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INFN - LNF, Accelerator Division

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FI.NU.DA. INTERACTION REGION PRELIMINARY DESIGN

C. Biscari

The FI.NU.DA. detector magnet design has been recently frozen[1] and its solenoidal field computed. The iron yoke configuration is shown in Fig. 1.

The detector solid angle is $\Delta\Omega \sim 2\pi\, d(\cos 45°)^2$, leaving a free cone of ~45° around the longitudinal axis for machine components.

The field profile on axis is given in Fig. 2, as computed[1] in cylindrical symmetry with POISSON. The total field integral is 2.6265 Tm, with a maximum field of 1.1 T, extending on a total length of ~ 2.5 m.

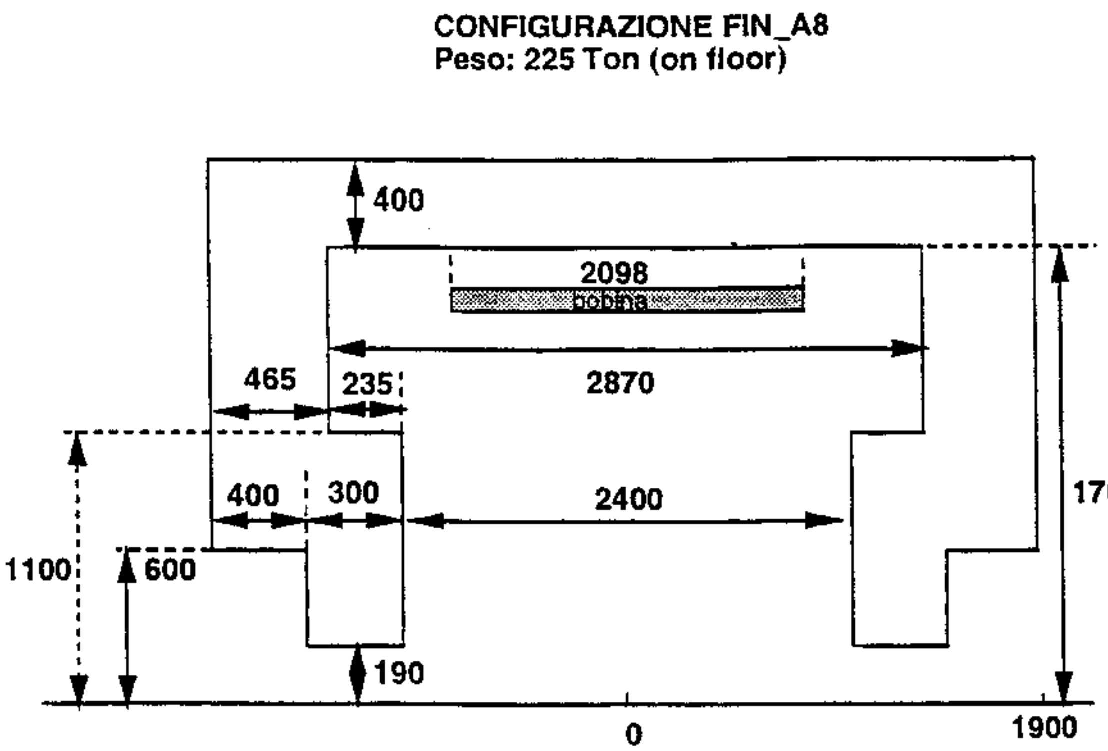

Fig. 1 - FI.NU.DA. magnet yoke sketch.

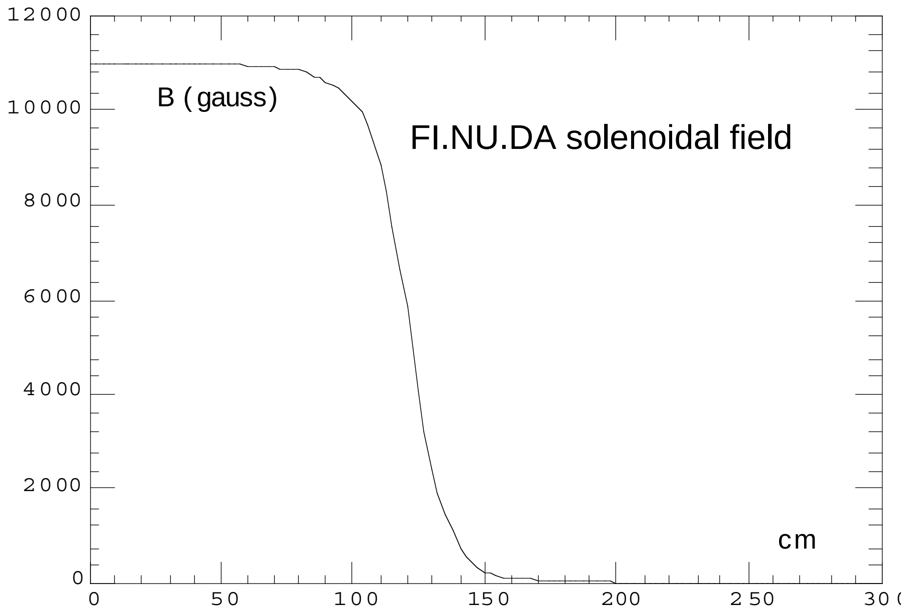

Fig. 2 - FI.NU.DA. detector magnetic field on axis.

The Interaction Region design has been defined with this magnetic field configuration, making the low beta focusing compatible with the solenoidal field compensation. The same superconducting compensator solenoid as in the opposite IR, which is dedicated to the KLOE experiment[3], will be used, since the total field integrals are very close to each other. They will be placed in the same positions with respect to the IP to simplify commissioning and operation procedures.

Only two permanent magnet quadrupoles can be placed inside the detector on each side of the Interaction Point (IP), because of the short length of the solenoid; two more quads are placed between the detector and the compensator; the choice of adding one quadrupole with respect to previous designs has been made to fit the 'transparency criterium'[4], once fixed the compensator length and position. Remind that the transparency criterion consists in the interchangeability of the IR configurations, allowed by the fact that the first order transport matrix of the whole IR is maintained unchanged whatever is the detector or the configuration of the region; this was obtained in the previous design using different compensator solenoids for the two different experiments, and different positions[4].

Table I lists the IR element positions and characteristics.

The proposed layout of half IR is plotted in Fig. 3, together with the longitudinal magnetic field profile on axis for both the detector and the compensator.

TABLE I - FI.NU.DA. IR elements for half IR.

Element	Lengths (m)	Position (m from IP)	Center position (m from IP)	K2 (m^{-2})	G (T/m)	Θ (deg)
S.F.*	0.350	0.000				
Q1+ S.F.*	0.150	0.350	0.425	5.790348	9.84	8.936
S.F.*	0.150	0.500				
Q2 + S.F.*	0.275	0.650	0.7875	-7.003811	11.91	14.915
S.F.*	0.575	0.925				
Drift	0.600	1.500				
Q3	0.300	2.100	2.250	2.450814	4.17	22.554
Drift	0.300	2.400				
Q4	0.300	2.700	2.850	-1.550021	2.64	22.554
Drift	0.485	3.000				
Compensator	1.150	3.485	4.060			
Drift	0.415	4.635				
Total length	5.050					

* S.F. = Detector Solenoidal Field

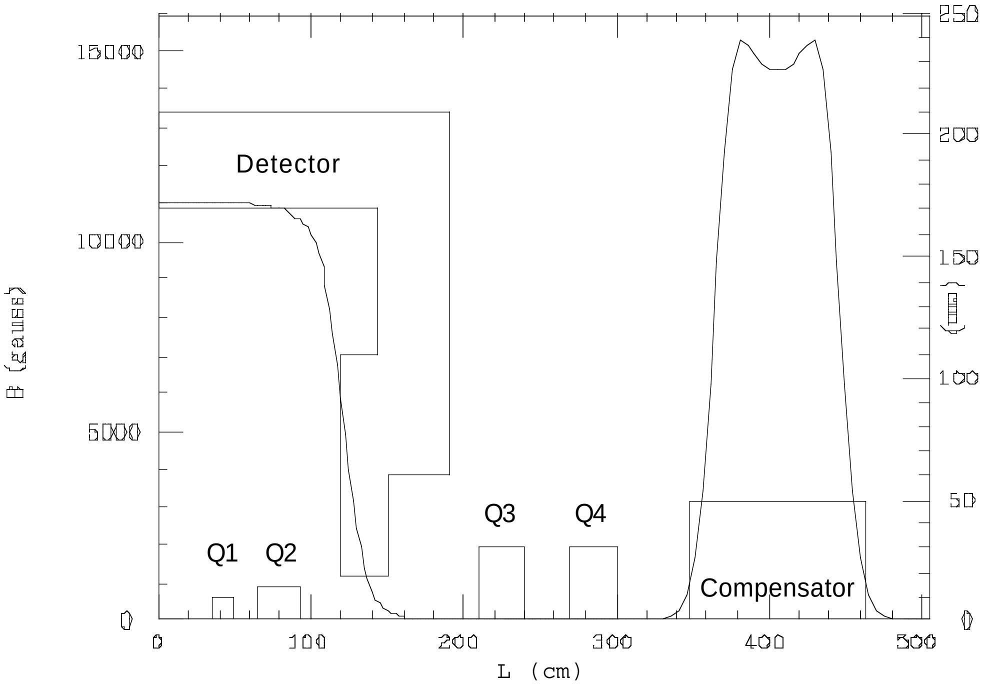

Fig. 3 - Half IR layout.

IR Optics

The optics calculations have been made representing the detector (compensator) solenoidal field with a chain of 2.5 (5.0) cm long rectangular solenoids following the field behaviour. The quadrupoles inside the detector are represented with n thin lenses, interleaved by the 2.5 cm rectangular solenoids. The quadrupoles will be rotated by an angle (θ in Tab I) proportional to the field integral from the IP to their center position. The two quadrupoles outside the detector will be rotated together by the same angle corresponding to half the total detector field integral. Small adjustments of these three angles plus a small correction of the compensator field will provide cancellation of the residual coupling[5].

The 4x4 first order transport matrix corresponding to half IR is given in Tab II. The separation of the two beams at the splitter entrance is equal to the nominal value[4], corresponding to the splitter nominal field and the following orbit horizontal corrector switched off. The optical parameters of the IR are summarized in Tab III.

TABLE II - Half IR first order transport matrix

0.943409	4.700000	0.000000	0.000000
-0.142512	0.350000	0.000000	0.000000
0.000000	0.000000	-4.277427	0.118836
0.000000	0.000000	-0.653399	-0.215633

TABLE III - IR optic parameters

@IP	
β_x (m)	4.5
α_x	0.0
β_y(m)	0.045
α_y	0.0
Δx(m)	0.0
$\Delta x'$(mrad)	12.5
@ splitter input	
β_x (m)	8.9140
α_x	0.2395
β_y(m)	1.1372
α_x	0.4437
Δx(cm)	5.8750
$\Delta x'$(mrad)	4.375
D_x (m)	-0.013
D_x'	-0.025
For Half IR	
ΔQ_x	0.1331
ΔQ_y	0.4120
Horizontal chromaticity	- 0.49
Vertical chromaticity	- 2.17

The optical functions and the separation for 12.5 mrad crossing angle along half IR are plotted in Fig. 4.

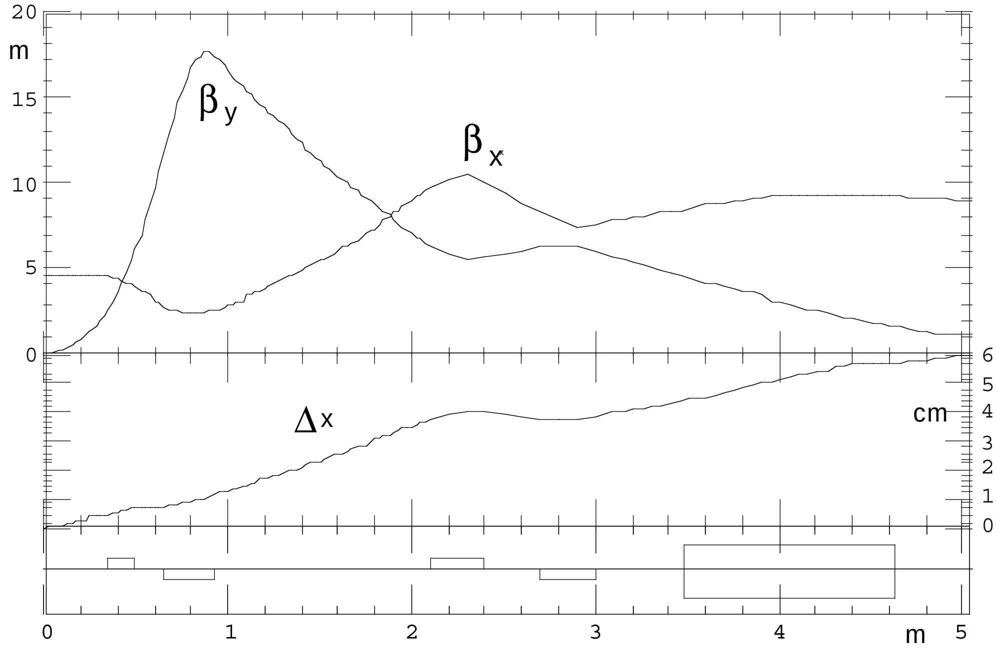

Fig. 4 - Optical functions and beam separation (Δx) (@12.5 mrad crossing angle).

The fact that the first two quadrupoles are nearer to the IP than in the opposite IR implies that the beam sizes and beam separation at the parasitic crossings (PC) are different. In table IV the parameters which influence the PC kicks are summarized. At the first PC the values are almost the same of the other IR and hence the effect should be comparable. At the second PC the beam separation is almost equal, but bigger in terms of σ_x; being the β_y value a little smaller, the effect of this 2nd PC should be weaker. Simulations of these effects are in progress.

TABLE IV - Beam parameters relevant for parasitic crossings

	z (m)	σ_x (mm)	Δx* (mm)	$\Delta x/\sigma_x$	β_x (m)	β_y (m)	ξ_x	ξ_y
1st PC	.407	2.1	8.1	3.9	4.38	3.77	.00273	.00235
2nd PC	.814	1.5	14.5	9.4	2.38	17.04	.00046	.00329
3rd PC	1.22	1.9	28.8	14.8	3.80	14.13	.00050	.00069

* Δx is the total separation corresponding to ± 10 mrad crossing angle.

The Beam Stay Clear (BSC) apertures have been computed with the usual assumptions[6] (10 σ_x + separation @ 15 mrad crossing angle, 10 σ_y @ full coupling + vertical bump @ IP of 2.5 mm). The results are plotted in Fig. 5 together with a possible shape of the vacuum chamber. Table V summarizes the IR main elements minimum apertures (allowance for closed orbit is included (minimum ±2 mm)). The compensator solenoid present aperture is of course compatible with the BSC, since the optical functions and the separation from the compensator to the splitter is nearly the same as the other IR, due to the already described transparency criterion.

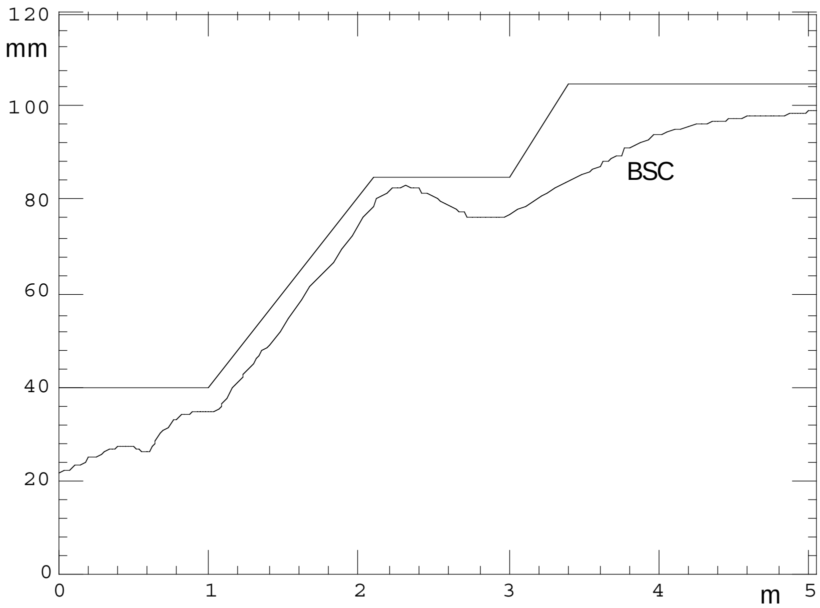

Fig. 5 - BSC apertures and proposed vacuum chamber shape.

TABLE V - Full aperture (mm) of IR magnets

Q1	80
Q2	80
Q3	170
Q4	170
Compensator	240

Changing the detector field

The possibility of changing the solenoid field is an important feature of the FI.NU.DA. experiment.

Any field variation, however, implies changing the optical characteristics of the IR; obviously, the compensator field must follow the main solenoid field variation, thus decreasing the focusing strength, which is stronger than the detector one because of the shorter length[5] and therefore the overall focusing properties are degraded. In order to maintain the transparency criterion it is necessary to modify the quadrupole gradients.

Assuming that correcting coils can be mounted on each quadrupole, with gradients up to ± 5% of the nominal ones, the possibility of matching the IR to the ring optics as a function of the main detector field has been investigated. Some of the transparency conditions have been slightly relaxed.

The change of the four quadrupoles gradient is represented in Fig. 6, in percent of the nominal value. Figs 7 trough 9 show the values of the horizontal and vertical phase advance variations in half IR, the maximum betatron functions inside the IR, and the chromaticity variation as functions of the detector field.

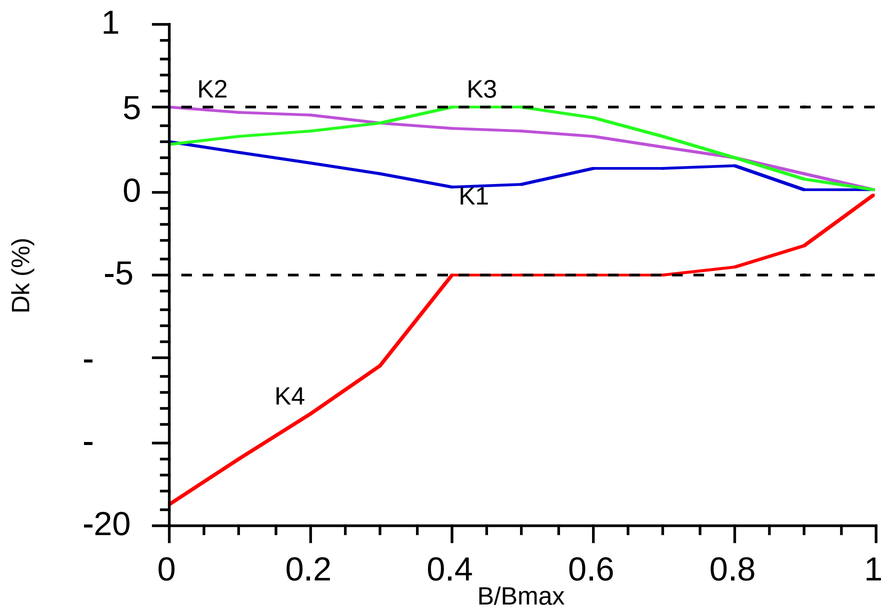

Fig. 6 - Change in percentage of quadrupole gradients.

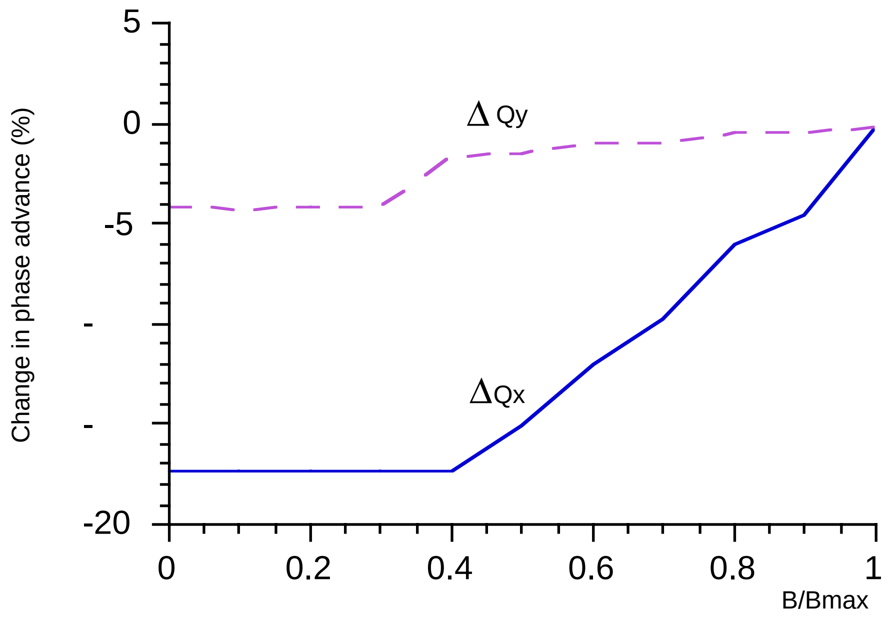

Fig. 7 - Phase advances variation in half IR.

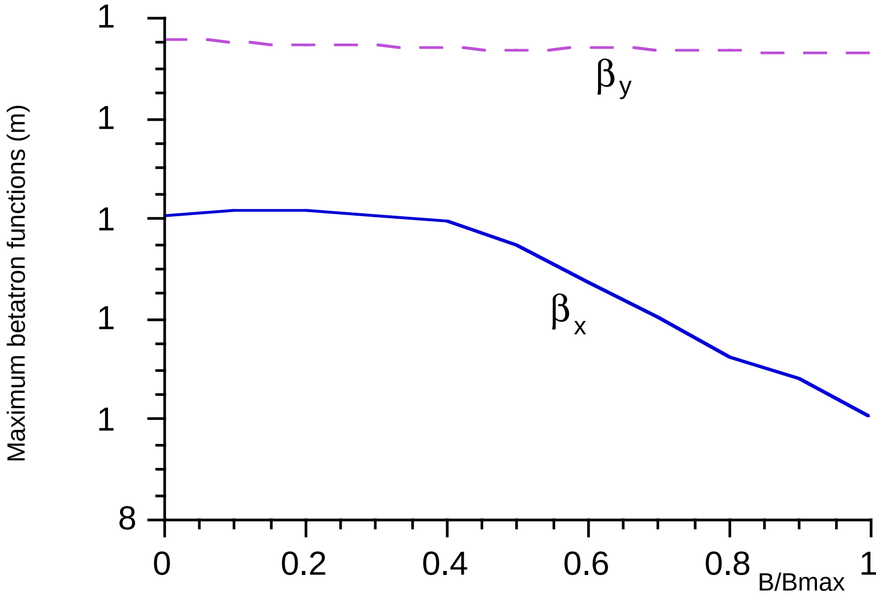

Fig. 8 - Maximum horizontal and vertical betatron function in the IR.

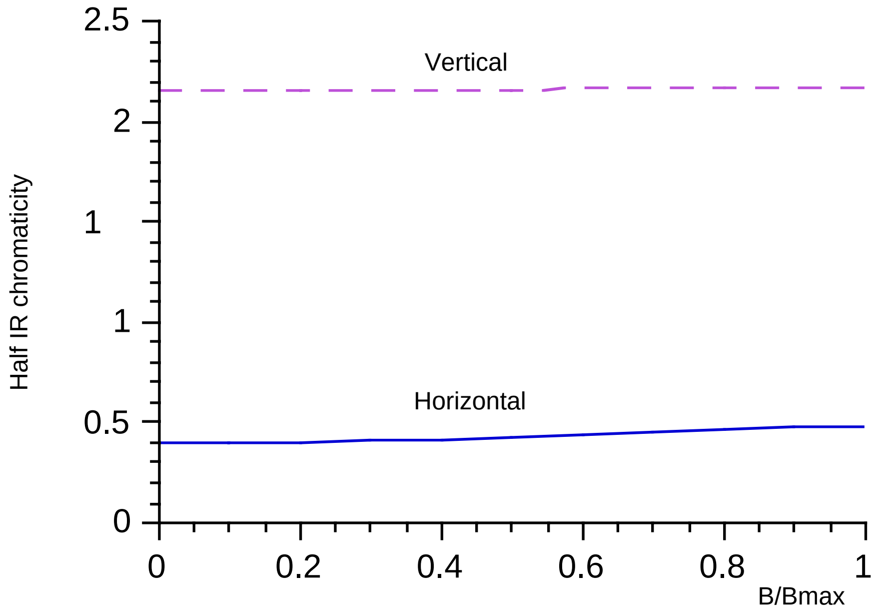

Fig. 9 - Chromaticity variation of the IR.

The chromaticity of the whole IR does not change much with the field variation. In the horizontal plane the increase of the 3rd quadrupole contribution is counterbalanced with the decrease of the compensator contribution, slightly lowering the chromaticity as the field detector decrease. In the vertical plane an increase of the order of up to 5% of the contribution of the 2nd quadrupole is cancelled by the corresponding decrease of the 4th one, thus mantaining the total chromaticity almost constant.

The beam separation and its slope, corresponding to 10 mrad crossing angle at the splitter entrance, are plotted in Fig 10. They differ at maximum from the nominal ones by ~ 3 mm and ~ 3.5 mrad respectively; the orbit change can be corrected by the splitter-corrector system. The value of the corresponding splitter and corrector angles for 12.5 mrad crossing angle are plotted in Fig. 11. Figure 12 represents the splitter field.

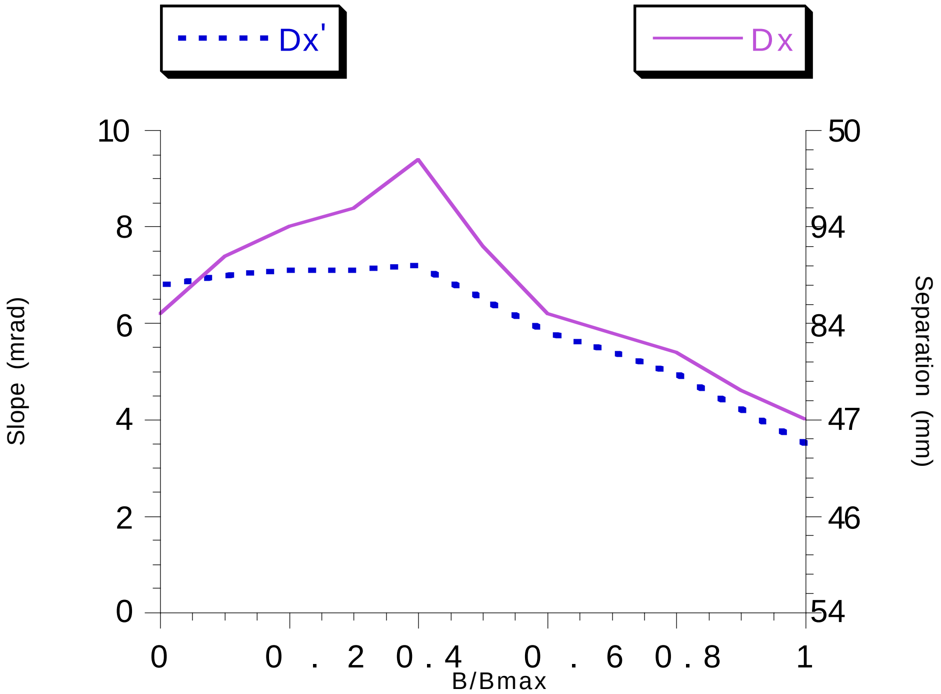

Fig. 10 - Separation and slope at the splitter entrance.

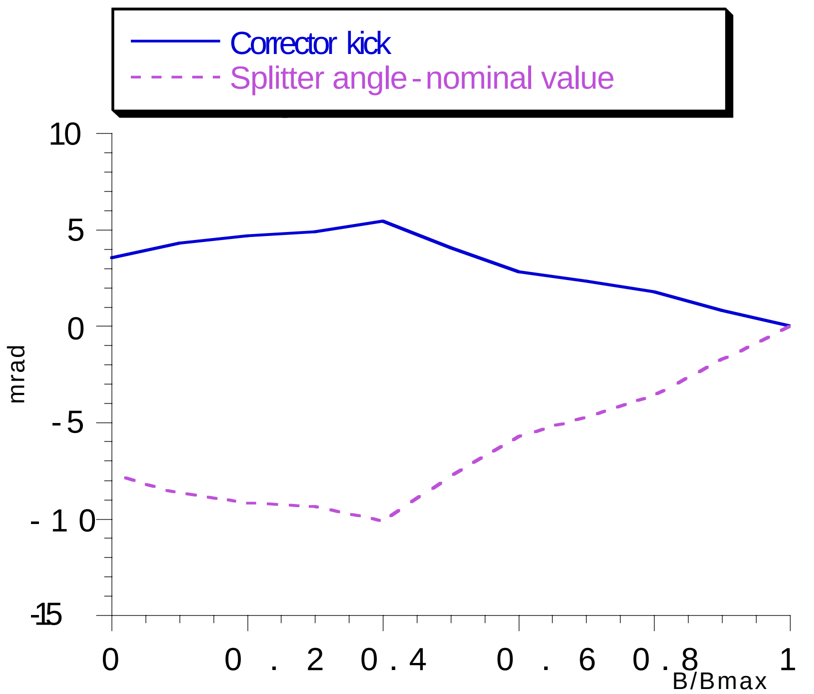

Fig. 11 - Splitter and corrector angle.

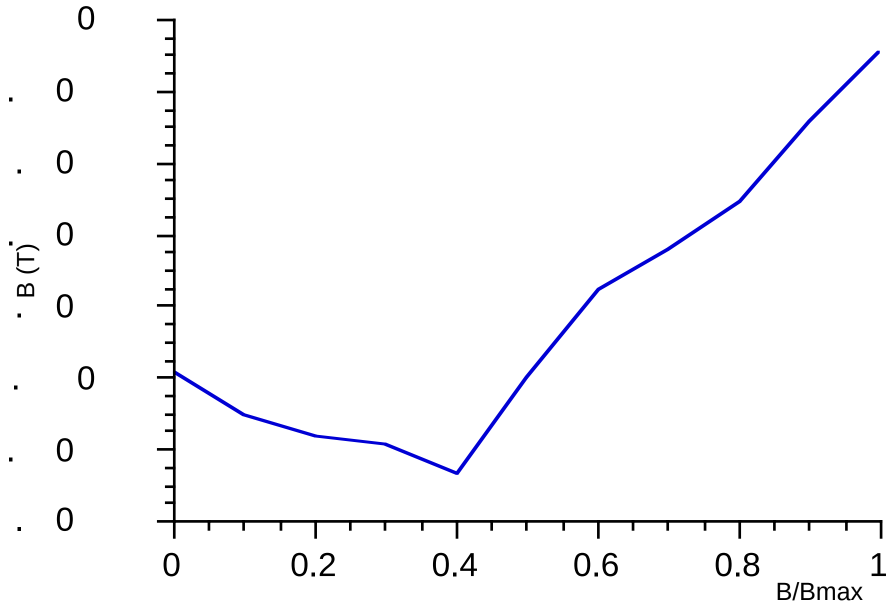

Fig. 12 - Splitter field.

Decreasing the detector field leads to an increase of the horizontal maximum beam size inside the IR, which occurs in the 3rd quadrupole. If apertures are designed taking into account the BSC corresponding to the nominal field, the configurations with lower detector field are compatible with a crossing angle smaller than 15 mrad; the nominal BSC (solid line), together with the BSC corresponding to B/Bmax = 0.4 computed at the crossing angle of 15 mrad (dot line) and 12.5 mrad (dashed line) are plotted in Fig. 13, showing that the latter is all within the proposed vacuum chamber shape (see Fig. 5).

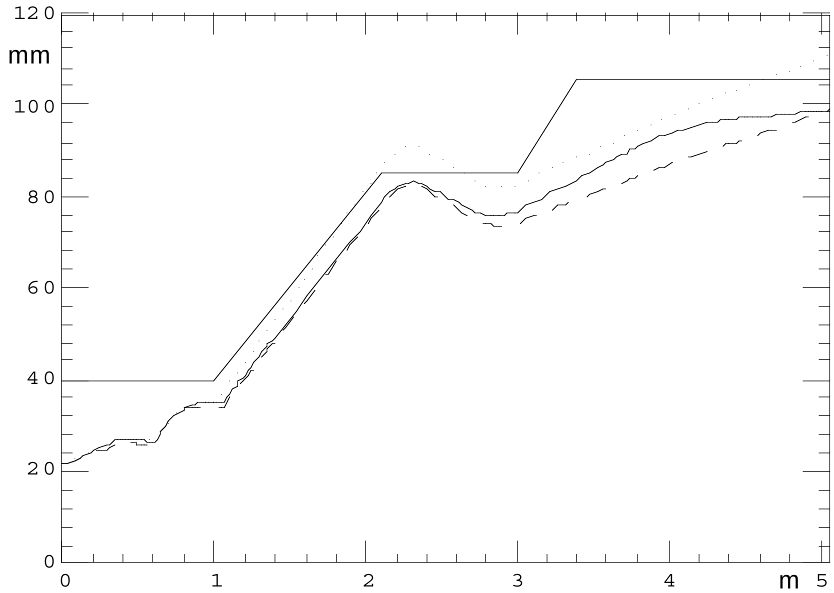

Fig. 13 - Apertures in IR.

We can conclude that a field decrease up to 60% from the nominal value can be obtained, within the ± 5% change of all quadrupole gradients. If the fourth quadrupole, which has a nominal gradient of only 3 T/m has a correcting coil giving a gradient change of 20% (corresponding to 0.6 T/m, equal to the 5% of the second quadrupole), any change in the detector field can be accomplished.

The rotation of the quadrupoles must follow of course the change in the field; this means that three independent rotations (two for the two quads inside the detector plus one for both quads outside it), must be provided. The rotating angles are represented in Fig. 14. To be noticed that they are not exactly proportional to the field change; this because they are modified to correct the residual coupling introduced by the quadrupoles themselves.

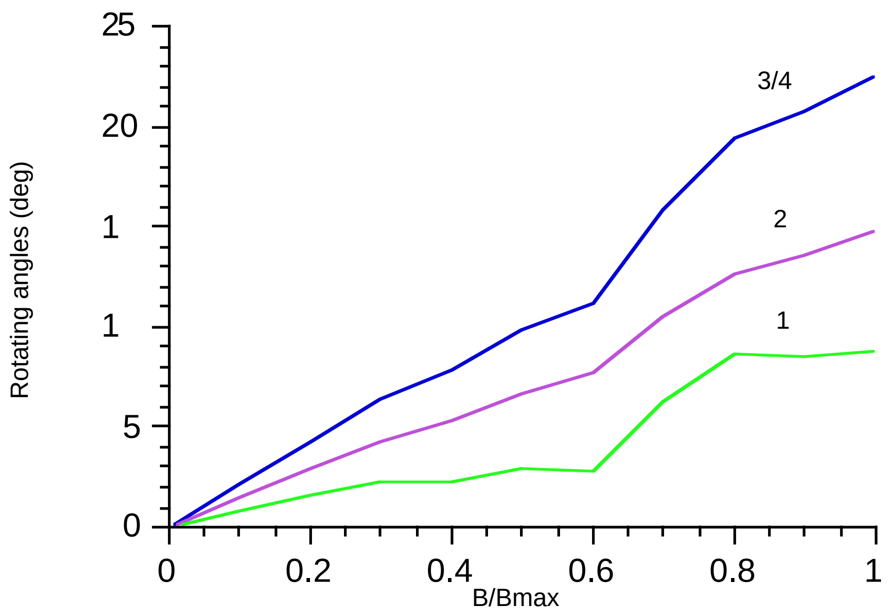

Fig. 14 - Quadrupoles rotating angles.

REFERENCES

[1] ANSALDO - private communication.

[2] F.Fabbri - private communication.

[3] M.E.Biagini - "KLOE Interaction Region Update " DAΦNE Technical Note - L-13, March 1994.

[4] M.E.Biagini, C.Biscari, S.Guiducci, J.Lu, M.R.Masullo, G.Vignola - "Review of DAΦNE Lattices " DAΦNE Technical Note - L-9, October 1993.

[5] M.Bassetti, M.E.Biagini, C.Biscari, M.A.Preger, G.Raffone, G.Vignola - "DAΦNE Interaction Region Design" - PAC 93, Washington, May 1993.

[6] C.Biscari - "DAΦNE Stay-Clear Apertures" DAΦNE Technical Note - L-6, March 1993.