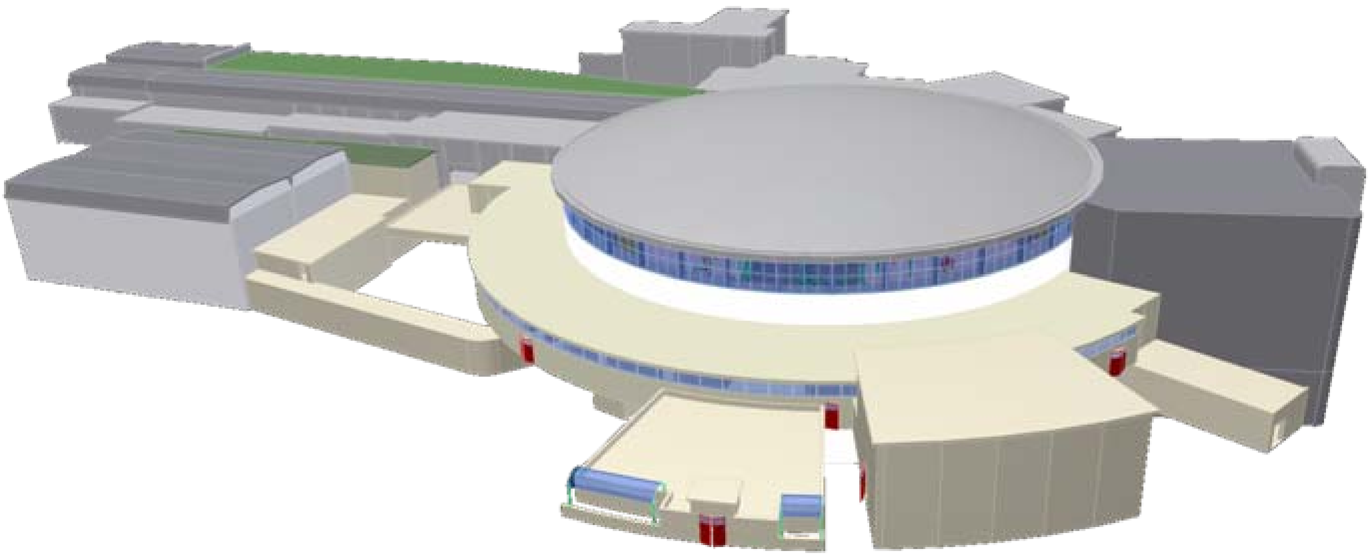
OVERVIEW OF BEAM DYNAMICS STUDIES AT DAΦNE

M. Zobov for DAΦNE Team



40th ICFA Advanced Beam Dynamics Workshop on
High Luminosity e+e- Factories

14-16 April 2008, BINP, Novosibirsk, Russia

DAΦNE Team

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(LNF INFN, Italy)

+

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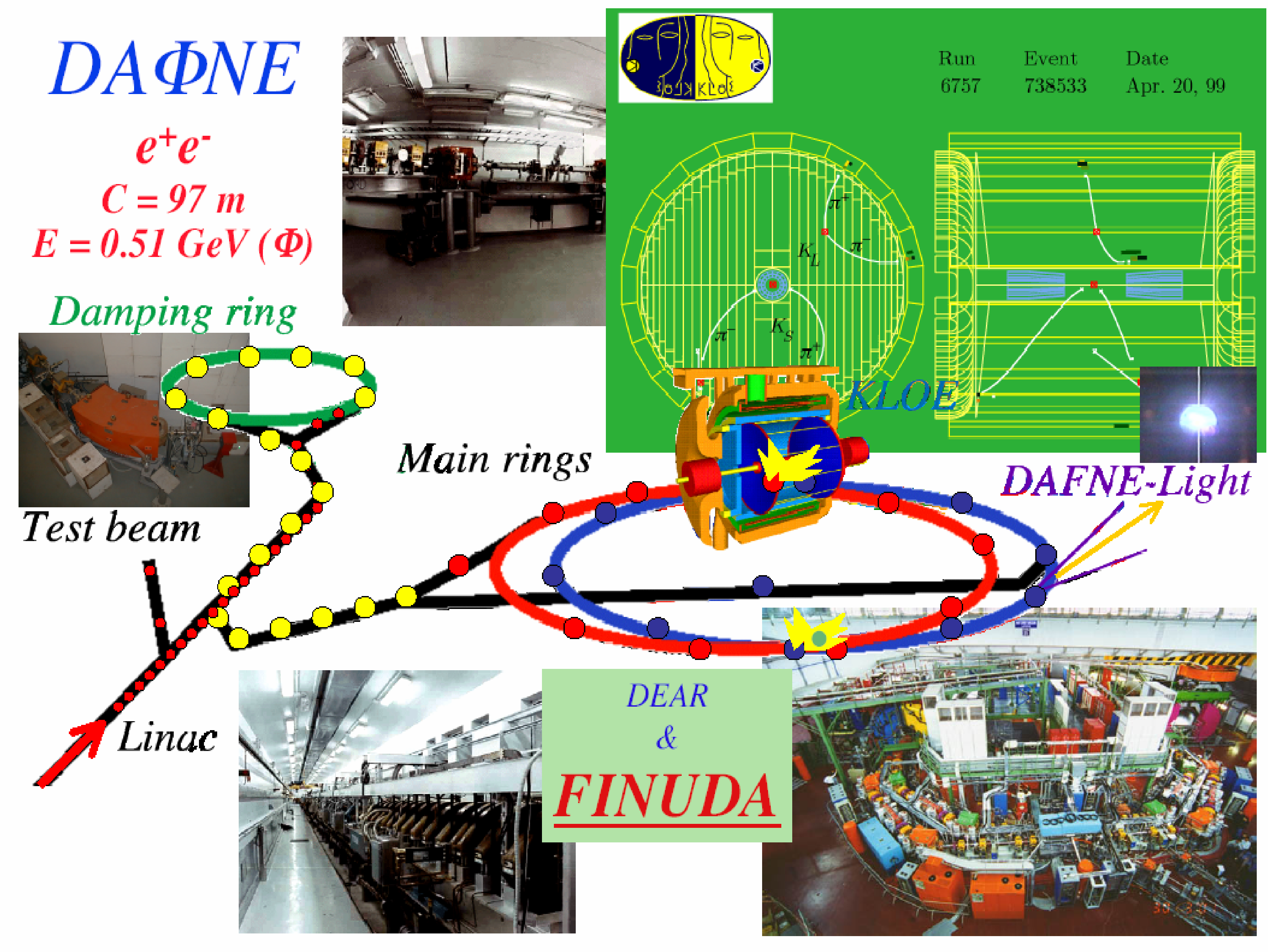
K. Ohmi (KEK, Japan)

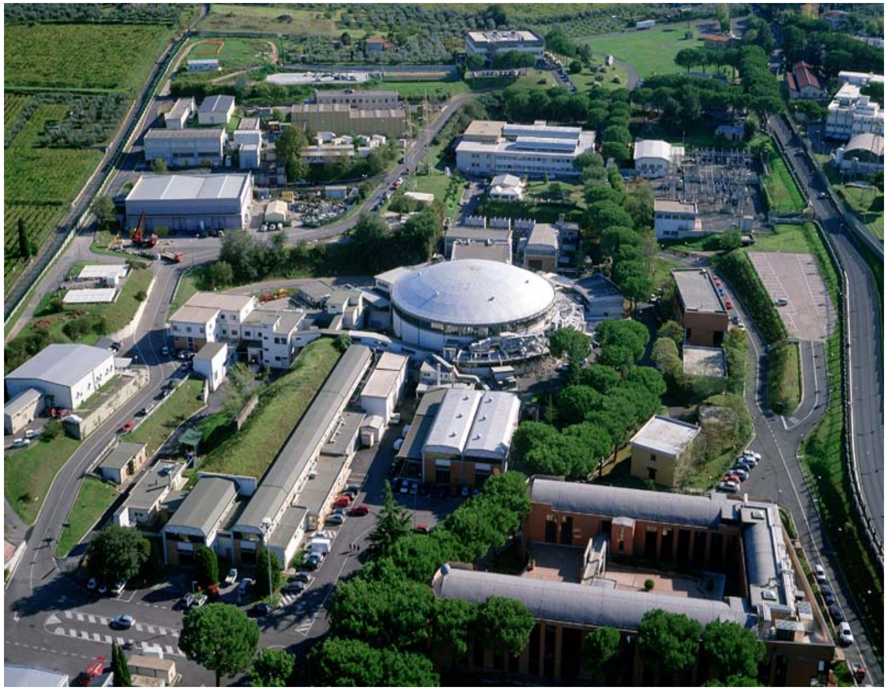
OUTLINE

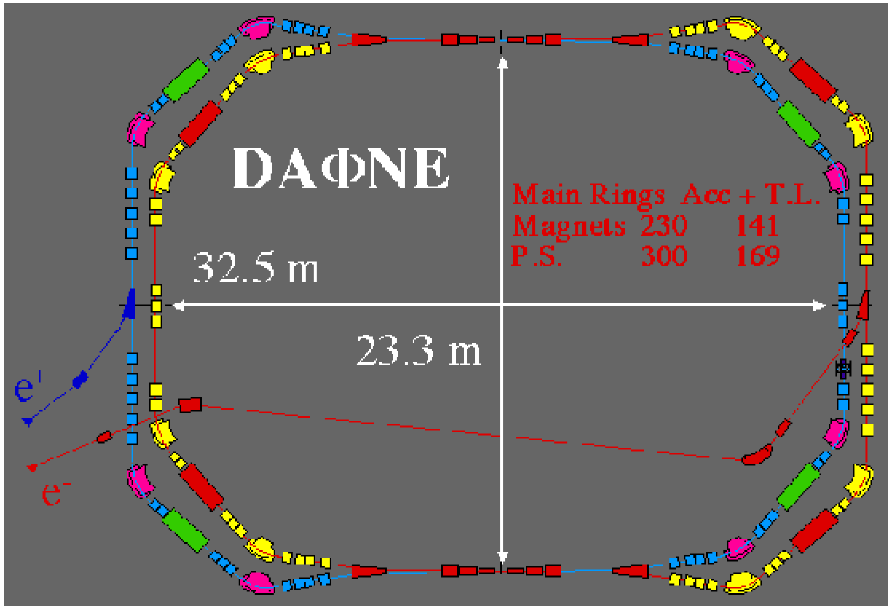
- DAΦNE: description and status (before the crab waist upgrade)
- Beam Dynamics: problems, solutions, experience
  a) Single bunch dynamics
  b) Multibunch Instabilities
  c) Beam-beam performance
- Major Upgrade Proposals
  a) Strong RF focusing experiment
  b) DANAE Proposal
  c) Crab Waist Collisions Scheme


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

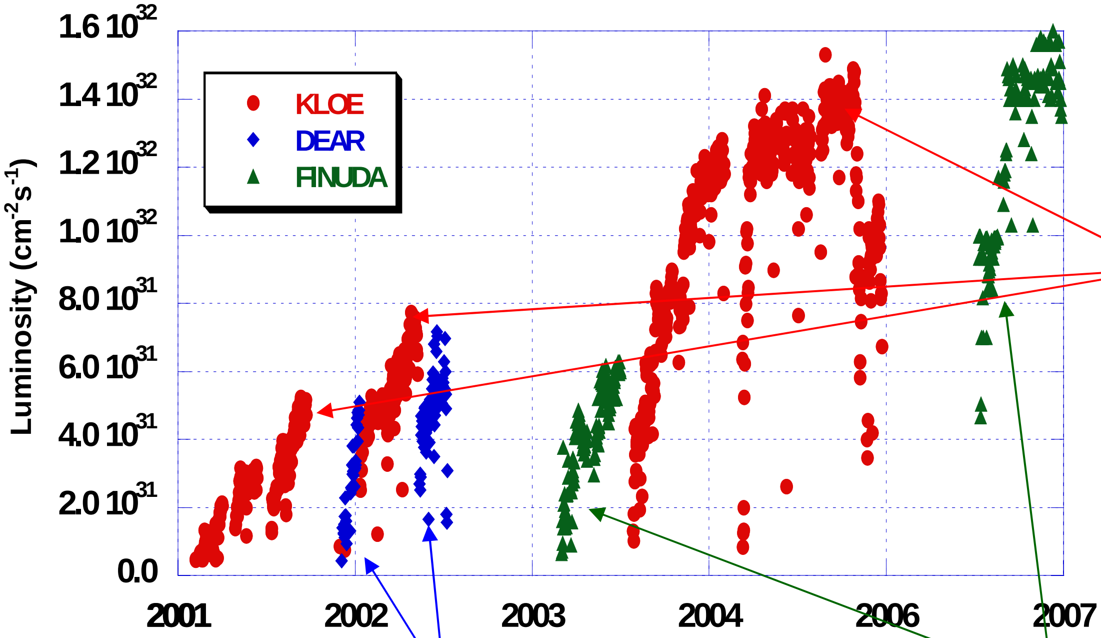
DAΦNE Parameters
(KLOE configuration)

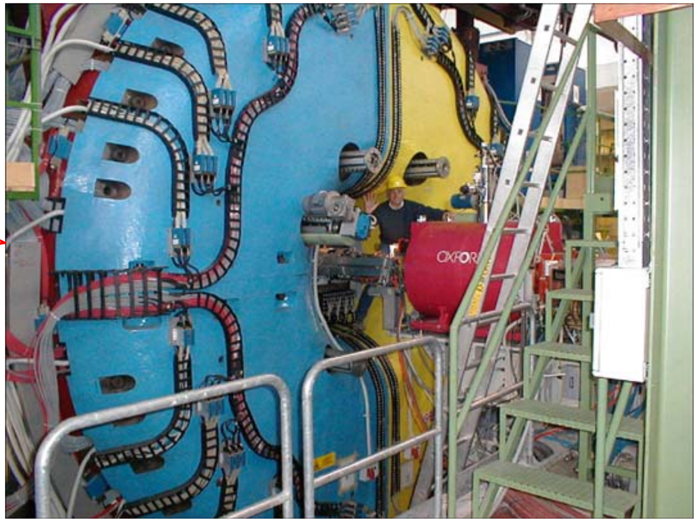
Energy, GeV	0.51
Circumference, m	97.69
RF Frequency, MHz	368.26
Harmonic Number	120
Damping Time, ms	17.8/36.0
Bunch Length, cm	1-3
Emittance, mmxmrad	0.34
Coupling, %	0.2-0.3
Beta Function at IP, m	1.7/0.017
Max. Tune Shifts	.03-.04
Number of Bunches	111
Max.Beam Currents, A	2.4/1.4

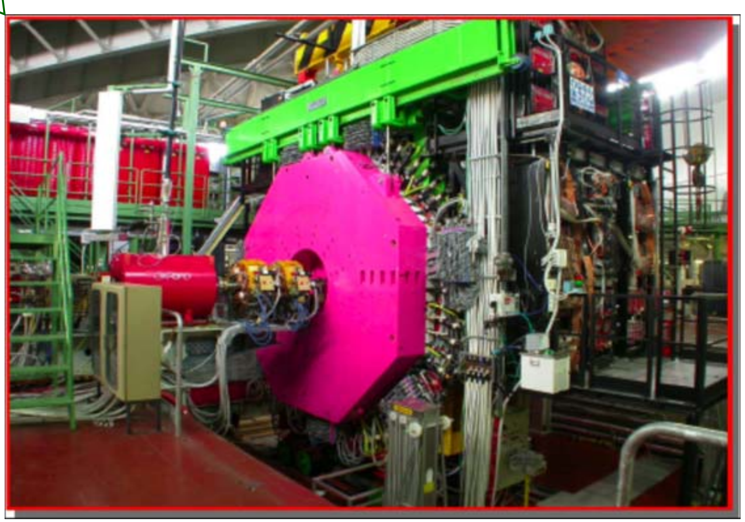




DAΦNE Peak Luminosity



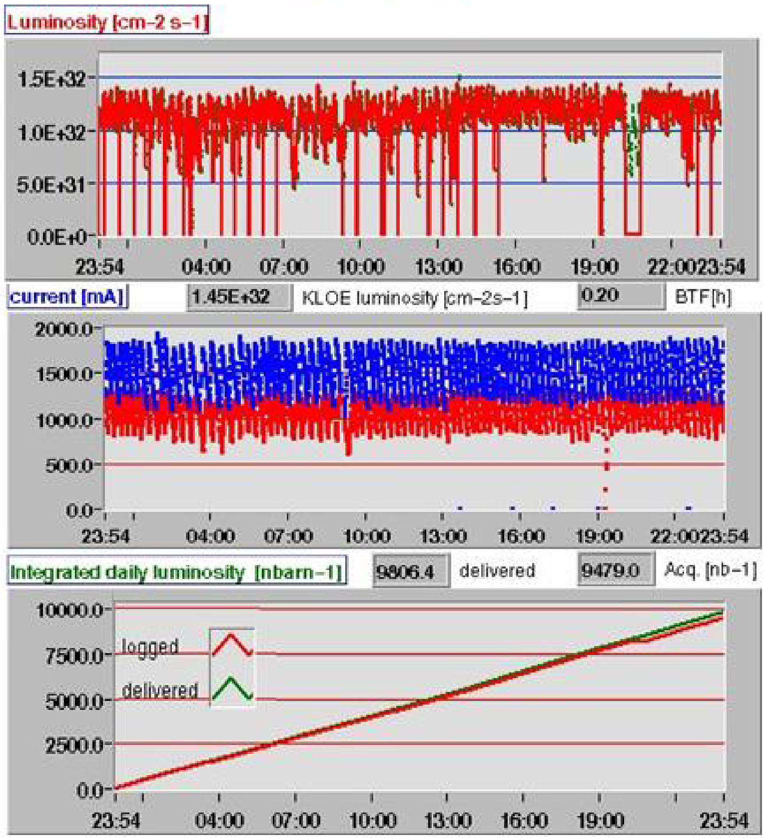




The nature of a Φ-factory in itself indictates a minimum target luminosity of 10^{32} cm^{-2} s^{-1}….

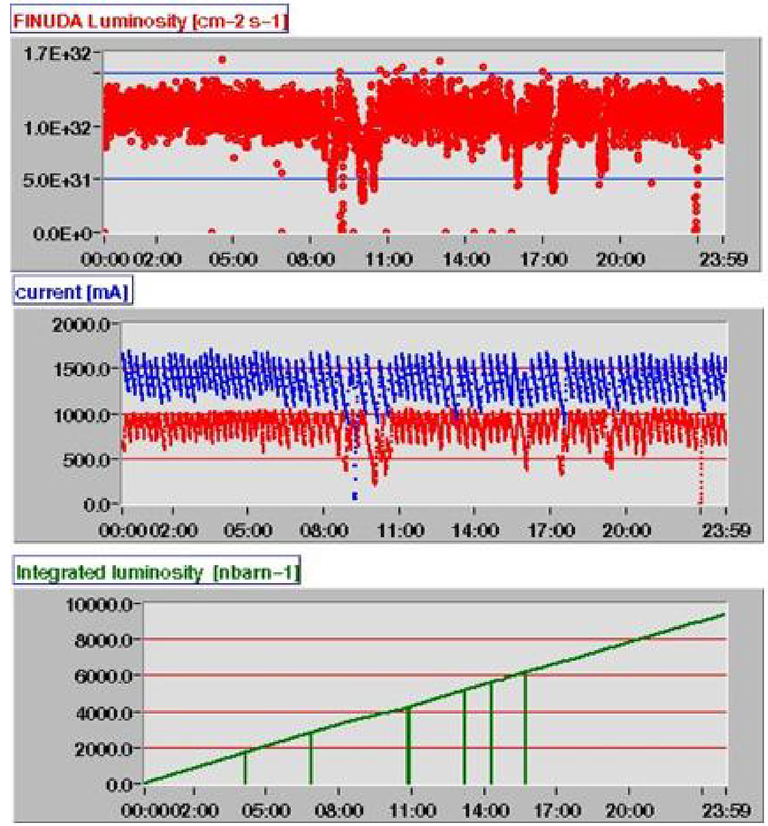
"Proposal for a Φ-factory", LNF-90/031 (IR),1990.

KLOE



111 bunches, $\beta_y^* = 1.8$ cm, $\beta_x^* = 1.5$ m

FINUDA

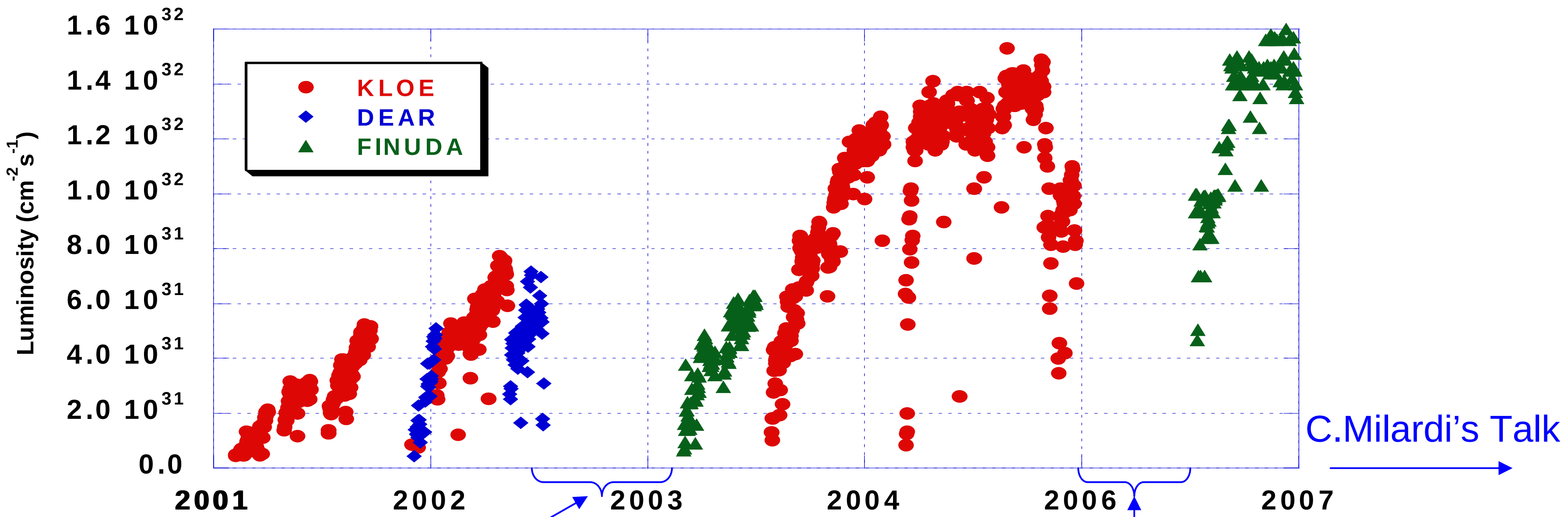


106 bunches, $\beta_y^* = 1.9$ cm, $\beta_x^* = 2.0$ m

Accelerator Physics Issues
(studied, understood, optimized…)

- Working point choice
- Coupling correction
- Careful optics modeling
- Nonlinear beam dynamics study
- Single- and multibunch instability cures
- Collision point parameter optimization
- Fine collider tuning in collisions

Hardware Modifications



1. FINUDA installation
2. New KLOE IR installation
3. Wiggler poles modification
4. Straifght sections modification
5. Injector kickers modification
6. Scrapers and Bellows modification
7. Clearing electrodes modification
8. Systems maintanance
9. Other

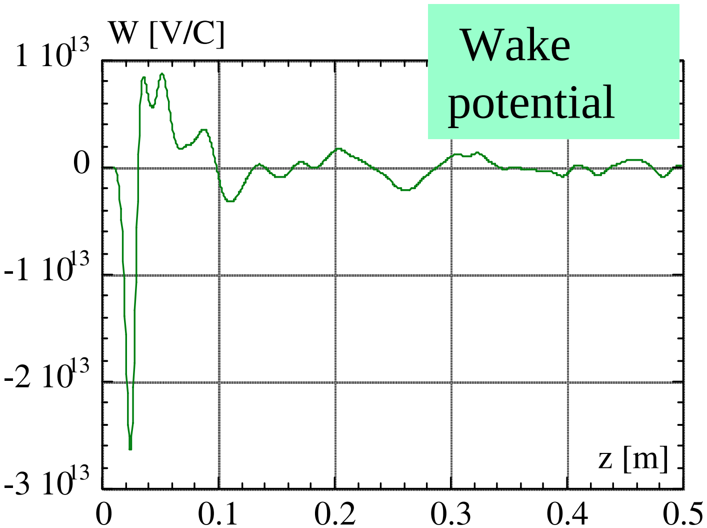
1. KLOE removal, FINUDA installation
2. New simplified interaction region 1
3. Wiggler ion clearing electrodes removal
4. New parasitic crossings compensating wires
5. New BPMs for single turn measurements
6. New 3° generation transverse feedbacks
7. Control system upgrade
8. Systems maintanence
9. Other

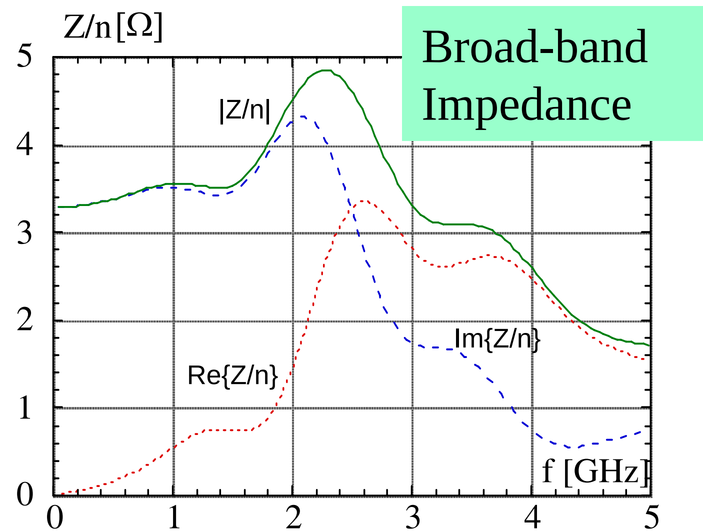
Single Bunch Dynamics

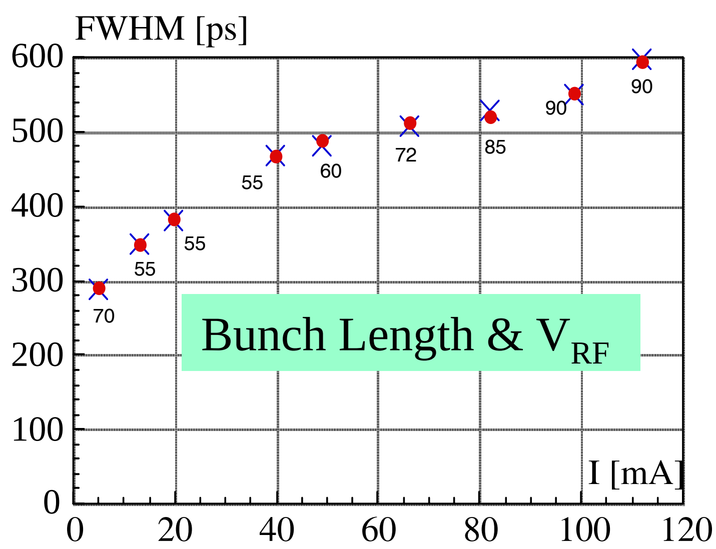
- Bunch lengthening
- Vertical bunch size blow up
- Broad-band impedance reduction

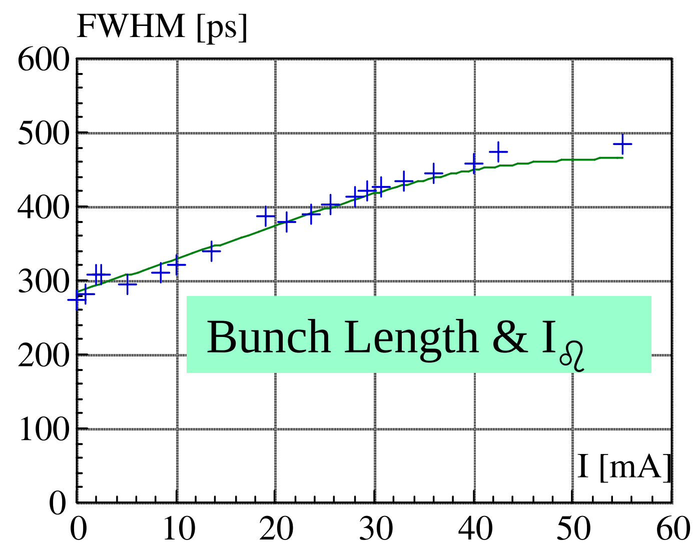
Bunch Lengthening in DAΦNE Accumulator Ring

(Nucl. Instrum. Meth. A418: 241-248, 1998)







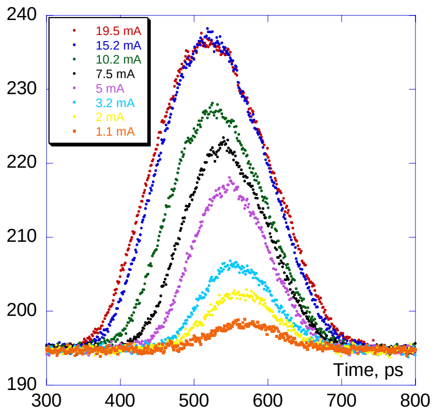


Bunch Lengthening in DAΦNE

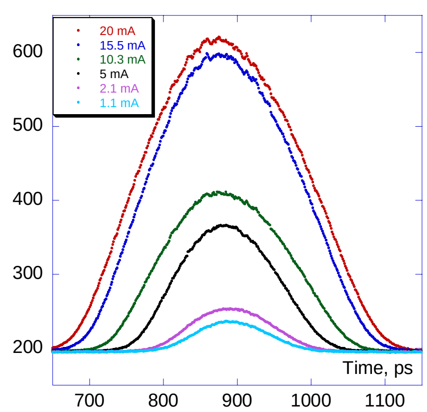
Typical Measured Bunch Distributions

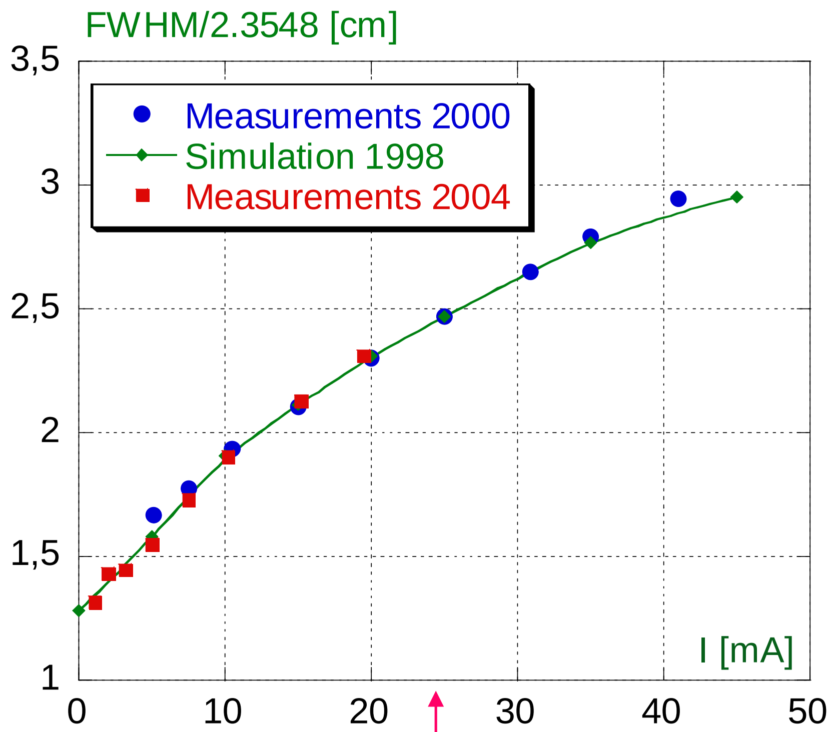
M. Zobov et al., e-Print: physics/0312072

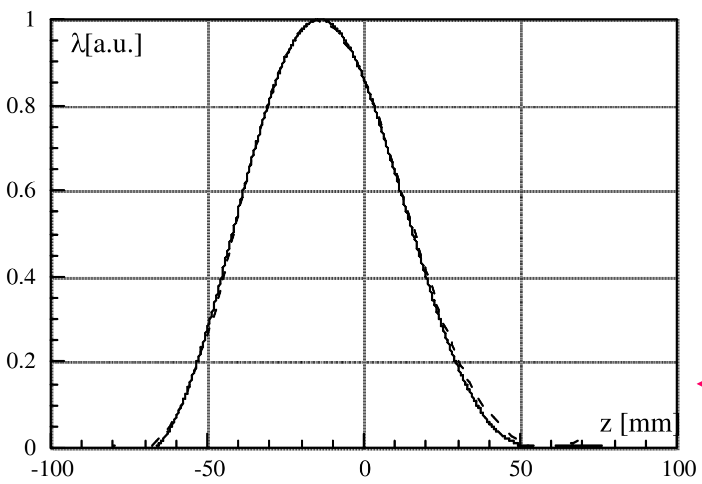
e+ Ring



e- Ring



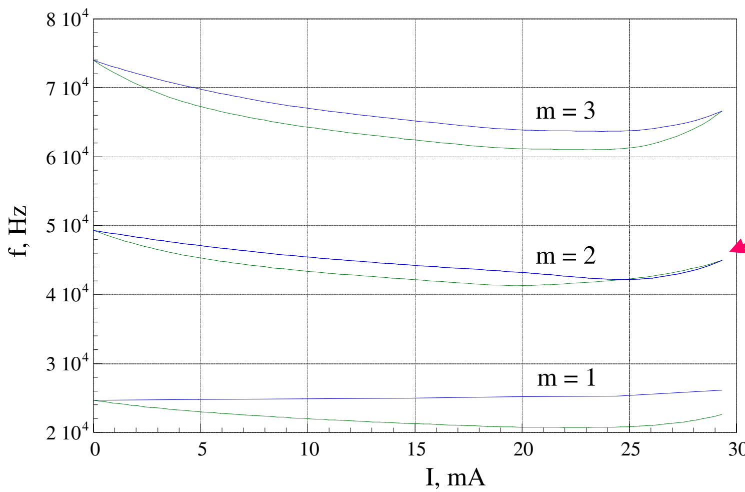




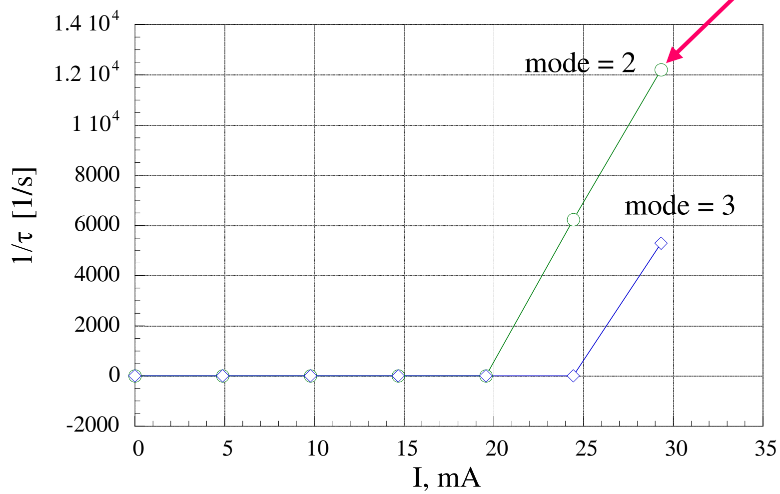
Comparison with Simulations

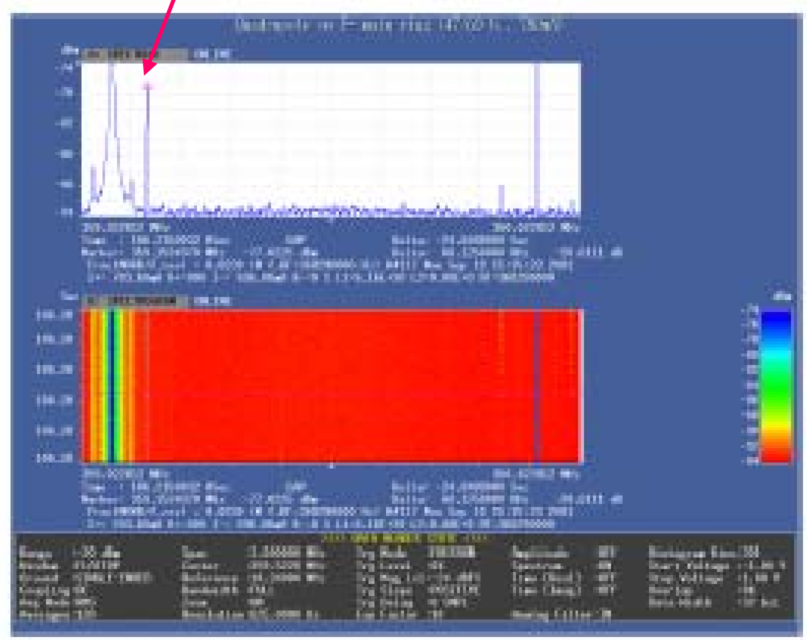
DAΦNE Quadrupole Instability

M. Zobov et al., e-Print: physics/0312072



$2f_s$

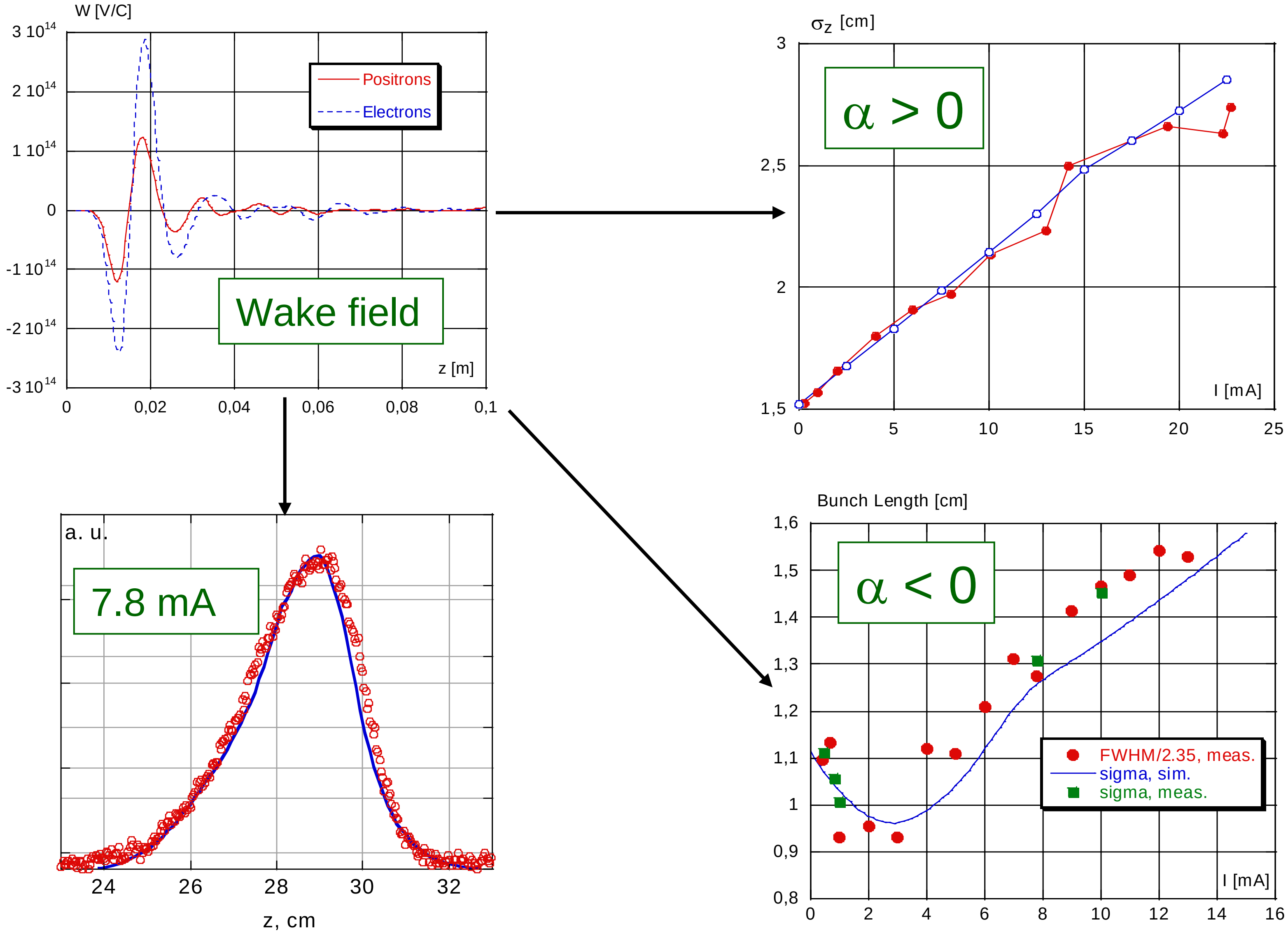




A. Drago et al., PRSTAB 6:052801,2003

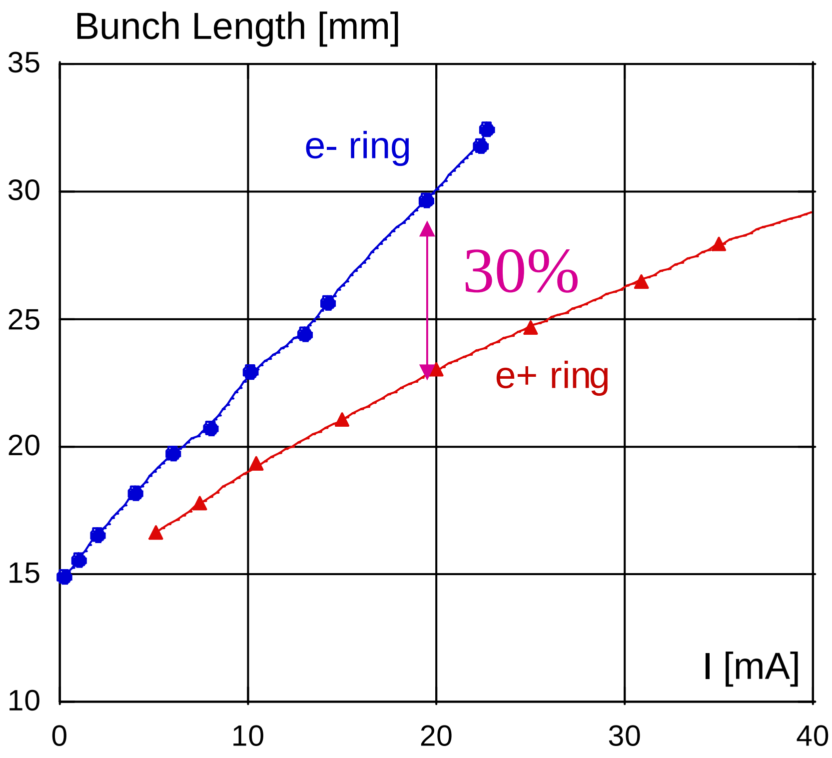
Bunch Lengthening in Electron Ring

B. Spataro and M. Zobov, DAΦNE Technical Note: G-64, 2005

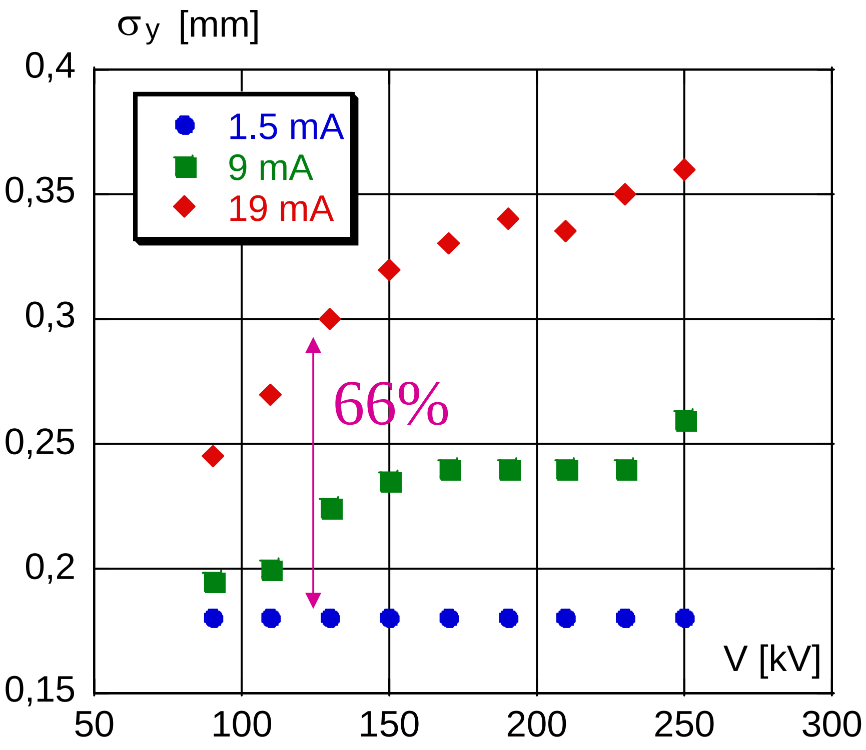


Impedance Effects in the e- Ring

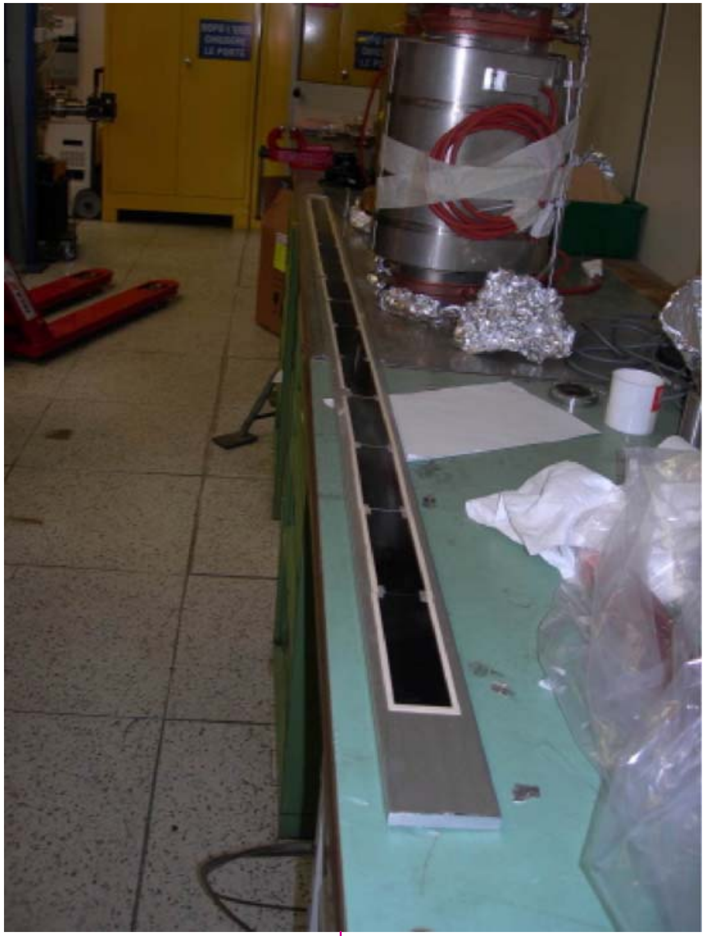
Stronger Bunch Lengthening

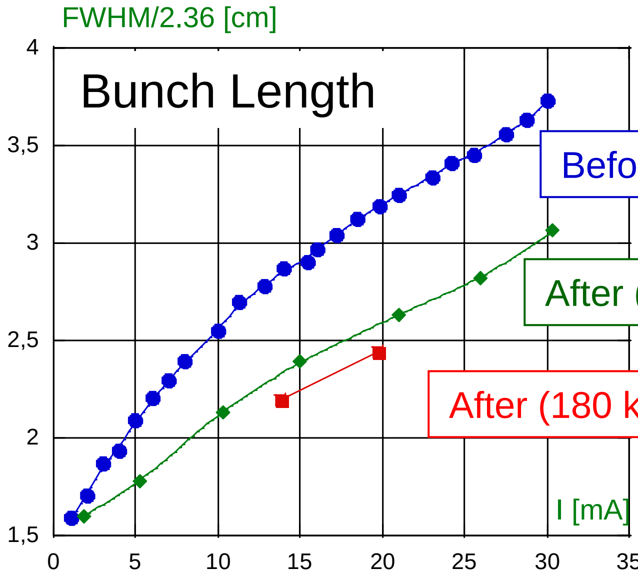


Vertical Size Blow f(V_{RF}, I_b)



After Ion Clearing Electrode Removal



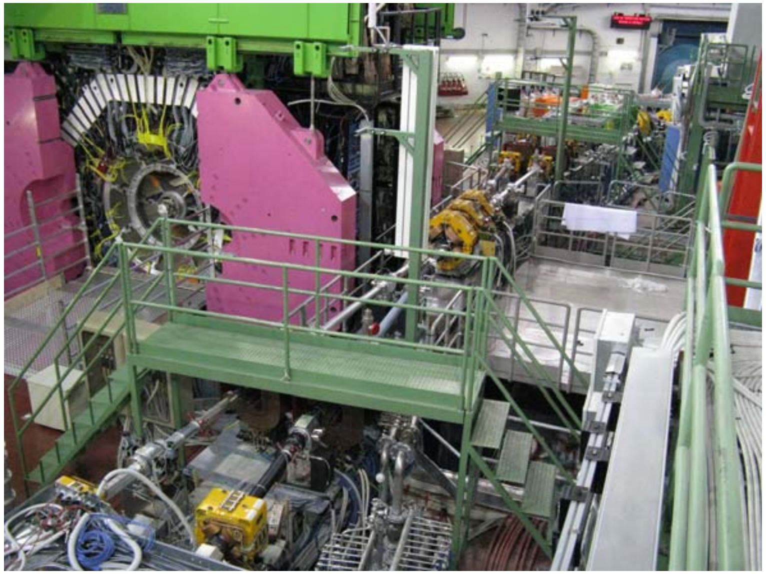


1. About 30% e- bunch length reduction
2. Twice higher longitudinal microwave instability threshold
3. No quadrupole instability
4. No single bunch vertical blow up

Geometric luminosity by 50% higher!

Modified Vacuum Chamber

Interaction Region 1



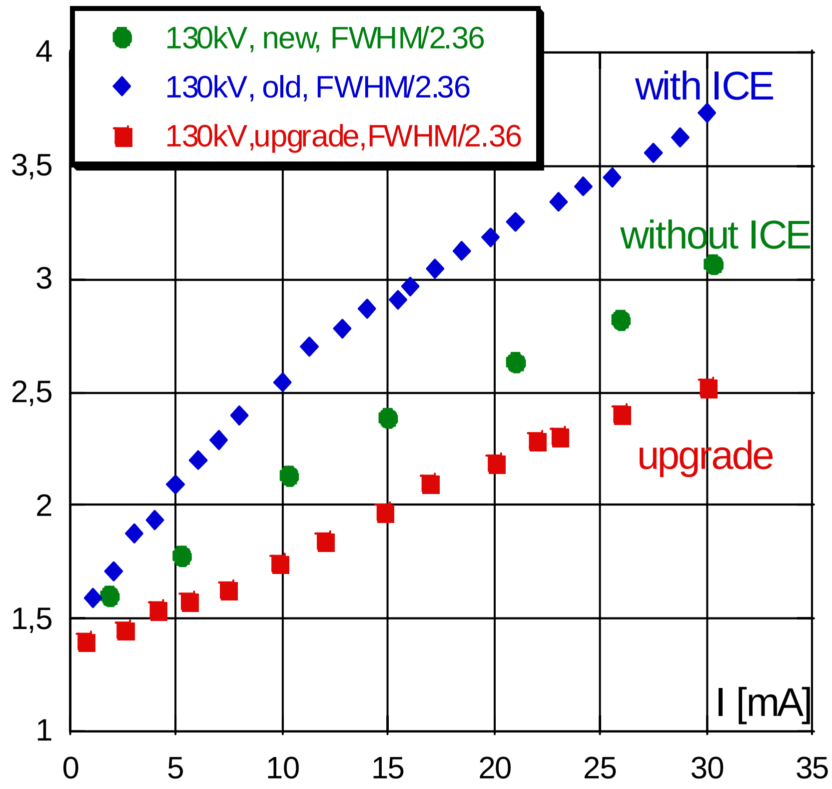
Interaction Region 2

New Injection Kickers

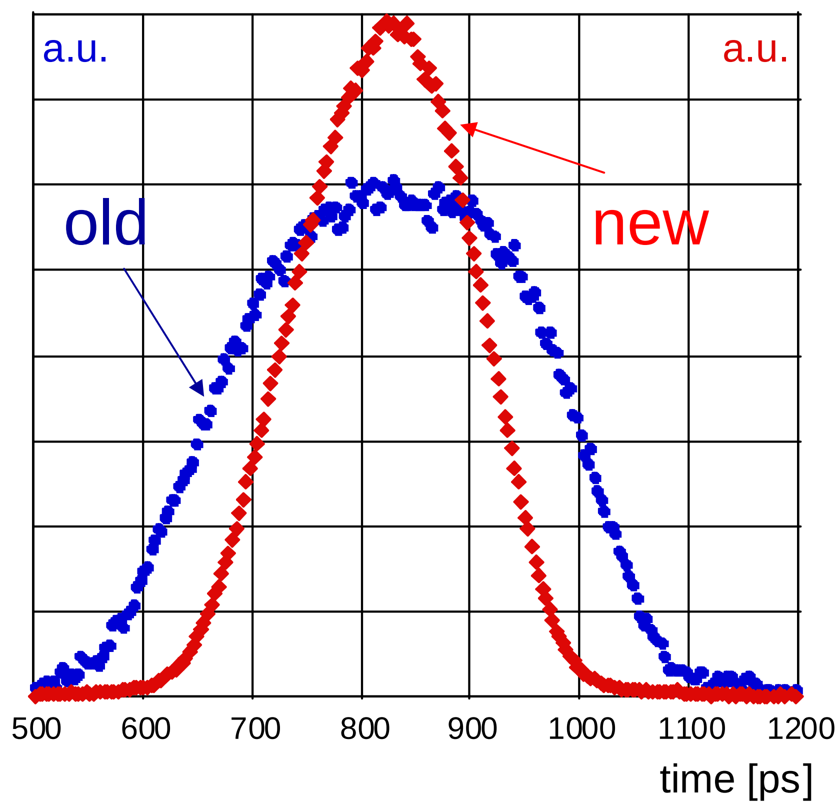
New Bellows

Bunch Lengthening in Upgraded Vacuum Chamber

Bunch Length



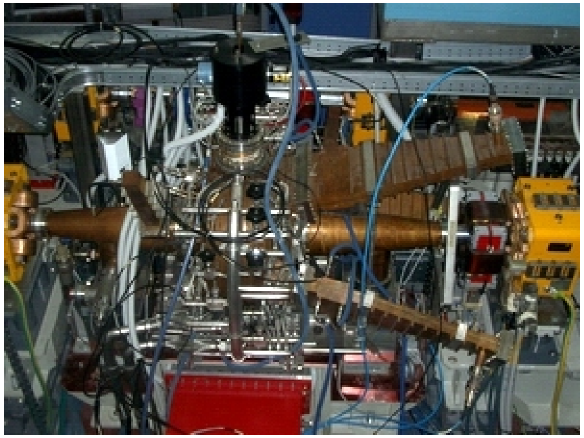
Charge Distribution



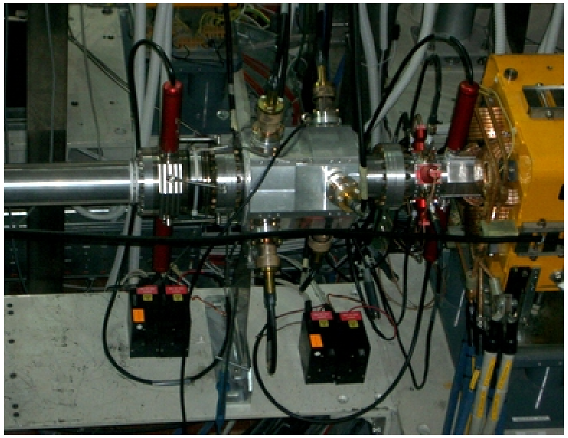
Multibunch Instabilities

- HOM Free Vacuum Chamber Design
- Longitudinal Quadrupole Instability
- Horizontal Instability in the Positron Ring

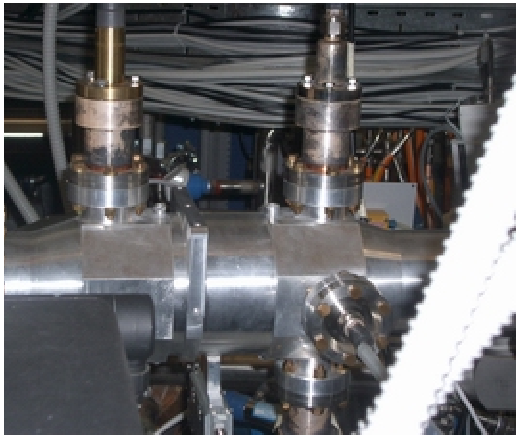
HOM Damped Vacuum Chamber Elements



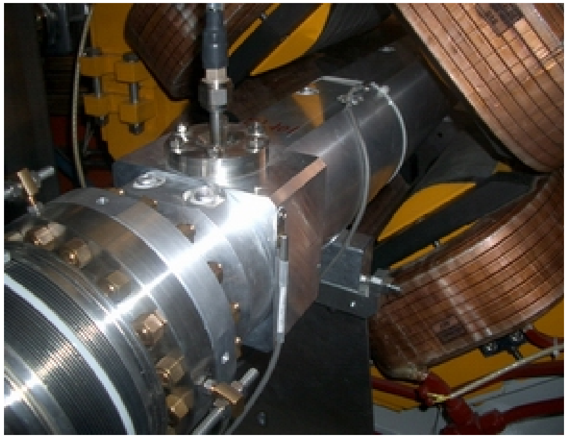
RF CAVITY



LONGITUDINAL KICKER

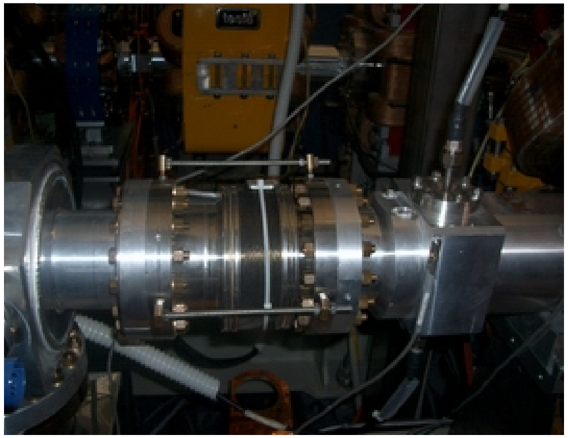


TRANSVERSE KICKER



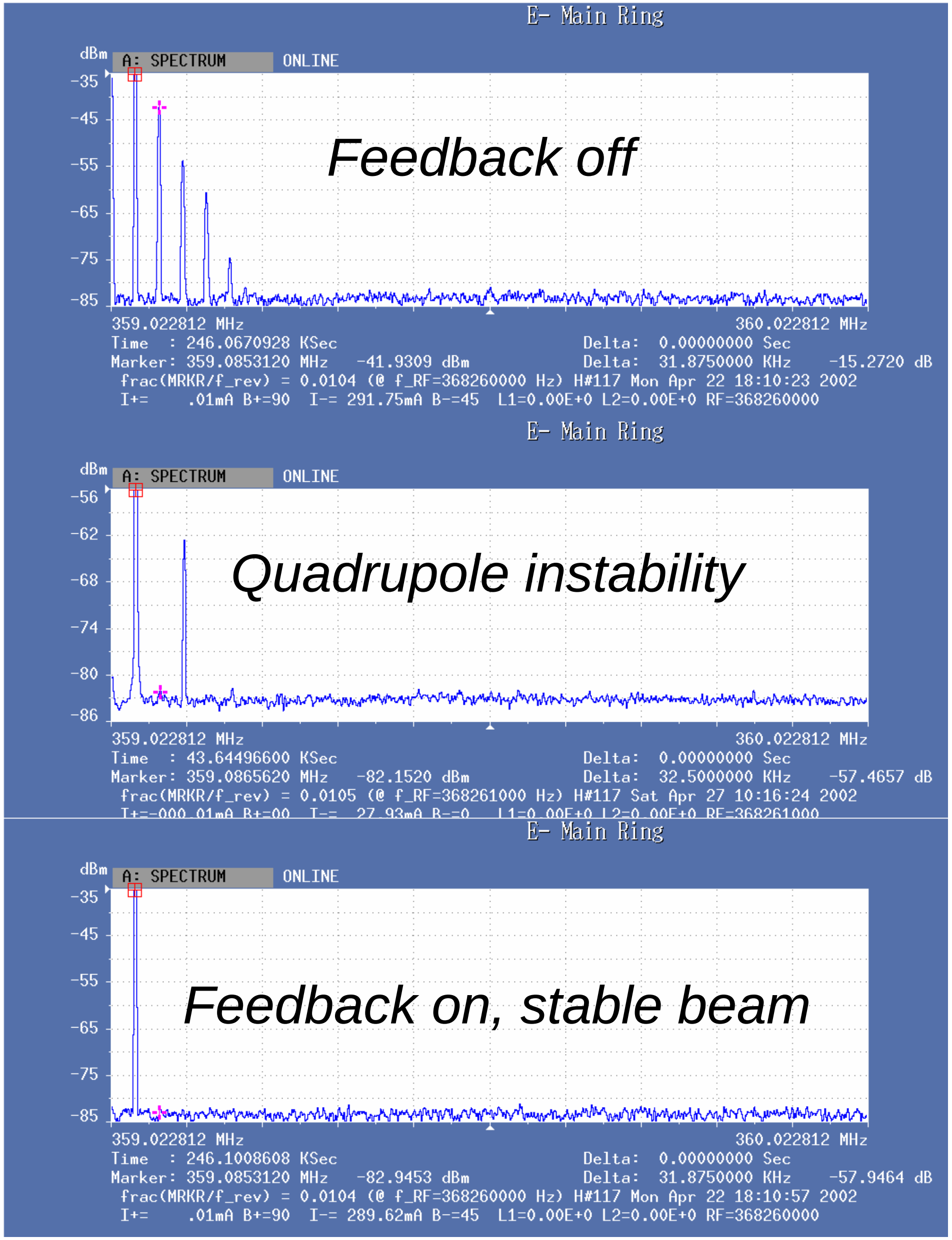
INJECTION KICKER

WALL CURRENT & DCCT MONITOR



SHIELDED BELLOWS

Longitudinal Feedback Systems



Damp:

- Dipole mode instability
- 0-mode instability
- Qudrupole mode instability

Maximim beam current

➢2.5 A in the e- ring (administrative limit)

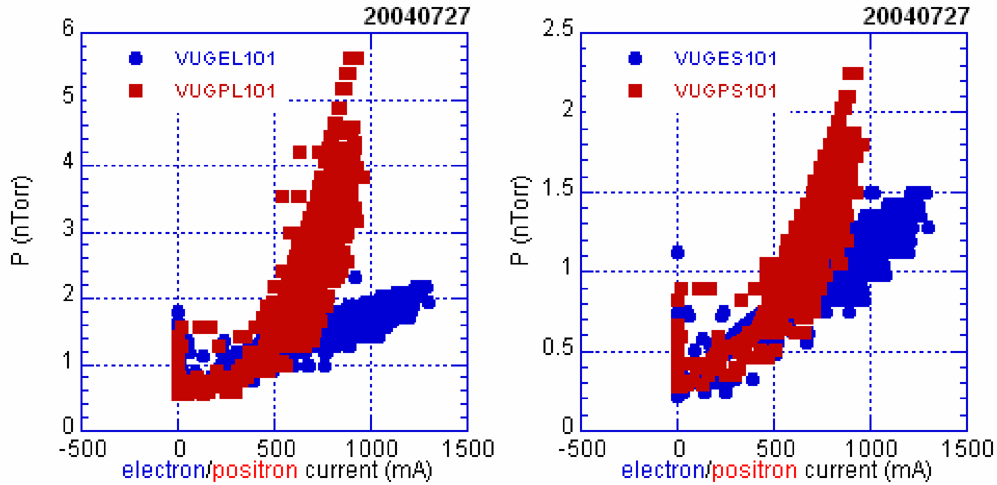
➢1.4 A in the e+ ring (limited by strong horizontal instability)

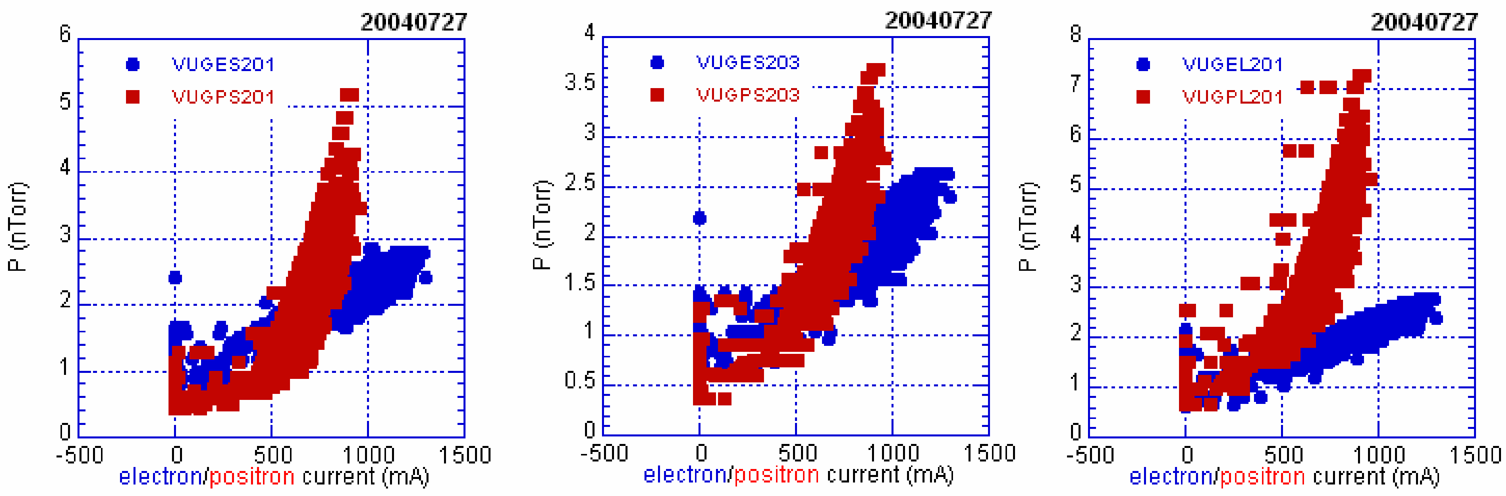
Features of Positron Instability

- Large positive tune shifts
- Anomalous presure rise
- Very fast growth rate (several μs)
- Bunch pattern dependence
- Some evidence of beam scrabbing
- Other

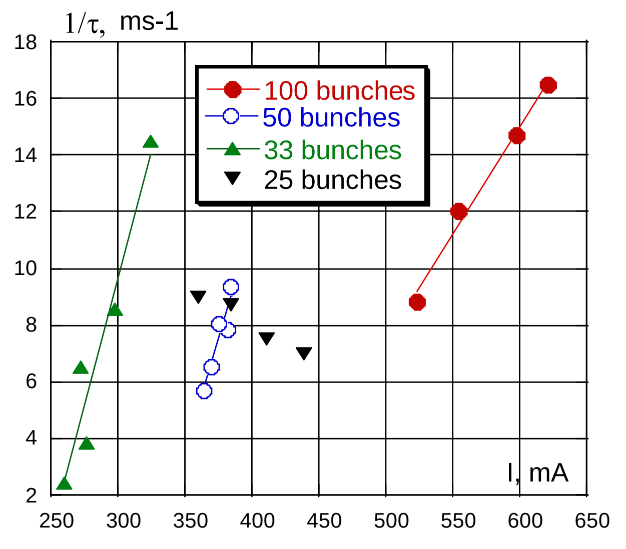
Anomalous Pressure Rise

Data Taking Jul. 27th 2004
Acquisition time = 15 s

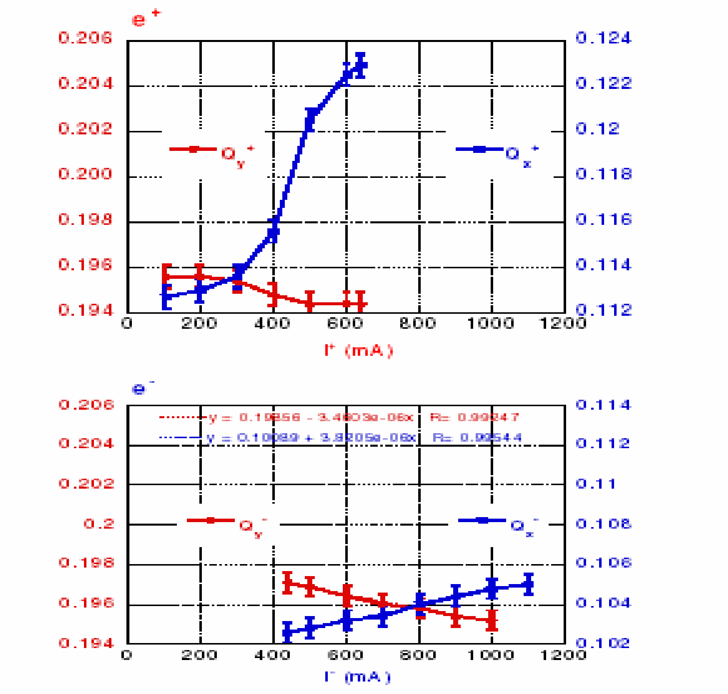




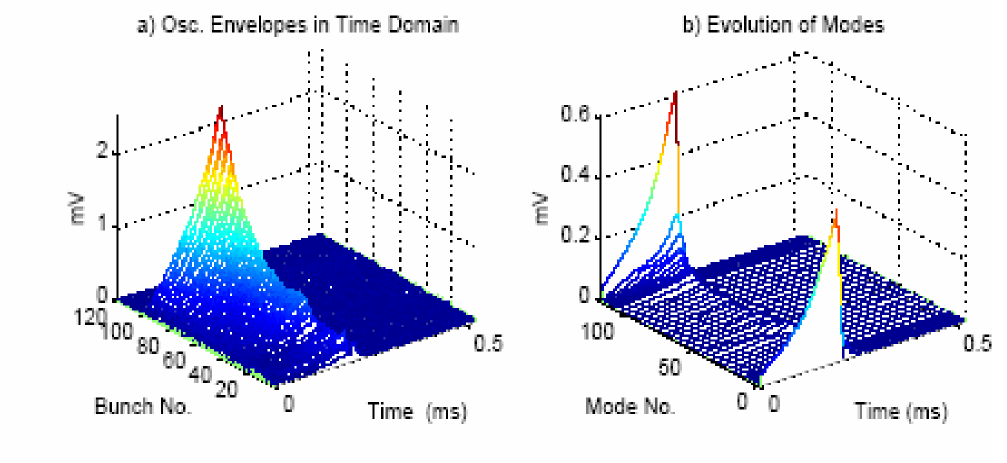
Typical Measurements



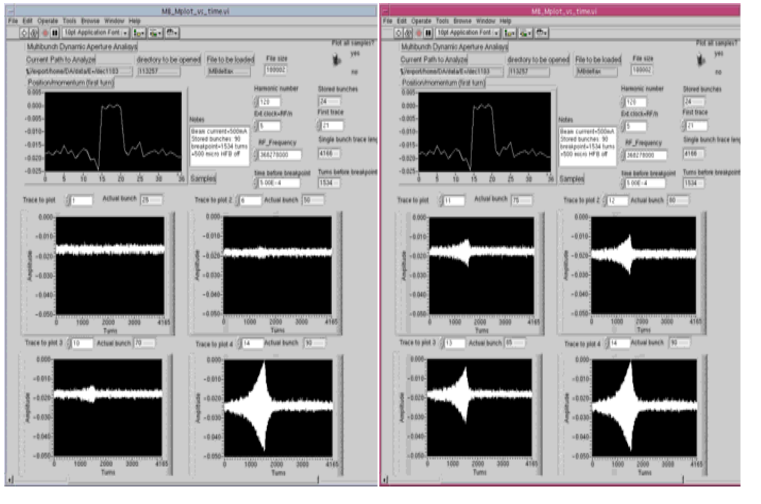
Pattern dependence



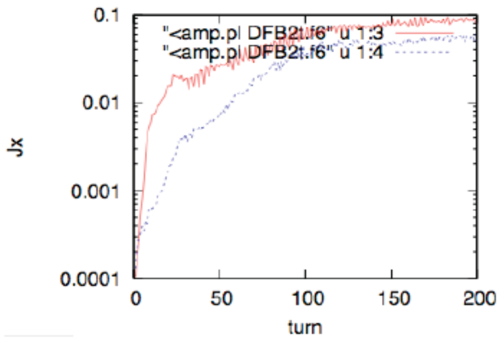
Tune shifts

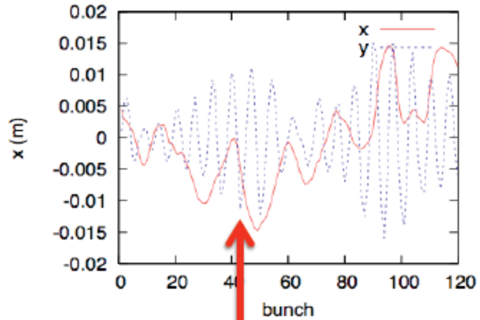


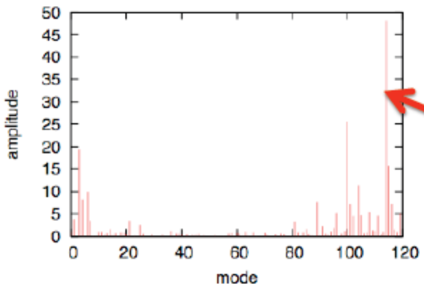
Grow-damp measurements



Tracking (by K. Ohmi)

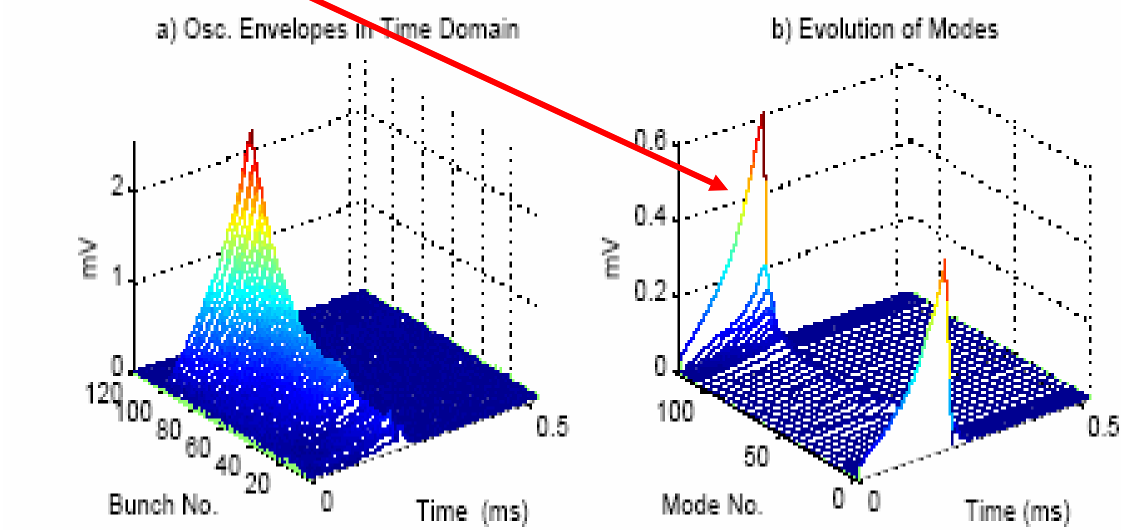






- Instability has two frequency components.
- One is given by the wake force.
- The other is slow frequency component as is observed in DAFNE, "-1" mode..

Measurements



Positron Instability Cures

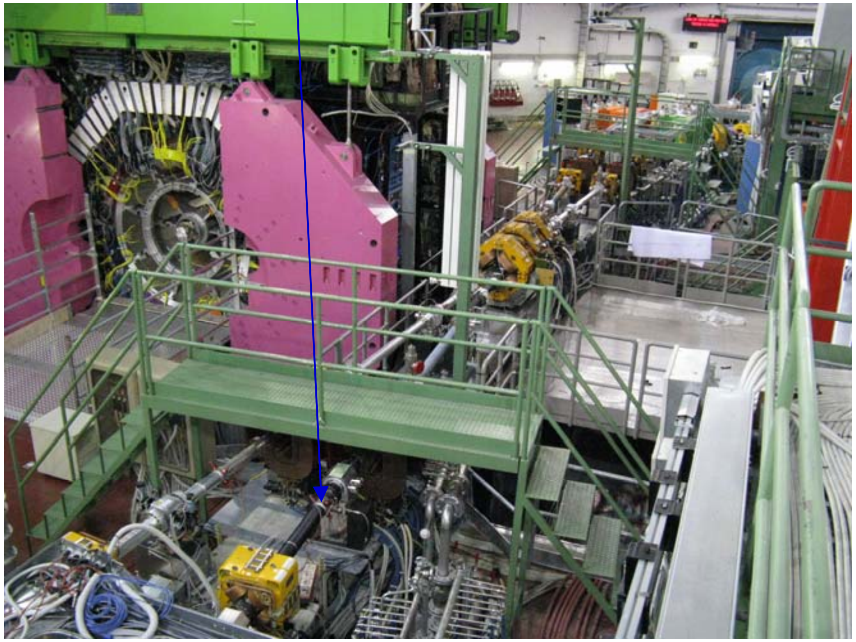
- Powerful transverse feedbacks (A. Drago’s Talk)
- Injection optimization:

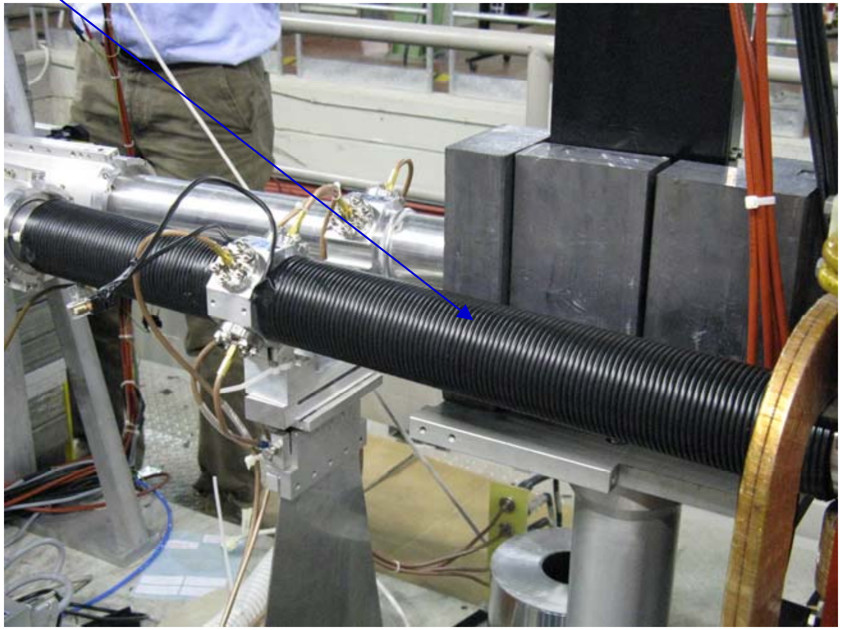
a) Injection kicker pulse length reduction

b) Careful injection bump optimization

- Long term scrabbing
- Solenoidal field in straight sections and IRs

Solenoids

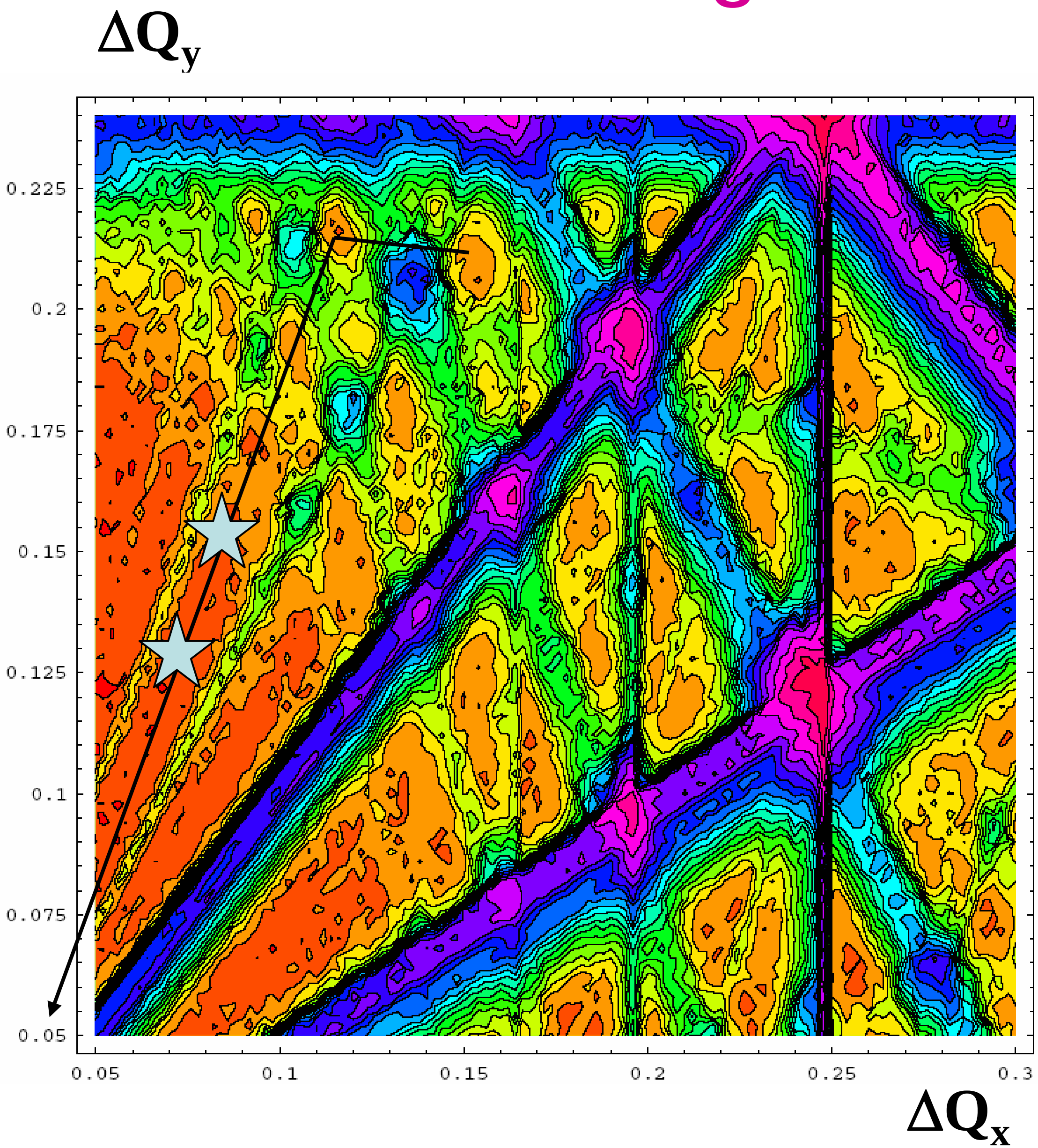


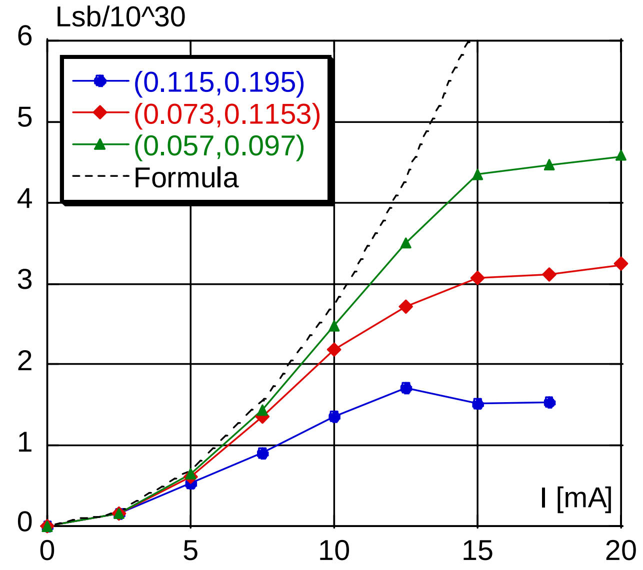


Beam-Beam Performance

- Working Point Choice
- Lattice Nonlinearity compensation with Octupoles
- Parasitic Crossing Compensation with Current-Carrying Wires

Working Point Tuning



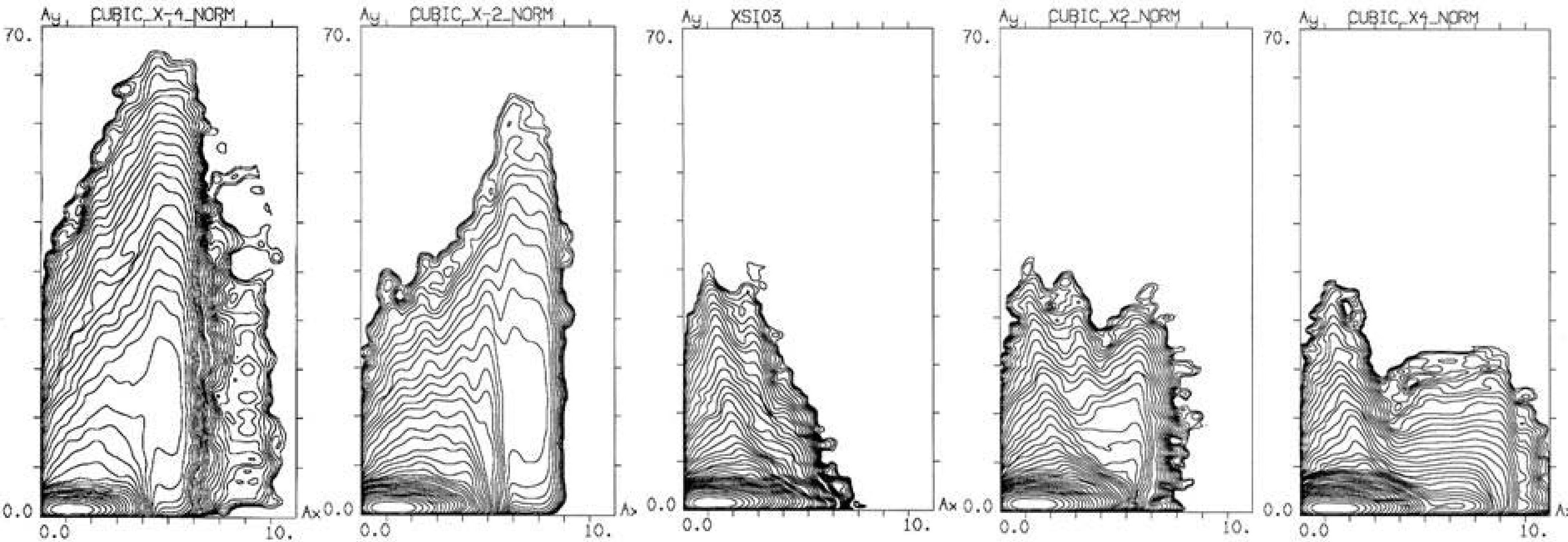


Going closer to the integers we have improved both the peak luminosity and lifetime

This was possible with the new wigglers since DA is satisfactory at low tunes!

Crosstalk between beam-beam effects and lattice nonlinearities

Only 1 IP + C_{11}.....

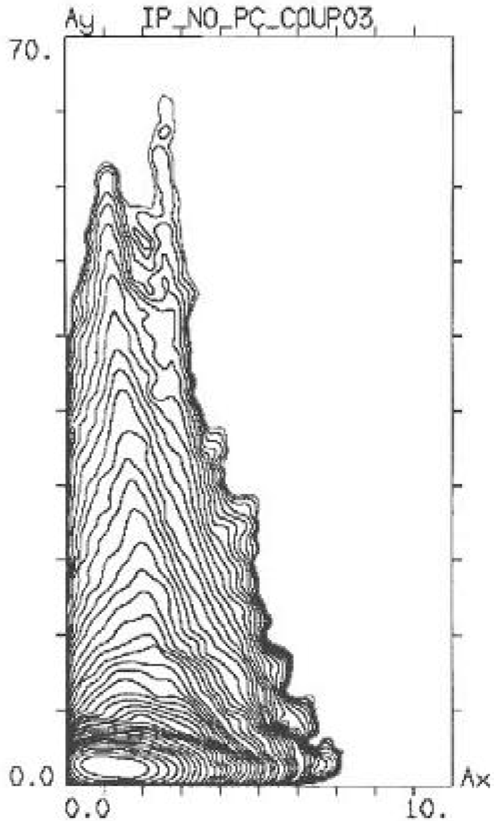


$C_{11} = -400$	$C_{11} = -200$	$C_{11} = 0$	$C_{11} = +200$	$C_{11} = +400$
$\sigma_x/\sigma_{x0} = 1.053$	$\sigma_x/\sigma_{x0} = 1.075$	$\sigma_x/\sigma_{x0} = 1.067$	$\sigma_x/\sigma_{x0} = 1.110$	$\sigma_x/\sigma_{x0} = 1.160$
$\sigma_y/\sigma_{y0} = 1.30$	$\sigma_y/\sigma_{y0} = 1.038$	$\sigma_y/\sigma_{y0} = 1.047$	$\sigma_y/\sigma_{y0} = 1.055$	$\sigma_y/\sigma_{y0} = 1.044$

$|C_{11}| < 200$

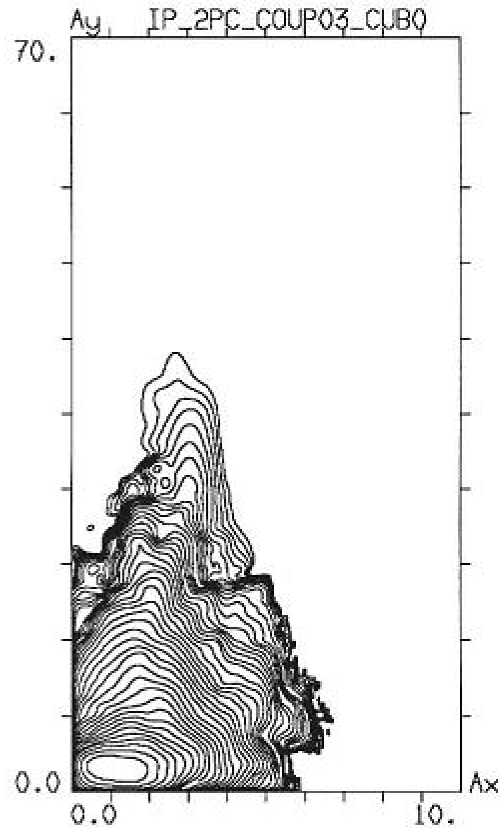
1 IP + 2 nearest PC + C_{11}…

1 IP



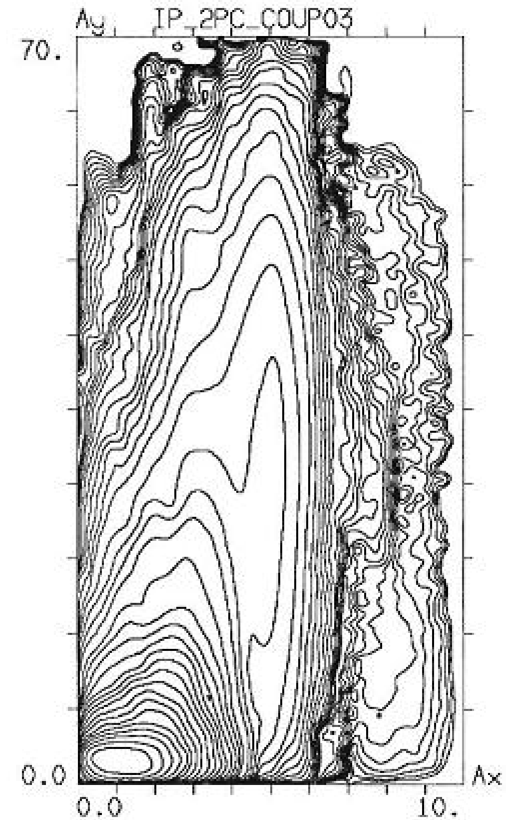
a)

1 IP+ 2 PC



b)

1 IP + 2 PC + C_{11}



c)

$\sigma_x/\sigma_y = 1.076$
$\sigma_y/\sigma_{y0} = 1.449$
$\tau = \infty$

→

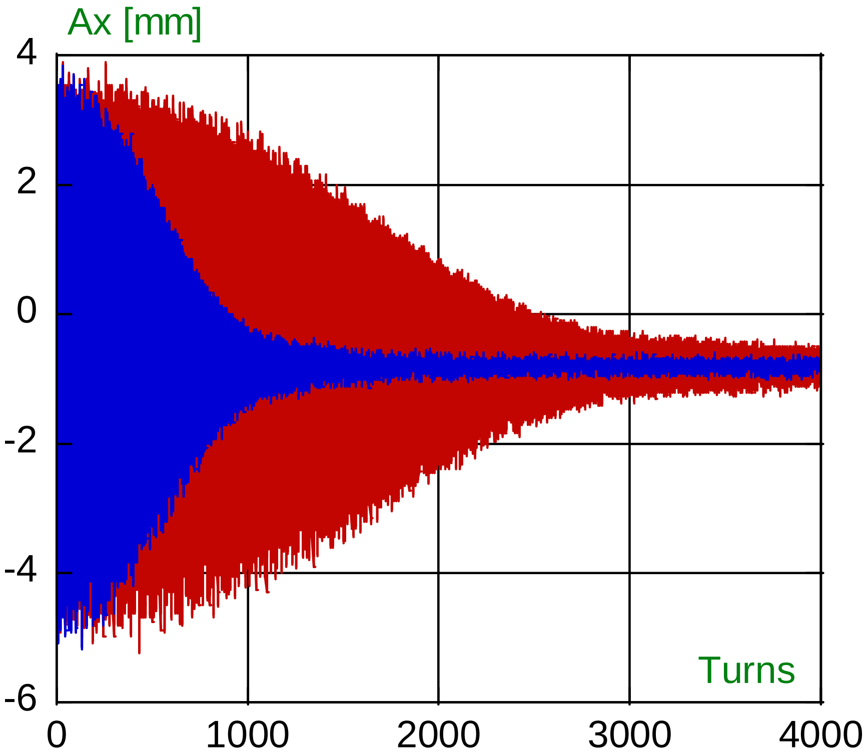
$\sigma_x/\sigma_{x0} = 1.097$
$\sigma_y/\sigma_{y0} = 1.954$
$\tau = \infty$

→

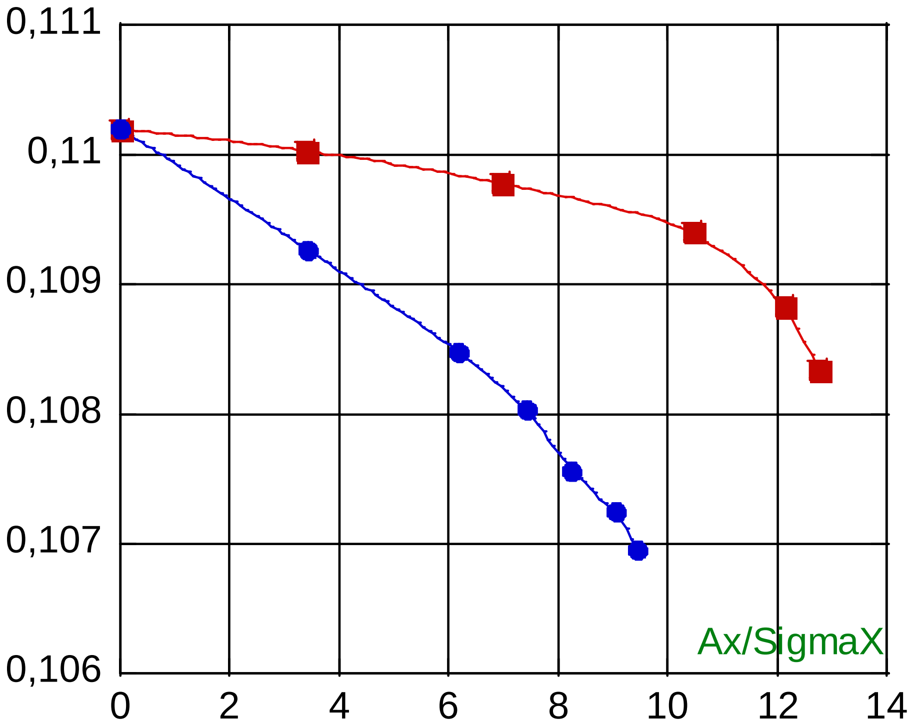
$\sigma_x/\sigma_{x0} = 1.099$
$\sigma_y/\sigma_{y0} = 2.498$
$\tau = 36$ sec

KLOE Lattice: Octupoles On and Off

Beam Decoherence



Tune Shift with Amplitude

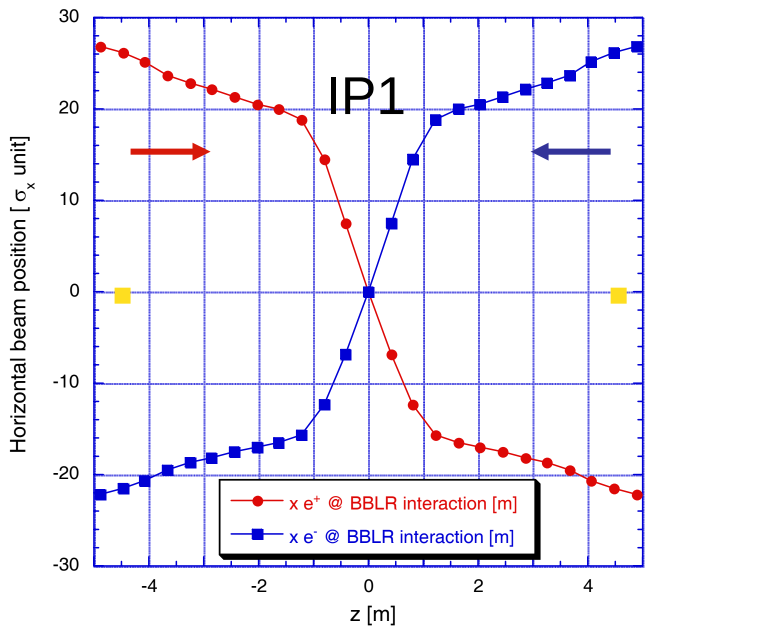


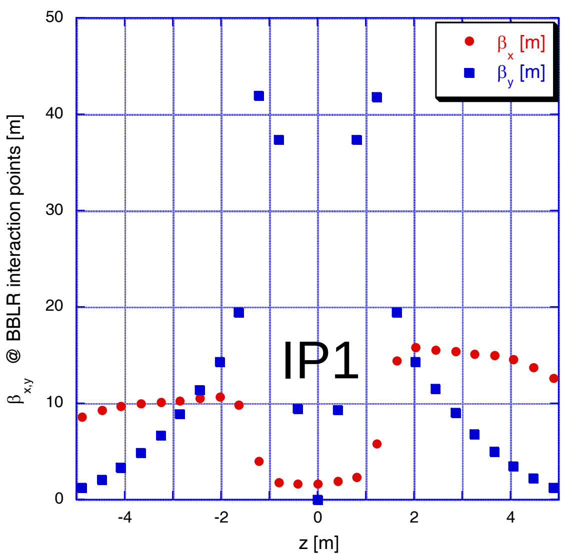
Parasitic Crossings in the DAΦNE IR1

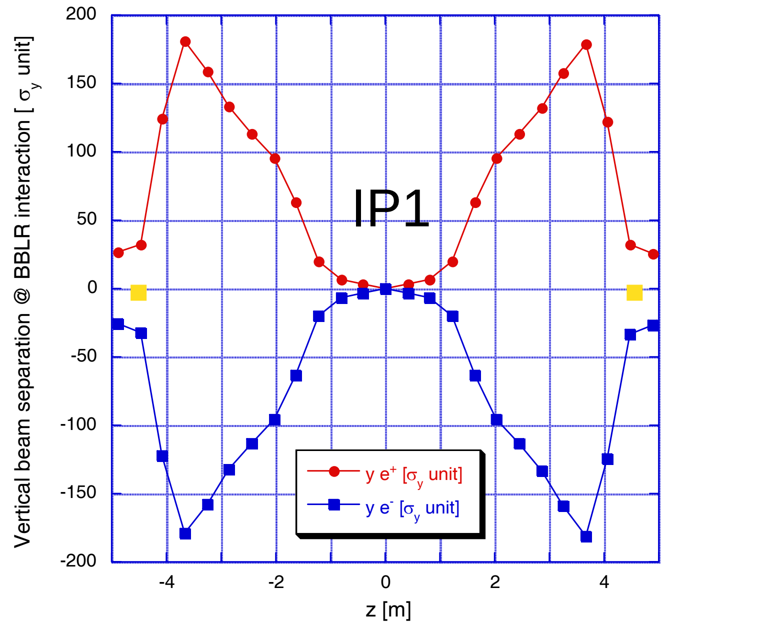
In the DAΦNE IRs the beams experience 24 Long Range Beam Beam interactions

Parameters for the Pcs, one every four, in IR1.

PC order	$Z-Z_{IP}$ [m]	β_x [m]	β_y [m]	$\mu_x-\mu_{IP}$	X [σ_x]	Y [σ_y]
BB12L	-4.884	8.599	1.210	0.167230	26.9050	26.238
BB8L	-3.256	10.177	6.710	0.140340	22.8540	159.05
BB4L	-1.628	9.819	19.416	0.115570	19.9720	63.176
BB1L	-0.407	1.639	9.426	0.038993	7.5209	3.5649
IP1	0.000	1.709	0.018	0.000000	0.0000	0.0000
BB1S	0.407	1.966	9.381	0.035538	-6.8666	3.5734
BB4S	1.628	14.447	19.404	0.092140	-16.4650	63.196
BB8S	3.256	15.194	6.823	0.108810	-18.7050	157.74
BB12S	4.884	12.647	1.281	0.126920	-22.1880	25.505

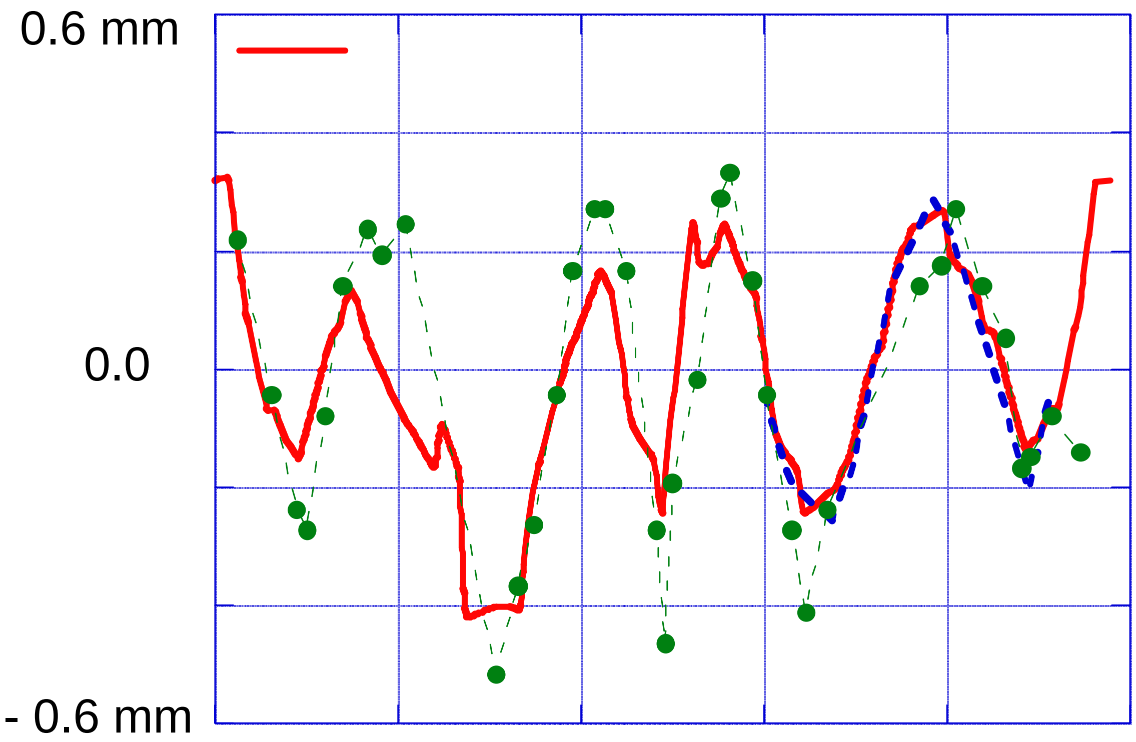




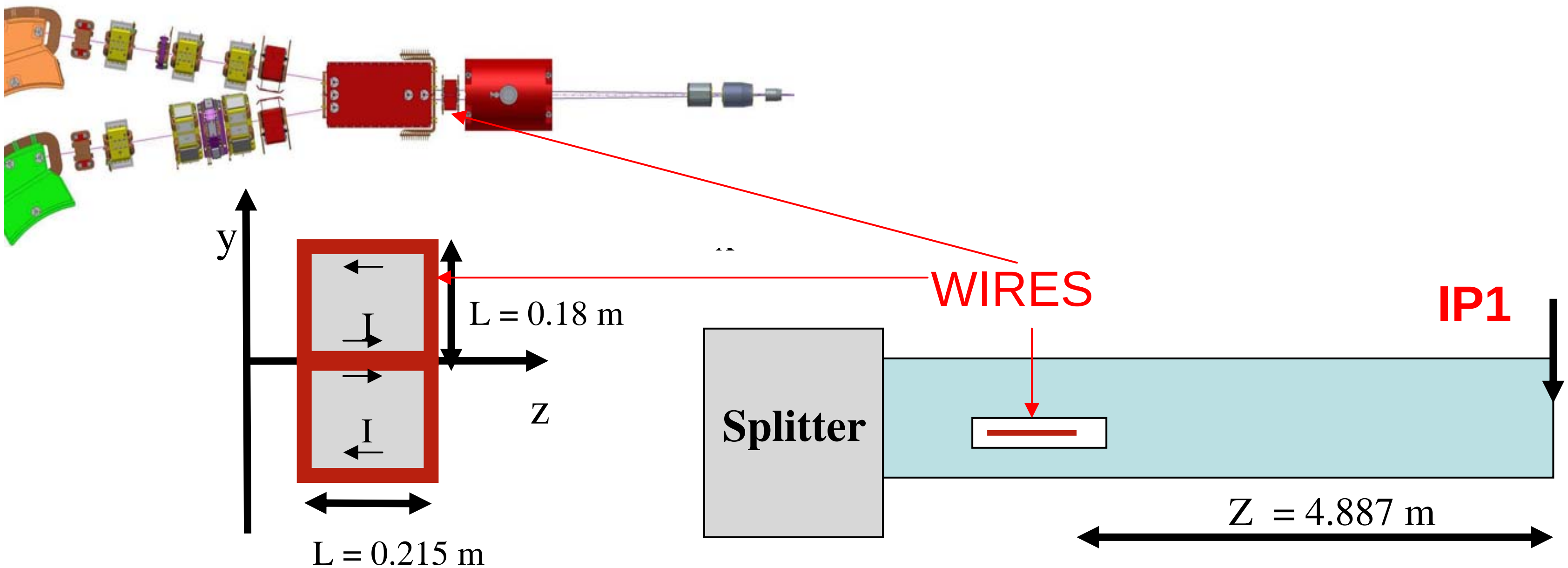


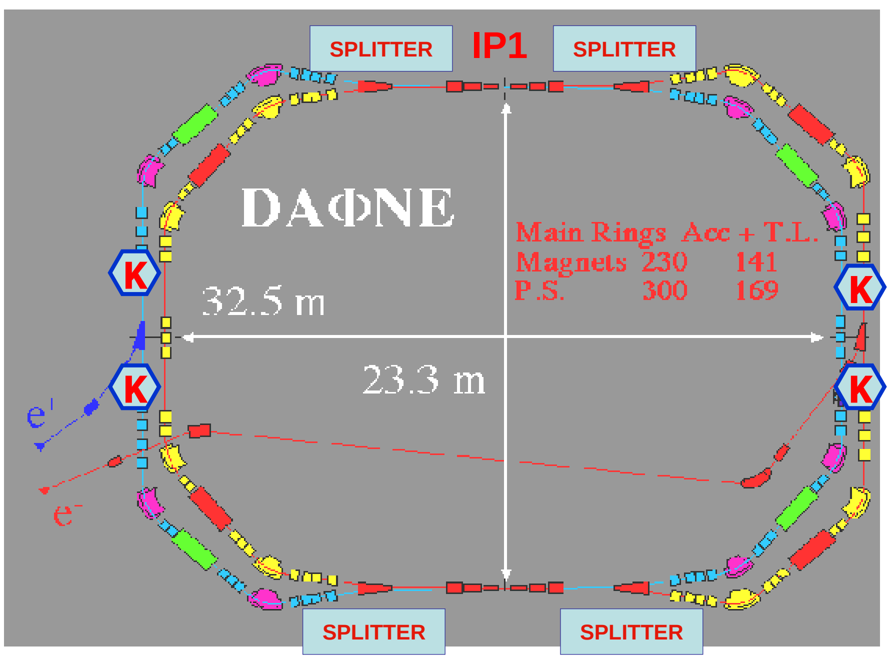
Orbit distortion due to LRBB interaction in IR1

computed orbit deflection due to 24 LRBB interactions for the positron bunch colliding against 10 mA electron bunches.

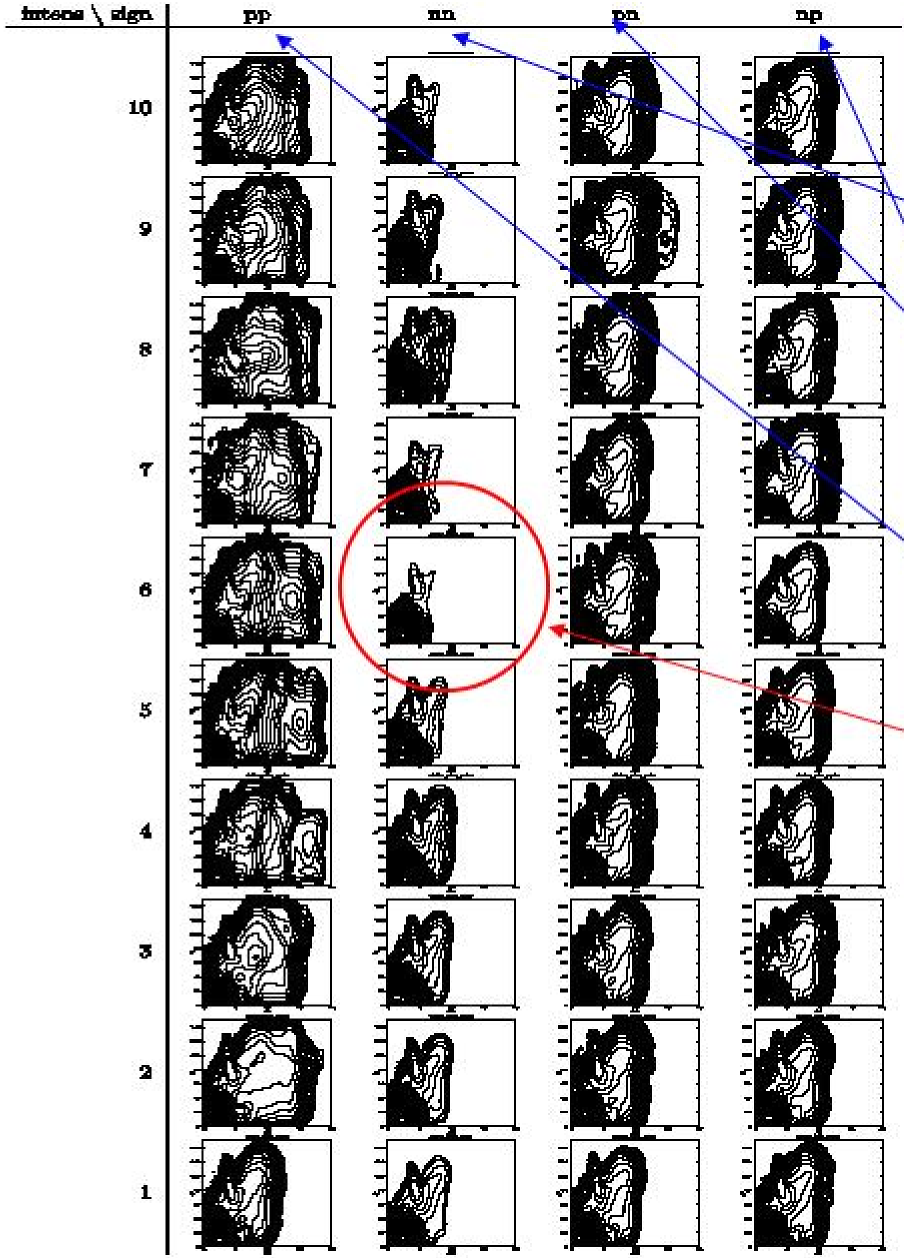


KLOE IR1

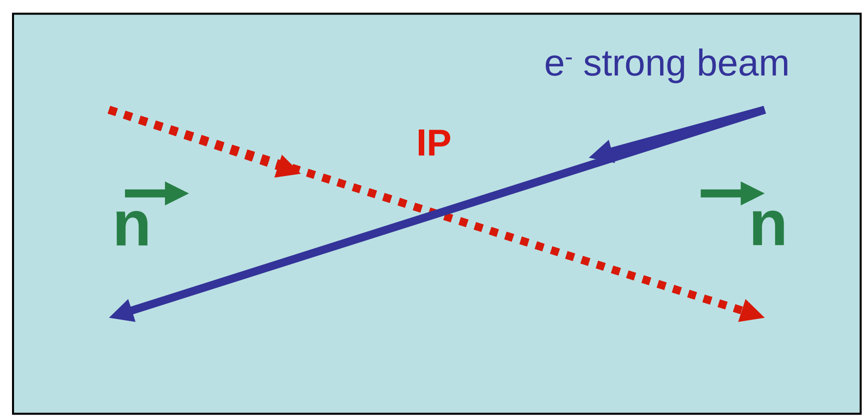




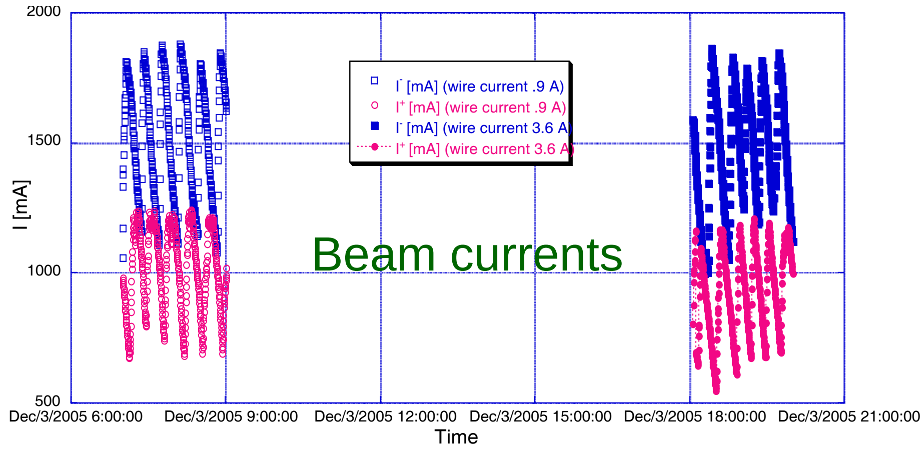
- ✓ The wires are installed outside the vacuum chamber using of a short section in IR1, just before the splitters, where the vacuum pipes are separated.
- ✓ The wires carry a tunable DC current, and produce a stationary magnetic field (1/r) with a shape similar to the one created by the opposite beam

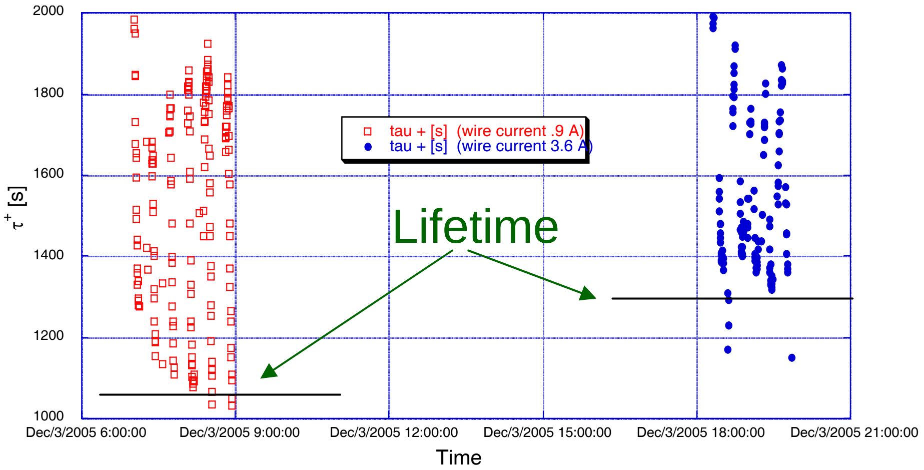


1. Simulations take into account 1 IP and 24 PCs
2. Tails are much shorter for the compesating “nn” wires polarity
3. The wires seem to compensate each other when they have opposite polarities “pn” or “np”
4. The tails explode with the wrong wires polarity “pp”
5. The best wire intensity correspond to the “6 equivalent PC” compensation (1 equivalent PC compensation = intensity necessary to compensate the only first PC)



Wires have been used for beam-beam parasitic crossing compensation





Ideas, Tests and Proposals for DAΦNE Upgrade

Ideas for Luminosity Increase

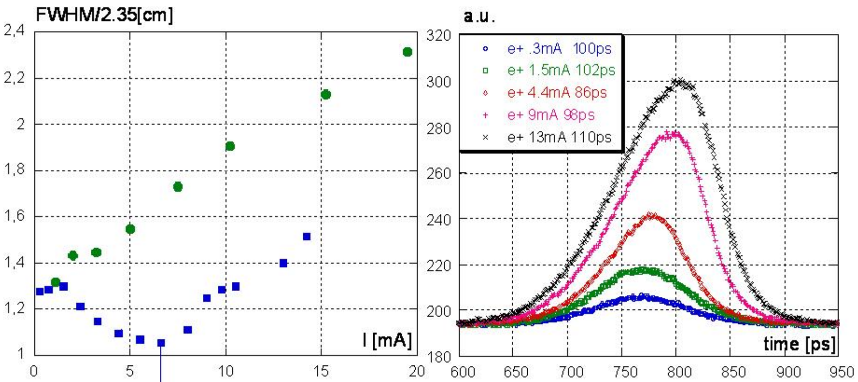
1. Collisions with negative momentum compaction (tested)
2. Parasitic crossing compensation with wires (operative)
3. All wiggling machine
4. Collisions with a very high crossing angle (new)
5. Strong RF focusing (new)
6. Crab waist collisions (new)

Written Proposals

1. DANAE (Letter of Intent)
2. Bunch lenght modulation experiment (long discussion, abandoned)
3. Crab waist collision scheme (studies under way)

$\alpha_c < 0$ in DAΦNE

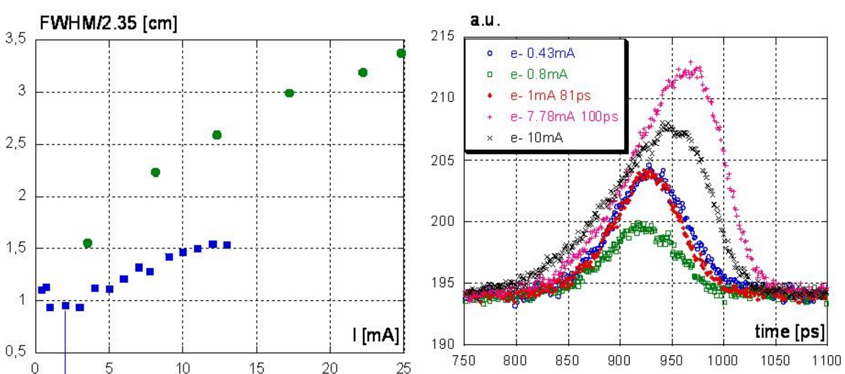
Bunch Shortening in the Positron Ring



I_{th} = 7 mA at $\alpha_c < 0$

I_{th} = 9 mA at $\alpha_c > 0$

Bunch Shortening in the Electron Ring

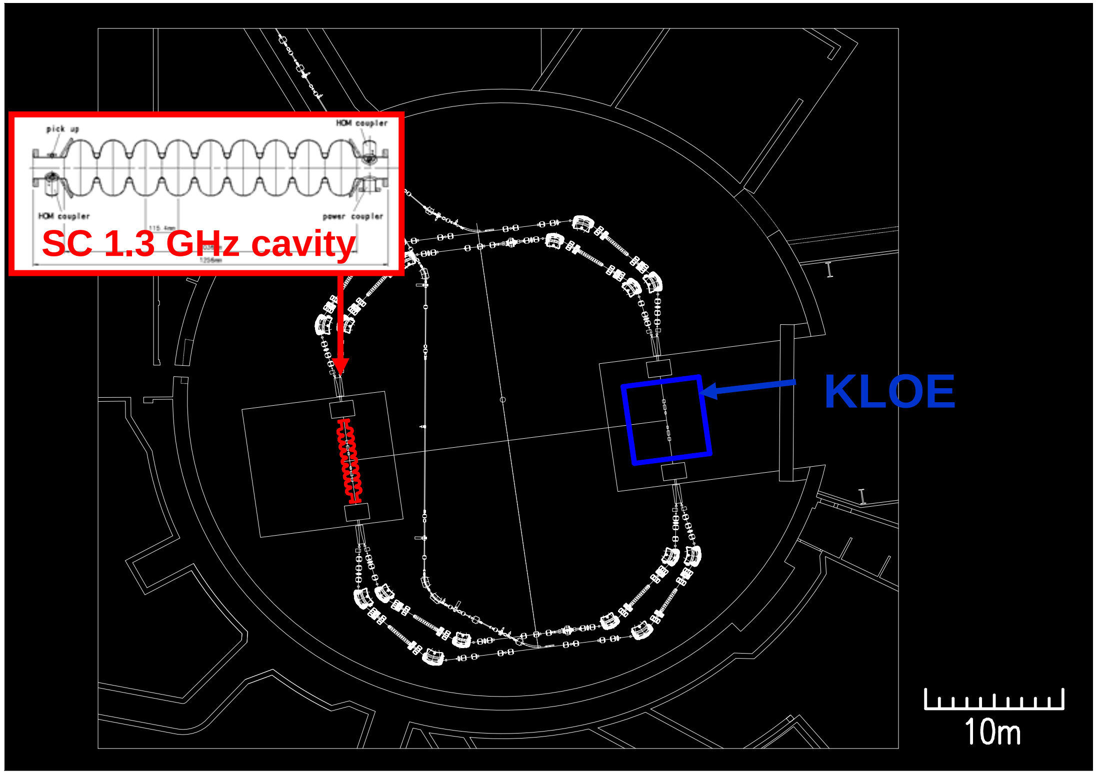


Low microwave instability threshold

Summary of Results

1. Flexible DAΦNE optics with α_c from +0.034 to -0.036.
2. Bunches shorten as predicted by numerical simulations.
3. It was possible to store high bunch current with large negative chromaticity
4. Stable multibunch beams with currents > 1 A
5. Specific luminosity gain of about 25% till 300 mA per beam
6. Higher current beam-beam collisions failed due to e- vertical size blow up above the microwave instability threshold

Strong RF Focusing Experiment at DAΦNE (proposal)



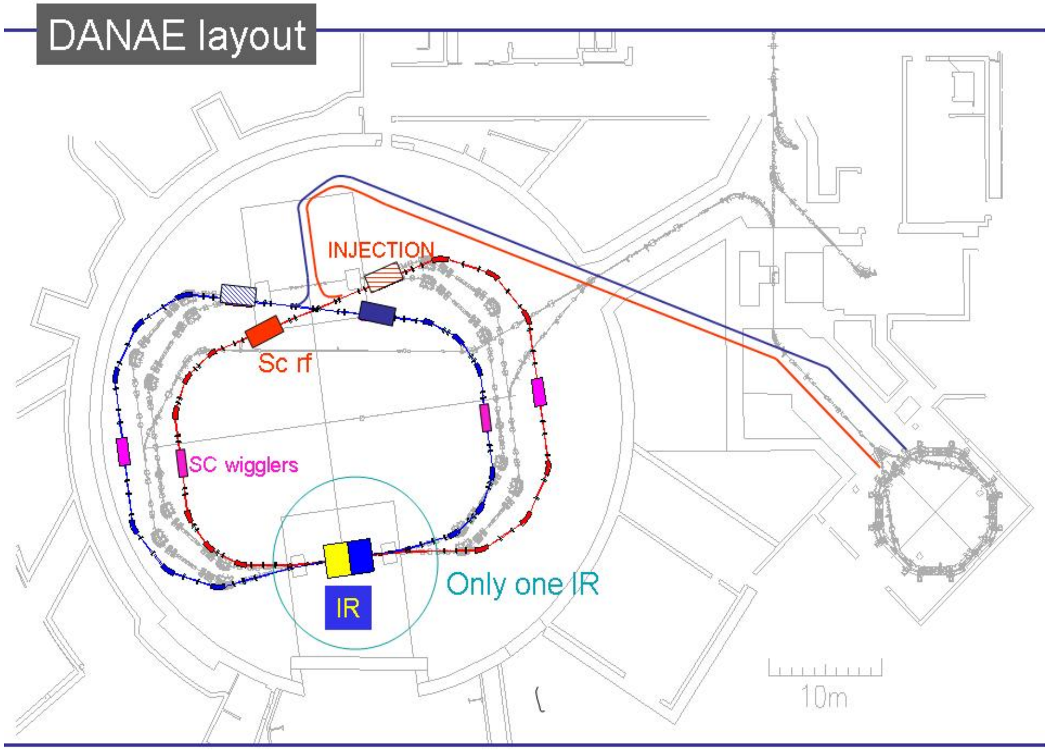
For a high momentum compaction factor and a high RF voltage:

$$\sigma_z(s) = \left(\frac{\sigma_E}{E}\right)\alpha_c L \sqrt{\frac{1}{2(1-\cos\mu)} - \frac{R_{56}(s)}{\alpha_c L}\left(1 - \frac{R_{56}(s)}{\alpha_c L}\right)}$$

$$\left(\frac{\sigma_E}{E}\right)^2 = \frac{1}{1+\cos\mu}\frac{55}{48\sqrt{3}}\frac{r_e\hbar}{m_e}\frac{\gamma^5\tau_d}{L}\oint\left[1-(1-\cos\mu)\frac{2R_{56}(s)}{\alpha_c L}\left(1-\frac{R_{56}(s)}{\alpha_c L}\right)\right]\frac{ds}{|\rho(s)|^3}$$

DANAE Proposal

(DAϕne New with Agjustable Energy)



Based on:

1. Shorter bunch length
2. Lower beta at IP
3. Stronger damping
4. Higher number of bunches
5. Higher colliding currents
6. Continuous injection

Energy (c.m., GeV)	1.02	2.4
Peak luminosity ($cm^{-2}s^{-1}$)	$>10^{33}$	$>10^{32}$
Required integrated luminosity (fb^{-1})	50	3

Crab Waist Collision Scheme
has been approved with

Main Purposes

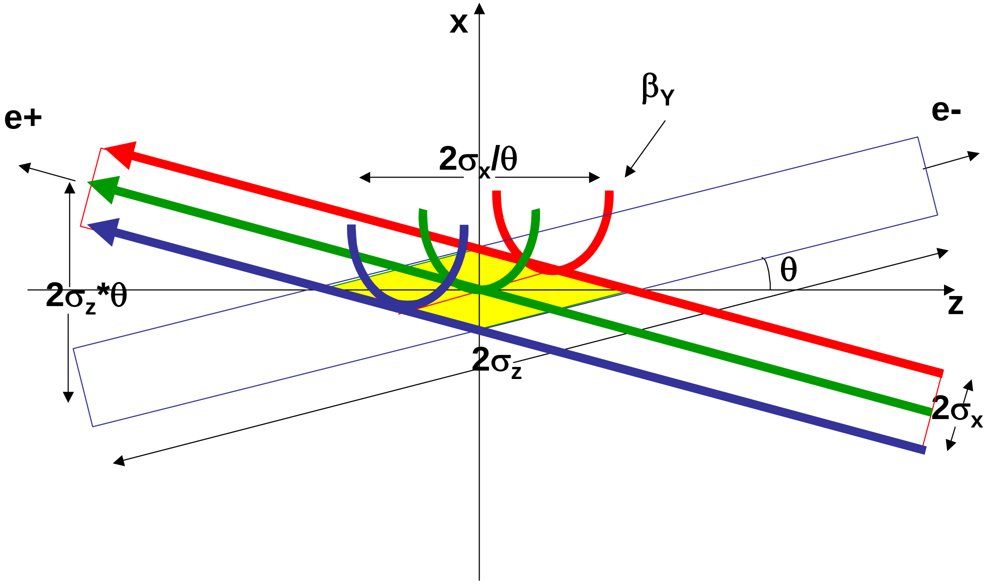
1. To increase substantially the DAΦNE luminosity
2. To test the “crab waist” idea – the basic idea of the SuperB project

Crab Waist in 3 Steps

1. Large Piwinski's angle $\Phi = tg(\theta)\sigma_z/\sigma_x$

2. Vertical beta comparable with overlap area $\beta_y \approx \sigma_x/\theta$

3. Crab waist transformation $y = xy'/(2\theta)$

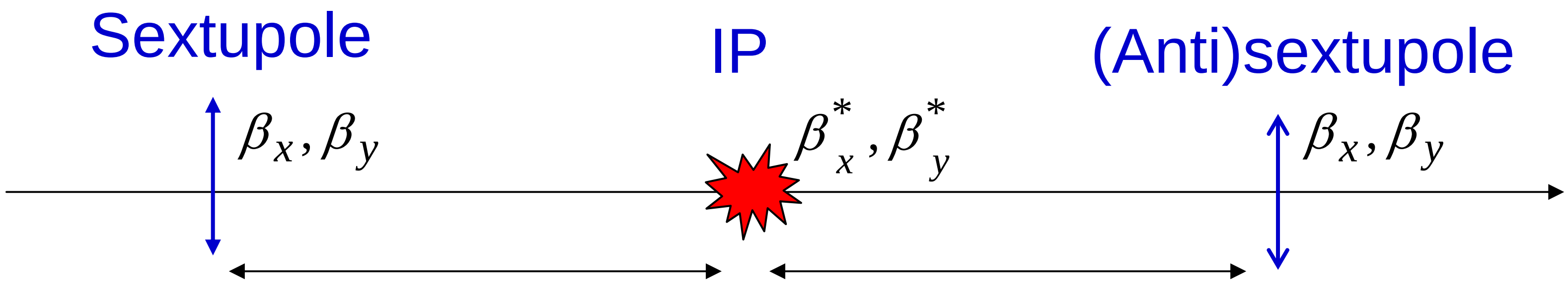


1. *P.Raimondi, 2° SuperB Workshop, March 2006*

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

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

Crabbed Waist Scheme



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

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

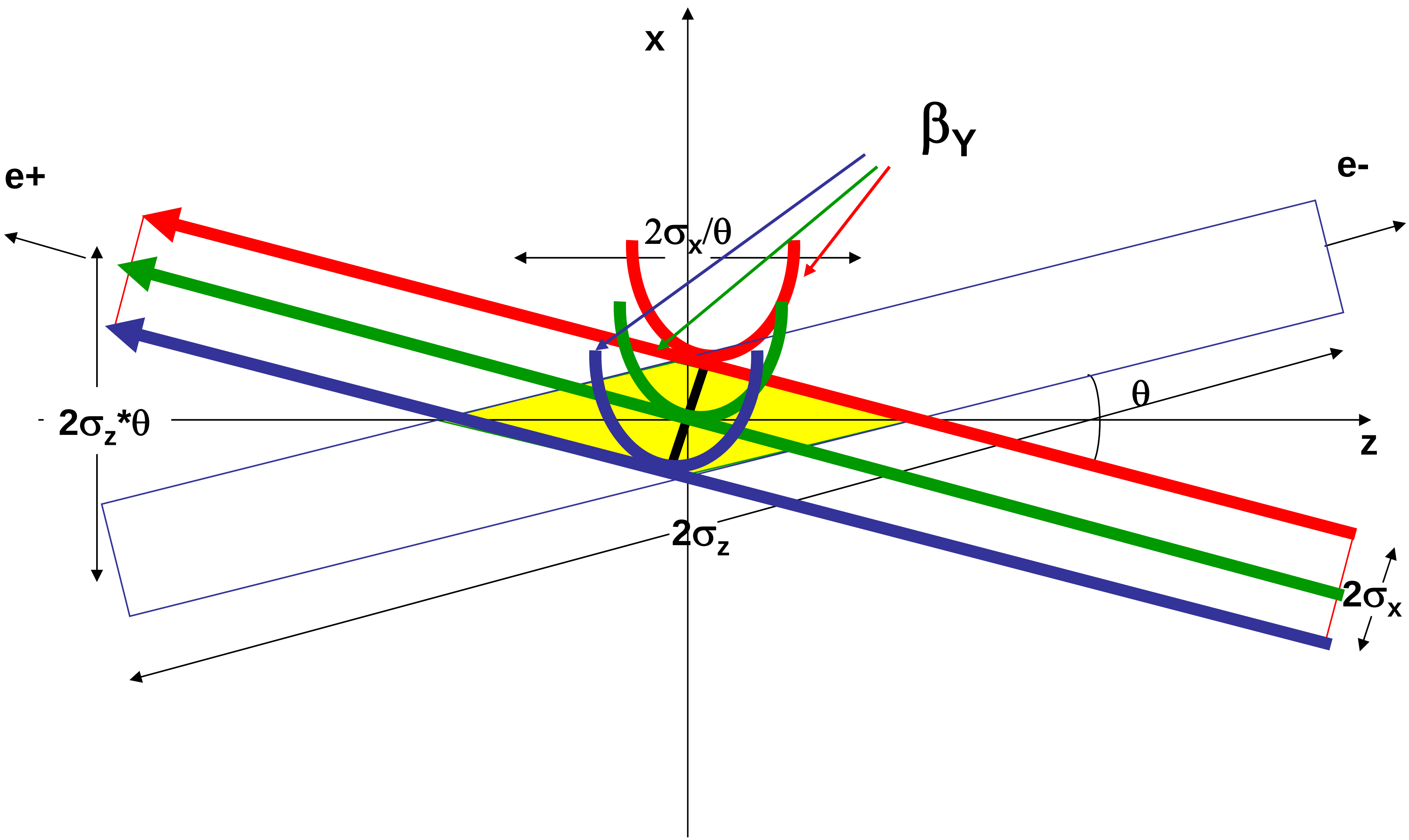
Sextupole strength

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

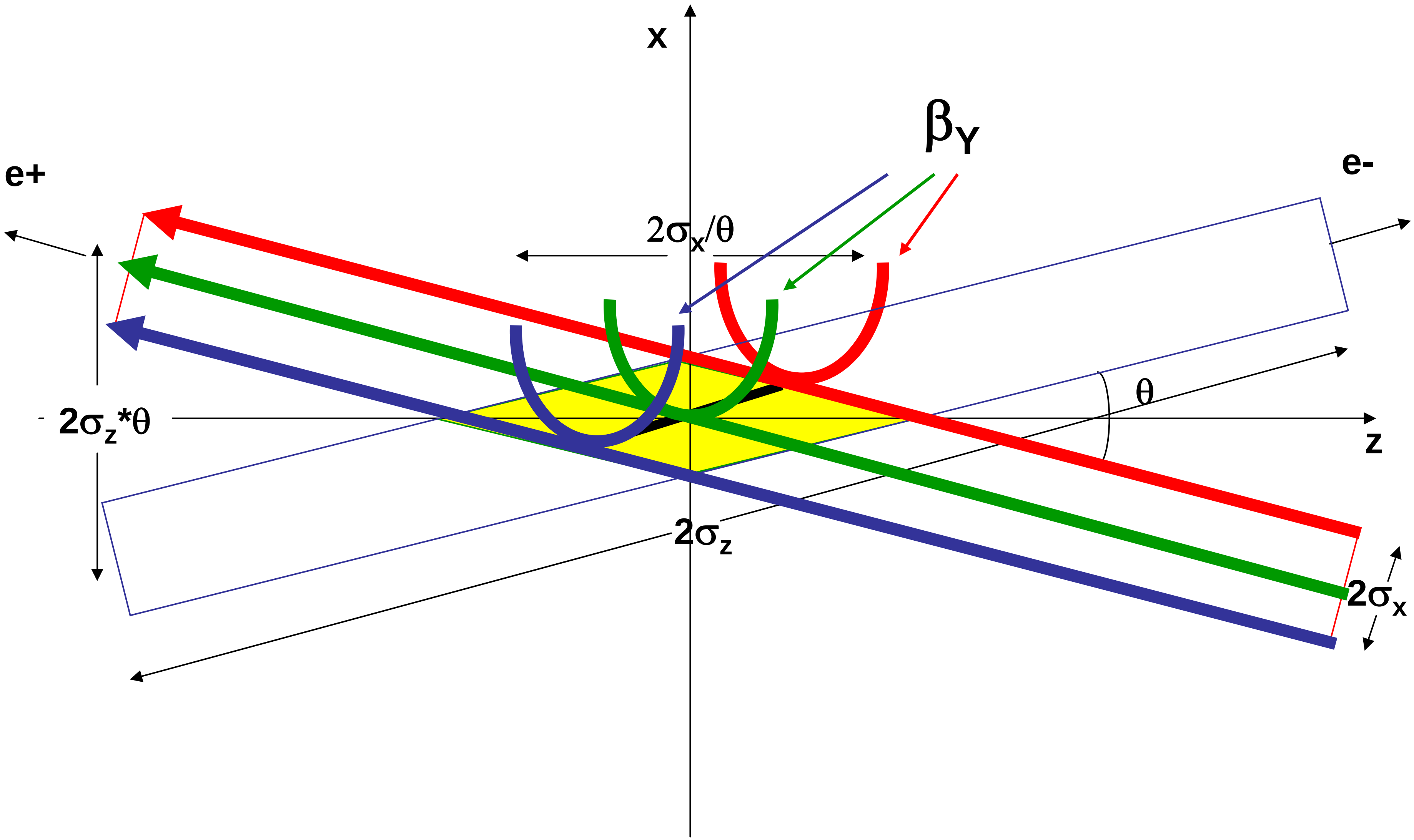
Equivalent Hamiltonian

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

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



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



x
βY
e+
e-
2σx/θ
2σz*θ
θ
z
2σz
2σx

Crabbed Waist Advantages

1. Large Piwinski's angle

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

- a) Geometric luminosity gain
- b) Very low horizontal tune shift

2. Vertical beta comparable with overlap area

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

- a) Geometric luminosity gain
- b) Lower vertical tune shift
- c) Vertical tune shift decreases with oscillation amplitude
- d) Suppression of vertical synchro-betatron resonances

3. Crabbed waist transformation

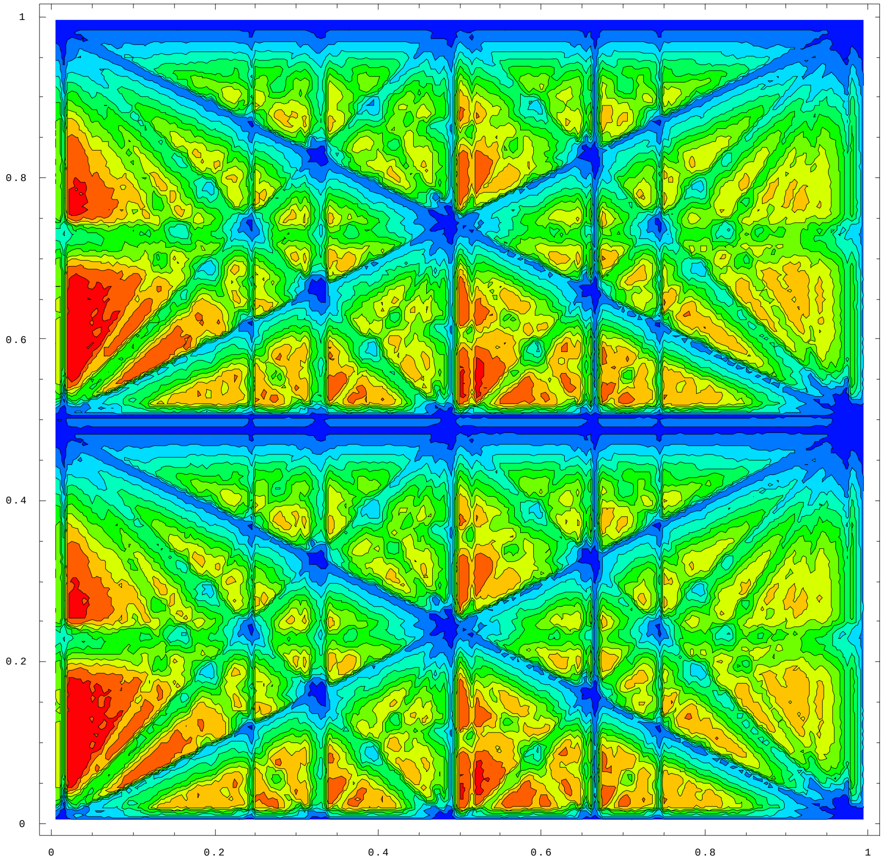
$$y = xy'/(2\theta)$$

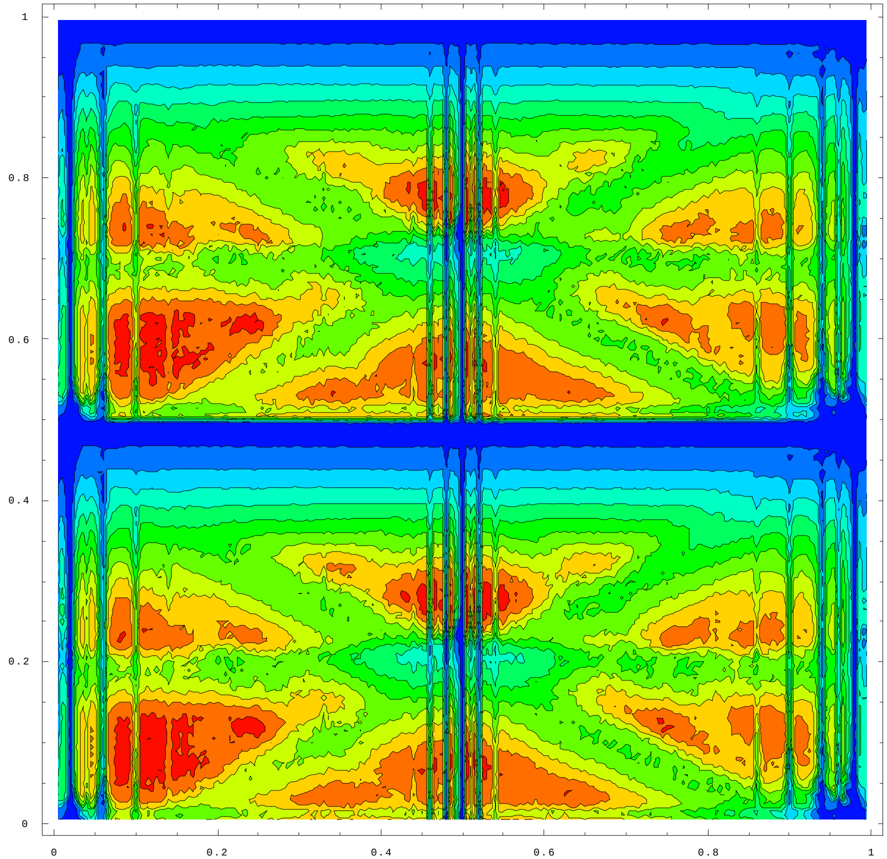
- a) Geometric luminosity gain
- b) Suppression of X-Y betatron and synchro-betatron resonances

X-Y Resonance Suppression

D.N.Shatilov's talk at this Workshop

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

..and besides,

a) There is no need to increase excessively beam current and to decrease the bunch length:

1) Beam instabilities are less severe
2) Manageable HOM heating
3) No coherent synchrotron radiation of short bunches
4) No excessive power consumption

b) The problem of parasitic collisions is automatically solved due to higher crossing angle and smaller horizontal beam size

Conclusions

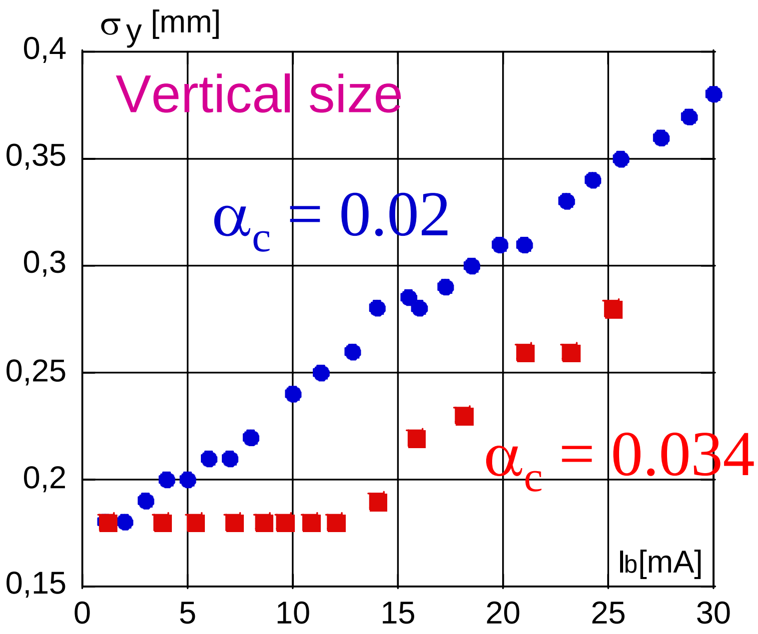
We continue working....

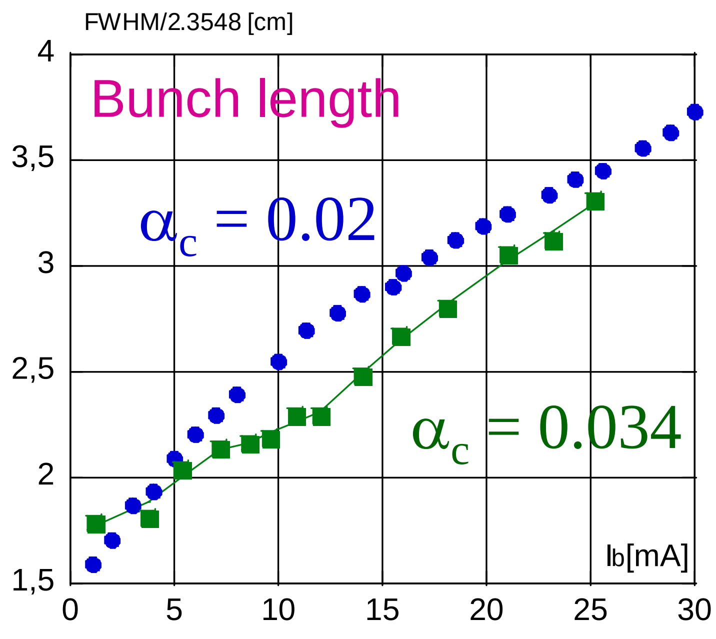
See the next talk

Thank you!

BACKUP SLIDES

Vertical Size Blow Up





- Single bunch (beam) effect
- It is correlated with the longitudinal microwave instability:

a) The same threshold

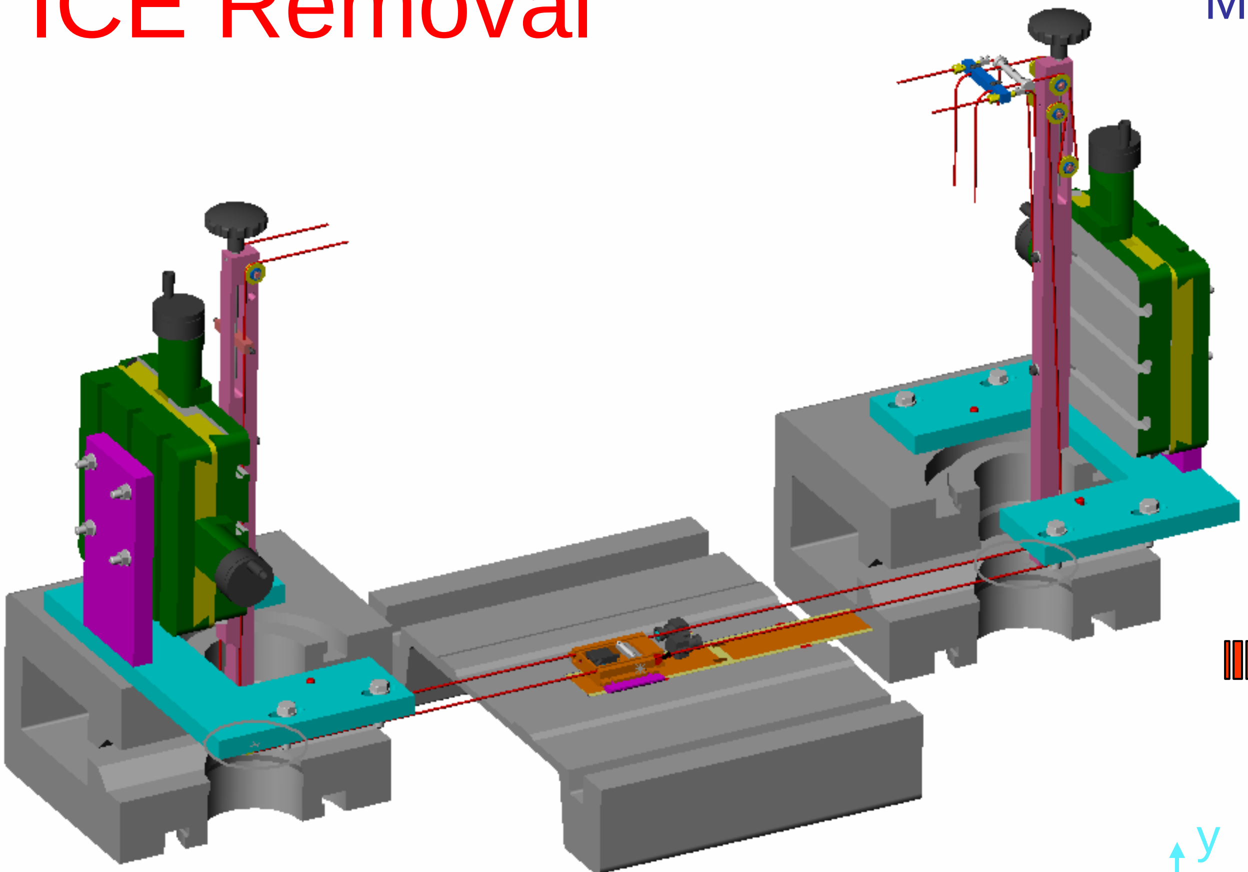
b) The same dependence on RF voltage

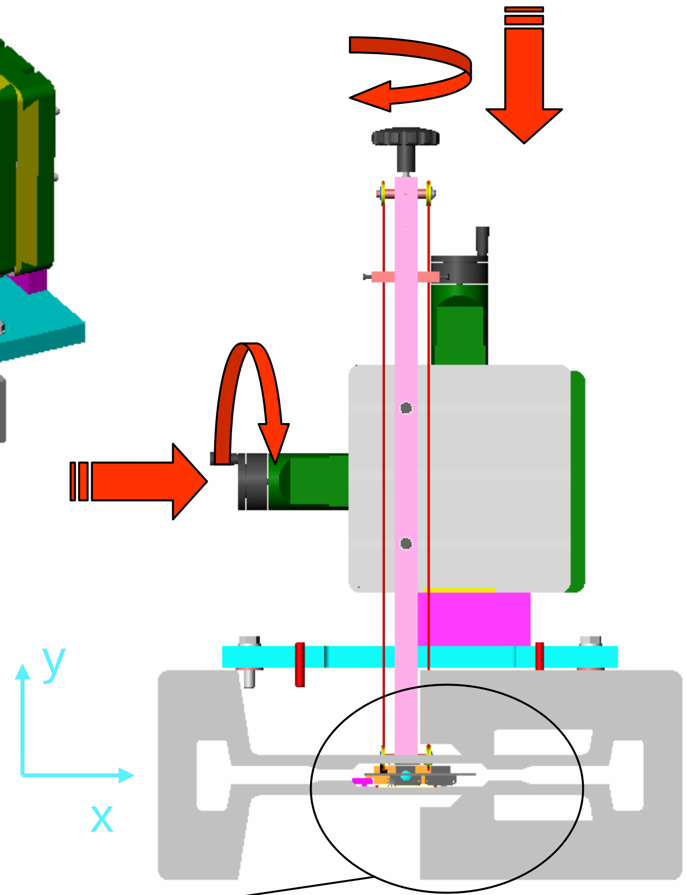
c) The threshold is higher for higher momentum compaction

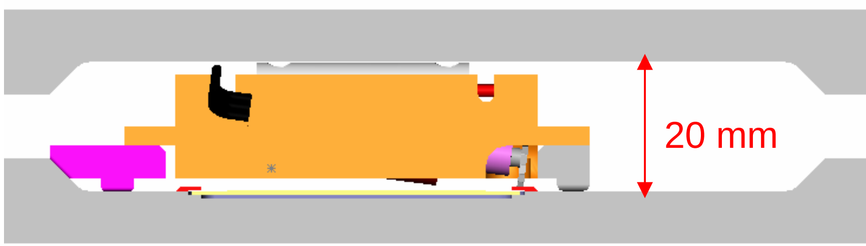
d) More pronounced for e- ring having higher coupling impedance

ICE Removal

Multipurpose remotized positioning system







S.R.S. Group S.r.l

Good Opportunity

for Physics Programs

1. Fits DAΦNE schedule (shut down for SIDDHARTA installation in mid 2007)
2. Satisfies new physics programs (SIDDHARTA, KLOE2, FINUDA...)
3. Requires minor modifications
4. Relatively low cost (1 mln Euro)

for Beam Dynamics

1. No detector solenoidal field
2. No splitter magnets
3. No compensating solenoids
4. No parasitic crossings
5. Lower beam impedance (simple IR, new bellows, new injection kickers)