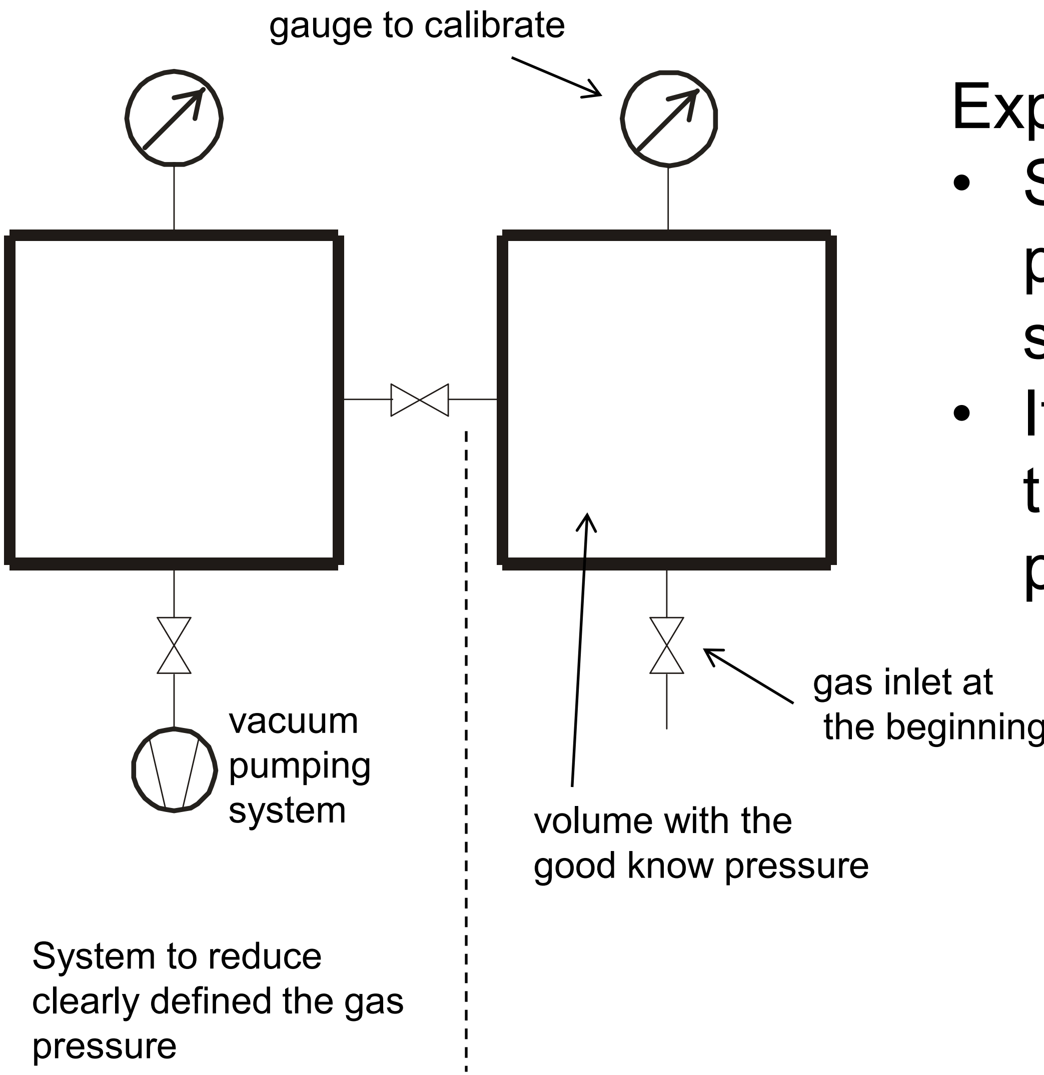
Some basics of the PITZ vacuum system

Dr. D. Richter
Helmholtz-Zentrum Berlin für Materialien und Energie
(BESSY II)

- We try to understand what is that – UHV
- Generation of vacuum at PITZ
- Methods to measure the total pressure
- A method to get partial pressures (RGA)
- Gas currents in an accelerator setup
- One of the influences of the plasma chamber on the PITZ vacuum system

Ultra high vacuum – what‘s that?



Experiment:

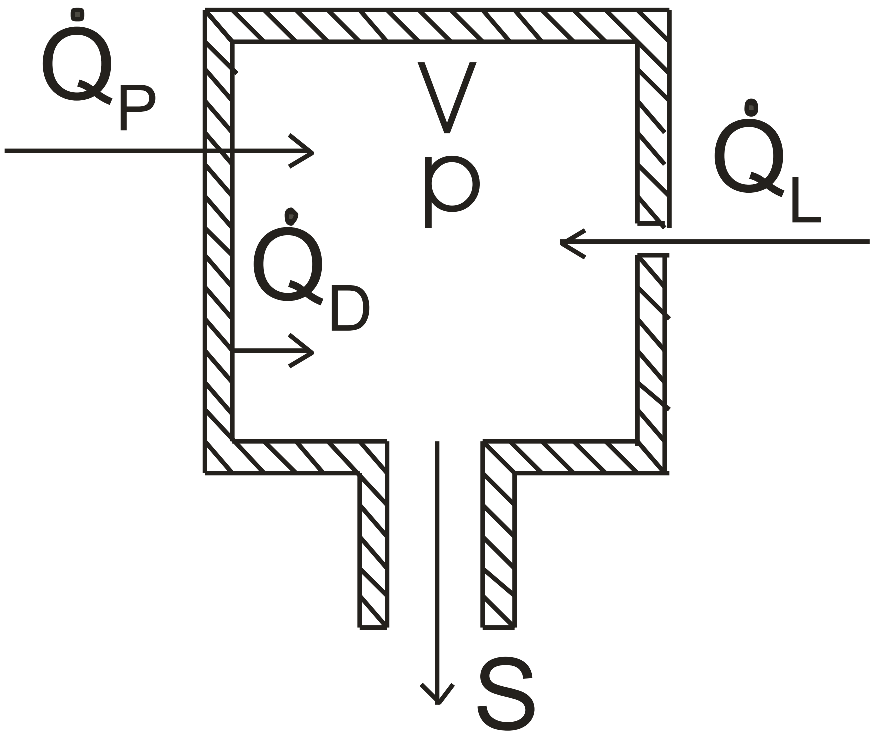
- Setup to calibrate a pressure measurement system
- It will not work properly in the ultra high vaccum pressure range

D. Richter

- Let‘s assume that we have at some places a total pressure of 10^{-8} Pa = 10^{-10} mbar
- 13 orders of magnitude smaller than normal pressure
- 10^{13} s = 317098 years (Homo Sapiens exists about 130000 years)
- Particle density = 2 700 000 cm^{-3}
- Average free path lenght = 590 km (Berlin – Munich)
- impingement rate = 3 x 10^{10} cm^{-2} s^{-1}
- collision rate = 7,7 x 10^{-4} s^{-1},

  i. e. time between a collision of two particles is 44 min

Gas balance of an UHV-chamber



$\dot{Q}_L$ ... *Leak gas current*

$\dot{Q}_P$ ... *Permeation gas current*

$\dot{Q}_D$ ... *Desorption gas current*

p ... *pressure*

V ... *volume*

S…pumping speed (no gas current)

$$\overset{\circ}{Q} = \frac{amount\ of\ gas}{time} = \frac{d}{dt}\left(p \cdot V\right) = V\,\frac{dp}{dt}$$

$$\overset{\circ}{Q}_{rate} = \frac{gas\ current}{area} = \frac{\overset{\circ}{Q}}{A} = \frac{V}{A}\,\frac{dp}{dt}$$

Realistic assumptions:

no leaks

no permeation gas current

$$\dot{Q}_L = 0, \quad \dot{Q}_P = 0 \quad \text{and} \quad \dot{Q}_D = \dot{Q}$$

$$\frac{d}{dt}(V \cdot p) = V\frac{dp}{dt} = \dot{Q} - S \cdot p$$

gas current due to the pump

Pumping down:

$$p(t=0) = p_0$$

$$p(t) = \left(p_0 - \frac{\dot{Q}}{S}\right) e^{-\frac{S}{V}\cdot t} + \frac{\dot{Q}}{S}$$

$$\frac{\dot{Q}}{S} = p_{stat}$$ basic pressure

At the beginning

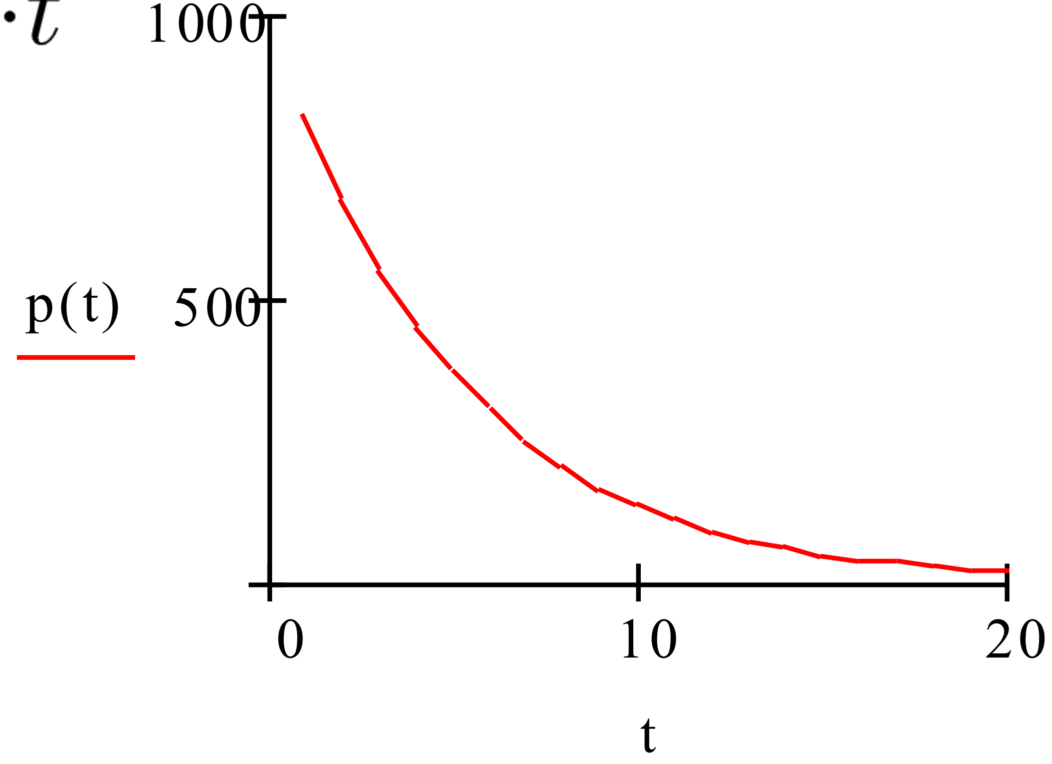
the desorption gas current is negligible

$$p(t) = p_0\, e^{-\frac{S}{V}\cdot t}$$

$$p_0 = 1000\, mbar$$

$$V = 10\, l$$

$$S = 2\,\frac{l}{s}$$



D. Richter

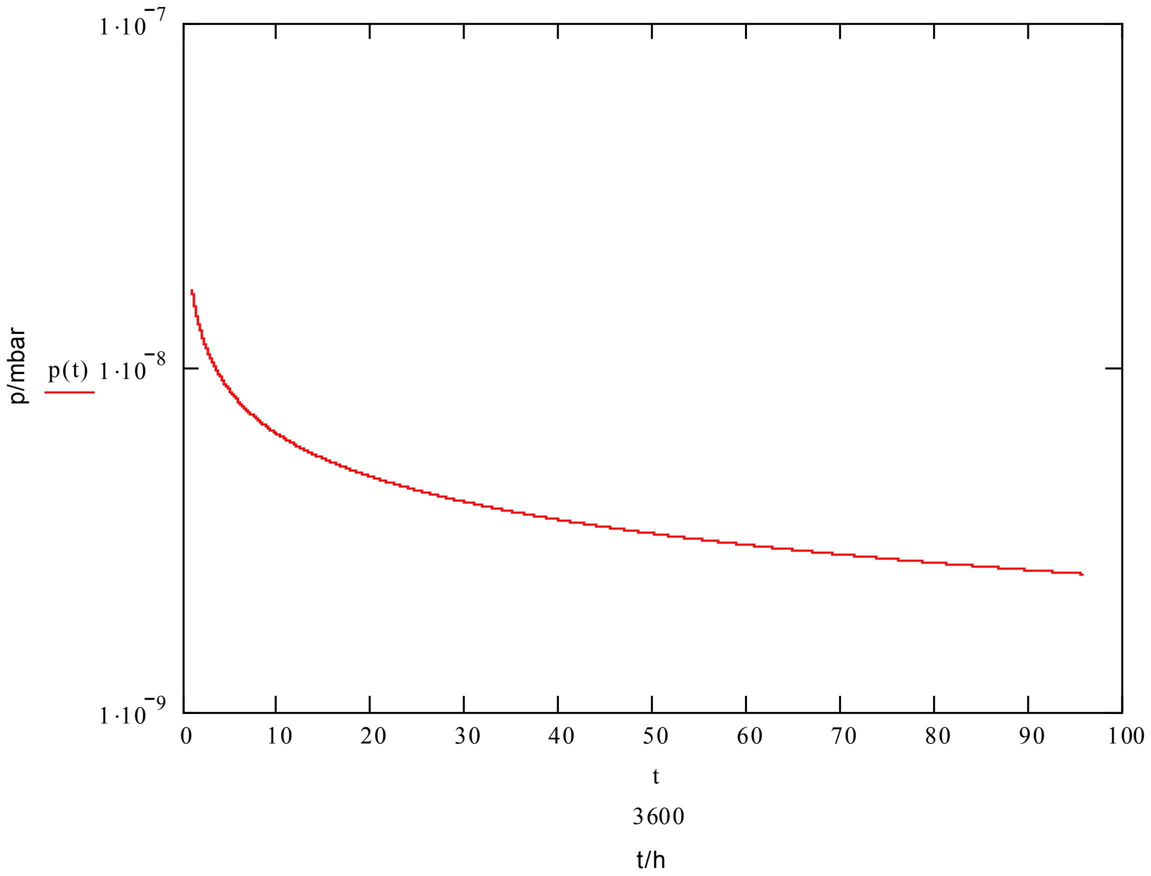
But then…

In the UHV-range the desorption gas current is not constant

If we have a metallic chamber the gas load is decreasing approximately with

$$\dot{Q}(t) = \dot{Q}_0 \cdot t^{-m} \quad \text{with} \quad m \approx \frac{1}{2}$$

empirical assumption for metals



V = 1 l, S = 0,82 l/s

baked chamber

after cooling down

D. Richter

Pressure increasing in the UHV range

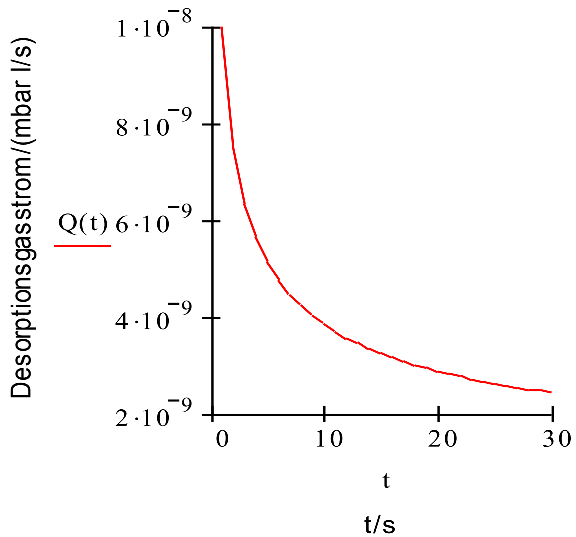
using $$\frac{d}{dt}(V \cdot p) = V\frac{dp}{dt} = \dot{Q} - S \cdot p$$

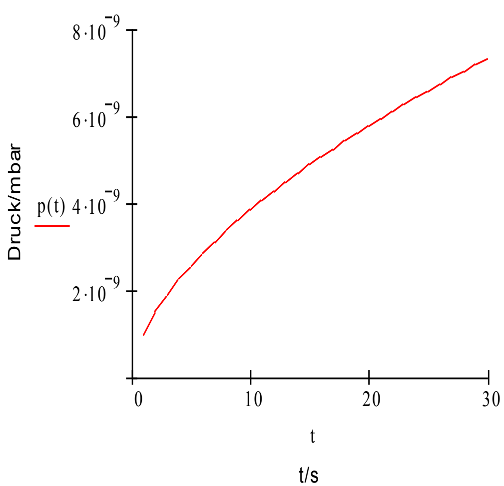
We get with p(0) = 0 $$p(t) = \frac{\dot{Q}}{S}\left(1 - e^{-\frac{S}{V}\cdot t}\right)$$

$$p(t) = \lim_{S \to 0}\left(\frac{\dot{Q}(t)}{S}\left(1 - e^{-\frac{S}{V}\cdot t}\right)\right) = \dot{Q}(t)\cdot\frac{t}{V}$$

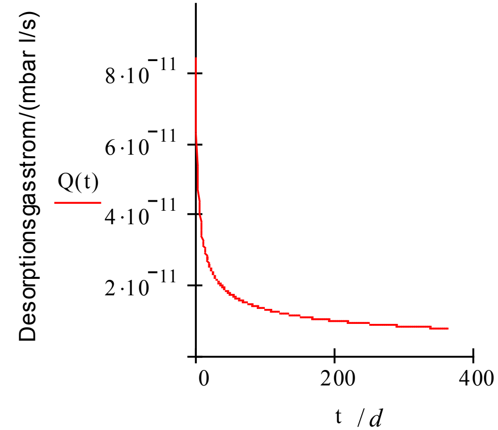
Realistic pressure increasing

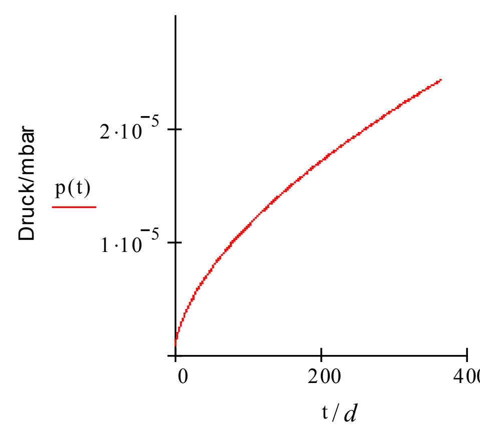
after some seconds…





and after one year

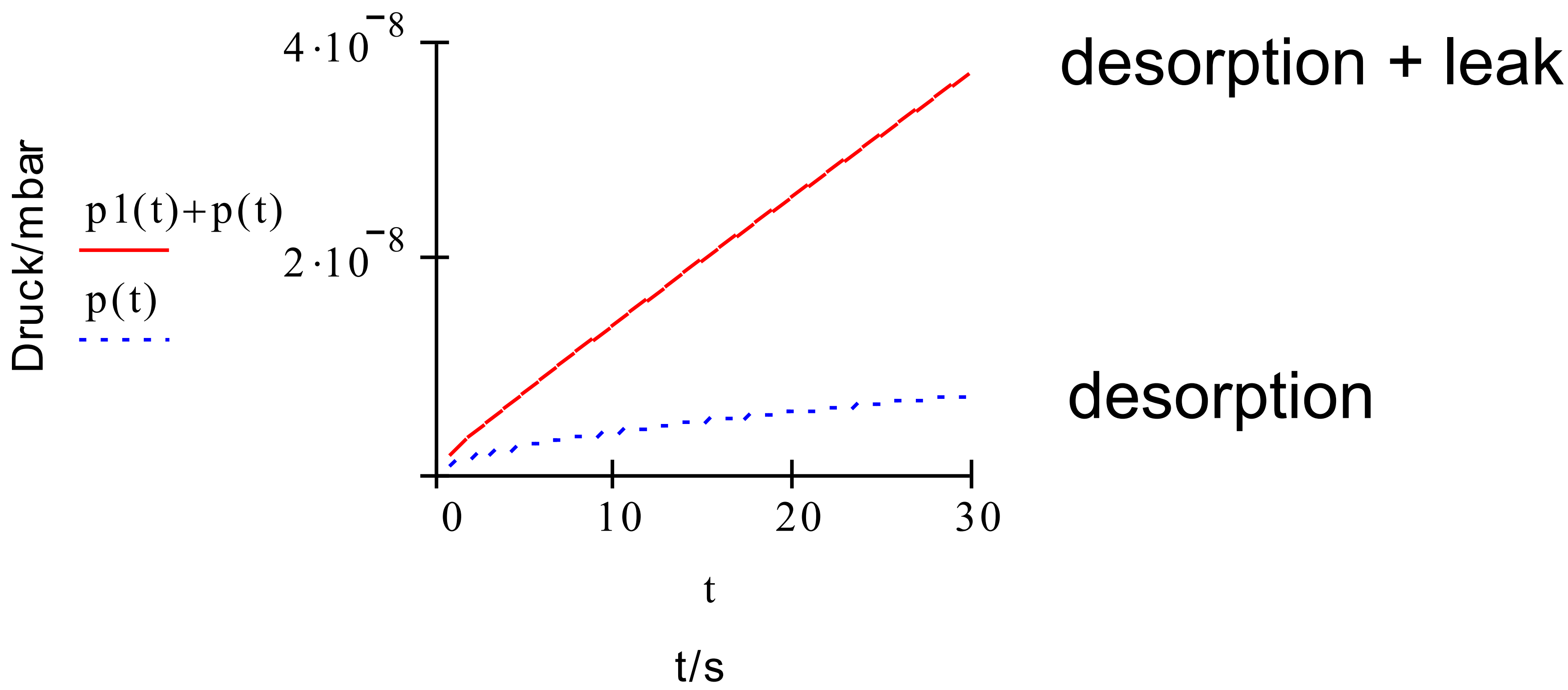




D. Richter

What is a leak at a flange connection?

- A metallic flange connection should have a leak rate less than 1×10^{-11} mbar l s^{-1}.
- That means, 1 cm^3 of a gas needs more than 3171 years to flow into the vacuum chamber passing the flange connection.



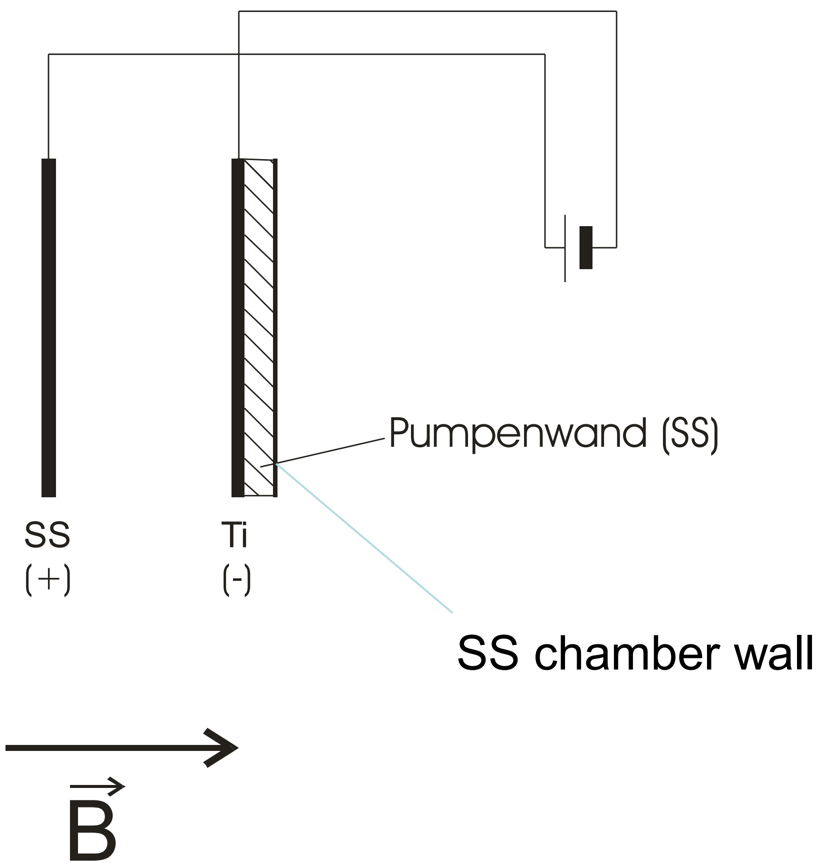
Druck/mbar
p1(t)+p(t)
p(t)
4·10−8
2·10−8
0
10
20
30
t
t/s
desorption + leak
desorption

Generation of vacuum

- Using a fore-vacuum pump in connection with a turbo molecular pump to get a pressure in the high vacuum range.
- Baking of the most important vacuum components to reduce the desorption gas flow.
- Using of ion getter pumps and sometimes of titanium sublimation pumps to get a pressure in the ultra high vacuum range.

Ion getter pump

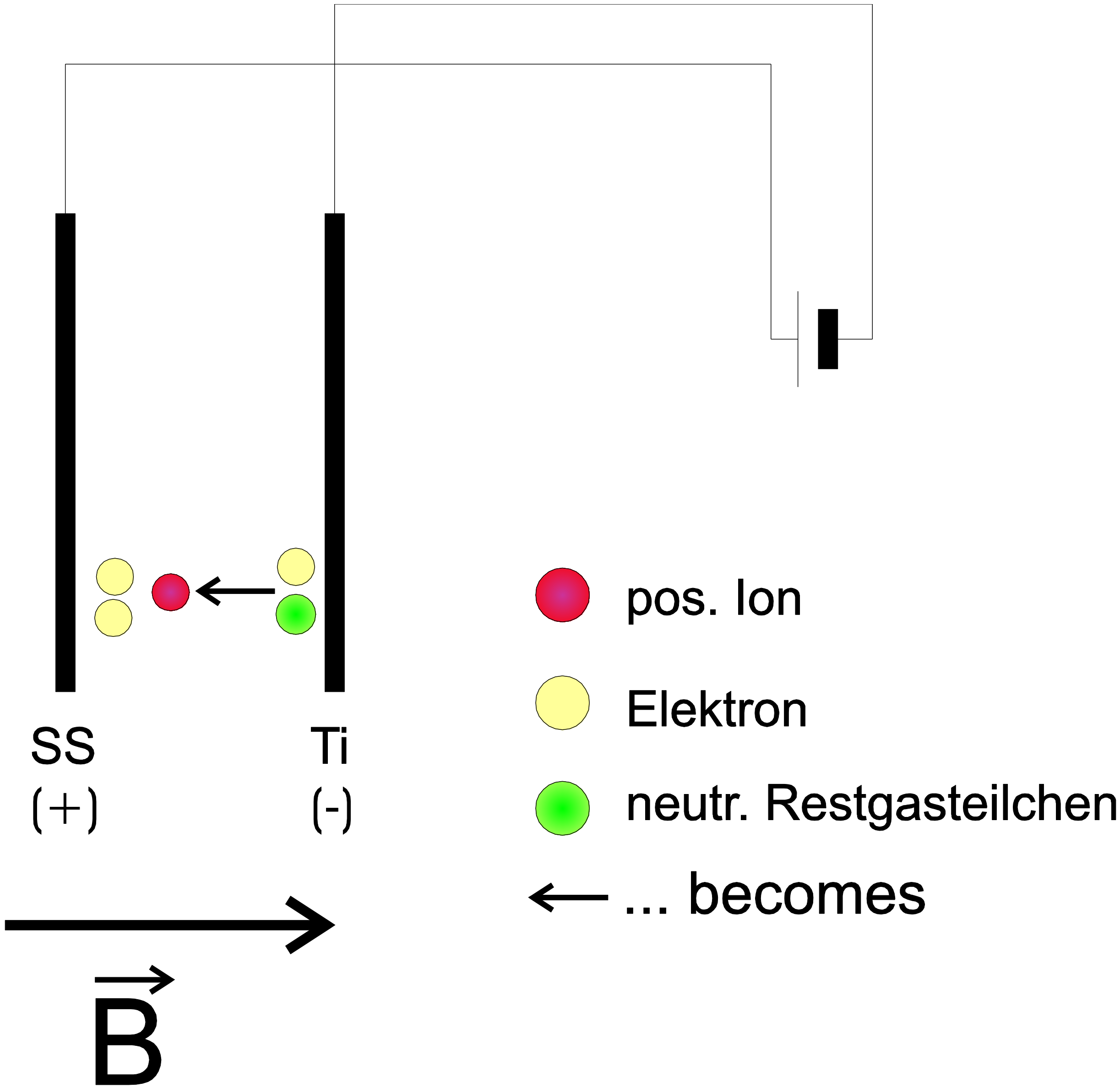
diode



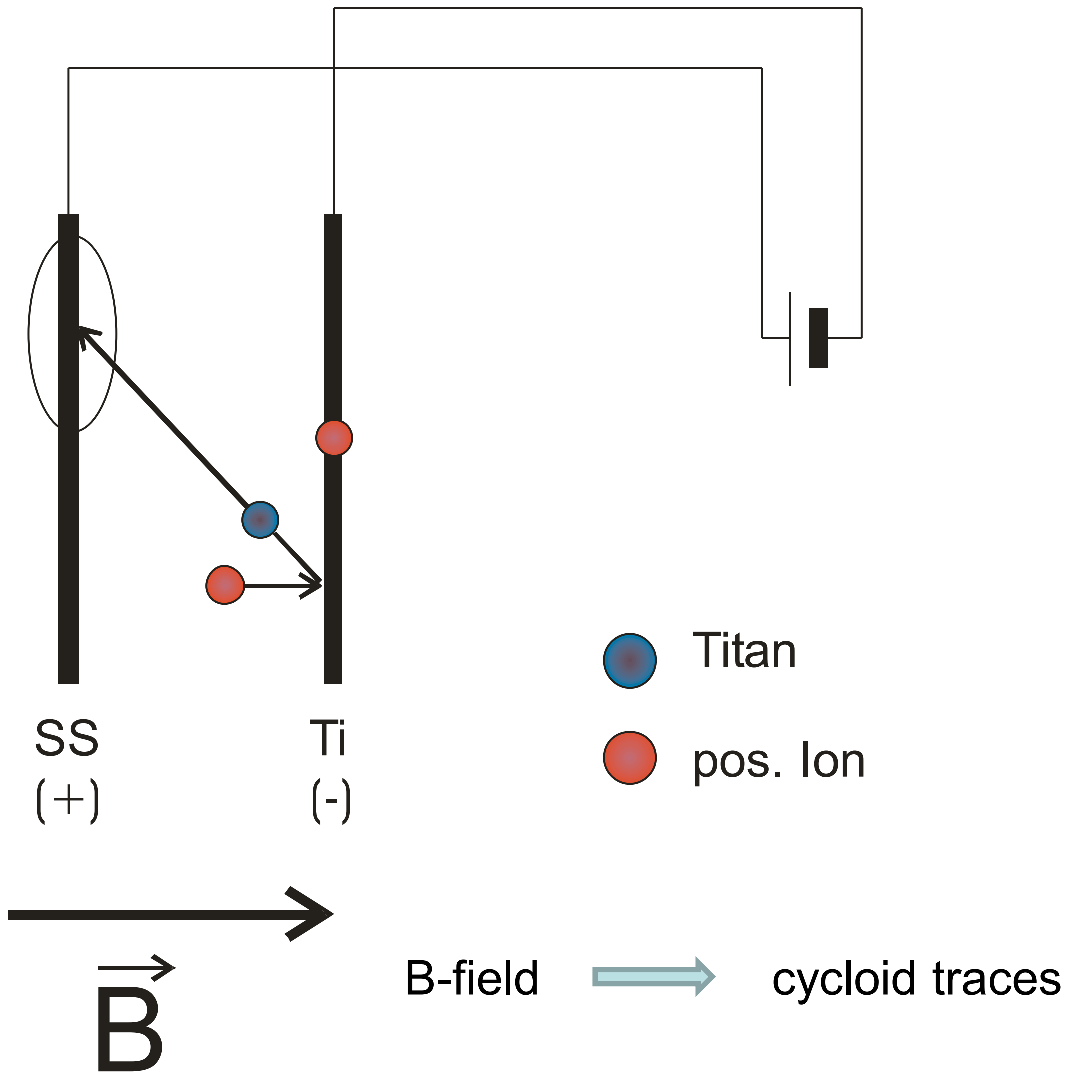
Ti …ground

Positive high voltage

from a power supply, (3…6) kV

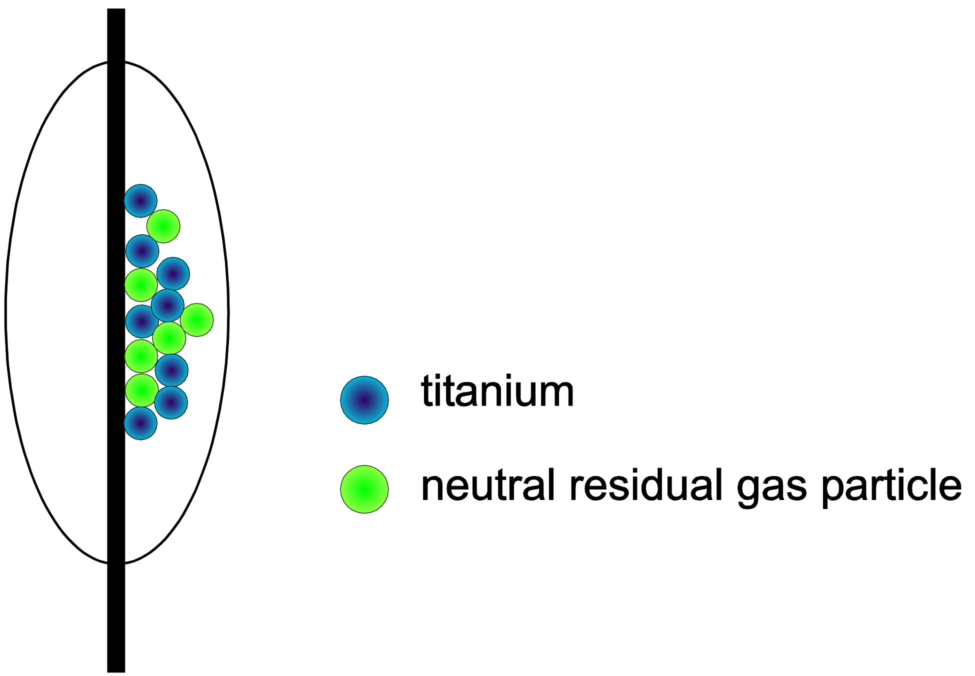


D. Richter



- ion implantation into the cathode surface (pump effect, memory effect)
- Sputtering of the Ti plate
- Ti atoms beat the SS surface

D. Richter



3 possibilities at the anode $(\approx 95\,\%)$

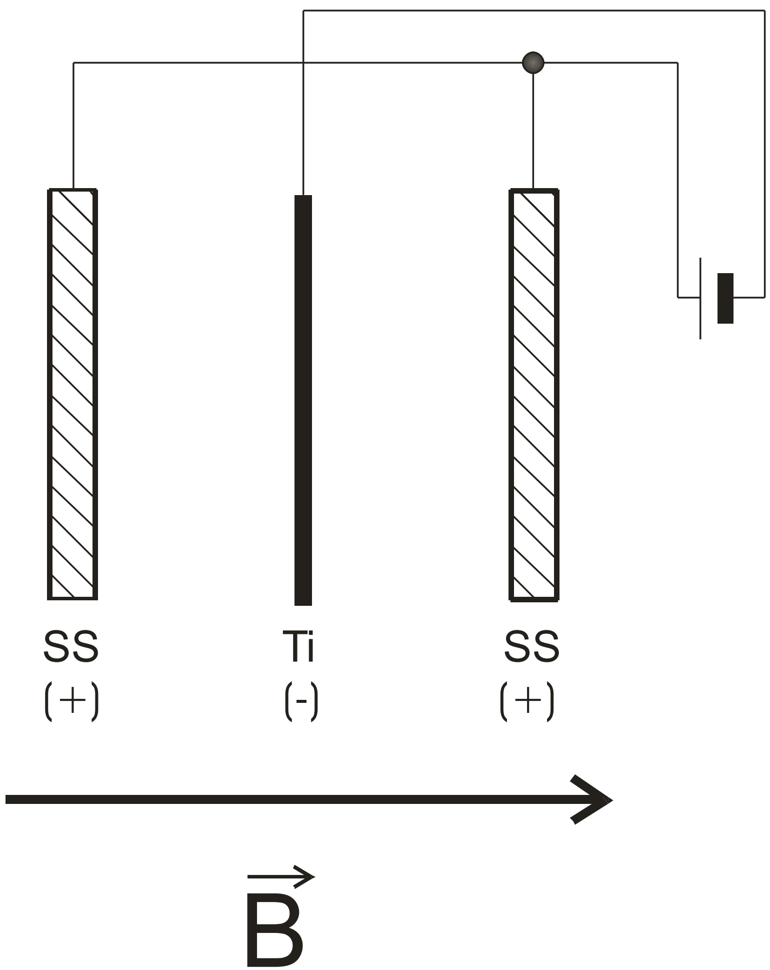
- covering atoms
- physical compound
- chemical compound

no noble gases

The only possibility to pump noble gases consists in ion implantation into the cathode surface $(\approx 5\,\%)$

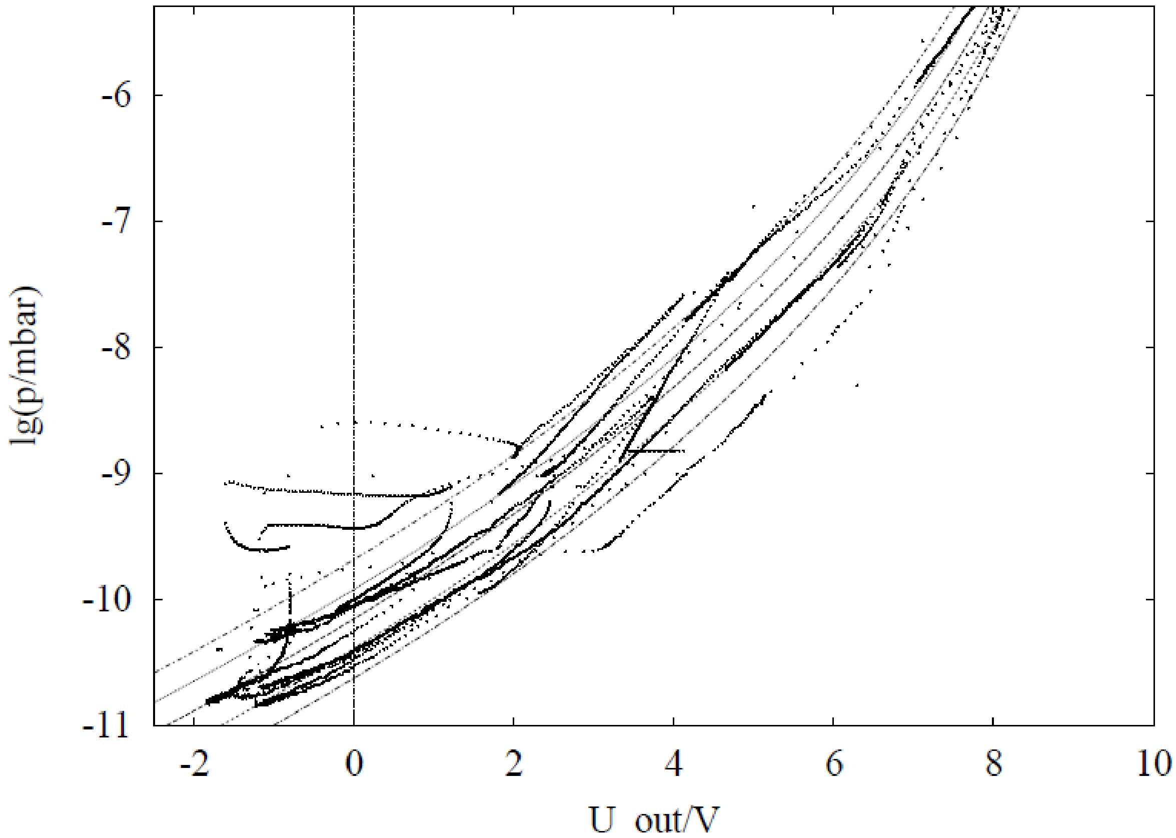
Pumping speed increases, if the pressure, i. e. the gas load, increases

Triode



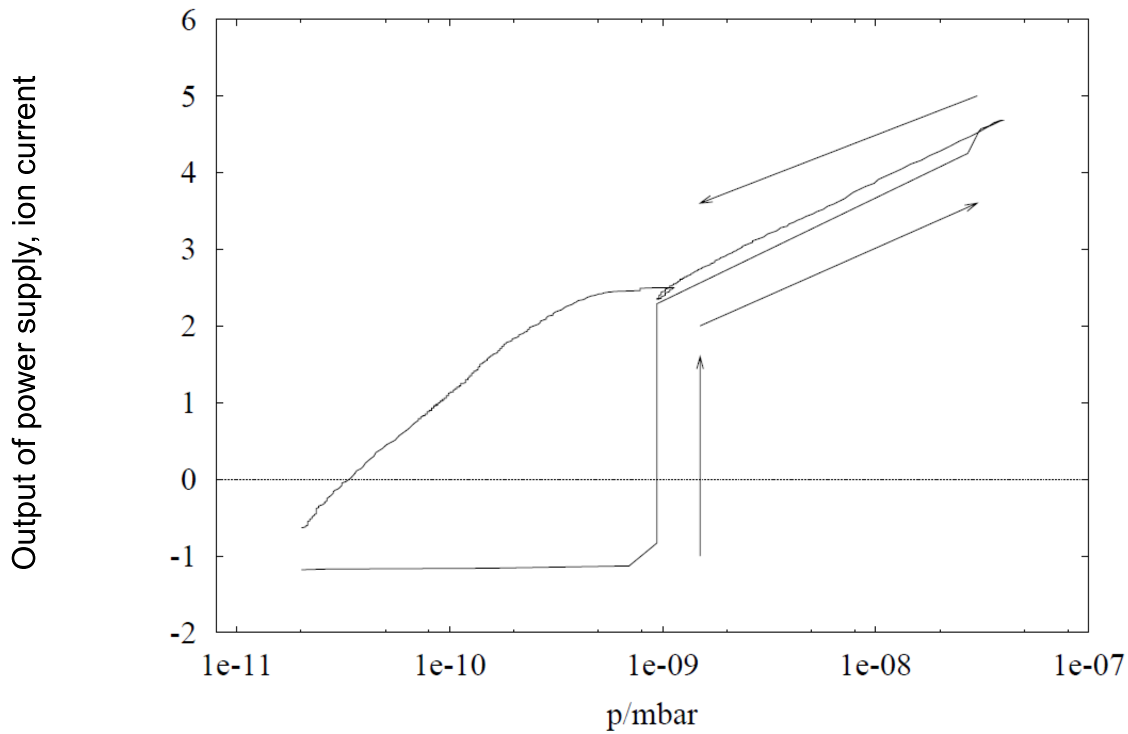
Ti … negative high Voltage, (-6…-3) kV

D. Richter



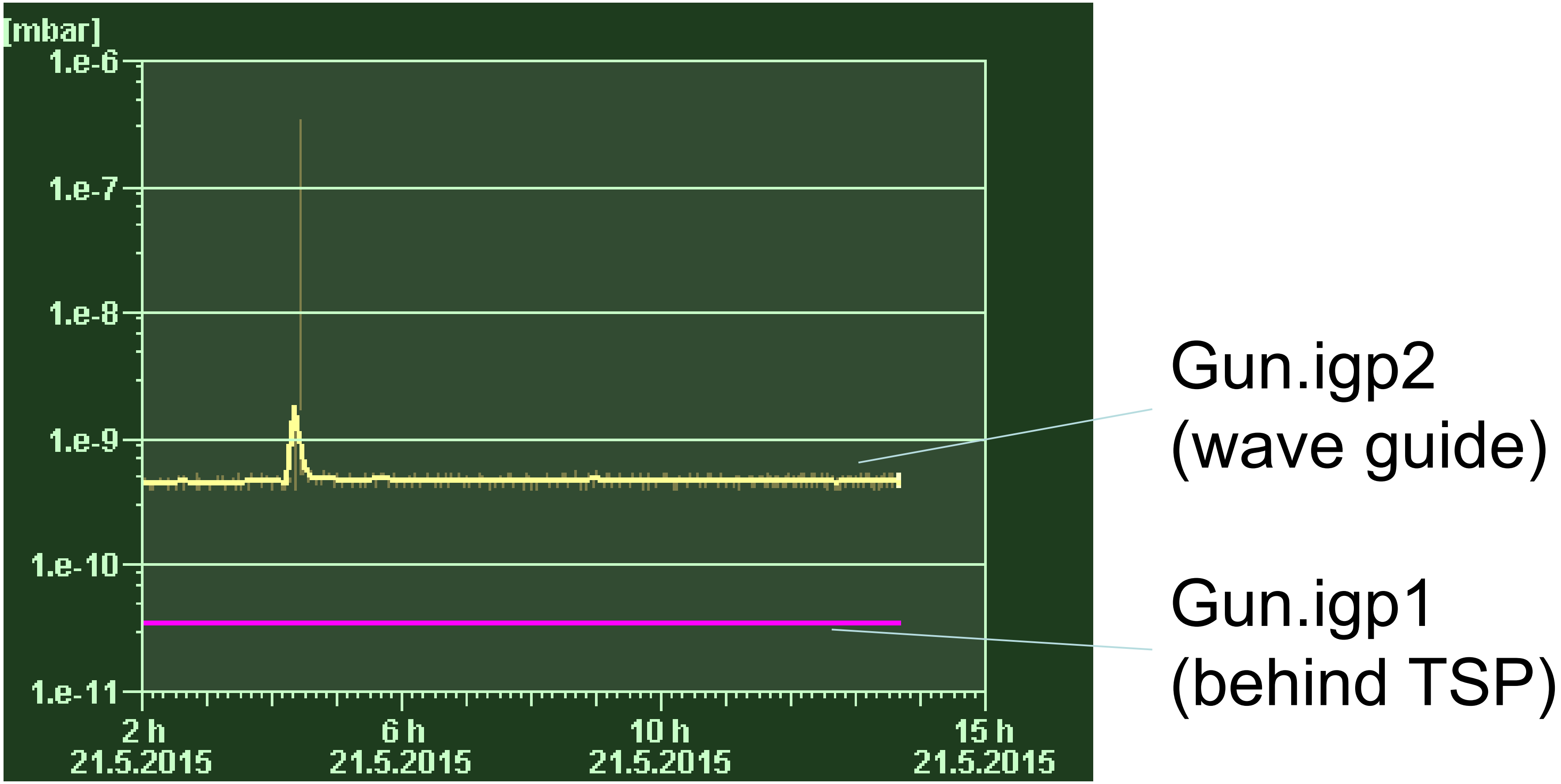
Calibration of the ion getter pump to get the pressure values

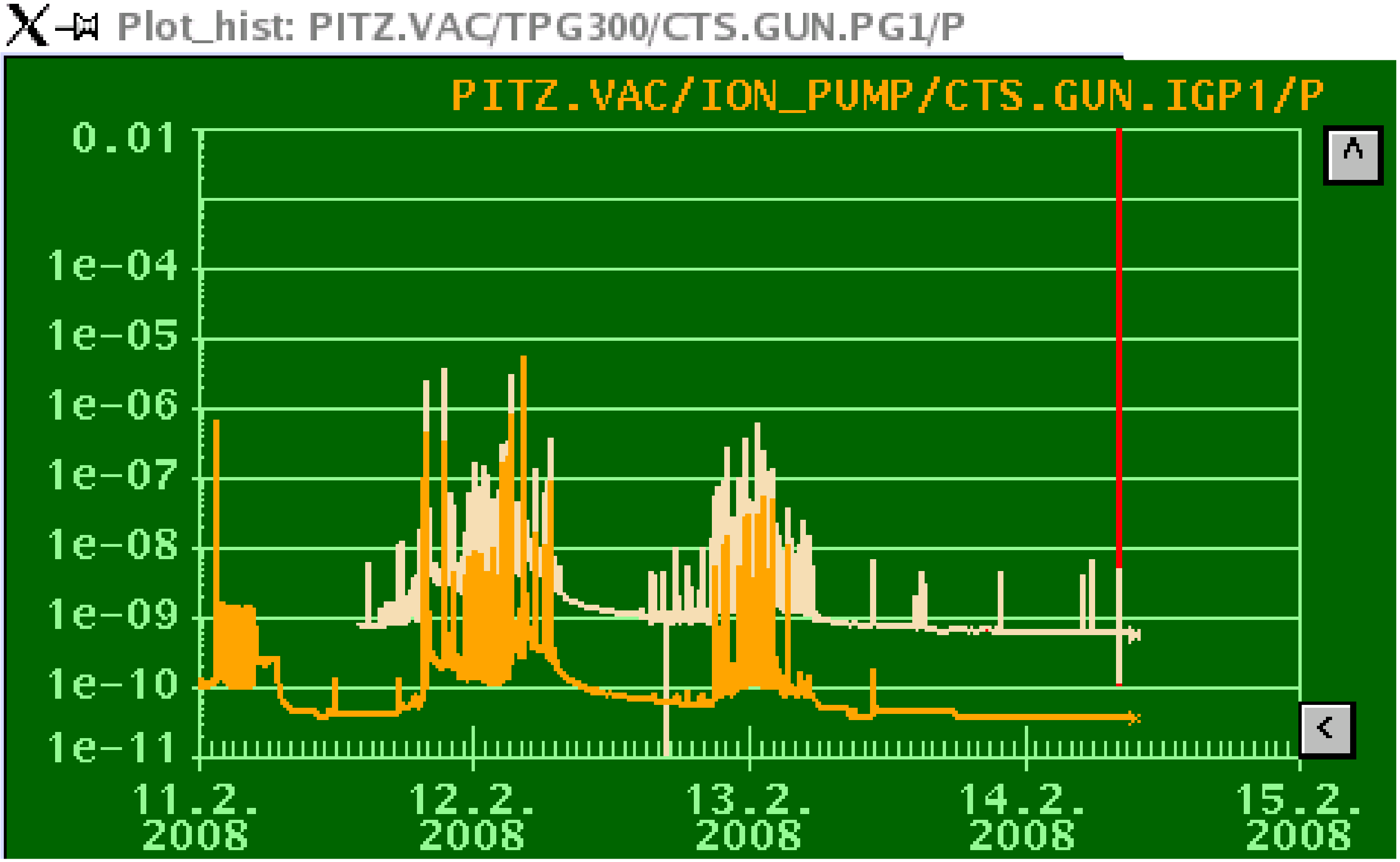
D. Richter



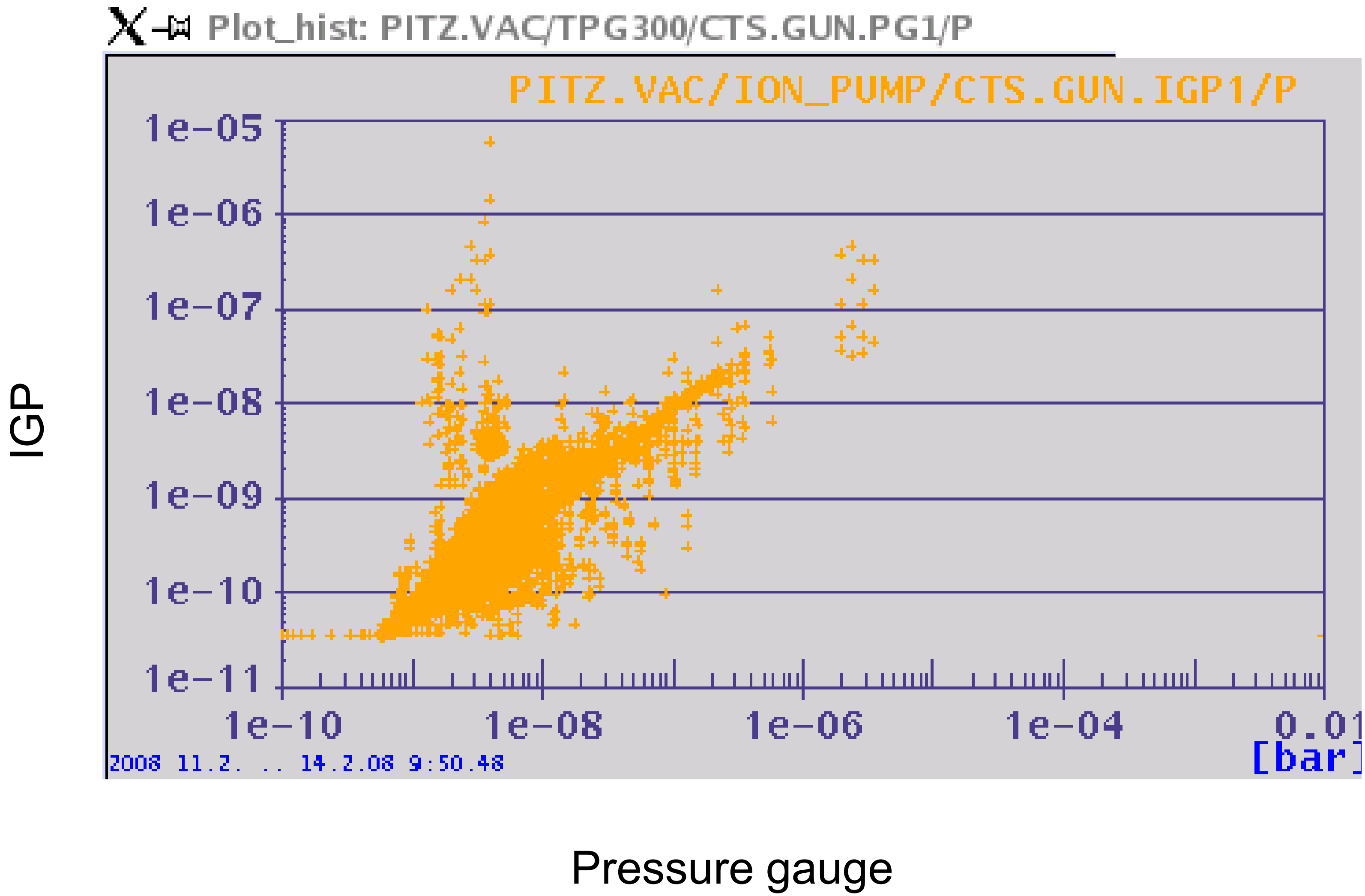
Output of power supply, ion current
6
5
4
3
2
1
0
-1
-2
1e-11
1e-10
1e-09
1e-08
1e-07
p/mbar

D. Richter


[mbar]
1.e-6
1.e-7
1.e-8
1.e-9
1.e-10
1.e-11
2 h
21.5.2015
6 h
21.5.2015
10 h
21.5.2015
15 h
21.5.2015
Gun.igp2
(wave guide)
Gun.igp1
(behind TSP)



Plot_hist: PITZ.VAC/TPG300/CTS.GUN.PG1/P
PITZ.VAC/ION_PUMP/CTS.GUN.IGP1/P
0.01
1e-04
1e-05
1e-06
1e-07
1e-08
1e-09
1e-10
1e-11
11.2. 2008
12.2. 2008
13.2. 2008
14.2. 2008
15.2. 2008



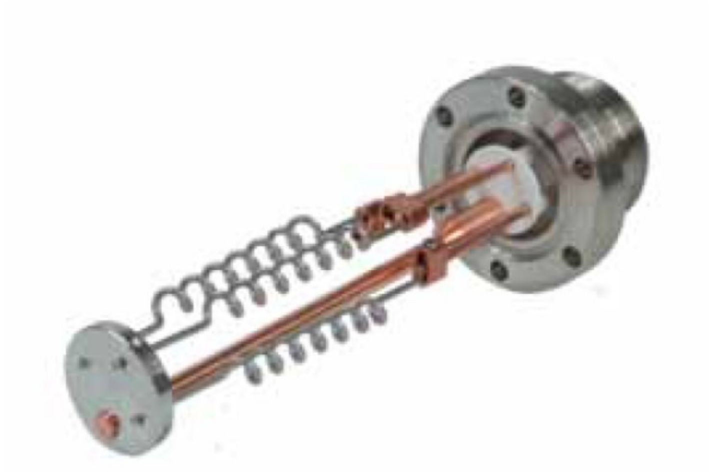
Plot_hist: PITZ.VAC/TPG300/CTS.GUN.PG1/P
PITZ.VAC/ION_PUMP/CTS.GUN.IGP1/P
1e-05
1e-06
1e-07
1e-08
1e-09
1e-10
1e-11
1e-10
1e-08
1e-06
1e-04
0.01
[bar]
2008 11.2. .. 14.2.08 9:50.48
IGP
Pressure gauge

TITANIUM SUBLIMATION PUMPING (TSP)

Titanium Sublimation Pumps (TSPs) are often used in combination with ion pumps or independently to remove reactive gases from the vacuum environment. Combined with an ion pump, the TSP allows for low ultimate pressures in a shorter amount of time. All TSP components are bakeable to 400 °C.

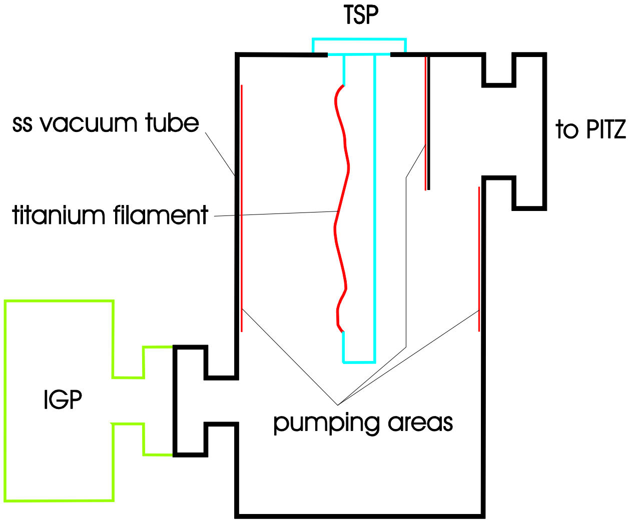
TSP FILAMENT CARTRIDGE

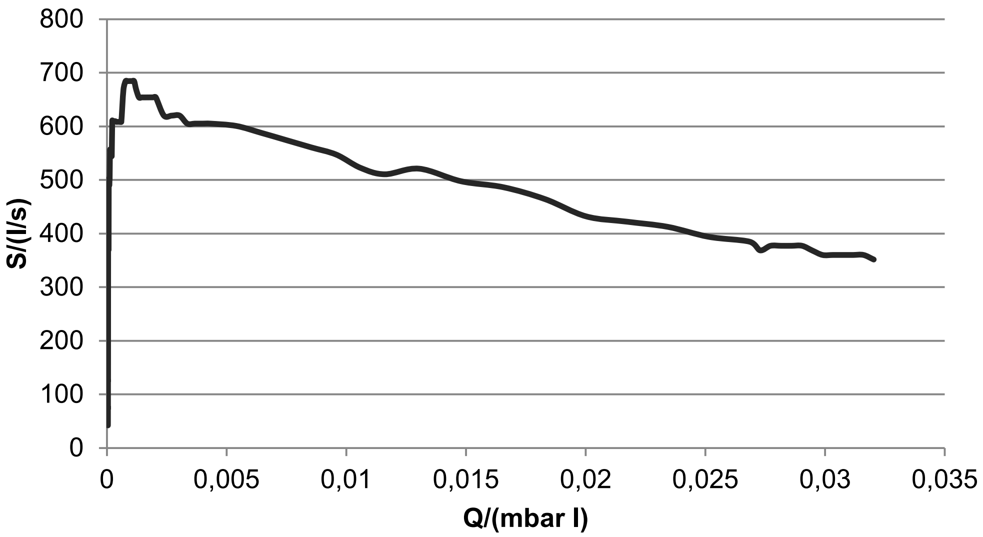
The filament cartridge is mounted on a 2- 3/4" CFF (NW 35). The feedthrough supports three titanium-molybdenum filaments and a return path for ground isolation. Each filament contains 1.5 grams of usable titanium and averages 20 hours of operation.



TSP arrangement at PITZ

pump procedure is the same as at the anode of an IGP





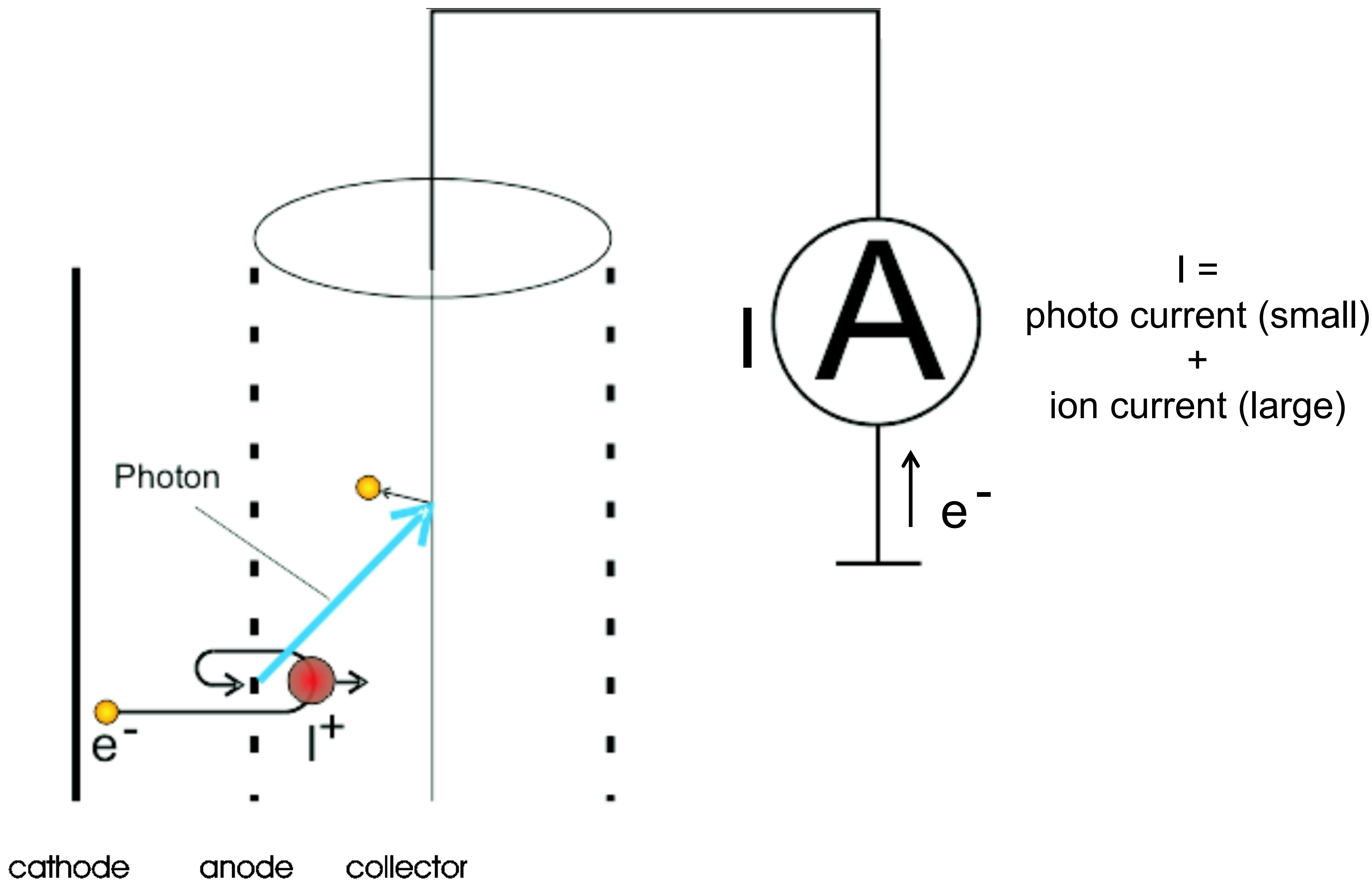
Pumping speed for noble gas = 0

Pumping speed decreases, if the pressure, i. e. the gas load, increases

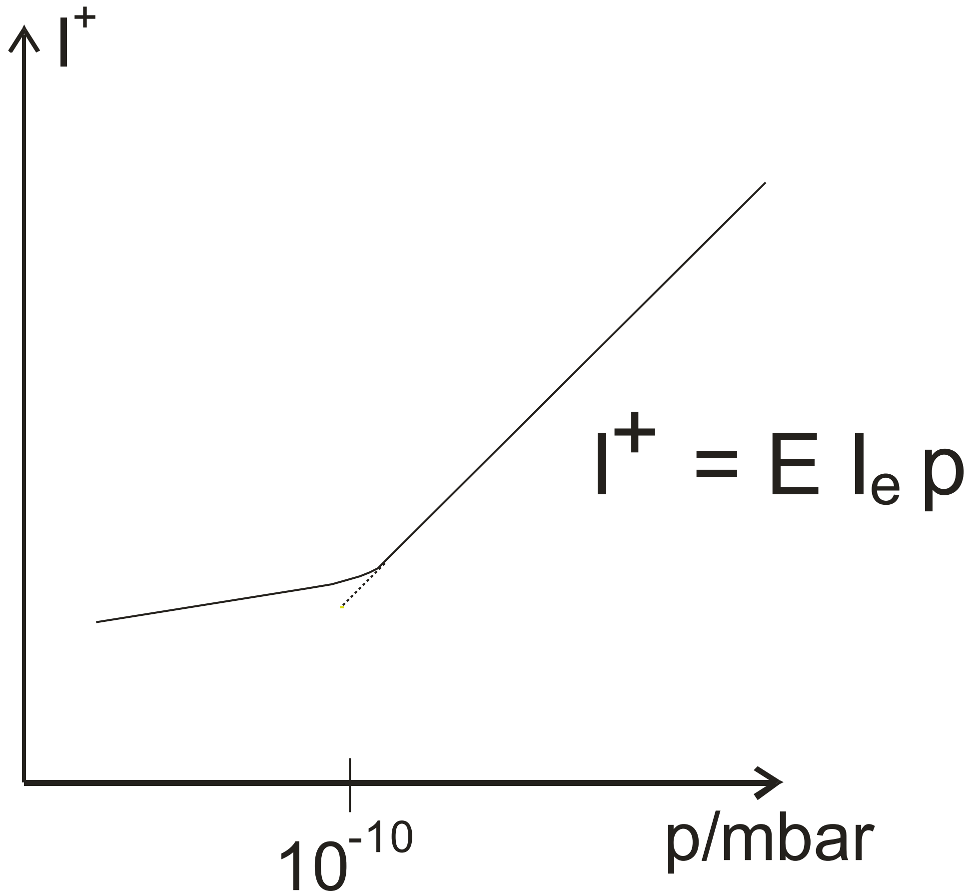
D. Richter

The Bayard Alpert pressure gauge

Hot cathode vacuum gauge for pressure in the range of some 10^{-5} mbar down to 1×10^{-10} mbar


I =
photo current (small)
+
ion current (large)
I
A
e-
Photon
e-
I+
cathode
anode
collector

D. Richter

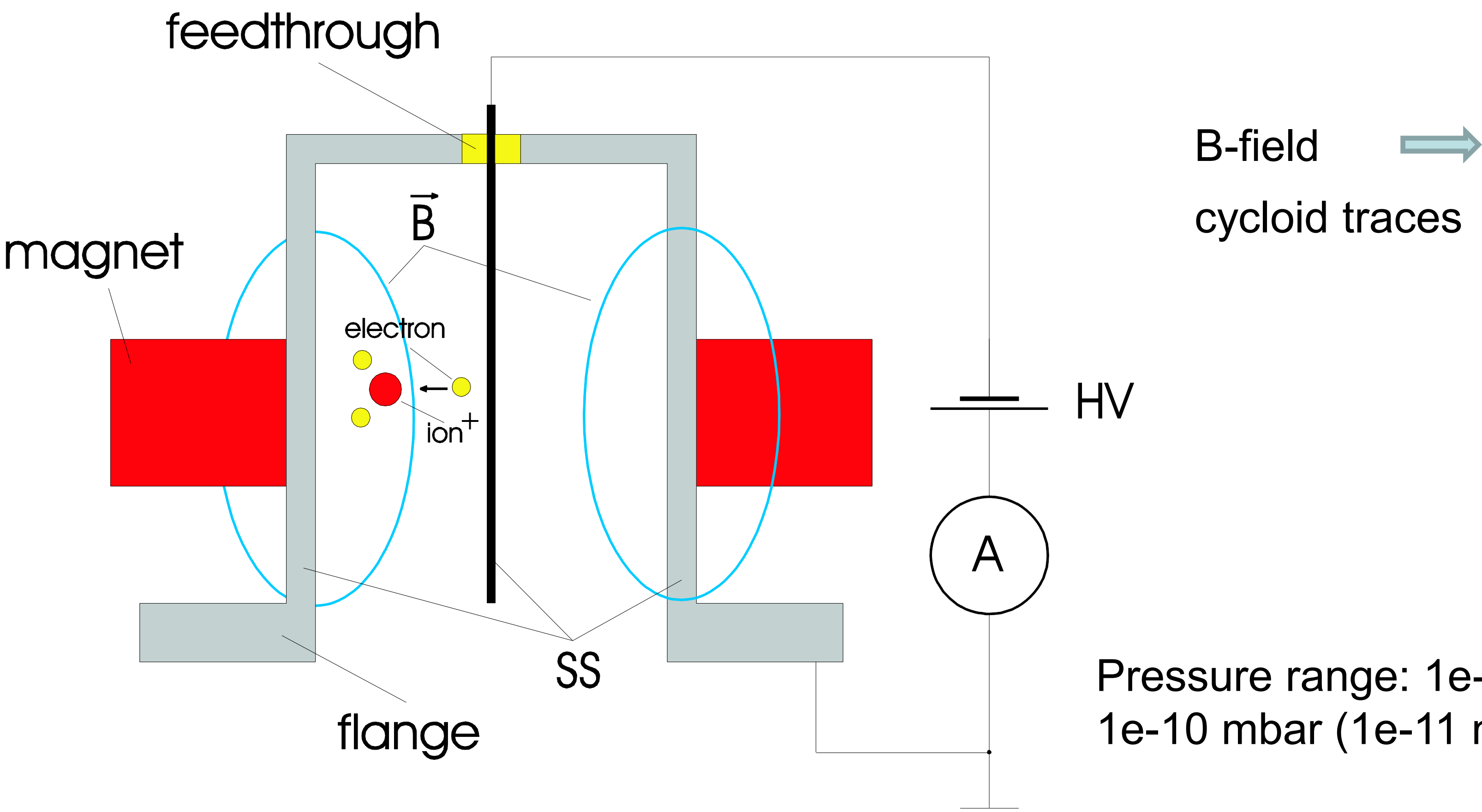


In the best case –
line function $I^{+} = I^{+}(p)$ down
to $1 \cdot 10^{-10}\ mbar$

After that –
photo current is not negligible

Cold cathode vacuum gauge

(Penning gauge)



Pressure range: 1e-3 mbar to 1e-10 mbar (1e-11 mbar)

D. Richter

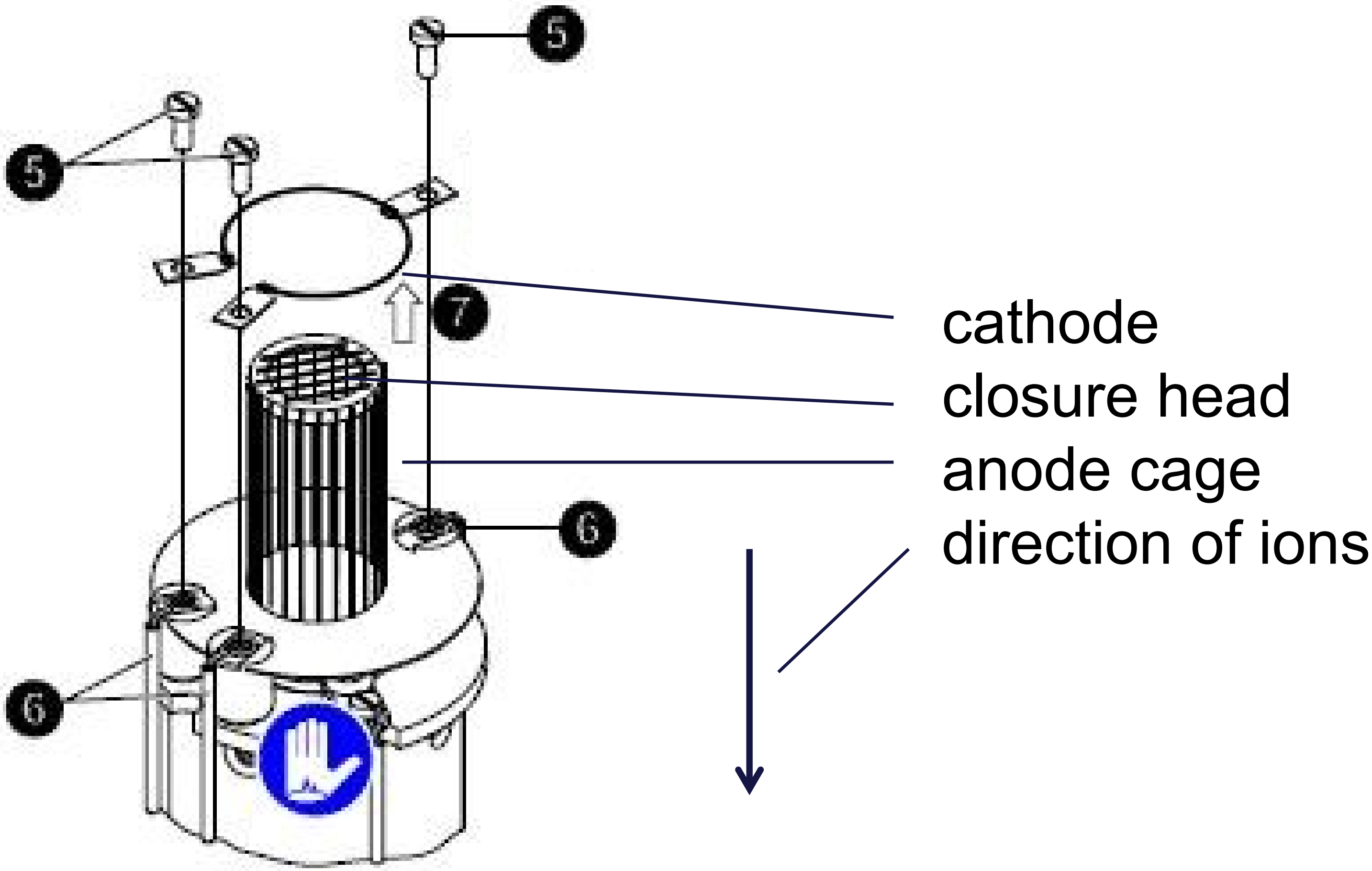
Residual gas analyser

Quadrupole mass spectrometer

- Measurement of partial pressure in the ultra high vacuum range
- All vacuum components mounted at PITZ are free of leaks and without pollution of hydrocarbons and other unrequested gases
- Therefore, the most interesting gases of the accelerator are only:
    - nitrogen, oxigen, argon (i. e. air), to detect a leak to the air
    - water, to detect a leak to the water cooling system
    - cracked components of SF_6, to detect a leak to the rf system

D. Richter

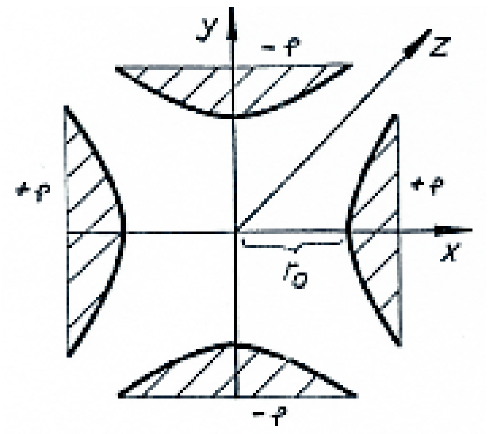
Ion source of RGA

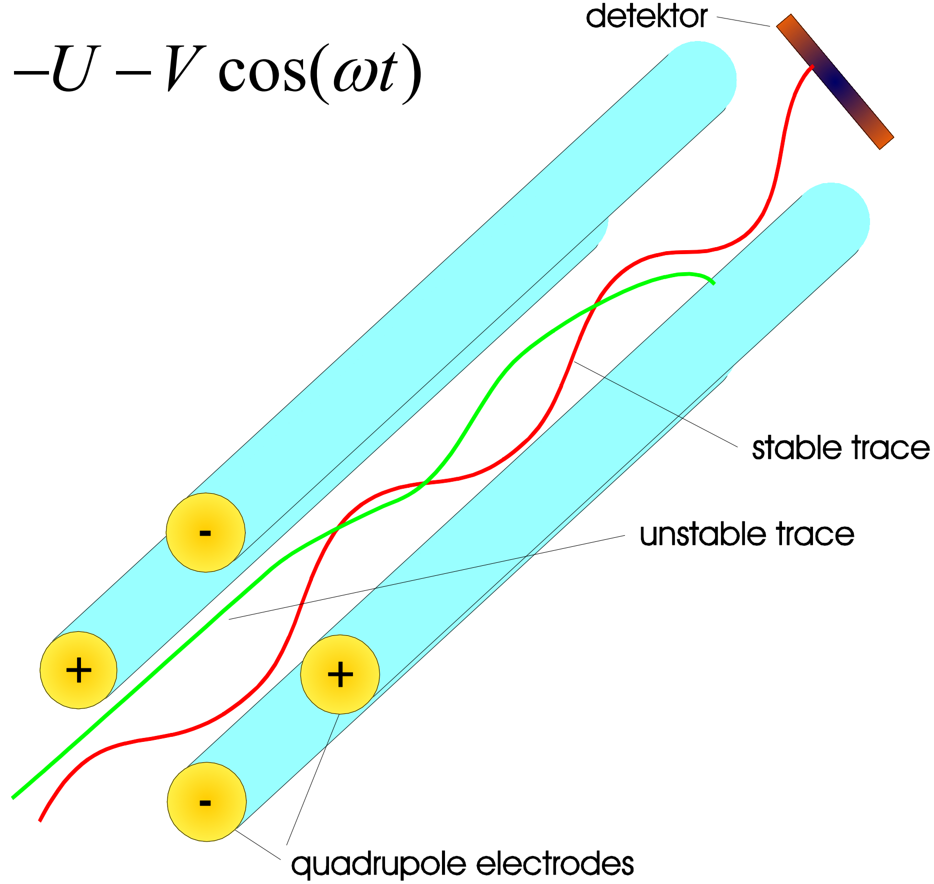


Seperate ion system

$$+\varphi = +U + V\cos(\omega t)$$

$$-\varphi = -U - V\cos(\omega t)$$



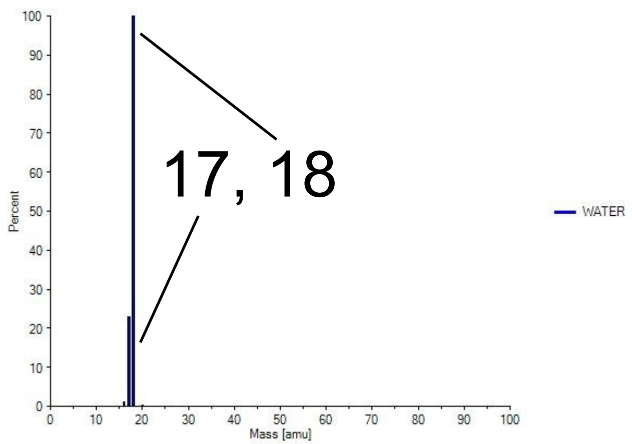


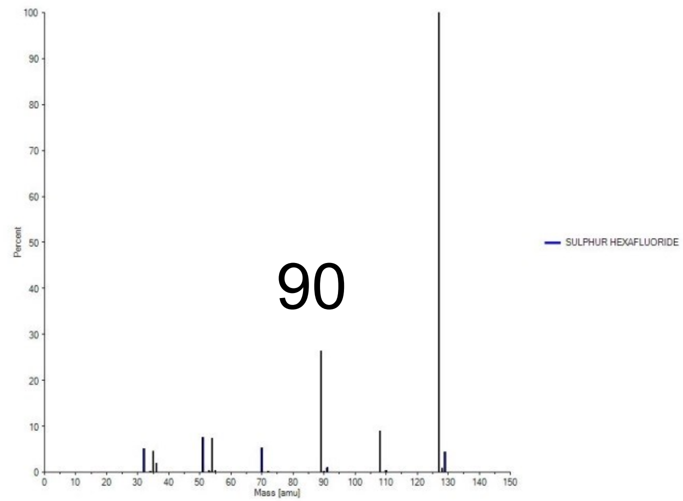
D. Richter

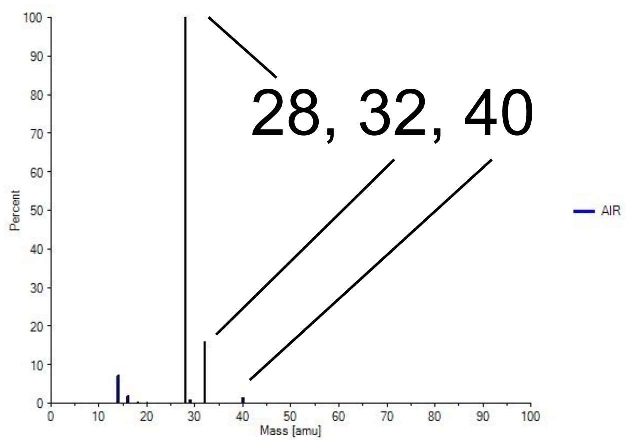
Detector

- Faraday cup, high vacuum range,lower boundary line for concentration measurements: 100 ppm
- Channel electron multiplier, ultra high vacuum range, lower boundary line for concentration measurements: 10 ppm

Most interesting residual gas components







- gas particle can be cracked $SF_6, \quad H_2O$
- gas particle can be ionized twice

$$Ar^{+} \leftrightarrow amu = 40, \quad Ar^{++} \leftrightarrow amu = 20$$

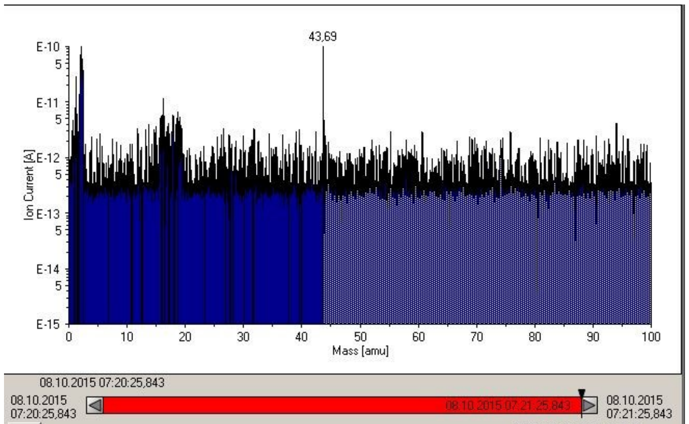
- different gas particles can have the same atomic mass $N_2, CO, CH_2^{+} \Leftrightarrow amu = 28$

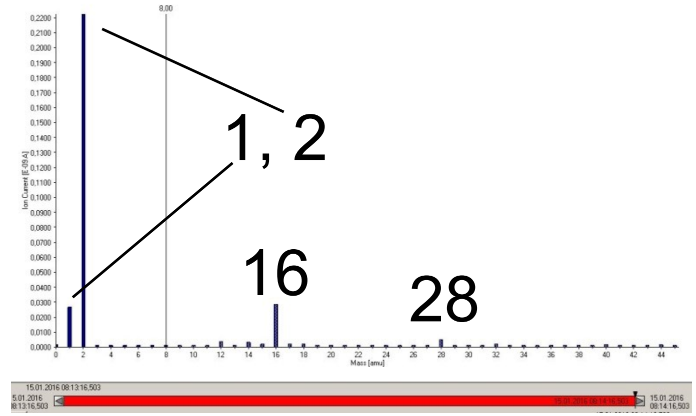
D. Richter

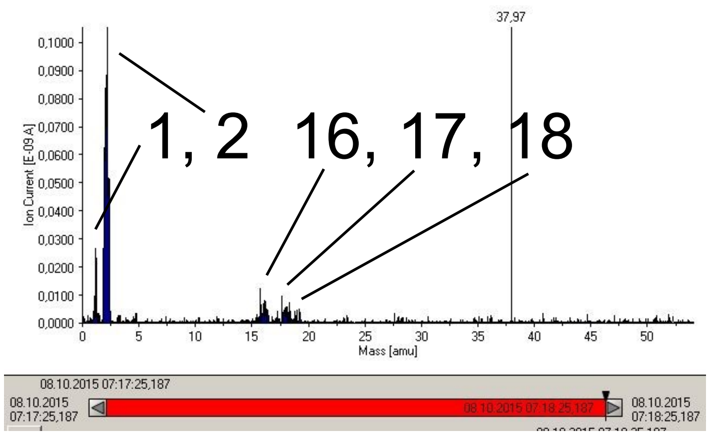
Some realistic examples

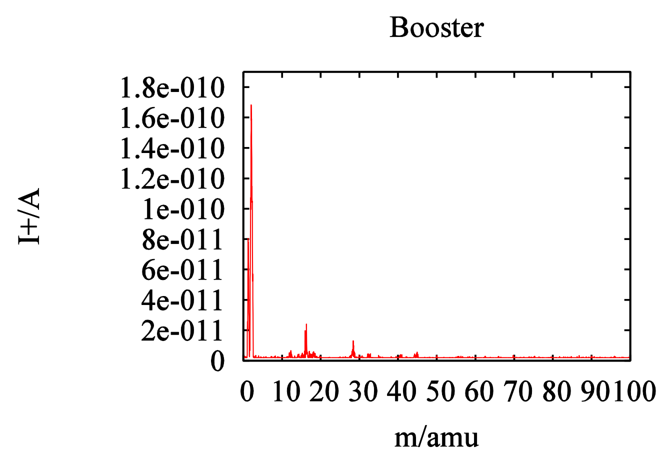
Gun 4.2 before taking apart

Booster 1/15/2016



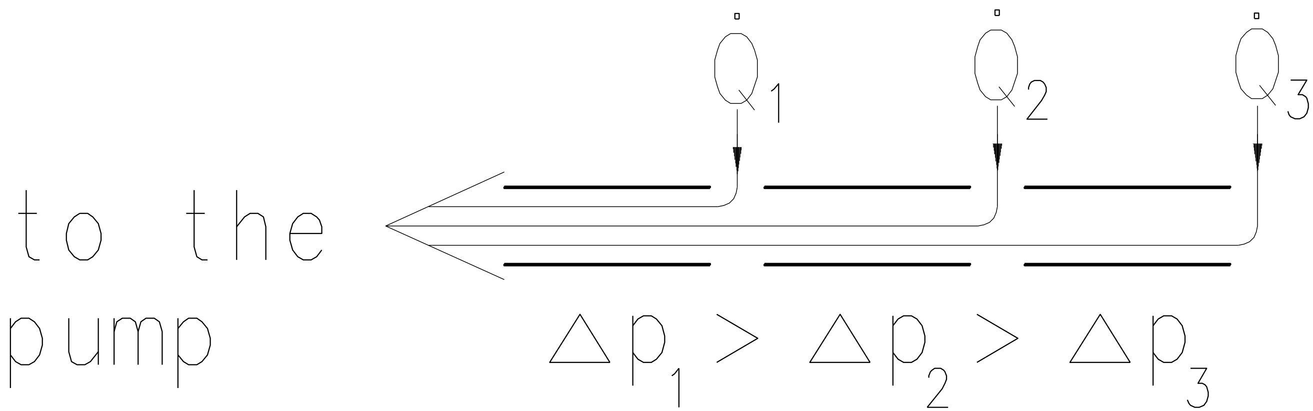




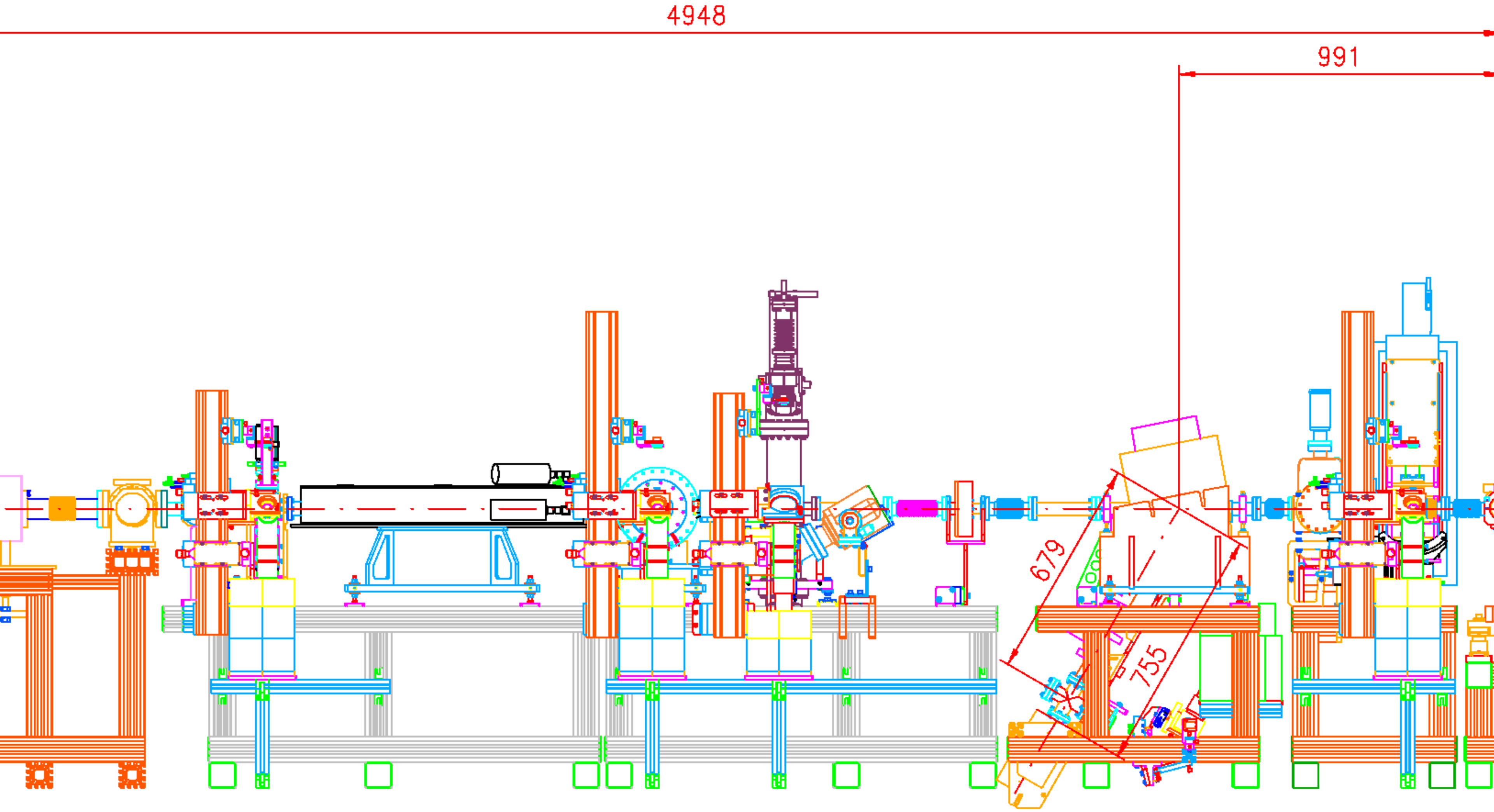


D. Richter

Gas currents in an accelerator setup pressure gradients



D. Richter



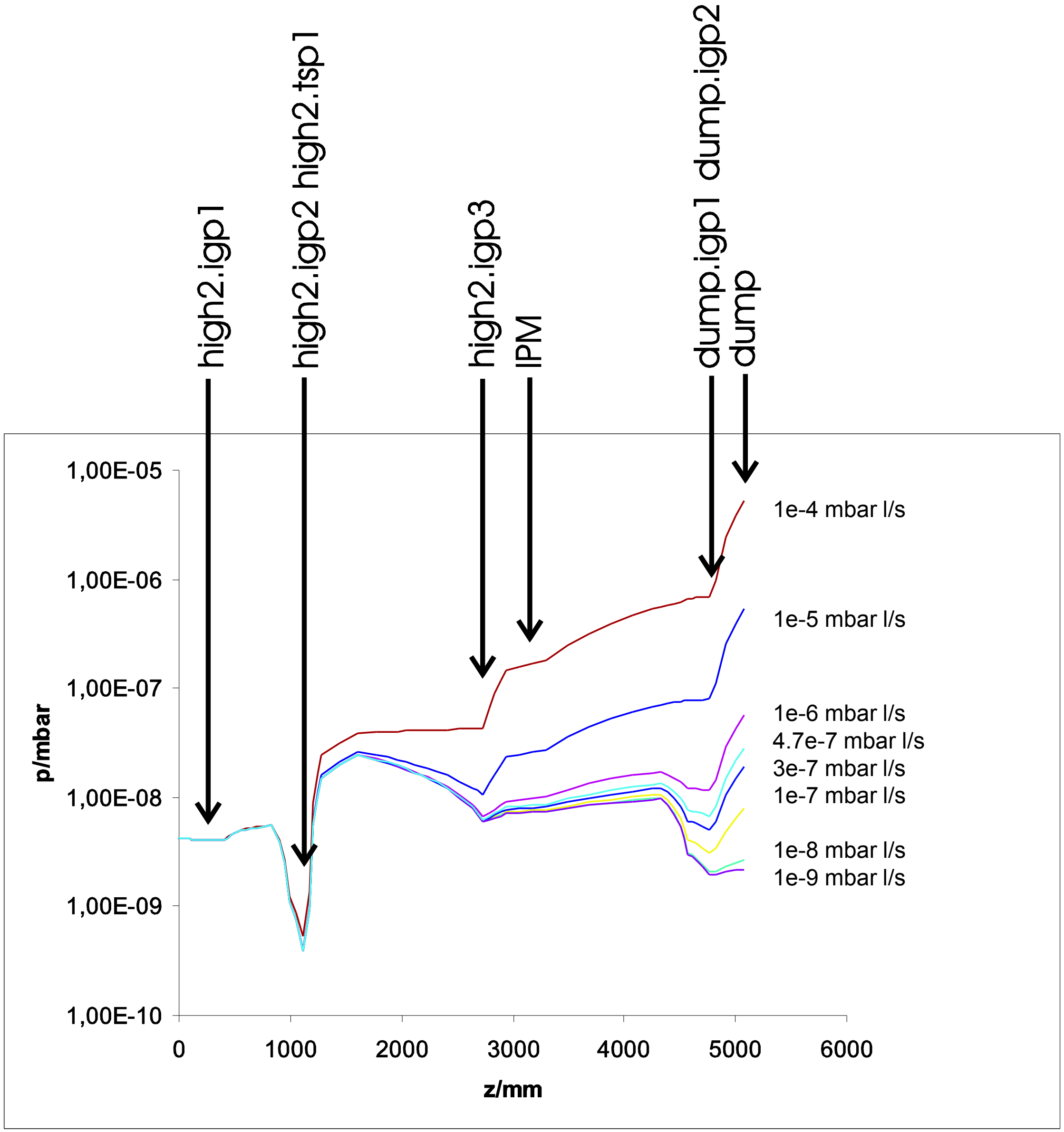
Tolerierungsgrundsatz: ISO 8015 Oberflächenkenngrößen nach DIN EN ISO 1302, 4287 bzw. 4288	Allg_Toleranzen nach DIN ISO 2768 Toleranzkl.:	Halbzeug:

Maßstab:

Werkstoff:

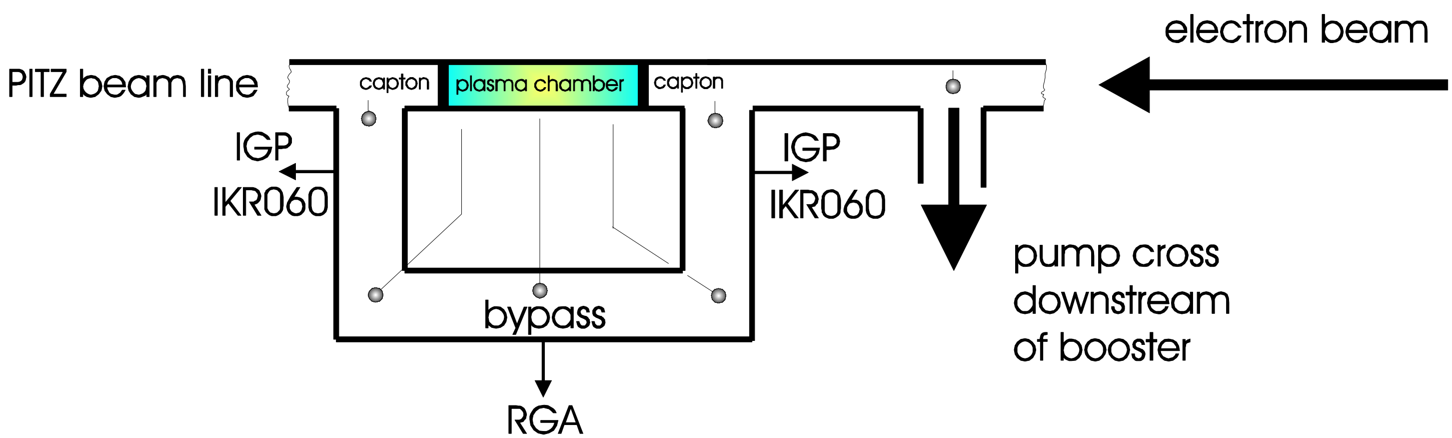
Pressure distributions depending on the gas load coming from the beam dump

real value: 4.7e-7 mbar l/s



D. Richter

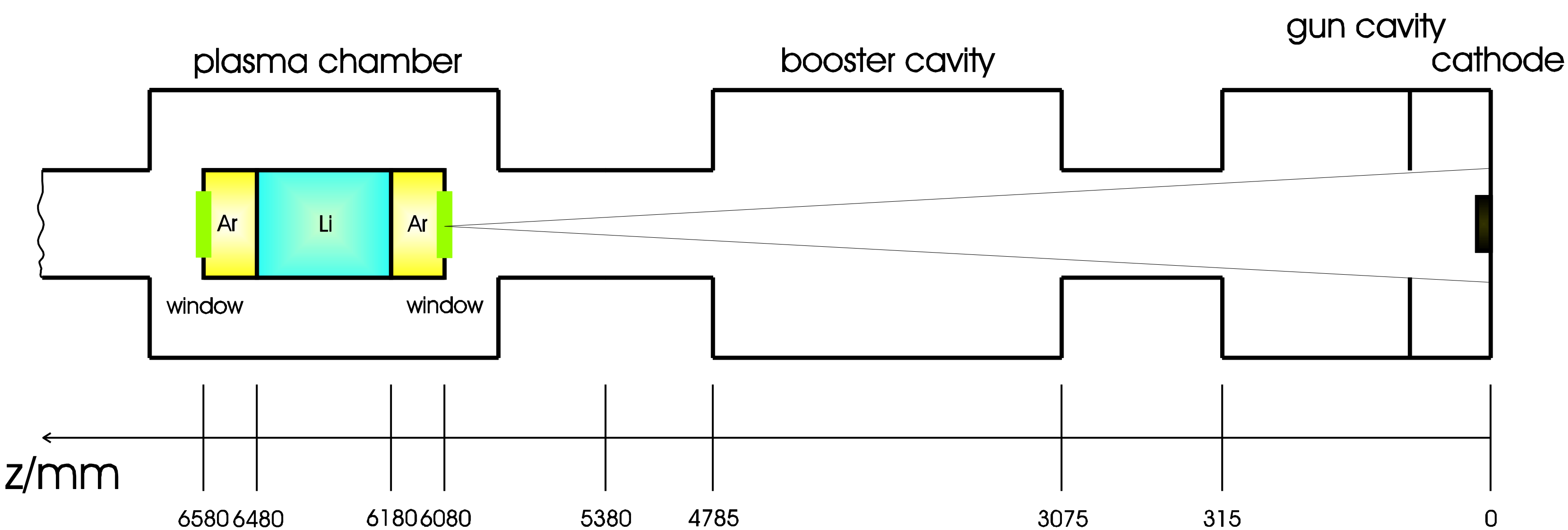
Setup of the plasma chamber vacuum components



2 independent vacuum sensors to register
an unrequested total pressure increase (IKR060)
1 sensor to register an argon partial pressure increase and a vacuum leak potentially (RGA)

D. Richter

Influence of the plasma chamber on the PITZ vacuum system



- permeation current passing the foil
- noble gas from the buffer passes a hole in the foil, possibly

D. Richter

diameter of hole

Pressure in the gas buffer after one second

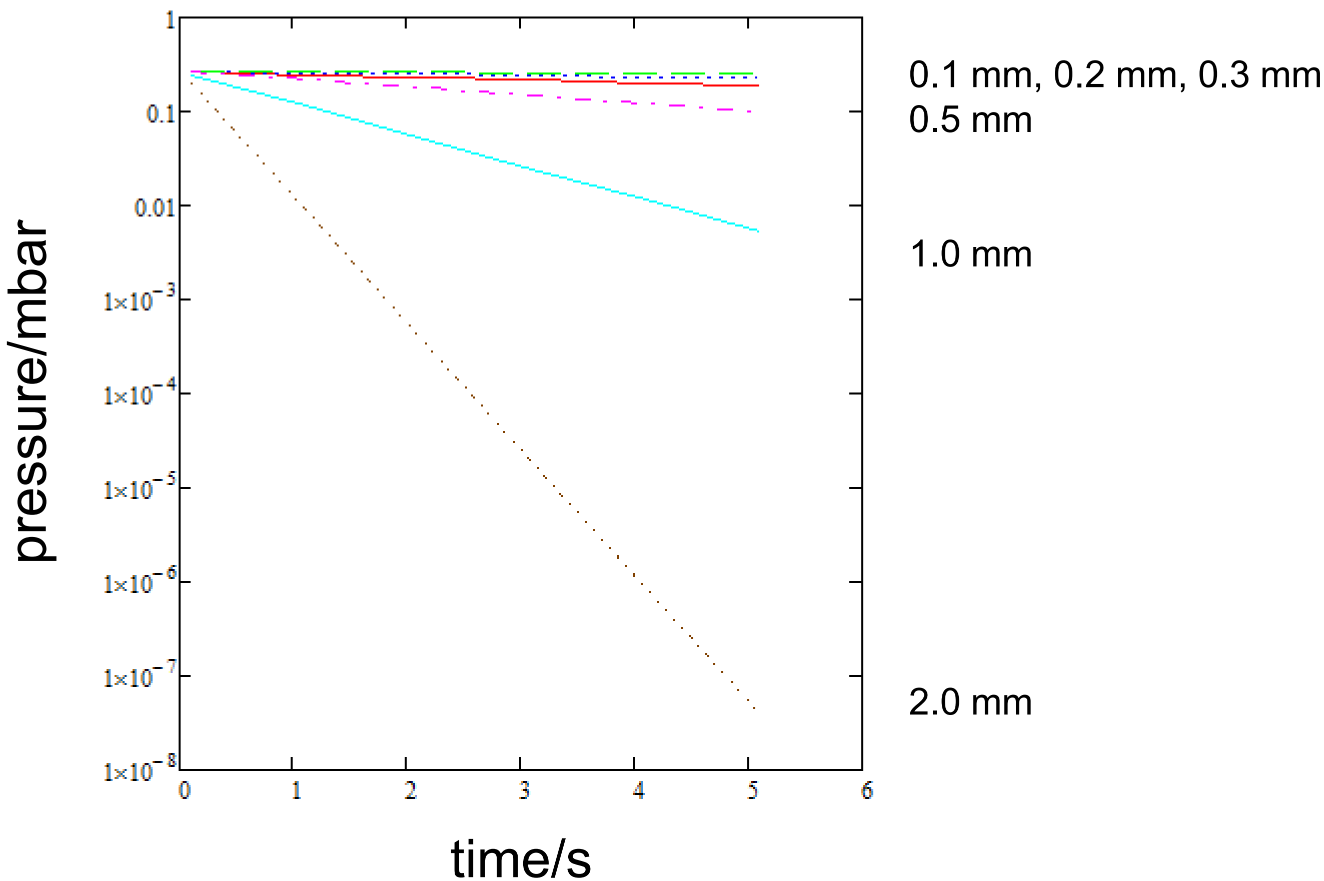
Li atoms passing the gas buffer and coming into the PITZ vacuum after one second

d/mm	p(t=1 s)/mbar	n
0,1	0,264	0
0,2	0,258	0
0,3	0,248	0
0,5	0,219	0
1	0,123	1,0E-14
2	0,0122	1,0E+13

D. Richter

Ar pressure inside of the buffer volume vs. the time

Parameter: diameter of the hole



D. Richter

Gas kinetics

D. Richter. *Mechanik der Gase.* Springer-Verlag, Heidelberg Dordrecht London New York, 2010.

Pressure distribution in vacuum chambers

D. Richter. Simulation of the BESSY II Vacuum System,

Nuclear Instruments and Methods in Physics Research A , 470, p. 18-22, 2001

Pressure measurement with ion getter pumps

S:\user\groups\zn\drichter\public\050330.pdf