Comparison of stainless steel and enamel clearing electrodes

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J.M. Jimenez, T. Linnecar, R. Steerenberg, F. Zimmermann;

thanks to the SPSU study team members for helpful discussions

Outline

o

- Introduction
- Electron cloud detectors in the PS & SPS
- Summary of 2007 & 2008 results
- Conclusions

Introduction (1)
PS observations

- During the 2000 run the electron cloud (EC) effect has been observed in the PS as a baseline distortion of electrostatic pickup signals [1].

- During an MD at the end of the 2006 run instabilities were observed that could be due to an EC build-up [2]. "*Nevertheless at intensities higher than nominal electron cloud instabilities could occur also for the standard LHC beam production scheme in the PS.*" [3].

- Also several other reports given in the APC.

[1] Electron cloud buildup and related instability in the CERN Proton Synchrotron.

R. Cappi, M. Giovannozzi, E. Métral, G. Métral, G. Rumolo, F. Zimmermann; PRST-AB 5, 094401 (2002).

[2] Observations of the high energy instability in the PS.

R. Steerenberg *et al.*, APC 15. December 2006.

[3] Intensity (and Brightness) Limitations in the LHC Proton Injectors.

G. Arduini; Proceedings of the CARE-HHH-APD LHC-LUMI-06 Workshop, Valencia, 2006.

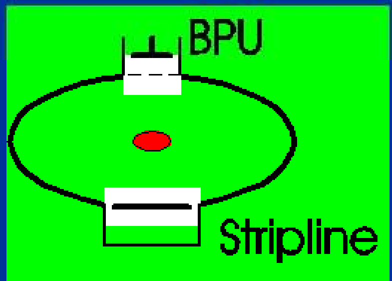
Introduction (2)

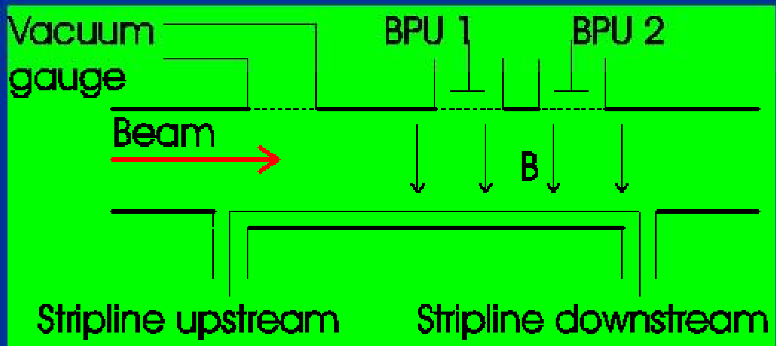
A new experiment in the PS

- January 2007: Suggestion (G. Arduini & E. M.) to install some EC diagnostics in the PS, if possible, still during the 2006/07 shut-down.
- Simulations (F. Zimmermann) show that an EC effect can be expected in a straight section, at least if there is a small magnetic dipole field (~10 G)...
- February 2007: Design, component fabrication, and assembly of a "simple" experiment to be installed in straight section 98, comprising: a shielded button pick-up, vacuum diagnostic and a small dipole magnet. A stripline electrode was added to examine the properties of clearing electrodes.
- Installation of the experiment right before the machine closure in the beginning of March 2007.

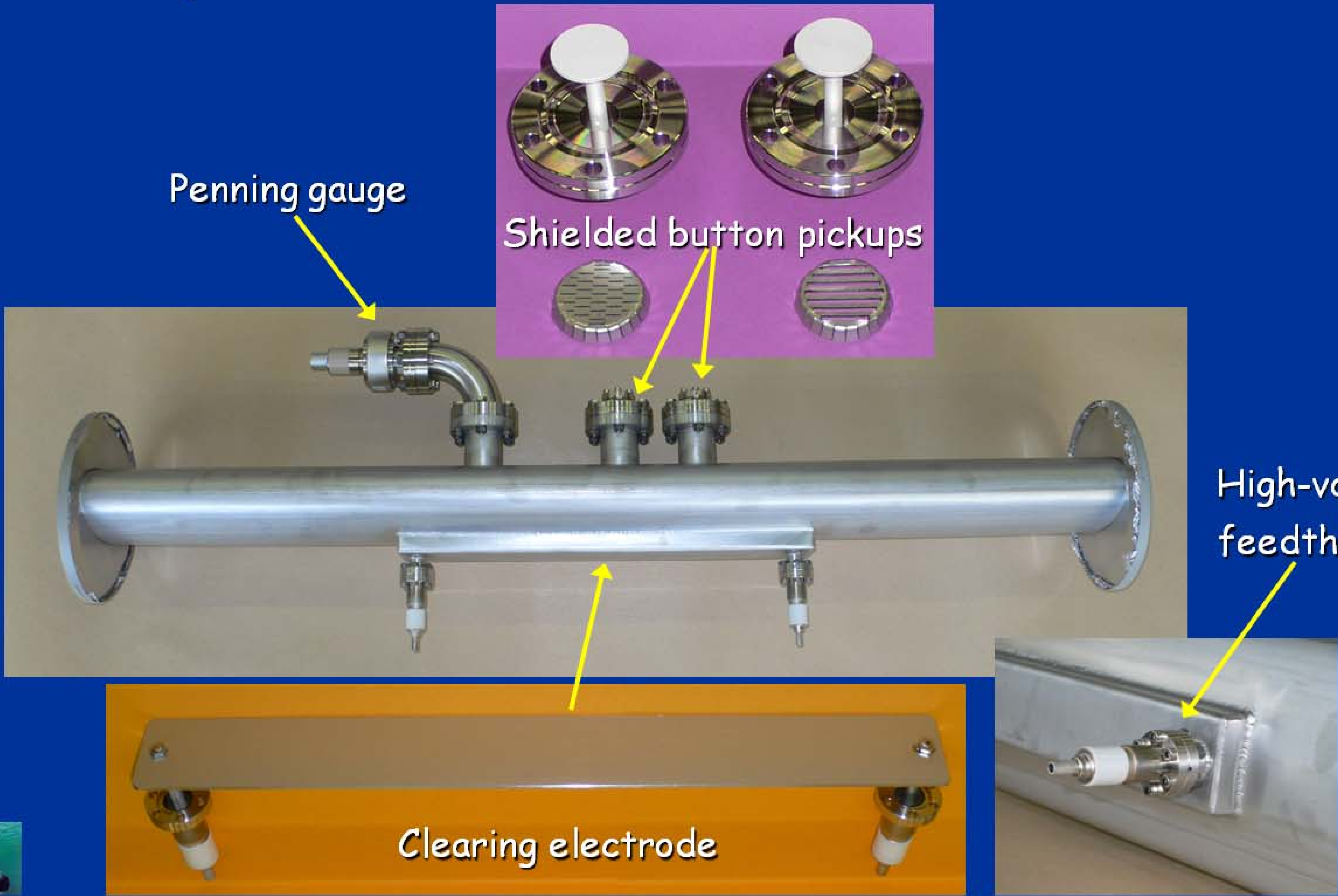
The PS electron cloud experiment in SS98

- PS elliptical vacuum chamber with dimensions 1050 x 146 x 70 mm.
- Special antechamber for clearing electrode without aperture reduction.
- Material: stainless steel 316 LN

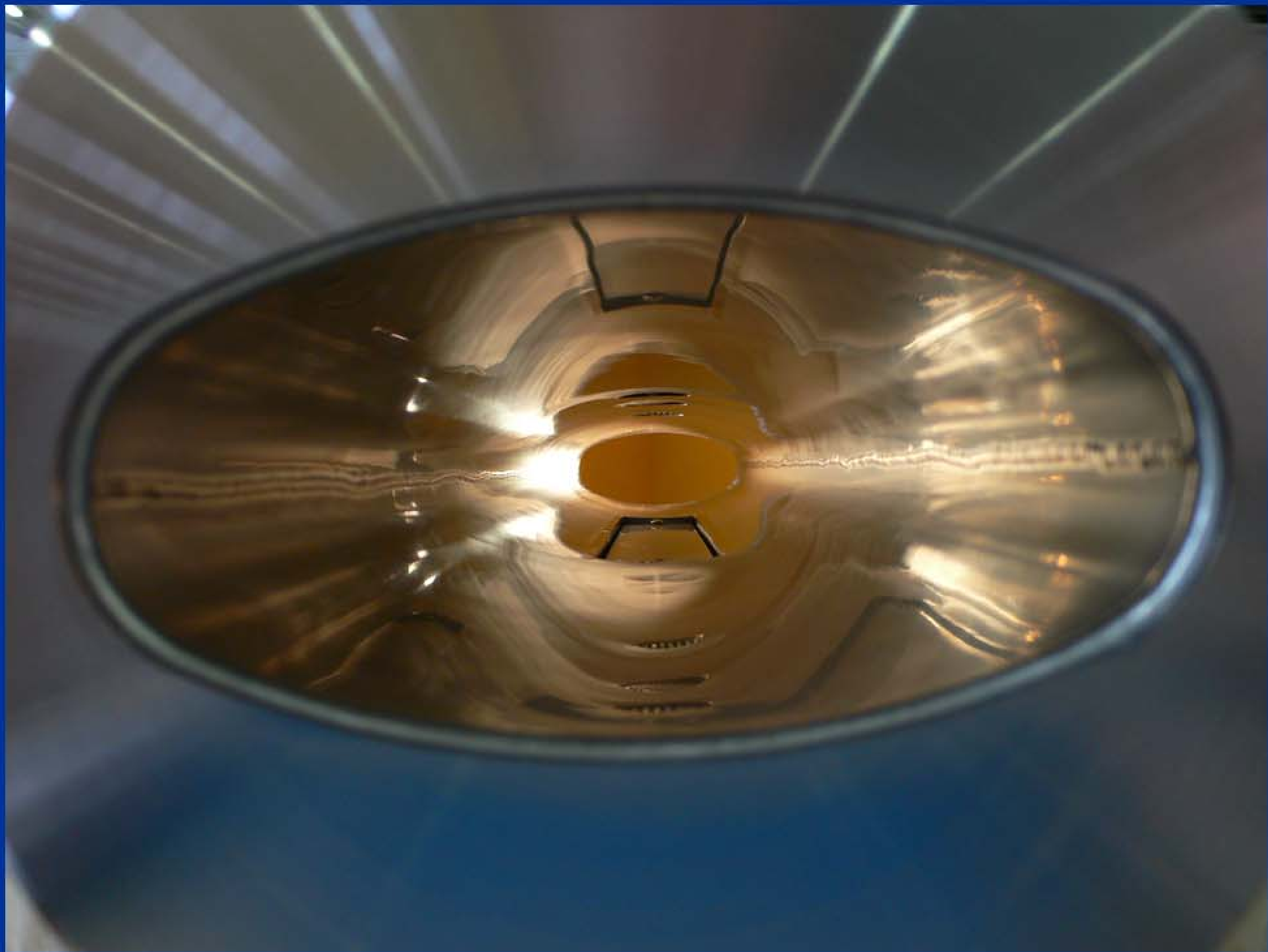




Components of the electron cloud setup



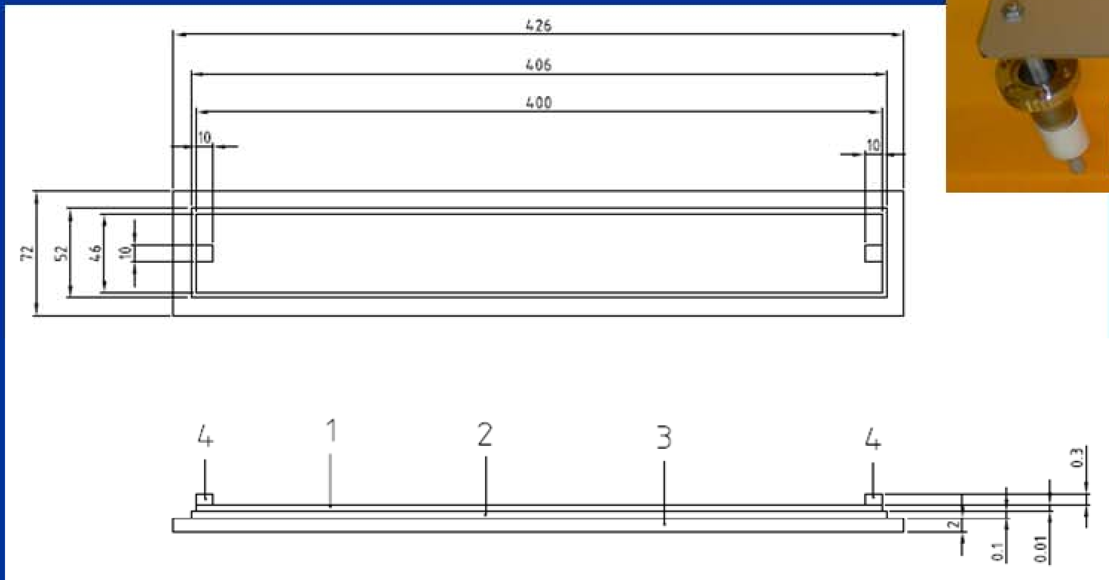
How the proton beam sees it…



Electron cloud detector in PS – SS84 installed in 2008

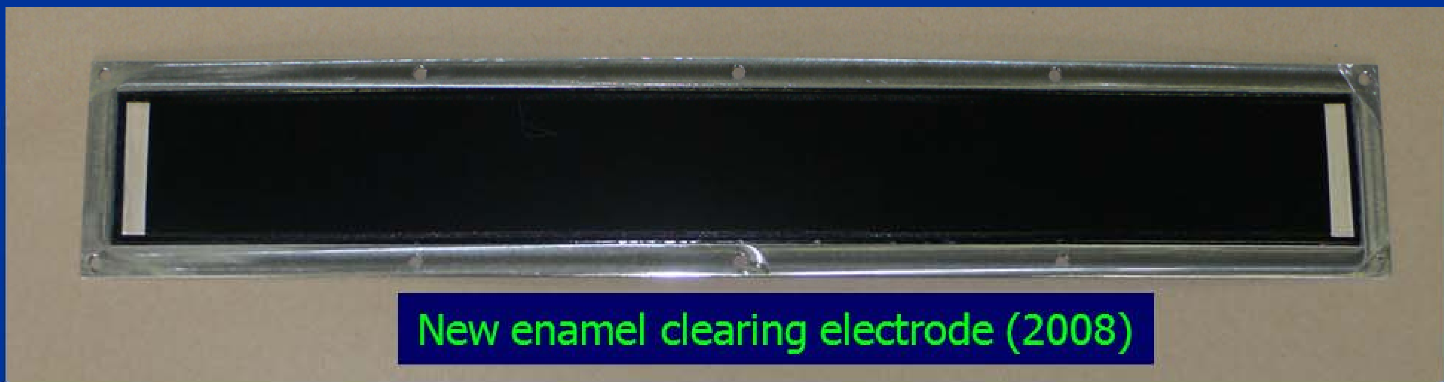
Very similar to the PS 2007 experiment in SS98, but stainless steel clearing electrode replaced by a new enamel electrode.


Stainless steel clearing electrode (2007)

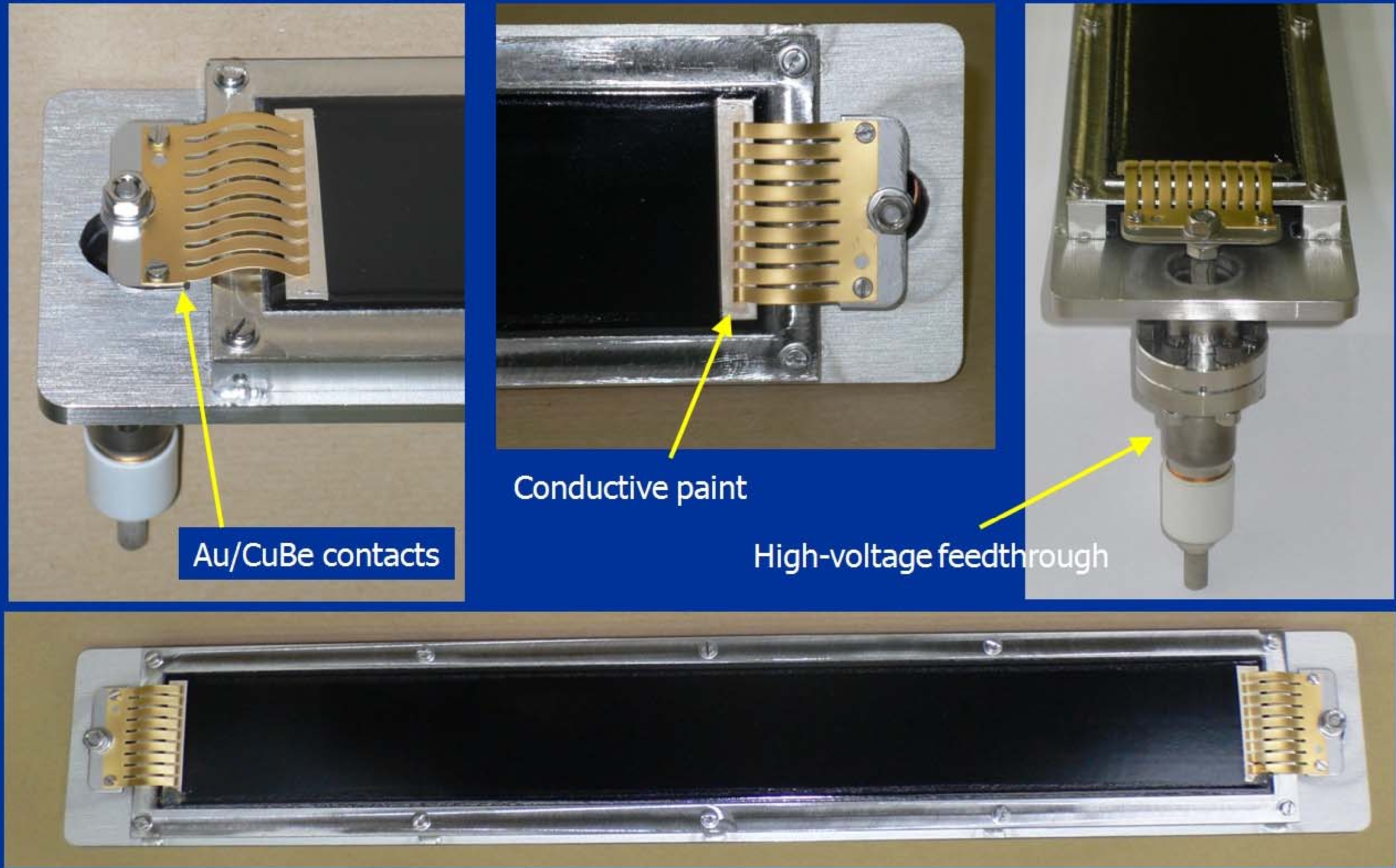


Enamel electrode with dimension 426 x 72 x 2.1 mm

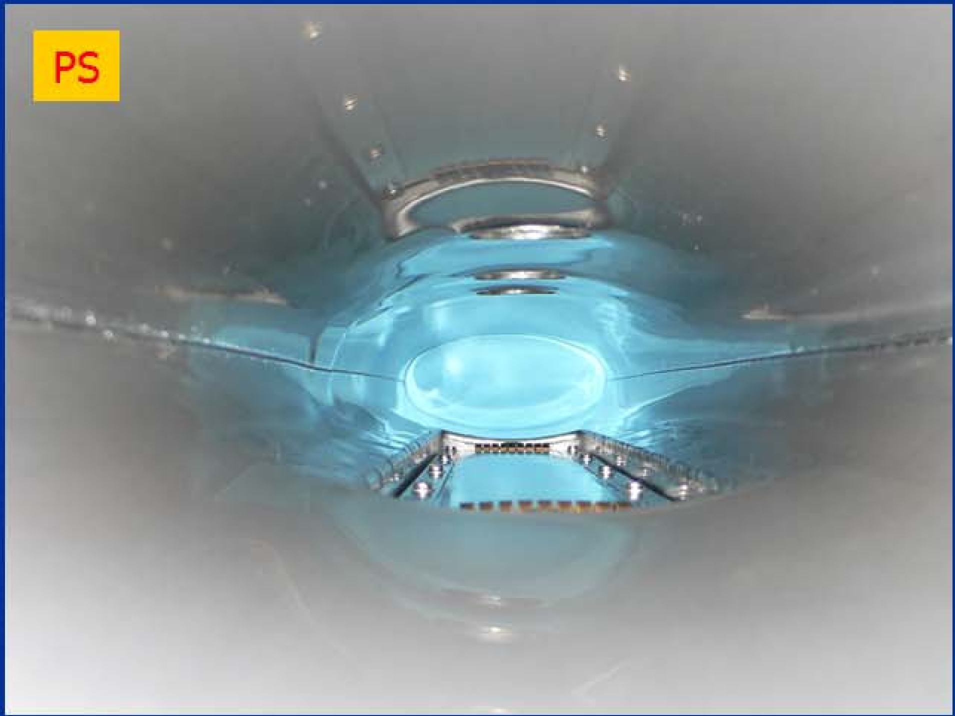
(4) Conductive paint
(1) Resistive Layer with R ≈ 10 kΩ (0.01 mm)
(2) Enamel (0.1 mm)
(3) Stainless steel 316 LN (2mm)


New enamel clearing electrode (2008)

Enamel clearing electrodes in PS – SS84 and SPS – BA5 installed in 2008



Electron cloud enamel clearing electrodes in PS+SPS installed in 2008



as seen by the proton beam
no aperture reduction!

Summary of 2007 & 2008 results

- A summary of the obtained PS electron cloud results can be found in various presentations given in 2007 at CERN.
  - APC's: 6th July, 3rd August, 23rd November; LHC MAC: 7th December;
  - papers in PRST-AB (2008); EPAC'08.
- Here, a brief summary of
  - Nominal LHC beam in the PS and machine parameters.
- The following electron cloud characteristics were studied in 2007 & 2008.
  - Fast pressure rise measured with shielded Penning gauge.
  - Button pickup and stripline signals.
  - Start of electron cloud buildup within the PS supercycle.
  - Effect of small dipole fields (up to 70 G).
  - Different filling pattern (72,48,36,24,12 bunches).
  - Effect of the stainless steel clearing electrode in SS98.
  - Comparison with the enamel clearing electrode in SS84.

Parameters for PS electron cloud experiments

ELECTRON CLOUD DETECTION AND ... Phys. Rev. ST Accel. Beams **11,** 094401 (2008)

TABLE I. Summary of the bunch length evolution during the last milliseconds in the PS cycle.

Operation	Time before ejection	Number of bunches	Bunch spacing	Bunch length (4σ)
Second bunch splitting	57 ms	36	50 ns	
Third bunch splitting	27 to 5 ms	72	25 ns	14 ns
Adiabatic bunch compression	5 to 0.3 ms	72	25 ns	11 ns
Bunch rotation	0.3 to 0.0 ms	72	25 ns	4 ns

TABLE II. The main machine and beam parameters for the PS electron cloud experiment.

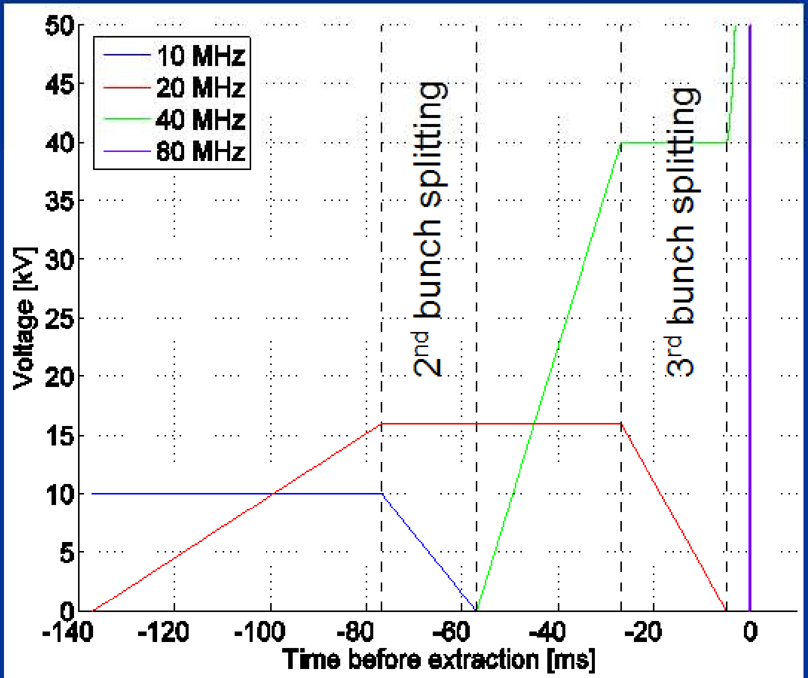
PS circumference	628 m
Proton energy	25 GeV
Revolution time	2.1 μs
Number of bunches	72
Bunch spacing	25 ns
Bunch length	4 ns
Bunch population	1.1×10^{11} protons/bunch
Bunch emittance	0.35 eVs
Vacuum chamber aperture (horizontal)	147 mm
Vacuum chamber aperture (vertical)	72 mm

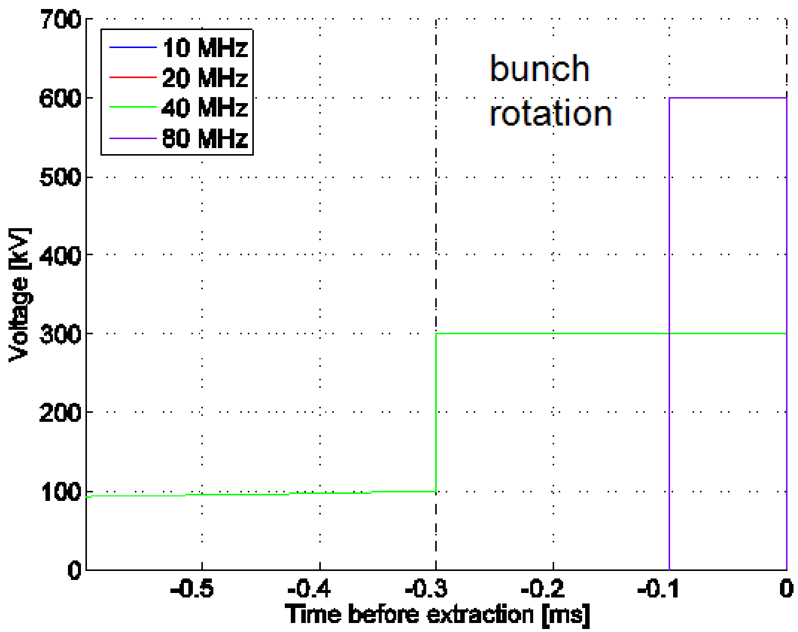
The nominal LHC beam in the PS

- Electron cloud effects are expected in particular shortly before ejection, when the bunches are short

- RF gymnastics:
- C2338 (57 ms before ejection): the second bunch splitting is finished, 36 bunches in the machine, bunch spacing 50 ns.
- C2368 to ~C2390 (27 to ~5 ms before ejection): The third bunch splitting. Afterwards 72 bunches, spacing 25 ns, 4σ length 14 ns.
- C2390 to ~C2395 (5 ms to ~300 μs before ejection): Adiabatic bunch compression to 11 ns.
- Last ~300 μs before ejection: bunch rotation with 40 MHz RF, in the last 100 μs also with 80 MHz RF. Bunch length reduced to 4 ns.
- ~C2395: ejection

- Intensity: 1.15e11 protons per bunch, 828e10 for 72 bunches.
- Transverse emittance (1σ): ~3 μm.





PS button pickup and stripline signals

PRST-AB 11,094401 (2008)

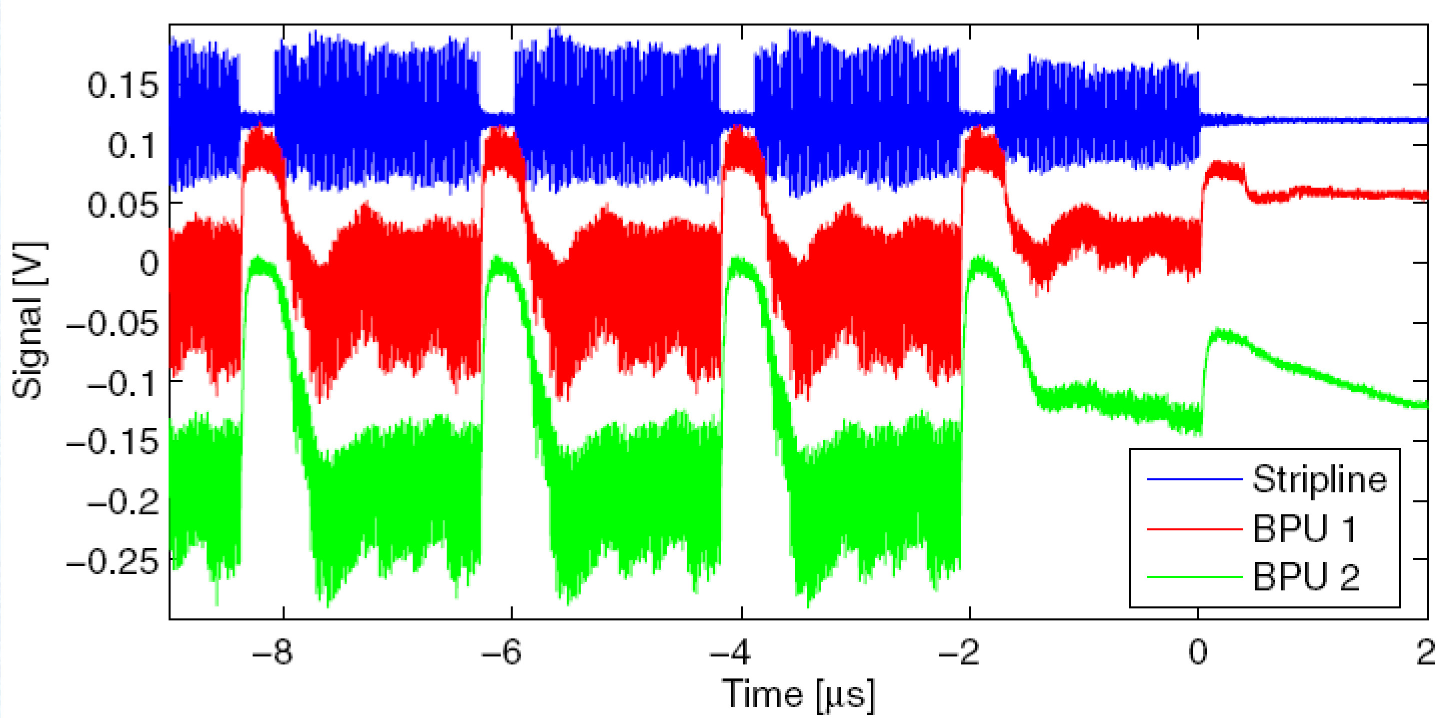


FIG. 4. (Color) Measured signals of the stripline electrode and the button pickups #1 and #2 during the passage of the nominal LHC beam. The last 4 turns before extraction from the PS are shown, the gap between successive recurrences of the same group of 72 bunches is 320 ns. The traces have been stacked vertically for clarity.

The results obtained for the last four turns before extraction of the nominal LHC beam from the PS are displayed in Fig. 4. The beam-induced signal observed on the clearing electrode, which acts essentially as a stripline beam position monitor, was used for synchronization and to monitor the basic beam properties. On both button pickups a clear electron signal was seen when the LHC beam passed. The time t = 0 s was set to the position of the last bunch at the last turn before ejection.

PS button pickup and stripline signals

PRST-AB 11,094401 (2008)

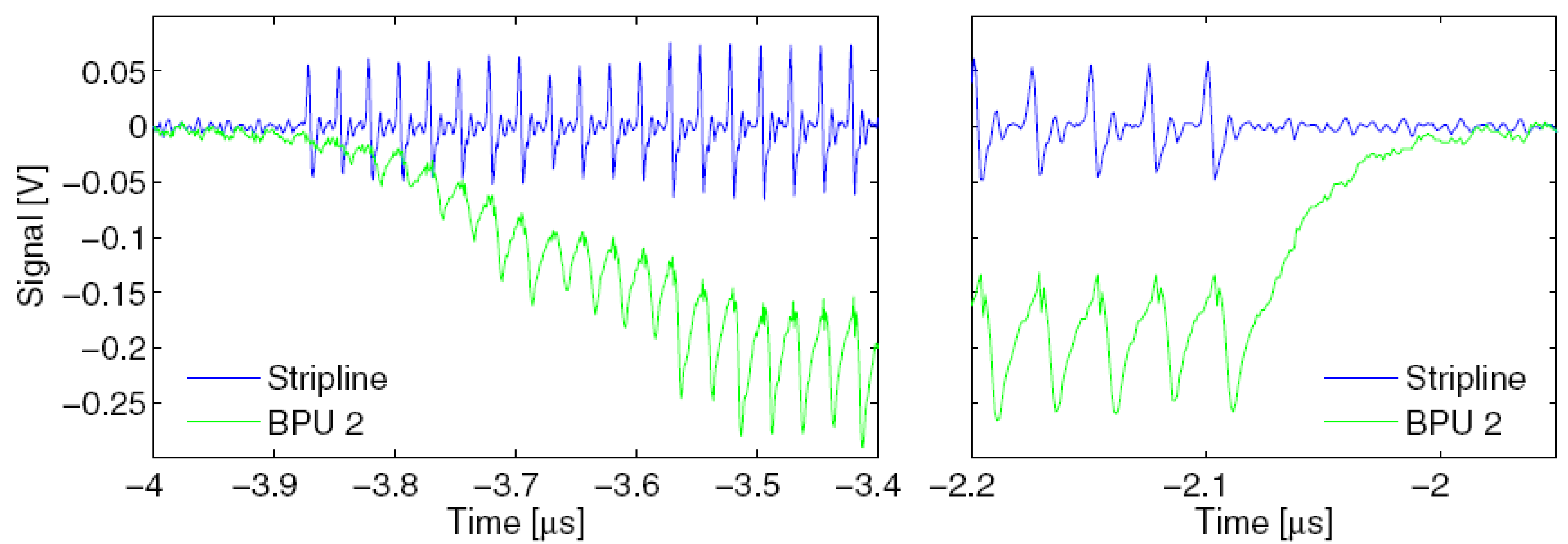


FIG. 5. (Color) Bunch-to-bunch electron cloud buildup (left) and decay (right) measured with button pickup #2 during the second last turn of the LHC beam. The 25 ns gap between successive bunches can be clearly resolved with the stripline electrode.

Measurements during the second last turn, showing the start of the electron cloud buildup with the first of the 72 bunches and decrease behind the last bunches, are displayed in Fig. 5. Every 4 ns (4σ) long bunch can be resolved on the stripline electrode and on the button pickups.

Start of PS electron cloud buildup

PRST-AB 11,094401 (2008)

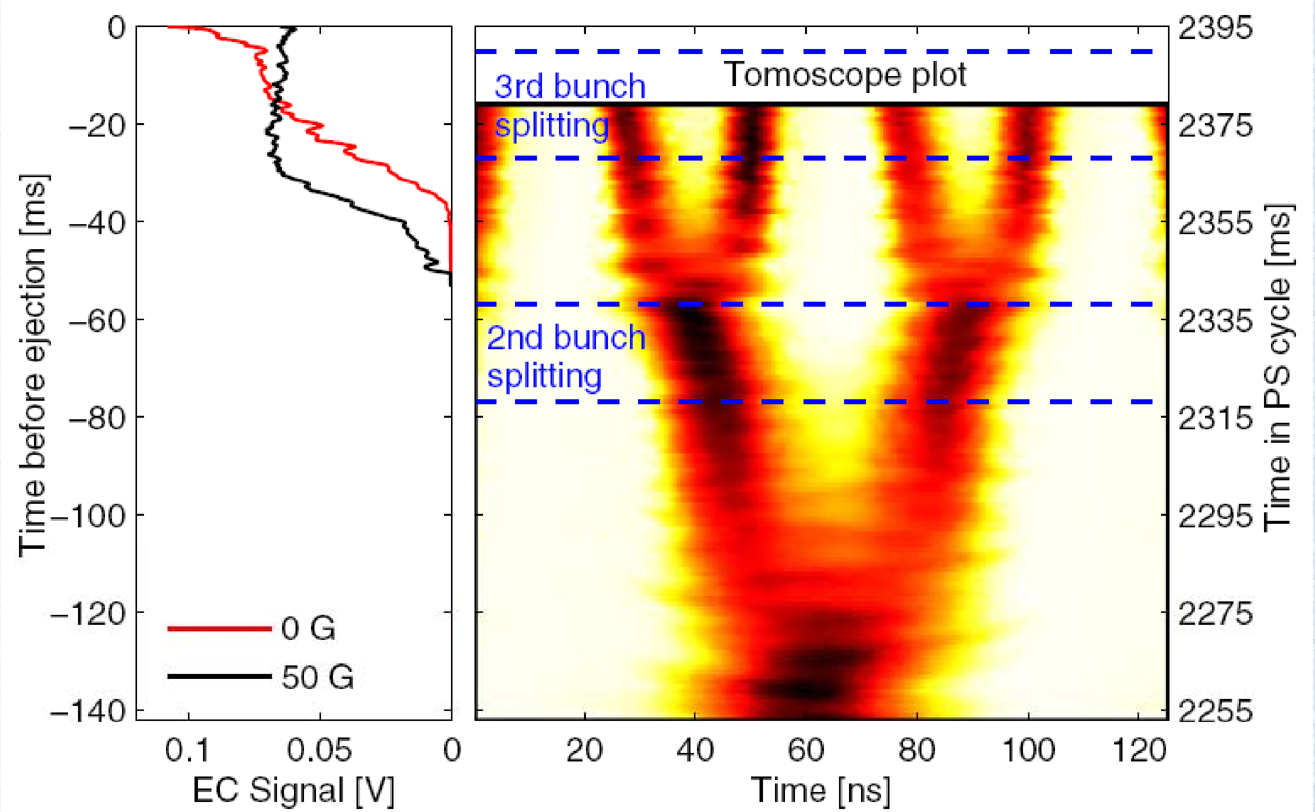


FIG. 7. (Color) The EC signal (left) compared with the bunch length during the rf gymnastics represented in a tomoscope plot (right, courtesy of Steven Hancock.). The EC buildup starts 40 to 50 ms before ejection, right after the second bunch splitting.

Some systematic measurements were performed to determine the exact time when the electron cloud buildup starts to be detectable in our experiment. In Fig. 7 the EC signal on pickup #1 is compared to a tomoscope plot of the longitudinal bunch profile. The EC is observed well before the end of the last bunch splitting (27 to 5 ms before ejection).

Effect of the st.st. clearing electrode

PRST-AB 11,094401 (2008)

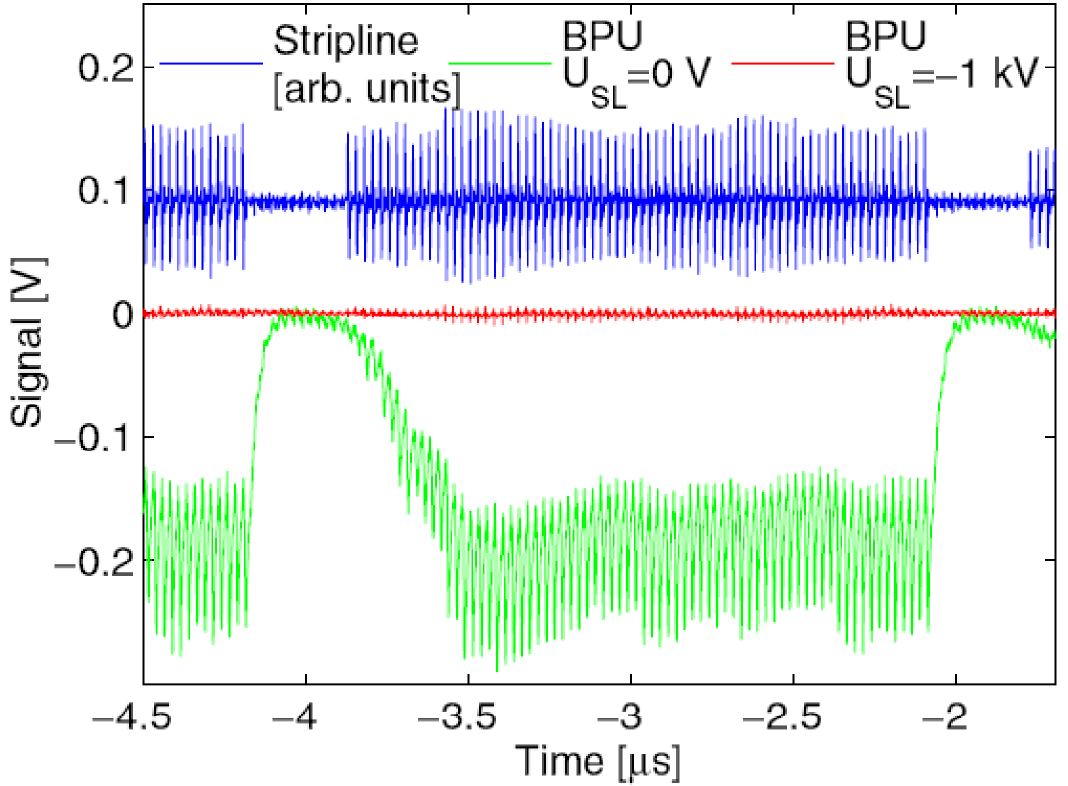


FIG. 8. (Color) The electron cloud was suppressed below the detection limit for large enough clearing voltages, e.g. $U_{SL} = -1$ kV, data from BPU 2 are plotted.

For large enough positive and negative clearing voltages $|U_{SL}| > 300$ V, the EC signals decreased below our detection limit. The case of $U_{SL} = -1$ kV is depicted in Fig. 8.

Electron cloud clearing: PU signal (t, U_{SL})

PRST-AB 11,094401 (2008)

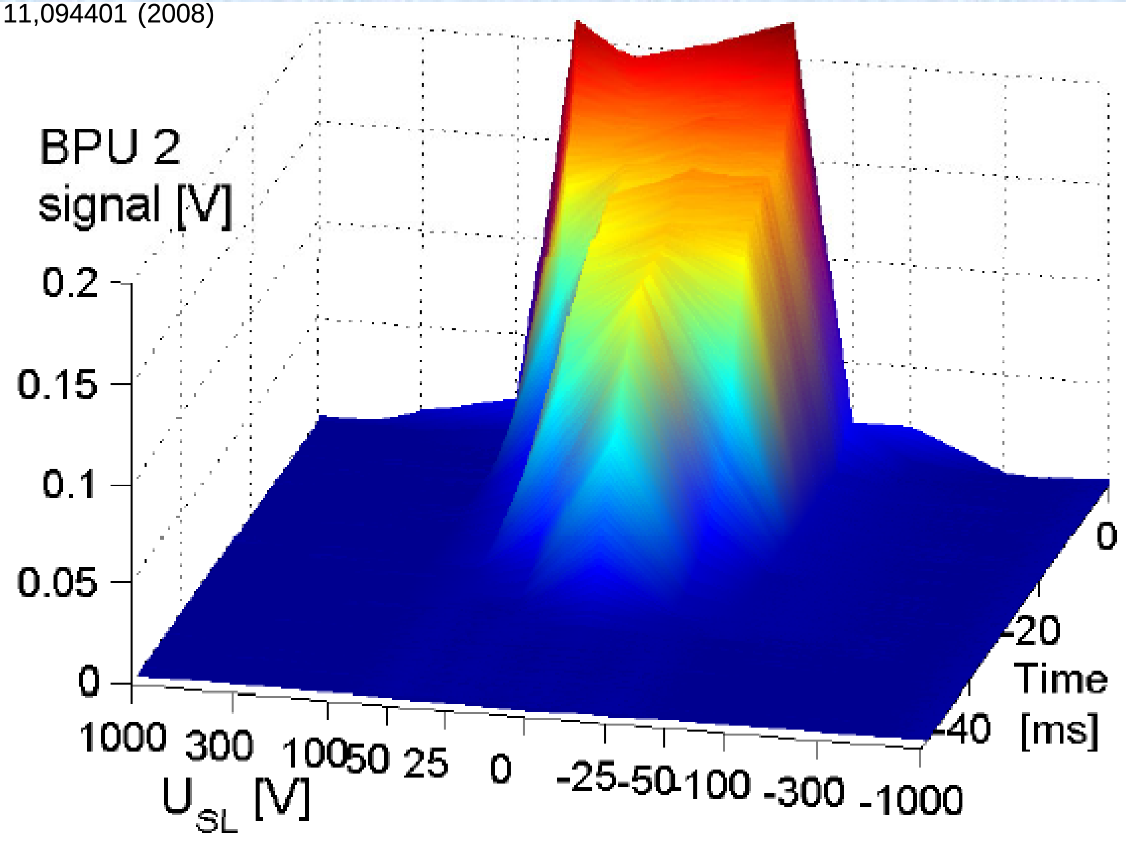


FIG. 9. (Color) Electron cloud button pickup #2 signal measured in SS98 for the nominal LHC beam. The color-coded signal height varies as a function of applied voltage on the clearing electrode and with time, no magnetic field was applied. The last 50 ms before ejection are shown.

The pickup signals have been measured for clearing voltages ranging from -1000 V to +1000 V.

Figure 9 shows the EC signal on pickup #2 averaged over the last 12 of 72 bunches in the PS machine as a function of clearing voltage.

The data cover the last 50 ms before the proton beam is ejected from the PS.

2008 electron cloud signals in SS 98

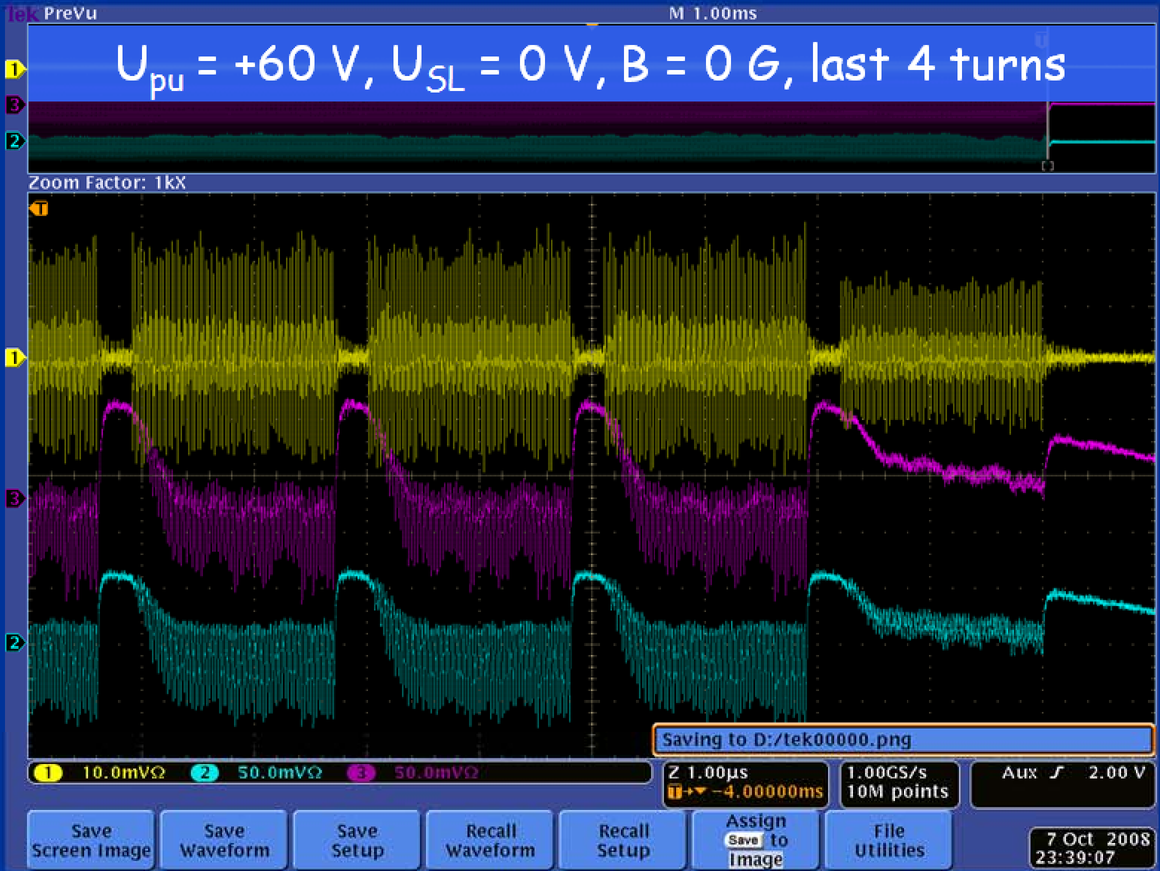
- Bias voltage on pickup (U_{pu} = +60 V)
- No voltage on stripline (U_{SL} = 0 V)
- No magnetic field (B = 0 G)

- Yellow: Beam signal from stripline
- Blue: pickup 1 (low transp.)
- Magenta: pickup 2 (high transp.)

- Triggered at extraction, looking at the last 4 turns
- Sampling rate: 1 GS/s
- Full time span: 10 μs

- On the pickups one can see when the LHC25 beam is passing SS98.

- During the last turn the stripline and pickup signals are different: orbit offset after firing of the extraction kicker



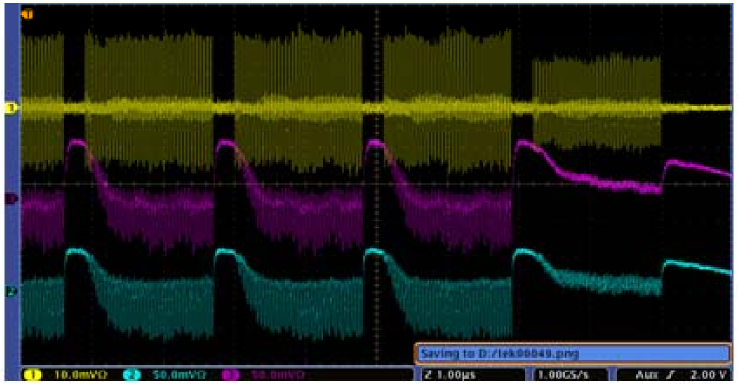
7. October 2008
LHC 25ns, 72 bunches, 908 x 10^{10} p

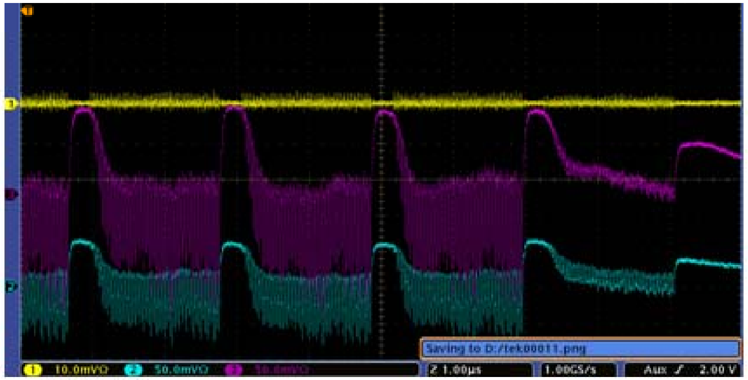
LHC 25ns nominal beam

Comparison SS 98 with SS 84 for *positive* stripline clearing voltages

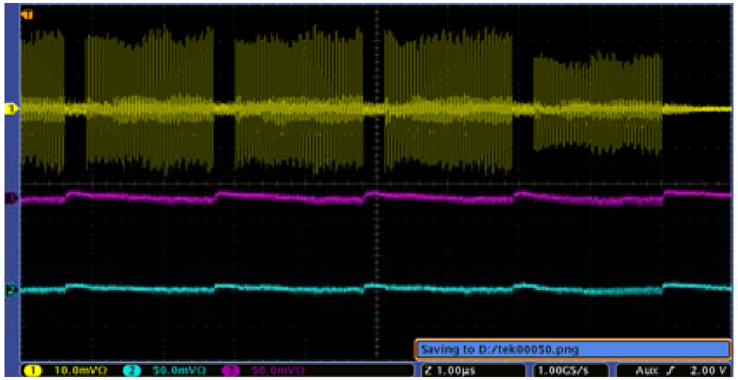
SS 98 – st.st. | SS 84 – enamel

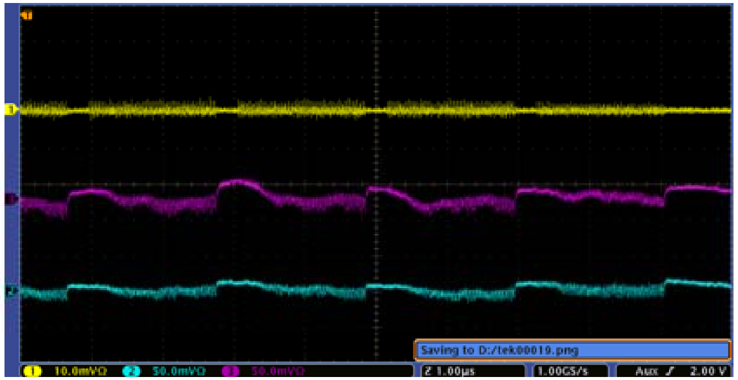
SL = 0



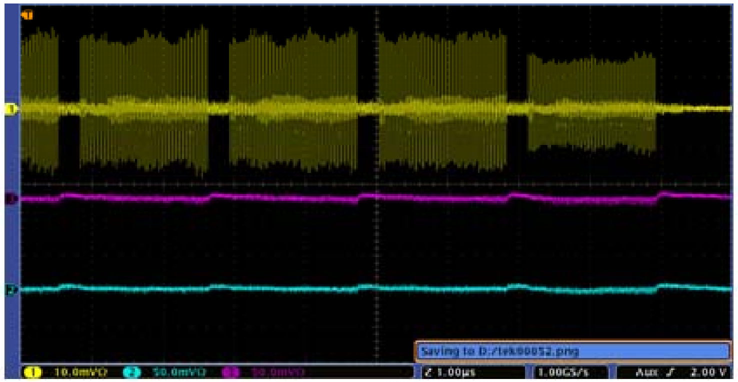


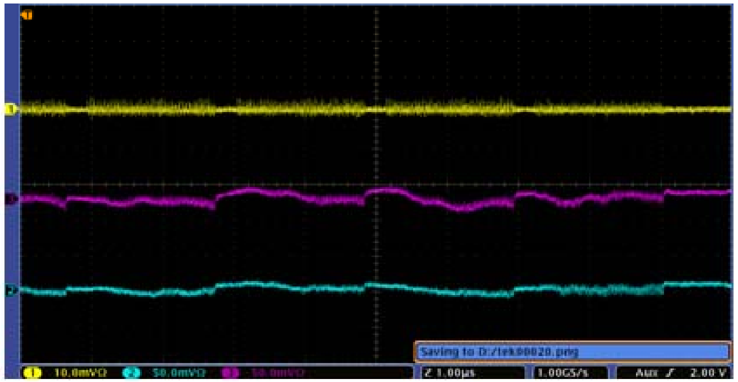
SL = +100V





SL = +150V



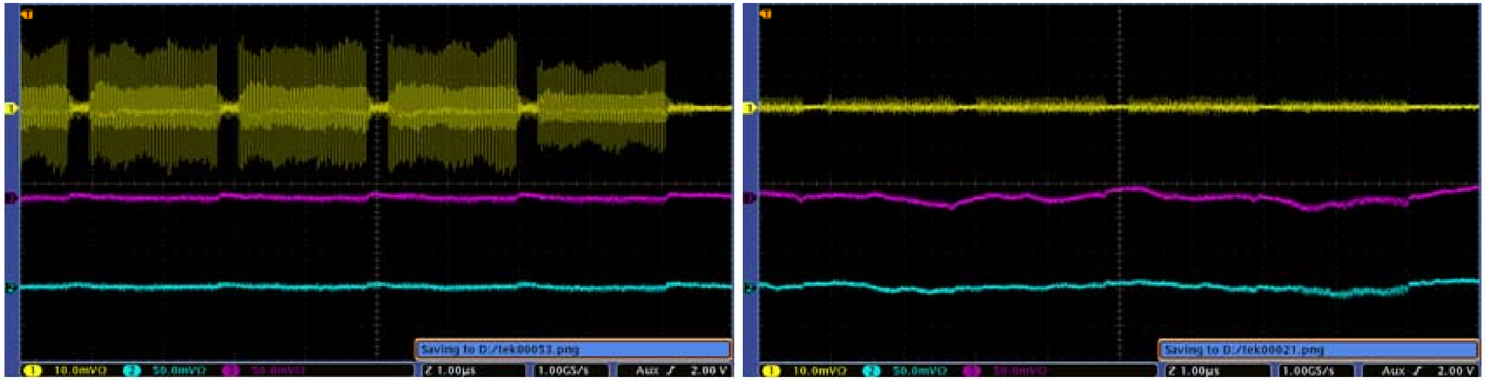


Comparison SS 98 with SS 84 for *positive* stripline clearing voltages

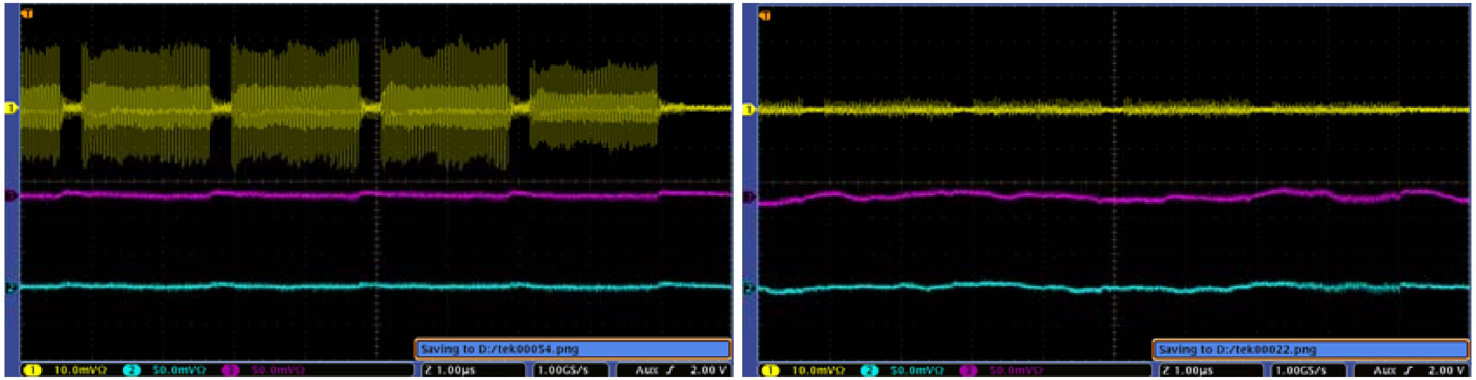
LHC 25ns nominal beam

SS 98 – st.st. | SS 84 – enamel

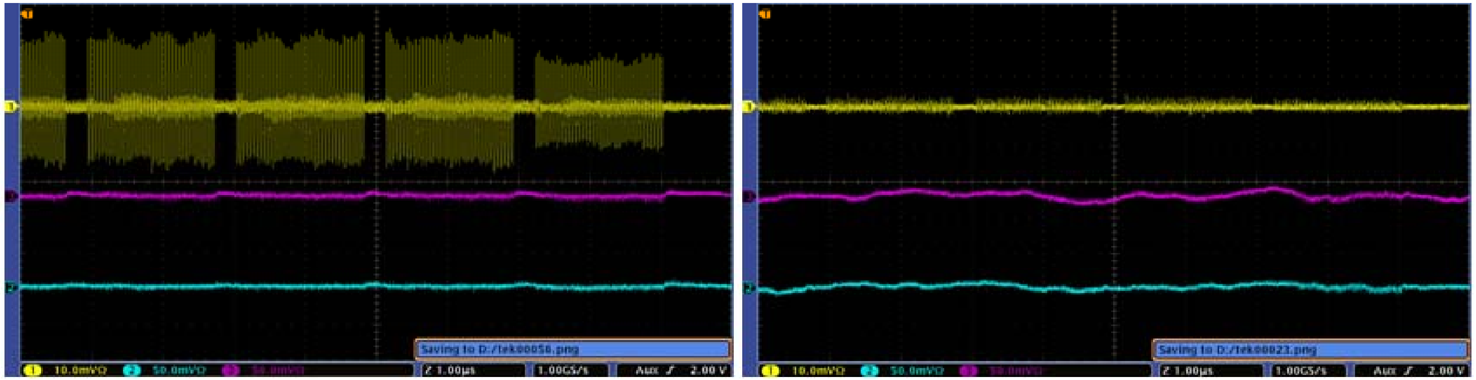
SL = +200V



SL = +225V



SL = +250V

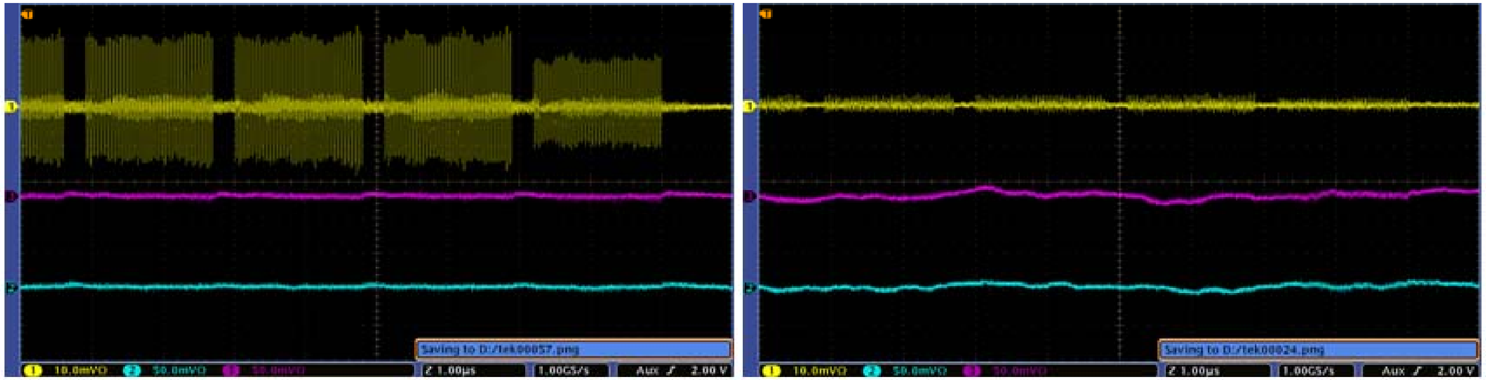


LHC 25ns nominal beam

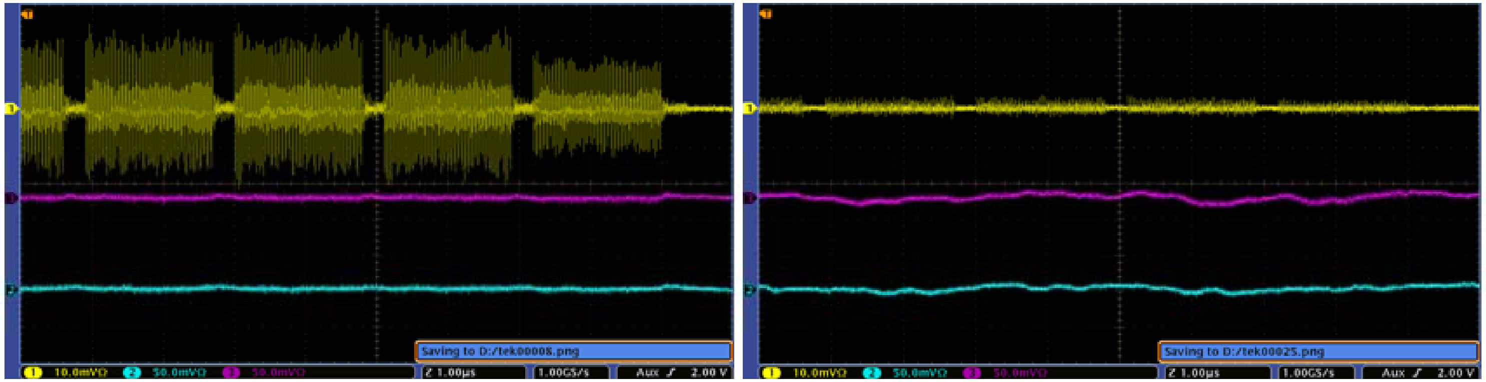
Comparison SS 98 with SS 84 for *positive* stripline clearing voltages

SS 98 – st.st. | SS 84 – enamel

SL = +300V



SL = +500V



For positive voltages, the stainless steel and enamel clearing electrode behave very similar -> electron cloud suppressions is obtained for U_{SL} > 300 V.

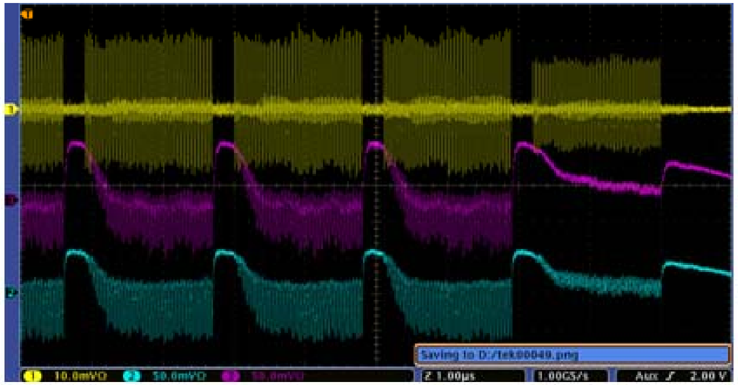
Comparison SS 98 with SS 84 for *negative* stripline clearing voltages

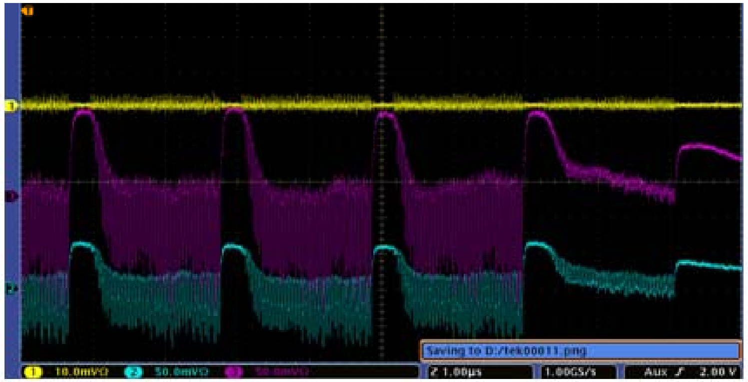
LHC 25ns nominal beam

SS 98 – st.st.

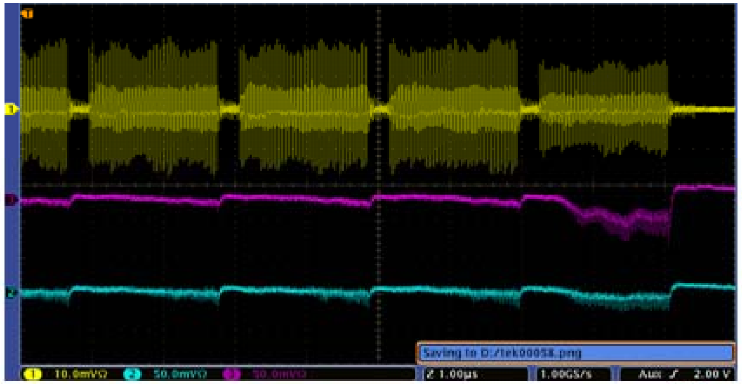
SS 84 – enamel

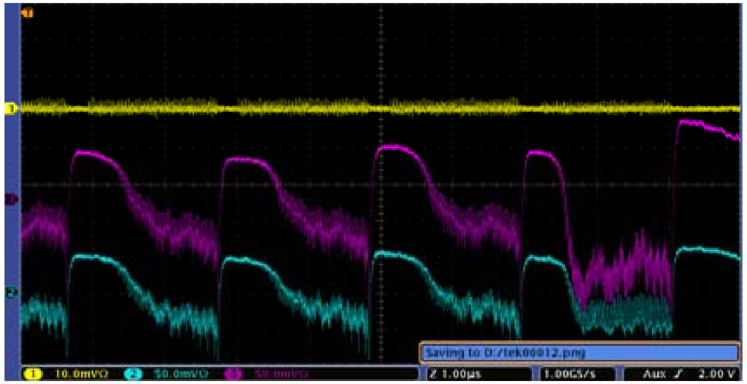
SL = 0



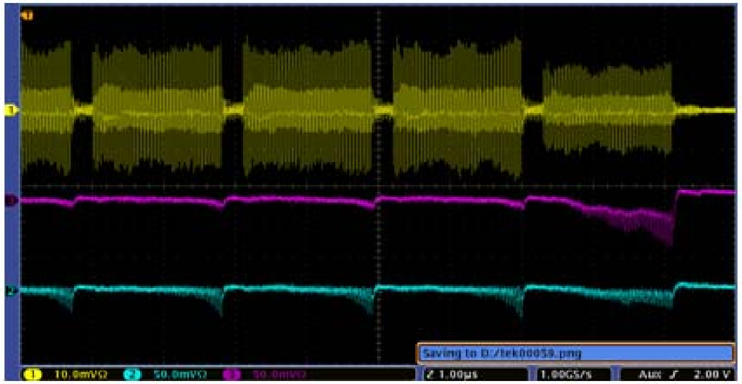


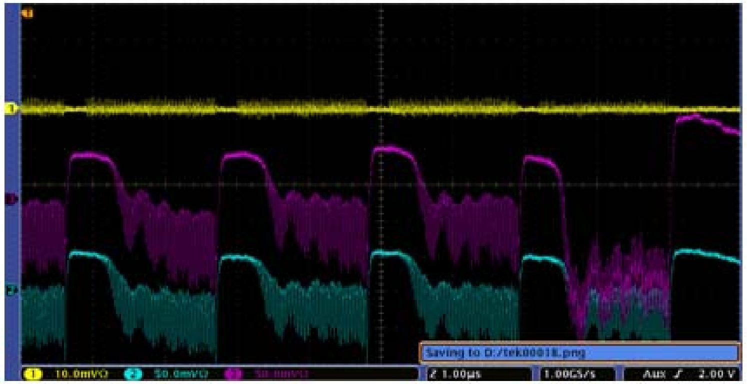
SL = -100V





SL = -150V





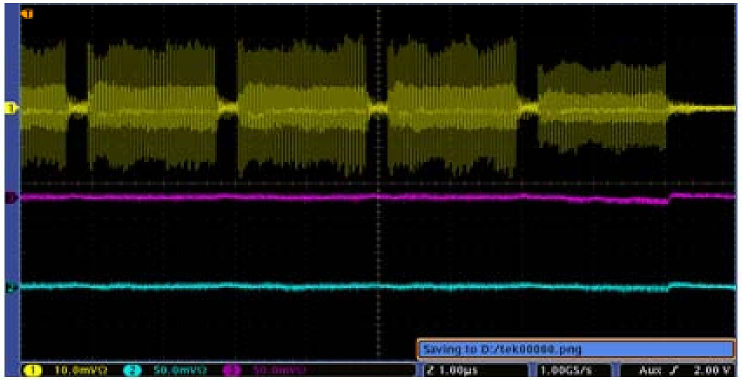
Comparison SS 98 with SS 84 for *negative* stripline clearing voltages

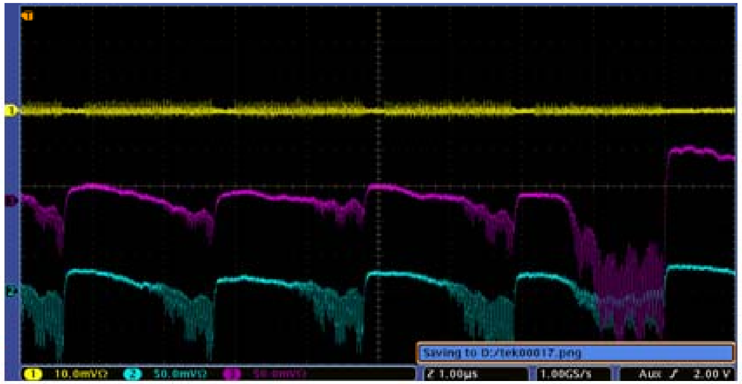
LHC 25ns nominal beam

SS 98 – st.st.

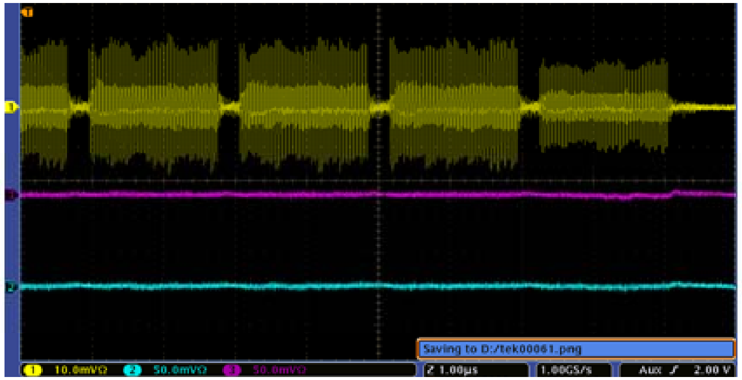
SS 84 – enamel

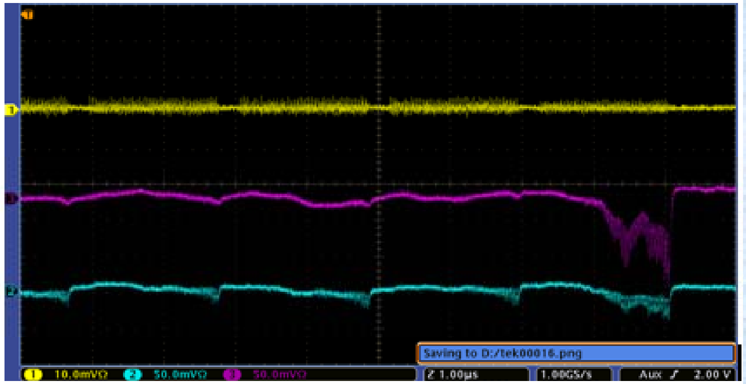
SL = -200V



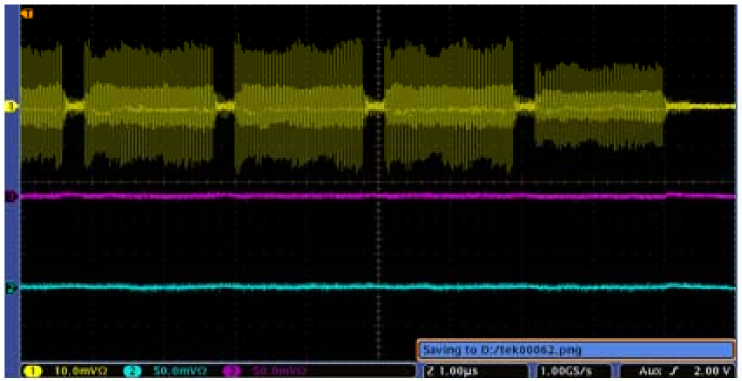


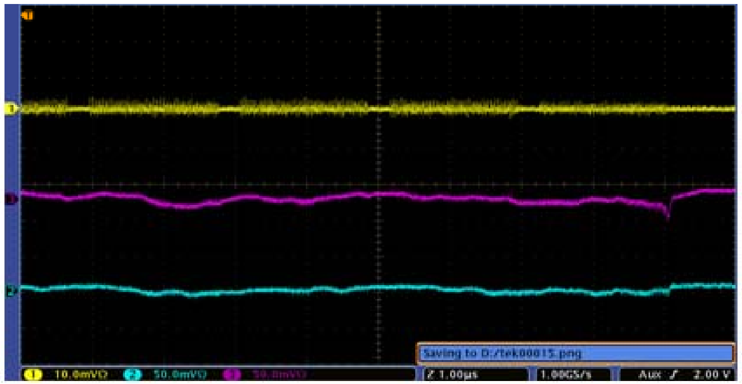
SL = -225V





SL = -250V



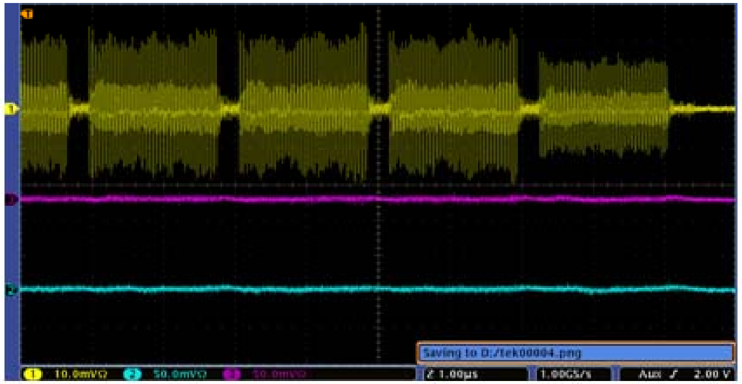


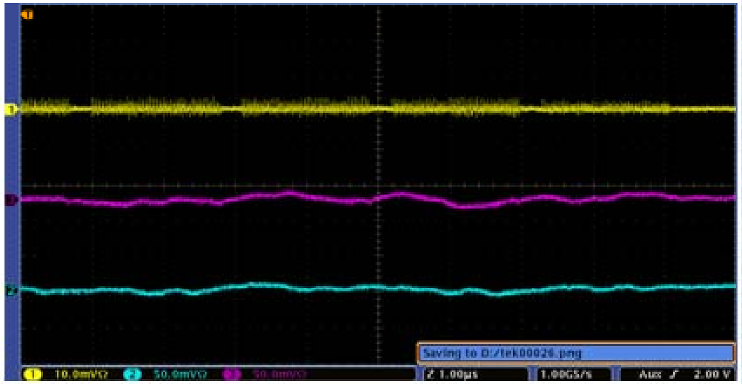
Comparison SS 98 with SS 84 for *negative* stripline clearing voltages

LHC 25ns nominal beam

SS 98 – st.st. | **SS 84 – enamel**

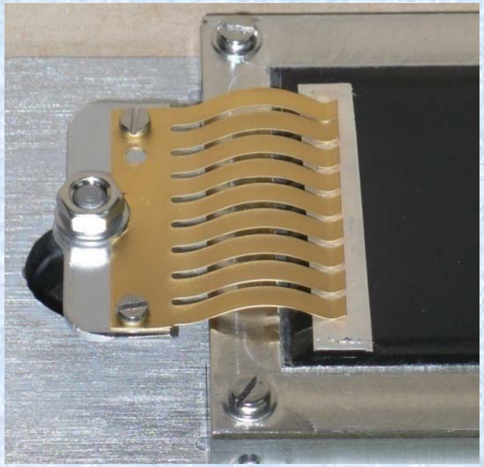
SL = -500V



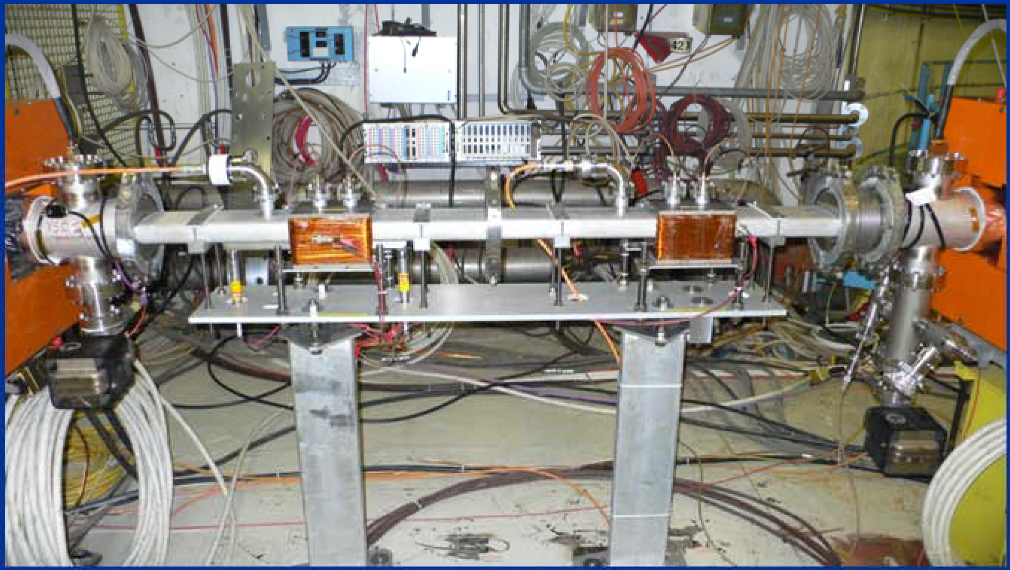


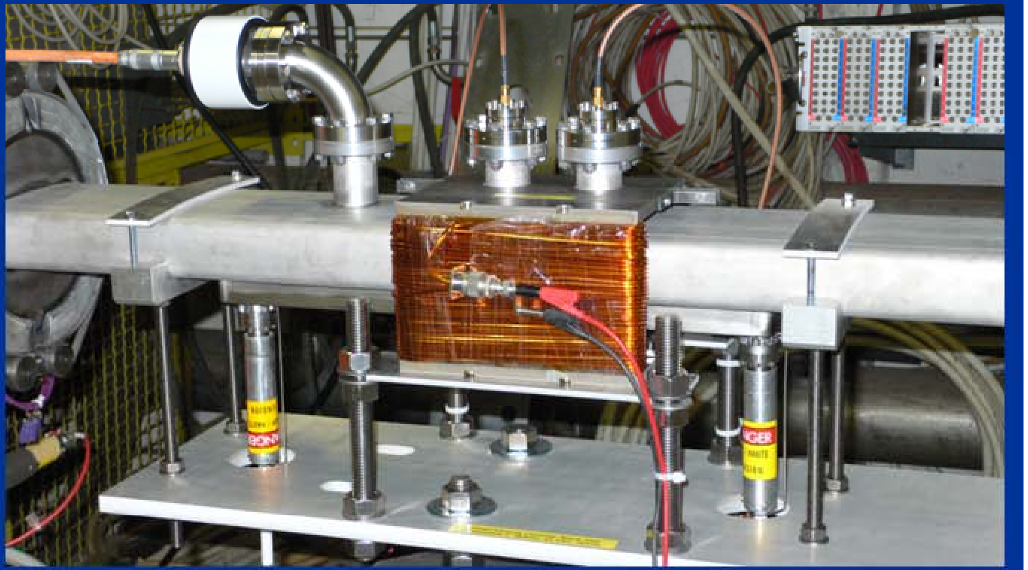
For negative voltages, the stainless steel and enamel clearing electrode behave a bit different for U_{SL} < 300 V. For higher stripline voltages (>500 V) the enamel electrode is as efficient as the stainless steel.

With the presently used design, the high-voltage contacts of the enamel electrode are probably too "complex" for large scale applications, sometimes also not easy to install...



Electron cloud detectors in the SPS (5)
new: pickups + enamel clearing electrode (ECD)





- Two MBN-type vacuum chambers (933 mm x 156 x 64 mm) installed between XSD1 and XSD1
  Removable setup for liner exchange in XSD1 and/or XSD2. Beam direction is from left to right
- Upstream chamber (#1) with anti-chamber contains enamel stripline, downstream chamber (#2) w/o enamel for reference
- PS-type shielded button pickups on both chambers
- C-shape dipole magnets on both chambers, are connected in series so that their B-fields are in opposite direction
- Fast vacuum logging (local) using shielded Penning gauges is possible

2008 scope data from SPS scrubbing run (June)

PS-type shielded button pickup signals

LHC 25 ns, 72 bunches, 1 batch

LHC 25 ns, 72 bunches, 4 batches

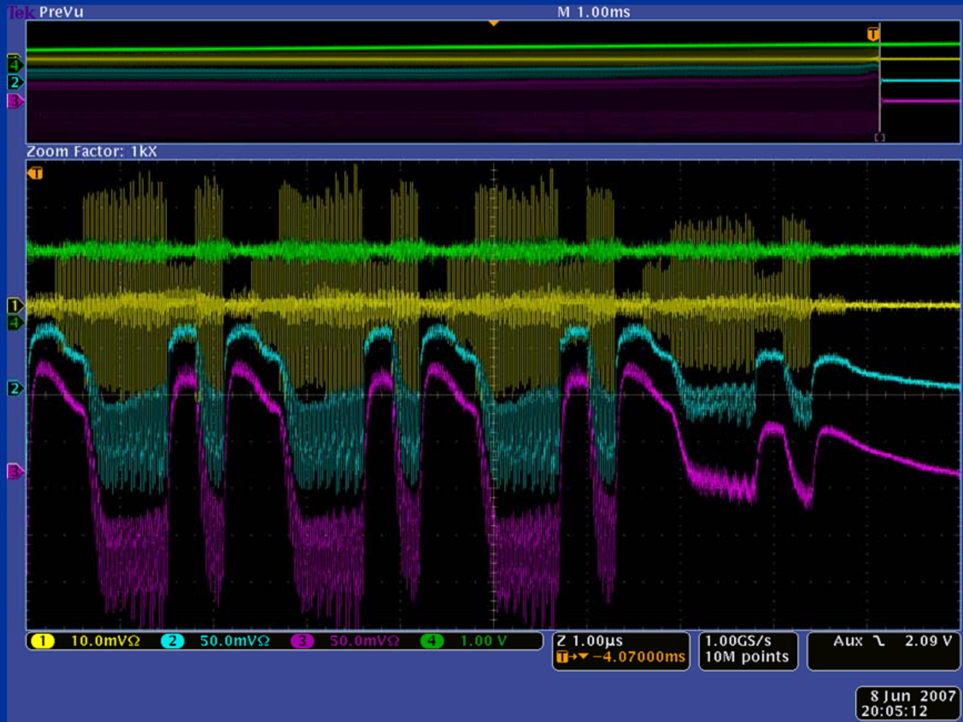
Yellow trace ⇨ enamel stripline in stainless steel chamber #1
Blue trace ⇨ pickup in chamber #1 containing enamel clearing electrode
Magenta trace ⇨ pickup in stainless steel chamber #2 w/o enamel, for reference.

Some (unexpected) low frequency "ringing" in the blue and magenta trace, but one can see (blue trace) the buildup of the e-cloud related current over the duration of the first batch. We will try to understand its origin and get it removed in the future.

Another "attractive" feature of a clearing electrode

Intensity dependence...

- A change in bunch intensity or missing LHC25 bunches in the PS are clearly visible on the button pickups in SS98.



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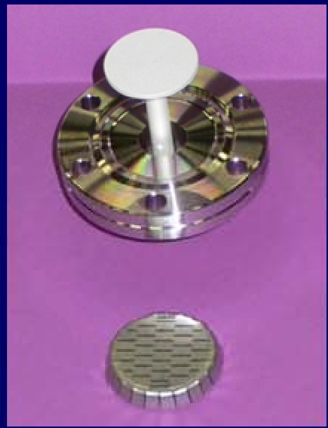
Apart from electron cloud suppresion, bunch-to-bunch intensity variations detected in the PS for the nominal LHC beam with 25ns bunch spacing.

Conclusions + Proposal

- Dedicated PS electron cloud detector operational since 2007, installed in SS98, comprises two shielded pickups, shielded Penning gauge for fast vacuum logging, a dipole magnet, and a stainless steel stripline electrode for electron cloud clearing.
- Since June 2007 clear signs of electron cloud found in the PS with nominal LHC beam:
  - fast vacuum pressure rise, characteristic signal on the shielded button pickups,
  - develops during the last 40 to 50 ms before ejection, when the bunches are shortened by the rf gymnastics.
- Electron cloud can be suppressed by putting a sufficiently large voltage of either polarity onto the clearing electrode. Comparison with a first enamel clearing electrode (new setup in SS84) performed in 2008.
- Enamel electrode acts very similar in terms of electron cloud suppression as the metallic electrode used last year. Thus the functionality of enamel technology as clearing electrode material has been clearly demonstrated.
- Some remaining questions and difficulties:
  - tests until now "only" with flat enamel electrode placed inside antechamber, not easy to apply to curved vacuum chambers over a considerable length, high-voltage biasing not obvious without aperture reduction.
  - Static & dynamic outgassing and SEY not yet measured for enamel. Feedback wished from the community how (if at all…) to continue with enamel or similar clearing electrodes.
- Positive aspect: distributed clearing electrodes are certainly less critical than low SEY films with respect to their long term behavior (ageing?), but films are less demanding in hardware needs.

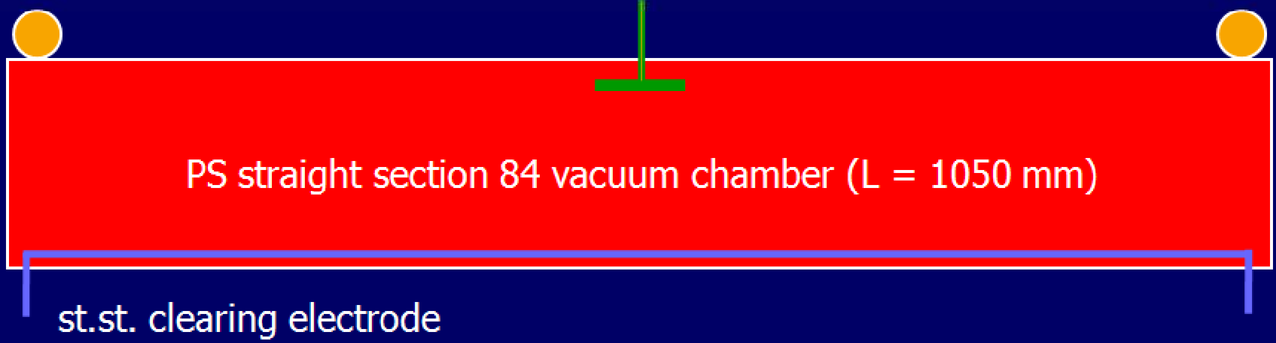
Proposal for a first PS microwave transmission experiment in 2009

Antenna1



shielded button pickup

Antenna2



11. Nov. 2008
E. Mahner, F. Caspers
PS cafeteria

to be installed in SS84