Thin Films for Particle Accelerators

Pedro Costa Pinto

The CERN Accelerator School

MAX IV LABORATORY

Thin Films for Particle Accelerators

1. Introduction
2. Sputtering (principles)
3. Sputtering technology
4. Basics of film growth & adhesion
5. Non Evaporable Getter thin films

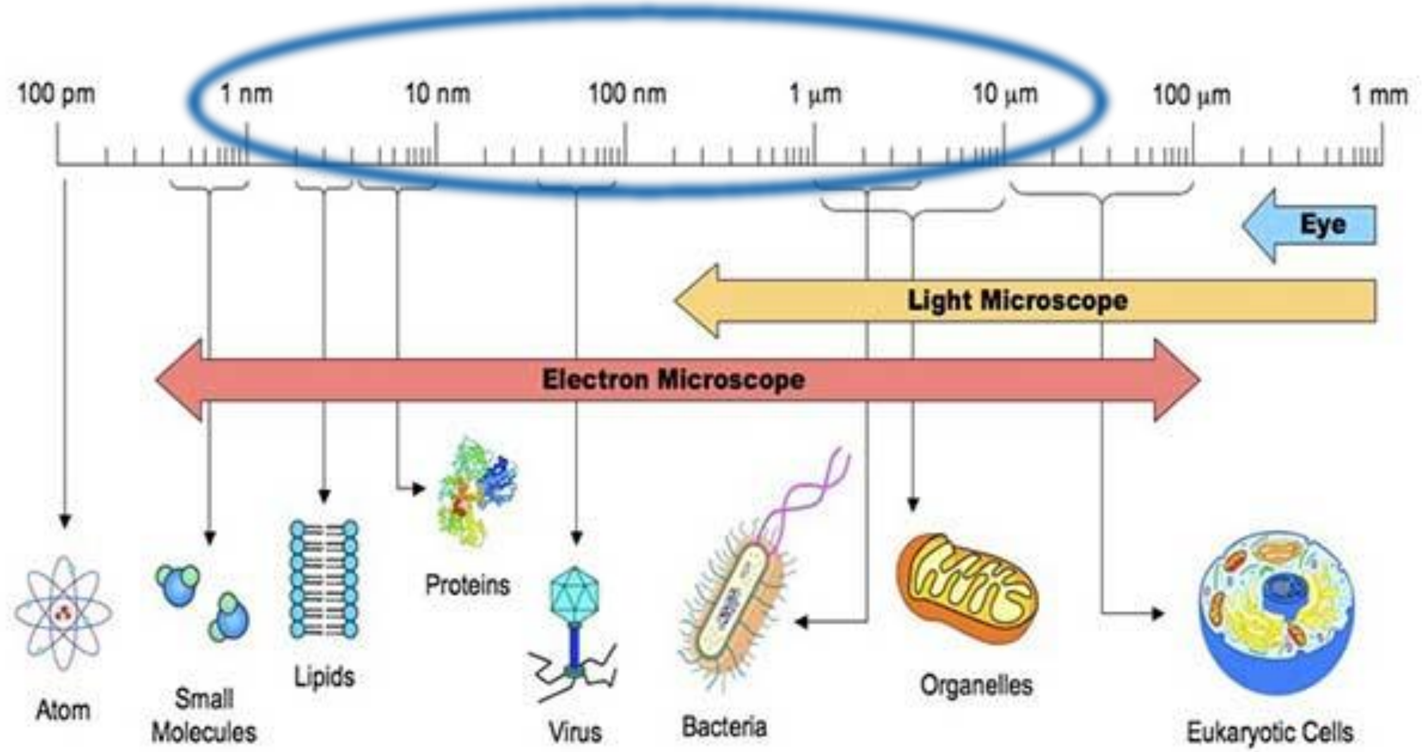
1. Introduction: What's a thin film?

WIKIPEDIA
The Free Encyclopedia

Thin film

From Wikipedia, the free encyclopedia

A **thin film** is a layer of material ranging from fractions of a nanometer (monolayer) to several micrometers in thickness.



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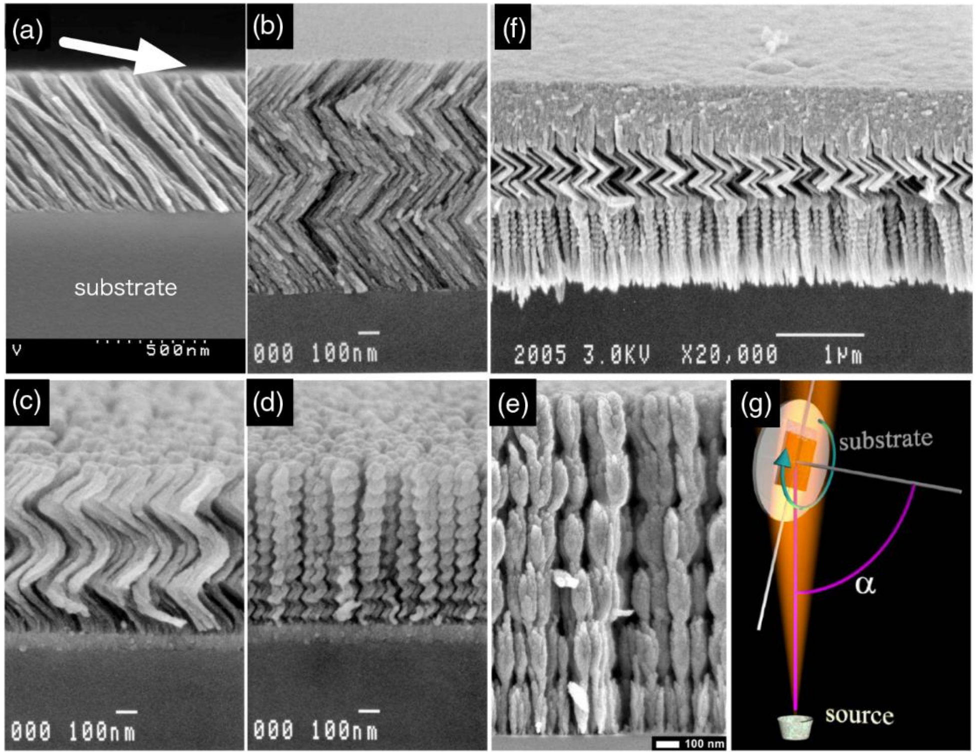

1. Introduction: for what purposes?

To change the surface properties of an object or a device.

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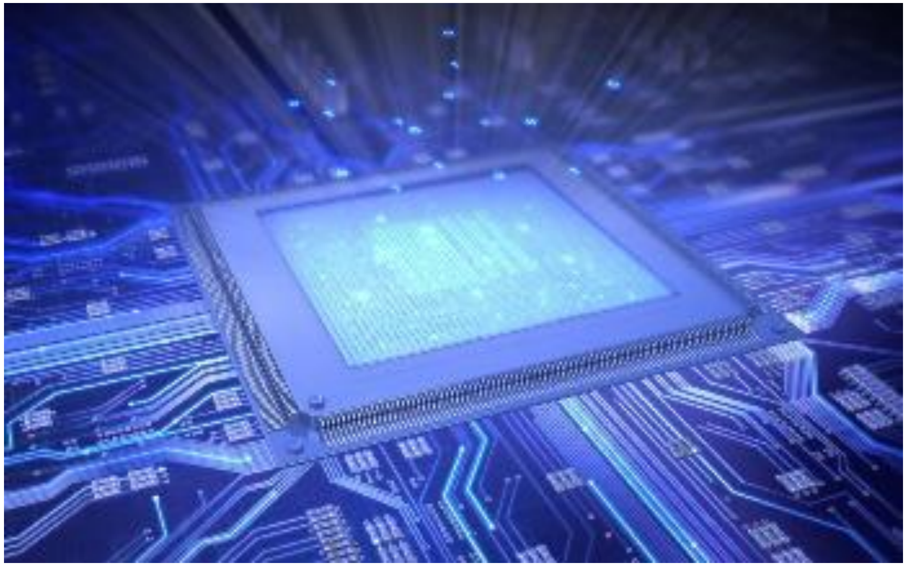

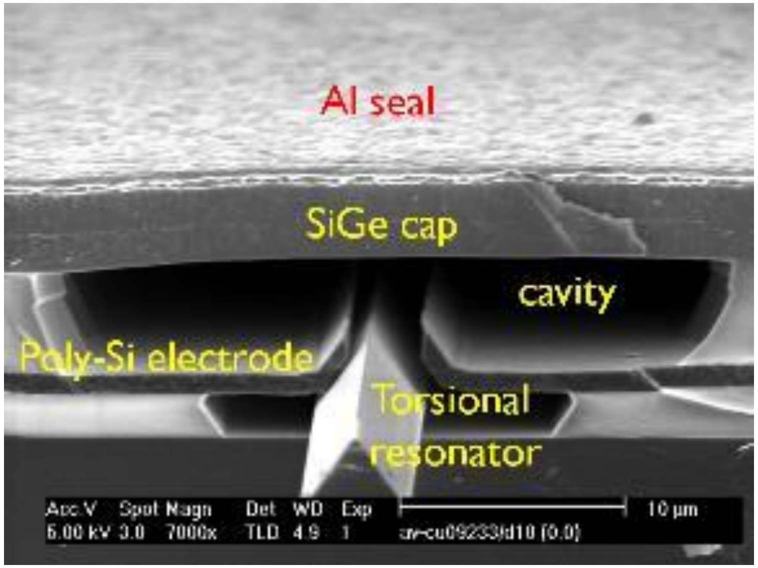

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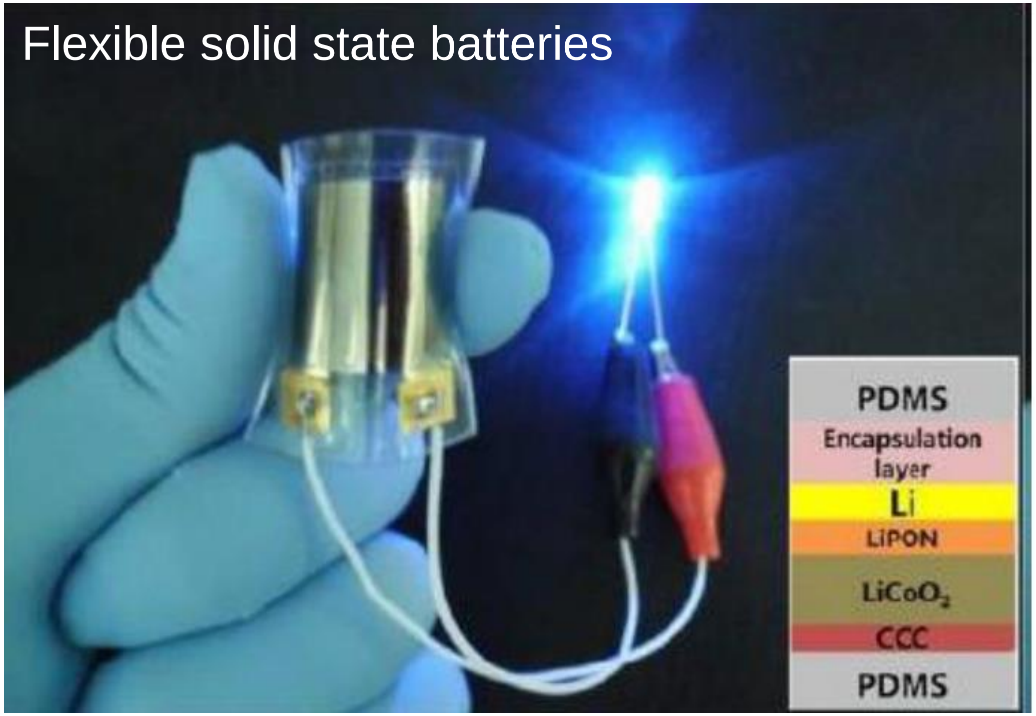


1. Introduction: for what purposes?

To change the surface properties of an object or a device.

1. Introduction: for what purposes?

And for Particle accelerators?

- Ti to reduce electron multipacting and surface impedance and to evacuate electrical charges from ceramic vacuum chambers (RF windows)
- Nb for superconducting RF accelerating cavities
- Cu to reduce surface impedance (absorbers for collimators, RF couplers, etc)
- NEG (Ti-Zr-V) for distributed pumping speed;
- TiN, NEG and a-C to mitigate e-cloud.

1. Introduction: how to produce thin films?

Chemical deposition

Liquid

- Plating
- Electroplating
- Sol-gel

Used for accelerators technology
but not discussed here

Vapour

- Chemical Vapour Deposition (CVD)
  (Assisted by plasma or laser)
- Atomic Layer Deposition (ALD)

1. Introduction: how to produce thin films?

Physical (Vapour) deposition

Thermal Evaporation

- Joule effect
- Electron beam

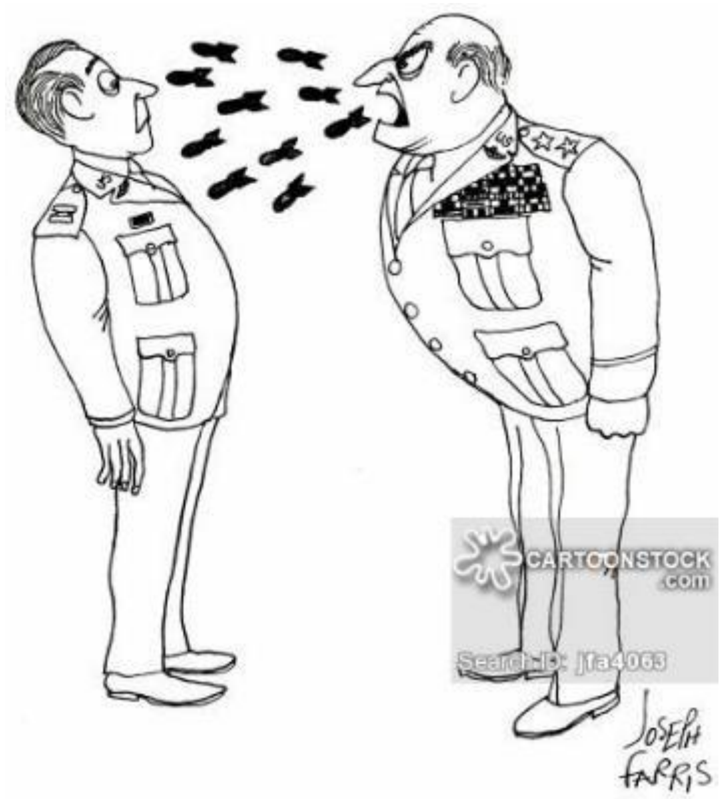
Laser ablation

Sputtering

- Ion beam
- Cathodic arc
- Glow discharge

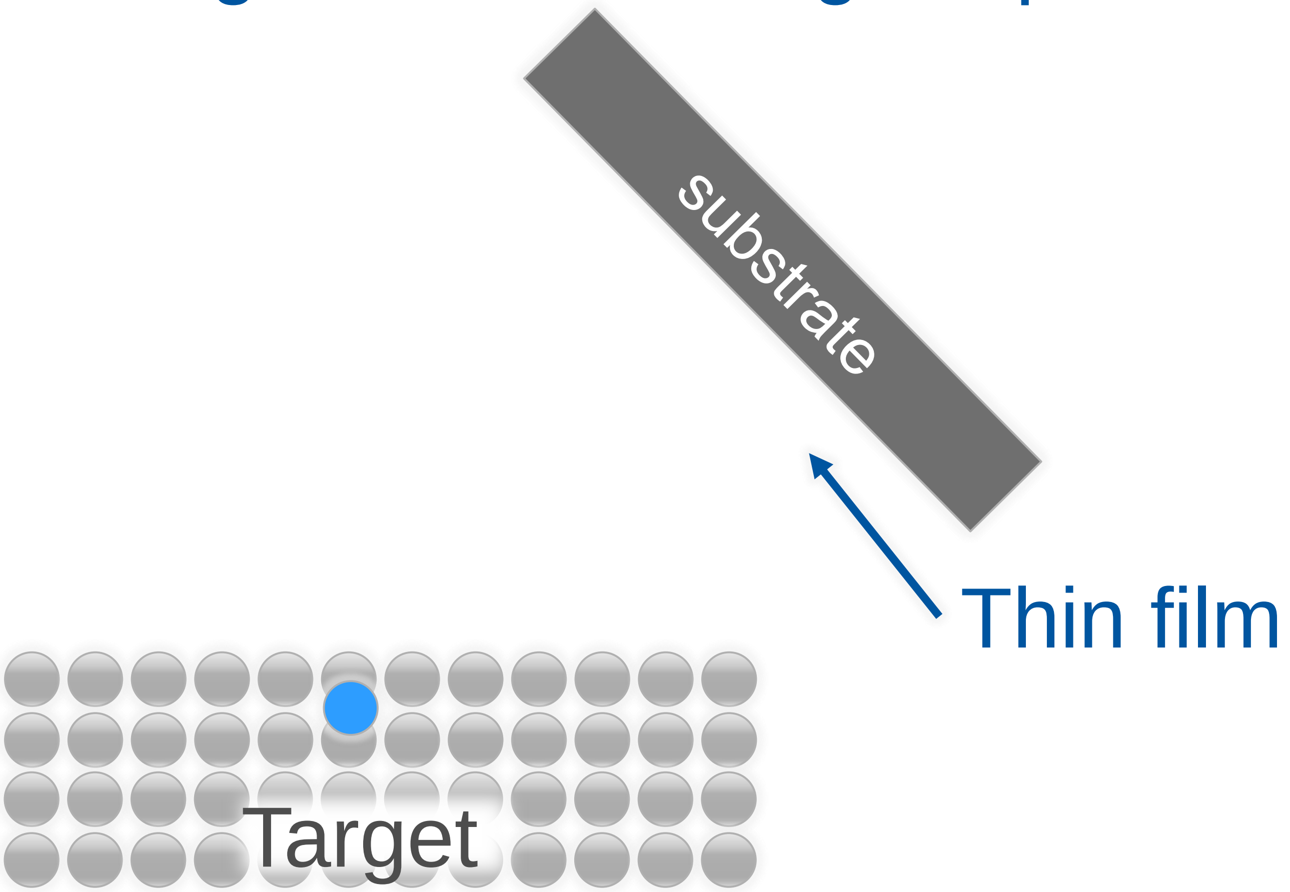
2. Sputtering: what is it?

to sputter originates from the Latin word *sputare*, meaning “to emit saliva with noise”.



2. Sputtering: what is it?

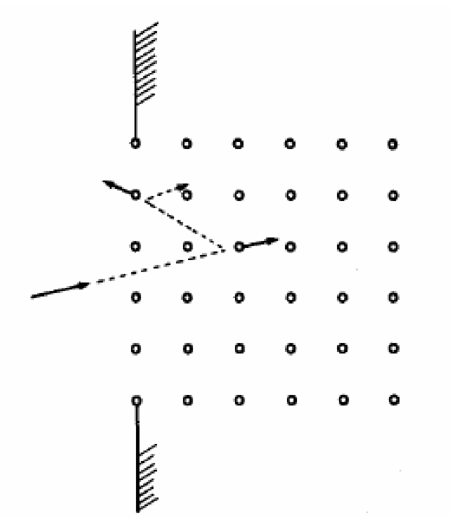
In physics, it means to remove atoms from a target by bombarding it with an energetic particle.



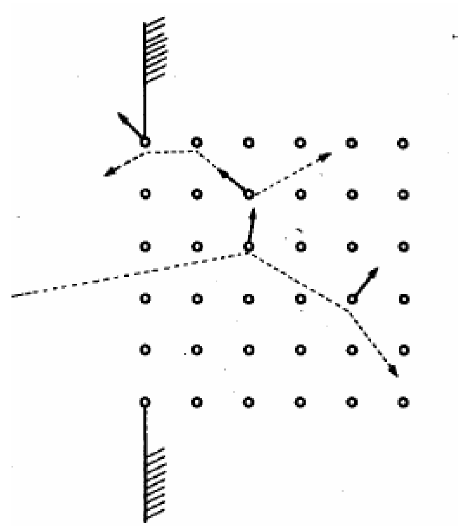
2. Sputtering: sputtering yield Y

Y = sputtered atoms / incident ion

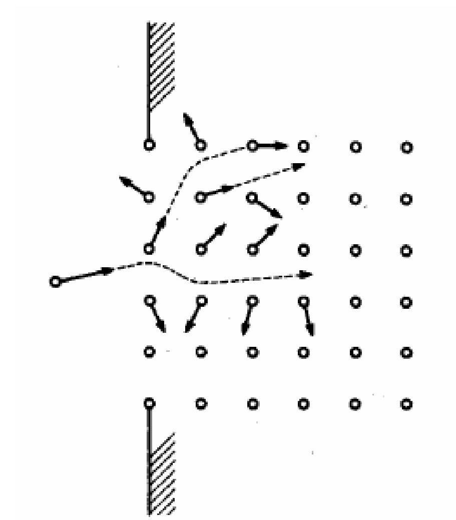
Depends on the chemical bonding of the target atoms & on the energy transferred by collision (ion specie and energy).



Threshold regime
(no cascades)



Linear cascade regime
Recoil cascade occurs, but collisions between moving atoms are rare



Spike regime
For high energy, most of the atoms in the "spike volume" are in motion

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PHYSICAL REVIEW VOLUME 184, NUMBER 2 10 AUGUST 1969

Theory of Sputtering. I. Sputtering Yield of Amorphous and Polycrystalline Targets*

PETER SIGMUND†
Metallurgy Division, Argonne National Laboratory, Argonne, Illinois 60439
(Received 3 April 1969)

ATOMIC DATA AND NUCLEAR DATA TABLES **62**, 149–253 (1996)

ENERGY DEPENDENCE OF ION-INDUCED SPUTTERING YIELDS FROM MONATOMIC SOLIDS AT NORMAL INCIDENCE

YASUNORI YAMAMURA* and HIRO TAWARA

2. Sputtering: sputtering yield Y

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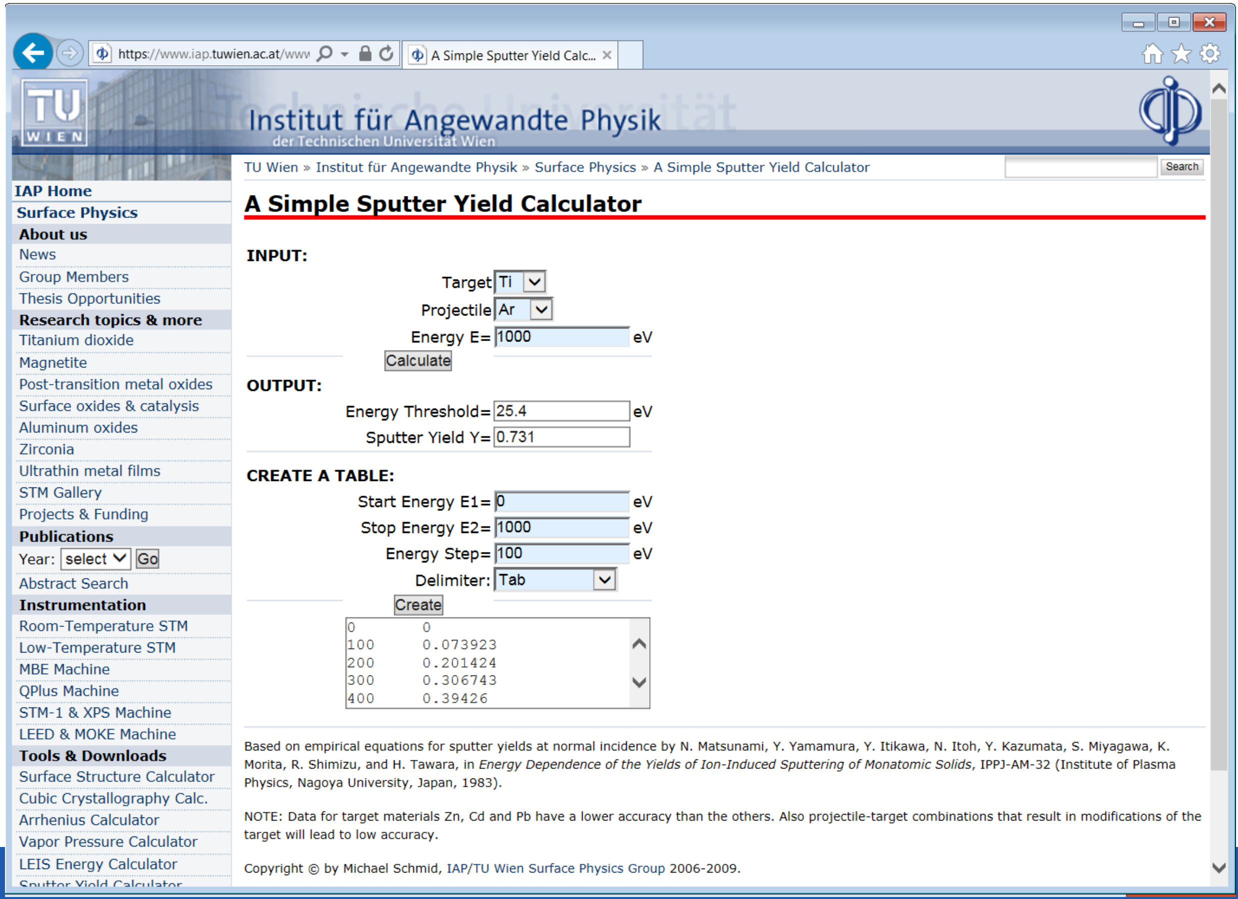
Online simple sputter yield calculator
(Technical University of Wien)



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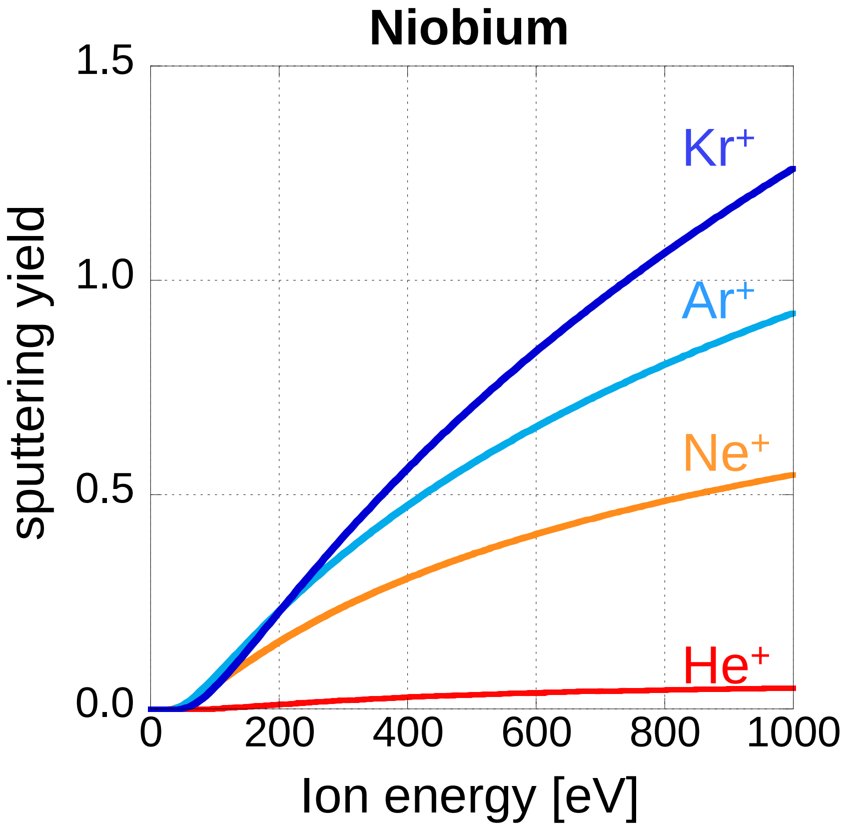

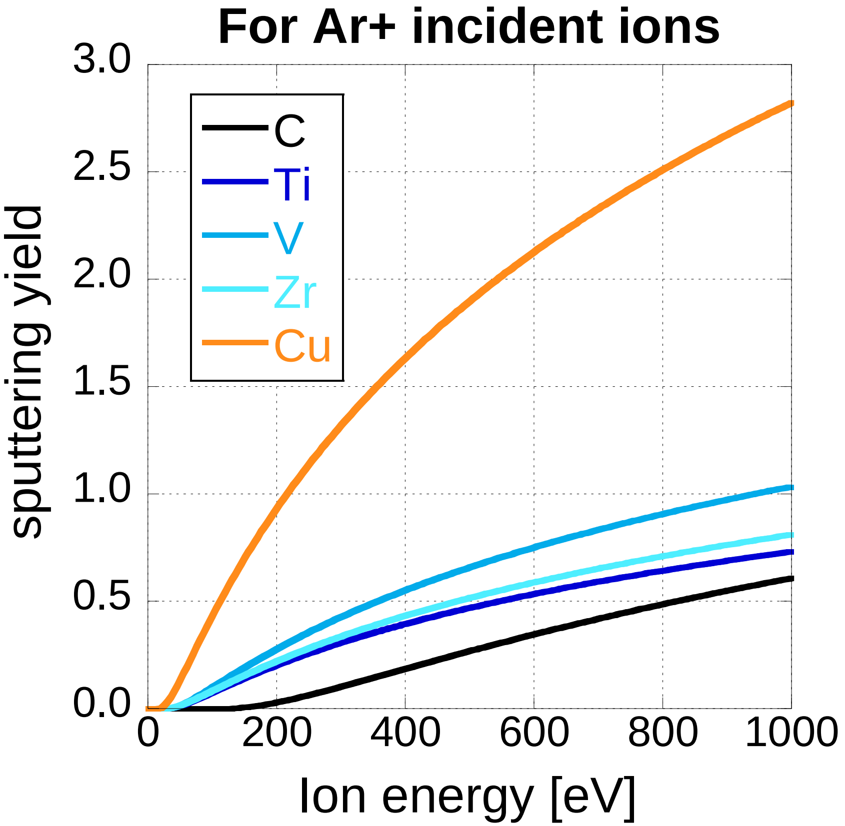

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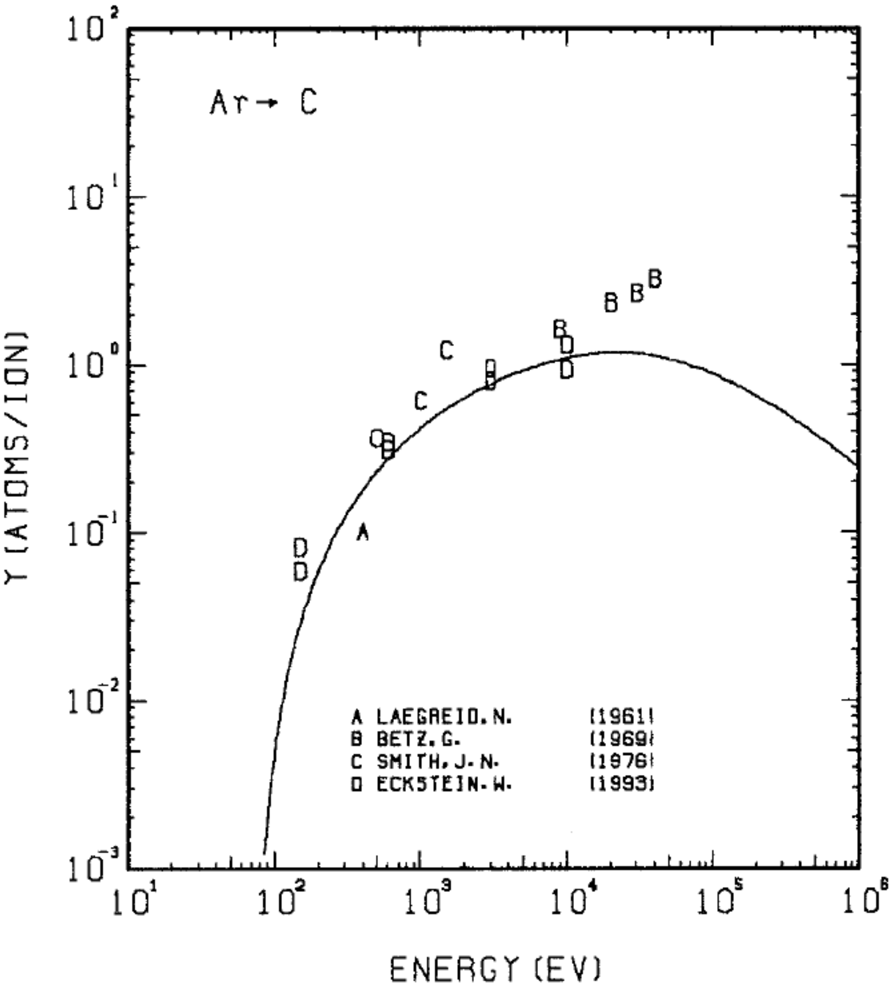

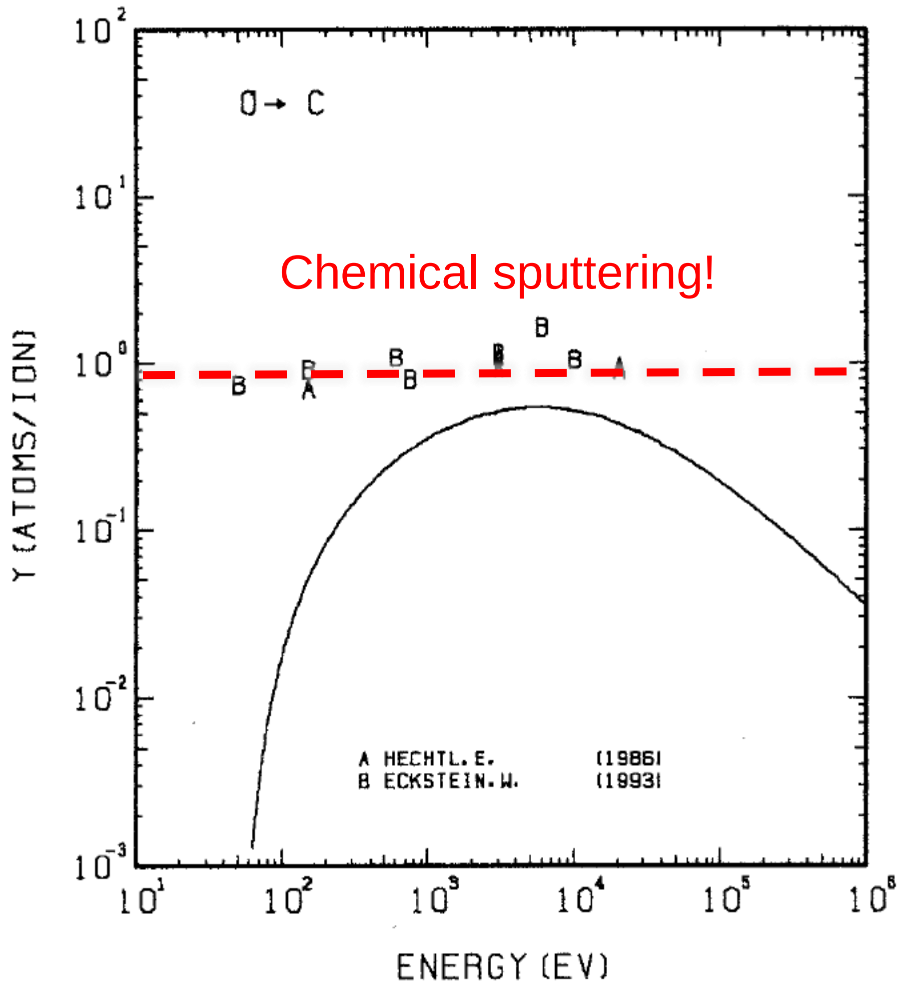

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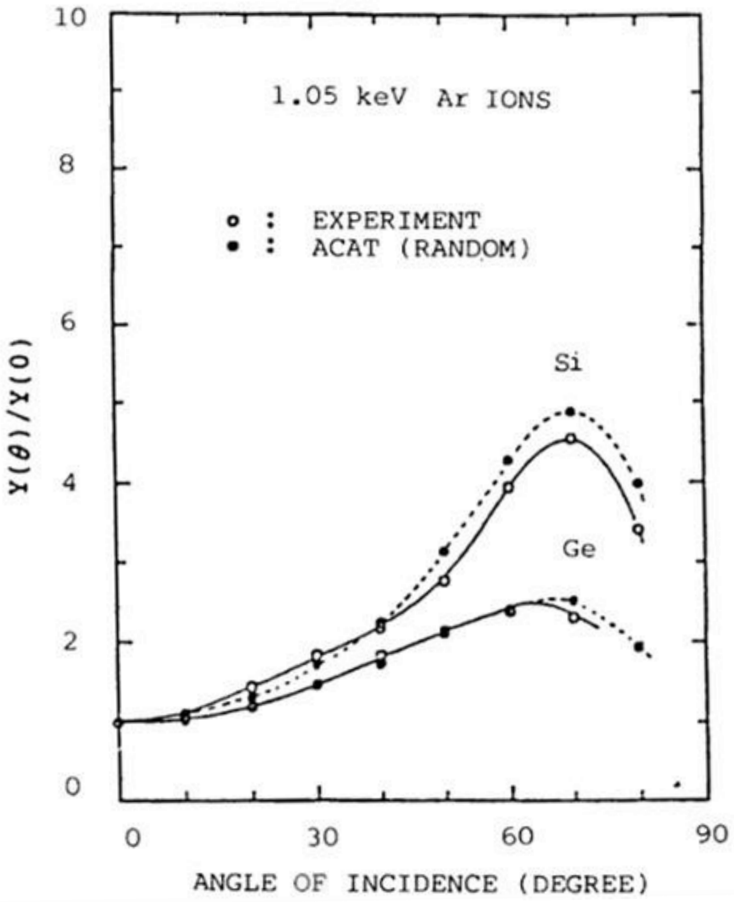


Yamamura, Y.; Itikawa, Y.; Itoh, N.; Angular dependence of sputtering yields of monatomic solids

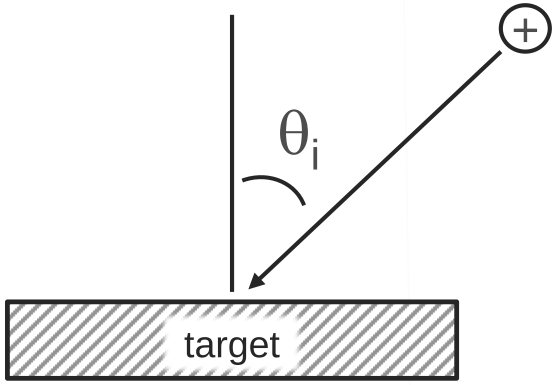
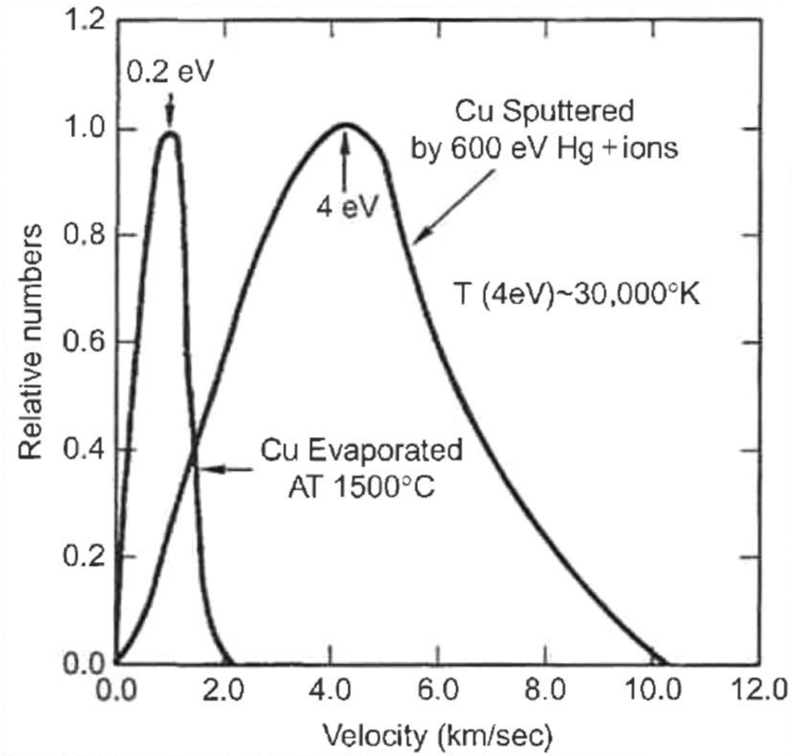


Fig. 4.20 The normalized yield $Y(\theta)/Y(0)$ for 1.05 Ar^+ on Si and Ge as a function of θ.
———— Ref. [72]
- - - - - ACAT (Ref. [31])

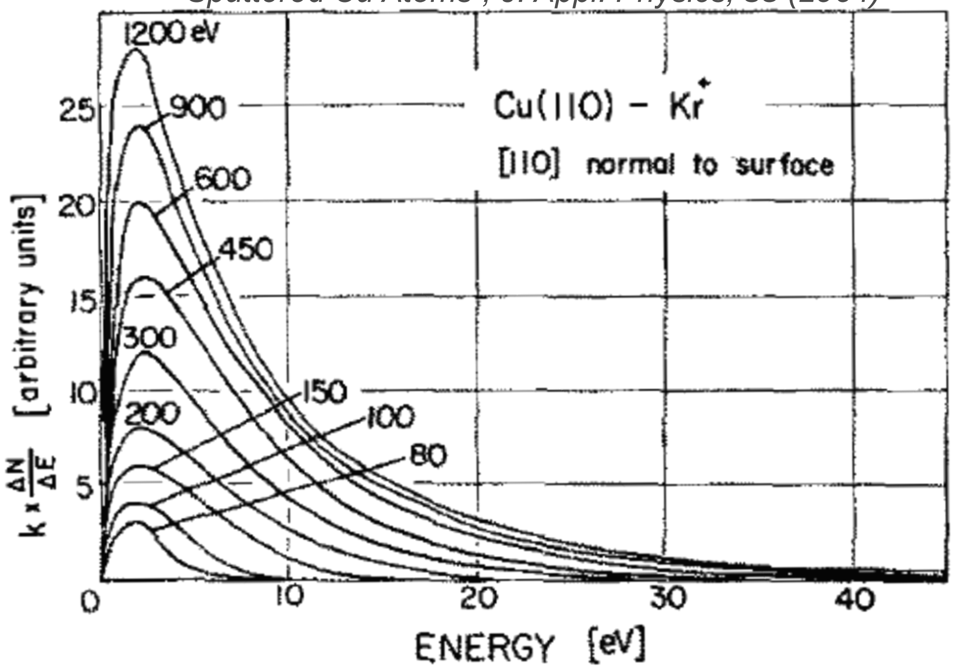
2. Sputtering: Energy of sputtered atoms

M.W. Thompson (1962). "Energy spectrum of ejected atoms during the high- energy sputtering of gold". Philos. Mag. ***18*** *(152):*

$$F(E) \propto \frac{E}{(E+U_{sb})^3}\left(1-\sqrt{\frac{E+U_{sb}}{\gamma E_{ion}}}\right) \qquad \gamma = \frac{4M_{target}M_{ion}}{\left(M_{target}+M_{ion}\right)^2}$$



Stuart & Wehner, Energy "Distribution od Sputtered Cu Atoms", J. Appl. Physics, ***35*** *(1964)*



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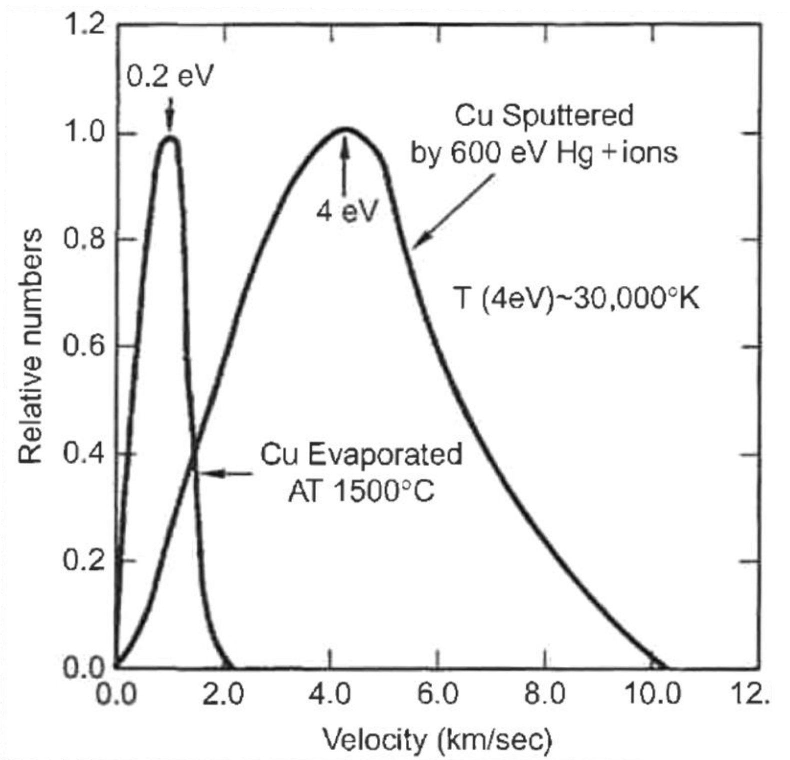

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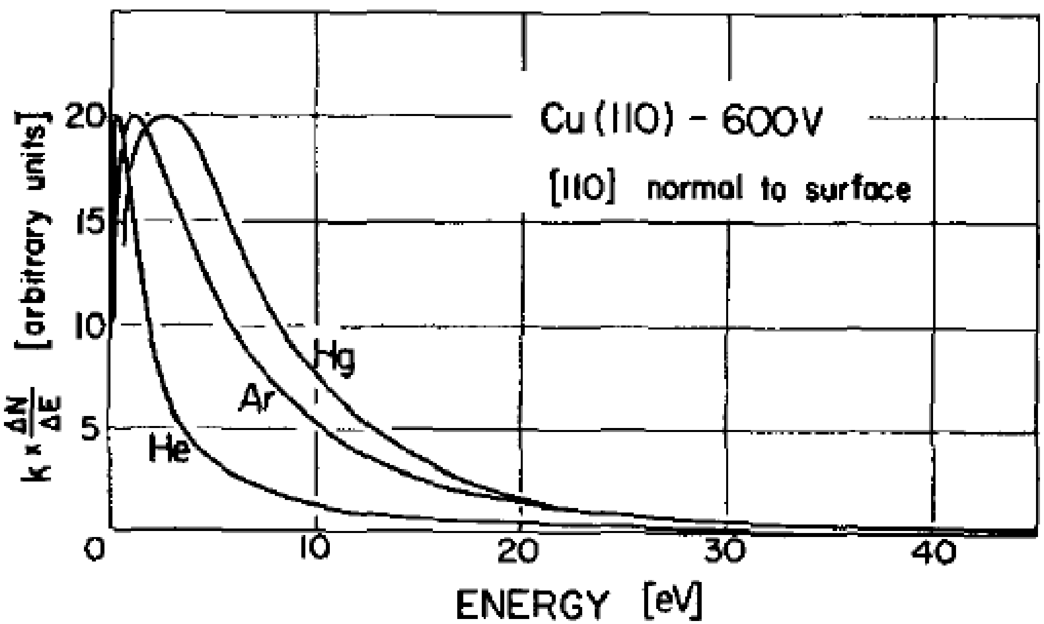


2. Sputtering: Angular distribution of atoms

Close to Knudsen's cosine law for E_{ion} >1 keV

… but slightly distorted for lower energies.

Wehner & Rosenberg (1960). "Angular Distribution of Sputtered Material". Journal of Applied Physics ***31****,177.*

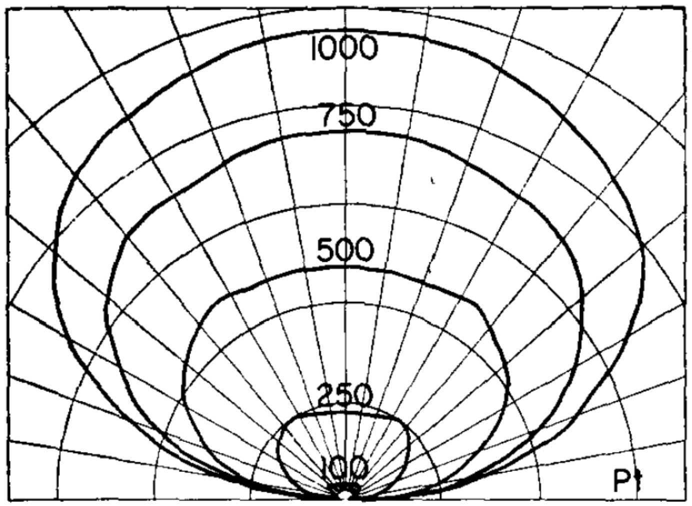


FIG. 3. Polar diagram of material sputtered from Pt by normally incident Hg^+ ions of 100 to 1000 ev energy.

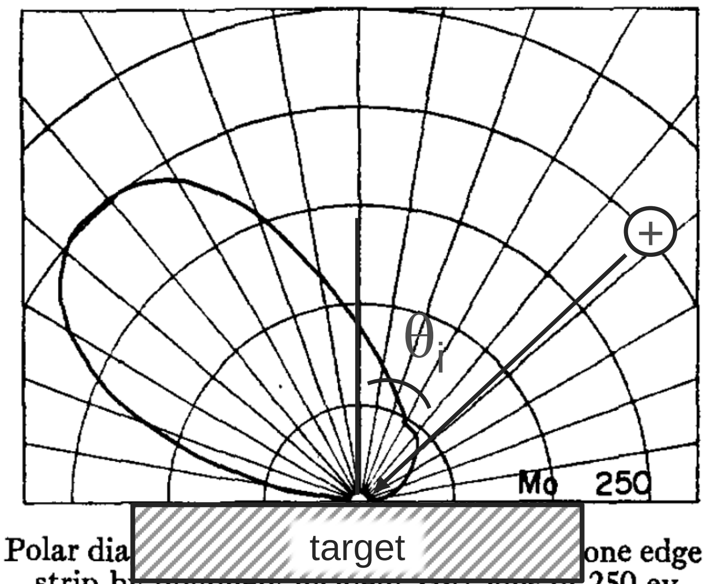


FIG. 9. Polar dia[illegible] one edge of a Mo strip by [illegible] ions of 250 ev.

2. Sputtering: Transport of atoms to substrate

$$Y(\theta) = Y_0 \cos\theta_{emission}$$

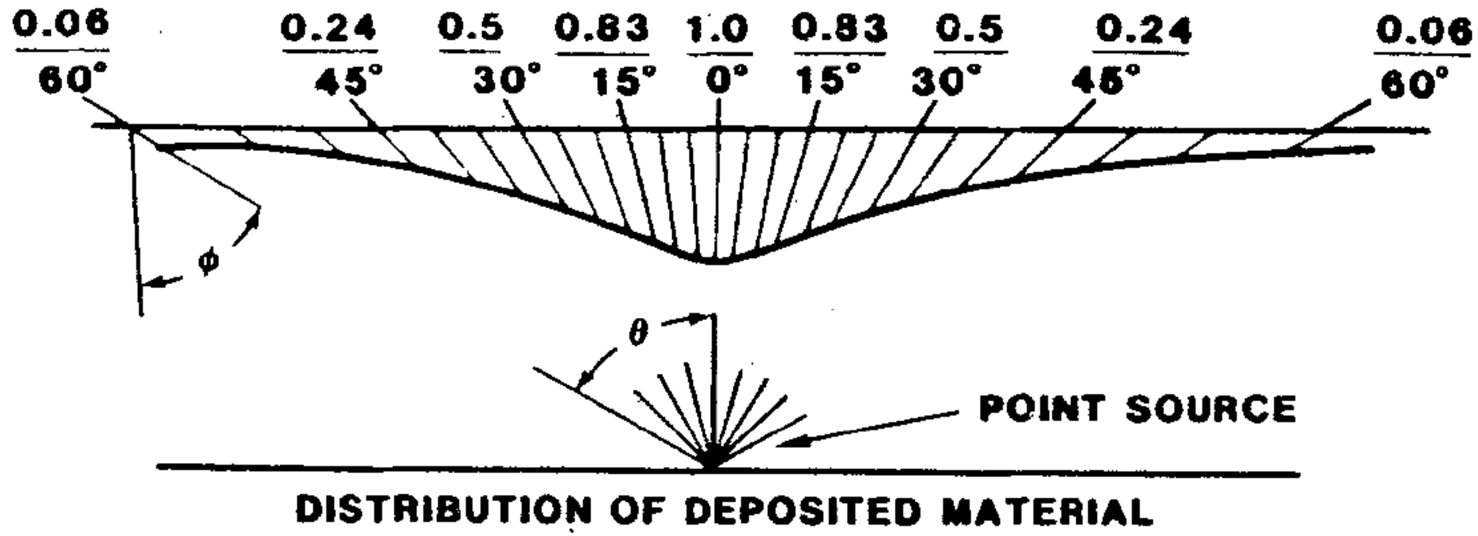


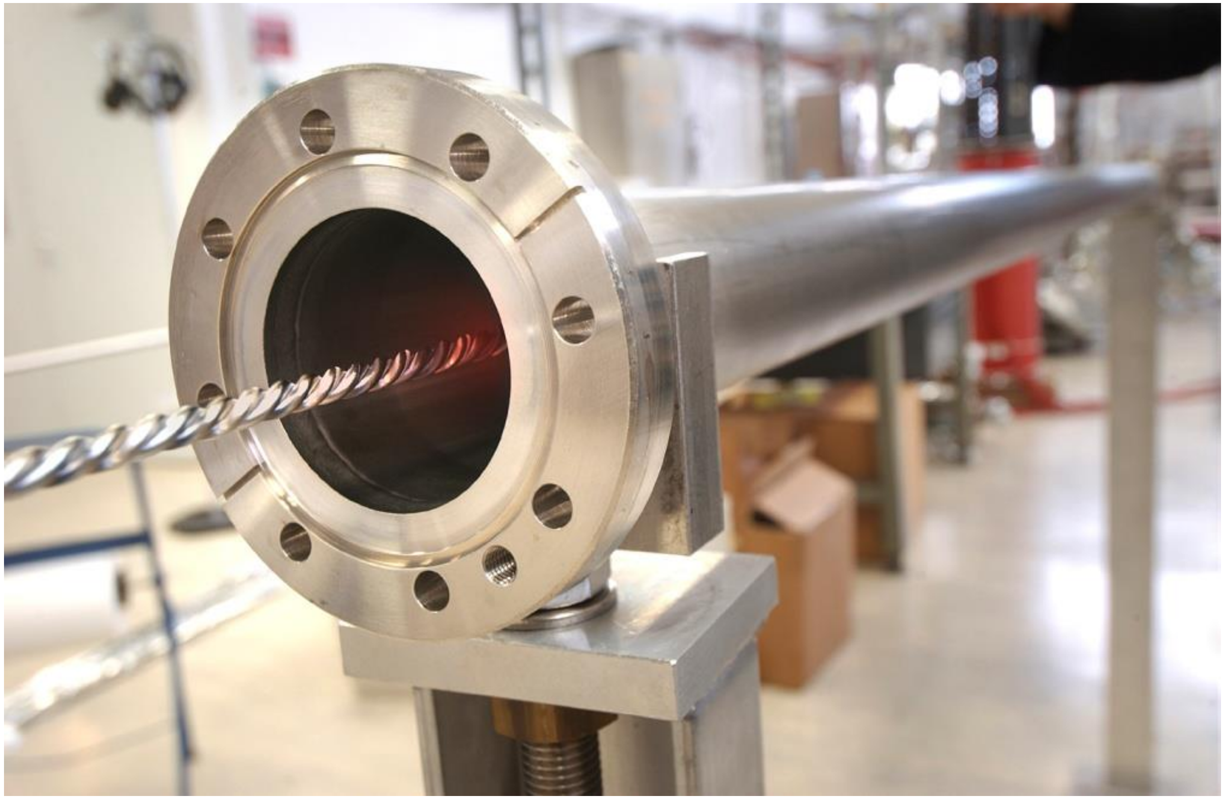
Fig. 4. Cosine distribution of vapor from a point source.

PHYSICAL VAPOR DEPOSITION (PVD) PROCESSES

by Donald M. Mattox

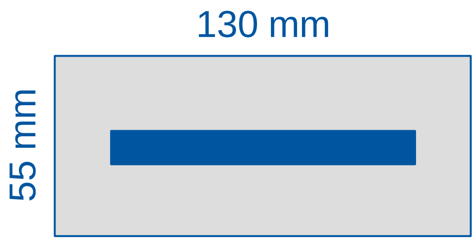
Society of Vacuum Coaters, Albuquerque, N.M.

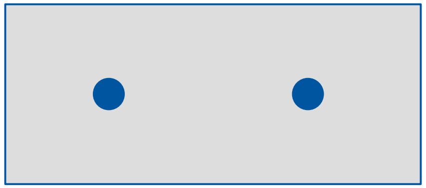
2. Sputtering: Transport of atoms to substrate

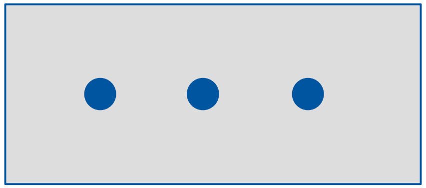


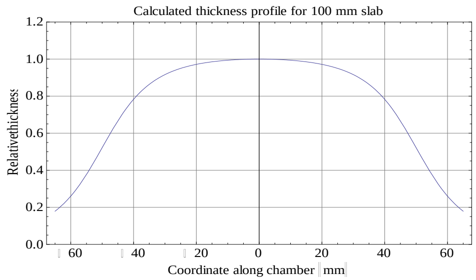
$$Thickness \propto \frac{Y_0}{d}$$

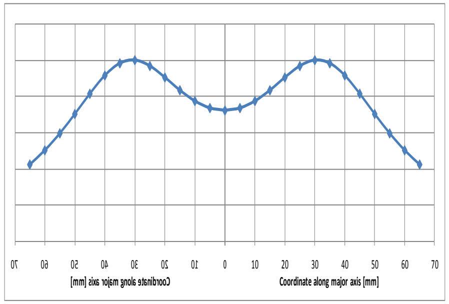
2. Sputtering: Transport of atoms to substrate

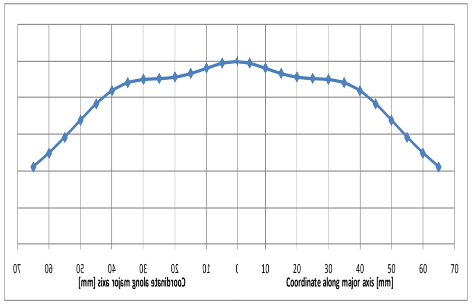


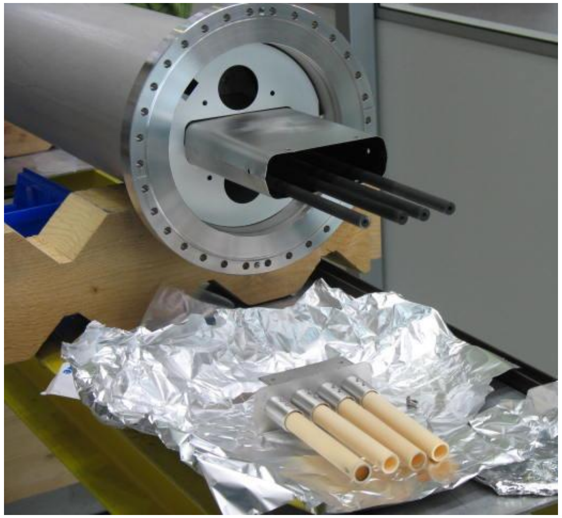








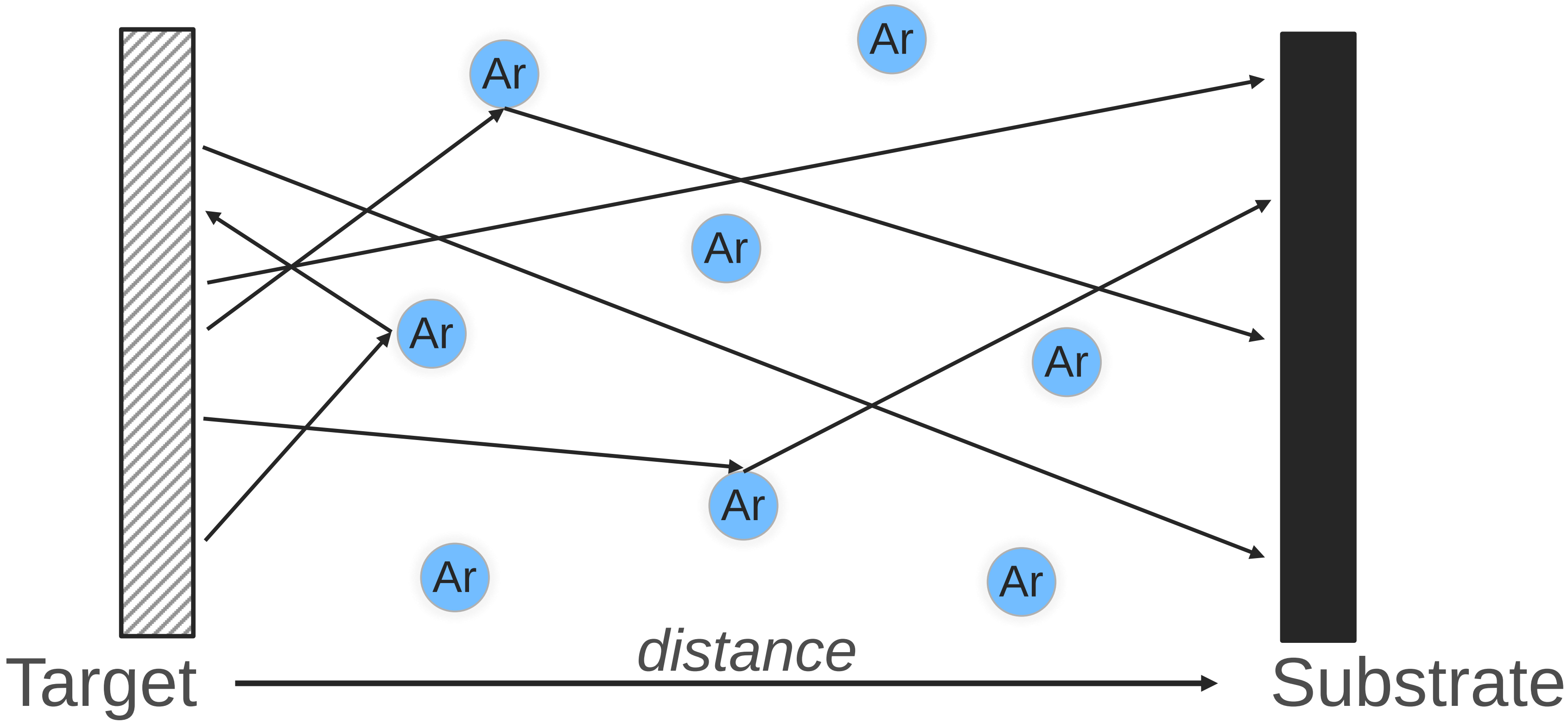




2. Sputtering: Transport of atoms to substrate

Collision with the residual gas:

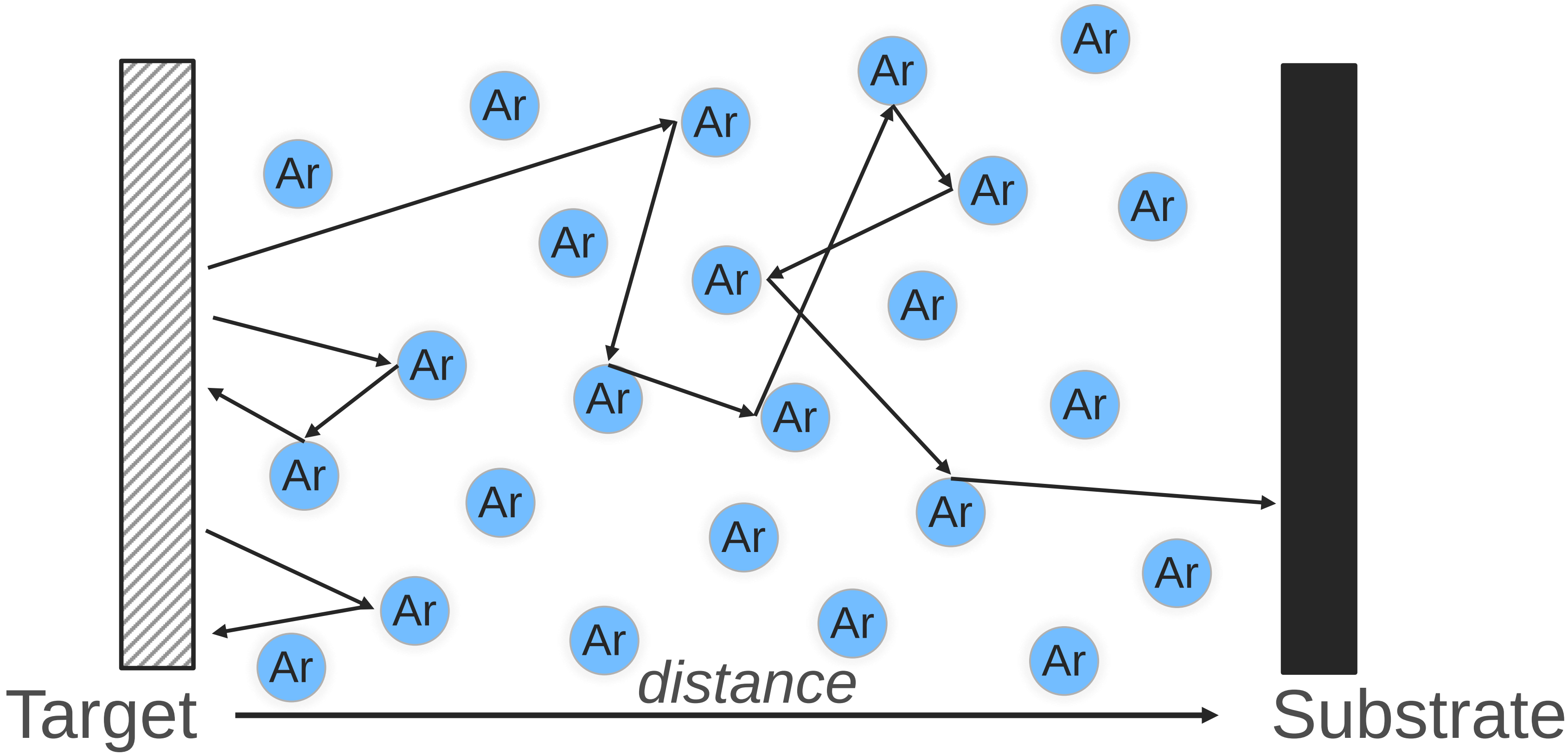
Low pressure (density): ~100% transmission.



2. Sputtering: Transport of atoms to substrate

Collision with the residual gas:

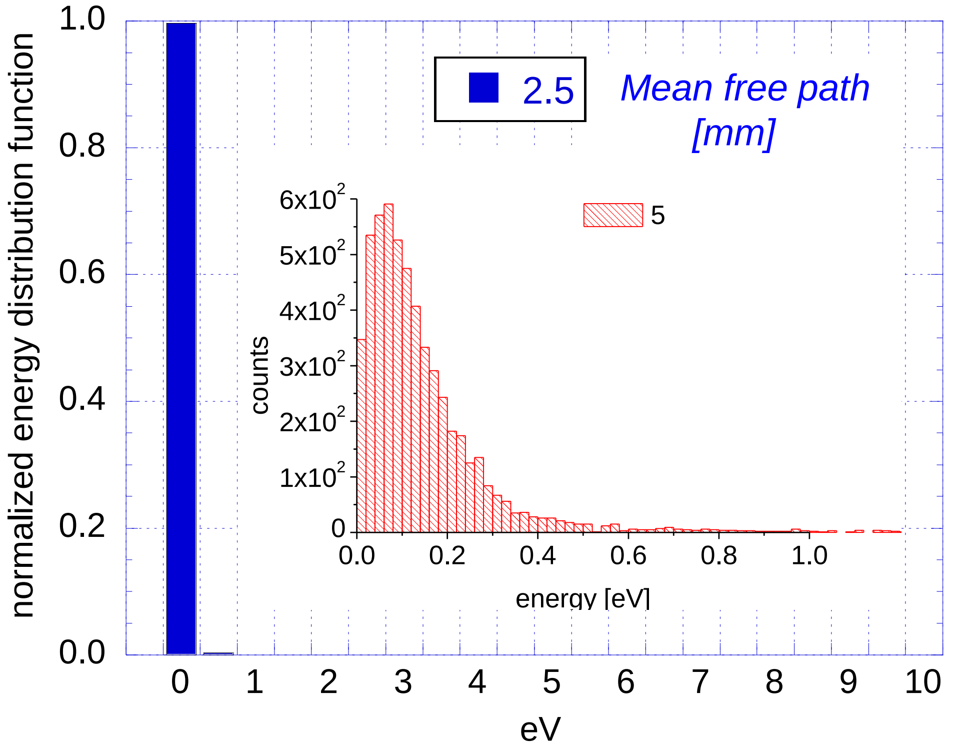
High pressure: low transmission & low energy



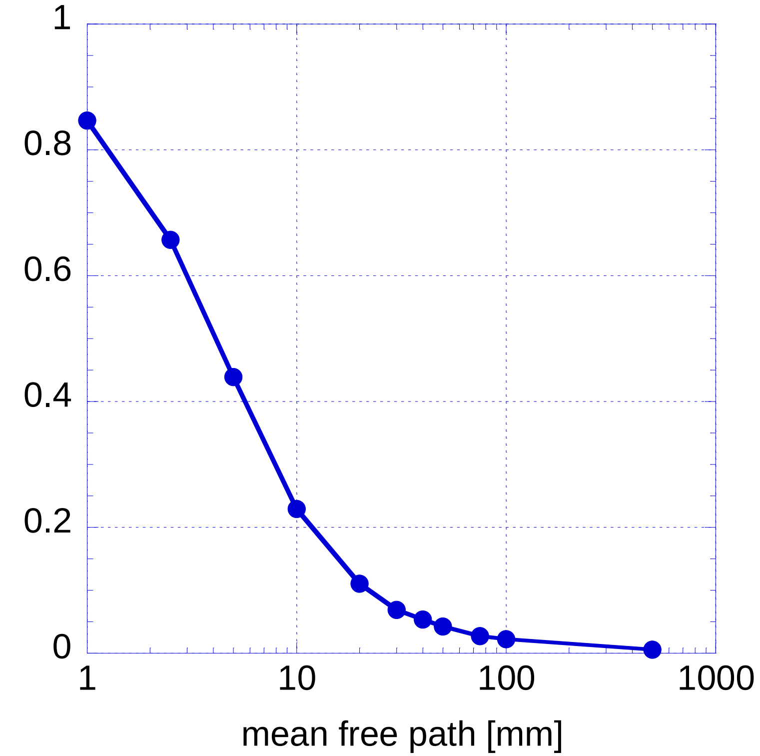
2. Sputtering: Transport of atoms to substrate

Thermalization and transmission can be simulated by Monte Carlo using the Hard Spheres model

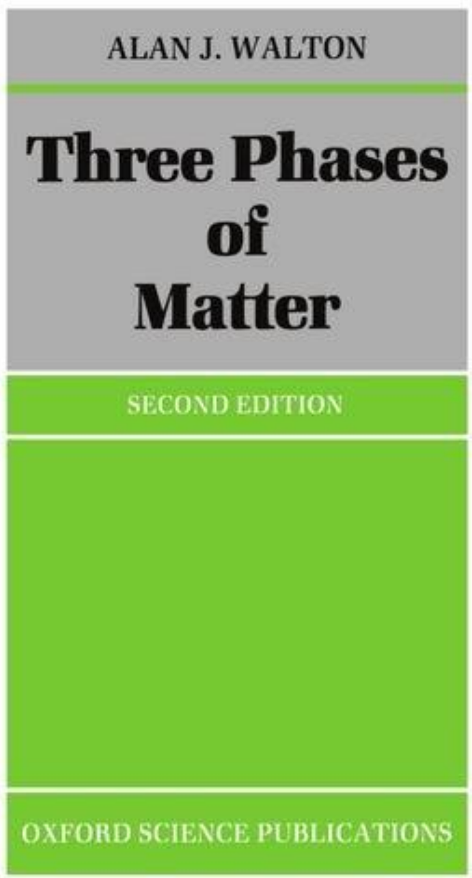
Loss of energy by collision (thermalizing)



Backscattering of atoms (return to target)



3. Sputtering technology



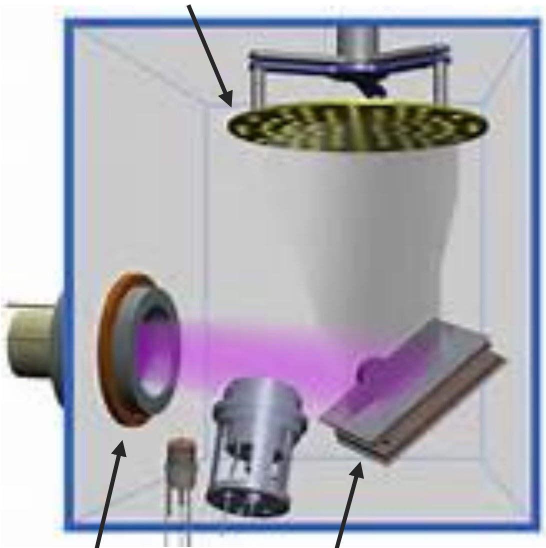
“The plasma phase is far and away the most common – stars are plasmas – but it is also by far the most difficult to discuss quantitatively.”

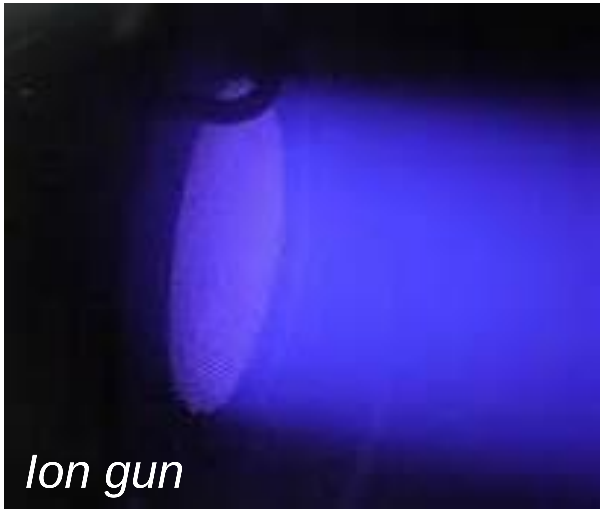
“For this reason we exclude it from further discussion.”

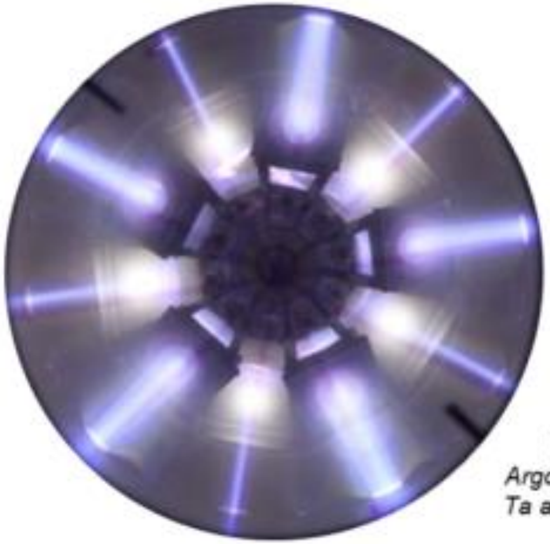
A. J. Walton, Three Phases of Matter, Oxford Univ. Press [1989]

3. Sputtering technology: IBD

Ion Beam Deposition





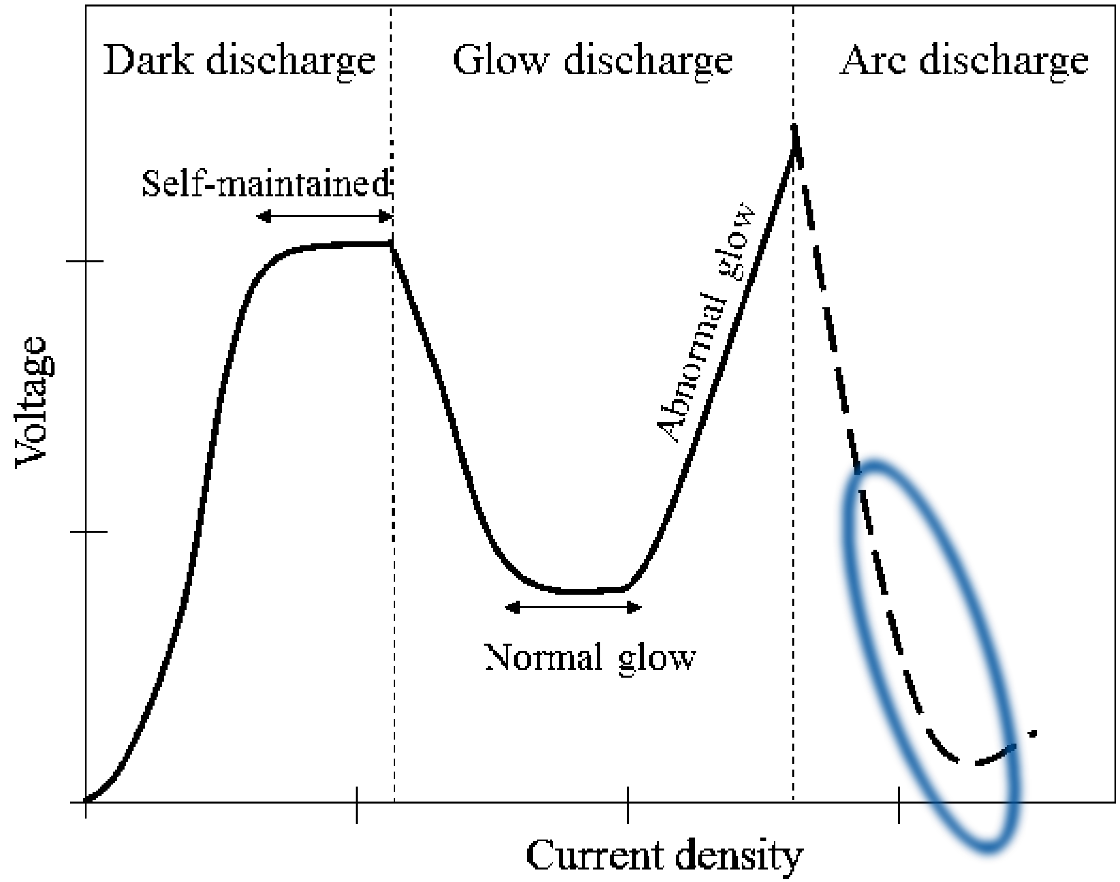


Multi beam
Multi target
Multi current
Argon beams on
Ta and C targets

Not convenient to coat tubes or large area substrates!

3. Sputtering technology: arc-PVD

Cathodic arc Vapor Deposition



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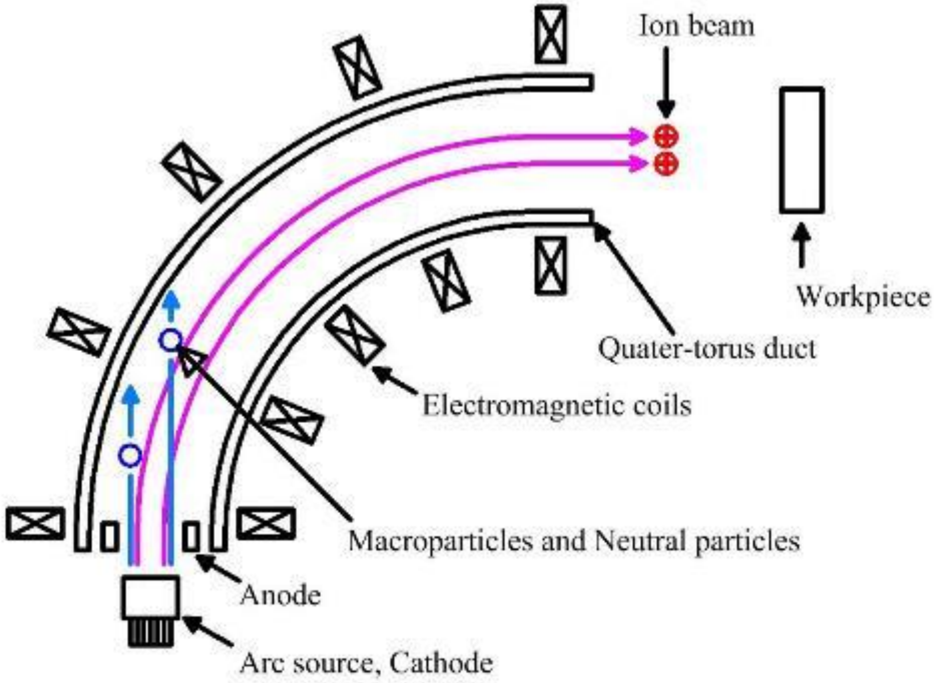
Cathodic arc Vapor Deposition



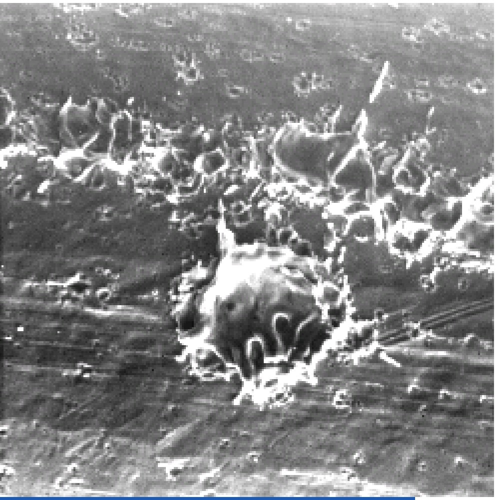
Aksenov's quater-torus macroparticle filter

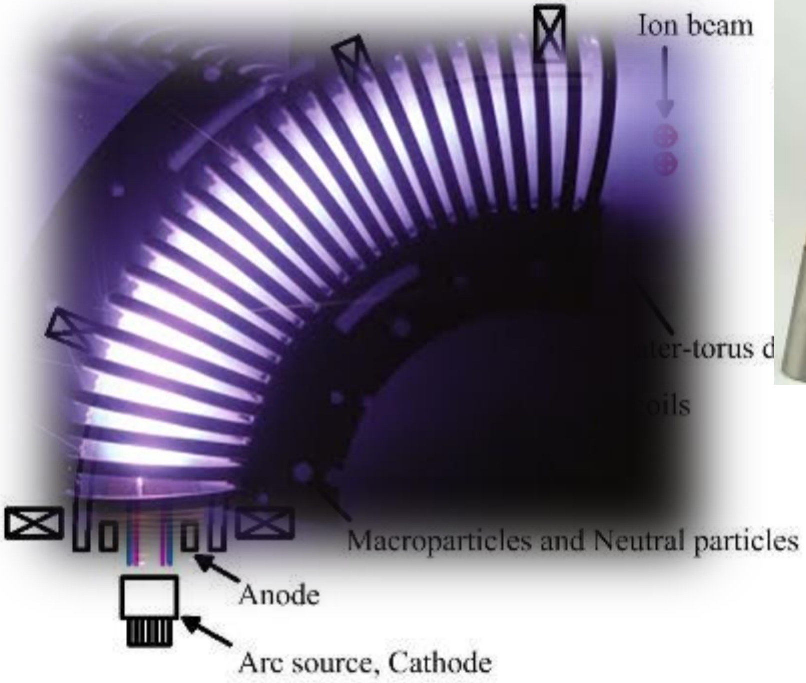
3. Sputtering technology: arc-PVD

Cathodic arc Vapor Deposition

Coating defects

Droplets



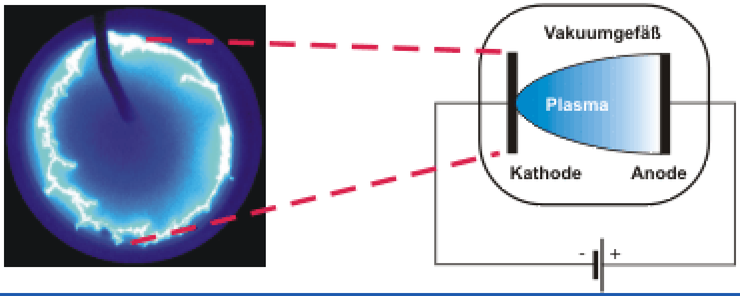


Hard coatings(TiN, AlTiN)

The sputtered material is ionized and can be deposited with high energy

Very good adhesion

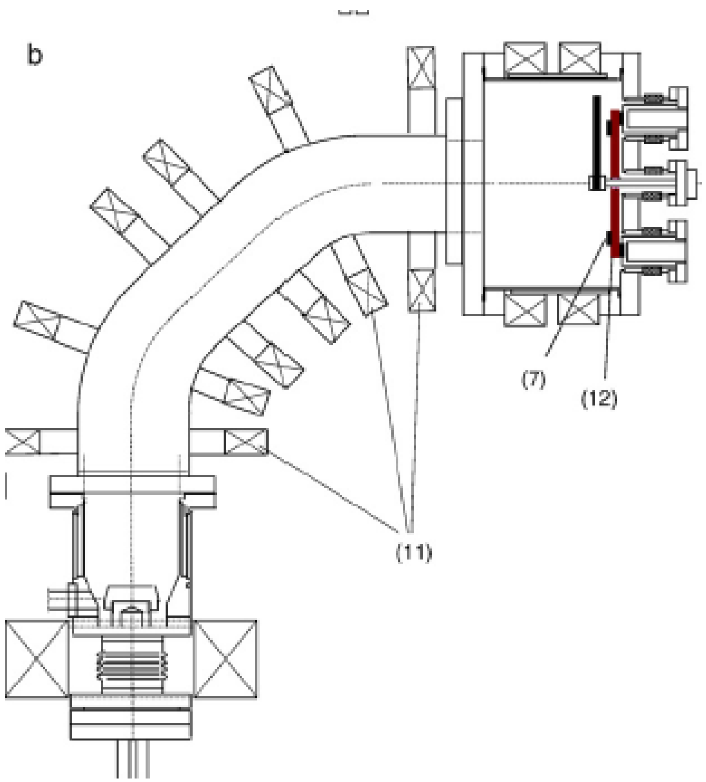
Very dense films



3. Sputtering technology: arc-PVD

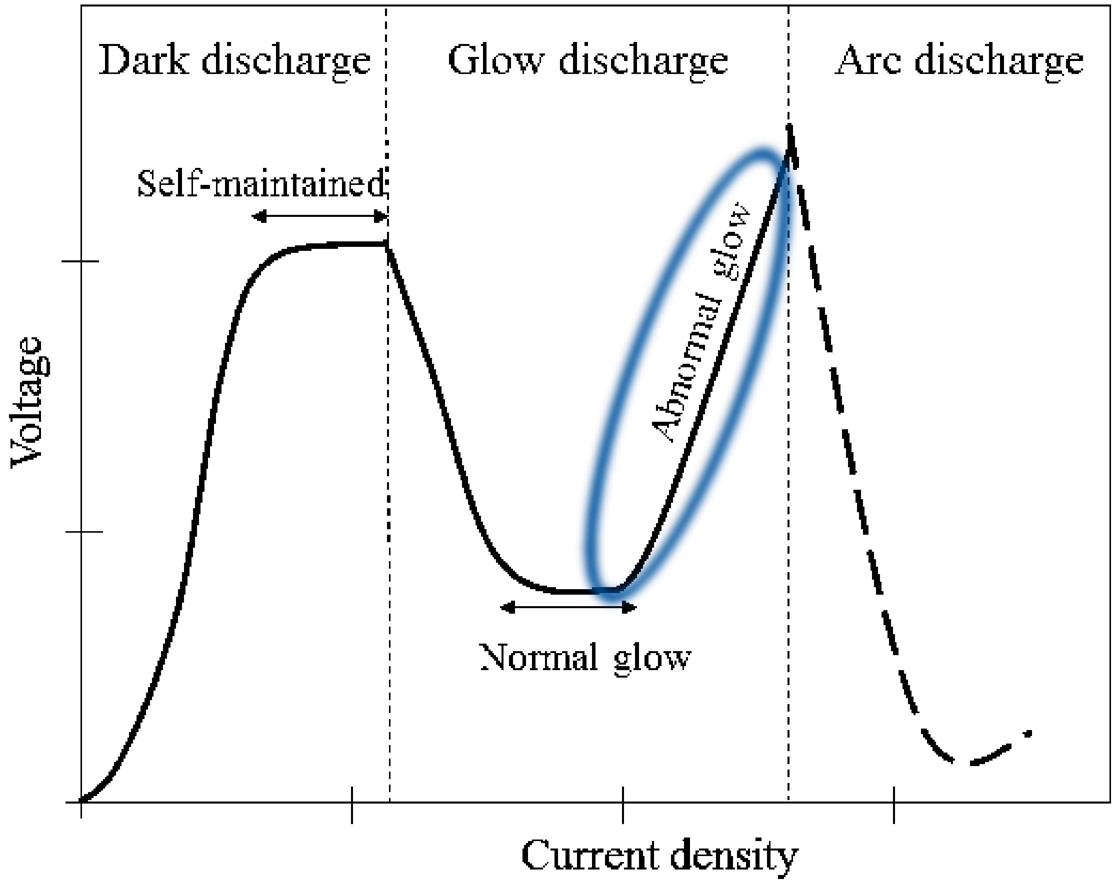
Cathodic arc Vapor Deposition

R. Russo, A. Cianchi, Y.H. Akhmadeev, L. Catani, J. Langner, J. Lorkiewicz, R. Polini, B. Ruggiero, M.J. Sadowski, S. Tazzari, N.N. Koval, Surface & Coatings Technology 201 (2006) 3987–3992



3. Sputtering technology: GDS

Glow Discharge Sputtering



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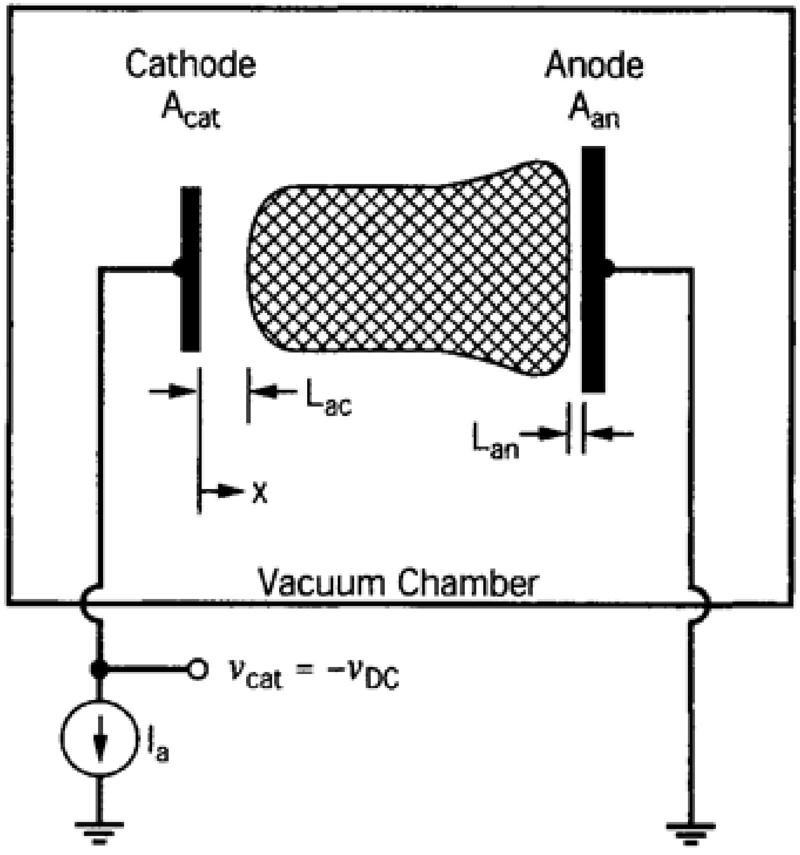
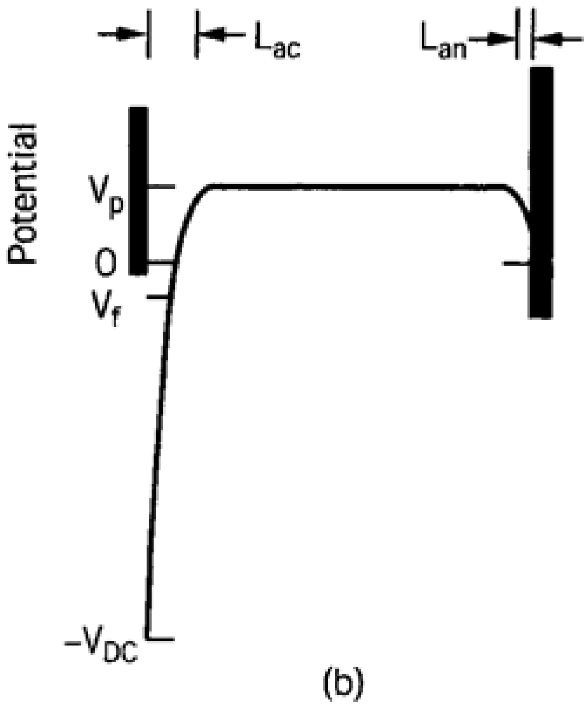
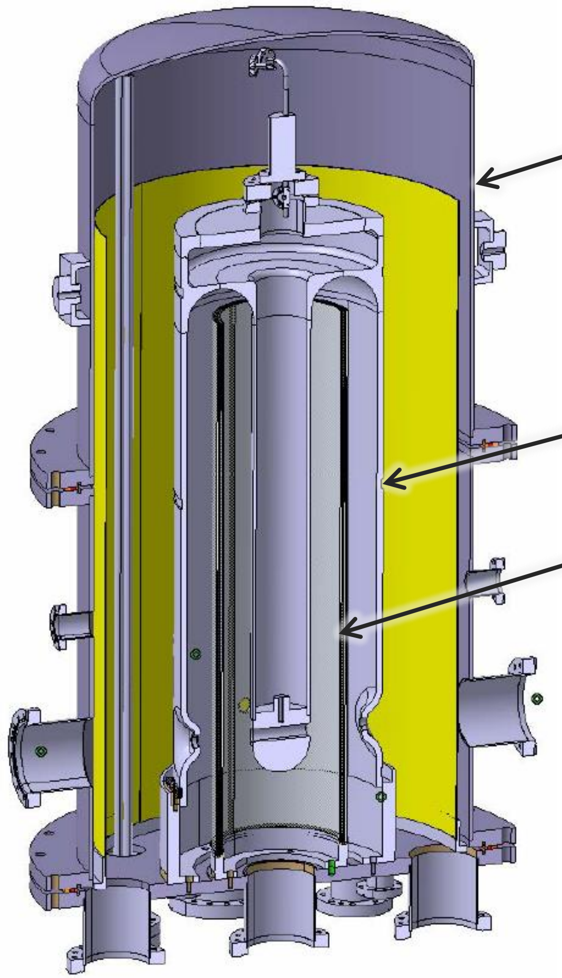
Glow Discharge Sputtering





3. Sputtering technology: GDS

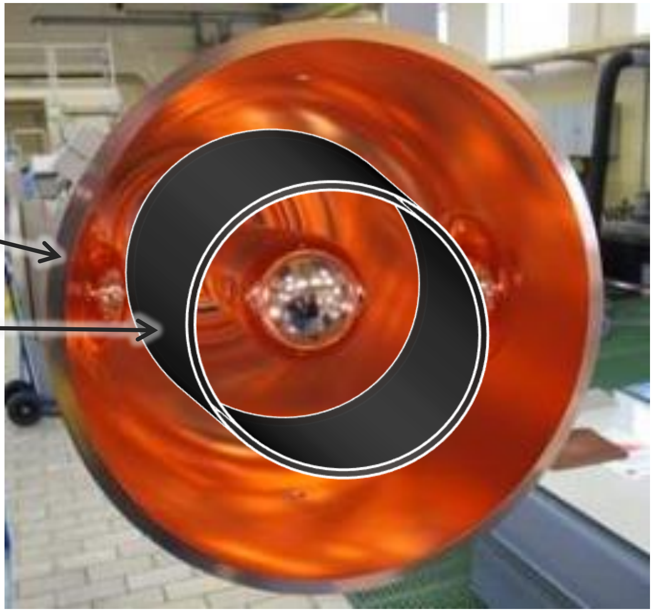
Example: Nb on Cu for the HIE-ISOLDE RF cavities



Vacuum tank

Cavity

Sputtering target (Nb)



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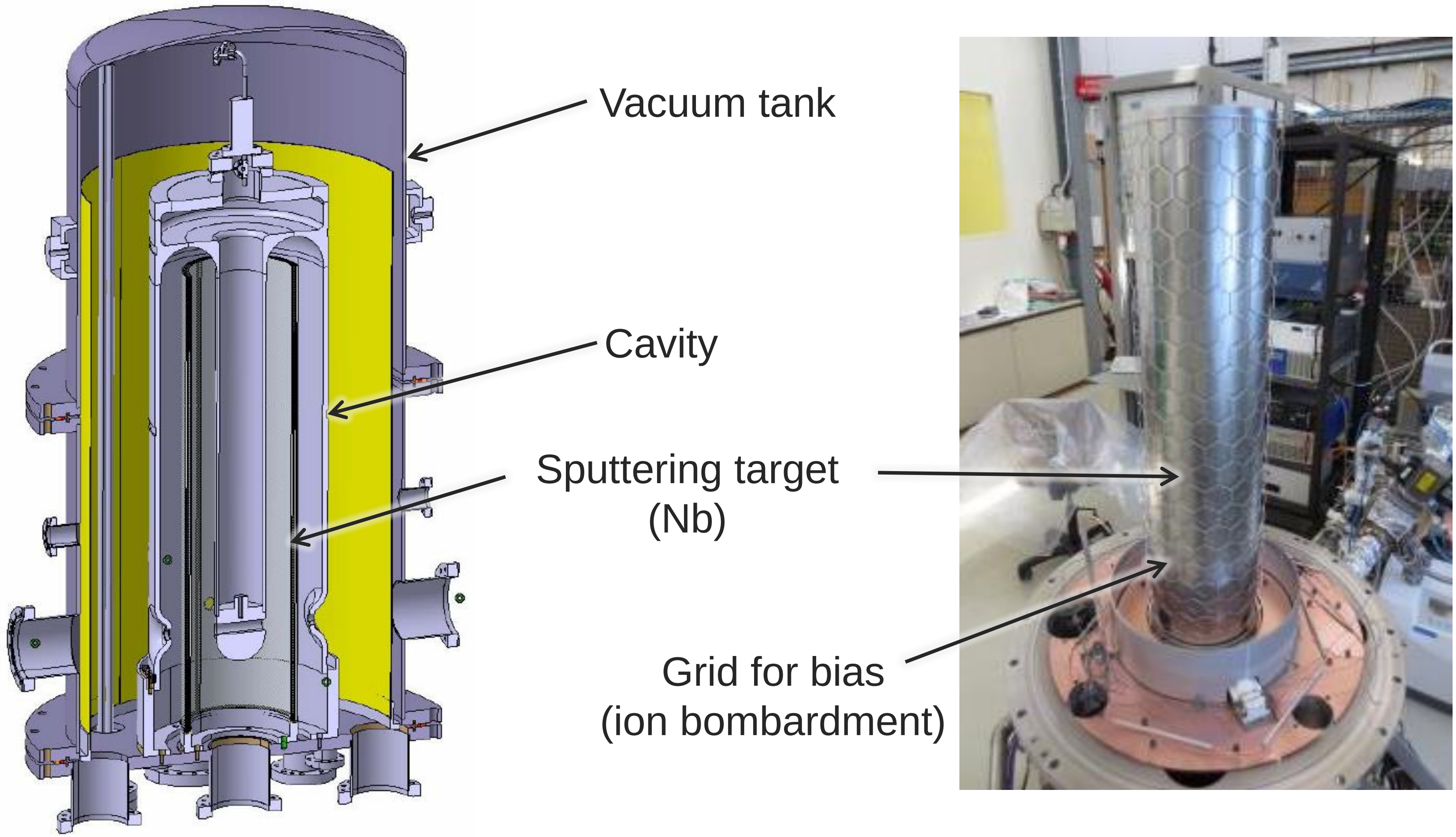

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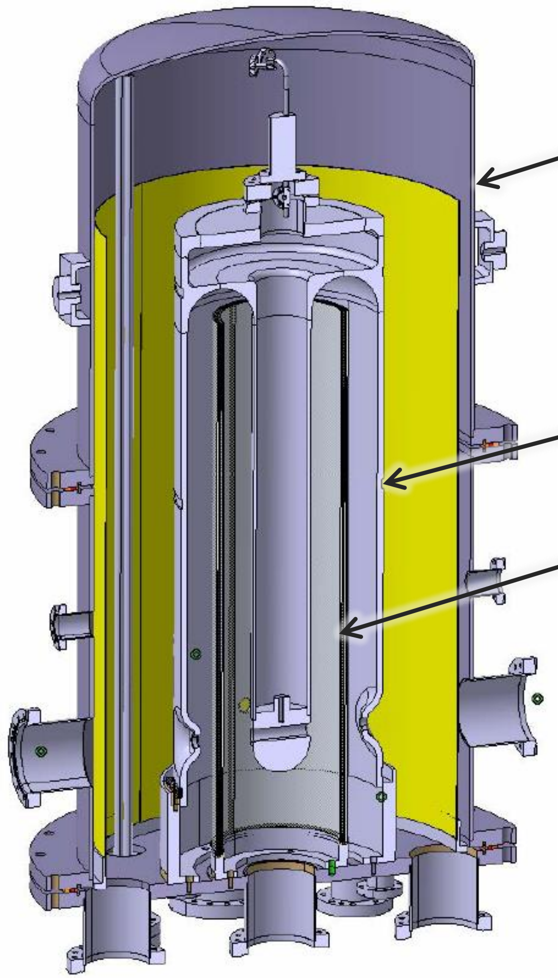

Vacuum tank

Cavity

Sputtering target (Nb)

Grid for bias (ion bombardment)

3. Sputtering technology: GDS

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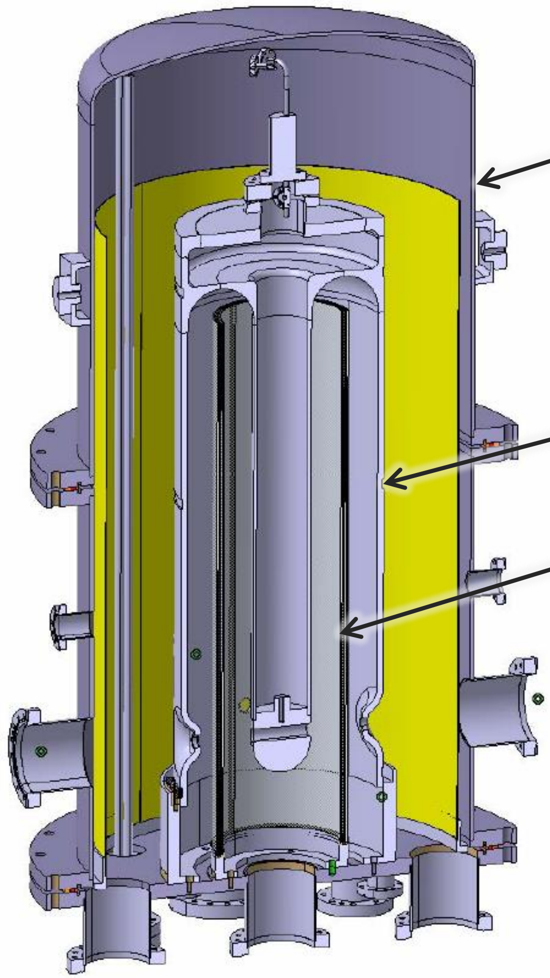
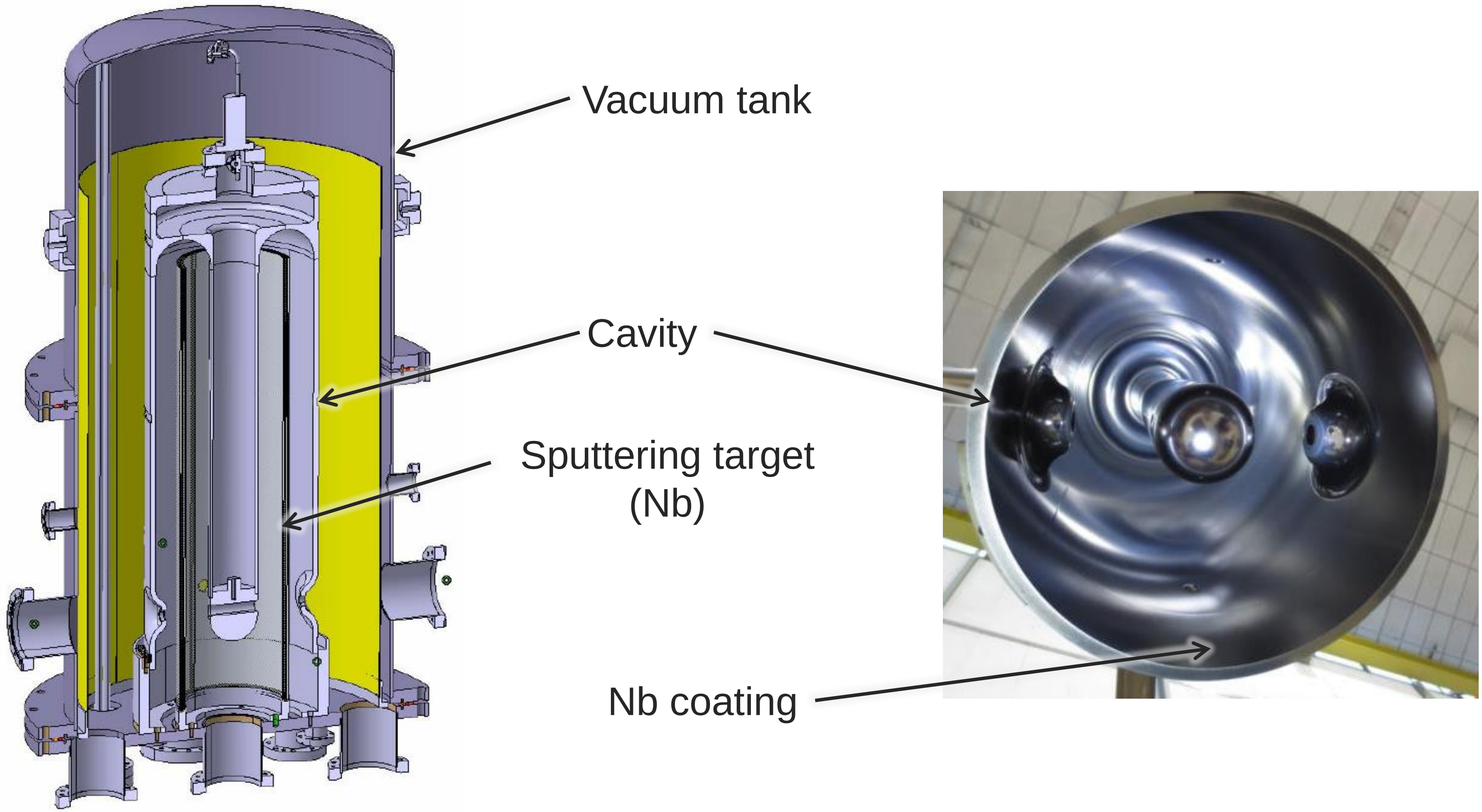


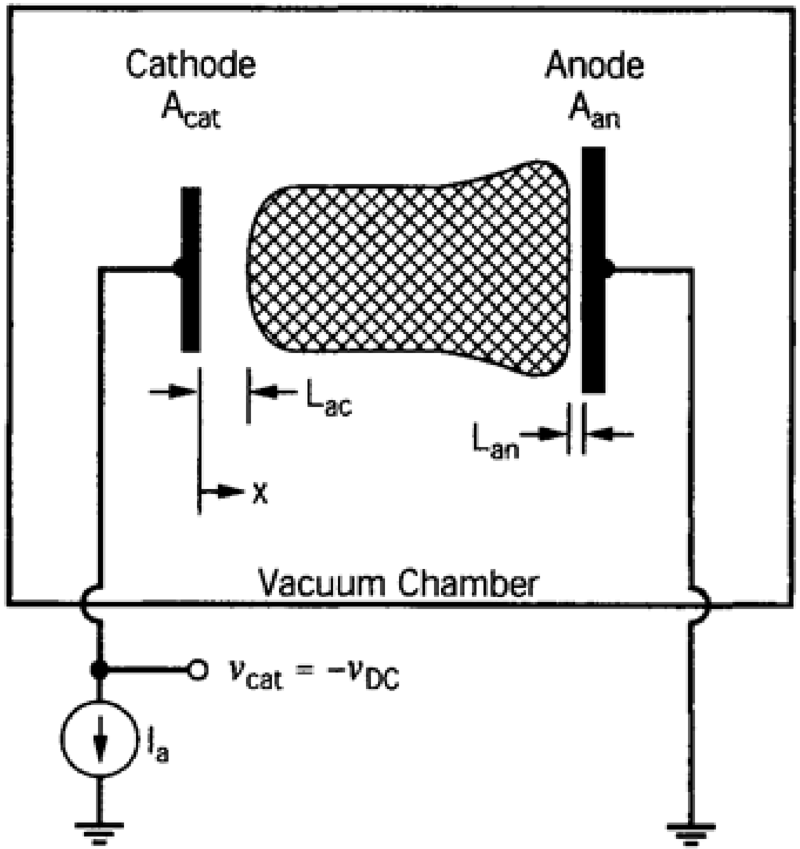
3. Sputtering technology: GDS

Example: Nb on Cu for the HIE-ISOLDE RF cavities



3. Sputtering technology: reduce pressure?

mean **f**ree **p**ath for electrons >> **mfp** for atoms



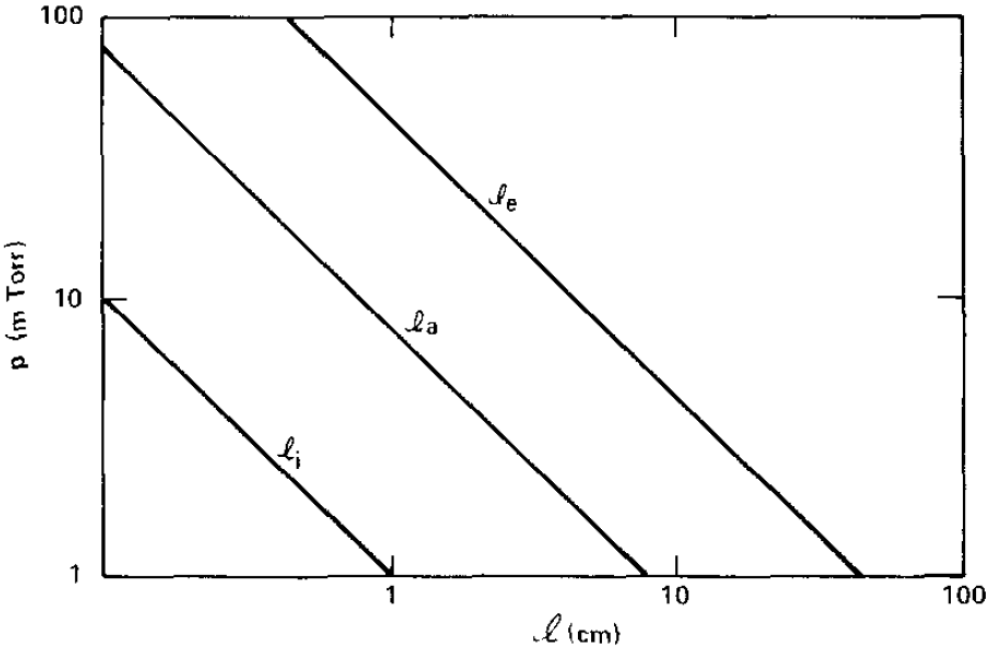
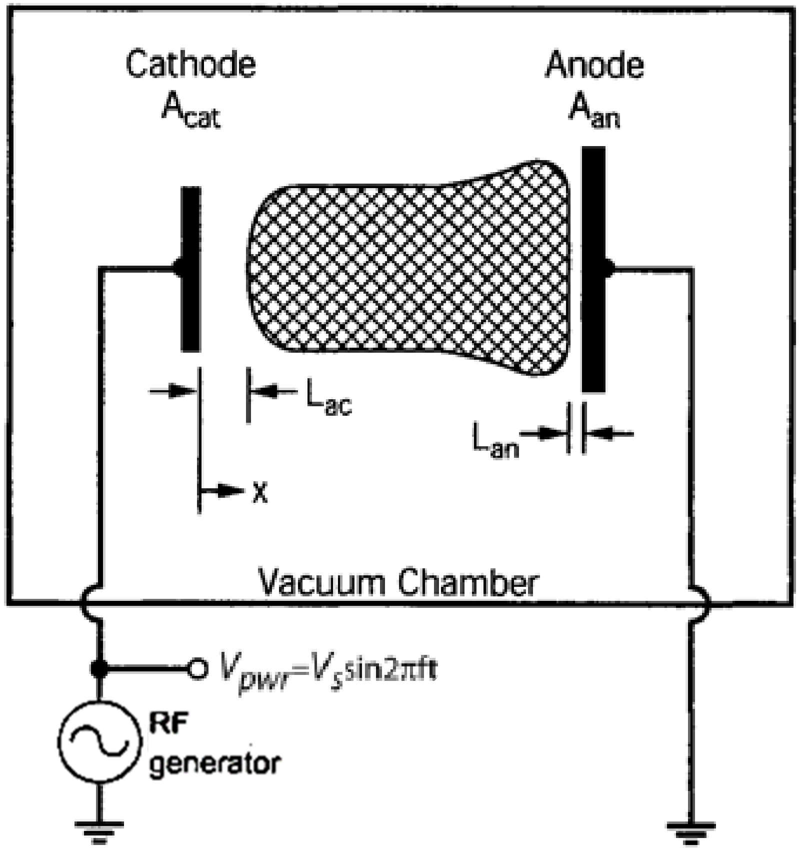


FIG. 2. Mean free paths for atoms, l_a, electrons, l_e, and ions, l_i, as a function of pressure in the argon glow discharge, calculated from kinetic gas theory.

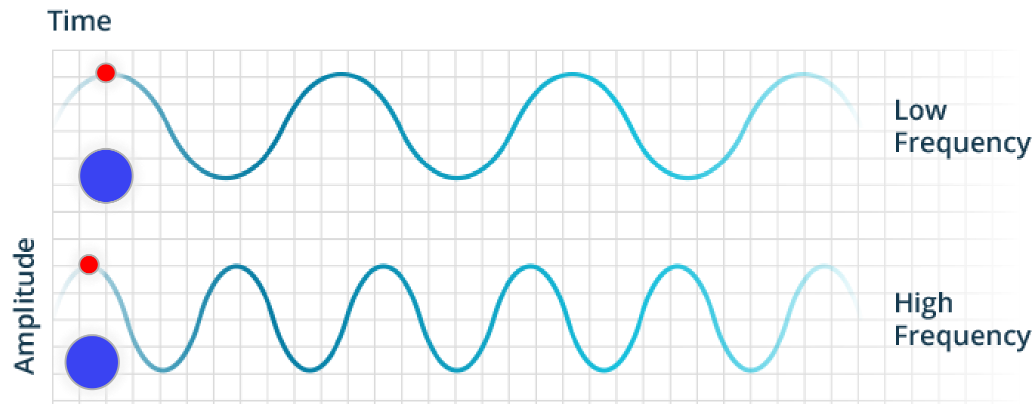
Westwood, "Glow Discharge Sputtering", Progress in Surface Science, vol. 7, pp. 71-111 (1976).

3. Sputtering technology: RF

Glow discharge RF



$$M_{ions} \gg M_{electrons}$$

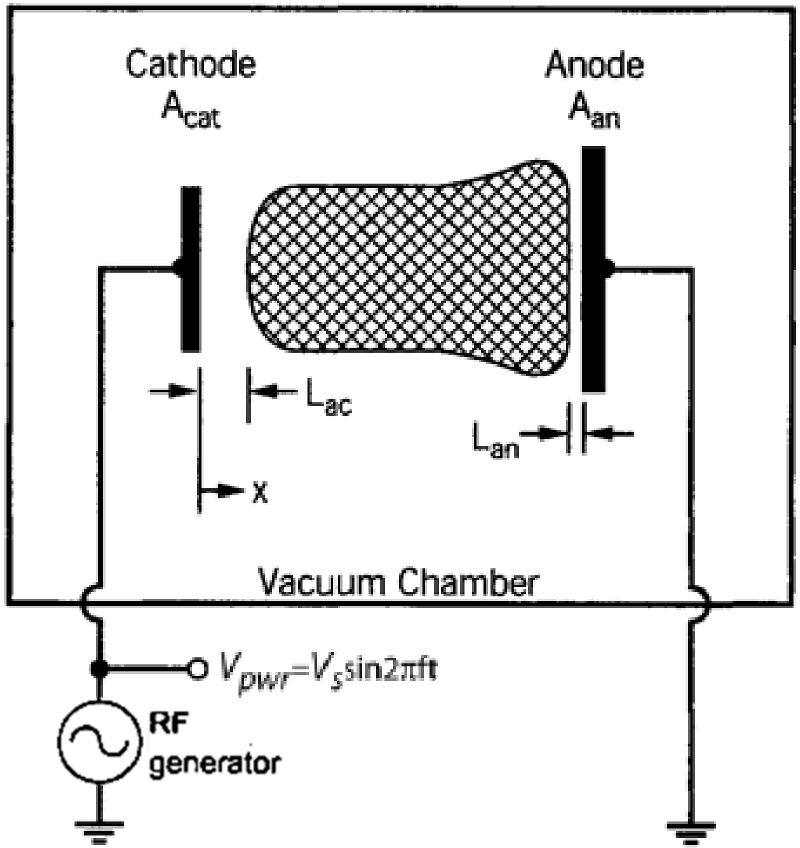


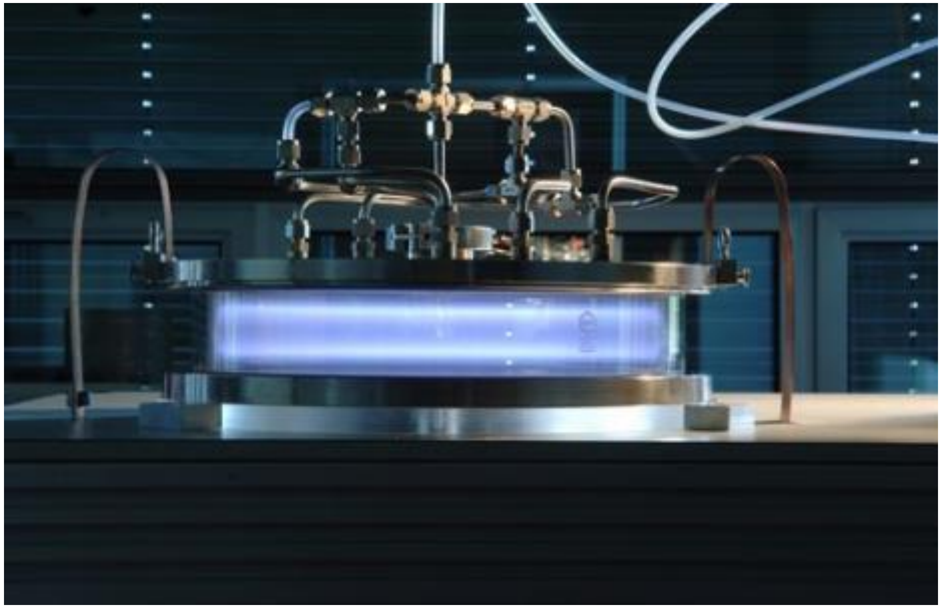
At **low frequencies (<50 kHz):**
both ions and electrons can follow the variations in electric fields.

At **high frequency (> 3000 kHz):**
Ions are unable to follow the variations.

3. Sputtering technology: RF

Glow discharge RF

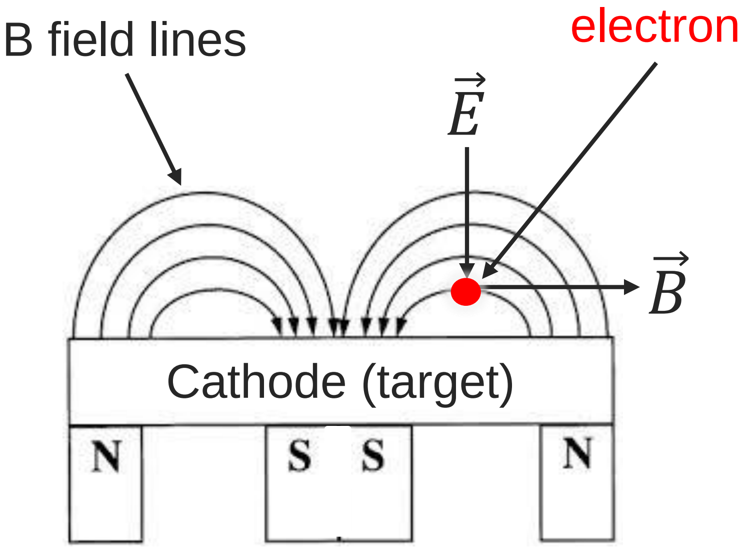




3. Sputtering technology: GDMS

Glow Discharge Magnetron Sputtering

A magnetron uses a static magnetic field parallel to the cathode (target) surface.



$$\vec{E} \times \vec{B} \text{ drift}$$

The secondary electrons emitted from the target by the ion bombardment move in a direction perpendicular to the $\vec{E}$ and $\vec{B}$.

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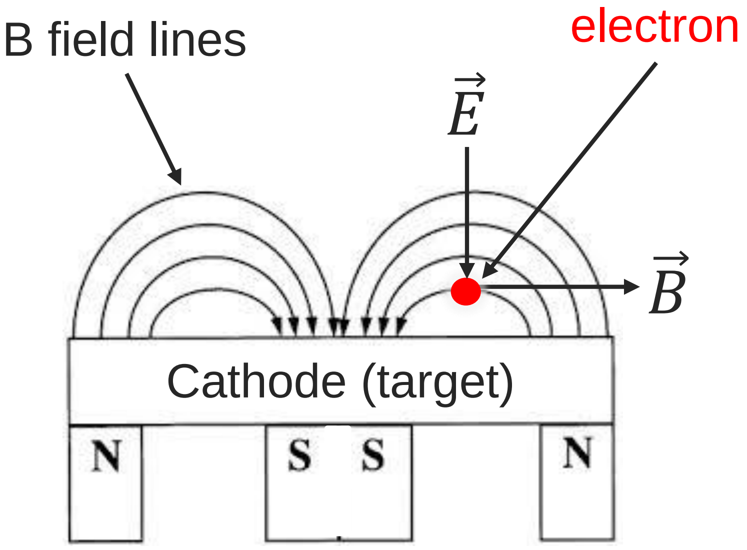

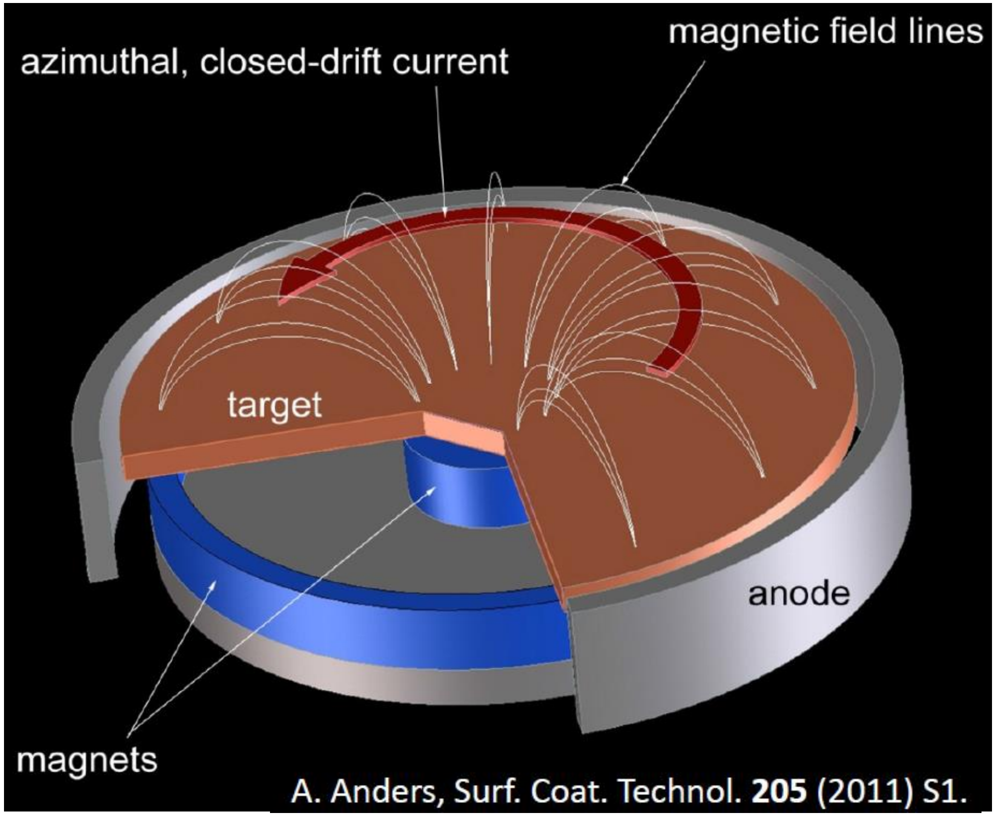

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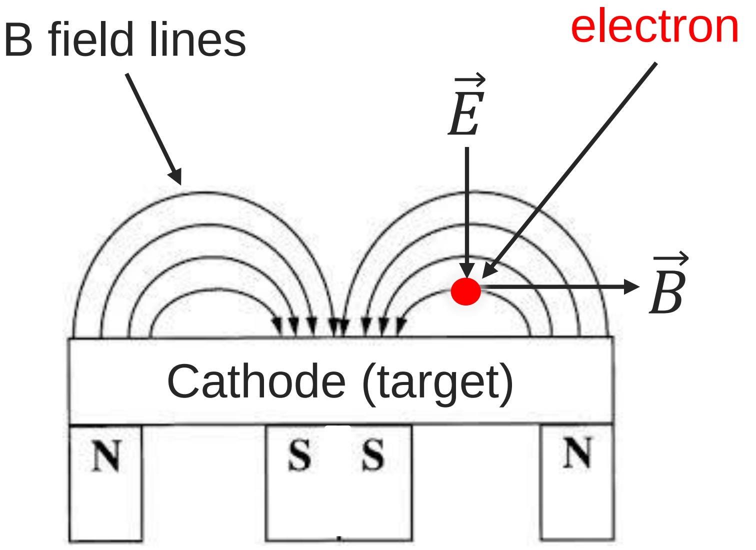

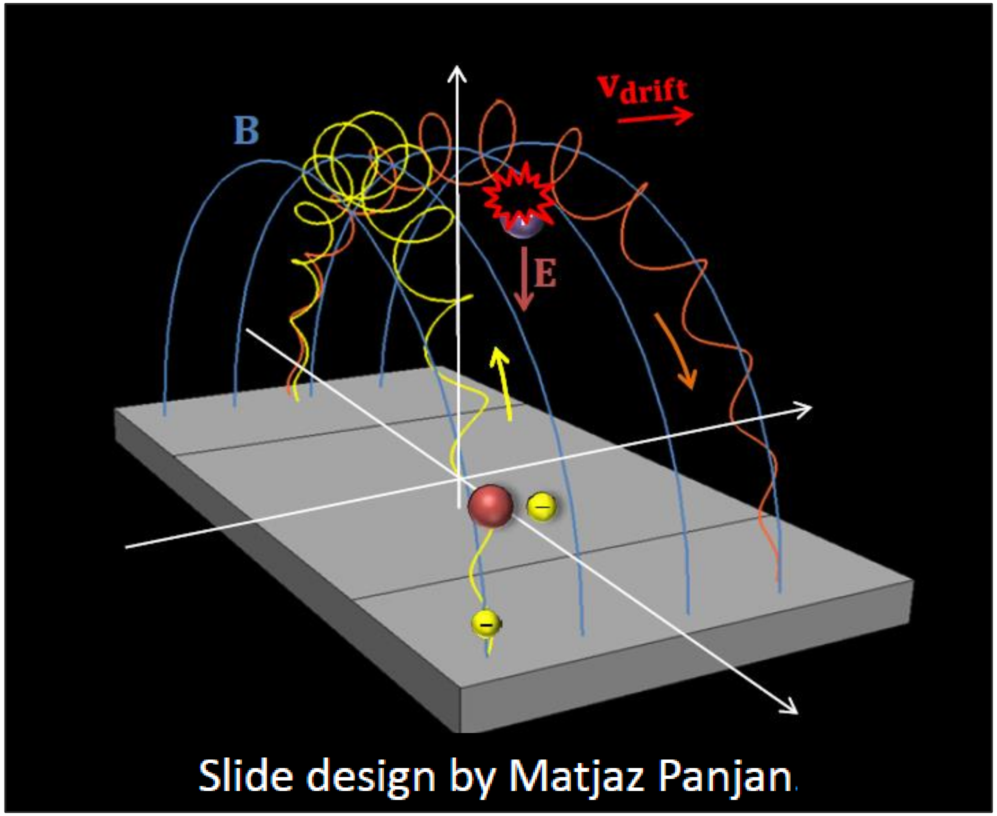

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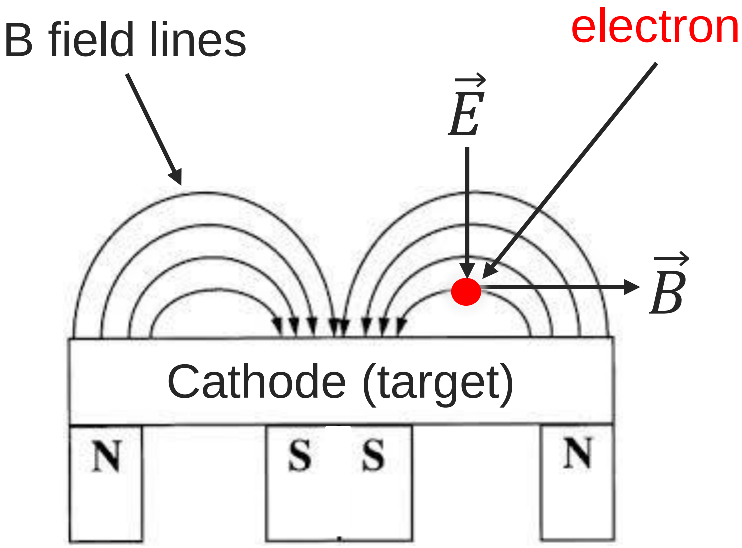

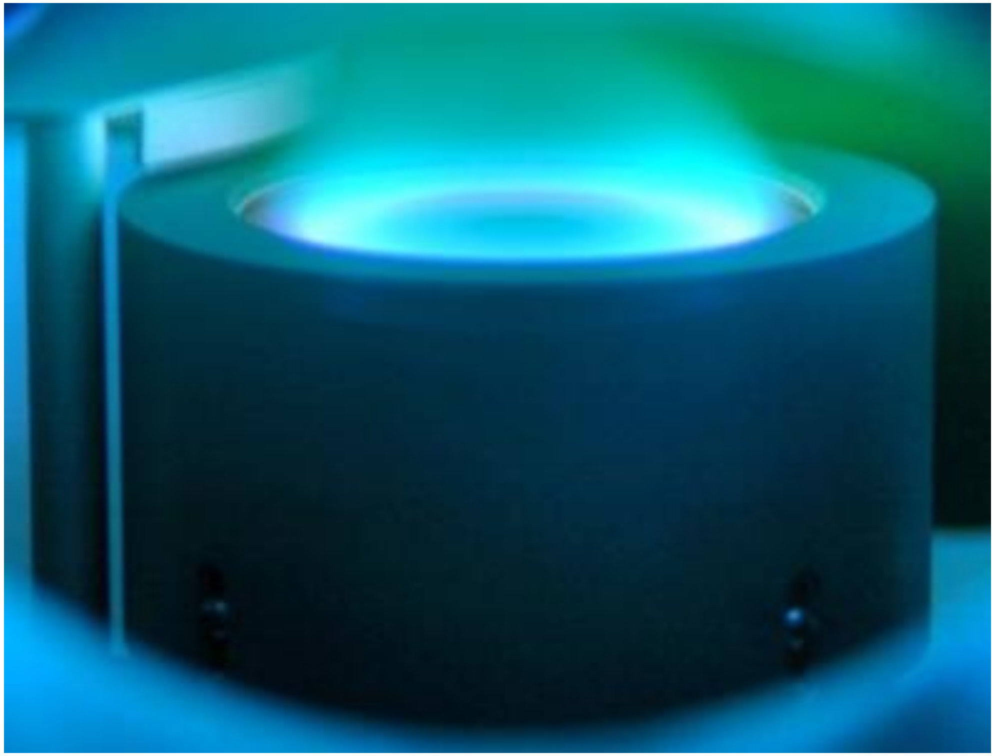

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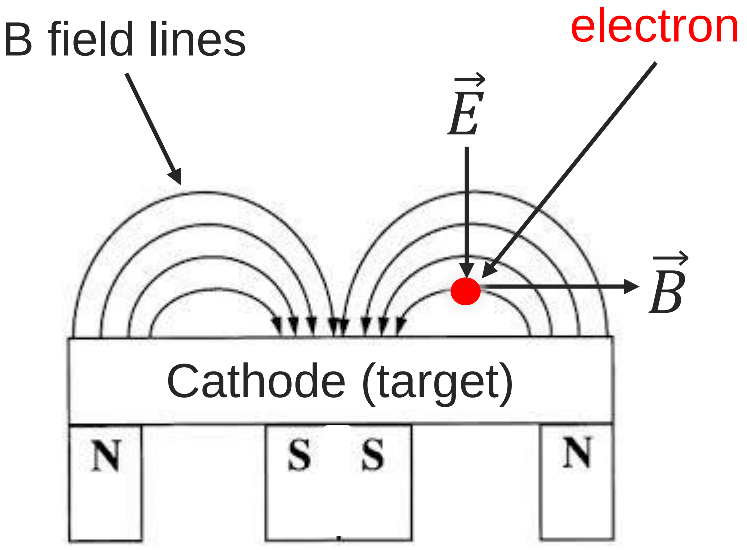

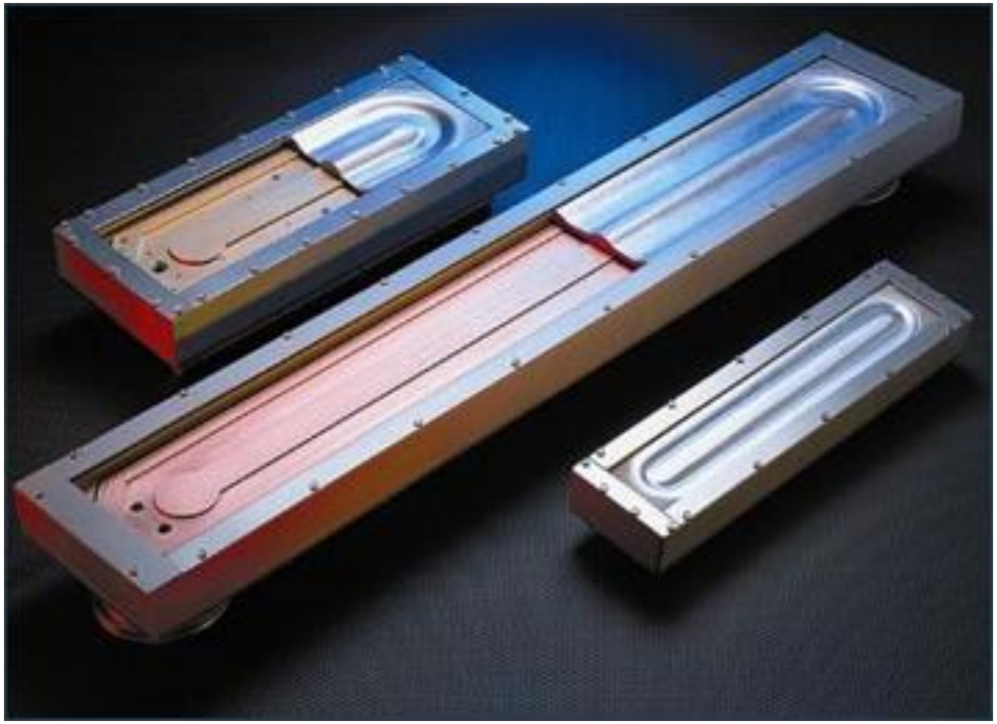

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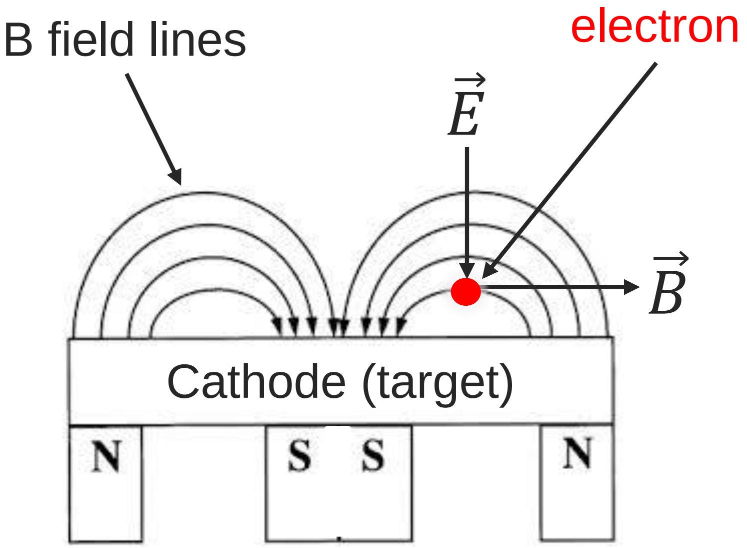
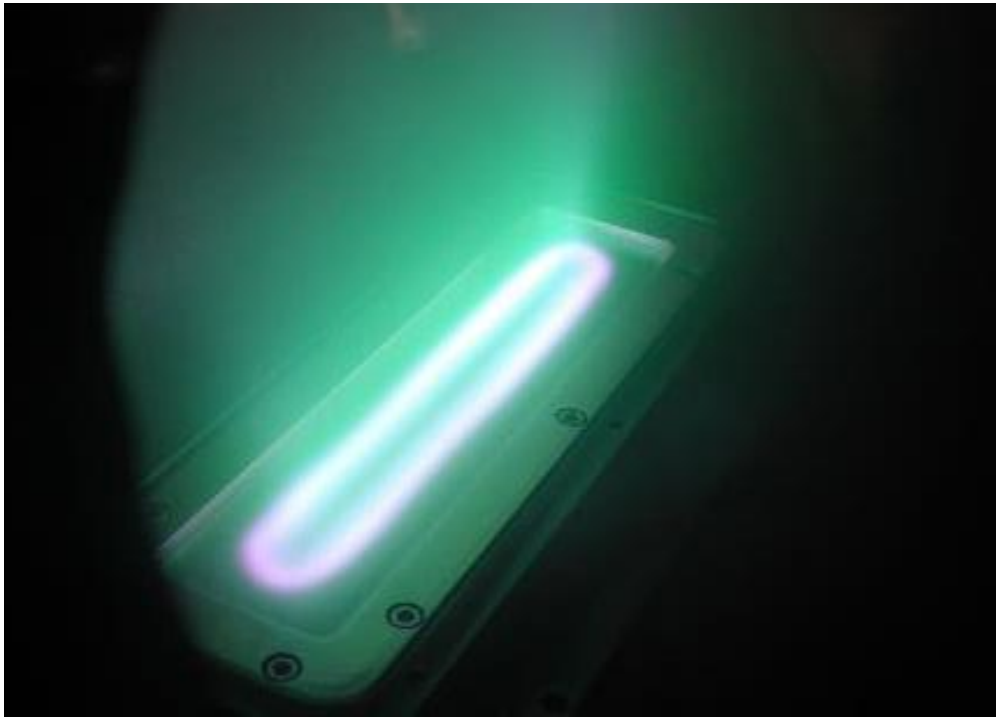
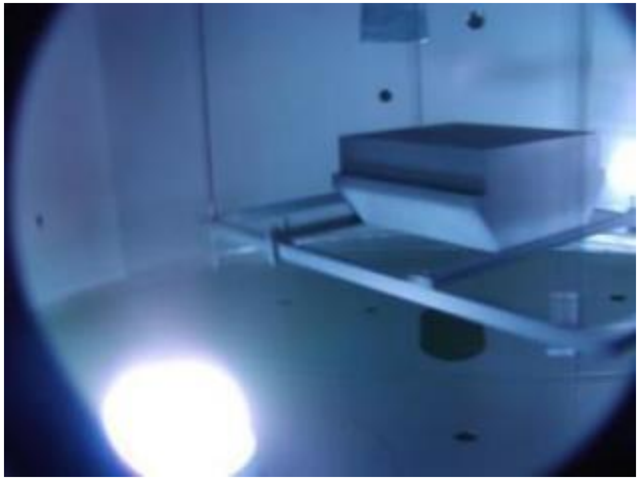




3. Sputtering technology: GDMS

Example: absorber blocks for collimators (CERN)



Material of the blocks: Graphite, CfC, BN, Mo-Graphite.

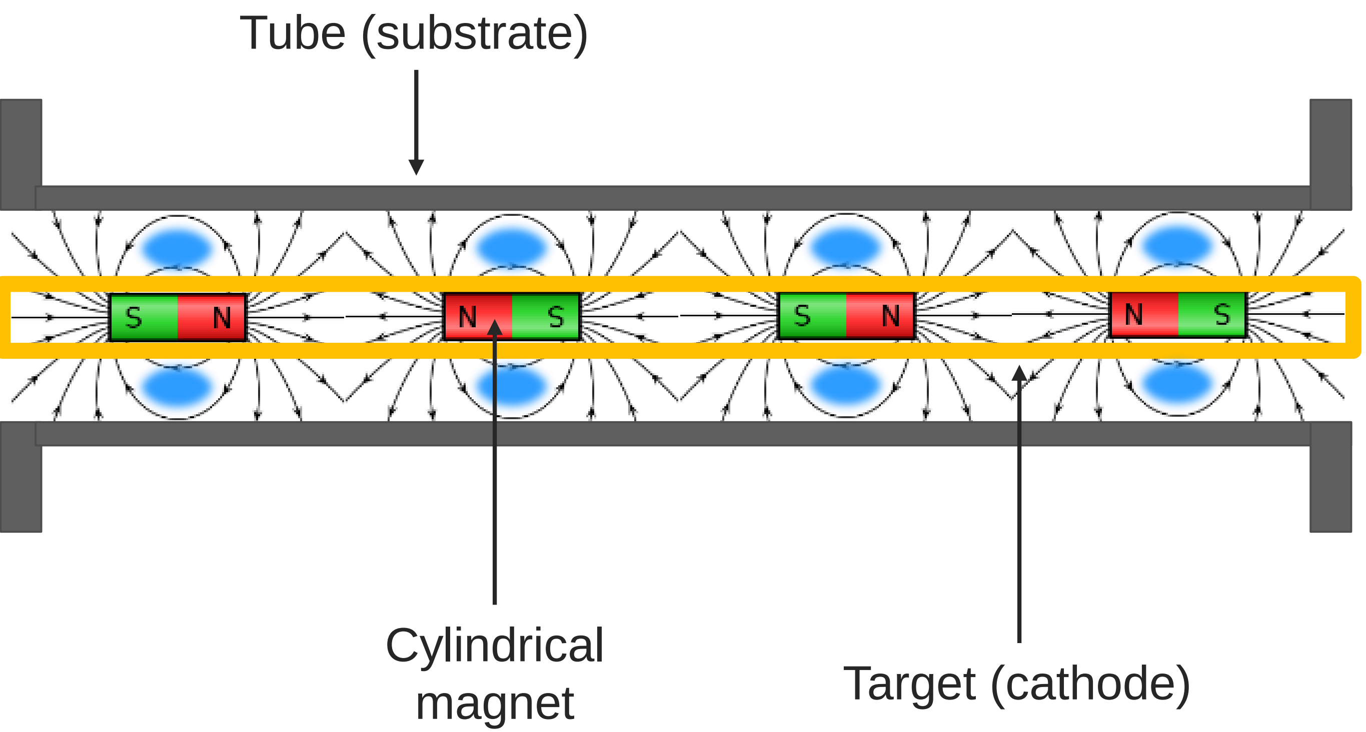
Coatings: Ti(200 nm) + Cu(~ 5 µm), Mo (~ µm).

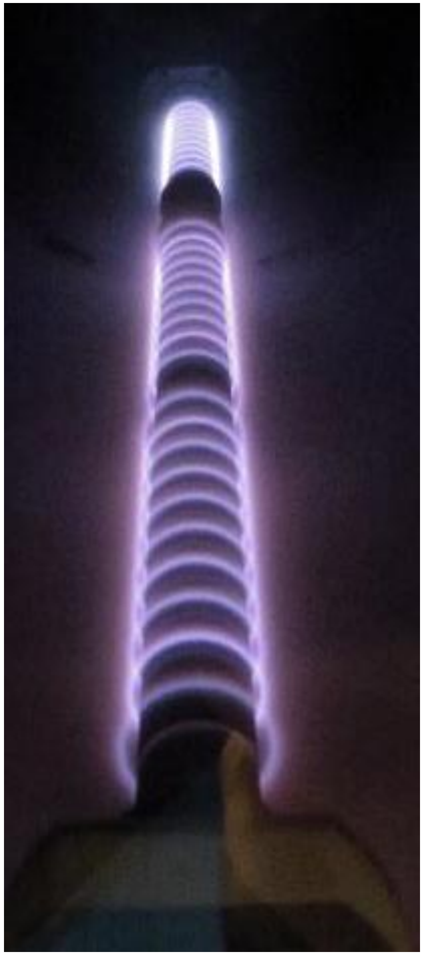
Up to 10 blocks / coating run

3. Sputtering technology: GDMS

Glow Discharge Magnetron Sputtering (Cylindrical)

Natural configuration to coat in tubes.





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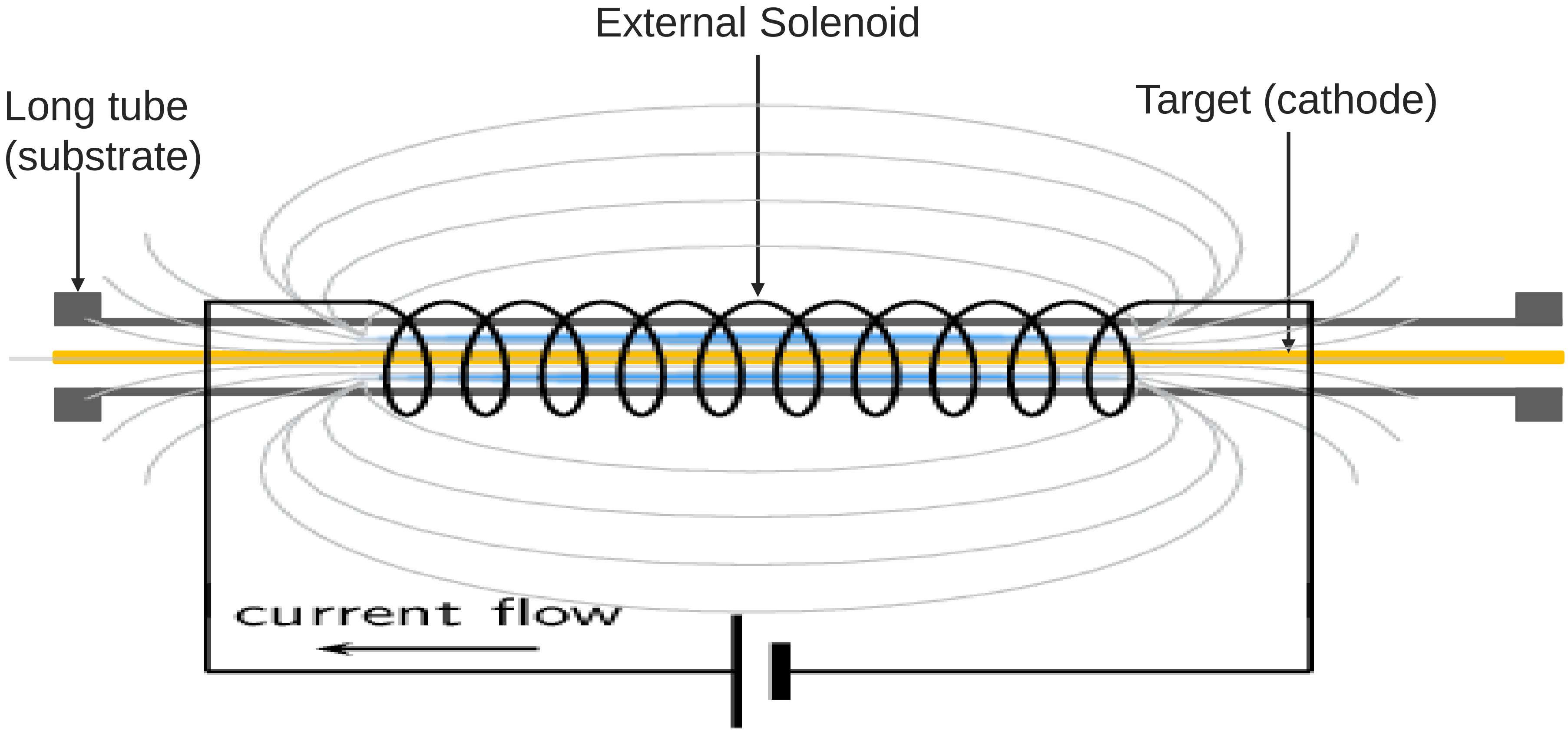


3. Sputtering technology: GDMS

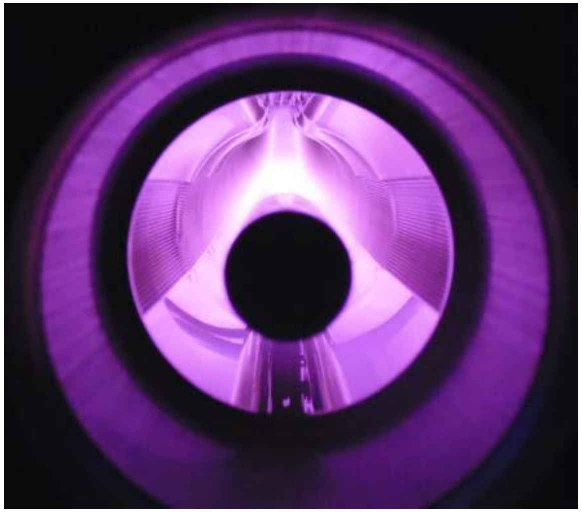
Example: anti e-cloud TiN coatings for SuperKEKB

KEK - Japan

3. Sputtering technology: GDMS

Example: anti e-cloud TiN coatings for SuperKEKB

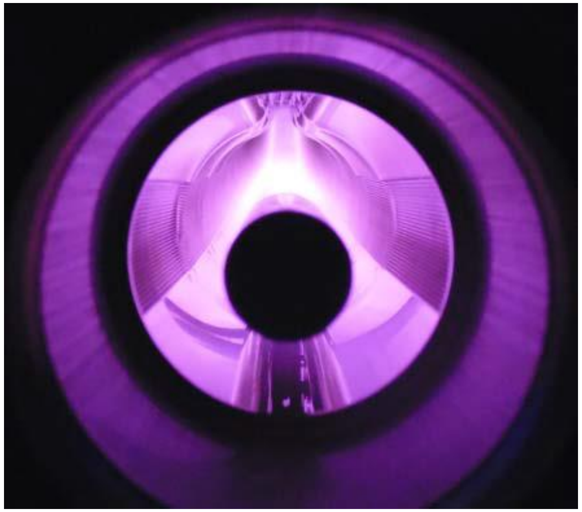
KEK - Japan

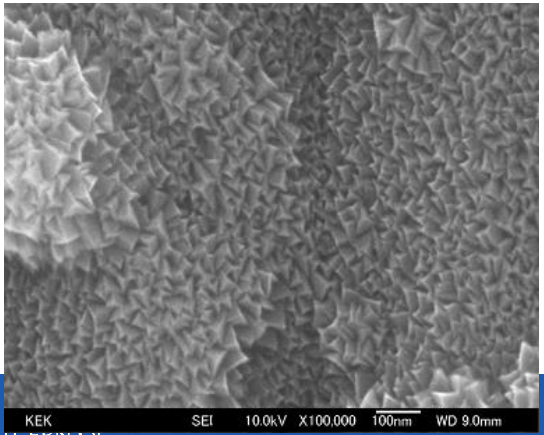


3. Sputtering technology: GDMS

Example: anti e-cloud TiN coatings for SuperKEKB

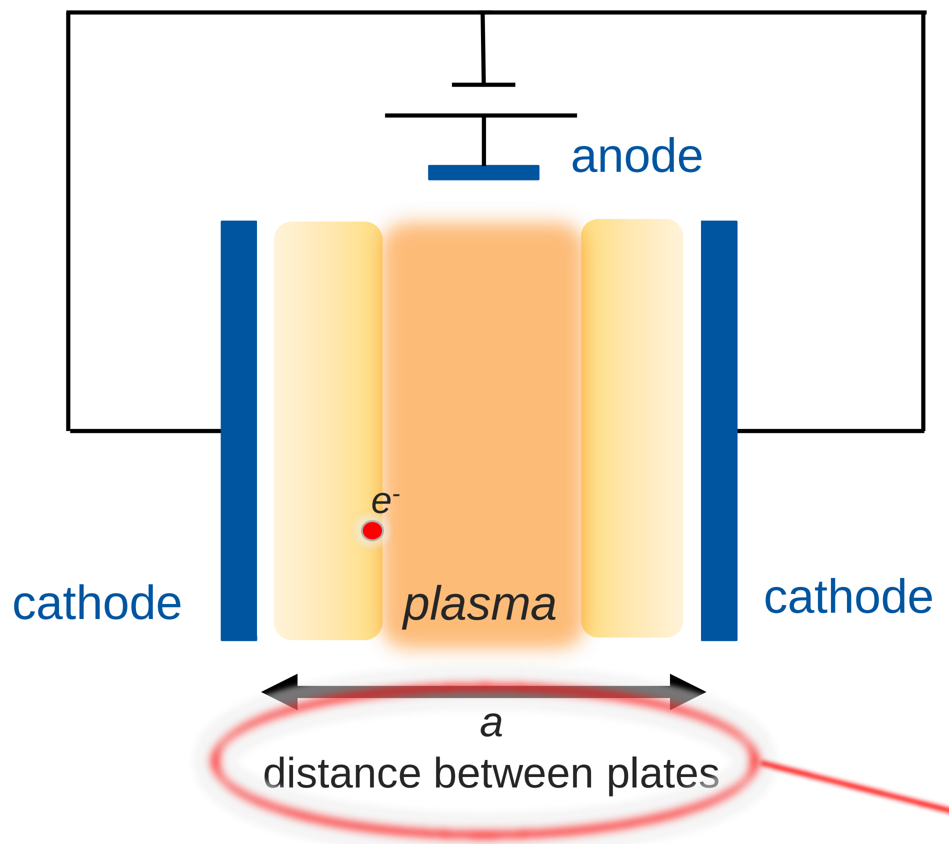
KEK - Japan



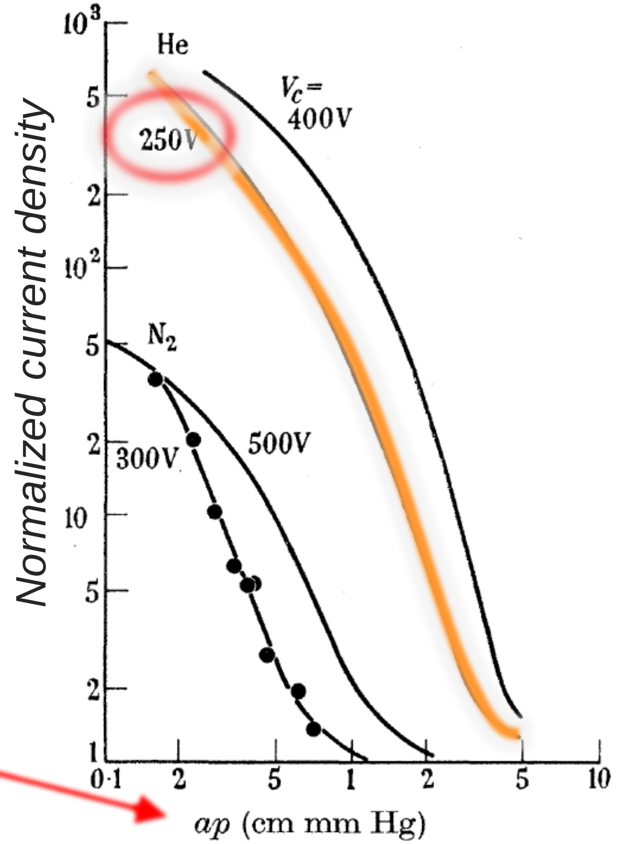


3. Sputtering technology: GDHC

Glow Discharge Hollow Cathode



P. F. Little & A. Von Engel, Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences, Vol. 224, No. 1157 (1954)



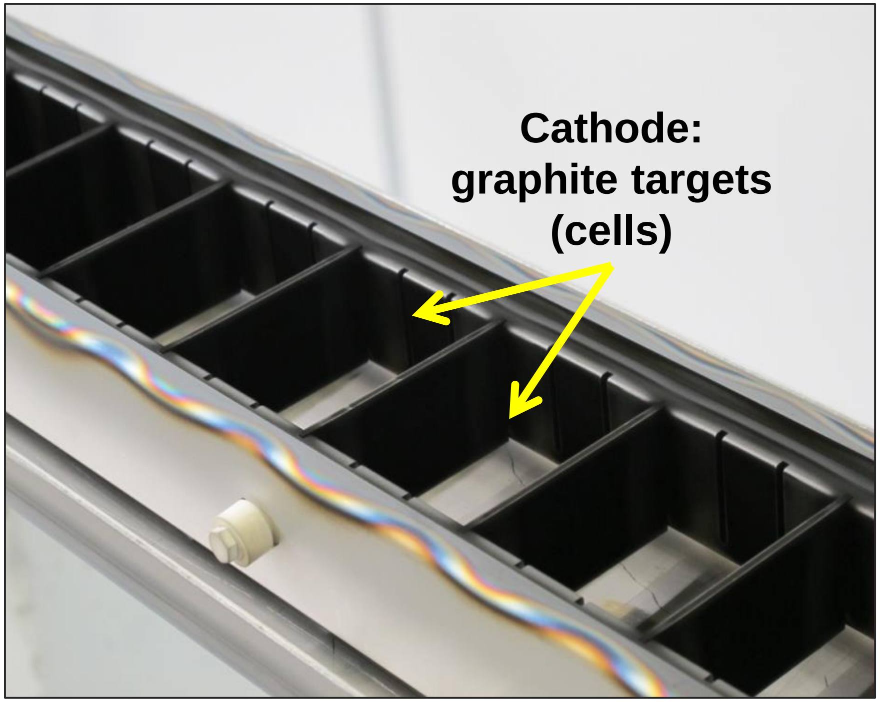
Pendel electrons -> increase ionization efficiency

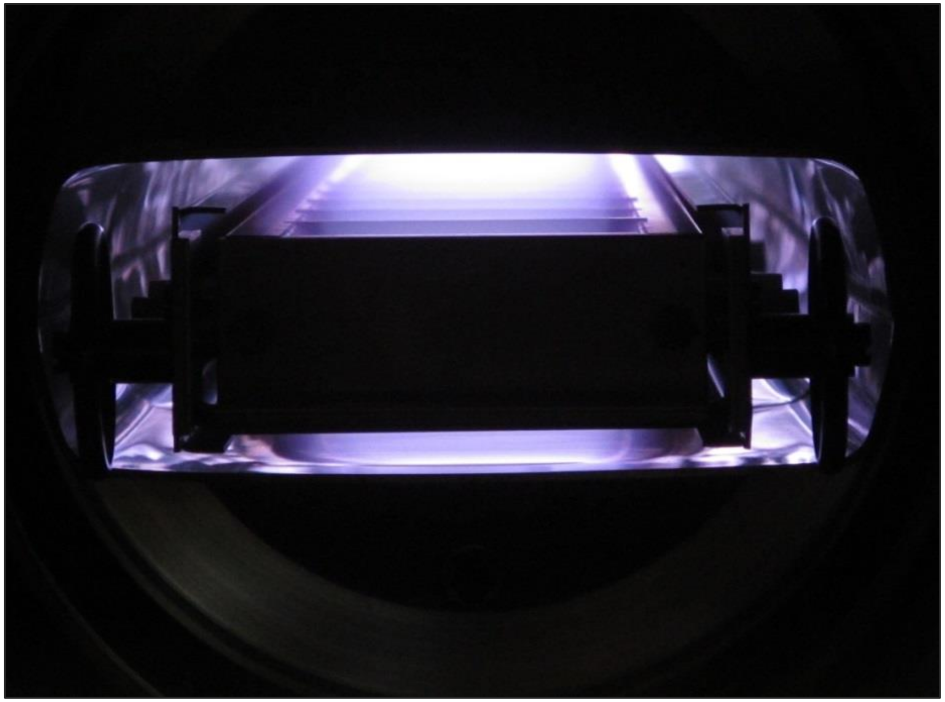
3. Sputtering technology: GDHC

Example: anti e-cloud a-C coatings for the SPS (CERN)

3. Sputtering technology: GDHC

Example: anti e-cloud a-C coatings for the SPS (CERN)

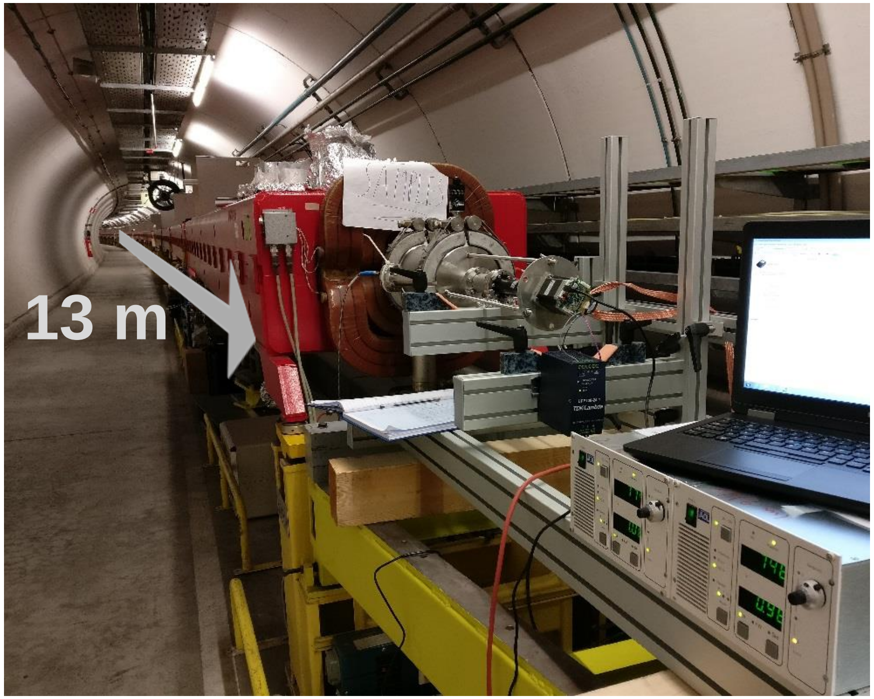


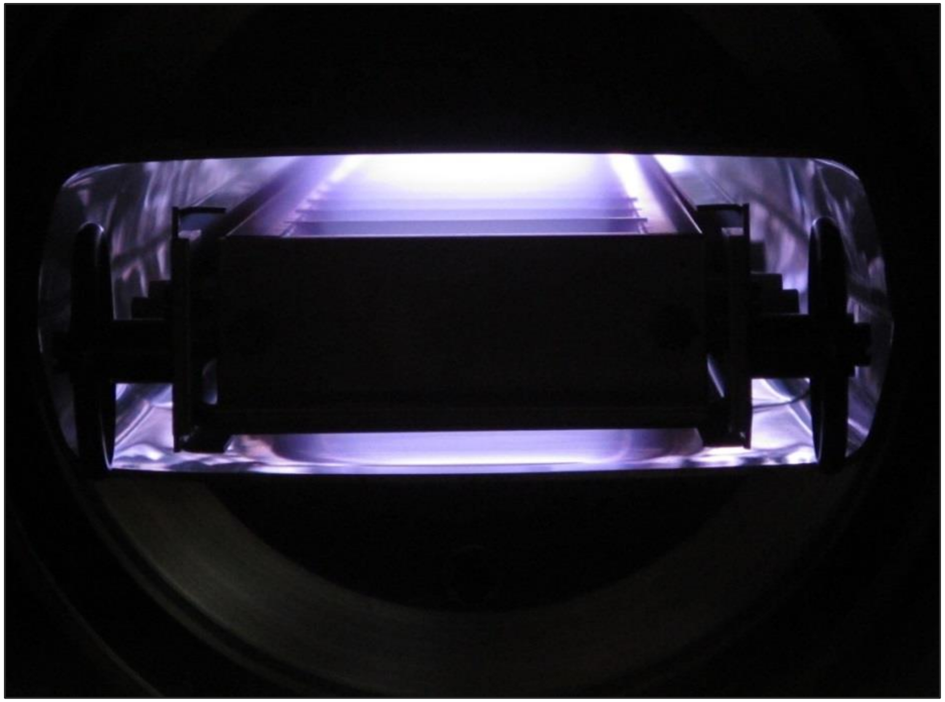


3. Sputtering technology: GDHC

Example: anti e-cloud a-C coatings for the SPS (CERN)

Jan & Feb 2017: first SPS "in-situ" coating campaign (~130 meters coated)





4. On growth & adhesion

Phases of film growth:

Condensation & nucleation

Interface formation

Film growth

4. On growth & adhesion

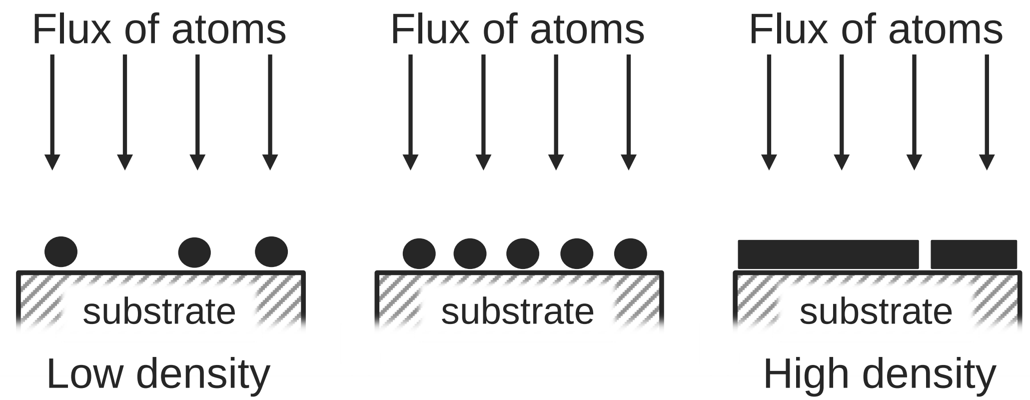
Phases of film growth: Condensation & nucleation

Nucleation density:

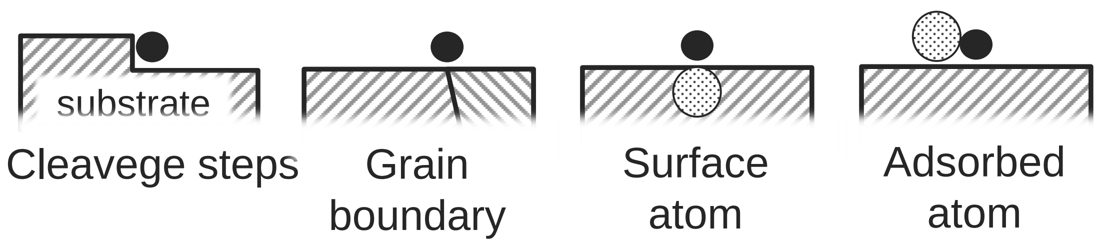
Deposition rate

Mobility of adatoms on the surface
(T_s, binding energies, contaminations, surface defects)

Concurrent bombardment
(ions, neutrals, electrons)



Preferential sites:



4. On growth & adhesion

Phases of film growth: Interface formation

The depositing film material may diffuse and react with the substrate to form a “interfacial region”.

Abrupt

Graded

Weak chemical reaction between atoms and substrate;

Low deposition temperature;

Surface contamination;

Low nucleation density;

By diffusion (solubility, temperature, time, contaminations);

Chemical reaction (oxygen-active metals on oxide substrates);

By co-deposition or implantation of energetic ions of the material.

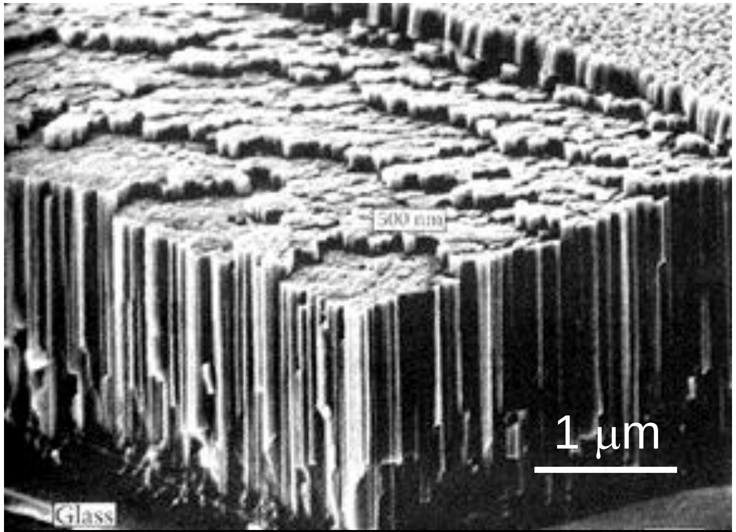
Impact on adhesion

4. On growth & adhesion

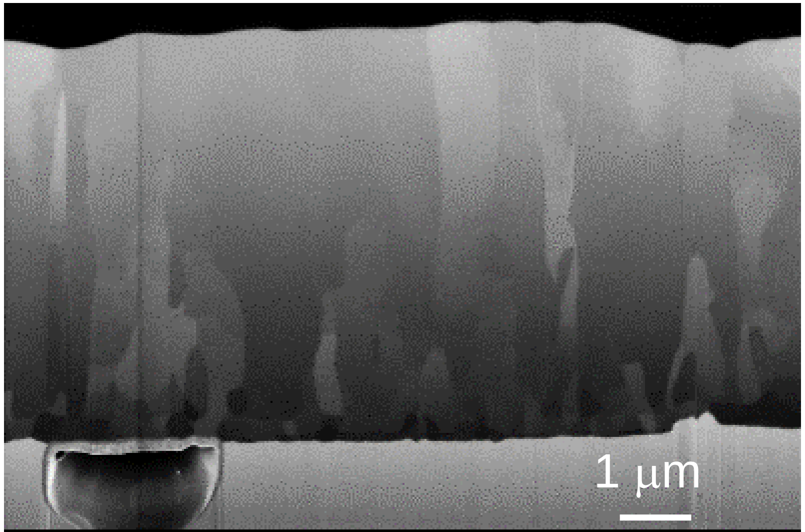
Phases of film growth: Film growth

Is the evolution of the nucleation, where arriving atoms are deposited on the previously deposited material.

Usually exhibits a columnar morphology.



TiN on glass from Macleod's book



Nb on Cu (A. Sublet, CERN)

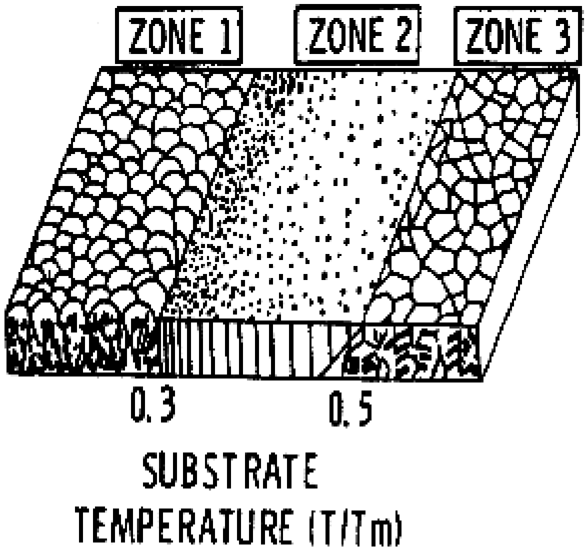
4. On growth & adhesion

Structure Zone Model (SZM)

Based on the compilation of the experimental results, is a guideline for "predicting" the structure of deposited thin films

1^{st} proposed in 1969 by Movchan & Demchishin for films deposited by thermal evaporation.

T_s -> temperature of the substrate
T_m -> melting point of the film material



Temperature

Movchan & Demchishin, Phys. Met. Metalogr. ***28*** *(1969) 83.*

4. On growth & adhesion

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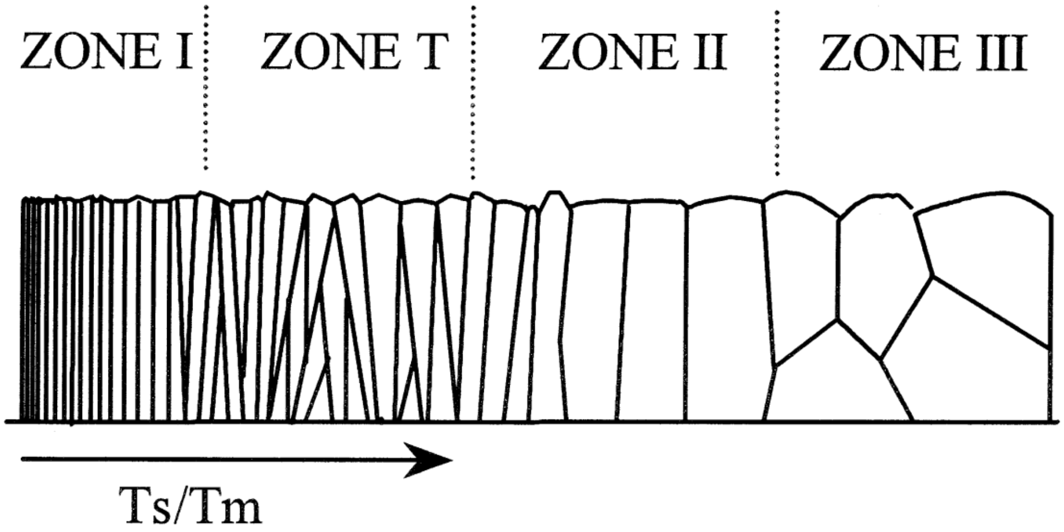

Barna & Adamik, Thin Solid Films 317 1998. 27–33.

4. On growth & adhesion

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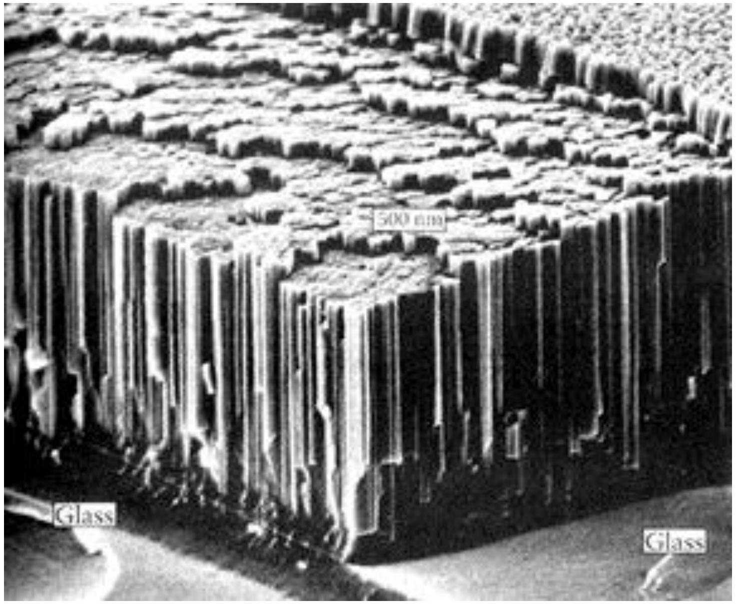

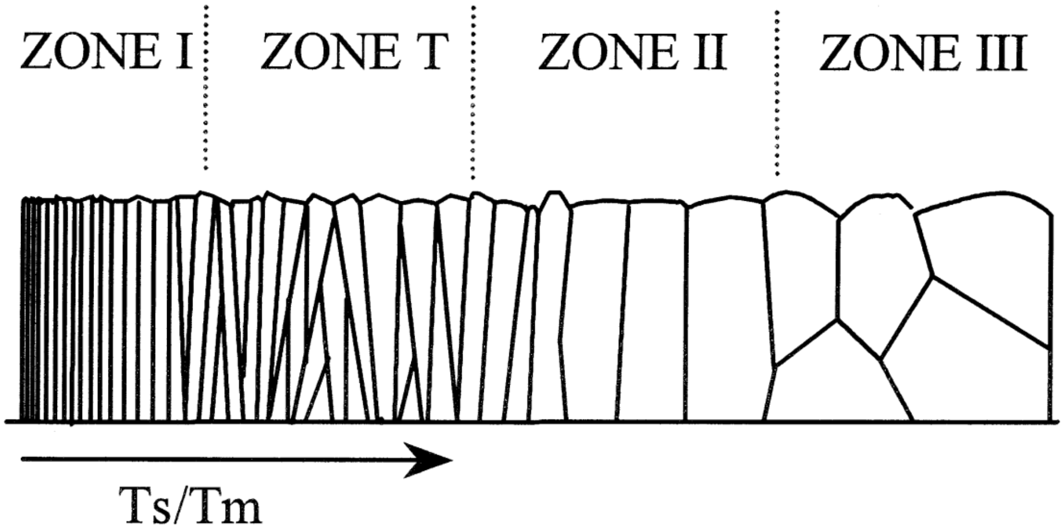

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4. On growth & adhesion

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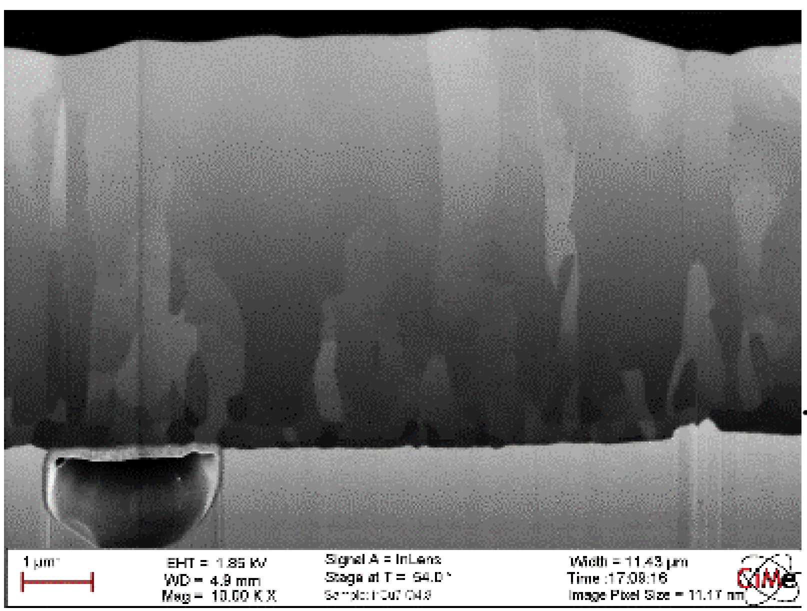
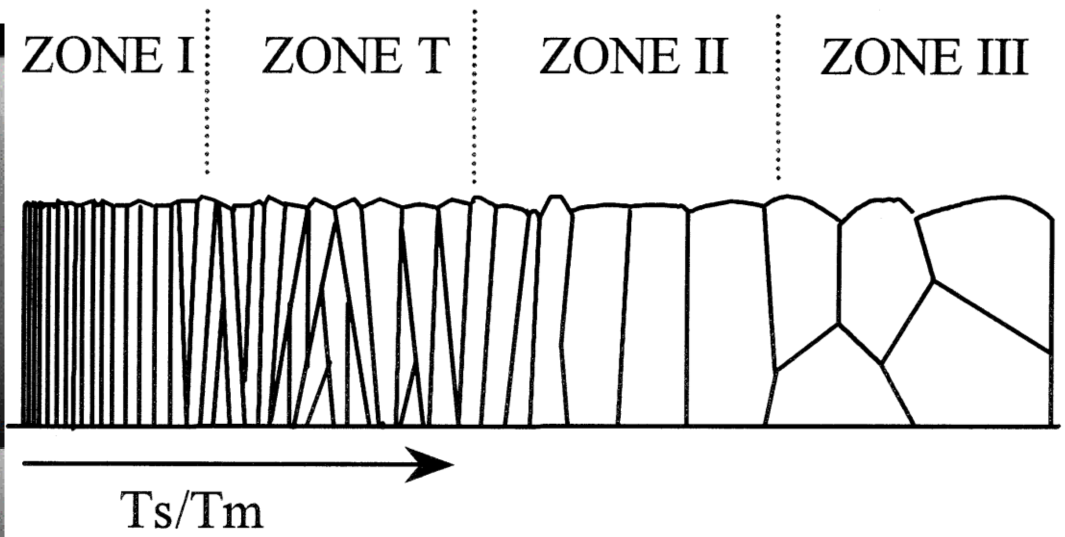




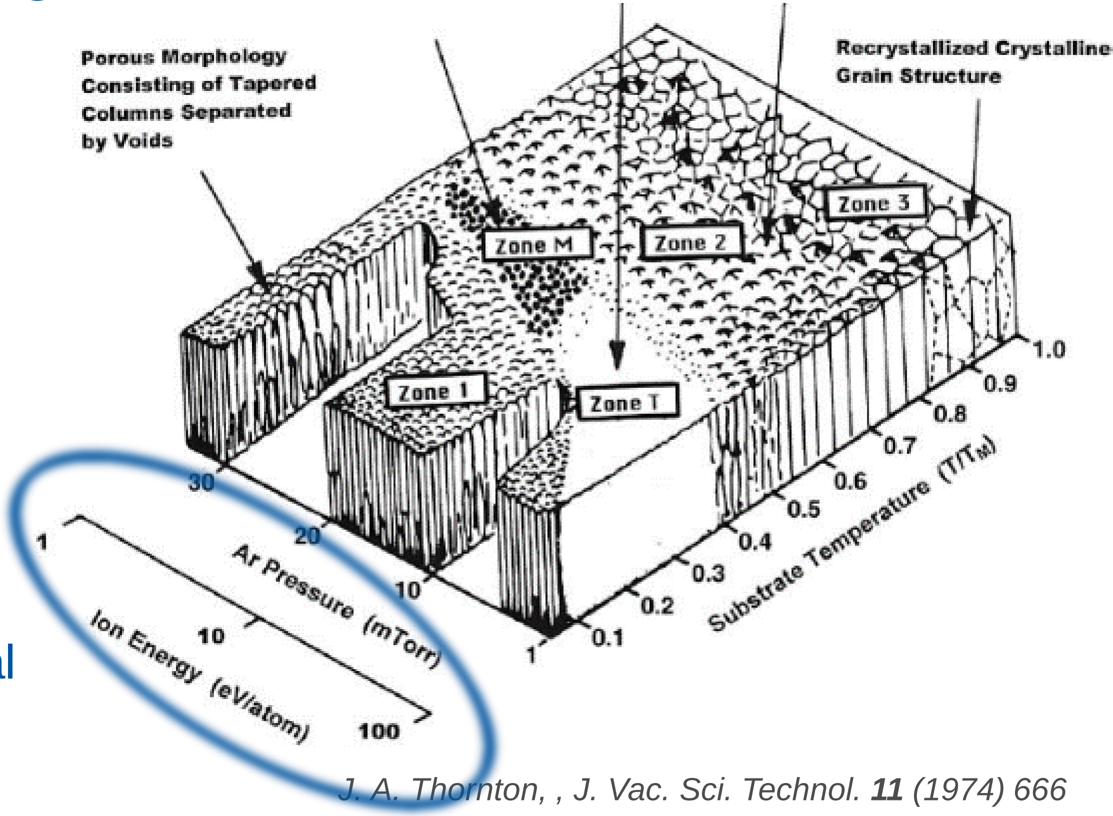
Barna & Adamik, Thin Solid Films 317 1998. 27–33.

4. On growth & adhesion

Structure Zone Model (SZM)

Based on the compilation of the experimental results, is a guideline for “predicting” the structure of deposited thin films

Thornton (1974) extended the model for sputtering. (included the pressure)



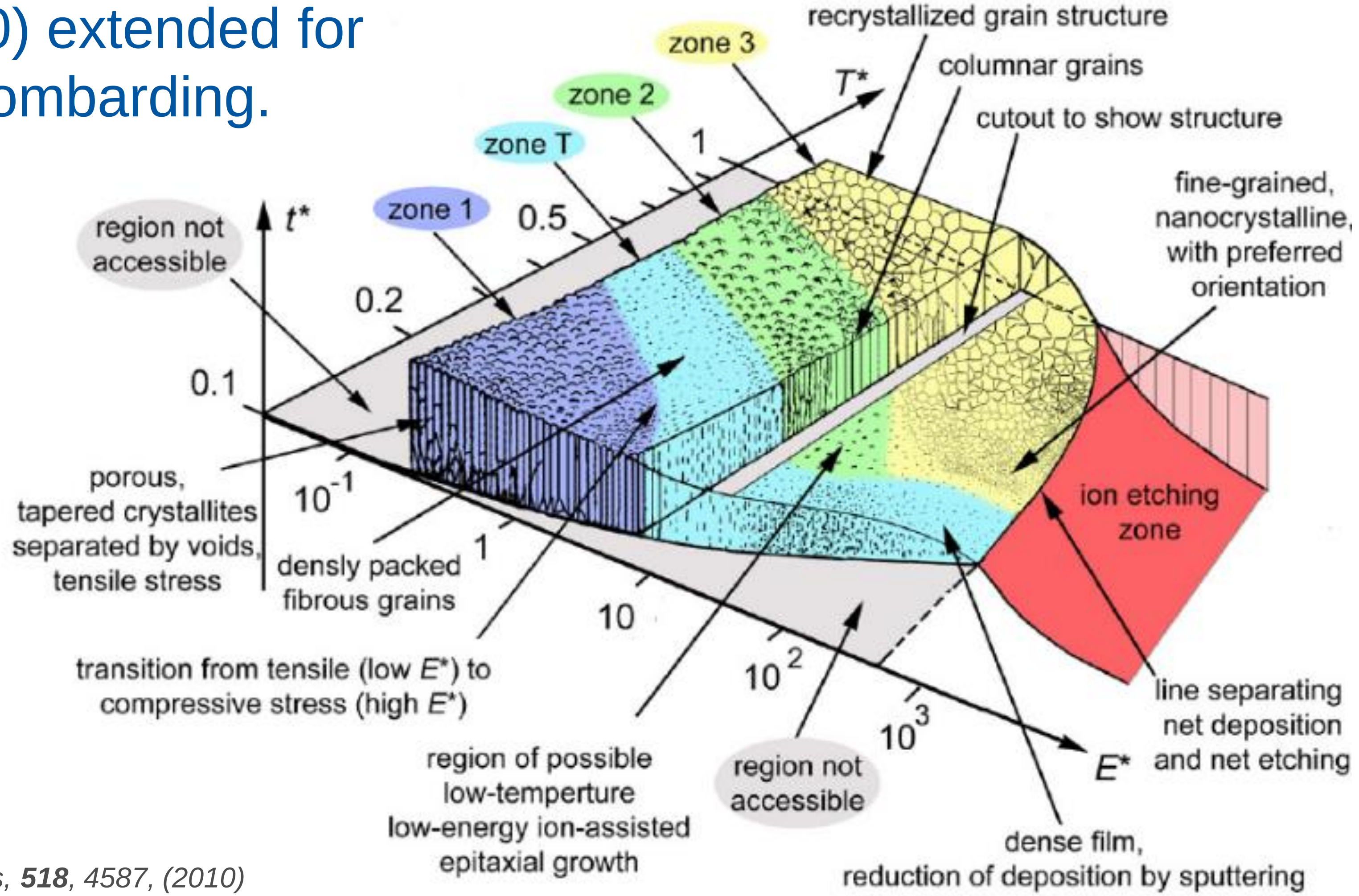
T_s -> temperature of the substrate
T_m -> melting point of the film material

J. A. Thornton, , J. Vac. Sci. Technol. **11** (1974) 666

4. On growth & adhesion

Structure Zone Model (SZM)

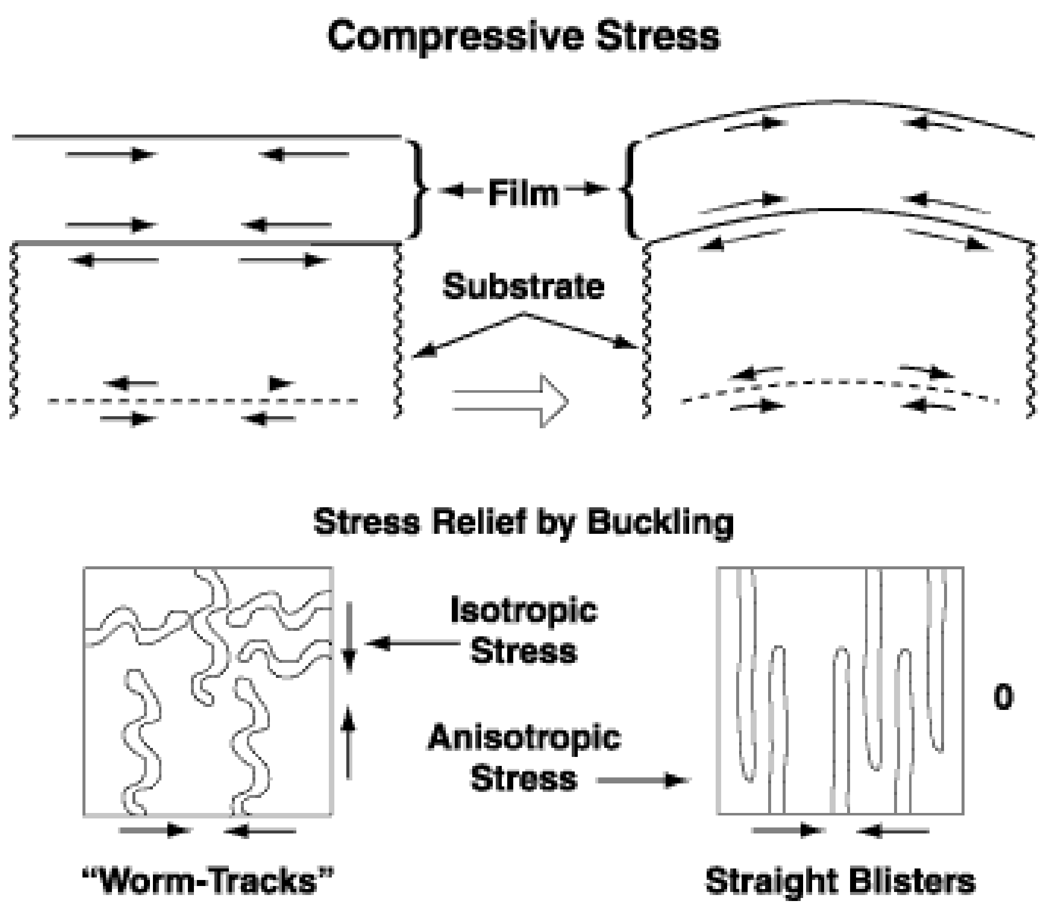
Anders (2010) extended for concurrent bombarding.



*Anders, Thin Solid Films, **518**, 4587, (2010)*

4. On growth & adhesion

Adhesion: bonding forces vs internal stresses



4. On growth & adhesion

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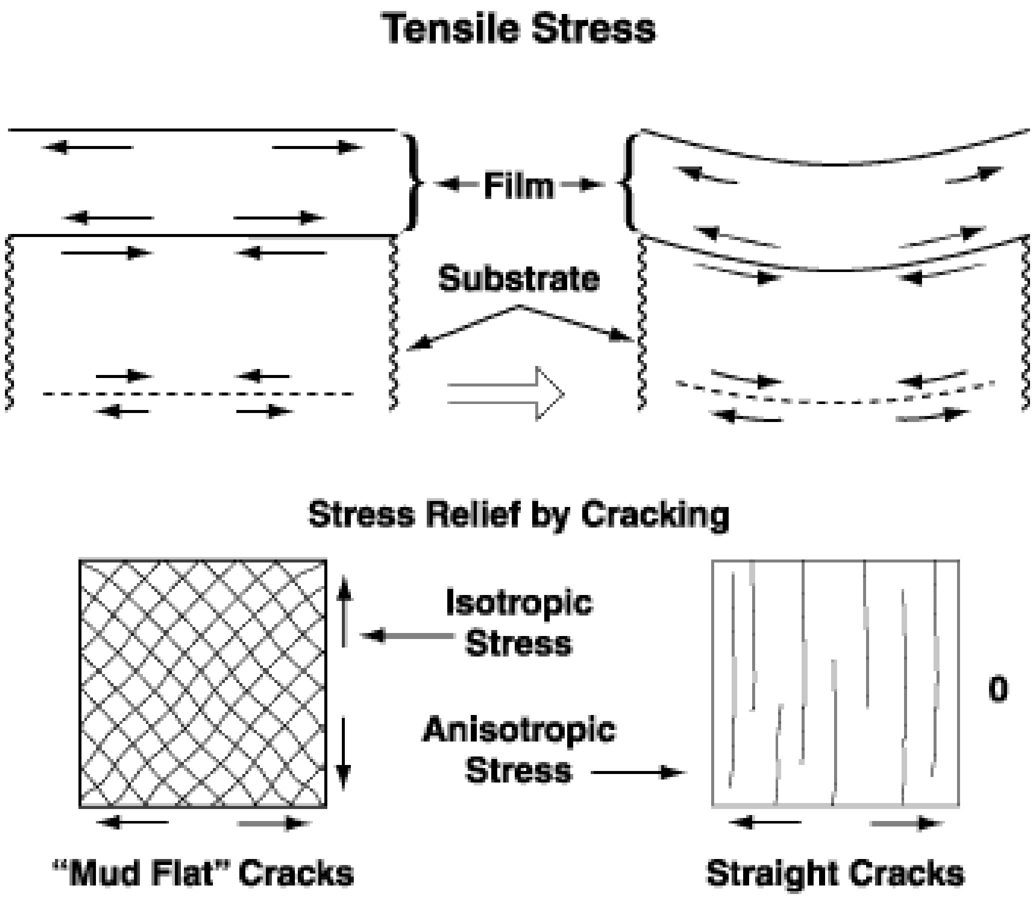
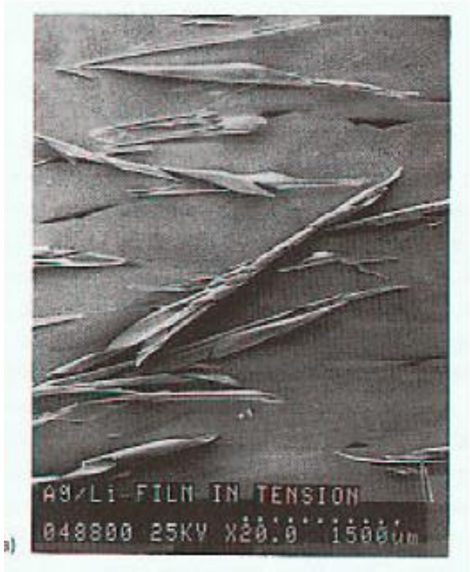




4. On growth & adhesion

Adhesion: internal stresses

total stress = intrinsic stress + thermal stress

determined by film deposition process

determined by difference in thermal expansion (contraction)

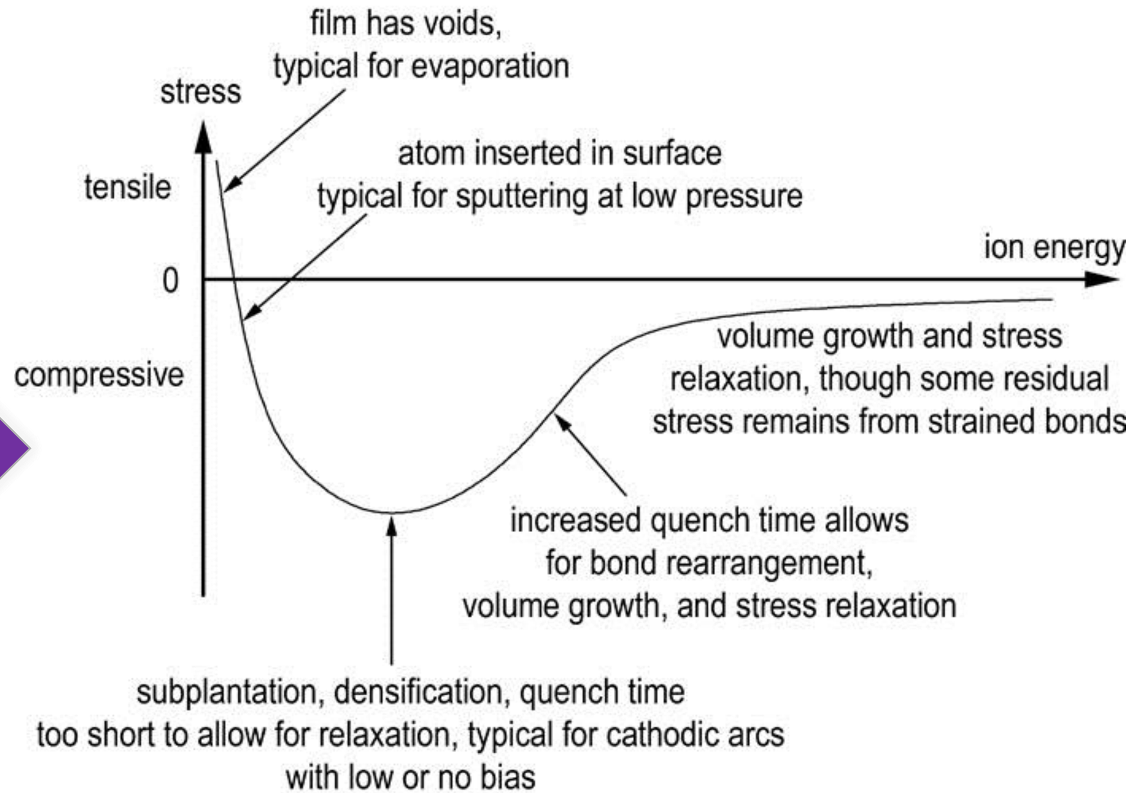
4. On growth & adhesion

Adhesion: internal stresses

total stress = intrinsic stress + thermal stress

determined by film deposition process

Ion bombardment can be used to influence stress



4. On growth & adhesion

Adhesion: the different types of bonding

Increasing adhesion strength

Mechanical adhesion: Roughness, interlocking of substrate and layer. Used for paints etc. Sandblasting of surfaces.

Wetting or Van der Waals adhesion: Two surfaces in close contact experience short range forces, (not due to chemical actions but rather to adsorption-like phenomena). Typical of oxides on oxides, or of polymer films

Chemical adhesion: The film and the substrate make a chemical bond. This can be of two natures: covalent or ionic:

> ***Covalent***: *usually the case of a metal film on top of an oxidised metal*
>
> ***Ionic***: *it is usually the case between two metals without oxide in between*

4. On growth & adhesion

Adhesion: the different types of bonding

Van der Waals is poor => requires to remove organic contamination from substrate (degreasing, UV-Ozone).

Covalent bonding can be good => requires to choose the right combination of metal/oxide.

Ionic bonding is better => requires to remove oxide by ion etching before coating: metal/metal.

Surface preparation prior to coat is CRUCIAL

4. On growth & adhesion

Adhesion: optimise covalent bonding

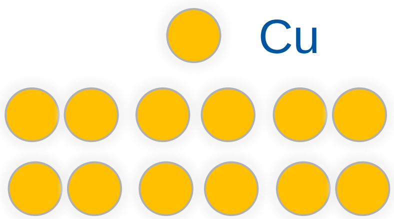
The free heat of formation of the metal-oxide of the deposited atoms must be lower (more negative) than that of the oxide at the surface of the substrate.

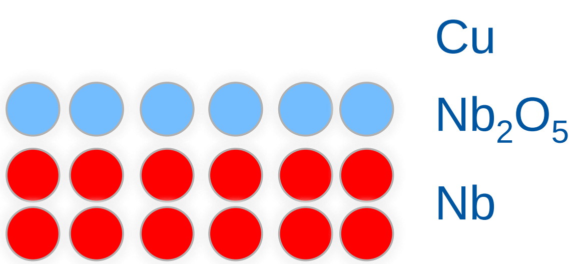
4. On growth & adhesion

Adhesion: optimise covalent bonding

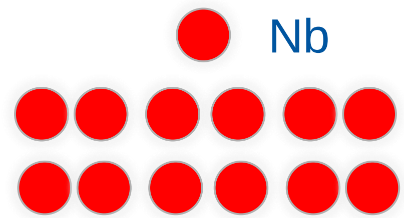
Nb and **Cu**: Nb_2O_5 = -1899.54 kJ/mol << CuO_2 = -156.06 kJ/mol

Deposition of **Cu** on **oxidised Nb**





Deposition of **Nb** on **oxidised Cu**



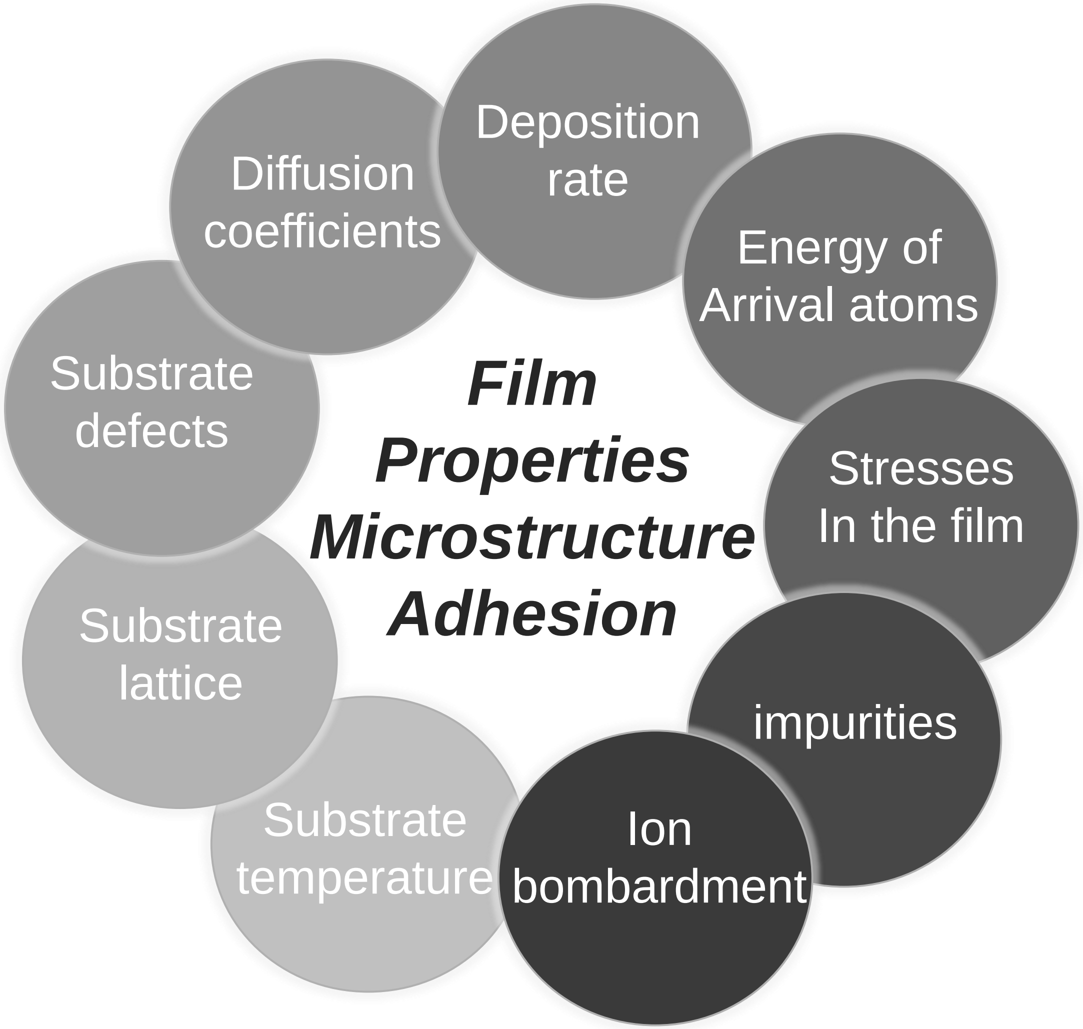
4. On growth & adhesion

Adhesion: optimise covalent bonding

Good pairs metal-oxide: Nb/Cu, Ti/S.Steel, NEG(TiZrV)/Cu, Ti/Al_2O_3, Al/glass.

Bad pairs metal-oxide: Cu/Nb, Cu/S.Steel, Cu/glass.

4. On growth & adhesion



5. Non Evaporable Getter Coatings.

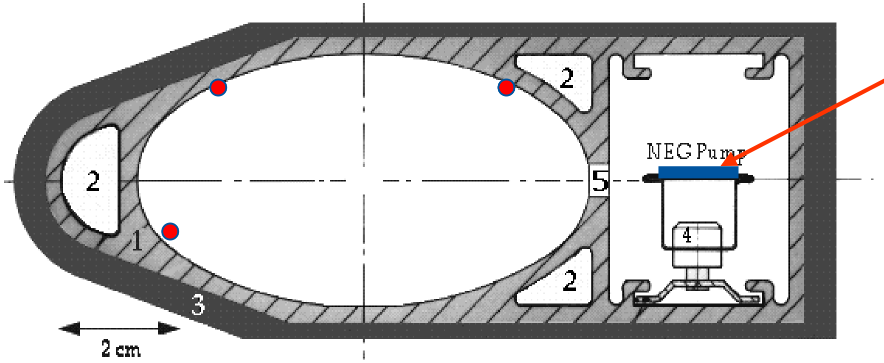
Motivation: improve dynamic vacuum on the warm sections of the LHC.

- Distributed pumping speed
- Low secondary electron yield (mitigation of electron multipacting)

5. Non Evaporable Getter Coatings.

Motivation: improve dynamic vacuum on the warm sections of the LHC.

Cross section of the LEP dipole vacuum chamber



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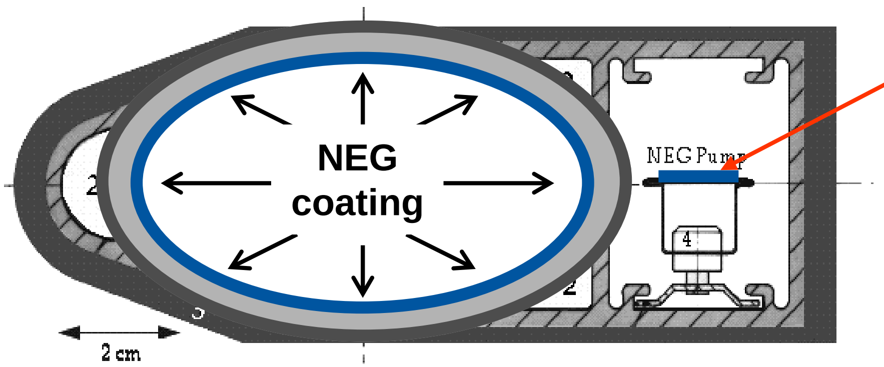
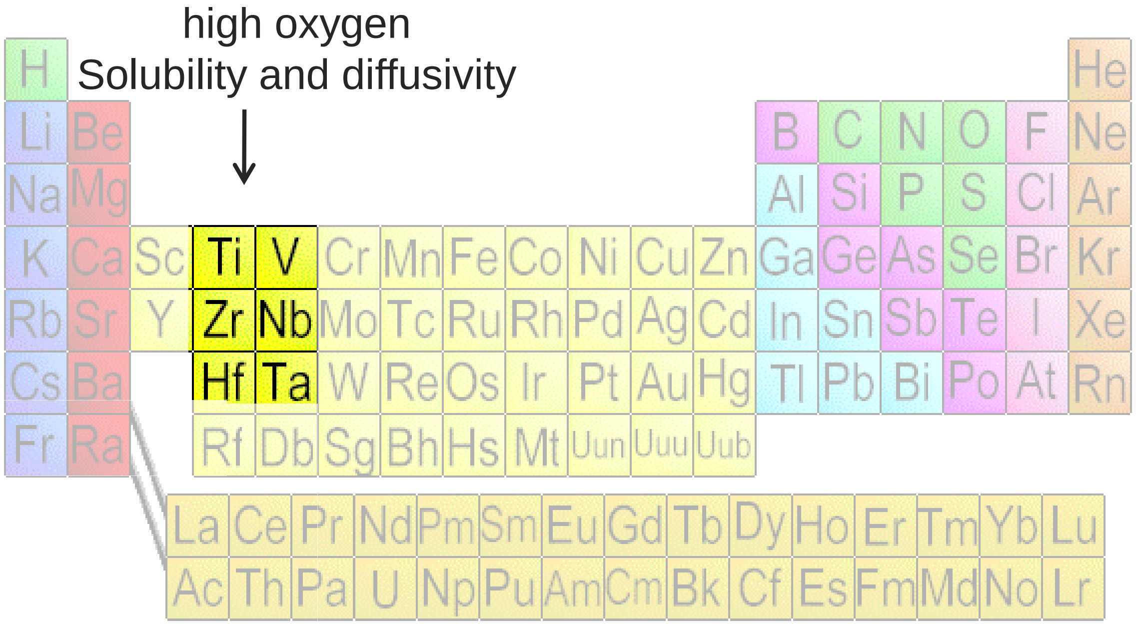


The vacuum chamber becomes a pump.

5. Non Evaporable Getter Coatings.

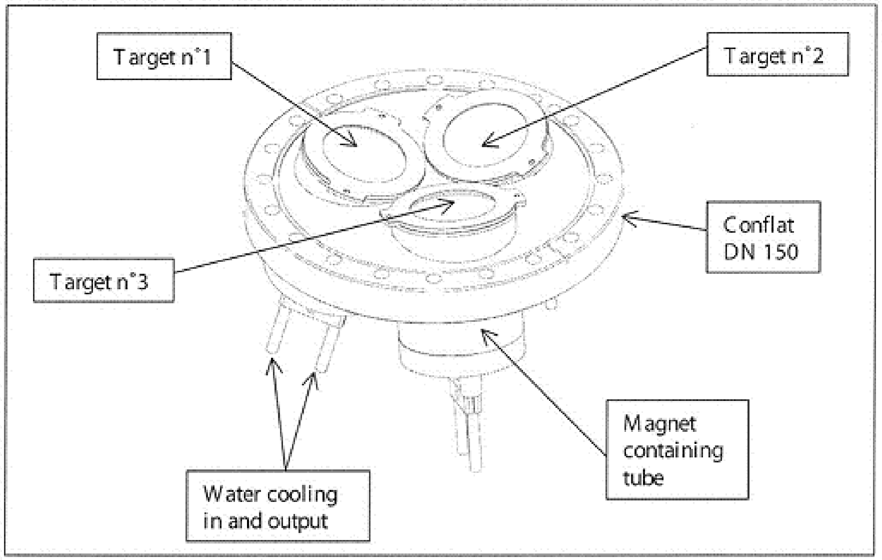
The NEG behavior of some elements were already known, but activation temperatures > 350ºC

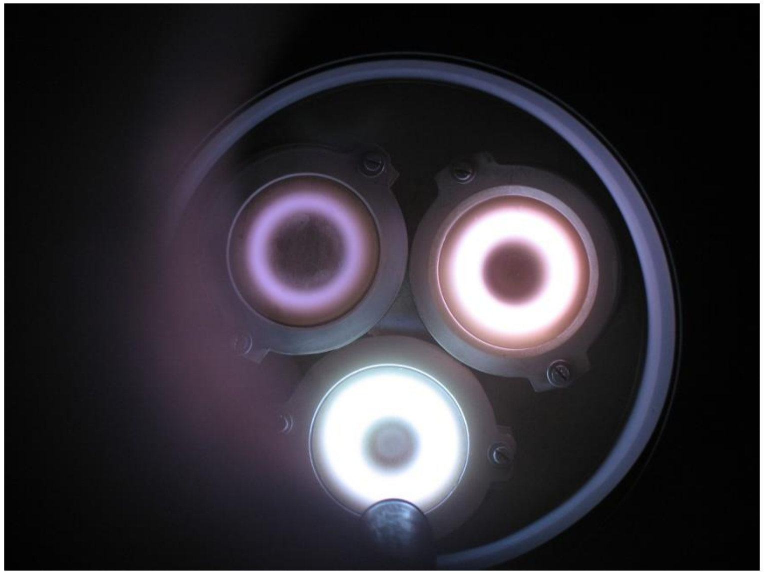


5. Non Evaporable Getter Coatings.

Mixing these elements to decrease the activation temperature.

(compatible with the materials used in the construction of beam pipes for accelerators)





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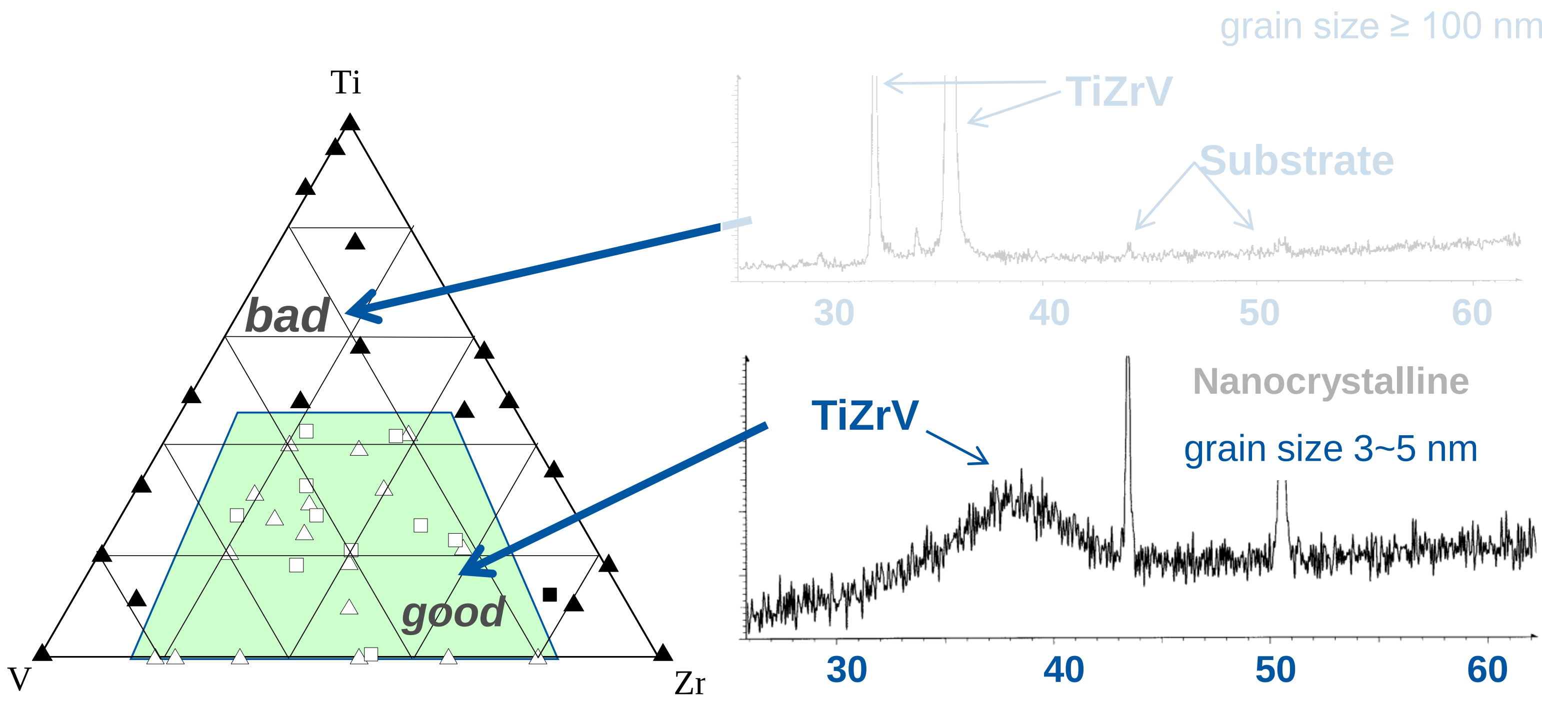
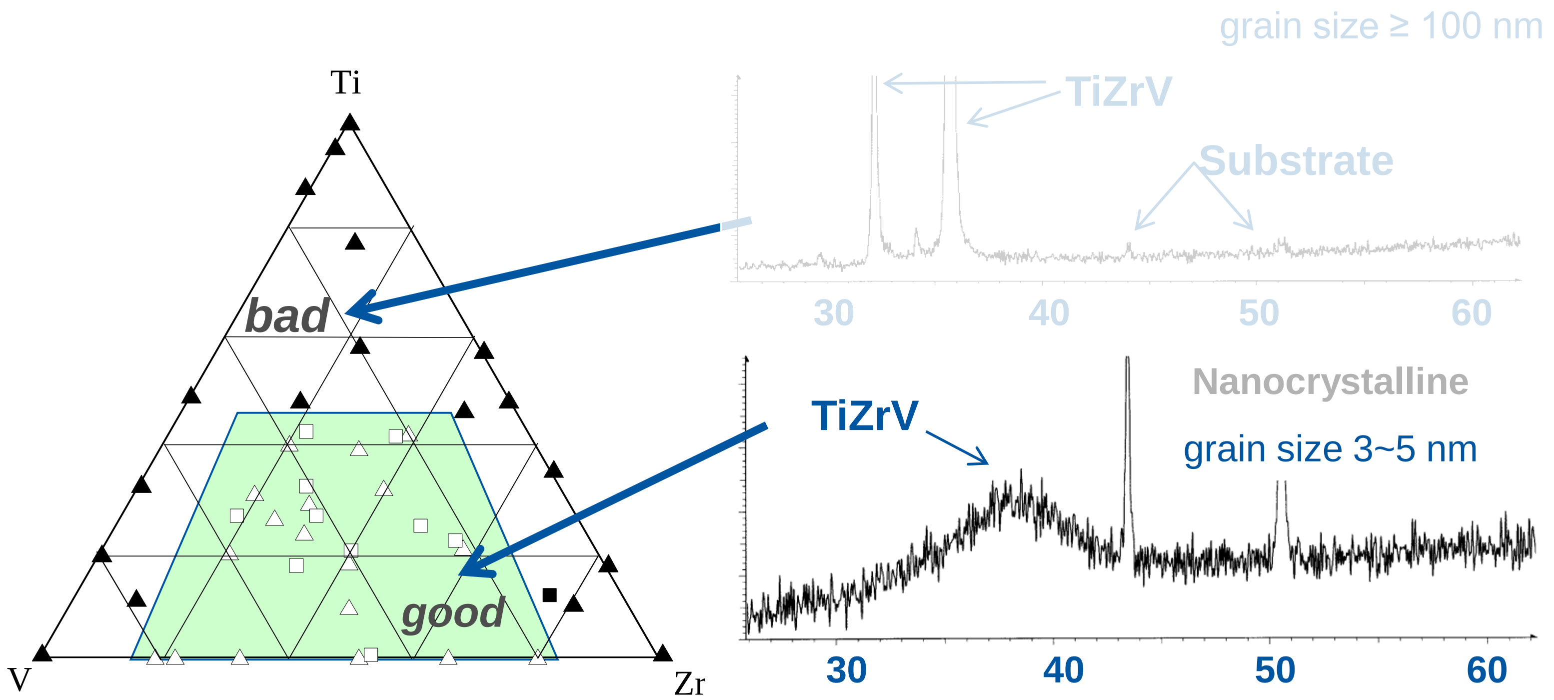


5. Non Evaporable Getter Coatings.

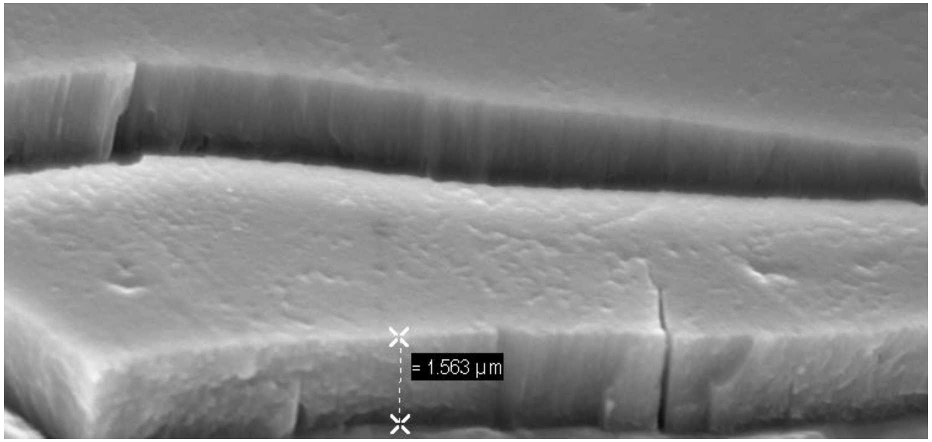
In 2002, Ti-Zr-V was retained for large scale production for the LHC. Activation: 24 hours at 180ºC

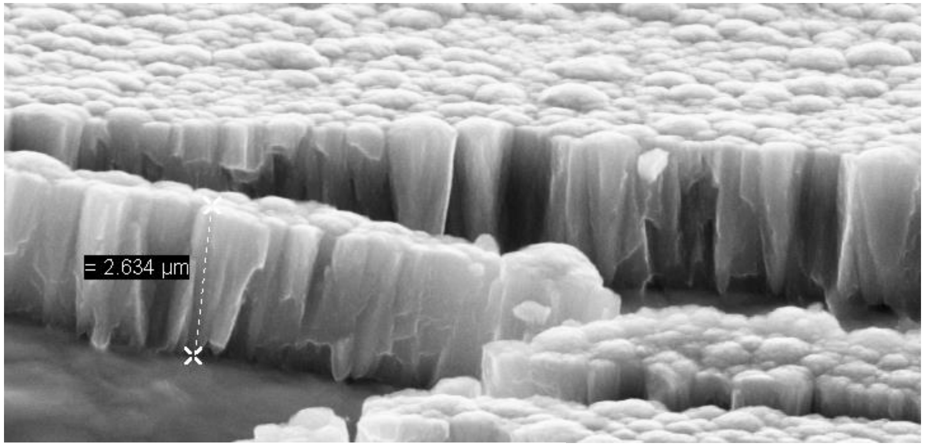


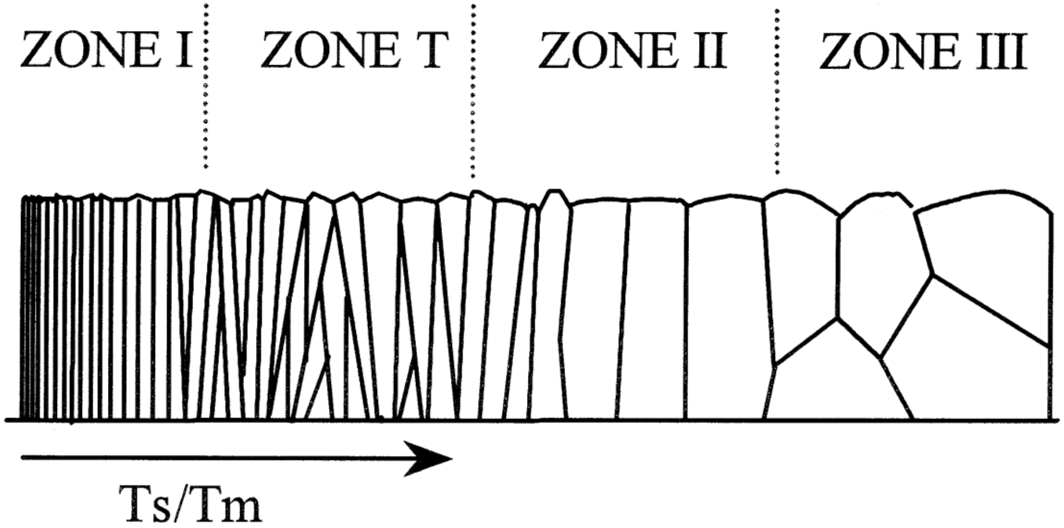
5. Non Evaporable Getter Coatings.

Vacuum properties 1: pumping speed versus coverage.

Smooth (coated at 100ºC) | Rough (coated at 300ºC)



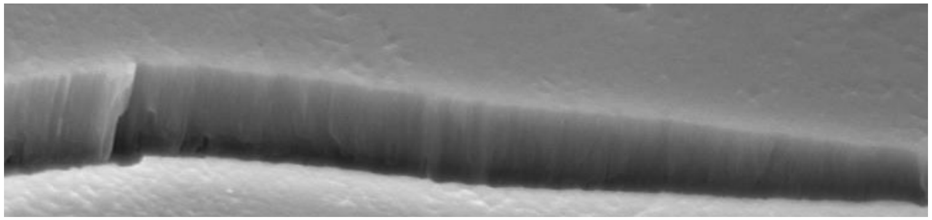


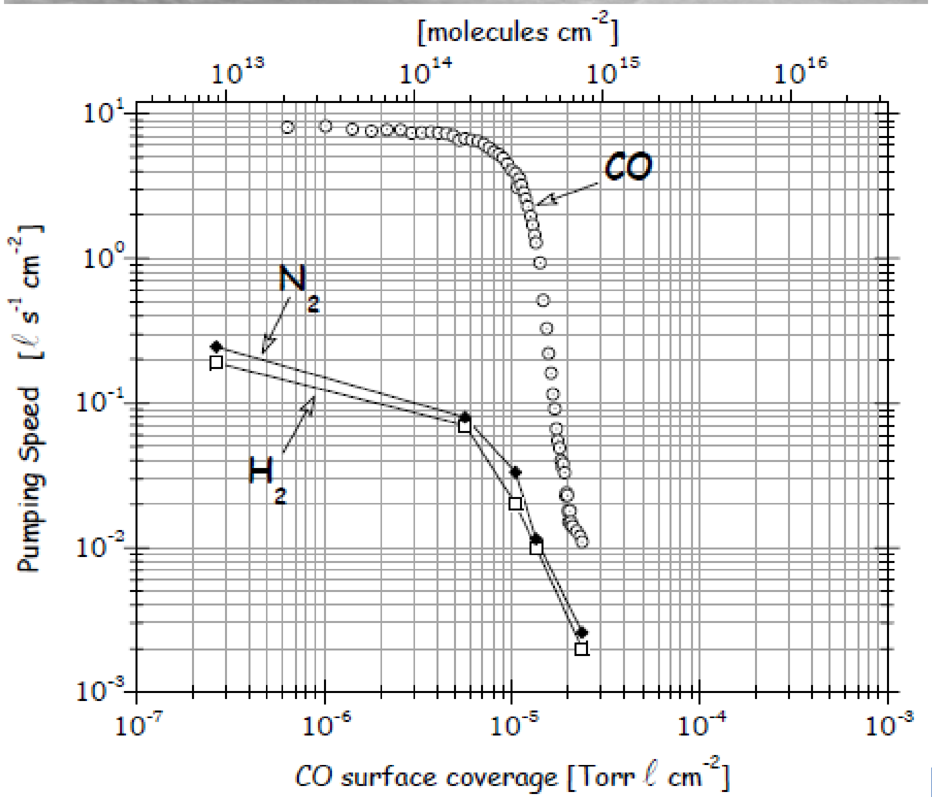


5. Non Evaporable Getter Coatings.

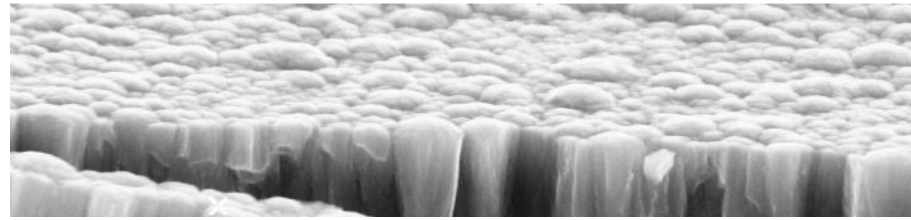
Vacuum properties 1: pumping speed versus coverage.

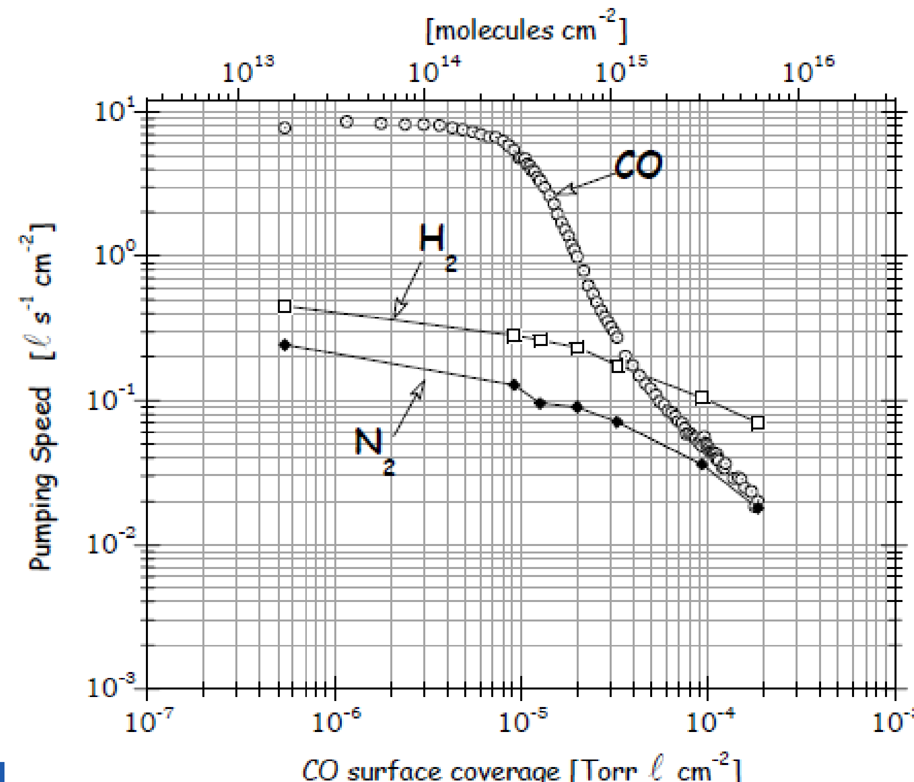
Smooth (coated at 100ºC)





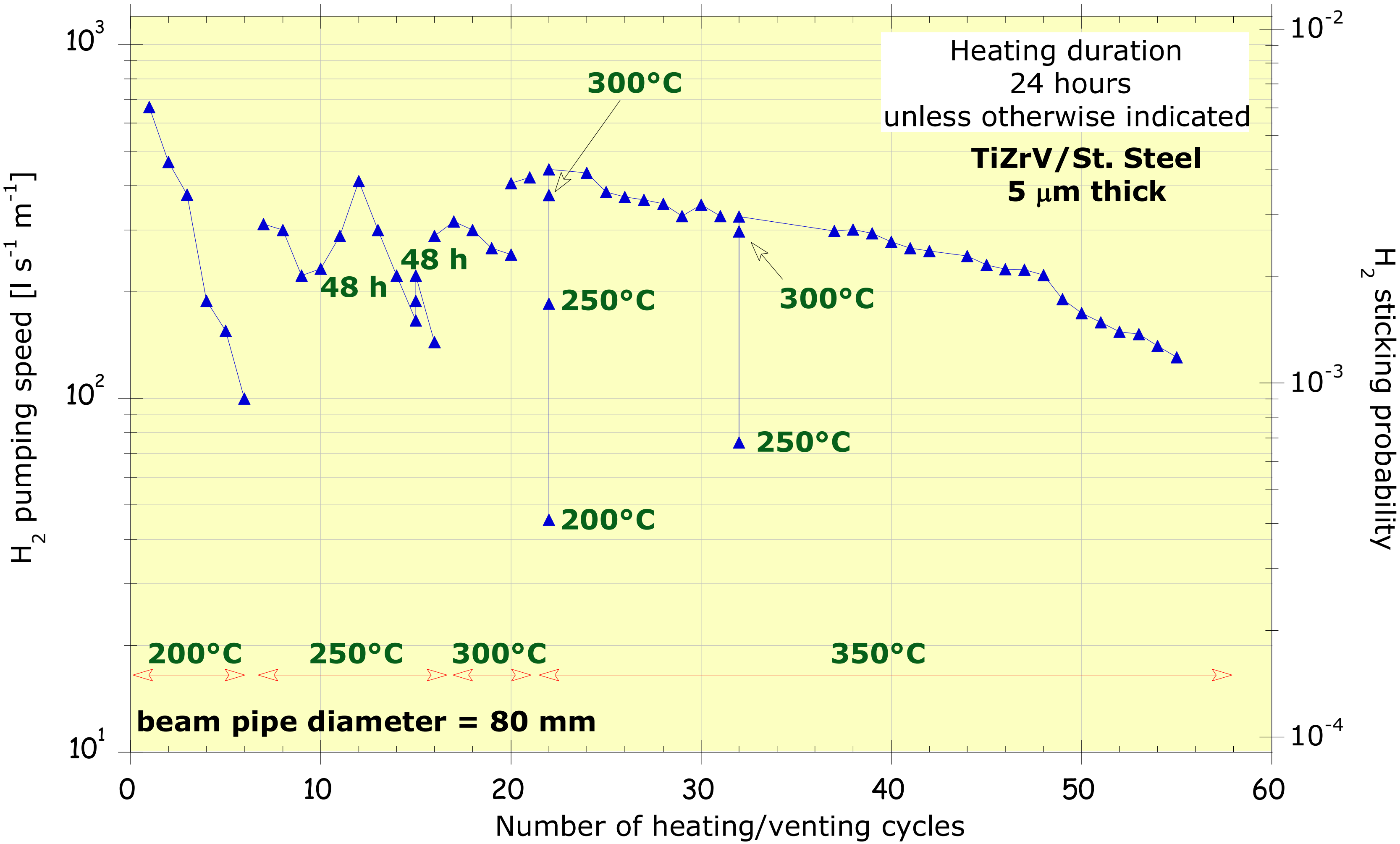
Rough (coated at 300ºC)





5. Non Evaporable Getter Coatings.

Vacuum properties 2: ageing (recovery after successive air venting).



5. Non Evaporable Getter Coatings.

Vacuum properties 3: photon induced desorption.

P. Chiggiato, R. Kersevan, Vacuum, 60 (2001) 67-72.

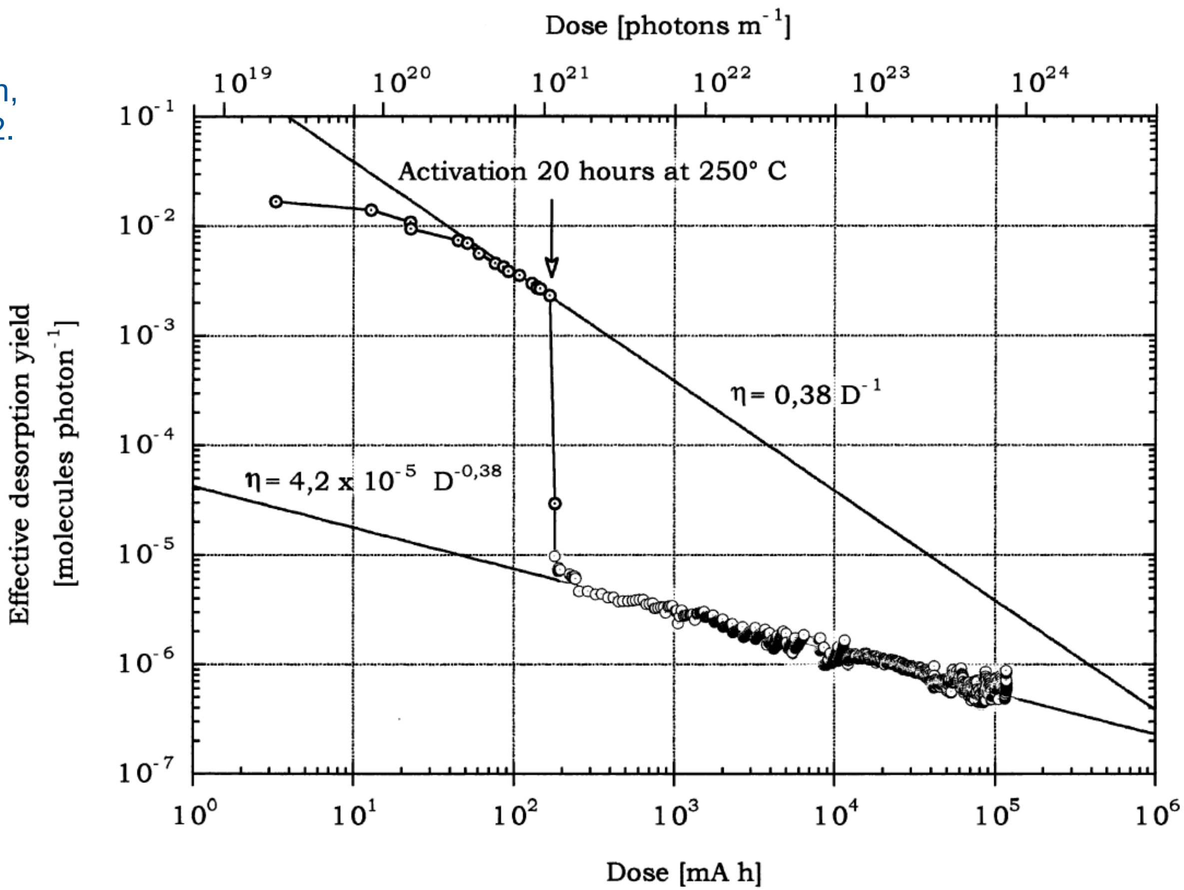
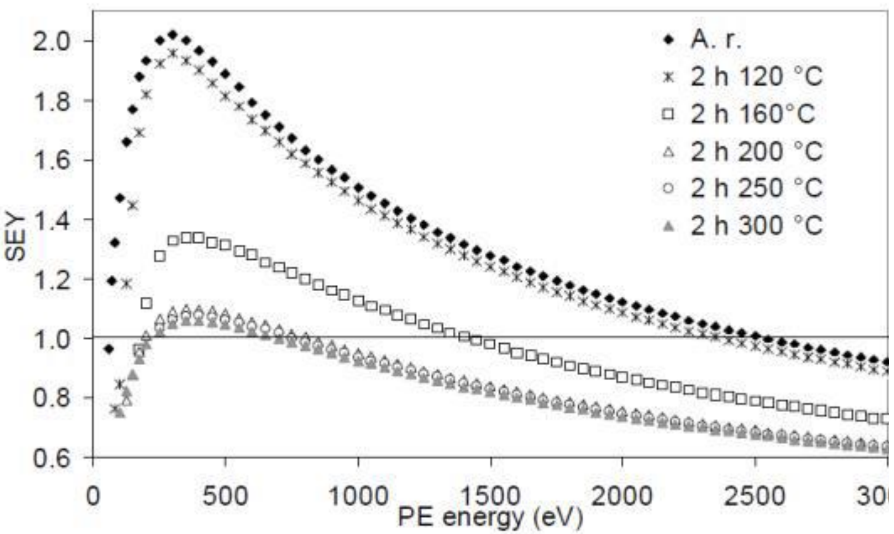
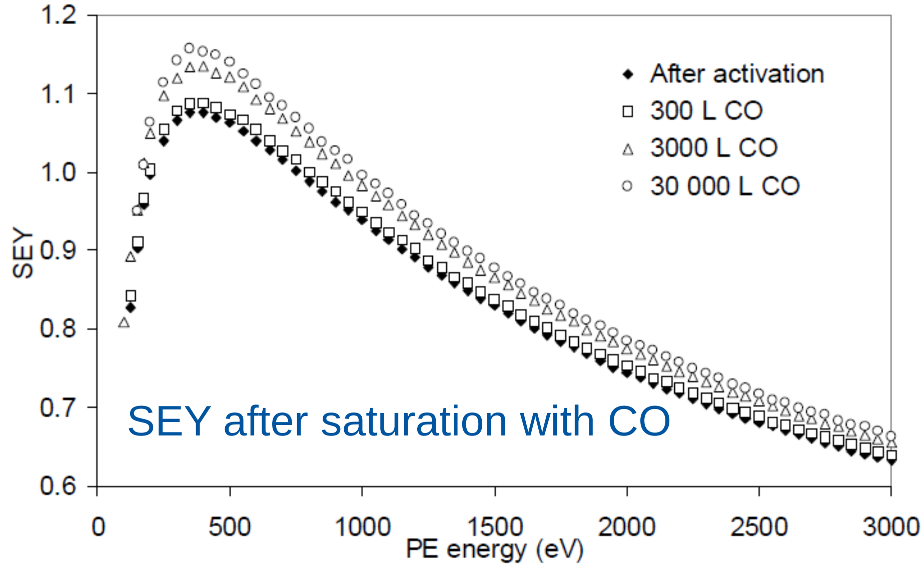


Fig. 2. Total molecular desorption yield η (N_2 equivalent) of the Ti–Zr–V coated stainless-steel chamber as a function of the accumulated dose before and after activation.

5. Non Evaporable Getter Coatings.

Secondary Electron Yield:

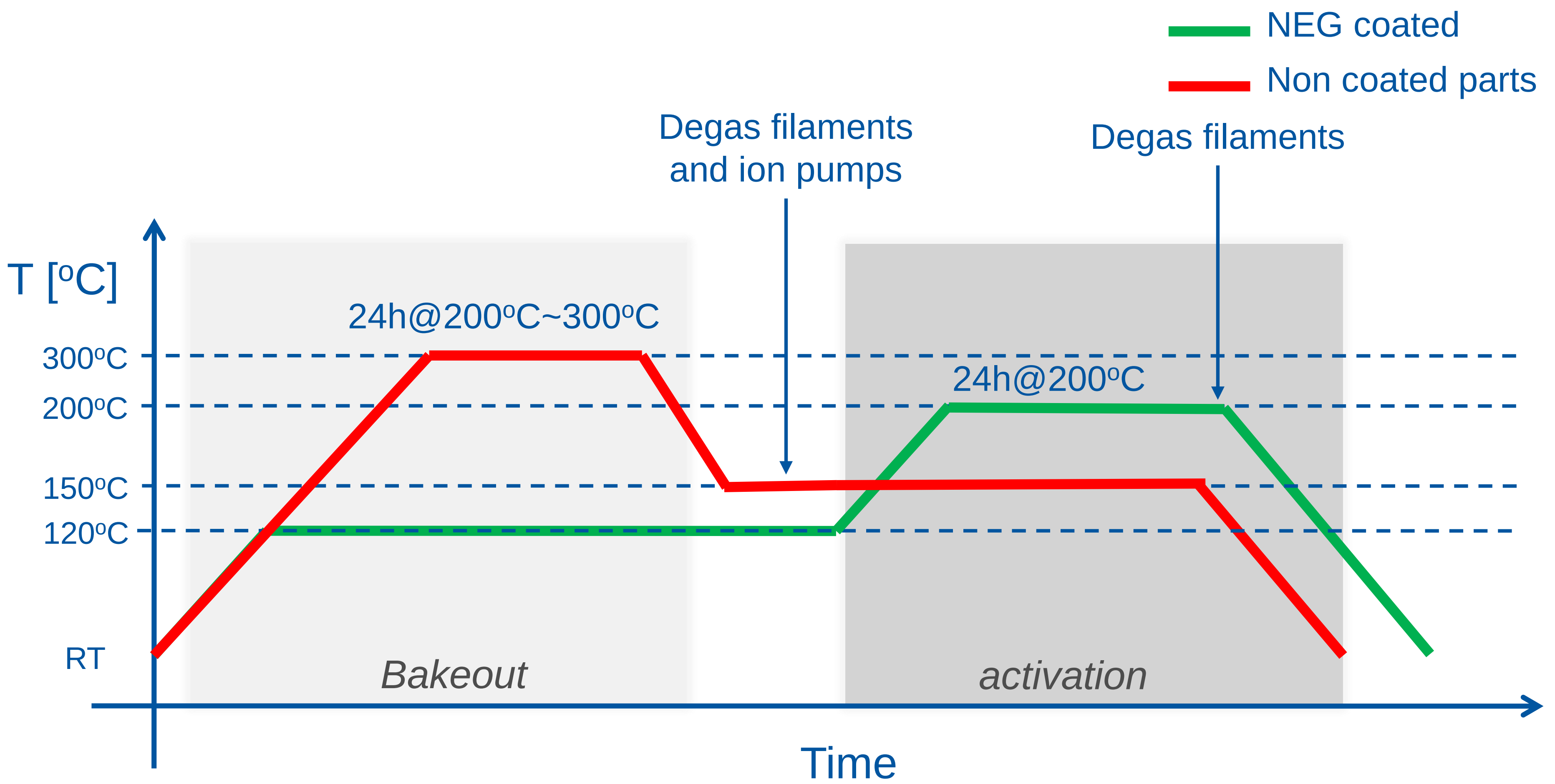




B. Henrist, N. Hilleret, C. Scheuerlein, M. Taborelli,
App. Surf. Sci. 172 (2001) 95.

5. Non Evaporable Getter Coatings.

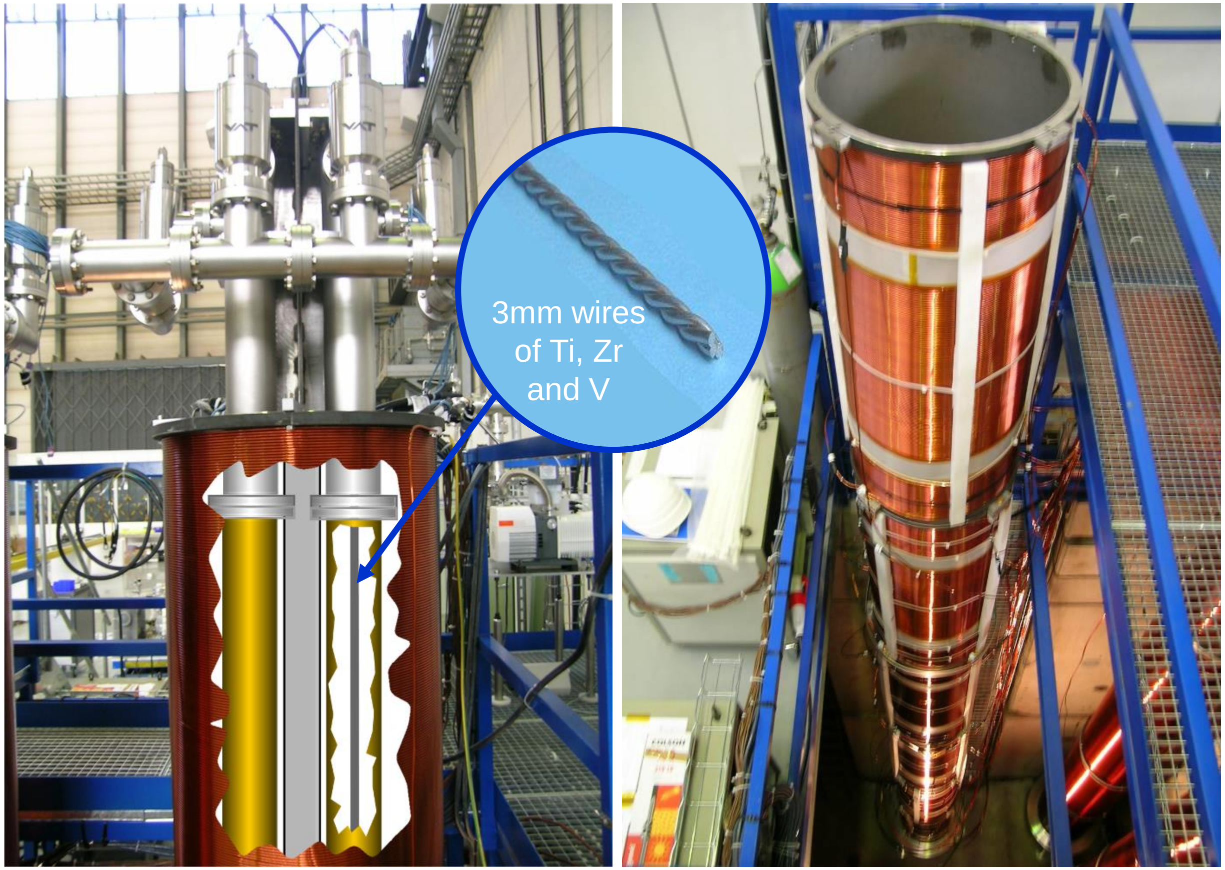
General procedure for activation



5. Non Evaporable Getter Coatings.

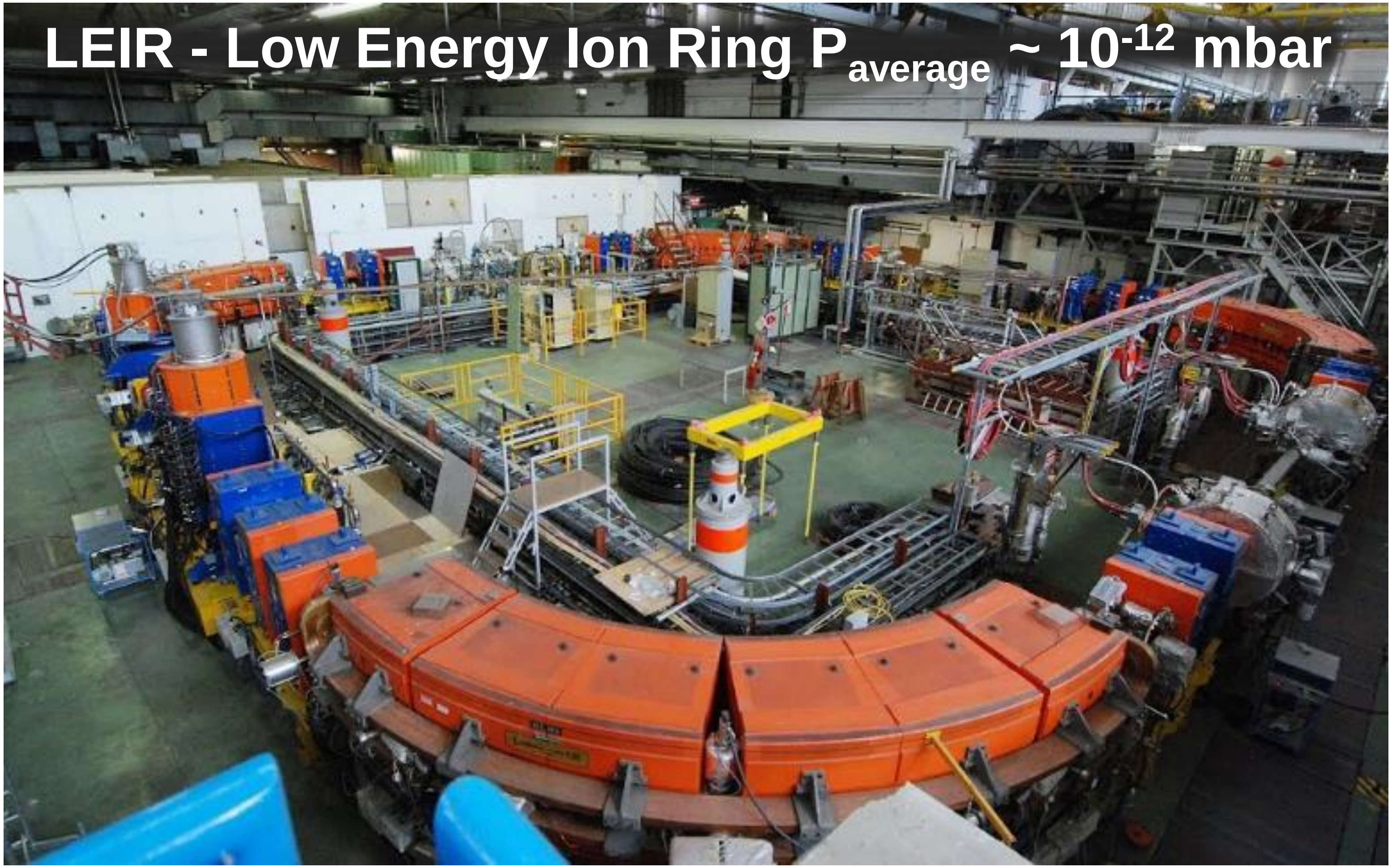
Production for the LHC

More than 1300 beam pipes, with different shapes and lengths.



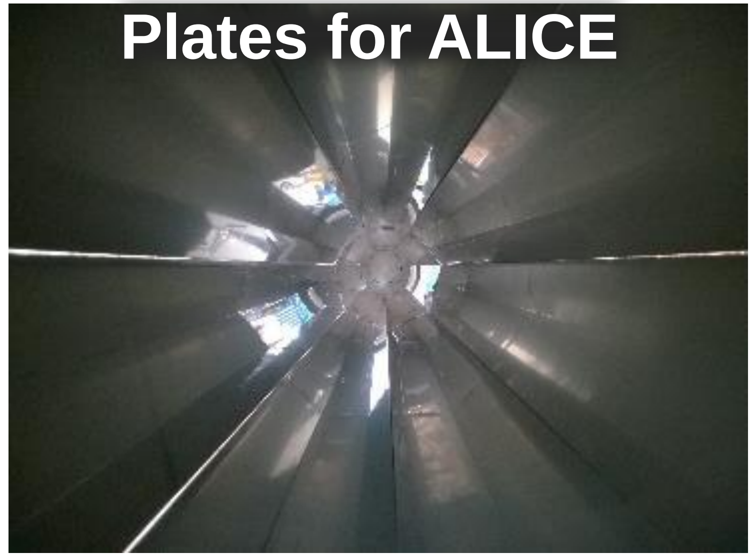
5. Non Evaporable Getter Coatings.

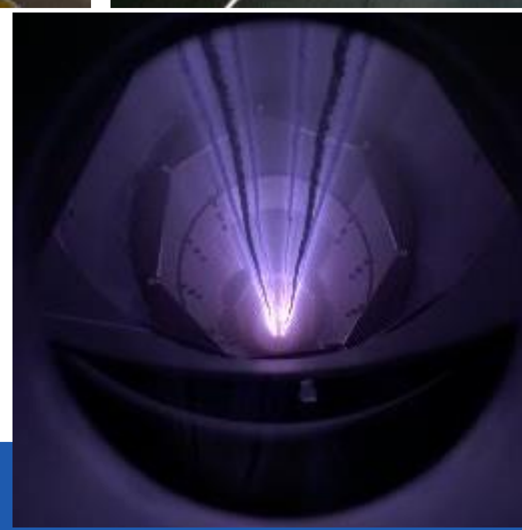
Other machines at CERN



5. Non Evaporable Getter Coatings.

Other machines at CERN

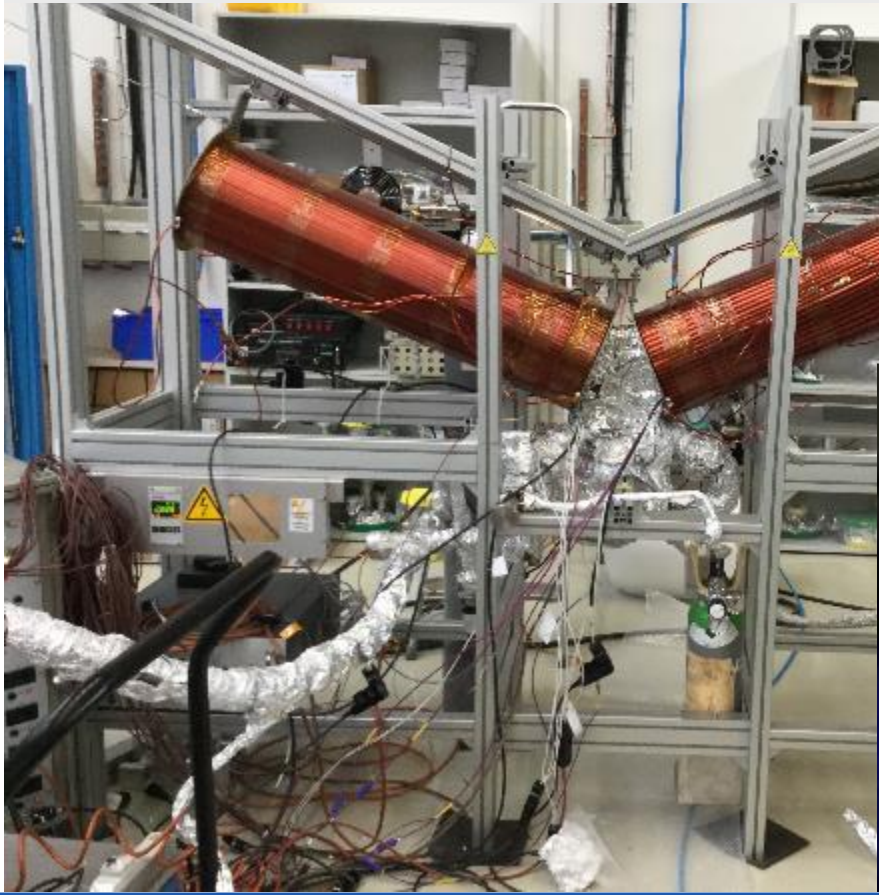




5. Non Evaporable Getter Coatings.

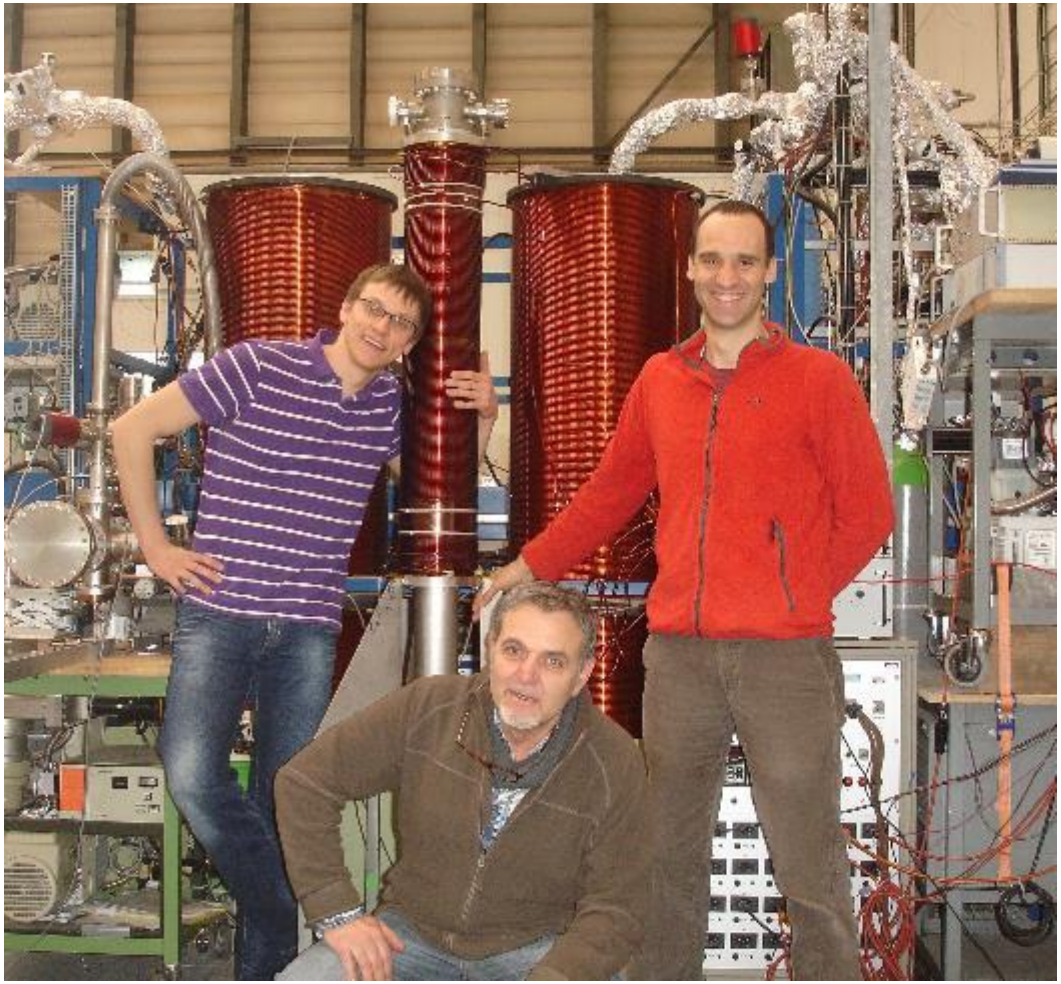
Other machines at CERN

Extra Low ENergy Antiptoton storage ring



5. Non Evaporable Getter Coatings.

Collaboration with MAX IV



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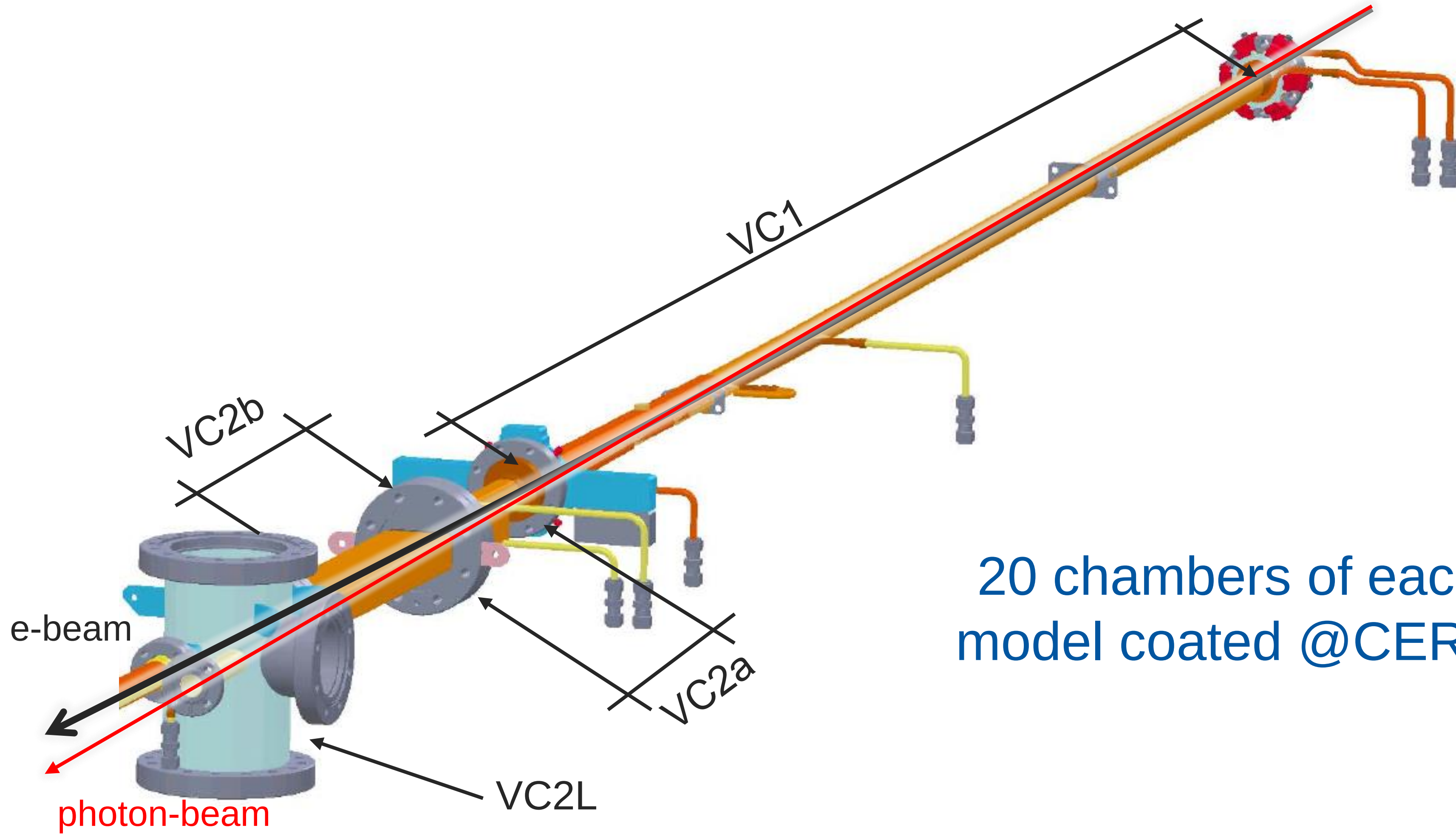
Collaboration with MAX IV



20 chambers of each model coated @CERN

5. Non Evaporable Getter Coatings.

Collaboration with MAX IV

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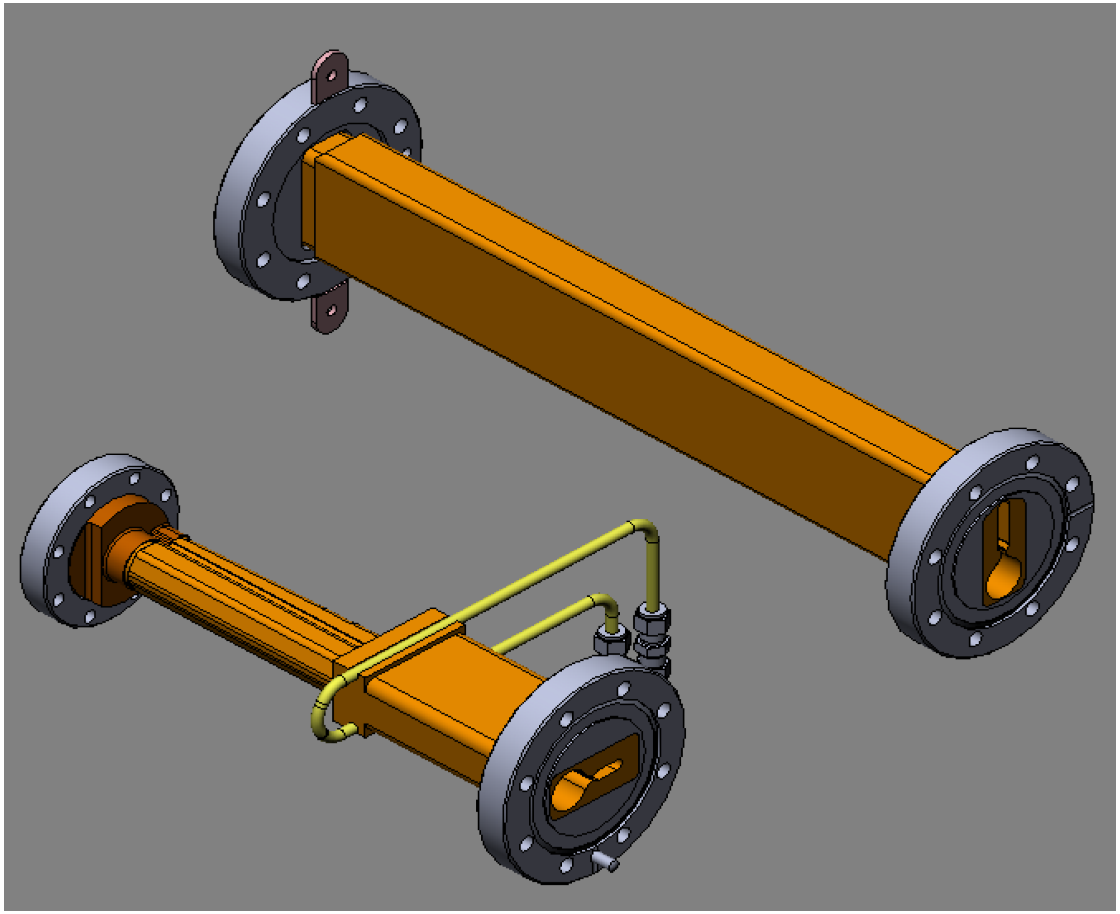
Collaboration with MAX IV



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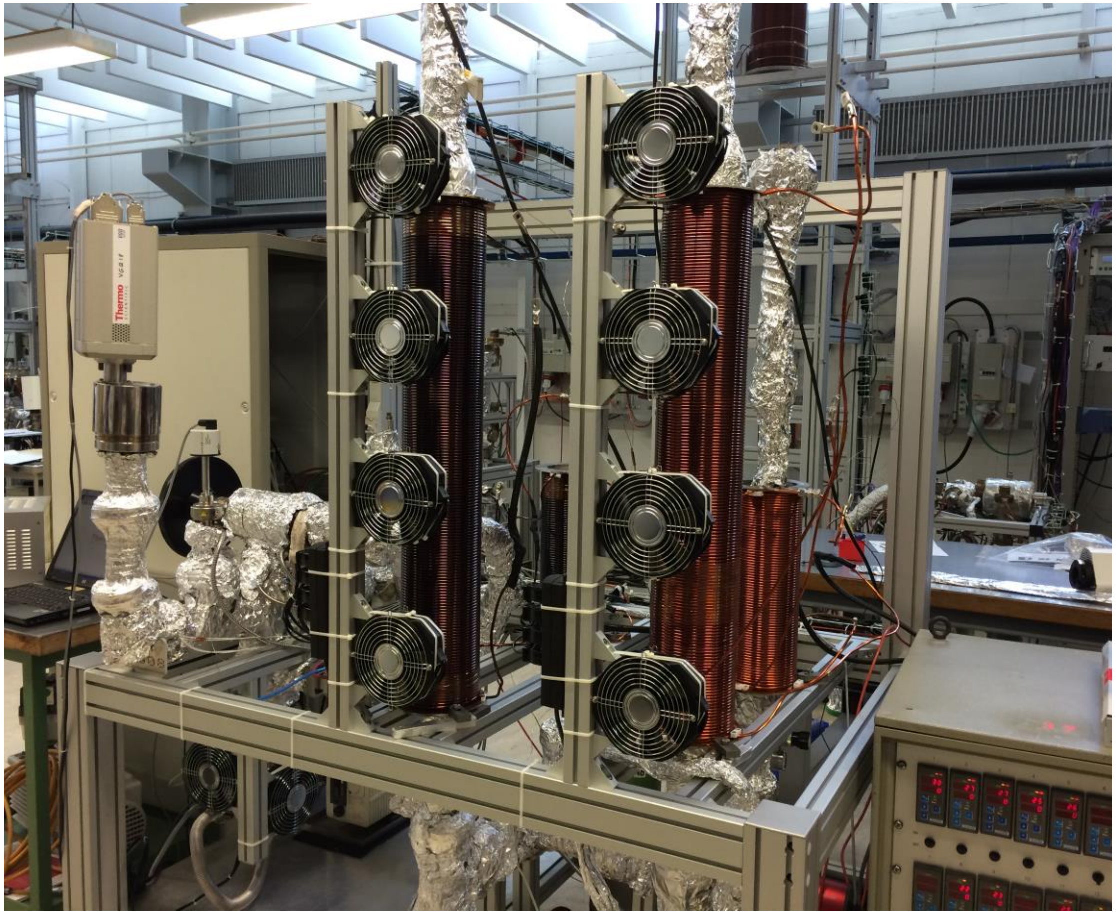

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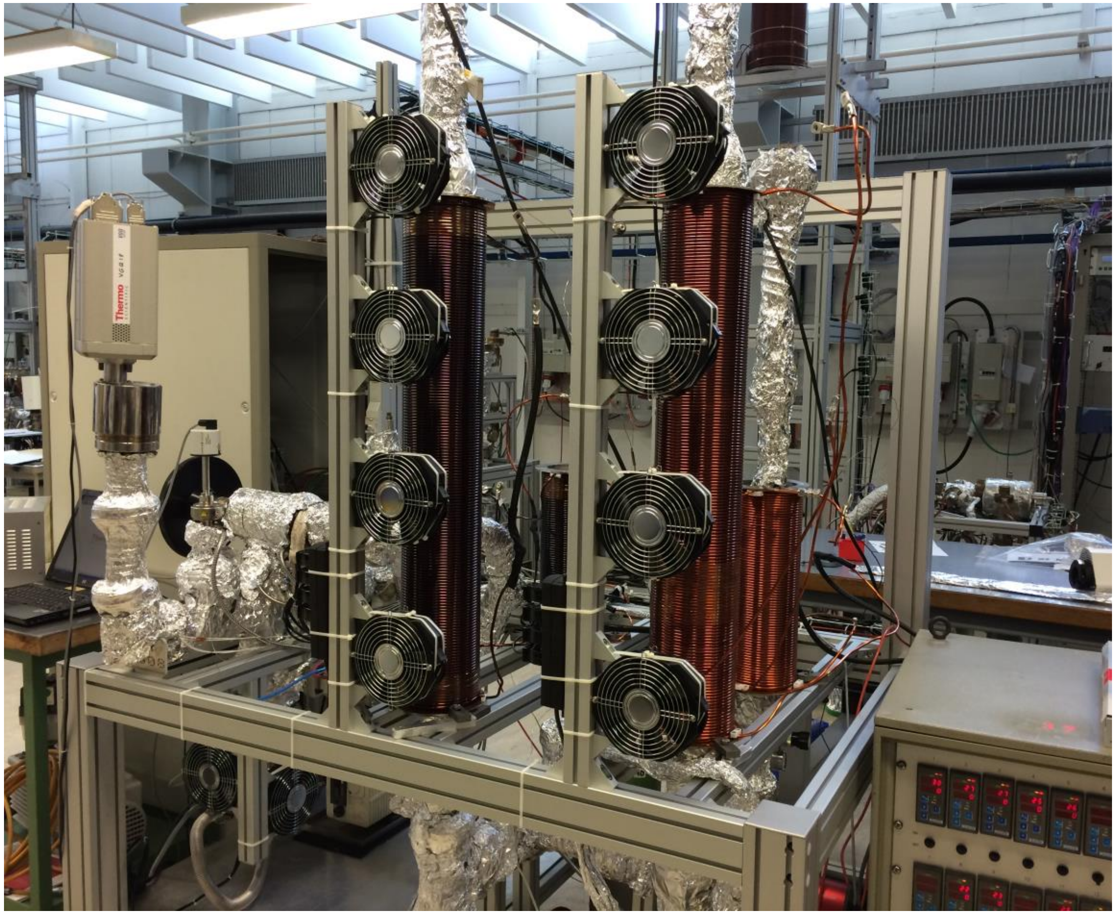
Collaboration with MAX IV



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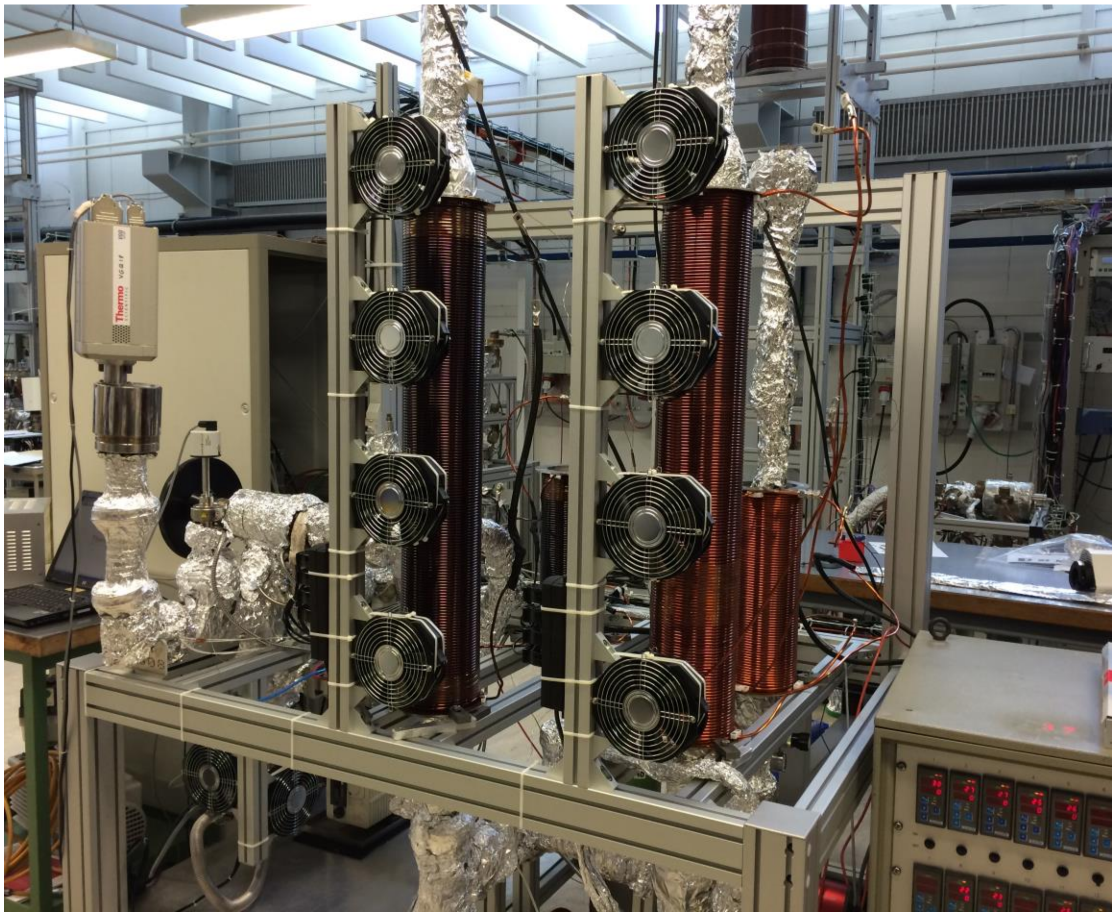
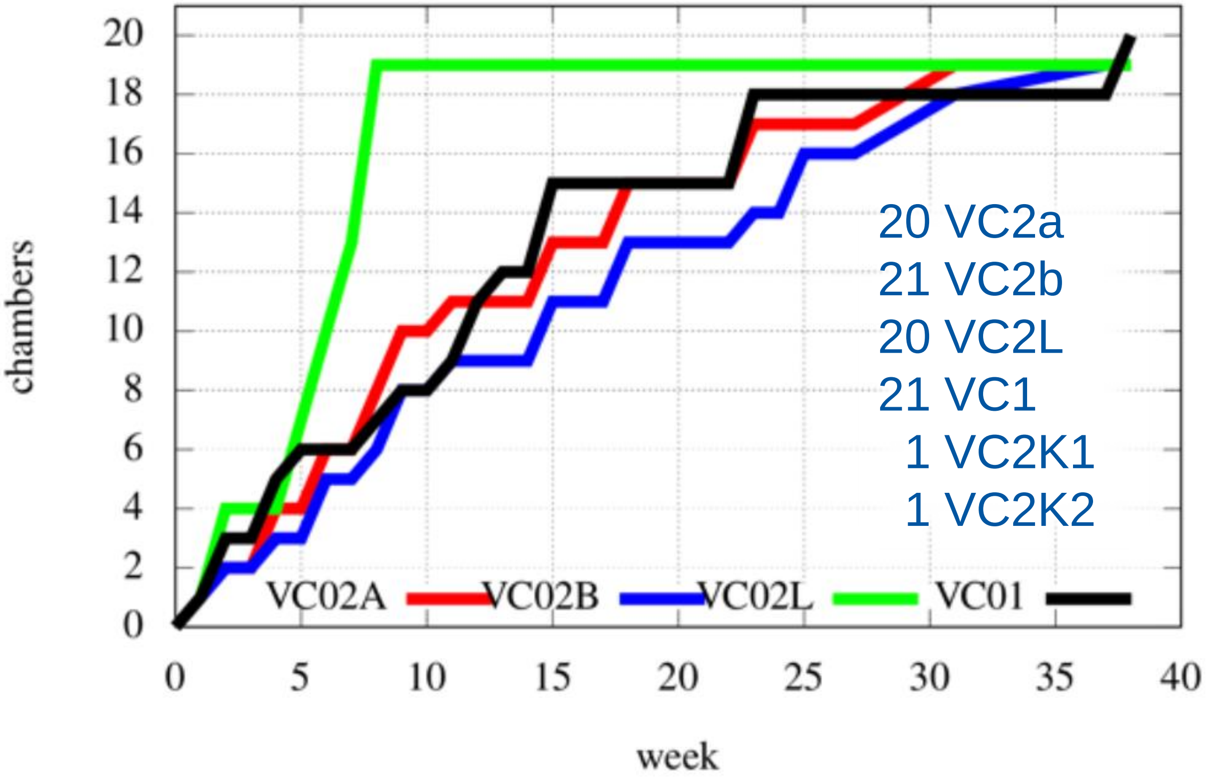


5. Non Evaporable Getter Coatings.

Collaboration with MAX IV

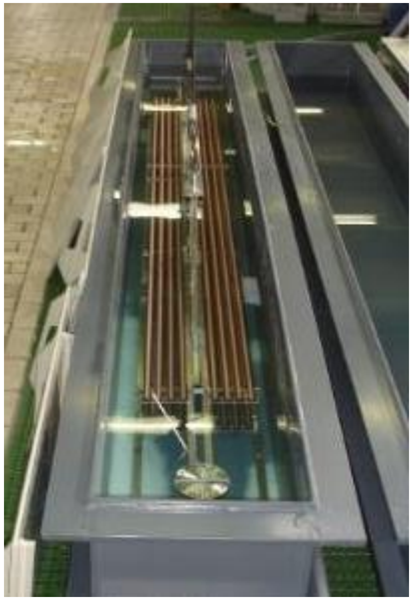
Between July 2014 and April 2015



5. Non Evaporable Getter Coatings.

Collaboration with MAX IV

Surface preparation prior to coat is CRUCIAL



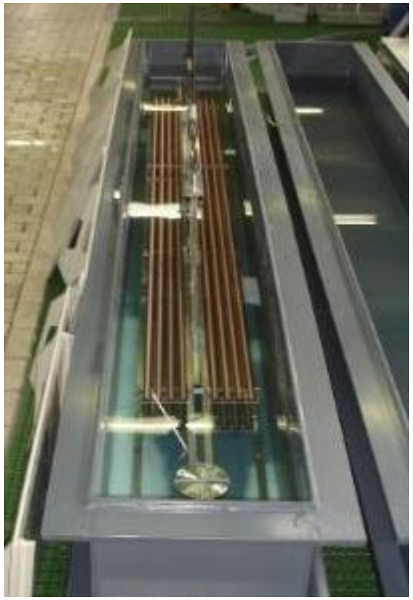
Mechanical removal of most of the Cu particles (Clothing and 100 bar water rinsing).

Chemical etching of the internal surface with $NH_4S_2O_3$ (about 60μm) + passivation

5. Non Evaporable Getter Coatings.

Collaboration with MAX IV

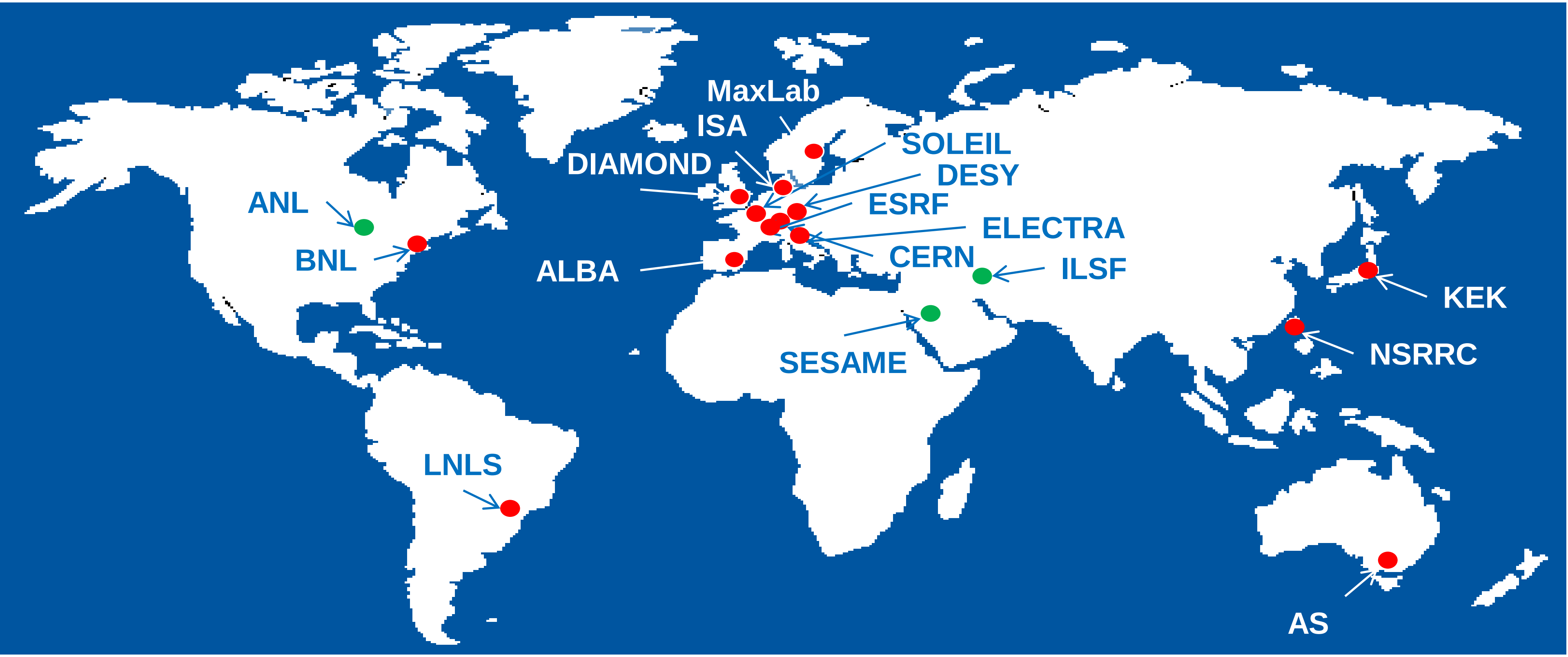
Surface preparation prior to coat is CRUCIAL



Careful inspection before acceptance for mechanical assembling

5. Non Evaporable Getter Coatings.

Worldwide users of NEG coatings



in design/study

5. Non Evaporable Getter Coatings.

Worldwide NEG coating producers

Final remarks

Thin films are part of the Particle Accelerators technology. (Km's of beam pipes are coated and in use)

Surface preparation is crucial.

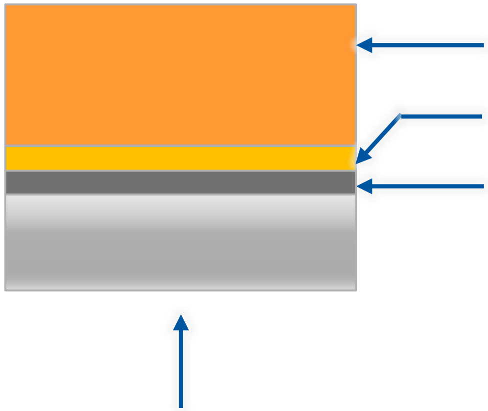
The coating must be take into account since de design phase of new components.

To follow the demand from the accelerators community, the coating technology needs to be able to develop new materials and coating configurations.

Sputtering is very "plastic" but the future may ask upside down solutions!

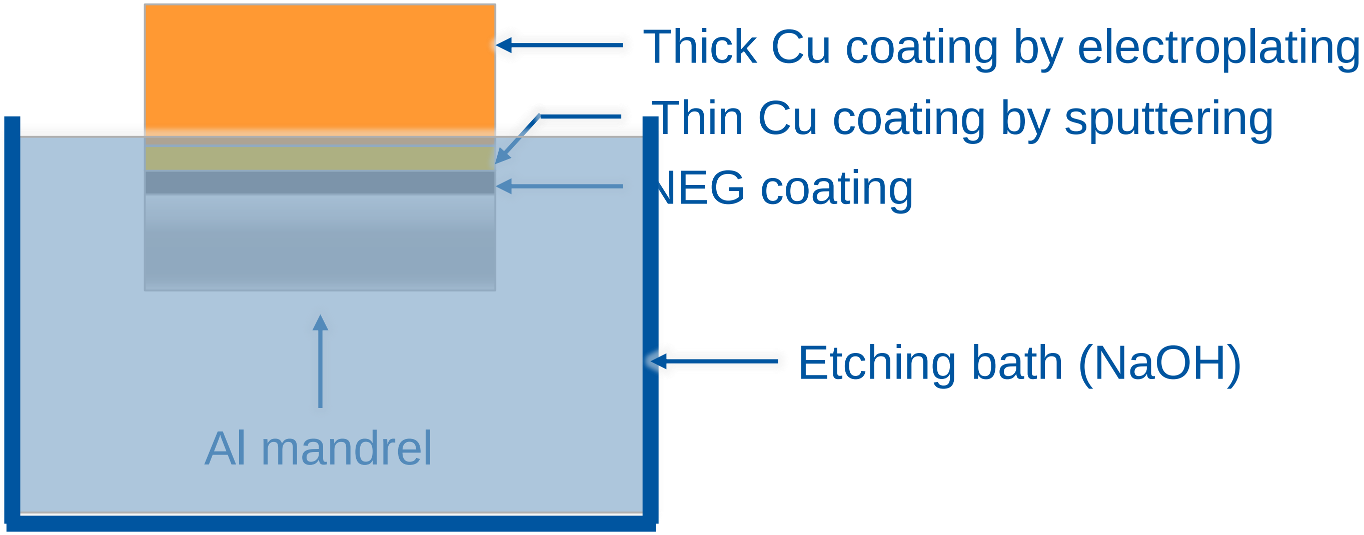
Summary

Inverse NEG?



Summary

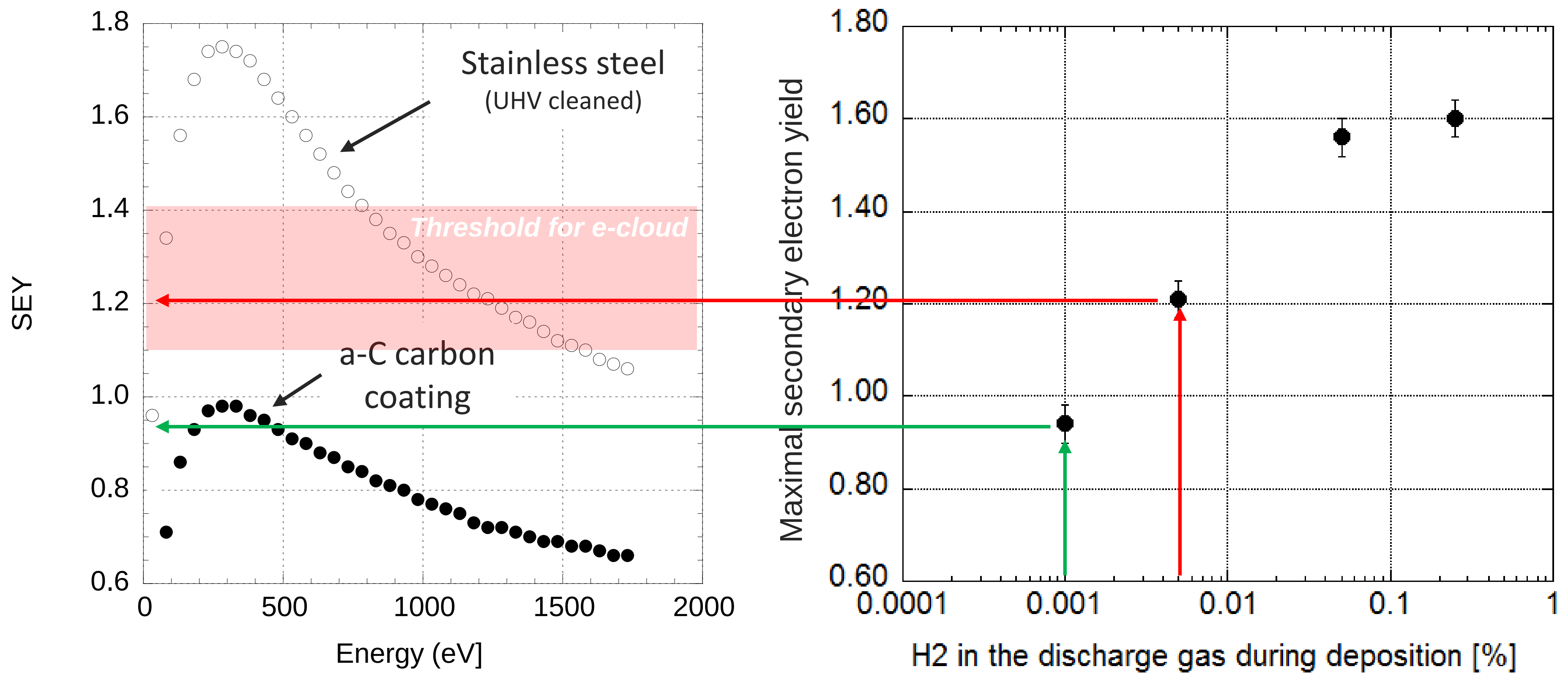
Inverse NEG?



Thanks for your attention ☺

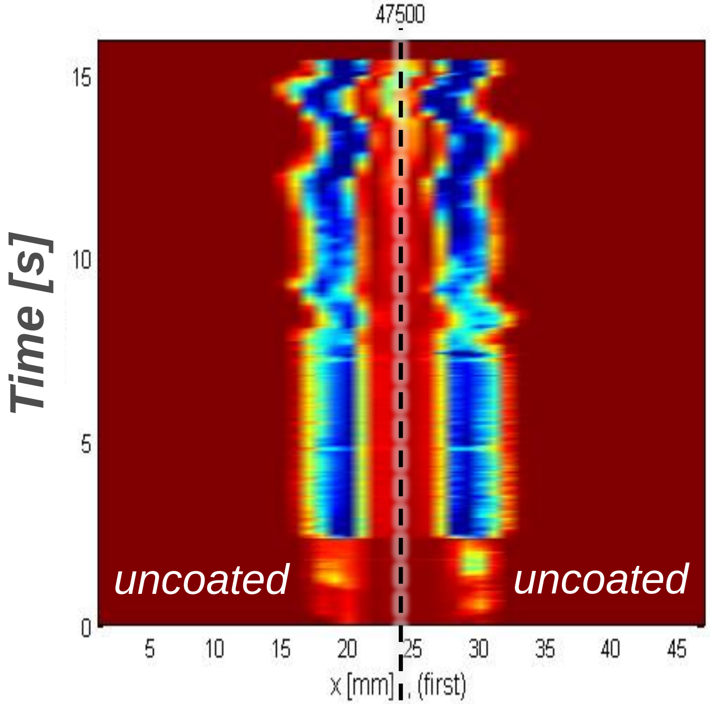
2. Carbon Coatings to mitigate e-cloud

Low Secondary Electron Yield Carbon coatings

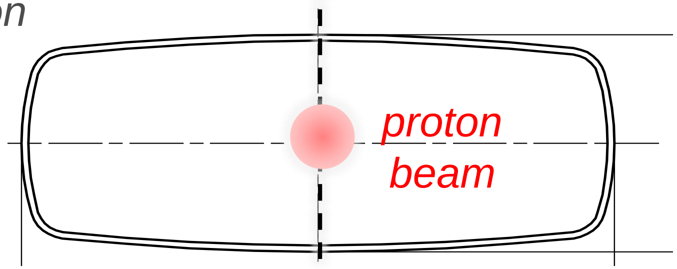


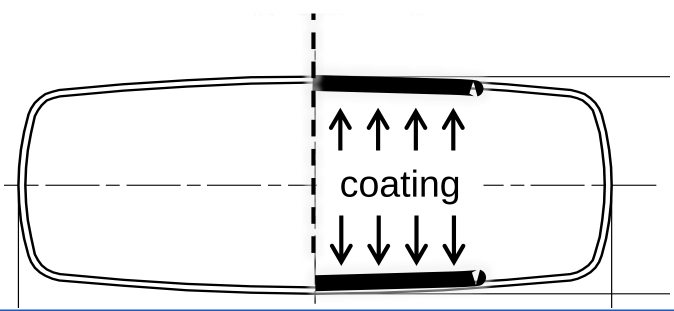
2. Carbon Coatings to mitigate e-cloud

Electron cloud current in the SPS with an electron cloud detector



Beam Cross section



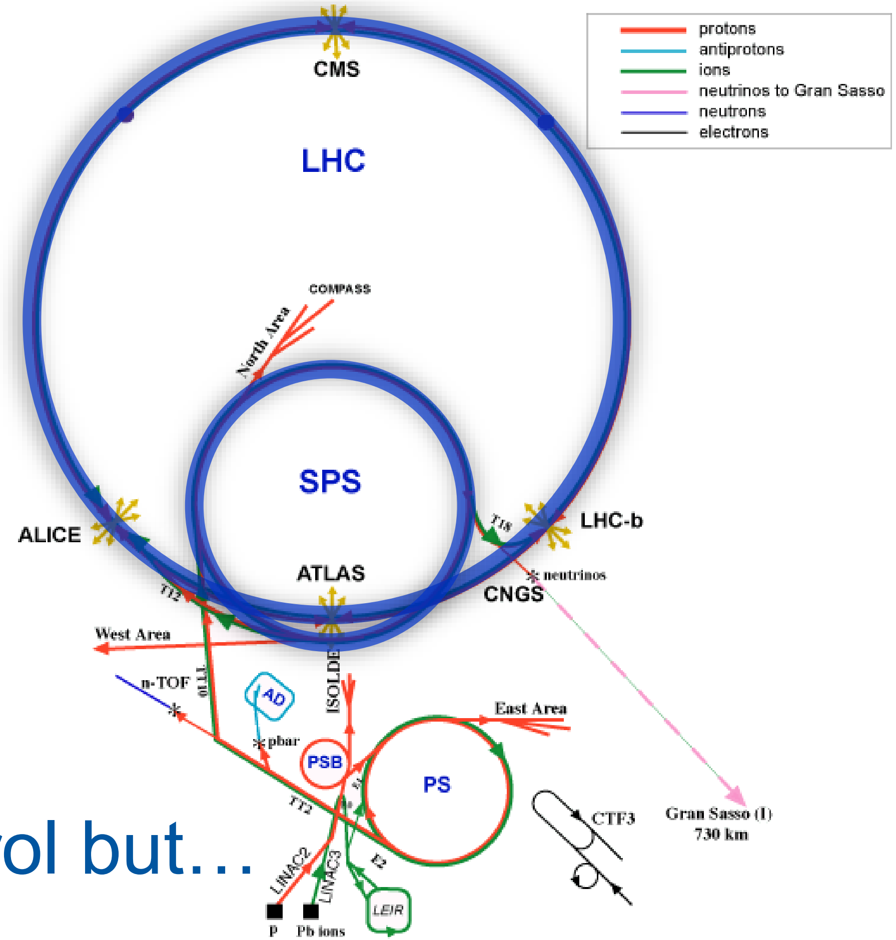


3. Application to accelerators

The CERN accelerators complex

LHC:
- Perimeter of 27 km.
- > 3 km coated with NEG (in bakeable parts)

SPS:
- Perimeter of 7 km.
- Non bakeable.



For now e-cloud is under control but…

3. Application to accelerators

More physics ➡ Higher intensity beams ➡ More problems

Increase the luminosity of the LHC by **4x**
by 2025

3. Application to accelerators

SPS: beam instabilities.

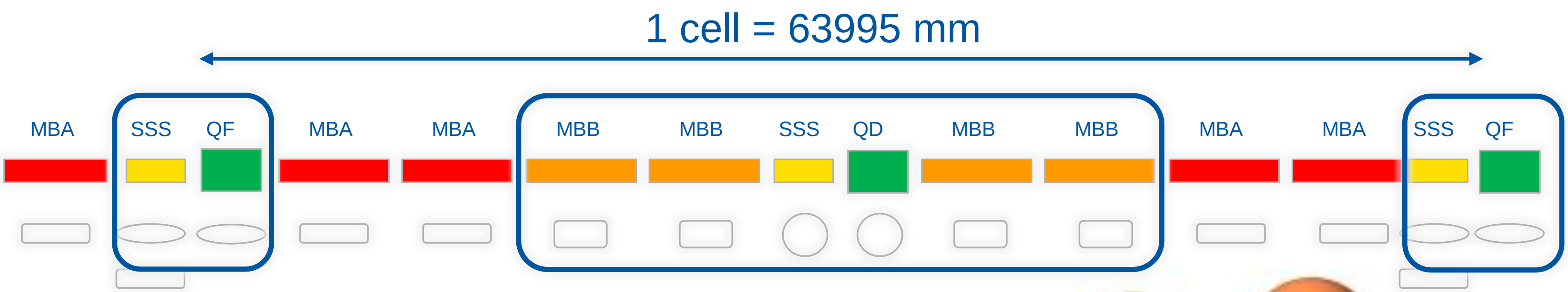
LHC: heat load to some superconductive magnets.

3. Application to accelerators: SPS

Built in the 70's

3. Application to accelerators: SPS

Layout

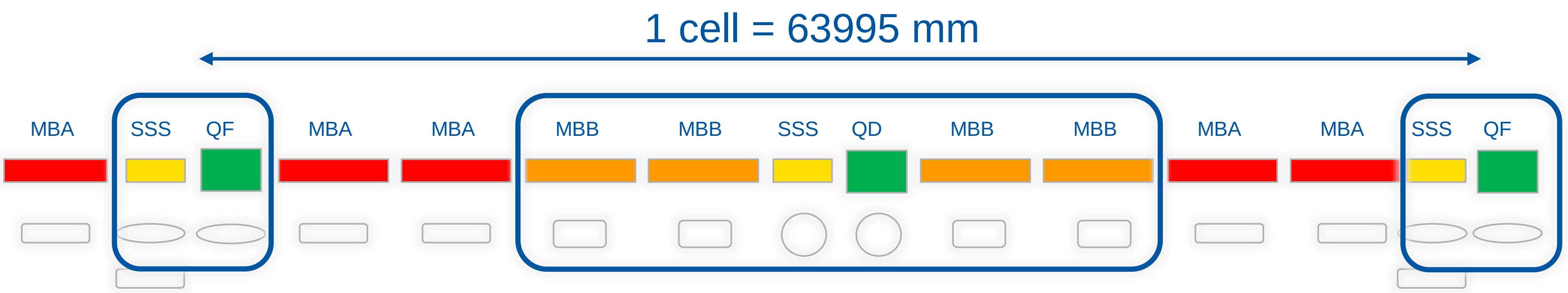


Risk & cost optimisation:

- Ranking components by "e-cloud"

3. Application to accelerators: SPS

Layout



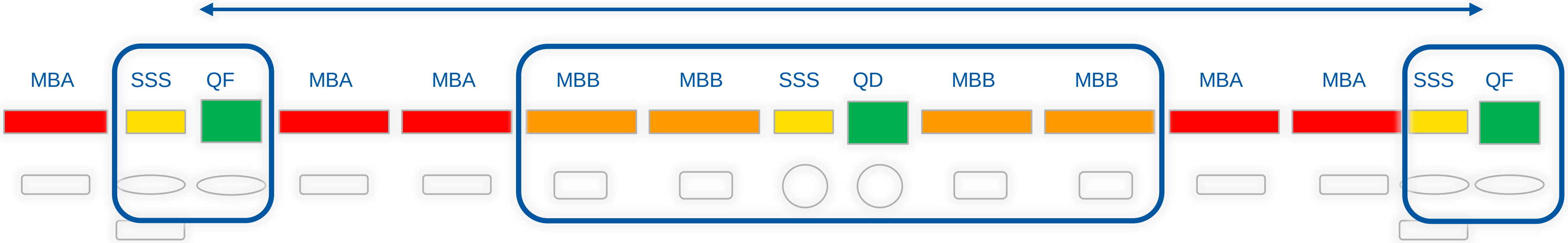
Risk & cost optimisation:

- Ranking components by “e-cloud”
- Coat chambers in the magnets

3. Application to accelerators: SPS

Layout

1 cell = 63995 mm

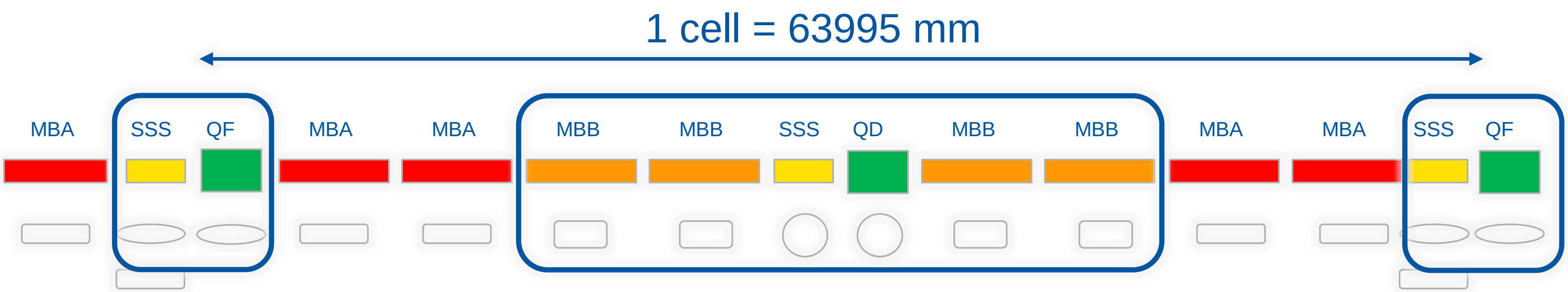


Risk & cost optimisation:

- Ranking components by “e-cloud”
- Coat chambers in the magnets
- Minimize transport/removal of magnets from the tunnel

3. Application to accelerators: SPS

Layout



Risk & cost optimisation:

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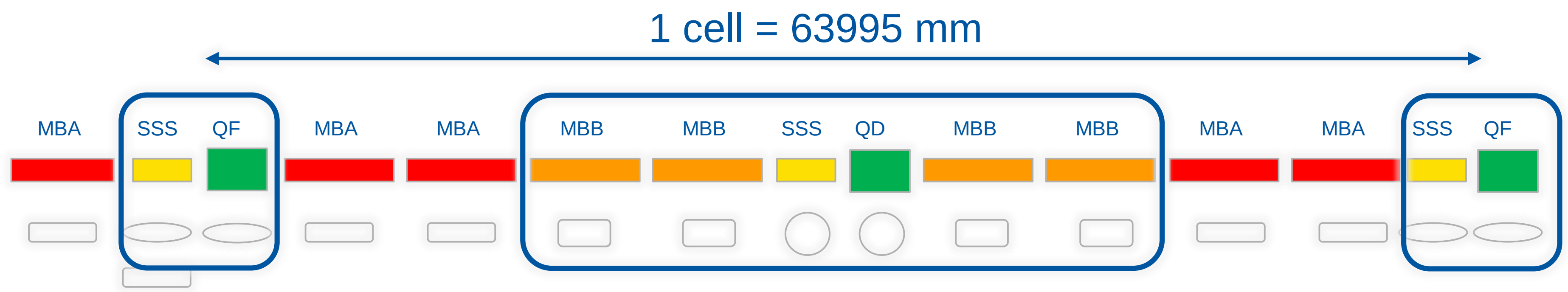
3. Application to accelerators: SPS

Layout



Risk & cost optimisation:

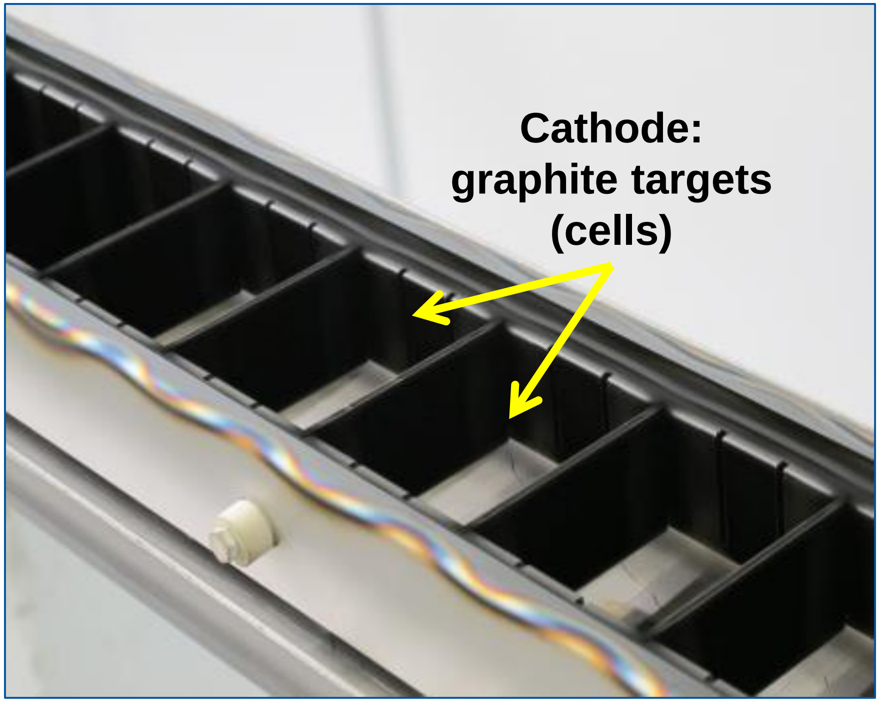
- Ranking components by “e-cloud”
- Coat chambers in the magnets
- Minimize transport/removal of magnets from the tunnel

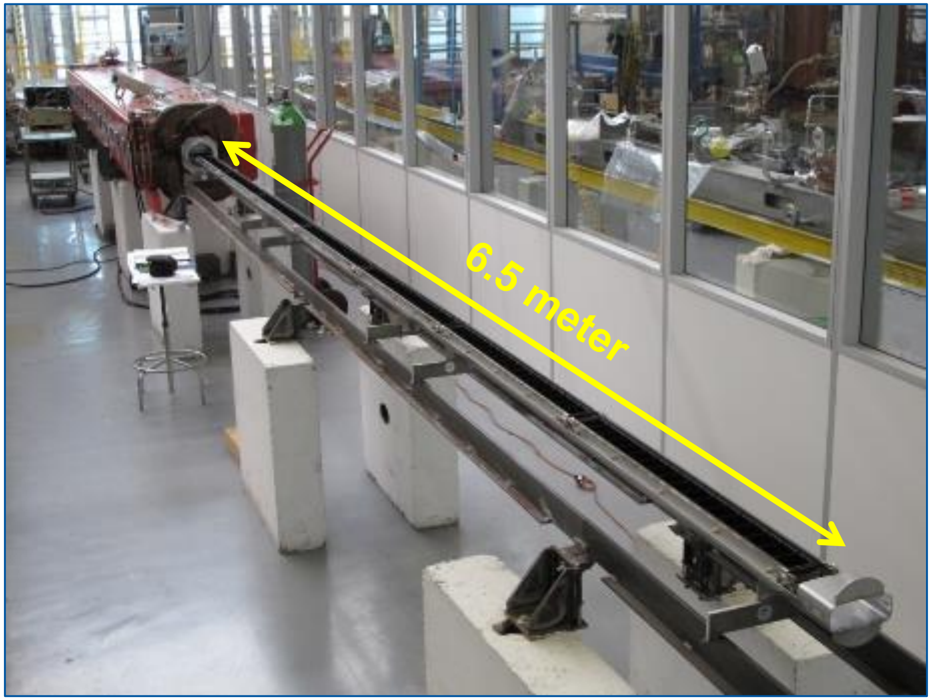
Efforts:

- ➢ Simulations
- ➢ Coating technology
- ➢ Logistics

3. Application to accelerators: SPS

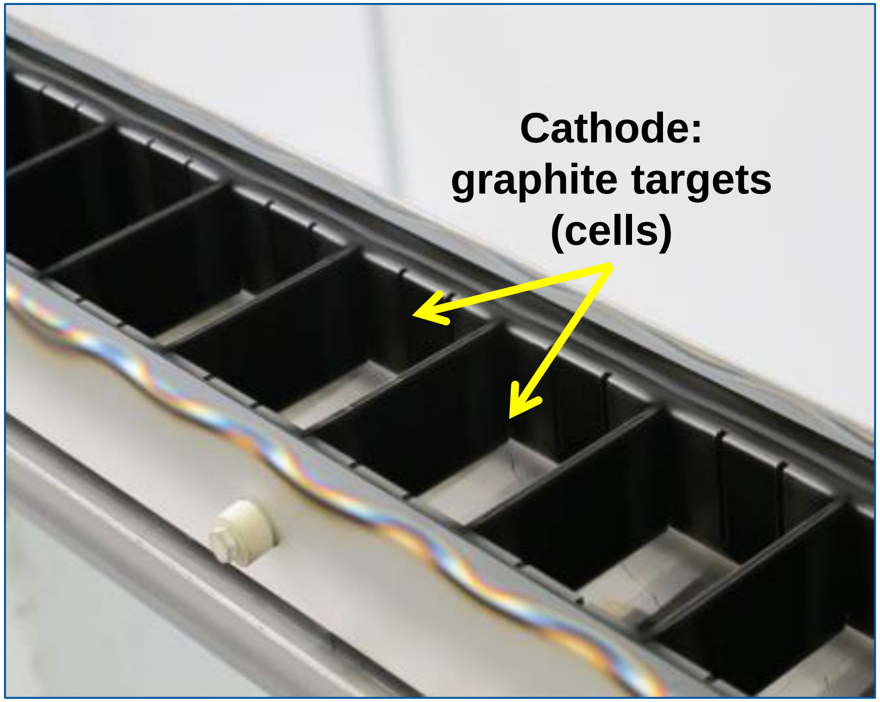
Coating technology: Hollow Cathode Sputtering

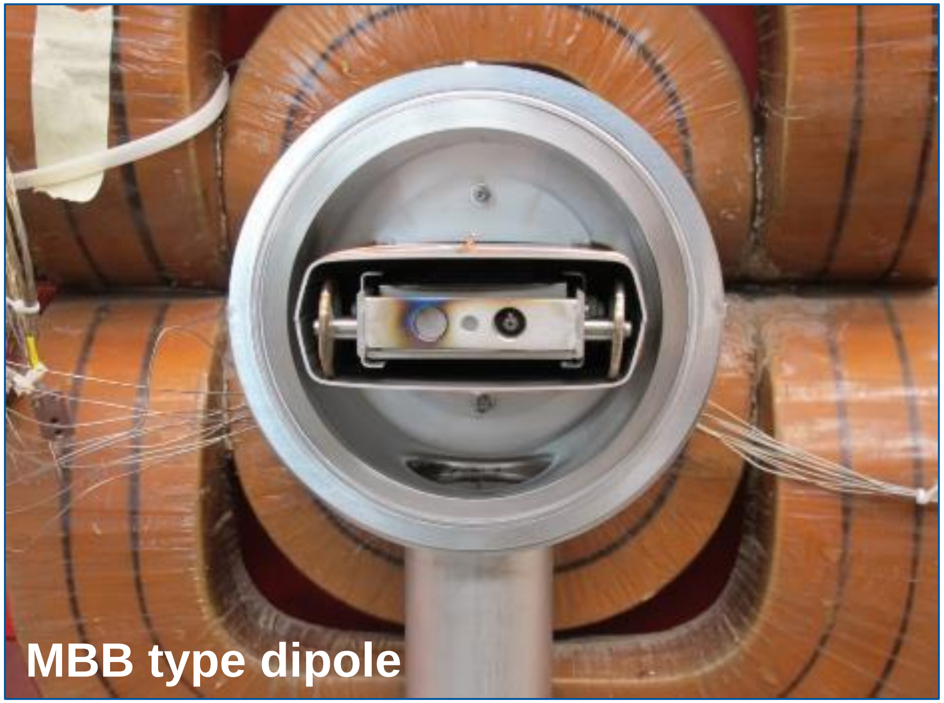




3. Application to accelerators: SPS

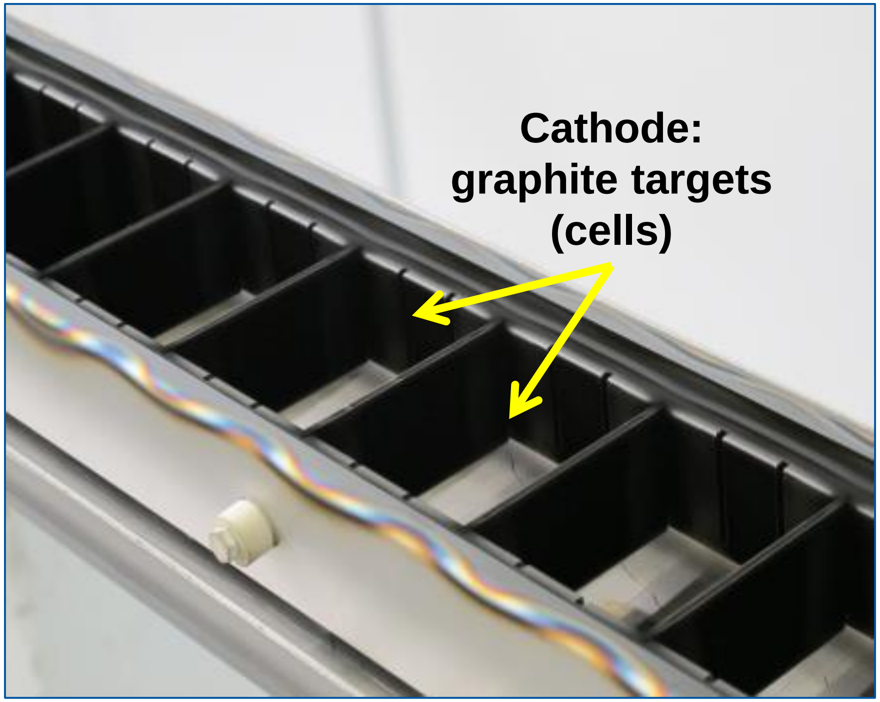
Coating technology: Hollow Cathode Sputtering

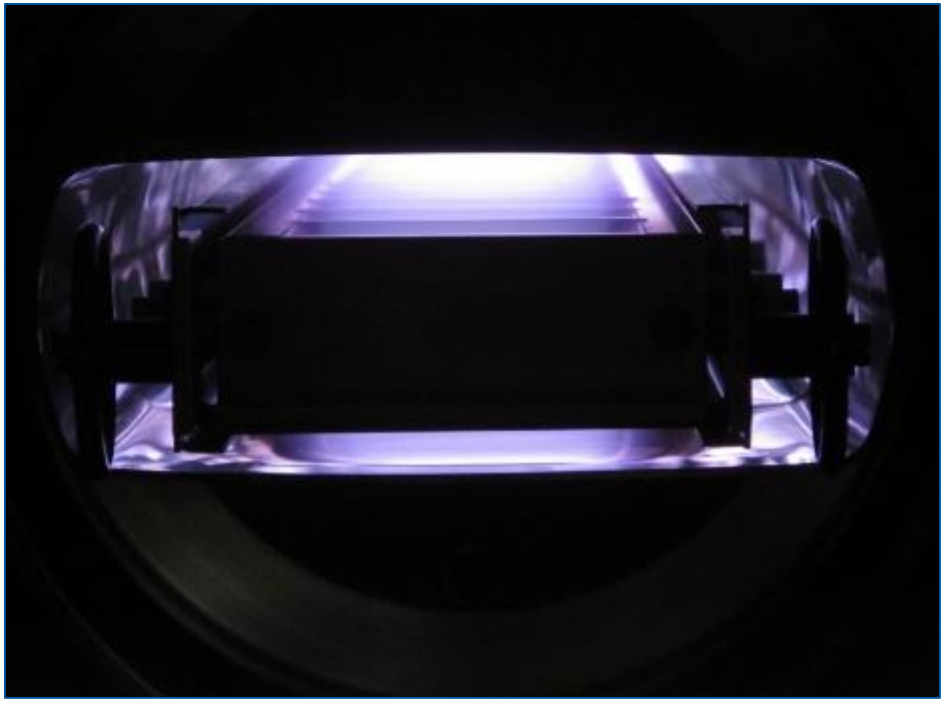




3. Application to accelerators: SPS

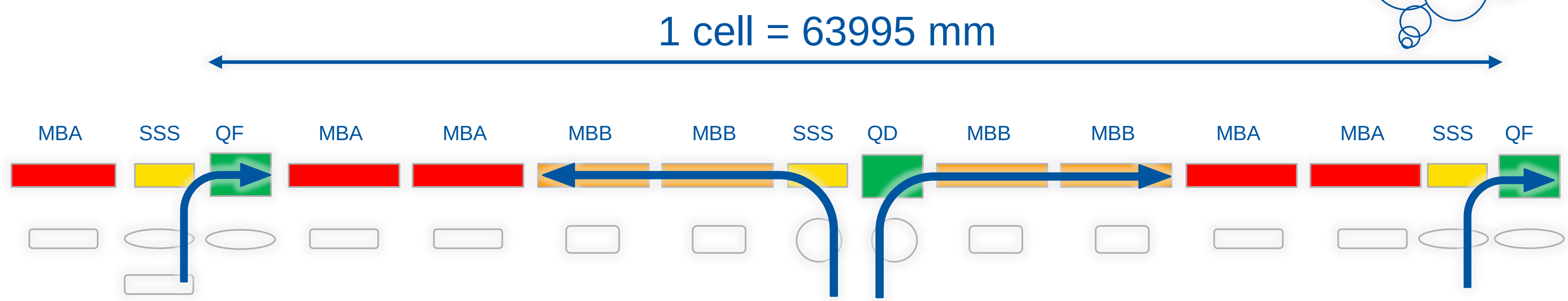
Coating technology: Hollow Cathode Sputtering





3. Application to accelerators: SPS

Logistics



Coating lab 1

Coating lab 2 (radioactive)

+ new long
drift tubes

3. Application to accelerators: SPS

Jan & Feb 2017: first SPS "in-situ" coating campaign

Goal: Check feasibility of logistics & identify problems.

Coating lab 1:
- 2 QD's
- 7 LSS runs (9 chambers)
- 3 crab cavity chambers
- 1 LOD chamber

3. Application to accelerators: SPS

Jan & Feb 2017: first SPS “in-situ” coating campaign

Goal: Check feasibility of logistics & identify problems.

Coating lab 1:
- 2 QD’s
- 7 LSS runs (9 chambers)
- 3 crab cavity chambers
- 1 LOD chamber

Coating lab 2 (radioactive):
- 7 SSS’s
- (9 magnets + 4 drifts)

3. Application to accelerators: SPS

Jan & Feb 2017: first SPS "in-situ" coating campaign

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Coating lab 1:
- 2 QD's
- 7 LSS runs (9 chambers)
- 3 crab cavity chambers
- 1 LOD chamber

Coating lab 2 (radioactive):
- 7 SSS's
- (9 magnets + 4 drifts)

SPS tunnel:
- 9 QF's
- 4x2 MBB's

3. Application to accelerators: SPS

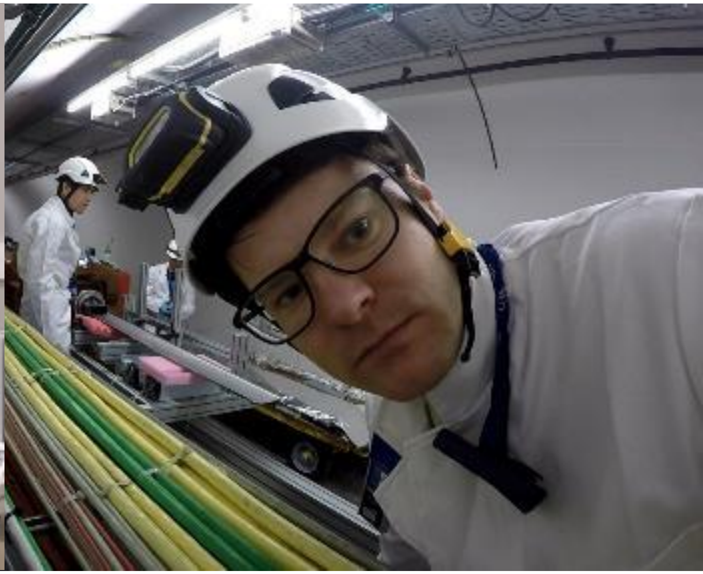
Jan & Feb 2017: first SPS “in-situ” coating campaign

Goal: Check feasibility of logistics & identify problems.

It’s feasible ☺ (small problems identified/solved)

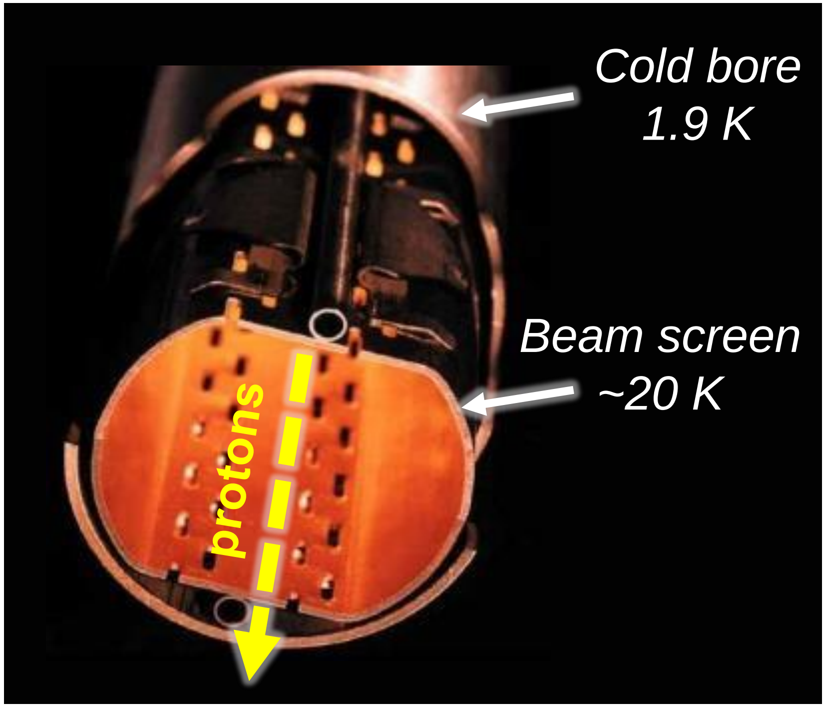
33 coating runs; ~140 meters in 2 months





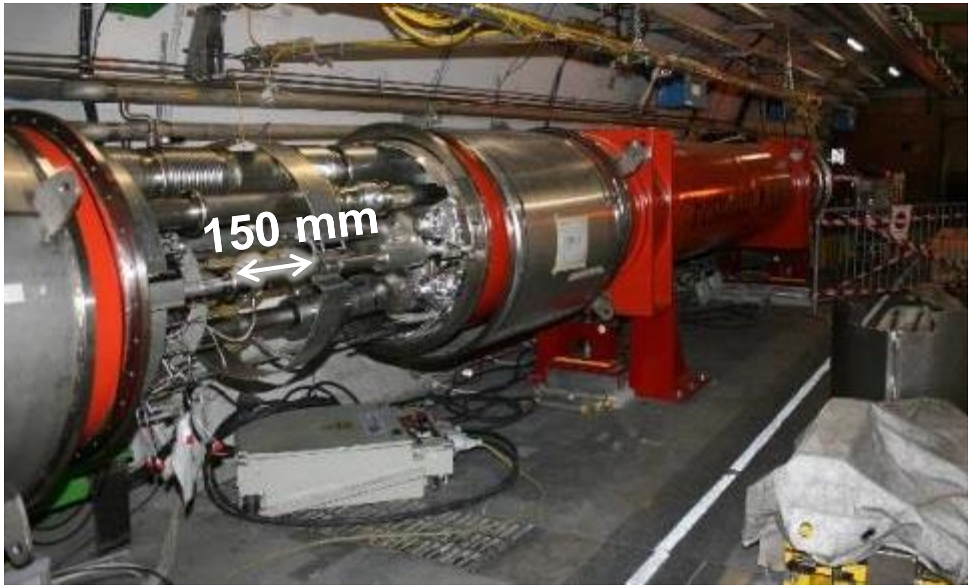
3. Application to accelerators: LHC

Heat load to the superconductive magnets that do the final focusing before the collisions



3. Application to accelerators: LHC

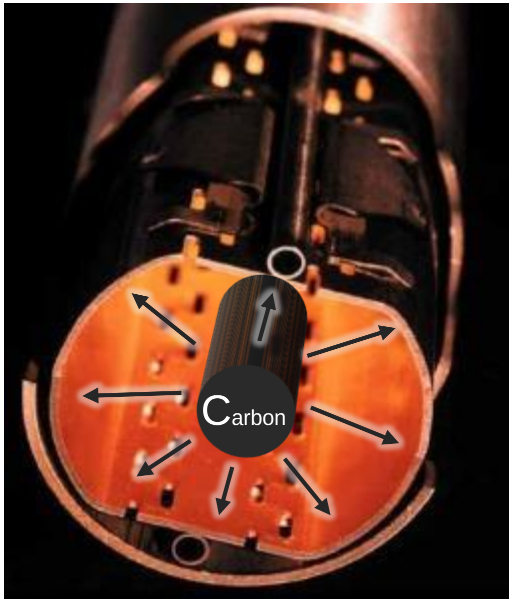
How it looks like?

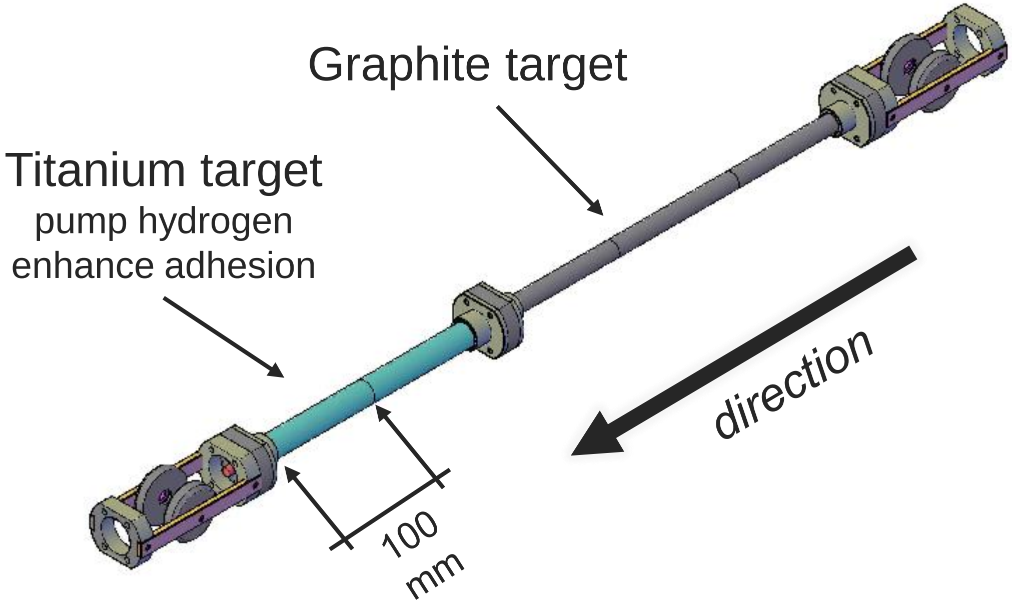


3. Application to accelerators: LHC

How to do it?

Modular sputtering source to be inserted in a 150 mm slot and pulled by cables all along the magnets.





3. Application to accelerators: LHC

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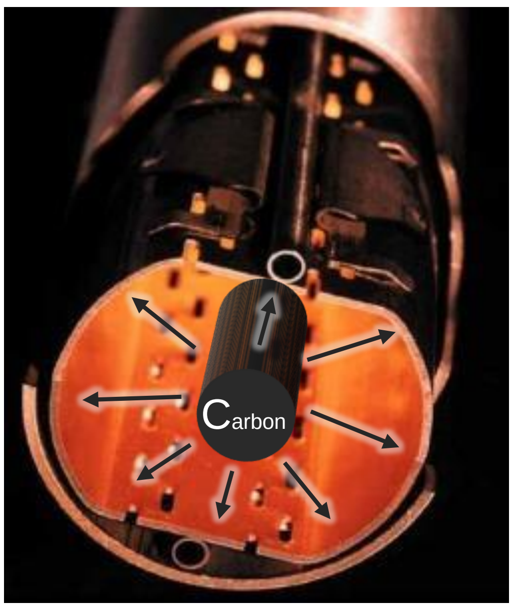
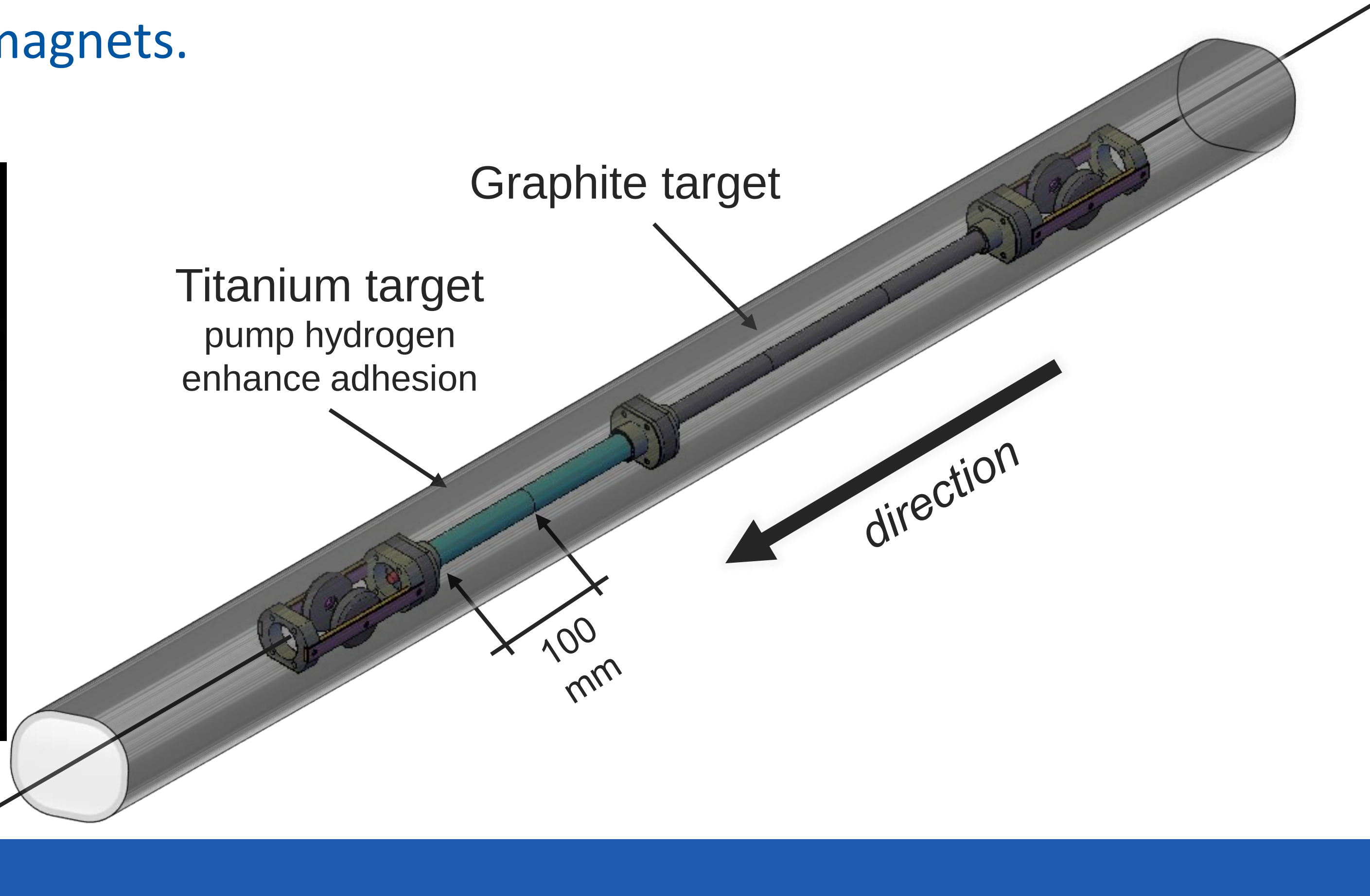
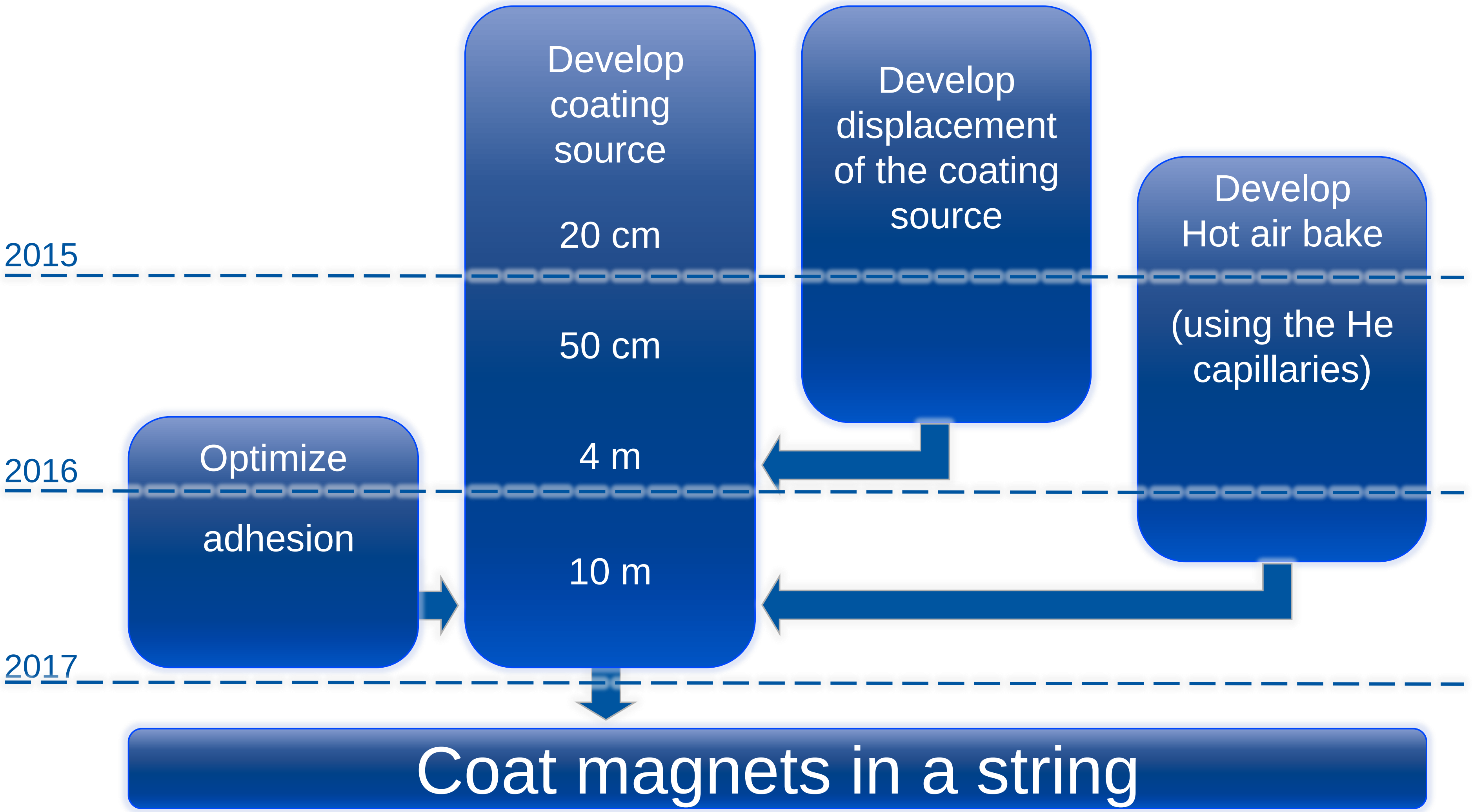
Modular sputtering source to be inserted in a 150 mm slot and pulled by cables all along the magnets.





3. Application to accelerators: LHC

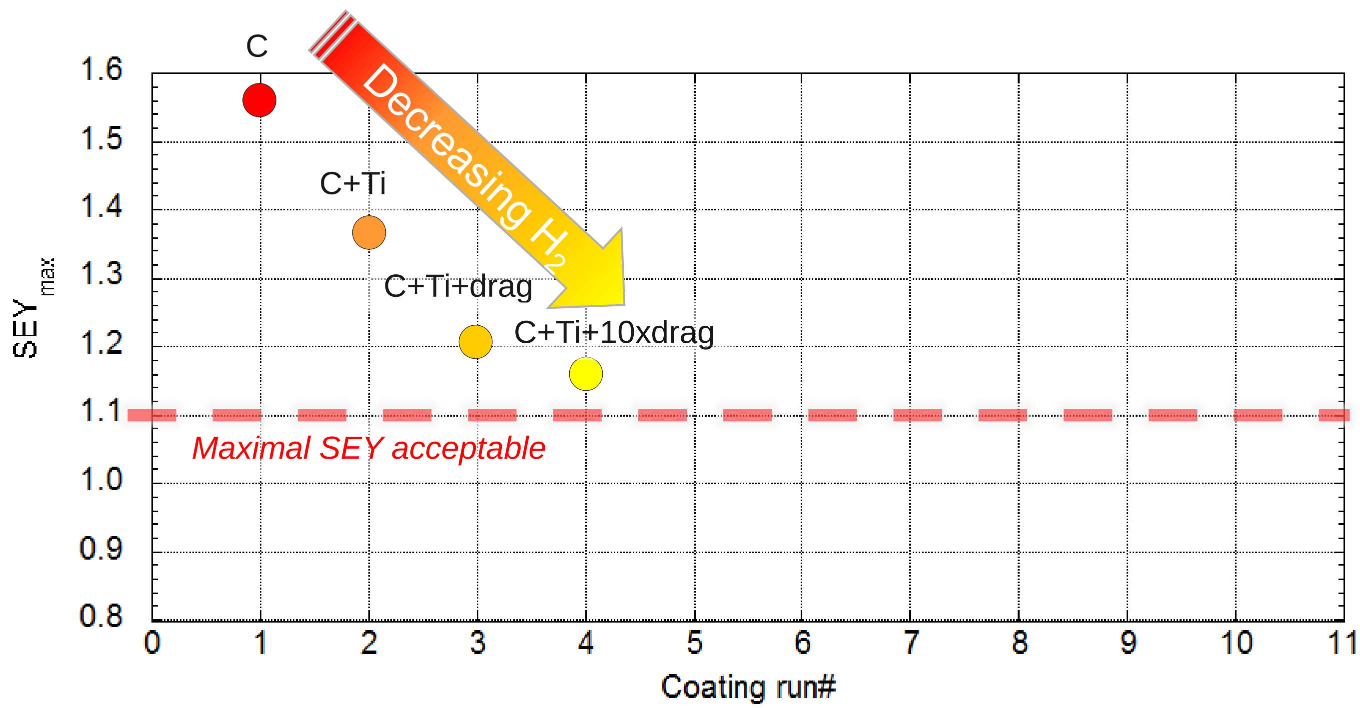
Strategy



3. Application to accelerators: LHC

Development of the coating source

Mitigate hydrogen outgassing by: **Ti gettering + molecular drag**

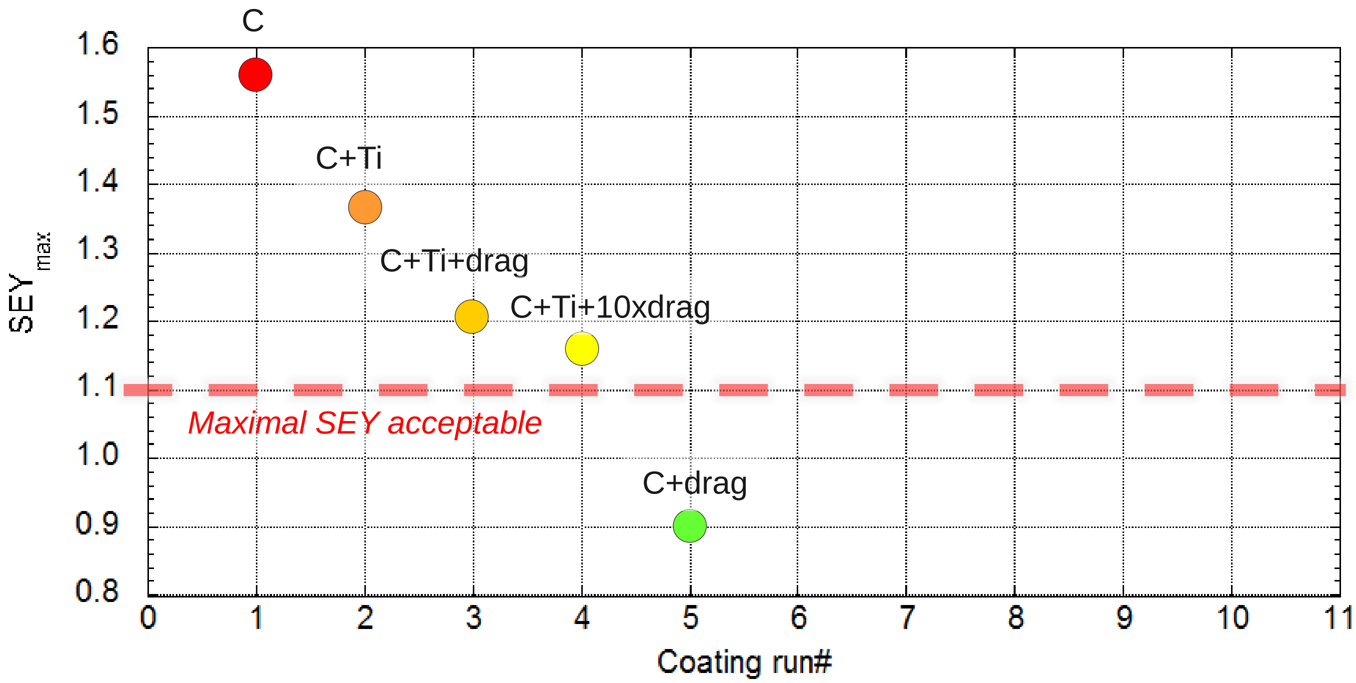


DC diode sputtering

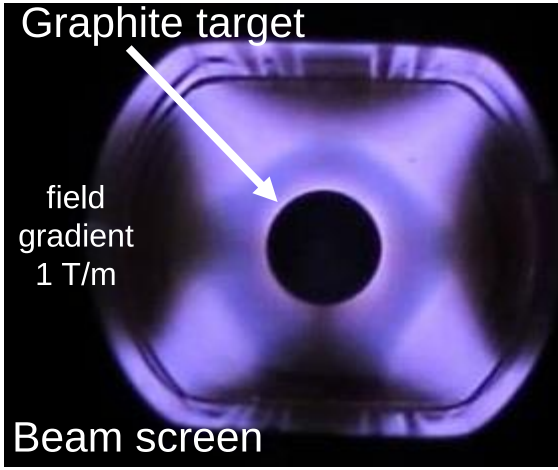
3. Application to accelerators: LHC

Development of the coating source

Mitigate hydrogen outgassing by: **Ti gettering** + **molecular drag**+ **increase the deposition rate**.



Magnetron using the Quadrupole magnet



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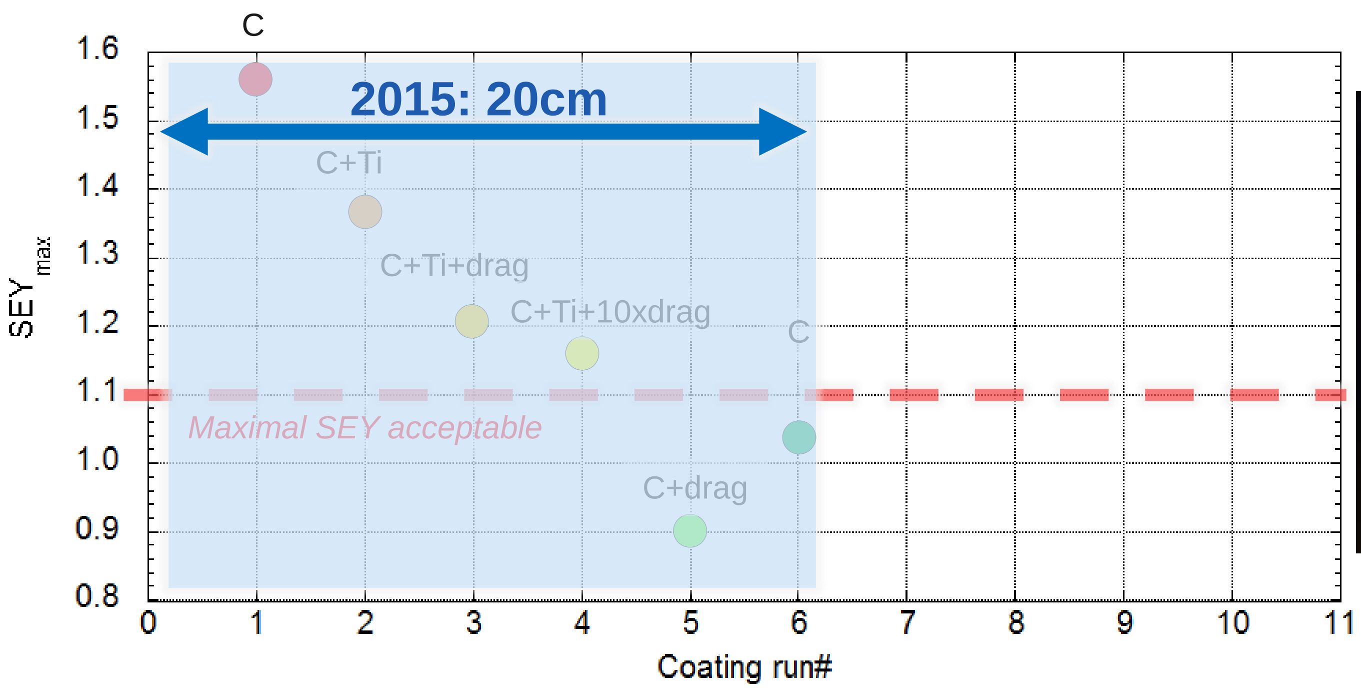
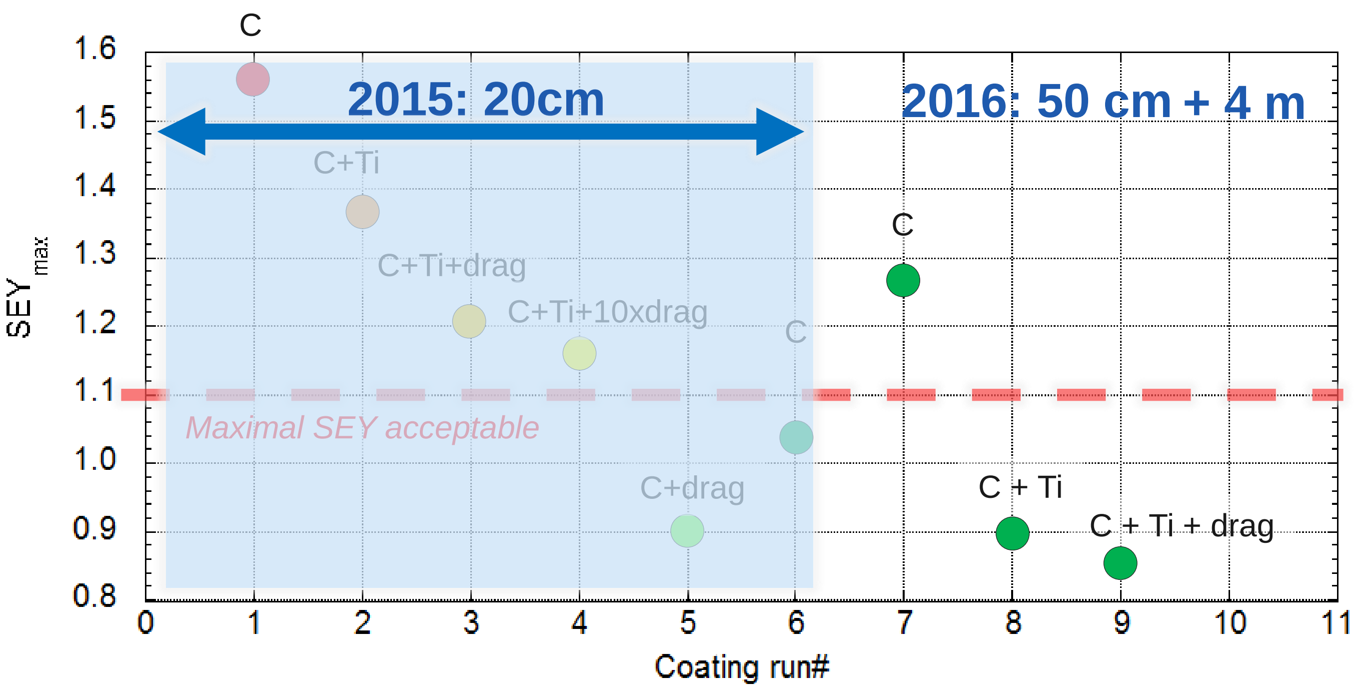


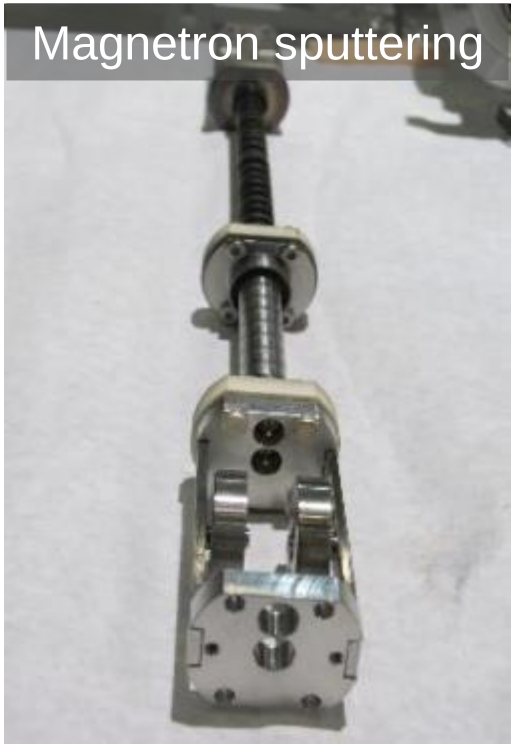
Magnetron using permanent magnets

3. Application to accelerators: LHC

Development of the coating source

Mitigate hydrogen outgassing by: **Ti gettering** + **molecular drag**+ **increase the deposition rate**.

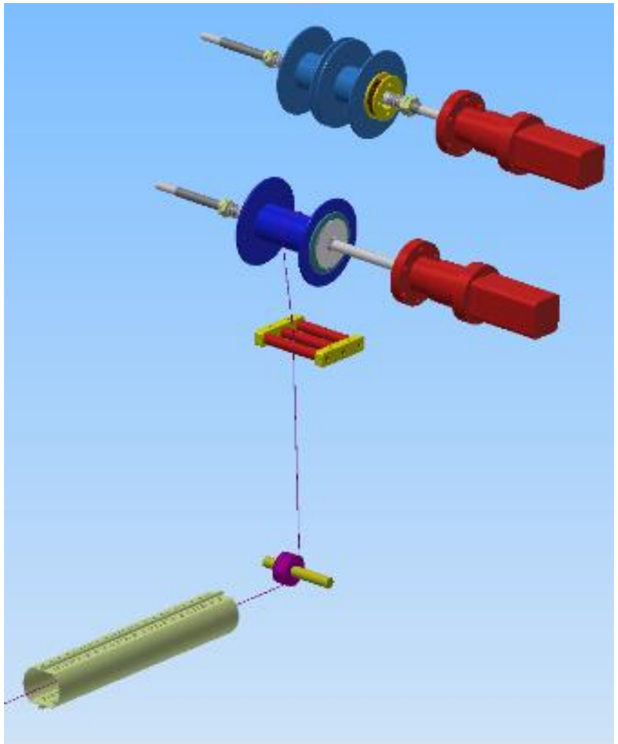


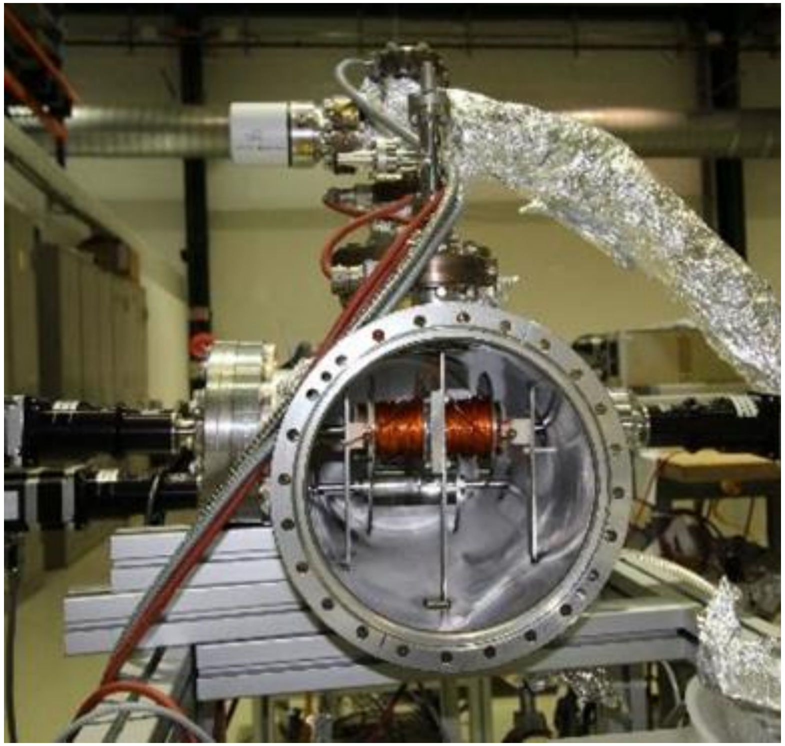


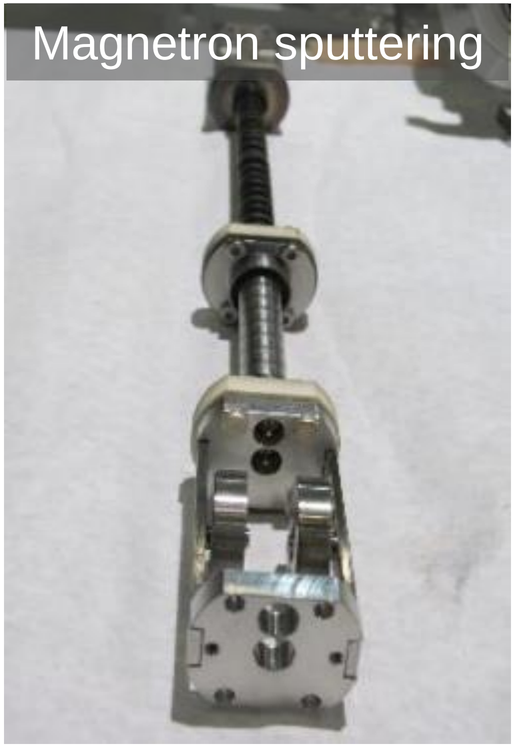
3. Application to accelerators: LHC

Development of the coating source

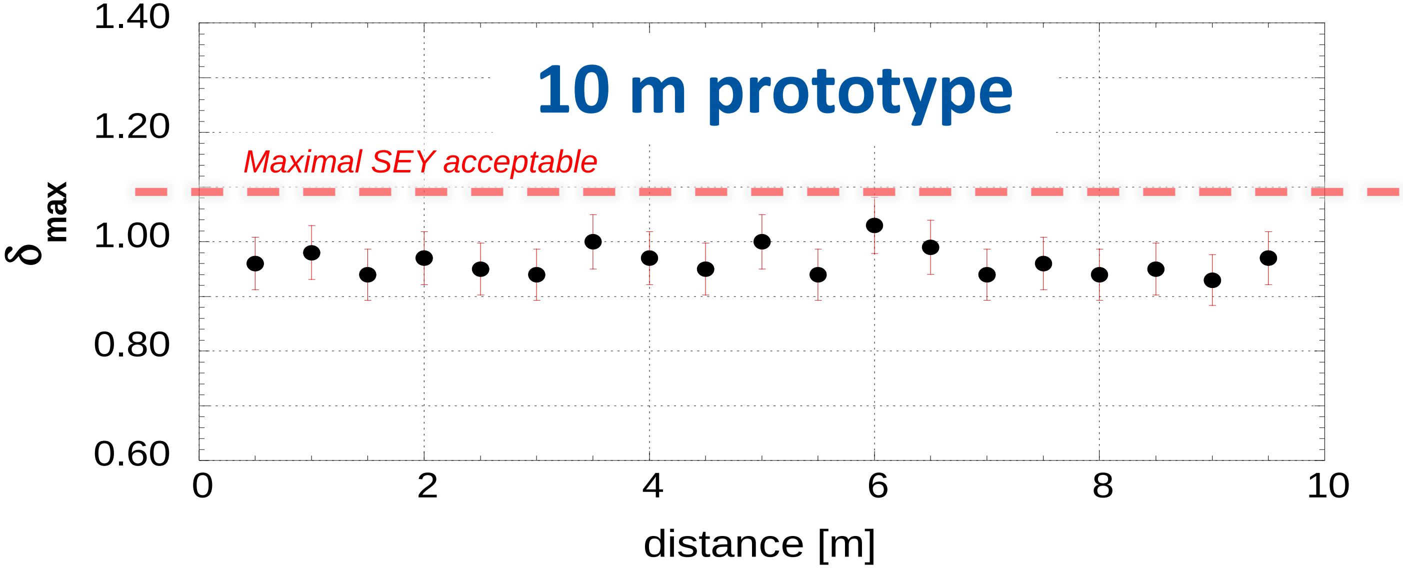
Displacement of the sputtering source.

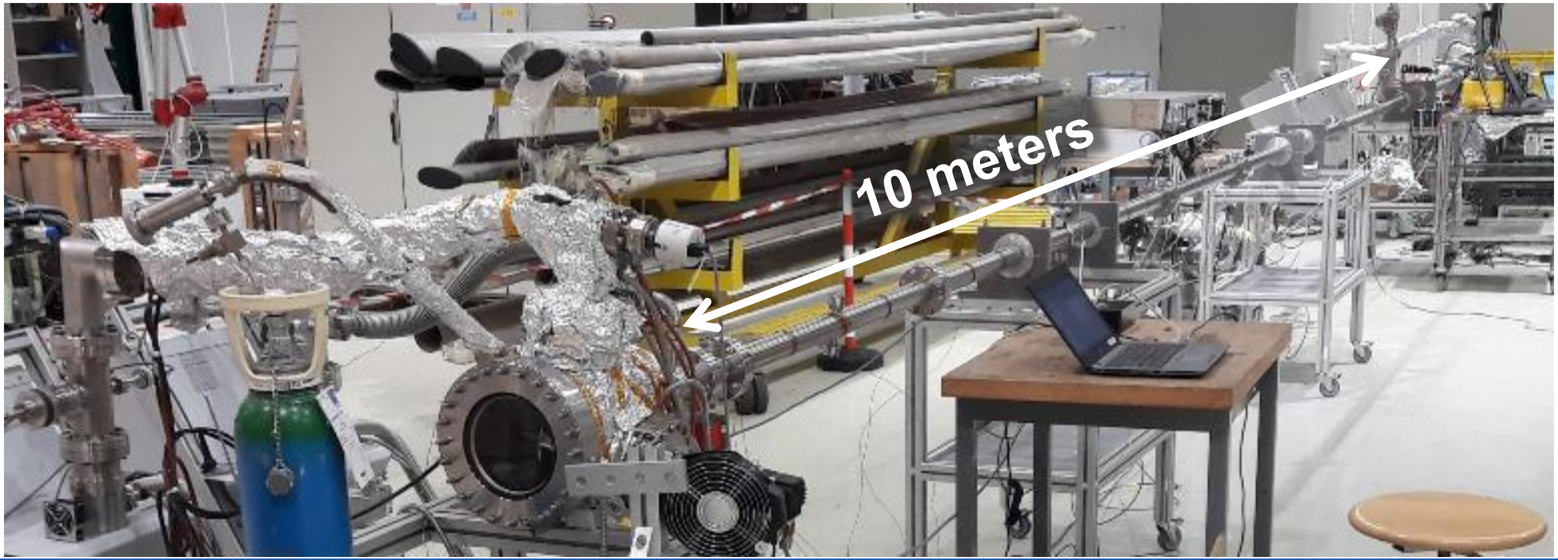






3. Application to accelerators: LHC





3. Application to accelerators: LHC

Still to be done:

- Demonstrate flawless adhesion (independent of the surface state of the substrate)
- Implement hot air bakeout through capillaries.
- Test radiation resistance of the coating (1GGy)
- Prototypes for larger diameter beam screens.
- Coat a string of magnets.
- How do we assess the coating quality in the real magnets?

4. Summary

- In-situ coating technology can minimize risks and costs on the upgrade of components already installed.
- The first coating campaign in the SPS was a success and allowed to optimise the process.
- Developments for the LHC are in good track, but still a hard way to pave!


Accept the risk, find the way, execute.

3. Application to accelerators: SPS

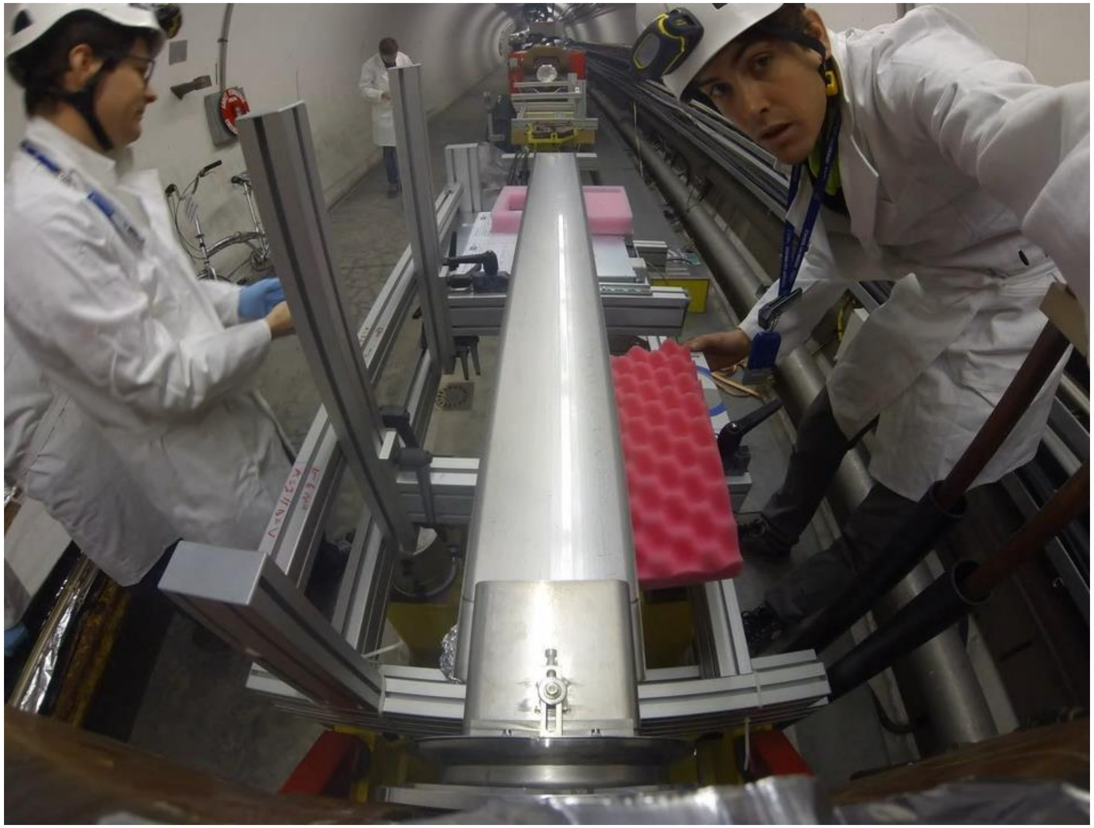
Jan & Feb 2017: first SPS “in-situ” coating campaign

Goal: Check feasibility of logistics & identify problems.

Coating lab 1:
- 2 QD’s
- 7 LSS runs (9 chambers)
- 3 crab cavity chambers
- 1 LOD chamber

Coating lab 2 (radioactive):
- 7 SSS’s
- (9 magnets + 4 drifts)

SPS tunnel:
- 9 QF’s
- 4x2 MBB’s



2. The SPS case

Developments started end of 2007

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1st step: coat beam pipes and install in the magnets



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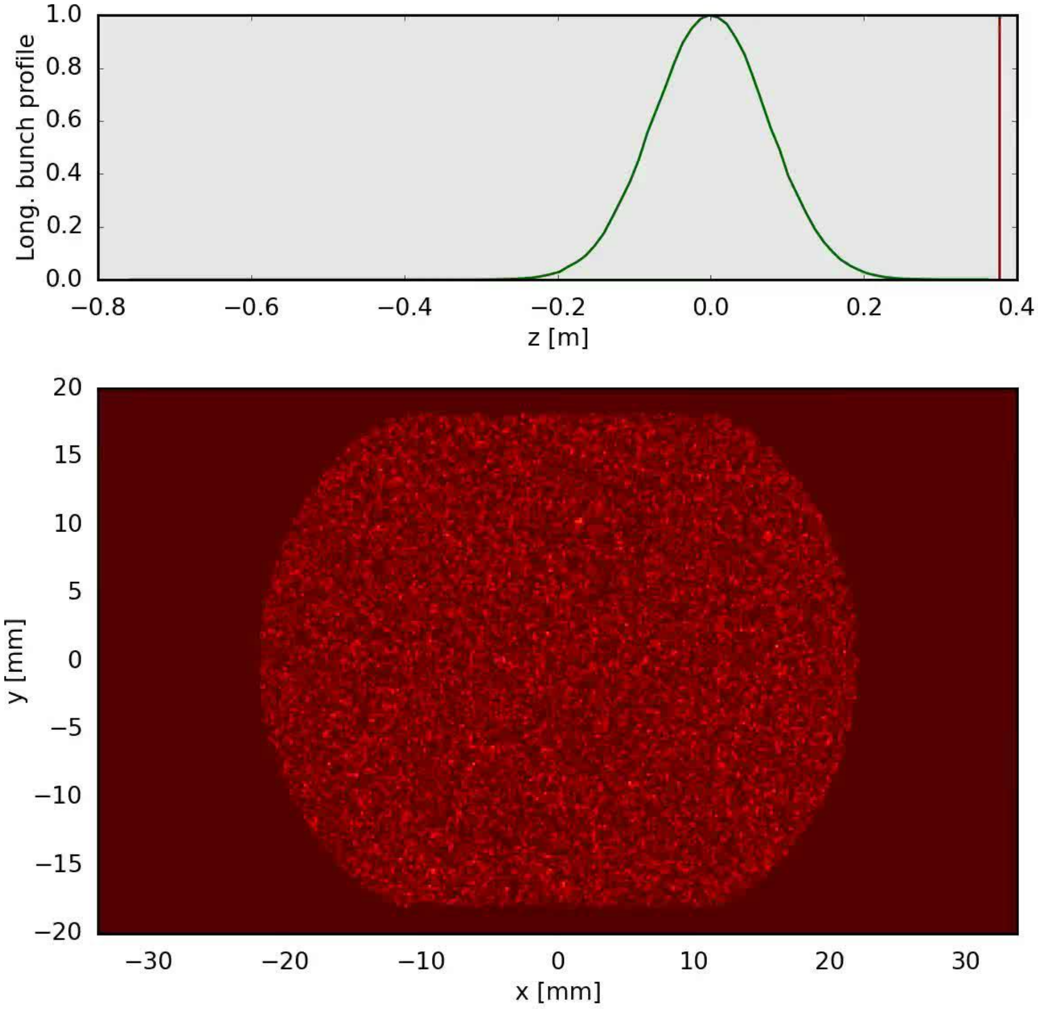
Developments started end of 2007

1st step: coat beam pipes and install in the magnets => very expensive! (~20 MCHF)

-> Dismount from tunnel
-> Open the yoke
-> remove the chamber
-> install coated chamber
-> close the yoke
-> pumping port and bellow
-> check magnetic length
-> mount in the tunnel
-> align



Long. bunch profile
1.0
0.8
0.6
0.4
0.2
0.0
−0.8
−0.6
−0.4
−0.2
0.0
0.2
0.4
z [m]
y [mm]
20
15
10
5
0
−5
−10
−15
−20
−30
−20
−10
0
10
20
30
x [mm]

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All done in due time ☺

(minor problems identified)

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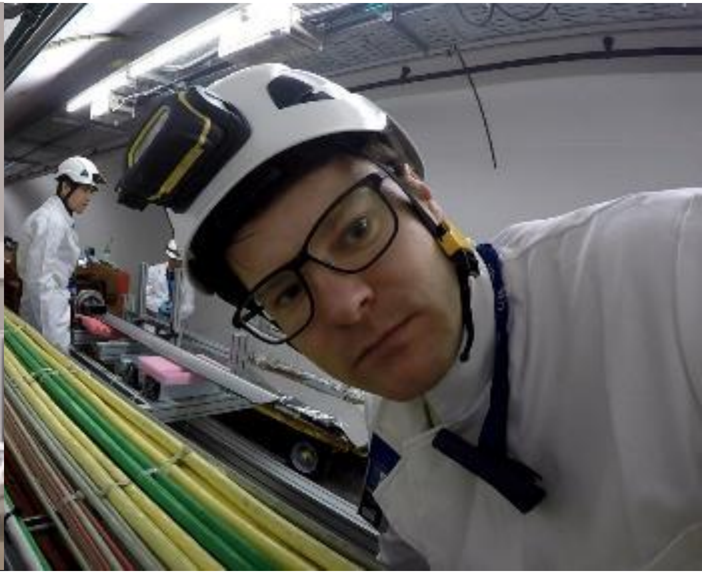

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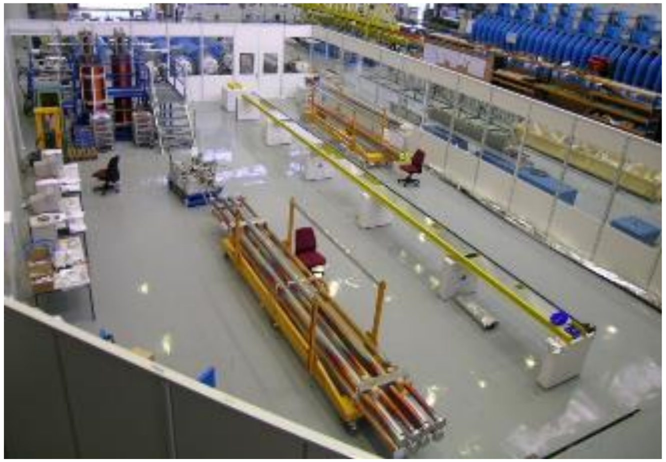
Coating lab 2



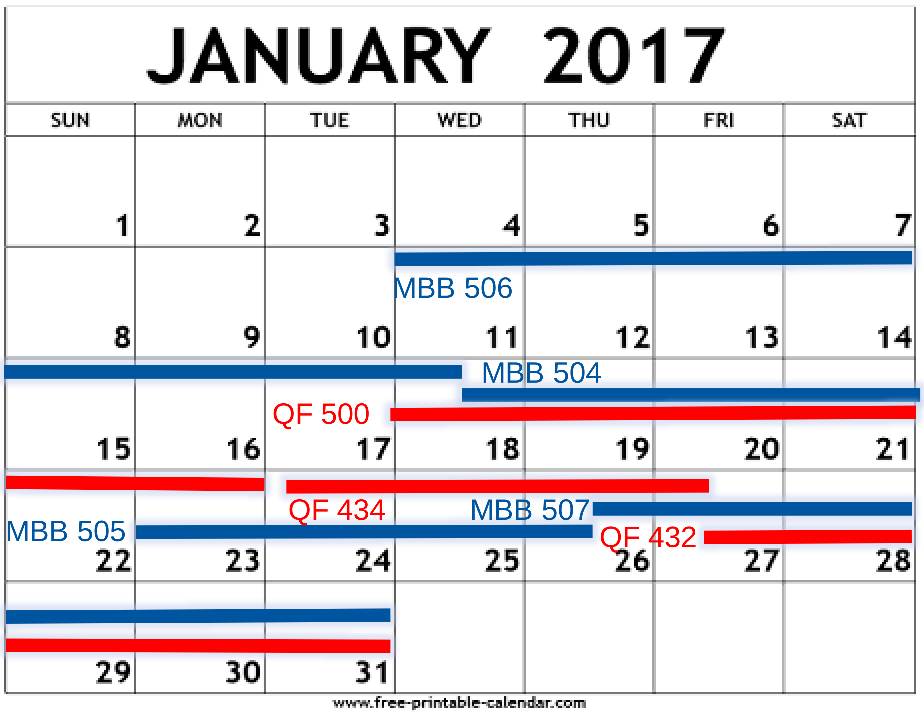
2 QD’s
7 LSS runs (9 chambers)
3 crab cavity chambers
1 LOD chamber

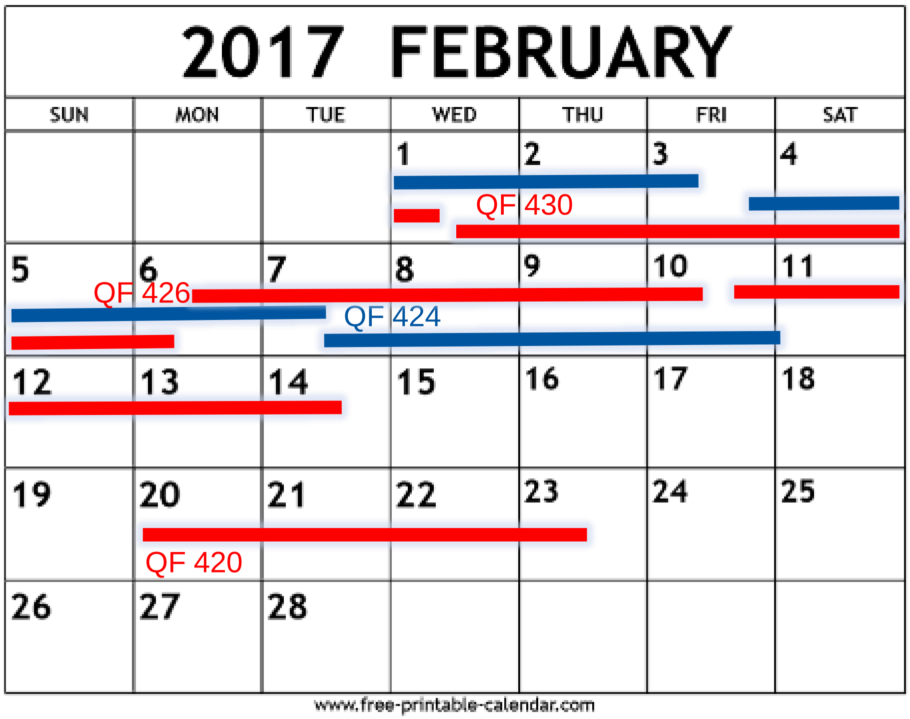
SPS tunnel

9 QF’s
4x2 MBB’s

3. Application to accelerators: SPS

33 coating runs; ~140 meters in 2 months



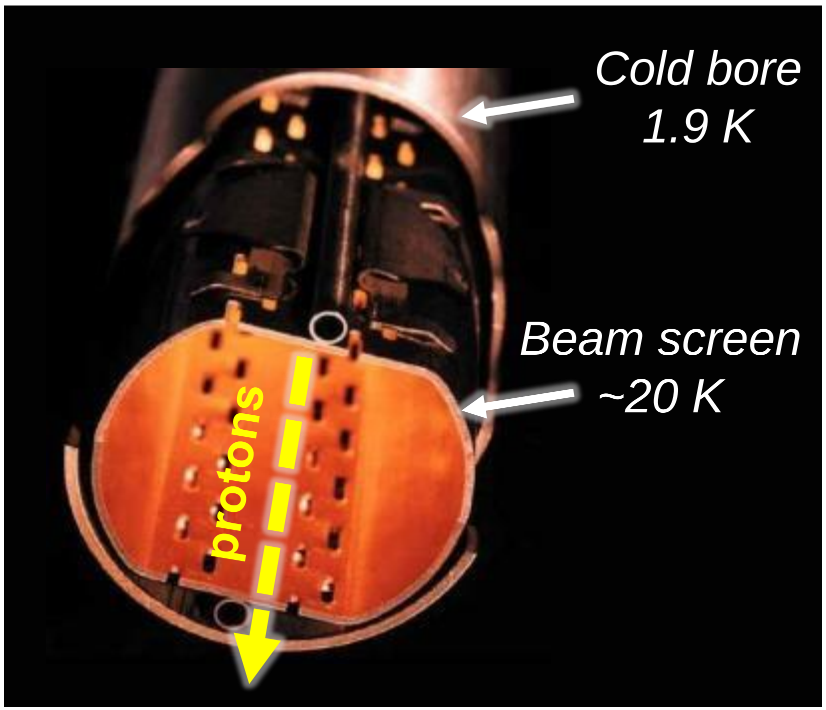


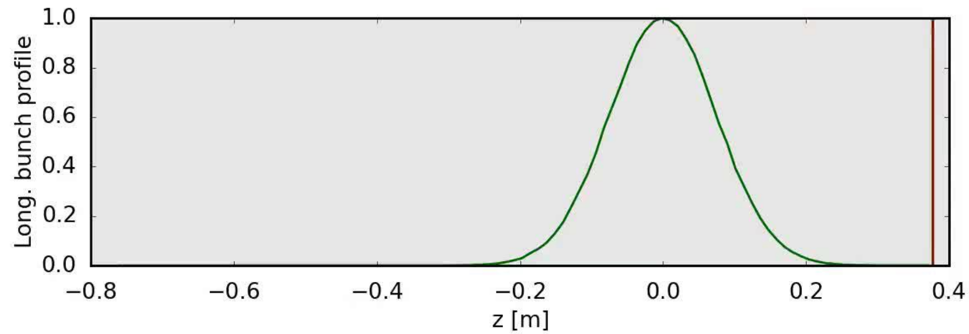
MBB coating system

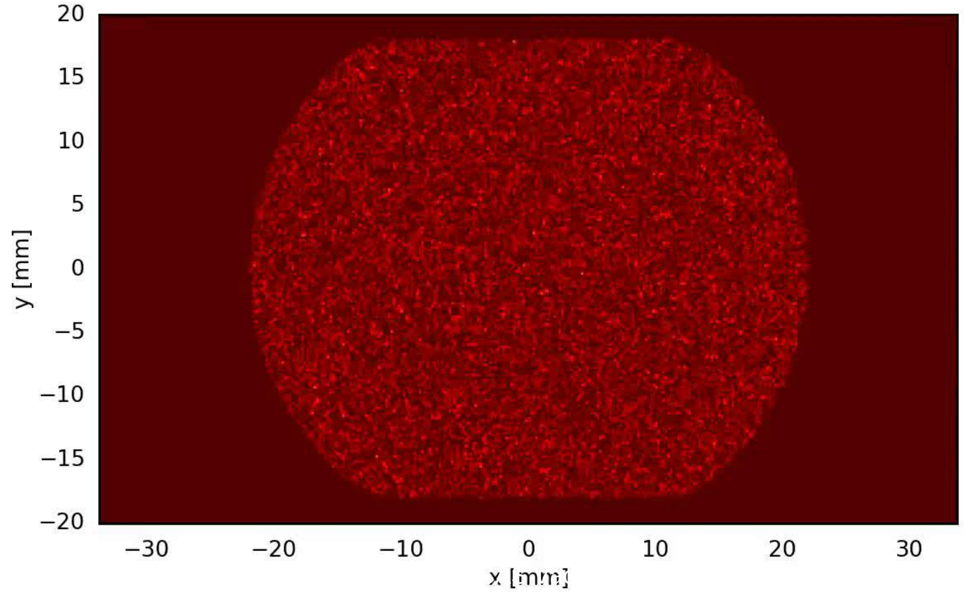
QF coating system

3. Application to accelerators: LHC

Heat load to the superconductive magnets that do the final focusing before the collisions







3. Application to accelerators: LHC

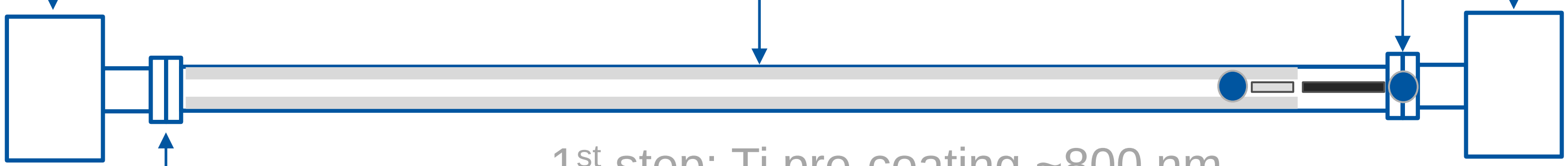
10 m prototype

1 spool for mechanical cable
+
2 spools for electrical cables

1 spool for mechanical cable

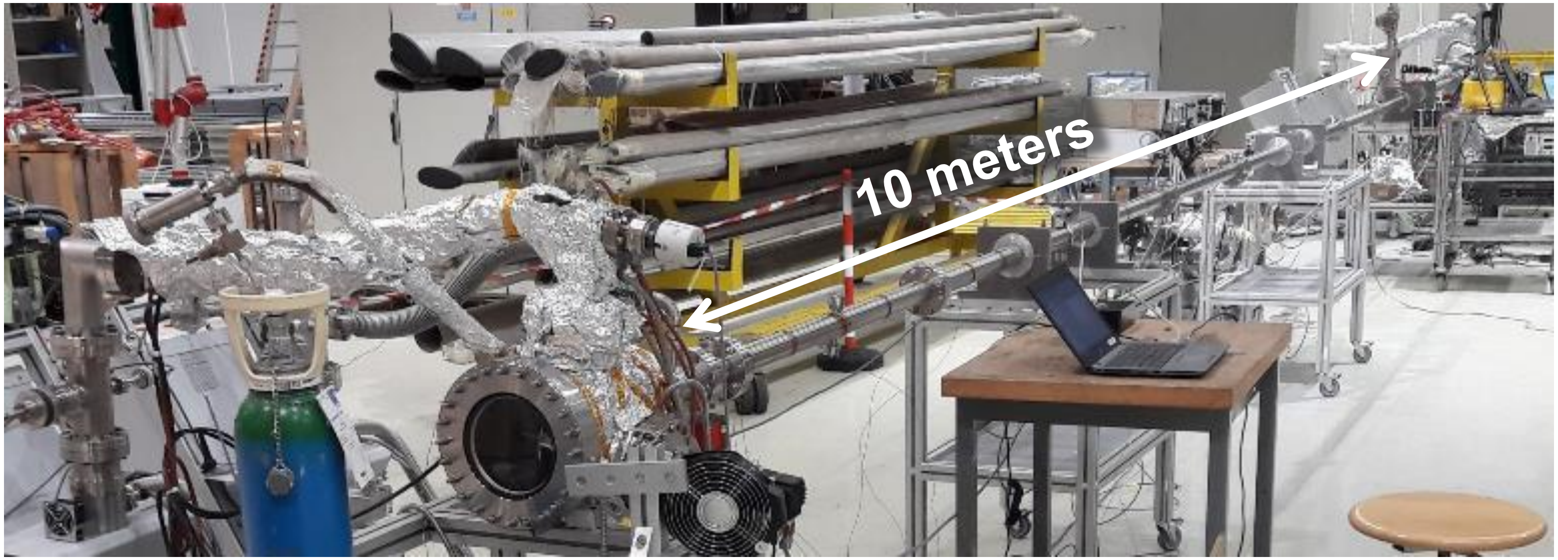
Cold bore + beam screen

Ar injection



Turbo molecular pump

1[st] step: Ti pre-coating ~800 nm



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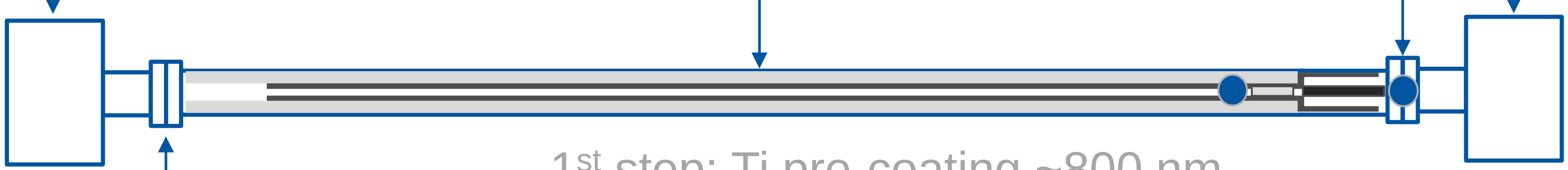
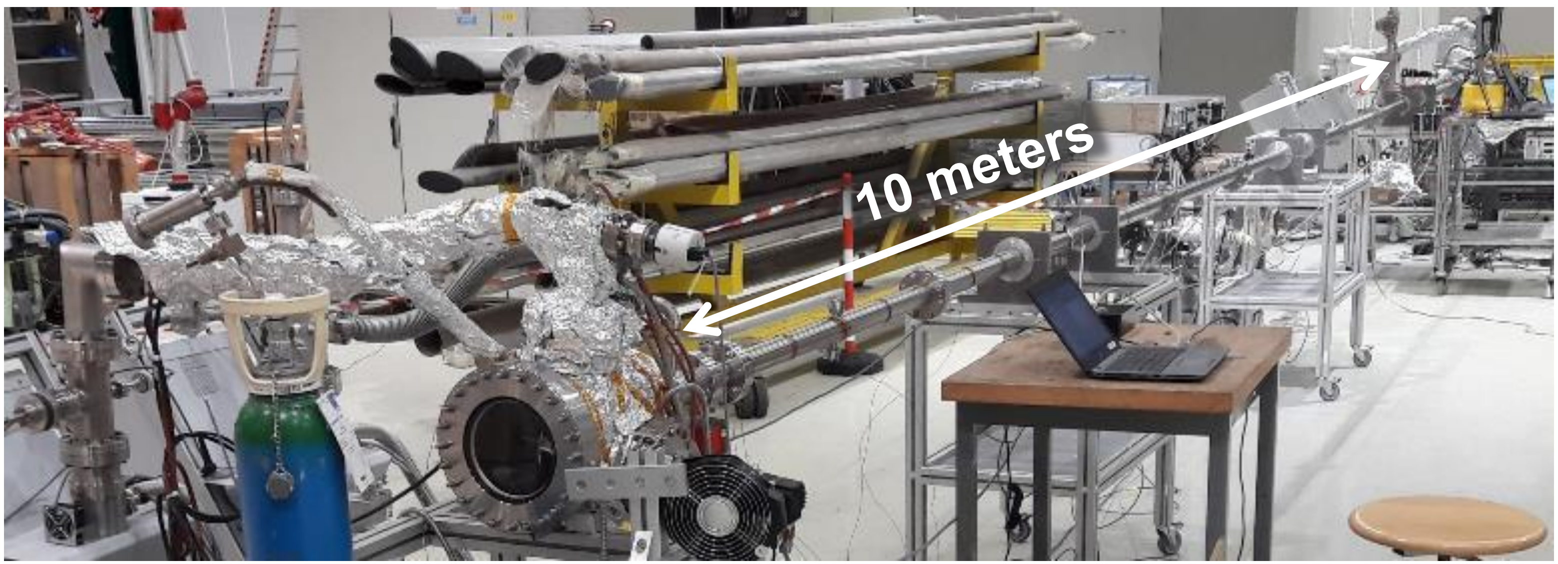


Turbo molecular pump

1[st] step: Ti pre-coating ~800 nm

2[st] step: carbon coating ~90 nm (with Ti flashes)



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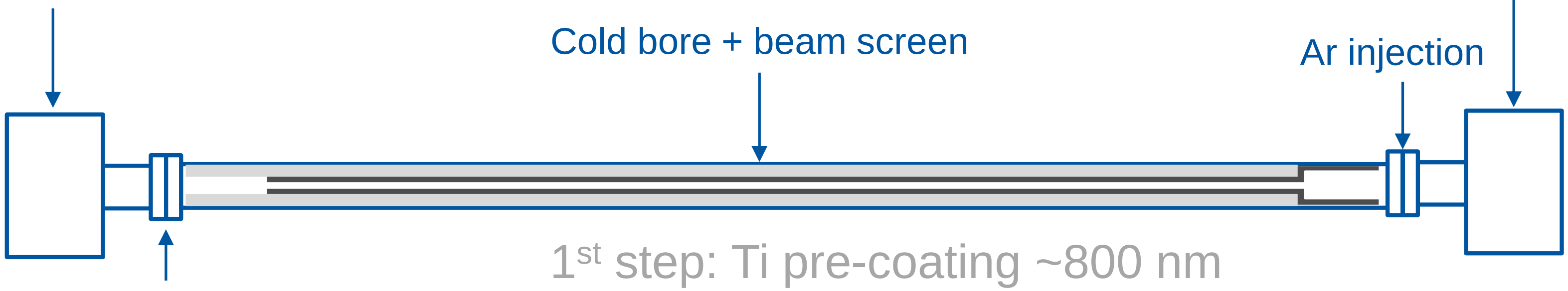

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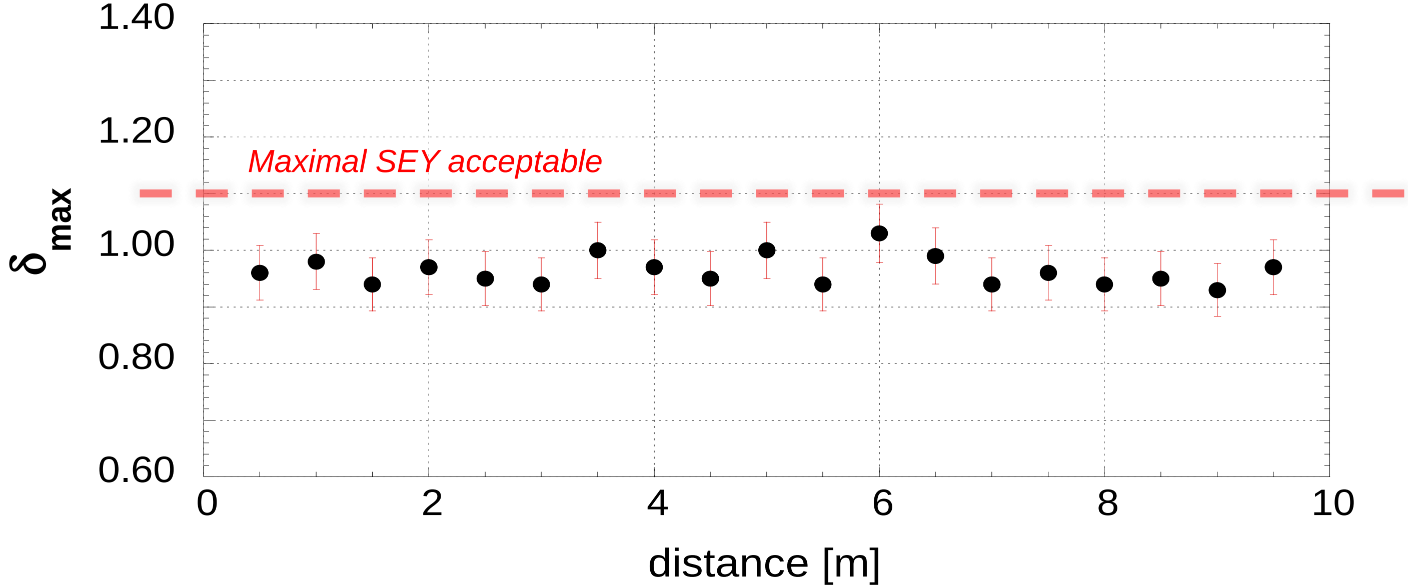
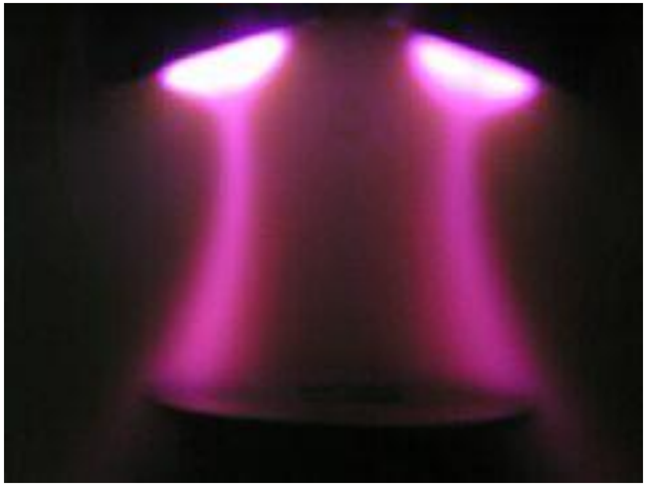
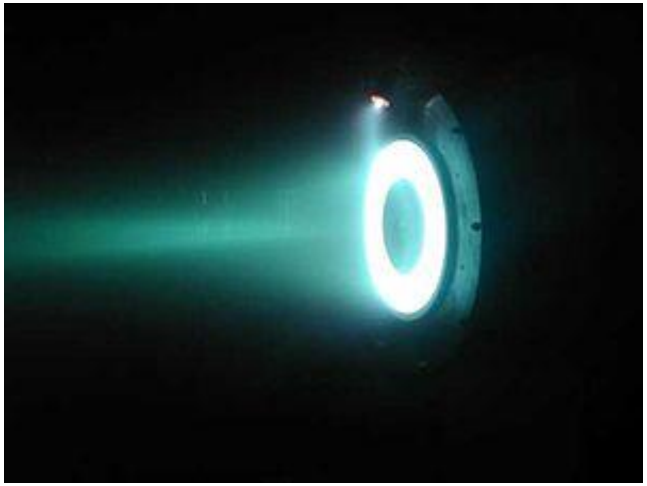


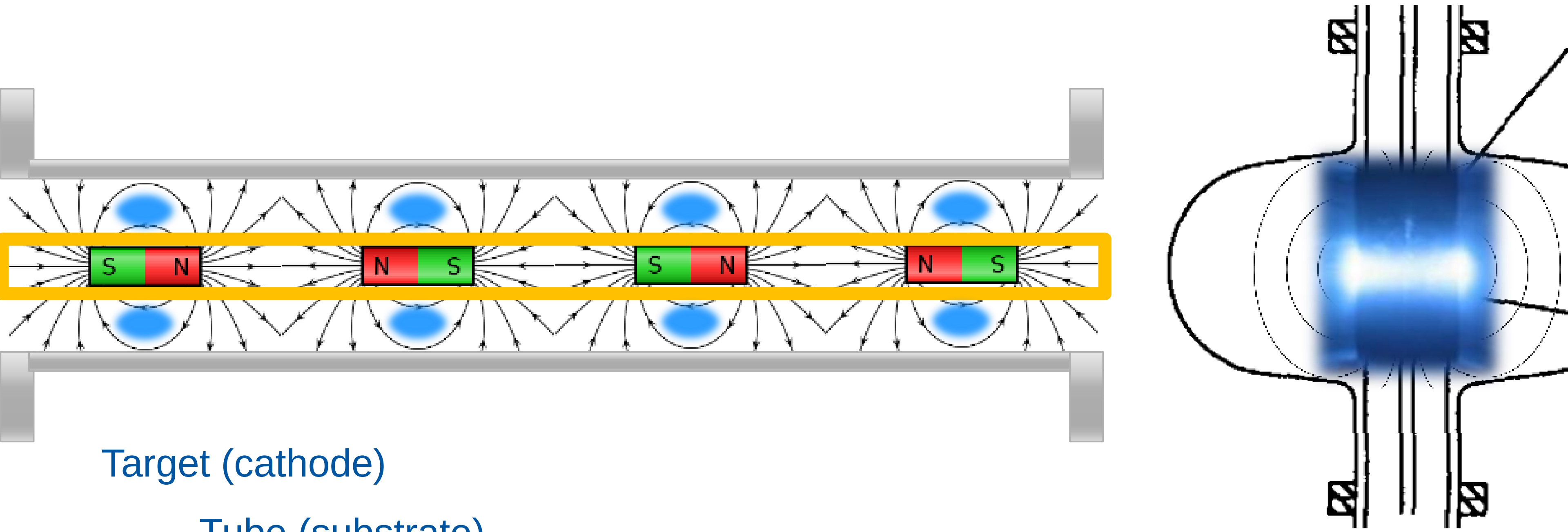




2. Sputtering: Coating technology

Glow discharge Cylindrical Magnetron

Natural configuration to coat in tubes.



Target (cathode)

Tube (substrate)

2. Sputtering: Coating technology

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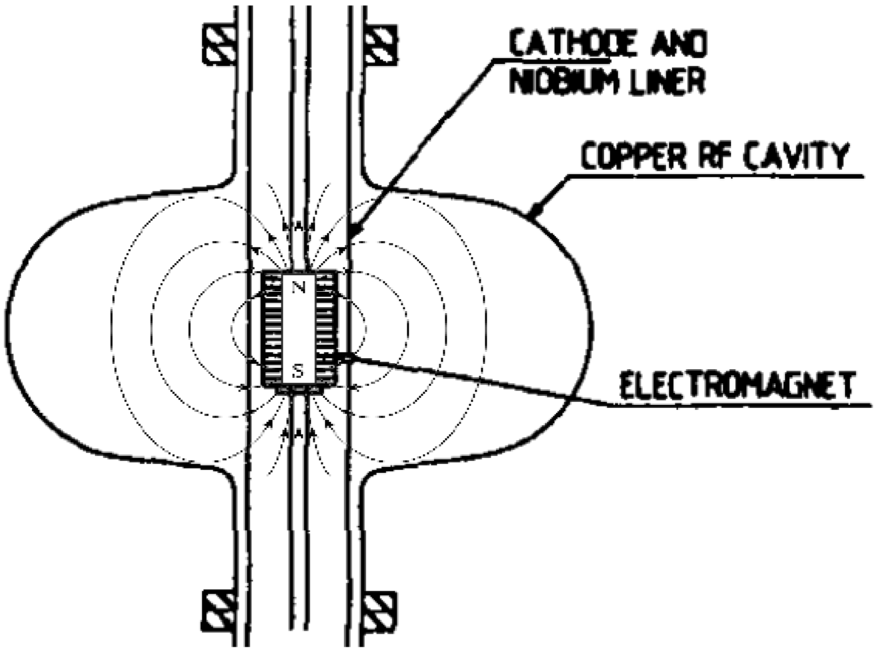

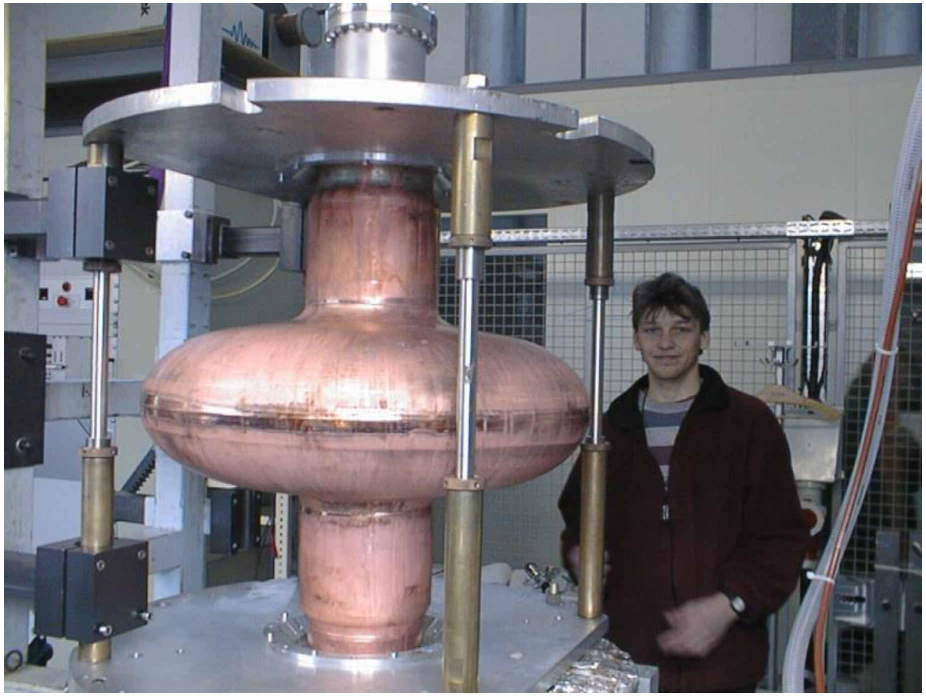

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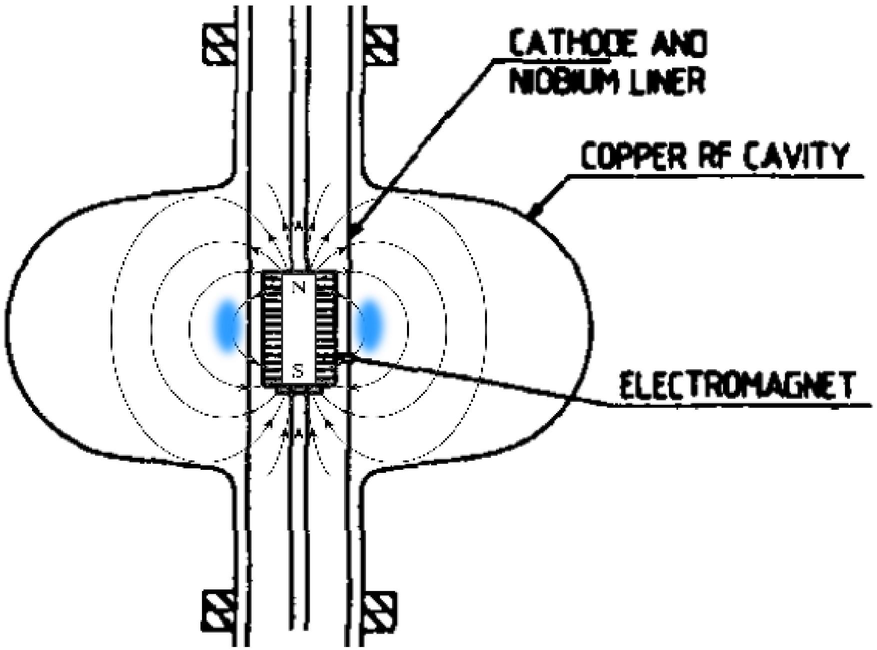

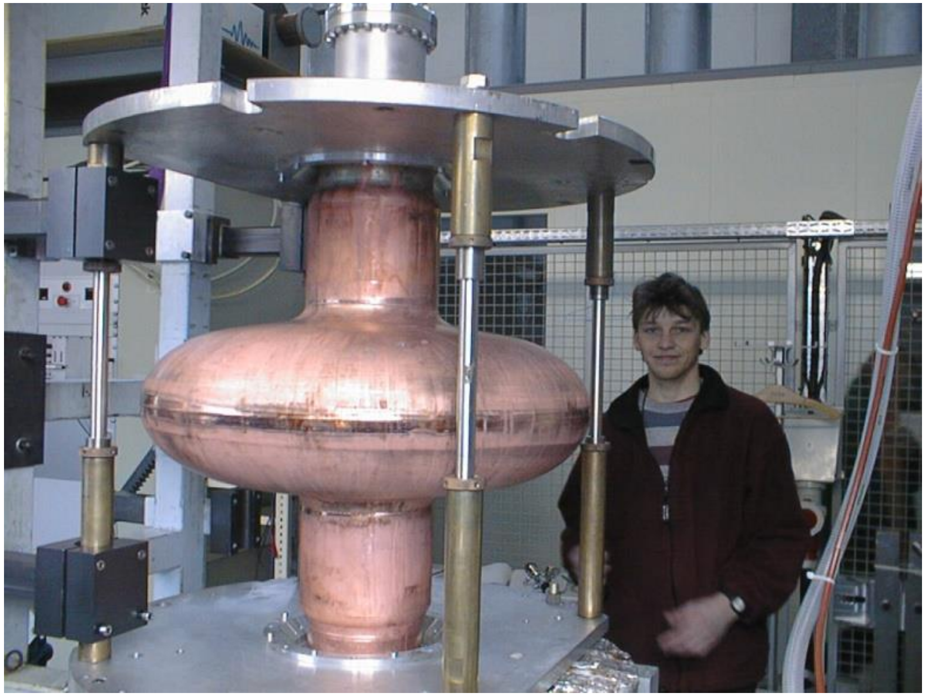

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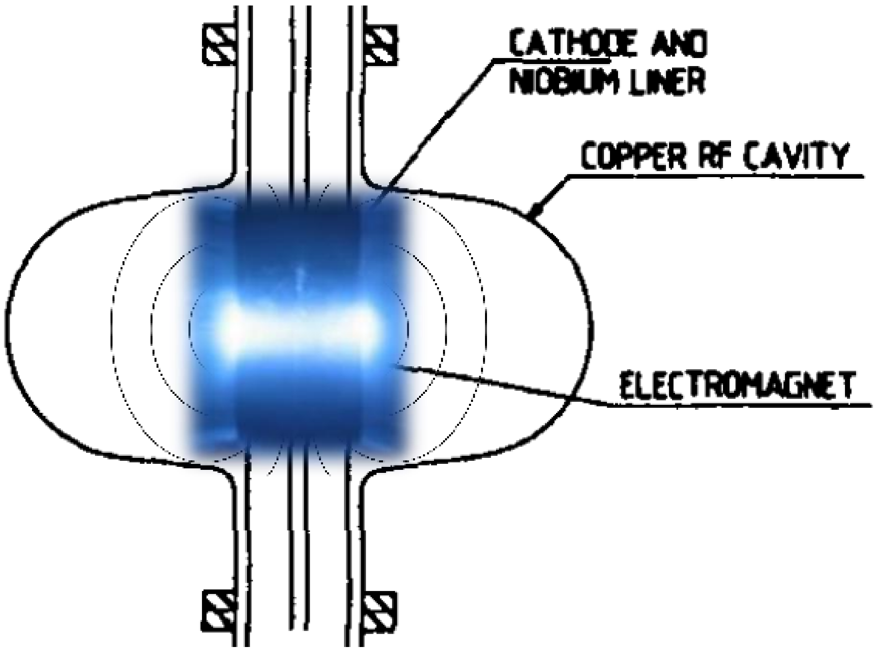

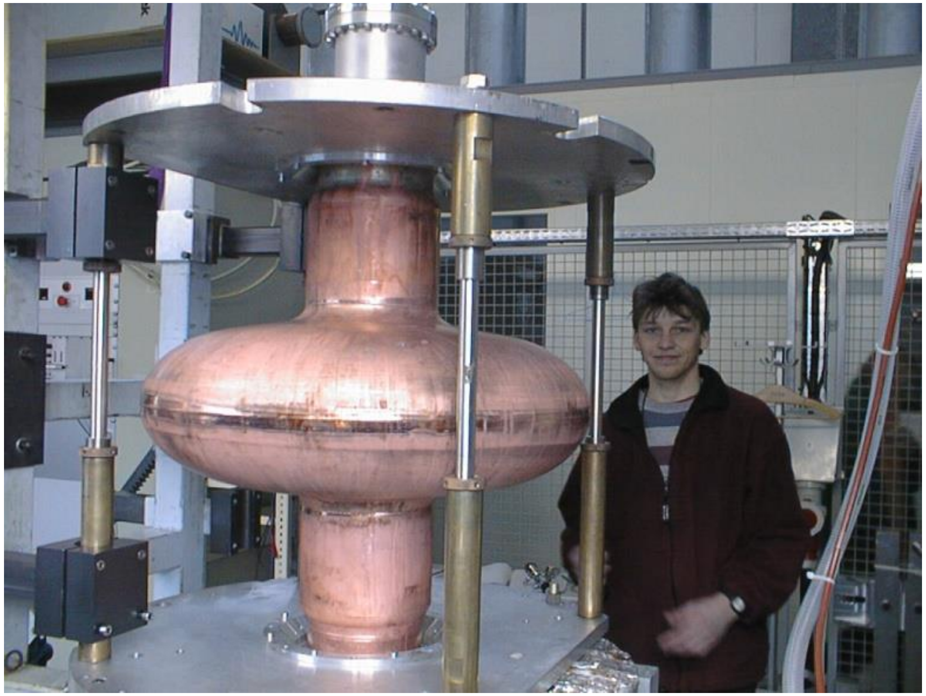

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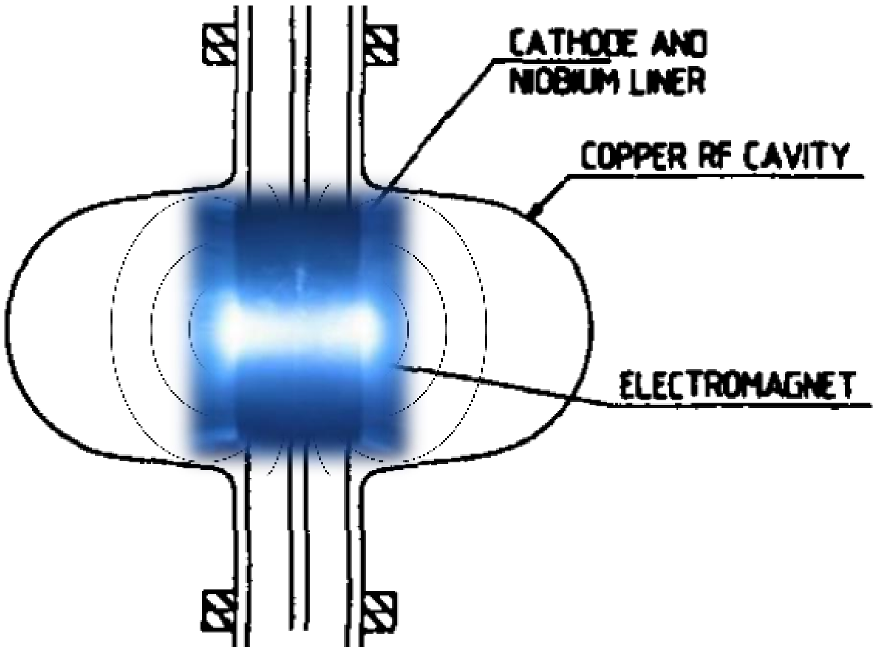
Glow discharge Magnetron

Cylindrical configuration.



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