Octupole correctors in SNS and damping of instabilities

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Damping of instability with octupoles

Questions which we want to answer:

- **How much tune spread we can introduce with octupole correctors?**
- **How is it effective with space charge?**

3. **How much tune spread do we need with space charge?**
4. **Does it introduce significant beam loss due to octupole resonances?**

Octupole correctors

4H and 4V; N=292 turns, I=10A (I_max=20A)

Octupole:: 150 [T/m^3] for I=10 A or 300 [T/m^3] for I_max=20A

Corresponding tune spread (rough estimate) : 0.006 (I=10A)

0.013 (I=20A)

PS allow I=20A, putting two together gives 40A.

However, current limitation comes from magnet itself with

only I_max=17A (nominal current I=10A).

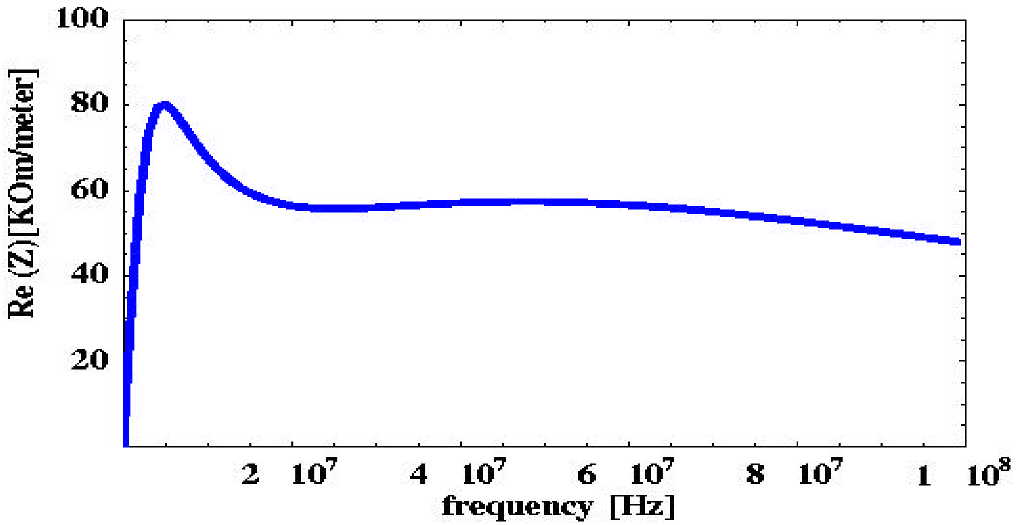
Octupole correctors are designed for resonance correction - not for generation of significant tune spread for Landau damping!

Expectation

- **Based on existing simplified theory we can stop right here with conclusion that introduced tune spread is too small compared to the space charge tune shift/spread and thus will have no stabilizing effect.**

- **However, the theory is oversimplified and we want to check what do we really get with a more detailed study.**

Re(Z) for full 14-kicker system (May 2002)



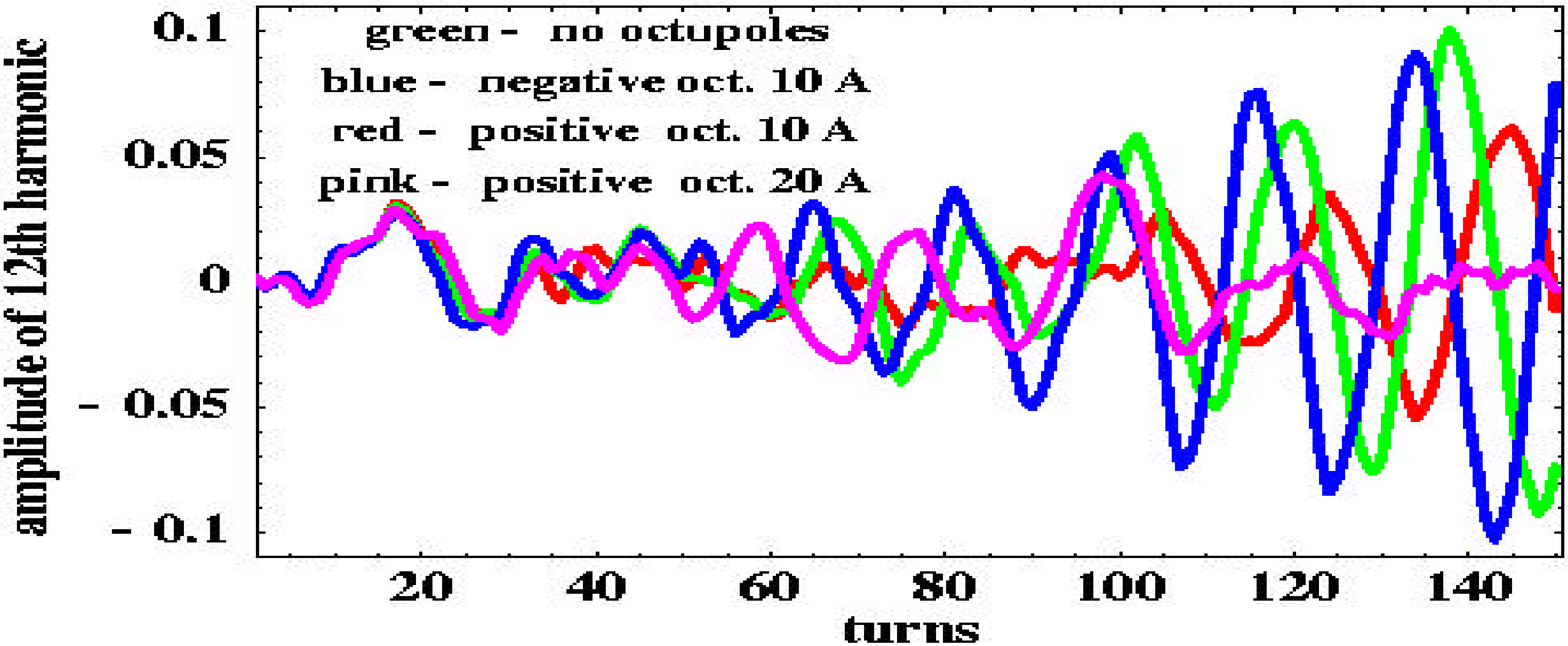
Impedance model (EK) used in simulations.

Note that present impedance is a factor of 2 smaller – no additional Landau damping with octupoles is required for the baseline intensity (we have "stable" beam: 1ms^{-1} growth rate without noticeable halo by the end of accumulation).

Simulations

- We first explore effect of octupoles by injecting full intensity beam with 2*10^14 protons with the distribution based on painting (half a million particles).
- We then proceed with realistic 1060-turn injection.
- We explore both growth rates of unstable harmonics and associated halo.

Effect of octupoles – full beam



Here Y-octupoles are used (octupoles which are located at large Beta_y and small Beta_x)

Using X-octupoles for Y damping

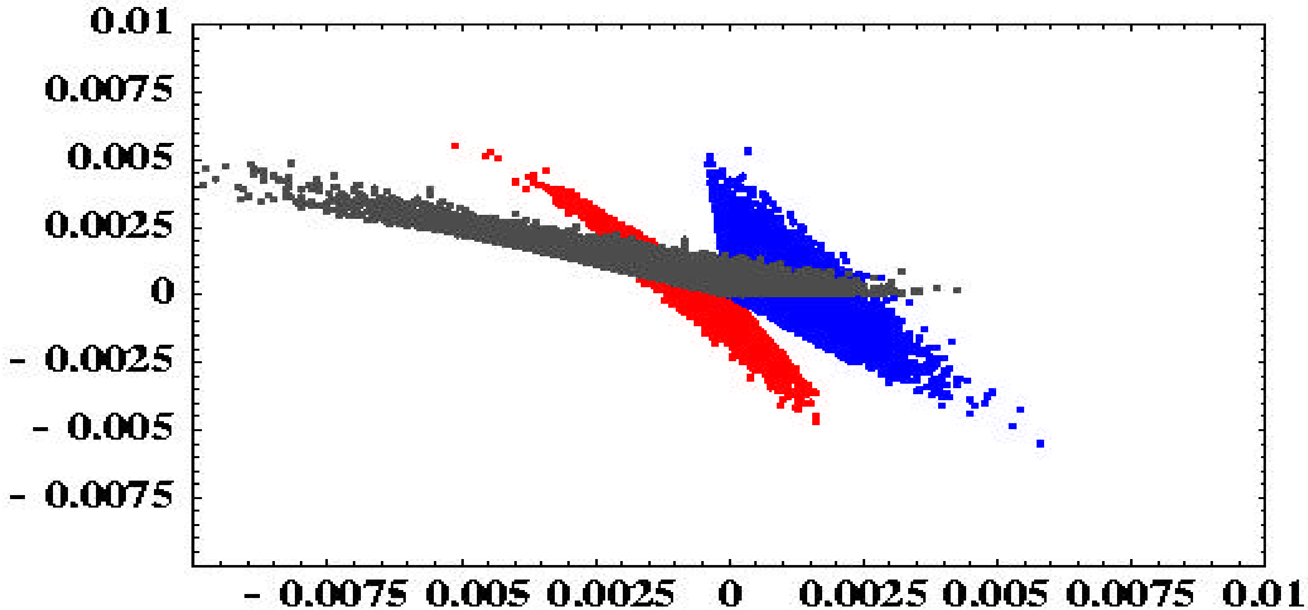
- Analyzing the tune spread we can see that we have both positive and negative spread in Y direction with Y-octupoles. However, negative part is not expected to be important since space charge depresses tunes in negative direction as well.

The question is then "How we can introduce the most effective tune spread which will work effectively with space charge?"

Proposal : Use X-octupoles with negative sign to produce such shift in Y-direction.

Is such X-octupole spread more effective?

Tune spreads



Red – positive (10 A) Y octupoles (b_y=11m)

Black- negative (10 A) X octupoles (b_x=11m)

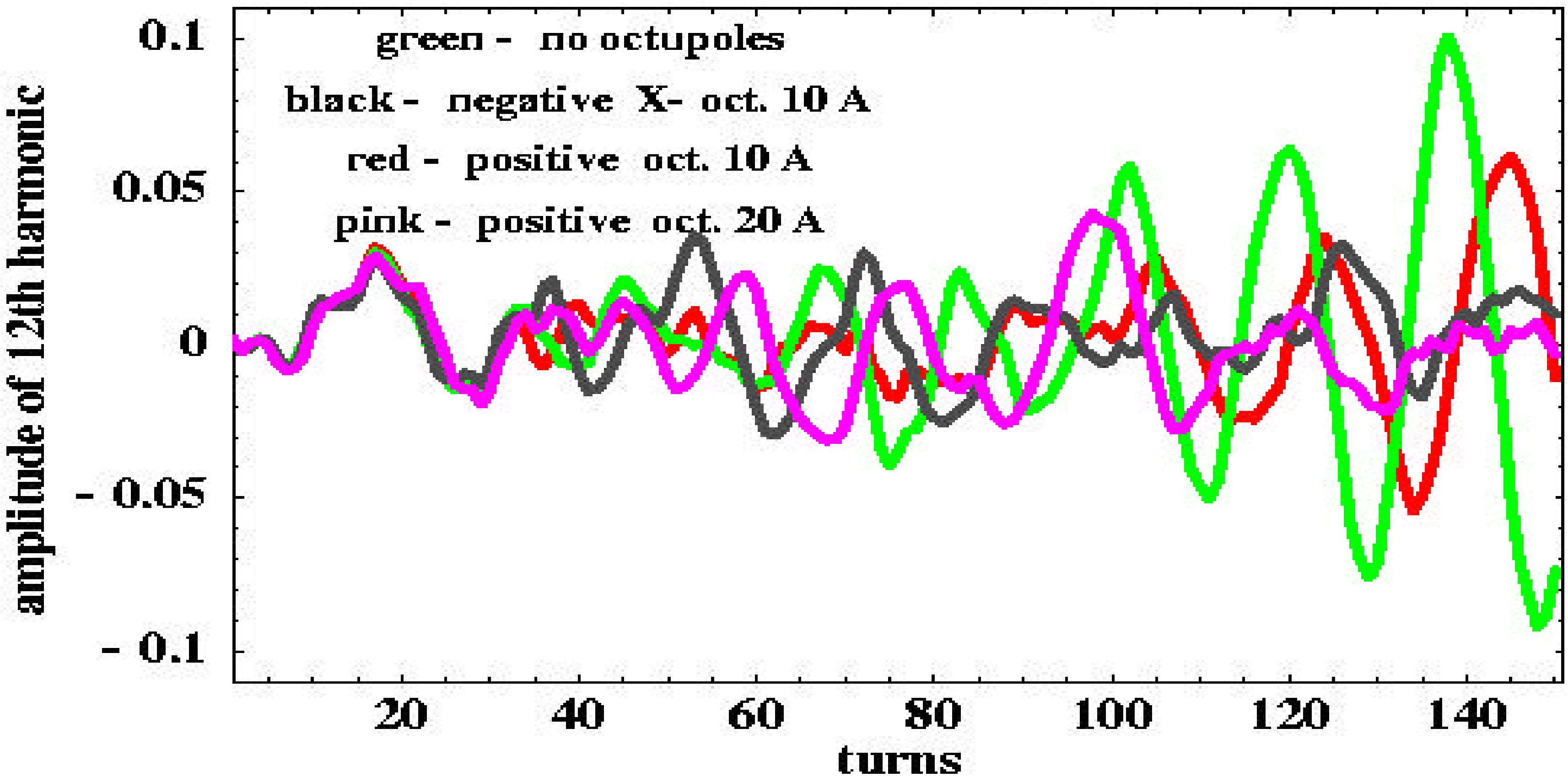
Blue – negative (10 A) Y octupoles (b_y=11m)

X-octupoles

- With such X-octupoles we can see that all tunes in X have now desired positive vertical spread in Y for Landau damping.

Next Figure demonstrates that with X-octupoles desired damping is achieved with twice less current than with Y-octupoles.

Effect of octupoles – full beam

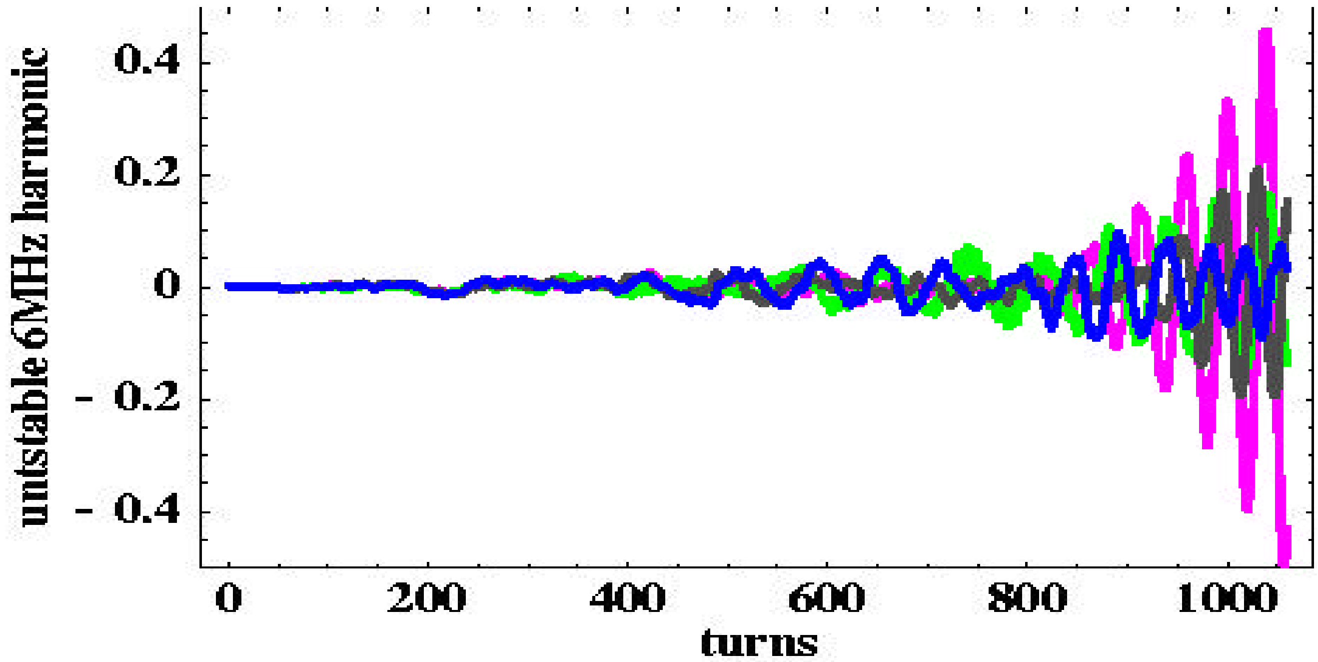


1060-turn injection

- Unfortunately, we do not have full-intensity beams and we have to check how this damping will work during accumulation process.

- Next Figures show that strength of octupole correctors which is sufficient for full beam is not enough for the case of multi-turn injection.

Growth rates with X-octupoles & Y-octupoles during painting.



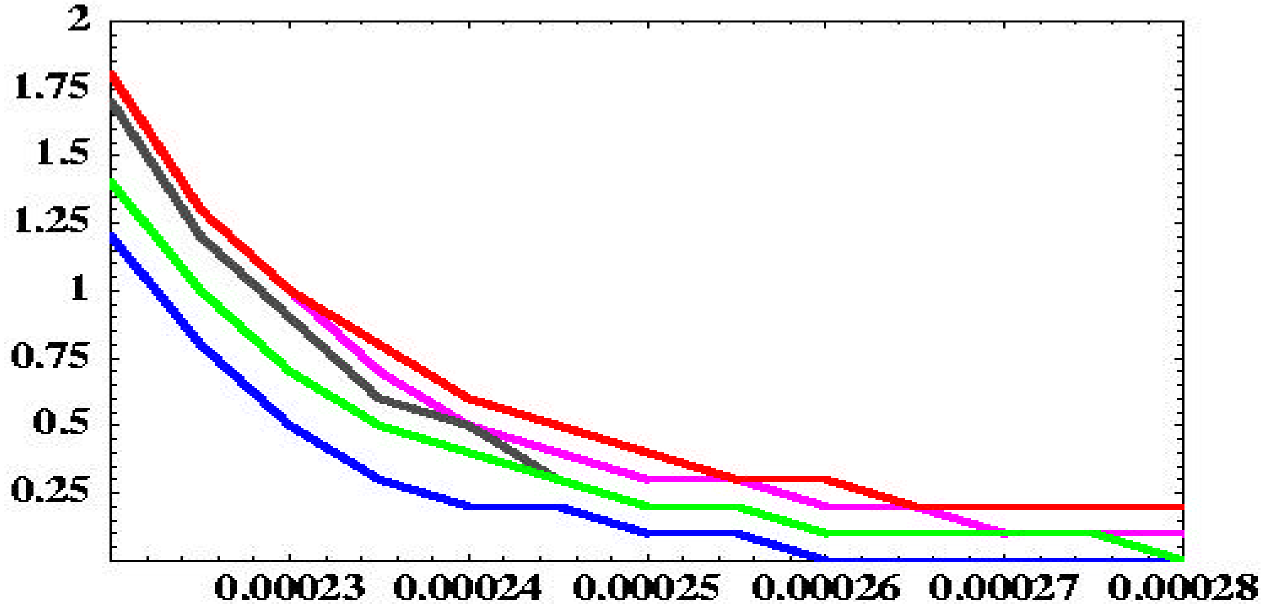
pink – positive y-octupoles (17 Amp)

green –positive y-octupoles (40 Amp)

black – negative x-octupoles (17 Amp)

blue – negative x-octupoles (40 Amp)

Halo after 1060-turn injection



Blue – no impedance

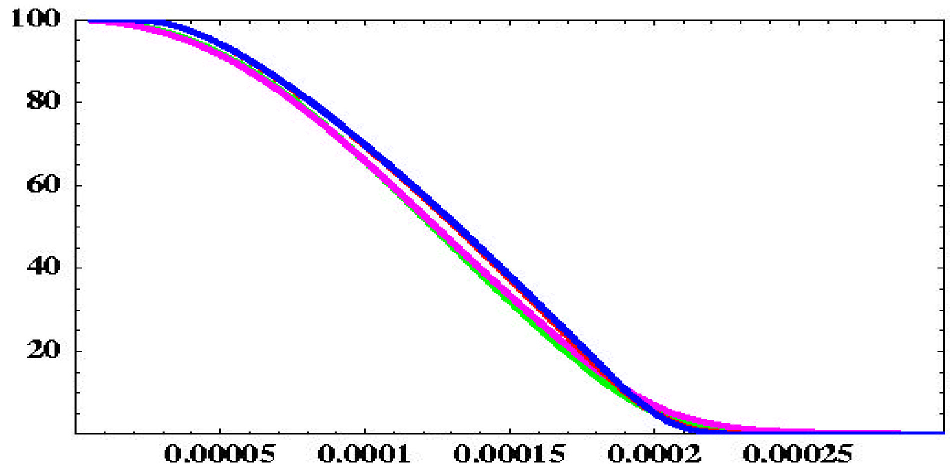
Red – impedance, no octupole correctors (halo due to instability)

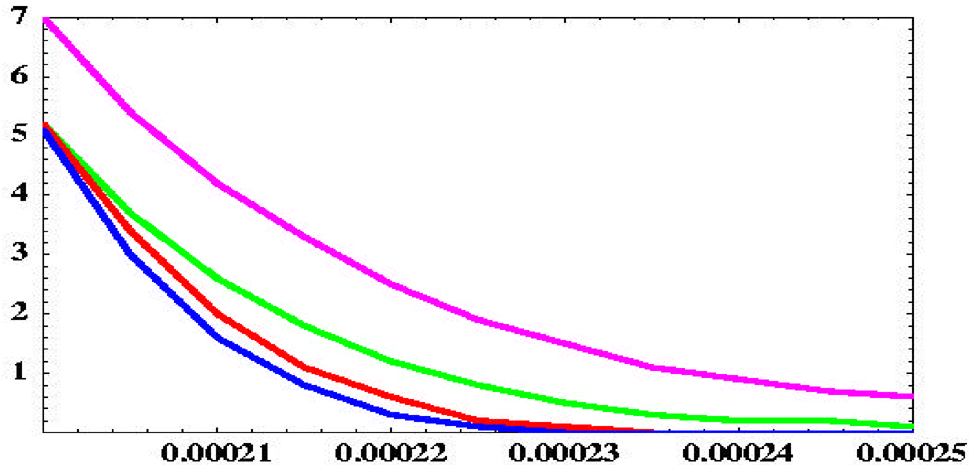
Black– 17A negative x-octupoles

Pink – 17A positive y-octupoles

Green- 40A positive y-octupoles

Total emittances





Blue- no sc, no octupoles

Red –no sc, oct- xn-40A

Green- sc, no oct

Pink – sc, oct-xn-40A

Question & answers

- For the same reason as Vertical octupoles did not drive ¼ resonaces at n=25, Horizontal octupoles should not as well.

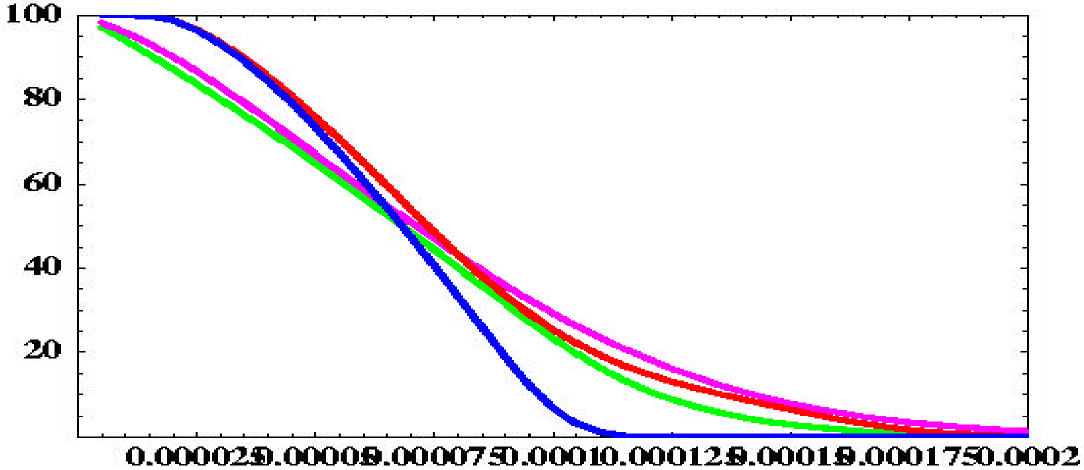
- What is then the source of emittance increase with Negative

Horizontal octupoles of 40A (needed to damp the instability)?

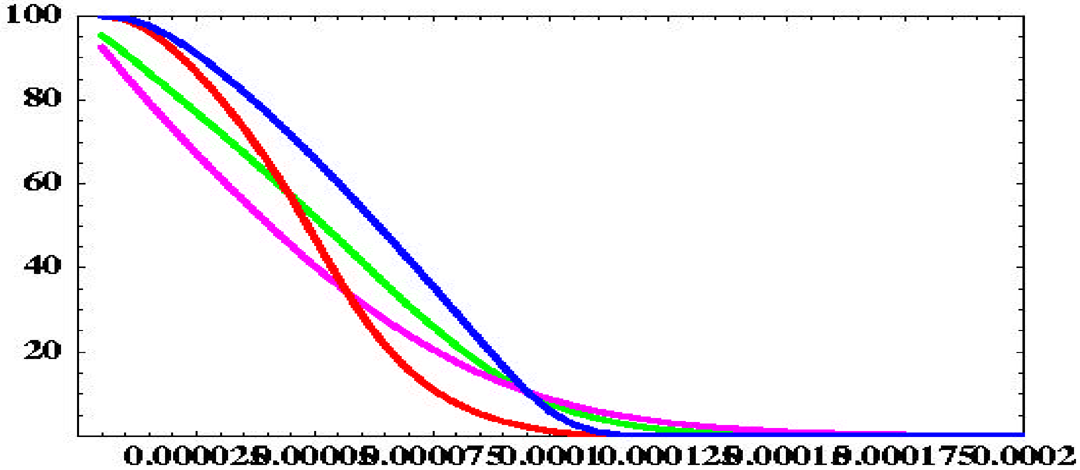
Is it some other resonance?

Is it space charge effect?

X and Y emittances:



x



y

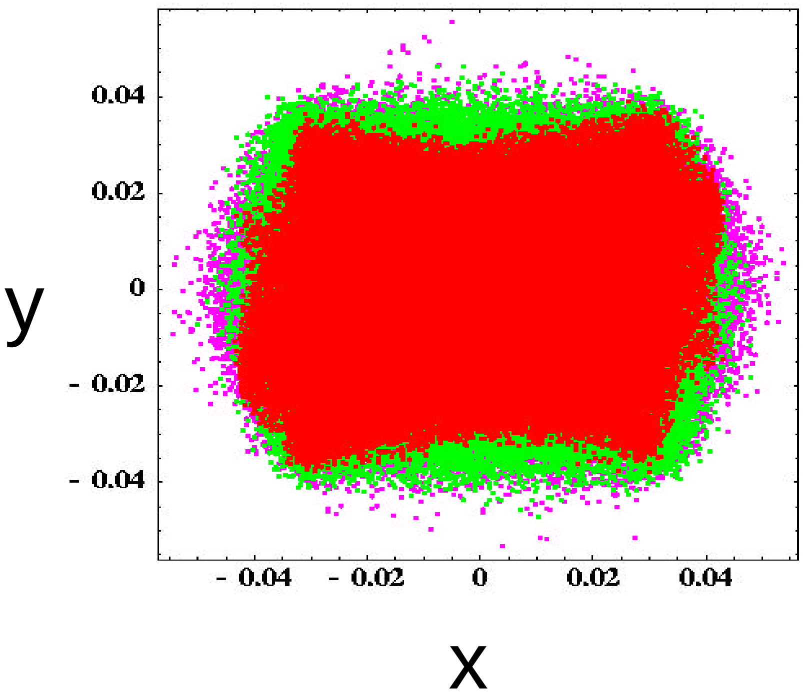
Blue- no sc, no octupoles

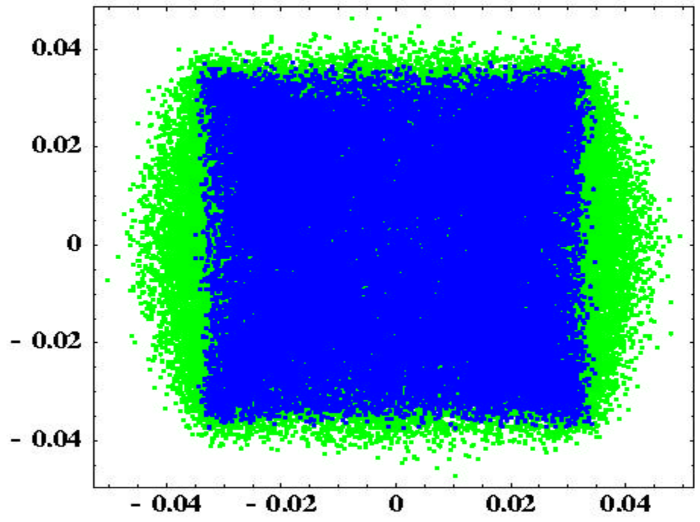
Red –no sc, oct- xn-40A

Green- sc, no oct

Pink – sc, oct-xn-40A

Beam profiles





Q & A continued

- Emittance growth is due to the motion in the strong nonlinear field – similar to the sextupoles effect which we had before.

- Also, similar to the case of sextupoles:

- Without space-charge - huge effect
- With the the space –charge – emittance growth and redistribution due to space-charge coupling is dominant.

Observations

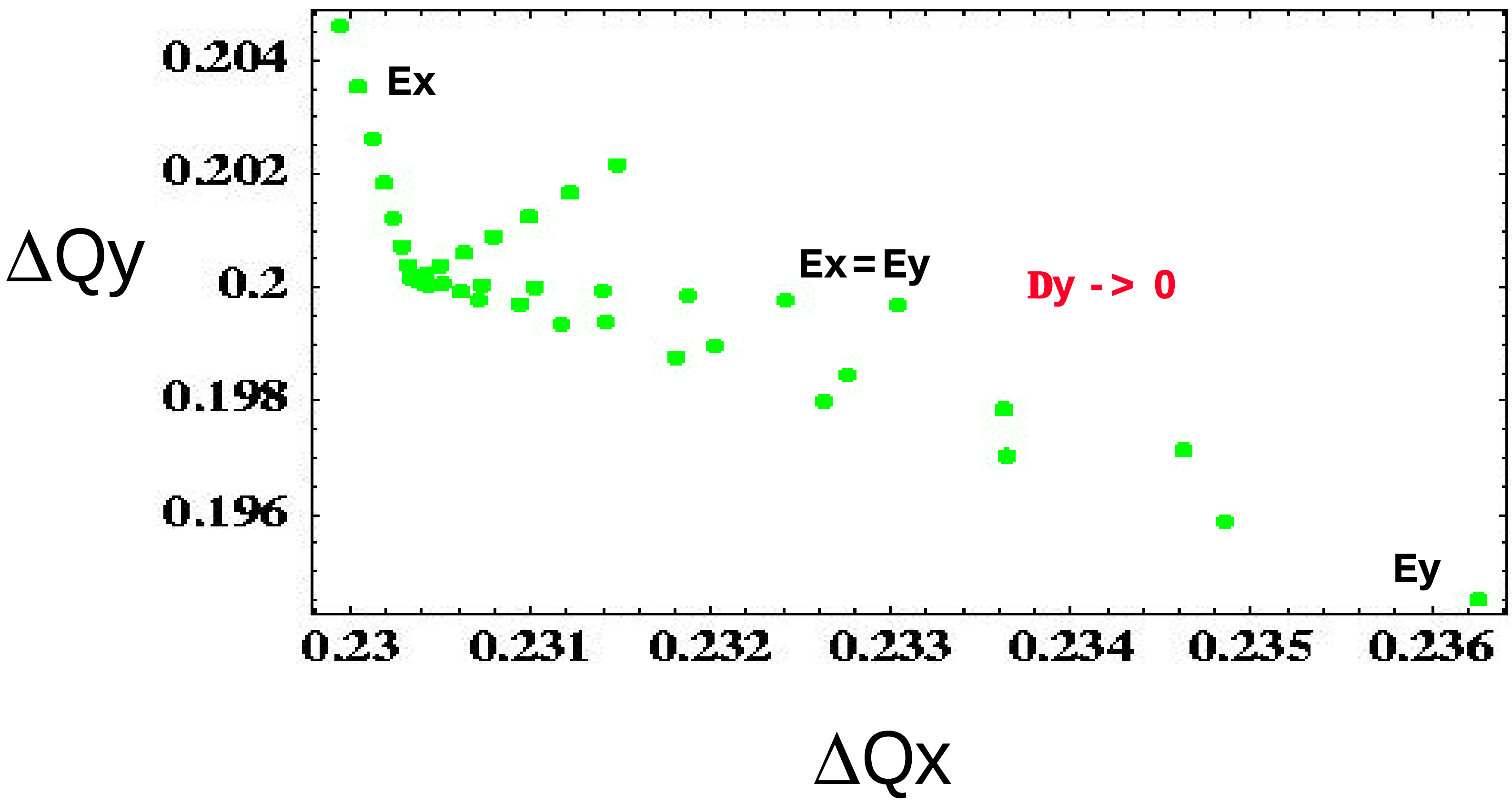
- X-octupoles are more effective than Y-octupoles
- Strength of octupoles correctors (Imax=17A) is not enough to damp instability but the growth rate can be significantly reduced.
- The growth rates were significantly reduced to 1ms^{-1} with only 0.015 (40Amp) tune spread (10 times smaller than space-charge spread of 0.15)
- For the base line working point, no strong reduction of dynamic aperture is expected since we have one corrector per arc. As a result, due to supersymmetry of 4, we do not drive strong resonances at harmonic N=25 (4Q=25).
- When we achieve required octupole strength to damp the instability, the emittance growth due to motion in nonlinear fields become important. Even in the presence of dominant space charge coupling such emittance increase becomes noticeable.

Learning about effective tune spread

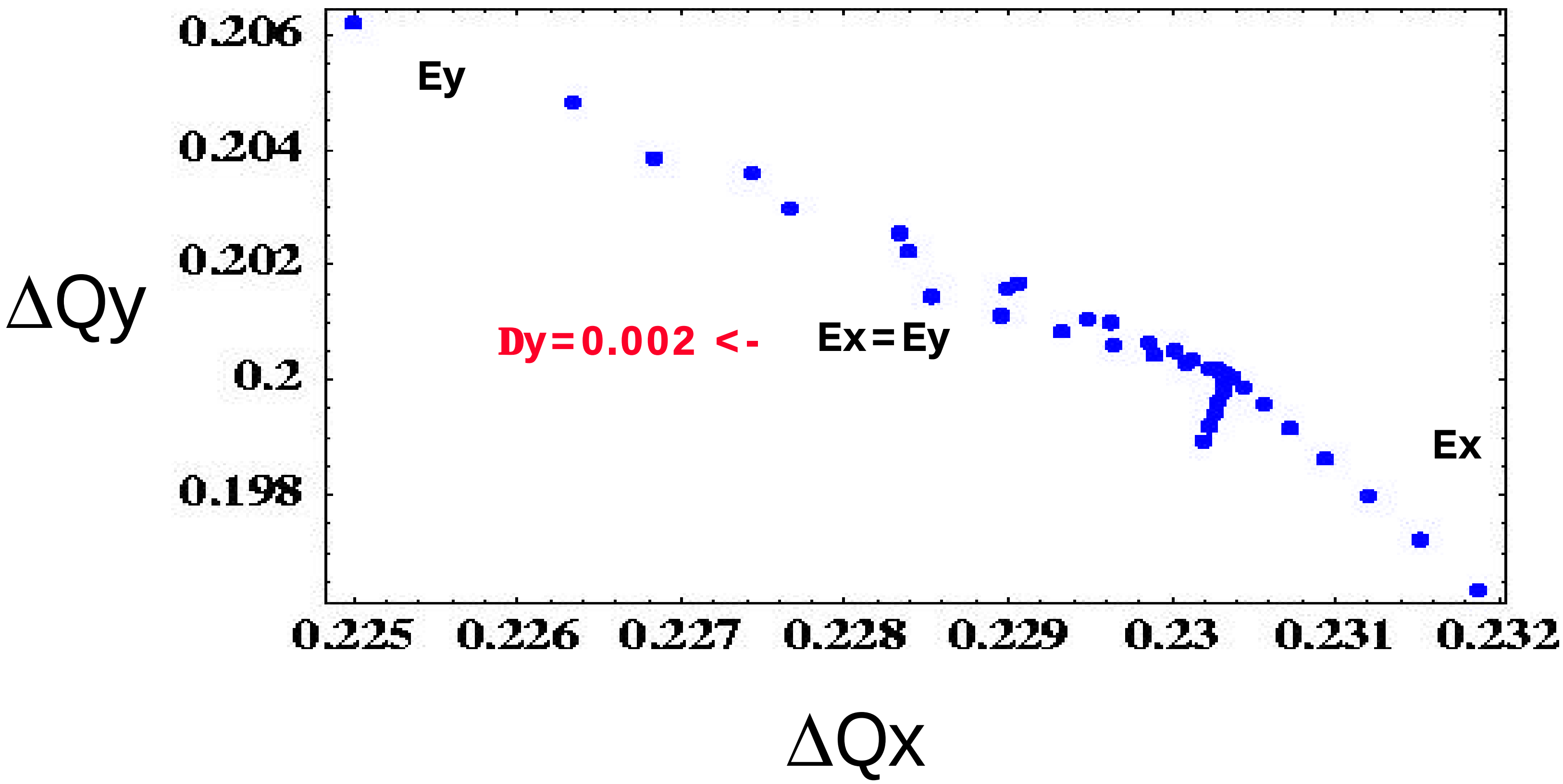
- Can we understand why one setting of octupoles is more effective then the other.
- What is the required sign of octupoles correctors?
- Can we do better job using both families of correctors?

- The answer to all of the above questions is yes.

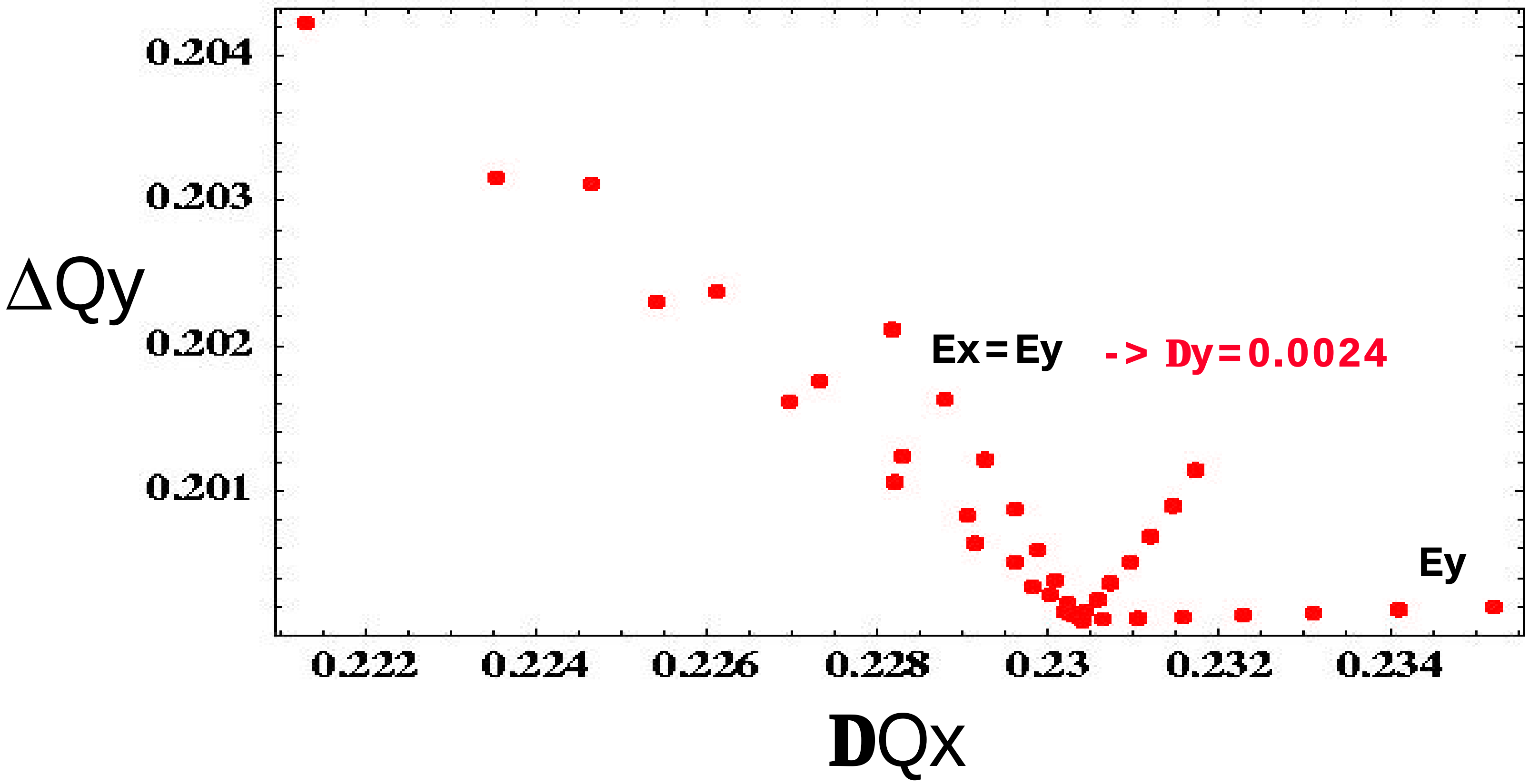
Negative sign y-octupoles



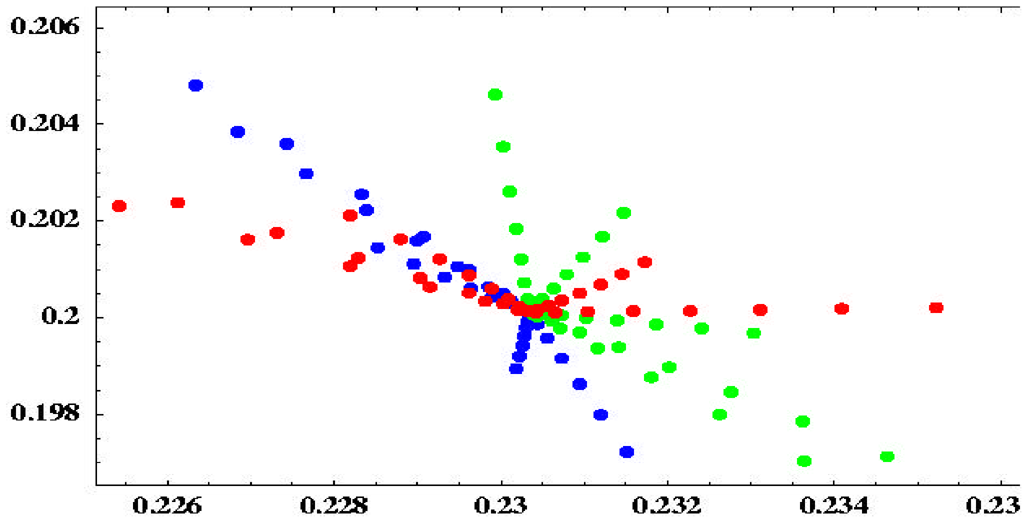
Positive y-octupoles



Negative x-octupoles



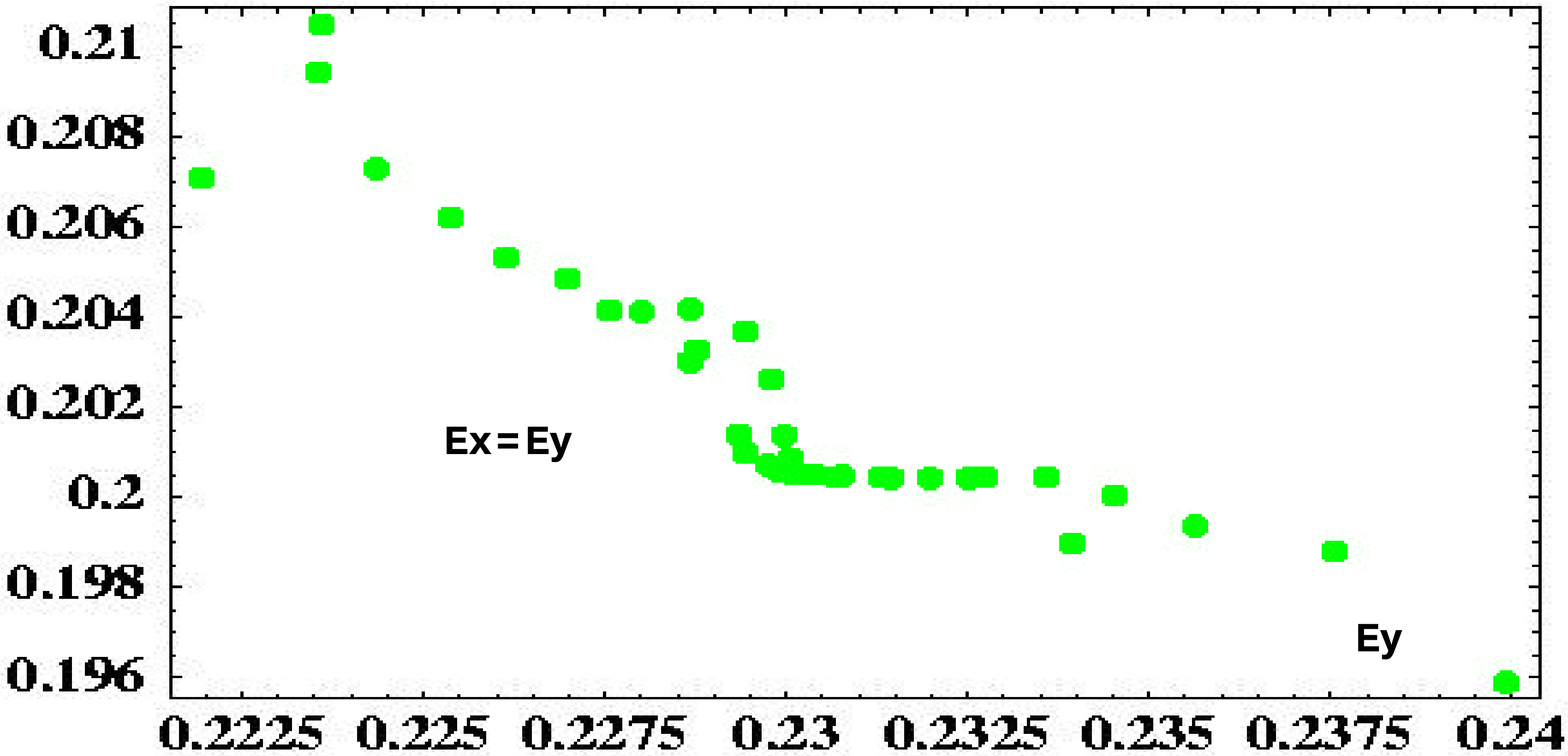
Tune spreads with negative y-oct. (green), positive y-oct. (blue) and negative x-oct. (red)



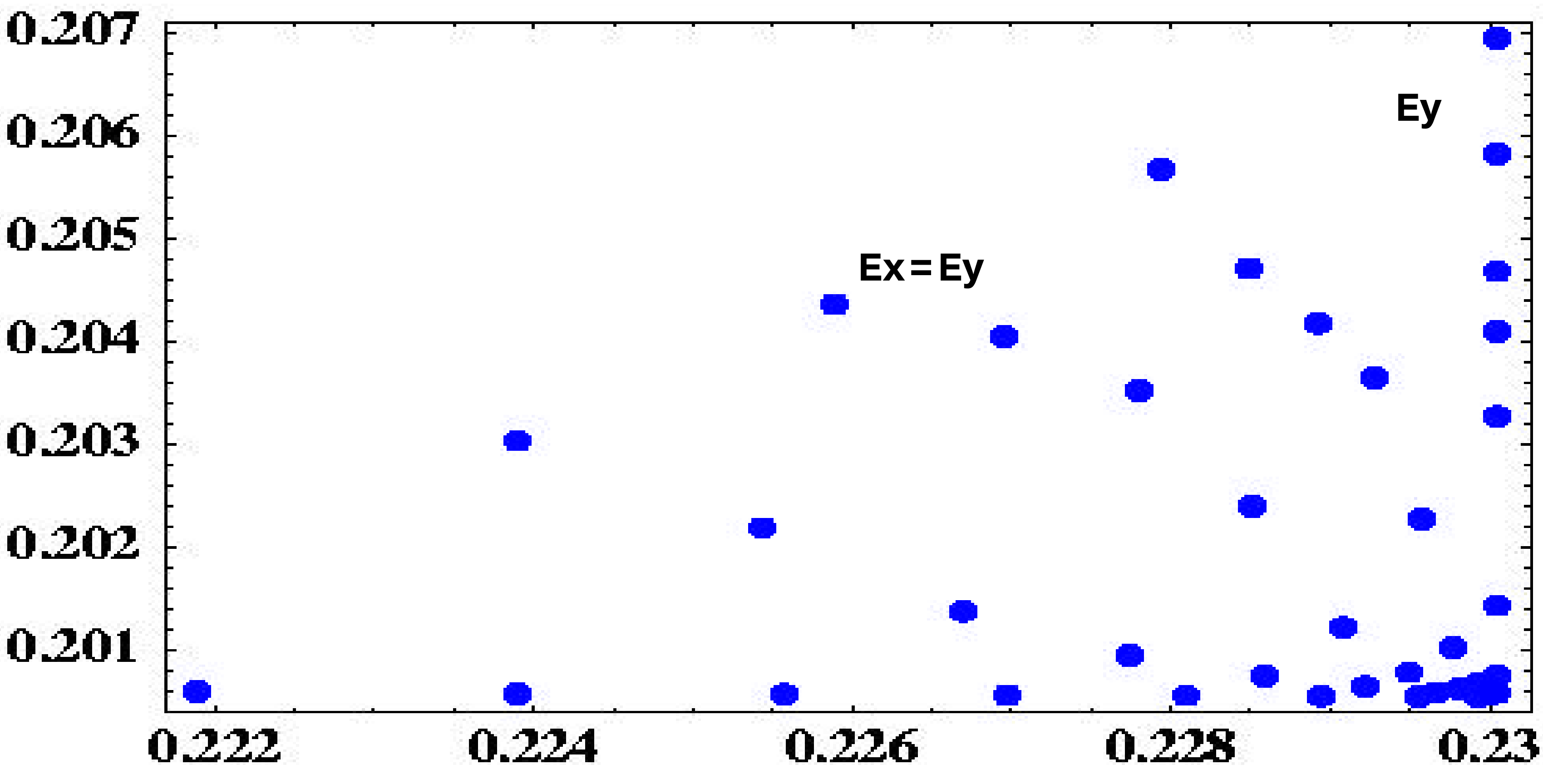
Based on the tune spreads we then conclude that positive Y-oct. and negative X-oct. give most effective tune spread for our distribution– this is confirmed in simulations.

It is then expected that YP-oct + XN-oct – is the most effective setting of two families. It is then suggested that with appropriate setting of both families me may even have significant damping with a nominal current.

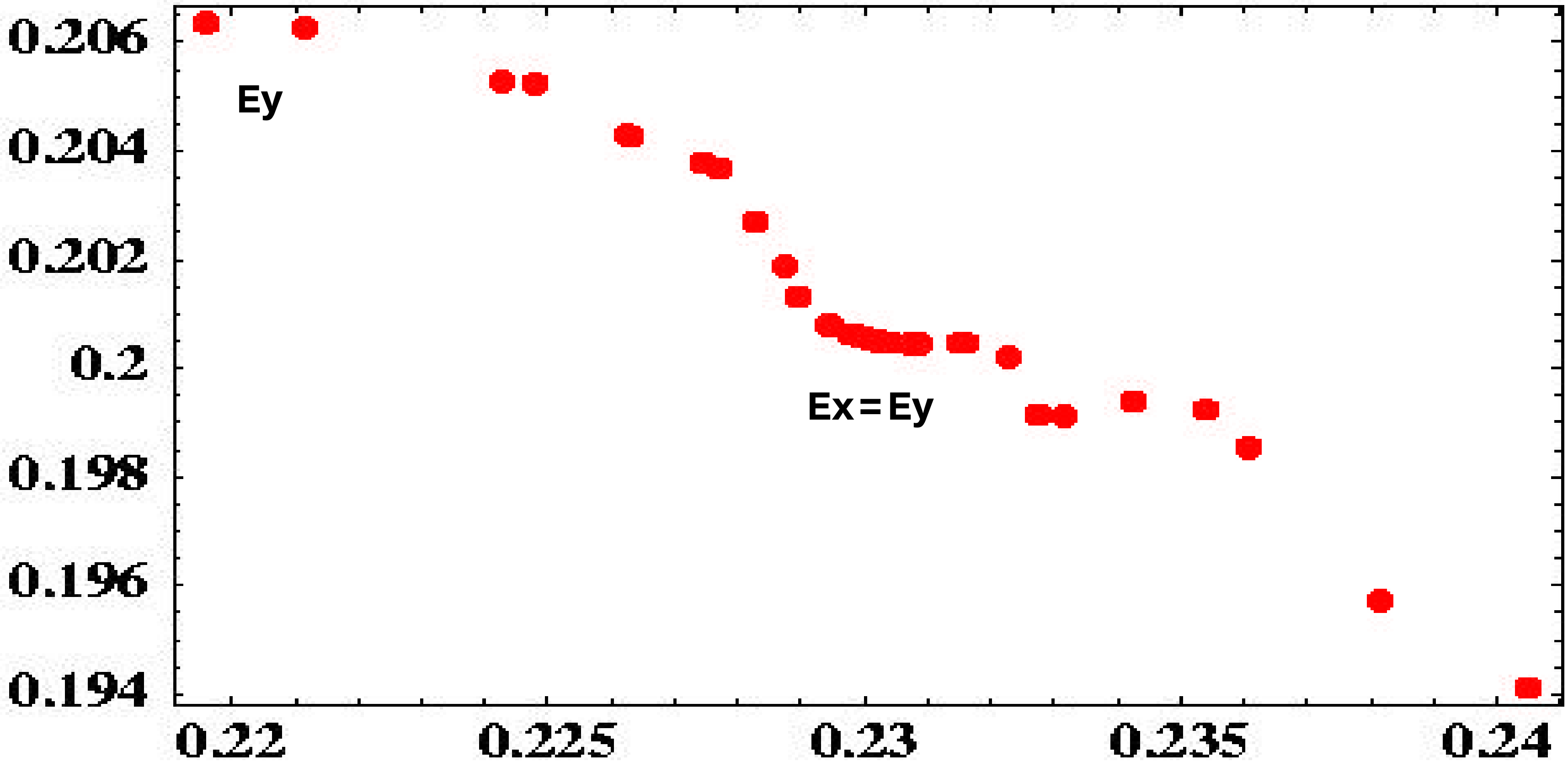
Tune spread with both negative x and y-oct. (10 Amps)



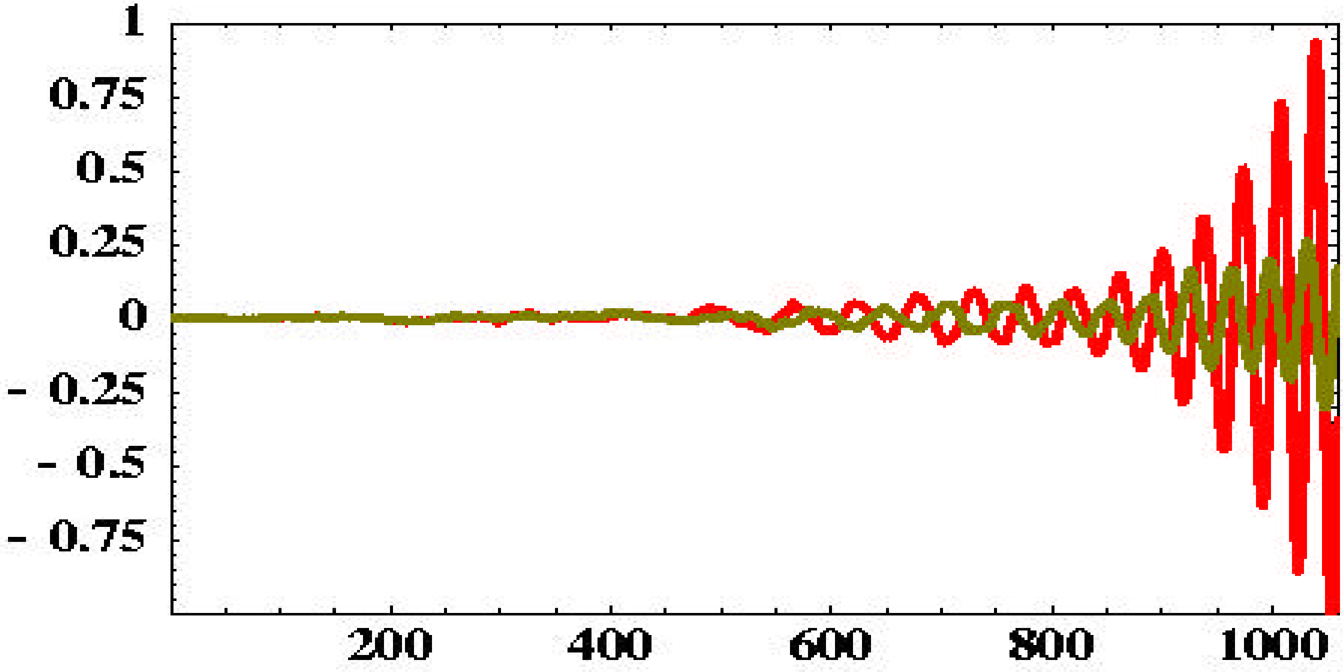
Tune spread with positive y and negative x octupoles (10 Amps)



Tune spread with positive x and y octupoles (10 Amps)



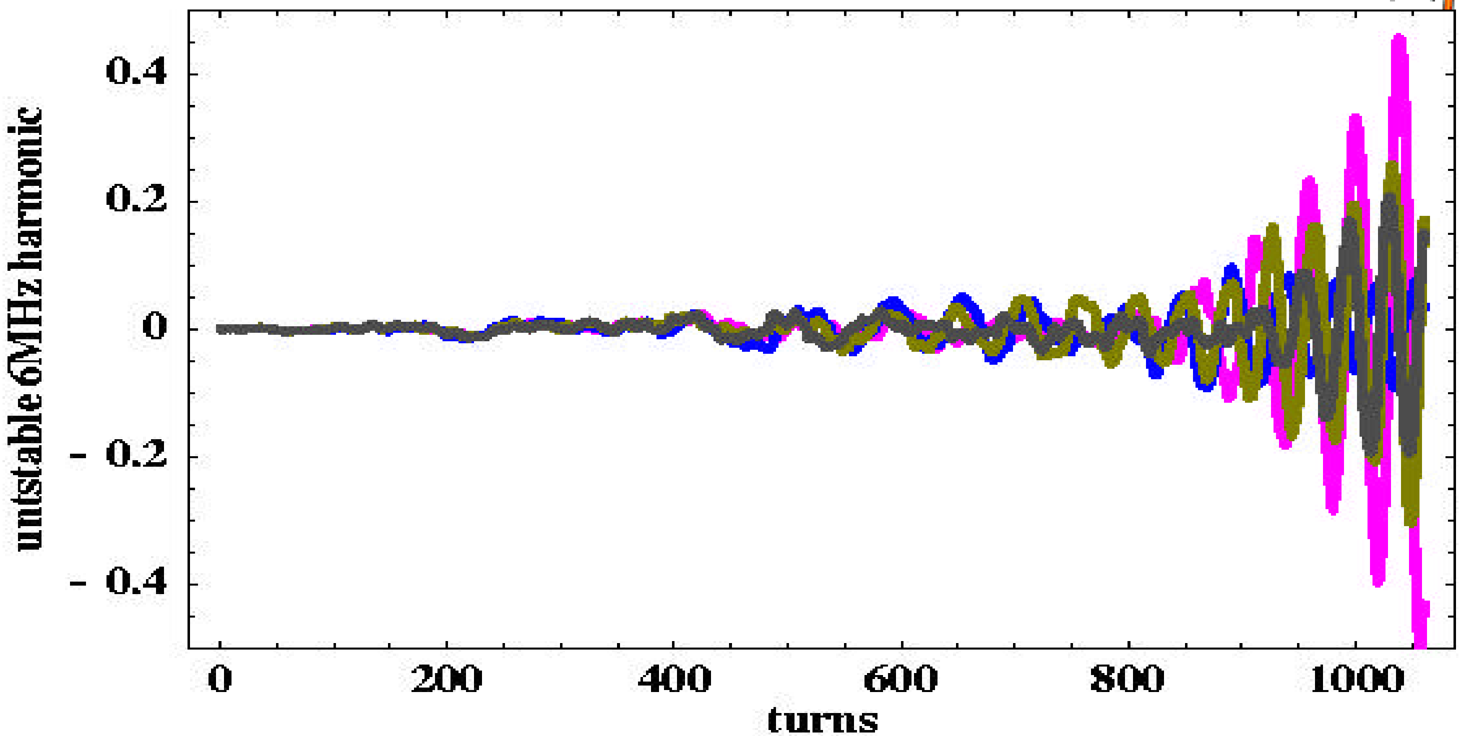
Growth rates with two familes of octupoles at nominal current of 10A.



red – yn & xn- octupoles (10 Amp)

green –yp & xn –octupoles (10 Amp)

Two families vs one



black – xn (17 Amp)

green – xn & yp (10 Amp)

Practical findings

- To begin with, “old impedance” was used to study instability damping with octupoles. For new impedance – the growth rates at baseline intensity are negligible. In addition, in simulations with old and new impedances the model impedance was used which is on conservative side (overestimate).
- Octupole correctors produce very small tune spread. However, simulations suggest that such a tune spread may be, in fact, effective.
- With appropriate settings of correctors, we can avoid driving imperfection harmonic stopbands and thus use octupoles for damping without introducing resonance loss.
- Damping is less effective during painting than for the full size beam – this is because the spread for large amplitudes becomes effective when we actually reach such amplitudes by the end of accumulation.

Interesting findings

- Very low spread due to octupoles (0.005-0.01) is found to have damping effect despite expectation from the theory that is too small. Possible explanation is that simplified theory does not take into account the fact that head and tail of the bunch are not depressed by the space charge. Thus even very small tune spread due to nonlinearities produce overlap of incoherent tunes with the coherent spectrum for these parts of the beam.
- Effect due to two families of octupoles - seems to suggest that by choosing appropriate sign of correctors we can have significant damping effect (of large growth rates produced by strong old impedance) even with realistic (low) current in correctors. For completeness, we should show such correctors are capable to damp very small growth rates with our present impedance & baseline intensity.
- For some reason no stabilizing effect is found due quadrupole fringe fields – still under study.