Experimental Study on the Electron Multipacting and Surface Conditioning

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Motivation of the Work

Simulation of the multipacting conditions inside the bending sections of particles accelerators

Outline

- Introduction
- Description of the experimental set-up
- 1^{st} test-bench: the SPS dipoles
  - Multipacting behavior inside MBA & MBB chambers
- 2^{nd} test-bench: the MDHW dipole
  - Multipacting behavior and Surface Conditioning of an MBB profiled liner
- Conclusions

Inside Accelerators

Particles beams produce primary electrons

- Synchrotron radiation
- Collisions with residual gas molecules

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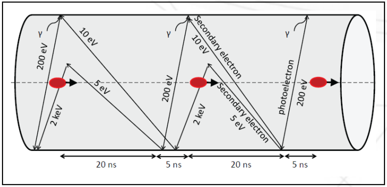
- Synchrotron radiation
- Collisions with residual gas molecules

The self-field of particles beams accelerate the primaries



Multipacting ignition → e-Cloud development

Why it is a problem?

Electrons irradiation of the beam-pipes

EFFECTS:

- Pressure Rise

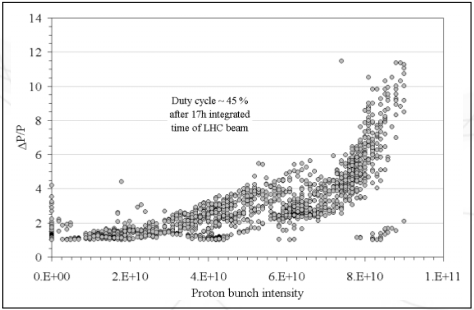


Figure: Arduini, LHC-Project-Report-490

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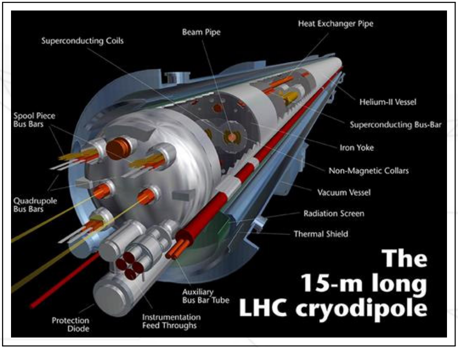
EFFECTS:

- Pressure Rise
- Heat Load

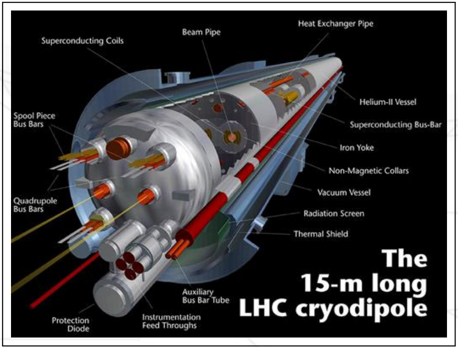


Why it is a problem?

Electrons irradiation of the beam-pipes

EFFECTS:

- Pressure Rise
- Heat Load
- Beam instabilities



Why it is a problem?

Strictly dependent on the beam parameters, the magnetic field and the surfaces SEY (δ)

$$\delta = \frac{i_{emitted}}{i_{primaries}}$$

IT IS A LIMITATION FOR:

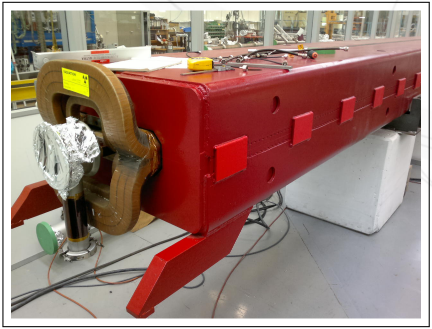
- Luminosity, $L \propto N_b^2 F(\nu)$

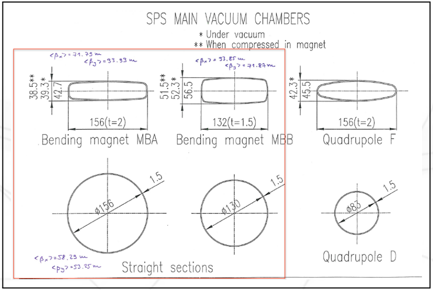
High Luminosity LHC

LHC Injectors Upgrade

SPS Requirement

SPS MBB bending sections $\delta_{max} < 1.3$





Solutions

Reduction of the surface SEY:

Coatings

- NEG
- C-coatings

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Surface Patterning

- Grooved Surface
- Magnetic Roughness

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- Magnetic Roughness

Surface Conditioning

- Beam Scrubbing

Beam Scrubbing

Beam Induced Multipacting → Electron Surface Conditioning

- Electron Stimulated Desorption, surface cleaning
- Surface, Graphitization

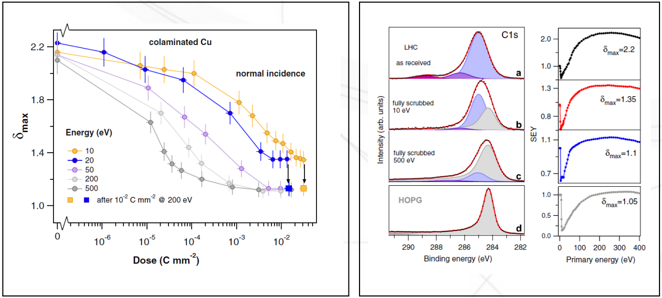
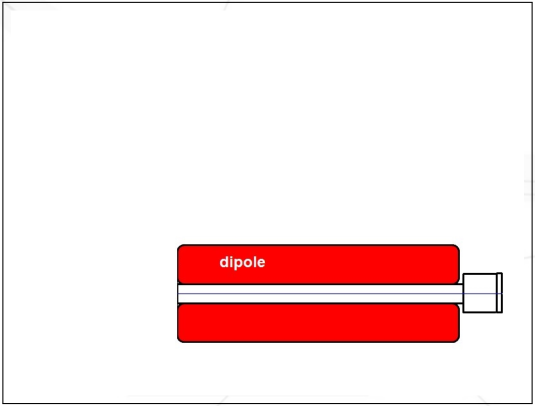


Figure : Cimino et. Al. Phys. Rev. Lett. 109, 064801

The Experimental Set-Up

The test-bench is a coaxial resonator for RF-TE waves



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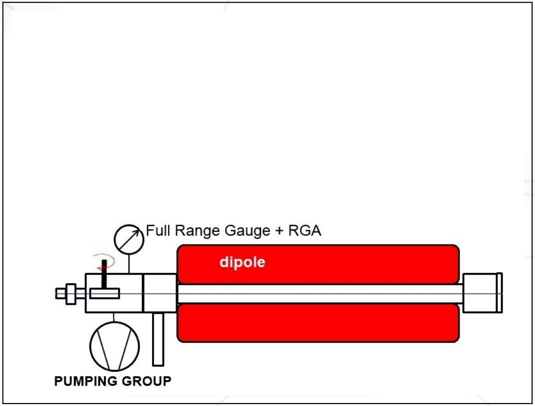

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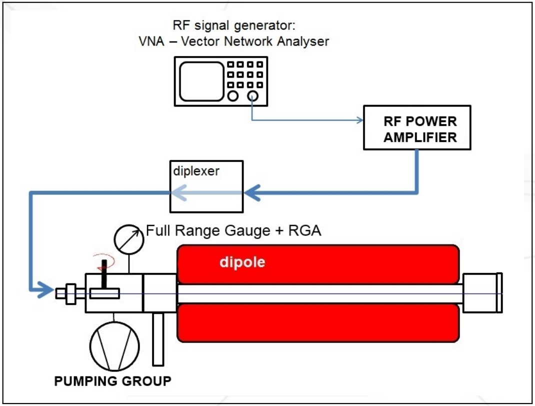

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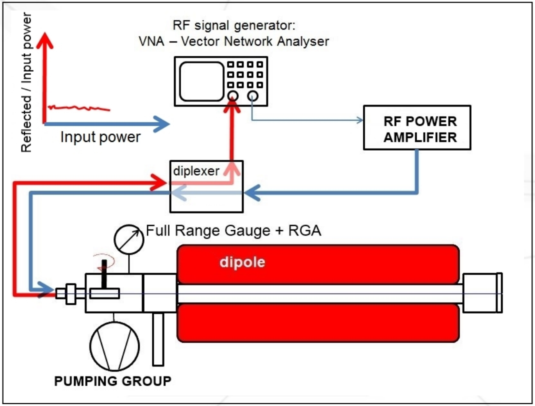

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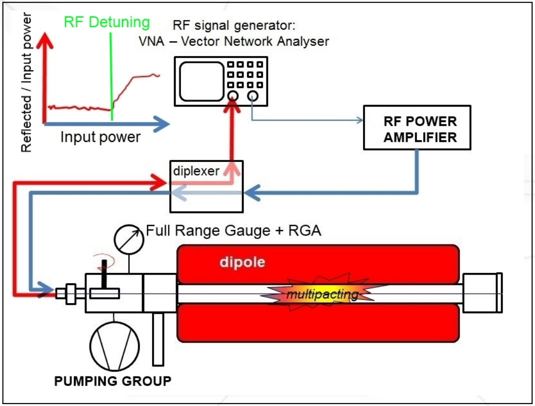


SPS Dipoles Results

Tests on the multipacting behavior of MBA and MBB SPS dipoles chambers
(Unbaked Chambers)

Multipacting detection:

- RF detuning
- ESD pressure peaks

Tests:

- Multipacting at cyclotron resonance
- C coating efficiency

Chambers:

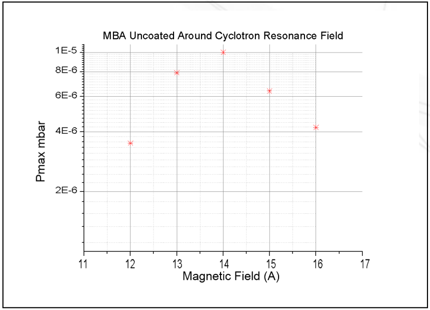
- MBA
- MBB

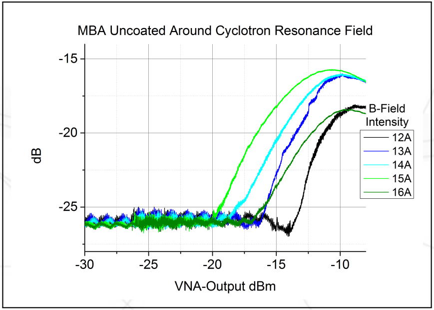
The Dipoles

SPS dipoles + MBA & MBB chambers 6.5m long

MBA Uncoated

Cyclotron Resonance field at 15A → minimum multipacting ignition power





$$P = 6.7E - 7mbar, \; f = 149.0346MHz$$

MBA Coated

Confirmation of the C coatings efficiency in suppressing the multipacting

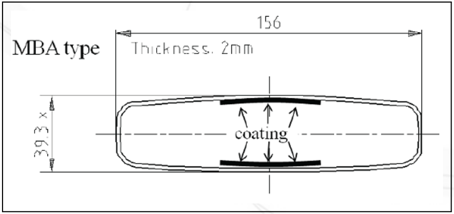


Figure : Which part of the SPS do we need to coat?

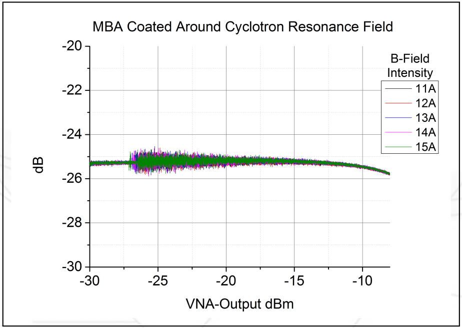
The coating is applied by Hollow Cathode Sputtering along two central strips, where the multipacting is more prone to develop

MBA Coated

No multipacting detected at cyclotron resonance field

ESD

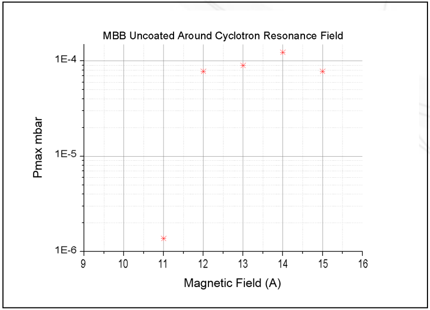
- NO PRESSURE PEAKS

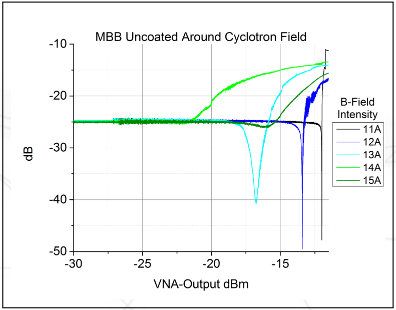


$$P_{system} = 4.3E - 7mbar,\ f = 148.255MHz$$

MBB Uncoated

Cyclotron resonance at 14A
The multipacting is weaker than expected

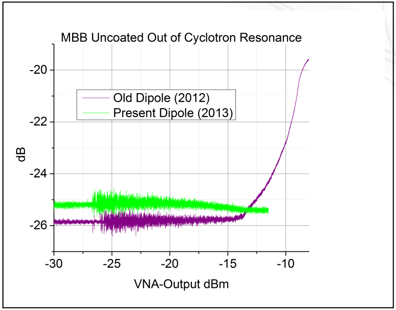


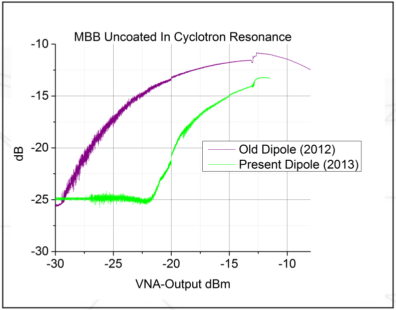


$$P_{system} = 8.1E - 7mbar, \ f = 148.9362MHz$$

MBB Uncoated

MBB geometry is the most prone to develop multipacting
The previous chambers demonstrated stronger e-cloud development





MBB Uncoated

The 2012 MBB dipole was a spare one: no beam exposure
The 2013 MBB dipole came from the SPS machine

Facts:

- 2013 MBB undergone beam conditioning
- 2013 MBB chemically cleaned before the multipacting tests
- Evidences of C residuals even after the cleaning

MBB Coated

Tests performed previously on an MBB coated chamber confirm the efficiency of the a-C in suppressing the multipacting

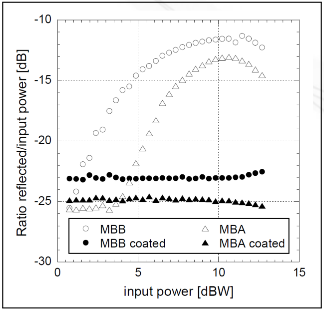


Figure : Comparison of MBB and MBA chambers, 2012.

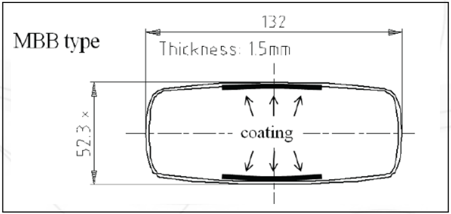


Figure : What part of the SPS do we need to coat?

MDHW Dipole Results

Tests on the multipacting behavior of the MBB profiled liner and its conditioning (Unbaked Chambers)

Multipacting measurements:

- RF detuning
- ESD pressure peaks
- e-Cloud monitor

Tests:

- Influence of the B field intensity
- Conditioning
- Accelerated conditioning
- Effect of the a-C

Chambers:

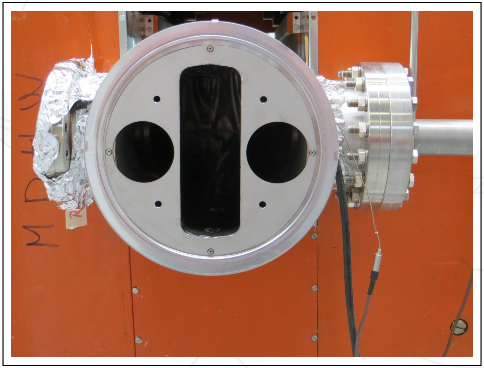
- $StSt$ liner
- C coated liner

The MDHW dipole

$\simeq 1.5m$ cylindrical chamber + MBB shaped liner

Add-ons:

- The electron cloud monitor
- The injection line
  - Leak valve
  - Gas source

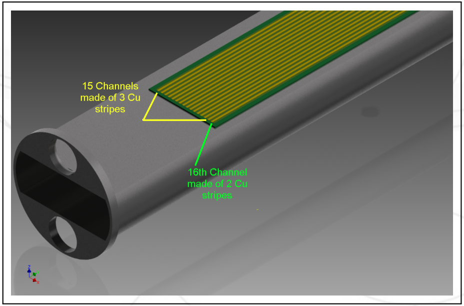


The Electron-Cloud Monitor

Device developed for the studies on the e-cloud inside the SPS
15Channels made of 3 Cu stripes and 1 made of 2

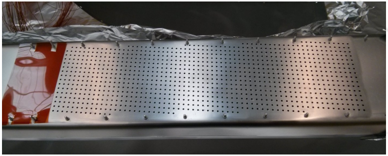
Measure:

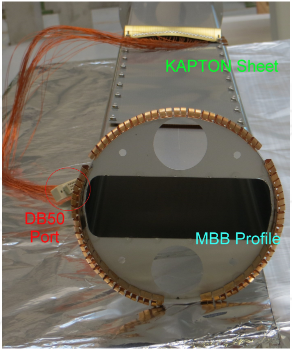
- Multipacting current (mA) $I_{ch}(t)$
- Electron dose (C/mm^2) $D_{monitor} = D_{liner} 7\%$



The Electron-Cloud Monitor

The liner is patterned of holes: total transparency 7%
The monitor has $47Cu$ stripes totally
The Kapton sheet insulates each stripe from the others





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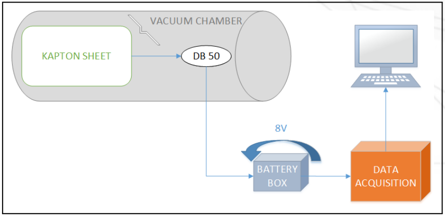
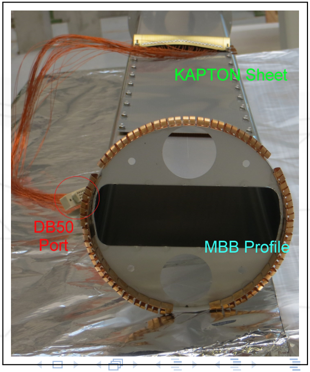
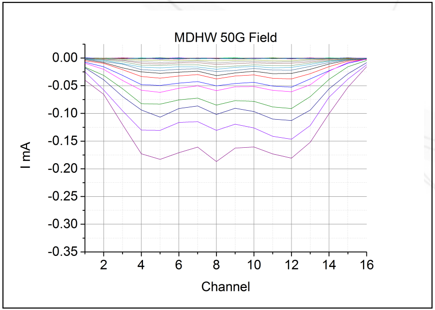
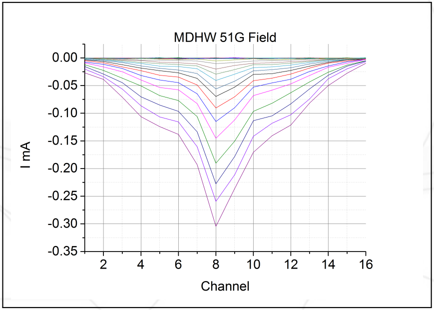




The Magnetic Field Effect

The distribution of the electrons current is affected by the magnetic field intensity, as observed in the SPS





$$f = 142.1343 MHz \rightarrow |B_{cyclotron}| \simeq 50.7G$$

Conditioning Tests

As long as the multipacting is stimulated on a surface, the latter gets conditioned

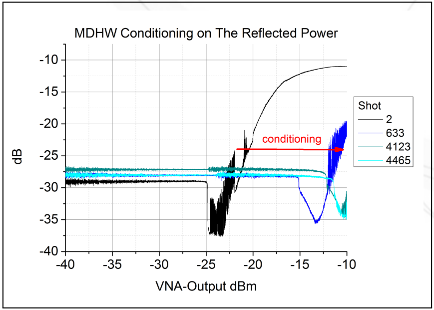
Automatic set-up: multipacting ignition every 120s

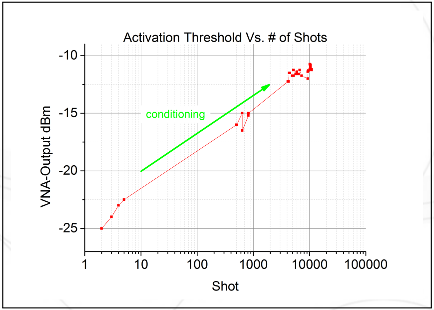
Working Conditions:

- $30s$ power ramps + $90s$ system recover
- $B < B_{cycltron} \rightarrow$ current widespread distribution

StSt liner

$$P = 7.7E - 7mbar,\ f = 142.567MHz,\ B = 49G$$

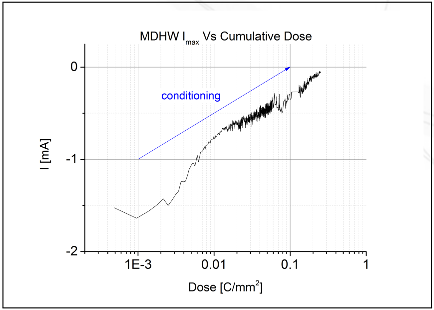


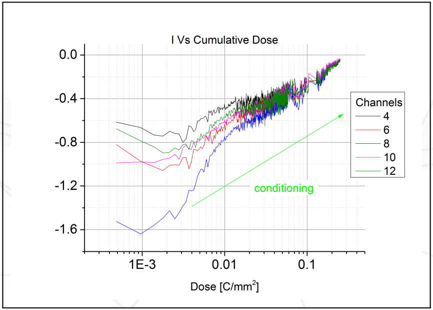


Conditioning:
The lower the surface SEY, the higher the power threshold to ignite the multipacting

StSt liner

Logarithmic current reduction
Does it fully scrub the surface?

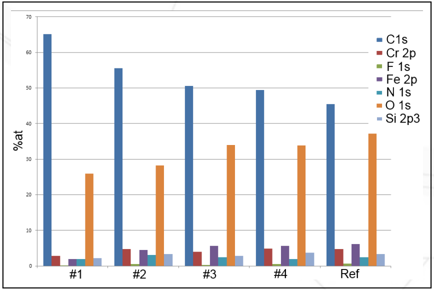




Extremely high dose → still weaker multipacting

StSt liner

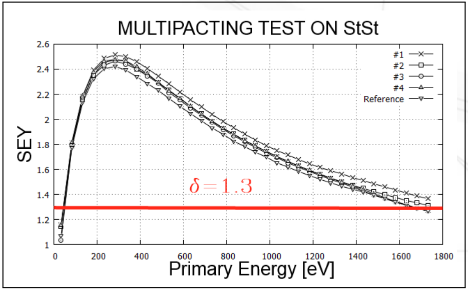
XPS



Extremely high dose → still (weaker) multipacting

StSt liner

Sample: high SEY, more than an unconditioned surface



problematics:

- sample exposure to air → air contamination
- inability of distinguish the carbon hybridizations

StSt liner

Logarithmic reduction of the multipacting currents in function of the dose

The set-up is unable to fully suppress the electron cloud

Are those results applicable to the SPS?

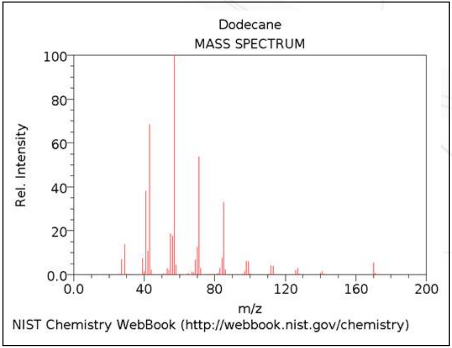
- Unknown electrons energy inside the system
- One order of magnitude higher pressure than the SPS
- Residual Gas composition differences

Accelerated Conditioning Tests

Hydrocarbon gas injection:

electron induced dissociation → increased surface graphitization

low H / C ratio → ideally, more C sp^2 hybridizations

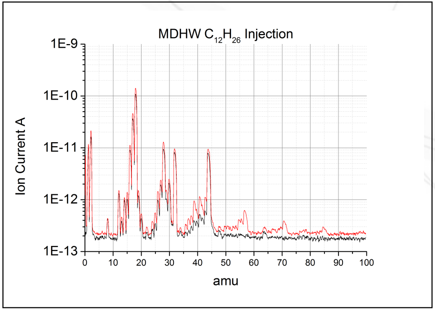


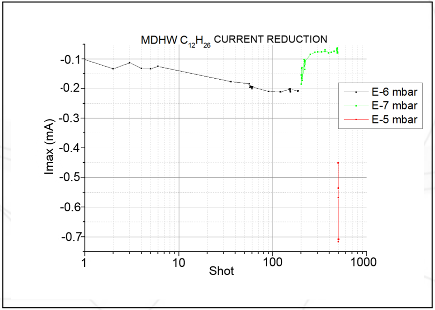
Dodecane $C_{12}H_{26}$

- heavy hydrocarbon
- $\Delta E_{des} = -29 + 42^n \ \frac{KJ}{mole}$
- $\tau = 10^{-19} e^{-\frac{\Delta E_{des}}{K_B T}}$ s

Accelerated Conditioning Tests

$$P(\text{before injection}) = 1.6E - 8mbar,\ B = 49G$$





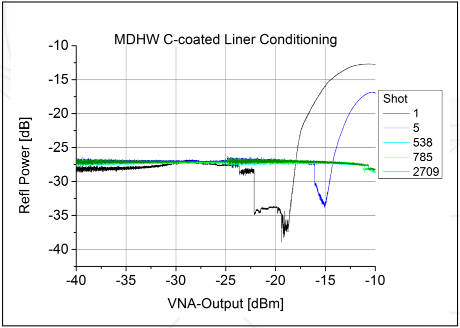
Higher injection pressure → higher currents

NO EVIDENCES OF CONDITIONING

C-Coating

Apparently the a-C coating seems not to fully suppress the multipacting:

- RF detuning



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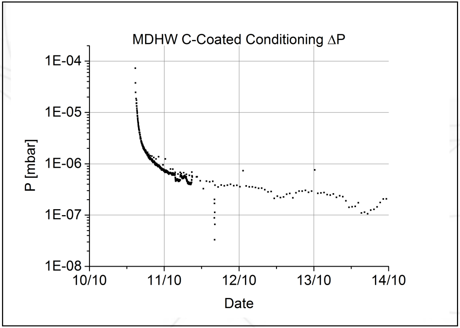
Apparently the a-C coating seems not to fully suppress the multipacting:

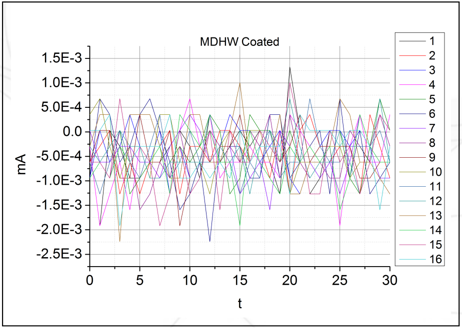
- RF detuning
- ESD pressure peaks



C-Coating

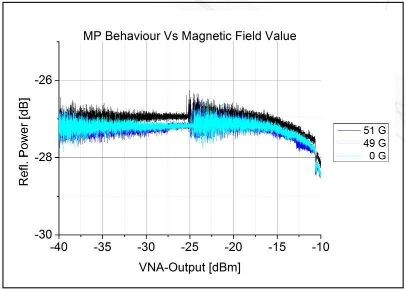
Apparently the a-C coating seems not to fully suppress the multipacting:

- RF detuning
- ESD pressure peaks
- **NO e-CLOUD CURRENT**



C-Coating

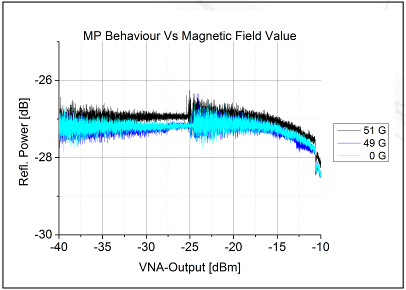
The multipacting develops independently of the B intensity

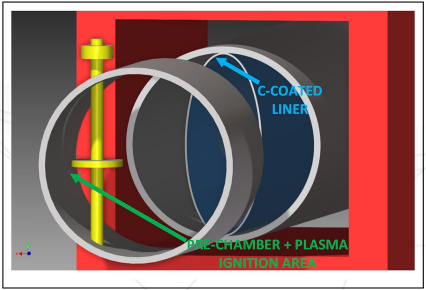


C-Coating

The multipacting develops independently of the B intensity

$C_{12}H_{26}$ injection + power increase up to plasma ignition





Multipacting outside the main chamber

C **suppresses the e-cloud on the coated surfaces**

Conclusions

Logarithmic behavior of the e-cloud current reduction.
The conditioning requires an unacceptable time (more than 2 weeks) to suppress the multipacting inside the test-bench

The conditioning acceleration appears inefficient with the gases used

The C-coating, instead, confirms its efficiency

Limitations for SPS comparison

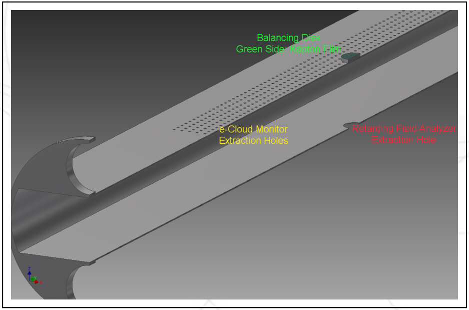
The set-up exhibits several limitations:

- Unknown electrons energy
- Unknown real time SEY
- The residual gas composition and the shots rate can reduce the conditioning efficiency
- The differences between the simulations and the test-bench can influence the limit value $\delta_{max} = 1.3$

Outlook

To overcome the present limitations, the set-up is going to be updated

- An electron energy detector
- C sputtering with H, for a tunable $SEY > 1$
- Application of a DC bias



Acknowledgments

Thanks to the VSC group

A special remark to ALL those who worked with me in building 181 for your help and teachings

QUESTIONS?

The Pressure Effect

Injection of an inert gas: no surface binding.
Development of a plasma: no influence on the threshold power, low current increase