BEAM STUDIES AT PS: BEAM BREAK-UP INSTABILITY NEAR TRANSITION

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Machine operation:

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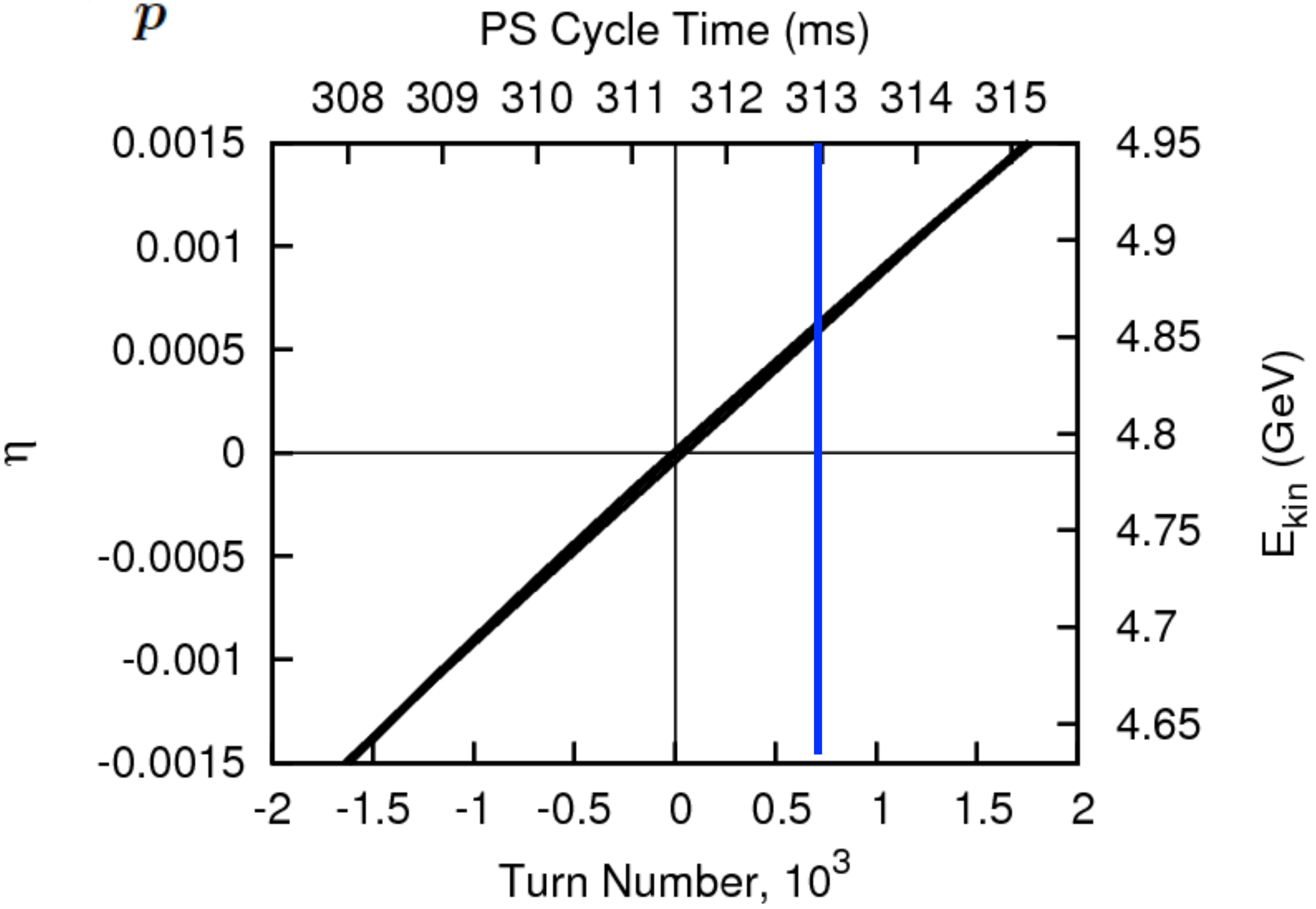
TRANSITION AT PS W/O γ-JUMP

$$\eta = \frac{1}{\gamma_t^2} - \frac{1}{\gamma^2}$$

$$\frac{\Delta f_0}{f_0} = -\eta \frac{\Delta p}{p}$$

strong transverse oscillations and fast losses around C313ms

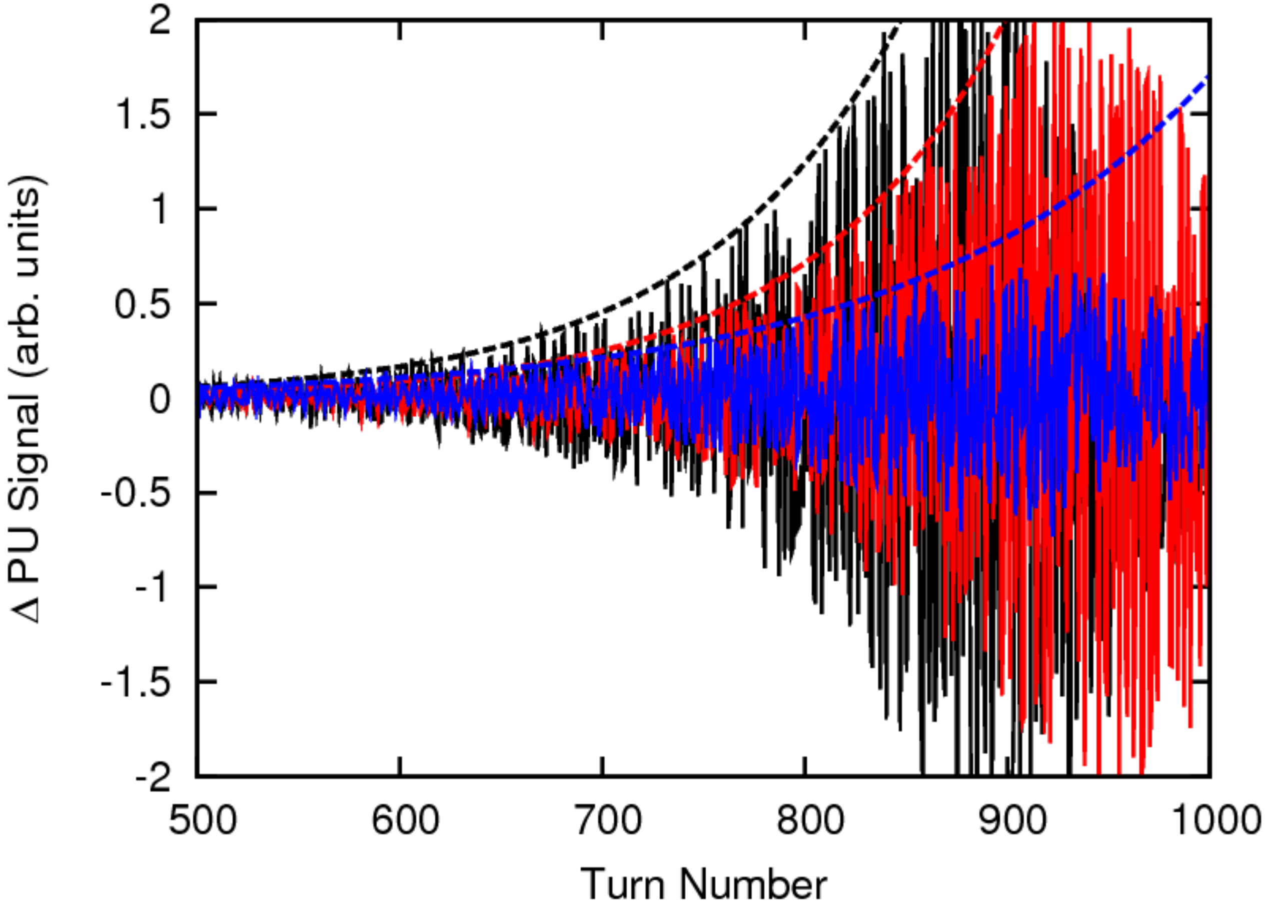


INSTABILITY NEAR TRANSITION

Scope Signal,
triggered at C312ms

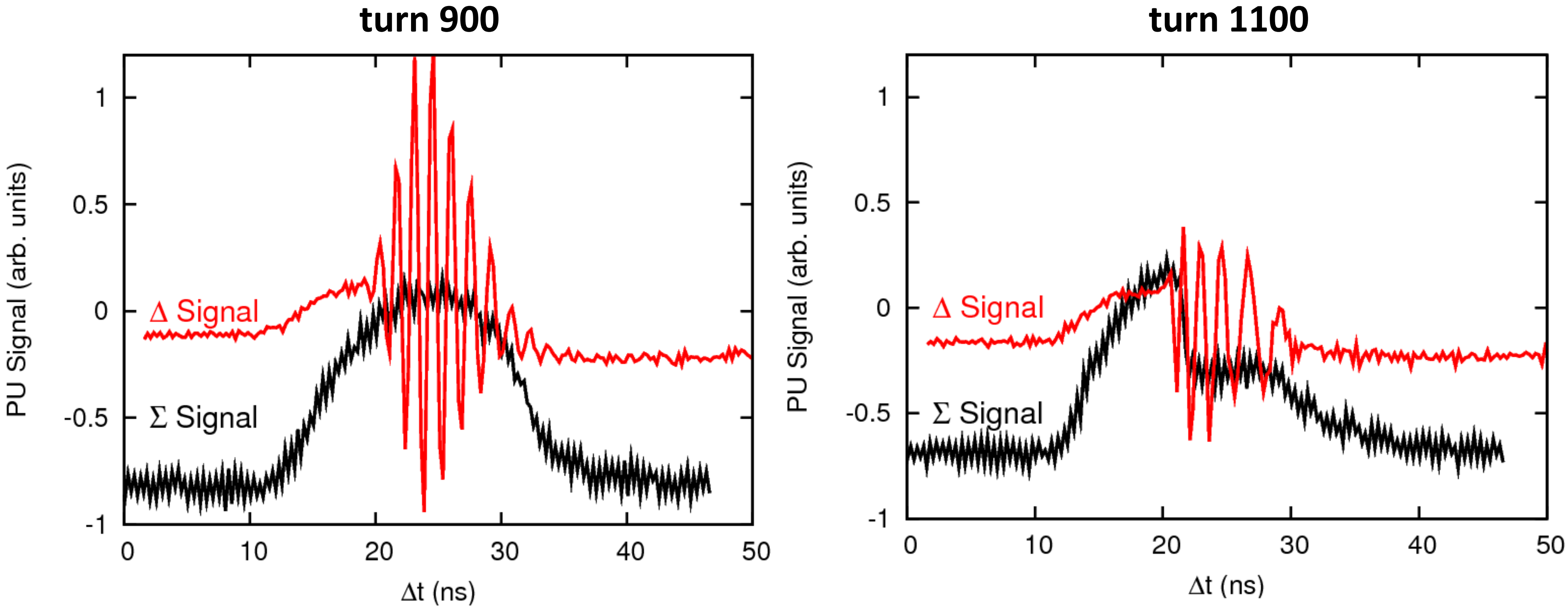
the growth rate varies,
occurrence time not

three shots for
V_0=200 kV
N_p=107e10 ppb



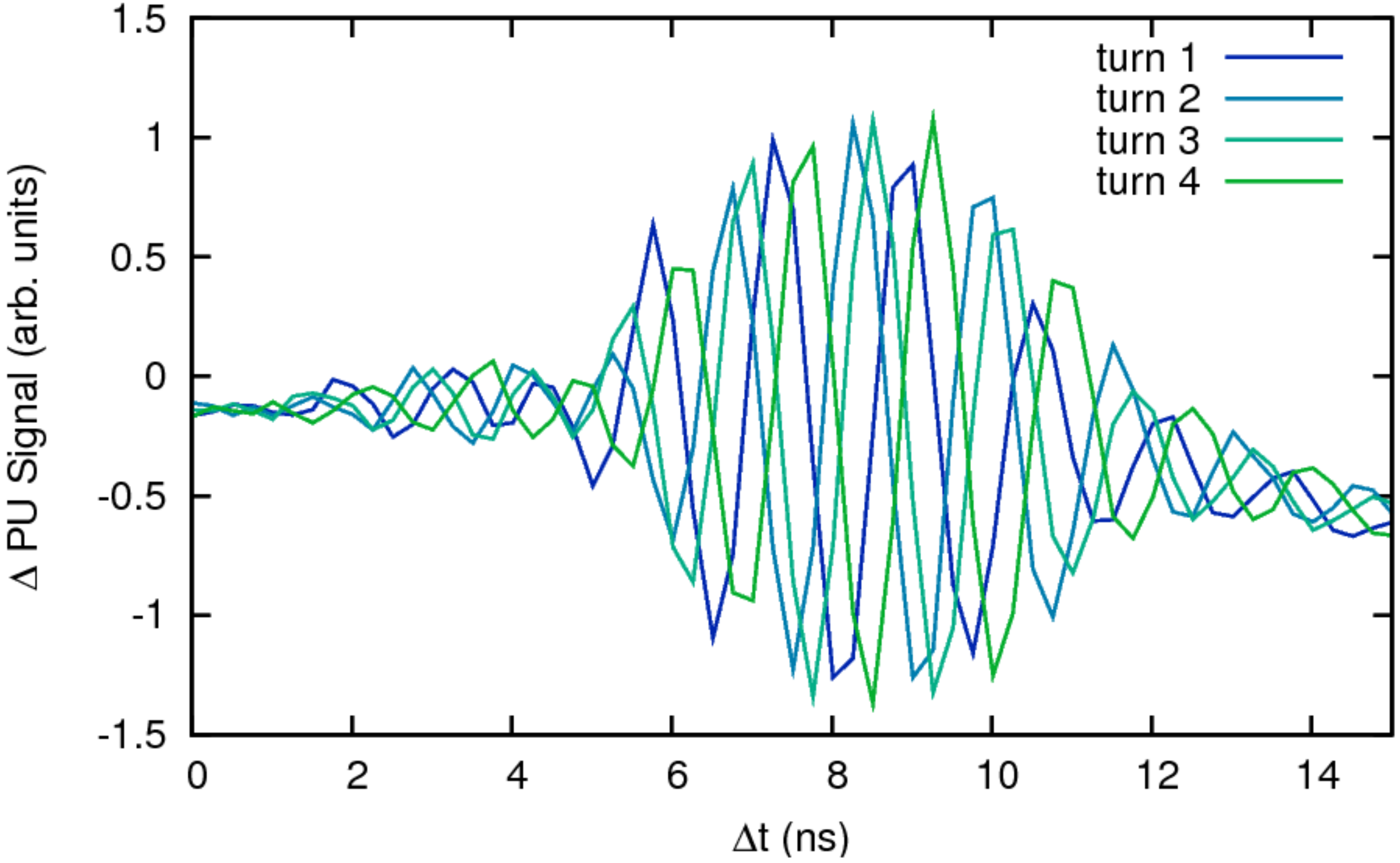
INSTABILITY NEAR TRANSITION

- high-frequency (0.7GHz) oscillations
- fast losses
- growth faster then the synchrotron motion, here $\Delta Q/Q_s$=11



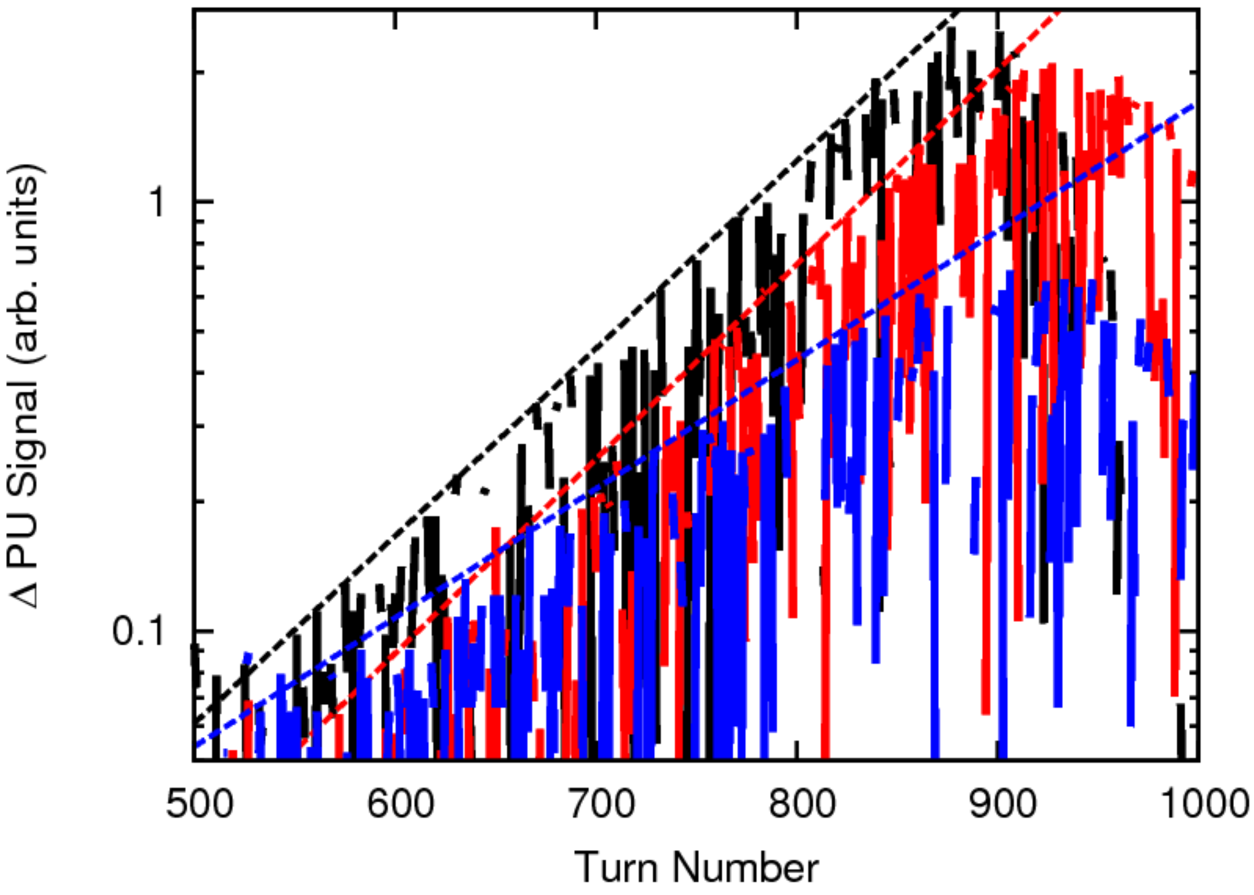
INSTABILITY NEAR TRANSITION

not a standing wave



INSTABILITY NEAR TRANSITION

V_0=200 kV
N_p=107e10 ppb
growth rates for the three shots:
ΔQ=1.6e-3
ΔQ=1.7e-3
ΔQ=1.1e-3
at Δt=24ns

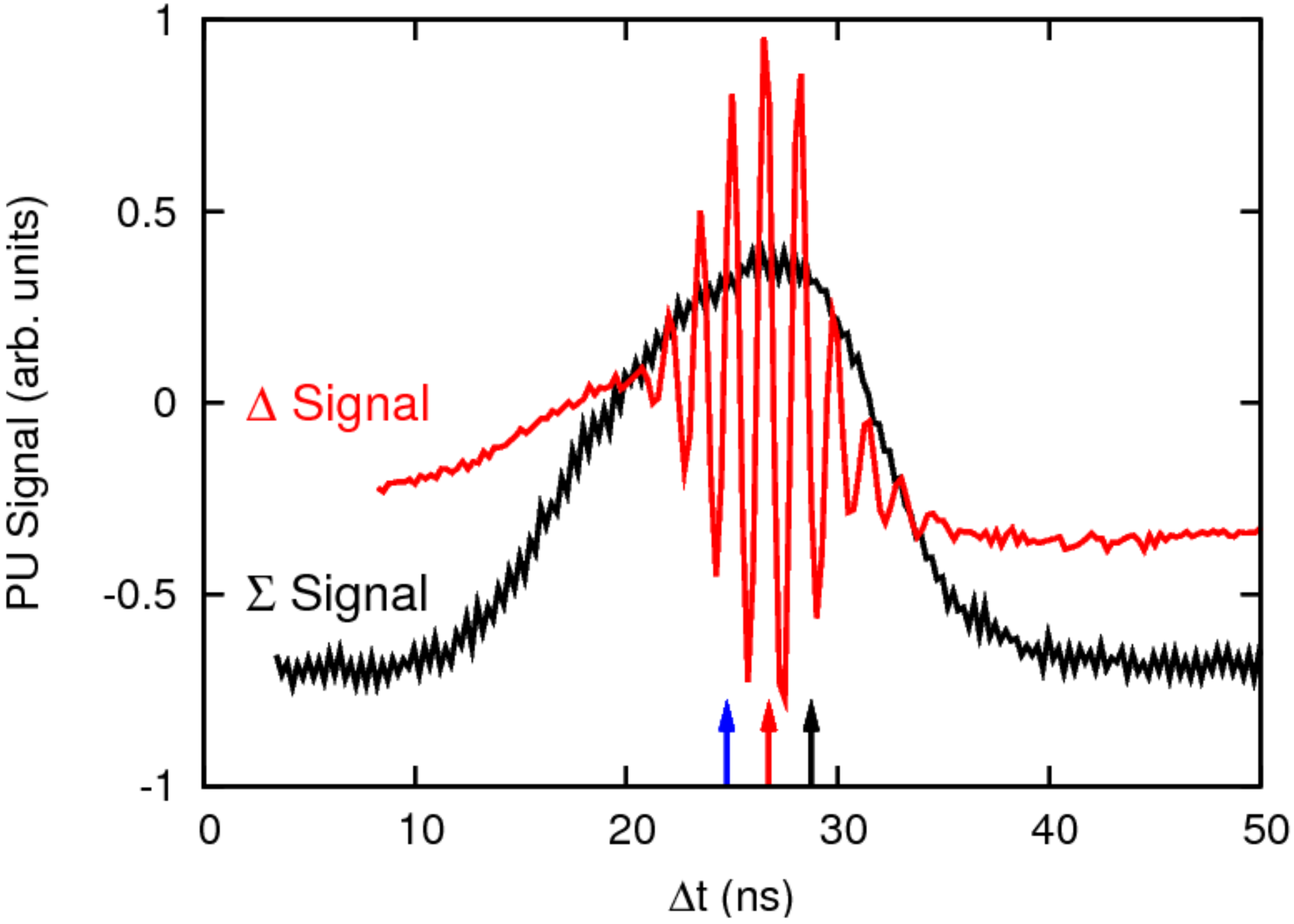


Is it an unstable eigenmode?
The growth is exponential.
But: I choose plotting the signal at one point in the bunch.
the reason?

IS IT AN ABSOLUTE INSTABILITY?

V_0=200 kV
N_p=116e10 ppb

If we look to the oscillations at:
head part
middle part
tail part

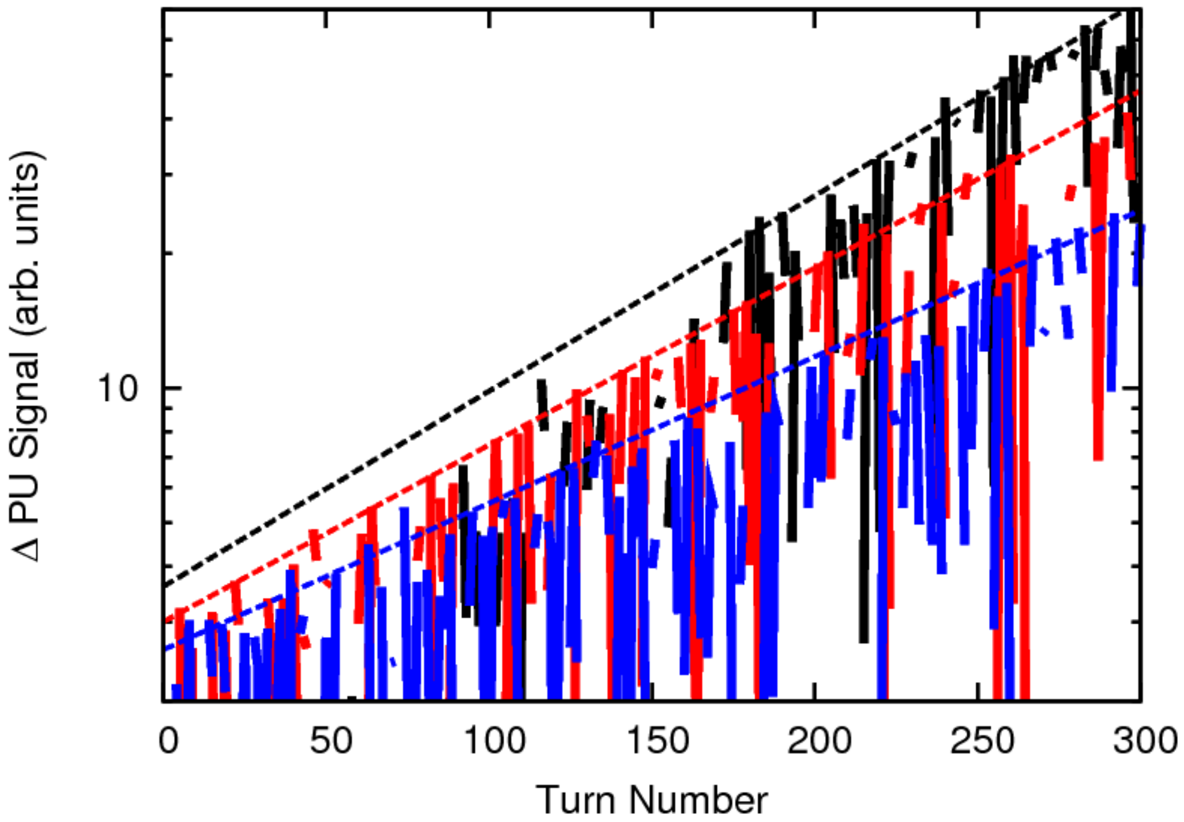


IS IT AN ABSOLUTE INSTABILITY?

V_0=200 kV
N_p=116e10 ppb

head: ΔQ=1.2e-3
middle: ΔQ=1.45e-3
tail: ΔQ=1.6e-3

shifted from C312
by 300 turns

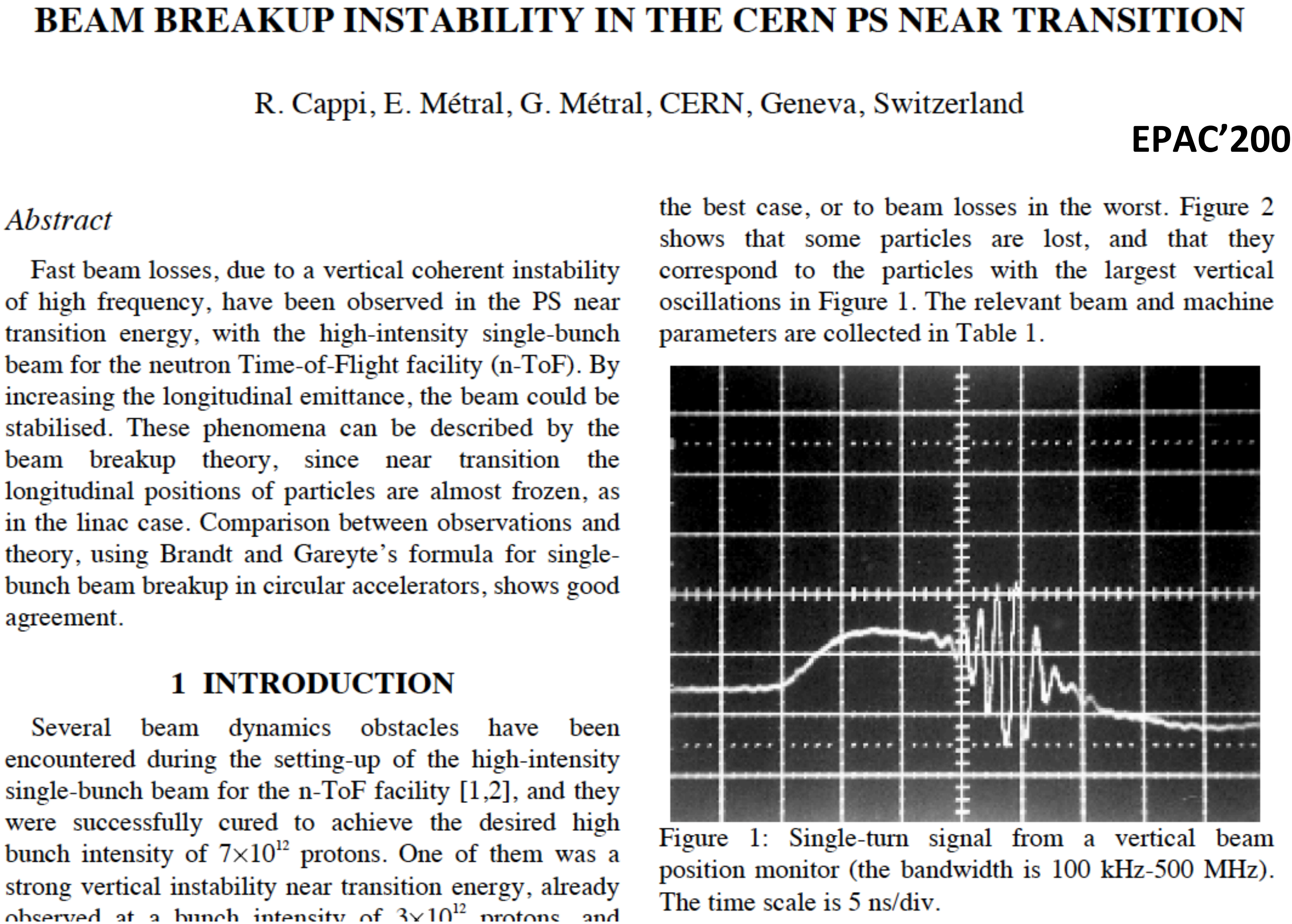


General feature: at the head part ΔQ is smaller
at the tail part ΔQ is larger
the oscillation migrates towards tail

=> This is probably not an unstable eigenmode

IS IT AN ABSOLUTE INSTABILITY?

Under $\Delta Q>Q_s$ there is no reinforcing mechanism, no clear exponential growth of an eigenmode. Thus: associated with the Beam Break-Up mechanism.



BEAM BREAKUP INSTABILITY IN THE CERN PS NEAR TRANSITION

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EPAC'2000

Abstract

Fast beam losses, due to a vertical coherent instability of high frequency, have been observed in the PS near transition energy, with the high-intensity single-bunch beam for the neutron Time-of-Flight facility (n-ToF). By increasing the longitudinal emittance, the beam could be stabilised. These phenomena can be described by the beam breakup theory, since near transition the longitudinal positions of particles are almost frozen, as in the linac case. Comparison between observations and theory, using Brandt and Gareyte's formula for single-bunch beam breakup in circular accelerators, shows good agreement.

1 INTRODUCTION

Several beam dynamics obstacles have been encountered during the setting-up of the high-intensity single-bunch beam for the n-ToF facility [1,2], and they were successfully cured to achieve the desired high bunch intensity of 7×10^{12} protons. One of them was a strong vertical instability near transition energy, already observed at a bunch intensity of 3×10^{12} protons, and

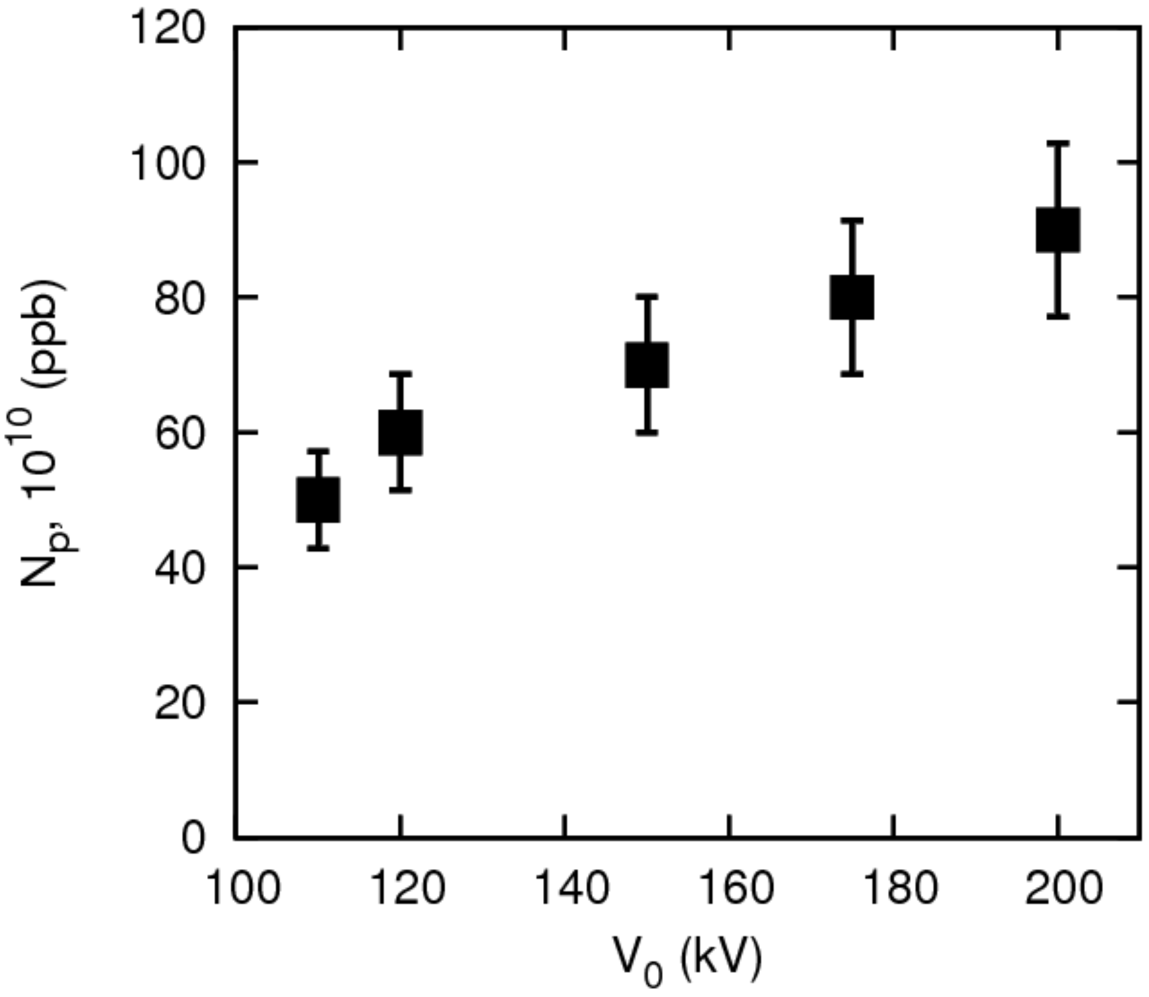
the best case, or to beam losses in the worst. Figure 2 shows that some particles are lost, and that they correspond to the particles with the largest vertical oscillations in Figure 1. The relevant beam and machine parameters are collected in Table 1.

Figure 1: Single-turn signal from a vertical beam position monitor (the bandwidth is 100 kHz-500 MHz). The time scale is 5 ns/div.

THRESHOLD SUMMARY

definitely higher
intensity thresholds
for larger rf voltage

additionally:
with *h*=16, no
instability at least
up to 150e10 ppb



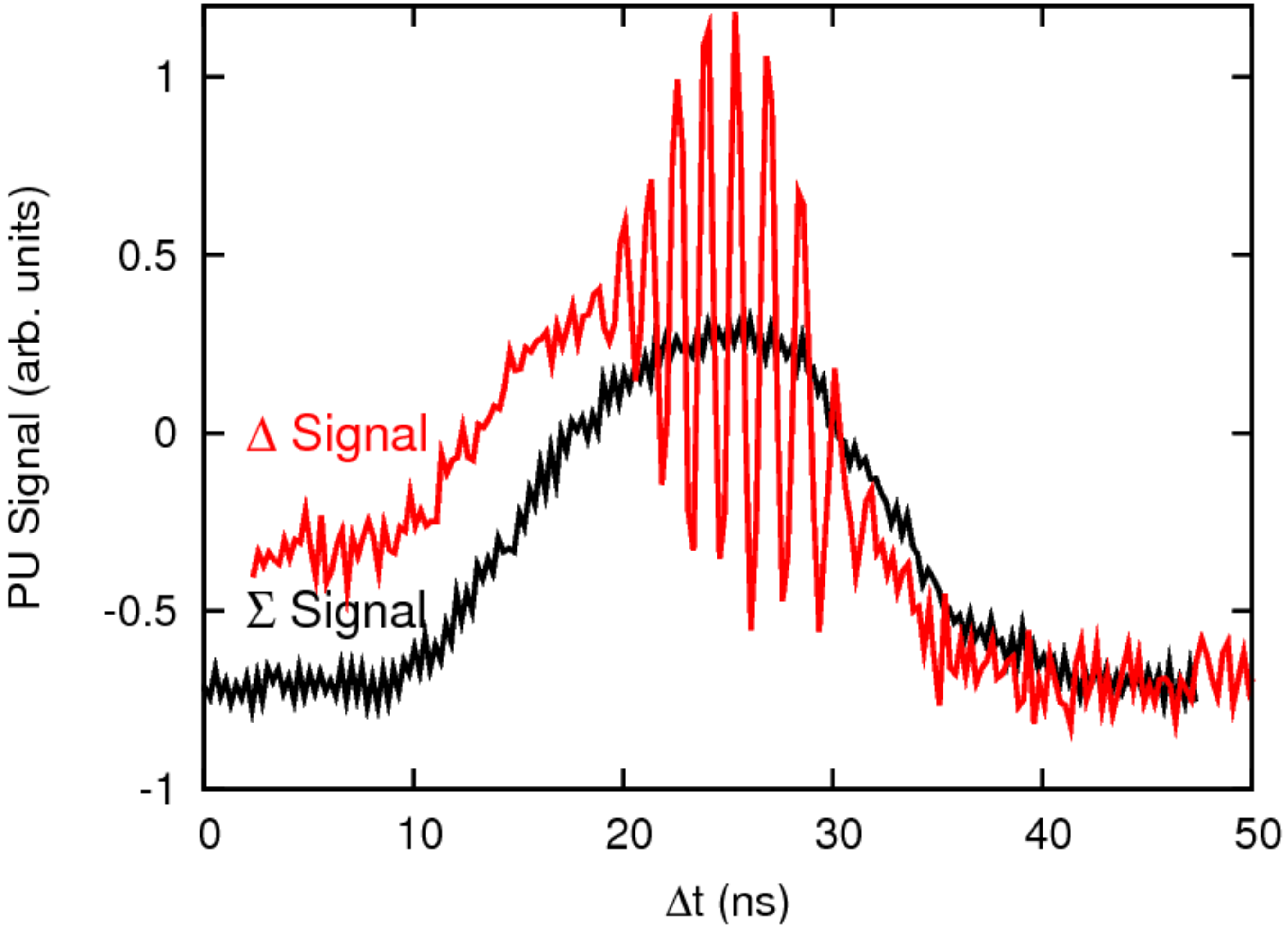
measurements for the
“ξ=0 near transition” lattice

EXAMPLE OF THE INSTABILITY

V=150kV

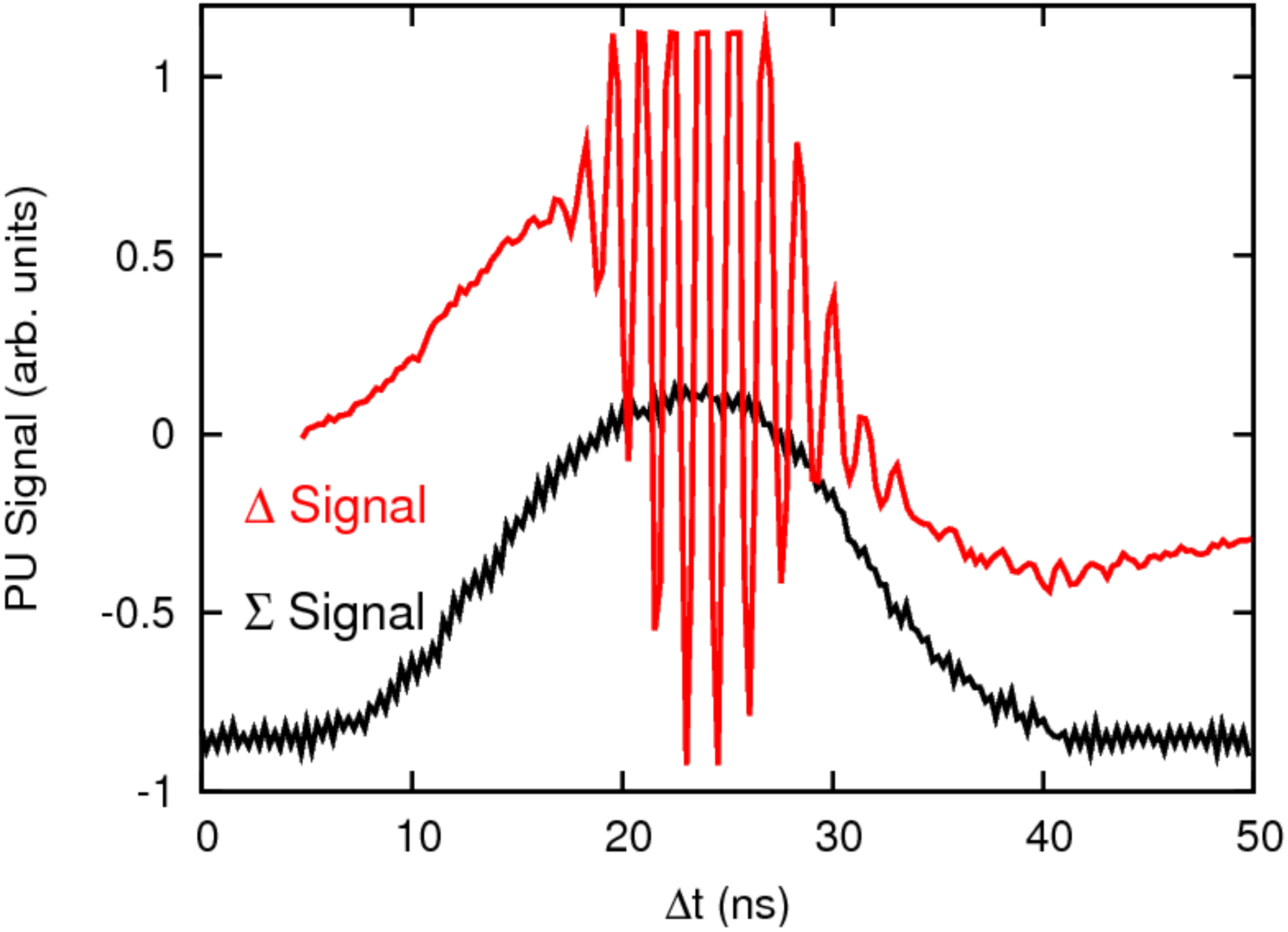
ΔQ=0.93e-3

$\Delta Q/Q_s$=5.8



EXAMPLE OF THE INSTABILITY

$V=120\mathrm{kV}$
$\Delta Q=1.25\mathrm{e}{-3}$
$\Delta Q/Q_s=7.9$

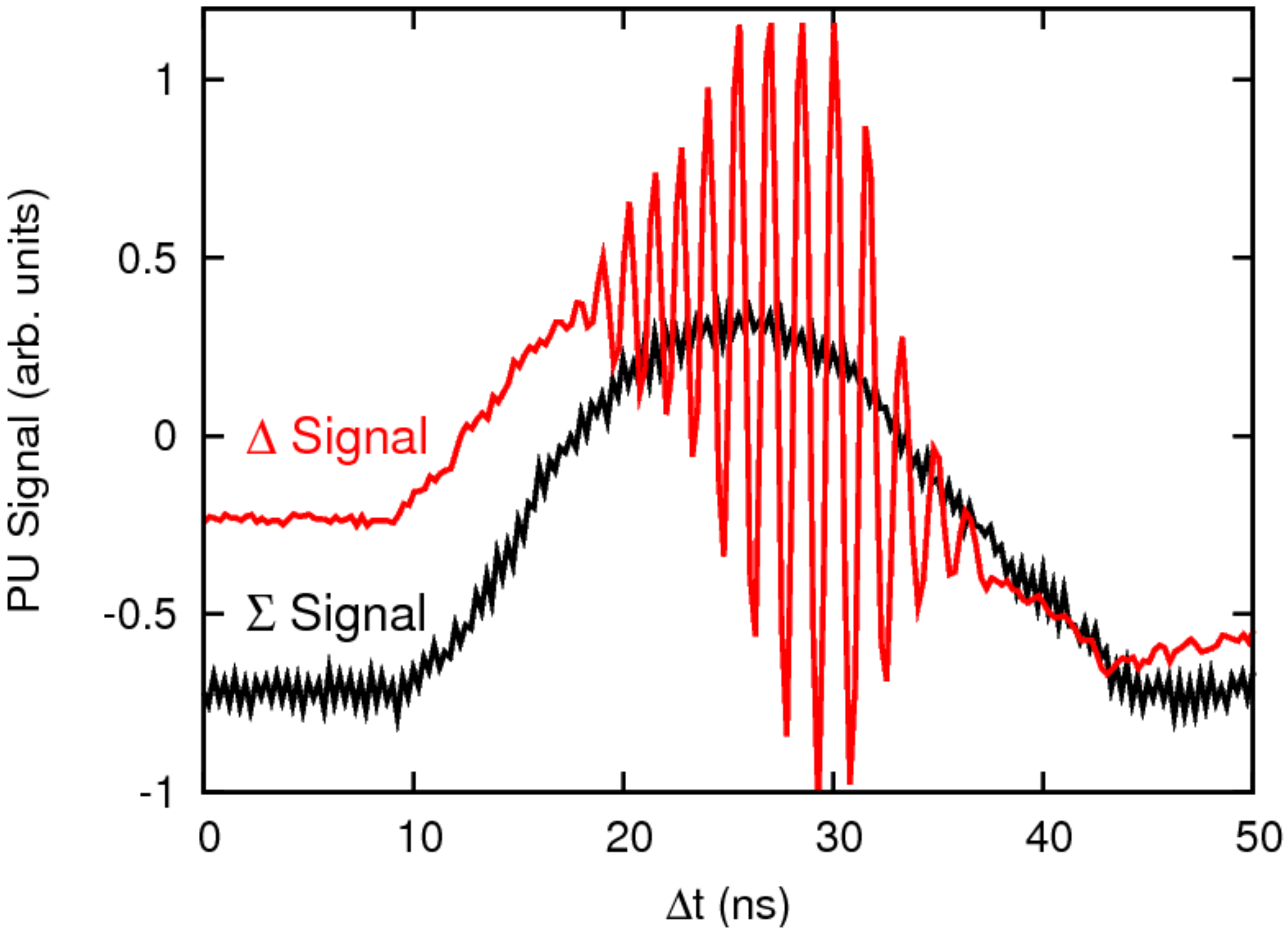


EXAMPLE OF THE INSTABILITY

$V=110kV$

$\Delta Q=0.6e-3$

$\Delta Q/Q_s=3.8$



INSTABILITY NEAR TRANSITION

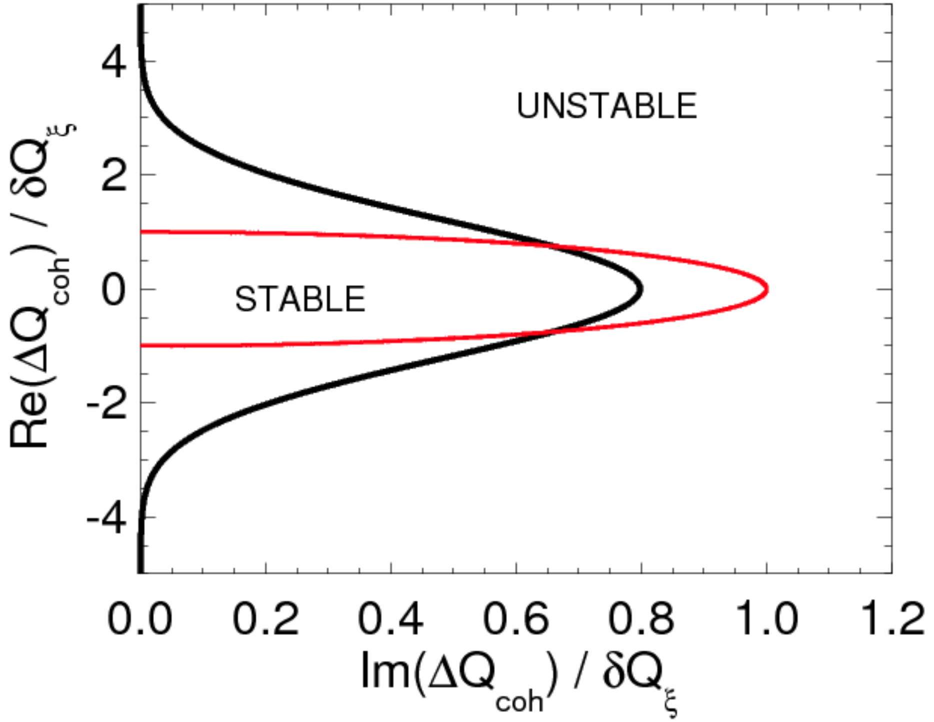
Observations at the PS we need to understand
bunches with larger hV_0 are more stable (higher V_0, higher thresholds; h=16 always stable)
for the "ξ=0 near transition" lattice the instability is around C313ms; while for the "ξ=−0.2 near transition" lattice the instability is around C315ms
increase of the transverse emittance, which means weaker space charge, does not make a difference

COASTING BEAM APPROACH

$$\Delta Q_{\mathrm{coh}} = \Upsilon i Z_\perp$$

$$\Upsilon = \frac{I_0 q_{\mathrm{ion}}}{4\pi\gamma m c Q_0 \omega_0}$$

$$\delta Q_\xi = |\eta(n - Q_0) + Q_0\xi|\delta_p$$



black line, dispersion relation:

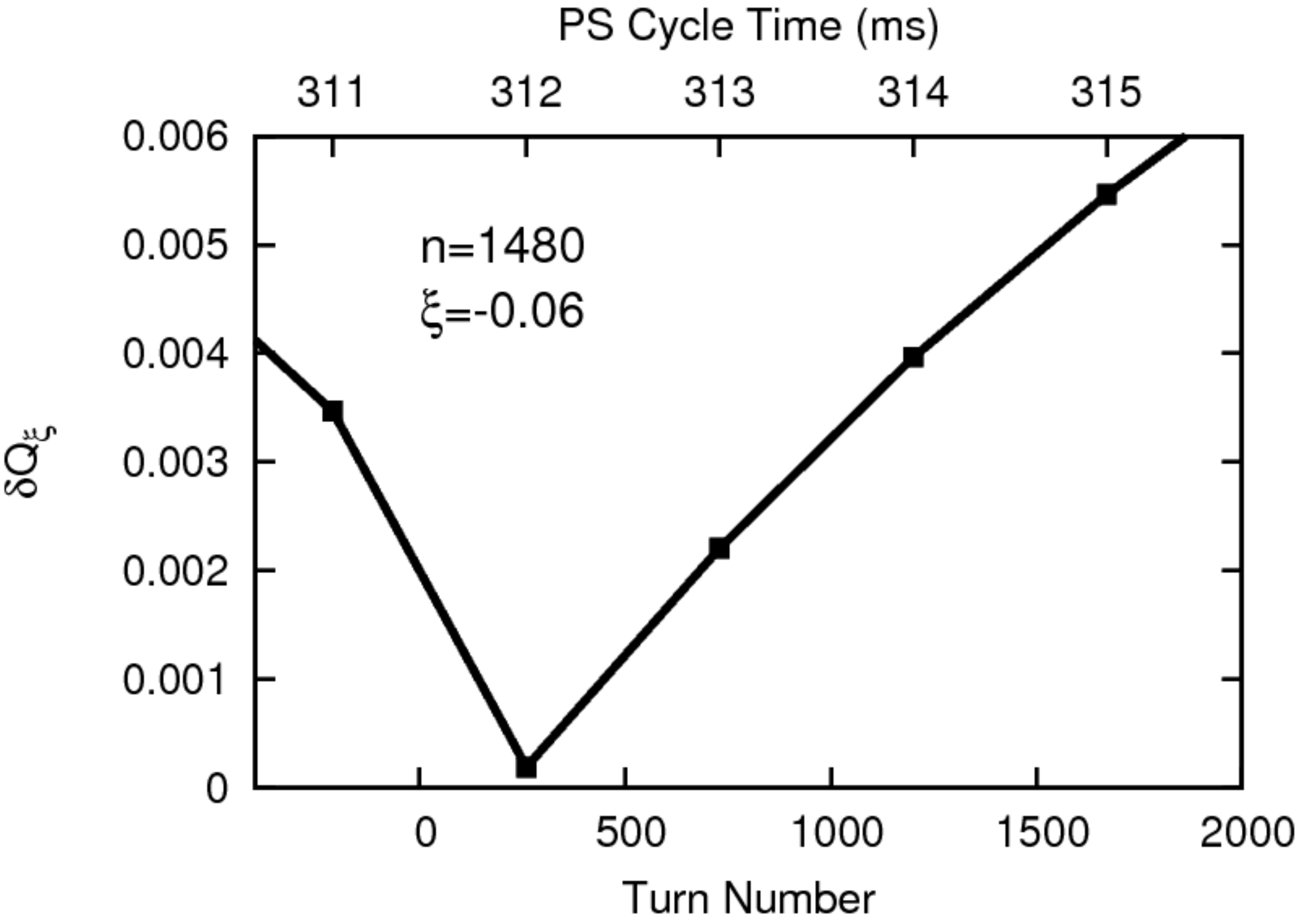
$$\Delta Q_{\mathrm{coh}} \int \frac{f(Q_x)dQ_x}{Q_x - \Delta Q} = 1$$

red line, circle criterion:

$$\frac{|\Delta Q_{\mathrm{coh}}|}{\delta Q_\xi} = 1$$

USUAL LANDAU DAMPING AT PS

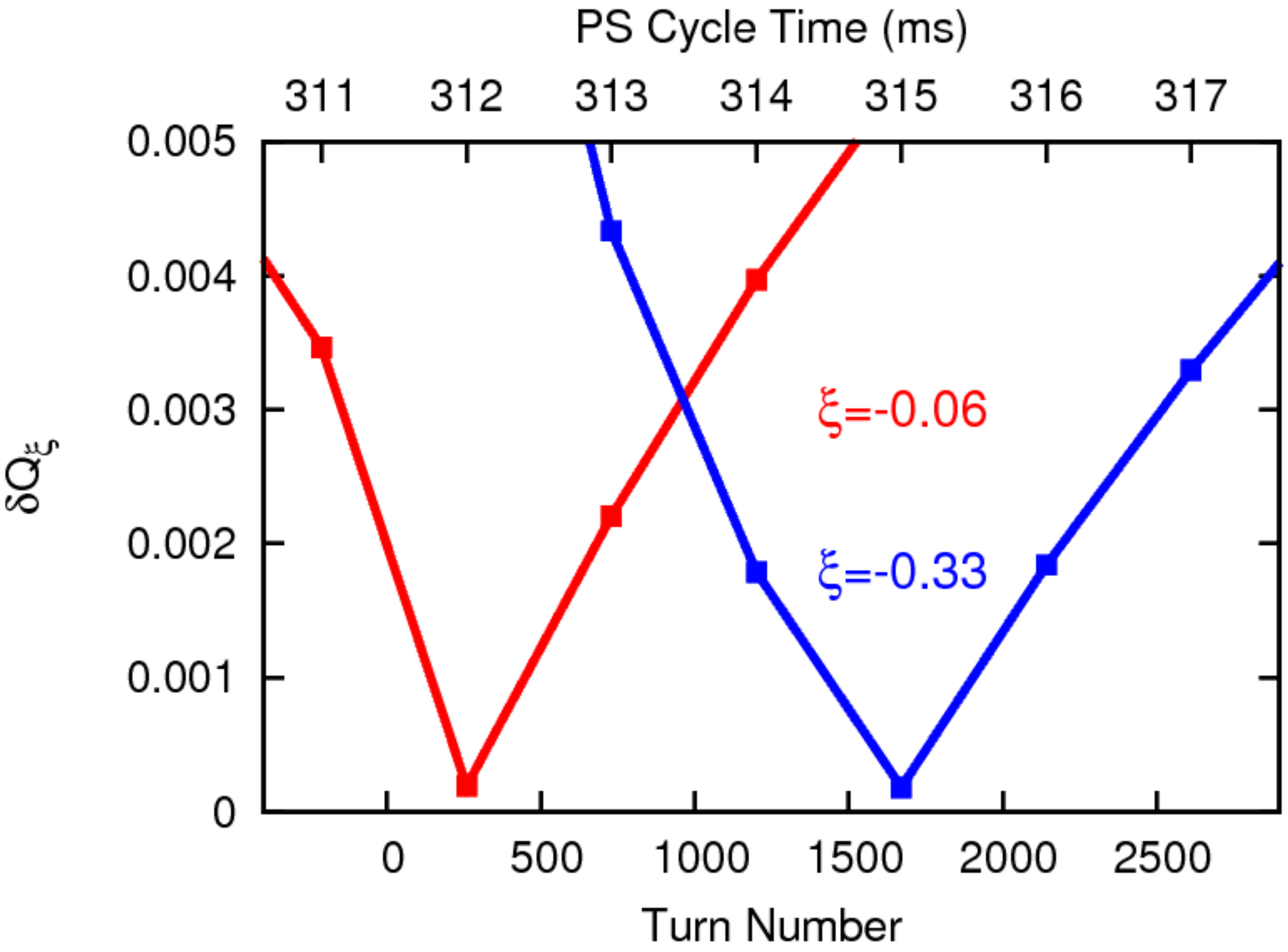
the measure for the usual (ξ and δp) Landau Damping



assuming a small chromaticity near transition

USUAL LANDAU DAMPING AT PS

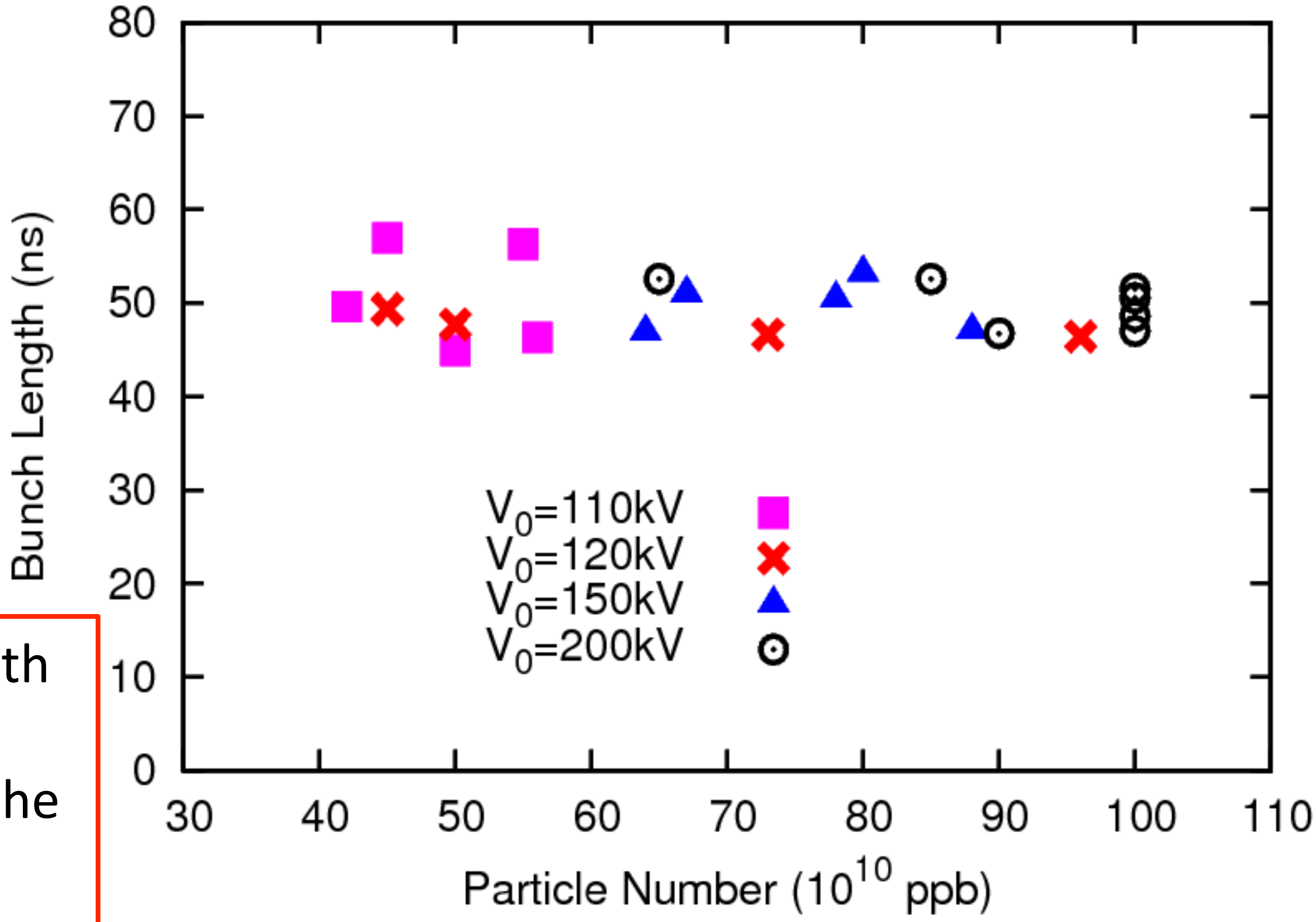
the measure for the usual (ξ and δp) Landau Damping



assuming stronger chromaticity near transition

=> similar to our observation

BUNCH LENGTH SUMMARY



the bunch length (as to C300ms) is const along the intensity and along the rf voltage

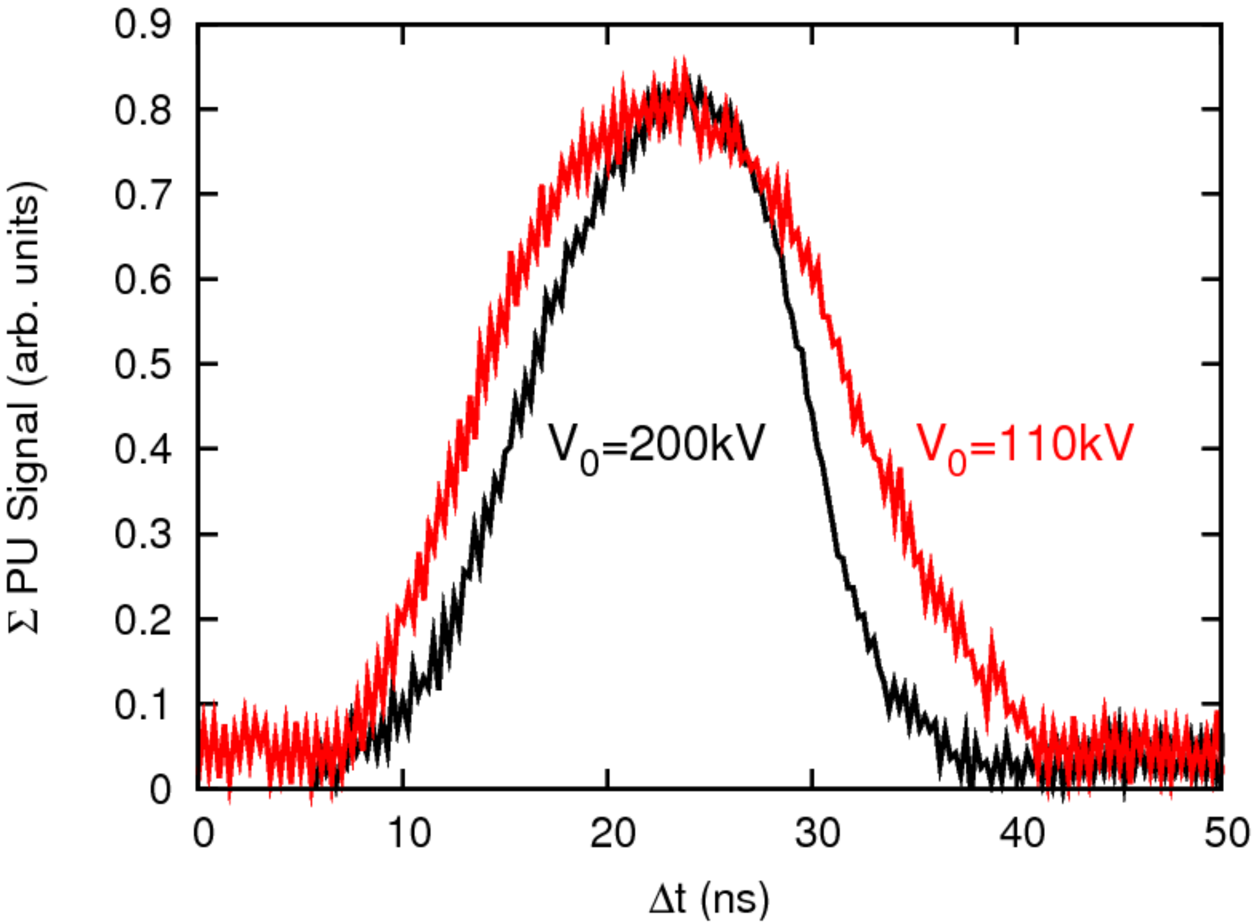
BUNCH LENGTH NEAR TRANSITION

But, if we look near the transition (here at C312ms), the bunch lengths are different

note: C312ms is for both well within the nonadiabatic time.

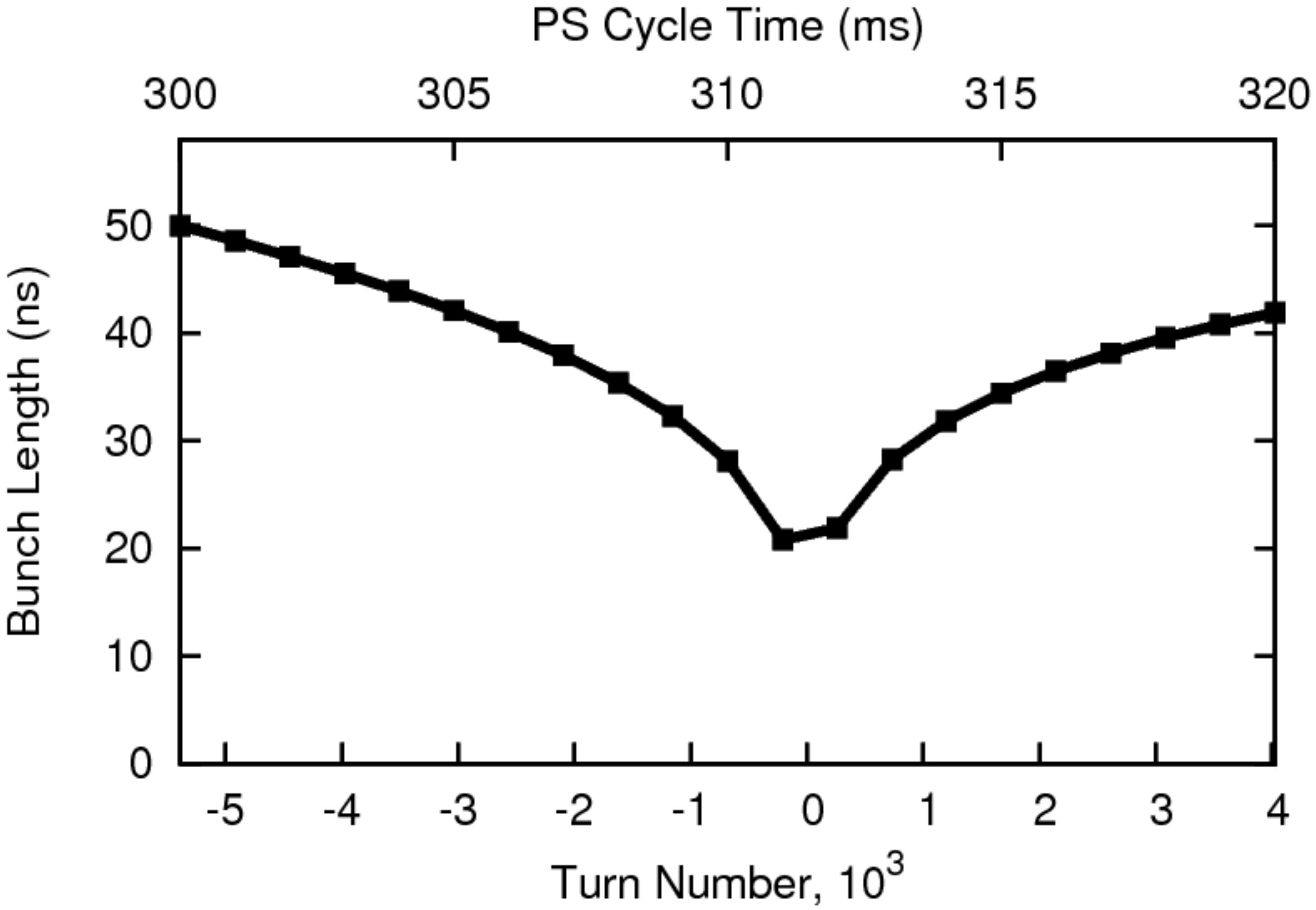
V_0=200kV: T_c=1.9ms

V_0=110kV: T_c=2.7ms

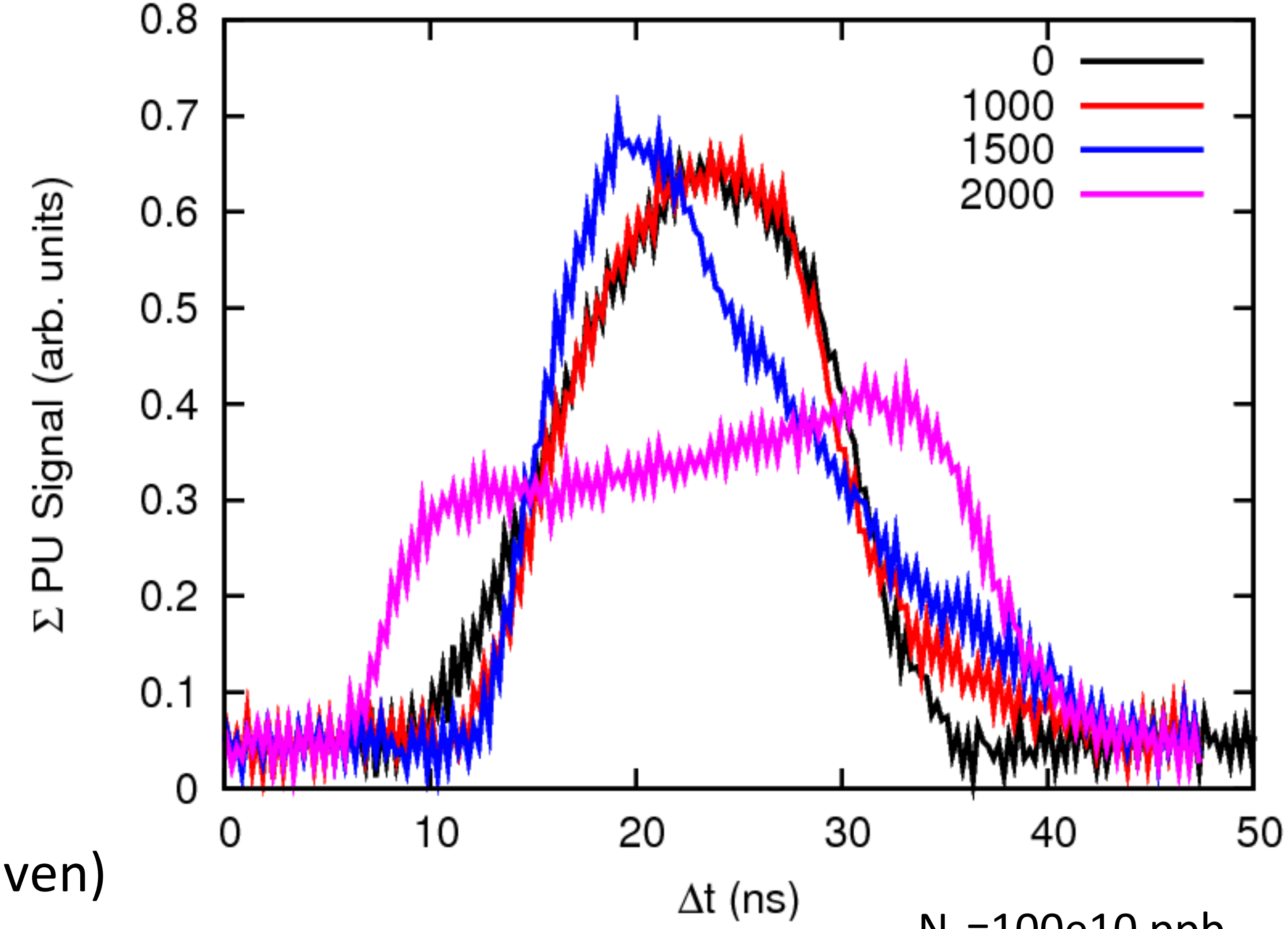


BUNCH LENGTH NEAR TRANSITION

A simplified picture: how the bunch length should evolve near transition (neglecting space charge, beam loading)



BUNCH LENGTH NEAR TRANSITION



… this actually happens for V_0=200kV

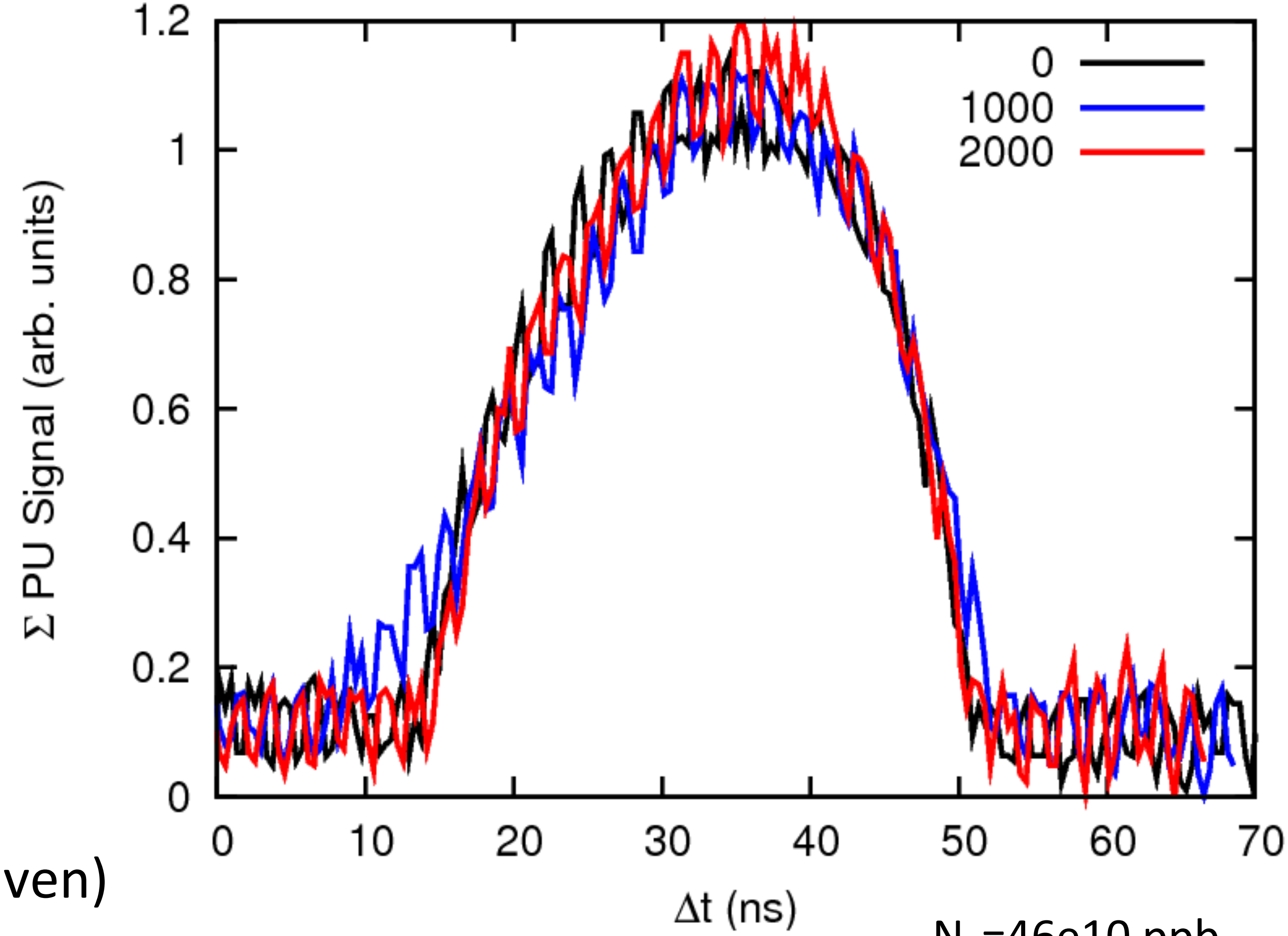
(the turn number after C312ms is given)

N_p=100e10 ppb

BUNCH LENGTH NEAR TRANSITION

…but not for V_0=110kV

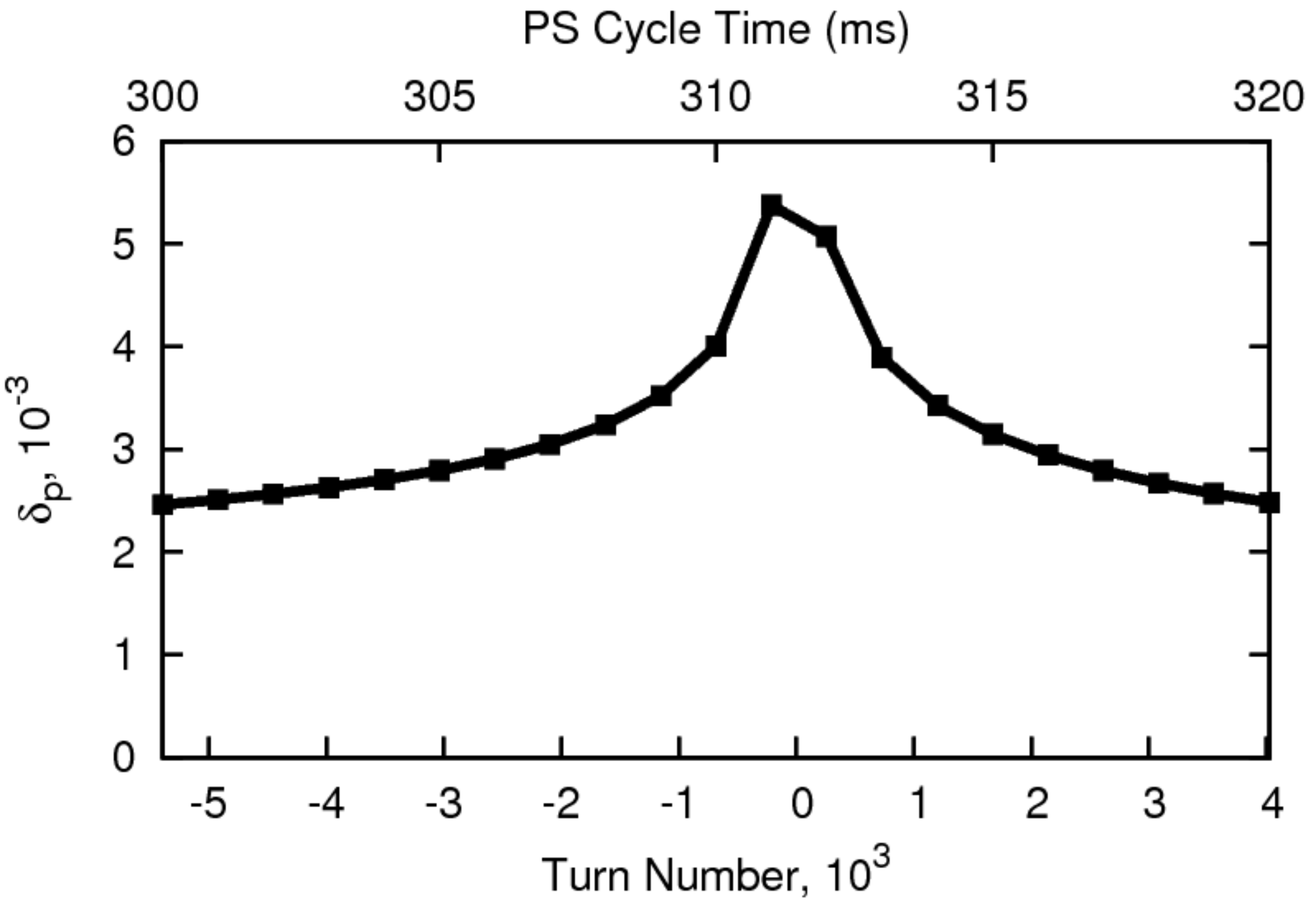
(the turn number after C312ms is given)



N_p=46e10 ppb

MOMENTUM SPREAD

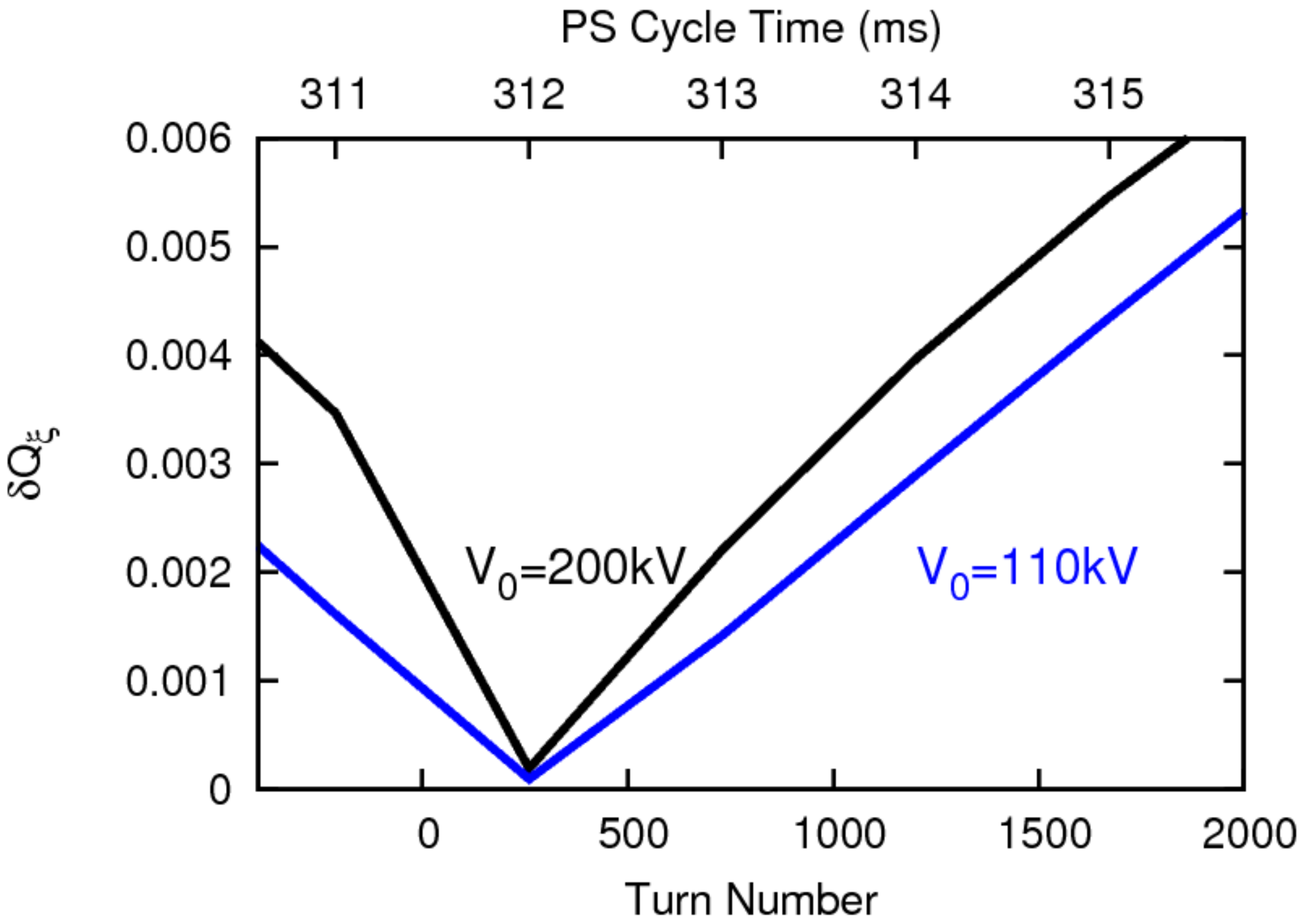
This means that for the low voltage V_0=110kV there is no increase of the momentum spread near transition like here:



Simplified calculation for ε_z=const, bunch parameters V_0=200kV

USUAL LANDAU DAMPING AT PS

For the Landau Damping from the coasting-beam approach this means:



Shorter bunch and thus larger δp provides stronger Landau damping for high rf voltage, meaning a higher instability threshold

BEAM BREAK-UP INSTABILITY

Other stabilizing aspects suggested:

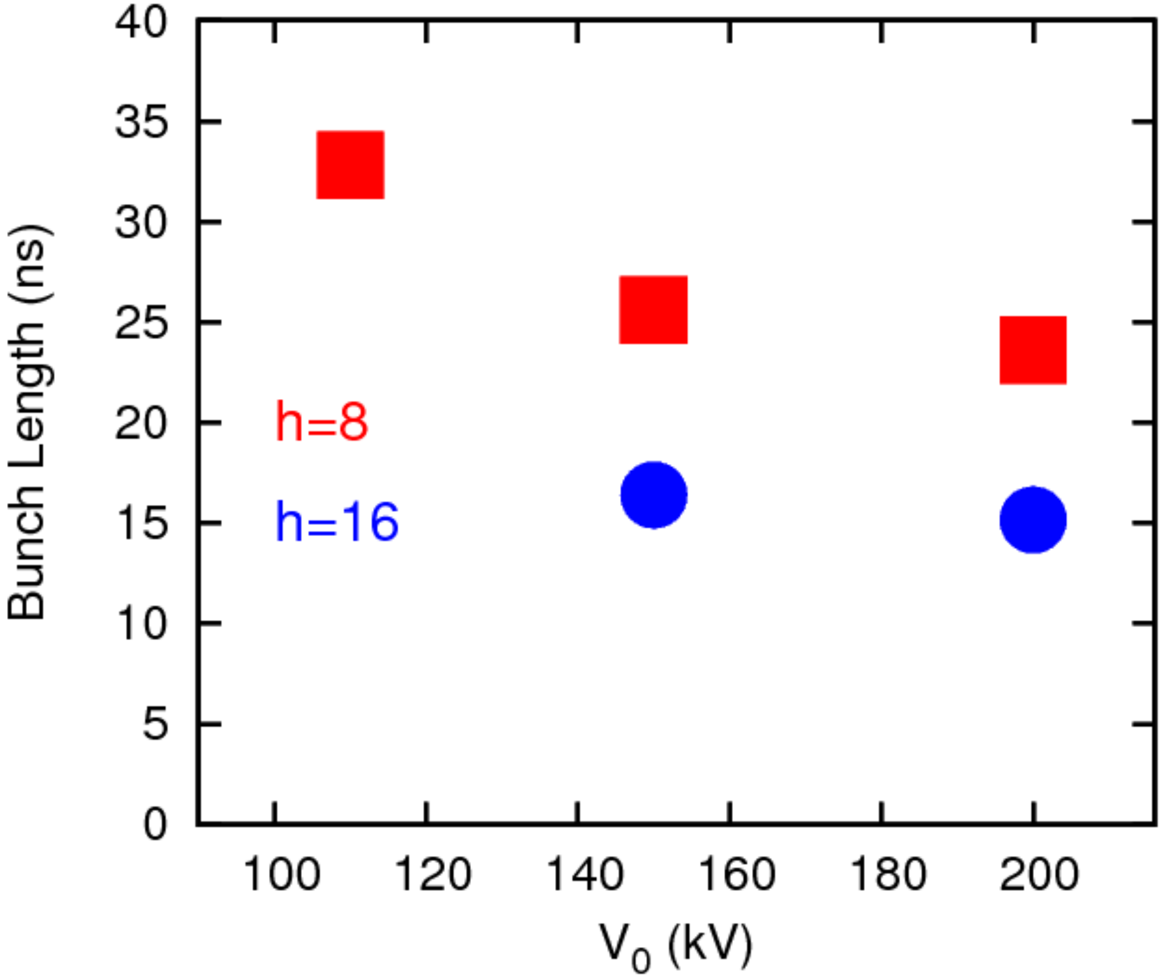
The absolute value of the synchrotron tune Q_s
(larger: stabilizing)

The bunch length relative
to the instability wave length L_b/λ_{bbu}
(smaller: stabilizing)

The characteristic frequency of particles sweeping
through the instability wiggles $Q_{wigg}=2\ t_b\ f_{BB}\ Q_s$
(larger: stabilizing)

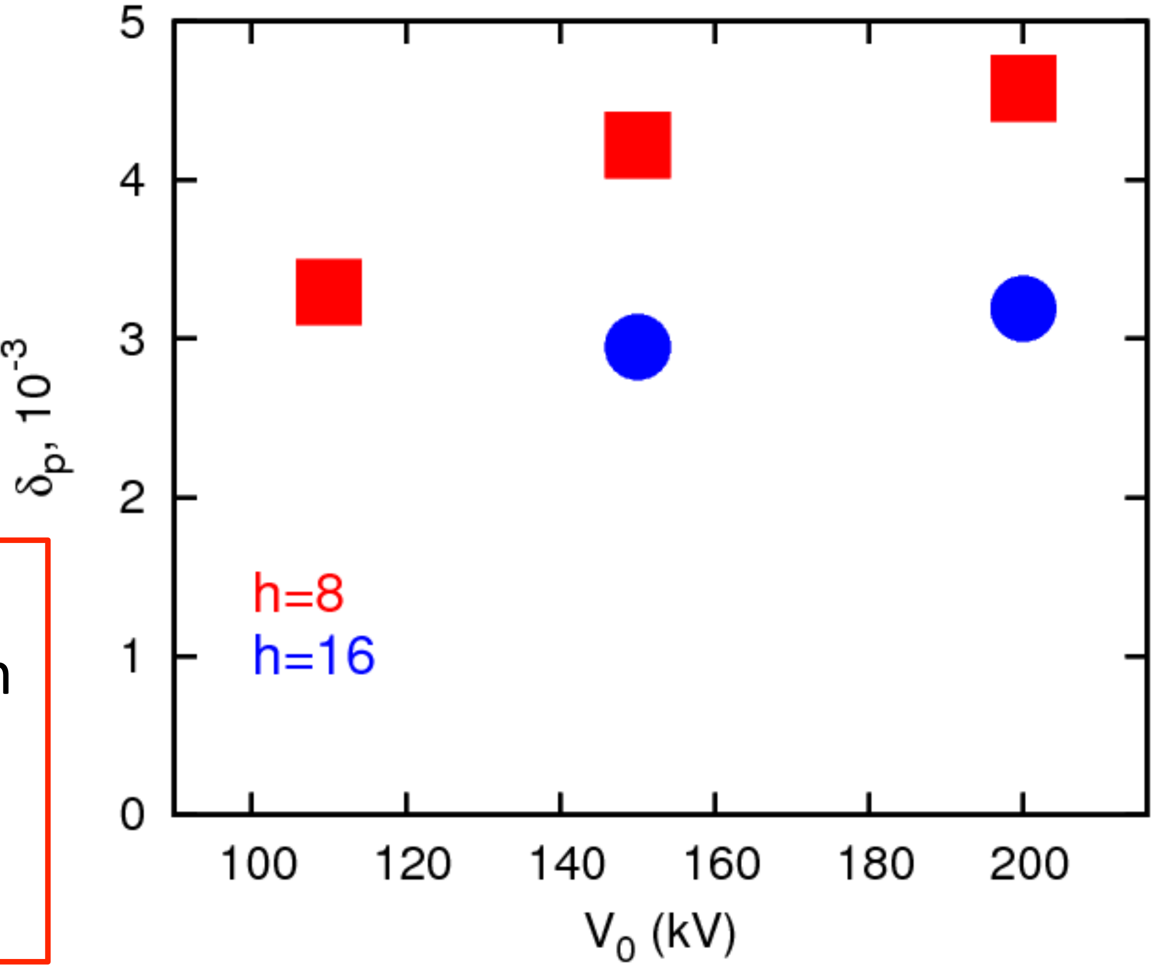
BEAM BREAK-UP INSTABILITY

Overview of bunch parameters relevant
to the Beam Break-Up Stabilization (measured during the MD):
the bunch length near transition



BEAM BREAK-UP INSTABILITY

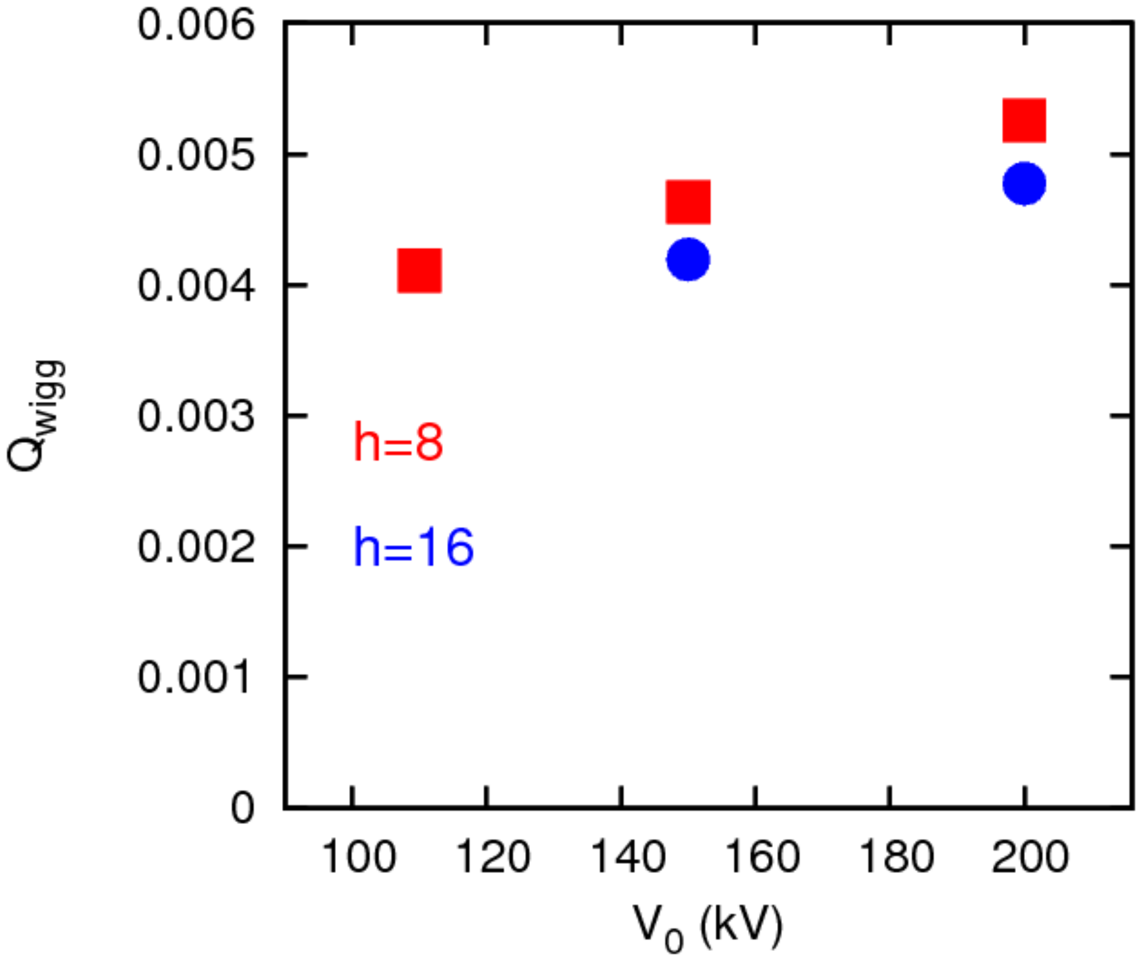
Overview of bunch parameters relevant
to the Beam Break-Up Stabilization (measured during the MD):
the momentum spread near transition



Can contribute to the differences with *h*=8, but can not be the reason for the stability with *h*=16

BEAM BREAK-UP INSTABILITY

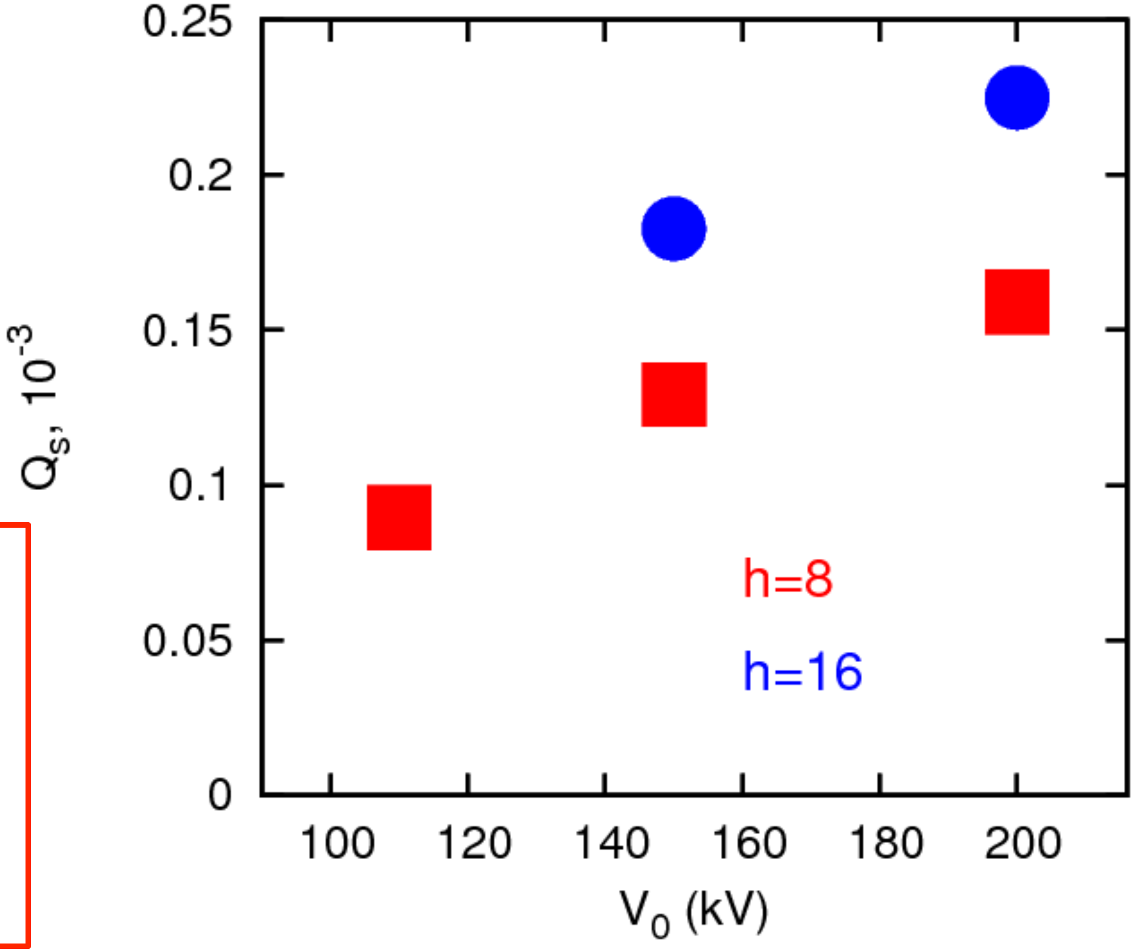
Overview of bunch parameters relevant
to the Beam Break-Up Stabilization (measured during the MD):
the particle-wave sweeping frequency



Can contribute to the differences with *h*=8, but can not be the reason for the stability with *h*=16

BEAM BREAK-UP INSTABILITY

Overview of bunch parameters relevant
to the Beam Break-Up Stabilization (measured during the MD):
The absolute value of the synchrotron tune Q_s

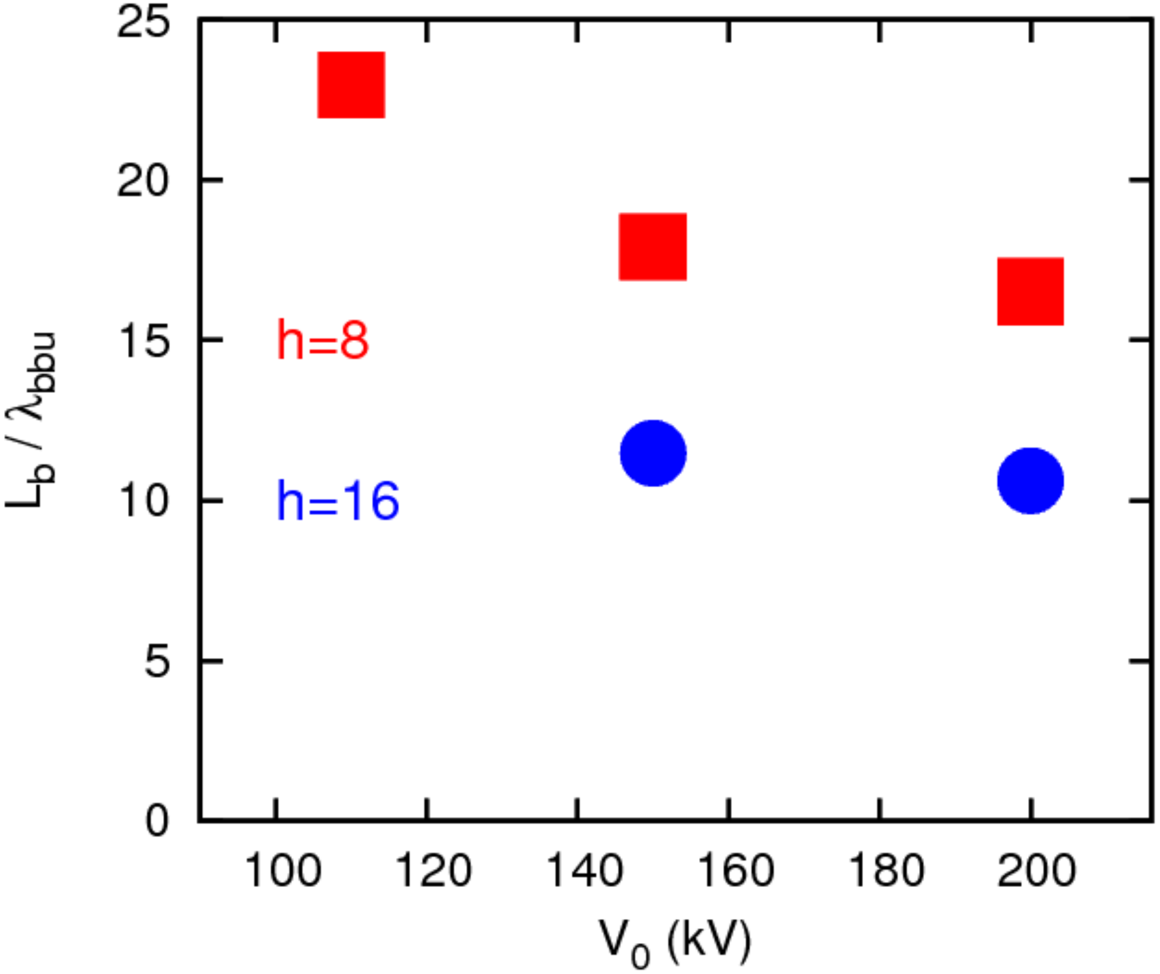


Can contribute to the differences with *h*=8, and also can contribute to the stability with *h*=16

BEAM BREAK-UP INSTABILITY

Overview of bunch parameters relevant
to the Beam Break-Up Stabilization (measured during the MD):
the bunch length relative to the instability wave length

Can contribute to the differences with *h*=8, and is it the main reason for the stability with *h*=16?



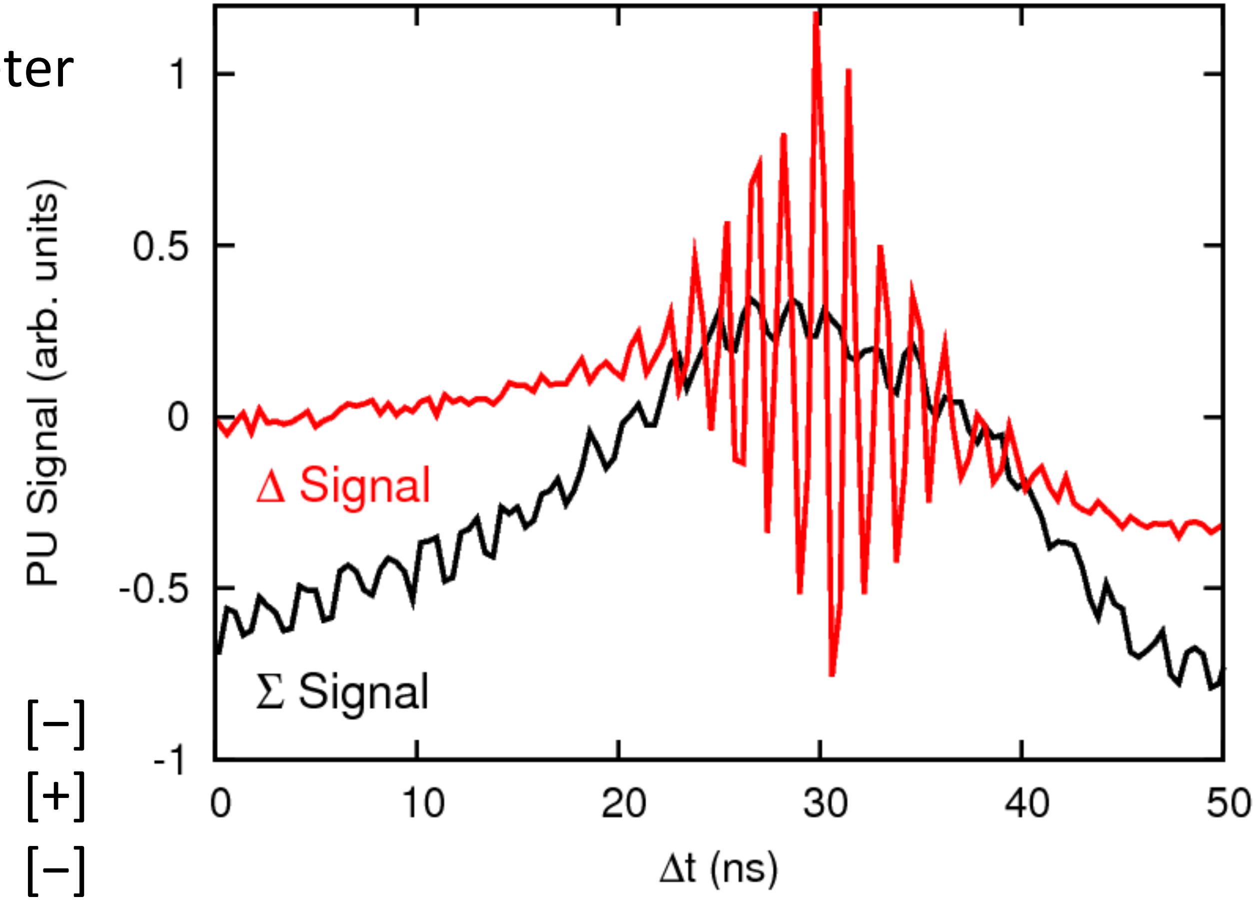
BEAM BREAK-UP INSTABILITY

An example for the parameter comparison

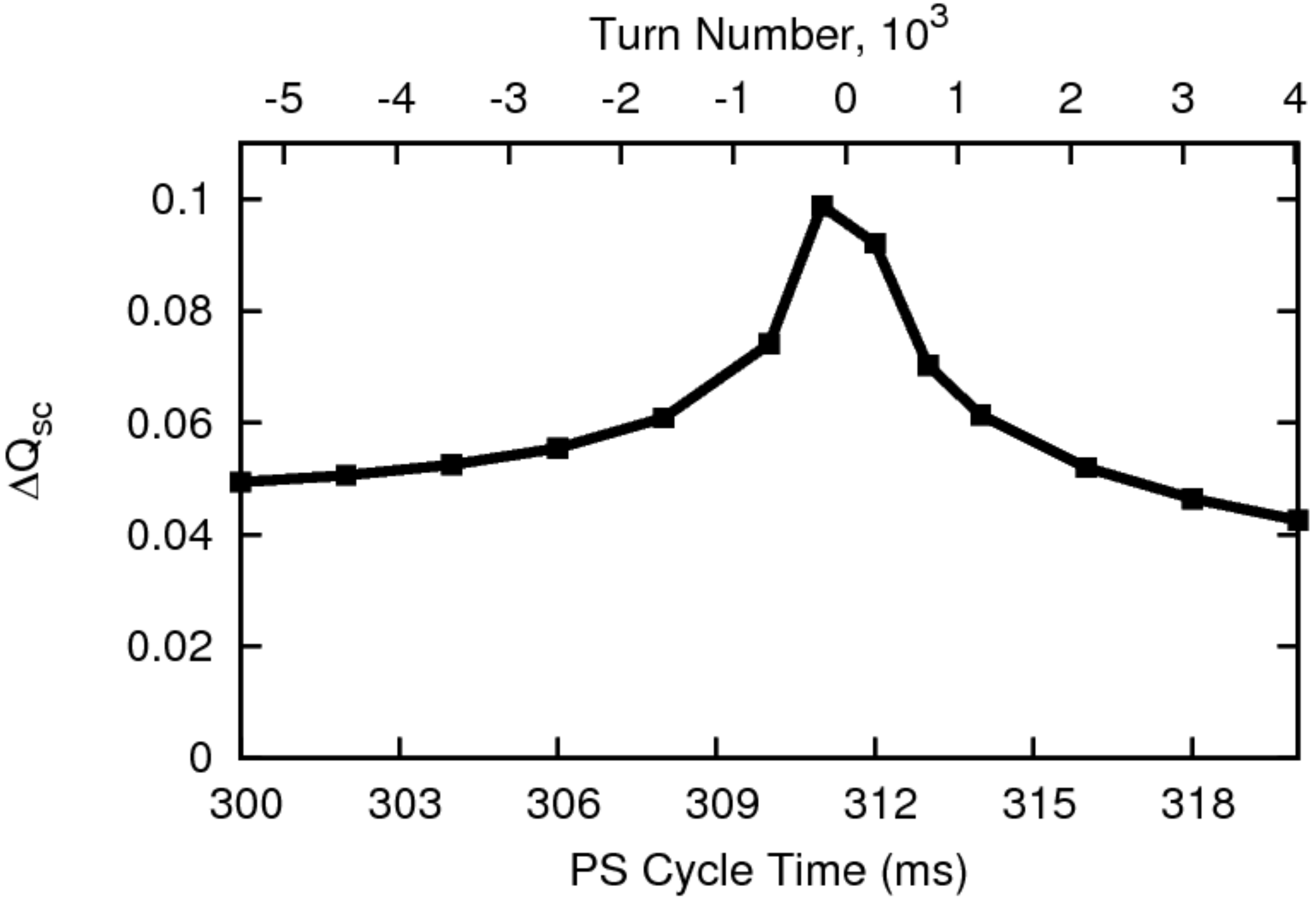
The instability at
at C317ms
93e10, 200kV
ΔQ=0.8e-3
$\Delta Q/Q_s$=2.8

L_b=38ns (C312: 23.6ns) [−]
Q_s=2.9e-4 (C312: 1.59e-4) [+]
L_b/λ_{bbu}=26 (C312: 16.5) [−]
Q_{wigg}=15e-3 (C312: 5.3e-3) [+]

… the threshold was the same

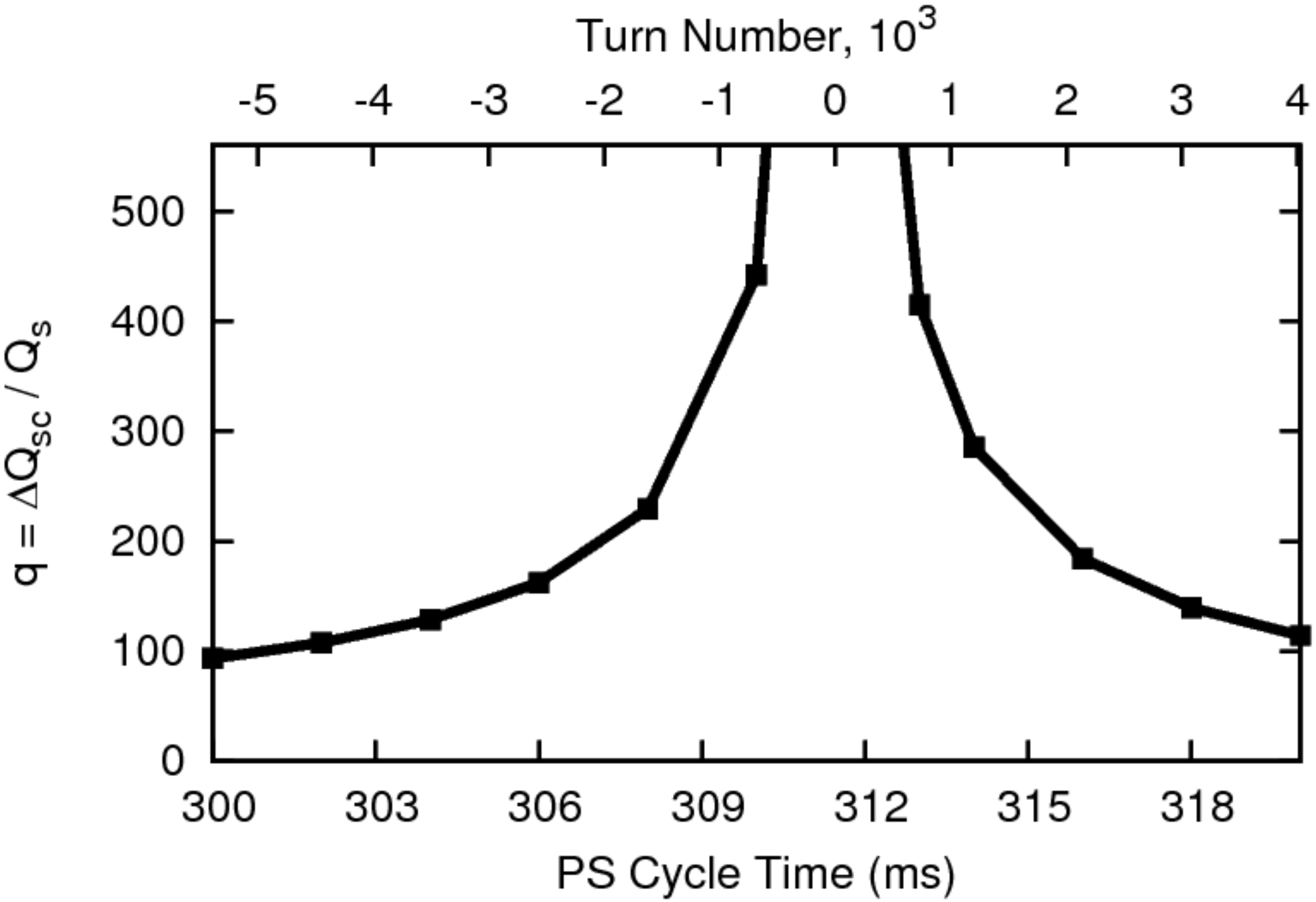


SPACE CHARGE AT PS



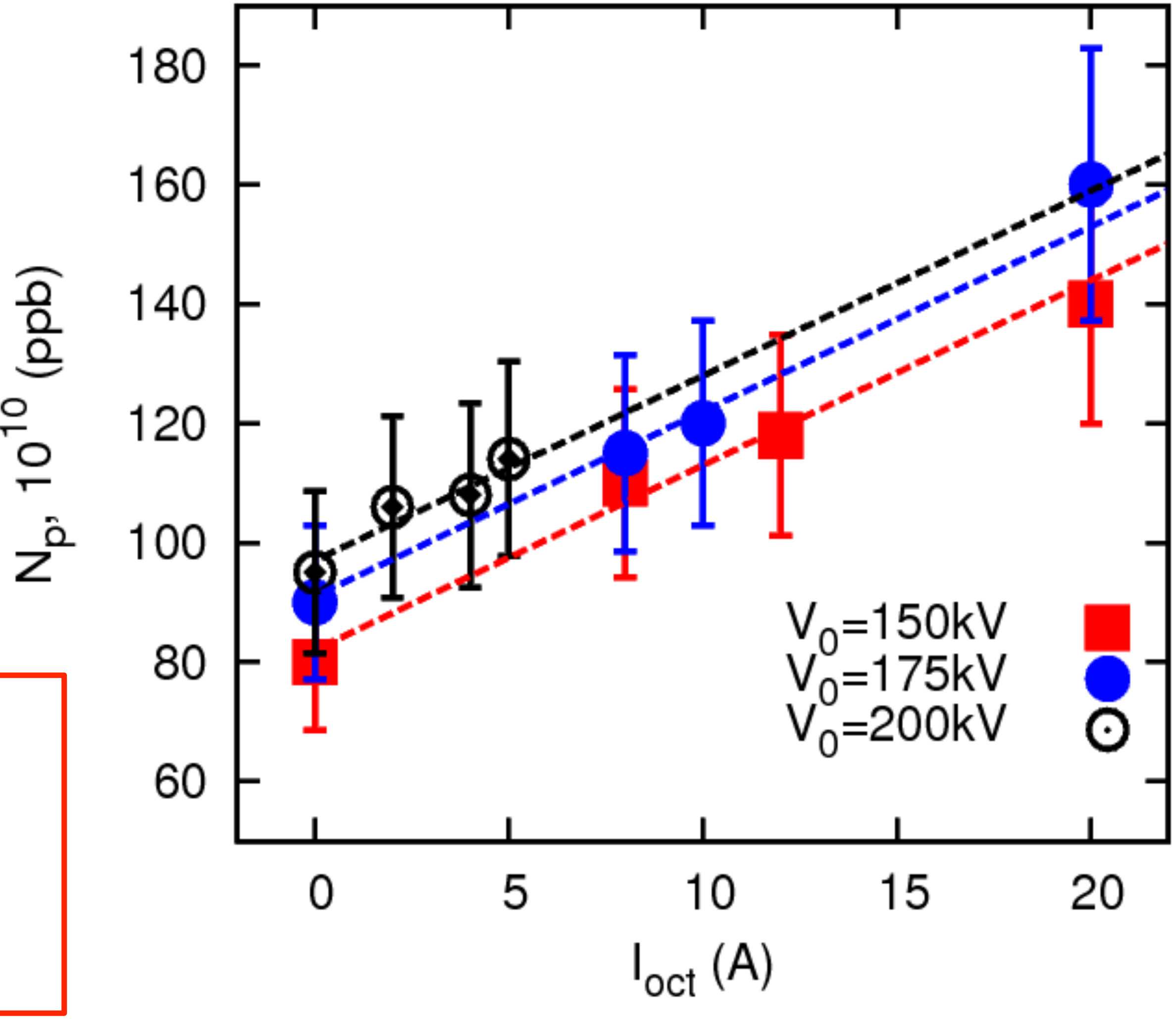
N_p=90e10, t_b=50ns at C300ms, V_0=200kV

SPACE CHARGE AT PS



Very strong space-charge regime

DAMPING BY OCTUPOLES



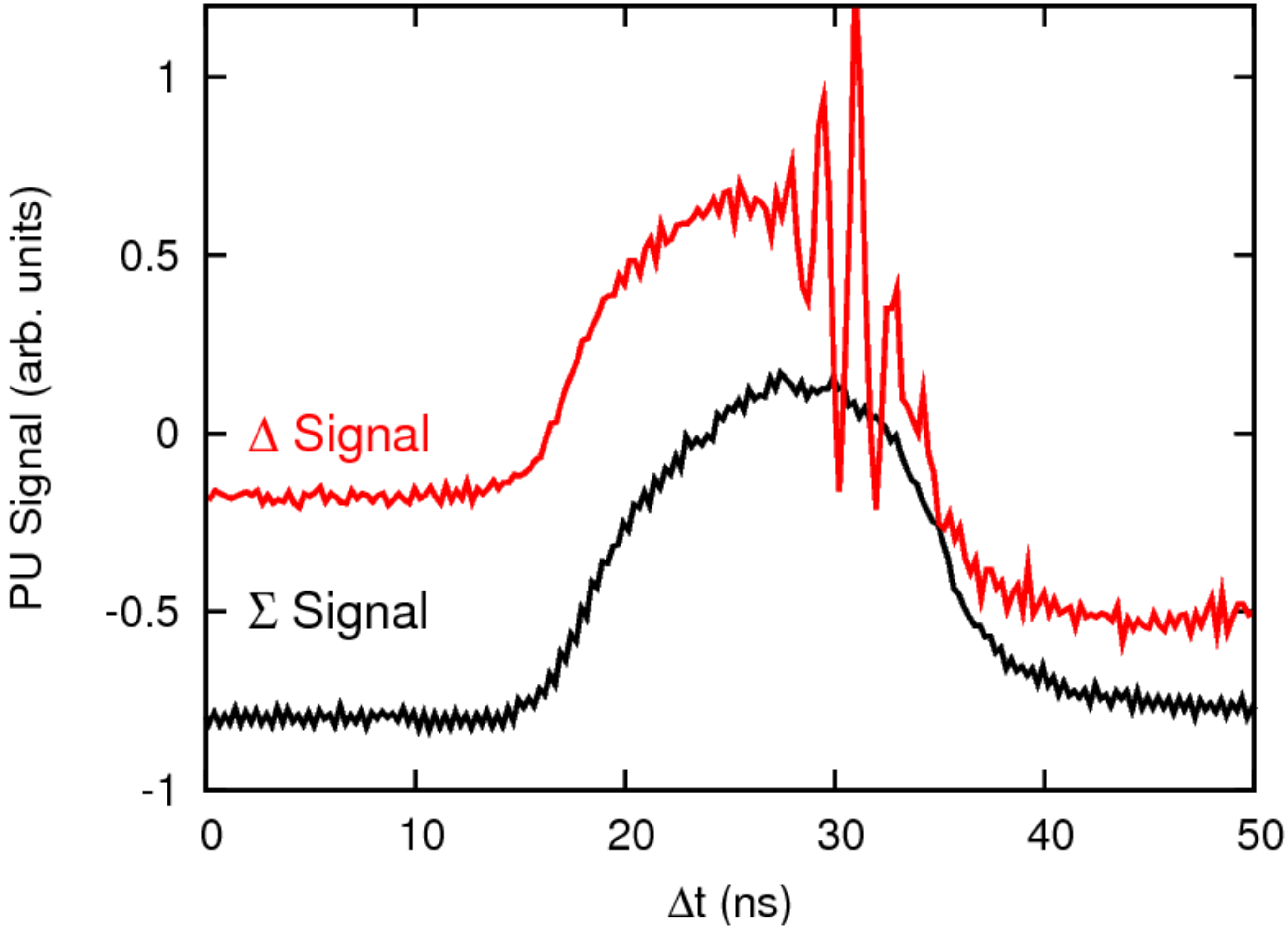
Linear contribution to Landau damping, should be quantitively verified (need PS data)

DAMPING BY OCTUPOLES

An example for stabilization with octupoles: oscillations, no losses.

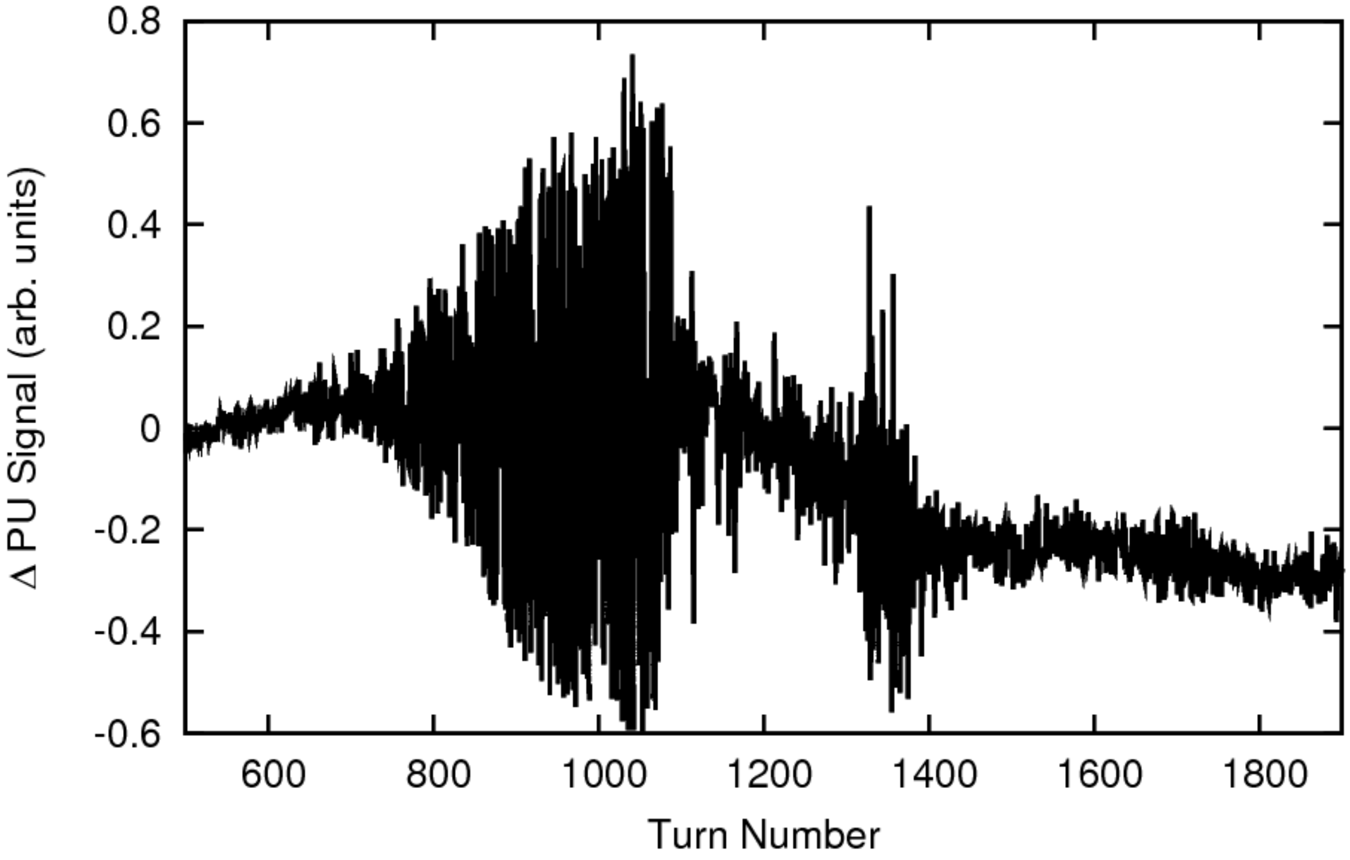
175kV, 20A, 164e10

turn 1000



DAMPING BY OCTUPOLES

An example for stabilization by octupoles: oscillations, no losses.
175kV, 20A, 164e10
at Δt=30ns



CONCLUSIONS BEAM BREAK-UP

The transverse oscillations near transition at PS seem not to be due to an absolute instability but are related to a Beam Break-Up mechanism

Landau damping from the coasting-beam approach illustrates the occurrence time of the instability and the ξ,δp-related damping

A higher instability threshold for large rf voltages seems to be due to shorter bunch and thus larger δp, providing stronger Landau damping

Other damping mechanisms: Q_s-value, bunch length / wave length, particle-wiggle sweeping frequency are analyzed and compared

The bunches are in the very strong space charge regime

The instability can be stabilized by octupoles