Beam-beam simulations with crossing anlge + crab-waist

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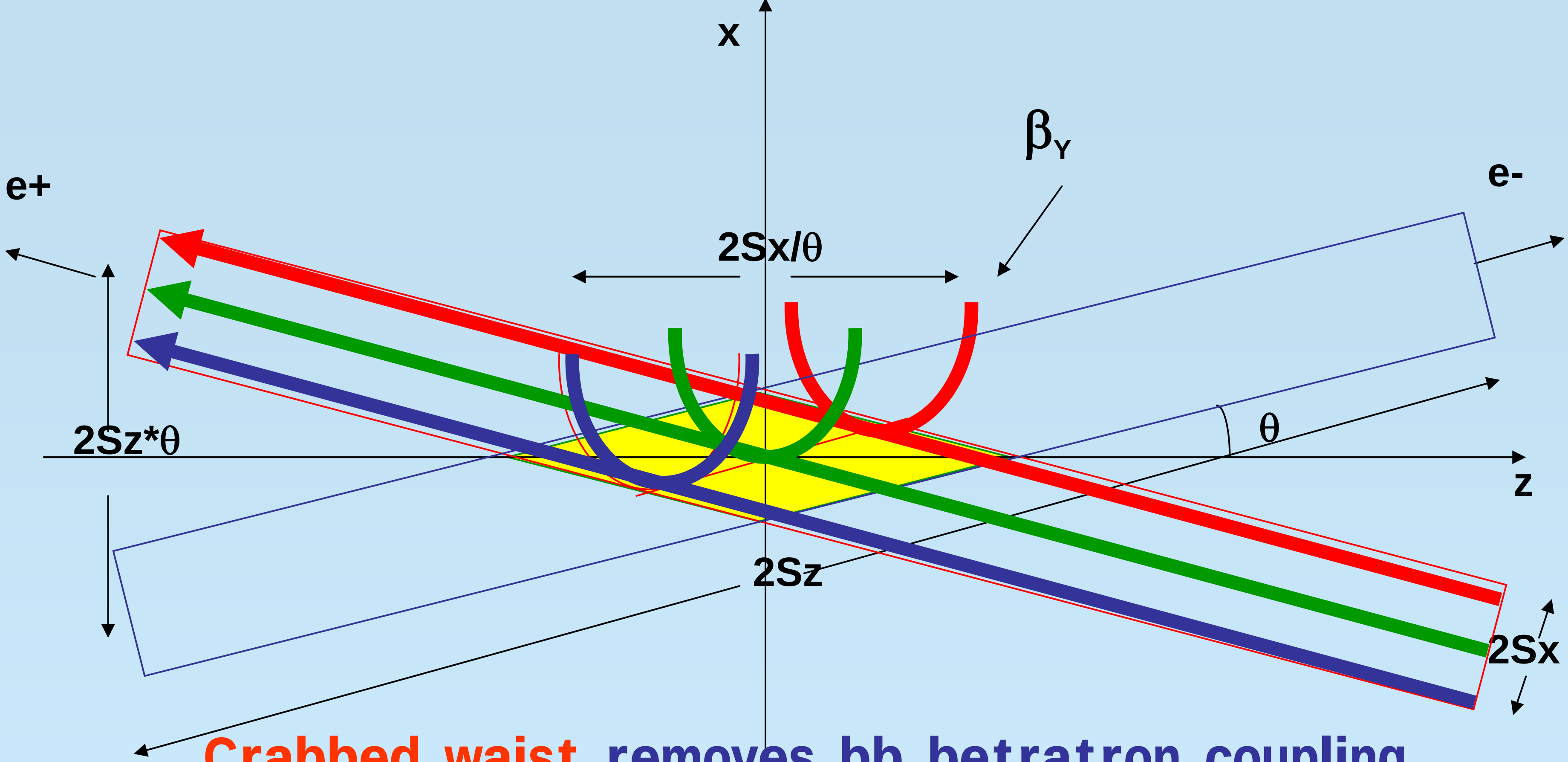
SuperB III Workshop, SLAC, 14-16 June 2006

BB simulations

- New "crossing angle + crab waist" idea has solved disruption problems related to collisions with high current, small sizes beams → back to two "conventional" rings
- With very small emittances and relatively low currents (comparable to present B-Factories values) a Luminosity of 10^{36} cm^{-2} s^{-1} is reachable without large emittance blow-up



Crabbed waist removes bb betratron coupling introduced by the crossing angle

Vertical waist has to be a function of x:

Z=0 for particles at $-\sigma_x$ ($-\sigma_x/2\theta$ at low current)

Z= σ_x/θ for particles at $+\sigma_x$ ($\sigma_x/2\theta$ at low current)

Crabbed waist realized with a sextupole in phase with the IP in X and at $\pi/2$ in Y

Luminosity considerations

Ineffectiveness of collisions with large crossing angle is illusive!!!
Loss due to short collision zone (say $l=\sigma_z/40$) is fully compensated by denser target beam (due to much smaller vertical beam size!)

Number of particles in collision zone: $\delta N_2 = N_2 \dfrac{l_{cross}}{\sigma_z}$ $\quad l_{cross} = 2\sigma_x/\theta$

$$L = \frac{N_1 \cdot \delta N_2 \cdot f_0}{4\pi\sigma_x\sigma_y} \qquad \xi_{1y} = \frac{r_e \cdot \delta N_2 \cdot \beta_y}{2\pi\gamma\sigma_y(\sigma_x+\sigma_y)}$$

$$L = \frac{\gamma\xi_{1y}N_1 f_0}{2r_e\beta_y}\left(1+\frac{\sigma_y}{\sigma_x}\right) \simeq 2.167\cdot10^{34}\,\frac{E(\mathrm{GeV})\cdot I(\mathrm{A})\cdot\xi_{1y}}{\beta_y(\mathrm{cm})} \simeq 1.2\cdot10^{36}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$$

No dependence on crossing angle!
Universal expression: valid for both, head-on and crossing angle collisions!

I. Koop et al, BINP

Tune shifts

Raimondi, Shatilov, Zobov:
(Beam Dynamics Newsletter, 37, August 2005)

$$\sigma_x \to \sqrt{\sigma_z^2 \tan^2(\theta/2) + \sigma_x^2}$$

$$\xi_x = \frac{r_e N}{2\pi\gamma} \frac{\beta_x}{\sqrt{\sigma_z^2 \tan^2(\theta/2) + \sigma_x^2}\left(\sqrt{\sigma_z^2 \tan^2(\theta/2) + \sigma_x^2} + \sigma_y\right)}$$

$$\xi_y = \frac{r_e N}{2\pi\gamma} \frac{\beta_y}{\sigma_y\left(\sqrt{\sigma_z^2 \tan^2(\theta/2) + \sigma_x^2} + \sigma_y\right)}$$

SuperB: $\sqrt{\sigma_z^2 \tan^2(\theta/2) + \sigma_x^2} = 100\ \mu m \gg \sigma_x = 2.67\ \mu m$

$$\frac{\sqrt{\sigma_z^2 \tan^2(\theta/2) + \sigma_x^2}}{\sigma_y} \simeq 8000\ !!!$$

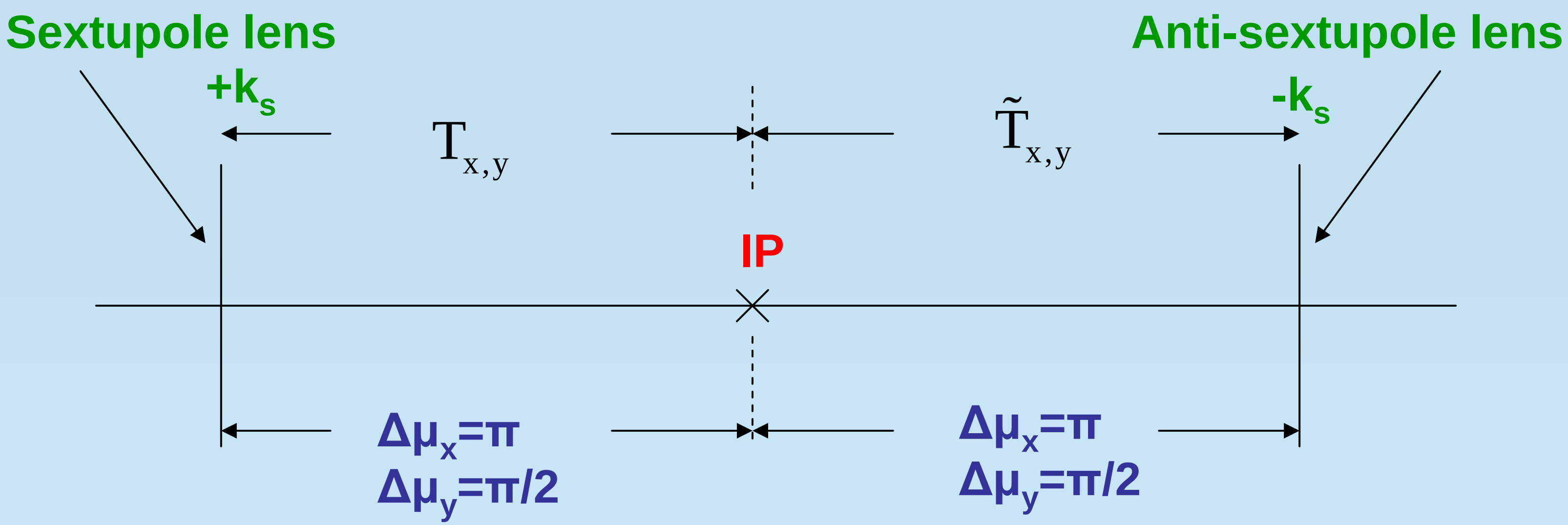
$$\xi_x = \frac{2 r_e N}{\pi\gamma} \frac{\beta_x}{\sigma_z^2 \theta^2} = 0.002$$

$$\xi_y = \frac{r_e N}{\pi\gamma} \frac{\beta_y}{\sigma_y \sigma_z \theta} = 0.072$$

One dimensional case for $\beta_y >> \sigma_x/\theta$ but with crabbed waist for $\beta_y < \sigma_x/\theta$ also!

I. Koop et al, BINP

“Crabbed” waist optics

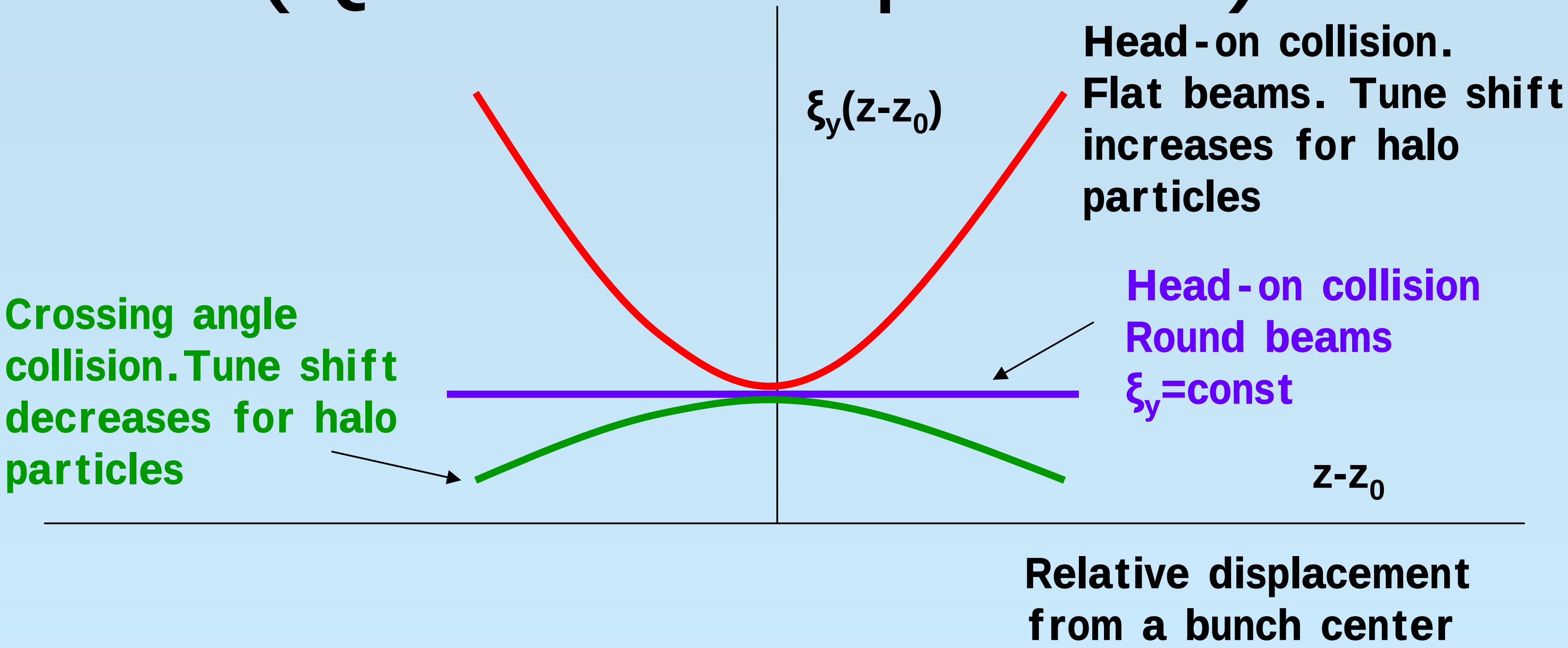


Appropriate transformations from first sextupole to IP and from IP to anti-sextupole:

$$T_x = \begin{pmatrix} u_x & 0 \\ -F_x^{-1} & u_x^{-1} \end{pmatrix} \quad \tilde{T}_x = \begin{pmatrix} u_x^{-1} & 0 \\ -F_x^{-1} & u_x \end{pmatrix} \quad \tilde{T}_x T_x = \begin{pmatrix} 1 & 0 \\ -2u_x F_x^{-1} & 1 \end{pmatrix}$$

$$T_y = \begin{pmatrix} u_y & F_y \\ -F_y^{-1} & 0 \end{pmatrix} \quad \tilde{T}_y = \begin{pmatrix} 0 & F_y \\ -F_y^{-1} & u_y \end{pmatrix} \quad \tilde{T}_y T_y = \begin{pmatrix} -1 & 0 \\ -2u_y F_y^{-1} & -1 \end{pmatrix}$$

Synchrotron modulation of ξ_y (Qualitative picture)



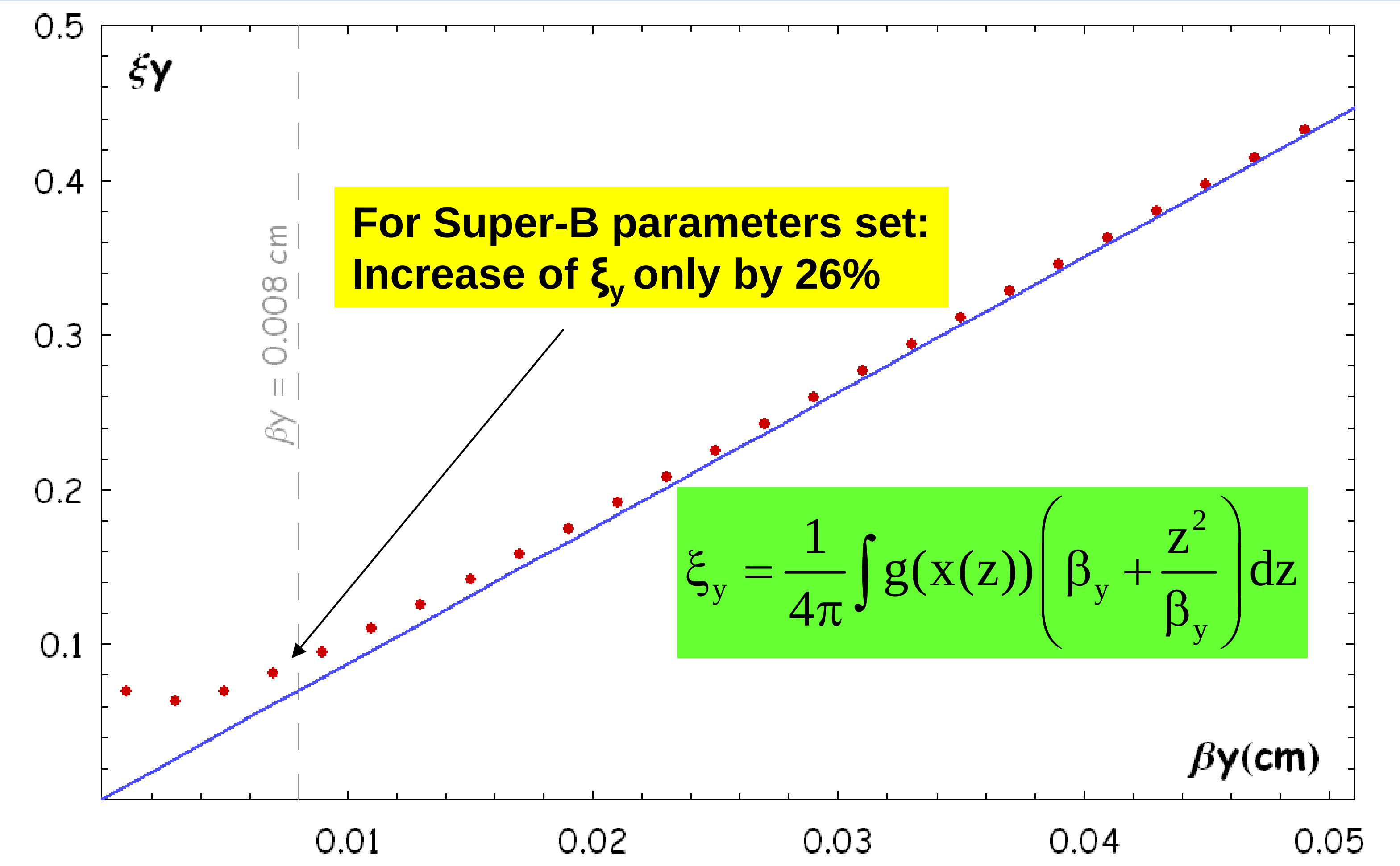
Conclusion: one can expect improvements of lifetime of halo-particles!

I. Koop et al, BINP

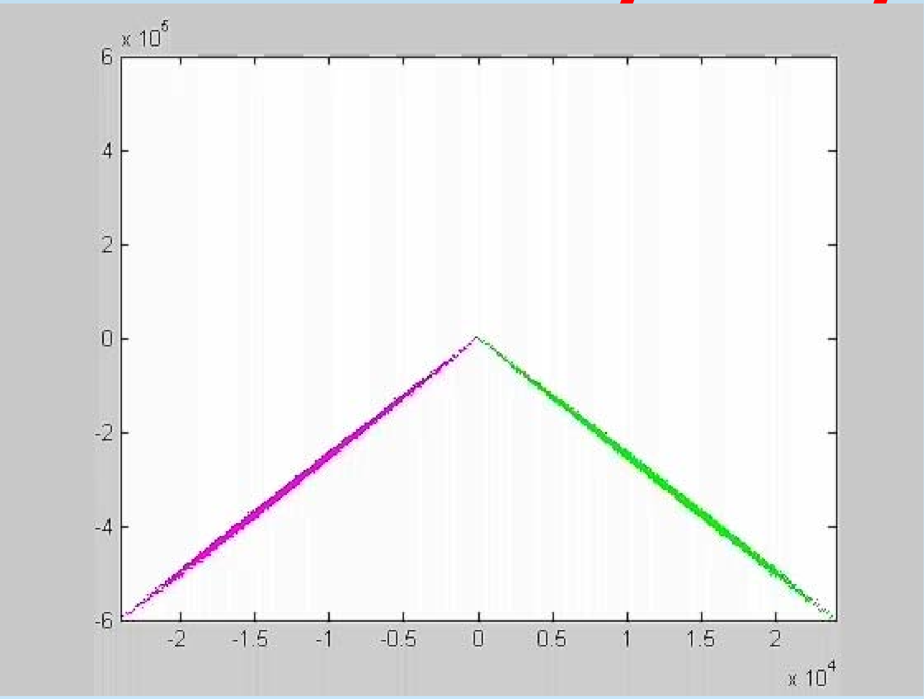
ξ_y increase caused by hourglass effect

I. Koop et al, BINP

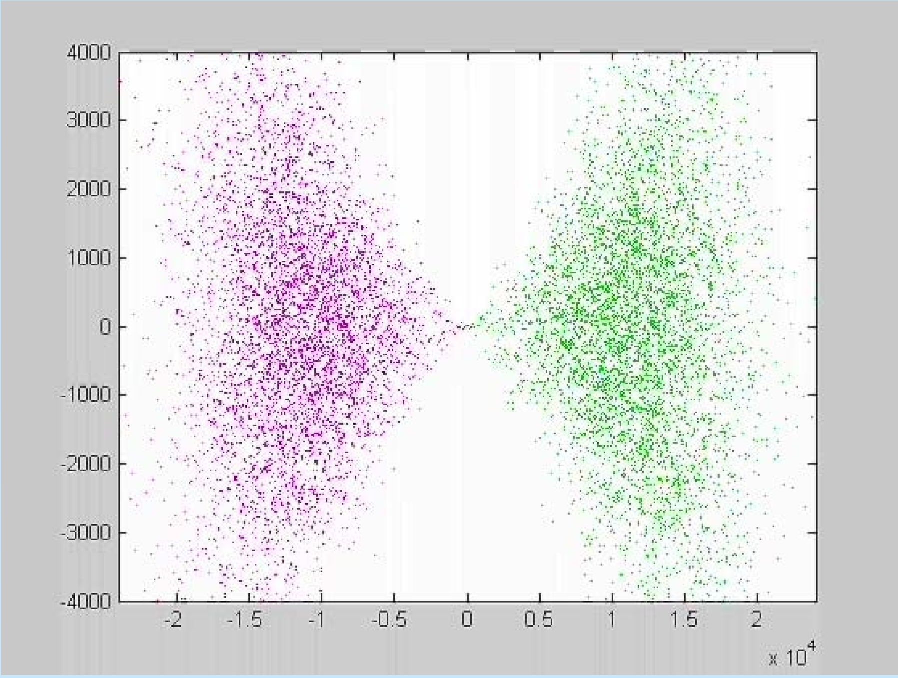
Dependence of ξ_y on β_y for constant beam sizes at IP



SuperB parameters



Horizontal Plane



Vertical Plane

Collisions with uncompressed beams

Crossing angle = 2*25mrad

Relative Emittance growth per collision about $1.5*10^{-3}$

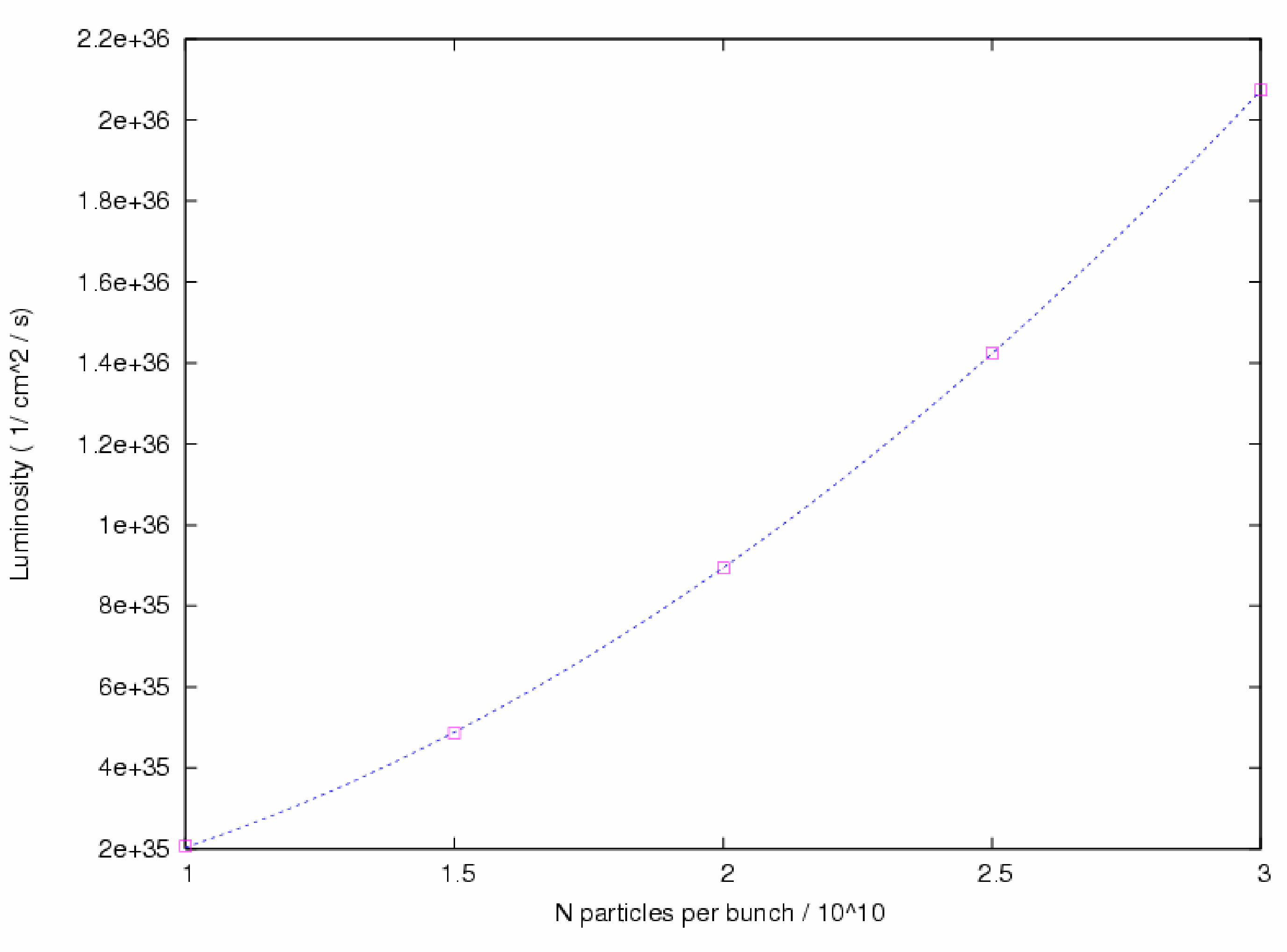
$\varepsilon_y^{out}/\varepsilon_y^{in}=1.0015$

GuineaPig modifications

- With the large crossing angle scheme and long bunches the actual collision region is very short
- The code solves Poisson equation for all the volume occupied by the particles → very long computing time, not needed !
- Modification of the code to perform fields calculation in the collision region only
- Computing time was reduced by a factor 10!!

E. Paoloni, Pisa

GuineaPig modified



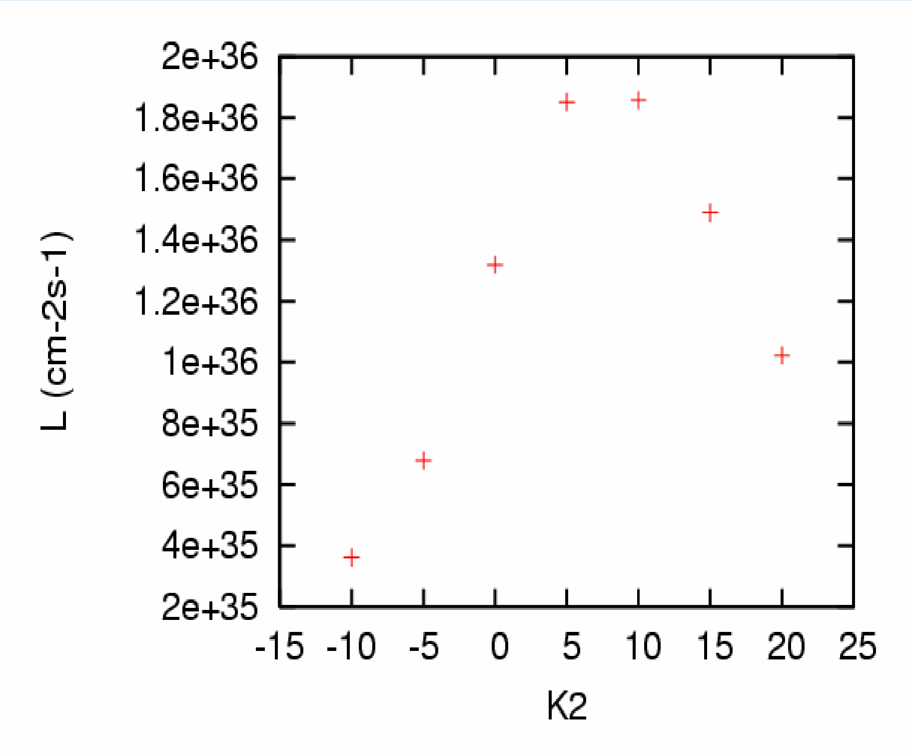
Luminosity vs Number of particles /bunch

Crab-waist simulations

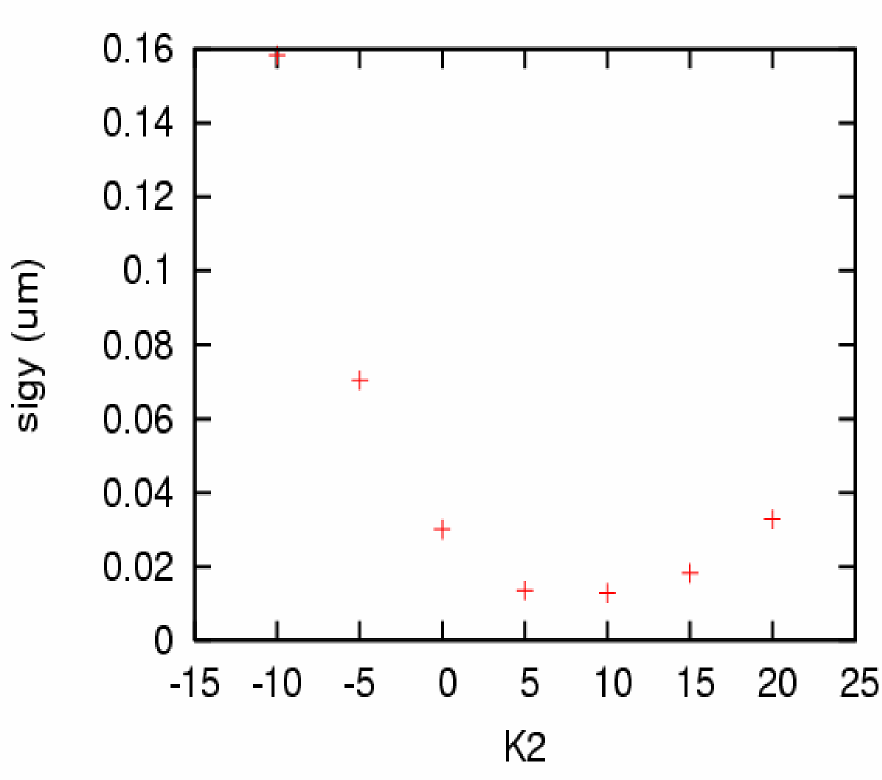
- The new idea is being checked by several beam-beam codes:
  - Guinea-Pig: strong-strong , ILC centered
  - BBC (Hirata): weak-strong
  - Lifetrack (Shatilov): weak-strong with tails growths calculation
  - Ohmi: weak-strong (strong-strong to be modified for long bunches and large angles)

Storage rings

Ohmi's weak-strong code



Luminosity



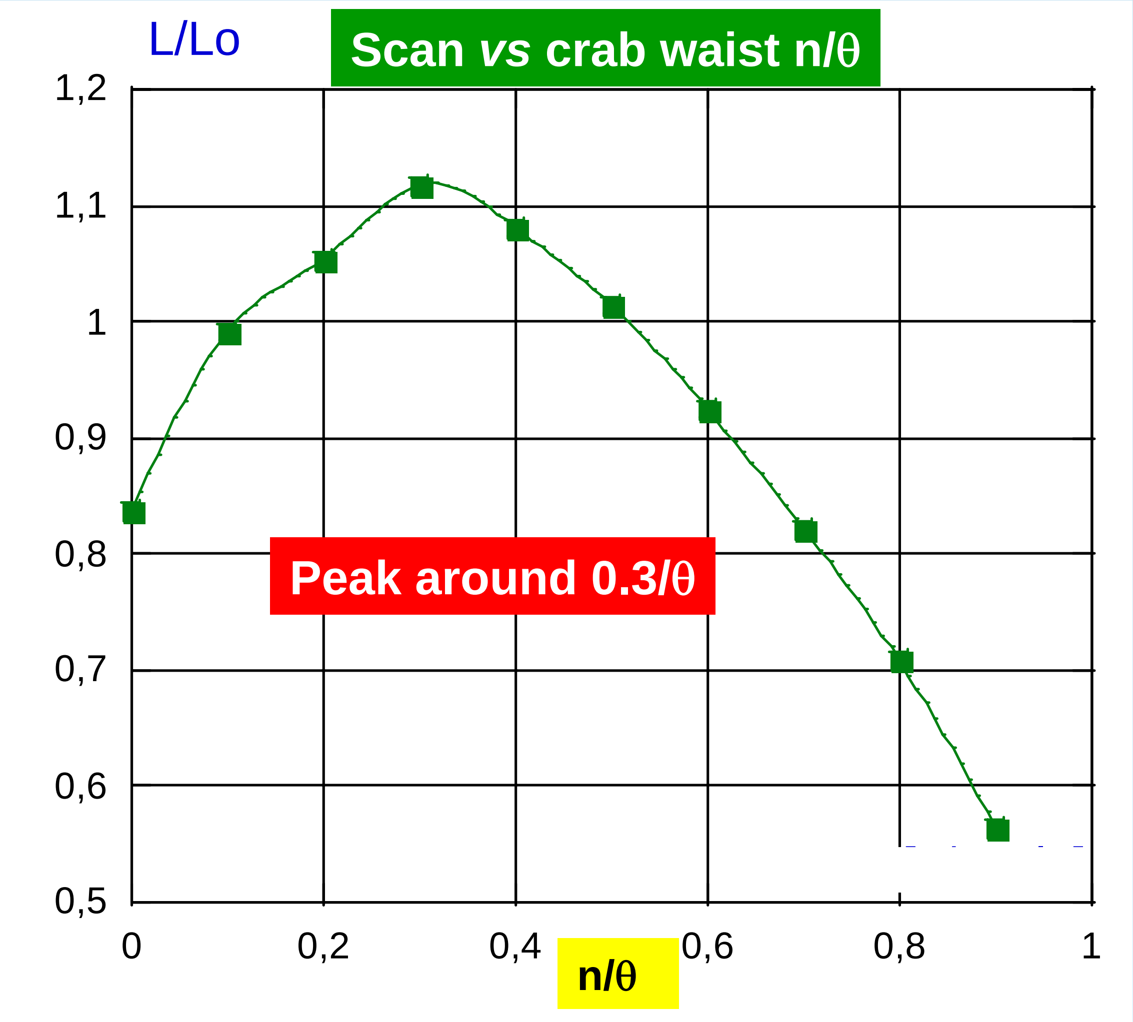
Vertical blow-up

K2 is the strength of the sextupolar nonlinearity introduced to have crab waist

DAΦNE (M.Zobov, LNF)

- Hirata's BBC code simulation
  (weak-strong, strong beam stays gaussian, weak beam has double crossing angle)
- $N_p = 2.65\text{x}10^{10}$, 110 bunches
- I_b = 13 mA (present working current)
- σ_x = 300 μm, σ_y = 3 μm
- β_x = 0.3 m, b_y = 6.5 mm
- σ_z = 25 mm (present electron bunch length)
- θ = 2x25 mrad
- $Y_{IP} = y + 0.4/(\theta * x * y')$ crabbed waist shift
- $L_o = 2.33\text{x}10^{24}$ (geometrical)
- L(110 bunches,1.43A) = $7.7\text{x}10^{32}$
- $L_{equil} = 6\text{x}10^{32}$

(Geometric) Luminosity



Takes into account both bb interactions and geometric factor due to crab waist

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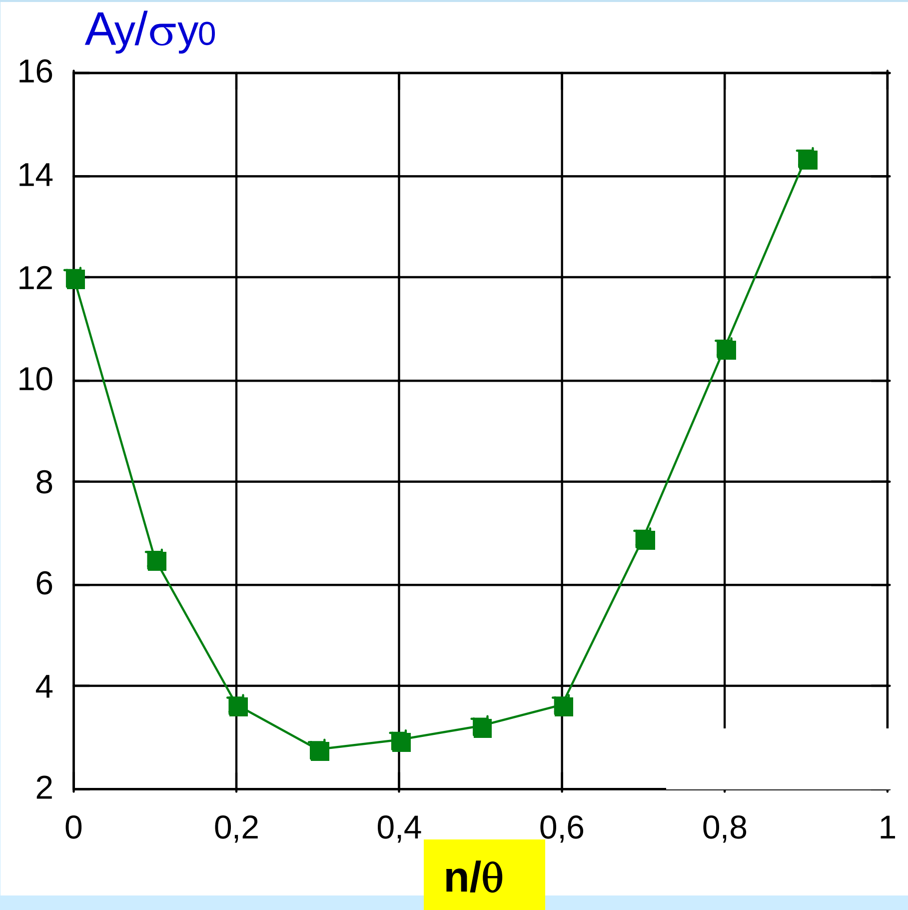
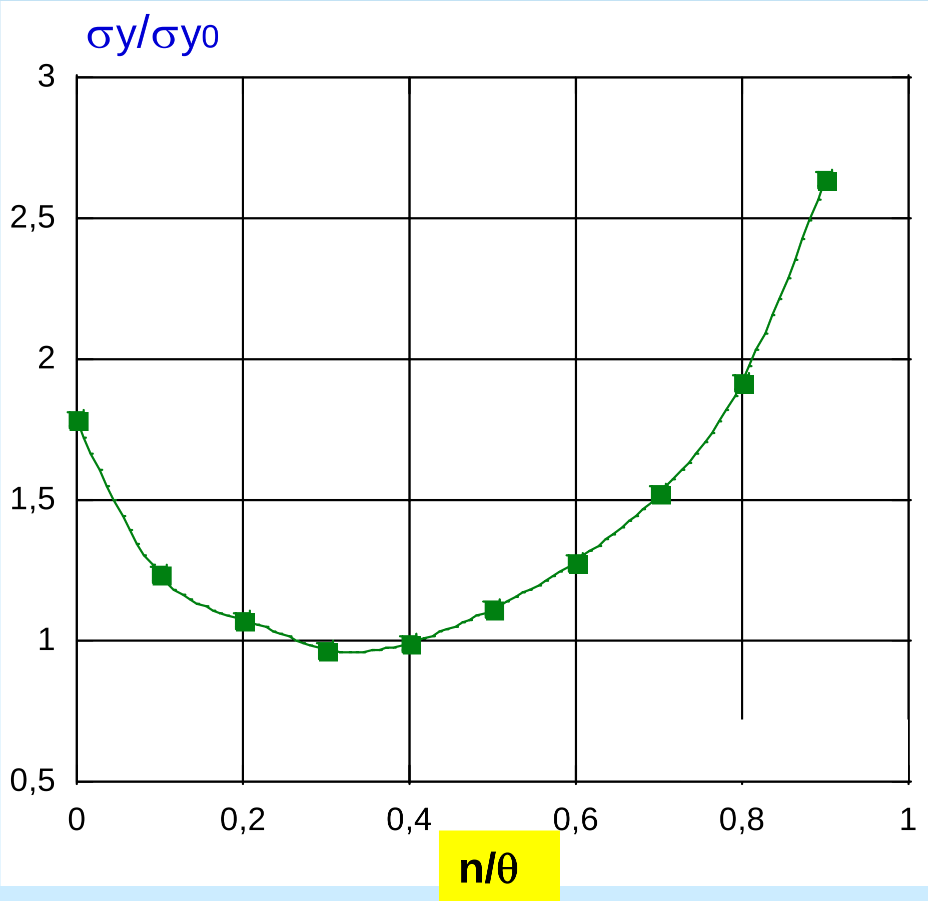
Vertical Tails

(max amplitude after 10 damping times)



Vertical Size Blow-up



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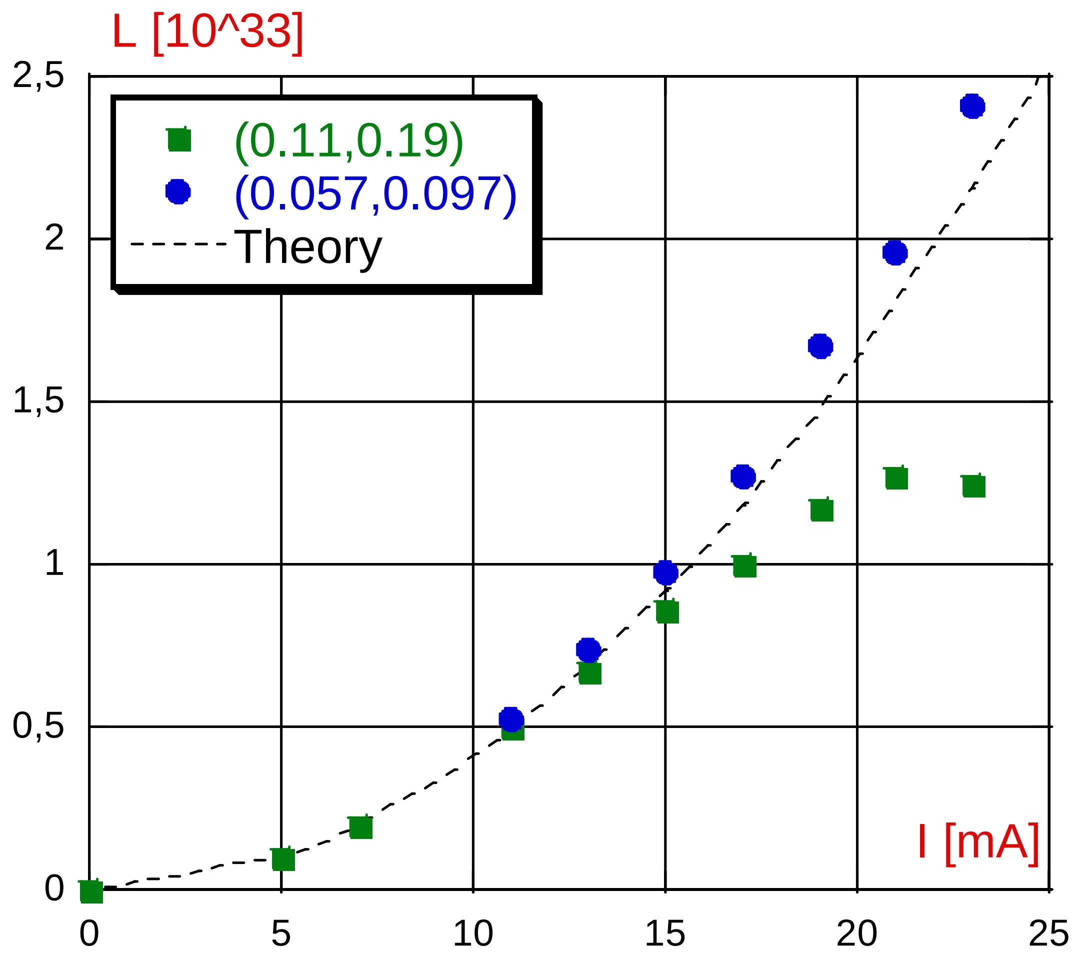
Luminosity vs bunch current for 2 different working points



Present WP:

ν_x = 0.11

ν_y = 0.19

Possible WP:

ν_x = 0.057 ν_y = 0.097

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Luminosity with shorter bunch, smaller σ_x

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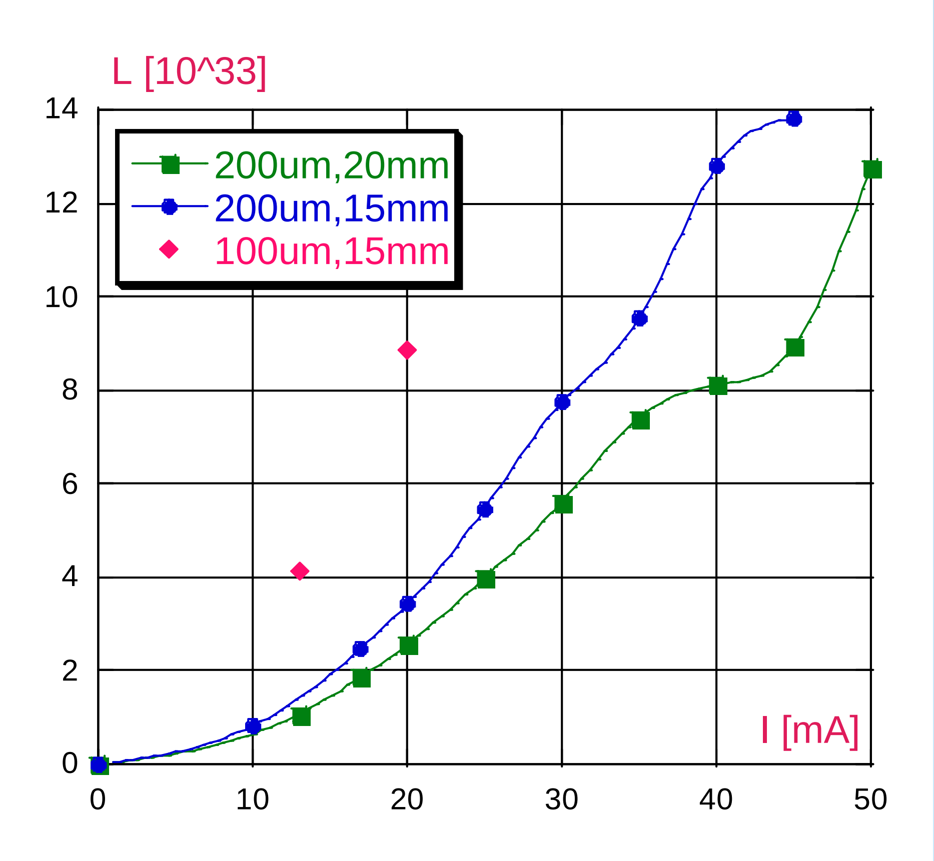
110 bunches



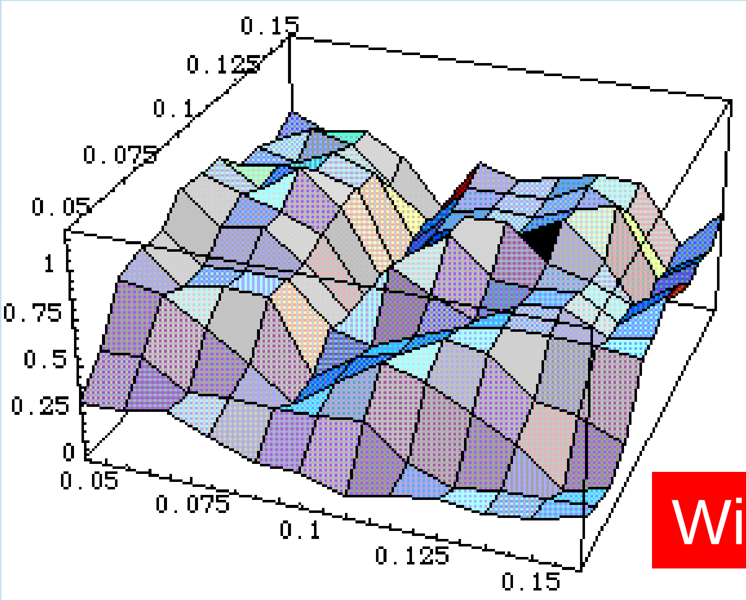
With the present achieved beam parameters (currents, emittances, bunchlenghts etc) a luminosity in excess of 10^{33} is predicted.

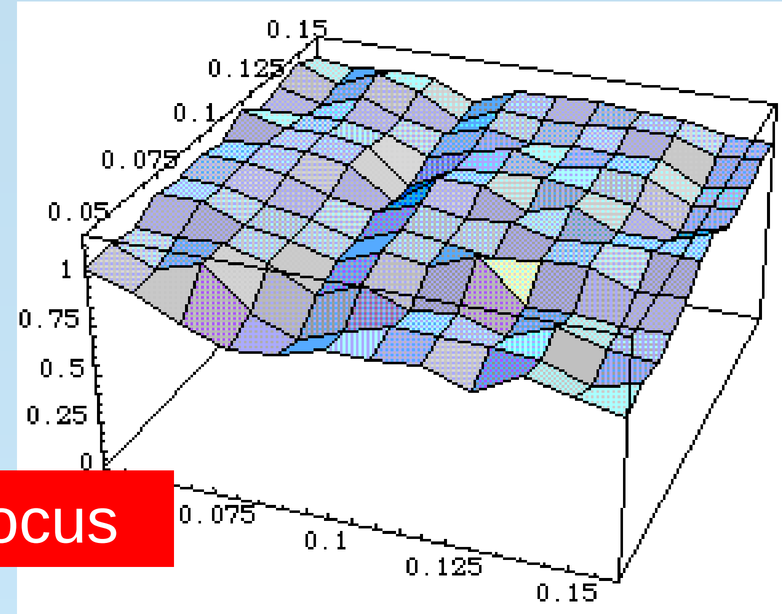
With 2A+2A L> $2*10^{33}$ is possible

Beam-Beam limit is way above the reachable currents

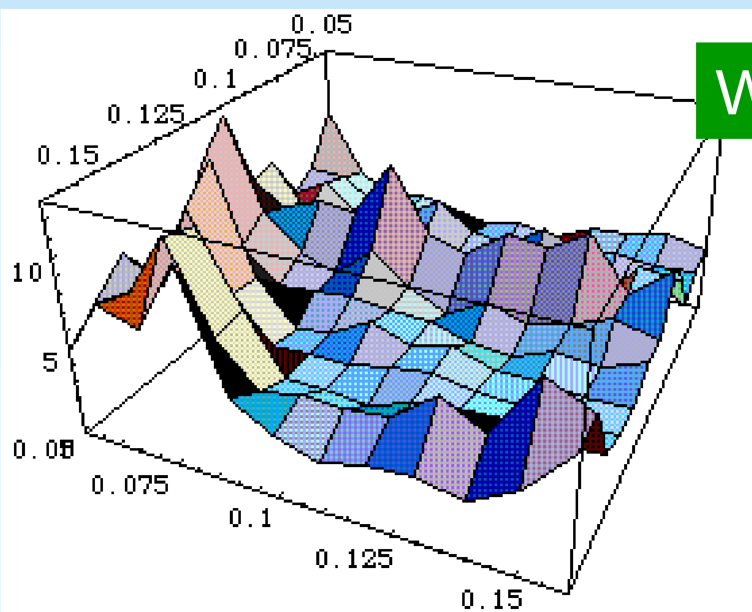
Luminosity scan | *Vertical Size blow-up scan*

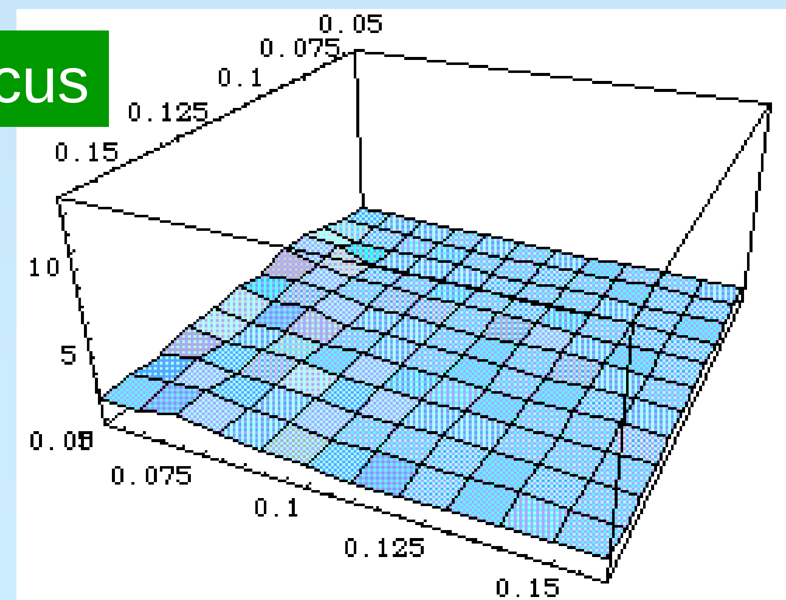
Without Crab Focus





With Crab Focus





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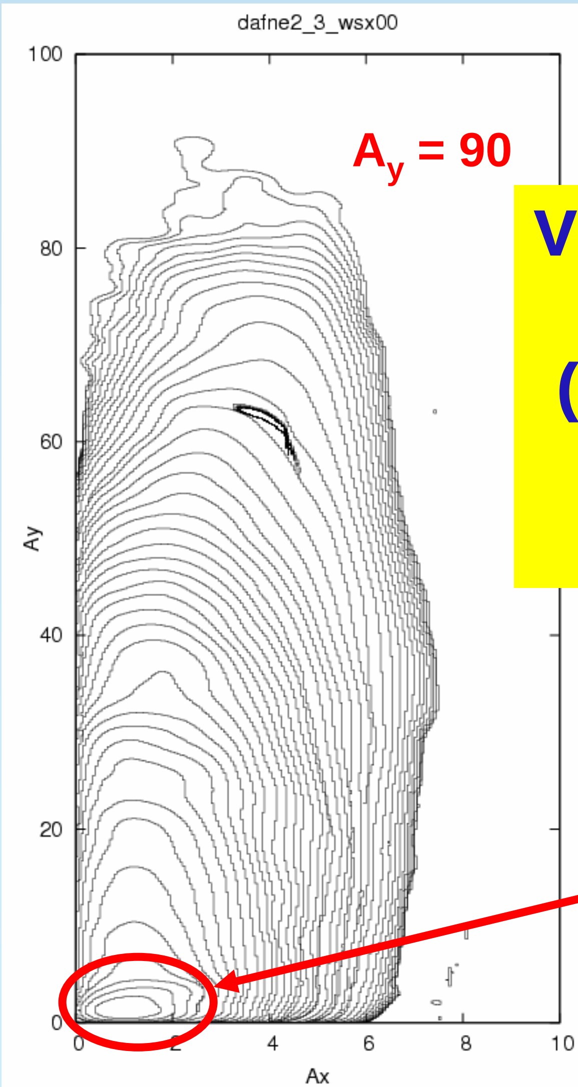
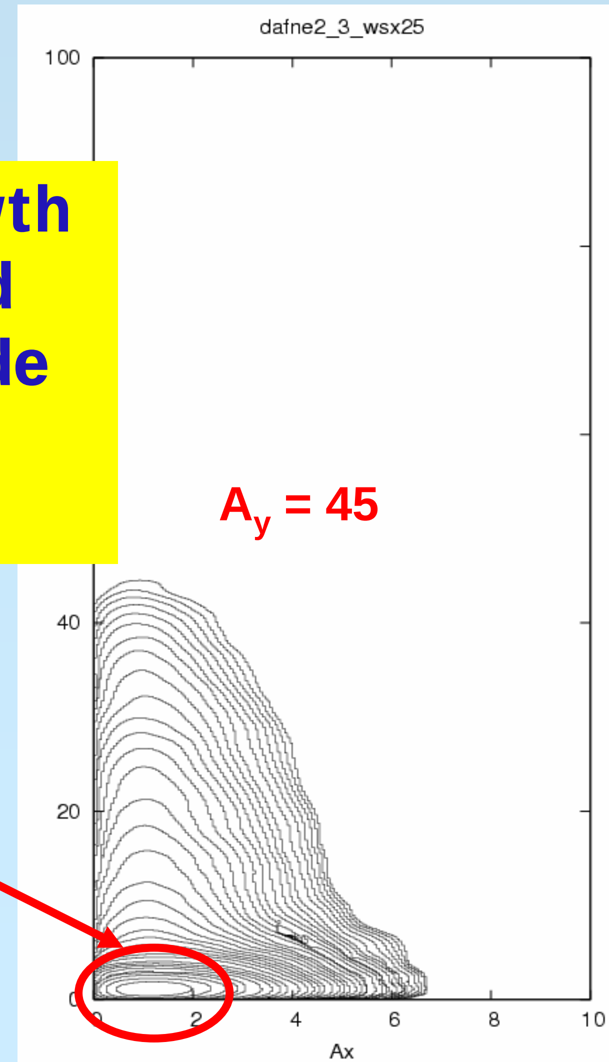
Beam-Beam Tails

Without Crab Waist



With Crab Waist



Vertical tails growth Greatly reduced (A is the amplitude in number of beamsize σ)

Bunch core blowup also reduced

Beam size and tails vs Crab-waist

Simulations with beam-beam code LIFETRAC

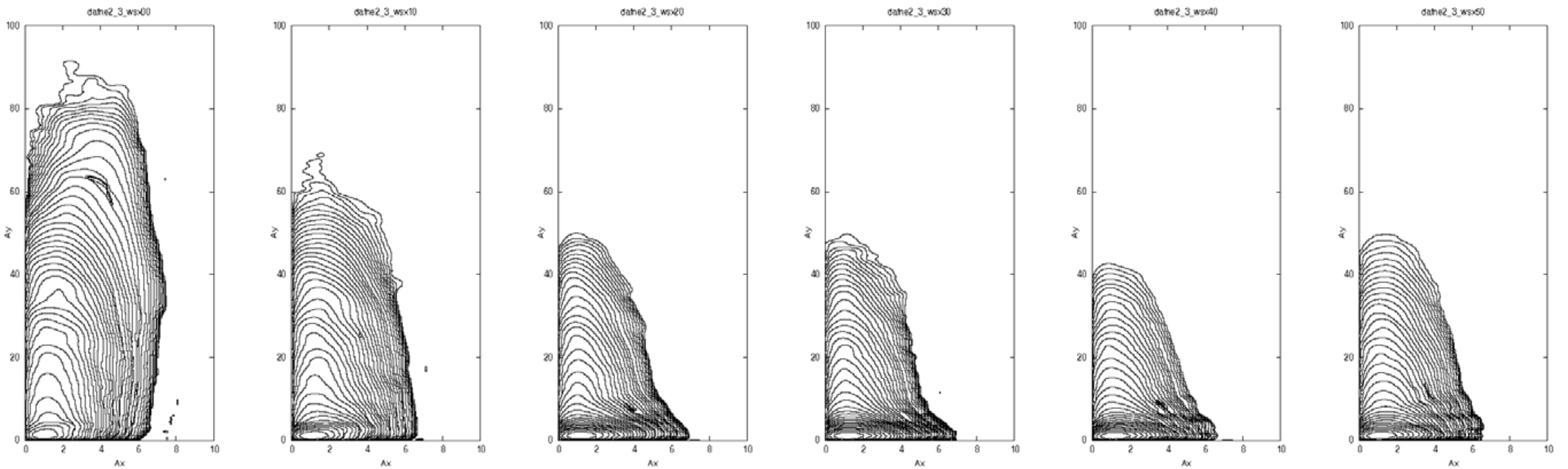
Beam parameters for DAΦNE2

An effective "crabbed" waist map at IP:

$$y = y_0 + \frac{V}{\theta} x y_0'$$

$$y' = y_0'$$

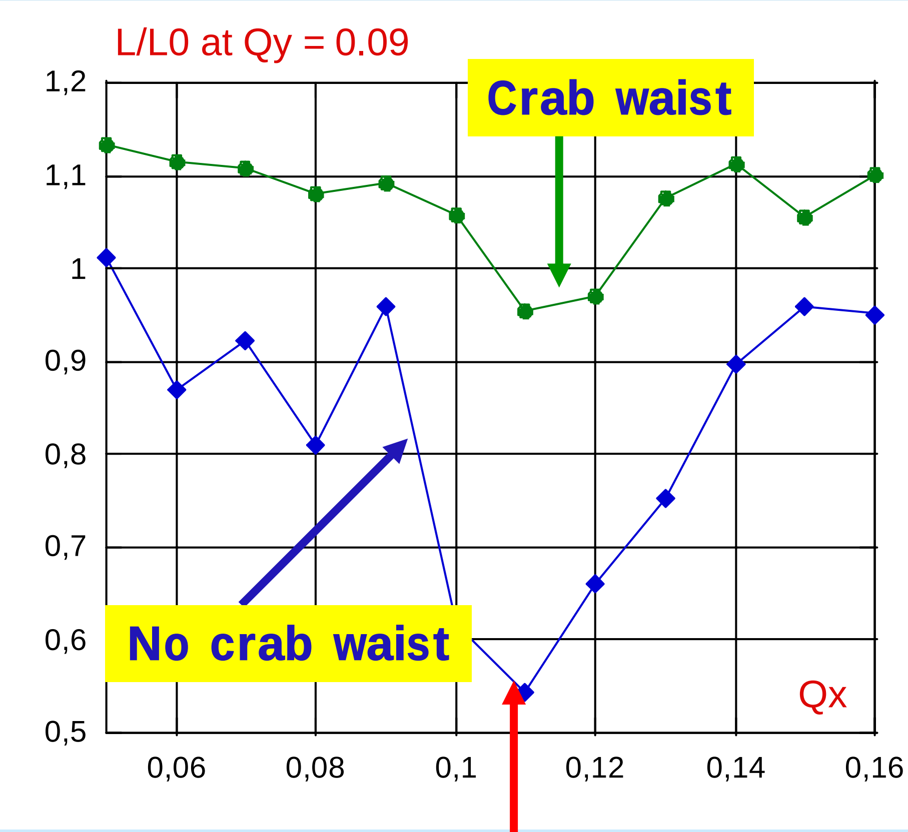
V	0.0	0.2	0.4	0.6	0.8	1.0
L/L_o	1.0	1.63	1.80	1.85	1.84	1.73

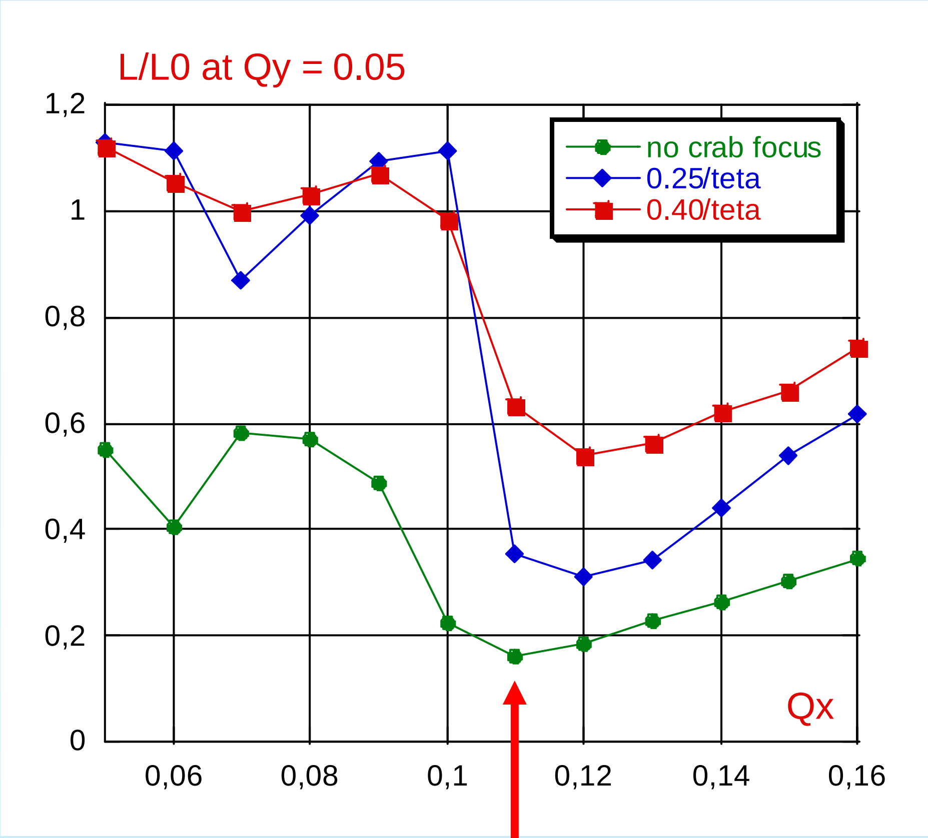


Optimum is shifted from the "theoretical" value V=1 to V=0.8, since it scales like $\sigma_z\theta/\mathrm{sqrt}((\sigma_z\theta)^2+\sigma_x^2)$

D.N. Shatilov, BINP

Some resonances





$2Q_x = 2Q_y$

$1Q_x = 2Q_y$
(present with crossing angle only)

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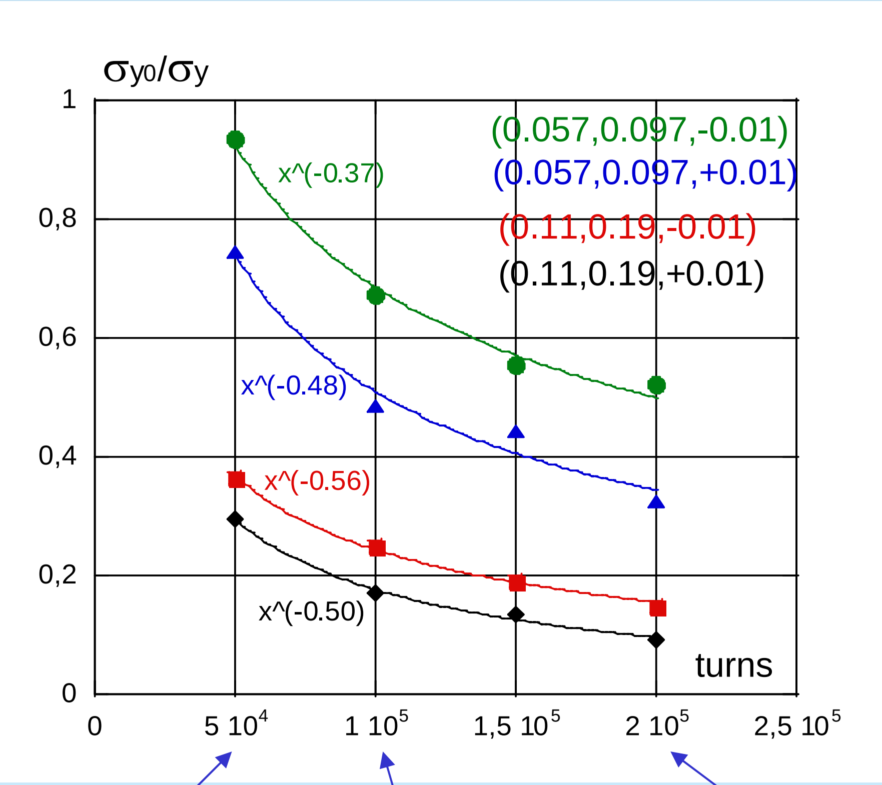
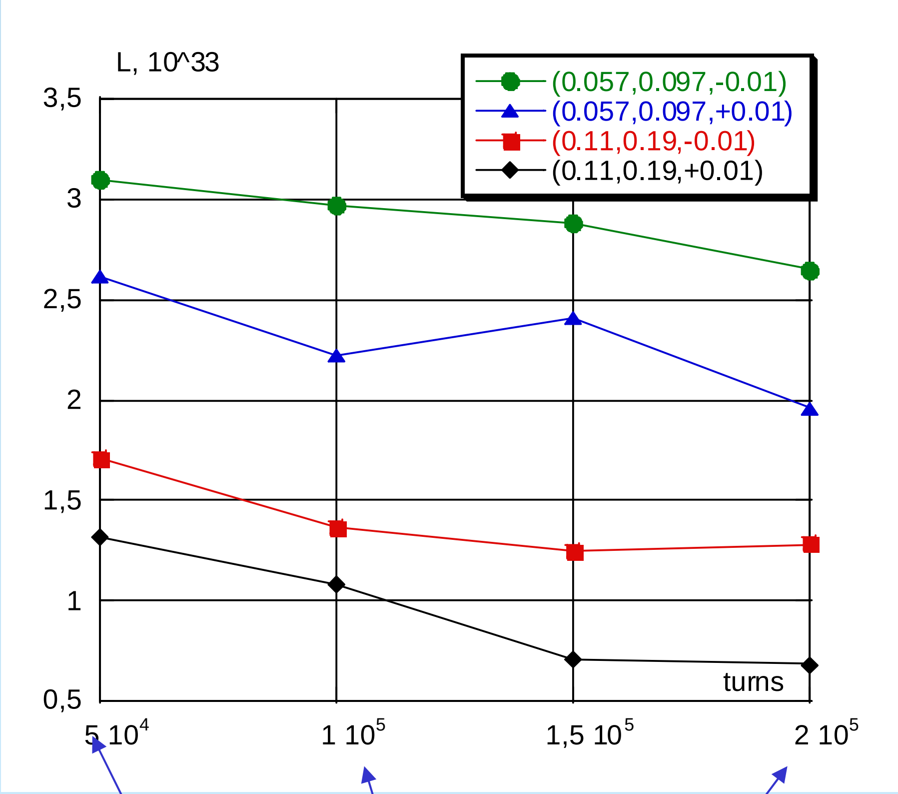
Vertical blow-up



Luminosity



SC Wigglers **DAΦNE Wigglers** **Wigglers off**

SC Wigglers **DAΦNE Wigglers** **Wigglers off**

Very weak luminosity dependence from damping time given the very small beam-beam blow-up

M. Zobov, LNF

Preliminary results on Super PEPII

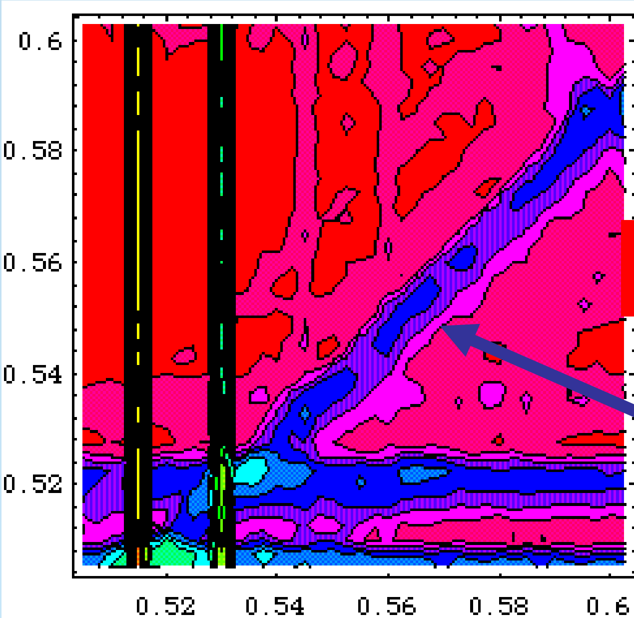
M. Zobov, D. Shatilov

First approach with new parameters, weak-strong code

$L = 1.65 \times 10^{35}$ cm^{-2}s^{-1}

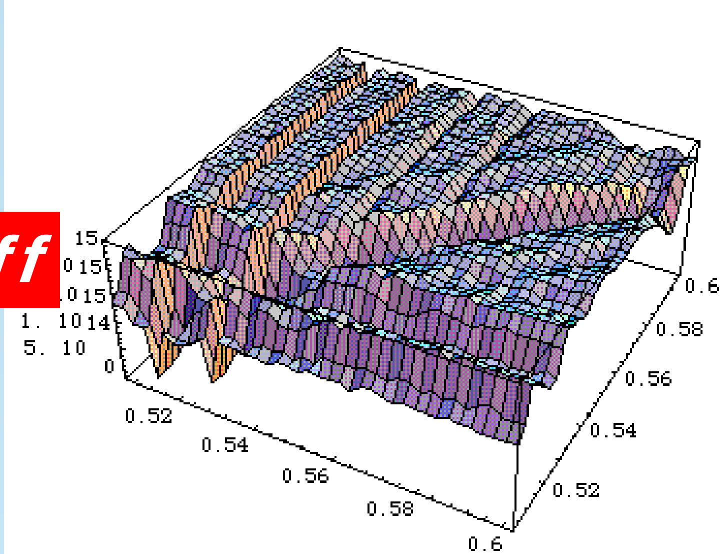
ε_x = 20 nm
ε_y = 0.2 nm
σ_x = 14.4 μm
σ_y = 0.4 μm
σ_z = 10 mm
σ_E = 7×10^{-4}
β_x = 10 mm
β_y = 0.8 mm
ν_s = 0.03
C = 2.2 km
f_{col} = 238 MHz
θ = 2 x 14 mrad
τ_x = 35 ms
N_1 = 1.3×10^{11}
N_2 = 4.4×10^{10}
I_1 = 5 A
I_2 = 1.7 A

Tune scan for Super-PEPII

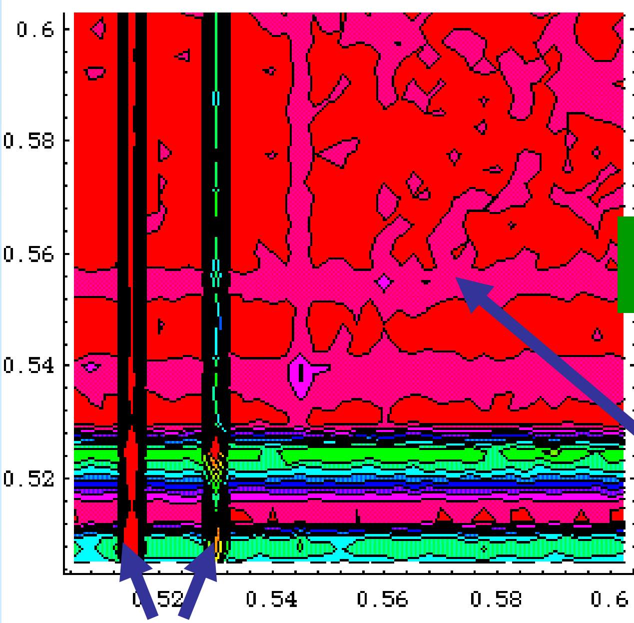


crab focus off

Coupling resonance

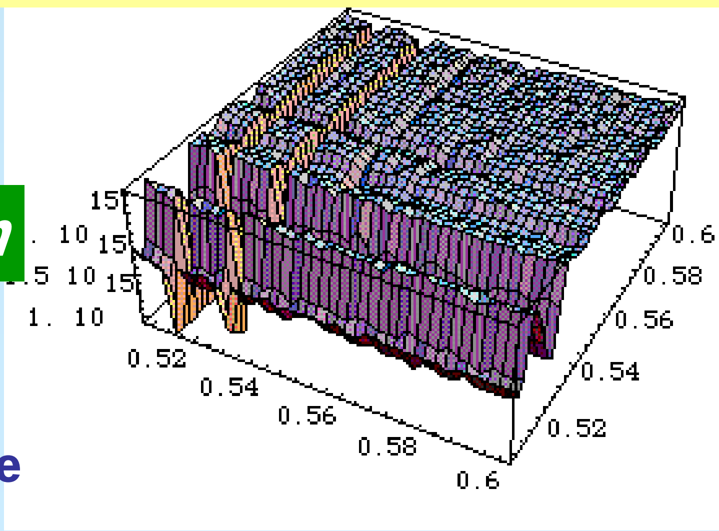


No dependence on tunes !!



crab focus on

Coupling resonance disappears



Synchrobetatron resonances

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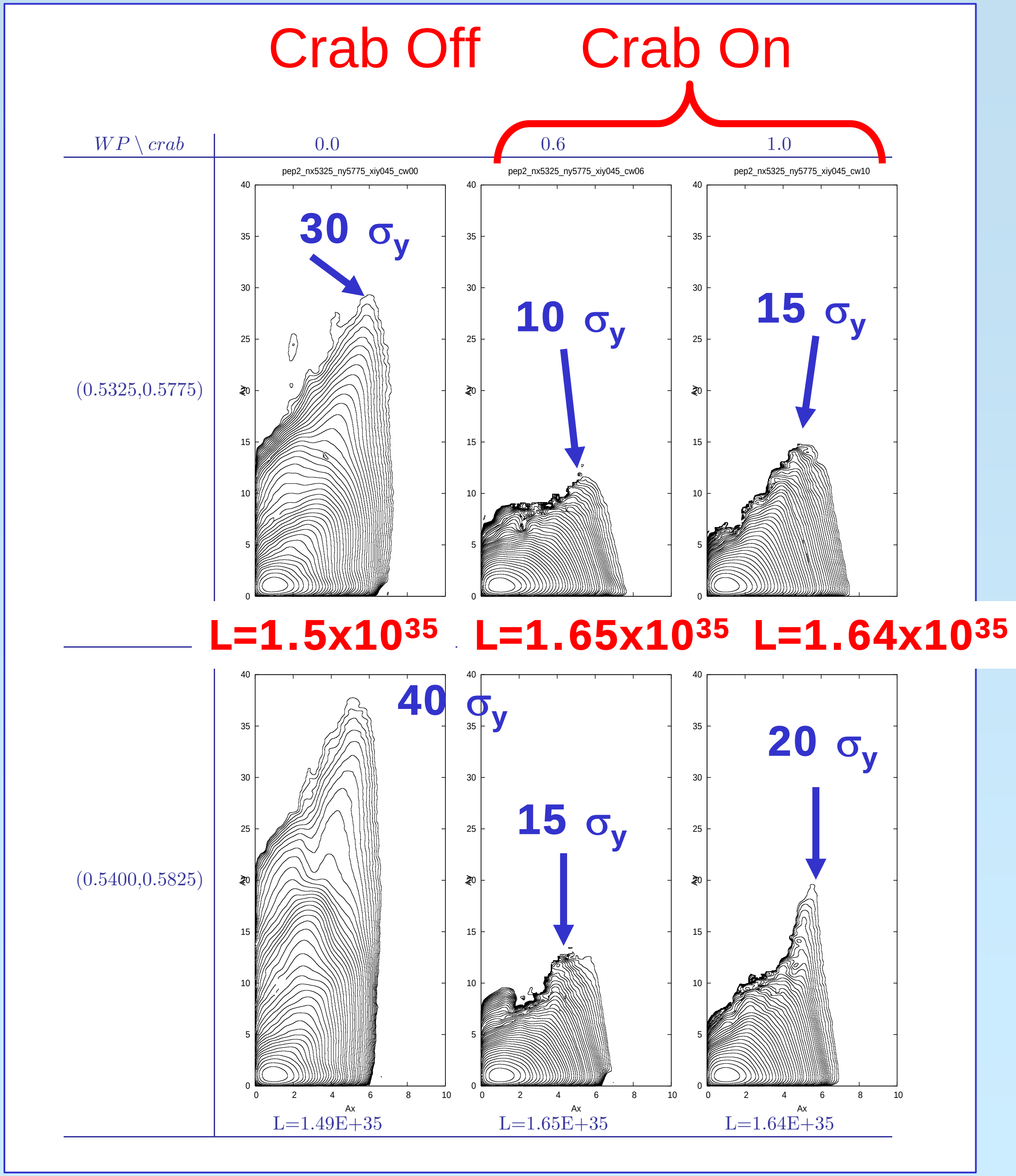
Tails growth



$n/\theta = 0$ $n/\theta = 0.6$ $n/\theta = 1$

$\nu_x = 0.5325,\ \nu_y = 0.5775$

$\nu_x = 0.54,\ \nu_y = 0.5825$

M.Zobov, D.Shatilov

Conclusions

- The “crossing angle with crab waist” scheme has shown big potentiality and exciting results → LNF, Pisa, BINP and KEKB physicists are working on the bb simulation with different codes to explore its properties and find the best set of parameters
- This scheme is promising also for increasing luminosity at existing factories, as DAΦNE, KEKB and possibly PEPII