# Dependence of the e-cloud instability threshold on energy

*G. Rumolo, in PAF Meeting (14/08/2006)*
** Thanks to E. Shaposhnikova, E. Métral and F. Zimmermann*

- Introduction
  - Background & context
  - SPS parameters
- Study of e-cloud threshold in the SPS with HEADTAIL simulations
- Toward a self-consistent ECLOUD-HEADTAIL model
- Conclusions

# Background and Context of the study

→ Main question:

**If the PS gets upgraded to the PS2, how does the electron cloud instability behave because of the higher injection energy into the SPS?**

→ E. Shaposhnikova already showed (*PAF, 17 October 2005*) a list of potential advantages of having higher injection energy:

⇒ Smaller space charge tune spread and IBS growth times

⇒ Threshold increase for the H coupled-bunch instability

⇒ Smaller physical transverse emittance - less injection losses

⇒ Shorter acceleration time

⇒ ...

# Background and Context (II)

## The effects of a higher injection energy in the SPS

E. Shaposhnikova, AB/RF

PAF, 17 October 2005

### Summary (2/2)

No obvious effect on the known "bottle-necks":

- Vertical e-cloud instability
- Longitudinal coupled-bunch instabilities
- Beam loading

Points to check

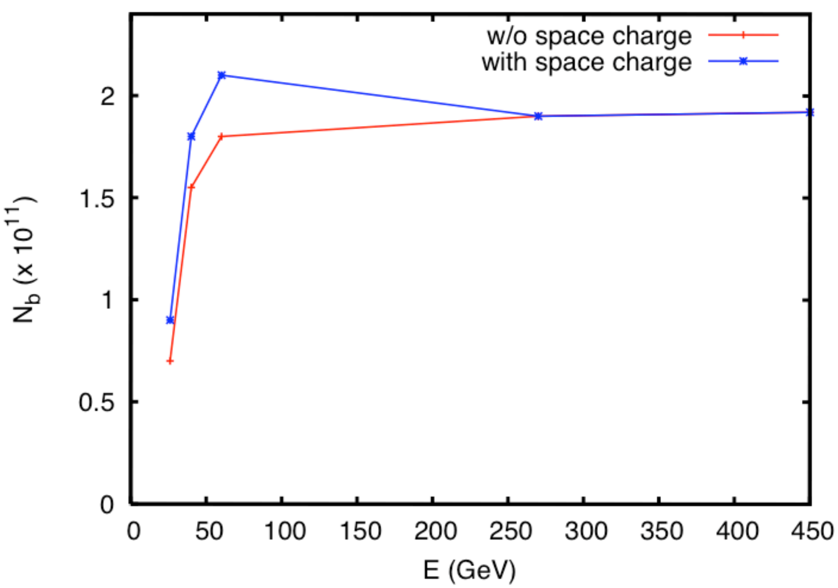
- Vertical e-cloud instability (measurements and simulations)
- TMCI threshold with effect of space charge included (simulations)

# Background and Context (III)

→ The effect on the TMCI threshold has been studied

*„Simulation Study on the Energy Dependence of the TMCI Threshold in the CERN-SPS*", G. Rumolo, E. Métral, E. Shaposhnikova, EPAC'06, Edinburgh

→




Based on HEADTAIL simulations, shows a scaling law **∝|η|**

# Background and Context (IV)

→ In the same paper we tried to understand the behaviour of the electron cloud instability by a broad-band TMCI model [E. Métral, F. Zimmermann]

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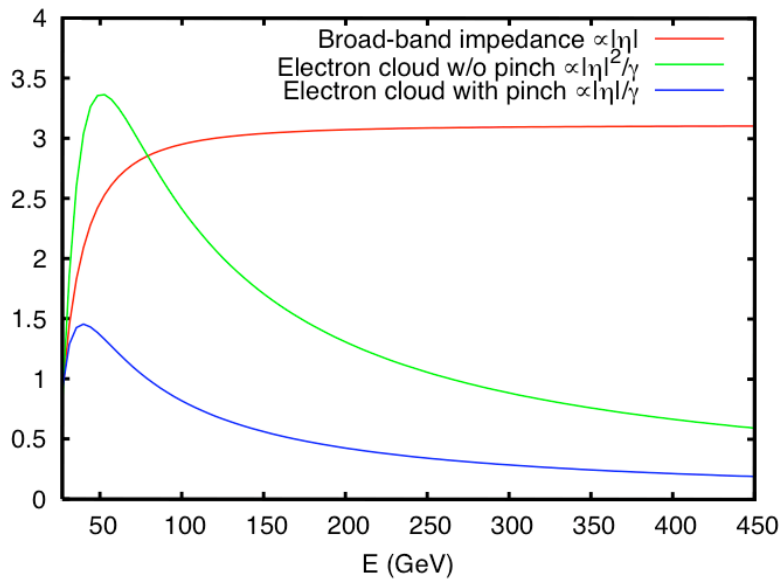



Unlike the conventional broad band impedance driven TMCI, the e-cloud instability threshold seems to scale like $\mathbf{\propto|\eta|^a/\gamma}$

→ Preliminary HEADTAIL simulations showed stronger instability at 60 GeV/c than at 26 GeV/c ⇒ **Detailed threshold study needed!**

# MAIN ASSUMPTIONS FOR THIS ANALYSIS

- Nominal (LHC) beam parameters at injection:
  - Longitudinal emittance $\varepsilon_z = 0.35$ eVs - unchanged
  - Bunch length $\sigma_z = 0.3$ m
  - Normalised transverse emittances: $\sim\varepsilon_{x,y} = 3.0$ μm
- Beam energy swept over a large range (14-270 GeV/c)
- Bunches are always matched to their buckets
- Considered electron cloud density is $10^{12}$ $m^{-3}$ (average value) and is concentrated in the MBB dipoles
- Simulations done in dipole field regions

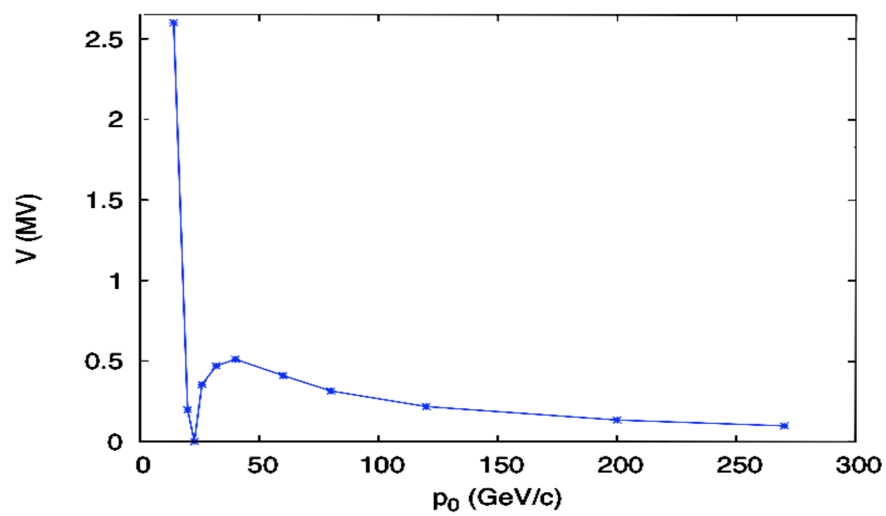
# Main assumptions for this analysis (II)
## - full overview on the parameters -

Table 1: SPS parameters used in the simulation

| Parameter | Symbol (unit) | Value |
|---|---|---|
| Momentum | $p_0$ (GeV/c) | scanned between 14 and 270 |
| Bunch intensity | $N_b(\times 10^{11})$ | scanned between 0.3 and 1.1 |
| Longitudinal emittance ($2\sigma$) | $\epsilon_z$ (eVs) | 0.35 |
| Bunch length ($1\cdot\sigma$) | $\sigma_z$ (m) | 0.3 |
| Mom. compaction | $\alpha$ | $1.92 \times 10^{-3}$ |
| Norm. r.m.s. emittances | $\epsilon_{x,y}$ ($\mu$m) | 2.8/2.8 |
| Tunes | $Q_{x,y}$ | 26.185/26.13 |
| Chromaticities | $\xi_{x,y}$ | corrected, corrected |
| E-cloud density (average) | $\rho_e$ (m$^{-3}$) | $0.3 - 1 \times 10^{12}$ |

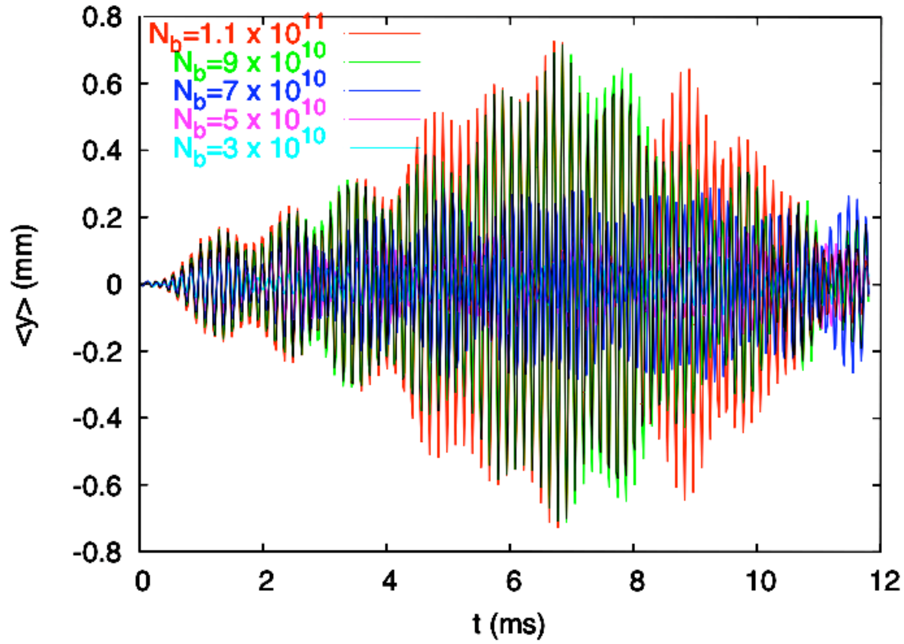
# Main implications of the assumptions

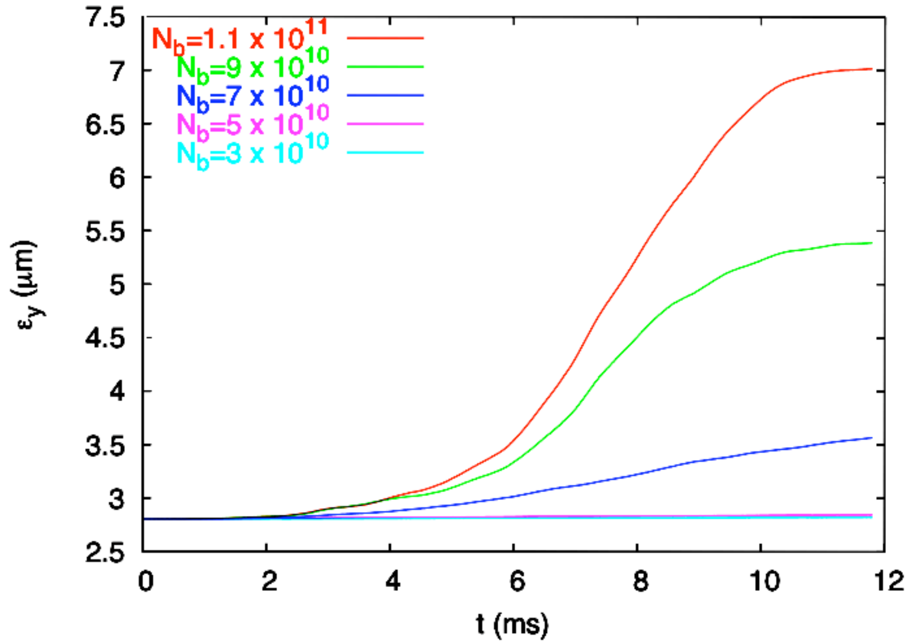
- Longitudinal emittance 0.35 eVs and rms bunch length 0.3 m:
  - Matched voltage scales like $|\eta|/\gamma$ and is re-adjusted for the simulations at different energies




- Normalised transverse emittances: ~3.0 µm implies that transverse beam sizes scale like $\gamma^{-1/2}$

# Centroid and emittance evolution



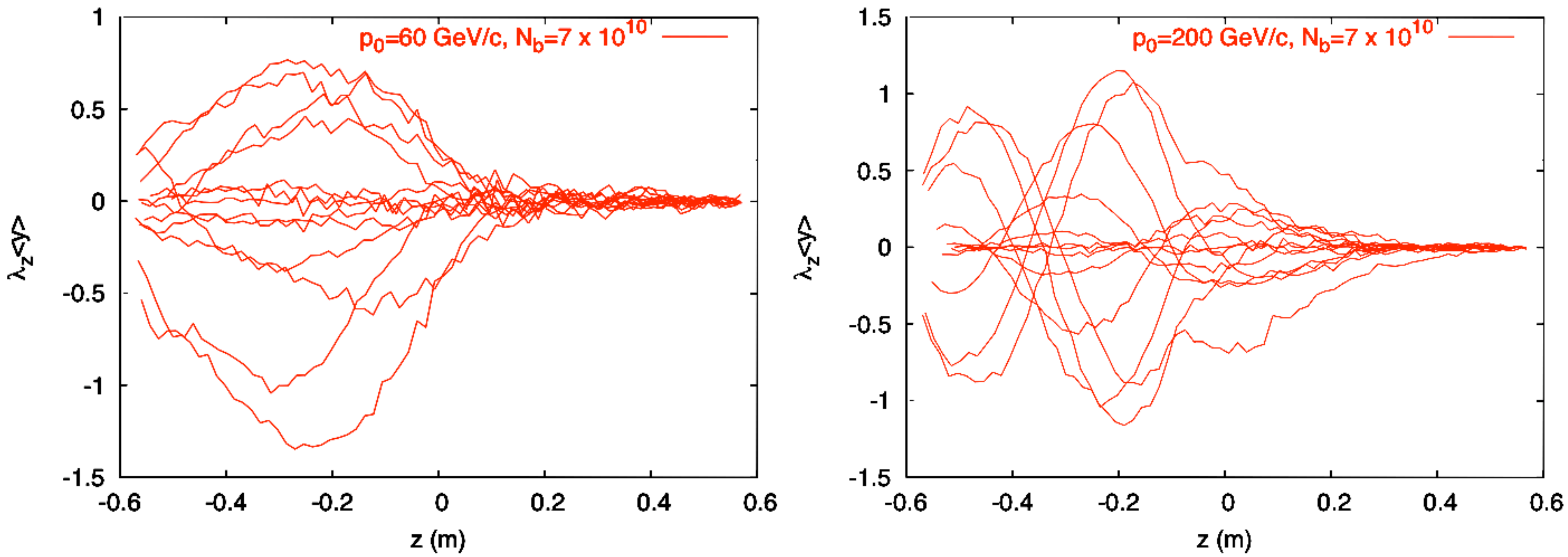




Example at 40 GeV/c:

→ There is a coherent motion of the bunch with threshold between 5 and 7 x $10^{10}$

→ simulations are in dipole field regions, the instability appears in the vertical plane.

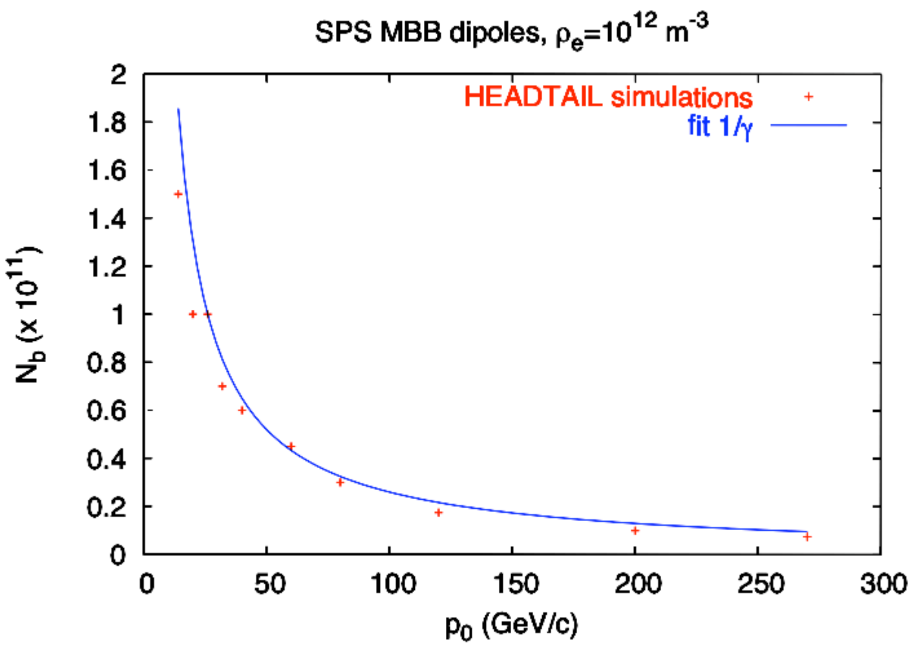
# Centroid motion along the bunch

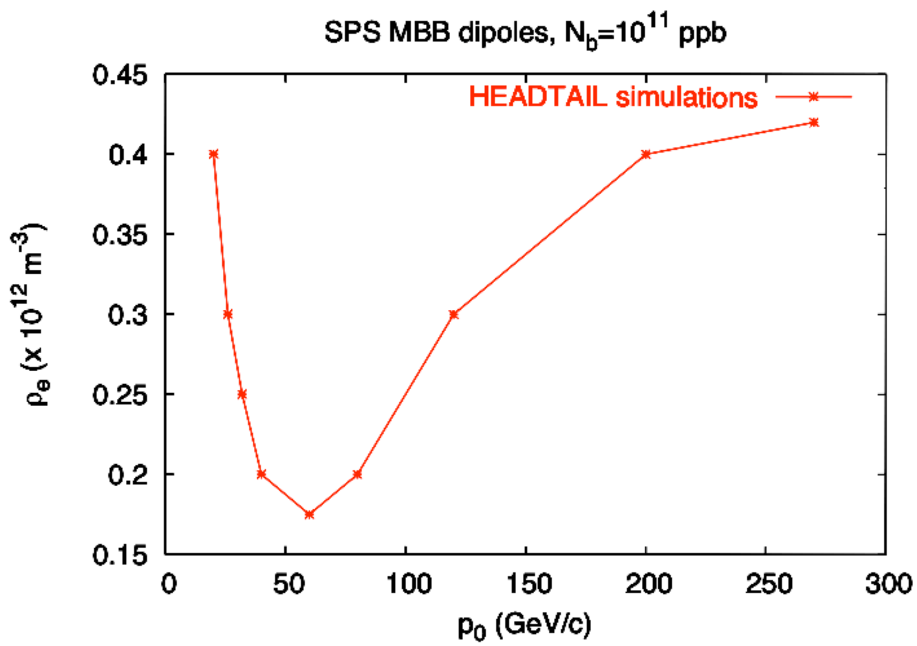



The coherent motion appears along the bunch with a typical TMCI pattern.

Example ➚ The figures above are superimposed snapshots of the centroid motion along the bunch at different times for the 60 and 200 GeV/c cases.

# Overview on the instability thresholds

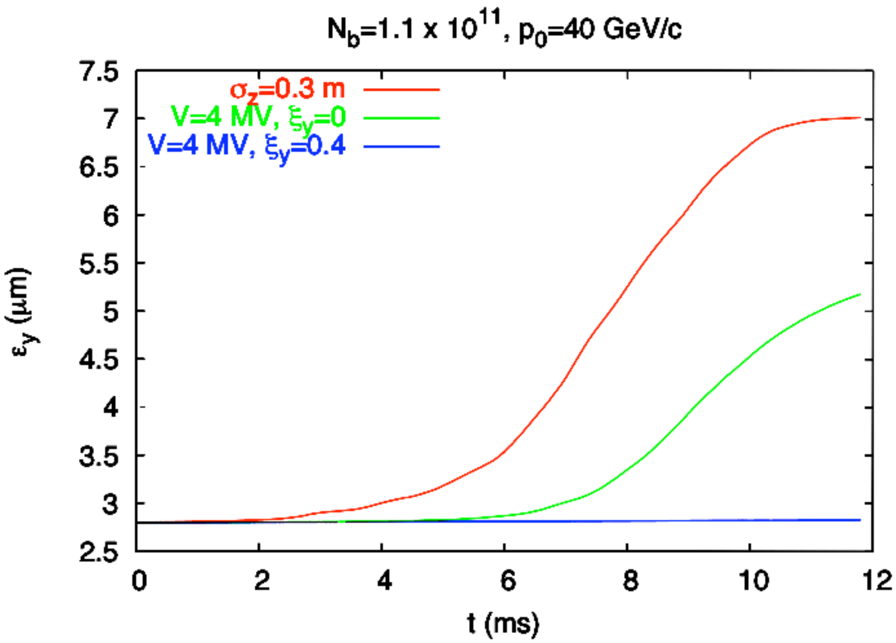


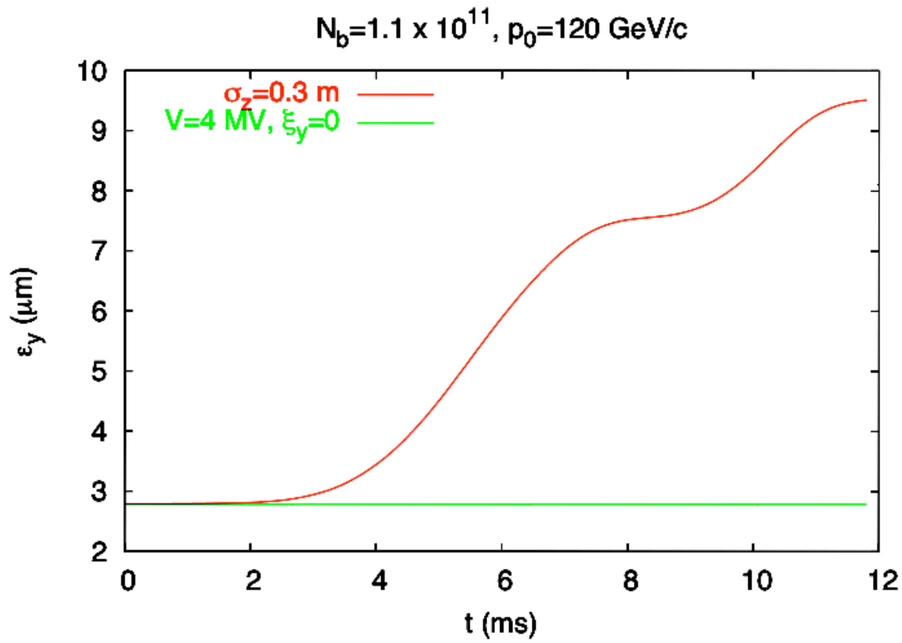




Instability thresholds as:

- Bunch intensity when the e-cloud density is fixed → **decreases with energy!**
- E-cloud density when the bunch intensity is fixed → it does not change by a large amount

# Changing assumptions: V=4 MV




Stronger voltage makes the beam more stable:

→ At 40 GeV/c 1.1 x $10^{11}$ ppb is less unstable than in matched condition and it is completely stabilized by a 0.4 units of vertical chromaticity.

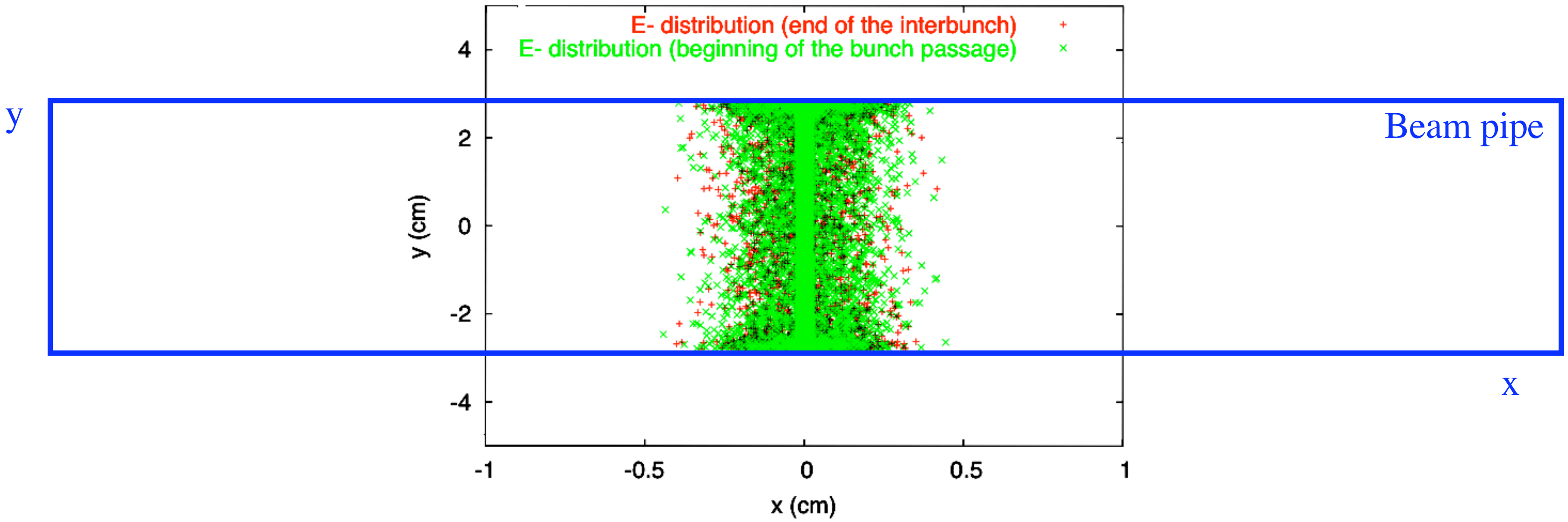
→ At 120 GeV/c 1.1 x $10^{11}$ ppb is stable even with zero chromaticity.

# HEADTAIL upgraded

The electron distribution used in HEADTAIL has been so far a uniform distribution in the beam pipe or a single- or two-stripe distribution to better fit the real distribution in a dipole field region.

→ We could improve the model by using as an input the real distribution of electrons as it comes out of the build up ECLOUD code

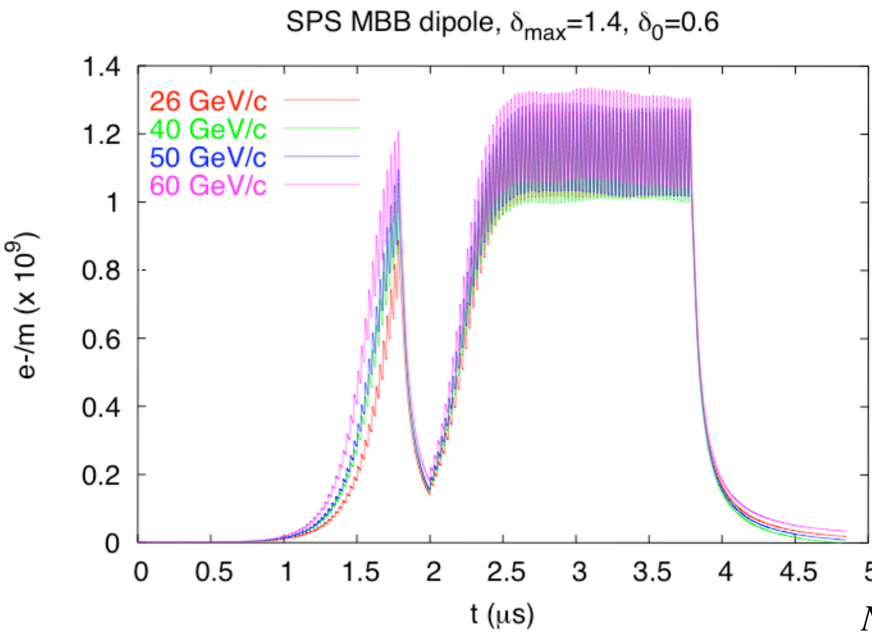
→ The electron distribution at the very beginning of a bunch passage is saved into a file from an ECLOUD run and subsequently fed into HEADTAIL. **This model is more self-consistent!**

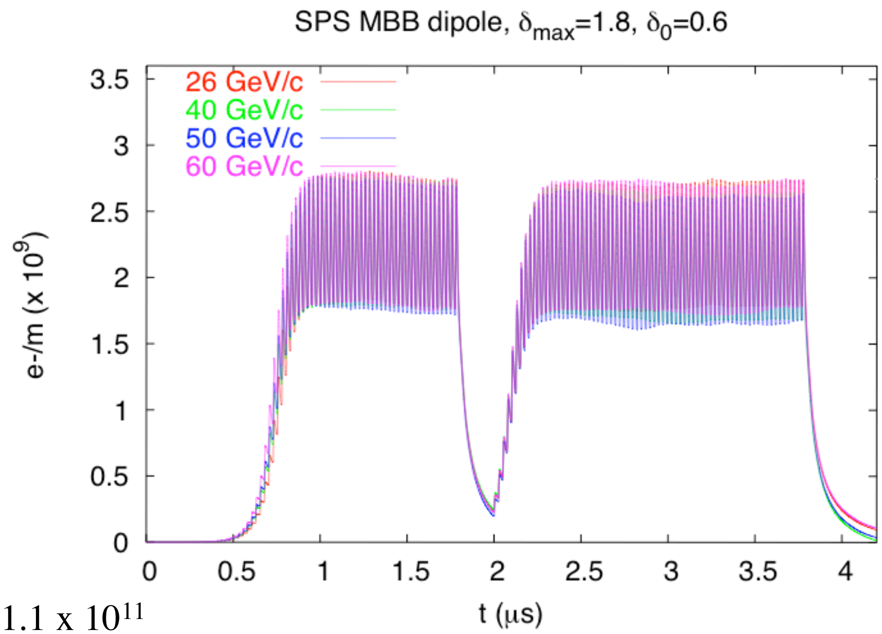


# Headtail upgraded (II)

→ The build up simulations show a very weak dependence of the saturated electron density on the beam energy (i.e. transverse beam sizes).

→ Changing $\delta_{max}$ from 1.4 to 1.8 the value of saturated density about doubles.



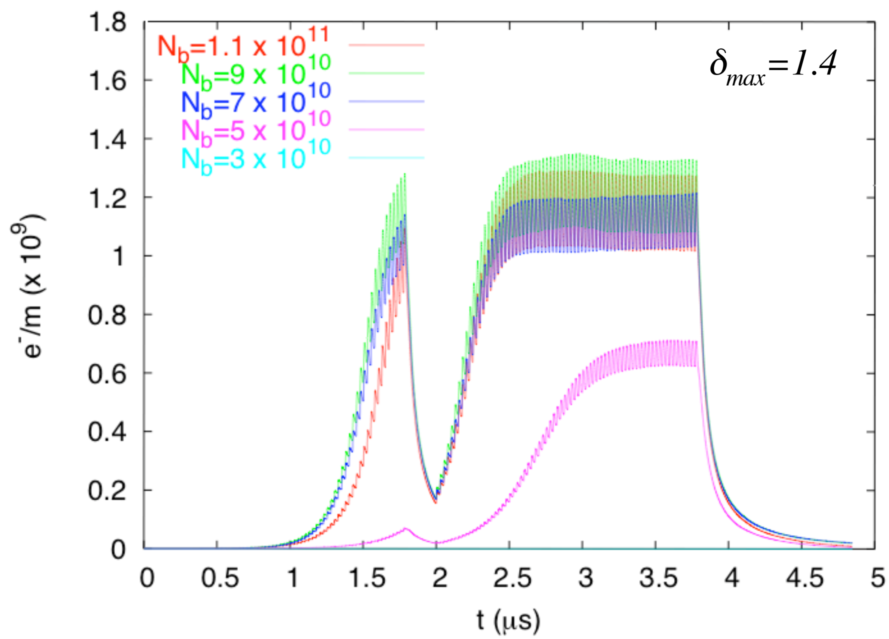



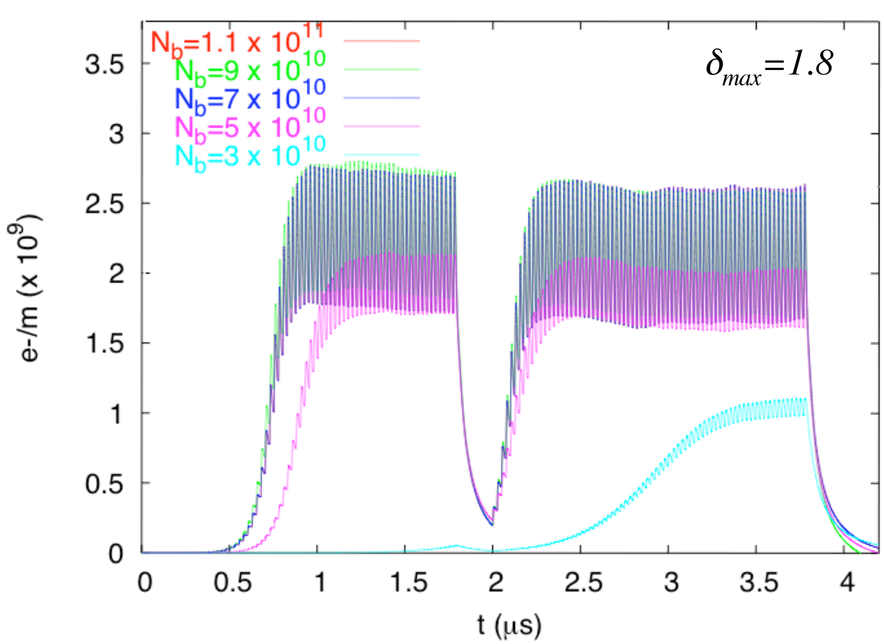

$N_b$=1.1 x $10^{11}$

# Headtail upgraded (III)

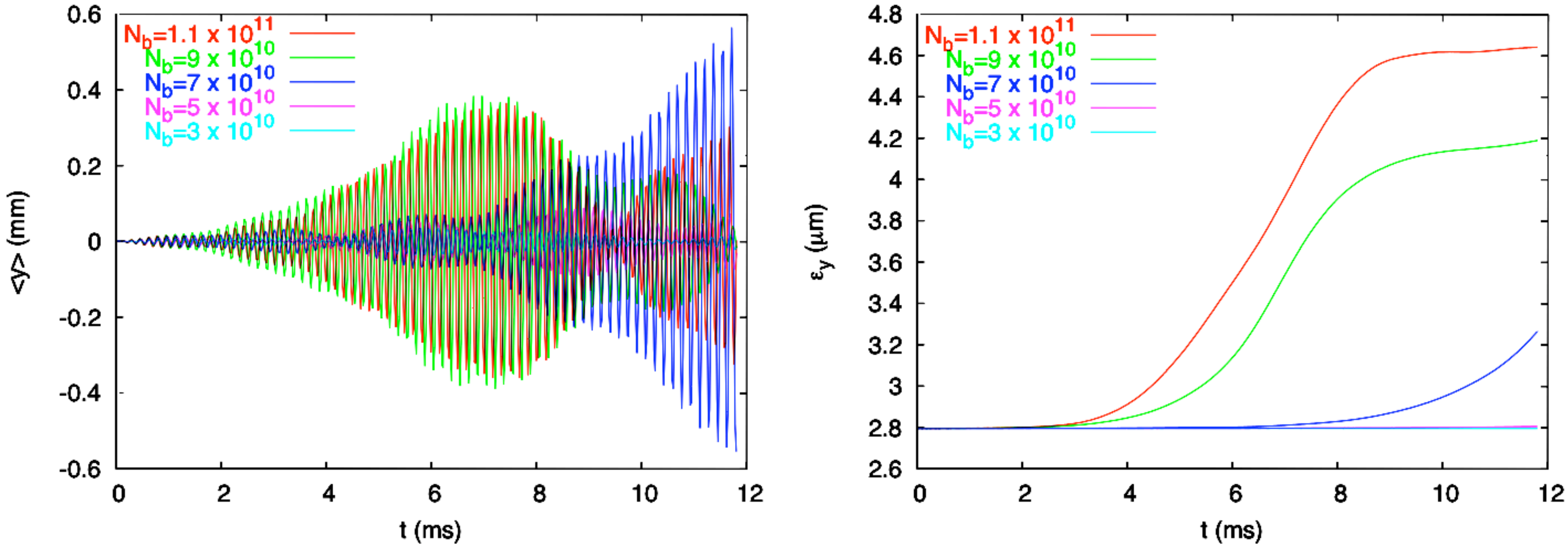
→ The dependence of the saturated electron density on the beam intensity is plotted for two values of the $\delta_{max}$

→ When $\delta_{max}$=1.4 the threshold for the e-cloud build up is at around 4 x $10^{10}$.



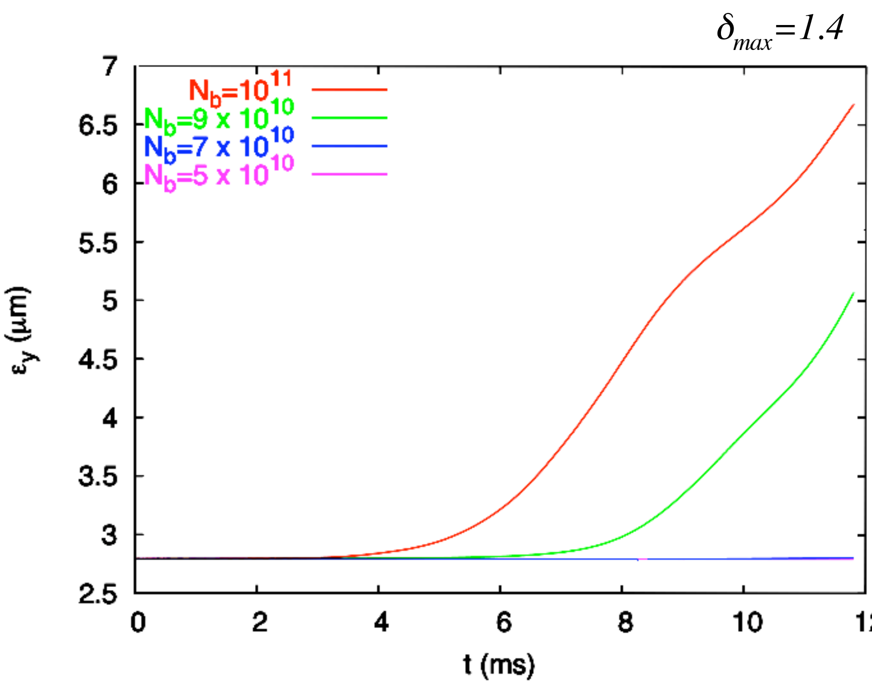
# Headtail upgraded (IV)

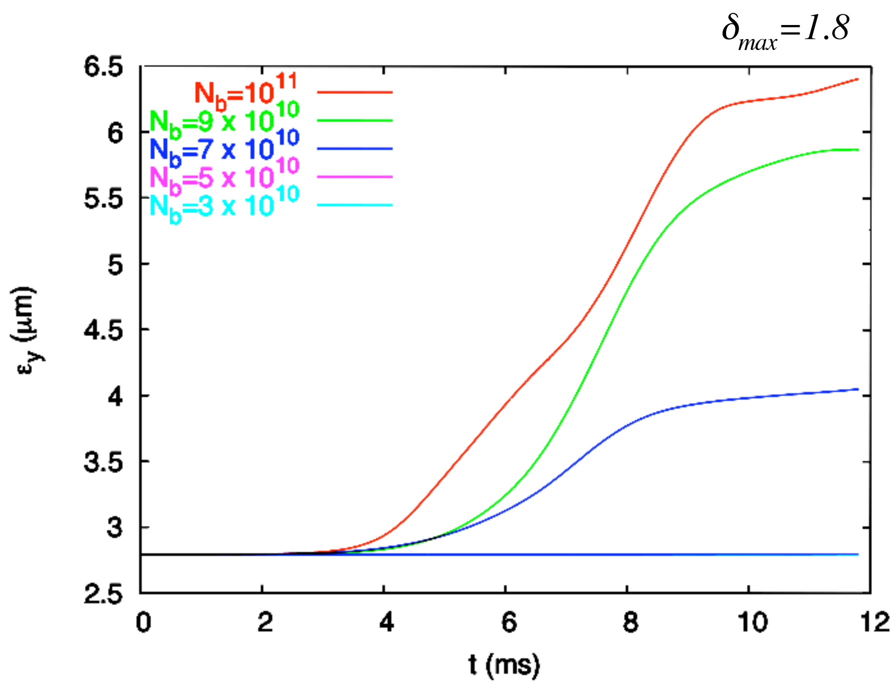



**Example at 40 GeV/c:**

→ The instability occurs in a very similar fashion to the case with electrons uniformly distributed inside the beam pipe. **The threshold is very close to the one previously computed!!**

# Headtail upgraded (V)




**Example at 50 GeV/c with two different values of $\delta_{max}$:**

→ $\delta_{max}$=1.4, the instability threshold is at around 7 x $10^{10}$

→ $\delta_{max}$=1.8, the instability threshold is at around 5 x $10^{10}$

# Summary & Conclusions

- The electron cloud instability exhibits a more complex behaviour than regular TMCI:
  - The **bunch intensity threshold ($N_b$)** for instability **decreases with energy**, most probably due to the shrinking transverse beam sizes
  - Unlike the conventional TMCI threshold, which increases with energy like $|\eta|$, the decay law for the e-cloud instability threshold seems to be $\propto 1/\gamma$.
- The **e-cloud density threshold ($\rho_{cl}$)** for instability **weakly depends on energy**, but anyway is minimum at around 40-60 GeV/c

# Conclusions & recommendations

- Self-consistent ECLOUD-HEADTAIL simulations have been set up for a more realistic modeling:
  - $N_b$ and $\rho_{cl}$ are not independent variables, but $\rho_{cl}=\rho_{cl}(N_b)$
  - The electron distribution used in HEADTAIL comes from the build up simulation.
- The self-consistent model confirms the results obtained with the uniform cloud model at 40-50 GeV/c
- **Based on this study, measures against electron cloud formation are necessary if the injection energy into the SPS is increased.**