Status on SuperB effort

P. Raimondi

SLAC, June 14, 2006

Outline

- Basic Concepts and Parameters
- Highlights of studies made since last workshop
- Layout for a Ring Collider with Linear Collider Parameters
- Some of the work to do
- Conclusions

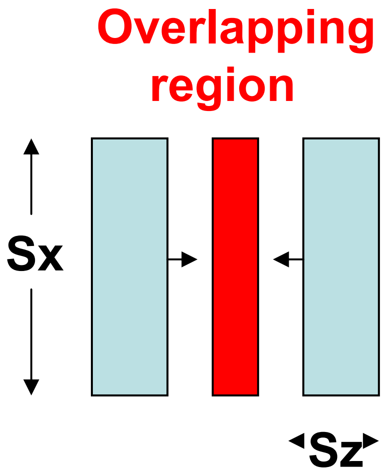
Summary from Oide's talk at 2005 2nd Hawaii SuperBF Workshop

- Present design of SuperKEKB hits fundamental limits in the beam-beam effect and the bunch length (HOM & CSR).
- Higher current is the only way to increase the luminosity.
- Many technical and cost issues are expected with a new RF system.
- **We need a completely different collider scheme.....**

Sigx*	μm	2.67
Etax	mm	0.0
Sigy	nm	12.6
Betx	mm	9.0
Bety	mm	0.080
Sigz_IP	mm	6.0
Sige_IP		1.3e-3
Sige_Lum		0.9e-3
Emix	nm	0.8
Emiy	nm	0.002
Emiz	μm	8.0
Cross_angle	mrad	2*25
Sigz_DR	mm	6.0
Sige_DR		1.3e-3
Np	10e10	2.3
Nbunches		6000
DR_length	km	3.0
Damping_time	msec	20
Nturns_betwe_coll		1
Collision freq	MHz	600
$L_{singleturn}$	1e36	1.2
$L_{multiturn}$	1e36	1.0

- Defined a parameters set based on ILC-like parameters
- Same DR emittances
- Same DR bunch length
- Same DR bunch charges
- Same DR damping time
- Same ILC-IP betas
- Crossing Angle and Crab Waist to minimize BB blowup

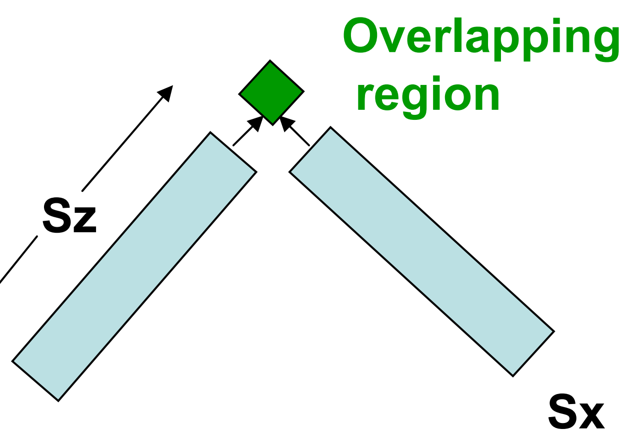
Crossing angle concepts



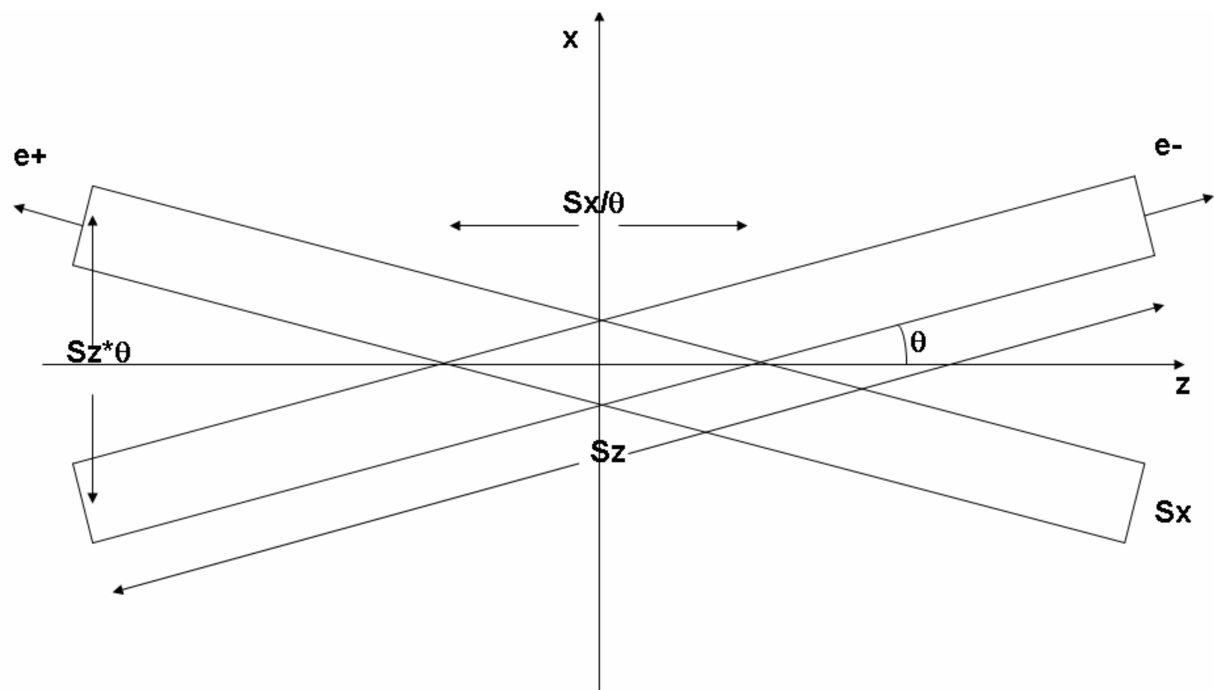
1) Standard
short bunches

Both cases have the same luminosity,
(2) has longer bunch and smaller σ_x

With large crossing angle X and Z
quantities are swapped: Very important!!!



2) Crossing angle



High luminosity requires:

- short bunches
- small vertical emittance
- large horizontal size and emittance to mimimize beam-beam

For a ring:

- easy to achieve small horizontal emittance and horizontal size
- Vertical emittance goes down with the horizontal
- Hard to make short bunches

Crossing angle swaps X with Z, so the high luminosity requirements are naturally met:

Luminosity goes with $1/\varepsilon_x$ and is weakly dependent by σ_z

- ‘Long Range Beam Beam’ is minimized with a proper choice of the crossing angle w.r.t. the other parameters:

$x_{crossing\_angle}$=2*25mrad σ_x=2.7μm

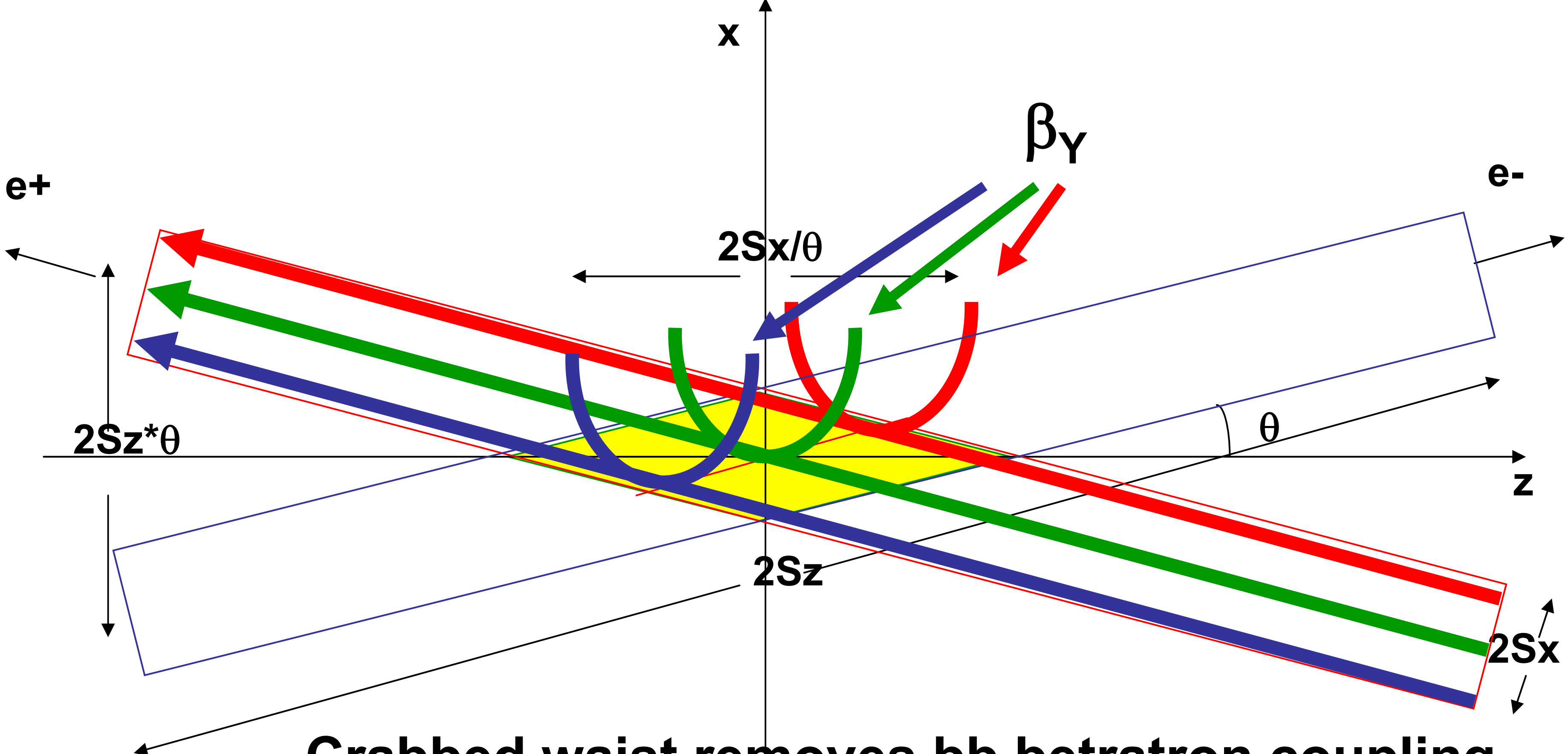
- LRBB is further decreased togheter with the betatron resonances by crabbing the Vertical waist.

Vertical waist position in z is a function of x:

Zy_waist(x)=x/2θ Crabbed waist

All components of the beam collide at a minimum β_y :

- the ‘hour glass’ is reduced
- the geometric luminosity is higher (5-10%)
- the bb effects are reduced (factor 2-4)



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

Emittance blowup due to the crossing angle

Colliding with no crossing angle and

σ_x=100μm, σ_z=100μm:

$\Delta\varepsilon_y$ (single pass)=4*10^{-4} L=2.1*10^{27}

Colliding with crossing angle=2*25mrad and

σ_x=2.67um, σ_z=4mm (σ_z*θ=100um, σ_x/θ=104um):

$\Delta\varepsilon_y$ =4*10^{-3} (single pass) L=2.14*10^{27}

Same geometric luminosity but 10 times more emittance blowup

Adding the "Crab-waist", Zy_waist(x)=x/2θ:

$\Delta\varepsilon_y$ =1.5*10^{-3} (single pass) L=2.29*10^{27}

- the 'hour glass' is reduced, the geometric luminosity is higher: small effect about 5% more luminosity
- the main effect: blowup due the the beam-beam is reduced, about a factor 2.4 less $\Delta\varepsilon_y$ (3.8 times the no-crossing case)

Colliding with an angle requires just the ILC DR and the ILC FF.

Short bunches are not needed

Crabbed y_{waist} is achieved by placing a sextupole upstream the IP (and symmetrically downstream) in a place in phase with the IP in X and at $\pi/2$ in Y.

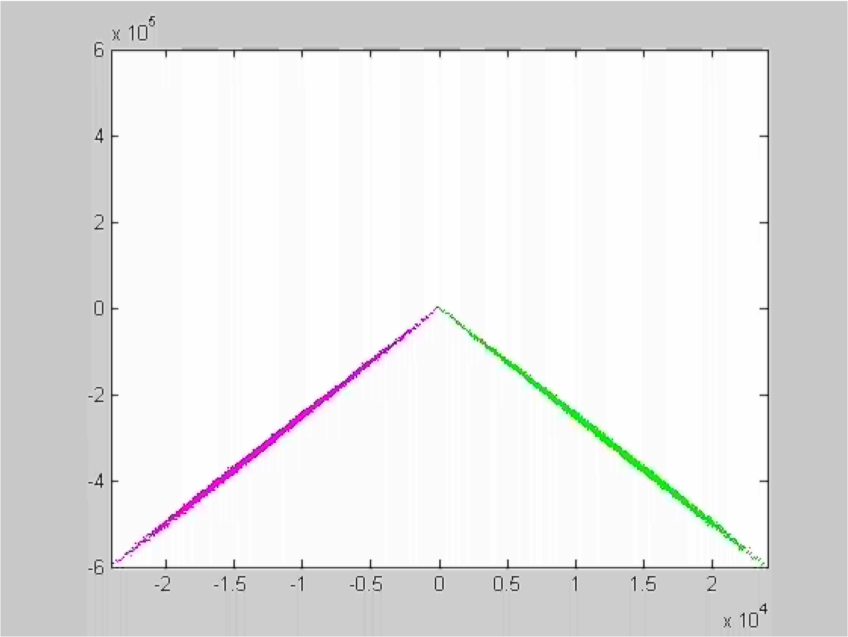
Only natural energy spread in the beams

Angular divergences about 150μrad in both planes

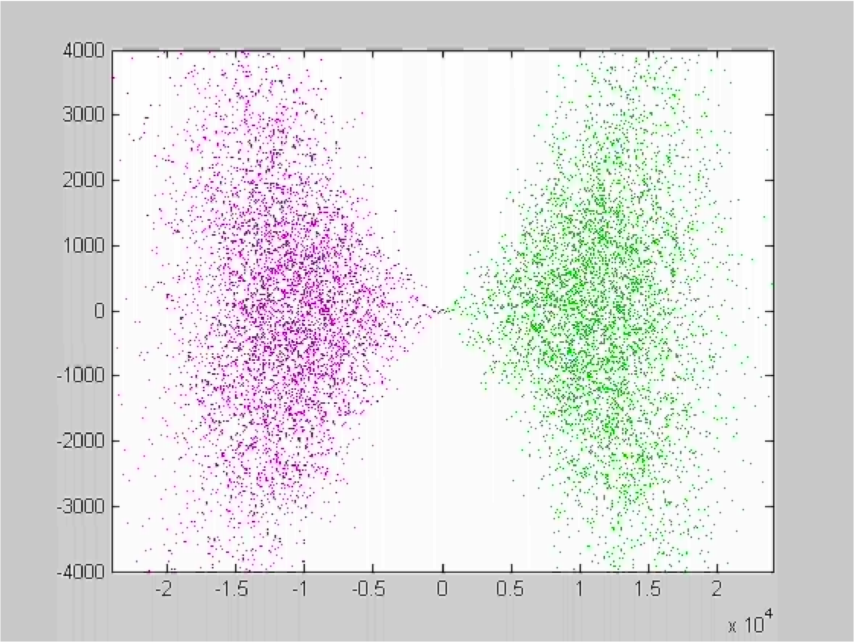
Crossing angle so large makes the IR (and the FF) design very easy

Low energy spread makes the FF very easy

Beam currents around 1.9Amps, possible better trade off current⇔damping time



Horizontal Plane



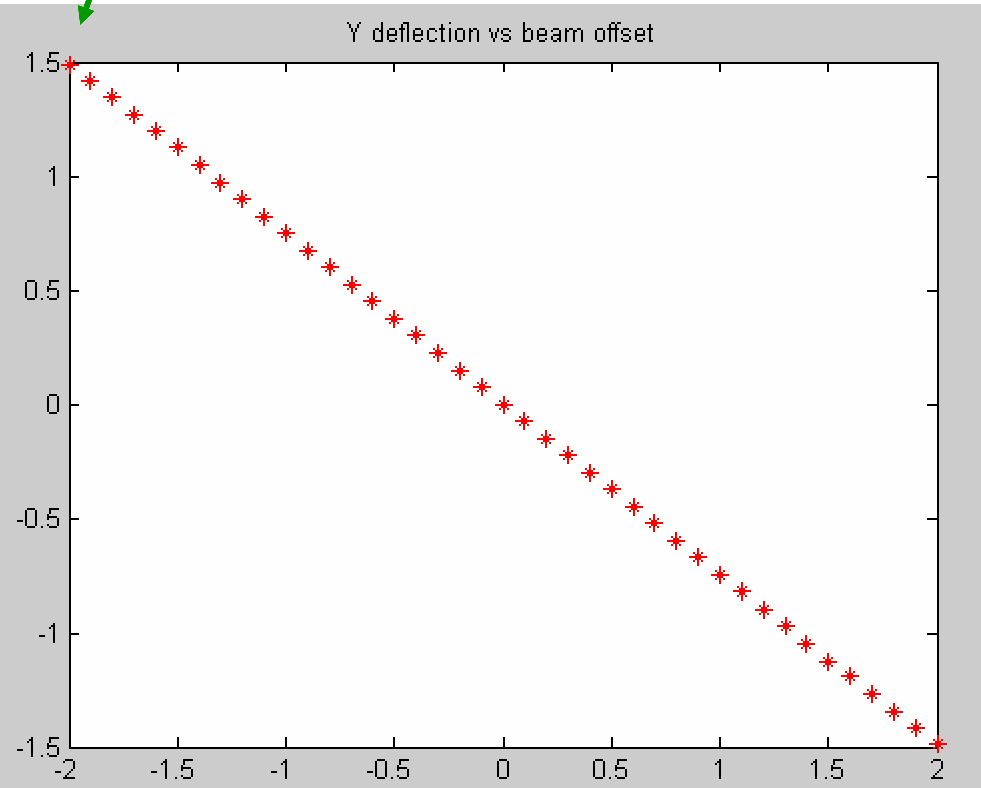
Vertical Plane

Collisions with uncompressed beams
Crossing angle = 2*25mrad
Relative Emittance growth per collision about $1.5*10^{-3}$

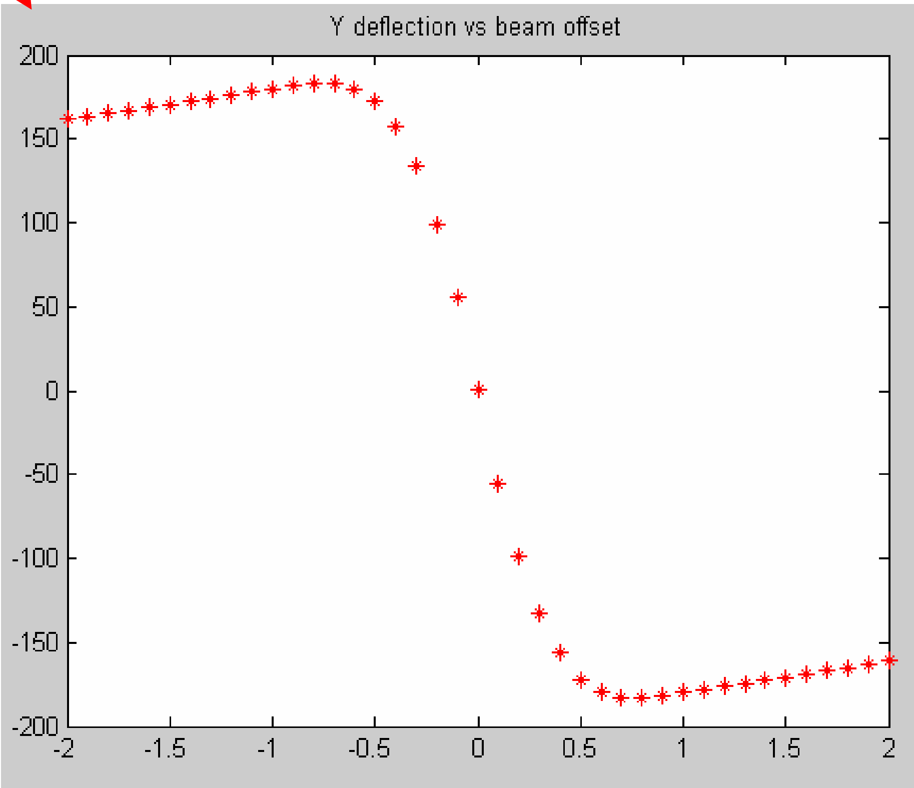
$\varepsilon_{yout}/\varepsilon_{yin}=1.0015$

Y bb_scan with 40μm horizontal separation

Y field linear and much smaller kick:
1.5μrad instead of 180μrad



No X separation y-scan



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: $\delta N_2 = N_2 \dfrac{l_{cross}}{\sigma_z}$ $\quad l_{cross} = 2\sigma_x/\theta$

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

$$L = \frac{\gamma\xi_{1y}N_1 f_0}{2r_e\beta_y}\left(1 + \frac{\sigma_y}{\sigma_x}\right) \approx 2.167 \cdot 10^{34}\,\frac{E(GeV) \cdot I(A) \cdot \xi_{1y}}{\beta_y(cm)} \approx 1.2 \cdot 10^{36}\ cm^{-2}s^{-1}$$

No dependence on crossing angle!

Universal expression: valid for both - head-on and crossing angle collisions!

I. Koop, Novosibirsk

Tune shifts

Raimondi-Shatilov-Zobov formulae:

(Beam Dynamics Newsletter, 37, August 2005)

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

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

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

Super-B: $\sqrt{\sigma_z^{\,2}\tan^2(\theta/2)+\sigma_x^{\,2}} = 100\ \mu\text{m} \ \square \ \ \sigma_x = 2.67\ \mu\text{m}$

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

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

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

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

I. Koop, Novosibirsk

Kicks that a particle receives while passing through the other beam

$$\left(x^p\right)' = \frac{2r_eN}{\gamma}(x^p - z^p tg(\theta/2))\int_0^\infty dw \frac{\exp\left\{-\frac{\left(x^p - z^p tg(\theta/2)\right)^2}{\left(2\left(\sigma_x^2+\sigma_z^2 tg^2(\theta/2)\right)+w\right)} - \frac{\left(y^p\right)^2}{\left(2\sigma_y^2+w\right)}\right\}}{\left(2\left(\sigma_x^2+\sigma_z^2 tg^2(\theta/2)\right)+w\right)^{3/2}\left(2\sigma_y^2+w\right)^{1/2}}$$

$$\left(y^p\right)' = \frac{2r_eN}{\gamma} y^p \int_0^\infty dw \frac{\exp\left\{-\frac{\left(x^p - z^p tg(\theta/2)\right)^2}{\left(2\left(\sigma_x^2+\sigma_z^2 tg^2(\theta/2)\right)+w\right)} - \frac{\left(y^p\right)^2}{\left(2\sigma_y^2+w\right)}\right\}}{\left(2\left(\sigma_x^2+\sigma_z^2 tg^2(\theta/2)\right)+w\right)^{1/2}\left(2\sigma_y^2+w\right)^{3/2}} \qquad (13)$$

$$\left(z^p\right)' = \left(x^p\right)' tg(\theta/2)$$

As we can see, a large crossing angle introduces strong coupling between the horizontal and longitudinal planes, provided that σz > σx (this is almost always true).

X-Z Coupling smaller then KeK:

σ_z*θ=100μm

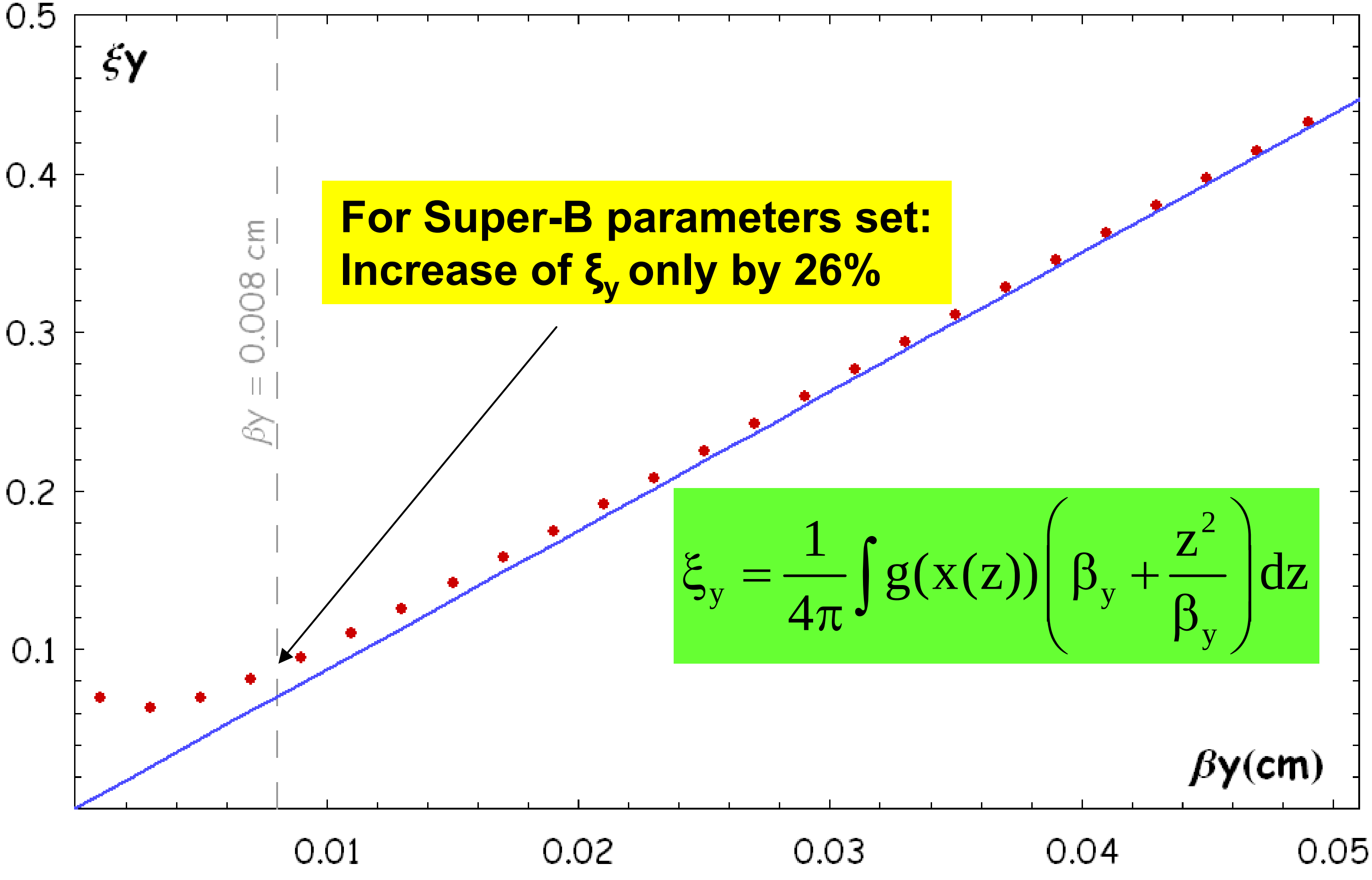
θ=25mrad

β_x=9mm

ξ_y-increase caused by hour-glass effect.

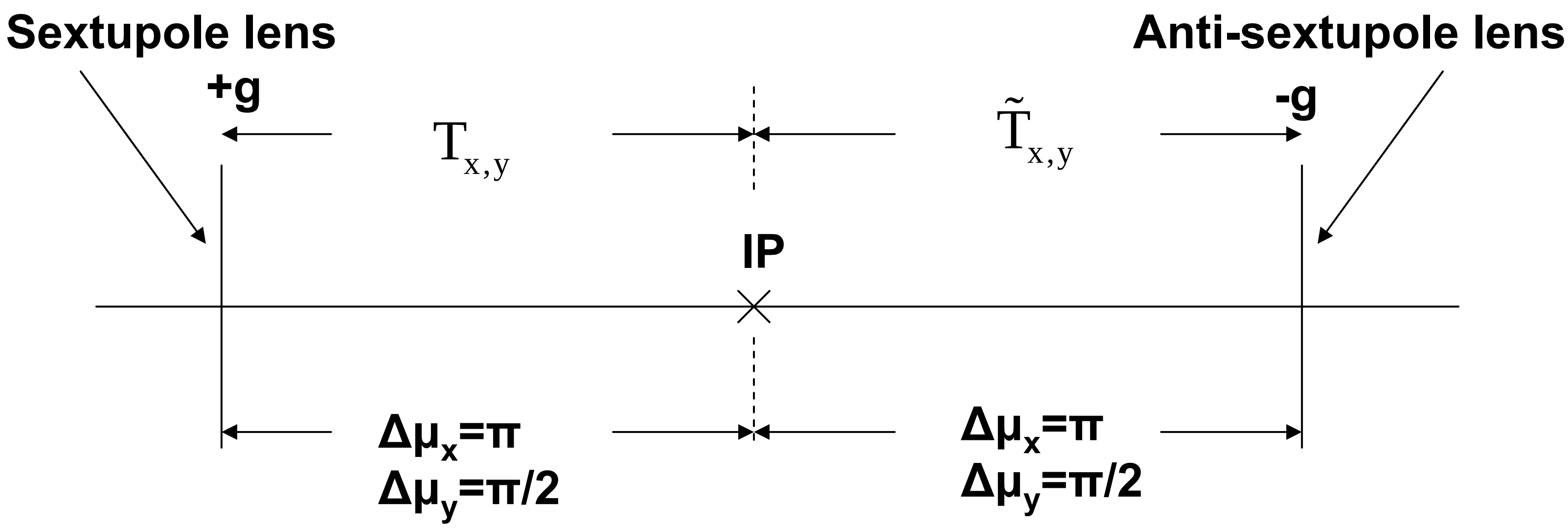
Dependence of ξ_y on β_y for constant beam sizes at IP

I. Koop, Novosibirsk



$$\xi_y = \frac{1}{4\pi}\int g(x(z))\left(\beta_y + \frac{z^2}{\beta_y}\right)dz$$

"Crabbed" waist optics

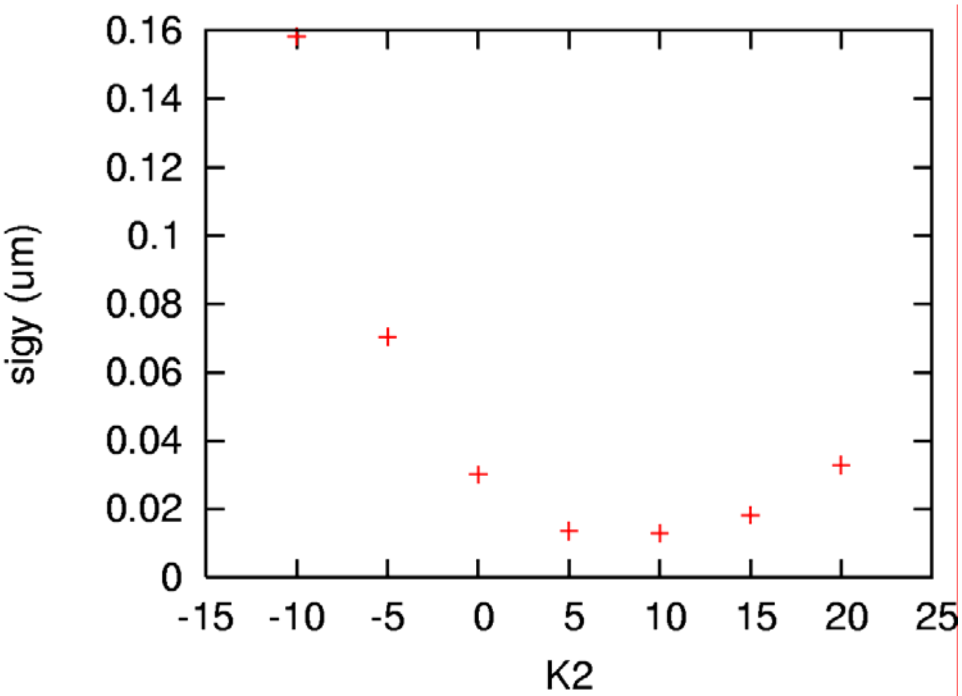


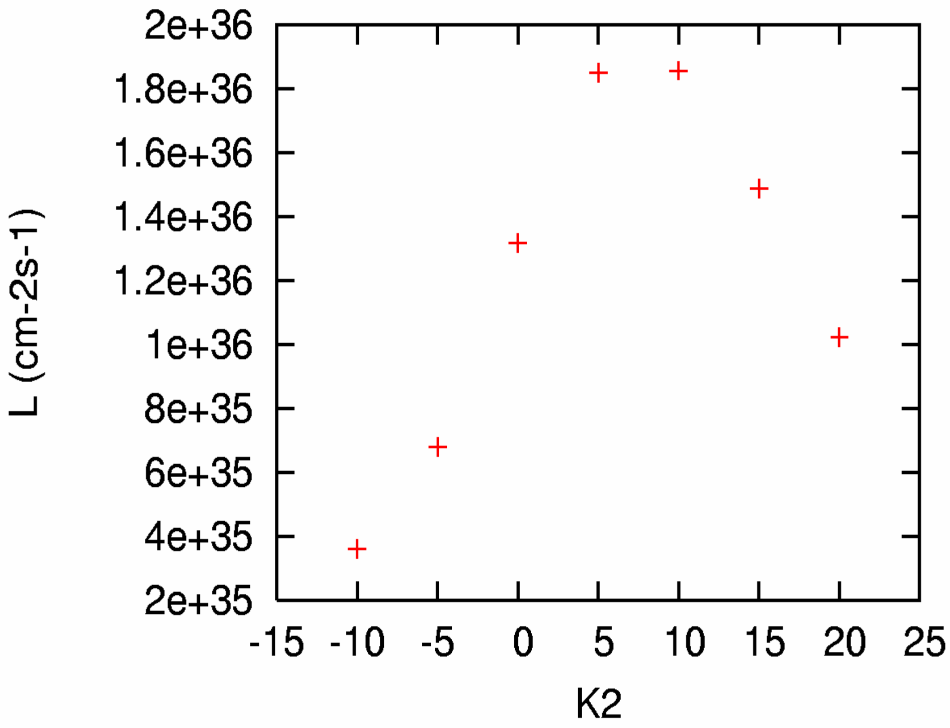
Appropriate transformations from first sextupole to IP and from IP to anti-sextupole:

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

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

I. Koop, Novosibirsk





Vertical beam size vs crab focus
K2=sextupole strength

Luminosity vs crab focus
K2=sextupole strength

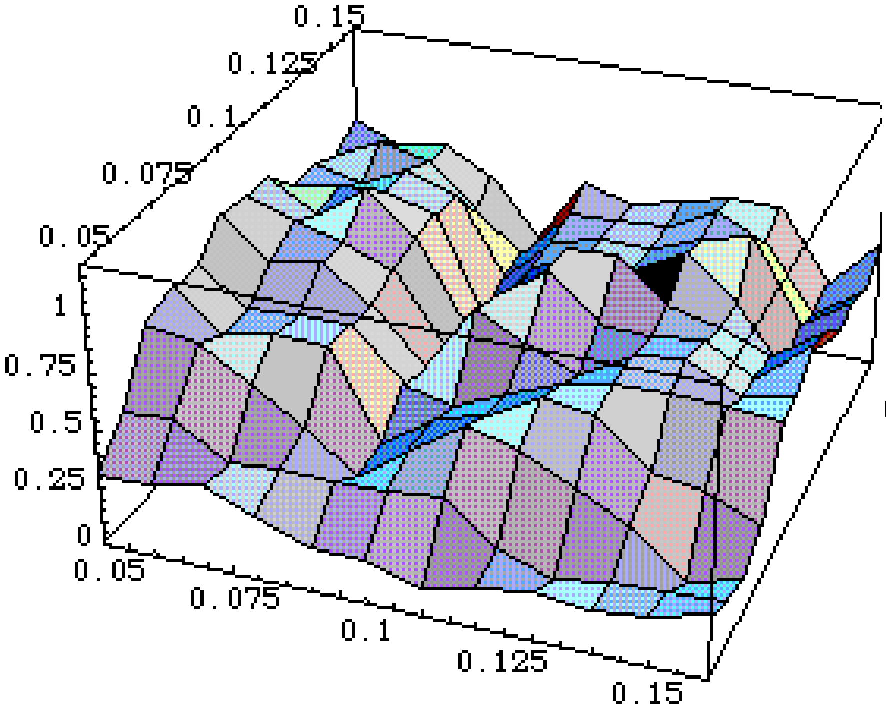
With k2=8 the vertical emittance blowup is < 20%
Luminosity gain about 70%
Vertical size rms reduction about a factor 2.5, large tails reduction

Luminosity in excess of 1e36 is achievable

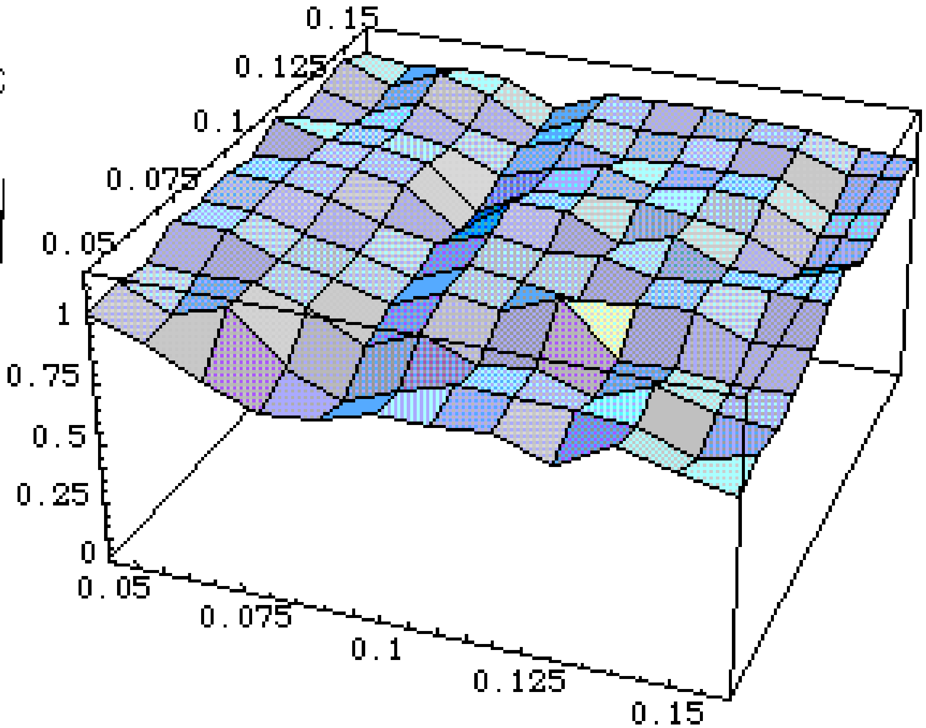
Ohmi (KEK) simulations

Normalised Luminosity vs x and y tunes
(Dafne parameters)

Without Crab Focus



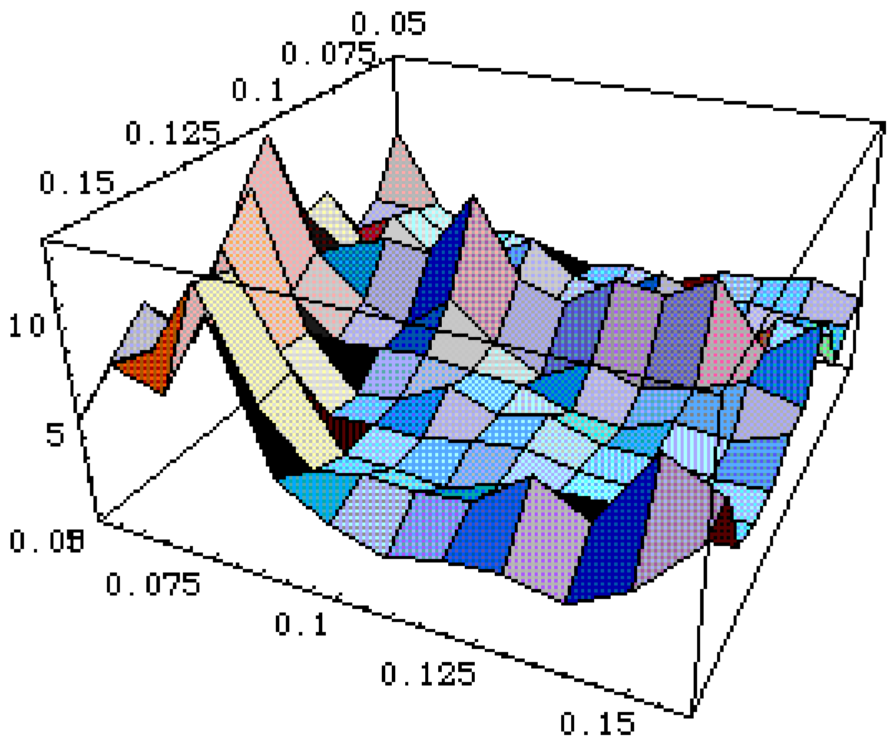
With Crab Focus



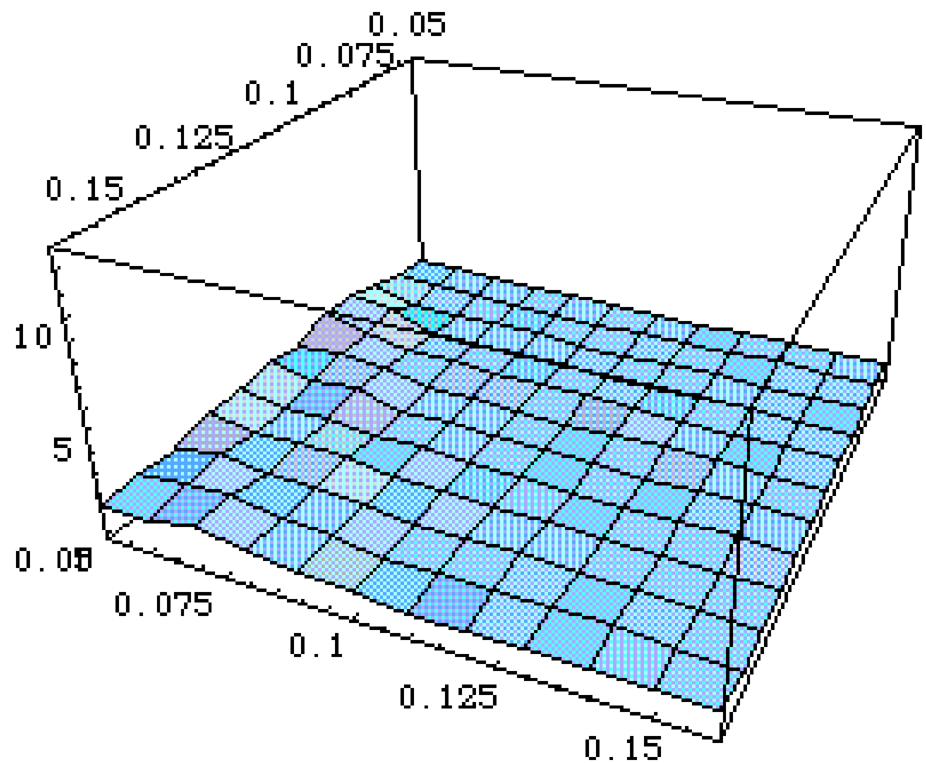
M. Zobof, INFN

Vertical Size Blow Up (rms) vs x and y tunes (Dafne parameters)

Without Crab Focus



With Crab Focus



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Beam size and tails vs Crab-waist

Simulations with beam-beam code LIFETRAC

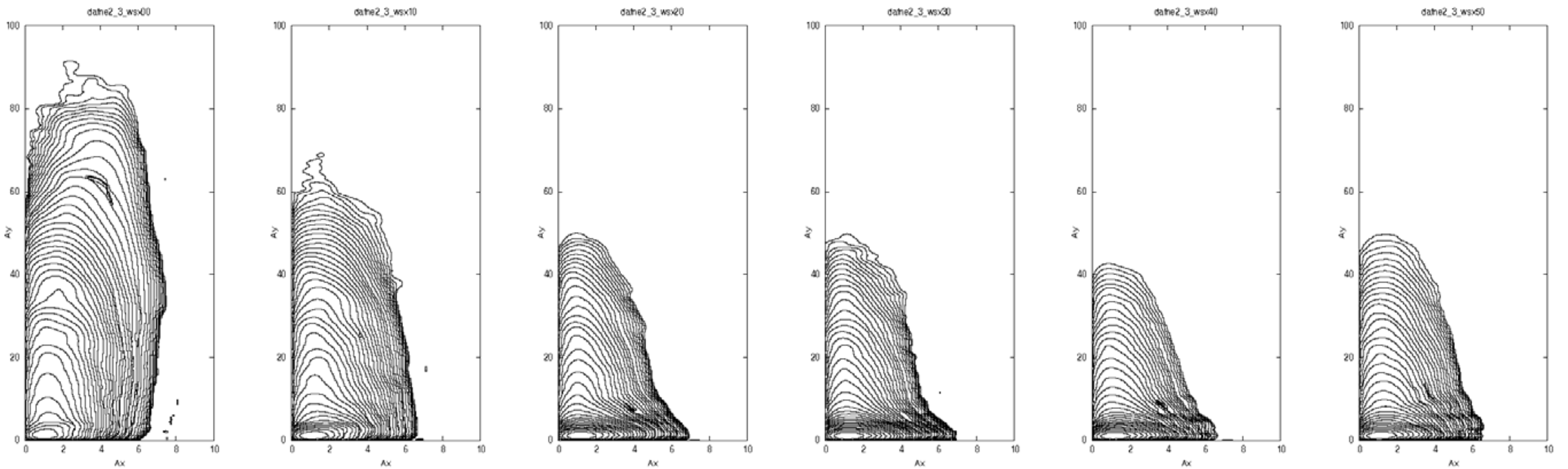
Beam parameters for DAFNE

An effective "crabbed" waist map at IP:

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

$$y' = y_0'$$

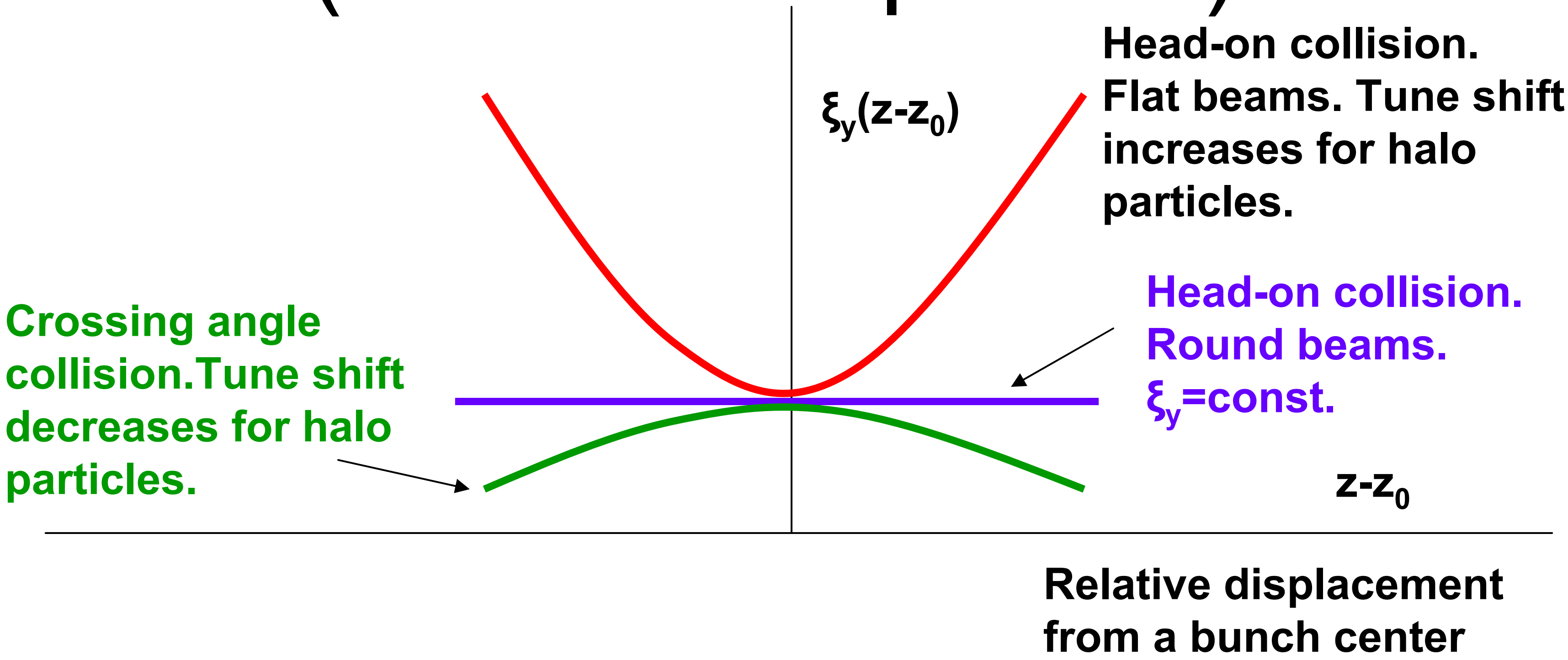
V	0.0	0.2	0.4	0.6	0.8	1.0
L/L_o	1.0	1.63	1.80	1.85	1.84	1.73



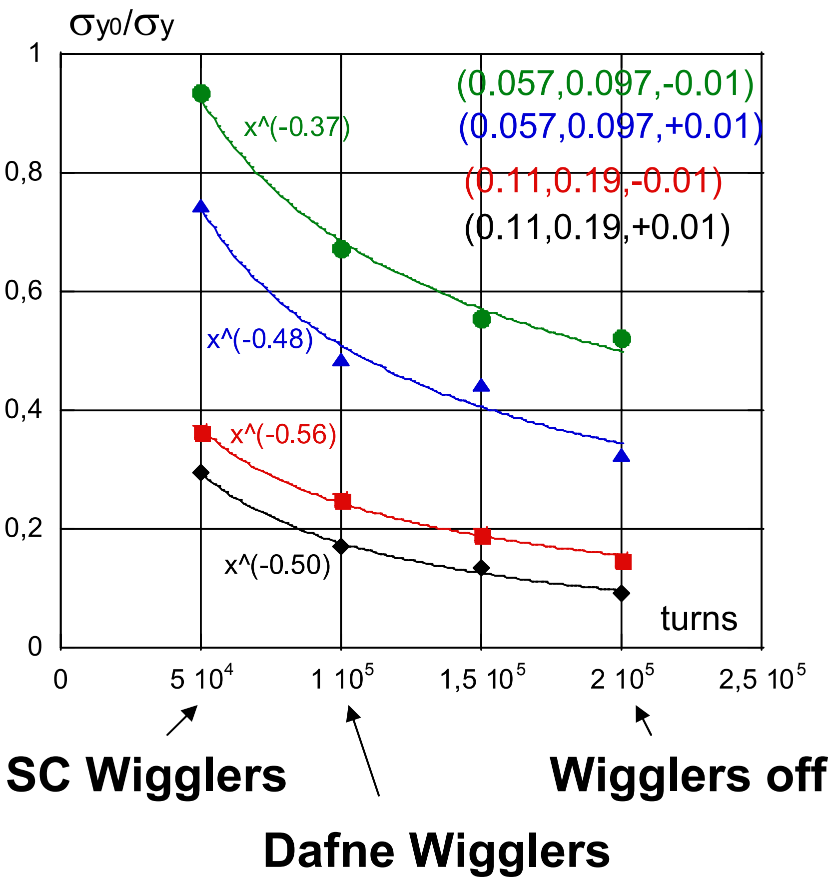
Optimum is shifted from the "theoretical" value V=1 to V=0.8, since it scales like $\sigma_z\theta/\mathrm{sqrt}((\sigma_z\theta)^2+\sigma_x^2)$

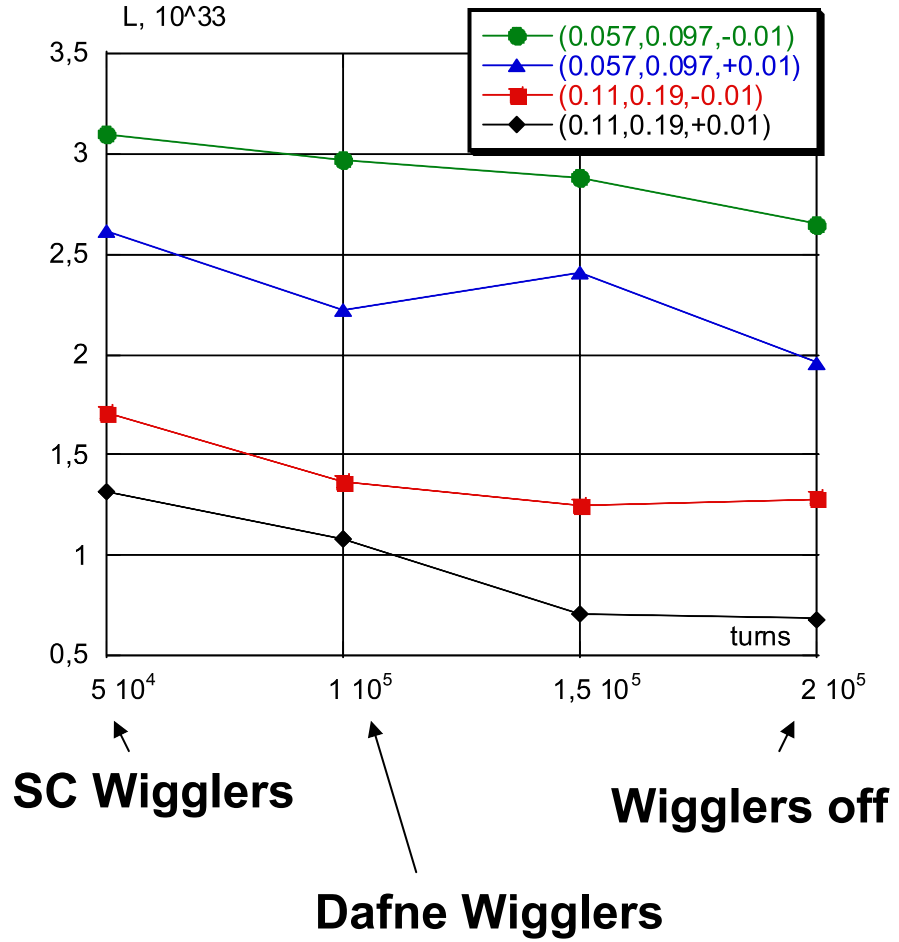
D.N. Shatilov, Novosibirsk

Synchrotron modulation of ξy (Qualitative picture)



Conclusion: one can expect improvement for lifetime of halo-particles!



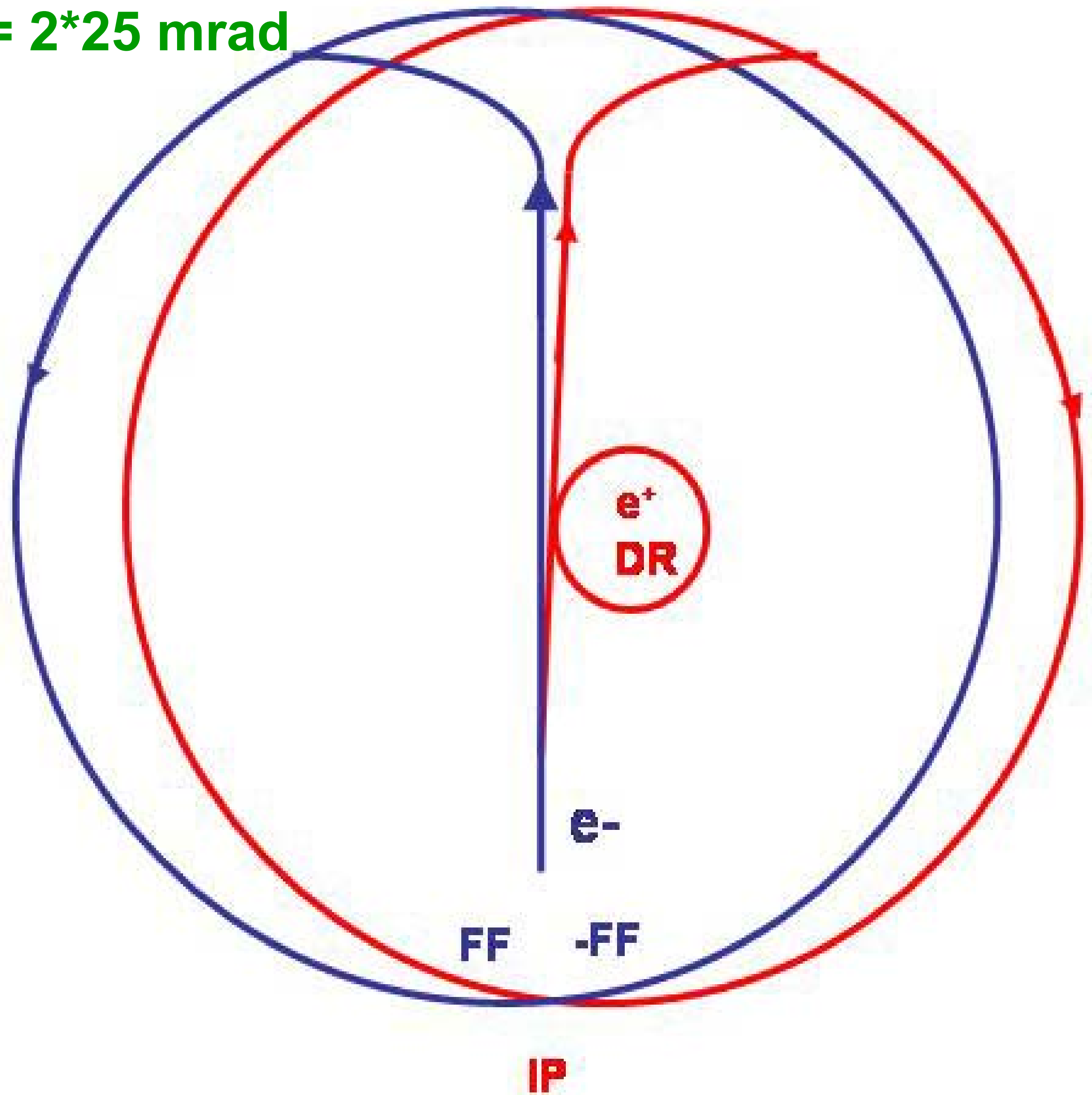


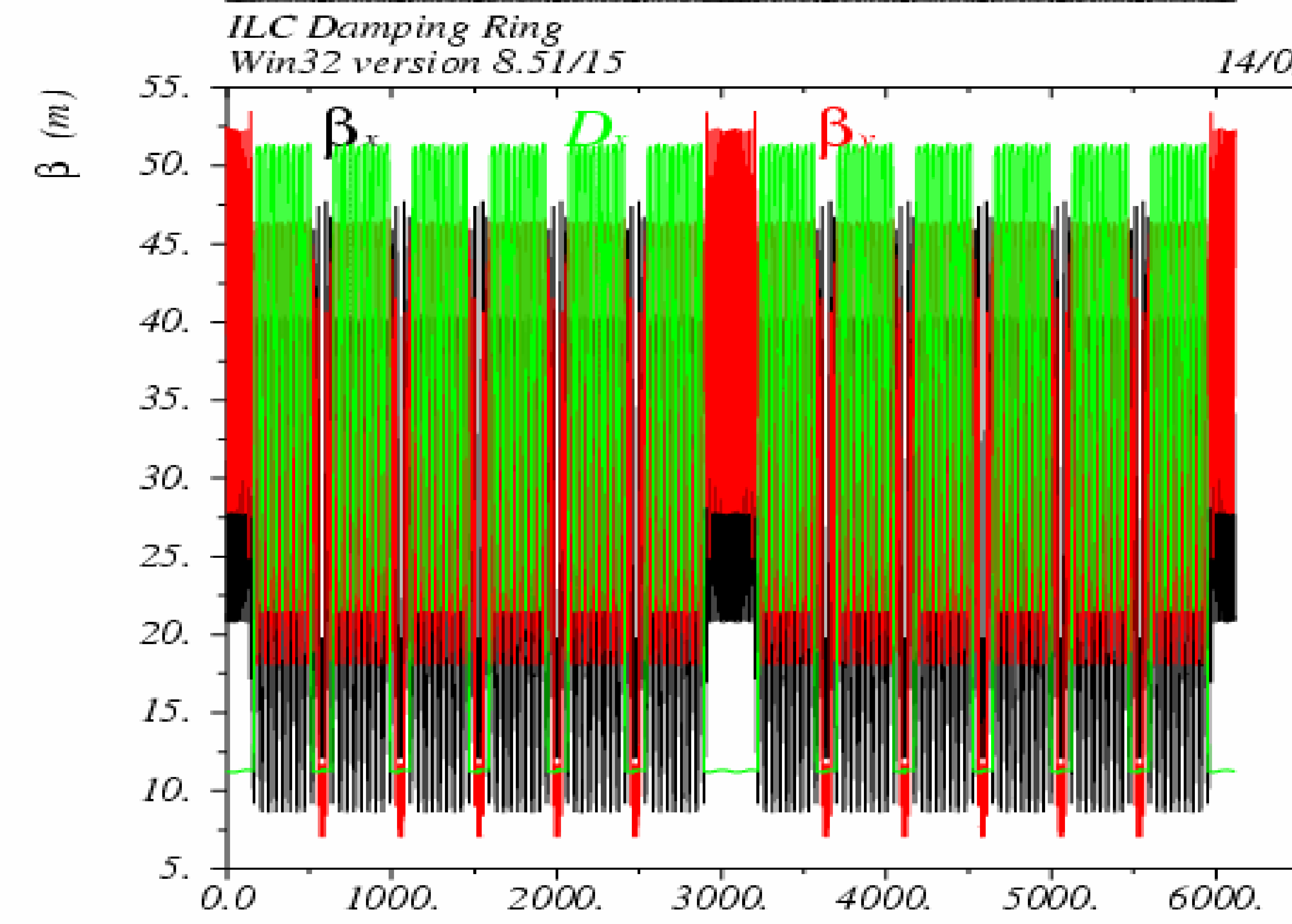
Very weak luminosity dependence from damping time given the very small bb-blowup (Dafne studies)

M. Zobov

Simplified SuperB layout
Crossing angle = 2*25 mrad

ILC ring & ILC FF





ILC Damping Ring
Win32 version 8.51/15
14/0
β (m)
βx
Dx
βy
55.
50.
45.
40.
35.
30.
25.
20.
15.
10.
5.
0.0
1000.
2000.
3000.
4000.
5000.
6000.

ILC-like rings

- OCS lattice used
- Scaled to 4 and 7 GeV
- Shortened to 3.2 Km
- Wiggler field 1.4 T (permanent magnet)
- 4 GeV has 5.6 m long bends
- 7 GeV has 10.6 m long bends

M. Biagini, INFN

	SBF 4 GeV	*SBF 7 GeV*
C (m)	3251.	3251.
B_w (T)	1.4	1.4
L_{bend}(m)	5.6	10.6
N. bends	96	96
B_{bend} (T)	0.155	0.144
Uo (MeV/turn)	4.4	6.4
N. wigg. cells	8	4
τ_x (ms)	19.8	24.
τ_s (ms)	10.	12.
ε_x (nm)	0.38	0.565
σ_E	1.1×10^{-3}	1.32×10^{-3}
I_{beam} (A)	2.5	1.4
P_{beam}(MW)	11.	9.

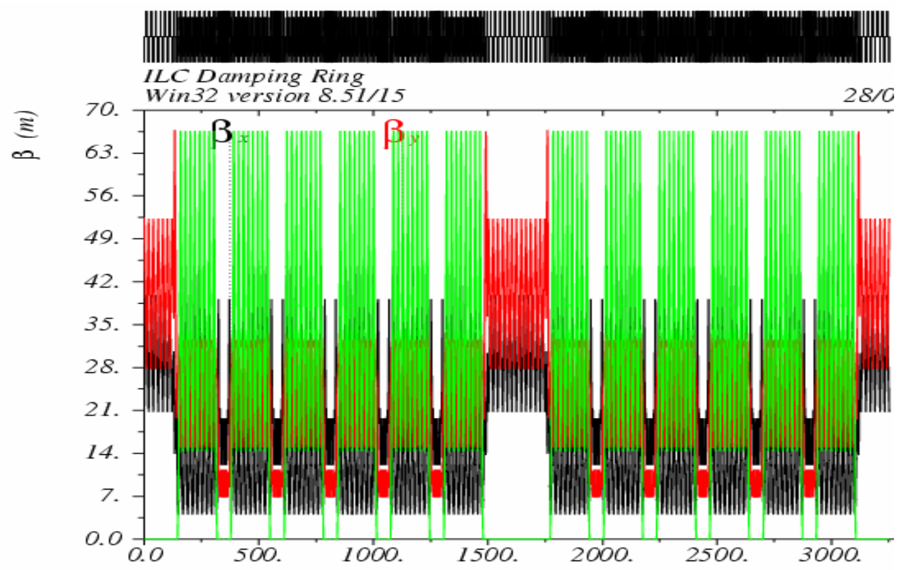
M. Biagini

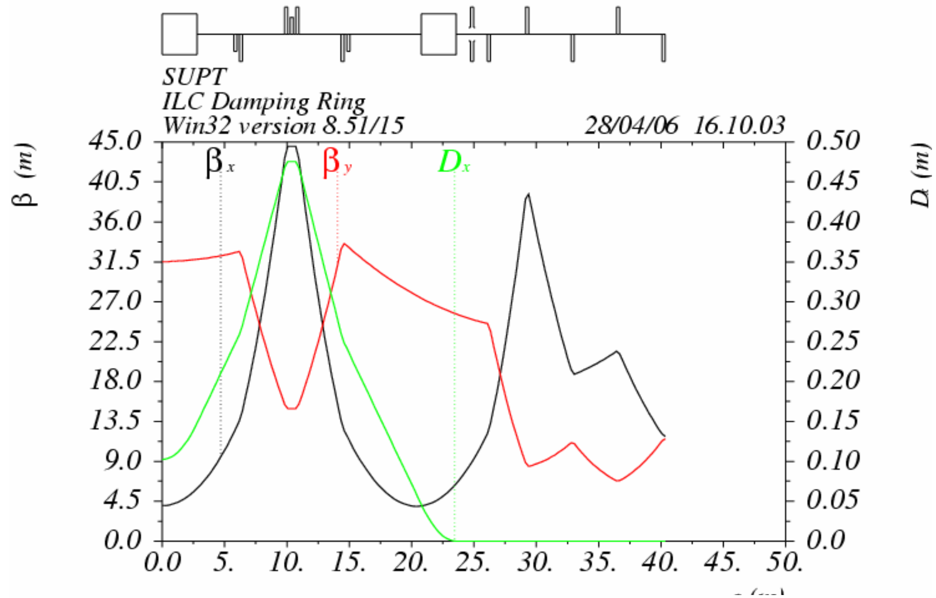
cm $\sigma_E = 0.85 \times 10^{-3}$

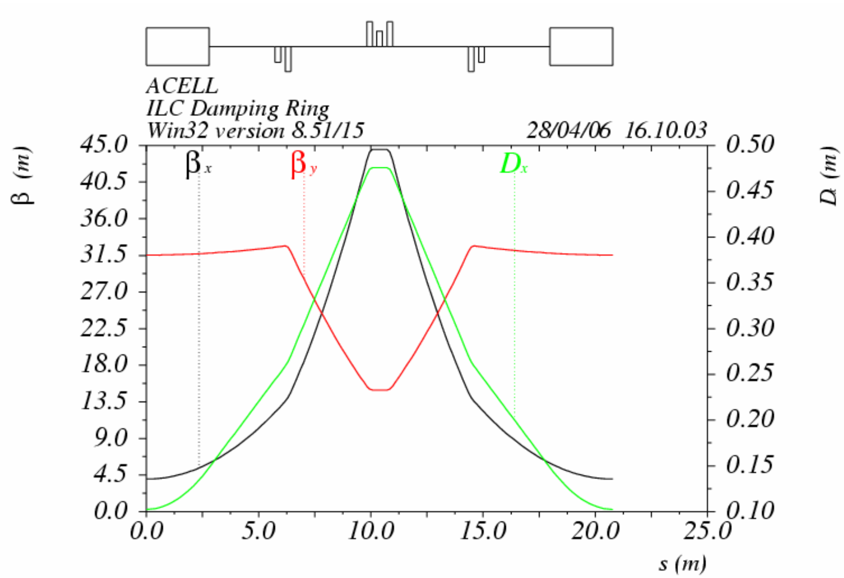
Total Wall Power (60% transfer eff.): 32 MW

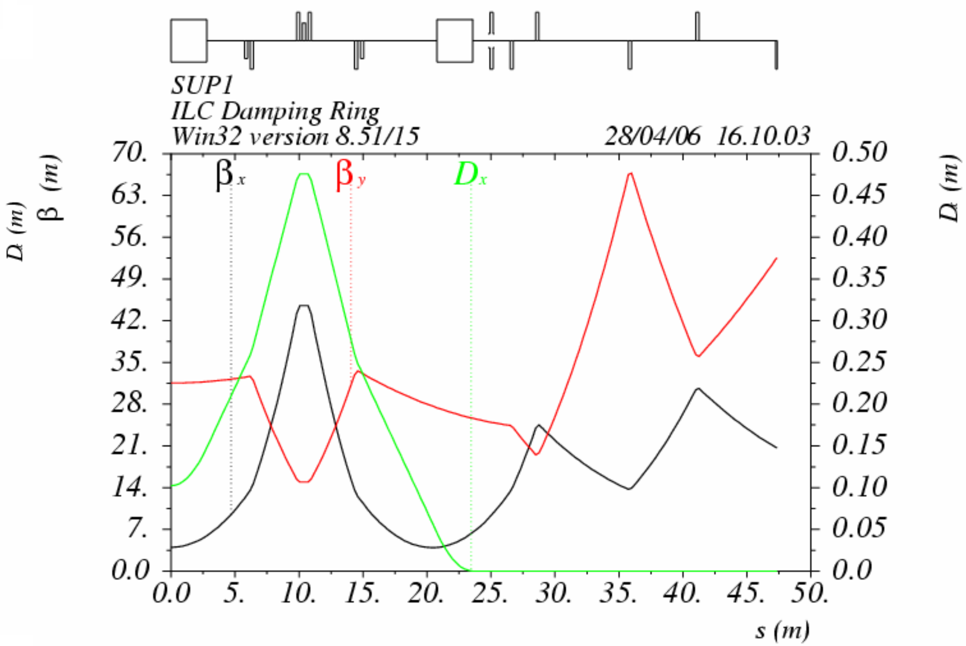
4 GeV ring

M. Biagini

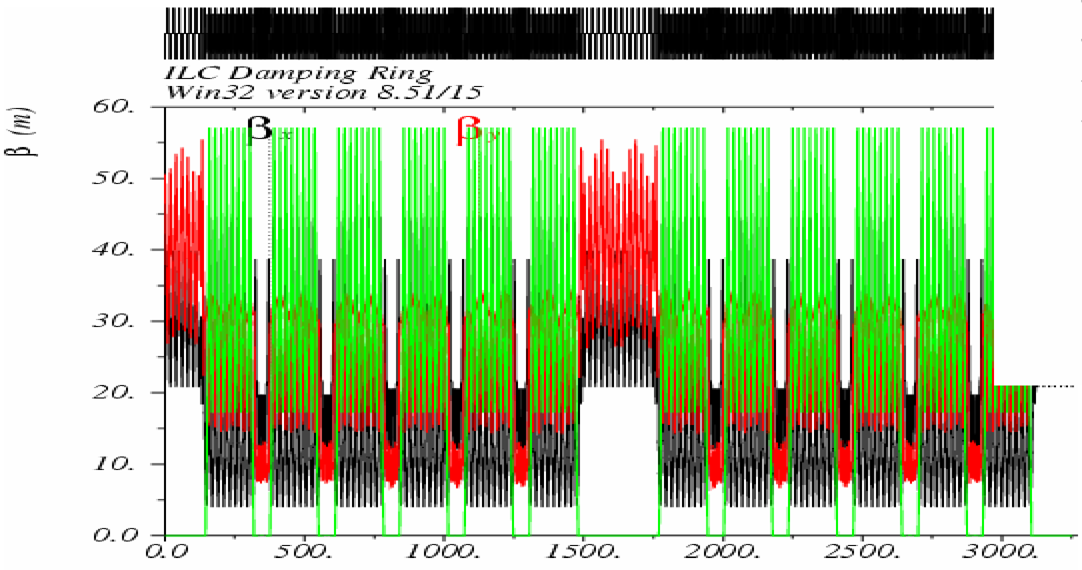


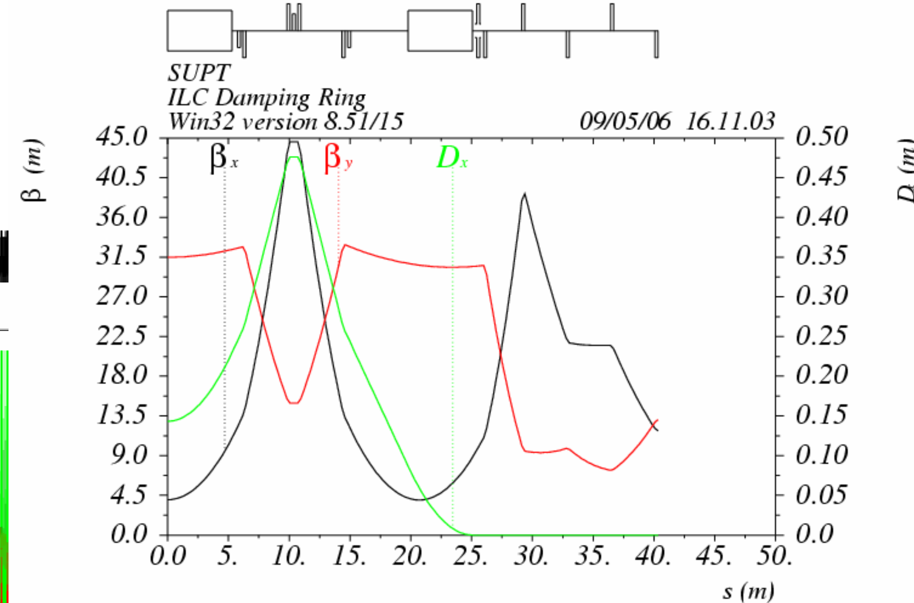


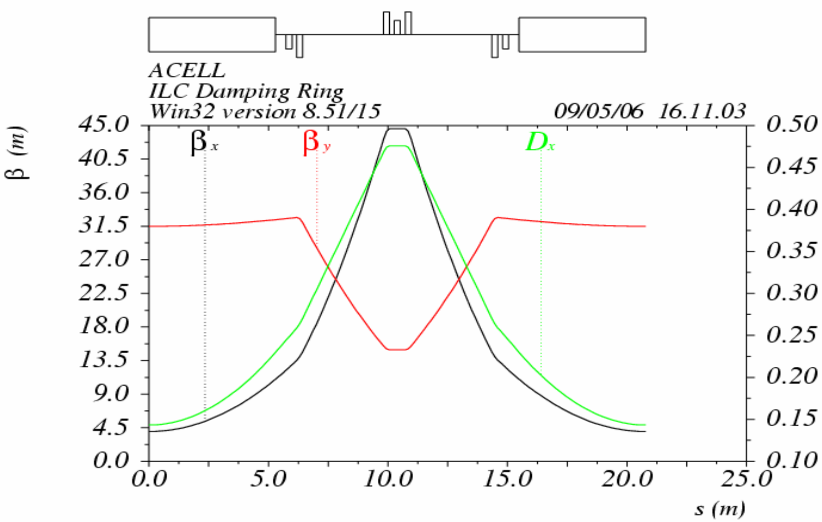


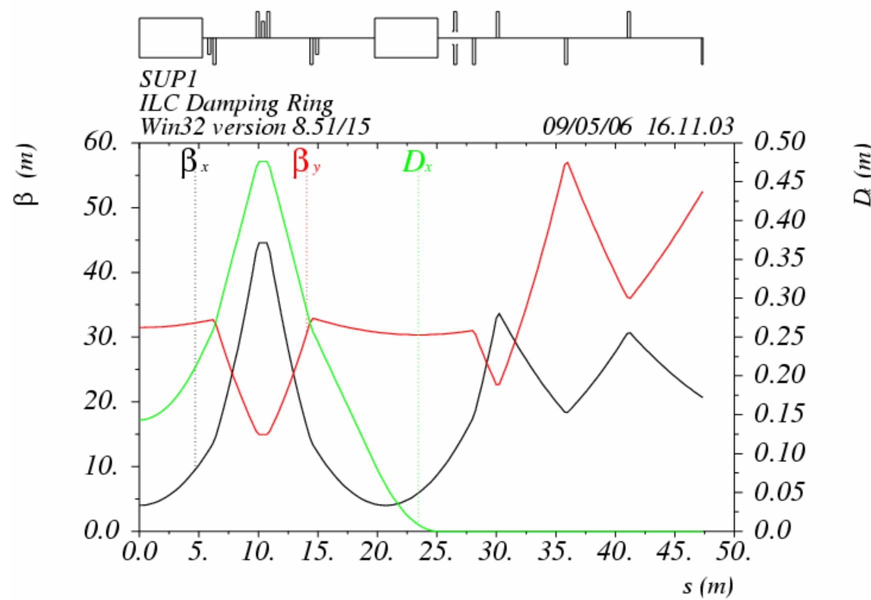


7 GeV ring



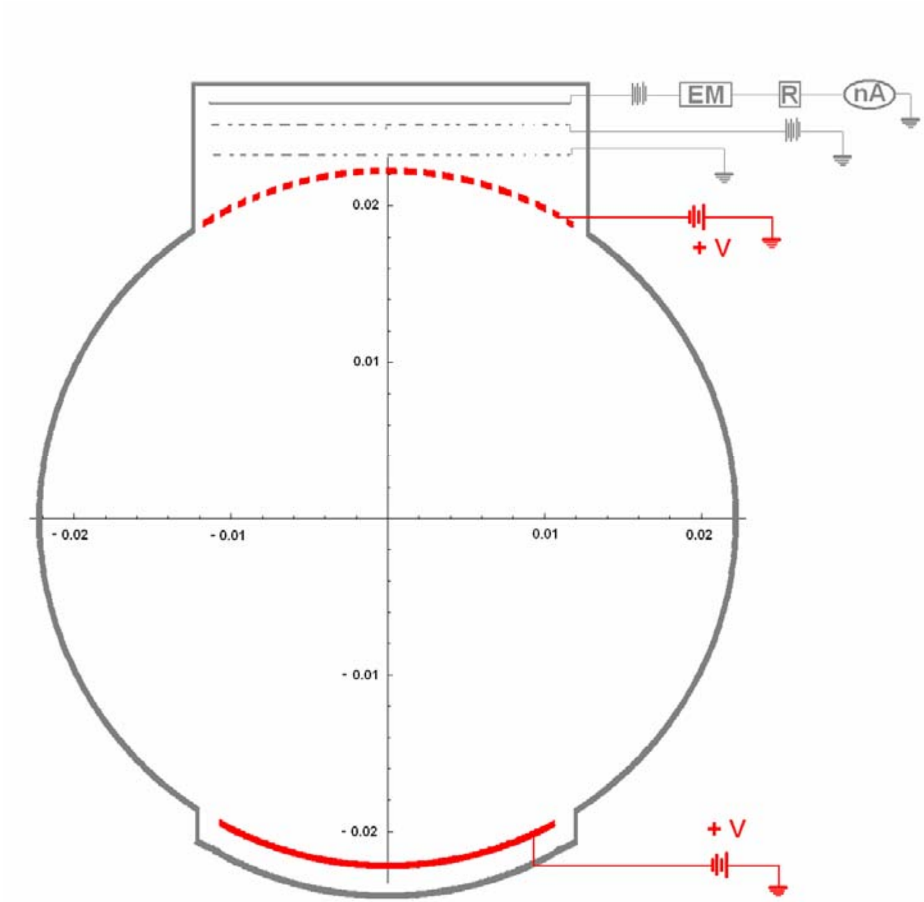


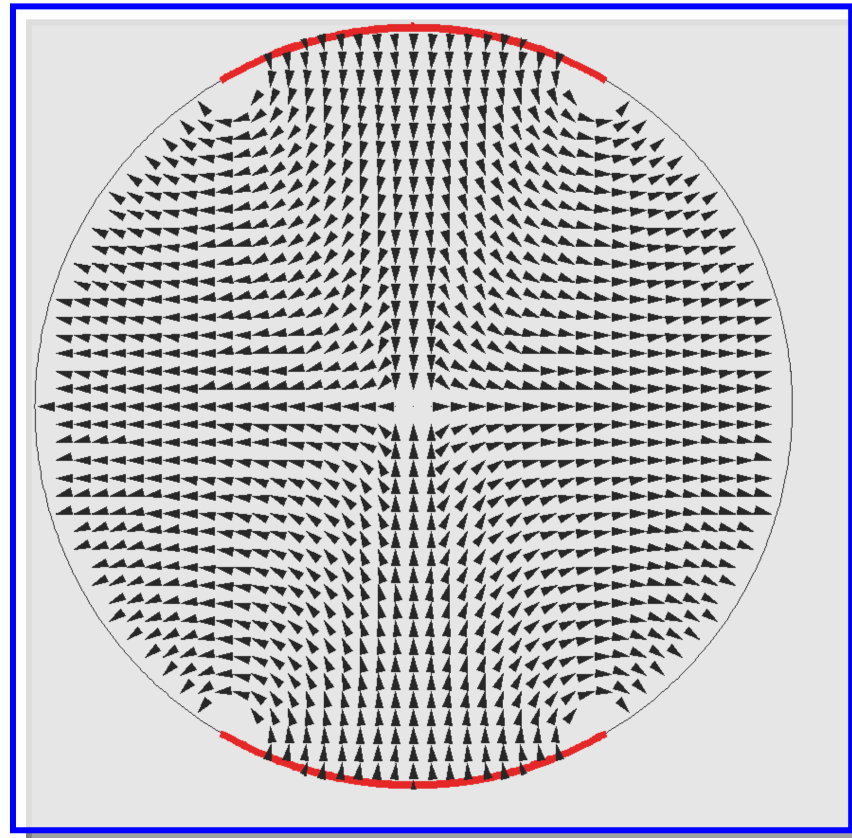




M. Biagini

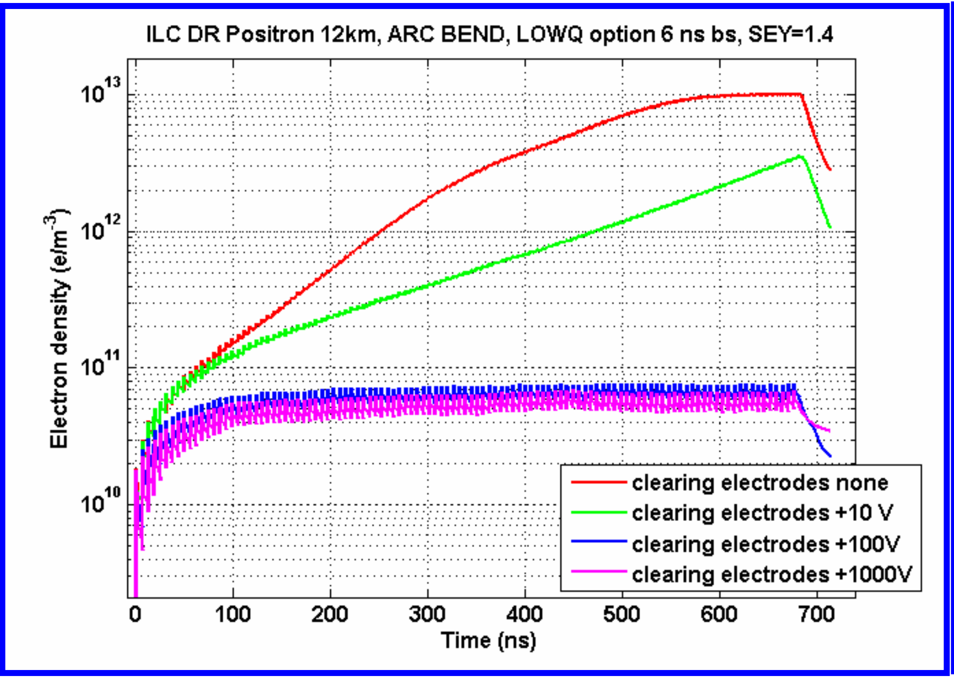
Curved clearing electrodes for electron cloud

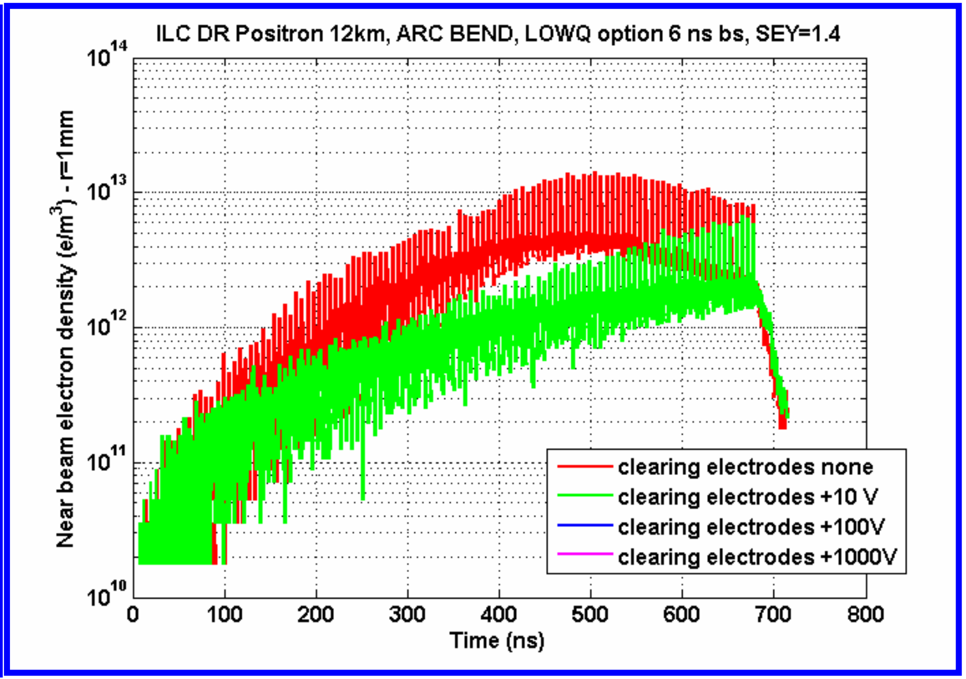




M. Pivi – L. Wang – T. Raubenheimer - P. Raimondi, SLAC

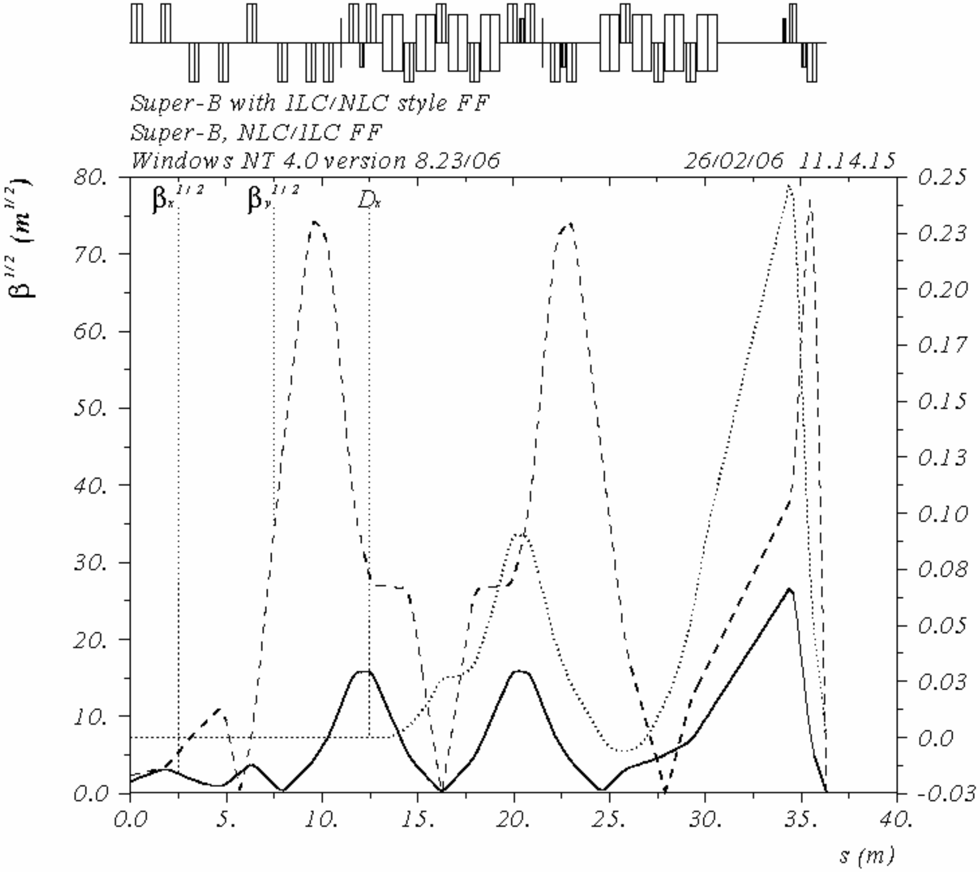
Curved clearing electrodes for electron cloud

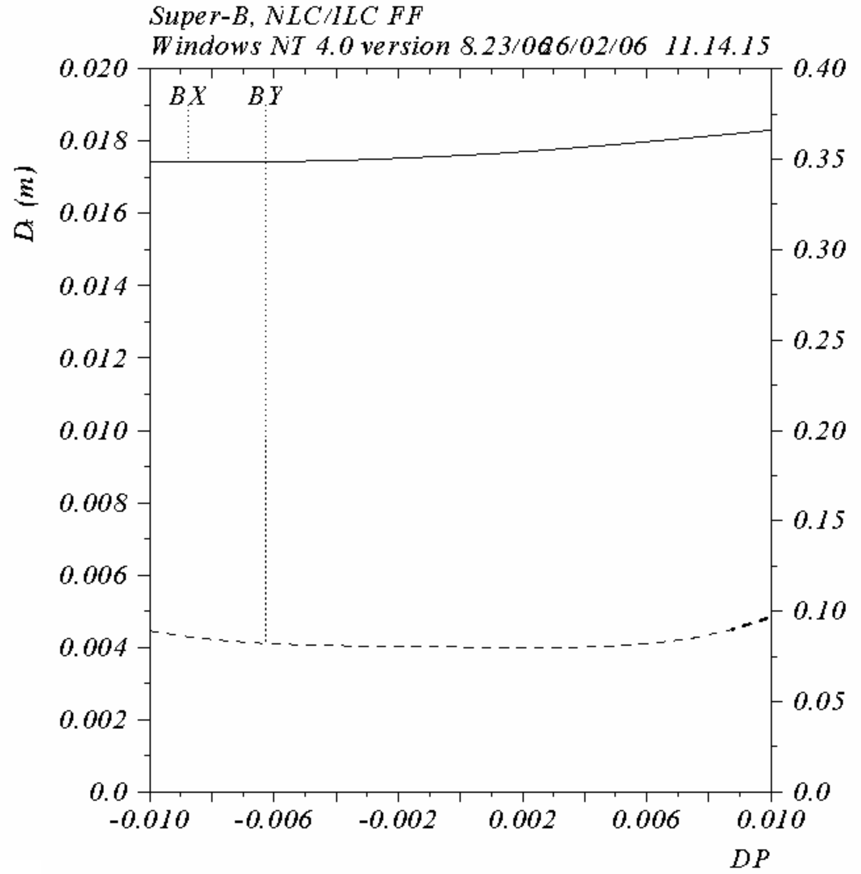




using POSINST

M. Pivi – P. Raimondi, SLAC, Mar 2006





35m long ILC-Like FF, seems to be able to deliver the small σ_y and β_y

Insertion in the ring seems ok (Biagini talk)

Further simplification-optimization possible by integrating crab-focus and chromatic correction

A.Seryi, SLAC

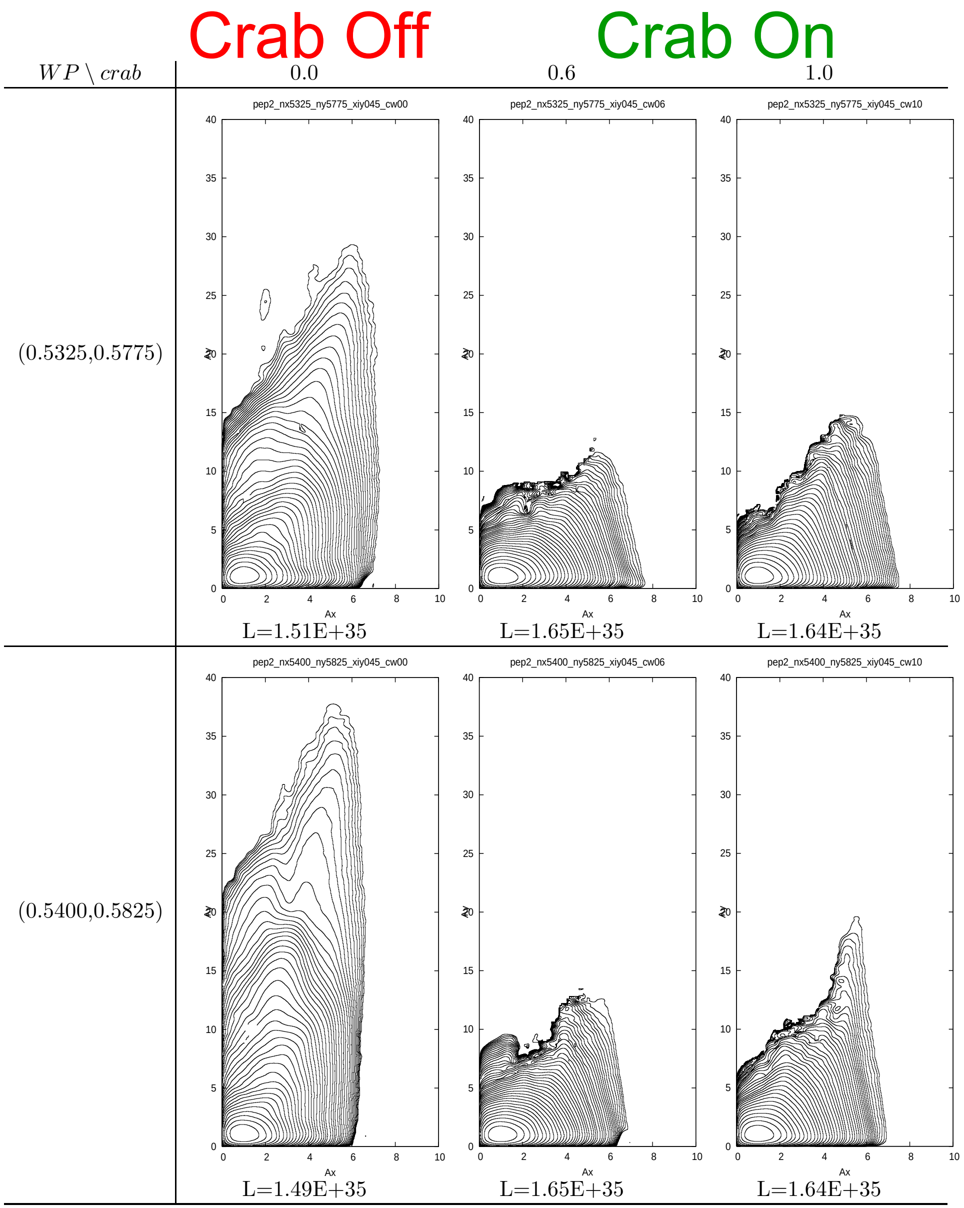
- Parameters optimizations and Luminosity scaling laws not yet done (in progress by D. Shatilov, M. Zobov and Ohmi)
- Possible other solutions with large vertical emittance/beta, for example: half the number of bunches with twice the bunch charge and 4 times the vertical emittance give roughly the same luminosity
- Possible to reduce the requirements on damping time, although the ILC-Ring naturally produces a small damping time, because of the wigglers needed for the small emittance.
- Ring and FF design in progress, but a lot has to be done…

SuperB-ILC synergy

- Potential size and cost reduction of the ILC complex
- Potential decrease of the ILC commissioning time
- Potential increase of the ILC performances
- Could the ILC community benefit by having an operating positron damping ring just 3km long delivering 6000 bunches with 2e10 particles/bunch?
- Could the ILC community benefit by having an operating BDS with ILC-IP beams sizes and betas?

Conclusions (1)

- Possible fall back on the existing factories
- The crabbed waist potentially beneficial also for the current factories
- Possibility to simultaneously boost the performances of the existing machines and do SuperB R&D
- Worth to study possible benefits also for LHC



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1

Parameters for a PEP IR upgrade

$\varepsilon_x = 20$ nm $\varepsilon_y = 0.20$ nm

$\sigma_x = 14.4\ \mu$m

$\sigma_y = 0.4\ \mu$m

$\sigma_z = 10$ mm

$\sigma_E = 7\text{x}10^{-4}$

$\beta_x = 10$ mm

$\beta_y = 0.8$ mm

C = 2.2 km

$f_{col} = 238$ MHz

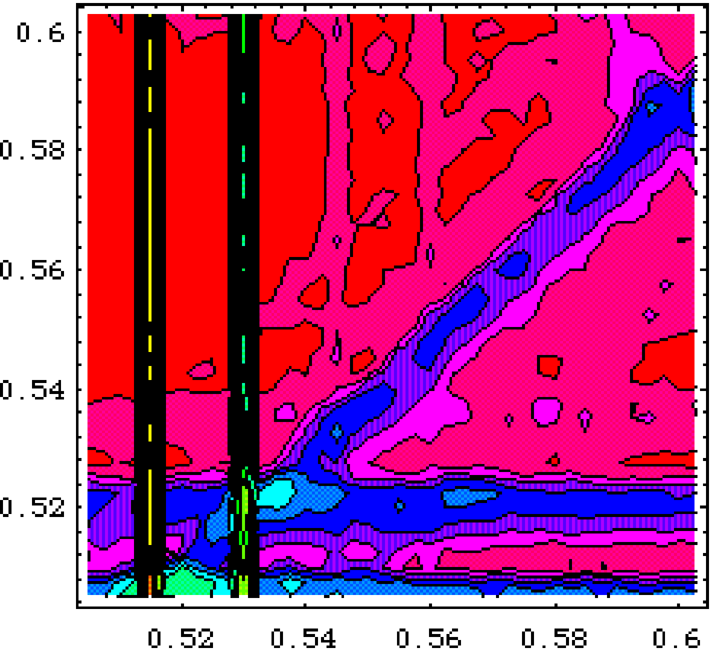
$\Phi = 2$ x 14 mrad

$N_1 = 7.9\text{x}10^{10}$ (3.0Amps)

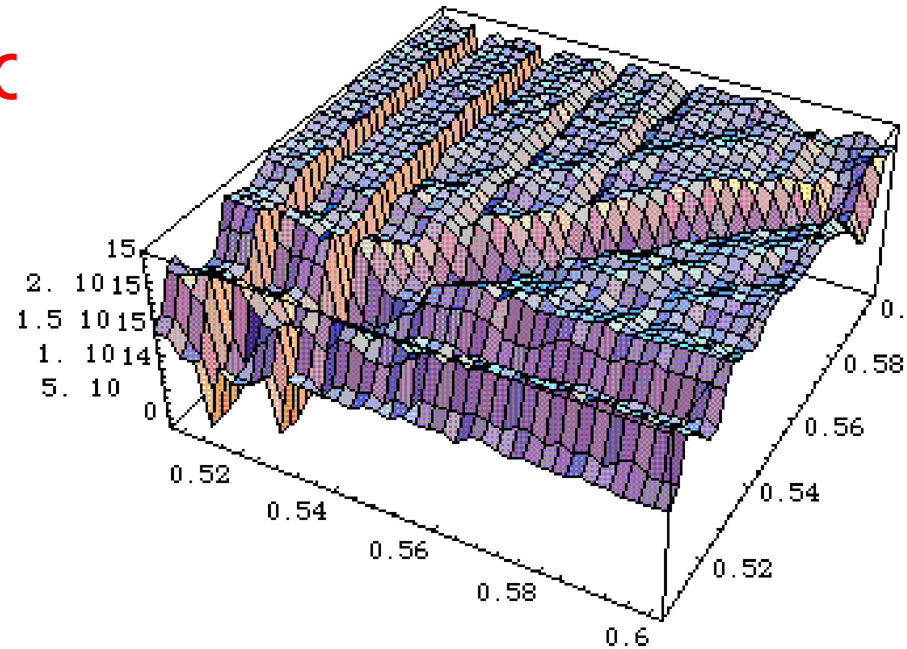
$N_2 = 4.4\text{x}10^{10}$ (1.7Amps)

L=1.00*10^{35}

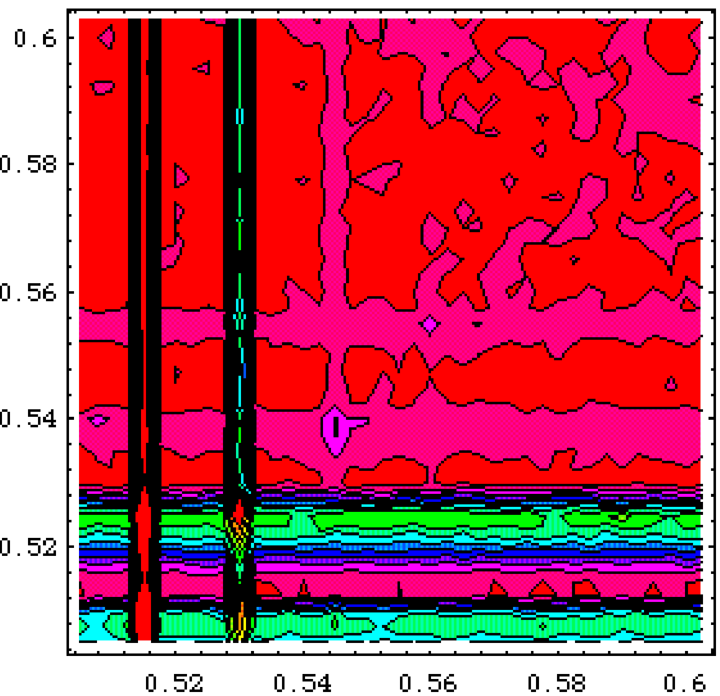
Tune Scan for Super-PEPII

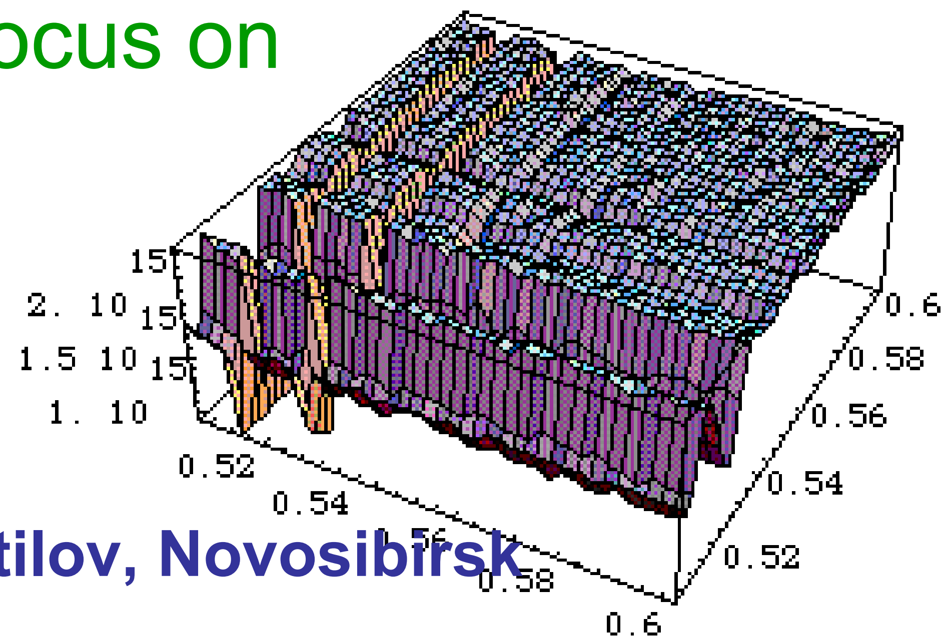


Crab fo



Crab focus on





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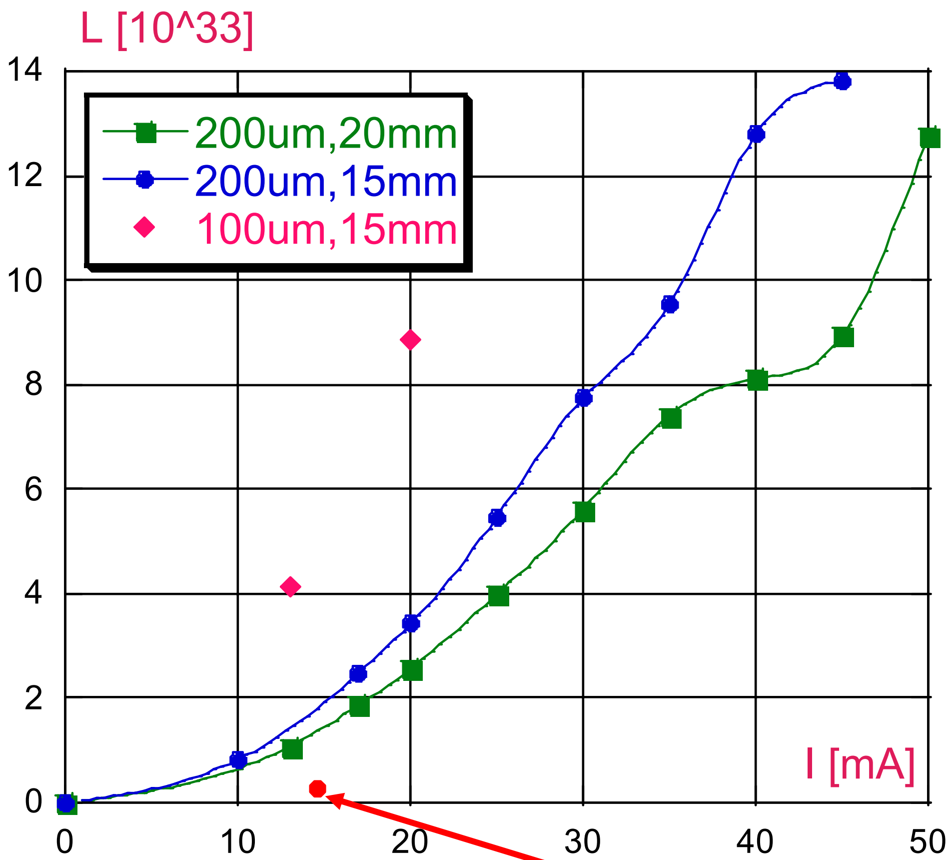

Luminosity expectations for a Dafne IR Upgrade

M. Zobov

L=0.15*10^{33} presently achieved

With the present achieved beam parameters (currents, emittances, bunchlenghts etc) a luminosity in excess of 10^{33} is predicted.
With 2Amps/2Amps more than 2*10^{33} is possible
Beam-Beam limit is way above the reachable currents

Conclusions (2)

Solution with ILC DR + ILC FF seems extremely promising:

- Crossing angle of about 25mrad
- Requires virtually no extra R&D
- Uses all the work done for ILC (e.g. Damping-Ring and FF)
- 100% Synergy with ILC
- IR extremely simplified
- Beam stay clear about 20sigmas supposing 1cm radius beam pipe
- Beam Currents around 2.0Amps
- Background should be better than PEP and KEKB
- Possibly to operate at the τ energy with $L=10^{35}$
- Total cost less than half of the ILC e+ DRs (2 e+ 6km rings in ILC)
- Power around 30MW, further optimization possible
- Possible to reuse PEP RF system, power supplies, Vacuum pumps, etc., further reducing the overall cost
- Needs the standard injector system, probably a C-band 7GeV linac like in KEKB upgrade (around 100ME)