Round Colliding Beams at VEPP-2000

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for the VEPP-2000 team,
with important contributions from
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Outline of the talk

- **Motivation of round colliding beams**
- **Options of round beams at VEPP-2000**
  - merits of the circular-mode option
- **Experimental summary**
- **Weak-strong simulations**
  - Dynamic beta and emittance, beam sizes
  - Tune dependence of the beam lifetime
- **Future work**

Increasing of Luminosity

- ❑ Number of bunches (i.e. collision frequency)
- ❑ Bunch-by-bunch luminosity

$$L = \frac{\pi\gamma^2 \xi_x \xi_y \varepsilon_x f}{r_e^2 \beta_y^*}\left(1 + \frac{\sigma_y}{\sigma_x}\right)^2$$

Round Beams:

$$L = \frac{4\pi\gamma^2\xi^2\varepsilon f}{r_e^2\beta^*}$$

✓Geometric factor (gain=4)

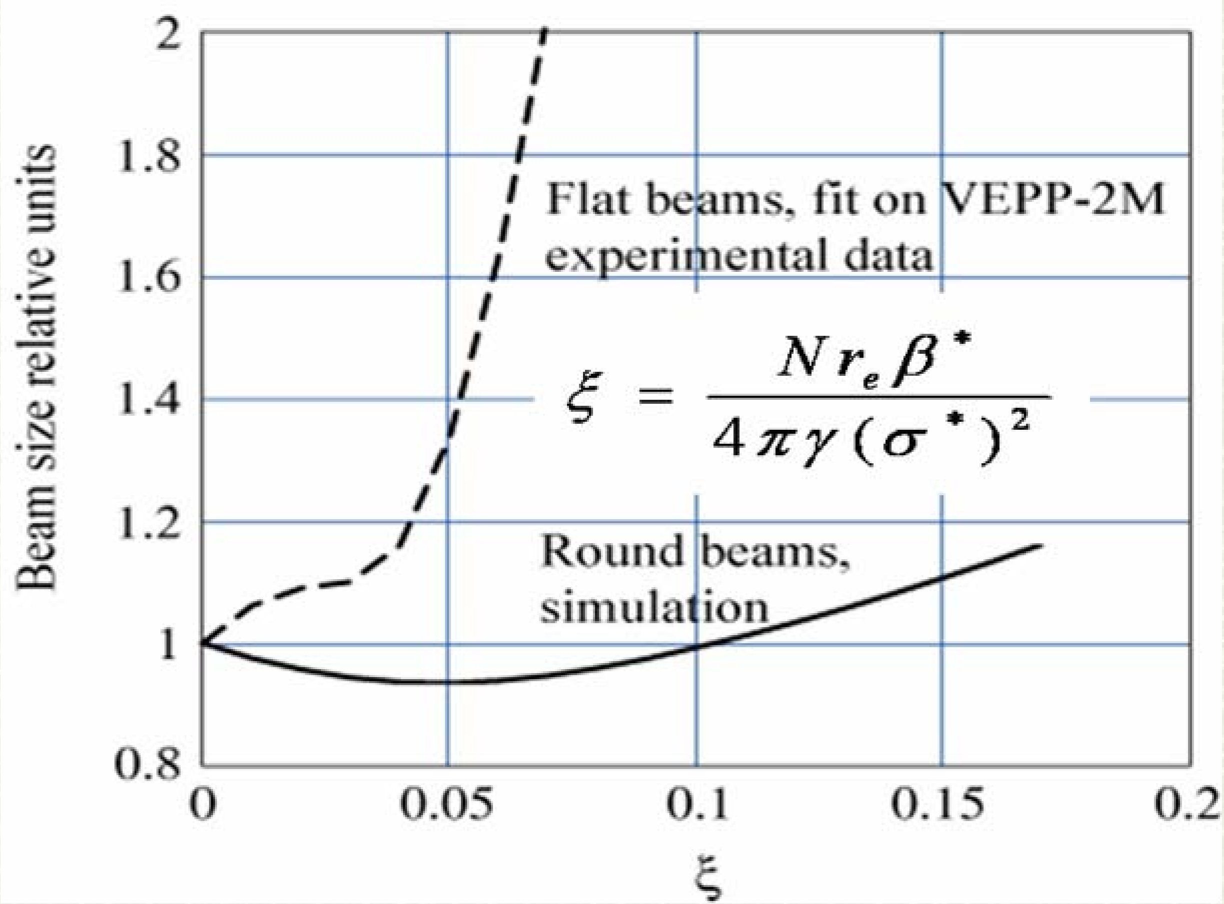
✓Beam-beam limit enhancement

✓IBS for low energy? better life time!

$$\xi \geq 0.1$$

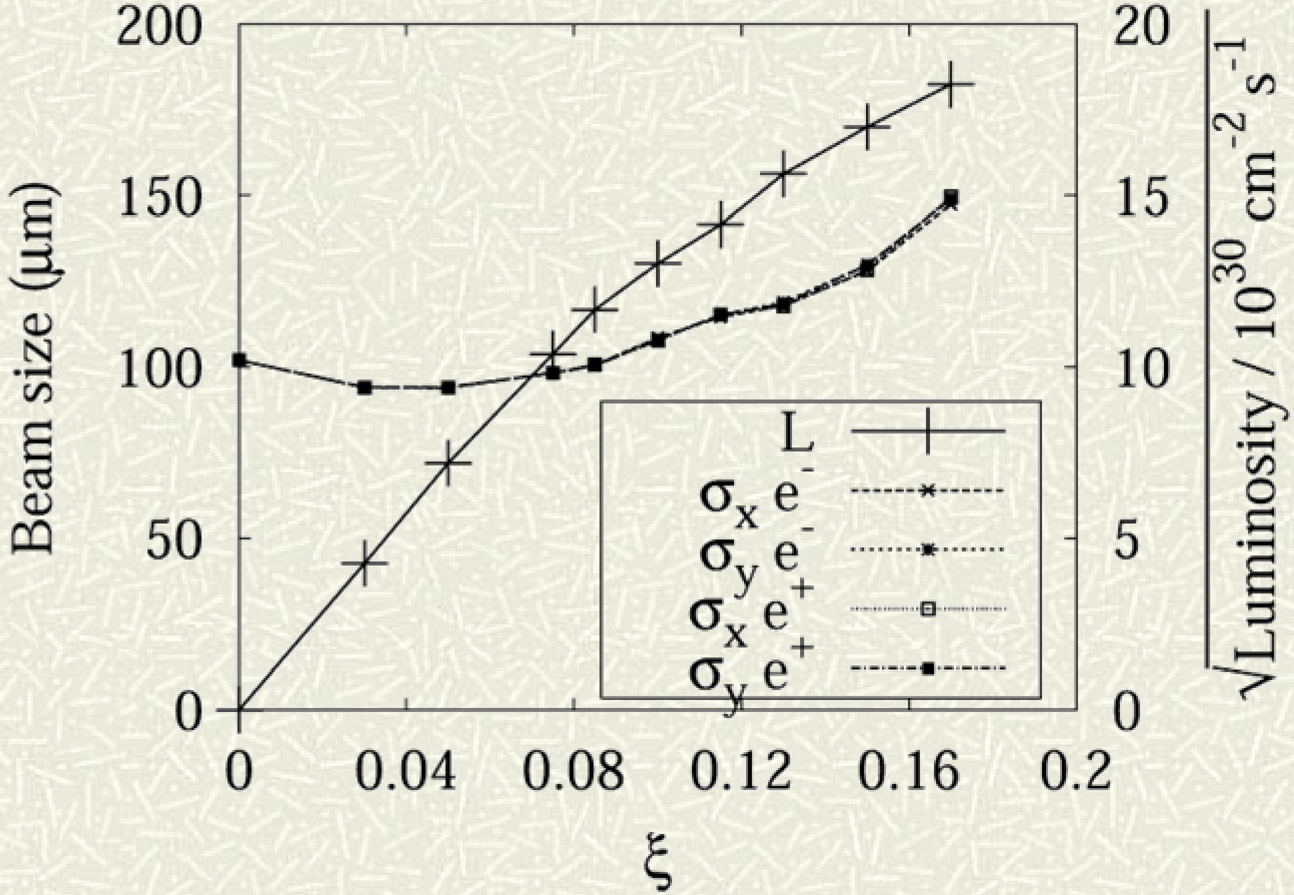
Vertical size dependence on beam-beam parameter ξ

“Weak-Strong” Beam-Beam Simulations



I.Nesterenko, D.Shatilov, E.Simonov, in Proc. of Mini-Workshop on “Round beams and related concepts in beam dynamics”, Fermilab, December 5-6, 1996

“Strong-Strong” Beam-Beam Simulations



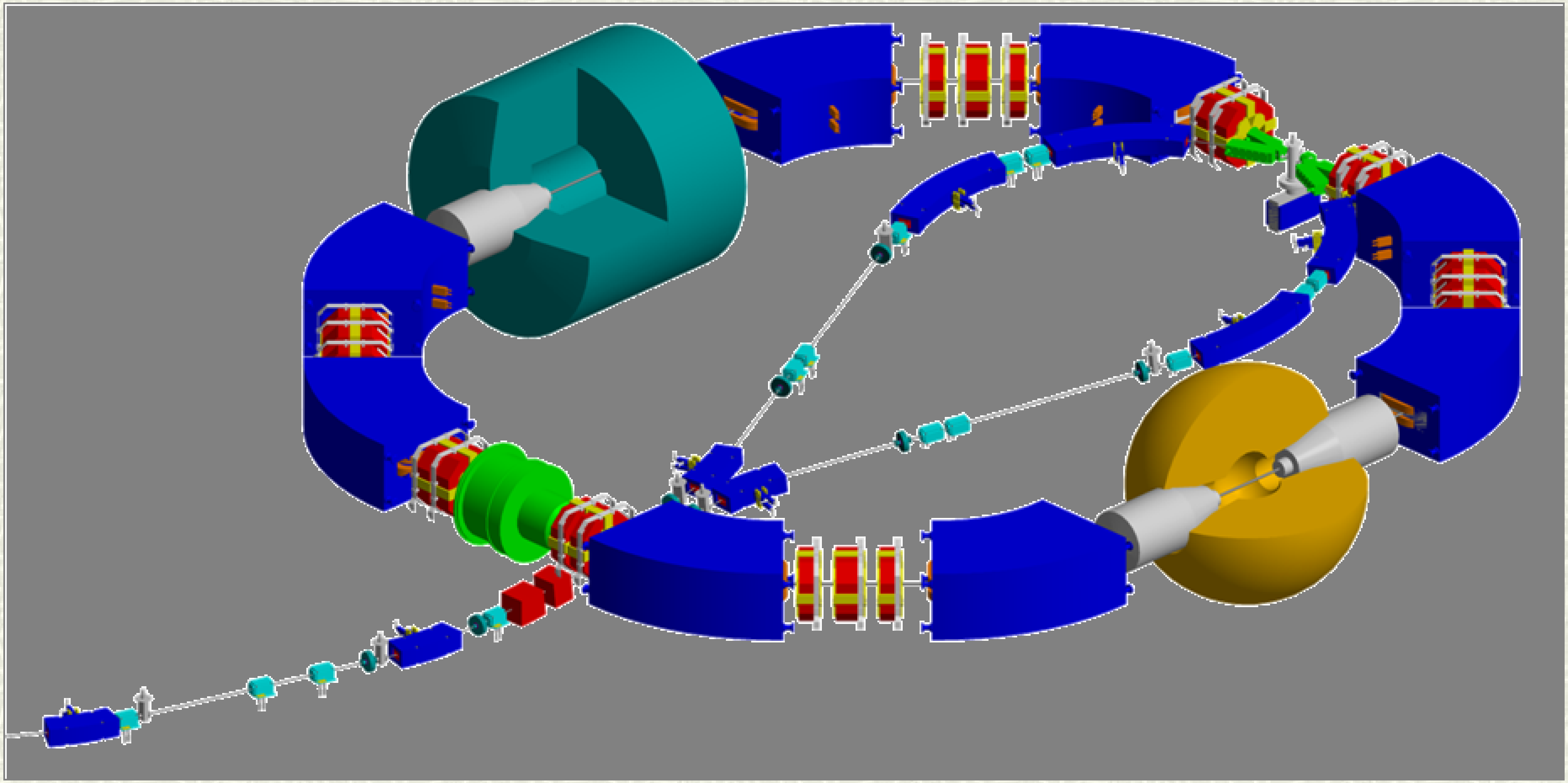
Beam size and luminosity vs. the nominal beam-beam parameter
(A. Valishev, E. Perevedentsev, K. Ohmi, *PAC’2003*)

The Concept of Round Colliding Beams

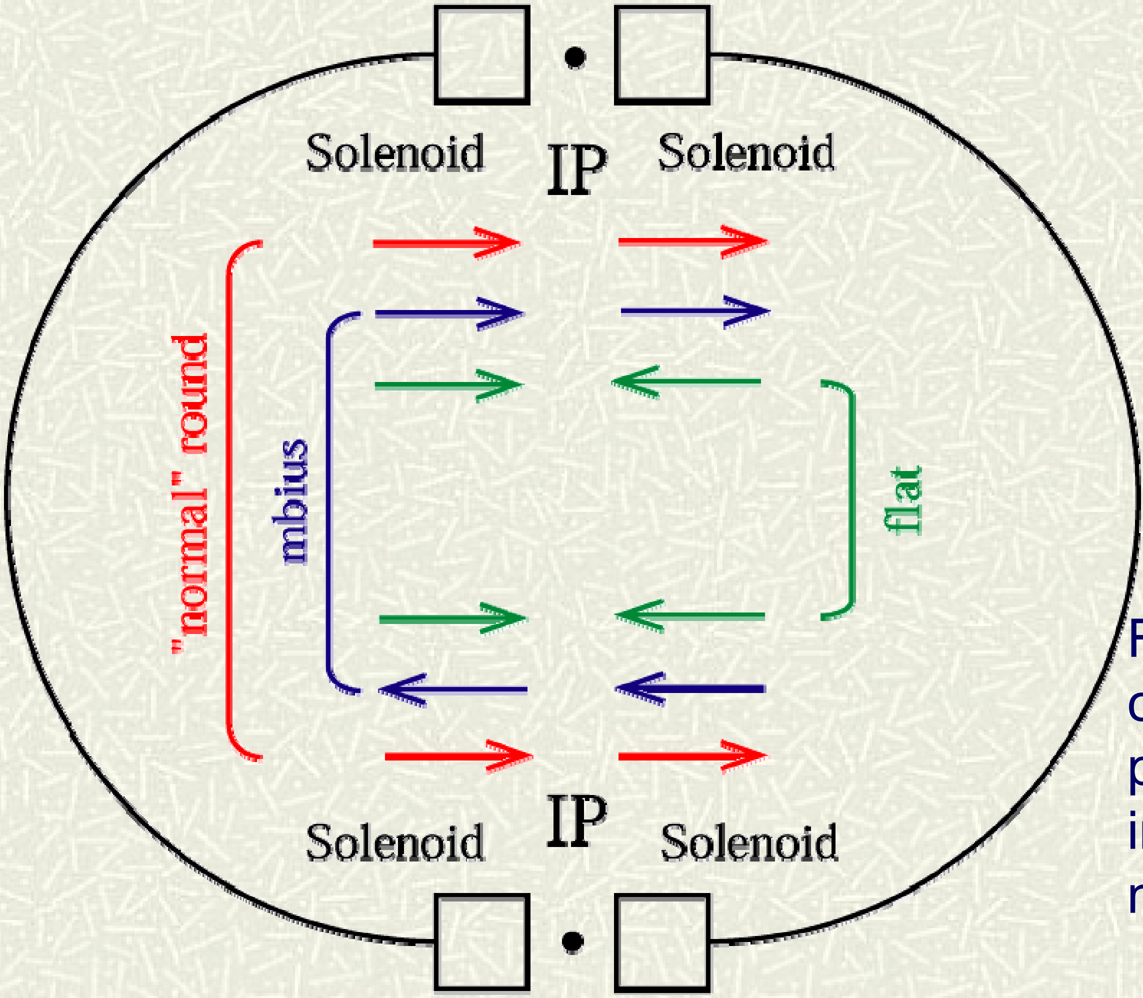
- Angular momentum conservation! $M_z = x'y - xy'$
- Small and equal β-functions at IP: $\beta_x = \beta_y$
- Equal beam emittances: why? $\varepsilon_x = \varepsilon_y$
- Equal betatron tunes: how close in reality? $\nu_x = \nu_y$
- Small and positive fractional tunes

(V.V.Danilov et al., EPAC'96, Barcelona, p.1149, (1996))

Cartoon view of VEPP-2000 Collider



Practical Realization of Round Beams: Options for VEPP-2000



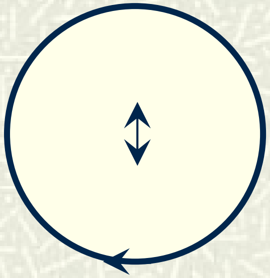
Flat to Round change needs polarity switch in solenoids and new alignment

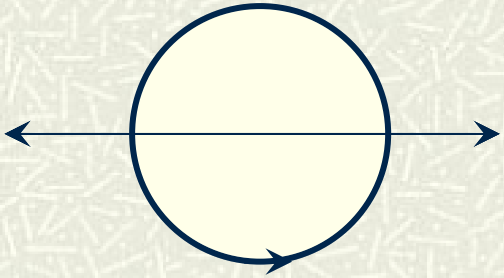
Circular betatron modes for round colliding beams

Apply a small twist by solenoids' decompensation

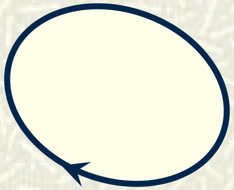
Right mode | **Left mode**

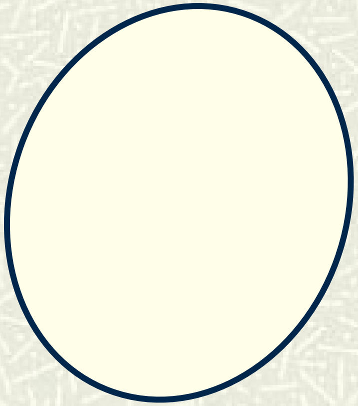
Exactly on the difference resonance





Slightly away from the difference resonance





Emittances become different, however the beam shape is still close to round

Arguments in favor of new option

Setting **(+,-,+,-)** comes naturally from the optics tuneup:

Beam-based alignment of solenoids is done starting with no-solenoid "weak" optics and using (+,-,0,0) and (0,0,+,-) polarities of 4 solenoids. Then the optics is changed to "strong" and we can set (+,-,+,-) in the solenoids

Advantages as compared to the basic mode (++,-,-):

1) **Easy switch between flat and round modes of colliding beams**
2) **Better sextupole solution, hope for wider dynamic aperture**

Disadvantages not yet known

The strong-strong simulation (in progress) may show some problems in beam-beam behavior with high beam-beam parameter (~ 0.1 is needed)

This circular-mode option has been experimentally tested

Weak-strong and strong-strong measurements have been done

Experimental summary (1)

- After orbit and optics correction @ 509 MeV, with e+ currents <20-30mA as limited by injection, the maximum e- current at collision raised to ~50 mA,
- Tunes were close to the coupling resonance and separation v1 – v2 = 0.02 was caused by non-compensated solenoids needed to form the circular betatron modes. Coupling in the arcs was corrected to 1/10 of that separation.
- Different tunes (v1 + v2)/2 = 0.11 – 0.15 were tried, the limiting strong-beam current was 40% sensitive to the tune. Mostly the beam-beam measurements were done with (v1 + v2)/2 = 0.125 and β^*=5cm. Lower tunes are desirable, not available as yet.

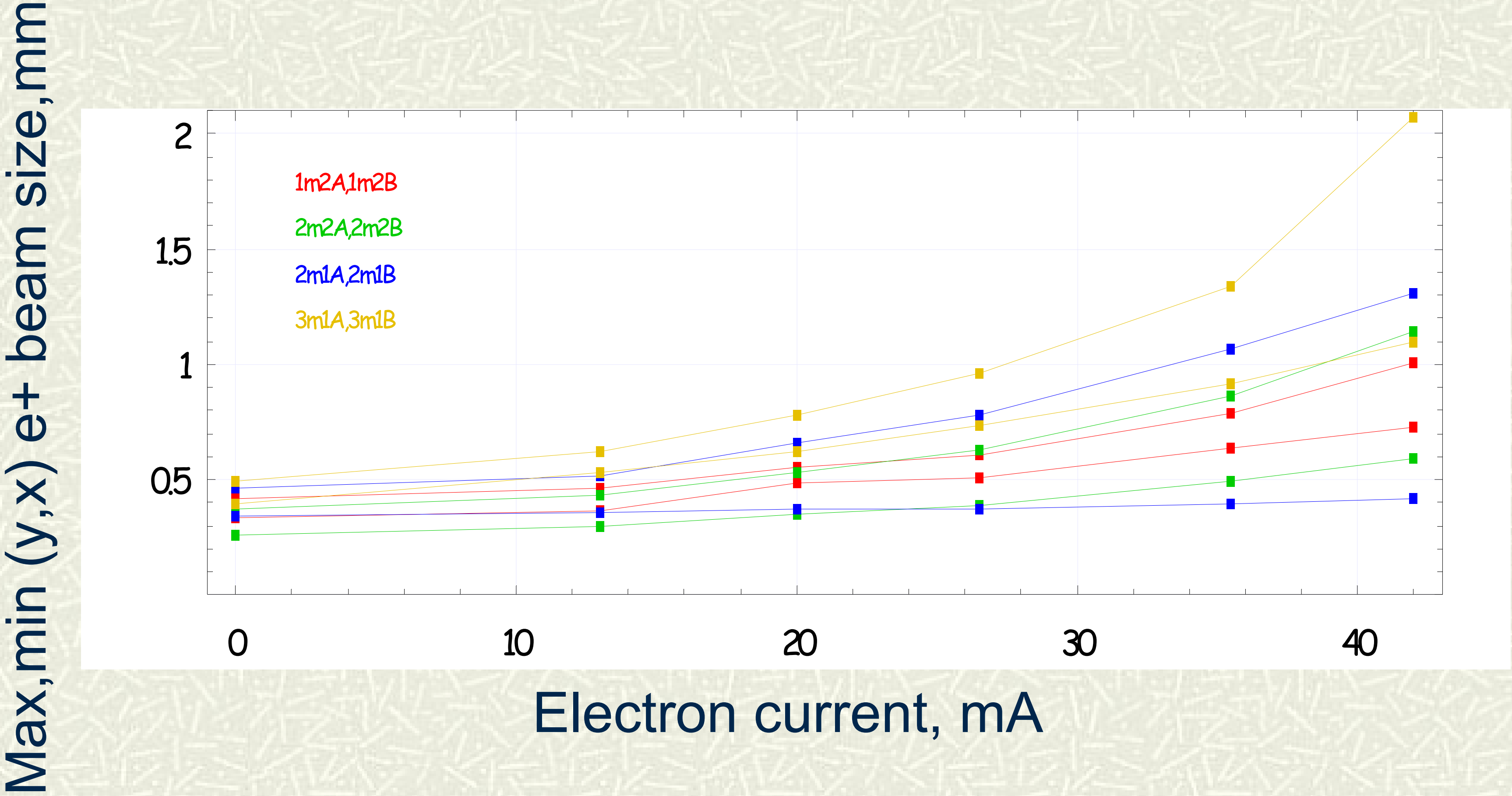
Experimental summary (2)

- Equal emittances were obtained with the arc tunes set exactly on resonance, resulting in round beam shape @IP with $\sigma \sim 50\ \mu m$
- 10^{10} particles correspond to 20 mA, $f_0 = 12.3$ MHz, the expected luminosity with 20 x 20 mA^2 comes to $L = 4 \times 10^{30}\ cm^{-2}s^{-1}$ and the nominal $\xi = 0.04$
- The peak lumi showed the record of $\sim 10^{31}\ cm^{-2}s^{-1}$, while the max $\xi > 0.08$ was recorded in the weak-strong measurement. $\xi \sim 0.1$ was limited by the weak beam lifetime rather than beam-size blowup @IP

Experimental summary (3)

- Very preliminary: the specific luminosity did not degrade in the available range of ξ.
- The strong-strong measurement showed continuous current dependence of beam sizes, no evidence of strong flip-flop effects.
- The weak-strong beam size measurement at 4 positions around the ring provided plenty of data for analysis of the dynamic beta-function

Weak beam sizes vs the strong beam current, Dec.14 2007



Weak-strong simulation

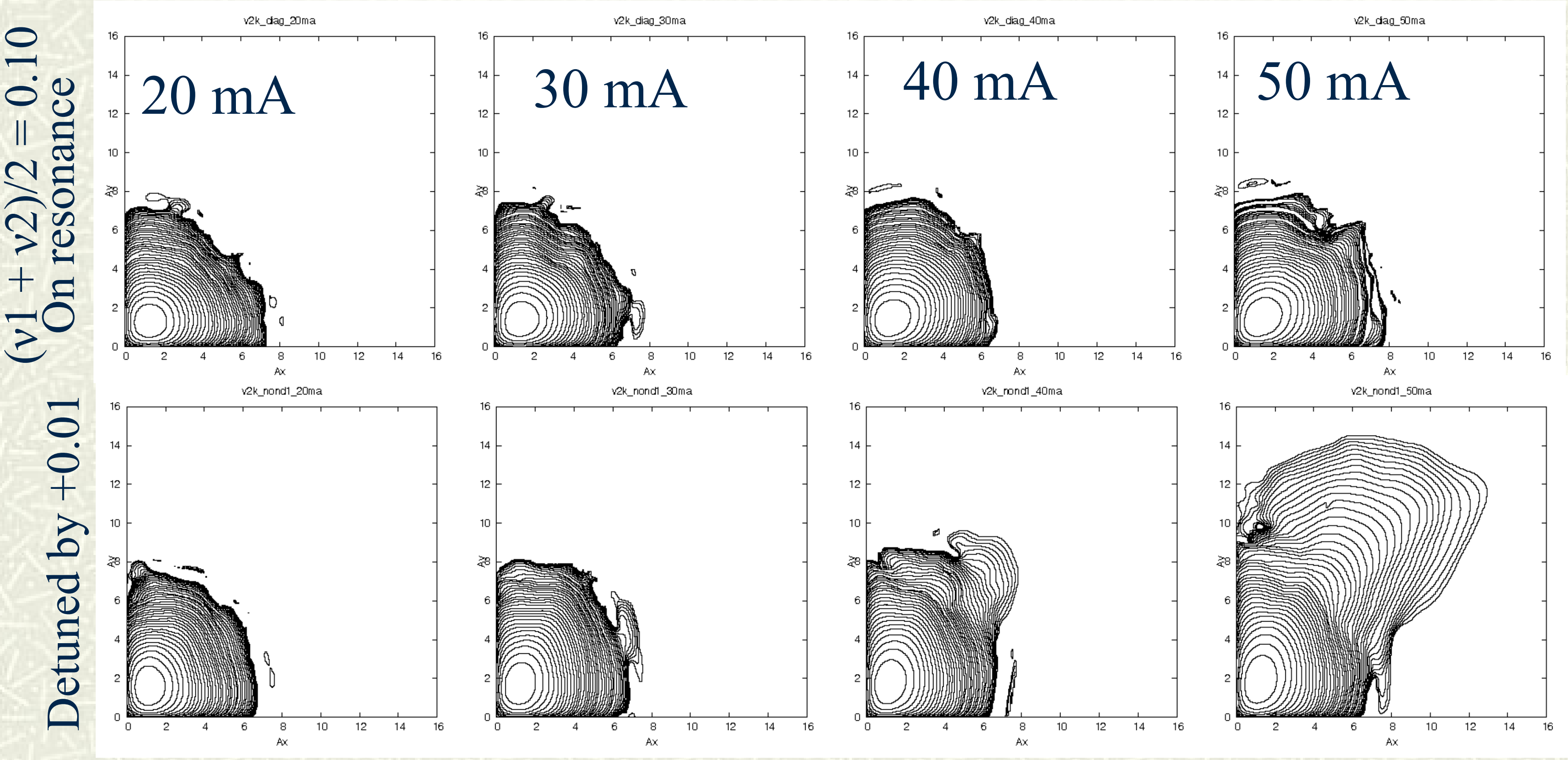
Deformation of the weak beam distribution is in question.

The simulation model for D.Shatilov's "Lifetrack" code:

1) 2-period lattice with the chromaticity correction sextupoles, synchrotron oscillations, longitudinal slicing
2) Whatever variations, E = 509 MeV and constant $\beta^* = 5$ cm, $\sigma_z = 17$mm, emittances ~46 – 48 nm
3) Tracking for 10^4 damping times ($\tau_{x,y}$~350,000 turns~28 ms)
4) Arc is tracked by P.Piminov's code, i.e. the natural chromaticity is correctly simulated, sextupoles (and other machine nonlinearities) can be included. Comparison with the previous "no sextupole" option is available.

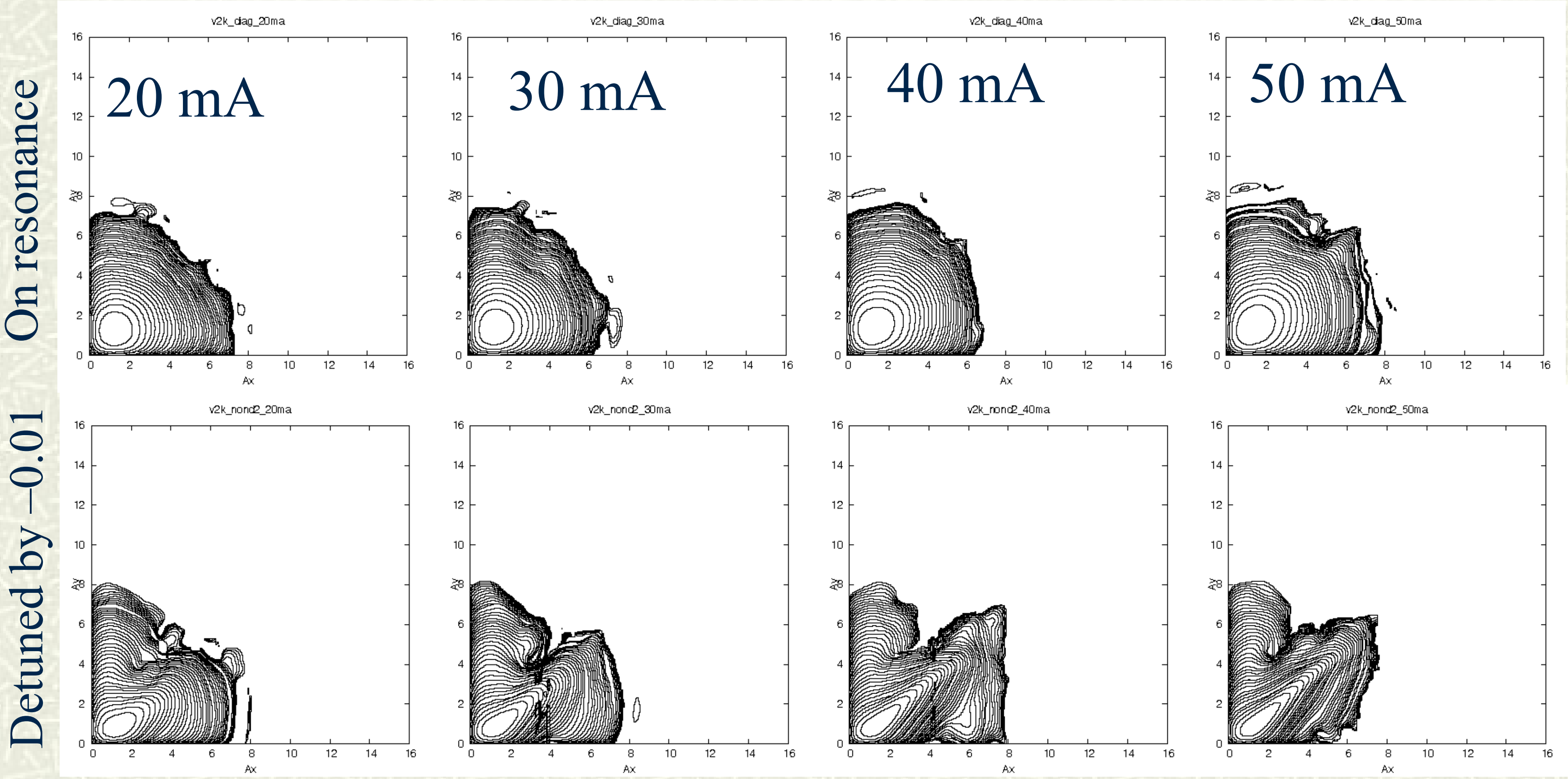
Things to be avoided in round colliding beam operation (1)

Detuning from the coupling resonance



Things to be avoided in round colliding beam operation (2)

Detuning from the coupling resonance

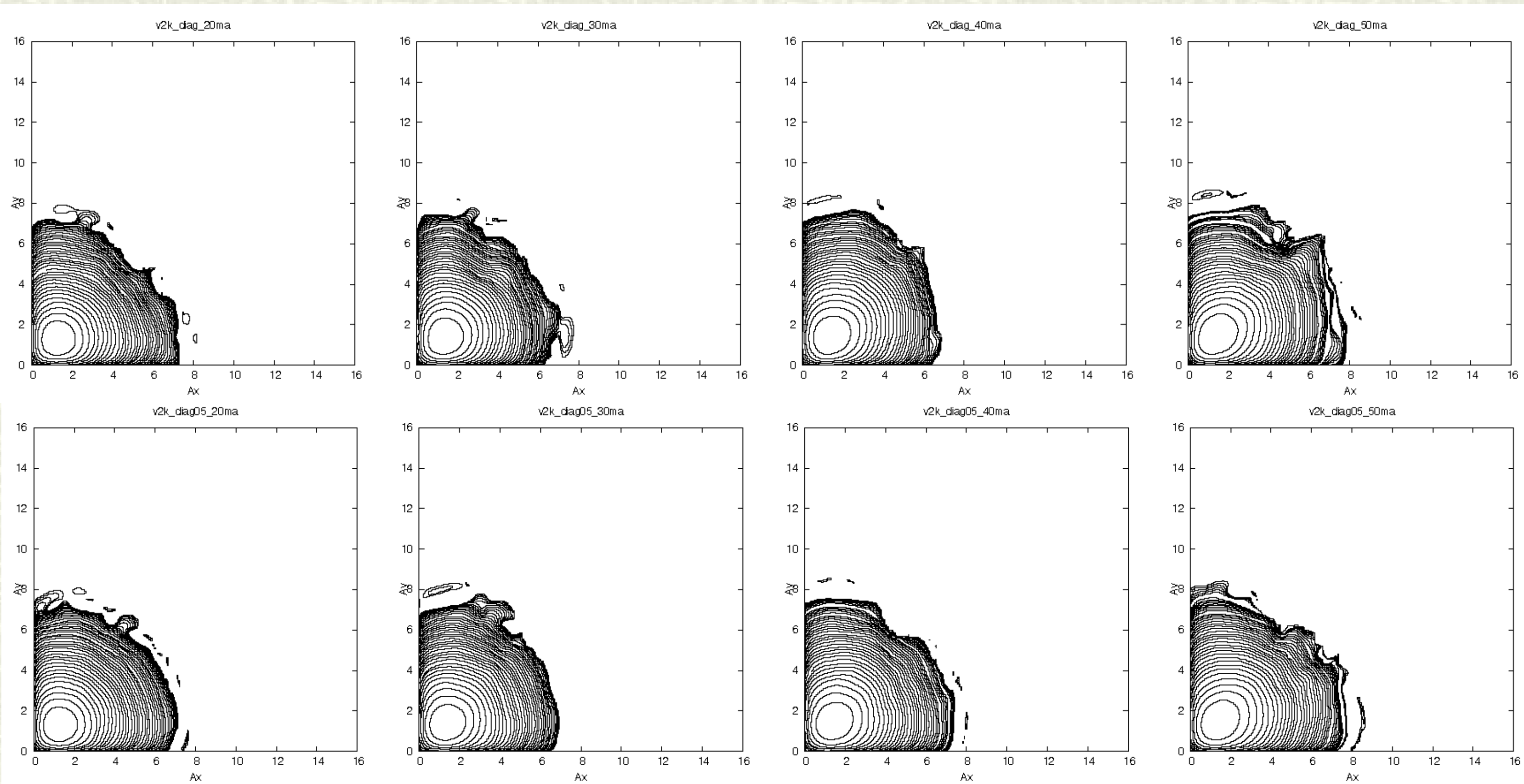


Things to be avoided in round colliding beam operation (3)

Large non-compensation of the solenoidal field

±0.01

±0.005



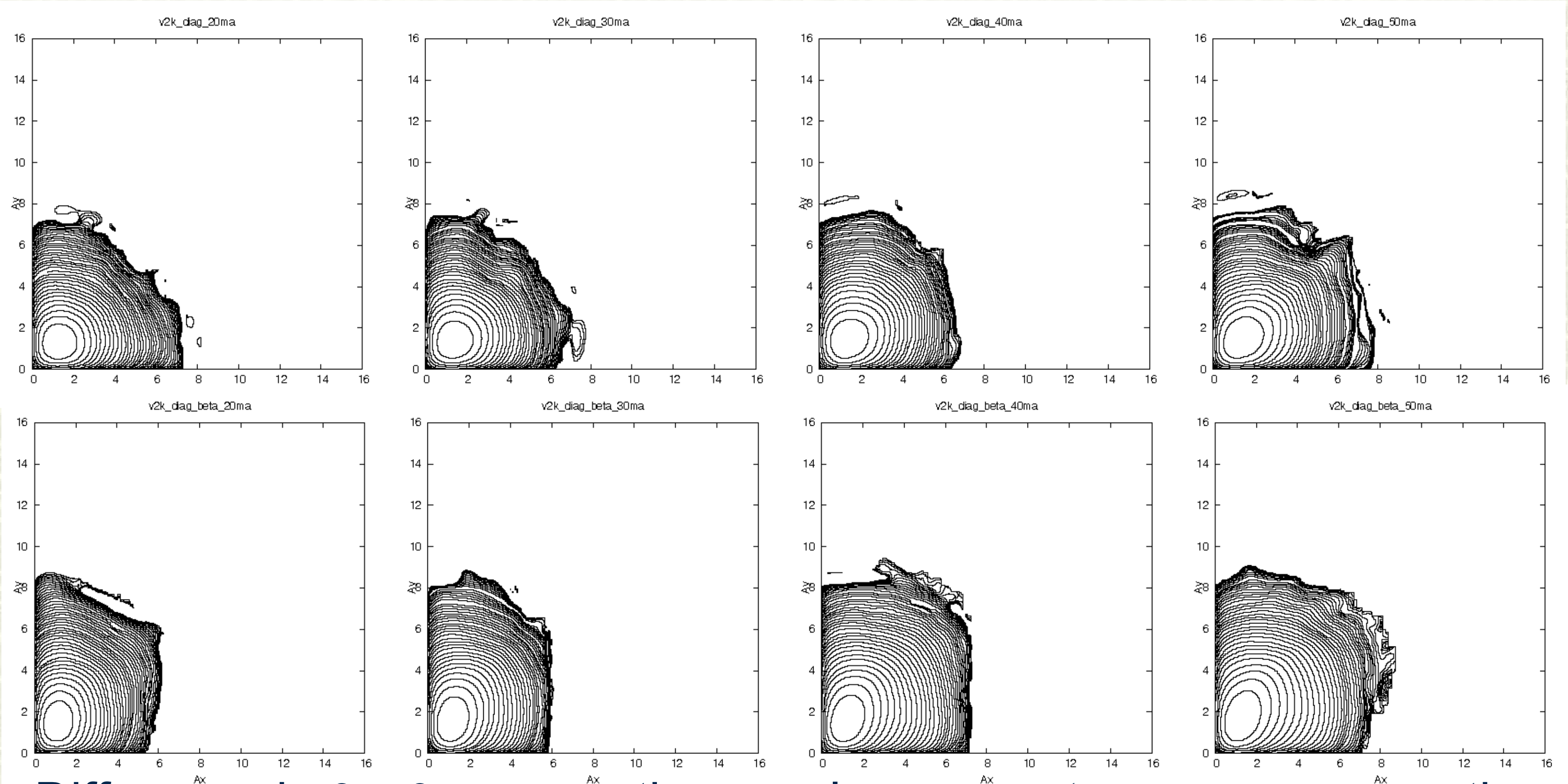
Different tune separation caused by solenoids

Things to be avoided in round colliding beam operation (4)

Non-round beta-functions @IP

βx = βy = 5cm

βx,y = (5±0.5)cm



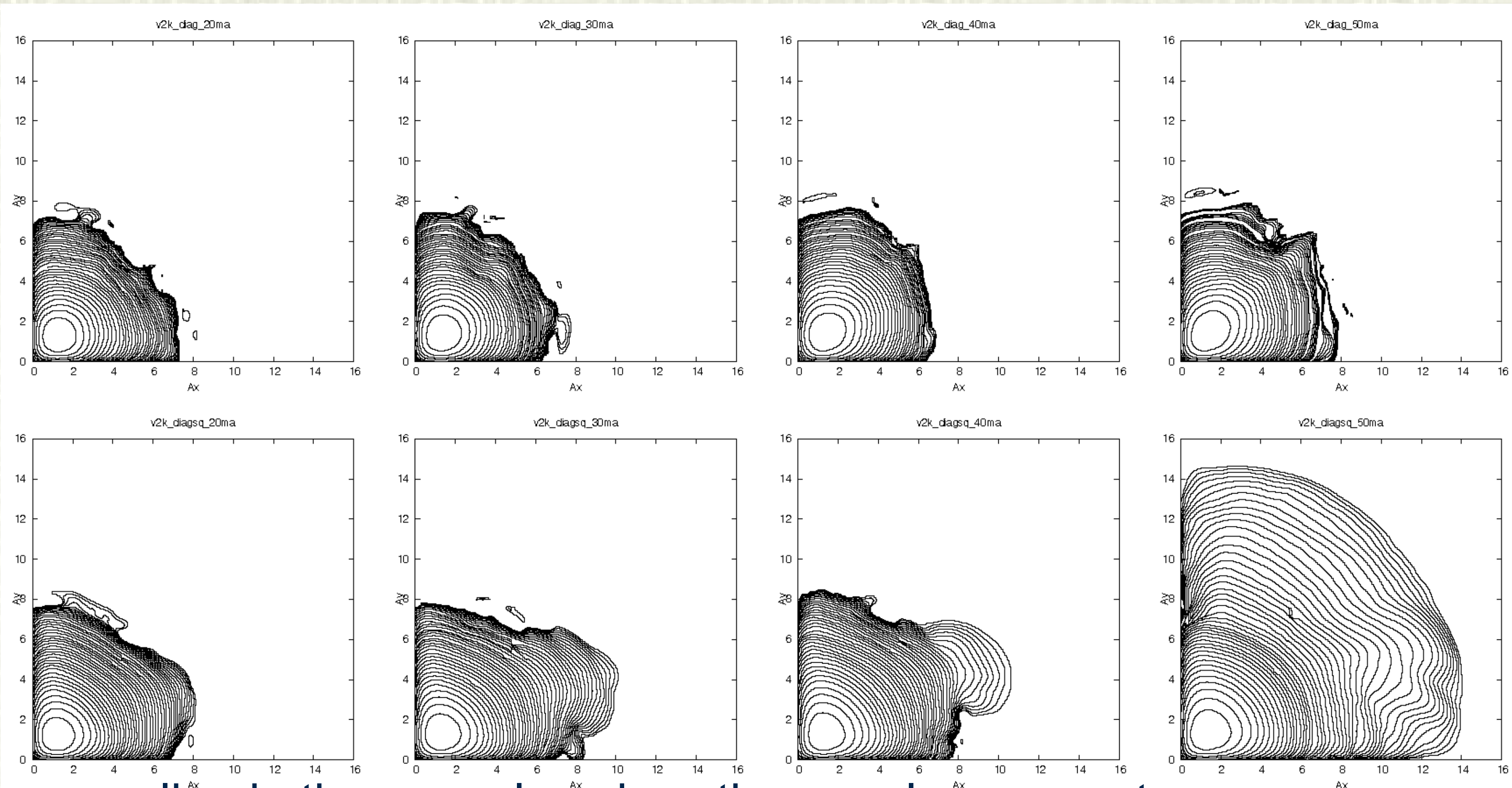
Difference in βx, βy means the angular momentum non-conservation

Things to be avoided in round colliding beam operation (5)

x-y coupling in the arcs

No coupling

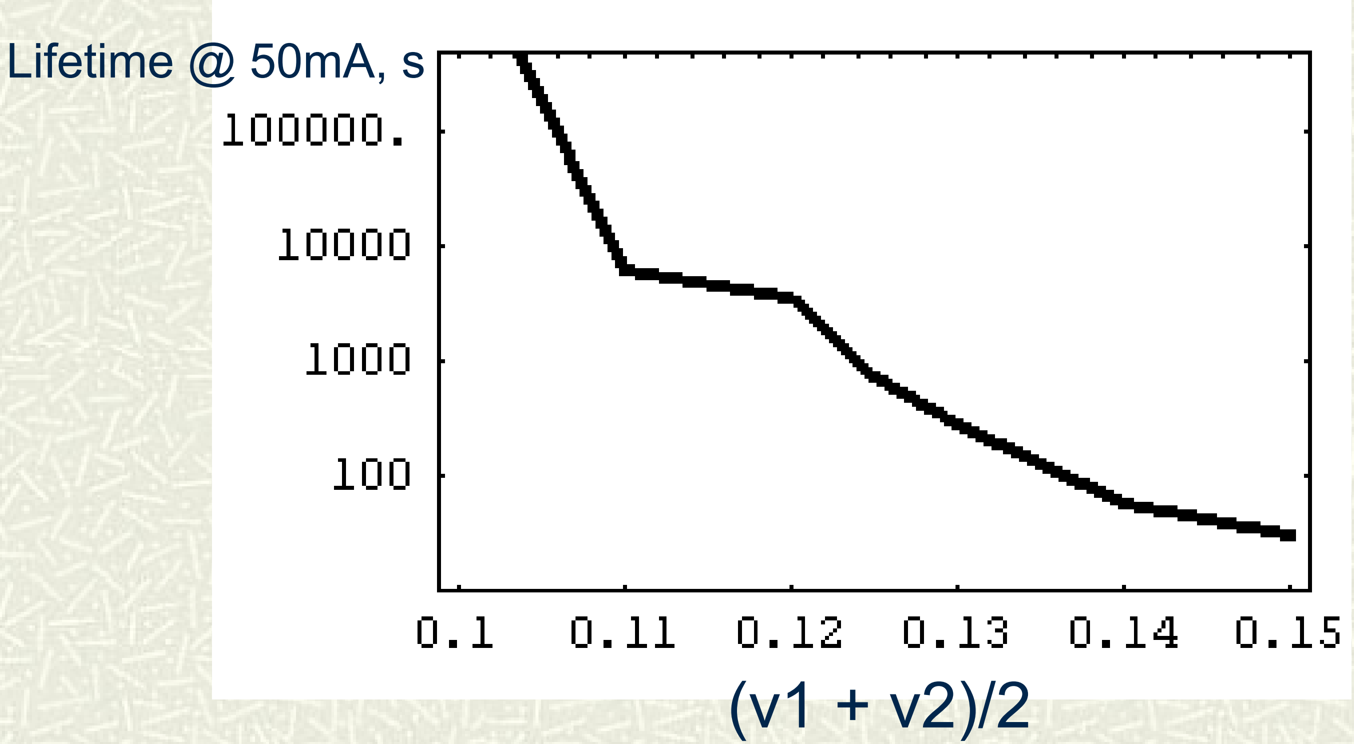
Tune separation 0.005

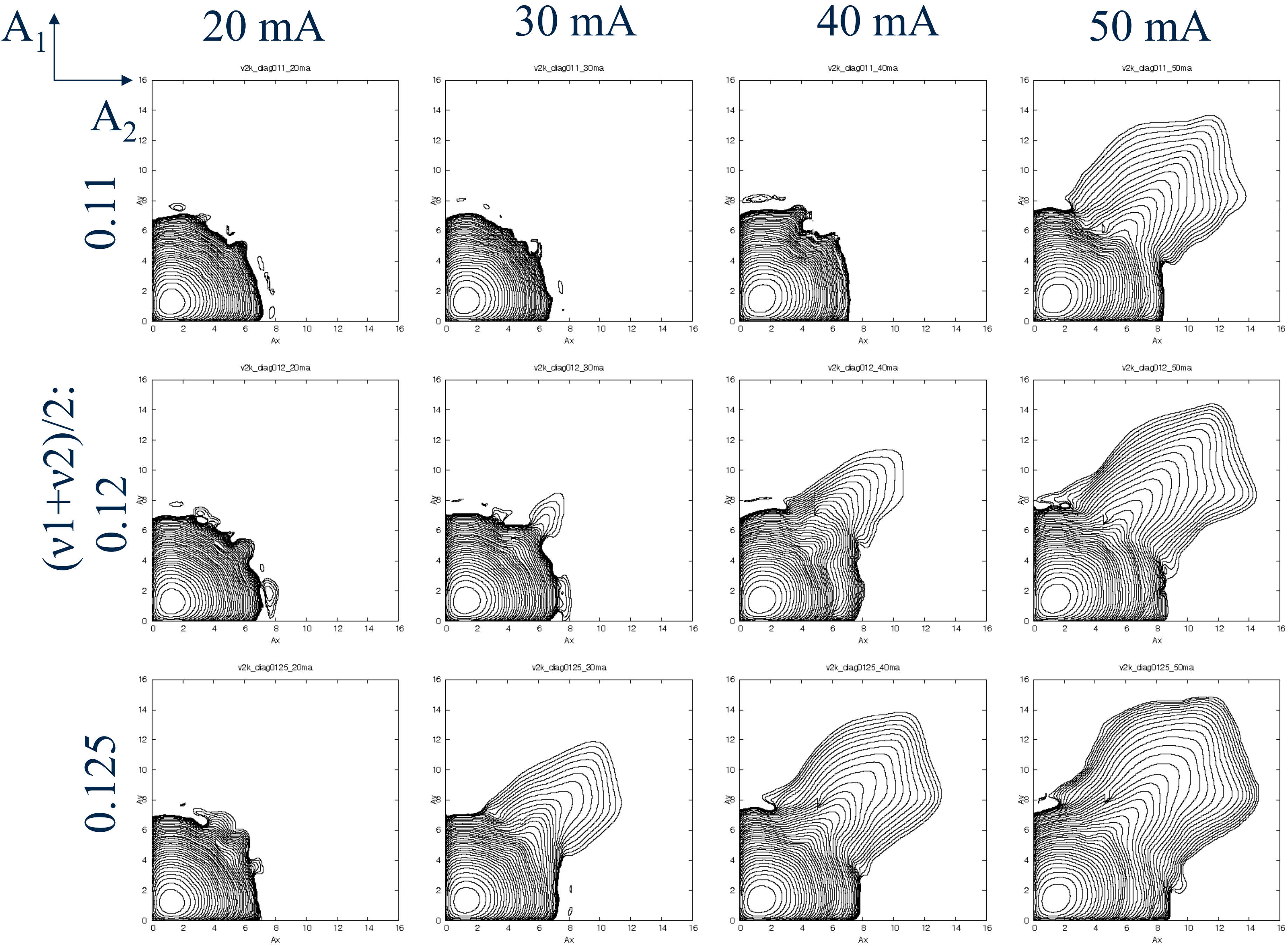


x-y coupling in the arcs also gives the angular momentum non-conservation

Tune scan along the diagonal

…reveals almost constant specific luminosity!
Namely, $L = 1 \times 10^{28}$ $cm^{-2}s^{-1}mA^{-2}$
Only the beam tails expand at higher tunes and cause limitation of the beam lifetime

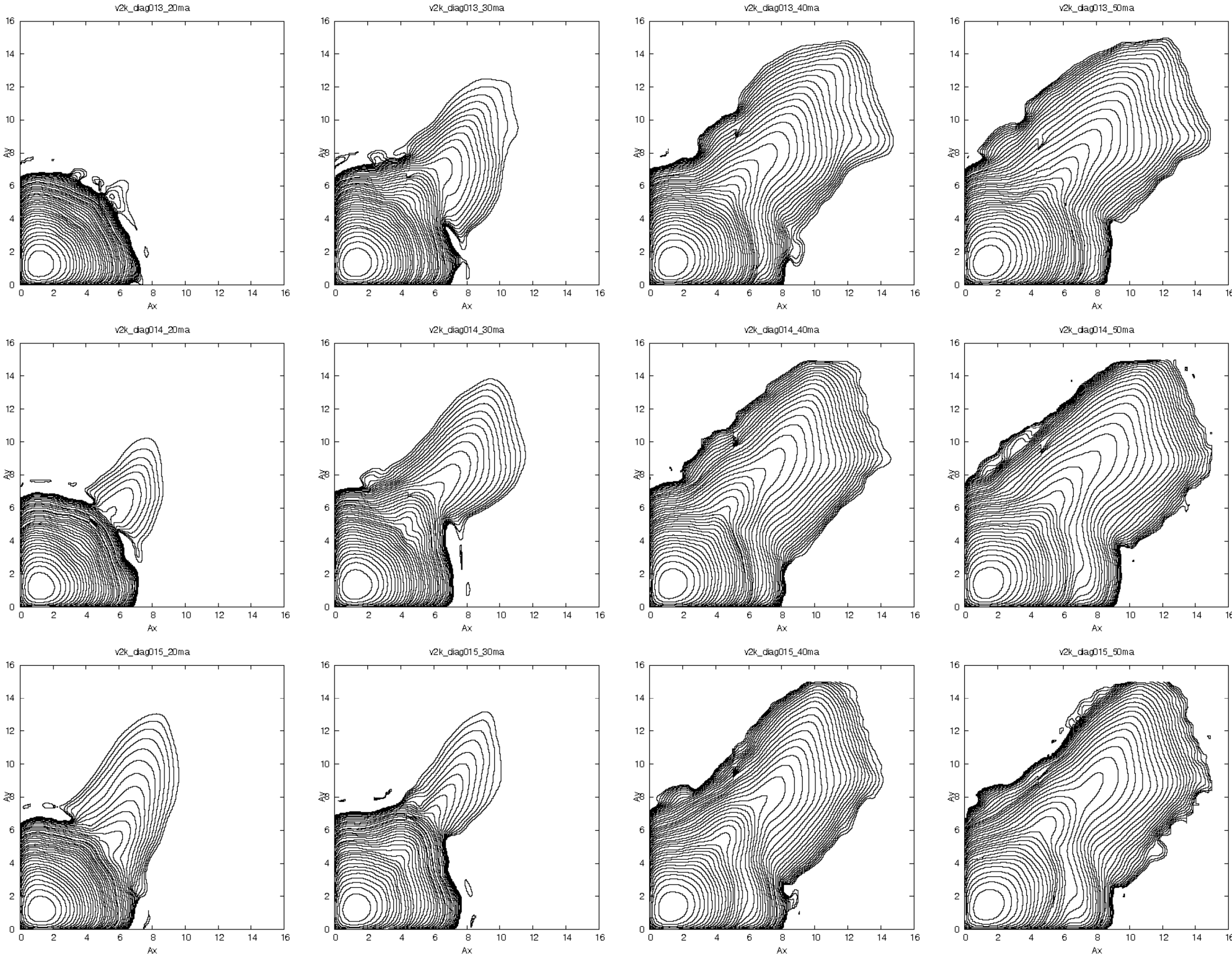




20 mA
30 mA
40 mA
50 mA
A1
A2
0.11
(ν1+ν2)/2:
0.12
0.125
v2k_diag011_20ma
v2k_diag011_30ma
v2k_diag011_40ma
v2k_diag011_50ma
v2k_diag012_20ma
v2k_diag012_30ma
v2k_diag012_40ma
v2k_diag012_50ma
v2k_diag0125_20ma
v2k_diag0125_30ma
v2k_diag0125_40ma
v2k_diag0125_50ma
Ax
Ay

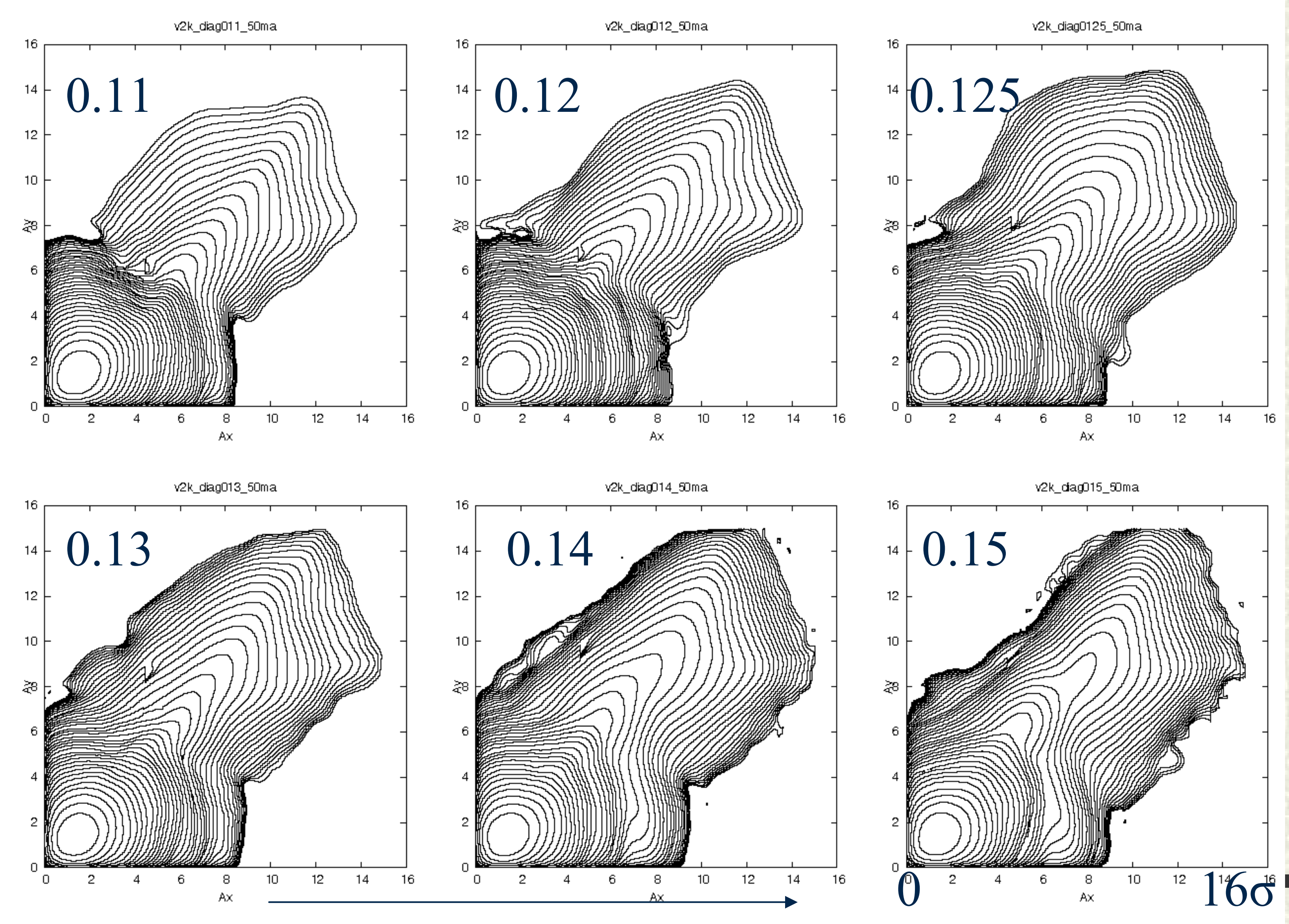
20 mA | 30 mA | 40 mA | 50 mA

(ν1+ν2)/2: 0.13, 0.14, 0.15



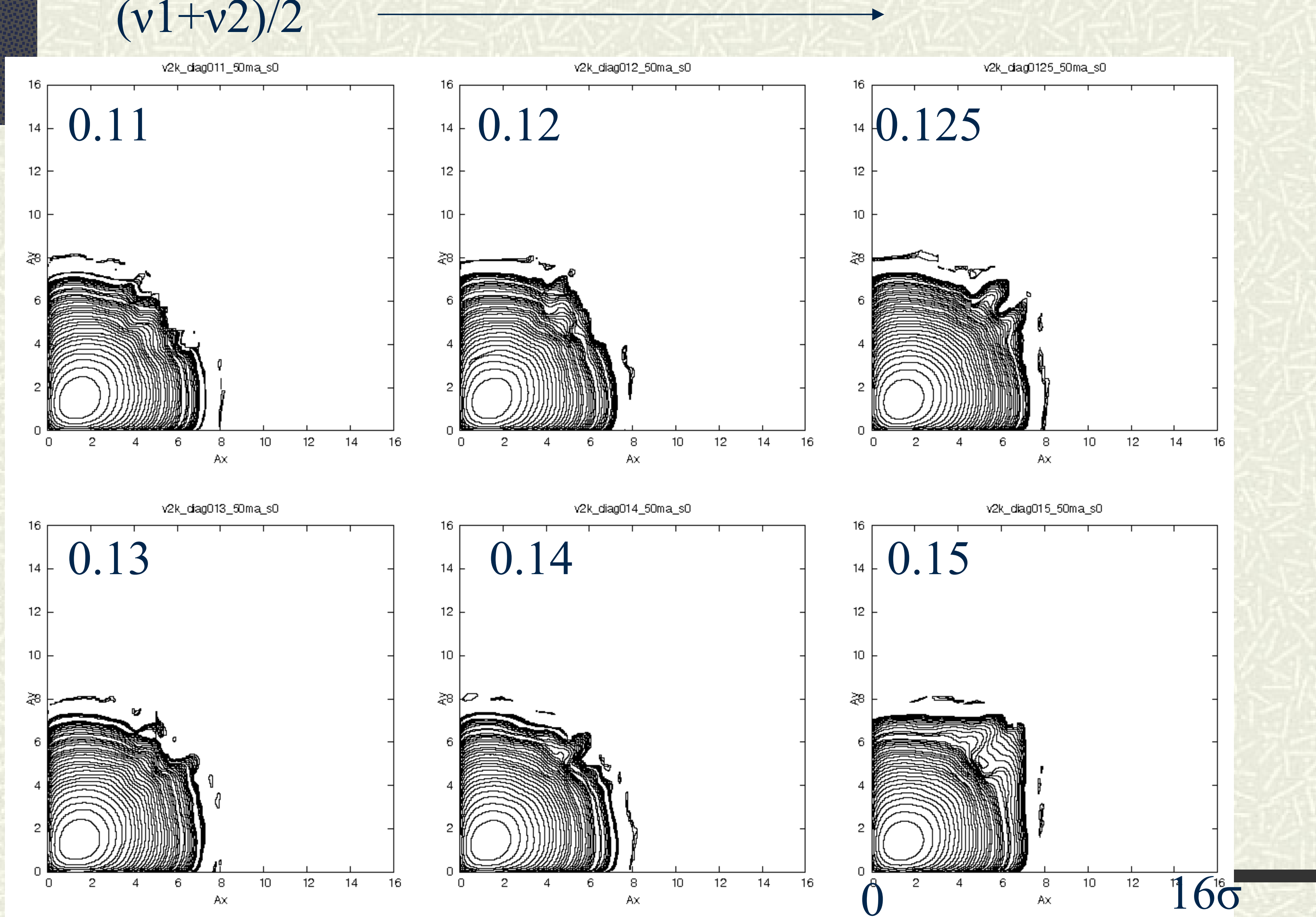
@50mA, with sextupoles: tune dependence of the tails

$(\nu 1+\nu 2)/2$



@50mA, without sextupoles: very weak beam-beam effect

(ν1+ν2)/2



Sextupoles

To preserve the angular momentum, the linear optics must be an equivalent of axi-symmetric focusing and rotation (commutable).

However, a sextupole changes the angular momentum

Field: $B_x = 2xy$ Kick: $k_x = -(x^2 - y^2)$

$B_y = x^2 - y^2$ $k_y = 2xy$

The angular momentum and its change:

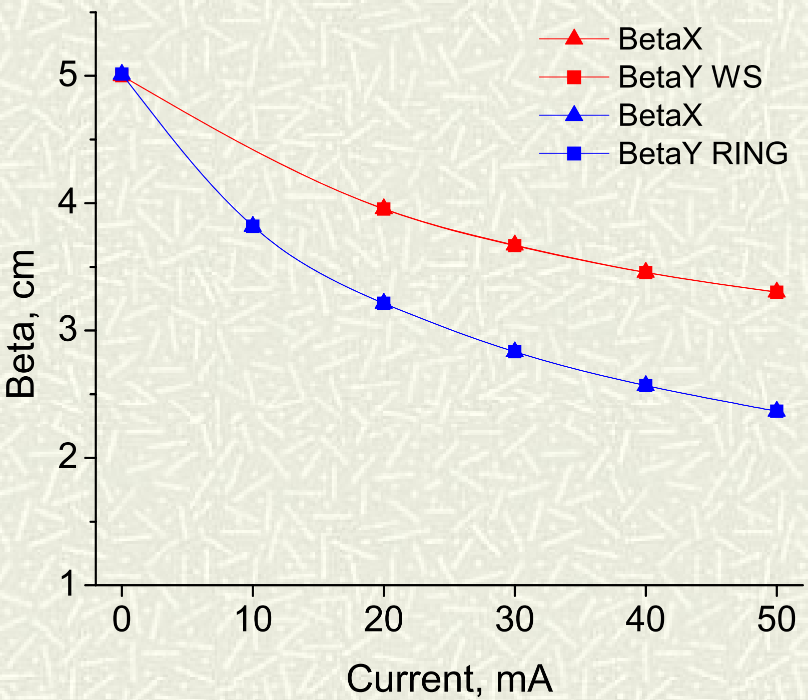
$$M = xy' - yx'$$

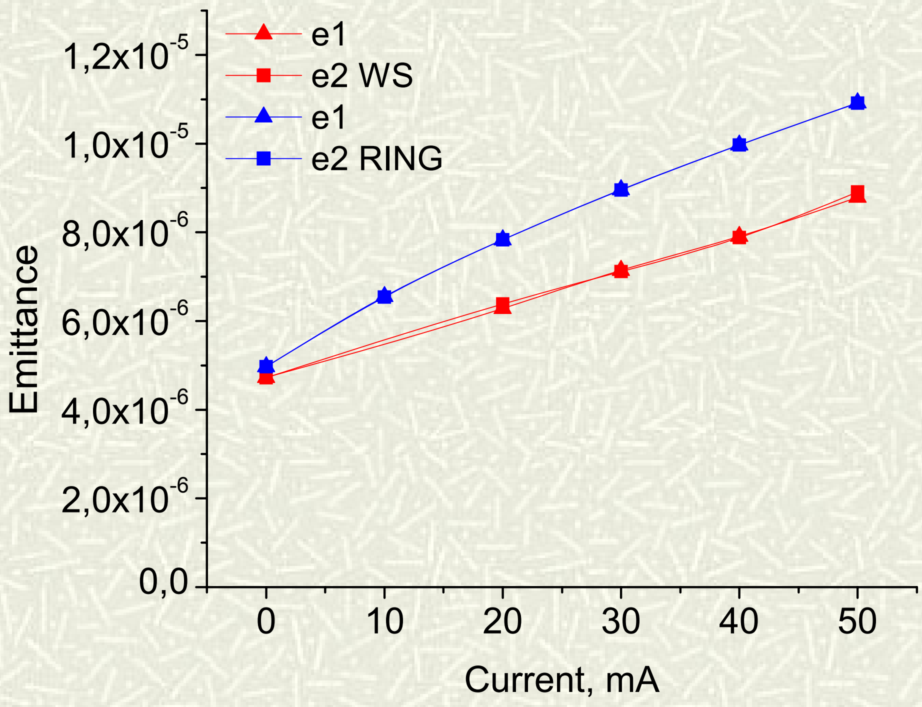
$$\Delta M = x\,\Delta y' - y\,\Delta x' = xk_y - yk_x = 3x^2 y - y^3$$

Thus, the change in the angular momentum has the same form as the skew sextupole Hamiltonian. To 1st order in the sextupole strength, minimization of the sextupole harmonic integral improves the angular momentum conservation.

Dynamic beta, emittance and size

(v1 + v2)/2 = 0.125





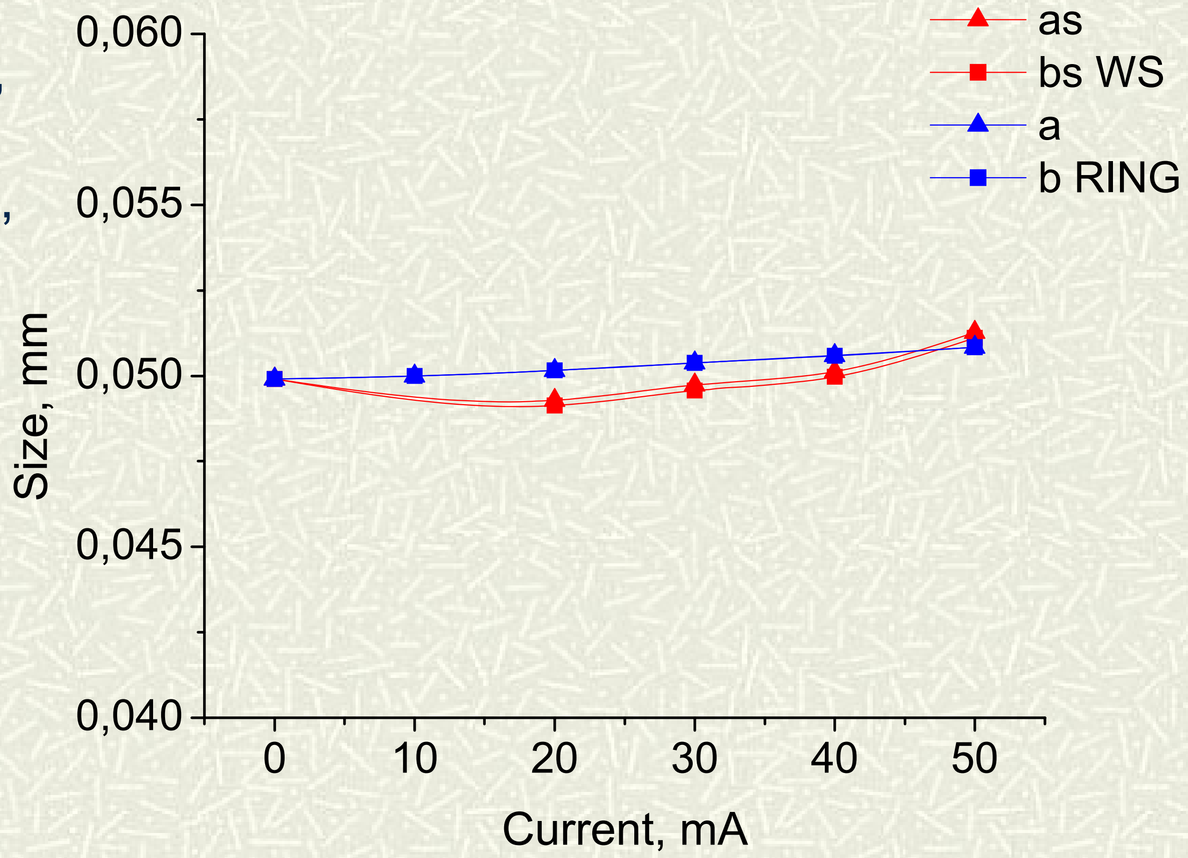
Dynamic beta, emittance and size

For VEPP-2000 optics, the dynamic beta and emittance compensate, sizes @IP = const

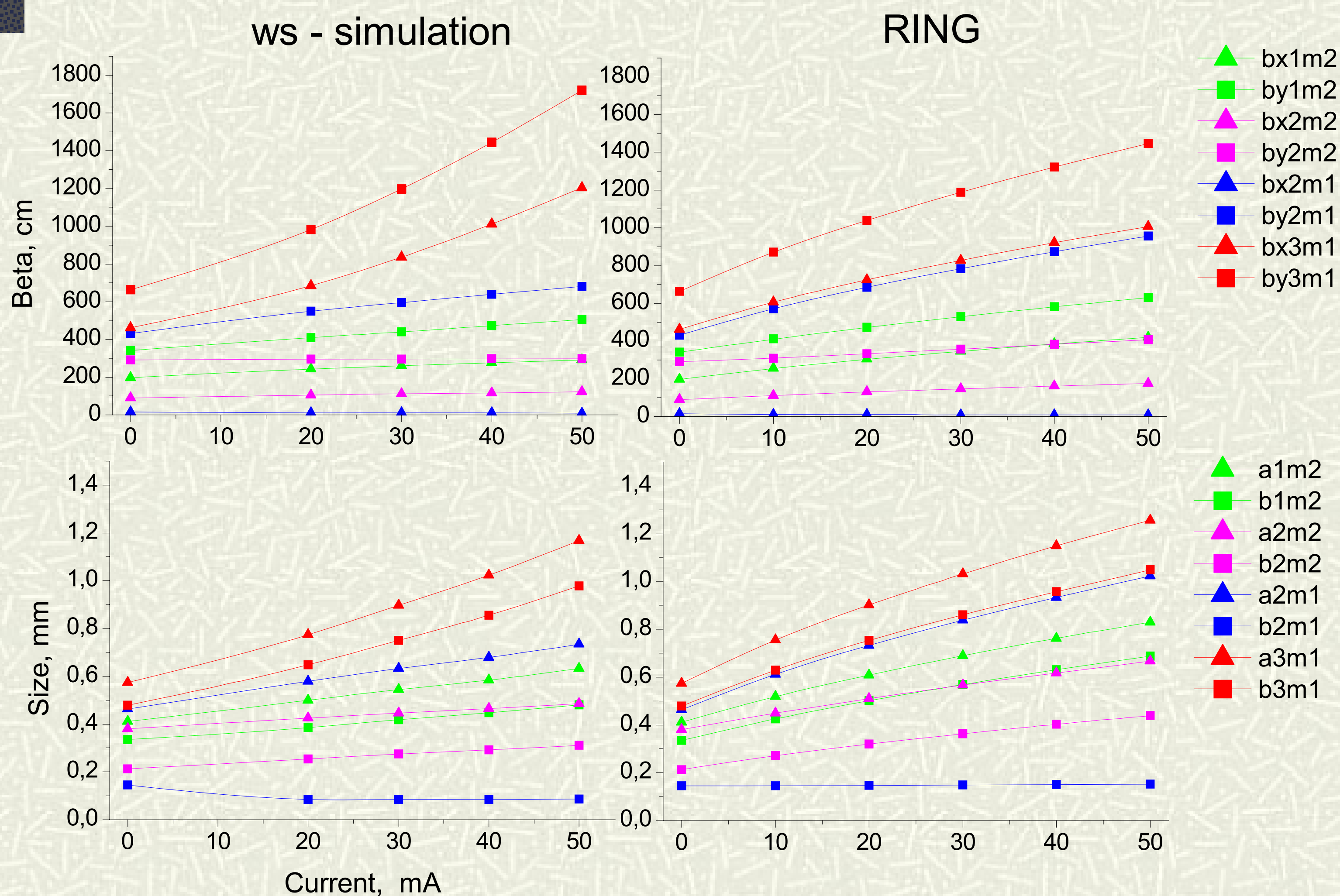
Hence:

1) No need to calculate the dynamic betas self-consistently

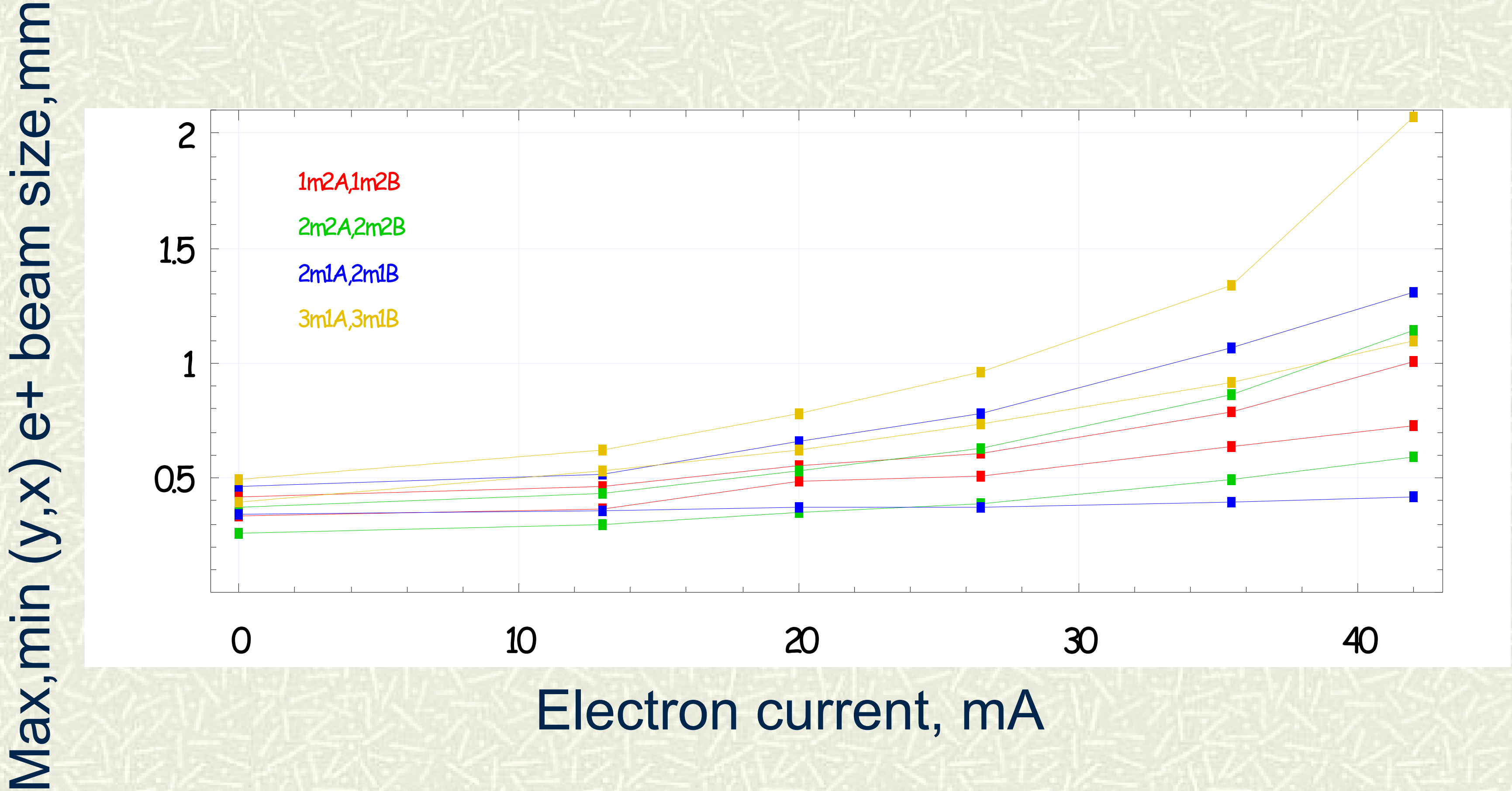
2) No expectations for flip-flop solutions



Dynamic beta and sizes at the e+ beam-size monitors



Weak beam sizes vs the strong beam current, Dec.14 2007



Future work

- The simulation clearly predicts better lifetime for lower tunes, we urgently need understanding of problems with optics at tunes < 0.11
- Optimization of sextupoles, although not needed for DA, may he helpful for the beam tails at collision: to be checked in the weak-strong simulation.
- Strong-strong simulation is important, however a correct account of the natural chromaticity is needed in the code.
- More beam-beam studies needed to improve understanding of current-dependent beam sizes
- Basic round beam option + + – – should be experimentally tried out
- **High-luminosity operation becomes possible only after the new linac-based Injection Complex lifts the positron production limit**

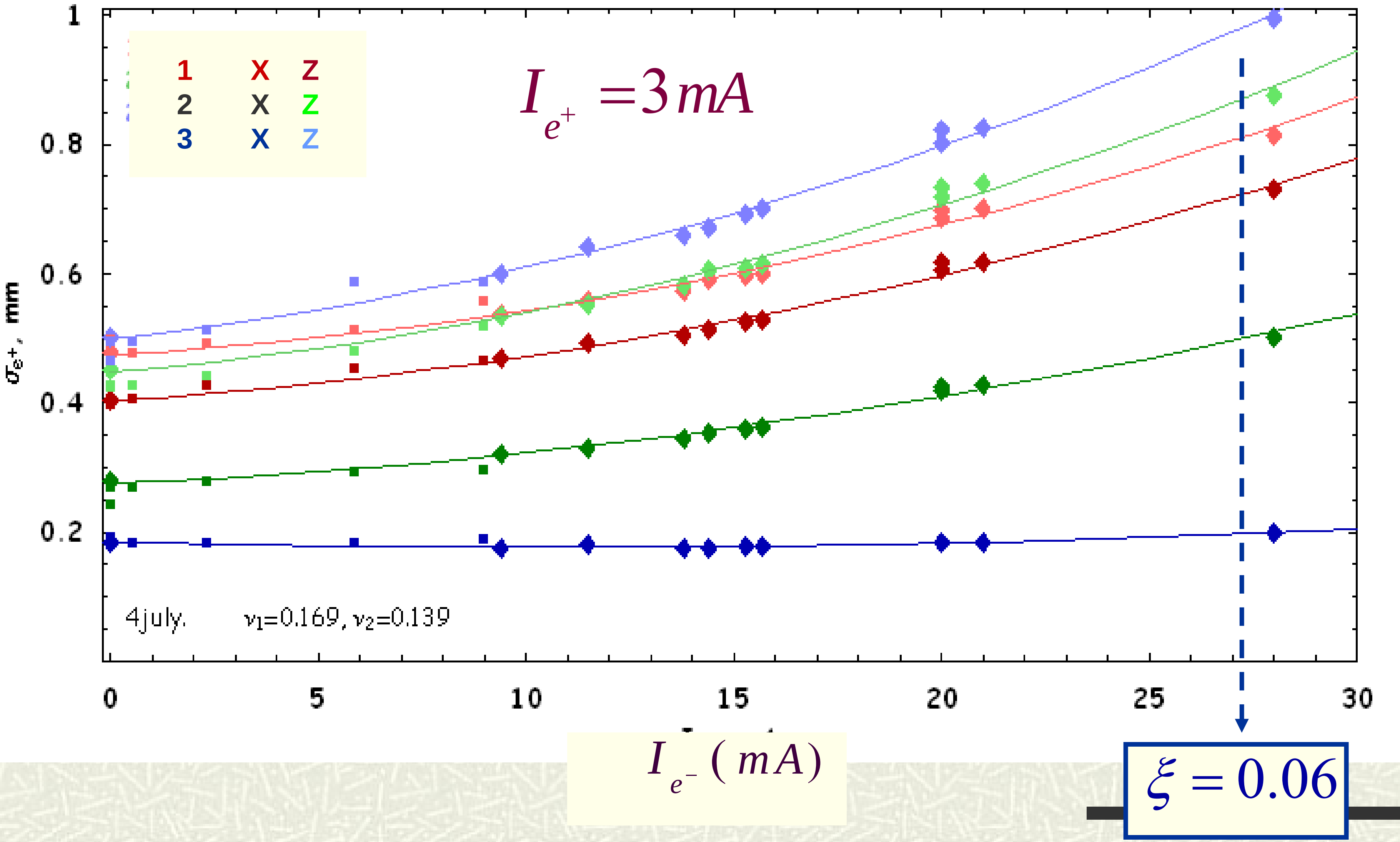
Thanks a lot

for your attention!

Positron life time ≈ 5000 s

Luminosity ≈ 0.5 ÷ 0.7 × 10^{30} $cm^{-2}s^{-1}$

“Weak-strong” beam-beam study

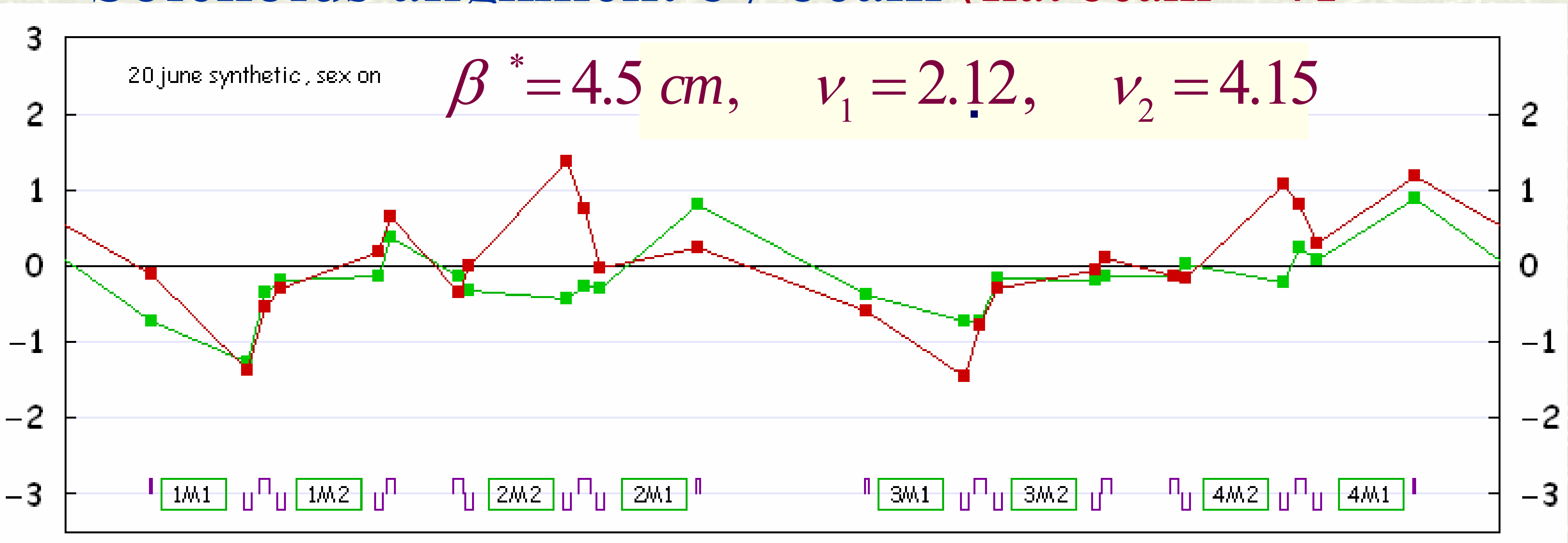


Main Parameters of VEPP-2000

Circumference	**24.38 m**
RF frequency	**172 MHz**
RF voltage	**100 kV**
RF harmonic number	**14**
Momentum compaction	**0.036**
Synchrotron tune	**0.0035**
Energy spread	**6.4×10^{-4}**
Beam emittances (in the round mode)	**1.29×10^{-7} m rad**
Dimensionless damping decrements (x,y,s)	**2.19×10^{-5}, 2.19×10^{-5}, 4.83×10^{-5}**
Betatron tunes	**4.05, 2.05**
Betatron functions at IP	**10 cm**
Number of bunches per beam	**1**
Number of particles per bunch	**1×10^{11}**
Beam-beam parameter (x,y)	**0.075, 0.075**
Luminosity per IP (at 1 GeV)	**1×10^{32} $cm^{-2}s^{-1}$**

Round beam operation

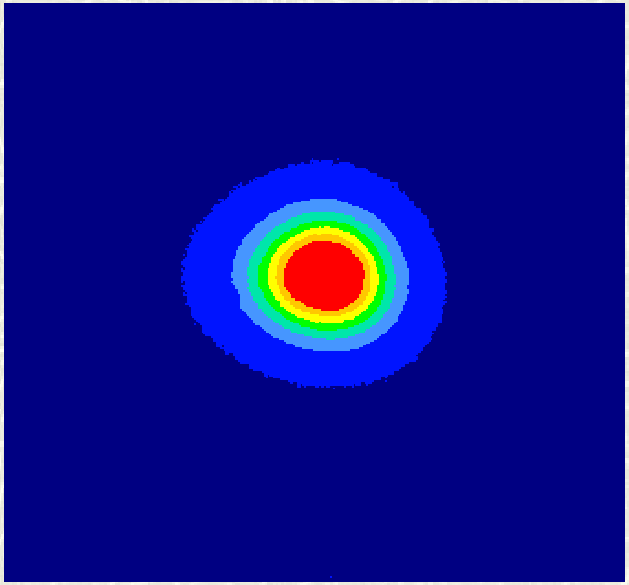
- E = 508 MeV
- Solenoids alignment by beam (flat beam + 4T



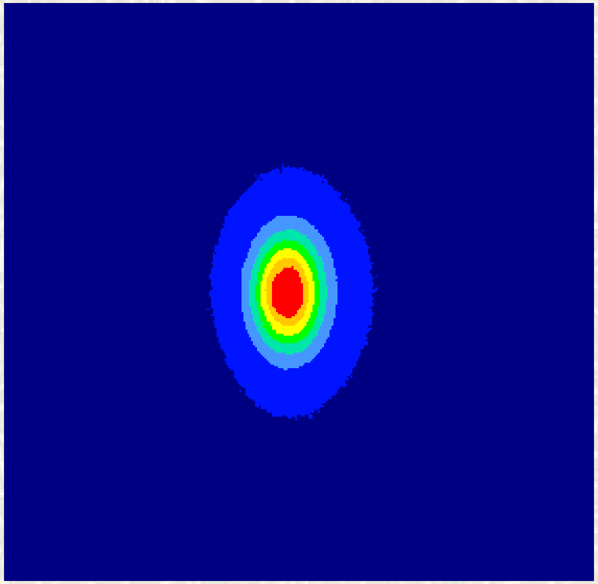
- CO + lattice symmetry corrections (tunes: 0.1 ÷ 0.15)
- Orbit response matrices to dipole and quadrupole corrections + Singular value decomposition

Round beams (solenoid field 10 T)

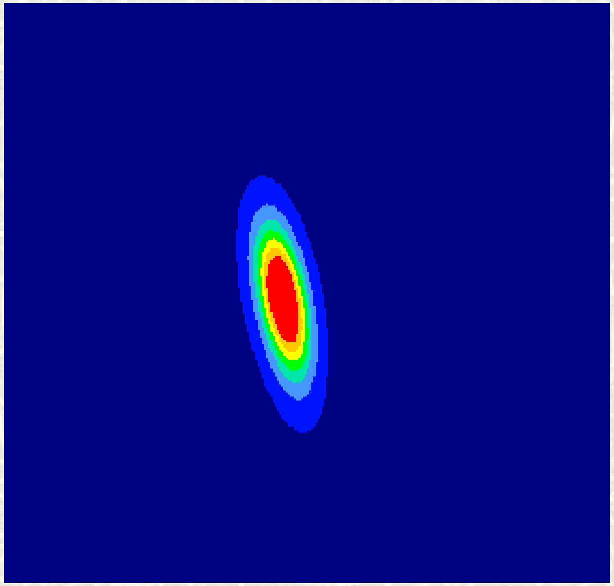
positron beam



#1 (1M2)

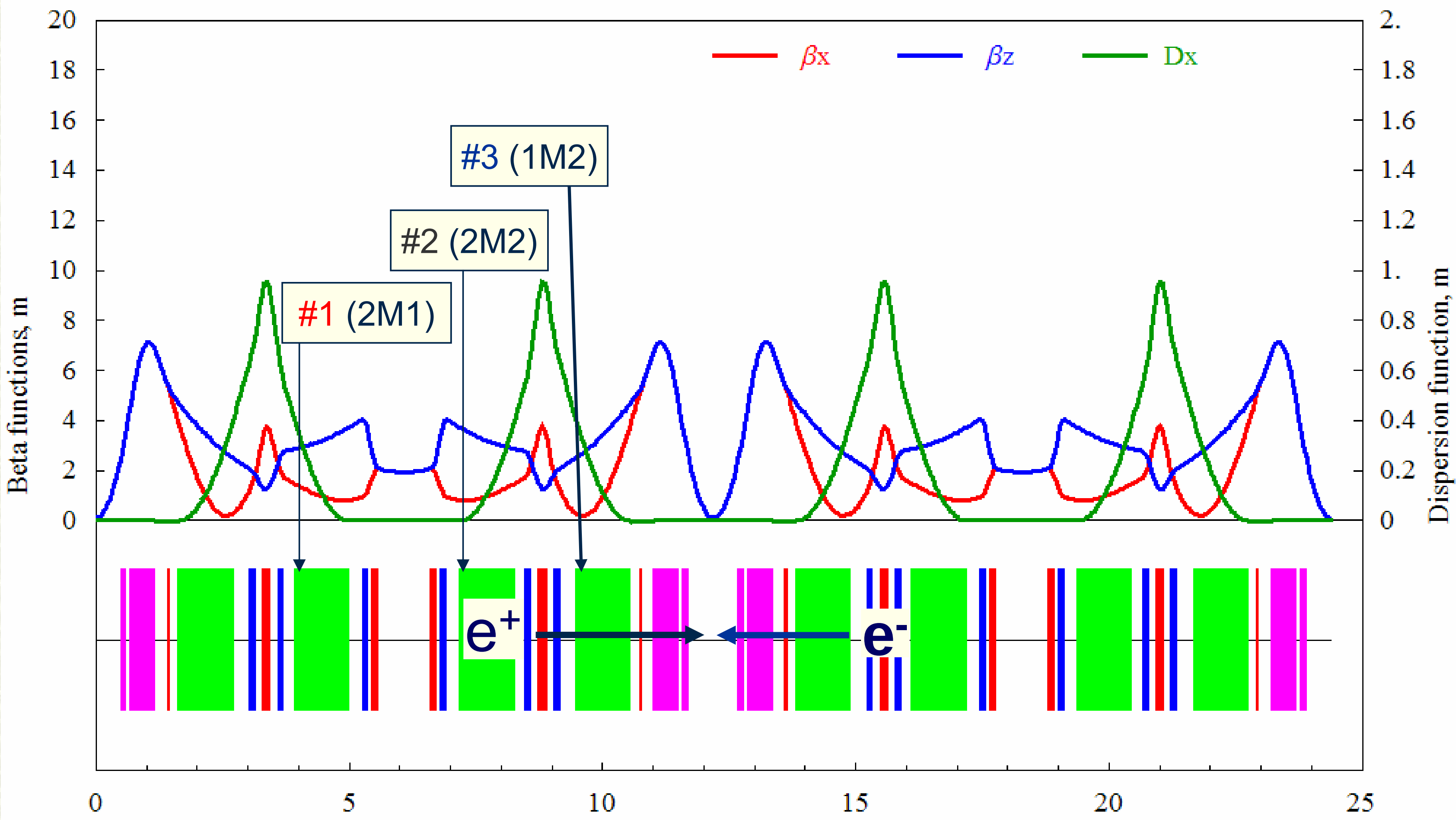


#2 (2M2)



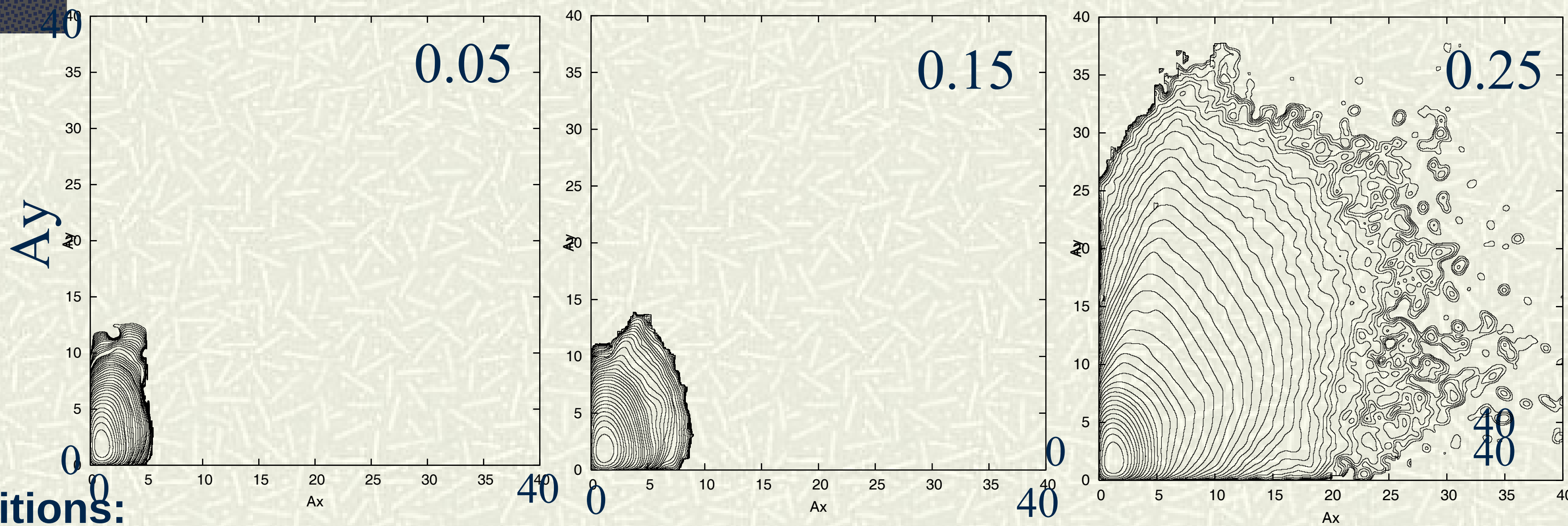
#3 (2M1)

Round beam lattice



Weak-strong beam-beam simulation by D.Shatilov

The beam-beam parameter varied:



Conditions:

arc tunes separation 0.02 by the doublet (D3,F3) & F1 lenses, beta* x,y kept equal;
circular modes and a wider tune split produced by twist 0.79kGs*66.5524cm:
Qx = 4.1115, Qy=2.0893,
alpha = 0.036, Qs = 0.0028, beta*=4.5cm
bunch length: 1.74cm (50kV RF), dE/Eo = 3.5e-04
emittances: Ex = 8.464e-06, Ey = 3.065e-06 cm*rad
decrements: dx = 1.905e-06, dy = 1.998e-06, de = 4.318e-06 (per 1/2 turn)