Numerical Study of Compensation of Long-Range Beam-Beam Interactions in LHC

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TOPICS

- **Wire Compensation of Long-Range Beam-Beam Interactions**
- **Global and Local Multipole Compensation of Long-Range Beam-Beam Interactions**

References:

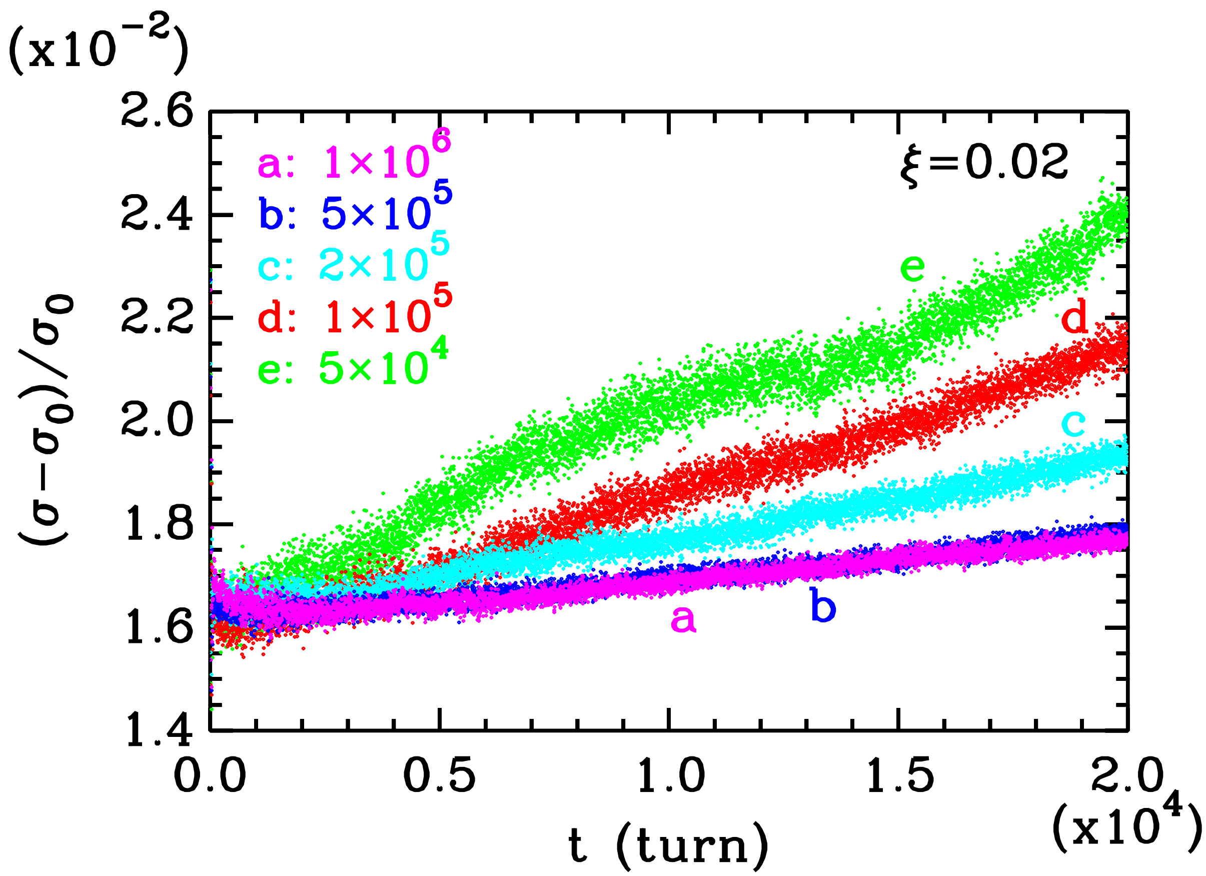
1. L. Jin, J. Shi, Nucl. Instr. & Meth. A550, 6 (2005)
2. J. Shi, L. Jin, O. Kheawpum, Phys. Rev. E69, 036502 (2004)
3. L. Jin, J. Shi, W. Herr, in Proc. of the 8th EPAC, Paris, (2002)

Simulation Model: LHC Collision Lattice

- **Two IPs (IP1 and IP5)**
- **15 parasitic collisions on each side of an IP**
- **Multipole field errors up to 10th order in IRs**
- **Crossing angle = 300 μrad**
  vertical crossing at IP1 and horizontal crossing at IP5
- $(\nu_x,\ \nu_y) = (0.31,\ 0.32)$
- **For the wire compensation, an electric wire was placed on each side of an IP. The distance from the wire to the beam is 9.5σ that is the average beam separation at the parasitic crossings.**
- **Headon beam-beam interactions were calculated with the particle-in-cell method.**
- **Long-range beam-beam interactions were calculated with weak-strong model.**

Simulation Of Beams

Each beam is represented by 5×10^5 macro-particles. The initial beam distribution is round Gaussian in the normalized transverse phase space truncated at 4σ. The number of macro-particles has to be large enough to ensure a numerical convergence.



Principle of Wire Compensation (J.-P. Koutchouk)

Since the beam separation at parasitic crossings $>> \sigma$, for long-range beam-beam interactions,

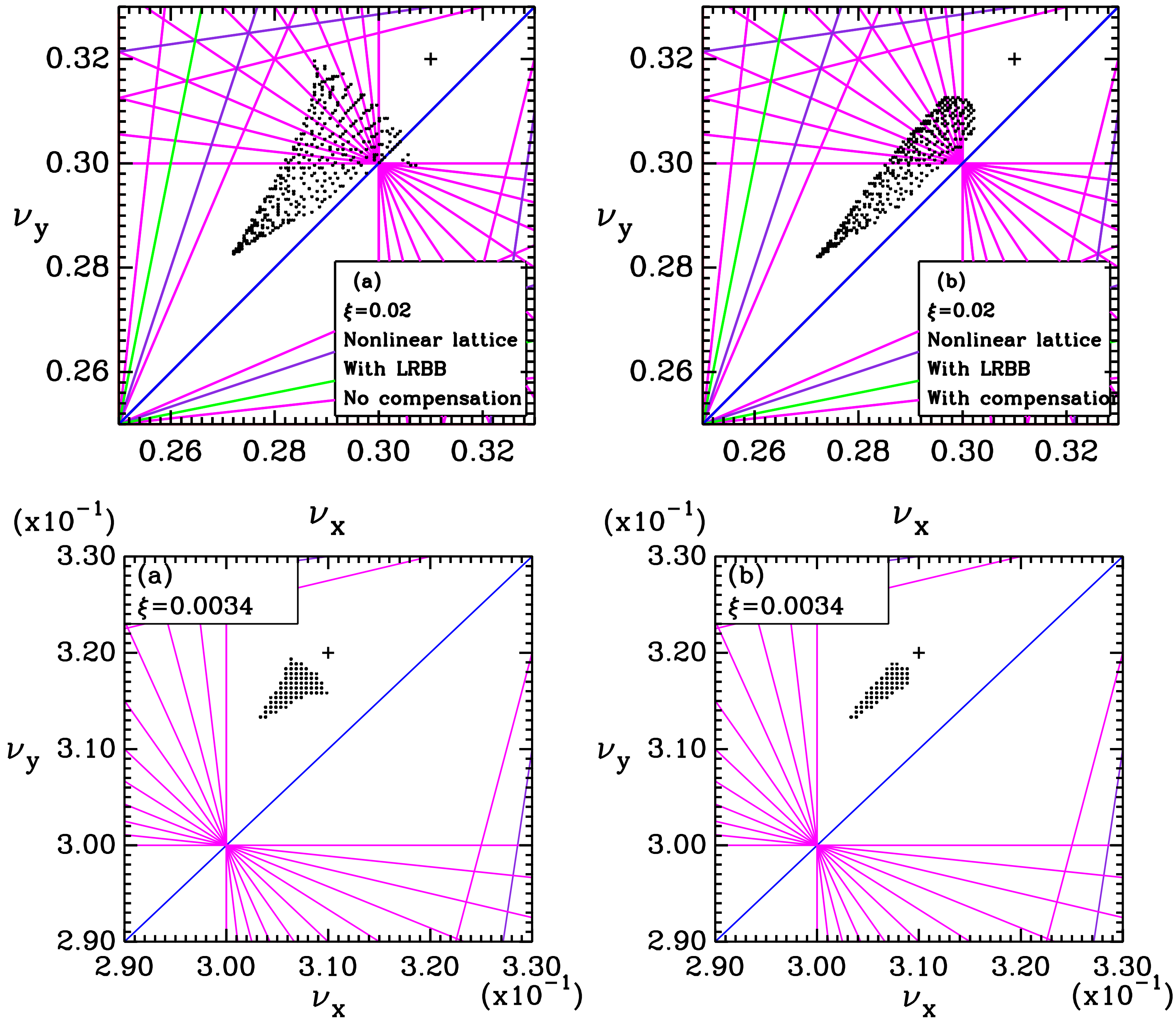
$$\Delta p \sim \xi \frac{\vec{r}}{r^2} \tag{1}$$

For beam-wire interactions,

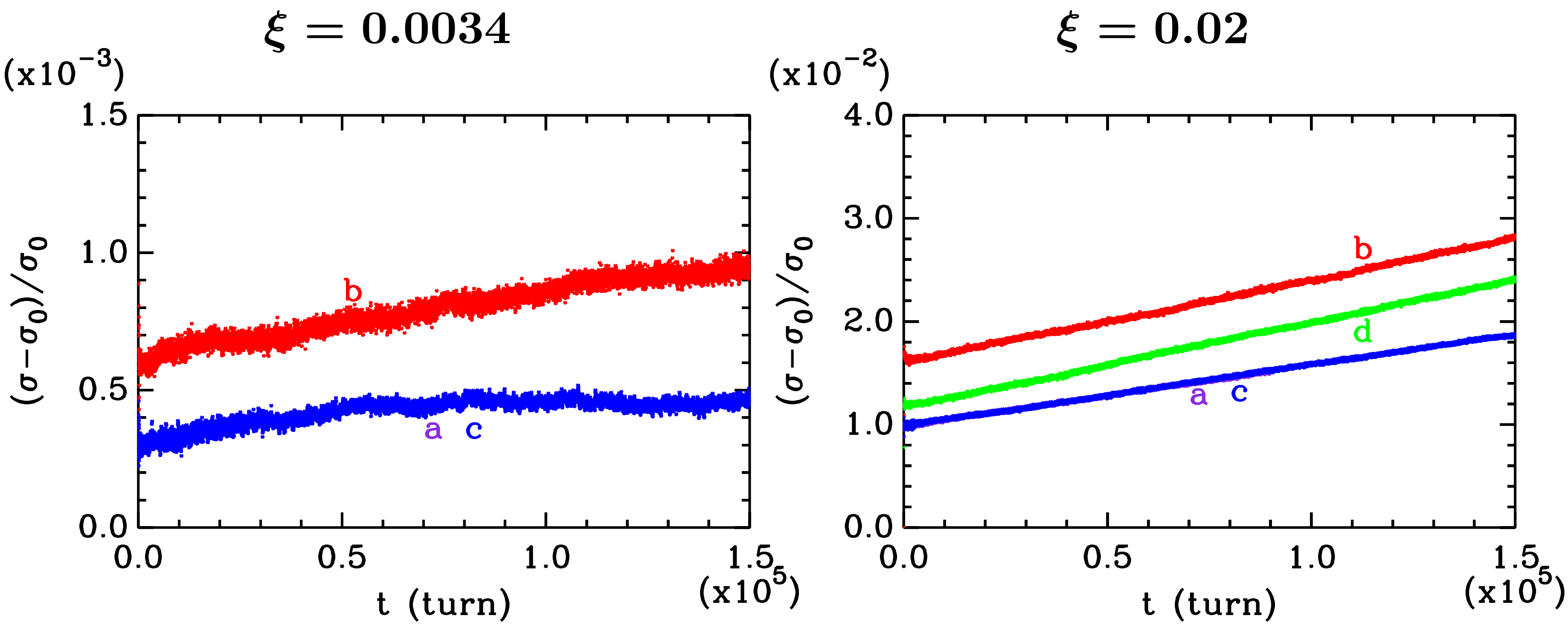
$$\Delta p \sim lI \frac{\vec{r}}{r^2} \tag{2}$$

A cancellation between Eqs. (1) and (2) can be achieved if (a) the phase advances between the locations of the parasitic crossings and the location of the wire are insignificant, and (b) $lI \simeq -\xi$.

Tune Spread Without/With Wire Compensation



Effect Of Wire Compensation On Emittance Growth



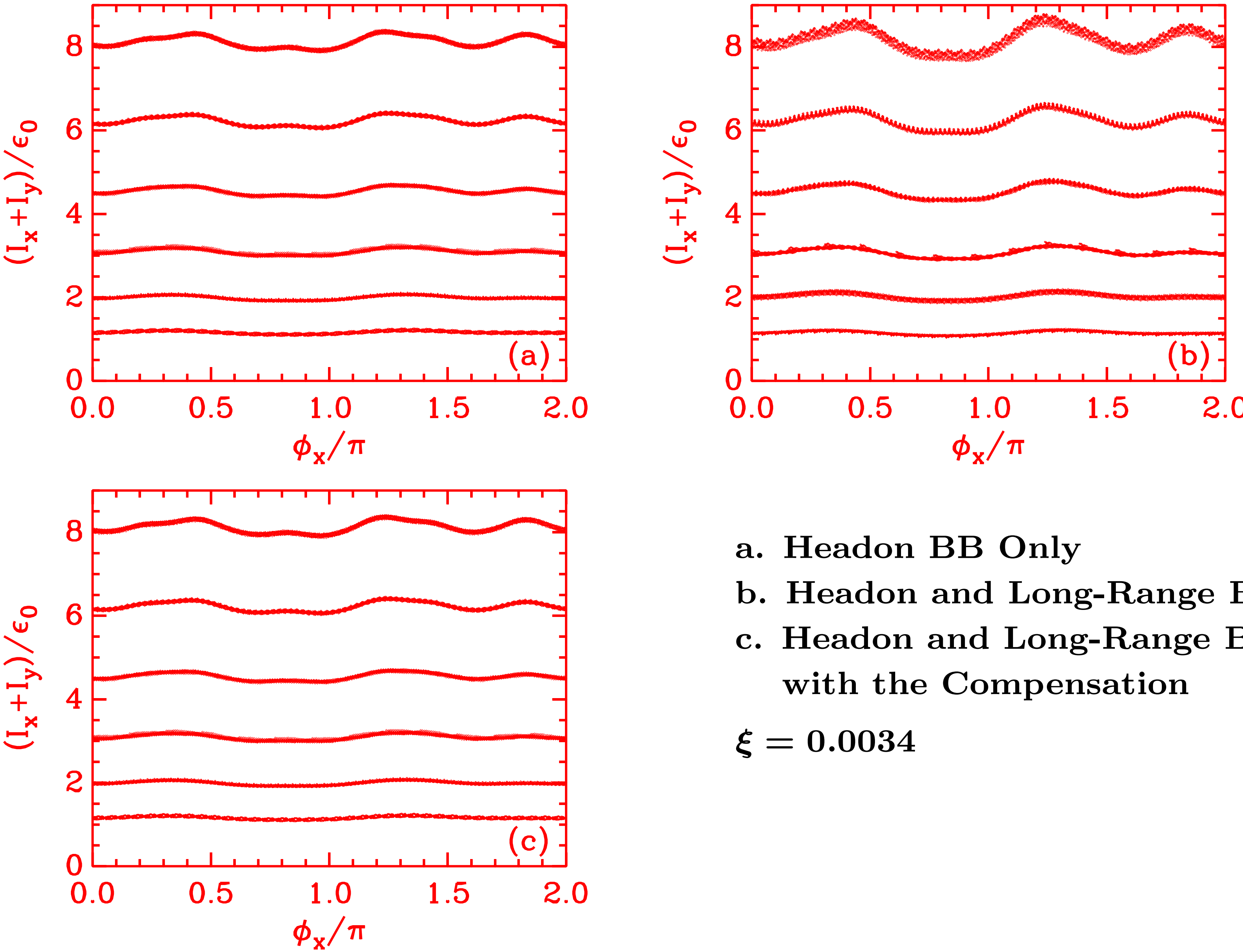
a. Without parasitic collisions.

b. With parasitic collisions but without the compensation.

c. With parasitic collisions and with the compensation.

d. The same as b but the initial beams are matched with linear beam-beam effects.

Wire Compensation And Phase-Space Distortion



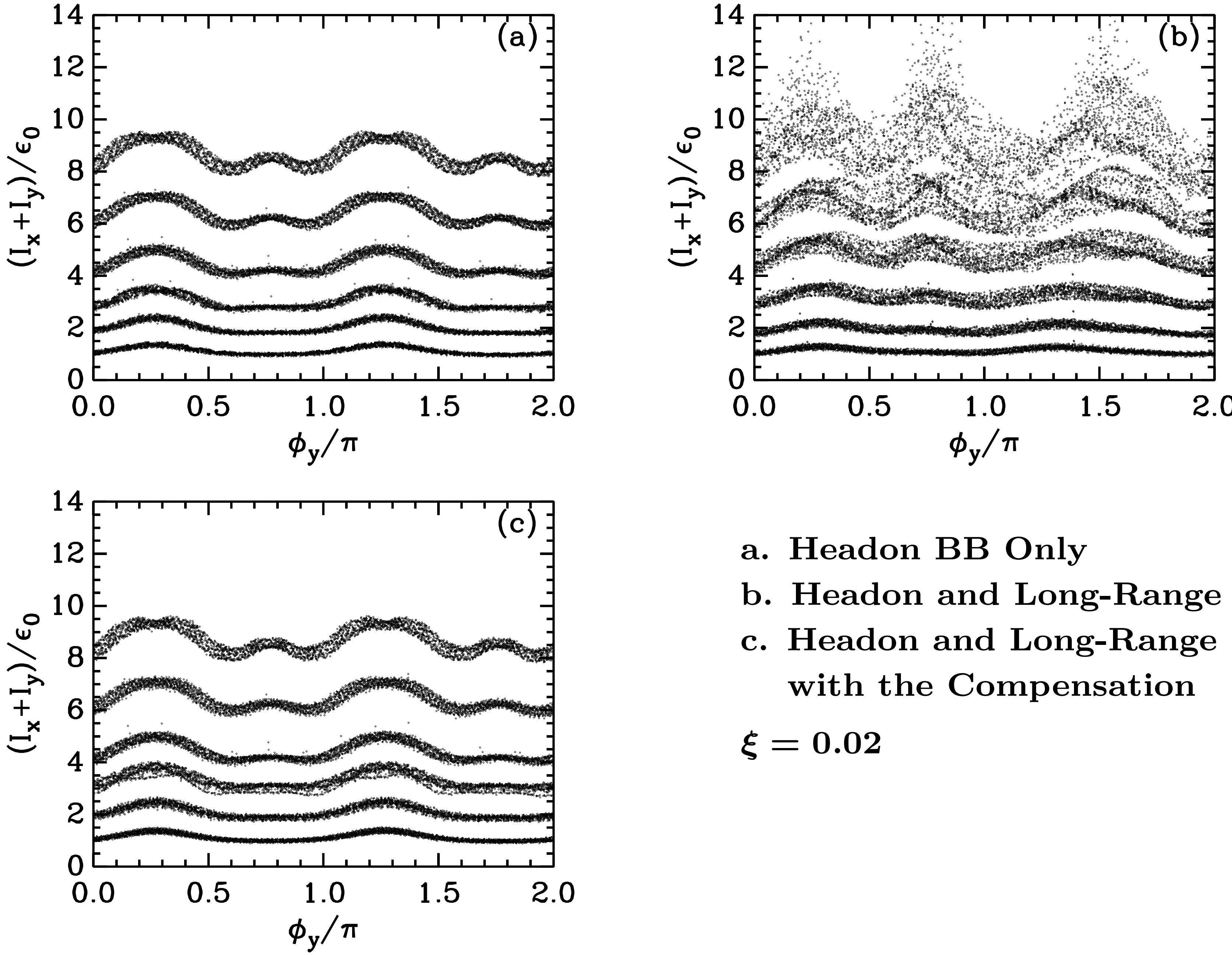
a. Headon BB Only

b. Headon and Long-Range BB

c. Headon and Long-Range BB with the Compensation

$\xi = 0.0034$

Wire Compensation And Phase-Space Distortion



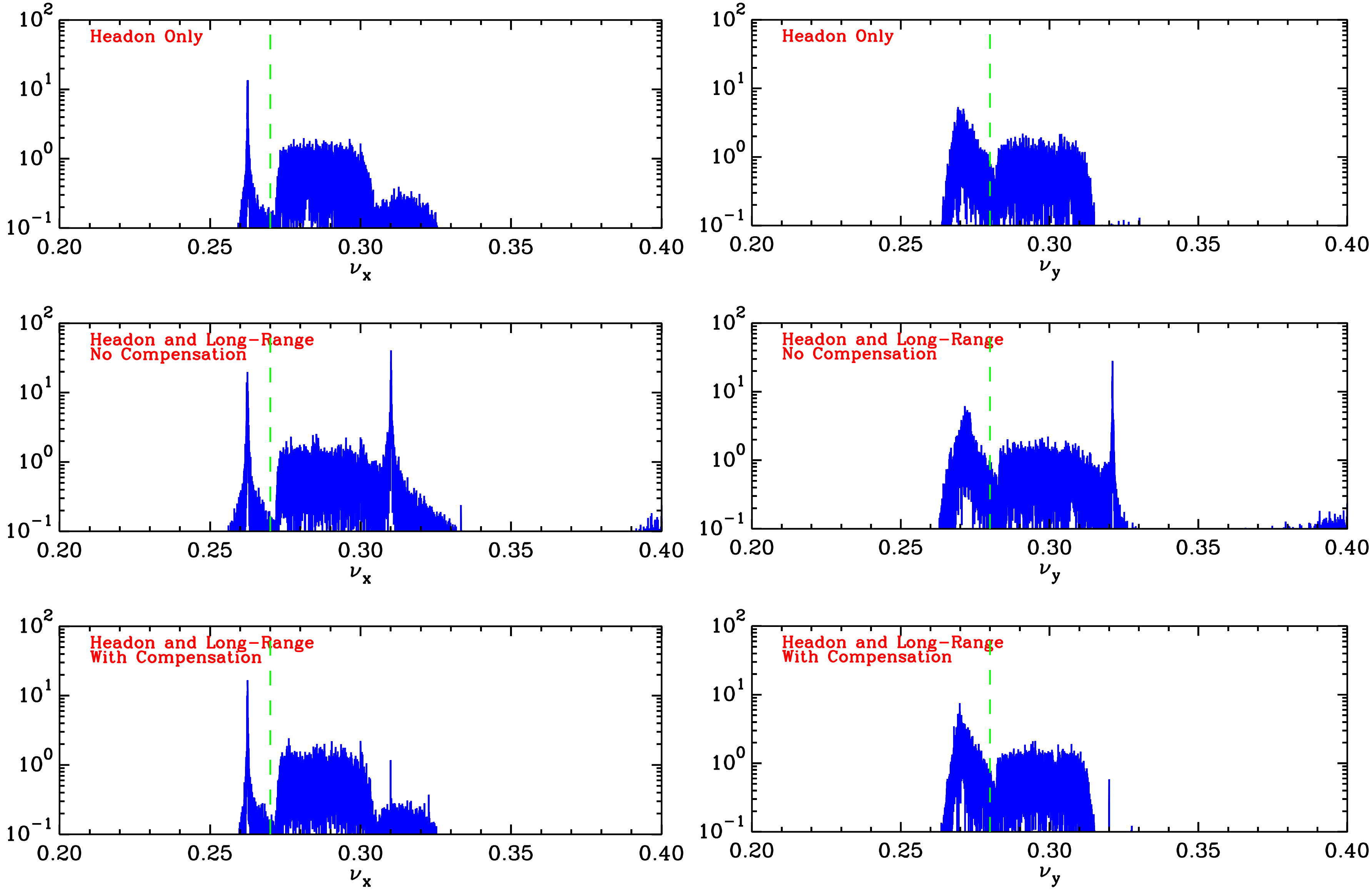
a. Headon BB Only

b. Headon and Long-Range BB

c. Headon and Long-Range BB with the Compensation

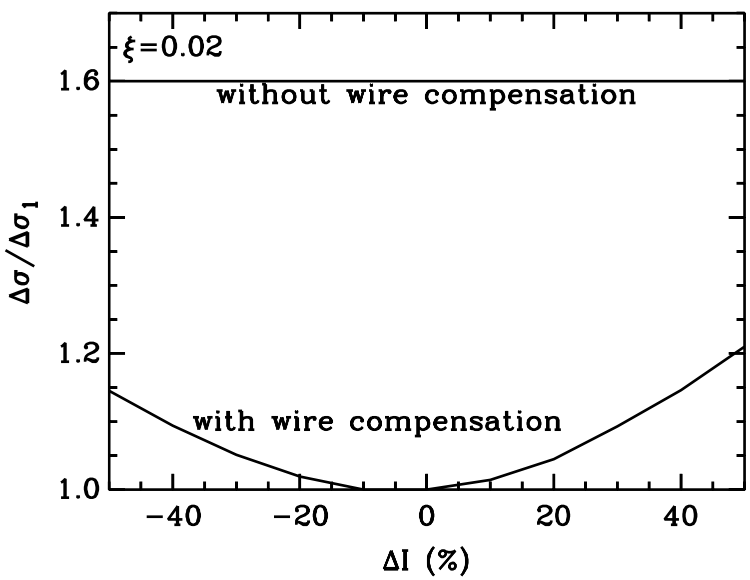
$\xi = 0.02$

Frequency Spectrum of Coherent Oscillaton



Wire Compensation With Current Error

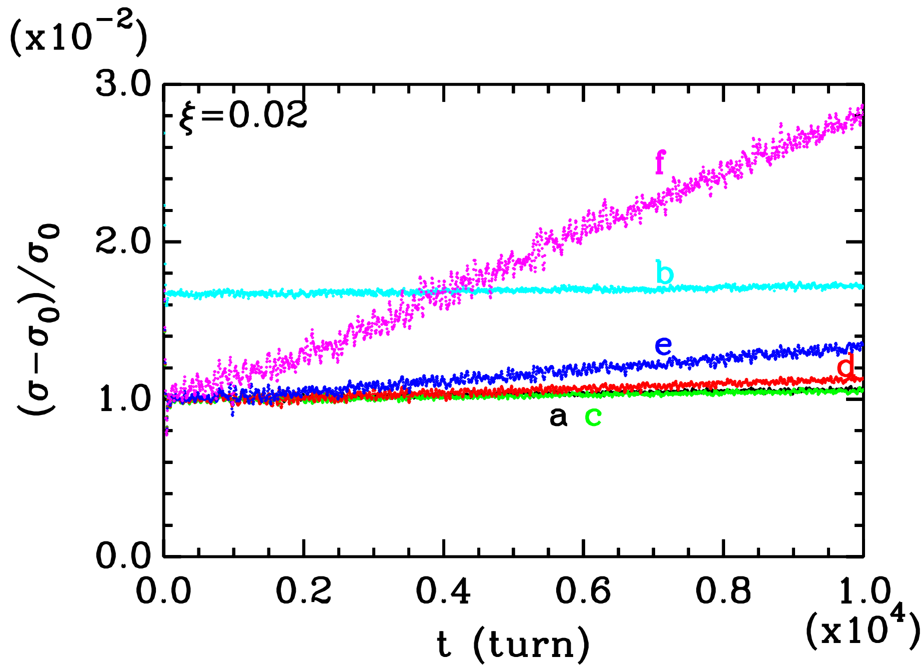
Static Current Error



$\Delta\sigma$ is the beam-size increase at the 10^4th turn.

$\Delta\sigma_1$ is the beam-size increase without long-range BB.

Current Fluctuation



a. Without long-range BB
b. Without compensation
c. 0% current fluctuation
d. 0.5% current fluctuation
e. 1.0% current fluctuation
f. 2.5% current fluctuation

Principle of Multipole Compensation (J. Shi)

Compensation With Maps:

By minimizing nonlinear terms of one-turn or/and sectional maps order-by-order with a few groups of multipole correctors, the nonlinearity of the system can be reduced locally and globally.

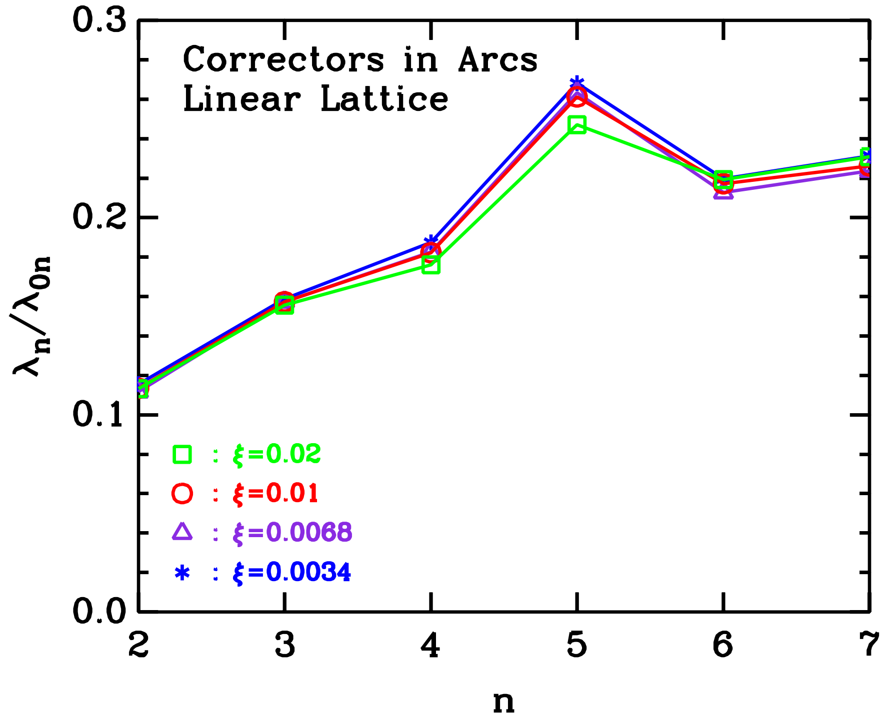
Maps Including Long-Range Beam-Beam Interactions:

If the beam separation at parasitic collisions is much larger than beam size, in the phase-space region occupied by the beams, the long-range beam-beam interaction can be expanded into a Taylor series at the beam separation and be included into the maps for the compensation.

Map Coefficients *v.s.* Order of Compensation

$$M = \sum_n \sum_{i+j+k+l=n} u^{(n)}_{ijkl} x^i p_x^j y^k p_y^l$$

$$\lambda_n = \left\{ \sum_{i+j+k+l=n} \left[u^{(n)}_{ijkl} \right]^2 \right\}^{1/2}$$

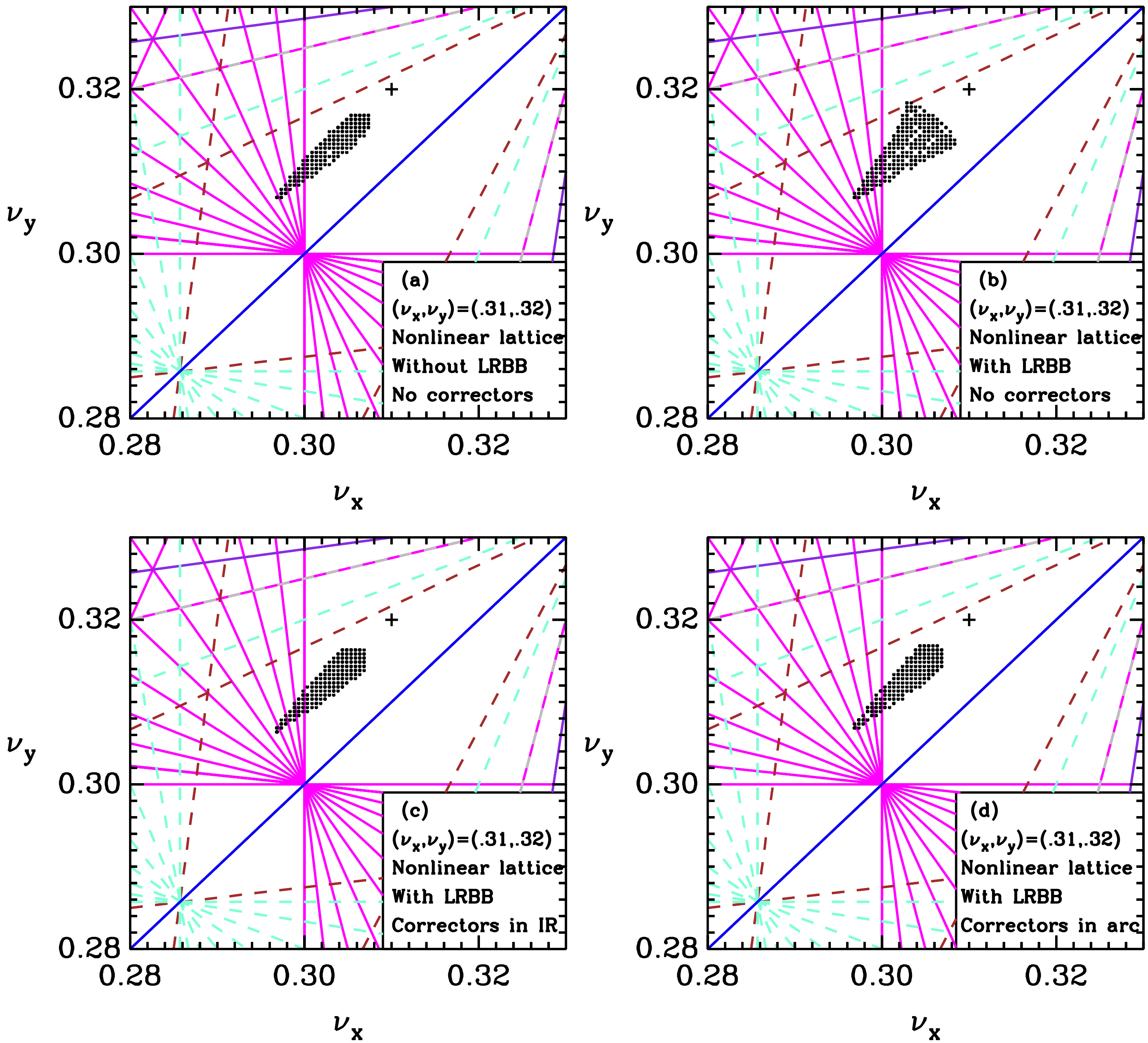


λ_n/λ_{0n}: Magnitude of the nth-order map coefficients with/without the compensation.

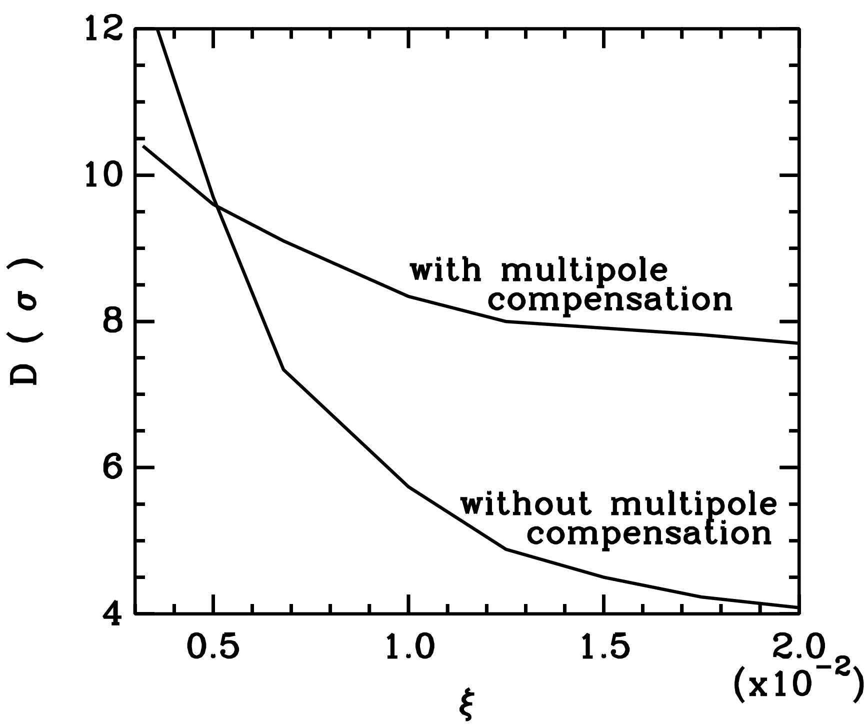
Reduction rate of λ_n decreases when $n > 5$ because of the difficulty in optimization in a large dimensional parameter space.

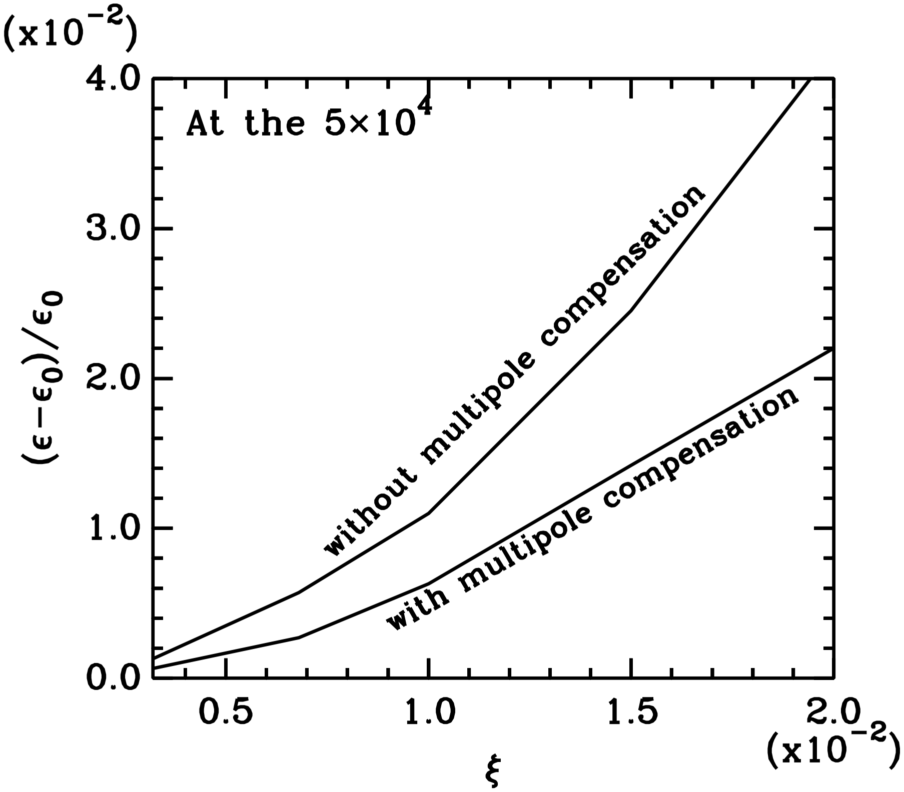
Tune Spread Without/With Multipole Compensation

$(\xi = 0.0068)$



Dynamic Aperture And Emittance Growth Without/With Multipole Compensation





- The reduction of DA over ξ is slower after the compensation.
- When DA $\sim$ the beam separation, the map is not valid and the compensation fails to improve DA.
- The compensation improves the linearity of the phase-space region of the beam even when it fails to improve DA.

Conclusions

- **Both the wire and the multipole compensation of long-range beam-beam interactions are effective in LHC.**

- **The wire compensation is not sensitive to the static current errors. A requirement of less than 0.1% ripple in the current should not be difficult to achieve with commercially available power supplies.**

- **With the multipole compensation, both the long-range beam-beam interactions and the field errors in the IRs can be treated systematically with the same group of multipole correctors inside the IRs.**