ACTIVE AND PASSIVE MITIGATION OF COLLECTIVE INSTABILITIES

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WP SIS100 Beam Dynamics

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SIS100BD

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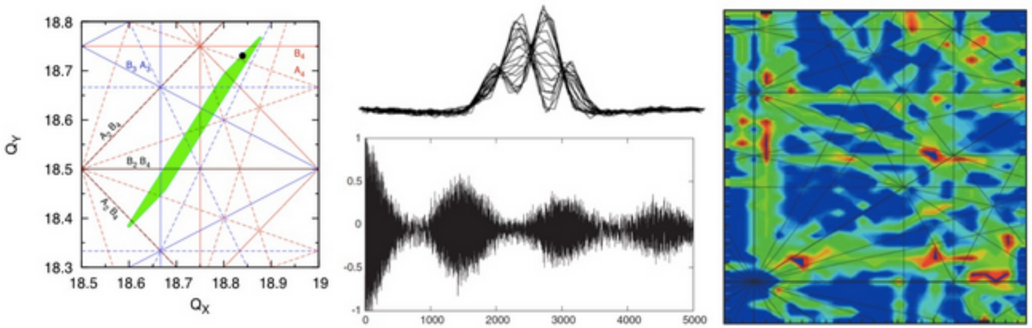
Welcome to the SIS100BD web

SIS100 Beam Dynamics



Available Information

- Present Tasks and Actions
- Sub-topics in SIS100 Beam Dynamics
- Project Meetings: Minutes, Slides
- Machine Advisory Committee (MAC) Talks
- Reports

SIS100BD Web Utilities

WP SIS100 Beam Dynamics

Beam Dynamics studies in SIS18

Necessary to achieve the design performance of SIS18

Important for the preparation of SIS100 operation

Collective Beam Dynamics
similarly applicable to SIS18↔SIS100:

- driving mechanisms and sources (impedances)
- effect of space-charge on drive and Landau damping
- high-intensity effects on diagnostics (Schottky, BTF)
- collective effects in the slow extraction
- 2rf, 1rf
- code development

Dual-RF (2RF) Bucket

Basic consideration of a passive/active mitigation

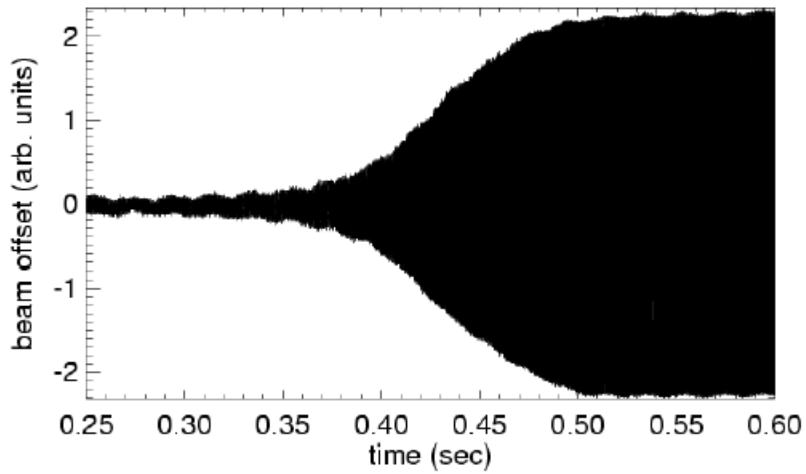
$$\Delta\Omega = \Delta\Omega_{\mathrm{Re}} + i\gamma_{\mathrm{drive}} + i\gamma_{\mathrm{damping}}$$

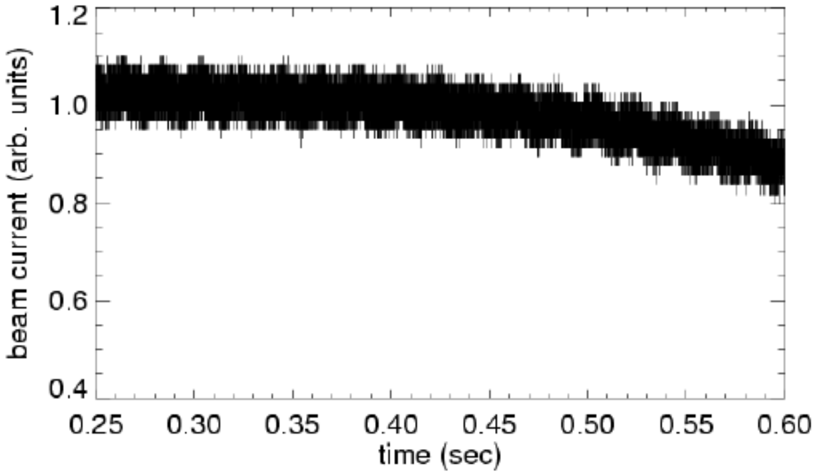
change the parameters and the source of the driving mechanism

use and enhance the damping mechanisms

$\gamma_{\mathrm{drive}} + \gamma_{\mathrm{damping}}$	$>$	0	Instability
$\gamma_{\mathrm{drive}} + \gamma_{\mathrm{damping}}$	$<$	0	Stabilized mode
γ_{drive}	$>$	0	Driven (unsuppressed) mode
γ_{drive}	$<$	0	Mode suppressed by its drive

Transverse Instability in SIS18

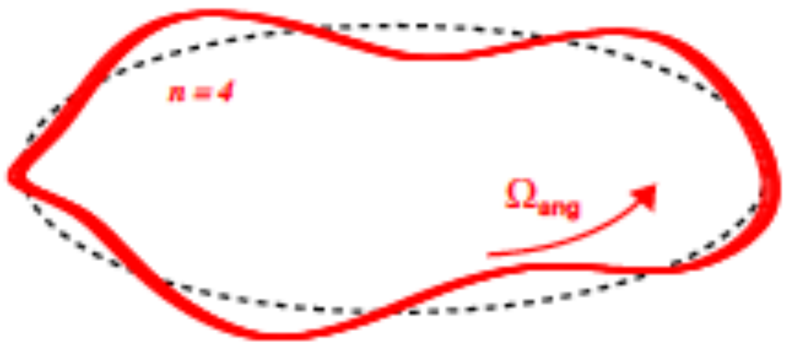


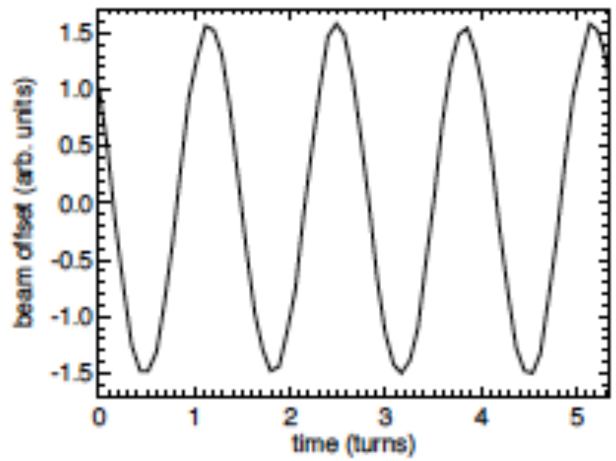


τ=38ms, at 160kHz

V.Kornilov, GSI ACC-Note-2009-008

Coasting Beam Instability

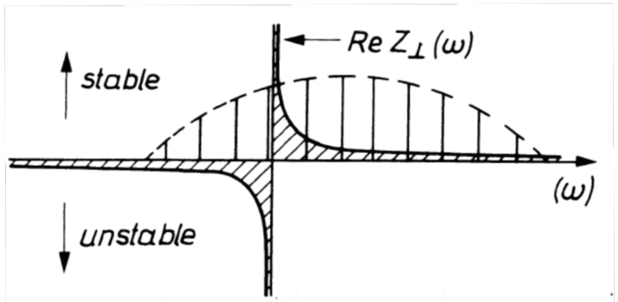


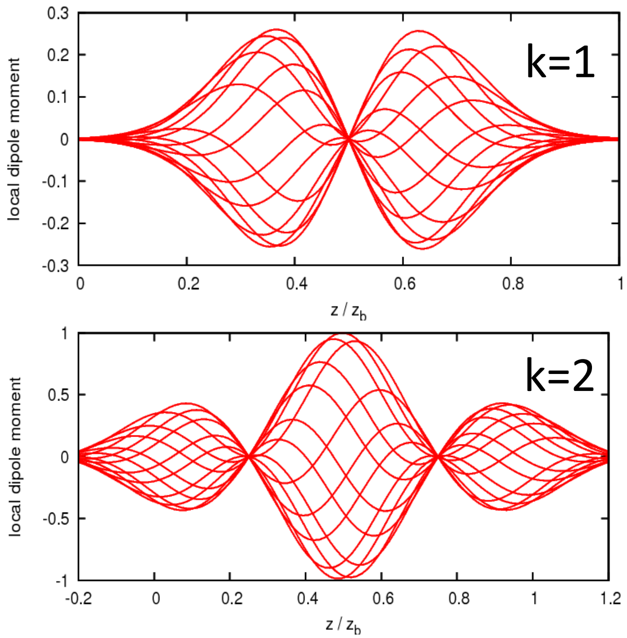


Head-Tail Instability

The standard approach of F. Sacherer 1974

$$
\begin{aligned}
\Delta Q_k &= \frac{\Upsilon}{1+k}\frac{\sum(-i)Z_\perp(\omega_p)h_k(\omega_p-\omega_\xi)}{\sum h_k(\omega_p-\omega_\xi)} \\
\omega_p &= (p+Q_0)\omega_0 + k\omega_s \\
\Upsilon &= \frac{I_0 q_{\text{ion}}}{4\pi\gamma m c Q_0 \omega_0} \qquad \omega_\xi = \frac{Q_0\xi}{\eta}\omega_0
\end{aligned}
$$



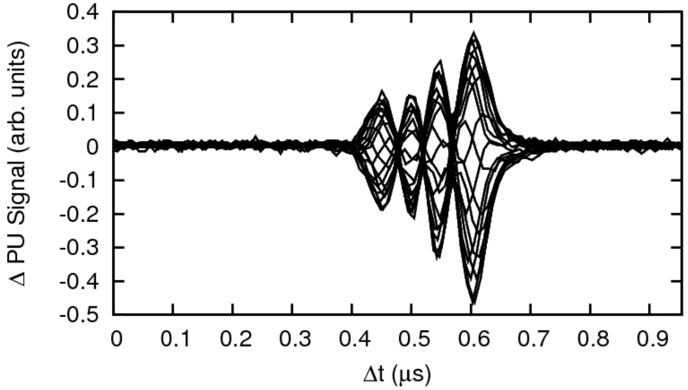


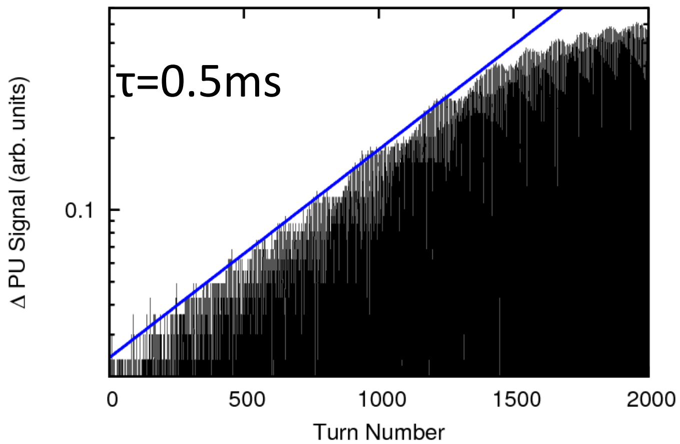
Does not include effects of space-charge, 2RF, strong wakes,…

Landau damping is decisive for the resulting stability/instability

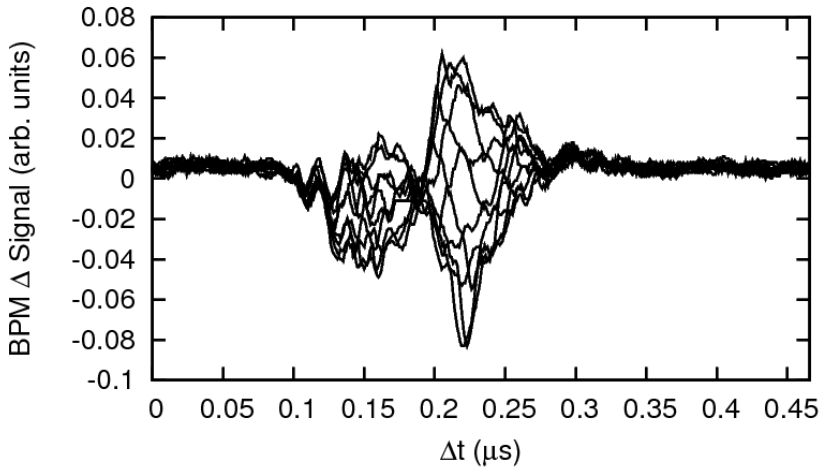
Head-Tail Instability

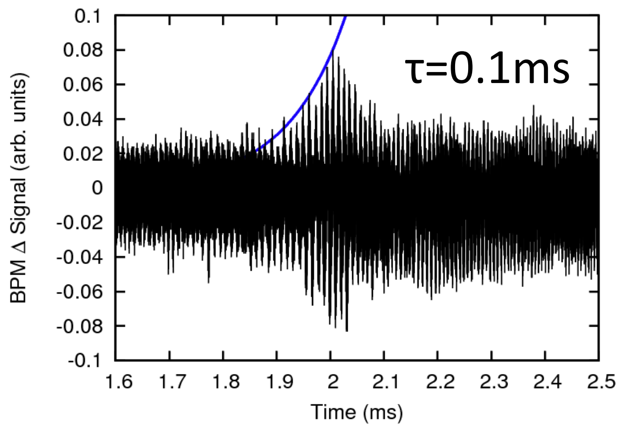
PS Booster at CERN





ISIS Synchrotron at RAL





Many observations in different rings could not be explained by the Sacherer theory. Puzzles about growth time, mode index, drive…

Head-Tail Instability

Beam time in SIS18:

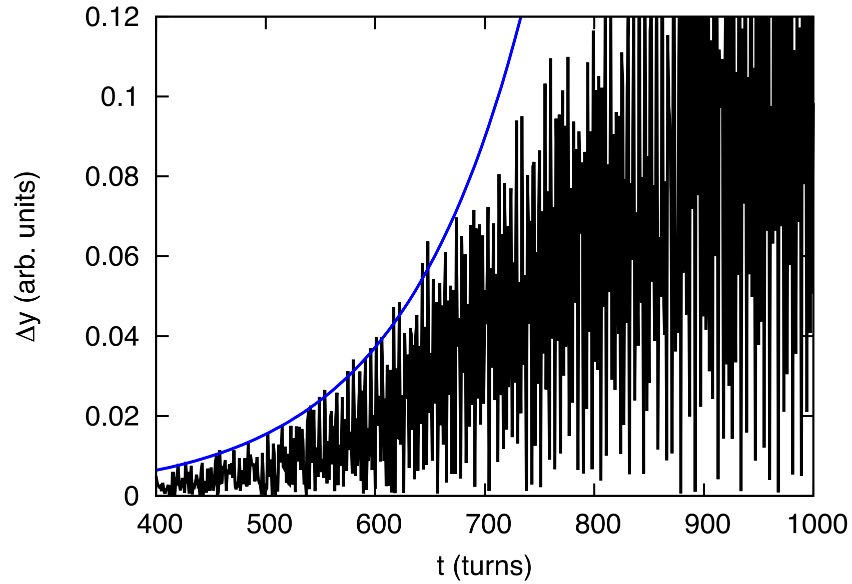
For tunes above $Q_y \approx 3.79$:
strong collective oscillations,
fast beam loss

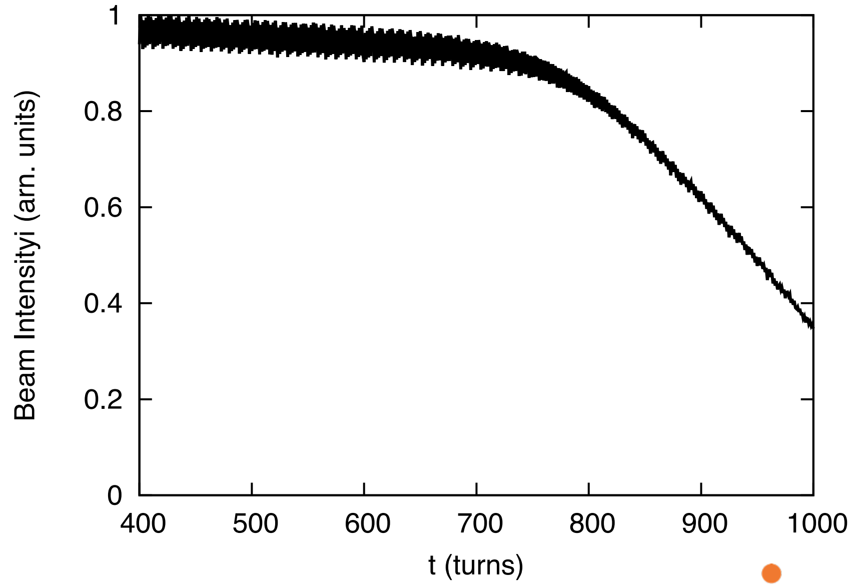
exponential growth with
$\tau = 0.11$ ms

$$A(t) = A_0 \exp\left\{\frac{t}{\tau}\right\}$$

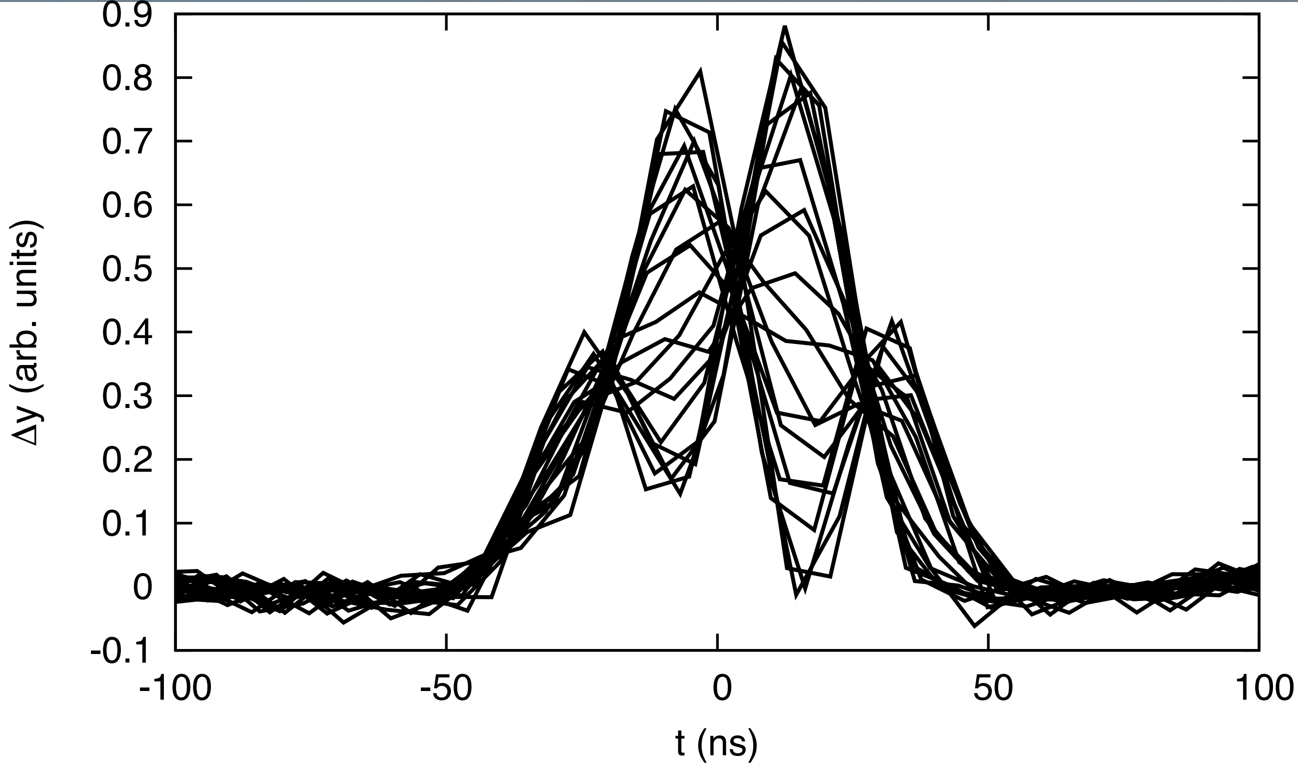
1 turn = 0.989 us

Kornilov, 2016, 2014





Head-Tail Instability

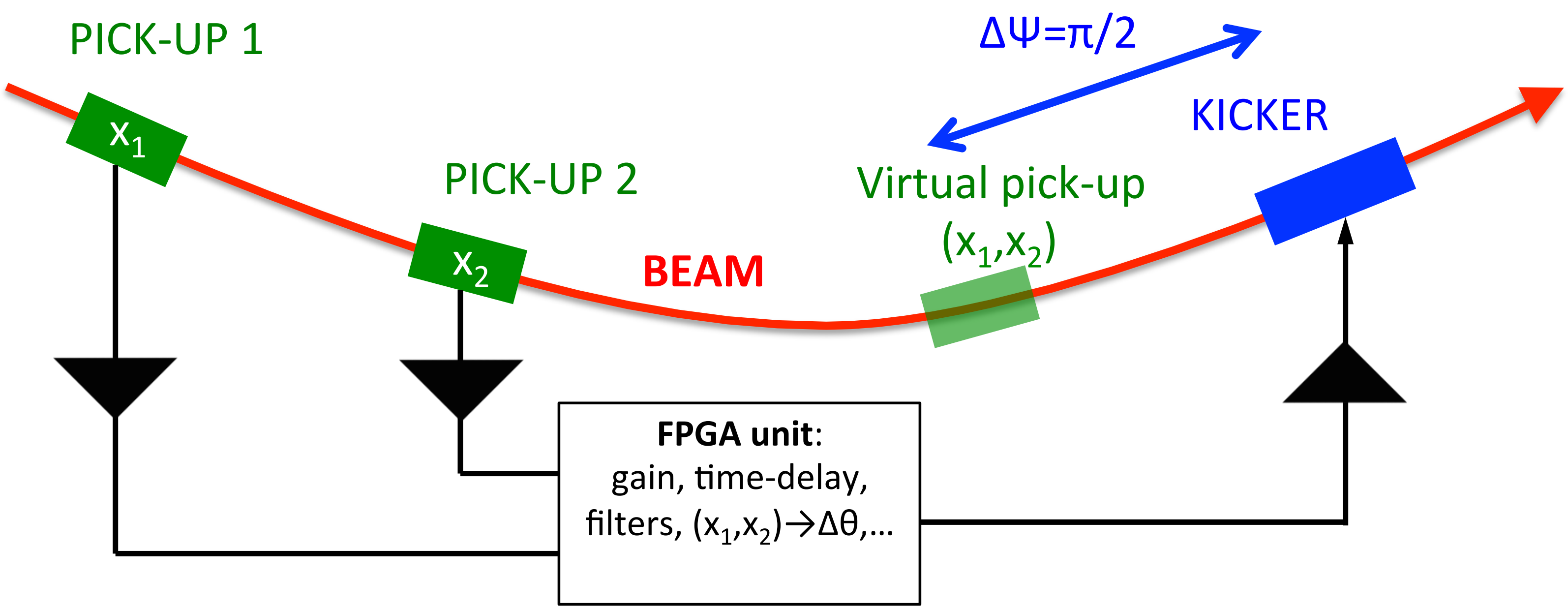


Head-Tail instability in SIS18
k=3 mode

- development of Transverse Feedback System for SIS18 and SIS100
- design of an octupole magnet set for SIS18 (role of space charge)
- understanding the impedances in SIS18 → SIS100

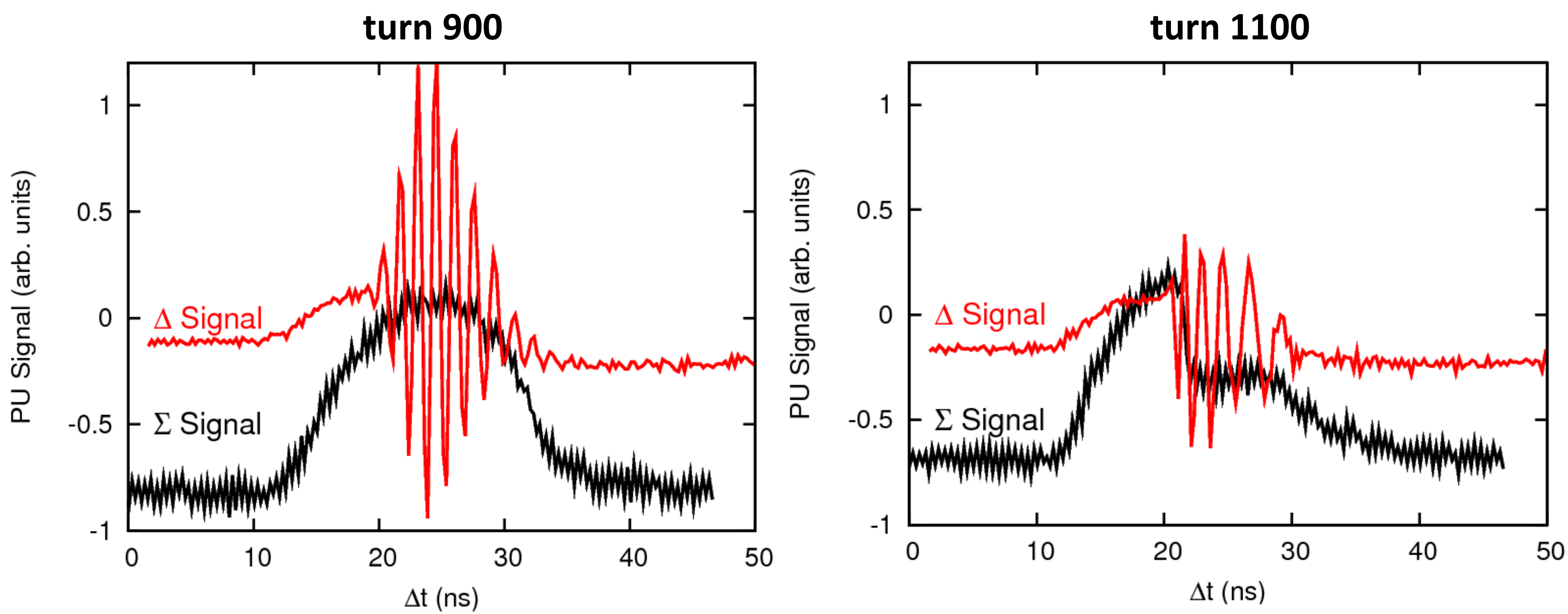
Transverse Feedback Systems

- no experience with a feedback system in SIS18
- use the experience from PS Booster and PS for the specifications of TFS in SIS100
- essential: broadband system (multisampling)
- focus on the function as an injection error damper



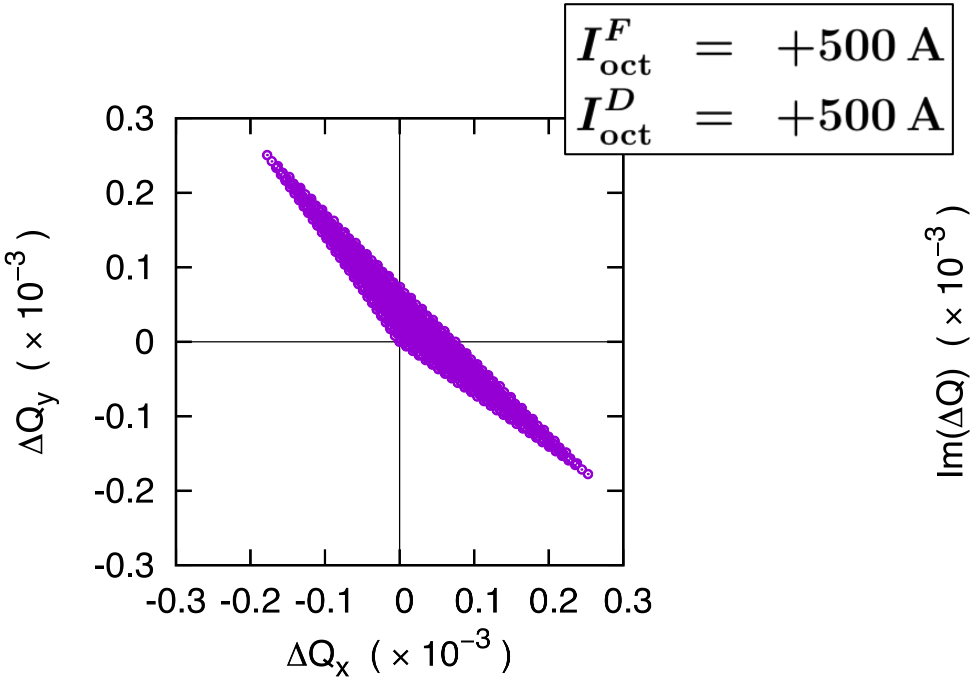
Transverse Instabilities

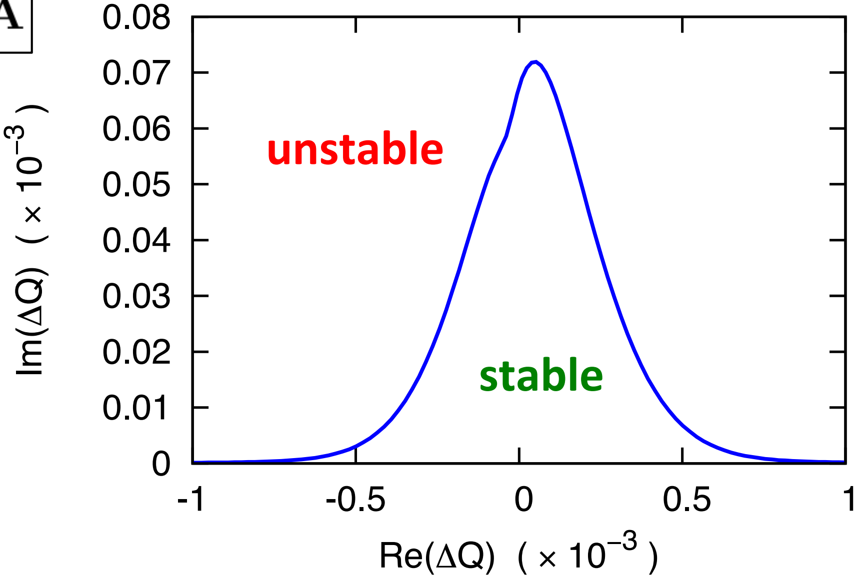
There are instabilities which can not be cured by a feedback.
Only a passive mitigation can help.



Beam Break-Up Instability at PS close to the transition

Passive Mitigation: Octupoles





$$
\begin{aligned}
\Delta Q_x &= \left\{\frac{3}{8\pi}\sum \hat{\beta}_x^2 \frac{O_3 L_m}{B\rho}\right\} J_x - \left\{\frac{3}{8\pi}\sum 2\hat{\beta}_x\hat{\beta}_y \frac{O_3 L_m}{B\rho}\right\} J_y \\
\Delta Q_y &= \left\{\frac{3}{8\pi}\sum \hat{\beta}_y^2 \frac{O_3 L_m}{B\rho}\right\} J_y - \left\{\frac{3}{8\pi}\sum 2\hat{\beta}_x\hat{\beta}_y \frac{O_3 L_m}{B\rho}\right\} J_x
\end{aligned}
$$

V.Kornilov,
FCC Week 2016,

Tune spread provides Landau damping

Passive Mitigation: Octupoles

L.Laslett, V.Neil, A.Sessler, 1965
D.Möhl, H.Schönauer, 1974
J.Berg, F.Ruggiero, CERN SL-96-71 AP 1996

$$\Delta Q_{\mathrm{coh}} \int \frac{1}{\Delta Q_{\mathrm{oct}} - \Omega/\omega_0} J_x \frac{\partial \psi_\perp}{\partial J_x} dJ_x dJ_y = 1$$

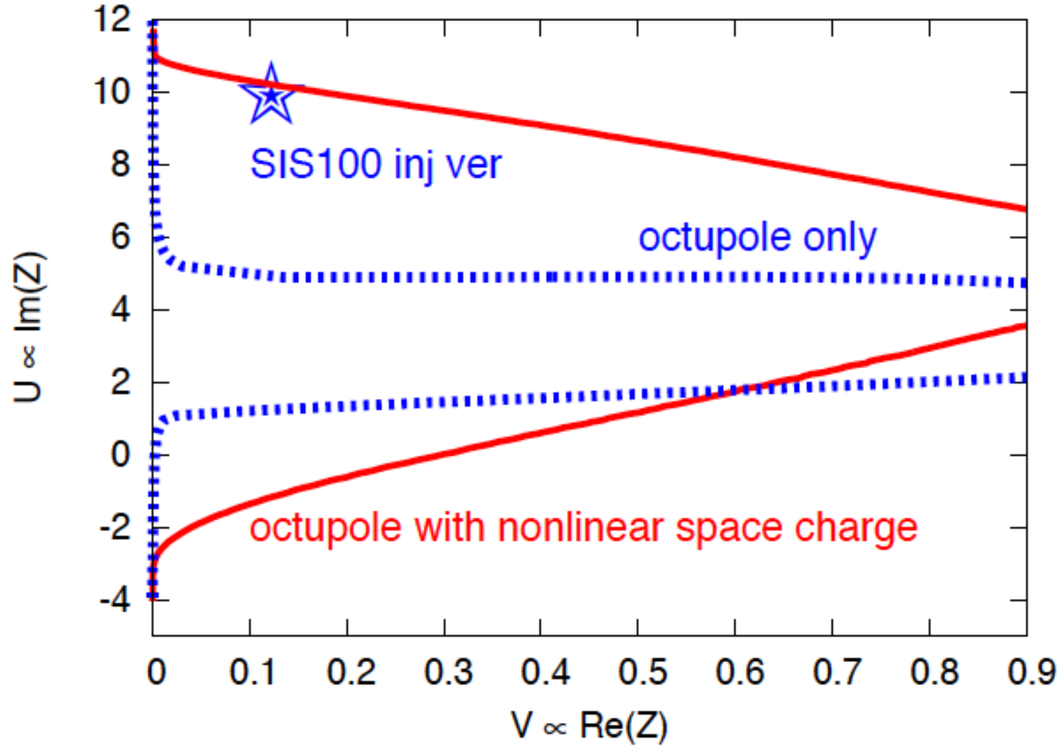
complex coherent tune shift for the beam without damping

The solution: collective mode frequency Ω for the given impedance and beam

The resulting damping is a complicated 2D convolution of the distribution $\{d\psi/dJ_x,\ \psi(J_y)\}$ and tune shifts $\Delta Q_{\mathrm{oct}}(J_x,J_y)$

This is a 2D approach for the k=0 mode
We need to understand damping for high-order modes

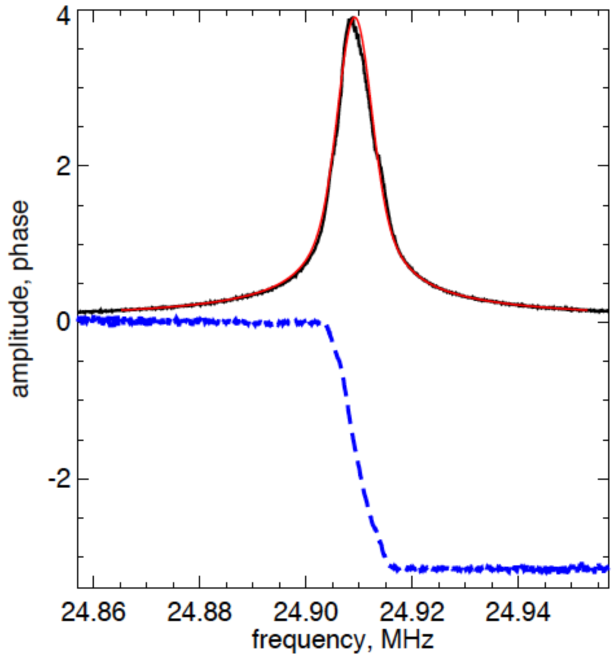
Passive Mitigation: Octupoles

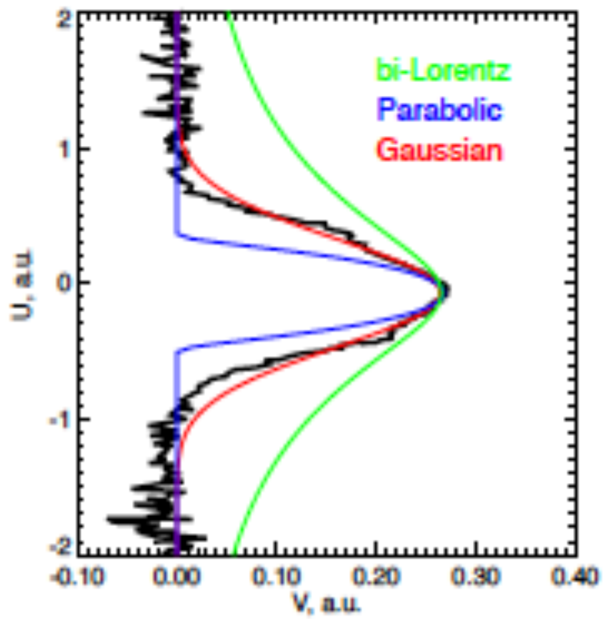


In the case of SIS100/SIS18,
space-charge modifies Landau damping

Beam Transfer Function

BTF can be measured with a network analyser.
Example here: the beam responses exactly as the theory for Gaussian beams.





Measurement in SIS18 at GSI Darmstadt, U^{73+} at 500 MeV/u, slow freq sweep (6sec) , m=24, m=50.
V. Kornilov, et.al., Measurements and Analysis of the Transverse Beam Transfer Function (BTF) at the SIS 18 Synchrotron, GSI-Acc-Note-2006-12-001, GSI Darmstadt (2006)

Beam Transfer Function

BTF in COSY

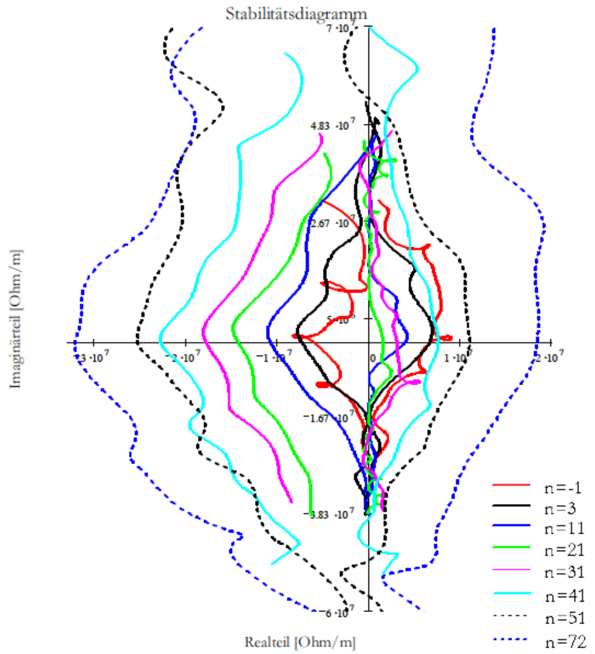
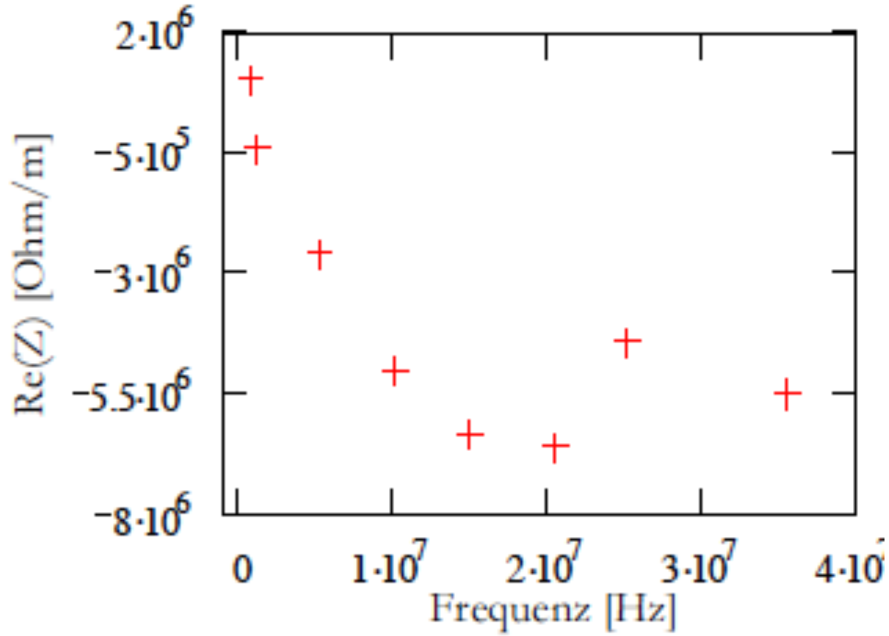


Abbildung 25: Stabilitätsdiagramm eines ungekühlten Protonenstrahls in der horizontalen Ebene für unterschiedliche Harmonische n.

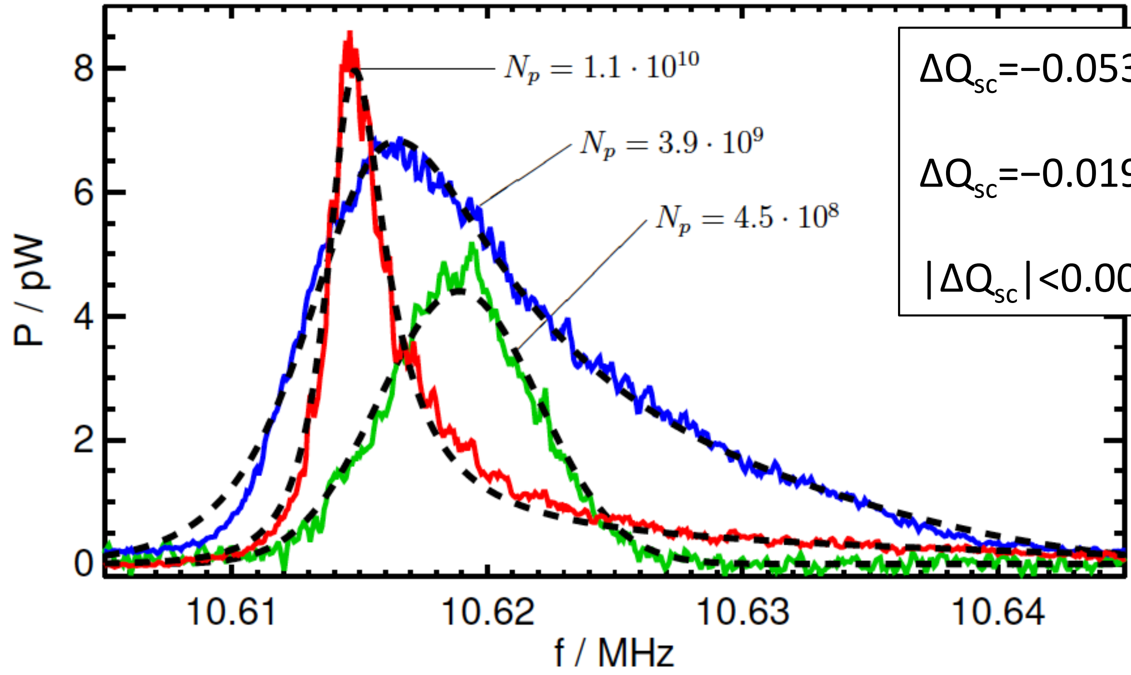


V.Kamerdzhiev, Diss. Dortmund Univ., 2003

Horizontal Impedance

Schottky Signals at High Intensity

Delta Schottky side-bands in a coasting beam

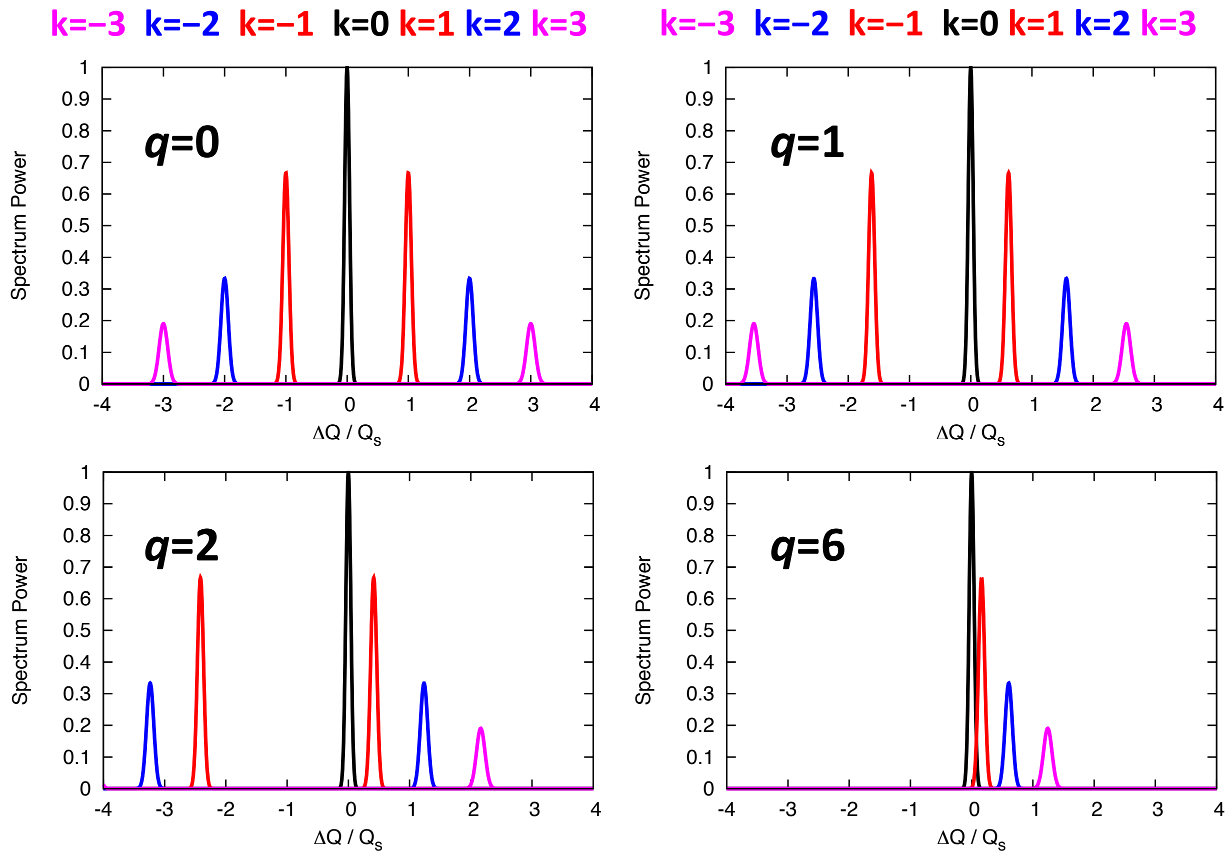


ΔQ_{sc}=−0.053	δ_p=0.78×10^{-3}
ΔQ_{sc}=−0.019	δ_p=0.67×10^{-3}
$\lvert\Delta Q_{sc}\rvert$<0.002	δ_p=0.28×10^{-3}

Lower sidebands for m=50, Ar^{18+} beams in SIS18 at GSI, f_0=214 kHz
S.Paret, V.Kornilov, O.Boine-Frankenheim, PRSTAB 13, 022802 (2010)

From the sideband deformation and shift,
the space-charge tune shift and/or the impedance can be determined

Space Charge in Bunches

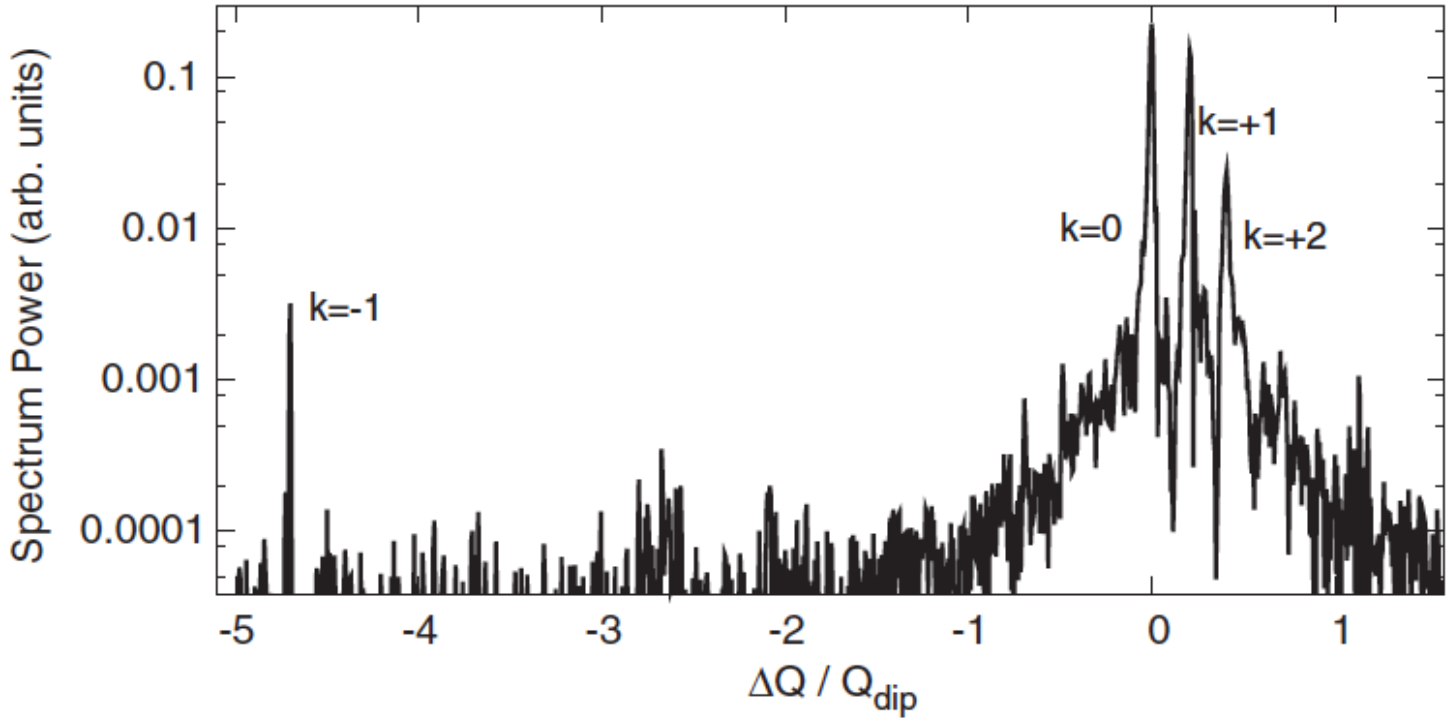


$$q = -\frac{\Delta Q_{\rm sc}}{Q_s}$$

Spectra of the bunch trasnverse oscillations are affetced by space charge.
Well understood in theory and simulations

Space Charge in Bunches

The space-charge tune shifts of the lines in the bunch spectrum can also be measured in experiment



Ar^{18+} bunches in SIS18 at GSI Darmstadt, Q_s=0.0032, q=4.5
V.Kornilov, O.Boine-Frankenheim, PRSTAB 15, 114201 (2012)

Decoherence

Beam time in SIS18:

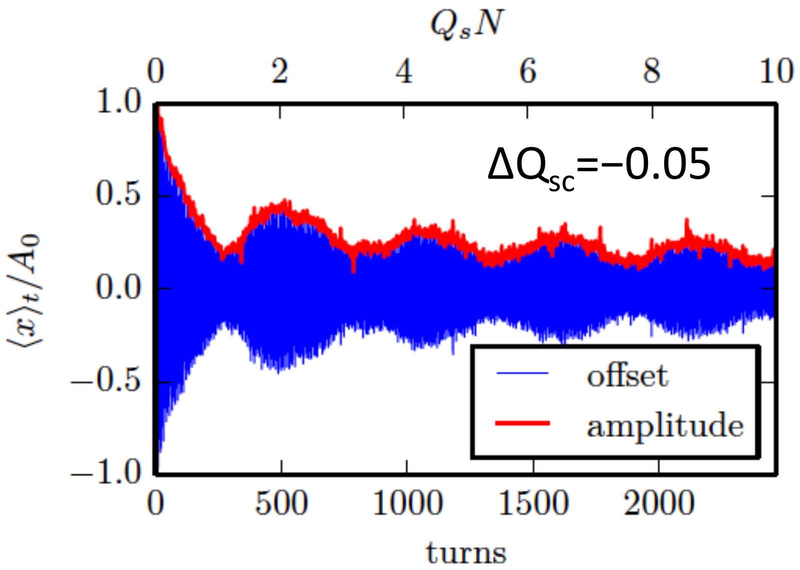
transverse bunch kick (4mm)

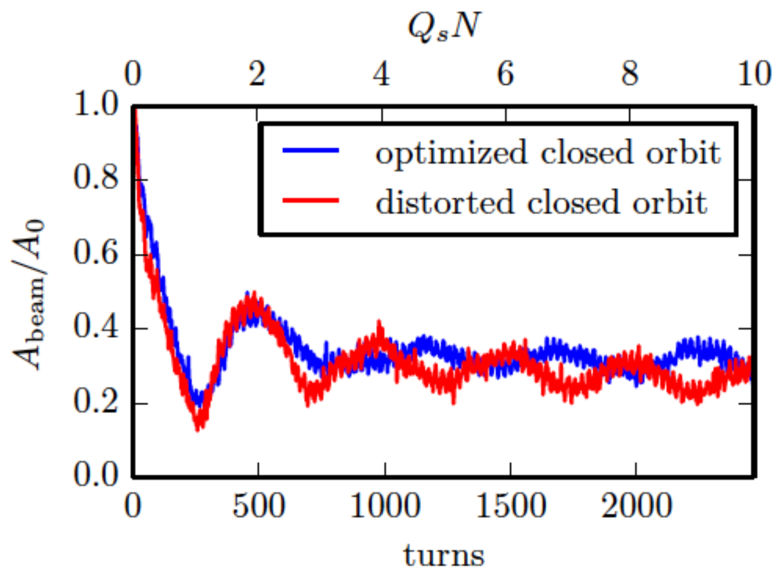
the resulting collective oscillations are defined by chromaticity, space charge

sensitive to nonlinearities.
SIS18 is a quite linear machine,
good magnets.

MD Kornilov, Karpov, 2016, 2014
PhD Karpov 2016

- diagnostics method
- development of TFS for SIS100, as the damper of the injection mismatch



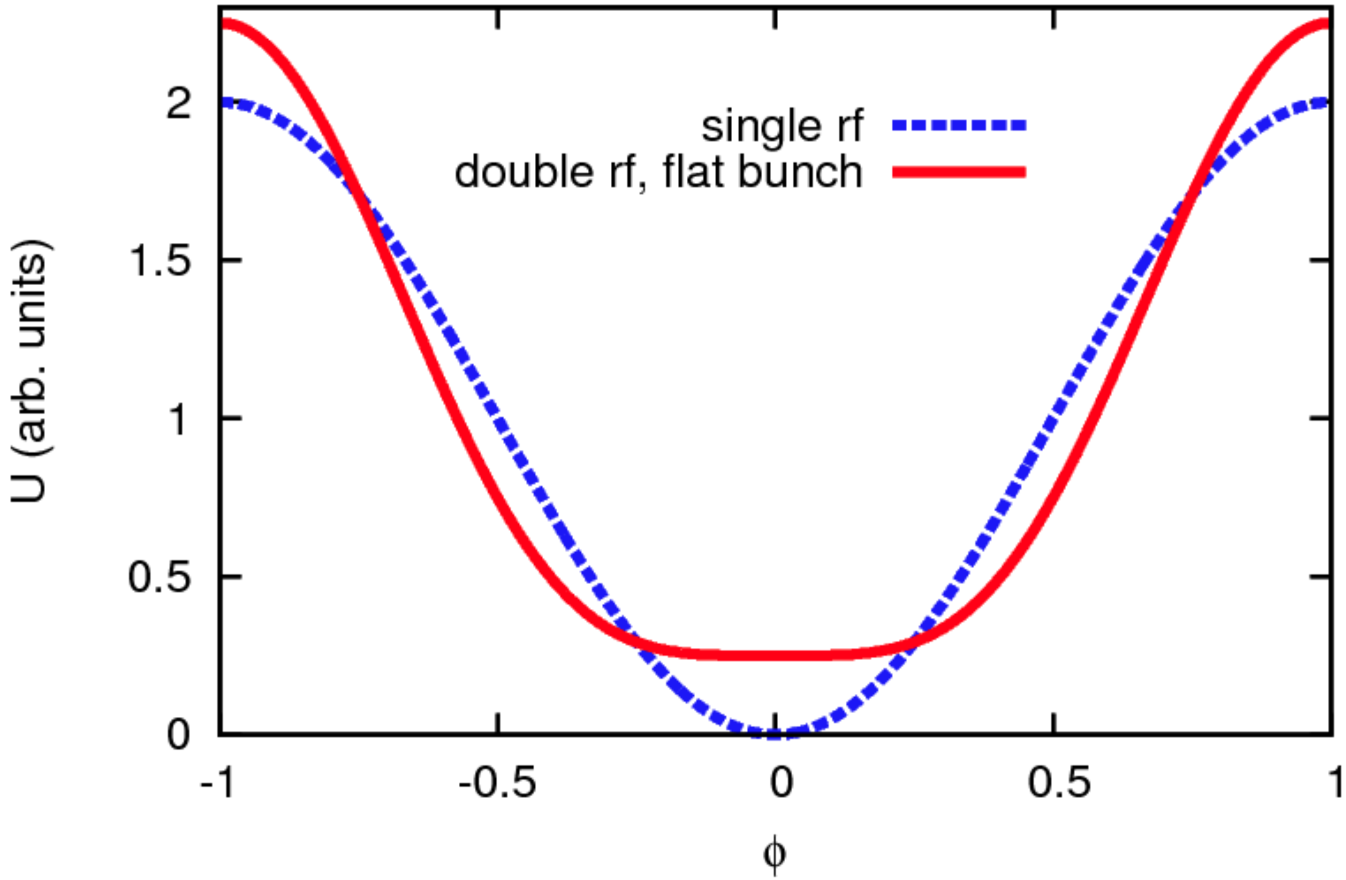


Dual-RF (2RF) Bucket

double rf,
flat bunch

basic cavity h, the 2h cavity is shifted by π, half the voltage.

Potential gain: weaker space charge, more Landau damping, less losses



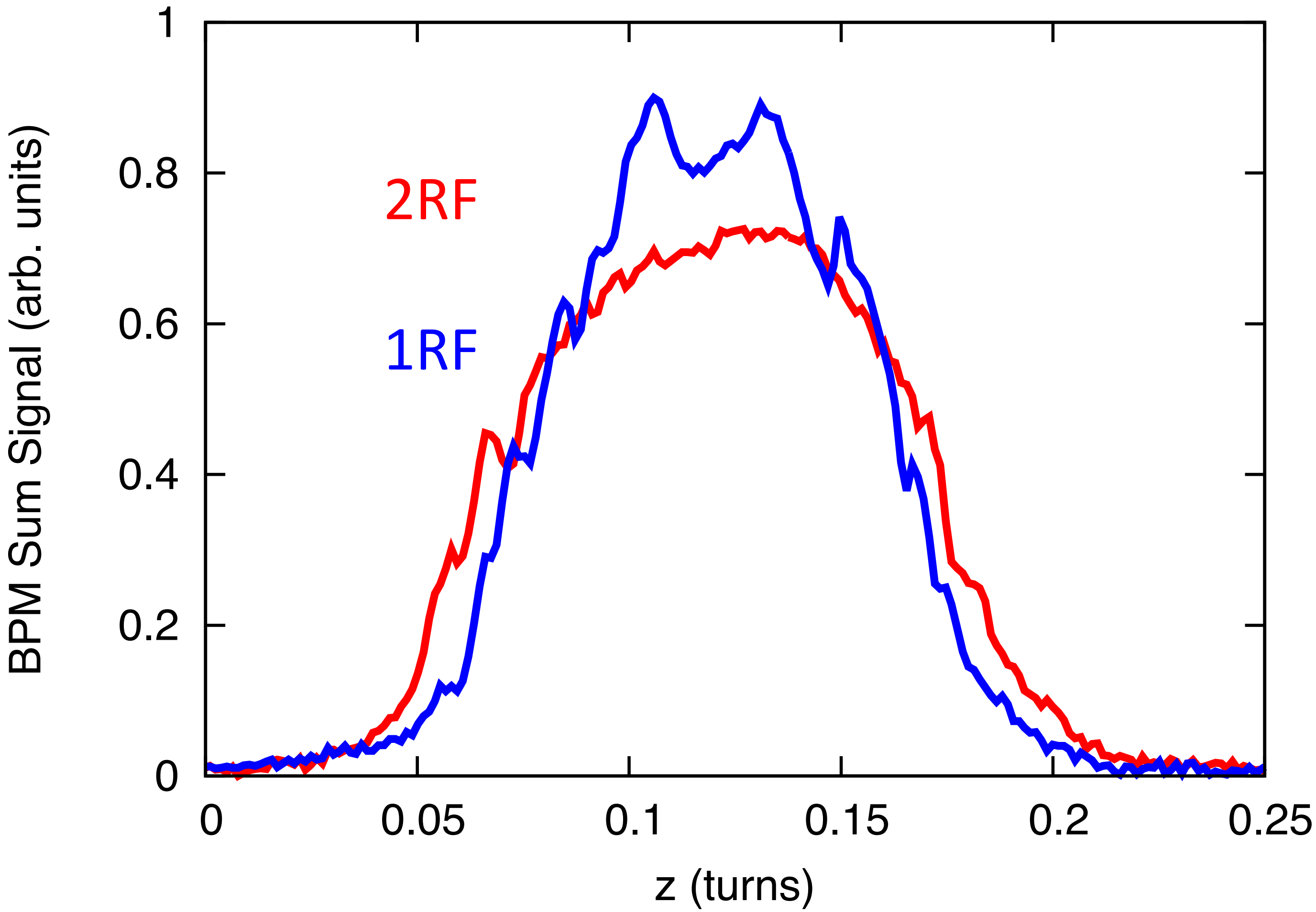
1RF and 2RF in SIS18

Beam time in SIS18:

$^{124}Xe^{43+}$ ions
12 June 2016
$N_p = 2\times10^9$
$E_K = 6.81$ MeV/u
MA   h=4 V=2.2kV
F   h=8 V=1.1kV

$\Delta Q_{sc} \approx -0.12$ (vert)
$\Delta Q_{sc} \approx -0.06$ (hor)

Kornilov, et.al.



Flatter, broader, less perturbed bunches in 2RF

Conclusions & Outlook

Experience from other machines is essential
for SIS18/SIS100 mitigation strategies

- instability drive: many puzzles at different machines
- knowledge about the impedances
- determining and enhancing Landau damping
- design and operation of feedback systems
- diagnostics with high-intensity effects
- 1RF & 2RF
- development of codes