Recent beam-beam effects at VEPP-4M & VEPP-2000

Dmitry Shwartz
BINP, Novosibirsk

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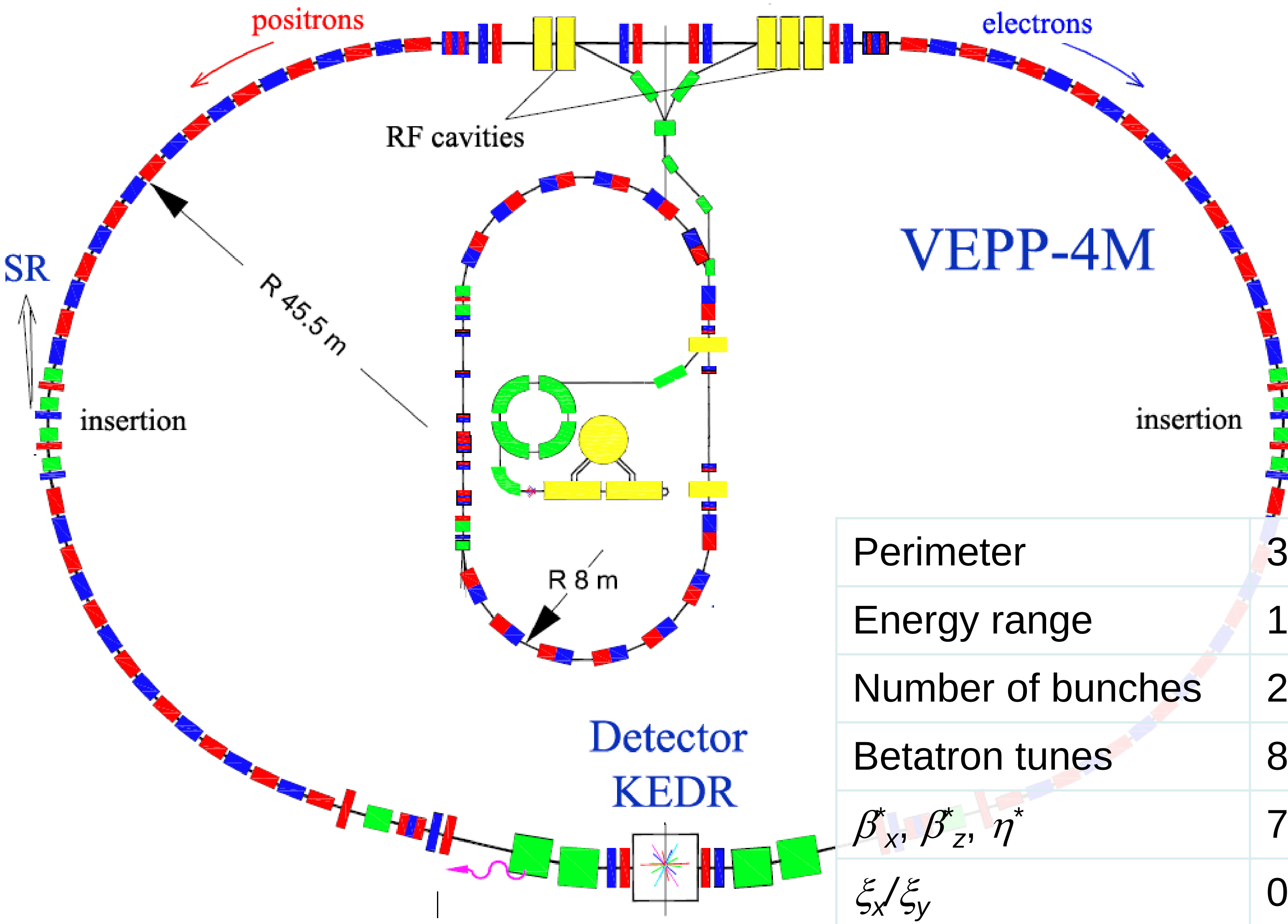
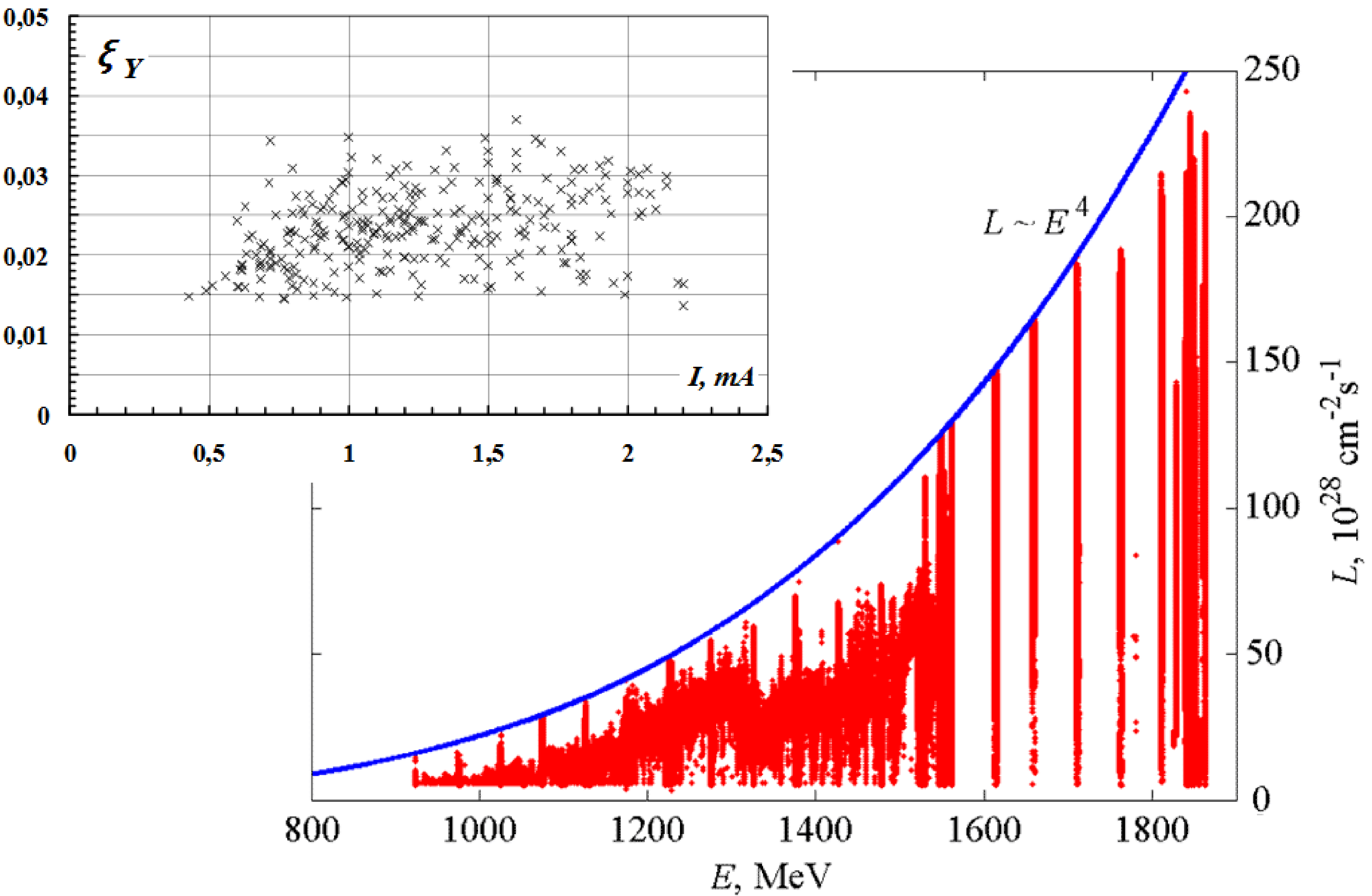
ICFA Mini-Workshop on Beam-Beam Effects in Hadron Colliders

VEPP-4M

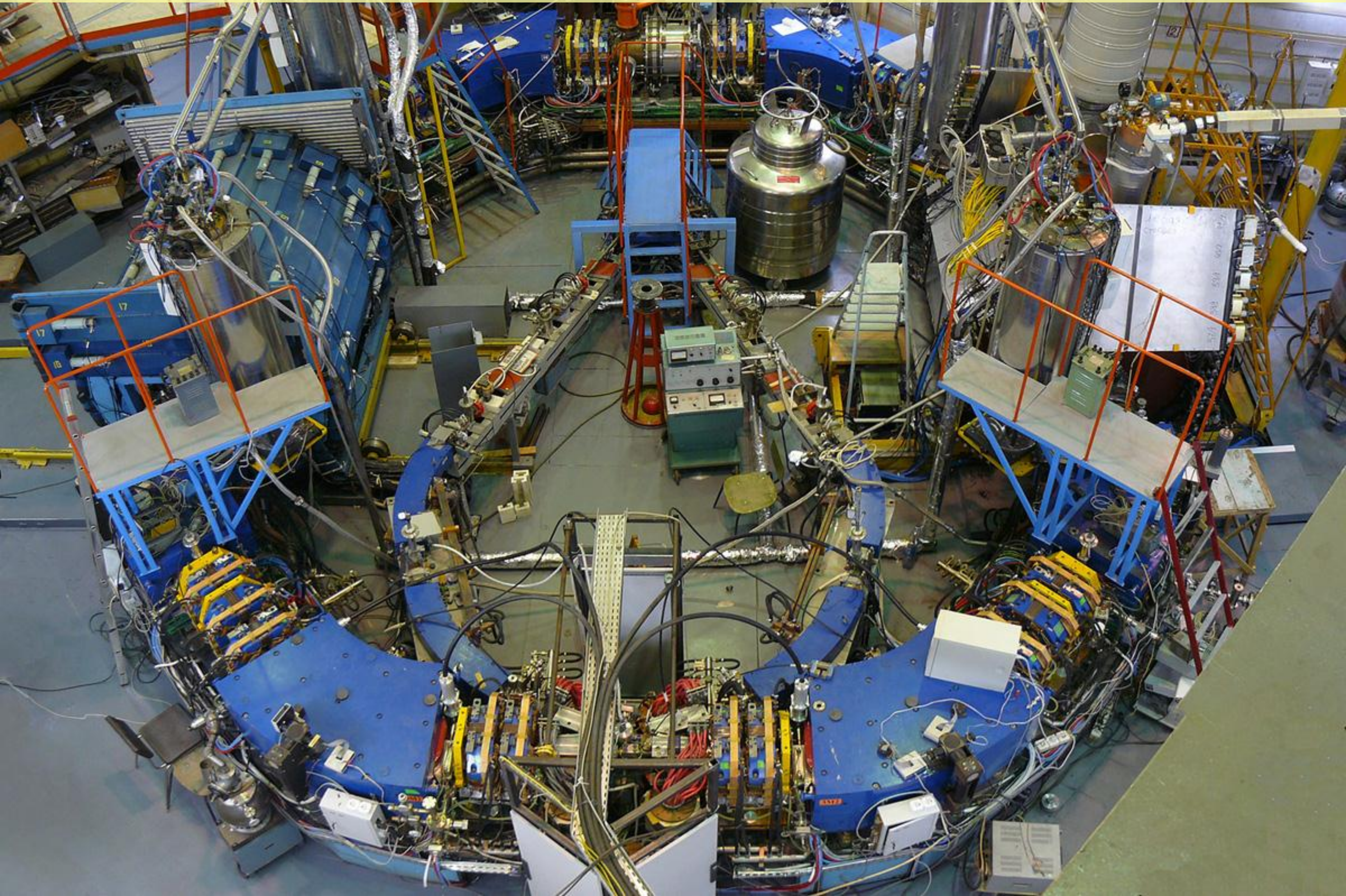


Perimeter	366 m
Energy range	$1 \div 5.5$ GeV
Number of bunches	2×2
Betatron tunes	8.54/7.57
β^*_x, β^*_z, η^*	75/ 5/ 80 cm
ξ_x/ξ_y	0.025/0.04
Luminosity @ 1.85 GeV	2.3×10^{30} cm^{-2}s^{-1}

VEPP-4M luminosity



VEPP-2000



Motivation of the round beam use in e+e- collider

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

Round Beams:

$$L = \frac{\pi\gamma^2 \xi_x \xi_y \varepsilon_x f}{r_e^2 \beta_y^*}\left(1 + \frac{\sigma_y}{\sigma_x}\right)^2 \Rightarrow L = \frac{4\pi\gamma^2 \xi^2 \varepsilon f}{r_e^2 \beta^*}$$

✓Geometric factor: $(1+\sigma_y/\sigma_x)^2 = 4$

✓Beam-beam limit enhancement: $\xi \geq 0.1$

✓IBS for low energy? Better life time!

The Concept of Round Colliding Beams

Axial symmetry of counter beam force together with x-y symmetry of transfer matrix should provide additional integral of motion (angular momentum $M_z = x'y - xy'$). Particle dynamics remains nonlinear, but becomes 1D.

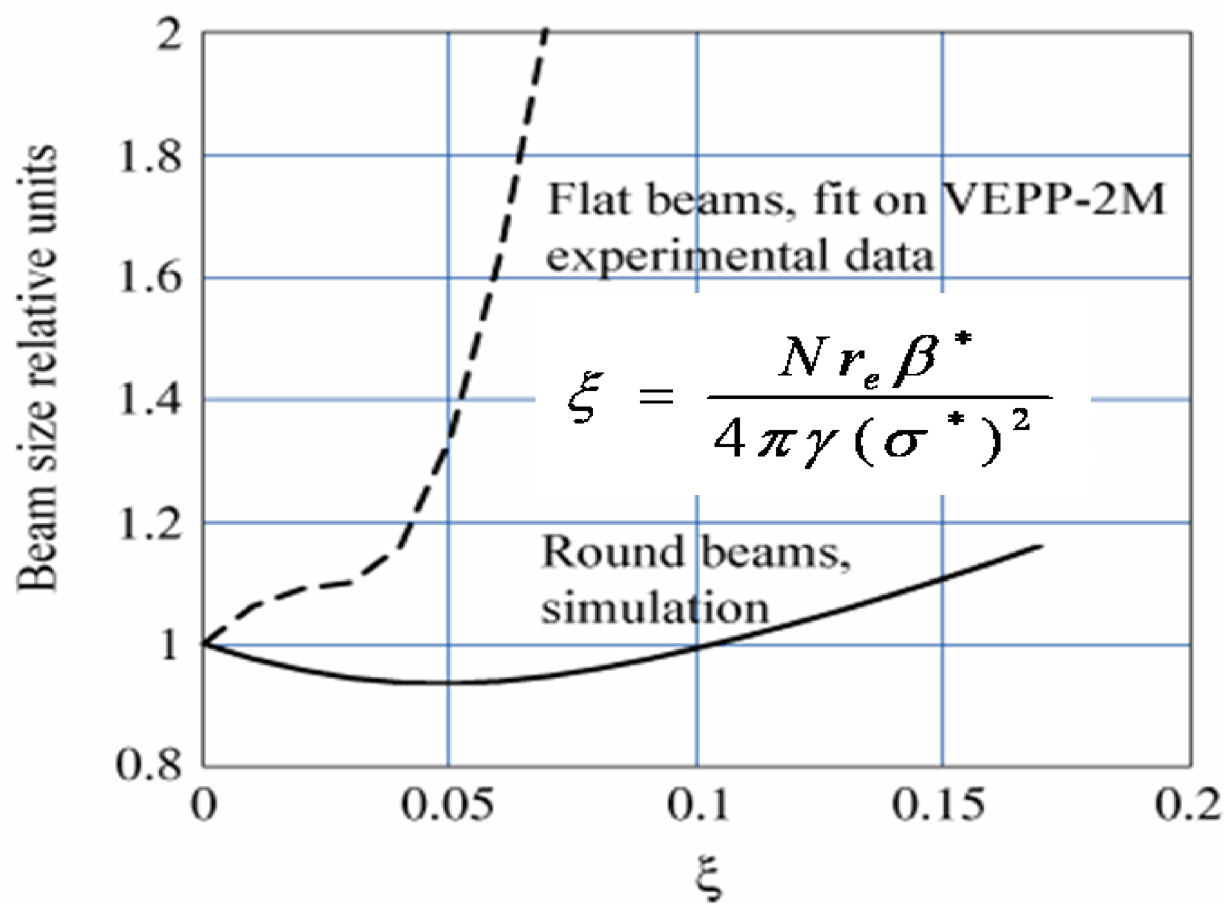
- Head-on collisions
- Small and equal β-functions at IP: $\beta_x = \beta_y$
- Equal beam emittances: $\varepsilon_x = \varepsilon_y$
- Equal fractional parts of betatron tunes: $\nu_x = \nu_y$

$\beta_x = \beta_y$, $\varepsilon_x = \varepsilon_y$ → Round beam

$\beta_x = \beta_y$, $\nu_x = \nu_y$ → $M_x = M_y$

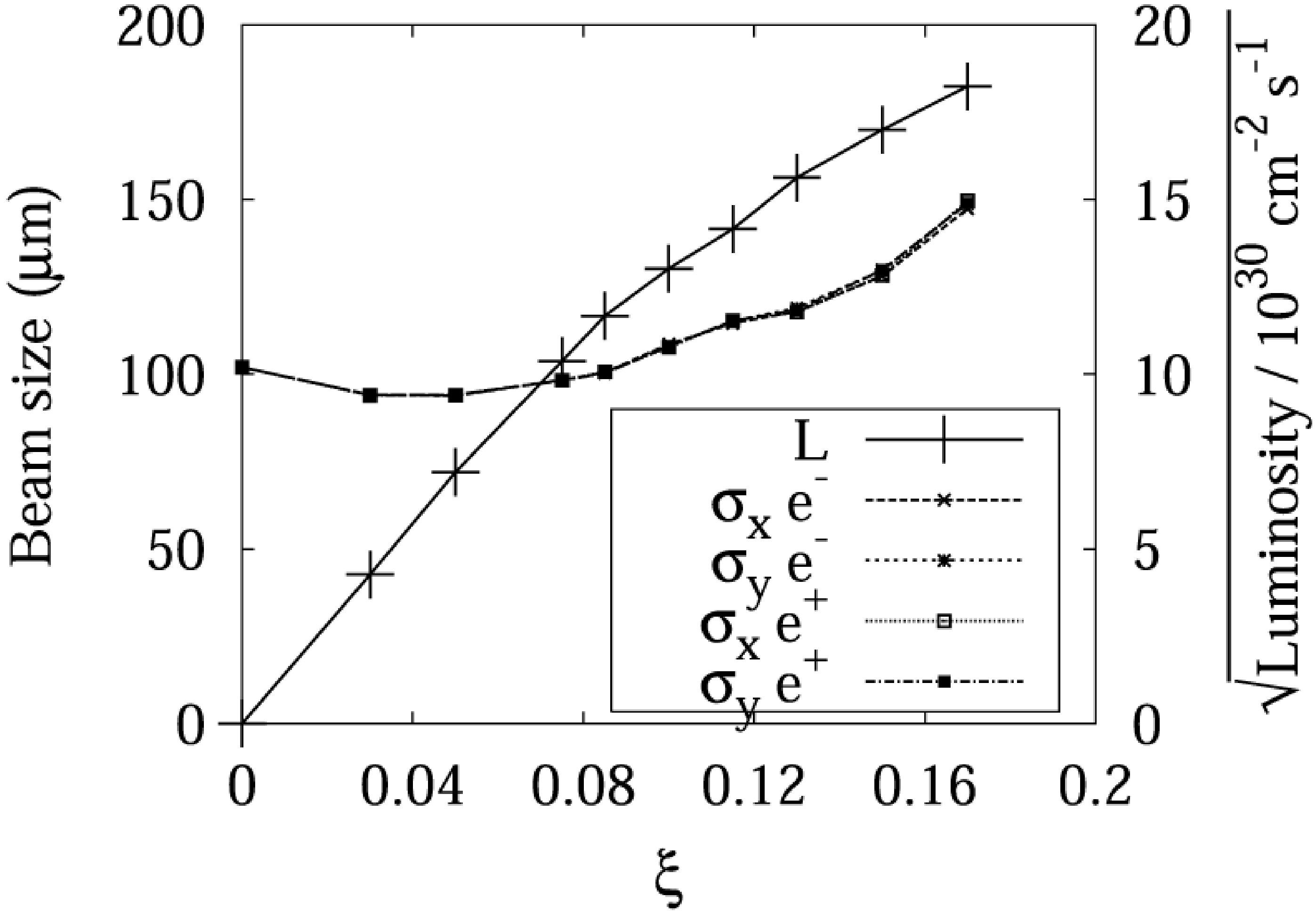
V.V.Danilov et al., EPAC'96, Barcelona, p.1149, (1996)

"Weak-Strong" Beam-Beam Simulations



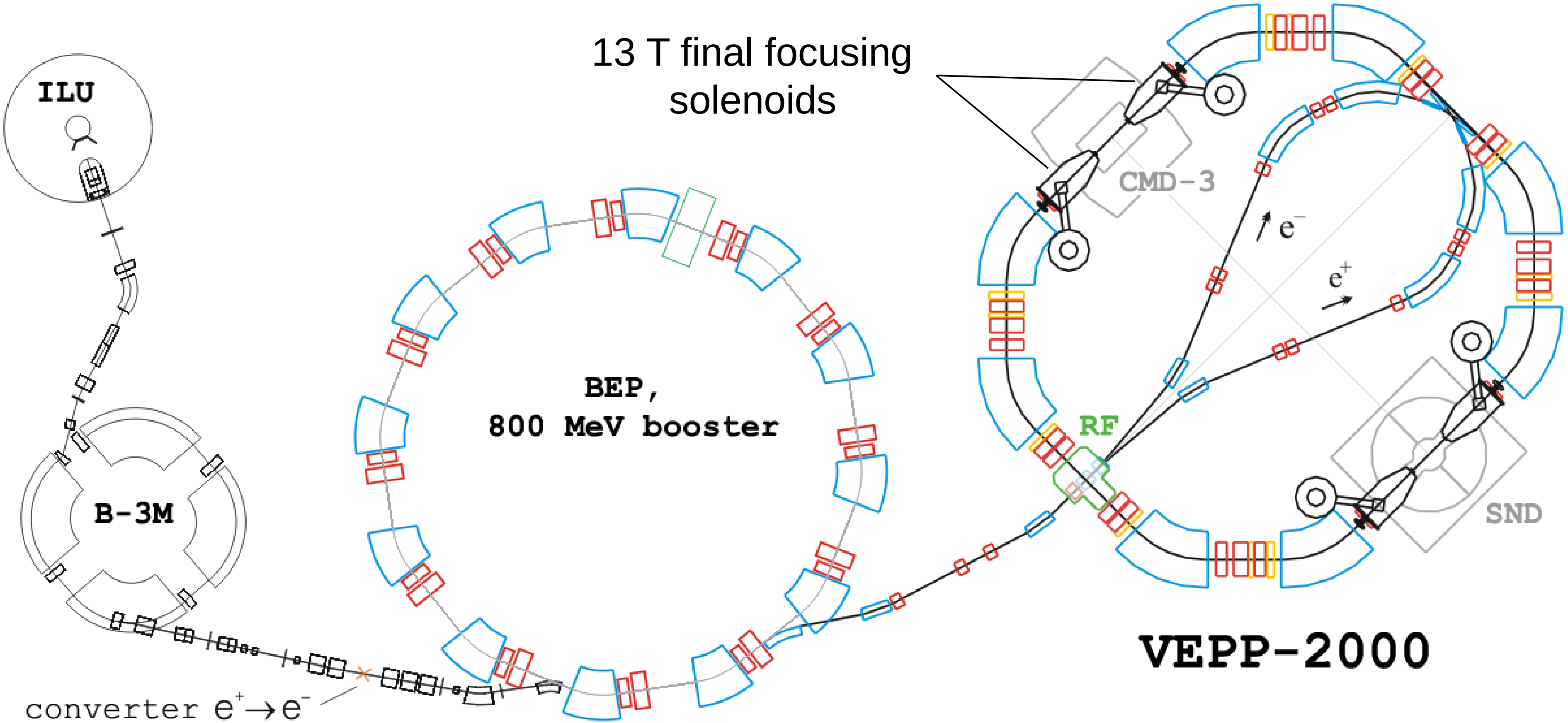
I.Nesterenko, D.Shatilov, E.Simonov, in Proc. of Mini-Workshop on "Round beams and related concepts in beam dynamics", Fermilab, December 5-6, 1996.

"Strong-Strong" Beam-Beam Simulations



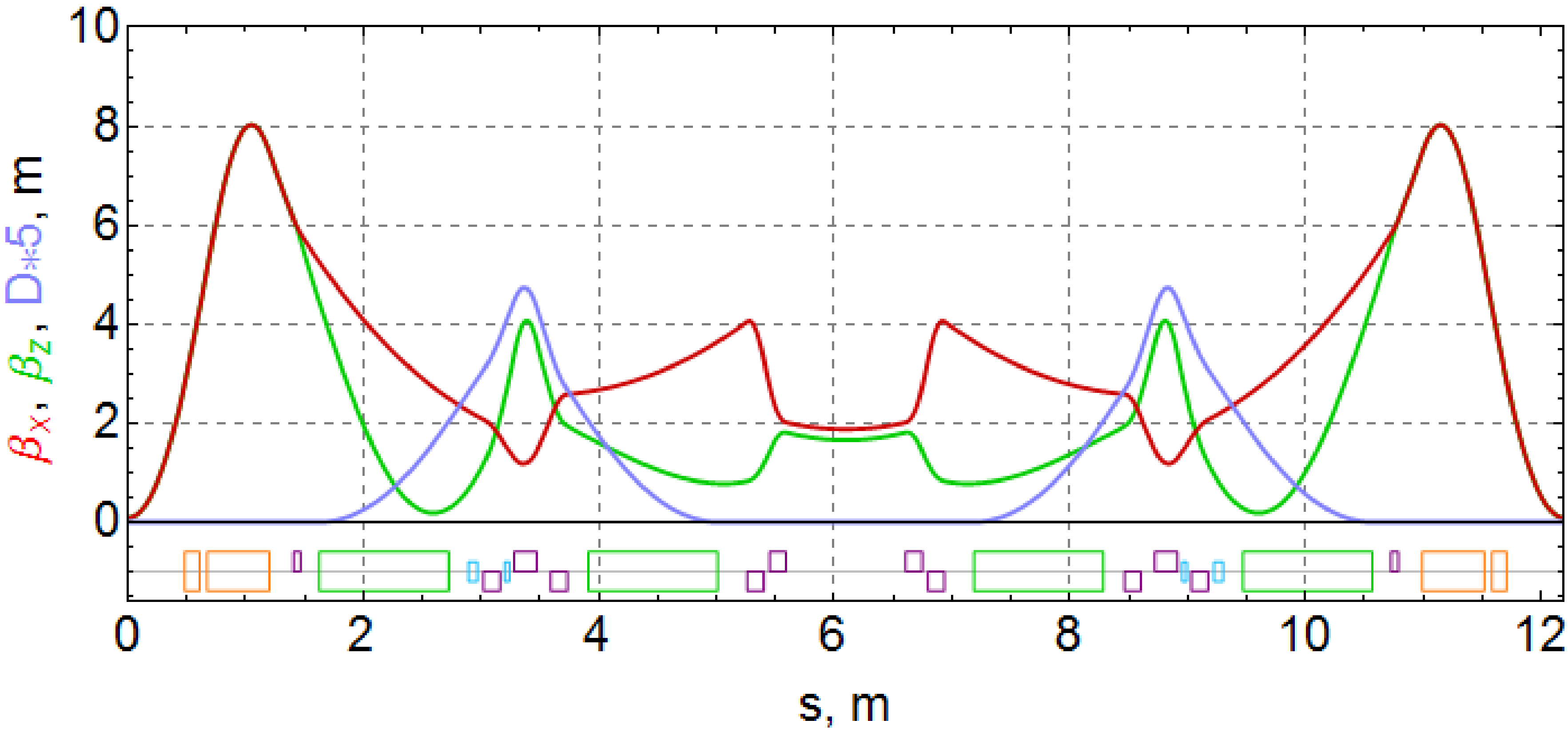
Beam size and luminosity vs. the nominal beam-beam parameter (A. Valishev, E. Perevedentsev, K. Ohmi, PAC'2003)

VEPP-2000 layout & parameters



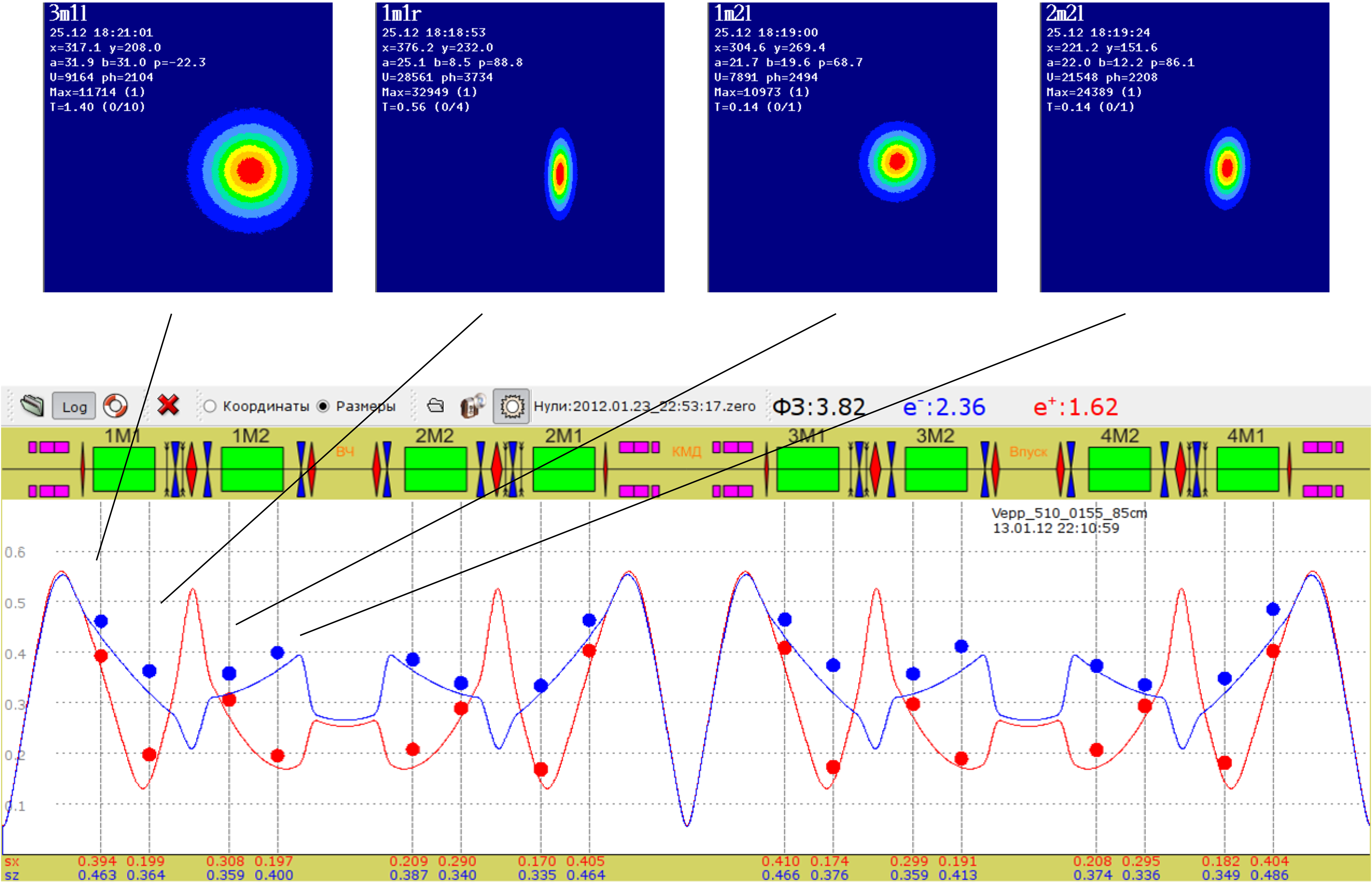
Main parameters @ 1GeV			
Circumference	24.388 m	Energy	200 ÷ 1000 MeV
Number of bunches	1	Number of particles	1×10^{11}
Betatron tunes	4.1/2.1	Beta-functions @ IP	8.5 cm
Beam-beam parameter	0.1	Luminosity	1×10^{32} cm^{-2}s^{-1}

Lattice functions of half of the ring

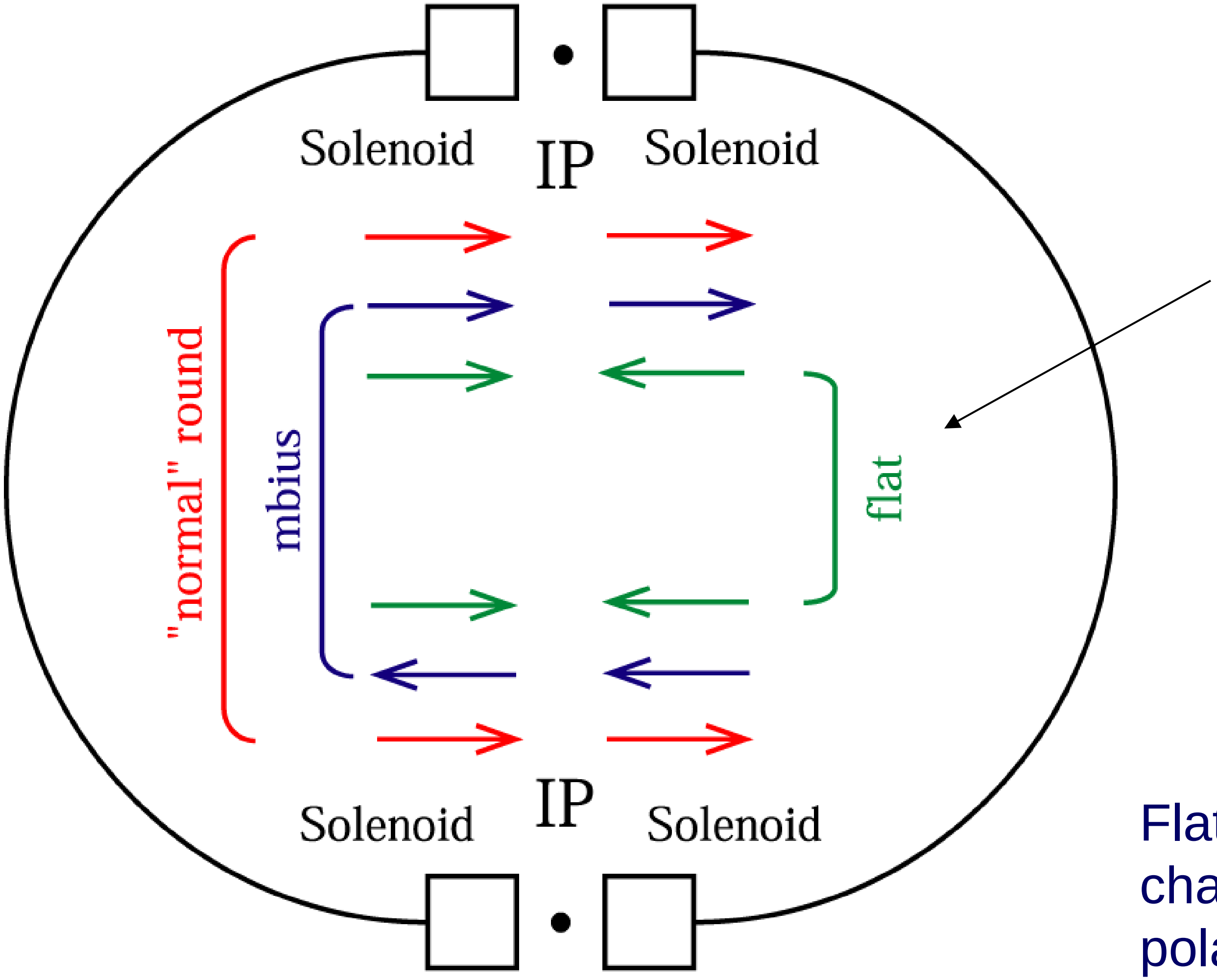


VEPP-2000 lattice special feature: β^* variation modifies radiative beam emittance in the way that $\beta^*\varepsilon = \sigma^{*2} = \text{inv}\ (\beta^*)$

Beam size measurement by CCD cameras



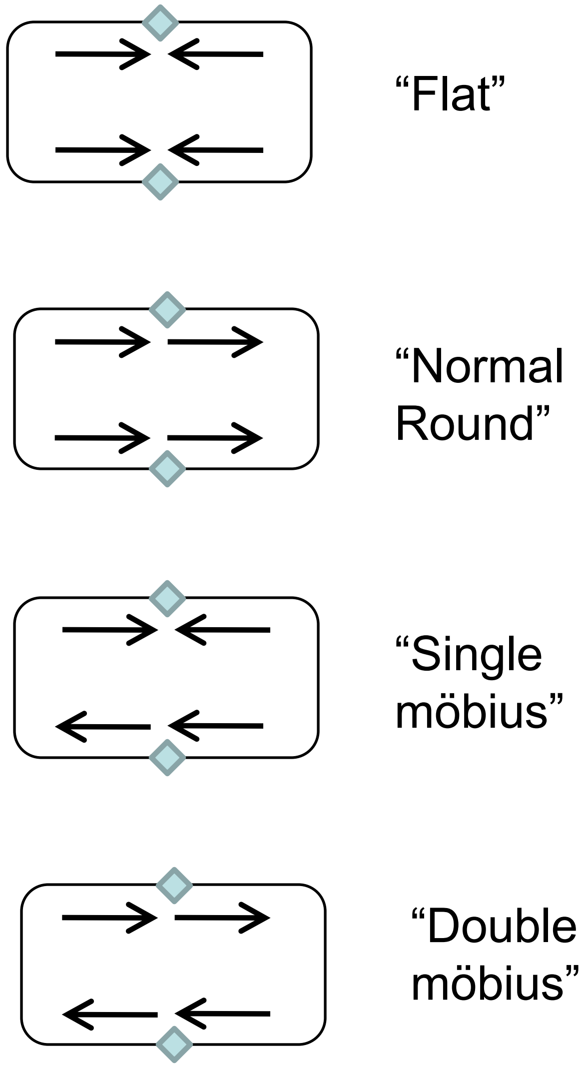
Round Beams Options for VEPP-2000

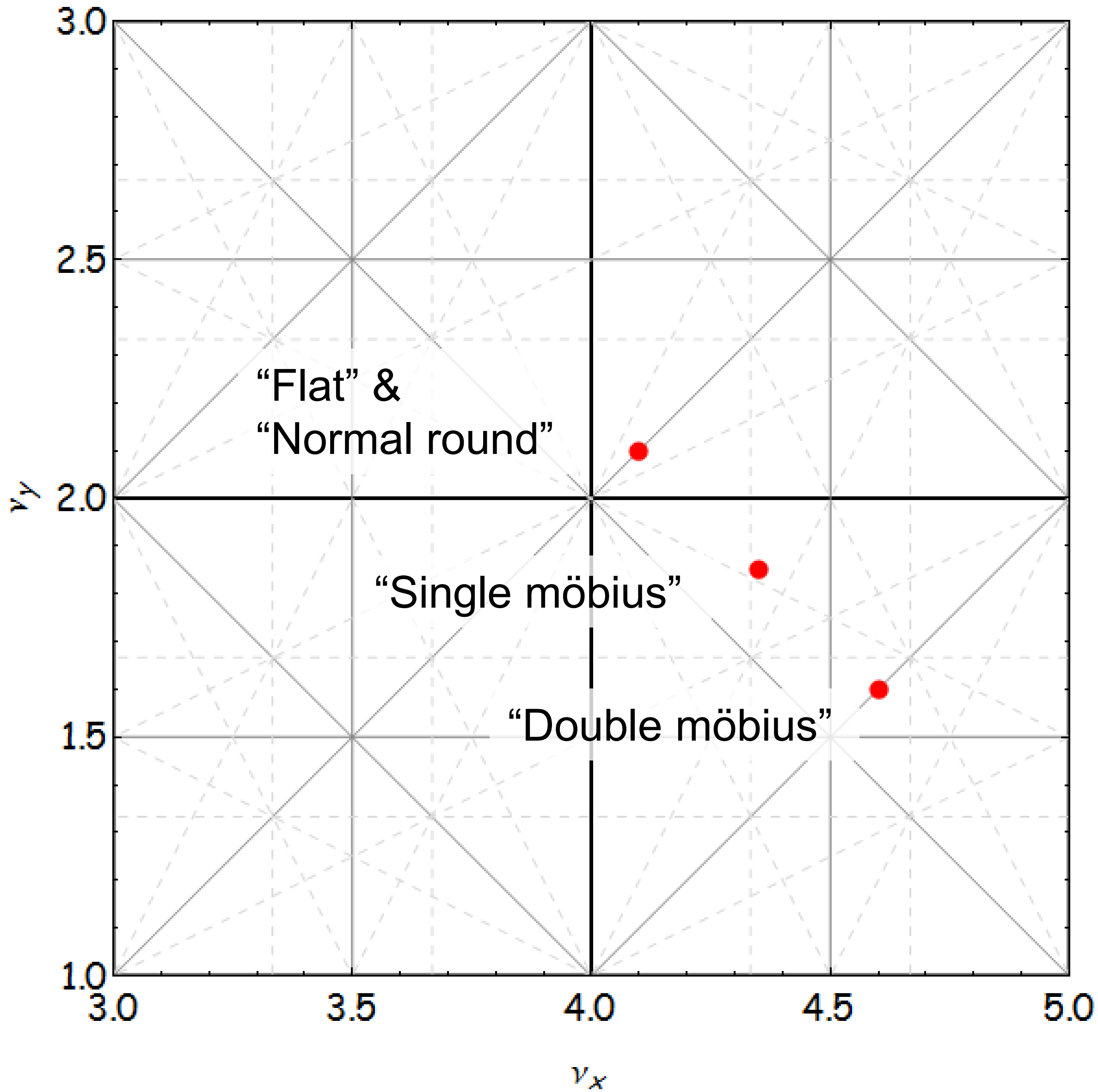


Round beam
due to coupling
resonance?
The simplest
practical solution!

Flat to Round or Mobius
change needs
polarity switch
in solenoids and
new orbit correction.

Working points for different options





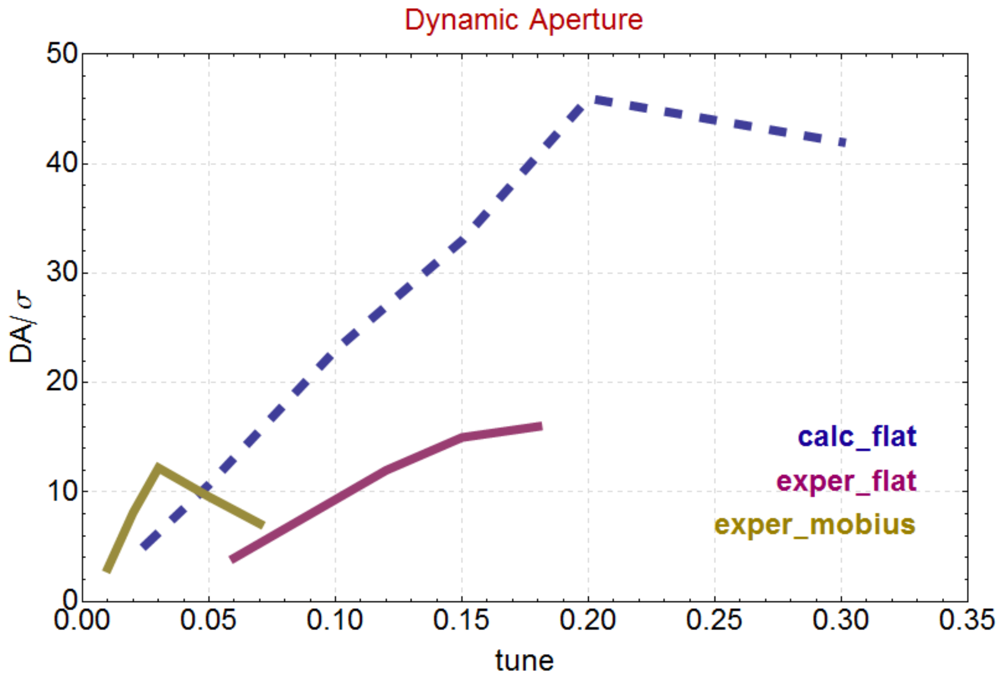
Arguments in favor of work on a coupling resonance

Advantages of (+– +–) option as compared to the “basic mode” (++ ––):

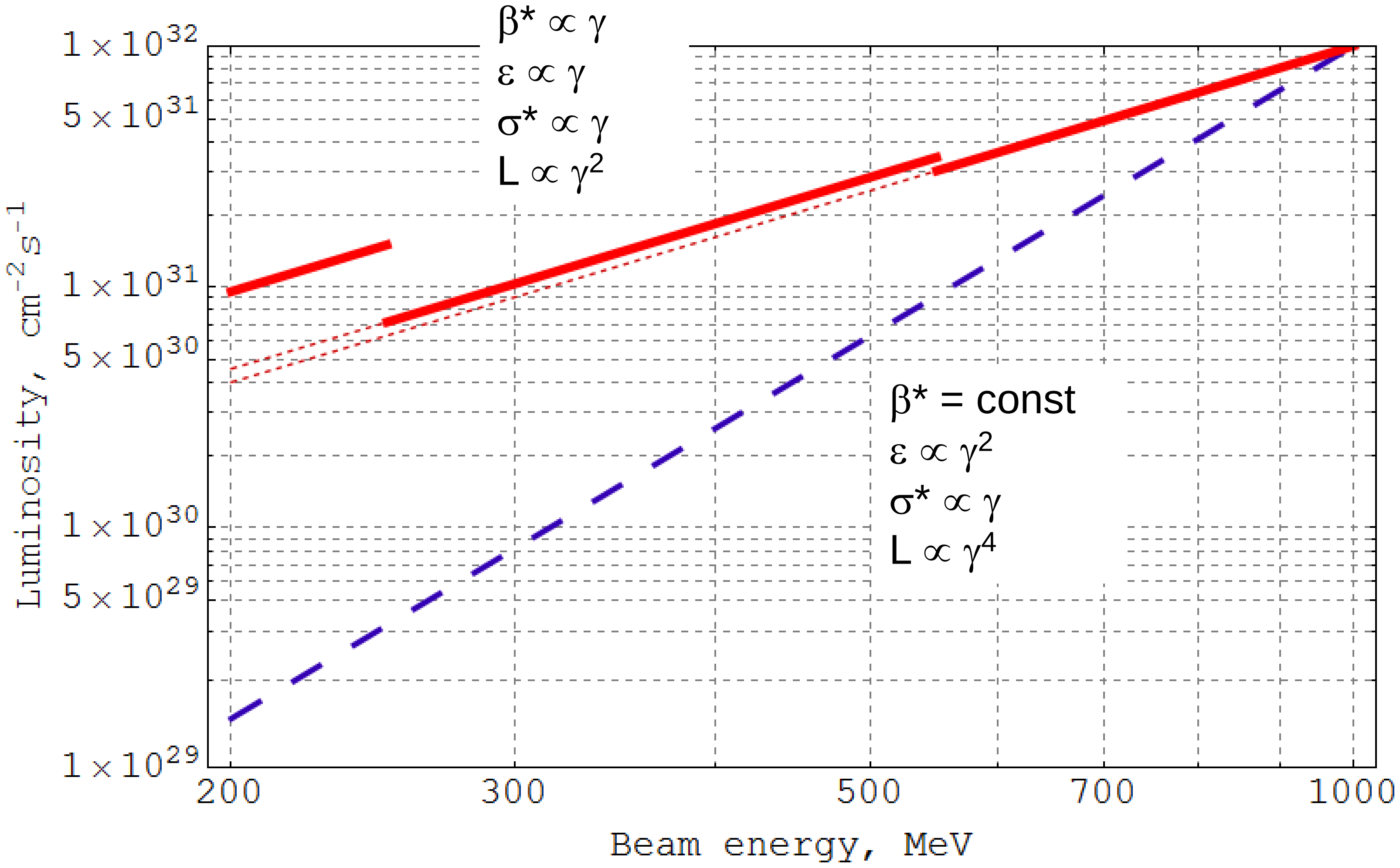
1) **Easy switch to flat beams**
2) **Better sextupole solution,**

wider dynamic aperture

Disadvantages not yet known



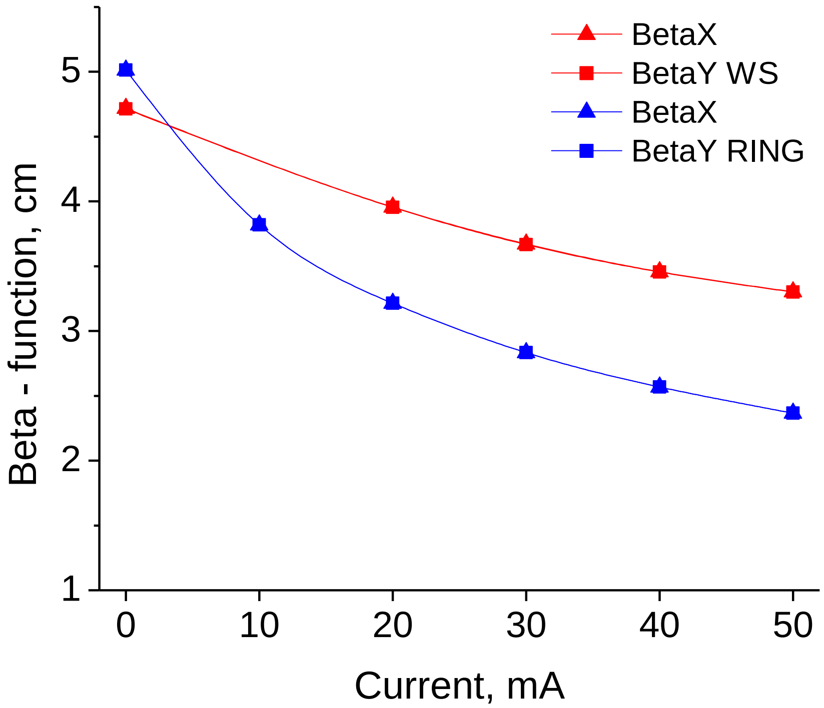
Luminosity scaling approach

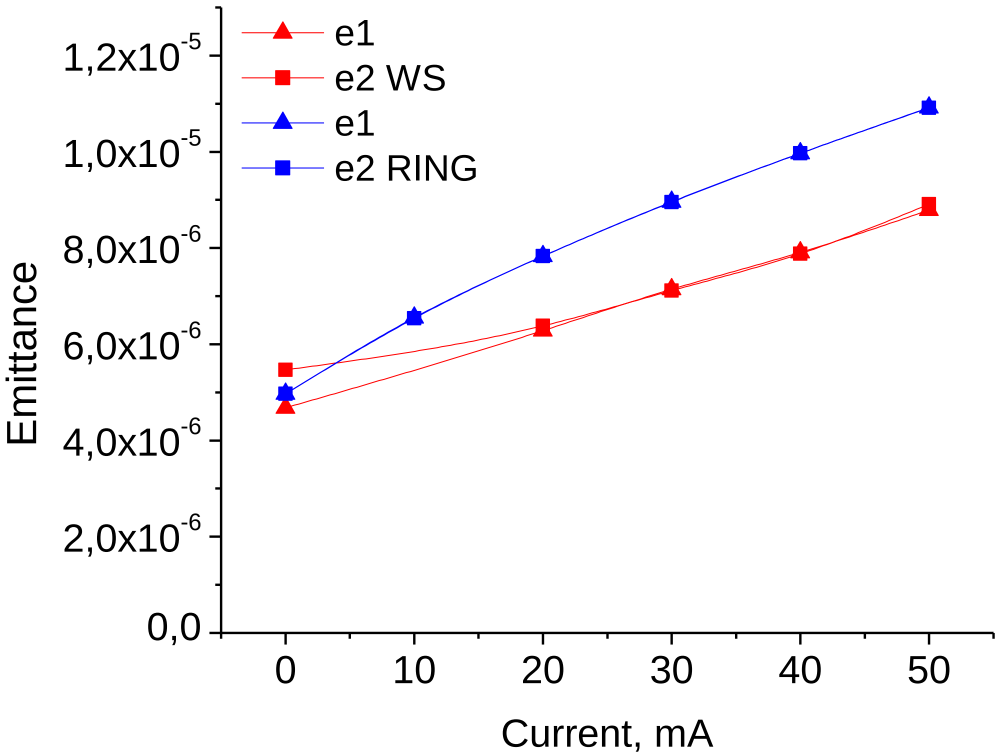


$$L = \frac{4\pi\gamma^2\xi^2\varepsilon f}{r_e^2\beta^*} = \frac{4\pi\gamma^2\xi^2\sigma^{*2} f}{r_e^2\beta^{*2}}$$

$$\sigma^{*2} = \varepsilon\beta^* = inv(\beta^*)$$

Dynamic beta, emittance and size

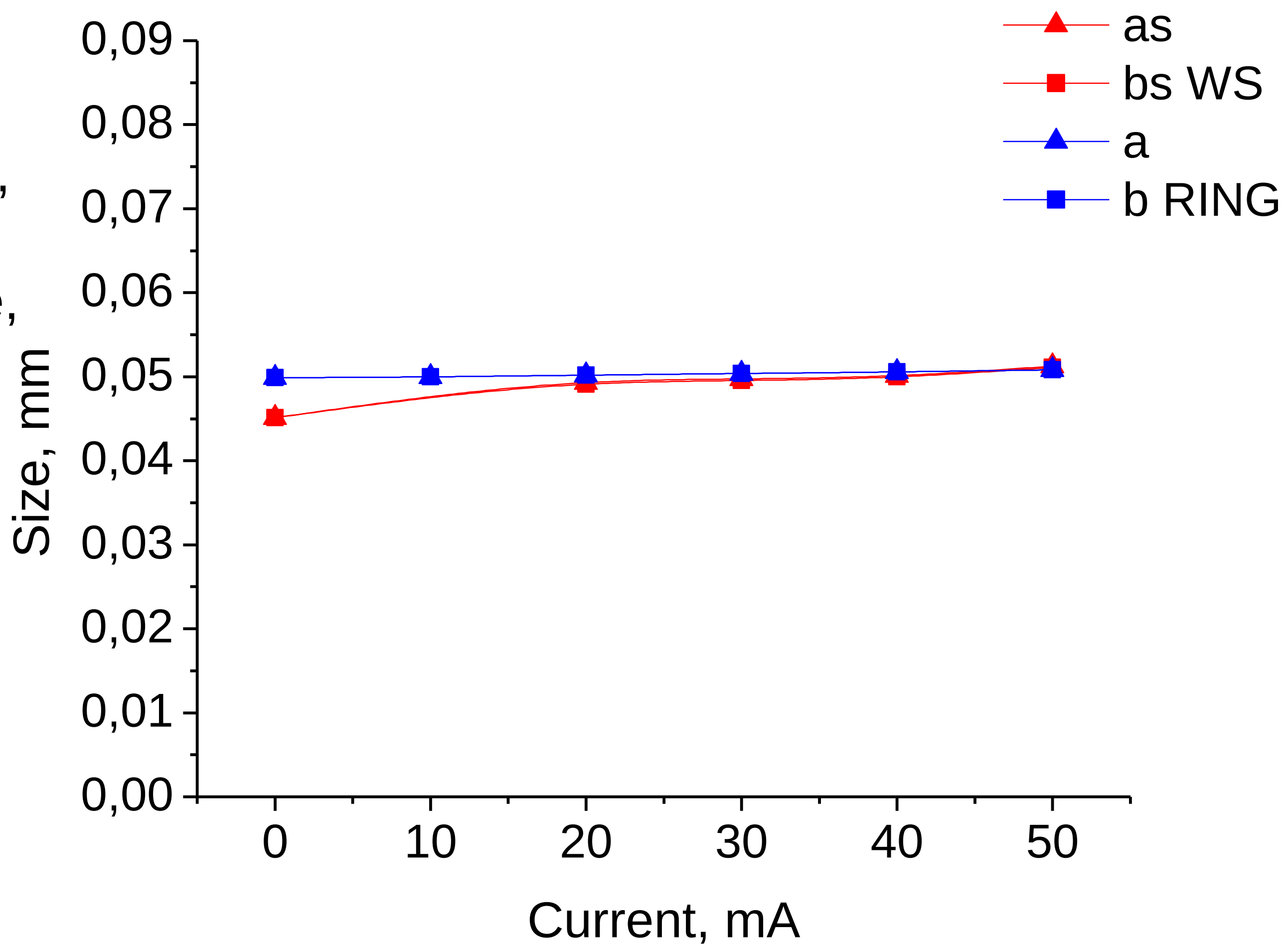




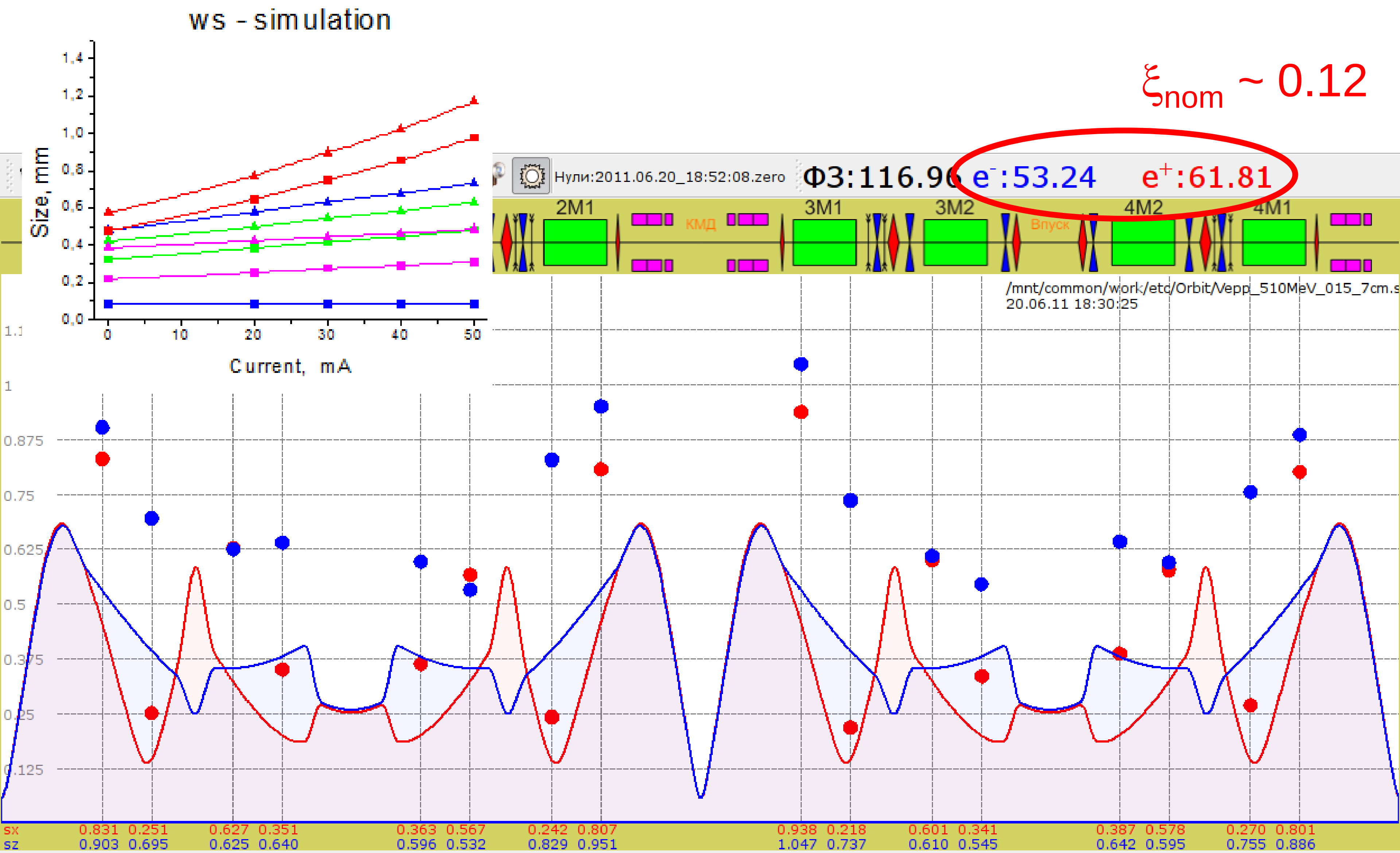
Calcs for E = 500 MeV. 50mA corresponds to $\xi \sim 0.1$

Dynamic beta, emittance and size

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

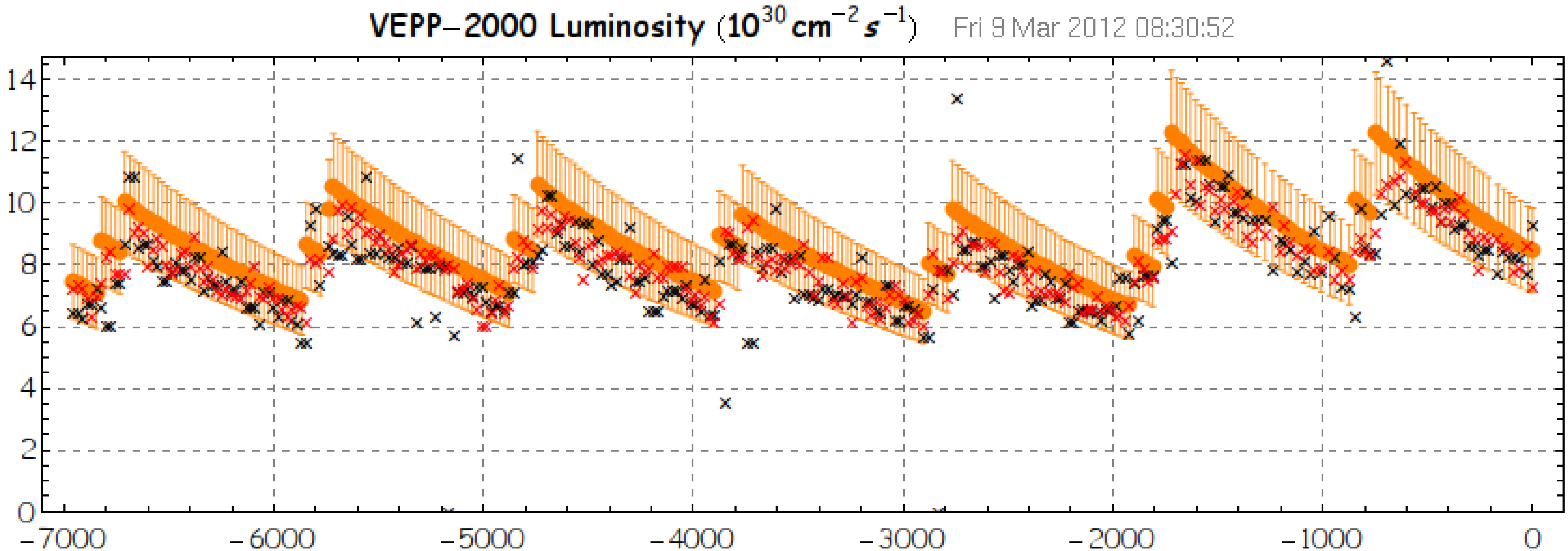


Dynamic sizes at the beam-size monitors



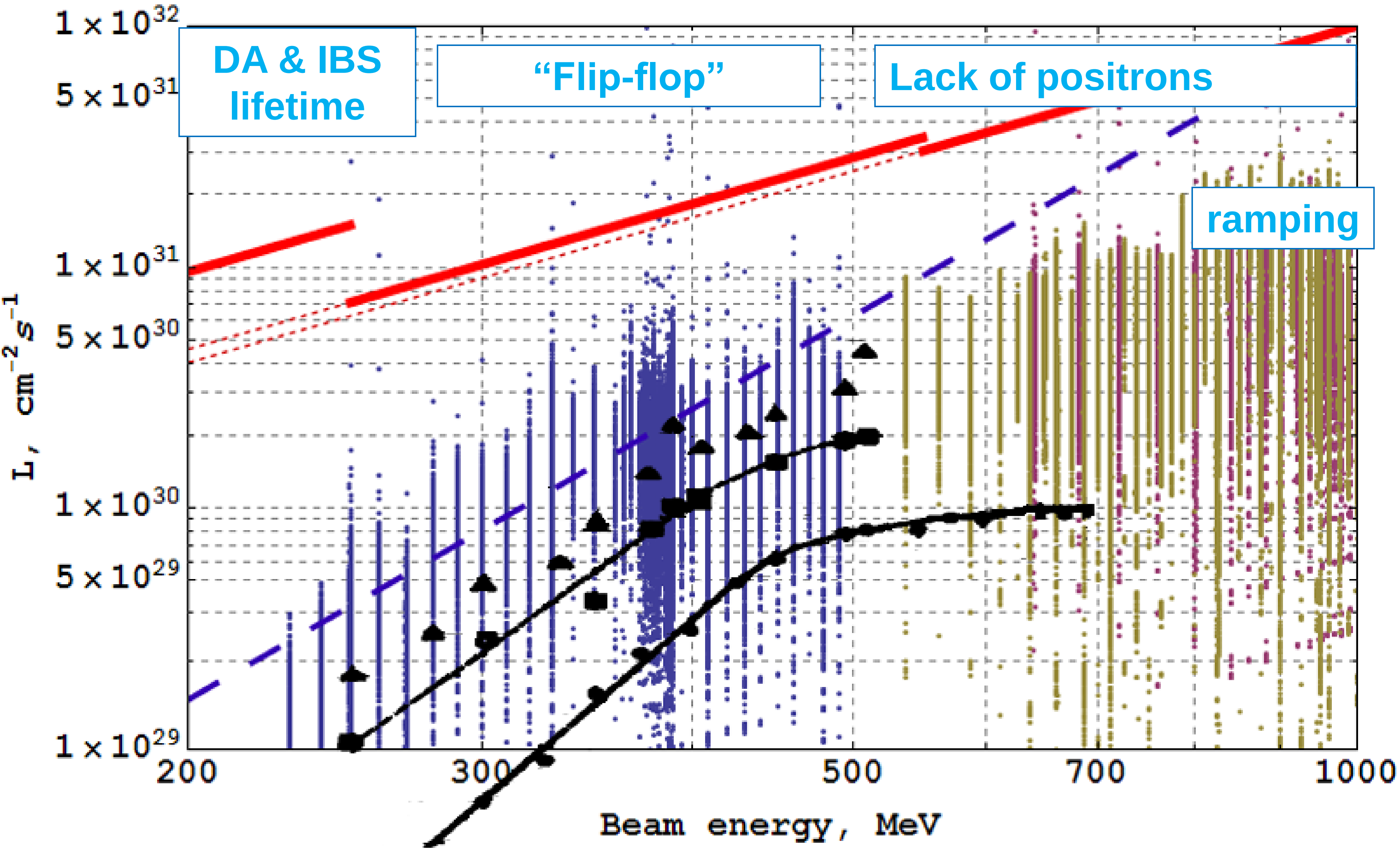
Luminosity measurement via beam sizes @ CCD cameras

$L = 8.477\times10^{30} \pm 1.37\times10^{30}$ = 30.52 nbn^{-1}/hour



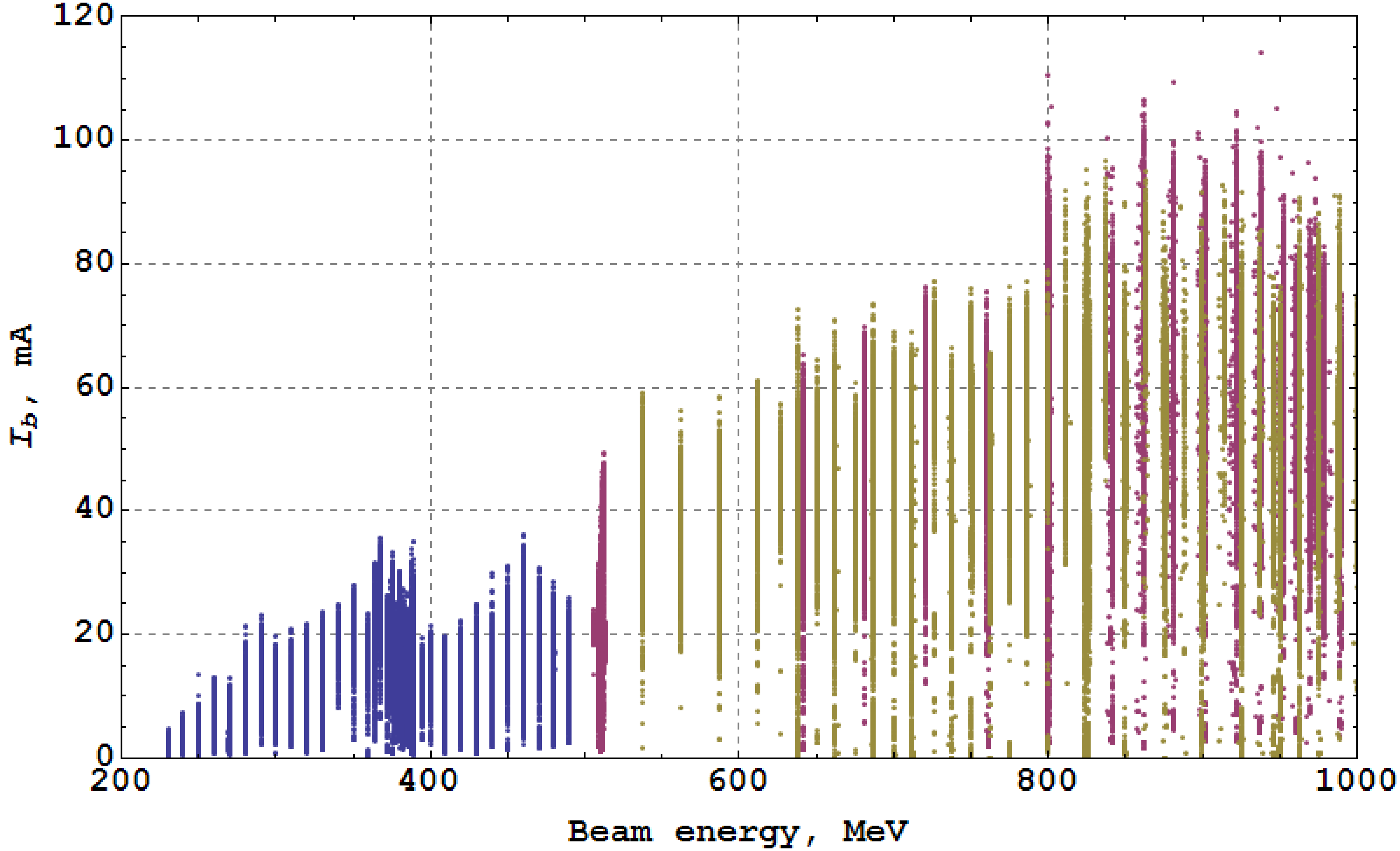
$$L = \frac{f_0 \cdot N^{+} \cdot N^{-}}{4\pi \cdot \sqrt{\left({\sigma^{+}_{x}}^{2} + {\sigma^{-}_{x}}^{2}\right)\left({\sigma^{+}_{z}}^{2} + {\sigma^{-}_{z}}^{2}\right)}}$$

Luminosity vs. beam energy



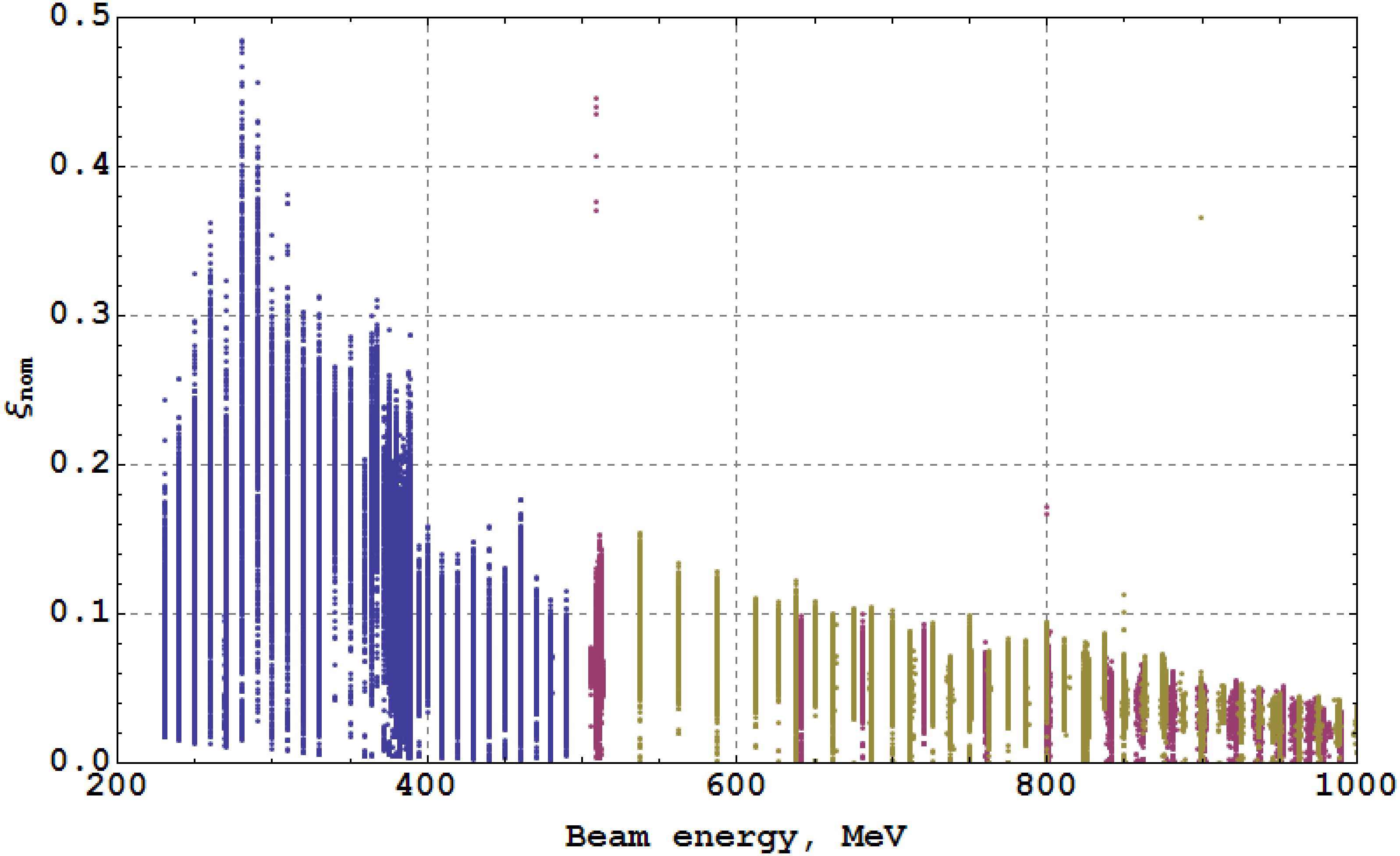
2010-2011 run, 2011-2012 run, 2012-2013 run

Beam current vs. energy

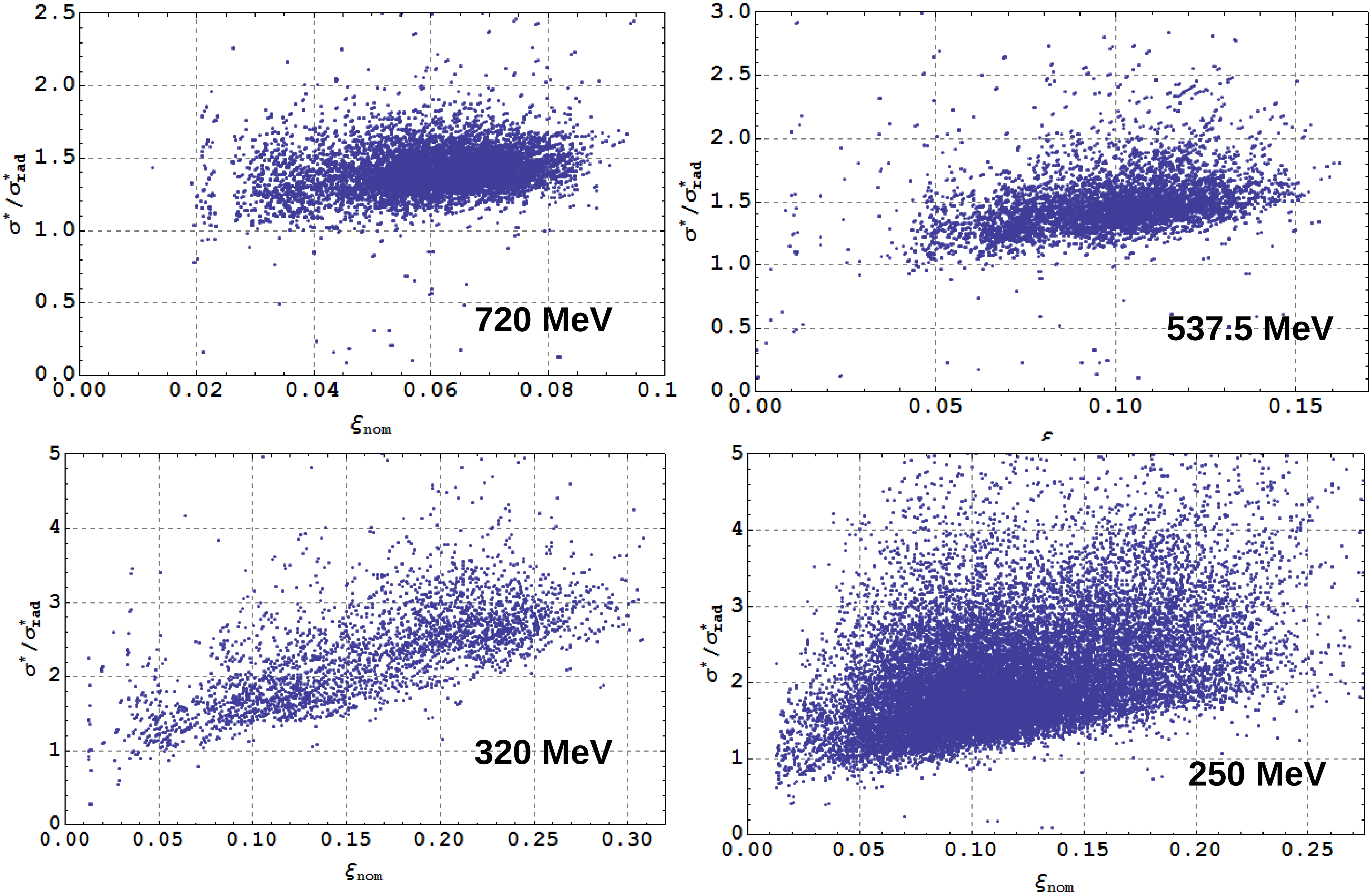


Nominal beam-beam parameter

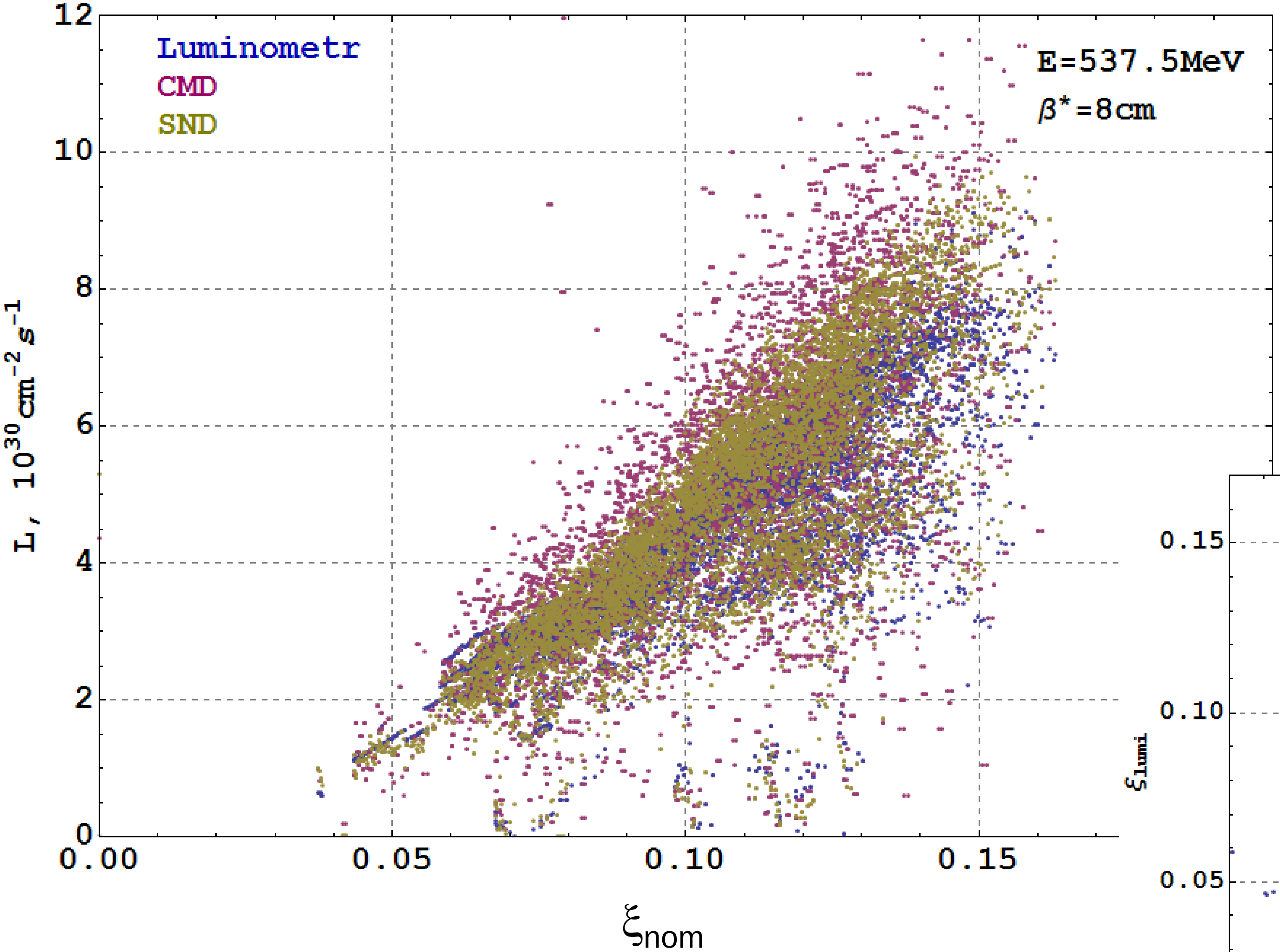
$$\xi_{nom} = \frac{N^- r_e \beta^*_{nom}}{4\pi\gamma\sigma^{*2}_{nom}} = \frac{N^- r_e}{4\pi\gamma\varepsilon_{nom}}$$



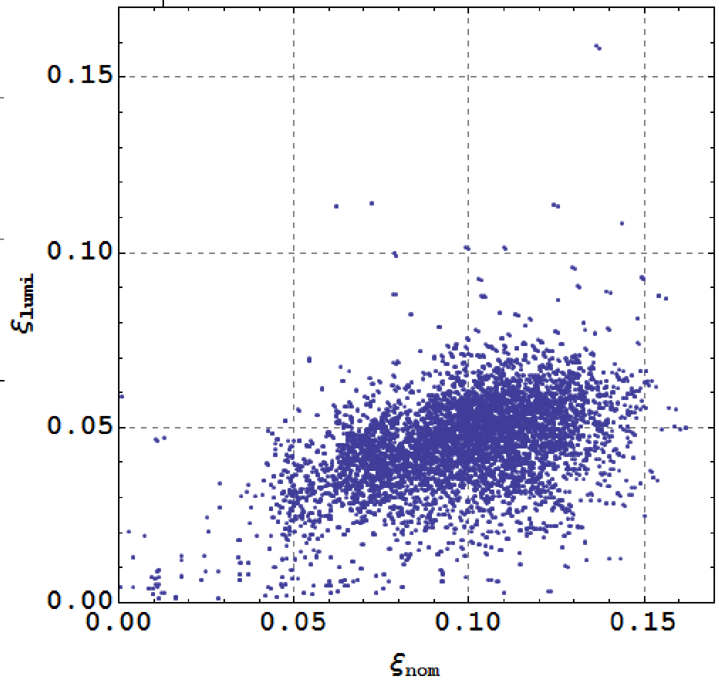
Beam size growth @ IP



Luminosity & "real" bb-parameter

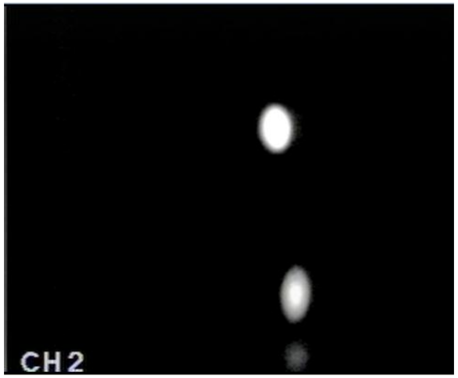


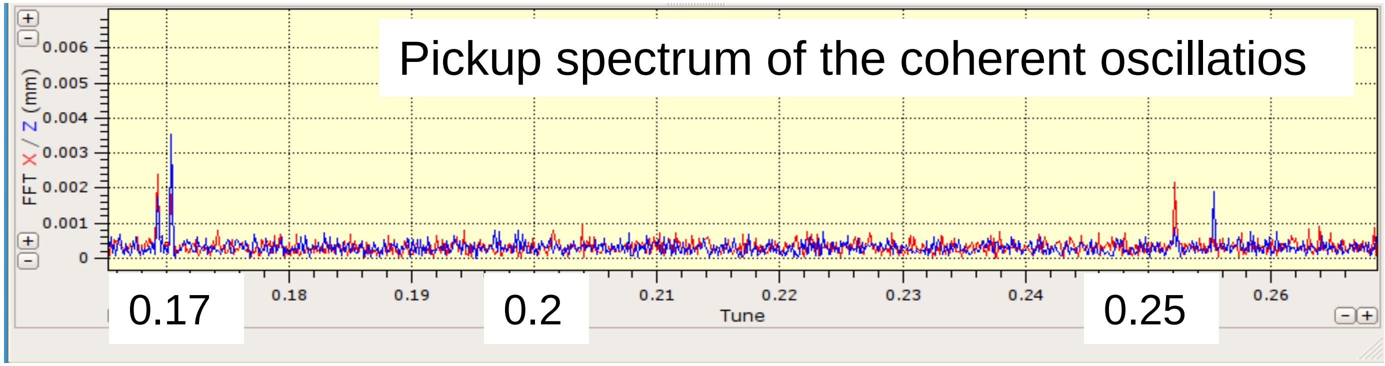
$$\xi_{lumi} = \frac{N^- r_e \beta^*_{nom}}{4\pi\gamma\sigma^{*2}_{lumi}}$$

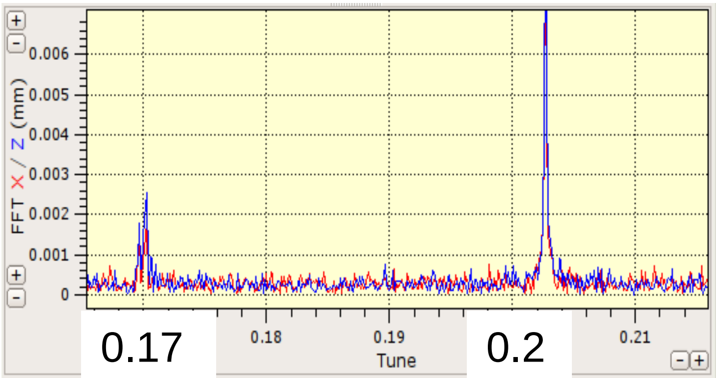


$$\xi_{nom} = \frac{N^- r_e \beta^*_{nom}}{4\pi\gamma\sigma^{*2}_{nom}}$$

"Flip-flop" effect

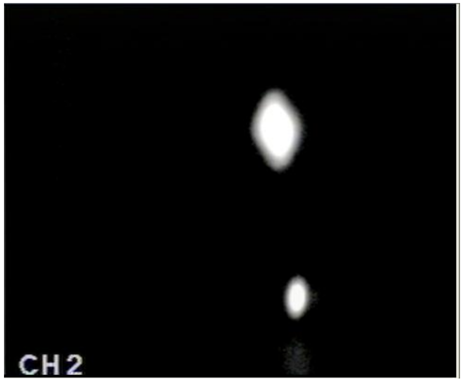


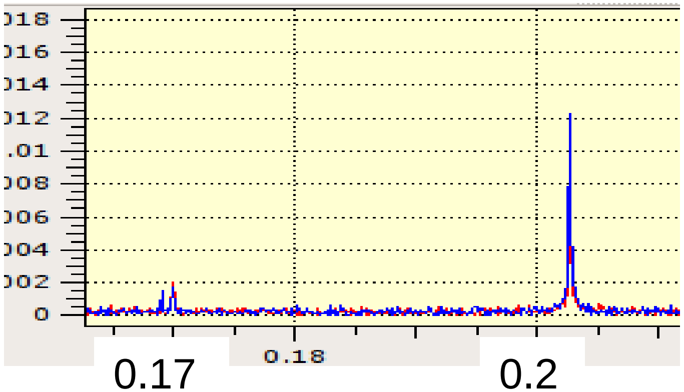




E = 240 MeV,

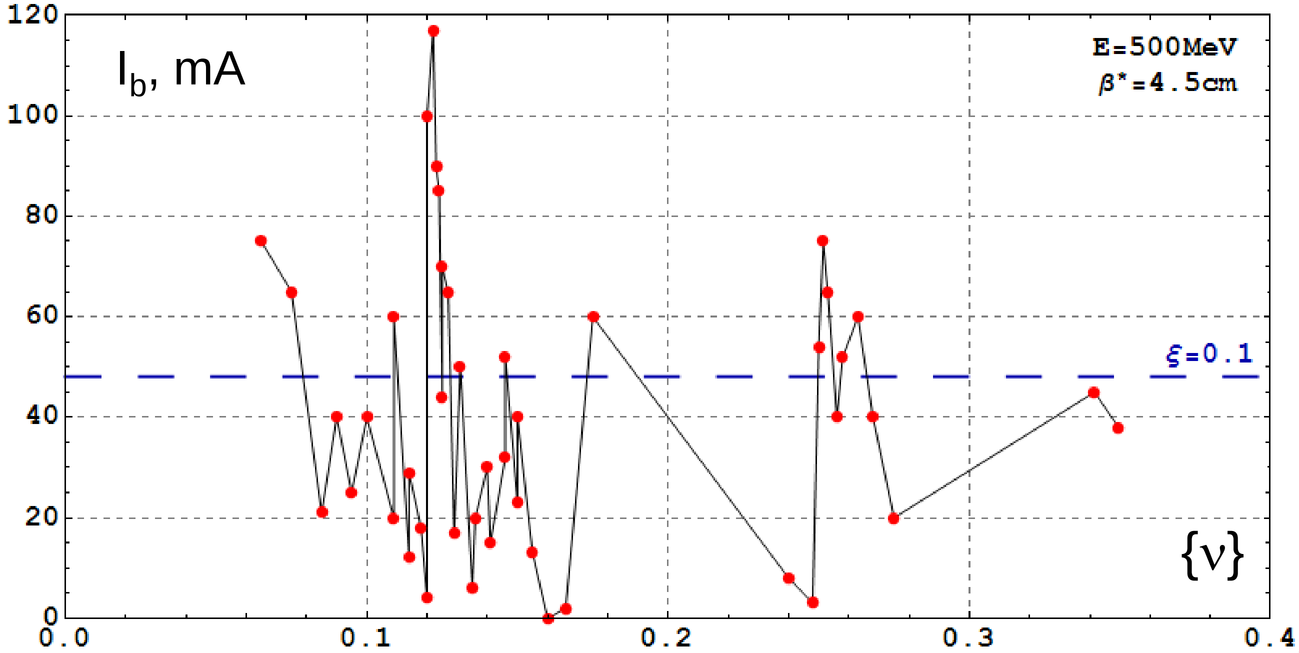
I_{beam} ~ 5×5 mA



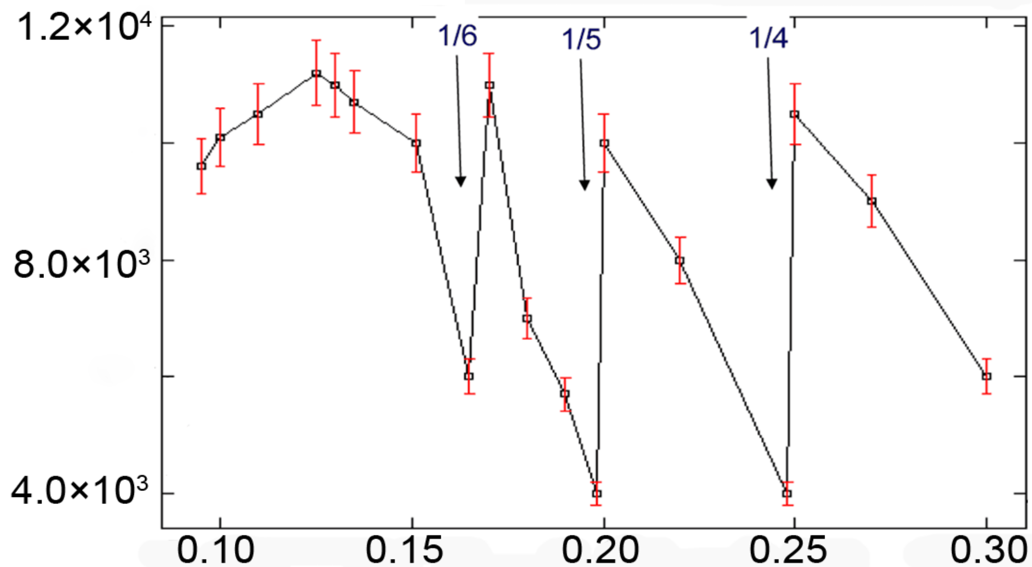


Coherent beam-beam π-mode interaction with machine nonlinear resonances?

High order resonances



Weak-strong tune scan of threshold counter beam current value.



Single positron beam lifetime as a function of betatron tune.
20mA @ 500MeV

Summary

- «Round beams» – not a bad idea!
- Maximum luminosity achieved: 1×10^{31} $cm^{-2}s^{-1}$ at φ-meson energy in 2008 run and 2.5×10^{31} $cm^{-2}s^{-1}$ at E=850 MeV in 2012.
- Potentially 2×10^{31} $cm^{-2}s^{-1}$ possible at φ and 1.6×10^{32} $cm^{-2}s^{-1}$ at 2 GeV.
- More positrons required! VEPP-5 injection complex will supply them in near future.
- The weak-strong simulation clearly predicts better lifetime for lower tunes. Dynamic aperture enhancement required to move working point lower as well as to squeeze β^* at low energy.

Weak-strong simulations

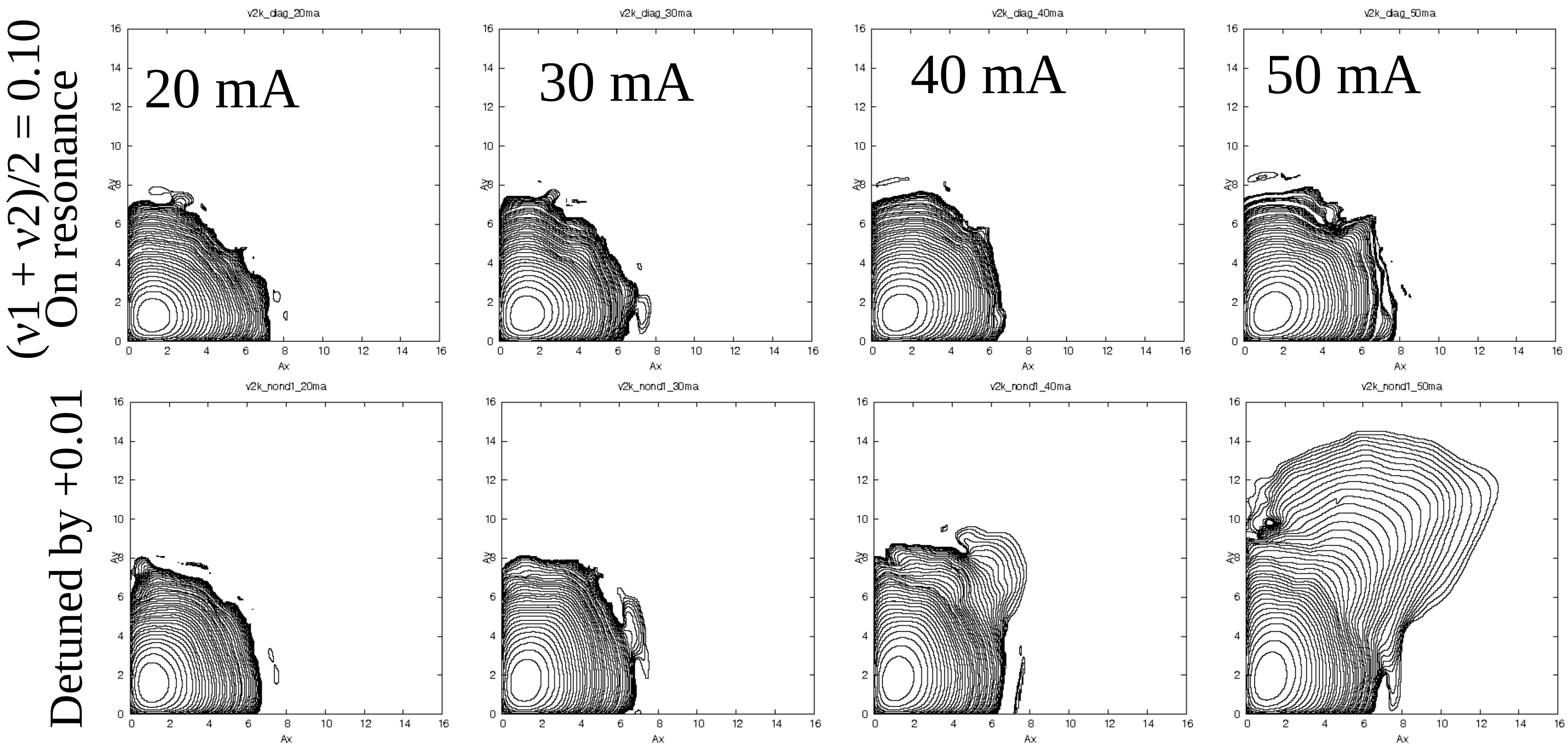
Deformation of the weak beam distribution is in question.

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

1) 2-period lattice with the chromaticity correction sextupoles, synchrotron oscillations, longitudinal slicing
2) Whatever variations, E = 509 MeV and constant β^* = 5 cm, σ_z = 17mm, 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 "*Acceleraticum*", 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.

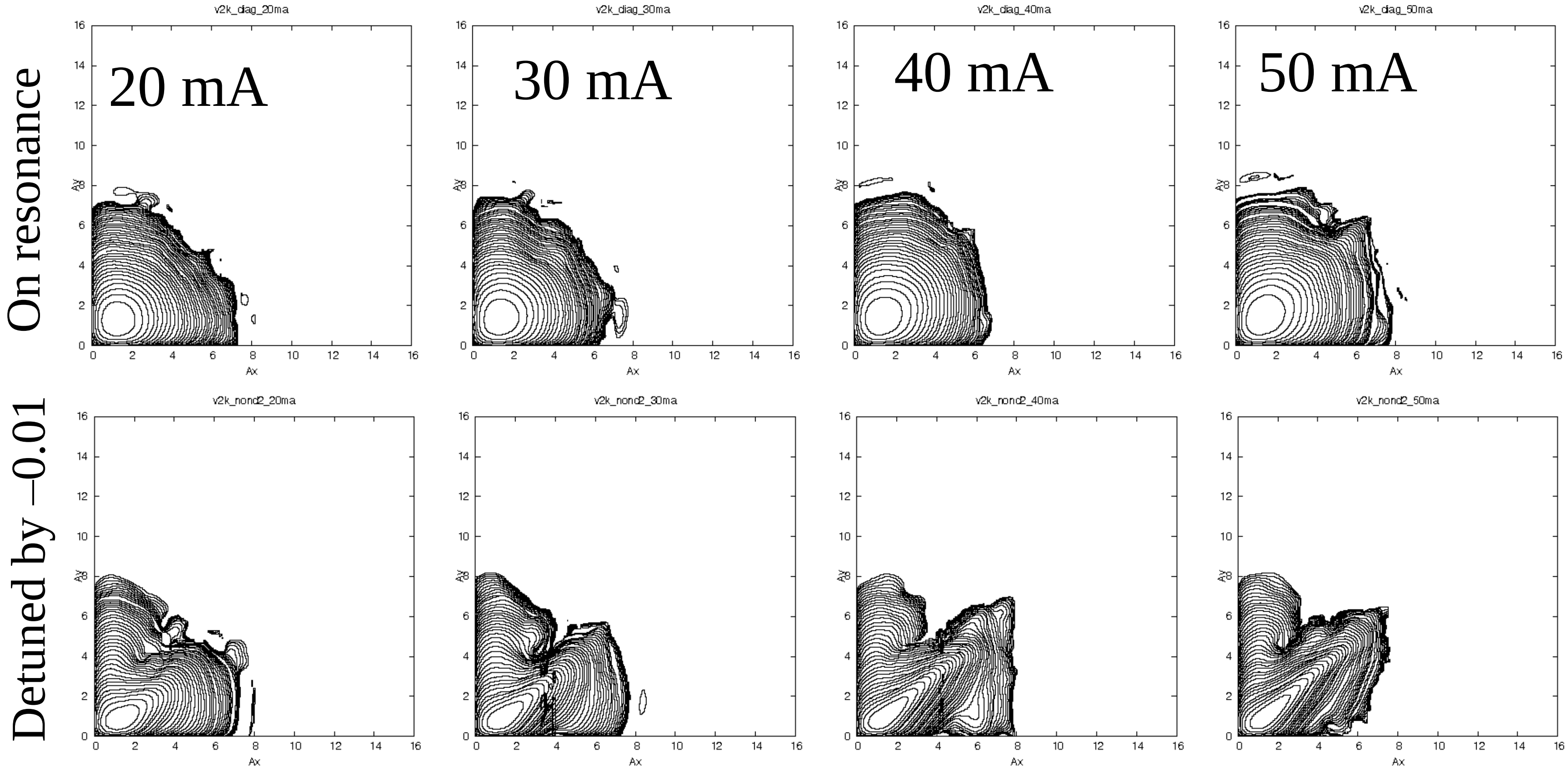
Things to be avoided in round colliding beam operation (1)

Detuning from the coupling resonance



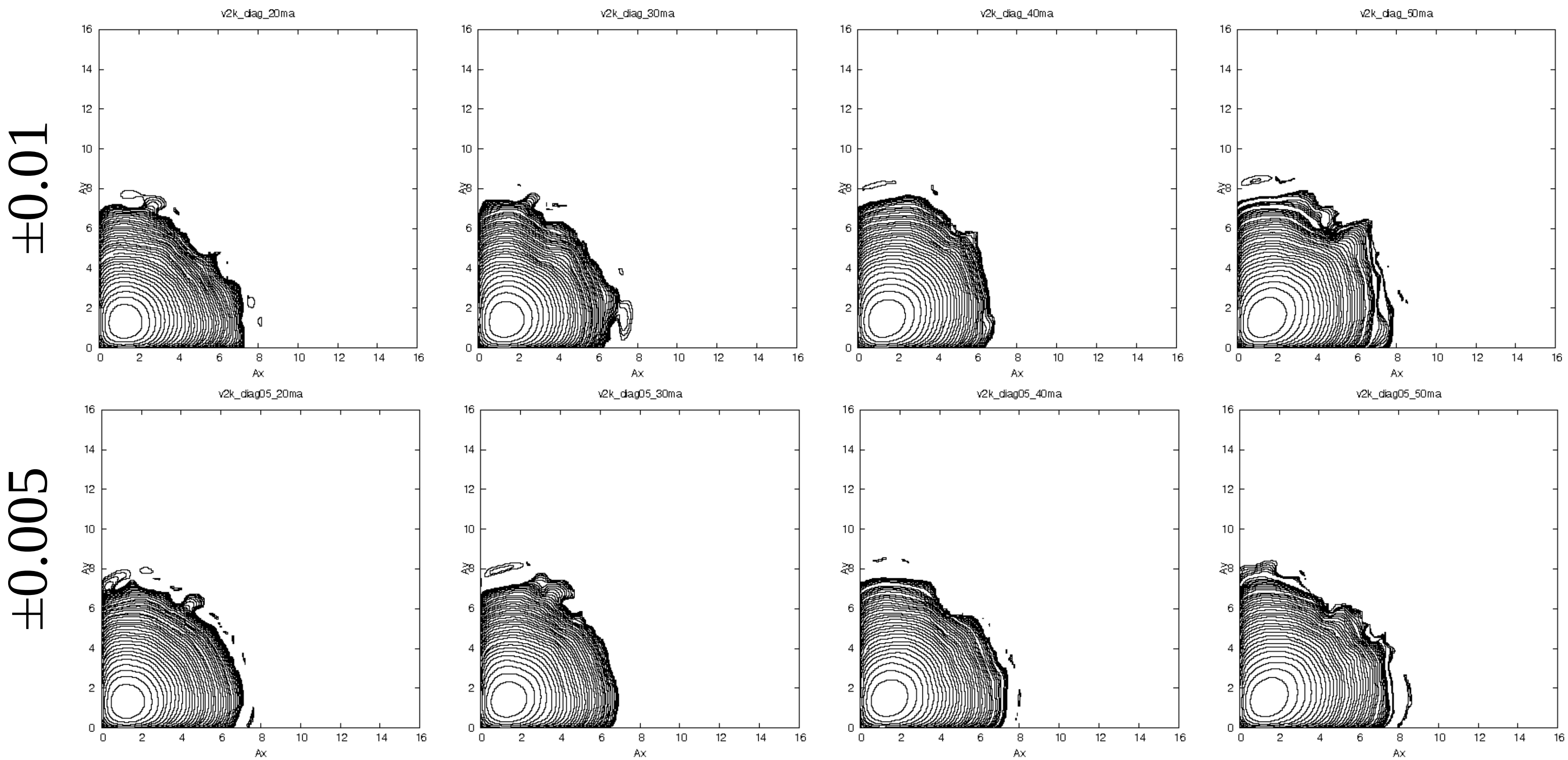
Things to be avoided in round colliding beam operation (2)

Detuning from the coupling resonance



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

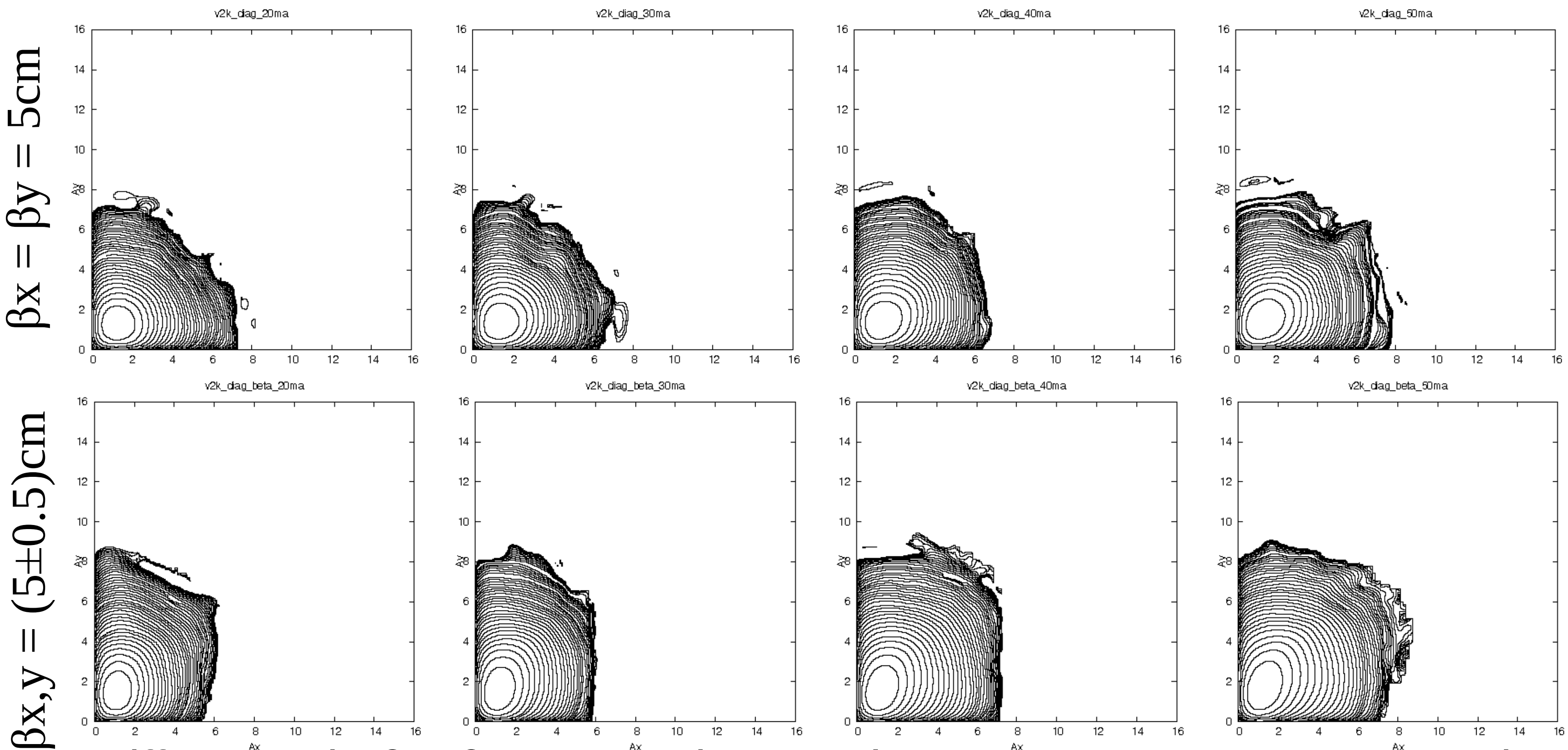
Large non-compensation of the solenoidal field



Different tune separation caused by solenoids

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

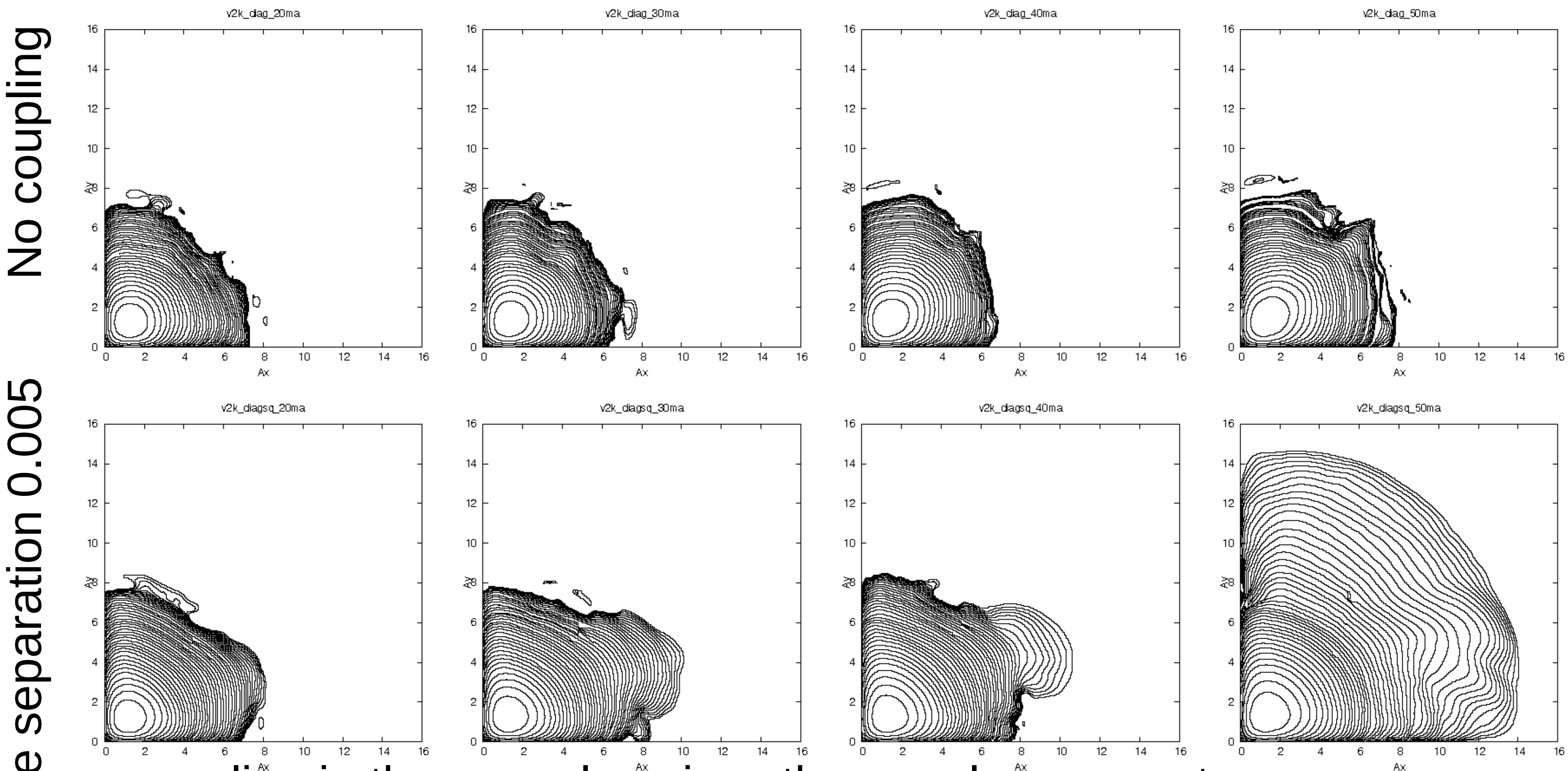
Non-round beta-functions @IP



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

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

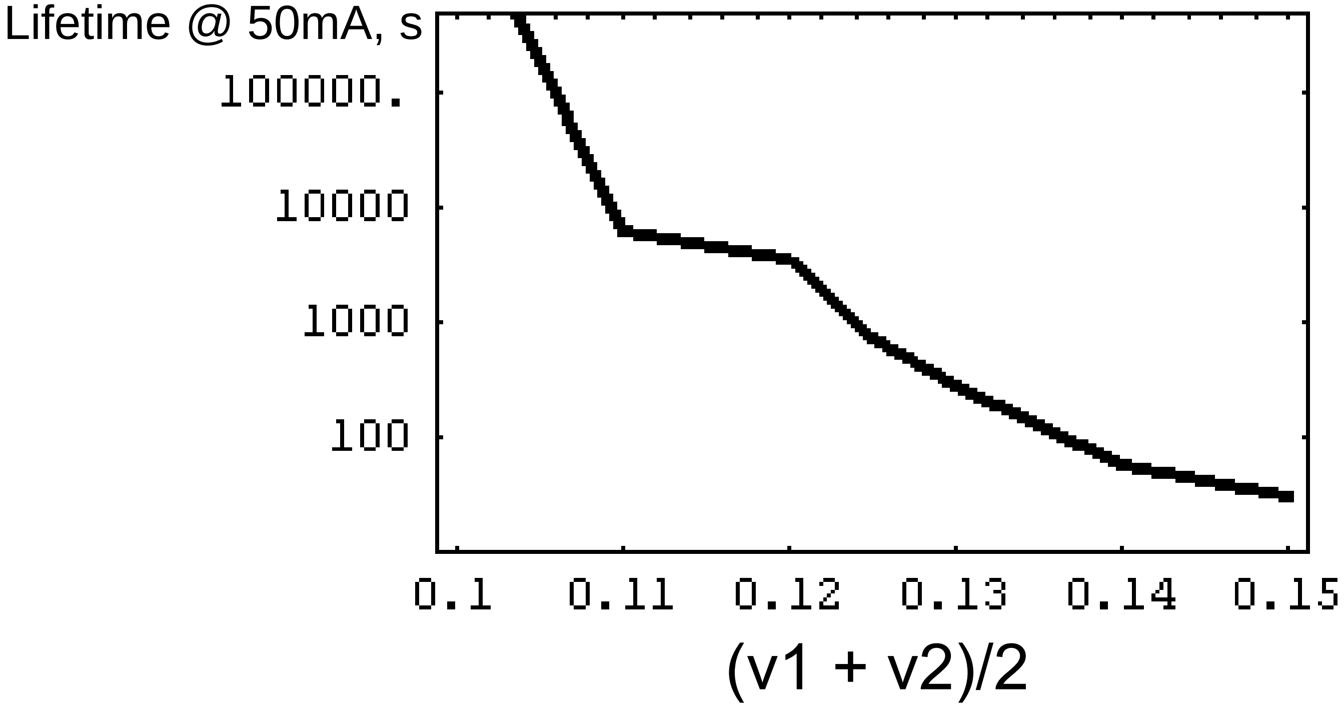
x-y coupling in the arcs

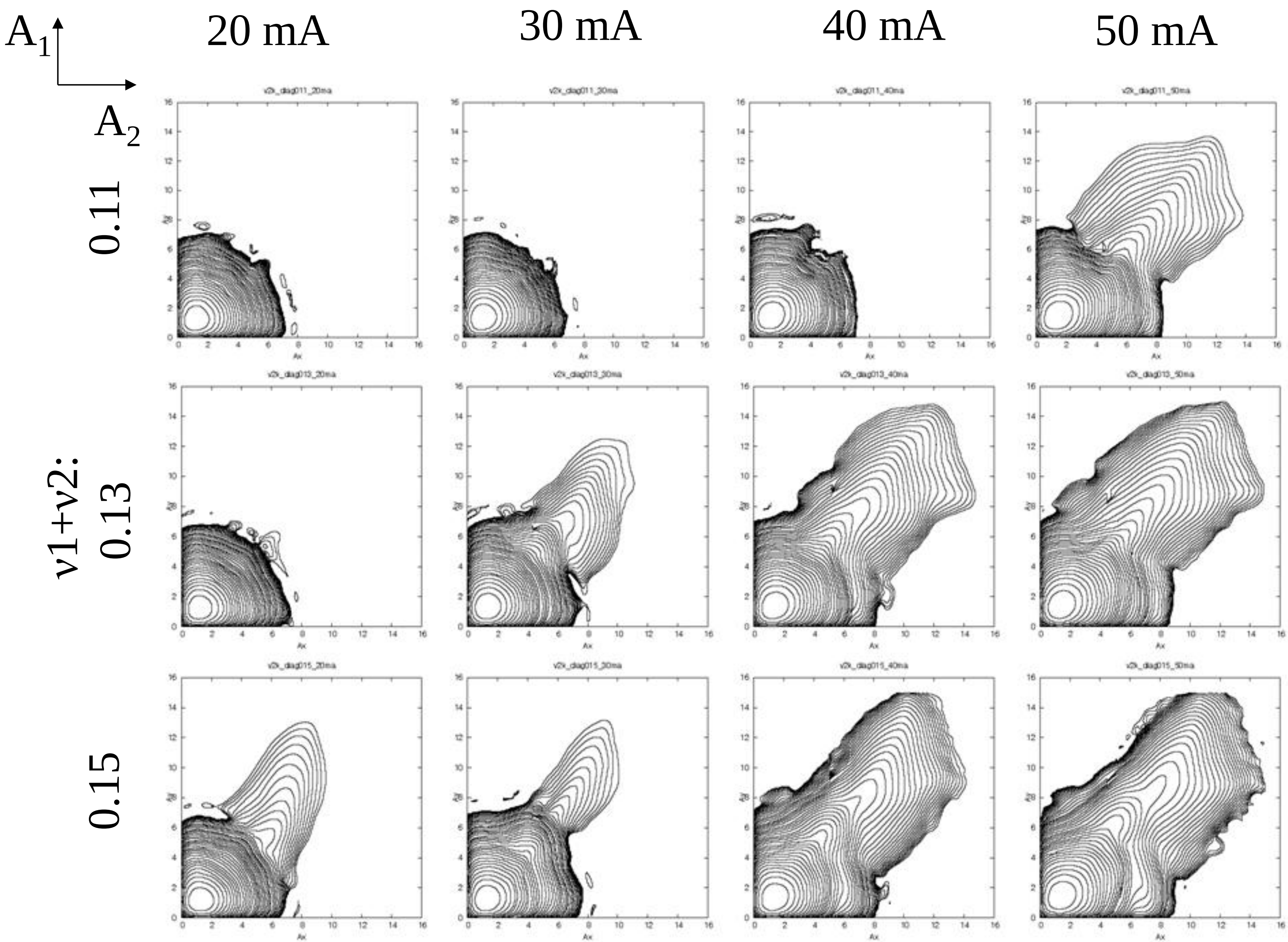


x-y coupling in the arcs also gives the angular momentum non-conservation

Tune scan along the diagonal

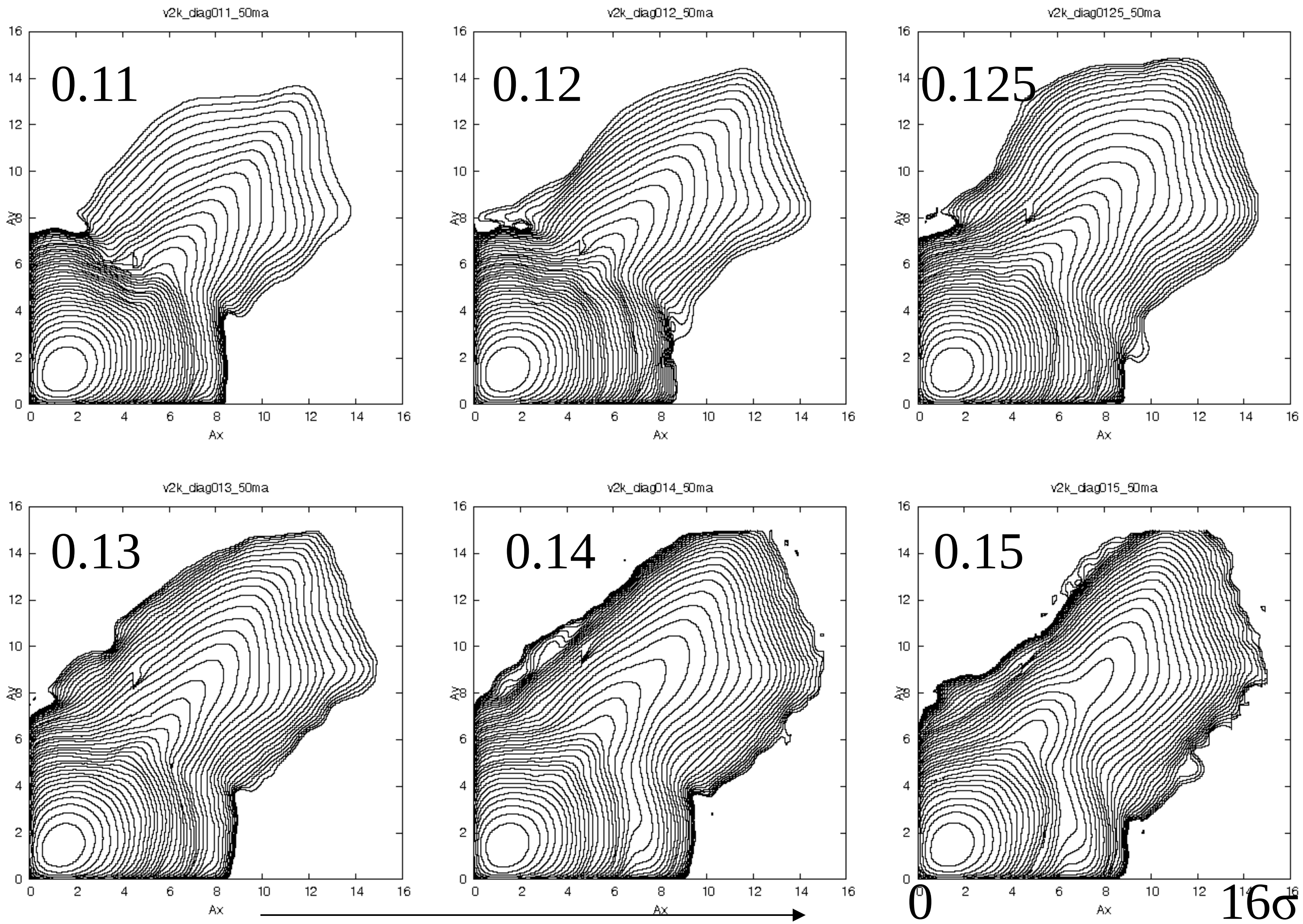
…reveals almost constant specific luminosity!
Namely, L = 1x10^{28} cm^{-2}s^{-1}mA^{-2}
Only the beam tails expand at higher tunes
and cause limitation of the beam lifetime




A1
A2
20 mA
30 mA
40 mA
50 mA
0.11
ν1+ν2:
0.13
0.15

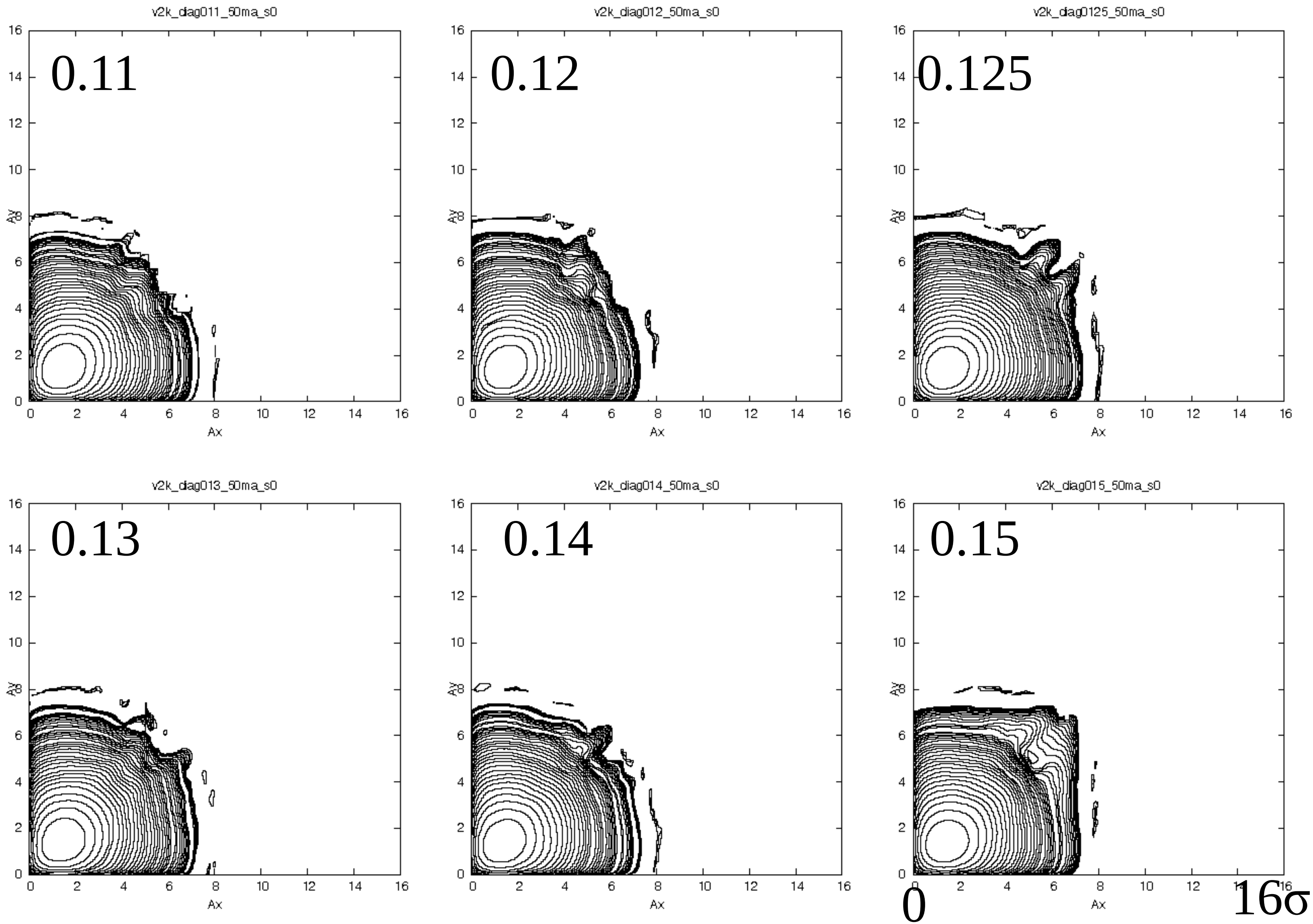
@50mA, with sextupoles: tune dependence of the tails

(ν1+ν2)/2 →



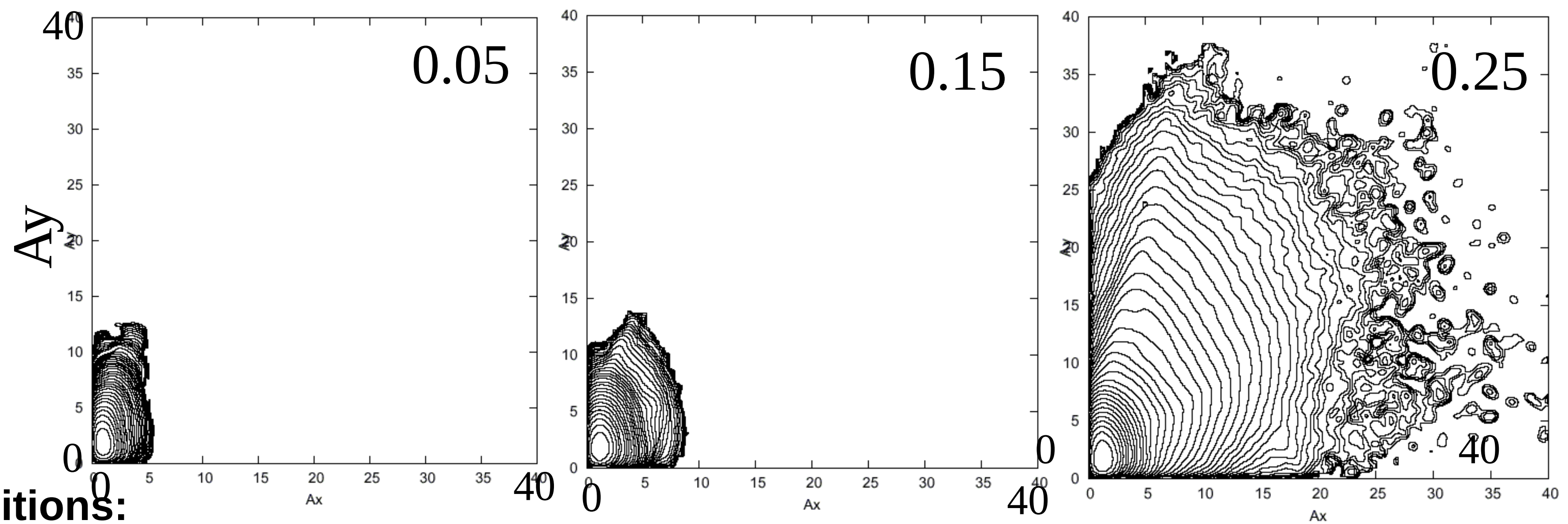
@50mA, without sextupoles: very weak beam-beam effect

$(\nu1+\nu2)/2$ →



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)