An Introduction to Ion Pumps

CERN Accelerator School , May 2006

M.Audi , Varian Vacuum Technologies

Inspiring Excellence

Summary

- History
- Penning cell
- Pumping mechanism for different gases
- Pump element types
- Pumping speed
- Ion Pumps for Synchrotrons and Particle Accelerators

Ion Pump History

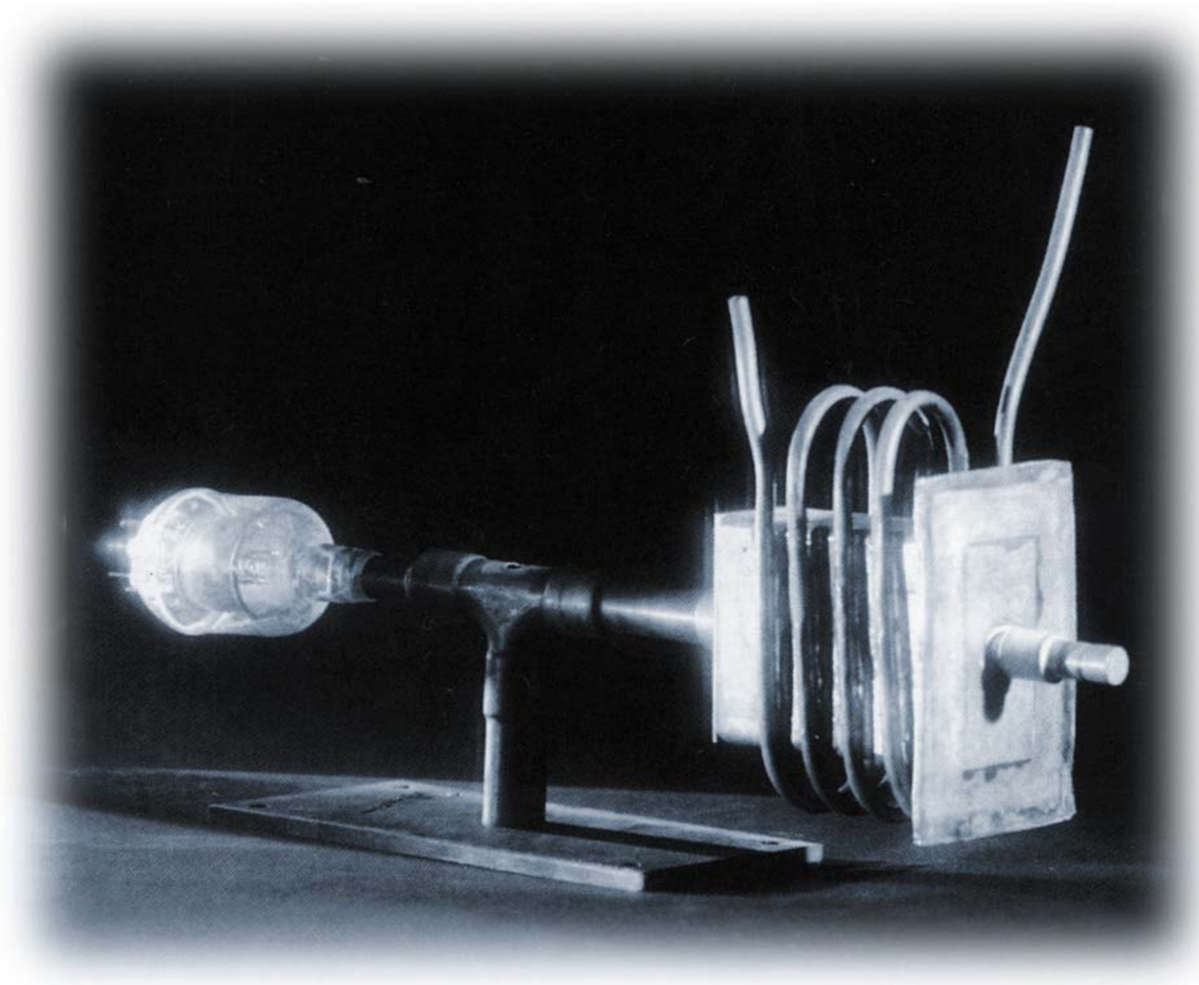
- In 1858 Plücker observed for the first time some pumping effect due to the electrical discharge.

- In 1937 F. Penning observed that his cold cathode gauge was evidencing a pumping effect.

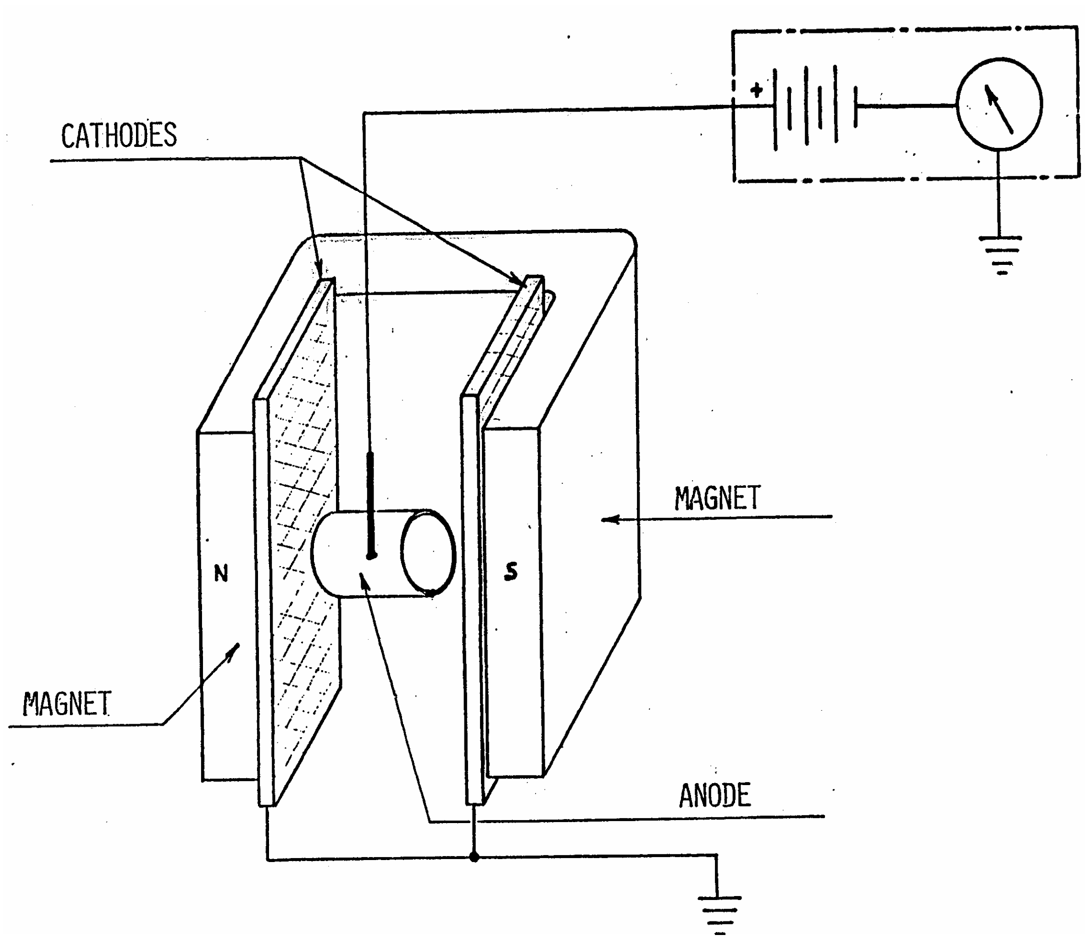
- In the late 50’s the Ion Pump has been invented at Varian Associates in Palo Alto by Helmer , Jepsen and Rutherford.

- First application was to keep klystrons under vacuum

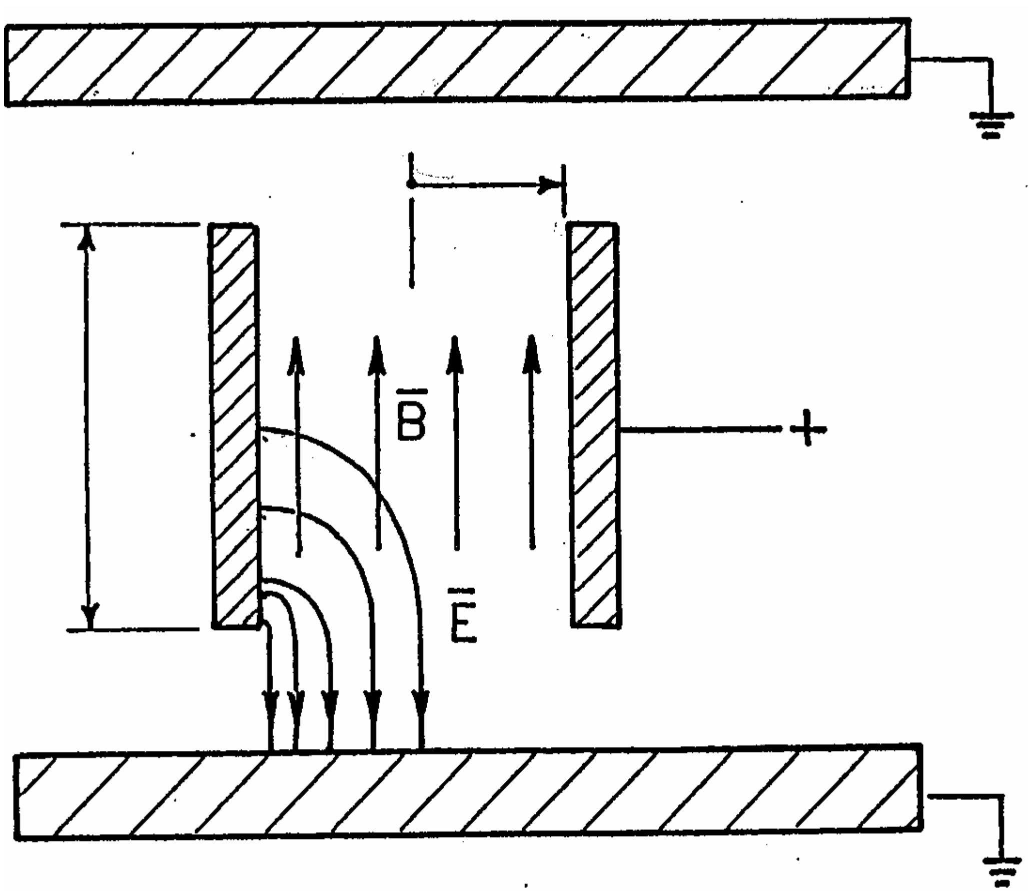
The first Ion Pump



The Penning Cell



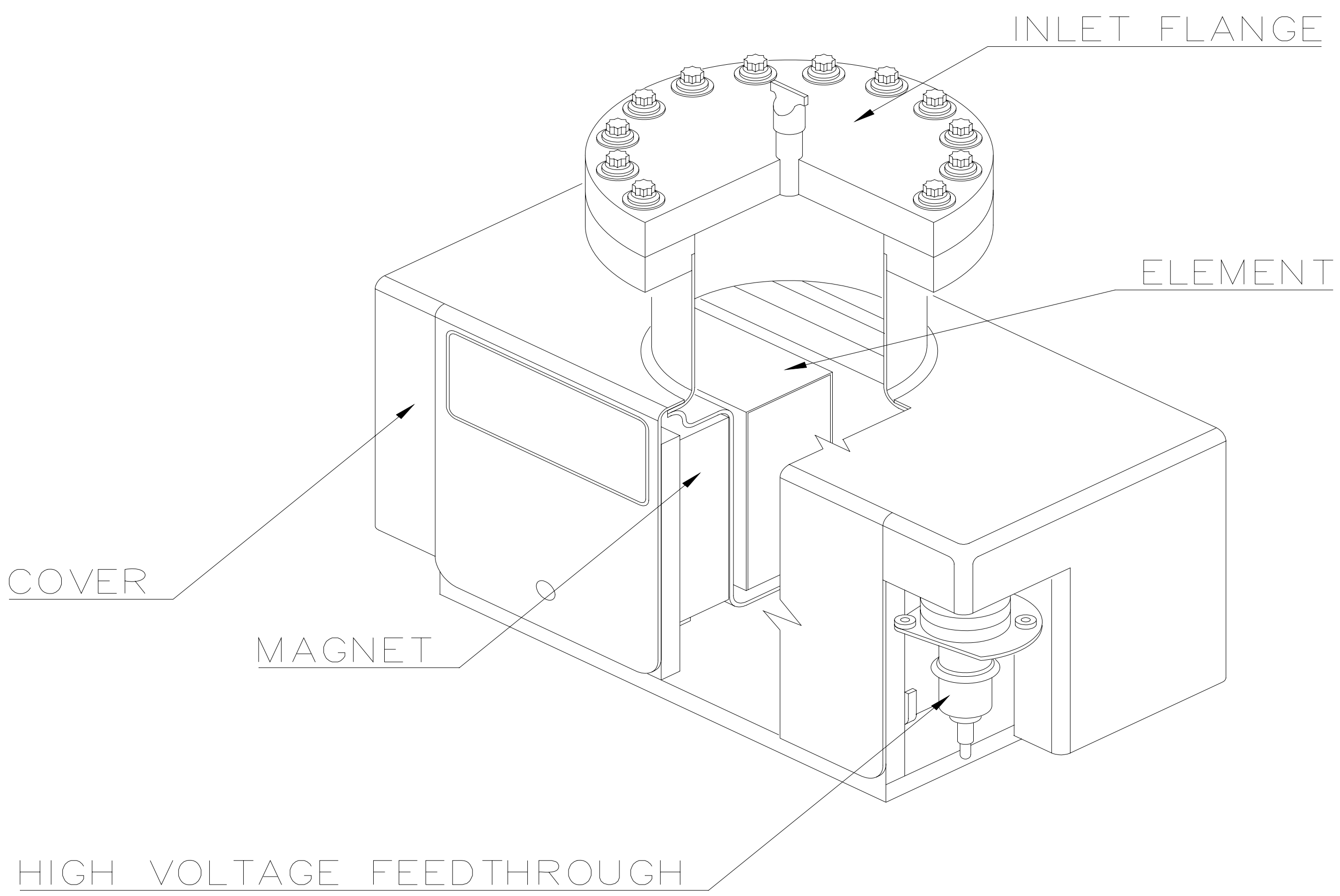
The Penning Cell



The Penning Cell

- Cylindrical anode, two flat cathodes made of getter material.
- Crossed Electric & Magnetic Fields
- Anode voltage from 3 to 7 kV.
- Axial magnetic field from 1000 to 1300 Gauss
- Cell dimension : 15 to 25 mm diameter , 20 to 35 mm height

The Ion Pump

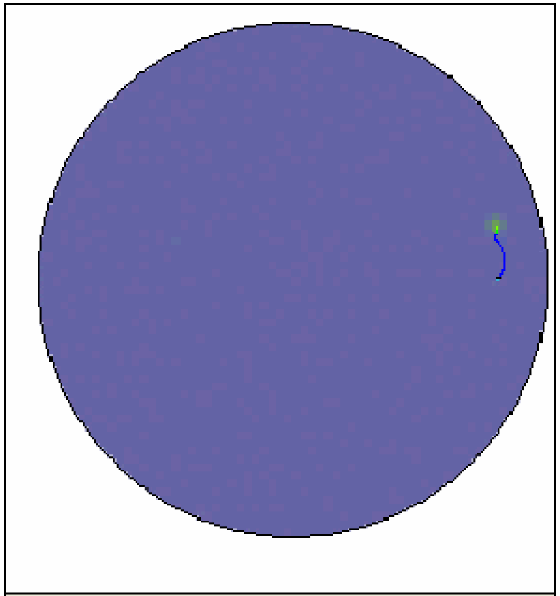


INLET FLANGE
ELEMENT
COVER
MAGNET
HIGH VOLTAGE FEEDTHROUGH

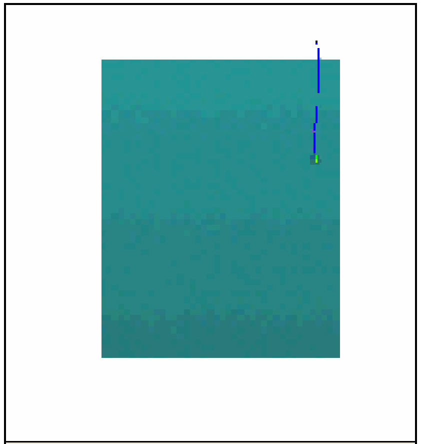
PRINCIPLES OF OPERATION

- Plasma discharge in crossed electric and magnetic field act as an electron trap
- Ionizing collision between electron and gas
- Ion bombardment of titanium cathode
- Some ions diffuse into the cathode
- Sputtering of chemically active Ti film on anode
- Gas molecules stick to Ti film (chemisorption) and are buried in the anode
- Ion pumps do not pump ions

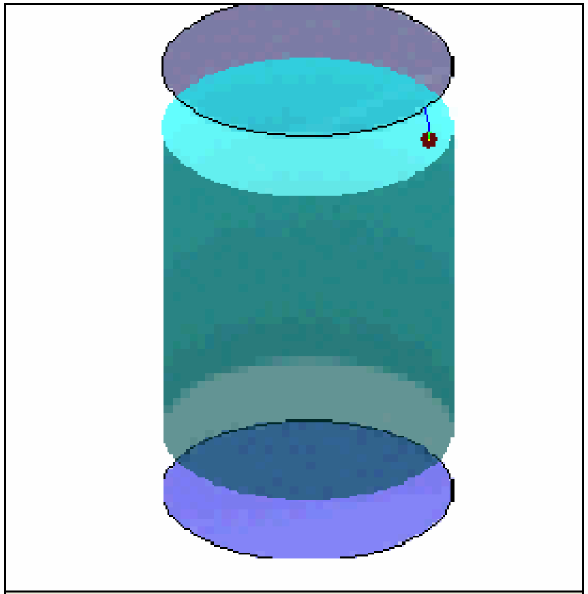
Electron trajectories



Electron_90.avi

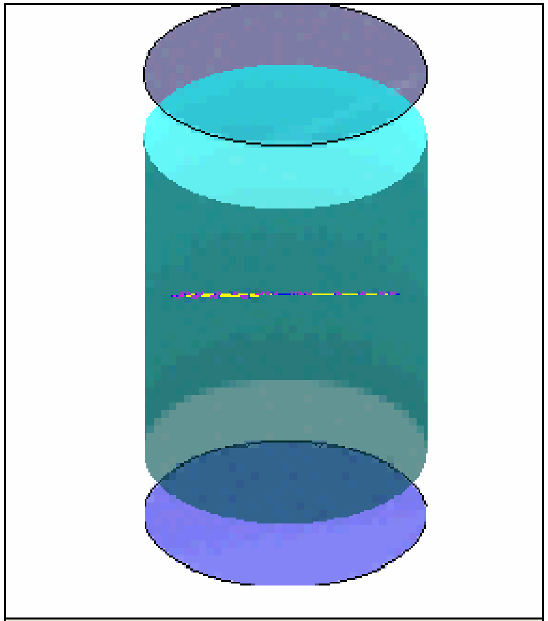


Electron_0.avi



Electron_30.avi

Ion Trajectories



Ion_30.avi

Chemically active gases

- CO_2 , CO , N_2 , H_2O , O_2
- Collision between electrons and gas molecules
- Some are ionizing collision .
- The ions that are generated are accelerated towards the cathodes.
- Some ions are trapped into the cathode (eventually reemitted)
- Some atoms of the Ti cathode are sputtered and deposited on the anode.
- The background gas molecules that collide with the chemically active titanium film are chemically trapped.
- Gas pumped at the anode will not be reemitted (no bombardment)

Noble Gases

- The noble gases are not chemically active.
- They are not pumped by the Titanium film.
- They are implanted into the cathode but this type of pumping is not stable.
- Conventional Ion pumps show the phenomenon known as Noble Gases Instability.
- A small fraction of ions when they hit the cathode are reflected as neutrals.
- Some of these neutrals maintain enough energy to be implanted into the anode
- They are phisically buried into the cathode (no chemical reaction)
- They will be buried by Titanium sputtered atoms
- Pumping is not very efficient

Hydrogen

- Hydrogen is chemically reactive , it is pumped by the Titanium film.

•Sputtering yeld for Hydrogen is very low , a very limited amount of Titanium is sputtered on the anode .

•Most of the pumping takes place into the cathode (unstable !)

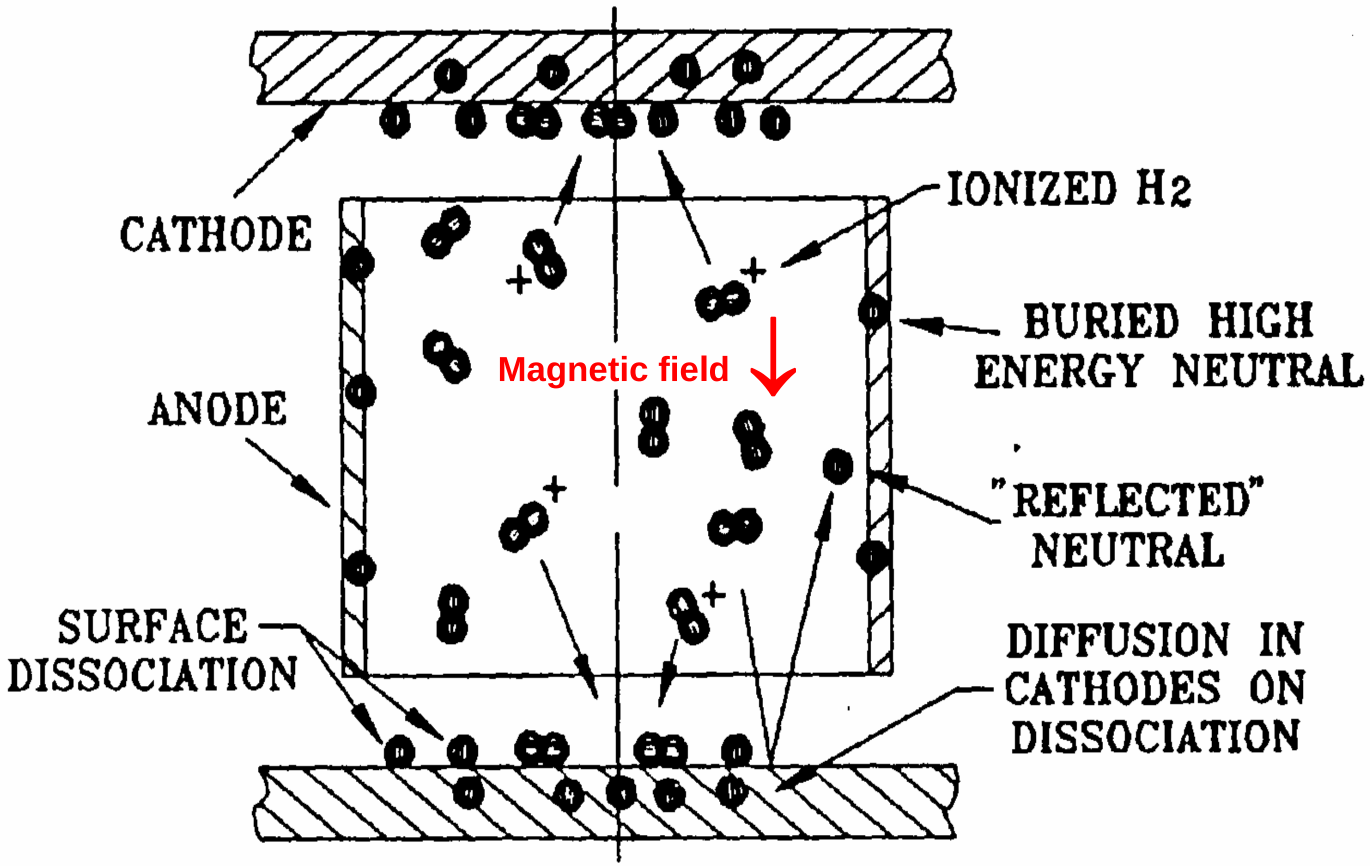
•Hydrogen has an high diffusivity and solubility in Titanium.

• Hydrogen is the only gas that after being implanted into the cathode diffuse into the cathode bulk (even at room T) .

•Hydrogen pumping into the cathode is stable .

•Hydrogen is pumped very well when in gas mixture with heavier gases (both at the anode and at the cathode)

Scheme


CATHODE
IONIZED H2
BURIED HIGH ENERGY NEUTRAL
Magnetic field
ANODE
"REFLECTED" NEUTRAL
SURFACE DISSOCIATION
DIFFUSION IN CATHODES ON DISSOCIATION

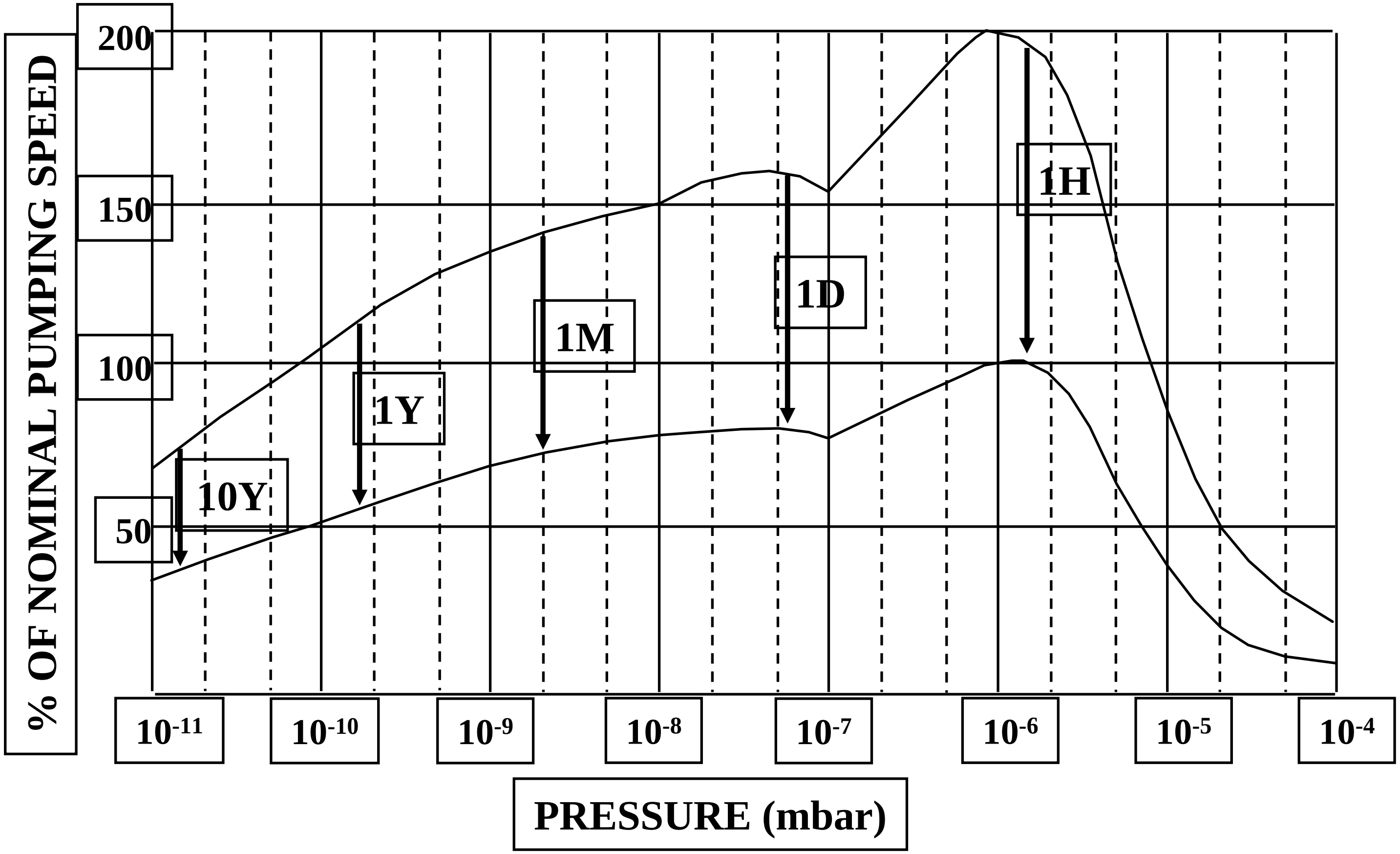
Pumping Speed & Saturation

- The pumping speed of Ion Pumps is a function of gas species , pressure and amount of pumped gas .
- Speed increases with pressure because the current (number of ions bombarding the cathode) increases more than linearly

$I = k P^n$ where n = 1.05 to 1.2

- Initial pumping speed is higher , then the pumping at the cathode becomes negligible , and the gas is pumped at the anode only
- The nominal pumping speed is the maximum speed of a pump after saturation .
- The amount of gas needed to saturate a pump depends on pump size
- A bake out regenerates an Ion pump to the initial condition

Saturation



% OF NOMINAL PUMPING SPEED
200
150
100
50
10Y
1Y
1M
1D
1H
10-11
10-10
10-9
10-8
10-7
10-6
10-5
10-4
PRESSURE (mbar)

Different types of pump for different applications - Diode, Noble Diode, StarCell

Ion Pump Technology

DIODE ION PUMP

Highest pumping speed for all getterable gases

(H_2 , CO, CO_2 , N_2 , H_2O)

Highest pumping speed at low pressures

Limited speed and stability when pumping noble gases such as Argon, Helium and Methane

The only reason for different and more expensive ion pumps is to improve pumping speed and stability for Noble Gases

Ion Pump Technology

DIODE

Limited Argon stability means :
Maximum capacity of approx 20 hours at 1 E-6 mbar of Argon
200 h at 1E-7 mbar
2,000 h at 1E-8 mbar
20,000 h at 1E-9 mbar   ……..

1% of air is Argon
200 h at 1E-5 mbar of Air   (1E-7 mbar of Ar)
2,000 h at 1E-6 mbar of Air (1E-8 mbar of Ar)
20,000 h at 1E-7 mbar of Air (1E-9 mbar of Ar) ……….

DIODE are useless in applications where Argon flows are present or Air is pumped at high pressures

Ion Pump Technology

In UHV application, where:

Ion pumps are started below 1E-6 mbar

The system is rarely vented to air

There are no air leaks

The ion pump is used to pump the outgassing of the vacuum chamber

The Pressure is lower than 1E -8 mbar

<u>Diode pumps can work for 20 years before showing Argon instability</u>

<u>Ion pumps with improved stability for noble gases may be a safer approach if they are cost competitive with diode</u>

ION PUMPS for NOBLE GASES

One single working principle : improve the number of Noble Gas ions that are reflected when bombarding the cathode , and are physically buried into the anode (no chemical interaction)

Two different approaches to obtain it :

A) Change of material

B) Change of geometry

Ion Pump Technology

ION PUMPS FOR NOBLE GASES

A) Heavier cathode material (Tantalum vs. Titanium)

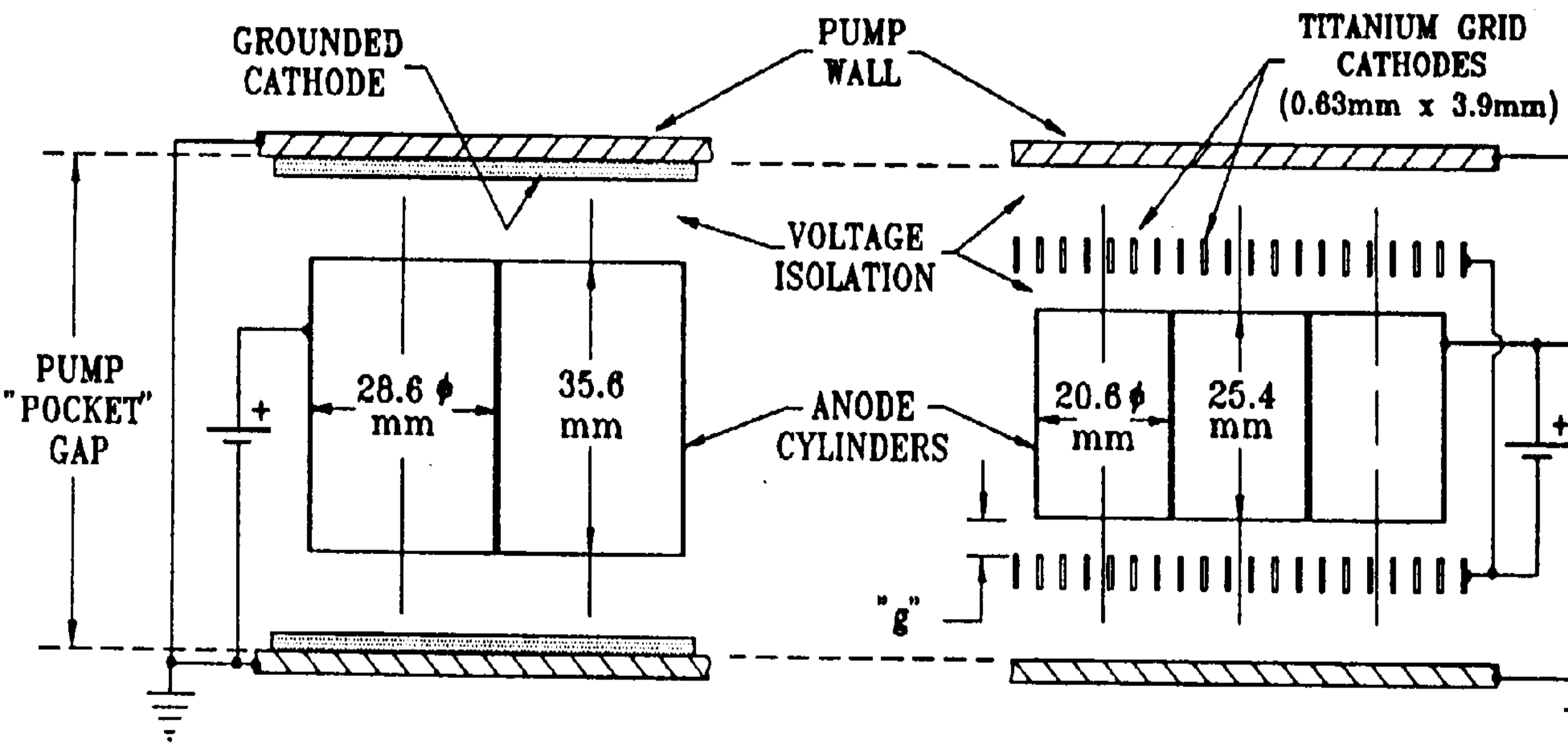
B) Different angle of incidence (Grazing vs. Normal)

A) Noble Diode

B) Triode / StarCell

Both solutions do improve the pumping speed and stability for noble gases

Triode



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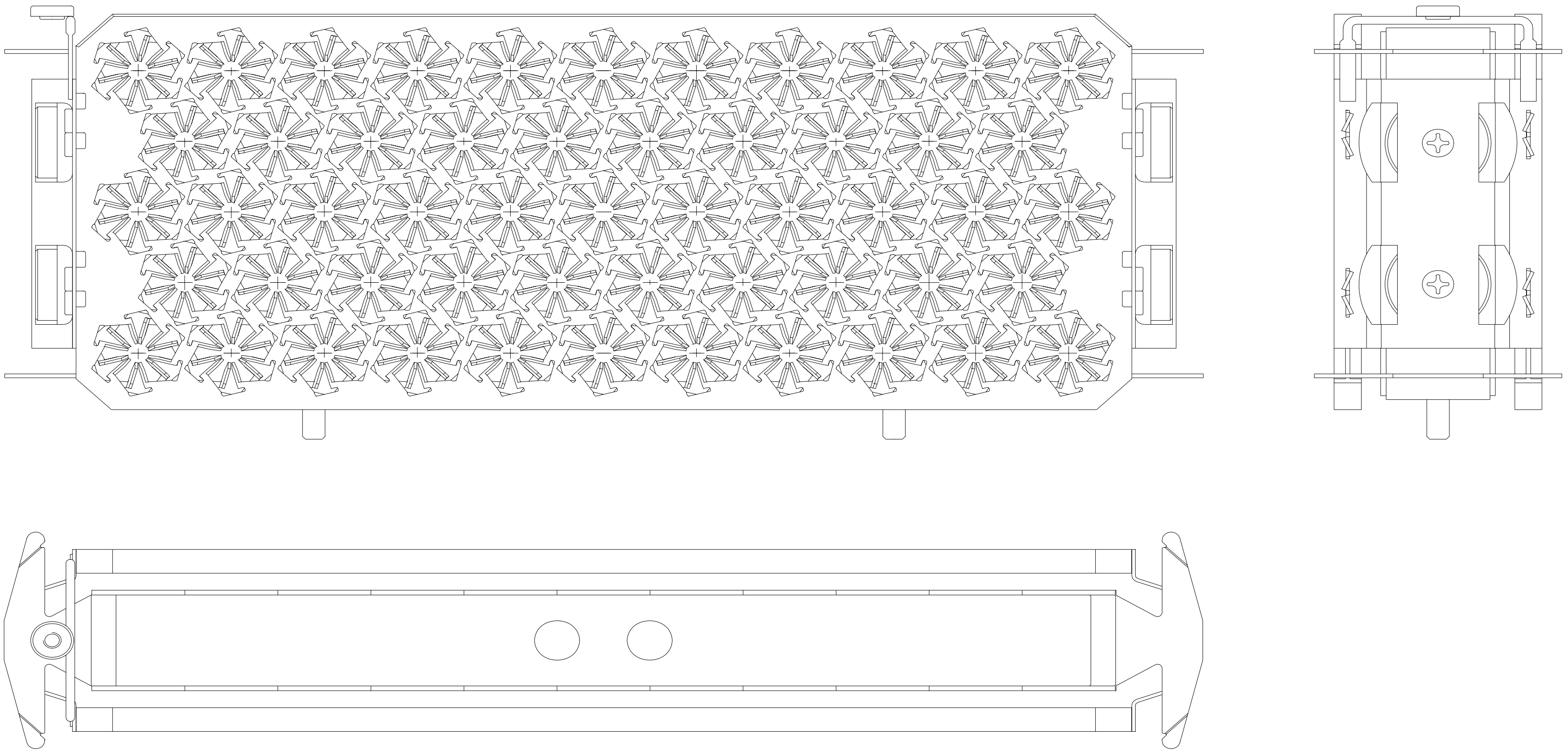
Starcell



Ion Pump Technology

A) Noble Diode

Same design as Diode

Much more expensive material

Cost of Tantalum is much higher than cost of Titanium

Noble Diode is more expensive than Diode

B) Triode/Starcell

Same material as Diode

More complex (more expensive) geometry

Proper design and tooling allow to build them at similar cost of a standard diode

Ion Pump Technology

Noble Diode vs Diode

Lower capacity and speed for H_2

Lower speed for all getterable gases (N_2 , CO , CO_2)

Improved stability and speed for Noble Gases

Starcell vs Diode

Lower speed for all getterable gases (N_2 , CO , CO_2)

Comparable speed for Hydrogen

Improved speed and stability for Noble Gases

Ion Pump Technology

StarCell vs. Noble Diode

Higher capacity for H_2

Same speed for all getterable gases (N_2 , CO , CO_2)

Higher capacity for Noble Gases

Higher stability and speed for Noble Gases

ION PUMP

SPECIFIC DESIGN FOR SYNCHROTRON & PARTICLE ACCELERATORS

WHY ION PUMPS ARE THE MAIN CHOICE FOR SYNCHROTRON ?

•Closed pump

Do not need any baking pump

No contamination from the roughing line

• No moving parts , no lubricant

Vibration free and contamination free

•Can withstand air inrush or improper use

Maintenance free , High reliability

SYNCHROTRON DESIGN ION PUMPS

Pumping speed is not the major concern…….

outgassing
contamination
vacuum leaks (corrosion)
safety hazard
resistance to radiation

…….may be more critical than pumping speed for Synchrotron

ION PUMPS

Pump designed to minimize outgassing/contamination

- Material choice
- Material cleaning
- Pump process

HV feedthrough and HV cable designed to be safe , radiation and corrosion proof

Pump designed to minimize stray magnetic field

MATERIAL

Only UHV compatible materials : Metals and Ceramic

Body,Flange,Anode : Stainless Steel 304 or 316 , L or LN

L, low C precipitation , better corrosion resistance

LN , Nitrogen for improved mechanical resistance

Cathode : Titanium grade A (Tantalum)

Insulators : Alumina Al_2O_3

TITANIUM

Degreasing in Alkaline bath (NaOH-Na2CO3)

Ultrasonic degreasing in Alkaline bath

Cold rinsing

Cold rinsing with deionized water

Pickling , in Nitric and Fluoridric acid bath (HF-HNO3)

Cold rinsing

Cold rinsing with deionized water

Hot rinsing with deionized water

Oven drying at 150°C

VARIAN ION PUMP PROCESS

The ion pump element must be the cleanest surface exposed to vacuum , because its outgassing is due to both thermal and bombardment induced effect

The surface will eventually be removed (sputtered): not only the surface , but the bulk too must be hydrogen free

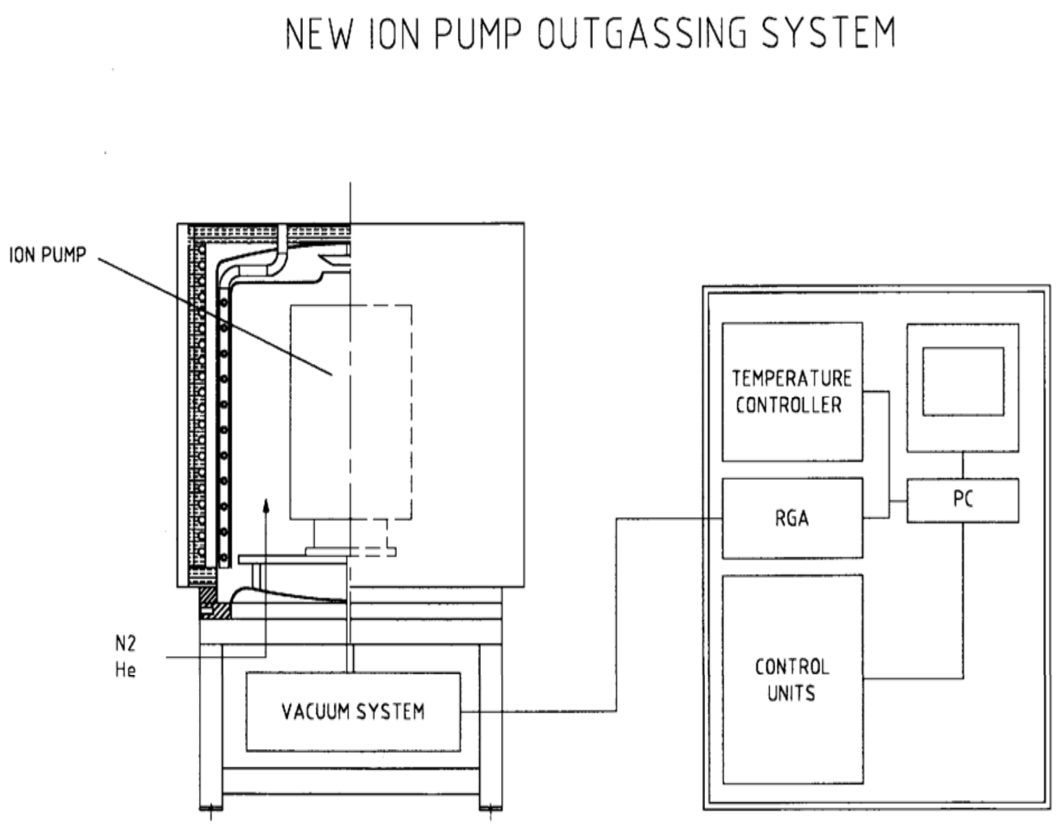
Ion pump element must be "vacuum fired"

2 hours @ 750 °C , at 1*E-5 mbar

Then, the complete pump is processed under vacuum at 450°C

VARIAN ION PUMP PROCESS

- Pumps are individually processed
- Residual gas analysis for each pump
- Process is not “time driven” but “pressure driven”
- Individual records of each pump (outgassing , spectra …)
- Pumps are processed in nitrogen atmosphere to prevent external oxidation (no more beadblasting needed)
- Pumps can be leak-checked at high temperature (Helium instead of Nitrogen)
- Vacuum performance are much more repeatable.



NEW ION PUMP OUTGASSING SYSTEM
ION PUMP
N2
He
VACUUM SYSTEM
TEMPERATURE CONTROLLER
RGA
PC
CONTROL UNITS

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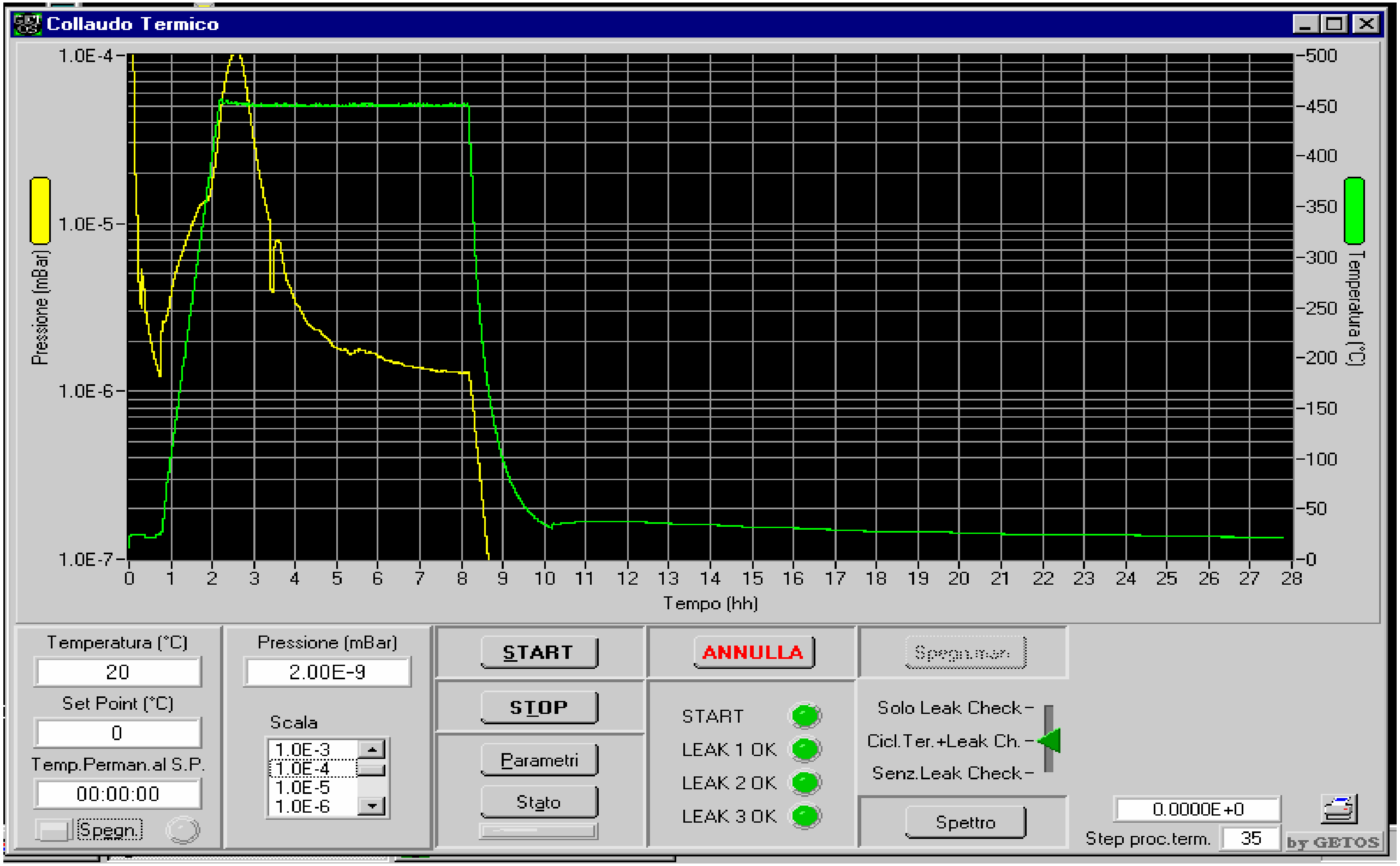
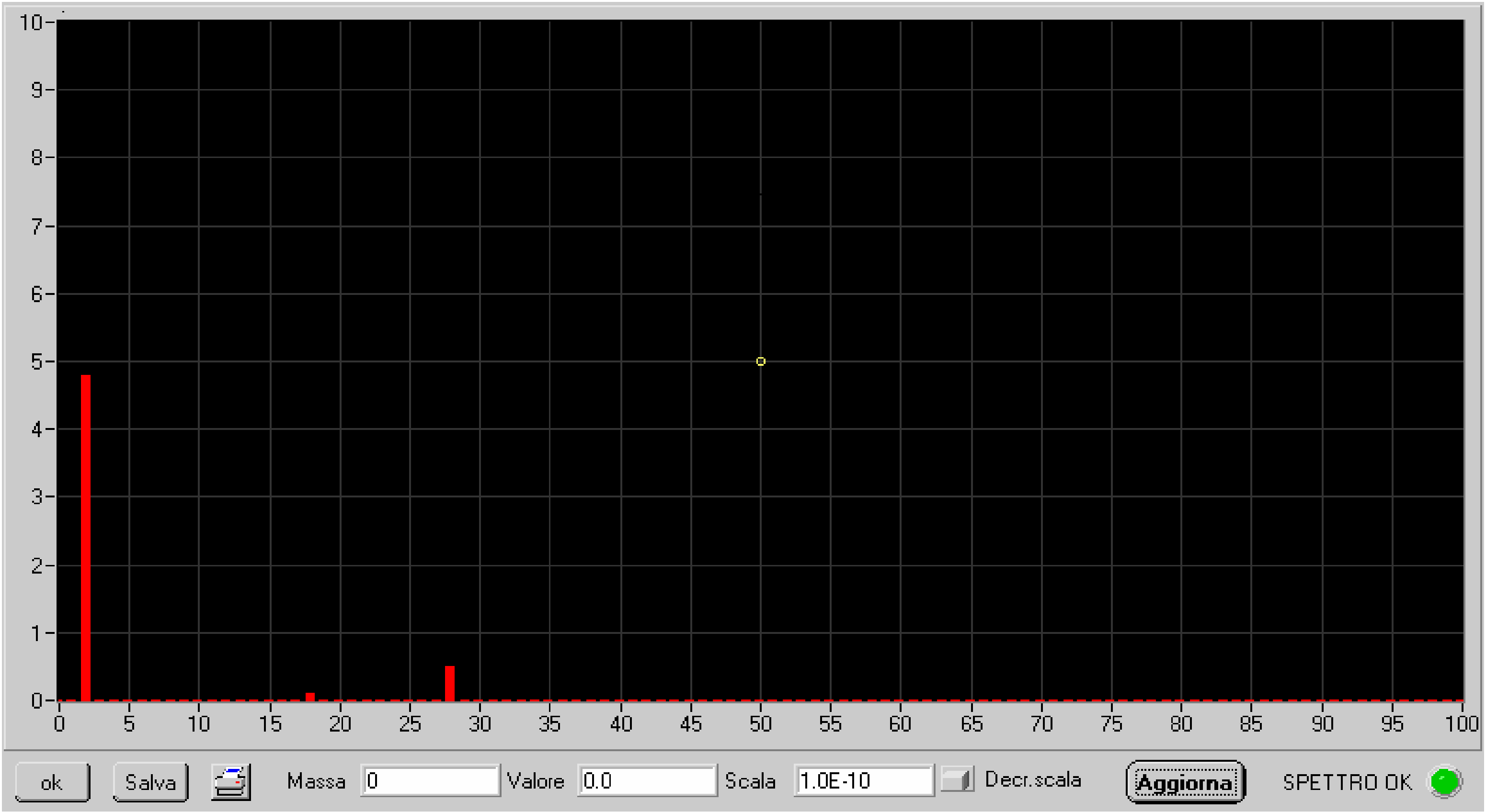


Collaudo Termico
Pressione (mBar)
Temperatura (°C)
Tempo (hh)
1.0E-4
1.0E-5
1.0E-6
1.0E-7
500
450
400
350
300
250
200
150
100
50
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
Temperatura (°C)
20
Set Point (°C)
0
Temp.Perman.al S.P.
00:00:00
Spegn.
Pressione (mBar)
2.00E-9
Scala
1.0E-3
1.0E-4
1.0E-5
1.0E-6
START
STOP
Parametri
Stato
ANNULLA
START
LEAK 1 OK
LEAK 2 OK
LEAK 3 OK
Spegn.man.
Solo Leak Check
Cicl.Ter.+Leak Ch.
Senz.Leak Check
Spettro
0.0000E+0
Step proc.term.
35
by GETOS



10
9
8
7
6
5
4
3
2
1
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
ok
Salva
Massa
0
Valore
0.0
Scala
1.0E-10
Decr.scala
Aggiorna
SPETTRO OK

ION PUMP SAFETY

Moved from passive to active safety

The control unit and HV cable connector must be intrinsically safe
No live parts can be touched
(passive safety)

Interlock on HV connection to ensure that HV is switched off whenever the HV cable is disconnected , either from the pump or from the controller (active safety)

VARIAN

ION PUMP CORROSION

Corrosion free feedthrough

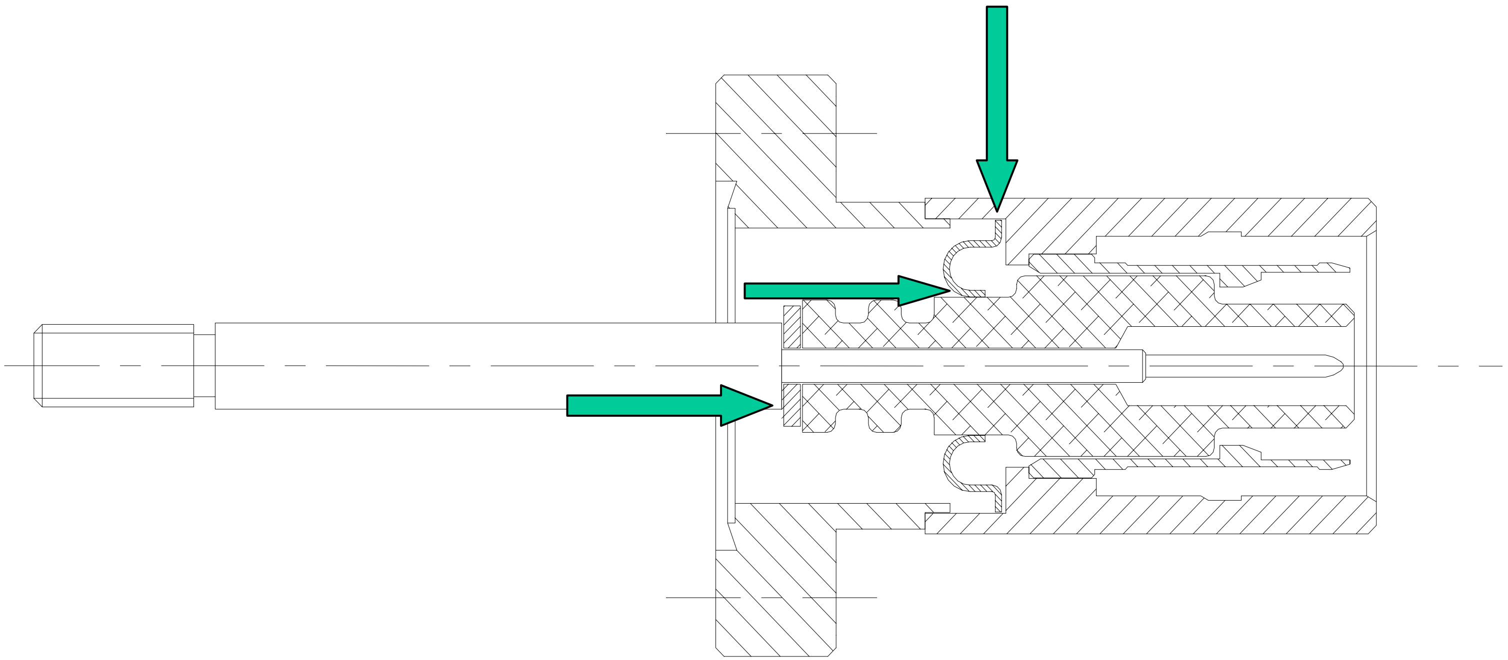
HV feedthrough and connector are subjected to corrosion

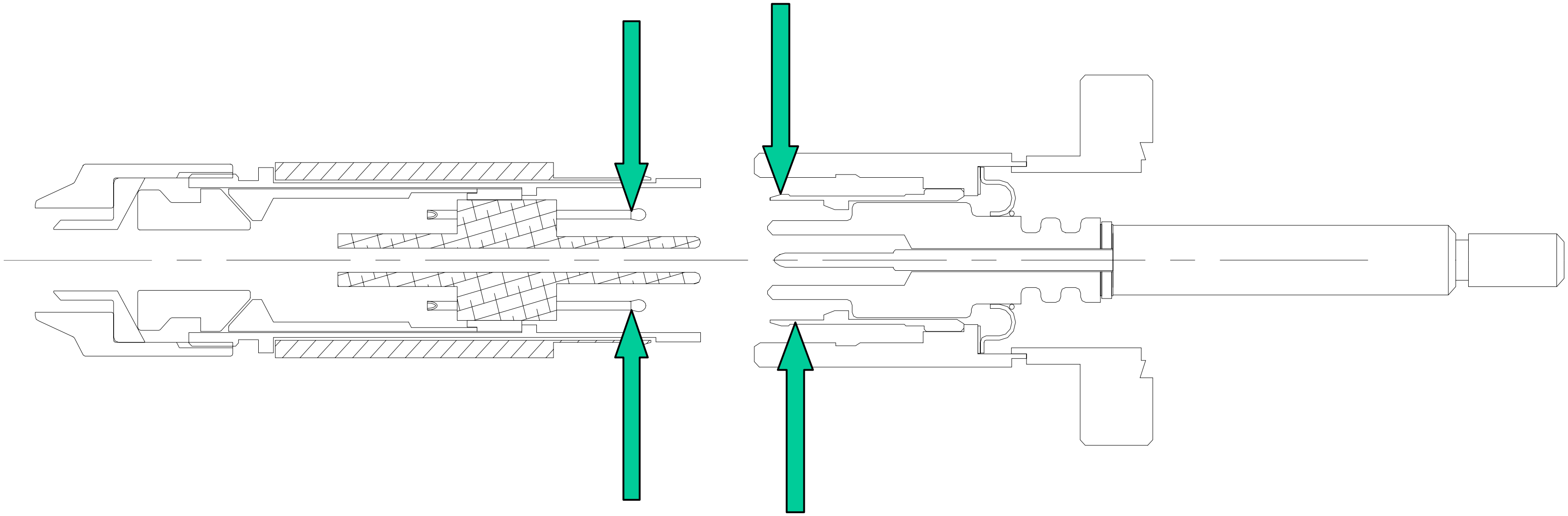
Transition metal to Kovar (or similar) to ceramic is critical

Temperature cycling , humidity , high electric field gradient may cause corrosion

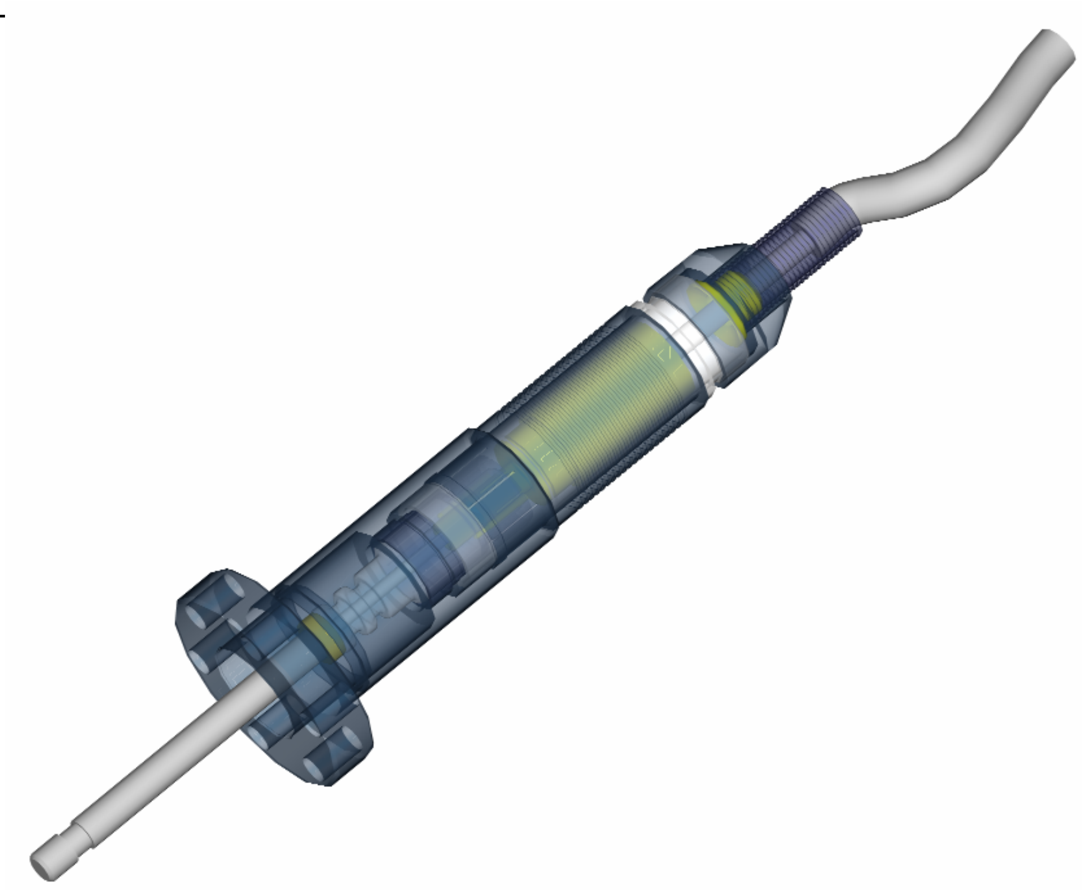
Water vapor trapped in between the connector and the feedthrough may cause oxidation

Specific design to minimize air trapping and critical surface exposed to air (vacuum side brazing)





ION PUMP - CONTROL UNIT CONNECTION



RADIATION RESISTANCE

Ion pumps must be radiation proof

HV connector , HV cable insulation , heaters must be specifically designed

PEEK , KAPTON or equivalent must be used as insulator

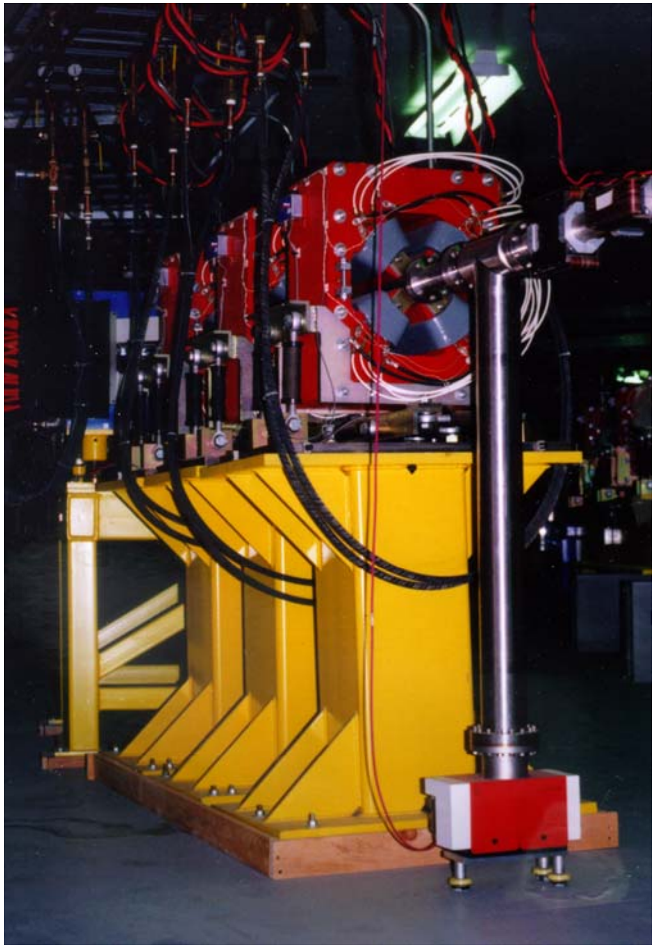
(250°C , 1E9 Rad)

No PVC , no TEFLON can be used

Electronic is not radiation proof

Power supply must be in a shielded location

Ion Pumps in Synchrotron & Particle Accelerators



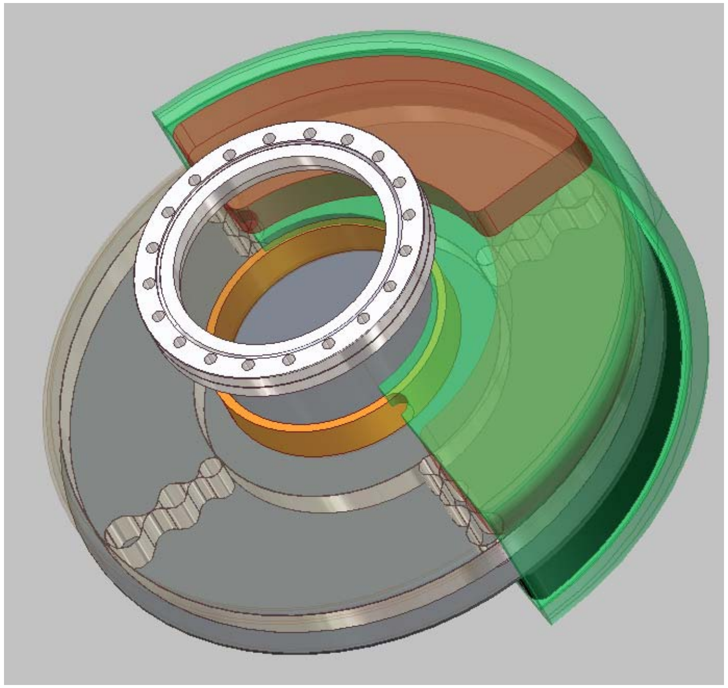
VARIAN

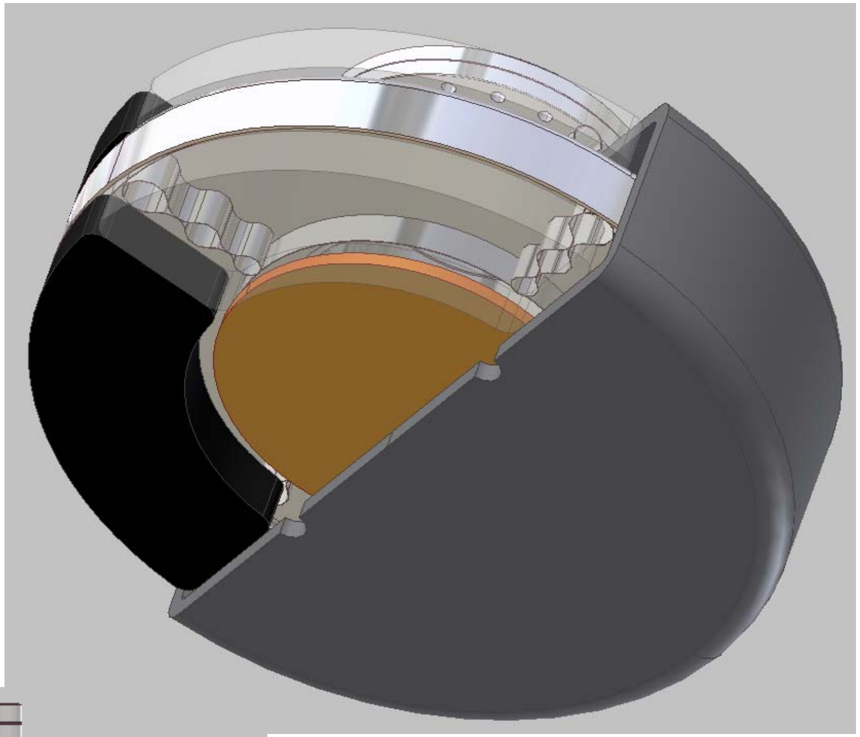
Latest development in Ion Pump Technology

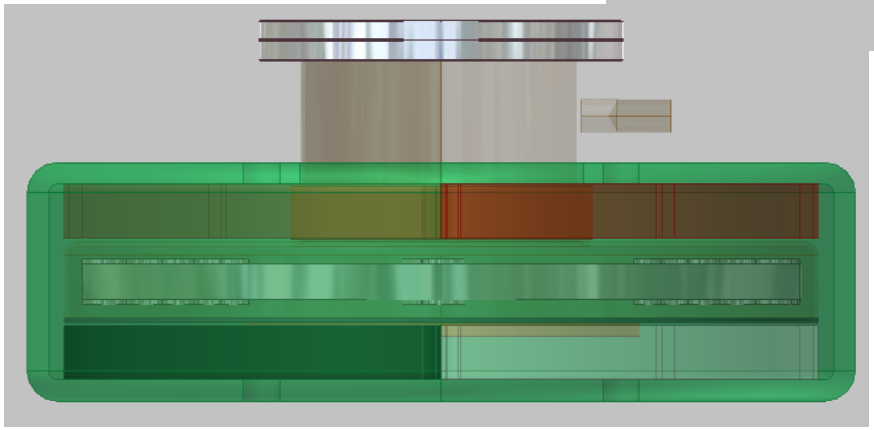
Ion Pump for UHV applications

Ion Pump with NEG coating

Round Ion Pump

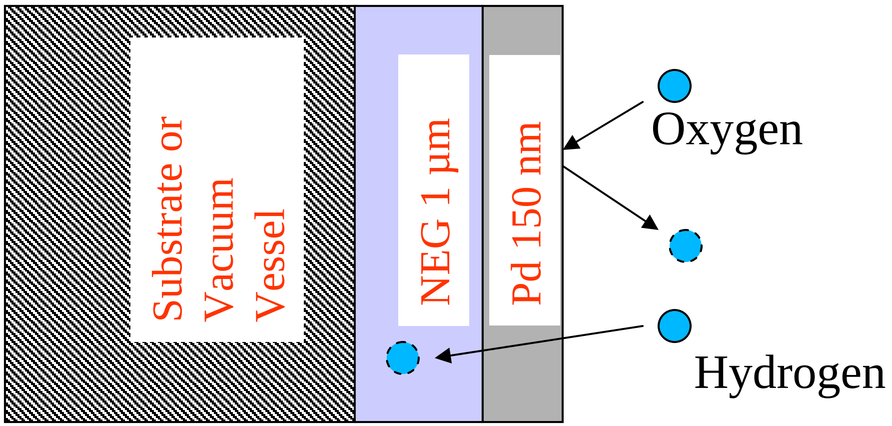






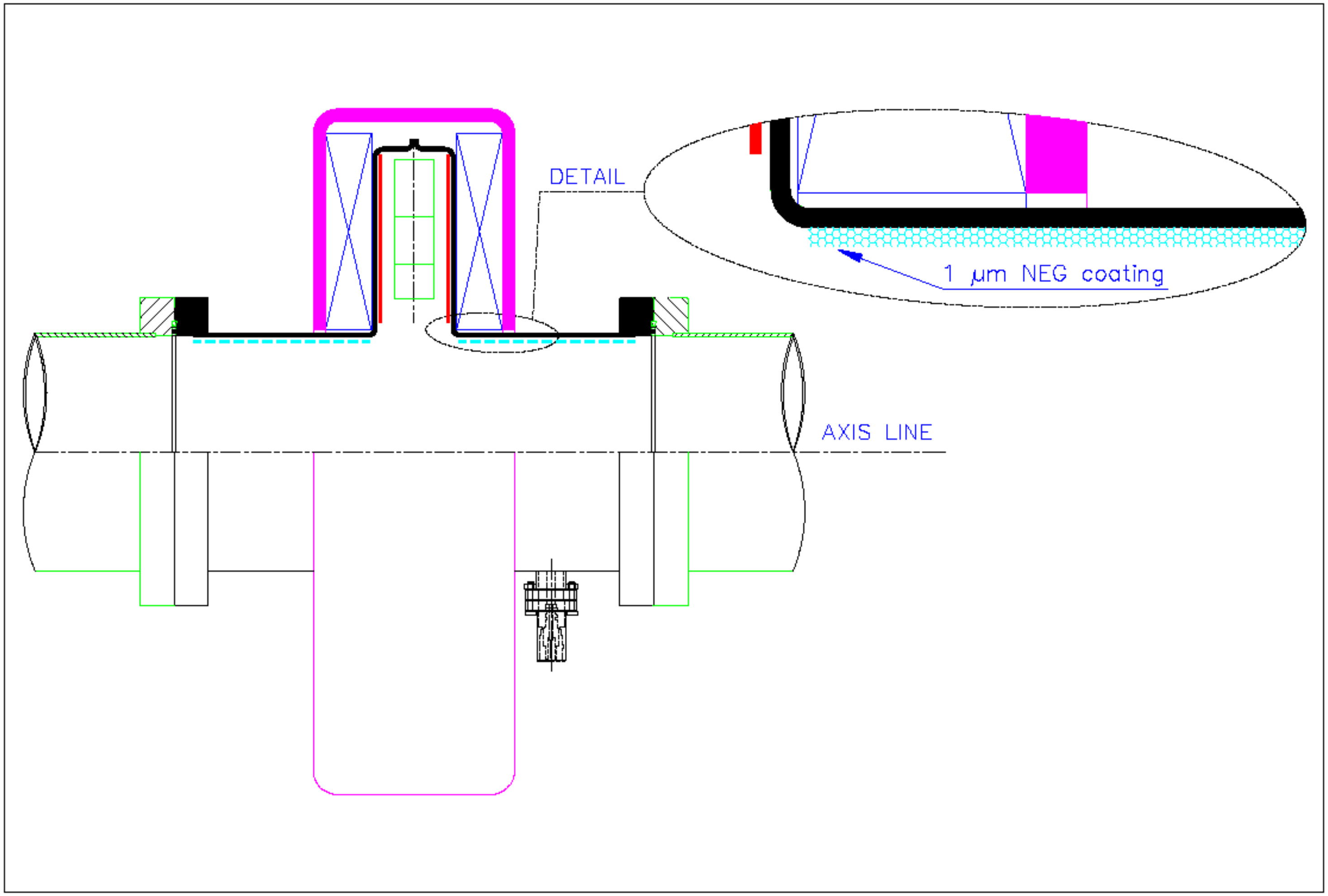
NEG + Palladium

NEG Deposition (Zr – V- Ti) plus an additional layer of a noble metal (Pd).



- Large amounts of H_2 can be pumped (and CO)
- NEG poisoning by heavier gases (O_2, CO_2, N_2) is prevented;
- for H_2 and CO **the pumping mechanism is thermally reversible**.

NEG coated Round Ion Pump



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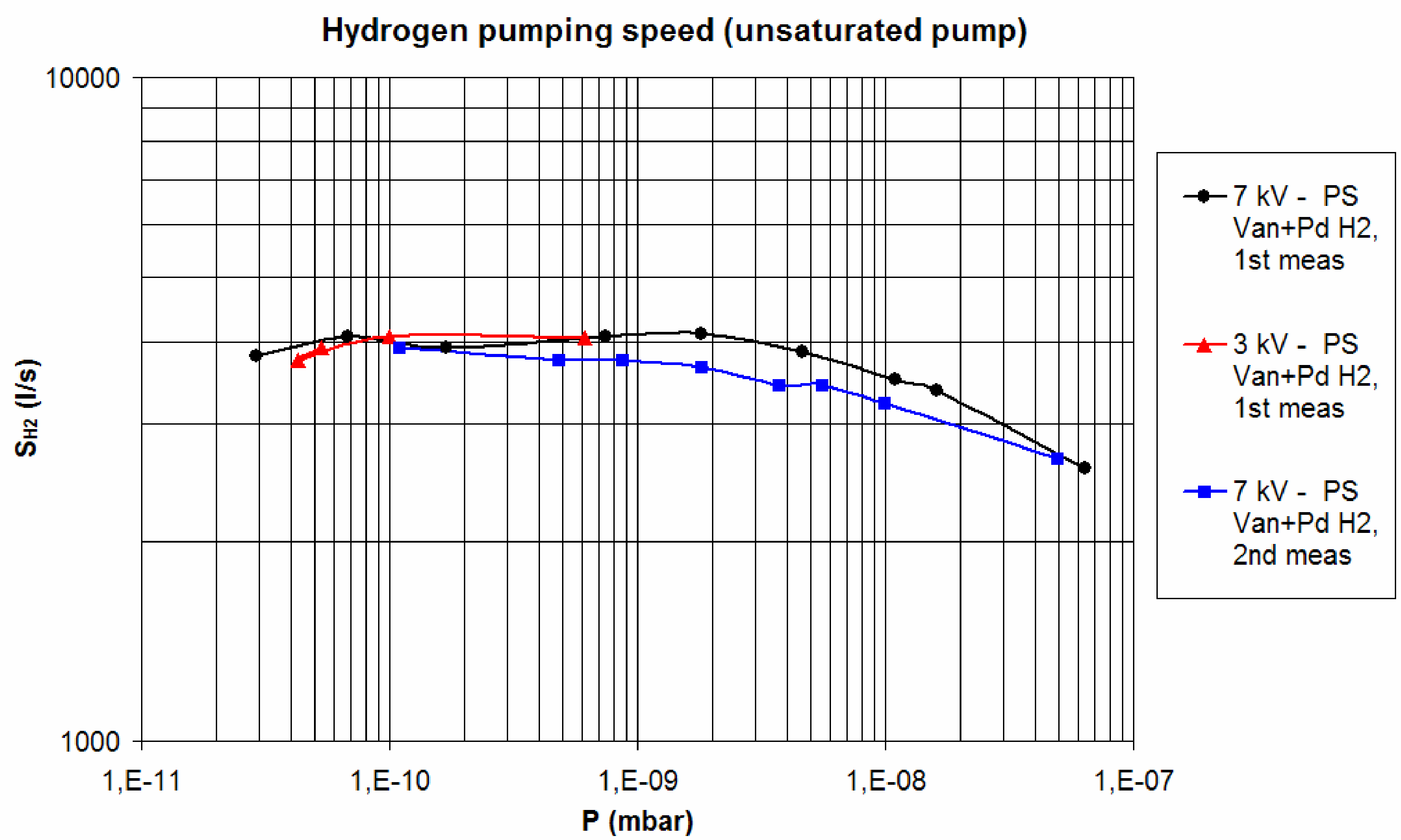
Round pump with NEG + Pd coating

Round pump with NEG + Pd coating



No activation or baking between measurements

Thank you !

CERN Accelerator School , May 2006

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