E-cloud studies for the SPSU Study Team and for PS2

G. Rumolo, LIS Meeting, 23.02.2009

*thanks to G. Arduini, E. Benedetto, M. Benedikt, S. Calatroni, P. Chiggiato, B. Henrist, M. Jimenez, E. Mahner, Y. Papahilippou, E. Shaposhnikova, M. Taborelli, C. Yin-Vallgren, F. Zimmermann....

- SPS Upgrade, studies of new coatings with low Secondary Emission Yield (SEY)
  - Carbon coating: rationale and lab measurements
  - SPS run 2008: MDs with c-coated liners
  - SPS run 2009: plans
  - conclusions
- Studies for PS2:
  - Electron cloud build-up simulations
    - LHC and FT beams
    - Injection and extraction
  - conclusions

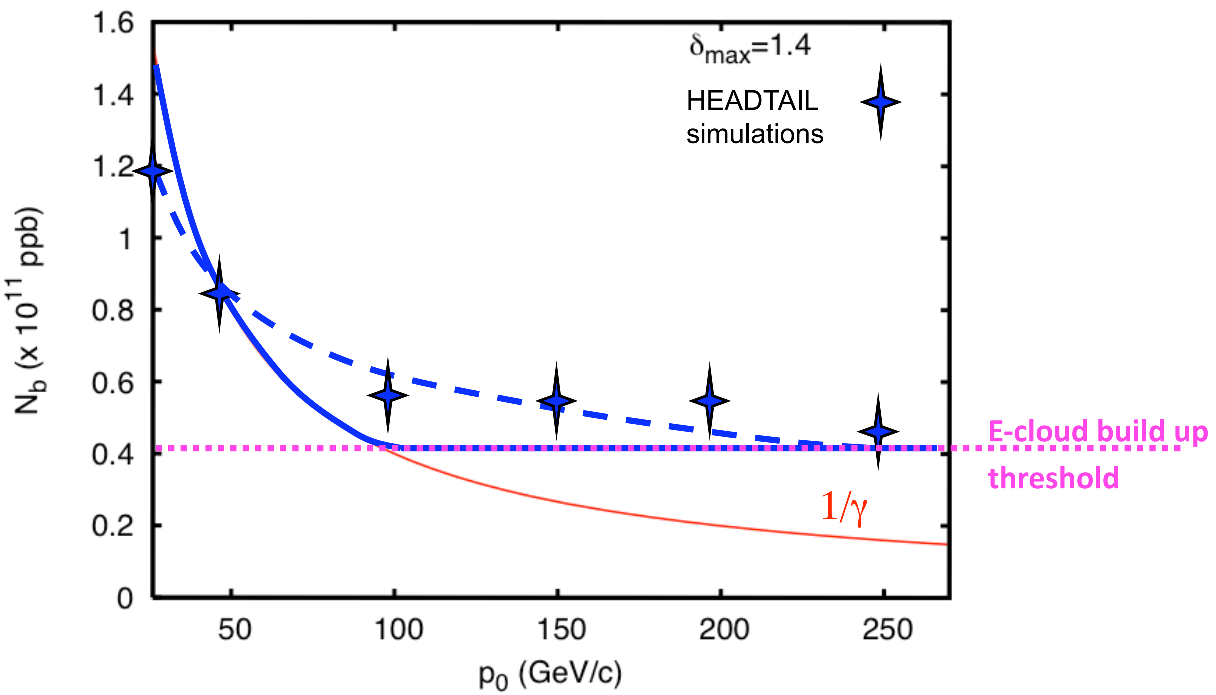
Future situation with PS2 + SPS

Parameters	PS2 offer per cycle at 50 GeV			SPS record at 450 GeV		LHC request at 450 GeV	
	25 ns	50 ns	FT	25 ns	FT	25 ns	50 ns
bunch intensity $/10^{11}$	4.4	**5.5**	1.6	**1.2**	0.13	1.7	**5.0**
number of bunches	168	84	840	288	4200	336	168
total intensity $/10^{13}$	7.4	4.6	**12.0**	3.5	**5.3**	5.7	8.4
long. emittance [eVs]	0.6	0.7	0.4	0.6	0.8	<1.0	<1.0
norm. H/V emitt. [μm]	3.5	3.5	15/8	**3.6**	8/5	3.5	3.5

E. Shaposhnikova, ECM'08

→ need to upgrade SPS, even if the higher injection energy is expected to improve the performance in many respects, electron cloud mitigation is necessary!
→ will PS2 suffer from electron cloud ?

Scaling of the electron cloud threshold with energy (self-consistent model)



For δ_{max}=1.4 the instability threshold is found to decrease with γ up to ~100 GeV/c, then it levels off at the value of the build up threshold

→ Conservation of longitudinal emittance, bunch length and normalized transverse emittances.

→ Bunch always matched to the bucket !

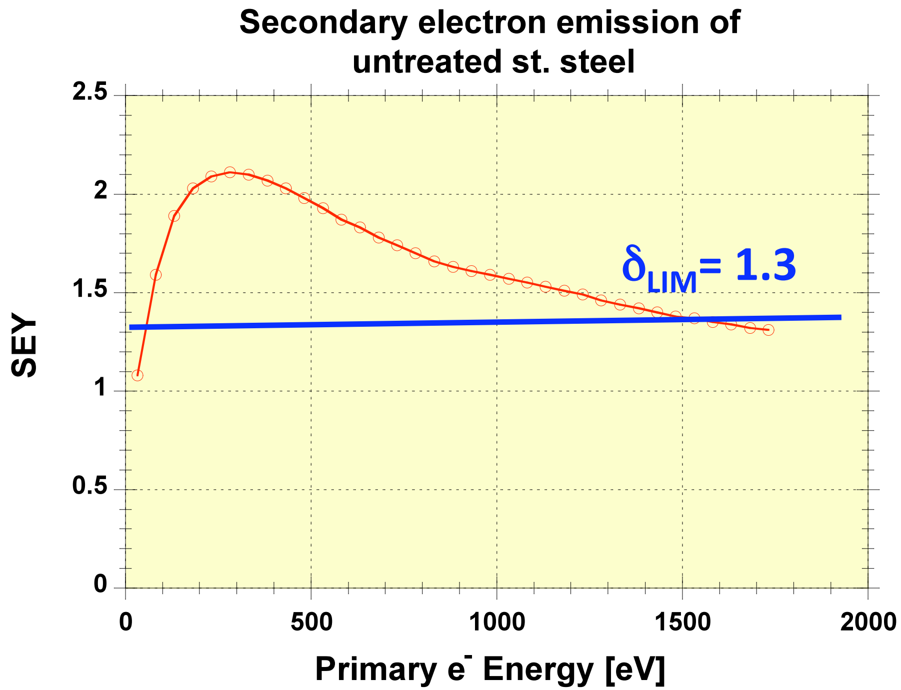
Looking out for mitigation techniques….

For traditional beam pipe metals, e.g. SS, after surface cleaning SEY is higher than 2.

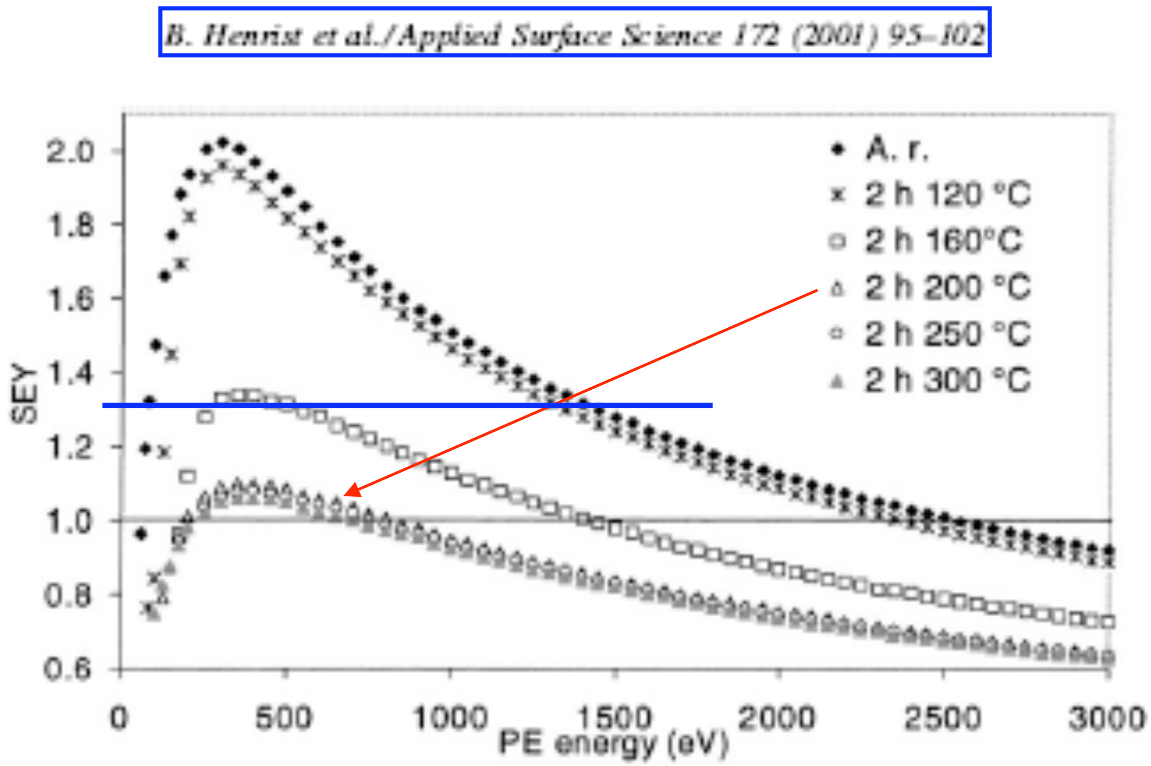
Build up simulations have shown that SEY as low as 1.3 would be sufficient to suppress the electron clouds in the dipoles of the SPS (MBB chambers, MBA chambers have higher SEY threshold).

SEY can be reduced by:

- **<u>in situ</u> bake-out (for T=300°C, δ_{max} of Cu: 2.3 ⇨ 1.5)**
- **increasing the electron impingement dose (so called conditioning or scrubbing): fully conditioned surface for 10^{-3} C mm^{-2}.**



Looking out for mitigation techniques….



Lower SEY are obtained for Ti-Zr-V coatings after heating in vacuum at a temperature as low as 180 °C. Additional benefits:

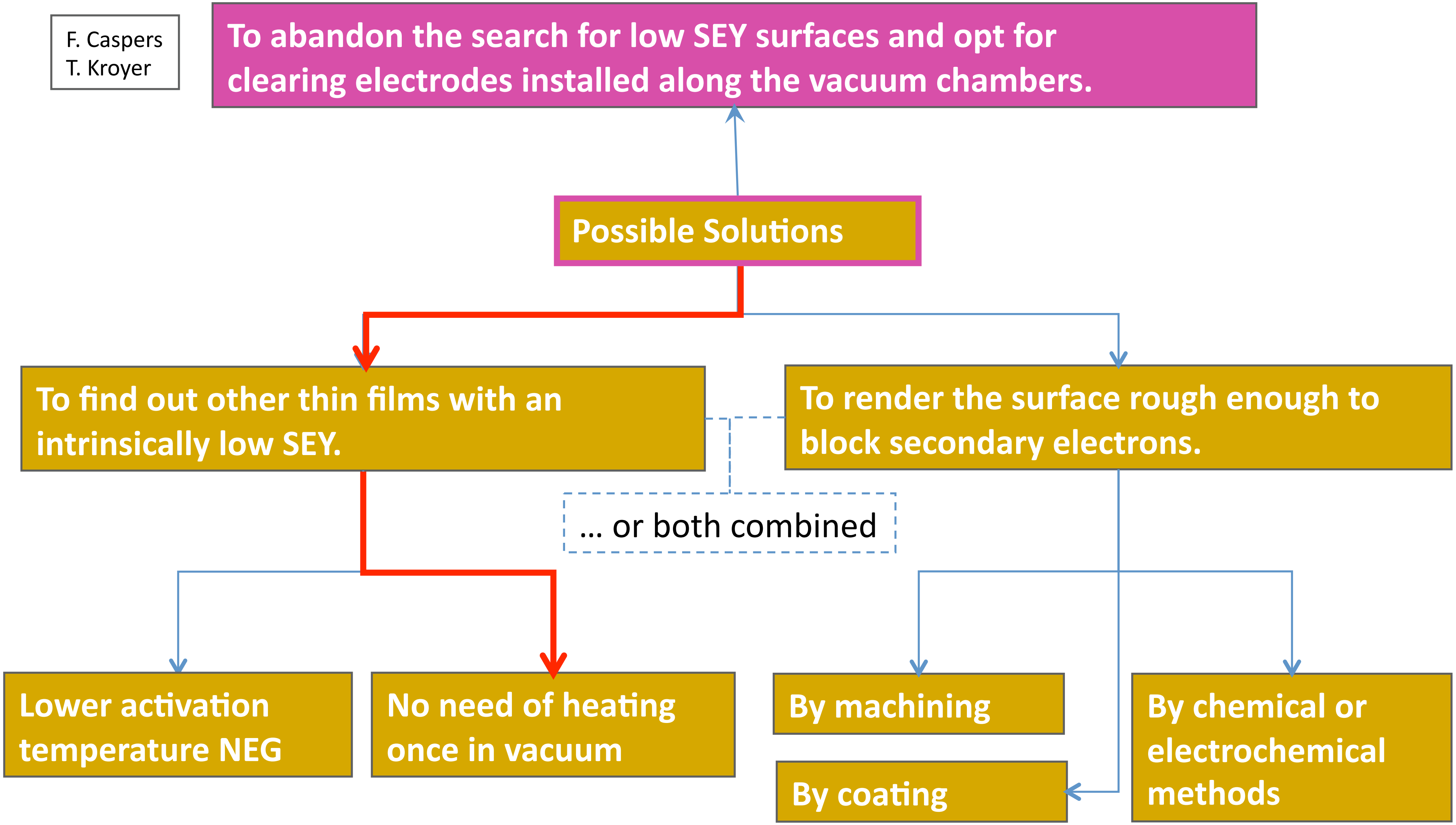
- **high distributed pumping speed**
- **low desorption yields**

Most of the Long Straight Sections of the LHC are coated with Ti-Zr-V.

However,

- **the SEY becomes as high as 1.4 after several cycles of venting/activating**
- **SPS dipole chambers cannot be heated because they are embedded in the magnets**

Looking out for mitigation techniques….



Looking out for mitigation techniques….

The ideal film material :

- **has intrinsically low SEY;**
- **is not prone to adsorb water vapor, oxygen and hydrocarbons;**
- **can be easily deposited on stainless steel beam pipes;**
- **is compact, smooth and not inclined to produce dust;**
- **is UHV compatible;**
- **has possibly low resistivity.**

Graphite could be a good compromise…

wherefrom the idea of trying to deposit amorphous carbon on the inner side of the vacuum chamber….

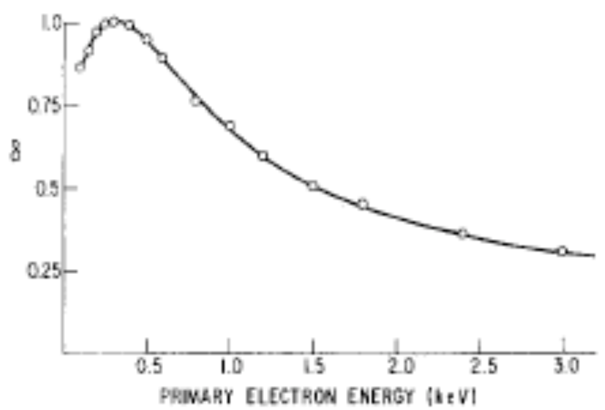
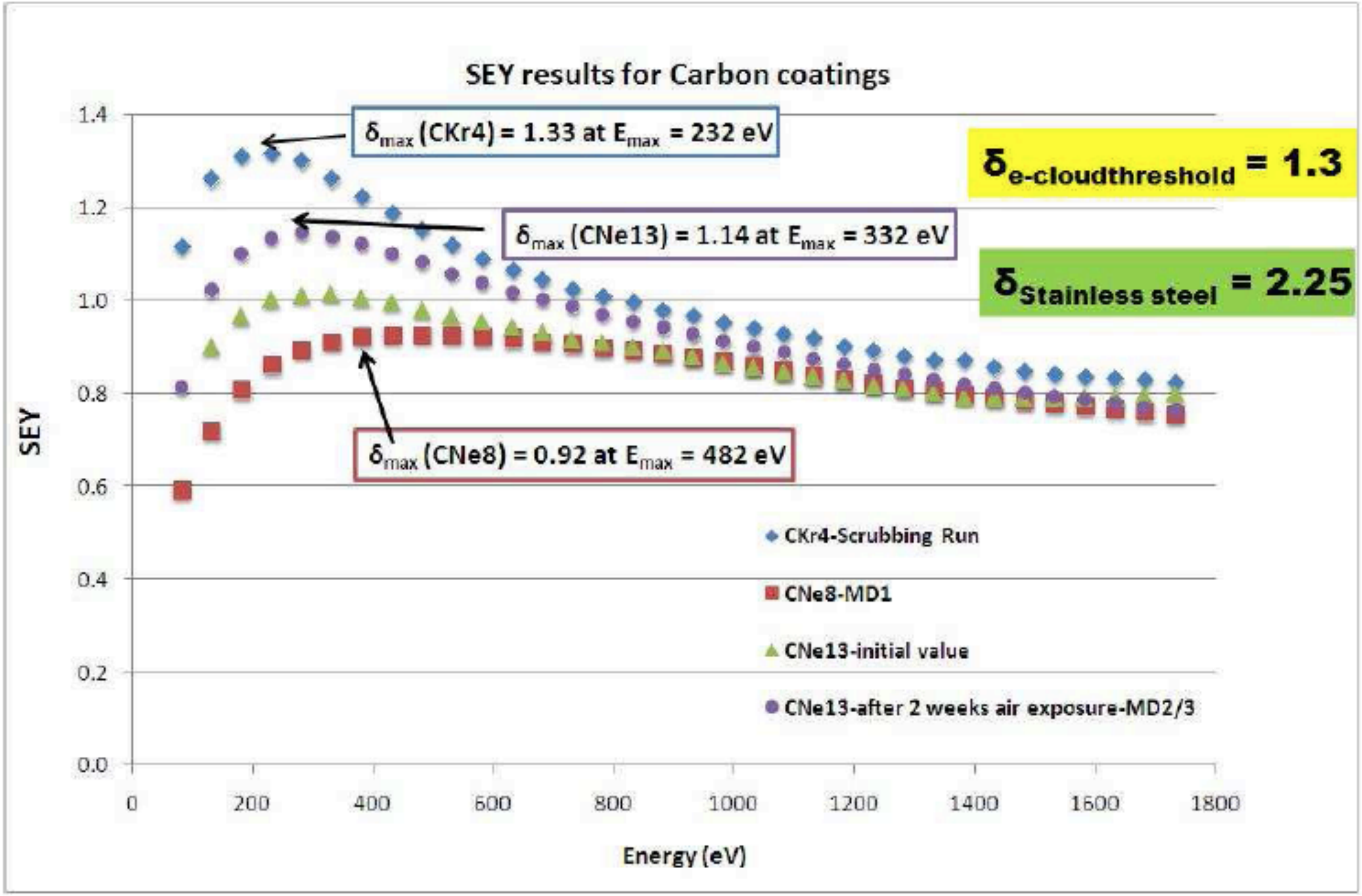
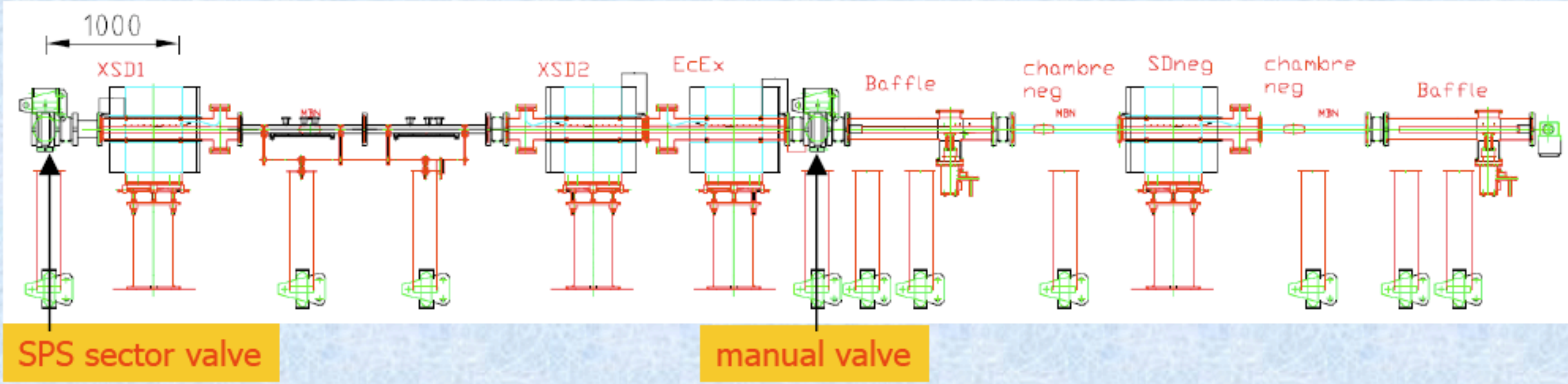


FIG. 2. The secondary electron emission yield δ is given as a function of primary electron energy for normal incident electrons on a pyrolytic graphite sample whose basal plane is parallel to the surface.

SEY of carbon coating (lab measurements)….



SPS installations for e-cloud MDs in 2008

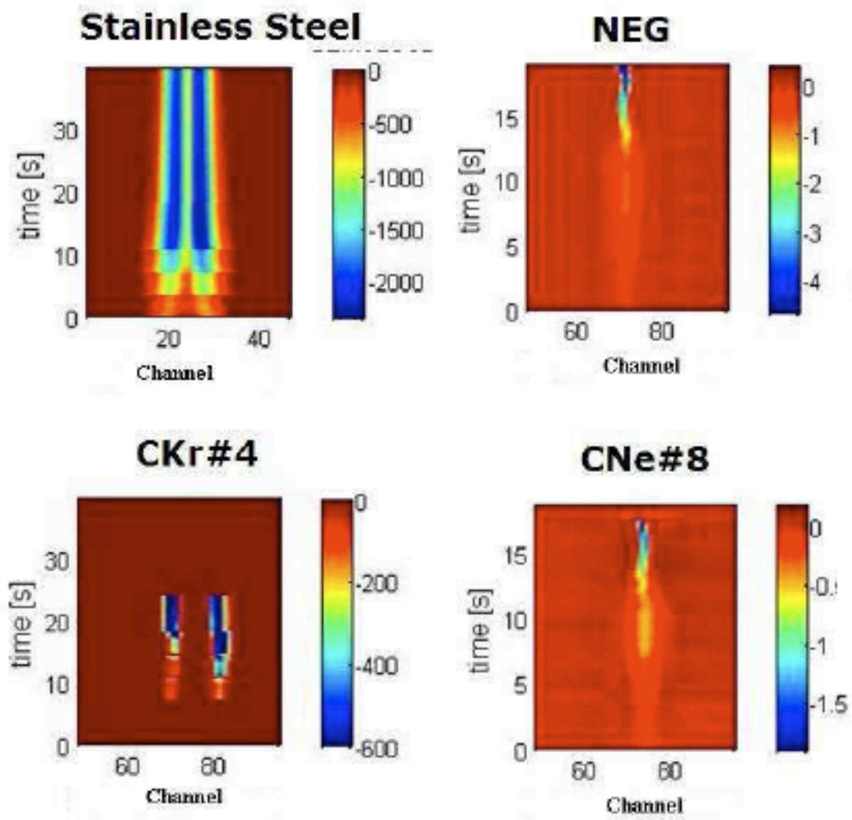


SPS Installation Status on 28/03/2008 (machine closure)

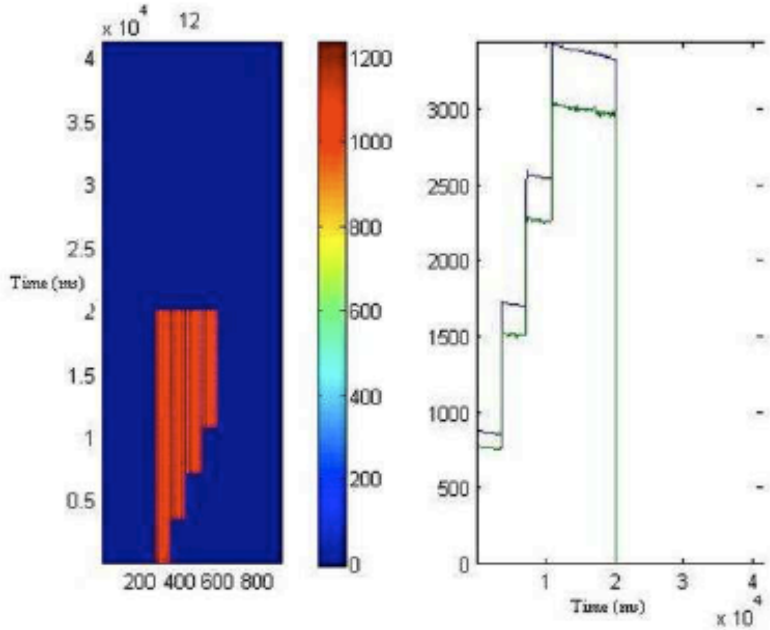
XSD1 ⇨ exchangable strip detector with stainless steel liner
ECD ⇨ ecloud detector with pickups and enamel clearing electrode
XSD2 ⇨ exchangable strip detector with amorphous carbon/st.st. liner
EcEx ⇨ electron cloud extractor ("repeller")
SDNEG ⇨ strip detector with NEG coated liner (could be exchanged)
Baffles + NEG chambers ⇨ protect SDNEG against water/saturation
Quadstrip ⇨ quadruploe strip detector (further downstream)

Examples of signals collected at the EC monitors +FastBCT

SEMCloud Monitors:



FBCT Monitor:



1. Stainless Steel
2. NEG coating
3. Carbon coating

- All the tests were done in the magnets at a field of 1.2 kGauss.
- The beam energy in the scrubbing run was 26 GeV and in the other MD runs 450 GeV

Overview on the 2008 MDs (which took place over long dedicated cycles)

- SPS Scrubbing run: 10 June - 12 June, 2008 → **SR**
- Injector MD with LHC beam: 8 July, 2008 → **MD1**
- Injector MD: 12 August, 2008 → **MD2**

Normally:
The beam consists of batches of 72 bunches with 25-ns bunch spacing.

- Injector MD: 6 October - 8 October, 2008 → **MD3**

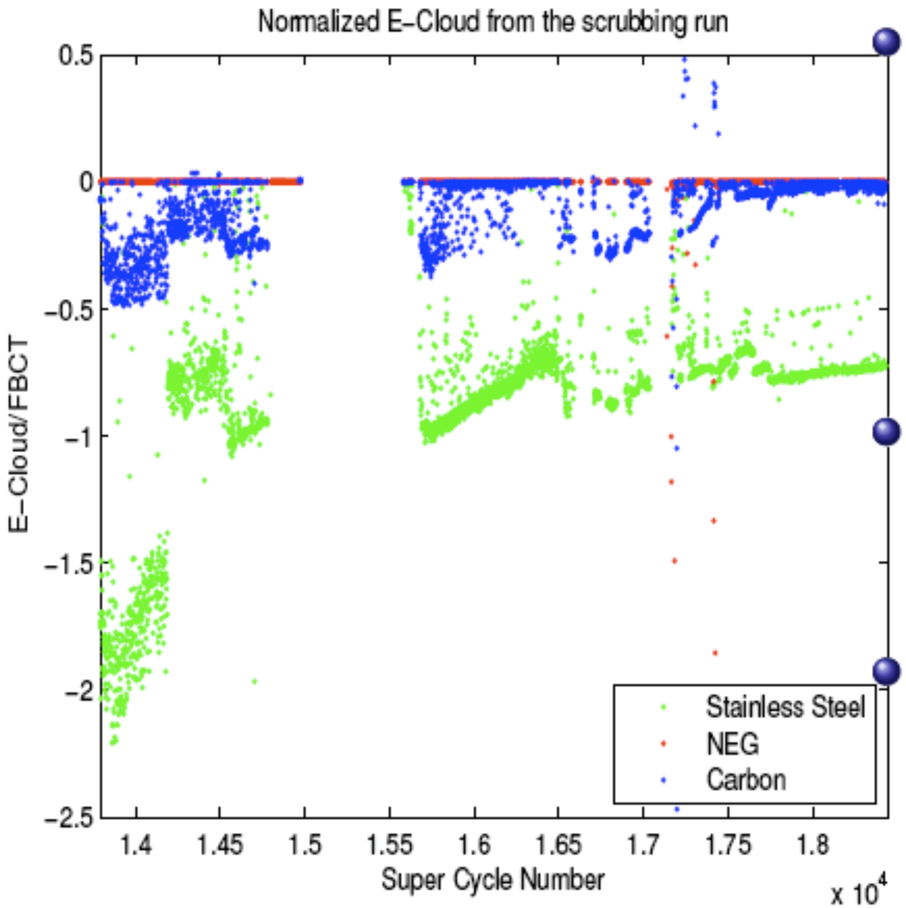
25-ns, 50-ns and 75-ns bunch spacing.

Overview on the 2008 MDs
(which took place over long dedicated cycles)

1. SPS Scrubbing run: Carbon with Krypton as discharge gas (CKr4) → **SR**
2. Injector MD with LHC beam: Carbon with Neon as discharge gas (CNe8) → **MD1**
3. Injector MD: Aged Carbon with Neon as discharge gas - 2 weeks venting in air before inserting (CNe13) → **MD2**
4. Injector MD: CNe13 - 2 months in SPS vacuum → **MD3**

Measurements during the SR (25ns bunch spacing & nominal intensity)

Normalized EC:

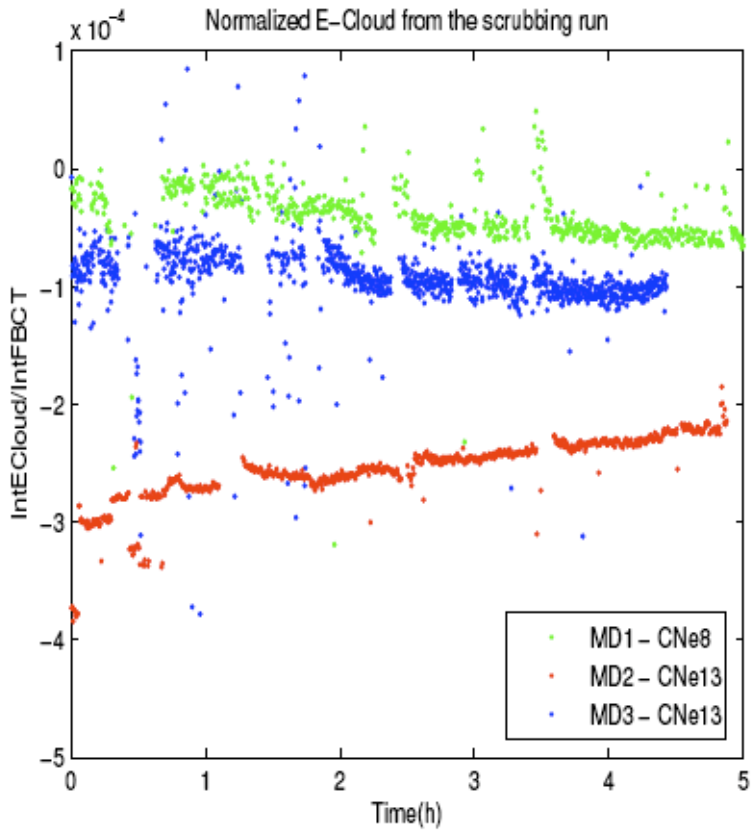


Conclusions:

- Stainless Steel ($\delta_{max} = 2.25$) - E-Cloud in Stainless Steel has been reduced by nearly a factor of 2.
- NEG ($\delta_{max} = 1.1$) - E-Cloud in NEG showed no activity.
- Carbon (CKr4) $\delta_{max} = 1.33$. - E-Cloud in Carbon was found to change by nearly a factor of 5.

Measurements during the other MD sessions (nominal intensity & 25ns bunch spacing)

Normalized EC: EC has a magnitude of 10^{-4}.

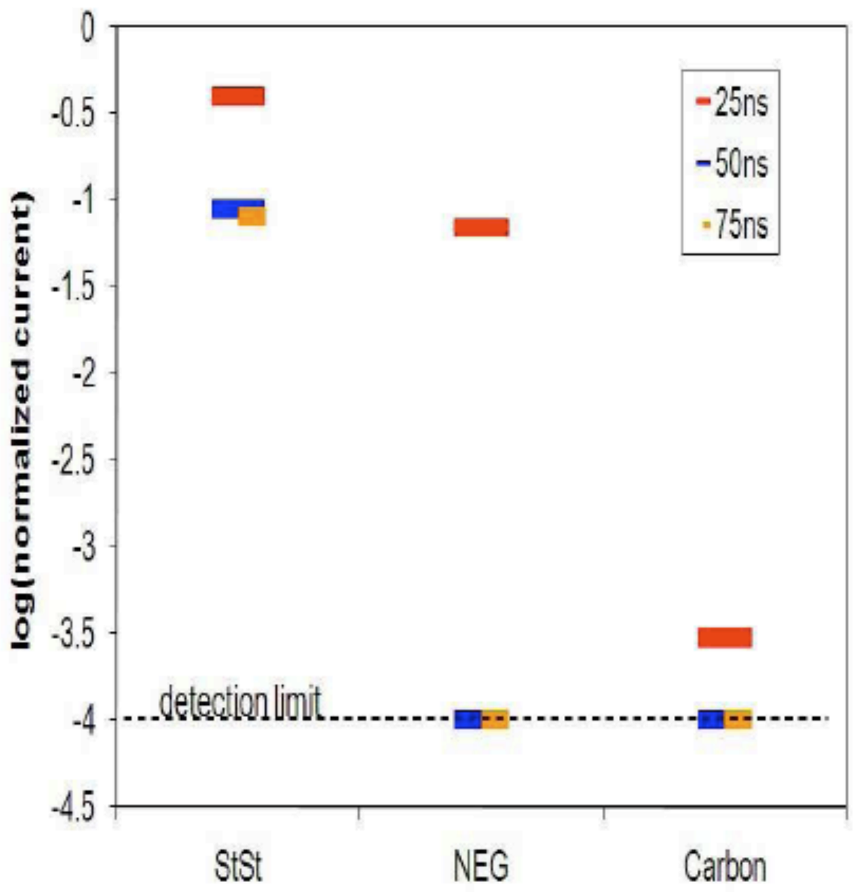


Conclusions:

1. MD1 - Carbon (CNe8)
   - E-Cloud in Carbon showed no activity.
   - $\delta_{max} = 0.92$.
2. MD2 - Carbon (CNe13)
   - Aged in air for 2 weeks before inserting.
   - Initial $\delta_{max} = 1.0$. Aged $\delta_{max} = 1.14$.
3. MD3 - Carbon (CNe13)
   - stayed in SPS vacuum for 2 months.

Measurements done in MD2 & MD3 (dependence of e-cloud on bunch spacing)

Normalized EC:



Conclusions:

1. Stainless Steel
   - 5 times less current at 50 ns and 75 ns
2. NEG
   - No detectable current at 50 ns and 75 ns
3. MD3 - Carbon (CNe13)
   - No detectable current at 50 ns and 75 ns

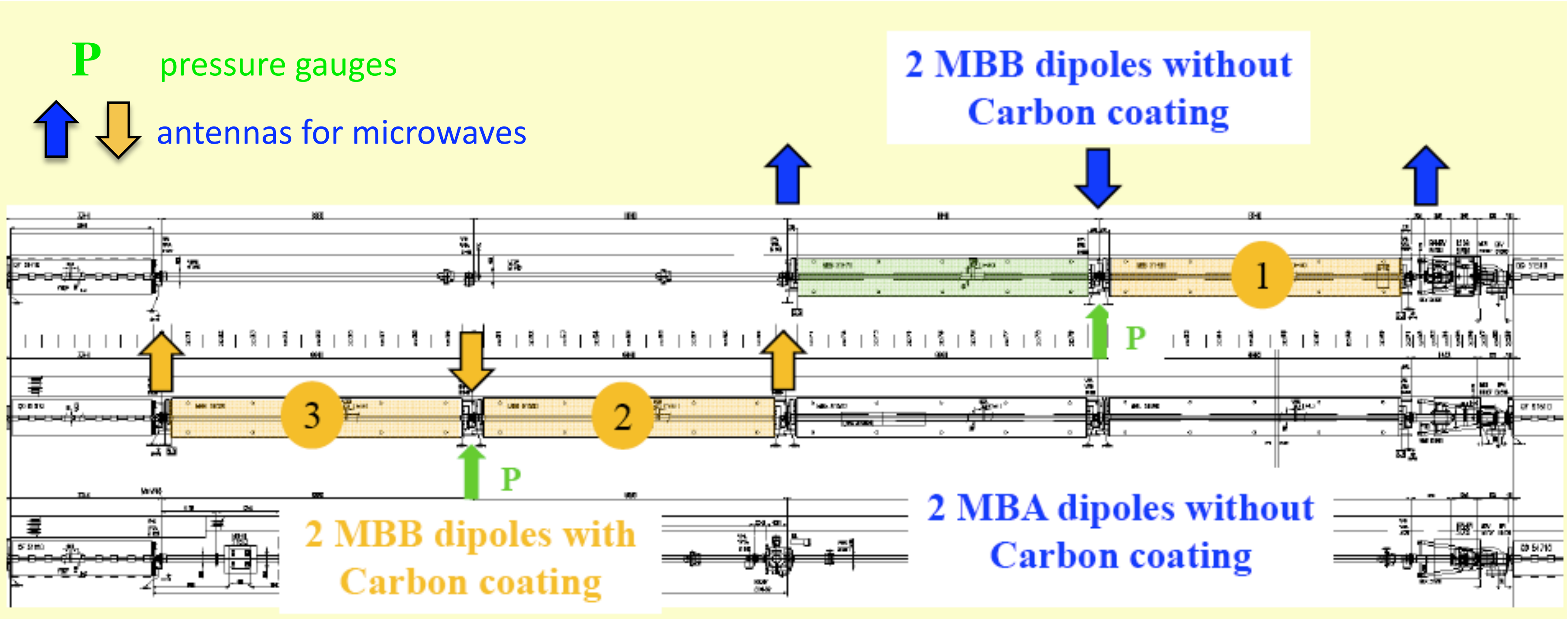
Summary of what was learnt in the 4 MD sessions

- Scrubbing run (CKr4):
  - Measured δ_{max} in lab was 1.33, electron cloud expected
  - Quite strong signal, not as strong as signal in Stainless Steel, but stronger than signal in activated NEG
  - After 3 days scrubbing the e-cloud signal decreased by a factor 5.
- MD1 (CNe8):
  - Measured δ_{max} in lab was 0.92, no electron cloud expected (below threshold)
  - Very low signal from electrons detectable
- MD2 (CNe9):
  - measured δ_{max} in lab was 1.0 initially, later grown to 1.14 after two weeks exposure, again no electron cloud expected (below threshold)
  - Low signal measured with 25ns bunch spacing (higher than in MD1), no signal detectable with 50/75ns bunch spacings.
- MD3 (CNe9, aged by two months in vacuum)
  - Lower electron cloud signal measured than during the MD2 session with 25ns bunch spacing
  - No signal detectable for 50/75ns bunch spacings and wide ranges of intensities.

Plans for the 2009 run: new arrangement for the liners

- **The set-ups**
  - Strip detectors inserted on dipole magnets, 4 sets are available:
    - 1 will be used as a reference – Stainless steel
    - 1 to study lifetime – Carbon layer
    - 2 others to study other coatings
      - Carbon on Zirconium for roughness
      - Carbon with other parameters
  - Pressure gauges to follow pressure rises
- Situation with respect to 2008
  - Vacuum sectorization stays in order to allow a fast replacement of the inserts.
  - Enamel strip line to validate the technical proposal stays
  - Repeller detector is removed since not ready on time
  - All shielded pickups to study the build-up stay
  - Cold baffles upstream and downstream the 4th strip detector are removed
  - C-Magnet with sample exchange set-up for SEY studies stay in place

Plans for the 2009 run: coating of the MBB dipole chambers



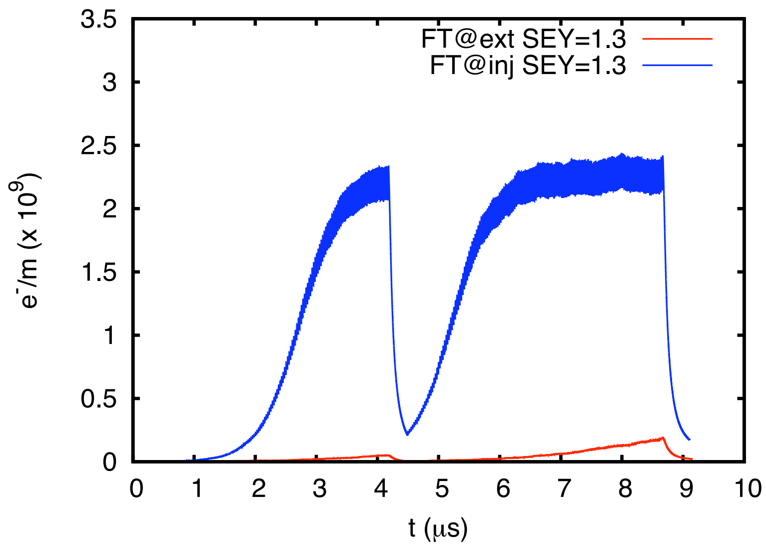
APC recommendation (16.01.2009): **It is recommended to install three carbon coated MBB chambers in the SPS with the antennas attached, necessary for the microwave measurements. Two close-by chambers with a pressure gauge between them will serve as pressure reference. The third one shall be connected to an uncoated chamber (also equipped with a pick-up antenna) for a differential microwave measurement. If for lack of time only two MBB chambers will be coated and installed, the two should go together and have a pressure gauge between them to ensure the pressure measurement, while the set-up of the microwave measurements could also have only one sending and receiving station for both pairs of coated and uncoated chambers.**

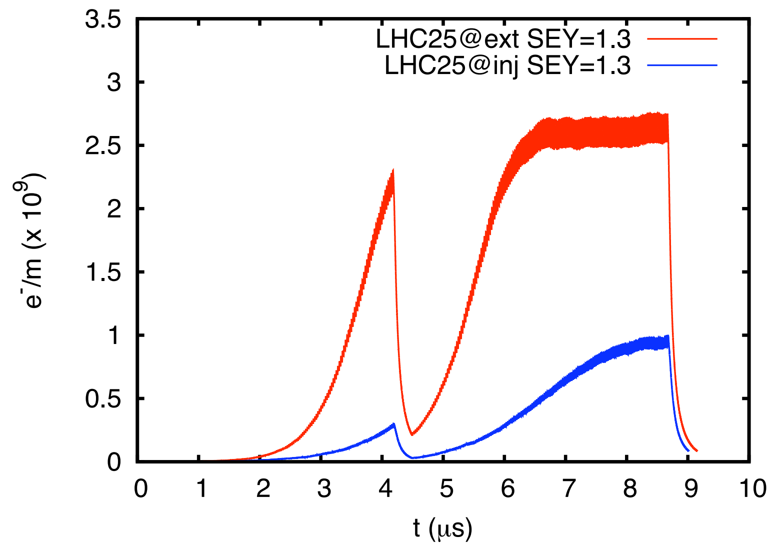
Electron cloud simulation study done for the PS2 parameters

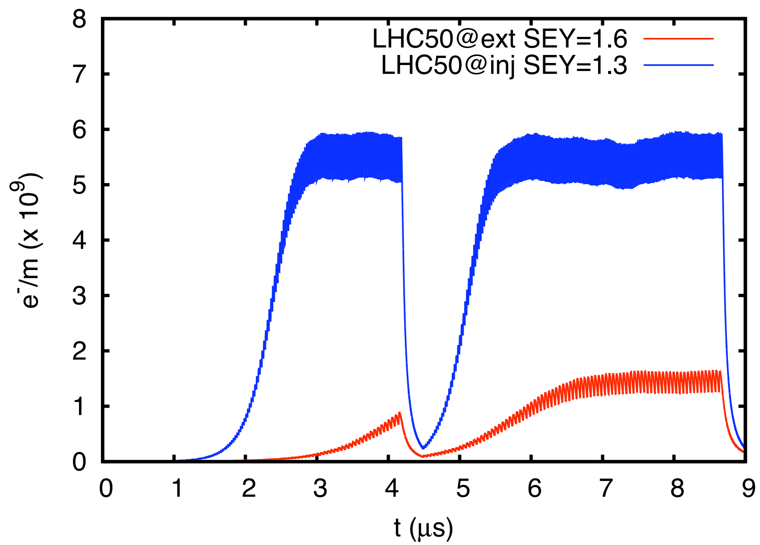
PS2 parameters used for the ECLOUD (e-cloud build up) simulations (M. Benedikt, Y. Papaphilippou)

	LHC25 inj	LHC25 extr	LHC50 inj	LHC50 extr	FT inj	FT extr
Batch structure	168 +12	168 + 12	168 + 12	84 + 6	168 + 12	168 + 12
Bunch length (4σ)	12 ns	4 ns	8 ns	4 ns	8 ns	4 ns
$\varepsilon_x \backslash \varepsilon_y$ (1σ)	3/3 μm	3/3 μm	3/3 μm	3/3 μm	15/8 μm	15/8 μm
B	0.136	1.7	0.136	1.7	0.136	1.7
N_b	4.2×10^{11}	4×10^{11}	3.1×10^{11}	5.9×10^{11}	7.9×10^{11}	7.5×10^{11}
$\langle\beta_x\rangle / \langle\beta_y\rangle$	30 / 26 m					
Aperture sizes (a,b)	6, 3.5 cm					

Sample results of electron cloud build-up close to the build up threshold for LHC25, LHC50 and Fixed Target beams at injection and before extraction



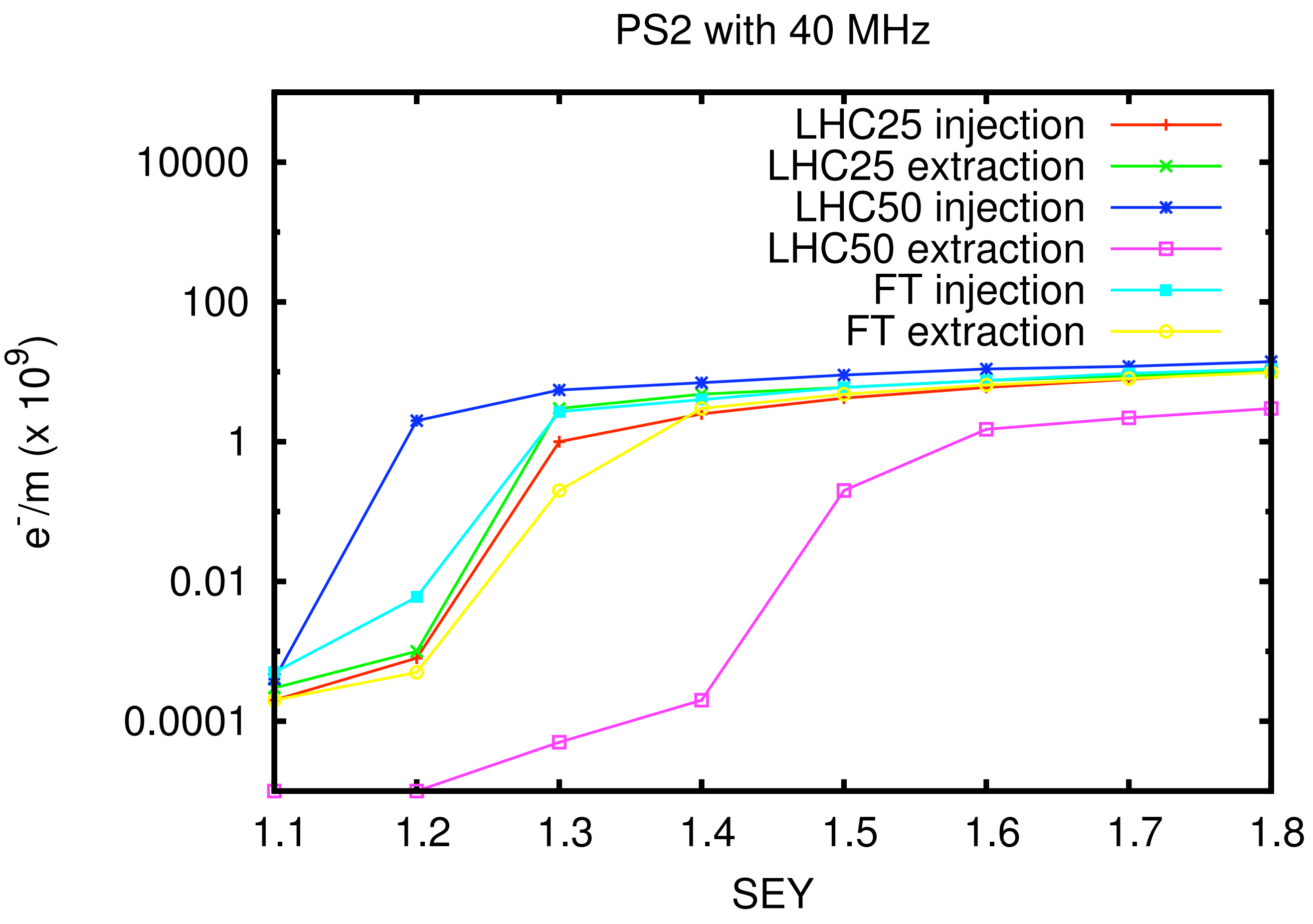




The electron cloud build up has been calculated over two turns of the beam inside the PS2.

For comparison of the different cases we will refer to the values reached by the electron cloud when the build up process reaches saturation.

Results of electron cloud build-up as a function of the maximum SEY for LHC25, LHC50 and Fixed Target beams at injection and before extraction



What is plotted here are the average values of the electron cloud line density at saturation for different values of maximum SEY input in the simulation

Some preliminary considerations on the e-cloud in the PS2
Summary of the simulation results and outlook

- The **build up threshold is δ_{max}=1.2** for almost all studied beams, except
  - ✓ LHC50@injection (and to some extent FT@injection, but takes longer to saturate) have a significant e-cloud with 1.2 (their threshold is 1.1)
  - ✓ LHC50@extraction has a threshold of 1.5 and produces in general a lower density electron cloud.

- The saturation values of the electron cloud (in the range of 1-10 x 10^9 e^-/m for the different types of beams) correspond to **densities of 1.5-15 x 10^{11} e^-/m^3**, which could be detrimental for the beam stability (from experience in other machines, we could expect the threshold to lie in this range). **To be checked with HEADTAIL simulations.**

- As discussed before, the investigation of the SPSU Study Team is trying to prove that **values of δ_{max} around or even below 1.0 can be achieved with the C coating**.
However, NEG coating could be also desired to help comply with the request of UHV for the PS2 to operate with ions (E. Mahner @PS2 Working Group Meeting 22.01.2009)
  - ✓ maybe more experience required with C coating
  - ✓ understand how stringent is the vacuum specification for ions and how critical is to have NEG coating to meet it.