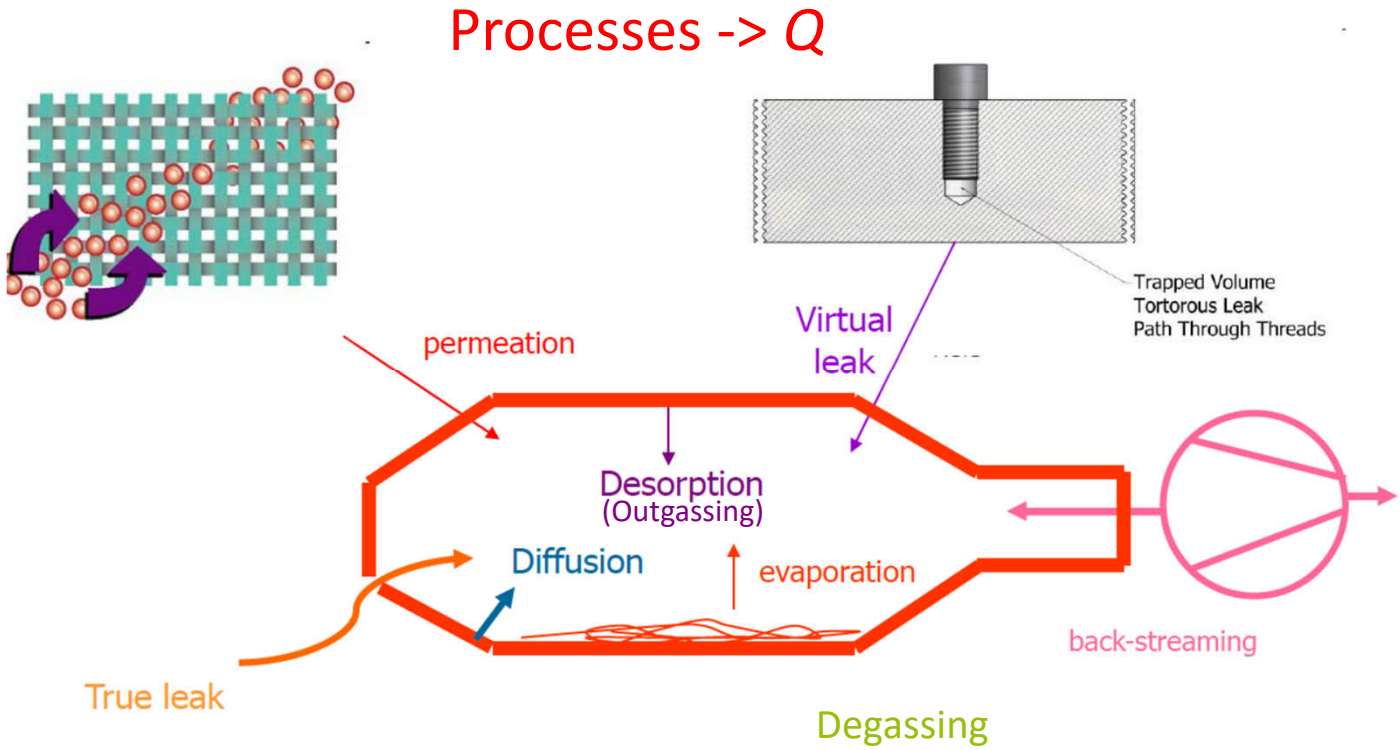
Mean free path:
At atm. Pressure = 6.5×10^{-8} m
At 10^{-9} mbar (storage ring) = 66 km

Vacuum Technology Know how by Pfeiffer Vacuum GmbH

Sources of gas

Sources of gases

Sources of static gas loads in vacuum system:

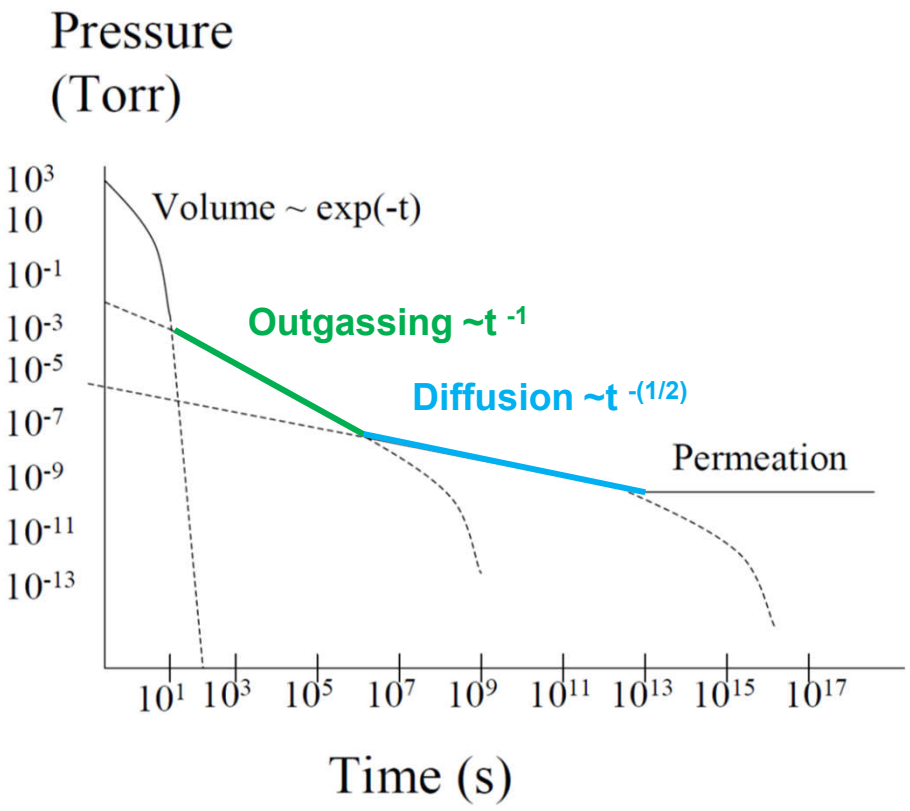


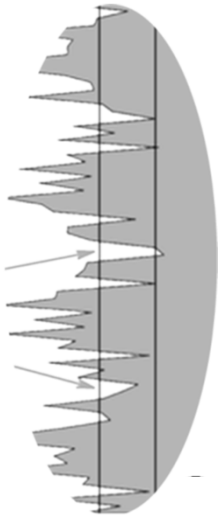
Vacuum chambers are sources of gas

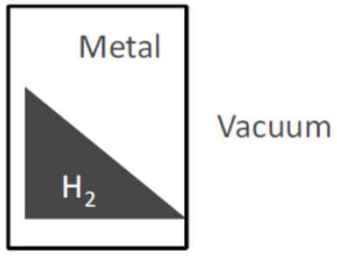
Courtesy of Eshraq Al-Dmour

What process defines pressure

What process defines the pressure over time?







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

Presented on day 3.

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 (desorption)

Thermal outgassing (static outgassing)

For metals:

- If not **baked** (not heated) 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 above ~120^{0}C in vacuum) in-situ hydrogen H_2 is the dominant gas

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

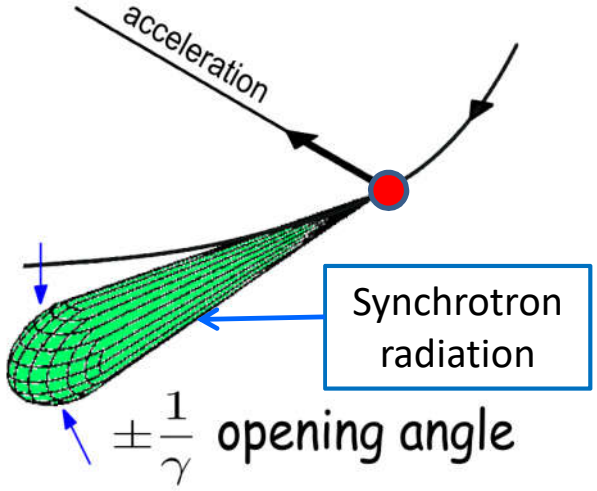
Austenitic stainless steel not baked, after 10 h pumping	3x10 ^{10} (main gas: H_2O)
Austenitic stainless steel baked in-situ for 24 h at 150^{0}C	2x10^{-12} (main gas: H_2)
OFS copper baked in-situ for 24 h at 200^{0}C	~10^{-14} (main gas: H_2)

Polymers (Viton, PEEK, Kapton) have high **water vapour solubility**, therefore have **much higher outgassing rates** than metals.

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

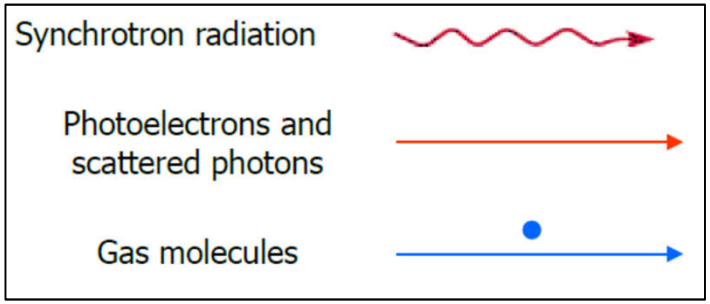
Dynamic outgassing

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

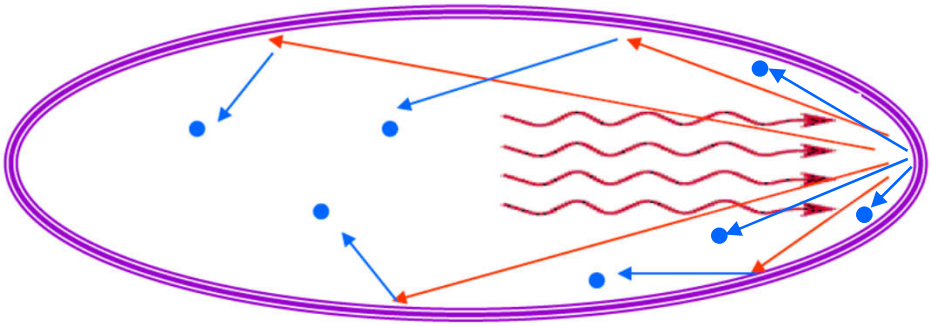


Photon Stimulated Desorption

When charged particles (moving at relativistic speeds) are accelerated they emit synchrotron radiation in a narrow cone. This photon flux impinging on vacuum surfaces 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

Dynamic outgassing

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

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

η – depends on many parameters:

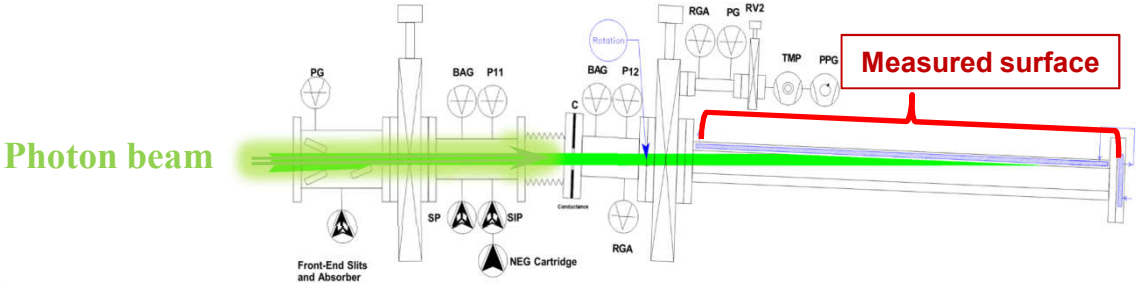
- incident particle: type, angle and energy,
- material,
- surface roughness,
- **cleanliness** of the surface,
- history of the material (dose),
- Particle flux.

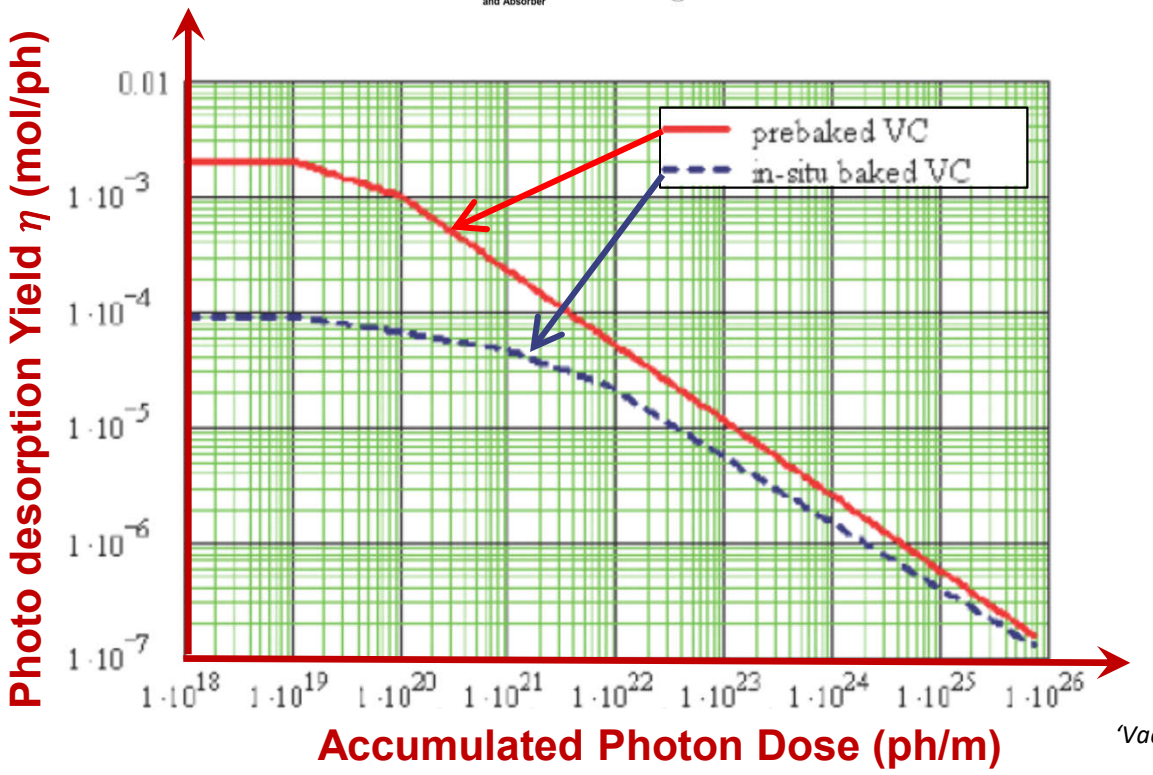
The desorption may be stimulated by:

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

Photon Stimulated Desorption

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:

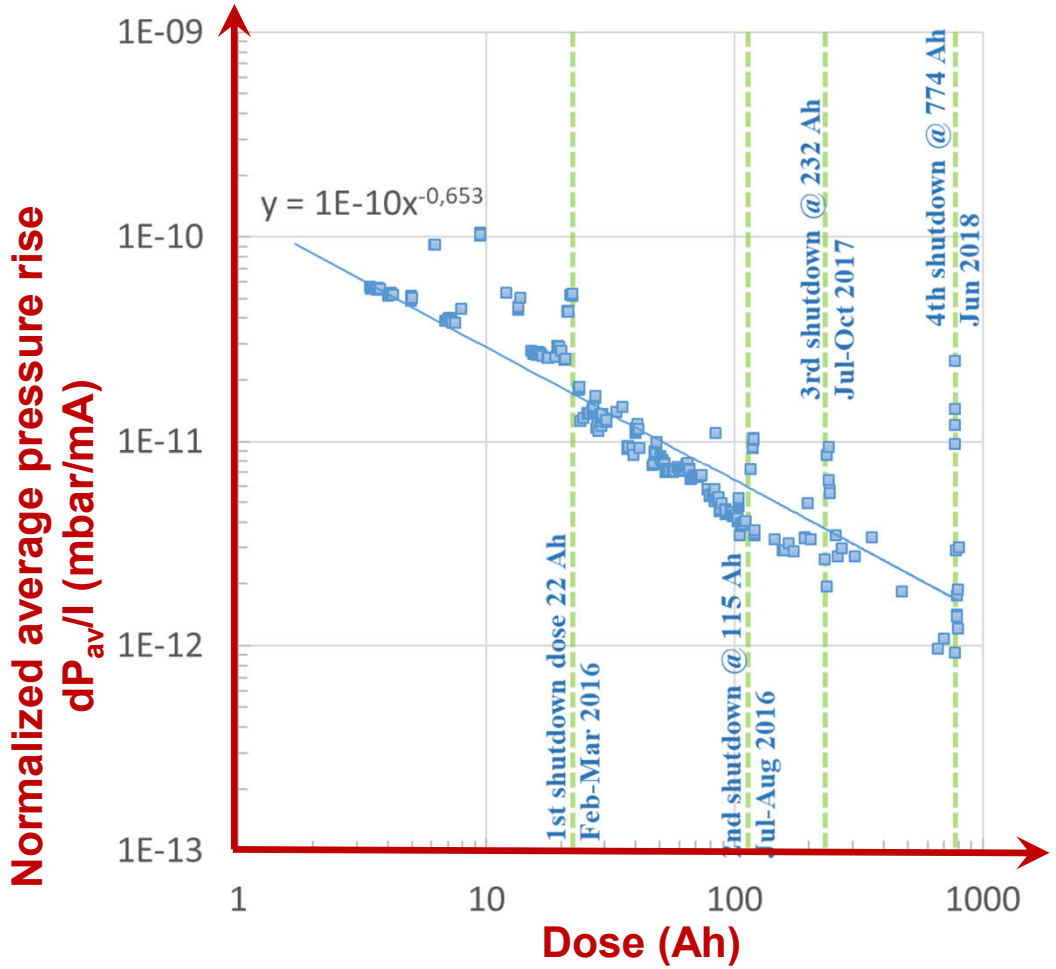
$$P \propto I$$

Dynamic pressure rise:

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

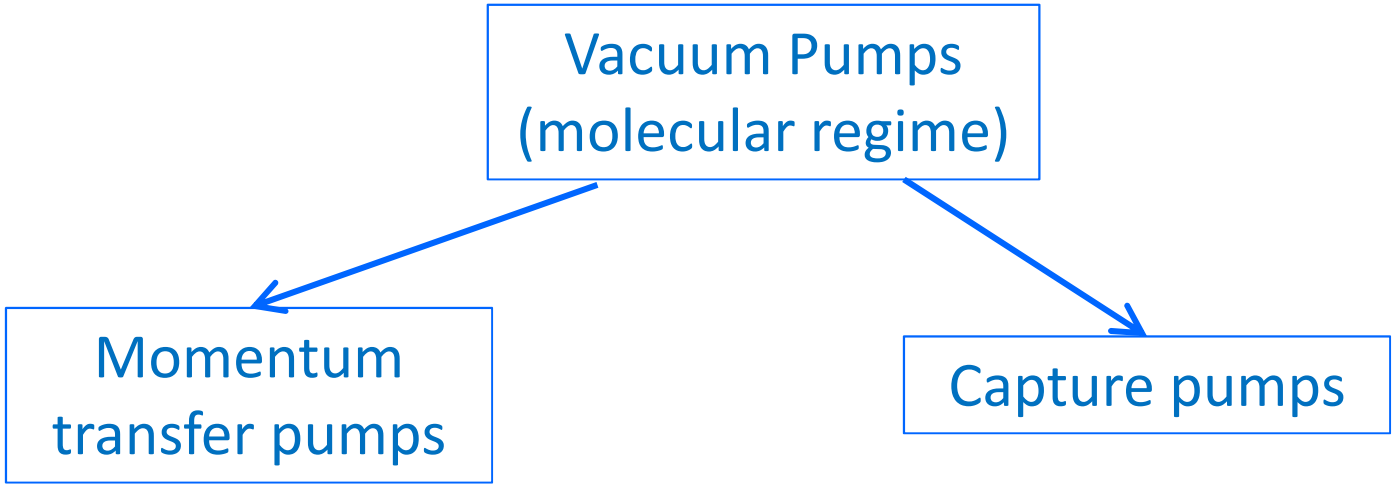
3 Gev ring vacuum conditioning:

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



Vacuum pumps and sensors

Pump clasification



Example: Turbomolecular Pump

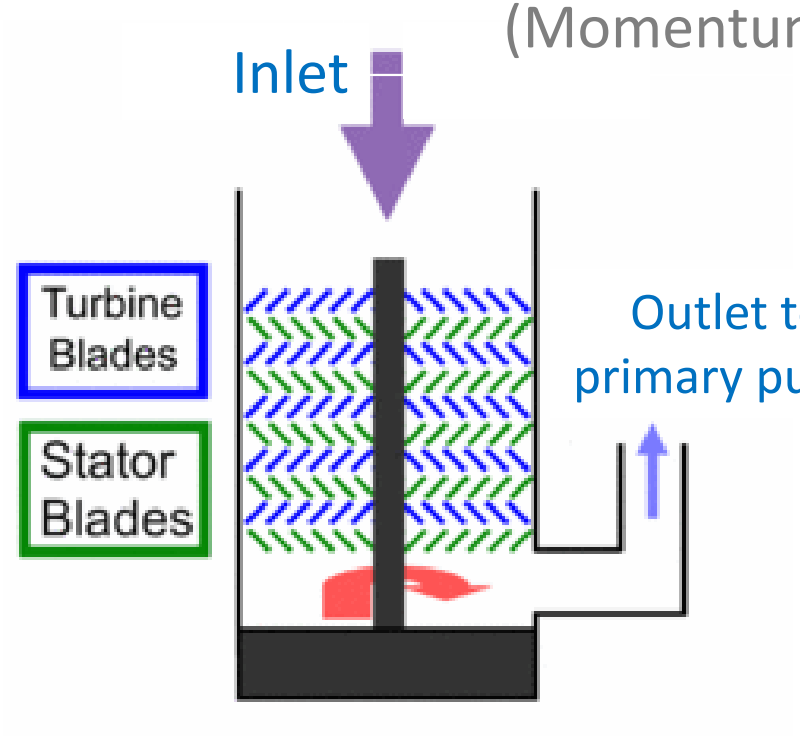
Principle: Molecules impinge on fast moving surfaces which direct them towards the pump outlet where they are evacuated by pumps operating in viscous flow. The molecules do not transfer energy to each other.

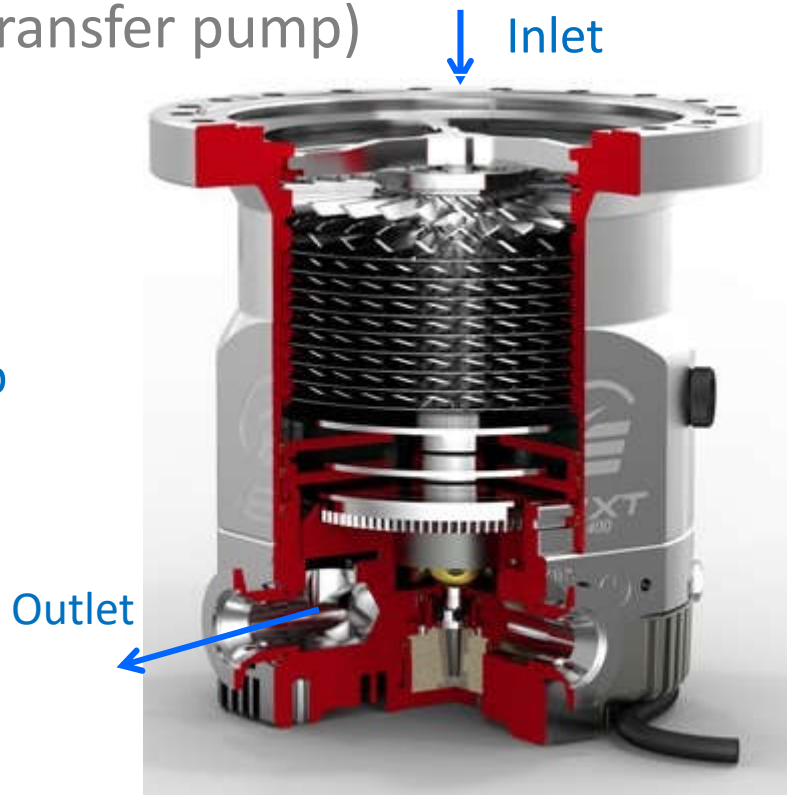
Example: Sputter Ion Pump, Getter pump, Cryo pump

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.

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

'Fundamentals of vacuum technology' (Leybold)

Turbomolecular Pumping station

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

Turbomolecular in series with primary pumps are widely used in particle accelerators to:

- evacuate vacuum systems from atmospheric to ultra high vacuum,
- Test (leak tests),
- Condition (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).

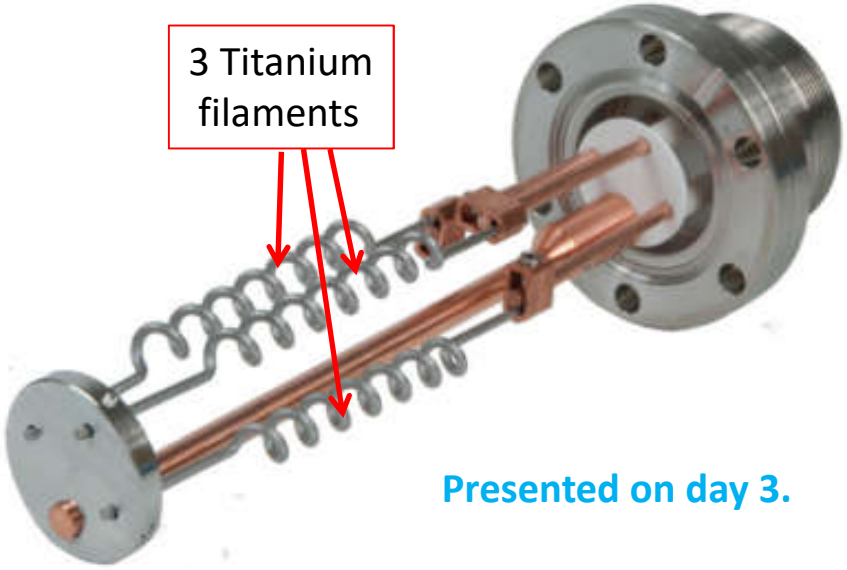
May be used for high gas loads at beamlines.

Presented on day 3.

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:

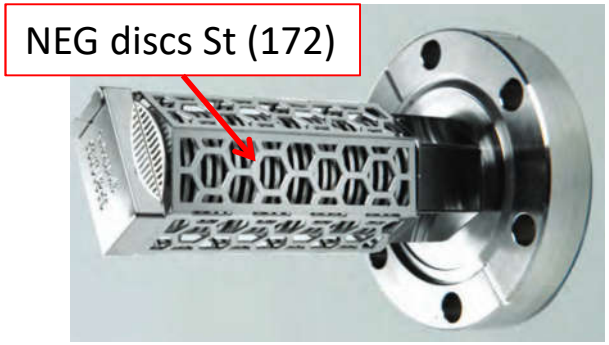
Sublimating (evaporating) at ~1500 deg C the reactive metal (Titanium) *in situ:* evaporable getters or sublimation pumps,



Presented on day 3.

Frequent sublimation needed as the reactive layer is thin and nonporous.

Dissolving the surface contamination into the bulk of the getter material by heating: non-evaporable getters (NEG); the dissolution process is called activation.



Full pumping speed obtained after heating at 450°C for 45 minutes.

Pump high quantities of gas without reactivation (cartridges are porous). After 40 venting cycles (with nitrogen) and reactivation 80% pumping speed is conserved.

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

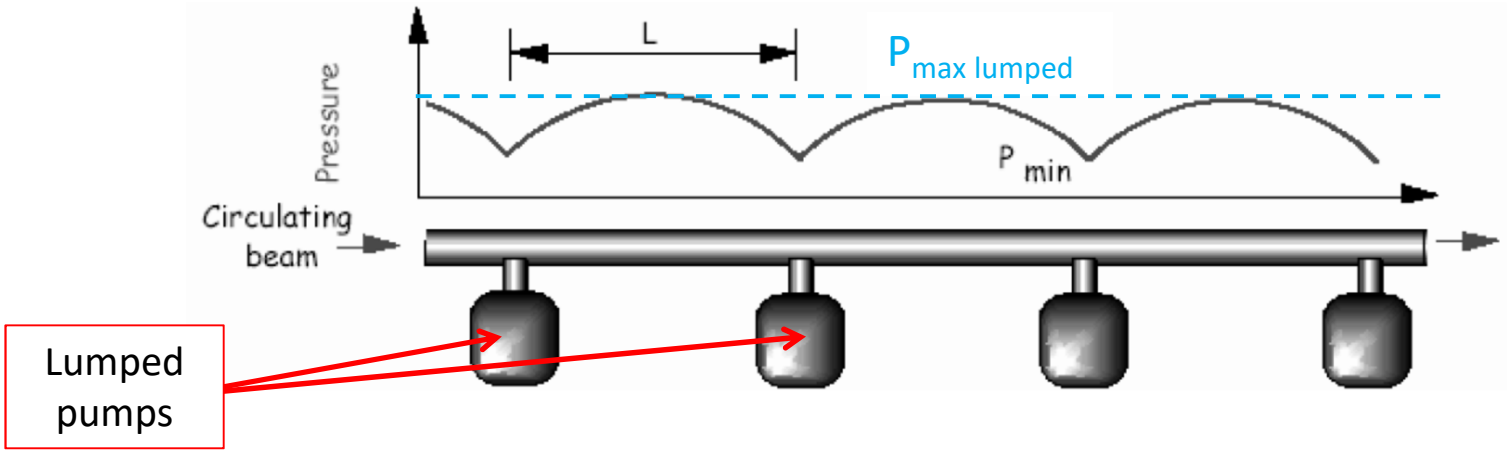
Paolo Chiggiato, Vacuum Technology for particle accelerators, 2013

Non-Evaporable Getters (NEG)

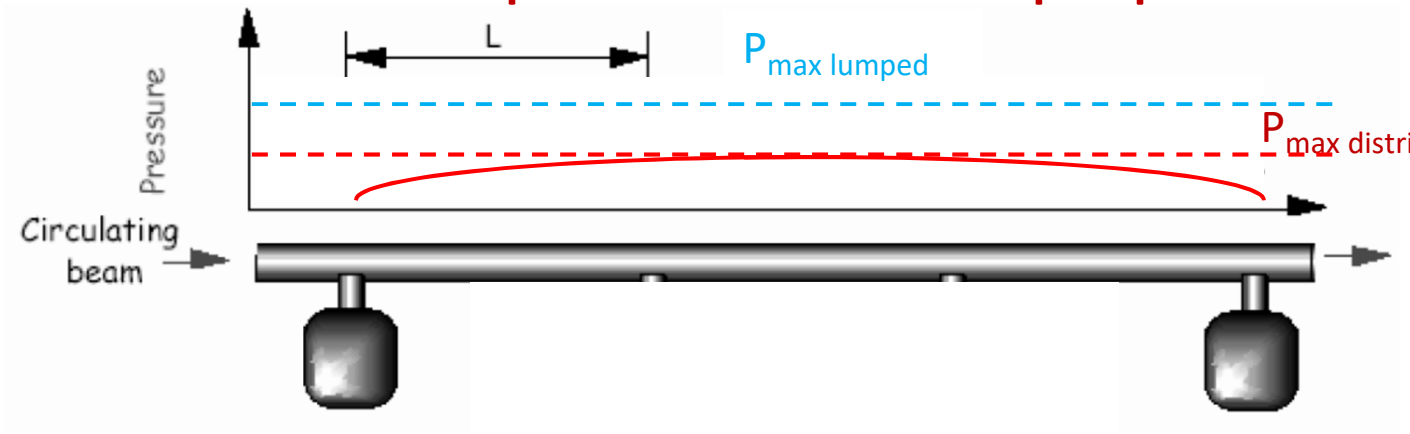
5 NEG pumps mounted on COSAXS Insertion Device (In-vacuum Undulator) inside 3 GeV storage ring.

Distributed pumping

Pressure profile with lumped pumps



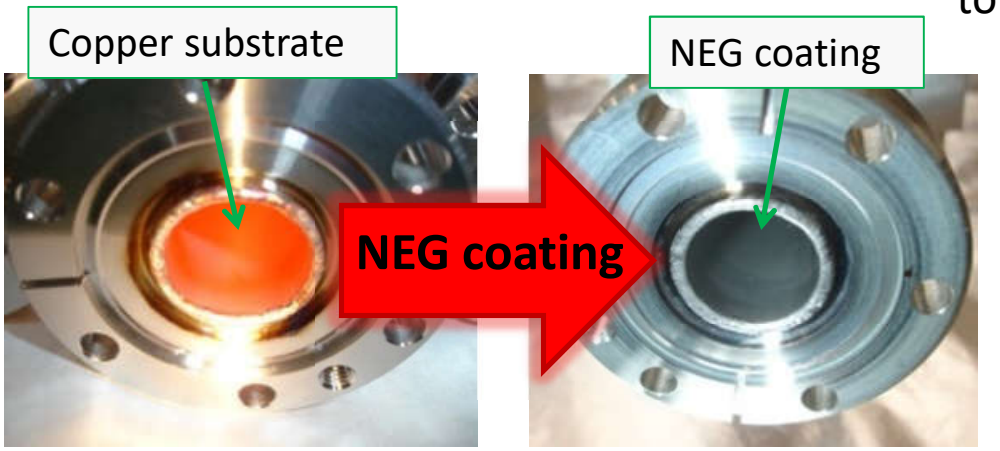
Pressure profile with distributed pumps



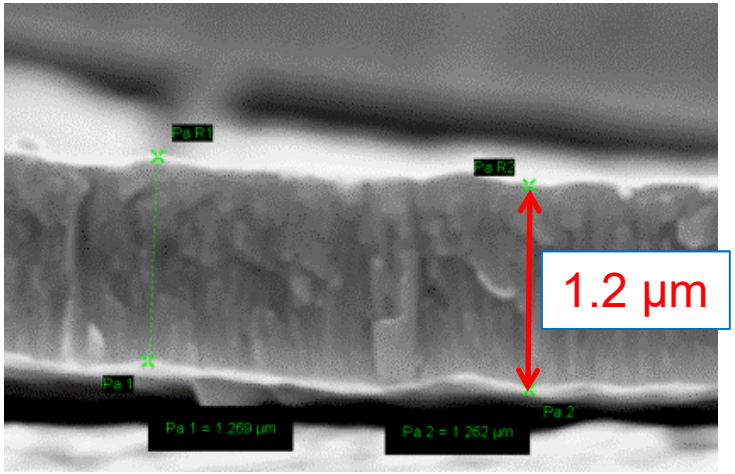
F. Mazzolini, 'The use of NEG pumps and coatings in large vacuum systems: experience and limitations', CAS 2006 Vacuum in accelerators

NEG coatings

NEG (Non-Evaporable Getter) 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.



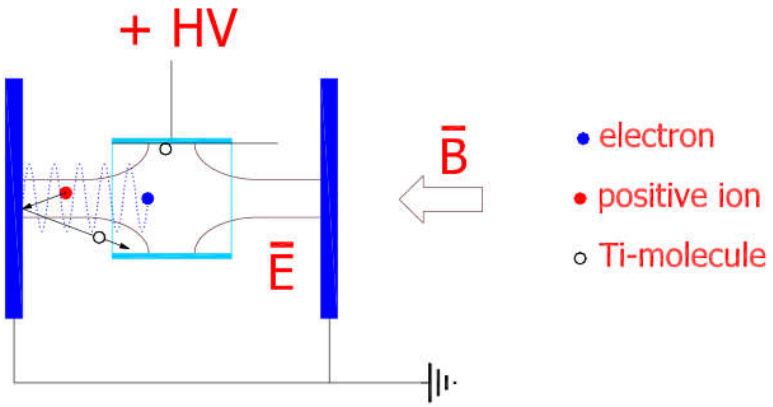
NEG film characteristics:

- 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.

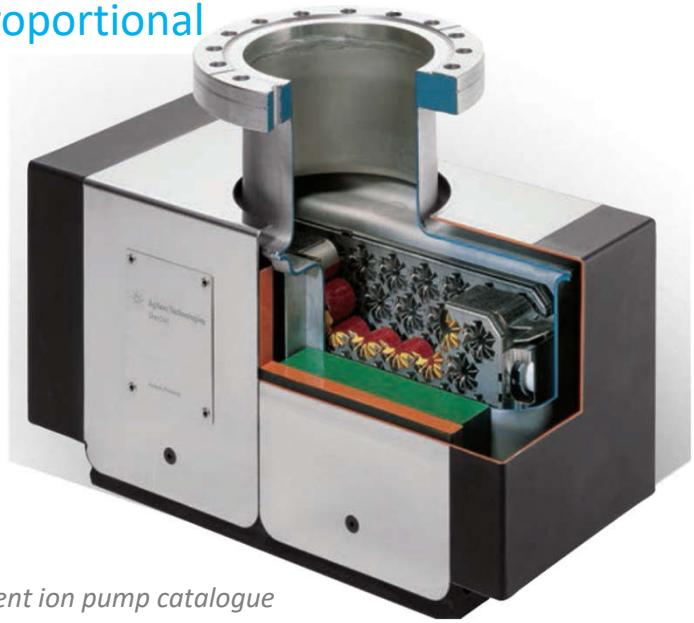
Sputter ion pumps

Penning cell



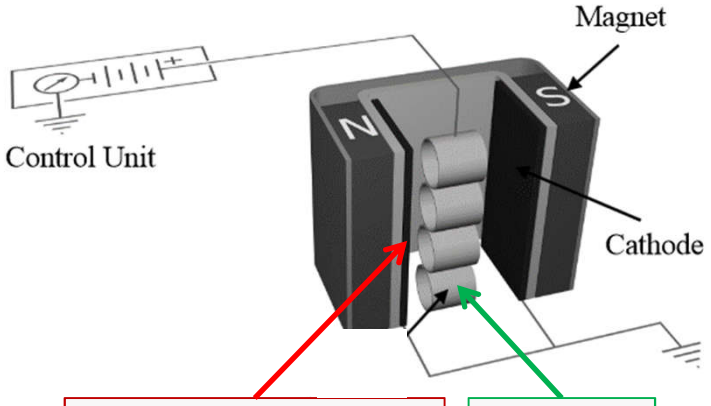
Used for pressure measurement as number of ions is proportional to pressure.

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

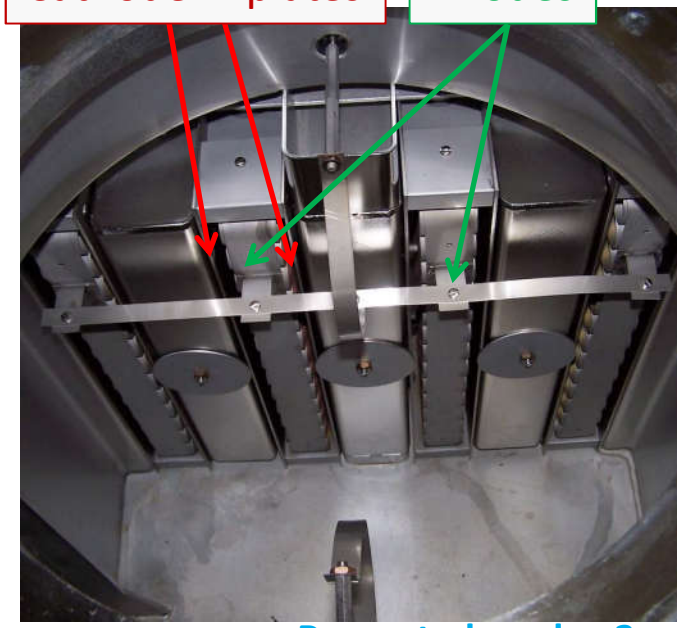


Agilent ion pump catalogue

Sputter ion pump



Cathode Ti plates | Anodes



L. Schulz, Sputter ion pumps, CAS 1999 proceedings

Presented on day 3.

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 = 0.2 l/s, 0.6 kg

S = 500 l/s, 260 kg

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

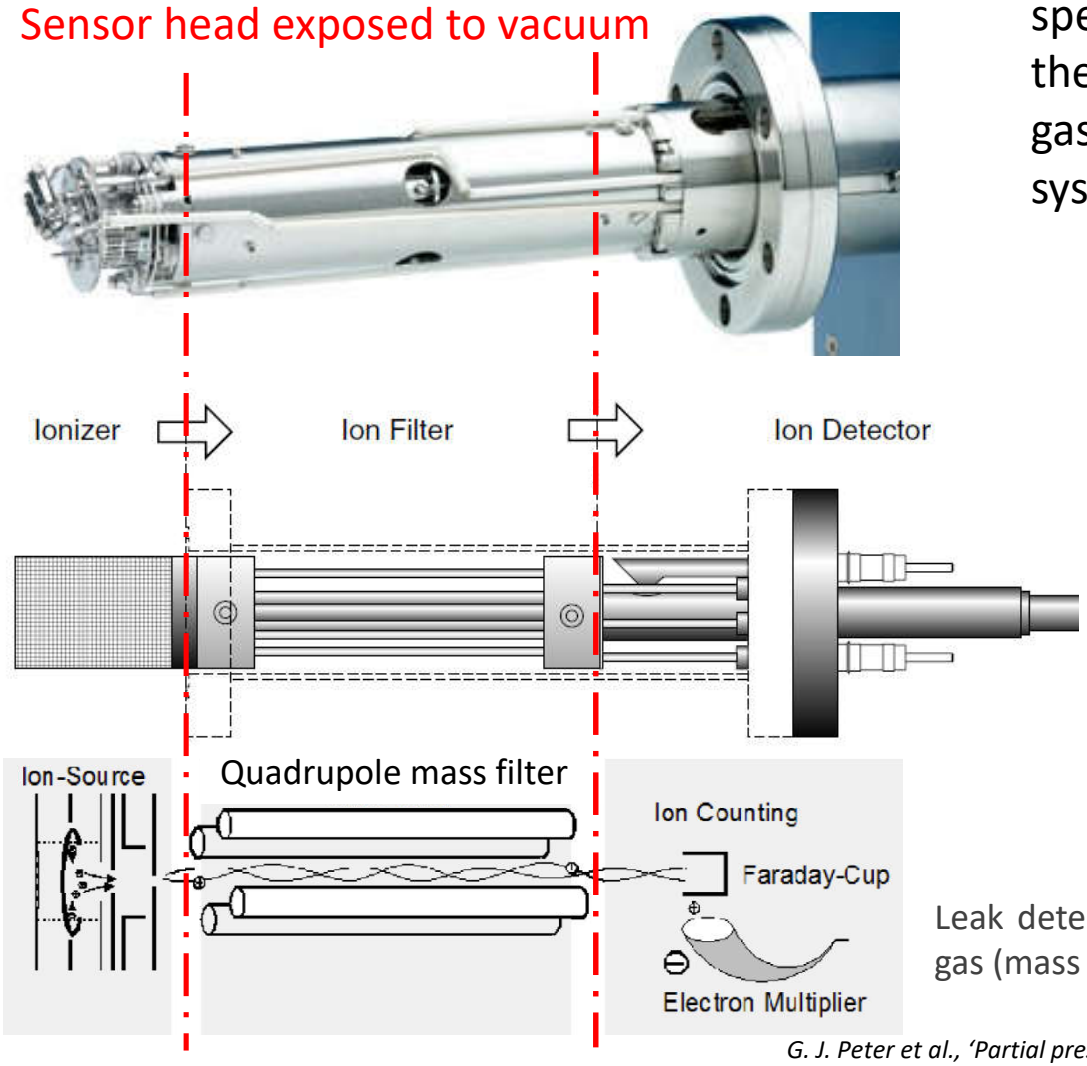
Gas	Air	N_2	O_2	H_2	CO	CO_2	H_2O	CH_4	Ar	He
Diode	1	1	1	1.5-2	0.9	0.9	0.8	0.6-1	0.03	0.1
Triode	1	1	1	1.5-2	0.9	0.9	0.8	0.6-1	0.25	0.3

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

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. **Presented on day 3.**

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.

Leak detectors – mass spectrometers set for helium gas (mass 4) usually combined with pumping system.

Presented on day 3.

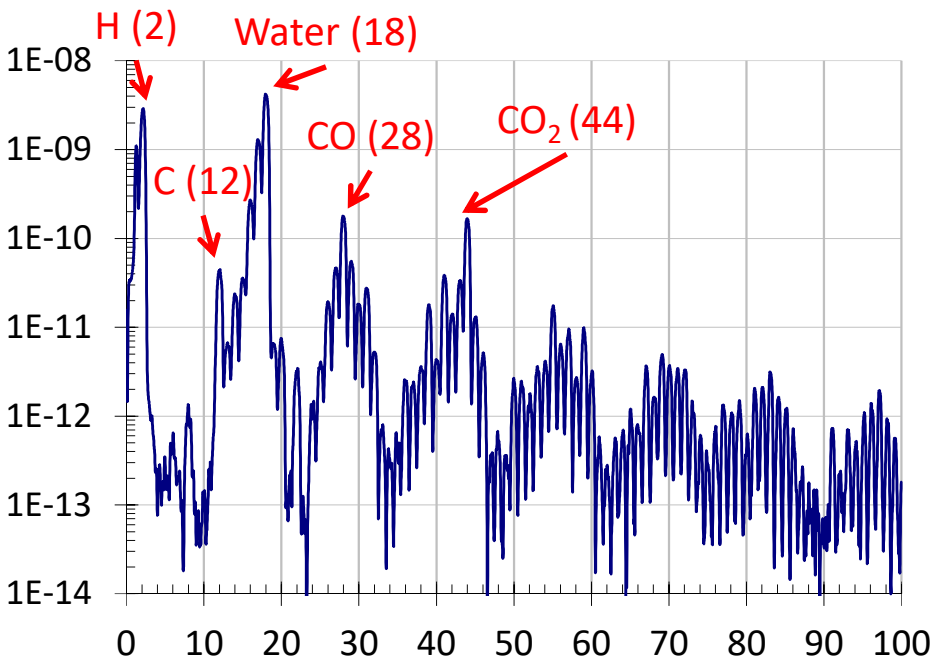
G. J. Peter et al., 'Partial pressure gauges', Vacuum in Accelerators, CAS 2006 proceedings

http://www.hidenanalytical.com/

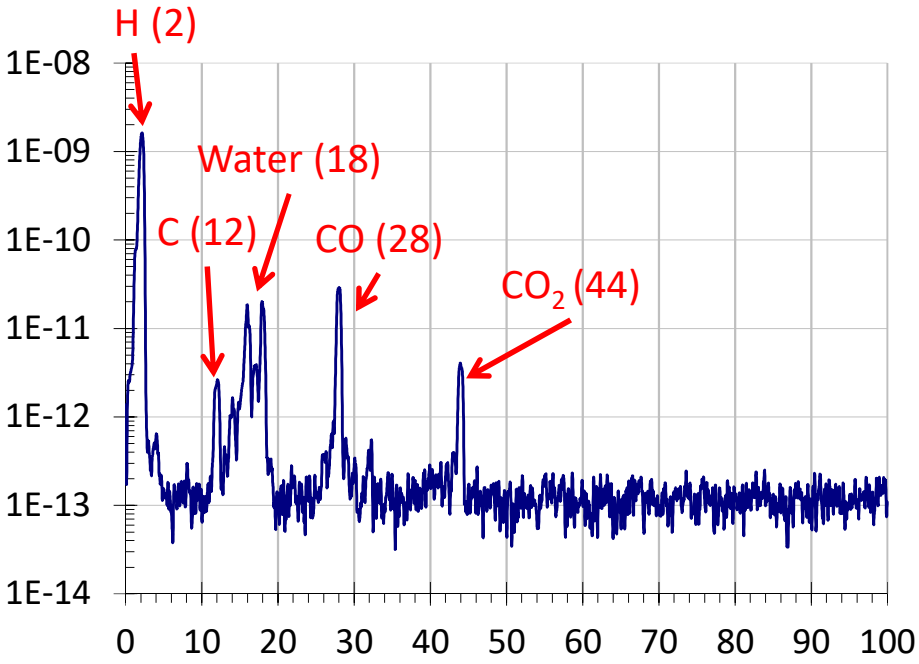
Partial pressure measurement

Residual gas spectrums of an UHV system:

at total pressure $4x10^{-9}$ mbar



at total pressure $4x10^{-11}$ mbar

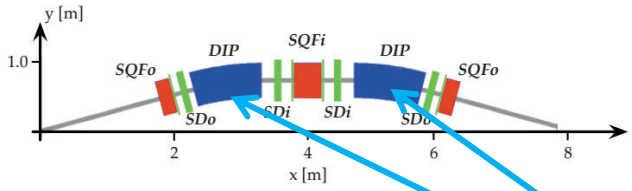


Paolo Chiggiato, Vacuum Technology for particle accelerators, 2013

MAXIV 3 GeV storage ring layout and design

Storage ring layout

1.5 GeV double-bend achromat (DBA) lattice:

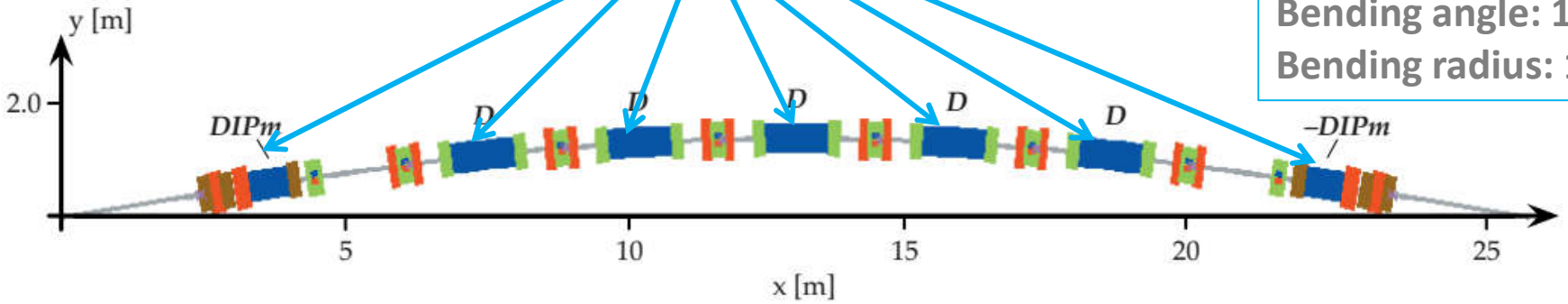


2 dipoles,
Bending angle: 30^0
Bending radius: 3.8 m

Energy:	**1.5 GeV**
Horizontal Emittance (bare lattice):	**6 nm rad**
Circumference:	**96 m**
#straight sections:	**12 x 3.3 m**

Dipole magnets

3 GeV 7-bend achromat lattice:



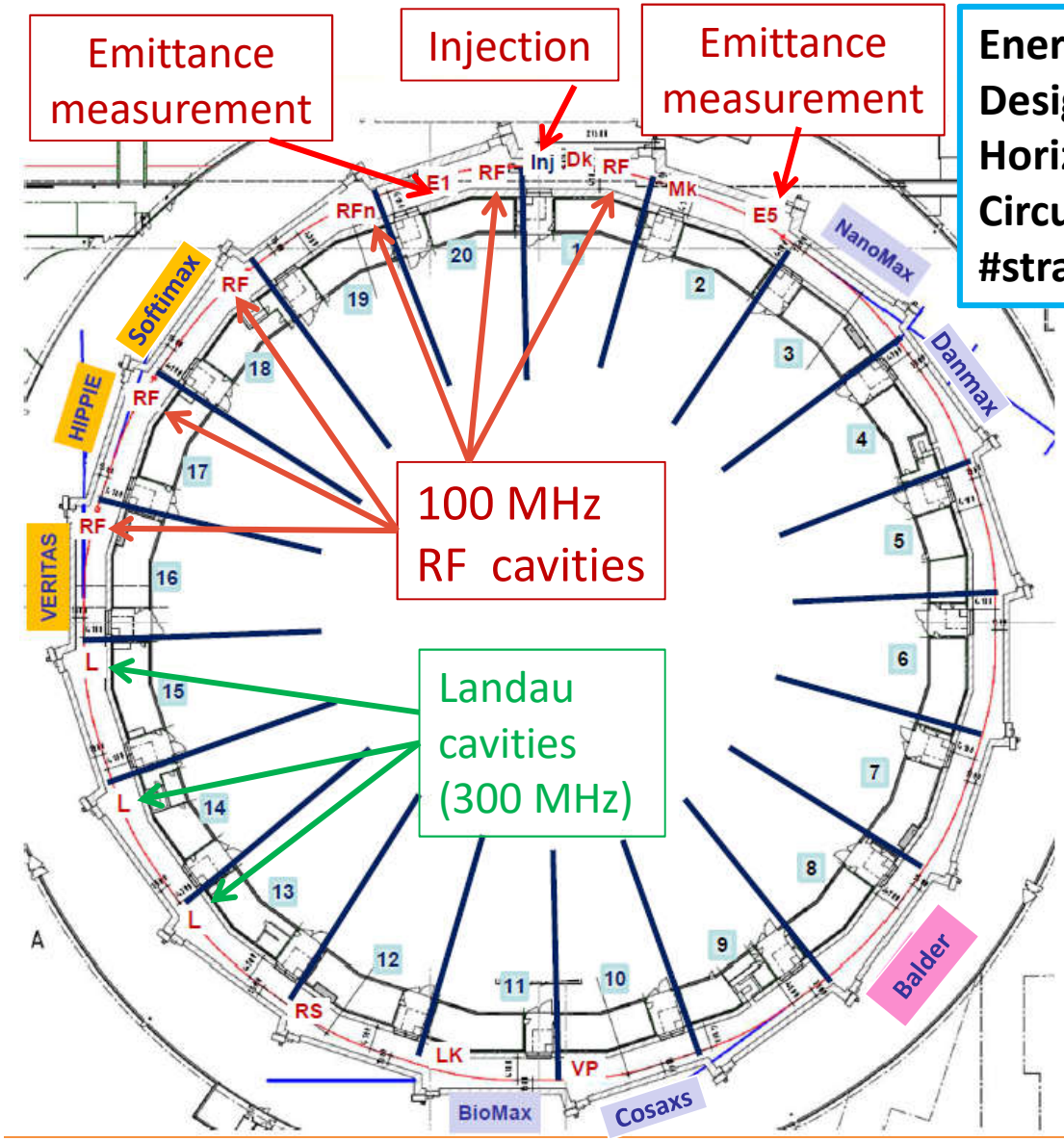
7 dipoles,
Bending angle: 18^0
Bending radius: 19 m

Lattice of choice for the 3 GeV ring: 7-bend achromat (multi-bend achromat). Choice of such lattice puts major constraints on the vacuum system design.

Energy:	**3 GeV**
Horizontal Emittance (bare lattice):	**0.33 nm rad**
Circumference:	**528 m**
#straight sections:	**20 x 4.5 m**

MAX IV DDR

3 GeV ring layout



Energy:	**3 GeV**
Design current:	**500 mA**
Horizontal Emittance:	**0.33 nm rad**
Circumference:	**528 m**
#straight sections:	**20 x 4.5 m**

Installed Insertion Devices:

4 In-vacuum Undulators:
- NanoMAX, BioMAX, Cosaxs, Danmax,

3 EPU (4 m long, min gap 11 mm):
- VERITAS, HIPPIE, Softimax

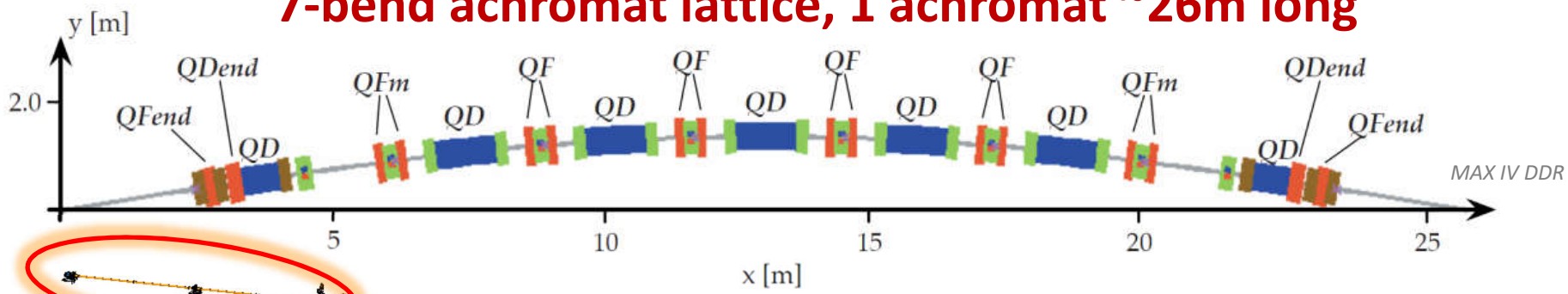
1 In-vacuum Wiggler (2.4 m long):
- BALDER IVW50

Legend:
- **Dk: Dipole kicker (S1)**
- **Mk: Multipole kicker (L)**
- **LK: Longitudinal kicker (S2)**
- **VP: Vertical pinger (S2)**

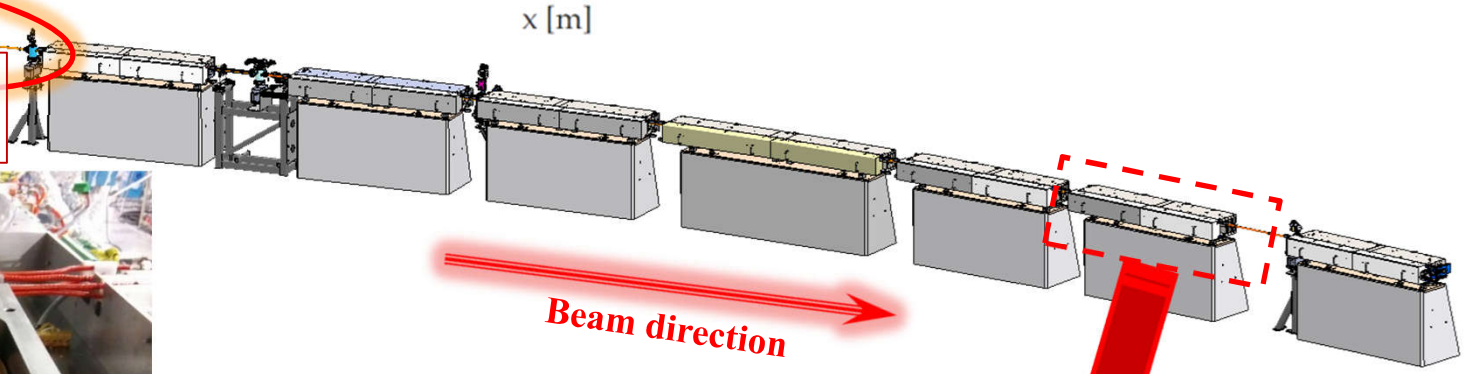
L=long straight,
S=short straight,

3 GeV achromat layout

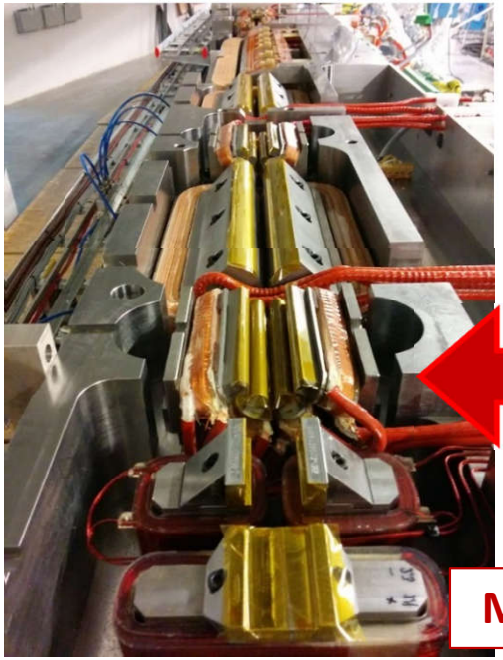
7-bend achromat lattice, 1 achromat ~26m long

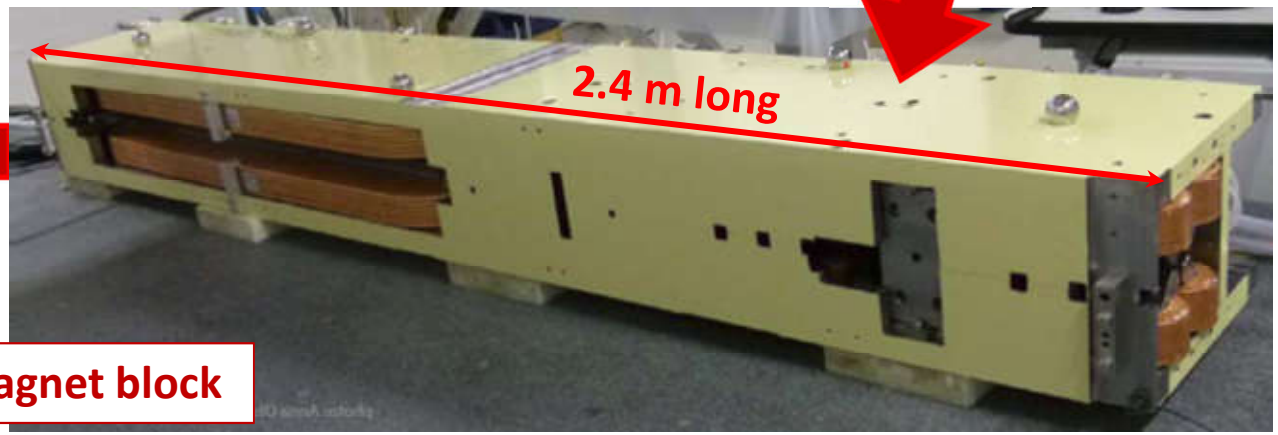


Straight section for insertion devices



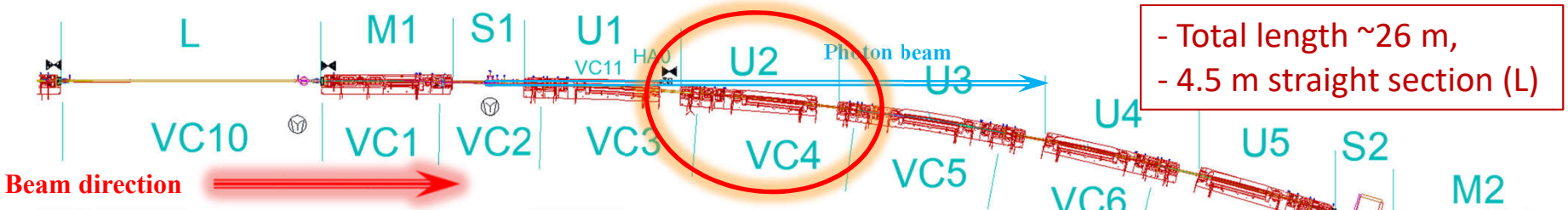
Beam direction



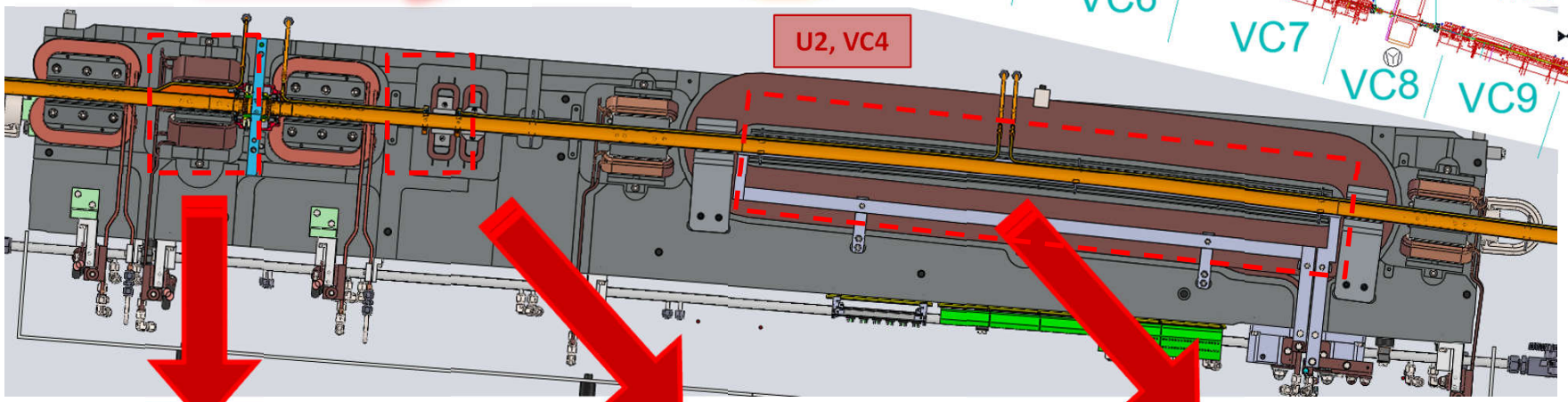


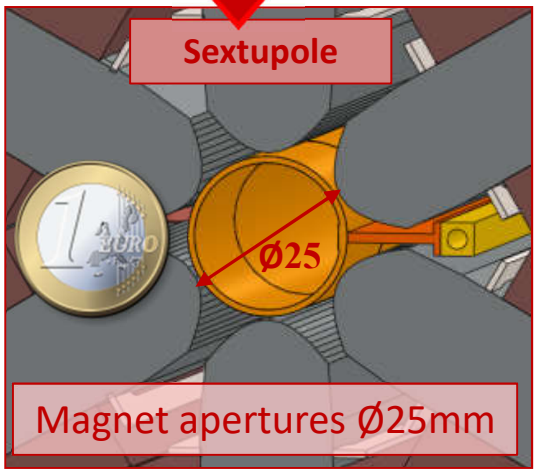
Magnet block

3 GeV magnet layout

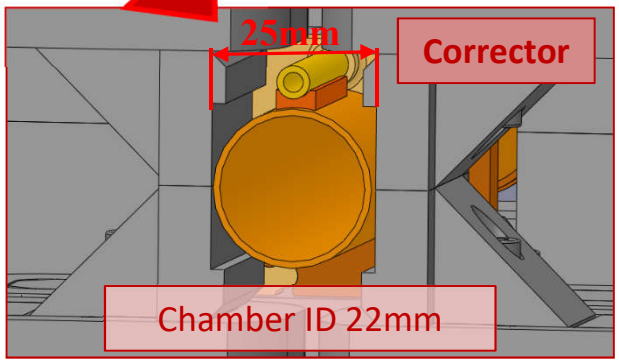


- Total length ~26 m,
- 4.5 m straight section (L)

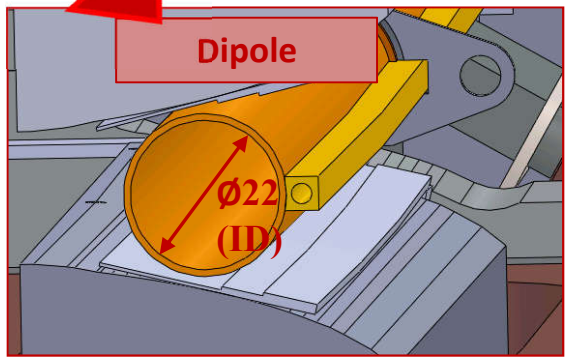




Magnet apertures Ø25mm



Min. clearance with the iron 0.5 mm



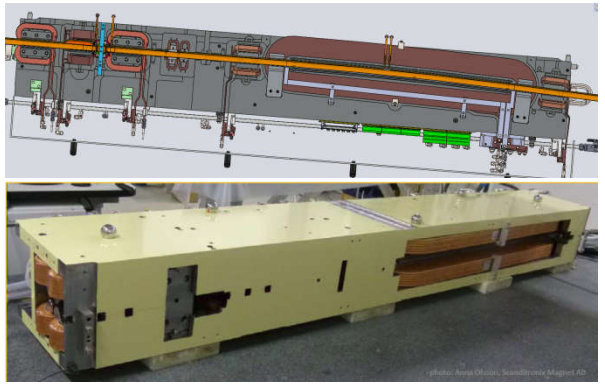
NEG coating + 3 ion pumps per achromat

Vacuum system constraints and requirements

- **Compact lattice**

  Small longitudinal distance between magnets.

No space for lumped absorbers



- **Closed solid magnet block**

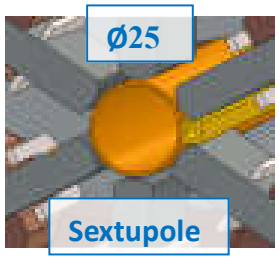
  Little place around the magnets.

No space for lumped pumps

- **Small aperture of the magnets**

  Magnets' aperture Ø25 mm.

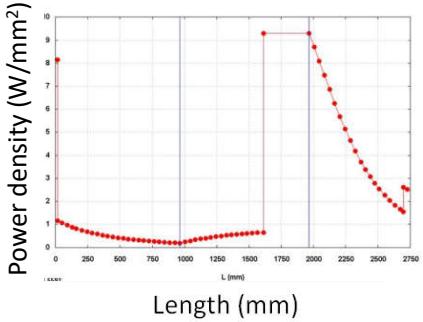
Low conductance of vacuum tubes



- **Low target dynamic pressure**

  Average pressure 1e-9 mbar.

Need of pumping and low PSD

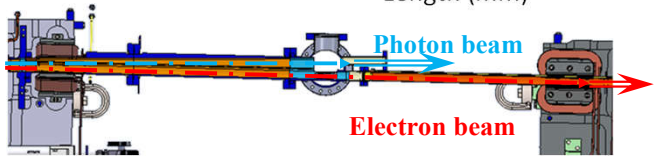


- **Removal of the SR power (BM & ID)**

  Power density along bent vacuum chamber walls and absorbers.

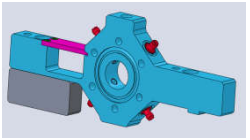
- **Extraction of synchrotron radiation**

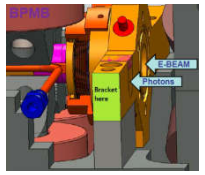
  Limited by small bending angle.



- **Stable positioning of BPM**

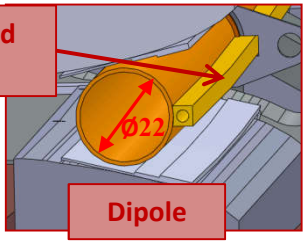
  Disentangling the BPMs from the chambers.

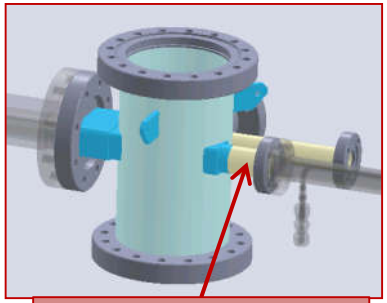


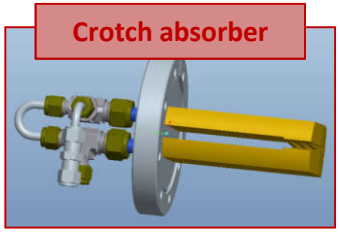


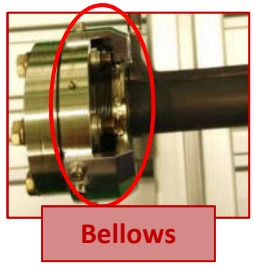
Vacuum system approach

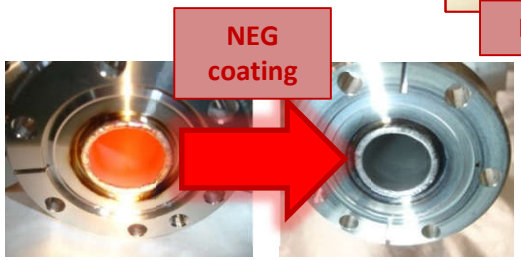
- **Geometry**: inside diameter **22 mm**, **1 mm** wall thickness, bends of 1.5^0 and 3^0 over 19 m radius.
- **Substrate: Silver bearing (OFS) Copper** vacuum chambers (resistance to thermal cycling)**.**
- **Distributed water cooling** to cope with SR**.**
- Areas made of **stainless steel** for fast corrector coils.
- One **Lumped absorber** per achromat needed to extract the photon beam to the front ends.
- **Welded bellows** at vacuum chamber extremities to allow expansion without affecting the BPM position and temperature.
- Distributed pumping and low PSD all along the conductance limited chamber, utilizing thin film **NEG-coating**.



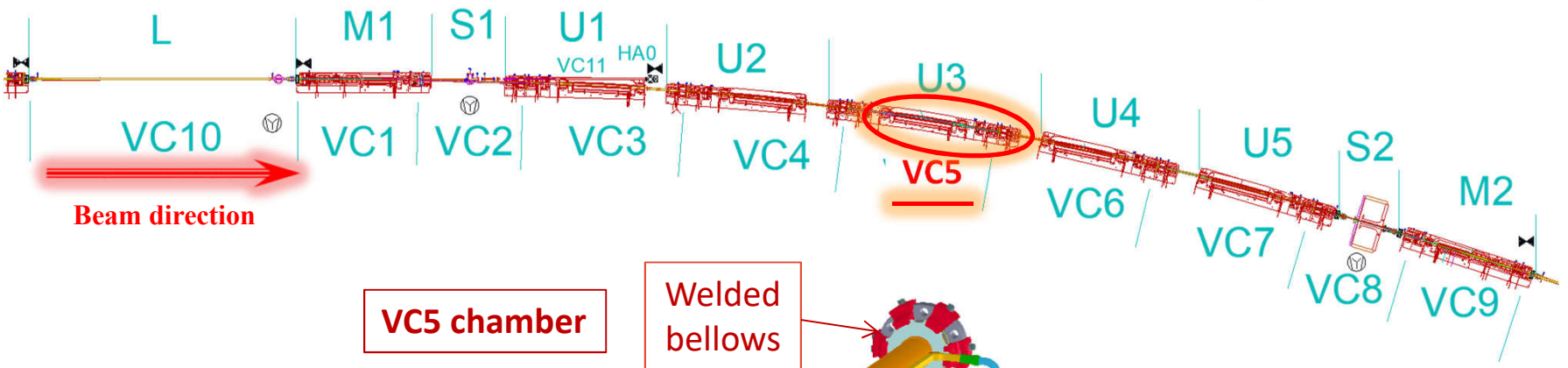


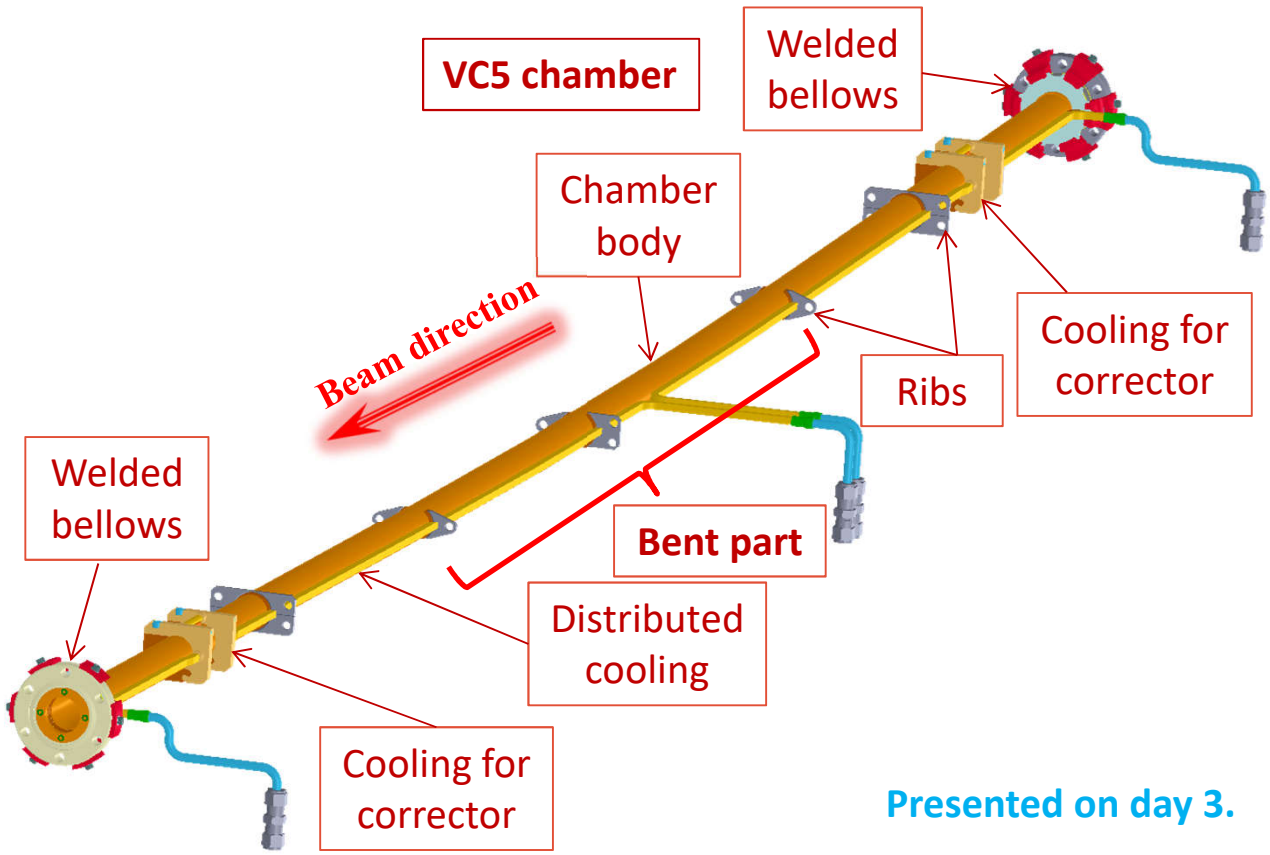






Standard vacuum chamber geometry





Material: OFS copper

Inside diameter: 22 mm,
Total length: 2.5 m,

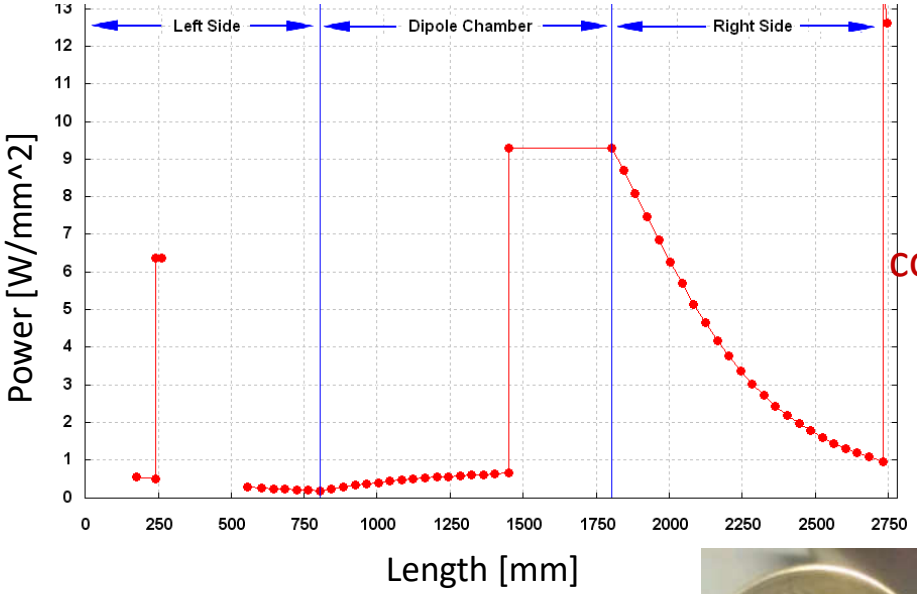
Bent part
Arc length: 1 m,
Bending angle: 3^0,
Bending radius: 19 m.

NEG-coated.

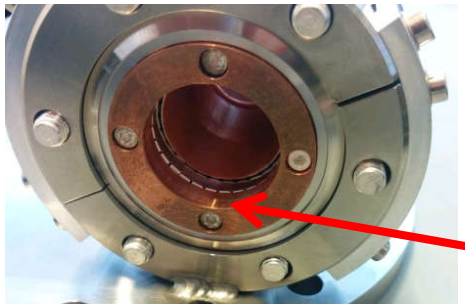
Presented on day 3.

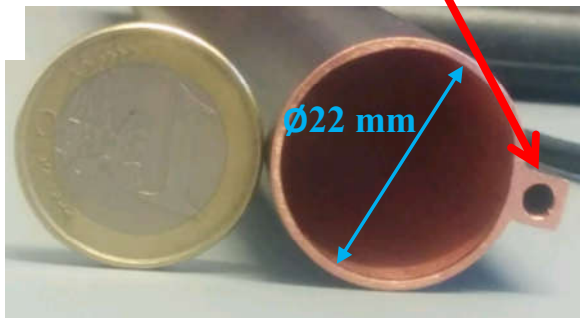
3 GeV standard vacuum chamber geometry

Power density deposited by synchrotron radiation on the outer wall of vacuum chamber vs. length



NEG coated inside





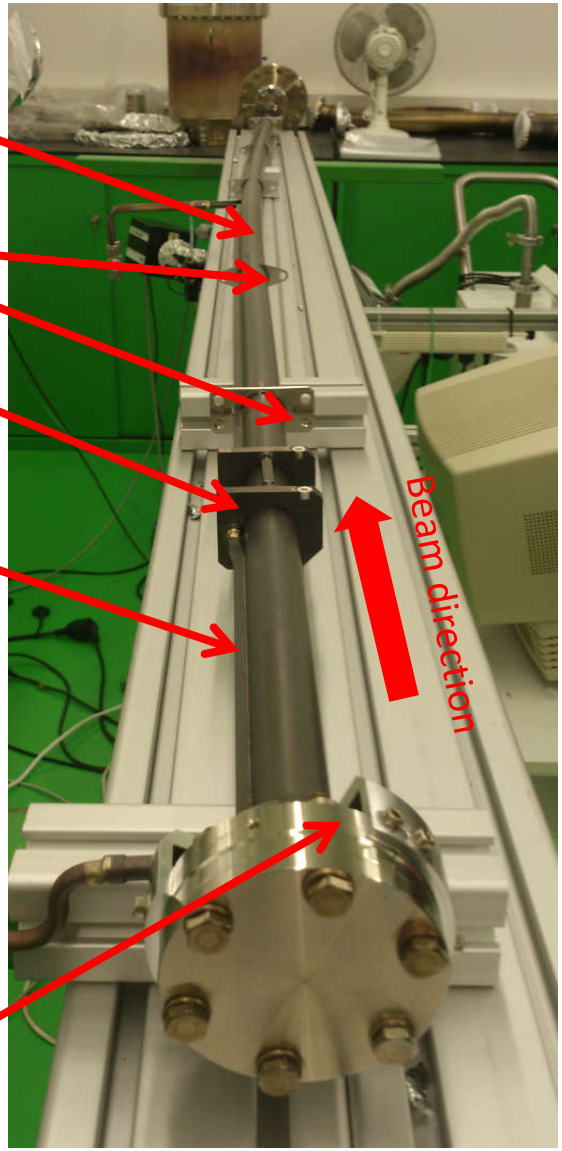
Copper Chamber body

Ribs

Cooling for corrector area

Distributed cooling

Welded bellows with RF shielding

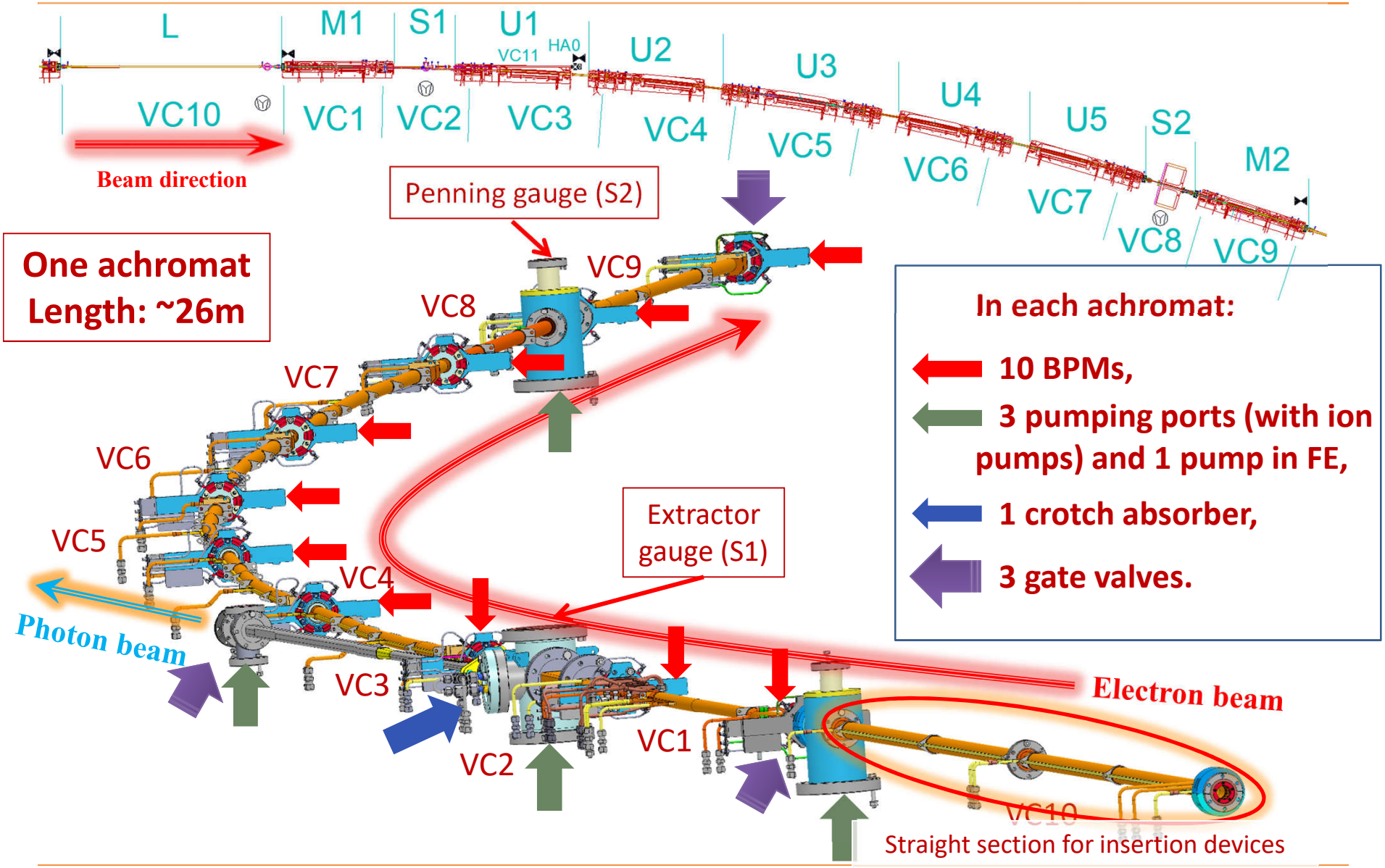


Consequences of excess power

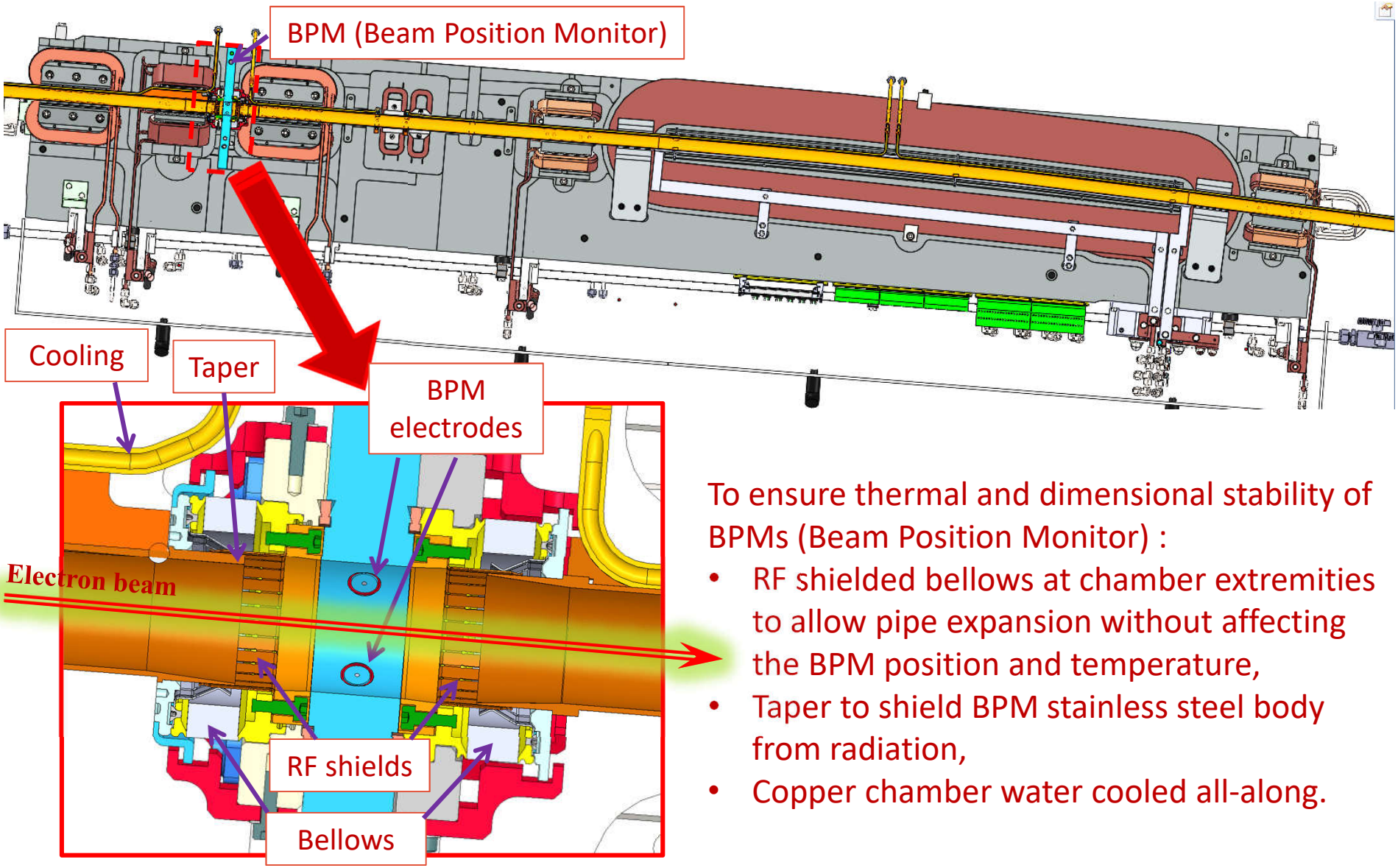
Melted hole in fast closing vacuum valve titanium plate due to undulator beam

Diamond Light Source Vacuum Systems: The First Seven Years of User Operations, OLAV IV 2014, Matthew Cox

Vacuum achromat layout



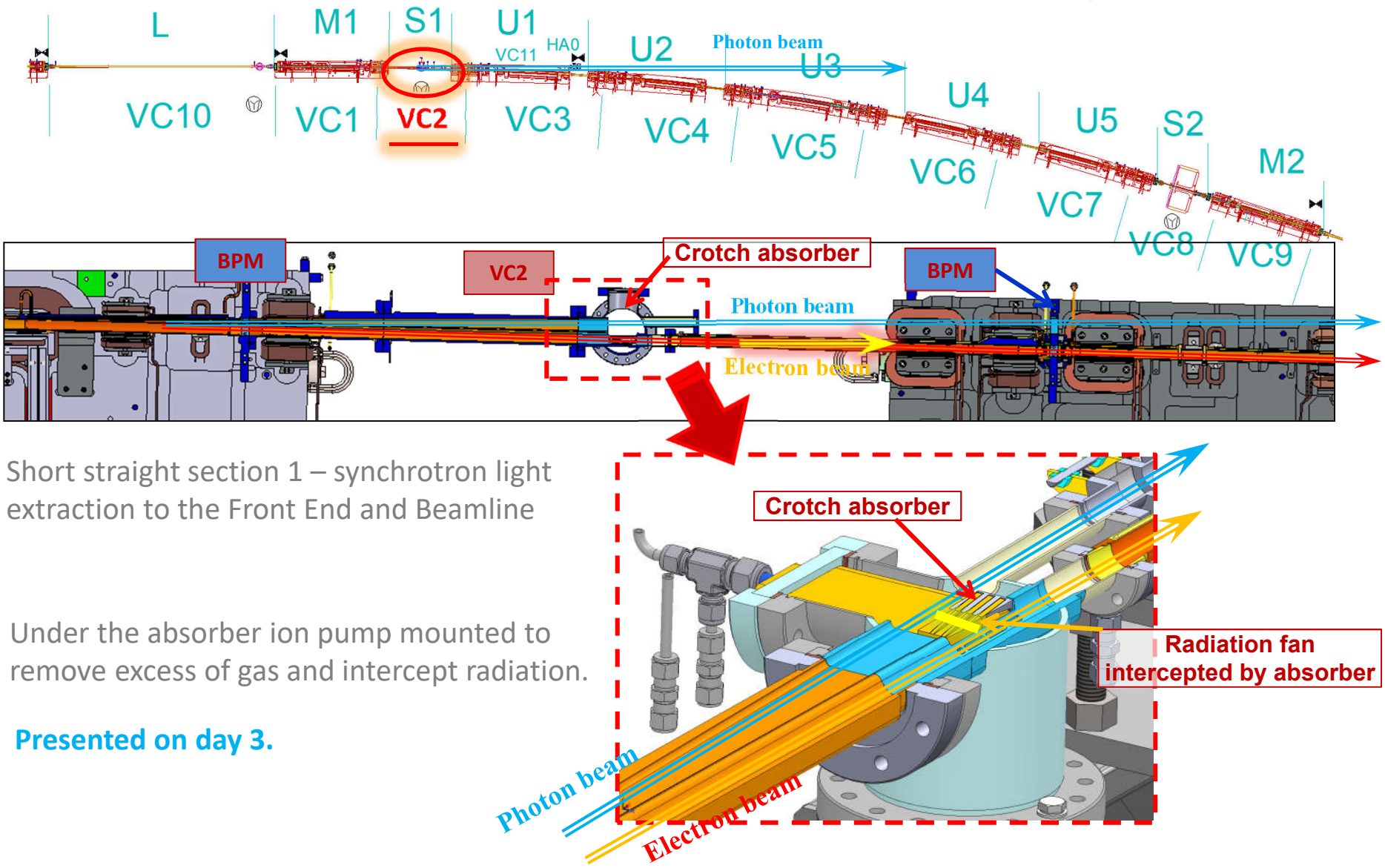
BPM stability



To ensure thermal and dimensional stability of BPMs (Beam Position Monitor) :

- RF shielded bellows at chamber extremities to allow pipe expansion without affecting the BPM position and temperature,
- Taper to shield BPM stainless steel body from radiation,
- Copper chamber water cooled all-along.

Synchrotron light extraction



Short straight section 1 – synchrotron light extraction to the Front End and Beamline

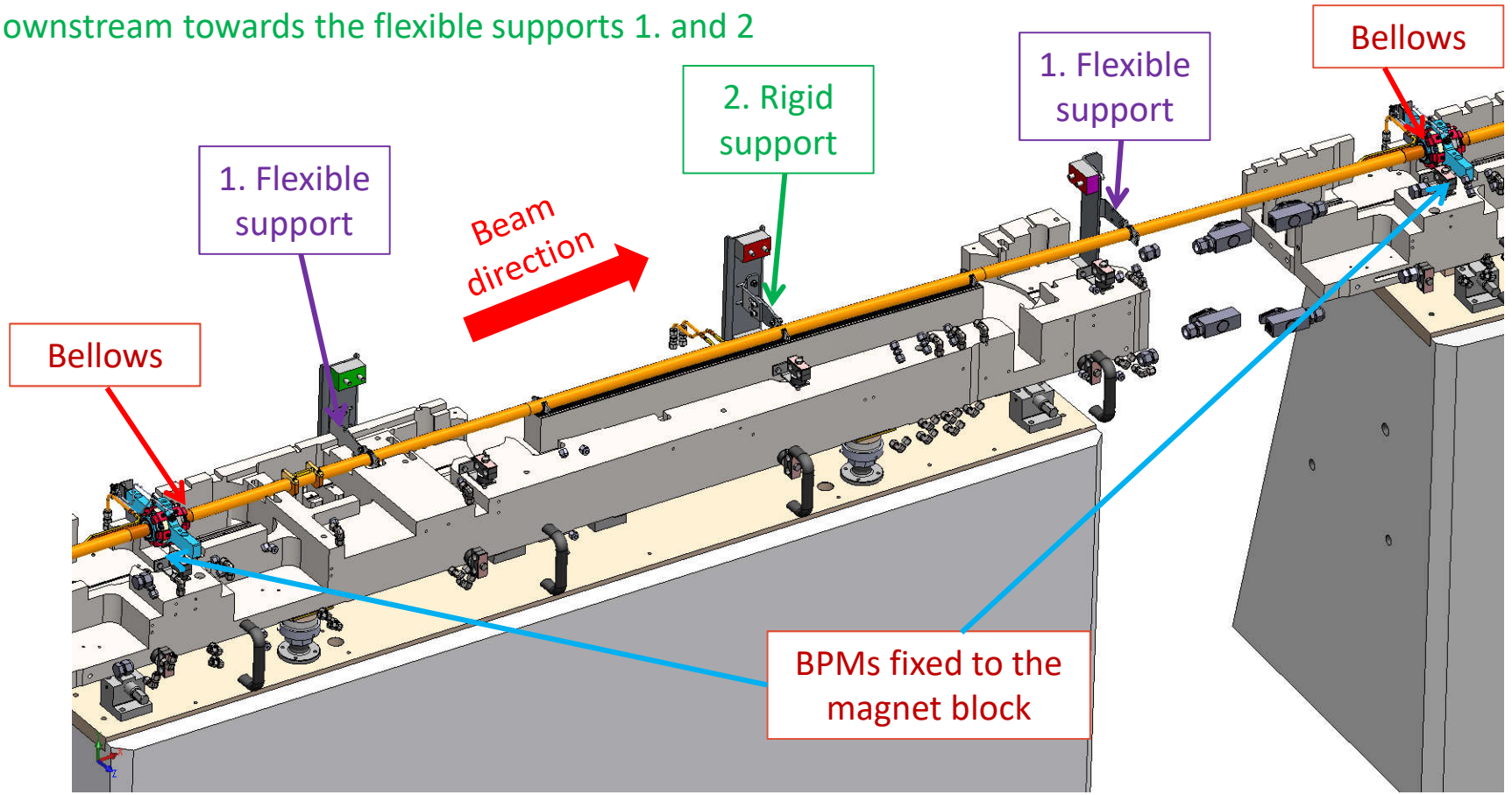
Under the absorber ion pump mounted to remove excess of gas and intercept radiation.

Presented on day 3.

Chamber fixation

1. Flexible support: allows longitudinal movement of the chamber in order to release the stresses from the chamber and block the transversal movement.

2. Rigid support: fixes the chamber in the middle of the dipole part and keeps the chamber in its nominal position both in transversal plane and longitudinally, allowing the chamber to expand upstream and downstream towards the flexible supports 1. and 2

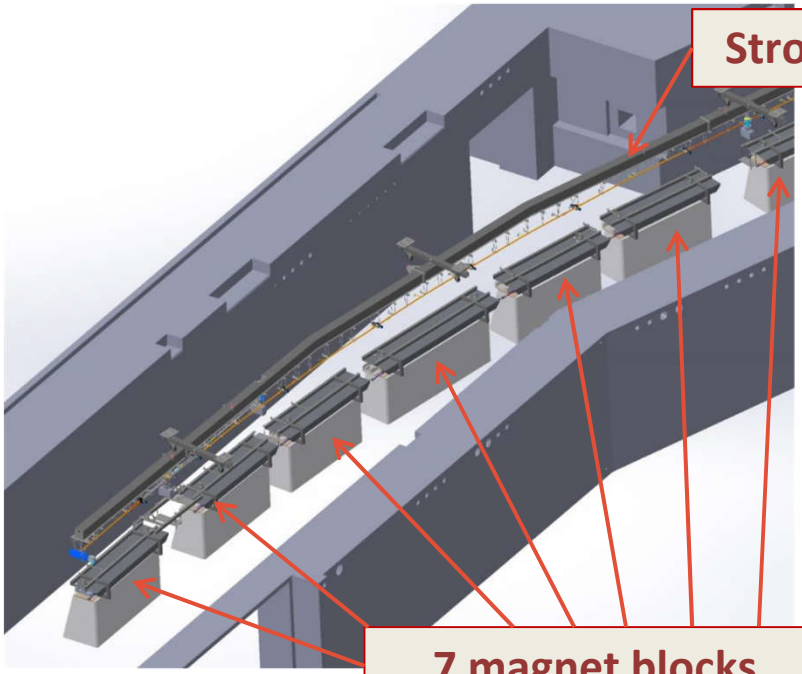


MAXIV 3 GeV storage ring installation

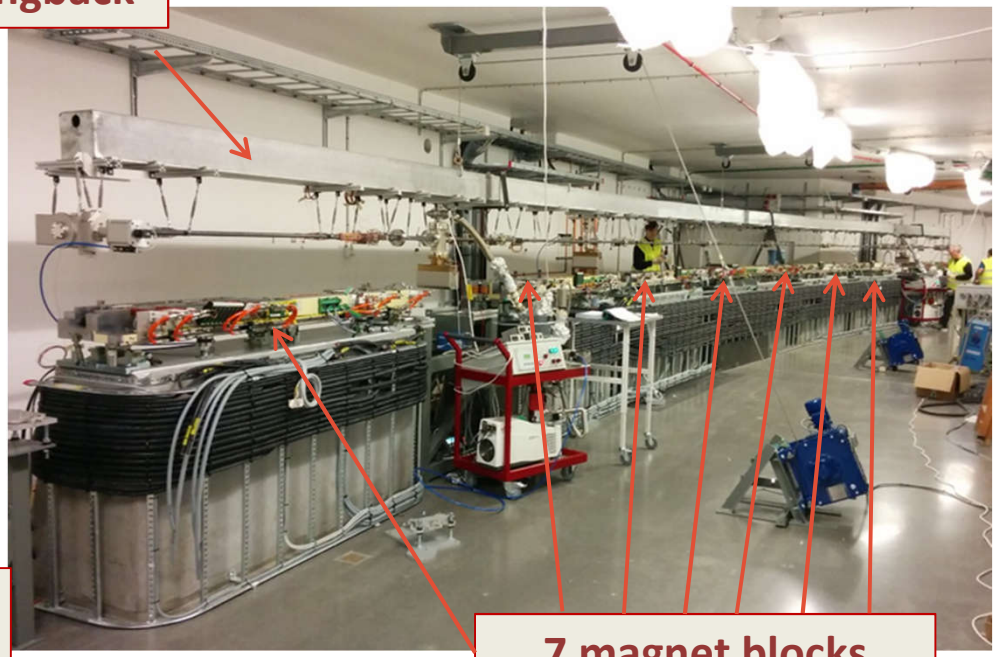
Installation procedure

Installation of NEG-coated ring

Tunnel view

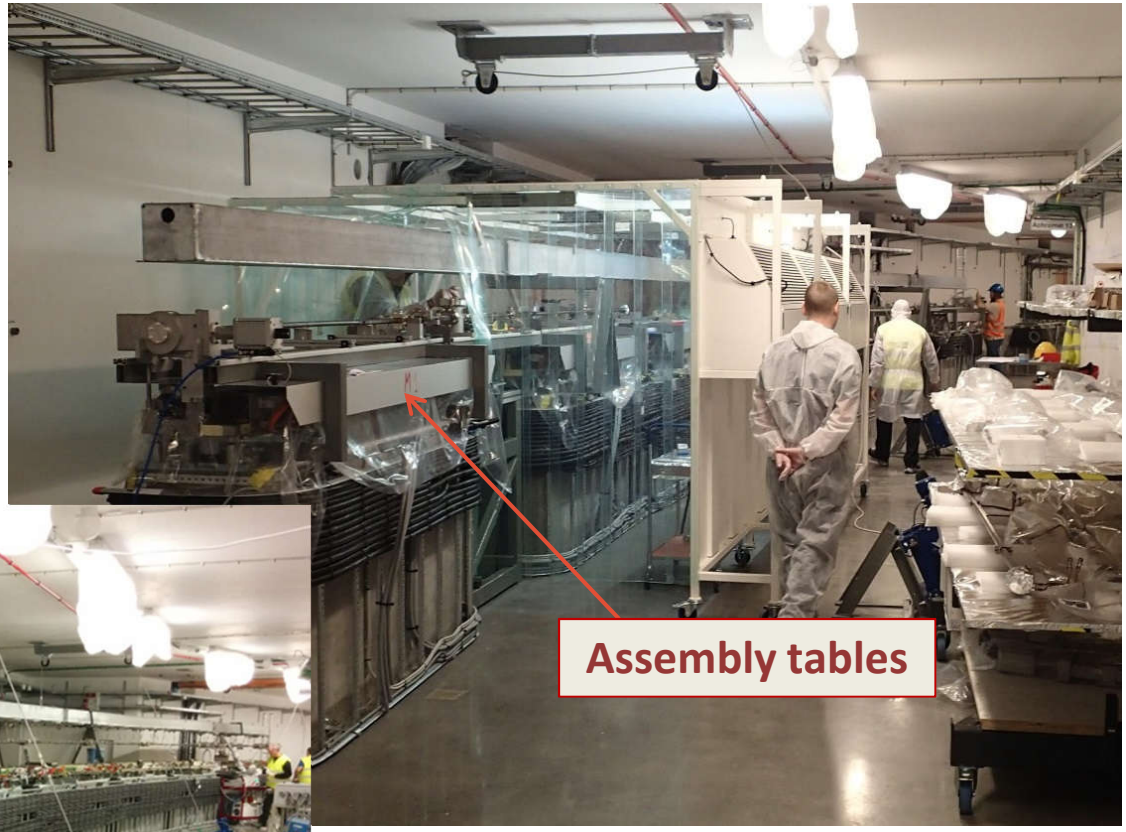


Actual installation started in
November 2014, ended June 2015



Installation procedure

- Assembly insitu (above magnets),
- **Pumpdown with turbomolecular pumping stations and leak testing with leak detectors,**
- Lifting,

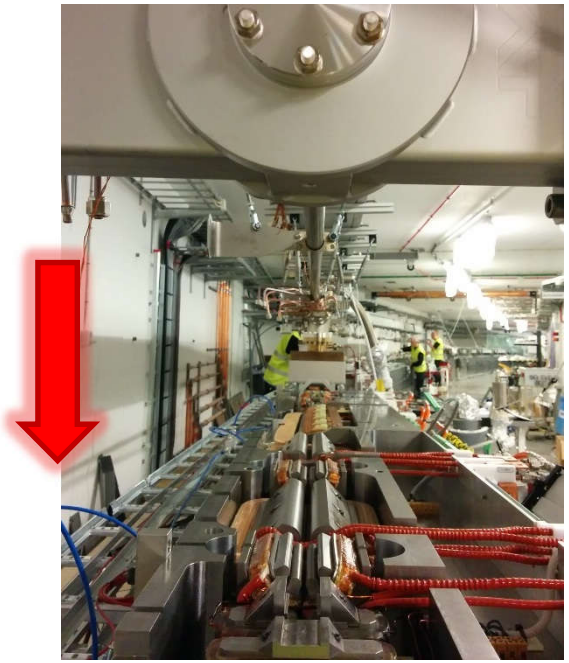


Installation procedure

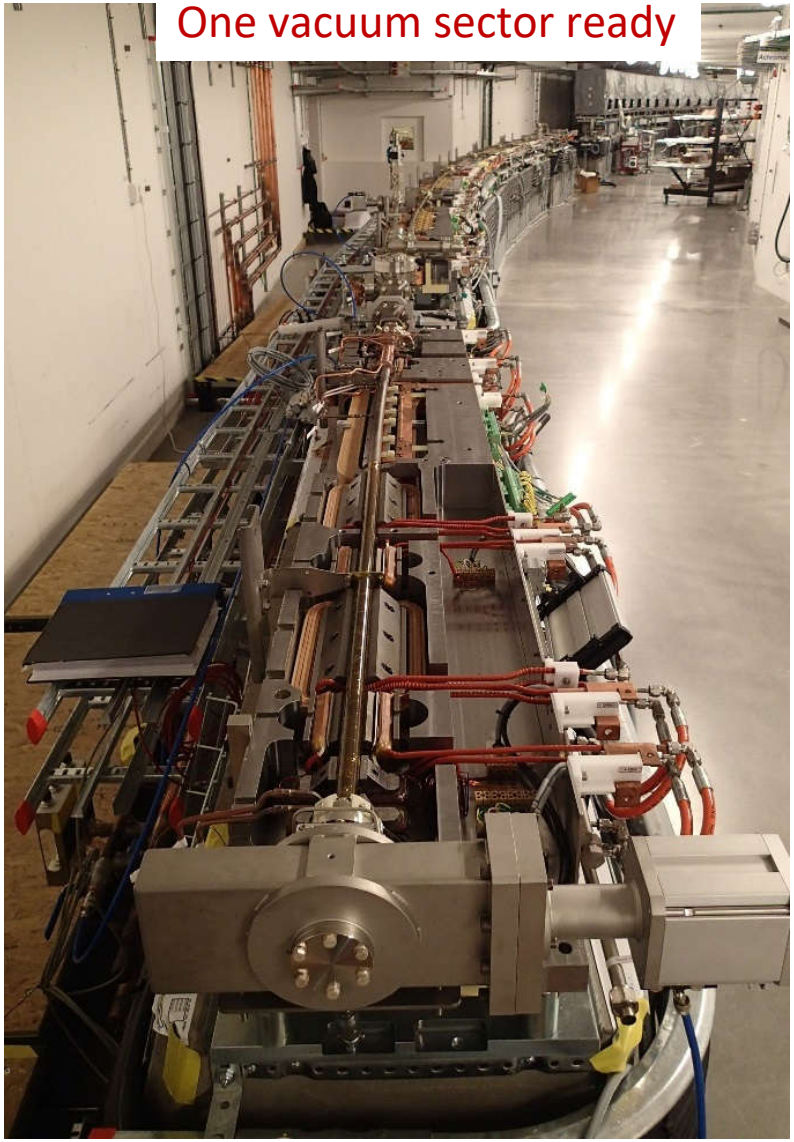
- **Baking** under vacuum at 160 deg C (1 day),
- NEG activation at 190 deg C (1 day),

Installation procedure

- Lowering to the bottom magnet half,
- Installation of final equipment (supports, BPM cables),
- closing magnet blocks.

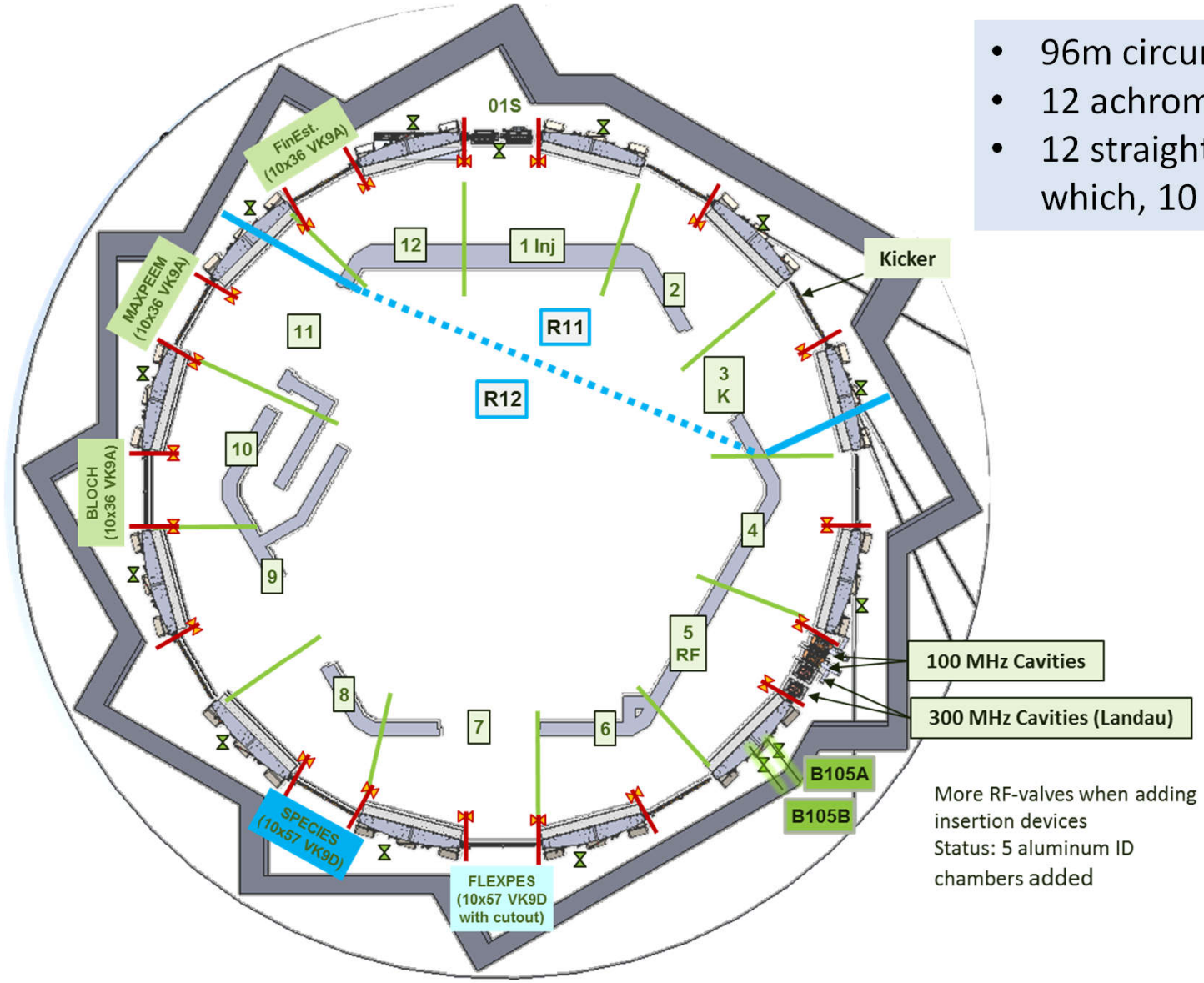


One vacuum sector ready



MAXIV 1.5 GeV storage ring layout and design

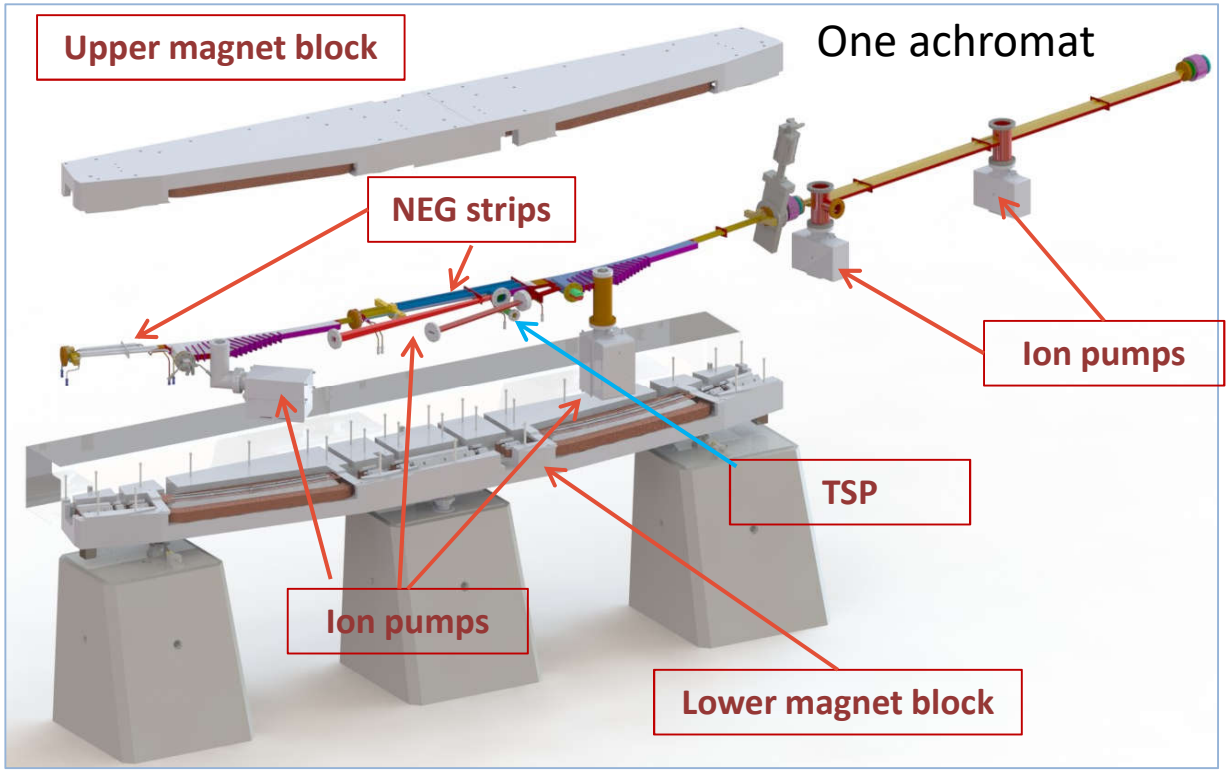
1.5 GeV storage ring layout



- 96m circumference
- 12 achromats (cells).
- 12 straight sections of which, 10 for IDs.

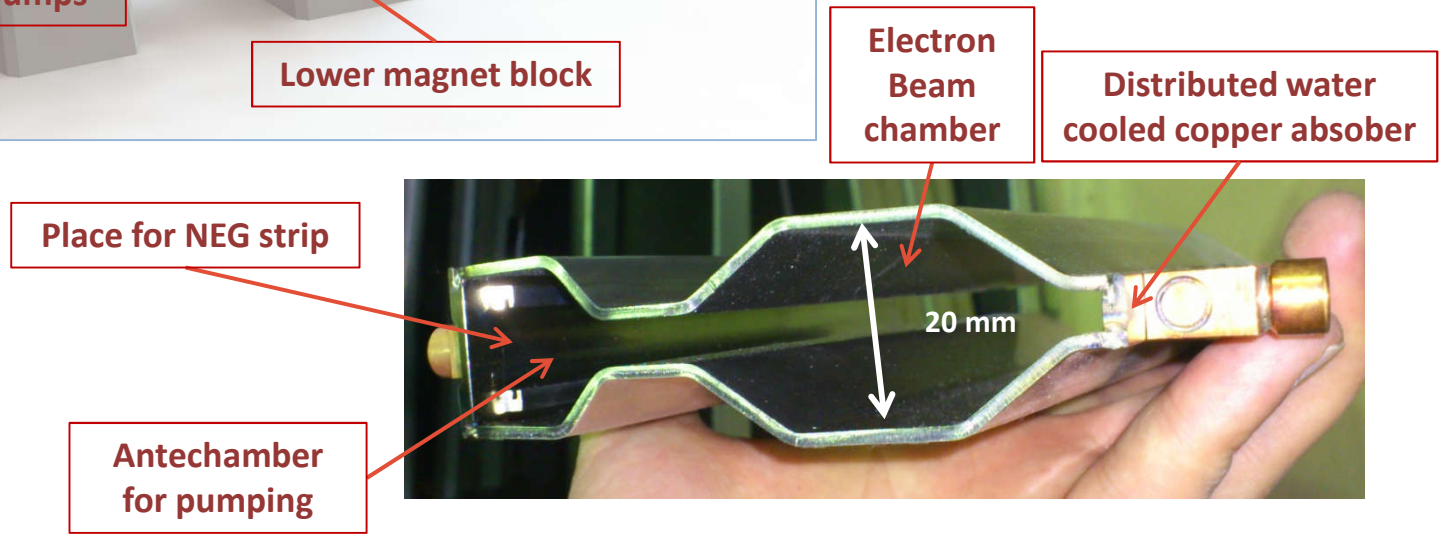
More RF-valves when adding insertion devices
Status: 5 aluminum ID chambers added

1.5 GeV storage ring vacuum system



Conventional vacuum system:

- St. steel VC with lumped and distributed absorbers to intercept synchrotron radiation.
- 5 Ion pumps, 1 TSP and 2 NEG strips.




Thank you for
your attention

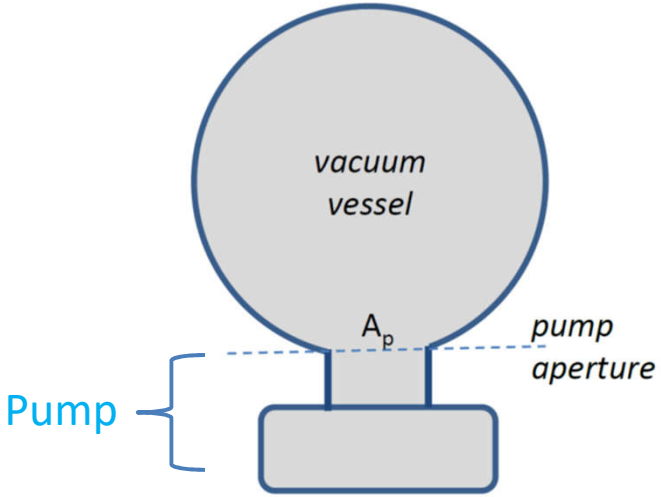
Backup slides

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.

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



From the definition of pumping speed:

$$S = A_p C' \alpha$$

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

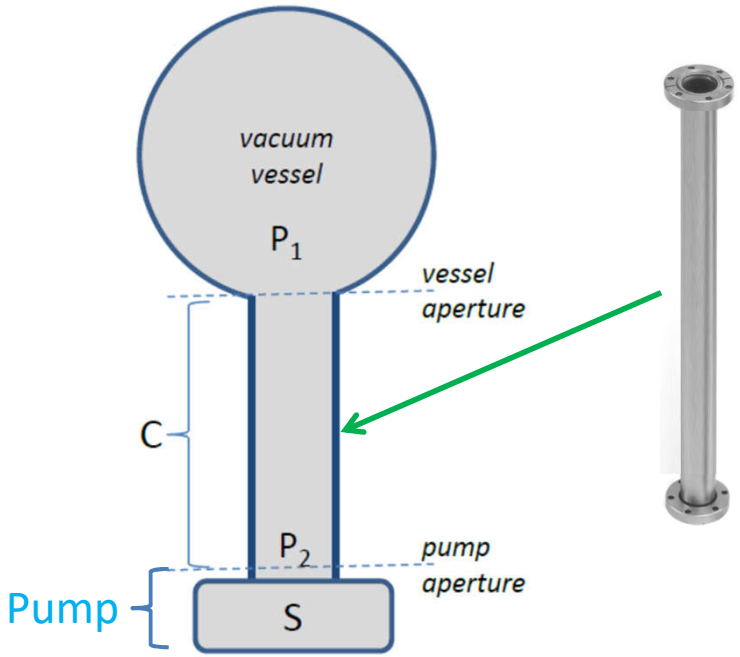
C' - is the conductance of the unit surface area for given gas [$\frac{l}{s\ cm^2}$]

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:

Conductance of 1 m long tube of 3,8 cm inside diameter (standard DN40CF vacuum pipe) for air (mass 28) is: **6,6 [l/s]**

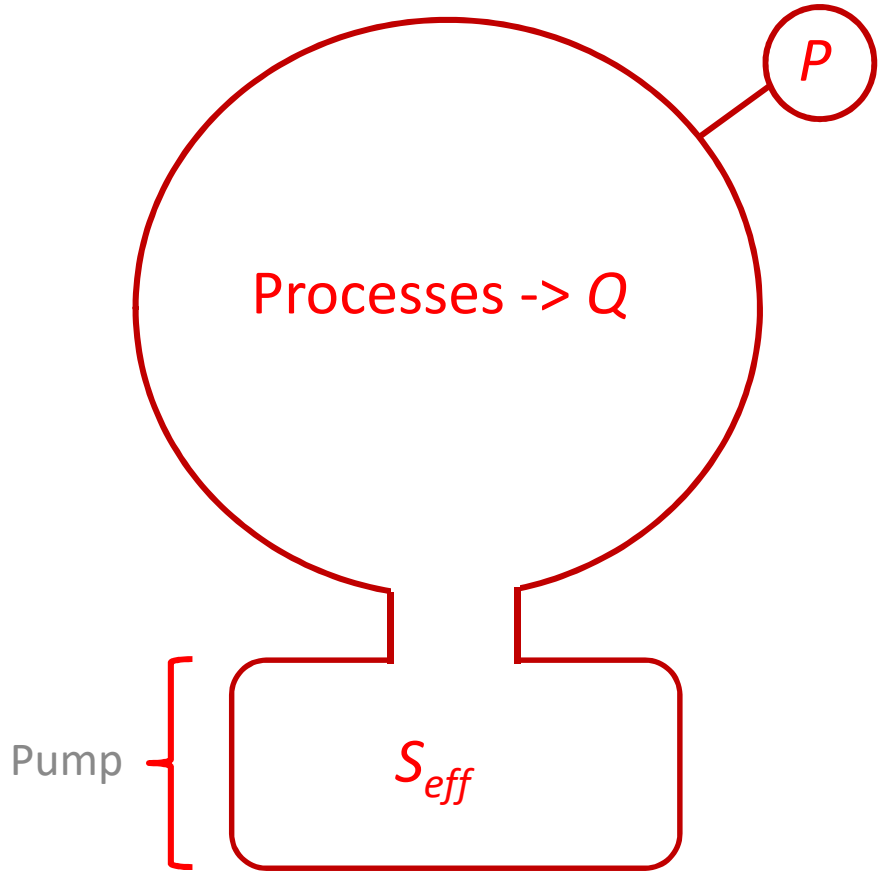
Connected pump of **100 [l/s]** to the tube will result in the effective pumping speed S_{eff}:

$$\frac{1}{S_{eff}} = \frac{1}{100\ l/s} + \frac{1}{6{,}6\ l/s} = 0{,}16$$

$$S_{eff} = 6{,}3\ \text{l/s}$$

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.

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 (evaporating) the reactive metal *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.

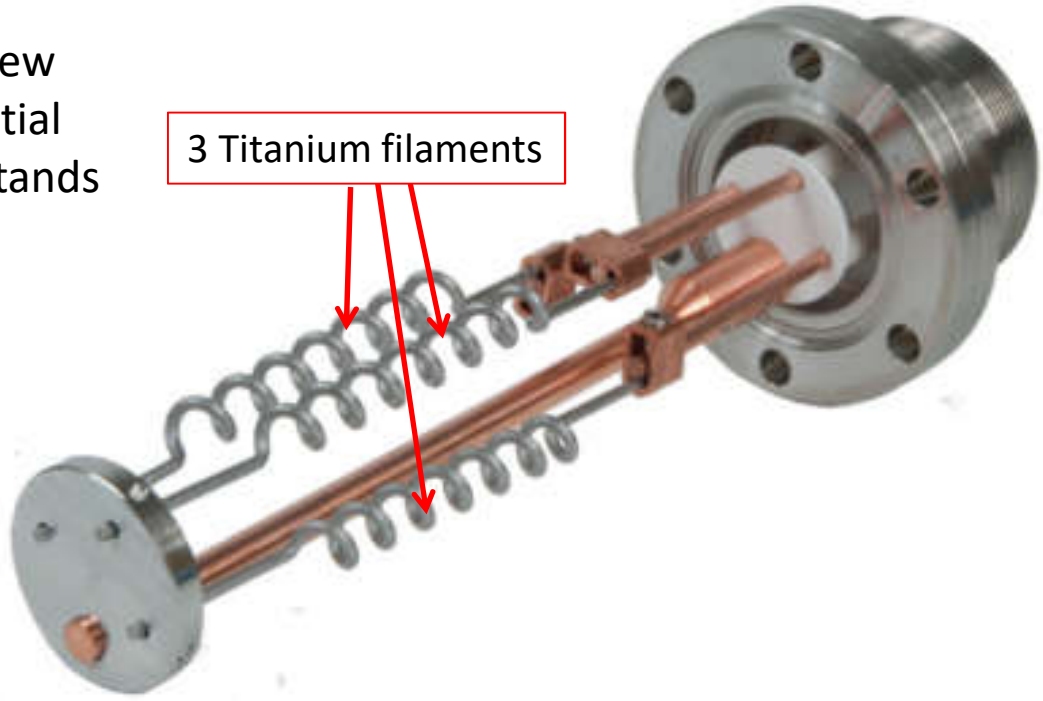
Getter materials do not pump noble gases and methane (CH_4) at room temperature. Therefore, they need auxiliary pumping to keep a stable pressure.

Evaporable Getters

Evaporable getters: TSP – Titanium Sublimation Pump

Titanium (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: $0.5 \leq \alpha \leq 1$

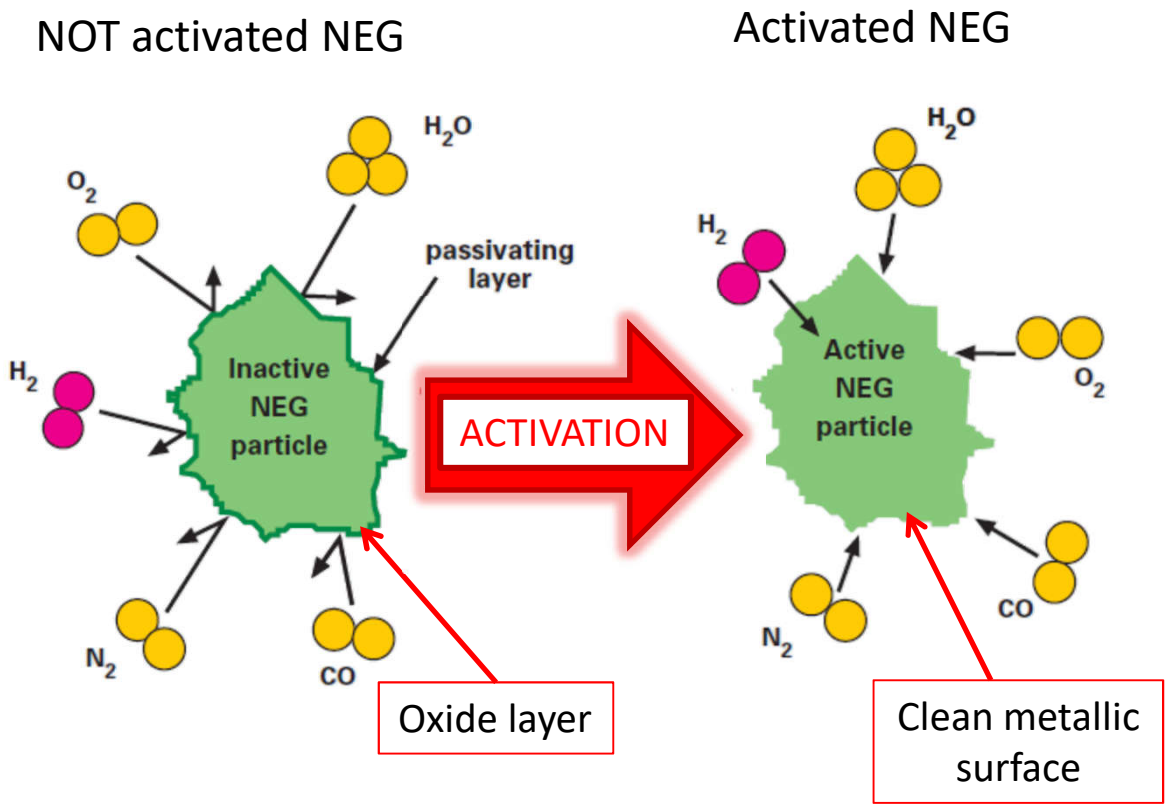
Film capacity:

- 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

Presented on day 3.

Non-Evaporable Getters (NEG)



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)

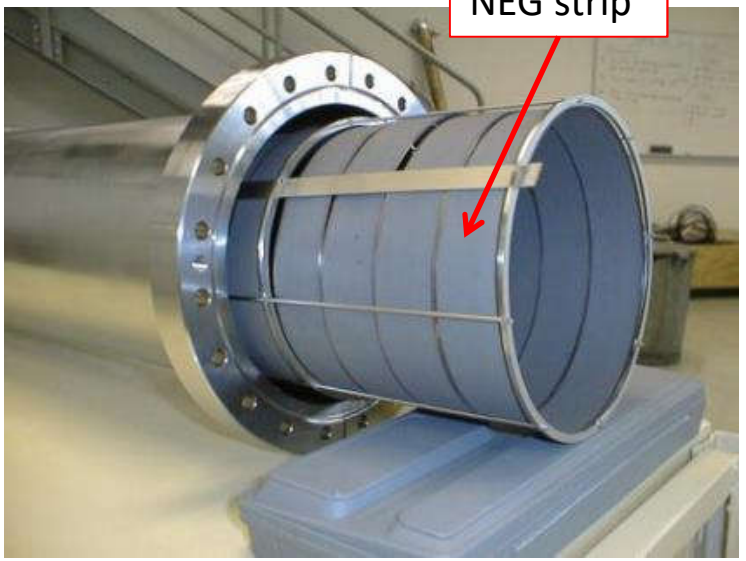
NEG materials are produced industrially by powder technology. The powder is sintered to form discs or strips.

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

NEG strips (St707)

NEG discs St (172)

NEG strip



SAES getters

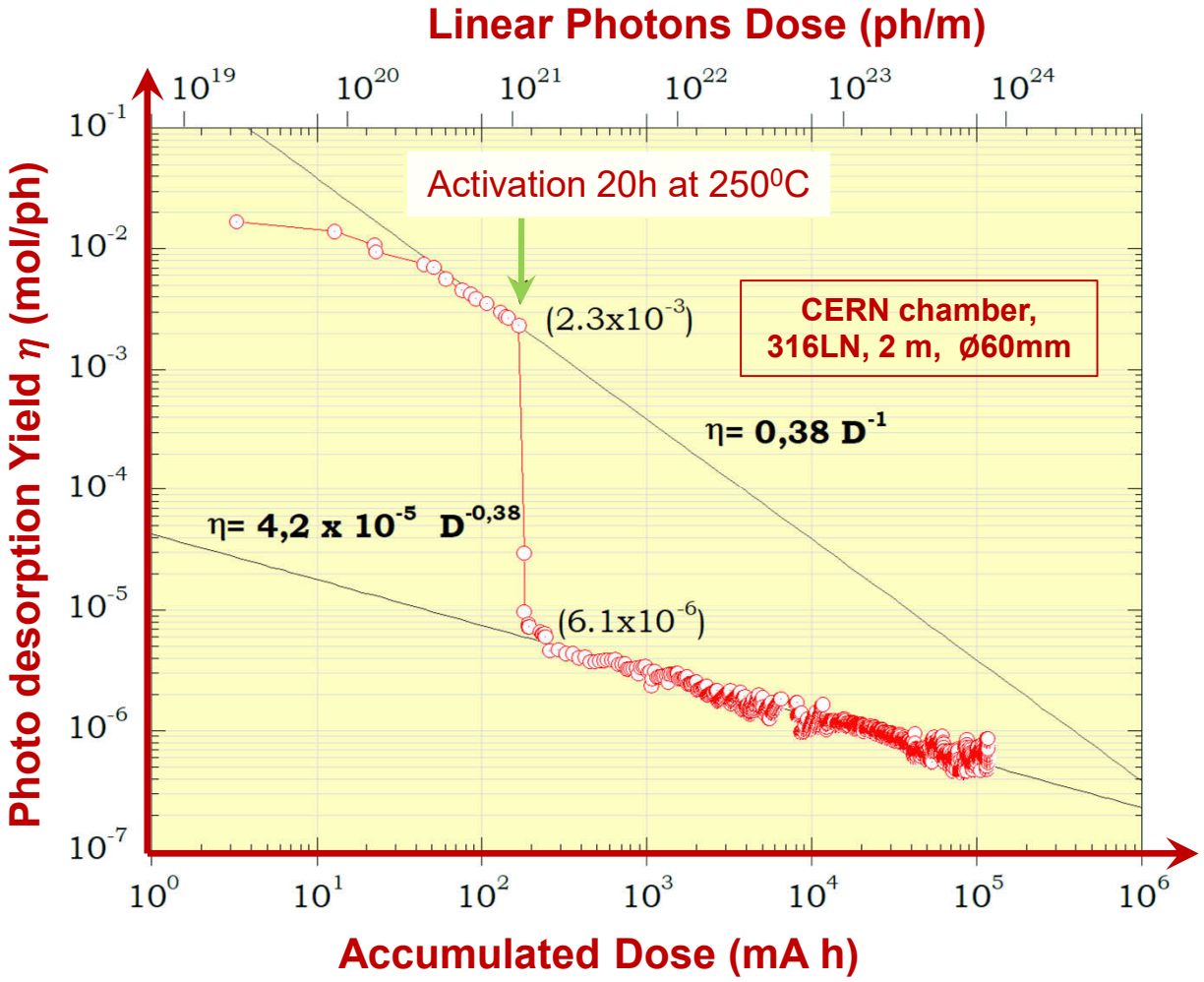
Paolo Chiggiato, Vacuum Technology for particle accelerators, 2013

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. After 40 venting cycles (with nitrogen) and reactivation 80% pumping speed is conserved.

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