DAΦNE TECHNICAL NOTE

INFN - LNF, Accelerator Division

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Note: **L-21**

LOWER β_y^* LATTICE FOR DAΦNE

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1. Introduction

The working point of DAΦNE has been recently optimized to better handle the beam-beam interaction. As it is well known the beam-beam limit is maximum when the betatron tunes are as near as possible to the integer. After an extensive study of beam-beam resonances [1] the following tune values have been proposed for DAΦNE:

$$Q_x = 5.09 \ , \ Q_y = 6.07$$

$$Q_x = 4.53 \ , \ Q_y = 6.06.$$

An overall redesign of the lattice has been carried out keeping fixed the hardware position and changing only the strengths of the magnetic elements [2].

Linear and nonlinear behavior, injection and lifetime for the new working points have been optimized obtaining an improvement of the dynamic aperture, which is now much larger than the vacuum chamber aperture.

The main difference with respect to the previous version of the lattice is a non zero dispersion in the injection straight section and, as a consequence, a higher value of the momentum compaction factor.

The higher momentum compaction value is an advantage for beam stability but, as a drawback, gives a reduction of the beam lifetime because the energy acceptance, for the same RF voltage, is smaller.

The bunch length and energy spread, calculated with the impedance model of the ring for the maximum design current, are smaller for the higher momentum compaction [3]. As a consequence Touschek scattering, which is inversely proportional to the bunch volume, is increased with a further reduction of the beam lifetime.

With a shorter bunch length and a larger dynamic aperture the value of the vertical beta function at the IP β_y* can be decreased to obtain a higher luminosity.

The lattice presented in this note has a lower β_y value at the interaction point and a dynamic aperture still larger than the physical aperture. The beam lifetime is larger than one hour at the maximum luminosity.

2. Preliminary hypothesis

The Luminosity formula can be written as:

$$L = \frac{\pi}{r_e^2}\gamma^2 f\xi_y^2 \frac{\varepsilon}{\beta_y}\frac{\left(1+\sqrt{\kappa\kappa_\beta}\right)^2}{1+\kappa}\sqrt{\frac{\kappa}{\kappa_\beta}}$$

and the vertical tune shift:

$$\xi_y = \frac{r_e}{2\pi\gamma}\frac{N(1+\kappa)}{\varepsilon\left(1+\sqrt{\kappa\kappa_\beta}\right)}\sqrt{\frac{\kappa_\beta}{\kappa}}$$

where all the symbols are well known; we just remind here the definition of κ and κ_β:

$$\kappa = \varepsilon_y / \varepsilon_x$$

$$\kappa_\beta = \beta_y^* / \beta_x^*.$$

In the following we have adopted some hypothesis used by Mario Bassetti [4] to make a fit of the experimental values of the ξ_y limit obtained in the existing e^+e^- colliders all operating with flat beams ($\sigma_x >> \sigma_y$). We summarize these hypothesis below.

The coupling factor κ and the limit value of ξ_y can be obtained by solving the above formulas, for given values of luminosity, current, emittance, β_x and β_y at the IP. In fact in the existing storage rings the emittance is generated only in the horizontal plane (there are no vertical bending magnets) and the vertical one is due to the coupling between the two planes. In presence of beam-beam interaction the vertical beam size, and therefore κ, can be reduced until ξ_y reaches its limit.

Mario Bassetti has obtained a good fit of the limit value of ξ_y for different colliders with the following parameters:

$$\xi_y = 3.10\cdot 10^{-3}\left(\frac{E}{\sigma_x{}'}\,\eta(R)\right)^{.49}\left(\rho_f\sqrt{n_i}\right)^{-.38}$$

where:

E = energy in GeV

$$\sigma_x' = \frac{\sqrt{\varepsilon\beta_x + \sigma_p^2 D_x^2}}{\beta_x}$$

$$\rho_f = \sqrt{\frac{2\pi}{\oint \frac{1}{\rho^3} ds}}$$

n_i = number of crossings

$\eta(R)$ is a function which enters in the formula to calculate the synchrotron radiation energy loss in the beam-beam interaction [5]. A good fit for $\eta(R)$ is given below:

$$\eta(R) = \frac{1}{3.309 + 7.288 * R + 3.308 * R^2}$$

$$R = \frac{\sigma_y}{\sigma_x}$$

This fit gives very good results for colliders operating in different configurations and in a large energy range, from .5 GeV of VEPPIIM to the maximum energy obtained at LEP (68 GeV). A plot of the ξ_y values obtained by the fit compared with the measured ones is shown in **Appendix A**.

The ξ_y value adopted in the following is the DAΦNE design value ($\xi_y \le .04$) and is always lower than that obtained by the fit.

It is interesting to point out that a similar attempt to fit ξ_x failed. It seems that there is no beam-beam limitation on ξ_x and its value is determined only by the choice of the operating point.

Therefore in the design of the lower β_y^* lattice the condition $\kappa=\kappa_\beta$ has been abandoned obtaining a configuration with ξ_x larger than the DAΦNE design value (ξ_x= .04).

3. Lower β_y^* lattice

In the DAΦNE design we have assumed that the maximum luminosity is achieved when $\beta_y^*=1.5\ \sigma_l$. With the higher momentum compaction the estimated bunch length for DAΦNE is σ_l=.02m, and therefore the optimum value of the beta function at the IP is: β_y^*=.03m.

The CESR storage ring [6] has the highest luminosity in the world with: $\beta_y^* = \sigma_l$; if this holds also for DAΦNE we have two possibilities:

- keep β_y^*=.03m and lengthen the bunch to increase the beam lifetime
  or
- keep a .02m bunch length and, after gaining enough experience with the machine, try and further reduce the value of β_y^*.

We assume as reference lattice the one with "Day-one" interaction regions and Q_x=4.53, Q_y=6.06 described in ref. [7]. The lattice with the lower β_y* has the same working point and is matched using only the arc quadrupoles, without modifying the interaction region.

The optical functions, the quadrupoles and sextupoles strengths and the dynamic aperture are shown in **Appendix B**.

The optical functions are compatible with the vacuum chamber apertures and with the vertical separation in the interaction region.

Of course the chromaticity is increased, but the dynamic aperture is still larger than the vacuum chamber aperture.

The values of the luminosity parameters for DAΦNE phase I (30 bunches) are shown in **Table I**.

In **Table II** the beam lifetime and the related parameters are shown.

The beam lifetime is calculated by taking into account the design of the vacuum chamber aperture. A residual gas pressure $P=10^{-9}$ Torr (biatomic gas, Z=8) is assumed. The RF voltage has been chosen in order to get 1% energy acceptance.

The Touschek scattering effect is the dominant contribution to the beam lifetime and therefore it is listed separately in the table. It is proportional to the bunch density and therefore an increase of the bunch volume, due to a larger coupling factor, increases the beam lifetime.

In the first column of Tables I and II the design values of the parameters for the reference lattice are shown. The data shown in columns a), b) and c) correspond to different versions of the lower β_y* lattice:

a) All the parameters have the design values: the gain in luminosity is only 20% but the ξ_y is lower and the beam transverse density can be increased further.

b) The number of particles per bunch and the emittance are adjusted to get ξ_y =.04 (the design value) and an appreciably higher luminosity.

c) All the parameters have the same values as in column b) except for κ, increased to get a longer lifetime at the design luminosity.

Table I - Luminosity parameters for DAΦNE phase I

	Design values	**a**	**b**	**c**
Energy (MeV)	510	510	510	510
Emittance (m·rad)	$1.0\ 10^{-6}$	$1.0\ 10^{-6}$	$0.9\ 10^{-6}$	$0.9\ 10^{-6}$
Betax (m)	4.5	4.5	4.5	4.5
Betay (m)	**0.045**	**0.03**	**0.03**	**0.03**
σ_x^* (m)	$2.1\ 10^{-3}$	$2.1\ 10^{-3}$	$2.0\ 10^{-3}$	$2.0\ 10^{-3}$
σ_y^* (m)	$2.1\ 10^{-5}$	$1.7\ 10^{-5}$	$1.6\ 10^{-5}$	$3.0\ 10^{-5}$
κ	0.01	0.010	0.010	0.030
κ_β	0.010	0.007	0.007	0.007
nb	30	30	30	30
N per bunch	$8.9\ 10^{10}$	$8.9\ 10^{10}$	$10.0\ 10^{10}$	$10.0\ 10^{10}$
Itot (A)	1.31	1.31	1.48	1.48
ξ_y lim. (Bassetti's fit)	0.049	0.049	0.050	0.050
ξ_x	0.040	0.040	0.050	0.050
$\boldsymbol{\xi_y}$	**0.040**	**0.033**	**0.040**	**0.024**
L ($cm^{-2}s^{-1}$)	**$1.3\ 10^{32}$**	**$1.6\ 10^{32}$**	**$2.2\ 10^{32}$**	**$1.3\ 10^{32}$**

Table II - Beam lifetime parameters

	Design values	**a**	**b**	**c**
Momentum compaction	.026	.025	.026	.026
V_{RF} (KV)	254	254	254	254
σ_p	$5.5\ 10^{-3}$	$5.5\ 10^{-3}$	$5.7\ 10^{-3}$	$5.7\ 10^{-3}$
σ_l (m)	.019	.019	.020	.020
RF acceptance	$9.8\ 10^{-3}$	$9.9\ 10^{-3}$	$9.9\ 10^{-3}$	$9.9\ 10^{-3}$
Touschek scattering lifetime (min)	94	95	90	152
Single beam lifetime (min)	**84**	**84**	**80**	**126**

Reducing the β_y* by a factor 1.5 and increasing by ten per cent the bunch current (see column **b**) the luminosity can be increased by a factor 1.7 with a small reduction of the beam lifetime. With the same lattice, if necessary, the beam lifetime can be increased by a factor 1.5 keeping the luminosity at the design value (see column **c**).

A higher integrated luminosity, which is the main parameter for the experiments, is obtained by increasing the peak luminosity at the expense of beam lifetime [8]. Therefore, if it is possible to operate DAΦNE with very frequent injections and if the background level is acceptable for the experiments, it is convenient to choose the configuration with the highest luminosity, shown in column **b**.

A lattice with a lower β_y* has been calculated also for a machine configuration with KLOE+FINUDA interaction region and is presented in **Appendix C**.

Since the transfer matrices of all the DAΦNE interaction regions are nearly equal the lattice is very similar to the one described above.

4. Conclusions

The strategy proposed is to accumulate in DAΦNE the maximum number of particles per bunch allowed by beam instabilities and reduce the value of β_y* until it is equal to the bunch length. The lattice presented here, with β_y*=.03m, is compatible with the vacuum chamber apertures and has a good dynamic aperture.

Once enough experience with the machine will be gained it will be possible to try to further reduce β_y*.

Finally coupling, emittance and β_x can be adjusted, optimizing the behavior of the beta-functions and the dynamic aperture, to get a small gain in the beam lifetime.

References

[1] K. Hirata, M. Zobov, "Beam-beam Interaction Study", 9th DAΦNE Machine Review, October 3-4 1995.

[2] M.E. Biagini, C. Biscari, S. Guiducci, "Optics Update", 9th DAΦNE Machine Review, October 3-4 1995.

[3] M. Migliorati, L. Palumbo, M. Zobov, "Longitudinal Single Bunch Dynamics", 9th DAΦNE Machine Review, October 3-4 1995.

[4] M. Bassetti, private communication.

[5] M. Bassetti, M. Gygi-Hanney, "Dependence of the Beam-Beam Synchrotron Radiation on the Transverse Dimension for Gaussian Beams", LEP Note 221 (22-4-1980).

[6] D. Rice, "CESR Luminosity Upgrades and Experiments", IEEE Part. Acc. Conf., Washington, D.C. (1993).

[7] M.E. Biagini, C. Biscari, S. Guiducci, "DAΦNE Main Rings Lattice Update", DAΦNE Technical Note , to be published.

[8] S. Guiducci, "Beam Lifetime in DAΦNE", DAΦNE Technical Note L-12, 2/24/1993.

APPENDIX A

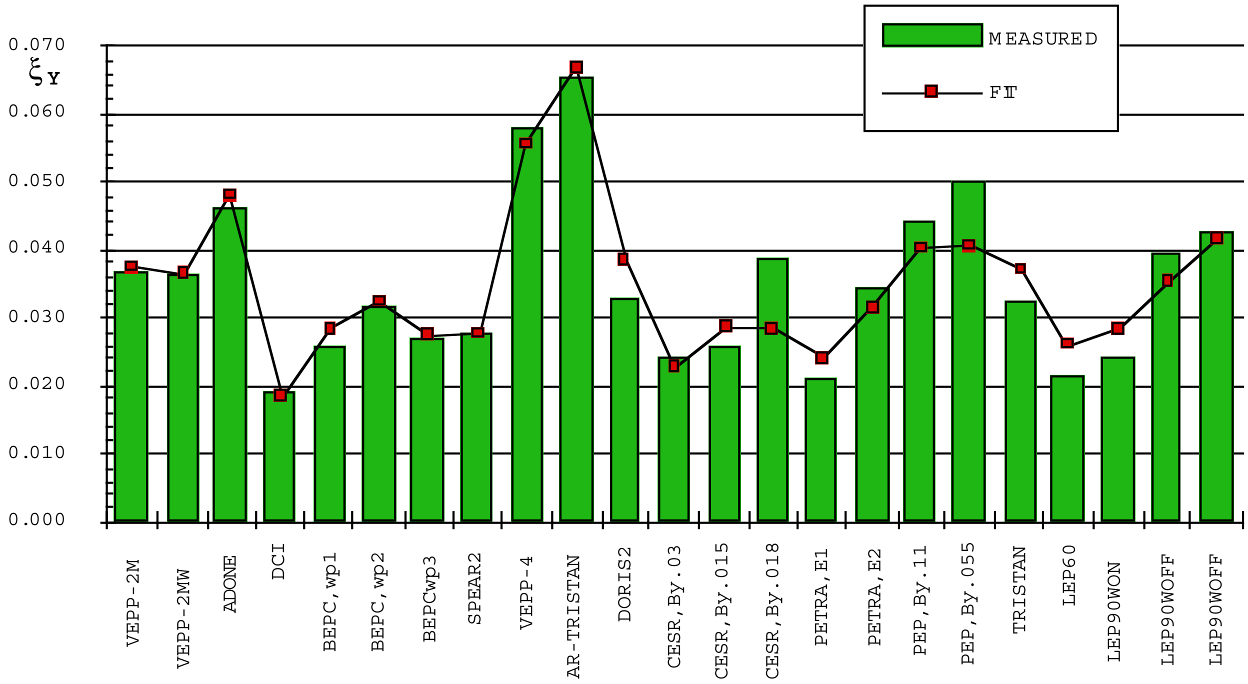

Fig. A1 - Limit value of ξ_y calculated by the Mario Bassetti fit for different operating colliders.
For comparison the solid columns represent the measured values.

APPENDIX B

Lower β_y^* lattice - DAY-ONE IR

β-functions at the IP (m):	β_x^*	4.5
	β_y^*	.03
Betatron wavenumbers:	Q_x	4.53
	Q_y	6.06
Chromaticities:	ξ_x	-7.1
	ξ_y	-24.5
Momentum compaction		**.025**
Natural emittance (m rad)		$1.0\ 10^{-6}$
σ_x^* (out of coupling) (m)		$2.1\ 10^{-3}$
σ_y^* (full coupling) (m)		$.12\ 10^{-3}$

Table BI - Quadrupole strengths

Name	**K^2 (m^{-2})**	**Name**	**K^2 (m^{-2})**
QUAI1004	2.29249381		
QUAI1005	-0.51231832		
QUAI1006	-3.75326949		
QUAI1007	2.04901099		
QUAES101	1.29684122	QUAEL201	1.35629009
QUAES102	-2.60278604	QUAEL202	-2.18265709
QUAES103	1.06506687	QUAEL203	0.32530995
QUAES104	-2.63521188	QUAEL204	-2.40489911
QUAES105	3.00881460	QUAEL205	2.85573967
QUAES106	1.91248811	QUAEL206	2.22750478
QUAES107	-1.41404042	QUAEL207	-1.02594039
QUAES108	1.08992888	QUAEL208	3.47459875
QUAES109	-1.45620749	QUAEL209	-3.10318921
QUAES110	2.26467587	QUAEL210	2.82583489

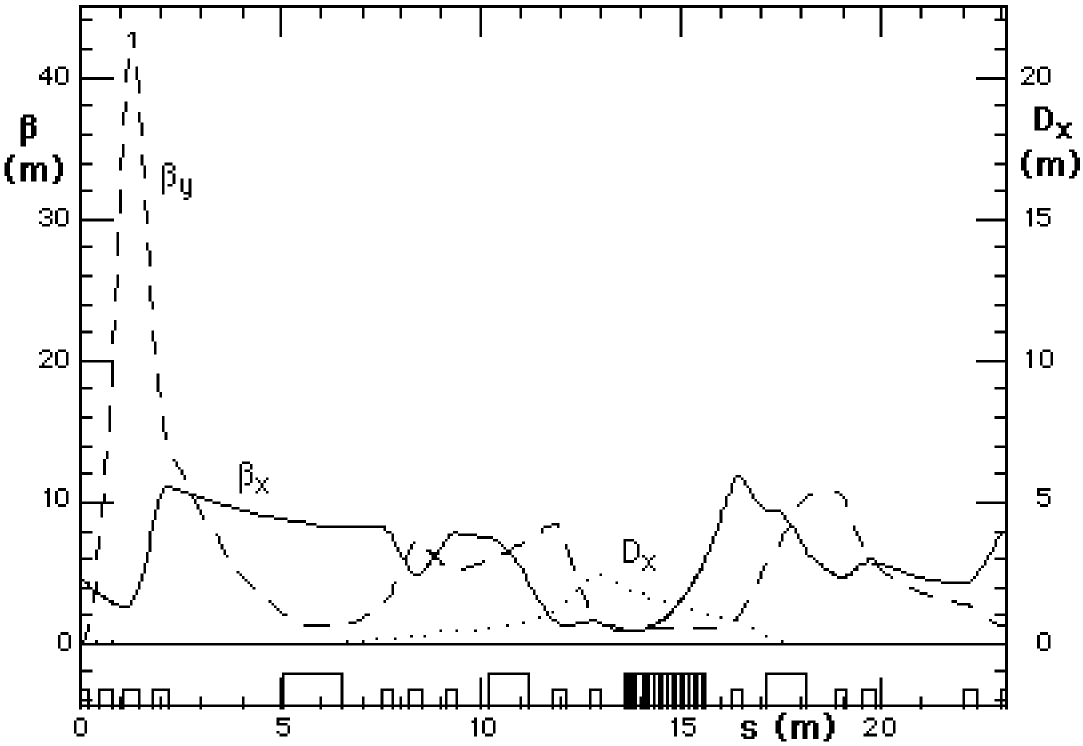

Fig. B1 - Half SHORT optical functions.

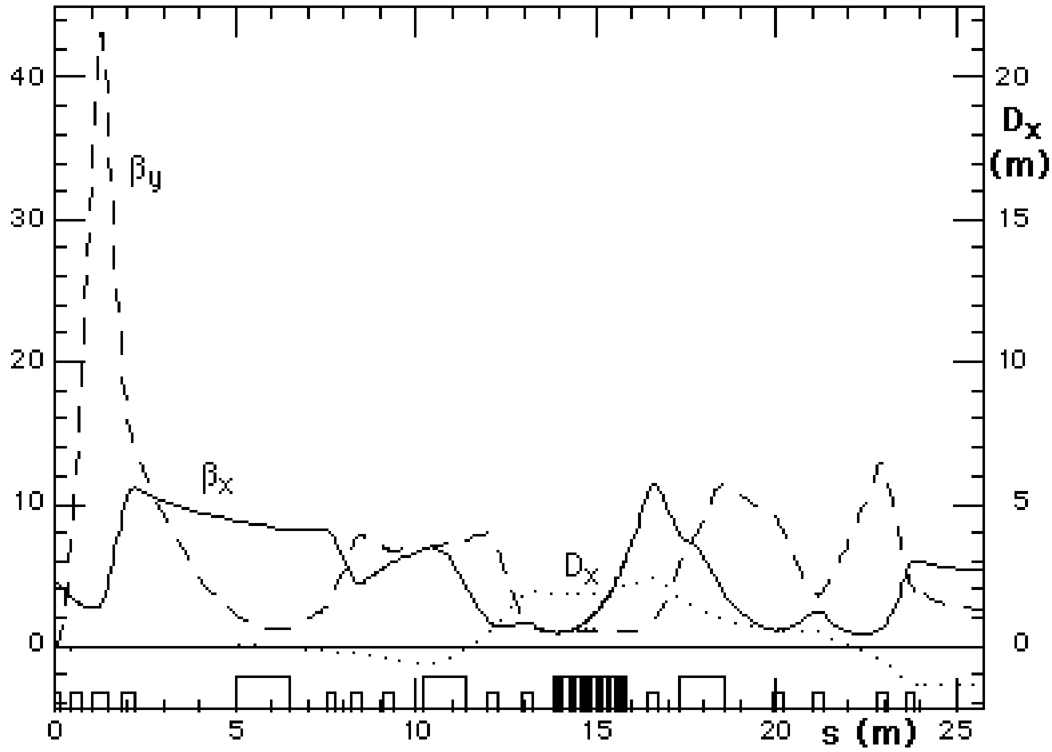

Fig. B2 - Half LONG optical functions.

Table BII - Sextupole strengths.

N sex	Name	K_s (m^{-2})
1	SXPES101	-0.50
2	SXPES102	9.658
3	SXPES103	-4.141
4	SXPES104	-0.20
5	SXPES201	-0.20
6	SXPES202	-4.141
7	SXPES203	9.658
8	SXPES204	-0.50
9	SXPEL201	-2.60
10	SXPEL202	9.50
11	SXPEL203	-3.30
12	SXPEL204	3.30
13	SXPEL101	3.30
14	SXPEL102	-3.30
15	SXPEL103	9.50
16	SXPEL104	-2.60

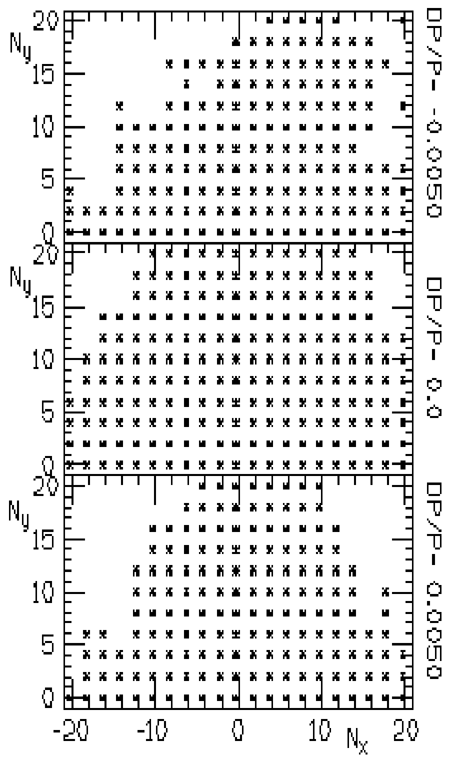

Fig. B3 - Dynamic Aperture in units of σ_x^* (out of coupling) and σ_y^* (full coupling).

APPENDIX C

Lower β_y^* lattice - KLOE + Fi.Nu.Da IRs

β-functions at the IP (m):	β_x^*	4.5
	β_y^*	.03
Betatron wavenumbers:	Q_x	4.53
	Q_y	6.06
Chromaticities:	ξ_x	-6.6
	ξ_y	-23.9
Momentum compaction		**.026**
Natural emittance (m rad)		1.0 10^{-6}
σ_x^* (out of coupling) (m)		2.1 10^{-3}
σ_y^* (full coupling) (m)		.12 10^{-3}

Table CI - Quadrupole strengths*

Name	K^2 (m^{-2})	Name	K^2 (m^{-2})
QUAES101	1.43843981	QUAES110	1.59364096
QUAES102	-2.91390208	QUAES201	-0.77185092
QUAES103	0.99824154	QUAES202	0.80688131
QUAES104	-2.37642658	QUAES203	-1.19882955
QUAES105	2.92324662	QUAES204	1.94606436
QUAES106	1.93498055	QUAES205	2.90566750
QUAES107	-1.22972591	QUAES206	-2.30956464
QUAES108	0.85632249	QUAES207	0.93372184
QUAES109	-0.86592817	QUAES208	-2.93099292
QUAES110	1.59364096	QUAES209	1.53136389
QUAEL201	1.57666747	QUAEL101	2.80121935
QUAEL202	-2.28757649	QUAEL102	-2.97166914
QUAEL203	-0.06544472	QUAEL103	3.26400954
QUAEL204	-1.94080041	QUAEL104	-0.93224021
QUAEL205	2.69954186	QUAEL105	2.27072326
QUAEL206	2.28214384	QUAEL106	2.73861914
QUAEL207	-0.92355315	QUAEL107	-2.05387611
QUAEL208	3.24298004	QUAEL108	0.08953710
QUAEL209	-2.95650805	QUAEL109	-2.35840351
QUAEL210	2.79834926	QUAEL110	1.49990937

***** The layout and quadrupole strengths for the KLOE and Fi.Nu.Da. interaction regions are given in ref. [7].

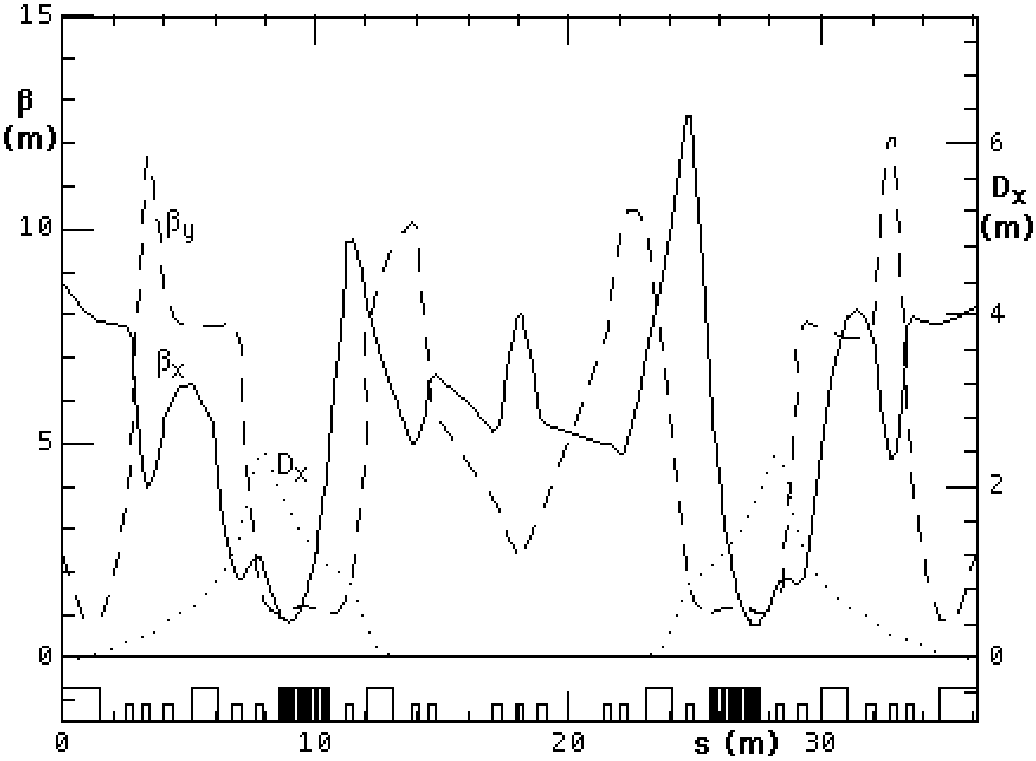

Fig. C1 - SHORT optical functions.

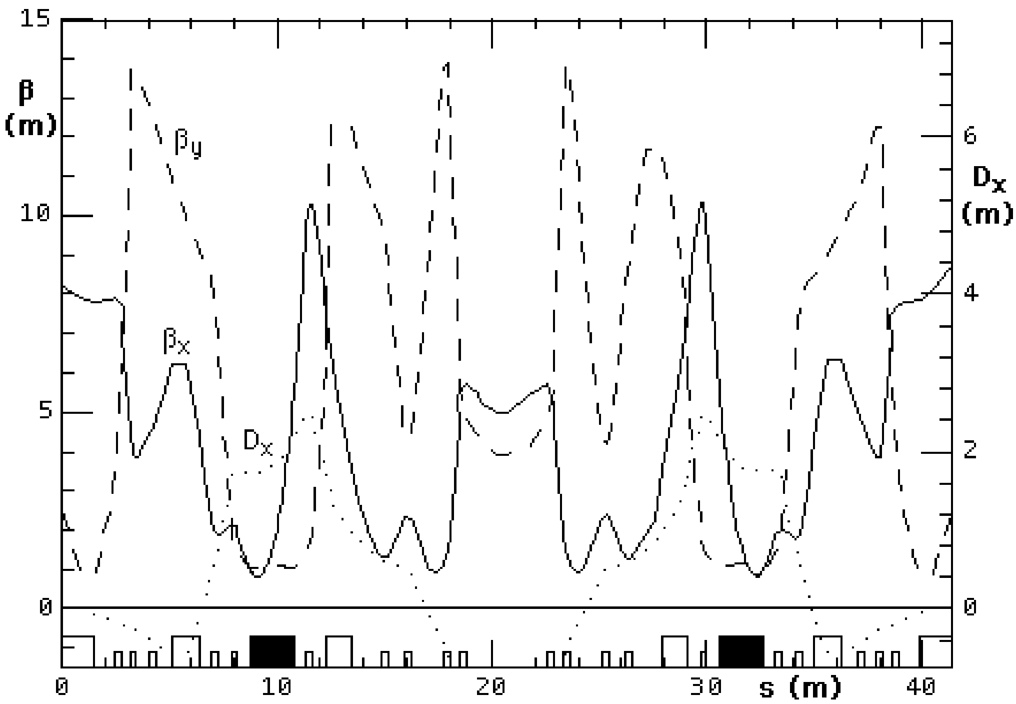

Fig. C2 - LONG optical functions.

Table CII - Sextupole strengths.

N sex	**Name**	**K_s** (m^{-2})
1	SXPES101	-1.05
2	SXPES102	10.5438
3	SXPES103	-5.6061
4	SXPES104	1.0
5	SXPES201	1.0
6	SXPES202	-4.6
7	SXPES203	8.3
8	SXPES204	-1.05
9	SXPEL201	-0.9
10	SXPEL202	8.2
11	SXPEL203	-3.4
12	SXPEL204	5.1
13	SXPEL101	5.1
14	SXPEL102	-3.4
15	SXPEL103	8.2
16	SXPEL104	-0.9

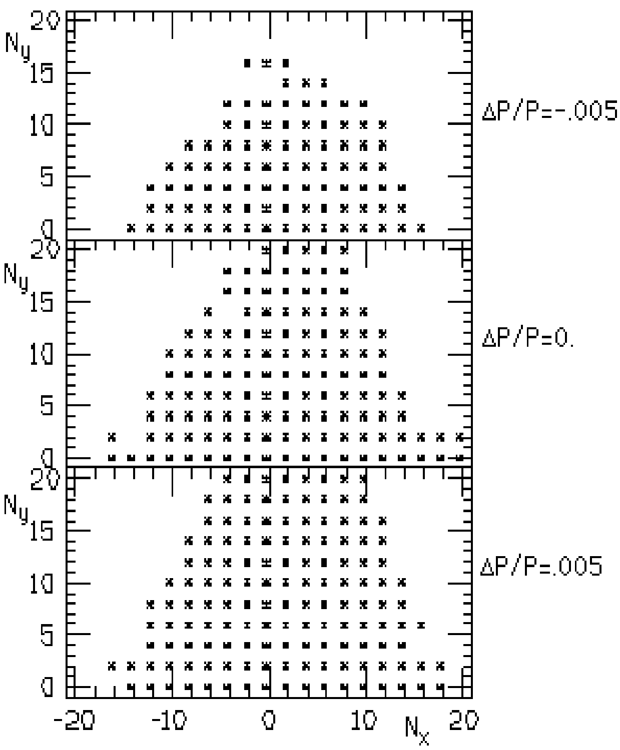

Fig. C3 - Dynamic Aperture in units of σ_x^* (out of coupling) and σ_y^* (full coupling).