Experimental Studies on SPS E-Cloud

G. Rumolo, in Beam07 -Upgrade of the LHC Injector Complex (05/10/2007)
MDs and data analysis with: G. Arduini, E. Benedetto, T. Bohl, R. Calaga, E. Métral, G. Papotti, F. Roncarolo, B. Salvant, E. Shaposhnikova, R. Tomás

- Background of the 2007 experimental study:
  - Dependence of the e-cloud instability threshold on energy as predicted by HEADTAIL
  - Code benchmark (thanks to K. Ohmi and H. Jin)
- 2007 MDs:
  - Measurements at 26 and 37 GeV/c with one batch
  - Measurements at 26 and 55 GeV/c with more batches
- Summary and conclusions

→ Experience from previous years SPS operation:

⇒ **E-cloud instability** is one of the main single bunch intensity limitations in the SPS for the LHC beam.

⇒ It is suppressed with **high positive chromaticity**

→ How does the electron cloud instability threshold change if the injection energy into the SPS becomes 50-70 GeV/c ?

→ Answer to this question is not straightforward:

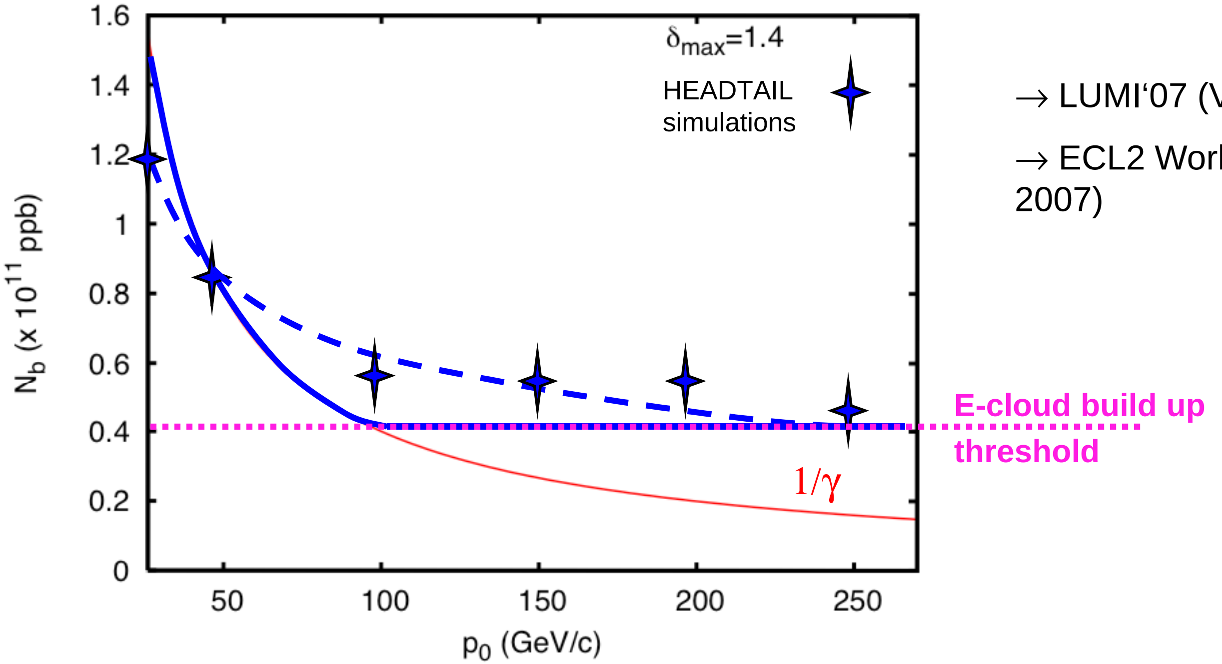
⇒ Higher energy means more rigid, therefore **more stable**, beam

⇒ At higher energy the beam gets **transversely smaller**, which enhances the pinch of the electrons as the bunch goes through them

⇒ The matched voltage is lower at higher energy, which translates into a **lower synchrotron tune** (destabilizing)

⊗ We carried out HEADTAIL simulations to answer the question !

HEADTAIL prediction using model with self-consistent e-cloud



→ LUMI'07 (Valencia, October 2006)

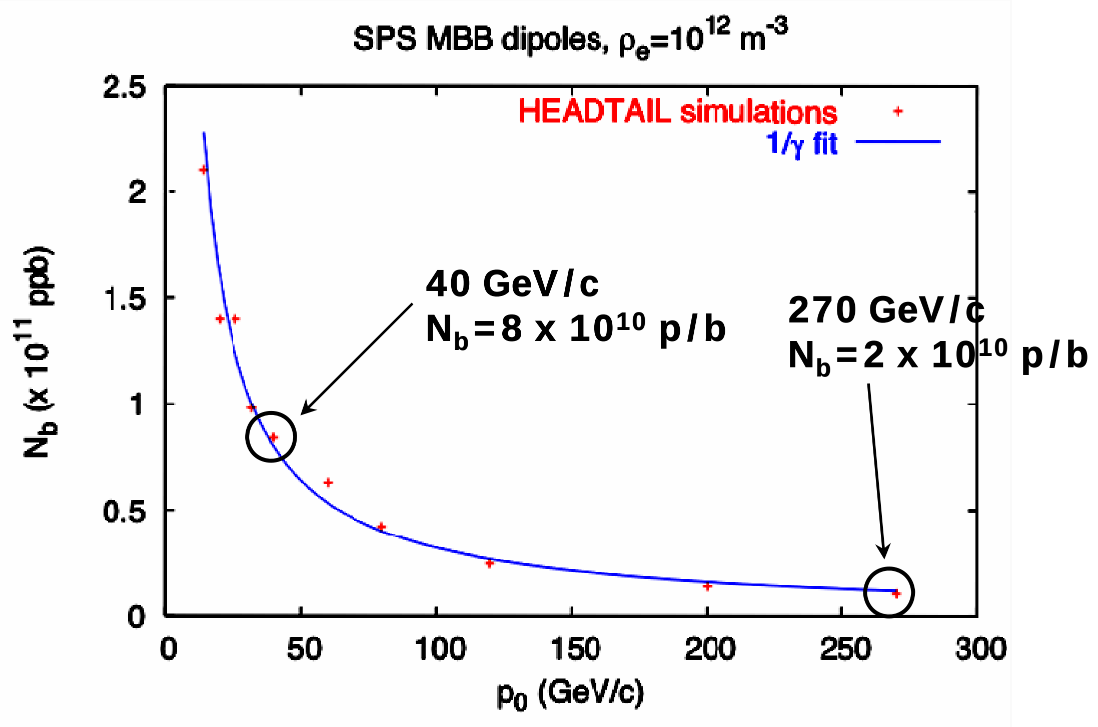
→ ECL2 Workshop (CERN, February 2007)

For δ_{max}=1.4 the instability threshold decreases 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 !

Model with uniform E-cloud
Overview on the instability thresholds

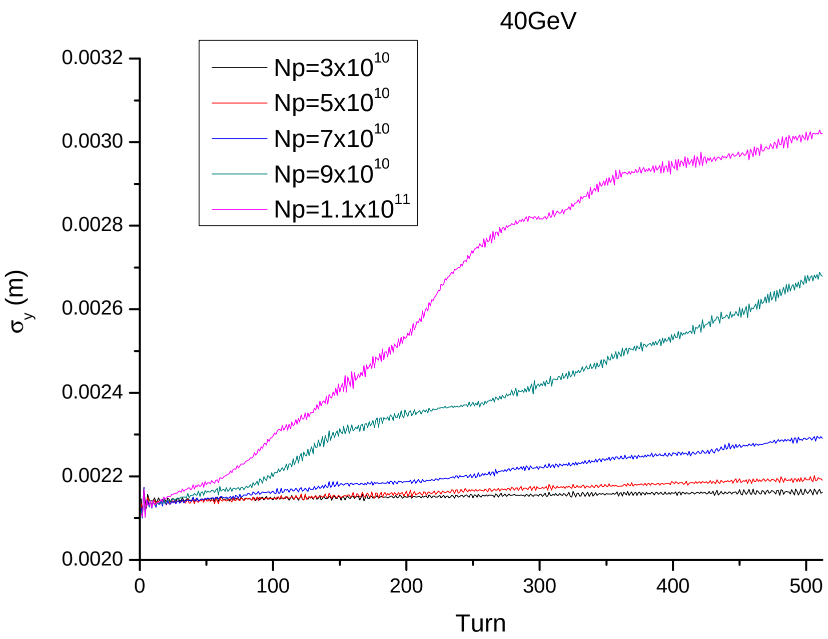


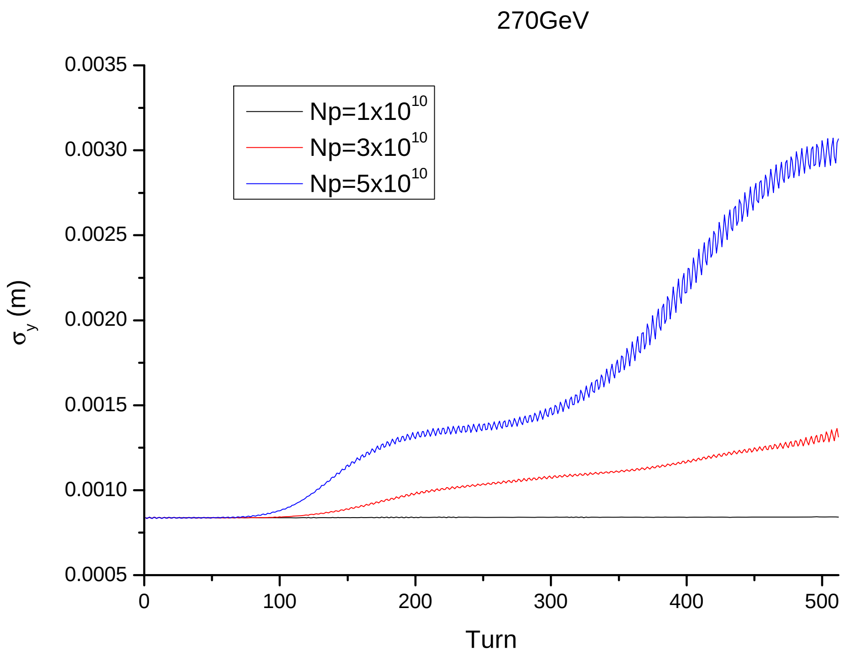
→ Under the same assumptions, threshold decreases with energy also with a uniform cloud model

→ This model has been benchmarked against K. Ohmi's code PEHTS (two highlighted points)

→ PEHTS shows a similar behaviour

→ N_b=7 x 10^{10} @ 40 GeV/c and N_b=2 x 10^{10} @ 270 Ge V/c



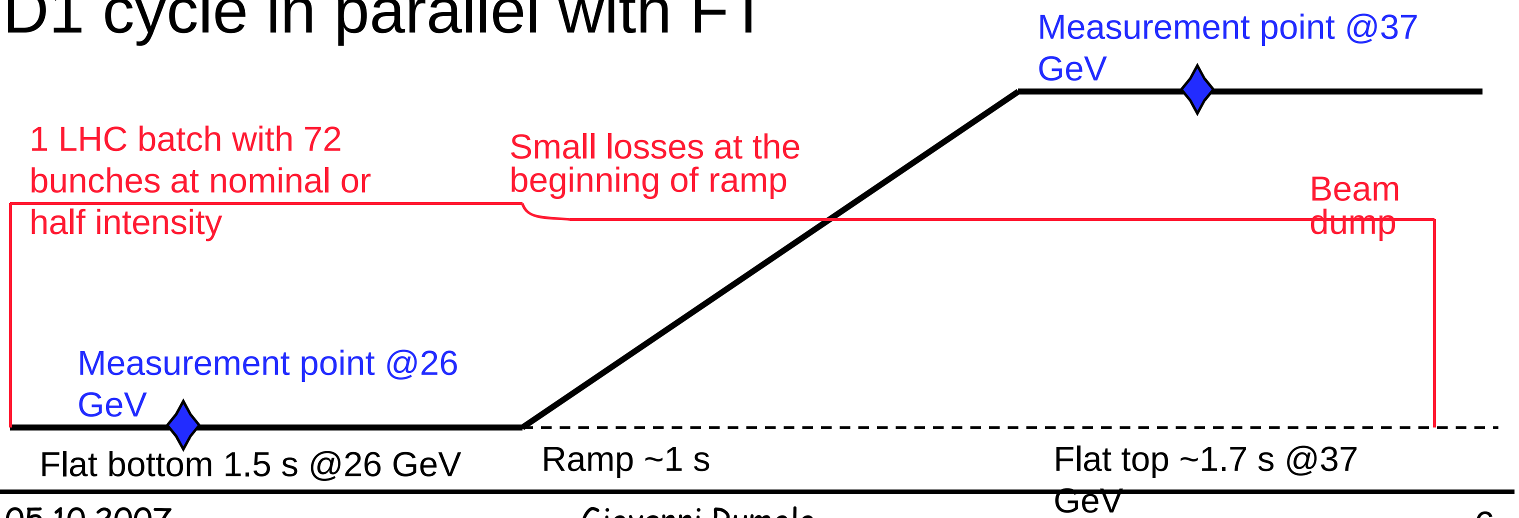


Many thanks to H. Jin and K. Ohmi for running the simulations

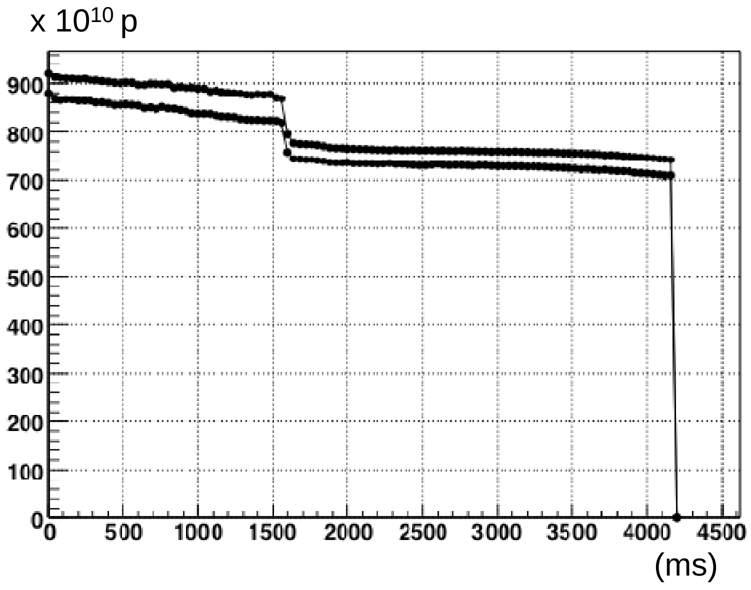
2007 MDs at 26 and 37 GeV/c

- Vertical chromaticity was lowered at the measurement points, till the beam becomes unstable. Look for *Q'* threshold for instability
- Measurements were done with different beam intensities
- Measurements were done with the damper on and off

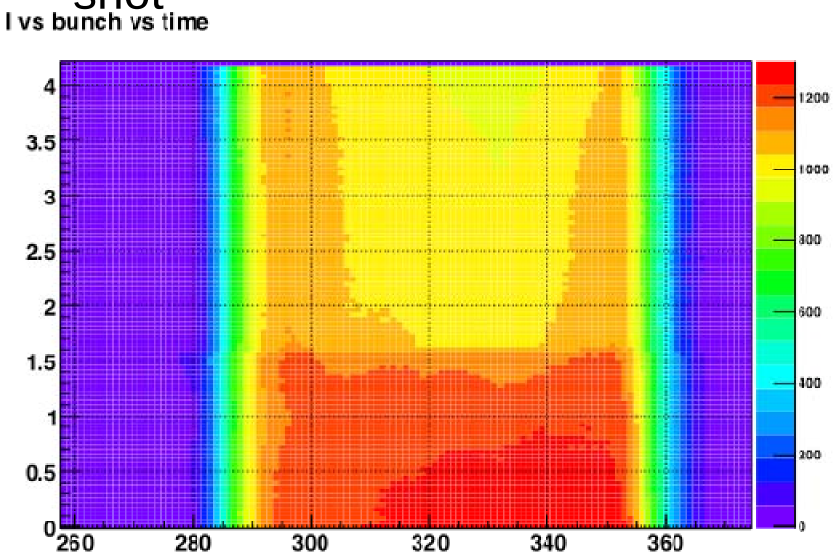
MD1 cycle in parallel with FT



Stable case



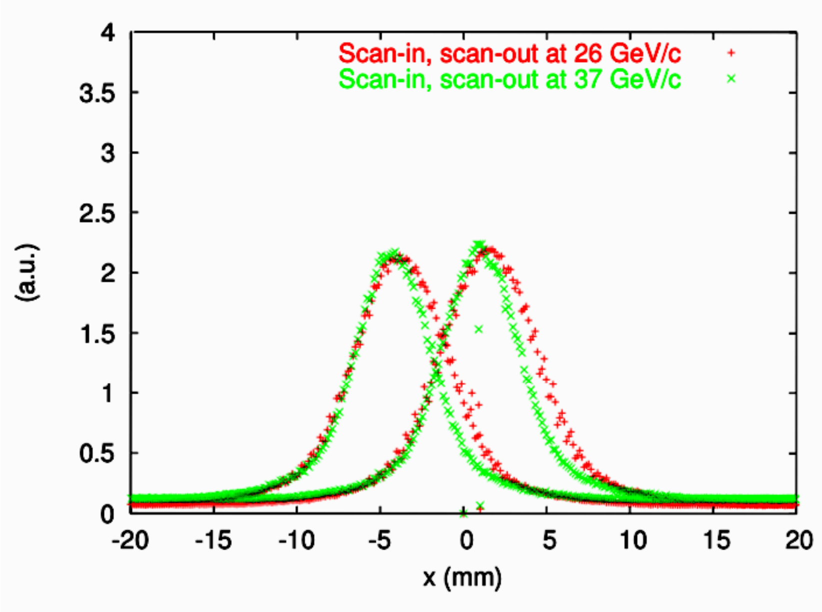
The BCT shows quite bad lifetime at flat bottom (~3% losses over 1.5 s) and 10 to 20% loss at the begining of the ramp, depending on the shot



The Fast BCT shows that most of the losses at the beginning of the ramp happen in the middle of the batch

Stable case

$\sigma_{x,y}$ measurement compatible with $\varepsilon_{x,yN}$=3.1 µm

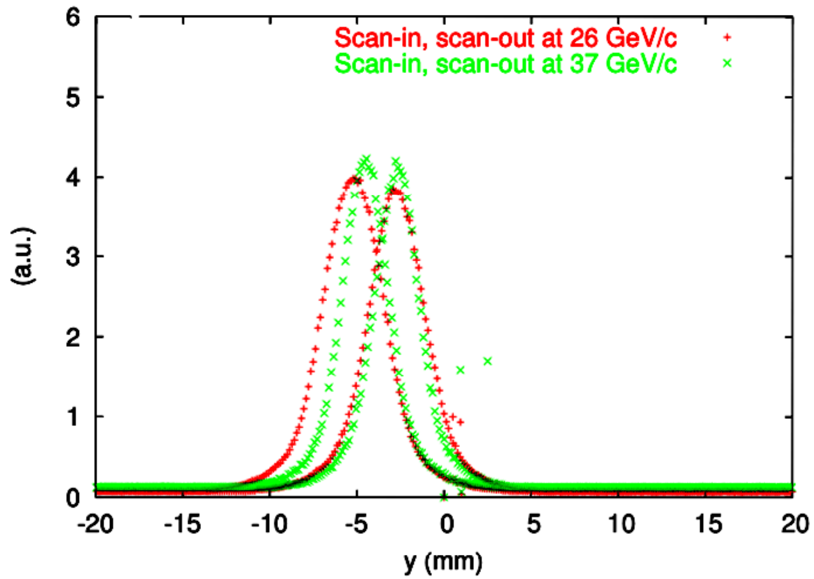


Measurements with the SPS-WS51995 give:

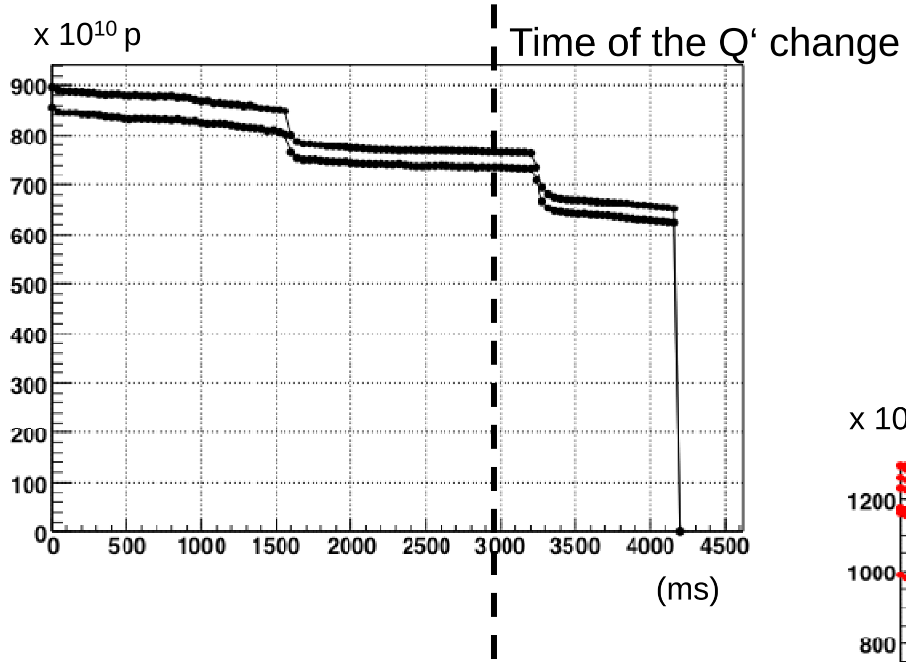
σ_x=2.9 mm @26 GeV/c and
σ_x=2.47 mm @37 GeV/c

Measurements with the SPS-WS51995 give:

σ_y=1.67 mm @26 GeV/c and
σ_y=1.36 mm @37 GeV/c

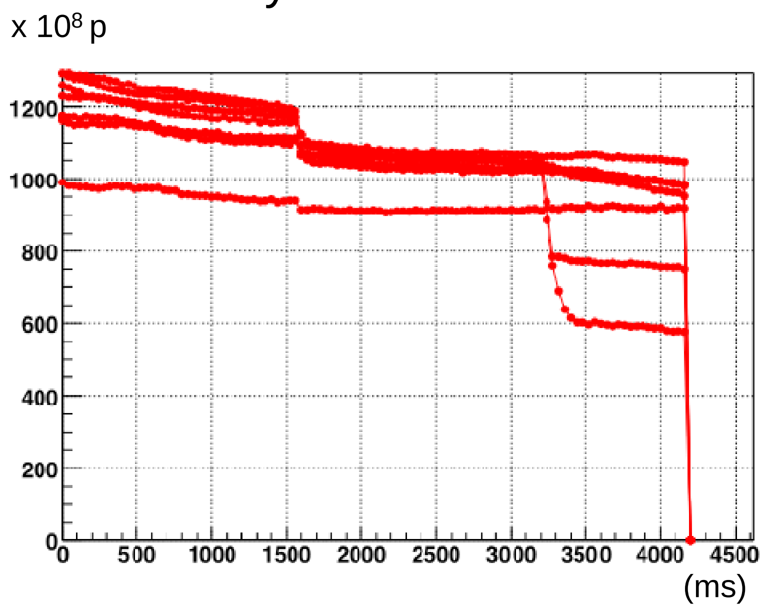


Example of instability@37 GeV - BCT and FBCT



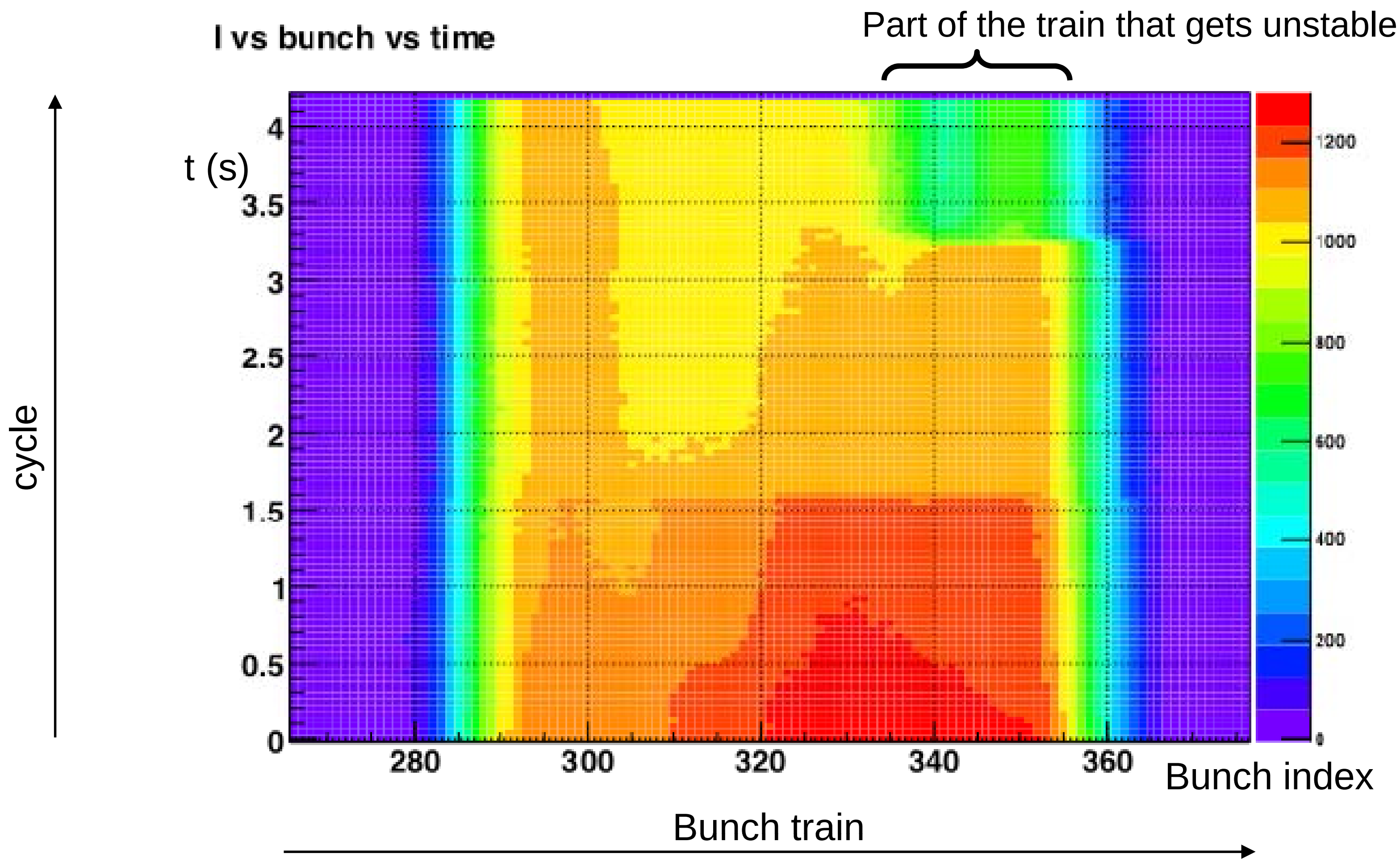
Q‘$_V$ was trimmed to ~3.3 units at 3000 ms.

Losses occur due to an instability



Only bunches at the end of the batch show losses

Example of instability@37 GeV - FBCT overview



Example of instability@37 GeV - LHC-BPM

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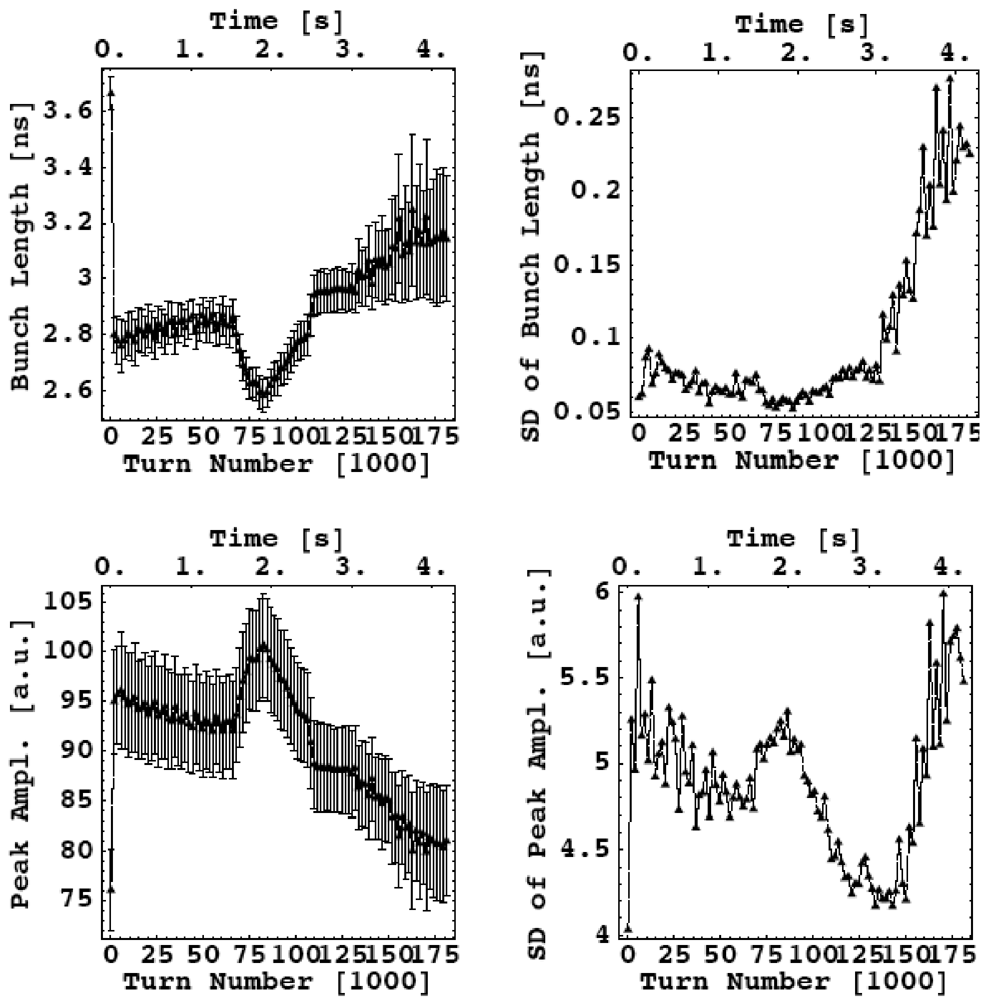
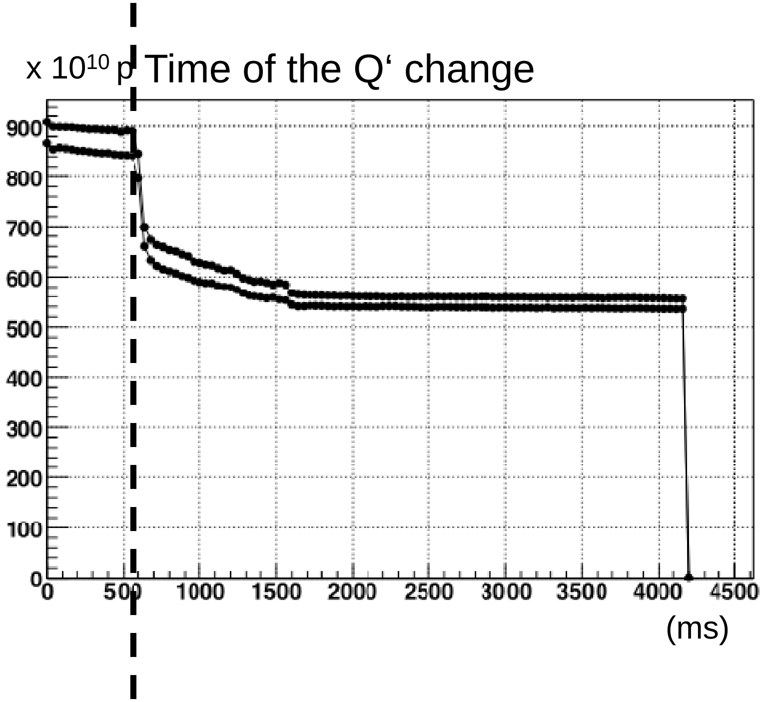
Instability@37 GeV, the longitudinal plane

In the longitudinal plane, there is bunch lengthening at the time of the instability

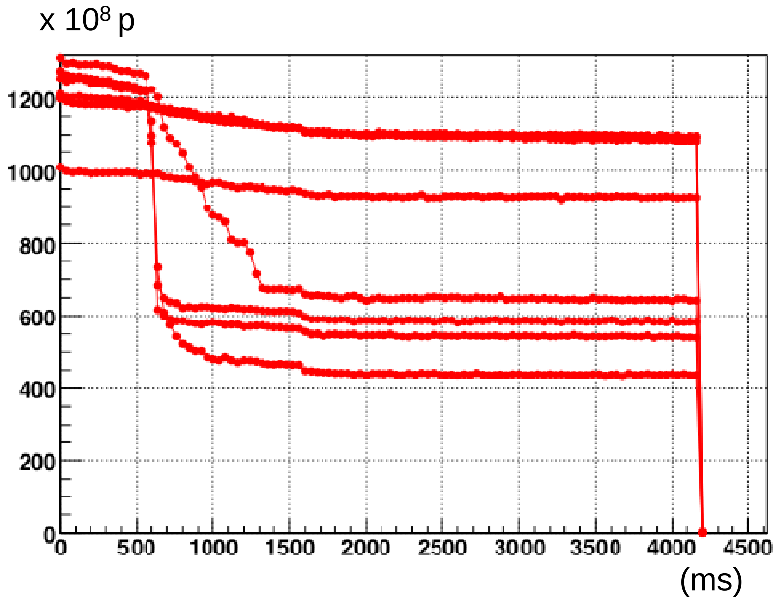


Example of instability@26 GeV

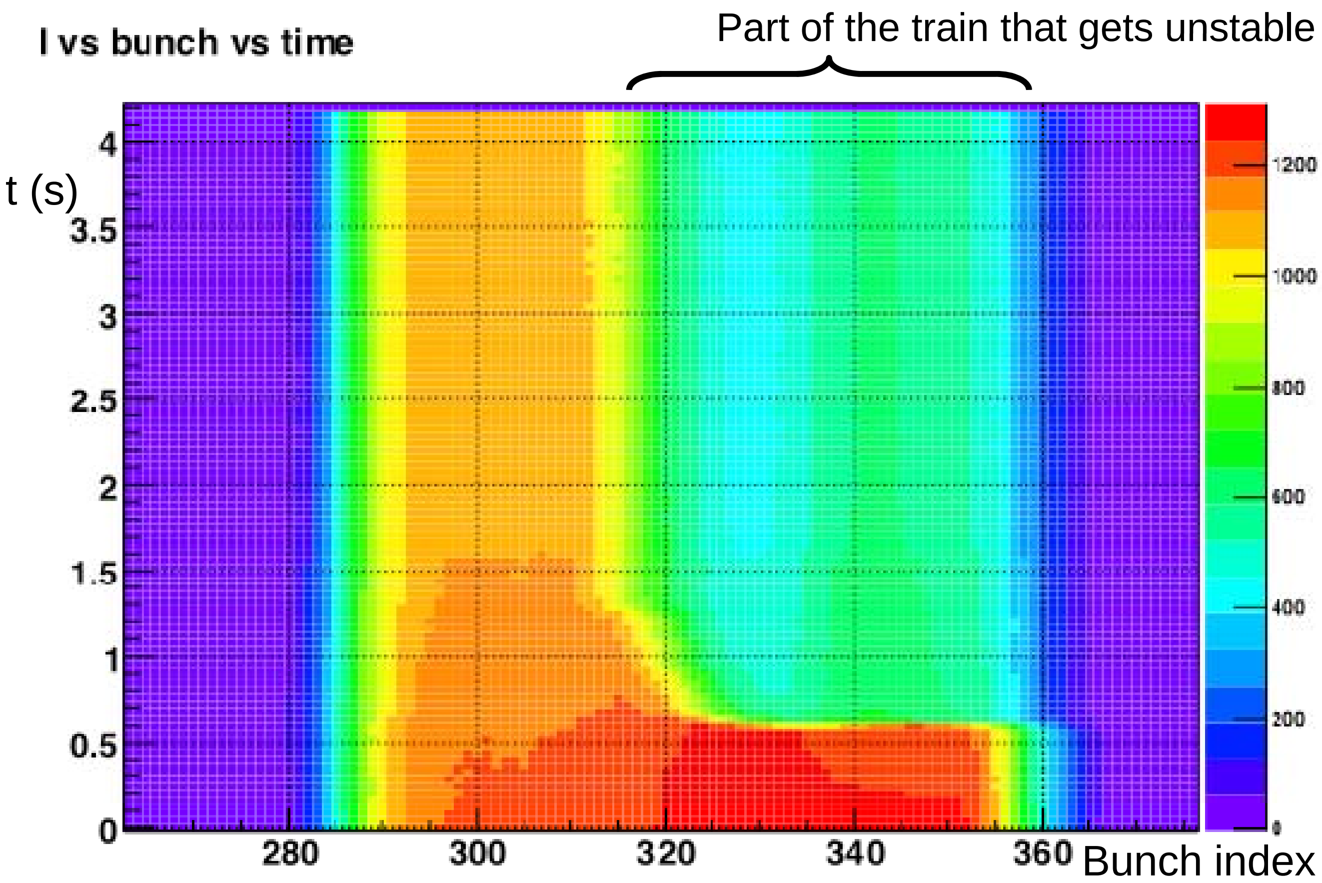


Here Q‘$_V$ was trimmed to ~2 units at 550 ms.

Losses occur due to an instability



Example of instability@26 GeV



Example of instability@26 GeV

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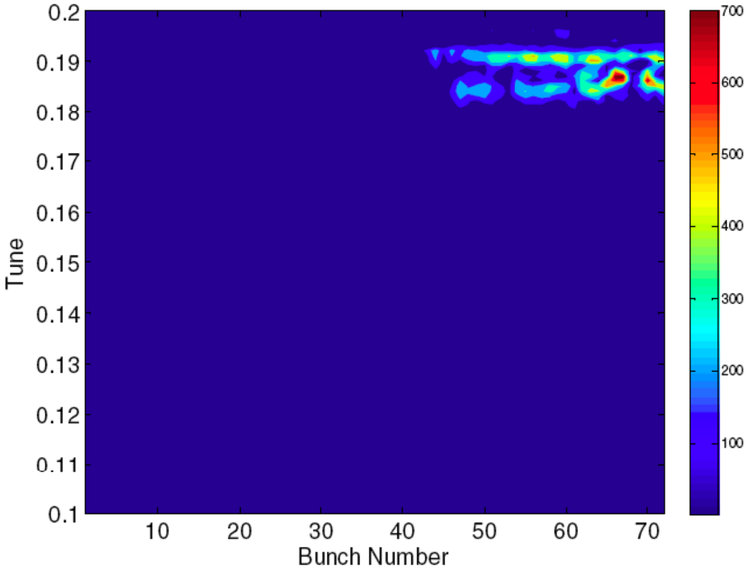
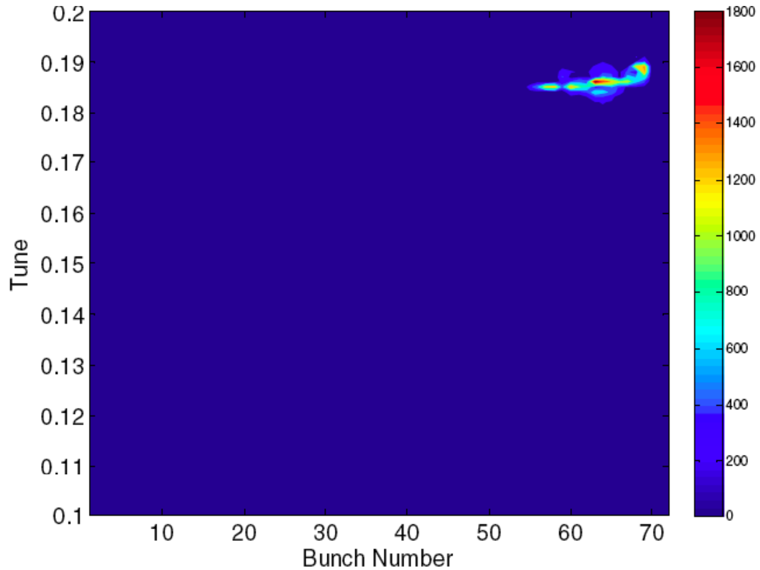
Harmonic analysis of the data (I)

26 GeV/c



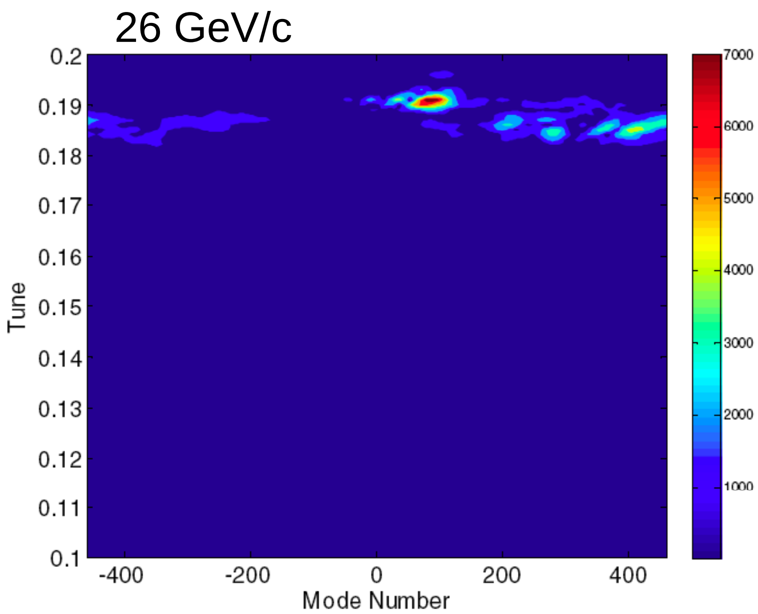
37 GeV/c

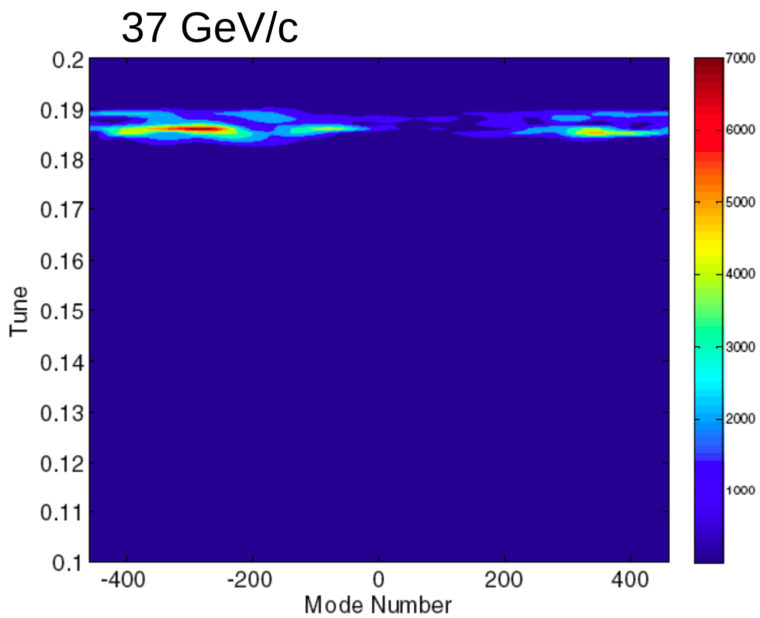


Tune bunch by bunch, signal visible only on last bunches of the train due to the instability (bunches at the head of the train were not kicked)

- Two lines visible at 26 GeV/c
- One line visible at 37 GeV/c, shifting upwards with the bunch number

Harmonic analysis of the data (II)





2D Fourier transforms from the time-bunch# signal

- Clear peak at (Q_y, n~40) at 26 GeV/c, while the second line in (tune, bunch#) space appears here more spread over mode numbers

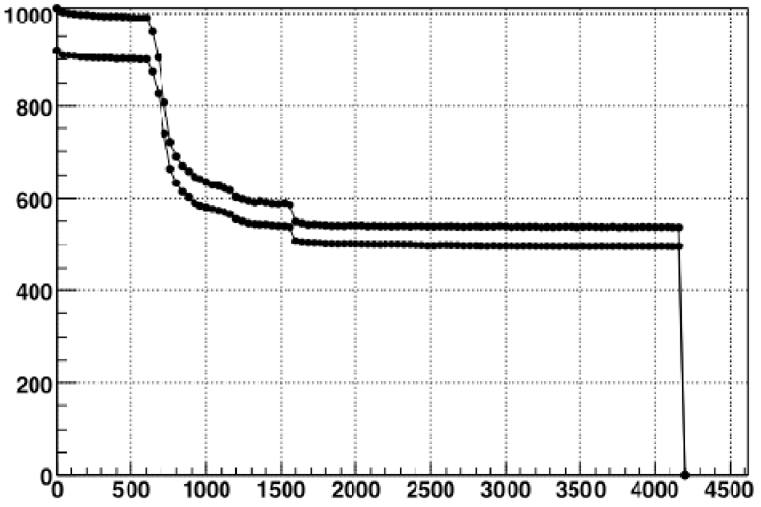
- The tune appears quite smeared over the mode numbers at 37 GeV/c

More MDs on the 26.06.07 with a better tuned beam showed the same features

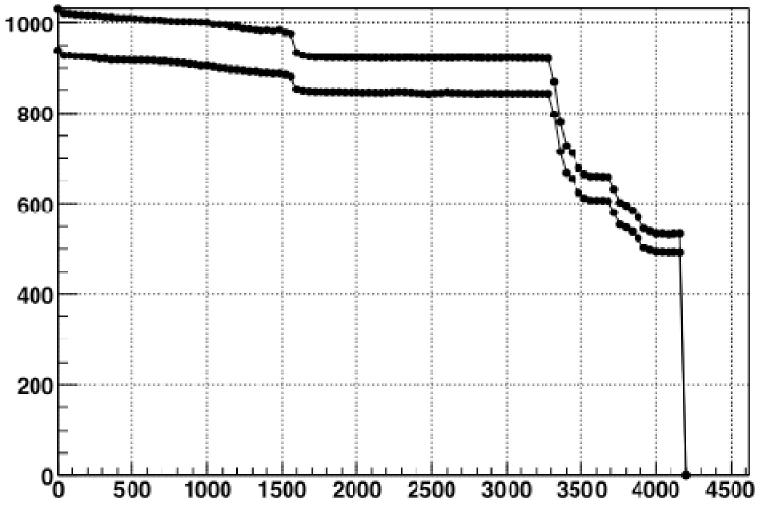
⇒ Less loss on the ramp

⇒ Instability@26GeV and 37GeV at full and half current

⇒ About the same Q‘ thresholds as on 08.06



Q‘ switched to ~2 at 550 ms

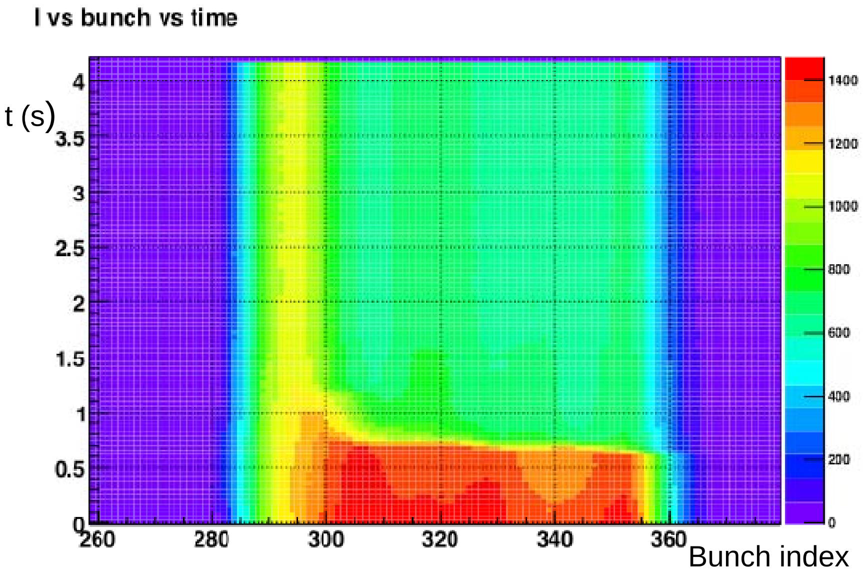


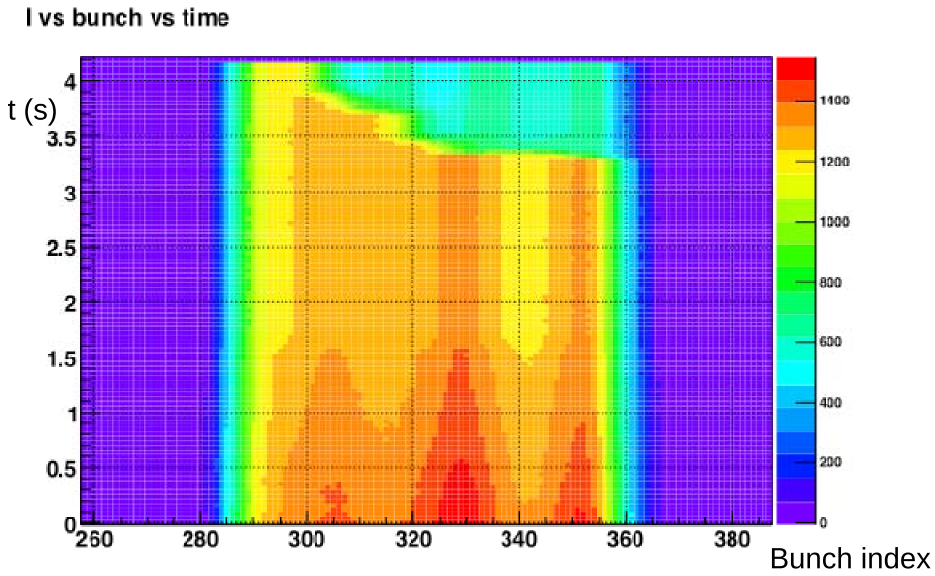
Q‘ switched to ~3 at 3000 ms

26.06 MDs

⇒ Shown: strong instability at 26 and 37 GeV/c (full current)

⇒ Instability was observed to occur also with half current





- Thresholds in chromaticity stay the same both at 26 and 37 GeV/c
- They seem to hold also with lower intensity, but lead to slower instabilities

26.06 MDs

⇒ Strong instability at 26 GeV/c

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26.06 MDs

$\Rightarrow$ Strong instability at 37 GeV/c

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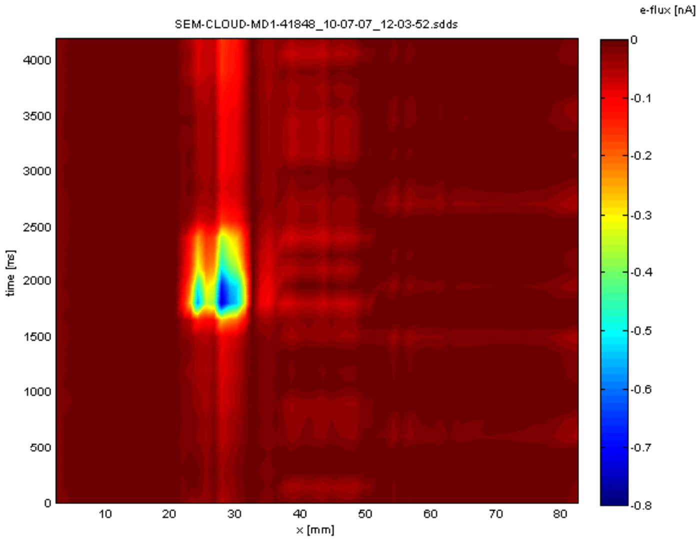
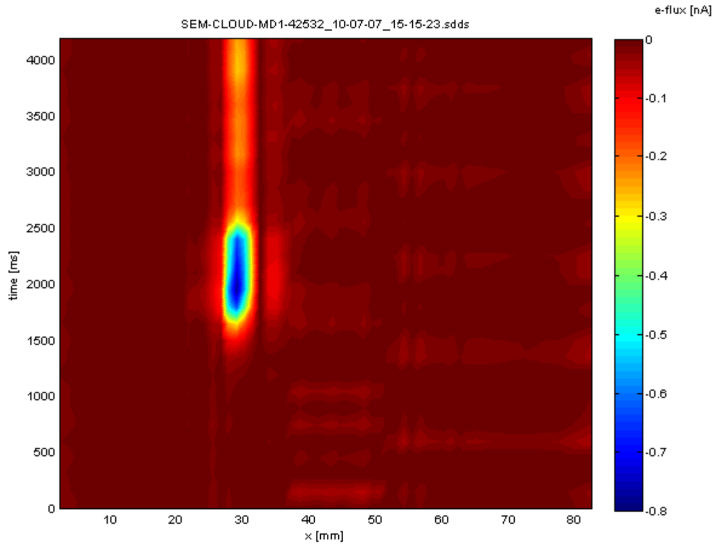
10.07 MDs
⇒ Measurements with the e-cloud monitor



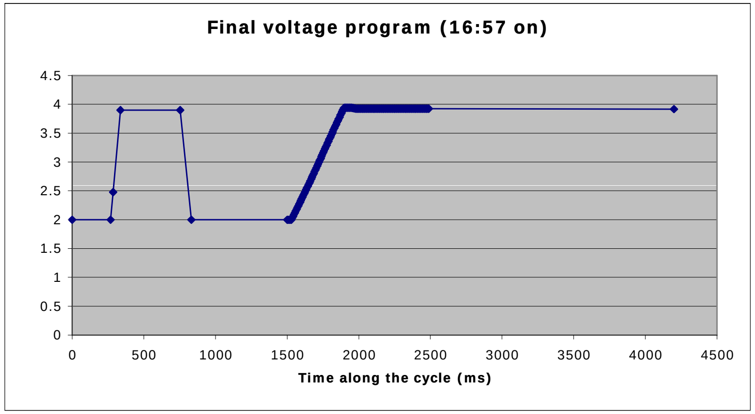


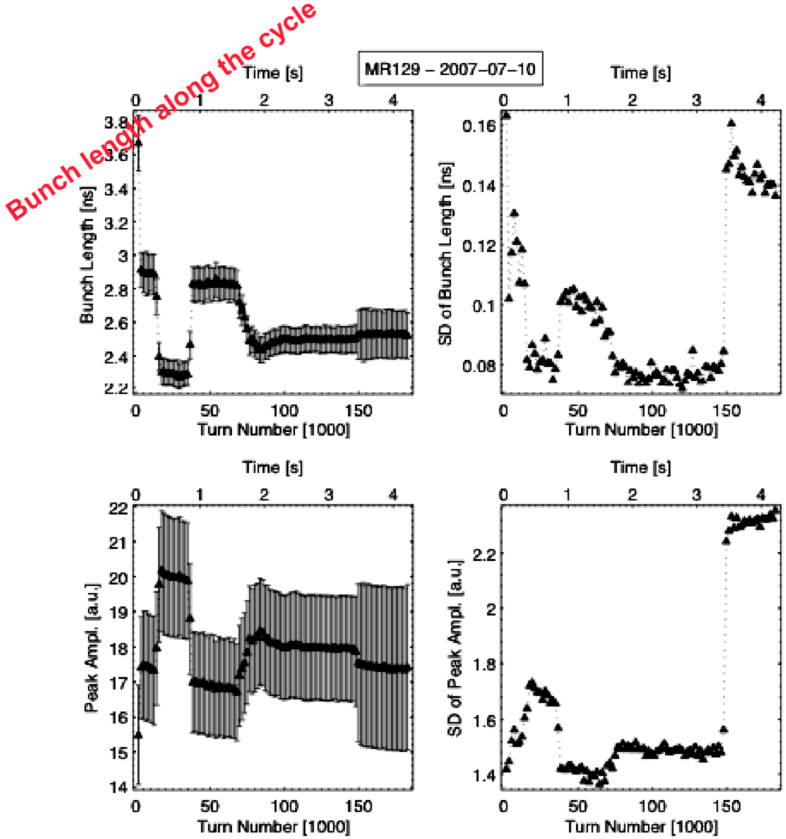
The measured signals show that:

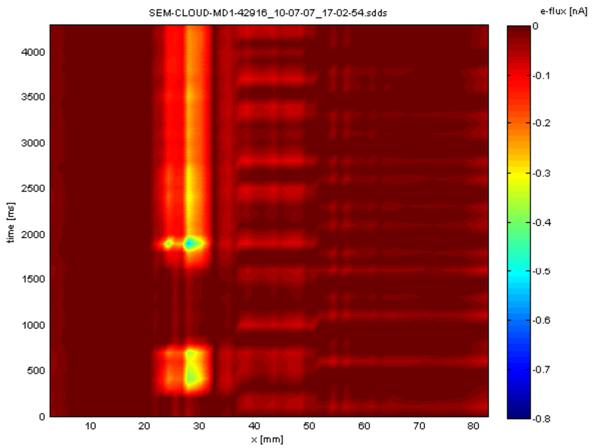
- Strong e-cloud signal always on the ramp, maybe because of the bunch shortening that occurs during acceleration
- Sometimes the signal also extended to the flat top at 37 GeV/c

10.07 MDs

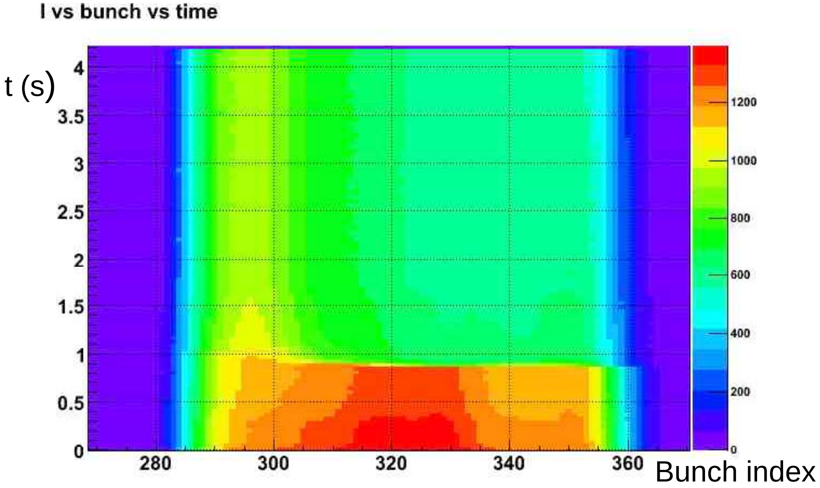
⇒ Then a voltage bump was created

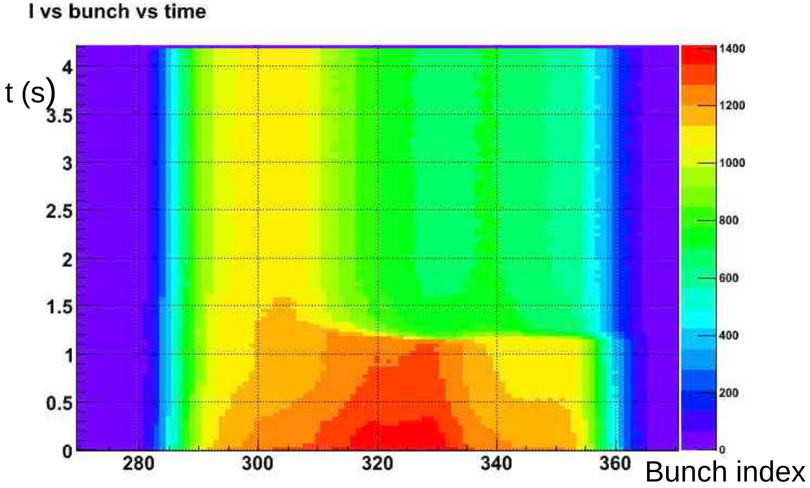






10.07 MDs
⇒ With the voltage bump



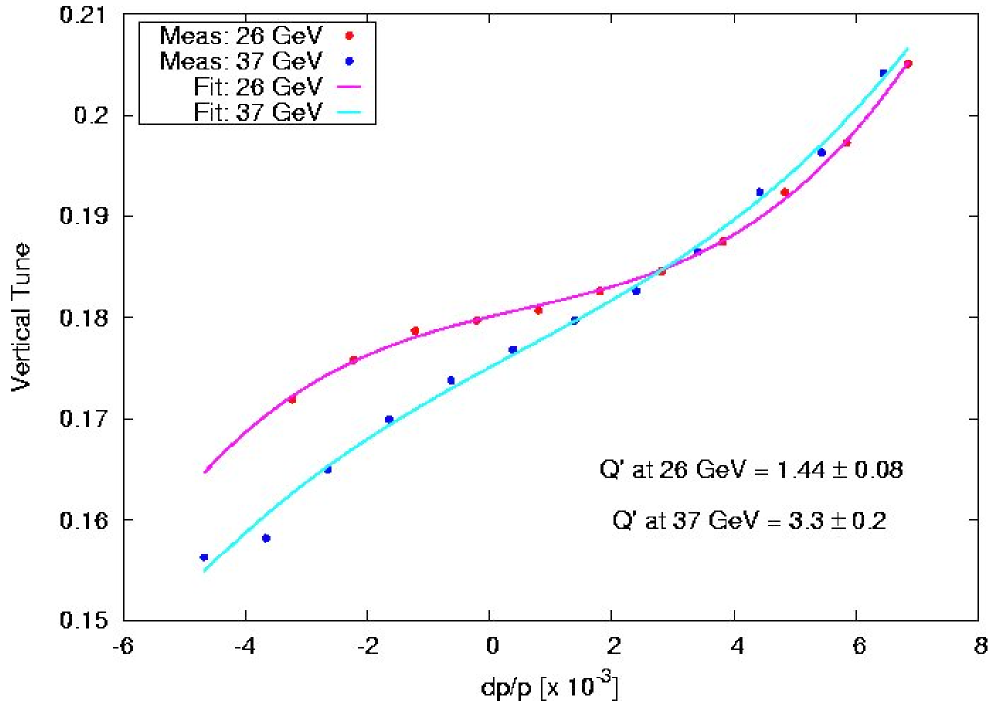


We observed that:

• The instability at 26 GeV/c appeared when the chromaticity was lowered both within the voltage bump and outside of it.

• Therefore no clear correlation with the measured e-cloud signal could be established

10.07 MDs
⇒ Chromaticity calibration



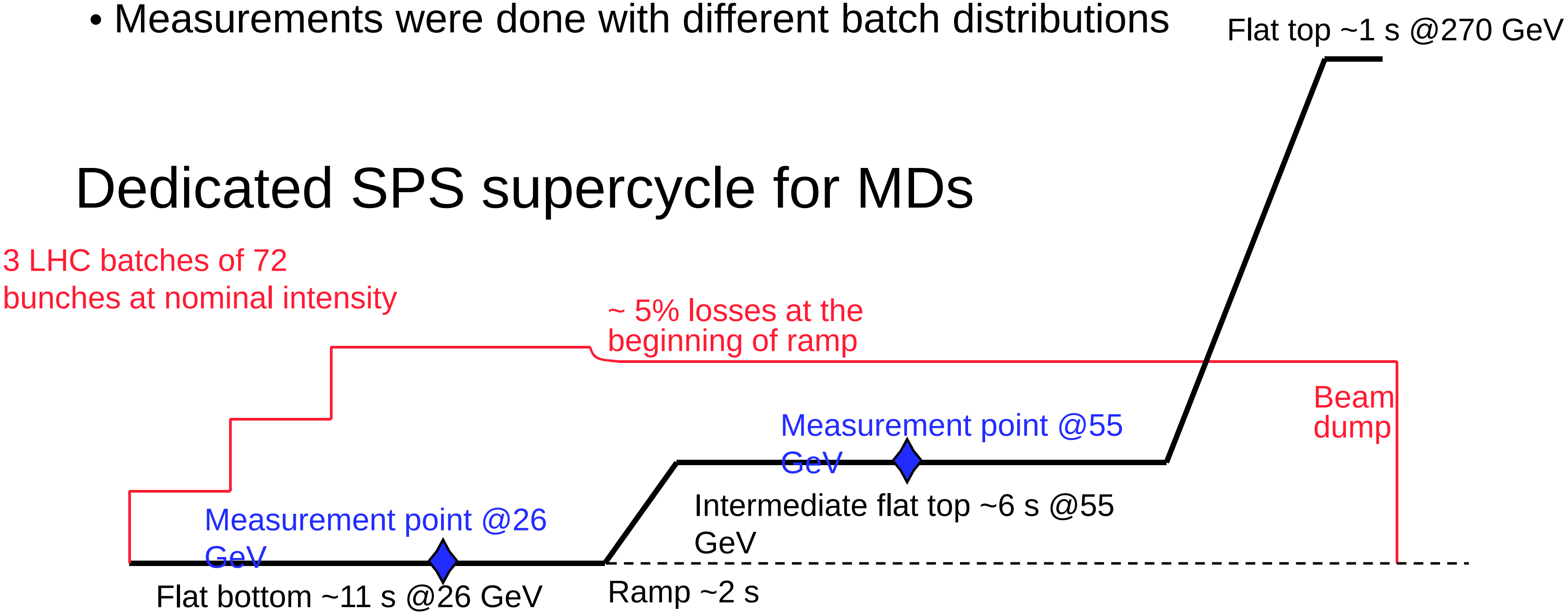
Chromaticity calibration done again on the same day at the threshold of instability confirms the values

- Beam gets unstable at 26 GeV/c below Q'~1.44
- Beam gets unstable at 37 GeV/c below Q'~3.3

2007 MDs at 26 and 55 GeV/c

- Vertical chromaticity was lowered at the measurement points, till the beam becomes unstable. Look for *Q'* threshold for instability
- Measurements were done with the damper on and off
- Measurements were done with different batch distributions

Dedicated SPS supercycle for MDs



2007 MDs at 26 and 55 GeV/c

Data are still being analyzed. However, some **preliminary** considerations can be made:

• The electron cloud monitor showed an e-cloud signal growing along the cycle. As expected, the signal was more intense with 2 or 3 batches (see next slide)

• *Q'* could be even set to a slightly negative at 26 GeV/c, provided that the damper was on. With the damper off, the beam would become unstable at about Q'~0.

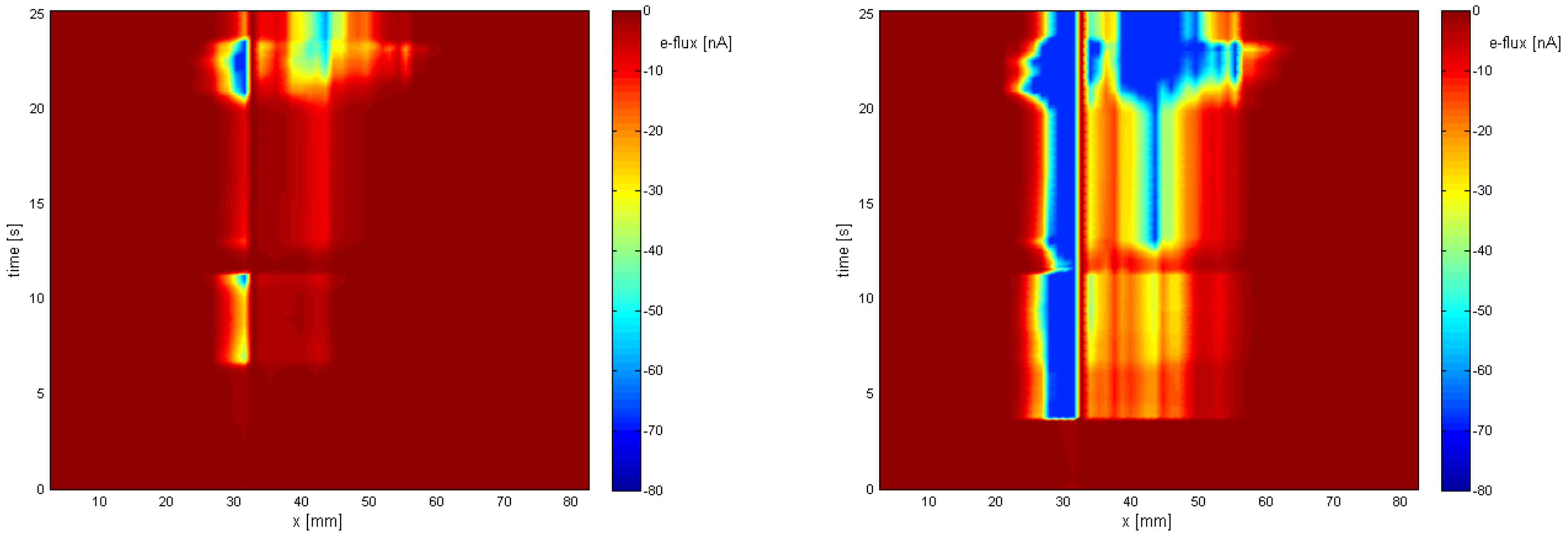
• At 55 GeV/c Q'~ 4 is the observed threshold for instability

• Measurements with a different batch distribution (3 batches uniformly distributed around the ring) seemed to significantly stabilize the beam at 55 GeV/c

• The instability always starts from the tail of the batch(es)

• However, the instability evolution along the batch(es) seems to point to coupled-bunch both at 26 and 55 GeV/c, even if a variety of modes is present, with probably some single bunch component.

2007 MDs at 26 and 55 GeV/c



Signal from the e-cloud monitor with one (left) or two (right) batches in the SPS

• Even if the flat bottom ends at ~11 s, the e-cloud is observed to appear at ~5 s because by that time the uncaptured beam has smeared all over the machine and traps the electrons (E. Shaposhnikova)

• That was proved by cleaning the gap and observing no e-cloud signal at the flat bottom (G. Arduini)

Summary of the observations

- The electron cloud has been observed in the SPS with the e-cloud monitor
  - At 26 GeV/c with a bunch shortening voltage bump or enhanced by untrapped coasting beam
  - Clear signal at higher energies (shorter bunch, smaller transverse sizes)
- The LHC beam is **vertically unstable** in the SPS at
  - **26 GeV/c** for $Q'_V \sim 0\text{-}2$ (with 1 to 3 batches)
  - **37 GeV/c** for $Q'_V \sim 3.3$ (with 1 batch)
  - **55 GeV/c** for $Q'_V \sim 4$ (with 1 to 3 batches)
- In most cases we observed that only the tail of the bunch train(s) is affected by the instability.
- Pattern of the instability along the bunch train seems to point to a coupled bunch instability (with possible single bunch effects) at 26 and 55 GeV/c. At 37 GeV/c this is not evident.

⇒ Correlation between the observed instability and the e-cloud is not straightforward, we would like to assess it by observing a dependence of the instability threshold on the beam transverse size!