CERN

Non Evaporable Getter thin films for Particles Accelerators

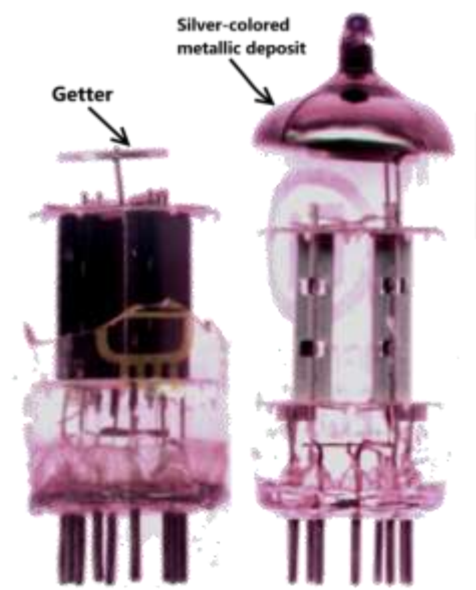
P. Costa Pinto, A. Sapountzis, T. Sinkovits, M. Taborelli
CERN, European Organization for Nuclear Research, Geneva, Switzerland

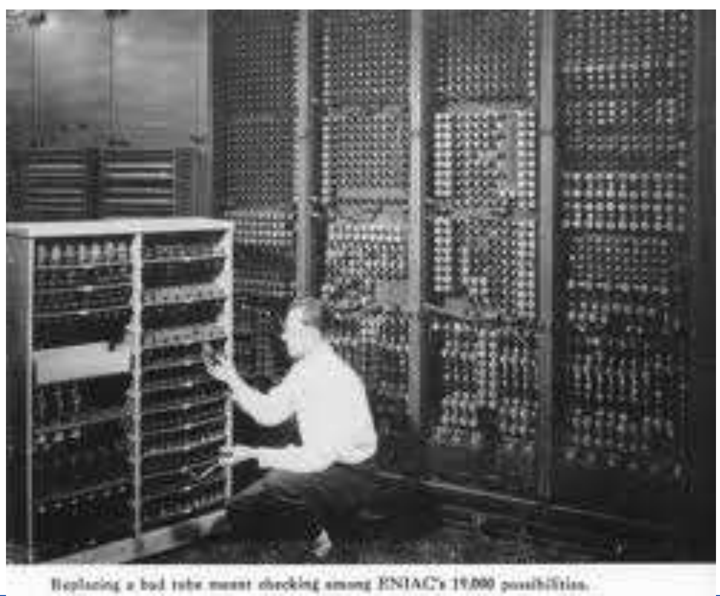
Outline

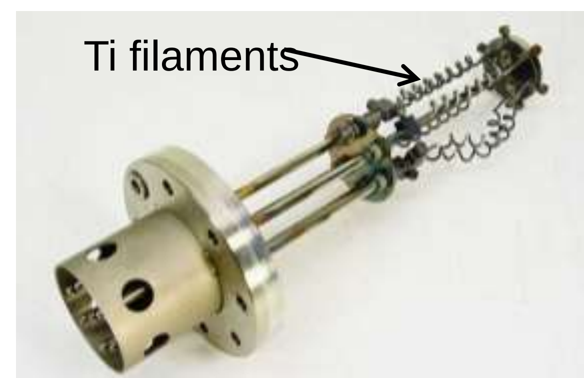
1. Introduction
2. NEG properties and performances
3. Production of NEG coatings
4. “Application to synchrotron light sources”
5. Summary & final remarks

Getters are materials capable of chemically adsorbing gas molecules (by chemisorption). To do so, their surface must be clean.

In situ deposition of a fresh getter film (under vacuum) ⇒ ***Evaporable Getters***







1 - Introduction

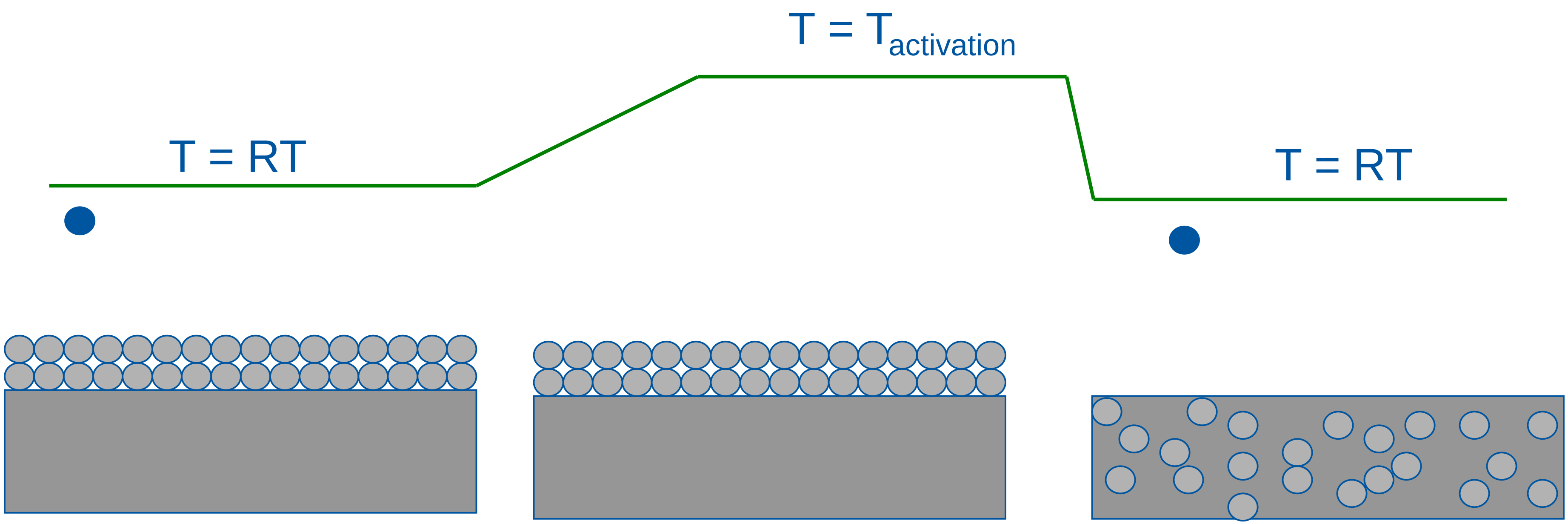
Getters are materials capable of chemically adsorbing gas molecules (by chemisorption). To do so, their surface must be clean.

In situ deposition of a fresh getter film (under vacuum) ⇒ ***Evaporable Getters***

Diffusion of the oxide layer into the bulk (usually by heating in vacuum to ***the activation temperature***) ⇒ ***Non Evaporable Getters (NEG)***

1 - Introduction

Activation temperature of a NEG



Native oxide layer
No pumping
High desorption rates

Heating in vacuum

Oxide dissolution -> activation

Reactive metalic surface
Pumping
low desorption rates

NEG pumps most of the gases except noble gases and methane at room temperature

1 - Introduction

Motivation

Distributed Pumping
in long beam pipes

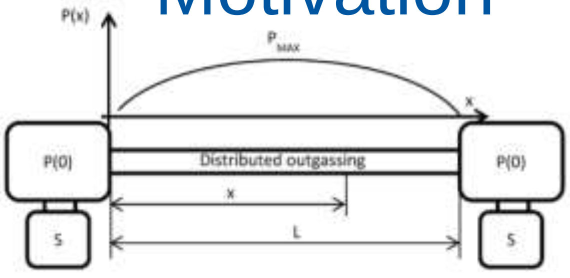
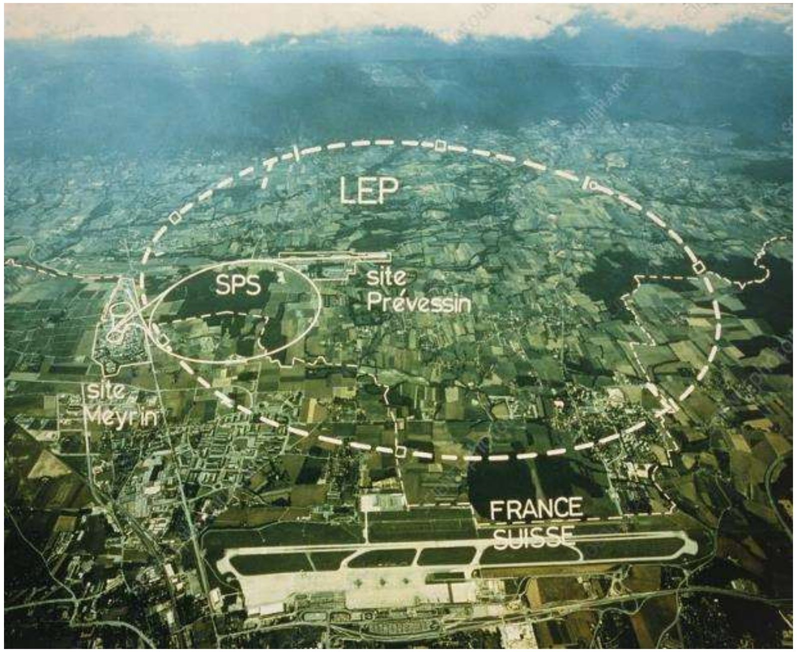


Fig. 11: Pressure profile in a tube pumped at both extremities with uniformly distributed outgassing rate

$$P_{max} = P(0) + \frac{Q_{total}}{8C}$$



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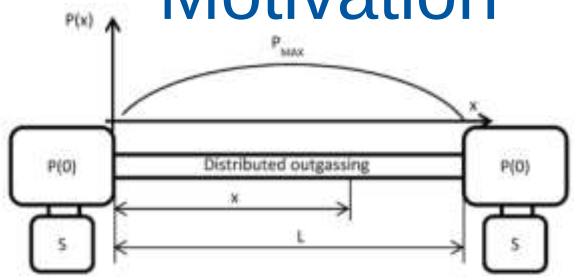
Distributed Pumping in long beam pipes



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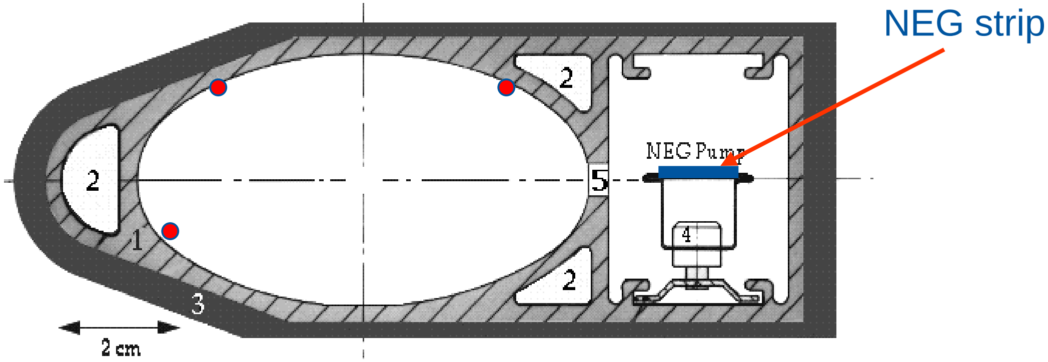
Cross section of the LEP dipole vacuum chamber



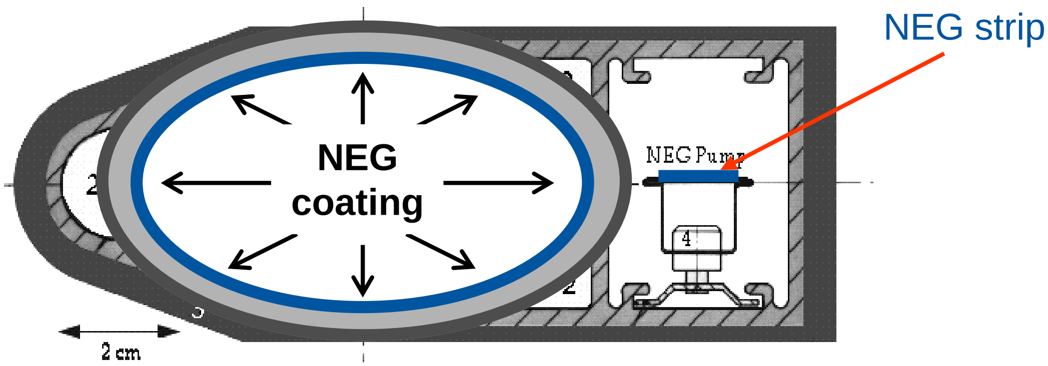
1 - Introduction

Motivation

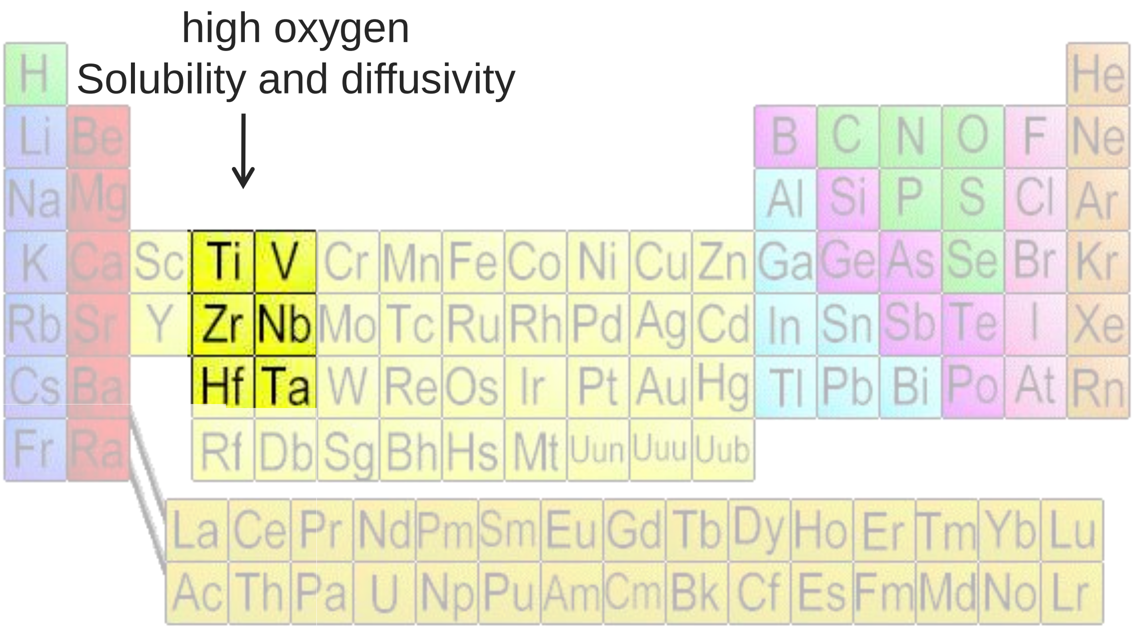
Distributed Pumping in long beam pipes

Transform the vacuum chamber into a pump

Low induced outgassing
Low secondary electron yield



NEG materials:



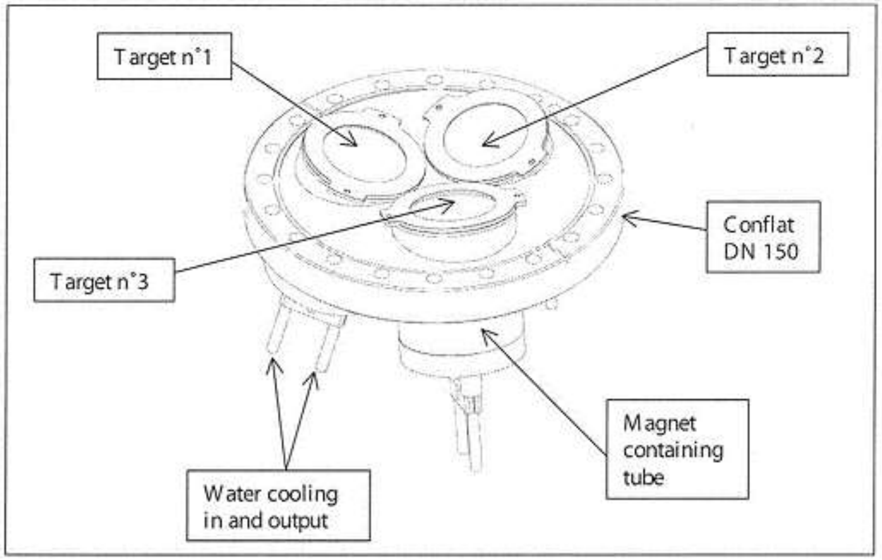
2 – NEG properties & performances

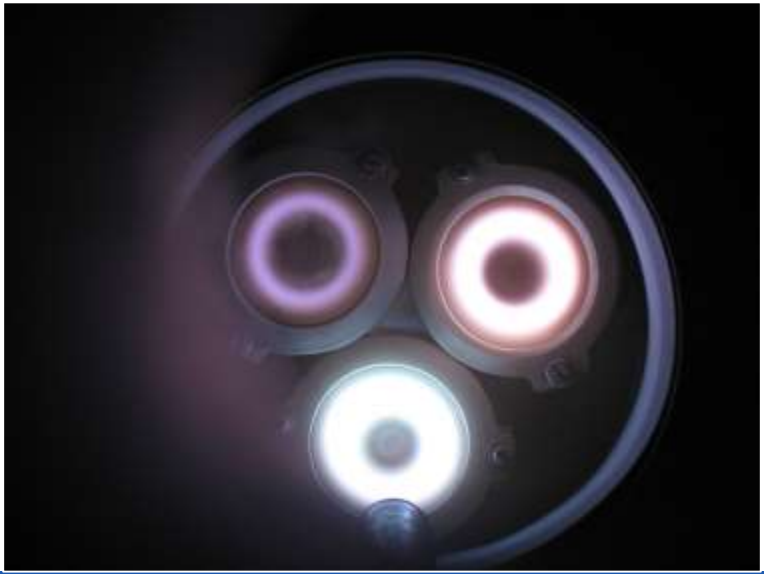
NEG materials:

NEG coatings have been produced by Magnetron Sputtering of elements and alloys from the IV and V group of the periodic table.

More than 20 materials were investigated by combining 2 or 3 of this elements in the form of thin films.

The thin films were produced in a triple DC magnetron coating system:





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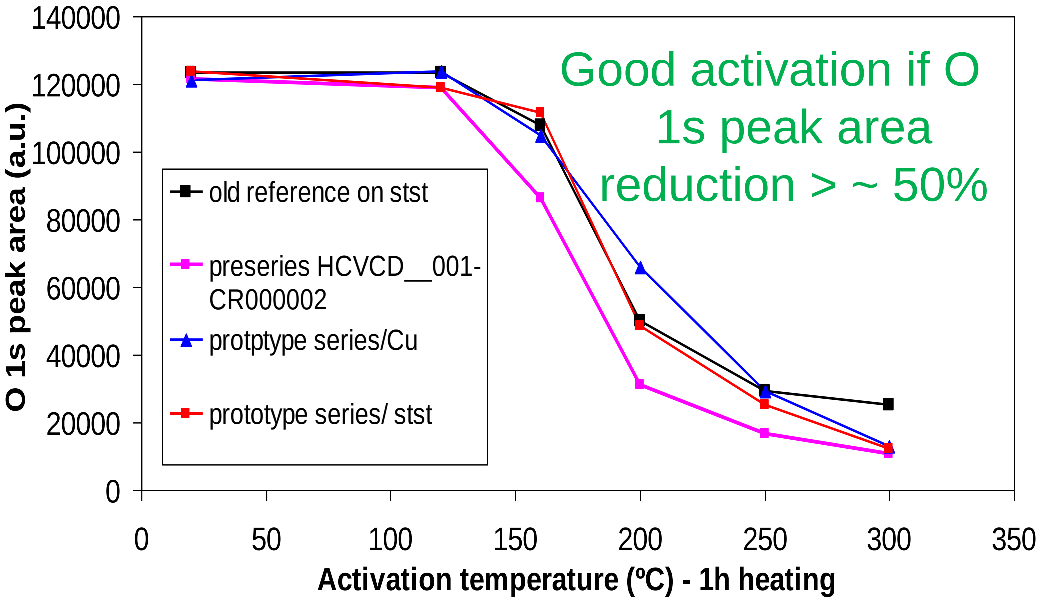
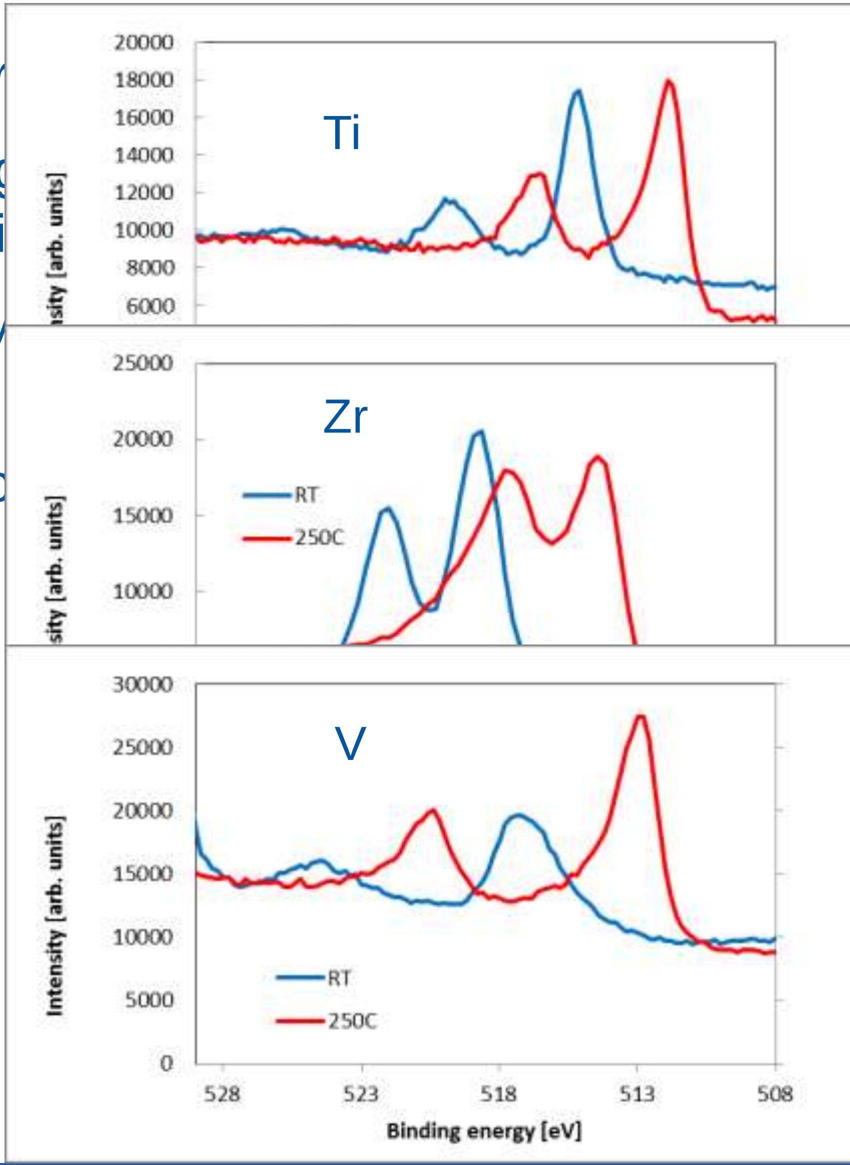
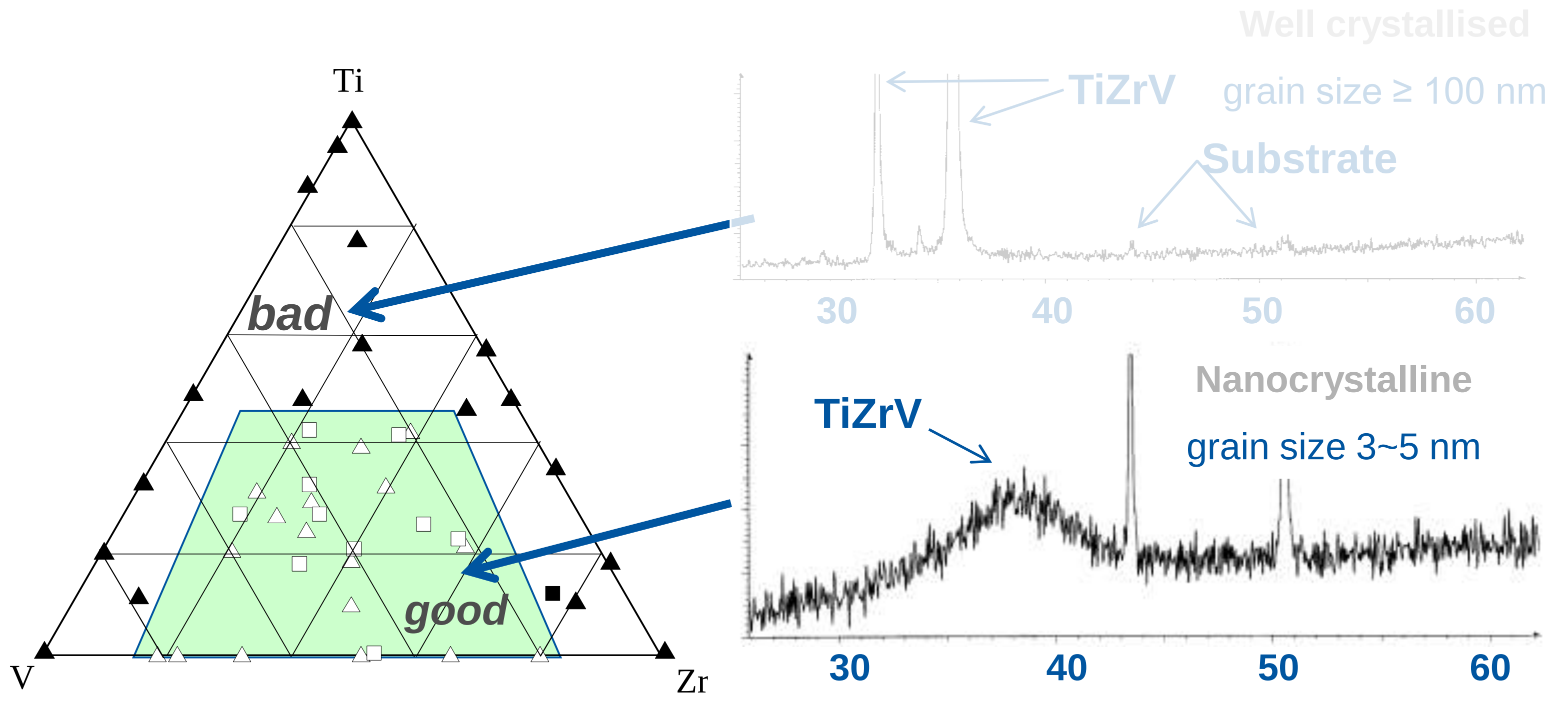
Evaluate NEG activation by X-ray Photoelec





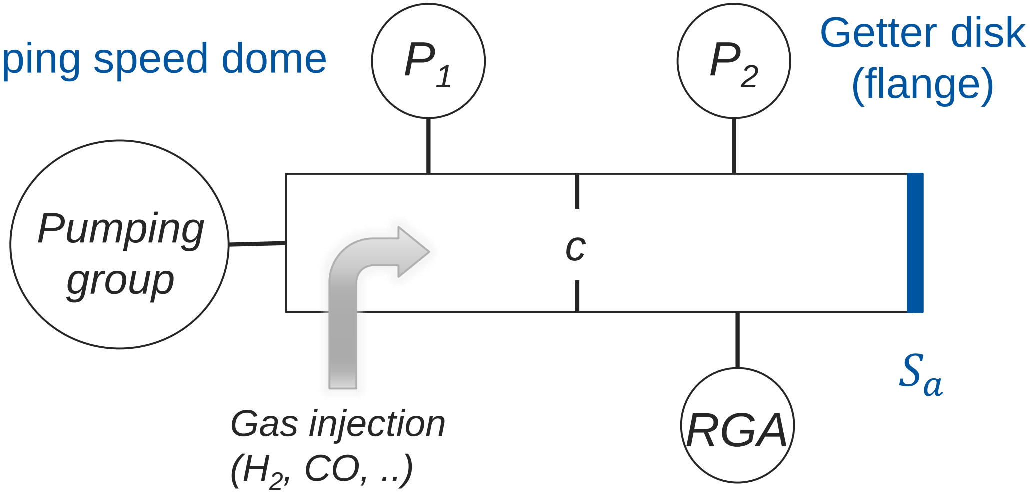
NEG materials:

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



2 – NEG properties & performances

Measure the pumping speed of a thin film: aperture method



$$S_{getter} = S_a = \frac{(P_1 - P_2)}{P_2} c$$

$$S_{getter} = A\sqrt{\frac{kT}{2\pi m}}\, s$$

$$\Rightarrow$$

$$s = \frac{(P_1 - P_2)}{P_2} c \frac{1}{A}\sqrt{\frac{2\pi m}{kT}}$$

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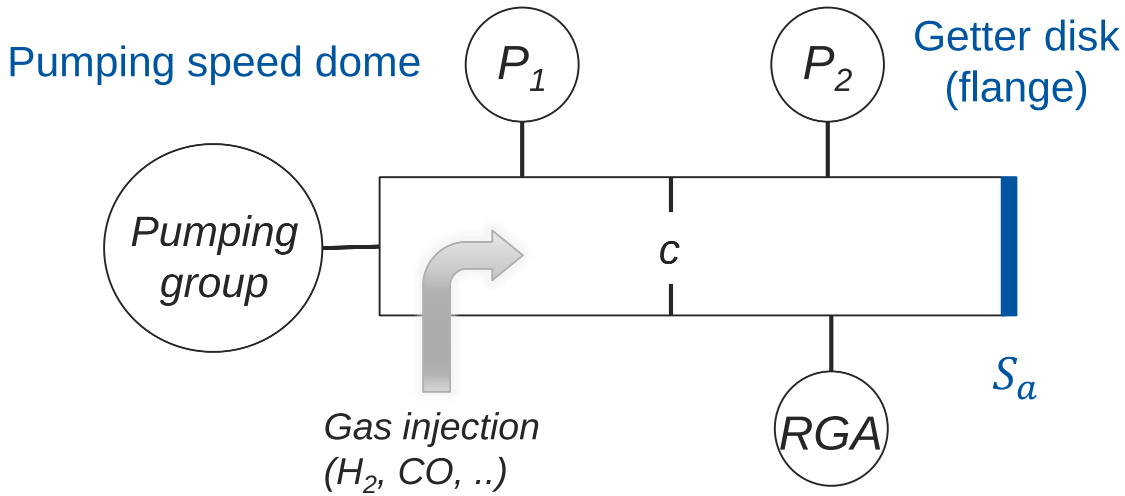

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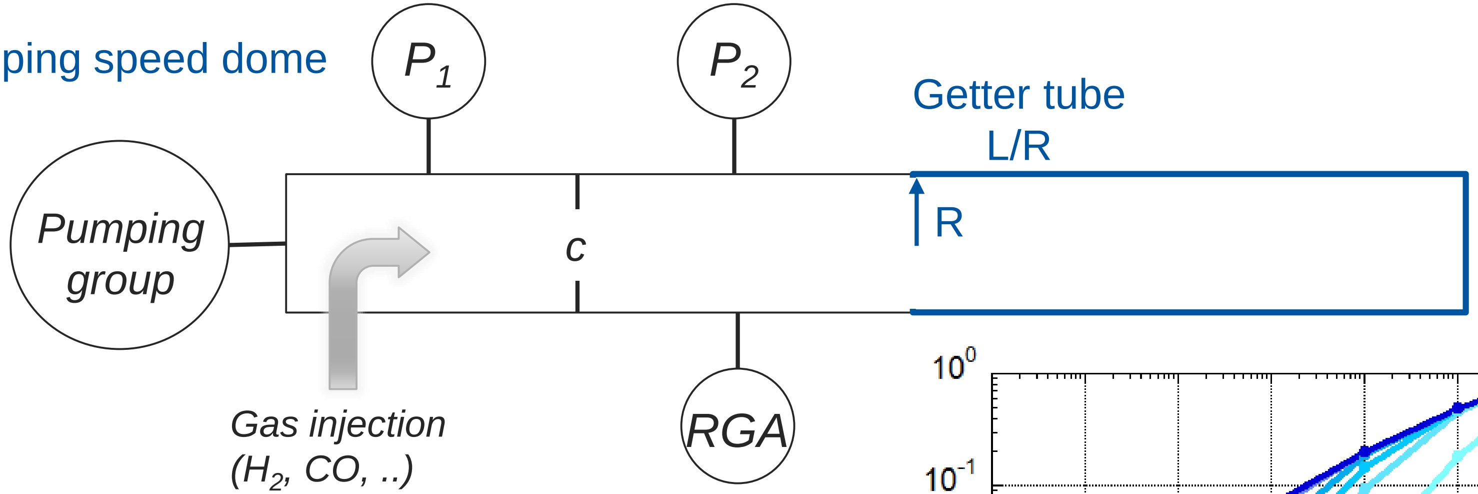
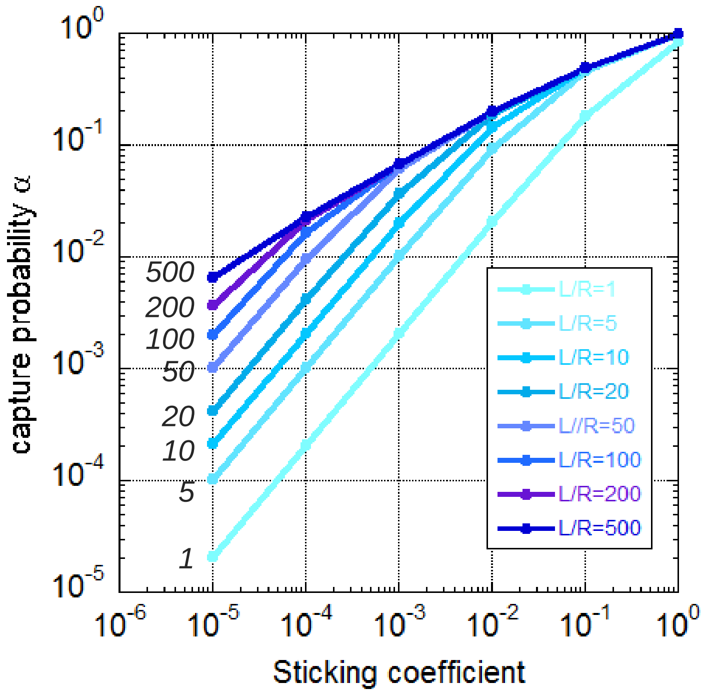


$$S_a = \frac{(P_1 - P_2)}{P_2} c$$

$$S_a = A\sqrt{\frac{kT}{2\pi m}}\,\alpha$$

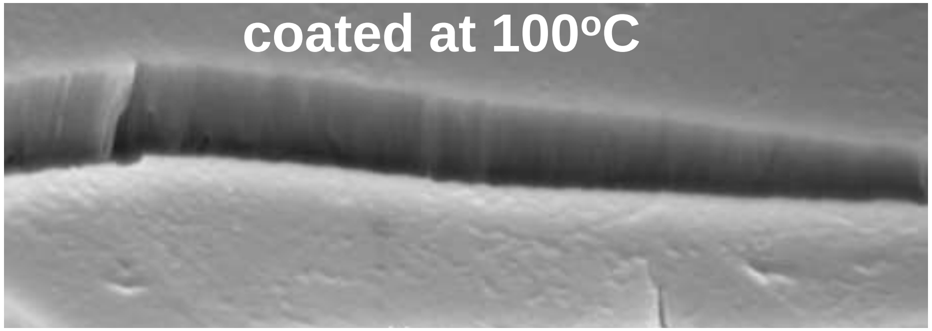
Monte Carlo simulation

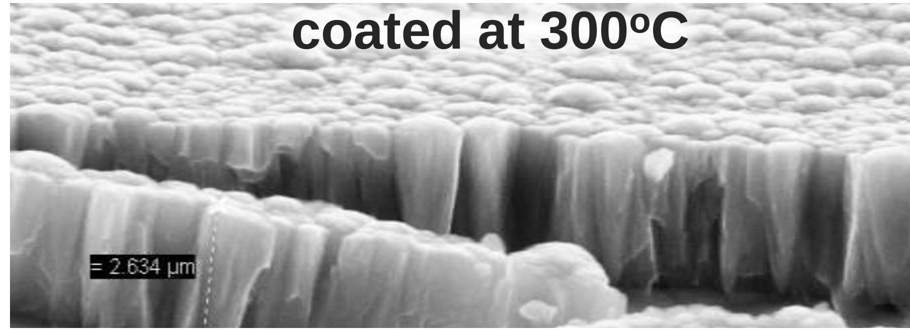
$\alpha \rightarrow capture\ probability$

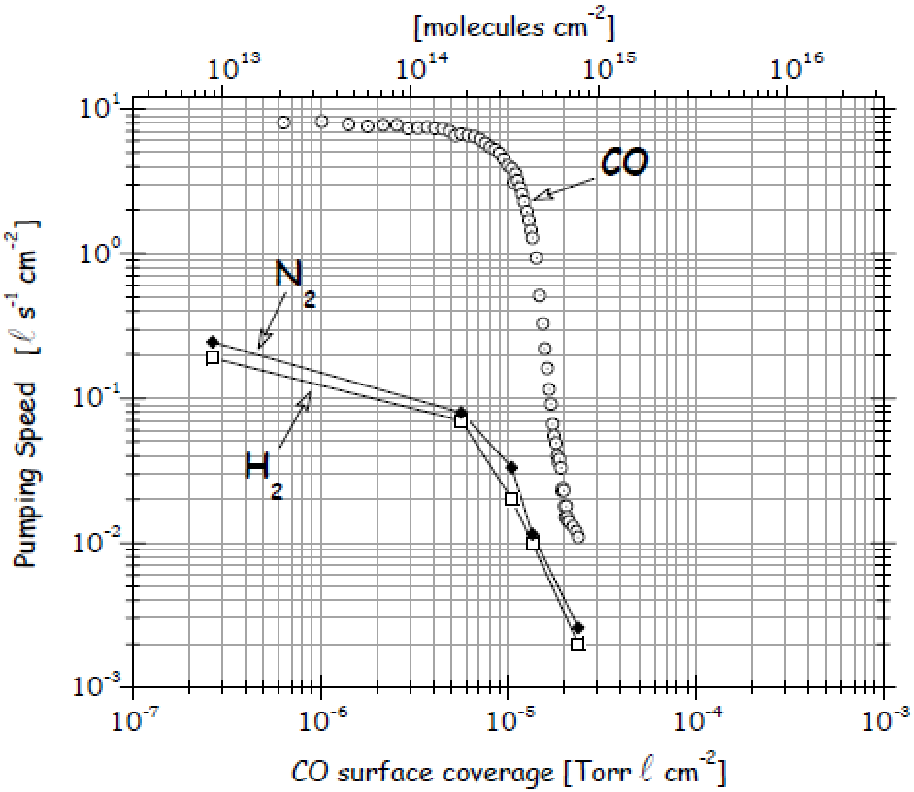


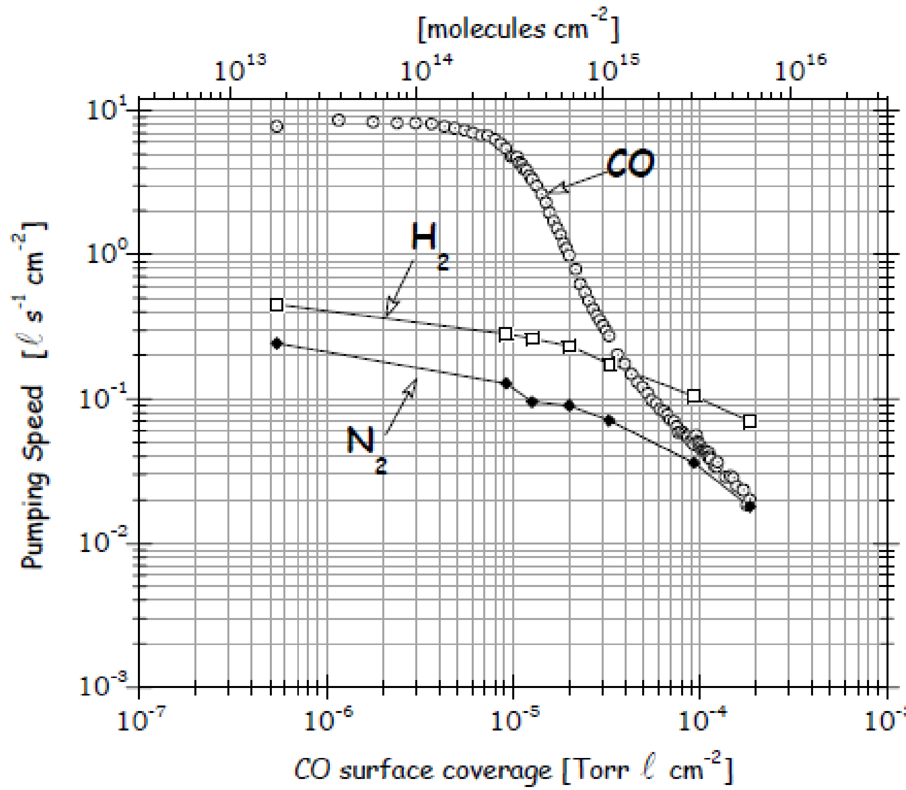
2 – NEG properties & performances

Pumping speed and surface capacity of TiZrV. (activation 24h@230ºC)

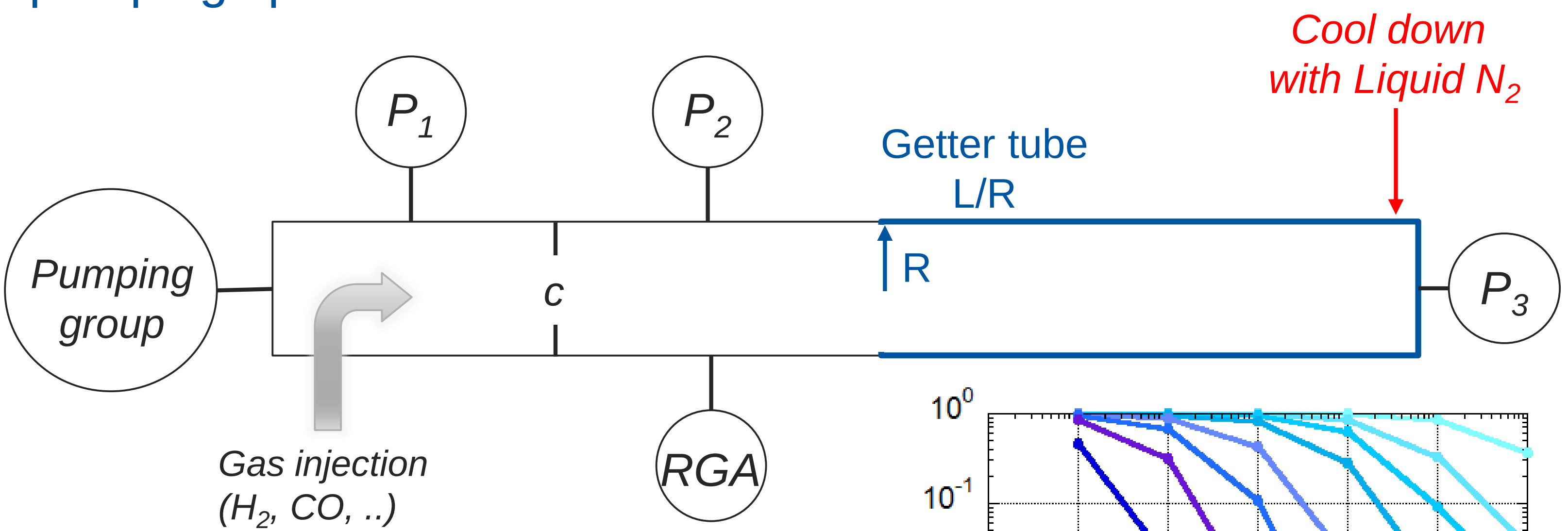






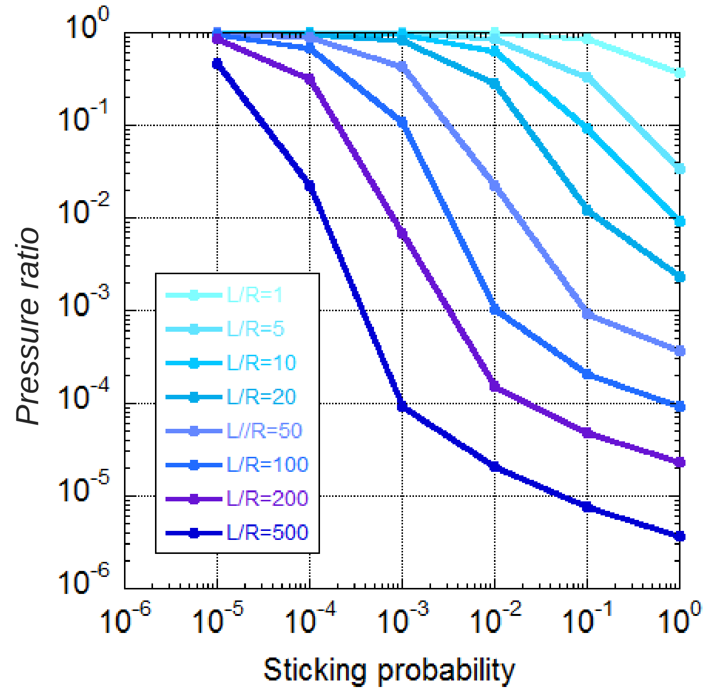


Measure the pumping speed of a thin film: transmission method



$$\text{Pressure ratio} = \frac{P_3}{P_2}$$

Monte Carlo simulation

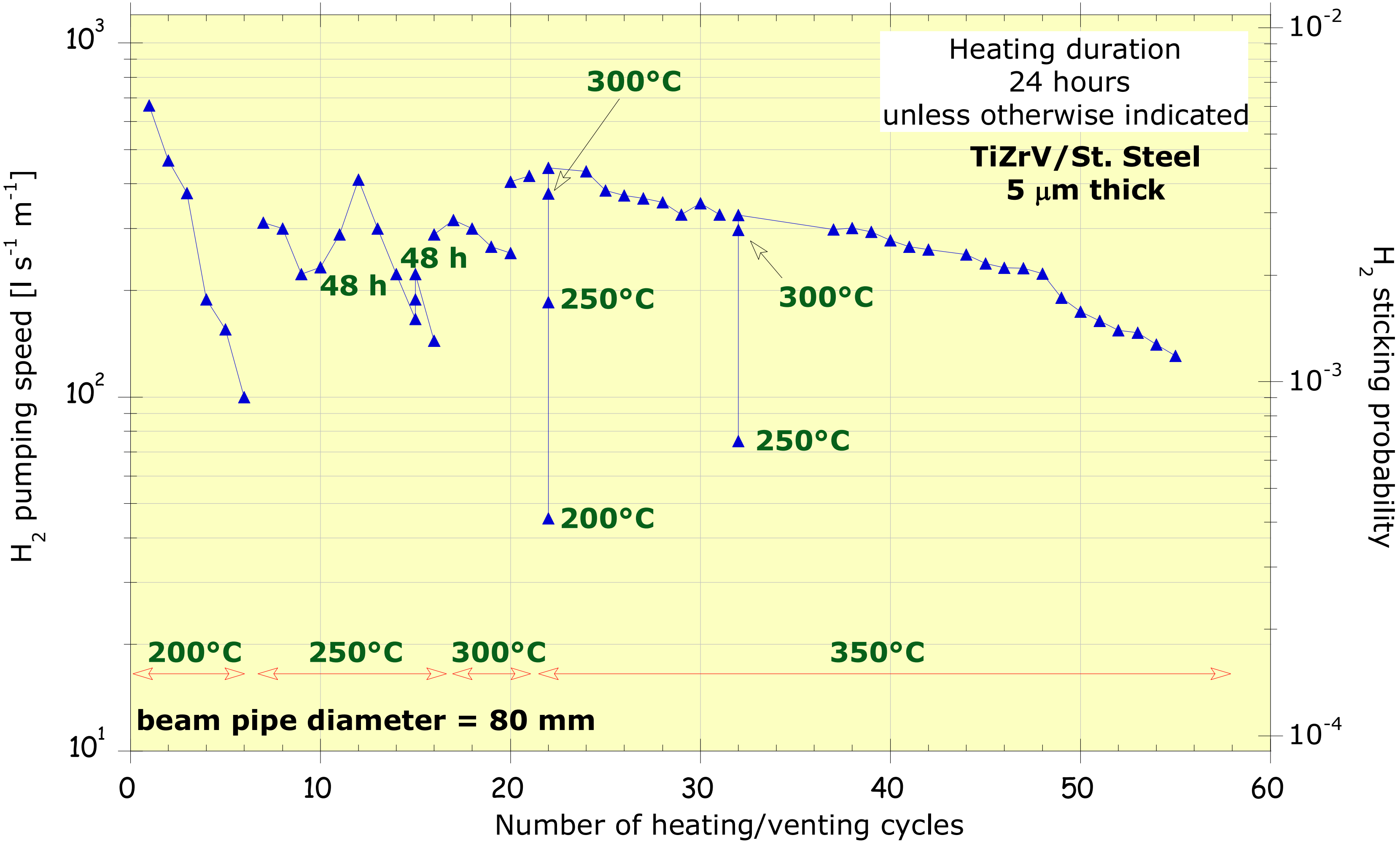


If pressure ratio too low:
very high P_2 is necessary to get signal in P_3

If using CO => fast saturation at the entrance

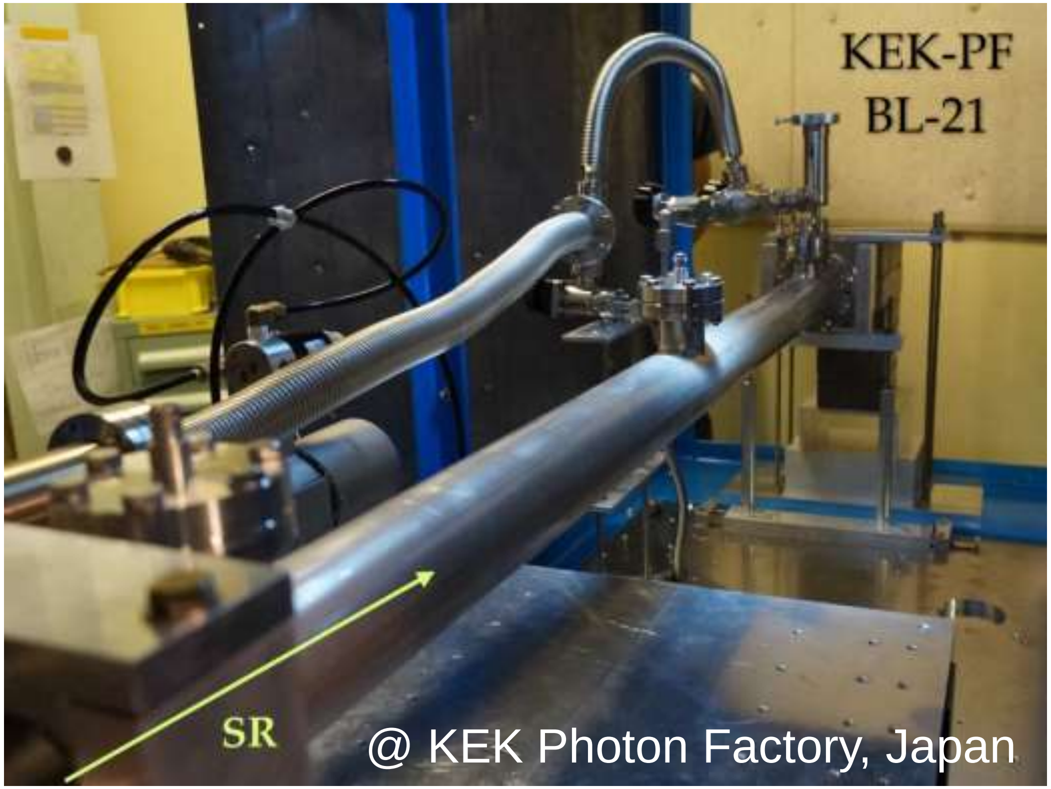
If using H_2 => dissociation of H_2 in hot filament => methane

Ageing: loss of pumping speed with successive air venting cycles



2 – NEG properties & performances

Photon Stimulated Desorption (PSD)



2 – NEG properties & performances

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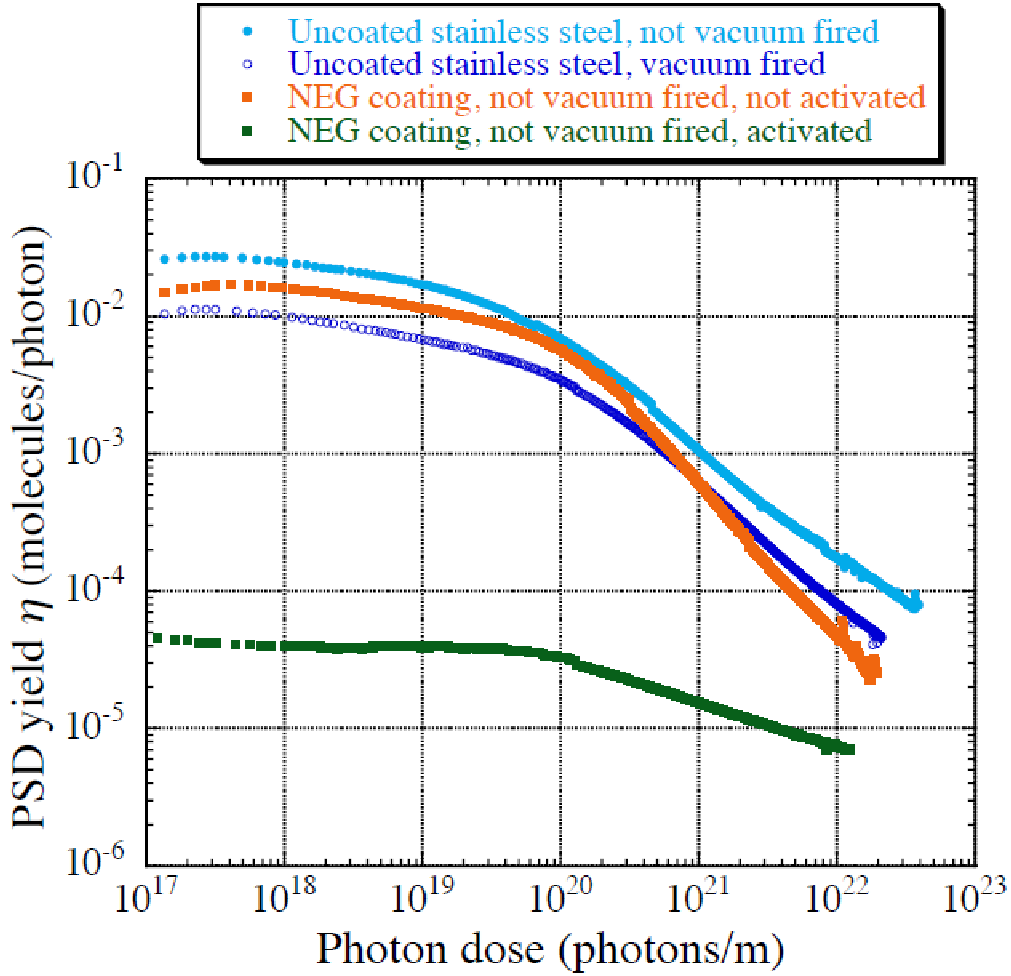
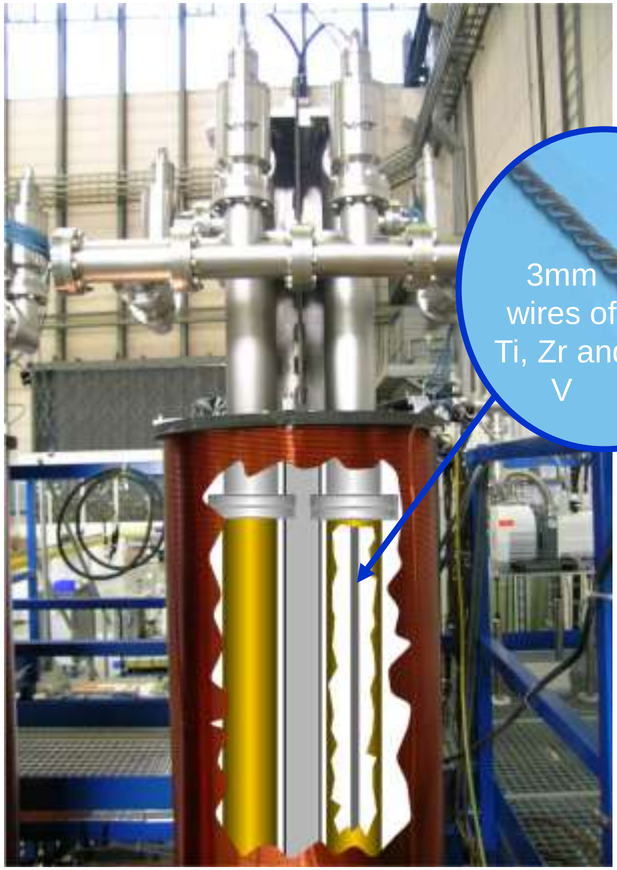
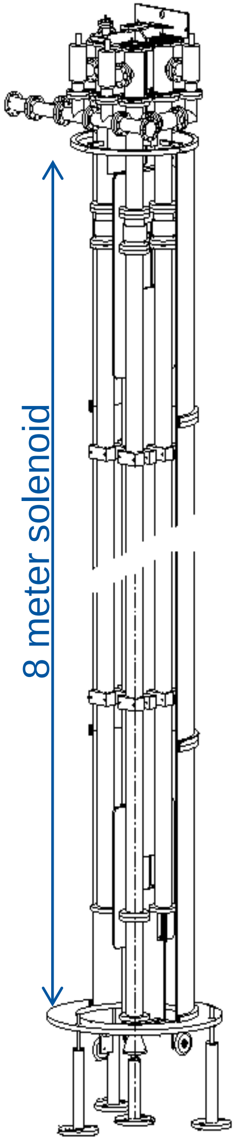


At CERN

The LHC: more than 1300 beam pipes coated.



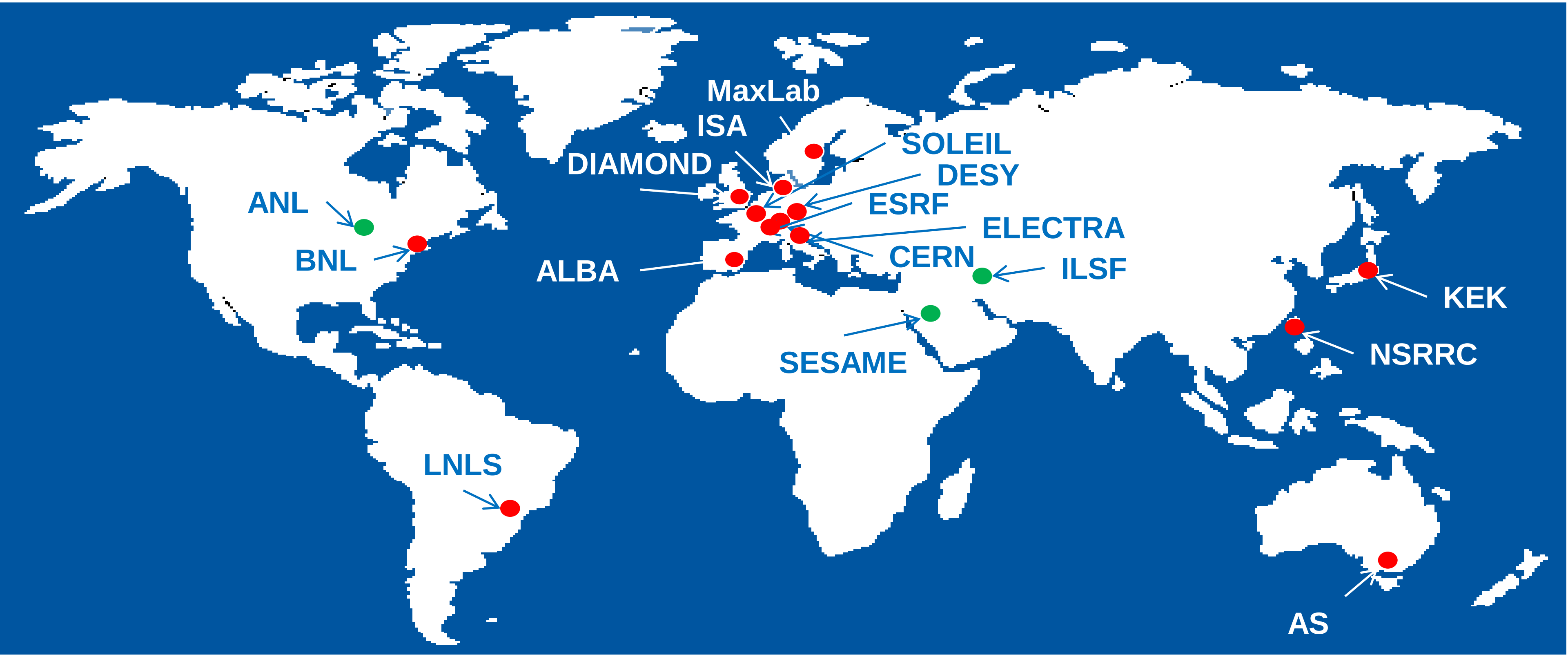


3 – Production of NEG coatings

NEG coating producers

3 – Production of NEG coatings

Worldwide users of NEG coatings

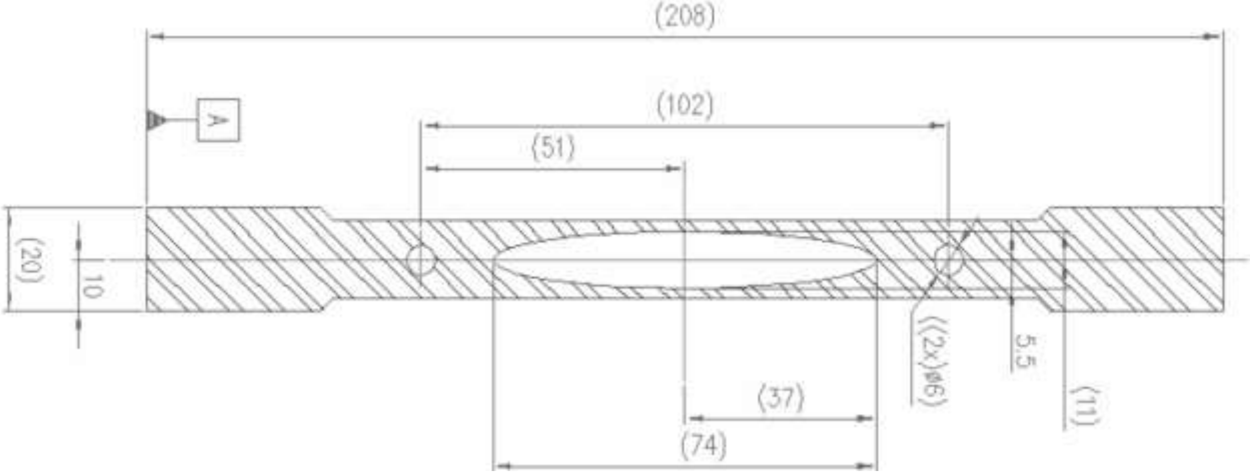


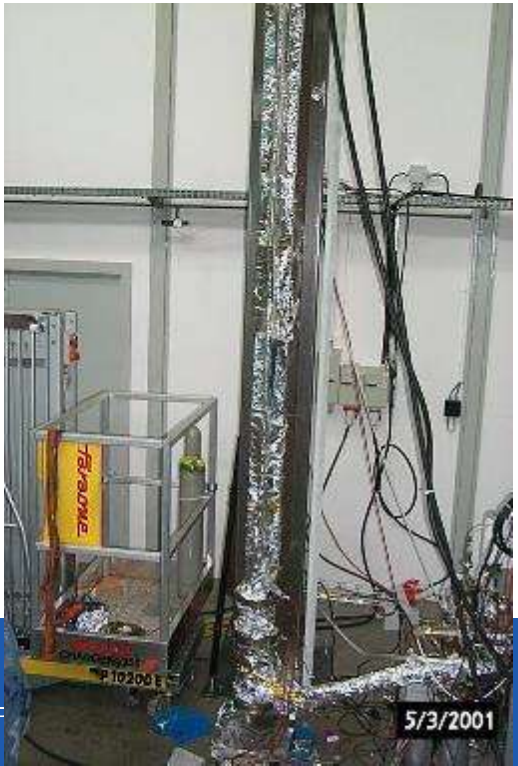
in design/study

NEG coatings for ESRF (2001)

The coating system was then dismantled: ESRF and SAES became the experts on high aspect ration chambers. No CERN demands for these type of chambers.

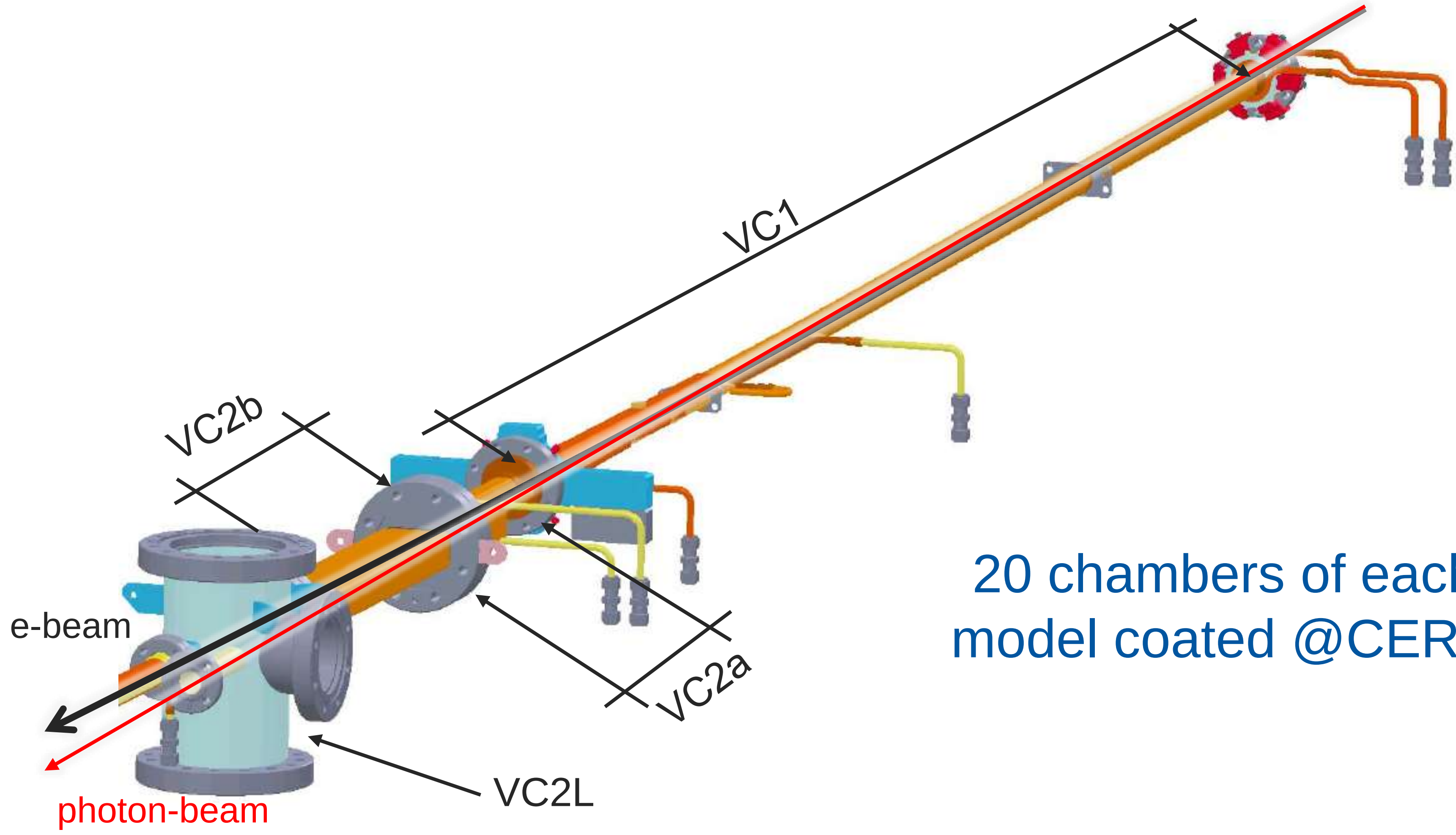
ESRF chamber CV5073 (L=5073 mm, 11 mm x 74 mm)





R. Kersevan, Proc. EPAC-2000 Conference, Vienna, June 2000, page 2289-2291, available at <u>http://accelconf.web.cern.ch/accelconf/e00/PAPERS/THP5B11.pdf</u>.

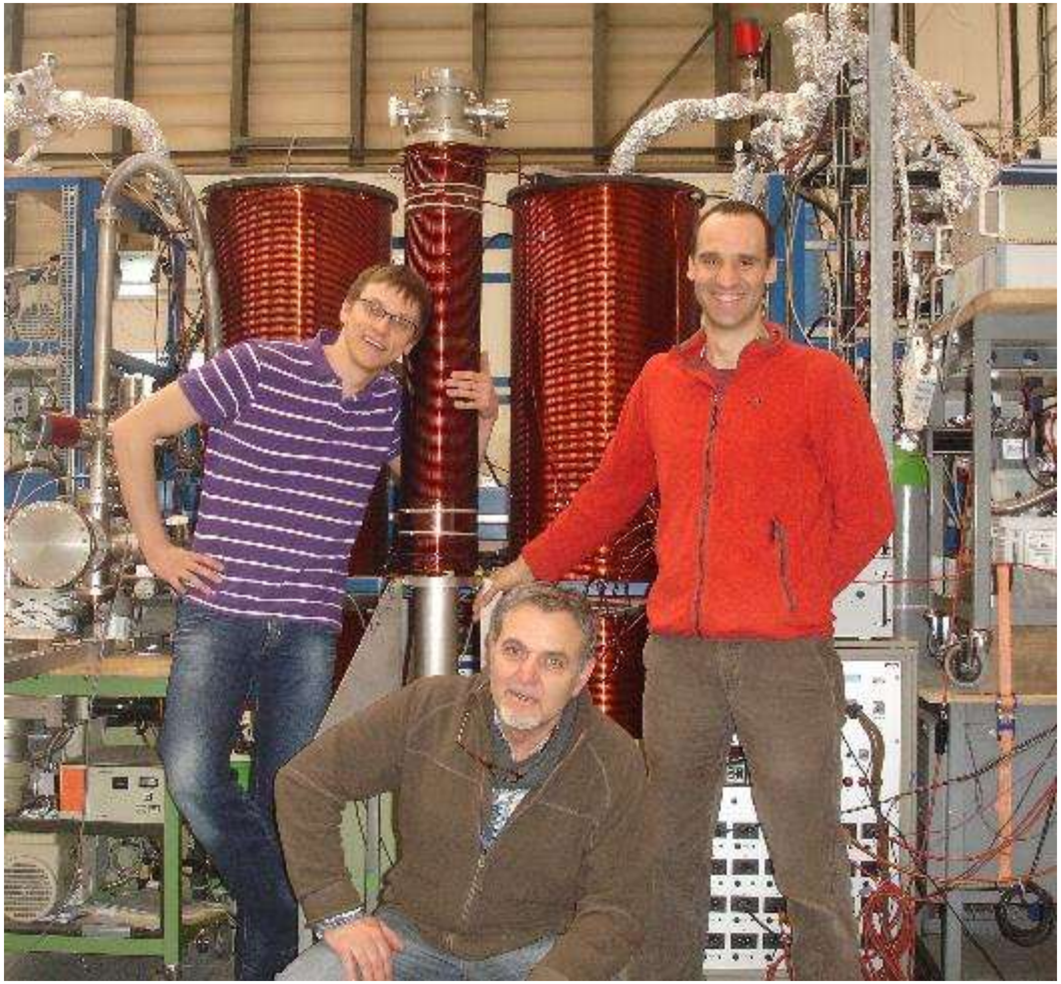
NEG coatings for MAX IV (2013 – 2015)



20 chambers of each model coated @CERN

4 – Application to synchrotrons light sources

NEG coatings for MAX IV (2013 – 2015)



Thickness uniformity

Sputtered atoms leave the target with a cosine distribution

PHYSICAL VAPOR DEPOSITION (PVD) PROCESSES
by Donald M. Mattox
Society of Vacuum Coaters, Albuquerque, N.M.

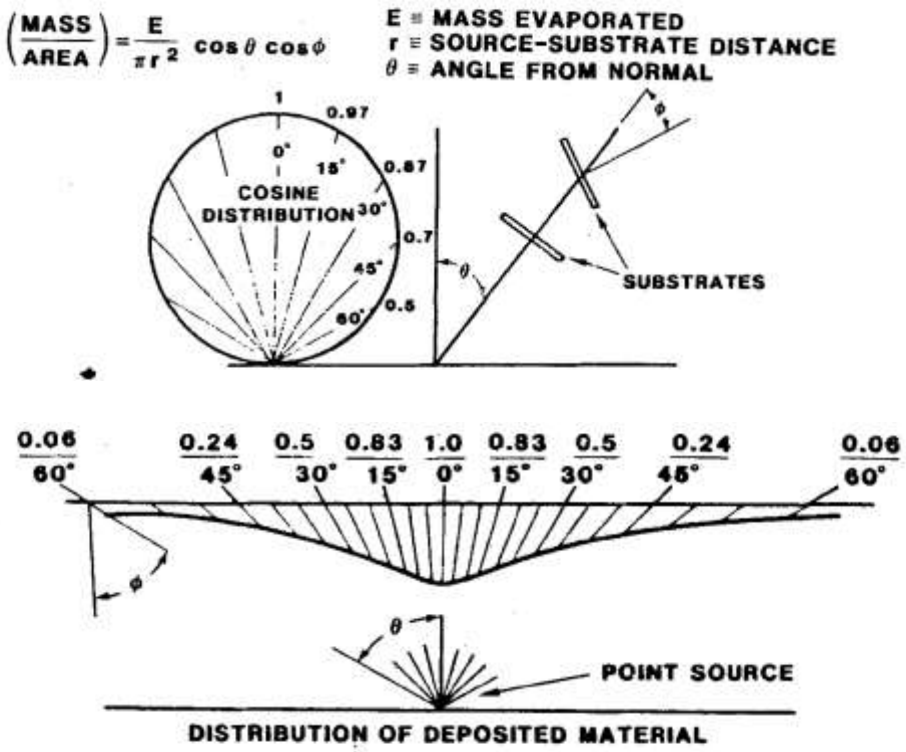
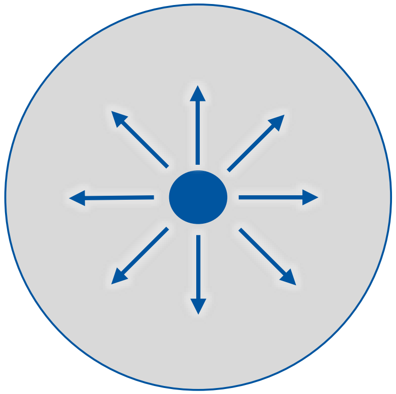


Fig. 4. Cosine distribution of vapor from a point source.

4 – Application to synchrotrons light sources

Thickness uniformity

Cross section:



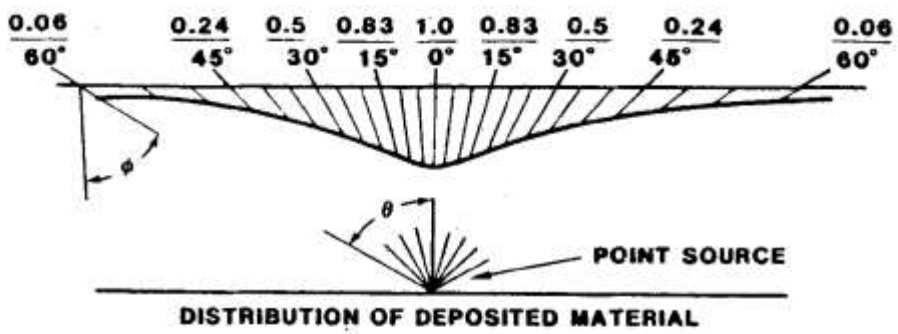


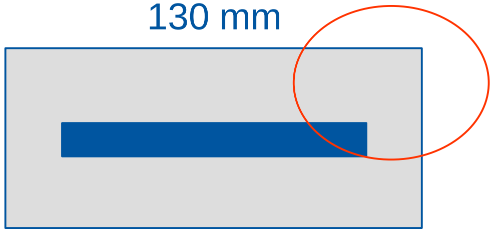
Fig. 4. Cosine distribution of vapor from a point source.

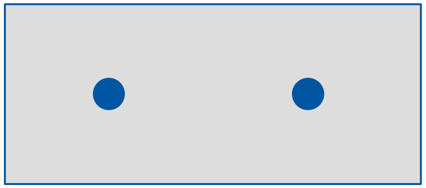
Thickness uniformity

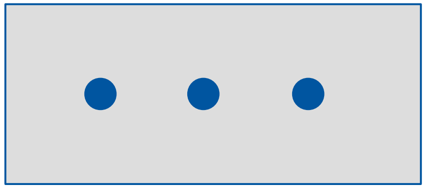
Cross section:

130 mm

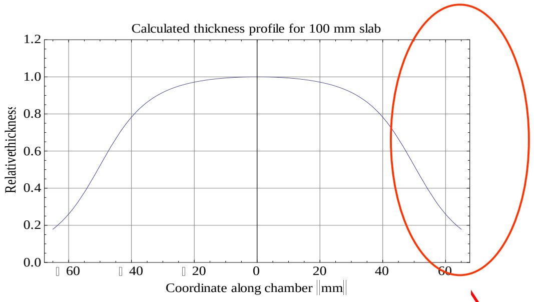
55 mm

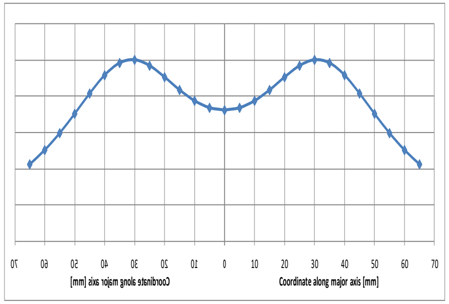


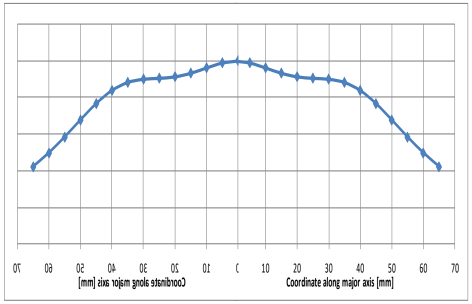




Which cathode gives the most uniform thickness profile?





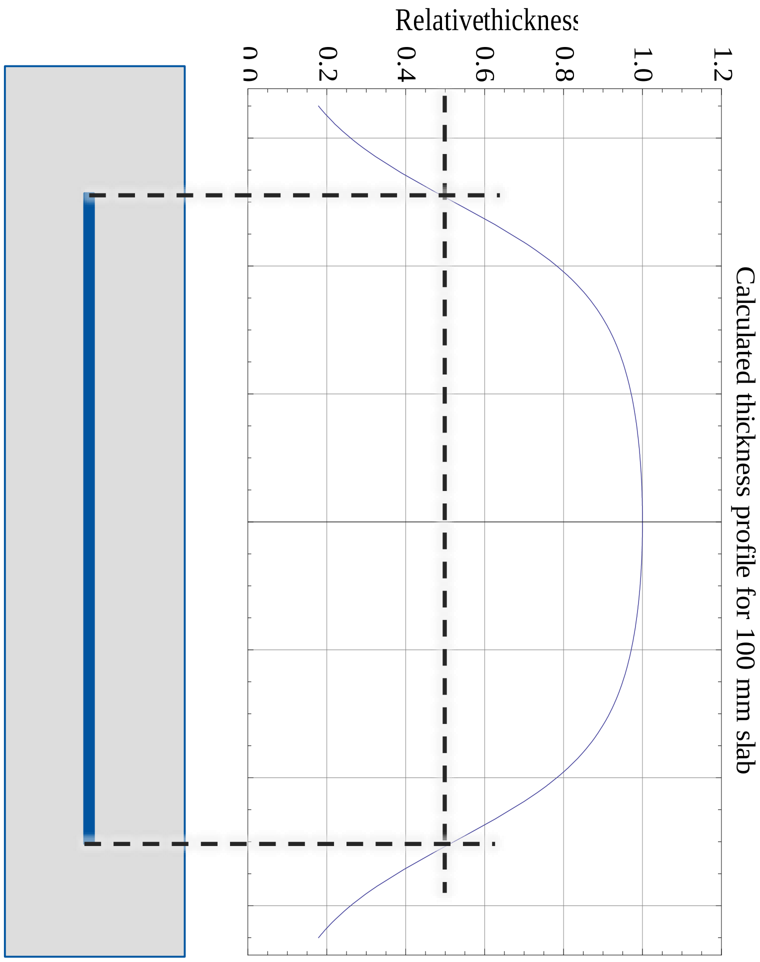


Edge effect

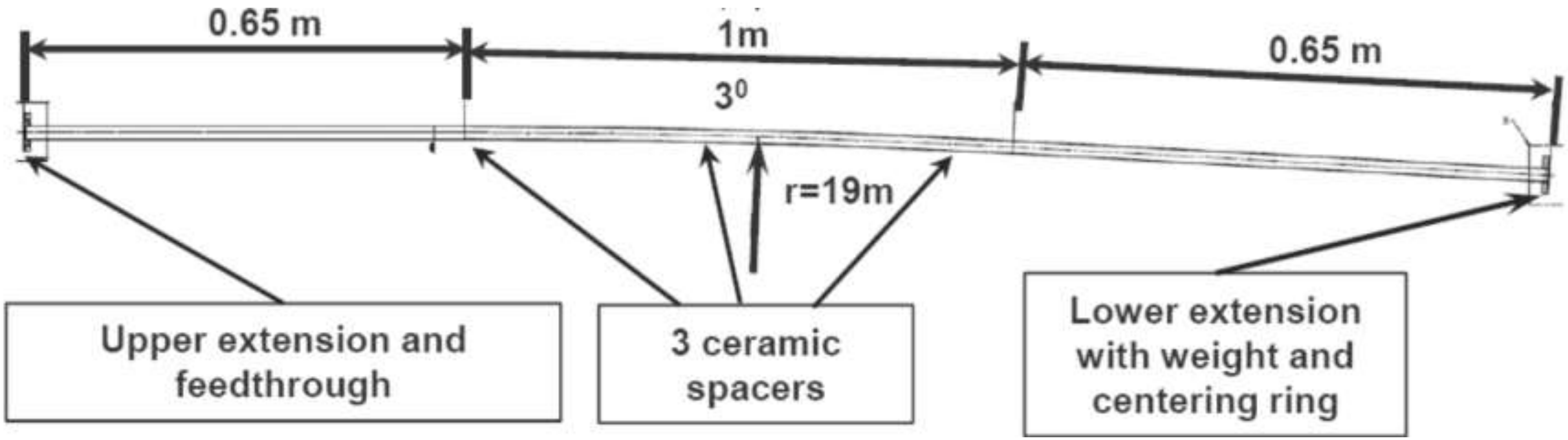
4 – Application to synchrotrons light sources

Thickness uniformity

Longitudinal:

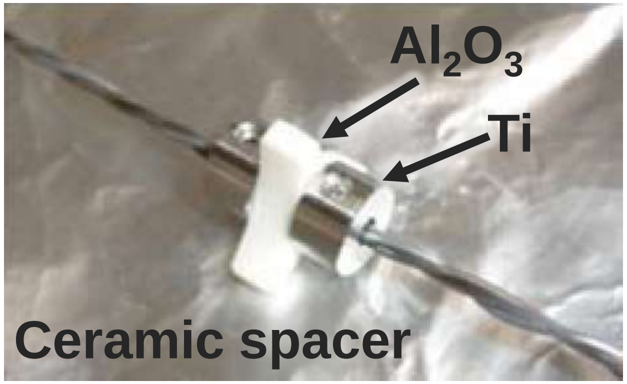


NEG coatings for MAX IV (2013 – 2015)



Chamber:
- ID22 mm
- L=2.3 m
- Angle 3º
- curvature radius 19 m

Coating:
- Pressure 0.11 mbar
- Magnetic field 180 Gauss
- Power density 25W/m



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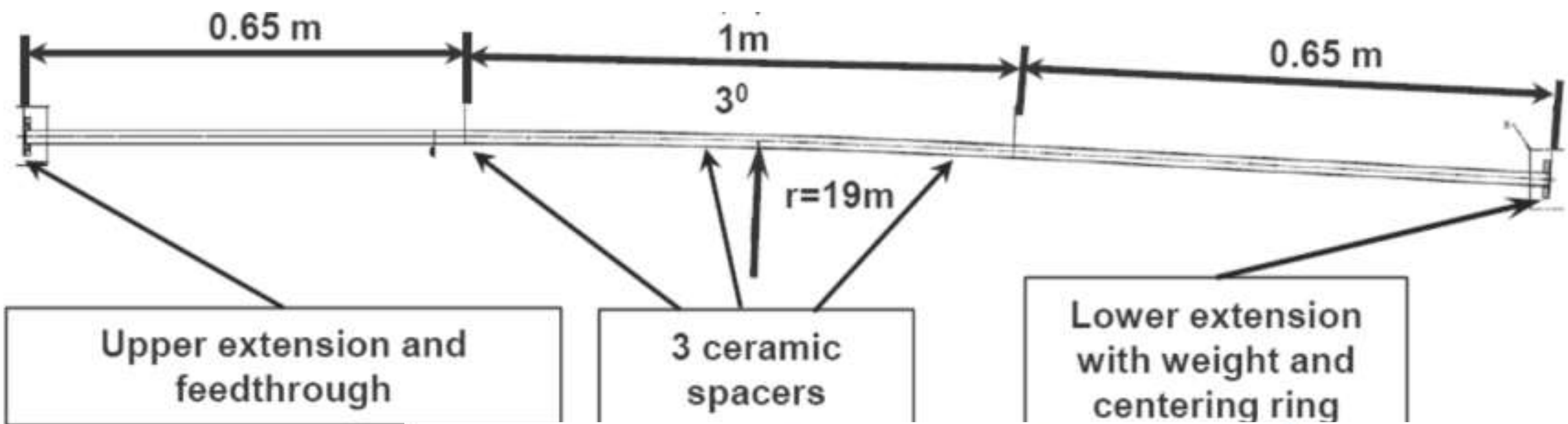
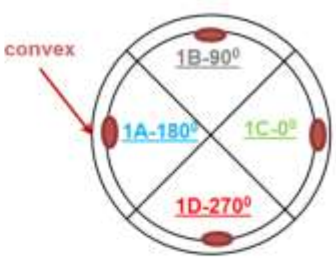
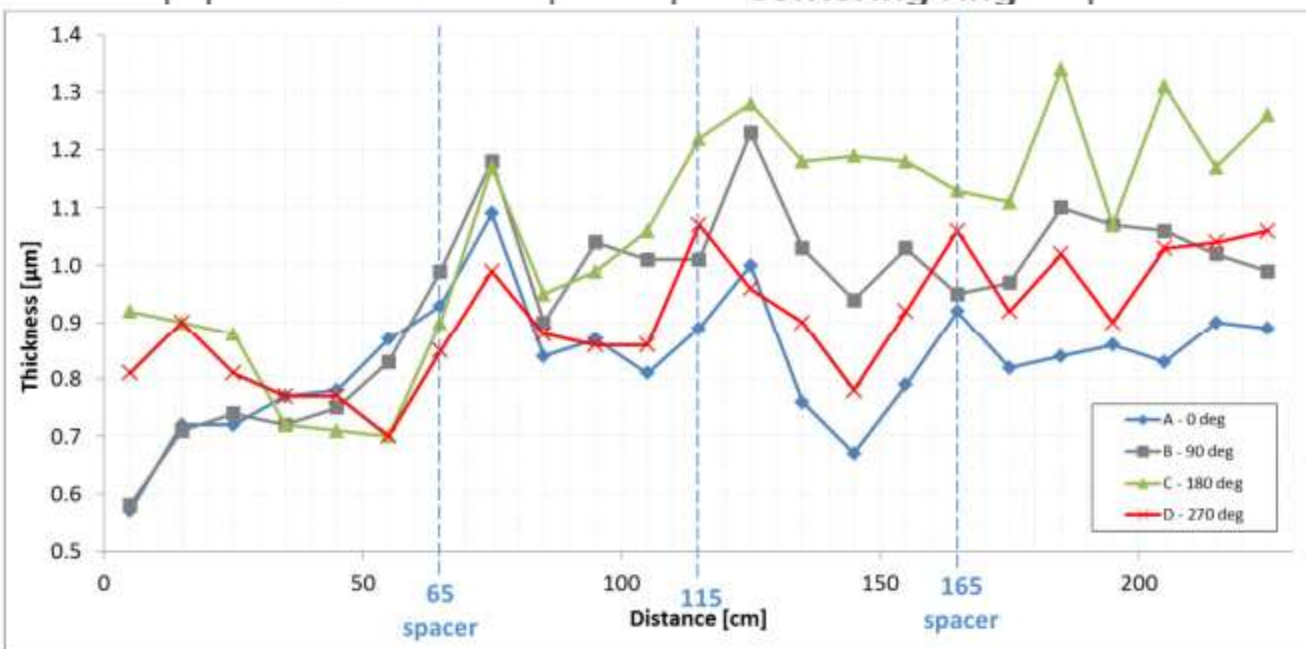


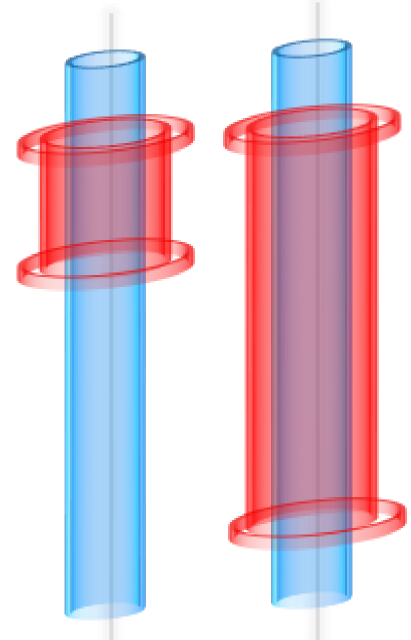


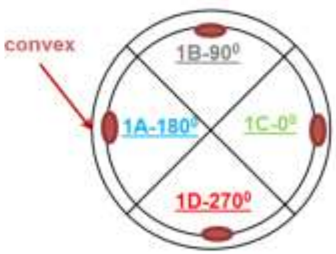


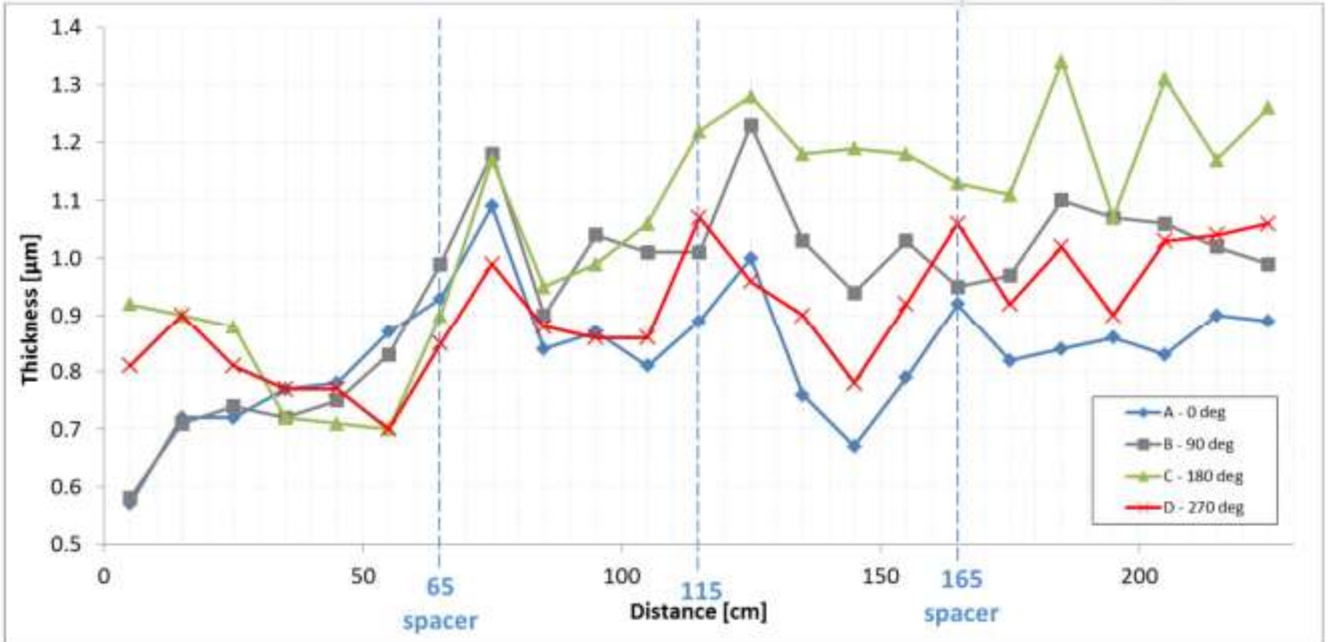
4 – Application to synchrotrons light sources

NEG coatings for MAX IV (2013 – 2015)

Use “short” solenoids? (plasma distribution)







4 – Application to synchrotrons light sources

NEG coatings for MAX IV (2013 – 2015)

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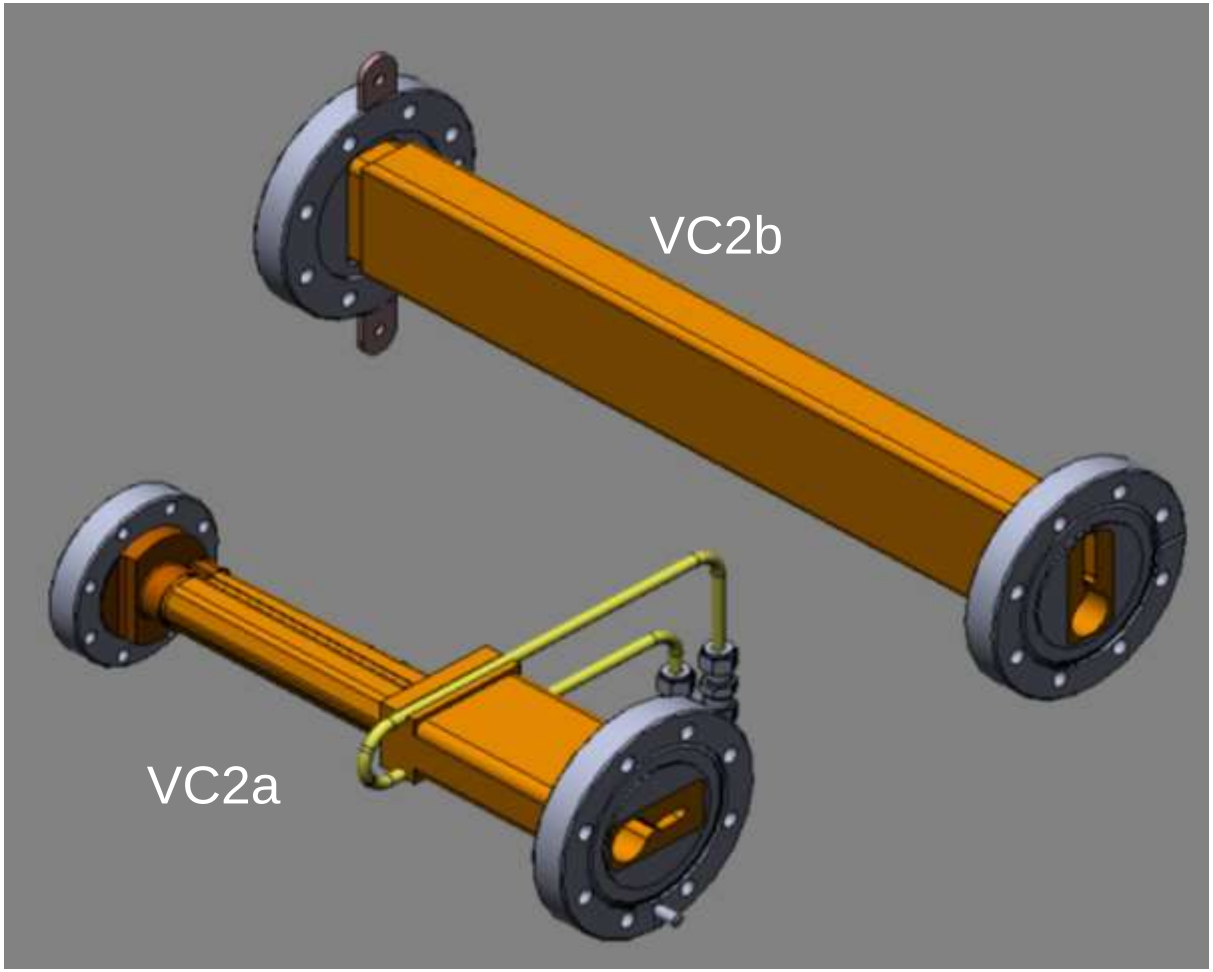

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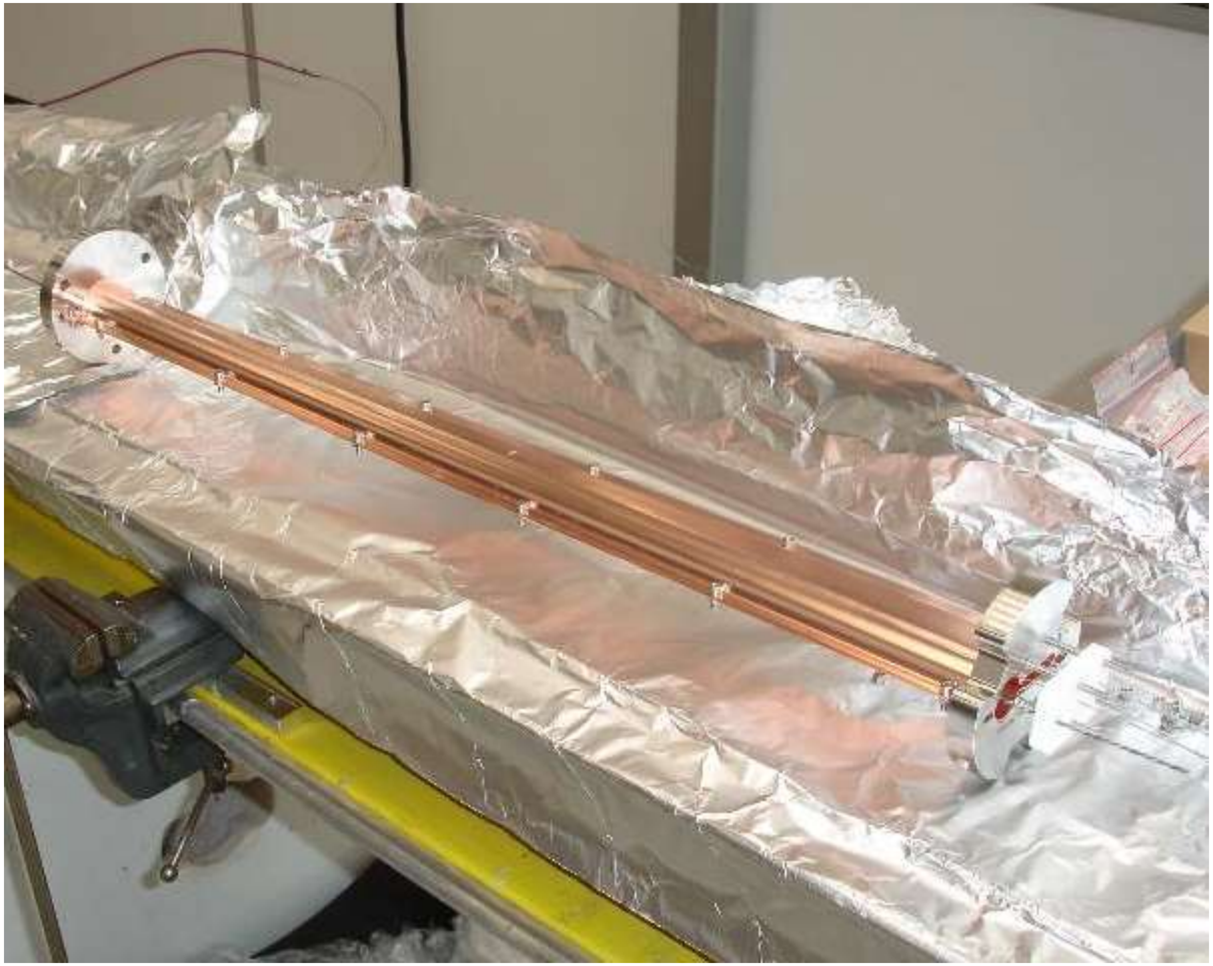

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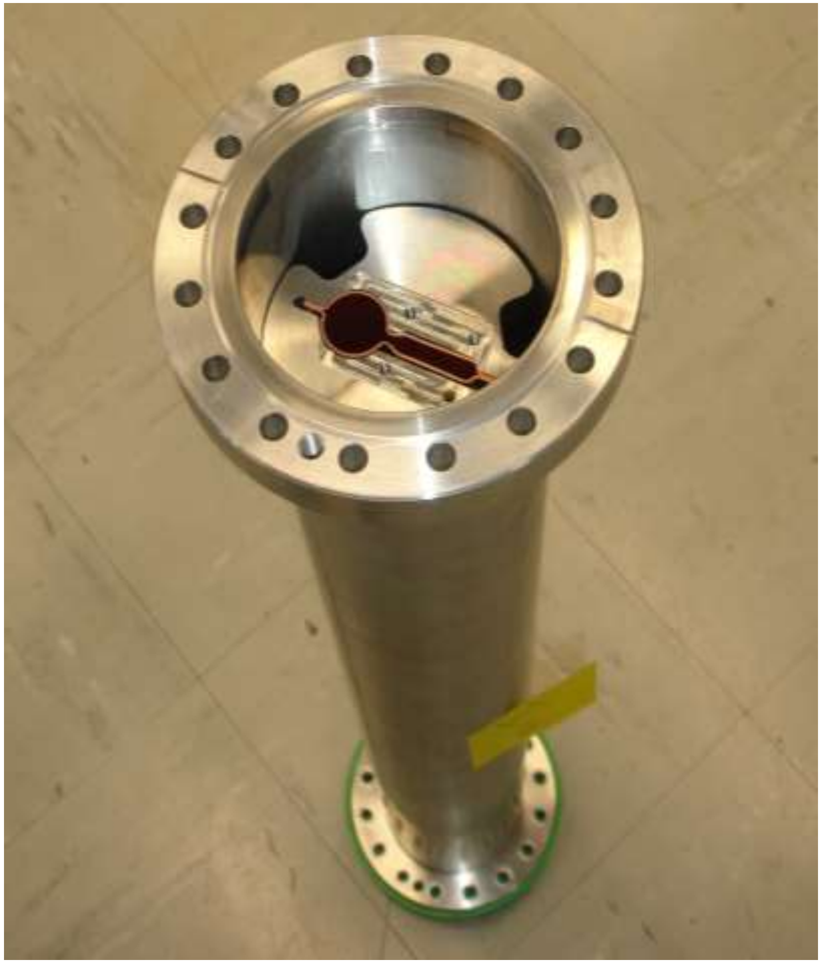

NEG coatings for MAX IV (2013 – 2015)

1st problem:

"spread" the plasma along the cathode

⇩

Requires high power

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Requires high power

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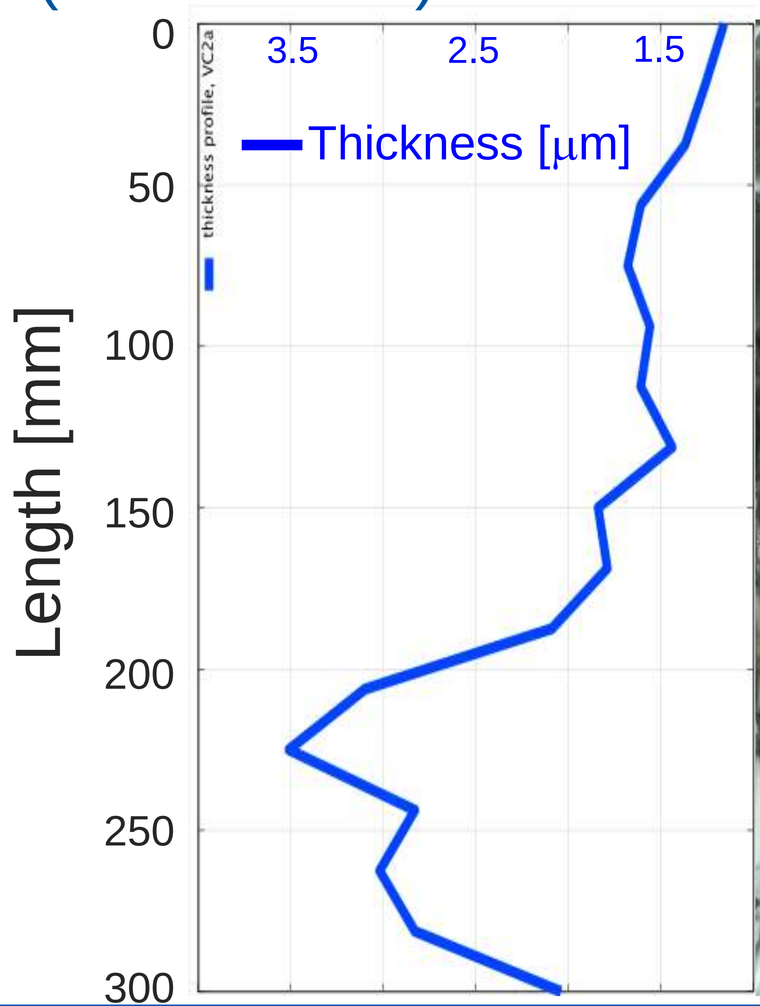
wrong stoichiometry (too much V)

⇩

Incomplete activation



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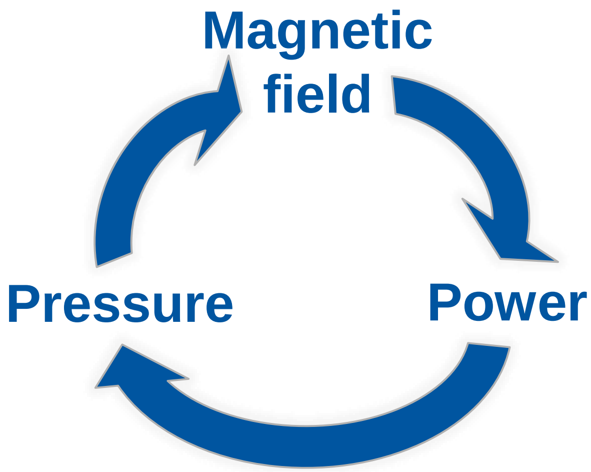

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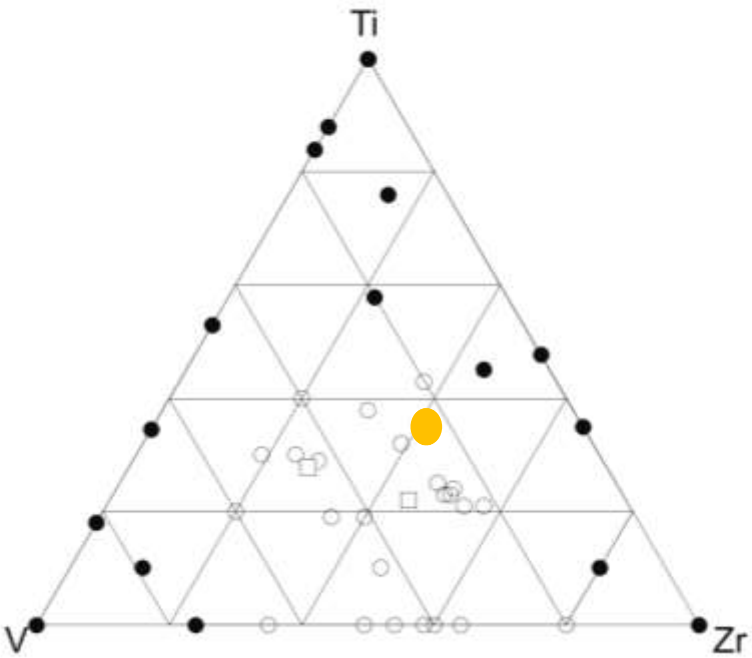
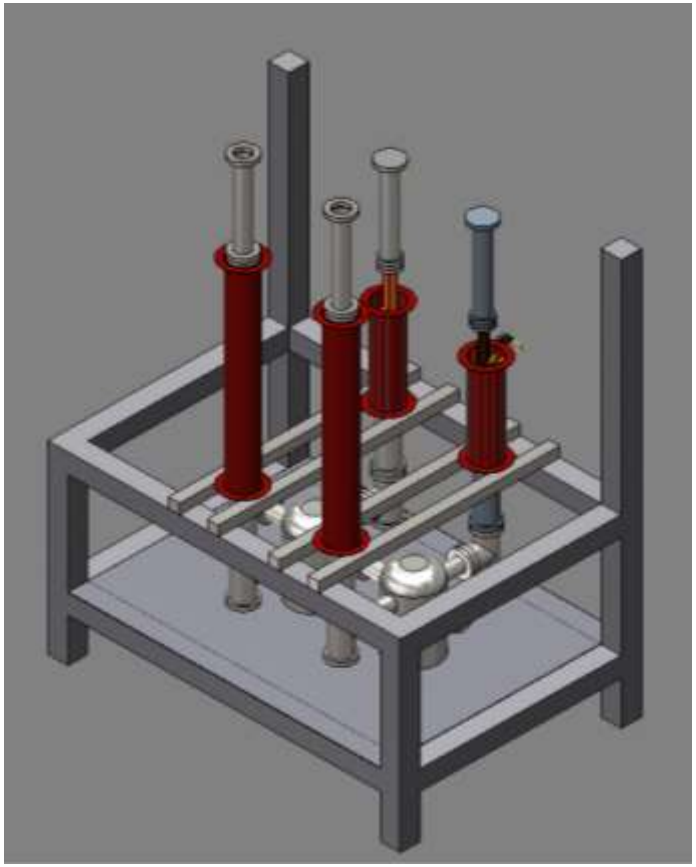
⇩

Incomplete activation



4 – Application to synchrotrons light sources

NEG coatings for MAX IV (2013 – 2015)

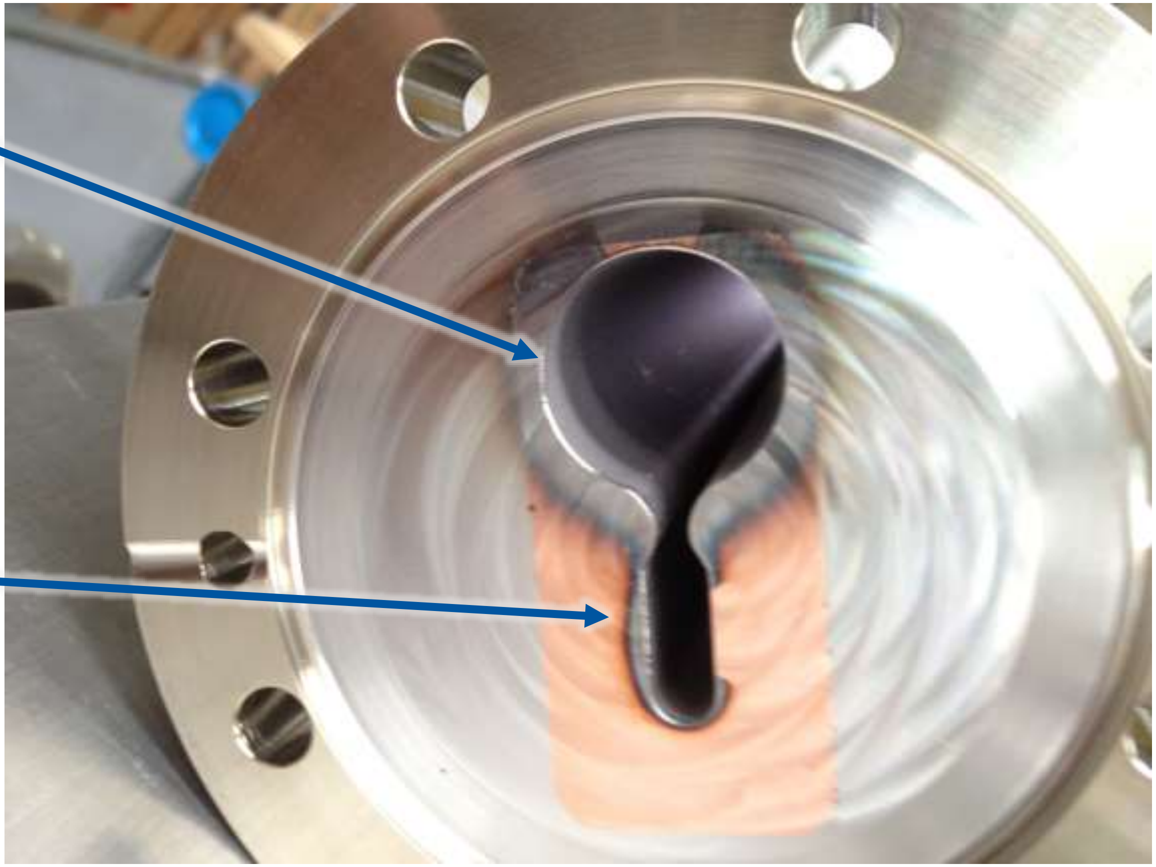


NEG coatings for MAX IV (2013 – 2015)

NEG coatings for MAX IV (2013 – 2015)

Electron chambers:
- ID22 mm
- L=300 (435) mm
- Pressure 0.06 mbar
- Magnetic field 180 Gauss
- Power Density 25 W/m

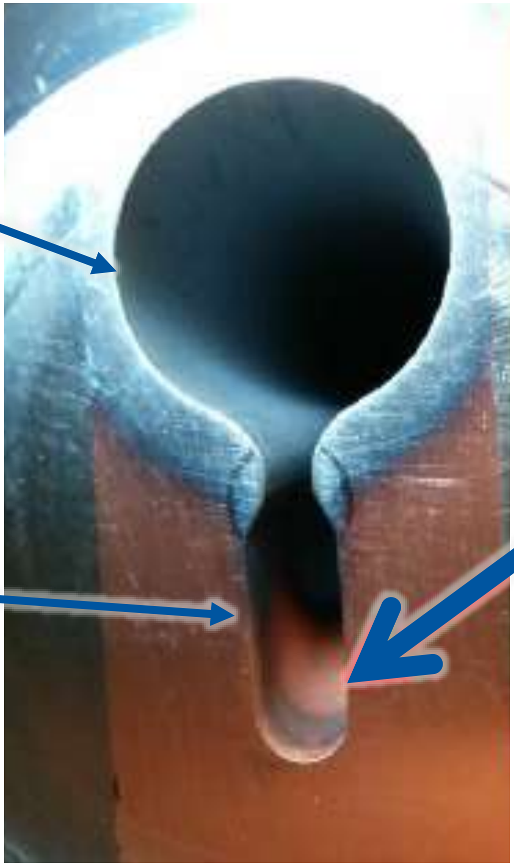
Photon chambers:
- From 6x11 mm to 7x34 mm
- L=300 (435) mm
- Pressure 0.66 mbar
- Magnetic field 500 Gauss
- Power Density 25 W/m



NEG coatings for MAX IV (2013 – 2015)

Electron chambers:

- ID22 mm
- L=300 (435) mm
- Pressure 0.06 mbar
- Magnetic field 180 Gauss
- Power Density 25 W/m



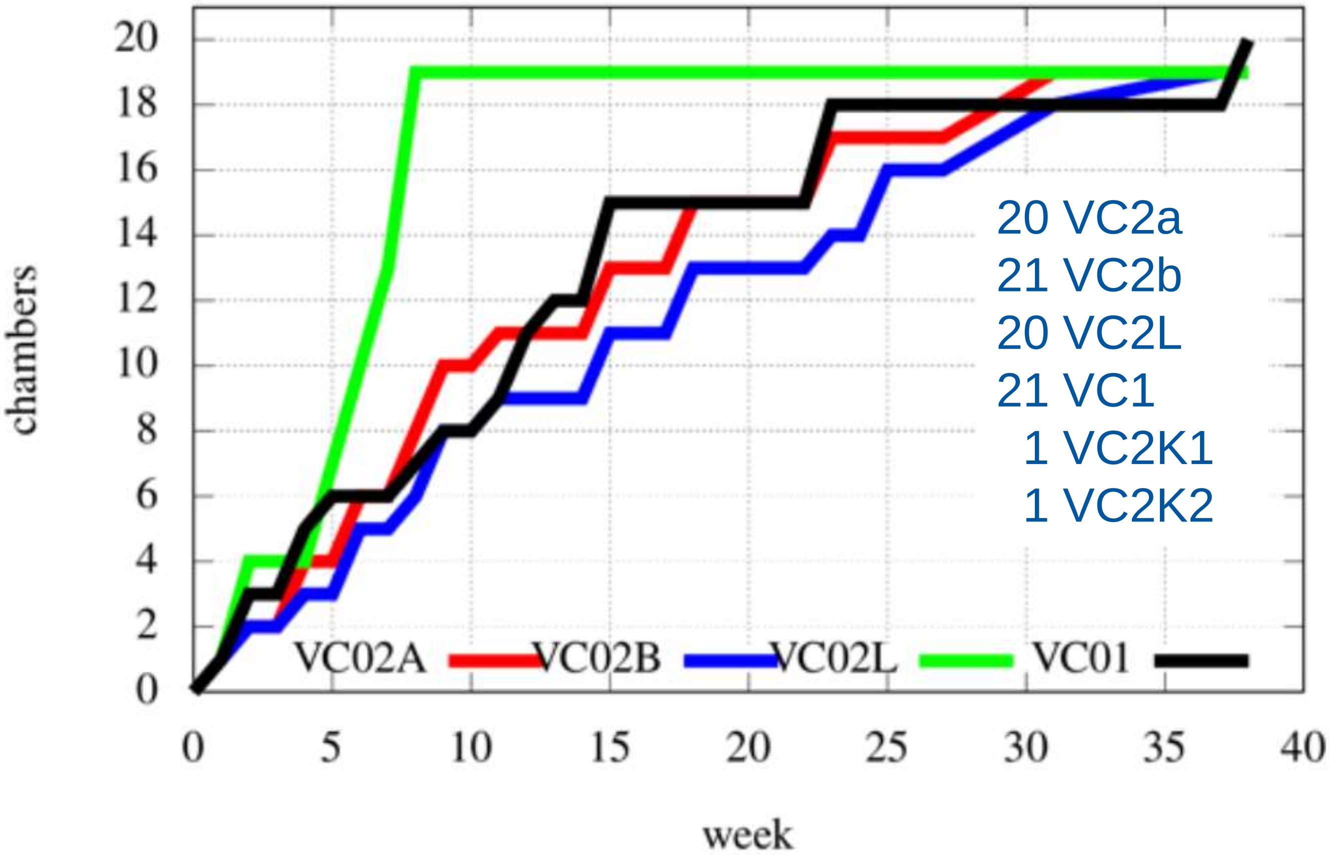
few chambers with ~3 cm^2 uncoated area on the smaller gap

Photon chambers:

- From 6x11 mm to 7x34 mm
- L=300 (435) mm
- Pressure 0.66 mbar
- Magnetic field 500 Gauss
- Power Density 25 W/m

NEG coatings for MAX IV (2013 – 2015)

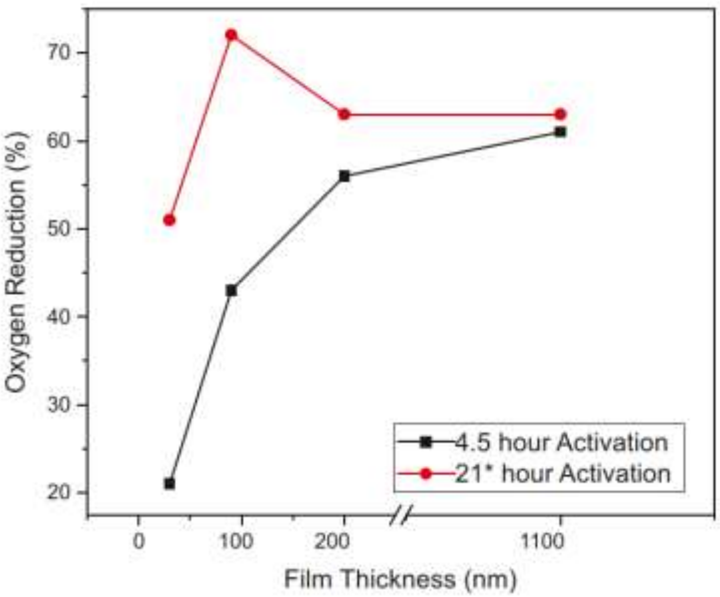
Between July 2014 and April 2015



What is the required thickness? => minimize beam impedance

Coat films with different thicknesses: 30 nm, 90 nm, 200 nm, 1100 nm.
(Motivation: minimize impedance for the Future Circular Collider)

Reduction of oxygen after 4 venting/activation cycles



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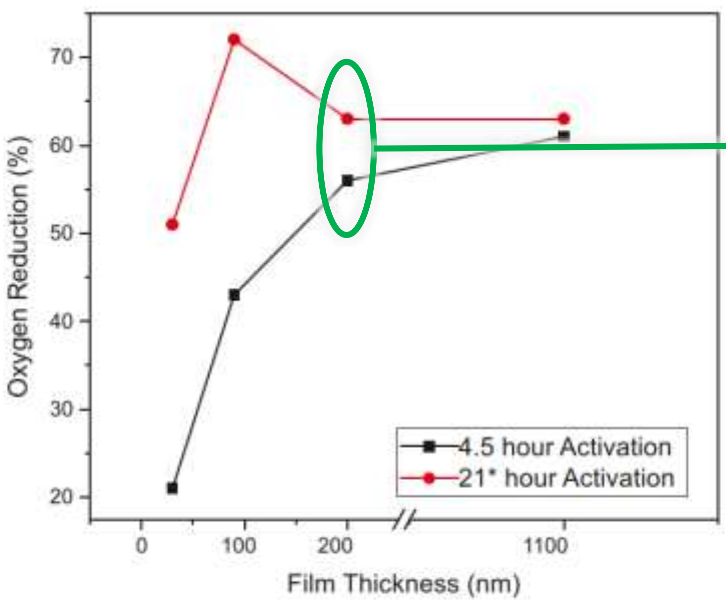
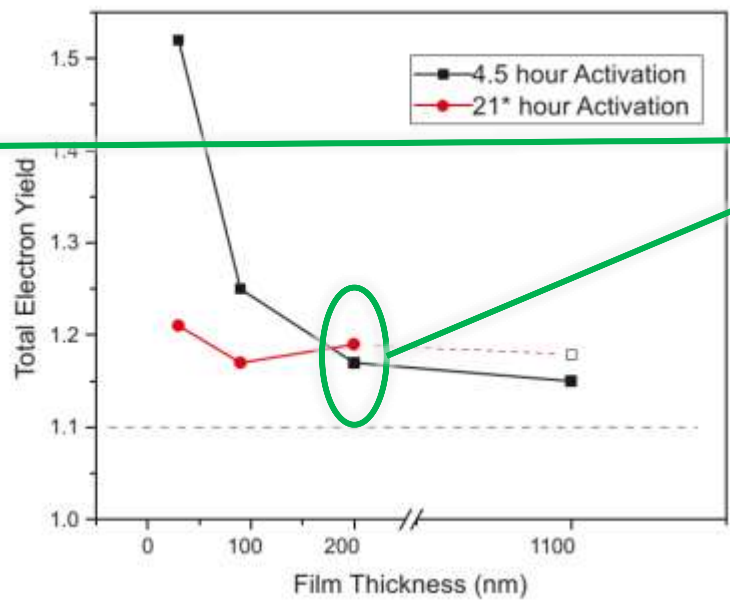


Secondary electron yield after 4 venting/activation cycles



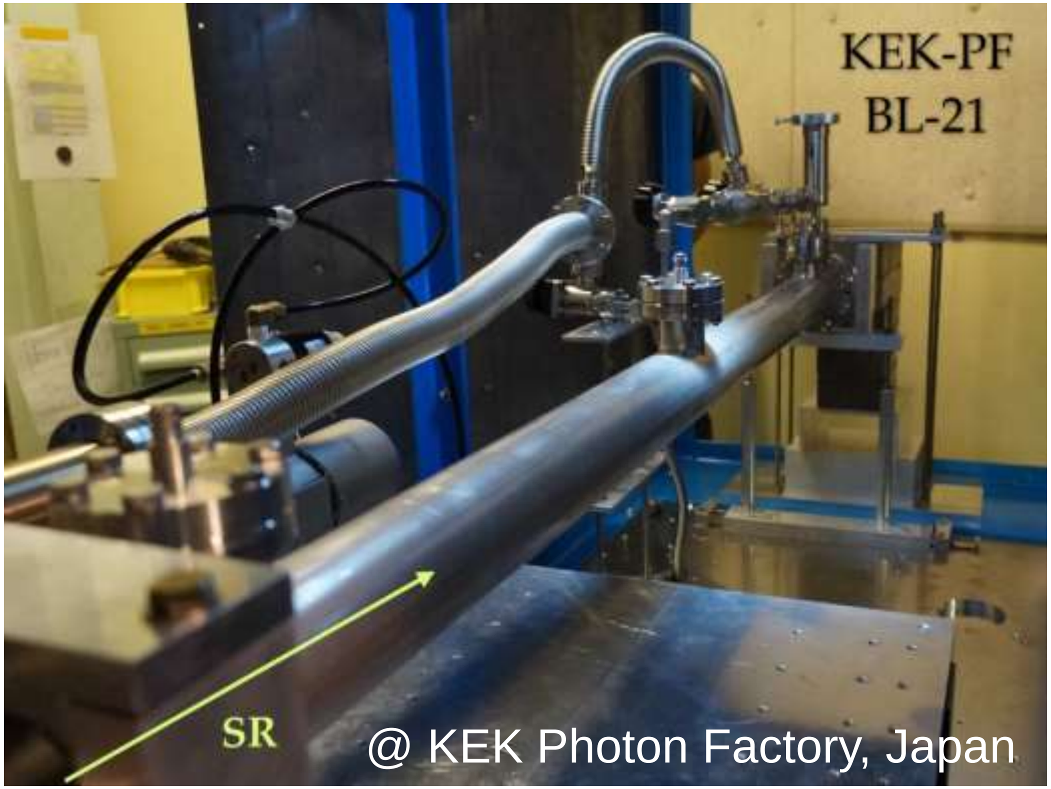
200 nm is enough

4x venting/activation cycles

4 – Application to synchrotrons light sources

What is the required thickness? => minimize beam impedance

What is the evolution of the PSD from a 200 nm film in function of venting/activation cycles?



4 – Application to synchrotrons light sources

What is the required thickness? => minimize beam impedance

What is the evolution of the PSD from a 200 nm film in function of venting/activation cycles?

	1	2	3	4	5	6	7	8	9	10	11
1. Vent with dry air, then expose to atmosphere		<30 min	<1 hour	45 min	50 min	50 min	50 min	50 min	50 min	50 min	50 min
2. System bakeout	200 °C 26 hours	200 °C 15 hours	200 °C 21 hours	200 °C 24 hours	200 °C 15 hours	200 °C 9 hours	200 °C 18 hours	200 °C 15 hours	200 °C 24 hours	200 °C 17 hours	200 °C 20 hours
3. Degas	Degas SIP, BAGx3, RGAx2 NEG C1300 activation (500 °C, 45 min)				RGA1	RGA1	Degas SIP, BAG, RGA NEG C1300 activation	RGA1	RGA1	Degas SIP, BAG, RGA NEG C1300 activation	Degas SIP, BAG, RGA NEG C1300 activation
4. NEG coating activation	250 °C 24 hours	250 °C 24 hours	250 °C 24 hours	250 °C 24 hours	250 °C 24 hours	250 °C 24 hours	250 °C 24 hours	250 °C 24 hours	250 °C 24 hours	250 °C 24 hours	-
5. Cool down	Cool down to room temperature				Cool down to room temperature					Cool down to room temperature	
6. SR irradiation	3.6 days 9.9×10^{21} ph/m	3.5 days 1.1×10^{22} ph/m	5.4 days 1.5×10^{22} ph/m	4.4 days 1.4×10^{22} ph/m	-	-	8.8 days 3.3×10^{22} ph/m		-	7.8 days 2.6×10^{22} ph/m	4.9 days 1.8×10^{22} ph/m

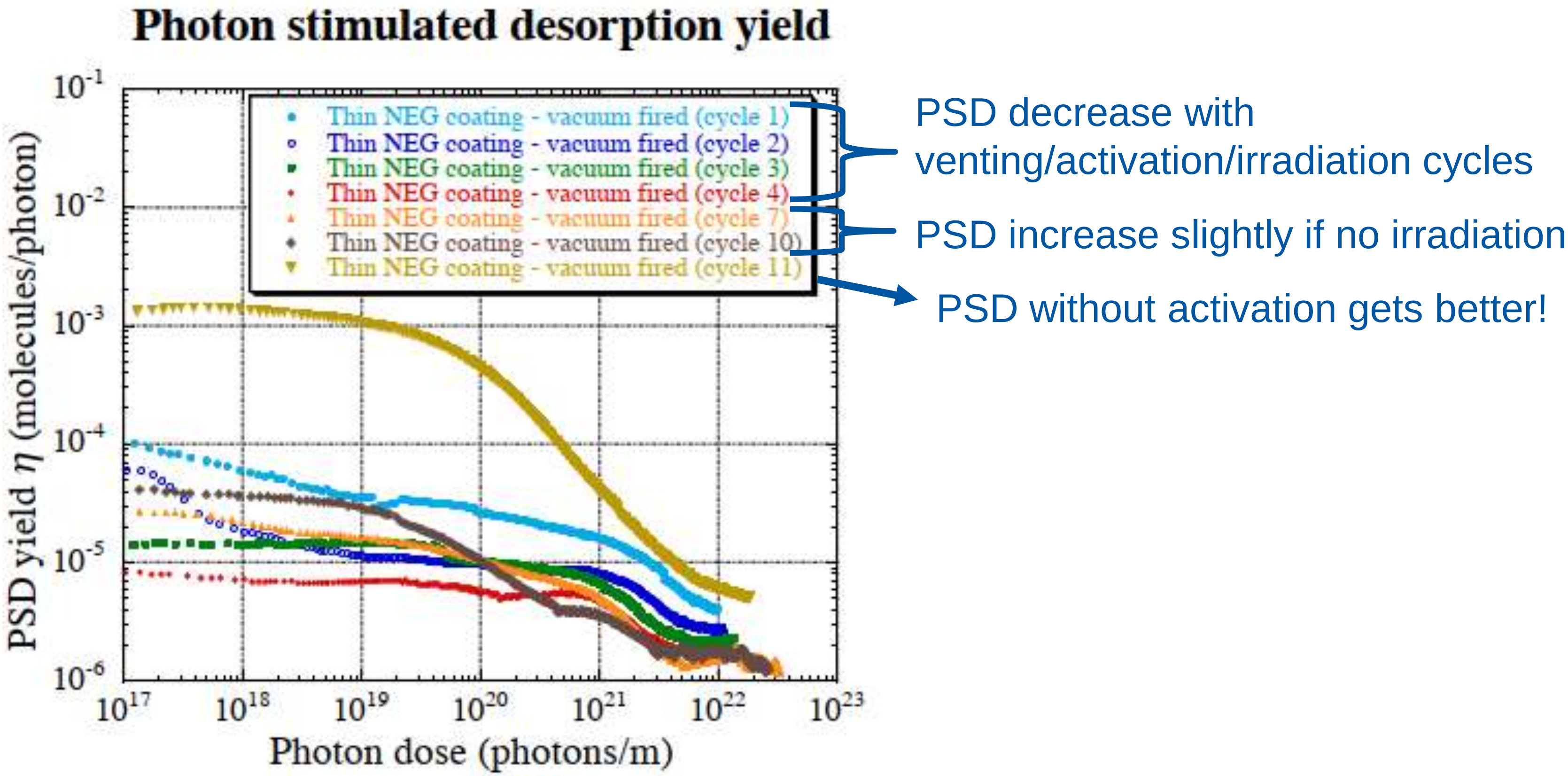
NO SR irradiation (5, 6)

NO SR irradiation (8, 9)

No NEG activation (11)

What is the required thickness? => minimize beam impedance

What is the evolution of the PSD from a 200 nm film in function of venting/activation cycles?



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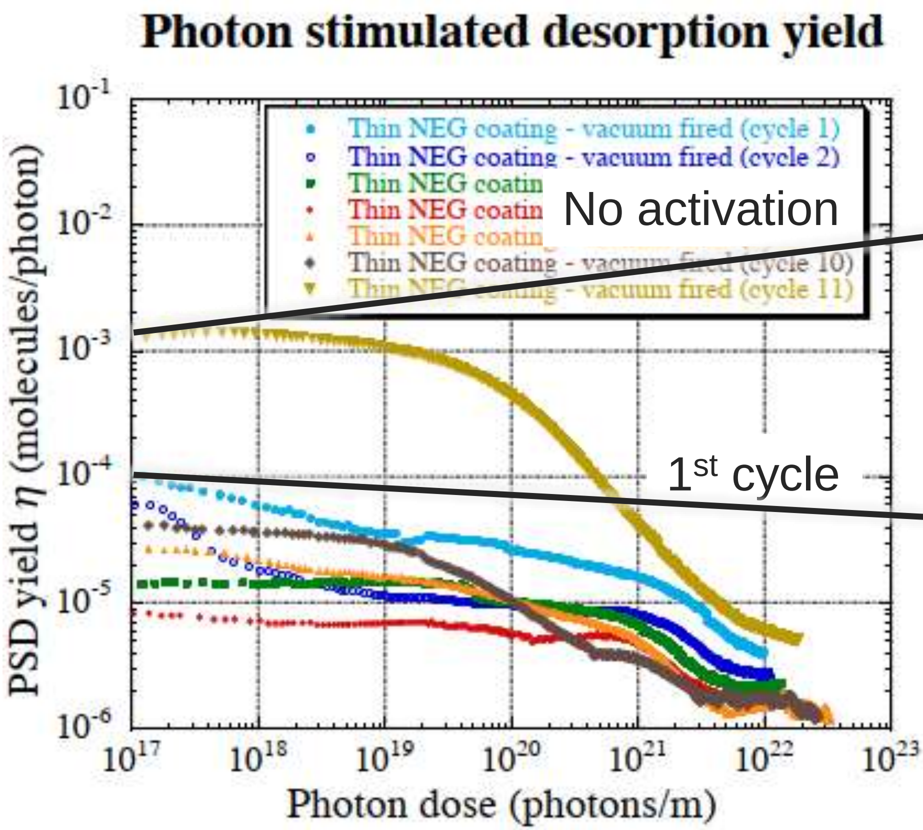

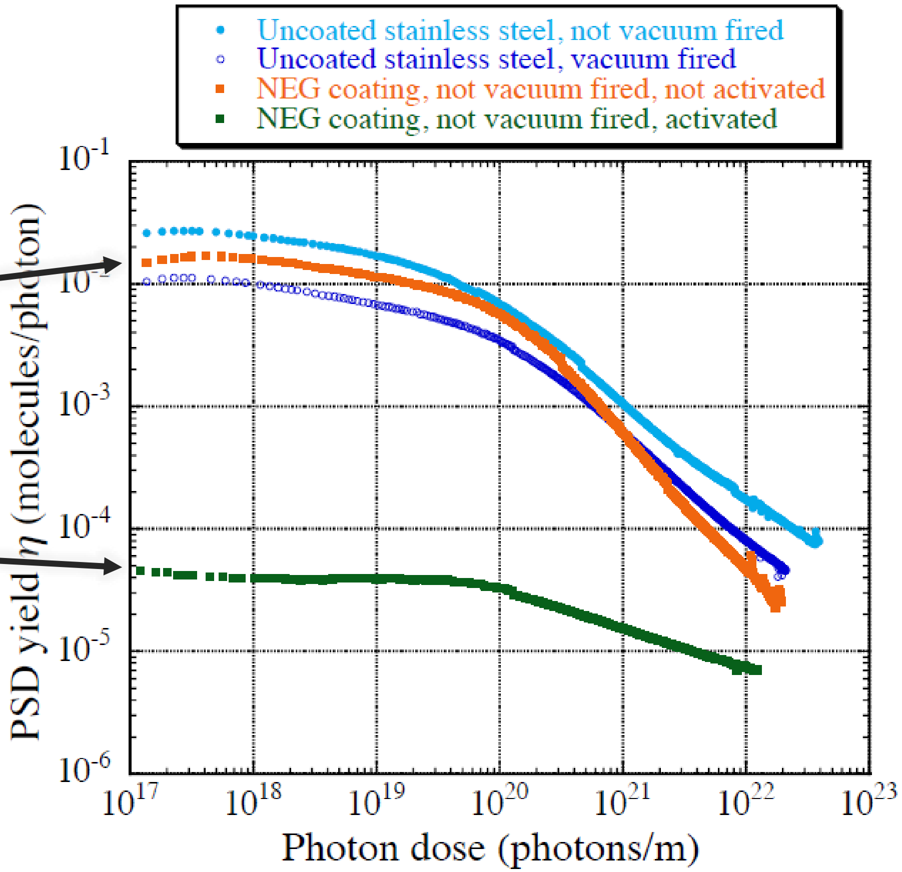

5 – Summary & final remarks

- NEG coatings can provide **distributed pumping speed** and **low PSD**, (and in addition low Secondary Electron Yield), and are now present in several kilometres of accelerators beam pipes all around the world.
- **Sputtering** have proven high "versatility", allowing to coat chambers with apertures ranging from 500 mm to 6 mm and different geometries.
- **Thickness uniformity**: at CERN, coating beam pipes with apertures down to 6 mm is still not fully mastered. Optimization requires the change of "standard" parameters… or the fabrication process of the chamber ("inverse NEG")
- **Minimum thickness**: down to 200 nm, the NEG is robust against air venting/activation cycles (tested up to 10; always goes down after irradiation). Thinner to be tested…
- **Adhesion** (no tackled): **surface treatment** before coating is **crucial**!

NEVER DISREGARD THE SURFACE TREATMENT

Thank you ☺