CARBON COATING OF THE SPS DIPOLES

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Introduction

Coating techniques

Results

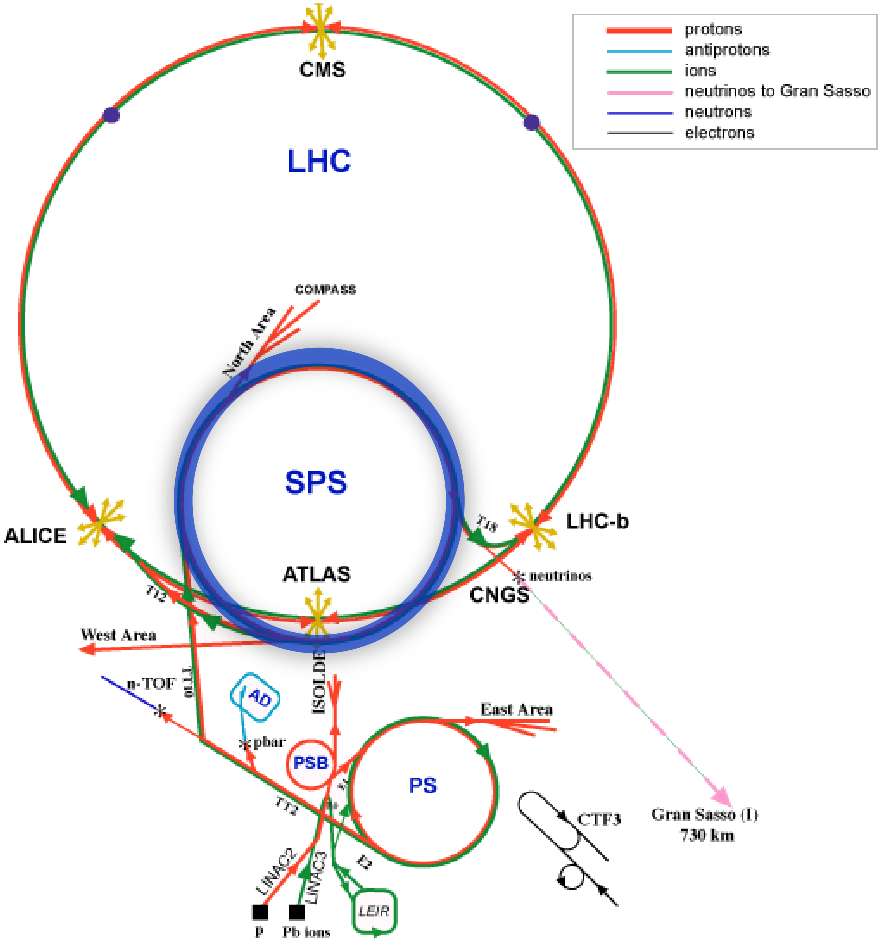
Conclusions

INTRODUCTION

For the Large Hadron Collider to work at his design luminosity, the Super Proton Syncrotron (SPS) must be able to feed him with proton beams 25 ns spaced bunches accelerated at 450 GeV.

With the actual configuration of the machine, this beam induces Electron Multipacting (EM), causing emmitance blow up and beam losses.

CERN accelerators complex



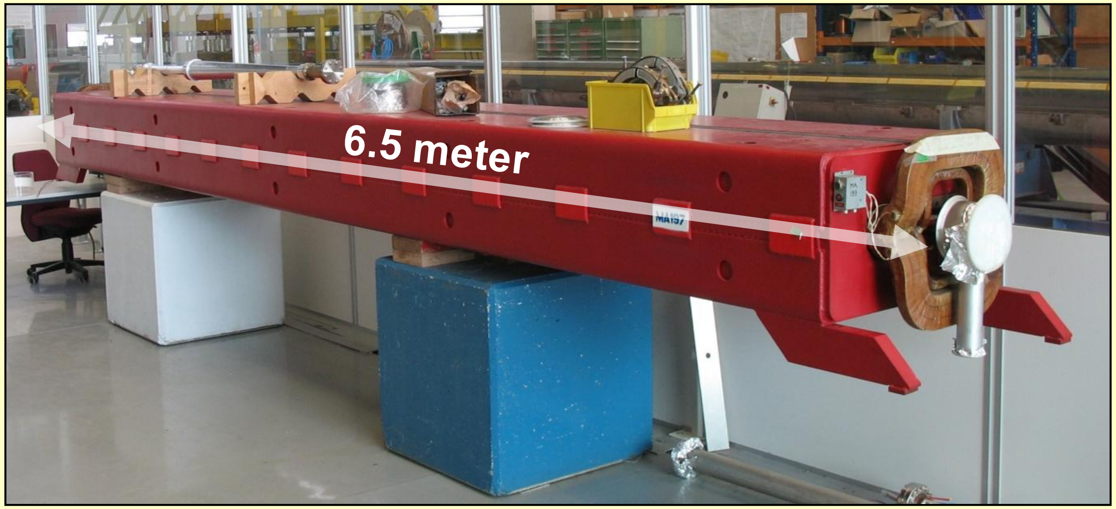
One way to mitigate EM is to coat the internal walls of the beampipes with a material having a maximal Secondary Electron Yield (SEY), below 1.3. ($\delta_{max} < 1.3$)

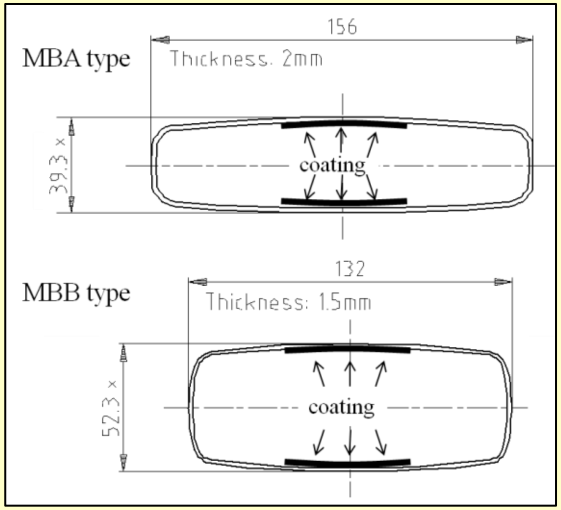
Carbon was chosen because of low SEY of graphite (~1.0) and low chemical reactivity

INTRODUCTION

Almost 5 km of the SPS are filled with MBB and MBA type dipoles (>700).

The length of each dipole is 6.5 m and weights ~18 tons.





The beampipes are embedded in the yoke.

coat new beampipes, open the dipole, insert beampipe, close the dipole.

Easy to coat

Too expensive (open/close dipole)

coat the actual beampipes directly in the dipole.

Easy to coat

cheaper

COATING TECHNIQUES

coat new beampipes, open the dipole, insert beampipe, close the dipole.

→ DC Cylindrical Magnetron Sputtering (DCCMS)

coat the actual beampipes directly in the dipole.

→ DC Planar Magnetron Sputtering (DCPMS) using the dipoles field

DC Planar Magnetron Sputtering (DCPMS) using Permanent Magnets

Plasma Enhanced Chemical Vapor Deposition (PECVD) from C_2H_2

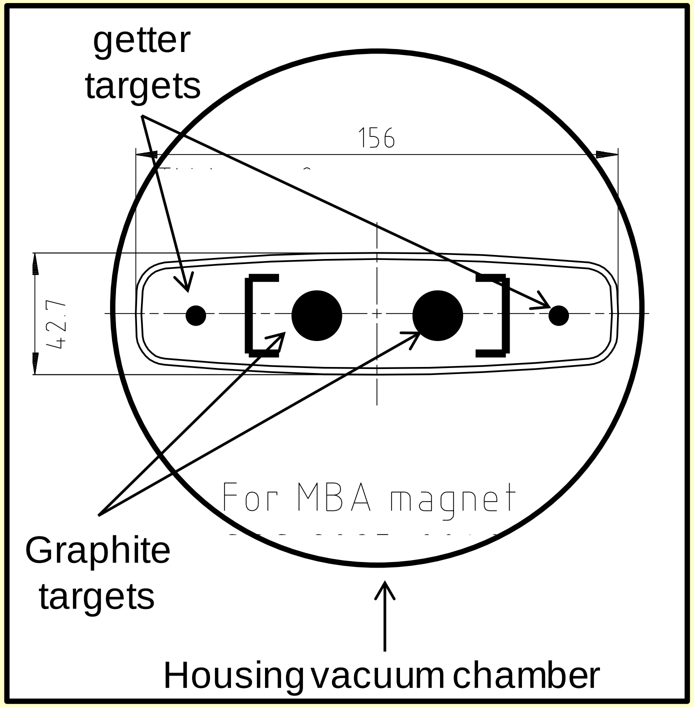
DC Hollow Cathode Sputtering (DCHCS)

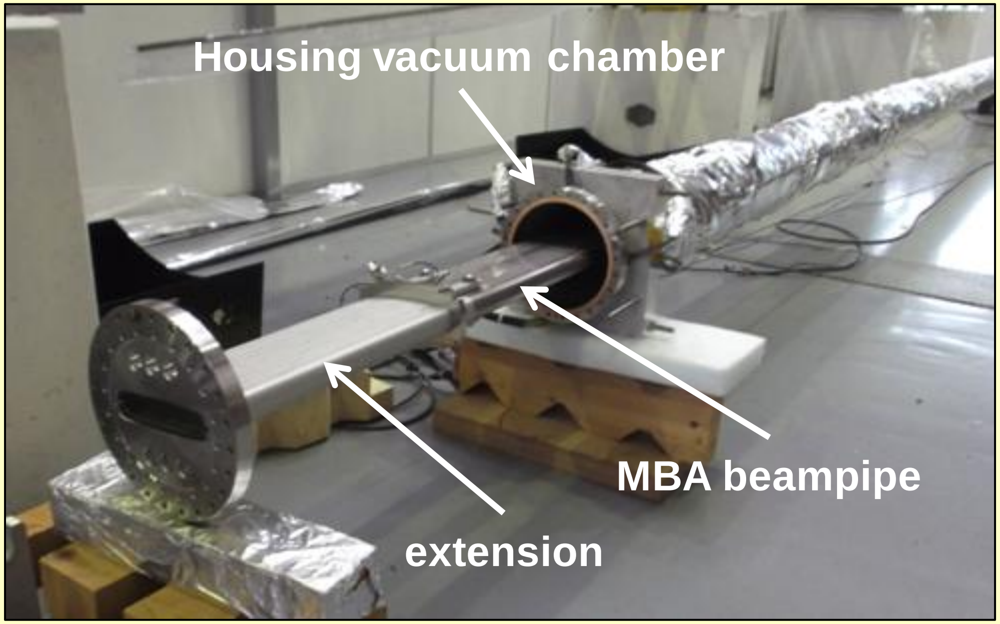
The sputtering techniques all give carbon coatings with δ_{max} ~ 1.

PECVD give carbon coatings with δ_{max} ~ 1.5.

COATING TECHNIQUES - DCCMS

Coat new beampipes by DC Cylindrical Magnetron Sputtering (DCCMS)





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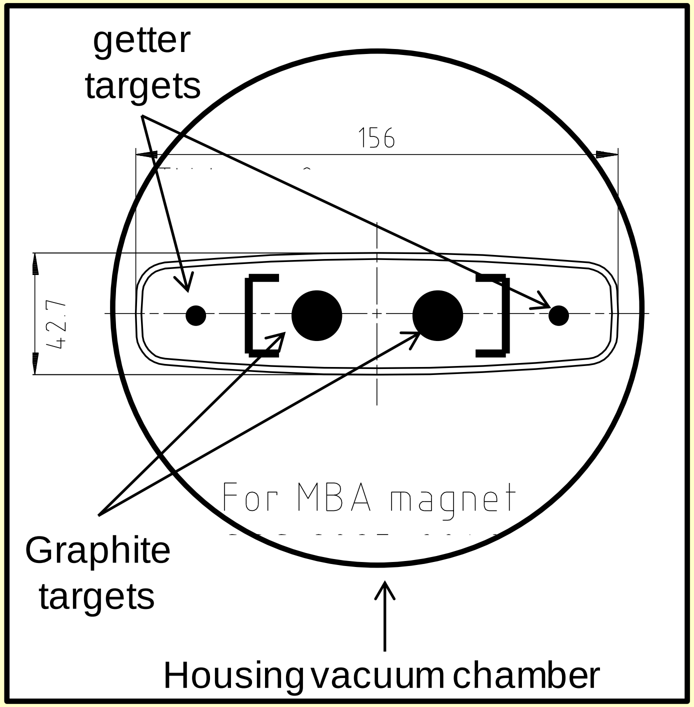

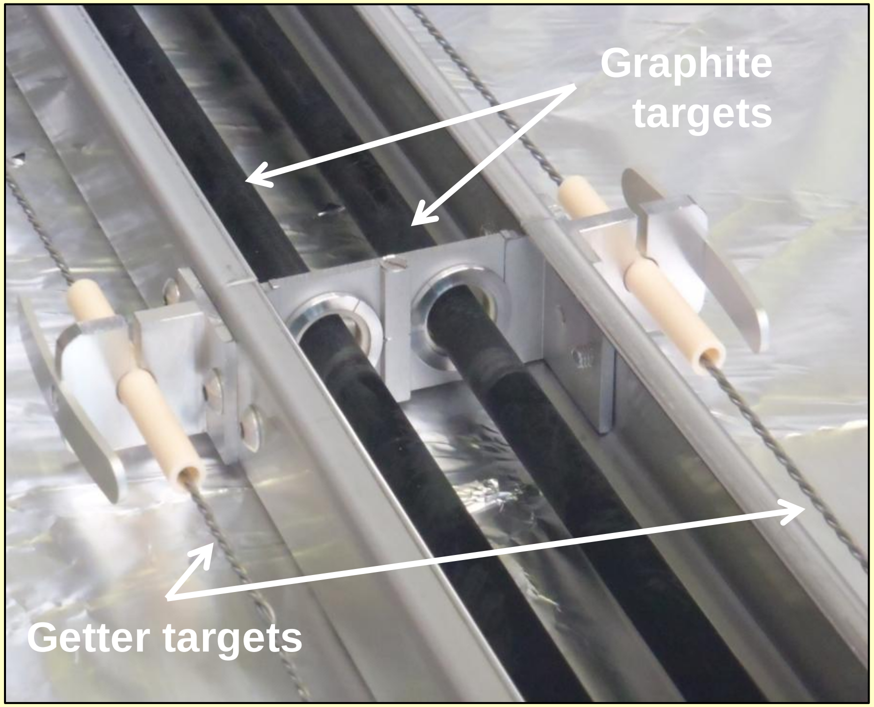

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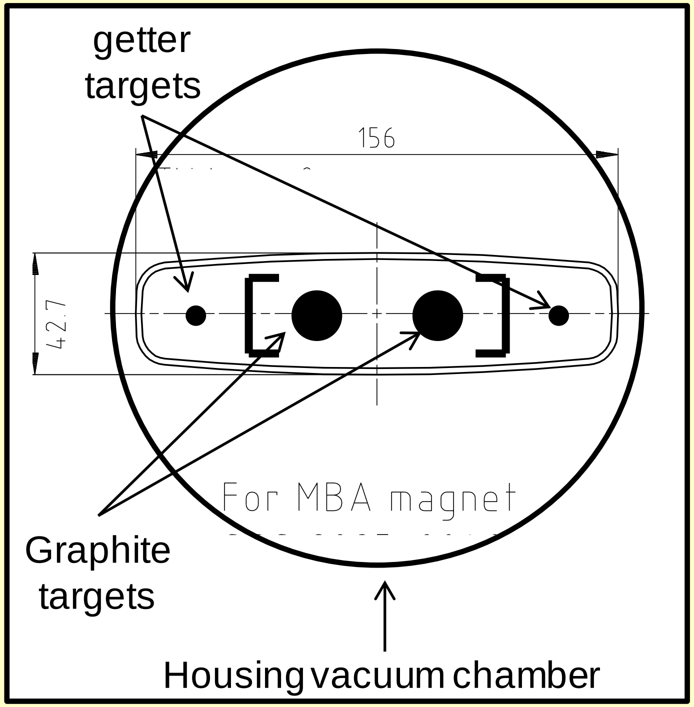

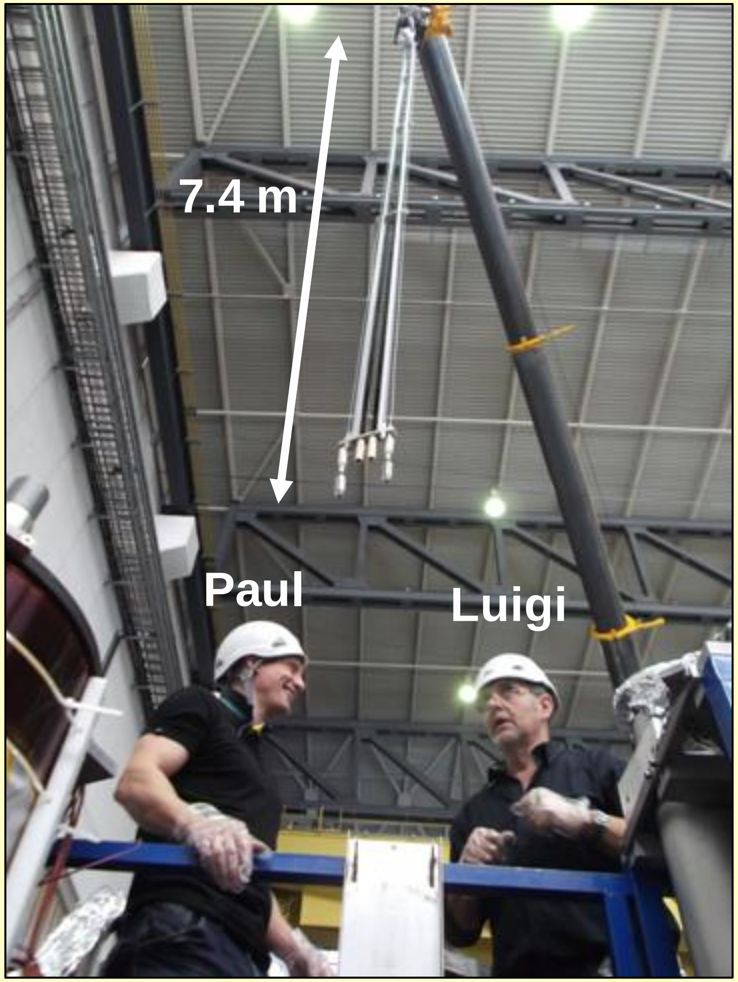

COATING TECHNIQUES - DCCMS

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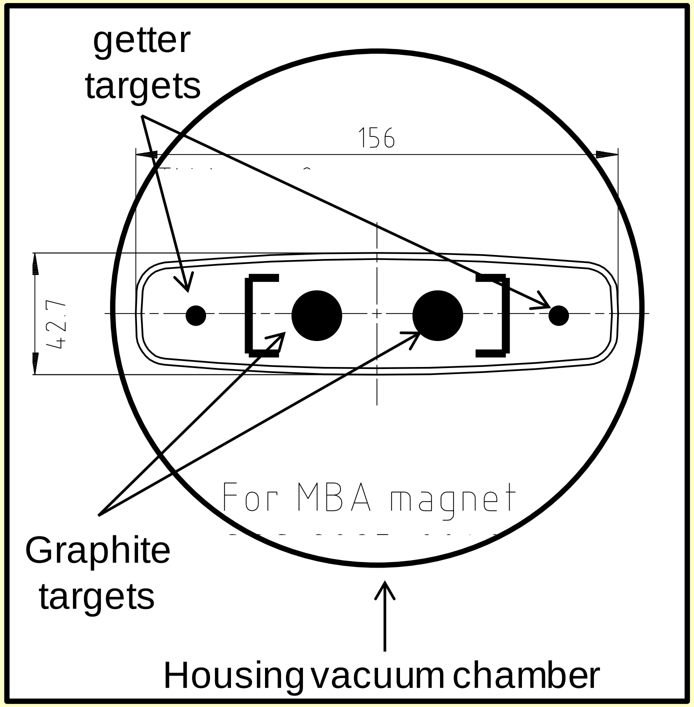
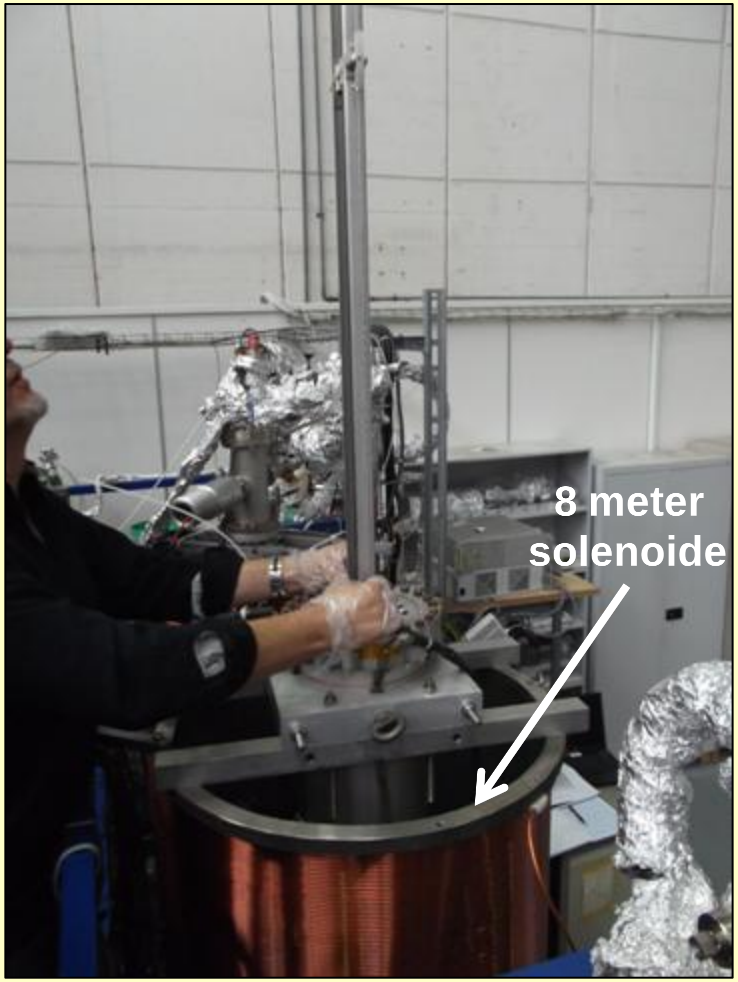
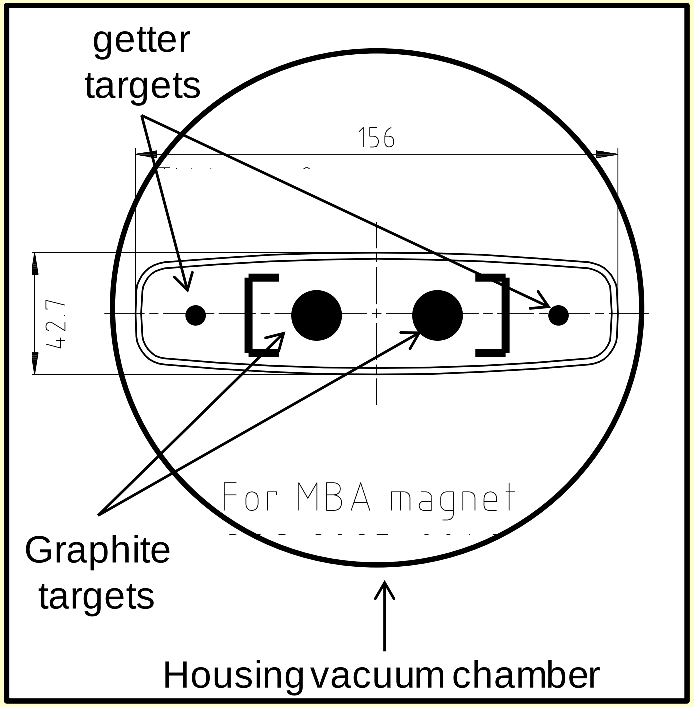


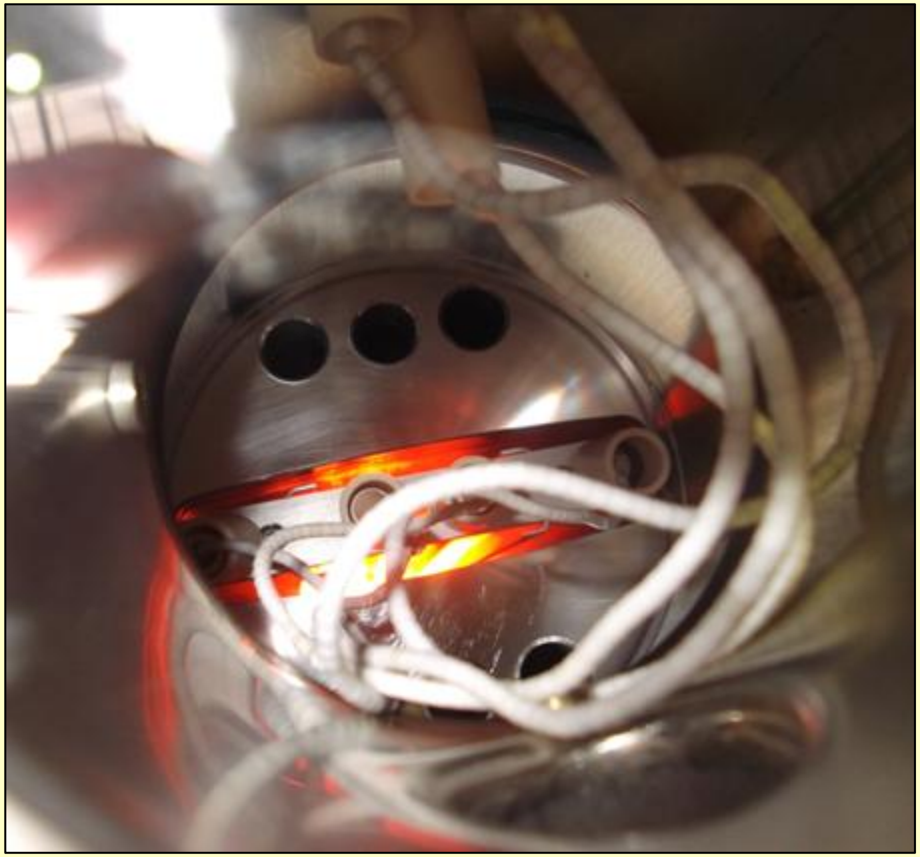


COATING TECHNIQUES - DCCMS

Vacuum Surfaces & Coatings

Coat new beampipes by DC Cylindrical Magnetron Sputtering (DCCMS)





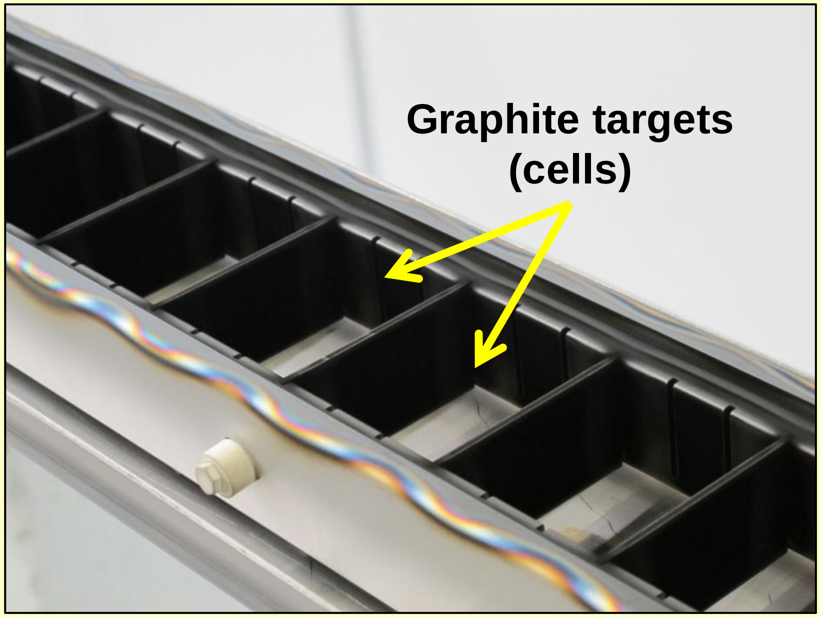
Pressure: 1.2x10^{-1} mbar (Ne)
Power: 1.8 kW (3A @ 600 V)
B: 180 Gauss

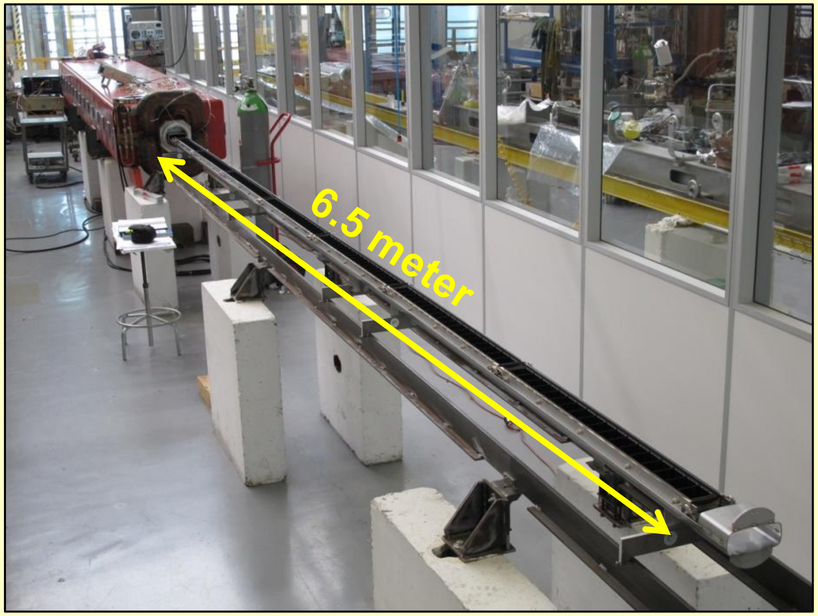
→ ***0.5 μm in 8 hours***

THE TECHNIQUE IS MATURE FOR LARGE SCALE PRODUCTION

COATING TECHNIQUES - DCHCS

Coat actual beampipes by DC Hollow Cathode Sputtering (DCHCS)





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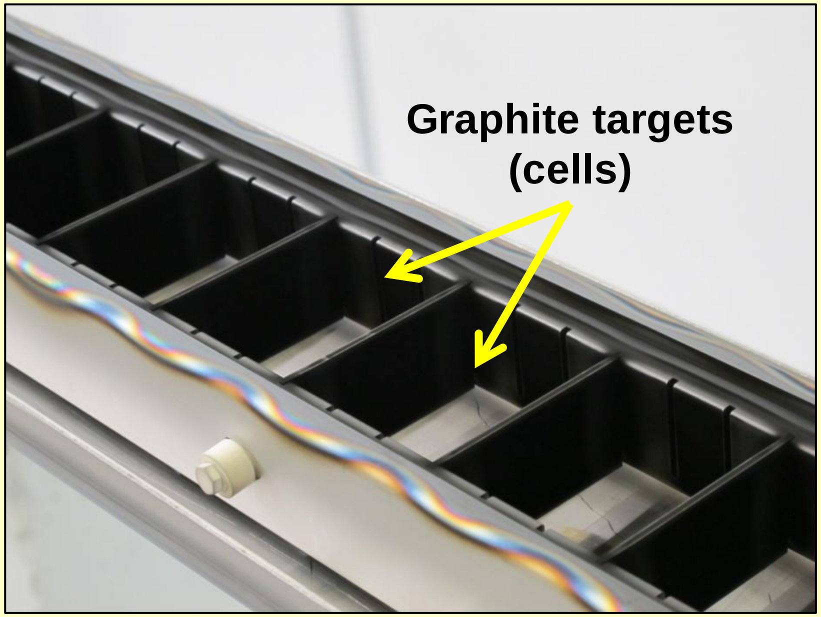

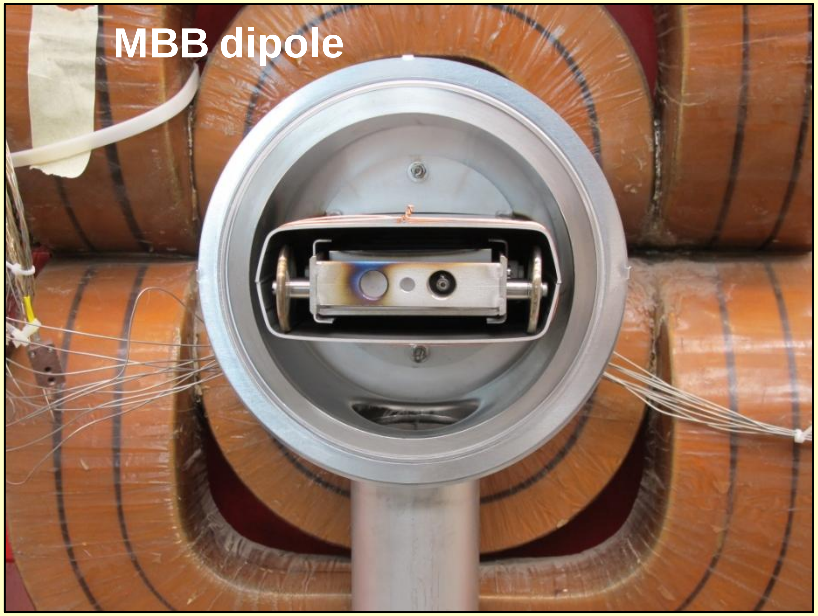

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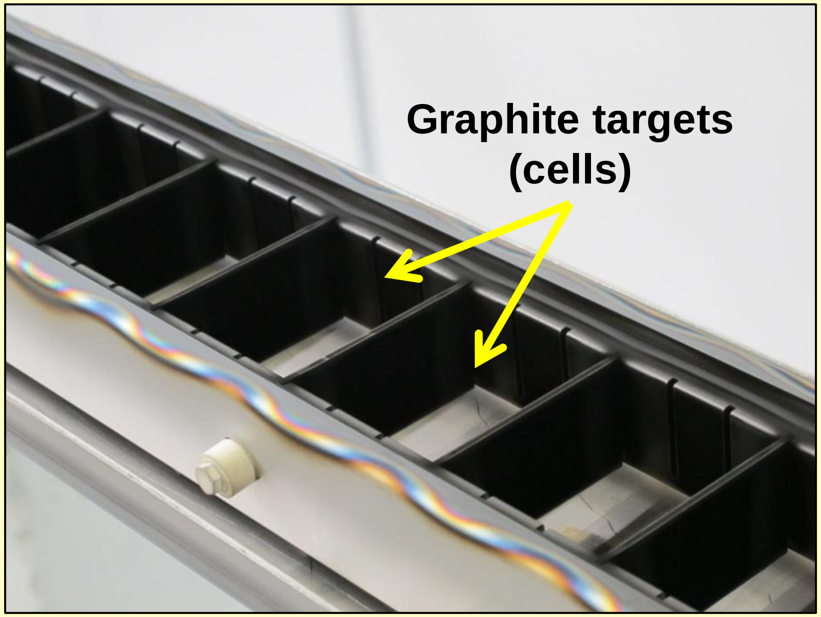
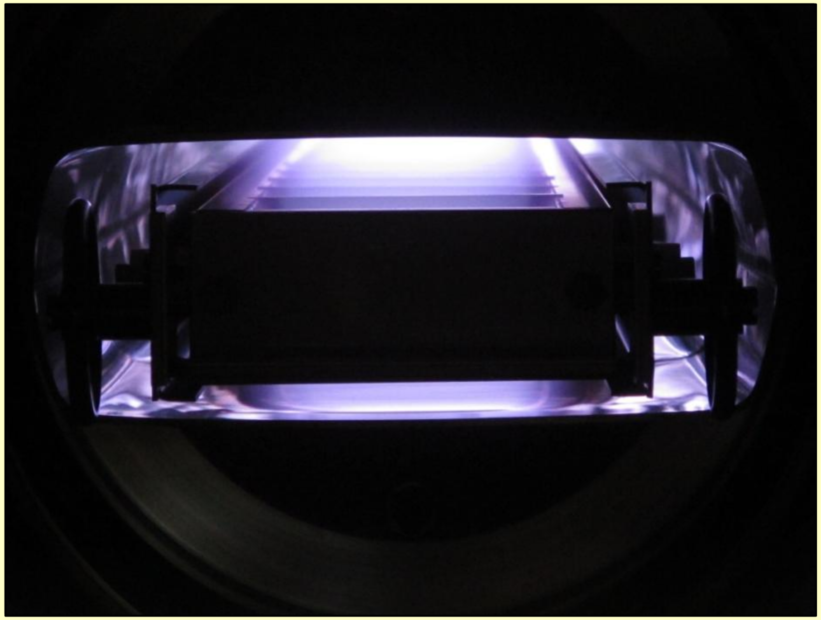




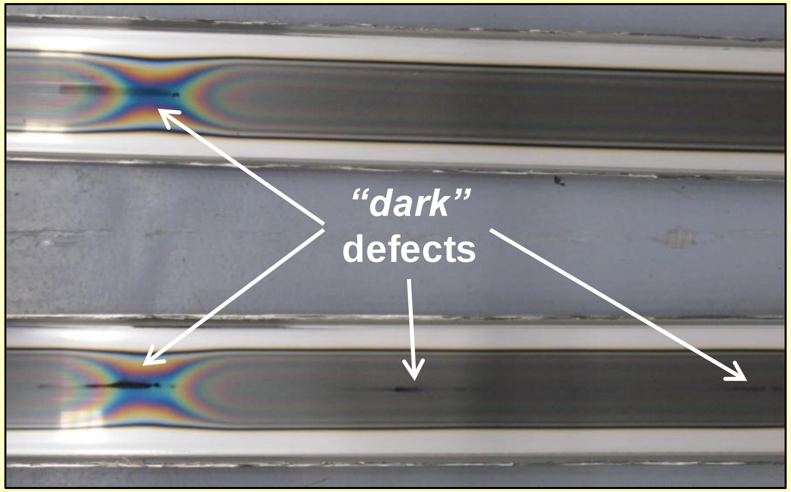
Pressure: 2.4 x10^{-1} mbar (Ar)
Power: 1.8 kW (3A @ 600 V)
0.5 μm in 20 hours

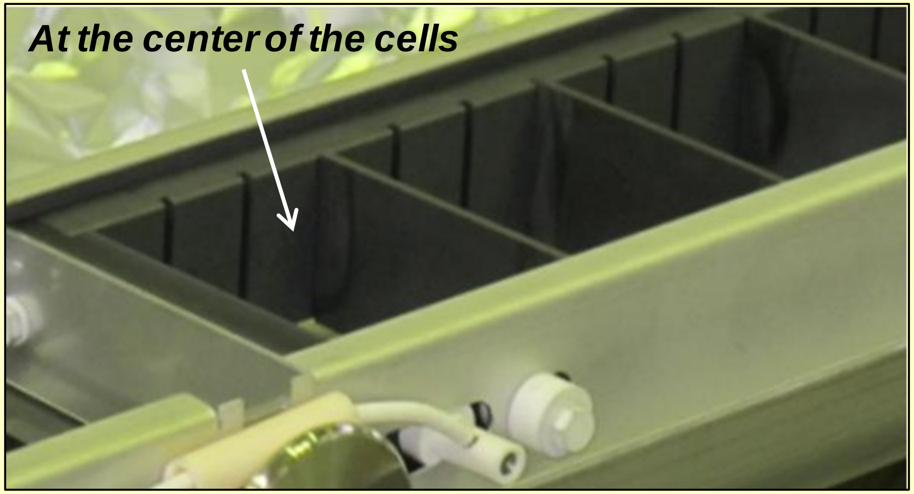
THE TECHNIQUE IS <u>ALMOST</u> MATURE FOR LARGE SCALE PRODUCTION

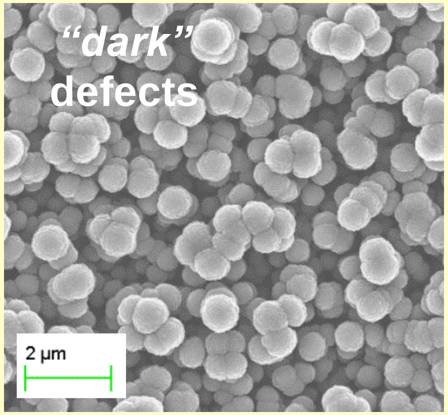
Vacuum Surfaces & Coatings

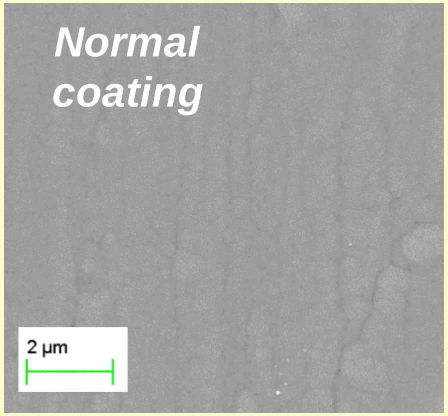
Why *almost*?

Some "dark" defects appear along the central line of the chamber









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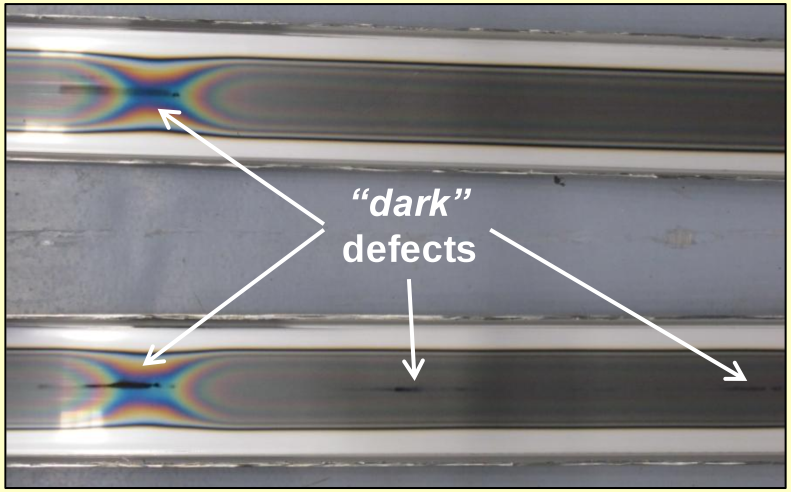
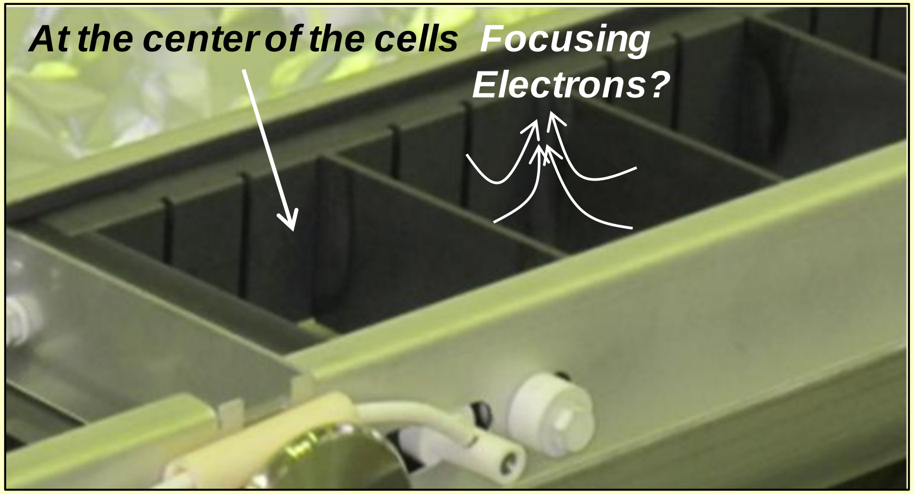


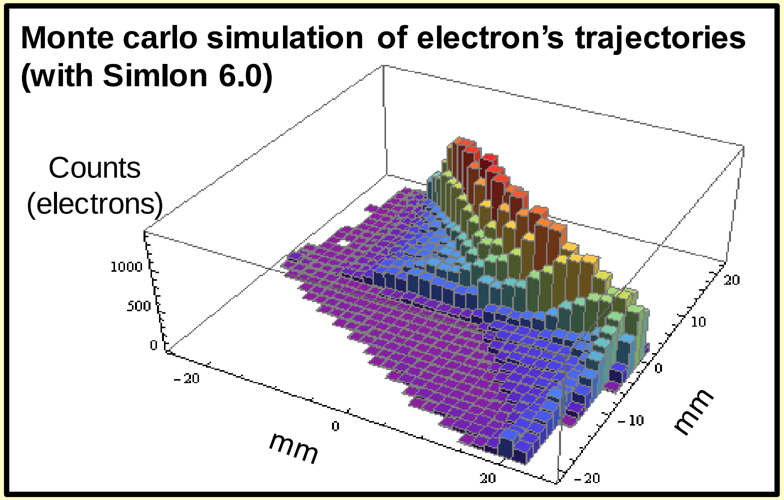


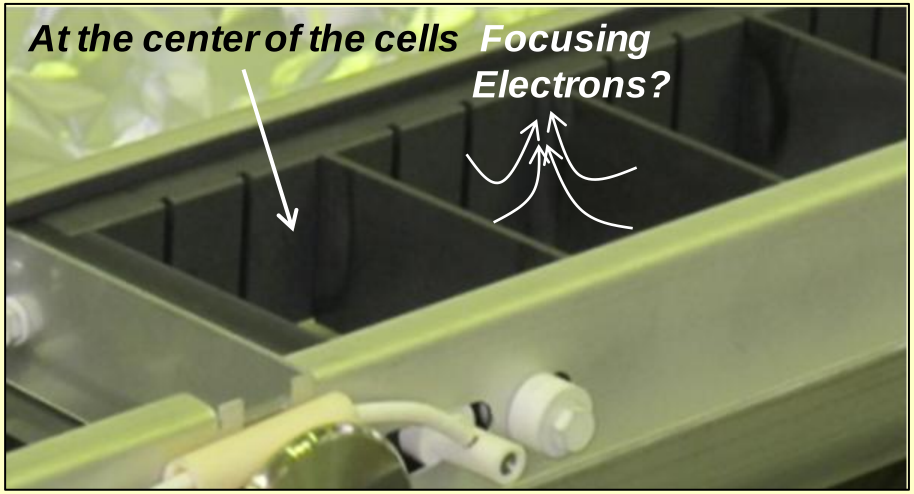
Electrons focused into the center of the cells → Increase ion density near the substrate → Low energy ion bombardment → Structure modification (equivalent to temperature)

COATING TECHNIQUES - DCHCS

Why *almost*?

Some "dark" defects appear along the central line of the chamber





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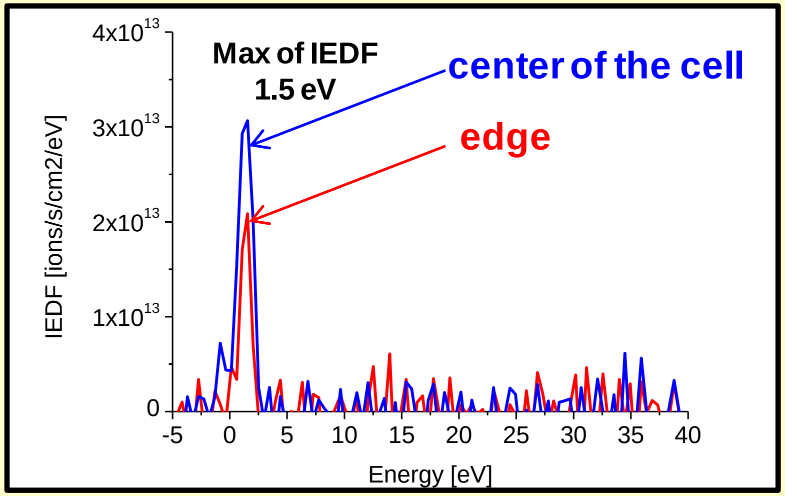
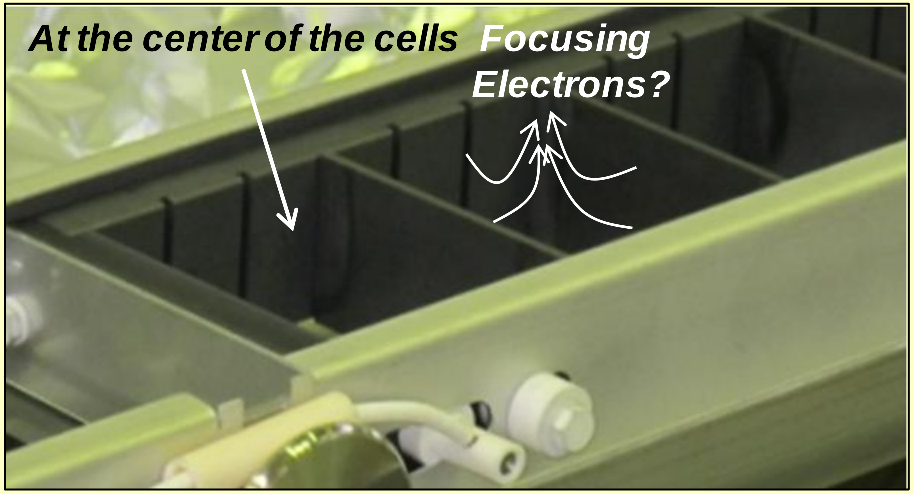
Ions Energy Distribution Function (measured with RFEA)





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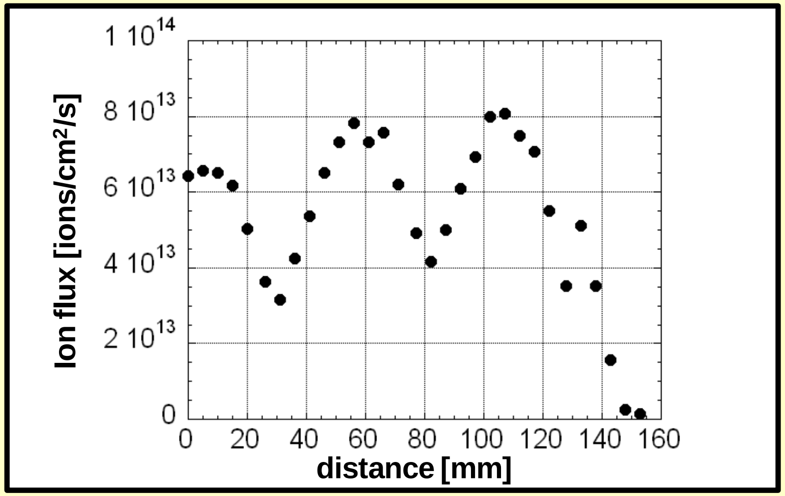
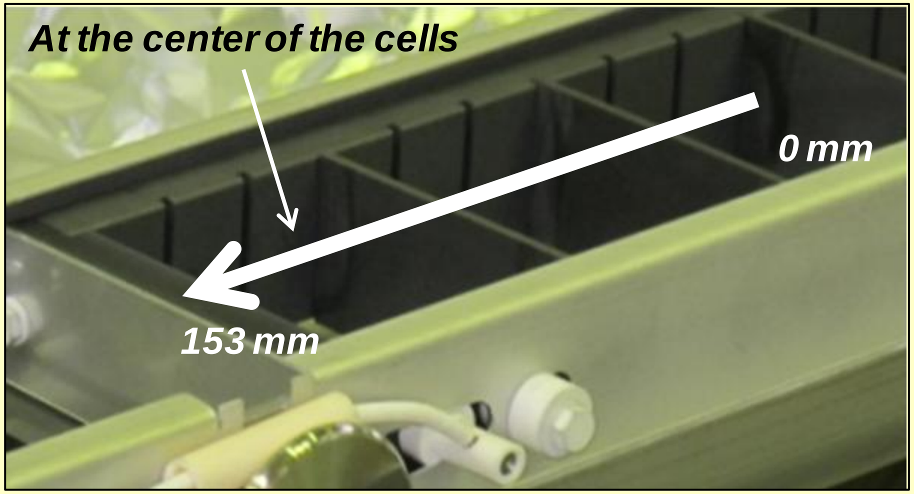
Ion flux along the cells





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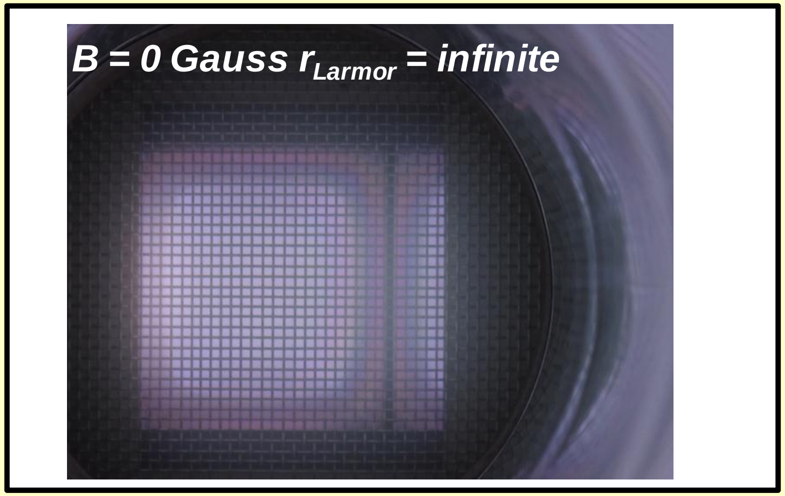
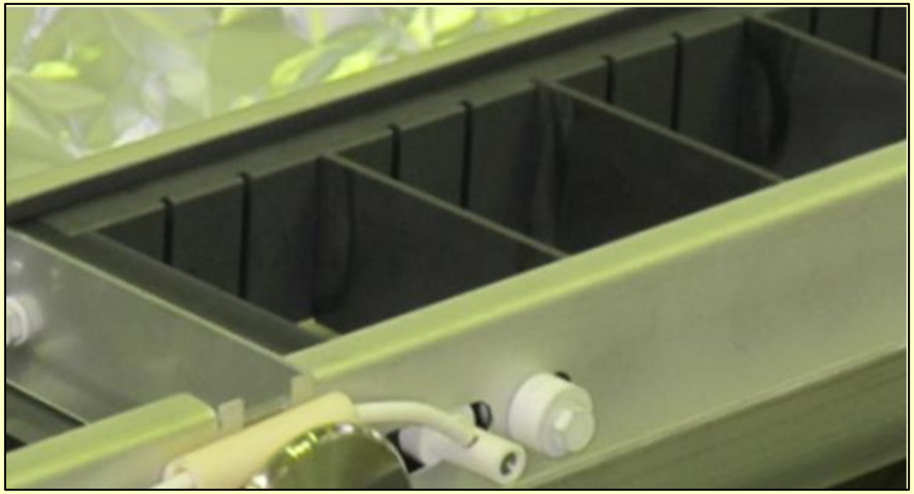
How to solve the problem?

Use the dipole's magnetic field to avoid the electrons to reach the center of the cell: Larmor radius << 25 mm (half cell)

Tests in 25cm prototype





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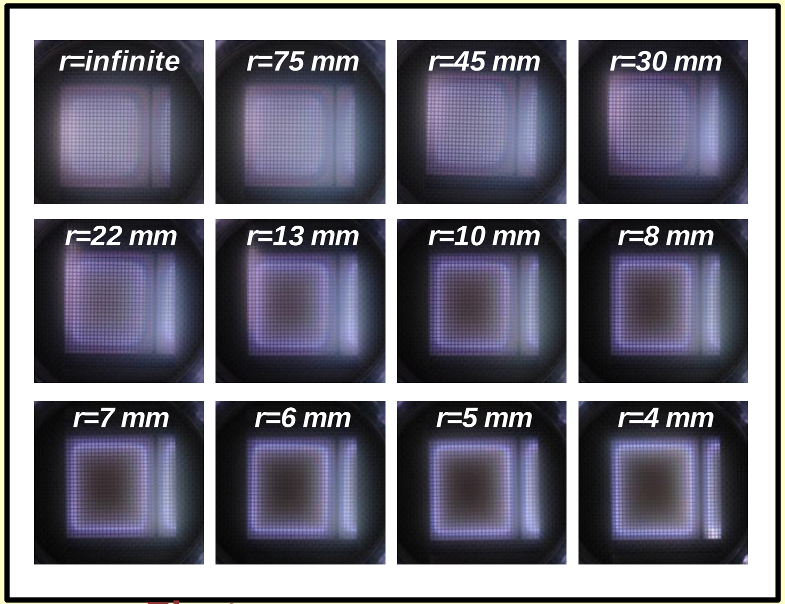
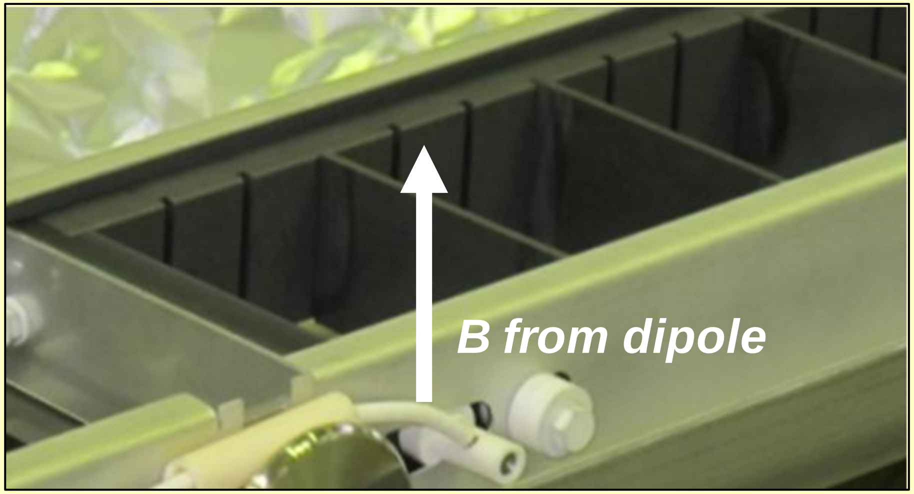


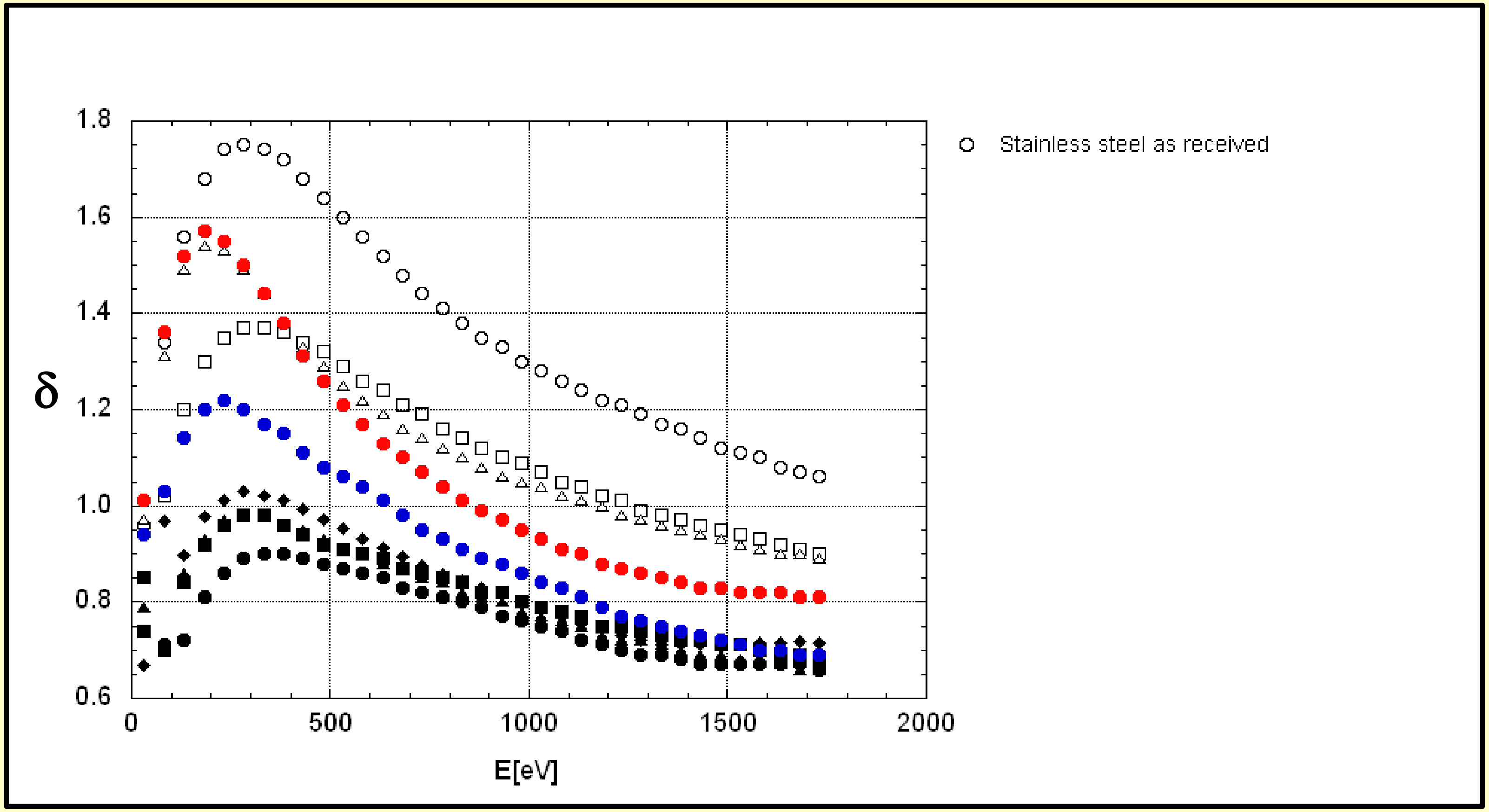


Electrons focused into the center of the cells → Increase ion density near the substrate → Low energy ion bombardment → Structure modification (equivalent to temperature)

Next steps: check if ion flux distribution follows; apply this to coat a real dipole

RESULTS – Lab - SEY

SEY versus the energy of primary electrons



RESULTS – Lab - SEY

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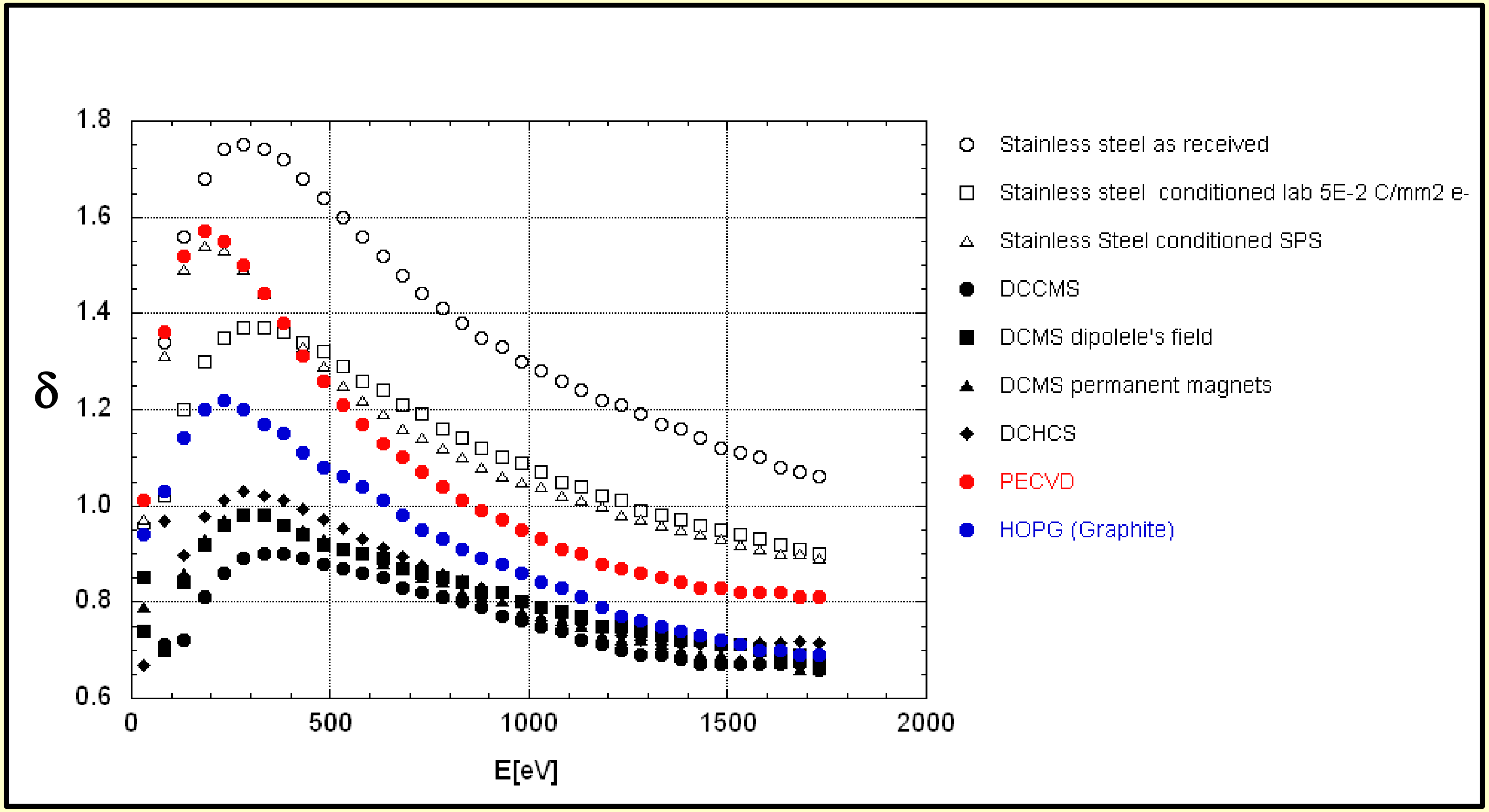
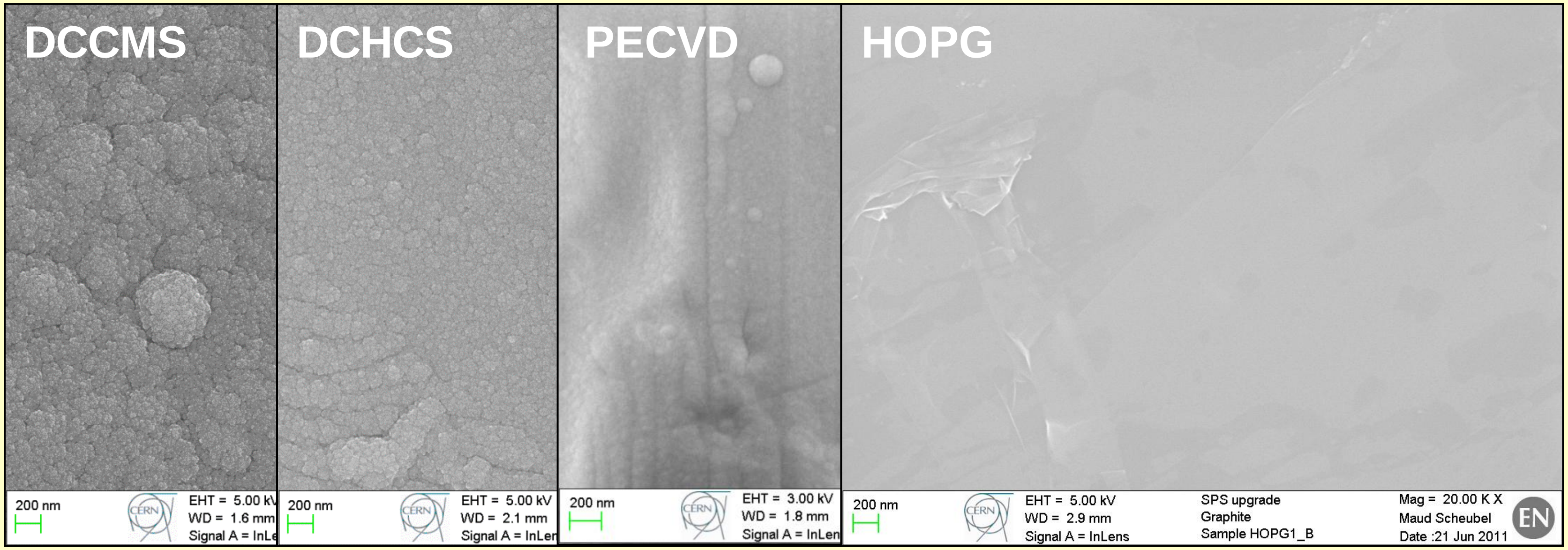


Coatings obtained by sputtering are similar

PECVD coatings have high SEY

RESULTS – Lab - Morphology

Coatings morphology

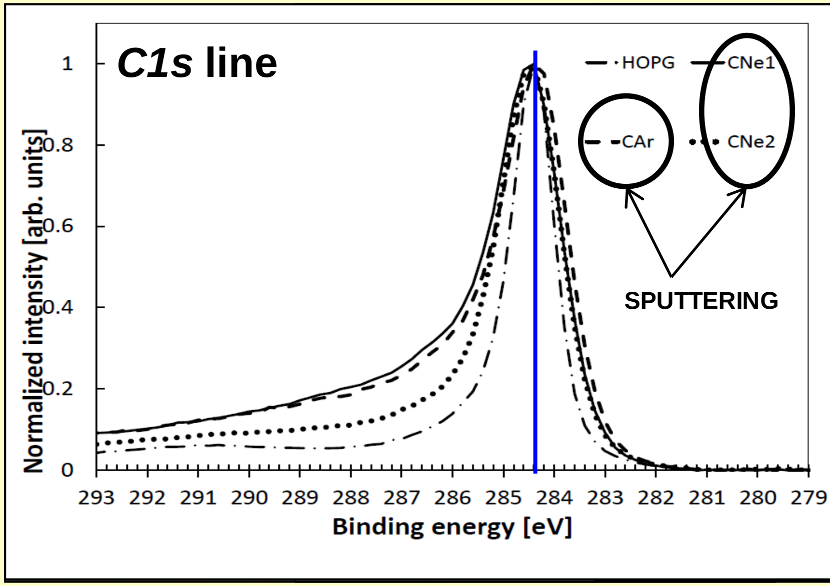


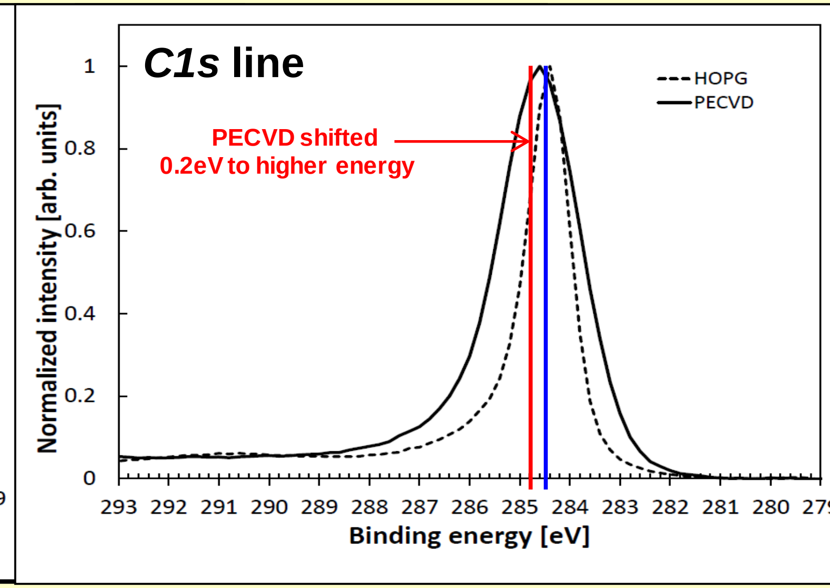
Roughness could explain the lower δ_{max} of sputtered coatings relative to HOPG

But not the high δ_{max} of PECVD coatings

Vacuum Surfaces & Coatings

XPS analysis





Sputtered coatings and HOPG have the maxima at 284.4 eV => typical of graphite, sp^2 bonds

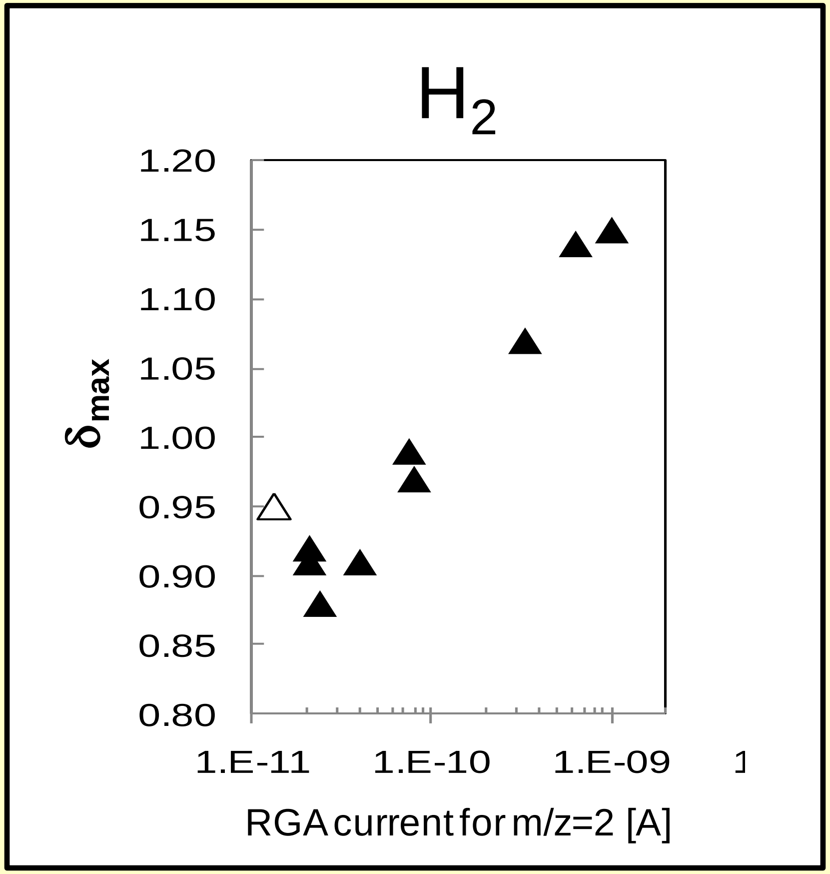
PECVD coatings have the maxima shifted by 0.2eV to high binding energies => the fraction of sp^3 bonds start to be important => more *"diamond like"*

Hydrogen in carbon coatings favors sp^3 bonds *[28] J. Robertson, Material Science and Engineering R37 (2002) 129-281.*

As hydrogen is inherent to the PECVD process (precursor is C_2H_2), this technique was discarded for low SEY coatings.

RESULTS – Lab - Hydrogen

Max SEY (δ_{max}) versus hydrogen in the plasma during the coating by sputtering



The influence of Hydrogen in sputtered coatings is confirmed by experiments where H_2 is deliberately injected during the coating process

RESULTS – Lab - Ageing

Vacuum Surfaces & Coatings

Max SEY (δ_{max}) versus time and storage conditions

C. Yin Vallgren *et al*
CERN, Geneva, Switzerland

Proceedings of IPAC2011, San Sebastián, Spain

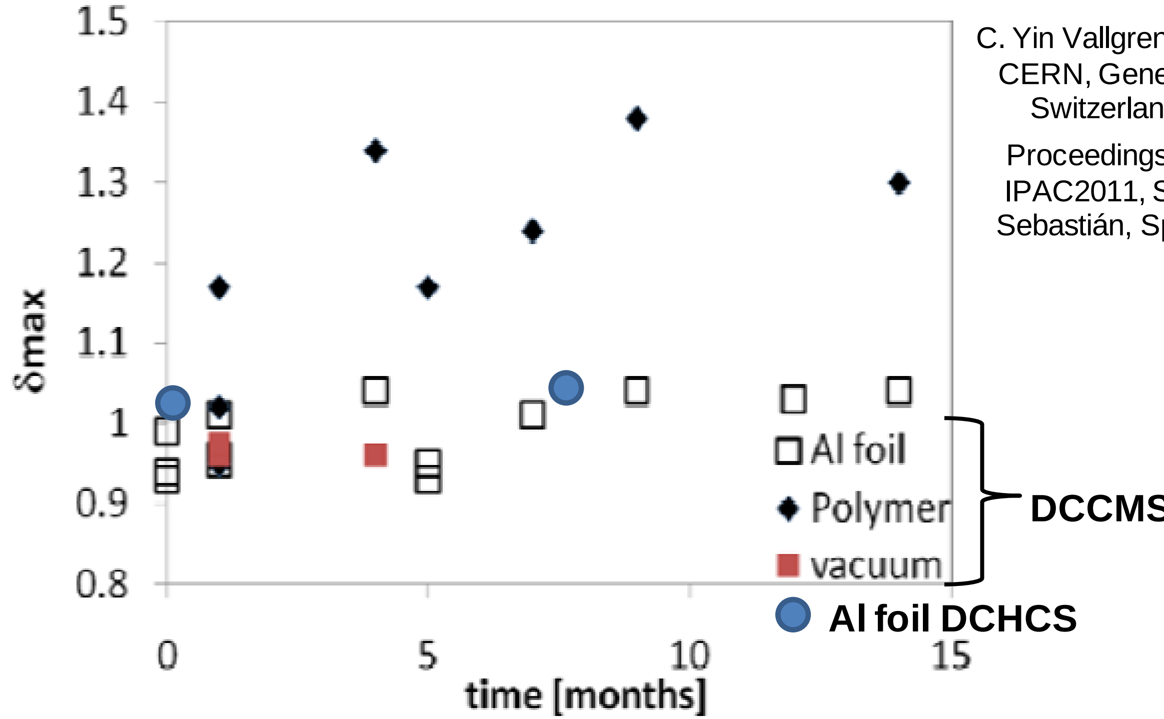


Figure 4: Change of the SEY as a function of time and storage.

Simple storage, (Al foil, flanges, etc.), is enough to prevent ageing in air.

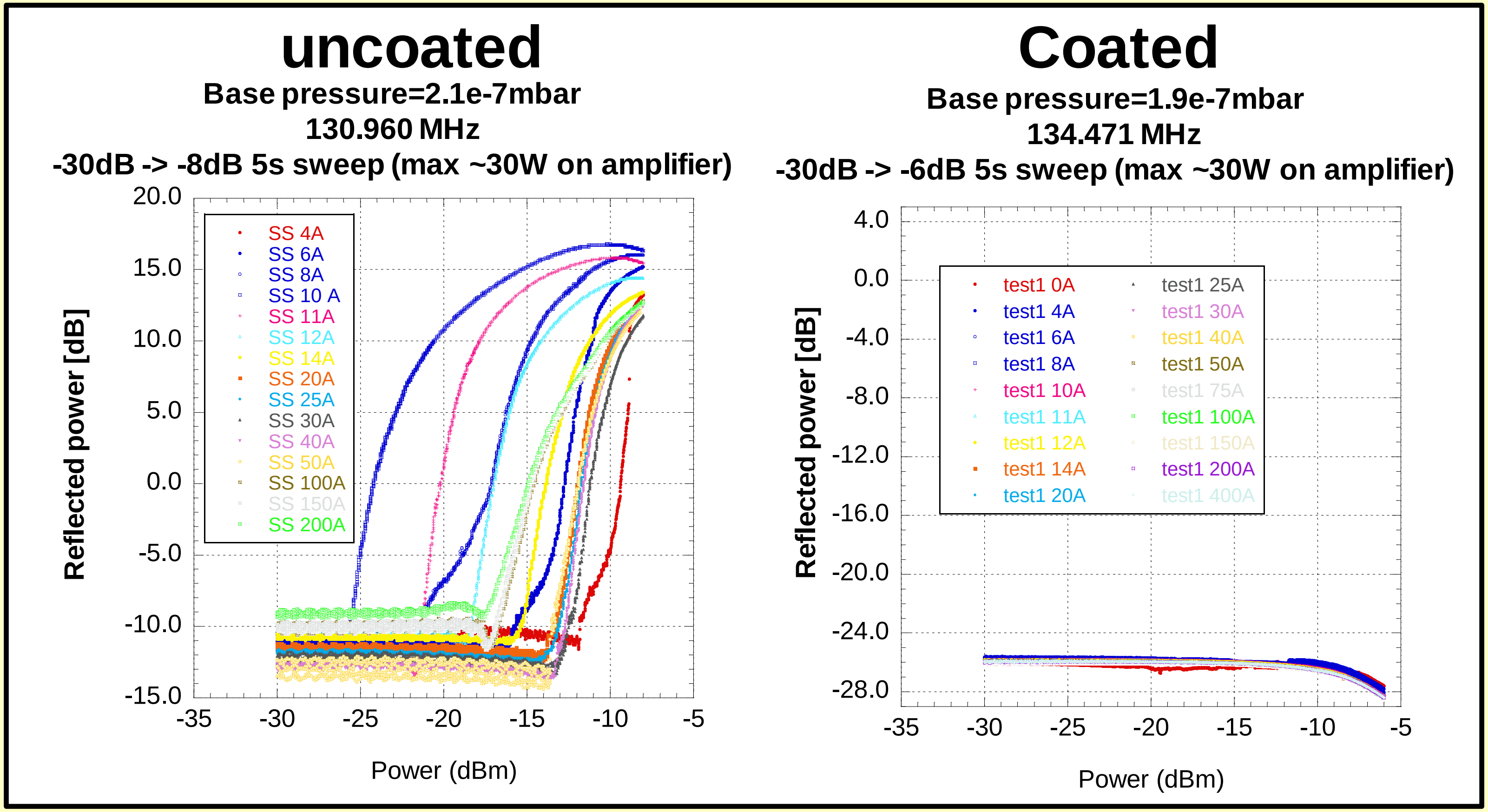
Ageing not yet understood… but mastered!

RESULTS – Lab - Multipactor

Vacuum Surfaces & Coatings

Tests in the "Multipactor" system

(see Fritz Caspers talk (79) this afternoon)



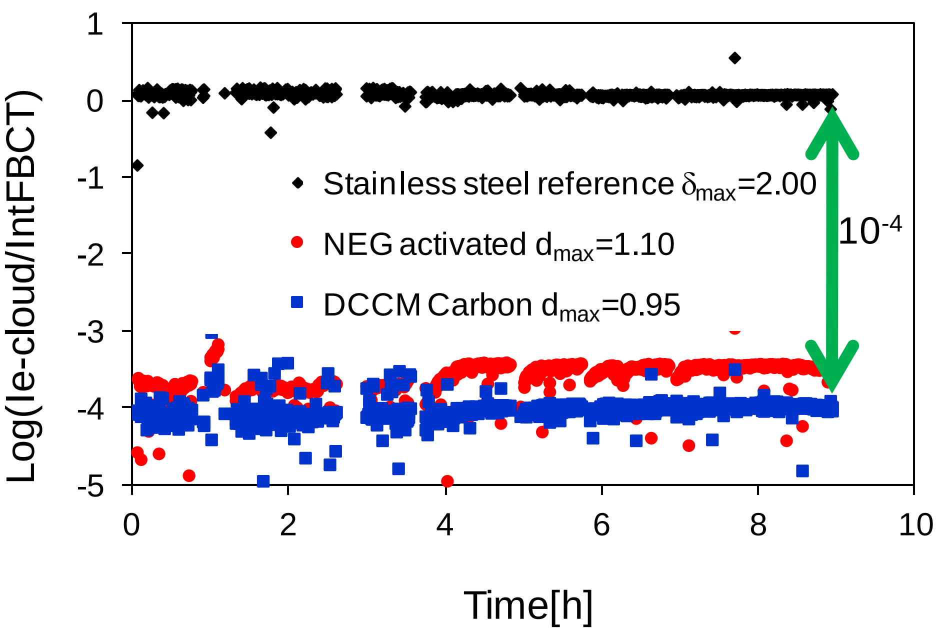
Uncoated dipoles present strong multipacting, dependent of the magnetic field (cyclotron resonnance)

Coated dipoles shows no multipacting

RESULTS – SPS – ECM

Results from Electron Cloud Monitors 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



Ageing in the SPS

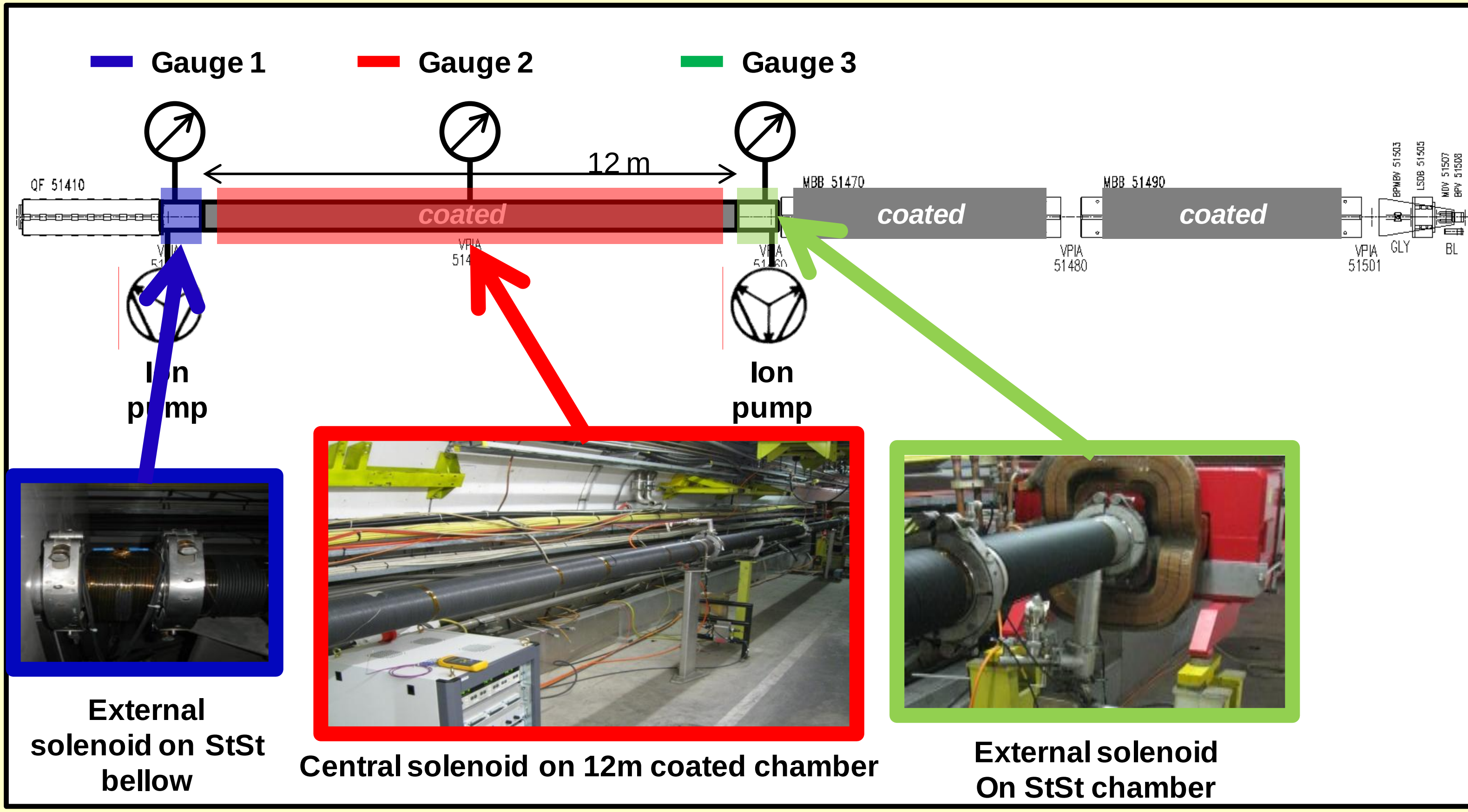
Liner	Time in SPS	δ_{max} initial	δ_{max} extracted
StSt (Ref)	1 year (5 MD runs)	2.25	1.72
C-strip (40mm)	1 year (5 MD runs)	0.92	0.97
C-Zr	1.5 years (9 MD runs)	0.95	0.99
CNe64	3 months (2 MD runs)	0.95	0.97
CNe65	3 months (2 MD runs)	0.95	0.97

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

Negligible ageing
(accuracy of SEY measuremets +/- 0.03)

RESULTS – SPS – Pressure

Dynamic pressure measurements in a drift zone of the SPS



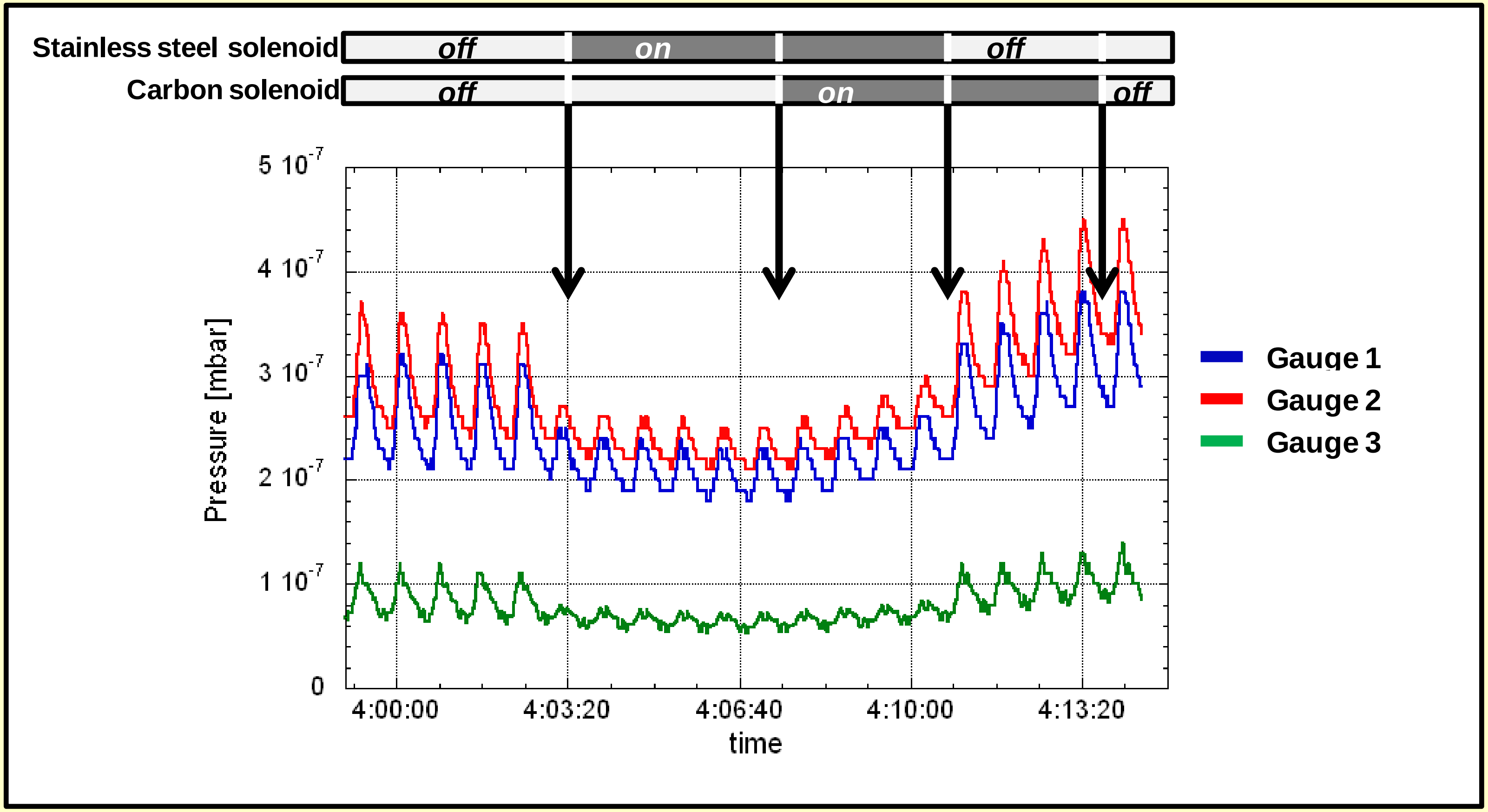
External solenoid on StSt bellow

Central solenoid on 12m coated chamber

External solenoid On StSt chamber

RESULTS – SPS – Pressure

Dynamic pressure measurements in a drift zone of the SPS



Solenoid in carbon coated chamber has no effect in pressure
=> NO E-CLOUD

Conclusions

1 – Sputtered films are better than PECVD. (very likely due to higher sp^2/sp^3 ratio)

2 – H_2 is the key parameter to keep δ_{max}~1.0 in sputtered films.

3 – ageing in air OK: negligible if sample protected(Al foil, flanges, etc.)

4 – ageing in the SPS OK: negligible (ECMs).

5 – ECM in SPS OK: coated liners have 10^4 less multipacting than stainless steel.

6 – Multipactor tests OK: multipacting before coating, no multipacting after coating.

7 – Dynamic pressure tests in SPS OK: effect of solenoid in stainless steel parts, no effect in coated parts.

8 – So far, the sputtered carbon coatings passed all the tests.

9 – DCCMS technique is "ready to go": can be used to coat parts that will not require disassembling/assembling magnets (pumping port shields, quadrupoles, drift tubes, etc)

10 – DCHCS technique is almost ready: need to solve the "dark area" problem and build 6.5 m cathode for MBA. Can be used to coat dipoles (MBB and MBA)

Thank you for your attention