DAΦNE TECHNICAL NOTE

INFN - LNF, Accelerator Division

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Note: **L-31**

MORE ABOUT THE COUPLING IN DAΦNE

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Any coupling source in a point of the ring produces all along the machine a perturbation of the two normal modes [1].

The behaviour of θ_a and C_{12} is a good representation of how much the optics is perturbed from the point of view of the coupling.

We consider as reference optics the description of the ring which corresponds to the perfectly compensated KLOE IR (no coupling source in the arcs), nominal betatron functions at the IP (4.5 m, 4.5 cm) and tunes (5.15, 5.21).

Figures 1a and 1b show the value of θ_a and C_{12} for this reference case. The small contribution to C_{12} is due to the non continuos tilting of the low β quadrupoles.

In the presence of a coupling source the value of θ_a oscillates in the ring and its maximum values correspond to the points where β_2 is larger. Both functions θ_a and C_{12} usually cross the zero near the IPs, i.e. near the second mode betatron waist.

The parameter γ is also a measure of the coupling: in the ideal case it is equal to 1 all along the ring, except inside the IR. The more it deviates from the unity, the larger the emittance induced.

The best condition for collision, apart of course ideal case, is the one in which:

$$\theta_a^+ = \theta_a^-$$

$$\frac{\partial \theta_a^+}{\partial z} = -\frac{\partial \theta_a^-}{\partial z}$$

$$C_{12}^+ = C_{12}^- = 0$$

where the derivatives versus *z* are defined in the reference frame of each beam. This means that a perturbation giving a positive tilt derivative on one ring around the IP, can be compensated by the opposite perturbation on the other ring. For example the tilts induced by the couple of Lambertson correctors used to separate the beams at the second IP will be opposite in IP1, so it will not fulfill the first condition, while will fulfill the second one.

From here it is clear that it is useful to have the tools to change independently the absolute value of the tilt without changing its derivative and viceversa.

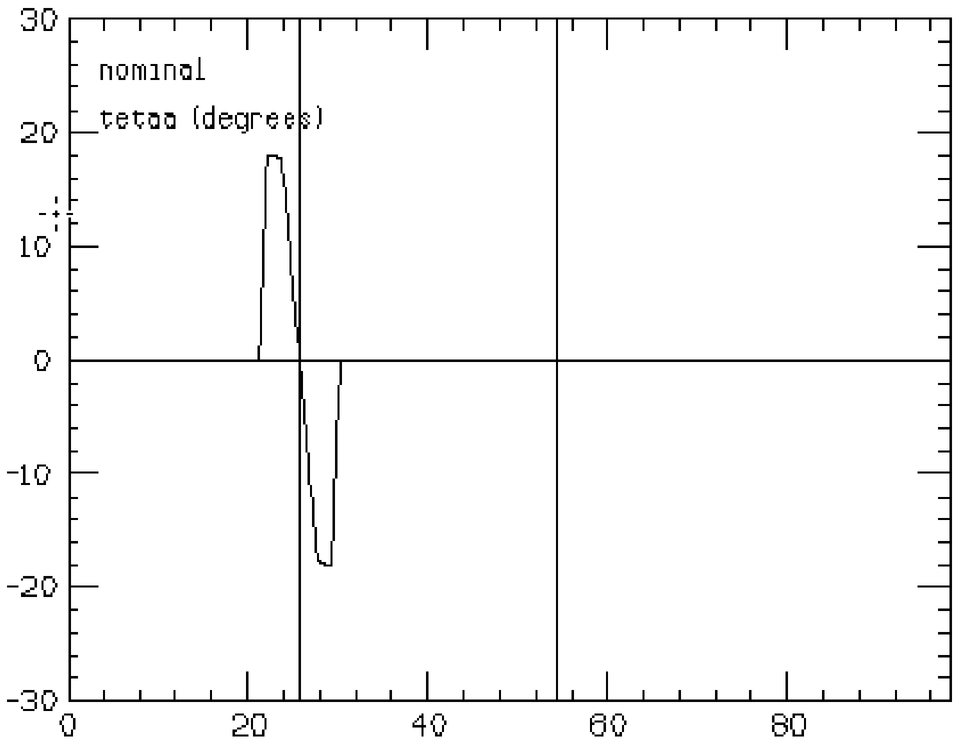


Figure 1a - θ_a *in the nominal case*

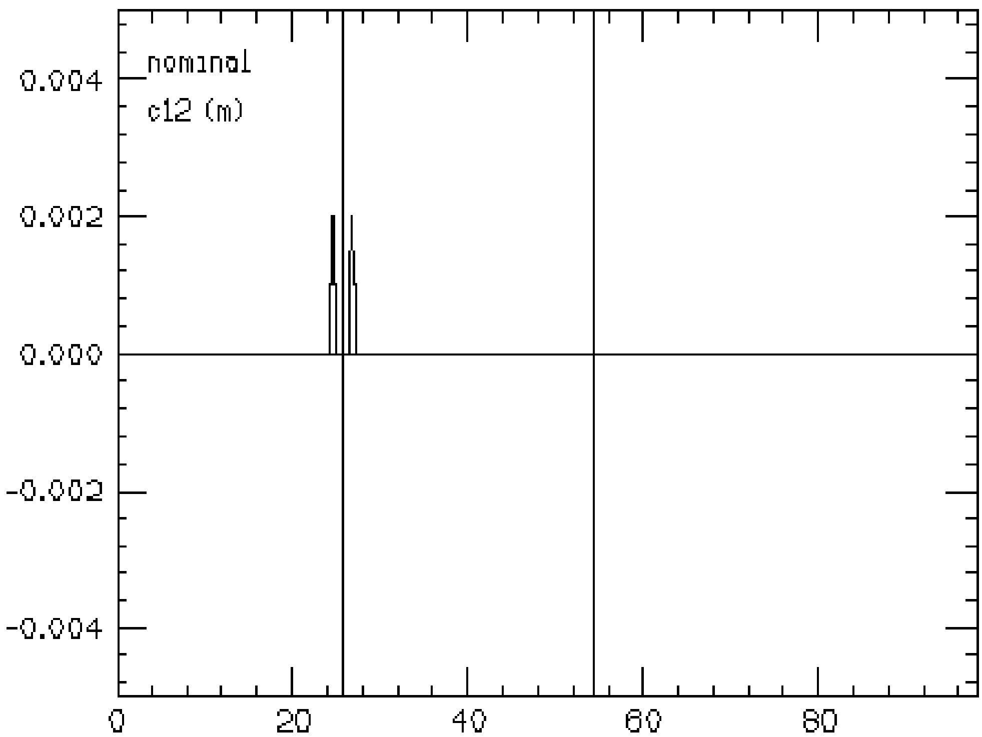


Figure 1b - C_{12} *in the nominal case*

The value of C_{12} which does not increase the beam size at the IP can be deduced from eq. 16 of [1]:

$$\sigma_{y,a} = \sqrt{\varepsilon_a}\sqrt{\beta_a C_{22}^2 + 2\alpha_a C_{12} C_{22} + \gamma_a C_{12}^2}$$

In the waist position

$$\beta_a = 4.5m$$
$$\alpha_a = 0$$
$$\beta_b = 4.5cm$$

If the tilt of the first mode is zero the only term which is left is the one given by C_{12}.

$$\sigma_{y,a} \approx C_{12}\sqrt{\frac{\varepsilon_a}{\beta_a}} = \frac{C_{12}}{10}\sqrt{\frac{\varepsilon_b}{\beta_b \kappa}}$$

Since

$$\sigma_{y,b} = \sqrt{\varepsilon_b \beta_b}$$

the contribution to the vertical dimension of the first mode is equal to the second mode one if

$$\frac{C_{12}}{10}\sqrt{\frac{\varepsilon_b}{\beta_b \kappa}} \approx \sqrt{\varepsilon_b \beta_b} \Leftrightarrow C_{12} \approx 10\ \sqrt{\kappa}\ \beta_b$$

increasing in this case the vertical dimension by a factor $\sqrt{2}$. For the nominal coupling, only if $C_{12} << \beta_b$ the first mode becomes negligible.

At the synchrotron light monitor

$$\beta_b \approx 2\beta_a \approx 7m$$

therefore the contribution of the first mode to the roundness becomes comparable to the second mode dimension if

$$C_{12} \approx \beta_b \sqrt{\frac{\kappa}{2}}$$

and for the nominal coupling it corresponds to $C_{12} << 0.5\ m$.

SKEW QUADRUPOLES

Eight skew quadrupoles are available in each ring of DAΦNE. They have been used to correct empirically the coupling during the day-one commissioning and the first months of operation with KLOE.

Simulation of the effect of each of them on the coupling of the rings follows.

The optical functions at the location of the skews for the unperturbed optics are listed in Table I.

Table I

#	name	β_1 (m)	α_1	β_2 (m)	α_2	Dx (m)
1	QSKES101	3.1	0.2	4.7	0.3	.4
2	QSKES104	2.3	0.2	9.4	-1.6	.2
3	QSKES202	2.6	-0.4	9.0	1.7	.2
4	QSKES205	3.1	0.0	9.2	-2.0	.1
5	QSKEL103	2.0	-1.4	20.1	0.3	.1
6	QSKEL106	8.2	-0.7	5.9	1.1	.5
7	QSKEL201	9.2	-0.3	14.3	1.2	.6
8	QSKEL204	2.6	1.7	16.6	-0.3	-.3

The emittance of the second mode (ε_b) induced by a skew quadrupole has a quadratic behaviour proportional to the absolute value of the gradient.

Figures 2a and 2b show the emittance ratio induced by each single skew, in the absence of other coupling perturbations and Table II shows the coefficients C_ε for the eight quadrupoles.

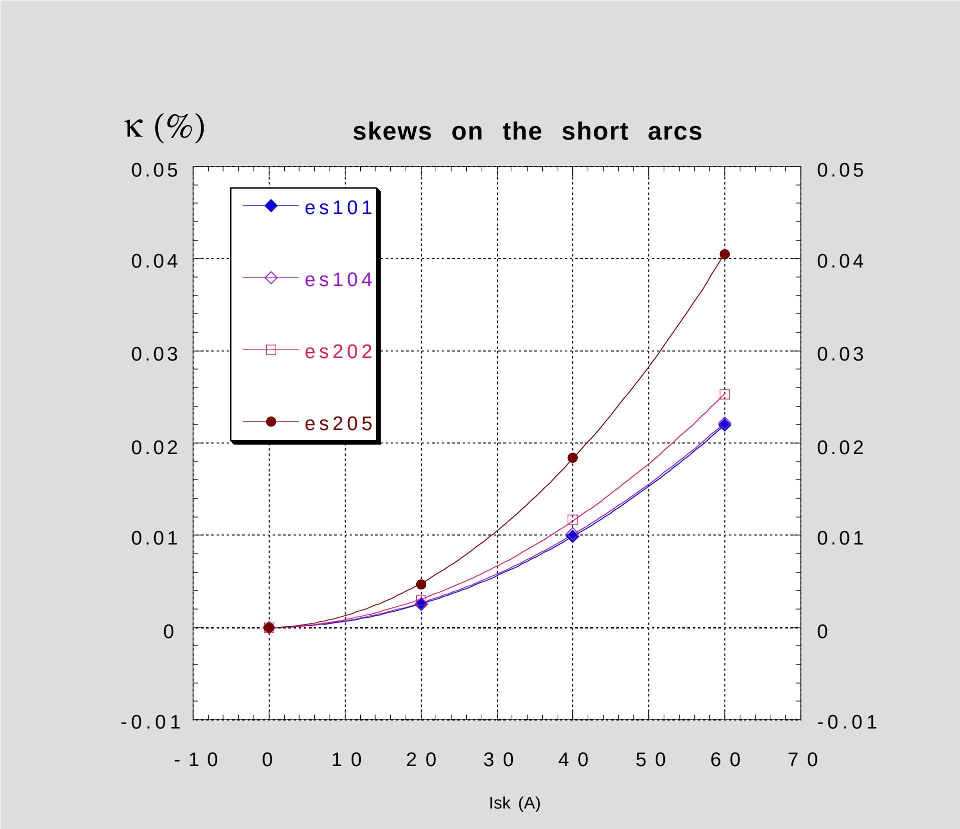


Figure 2a - 2nd mode emittance due to skews in short arcs

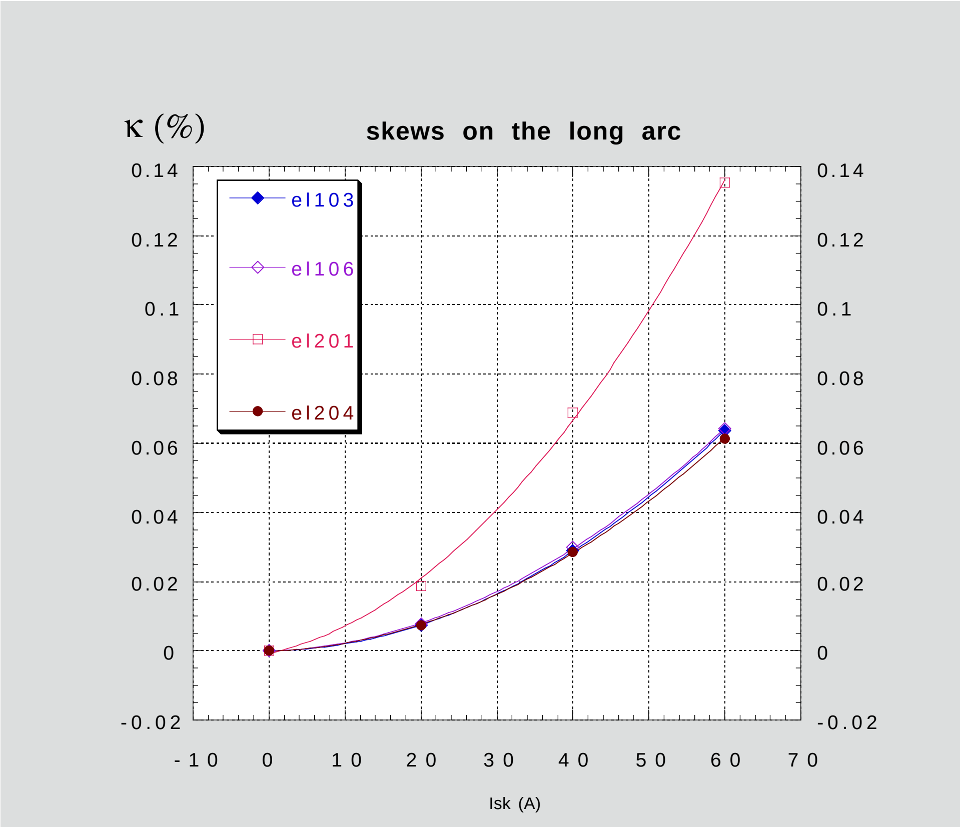


Figure 2b - 2nd mode emittance due to skews in long arcs

Table II

#	name	C_ε	(1-γ) (20A)
1	QSKES101	$5.9\ 10^{-6}$	.0014
2	QSKES104	$5.9\ 10^{-6}$	.0020
3	QSKES202	$6.6\ 10^{-6}$	.0022
4	QSKEL103	$10.9\ 10^{-6}$	.0027
5	QSKES205	$17.1\ 10^{-6}$	.0036
6	QSKEL106	$16.6\ 10^{-6}$	.0045
7	QSKEL201	$29.9\ 10^{-6}$	.0121
8	QSKEL204	$16.0\ 10^{-6}$	.0043

The dependence of the 1st mode tilt (θ_a), of C_{12} and of γ along the ring can be easily simulated with MAD for each skew. In the Appendix the figs show θ_a and C_{12} for 20A in each skew. The nominal tilt inside the IR due to the solenoids (fig.1) is substracted in the figures 5/19 and in the Appendix.

Let us make some considerations: θ_a is linear with the skew strength up to values of π/2. For values greater than π/2 the modes flip and this formalism is not valid anymore.

C_{12} is also linear, thus meaning that the effect of n different perturbations can be computed as the sum of the individual contributions as far as the coupling is weak.

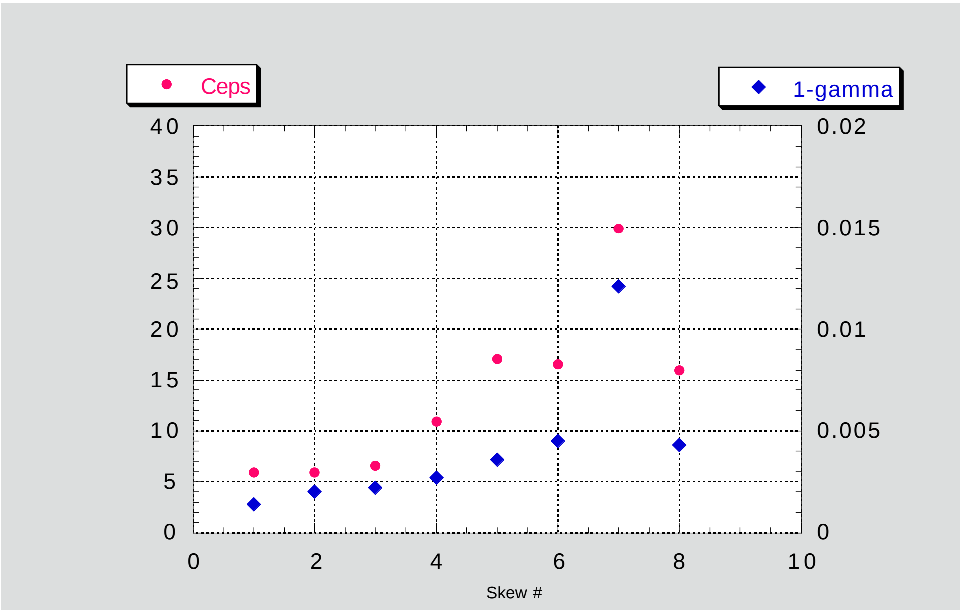


Figure 3 - C_ε and (1-γ) for the right skew quadrupoles

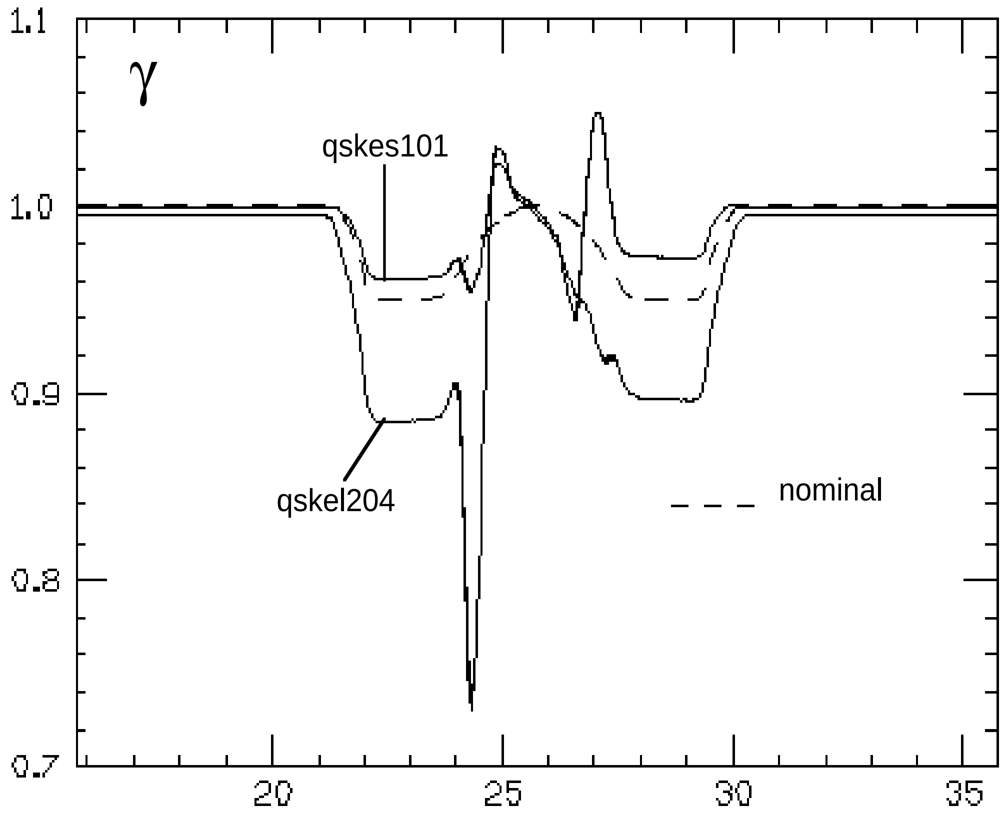


Figure 4 – Behaviour of γ along the IR in three different configurations.

Effect of skews around IP1

Both θ_a and C_{12} cross zero near the IP, so that at the IP we can deduce from the above considerations that for emittance coupling of the order of 1%, tilt angles of the order of ± 0.5° can be expected.

In the interaction the bunches cross along a distance of the order of 10 cm. Along this distance the derivative of the tilt can even change the slope since the derivative due to the KLOE solenoid is of the order of 1° over 10 cm. All the skews from the short arc produce a positive derivative for positive currents, while those from the long have opposite signs.

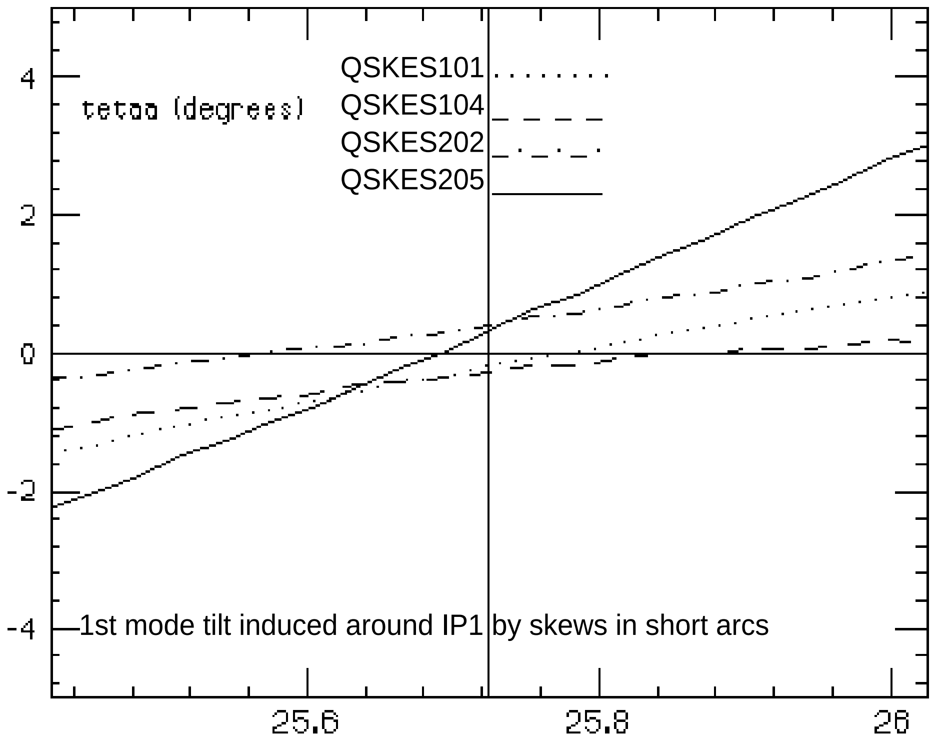


Figure 5 – 1st mode tilt induced around IP1 by skews in short arcs

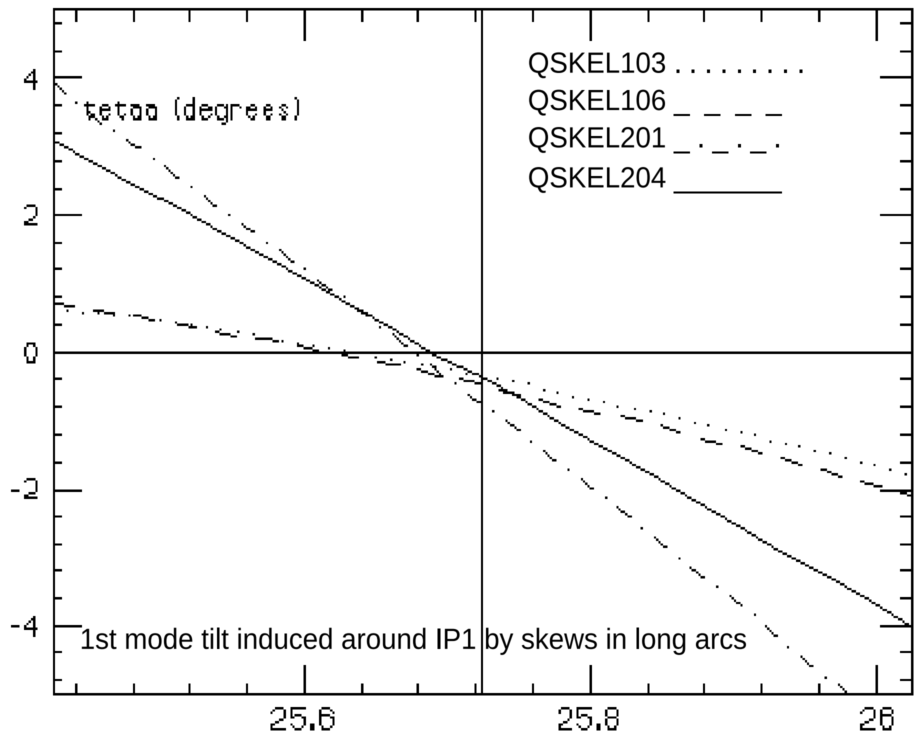


Figure 6 – 1st mode tilt induced around IP1 by skews in long arcs

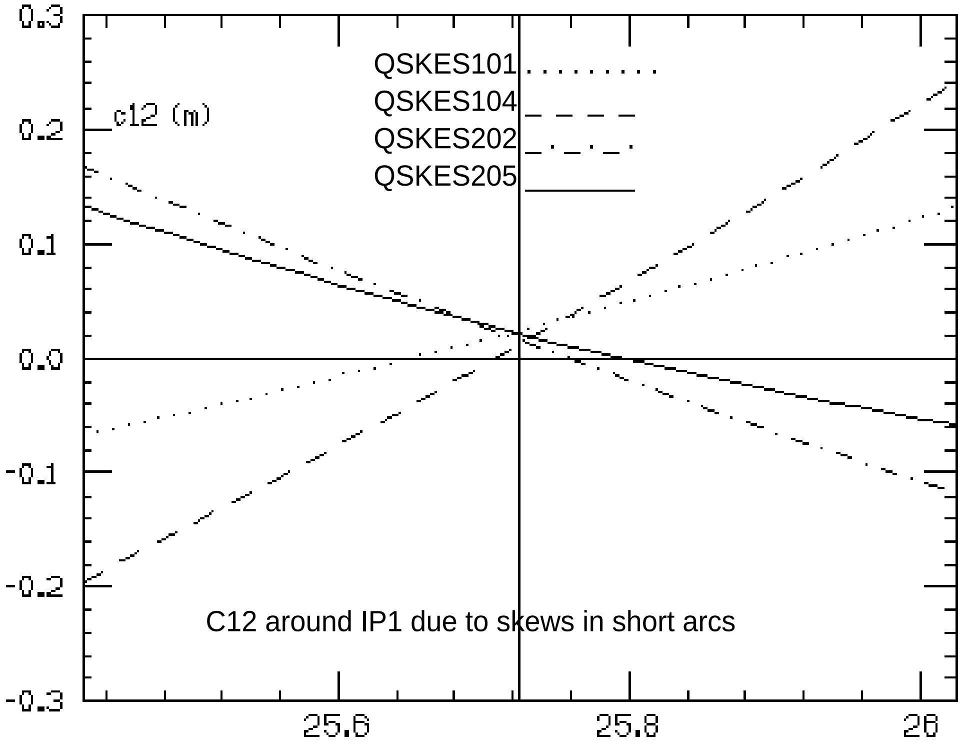


Figure 7 – C_{12} around IP1 due to skews in short arcs

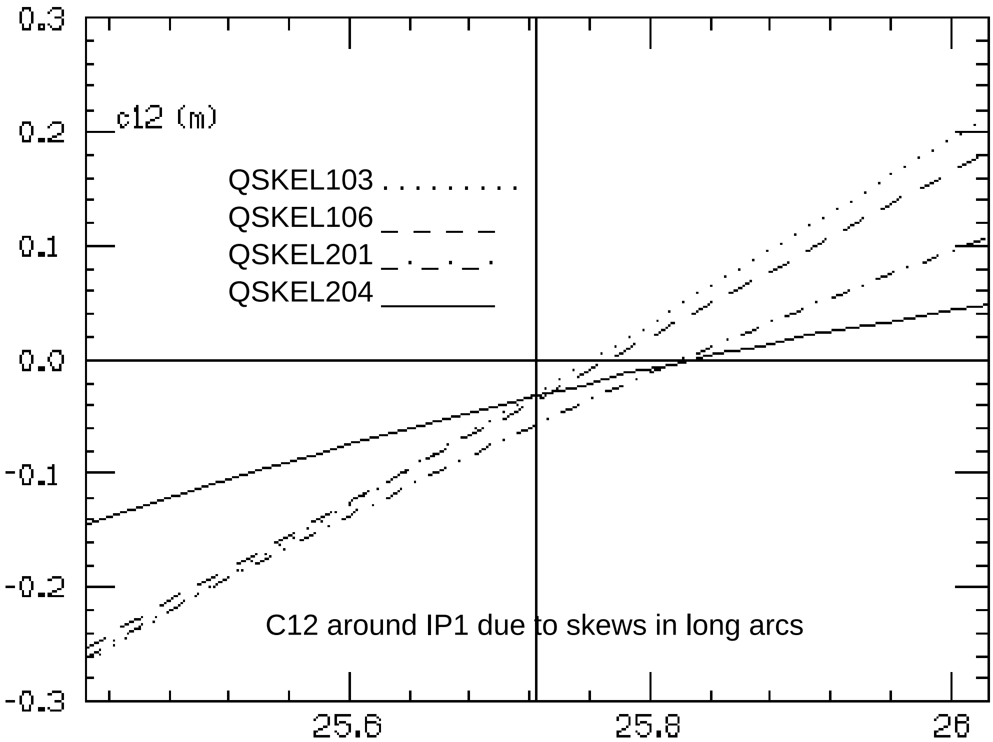


Figure 8 – C_{12} around IP1 due to skews in long arcs

COMPENSATION OF KLOE IR

Let us consider the possible causes of errors which can be present inside the KLOE IR, and let us look at the effect on the whole ring and inside the IR for both rings.

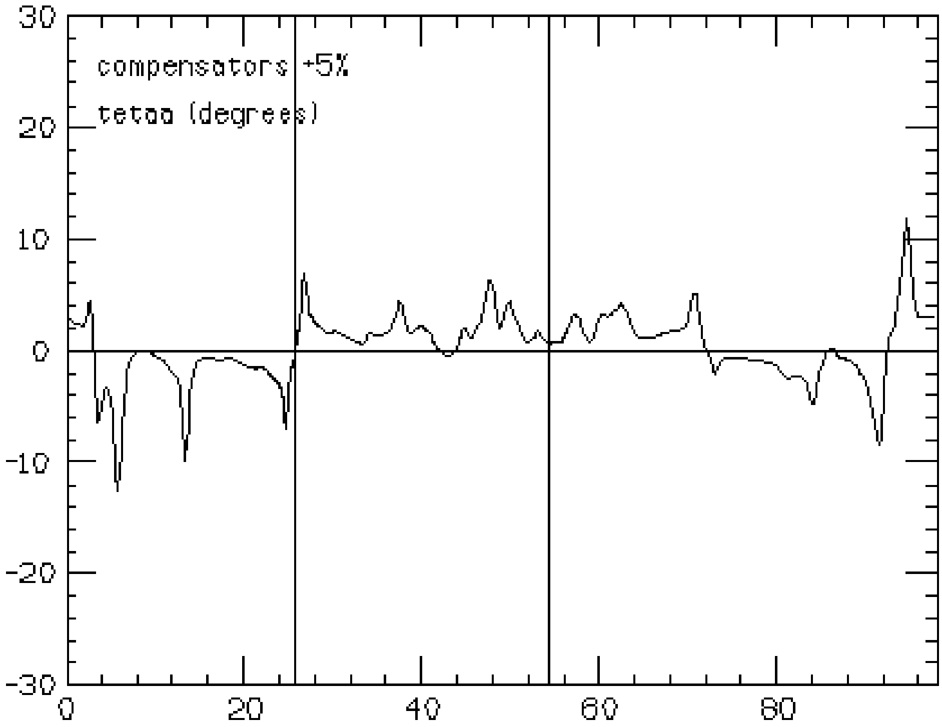


Figure 9 – 1st mode tilt for symmetric change in both compensators.

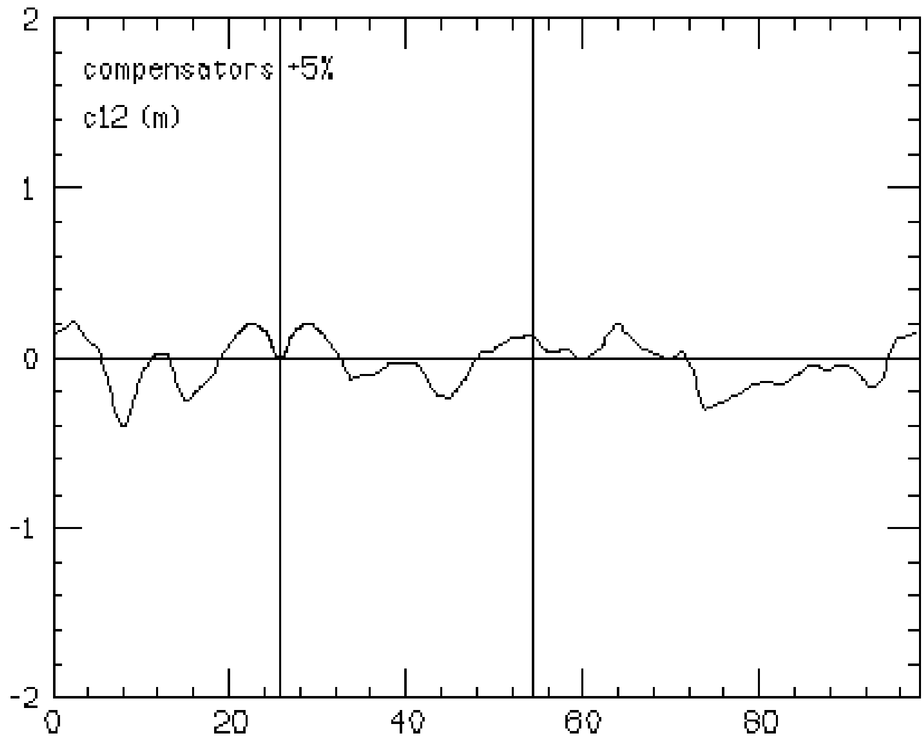


Figure 10 – C_{12} for symmetric change in both compensators.

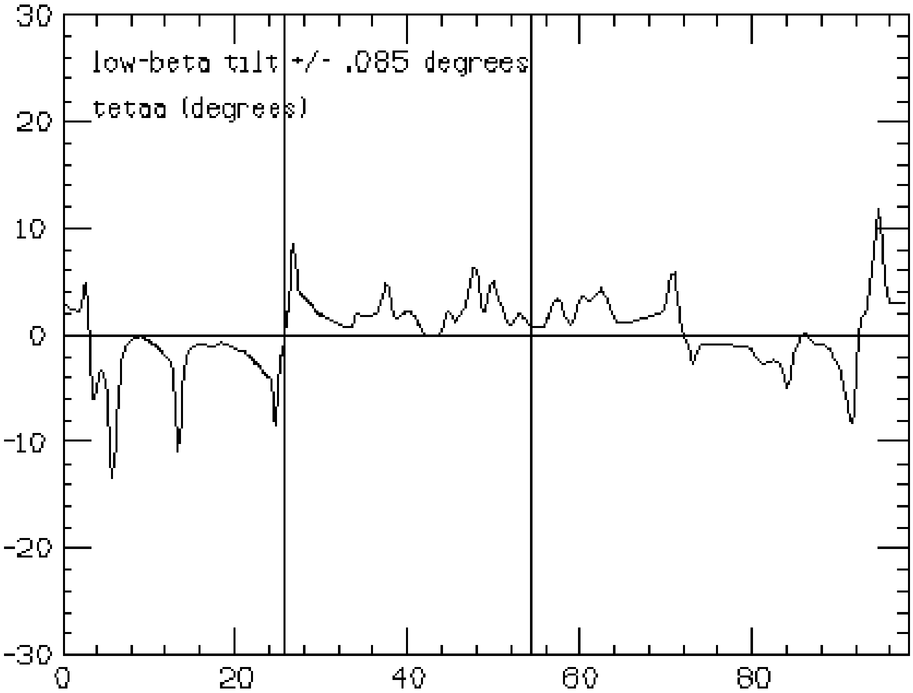


Figure 11 – 1st mode tilt for antisymmetric change in low beta quads tilts.

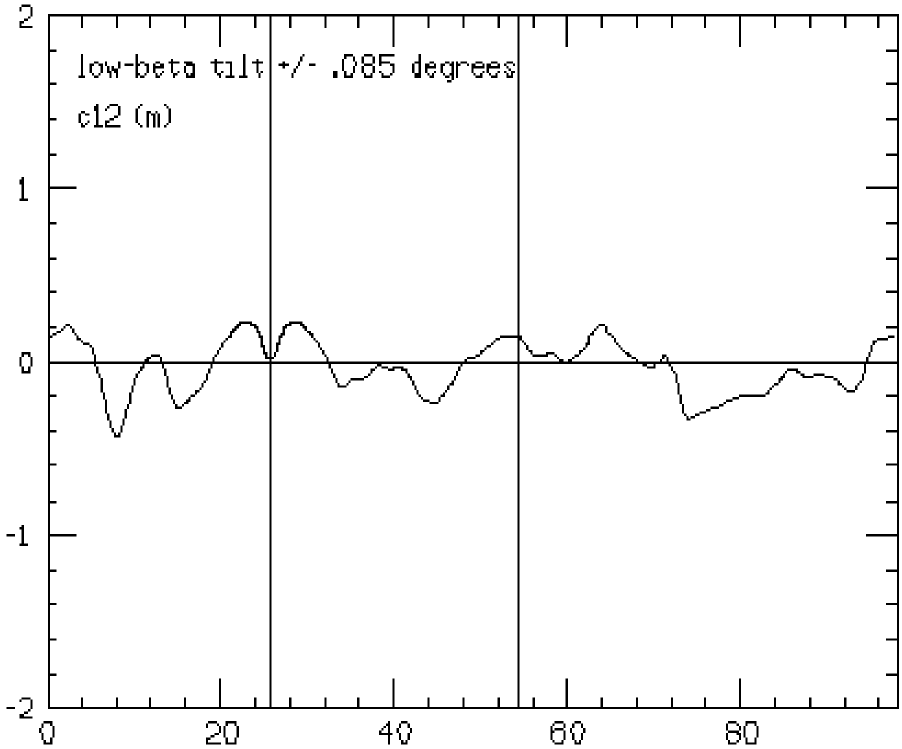


Figure 12 – C_{12} for antisymmetric change in low beta quads tilts.

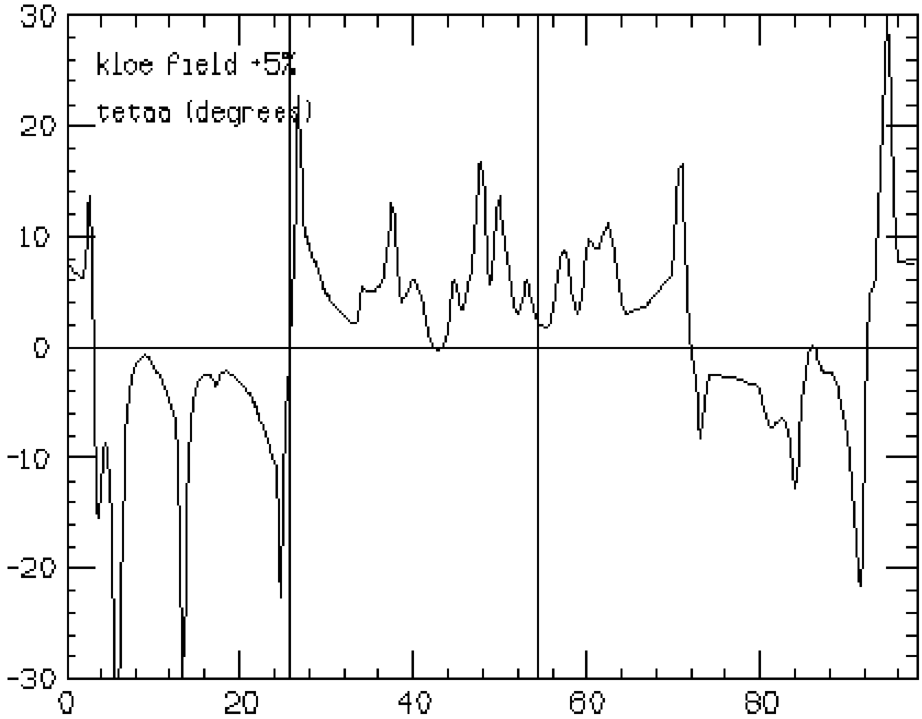


Figure 13 – 1st mode tilt for change in KLOE field.

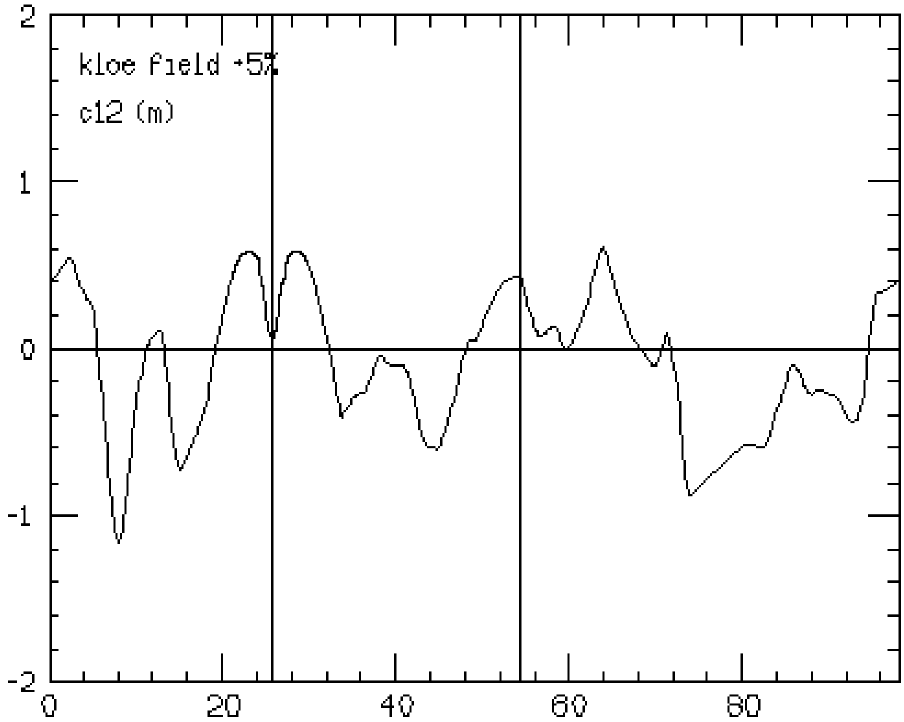


Figure 14 – C_{12} for change in KLOE field.

From the observation of the three above contributions it can be deduced that the tilt due to any of this symmetric cases has always the same phase along the ring, and it can be corrected tuning the compensators. The contribution to C_{12} at the IP is zero for the case of the compensators, while it is different from zero in the presence of a skew component, which appears in the two second cases.

Correcting the mismatch between the KLOE field and the position of the triplets needs the use of skew quadrupoles.

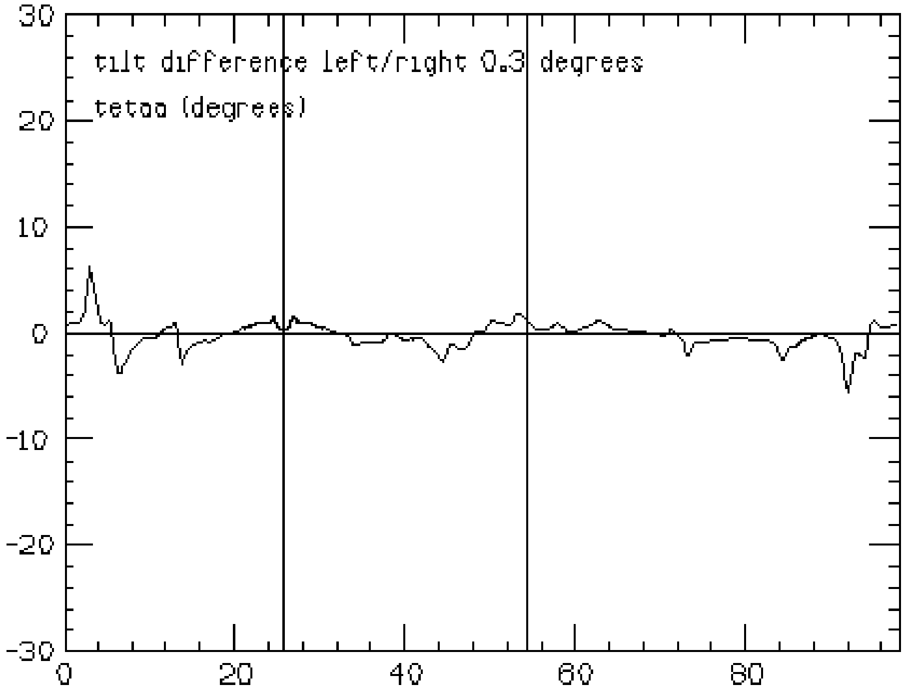


Figure 15 – 1st mode tilt for asymmetric tilt of low-beta quads as estimated from the measurements [2].

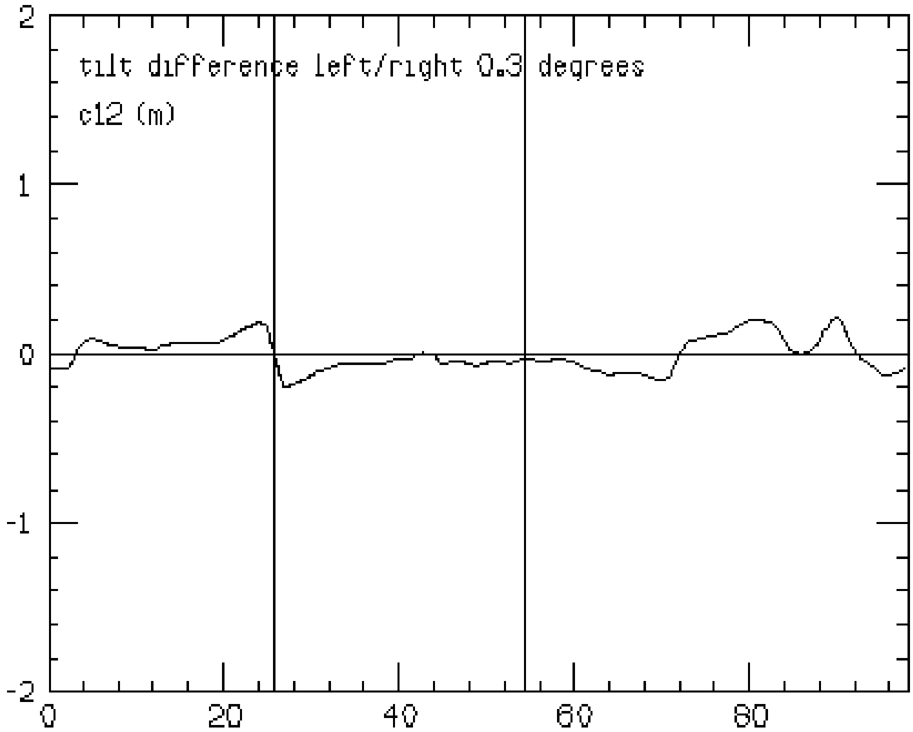


Figure 16 – C_{12} for asymmetric tilt of low-beta quads as estimated from the measurements [2].

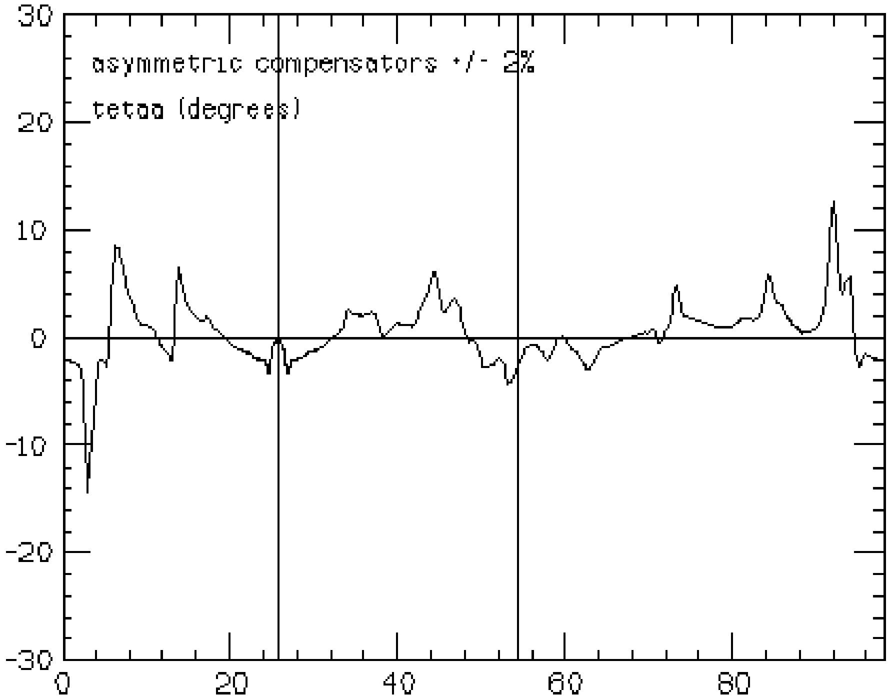


Figure 17 – 1st mode tilt for asymmetric mismatch in compensators.

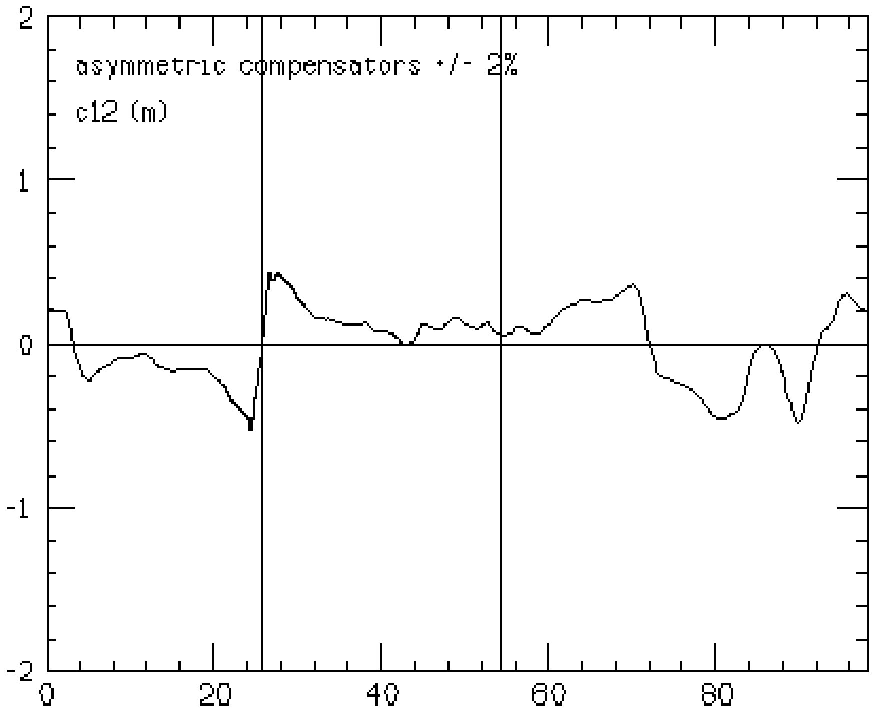


Figure 18 – C_{12} for asymmetric mismatch in compensators.

We can conclude that the asymmetry in the triplet alignment as estimated from measurements [2] (0.3°) can be corrected by powering asymmetrically the two compensators by about 2A. The value of C_{12} can be annulled by the outside skews[1] or by lowering the field of KLOE to 2400A. If we trust on the measurements of KLOE and compensator fields and of quadrupole tilt alignment, a good correction of all the effects is obtained therefore with a value of 2400 A in KLOE and the two compensators powered with - 87A and + 83.6A, taking into account the small difference of the order of 2% between the integrated fields of the compensators for the same current.

Figures 19 and 20 (notice that the vertical scales are a factor 10 below the scales of previous figures) show the residual value of θ_a and C_{12} along the ring, with a total contribution to the emittance of the second mode negligible (<< 0.1%).

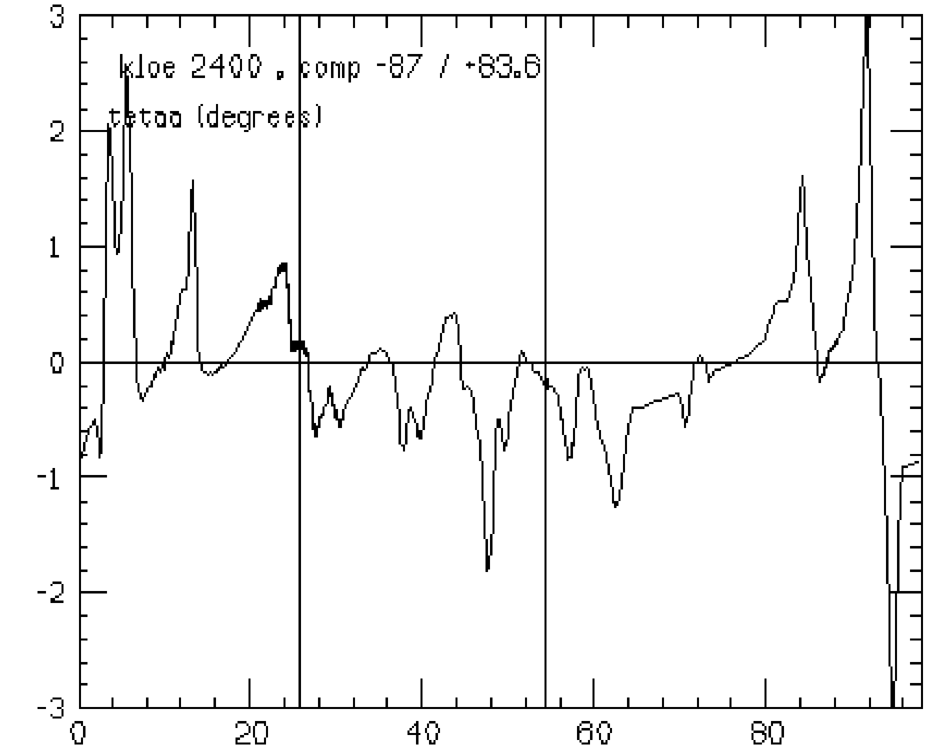


Figure 19 – 1st mode tilt for correction of coupling with change in KLOE field and in the two compensators.

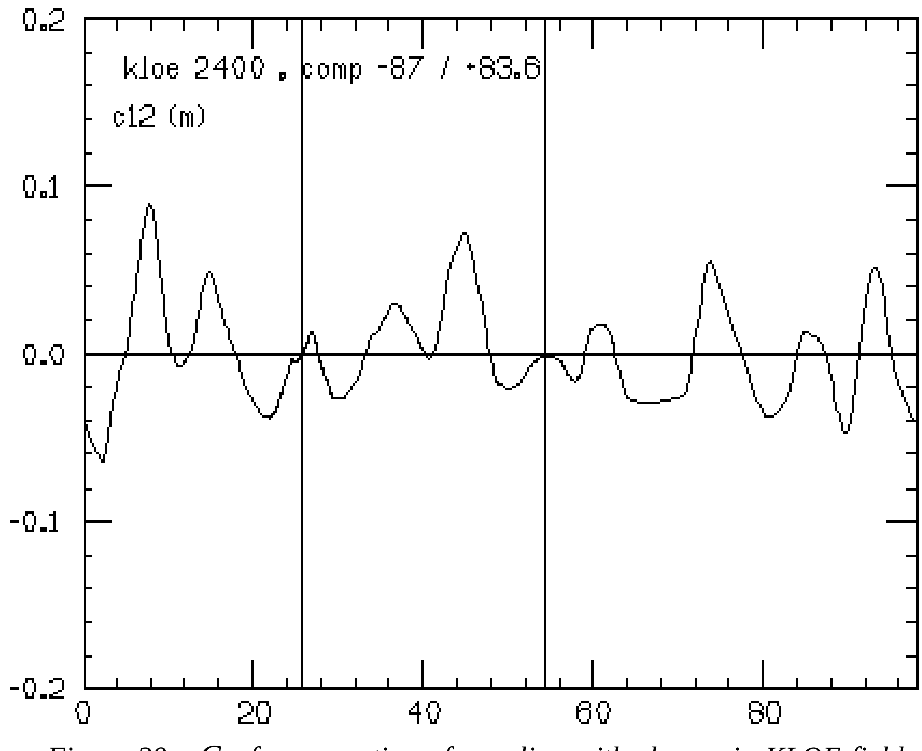


Figure 20 – C_{12} for correction of coupling with change in KLOE field and in the two compensators.

Dependence on the Model

It is interesting to control the dependence of the coupling on the optical model of the ring.

Let us compute first the dependence of the KLOE IR correction on the model of the IR. The strongest optical parameter inside the IR is the integrated gradient of the defocusing quadrupole. Changing this gradient of +0.5 % does not give appreciable changes in the coupling behaviour, while it does the negative change of the same amount, just because in the first case the two modes-tunes go in opposite directions, while in the second case the two tunes are very close and inside the coupling resonance; in this second case (see Figs. 21 and 22) the coupling in the ring is much larger.

Another example corresponds to the application of the same correction to the two optical descriptions of the rings which are being used for modelling the two different rings, with the quadrupole settings corresponding to the runs of December 1999.

Figures 23 and 24 correspond to the electron and positron model; the dashed lines represent the rings with the KLOE IR as it was modelled in 1999, and no other coupling source in the rings; the solid lines corresponds to the ring with the correction of the KLOE IR as computed before.

The dependence on the model of the IR is not strong.

References

[1] C. Biscari, G. Benedetti, S. Di Mitri, C. Milardi, S. Guiducci, M.A. Preger, C. Vaccarezza, G. Vignola: “Coupling in DAΦNE”, DAΦNE Technical Note L-30 (March 3, 2000).

[2] F. Sgamma, M. Paris, M. Troiani: “Zona di Interazione di KLOE: Misure di Febbraio e Riallineamento di Marzo 2000”, DAΦNE Technical Note ME-9 (March 28, 2000).

[3] C. Sanelli - Private communication.

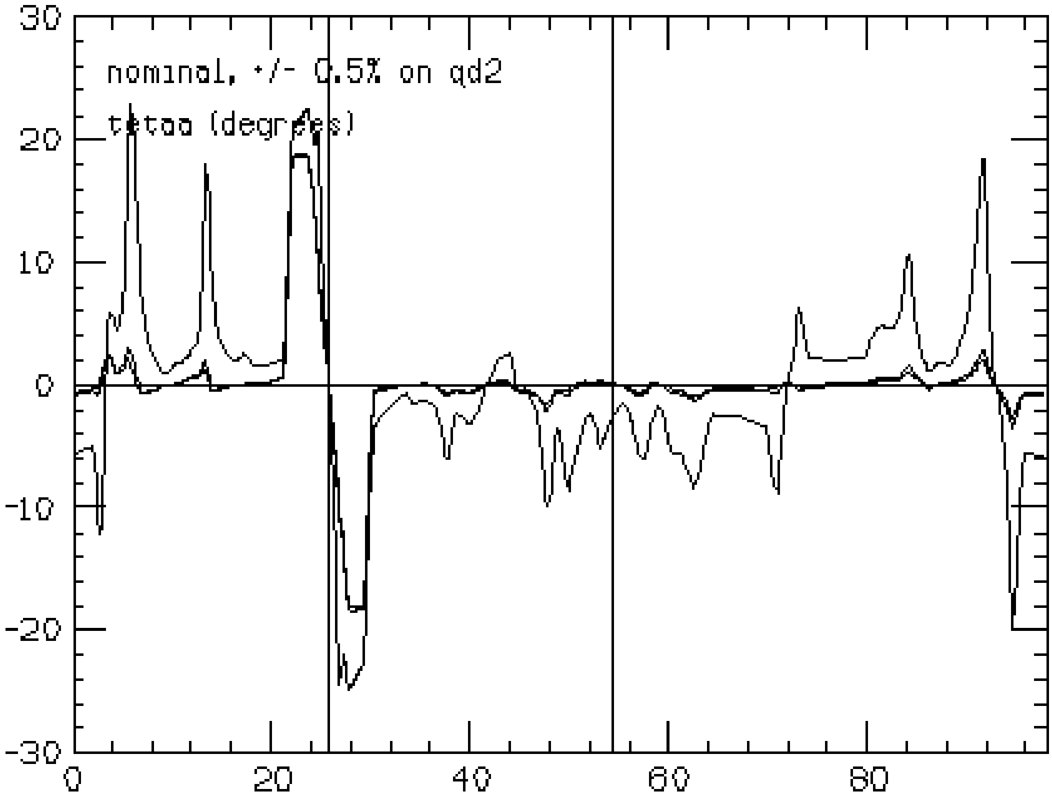


Figure 21 – Tilt in the corrected coupling case and with an error on the QD gradient.

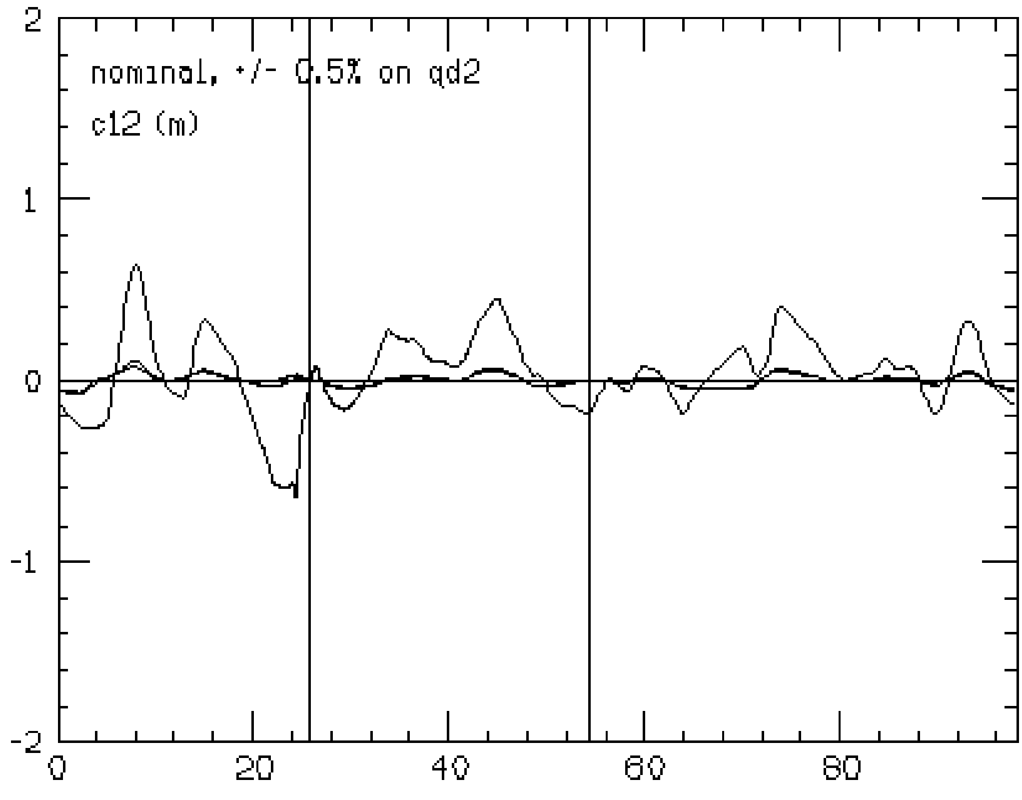


Figure 22 – C_{12} in the corrected coupling case and with an error on the QD gradient.

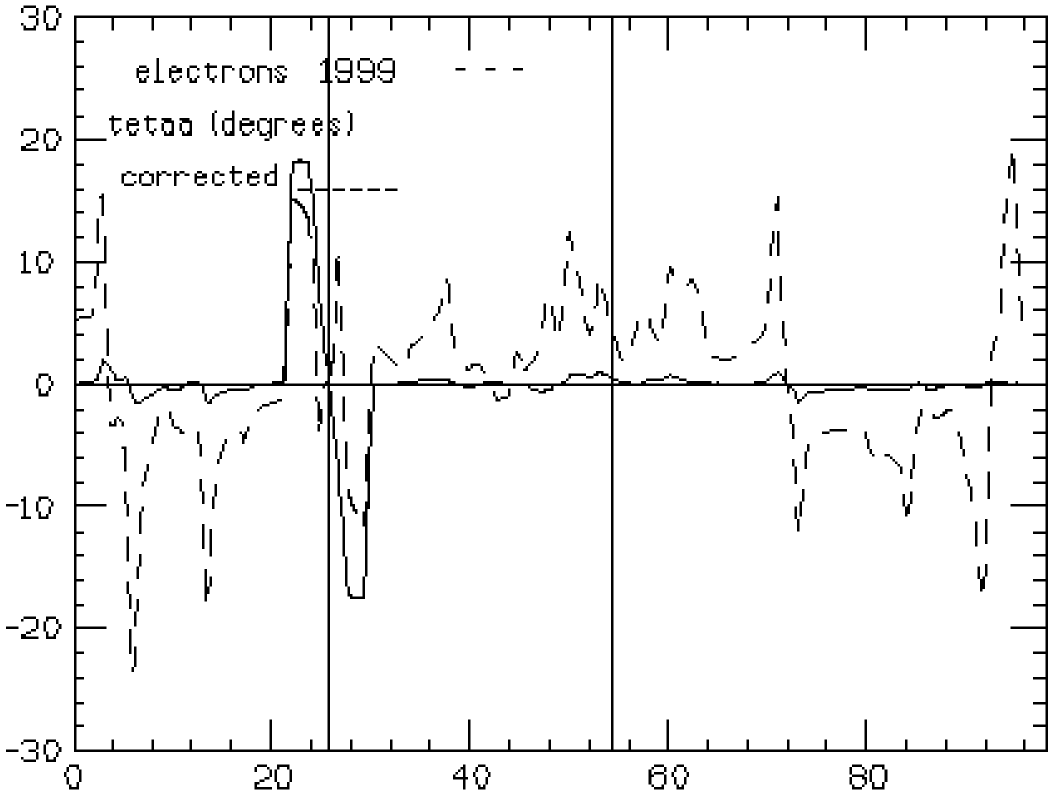


Figure 23 – Electron ring.

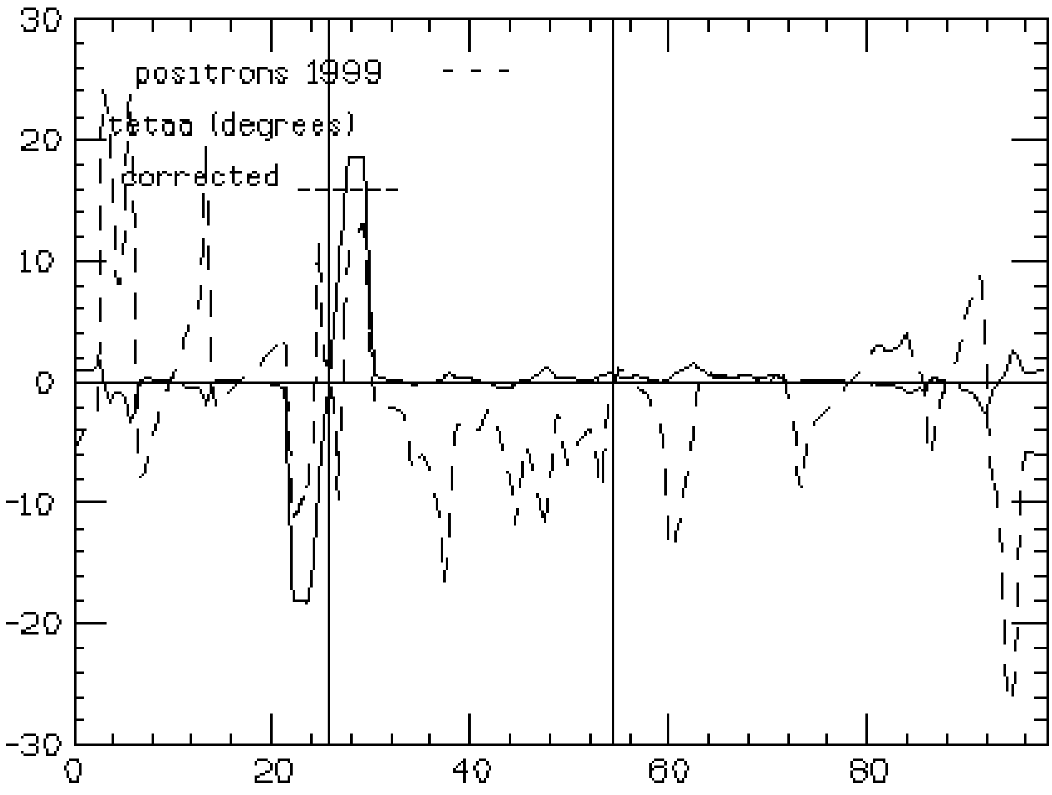
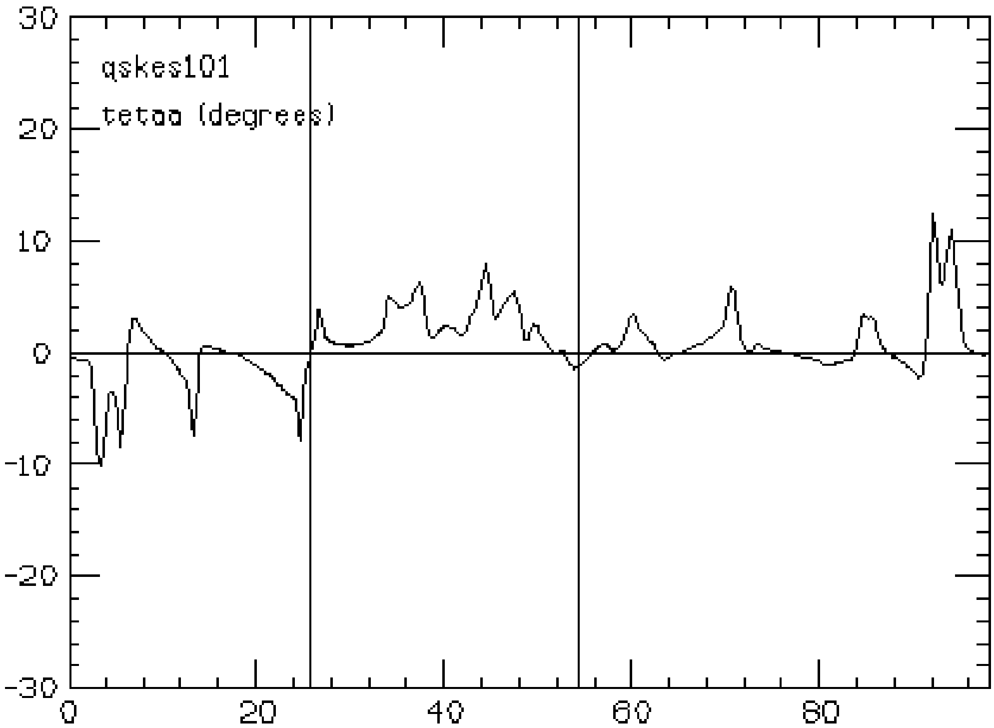
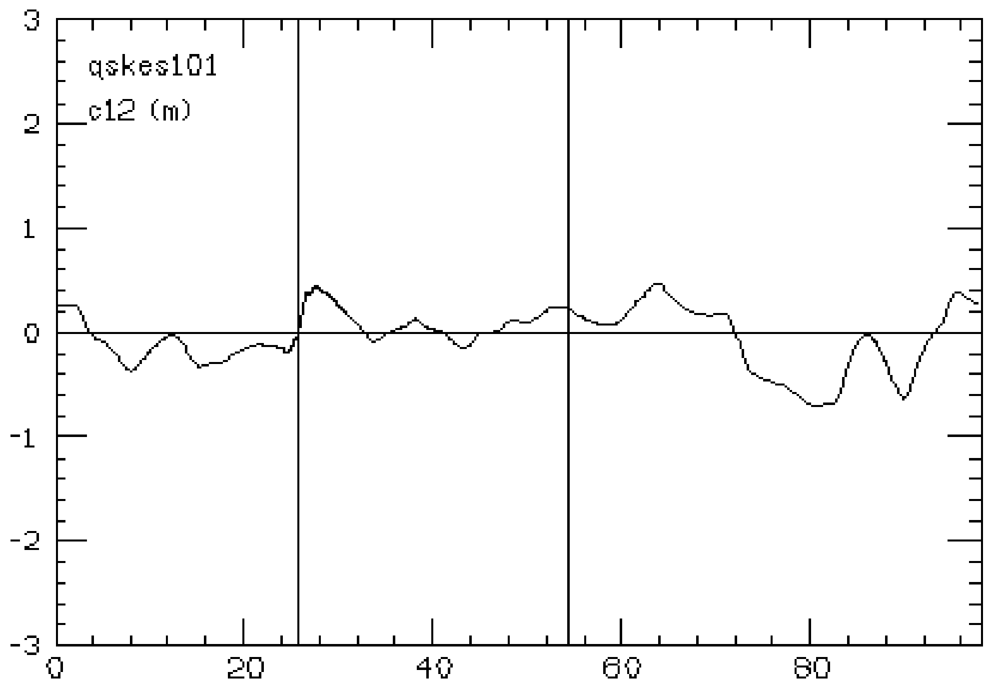


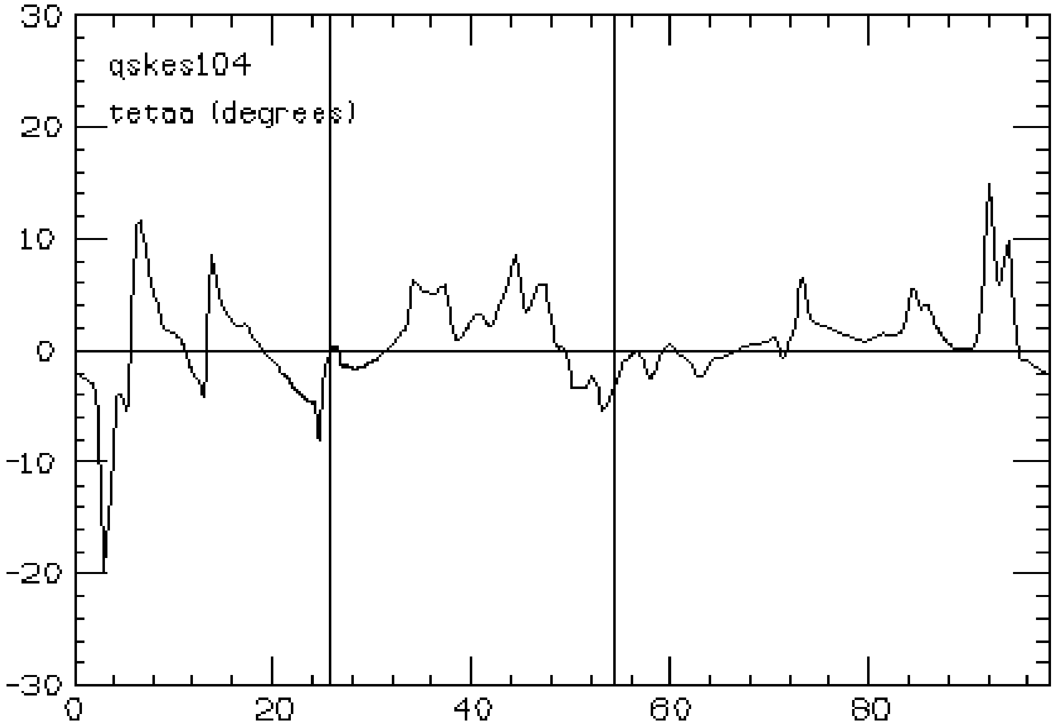
Figure 24 – Positron ring.

APPENDIX A

Tilt angle of the first mode and value of C_{12} along the ring for each one of the eight skew quadrupoles powered at 20A.



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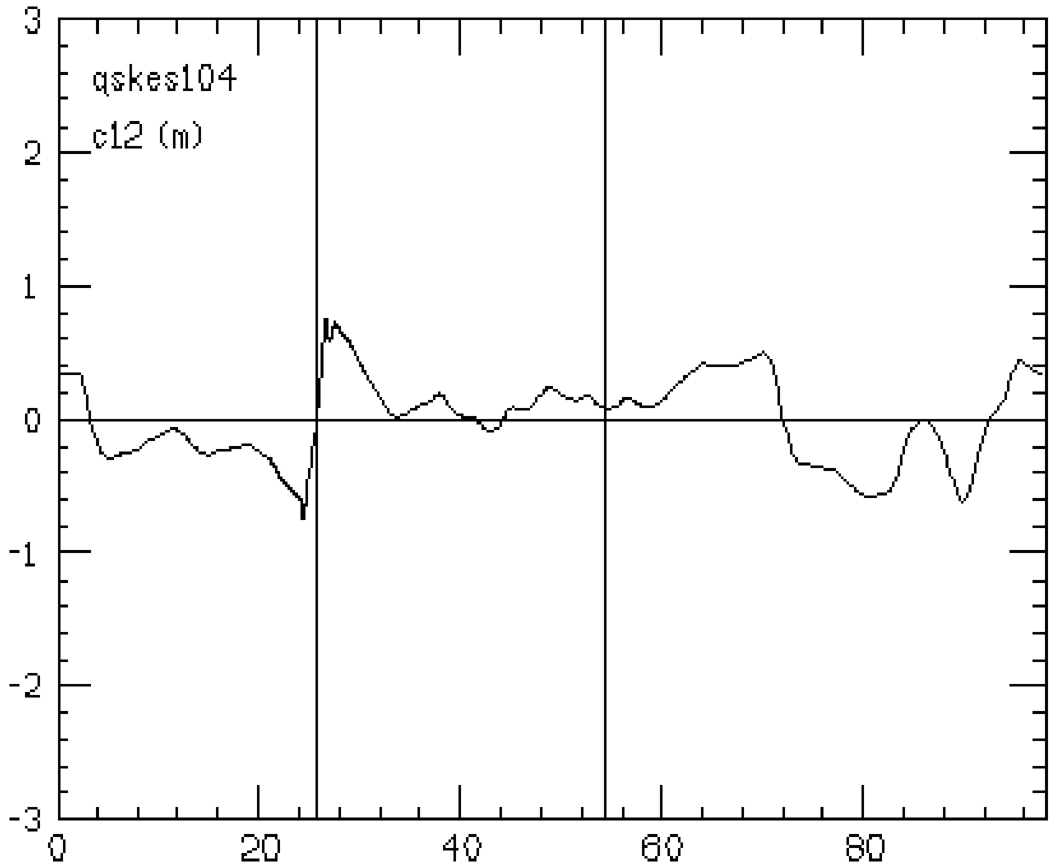
tetaa (degrees)
30
20
10
0
-10
-20
-30
0
20
40
60
80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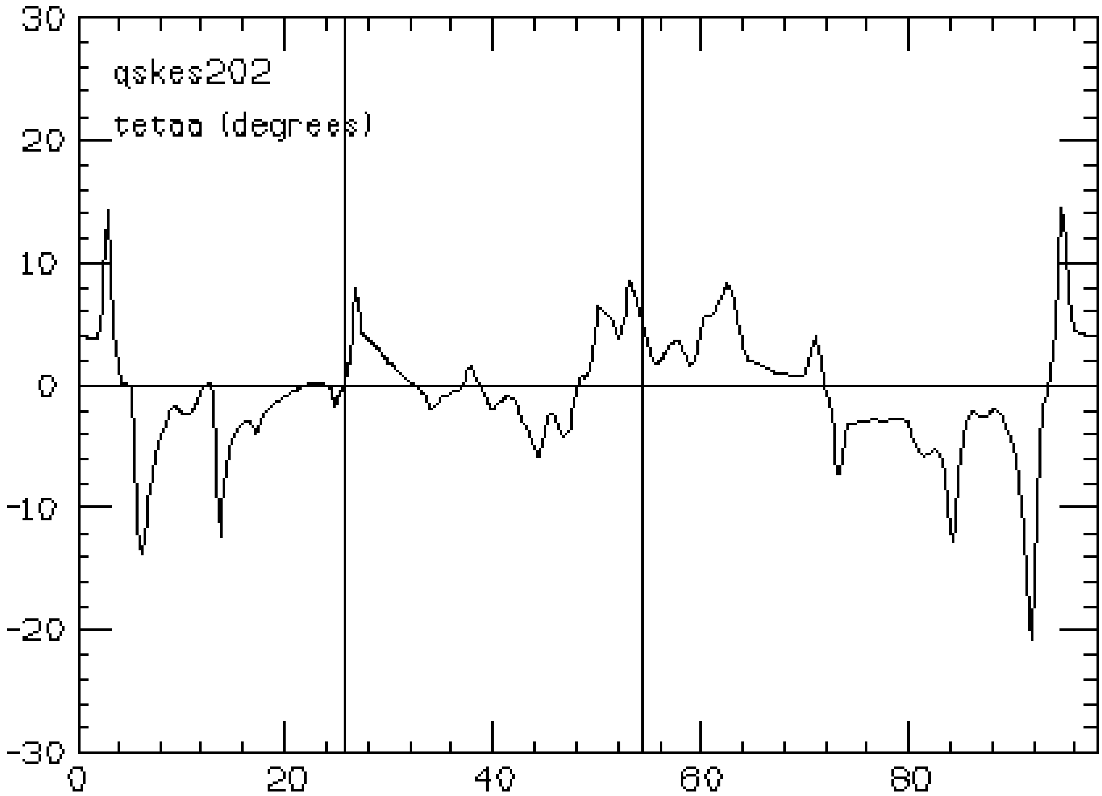
c12 (m)
3
2
1
0
-1
-2
-3
0
20
40
60
80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tetaa (degrees)
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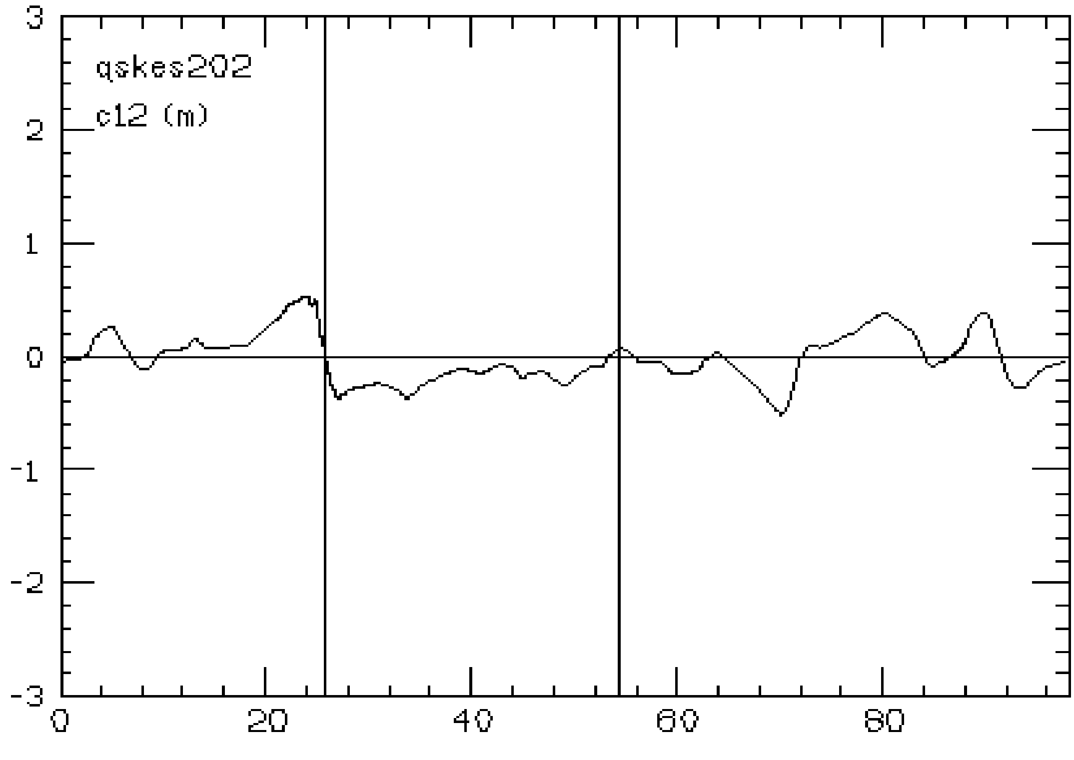
20
10
0
-10
-20
-30
0
20
40
60
80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c12 (m)
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2
1
0
-1
-2
-3
0
20
40
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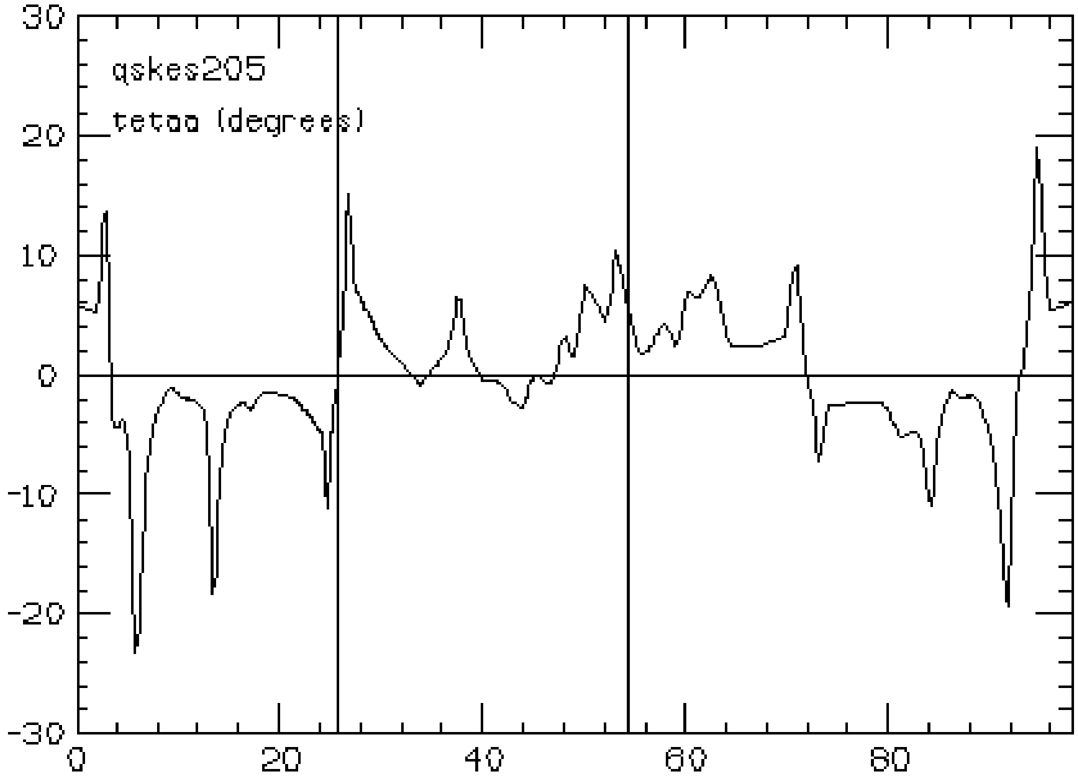
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tetaa (degrees)
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20
10
0
-10
-20
-30
0
20
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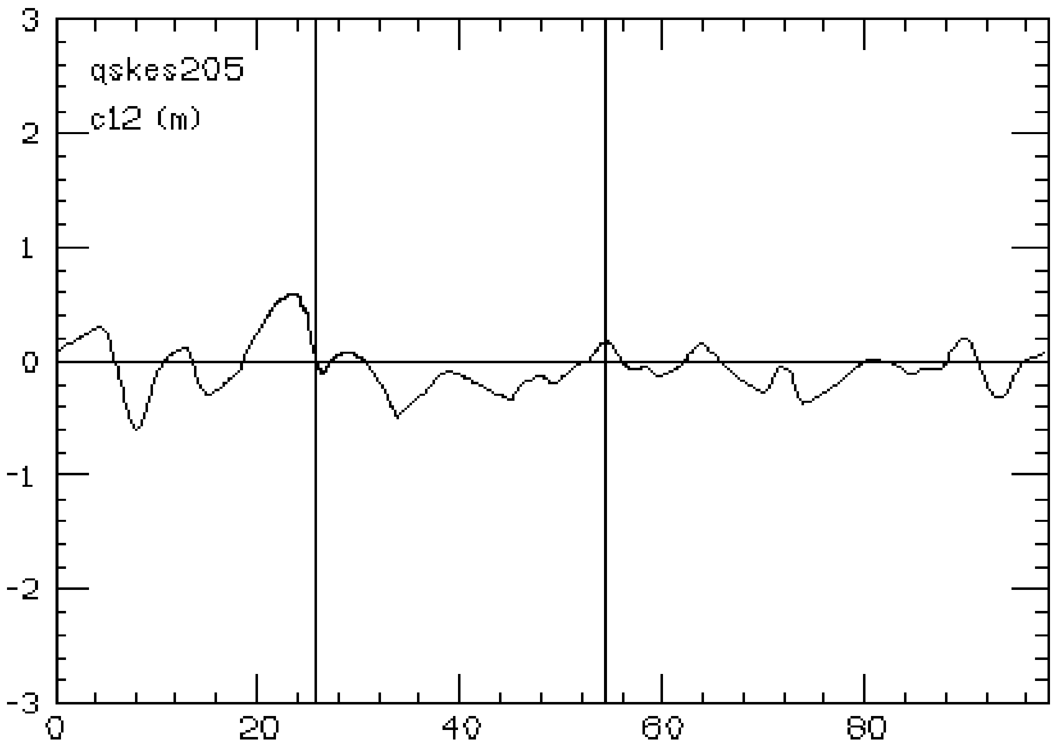
80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c12 (m)
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2
1
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-2
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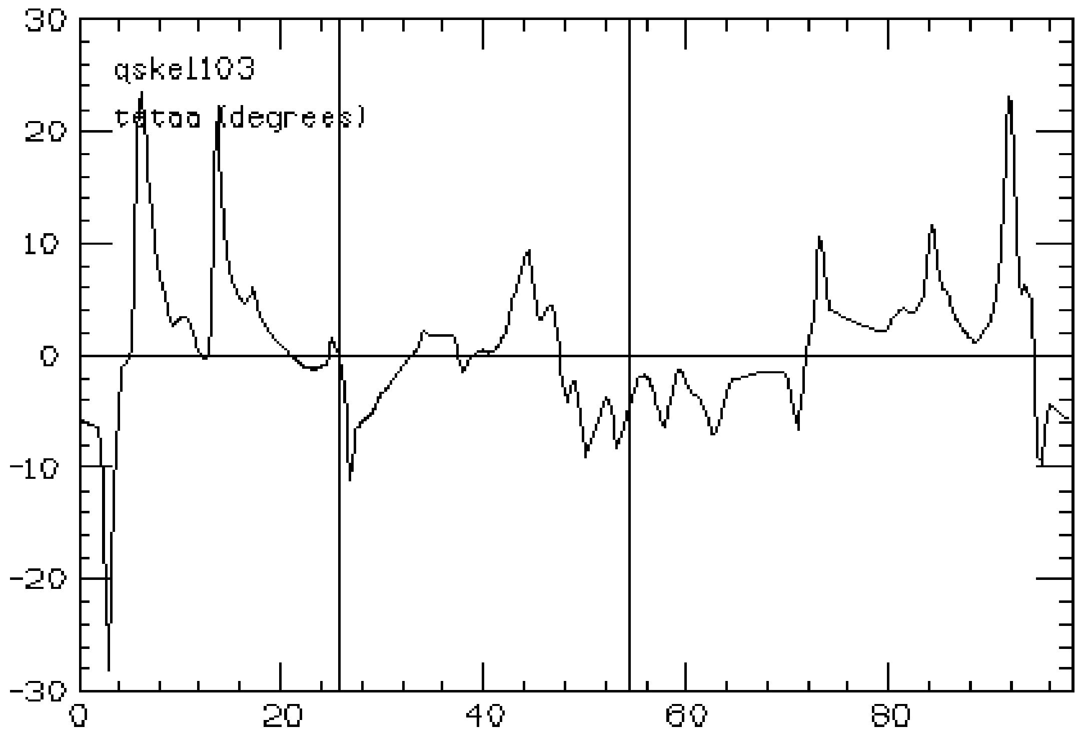
80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tetaa (degrees)
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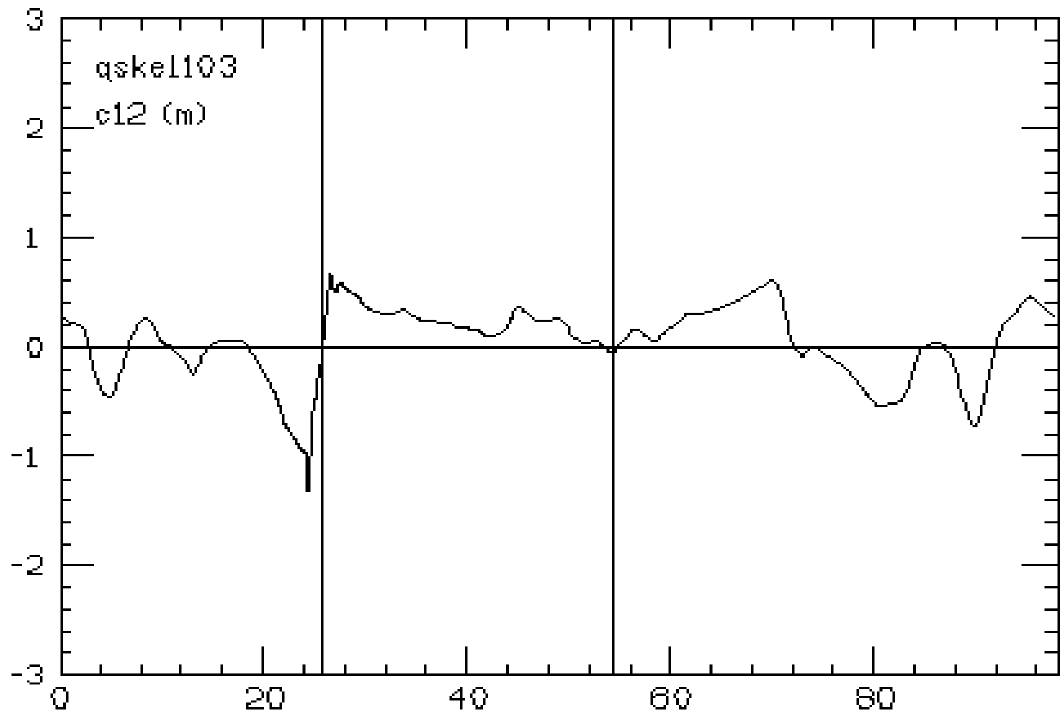
20
10
0
-10
-20
-30
0
20
40
60
80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40
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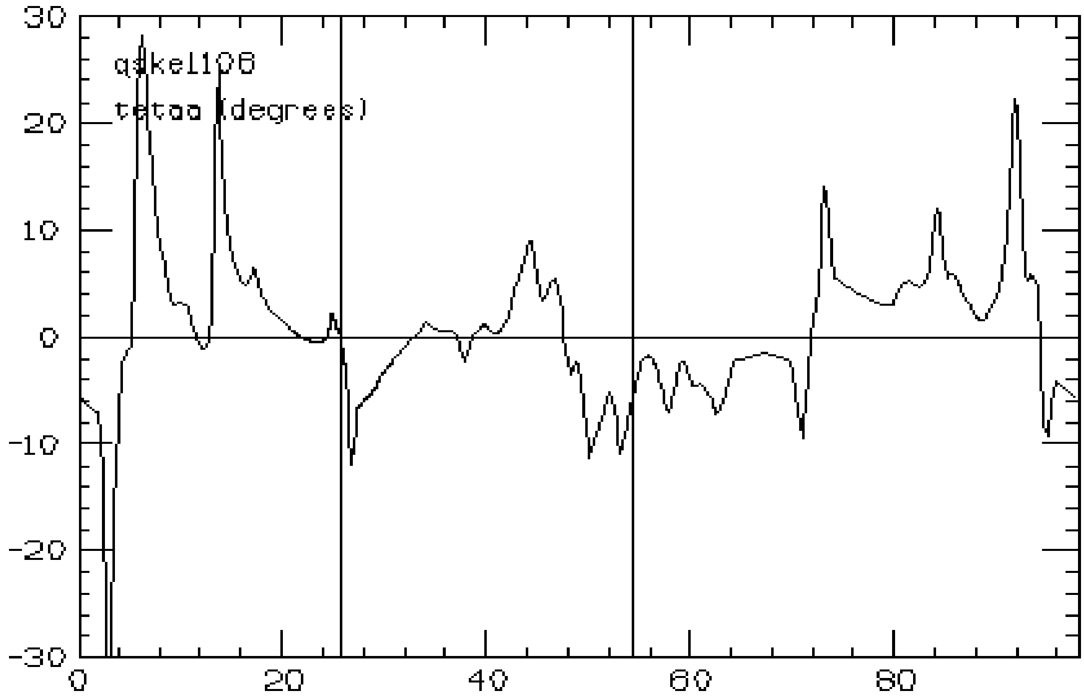

qskel108
tetaa (degrees)
30
20
10
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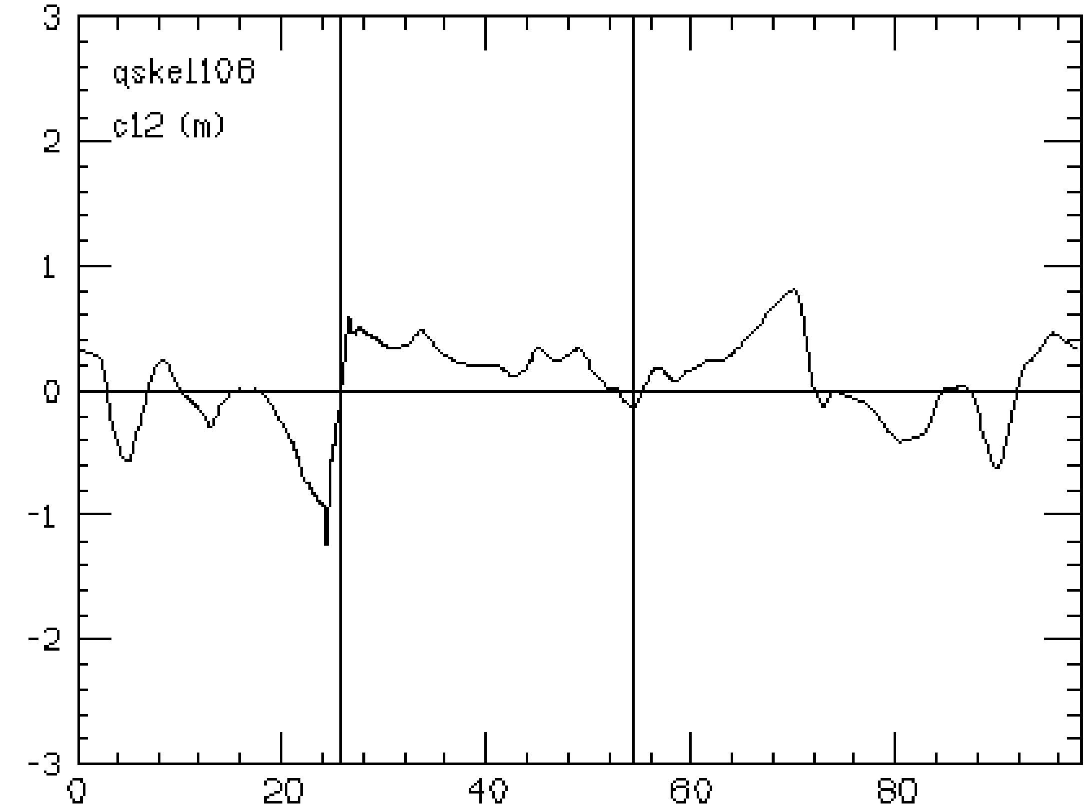
-10
-20
-30
0
20
40
60
80



qskel108
c12 (m)
3
2
1
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-2
-3
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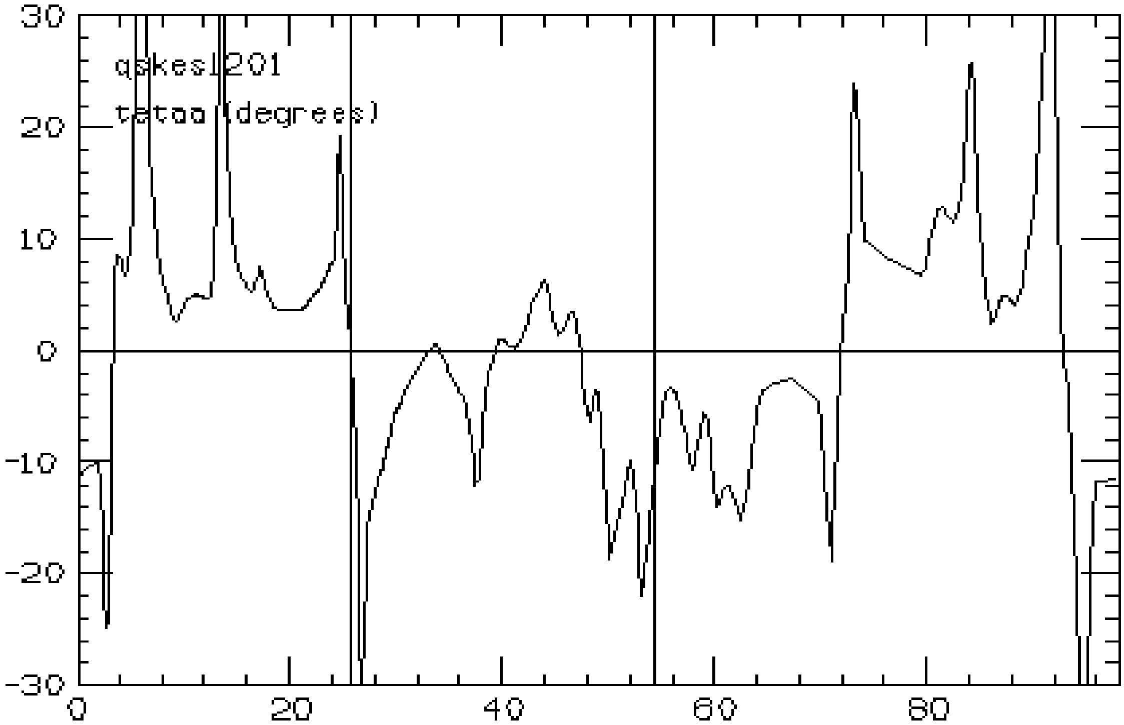
80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-30
0
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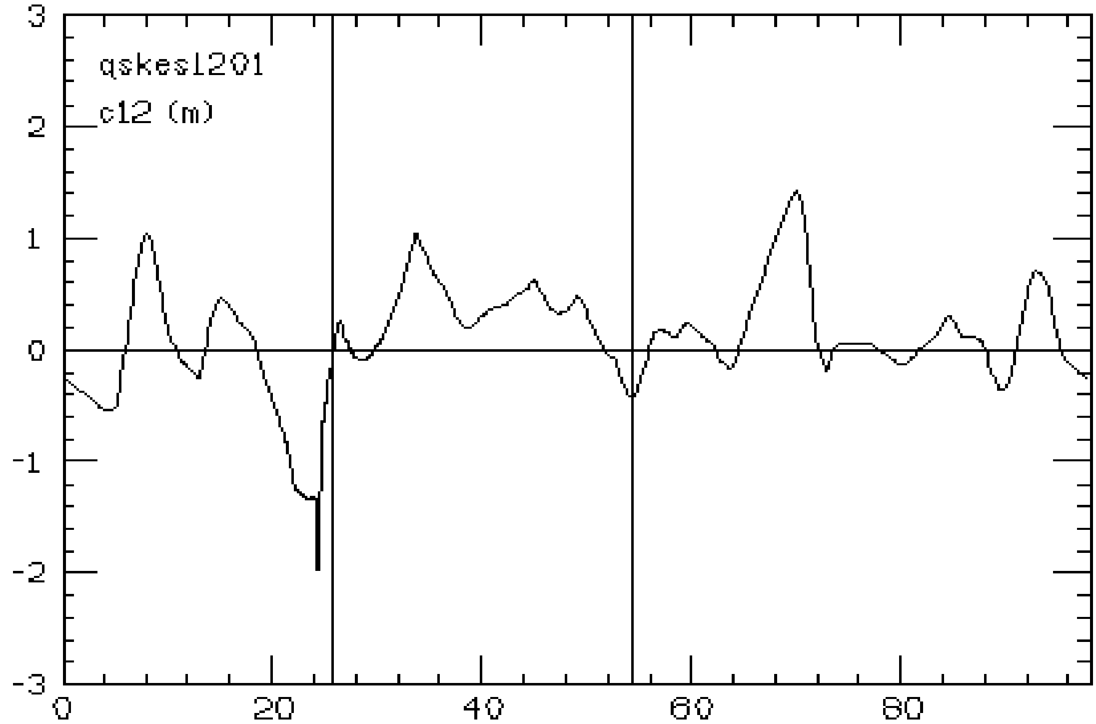
40
60
80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c12 (m)
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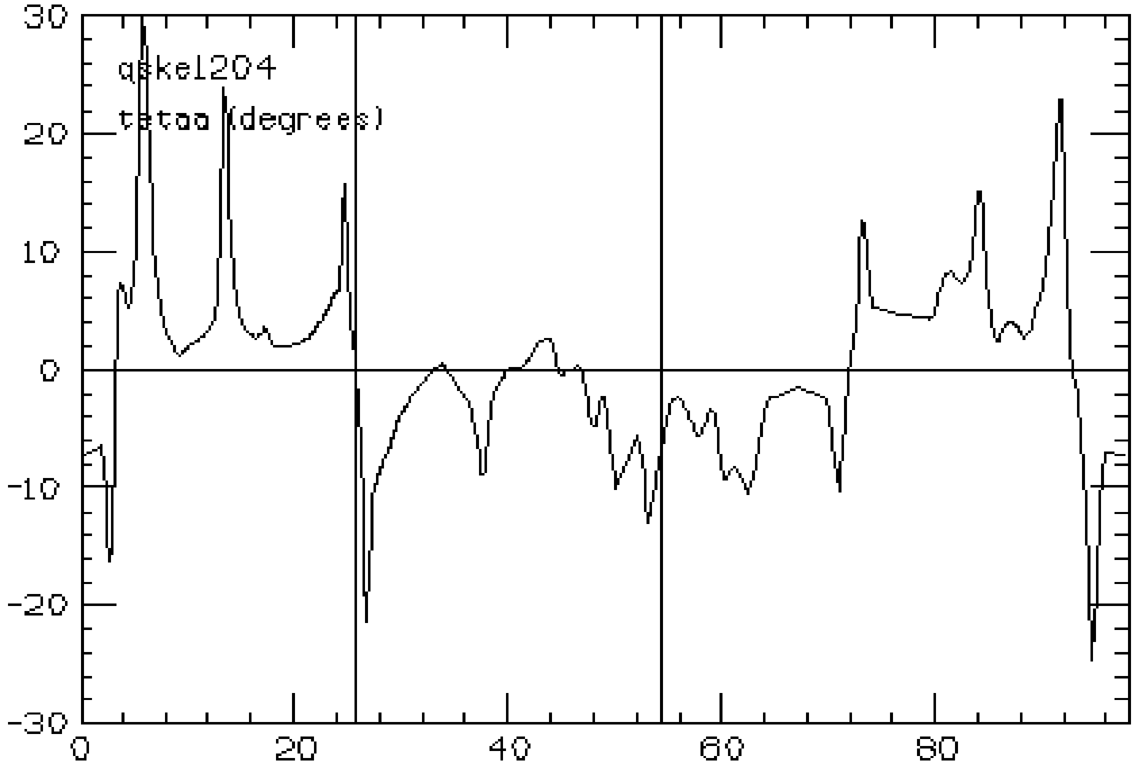
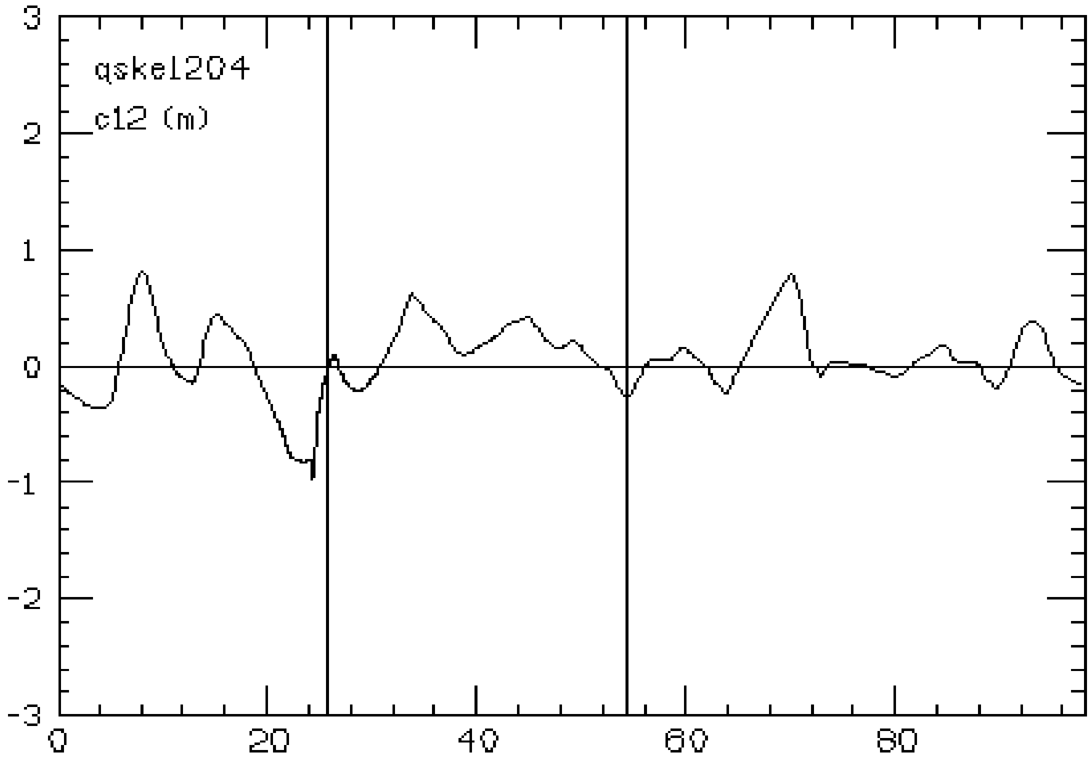

qskel204
tetaa (degrees)
30
20
10
0
-10
-20
-30
0
20
40
60
80


qskel204
c12 (m)
3
2
1
0
-1
-2
-3
0
20
40
60
80