Measurements and interpretation of the betatron tune spectra of high intensity bunched beam in the SIS18.

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Overview

- Motivation
- Introduction
- Tune measurement systems
- Theoretical description of betatron tune spectra
- Tune spectra at different intensities
- Chromaticity measurements
- Summary and Outlook

Motivation

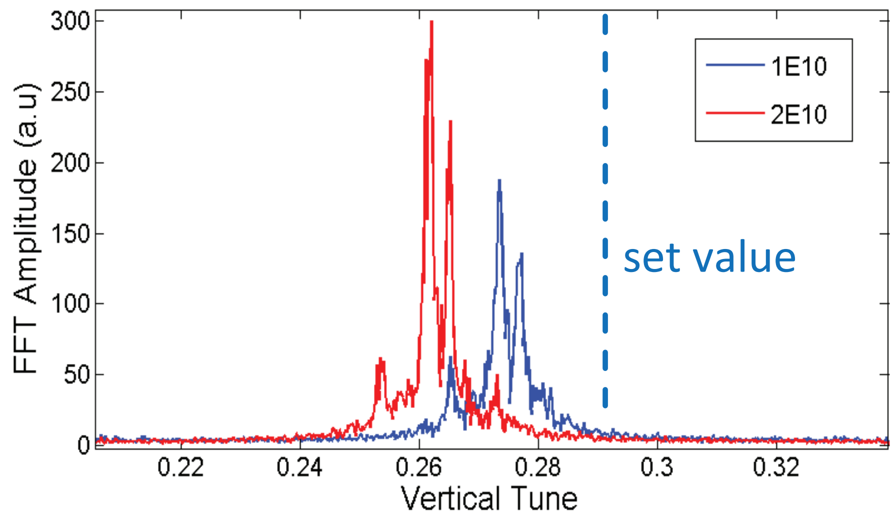
Just one of many measurements...

Beam parameters in the measurement:

Beam type	Ar^{18+}
Injection energy, E_{inj}	11.4 MeV/u
Harmonic number, h	4
Bunching factor, B_f	0.35
Vertical tune (set), Q_y	3.29

Measurements were done at injection energy, no acceleration

Spectra of signal from vertical BPM plates

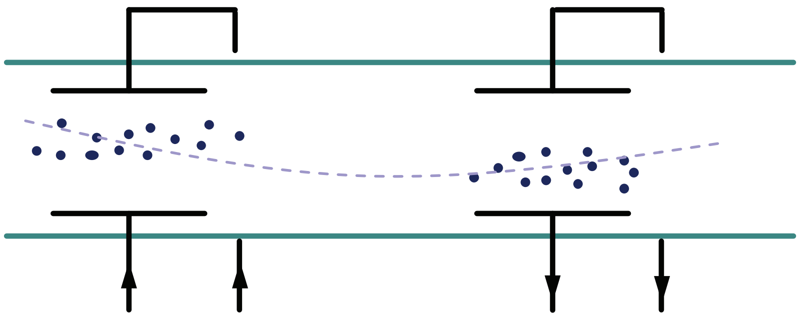


How to obtain the bare betatrone tune from a such complicated spectrum?

R. Singh et al., "Tune Measurements with High Intensity Beams at SIS-18", DIPAC'11,

Introduction

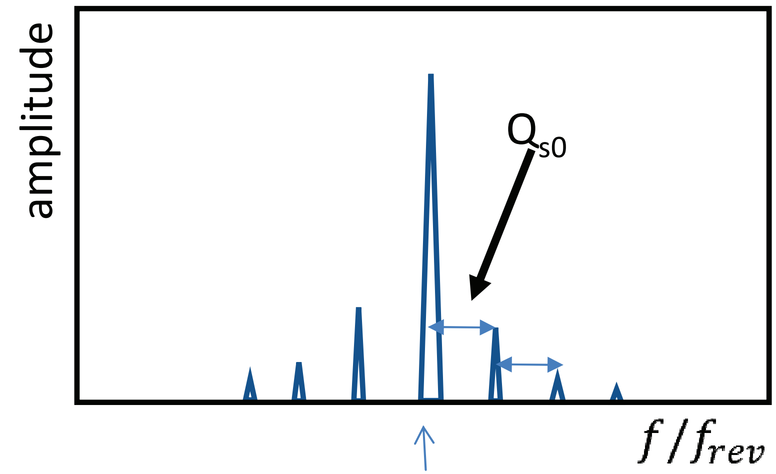
Principle of measurements



Dipole excitation
(white noise)

Difference signal

Expected spectrum of difference signal (low intensity)



Fractional betatron tune = Q_y-[Q_y]

Typical parameters

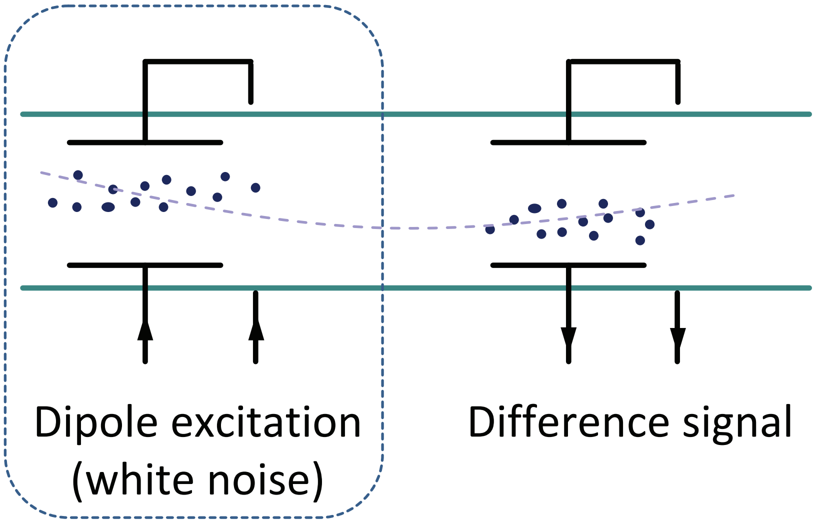
Frequency of transverse oscillations $Q_y \cdot f_{rev}$

Frequency of longitudinal oscillations (synchrotron motion) $Q_{s0} \cdot f_{rev}$

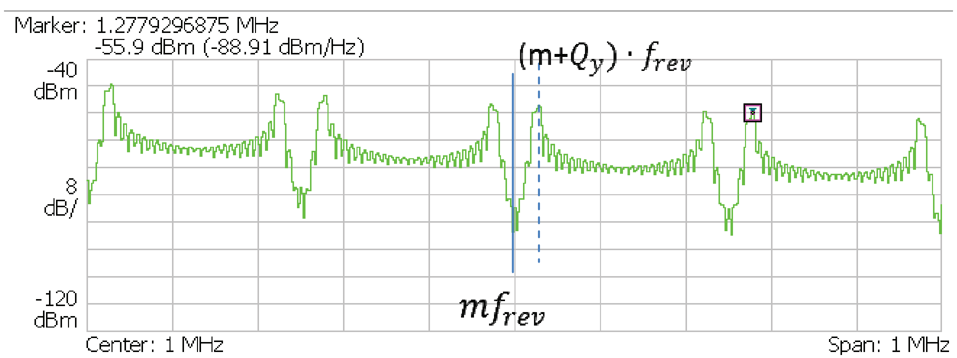
	f_{rev}	214 MHz
betatron tune	Q_y	3.29
synchrotron tune	Q_{s0}	0.007

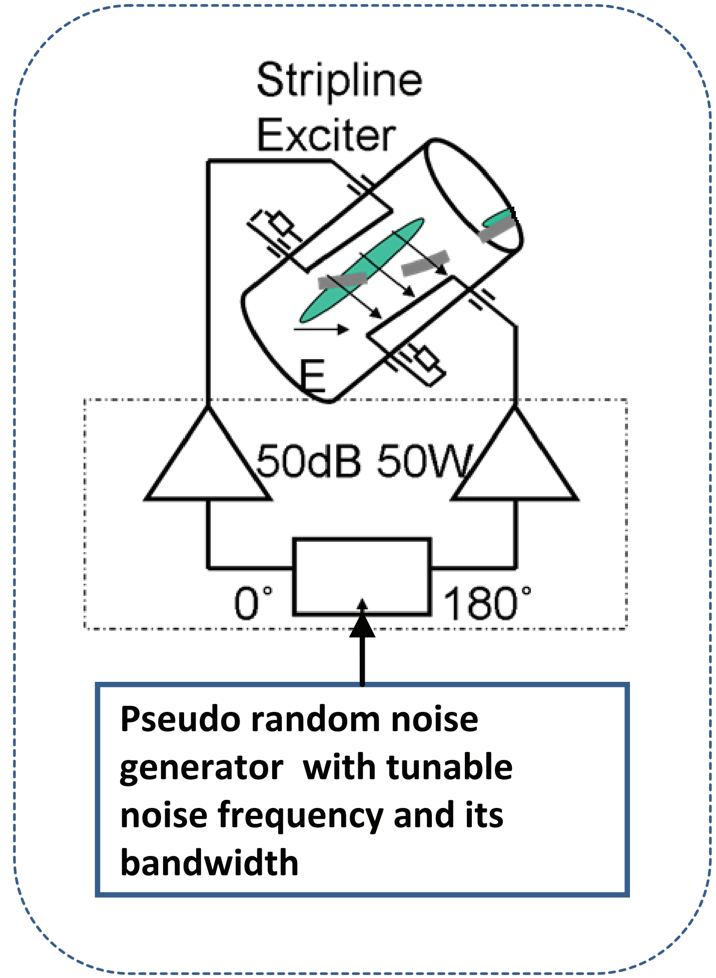
Narrow band noise excitation

Principle of measurements



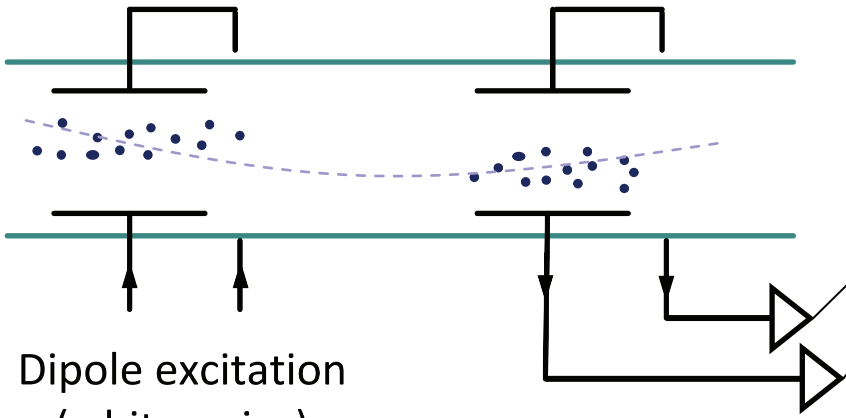
Generator spectrum
(short region around expected tune is excited)





Measurement systems. TOPOS

Principle of measurements

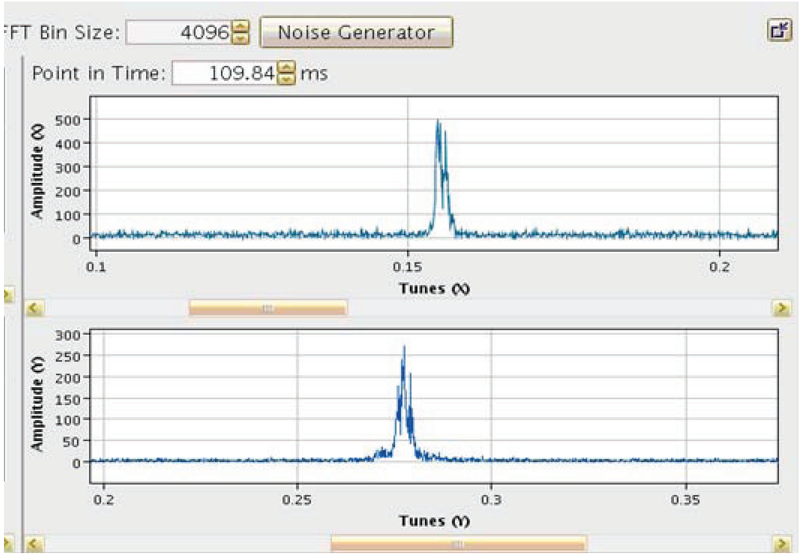


Dipole excitation
(white noise)

TOPOS system

Bunch position measurements

Part of the GUI in control room



Main advantages of the TOPOS system:

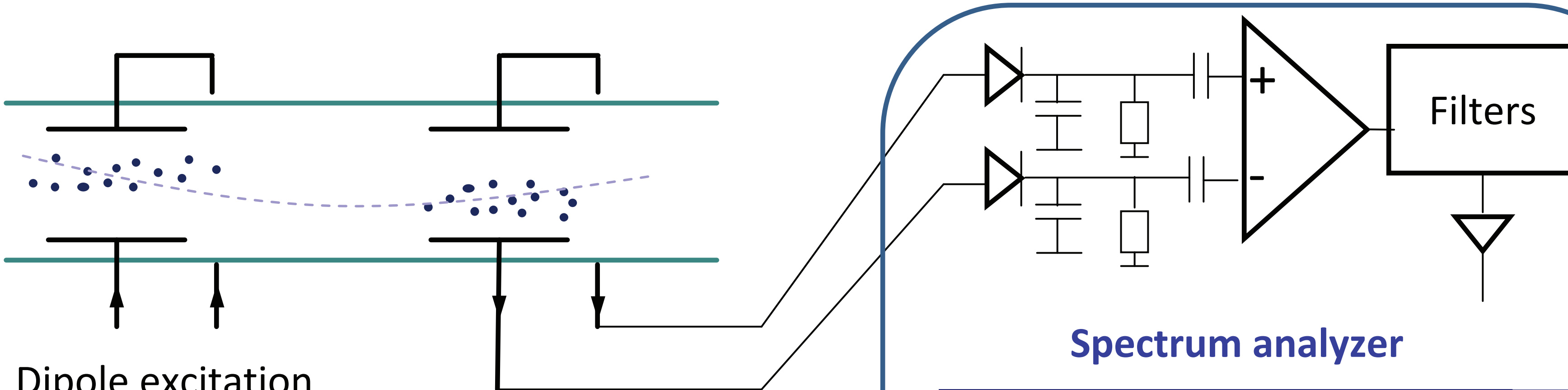
- Record bunch signals from all plates (time domain information)
- Calculation of bunch position, tune, orbit.

Application results:
R. Singh et al., “Tune Measurements with High Intensity Beams at SIS-18”, DIPAC’11,

Measurement systems. BBQ

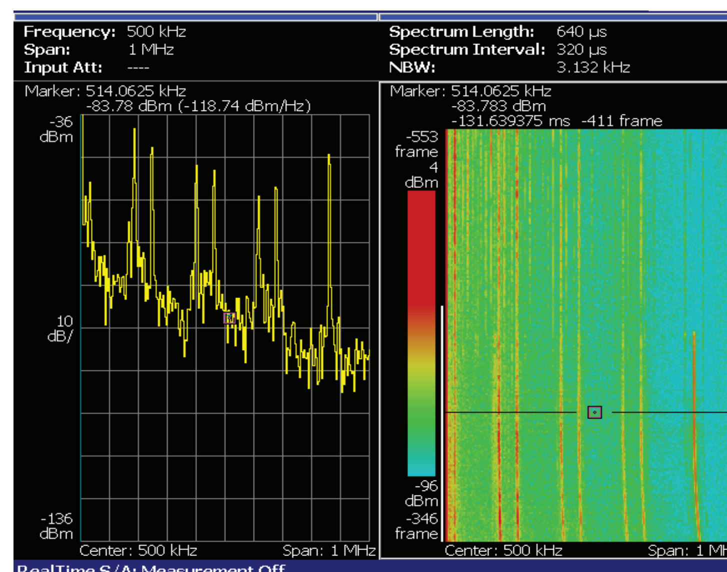
Principle of measurements

"BaseBand Q" system



Dipole excitation
(white noise)

Spectrum analyzer



Main advantages of the BBQ system:

- 10-15 dB higher sensitivity as compared to the TOPOS in present configuration
- much lower ADC are needed
- Common mode reduction via peak detection

Direct Diode Detection method described in:
M. Gasior, R. Jones, **HIGH SENSITIVITY TUNE MEASUREMENT BY DIRECT DIODE DETECTION**, DIPAC 2005

Position of peaks in tune spectra

Frequency of the head-tail modes without "intensity effects"

$$Q_k = Q_0 + kQ_s$$

head-tail mode number $k = .., -2, -1, 0, 1, 2, ...$

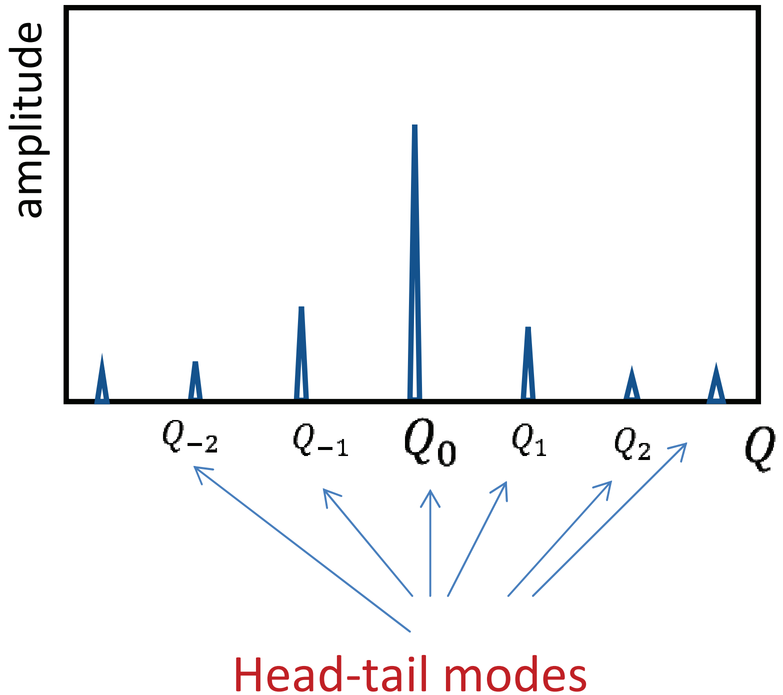
Direct space charge effect

$$\Delta Q_{sc} = \frac{q I_p R}{4\pi\epsilon_0 c E_0 {\gamma_0}^2 {\beta_0}^2 \varepsilon_x}$$

Image fields effects

$$\Delta Q_{coh} = \frac{a^2}{b^2} \Delta Q_{sc}$$

Schematically beam spectrum



The positions of the head-tail modes including "intensity effects"

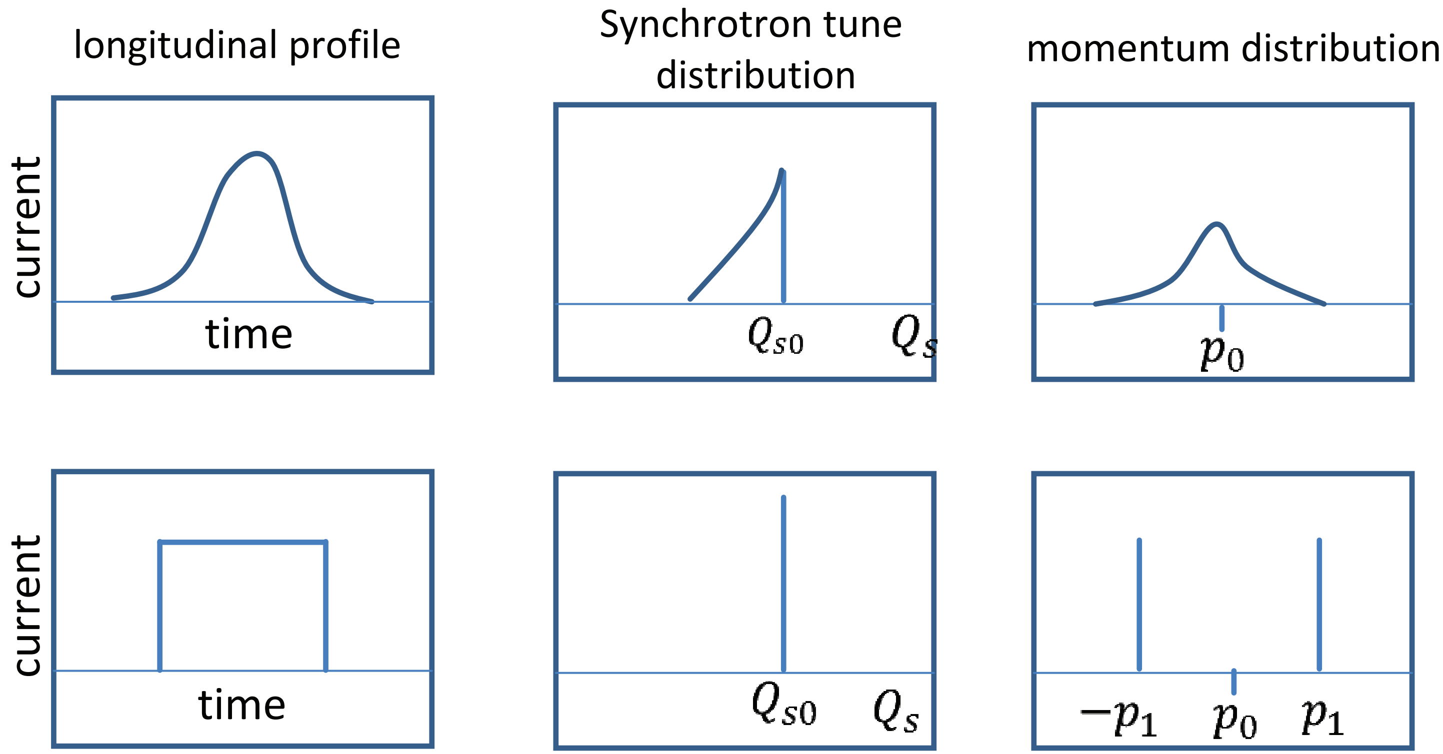
$$Q_k = Q_0 + \Delta Q_k(Q_s, Q_{sc}, Q_{coh})$$

In order to get analytical expression a simplified modeling is shown on the next slide

Analytical model for head-tail modes

Realistic bunch

Model bunch
(Airbag distribution)



Head-tail tune shift: $$\Delta Q_k = -\frac{\Delta Q_{sc}+\Delta Q_{coh}}{2} \pm \sqrt{\frac{(Q_{sc}-\Delta Q_{coh})^2}{4} + (kQ_{s0})^2}$$

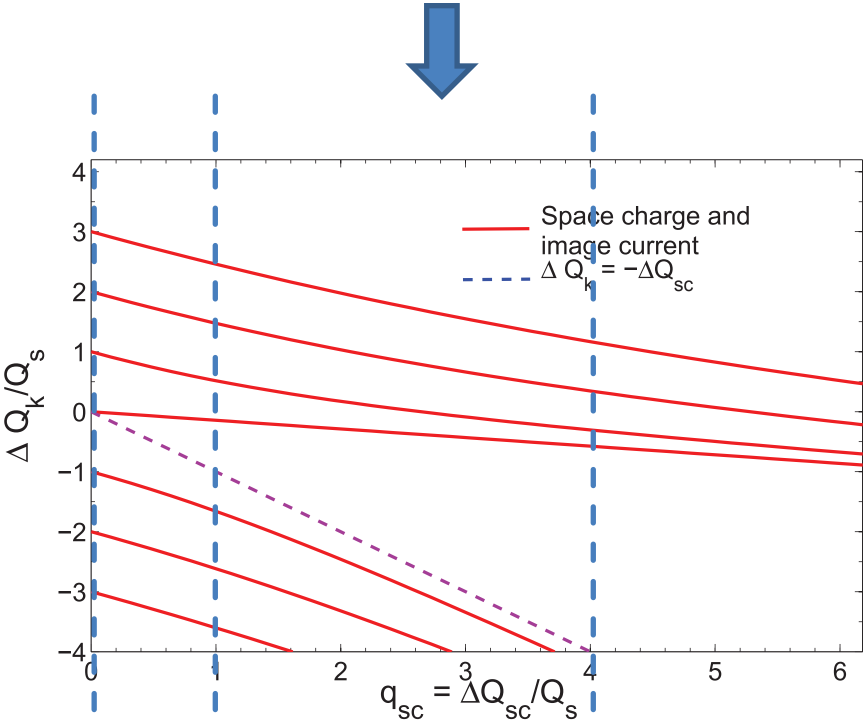
M. Blazkiewicz, Fast head tail instability with space charge, Phys. Rev ST Accel. Beams 1, 044201, (1998)

O. Boine-Frankenheim and V. Kornilov, Transverse Schottky noise spectrum for bunches with space charge,Phys. Rev ST Accel. Beams 12, 114201, (2009)

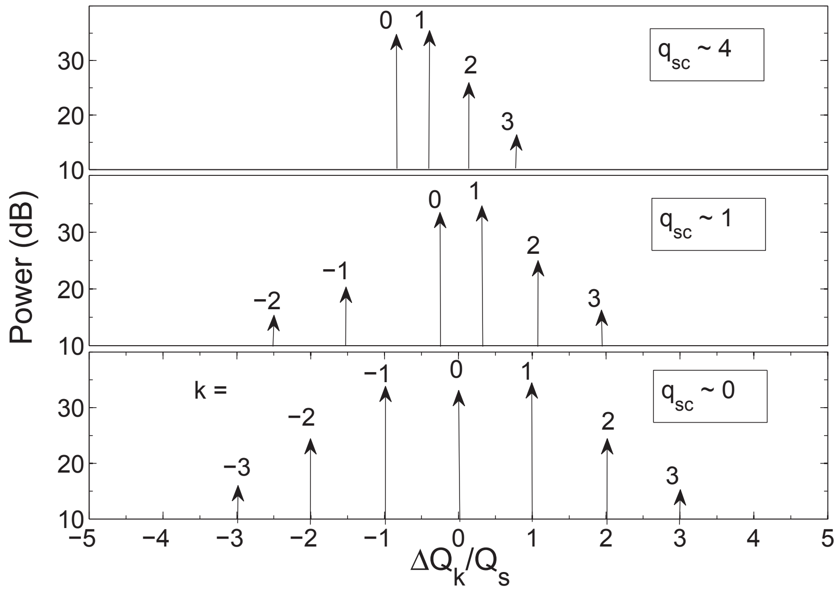
Moving of head tail modes with intensity

Head-tail tune shift:

$$\Delta Q_k = \frac{\Delta Q_{sc} + \Delta Q_{coh}}{2} \pm \sqrt{\frac{(Q_{sc} - \Delta Q_{coh})^2}{2} + (kQ_{s0})^2}$$



Positions of the head-tail modes as seen in beam spectra:

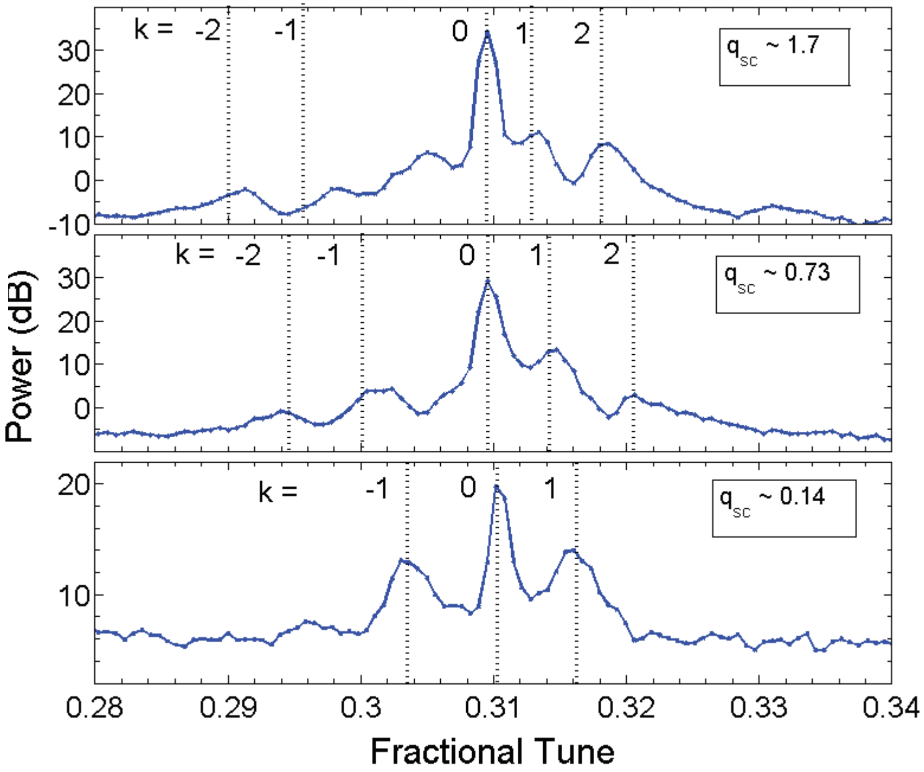


Fit of the peaks position by head-tail modes

Horizontal tune spectra with Uranium beam

Beam parameters in the measurements:

Beam/Machine parameters	Values
Atomic mass(A), Charge state(q)	238, 73
Q_x, Q_y	4.31, 3.27
ξ_x, ξ_y	-0.94, -1.85
Transverse emittances$(\epsilon_x, \epsilon_y)(2\sigma)$	45, 22 mm-mrad
Slip factor(η)	0.94
Bunching factor (B_f)	0.4
Synchrotron tune (Q_{s0}, Q_{s1})	0.007, 0.0065

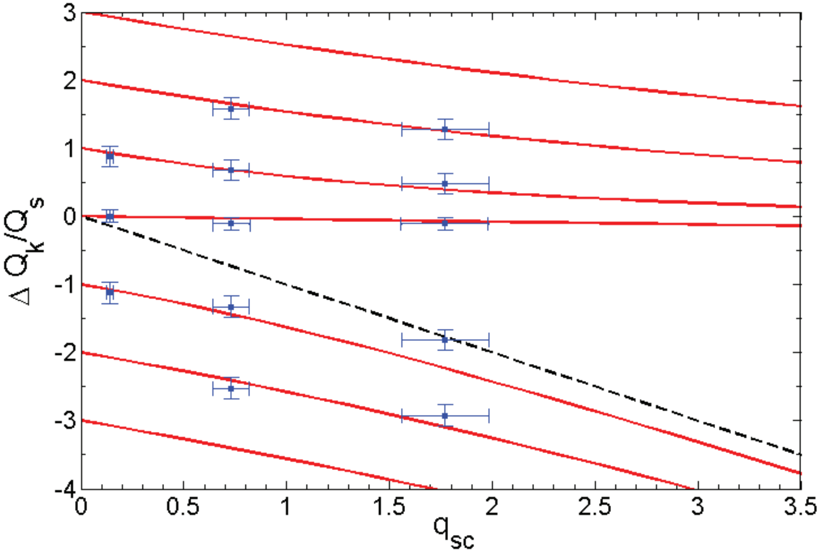


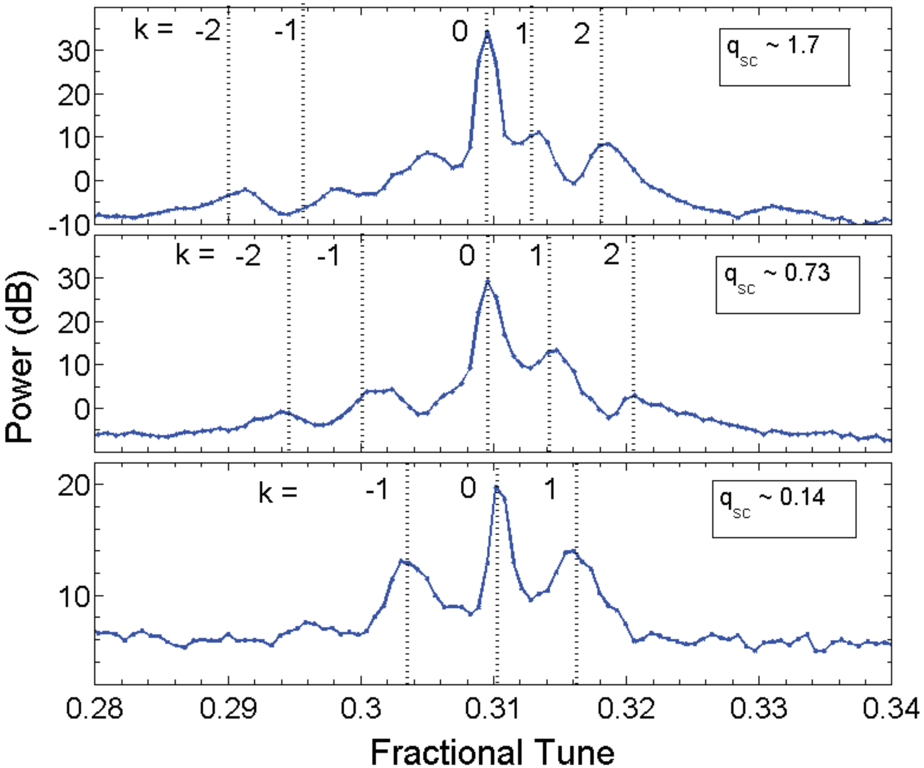
Longitudinal spectra -> syn. tune
RGM -> Transverse emittance
Pickup -> Bunching factor

Fit of the peaks position by head-tail modes

Horizontal tune spectra with Uranium beam

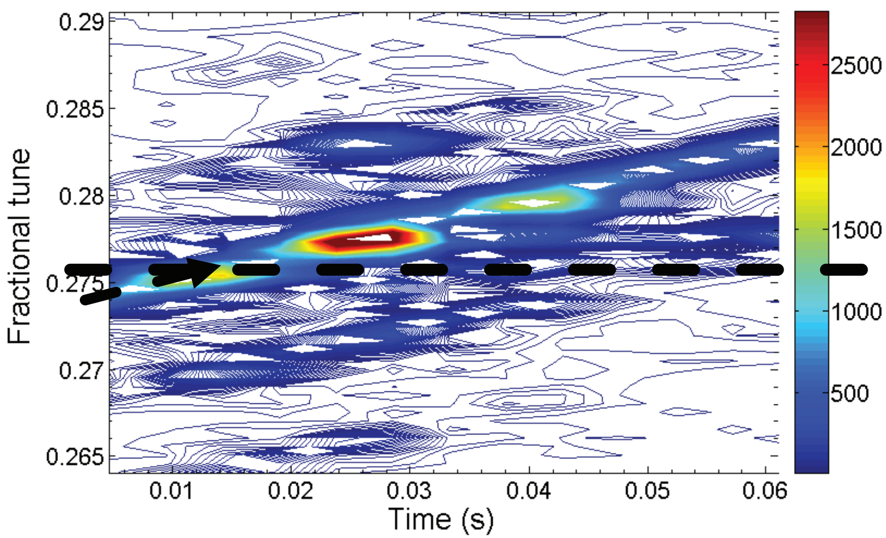
Head-tail tune shift:



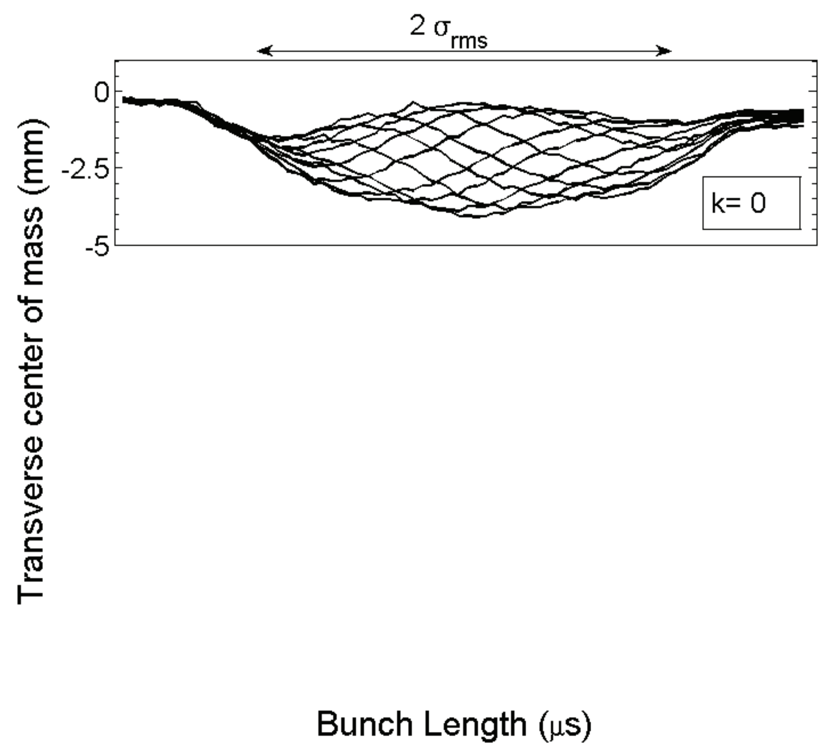


Excitation of particular head tail modes

- In order to excite particular modes we apply the frequency sweep.
- As soon as modulation frequency coincide with any mode frequency, the corresponding form of the mode was observed.



Bunch signal recorded by TOPOS (each curve is bunch signal)



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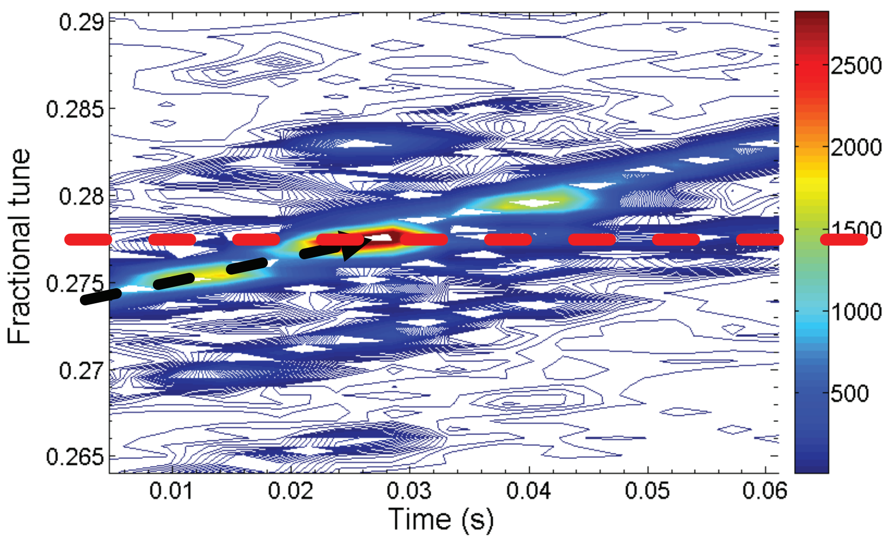

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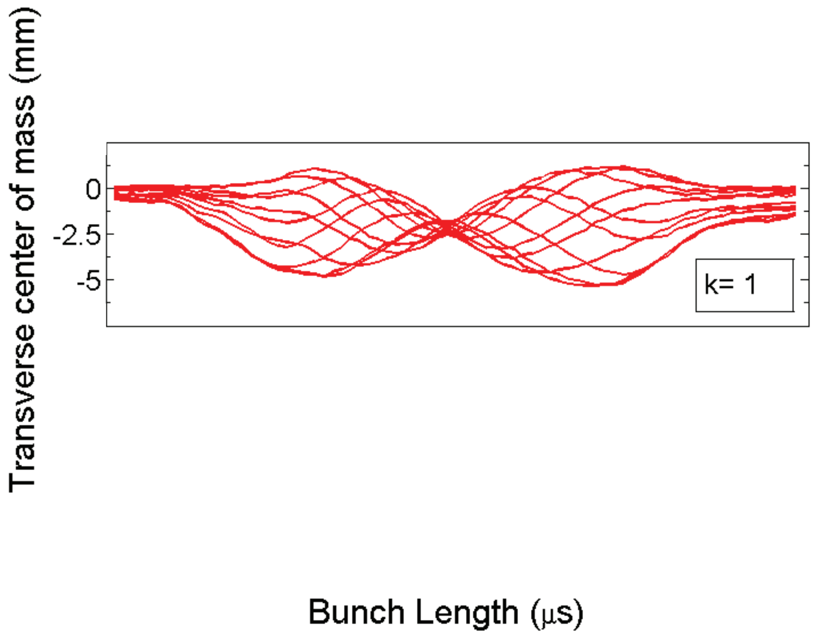

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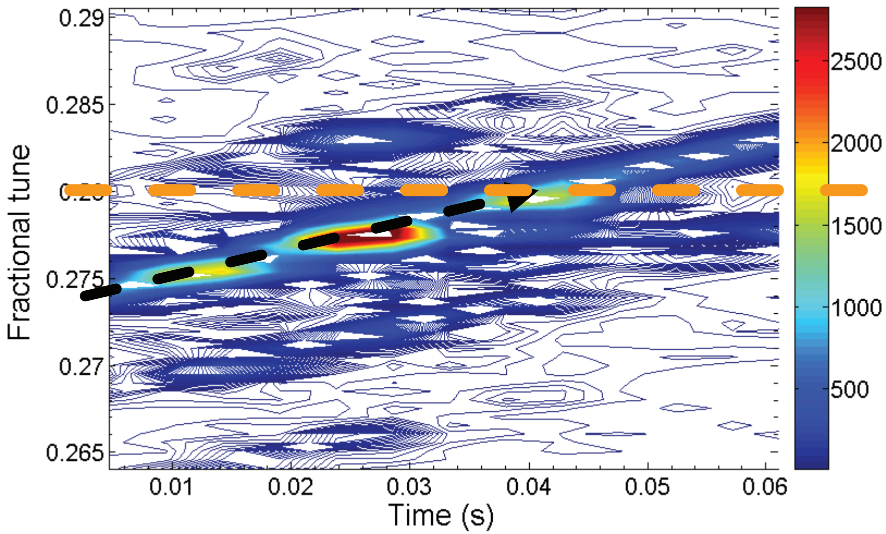

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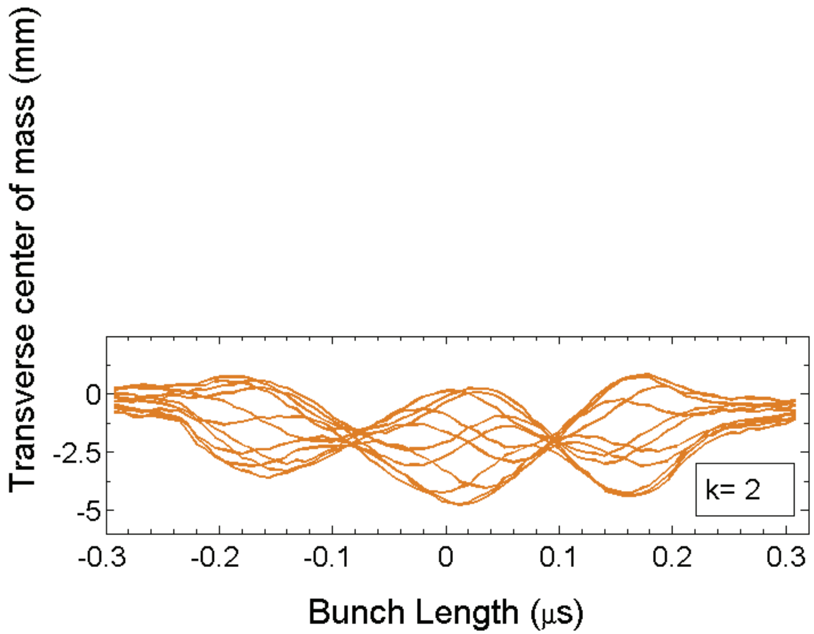

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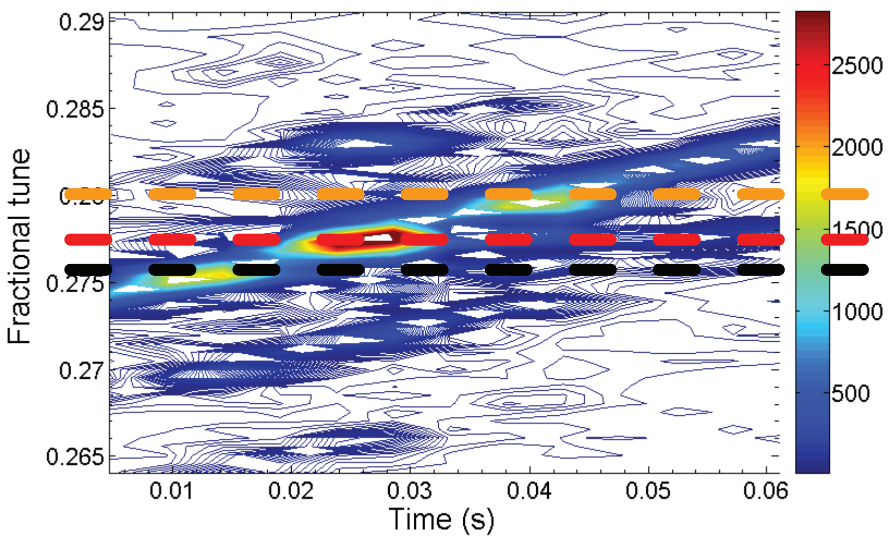

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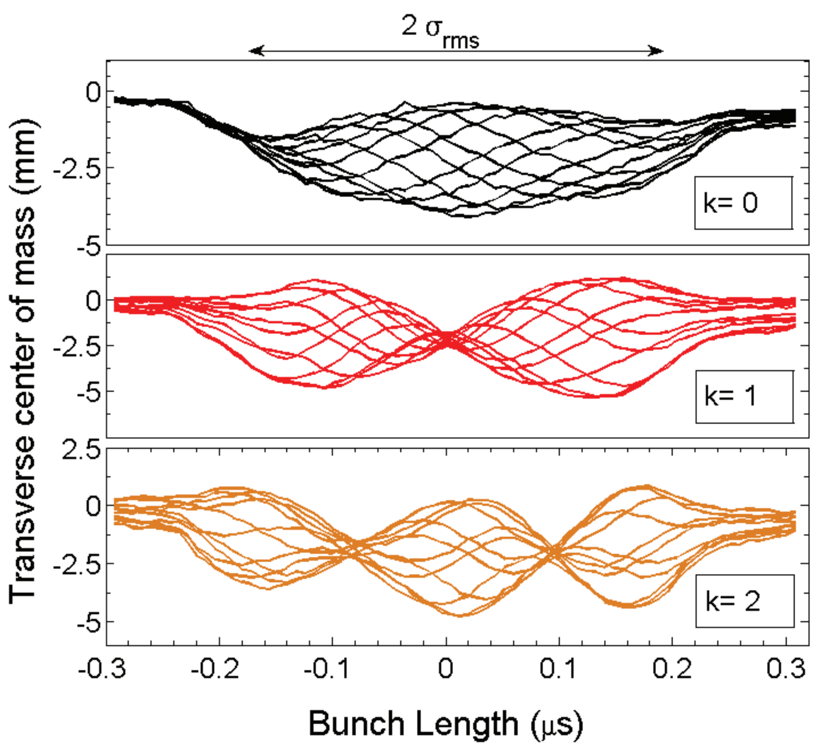
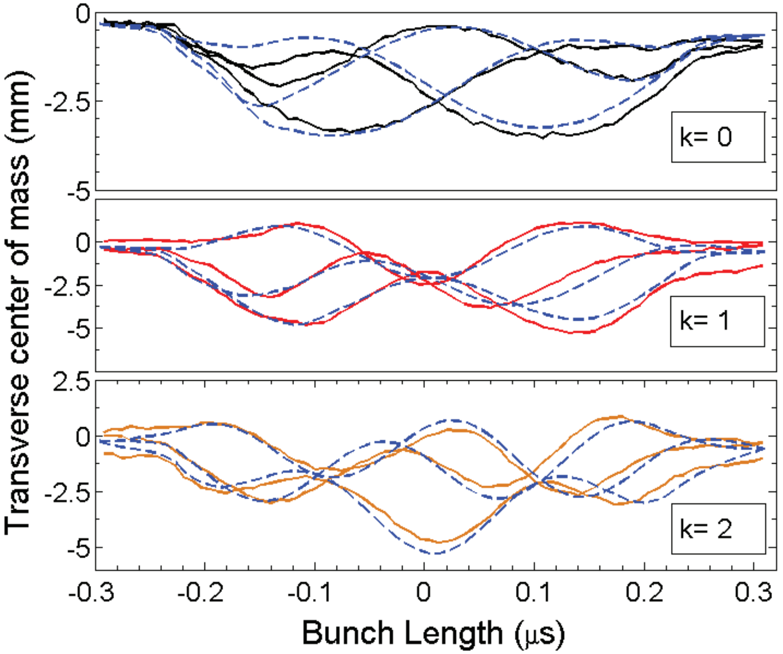


Chromaticity calculation using head-tail function

Measured transverse signal, fitted by the analytic formula



Bunch by bunch each revolution

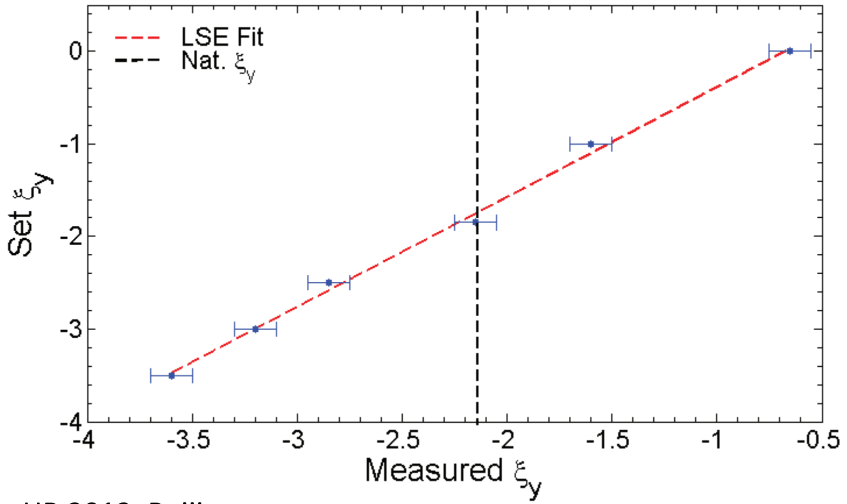
According to considered model, the corresponding mode function:

$$x_{kt}(t) \approx \lambda(t) \cdot a_k \cdot \cos k\pi \frac{t}{\tau_b} \cdot \cos \chi_b \frac{t}{\tau_b}$$

Chromatic phase shift over the bunch length

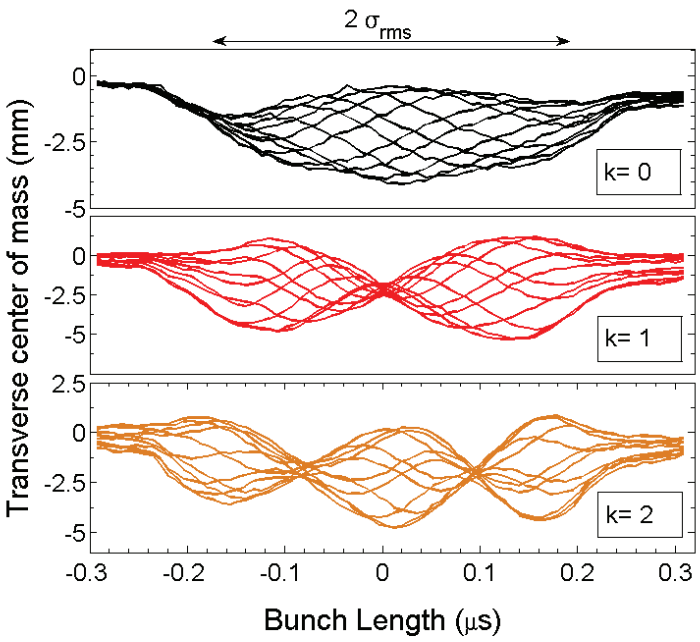
$$\chi_b = \omega_{rev} \tau_b \frac{Q_0 \xi}{\eta_0}$$

Measured chromaticity vs set chromaticity



Amplitude of head-tail mode

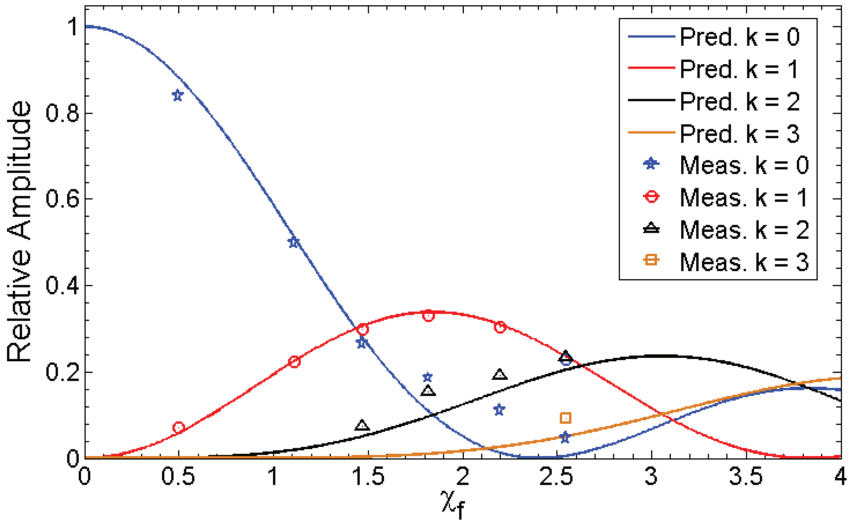
Bunch signal recorded by TOPOS (each curve is bunch signal)



Assuming that mode amplitude has similar law that single particle amplitude has:

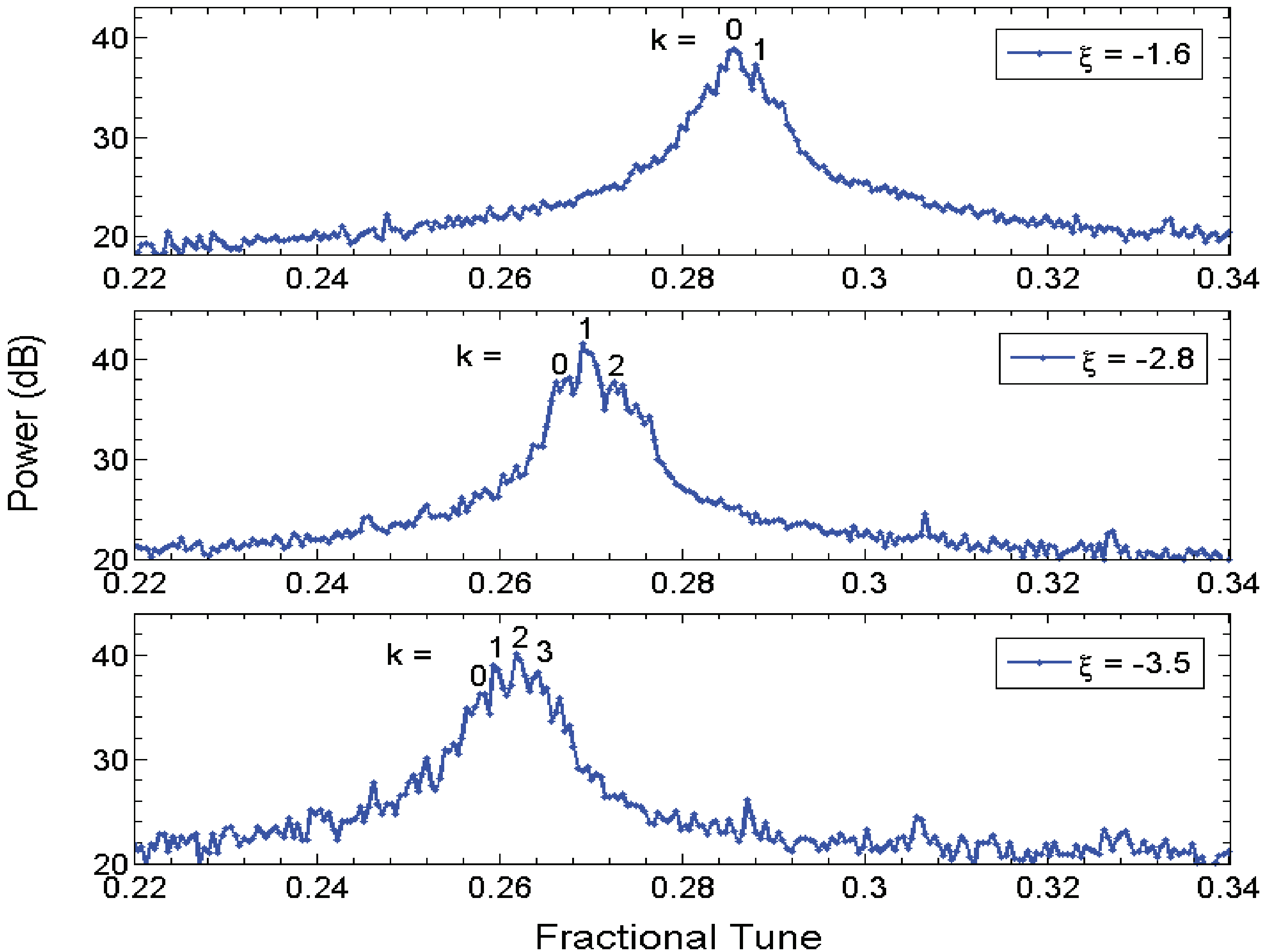
$$a_k \sim J_k\left(\frac{\chi_b}{2}\right)$$

Amplitude of the modes compared with corresponding Bessel functions



S. Chattopadhyay, "Some fundamental aspects of fluctuations and coherence in charged particle beams in storagerings", Super Proton Synchrotron Division, CERN 84-11, (1984)

Spectra at different chromaticities



Summary and Outlook

- Two complementary tune measurement systems TOPOS and BBQ are presently in operation in the SIS 18
- Both narrow-banded noise excitation and frequency sweep provide similar results. In general, for determination of the betatron tune the time structure has to be known.
- Within experimental range the measured mode positions, functions and amplitudes agrees well with values predicted by simple model
- Another method for determining the chromaticity was found
- Systems are ready for further detailed investigations (different rf forms, combination with longitudinal intensity effects, etc.)

THANK YOU FOR ATTENTION!