Low Secondary Electron Yield Carbon Coatings for E-cloud Mitigation in Modern Particle Accelerators

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Outline

1. Motivation
   - Electron Cloud Build-Up
   - SPS-U: Super Proton Synchrotron Upgrade
   - New solution!? $\longrightarrow$ Amorphous Carbon Coating
2. Experiments
   - Experiments in the lab: Thin Film Coatings + SEY measurements
   - Implementation in the SPS: Coatings + E-cloud experiments
   - Ageing observation of a-C coating: in the lab + in the SPS
3. Applications and Conclusions
   - Application on the dipole magnets in the SPS
   - Summary

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Electron Cloud Build-Up

In the beam pipe of high-energy proton or positron particle accelerators, an 'Electron Cloud' can be generated:

- by residual gas ionization.
- by photoemission from synchrotron radiation.
- by subsequent secondary electron emission via a beam-induced multipactoring process.

The electron cloud leads to:

- dynamic pressure rise (electron stimulated desorption).
- transverse emittance blow-up (bunch expansion).
- thermal load in cryogenic vacuum systems.
- fast or slow beam losses.

The goal of this work

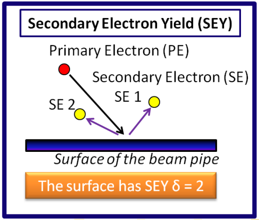
SPS-U: make the SPS able to deliver the above nominal beams to LHC and reach maximum luminosity.

Find a solution to eliminate e-cloud in the SPS, which

- can be implemented in the present SPS-dipoles
- does not require bake-out
- is robust against air venting (maintenance, installation...)
- has a long life time

The condition to avoid e-cloud in SPS dipoles with nominal LHC beam is (G.Rumolo et al.)

$$\delta_{max} < 1.3$$



Possible remedies for the electron cloud in the beam pipe:

- Low Secondary Electron Yield (SEY) thin-film coatings
- surface conditioning
- clearing electrodes
- chamber with grooves or slots

Ti-Zr-V film coating (implemented in straight sections of LHC) have $\delta_{max} = \mathbf{1.1}$ after **activation** at temperature higher than **180°C** (24h). But they cannot be applied to the **SPS** because the SPS magnet vacuum chambers are **not bakeable**.

TiN works well under the effect of photon conditioning in situ. But **no photons** in the **SPS**.

Which material to start with:

Known facts

- For air exposed stainless steel, Cu and Al $\delta_{max} > 2$.
- In the periodic system, elements with fewer electrons (on the left side) => lower SEY.
- Insulators have high SEY (electrons escape from deep layers).
- 'Beam scrubbed' surfaces are covered by more carbon (at least Cu and StSt).

Try Carbon, which has few electrons

- SEY of graphite is much lower than diamond, so try to make graphite-like coatings.
- Graphite is not very reactive, should be less affected by air exposure.
- Graphite-like Amorphous Carbon (a-C) Thin Film Coating.

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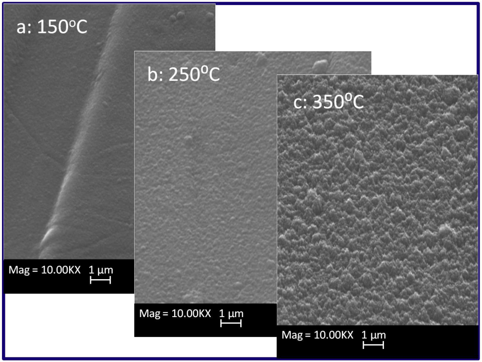
Surface morphology by SEM (Scanning electron microscope)

Amorphous Carbon Coating: DC magnetron sputtering
The SEM images of a-C coatings
Thicknesses from 50 nm to 1500 nm.
Variation of surface roughness with substrate coating temperatures.



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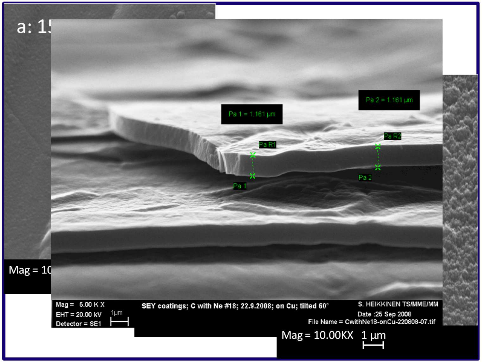
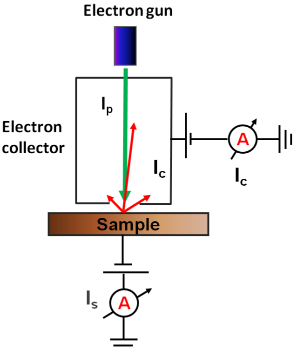


Experimental setup for SEY measurement



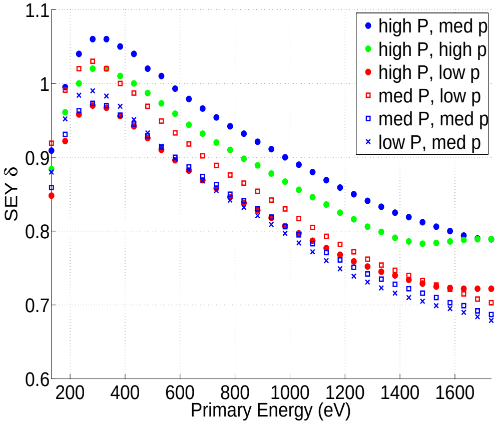
The electron dose during the measurement is calculated to be below 1x10^{-6} C/mm^2.

SEY δ is calculated as:

- $\delta = \frac{I_c}{I_c + I_s}$
- I_c: collector current.
- I_s: sample to ground current.
- I_p: $I_c + I_s$, the primary electron current (PE).

The SEY as a function of PE

P: power, p: pressure



- Measured directly after extraction from the deposition chamber and transfer to the SEY apparatus through air.
- The precision of the presented SEY values is estimated to ±0.03.
- δ_{max} is between 0.9 and 1.1 and E_{max} = 300 eV. (not sensitive to coating parameters as pressure, power.)

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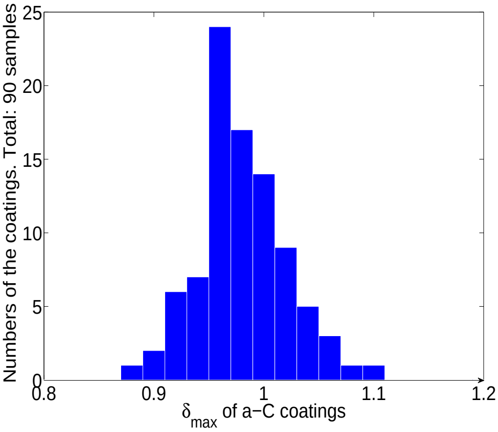

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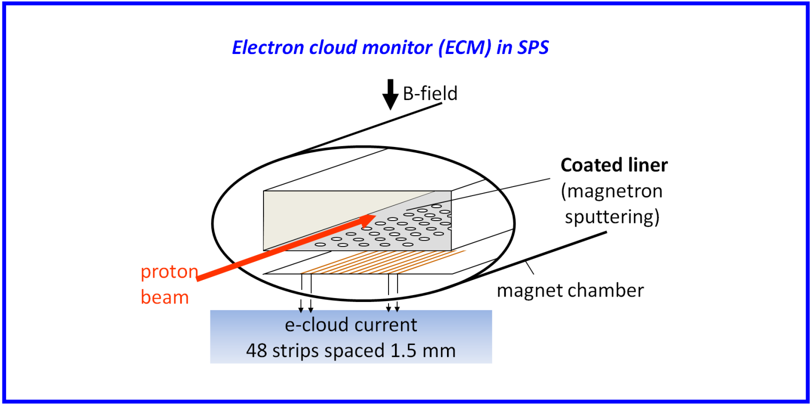
Coating for the Electron Cloud Monitor in the SPS



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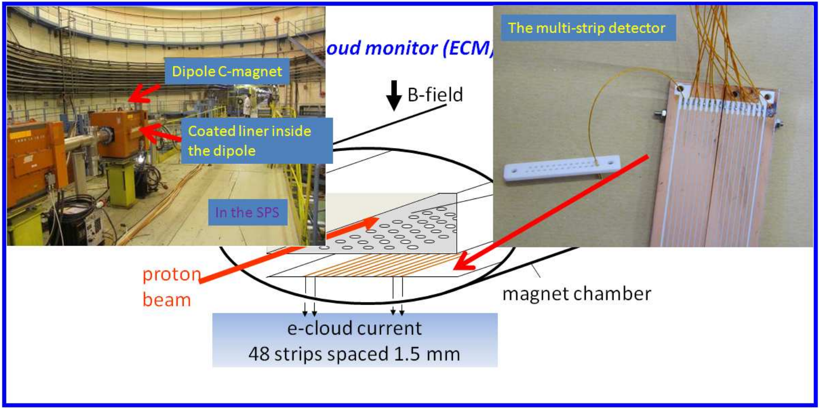
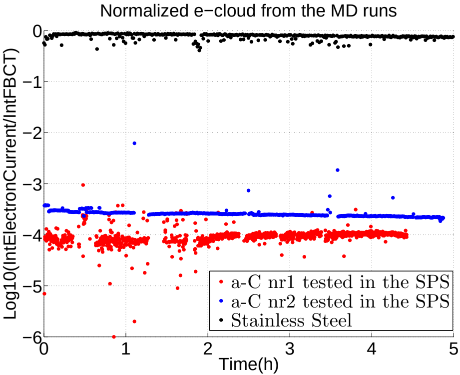
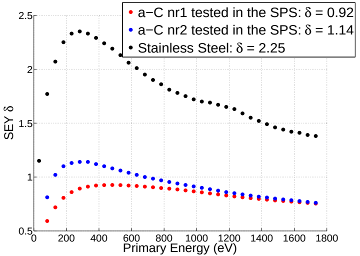


Electron Cloud Monitor (ECM)

- Normalized EC v.s time, measured by ECM in the SPS.
- 3-4 batches of nominal LHC beam. $(1.15 \cdot 10^{11}$ protons/bunch$)$



- SEY measurements in the lab.



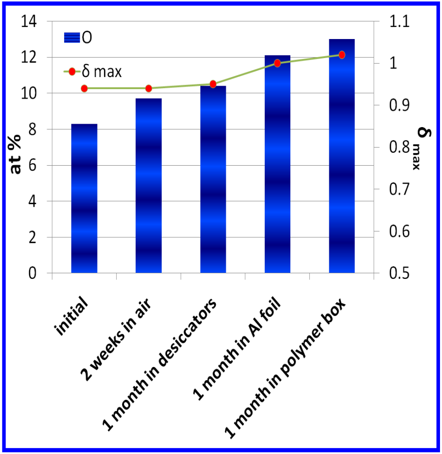
Observe!

- EC signal is 10^4 higher on StSt than a-C.
- Low SEY $\Rightarrow$ Low electron current signal.

Ageing observation under different conditions **in the lab**

3 identical a-C samples have been stored in different conditions and compared after 1 month.

- By storing the sample in desiccators, the ageing seems to be suppressed completely.
- A weak correlation between the O content and the SEY can be seen in this sample.
- **1 month in air, still below the threshold value for the SPS,** $\delta_{max} = 1.3$.



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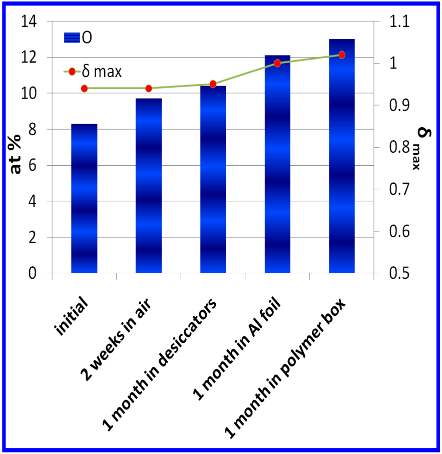

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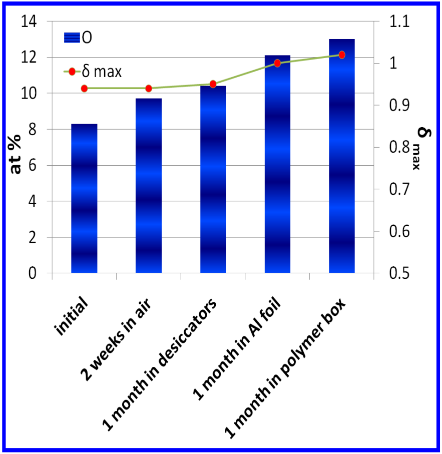

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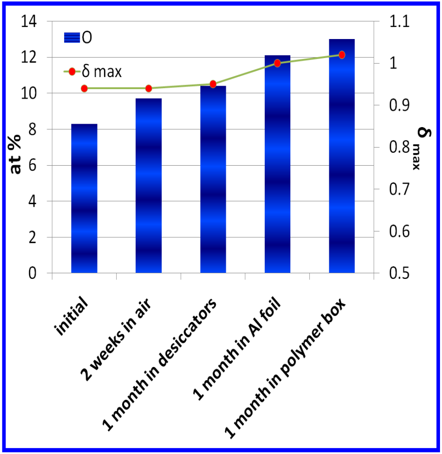
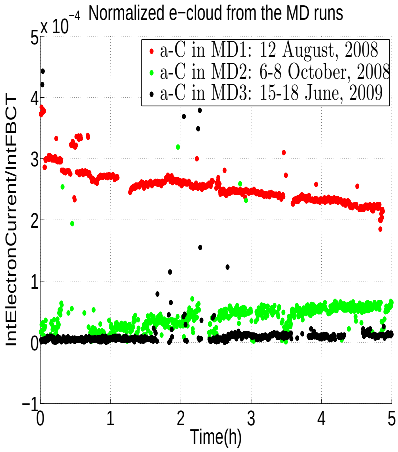


Ageing observation of a-C **in the SPS**

One a-C coated liner has been tested during 3 Machine Development (MD) Runs with 3-4 batches of nominal LHC beam accelerated to 450 GeV/c.

- Vertical unit: nC/10^{10} protons per bunch
- The a-C coated liner was kept in the SPS for more than one year operation. (more than 2 months of venting, maintenance, installation...)
- **No sign of ageing in the SPS**.



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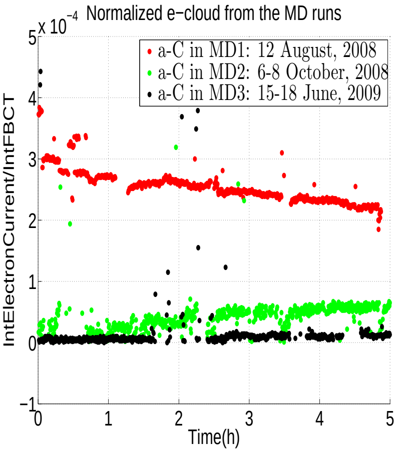

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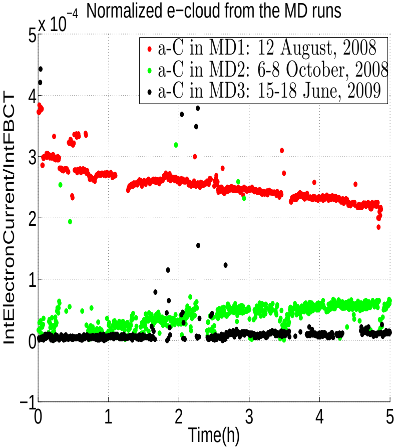
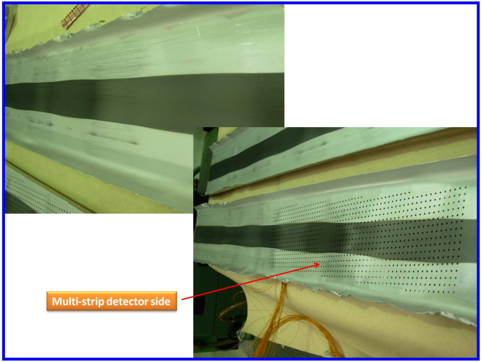


Inspection of one a-C liner extracted from **the SPS**

- One a-C coated liner has been tested during 5 Machine Development (MD) Runs in 2009, with 3-4 batches of nominal LHC beam accelerated to 450 GeV/c.
- Inserted in SPS in March 2009, and extracted in February 2010 and inspected.



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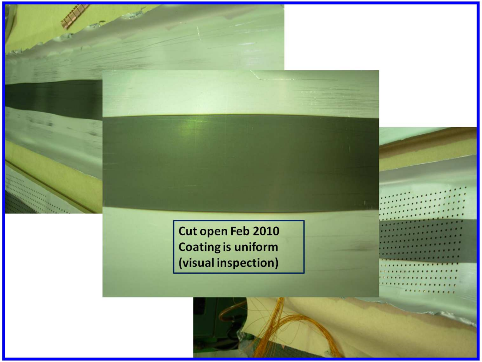

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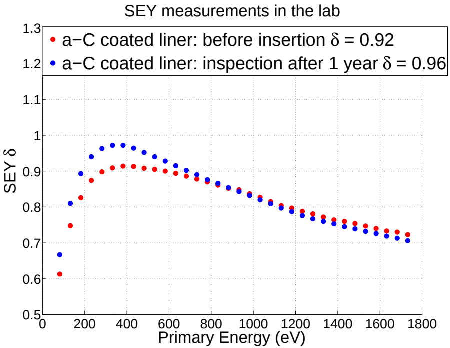
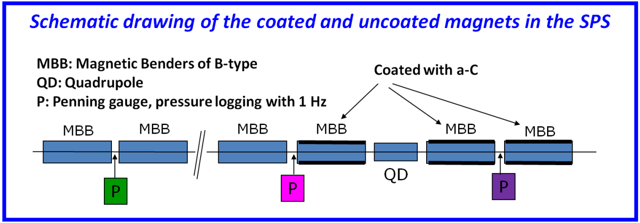


Outline

Three Magnetic Benders of B-type (MBB) have been coated with a-C coating



- **Microwave transmission measurements detected e-cloud related signal in the coated and uncoated magnets.** by S. Federmann et al (Poster ID: TUPEA076)
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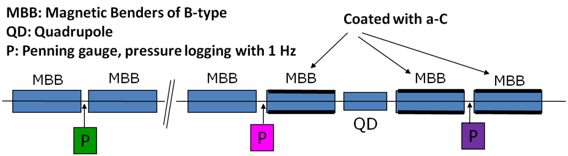
Schematic drawing of the coated and uncoated magnets in the SPS



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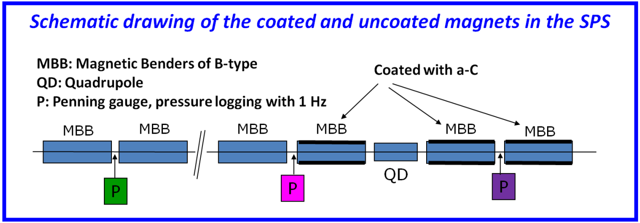

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Summary!!

- Magnetron sputtered a-C film is a potential solution to eliminate e-cloud.
- especially in an un-bakeable accelerator as SPS.
- Future activities:
  - Study of ageing with storage in different atmospheres.
  - Modifying the coating system in order to find a solution to coat the dipole magnets with the best quality of a-C coating.
- More details can be found in ***Low Secondary Electron Yield Carbon Coatings for Electron-cloud Mitigation in Modern Particle Accelerators*** and ***Amorphous Carbon Coatings for the Mitigation of Electron Cloud in the CERN SPS*** by Christina Yin Vallgren et al (WEOAMH03, TUPD048).

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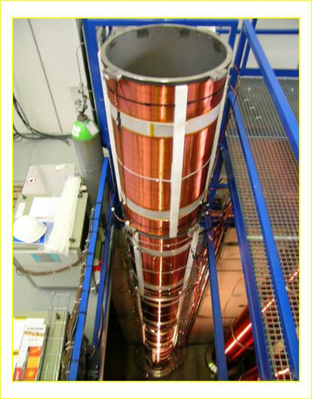
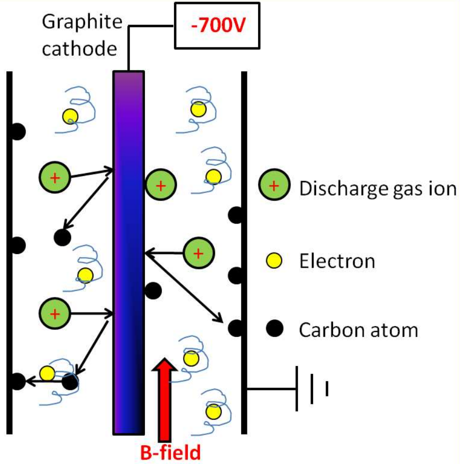
Thanks

Many thanks to all the members of the SPS-U Study team handed by E .Shaposhnikova!

Thanks for your attention ! and Questions

Backup Slide
Cylindrical configuration (Lab samples)





Backup Slide

Coating configuration - DC magnetron sputtering

Different coating configurations were used:

- Cylindrical tube with graphite rod as shown (for lab measurements)
- Liner in tube with 4 graphite rods (for e-cloud monitors, will be explained later)
- Multi-electrode geometry in MBB magnets (for SPS dipoles)

Different discharge gases (Ne, Kr, Ar) and different coating parameters (Temperature of substrate, discharge gas pressure, power) can be used.