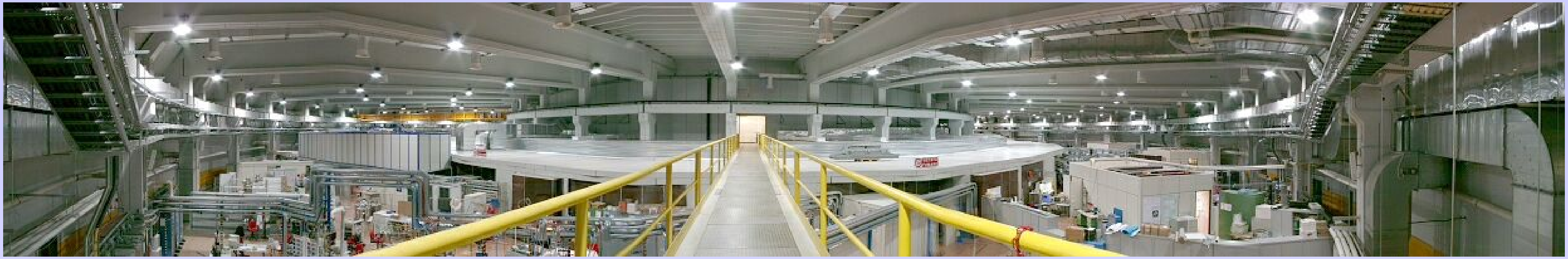


The use of NEG Pumps and Coatings in Large Vacuum Systems: Experience and limitations

Fabio Mazzolini

Elettra - Sincrotrone Trieste S.C.p.A., Trieste, Italy

Outlook

Non Evaporable Getters (NEGs)

- NEG Pumps (strip, wafer, cartridge, ...)
- NEG Coatings

Large vacuum systems

- Particle accelerators
  - Synchrotrons Light Sources
  - Ion colliders

Non Evaporable Getters (NEG) Pumps

Principles, definitions, properties, etc.

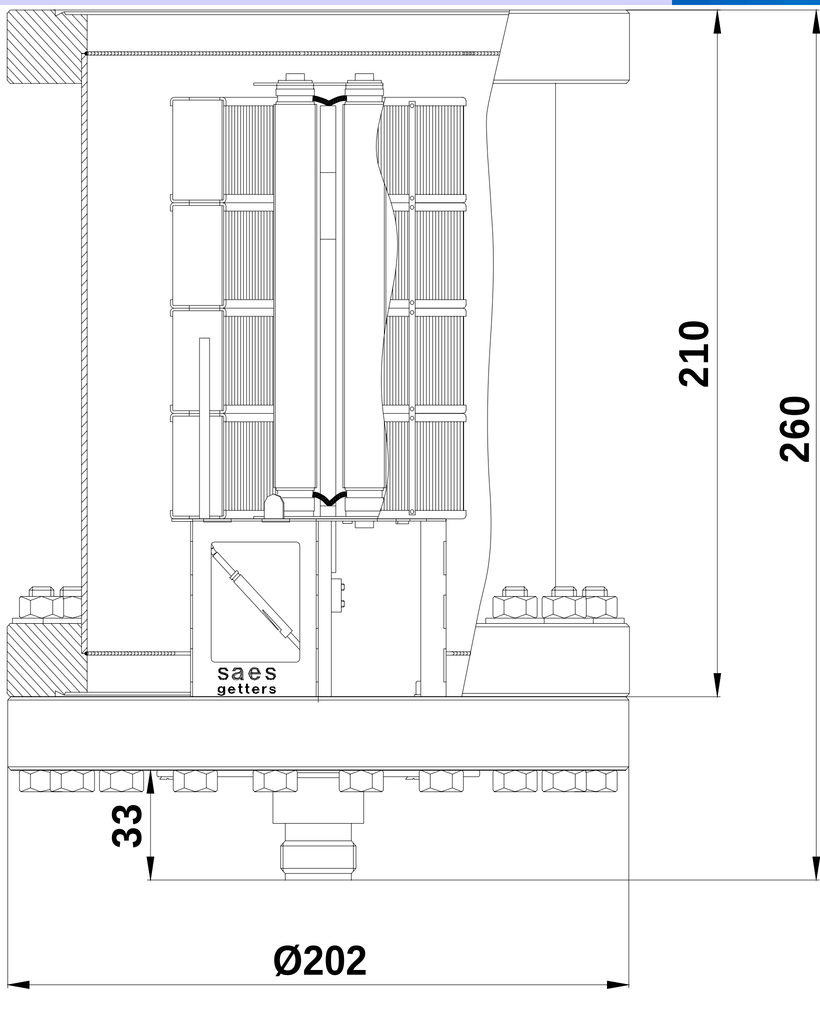
See C.Benvenuti’s lecture (this morning)

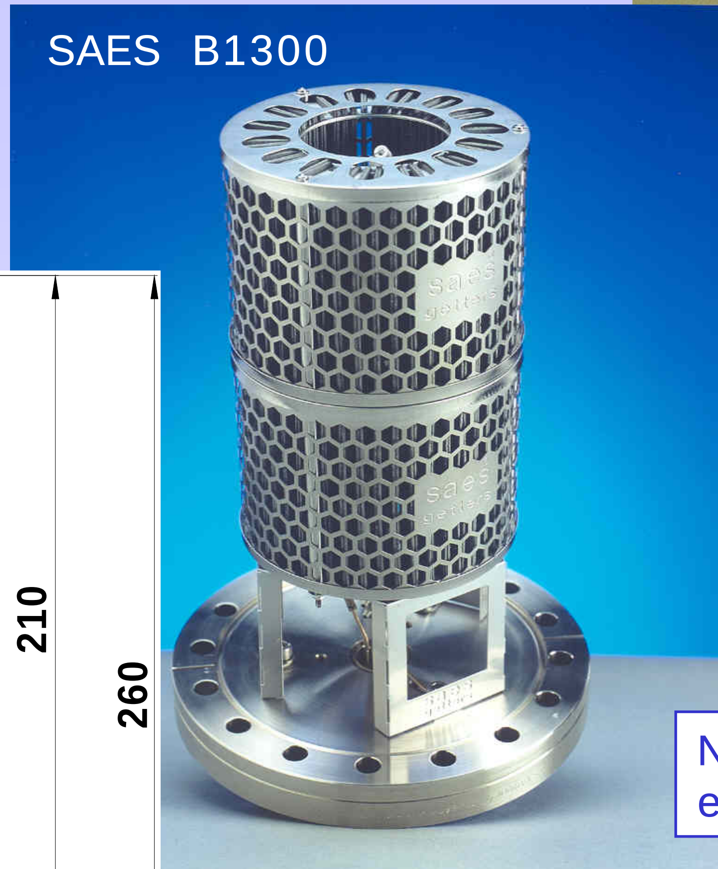
NEG pumps: main (practical) features

- High pumping speed for active gases *(especially for hydrogen)*
- High capacity *(= long life: Front-Ends@Elettra > 12 years)*
- Compact size *(easy to add in an existing vacuum system)*
- Light weight
- Very clean *(NEG powder ?)*
- Vibration-free
- Operation without power consumption *(after activation !)*
- Operation in the presence of high magnetic fields
- Reversible pumping of hydrogen
- Relatively Expensive *(initial cost)*

NEG Pumps:

Cartridge





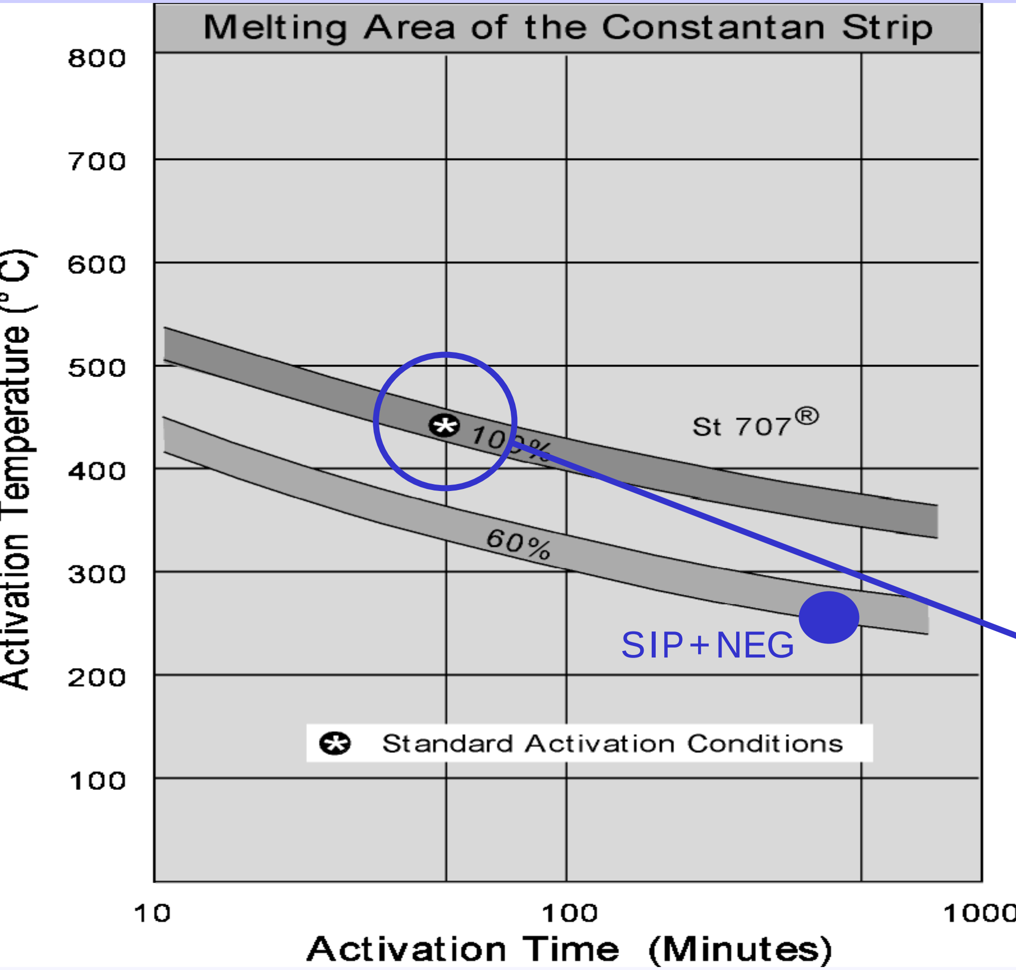
SAES D400-2

SAES B200

NEG cartridge replacement: easy

SAES GP 500 MK5 (SAES)		
Alloy Type		**ST 707**
Getter Alloy Mass (g)		**540**
Getter Surface (cm2)		**14290**
Pumping Speed (l/s)	H_2	**1200**
	CO	**500**

NEG activation (an example):



NEG pump activation efficiency curves

(GP Series)

1) pump the vacuum system down
   (turbomolecular pump, vac. valve open)

2) bake the vacuum system

   24 h @ 150 °C

3) hold the temp. @ 100 °C

4) “degas” ion pumps (switch them on–off
   3-4 times, until the pressure decrese)

5) switch all the pressure gauges off

6) activate NEGs

   1 h @ 430 °C

7) “degas” filaments

8) switch ion pumps and press. gauges on

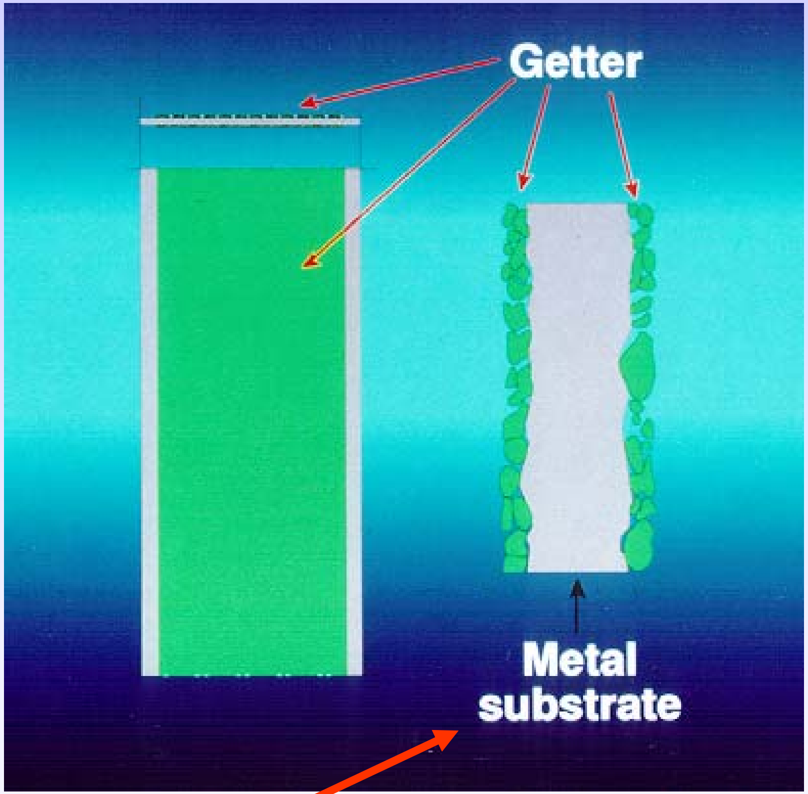
9) cool the vac. sys. down to room temp.

10) close the valves connecting the turbos to
    the vacuum system

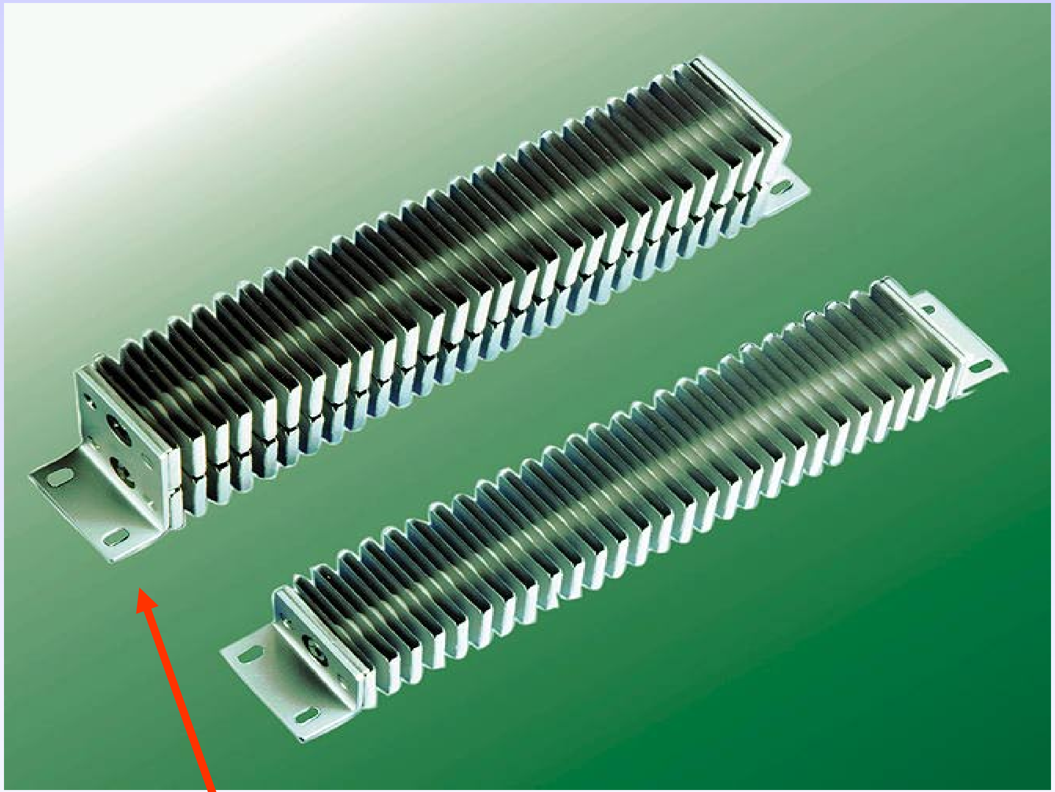
NEG Pumps:

Strips and Wafer

NEG Strips



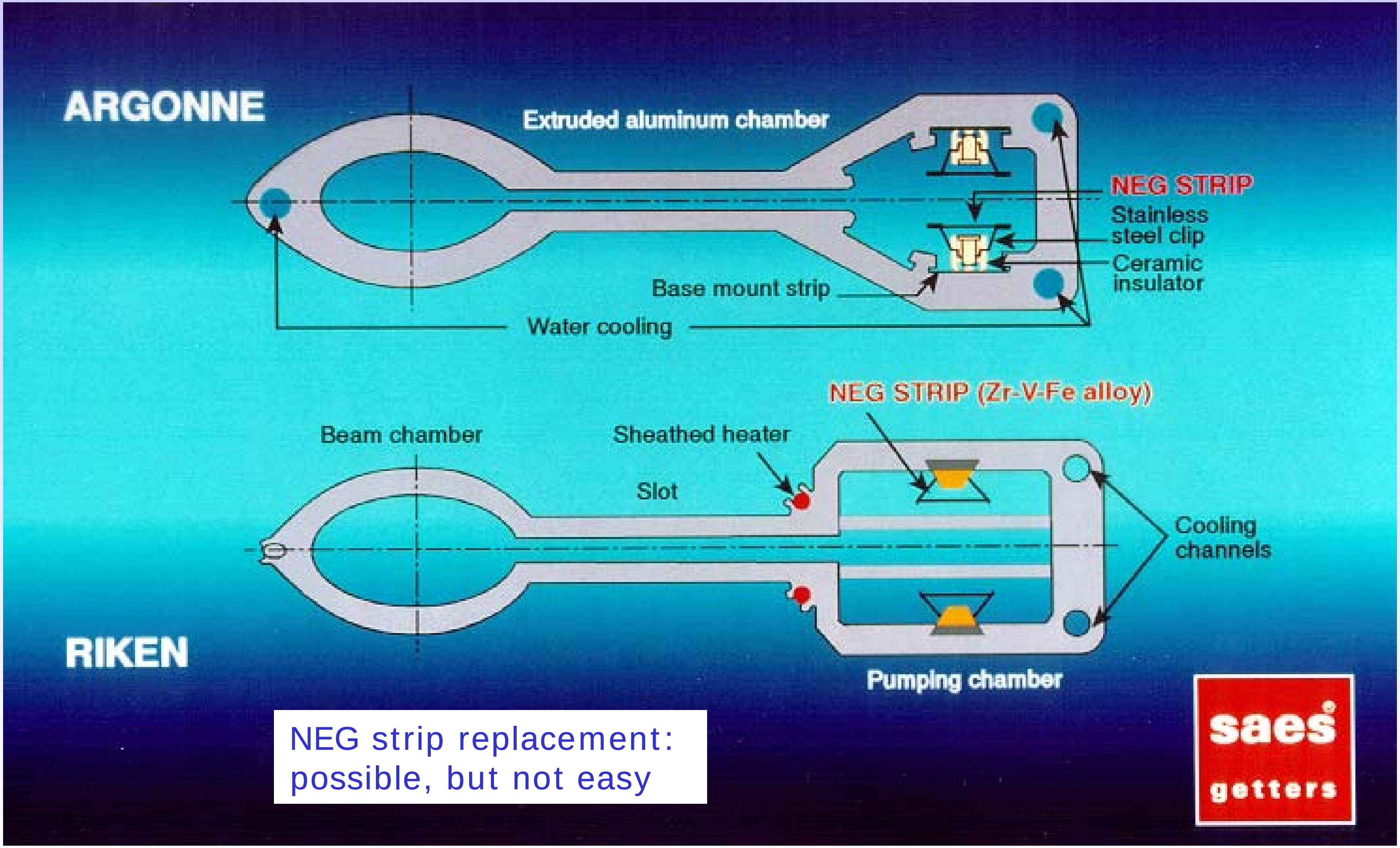
NEG Wafer Modules (SAES)



Constantane = support & heater
(high electrical resistivity)

Need of electrical insulators (vacuum chamber)
+ electrical feedtrough

NEG Strips

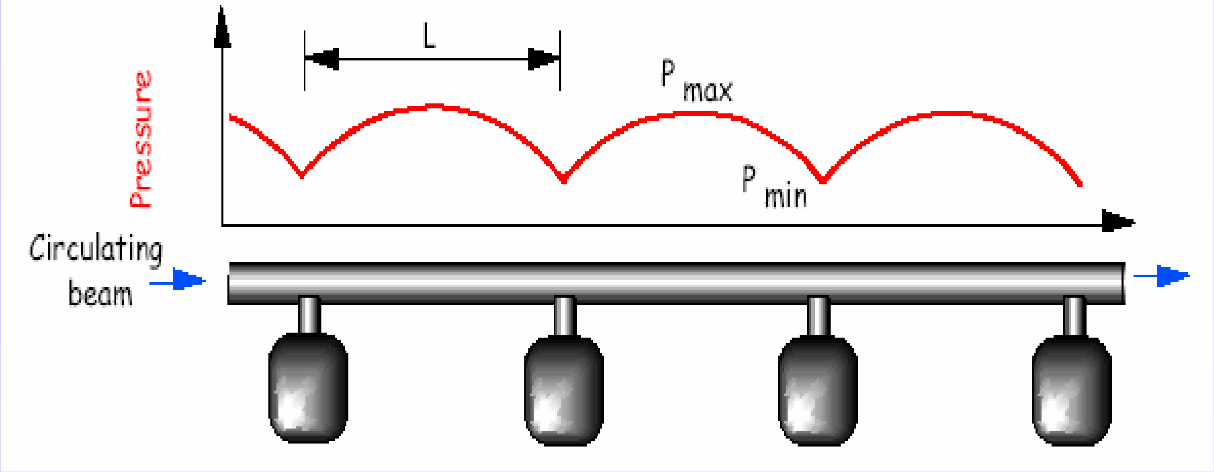


NEG strip replacement: possible, but not easy

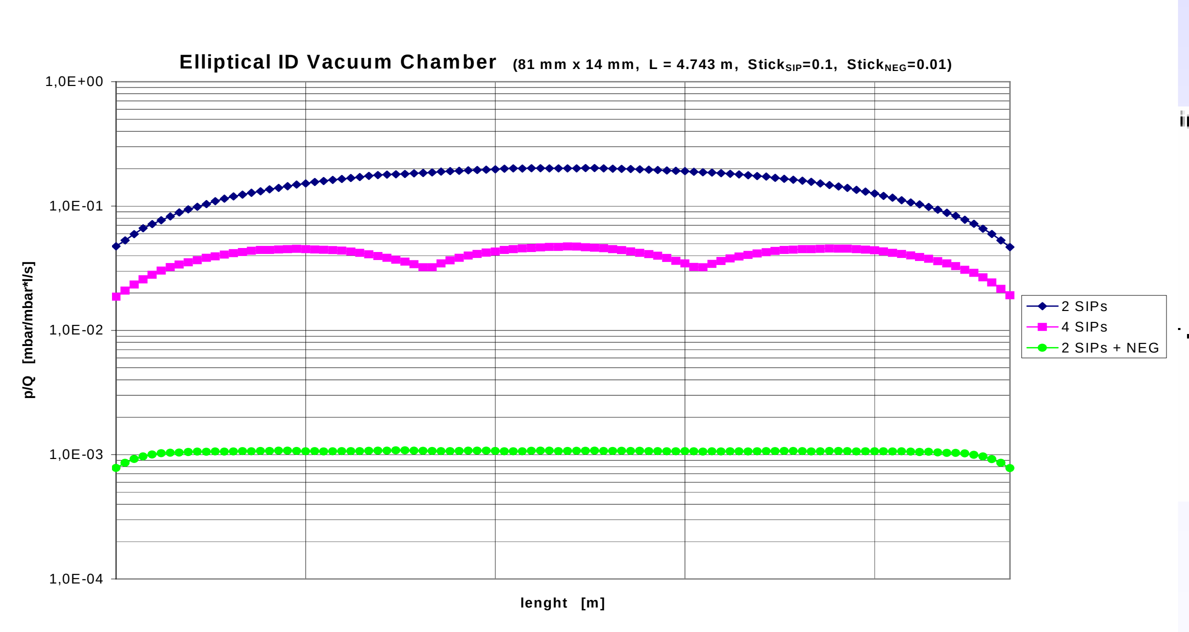
Towards the NEG coating

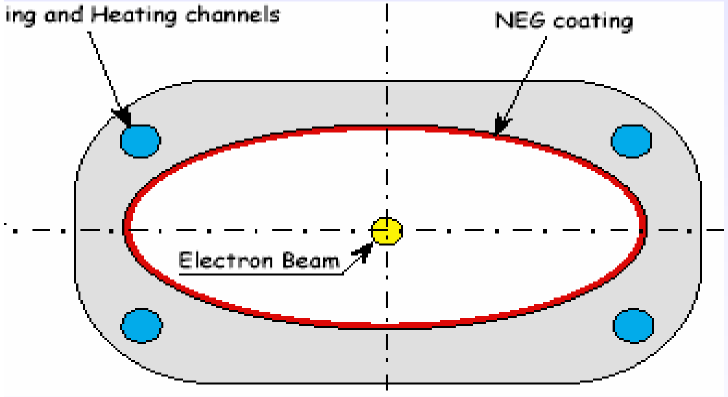
The use of a new distributed pumping concept in pipes started in 1995 at CERN for the LHC project.

A. E. Prodomides et al., Vacuum 60 (2001), 35-41



1) Discrete pump system





3) Distributed pump system (LHC)

Non Evaporable Getter (NEG)

Zr-Al alloy, Zr-V-Fe alloy, ...

commonly used for Ultra High Vacuum (UHV) applications

very effective in pumping active gas (H_2, CO, ...)

not suitable for pumping He, Ar, CH_4, ...

limited number of activation/venting cycles

not suitable for vacuum systems routinely open to air

an “in situ” bake-out is required (high temperature)

usually available as strips or cartridges (thick powder layer)

NEG coating

Produced by sputtering:

uniform and distributed coating
different alloys/compounds *(composite cathodes)*

Getter materials:
Ti, Zr, Hf, V, ...

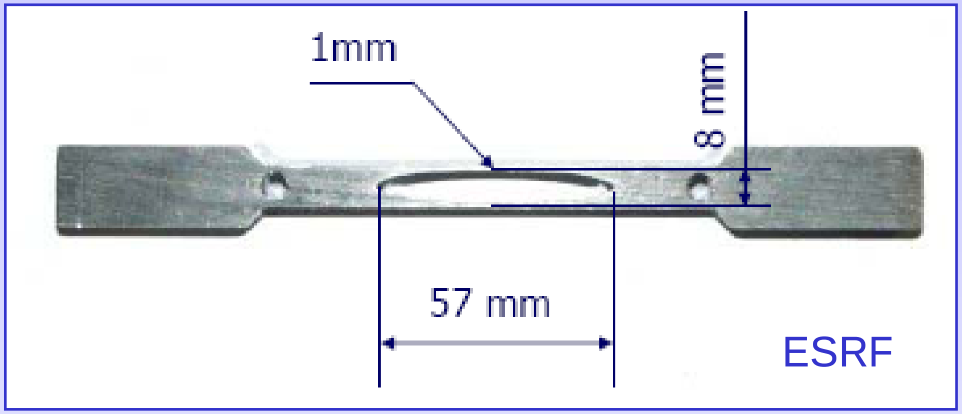
Thickness: 1 micron

Low activation temperature (<200 °C for **Ti-Zr-V**)
=> compatible with aluminium alloy

C. Benvenuti, Non-evaporable getters: from pumping strips to thin film coatings, Proceedings of EPAC 1998, Stockholm, June 1998

C. Benvenuti et al., A novel route to extreme vacua: the non-evaporable getters thin film coatings, Vacuum 53 (1999) 219-225

Synchrotron light sources: vacuum chambers for Insertion Devices



Long and narrow vacuum chambers:

=> low vacuum conductance

(conductance limited system)

=> high "gas load" (high photon flux)

=> short e-beam lifetime

=> high "bremsstrahlung" emission

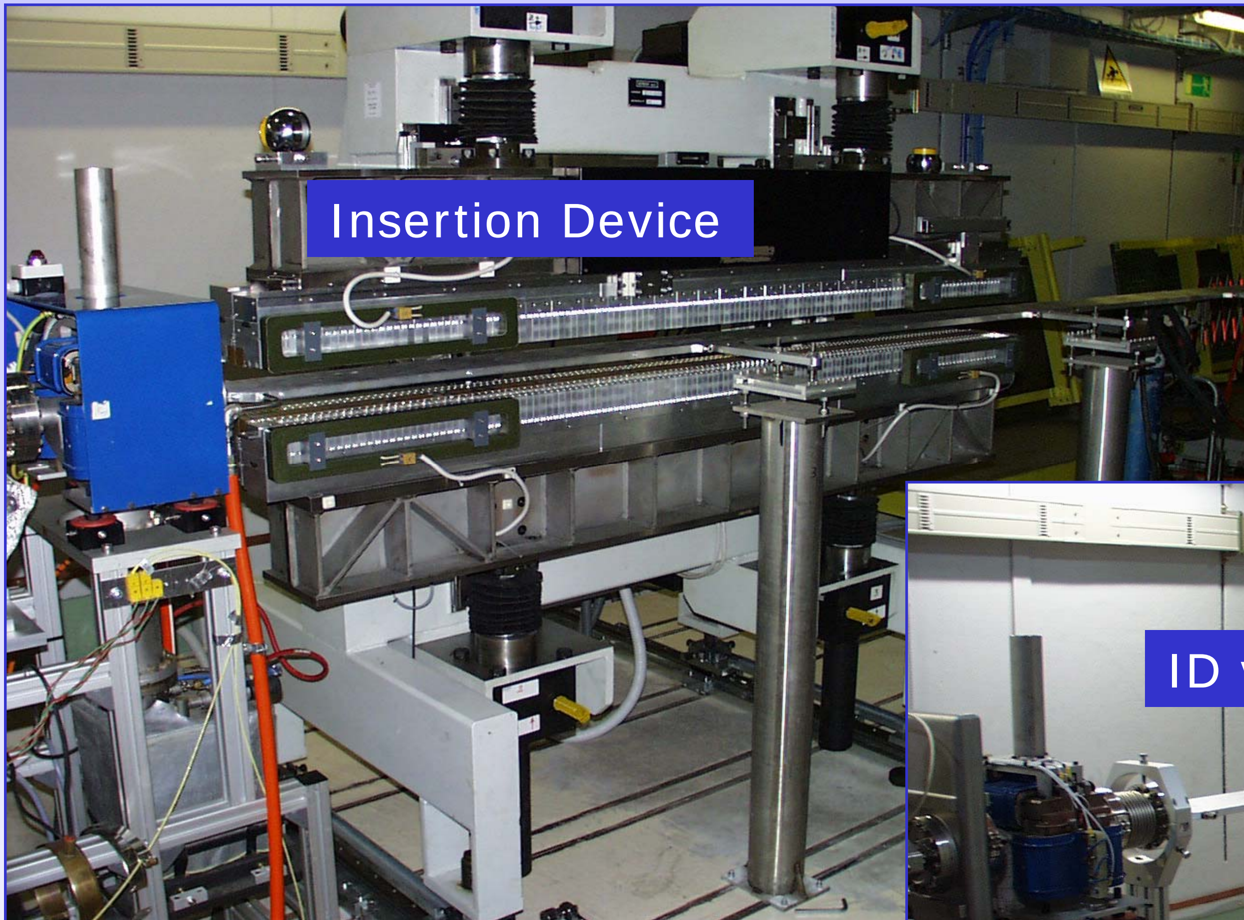
Need of a *distributed vacuum pumping system*:

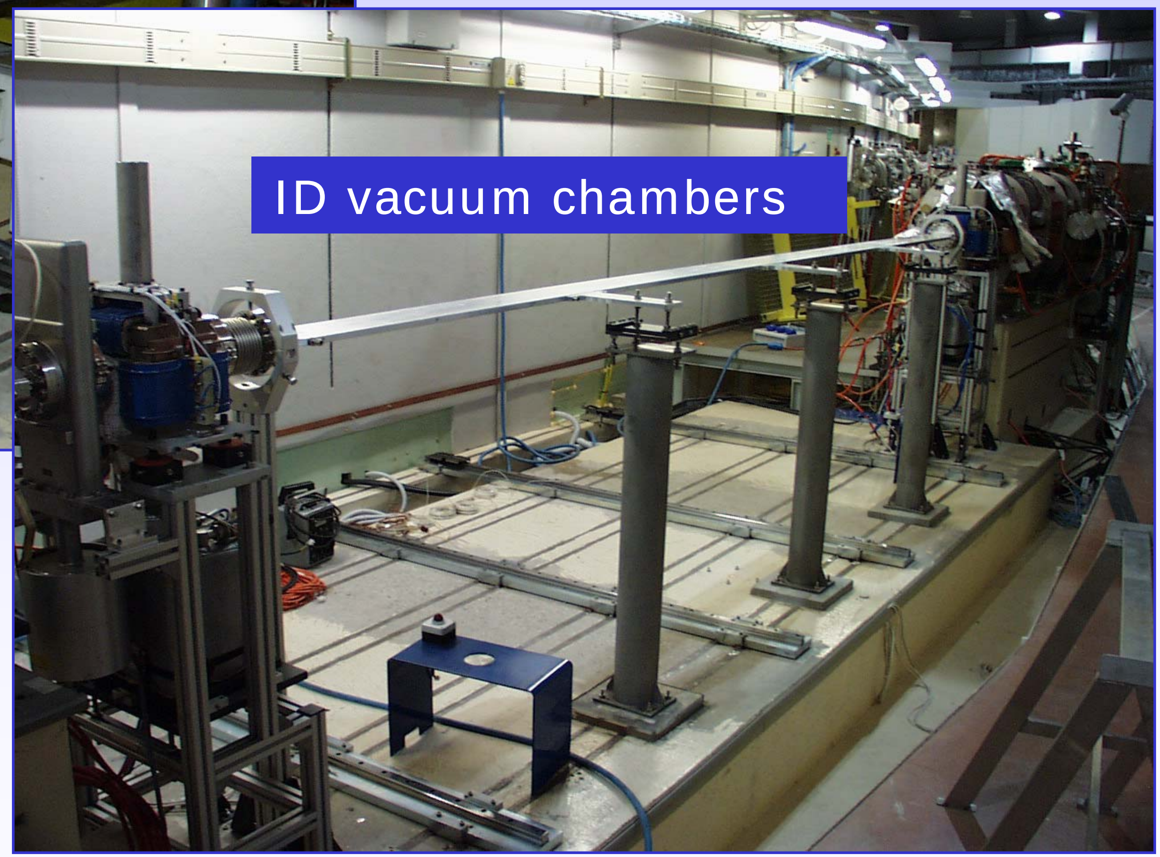
=> Ion Pumps (IP) + high conductance ante-chamber (HCAC)

=> IPs + HCAC + NEG strips

=> SIPs + NEG coatings (w/o HCAC)

Synchrotron Light source: vacuum chambers for Insertion Devices

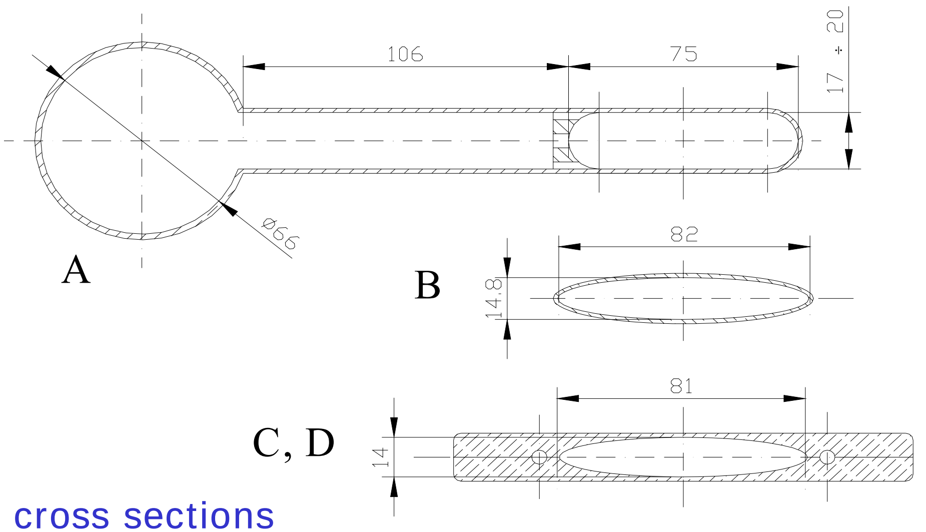




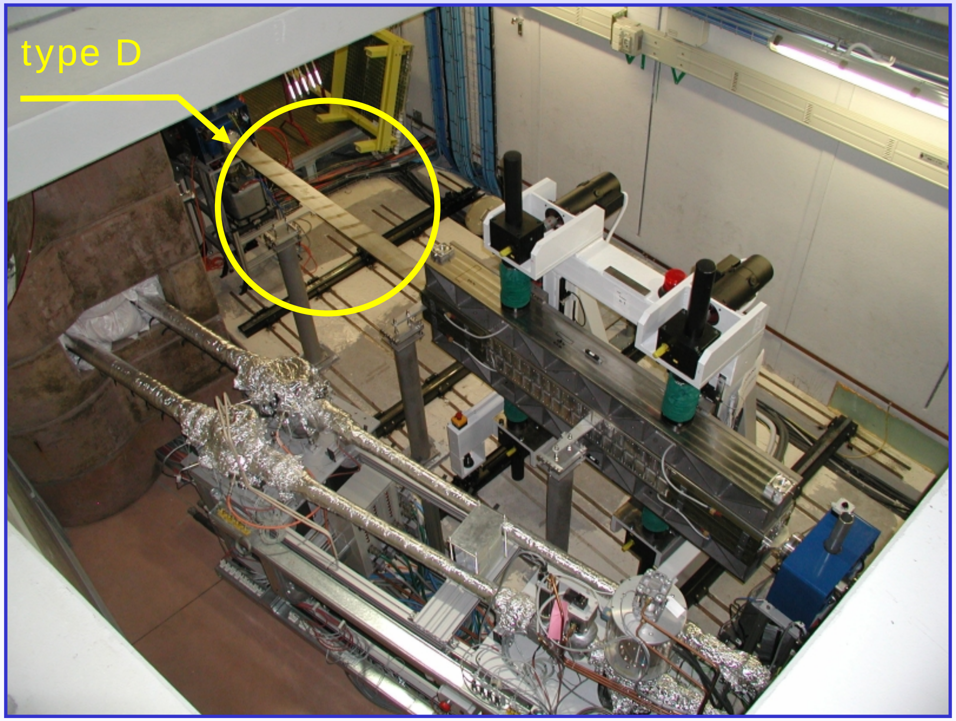
ID vacuum chambers @ Elettra

I.D.	Material of the I.D. Vacuum Chambers	Type
1	Aluminum (no ante-chamber)	C
2	Aluminum (no ante-chamber) (+ NEG)	D
3	Stainless Steel (with ante-chamber)	A
4	Stainless Steel (no ante-chamber)	B
5	Stainless Steel (with ante-chamber)	A
6	Stainless Steel (with ante-chamber)	A
7	Aluminum (no ante-chamber) + NEG	D
8	Aluminum (no ante-chamber)	C
9	Aluminum (no ante-chamber) + NEG	D
10	Aluminum (no ante-chamber) + NEG	D
11	Copper (*)	(*)

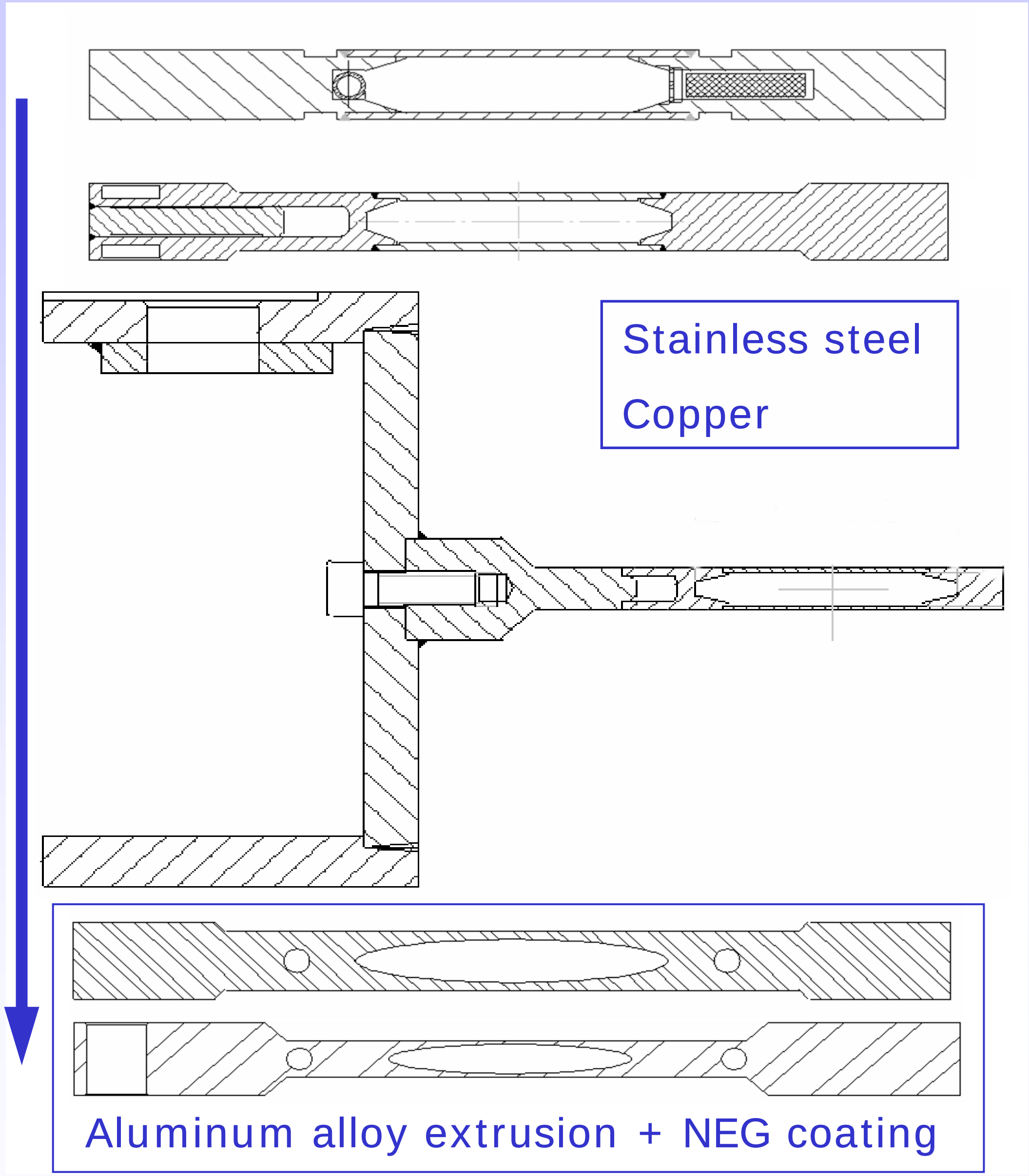
(*) Super Conducting Wiggler + 3rd Harmonic Cavity



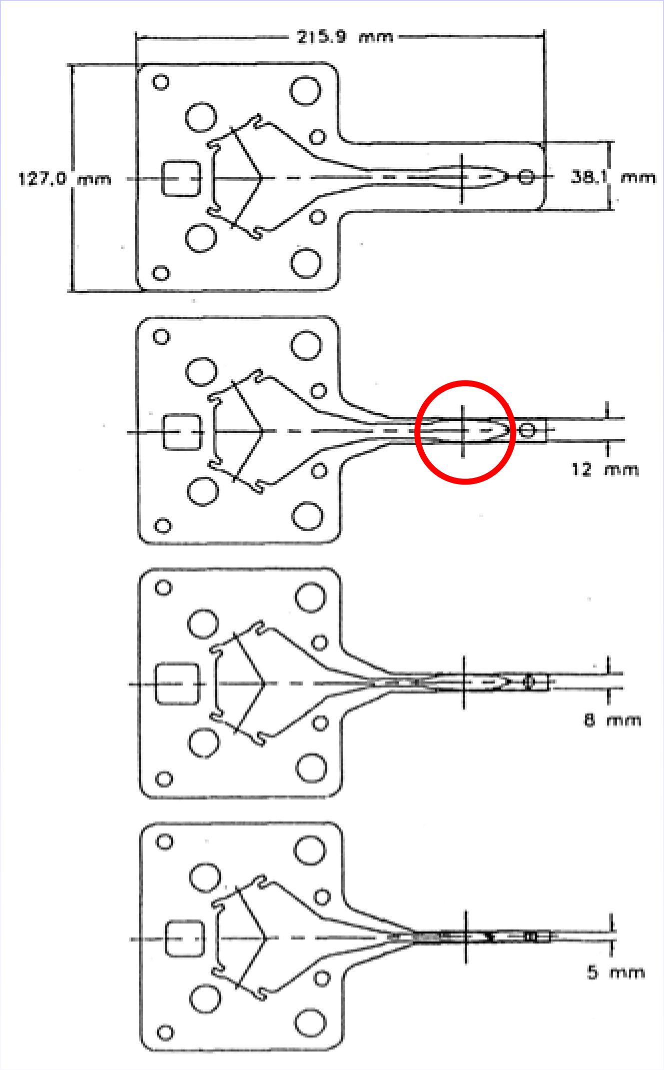
cross sections



History of Insertion Device (ID) vacuum chambers @ ESRF *(M. Hahn, ESRF)*



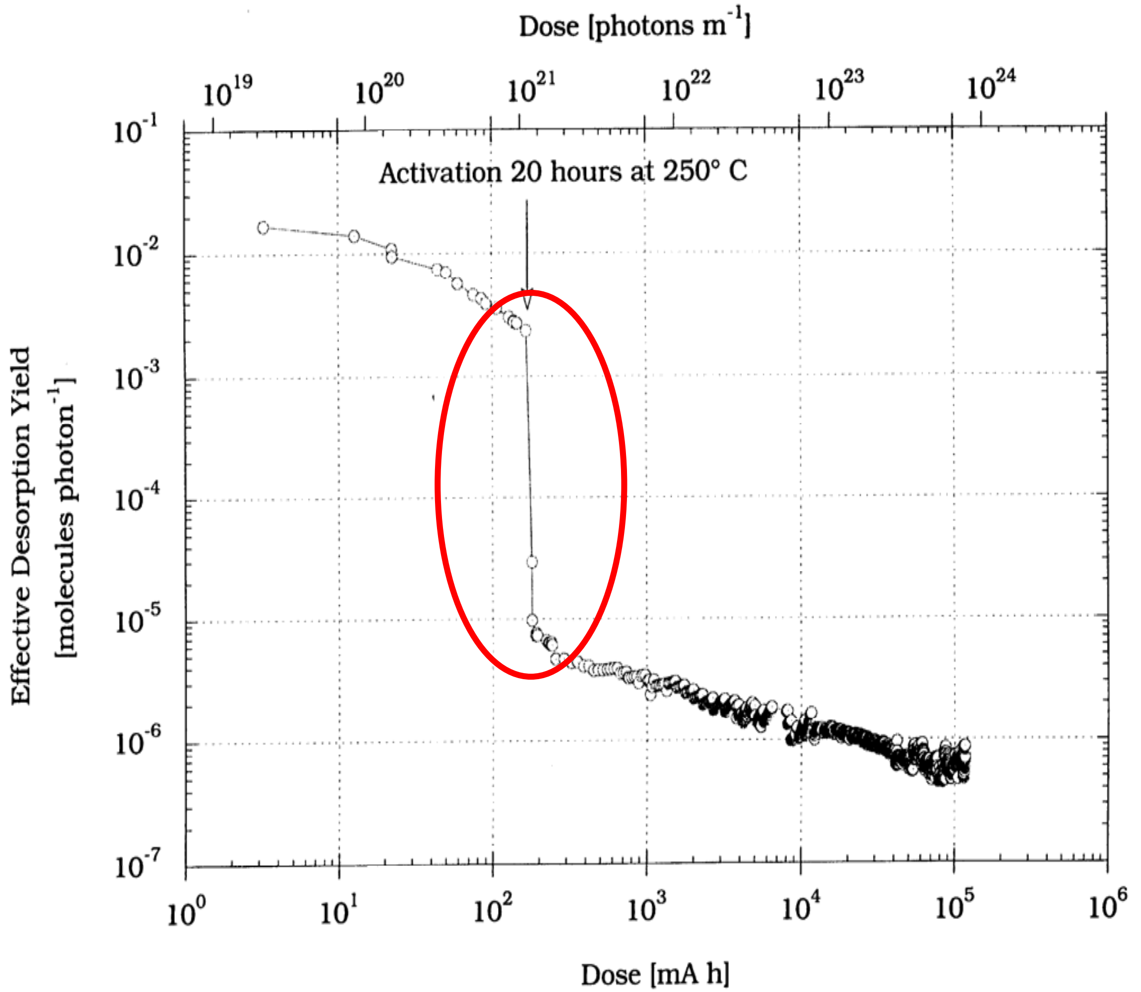
Insertion Device (ID) vacuum chambers @ APS



Aluminum alloy extrusions

NEG coatings & Photon Induced Desorption *(see N.Hilleret's lecture)*:

Are these coatings suitable for the use in a particle accelertor?



"Variation of the effective molecular desorption yield as a function of the beam and photon dose measured on a TiZrV coated stainless steel chamber installed on a beamline at ESRF Grenoble.

The getter coating activation (250 °C for 20 h) is accompanied by a sharp decrease of the desorption yield (about a factor 380), due to both surface cleaning and pumping."

C.Benvenuti et al., EVC-6, 1999

NEG coated vacuum chambers in a "working" particle accelerator: Do they work?

Synchrotron light sources

The ESRF experience (2000-2006)

The Elettra experience (2002-2006)

Ion Collider

The RHIC experience (2004-2006)

The ESRF experience

(R.Kersevan, M.Hahn, F.Demarcq, ESRF, 45th IUVSTA Workshop, Catania 2006)

First NEG coated chamber installed in 2000

Reduced BS levels

Faster vacuum conditioning

Resistance to several venting/activation cycles

No adverse effect on the machine:

i.e. peeling-off of the coating, impedance budget, ...

NEG coating: impedance budget

(R.Kersevan, ESRF, 45th IUVSTA workshop, Catania 2006)

“The machine division of the ESRF, in conjunction with Elettra and Soleil, has carried out throughout several years a rather detailed study of the effect of NEG-coated chambers, both made of SS and Al, as far as the resistive-wall impedance budget is concerned, especially on its effect on the single-bunch threshold

Resistivity of the NEG-coating:

the rather poor resistivity of Ti, Zr and V should enhance the imaginary part of the **resistive wall impedance**, affecting the single-bunch threshold: coating thicknesses have been reduced, from 1μm to 0.5μm (nominal), and the effect measured in good agreement with theory”

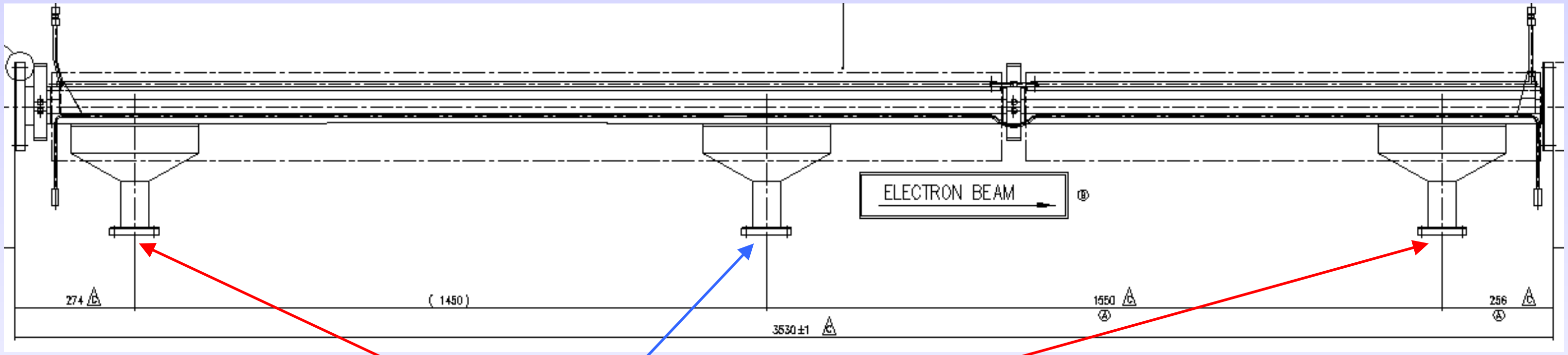
⇒ **Reduction of the nominal thickness of the coatings, from 1 μm to 0.5 μm.**

⇒ **The vacuum performance has not been affected by the change, as predicted by measurements done at CERN** *(P.Chiggiato, 41st IUVSTA workshop, 2004)*.”

Recent developments, machine upgrade plans

(R.Kersevan, ESRF, 45th IUVSTA workshop, Catania 2006)

"Vacuum chamber based on a new NEG-coating-based concept, where most lumped pumps are removed and the reduced desorption of the NEG-coating does the job."



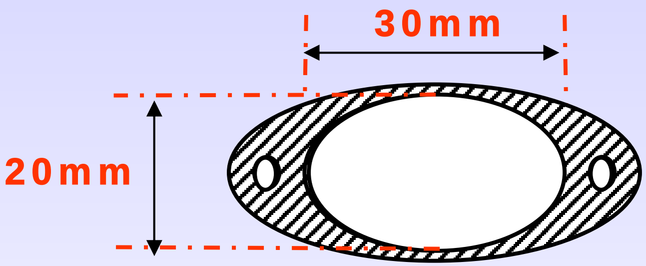
"CV3" ESRF STANDARD PROFILE:

3.5 m-long, pumped by 2 NEG cartridges (200 l/s each), and 1 ion-pump (45 l/s).

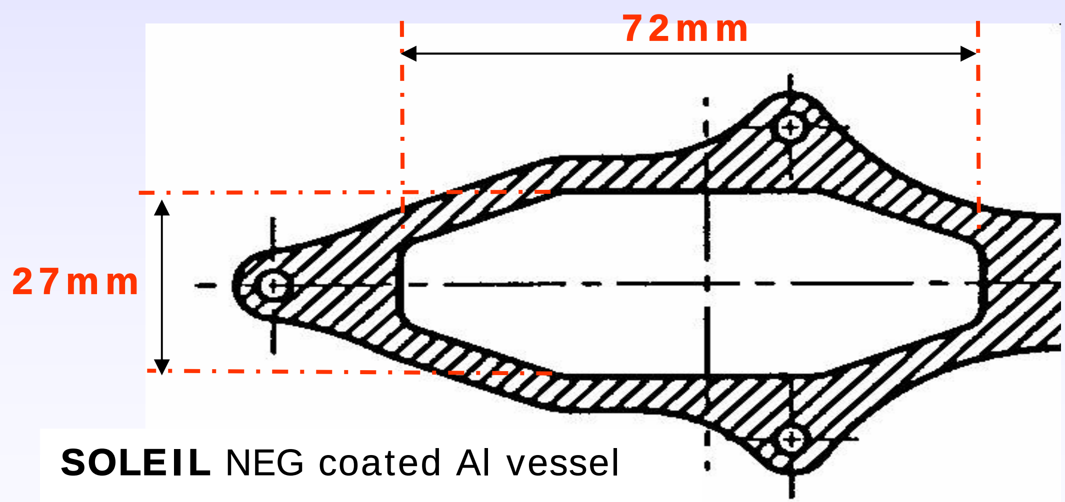
In the machine, there are 32 ""CV15" chambers which are symmetrical: there are therefore 64x2 = 128 NEG cartridges + 64 IPs which could be spared by moving to a "pump-less solution

Machine development – NEG-coated CV3s: both the SOLEIL and "ESRF-2" extrusions, with no lumped pumps, have been coated in house. They have performed remarkably in terms of prompt vacuum conditionings and low bremsstrahlung rates.

(R.Kersevan, ESRF, 45th IUVSTA workshop, Catania 2006)



ESRF-2 PROFILE NEG coated Al vessel (2005)



SOLEIL NEG coated Al vessel (2005)

The Elettra experience

(F.Mazzolini, Elettra, 45th IUVSTA Workshop, Catania 2006)

First NEG coated Aluminium alloy chamber installed in 2002

Reduced BS levels

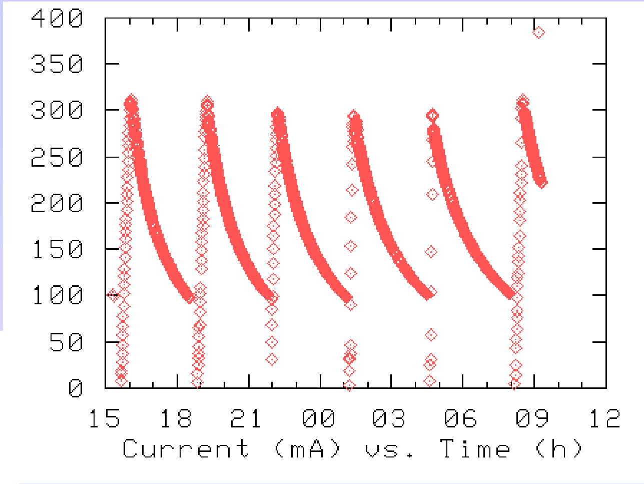
Faster vacuum conditioning

Resistance to several venting/activation cycles

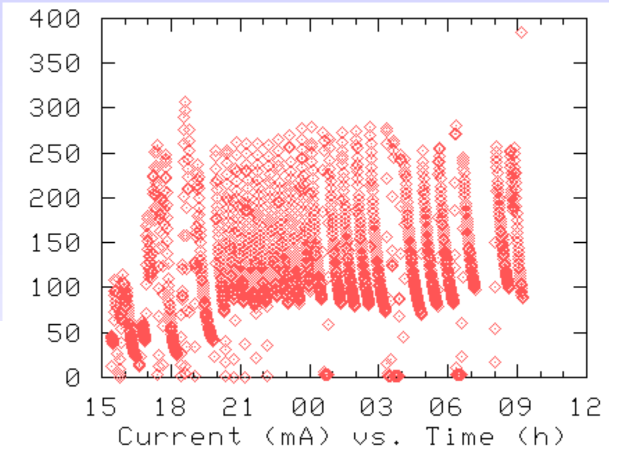
Some adverse effect on the machine:

impedance budget (increase)

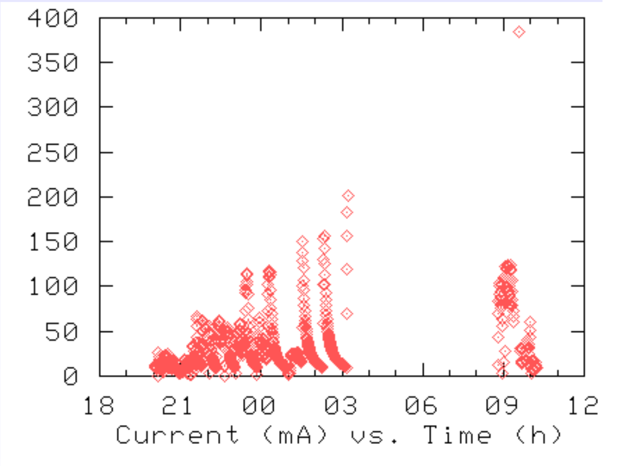
Trying to reinject an e-beam after the installation of the first aluminum vacuum chamber for ID (November 2000)



24/11/00



21/11/00



19/11/00

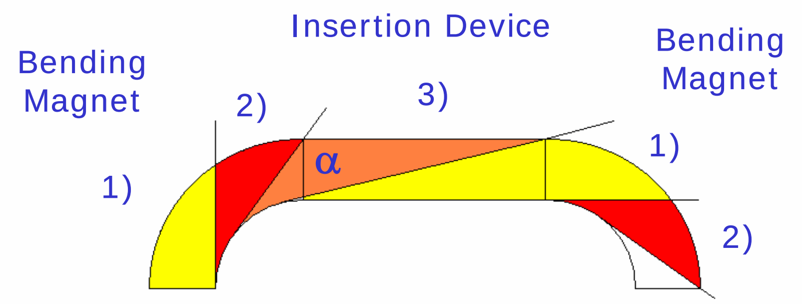
5 days

ID vacuum chambers @ Elettra

ID	Type	L* [mm]	α [mrad]
1	Al (no ante-chamber)	4743	7.6
2	Al + NEG (no ante-ch.)	4651	7.3
3	SS (with ante-chamber)	4800	7.8
4	SS (no ante-chamber)	4020	6.1
5	SS (with ante-chamber)	4800	7.8
6	SS (with ante-chamber)	4800	7.8
7	Al + NEG (no ante-ch.)	3000	7.8
8	Al (no ante-chamber)	4743	7.6
9	Al + NEG (no ante-ch.)	4743	**7.6**
10	Al + NEG (no ante-ch.)	4743	7.6

L* = chamber length without tapers (usable length for ID)

α = horizontal angle of the photon-beam, from the previous bending magnet, hitting the straight vacuum chamber



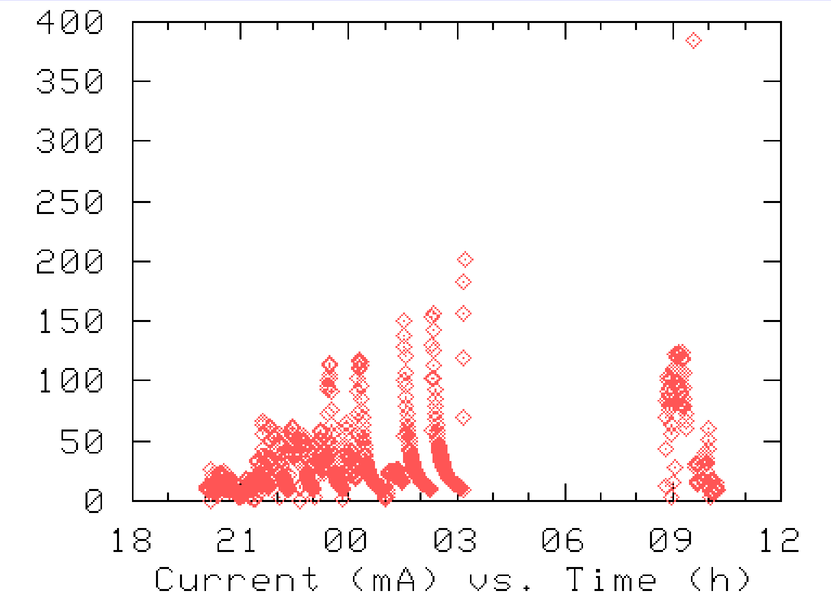
Photons:

1) from the previous bending magnets

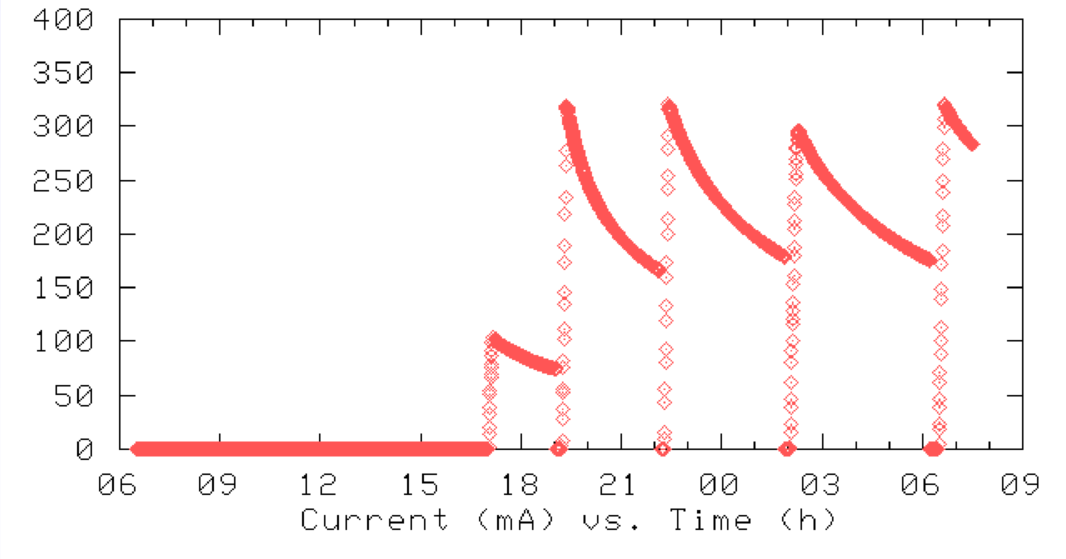
2) to the bent chamber

3) to the straight chamber

Start-up comparison



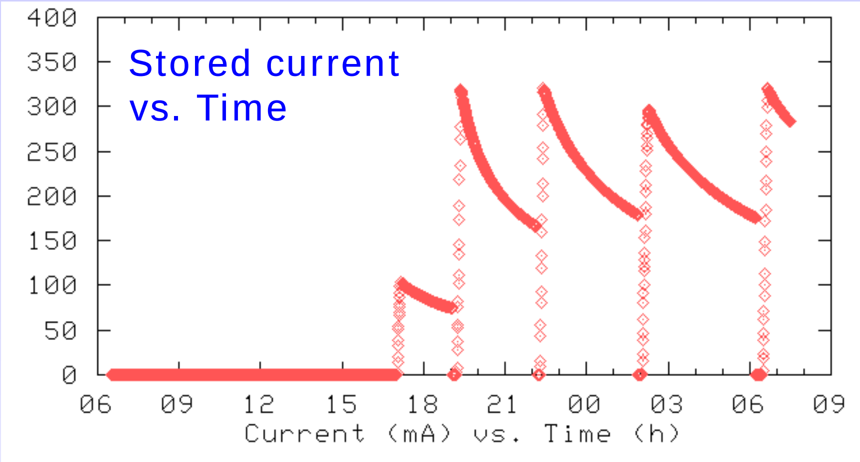
ID8 (Al)

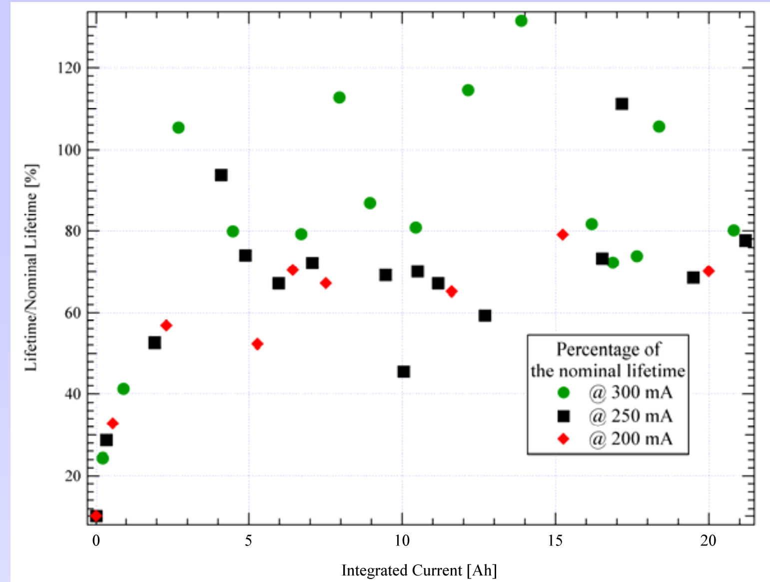


ID10 (Al+NEG)

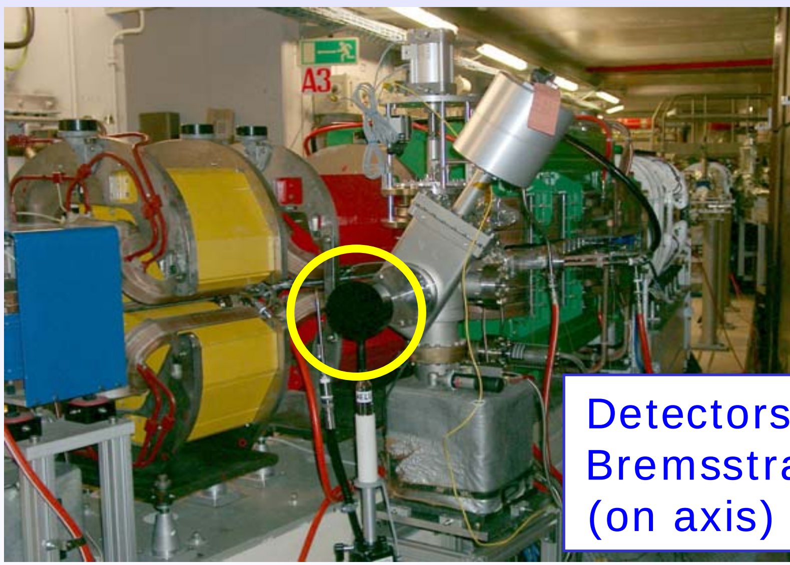
ELETTRA Start-up after the installation of the first NEG coated Al ID chamber.

(Run 76 - January 16, 2002)

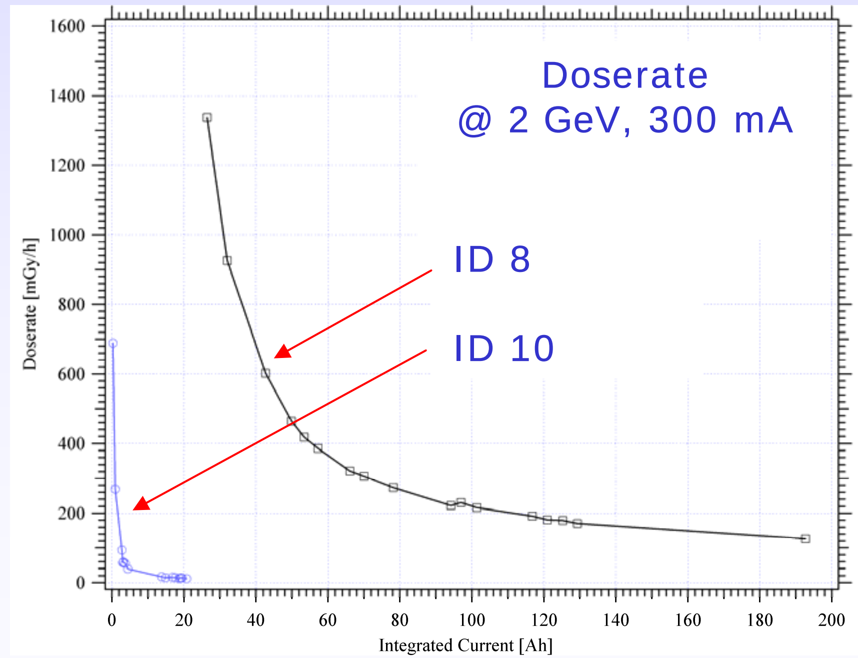




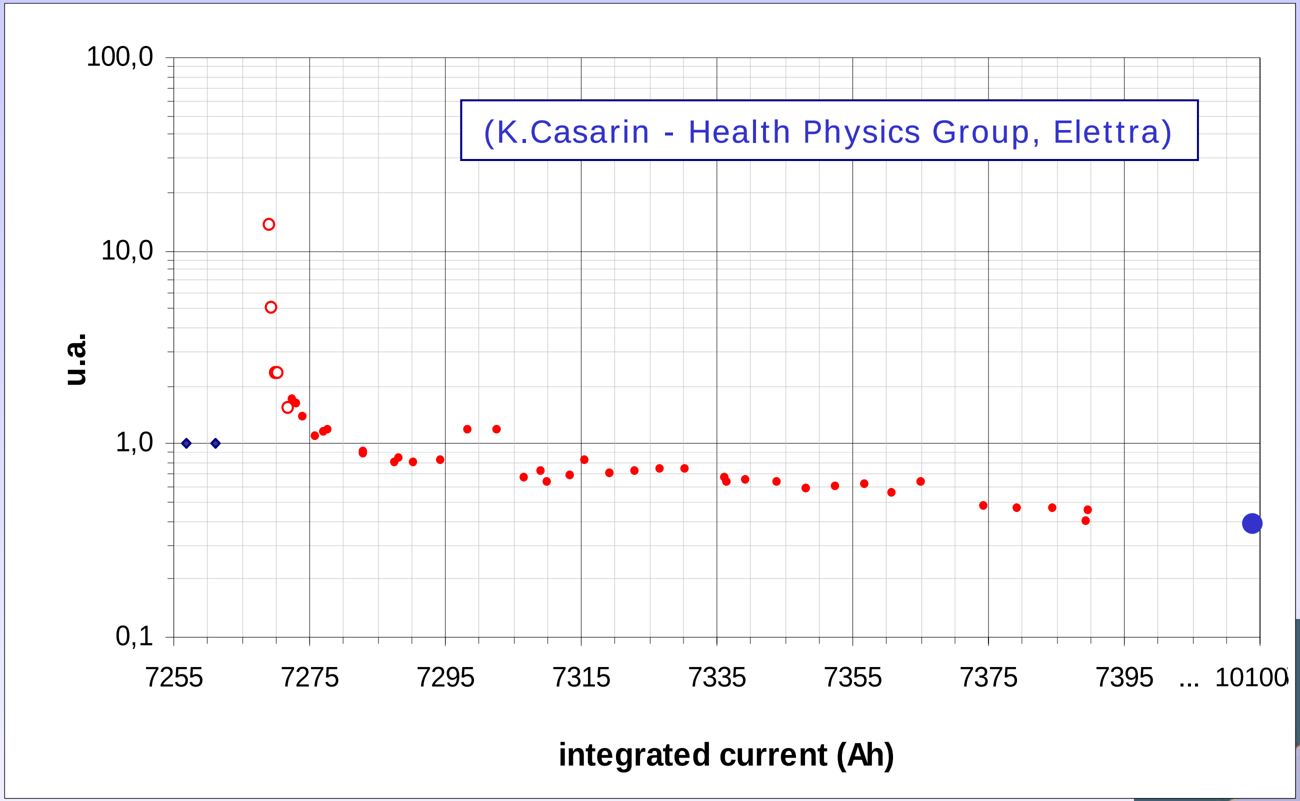
Lifetime / Nominal Lifetime [%]

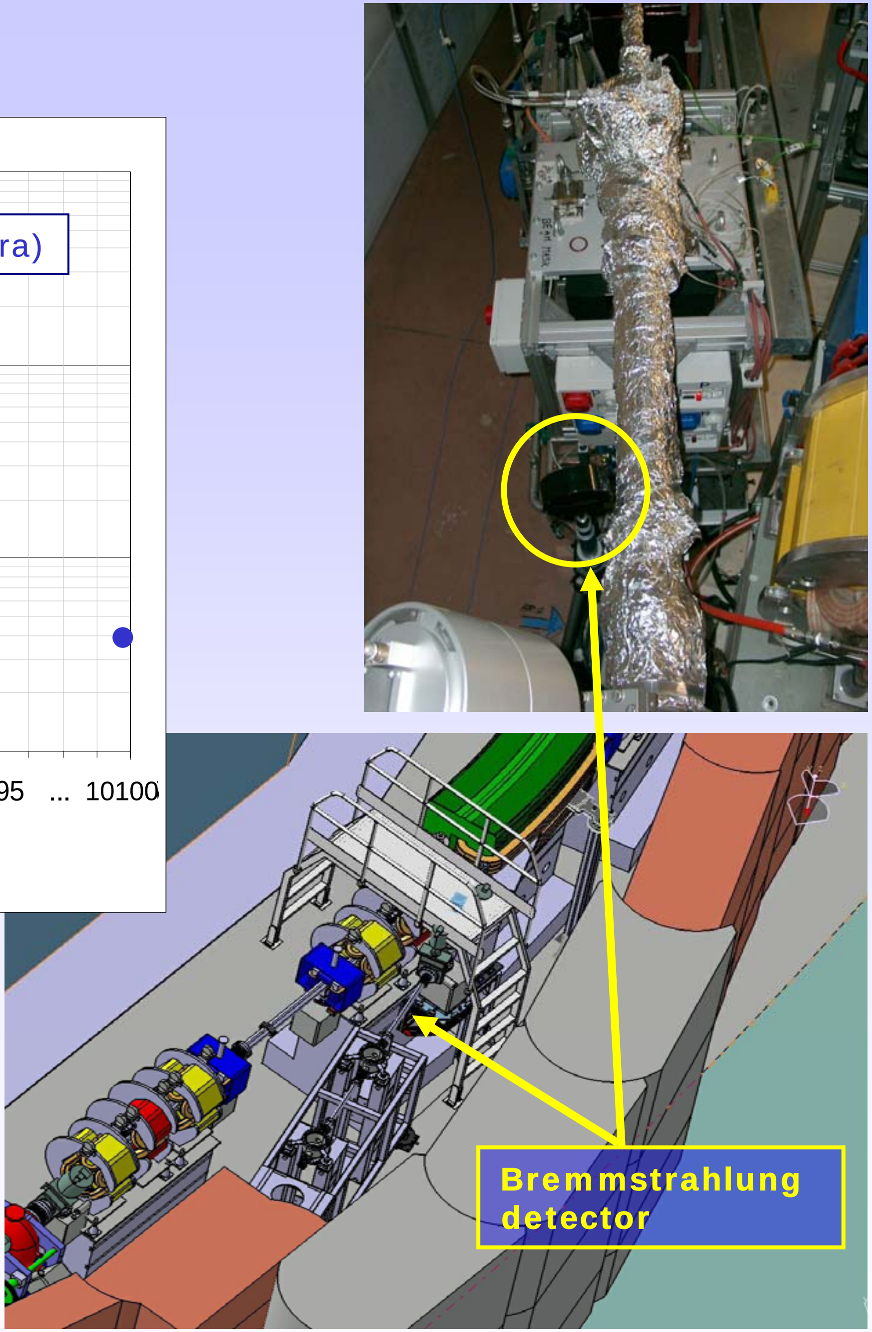


Detectors for Bremsstrahlung (on axis)



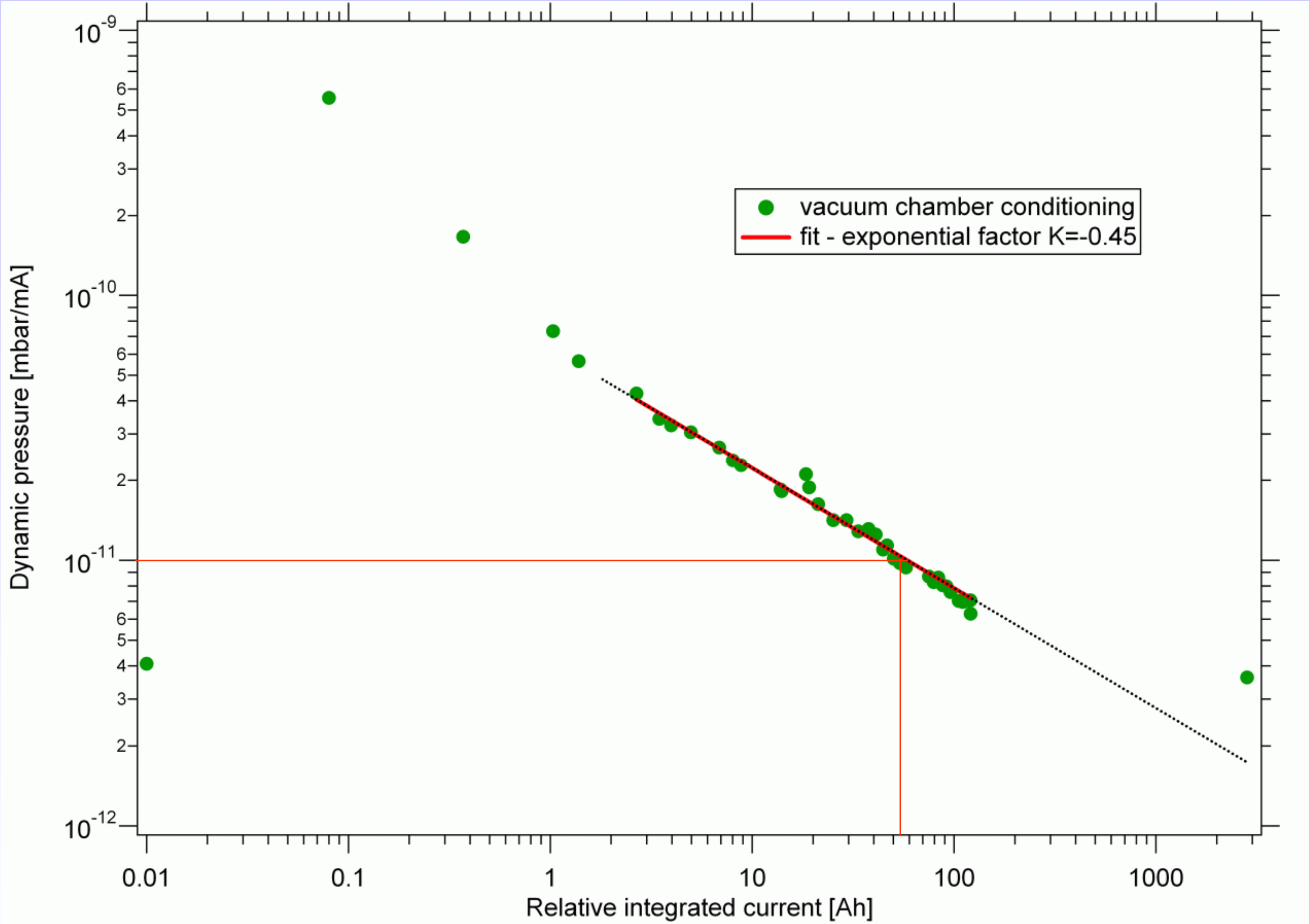
Bremsstrahlung measurement





In a particle accelerator, the measurement of the gas-bremsstrahlung provides an indirect information about the total pressure inside the vacuum chamber.

ID 9 vacuum chamber conditioning



Transverse (vertical) impedance evolution @ the ELETTRA storage ring

(E. Karantzoulis, Head of Machine Operation Group, Elettra)

1) “The impedance status is reflected greatly by the maximum achievable stored current. During the first year of commissioning 1993-94 it was possible to store more than 60 mA in single bunch and more than 700 mA in multibunch.

2) Since then many new installations took place, the most serious from the impedance point of view I ... with low gap ones. With ea ... ease has been measure

Reduction of the nominal thickness of the NEG coatings, from 1 μm to 0.5 μm

3) Whereas an even greater increase has been measured when Aluminum chambers with NEG (Ti, Va, Zr) sputtered material was used”

[E. Karantzoulis, C. J. Bocchetta, F. Iazzourene, R. Nagaoka, L. Tosi, R. P. Walker, A. Wrulich, Observation of instabilities in the ELETTRA Storage Ring, EPAC-94, London, 1994]

[E. Karantzoulis, V. Smaluk and L. Tosi “Broad band impedance measurements on the electron storage ring ELETTRA”, Phys. Rev. ST Accel. Beams 6, 030703 (2003)]

[E. Karantzoulis and L. Tosi, Measurements of the broad band Transverse reactive impedance evolution at ELETTRA and the NEG chambers, ST-TN 03/04, April 2003]

Ageing of TiZrV 1 μm coating (dedicated Light Port 11.1 L)

(L.Rumiz, Vacuum Group, Elettra)

Setup evacuation (turbomolecular pump)

Bake out of the setup [12 hours @ 150 °C]

Temp. of the setup during NEG activation [100 °C]

NEG Activation [2 hour @ 180 °C]

Cooling down to room temperature

Photon irradiation [> 7 Ah (white light) @ 2 GeV ,e_c = 3.2 keV]

Dynamic pressure measurement [mbar/mA] during the photon irradiation

Venting

Up to now: 26 cycles

No evidence of any degradation of NEG vacuum performance

WhITE

(Front-End 11.1 L)

MEASUREMENTS OF
PHOTON INDUCED DESORPTION
FROM TECHNOLOGICAL
MATERIALS
AND IRRADIATION TESTS
BY MEANS OF WHITE LIGHT
FROM A BENDING MAGNET

WhITE main parameters

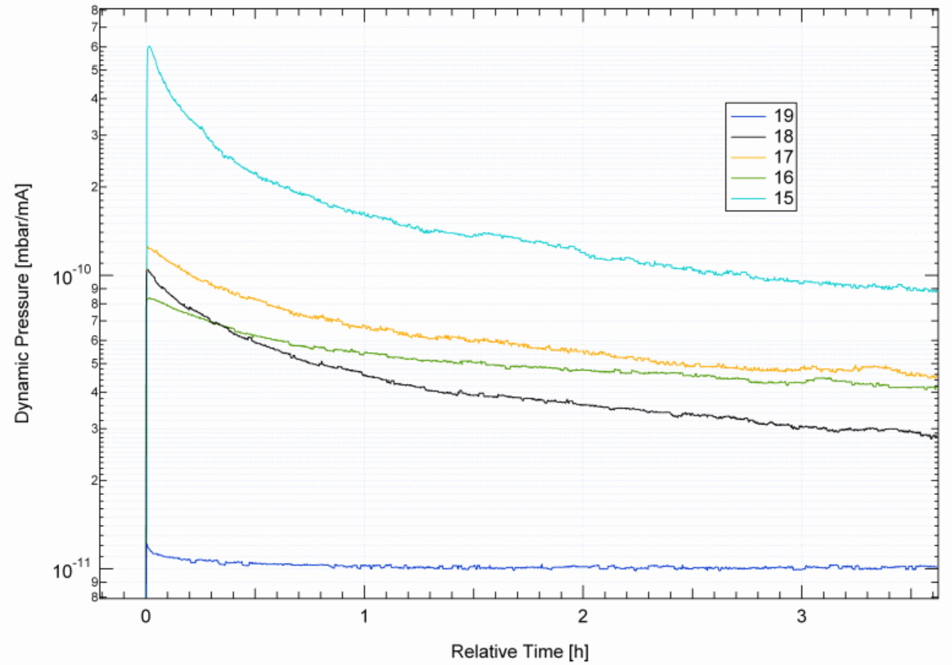
Source	**Bending Magnet**
BM Radius [m]	5.5 m
Electron Beam Characteristic	300 mA @ 2.0 GeV 120 mA @ 2.4 GeV
Horizontal Angular acceptance [mrad]	**2**
Photon Beam @ 2.0 GeV Total Photon Flux @ 2 mrad (E_{ph} > 10 eV) [Phot/s] Total Photon Power @ 2 mrad [W]	 **$1.52 \cdot 10^{17}$** 24.6
Photon Beam @ 2.4 GeV Total Photon Flux @ 2 mrad (E_{ph} > 10 eV) [Phot/s] Total Photon Power @ 2 mrad [W]	 **$1.37 \cdot 10^{17}$** 22.0
Minimum distance from the source [m]	12.0
Minimun width of the photon beam (H) [mm]	24
Maximum length of the sample [m]	2.0
γ @ 2 GeV [$E/(m\,c^2)$]	3914
γ @ 2.4 GeV [$E/(m\,c^2)$]	4697
Critical Energy @ 2 GeV [eV]	3227
Critical Energy @ 2.4 GeV [eV]	5575

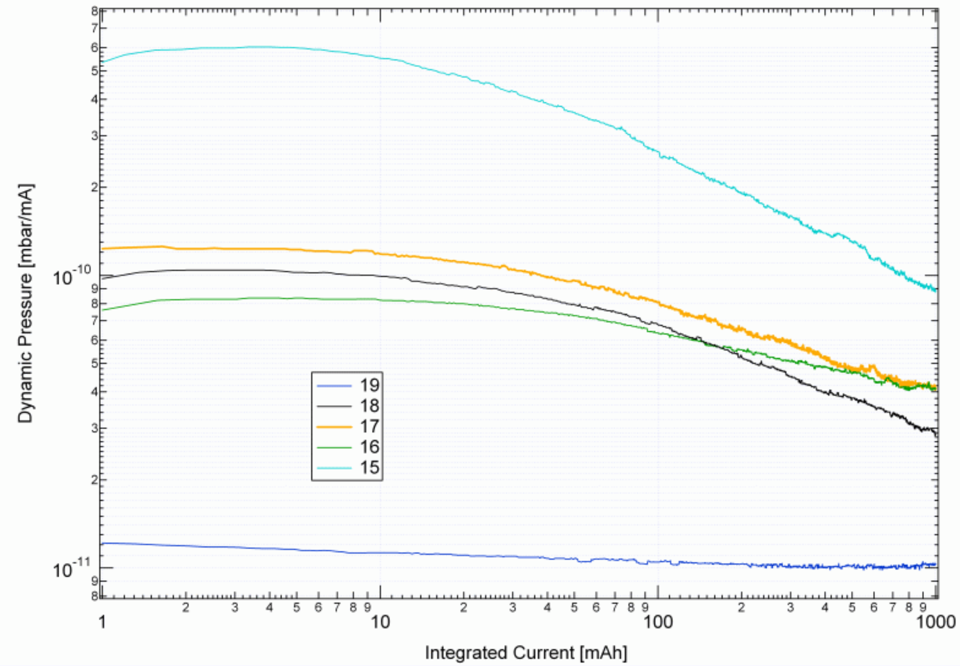
First trial (activations #1-12)

2 h @ 180 °C

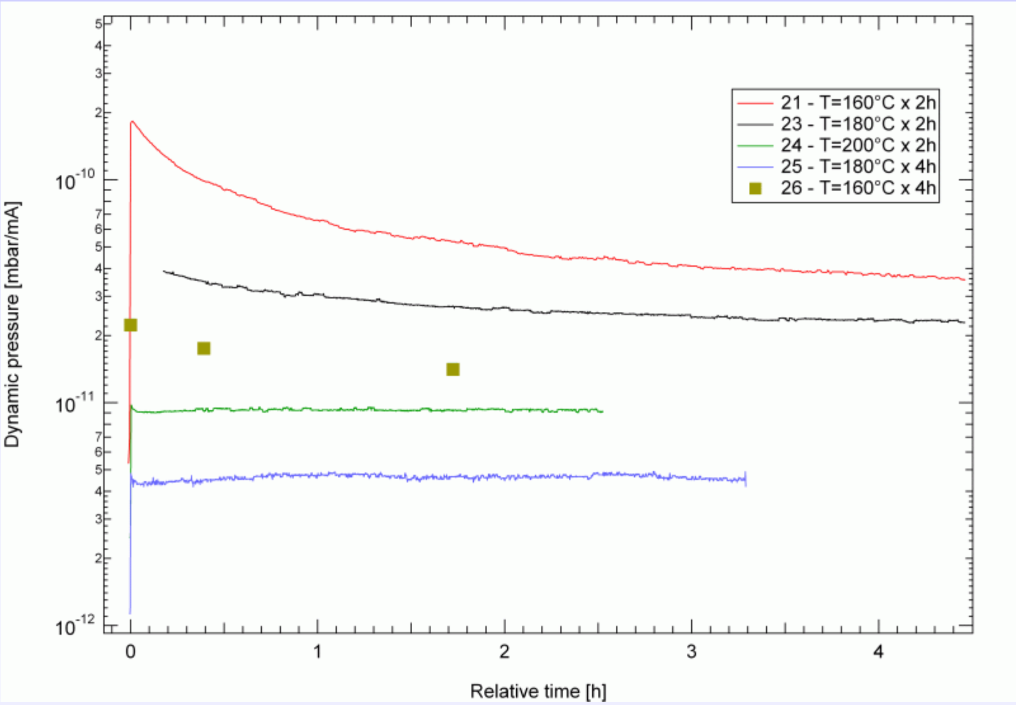
Second trial (activations #13-20)

Activation #	time [h]	temp. [C]	notes
13	2	180	No photons
14	2	180	No photons
15	2	180	.
16	5	180	
17	2	180	
18	3	180	
19	29	180	
20	2	180	No photons



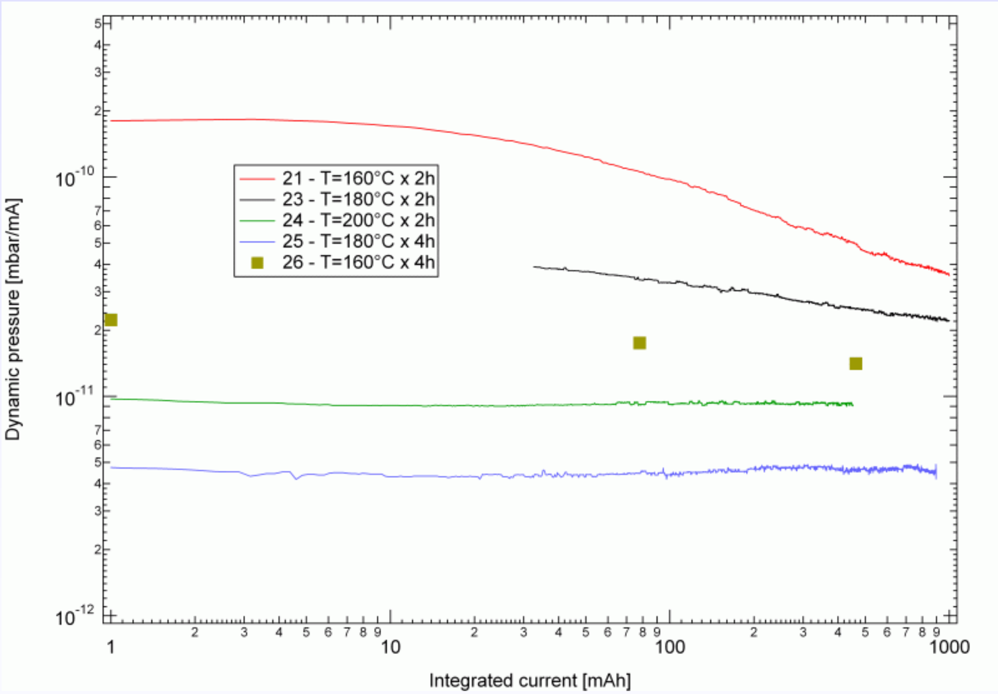


Third trial (activations #21-26)



Activation #	time [h]	temp. [C]	notes
21	2	160	
22	2	180	Data lost
23	2	180	
24	2	200	
25	4	180	
26	4	160	Data partially lost

t [h] / T[C]	160	180	200
1			
2	21	22,23	24
4	26	25	

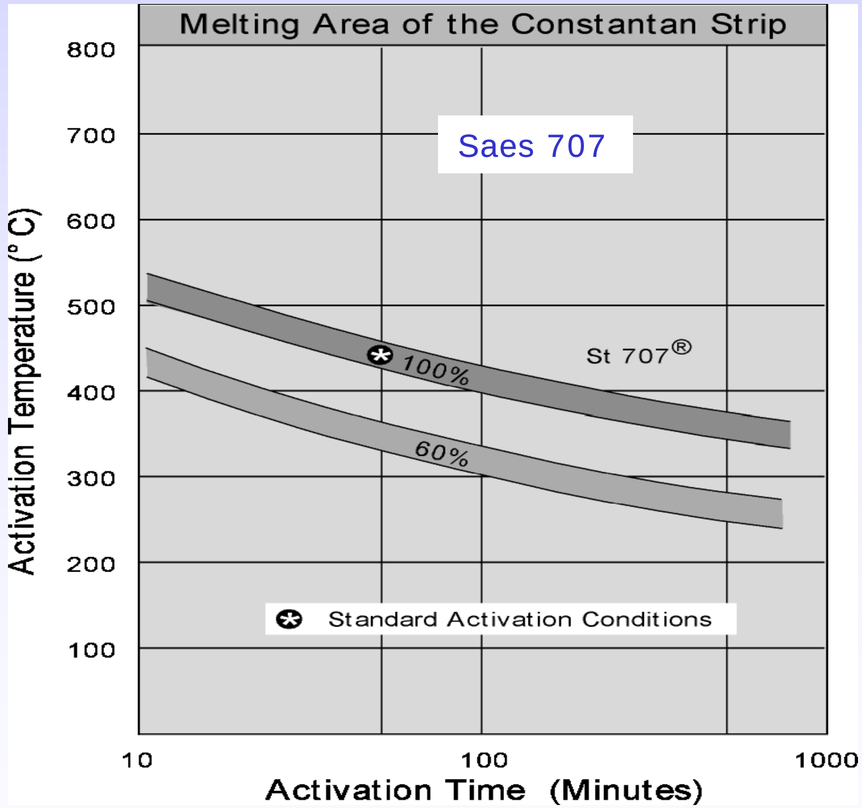


NEG coating activation:

There isn't any magic rule: you have to find the best compromise for your vacuum system!

A possible starting point is:

12 h @ 180 °C



The RHIC experience

(H.C.Hseuh, S.Y.Zhang, RHIC, 45th IUVSTA Workshop, Catania 2006)

435 m of NEG coated chamber already installed (total 600)

Activation: 4 h @ 250 °C

Significant pressure rise reduction (electron cloud) at the locations with NEG pipes.

NEG COATINGS FOR PARTICLE ACCELERATORS AND VACUUM SYSTEMS

Organized by ASTeC & the Italian Vacuum Association

1) NEG coating technology
2) Underlying physics, properties, preparation technology, and future directions
3) Laboratory Measurements: methodologies and experimental results
4) Electronic properties, surface chemistry, film morphology, film mechanical properties
5) Experience of NEG coated vessels installed in working machines
6) Electron, photon and ion stimulated desorption from NEG films
7) Use of NEG coating in future projects and further areas of research

NEG COATINGS FOR PARTICLE ACCELERATORS AND VACUUM SYSTEMS

Catania, 4-8 April 2006

- Final remarks collected by O.Malishev (ASTeC)-

“It was concluded that there is a huge increase in use of TiZrV NEG coating in the following areas:

1) In the particle accelerator technology: except for a few cases, NEG-coated chambers have proved very effective at improving the performance of particle accelerators.

Synchrotron radiation light sources clearly benefit from NEG-coated chambers reducing the residual gas pressure and commissioning time of whole or some parts of the machine.

New machines will use NEG coated chambers: Soleil (first e-beam stored May 2006), Diamond (first e-beam stored May 2006), NSRRC, ALBA, ...”

“In particle colliders the NEG coating is used also as an anti-mulipactoring coating: RHIC, KEK-B, LHC, ...

RHIC has proved without any doubts that NEG-coated chambers are very effective at reducing the impact of the electron-cloud instability on the machine.

KEK-B is the only case where NEG-coated chambers were only marginally better than un-coated chambers (or TiN-coated ones), but a big issue is the bake-out/activation set-up (un-baked chambers nearby).

Heavy ion machines will use the NEG coating to reduce pressure and deal with the lost heavy ion induced pressure instability: SIS-18, LEAR, ...”

“The most promising remedies to e-cloud seems to use thin film coatings.TiZrV NEG will also bring linear pumping upon activation.
(Electron Cloud Mitigation by Use of TiZrV and TiN Thin Film, F. Le Pimpec et al. PSI, SLAC)”

“2) In vacuum technology there are a few application:

Possible use for improving the ultimate pressure with a turbo-molecular pump (CERN)

Use for improving the ultimate pressure and pumping speed for H2 in the SIPs (CERN and Varian)”

Although the TiZrV NEG coating is already actively used or considered in accelerator vacuum design there still uncertainties and unknowns which are needed to be studied.”

NEG coatings (TiZrV) in large vacuum system

Pros/

- simplify the design of a complex vacuum chamber
- pump without requiring additional space
- can substitute a “traditional” pumping system (ESRF, SOLEIL)
- are compatibile with many materials (low activation temperature)
- reduce the outgassing of a surface
- reduce SEY (RHIC, LHC, ...)

Cons/

- not suitable for noble gases and methane
- not suitable for systems frequently vented
- not replaceable !!!
- ageing *(> 30 – 50 activation/venting cycles ?)*
- require to be baked (activation)
- cost (?)
- relatively new technology

C. Benvenuti, Non-evaporable getters: from pumping strips to thin film coatings, Proceedings of EPAC 1998, Stockholm, June **1998**

C. Benvenuti et al., A novel route to extreme vacua: the non-evaporable getters thin film coatings, Vacuum 53 (**1999**) 219-225

P. Chiggiato and R. Kersevan, Synchrotron Radiation-Induced Desorption from NEG-Coated Vacuum Chambers, Proceedings of EVC-6, Lyon, December 7-10 **1999**

Proceedings of the 45th IUVSTA workshop on “NEG coating for particle accelerators and vacuum systems”, Catania, **2006** (*www.aiv.it/ita/scuole/simposi.asp)*

Thank you for your attention!

Fabio Mazzolini

Elettra - Sincrotrone Trieste S.C.p.A.

Trieste, Italy

fabio.mazzolini@elettra.trieste.it

tel. +39 040 3758550