Electron Cloud Studies at the SPS
Beam Stability Issues

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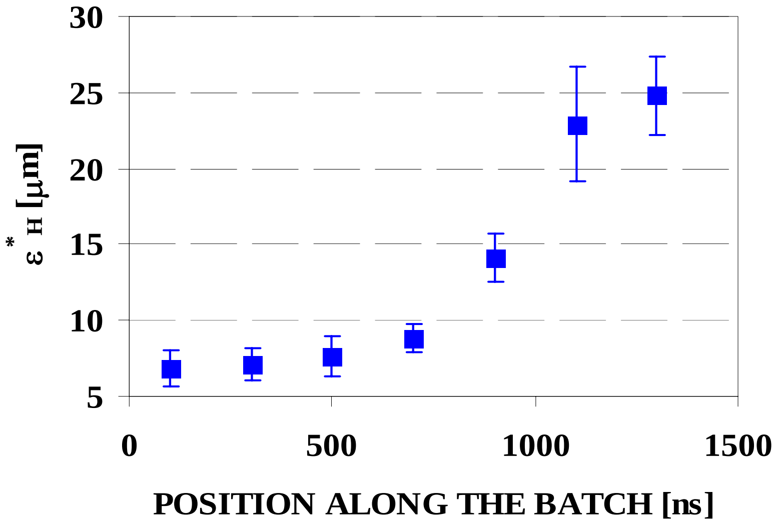
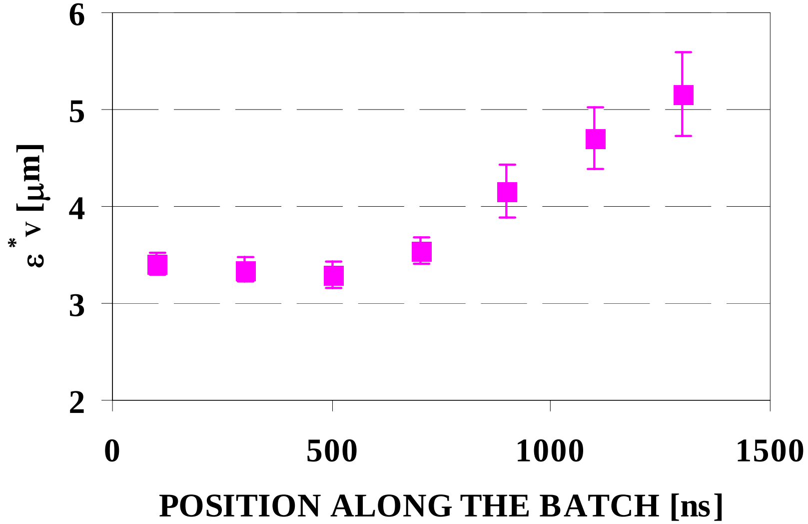
- LHC beam in the SPS
- Electron cloud effects on the beam
- Electron Cloud Instability in the SPS
- Cures for the Electron Cloud Instability
- Summary and Outlook

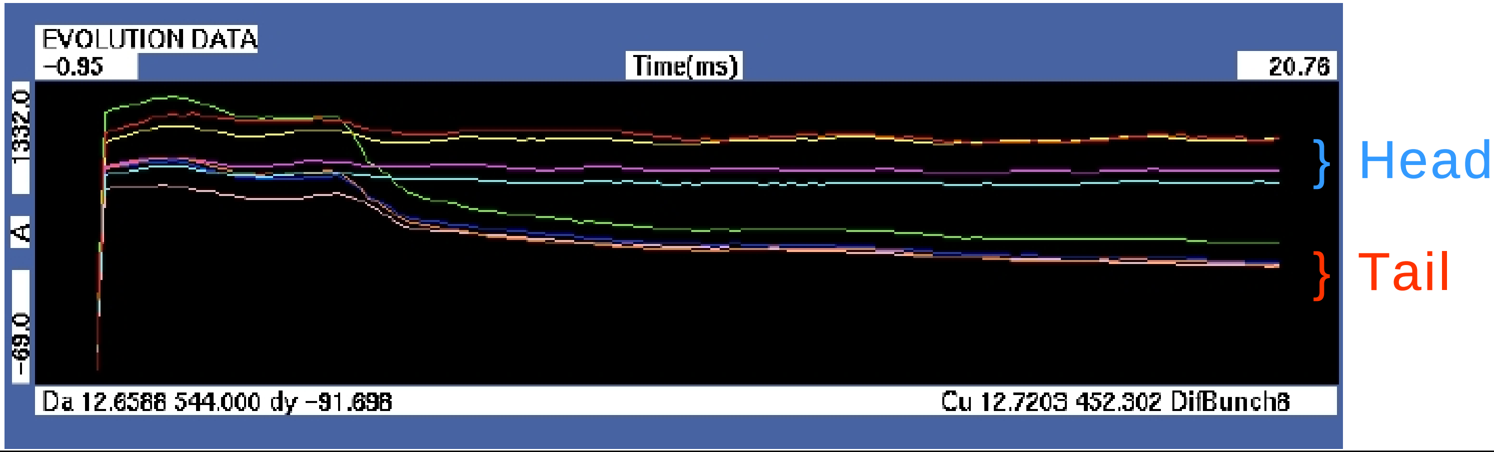
Momentum [GeV/c]	26	450
Revolution period [μs]	23.07	23.05
Tunes (H/V)	26.18/26.13	
Gamma transition	22.8	
Max. n. of batches	4	
n. bunches/batch	72	
Nominal N_{bunch} [10^{11} p]	1.15	
Bunch spacing [ns]	24.97/74.91	24.95/74.85
Full bunch length [ns]	4	<2
Batch spacing [ns]	224.7	224.6
r.m.s. $\varepsilon^*_{H,V}$ [μm]	<3	<3.5
ε_L [eV s]	0.35	<0.8

H & V emittance blow-up mainly in the tail of the batch (few ms after inj.)





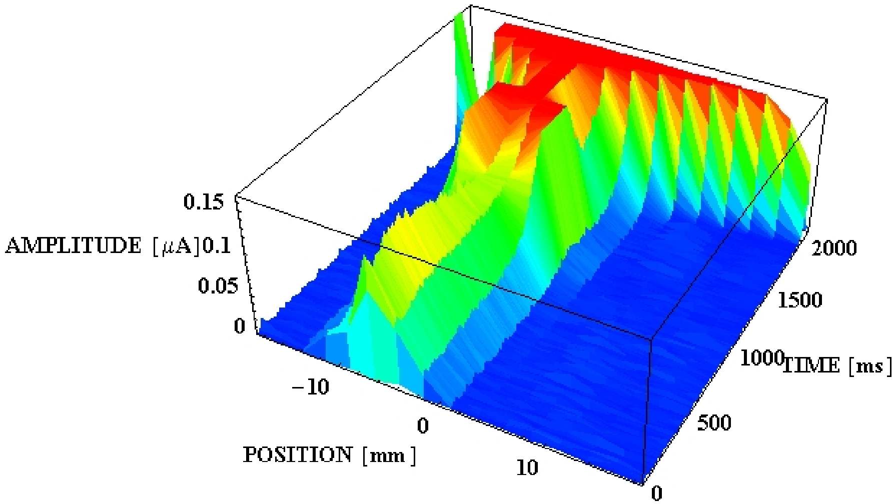
Beam losses mainly affecting the tail of the batch (few ms after inj.)



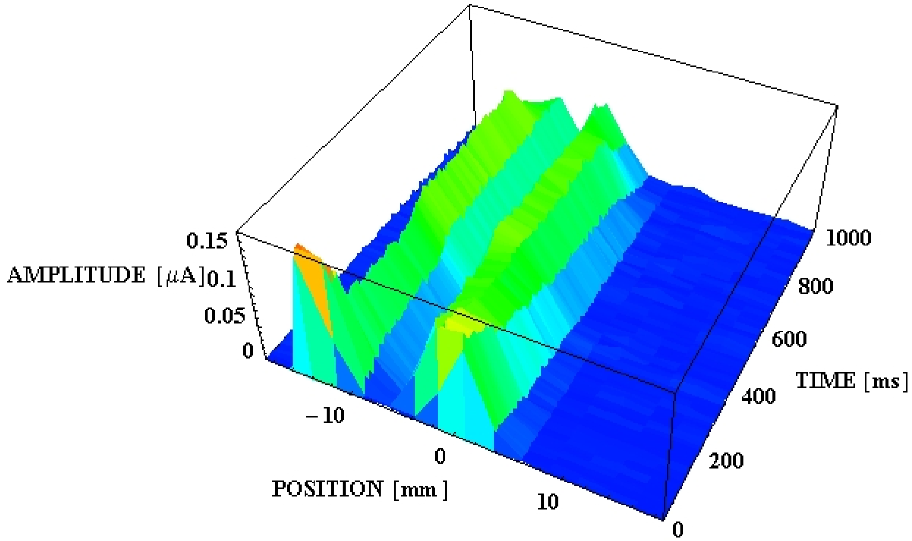
E-Cloud Instability in the SPS

About 70 % of the SPS circumference filled with bends and threshold for electron mutipacing N_{th} is lower in dipole field regions than in field-free sections (after scrubbing N_{th} ~ 0.8×10^{11} p in the arcs, $N_{th} \geq 1.1\times10^{11}$ p in the straight sections)
➔ the behaviour of the electron cloud in the arcs determines the characteristics of the ECI.

$N_{th}=0.2\times10^{11}$ p $<N_{bunch}<0.5\times10^{11}$ p



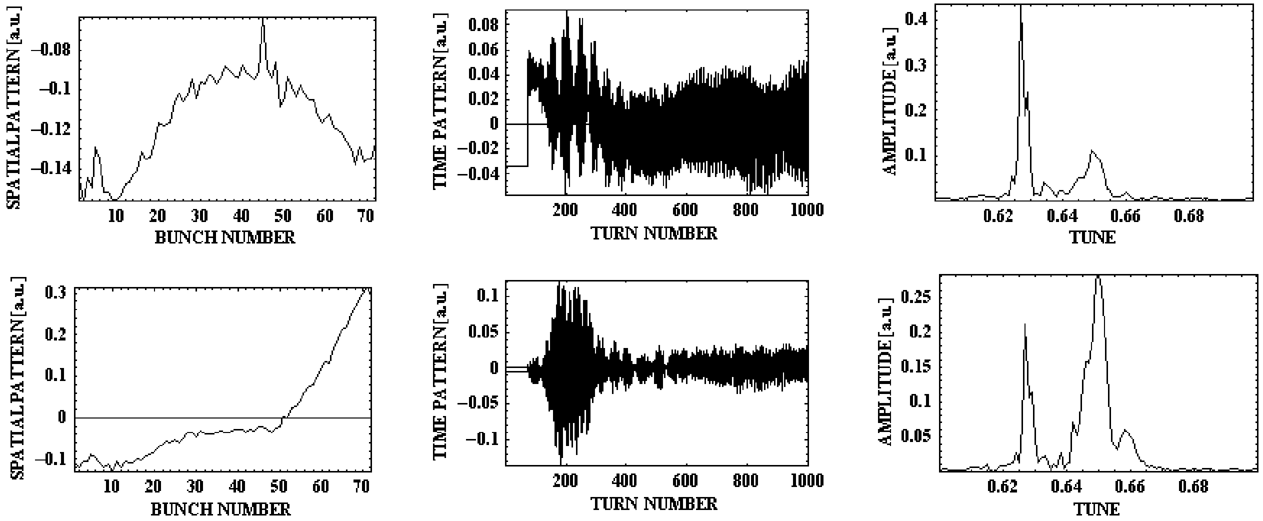
$N_{th}<0.5\times10^{11}$ p $<N_{bunch}<1.1\times10^{11}$ p

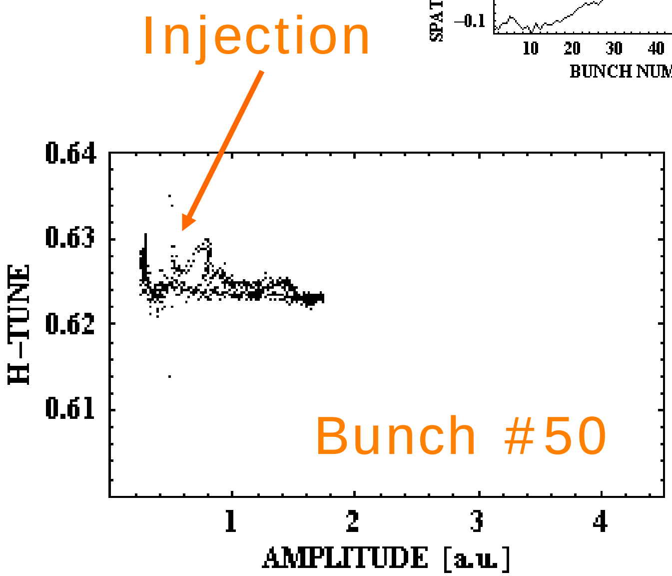


Above 1.1 $\times10^{11}$ a third central stripe appears

$N_{bunch}=0.3\times10^{11}$ p > $N_{th}=0.2\times10^{11}$ p – Linear machine - TFB OFF

Bunch-by-bunch centroid position meas.



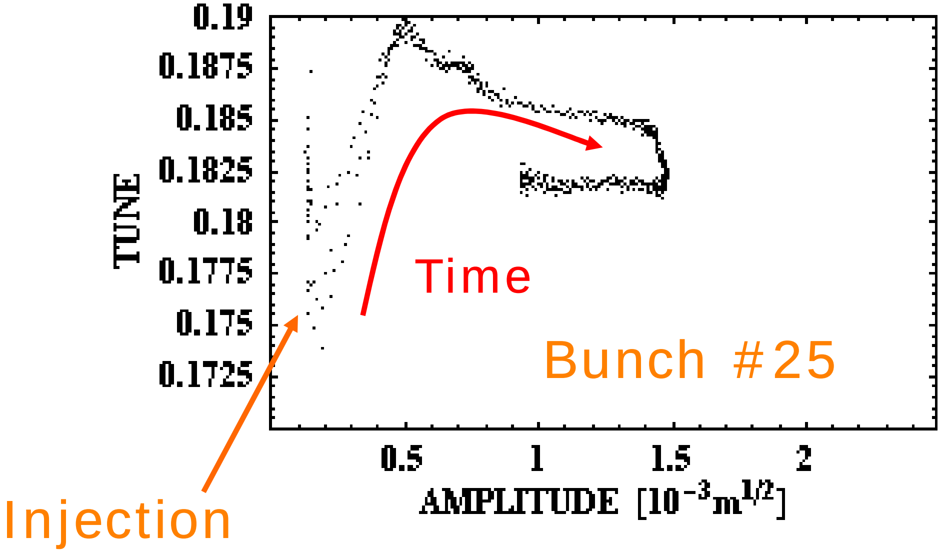


- One central electron stripe
- Coupled bunch instability (low order modes)
- τ_{ECI-H}~40 turns
- Second mode (+0.025) appearing in the tail of the batch (> bunch #50)

Detuning with amplitude of oscillation

$N_{bunch}=1.1\times10^{11}$ p > $N_{th}=0.8\times10^{11}$ p – Linear machine - TFB OFF

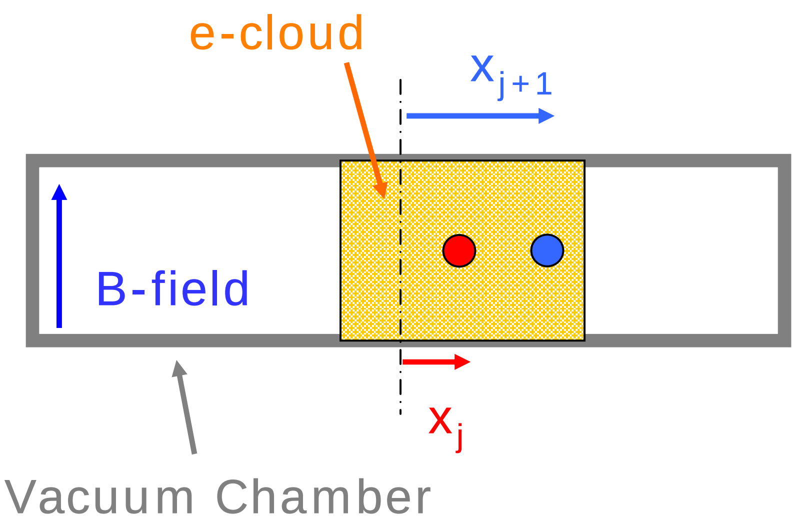
- Three electron stripes
- τ_{ECI-H}~40 turns
- CB instability mainly affecting bunch > 15
- Positive detuning for low amplitudes and negative detuning for higher amplitudes
- Non-linear forces coupling bunches



Energy dependence

Momentum [GeV/c]	τ_{ECI-H}[turns]
26	40
55	200
450	1500

For $N_{th} < N_{bunch} < 5\text{-}6 \times 10^{10}$ p e-cloud ~ vertical ribbon of uniform density starting from a given bunch n.



B-field freezes H-motion of the electrons ➔ no distortion of the e-cloud distribution ➔ e-cloud can couple only subsequent bunches.

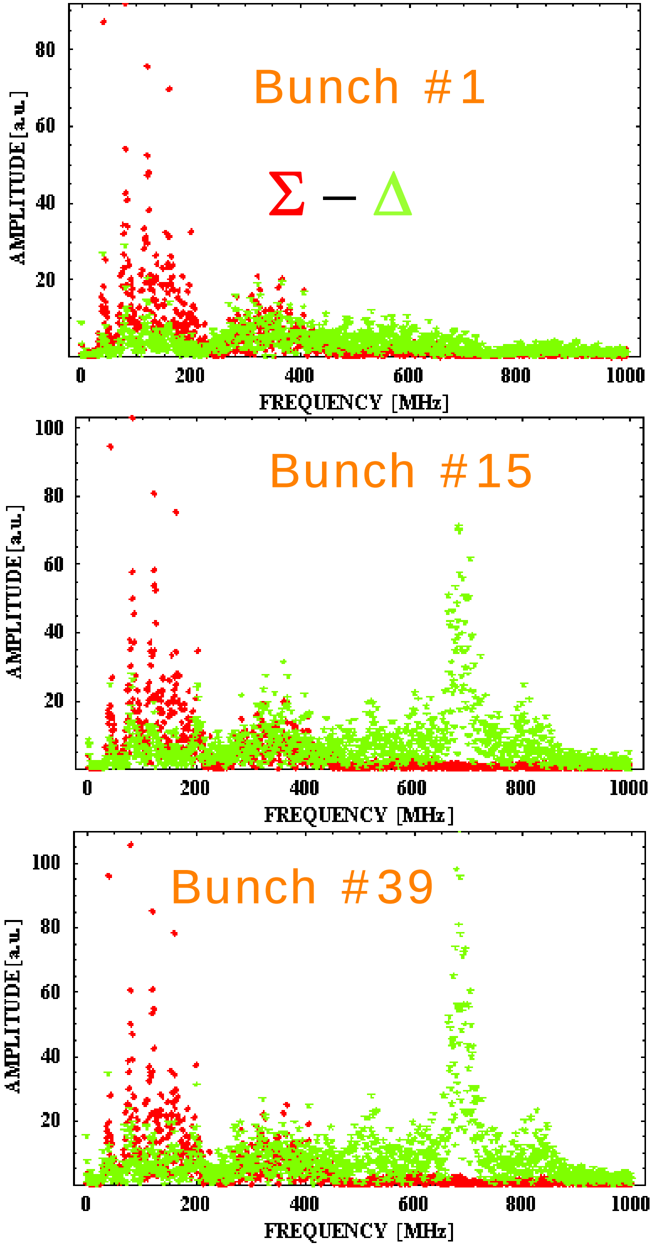
Linear coupling force F:

$$F = -\frac{e\rho_{ec}}{\varepsilon_0}\left(x_{j+1} - x_j\right)\chi(j-n)$$

F depends on N_{bunch} via ρ_{ec} ➔ mild dependence on N_{bunch} above threshold. Only the number of bunches affected increases with N_{bunch}

For $N_{bunch} > 5\text{-}6 \times 10^{10}$ p> N_{th} the above approx. is no more valid ➔ non-uniform density ➔ non linear behaviour of the coupling force

Vertical ECI in the SPS



$N_{bunch}=0.8\times10^{11}$ p > $N_{th}=0.2\times10^{11}$ p – Linear machine - TFB OFF

Single bunch instability (~700 MHz) affecting only the trailing bunches (after bunch 15)

V electron motion is not frozen by the dipole field ➔ electron cloud is pinched during the bunch passage and couples the head and the tail of the bunches.

N_{bunch} [10^{11} p]	τ_{ECI-V} [turns]
0.3	500
0.5	100
1.1	40

Horizontal instability

Can be cured by the Transverse Feedback:

- enough gain and bandwidth up to nominal intensity
- essential for scrubbing

New working point below the half integer:

- Reduced resistive wall growth rate
- Wider resonance-free space in tune diagram

Vertical Instability

- Cannot be cured by the TFB
- Chromaticity ($\xi_V > 0.4$) used to control ECI
- Limited blow-up (~30%) in 40 s at SPS injection energy during last scrubbing run.

Cures for ECI

With these cures LHC beam with nominal intensity and longitudinal emittance and with transverse emittances close to nominal ($\varepsilon_H{}^* < \varepsilon^*_{nominal}$ and $\varepsilon_V{}^* \sim 1.2\ \varepsilon^*_{nominal}$) has been accelerated up to the SPS extraction energy in 2003.

Drawbacks of high ξ_V:

- Limited lifetime (~20 min) at 26 GeV/c for large $\Delta p/p$ ($>2\times10^{-3}$): ξ_V + diffusion process in the longitudinal plane: very likely RF noise.

Other solutions being investigated :

- Coupling as a tool to stabilize the vertical ECI (with working point close to the coupling resonance). Preliminary results are encouraging ➔ Reduction of the chromaticity.
- Measurement and correction of second order chromaticity to minimize detuning with $\Delta p/p$

ECI properties determined by the behaviour of the e-cloud in the dipoles ➔ expect the same in the LHC at low energy.

Horizontal ECI

Cure: Transverse Feedback ➔ Crucial for the scrubbing in the SPS and LHC.

Vertical ECI

Cure: high ξ_V

Need to study energy dependence and long term emittance blow-up with coasts at 26 GeV/c and 270 GeV/c (input for LHC scrubbing scenario) ➔ started in 2003 ➔ part of the MD planning 2004.

Investigation of possible other solutions (e.g. coupling) being pursued.