Space charge and Instabilities

Topics:

- Longitudinal impedance with electron clouds.

  talk by R. Hasse

- Dispersion relations with nonlinear space charge forces.

  talks by V. Kornilov, O. Boine-Frankenheim

- Measurements of space charge effects in the PSB and in SIS 18.

  talks by M. Chanel, S. Paret, O. Boine-Frankenheim

- Simulation studies of coherent instabilities and space charge effects.

  talks by M. Aiba, B. Salvant, V. Kornilov,

Longitudinal impedances with electron clouds

R. Hasse, et al.

Longitudinal space charge impedance assuming a homogeneous electron cloud in a beam pipe.

$\omega > \omega_{ec}$

$\omega < \omega_{ec}$

n=1

n=10

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

evanescent and
surface-waves

n=100

electron plasma frequency:

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Transverse beam stability with nonlinear space charge

Vladimir Kornilov, et al.

Dispersion relation (Möhl, 1969)
with nonlinear space charge.

$$\int \frac{\Delta Q_{\rm coh} - \Delta Q_{\rm inc}}{\Omega/\omega_0 - (Q_{\rm ex} + \Delta Q_{\rm inc})} \left(-\frac{a^2}{2} \frac{{\rm d}\psi_a}{{\rm d}a} \right) b\,\psi_b(b)\;\psi_p(p)\,{\rm d}a\,{\rm d}b\,{\rm d}p = 1$$

"external" incoherent tune shifts:

$$Q_{\rm ex}(a,b,p) = Q_0 + \Delta Q_{\rm oct}(a,b) + \Delta Q_\xi(p)$$

nonlinear space charge:

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

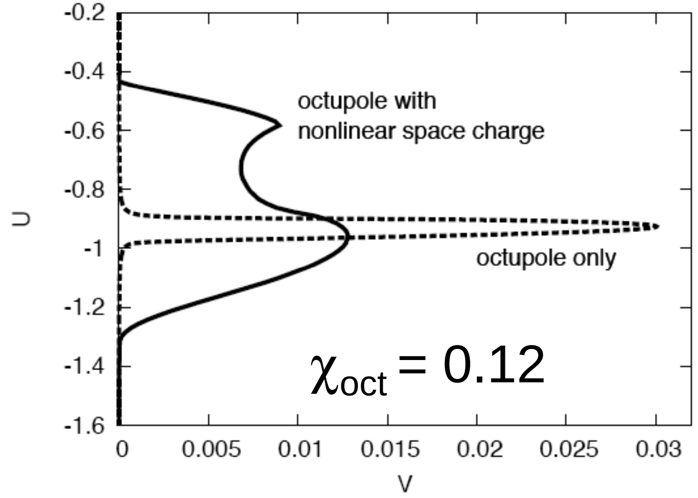
characteristic tune spreads:

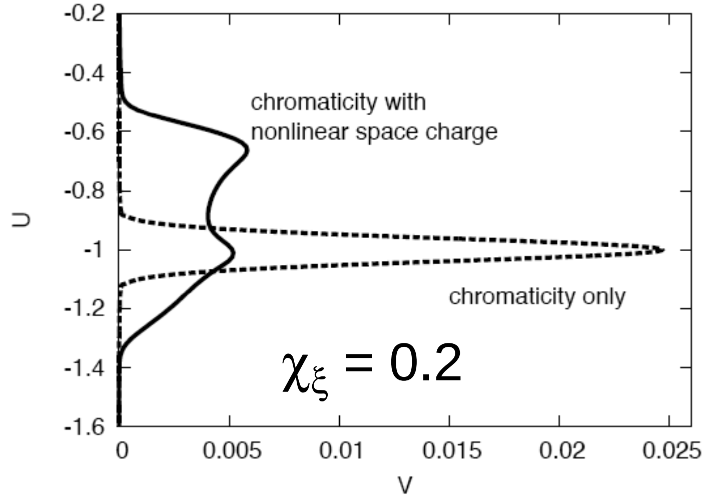
octupole

$$\chi_{\rm oct} = \frac{\delta Q_{\rm oct}}{\delta Q_{\rm sc}}$$

chromaticity

$$\chi_\xi = \frac{\delta Q_\xi}{\delta Q_{\rm sc}}$$





Transverse beam stability with nonlinear space charge

Vladimir Kornilov, et al.

Comparison of the dispersion relation with PATRIC simulations

octupole of the
advantageous polarity

octupole of the
disadvantageous polarity

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

anti-damping
(not found in
simulations)

Stability of coherent synchrotron oscillations with space charge

Oliver Boine-Frankenheim, O. Chorniy

Coherent (dipole) frequency shift:

$$\Delta\Omega_c = \frac{i\omega_{s0}}{2}\left(Z^R_{eff} + iZ^I_{eff}\right)$$

Dispersion relation (Moehl, CERN 1997):

$$1 = -\pi \int_0^{\pi} [\Delta\Omega - \Delta\omega_s(\hat{\phi})] \frac{2\omega_{s0} f'(\hat{\phi})\hat{\phi}^2 d\hat{\phi}}{\Omega^2 - \omega_s^2(\hat{\phi}) + i\gamma\omega_{s0}}$$

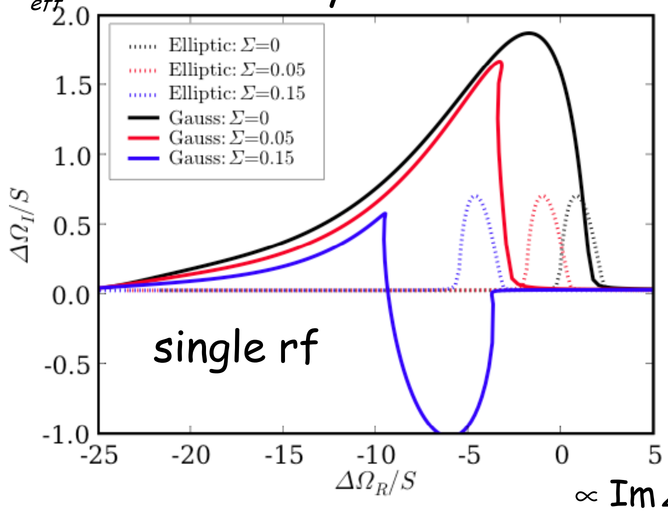
For an elliptic bunch distribution (const. $\Delta\omega_s$):

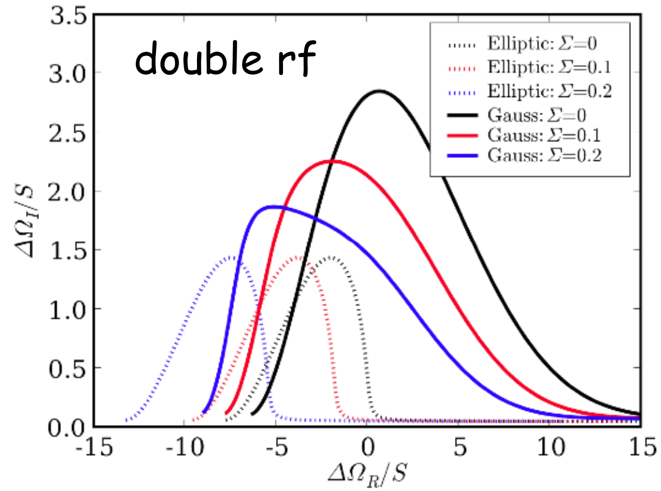
$$1 = -\pi(\Delta\Omega - \Delta\omega_s)\int_0^{\pi} \frac{f'(\hat{\phi})\hat{\phi}^2 d\hat{\phi}}{\Omega - \omega_s + i\gamma}$$

K.Y. Ng, FNAL report (2005)

Nonlinear space charge strongly reduces the stability area for single rf buckets

Stability boundaries



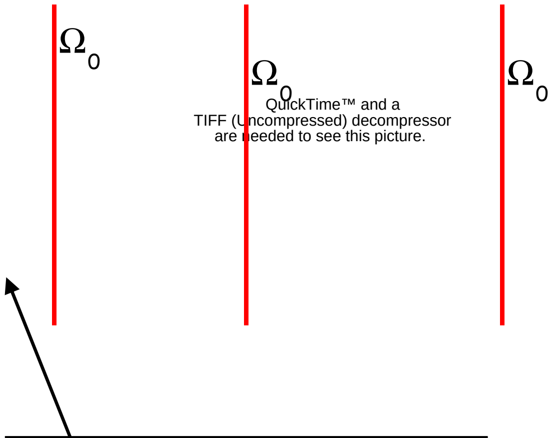


Stability of coherent synchrotron oscillations with space charge

Oliver Boine-Frankenheim, O. Chorniy

BTF measurements with space charge in SIS 18

$\Sigma > \Sigma_{th}$



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are needed to see this picture.

$$r(\Omega_m) = \frac{\Omega_m^2}{\Omega_c^2 - \Omega_m^2 + i2\gamma\Omega_m}$$

$$\Omega_c = \Omega_0 + \Delta\Omega_c$$

$$\Delta\Omega_c = \frac{i\omega_{s0}}{2}\left(Z_{eff}^R + iZ_{eff}^I\right)$$

Obtain the effective dipole impedance from the fit:

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TIFF (Uncompressed) decompressor
are needed to see this picture.

Measurement of transverse Schottky and BTF signals in SIS

S.Paret, et al.

BTF with linear space charge: QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

space charge factor: QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

Schottky spectrum: QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

f_0 : revolution frequency
σ_f : tune spread
ΔQ : space charge tune shift

$\chi \approx 1$

Measured Schottky side band and analytic result (fit)

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

$\chi \approx 0.15$

Measured BTF amplitude and analytic results (fits).

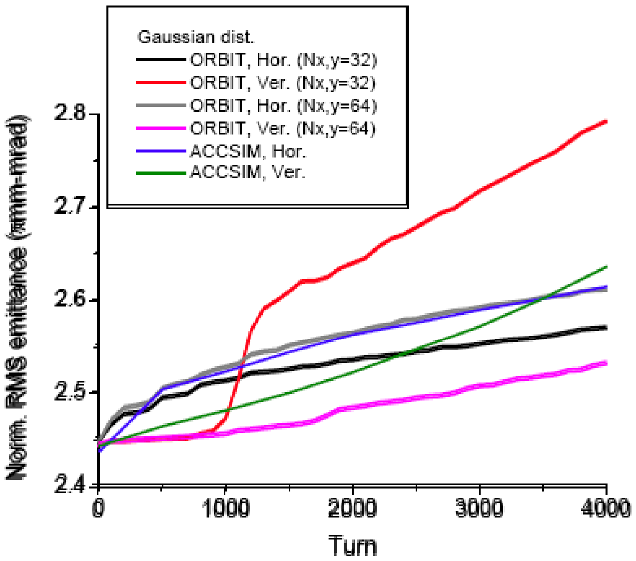
QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

Gaussian

Parabolic momentum distribution

Benchmark of the ACCSIM-ORBIT codes for space charge and e-lens compensation

M.Aiba, et al.

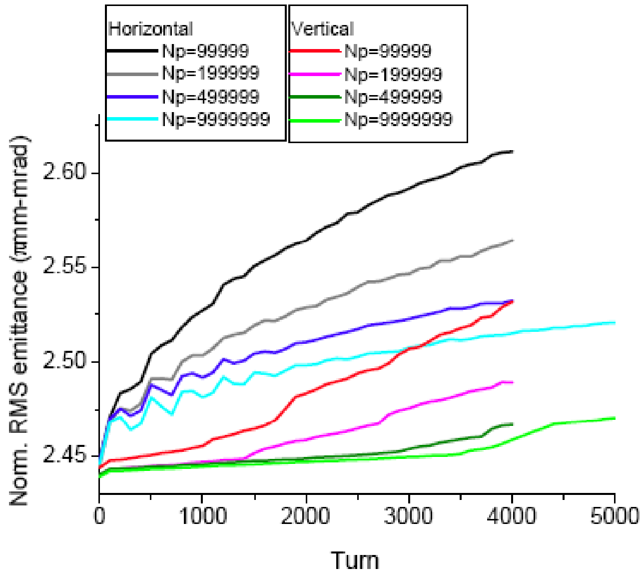


Emittance growth in the PSB at 160 MeV due to space charge. Simulated with ACCSIM and ORBIT

- Sensitive to number of grids
- Sudden blow-up in vertical (ORBIT)
- Rather good agreement in horizontal

(ACCSIM simulation by M. Martini)

Results also sensitive to the number of macroparticles....

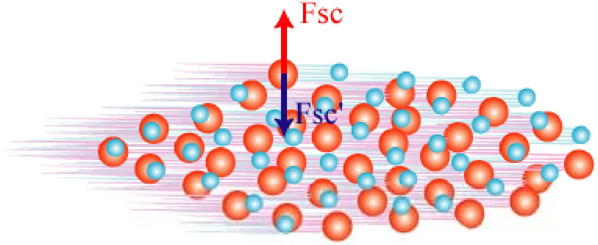


Benchmark of the ACCSIM-ORBIT codes for space charge and e-lens compensation

M.Aiba, et al.

E-lens compensation

Apply electron beam(s) to neutralize space charge force in proton beam



Reference: A.V.Burov, Q.W.Foster and V.D.Shiltsev, PAC01, P2896

Simulation with ORBIT

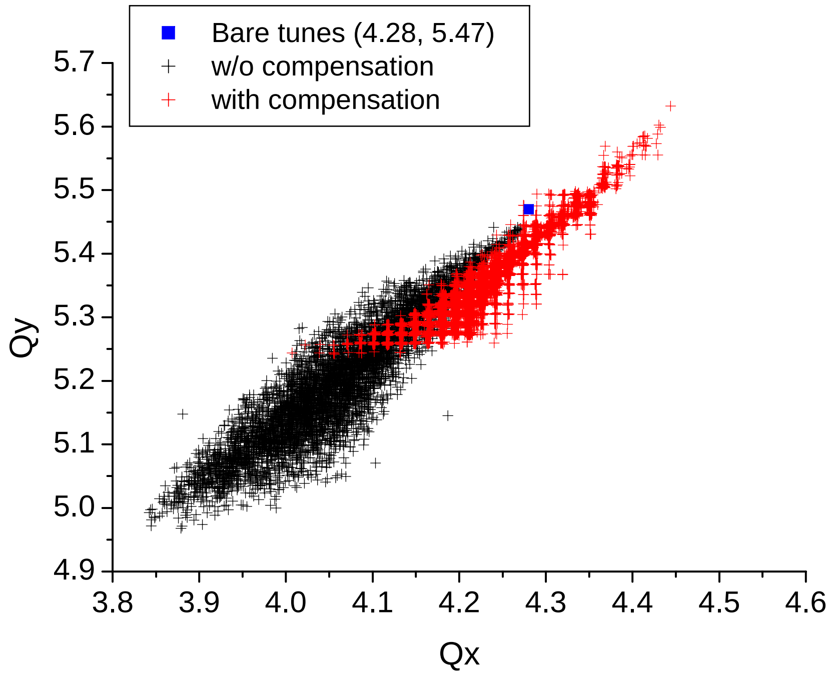
New routine to install e-lens is under development and testing

Benchmark of the ACCSIM-ORBIT codes for space charge and e-lens compensation

M.Aiba, et al.

Simulation in PSB

- Proton beam
  - Bunched beam
  - 3.25E12 protons / ring
  - Gaussian dist., $\varepsilon_{x,yN}$= 2.5 μm
- Electron lens
  - DC localized, ~2 m * 4 lenses
  - 2.54 A, 10 keV
  - Gaussian dist., 2.5 μm



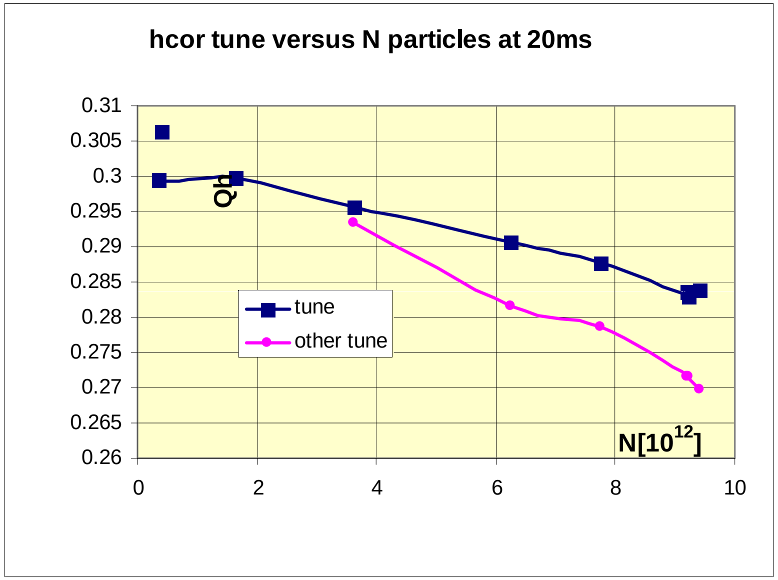
Over/Under compensation with DC lens: Employ a pulsed lens ?
Simulations show that the e-lens causes more emittance growth!

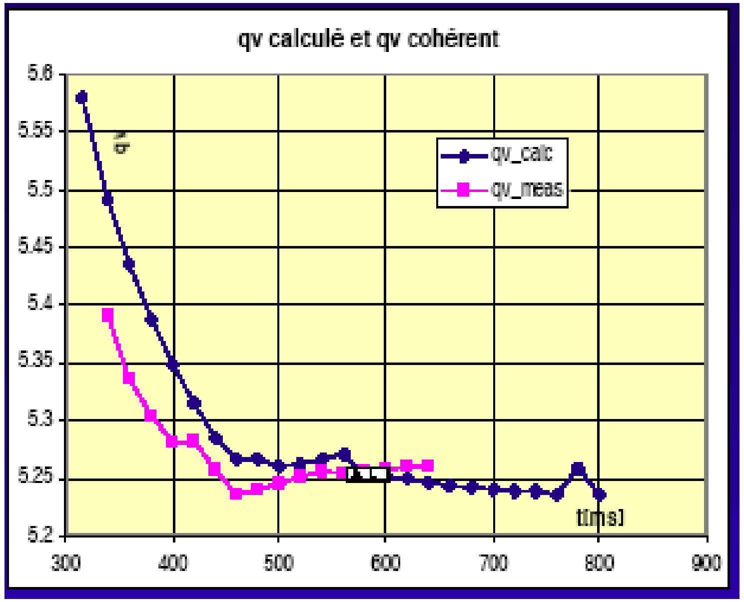
Space charge measurements at the PSB

M. Chanel

- Horizontal multiturn injection
- Dynamical working point to absorb tune spreads and shifts: from (4.29,4.6) at injection to (4.17,4.23) after 200ms up to extraction
- Coherent tune shift ~-0.18, Laslett tune shift ~-0.5 with high N even with h1&2 to increase Bf.

coherent tunes

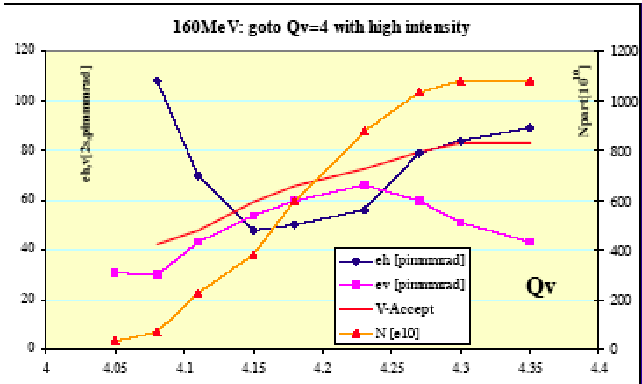


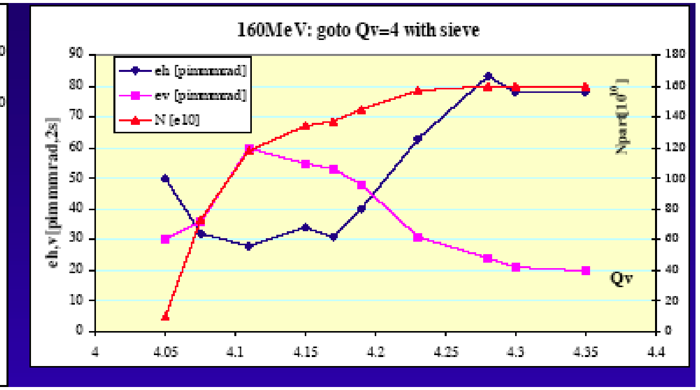


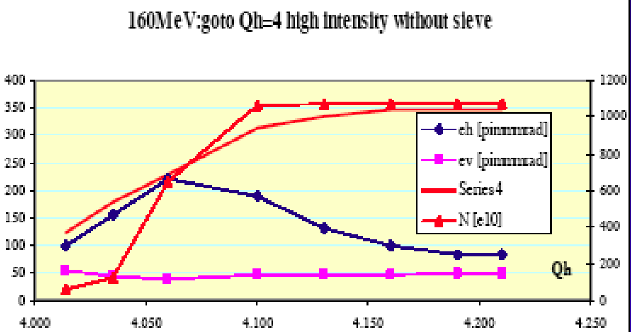
Space charge measurements at the PSB

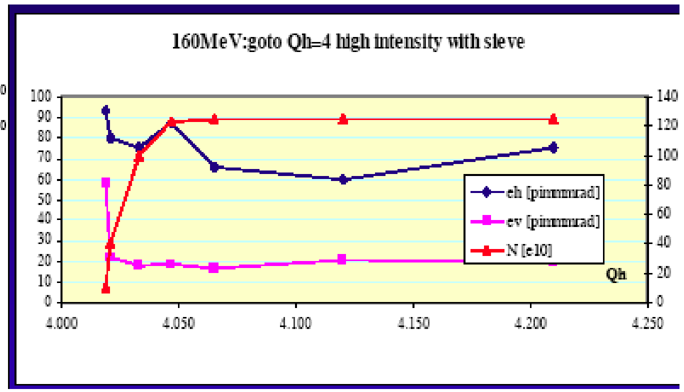
M. Chanel

- Moving the working point close to integer resonance (Q_H=4 or Q_V=4)
- The sieve in or out gives about a factor 5 different intensities
- Emittance and intensity evolutions at 160 MeV after injecting 13 turns





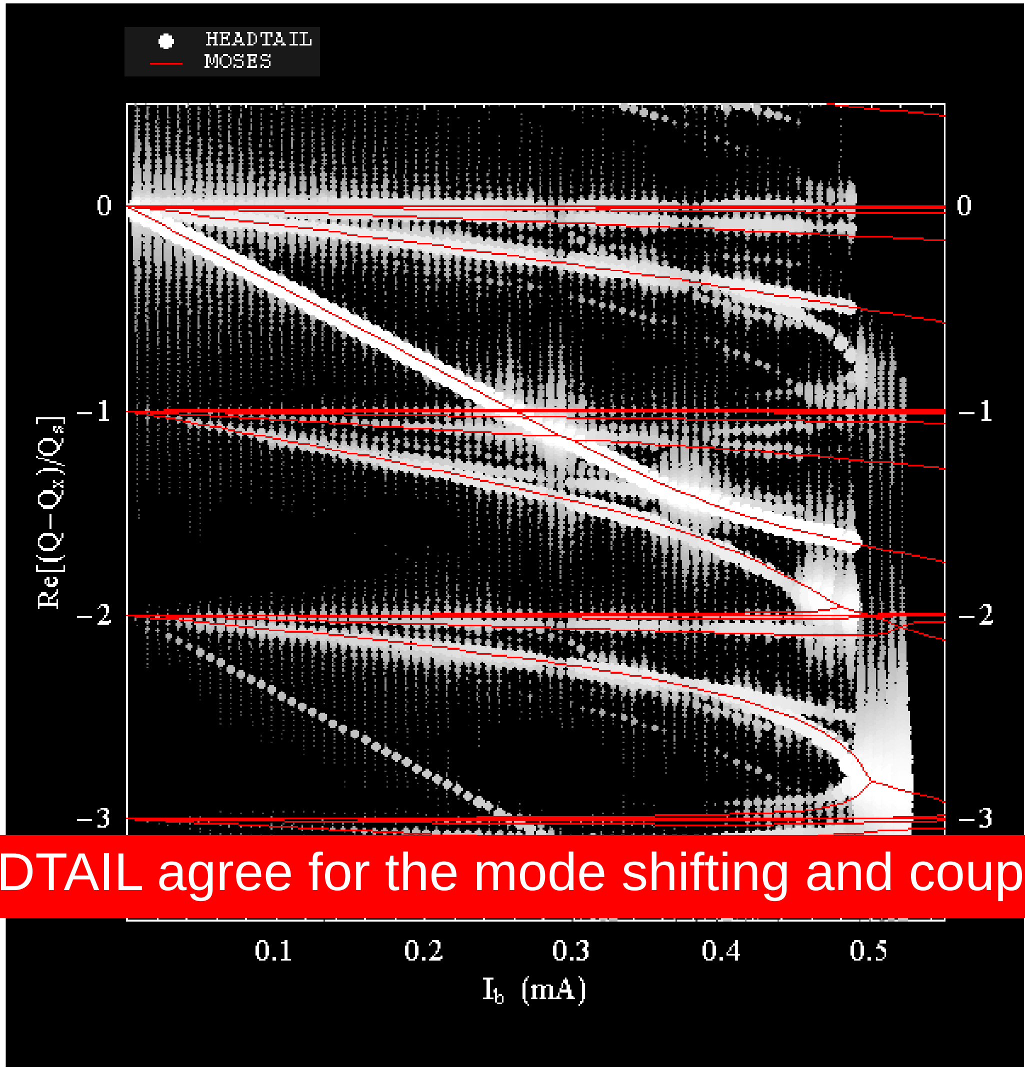




Transverse mode coupling instability in the SPS HEADTAIL simulations and MOSES calculations

B. Salvant et al.

Simulation Results:
Sample case that can be easily compared with analytical solutions
- Round beam pipe
- Zero chromaticity
- No coupling



MOSES and HEADTAIL agree for the mode shifting and coupling

Summary of the session

Results from a variety of tools for space charge and collective effects were shown in this session:

- Transverse, simulation
  - o SC $\rightarrow$ ACCSIM, ORBIT
  - o Inst $\rightarrow$ HEADTAIL, PATRIC (single bunch, coasting)
- Longitudinal, simulation
  - o SC $\rightarrow$ LOBO
  - o Inst + higher harmonic RF $\rightarrow$ HEADTAIL, LOBO
- Transverse & longitudinal, semi-analytical
  - o Dispersion relations leading to stability charts
  - o Coherent mode analysis (MOSES)

Space charge and collective instabilities observed in some machines: PSB (SC), SIS18 (BTF with SC), SPS (TMCI)