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

IPAC '10, Kyoto Japan

Christina Yin Vallgren

A. Ashraf, S. Calatroni, P. Chiggiato, P. Costa Pinto, H.P. Marques
H. Neupert, M. Taborelli, W. Vollenberg, I. Wevers, K. Yaqub
Vacuum, Surfaces and Coatings Group (VSC), TE-department
CERN, CH-1211, Geneva, Switzerland

May 26 2010

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

Outline

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

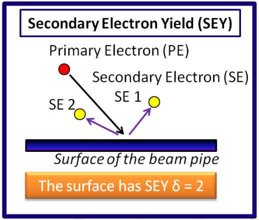
SPS-U: make the SPS able to deliver the above nominal beams to LHC and reach maximum luminosity.

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.

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).

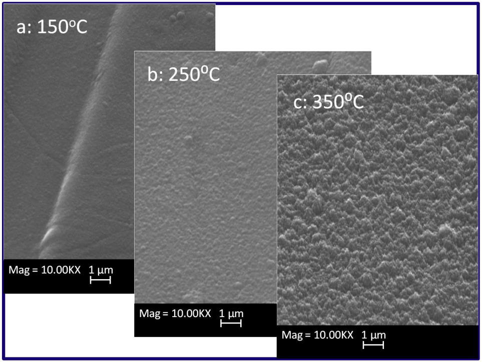
Try Carbon, which has few electrons

- 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.

Outline

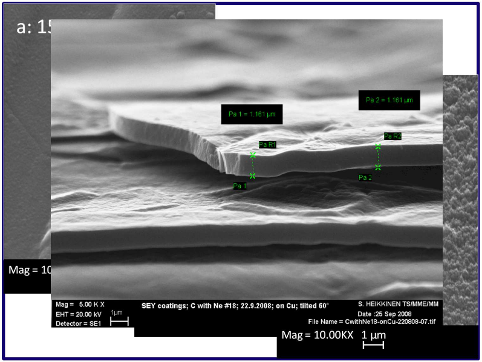
Surface morphology by SEM (Scanning electron microscope)

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.

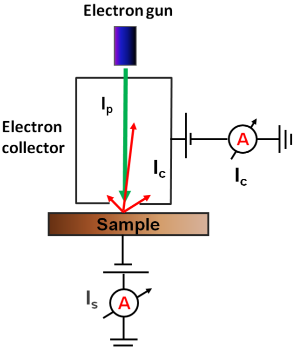


Surface morphology by SEM (Scanning electron microscope)

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.



Experimental setup for SEY measurement



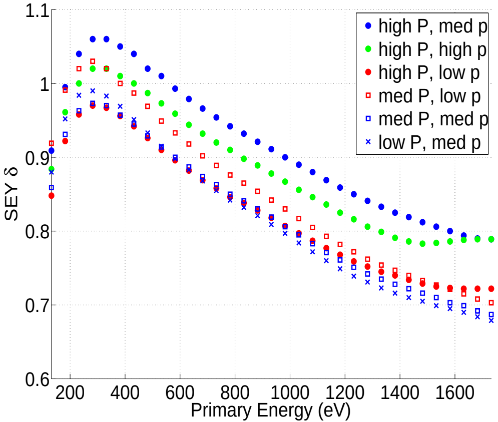
The electron dose during the measurement is calculated to be below 1x10^{-6} C/mm^2.

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

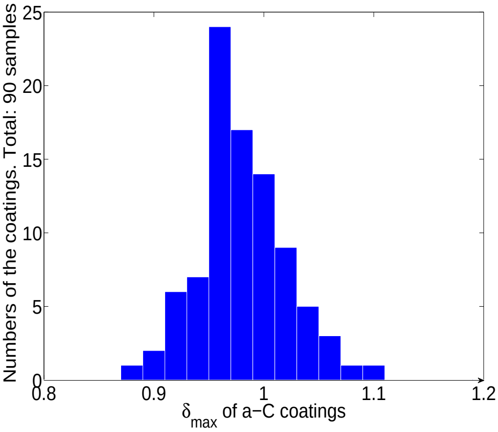
P: power, p: pressure



- 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.)

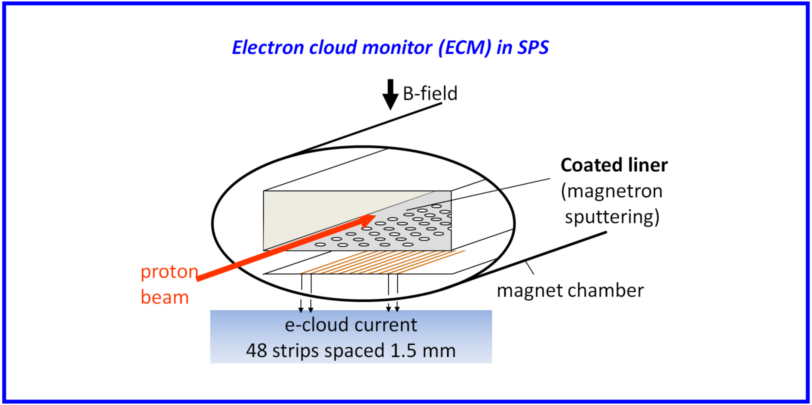
The SEY as a function of PE

P: power, p: pressure

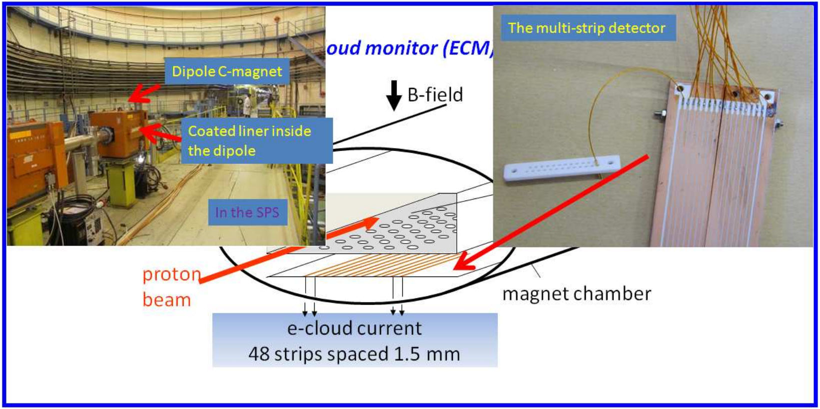


- Measured directly after extraction from the deposition chamber and transfer to the SEY apparatus through air.
- The precision of the presented SEY values is estimated to ± 0.03.
- δ_{max} is between 0.9 and 1.1 and $E_{max} =$ 300 eV. (not sensitive to coating parameters as pressure, power.)

Coating for the Electron Cloud Monitor in the SPS

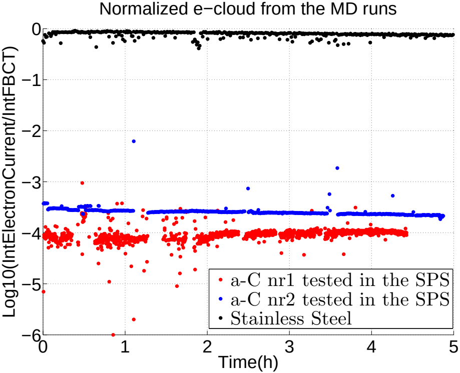


Coating for the Electron Cloud Monitor in the SPS

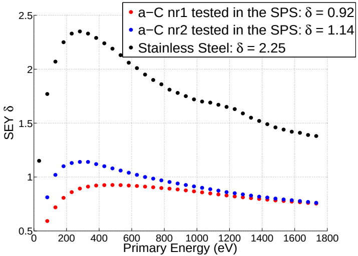


Electron Cloud Monitor (ECM)

- 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.



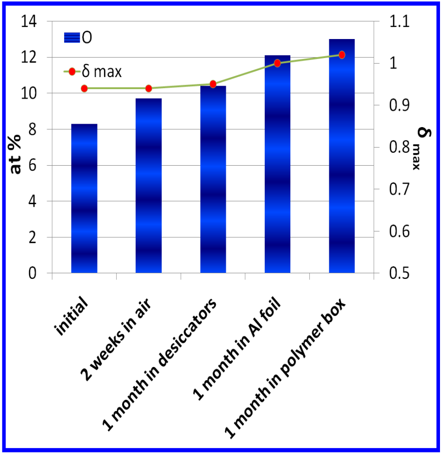
Observe!

- EC signal is 10^4 higher on StSt than a-C.
- Low SEY ⇒ 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.

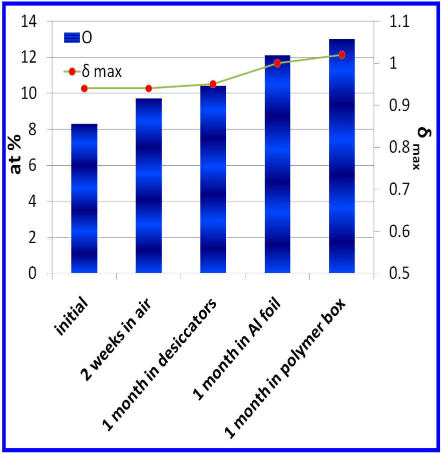
- By storing the sample in desiccators, the ageing seems to be suppressed completely.
- A weak correlation between the O content and the SEY can be seen in this sample.
- **1 month in air, still below the threshold value for the SPS,** $\delta_{max} = 1.3$.



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

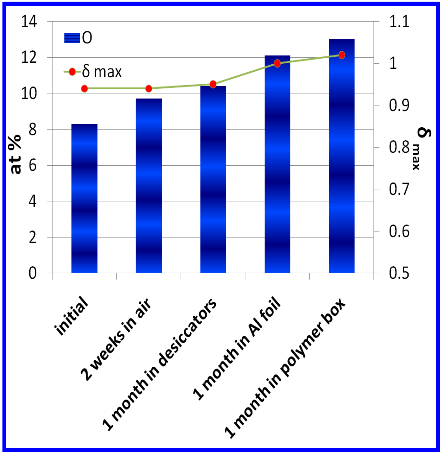
3 identical a-C samples have been stored in different conditions and compared after 1 month.

- 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, $\delta_{max} = 1.3$.**



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

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

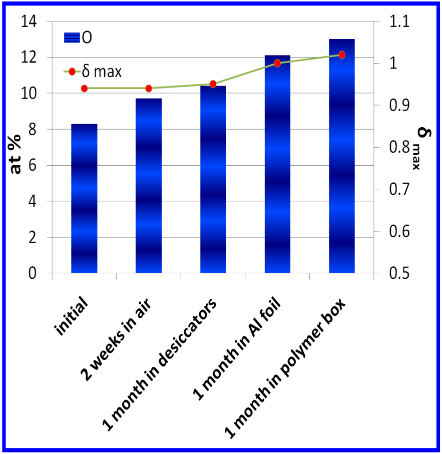


- By storing the sample in desiccators, the ageing seems to be suppressed completely.
- A weak correlation between the O content and the SEY can be seen in this sample.
- 1 month in air, still below the threshold value for the SPS, $\delta_{max} = 1.3$.

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

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

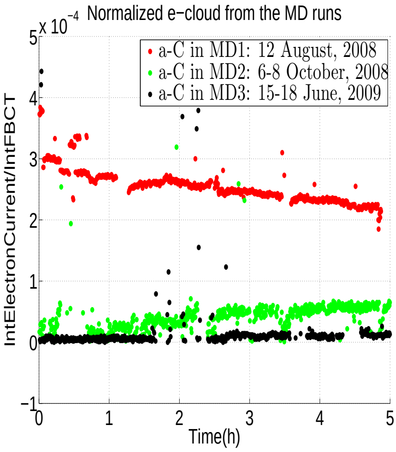
- By storing the sample in desiccators, the ageing seems to be suppressed completely.
- A weak correlation between the O content and the SEY can be seen in this sample.
- **1 month in air, still below the threshold value for the SPS, $\delta_{max} = 1.3$.**



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.

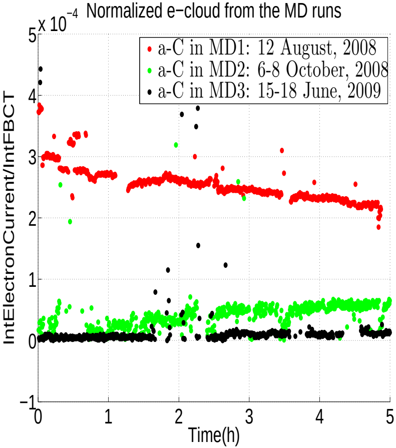
- Vertical unit: nC/10^{10} protons per bunch
- The a-C coated liner was kept in the SPS for more than one year operation. (more than 2 months of venting, maintenance, installation...)
- **No sign of ageing in the SPS.**



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.

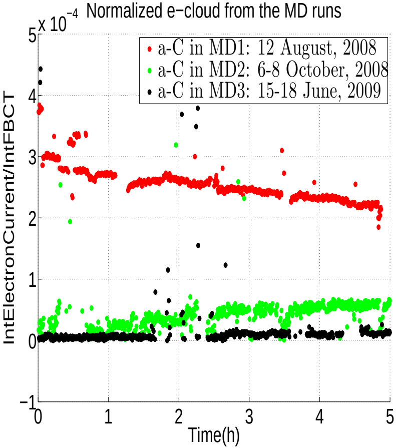
- Vertical unit: nC/10^{10} protons per bunch
- The a-C coated liner was kept in the SPS for more than one year operation. (more than 2 months of venting, maintenance, installation...)
- No sign of ageing in the SPS.



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

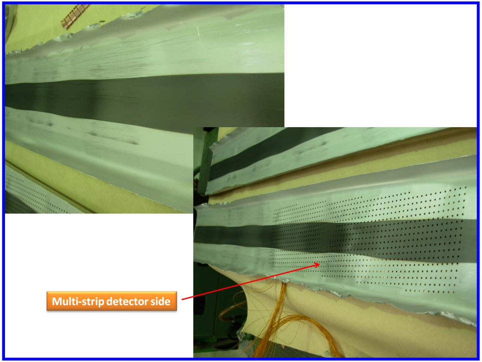
One a-C coated liner has been tested during 3 Machine Development (MD) Runs with 3-4 batches of nominal LHC beam accelerated to 450 GeV/c.

- 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**.



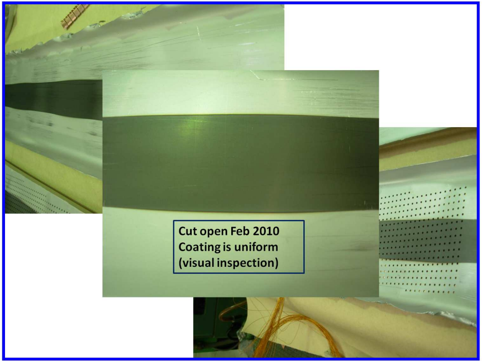
Inspection of one a-C liner extracted from **the SPS**

- 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.



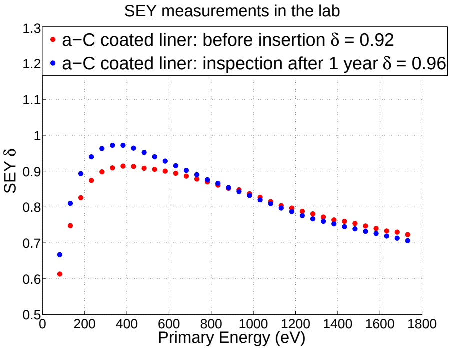
Inspection of one a-C liner extracted from **the SPS**

- 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.



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

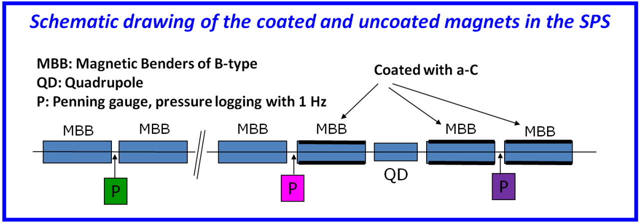
- One a-C coated liner has been tested during 5 Machine Development (MD) Runs in 2009, with 3-4 batches of nominal LHC beam accelerated to 450 GeV/c.
- Inserted in SPS in March 2009, and extracted in February 2010 and inspected.



Outline

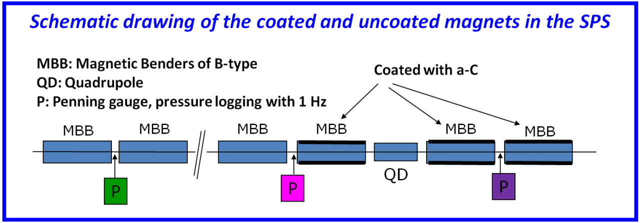
1. Motivation
   - Electron Cloud Build-Up
   - SPS-U: Super Proton Synchrotron Upgrade
   - New solution!? → Amorphous Carbon Coating
2. Experiments
   - Experiments in the lab: Thin Film Coatings + SEY measurements
   - Implementation in the SPS: Coatings + E-cloud experiments
   - Ageing observation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

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



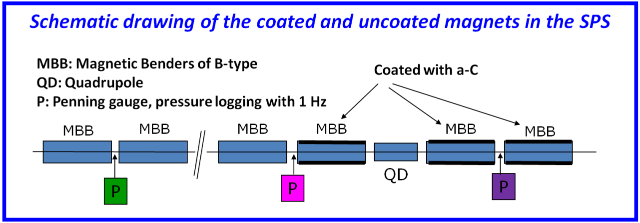
- **Microwave transmission measurements detected e-cloud related signal in the coated and uncoated magnets.** by S. Federmann et al (Poster ID: TUPEA076)
- **Dynamic pressure rise used to monitor the behavior of the coated and uncoated magnets.** by C. Yin Vallgren et al (Poster ID: TUPD048)

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)
- **Dynamic pressure rise used to monitor the behavior of the coated and uncoated magnets.** by C. Yin Vallgren et al (Poster ID: TUPD048)

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)
- **Dynamic pressure rise used to monitor the behavior of the coated and uncoated magnets.** by C. Yin Vallgren et al (Poster ID: TUPD048)

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).

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).

Summary!!

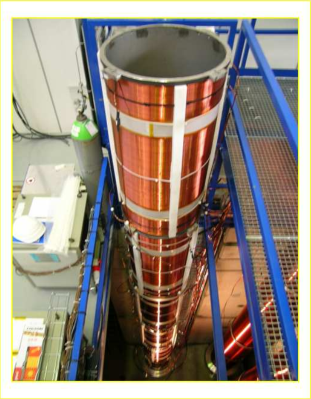
- Magnetron sputtered a-C film is a potential solution to eliminate e-cloud.
- especially in an un-bakeable accelerator as SPS.
- Future activities:
  - Study of ageing with storage in different atmospheres.
  - Modifying the coating system in order to find a solution to coat the dipole magnets with 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).

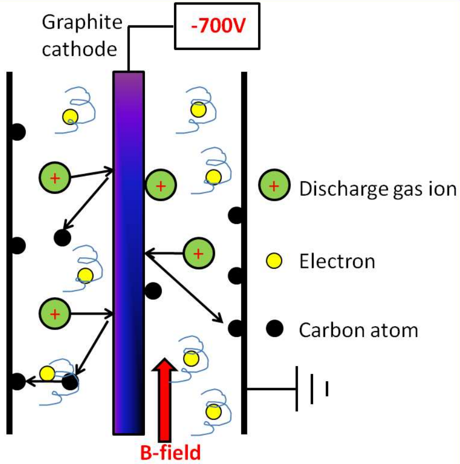
Thanks

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.