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CHROMATIC PROPERTIES OF THE SSC CONCEPTUAL DESIGN REPORT LATTICE

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ABSTRACT

The chromatic properties of the lattice designed for the Conceptual Design Report have been studied with optical configurations corresponding to a number of different operational conditions. Although the lattice was designed with four pairs of optically identical interaction regions, it is shown that each IR may be tuned independently.

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Introduction

The lattice of the CDR[1] has a racetrack shape with eight long straight sections placed in two clusters of four each, see Fig. 1. Two straight sections in each cluster contain crossing interaction regions. The IRs in the East cluster are the medium-β IRs *M1* and *M2* with ±100 m free space about the IPs; those in the West cluster are the low-β IRs *L1* and *L2* with ±20 m. The other two straight sections *U* in the East cluster are utility regions; the two labeled *XF* in the West cluster are identical to the *U* straight sections, but are reserved for future development as IRs.

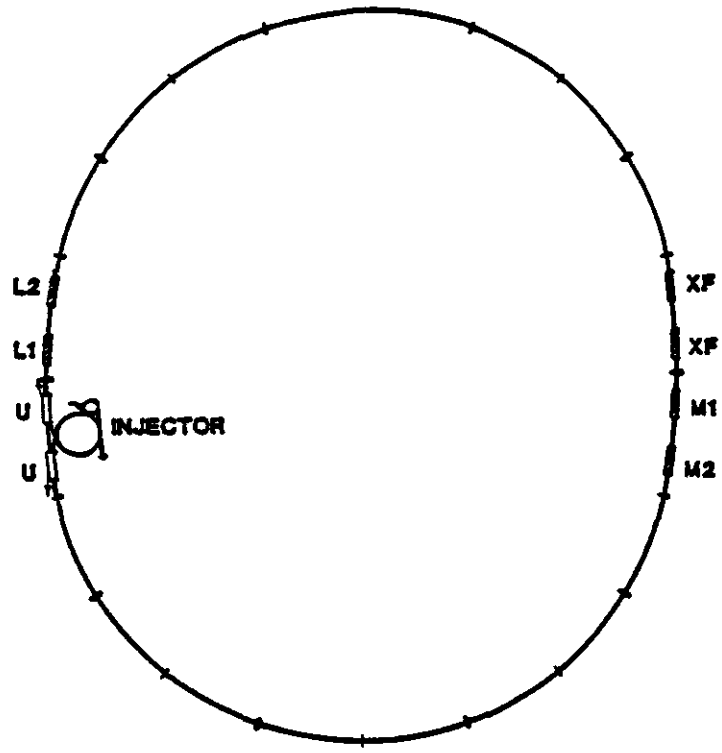

Fig. 1 SSC straight section layout

Two principal optical configurations are included in the CDR design, an injection optics where all of the interaction points have relatively large beta values, and an experimental optics where the betas are much smaller. For each optics, both medium-β IRs are tuned identically as are the low-β IRs. The reason that this clustered arrangement works well is that the IPs of each pair of IRs are designed to be exactly an odd multiple of 90° from each other in betatron phase, which results in a cancellation of chromatic perturbations from the two paired IRs.[1–5] The question arises as to the feasibility of operating the ring in configurations that partly violate the pairing of the IRs, as it would be most desirable to be able to choose β^* arbitrarily at each of the four IPs, at any value between the injection and lowest possible collision levels. This report presents the results of a study intended to answer this question.

Description

A smooth path between the injection and standard collision optics configurations has been obtained previously.[6] In the report cited the gradients are tabulated for seven different β^* levels for the low and medium-β IRs. For the present study, three of the low-β and two of the medium-β tuning configurations have been arranged in different ways to make four optics cases. These four optics, defined by the β^* values at the four IPs, are displayed in Table I. Cases 1 and 4 are the CDR collision and injection optics respectively. In both of these optics the low and medium-β IRs are paired. Optics 2 and 3 represent experimental configurations in which one of the low-β IRs is tuned to the lowest β^* value, 1/2 m, while the other one is at a higher value.

Table I

Beta function values at IP's for the optics cases studied. L1, L2 are low-beta IP's and M1, M2 are medium-beta IP's.

	L1		L2		M1		M2	
Optics	β_x^*	β_y^*	β_x^*	β_y^*	β_x^*	β_y^*	β_x^*	β_y^*
1	.5	.5	.5	.5	10	10	10	10
2	.5	.5	1	1	10	10	10	10
3	.5	.5	6	6	10	10	10	10
4	6	6	6	6	64	64	64	64

The calculations were done using the SYNCH program. For each of nine values of the momentum deviation $\Delta p/p$ between ± 0.002, the program calculates the closed orbit, tunes and betatron functions. By way of comparison, the rms momentum spread at injection is $\pm 1.75 \times 10^{-4}$. For each optics, the sextupoles are adjusted to produce zero chromaticity.

Tunes

The chromatic behavior of the tunes is displayed in Table II and plotted in Fig. 2. In order of increasing momentum dependence, the ranking of the optics cases is 4, 3, 2, 1; it appears that larger β^* values at any IP improve the tune behavior, even if the pairing is compromised. This result is not too surprising, since the proper phase relations are maintained, giving partial chromatic cancellation, while the larger β^* values lower the sextupole strengths.

Table II

Momentum dependence of the tunes for the optics cases of Table I. $\Delta p/p$ is in parts per thousand.

$\Delta p/p$	Optics 1		Optics 2		Optics 3		Optics 4	
(o/oo)	ν_x–78	ν_y–78	ν_x–78	ν_y–78	ν_x–78	ν_y–78	ν_x–78	ν_y–78
−2.0	.3002	.3187	.2712	.3009	.2480	.2830	.2653	.2803
−1.5	.2816	.2975	.2667	.2898	.2570	.2826	.2652	.2802
−1.0	.2701	.2851	.2650	.2834	.2622	.2815	.2651	.2801
−0.5	.2655	.2805	.2649	.2807	.2646	.2804	.2650	.2800
0.0	.2650	.2800	.2652	.2801	.2651	.2800	.2650	.2800
0.5	.2641	.2791	.2646	.2801	.2650	.2806	.2650	.2800
1.0	.2593	.2744	.2625	.2793	.2659	.2827	.2650	.2800
1.5	.2502	.2660	.2594	.2769	.2693	.2865	.2650	.2800
2.0	.2405	.2582	.2567	.2732	.2768	.2922	.2650	.2800

Beta Functions

The chromatic behavior of the beta functions at the IPs, shown in Table III and in Figs. 3 and 4, is different from that of the tunes. In terms of relative β^* variation, the ranking from best to worst is 4, 2, 3, 1. For the betas, pairing is more important than lower sextupole strength, at least in some cases.

Table III

Momentum dependence of the beta function at the IP's for the optics cases of Table I. $\Delta p/p$ is in parts per thousand, beta in meters.

	$\Delta p/p$	L1		L2		M1		M2	
Optics	(o/oo)	β_x^*	β_y^*	β_x^*	β_y^*	β_x^*	β_y^*	β_x^*	β_y^*
	−2	.360	.301	.310	.354	8.60	15.58	15.19	8.69
	−1	.469	.443	.444	.469	9.29	10.87	10.85	9.29
1	0	.501	.501	.500	.501	9.98	10.00	10.00	9.99
	1	.453	.451	.450	.454	9.05	11.13	11.12	9.05
	2	.370	.360	.347	.384	8.41	16.13	16.09	8.40
	−2	.518	.390	.764	.719	6.87	9.83	13.88	12.22
	−1	.514	.458	.961	.922	8.61	9.19	11.49	11.08
2	0	.501	.501	.999	.999	9.99	10.00	10.00	9.99
	1	.488	.516	.863	.932	10.80	11.72	9.42	8.32
	2	.489	.503	.646	.761	11.76	14.64	10.51	6.49
	−2	.640	.484	8.37	3.12	6.68	6.47	15.63	16.58
	−1	.534	.477	7.41	4.46	8.03	7.84	12.67	13.01
3	0	.501	.500	5.99	6.00	9.98	9.99	10.00	9.99
	1	.528	.559	4.60	7.19	12.65	12.91	8.04	7.68
	2	.638	.662	3.86	7.65	16.05	16.31	6.99	5.89
	−2	5.97	5.63	5.63	5.97	61.8	63.9	64.0	61.8
	−1	6.01	5.81	5.81	6.00	62.8	64.1	64.2	62.8
4	0	6.01	6.00	5.99	6.01	63.9	64.0	64.0	63.0
	1	5.97	6.17	6.17	5.97	65.0	63.4	63.5	65.0
	2	5.91	6.35	6.35	5.91	66.3	62.7	62.8	66.4

Alpha Function

The α^* momentum dependences are shown in Table IV on the next page. All of the IPs with one exception are tuned to $\alpha^* = 0$ for the on-momentum particles. The exception is that the medium-β IPs are tuned to finite α^* values at injection.

For the other cases, the non-zero α^* values for off-momentum particles show that the waist positions vary with energy. Specifically, the minimum beta value β_0 and the waist displacement Δs are given by

$$\beta_0 = \frac{1}{\gamma_0} = \frac{1}{\gamma^*} = \frac{\beta^*}{1+\alpha^{*2}}$$

$$\Delta s = -\frac{\alpha^*}{\gamma^*} = -\frac{\alpha^*\beta^*}{1+\alpha^{*2}}$$

For example, we find from Tables III and IV for optics 1 at $\Delta p/p = -0.001$, that $\beta_{0x} = 0.43$m, and $\Delta s = 0.12$m at *L1* and that $\beta_{0y} = 10.2$m, and $\Delta s = 2.6$m at *M1* .

Table IV

Momentum dependence of the alpha function at the IP's for the optics cases of Table I. $\Delta p/p$ is in parts per thousand.

Optics	$\Delta p/p$ (o/oo)	L1 α_x^*	L1 α_y^*	L2 α_x^*	L2 α_y^*	M1 α_x^*	M1 α_y^*	M2 α_x^*	M2 α_y^*
	−2	−.37	−.31	.25	.44	−.77	−.97	.92	.82
	−1	−.28	−.27	.25	.30	−.22	−.25	.25	.23
1	0	.00	.00	.00	.00	.00	.00	.00	.00
	1	.21	.19	−.21	−.20	−.10	−.07	.07	.10
	2	.13	.02	−.08	−.08	−.53	−.36	.36	.53
	−2	−.31	−.20	.49	.47	−.21	−.71	.36	.74
	−1	−.16	−.13	.30	.29	−.04	−.26	.08	.27
2	0	.00	.00	.00	.00	.00	.00	.00	.00
	1	.09	.11	−.21	.25	−.11	.11	.11	−.07
	2	.07	.11	−.16	−.31	−.37	.12	.37	.06
	−2	−.08	−.01	.64	.01	.20	−.49	−.01	.67
	−1	−.02	.00	.24	.11	.10	−.25	−.05	.29
3	0	.00	.00	.00	.00	.00	.00	.00	.00
	1	−.02	−.01	−.02	−.24	−.09	.26	.13	−.20
	2	−.07	−.03	.19	−.52	−.17	.55	.33	−.33
	−2	−.04	−.08	.07	.04	.51	−.62	.62	−.51
	−1	−.02	−.04	.04	.02	.55	−.60	.60	−.55
4	0	.00	.00	.00	.00	.59	−.59	.59	−.59
	1	.01	.03	−.04	−.01	.62	−.58	.58	−.62
	2	.01	.06	−.07	.00	.65	−.57	.57	−.65

Closed Orbit Deviations

The closed orbit displacement momentum dependences are shown in Table V. The small horizontal and vertical displacements represent non-linear dispersion. The vertical values come from the energy dependence of the vertical dispersion-matching system, and the fact that this system was slightly modified to improve the β behavior in the IRs.[1]

Table V

Momentum dependence of the closed orbit displacements at the IP's for the optics cases of Table I. $\Delta p/p$ is in parts per thousand, displacements in μm.

	$\Delta p/p$	L1		L2		M1		M2	
Optics	(o/oo)	x^*_{co}	y^*_{co}	x^*_{co}	y^*_{co}	x^*_{co}	y^*_{co}	x^*_{co}	y^*_{co}
	−2	1.4	−2.5	.5	−.7	1.7	10.6	−1.5	2.5
	−1	.6	−.6	−.1	.6	1.7	−.1	.5	−1.1
1	0	.0	.0	.0	.0	.0	.0	.0	.0
	1	.2	−.3	.0	−1.7	−5.0	12.3	−.6	7.0
	2	1.7	.5	−1.0	−3.2	−17.8	54.1	−6.3	1.7
	−2	2.0	−1.1	.1	−1.5	2.0	8.4	−1.3	7.9
	−1	.8	−1.1	−.2	.3	1.8	−.2	.3	1.3
2	0	.0	.0	.0	.0	.0	.0	.0	.0
	1	.1	.1	.0	−1.7	−5.1	8.9	−.1	1.8
	2	1.1	−.1	−1.1	−4.3	−15.8	32.6	.5	7.4
	−2	2.8	−3.9	−4.4	−5.5	3.3	4.3	−3.2	6.6
	−1	.8	−1.3	−1.5	.5	1.9	−1.9	.1	1.1
3	0	.0	.0	.0	.0	.0	.0	.0	.0
	1	.0	.7	−.7	−5.9	−5.2	9.2	.3	−1.4
	2	.8	1.2	−5.0	−15.4	−14.5	24.4	3.8	−5.1
	−2	8.4	−11.2	−3.5	−4.3	−5.3	22.8	7.5	16.0
	−1	2.8	−4.4	−1.3	−1.4	2.7	8.6	4.1	6.0
4	0	.0	.0	.0	.0	.0	.0	.0	.0
	1	.2	2.0	−.4	.0	−15.5	−3.6	−5.9	−6.3
	2	3.0	1.6	−3.2	−1.0	−46.0	−2.6	−15.0	−.9

Conclusion

Since the momentum dependences of the tunes and orbit functions for various combinations of β^* values are rather moderate, it is predicted that the IRs may be operated independently without undue difficulty.

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FIGURE CAPTIONS

1. SSC straight section layout
2. Momentum dependence of the tunes for the four optical cases of Table I
3. Momentum dependence of β^* at *L1* for optics 1,3,and 4 of Table I
4. Momentum dependence of β^* at *M1* for optics 1,3,and 4 of Table I

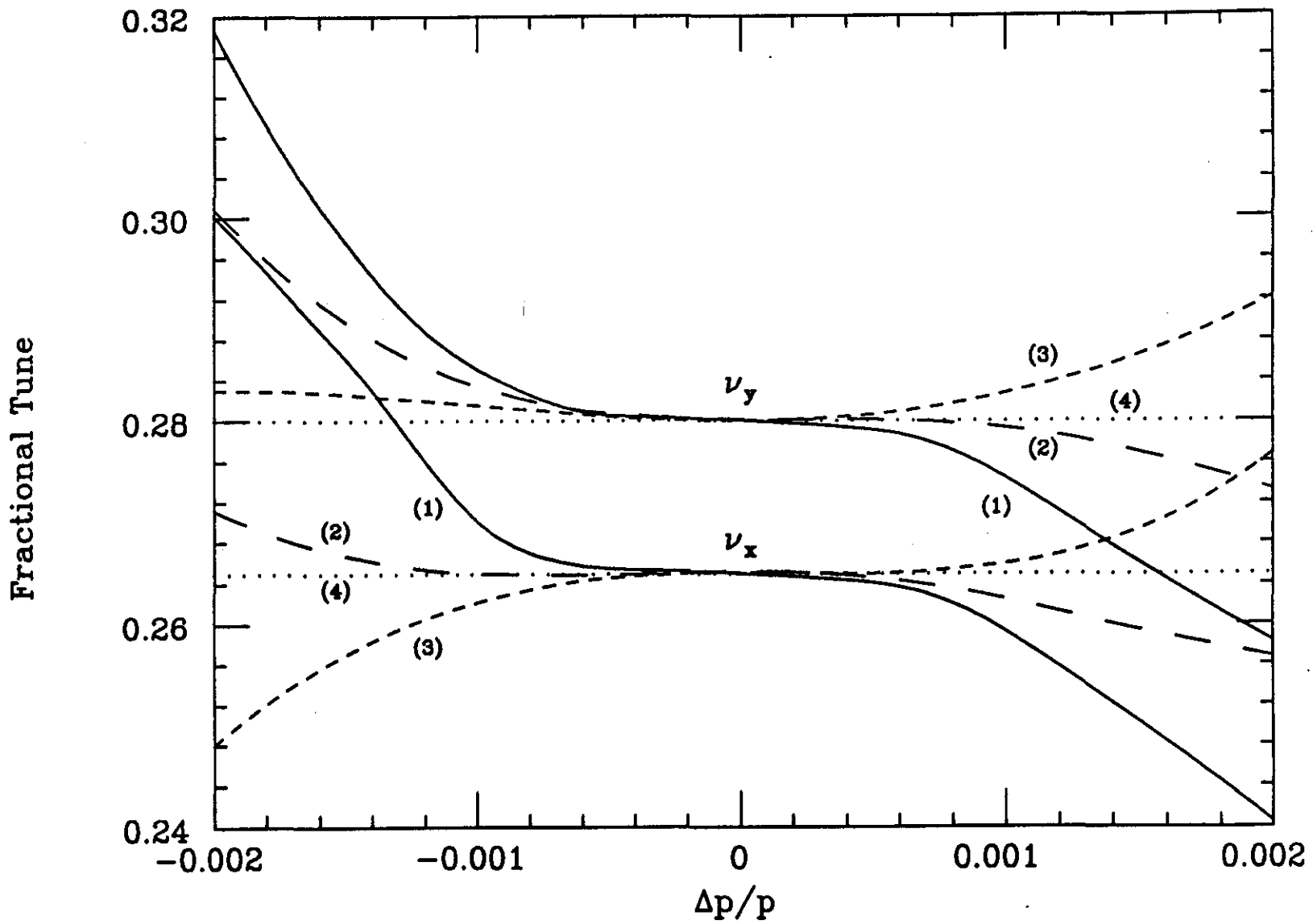
0.32
0.30
0.28
0.26
0.24
Fractional Tune
−0.002
−0.001
0
0.001
0.002
Δp/p
ν_y
ν_x
(1)
(2)
(3)
(4)

Figure 2

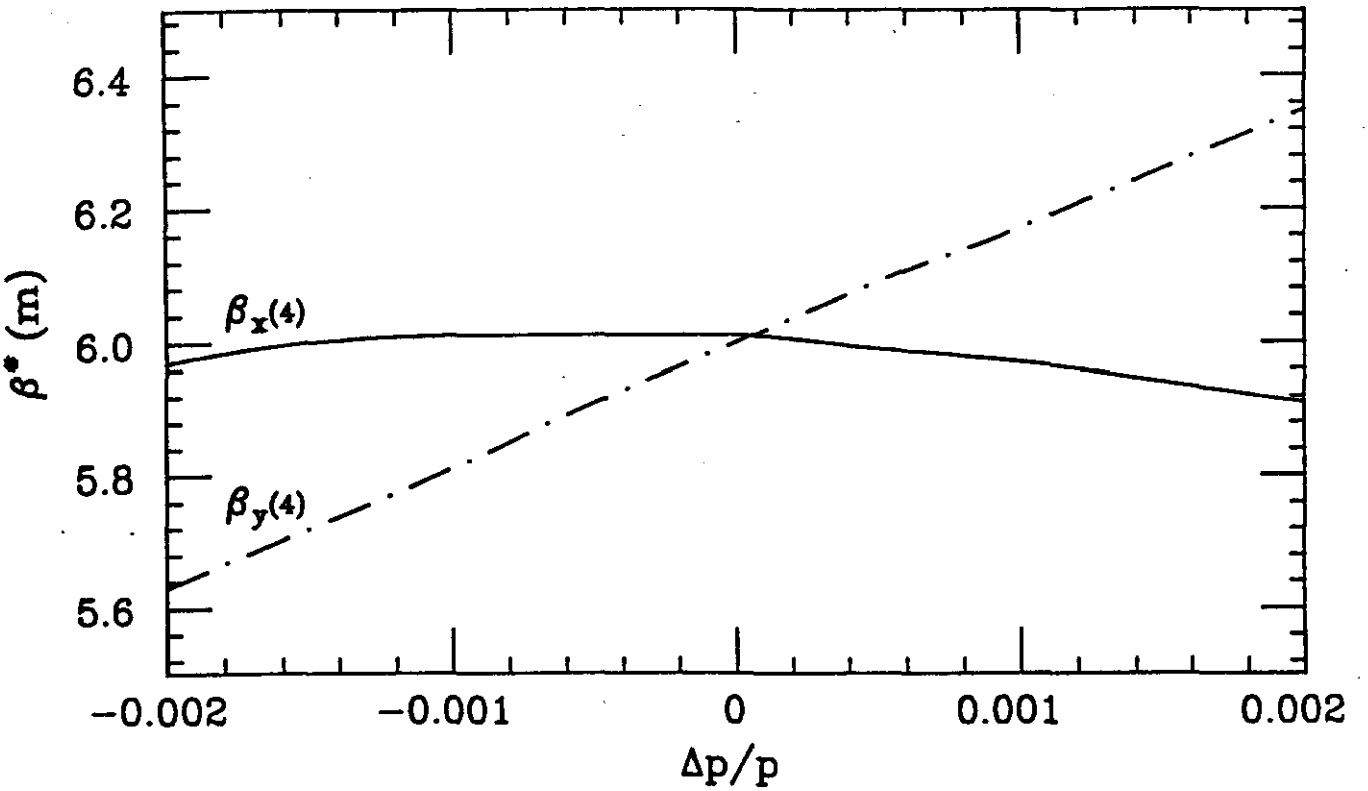

Figure 3a Low−beta IR

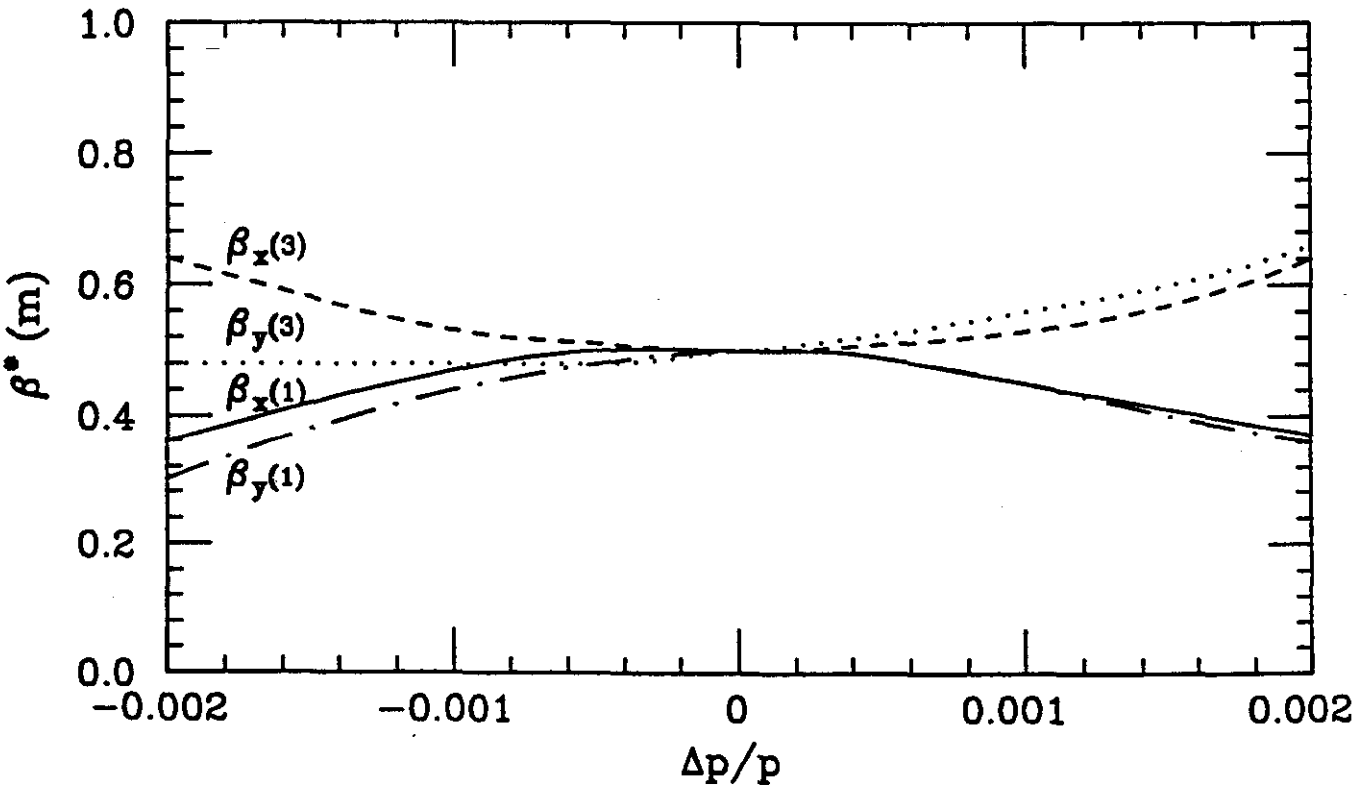

Figure 3b Low−beta IR

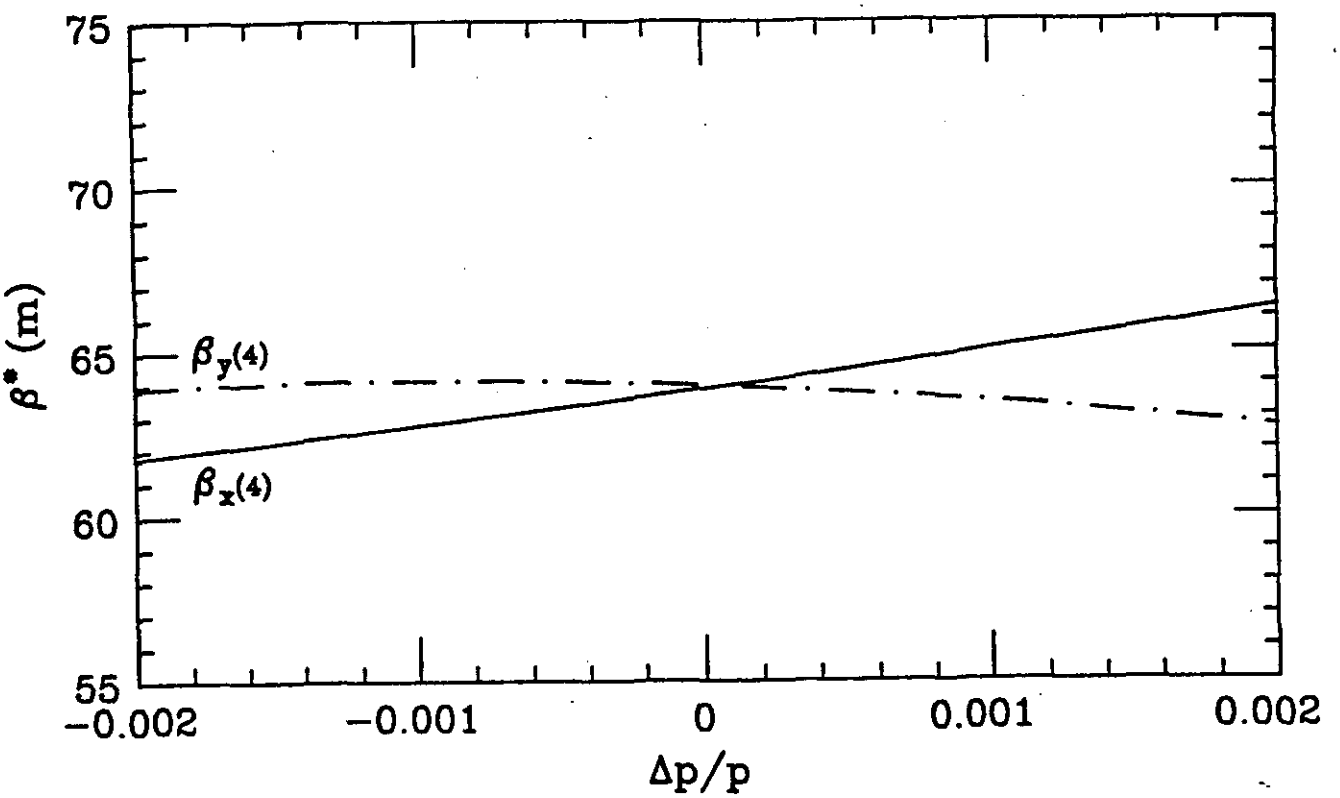

Figure 4a Medium−beta IR

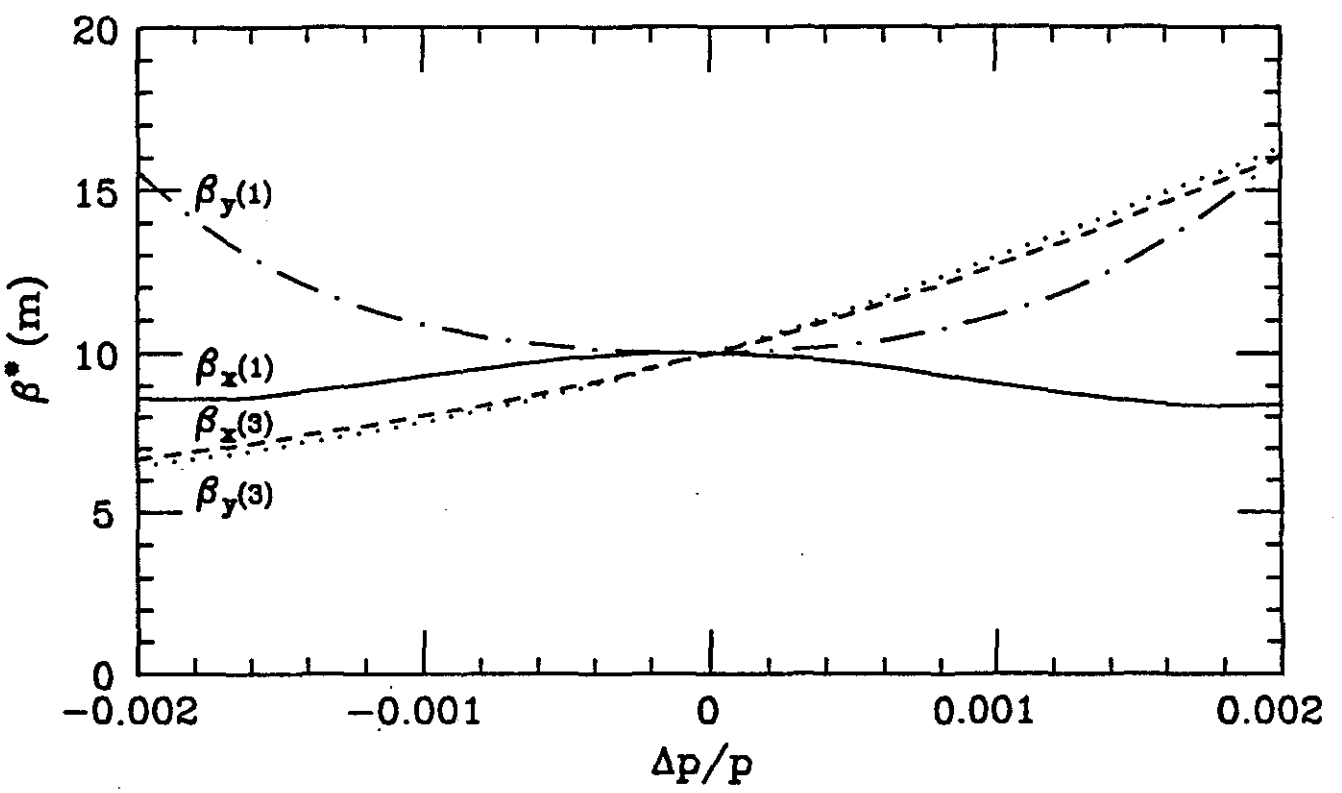

Figure 4b Medium−beta IR