DAΦNE TECHNICAL NOTE

INFN - LNF, Accelerator Division

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Note: **BM-9**

HALF β_x^* AT IP2

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INTRODUCTION

The DAFNE luminosity design parameters are based on the equal beam-beam tune shift in the horizontal and in the vertical plane. In the present operation this hypothesis is not fulfilled: it is based in fact on the equal ratio between the vertical to horizontal emittances and the vertical to horizontal β* at the Interaction Point (IP). Since the coupling is corrected well above the design value, and the vertical β* has been lowered up to the limit of the hour-glass effect [1, 2], in both IPs, the equality between the two beam-beam tune shifts does not hold anymore. The horizontal β* has been kept near to the design value (4.5 m) which was defined to limit the 'badness factor' of the crossing angle, and to fit the aperture requirements in the splitters nearby the Interaction Regions (IRs).

Two days machine shifts (March 21 and 22, 2002) have been dedicated to the first investigation of a different IR design, in which β_x^* is half the design value. This should make less dangerous the parasitic crossings, allowing the interactions with all buckets filled.

First results and perspectives for the future are described in this note.

SECOND INTERACTION REGION OPTICS

The second IR houses presently two quadrupole triplets around the DEAR experiment. In the usual IR design the quadrupole triplet is FDF. This configuration is optimized in order to fit aperture requirements, beam separation and crossing angle in the range of 10/15 mrad.

Figures 1 and 2 show the optical functions and the beam separation corresponding to a crossing angle of 10 mrad and $\beta_x^* = 4\ m$ and $\beta_y^* = 3\ cm$ for the nominal optics [2].

Lowering by a factor two the value of β_x^* is obtained by switching off the first quadrupole of the triplet, and increasing the strength of the outer one by ~ 25%. The defocusing quadrupole strength is lowered by a few percent. The maximum β_y for the same β_y^* is decreased by 30% with the corresponding benefit in the local chromaticity. The horizontal beam size at the splitter is kept within the aperture requirements. In Figs.3 and 4 the optical functions and the beam trajectory for a crossing angle of 10 mrad are shown respectively.

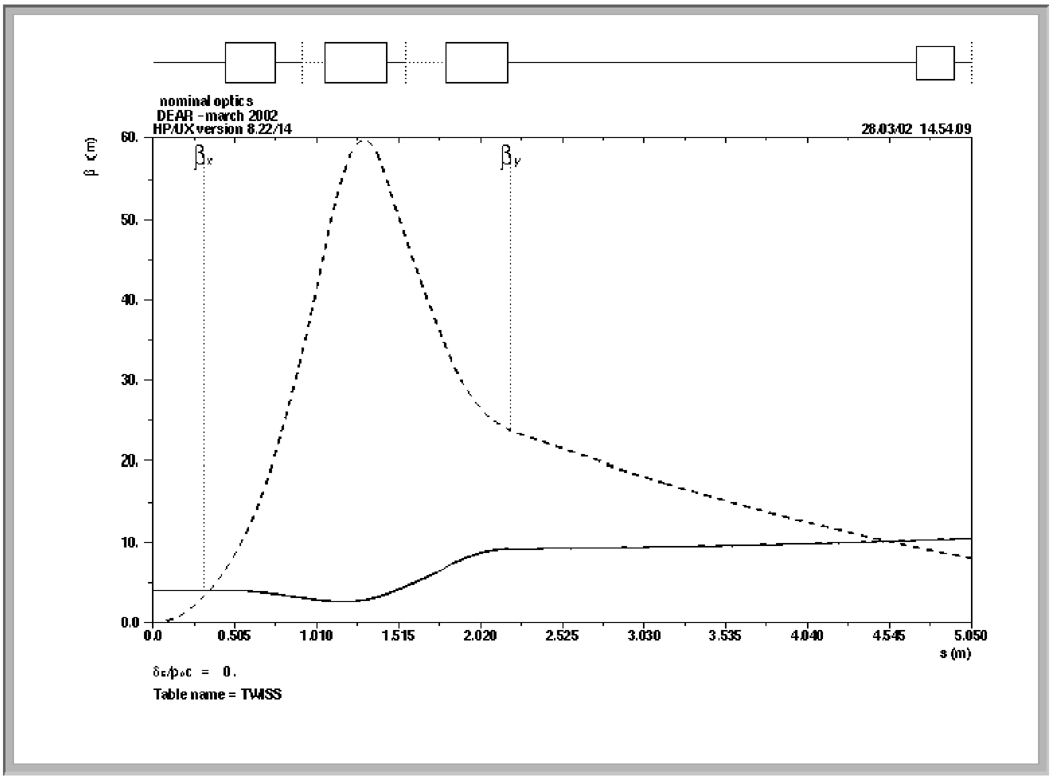

Figure 1 – Optical functions for the usual DEAR Interaction Region

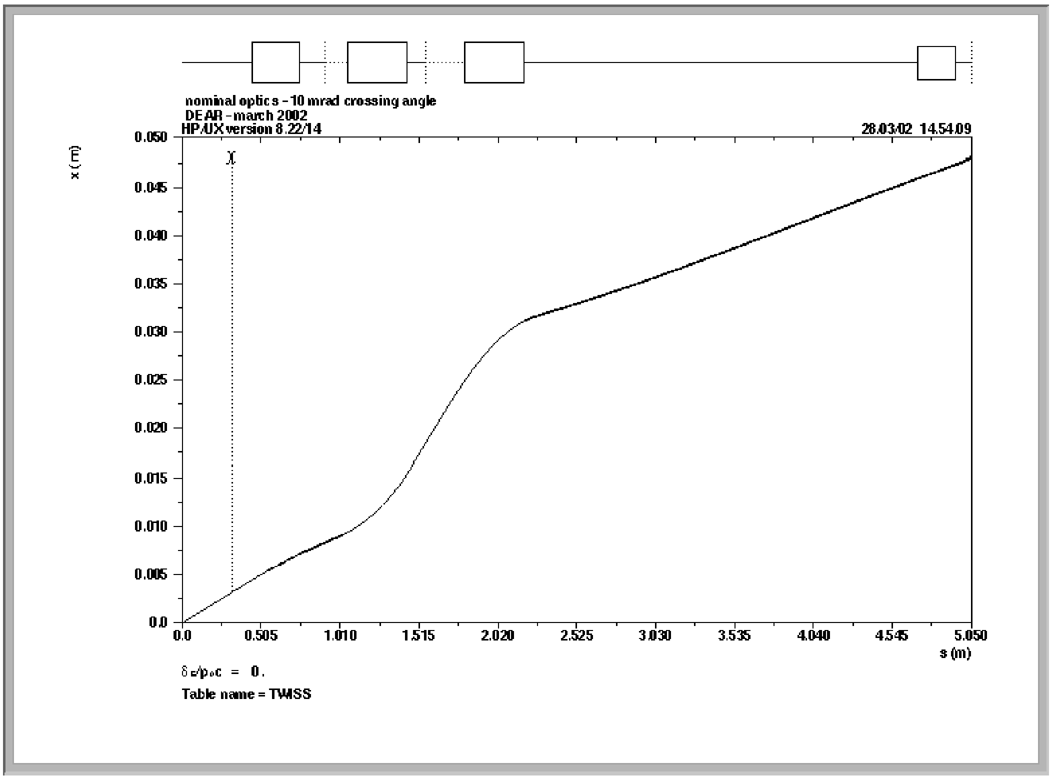

Figure 2 – Beam trajectory in the usual DEAR Interaction Region for θ = 10 mrad

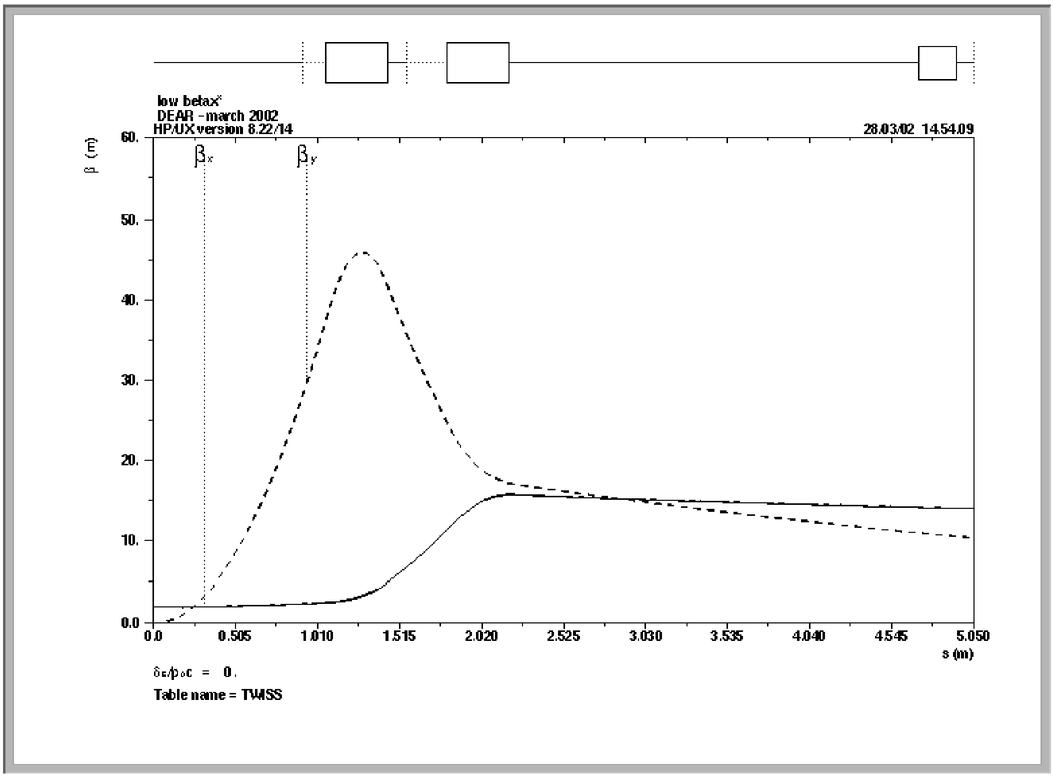

Figure 3 – Optical functions for the modified DEAR Interaction Region

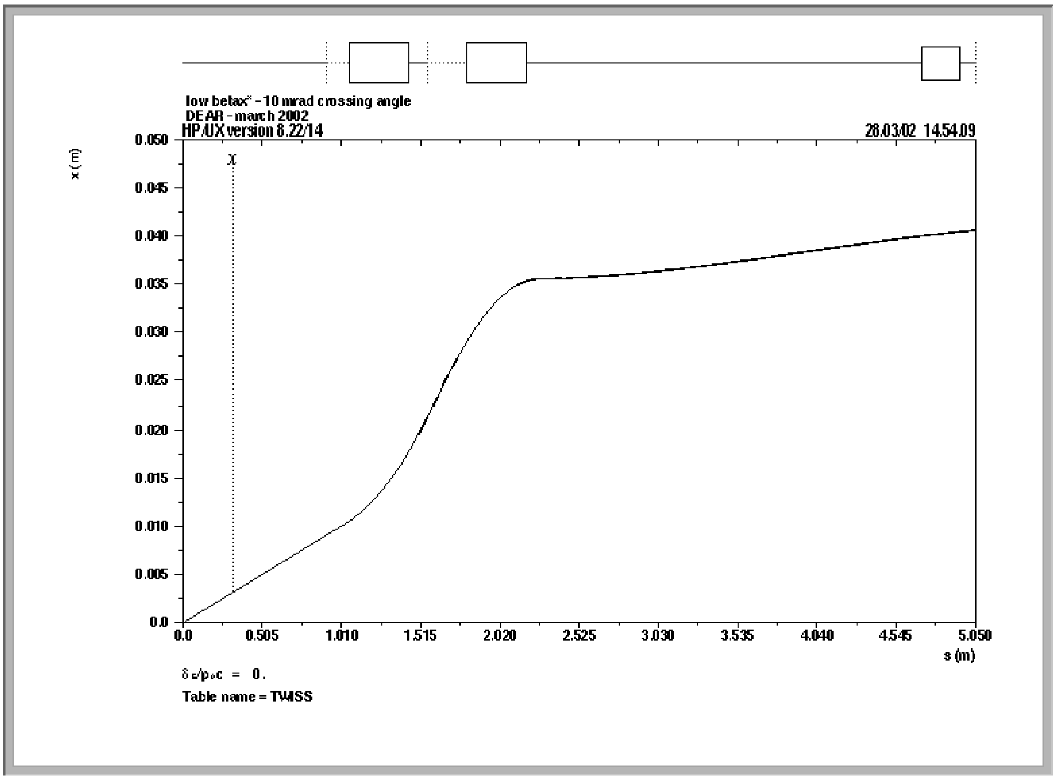

Figure 4 – Beam trajectory in the modified DEAR Interaction Region for θ = 10 mrad

Let's call $\mathbf{M}_{IR}$ the first-order transport matrix of half IR from the IP to the splitter entrance. The term $M_{IR}(1,2)$ is the value of the trajectory and $M_{IR}(2,2)$ its derivative at the splitter entrance for a unit-crossing angle. For the modified β_x^* optics it is smaller than the design (see Table I), which means that for the same aperture requirements the crossing angle can be varied between 12 and 18 mrad, instead of the usual 10/15 mrad. The values of the currents of the splitter and the 'C' corrector for tuning the crossing angle are represented in Fig. 5. The crossing angle corresponding to switching off the 'C' corrector is ~15 mrad.

Table I – Terms of the half IR first-order transport matrix for DEAR

	nominal DEAR	modified DEAR
$M_{IR}(1,2)$ (m)	4.80	4.07
$M_{IR}(2,2)$ (rad)	0.59	0.19

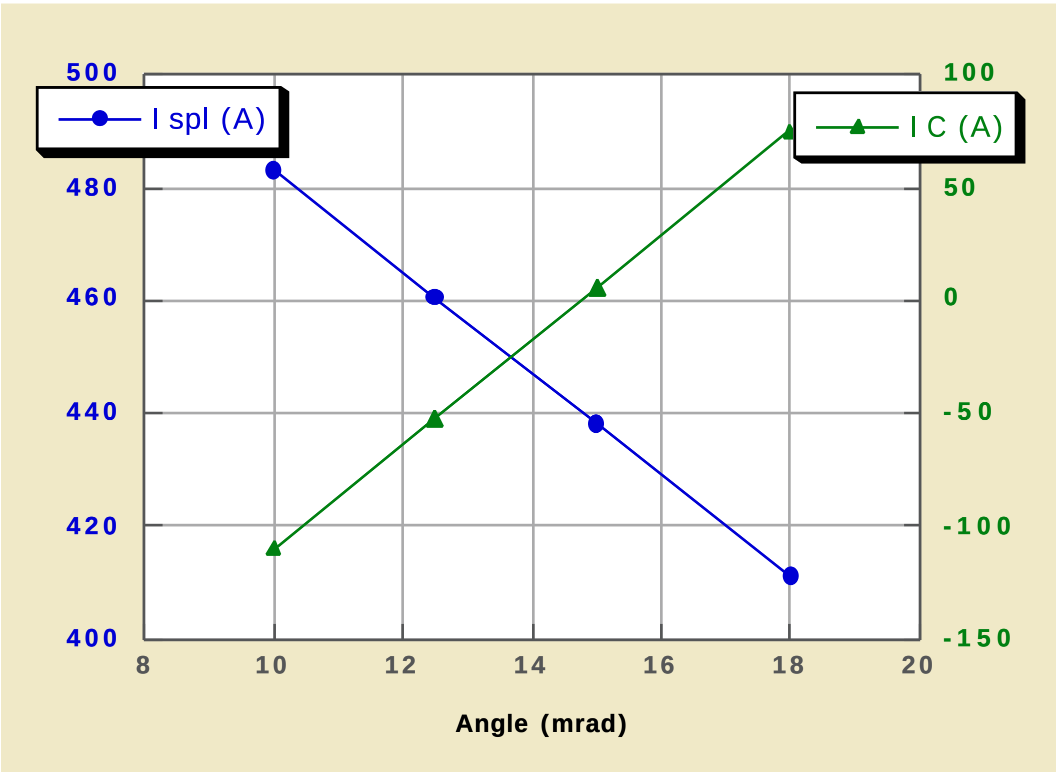

Figure 5 – Currents of the splitter and 'C' corrector for tuning the crossing angle in the modified DEAR IR

BEAM-BEAM TUNE SHIFT AND LUMINOSITY

Let's make some considerations about the beam-beam parameters.

Luminosity

It is straightforward to note that decreasing the horizontal beam size at the IP of a factor $\sqrt{2}$, the single bunch luminosity at a certain bunch current is increased by ~40%, or the same single bunch luminosity can be achieved with a current per bunch smaller by ~20%.

$$L = \frac{1}{4\pi}\frac{N^2}{\sigma_x \sigma_y} f$$

Beam-beam tune shift

Let's recall once more the well-known beam-beam tune shift expressions in the hypothesis of two equal beams (in currents and sizes at the IP):

$$\xi_x = \frac{r_e N}{2\pi\gamma}\frac{\beta_x^*}{\sigma_x(\sigma_x + \sigma_y)} \approx \frac{r_e N}{2\pi\gamma}\frac{\beta_x^*}{\sigma_x^2}$$

$$\xi_y = \frac{r_e N}{2\pi\gamma}\frac{\beta_y^*}{\sigma_y(\sigma_x + \sigma_y)} \approx \frac{r_e N}{2\pi\gamma}\frac{\beta_y^*}{\sigma_x \sigma_y}$$

The ratio between the horizontal and vertical beam-beam tune shifts is therefore:

$$\frac{\xi_x}{\xi_y} = \frac{\beta_x^*}{\beta_y^*}\frac{\sigma_y}{\sigma_x} = \sqrt{k}\sqrt{\frac{\beta_x^*}{\beta_y^*}}$$

where $k = \dfrac{\varepsilon_y}{\varepsilon_x}$ is the ratio between the vertical and the horizontal emittances.

In the DAFNE design the ratio between the betatron functions at the IP was equal (1%) to the coupling ratio between the emittances, and therefore

$$\xi_x = \xi_y$$

Since the present coupling ratio is smaller, of the order of 0.3 ~ 0.5 %, and the vertical betatron function has been minimized up to the hour-glass limit, ($\beta_y^* \approx 3cm$), we use to work with values of

$$\xi_x \approx 0.85\xi_y$$

Halvening β_x^* the relationship between the beam-beam tune shifts in the two planes becomes smaller

$$\xi_x \approx 0.6\xi_y$$

Crossing angle and badness factor

Due to the different M_{12} (see Table I) the crossing angle for the same beam stay clear at the splitters is increased by ~20%. The ratio between the horizontal and longitudinal beam size is decreased by $\sqrt{2}$. The badness factor

$$a = \theta \frac{\sigma_L}{\sigma_x}$$

is therefore increased by about 70%, but still smaller than what is considered dangerous for the synchro-betatron coupling (*a* < *1*.)

Parasitic crossings

The most important reason to investigate this optics is the possibility of filling all buckets in collision, due to the reduction of parasitic crossings (PCs) effect.

The PCs occur at each s_{pc} = 0.405m from the IP. In this configuration the first and the second PC occur in straight drifts from the IP. The separation is therefore 2 n_{pc} s_{pc} θ for n_{pc} = 1, 2. The horizontal betatron function growth is limited to few percent, and the separation in terms of sigmas is already larger than 7 in the first PC even for the angle of 12.5 mrad. The following table shows the main PC parameters for the 1st and 2nd PCs, corresponding to a crossing angle of 13.5 mrad, and an emittance of 0.85 mm.mrad.

Table II – Beam parameters at first PCs

	s (m)	β_x (m)	β_y (m)	x (mm) (θ = 13.5 mrad)	x/σ_x
<u>IP</u>	0	2.0	0.03	0	0
1st	.405	2.08	5.50	± 5.5	± 4.1
2nd	.810	2.33	21.9	± 10.9	± 7.7

Beam-beam simulations have been done with the code [3] including the effect of the parasitic crossings, and taking into account the cubic non-linearity.

In Fig. 6 the beam distributions as a function of C_{11} are shown, for a vertical beam-beam tune shift of 0.03, corresponding to a current per bunch of ~14 mA, and a horizontal tune shift of ~0.0154. The crossing angle is ± 13.5 mrad.

The behaviour is slightly different in the two rings, due to the different working point: (0.15, 0.21) for e^+ and (0.11, 0.17) for e^-.

The tuning of C_{11} seems to be a powerful tool to optimise luminosity and lifetime.

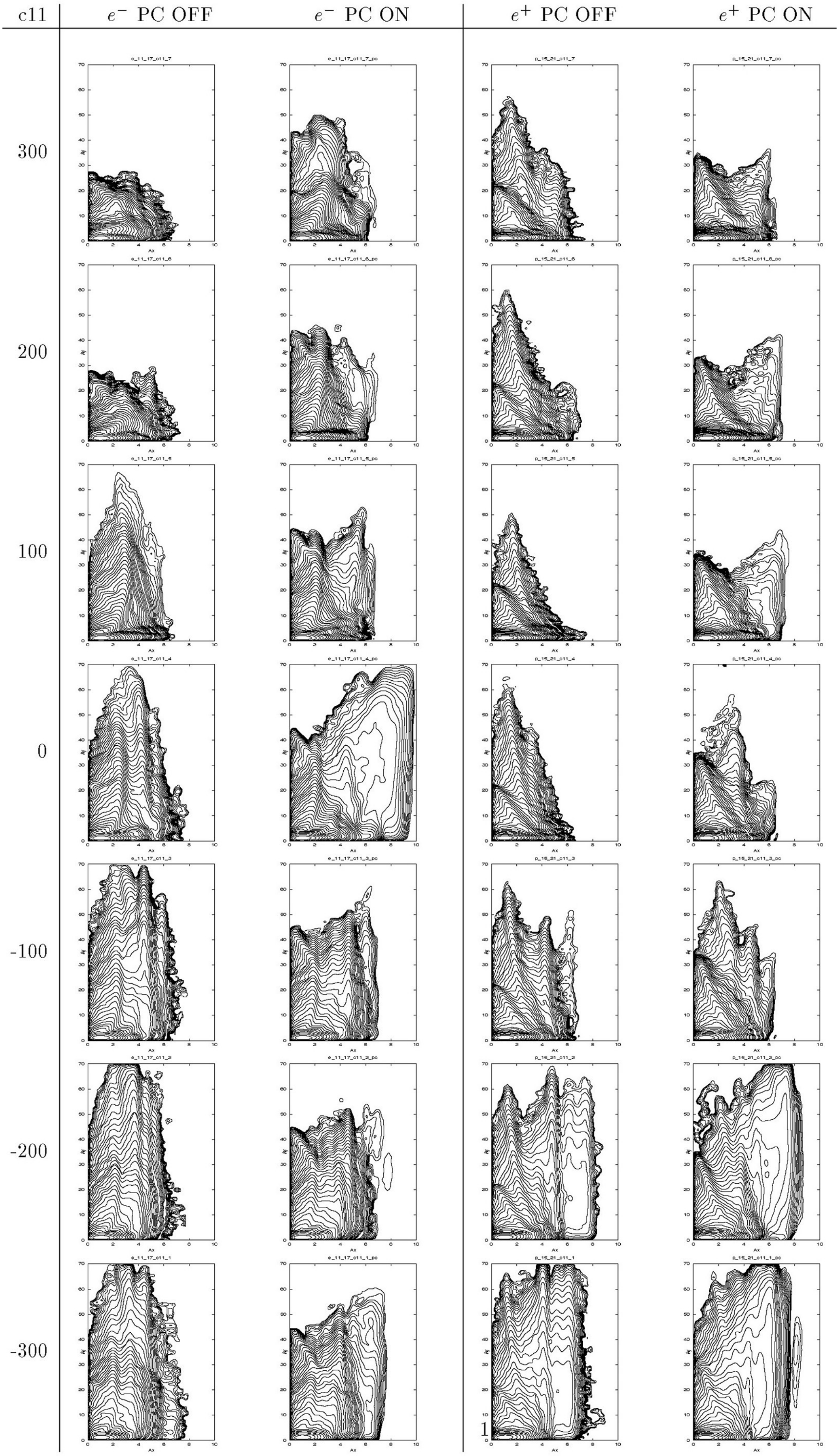

Figure 7 – Results of beam-beam simulations with/without PCs.

MAIN RING OPTICS

The main rings optics has been matched to the above modified DEAR IR and to a KLOE IR with the following IP betatron functions: $\beta_x^* = 3\ m$ smaller than the usual 4m, so that the effect of the parasitic crossing at the 2nd IP is minimised; $\beta_y^* = 15\ cm$, increased with respect to the usual low-beta so that its contribution to the vertical chromaticity is lowered.

Values of emittance, momentum compaction, horizontal betas at the wigglers, are similar to those of the KLOE detuned optics.

The model parameters used are those contained in the dxcalc file:

/exp/dafne/soft/optics/mad8/susanna/p_dear_dec_01.loc,

the same used for the nominal DEAR optics [2].

The two rings have equal quadrupoles settings, except for the seven quads of the tune knob, which have been independently changed to fix the tunes at the usual values. The currents of the main ring quadrupoles are listed in the Appendix. With these set of currents the model predicts for both rings betatron frequencies slightly larger than the measured ones (see Table III). It could be compatible with an energy difference of the order of 0.4% (~ 2 MeV), which may be explained by the different orbits, especially in the splitters around IR2.

Table III – Measured and modelled betatron tunes

	Q_x^-	Q_y^-	Q_x^+	Q_y^+
measured	5.10	5.17	5.15	5.21
model	5.13	5.19	5.17	5.24
model, $\Delta p/p = 0.4\%$	5.11	5.17	5.15	5.21

The splitters have been set at 450 A, corresponding to a crossing angle of 13.7 mrad (see Fig. 5). Since the natural horizontal orbit, before applying the correction, was mainly on the outside of the ring, the rf frequency has been increased by 20 kHz, going to 368.280 MHz.
The response matrices have been acquired and saved as ‘p_DEAR-lowbx’ and ‘e_DEAR-lowbx’. With these matrices the correction of the absolute orbits has been done together with the minimisation of the correctors kicks. Tunes and IP closed bumps have been saved on the folder ‘DEAR_low_bx’.

Measurements of the betatron functions in both rings and of the dispersion on the positron ring are shown in Figs. 8 to 12, compared to the model. The synchrotron frequency measured in the positron ring, 35 kHz @ 120 kV, corresponds to a momentum compaction of 0.029, while the model predicts 0.032. This difference is compatible with the difference between the model dispersion function and the measured one (see Fig. 12).

Beams have been separated at KLOE in order to collide in the 2nd IP. As usual the IP bumps change the rings coupling. A scan with the KLOE field to find the optimum coupling with the separation on has been done. The best coupling correction corresponds to a field slightly higher than the usual one, at a current of 2330 A. With this value the separation between the two beams has been increased up to 4 mm total, maintaining the coupling of both rings less than 0.5%.

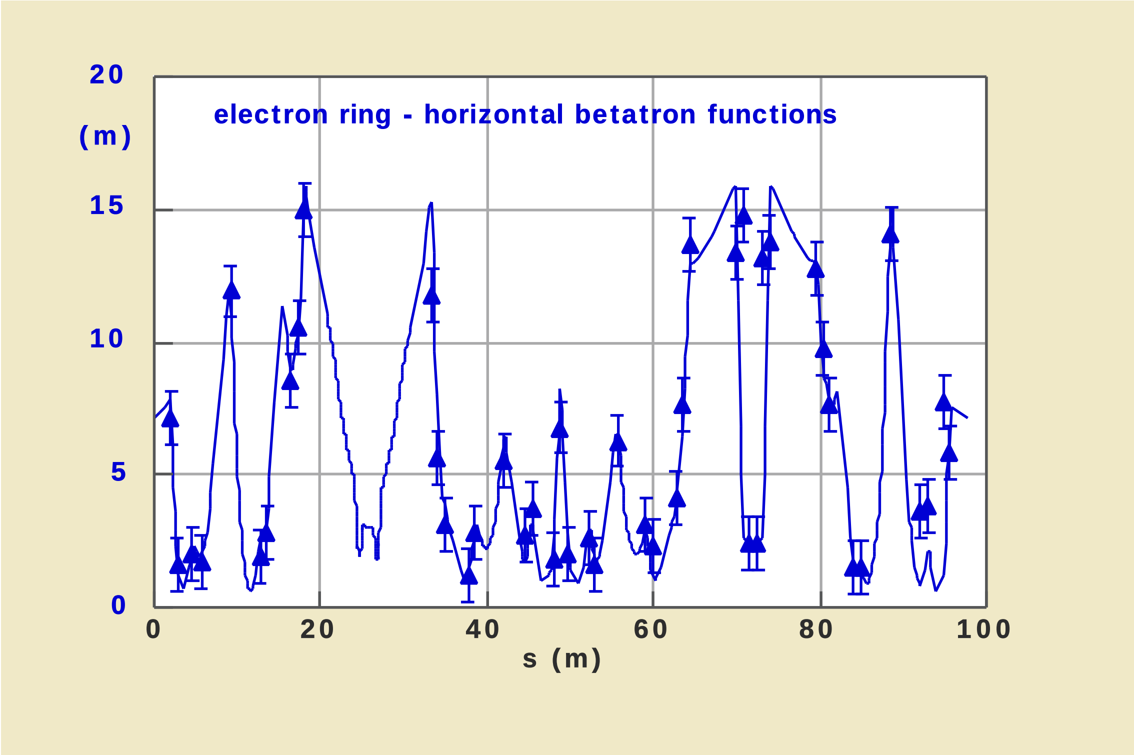

Figure 8 – Horizontal betatron functions in the electron ring – model (full line) and measurements (triangles)

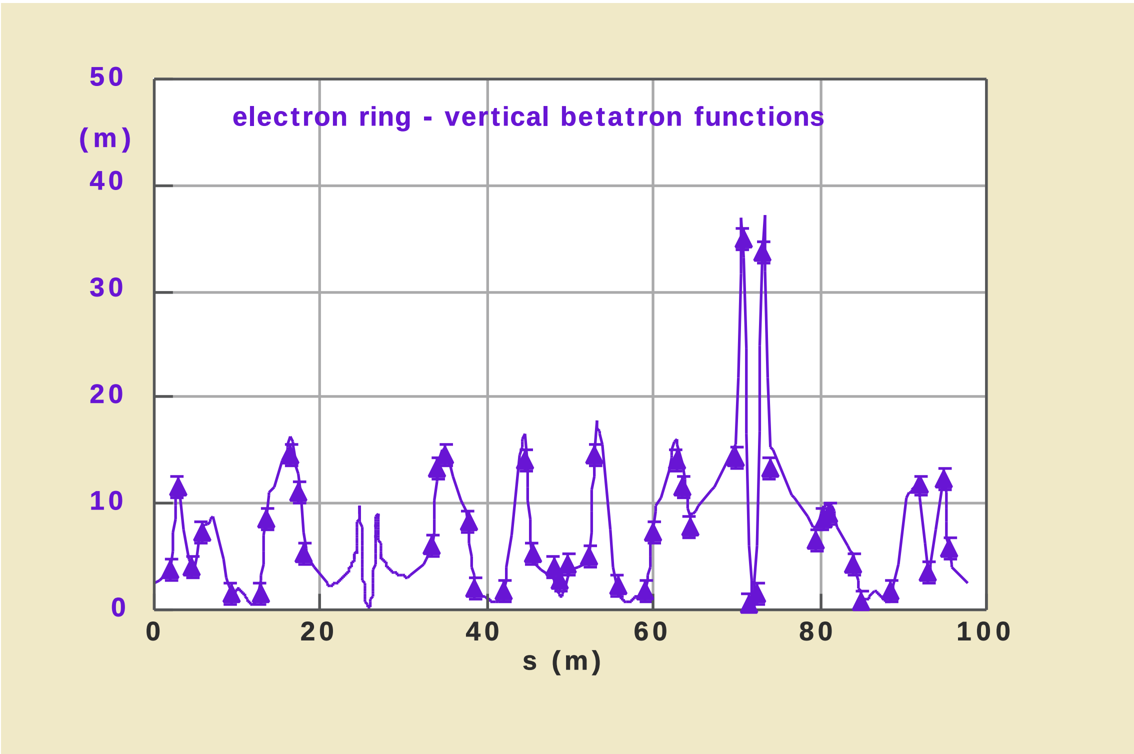

Figure 9 – Vertical betatron functions in the electron ring – model (full line) and measurements (triangles)

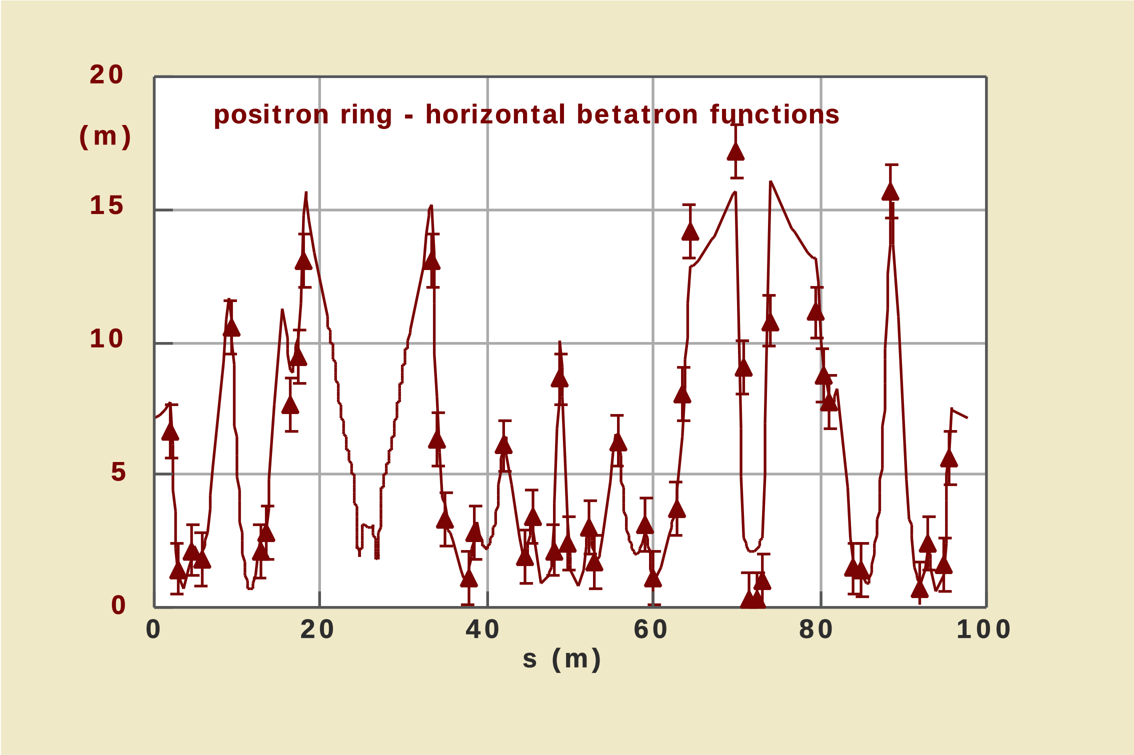

Figure 10 – Horizontal betatron functions in the positron ring – model (full line) and measurements (triangles)

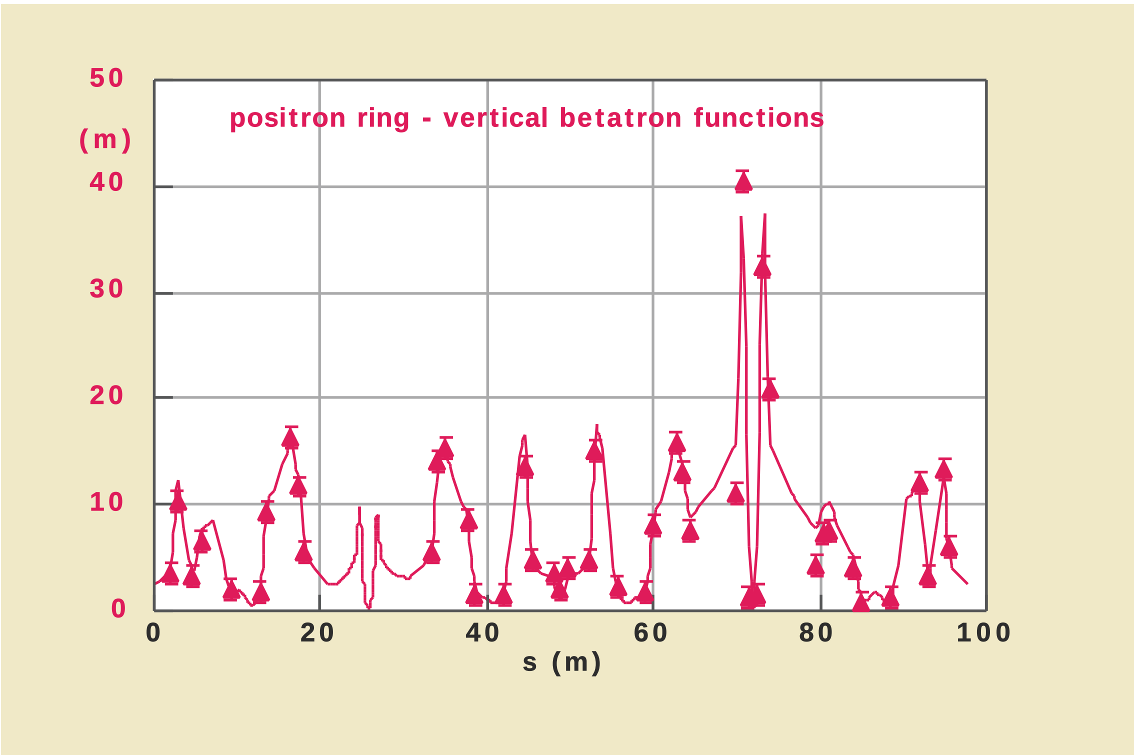

Figure 11 – Vertical betatron functions in the positron ring – model (full line) and measurements (triangles)

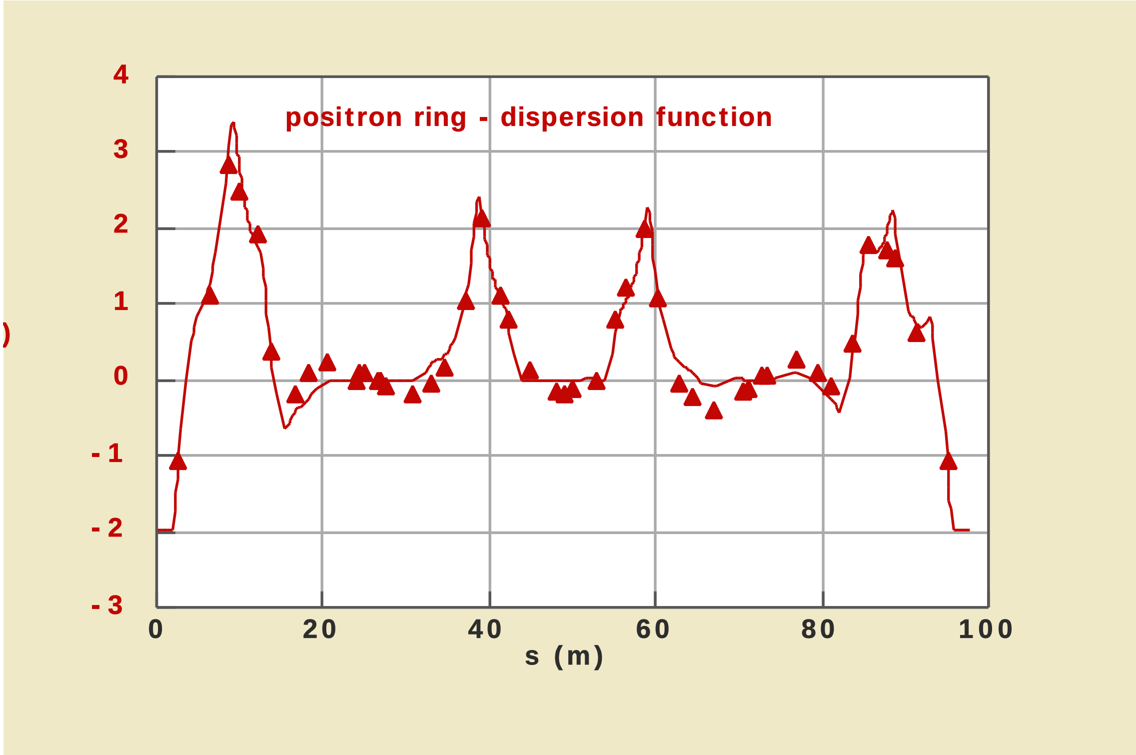

Figure 12– Horizontal dispersion function in the positron ring – model (full line) and measurements (triangles)

PRELIMINARY RESULTS

Measurements of the tune shift on amplitude have been done on both rings. Results are summarised in Table IV.

Table IV – Measurements of cubic non-linearity

ring	V (kV)	n	Q_x	A_x	sext	oct	C_{11}
e^+	3	200	.1521	3.7579	on	off	-310
e^+	4	130	.15071	5.5588	on	off	-321
e^+	5	93	.14877	7.3911	on	off	-338
e^+	3	169	.15716	3.8165	off	off	-360
e^+	4	119	.15583	5.451	off	off	-358
e^+	5	95	.1539	6.5093	off	off	-375
e^-	3	561	.11431	3.7248	on	EL201/25	-111
e^-	3	282	.11341	3.7457	on	off	-220
e^-	4	204	.11267	5.2635	on	off	-216
e^-	5	161	.11168	6.7165	on	off	-215
e^-	3	174	.11053	3.6031	off	off	-370
e^-	4	119	.1091	5.239	off	off	-372
e^-	5	89	.10724	6.8582	off	off	-380

The natural value of C_{11}, with sextupoles and octupoles off, is almost equal in both rings, as expected, since the two rings have the same optics. Measurements done with the preliminary set of sextupoles (see Appendix) show a better correction in the e^- ring than in the positron one, which is compatible with the fact that the two rings chromaticity was not equally corrected $\left(\zeta_x^- = -3.6, \quad \zeta_y^- = 0.9, \quad \zeta_x^+ = -2.7, \quad \zeta_y^+ = -1.0\right)$. The positive effect of the octupole placed in the dispersive region has been checked once more in the electron ring.

The structure has been tested with high currents. In the electron ring a current up to 900 mA in 90 contiguous bunches has been stored. All the feedbacks, longitudinal and transverse, have maintained the usual set up in terms of timing and synchronization. The vertical one needs more gain (at least a factor 2) to compensate the lowest vertical betatron functions in the pickup and in the kicker areas.

Dynamic aperture

The process of optimizing the dynamic aperture has been only initiated. The set of sextupoles used in both rings (see Appendix) corresponds to a d.a. of the order of 10 sigmas in both rings, not taking into account higher order non-linearities.

Beam- beam

Beam-beam scans at low current in multibunch operation have been done optimizing the beams-overlap. The measured vertical beam size at the IP is

$$\Sigma_y = \sqrt{\sigma_{y+}^2 + \sigma_{y-}^2} = 14\ \mu m$$

which, in the hypothesis of $\beta_y^* = 3\ cm$ for both beams, is compatible with an average coupling of ~ 0.4%, confirmed also by the measurement at the synchrotron light monitor.
Collisions with 10 and 20 bunches have been done with different bucket fillings. In the case of one bucket full, three empties, the best condition was obtained with about 10 mA per bunch. Few time has been dedicated to the optimization of the collision (working point tuning, sextupole and octupole settings, coupling, etc.), so we cannot say if this is the upper limit for the collision.

Luminosity and beam-beam behaviour as a function of the bunch spacing have been investigated, and it has been found that the beam-beam blow-up and lifetime do not depend at these currents on it. It is therefore promising from the point of view of the PC effect, but it is still to be investigated if the larger crossing angle could be a limit for the luminosity.

A short attempt to collide with a higher number of bunches has also been done: with 90 bunches (ion-clearing gap of 1/4 of the ring) a total current of ~600 mA in both rings has been stored. No difficulties to inject in collision have been found.

The e^- beam seemed in all these proves stronger than the positron one. To increase the positron lifetime it has been very effective to decrease some of the defocusing sextupoles and to increase up to its limit value the octupole PL201, which according to simulations should increase by ~ 400 the value of C_{11}, making it sligtly positive.

KLOE IR

Further investigation is needed to reach a conclusion on the possible benefits of this optics. If it were the case, a similar modification could be done in KLOE, by taking out the two inner quadrupoles and modifying the outer ones.

We report here first the present KLOE IR optics (Fig. 13), with $\beta_x^* = 4\ m$ and $\beta_y^* = 3\ cm$. To be noticed that the horizontal betatron function at the splitter entrance, β_x^{spl}, is of the order of 10 m, well compatible with the aperture requirements. As the value of β_x^* decreases β_x^{spl} increases. Figure 14 shows for example the case with $\beta_x^* = 2\ m$, in which $\beta_x^{spl} = 15\ m$, and with a derivative such that at the first focusing quadrupole on the arc the aperture requirements are not met any more. The trajectory along the IR for $\theta = 10\ mrad$ is plotted in Fig. 15.

In the hypothesis of taking out the inner quadrupole and increase by 50% the outer one, the $\beta_x^* = 2\ m$ IR optics is well compatible with the aperture requirements, with crossing angles increased of about 40 %. Figures 16 and 17 show the optical functions and the trajectory along the IR, mormalized as in the other cases to a crossing angle of 10 mrad.

Table V shows, for the two KLOE IR configurations, the terms of the 1st order transport matrix defining the trajectory at the splitter.

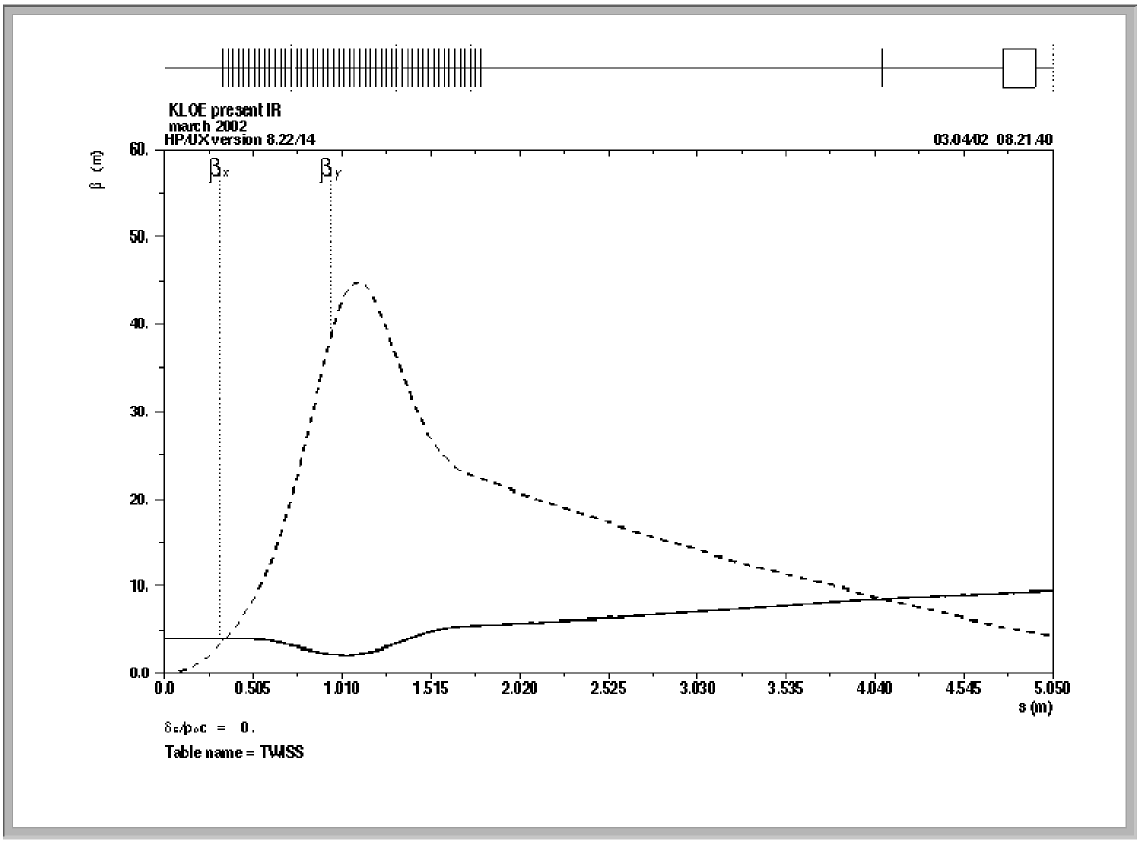

Figure 13 – Present KLOE optical functions

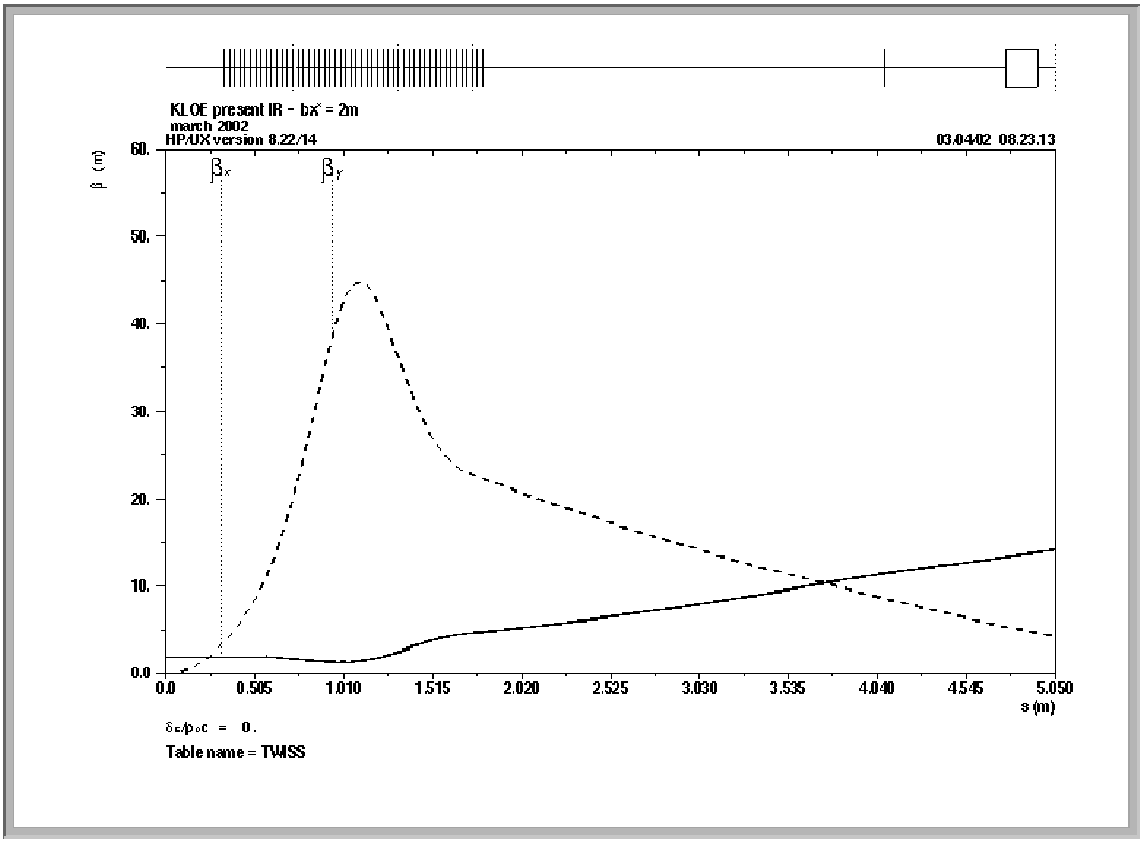

Figure 14 – β_x = 2 m with the present KLOE IR

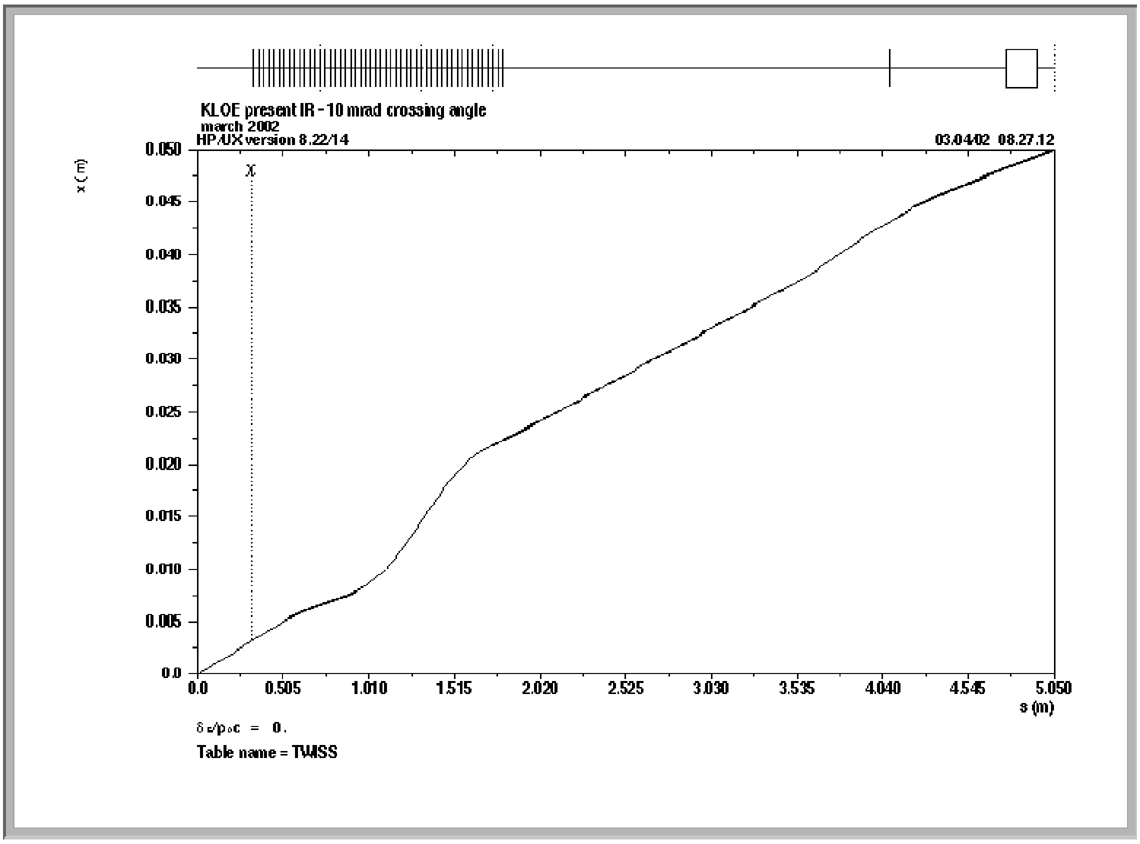

Figure 15 – Beam trajectory in the present KLOE Interaction Region for θ = 10 mrad

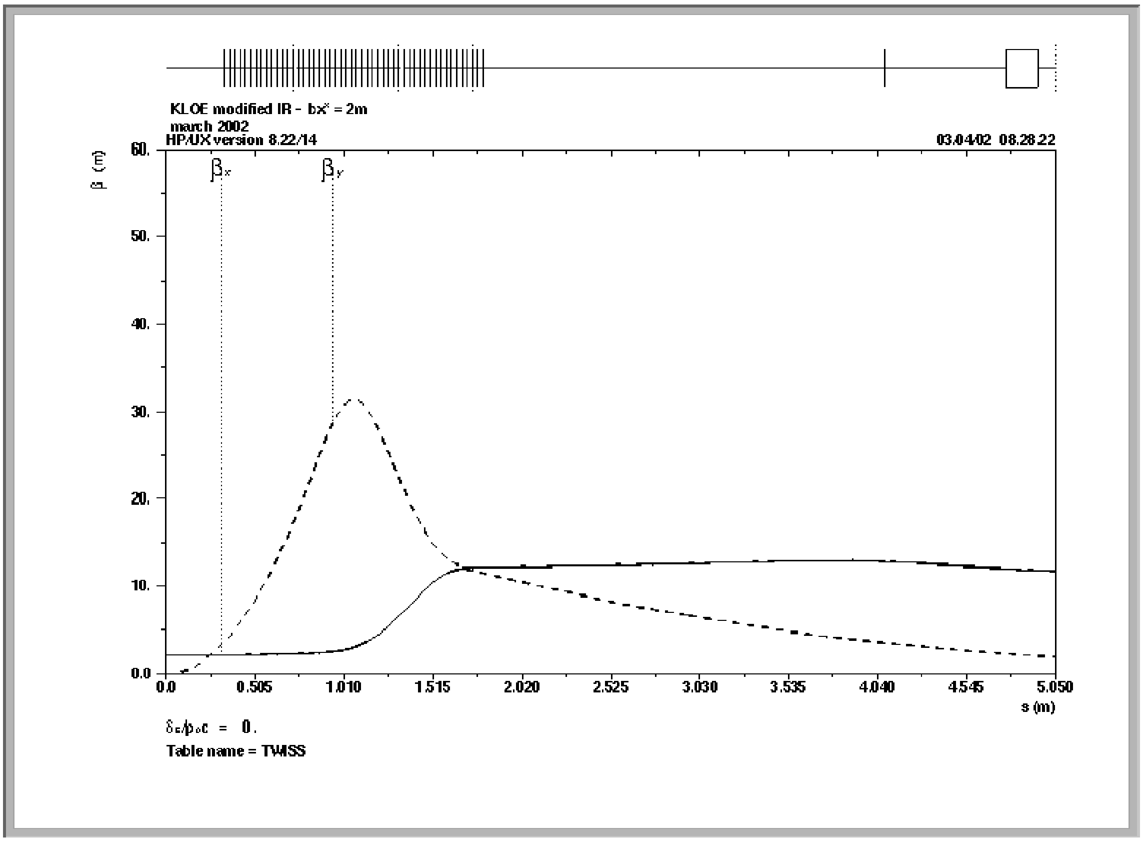

Figure 16 – Optical functions for the modified KLOE Interaction Region

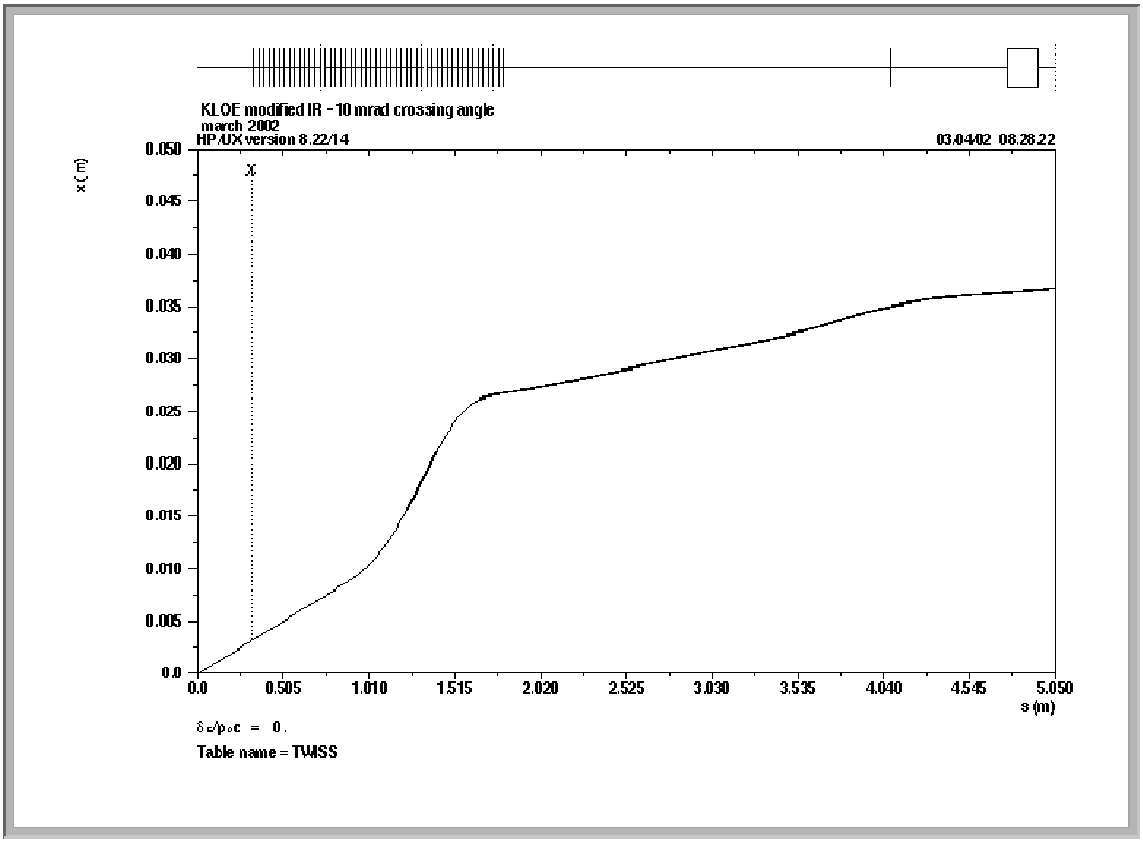

Figure 17 – Beam trajectory in the modified KLOE Interaction Region for θ = 10 mrad

Table V – Terms of the half IR first-order transport matrix for KLOE

	nominal KLOE	modified KLOE
$M_{IR}(1,2)$ (m)	5.00	3.67
$M_{IR}(2,2)$ (rad)	0.63	0.12

CONCLUSIONS

The first preliminary results on the lower β_x^* have been obtained and seem to show that the collisions with all buckets filled behaves similar to those with even buckets. The bunch current limit is in both cases of the order of 10mA. Further investigation to prove whether this limit can be raised is needed. The following steps must be done:

- optimization of single bunch luminosity with special care on non linear optics;
- investigation of single bunch luminosity versus crossing angle;
- multibunch luminosity at the highest possible current per bunch versus different filling patterns;
- background simulations and measurements;
- in the usual KLOE set-up measurement of beam-lifetime as β_x^* is decreased using the quadrupoles in the arcs to check the aperture limitation of the present IR configuration.

ACKNOWLEDGMENTS

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REFERENCES

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[2] *Report of DEAR shifts* – S.Guiducci for the DAFNE team – DAFNE Technical Note BM-8, January 2002.

[3] D.N.Shatilov, “Beam-beam simulation at large amplitudes and Lifetime Determination”, Part. Acc. 52, 65 (1996).

APPENDIX

Quadrupoles	Quadrupoles	Sextupoles
QUAI2001 = +294.000	QUAI2001 = +294.000	SXPPL101 = - 10.000
QUAI2002 = -550.000	QUAI2002 = -550.000	SXPPL102 = 28.800
QUAI2003 = +0.000	QUAI2003 = +0.000	SXPPL103 = - 56.800
QUAI2005 = +0.000	QUAI2005 = +0.000	SXPPL104 = 0.000
QUAI2006 = -550.000	QUAI2006 = -550.000	SXPPS101 = 0.000
QUAI2007 = +294.000	QUAI2007 = +294.000	SXPPS102 = - 76.800
QUAEL101 = +158.270	QUAPL101 = +158.270	SXPPS103 = 17.280
QUAEL102 = -172.100	QUAPL102 = -172.100	SXPPS104 = 0.000
QUAEL103 = +169.060	QUAPL103 = +169.060	SXPPS201 = 0.000
QUAEL104 = -57.170	QUAPL104 = -57.170	SXPPS202 = 15.360
QUAEL105 = +64.630	QUAPL105 = +64.630	SXPPS203 = - 66.000
QUAEL106 = +69.560	QUAPL106 = +69.560	SXPPS204 = 0.000
QUAEL107 = -63.770	QUAPL107 = -63.770	SXPPL201 = 9.600
QUAEL108 = -48.340	QUAPL108 = -48.340	SXPPL202 = - 77.000
QUAEL109 = -39.100	QUAPL109 = -39.100	SXPPL203 = 28.800
QUAEL110 = +65.000	QUAPL110 = +65.000	SXPPL204 = - 20.000
QUAEL201 = +40.460	QUAPL201 = +40.460	
QUAEL202 = -23.200	QUAPL202 = -23.200	
QUAEL203 = -31.460	QUAPL203 = -31.460	
QUAEL204 = -61.450	QUAPL204 = -61.450	
QUAEL205 = +84.250	QUAPL205 = +84.250	SXPEL101 = - 14.400
QUAEL206 = +65.860	QUAPL206 = +65.860	SXPEL102 = 28.800
QUAEL207 = -99.100	QUAPL207 = -99.100	SXPEL103 = - 76.800
QUAEL208 = +254.510	QUAPL208 = +254.510	SXPEL104 = 10.000
QUAEL209 = -190.440	QUAPL209 = -190.440	SXPES101 = 0.000
QUAEL210 = +176.030	QUAPL210 = +176.030	SXPES102 = - 76.800
QUAES101 = +62.490	QUAPS101 = +62.490	SXPES103 = 16.800
QUAES102 = -48.200	QUAPS102 = -48.200	SXPES104 = 0.000
QUAES103 = -28.960	QUAPS103 = -28.960	SXPES201 = 0.000
QUAES104 = -56.350	QUAPS104 = -56.350	SXPES202 = 15.600
QUAES105 = +86.290	QUAPS105 = +86.290	SXPES203 = - 76.800
QUAES106 = +58.030	QUAPS106 = +58.030	SXPES204 = 0.000
QUAES107 = -146.777	QUAPS107 = -152.141	SXPEL201 = 11.000
QUAES108 = +199.152	QUAPS108 = +212.547	SXPEL202 = - 80.000
QUAES109 = -108.823	QUAPS109 = -122.596	SXPEL203 = 28.800
QUAES110 = +234.109	QUAPS110 = +244.903	SXPEL204 = 0.000
QUAES201 = -108.823	QUAPS201 = -122.596	
QUAES202 = +199.152	QUAPS202 = +212.547	
QUAES203 = -146.777	QUAPS203 = -152.141	
QUAES204 = +60.750	QUAPS204 = +60.750	
QUAES205 = +87.200	QUAPS205 = +87.200	
QUAES206 = -53.770	QUAPS206 = -53.770	
QUAES207 = -42.650	QUAPS207 = -42.650	
QUAES208 = -28.900	QUAPS208 = -28.940	
QUAES209 = +69.320	QUAPS209 = +69.320	