European Organization for Nuclear Research

CERN

THIN FILM COATINGS TO SUPPRESS ELECTRON MULTIPACTING IN PARTICLE ACCELERATORS

P. Costa Pinto, S. Calatroni, P. Chiggiato, H. Neupert, W. Vollenberg, E. Shaposhnikova, M. Taborelli, C. Yin Vallgren,
CERN, Geneva, Switzerland.

CERN - Vacuum Surfaces and Coatings group

PAC'11 March 2011, New York

CERN

European Organization for Nuclear Research

THIN FILM COATINGS TO SUPPRESS ELECTRON MULTIPACTING IN PARTICLE ACCELERATORS

- Motivation
- Non Evaporable Getter (NEG) coatings
- Carbon coatings
- Summary and future work

PAC'11 March 2011, New York

MOTIVATION

Electron clouds are created in accelerators when bunches of positive charge accelerates the stray electrons already floating in the tube towards the walls, producing secondary electrons that are again accelerated by the next bunch, resulting in electrons multiplication bunch after bunch.

UNDESIRABLE EFFECTS: emitance blow up, thermal loads, pressure rises, beam losses, rise of detector's background.

CURES: clearing electrodes (pull electrons with a polarized electrode), trap electrons with an axial magnetic field, limit electron multiplication by **reducing the Secondary Electron Yield (SEY)** of the walls of the beam pipe.

Reduction of SEY by coating the internal surface of the beampipes.

MOTIVATION

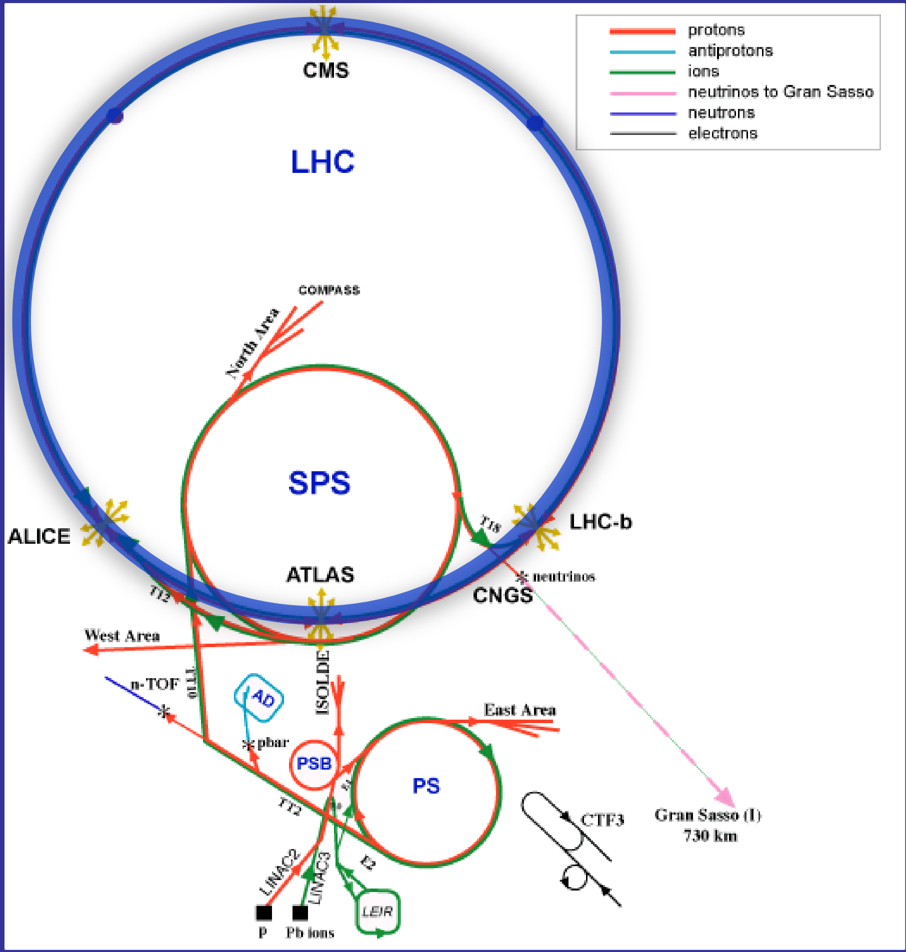
Motivation to develop NEG coating

Long Straight Sections (LSS) of the Large Hadron Collider (LHC)

•e-cloud threshold δ_{max}=1.3

•Bakeable Beampipes (T>180°C)

CERN accelerators complex



MOTIVATION

Motivation to develop NEG coating

Long Straight Sections (LSS) of the Large Hadron Collider (LHC)

- e-cloud threshold δ_{max}=1.3
- Bakeable Beampipes (T>180^{o}C)

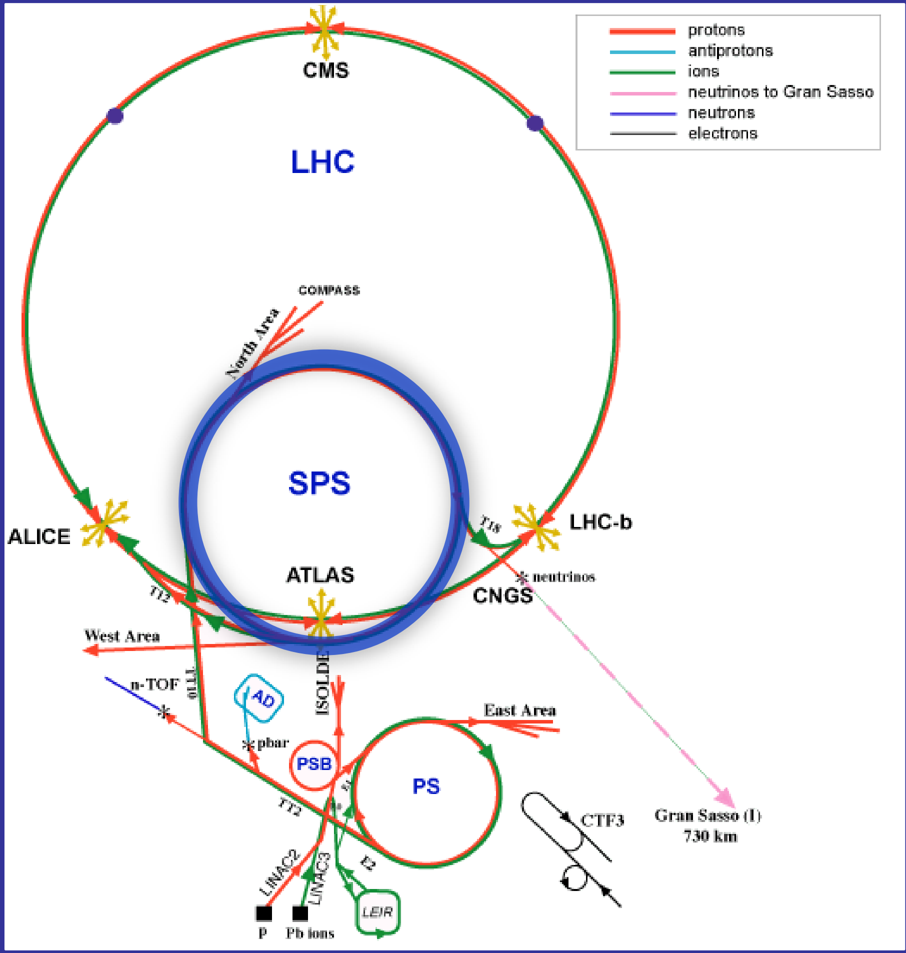
Motivation to develop Carbon coatings

Upgrade the Super Proton Synchrotron (SPS)

To feed the LHC with 25 ns bunch spaced beam

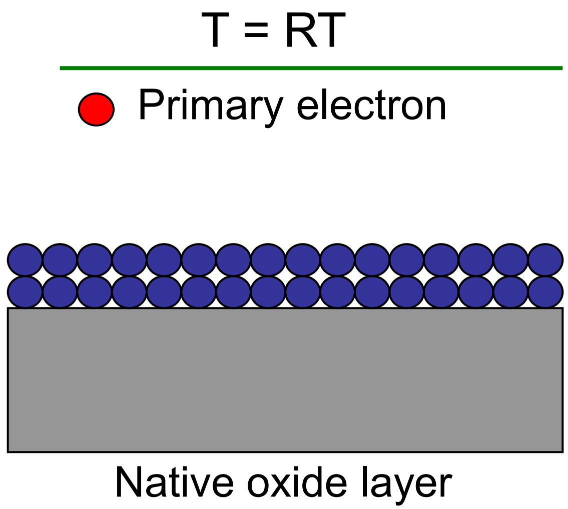
- e-cloud threshold δ_{max}=1.3
- **Non Bakeable Beampipes**

CERN accelerators complex



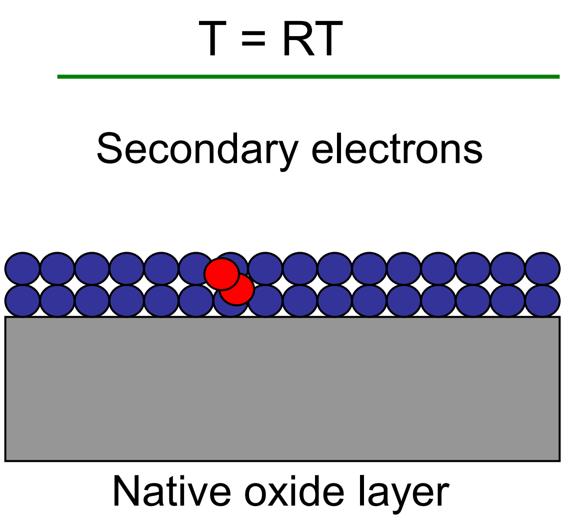
NEG COATINGS

Why NEG? Because heating to its activation temperature **dissolves the native oxide layer** into the bulk leaving a free oxide surface with low SEY.



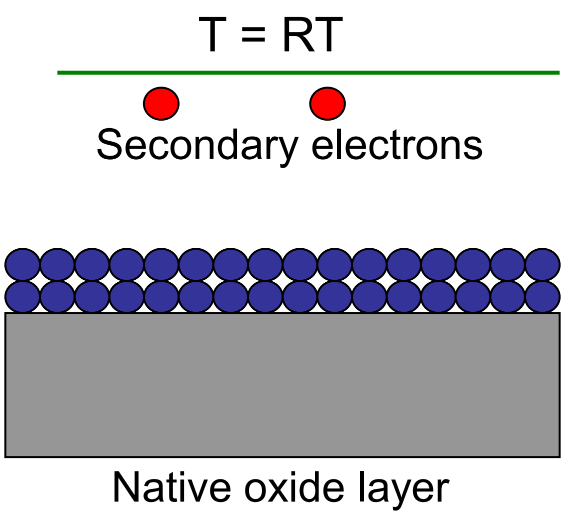
NEG COATINGS

Why NEG? Because heating to its activation temperature **dissolves the native oxide layer** into the bulk leaving a free oxide surface with low SEY.



NEG COATINGS

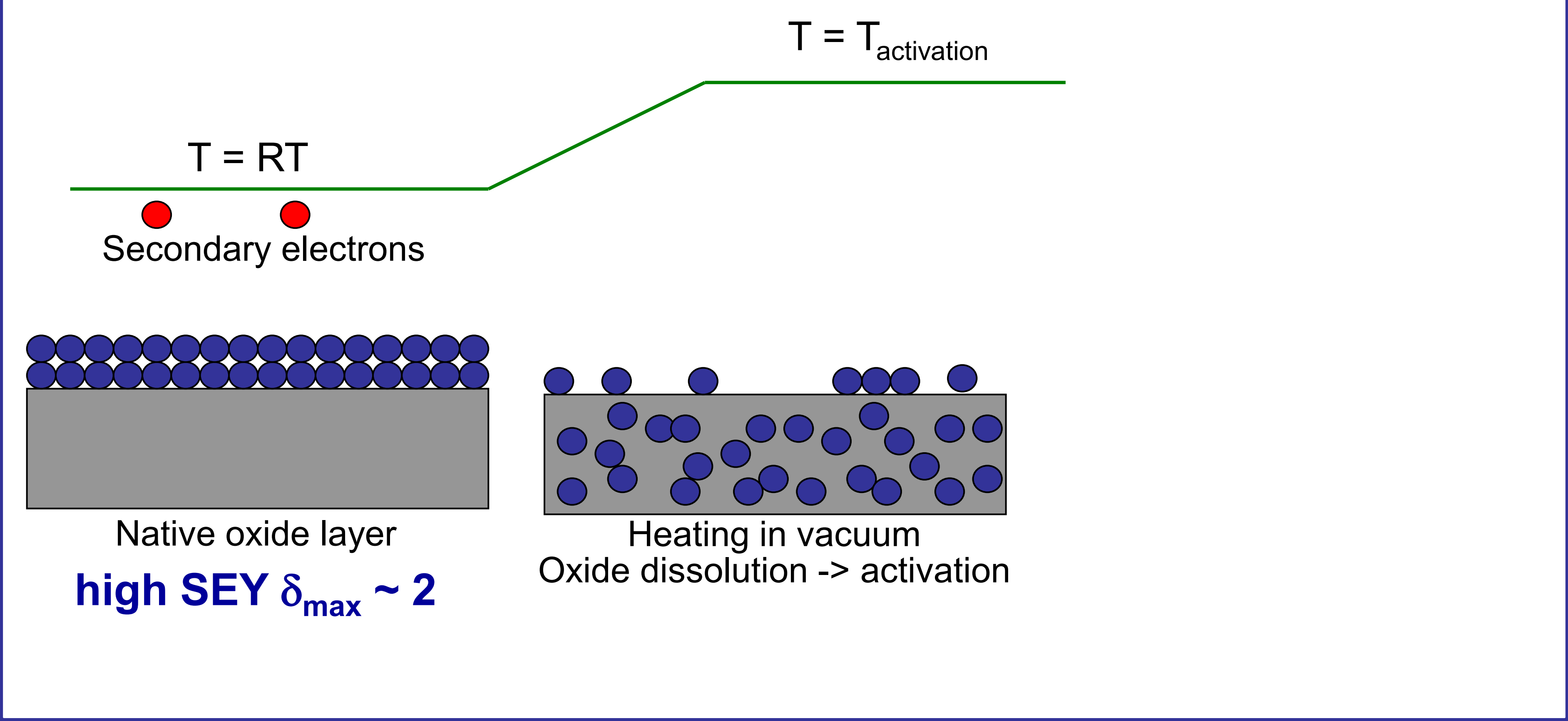
Why NEG? Because heating to its activation temperature **dissolves the native oxide layer** into the bulk leaving a free oxide surface with low SEY.



high SEY δ_{max} ~ 2

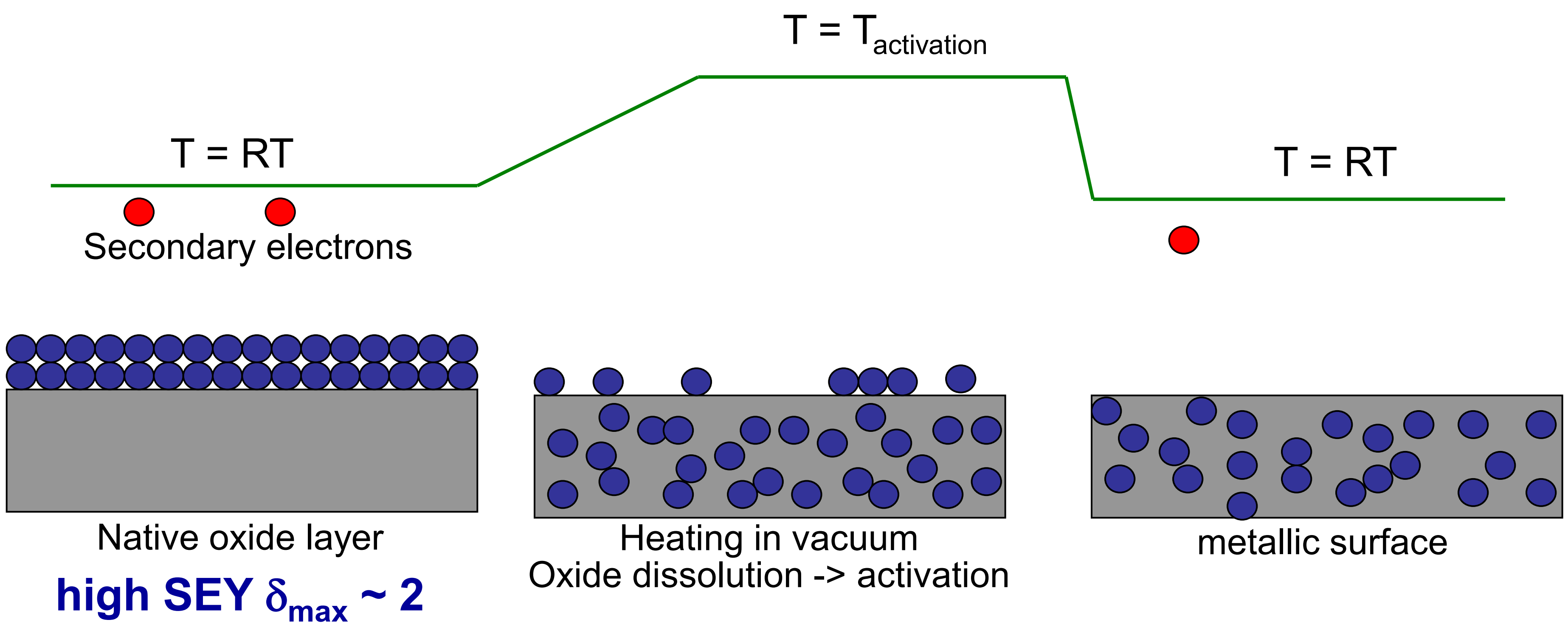
NEG COATINGS

Why NEG? Because heating to its activation temperature **dissolves the native oxide layer** into the bulk leaving a free oxide surface with low SEY.



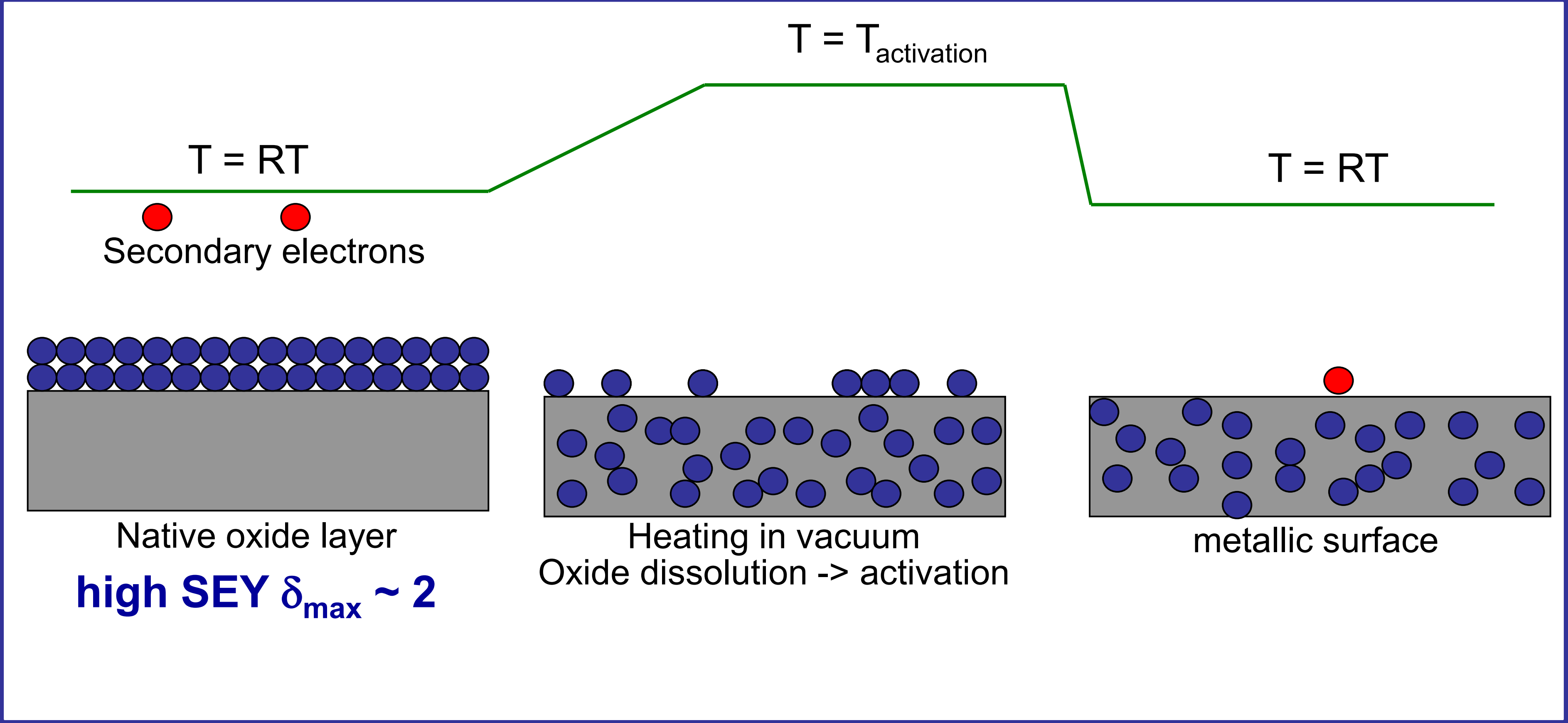
NEG COATINGS

Why NEG? Because heating to its activation temperature **dissolves the native oxide layer** into the bulk leaving a free oxide surface with low SEY.



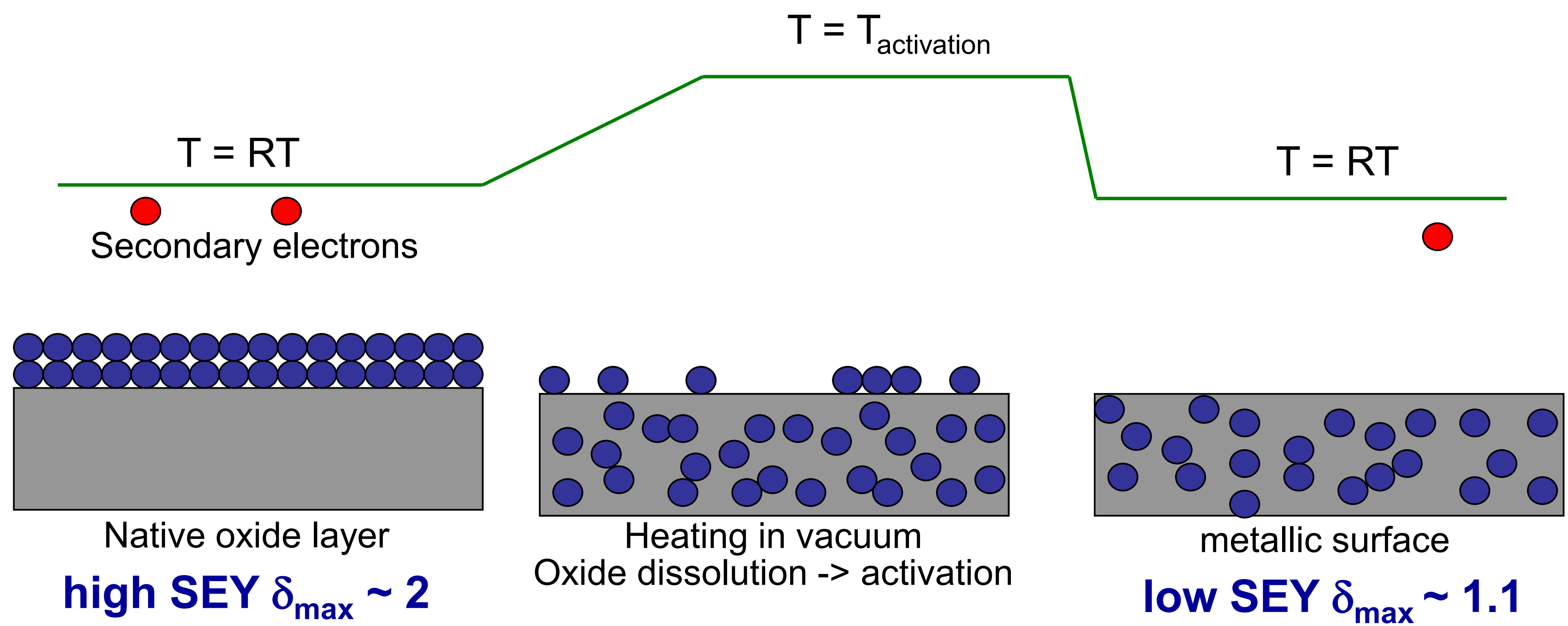
NEG COATINGS

Why NEG? Because heating to its activation temperature **dissolves the native oxide layer** into the bulk leaving a free oxide surface with low SEY.



NEG COATINGS

Why NEG? Because heating to its activation temperature **dissolves the native oxide layer** into the bulk leaving a free oxide surface with low SEY.

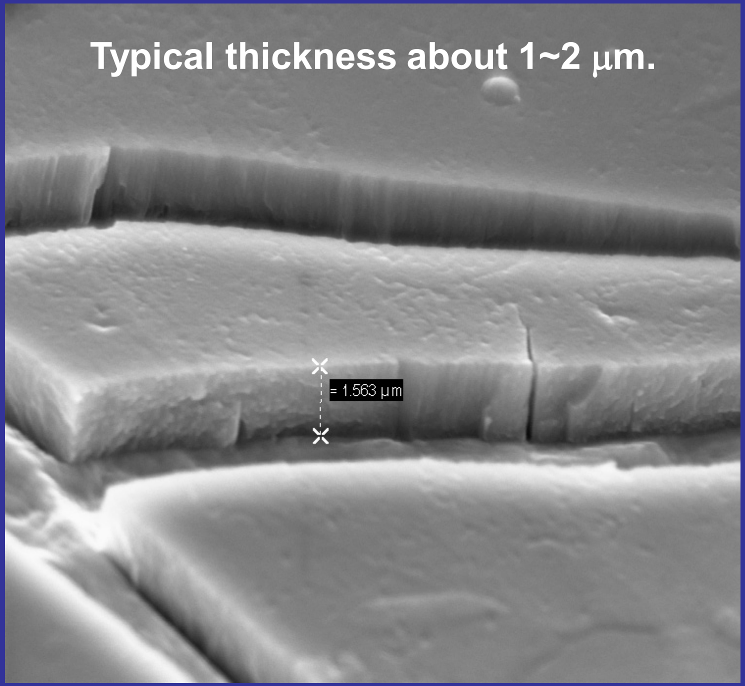


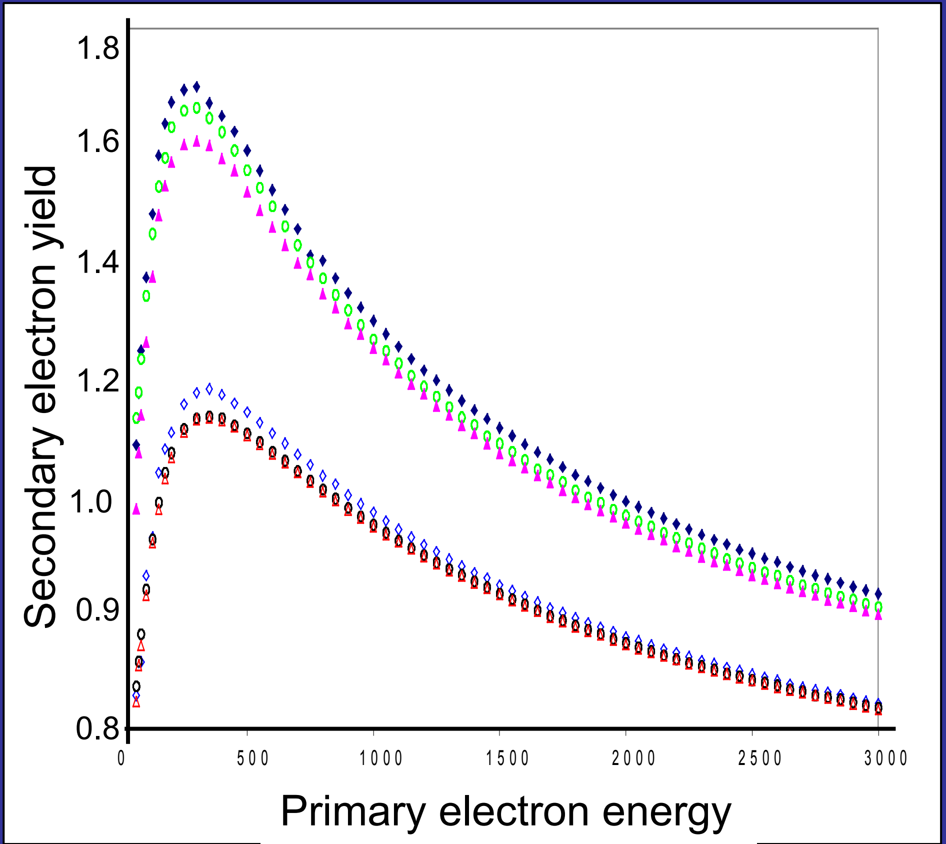
In addition: **activated NEG surface pumps most of the gas species in UHV**

NEG COATINGS

Why NEG? Because heating to its activation temperature **dissolves the native oxide layer** into the bulk leaving a free oxide surface with low SEY.

Ti-Zr-V NEG can be activated at 180°C for 24h (or 250°C for 2 hours)

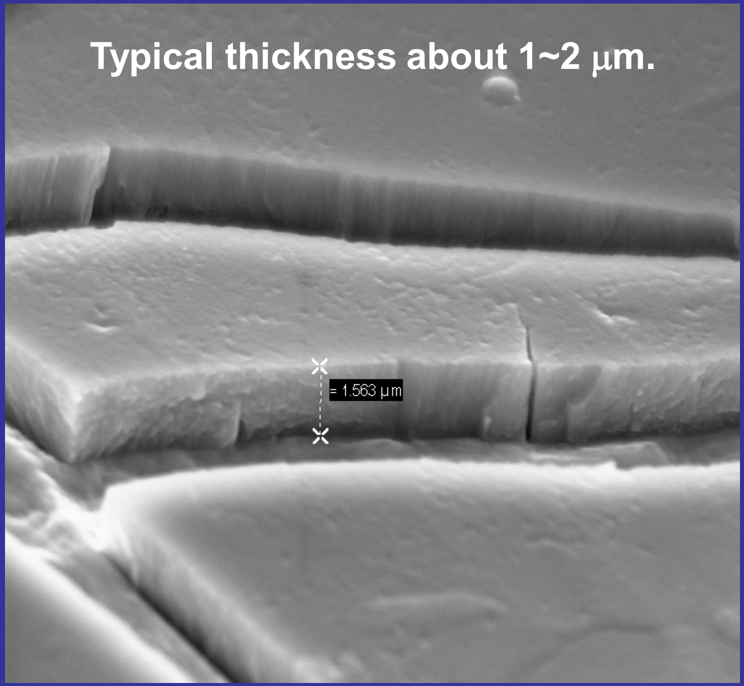


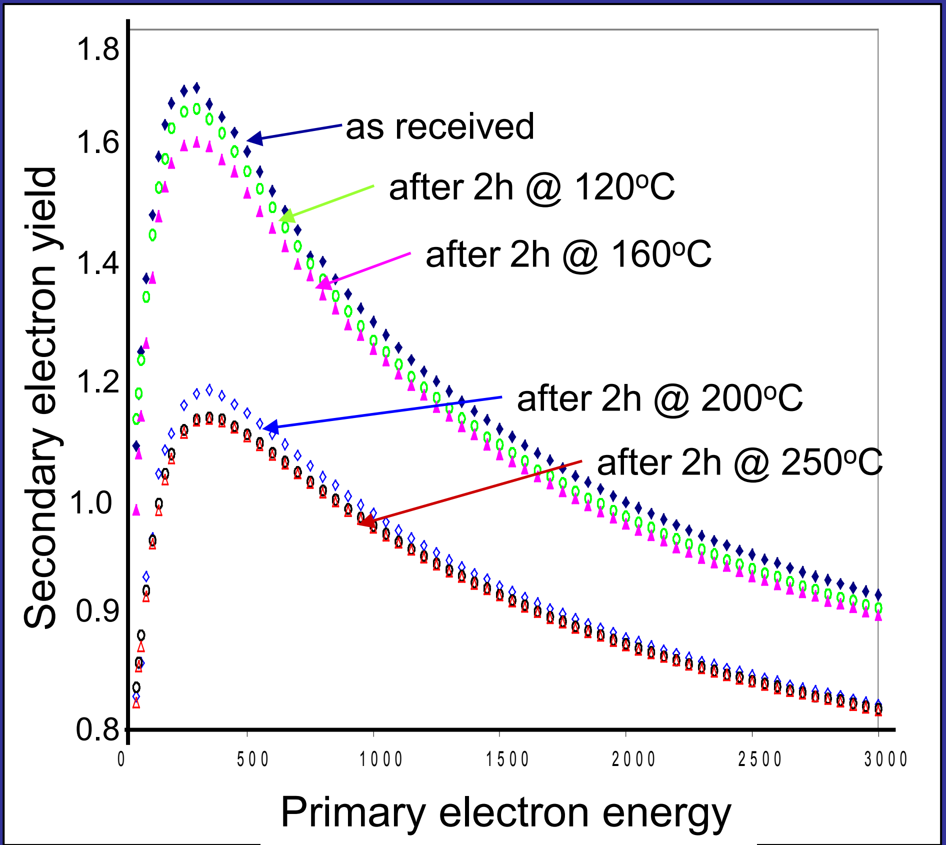


NEG COATINGS

Why NEG? Because heating to its activation temperature **dissolves the native oxide layer** into the bulk leaving a free oxide surface with low SEY.

Ti-Zr-V NEG can be activated at 180°C for 24h (or 250°C for 2 hours)

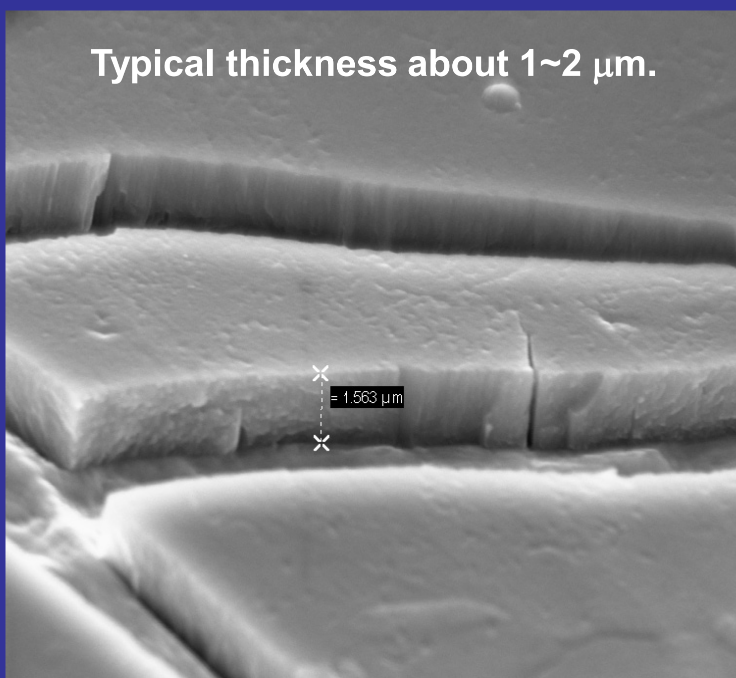


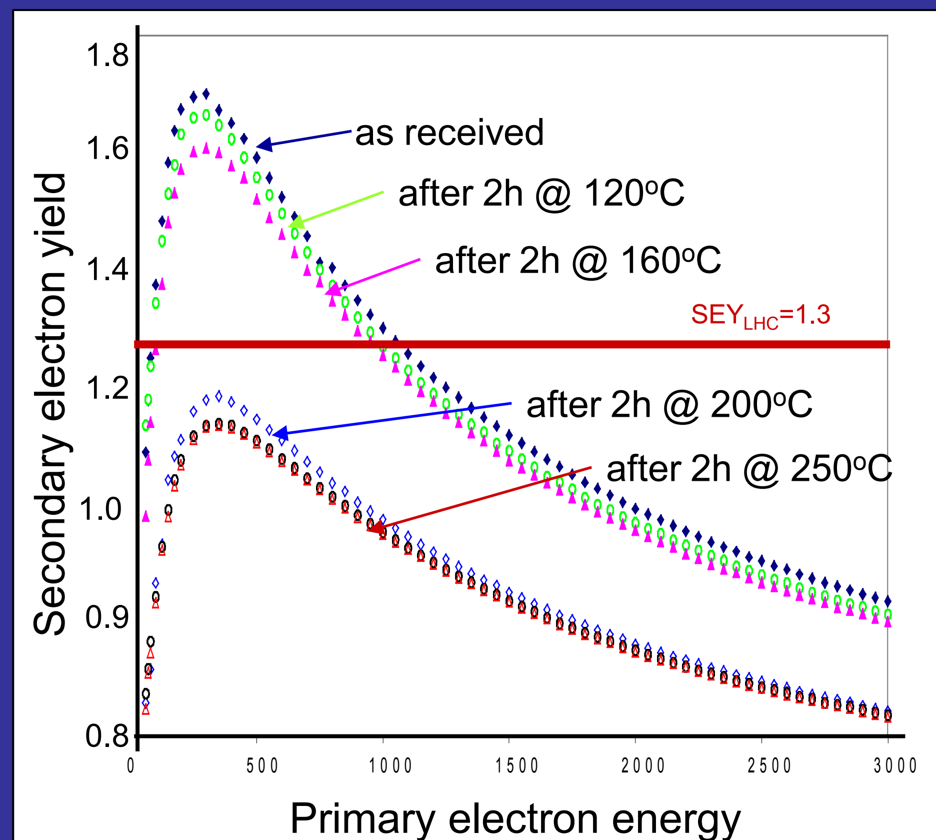


NEG COATINGS

Why NEG? Because heating to its activation temperature **dissolves the native oxide layer** into the bulk leaving a free oxide surface with low SEY.

Ti-Zr-V NEG can be activated at 180°C for 24h (or 250°C for 2 hours)



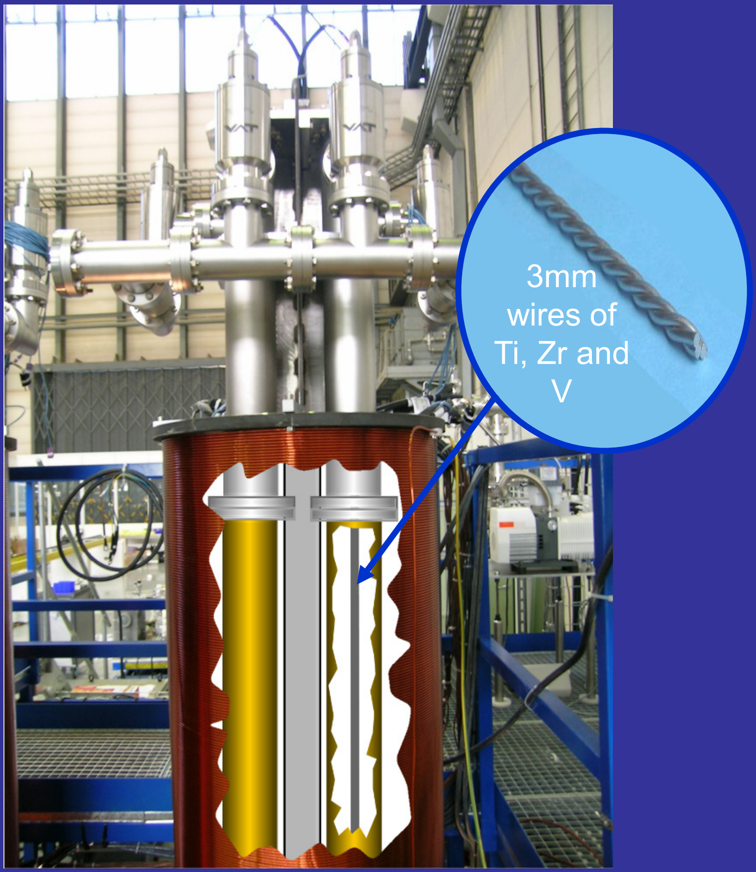


NEG COATINGS

Large scale production for the LHC and experiments by DC Cylinder Magnetron sputtering (DCCM) from a target of Ti, Zr and V wires (more than 1300 chambers)

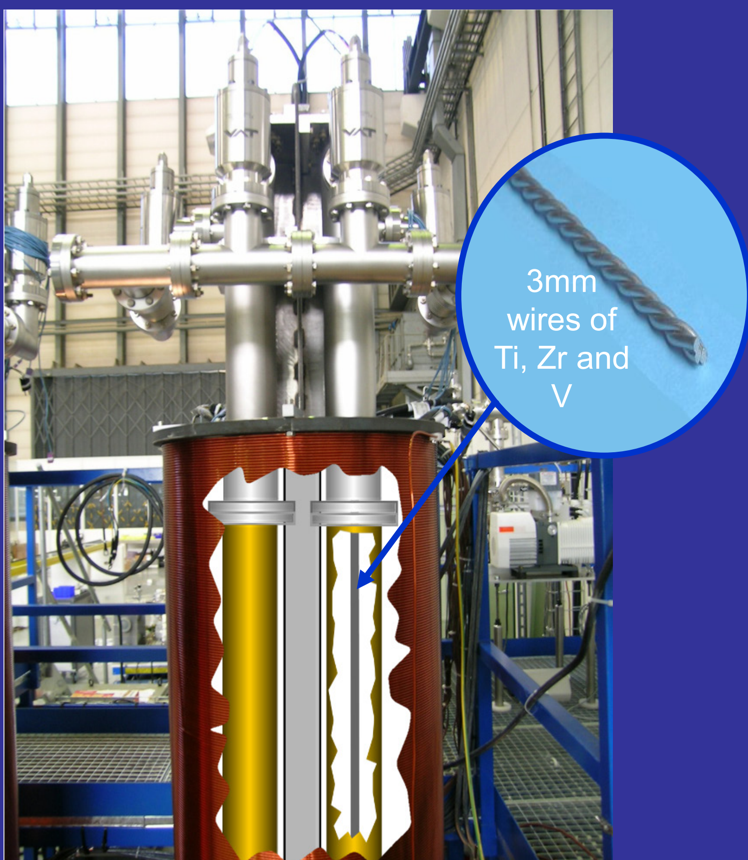
NEG COATINGS

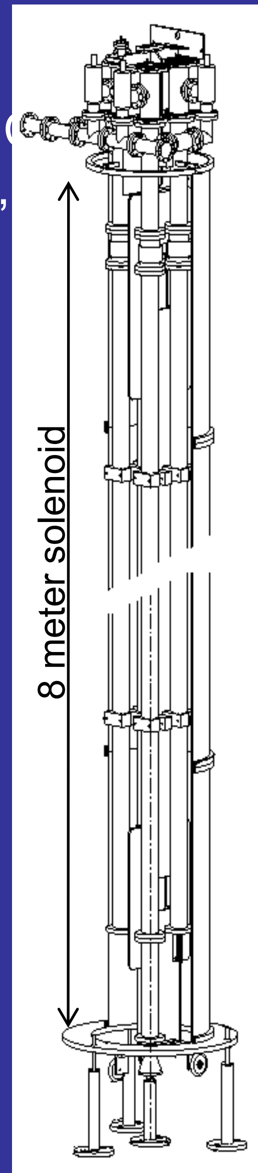
Large scale production for the LHC and experiments by DC Cylinder Magnetron sputtering (DCCM) from a target of Ti, Zr and V wires (more than 1300 chambers)



NEG COATINGS

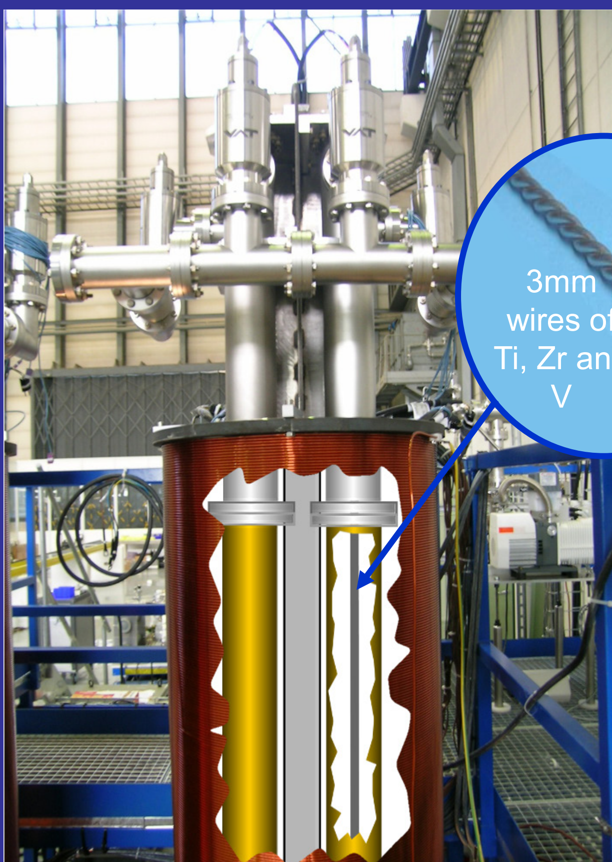
Large scale production for the LH… …eriments by DC Cylinder Magnetron sputtering (DCCM) from a target of Ti, … …res (more than 1300 chambers)

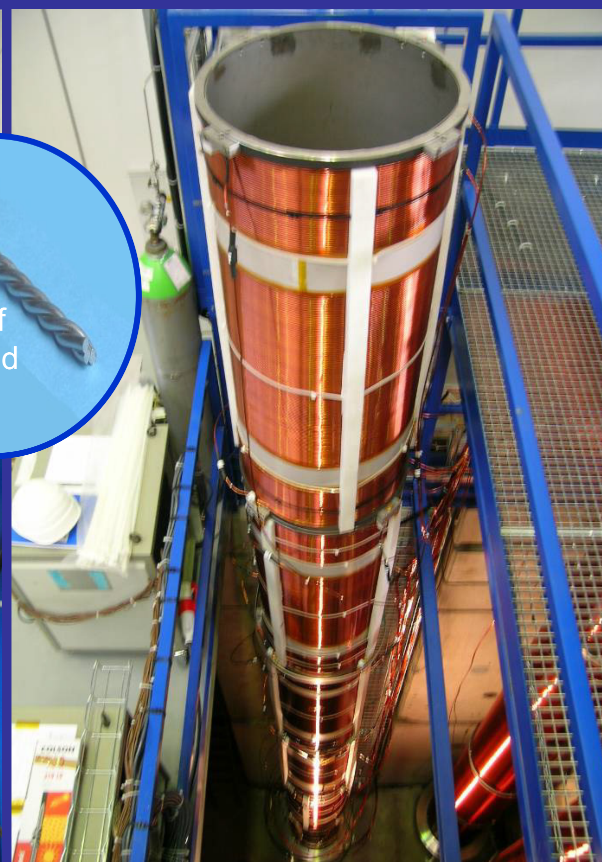




NEG COATINGS

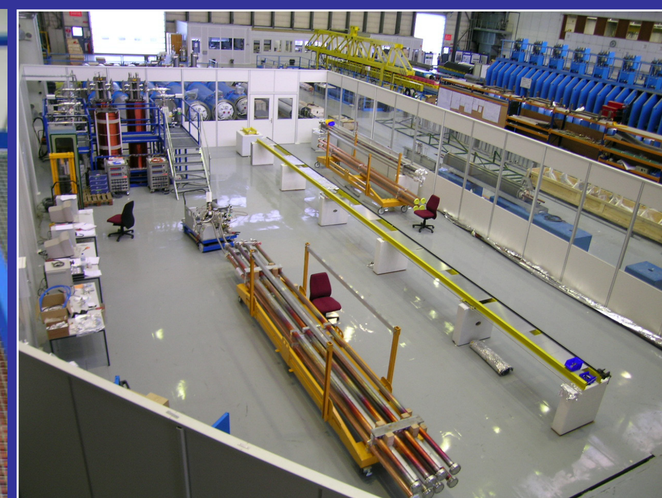
Large scale production for the LHC and experiments by DC Cylinder Magnetron sputtering (DCCM) from a target of Ti, Zr and V wires (more than 1300 chambers)





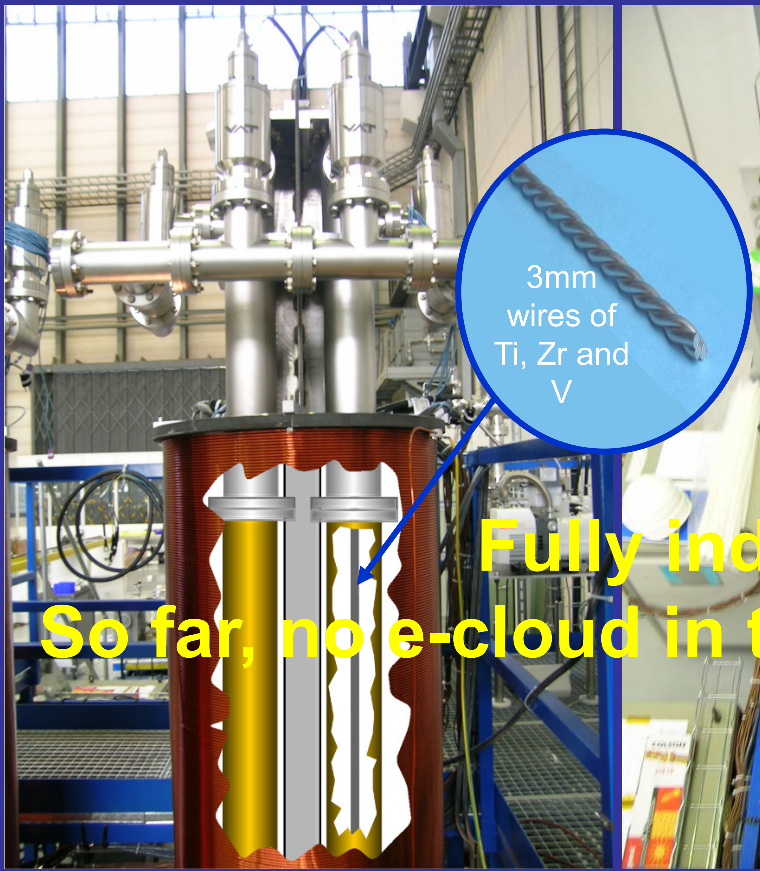
NEG COATINGS

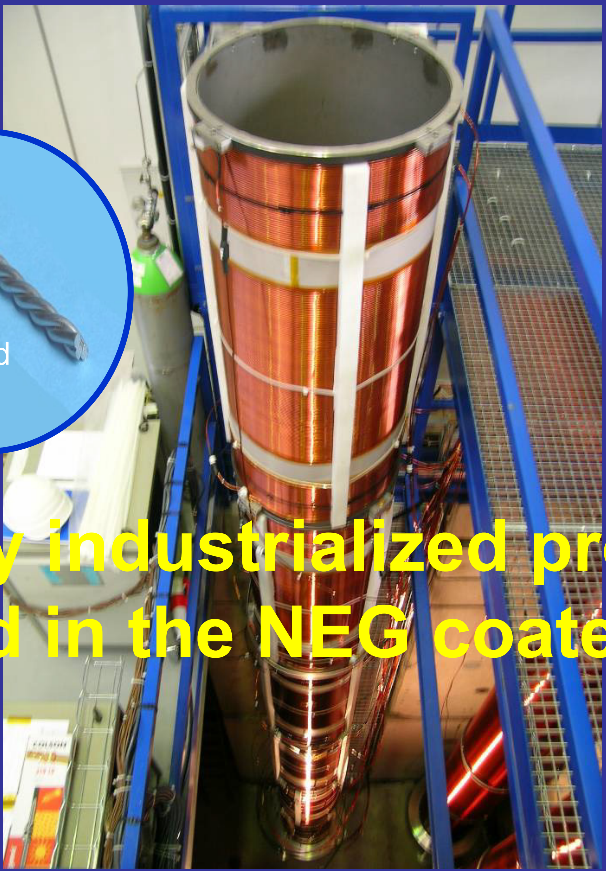
Large scale production for the LHC and experiments by DC Cylinder Magnetron sputtering (DCCM) from a target of Ti, Zr and V wires (more than 1300 chambers)

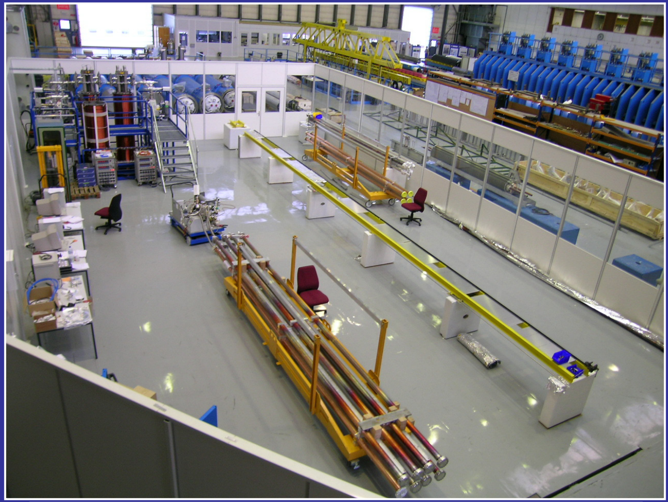


NEG COATINGS

Large scale production for the LHC and experiments by DC Cylinder Magnetron sputtering (DCCM) from a target of Ti, Zr and V wires (more than 1300 chambers)





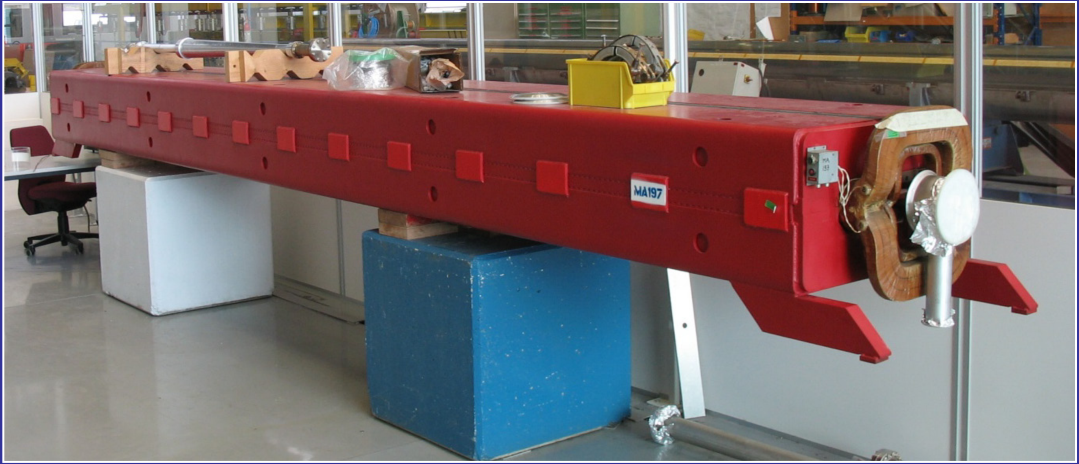


Fully industrialized process.

So far, no e-cloud in the NEG coated parts of the LHC.

CARBON COATINGS

SPS dipole: 6.5 m, ~16 tons, non bakeable, Radioactive, >700 magnets to be coated.



Why carbon? Because graphite has low SEY and is not very reactive.

Why sputtering? Because it favours sp2 hybridization in C-C bonds.

Diamond: 100% sp3 HIGH SEY

Graphite: 100% sp2 LOW SEY

How to do it?... Two possible scenarios:

1) Coat new beampipes: disassemble the magnets, insert coated beampipes, re-assemble magnets.

Easy for coating process (< 0.5M USD)

Expensive to disassemble/re-assemble: 17M USD

2) Coat actual beampipes inside the magnets.

Difficult for coating process

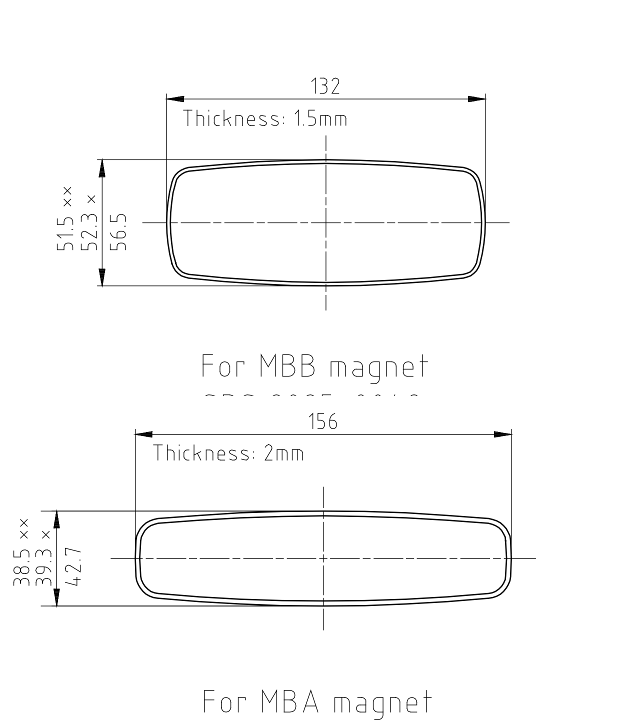
Cheaper: 4M USD (coating < 0.5M USD)

CARBON COATINGS

Scenario 1) coat new beampipes: the coating setup.

The coating is done by DC Cylindrical Magnetron sputtering (DCCM) in the solenoids used for the NEG.

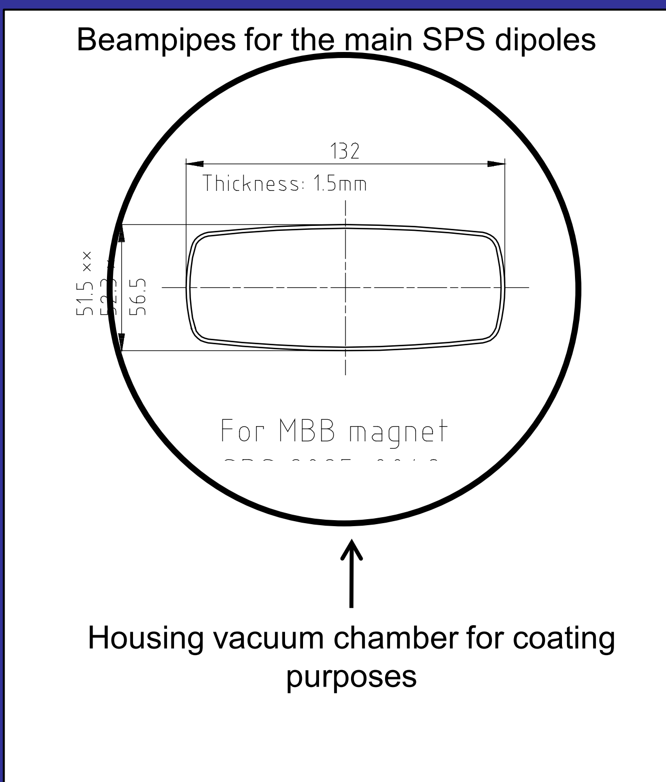
Beampipes for the main SPS dipoles

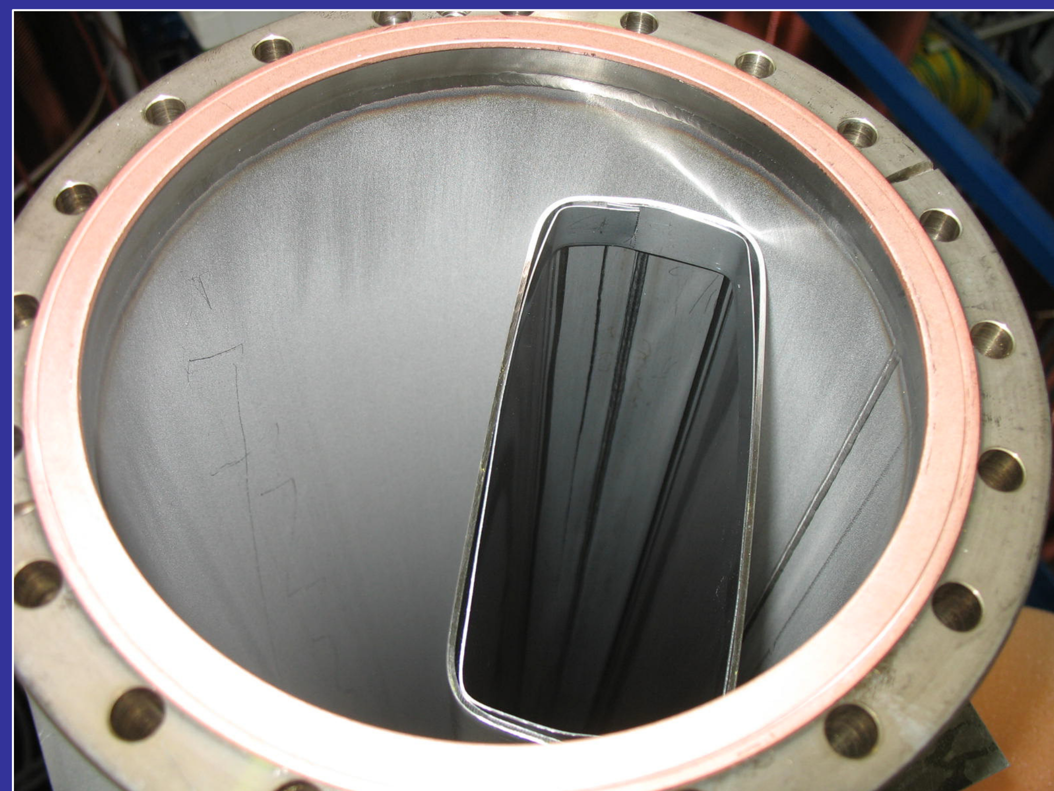


CARBON COATINGS

Scenario 1) coat new beampipes: the coating setup.

The coating is done by DC Cylindrical Magnetron sputtering (DCCM) in the solenoids used for the NEG.

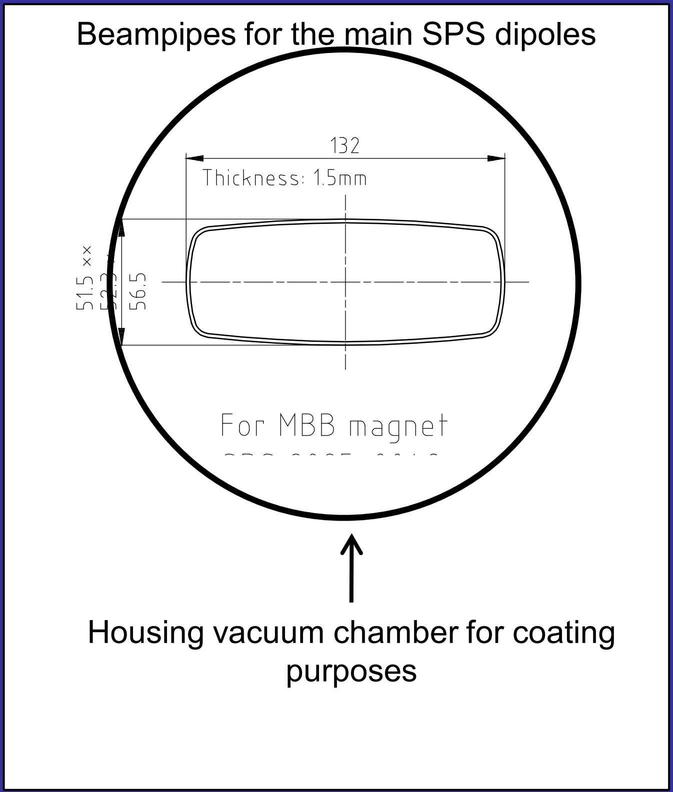


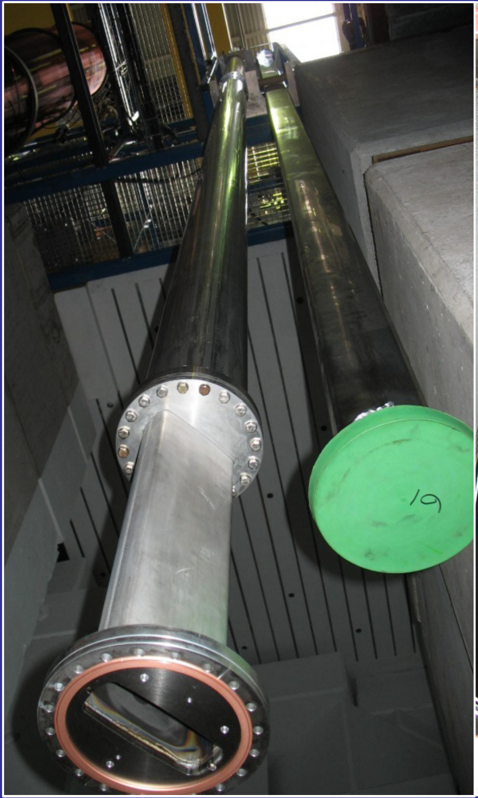


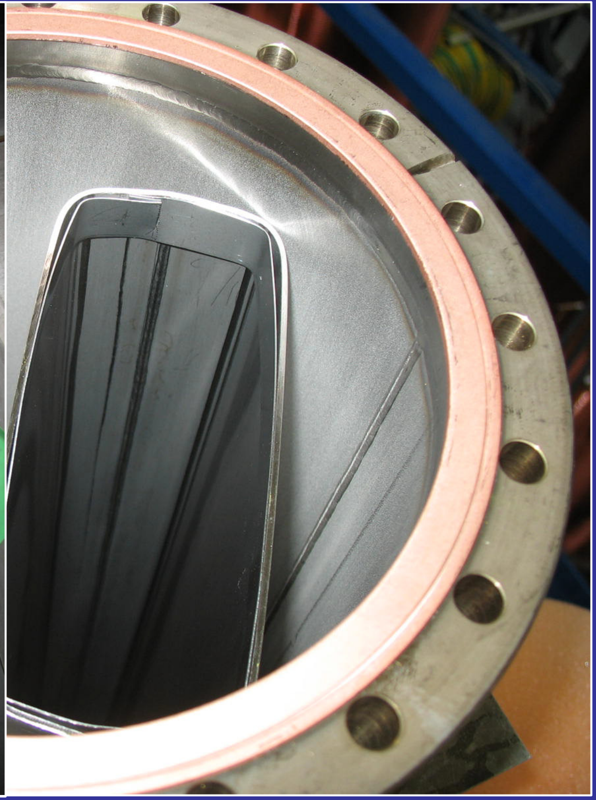
CARBON COATINGS

Scenario 1) coat new beampipes: the coating setup.

The coating is done by DC Cylindrical Magnetron sputtering (DCCM) in the solenoids used for the NEG.



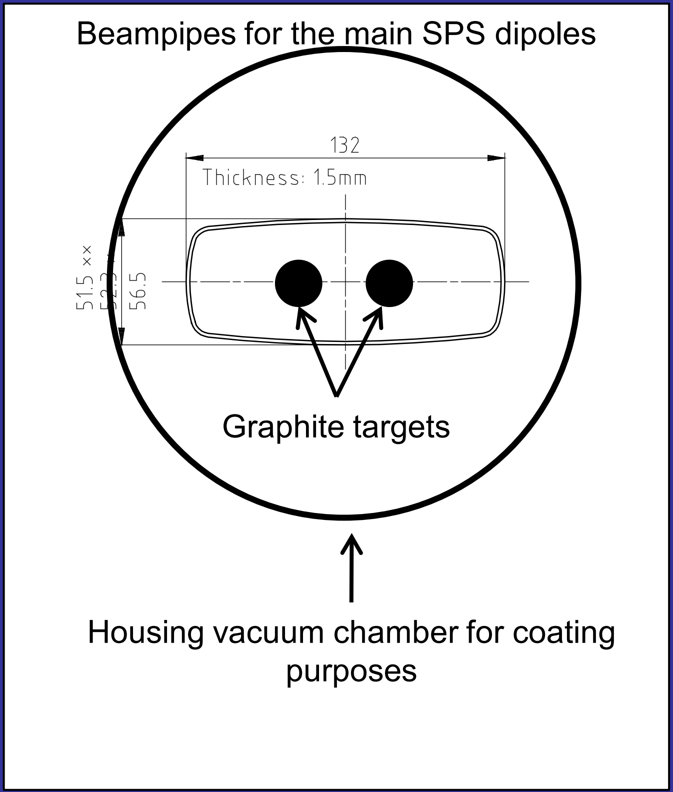


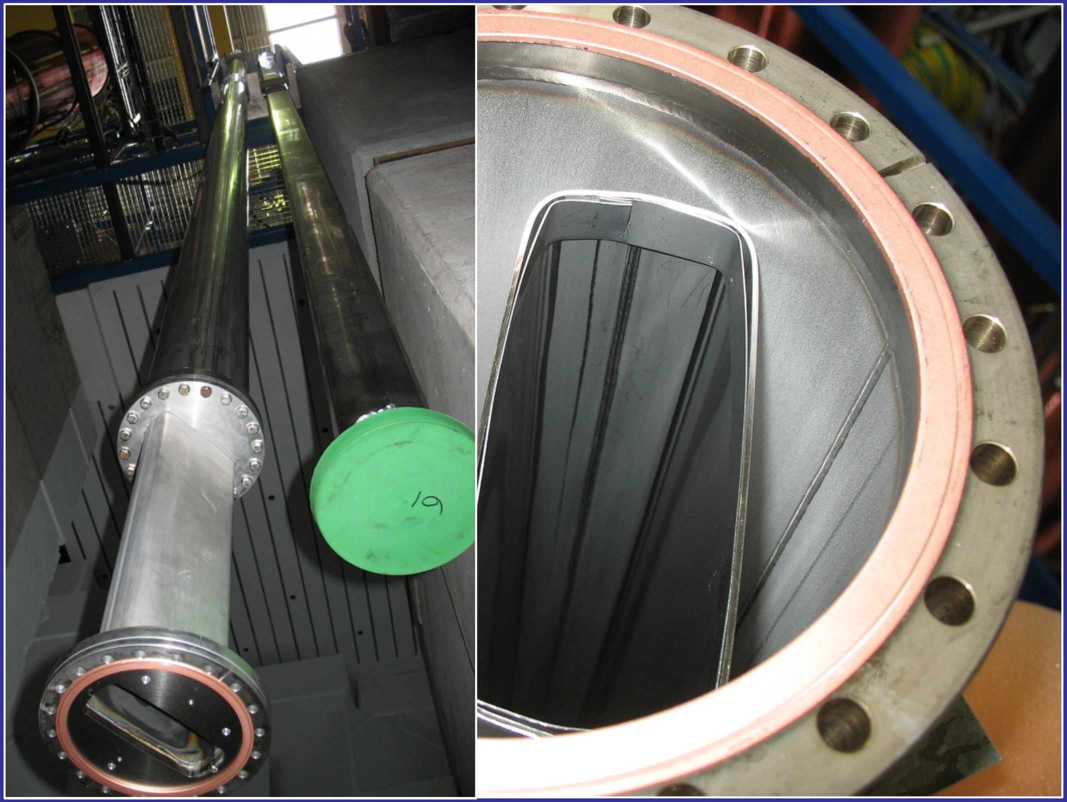


CARBON COATINGS

Scenario 1) coat new beampipes: the coating setup.

The coating is done by DC Cylindrical Magnetron sputtering (DCCM) in the solenoids used for the NEG.

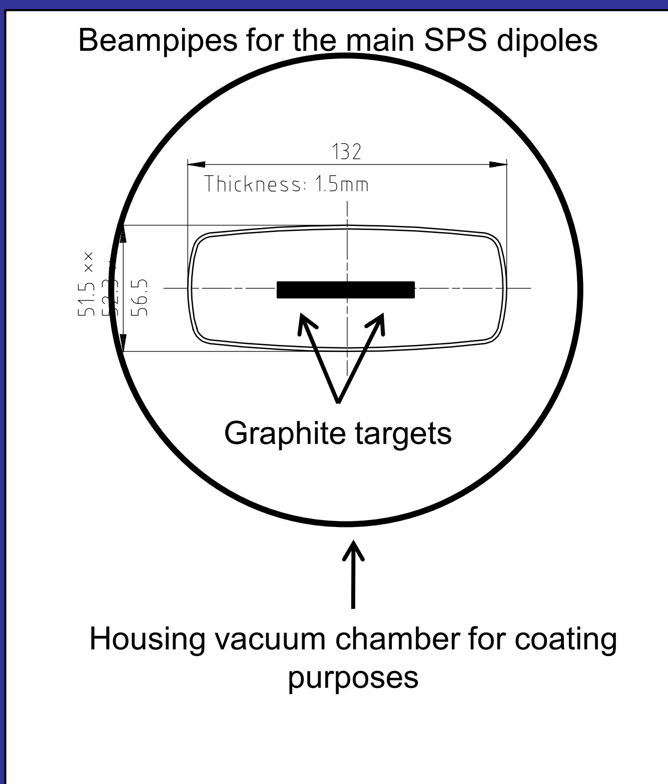


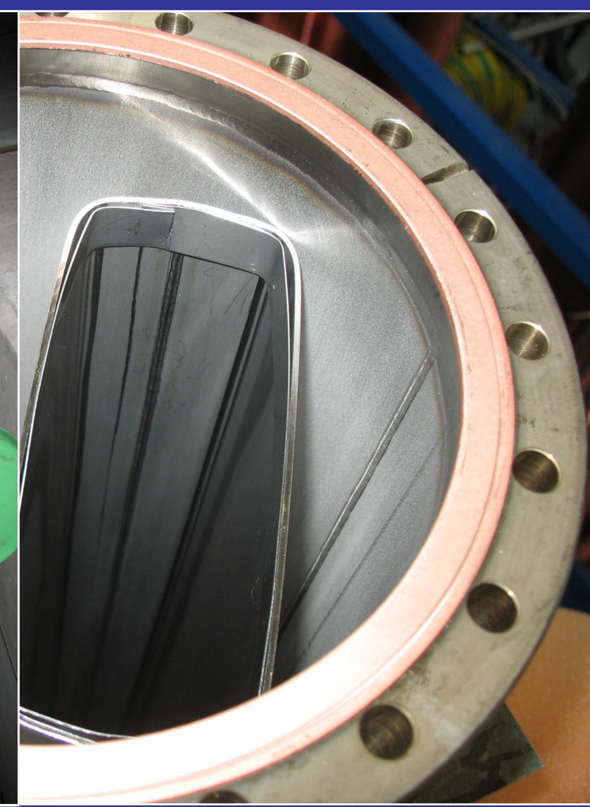


CARBON COATINGS

Scenario 1) coat new beampipes: the coating setup.

The coating is done by DC Cylindrical Magnetron sputtering (DCCM) in the solenoids used for the NEG.

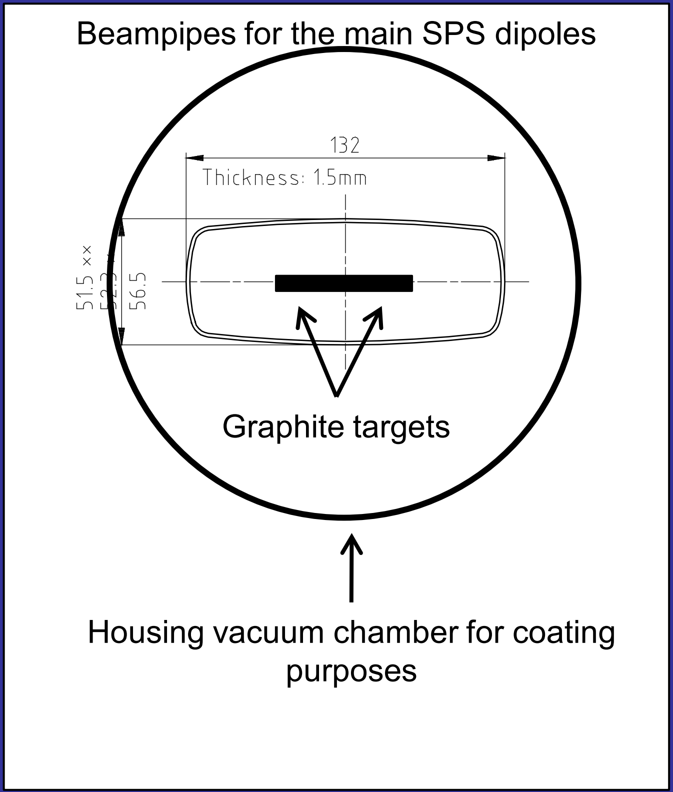


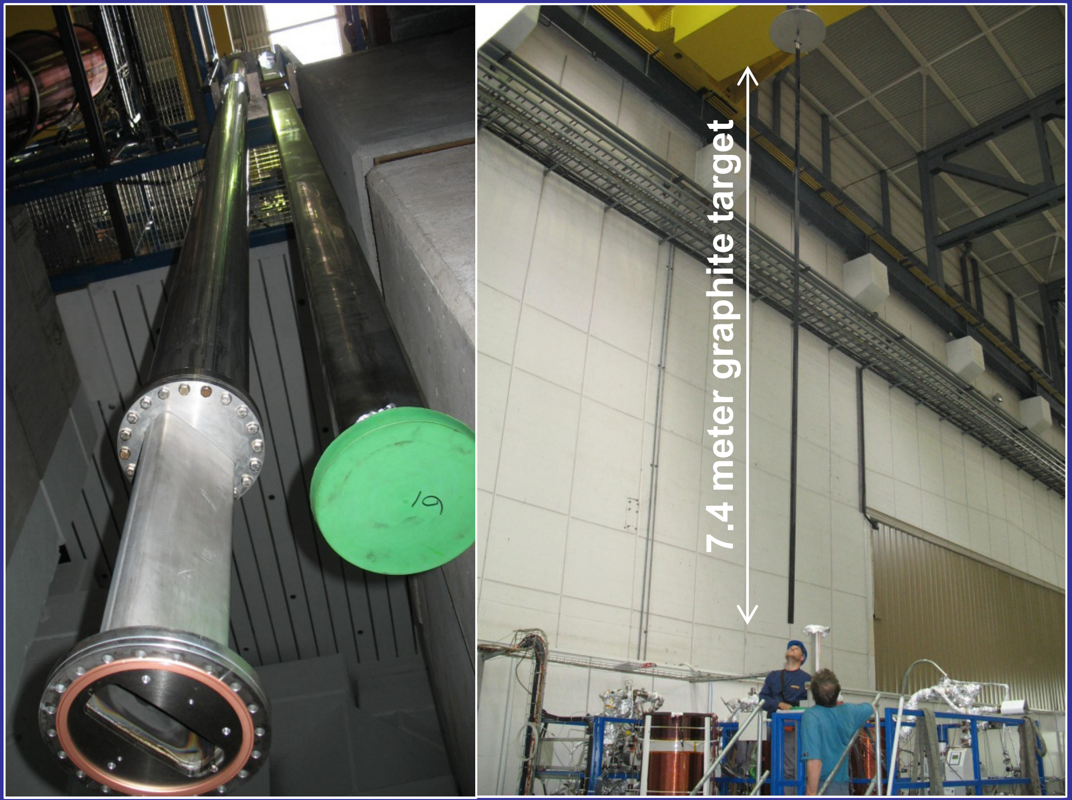


CARBON COATINGS

Scenario 1) coat new beampipes: the coating setup.

The coating is done by DC Cylindrical Magnetron sputtering (DCCM) in the solenoids used for the NEG.

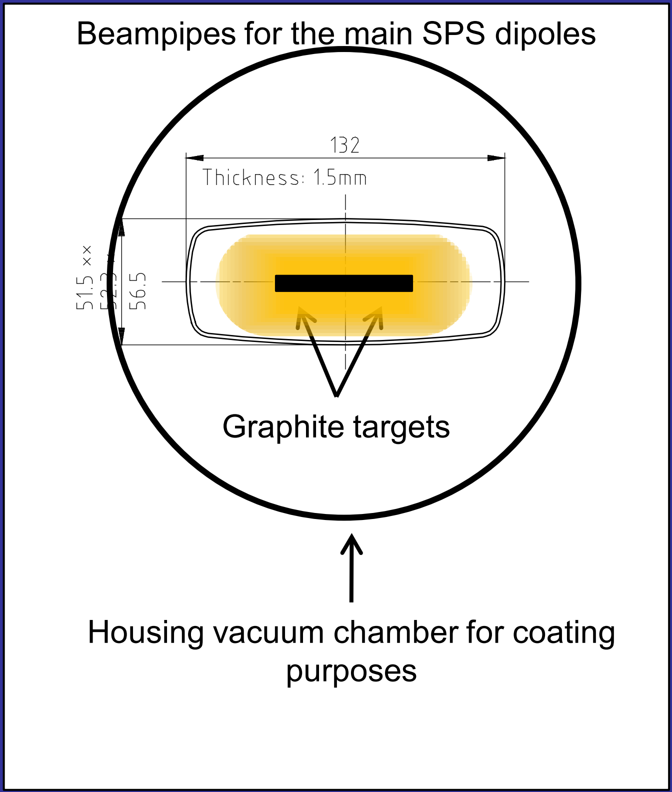


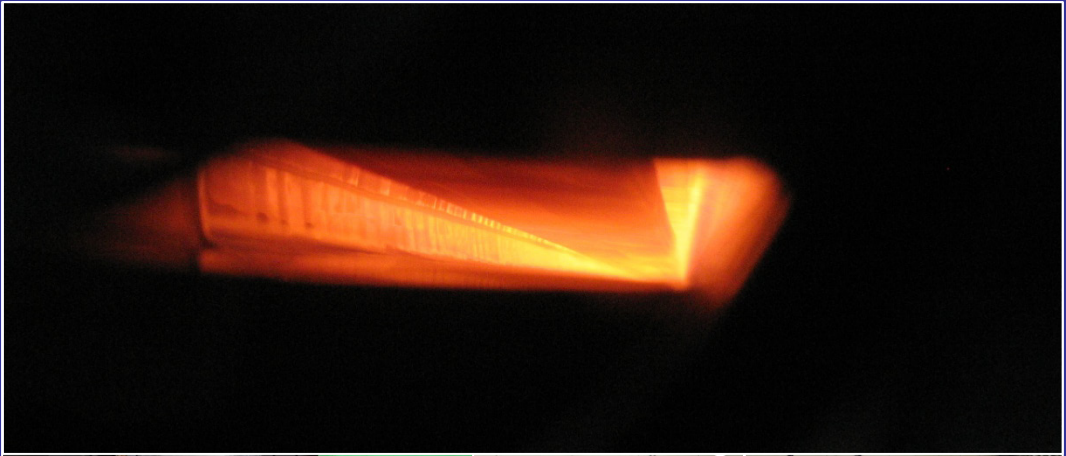


CARBON COATINGS

Scenario 1) coat new beampipes: the coating setup.

The coating is done by DC Cylindrical Magnetron sputtering (DCCM) in the solenoids used for the NEG.



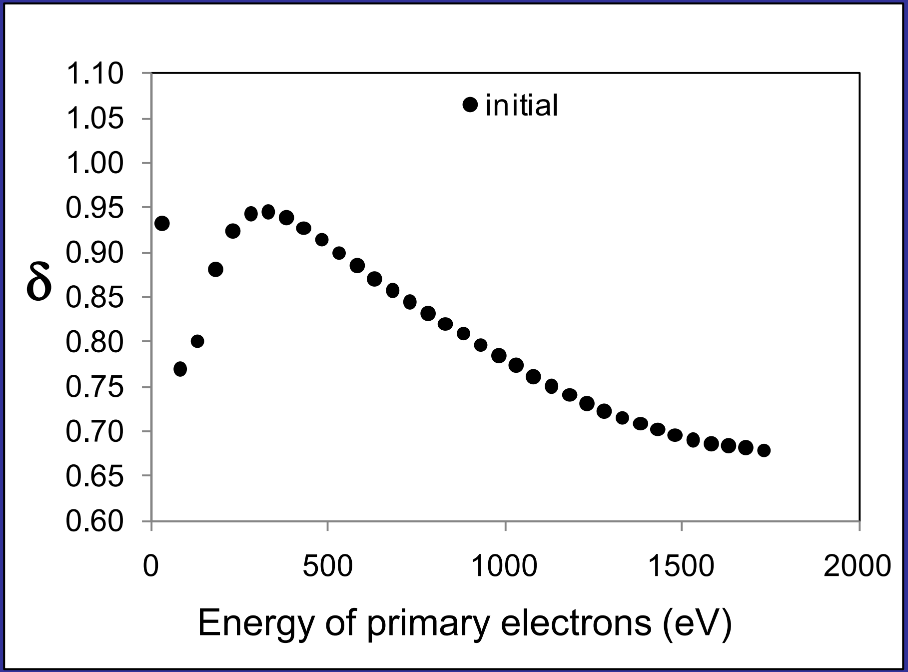


Ne pressure 8×10^{-2} mbar
Power 400 Watt / meter of cathode
Target bias -650 V
Substrate temperature 300°C
Magnetic field 180 Gauss

CARBON COATINGS

Scenario 1) coat new beampipes: characterization in laboratory.

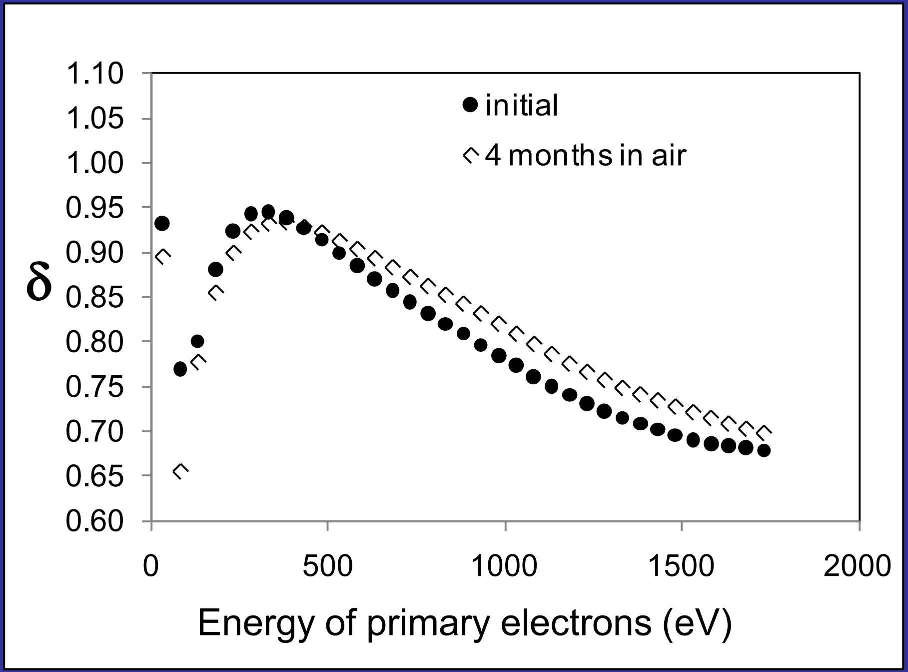
SEY measured in laboratory



CARBON COATINGS

Scenario 1) coat new beampipes: characterization in laboratory.

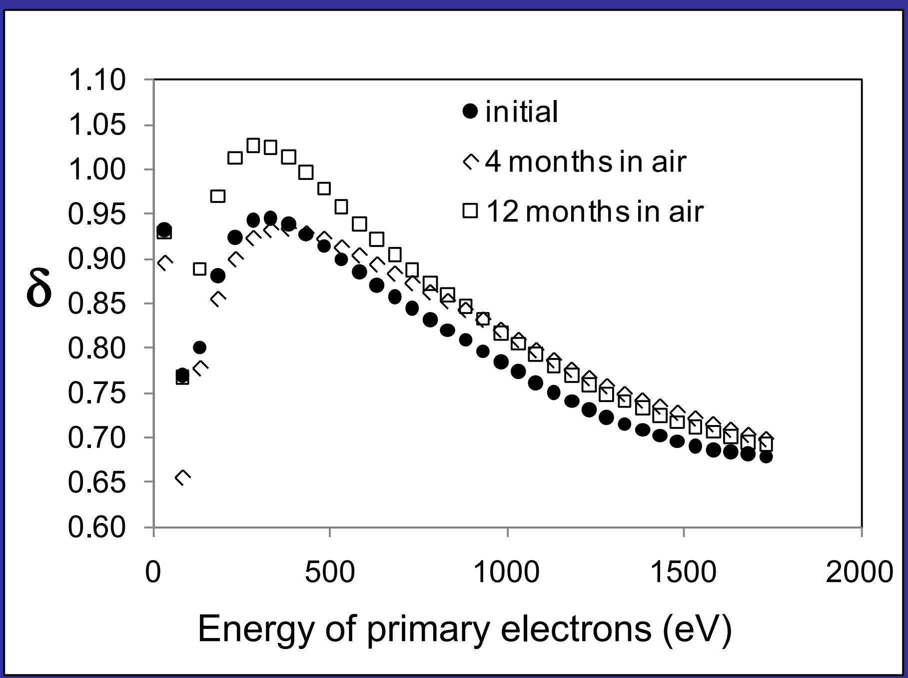
SEY measured in laboratory



CARBON COATINGS

Scenario 1) coat new beampipes: characterization in laboratory.

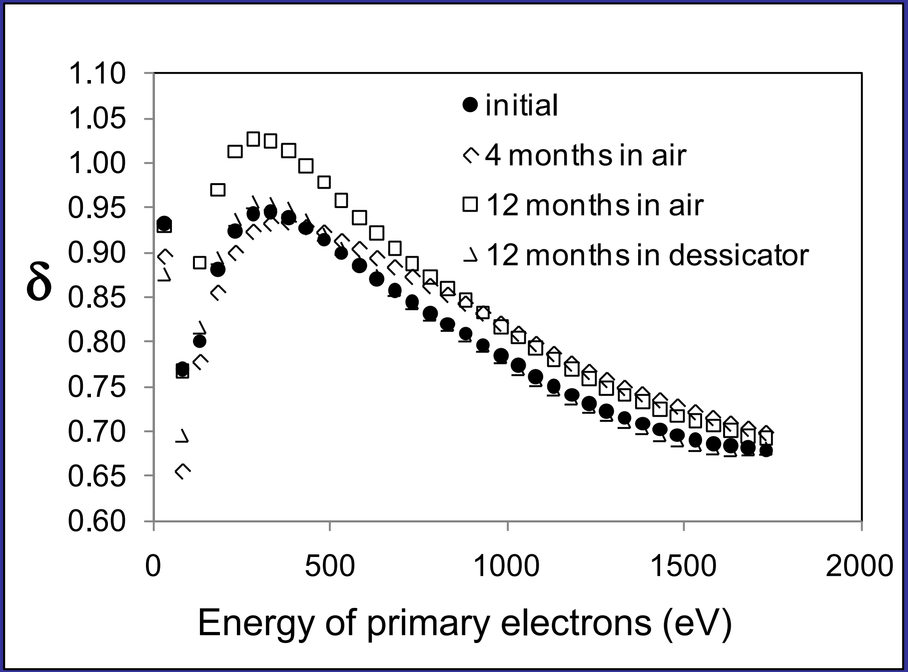
SEY measured in laboratory



CARBON COATINGS

Scenario 1) coat new beampipes: characterization in laboratory.

SEY measured in laboratory

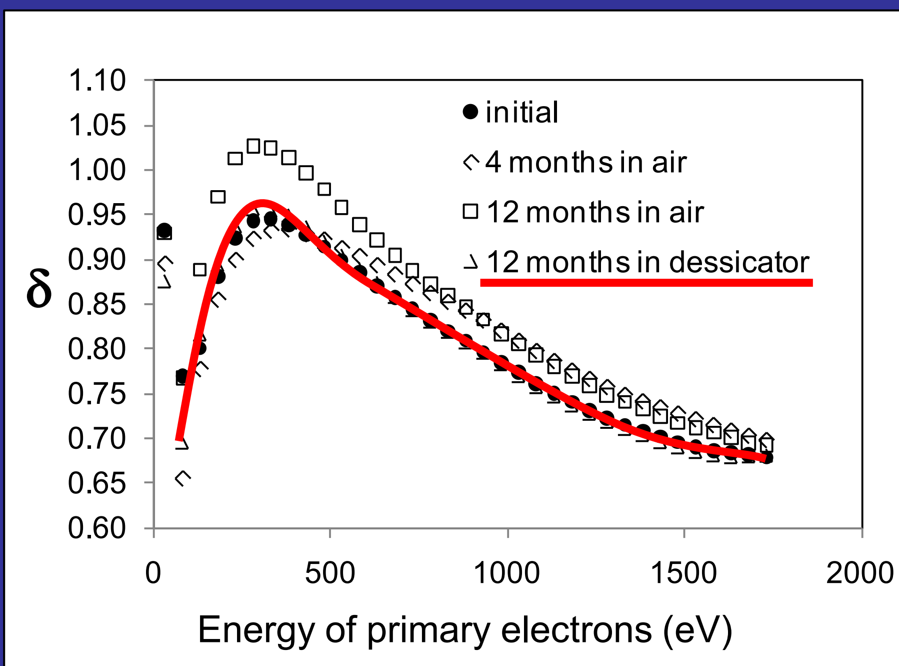


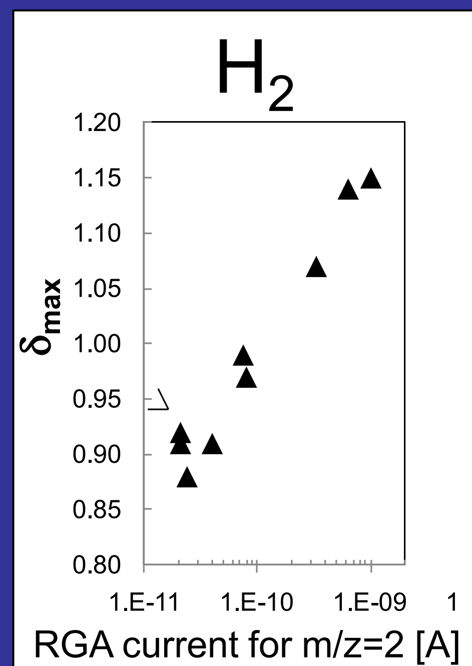
CARBON COATINGS

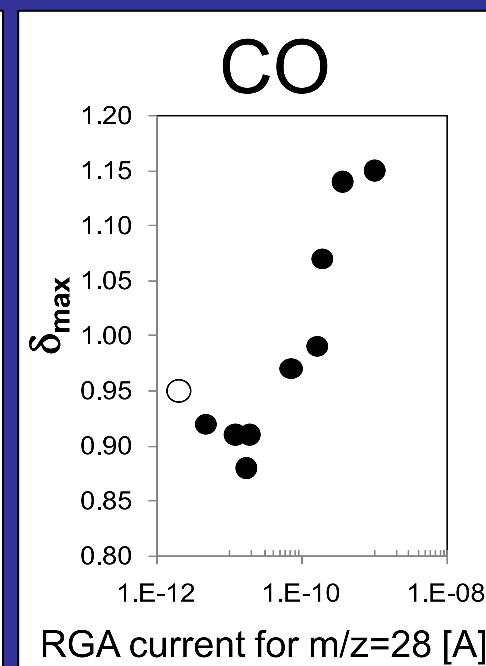
Scenario 1) coat new beampipes: characterization in laboratory.

SEY measured in laboratory

δ_{max} seems to correlate with the gas impurities in the plasma at the end of the sputtering process







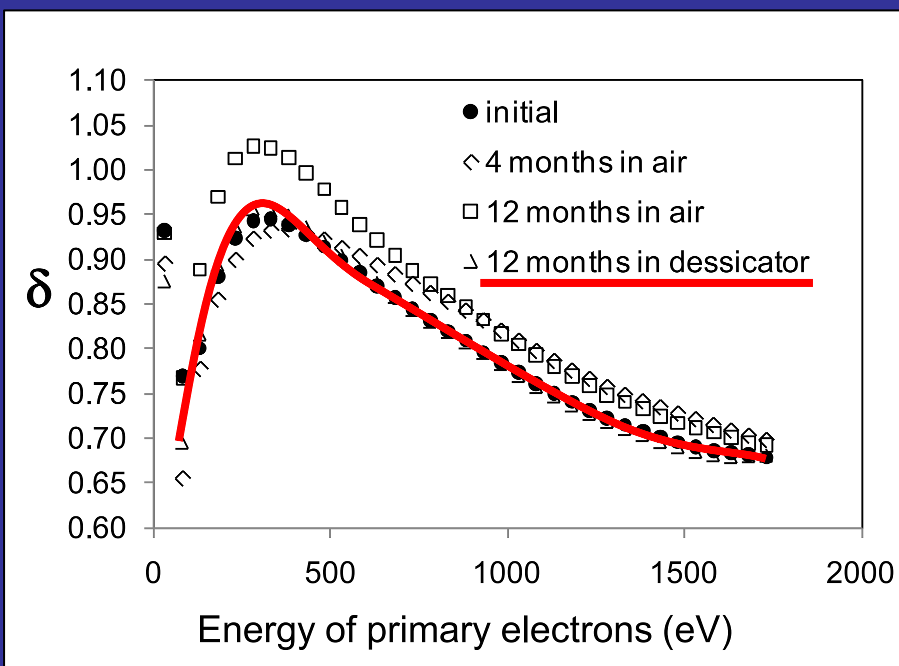
water is possibly related with ageing

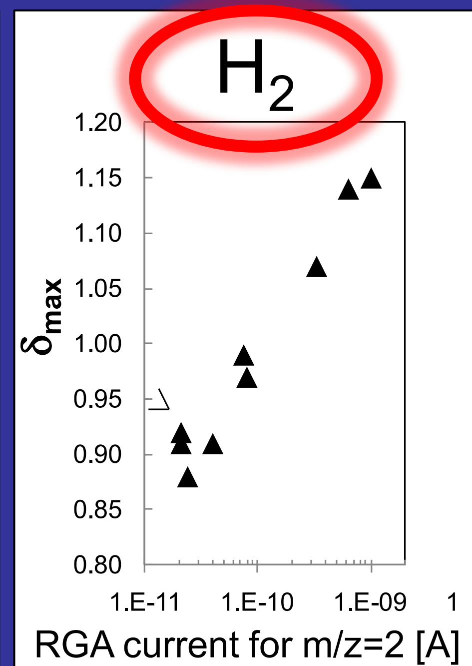
CARBON COATINGS

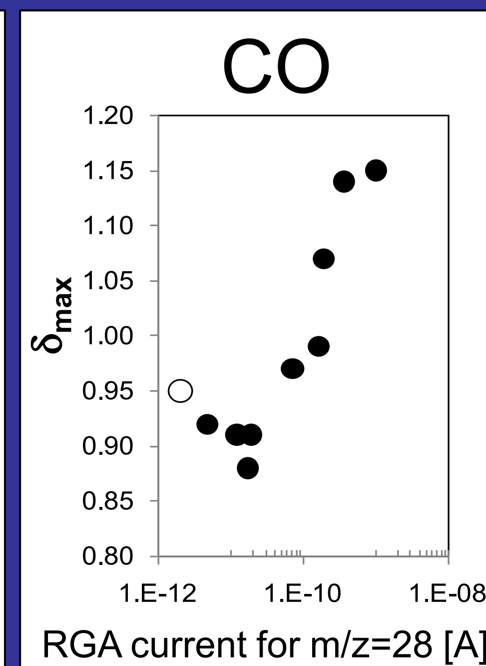
Scenario 1) coat new beampipes: characterization in laboratory.

SEY measured in laboratory

δ_{max} seems to correlate with the gas impurities in the plasma at the end of the sputtering process





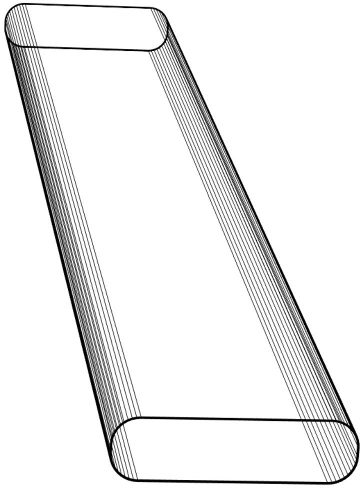


water is possibly related with ageing

CARBON COATINGS

Scenario 1) coat new beampipes: tests in the SPS

Electron-Cloud Monitors

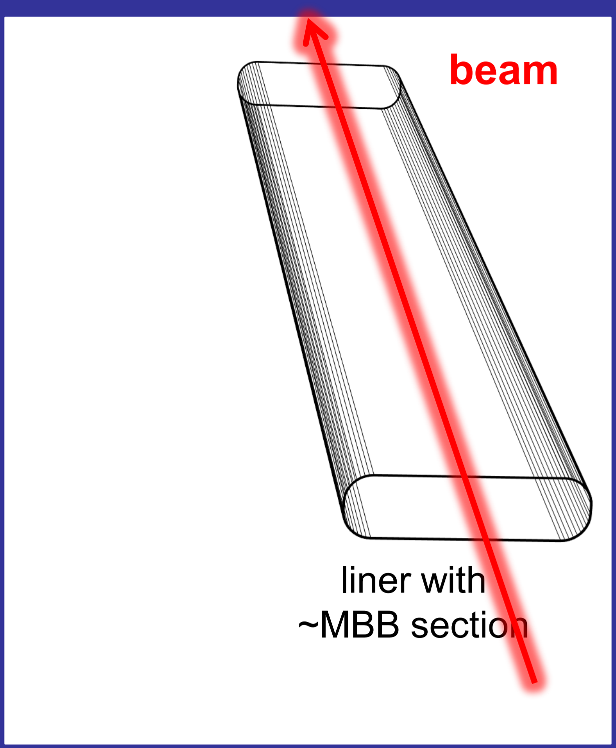


liner with
~MBB section

CARBON COATINGS

Scenario 1) coat new beampipes: tests in the SPS

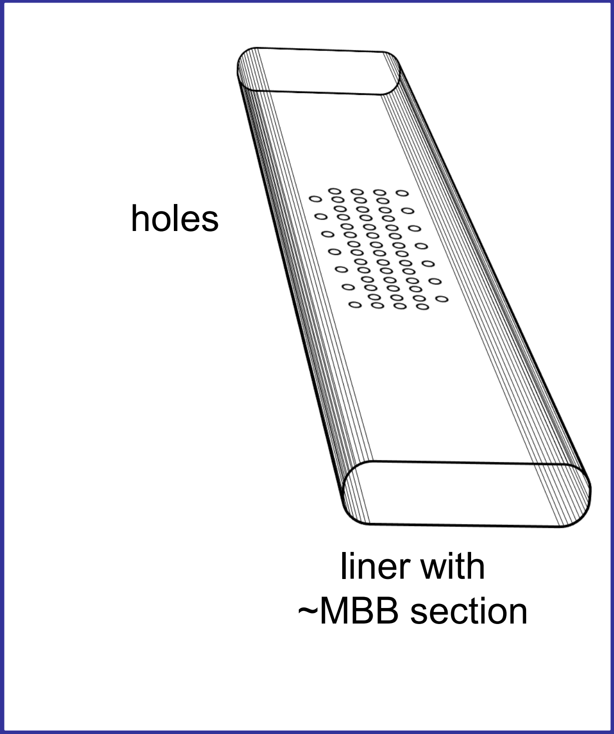
Electron-Cloud Monitors



CARBON COATINGS

Scenario 1) coat new beampipes: tests in the SPS

Electron-Cloud Monitors

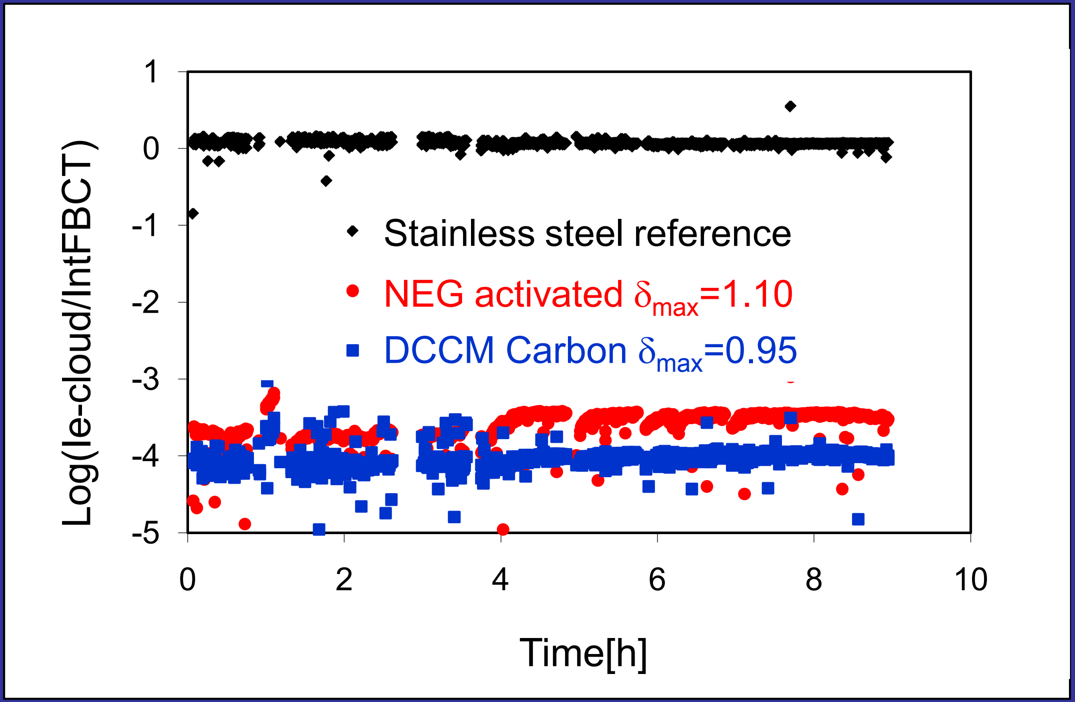


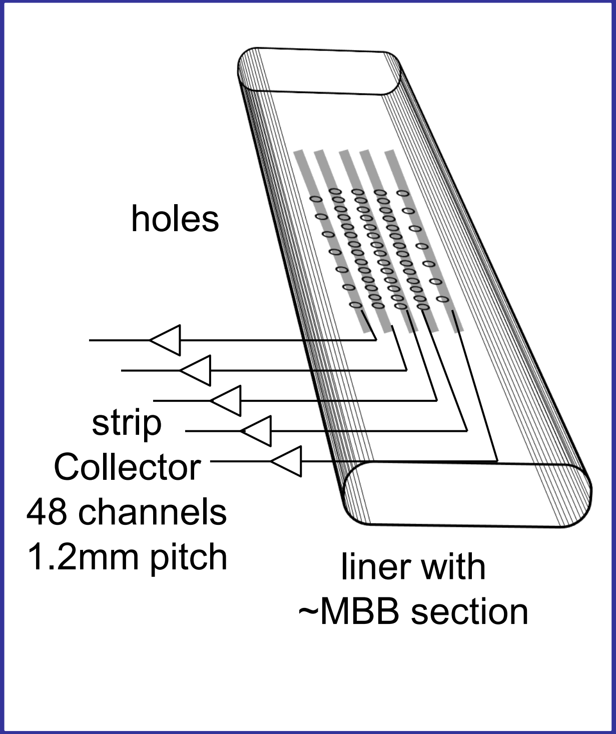
CARBON COATINGS

Scenario 1) coat new beampipes: tests in the SPS

Electron-Cloud Monitors

Set-up: carbon coated liners with strip detector in 1.2K Gauss field
Beam: 2-3 batches, 72 proton bunches, 25 ns spacing, 450 GeV





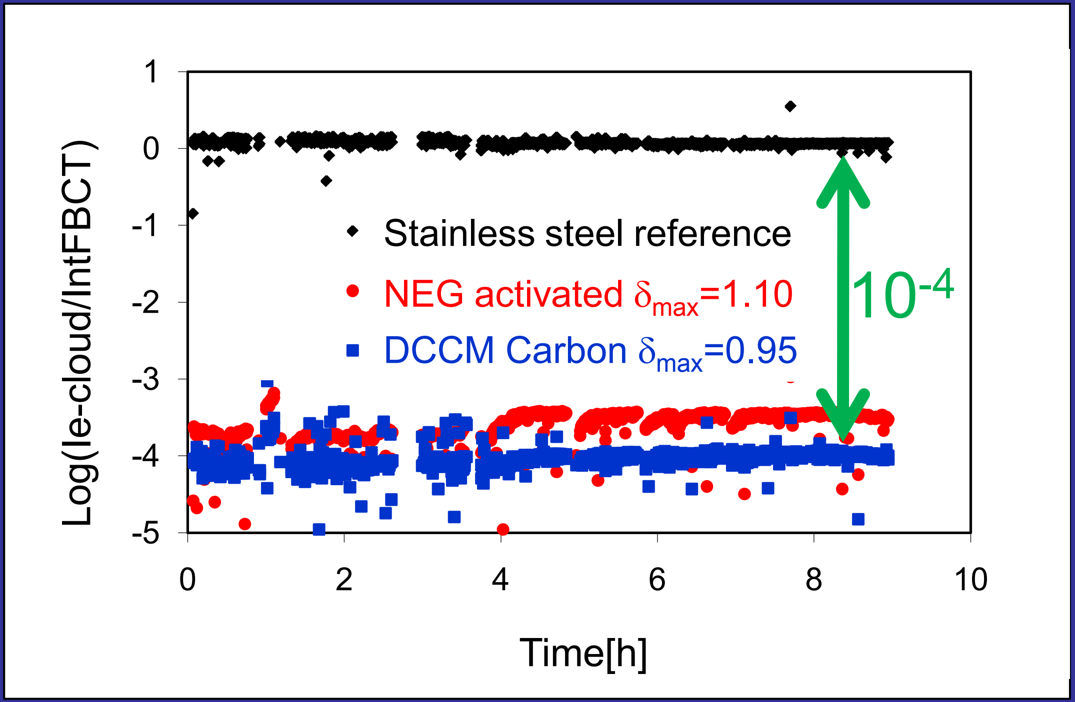
CARBON COATINGS

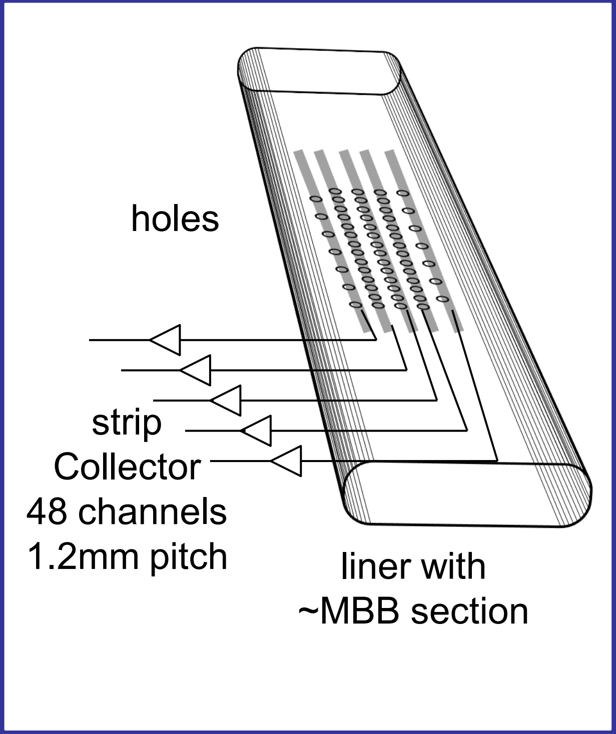
Scenario 1) coat new beampipes: tests in the SPS

Electron-Cloud Monitors

Set-up: carbon coated liners with strip detector in 1.2K Gauss field

Beam: 2-3 batches, 72 proton bunches, 25 ns spacing, 450 GeV



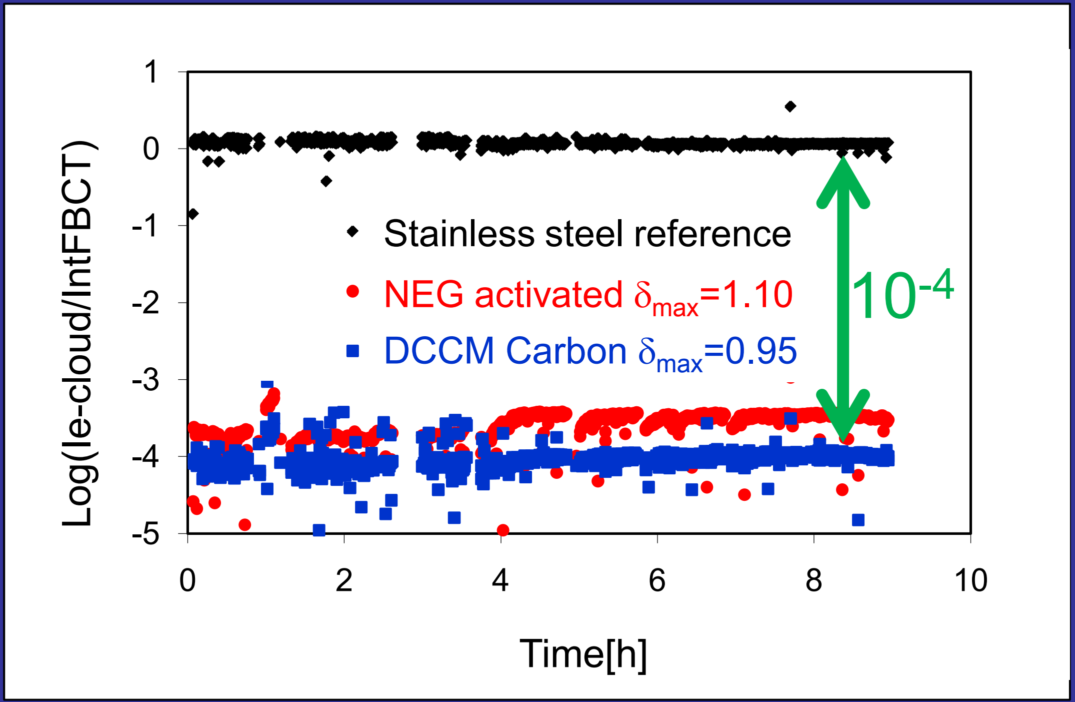


E-cloud signal for carbon is 4 orders of magnitude below that for stainless steel.

CARBON COATINGS

Scenario 1) coat new beampipes: tests in the SPS

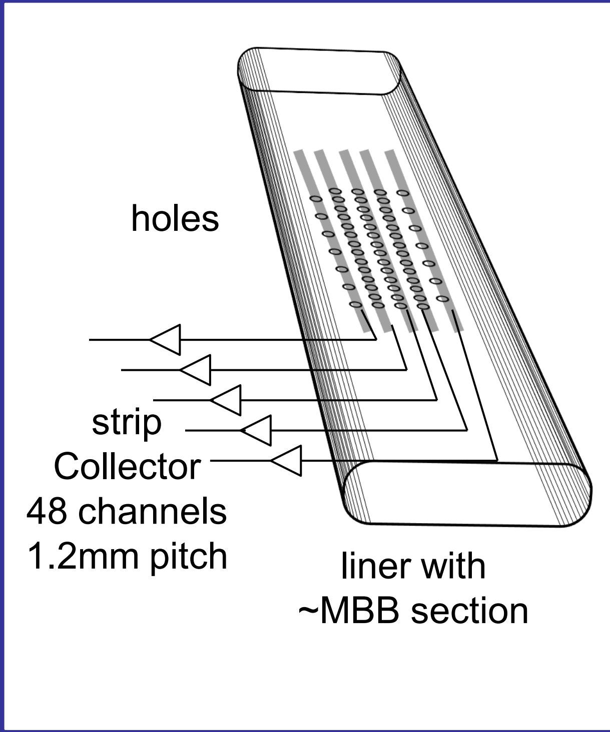
Set-up: carbon coated liners with strip detector in 1.2K Gauss field
Beam: 2-3 batches, 72 proton bunches, 25 ns spacing, 450 GeV



E-cloud signal for carbon is 4 orders of magnitude below that for stainless steel.

Electron-Cloud Monitors

Several liners coated with carbon and tested during MD runs with LHC type beam



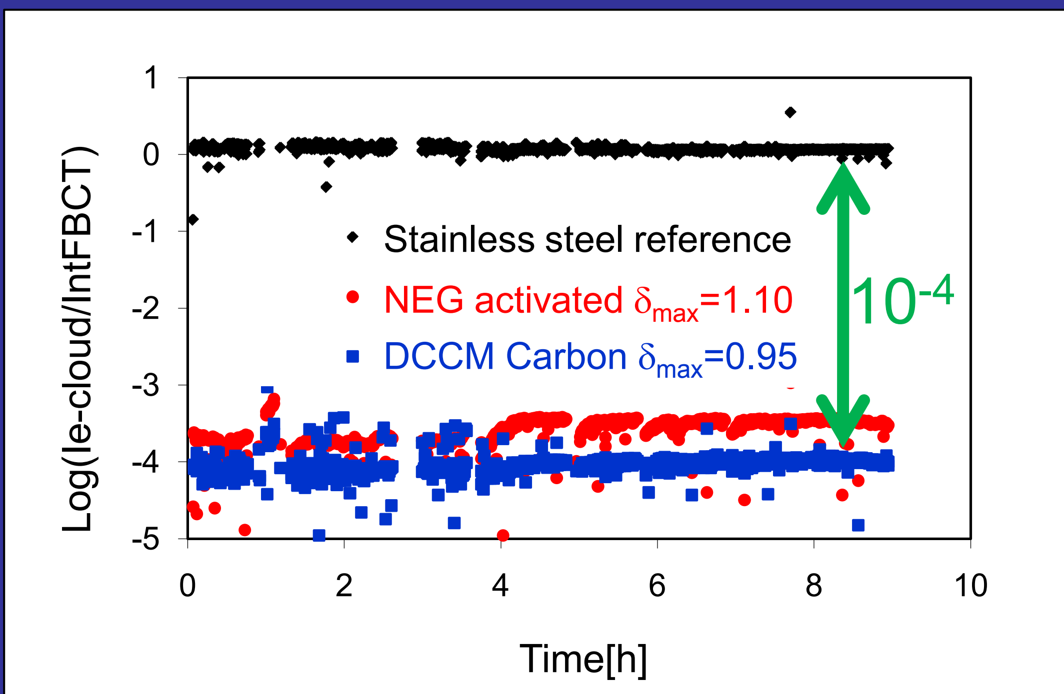
CARBON COATINGS

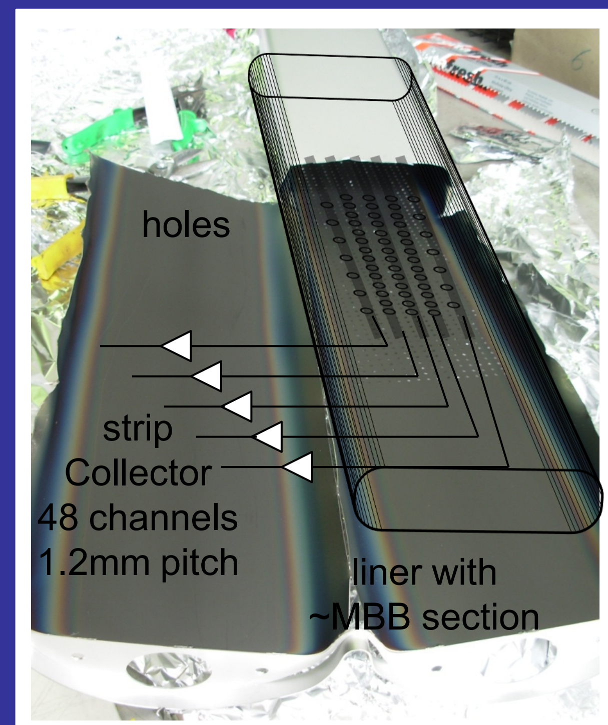
Scenario 1) coat new beampipes: tests in the SPS

Electron-Cloud Monitors

Set-up: carbon coated liners with strip detector in 1.2K Gauss field
Beam: 2-3 batches, 72 proton bunches, 25 ns spacing, 450 GeV

Several liners coated with carbon and tested during MD runs with LHC type beam



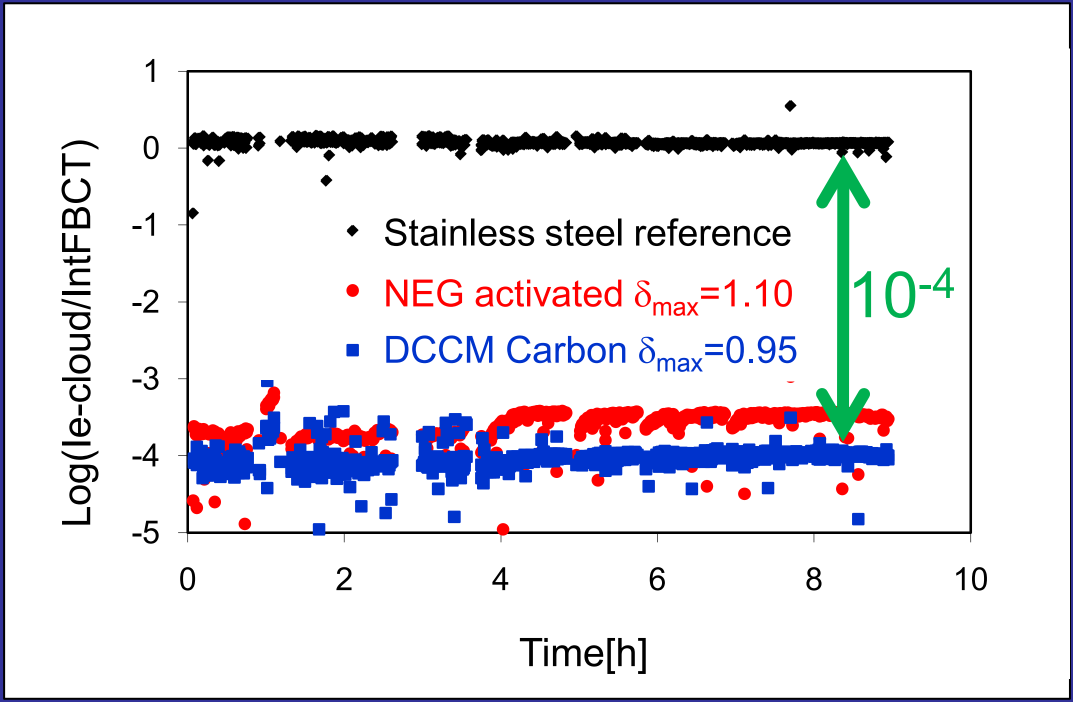


E-cloud signal for carbon is 4 orders of magnitude below that for stainless steel.

CARBON COATINGS

Scenario 1) coat new beampipes: tests in the SPS

Set-up: carbon coated liners with strip detector in 1.2K Gauss field
Beam: 2-3 batches, 72 proton bunches, 25 ns spacing, 450 GeV



Electron-Cloud Monitors

Several liners coated with carbon and tested during MD runs with LHC type beam

Liner	SPS operation time	δ_{max} initial	δ_{max} extracted
StSt (Ref)	1 year (5 MD runs)	2.25	1.72
C-strip	1 year (5 MD runs)	0.92	0.97
C-Zr	1.5 years (9 MD runs)	0.95	0.99
CNe64	3 months (2 MD runs)	0.95	0.97
CNe65	3 months (2 MD runs)	0.95	0.97

E-cloud signal for carbon is 4 orders of magnitude below that for stainless steel.

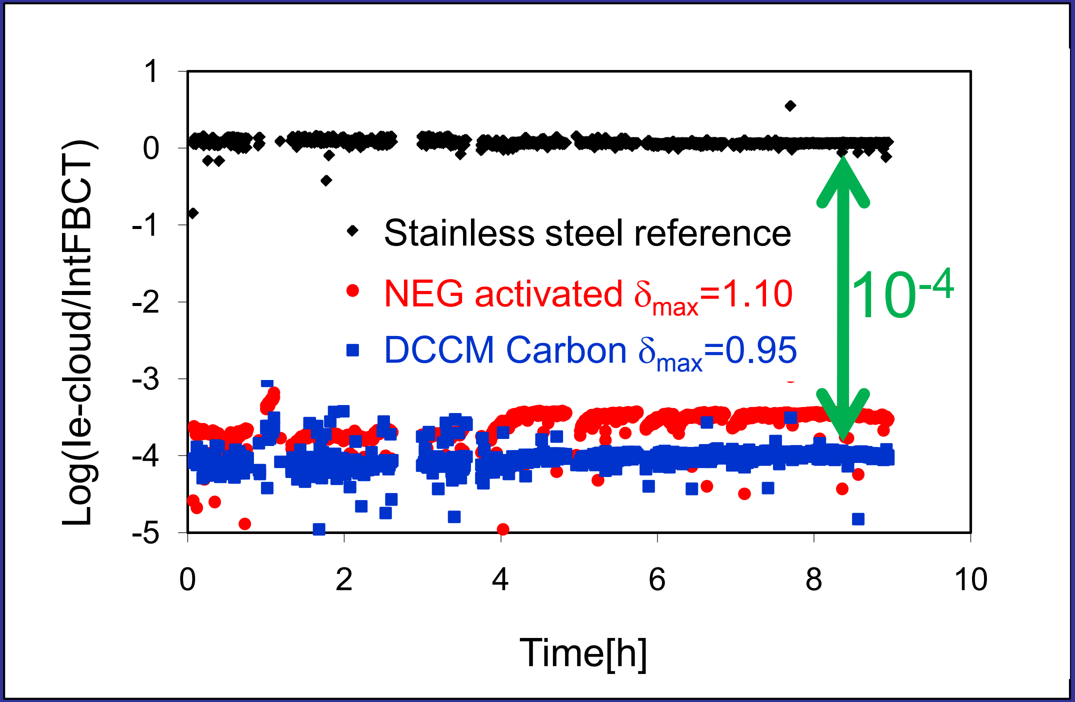
CARBON COATINGS

Scenario 1) coat new beampipes: tests in the SPS

Electron-Cloud Monitors

Set-up: carbon coated liners with strip detector in 1.2K Gauss field
Beam: 2-3 batches, 72 proton bunches, 25 ns spacing, 450 GeV

Several liners coated with carbon and tested during MD runs with LHC type beam



E-cloud signal for carbon is 4 orders of magnitude below that for stainless steel.

Liner	SPS operation time	δ_{max} initial	δ_{max} extracted
StSt (Ref)	1 year (5 MD runs)	2.25	1.72
C-strip	1 year (5 MD runs)	0.92	0.97
C-Zr	1.5 years (9 MD runs)	0.95	0.99
CNe64	3 months (2 MD runs)	0.95	0.97
CNe65	3 months (2 MD runs)	0.95	0.97

Negligible ageing

(accuracy of SEY measuremets +/- 0.03)

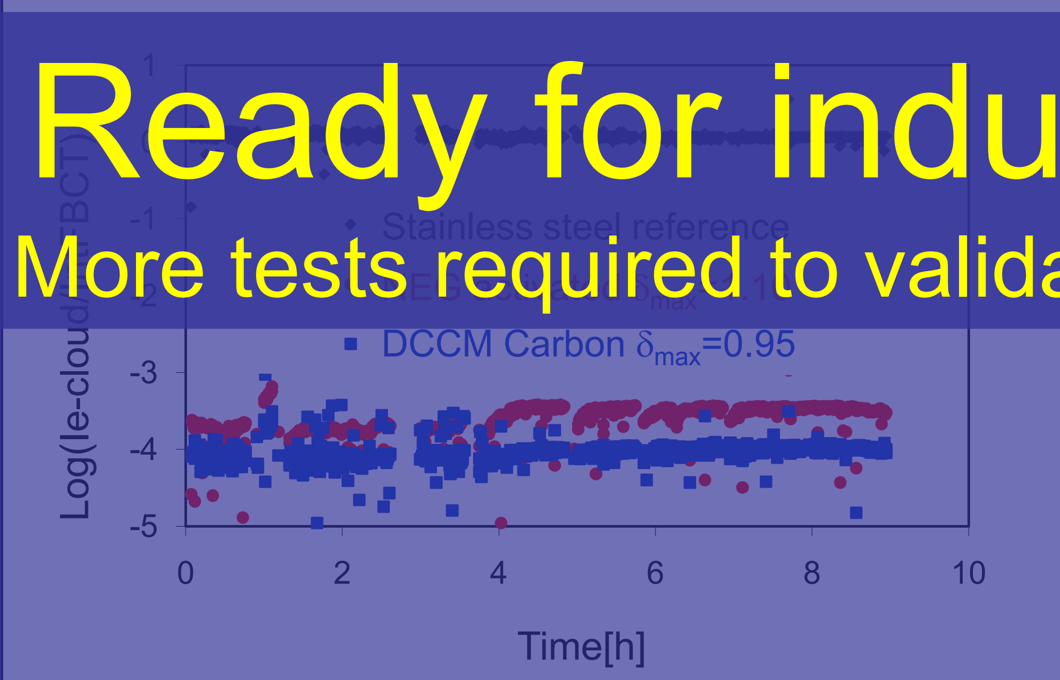
CARBON COATINGS

Scenario 1) coat new beampipes: tests in the SPS

Electron-Cloud Monitors in SPS

Set-up: carbon coated liner with strip detector in1.2K Gauss field
Beam: 2-3 batches, 72 proton bunches, 25 ns spacing, 450 GeV

Several liners coated with carbon and tested during MD runs with LHC type beam



E-cloud signal for carbon is 4 orders of magnitude below that for stainless steel.

Liner	SPS operation time	δ_{max} initial	δ_{max} expected
StSt (Ref)	1 year (5 MD runs)	[illegible]	[illegible]
C-strip	1 year (5 MD runs)	0.92	0.97
C-Zr	1.5 years (9 MD runs)	0.95	0.99
CNe64	3 months (2 MD runs)	0.95	0.97
CNe65	3 months (2 MD runs)	0.95	0.97

Negligible ageing

(accuracy of SEY measuremets +/- 0.03)

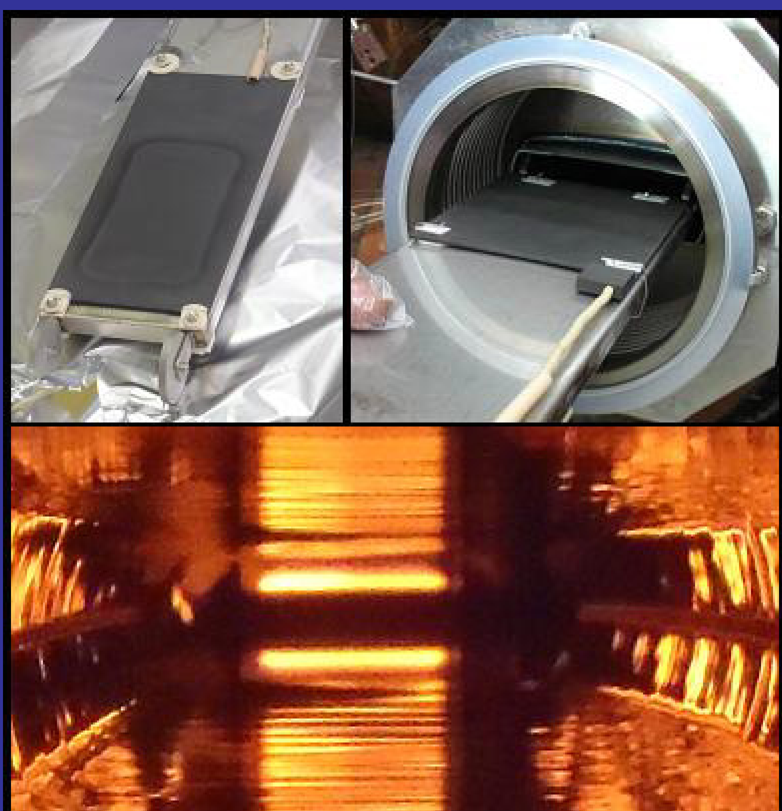
Ready for industrialization

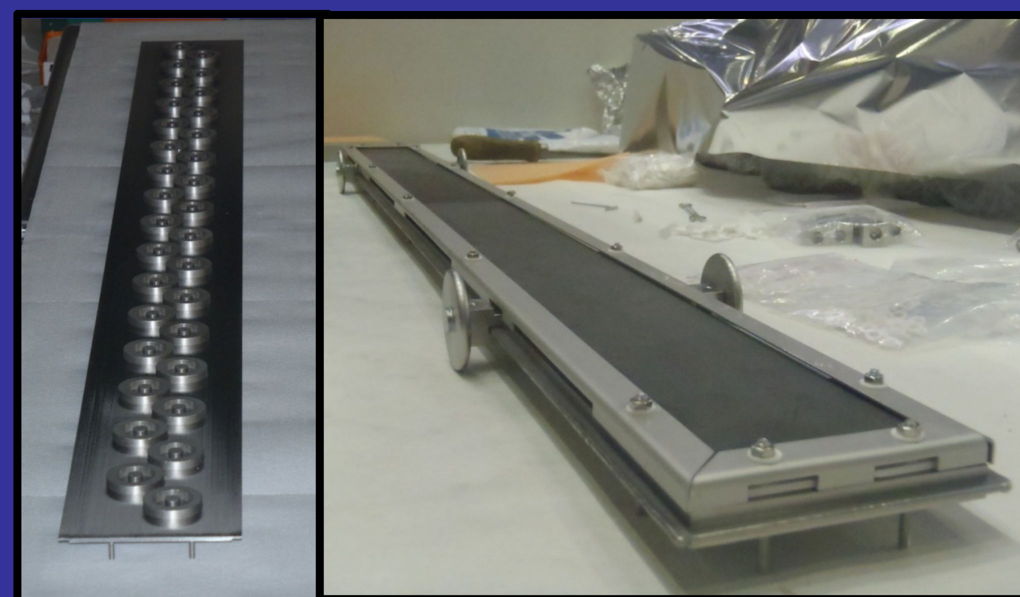
More tests required to validate the carbon coating

CARBON COATINGS

Scenario 2) coat actual beampipes: coating techniques being explored

DC magnetron using permanent magnets: good results on 30 cm prototype: δ_{max} =0.96, 0.98 after 3 months in air. 2 meter ready to be tested. If ok go for 7 meter.

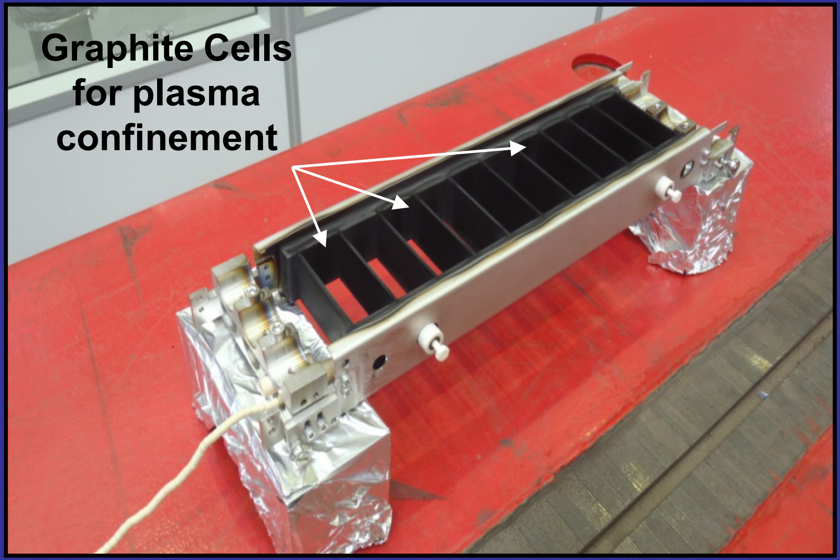




CARBON COATINGS

Scenario 2) coat actual beampipes: coating techniques being explored

DC hollow cathode: good results on 30 cm prototype: δ_{max} =0.96, 0.99 after 1 month in air. 2 meter in fabrication. If ok go for 7 meter.



Summary and Future work

Thin film coatings are effective to suppress e-cloud

For bakeable (T>180^{o}C) beampipes: NEG coatings are reliable and fully industrialised.

For unbakeable beampipes: Carbon coatings enters the last phase of development / validation.

understand ageing process, role of plasma contaminants and substrate temperature during film growth. Do more tests in the SPS with real dipoles.

Coat new chambers for SPS (scenario 1): technology ready to be industrialized. EXPENSIVE TO DISASSEMBLING / REASSEMBLING DIPOLES.

Coat the actual SPS chambers (scenario 2): promising results on small prototypes; go for 7 meter. Tests on e-cloud monitors and real dipoles will follow.

If carbon coatings are chosen to suppress e-cloud in the SPS, the whole 6 km of the machine will be coated.

THANK YOU

Summary and Future work

Thin film coatings are effective to suppress e-cloud

For bakeable ($T>180^oC$) beampipes: NEG coatings are reliable and fully industrialised.

For unbakeable beampipes: Carbon coatings enters the last phase of development / validation.

understand ageing process, role of plasma contaminants and substrate temperature during film growth. Do more tests in the SPS with real dipoles.

Carbon coatings of new chambers for SPS (scenario 1): technology ready to be industrialized. **EXPENSIVE**.

Carbon coatings of actual chambers for SPS (scenario 2): promising results on small prototypes; go for 7 meter. Tests on e-cloud monitors and real dipoles will follow.

If carbon coatings are chosen to suppress e-cloud in the SPS, the whole 6 km of the machine will be coated.

THANK YOU