MEASUREMENTS AND COMPENSATION OF RESONANCES

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13 July 2010, GSI, Darmstadt

CONTENT

- INTRODUCTION: WHAT DRIVES NONLINEAR RESONACES?

- CROSSING RESONANCES, TUNE DIAGRAM AND RESONANCE STOPBAND

- EXPERIENCES OF (METHODS AND MEASUREMENTS):

- CERN-PS BOOSTER
- JPARC RCS

- DISCUSSION FOR SIS18

- CARRIED OUT BEAM LOSS MEASUREMENTS
- CORRECTION ELEMENTS INSTALLED
- SUGGESTIONS FOR COMING MEASUREMENTS

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MOTION IN THE TRANSVERSAL PLANE

is collective involving the
interaction between particles

$$q'' = K_q^{lin} \times q + F_q^{SC} + F_q^{nl}$$

are external forces involving no
interaction between particles

$q(s) = \{x, y\}$ particle coordinates

Ref. J. A. Holmes *et. al.*, "Space charge dynamics in high intensity rings", PRSTAB, vol.2,114202, 1999.

BETATRON MOTION

For any nonlinear Hamiltonian, the motion of a charged particle can be characterized in terms of regular and chaotic orbits. **Regular orbits can be stable and unstable:** the motion on regular stable orbits is periodic and can be decomposed in a series of harmonic spectral lines with discrete frequencies

$$x(n) = \sum_{k=1}^{\infty} a_k e^{i(2\pi \nu_k n + \varphi_k)}$$

Frequencies ν_k are linear combinations of the betatron tunes ν_x and ν_y

$$\nu_{x,y} = \frac{1}{2\pi}\int_0^C \frac{ds}{\beta_{x,y}}.$$

The amplitude of the spectral lines decreases exponentially with the order of the linear combination. For chaotic orbits this decomposition breaks down and a broad continuous set of frequencies will be excited in the spectrum.

Ref. R. Bartolini "Resonance driving term experiments: an overview", Proceed. ICAP 2006.

Ref. E.D. Courant and H. S. Snyder, "Theory of the alternating-gradient synchrotron", 1957, NY.

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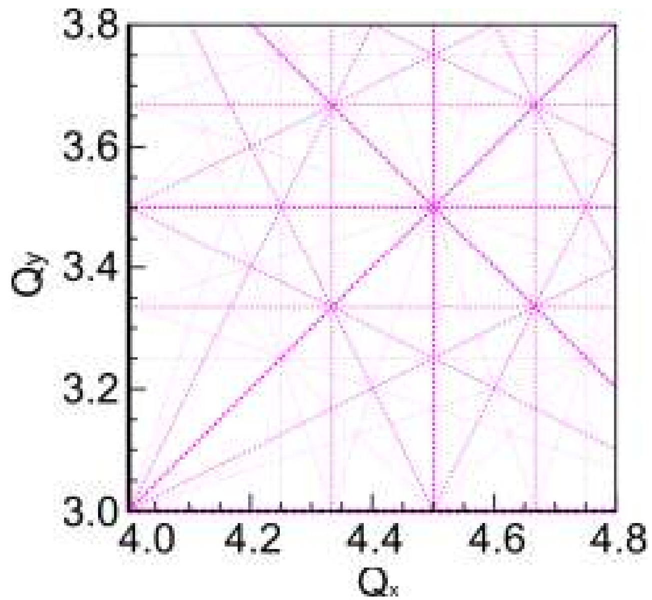
RESONANCES IN CIRCULAR ACCELERATORS

RESONANCE PROPERTY OF THE SOLUTION FOR BETATRON MOTION AS EFFECT OF MAGNET IMPERFECTIONS

CO distortion (displacement of equilibrium orbits)

leakage fields, imperfection of linear fields of the ring's magnets

SIS18 tune diagram



nonlinear components of the ring's magnets

nonlinear correction magnets, if present (chromaticity sextupoles)

Space charge

$$mQ_x + nQ_y = p$$

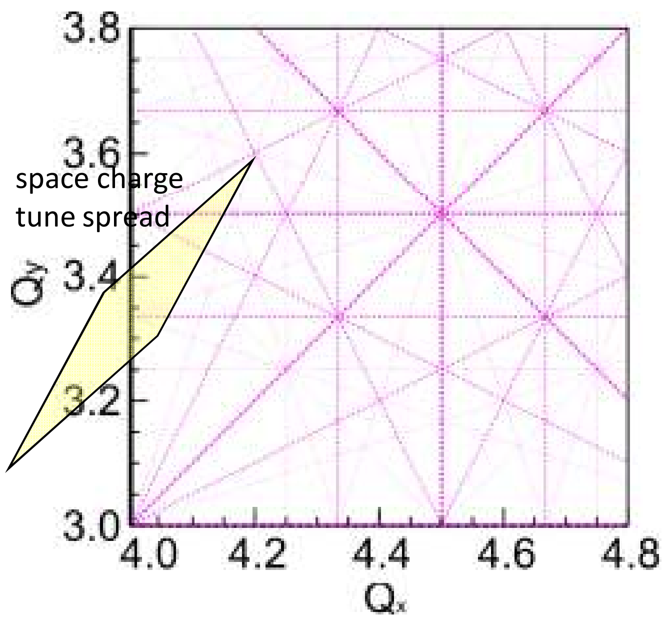
$$|m| + |n| = l$$

l is the order of resonance

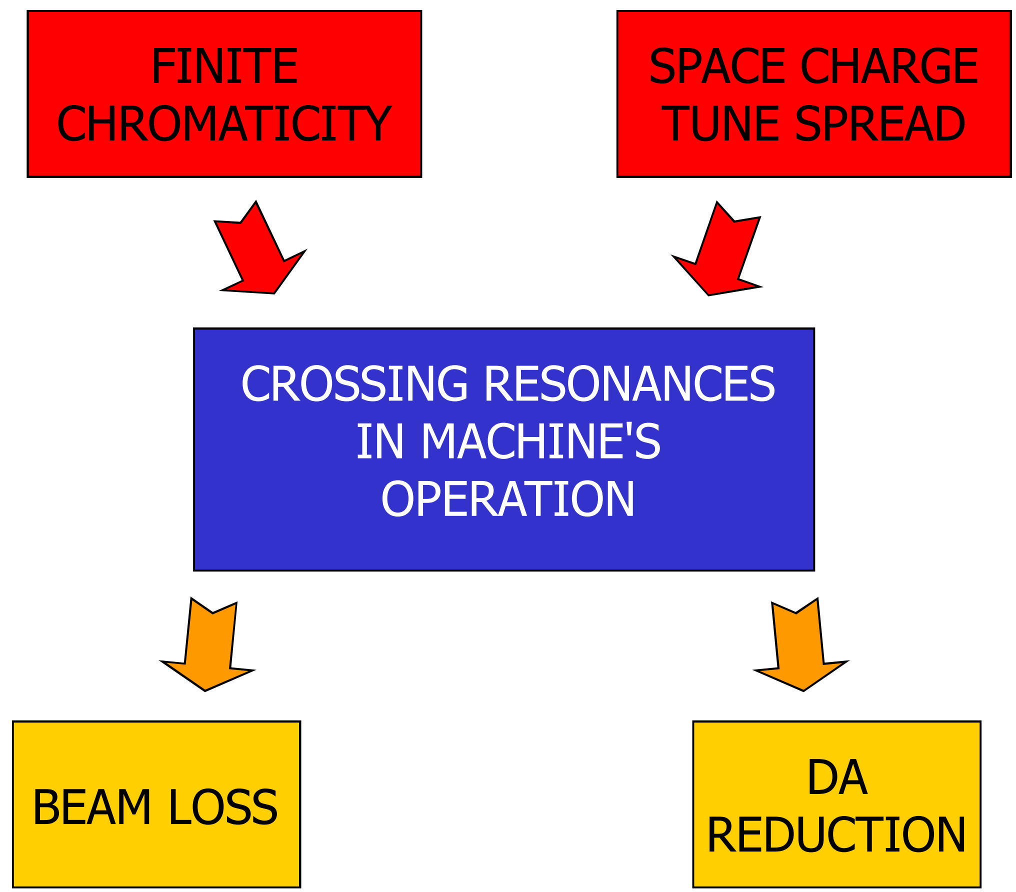
Ref. E.D. Courant and H. S. Snyder, "Theory of the alternating-gradient synchrotron", 1957, NY.

CROSSING RESONANCES

SIS18 tune diagram



STOPBAND is
the area of instability



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RESONANCE DRIVING TERM

is applied in CERN-PS Booster and J-PARC RCS to determine amplitude and phase of the driving resonance components

REQUIREMENTS:
2 simultaneous-BPM acquisition system, (NOT IN SIS AT THE MOMENT)
excited betatron oscillations by a fast Q-kick,
analyze their frequency spectra in the vicinity of the resonant tune

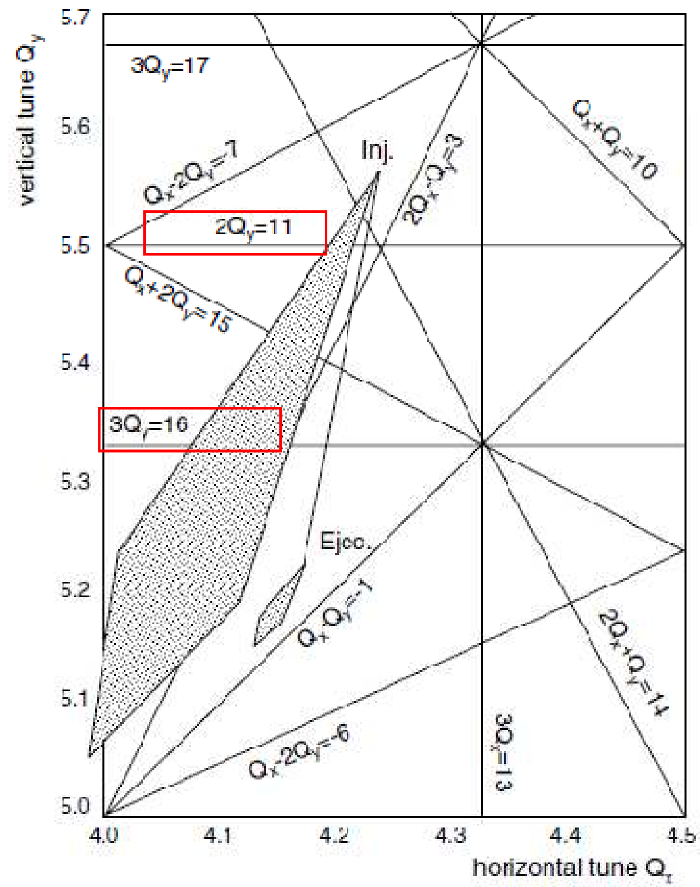
LIMITS:
BPM gain and nonlinearities in the response,
present of nonlinear elements between BPMs,
decoherence of the signal

CERN PS-BOOSTER

The tune spread shrinks proportionally to ***1/***$\beta\gamma$ as the beam is accelerated. The working point is lowered during acceleration towards the nominal values in an area clear of resonances (dynamic working point).

Ref. M.Benedikt et al., PRSTAB 10, 034002 (2007)

CERN-PS Booster tune diagram



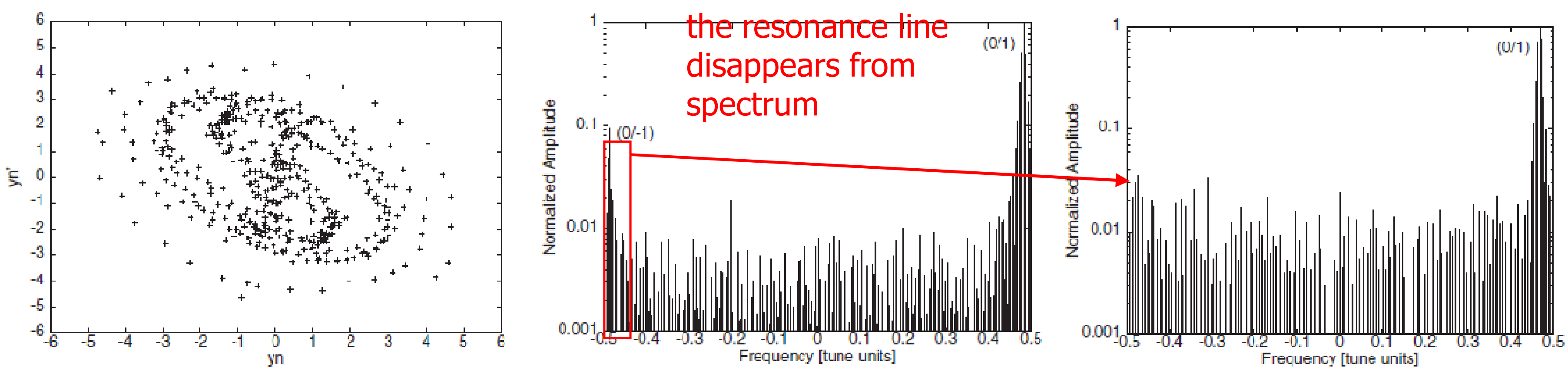
CERN PS-BOOSTER
Vertical half-integer resonance 2Qy=11

With the knowledge of the strength $|h_{jklm}|$ and the phase ψ_{jklm} of the resonance driving term, the compensation currents I for two independent multipole families were calculated with

$$\begin{pmatrix} I_1 \\ I_2 \end{pmatrix} = M^{-1} \begin{pmatrix} |h_{jklm}| \cos\psi_{jklm} \\ |h_{jklm}| \sin\psi_{jklm} \end{pmatrix},$$

Ref. M.Benedikt et al., PRSTAB 10, 034002 (2007)

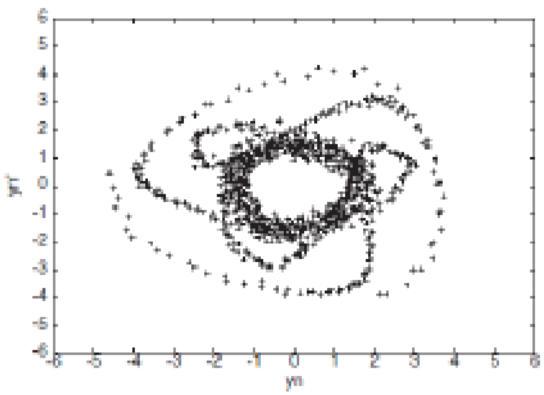
AFTER THE CORRECTION:



CERN PS-BOOSTER
Vertical 3d order resonance 3Qy=16

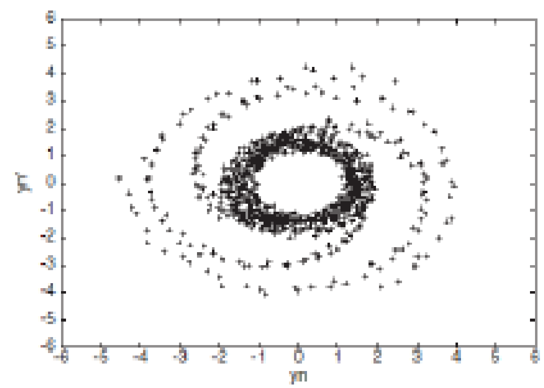
Adjusting vertical tune close to the resonance condition Qy=5.345

BEFORE:

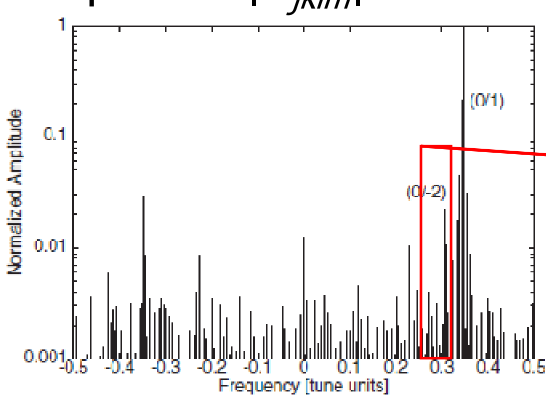


Ref. M.Benedikt et al., PRSTAB 10, 034002 (2007)

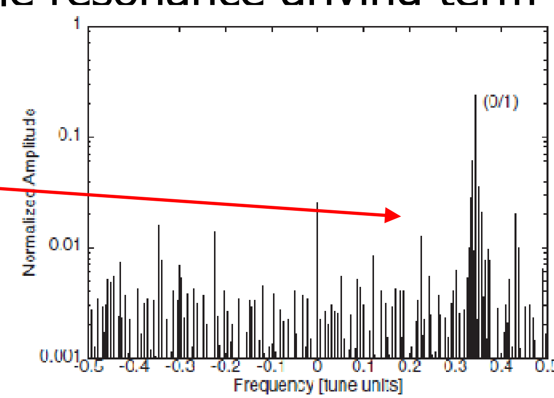
AFTER THE CORRECTION:



The amplitude $|h_{jklm}|$ and the phase ψ_{jklm} of the resonance driving term

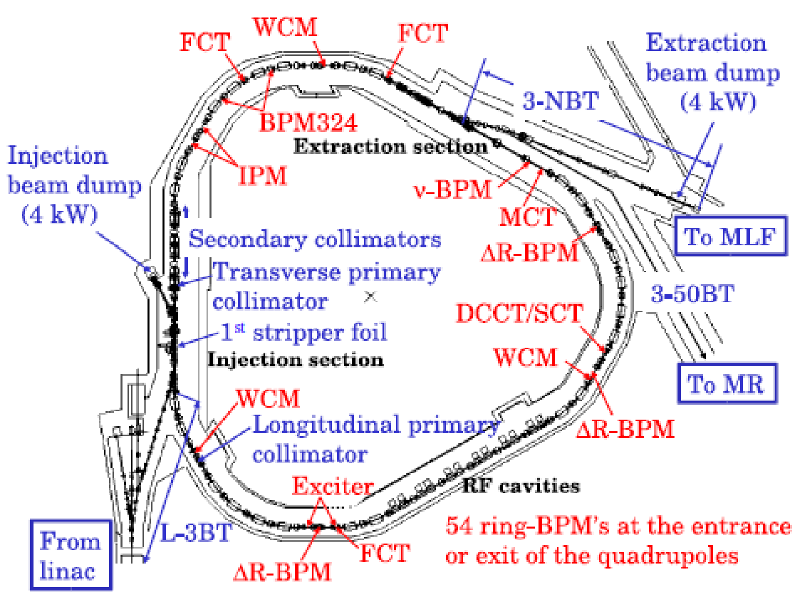


the resonance line disappears from spectrum



J-PARC RCS

Resonance loss is driven by:



Ref. H. Hotchi et al.,
Effects of intrinsic nonlinear fields in the J-PARC RCS, EPAC 2006

Ref. H. Hotchi et al., "Beam commissioning of the 3 GeV rapid cycling synchrotron of the J-PARC", PRSTAB, vol.2, 040402, 2009.

1. possible intrinsic nonlinear fields of the ring's magnets (K_3, K_5 for quadrupoles and K_1, K_2, K_3, K_4, K_5, K_6 for dipoles are considered) + misalignment ;

2. static leakage from extraction beam line (normal and skew quadrupolar componens);

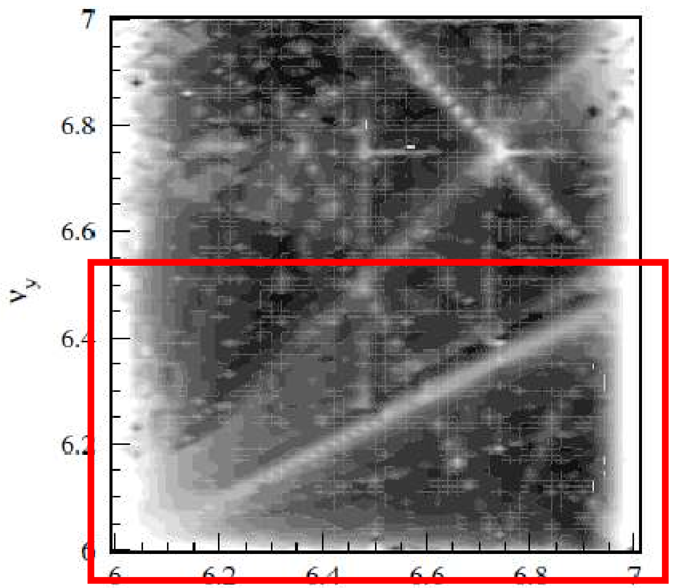
3. fields of the chromaticity sextupoles (sextupolar components);

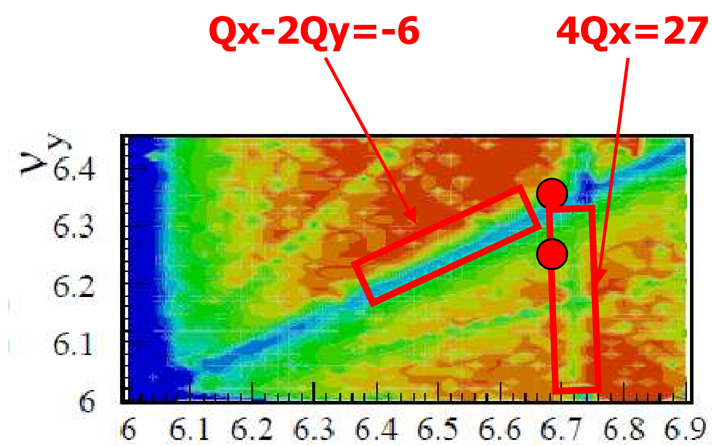
CALCULATED RCS TUNE DIAGRAMS: trade off chromaticity correction

ONLY 1. intrinsic nonlinear fields of the ring's magnets

INCLUDING

3. effect of the chromaticity sextupoles turned ON





They worked out a correction of its' RDT, additional correction sextupole system is required, not installed

$$G_{1,-2,-6}e^{j\zeta} = -\frac{\sqrt{2}}{8\pi}\oint \frac{B_y^{(2)}}{B\rho}\sqrt{\beta_x\beta_y^2}\times$$
$$\exp j\{\chi_x(s) - 2\chi_y(s) - (\nu_x - 2\nu_y + 6)\theta\}ds$$

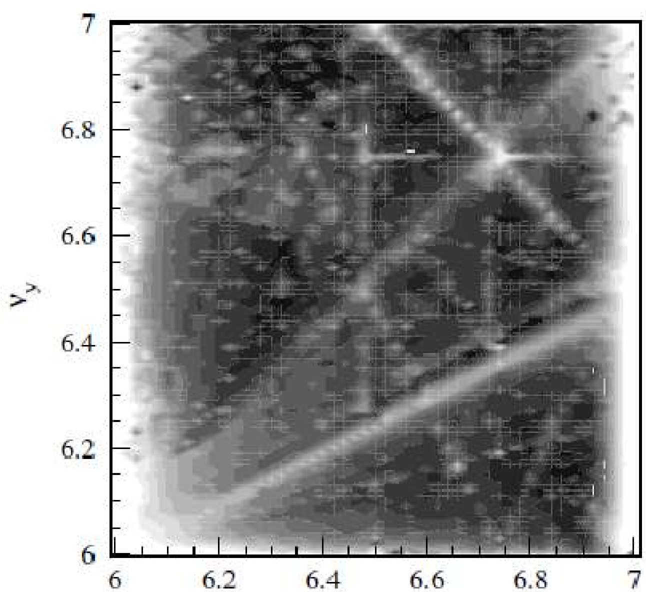
CALCULATED RCS TUNE DIAGRAMS:

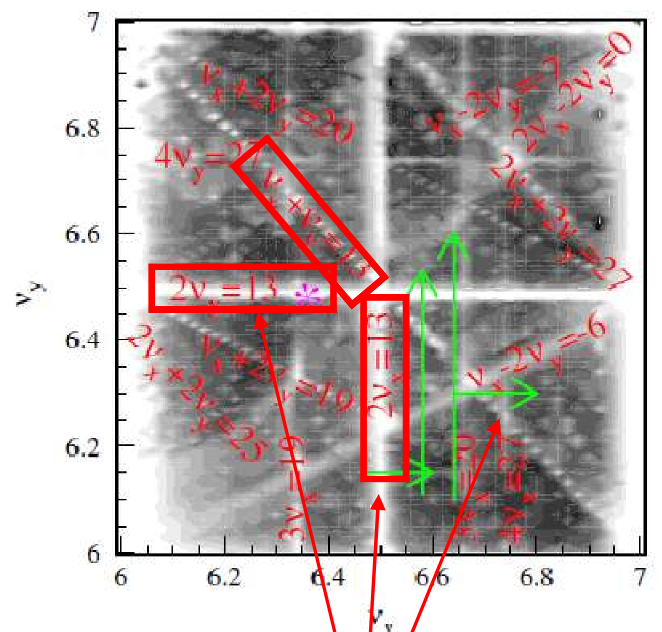
strong leakage fields

ONLY 1. intrinsic nonlinear fields of the ring's magnets

INCLUDING

2. static leakage from extraction beam line

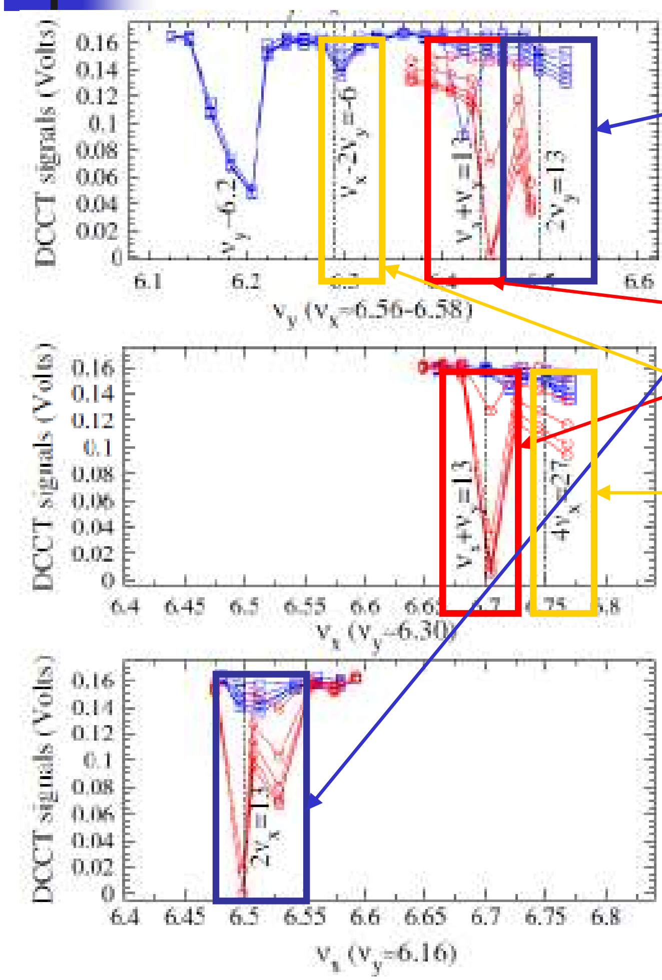




TOP PRIORITY, since a strong limitation on the betatron tunability is imposed

the excited resonances are two the horizontal and vertical half integer and one linear coupling resonance

MEASURED BEAM LOSS IN RCS



half integer resonances
2Qx=13 and 2Qy=13

linear coupling
Qx+Qy=13

Excited by the chromaticity sextupoles 4Qx=27 and Qx-2Qy=-6 <u>tend to dim in this measurements</u>

Ref. H. Hotchi et al., "Beam commissioning of the 3 GeV rapid cycling synchrotron of the J-PARC", PRSTAB, vol.2, 040402, 2009.

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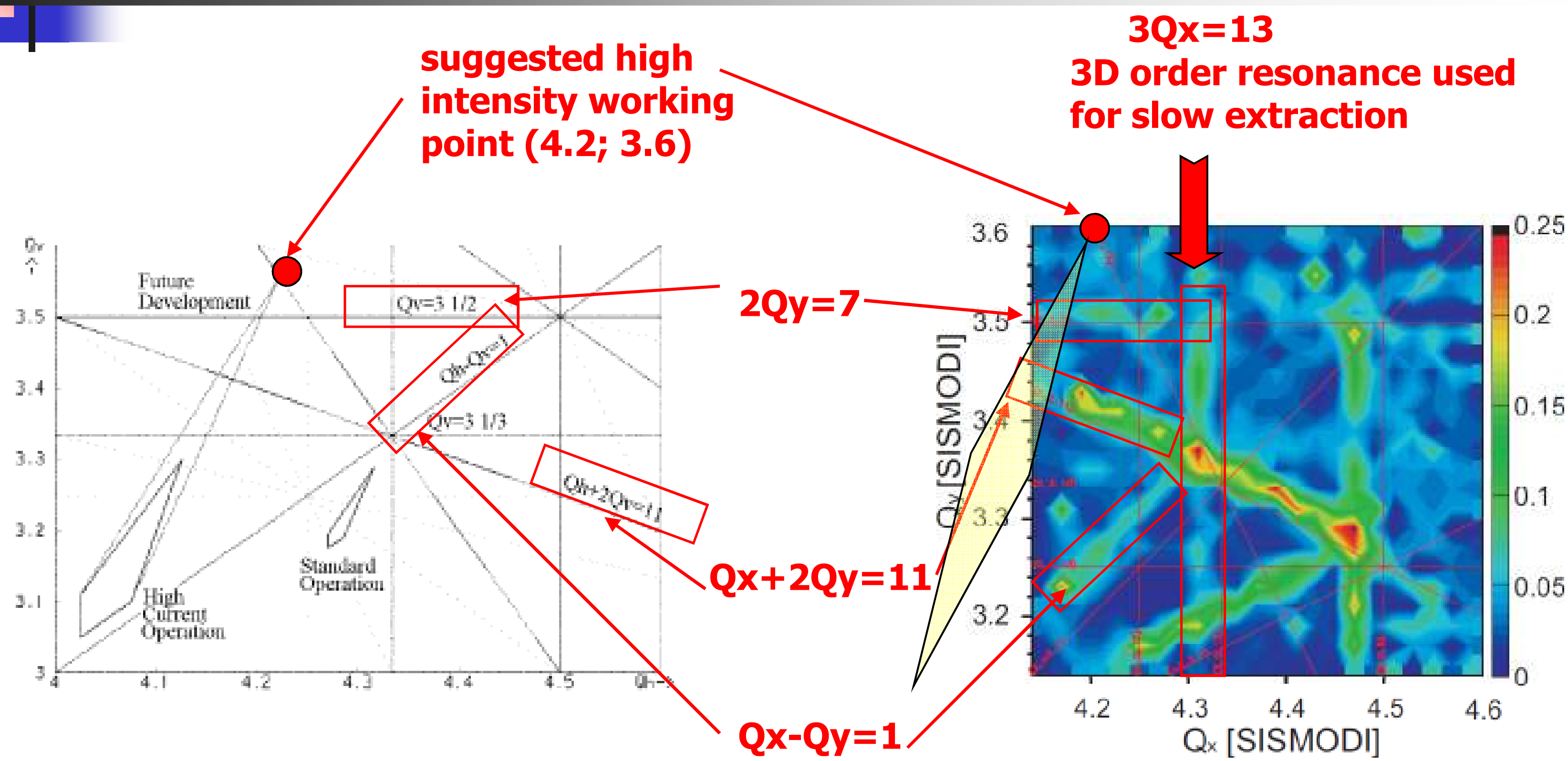
RESONANCES IN THE SIS18: THE MOST RELEVANT



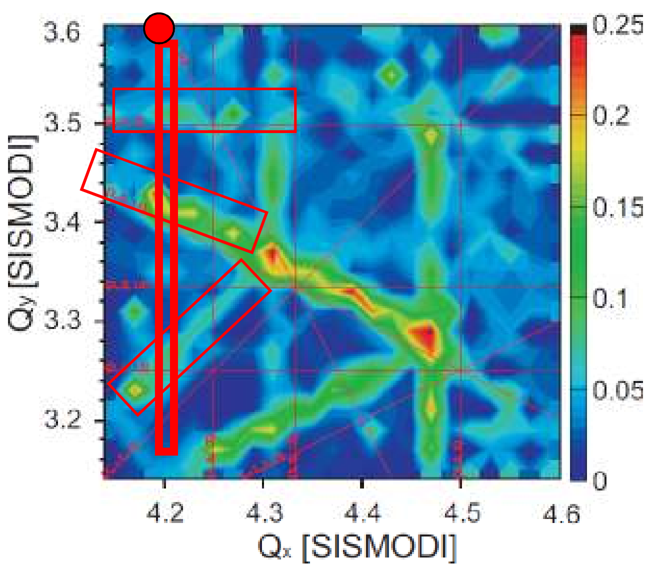
Ref. K. Blasche et al.,
SIS Operation at High Beam Intensities,
PAC **1999**

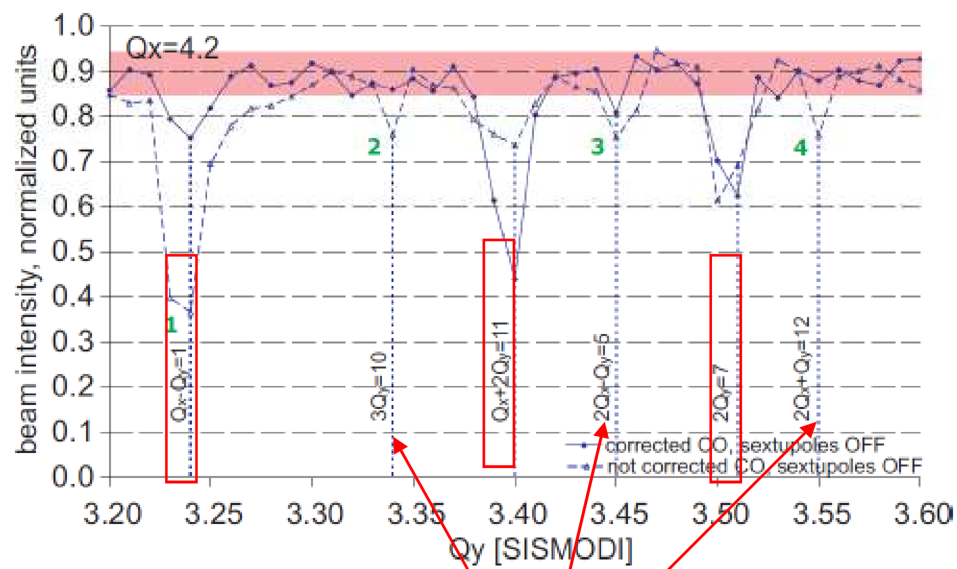
Measurement .G. Franchetti, **2004**

MEASUREMENTS OF BEAM LOSS IN THE SIS18

WHAT IS THE BEST WAY TO MEASURE RESONANCES?!

DYNAMIC OR STATIC BEAM LOSS SCAN?

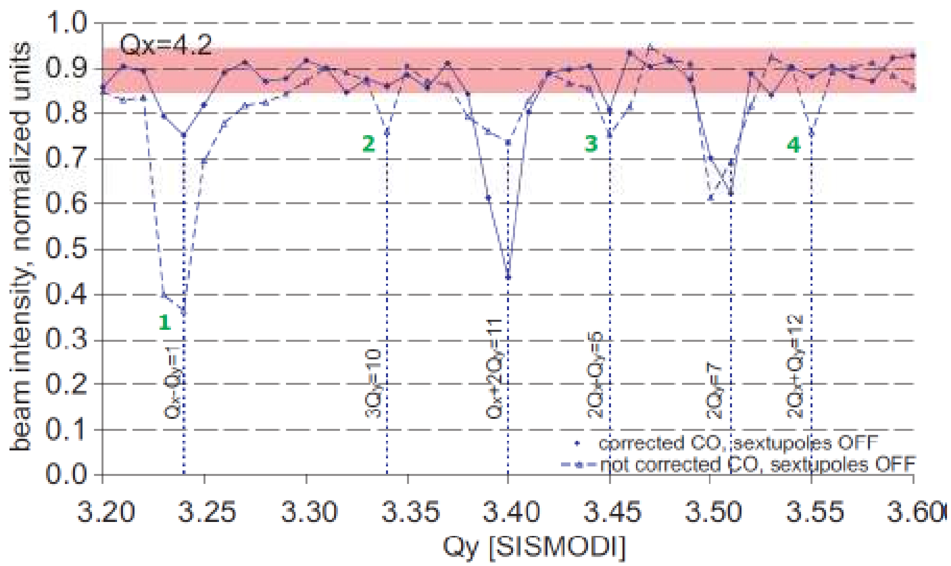


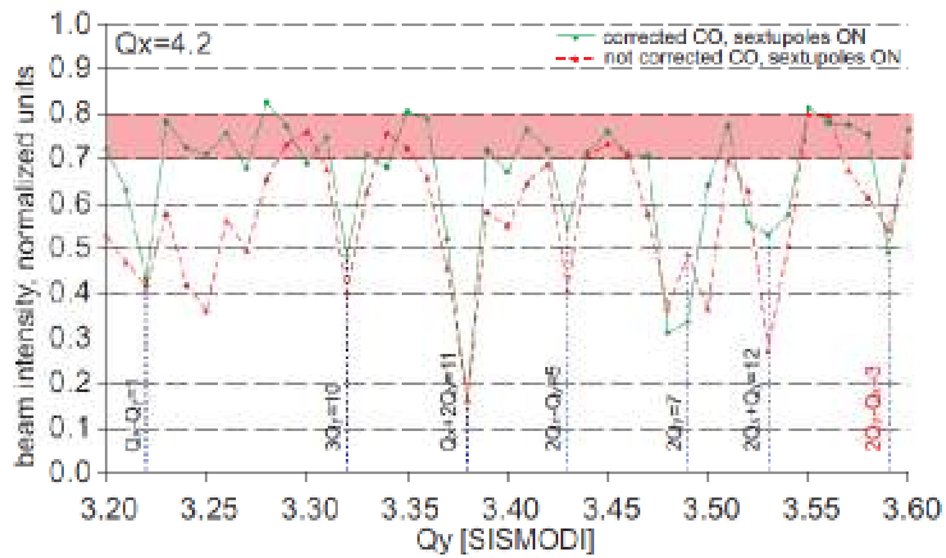


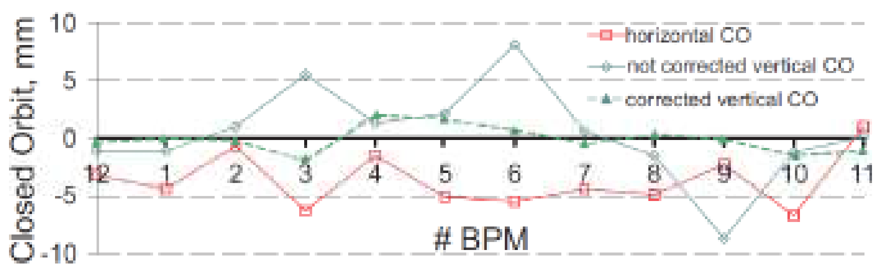
THE SAME 3 STRONG RESONANCES ARE IDENTIFIRED IN THE STATIC SCAN

other visible third order resonances appeared due to the CO distortion

BEAM LOSS IN PRESENCE OF CO DISTORTION AND CHROMATICITY SEXTUPOLES







ONLY VERTICAL CO DISTORTION BY MEANS OF 3 LOCAL BUMPS

CORRECTION ELEMENTS OF THE SIS18

4 normal quadrupoles to correct **2Qy=7**
S02KQ4, S04KQ4, S08KQ4, S10KQ4
Their calibrations have been checked in my measurement in 2009

8 skew quadrupoles to correct linear coupling **Qx-Qy=1**
S01KM3QS, S02KM3QS, S04KM3QS, S06KM3QS, S07KM3QS, S08KM3QS, S10KM3QS, S12KM3QS

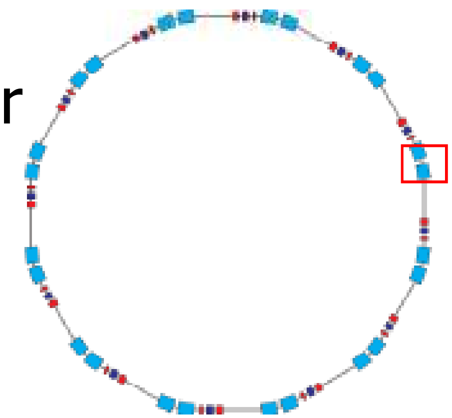
2 skew sextupoles **S02KM5SS and S08KM5SS** to correct vertical 3D order resonances **3Qy=10**
Their calibrations have been checedk in my measurement in 2008

All chromaticity sextupoles are powered separately and could be used for correction purpose **4Qx=13, Qx+2Qy=11**

Ref. K. Blasche et al., SIS Operation at High Beam Intensities, PAC 1999

SUGGESTIONS FOR COMING MEASUREMENTS & DISCUSSION

to measure dynamically TUNE DIAGRAM together with NTRM reconstruction of 12 normal integrated sextupolar errors for 3 different working points (1 error pro 2 dipoles)



3D ORDER CANDIDATES:

3Qx=13 (used for the slow extraction)

Qx+2Qy=11 (strong loss)

SUGGESTIONS FOR COMING MEASUREMENTS & DISCUSSION

TO CONSIDER METHODS TO GET LINEAR/NONLINEAR ERRORS DRIVING RESONANCES:

- ORM (to get quadrupolar field errors)
- NTRM (to get sextupolar error-components)
- INDEPENDENT COMPONENTS ANALYSIS, SY. LEE, (2 SIM. BPMs ARE NEEDED),
- RESONANCE DRYVING TERM (2 SIM. BPMs ARE NEEDED), R. TOMAS, CERN
- NONLINEAR CHROMATICITY, CERN (A. FRANCHI AT GSI, ANOTHER TRY AT GSI ?)