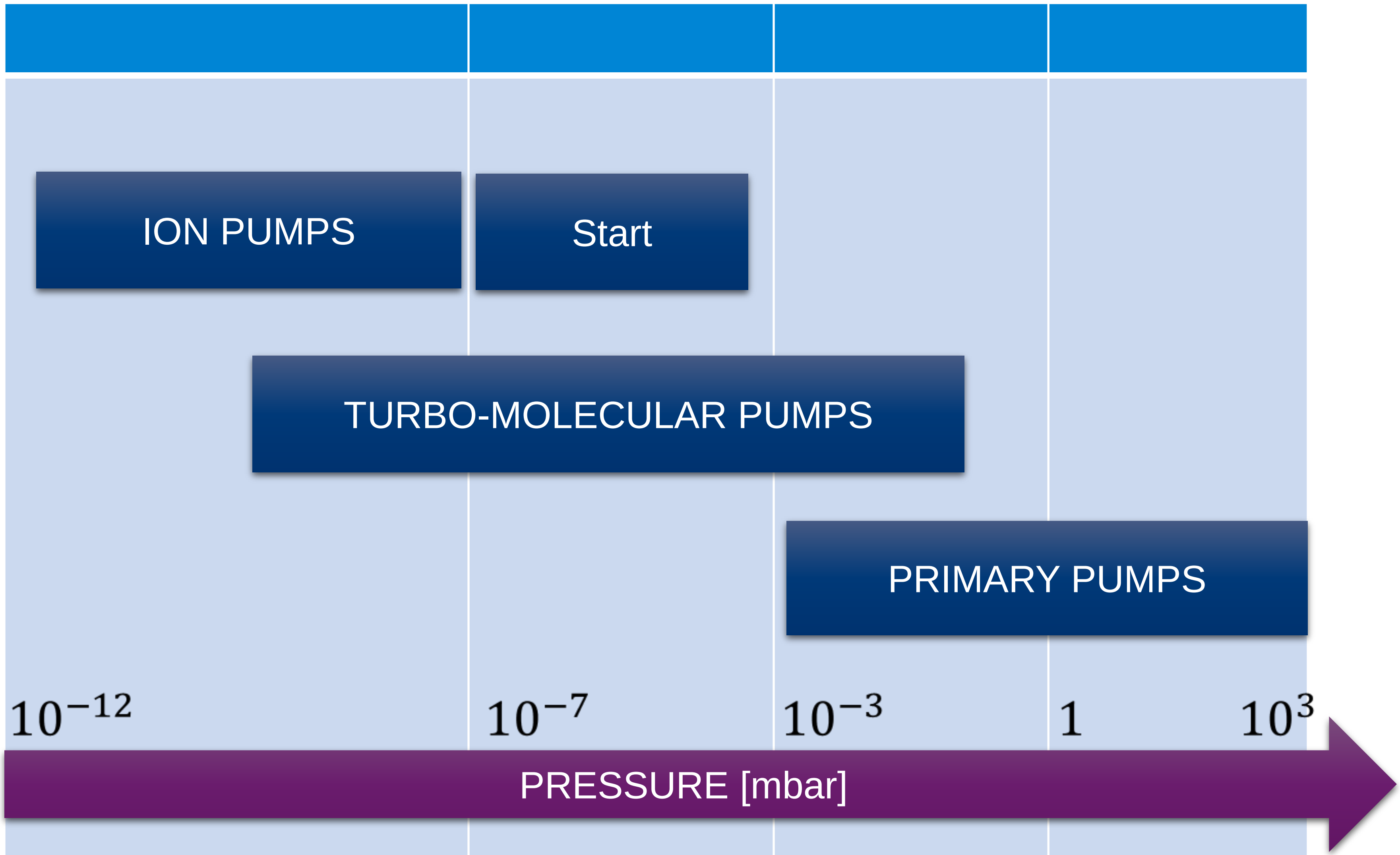


Ion Getter Pumps
CAS-2017

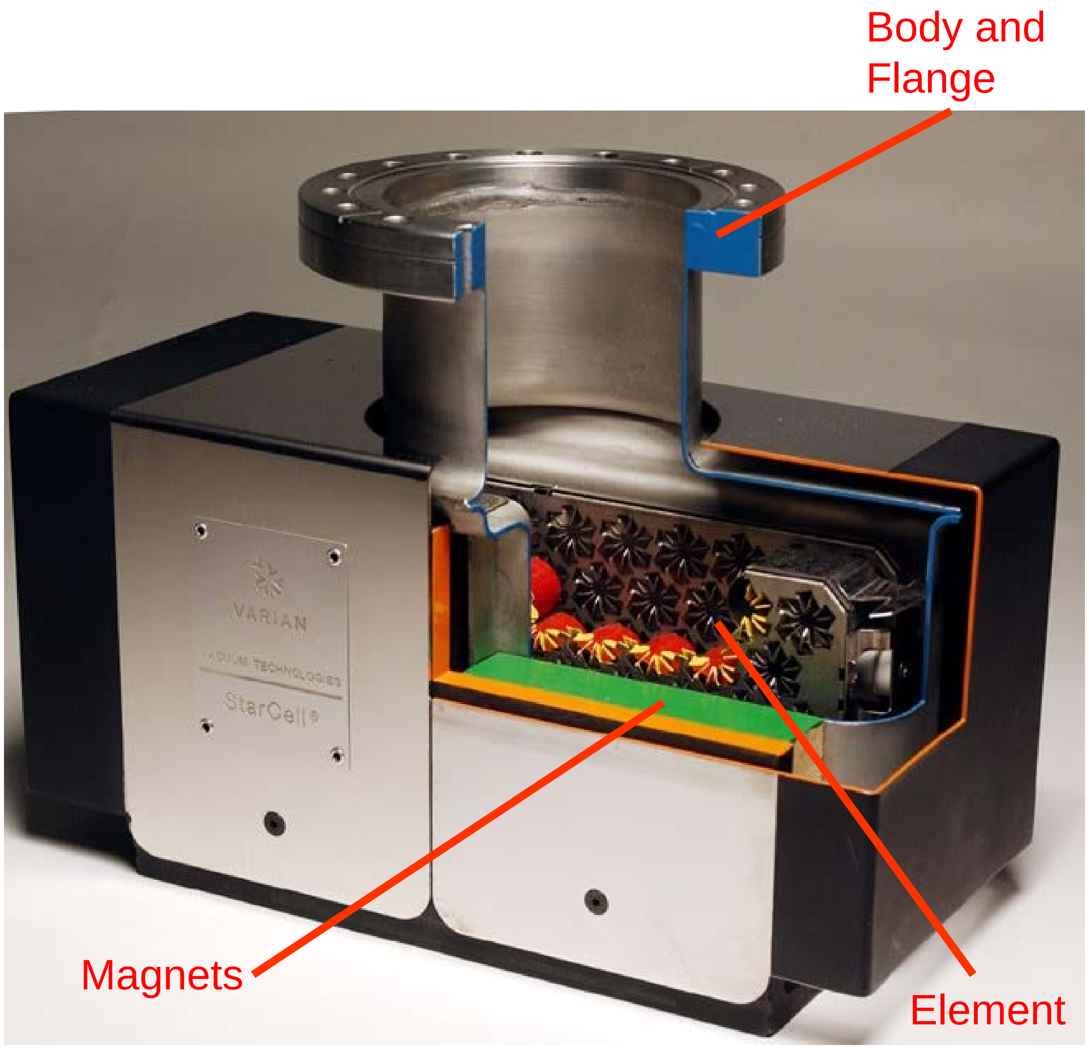
June 2017



Ion Pumps Pressure Range

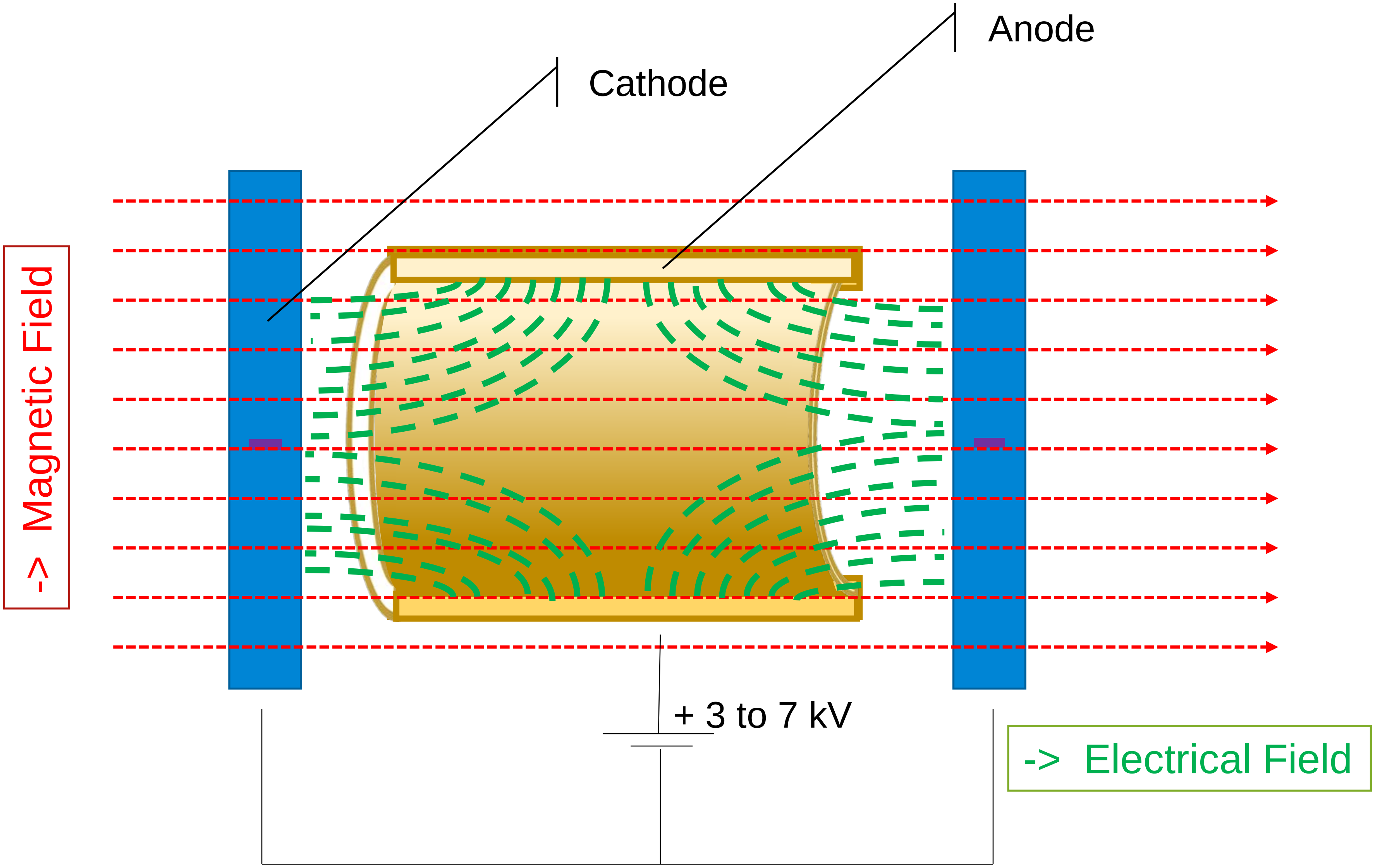


Ion Pumps Structure



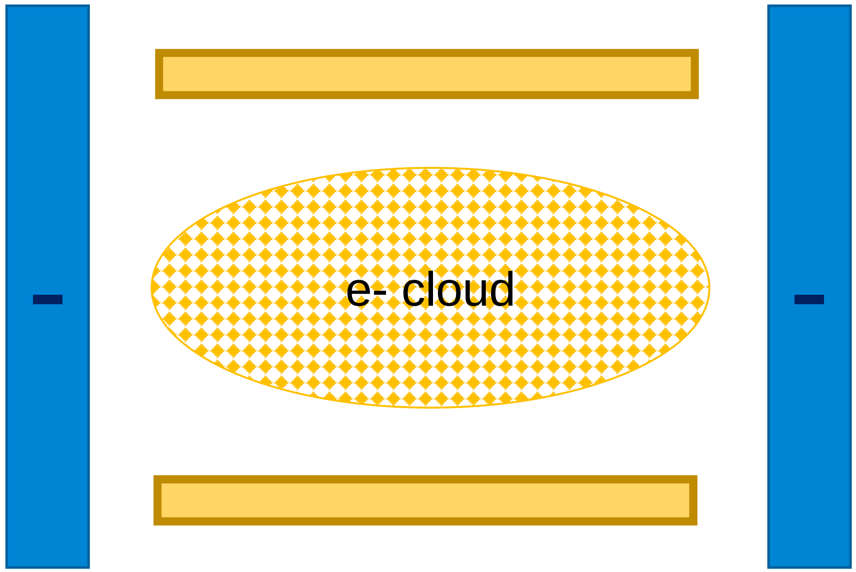
- IGP are **closed pump**: no foreline, only inlet
- Whatever is pumped by IGP will remain into the IGP!
- Three **different** pumping **elements** but all of them are **based on Penning Cell**
- Penning cell is made of anode and cathode with high voltage applied
- That’s why in a IGP we have **ceramics insulators and HV feed-through**

Penning Cell - Structure



Penning Cell – Electron Trap

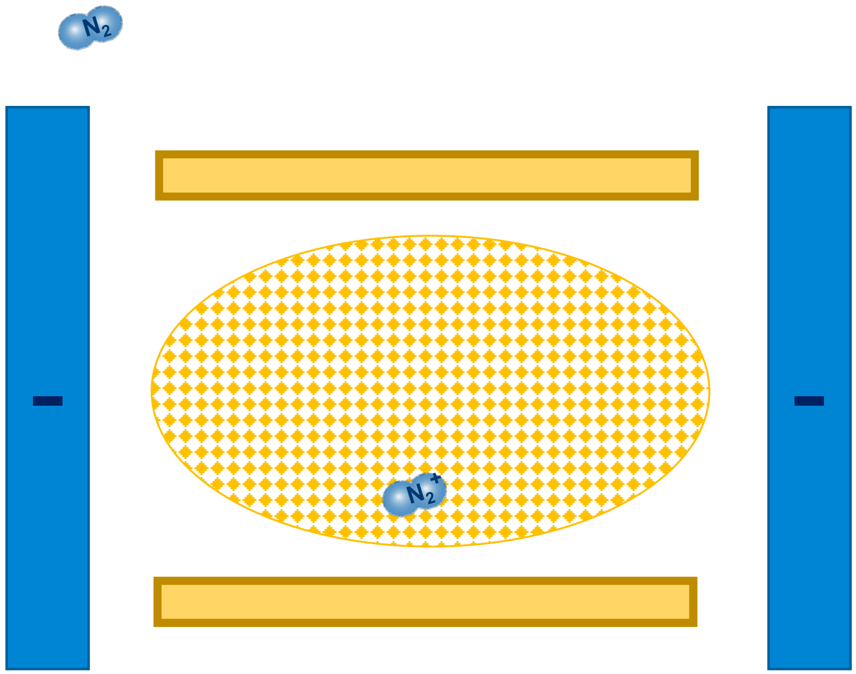
- Combination of Electrical field and Mag field creates a trap for e-



Penning Cell - Ionization

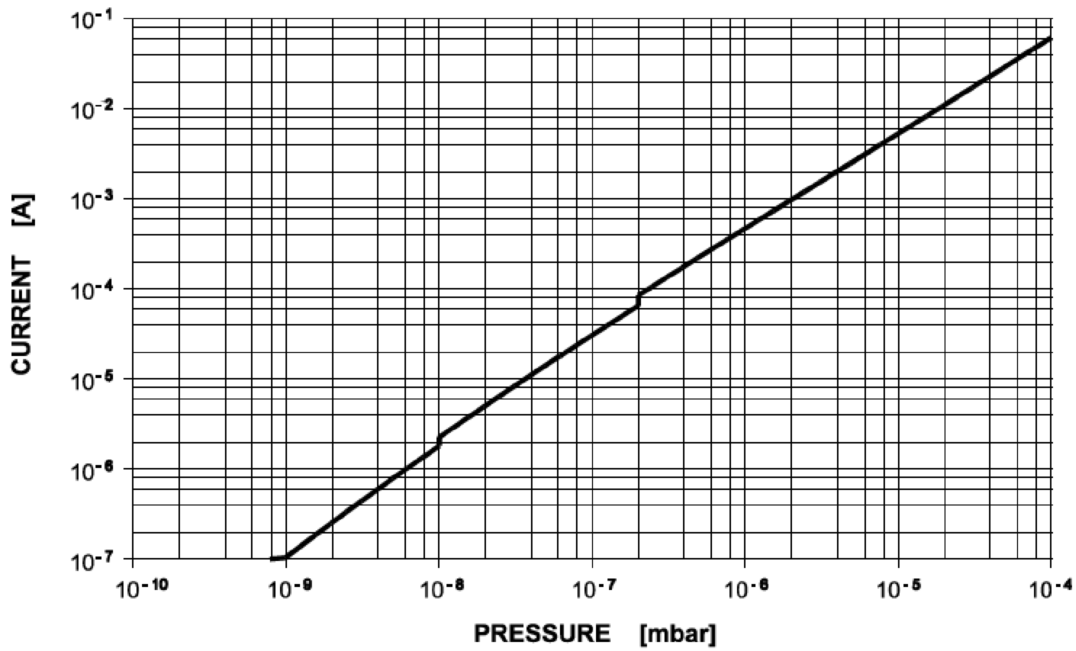
- Gas molecules that enter into the cell can be ionized
  - resulting ions are attracted towards cathode
  - extracted e- is trapped as well
- The number of ions / sec (current) depends form pressure

- **That's why IGP are used as pressure gauge**
- **At given Pressure**, the current or better **the discharge intensity I/P** depends from:
  - Geometry of the cell
  - Number of cells
  - Mag field
  - Voltage



Penning Cell – IGP as Gauge

- Gas molecules that enter into the cell can be ionized and current is generated
- This **current is almost linearly dependent from the pressure** (with others parameters like cell geometry, number of cells, voltage, mag-field, fixed)
- **Order of magnitude: a medium size pump (55 l/s) adsorbs about 1mA at 1*10-6 mbar**
- @ 1*10-7 mbar the current will be roughly 0.1mA, etc...
- Lowest measurable pressure is limited by:
  - **Resolution** and precision of the power supply
  - **Leakage** current

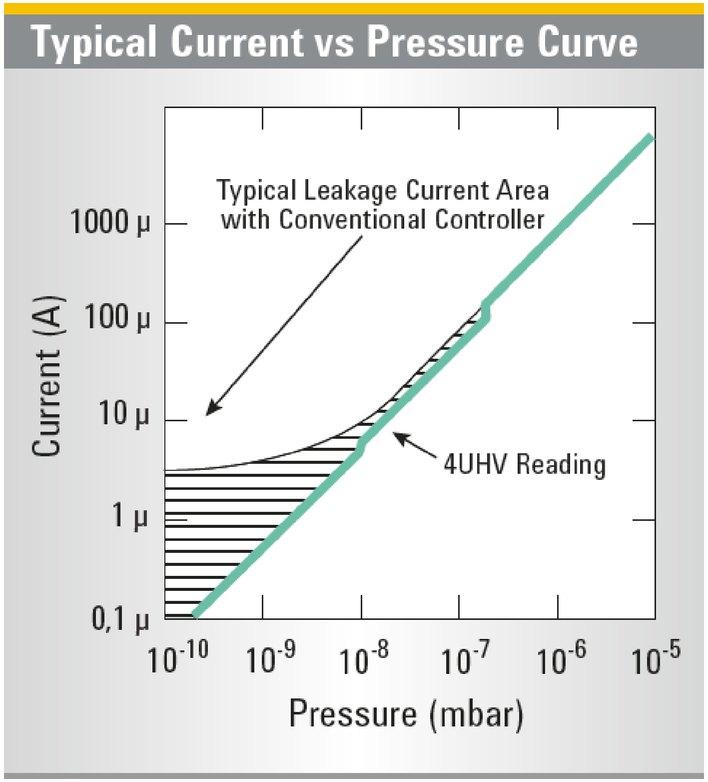


Penning Cell – IGP as Gauge

- **Resolution***
  - With a resolution of 100 nA the lowest measurable pressure is in the low 10-10 mbar. With a resolution of 10 nA we can read down to low 10-11 mbar range...

- **Leakage Current***
  - Leakage current is mainly due to

    Electrons Field Emission from cathode
  - This current does not depends from pressure
  - Depends exponentially from voltage
  - At low pressure the impact can be high



** example of a single element made of*

*53 cells with 1mA @ 1*10-6mbar*

Penning Cell – IGP as Gauge

- **Leakage Current***
  - Example-1
    - pump at 1*10-11mbar -> ionization current about 10nA
    - If we have a leakage of 100nA -> total current of 110nA
    - equivalent to 10-10 mbar! -> error of one decade!
  - Example-2
    - pump at 1*10-10mbar -> ionization current about 100nA
    - If we have a leakage of 100nA -> total current of 200nA
    - equivalent to 2*10-10 mbar! -> error of 50%!

** example of a single element made of 53 cells with 1mA @ 1*10-6mbar*

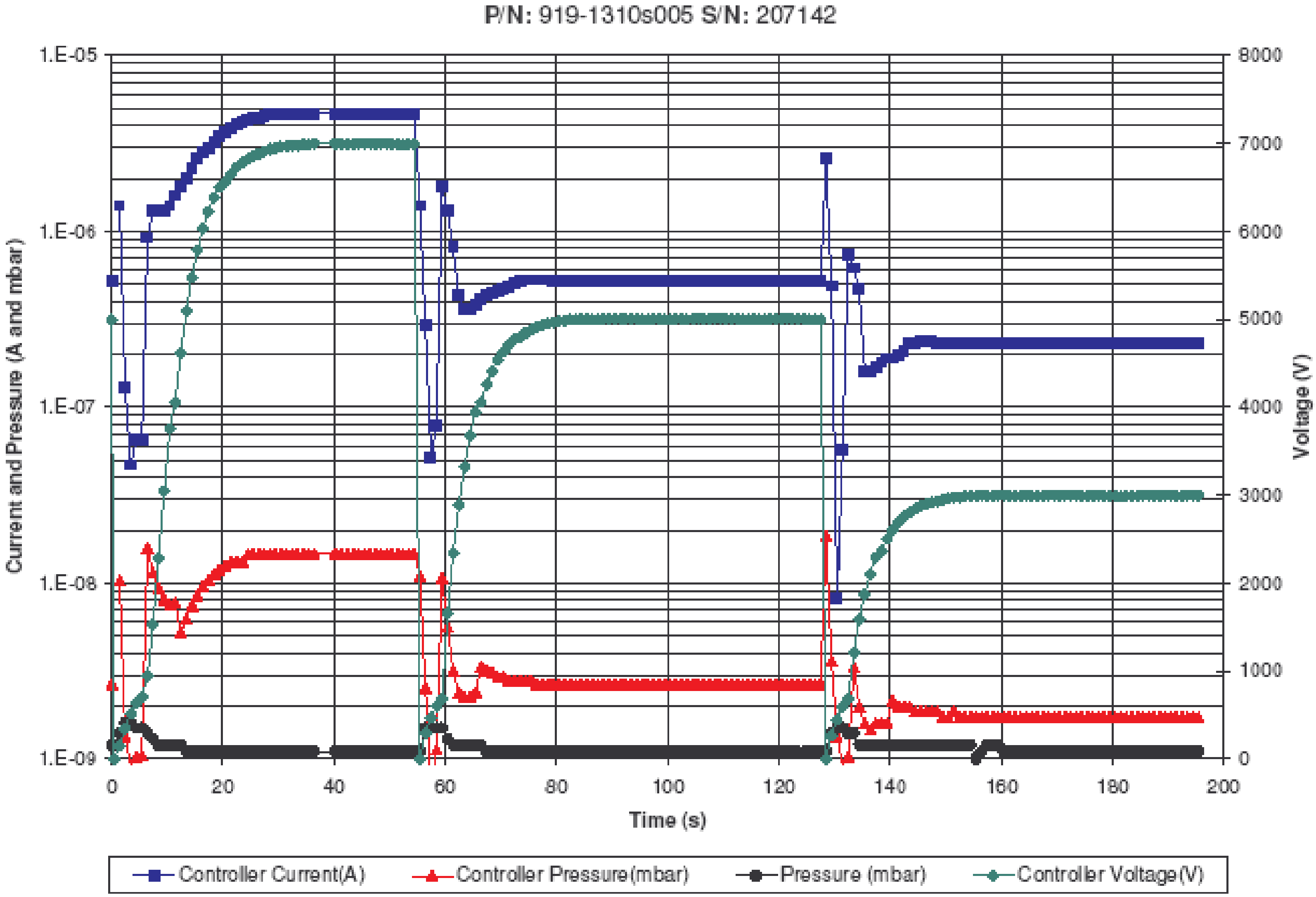
How to minimize the leakage current effect?

By reducing the voltage!

Field Emission is proportional to exponential of Voltage

Let's see a real measurement example:

Penning Cell – IGP as Gauge



Pumping Mechanism

- Till now we have seen:
  - Penning cell -> trap of electrons
  - Ionization of gas molecules by interaction with e- cloud
  - Ionization current is proportional to pressure -> penning cell (and hence IGP) are used as pressure gauge

Now we have to see how an IGP pumps the gas…

Pumping mechanism (and also efficiency) is dependent form gas type:

- Getterable gases
- Noble gases
- Hydrogen

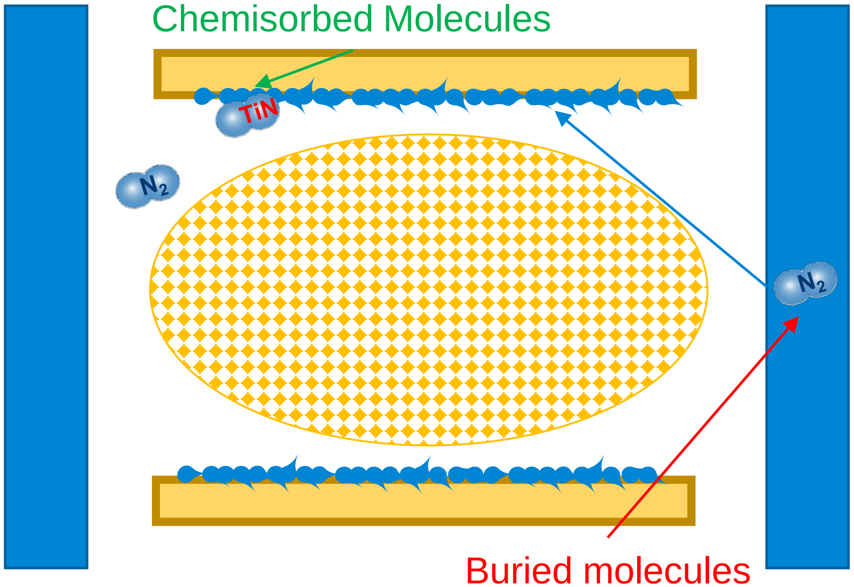
In order to better pump one type of gas above, there are different configurations of IGP:

- Diode (penning cell structure seen till now)
- Noble diode
- Triode / Starcell

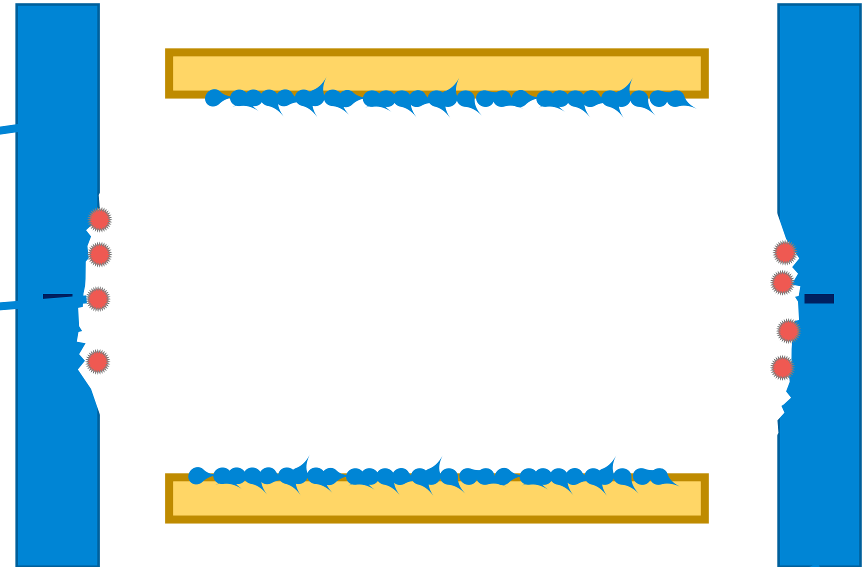
Pumping Mechanism – Getterable Gases

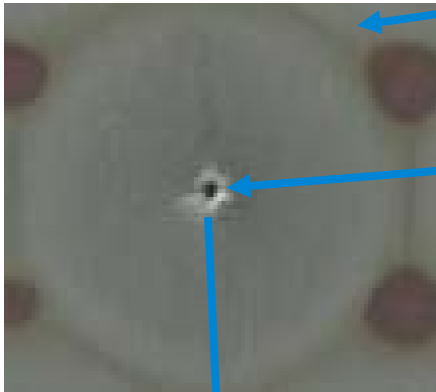
- Ions (positively charged) are accelerated towards the cathodes:
  - Impact sputter some Ti cathode atoms that stick on the anode surface
  - Some of the ions accelerated towards the cathodes are neutralized and buried into the cathode (Ionization Pumping)
    - Not stable pumping!

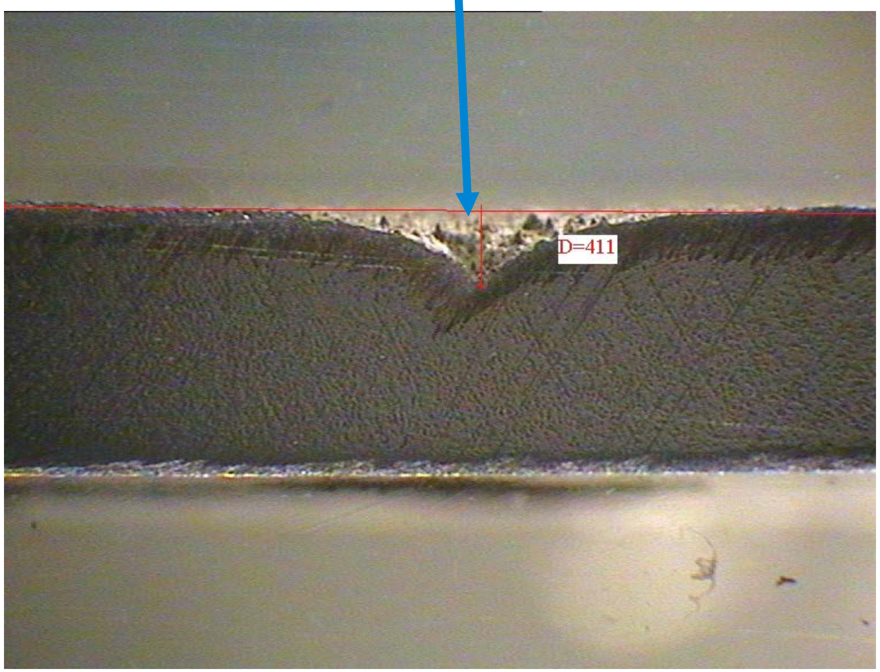
- Some other gas molecules can hit the active titanium film are chemically trapped (Getter Pumping)
  - Stable and permanent pumping

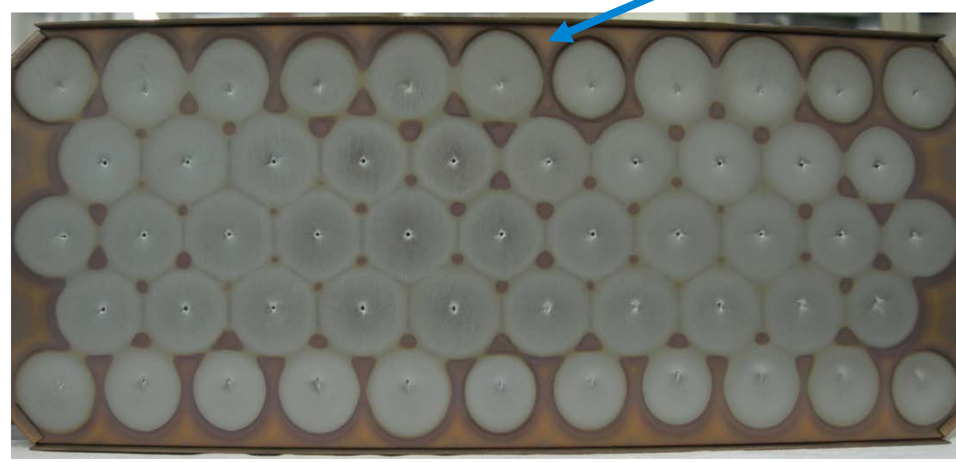


Cathode Erosion









Saturation

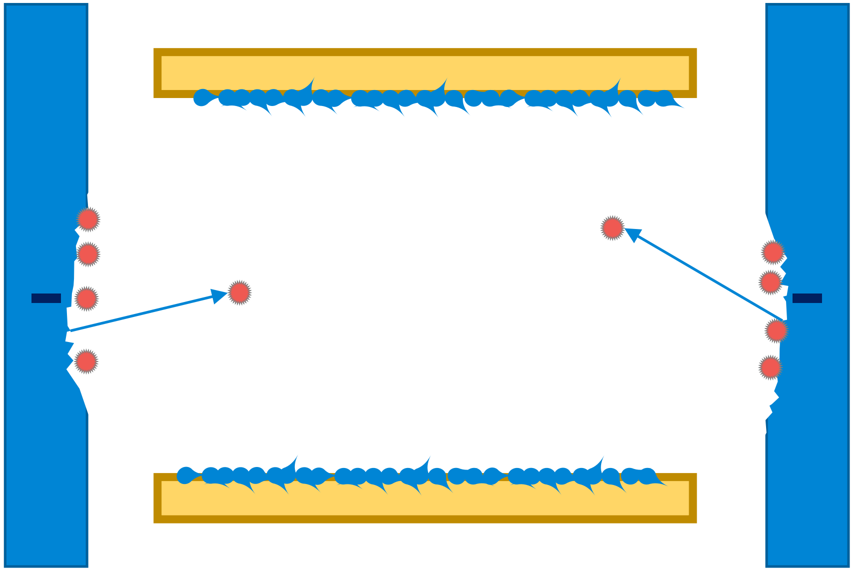
Pumping at the cathodes is not permanent due to cathode’s erosion

Previously implanted atoms are released

As a consequence, the net pumping speed decreases until an equilibrium condition between ion implantation and gas re-emission is reached

At equilibrium the pump is called “**saturated**”

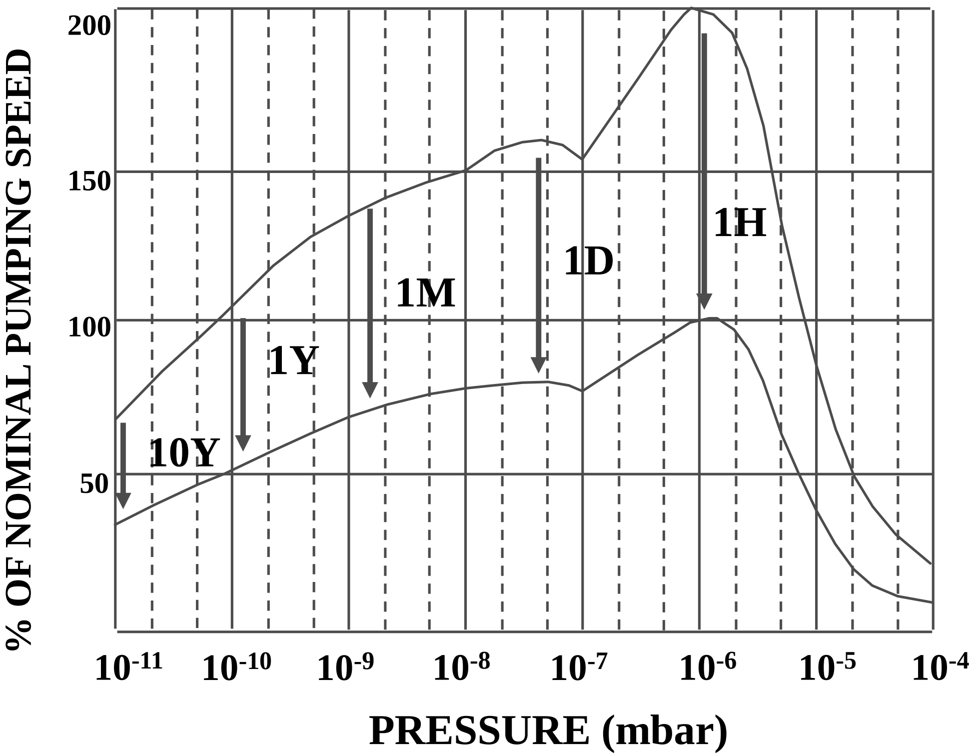
Saturated indicates stable operation mode of IGP, not the end of pump life !



IGP Saturation

Time to get to saturated condition depends from pressure

Higher the pressure -> higher the erosion rate -> faster the time to get to equilibrium (saturation)

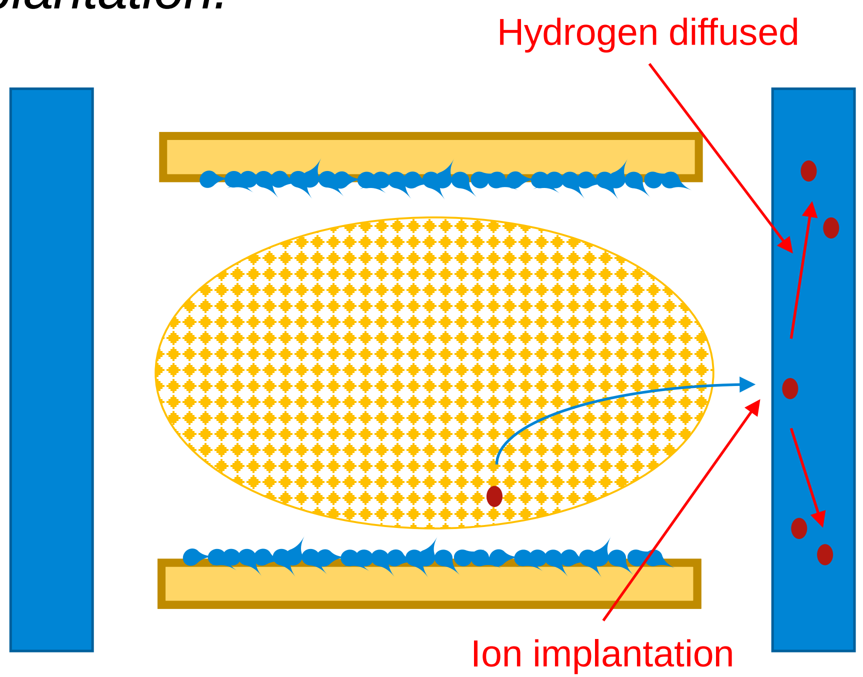


Pumping Mechanism – Hydrogen

- Titanium sputtering yield for hydrogen is very low, so only a small quantity of hydrogen is re-emitted by the cathode.
- Hydrogen is chemically reactive so it is pumped by the titanium film.
- Hydrogen has a high **solubility** in titanium (Ti acts as a “sponge”):

  → *diffusion into cathode after implantation.*

- Anyway pumping speed of H2 is roughly 50 to 100 % higher than for N2
- Pumps remains almost unsaturated for H2

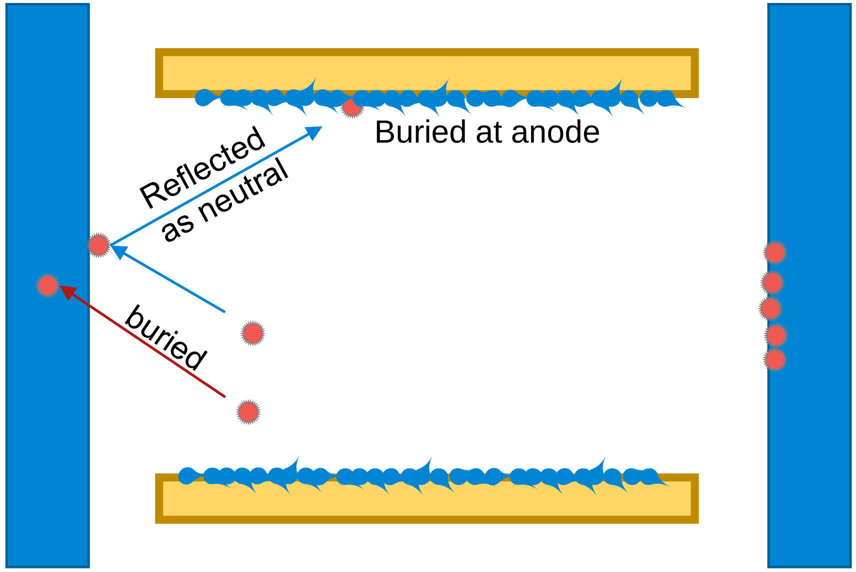


Agilent Technologies

Pumping Mechanism – Diode - Noble Gases

- Noble gases are not chemically active, so they are not chemisorbed by the titanium film at the anode
- We have **two types of pumping mechanism of noble gases**:
  - **implanted** into the cathode
    - this type of pumping is **not stable** and after saturation gas is released back → ***noble gas instability occurs***
  - **Buried at anode**
    - Ions can be neutralized and reflected back (“bounced”) from the cathodes as high energy neutrals
    - Hence noble gases can be implanted into the titanium sputtered on the anode:

    → ***stable pumping***



Typical Noble Gas Instability

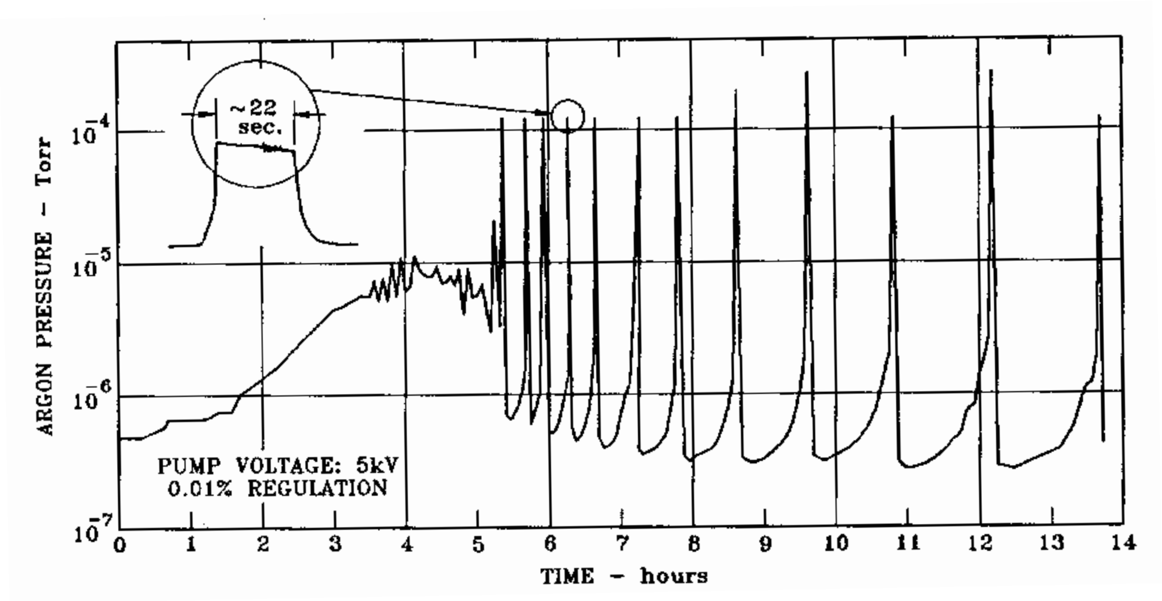
Re-emission of Noble Gas implanted into he cathode happens suddenly

Pressure increases of one or few decades

After emission the gas is re-implanted into the cathode and stays there till the cathode erosion reach it and another re-emission (pressure increase) happens.

Periodicity of pressure peaks is a key indicator of NG instability

Time to show the instability depends from pressure -> need certain amount of gas pumped

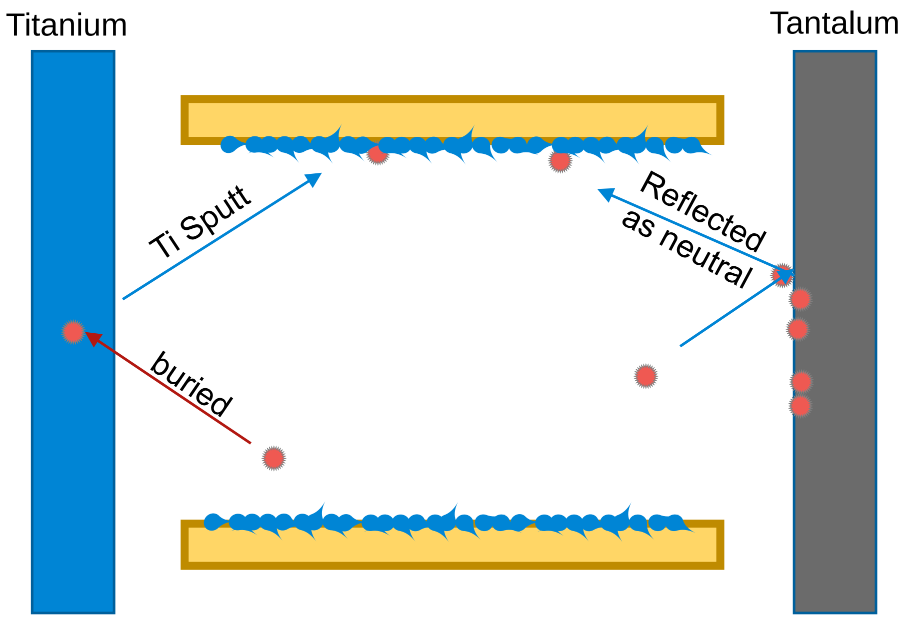


Pumping Mechanism – Noble Diode Element

Goal: improve noble gases capacity and pumping speed

- One cathode made of Tantalum in order to increase the probability of reflecting noble gases as high energy neutrals.
- More stable and higher speed for noble gases with respect to diode.

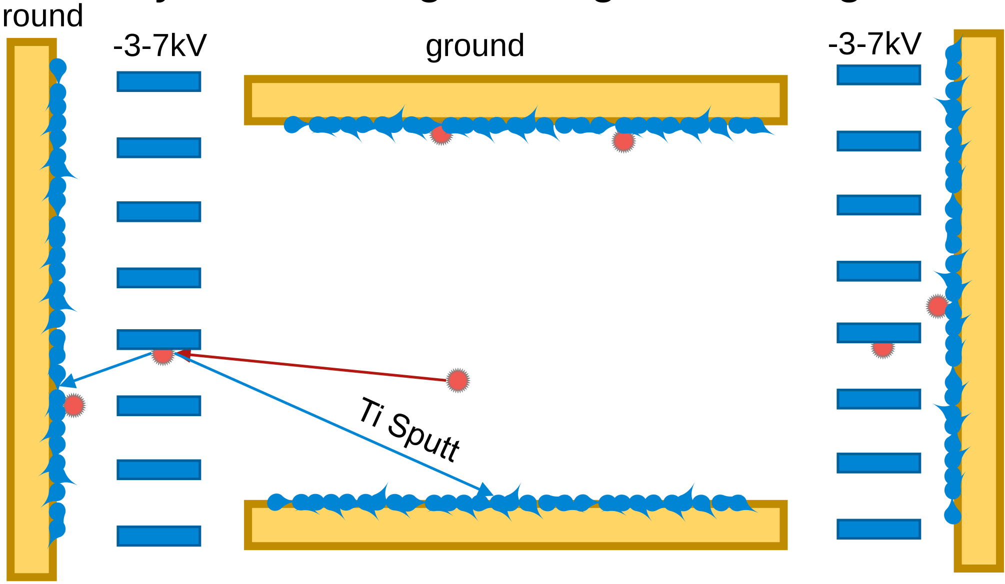
- About the 80% of the speed for Nitrogen with respect to the diode.
- Reduced pumping speed and capacity for hydrogen.
- More expensive than diode.



Pumping Mechanism – Triode and Starcell Elements

Goal: improve noble gases pumping capacity and high hydrogen pump speed

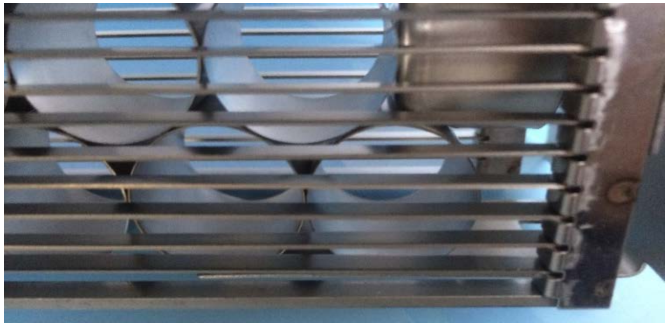
- Cathode is made of Ti strips not anymore a flat plate like in the diode
- Anode is grounded, cathode is at negative voltage, Penning cell ionization mechanism still the same as in the diode
- New cathode shape increases the probability of reflecting noble gases as high energy neutrals.
- Ions hitting the cathode with a glancing angle, have an increased probability to be emitted as neutrals
- Hence being buried in stable way at anode and on body

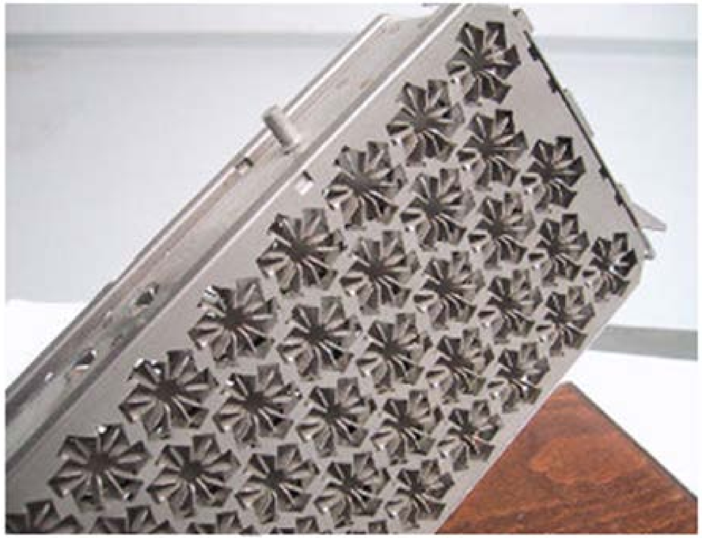


Pumping Mechanism – Triode and Starcell Elements

Stracell

- It is an improved version of the triode.
- Longer lifetime than diode element (titanium consumption is optimized).
- The shape of the small wings of the stars is optimized in order to maximize the reflection of neutrals (maximum pumping speed for noble gases).
- Pumping speed for nitrogen is about 80% with respect to the diode.
- Highest pumping speed and stability for noble gases.
- It can pump larger quantities of hydrogen than the noble diode, because both the cathodes are made out of titanium.





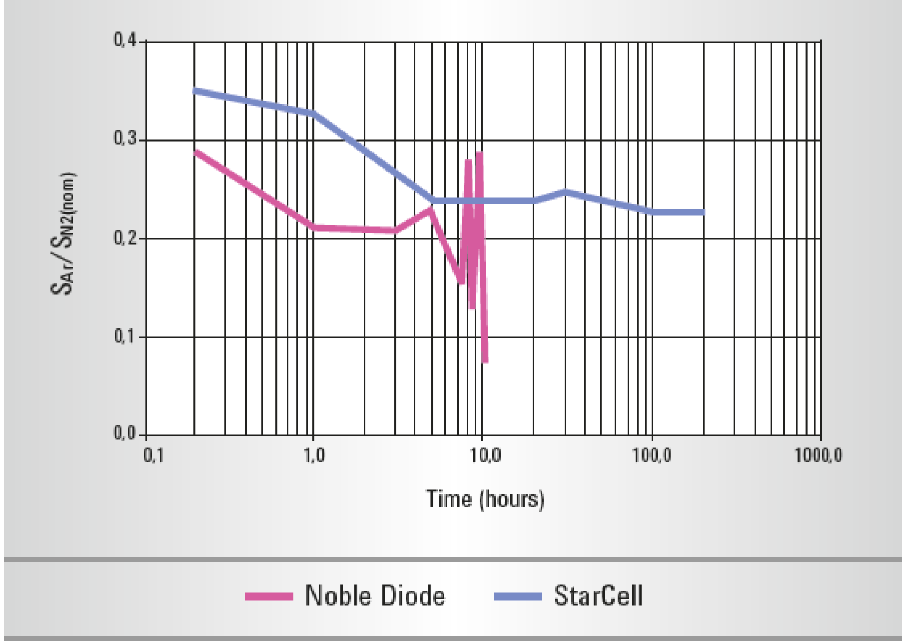
Noble Gases Instability Element Comparison

Diode with Argon:
- maximum capacity of about **2 hours at 1E-5 mbar of Argon**;
- 200 h at 1E-7 mbar of Ar
- 2000 h at 1E-8 mbar of Ar

Noble Diode with Argon:
- maximum capacity of about **10 hours at 1E-5 mbar of Argon**;
- 1000 h at 1E-7 mbar of Ar
- 10000 h at 1E-8 mbar of Ar

Starcell with Argon:
- maximum capacity of about **200 hours at 1E-5 mbar of Argon**;
- 20000 h at 1E-7 mbar of Ar
- 200000 h at 1E-8 mbar of Ar

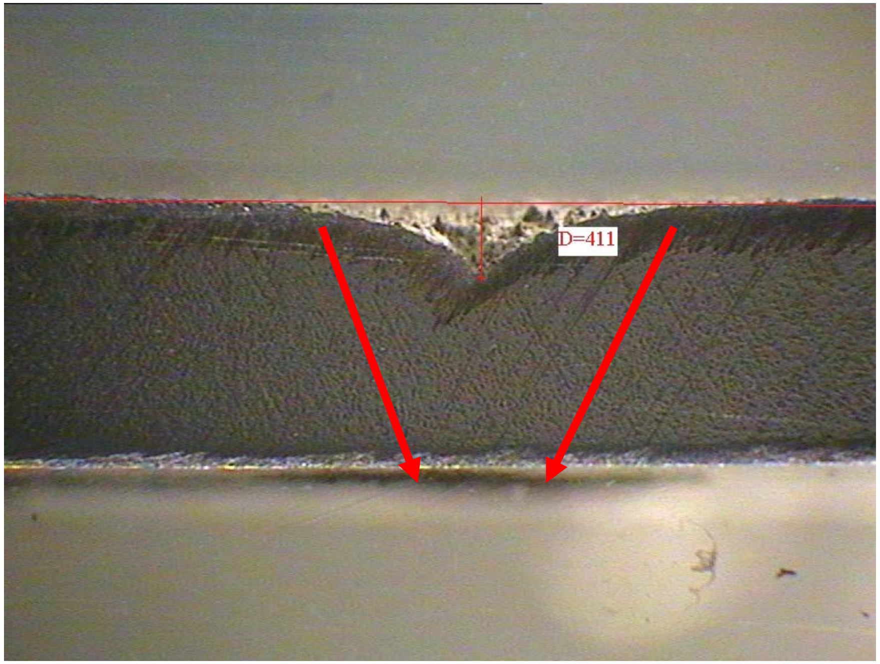
Fig. 15 - Starcell and Noble Diode instability at P=1 10^{-5} mbar



IGP Life Time

Reason that can lead to IGP life end

- Vacuum leak
  - very unlikely, if not happen at the beginning will not happen long term
- Low Magnetic Field
  - can happen if during bake out cross the Curie temperature – usually very unlikely
- Noble Gases Instability
- Short Circuit
  - In case of complete metallization of insulators or due to cathode deformation
- Leakage Current
  - If too high can affect the pressure indication
  - Does not affect the pumping speed!
- End of Titanium
  - When the erosion drilled completely the cathode -> no more sputtering



Agilent Technologies

IGP Life Time

End of Titanium

- Time to end or drill the titanium depends from
  - Titanium thickness
  - Working pressure
  - Ten times higher the pressure -> ten times higher the sputtering rate

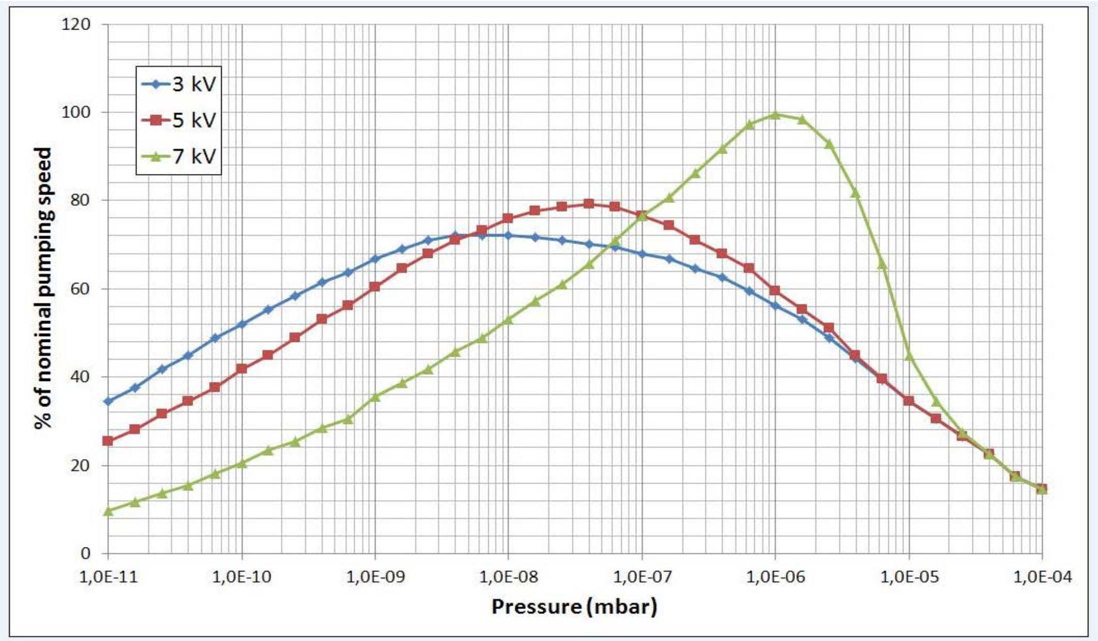
- Rough values
  - Diode 50’000 hours @ 1*10-6 mbar
  - Noble Diode 50’000 hours @ 1*10-6 mbar
  - Starcell 80’000 hours @ 1*10-6 mbar

Pumping Mechanism - Voltage

- We have seen that by reducing the voltage, we reduce the leakage current but:

what happens to the pumping speed?

- At lower pressure, reducing the voltage, optimize the sputtering yield (and hence the pumping speed):



- This is due to the space charge effect

IGP – Pro and Cons

PRO

- Closed pump -> no risk of venting the system
- Do not need any baking pump (only at start-up)
- 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
- Can work in high radiation areas

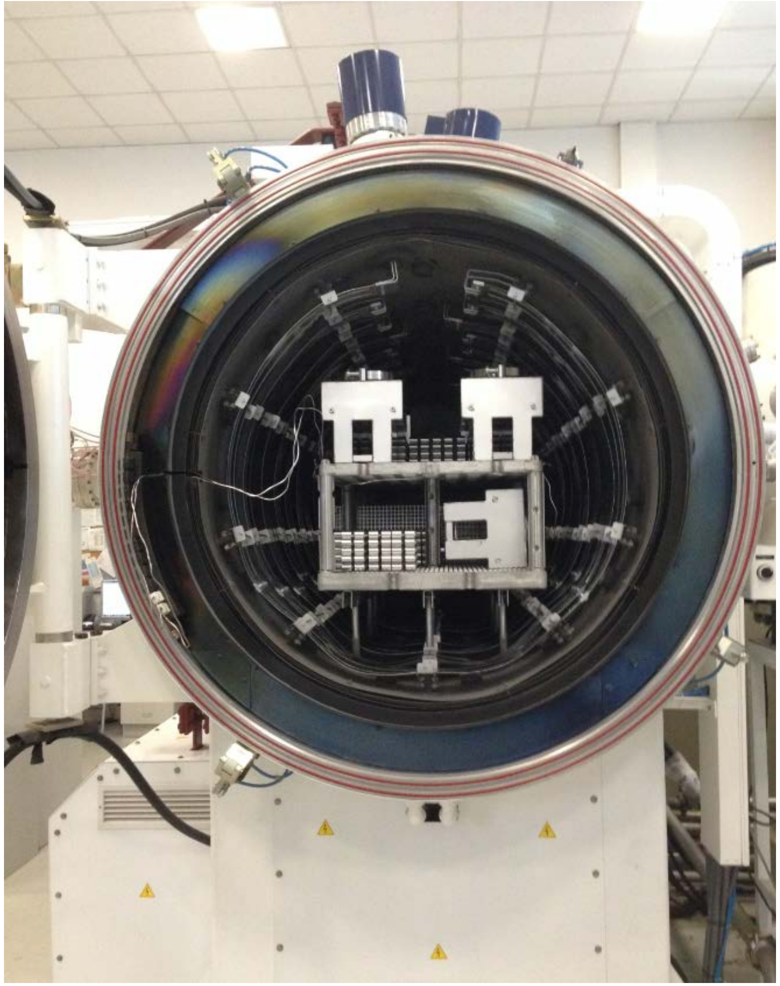
CONcerns

- Base Pressure – can be limited by
    - self outgassing
    - contamination
        - cleaning and first bake out process are critichal
- Pumping Speed decreases with Pressure
- Particles emissions

28

Trends vs CONcerns – Cleaning and Outgassing

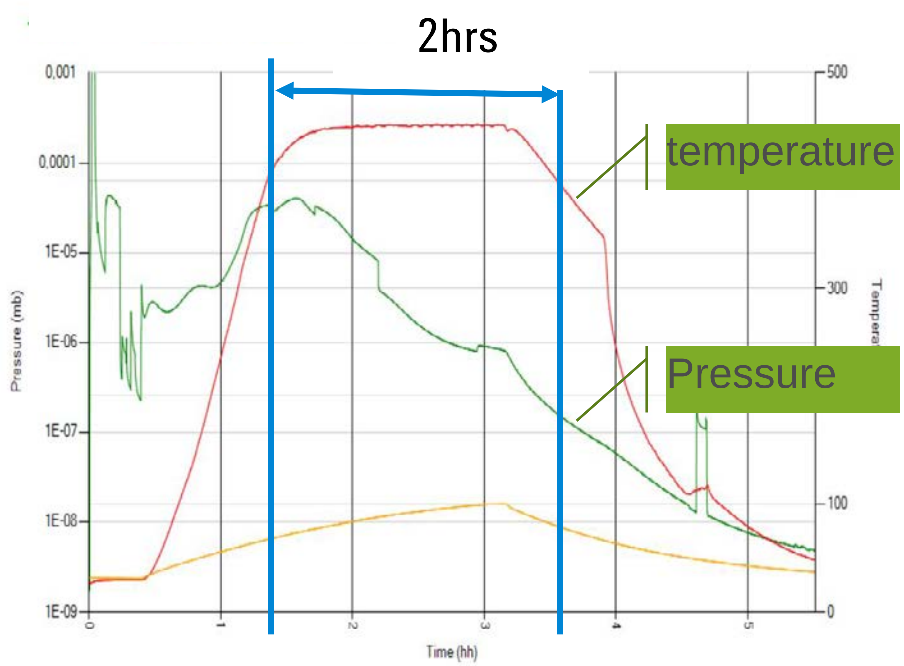
- Improve cleaning and self outgassing
  - Vacuum firing of Ti cathodes (well known)
  - Vacuum firing of anodes
    - Introduced since few years on all pumps
    - Anode is the second source of outgassing in a IGP
    - Started to introduce vacuum firing for the entire body



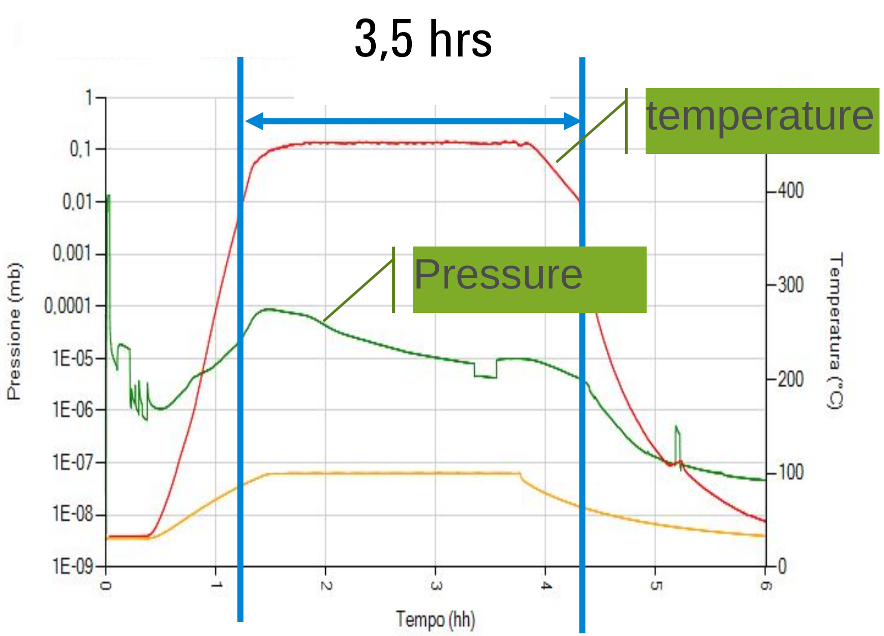
Vacuum Firing
Furnace view
All parts are first cleaned and all weldings done.
After vacuum firing pump is assembled and finally baked-out.

Trends vs CONcerns – Cleaning and Outgassing

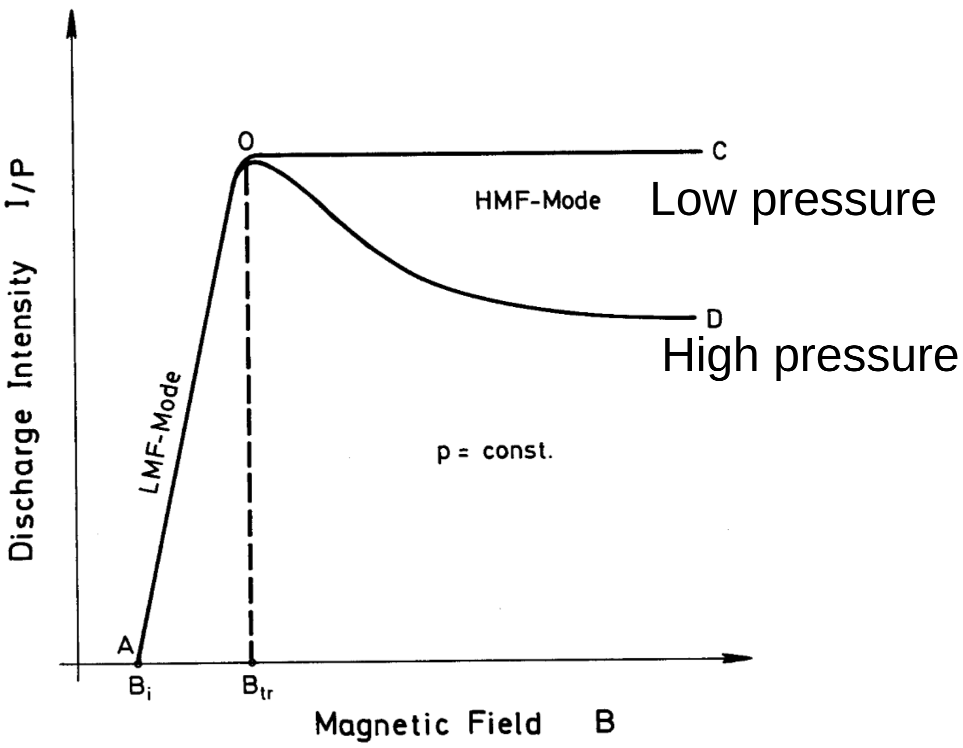
With vacuum firing



Standard process



Trends vs CONcerns – Pumping Speed at low Pressure
Penning Cell - Discharge Intensity

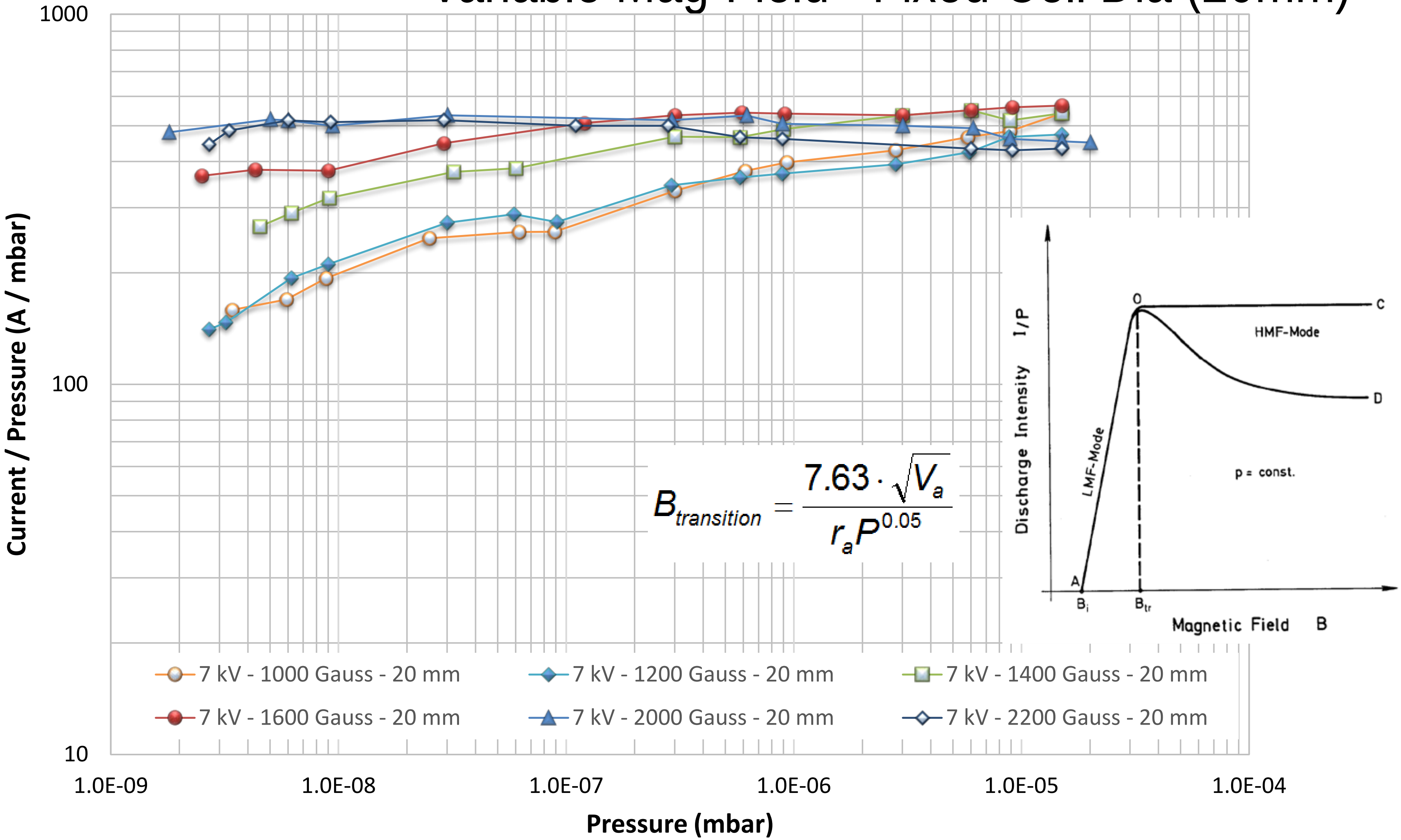


$$B_{transition} = \frac{7.63 \cdot \sqrt{V_a}}{r_a P^{0.05}}$$

20 mm dia 25mm heigh cell

P (mbar)	@ 7 kV	@ 5 kV	@ 3 kV
1,00E-06	1256	1061	823
1,00E-07	1409	1191	922
1,00E-08	1580	1336	1035
1,00E-09	1774	1499	1161

Trends vs CONcerns – Pumping Speed at low Pressure
Variable Mag-Field - Fixed Cell Dia (20mm)

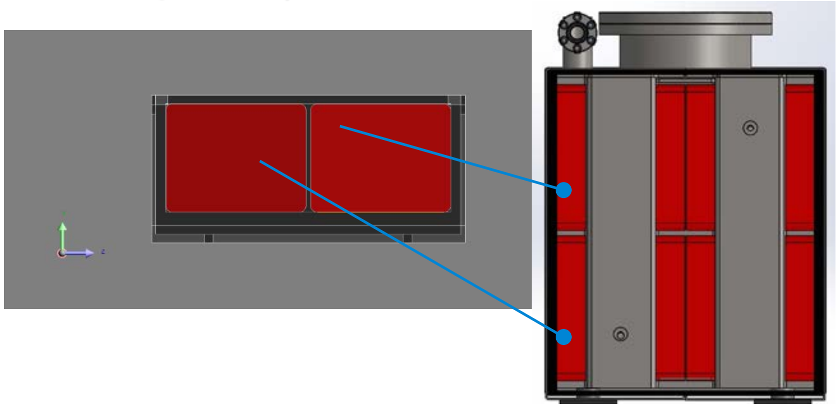


$$B_{transition} = \frac{7.63 \cdot \sqrt{V_a}}{r_a P^{0.05}}$$

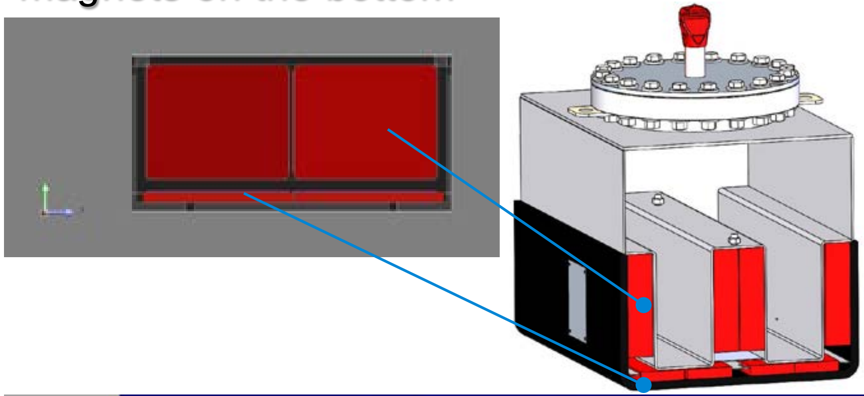
Trends vs CONcerns – Pumping Speed at low Pressure

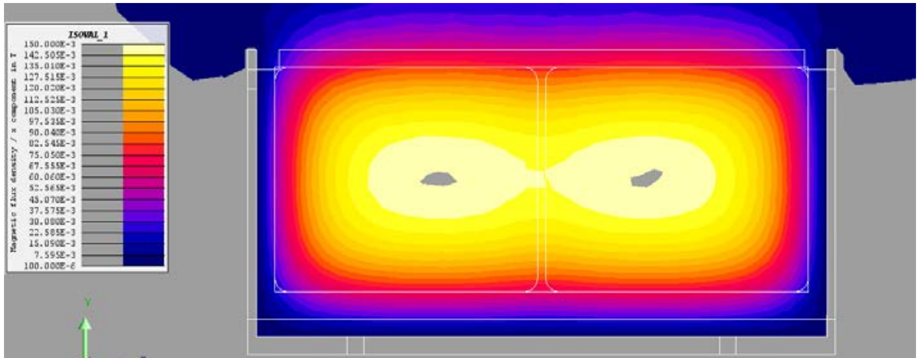
Classic	vs	Optimized

Classic magnetic field configuration (section of the pocket)

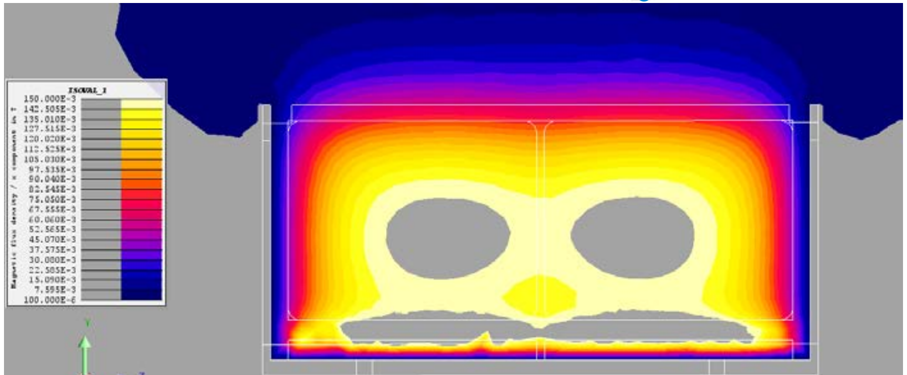


Optimized magnetic field configuration (section of the pump pocket)→ added magnets on the bottom



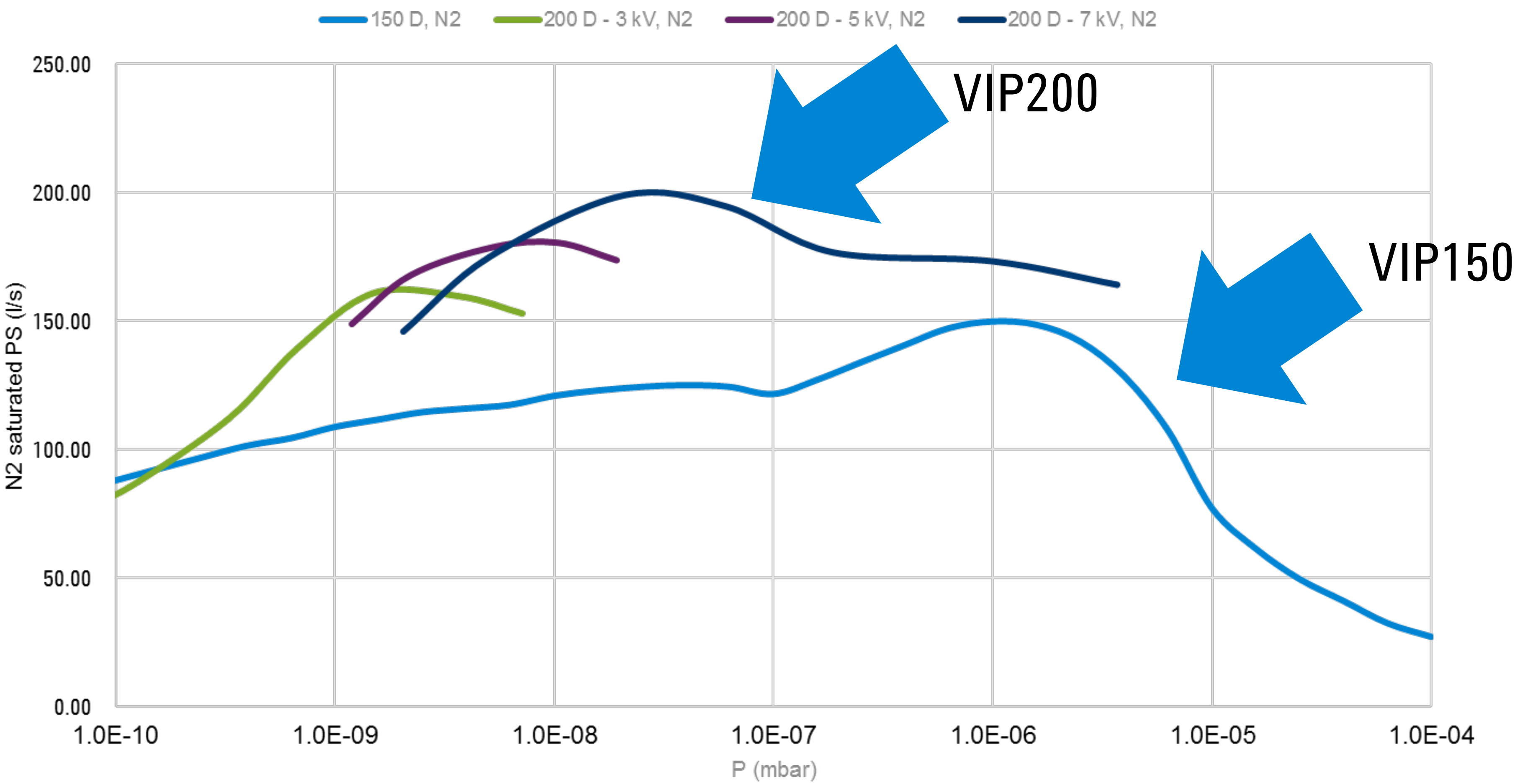


Red: 900G – Oran: 1000G

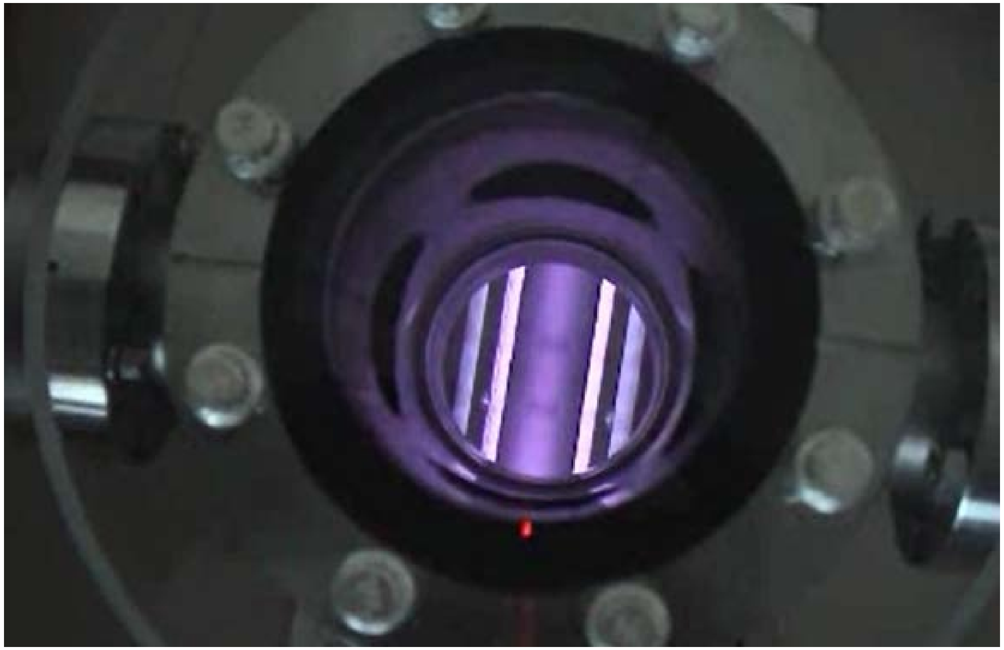


Yellow: 1250G – Grey: >1500G

Trends vs CONcerns – Pumping Speed at low Pressure



Trends vs CONcerns – Particle Emission



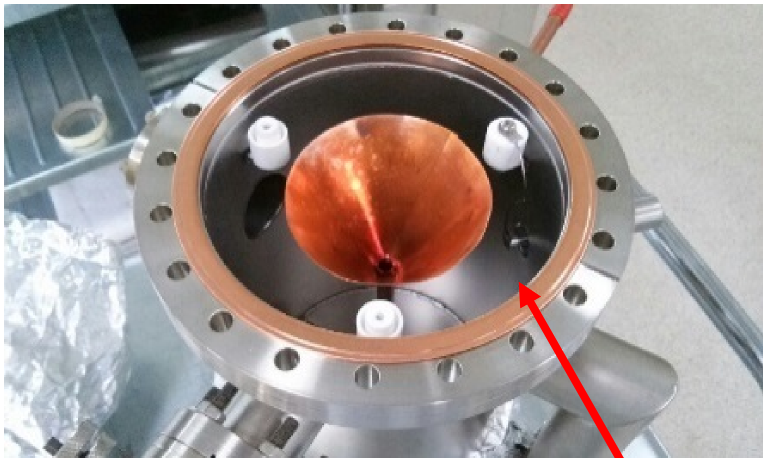
- Plasma inside the IGP generates:
  - *Ions*
  - *Electrons*
  - *Visible light*
  - *Sputtered Ti*

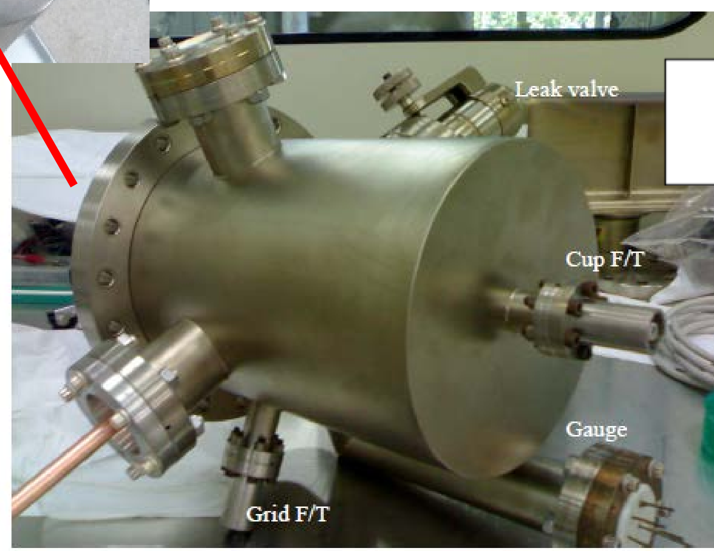
Most of these emissions can be stopped or drastically reduced by optical shields

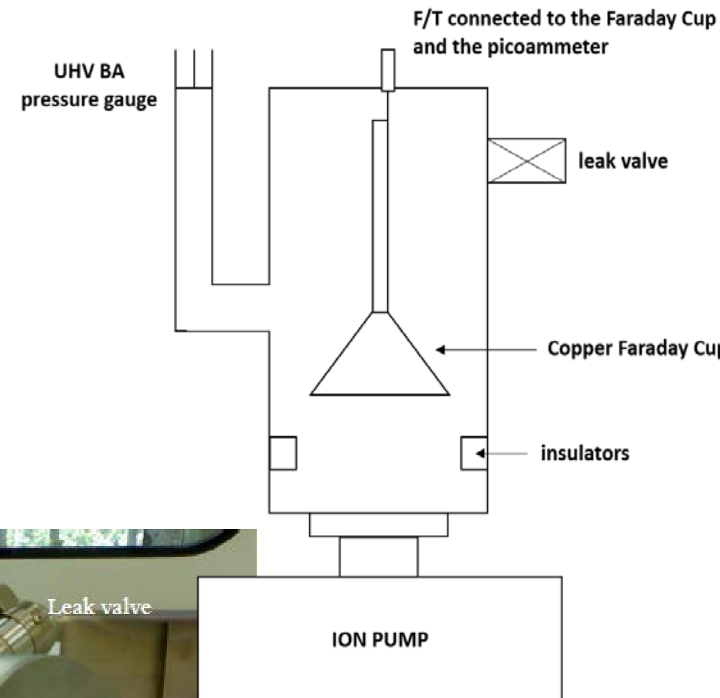
Also for chanrged particles?

Some data from internal test on particle emission

TEST SET-UP PICTURES





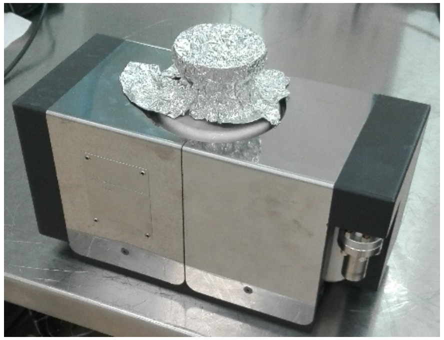


Some data from internal test on particle emission

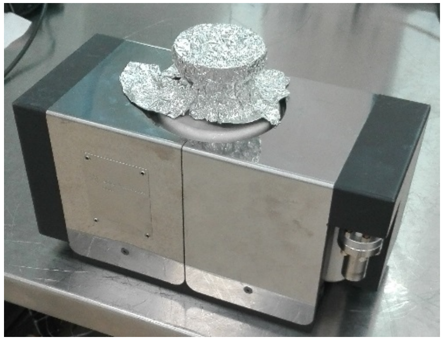
- Roughly, in our set-up (that collects all particles and the collector is very close to the pump) the **emission current is 4 order of magnitude lower than pump current**
- Emission current is directly proportional to pressure
- In the emission (Cup) current **ions are predominant** to electrons (when direct sight cup-element is present)
- There **no direct proportionality to voltage**

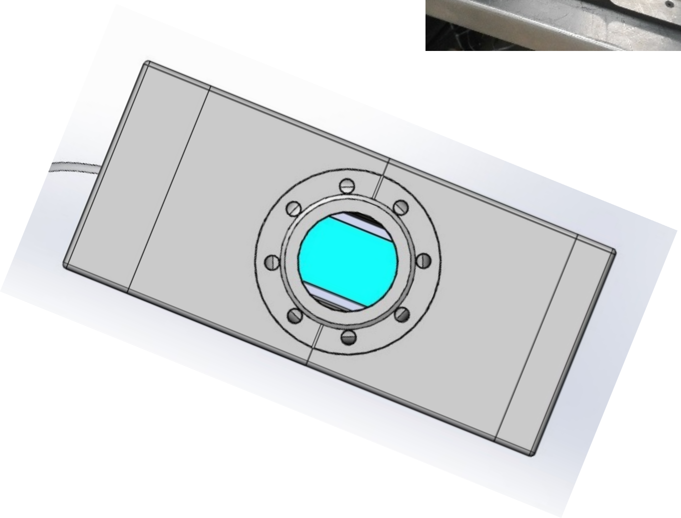
Shields Test

1- Agilent Diode 40 l/s

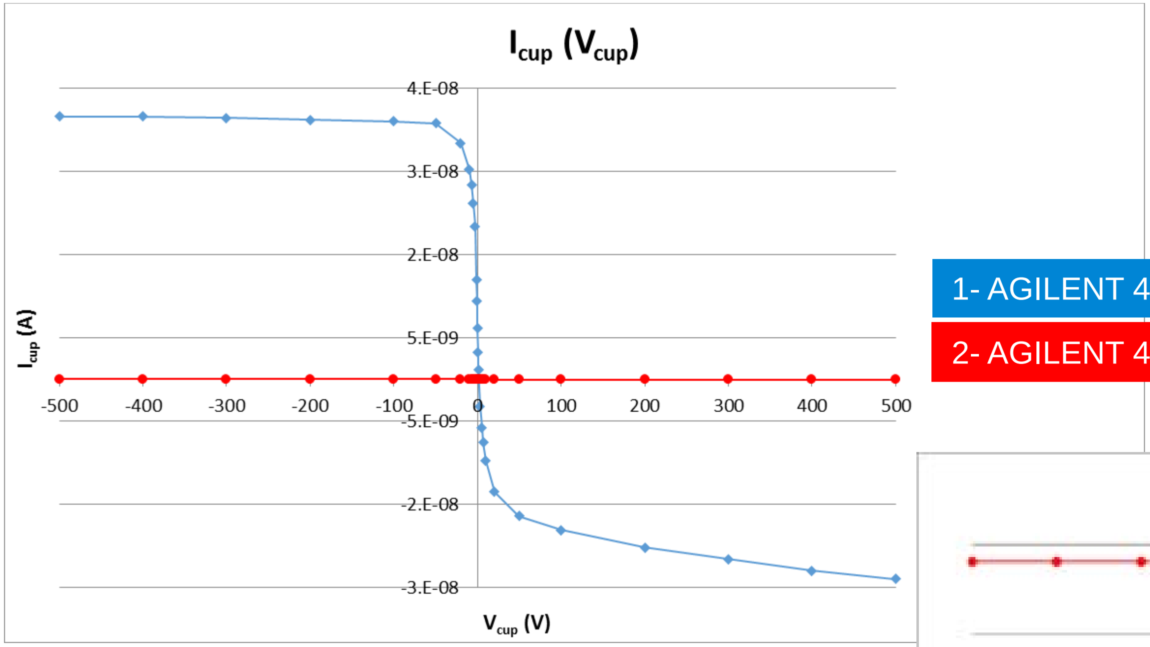


2- Diode 40 l/s +
Optimized Optical Shield



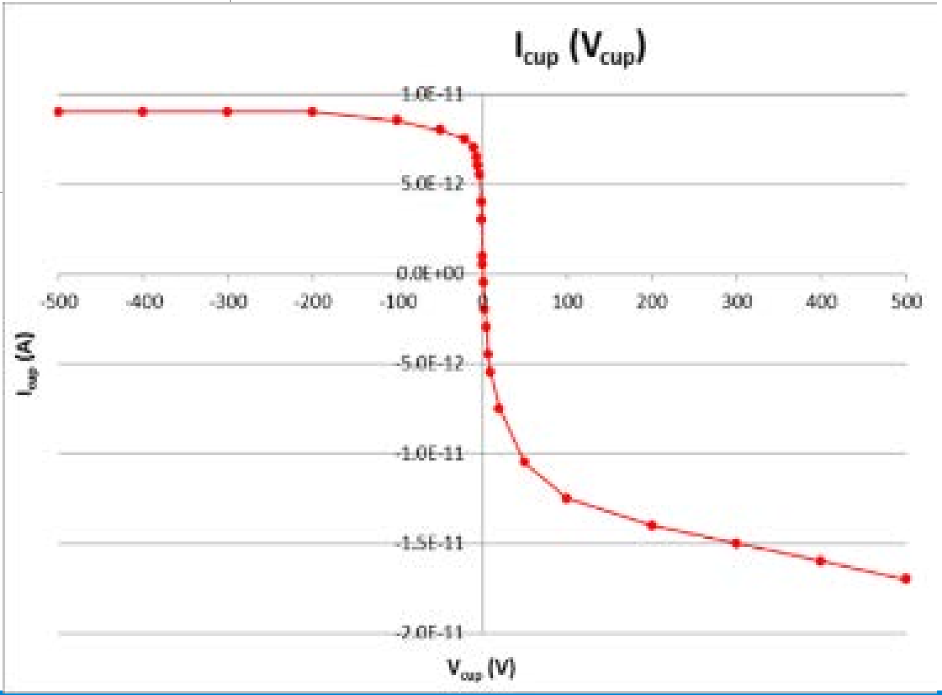


Results: Agilent Diode 40 vs Diode 40 + shield



1- AGILENT 40 NO SHIELD

2- AGILENT 40 WITH OPTICAL SHIELD






Thank You!