Crab Waist Approach: from DAΦNE to SuperB

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for DAΦNE Collaboration Team

and SuperB Accelerator Team

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XXII Russian Particle Accelerator Conference RuPAC-2010

27.09 – 01.10.2010, Protvino, Russia

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OUTLINE

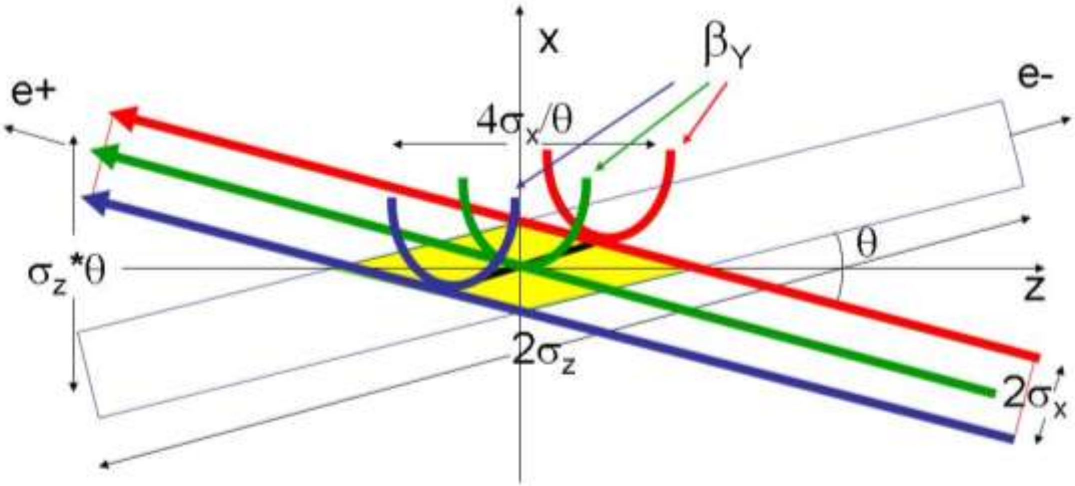
- Crab Waist Collision Concept
- Experimental Test at DAΦNE
- Status of SuperB Accelerator Project

Crab Waist Colliders (after 2006)

DAΦNE,	Φ-factory	Italy	*Operational*
SuperKEKB,	B-factory	Japan	*Partially funded*
SuperB,	B-factory	Italy	*Waiting for approval*
SuperC-Tau,	Tau-Charm	Russia	*Waiting for approval*
BEPCII,	Tau-Charm	China	*Upgrade option studies*
LHC		Switzerland	*Upgrade option studies*

Crab Waist in 3 Steps

1. Large Piwinski's angle $\Phi = tg(\theta/2)\sigma_z/\sigma_x$
2. Vertical beta comparable with overlap area $\beta_y \approx 2\sigma_x/\theta$
3. Crab waist transformation $y = xy'/\theta$

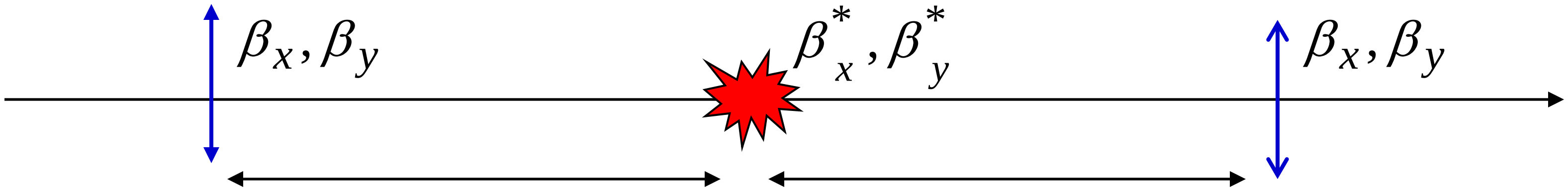


1. *P.Raimondi, 2° SuperB Workshop, March 2006*

2. *P.Raimondi, D.Shatilov, M.Zobov, physics/0702033*

Crabbed Waist Scheme

Sextupole | IP | (Anti)sextupole



$$\Delta\mu_y = \frac{\pi}{2} \qquad \Delta\mu_y = \frac{\pi}{2}$$

$$\Delta\mu_x = \pi \qquad \Delta\mu_x = \pi$$

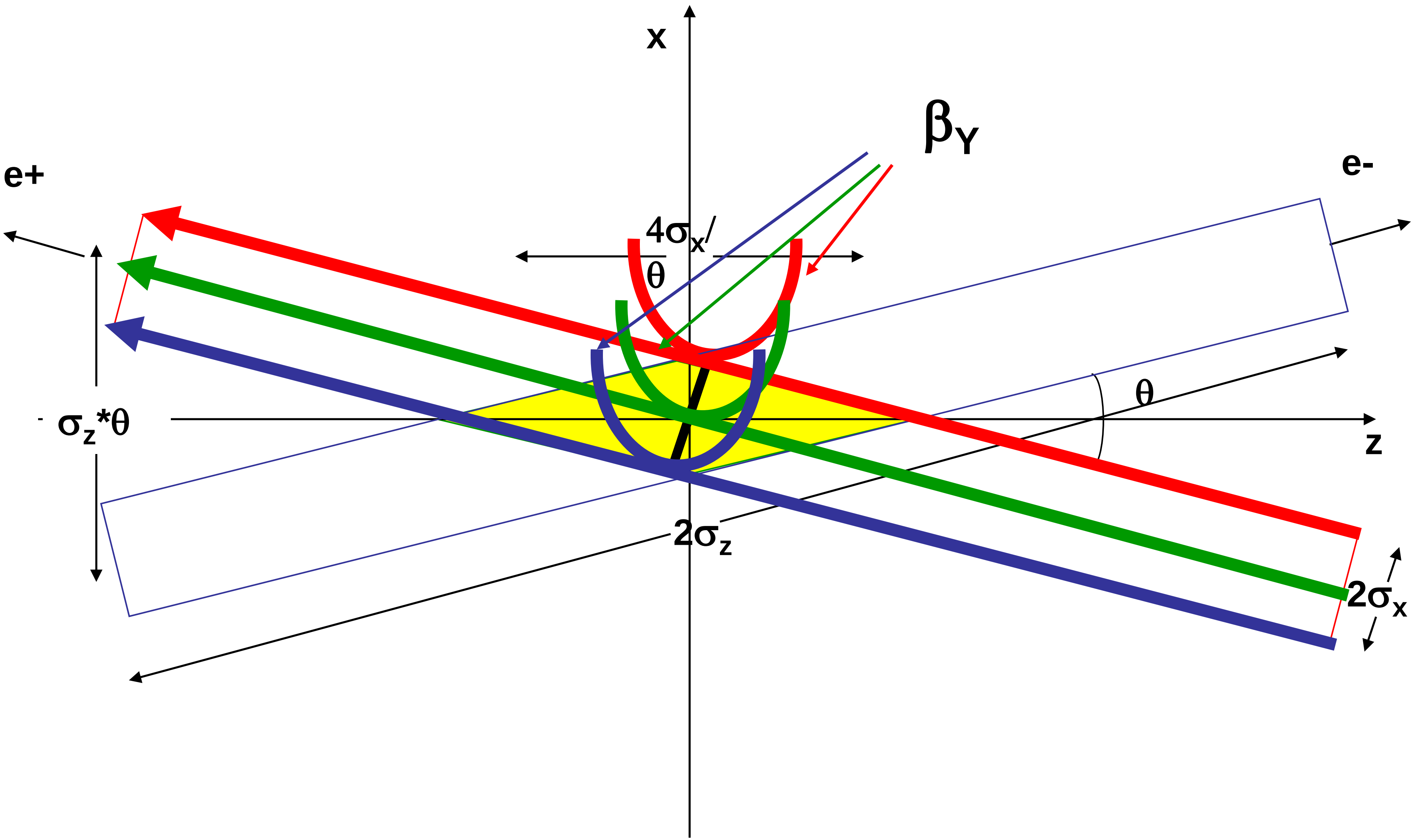
Sextupole strength

$$K = \frac{1}{2\theta}\frac{1}{\beta^*_y \beta_y}\sqrt{\frac{\beta^*_x}{\beta_x}}$$

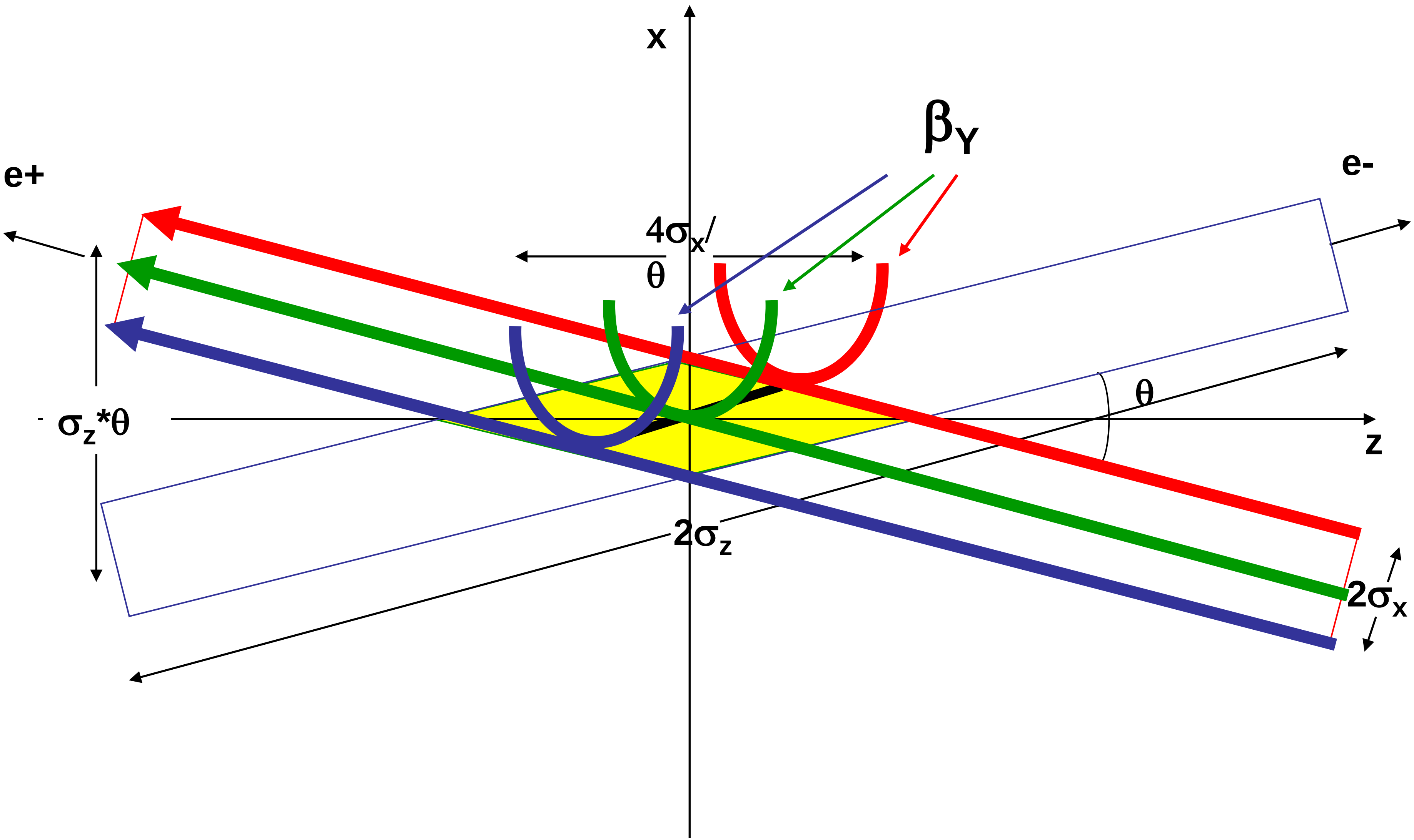
Equivalent Hamiltonian

$$H = H_0 + \frac{1}{2\theta} x p_y^2$$

$$\beta_y = \beta^*_y + \frac{(s - x/\theta)^2}{\beta^*_y}$$



x
β_Y
e+
e-
$4\sigma_x/\theta$
θ
$\sigma_z*\theta$
z
$2\sigma_z$
$2\sigma_x$


x
βY
e+
e-
4σx/
θ
σz*θ
θ
z
2σz
2σx

Crabbed Waist Advantages

1. Large Piwinski's angle

$$\Phi = tg(\theta/2)\sigma_z/\sigma_x$$

→

a) Luminosity gain with N

b) Very low horizontal tune shift

c) Vertical tune shift decreases with oscillation amplitude

2. Vertical beta comparable with overlap area

$$\beta_y \approx 2\sigma_x/\theta$$

→

a) Geometric luminosity gain

b) Lower vertical tune shift

c) Suppression of vertical synchro-betatron resonances

3. Crabbed waist transformation

$$y = xy'/\theta$$

→

a) Geometric luminosity gain

b) Suppression of X-Y betatron and synchro-betatron resonances

Large Piwinski's Angle

O. Napoly, Particle Accelerators: Vol. 40, pp. 181-203,1993

P.Raimondi, M.Zobov, DAΦNE Technical Note G-58, April 2003

$$L = n_b f_0 \frac{1}{4\pi\sigma_x\sigma_y}\left[\frac{N^2}{\sqrt{1+\Phi^2}}\right]; \quad \xi_y = \frac{r_e\beta_y}{2\pi\gamma\sigma_y\sigma_x}\left[\frac{N}{\sqrt{1+\Phi^2}}\right]; \quad \xi_x = \frac{r_e\beta_x}{2\pi\gamma\sigma_x^2}\left[\frac{N}{1+\Phi^2}\right]$$

If we can increase *N* proportionally to Φ*:

1) *L* grows proportionally to Φ;
2) ξ_y remains constant;
3) ξ_x decreases as $1/\Phi$;

*Φ is increased by:

a) increasing the crossing angle θ and increasing the bunch length σ_z for LHC upgrade (F. Ruggiero and F. Zimmermann)

b) increasing the crossing angle θ and decreasing the horizontal beam size σ_x in crabbed waist scheme

Low Vertical Beta Function

$$L = n_b f_0 \frac{1}{4\pi\sigma_x\sigma_y}\left[\frac{N^2}{\sqrt{1+\Phi^2}}\right] = n_b f_0 \frac{1}{4\pi\sigma_x\sqrt{\beta_y\varepsilon_y}}\left[\frac{N^2}{\sqrt{1+\Phi^2}}\right] \propto \frac{1}{\sqrt{\beta_y}}$$

$$\xi_y = \frac{r_e\beta_y}{2\pi\gamma\sigma_x\sigma_y}\left[\frac{N}{\sqrt{1+\Phi^2}}\right] = \frac{r_e\beta_y}{2\pi\gamma\sigma_x\sqrt{\beta_y\varepsilon_y}}\left[\frac{N}{\sqrt{1+\Phi^2}}\right] \propto \sqrt{\beta_y}$$

Note that keeping ξ_y constant by increasing the number of particles N proportionally to $(1/\beta_y)^{1/2}$:

$$L \propto \left(\frac{1}{\beta_y}\right)^{3/2}$$

(If ξ_x allows...)

Vertical Synchro-Betatron Resonances

For all (except, maybe, integer and parametric) resonances the values of $(Y_m^{\mathrm{I}})_0$ become very small [8] in the region $\beta_z^* \simeq \sigma_x/\phi \ll \sigma_s$, which corresponds to very long bunches, or to a micro-β lattice. In this region the value of the luminosity will be determined by limitations due to horizontal

D.Pestrikov, Nucl.Instrum.Meth.A336:427-437,1993

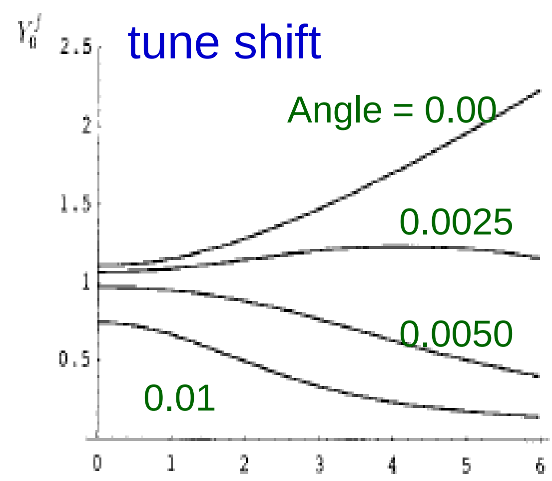
This results in the following expression

$$Y_m^{\mathrm{f}} = \frac{\sigma_x}{\phi\sigma_s} \mathcal{I}_{m_s}(a_s/\sigma_s)(Y_m^{\mathrm{f}})_0, \qquad (34)$$

Resonance suppression factor

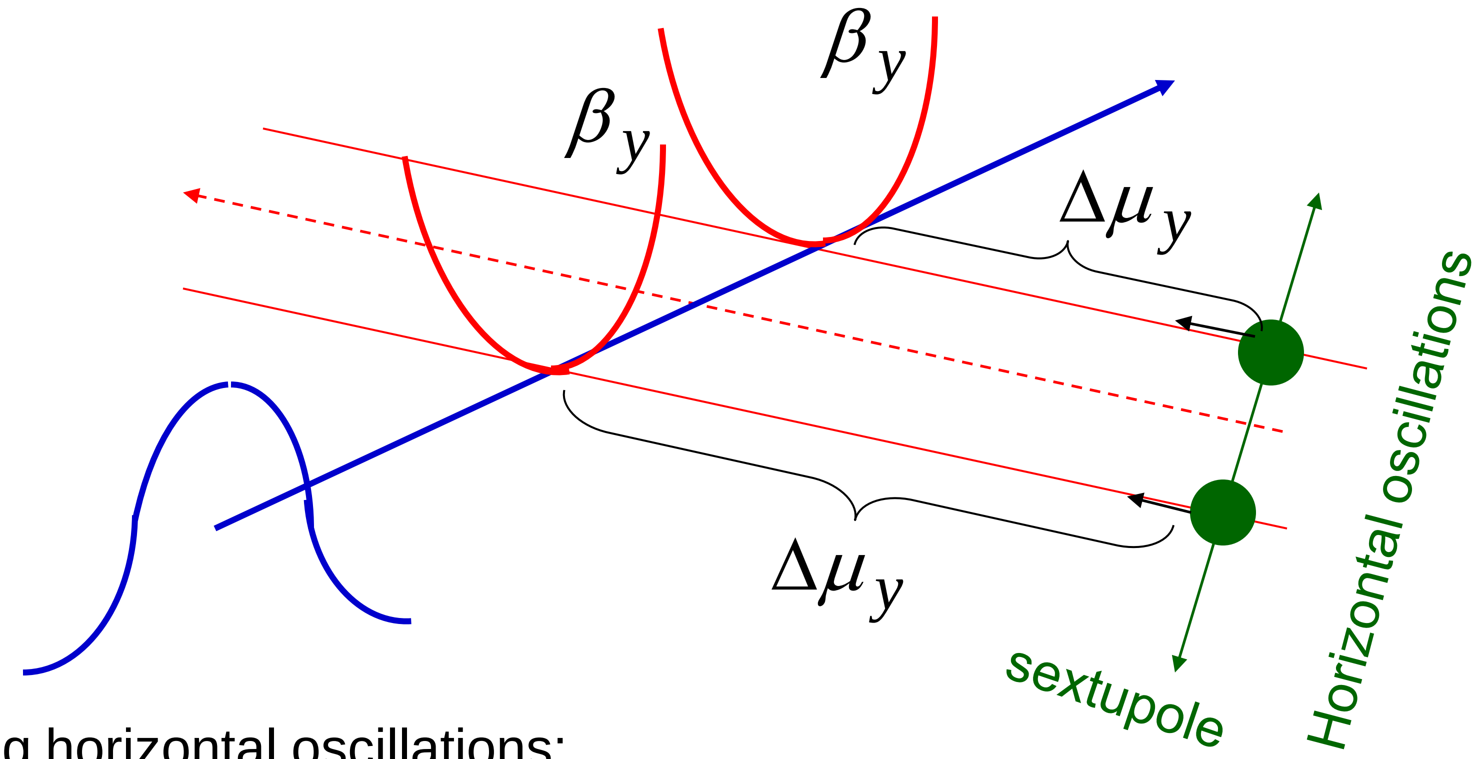
where the factor $(Y_m^{\mathrm{f}})_0$ coincides with a resonance suppressing factor of the synchronous particle $(a_s = 0)$, calculated for the bunch length $\sigma_s' = \sigma_x/\phi$:

$$(Y_m^{\mathrm{f}})_0 = \sqrt{2/\pi} \int_{-\infty}^{\infty} \mathrm{d}u \exp[-2u^2 + \mathrm{i}m_z\psi_z(\zeta_\phi u)] \sqrt{1 + \zeta_\phi^2 u^2}, \quad \zeta_\phi = \frac{\sigma_x}{\phi\beta_z^*}. \qquad (35)$$



Synchrotron amplitude in σ_z

Suppression of X-Y Resonances



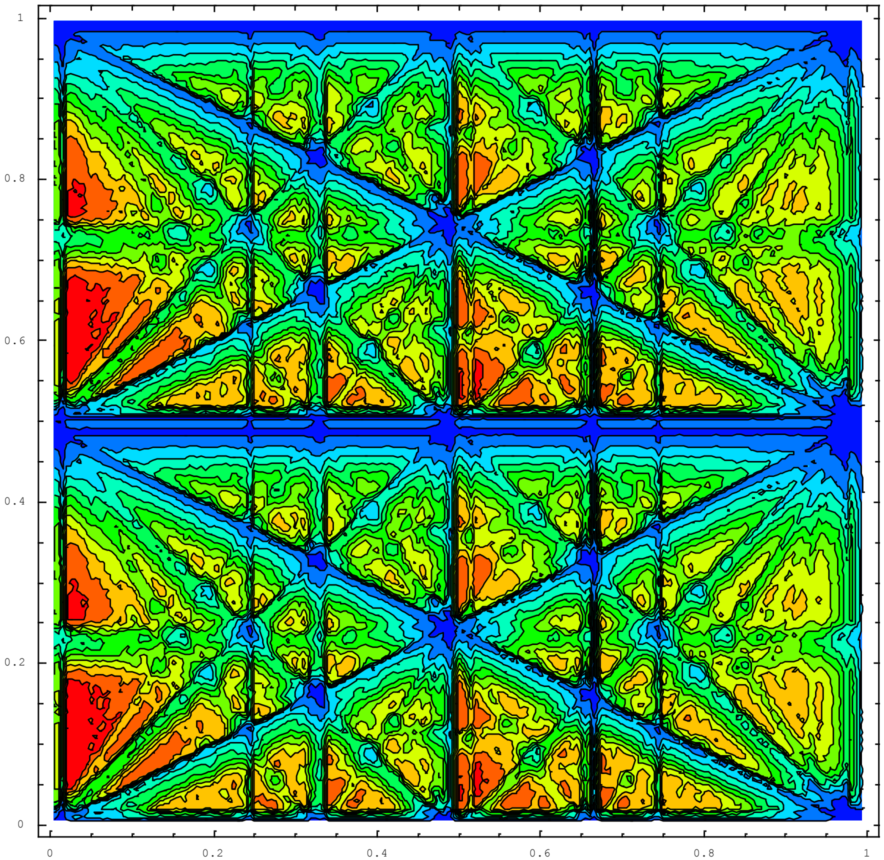
Performing horizontal oscillations:

1. Particles see the same density and the same (minimum) vertical beta function

2. The vertical phase advance between the sextupole and the collision point remains the same ($\pi/2$)

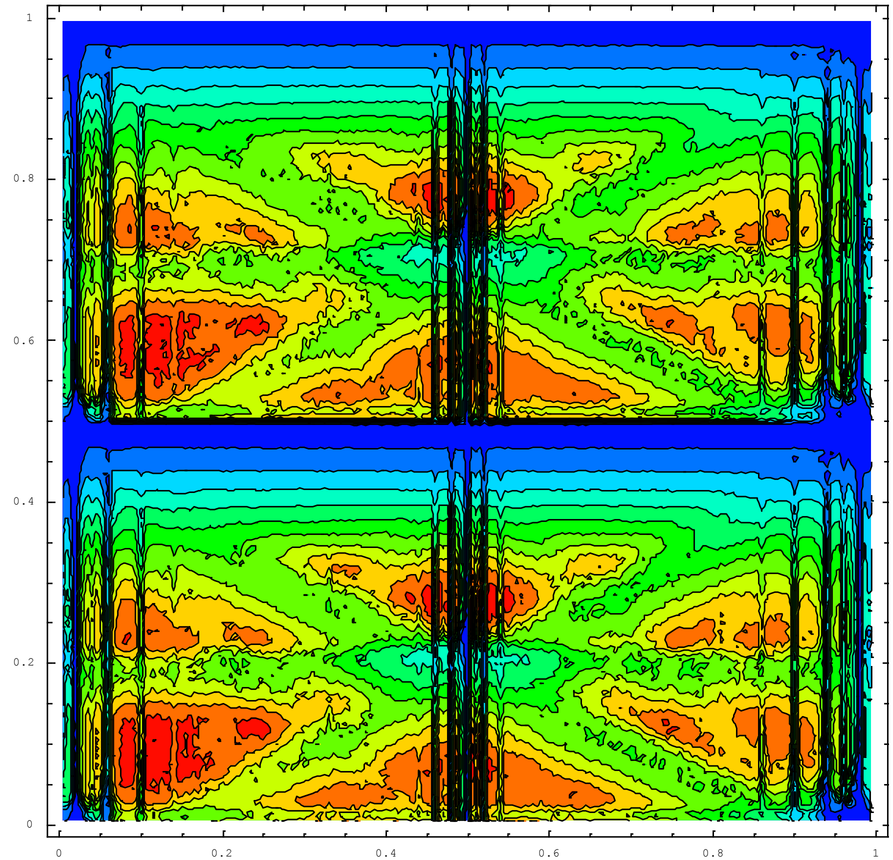
X-Y Resonance Suppression

Much higher luminosity!



Typical case (KEKB, DAΦNE etc.):

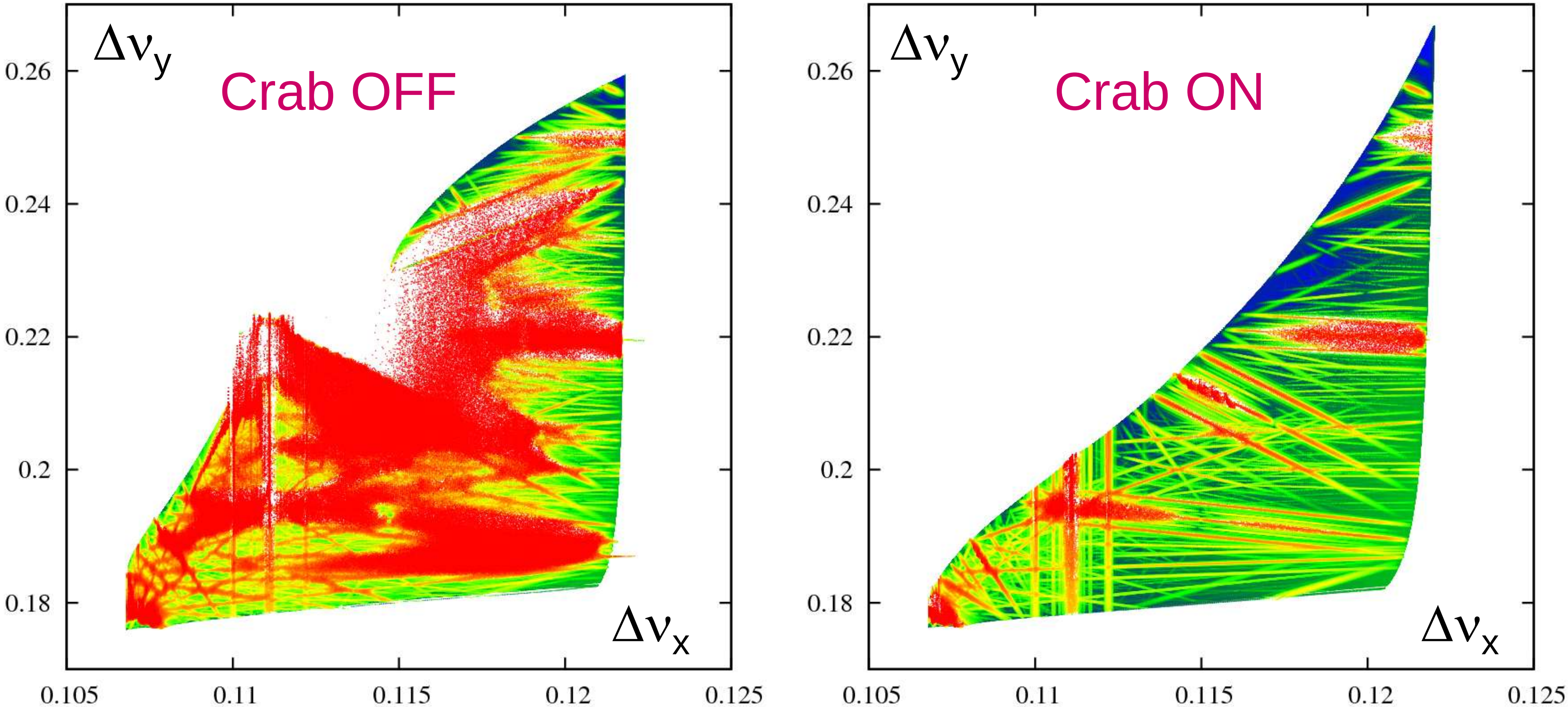
1. low Piwinski angle $\Phi < 1$
2. β_y comparable with σ_z



Crab Waist On:

1. large Piwinski angle $\Phi >> 1$
2. β_y comparable with σ_x/θ

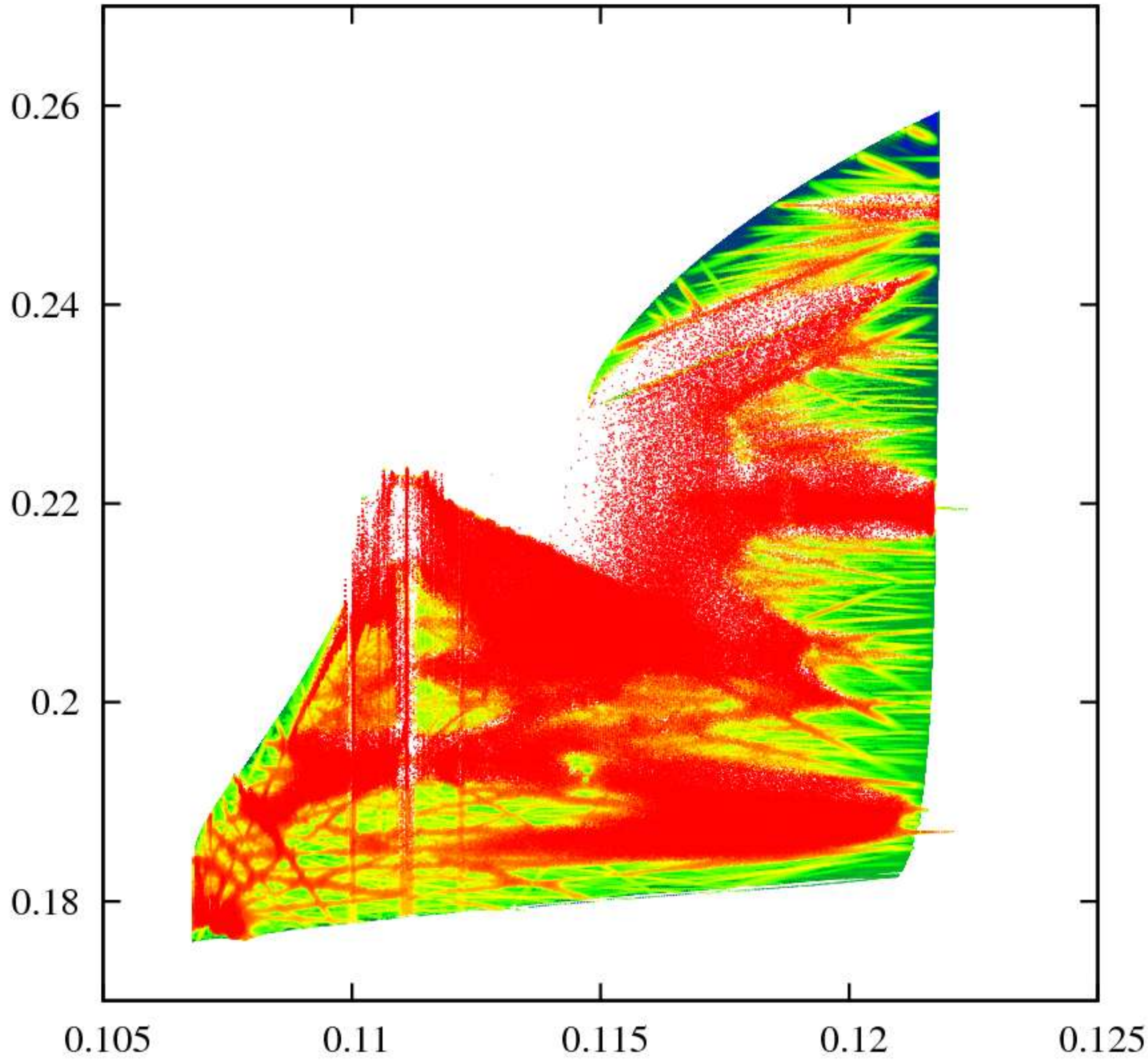
Frequency Map Analysis of Beam-Beam Interaction



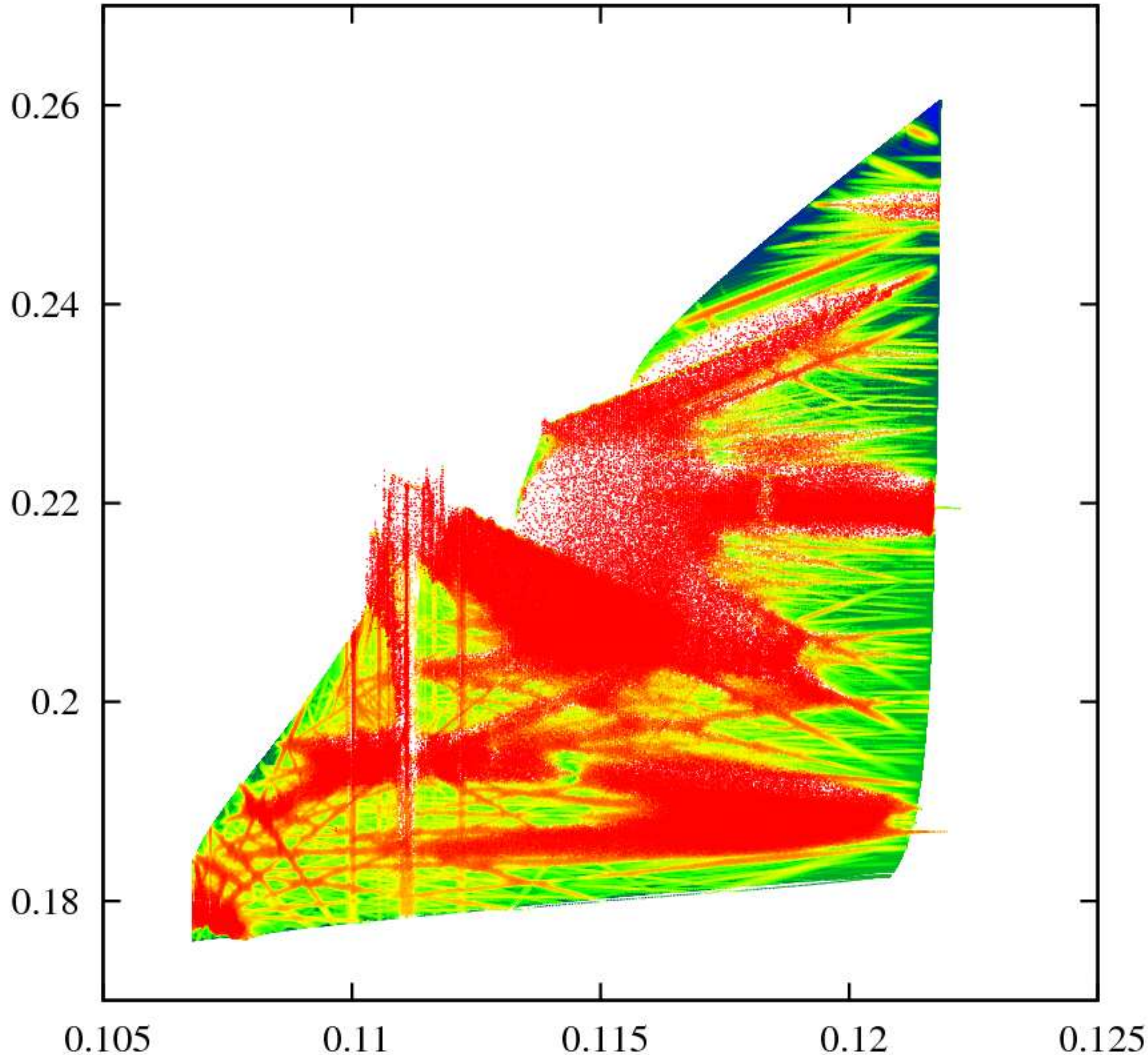
E.Levichev, D.Shatilov and E.Simonov,

e-Print: arXiV:1002.3733, also IPAC10, THPE075

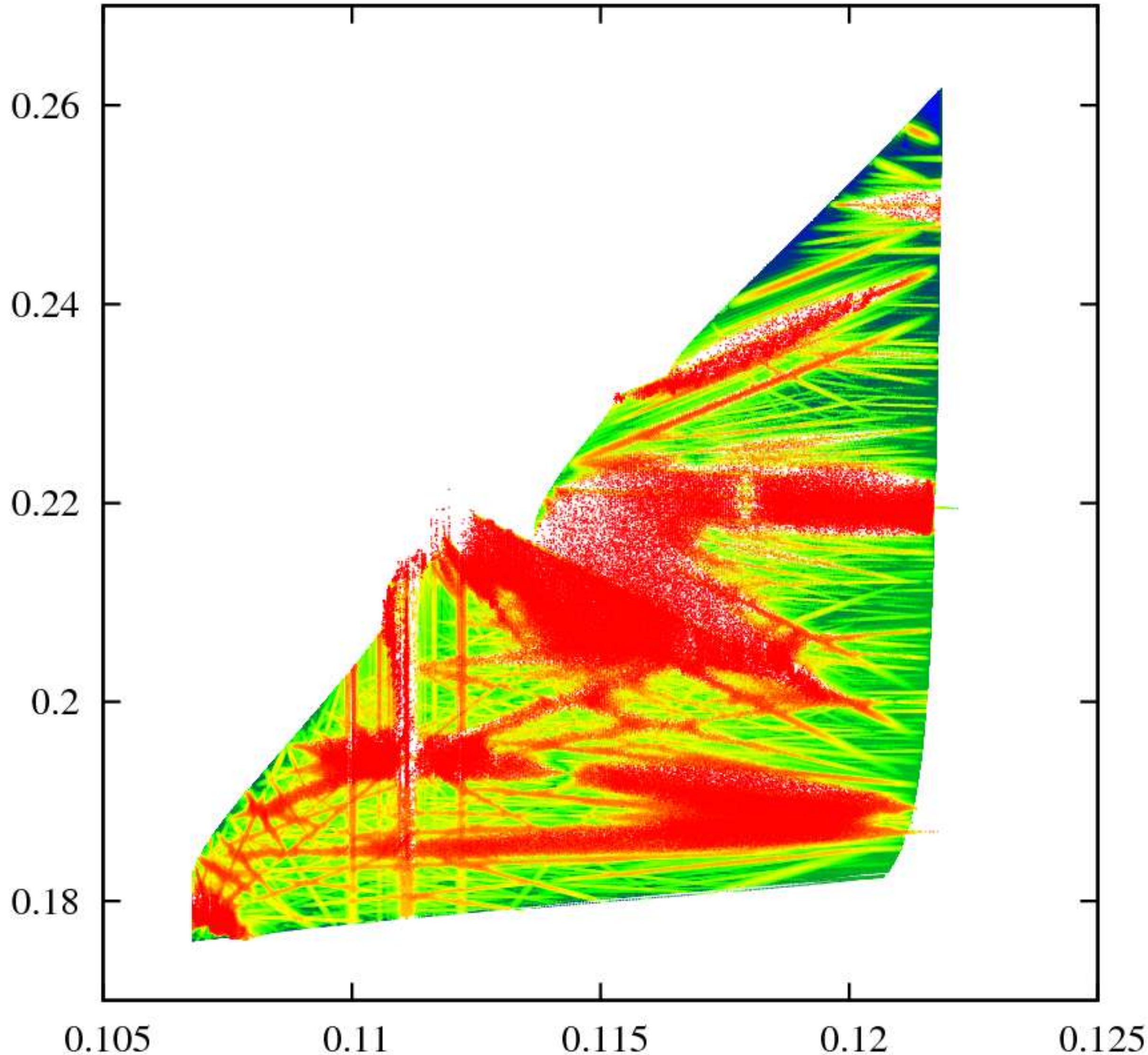
Crab = 0.0



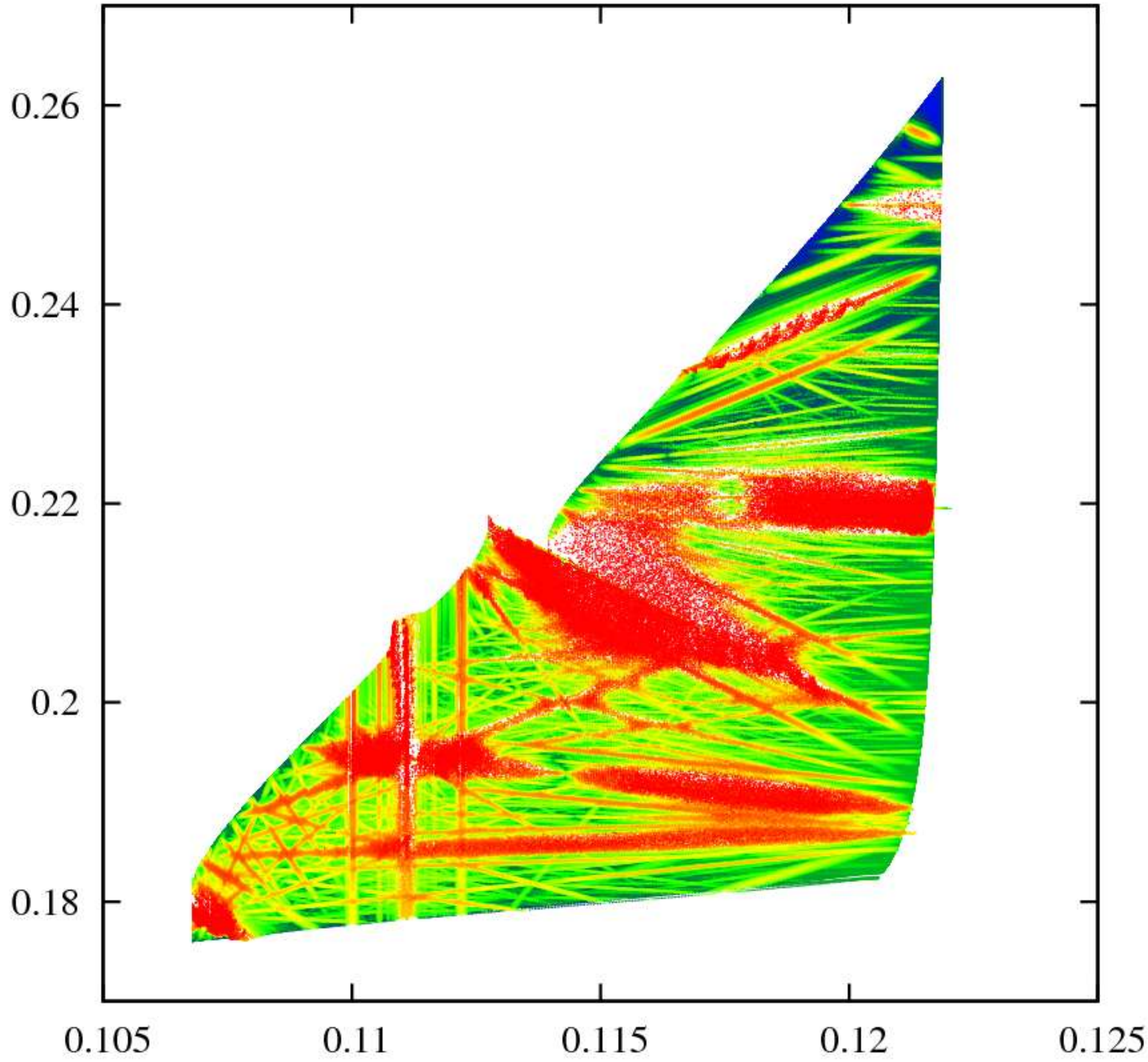
Crab = 0.1



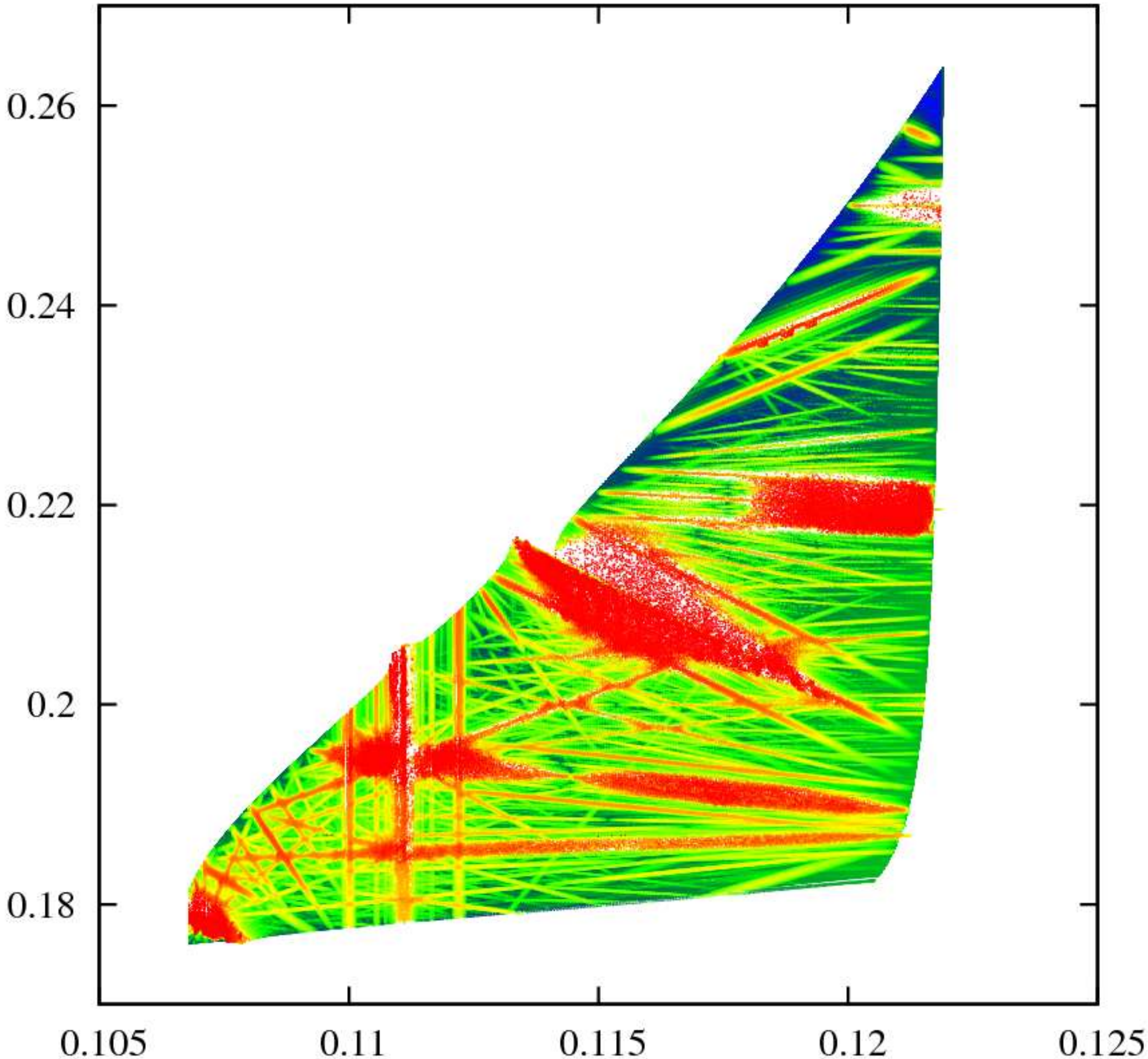
Crab = 0.2



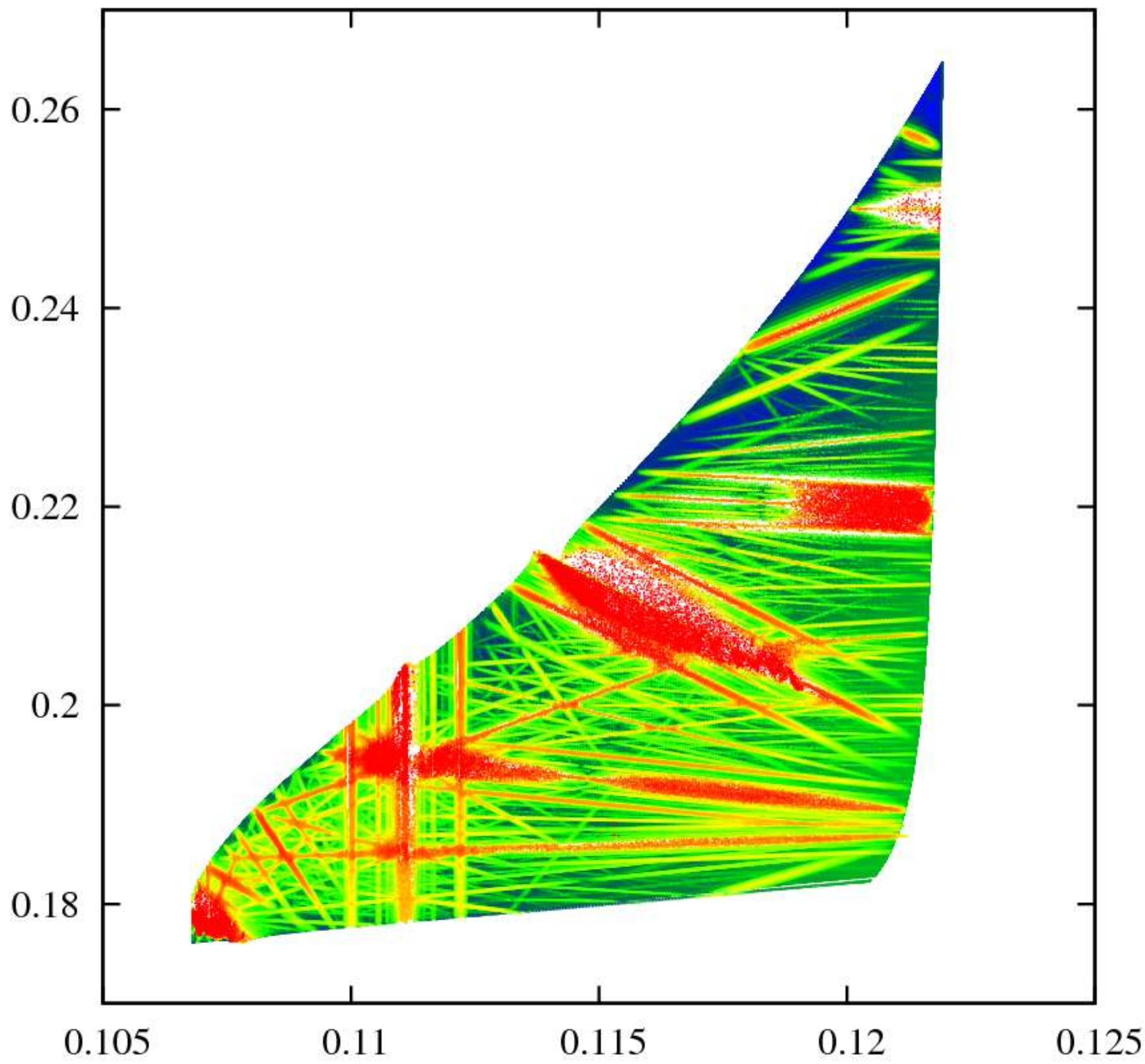
Crab = 0.3



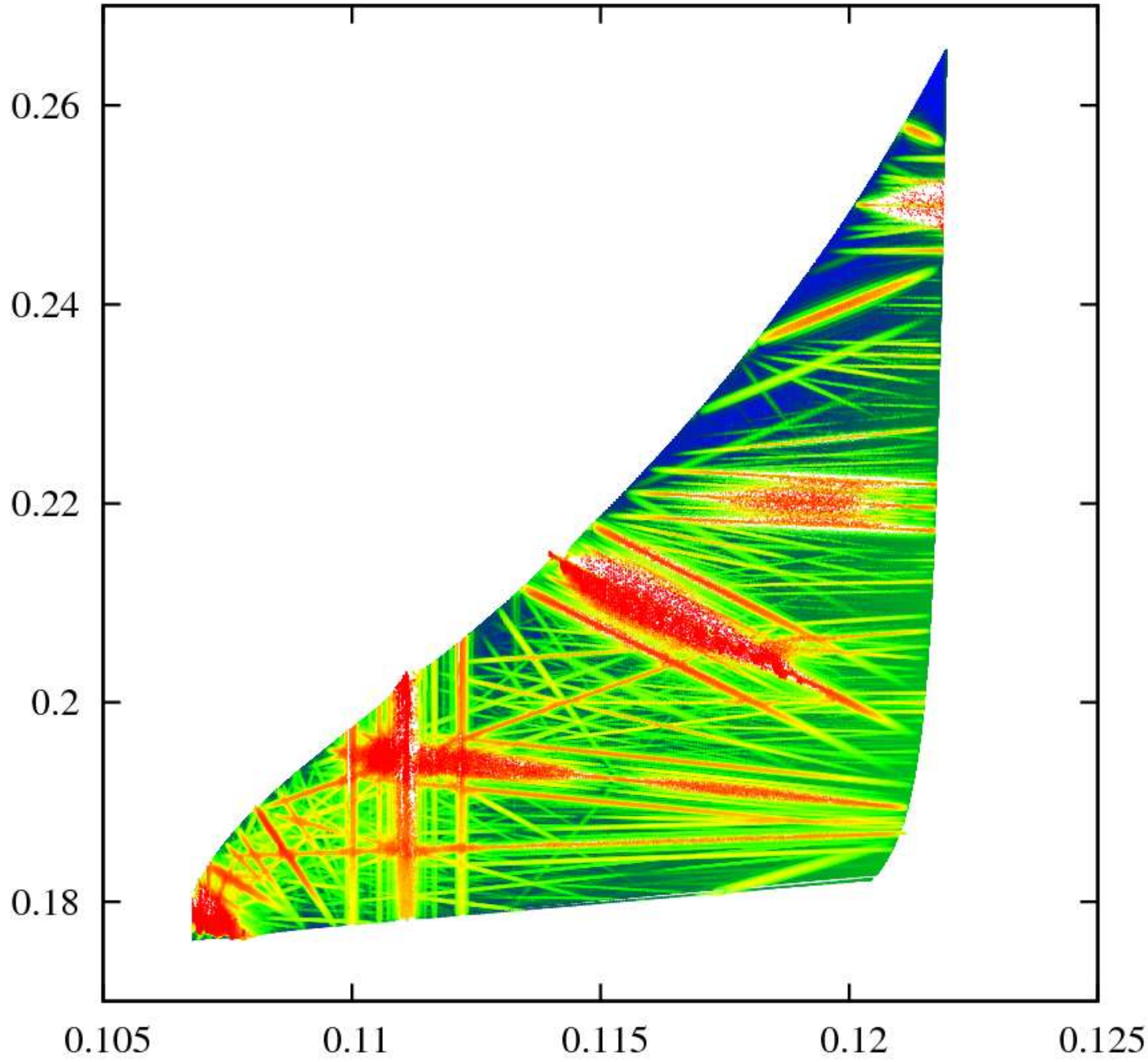
Crab = 0.4



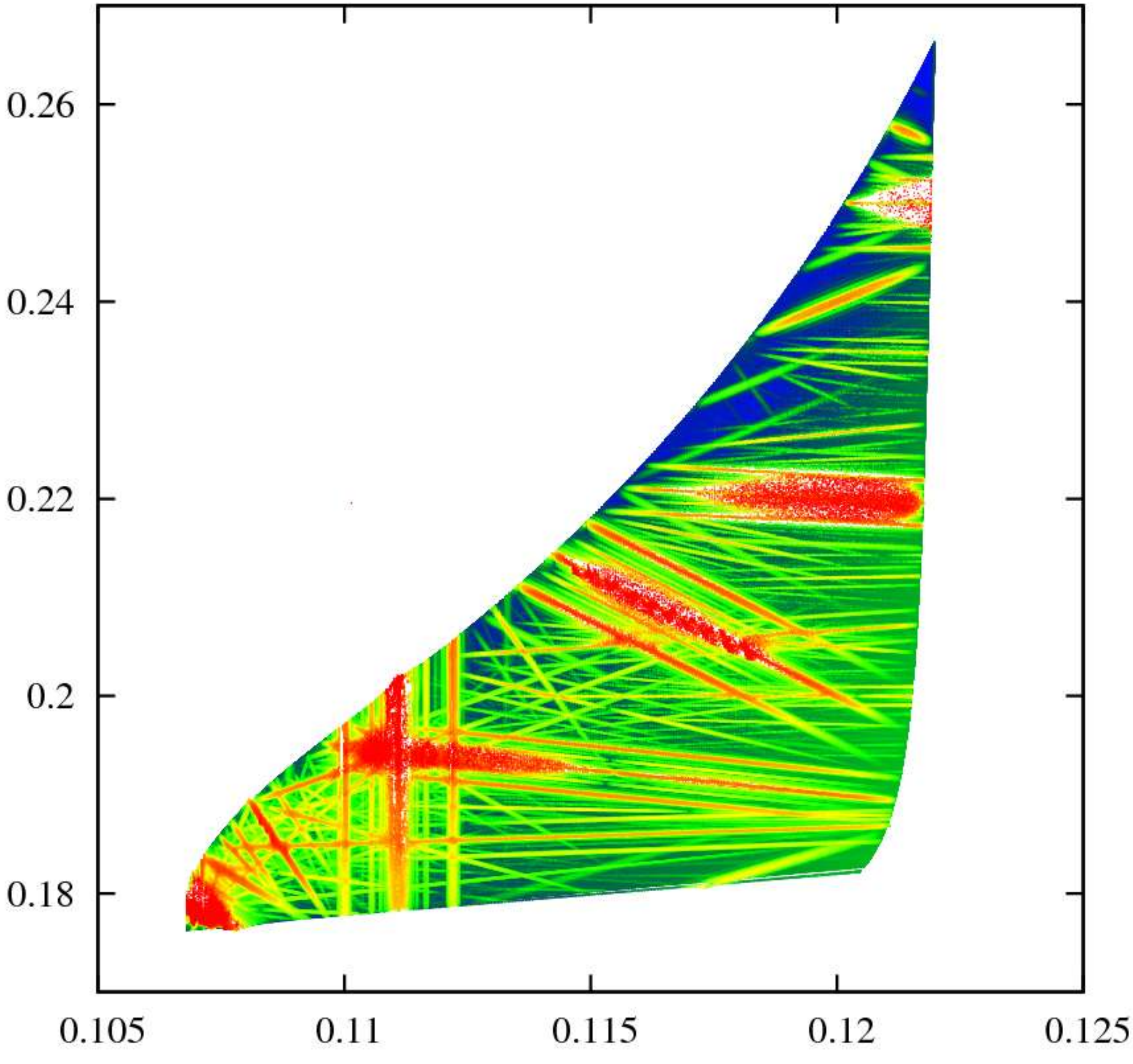
Crab = 0.5



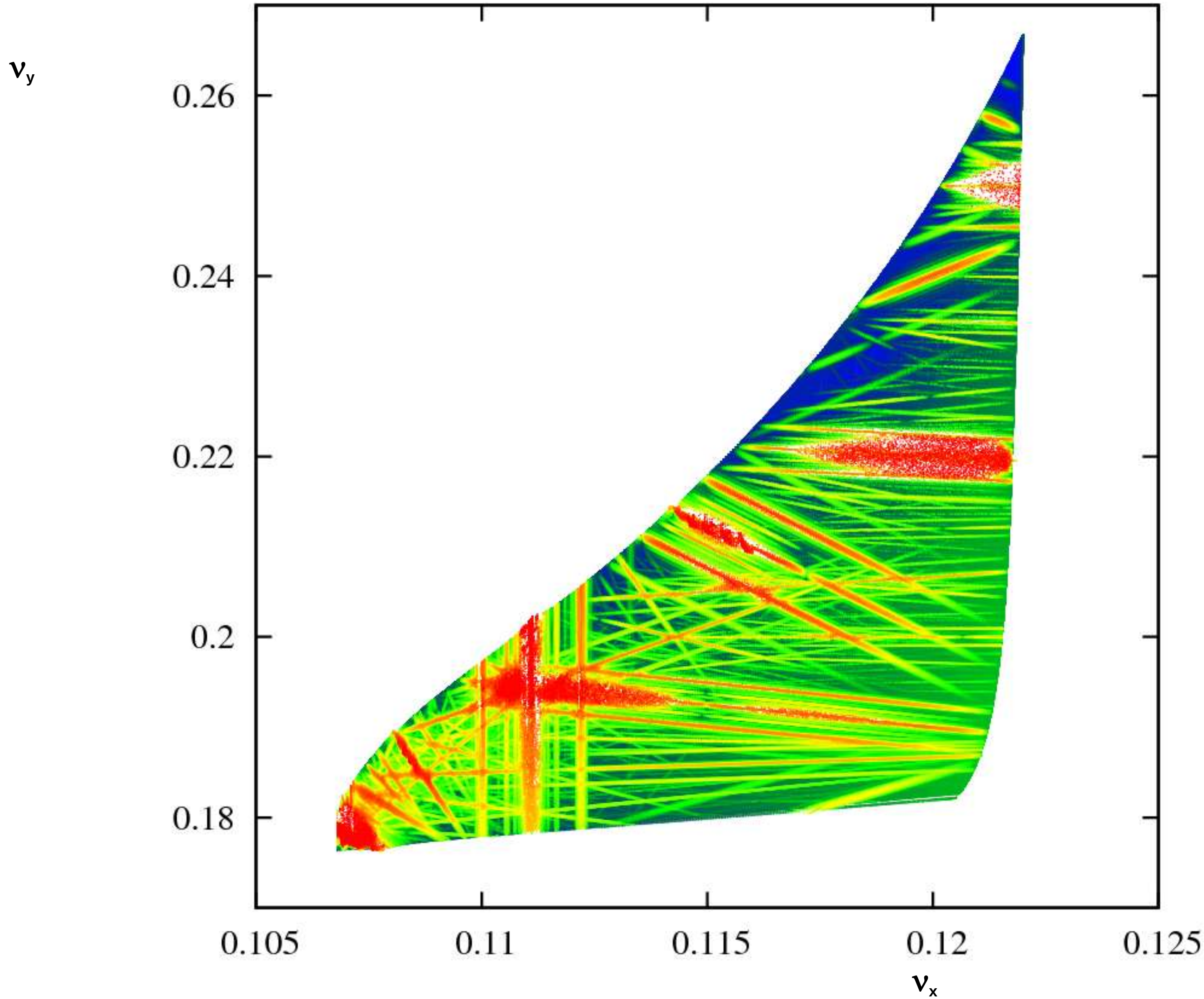
Crab = 0.6



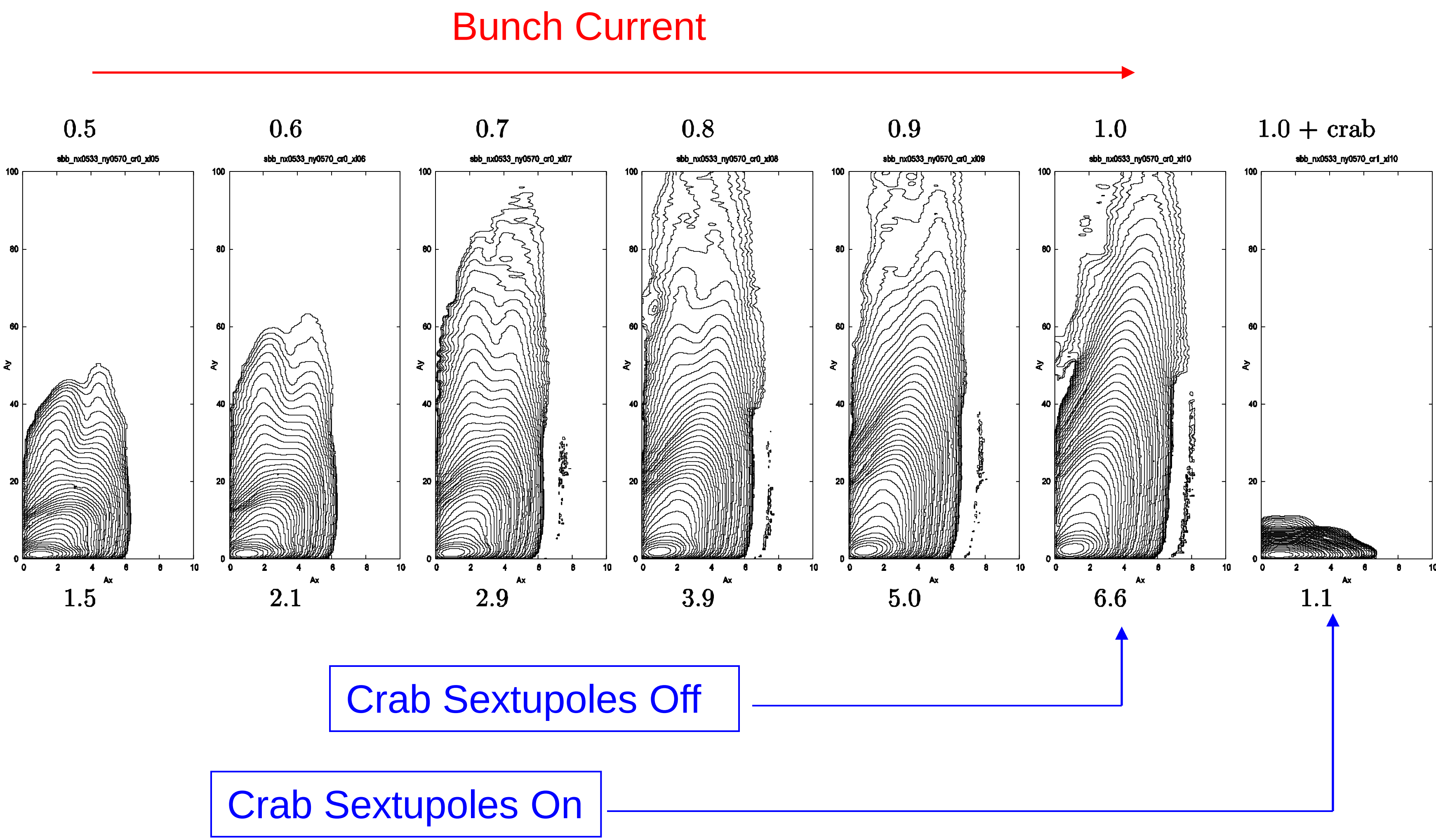
Crab = 0.7

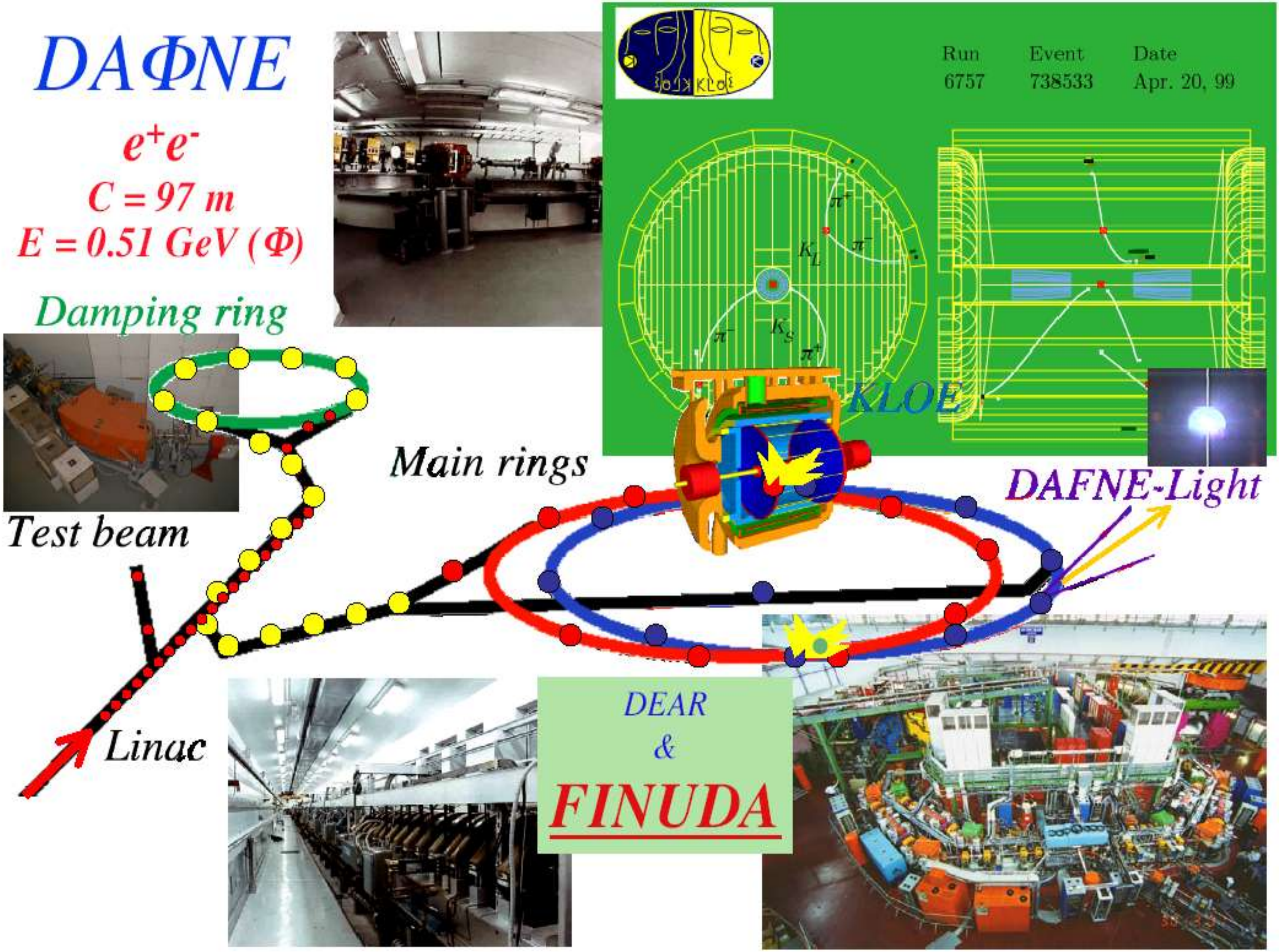


Crab = 0.8



Beam Blowup and Tails in SuperB



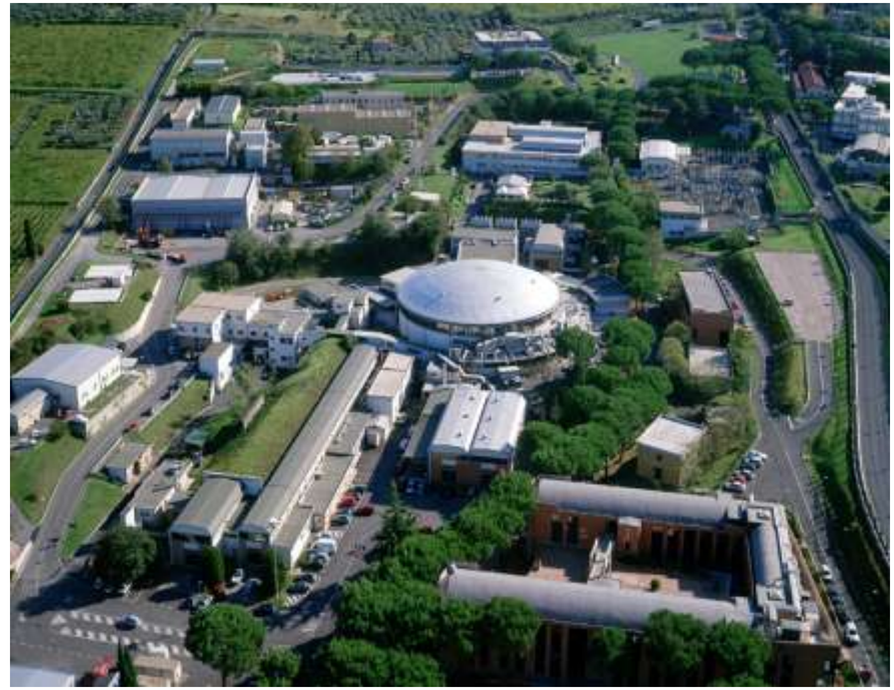


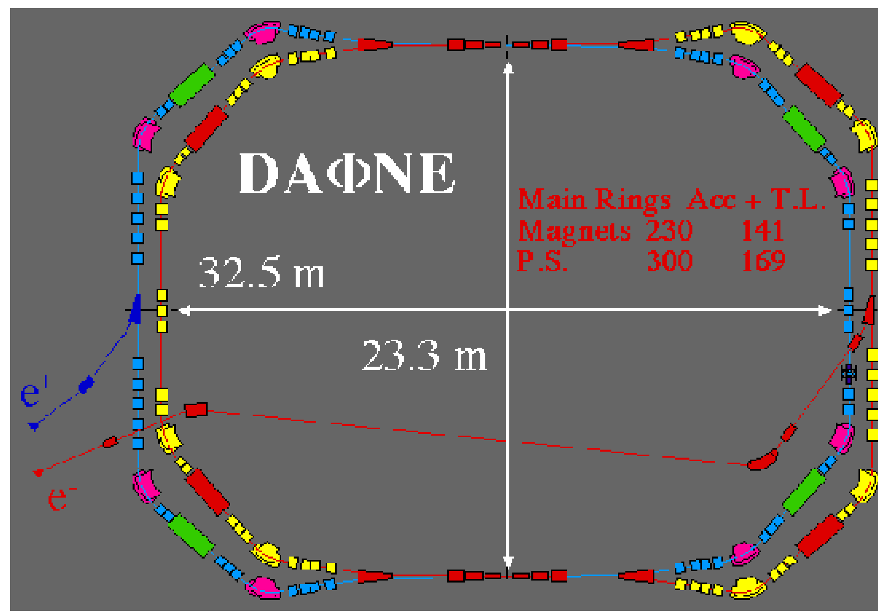
DAΦNE
e+e-
C = 97 m
E = 0.51 GeV (Φ)
Damping ring
Test beam
Main rings
Linac
Run 6757
Event 738533
Date Apr. 20, 99
π+
π-
K_L
K_S
KLOE
DAFNE-Light
DEAR
&
FINUDA

DAΦNE Parameters

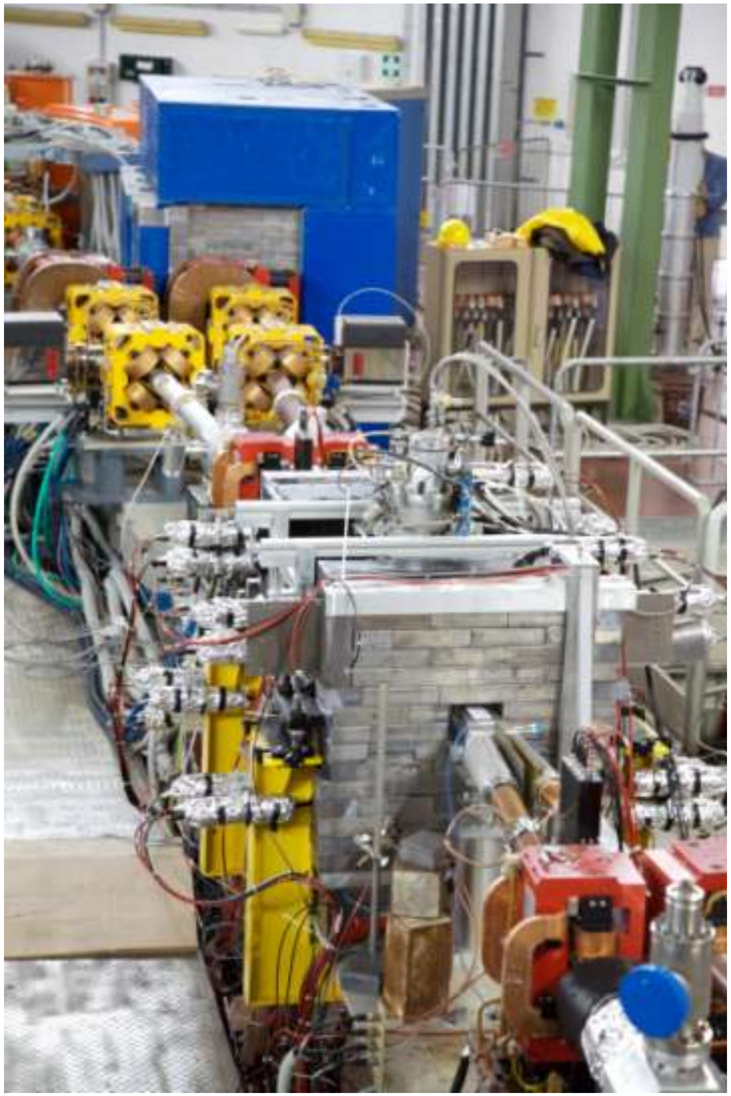
(KLOE configuration)

Energy, GeV	0.51
Circumference, m	97.69
RF Frequency, MHz	368.26
Harmonic Number	120
Damping Time, ms	17.8/36.0
Bunch Length, cm	1-3
Emittance, mmxmrad	0.34
Coupling, %	0.2-0.3
Beta Function at IP, m	1.7/0.017
Max. Tune Shifts	.03-.04
Number of Bunches	111
Max.Beam Currents, A	2.4/1.4



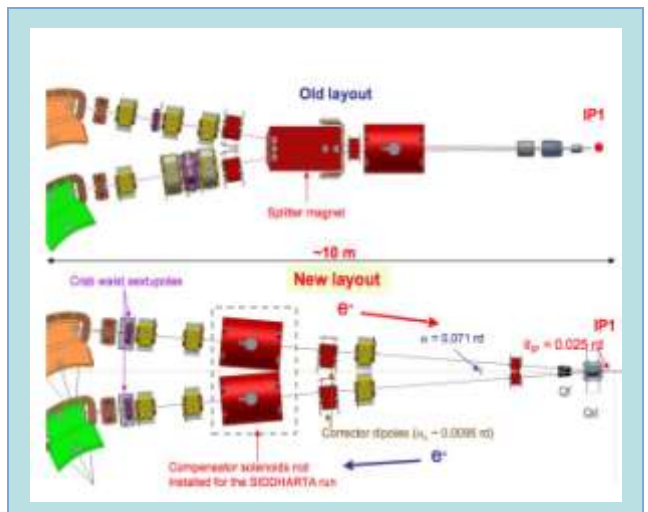


New Interaction Region

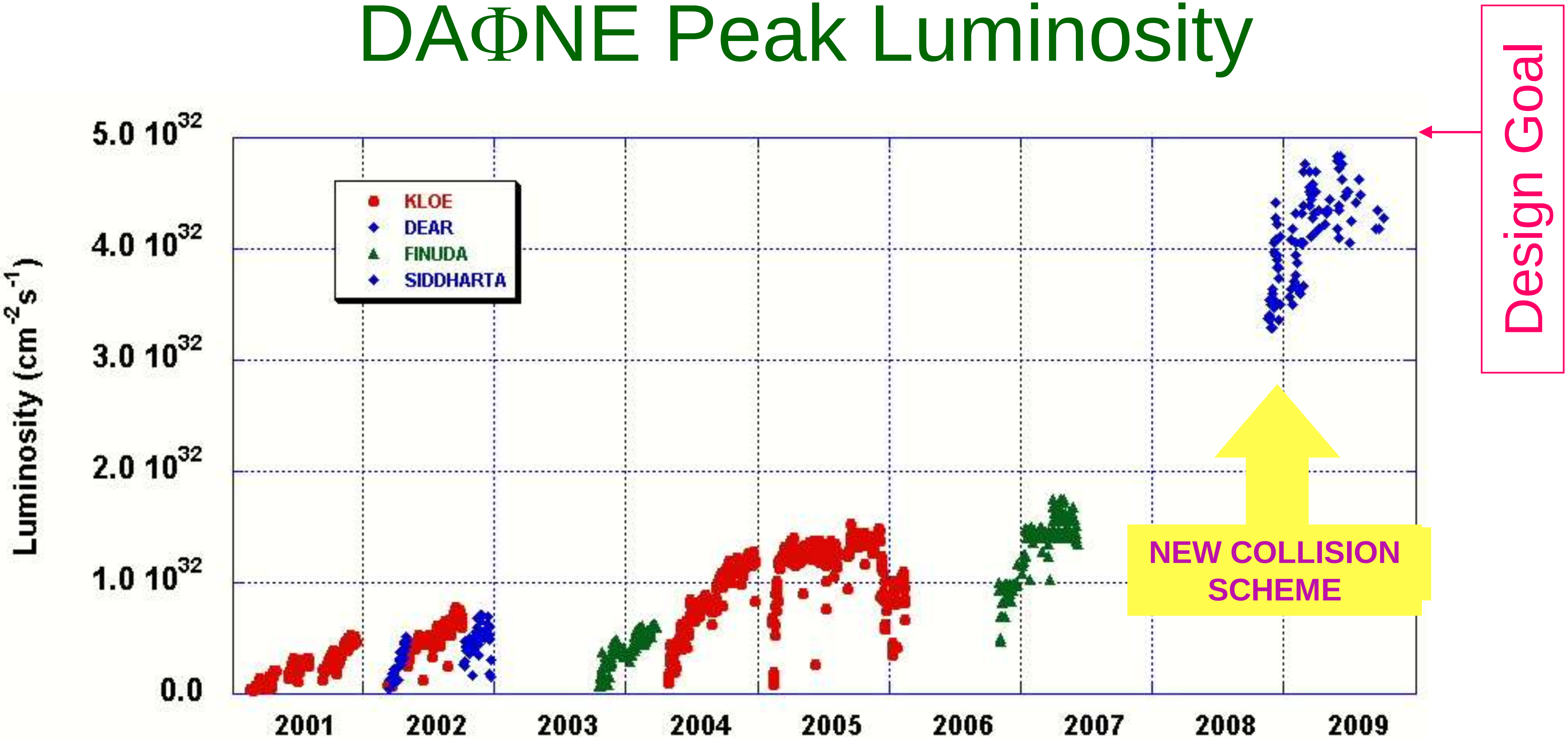


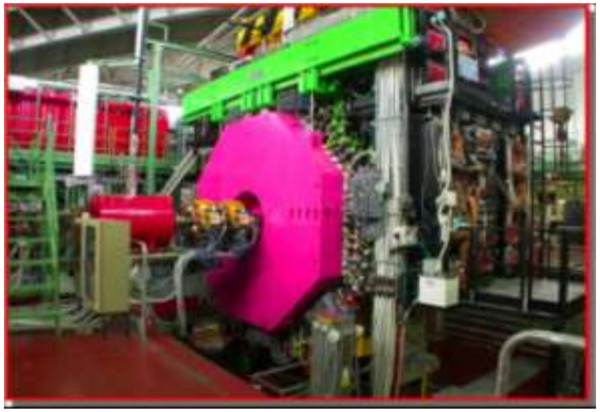
DAΦNE IP Parameters

Parameter	*KLOE*	*FINUDA*	*SIDDHARTA*
Date	Sept. 2005	Apr. 2007	June 2009
ε_x, mm mrad	0.34	0.34	0.25
β_x, m	1.5	2.0	0.25
σ_x, mm	0.71	0.82	0.25
θ, mrad	25	25	50
σ_z, cm	2.5	2.2	1.7
Φ	0.44	0.34	1.70
β_y, cm	1.8	1.9	0.93

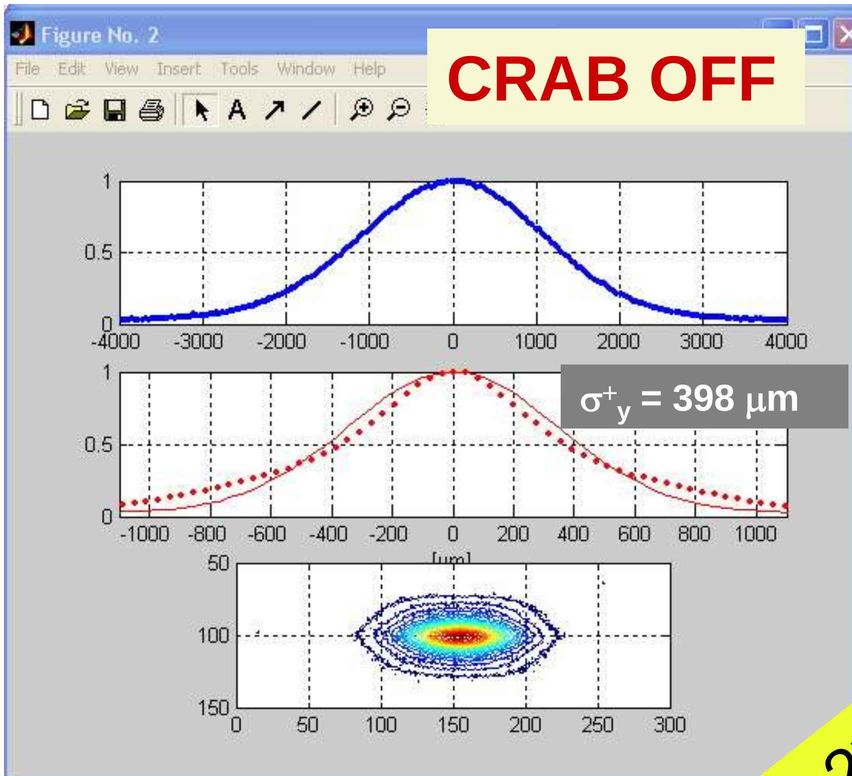


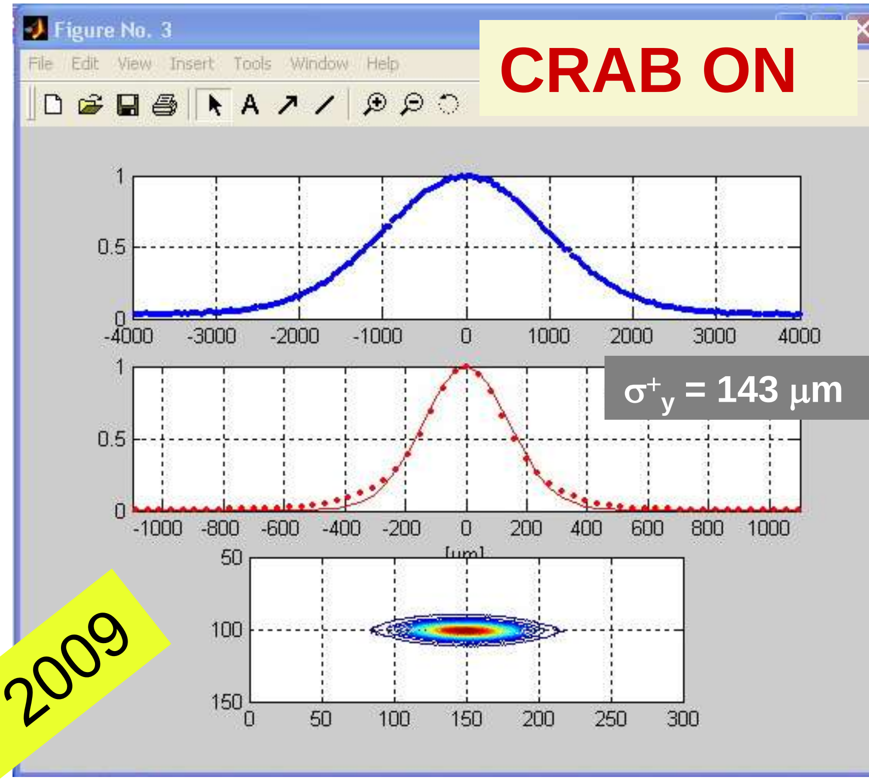
DAΦNE Peak Luminosity





Transverse Beam Profile Measurements



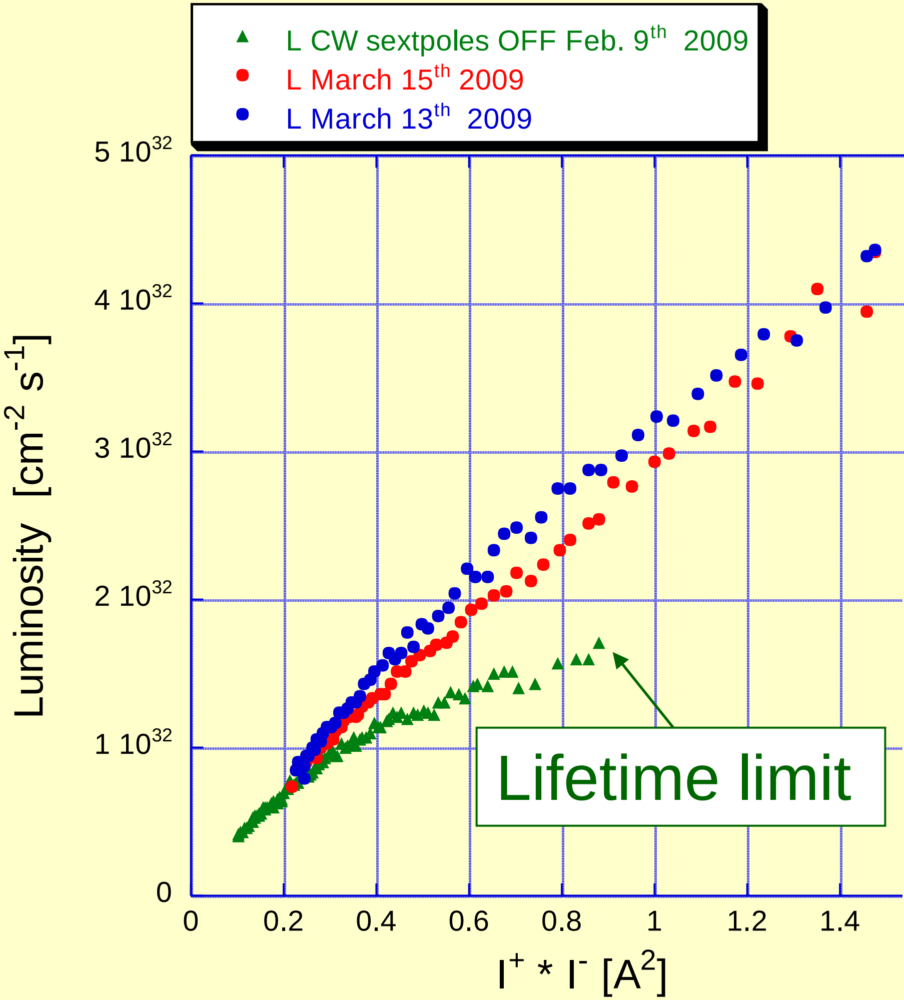


Nov. 2nd 2009

103 colliding bunches

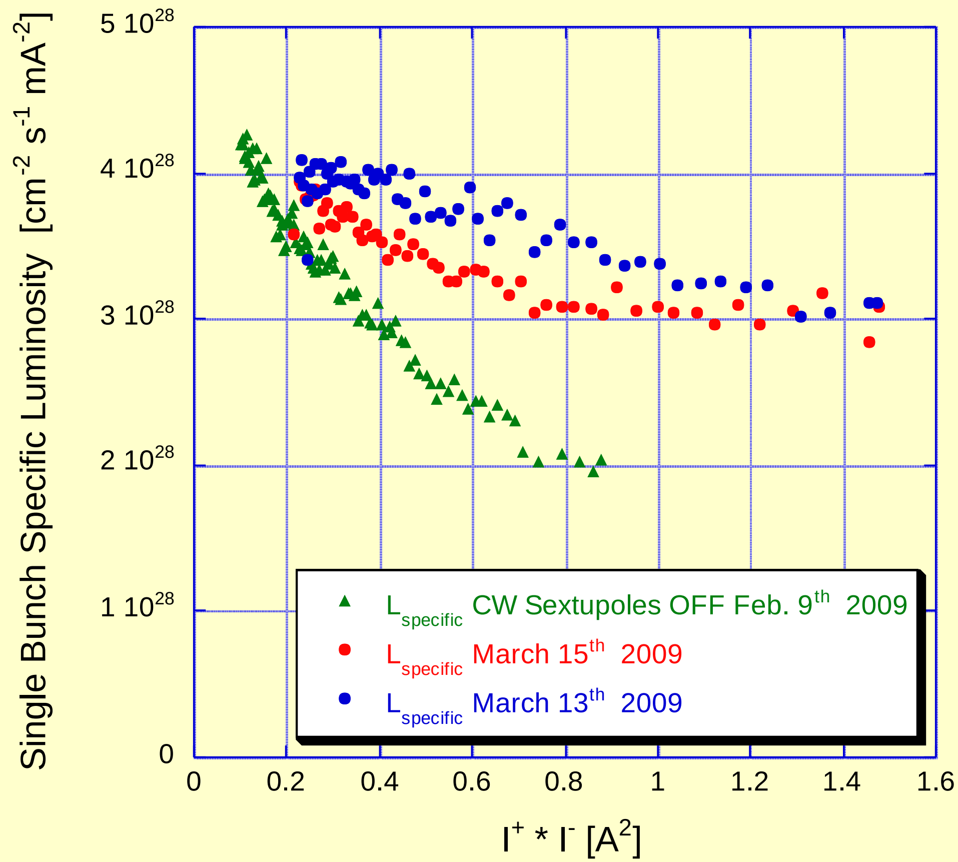
DAΦNE Luminosity and Tune Shifts

Parameter	*KLOE*	*FINUDA*	*SIDDHARTA*
Date	Sept. 2005	Apr. 2007	June 2009
Luminosity, $cm^{-2}\ s^{-1}$	1.53×10^{32}	1.60×10^{32}	4.53×10^{32}
e- current, A	1.38	1.50	1.52
e+ current, A	1.18	1.10	1.00
Number of bunches	111	106	105
ε_x, mm mrad	0.34	0.34	0.25
β_x, m	1.5	2.0	0.25
β_y, cm	1.8	1.9	0.93
ξ_y	0.0245	0.0291	0.0443(0.089)



Crab on/off Luminosity vs Current Product

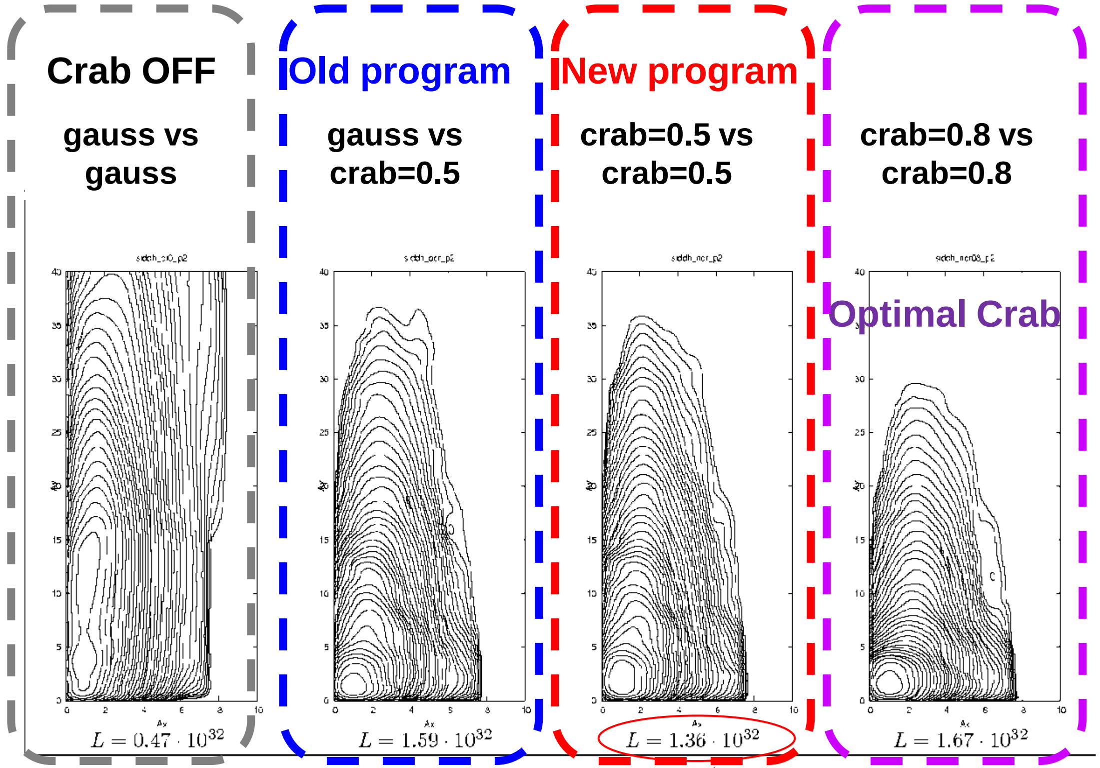
Crab on/off Specific Luminosity vs Current Product



Weak-Strong Simulations

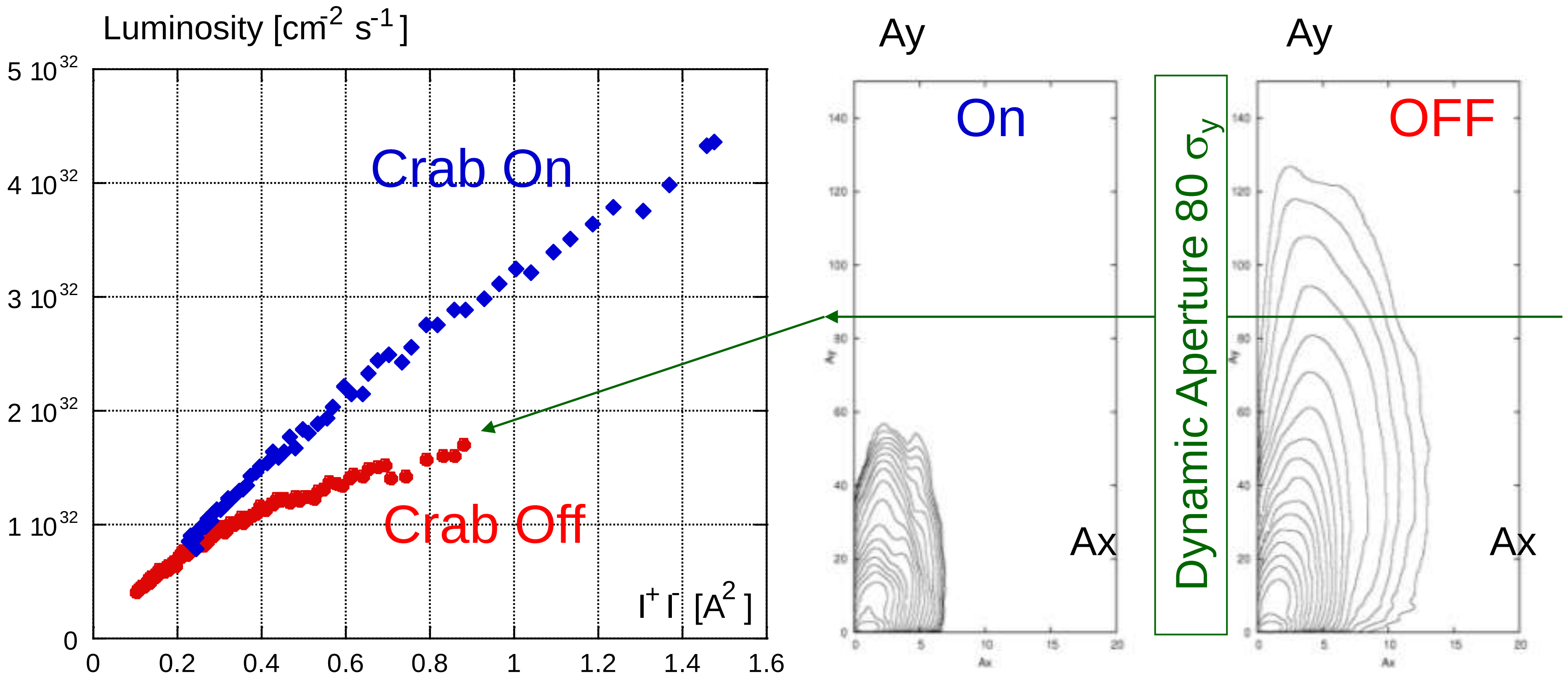
(Crabbed Strong Beam)

$\Delta\nu_y = 0.0894$



L = 1.36E+32

Beam-Beam interaction in DAΦNE nonlinear lattice



LIFETRAC + ACCELERATICUM

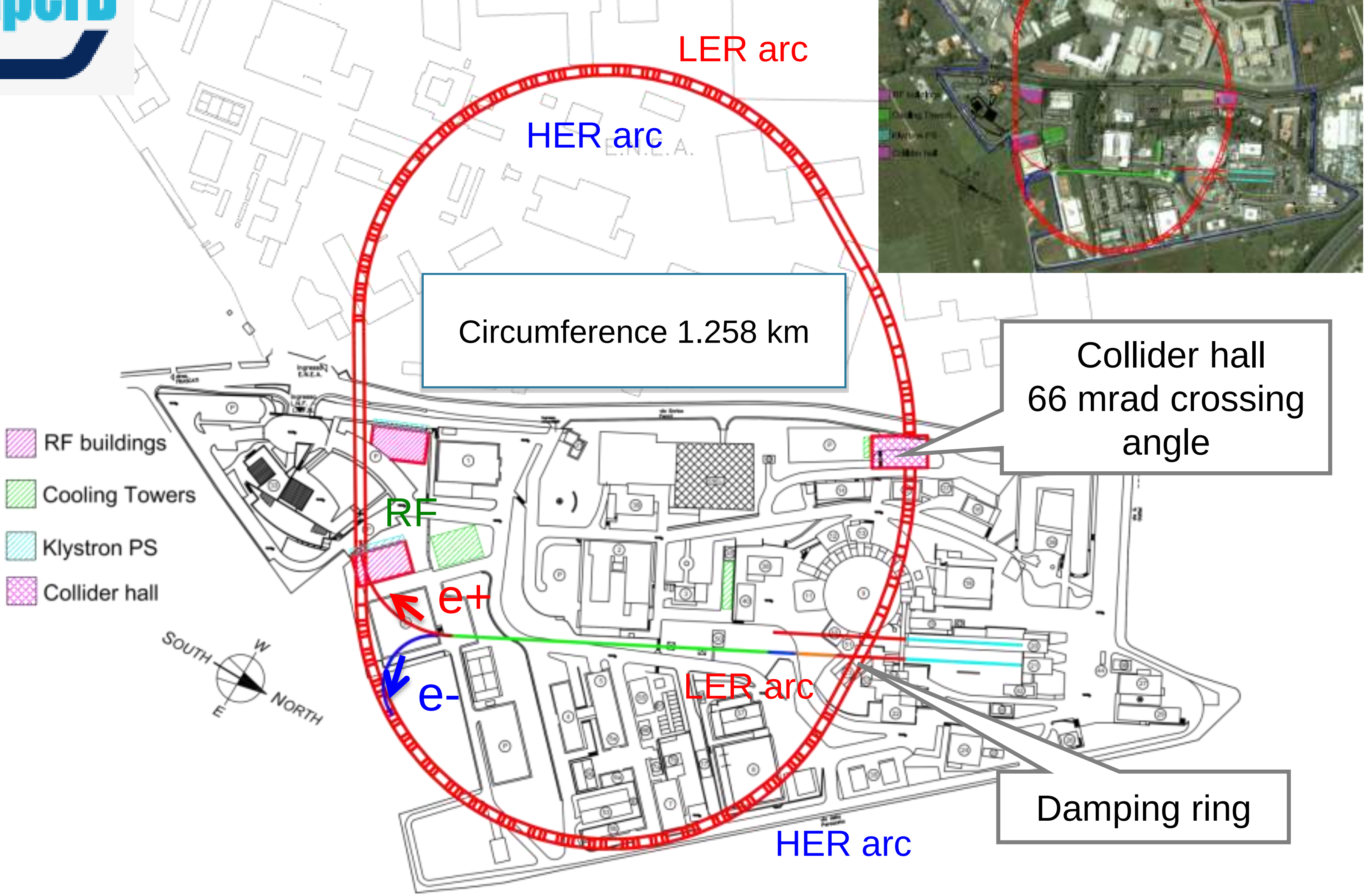
CONCLUSIONS (Part I - DAΦNE)

1. Crab waist works well, no doubts
2. Existing numerical codes are reliable in predicting the luminosity with crab waist
3. Crab waist sextupoles are of great importance for the collider luminosity increase
4. DAΦNE scientific program has been approved for the next 3 years

Super-B Project

- *Super-B* aims at the construction of a very high luminosity (1x 10^{36} cm^{-2} s^{-1}) asymmetric e^+e^- flavor factory with a possible location on or near the campuses of the University of Rome at Tor Vergata or the INFN Frascati National Lab.
- Goals:
  - Peak luminosity >10^{36} $cm^{-2}s^{-1}$ at Y(4S)
  - Integrated luminosity 75 ab^{-1}
  - Longitudinally polarized beam (e-) at the IP (60-85%)
  - Ability to collide at the Charm threshold
  - Flexible parameter choices
  - High reliability

SuperB at Frascati

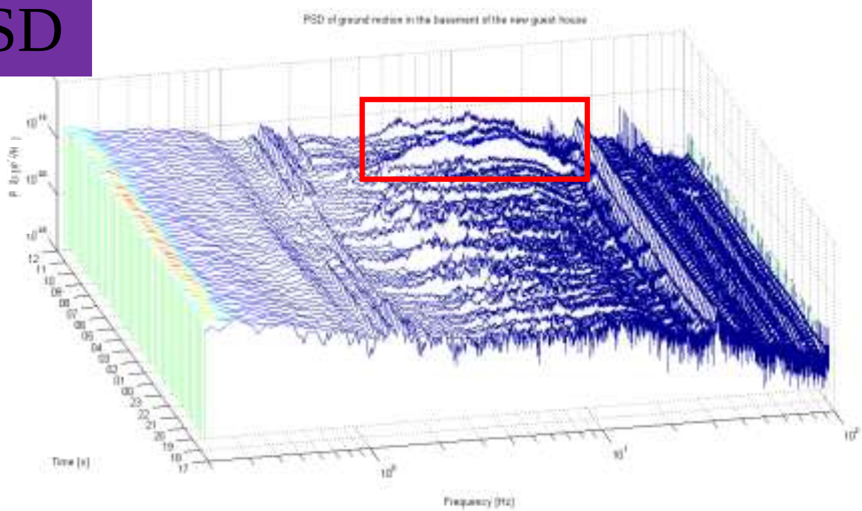


Collaboration: INFN, SLAC, IN2P3, BINP, Canada

Geological Survey

PSD of ground motion versus time and frequency

PSD

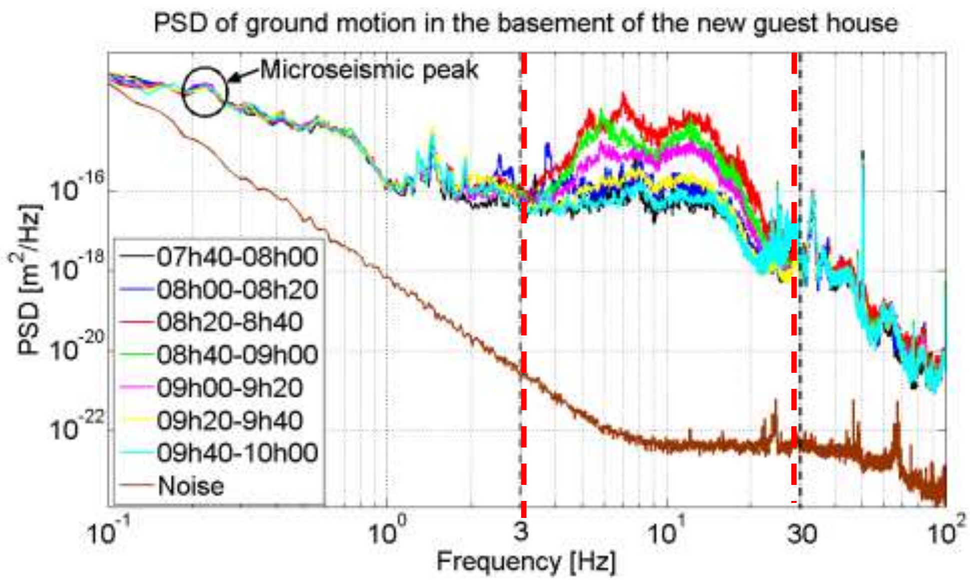


Quite same spectra with time except **for one area**

from 8h to 9h40: high increase of amplitude in the range **[3; 30]Hz**

➔ **correspond exactly to traffic**

Time area of the increase	Peak observed in the range [3; 30]Hz
7h40-8h00	no peak
8h00-8h20	low level
8h20-8h40	highest level
8h40-9h40 (step: 20 min)	decrease of level step by step
9h40-10h00	no (same spectra as for 7h40-8h00)



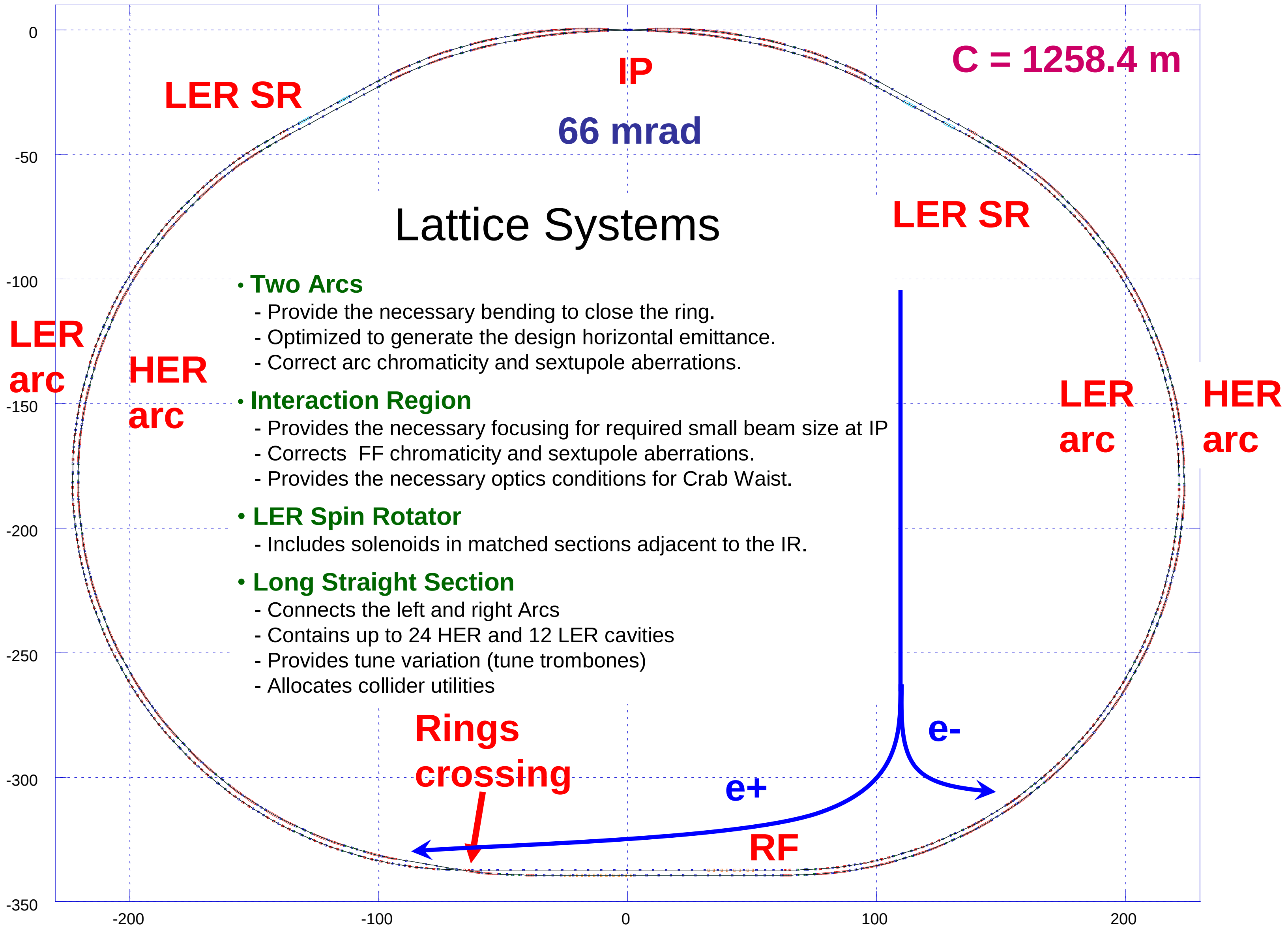
Microsismic peak (waves of ocean)

Cultural noise (human activities)

SuperB Basic Parameters

Parameter	Units	Base Line HER (e+)	Base Line LER (e-)	Low Emittance HER (e+)	Low Emittance LER (e-)	High Current HER (e+)	High Current LER (e-)	τ-charm HER (e+)	τ-charm LER (e-)
LUMINOSITY	$cm^{-2} s^{-1}$	1.00E+36		1.00E+36		1.00E+36		1.00E+35	
Energy	GeV	6.7	4.18	6.7	4.18	6.7	4.18	2.58	1.61
Circumference	m	1258.4		1258.4		1258.4		1258.4	
X-Angle (full)	mrad	66		66		66		66	
β_x @ IP	cm	2.6	3.2	2.6	3.2	5.06	6.22	6.76	8.32
β_y @ IP	cm	0.0253	0.0205	0.0179	0.0145	0.0292	0.0237	0.0658	0.0533
Coupling (full current)	%	0.25	0.25	0.25	0.25	0.5	0.5	0.25	0.25
Emittance x (with IBS)	nm	2.00	2.46	1.00	1.23	2.00	2.46	5.20	6.4
Emittance y	pm	5	6.15	2.5	3.075	10	12.3	13	16
Bunch length (full current)	mm	5	5	5	5	4.4	4.4	5	5
Beam current	mA	1892	2447	1460	1888	3094	4000	1365	1766
RF frequency	MHz	476.		476.		476.		476.	
Number of bunches	#	978		978		1956		1956	
Tune shift x		0.0021	0.0033	0.0017	0.0025	0.0044	0.0067	0.0052	0.0080
Tune shift y		0.097	0.097	0.0891	0.0892	0.0684	0.0687	0.0909	0.0910
Total RF Wall Plug Power	MW	16.38		12.37		28.83		2.81	

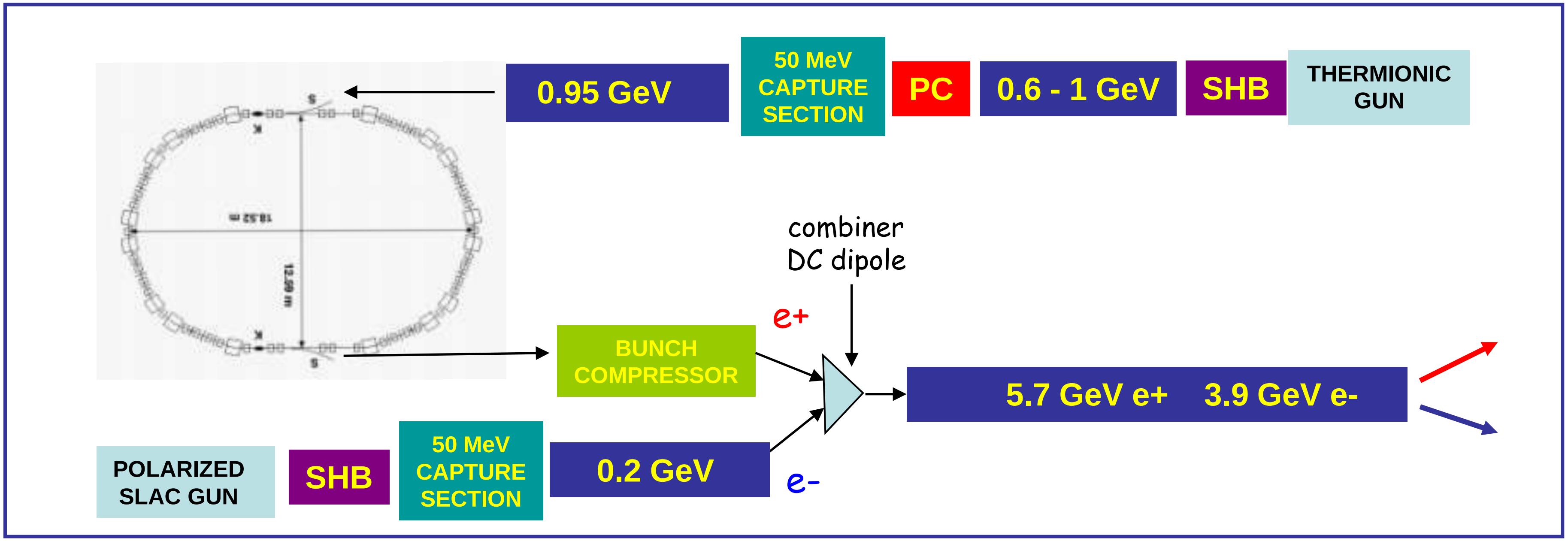
Collider Layout



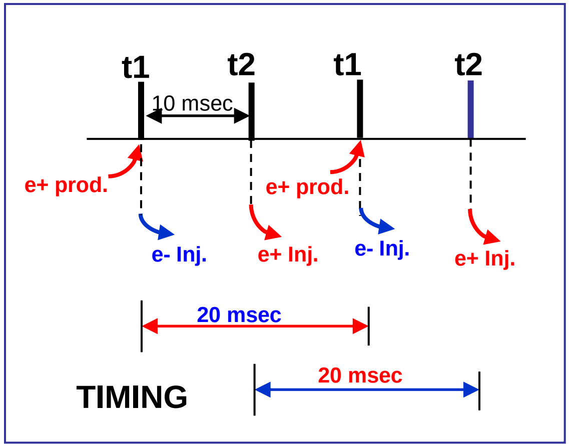
Lattice Systems

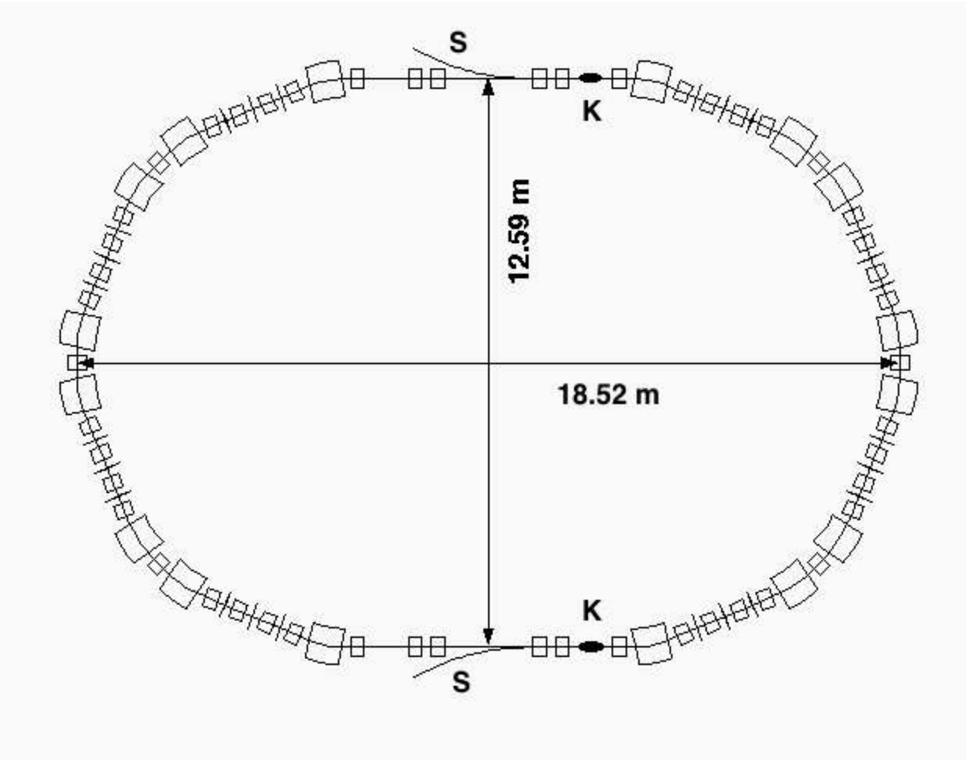
- **Two Arcs**
  - Provide the necessary bending to close the ring.
  - Optimized to generate the design horizontal emittance.
  - Correct arc chromaticity and sextupole aberrations.
- **Interaction Region**
  - Provides the necessary focusing for required small beam size at IP
  - Corrects FF chromaticity and sextupole aberrations.
  - Provides the necessary optics conditions for Crab Waist.
- **LER Spin Rotator**
  - Includes solenoids in matched sections adjacent to the IR.
- **Long Straight Section**
  - Connects the left and right Arcs
  - Contains up to 24 HER and 12 LER cavities
  - Provides tune variation (tune trombones)
  - Allocates collider utilities

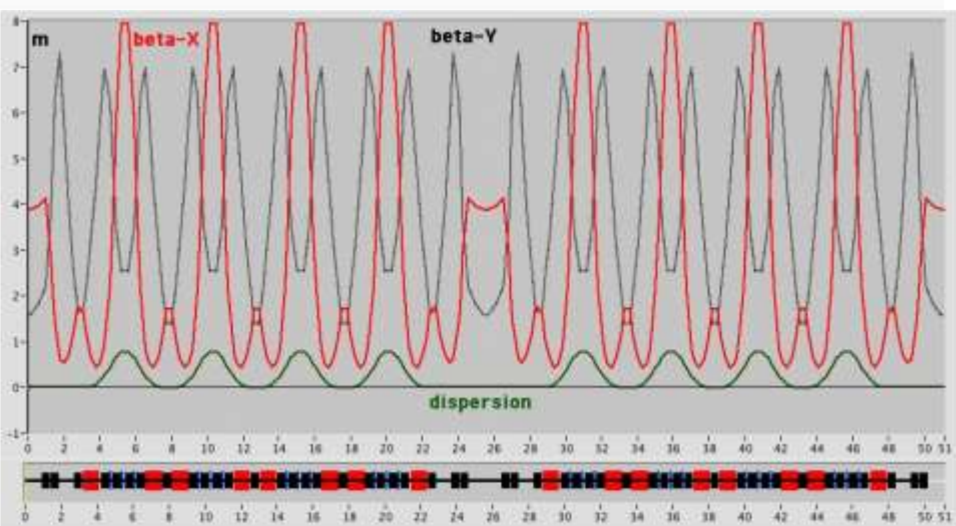
New scheme proposed recently (june 2010) …
… and under refinement



- Damping Ring operates just for positrons
- Only 2 Transfer Lines between Linacs and D.R., instead of 4; no special dipoles
- No long flat top kickers in the damping ring and transfer lines
- The gun for the positron line can be thermionic, thus delivering larger current
- The polarized gun for the electrons can work at a much lower current
- Main Rings injection rate: 50 Hz instead of 25
- Main Linac Klystron rep. rate: 100 Hz
- The e- beam vertical emittance increases…. can be reduced with scrapers/collimators …







Super-B Damping Ring

compact structure (51 m) for storing alternatively electrons and positrons

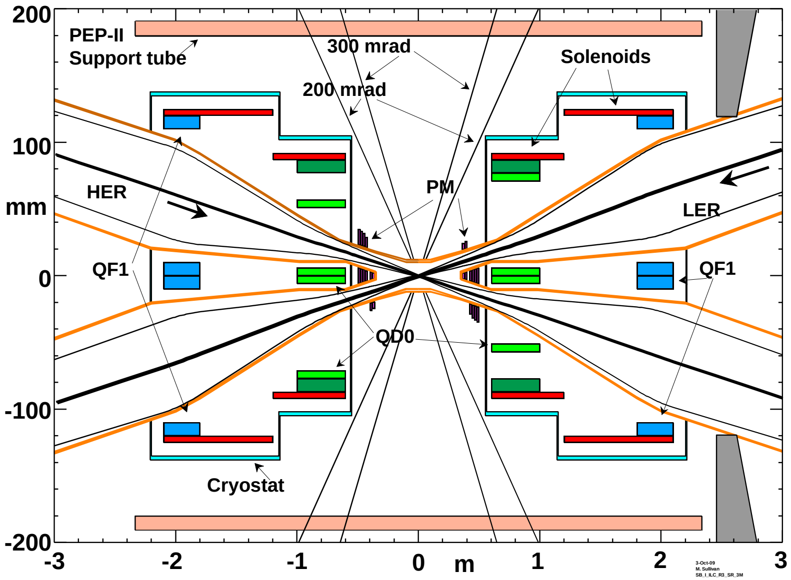
small equilibrium emittance:
23 nm @ 1 GeV

short betatron damping time:
7.3 ms

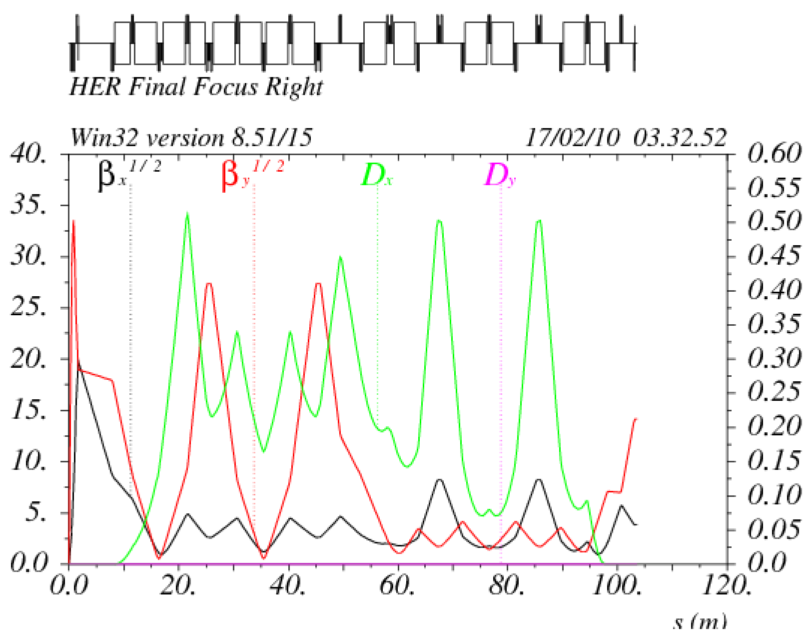
small momentum compaction:
$5.7x10^{-3}$ => short bunch length

large dynamic aperture: ± 20 mm
horizontal, ± 15 mm vertical for
-2% < Δp/p < +2%

Interaction Region



Parameter	HER (e+)	LER (e-)
Beam Energy (GeV)	**6.70**	**4.18**
Beam current (A)	**1.89**	**2.45**
β^*_x (mm)	**26**	**32**
β^*_y (mm)	**0.25**	**0.21**
Emittance X (nm-rad)	**2.00**	**2.46**
Emittance Y (pm-rad)	**5.00**	**6.15**
Crossing angle (mrad)	**±33**	



IR Optics

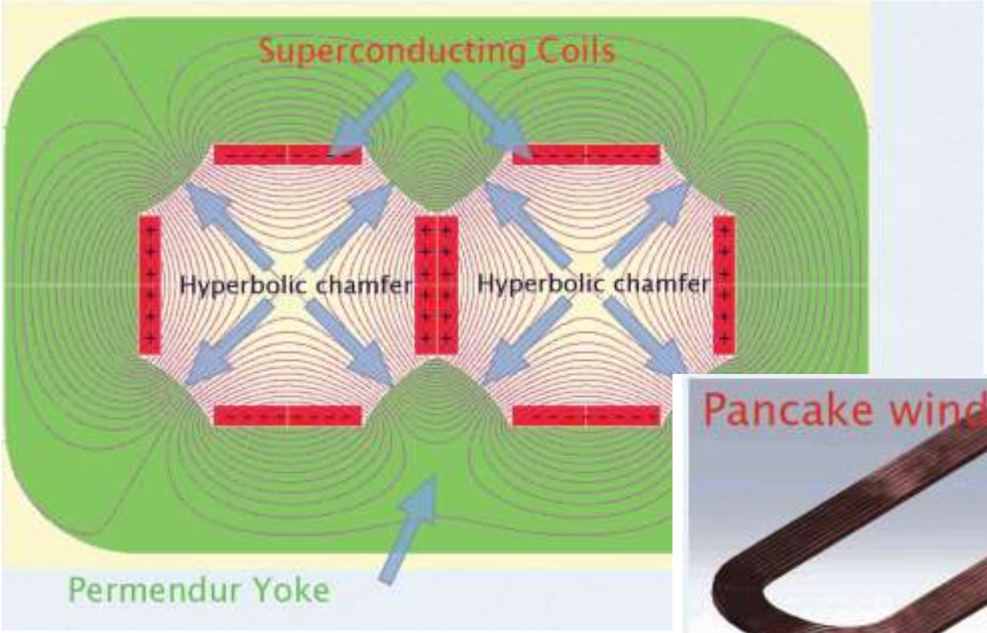
Provides the necessary focusing for required small beam sizes

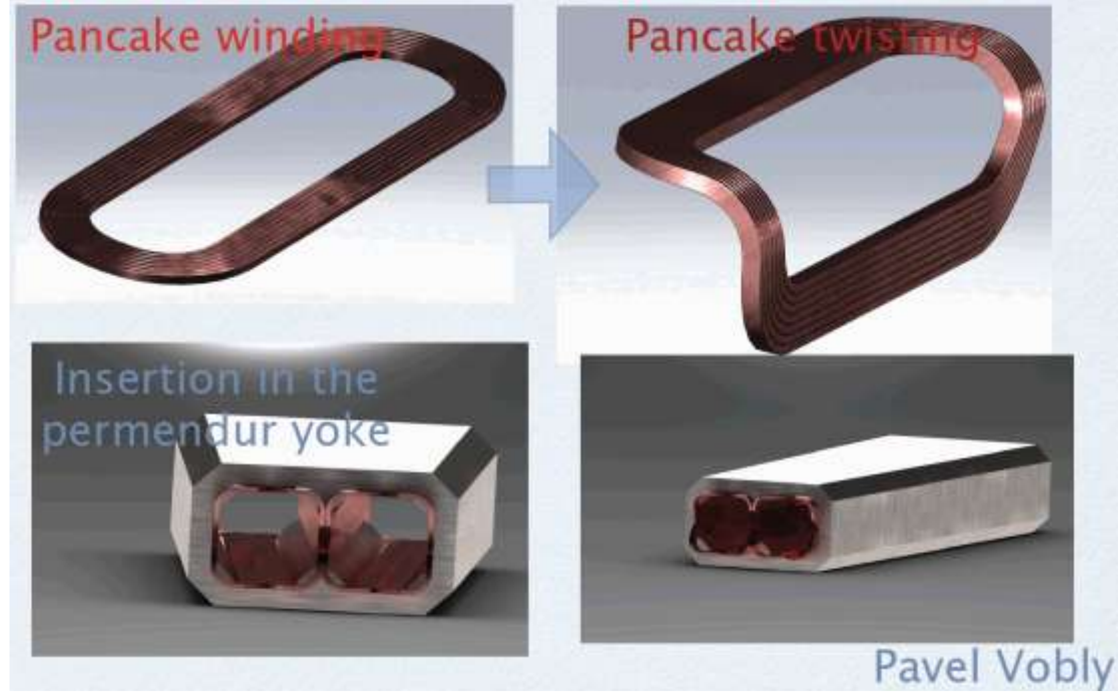
Corrects final focus chromaticity and sextupole abberations

Provides conditions for Crab Waist

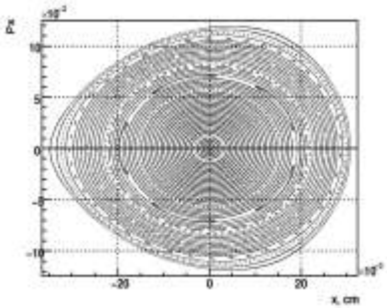
QD0 DESIGN

Siberian Style QD0

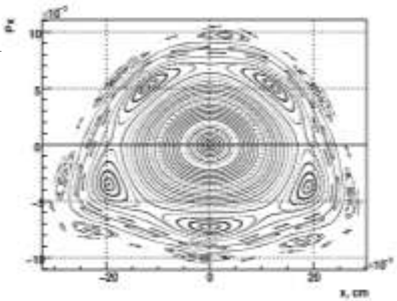


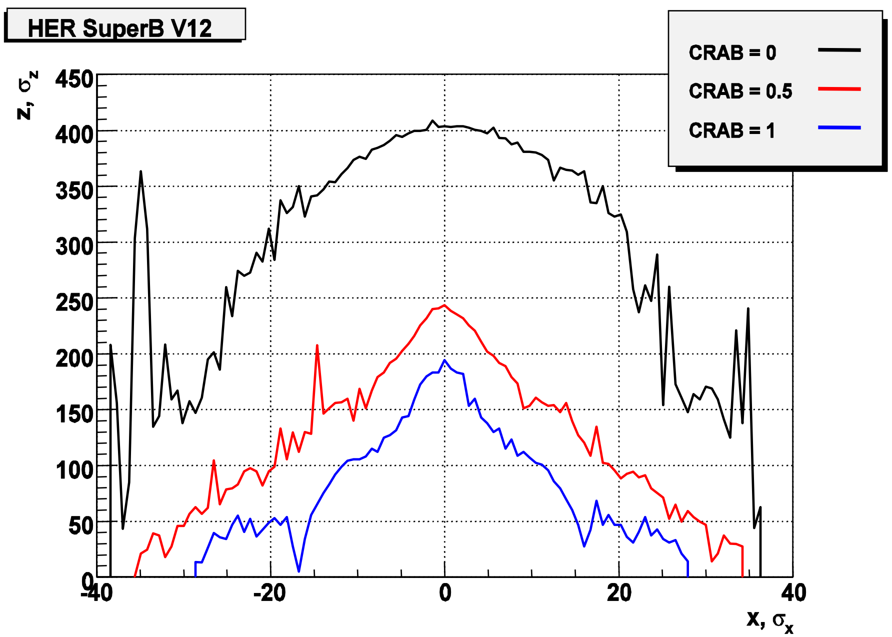


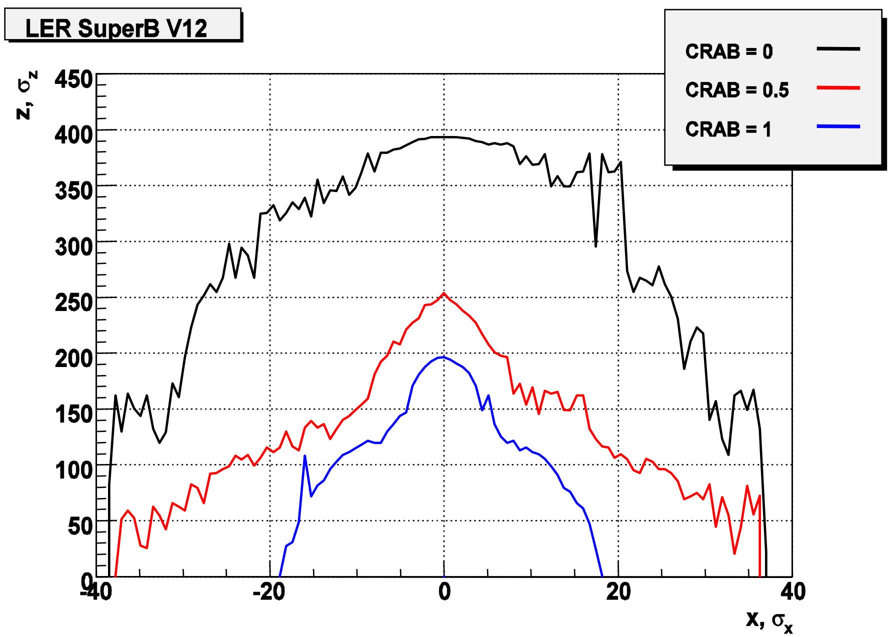
On Energy Dynamic Aperture



Parameters of Crab Sexts	LER	HER	Units
Length, L	35	35	cm
Strength, K_2	±16.67	±16.67	m^{-3}
Horizontal beta, β_x	14.6	14.6	m
Vertical beta, β_z	200	200	m



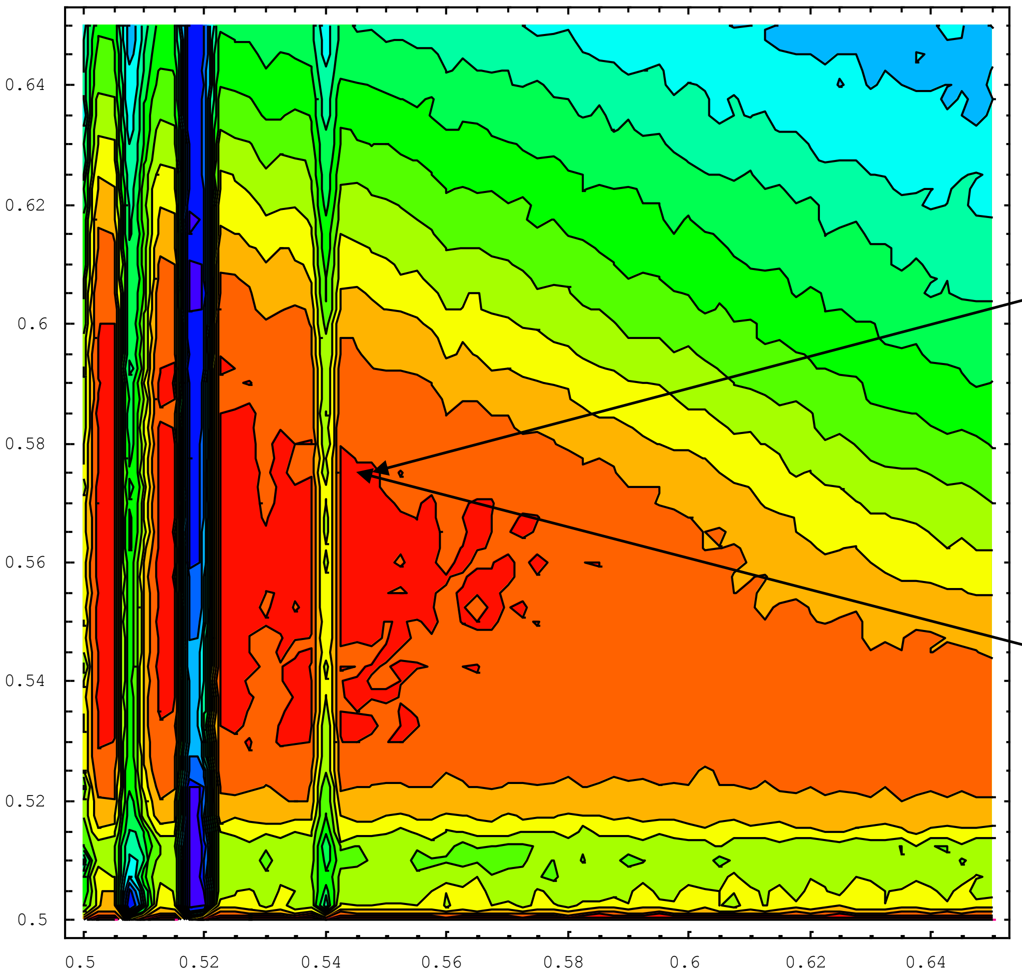


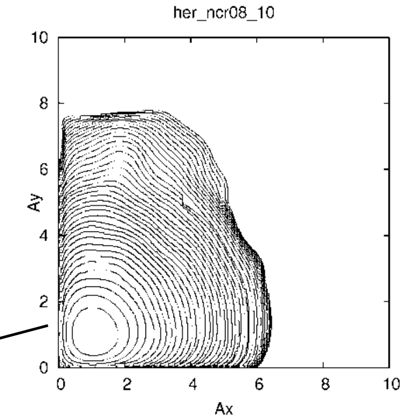


CRAB Sextupoles is Switched On

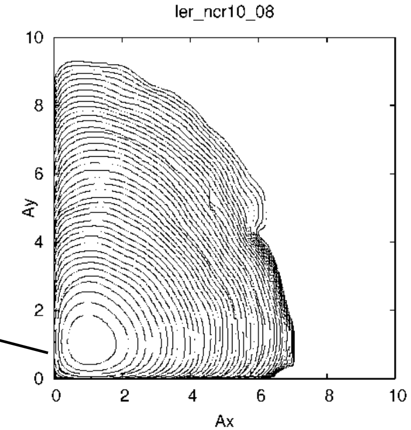
SuperB Luminosity Tune Scan

$\xi_y = 0.17$





HER



LER

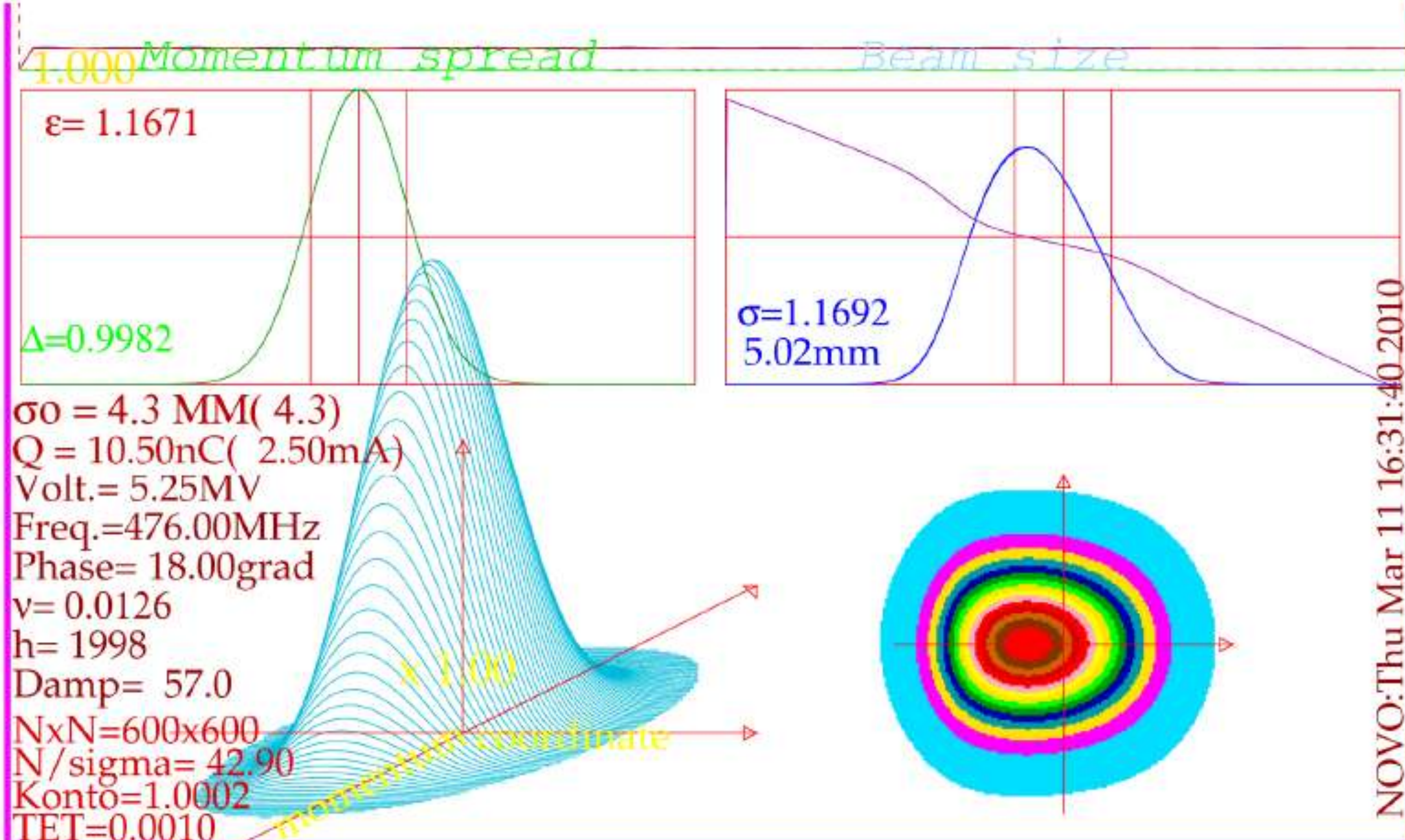
Tunes: (0.542, 0.580, 0.01)
$N_p = 5.74 \cdot 10^{10}$; $N_b = 1011$

$L = 1.04 \times 10^{36}\ cm^{-2}s^{-1}$

D.N.Shatilov, M. Zobov

Bunch lengthening in Super-B. Base line

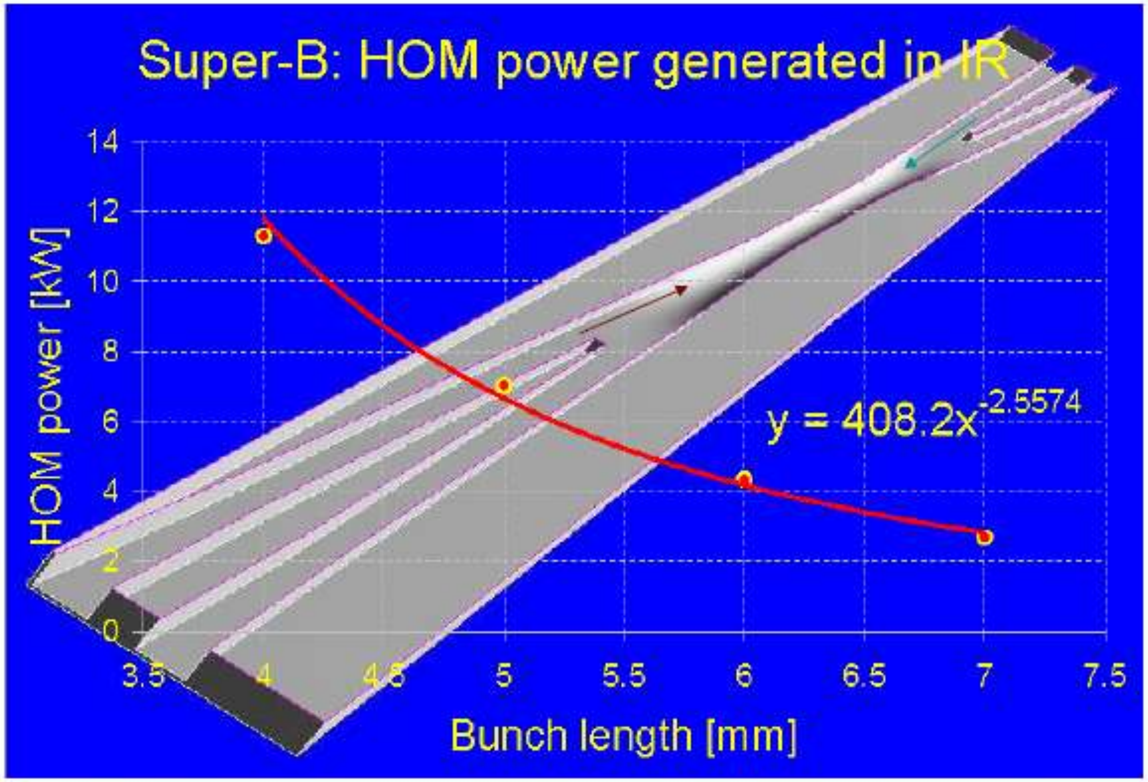
Sasha Novokhatski "Single bunch lengthening"



Lbase.gre

SLAC Stanford

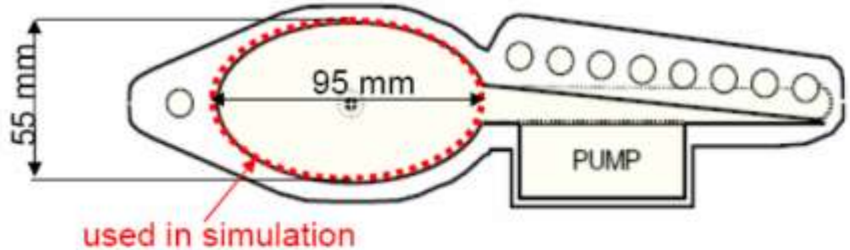
Wake field simulations for the Super-B Interaction Region

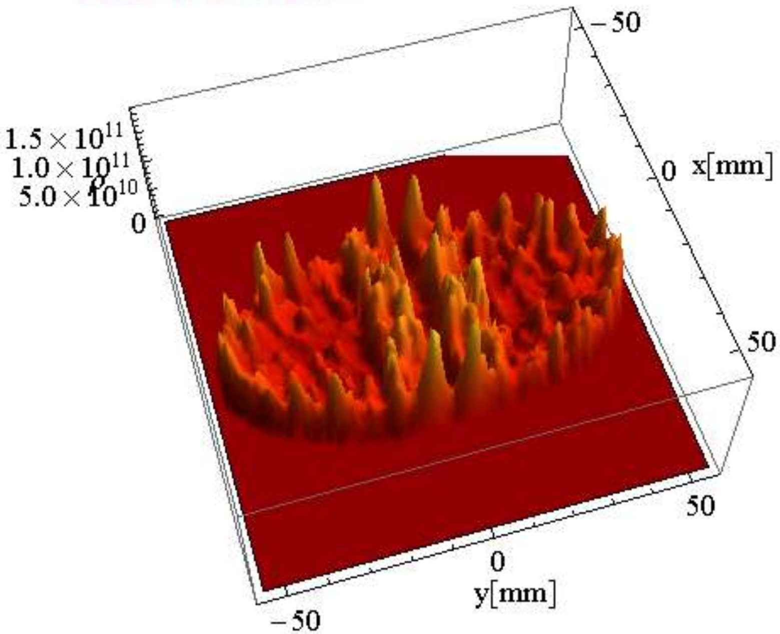


Sasha Novokhatski "RF/Impedance"

Buildup in the SuperB arcs: Dipoles

LER dipole vacuum chamber (CDR)

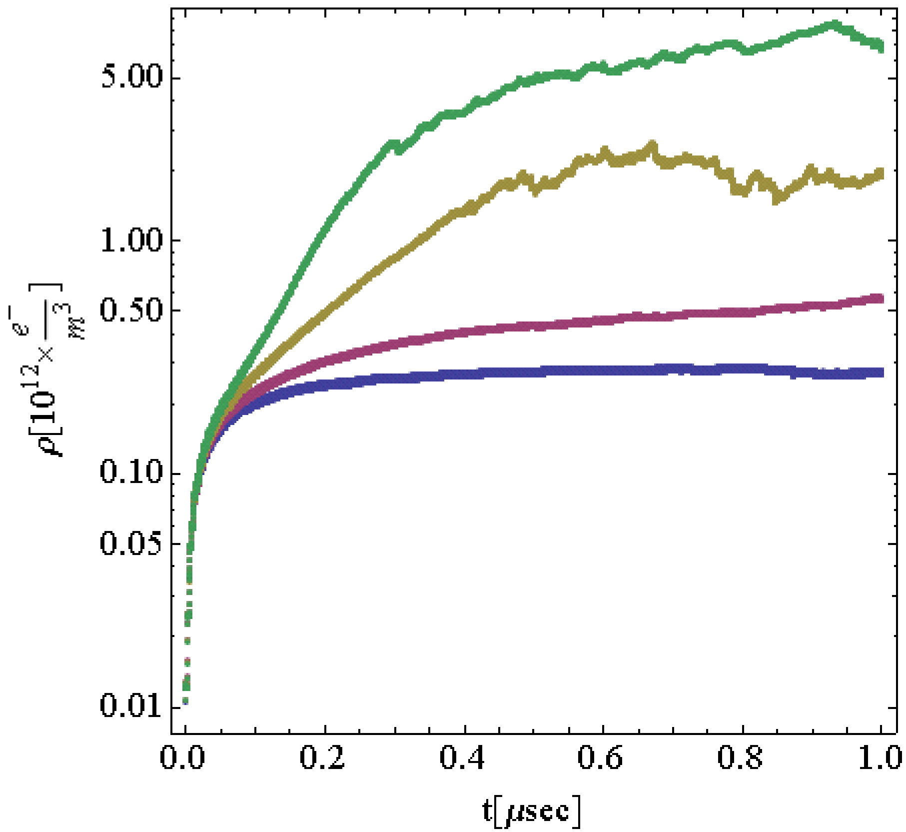




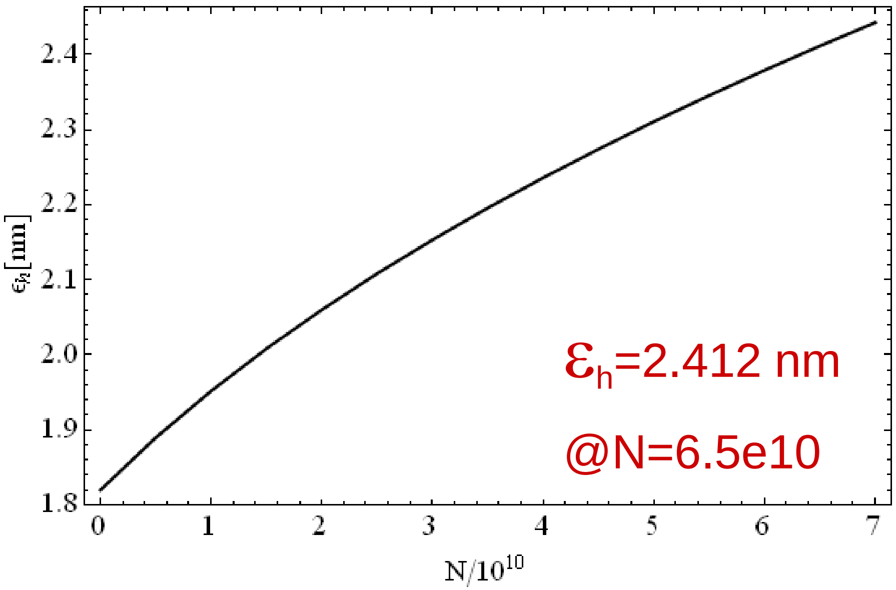
Snapshot of the electron (x,y) distribution "just before" the passage of the last bunch

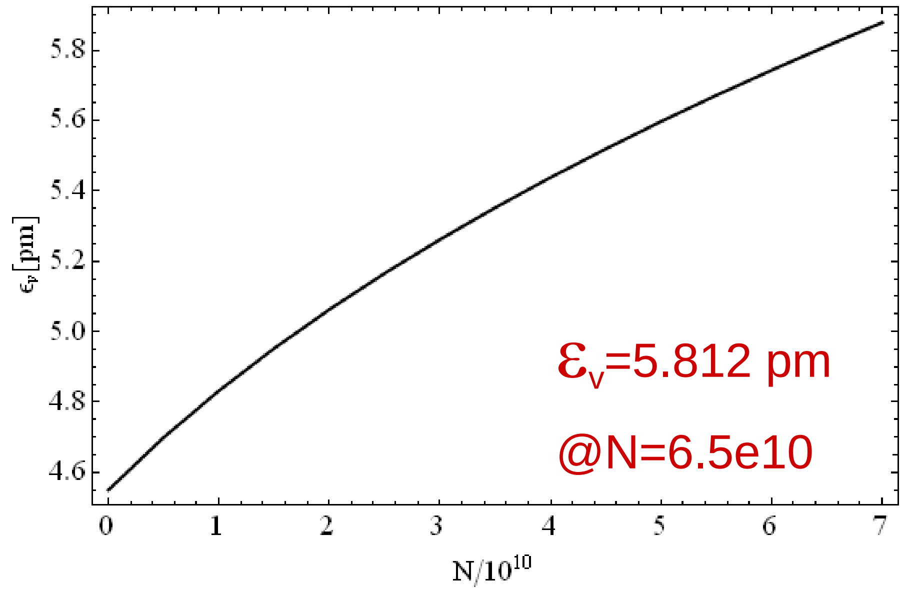
Average e-cloud density for:

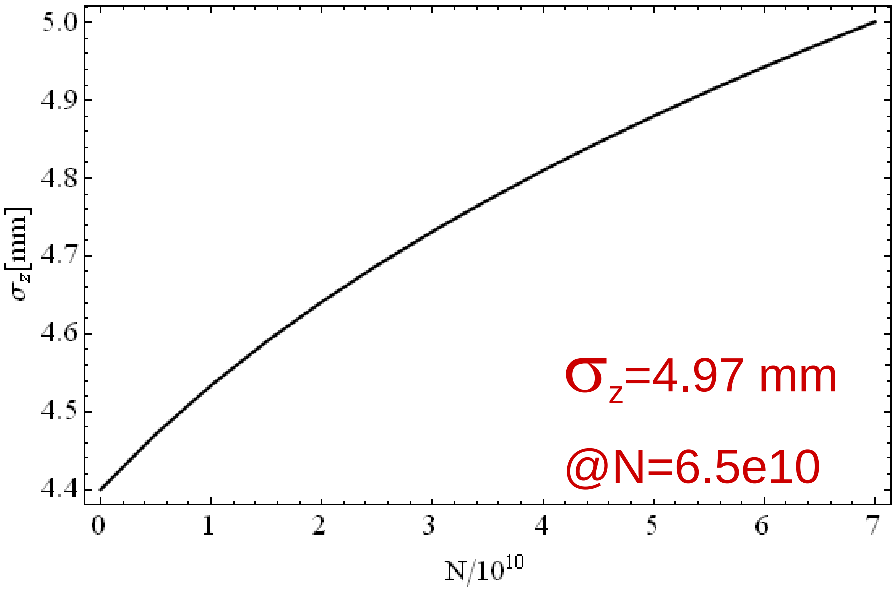
SEY=1.1 SEY=1.2 SEY=1.3 SEY=1.4



IBS in SuperB LER (lattice V12)





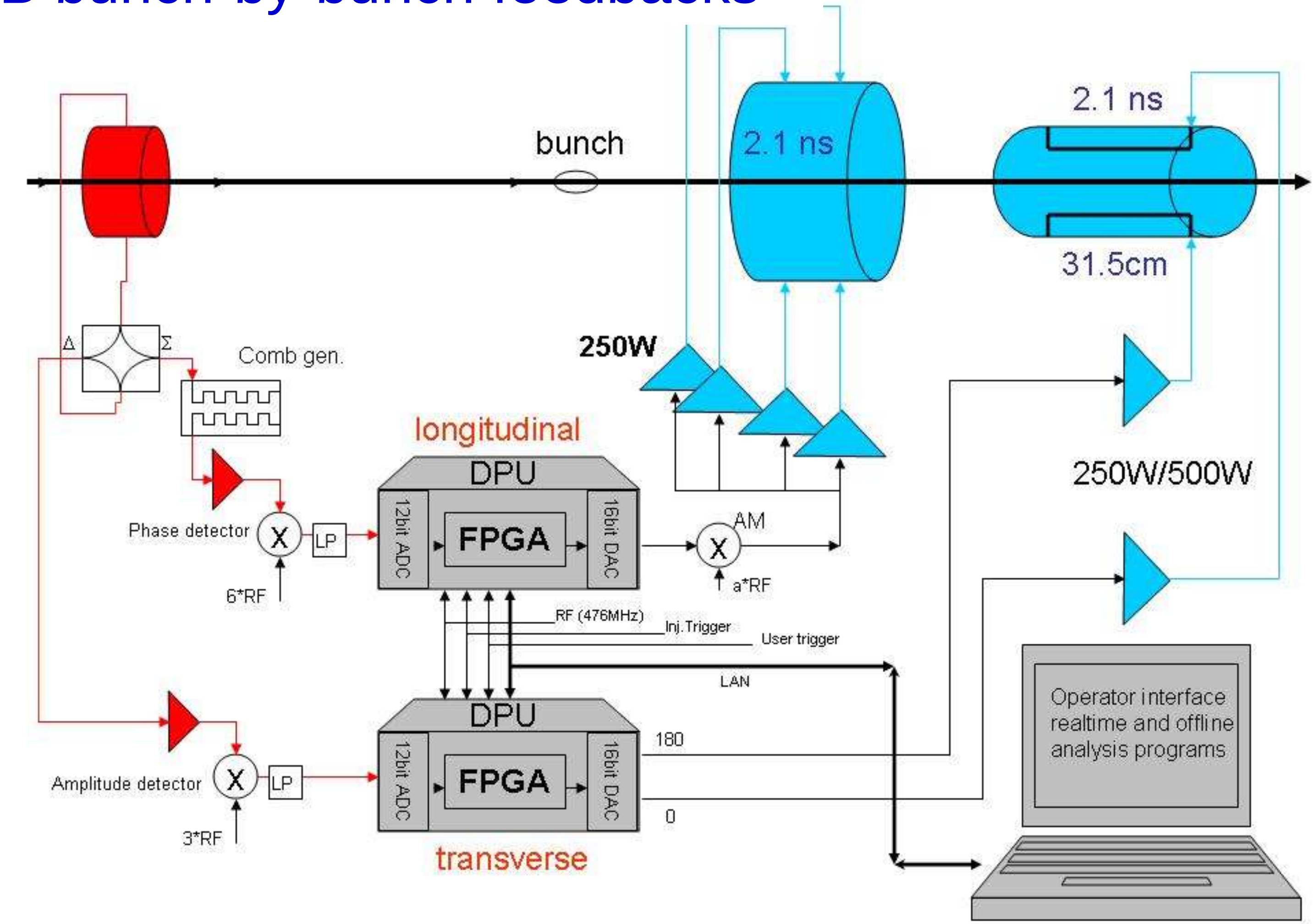


Effect is reasonably small. Nonetheless, there are some interesting questions to answer:

- *What will be the impact of IBS during the damping process? We have calculated the equilibrium emittances in the presence of IBS, but the beam is extracted before it reaches equilibrium…*
- *Could IBS affect the beam distribution, perhaps generating tails?*
- *What happens when vertical emittance is very small as in SuperB?*

M.Boscolo, T.Demma, A.W.Chao

SuperB bunch-by-bunch feedbacks



SuperB bunch-by-bunch feedbacks are based on identical DPU (digital processing unit) for both longitudinal and transverse systems. The DPU core is implemented by a single powerful FPGA (field programmable gate array) containing >2000 DSP (digital signal processor).

A. Drago

More details can be found in:

Super*B*
Progress Reports

The Collider

July 31, 2010

Abstract

This report details the progress made in by the SuperB Project in the area of the Collider since the publication of the SuperB Conceptual Design Report in 2007 and the Proceedings of SuperB Workshop VI in Valencia in 2008.

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159 pages

National Research Plan

Mer 14/04/2010 — Il Sole 24 ORE

Innovazione. Più spazio all'industria

Gelmini aggiorna il piano nazionale

Eugenio Bruno
ROMA

Un acceleratore di particelle complementare a quello del Cern di Ginevra. Un network dei laboratori di nanotecnologia. Una «fabbrica del futuro» per rilanciare il manifatturiero. Uno studio approfondito nell'epigenetica. Sono alcuni dei «progetti bandiera» che il ministro dell'Istruzione Mariastella Gelmini punta a inserire tra le priorità del programma nazionale della ricerca (Pnr) 2010-2012.

La lista degli interventi su cui il Miur vuole dirottare le prime risorse che il Pnr intercetterà contiene 14 voci. Fermo restando che da qui alla sua ufficializzazione potrebbe anche subire delle modifiche, l'elenco si presenta estremamente variegato.

Gli interventi

Progetto	Settore	Valore stimato (milioni)
Super B Factory	Fisica	650
Cosmo - Skymed II generation	Aerospazio	N.D.
Epigenomica	Medicina	N.D.
3N - Network nazionale delle nanotecnologie	Industria	300
Ritmare - Ricerca ita. per il mare	Industria	795
Sintonia - Sistema integrato di telecomunicazioni	Aerospazio	671
Ipi - Invecchiamento e pop. isolate	Medicina	90
Agro Alimentare	Agricoltura	100
L'ambito nucleare	Energia	53,5
Recupero e rilancio della Villa dei Papiri	Beni cluturali	20
Elettra-Fermi-Eurofel	Industria	191
Astri - Astrofisica con specchi a tecnologia replicante italiana	Aerospazio	8
Controllo delle crisi nei sistemi complessi socio-economici	Economica	30
La fabbrica del futuro	Industria	30

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Ministero — Istruzione

Ufficio Stampa

Roma, 26 Aprile 2010

RICERCA, VERTICE ITALIA-RUSSIA, GELMINI FIRMA ACCORDO SU RICERCA NUCLEARE

Oggi, il ministro Mariastella Gelmini, in occasione del vertice italo-russo di Lesmo, ha firmato una dichiarazione d'intenti tra il MIUR e il Ministero della ricerca scientifica russo per la realizzazione di due importanti progetti per la promozione della ricerca nel settore della fusione nucleare.

L'intesa riguarda i programmi di ricerca denominati "IGNITOR" e "SUPER B". Il programma "IGNITOR" prevede la realizzazione in Russia di un innovativo reattore sperimentale a fusione nucleare che verrà utilizzato come fonte di energia.

Il programma "SUPER B" riguarda la realizzazione in Italia di un acceleratore di particelle di nuova generazione che consentirà una più alta intensità di collisioni tra particelle, permettendo la produzione di "quark pesanti".

Ministry's Press Release