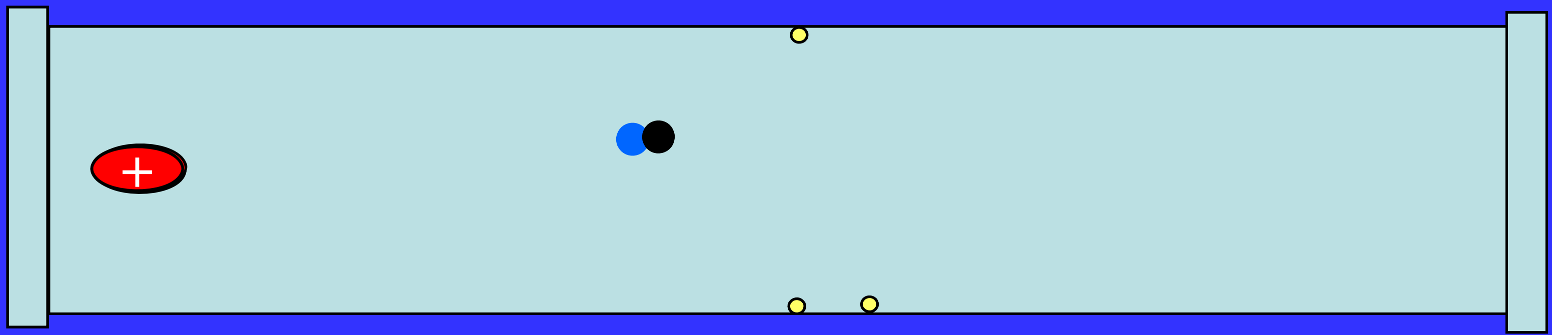
Low secondary electron yield carbon coatings for electron-cloud mitigation in modern particle accelerators

M.Taborelli

- Introduction
- a-C coatings: production, characterization
- Tests on SPS
- Aging
- Conclusions

Electron cloud

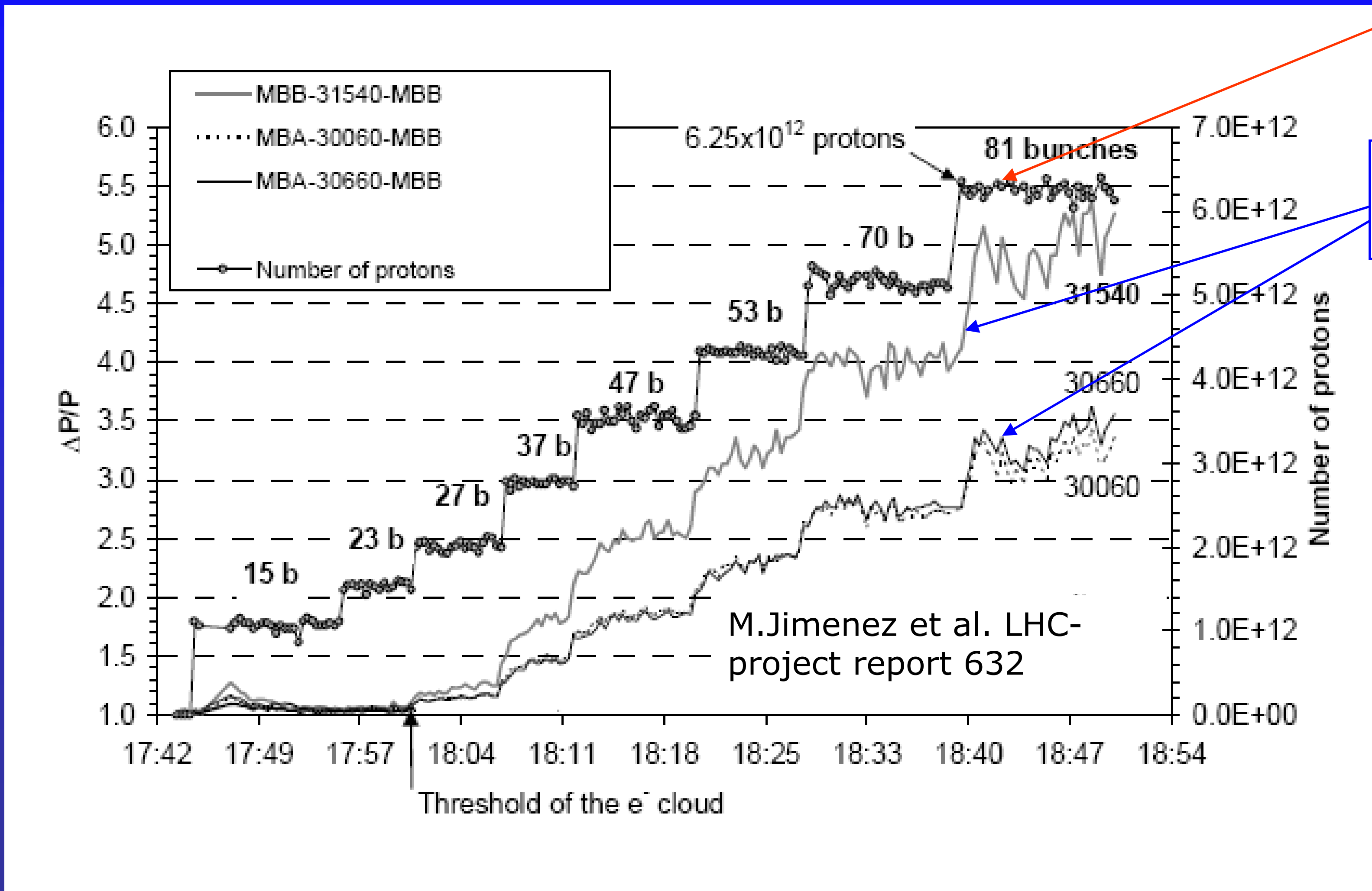


Proton bunch   Electron   Gas molecule

Electrons can be generated by residual gas ionization, photoemission (synchrotron radiation) or beam loss at the chamber walls. Reducing the secondary electron yield of the walls can reduce the effect

Effects:
-Pressure rise (electron stimulated desorption)
-Beam perturbation (emittance growth, bunch-to-bunch coupling)
-Heat load (V. Baglin et al.) in a cryogenic case
-Interference with beam monitors (pick-up)
Relevant for high beam currents (beam potential), short bunch spacing

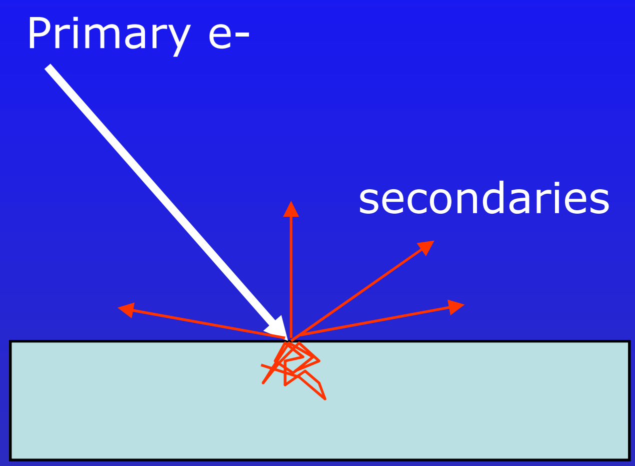
Example: pressure rise in the SPS

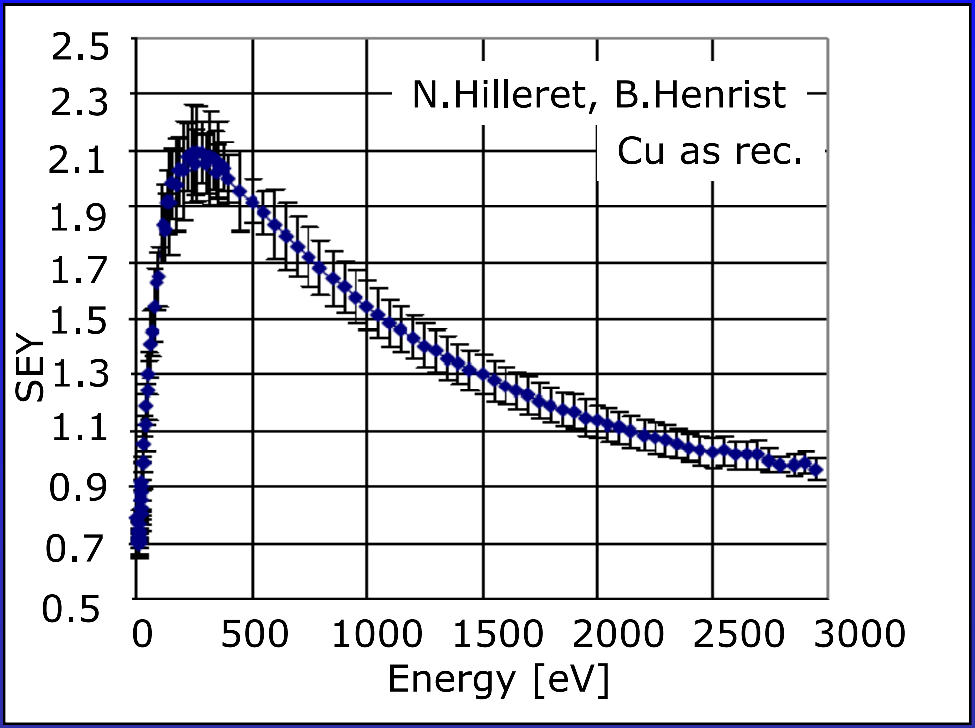


intro

Definition of secondary electron yield

$$SEY = \frac{\text{number of emitted electrons (secondary)}}{\text{number of impinging electrons (primary)}}$$





Typical quantitites:

δ_{max} or SEY_{max} =maximum value as a function of primary energy

E_{max} = primary energy of the maximum

Depth: true secondaries have energy below 50eV and escape from the topmost 10-30 nm

A lot of studies in the past at CERN :

- SEY of technical surfaces, NEG, Nb ….
- Effect of thermal treatments and glow discharge on SEY of copper
- Conditioning by beam scrubbing, especially on copper, in the lab and on SPS
- Measurements of e-cloud on SPS (e-cloud monitors)
- Experiments of e-cloud suppression in PS (clearing electrodes)
- e-cloud diagnostics by RF on PS
- Simulation of e-cloud in LHC, in SPS, in PS2, in CLIC DR

Relevance for present and future projects

SPS Upgrade, PS2, CLIC and ILC damping rings……

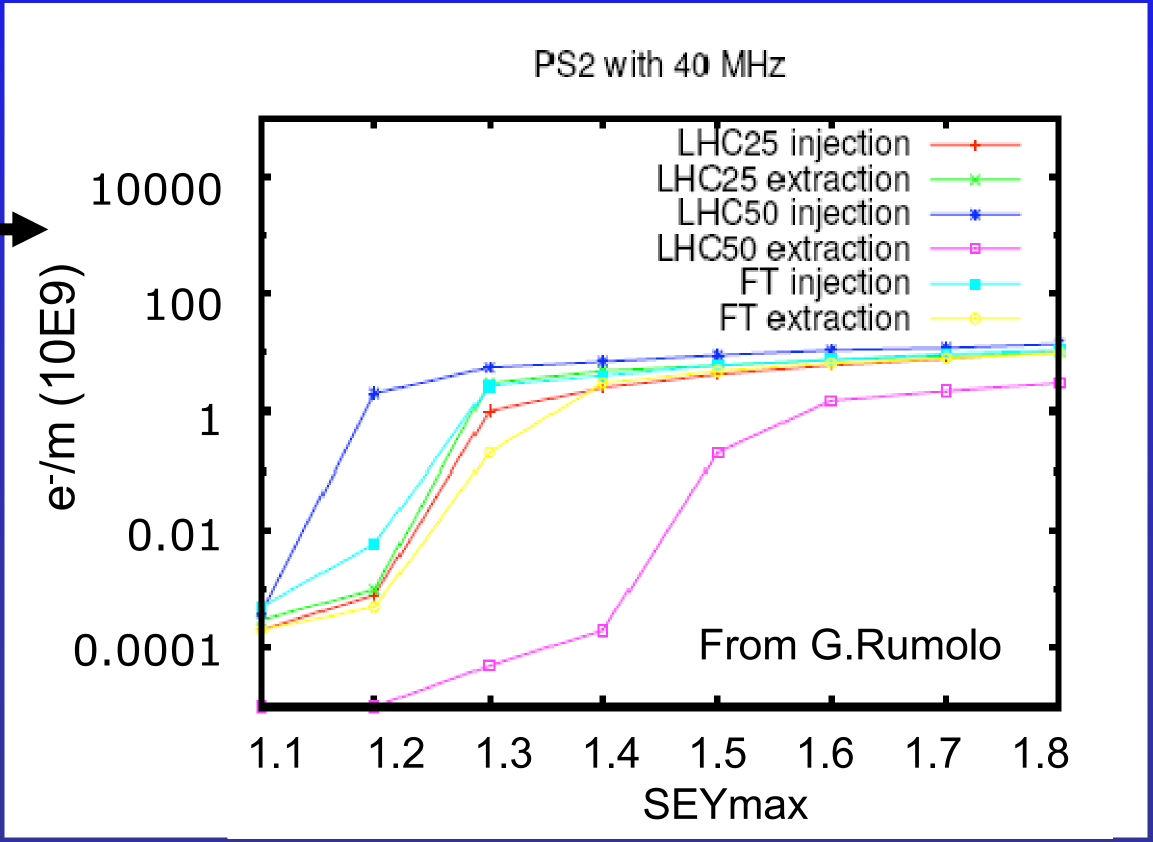
SPS:

-nominal LHC beam, 1.15×10^{11} protons in 72 bunches, 25 ns (50ns) spacing, 4 batches

- calculated threshold in the MBB dipole magnets δmax = 1.3 (G.Rumolo)

PS2:

-Similar situation with even lower threshold



CLIC/ILC positron DR:

-e-cloud in the arcs and wigglers

-secondary electrons and photoelectrons

The LHC bea ... d in the SPS
dipoles with

Find a solu

- can be
- does n
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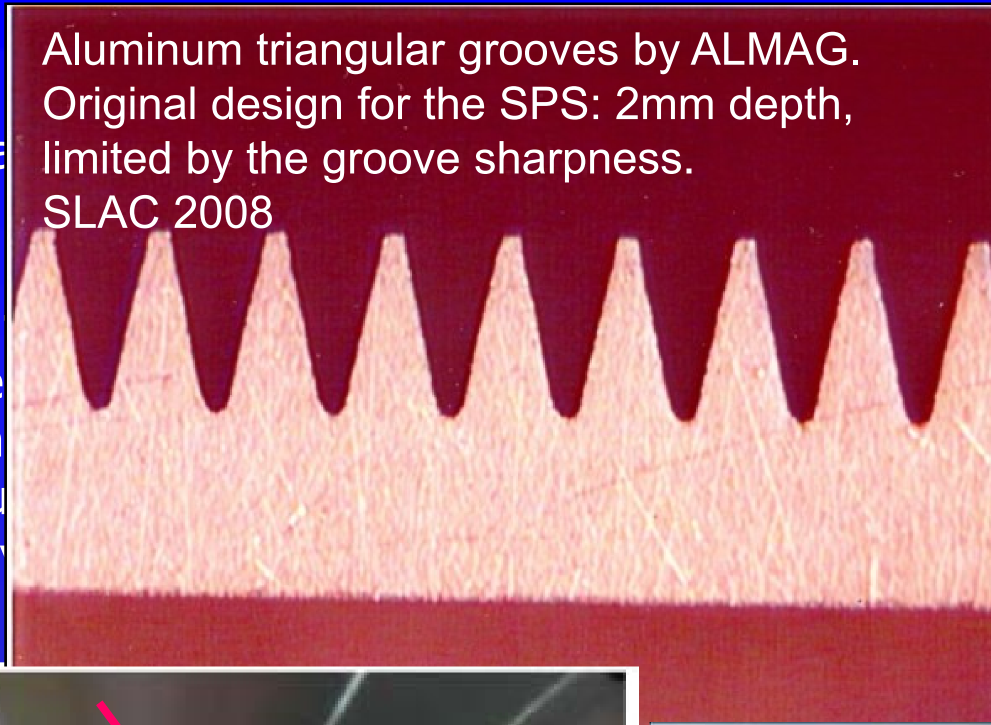
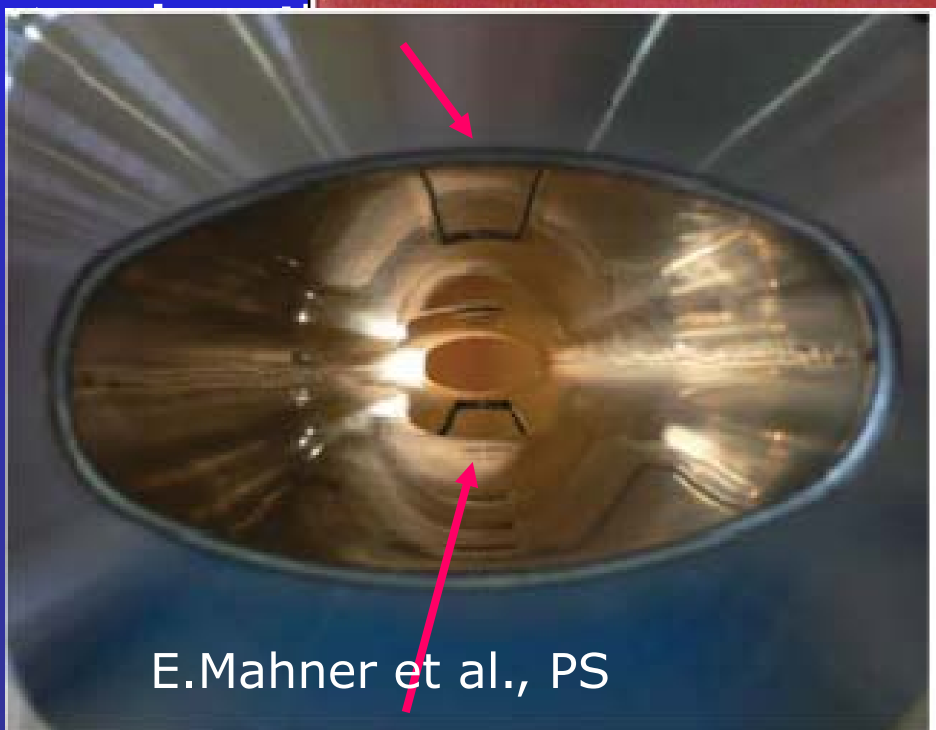
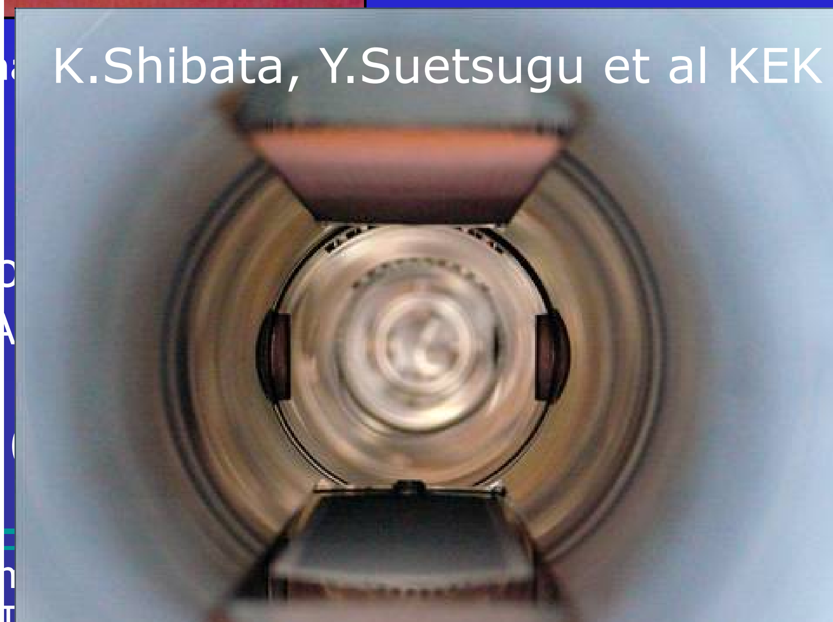
... uum pipe wall







What material to start with?

No theory able to to predict the SEY for a given material

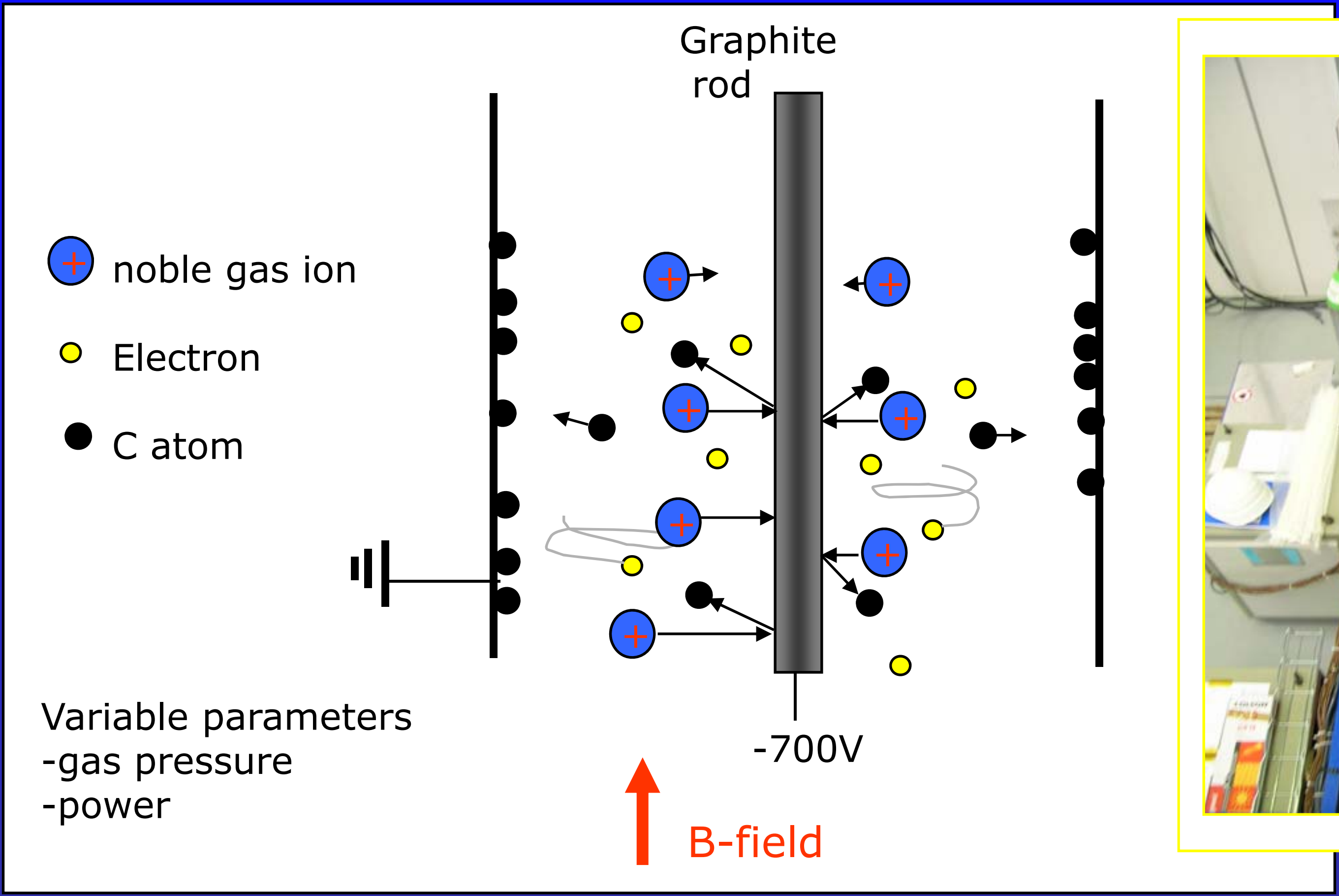
Known facts:
- in the periodic system, elements with **less electrons** (on the left side) have in general lower SEY (…and lower work function)
- insulators have high SEY (electrons escape from deep layers)
- air exposed metallic surfaces have SEY around 2
-”beam scrubbed” surfaces are covered by more **carbon**

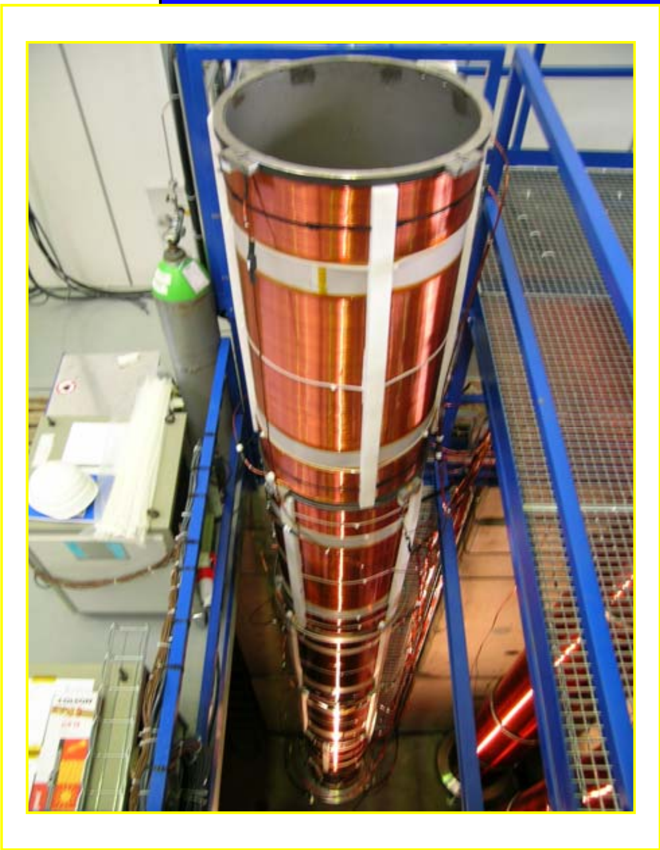
➔ take C, which has few electrons

➔ SEY of graphite (100% sp^2) is much lower than diamond (100% sp^3), so try to make sp^2 and avoid sp^3

➔ graphite is not very reactive, should be less affected by air exposure

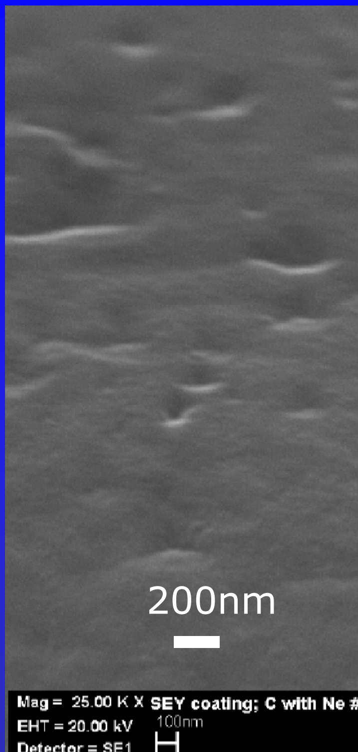
Thin film coating by magnetron sputtering:

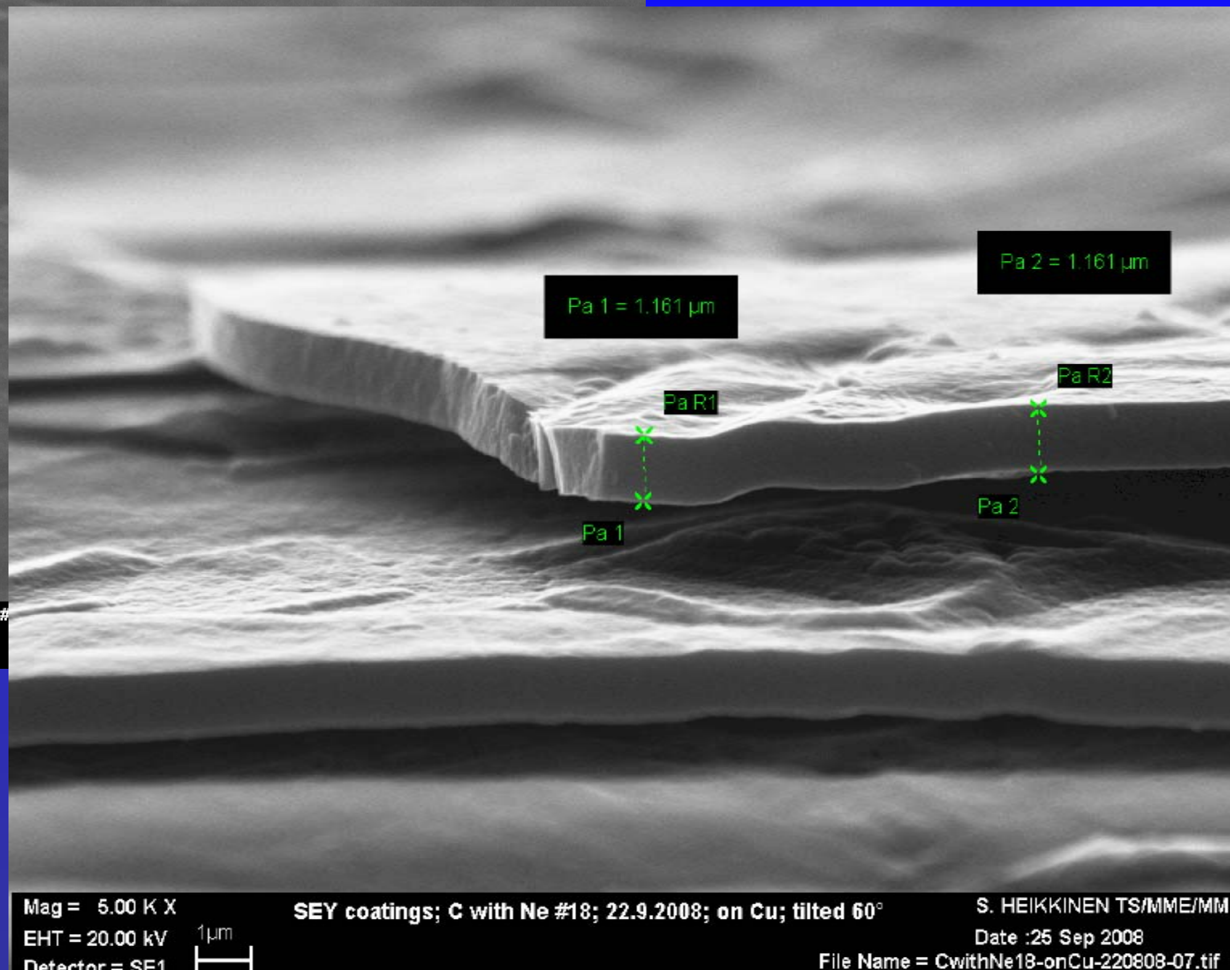


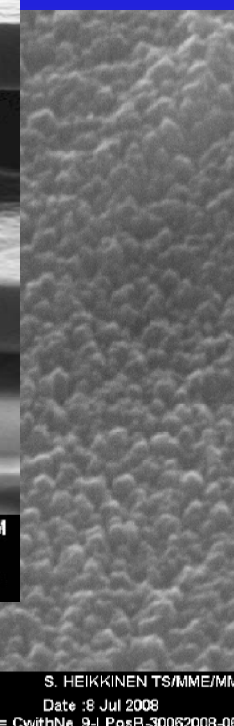


4 different configurations were used:
-Tube in coil with graphite rod (development)
-Planar target (development)
-Liner in tube with 3 graphite rods (for e-cloud monitors)
-Multi-electrode geometry in MBB magnets (for SPS dipoles)

SEM images of various coatings

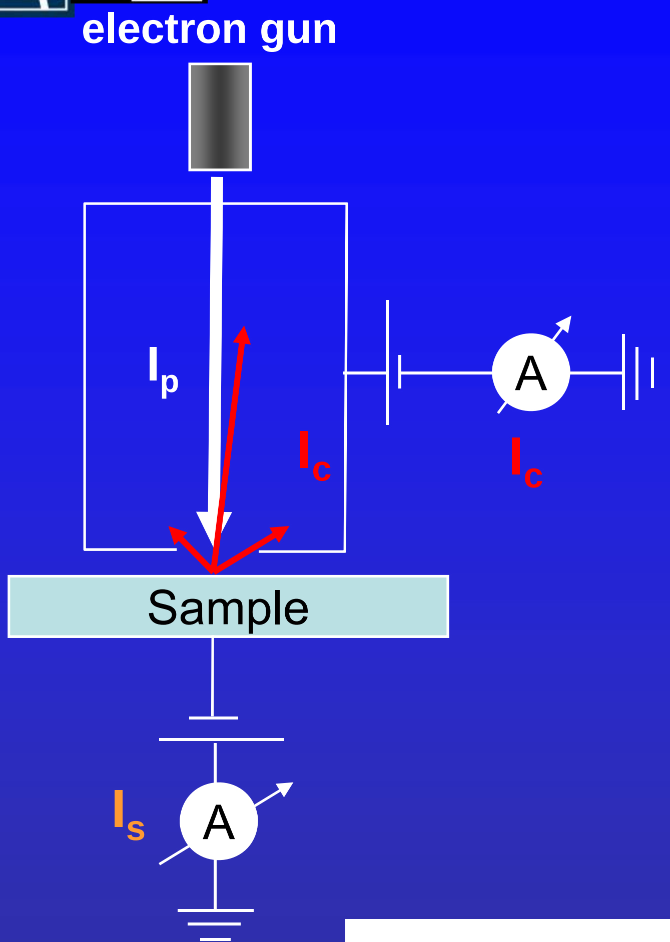


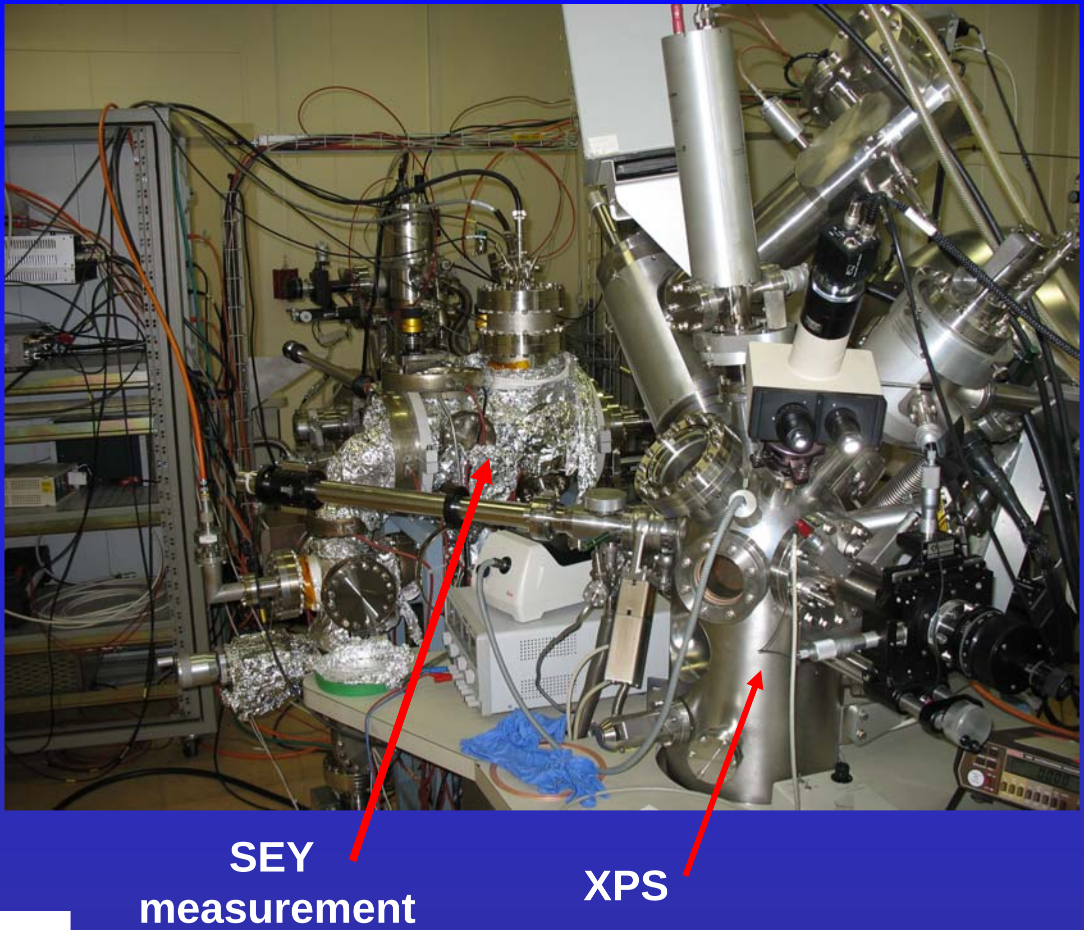




Thicknesses from 50 nm to 1500 nm

Measurement of SEY

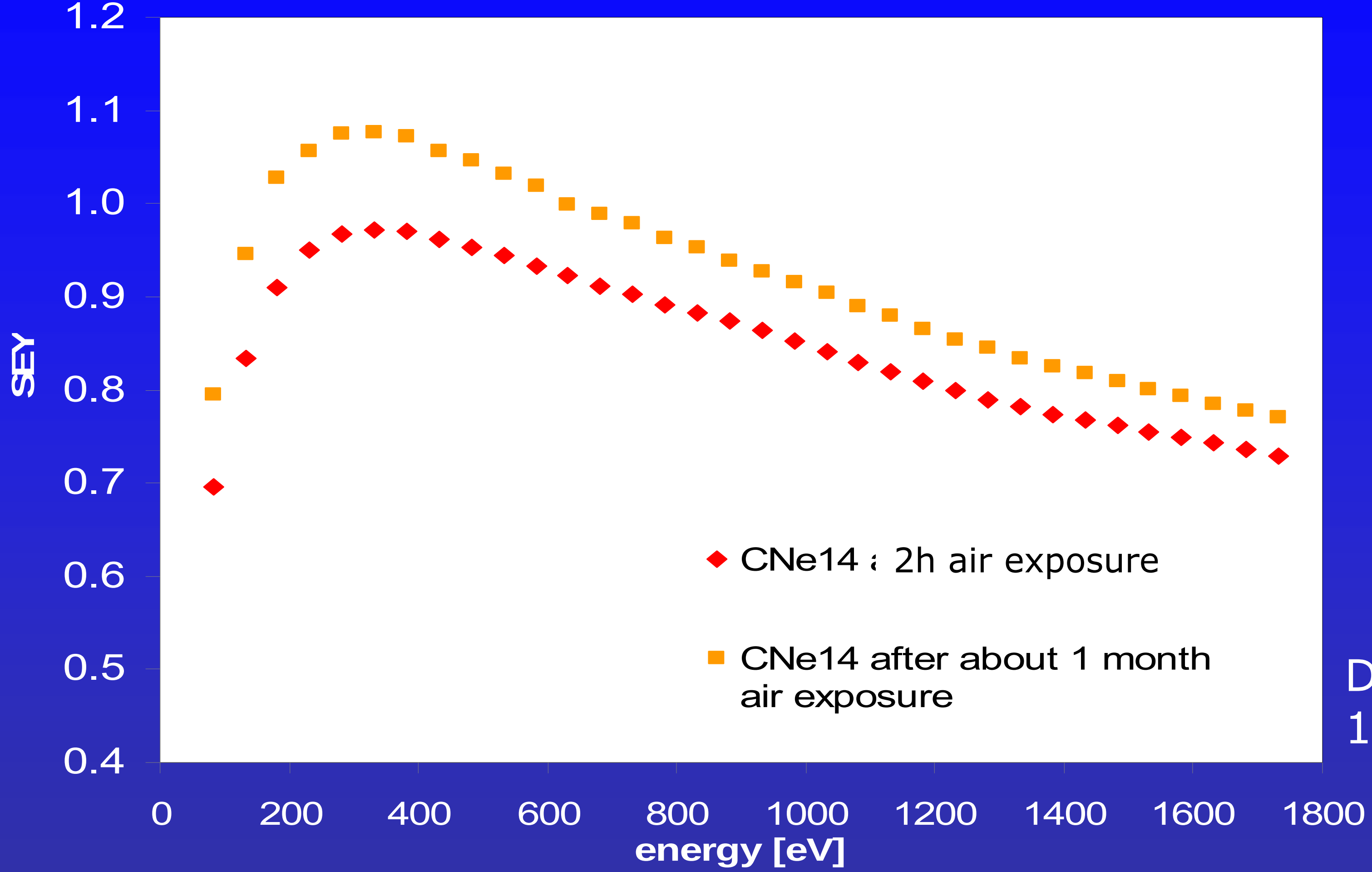




$$I_p = I_s + I_c$$

$$\delta = I_c / (I_s + I_c)$$

SEY of carbon a-C coatings



Dose below 10^{-6} Clb/mm^2

- -a-C coating on copper deposited by magnetron sputtering (in Ne)
- -no bake-out
- -as expected SEY does not change for thicknesses above 50 nm

Powder, dust and particles: optical particle counter

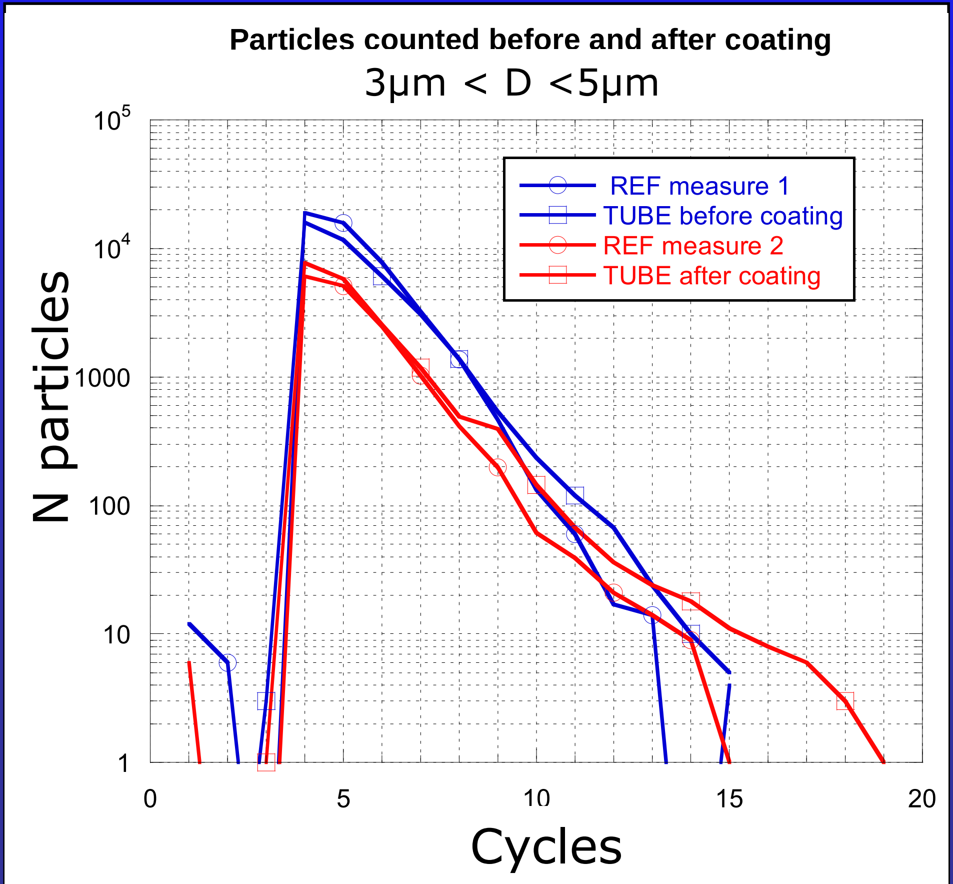
2 StSt tubes measured in clean-room → 1 coated with carbon / 1 reference (in the lab. with plastic covers) → both measured again in clean-room

-No difference in particles between coated and uncoated tube

-No increase after shaking and gentle hammering of the chamber

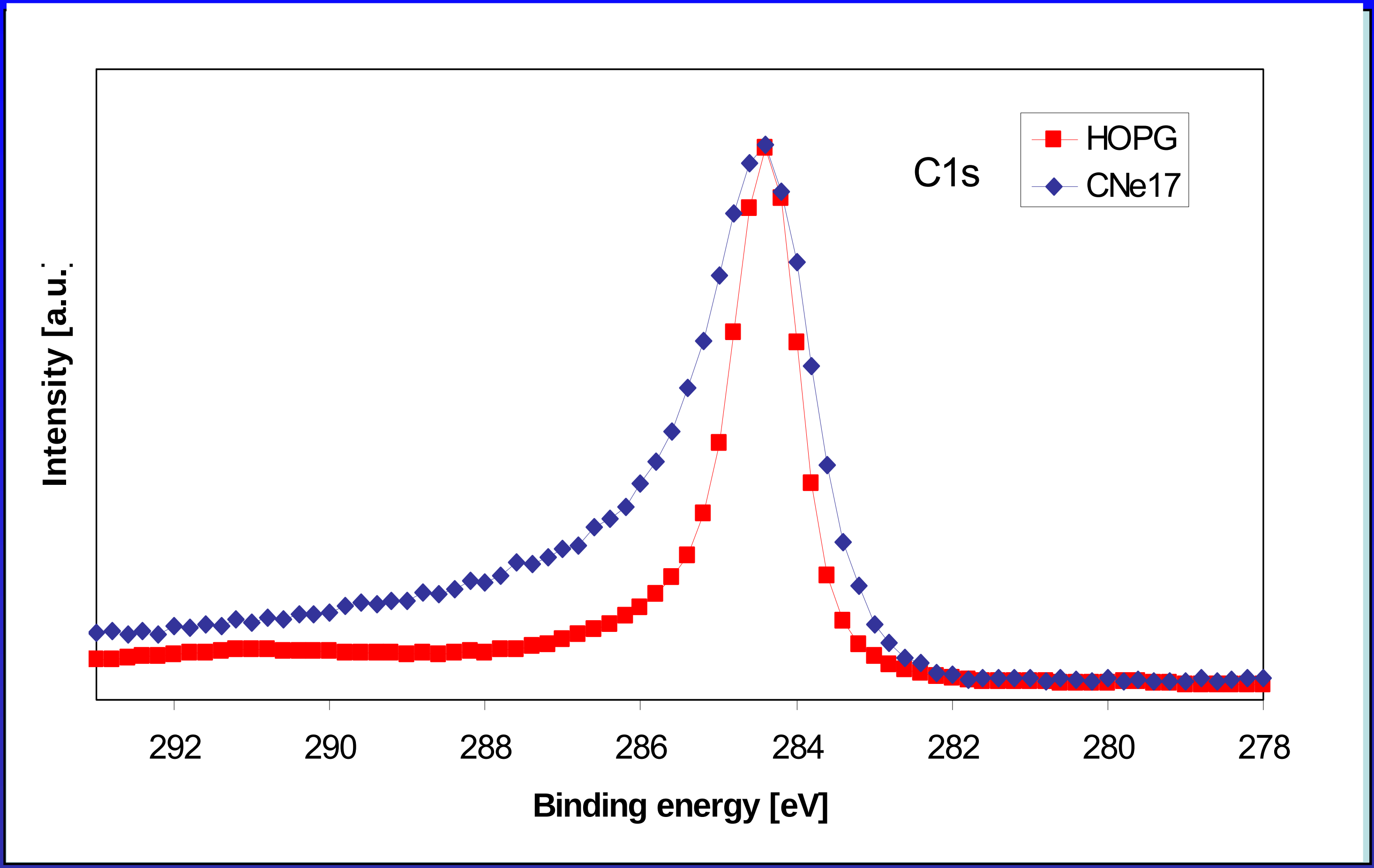
-No increase for a chamber left in air for months

-Same result for size above 5 µm



characterization

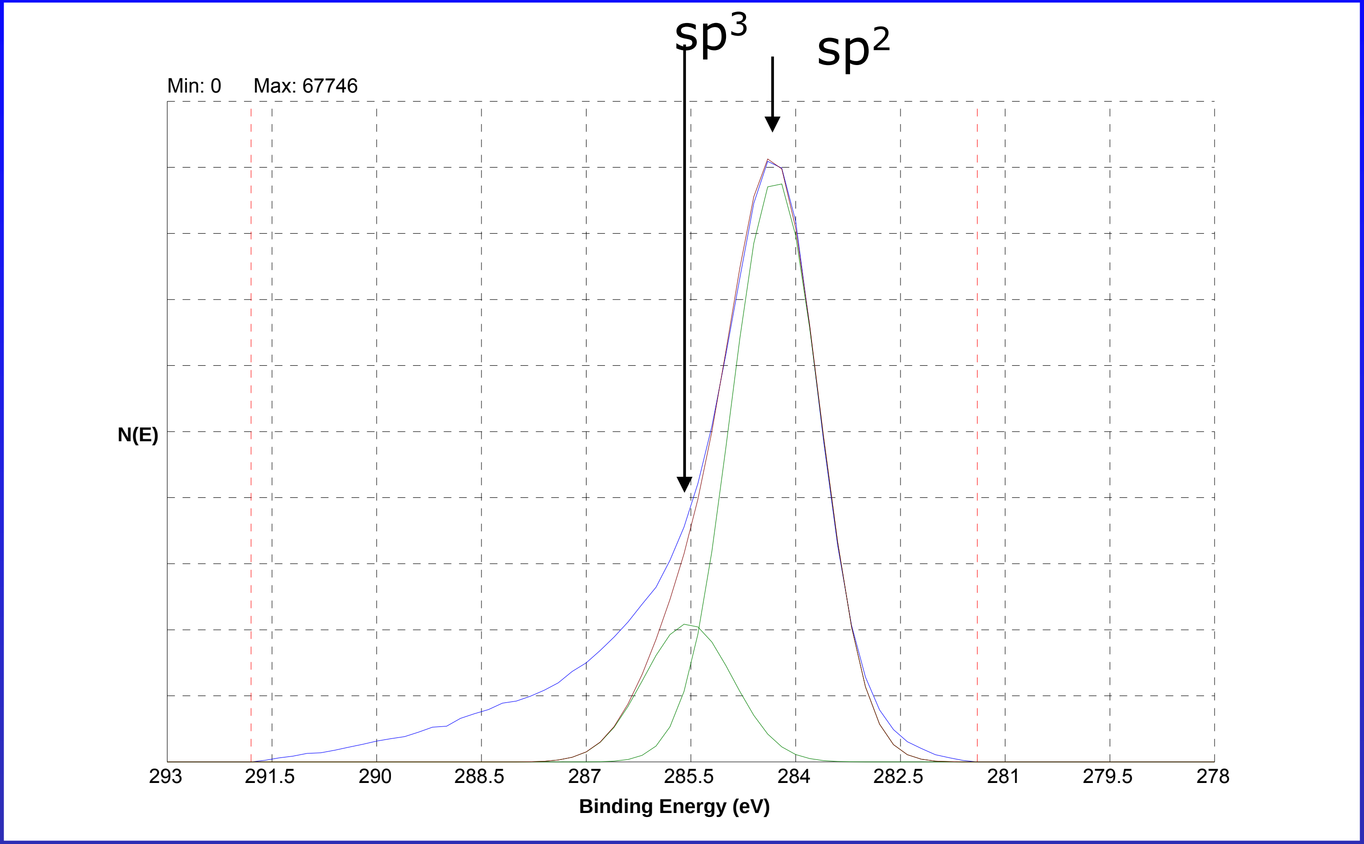
Surface analysis (XPS)



Peak broadening of C1s line compared to HOP-Graphite (cleaved in air), indicating the presence of more types of carbon atoms (or bonds)

No correlation of SEY with initial amount of O (6-10%)

De-convolute in two main components

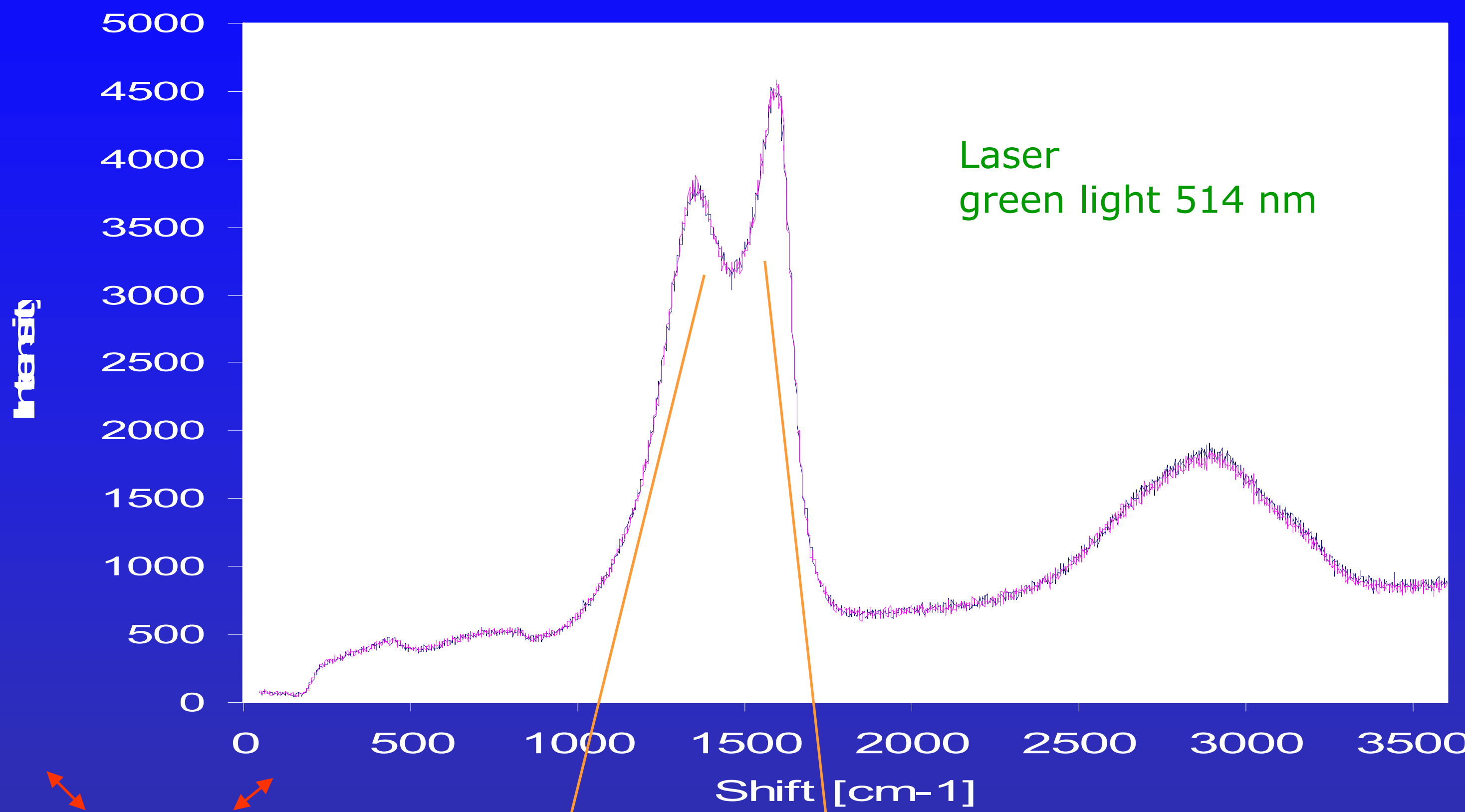


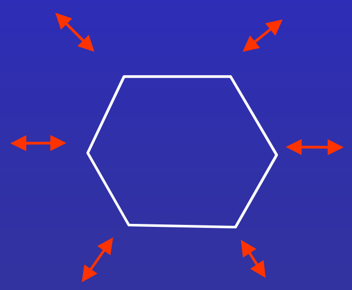
-Peaks as from Jackson and Nuzzo: 284.3eV +/-0.1 eV and 285.5 eV+/-0.1 , FWHM 1.5eV for both peaks, interpreted as sp^2 and sp^3

-11-27% of the intensity in the sp^3 peak in a-C (no correlation with SEY values)

Structural order: Raman spectroscopy

(measurements at the University of Cambridge UK, A.Ferrari group)





D peak,
breathing mode
(disorder)

G peak, chain stretching (Graphite)

→ Extract ratio D/G and G position

Result from Raman

Based on the ratios of D/G peaks and G position:

➔the coatings are all in the region of high **sp^2** content

➔at a more detailed level there is no obvious correlation between the Raman measured "order" and the SEY values

➔a more systematic study is necessary to identify a possible correlation between Raman result and deposition parameters (power or pressure)

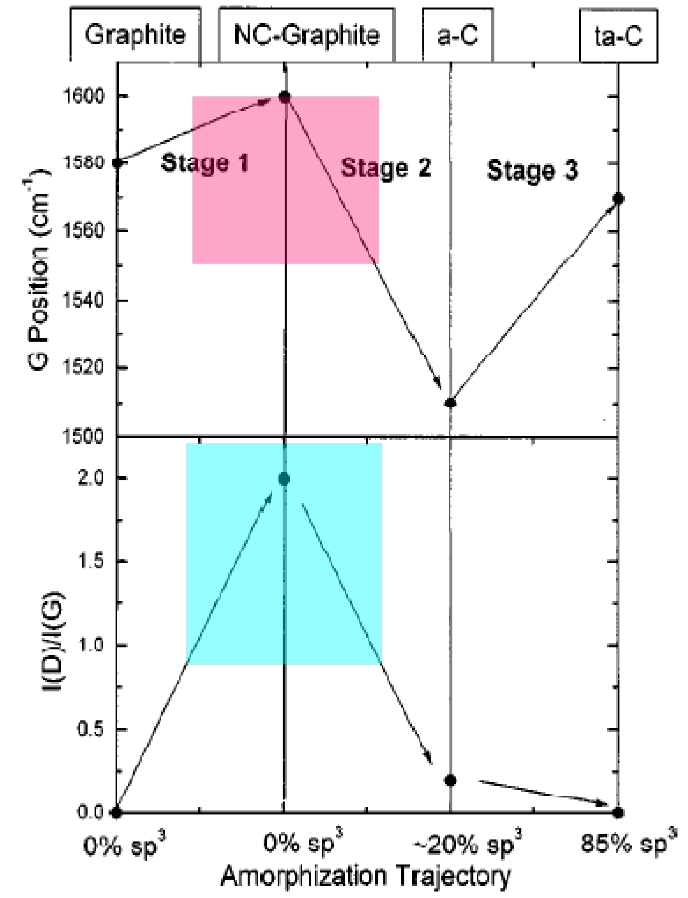
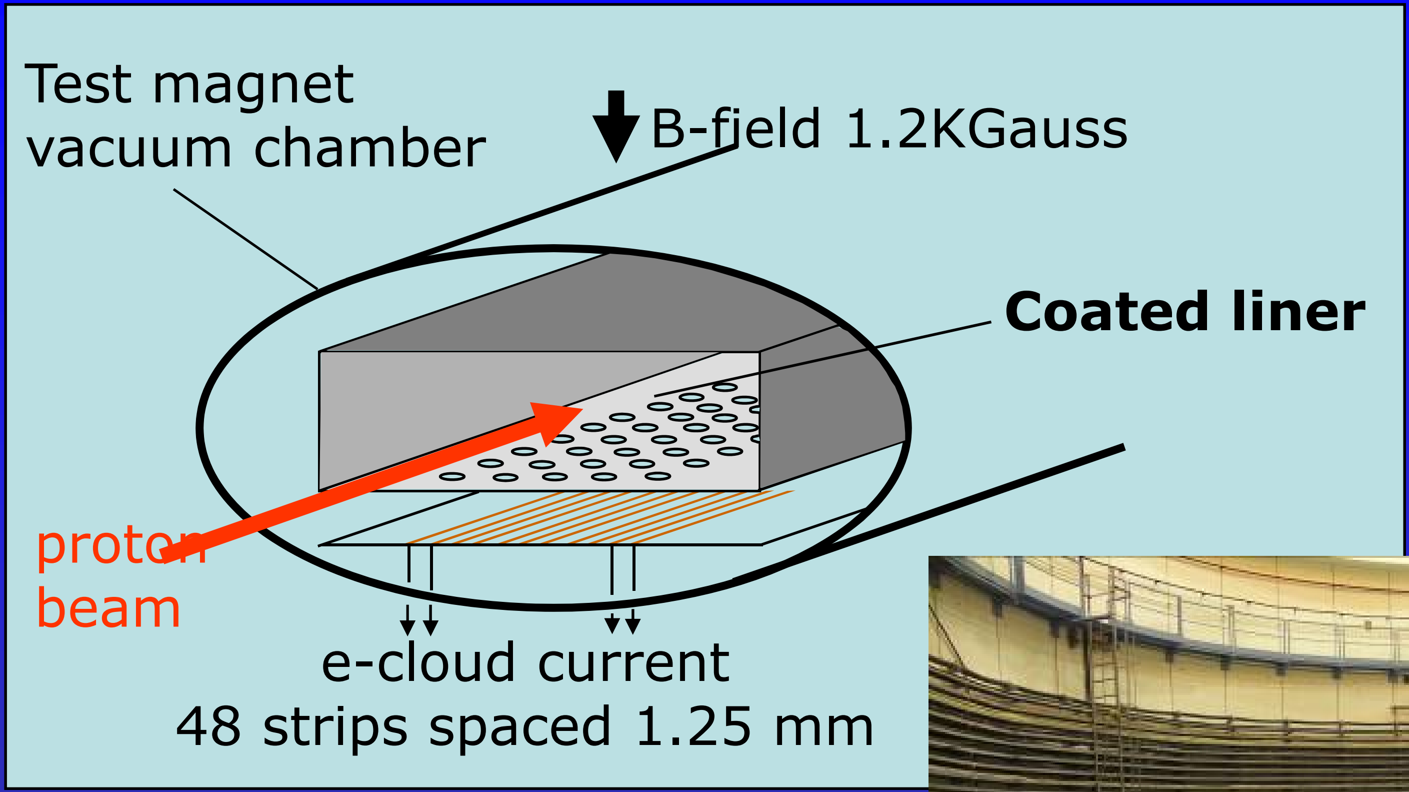


FIG. 7. Amorphization trajectory, showing a schematic variation of the G position and $I(D)/I(G)$ ratio

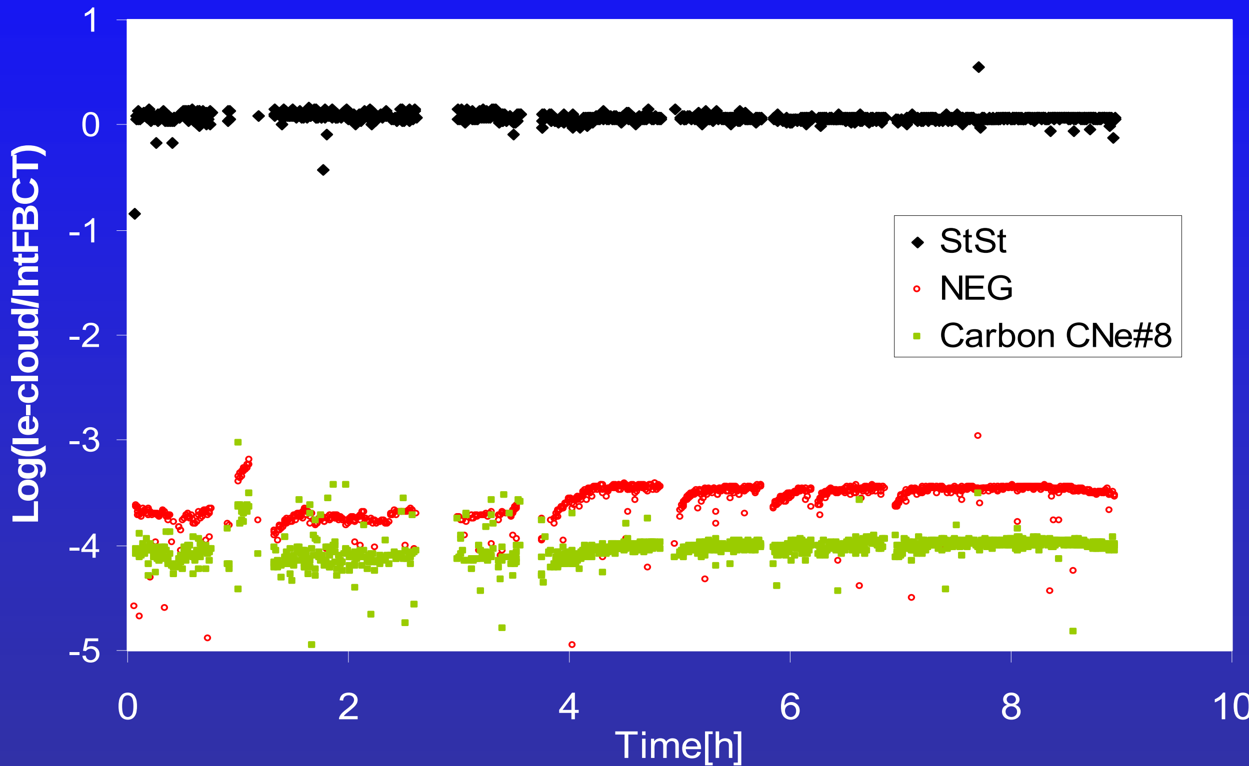
A.Ferrari et al PRB65

SPS tests: Electron cloud monitors



a-C coating in e-cloud monitors in SPS, MD run w28

Set-up: a-C coated liner with strip detector in 1.2KGauss field
Beam: 2-3 batches, 72 proton bunches, 25 ns spacing, 450 Gev/c



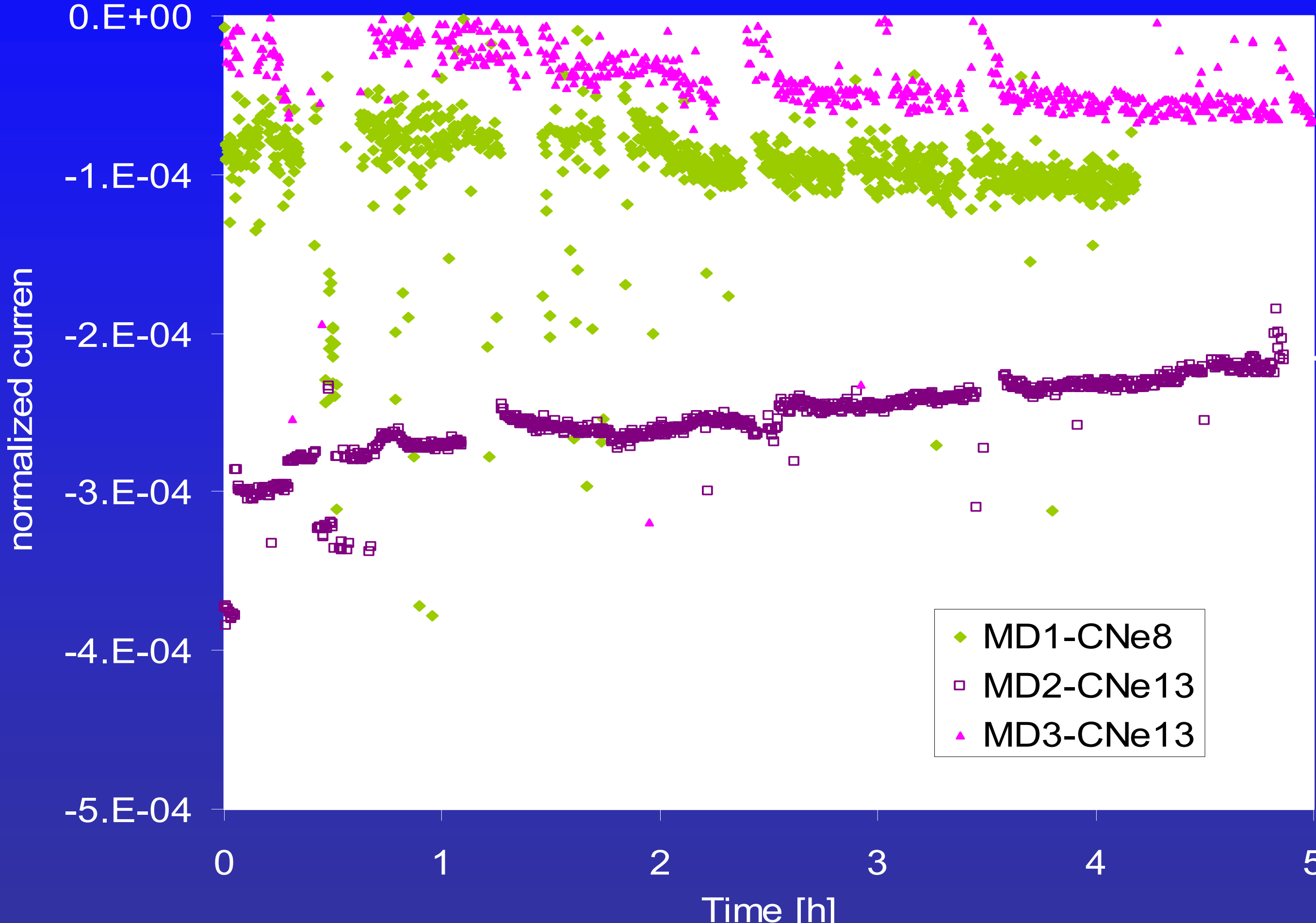
StSt for 2h air exp. δmax=2.5

TiZrV-NEG fully activated, δmax=1.1

CNe for 2h air exp.δmax=0.95

-Coating CNe8 gives 10^{-4} times current compared to StSt, consistent with measured δmax

Summary of MD runs (2008)



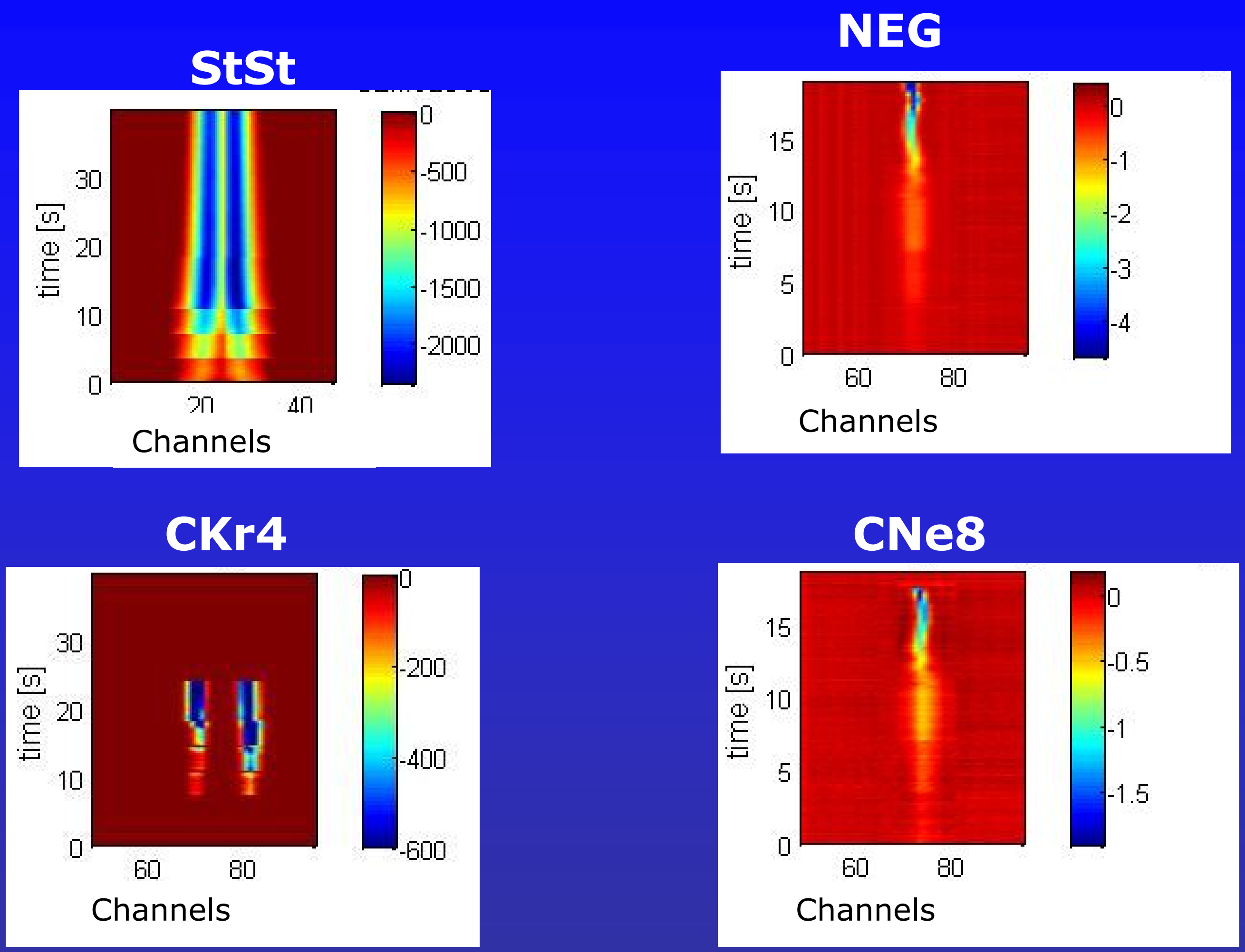
CNe13
2 weeks air
+2 month in SPS

CNe8 2h air
δmax=0.95

CNe13
2 weeks air
δmax=1.14

NB: linear vertical scale!

Spatially resolved



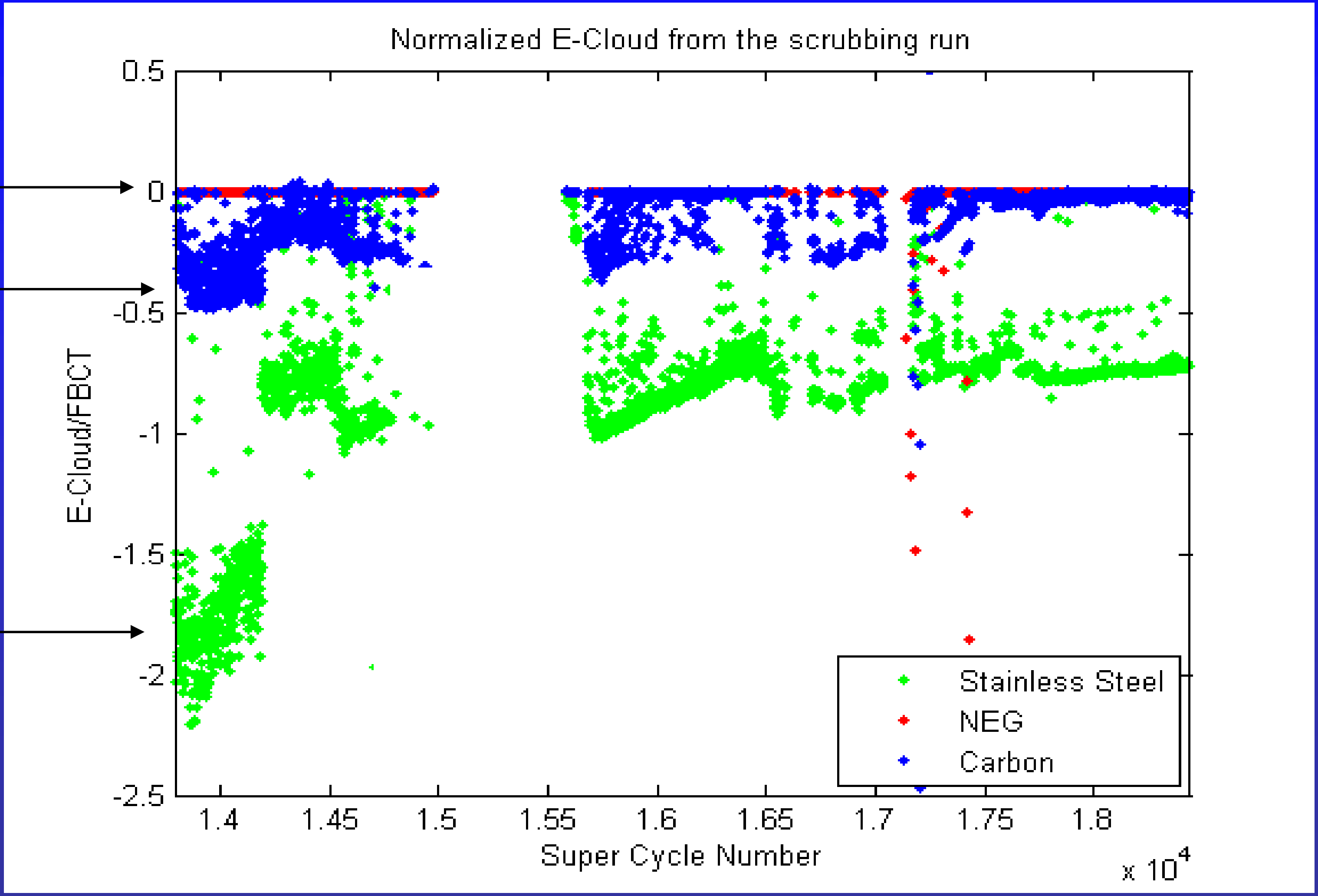
The single stripe could be just due to ionization of residual gas; the order of magnitude is close to this

Agreement with the prediction of the simulation: above 1.3 is bad!

NEG (1.1)

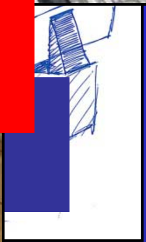
CKr4 (1.33)

StSt 2.5)



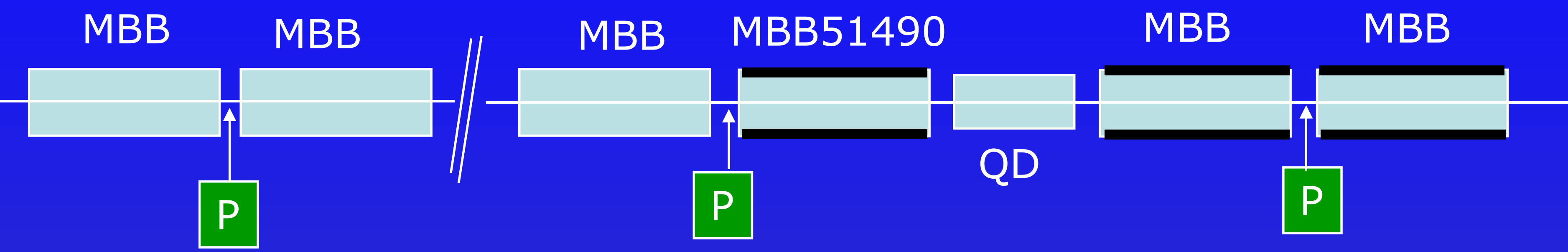
Coating of 3 MBB S

It was a real race and a real success thanks to an excellent collaboration

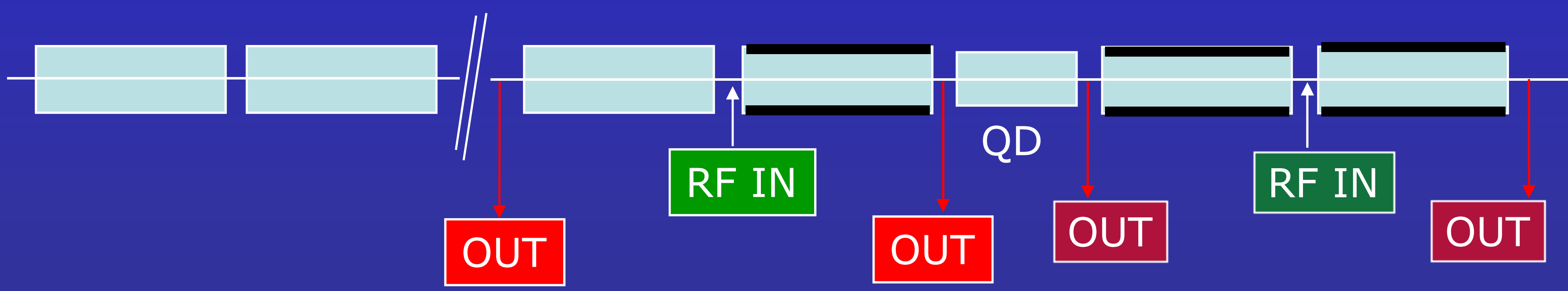


Diagnostics in the coated MBB installed in SPS:

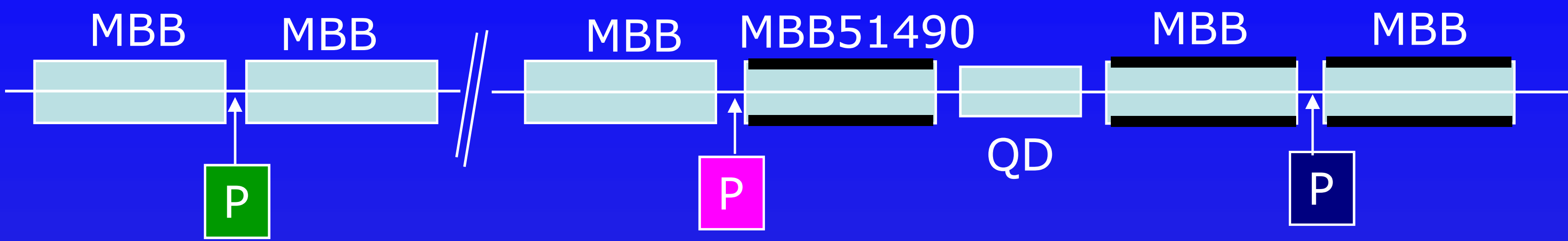
Pressure gauges

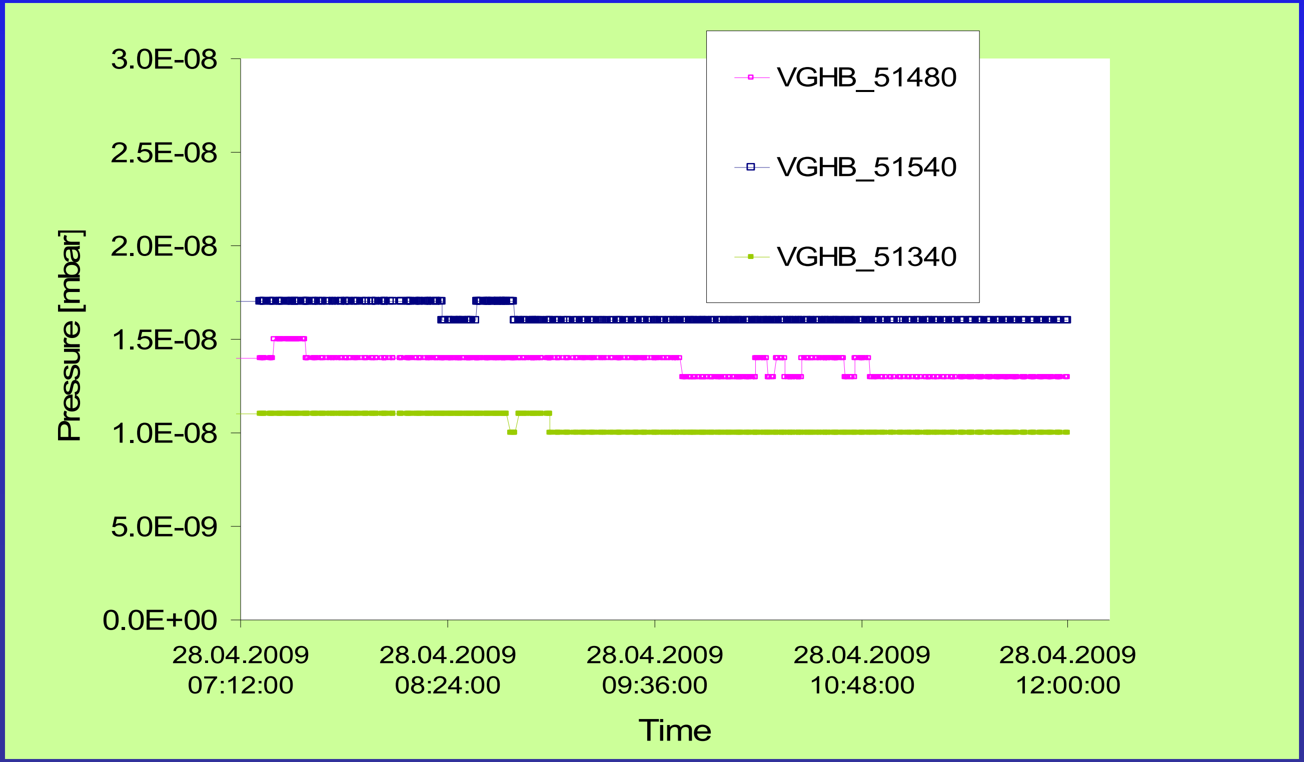


RF transmission (F.Caspers, E.Mahner)

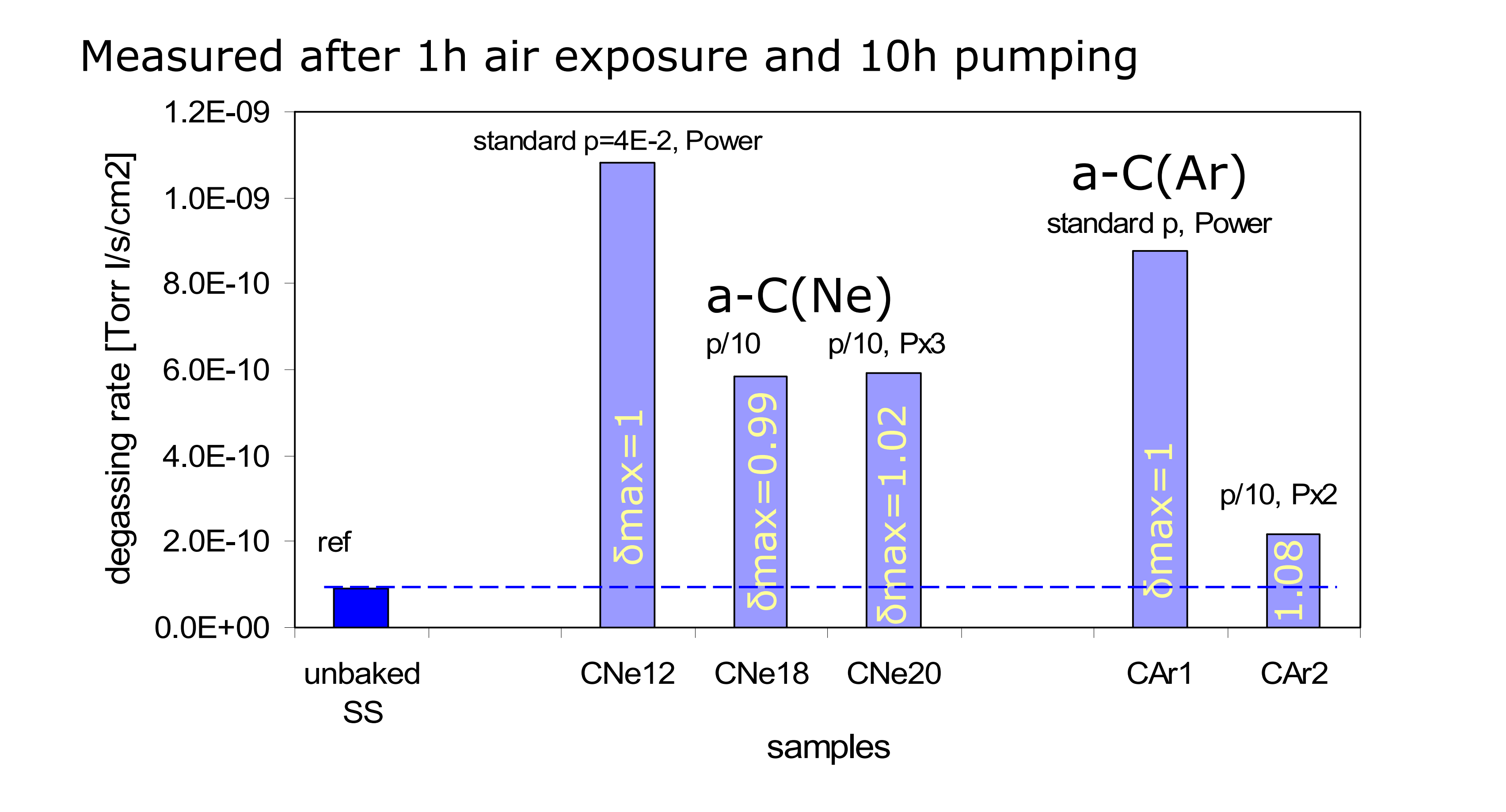


SPS pressure readings 28/5/09



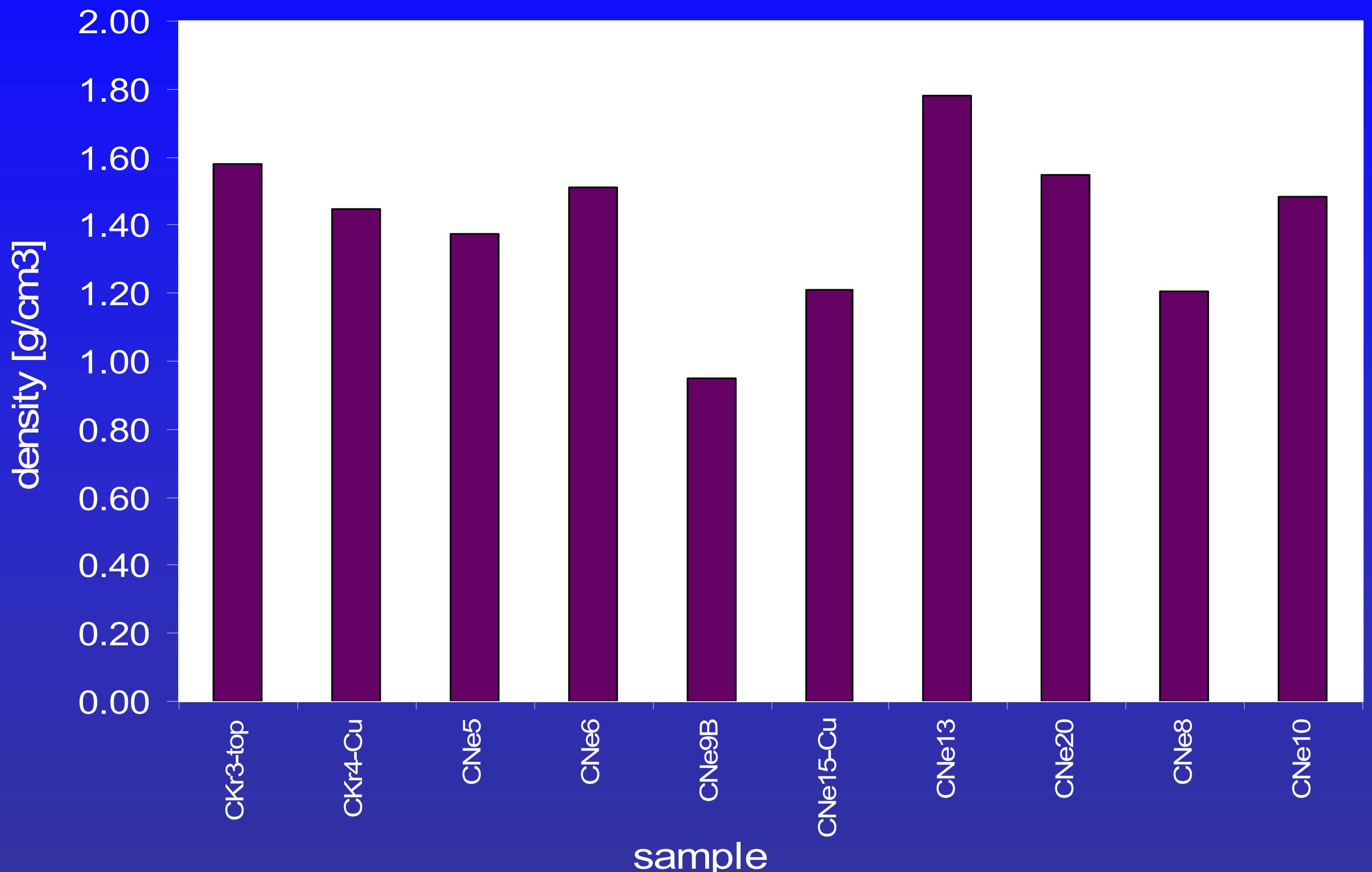


Degassing rate for different coatings



-less porous at low pressure of deposition (less voids for faster ions F.Rossi, J.Appl. Phys. 75, 3121, 1994)?

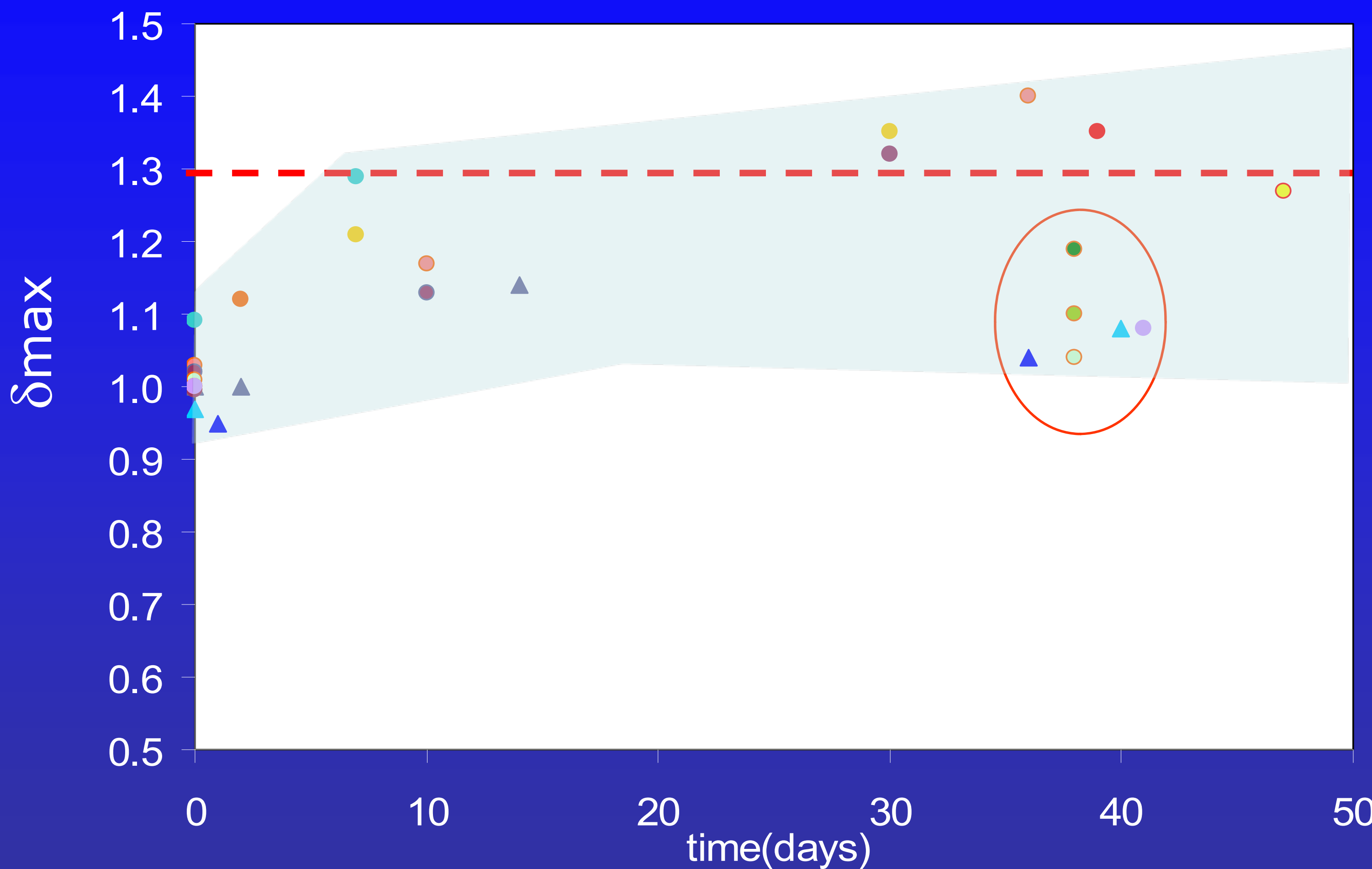
Density of the coatings



Area density measured by Nuclear Reaction Analysis (J.Colaux LARN Namur, B)

The low density could be explained by porosity

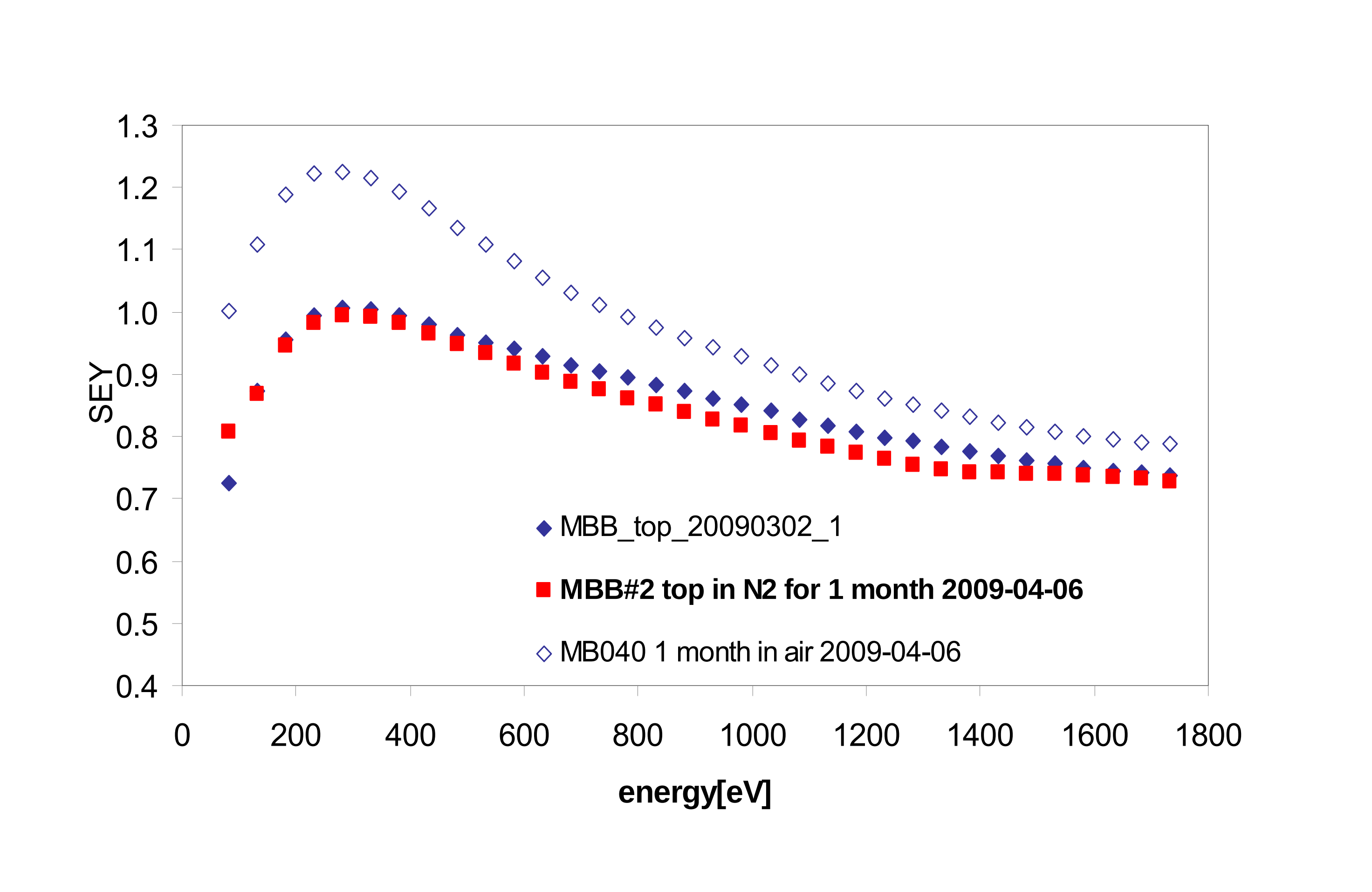
Aging as a function of air (sample box) exposure time



No cumulated dose

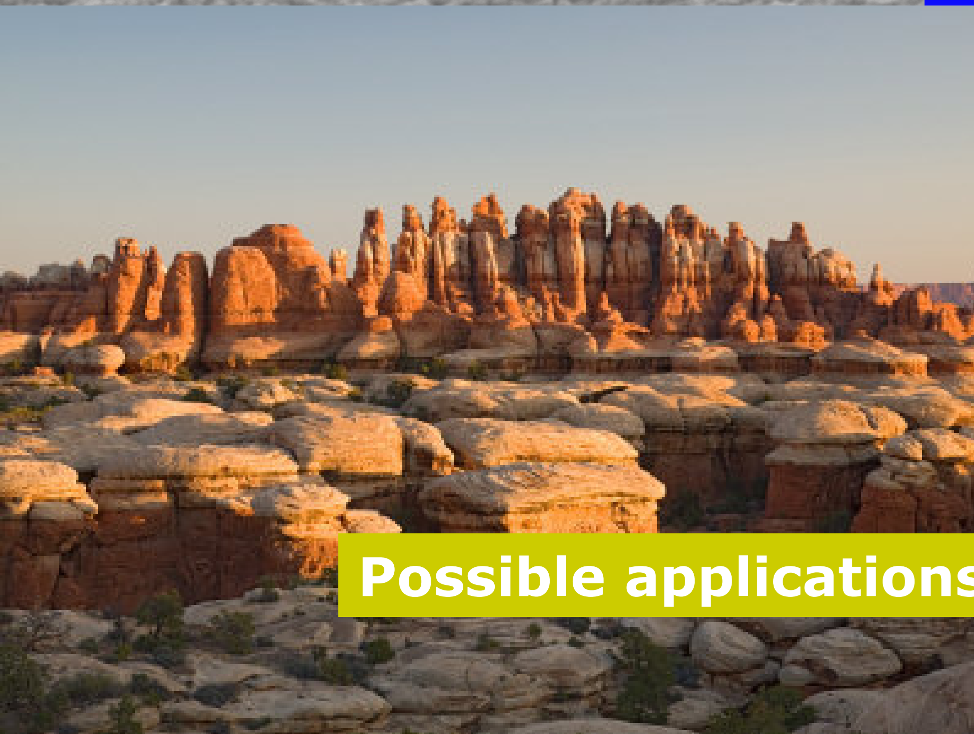
The origin of aging is not explained yet (for instance no correlation of the initial amount of O with the SEY). For metal surfaces is known to be related to the airborne contamination (N.Hilleret et al. Ap.Phys. A76, 2003, 1085)

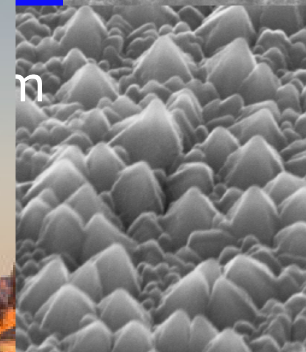
Storage and aging of a-C: air vs N_2

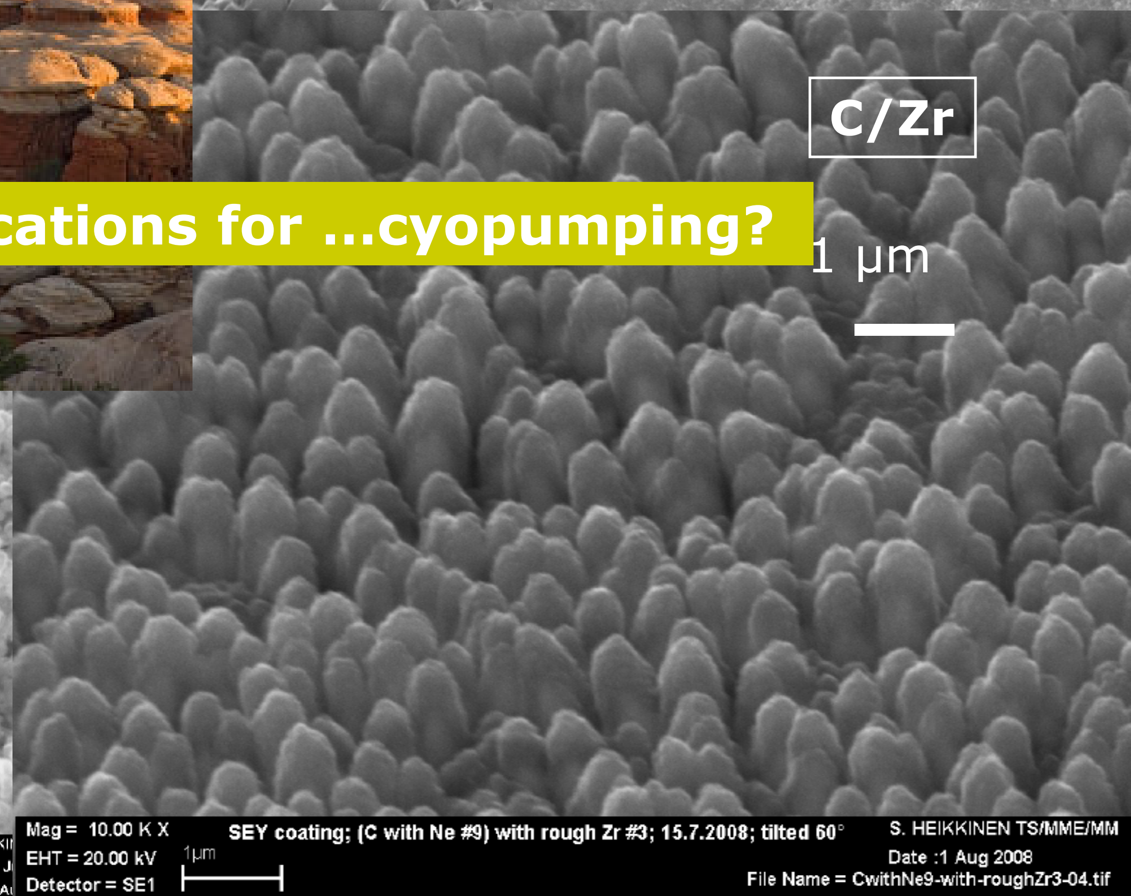


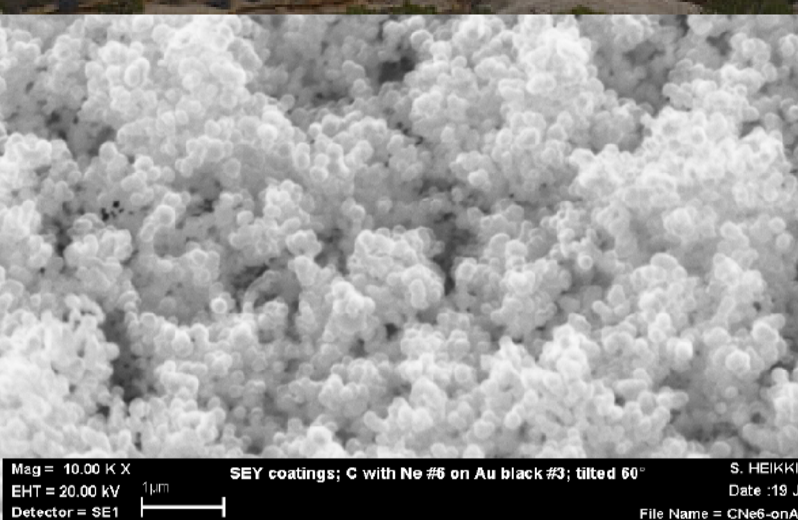
- preliminary…. only 2 samples for the moment
-useful for storage before installation or during machine maintenance

Rough coatings to lower the SEY



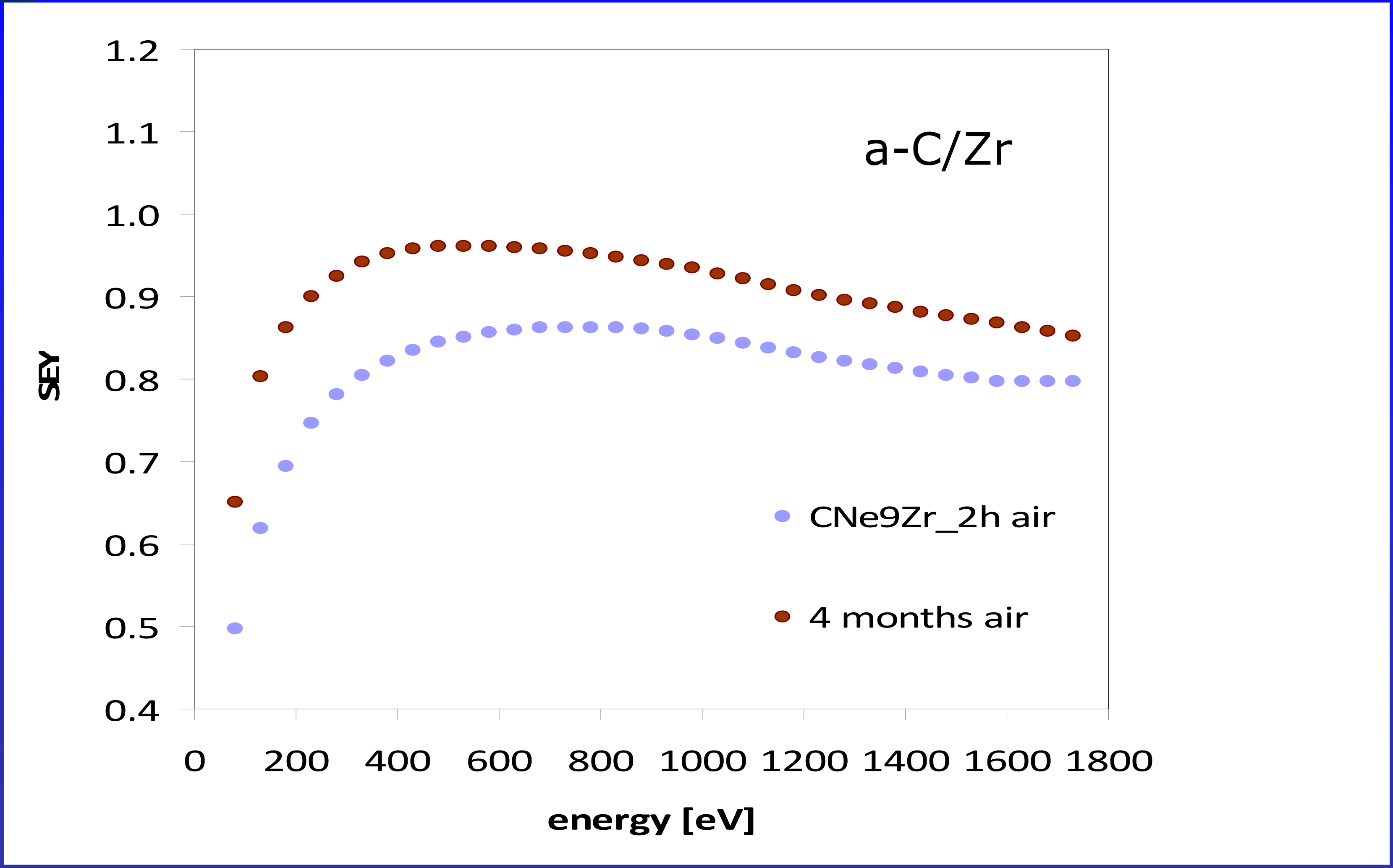






Possible applications for ...cyopumping?

Improvement with a-C on rough coatings

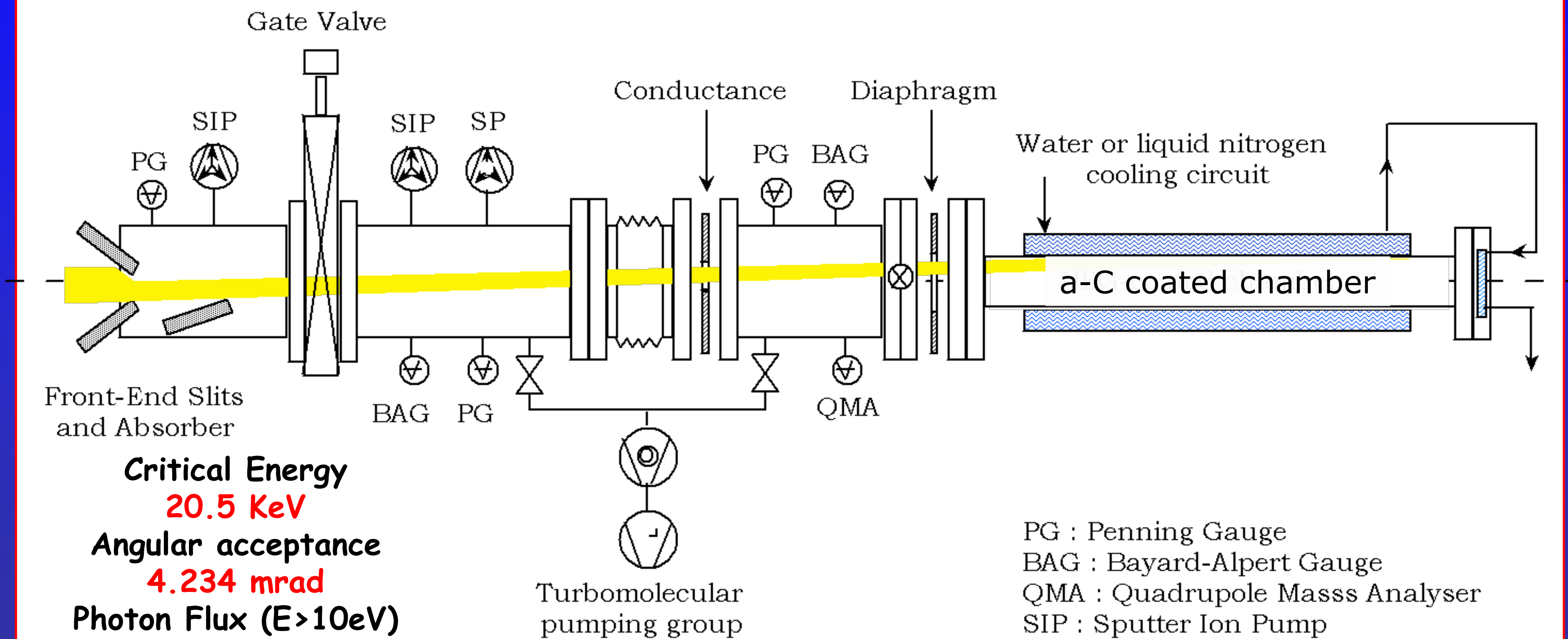


-advantage: low SEY, possibly less sensitive to aging
-disadvantage: 2 subsequent coatings, more outgassing due to larger effective surface (?)

Photon Stimulated Desorption at ESRF

D31

Angle of incidence = 25 mrad

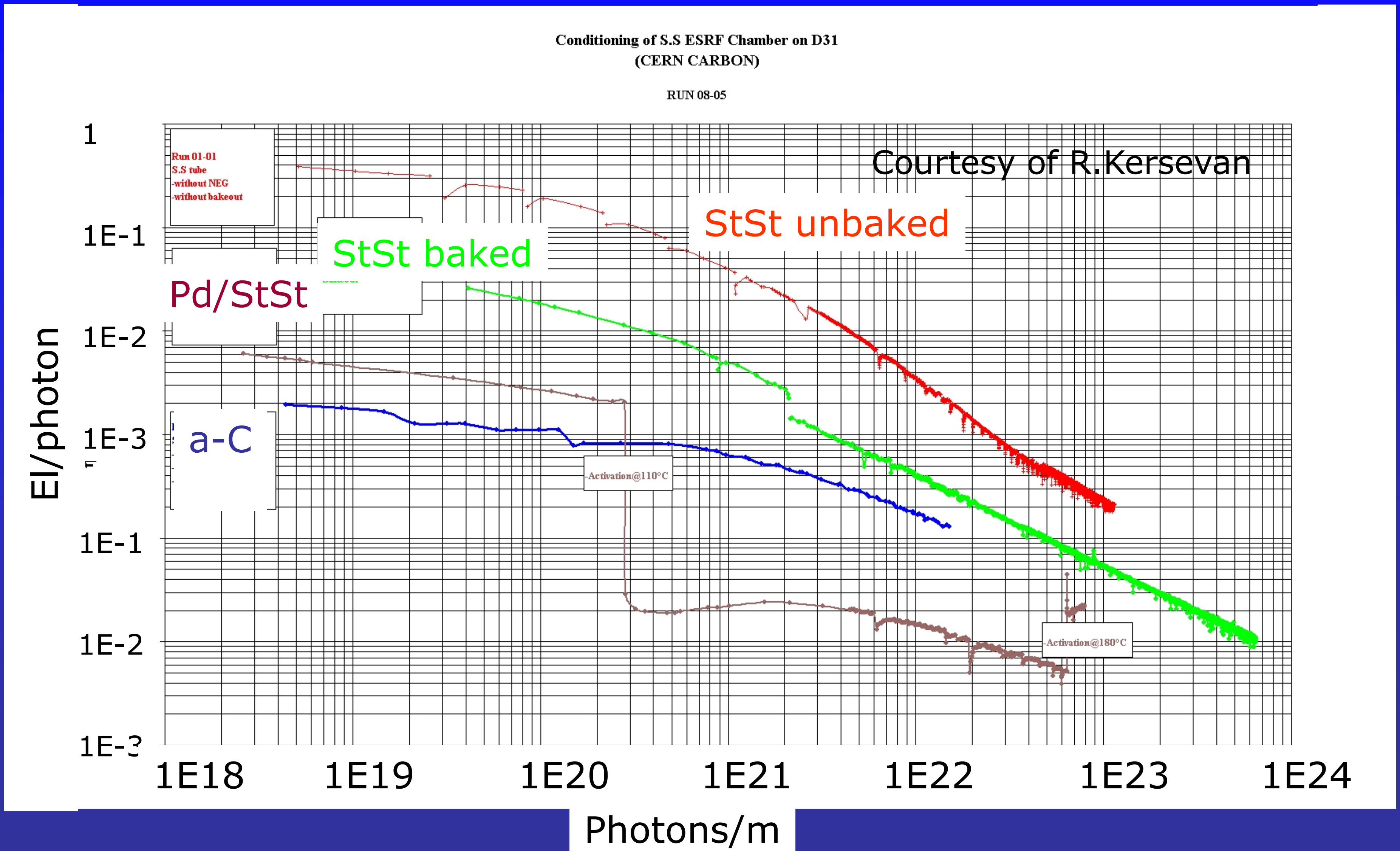


PG : Penning Gauge
BAG : Bayard-Alpert Gauge
QMA : Quadrupole Masss Analyser
SIP : Sputter Ion Pump
SP : Sublimation Pump

Critical Energy
20.5 KeV
Angular acceptance
4.234 mrad
Photon Flux (E>10eV)
2.94×10^{15} photons $(s\ mA)^{-1}$
Beam Energy
6 GeV
Typical Beam Current
185 mA

Courtesy of R.Kersevan

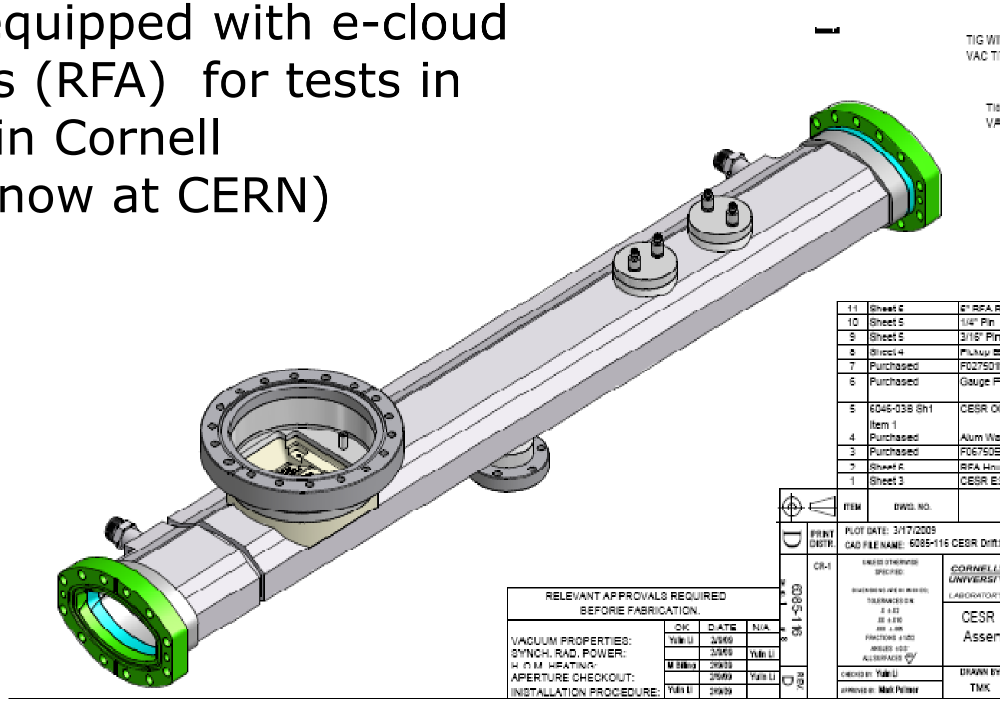
Photon Stimulated Desorption



Tests at CesrTa (Cornell) for the damping ring case

-For damping rings (CLIC, ILC): e-cloud in arcs and wigglers
-Photons! The photoyield (PY) also plays a role
-Strong e-cloud for δmax>1.3 independently of PY
-For lower SEY it depends on PY

Coating of an Al vacuum chamber equipped with e-cloud diagnostics (RFA) for tests in july 2009 in Cornell
(chamber now at CERN)



Conclusions

-a-C coatings with low SEY are successfully produced by magnetron sputtering
-they demonstrate e-cloud supression in e-cloud monitors
-Are under test in real MBB dipoles for e-cloud, vacuum and for robustness in accelerator environment

Next:
-investigate the aging in air and various gases
-characterization in ESD
-optimize deposition in MBB and MBA dipoles (uniformity etc..)
-optimize the width to be coated with tests in e-cloud monitors
-develop the logistics for the implementation of the coating operations in the SPS cavern (transport and coating strategy, cleaning process before coating……)

This work is the fruit of the collaboration of :

SPSU team, chaired by E. Shaposhnikova

EN-MME

DG-SCR

TE-MSC

TE-VSC

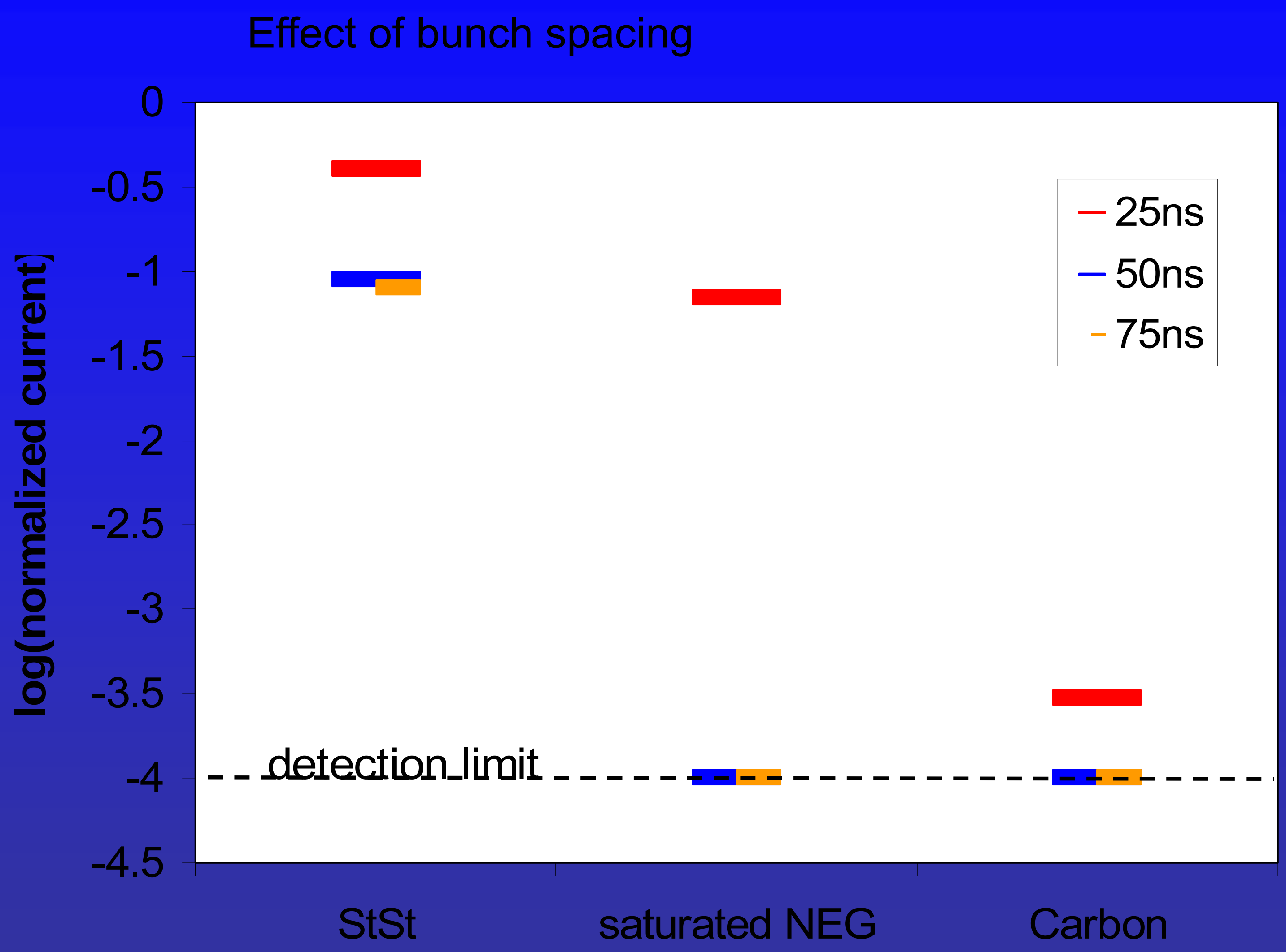
LARN-Namur (J.Colaux, S.Lucas)

University Cambridge (A.Ferrari)

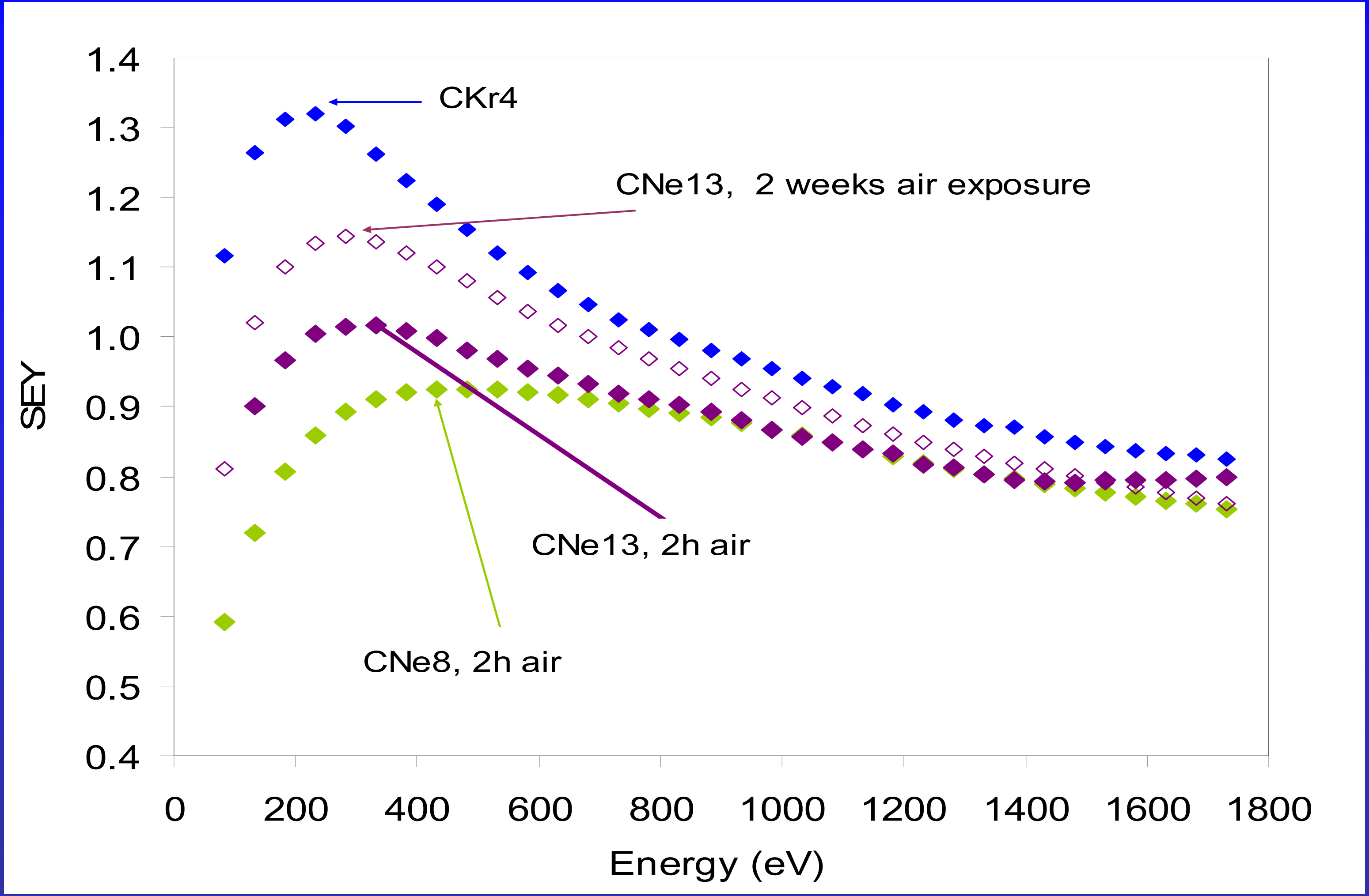
ESRF (R.Kersevan)

Thank you so much!

Effect at different bunch spacings (MD3)



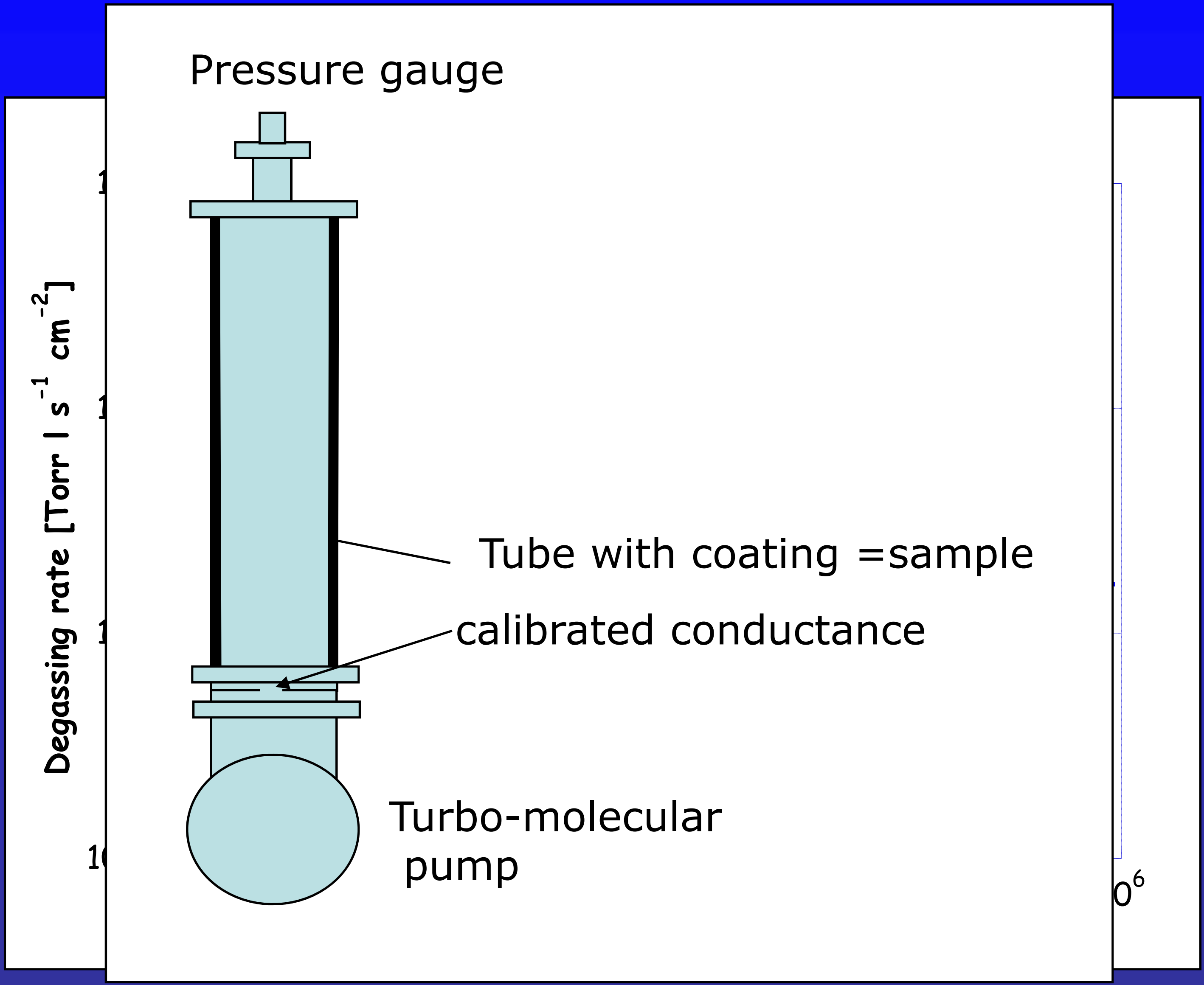
a-C coatings in the e-cloud monitors in 2008



In addition two reference liners:
StSt with δmax measured as **2.5** and TiZrV (activated) with δmax **1.1**

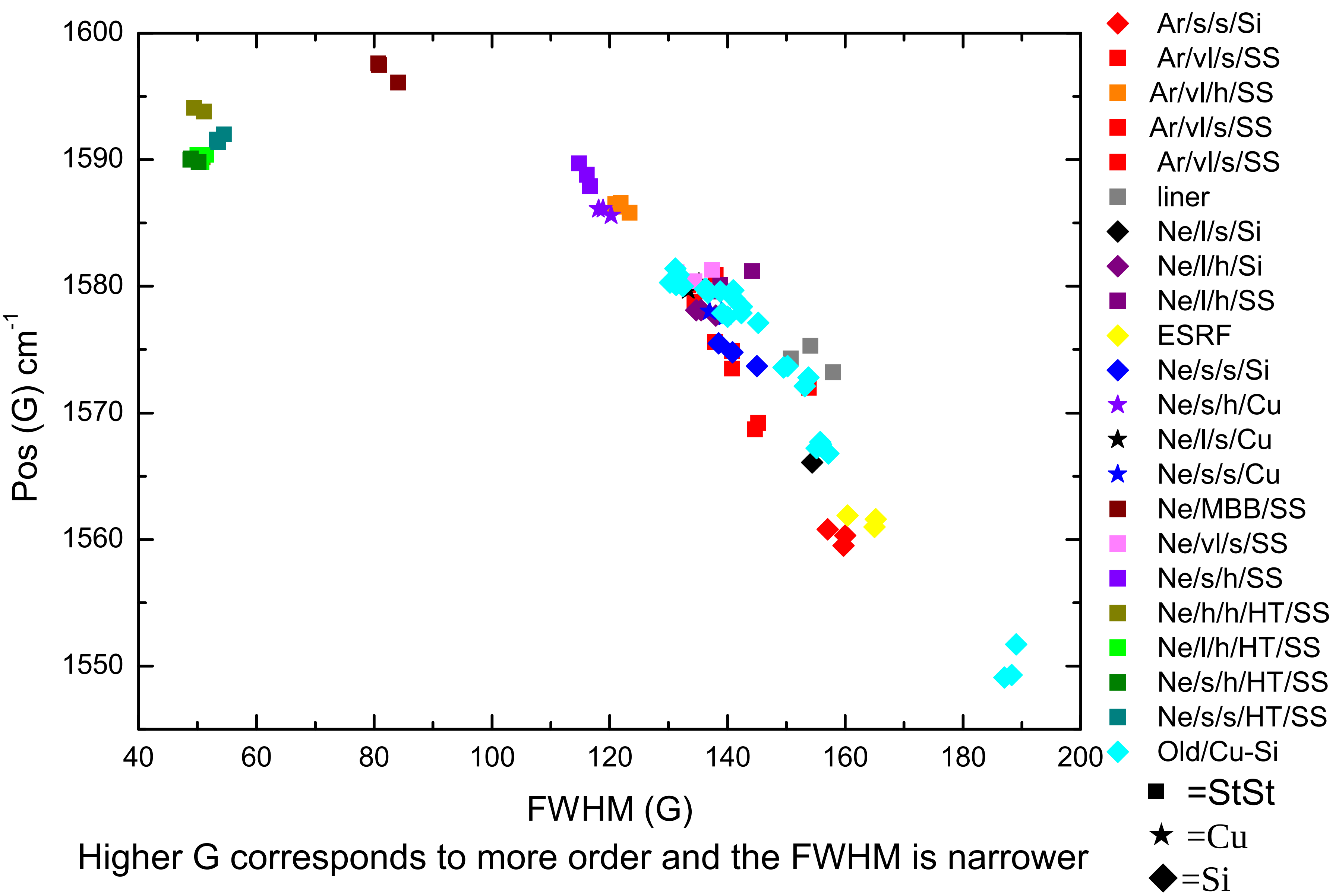
characterization

UHV compatibility: pumpdown curve



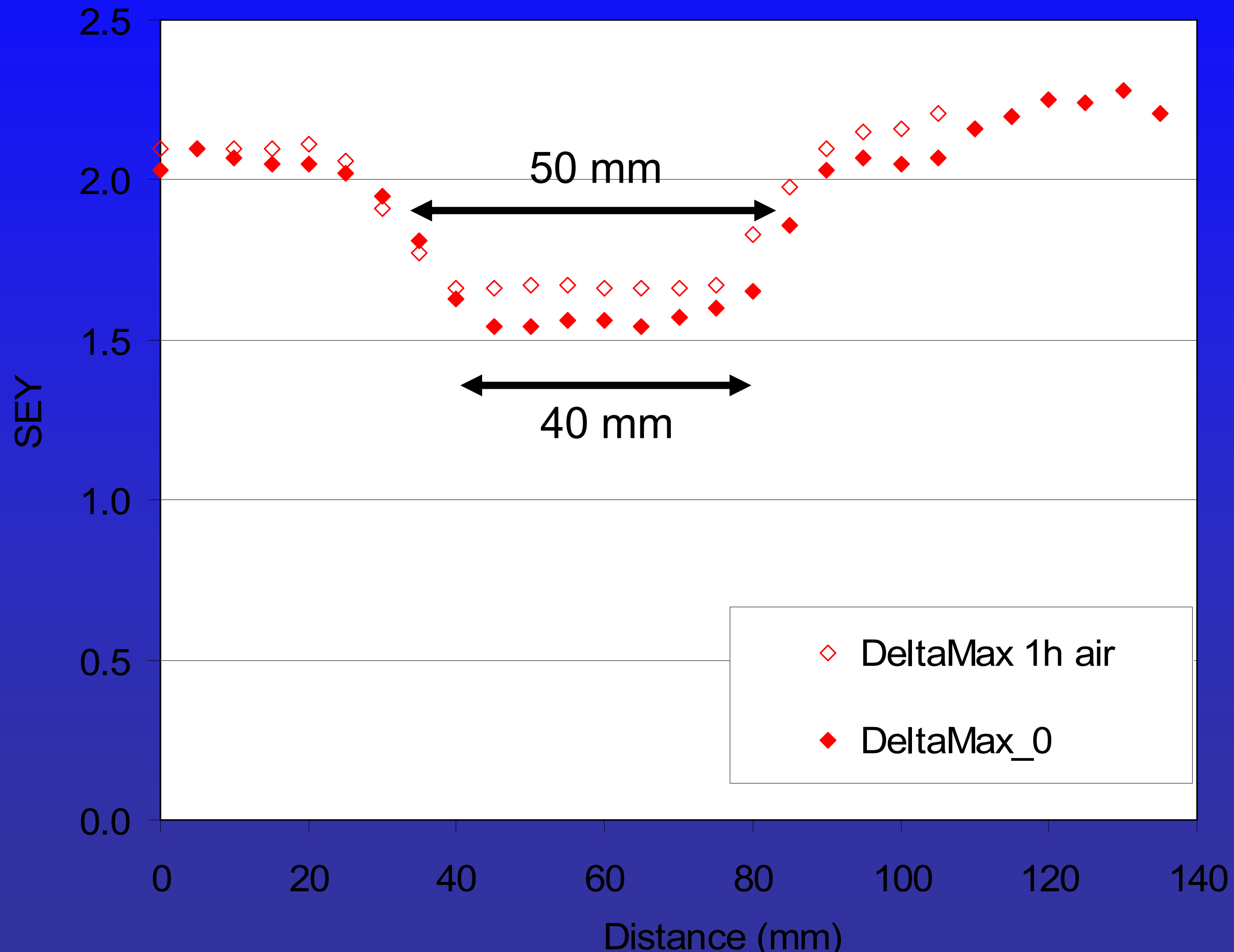
Range of degassing wrto StSt after 10h

G peak position and FWHM



Higher G corresponds to more order and the FWHM is narrower

Previous experiment (2008) in C-magnet with StSt reference sample



SEY of the inserted materials

TiZrV-NEG, δmax=1.1 fully activated
C#4, (scrub. run), δmax~1.4 for 2h air exp. (measurements at 500eV only)
C#8,(MD) δmax=0.95 for 2h air exp.
SS, δmax=2.5 for 2h air exp.