BEAM STUDIES AT PS: HEAD-TAIL INSTABILITY AT THE INJECTION ENERGY

Vladimir Kornilov, GSI Darmstadt

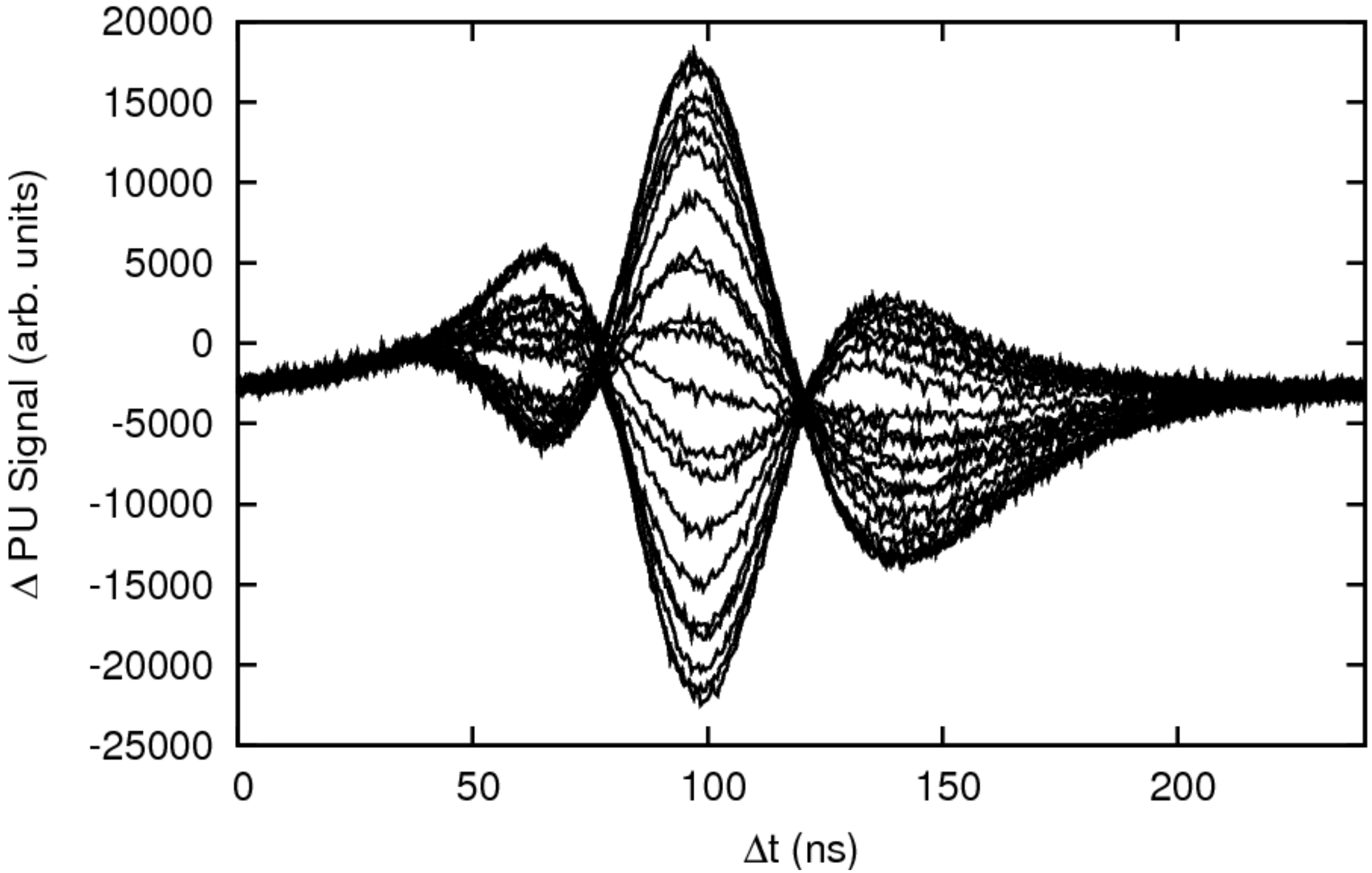
Machine operation:

Sandra Aumon, Simone Gilardoni, PS Operation Group

HEAD-TAIL INSTABILITY AT PS

N_p=425e10 ppb,
at C364ms,
V_0=60kV,

ΔQ=0.65e-4,
τ=5.6ms,
$\Delta Q/Q_s$=0.028

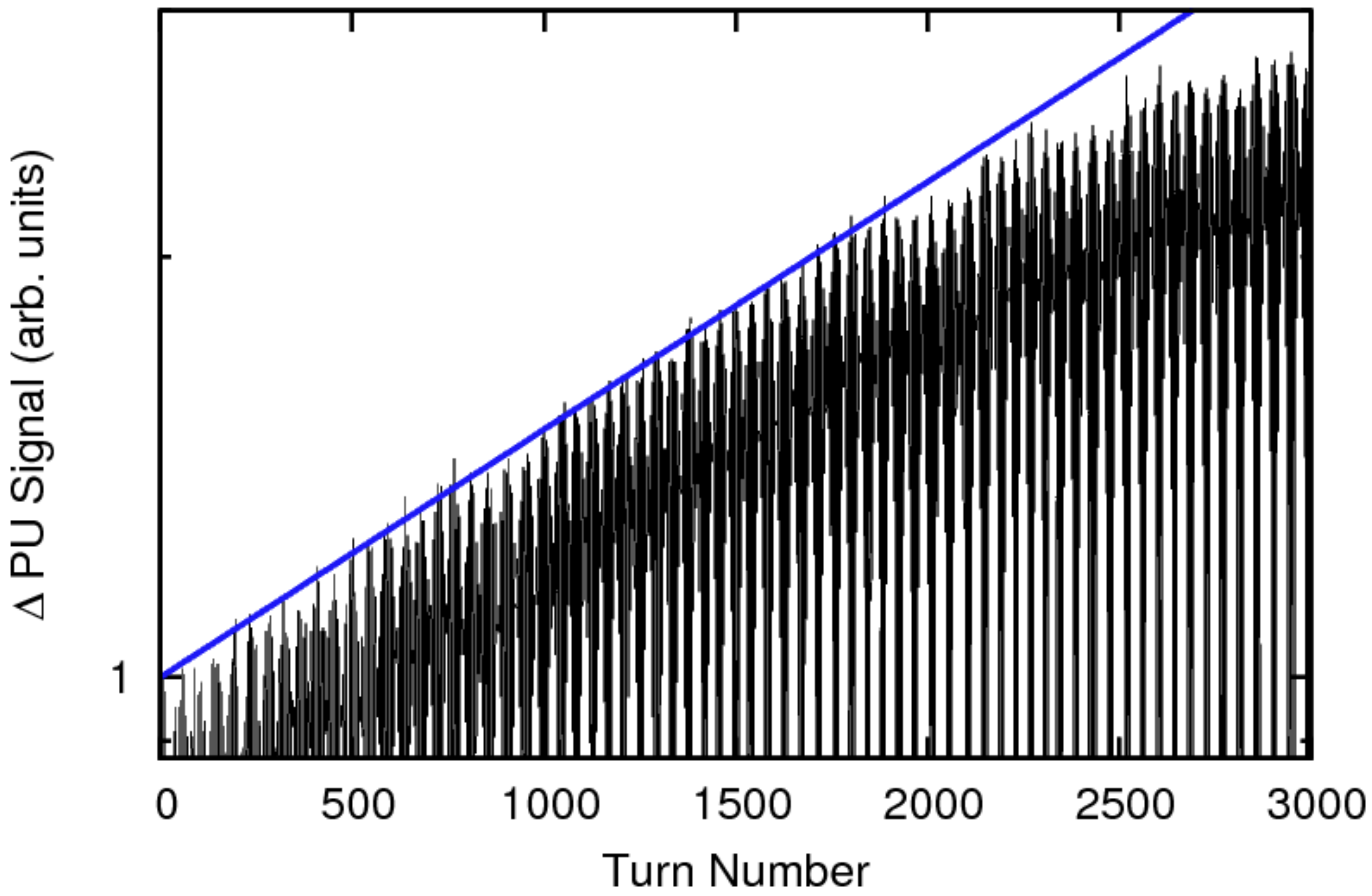


Plateau at the injection energy, $\xi_x = -0.1$
Instability occurs irregularly at C250ms...C500ms,
difficult to catch with the scope;
always the mode *k*=2 observed.

HEAD-TAIL INSTABILITY AT PS

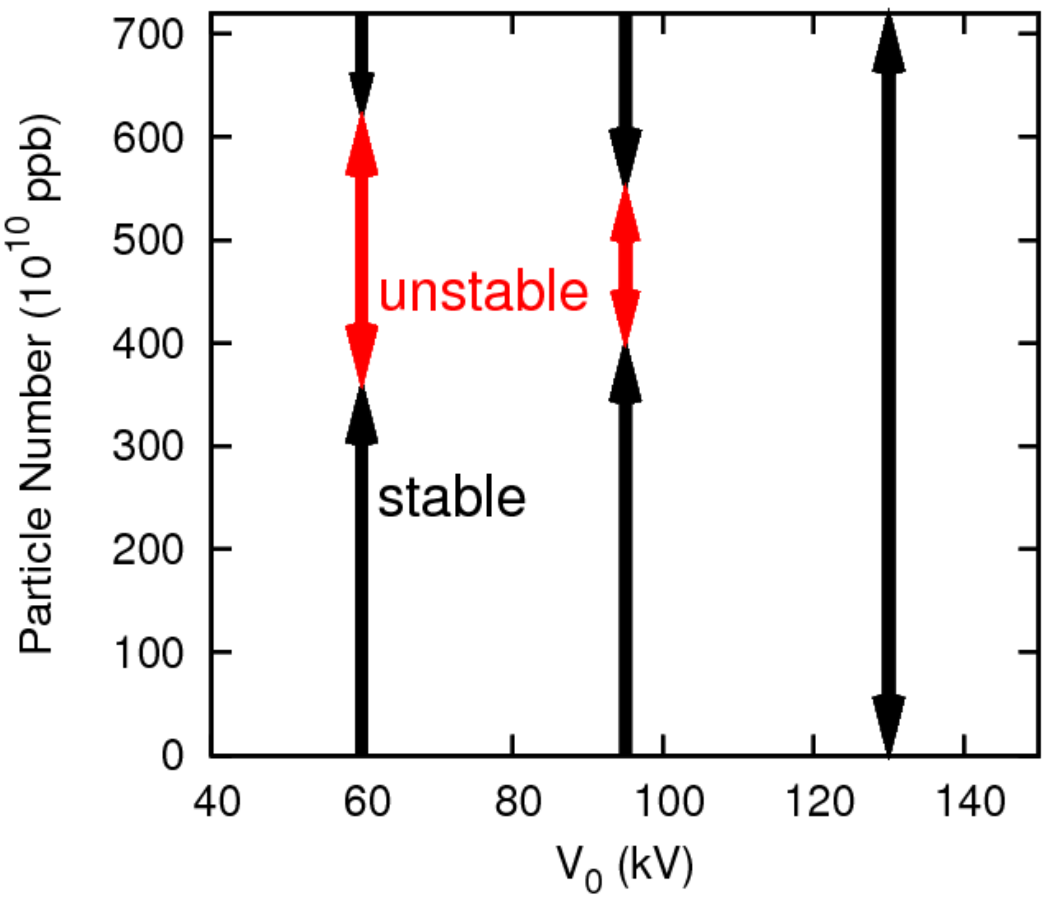
N_p=425e10 ppb,
at C364ms,
V_0=60kV,

ΔQ=0.65e-4,
$\Delta Q/Q_s$=0.028



For every point in the bunch:
a nice exponential growth

HEAD-TAIL INSTABILITY AT PS



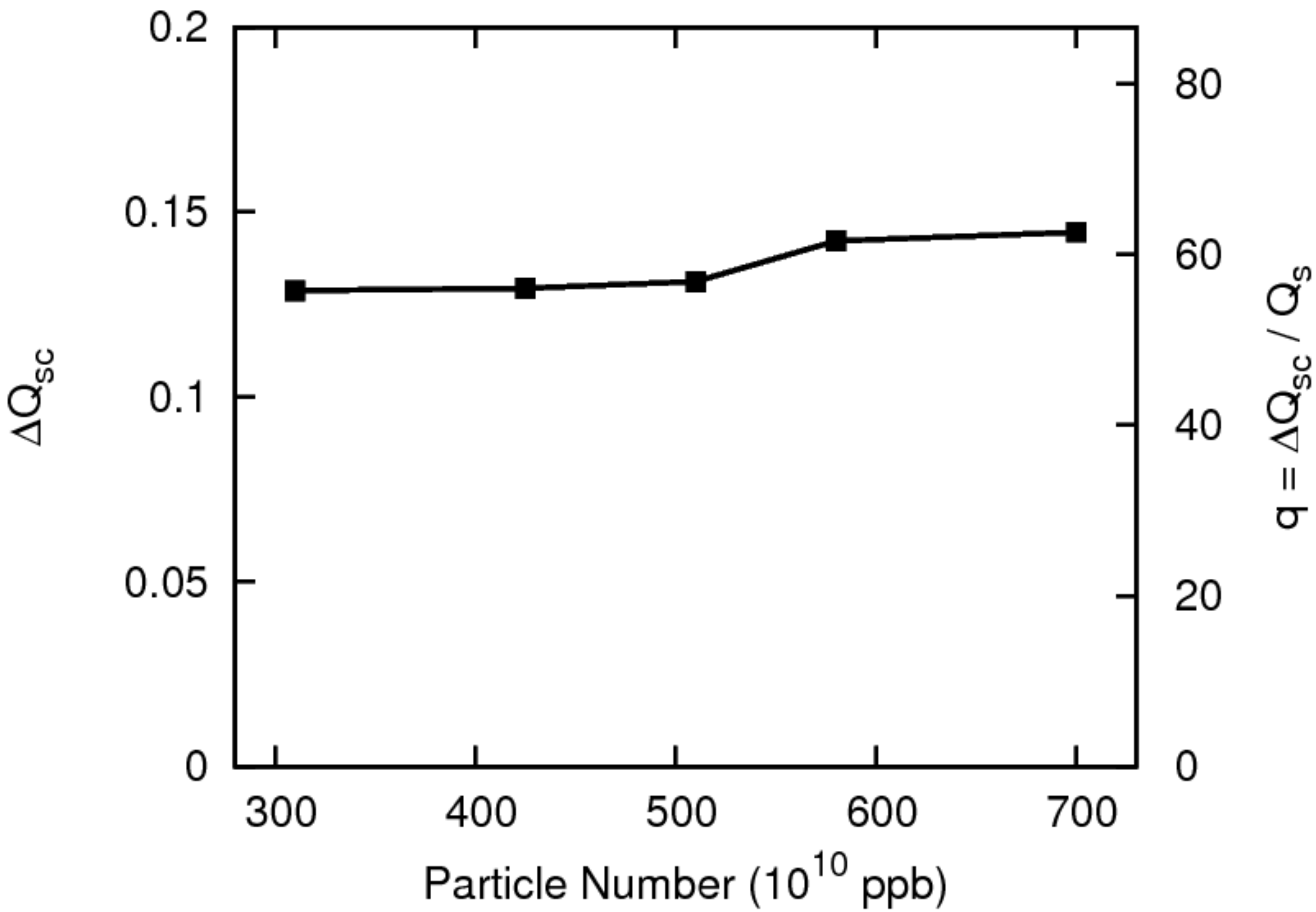
why second threshold?

why k=2?

why higher rf voltage less unstable?

two intensity thresholds;
very different depending on the rf voltage.

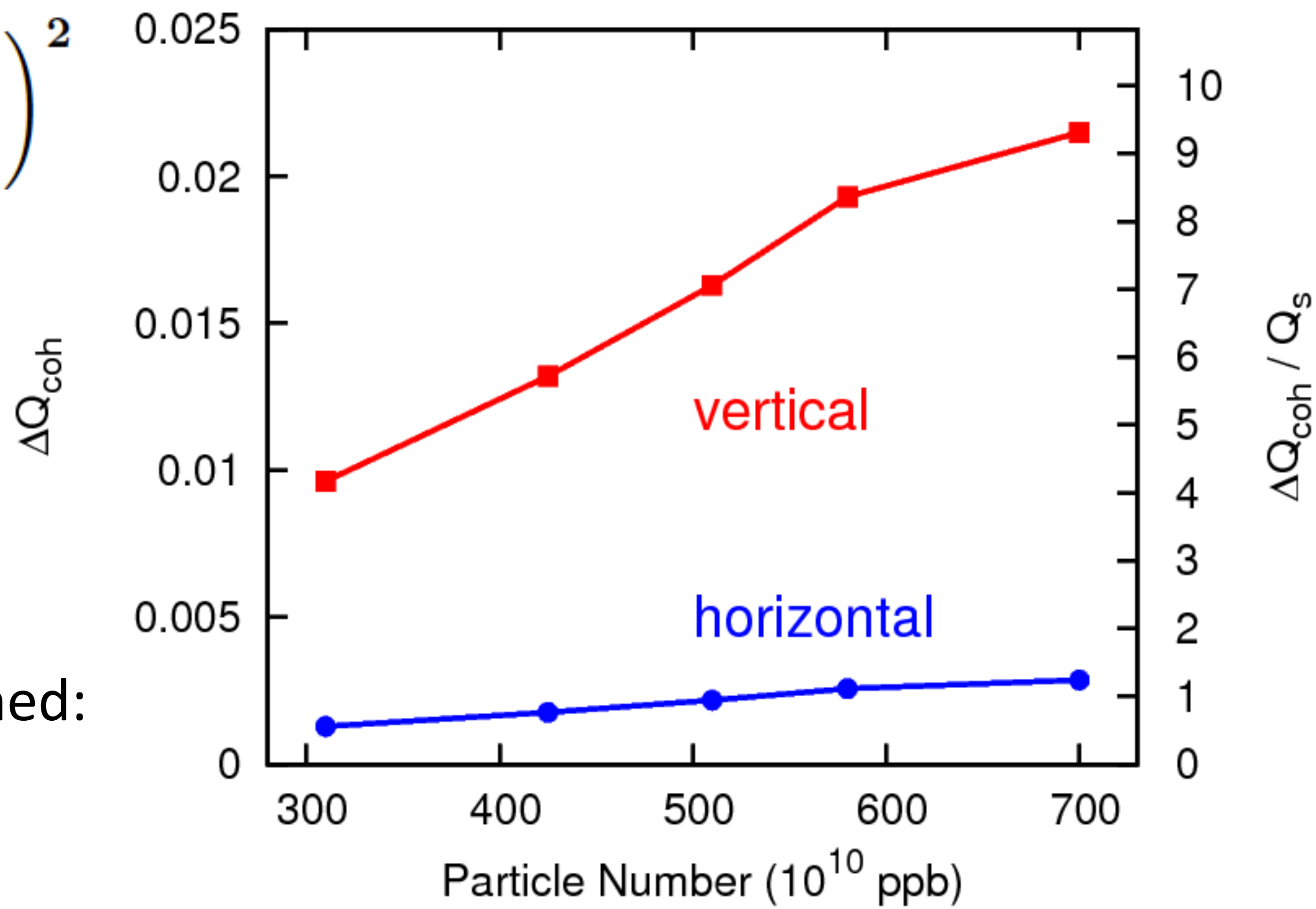
SPACE CHARGE AT THE INJECTION



the space-charge parameter is flat along the intensity;
very strong space charge regime => a minor change not crucial;
no Landau damping for lower-order (k<10) head-tail modes

IMAGE CHARGES

$$\frac{\Delta Q_{\rm coh}}{\Delta Q_{\rm sc}} = \left(\frac{a_{\rm beam}}{b_{\rm pipe}}\right)^2$$



here for the PS vacuum pipe assumed: elliptic,
horizontal h=7cm,
vertical w=3.5cm

SPACE CHARGE & IMAGE CHARGES

the eigenfrequencies of the bunch head-tail modes
for the airbag bunch model
with arbitrary space-charge and coherent force:

$$\Delta Q_k = -\frac{\Delta Q_{\rm sc} + \Delta Q_{\rm coh}}{2} \pm \sqrt{\left(\frac{\Delta Q_{\rm sc} - \Delta Q_{\rm coh}}{2}\right)^2 + k^2 Q_s^2}$$

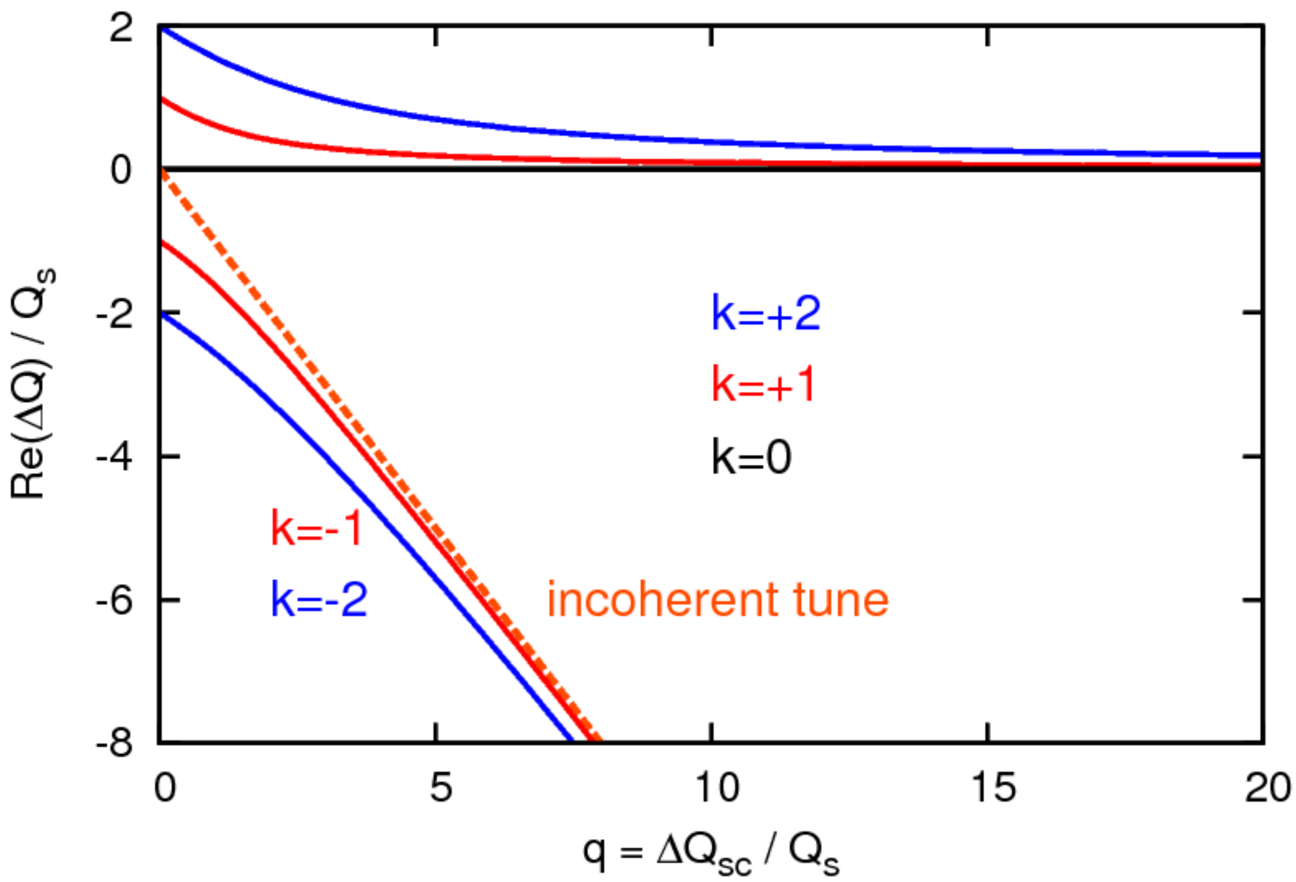
$$\frac{\Delta Q_k}{Q_s} = -\frac{q}{2}\left(1 + \frac{\Delta Q_{\rm coh}}{\Delta Q_{\rm sc}}\right) \pm \sqrt{\frac{q^2}{4}\left(1 - \frac{\Delta Q_{\rm coh}}{\Delta Q_{\rm sc}}\right)^2 + k^2}$$

O.Boine-Frankenheim, V.Kornilov, PRSTAB **12**, 114201 (2009)
V.Kornilov, O.Boine-Frankenheim, PRSTAB **13**, 114201 (2010)
M.Blaskiewicz, PRSTAB **1**, 044202 (1998)

SPACE CHARGE

with space charge only, $\Delta Q_{coh}=0$

the k=0 mode is not affected;
the positive modes close to Q_0;
the negative modes close to the incoherent tune and are strongly damped



SPACE CHARGE & IMAGE CHARGES

with a coherent tune shift,
$\Delta Q_{coh}/\Delta Q_{sc} = 0.1$

the k=0 mode:
$\Delta Q = -\Delta Q_{coh}$
the k>0 modes enter the incoherent spectrum
$-2\Delta Q_{sc} < \Delta Q < 0$
=> Landau damping

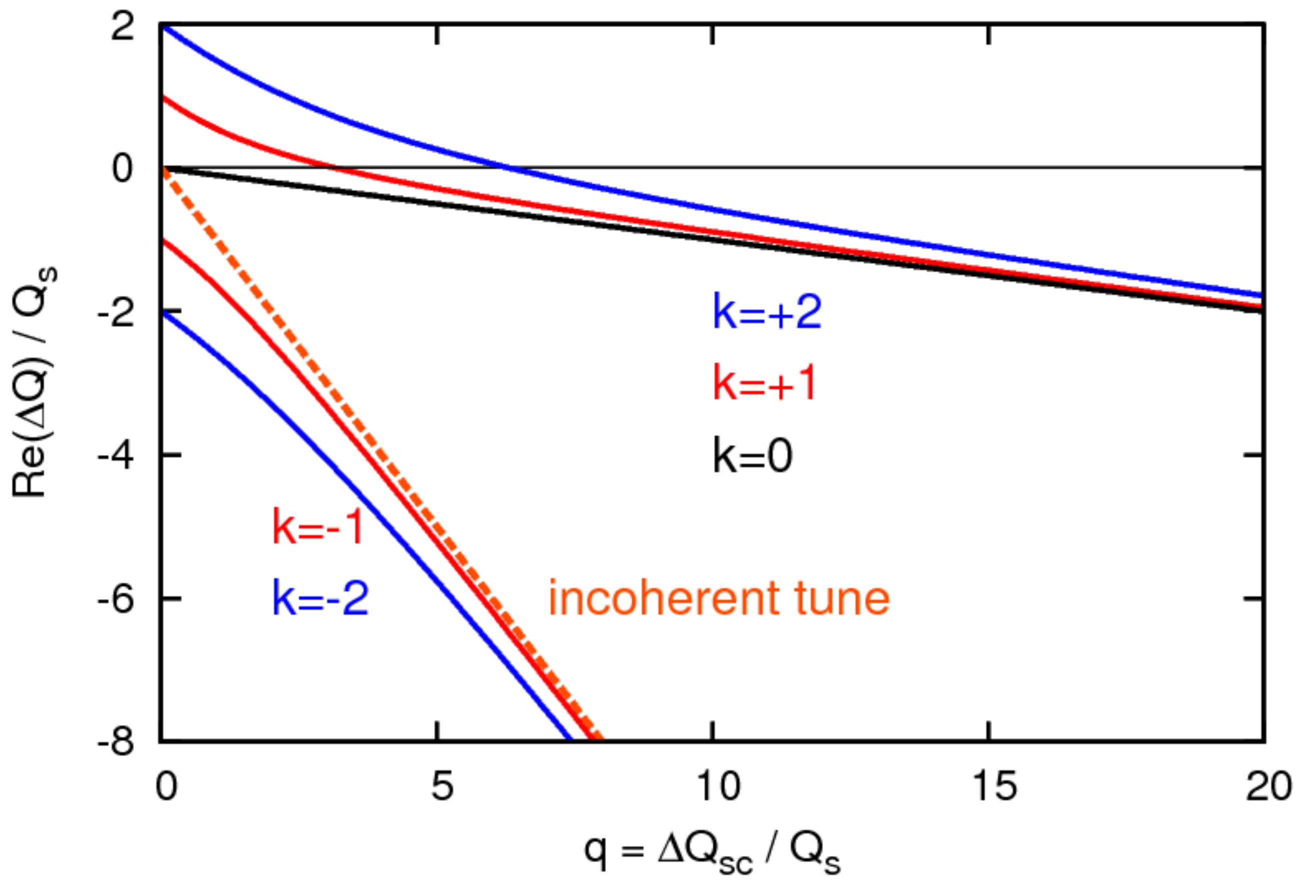
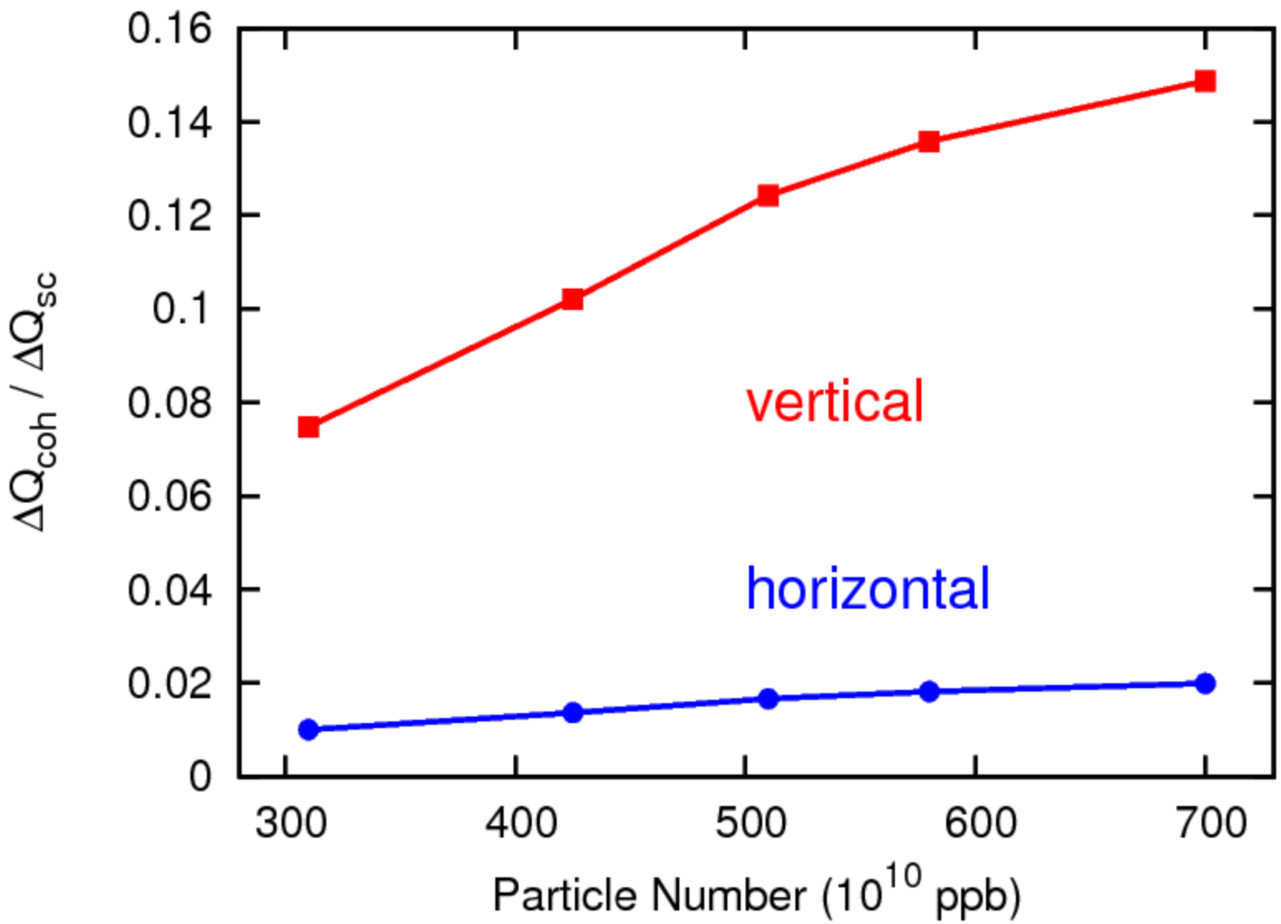
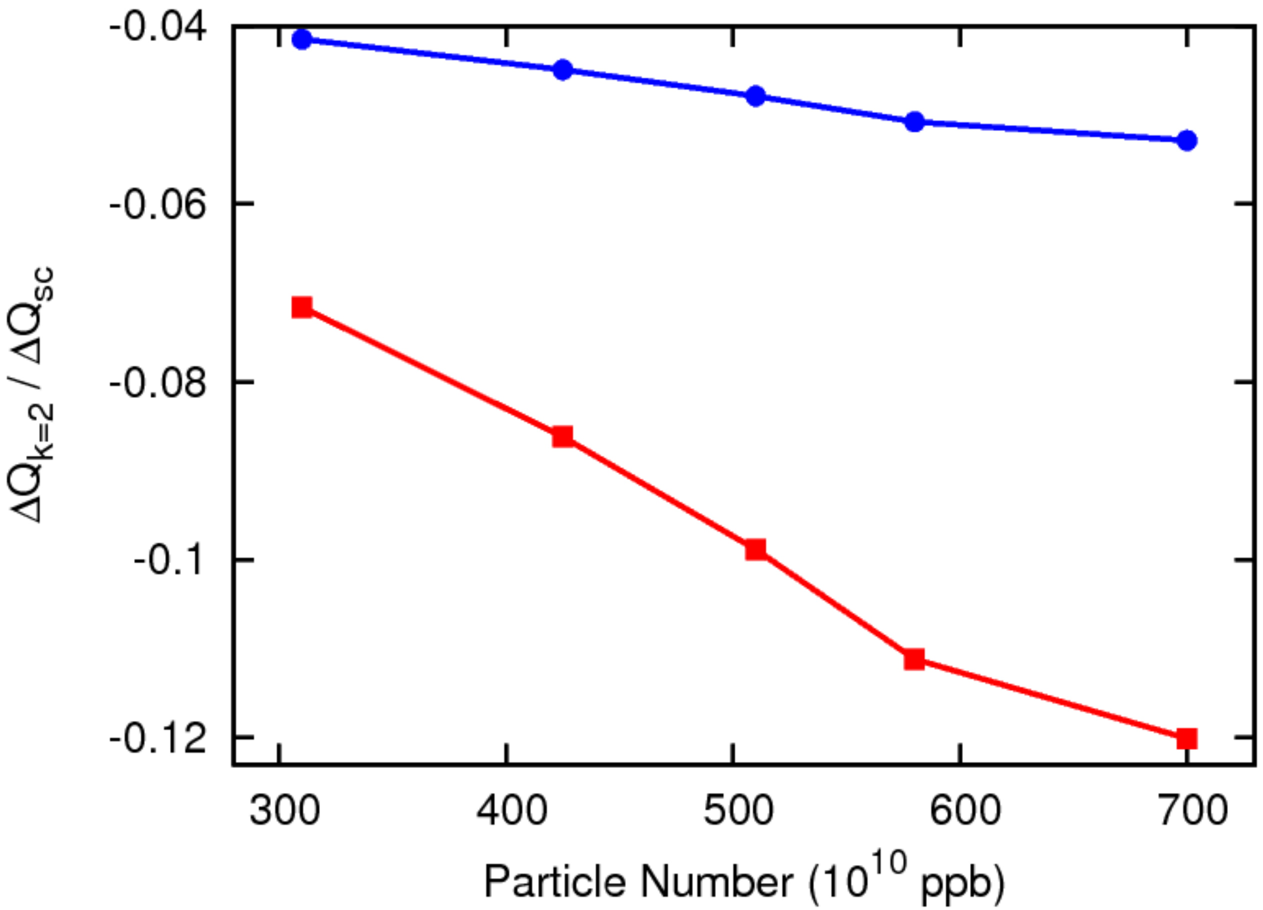


IMAGE CHARGES AT INJECTION



Landau damping is stronger in the vertical plane;
the damping contribution increases with the intensity
This could be the reason for the horizontal exclusiveness and can contribute to the second intensity threshold, together with the coupling

SPACE CHARGE & IMAGE CHARGES

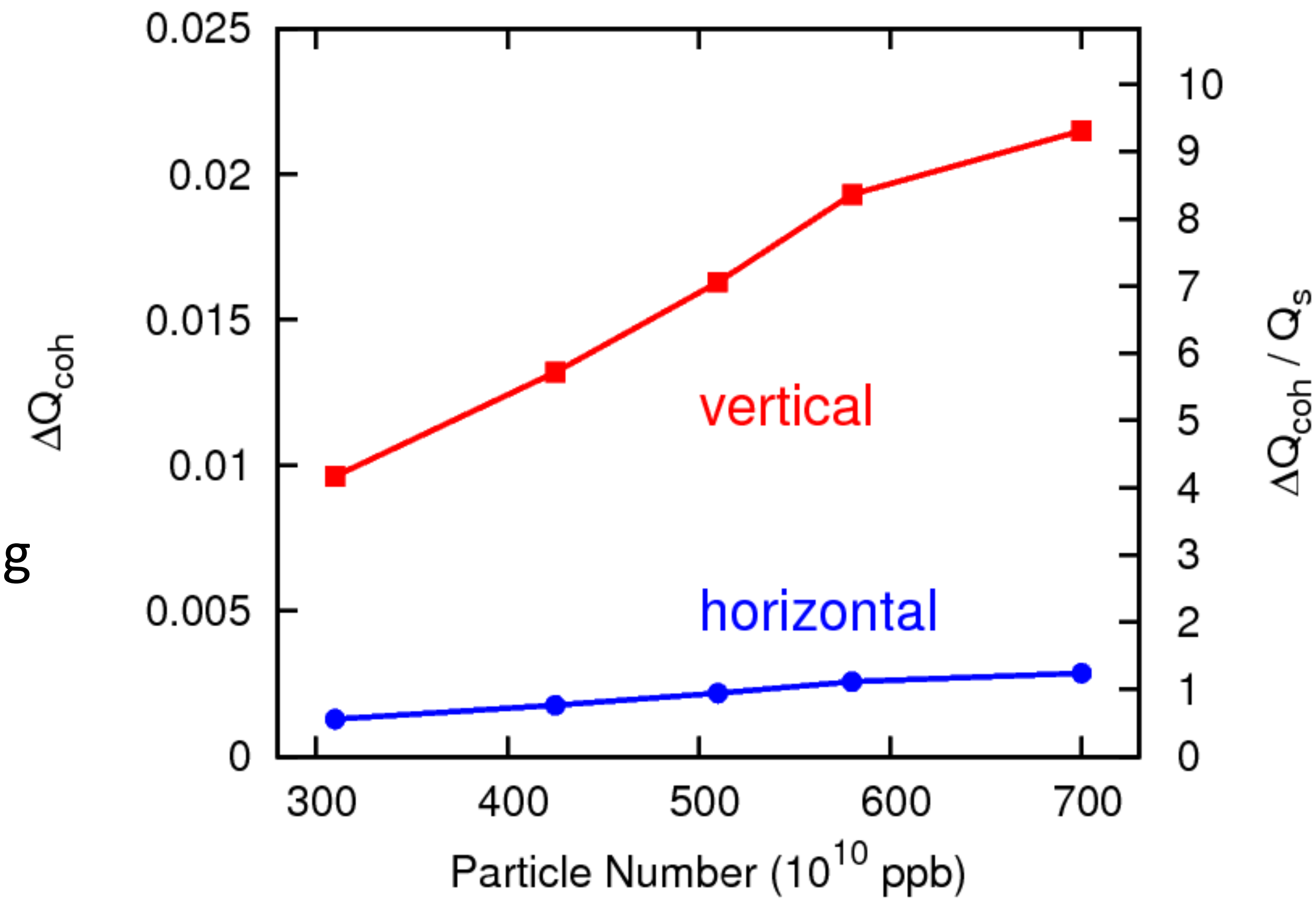


Landau damping is stronger in the vertical plane;
the damping contribution increases with the intensity
This could be the reason for the horizontal exclusiveness and can contribute to the second intensity threshold, together with the coupling

SPACE CHARGE & IMAGE CHARGES

The real ΔQ_{coh} is larger then the synchrotron tune.

Other transverse impedance should cause mode coupling and a fast TMCI. Space-charge tune shifts prevent it?

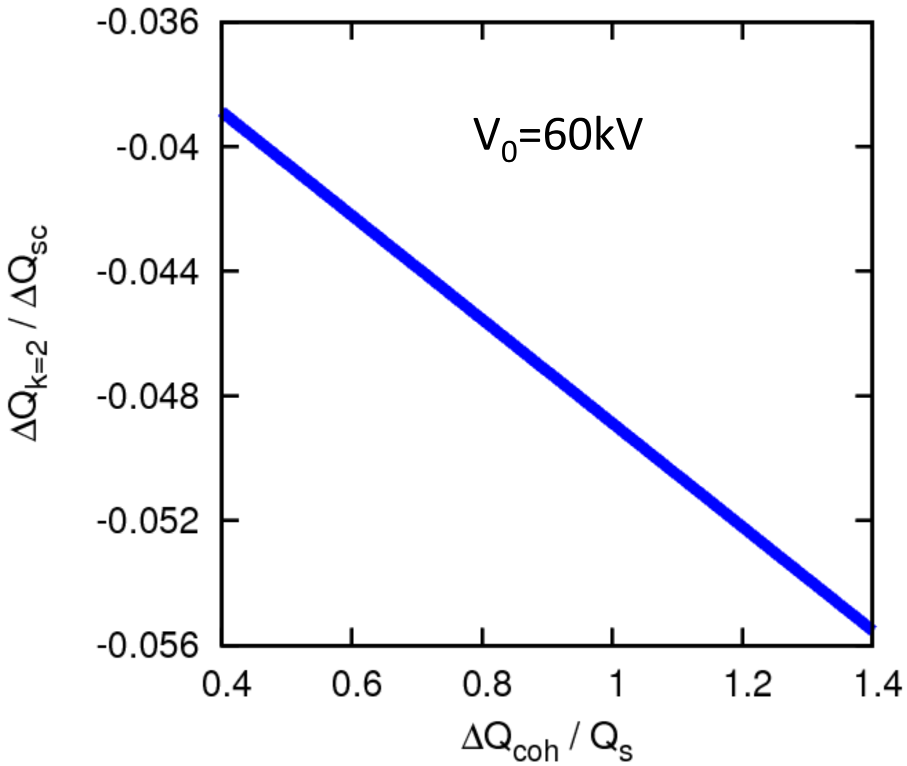


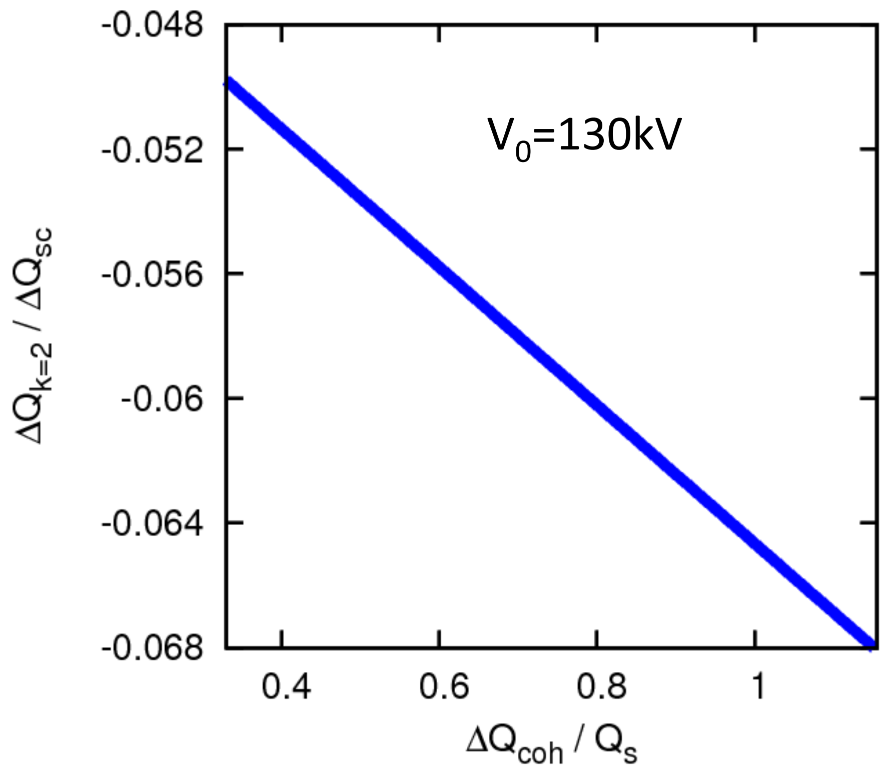
This can be an experimental proof of the mode coupling suppression by space charge

Theory predictions: Blaskiewicz prstab 1998; Burov prstab 2009

RF VOLTAGE RELATED STABILITY

Frequency of k=2 mode in the horizontal plane for different rf voltage





With the higher voltage the Landau damping should be stronger.
But it is not likely to suppress completely the instability.

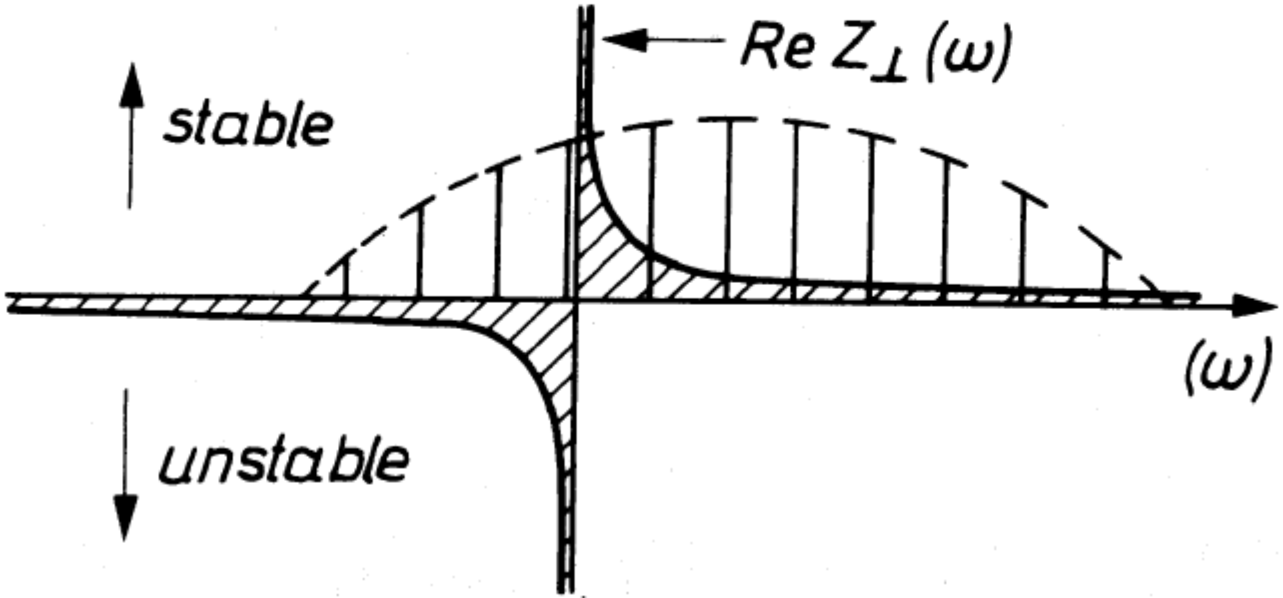
THE HEAD-TAIL INSTABILITY

F.Sacherer 1974

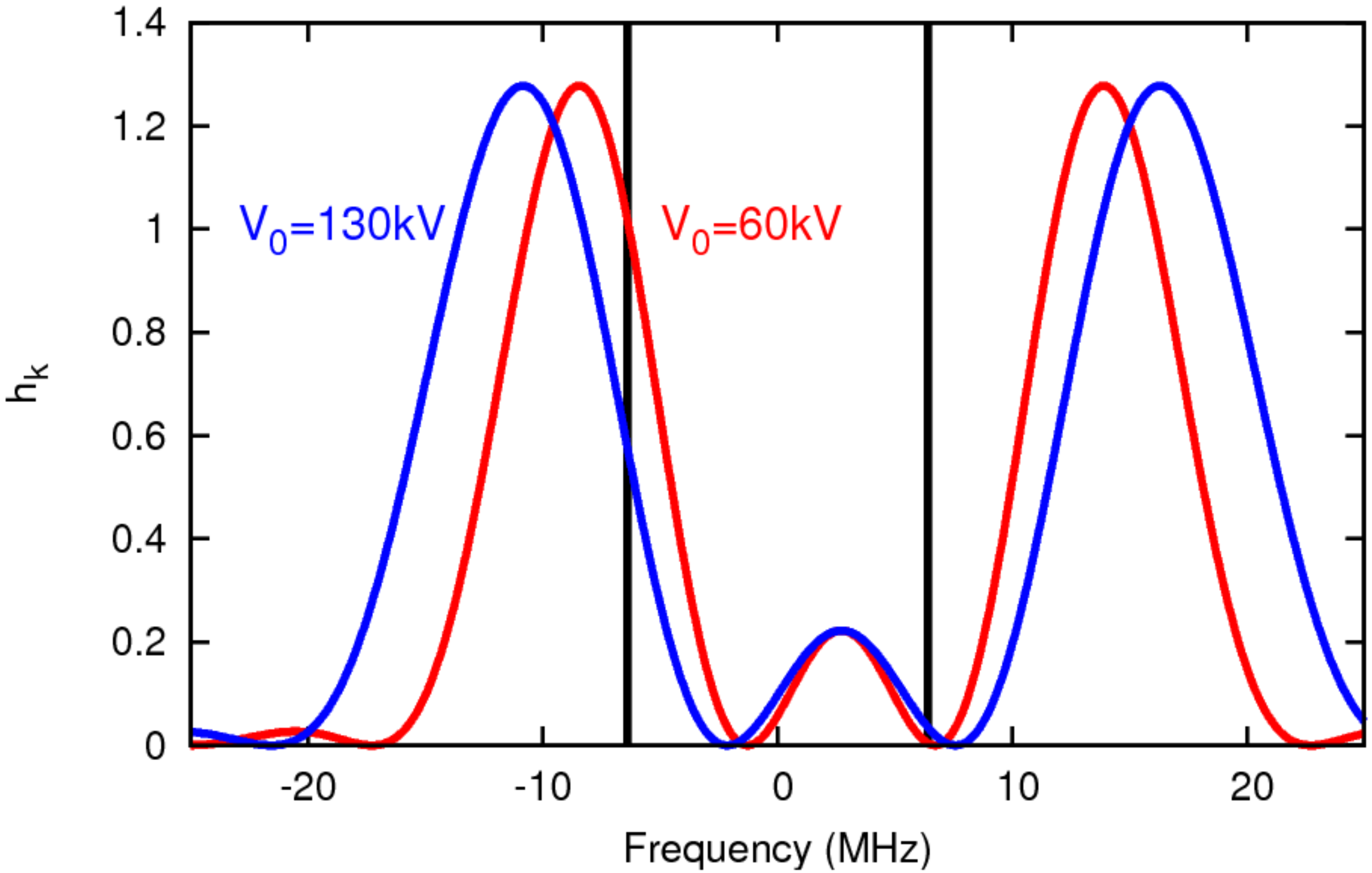
$$\Delta Q_k = \frac{\Upsilon}{1+k} \frac{\sum(-i)Z_\perp(\omega_p)h_k(\omega_p - \omega_\xi)}{\sum h_k(\omega_p - \omega_\xi)}$$

$$\omega_p = (p + Q_0)\omega_0 + k\omega_s$$

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

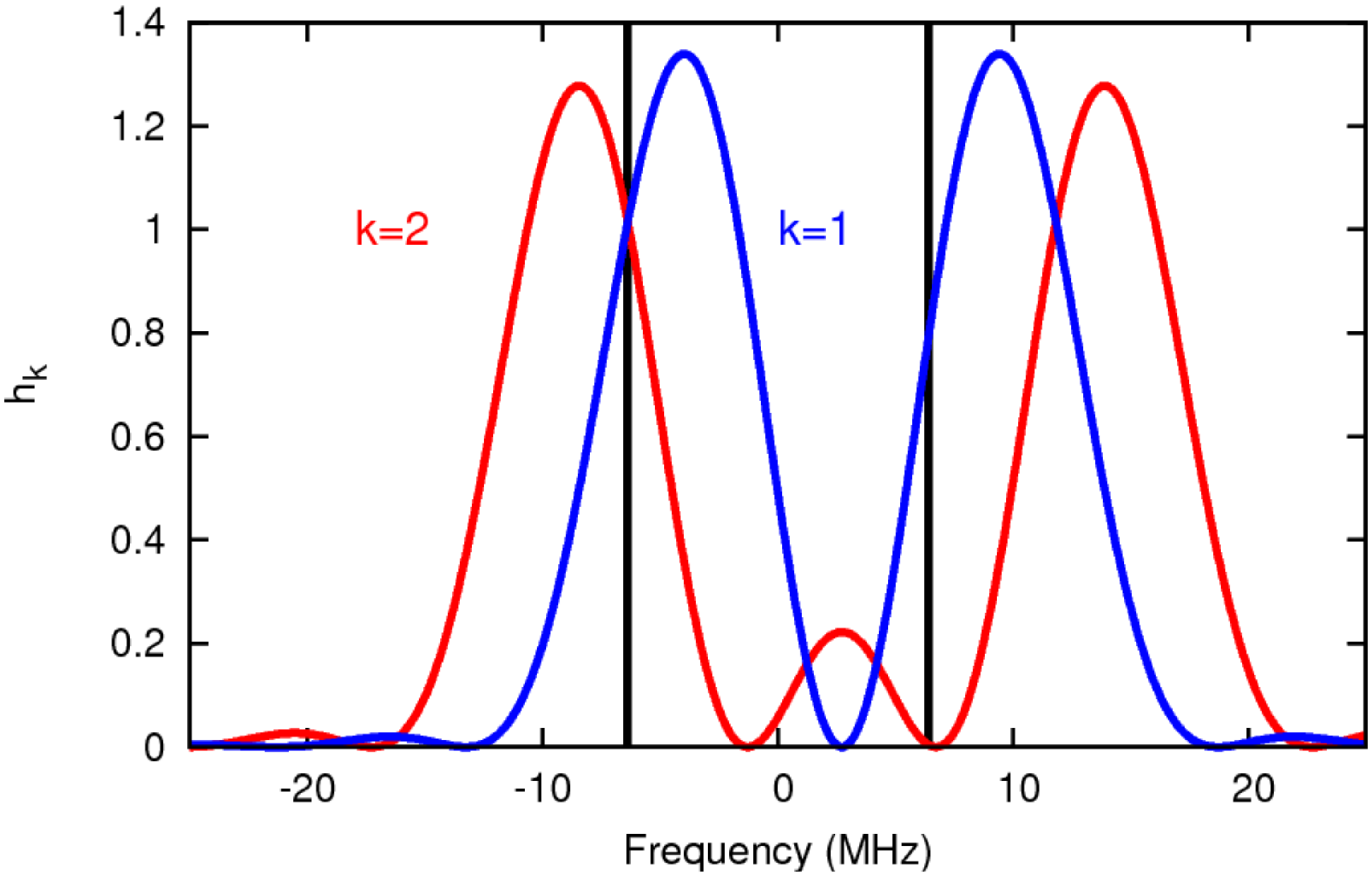


THE BUNCH SPECTRUM



An example: the spectrum of the k=2 mode with
a narrowband impedance at 6.4MHz.
With V_0=60kV the growth rate is higher.

THE BUNCH SPECTRUM



An example: the spectrum for V_0=60kV with a narrowband impedance at 6.4MHz. For the *k*=2 mode the growth rate is higher.

CONCLUSIONS HEAD-TAIL

A classical unstable head-tail mode k=2 is observed at the PS injection plateau

The PS bunches are in the strong space-charge regime

The Landau damping due to image charges in the combination with the direct space charge may be the reason for the horizontal instability and can contribute to the second threshold (together with the coupling)

A narrowband impedance around 6MHz as a driving force may explain the observation of the k=2 mode and can contribute to the better stability at higher rf voltages