Issues of 4 IP collision

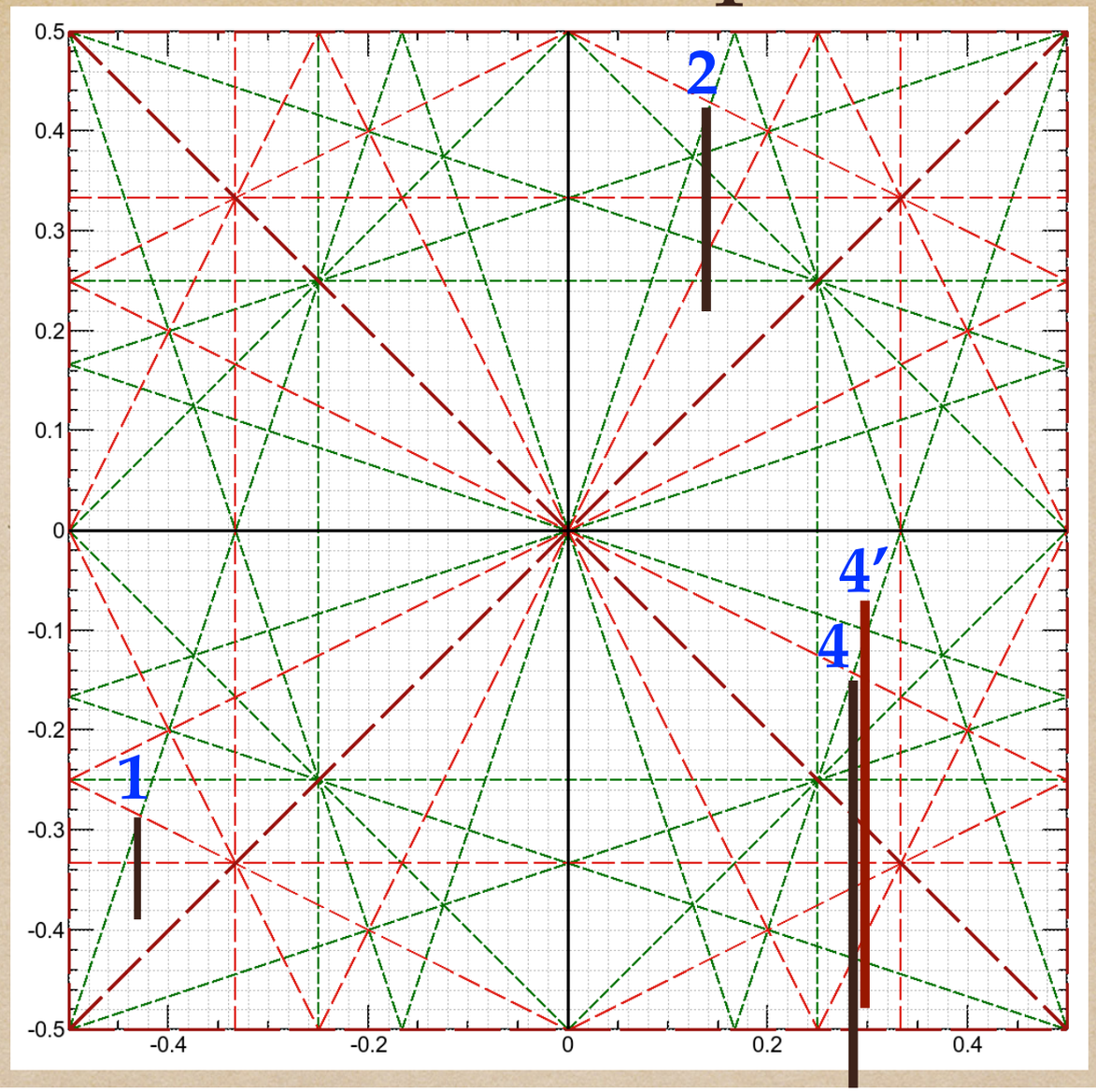
K. Oide

Sept. 9, 2019

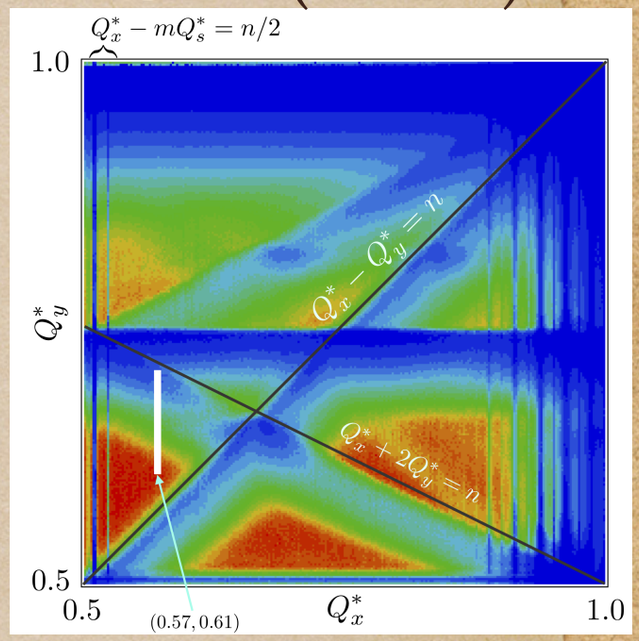
FCC-ee 3rd MDI Workshop

Great thanks to D. Shatilov, as most materials are from his slides.

Beam-beam footprint at Z



CDR ("1 IP")



- The tune footprint of beam-beam depends on the perfectness of the periodicity. If there is a perfect periodicity of the system, only the "1 IP" footprint matters as shown in the CDR.
- If the periodicity violates due to machine errors such as by β-beat and x-y couplings, the effective footprints become larger for 2 IP and 4 IP, as shown above.
- The footprint 4′ above is an alternative working point for 4 IP to avoid $\nu_y = -0.5$ resonance, suggested by D. Shatilov
- The strength of each resonance line depends on the errors and corrections of the lattice.

Large footprint with 4 IP (can cross half-integer), discussion and mitigation

Dmitry Shatilov

BINP, Novosibirsk

100th FCC-ee Optics Design Meeting
CERN, 19 July 2019

Introduction

- In the CDR, the vertical tune per superperiod (one quarter of the ring in case of 4 IP) is 0.59 ÷ 0.61. It means, the full vertical tune will be in the range of 0.36 ÷ 0.44.

- The footprint height per IP (which is smaller than ξ_y) is about 0.08 ÷ 0.11. The full height will be four times as large, so the footprint crosses the half-integer resonance.

- If we have a perfect 4-fold symmetry, the width of this resonance is zero. But the reality is more complicated… What is the tolerance for acceptable lattice errors?

- Can we avoid the intersection of half-integer resonance? What is the price?

- What is the tolerance for vertical orbit at IP (offsets and crossing angle)?

The Model for 4 IP

- Low energy (Z-pole, 45.6 GeV).
- Weak-strong simulations without beamstrahlung.
- Linear lattice between IPs.
- All errors occur only in the vertical plane.
- A few random vertical kicks (correctors) between IPs. The orbit distortions within acceptable limits.
- The strong bunch population in IP2 and IP4 differs by 3% compared with IP1 and IP3.
- A few random errors for quads between IPs, which result in some beta-beating.

D. Shatilov

Three Cases to Compare

The most important is beta-beating, as the footprint intersects the half-integer resonance. The beta-beating is different at different quarters of the ring (otherwise there is no effect).

We tried two cases at the nominal working point (0.57, 0.61): beta-beating within 3% and 6%.

The third case: same errors as in case 2, but the working point shifted to (0.57, 0.63). The full tunes become (0.28, 0.52), the footprint is located between half-integer and integer and does not cross them. Beta-beating becomes ~25%, since we stay close to half-integer.

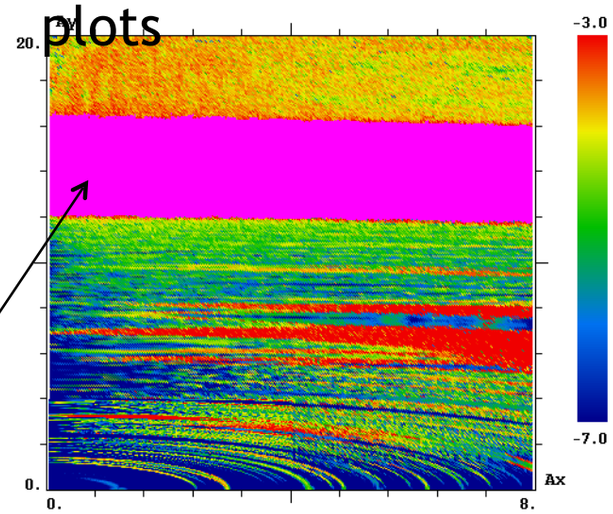
Simulation Results

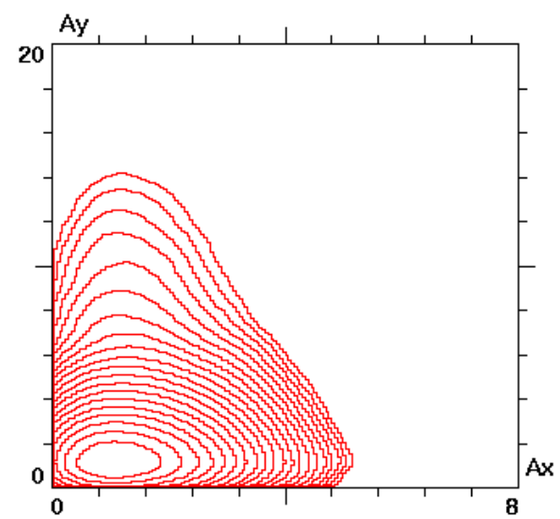
FMA (amplitudes) plots

Density contour

Case 1

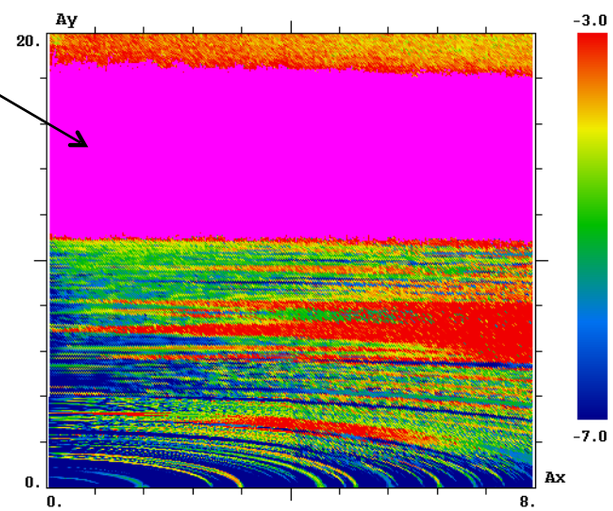
$2\nu_y = 1$

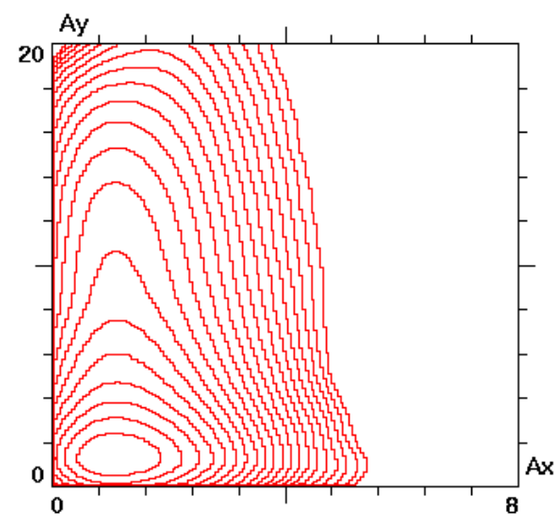




$L / L_0 = 0.99$
β-beat: 3%
$\nu_y = 0.44$

Case 2



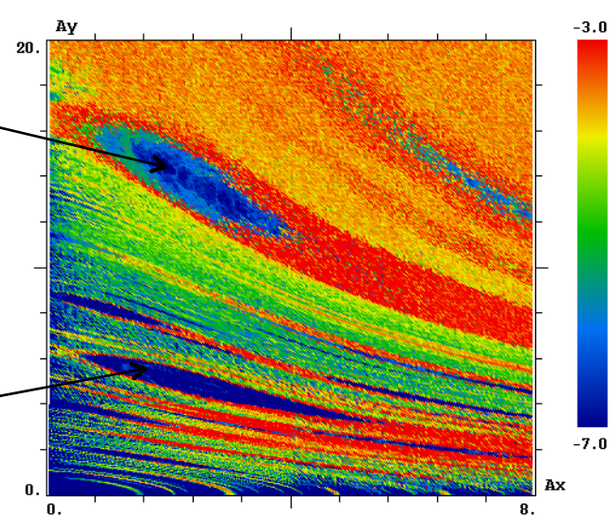


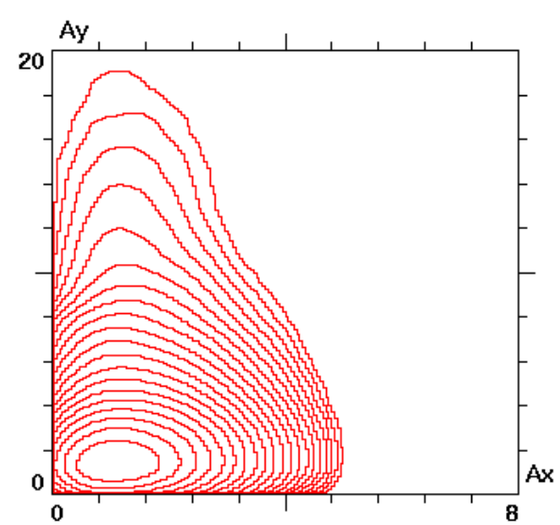
$L / L_0 = 0.80$
β-beat: 6%
$\nu_y = 0.44$

Case 3

$4\nu_y - \nu_x = 2$

$3\nu_y = 2$





$L / L_0 = 0.92$
β-beat: 25%
$\nu_y = 0.52$

Crab sextupoles need to reconfigure?

D. Shatilov

Discussion and Next Steps

- When increasing ν_y , we decrease the room for the footprint which is bounded above by the resonance $\nu_x + 2\nu_y = n$. On the other hand, ξ_y with 4 IP decreases by 10÷20 %, so we can allow this.
- At ttbar, ξ_x is not small and footprint crosses the resonance $3\nu_x = 1$. On the other hand, damping is very stronger at this energy.
- The next step: perform simulations for a realistic nonlinear lattice with errors. Before applying beam-beam, the orbit at all IPs need to be well corrected. When correcting the betatron coupling, not only vertical emittance is important, but also the X-Y tilts at all IPs.
- Preliminary conclusion: **if we keep the beta-beating within 3%, there should be no problem in any case**.
- In the case of 2 IP, we can allow much softer requirements.

D. Shatilov

Beam-Beam Simulations with Nonlinear Lattice at Z for 4 IP

Dmitry Shatilov

BINP, Novosibirsk

102nd FCC-ee Optics Design Meeting
CERN, 02 August 2019

Simulations with Nonlinear Lattice

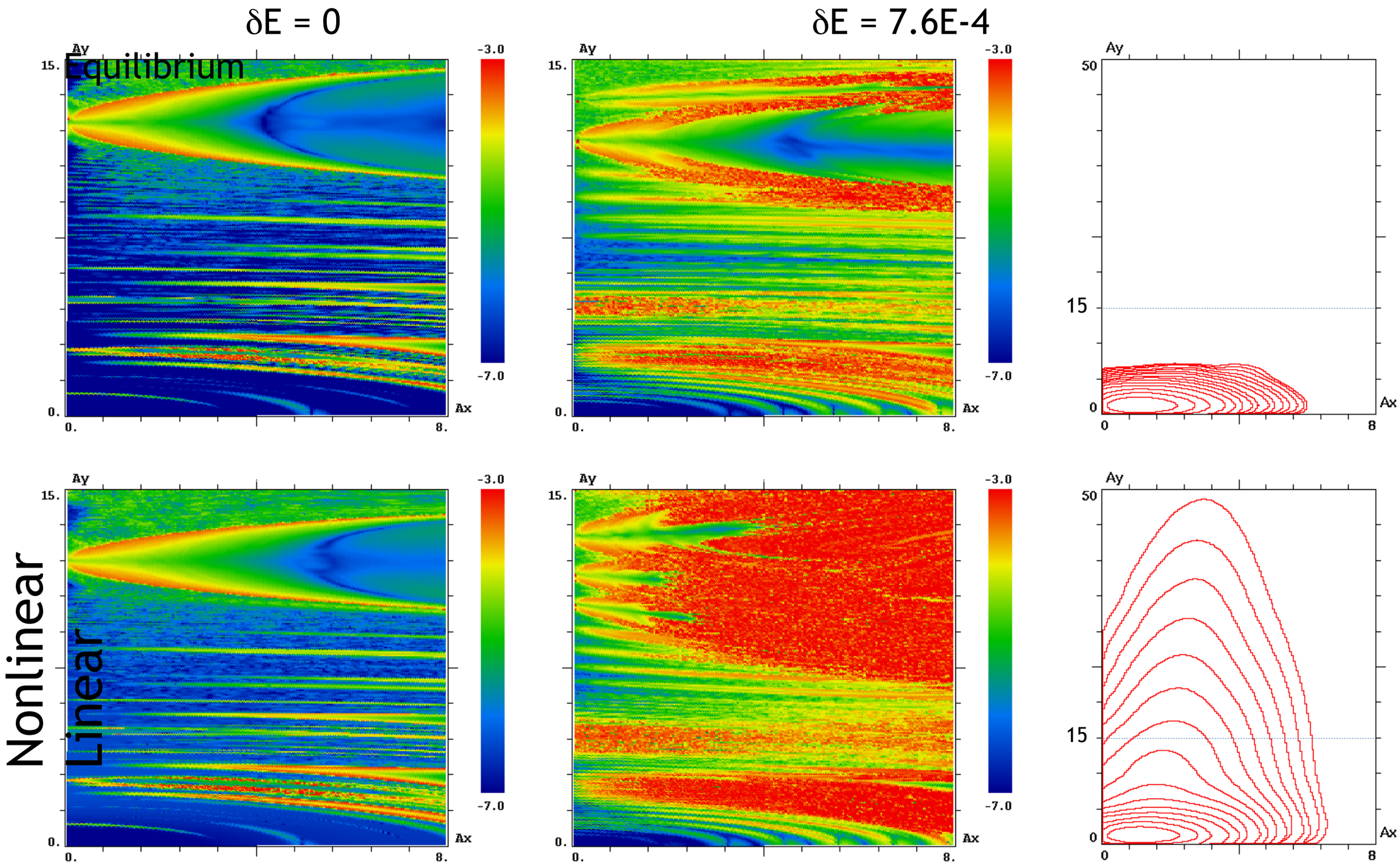
1) Lattice conversion from SAD to MADX.
2) Errors and misalignments, corrections (in MADX).
3) Save the final (corrected) lattice and misalignments.
4) Conversion from MADX to Lifetrac.
5) Damping and diffusion matrices are needed! For this, probably we need a back conversion from MADX to SAD.
6) Tracking in Lifetrac, with or w/o beam-beam.

<u>Simplified variant: without 2), 3), 5)</u>

- There is no explicit betatron coupling.
- Nominal emittances are generated by artificial noise, damping and diffusion matrices are diagonal.
- Beta-beatings are implemented by changing the strength of several quads in the arcs. The orbit is not affected.

D. Shatilov

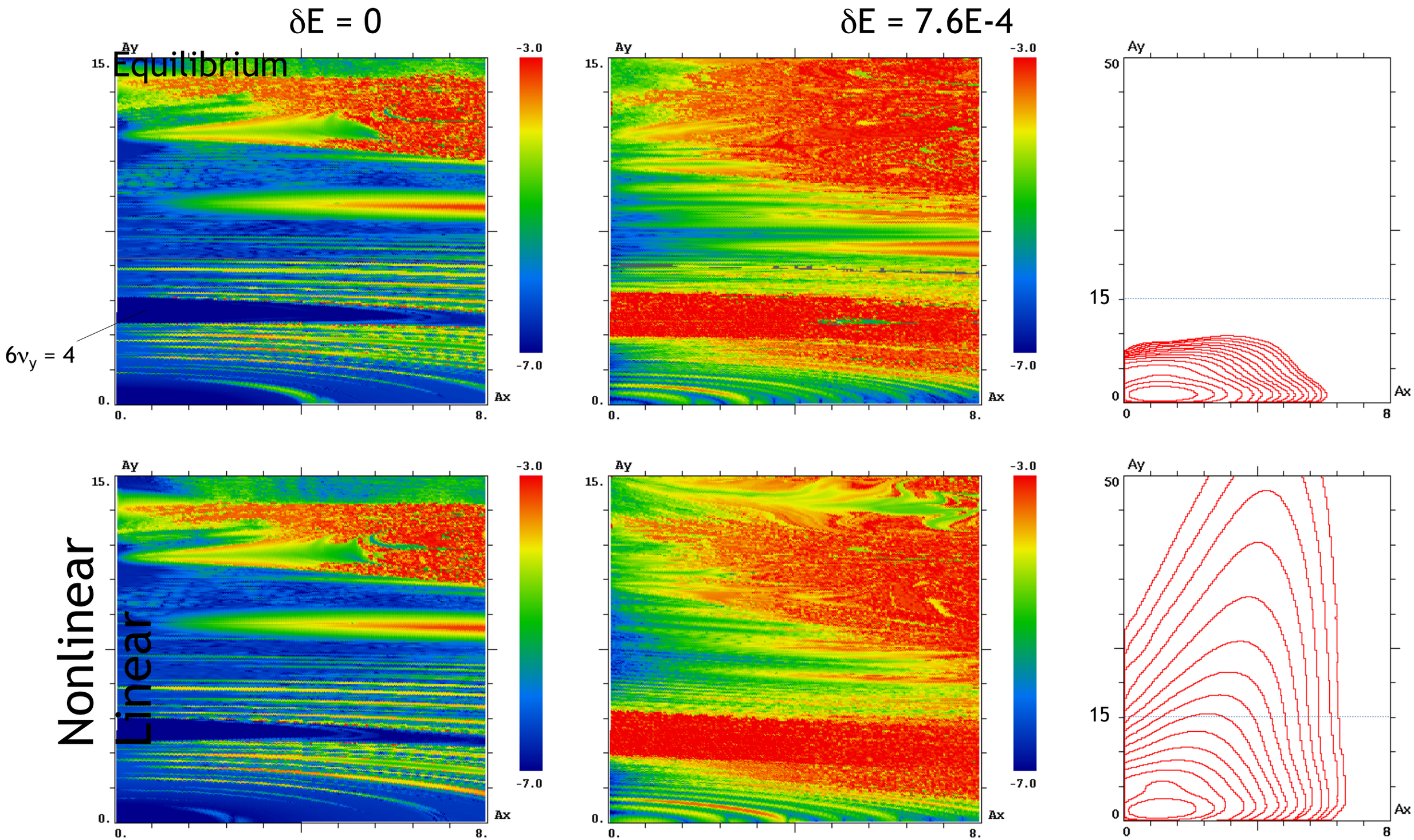
Linear vs. Nonlinear (ideal) Lattice , ν_y = 0.595



In the nonlinear case, luminosity drops by **5%** and lifetime due to vertical aperture **~6 hours**.

D. Shatilov

Linear vs. Nonlinear (ideal) Lattice , ν_y = 0.63



In the nonlinear case, luminosity drops by **30%** and lifetime due to vertical aperture **~15 min**.

D. Shatilov

Discussion

- In the new working point, after implementation of beta-beatings within 3-4%, the results remained almost unchanged. But the symmetrical case is no longer good…
- Chromatic aberrations in the IR (between IP and crab sextupoles) affect the efficiency of crab waist. Can we perform a dedicated optimization of sextupoles to mitigate this effect?
- The negative impact also depends on the working point: where the low-order resonances are located, etc. Future optimization is possible.
- The case of 2 IP is simpler, there is more room for optimization.
- Next step: nonlinear lattice with realistic errors, misalignments and corrections.

4 IP is not the baseline yet…

- As shown by D. Shatilov, the 4 IP option has issues due to machine imperfection violating the periodicity, which appears more severe than the 2 IP case.
- Further studies are necessary on machine errors and corrections, especially looking at β-beats and x-y couplings as well as vertical emittance.
- Thus it is too early to consider the 4 IP as the baseline at this moment.