DAΦNE TECHNICAL NOTE

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NUMERICAL STUDIES OF COLLISIONS WITH TWO INTERACTION POINTS IN DAΦNE

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Abstract

Numerical simulations have been carried out in order to find a suitable working point (WP) for beam-beam collisions with two interaction points (IP).

During the *Day-One* phase of the commissioning the first tests with two IPs had been performed, showing 40% of luminosity reduction per IP and lifetime degradation. This pushed us to perform a study aimed to search a working point which could provide a good luminosity and acceptable lifetime while working for two experiments simultaneously. Now, after the KLOE detector installation, with the DEAR experiment ready to take data, the task of finding such a working point is getting more urgent.

Different working points have been investigated using the beam-beam code LIFETRAC[1] and varying the phase advance difference between the two IPs with the aim to obtain decent machine performance in both single IP and two IPs collisions at the same time.

Introduction

An increase of the number of IPs usually leads to a luminosity reduction. In principle different phase advances of betatron oscillations between the two IPs produce a luminosity reduction because of the introduction of new beam-beam low order resonances[2]. But the phase difference between the two IPs can also be adjusted in such a way to destroy otherwise dangerous resonances. So, a scan on the tune advance difference between the two IPs has been performed for each investigated working point in order to optimise the luminosity performance by varying this free parameter.

A good working point for the two IPs collision scheme in DAΦNE must satisfy the following requirements:

- it must provide a good dynamic aperture;
- it must provide a good luminosity and lifetime with a single IP in order to allow the tuning of each IP separately;
- and finally it must provide a good luminosity and lifetime with the two IPs.

The investigated tunes with the weak-strong code LIFETRAC are the following ones:
(5.15; 5.21); (5.16; 5.21); (5.11; 5.21); (5.145; 5.09); (5.10; 5.14); (5.52; 5.59).

The first working point is that which has been used during the *Day-One* commissioning phase, our studies start from here.

The second and the third working points are situated near the present working point and it is not necessary to modify substantially the machine lattice to tune the collider at these points. Moreover, the second one has been experimentally found to be a good point during the commissioning with the *KLOE* optics providing the best lifetime.

The third, fourth and fifth points have been investigated after the satisfactory results of a luminosity scan with the BBC code[3]. These points provide good luminosities and lifetime in single IP collisions.

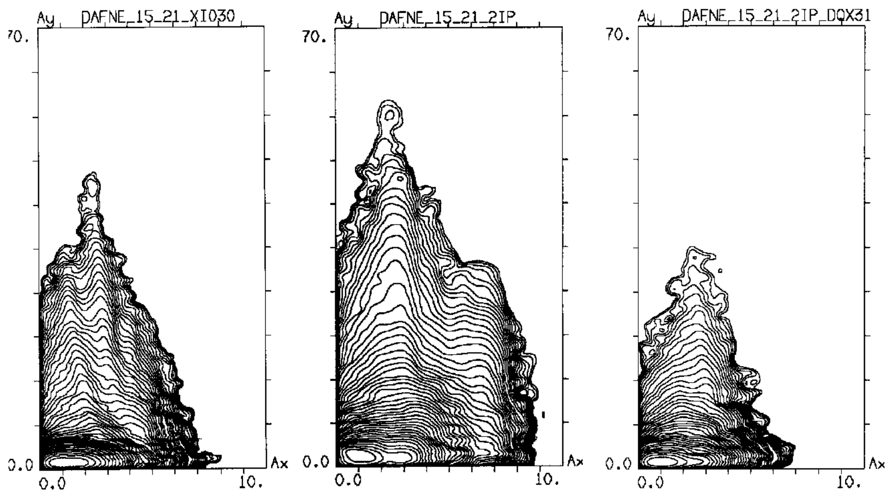
The last point is the one where CESR collider successfully works[4]. This point is also suitable for DAΦNE, since it is one of the few working points where the DAΦNE nominal luminosity of $L = 4.3 \cdot 10^{30} cm^{-2} s^{-1}$ is predicted by the code in single IP collision with a tune shift of $\xi_{x,y} = 0.04$ and with the machine nominal parameters..

For all the simulations a space charge tune shift parameter of $\xi_{x,y} = 0.03$ has been adopted and the DAΦNE nominal beam parameters have been used. We have also assumed no vertical phase advance difference between IPs, as it is for the machine. Only the horizontal phase advance difference is optimised.

In the following we describe in more details the luminosity performance for each of these tunes.

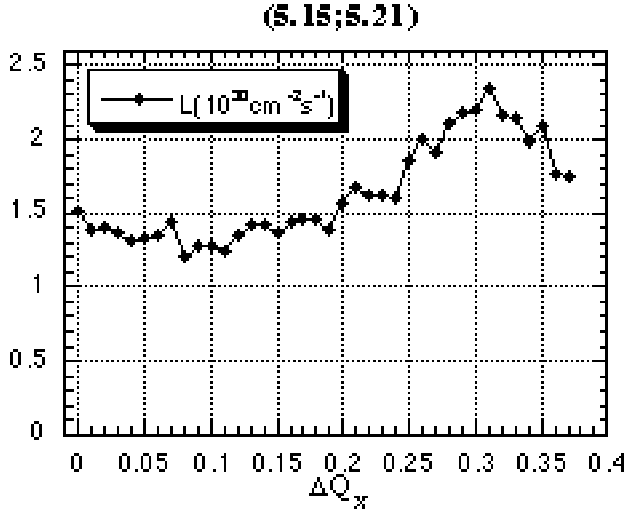
Studies on the WP (5.15; 5.21)

Since the working point (5.15; 5.21) has been adopted as the nominal one for the *Day-One* commissioning it has been fully analysed in the[5] . Here we report the results concerning the beam-beam interaction at the two IPs at this point.



(a) (b) (c)

Figure 1. *Equilibrium density in the space of the normalised betatron amplitudes for the WP (5.15; 5.21) for the following three cases:* (a) *1-IP ;* (b) *2-IPs and a tune advance difference between them of* $\Delta Q_x = .24$ *;* (c) *2-IPs and a tune advance difference of* $\Delta Q_x = .31$.



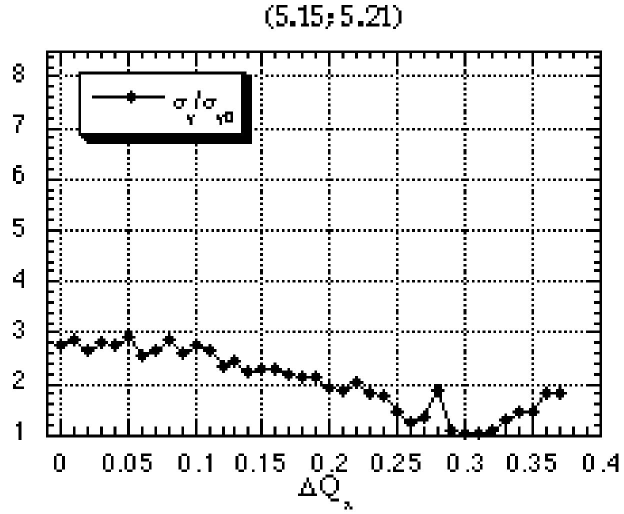


Figure 2. *Luminosity* (above) *and normalised vertical beam size* (below) *as functions of the horizontal tune advance difference for the working point (5.15; 5.21).*

Figure 1 shows the beam equilibrium distributions for the working point (5.15; 5.21) corresponding to the space charge tune shift parameter of $\xi_{x,y} = 0.03$. Figure 1(a) shows the beam distribution for one IP, for which a luminosity of $L = 2.2 \cdot 10^{30} cm^{-2} s^{-1}$ is predicted with normalised horizontal and vertical beam sizes of $\sigma_x / \sigma_{x0} = 1.08$ and $\sigma_y / \sigma_{y0} = 1.04$, respectively. Figure 1(b) and 1(c) show the beam behaviour for two IPs with different tune advance between them: $\Delta Q_x = .24$ corresponds to the *Day-One* experimental situation, while $\Delta Q_x = .31$ corresponds to the maximum predicted luminosity by the code, as it can be seen in Figure 2. In all the three cases the beam tails are within the dynamic aperture, but it can be observed comparing Fig.1(b) and 1(c) that not only the luminosity is higher but also the tails result shorter for the case 1(c), even in comparison with the single IP collision shown in Figure 1(a). At $\Delta Q_x = .24$ it was experimentally found a 40% reduction of the luminosity per single IP. Simulations give a value near to 30-35%.

Figure 2 shows the dependence of the luminosity -per each IP- calculated with the LIFETRAC code as a function of the horizontal tune advance difference. It appears that the maximum luminosity of $L = 2.35 \cdot 10^{30} cm^{-2}s^{-1}$ is to be expected for a tune difference of $\Delta Q_x = .31$. This means that the phase differences may create new beam-beam resonances but they may also destroy some of the old strong ones. As expected from the luminosity values, the vertical size minimum blow-up is reached at $\Delta Q_x = .31$ (see Figure 2).

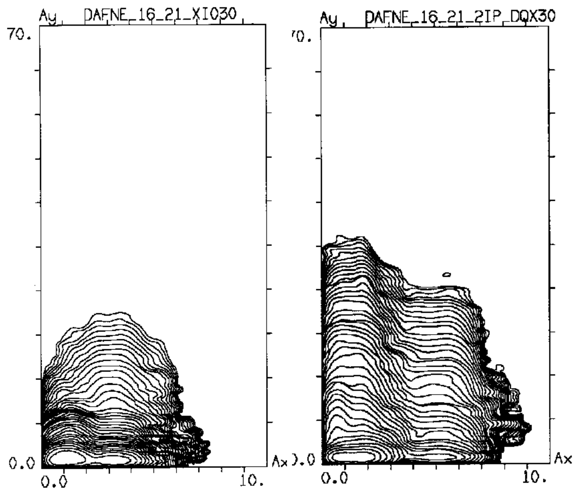
The radial size has not been reported since no noticeable horizontal blow up has been observed at any variations of the parameter ΔQ_x.

Studies on the WP (5.16; 5.21)

During the commissioning of the machine in the *KLOE-IR* configuration it has been noted that the beam lifetime improves working with a higher radial tune with respect to $Q_x = 5.15$, but always near to it. So the point $Q_x = 5.16$ and $Q_y = 5.21$.can be interesting as it shows the beam behavior for an increase of 10^{-2} of Q_x with respect to the starting point.

The beam tails for this working point are shown in Figure 3. In Figure 3(a) the beam distribution corresponds to one IP; Figure 3(b) corresponds instead to two IPs with a tune advance difference of $\Delta Q_x = .30$ between them being the situation with the maximum predicted luminosity, as it appears from the peak in the above plot of Figure 4.

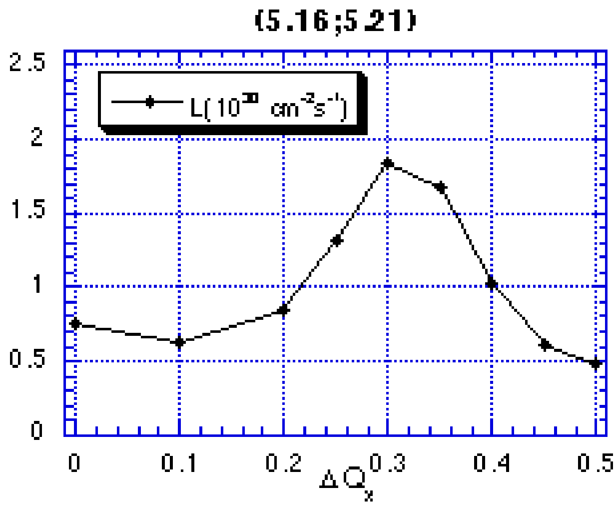
Figure 4 shows in fact a rough scan with steps of 0.10 in the horizontal phase difference. As just discussed there is a peak of the luminosity around $\Delta Q_x = .30$ and respectively a minimum for the beam sizes (Figure 4 below).



(a) (b)

Figure 3. *Beam distribution tails relative to the tunes (5.16; 5.21) (a) for 1-IP and (b) for 2-IPs and a radial tune advance difference between them of* $\Delta Q_x = .30$.

The estimated luminosity for this WP with a single IP is $L = 1.64 \cdot 10^{30} cm^{-2}s^{-1}$ while the maximum luminosity for the two IPs configuration of $L = 1.8 \cdot 10^{30} cm^{-2}s^{-1}$ is predicted for a radial tune difference of $\Delta Q_x = .30$. It must be pointed out that in both cases the core and the tails enlarge horizontally leading to luminosity reduction in comparison to the point (5.15; 5.21) and with 2-IPs the horizontal tails tend to reach the dynamic aperture.



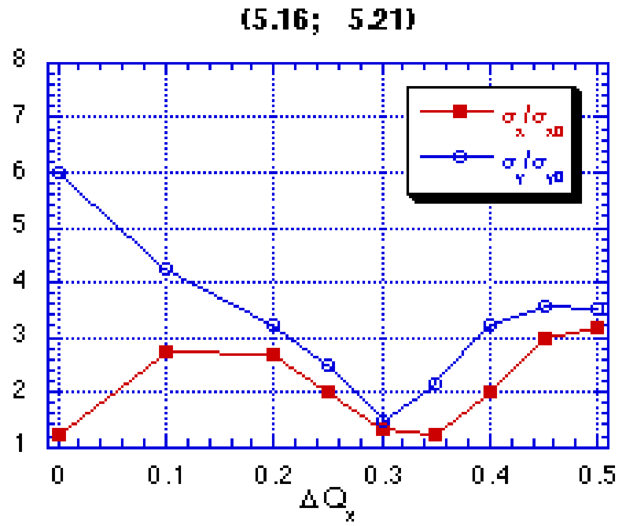


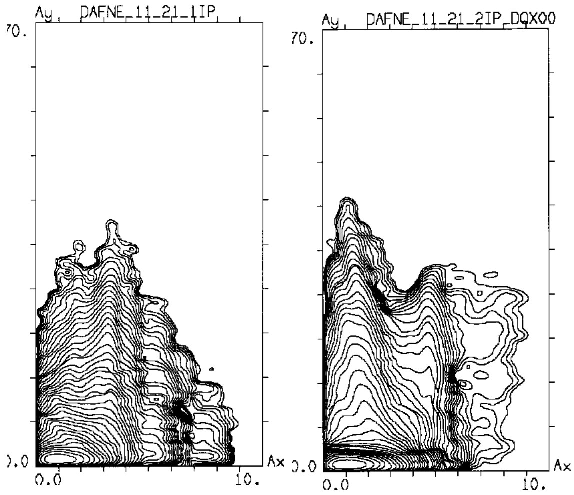
Figure 4. *Luminosity (*above*) and normalised vertical and horizontal beam sizes (*below*) as functions of the horizontal tune advance difference for the point (5.16; 5.21).*

Studies on the WP (5.11; 5.21)

We should note that this working point is close to the sextupole resonance $2Q_x - Q_y = 5$. In fact, while tuning the ring at this point it has been observed a decrease of the dynamic aperture and an increase of coupling with the result that the beam was not stable.

Anyway, from the beam-beam point of view this working point is a good point and it is situated not very far from the actual tune of (5.15; 5.21). LIFETRAC predicts a luminosity of $L = 2.24 \cdot 10^{30} \mathrm{cm}^{-2}\mathrm{s}^{-1}$ in single IP collision for this WP. The corresponding beam tails are shown in Figure 5(a).

For two IPs the maximum luminosity is expected in the symmetric configuration with no tune difference between the two IPs, as it appears from Figure 6. In Figure 5(b) is shown the beam distribution for this symmetric case where the maximum luminosity of $L = 2.47 \cdot 10^{30} \mathrm{cm}^{-2}\mathrm{s}^{-1}$ is reached.



(a) (b)

Figure 5. *Beam tails* (a) *for 1-IP and* (b) *for 2-IPs and no tune advance difference between them.*

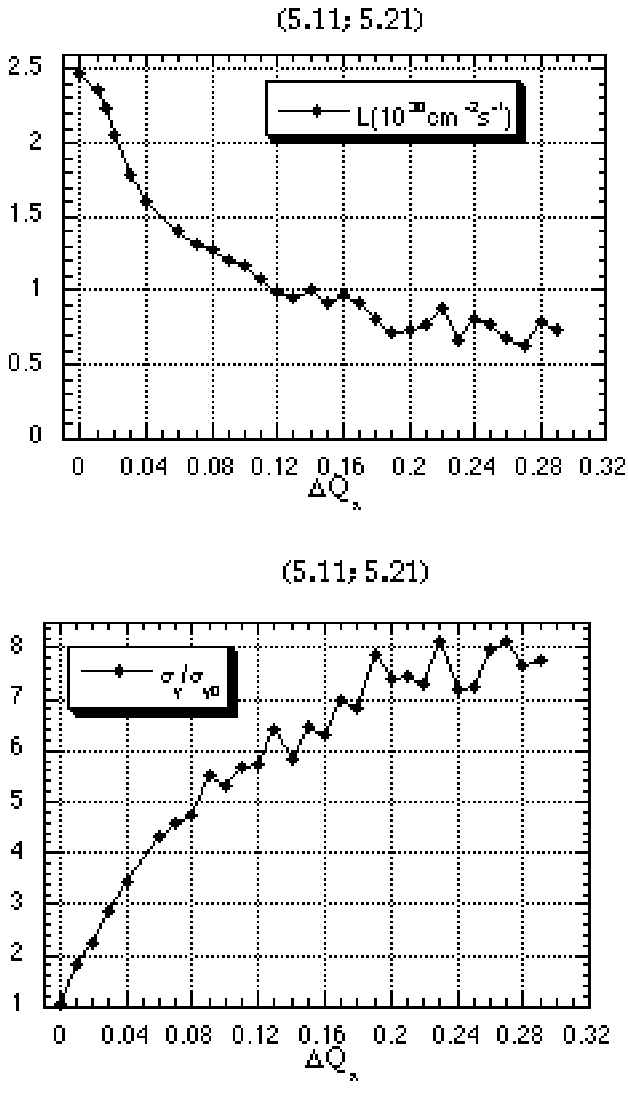
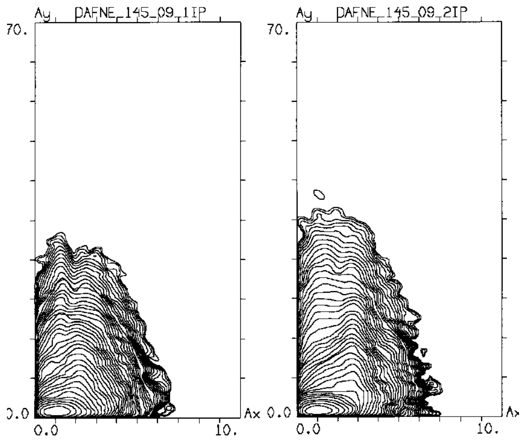


Figure 6. *Luminosity* (above) *and normalised vertical beam size* (below) *as functions of the horizontal tune advance difference for the point (5.11; 5.21).*

Studies on the WP (5.145; 5.09)

This point has been investigated after the indications given by the BBC code [3]. The horizontal tune is very close to the actual one $Q_x = 5.15$, the vertical one is instead lower being closer to the integer. As for the previous points, Figures 7(a) and 7(b) show the beam tails for one IP and for two IPs. In the first case a luminosity of $L = 2.20 \cdot 10^{30}\,cm^{-2}s^{-1}$ is predicted, in the second one of $L = 2.40 \cdot 10^{30}\,cm^{-2}s^{-1}$. The tails are well within the dynamic aperture in both cases.



(a) (b)

Figure 7. *Beam tails for the WP (5.145; 5.09):* (a) *for 1-IP;* (b) *for 2-IPs and no tune advance difference between them.*

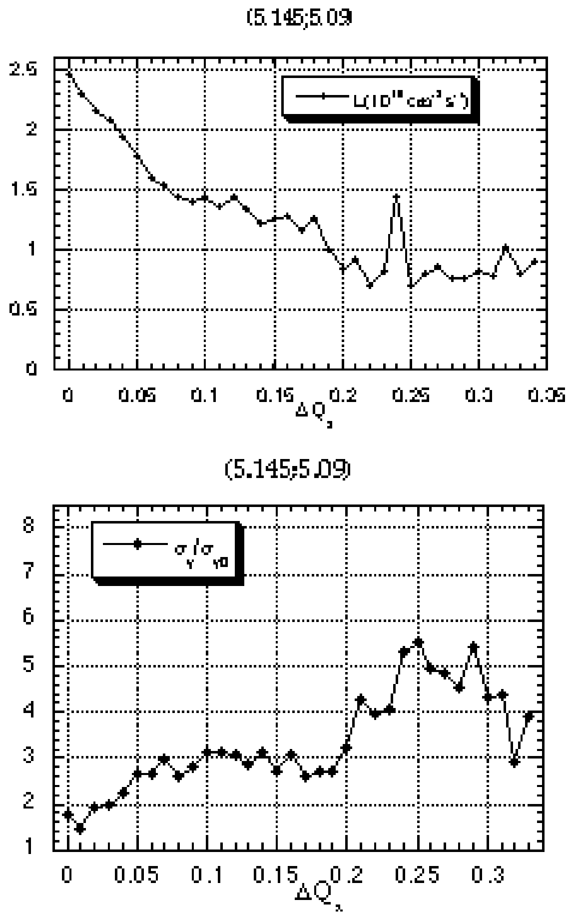


Figure 8. *Luminosity* (above) *and normalised vertical beam size* (below) *as functions of the horizontal tune advance difference for the point (5.145; 5.09).*

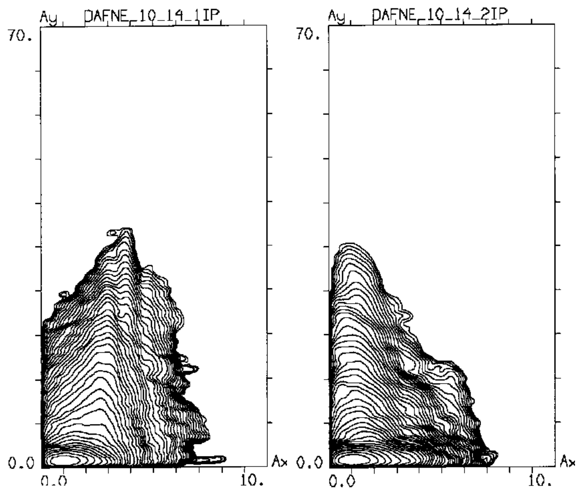
As it appears from Figure 8 the maximum luminosity is obtained when the phase advance difference is equal to zero, just like the previously discussed case of tunes (5.11;5.21), but for $\Delta Q_x = 0.1$ the vertical beam size is smaller.

Studies on the WP (5.10; 5.14)

The working point (5.10; 5.14) could be a good one for DAΦNE.

The beam tails, as Figures 9 (a) and 9(b) show, stay well within the dynamic aperture and the estimated luminosity is as high as for all the other described points: for the 1-IP caseis $L = 2.34 \cdot 10^{30} cm^{-2}s^{-1}$, for the 2-Ps case is equal to $L = 2.43 \cdot 10^{30} cm^{-2}s^{-1}$.

Moreover for these betatron tunes, as we can notice from Figure 10, the luminosity remains almost unchanged around the value of $2 \cdot 10^{30}$ for different tune advances. Anyway the highest value corresponds to the symmetric case with equal phase advances. In Figure 10 we observe that the normalised vertical beam size increases together with the decrease of the luminosity, but the luminosity reduction does not seem to be big even for $\sigma_y / \sigma_{y0} \approx 3.5$.

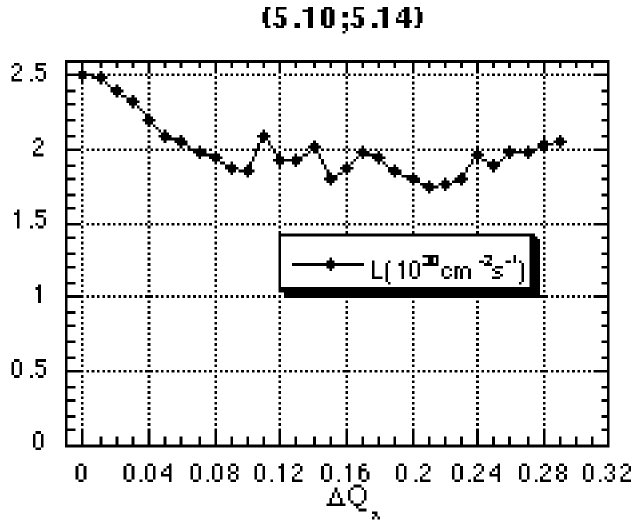


(a) (b)

Figure 9. *Beam tails for (5.10; 5.14):* (a) *for 1-IP and* (b) *for 2-IPs and no tune advance difference between them.*

In this case the simulation with the design tune shift value of $\xi_{x,y} = 0.04$ has been carried out. The expected luminosity results $L = 3.50 \cdot 10^{30} cm^{-2}s^{-1}$ with normalised beams sizes of $\sigma_x / \sigma_{x0} = 1.01$ and $\sigma_y / \sigma_{y0} = 2.07$, that is there is a vertical blow-up but the luminosity value is quite close to the nominal one of $L = 4.3 \cdot 10^{30} cm^{-2}s^{-1}$.

Cubic nonlinearities have been added to the simulations for 1-IP and 2-IPs with the tune shift of $\xi_{x,y} = 0.03$. The lifetime is not reduced even if there is an enlargement of the beam tails. For the 1-IP case simulations give a luminosity value of $L = 2.25 \cdot 10^{30} cm^{-2}s^{-1}$ and beam sizes $\sigma_x / \sigma_{x0} = .99$ and $\sigma_y / \sigma_{y0} = 1.60$. For the 2-IPs case the expected values are: $L = 2.42 \cdot 10^{30} cm^{-2}s^{-1}$ and $\sigma_x / \sigma_{x0} = 0.94; \sigma_y / \sigma_{y0} = 1.18$.



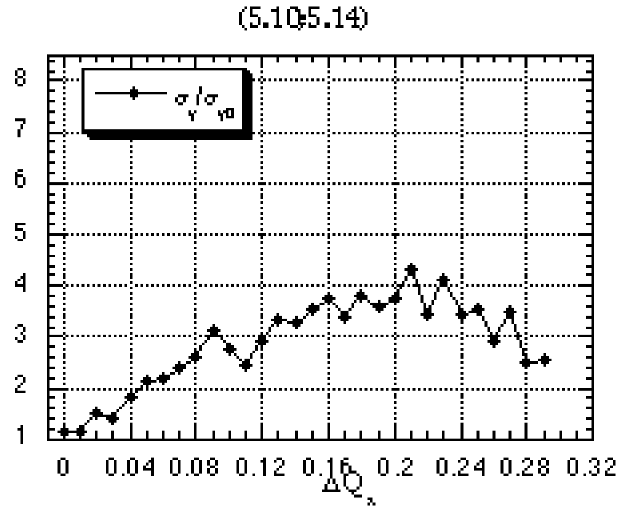


Figure 10. *Luminosity* (above) *and normalised vertical beam size* (below) *as functions of the horizontal tune advance difference for the WP (5.10; 5.14).*

Studies on the WP (5.52; 5.59)

This WP is very close to the half integer, so it would be very desirable to tune the machine at this point, in order to have higher allowable beam-beam tune shifts and luminosity values.

However, since the collider nonlinear behaviour has not been completely studied yet, it is difficult to say apriori whether the working point will fall within a stop band of the half-integer resonance. Nevertheless beam-beam simulations for these tunes may result useful in future, when the machine nonlinearities are studied and possibly corrected, for example, by sextupole adjustment.

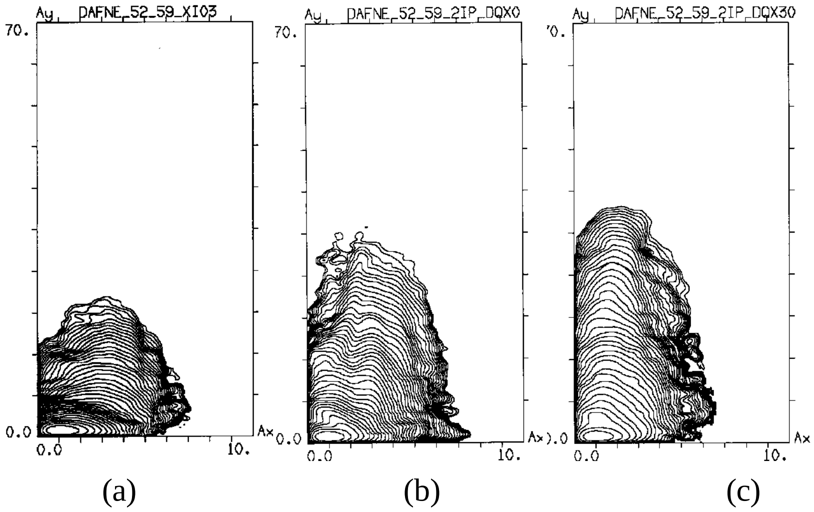


Figure 11. *Beam tails for the WP (5.52; 5.59):* (a) *for 1-IP;* (b) *for 2-IPs and no tune advance difference between them and* (c) *for a radial tune difference of* $\Delta Q_X = 0.30$.

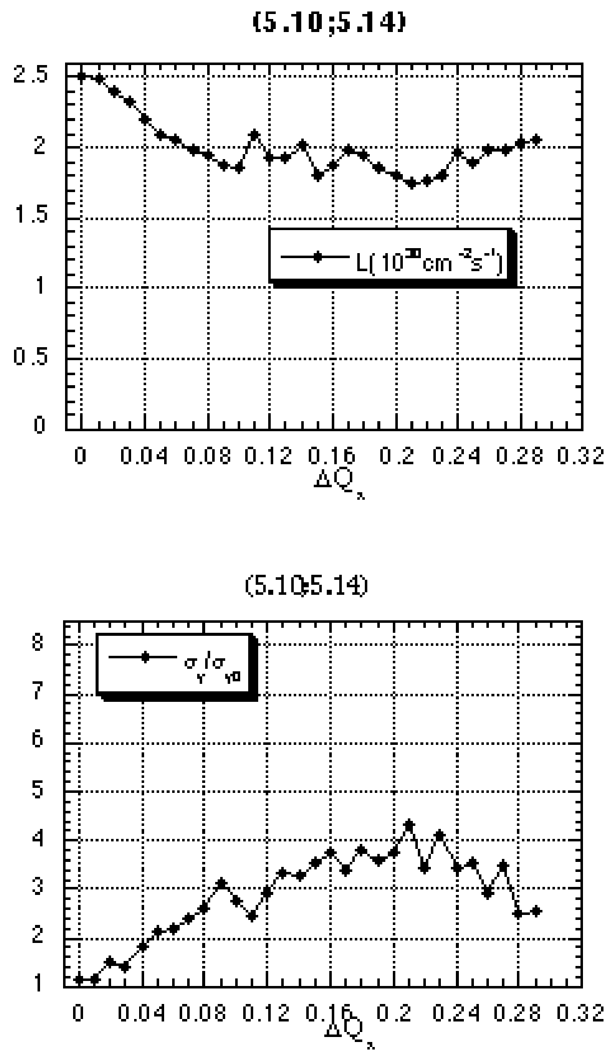


Figure 12. *Luminosity* (above) *and normalised vertical and horizontal beam sizes* (below) *as functions of the horizontal tune advance difference for the WP (5.52; 5.59).*

Figure 11 shows the beam distribution tails in the three following cases: (a) single IP; (b) two symmetric IPs and (c) a tune advance difference between the two IPs of $\Delta Q_x = 0.30$. The beam tails do not enlarge much and the beam appears quite stable in all the three cases. For the 1-IP case the expected luminosity is of $L = 2.5 \cdot 10^{30} cm^{-2}s^{-1}$; for the symmetric case is of $L = 1.9 \cdot 10^{30} cm^{-2}s^{-1}$ and for a tune difference between the two IPs of $\Delta Q_x = 0.30$ the very similar value of $L = 1.84 \cdot 10^{30} cm^{-2}s^{-1}$ is predicted.

Figure 12 shows in fact that moving the phase advance between the two IPs from $\Delta Q_x = 0$ to $\Delta Q_x \approx 0.3$ the luminosity values do not vary much from values slightly below $2 \cdot 10^{30}$.

The case of a single IP has been simulated also with the nominal tune shift parameter and the given luminosity is just the nominal value $L = 4.3 \cdot 10^{30} cm^{-2}s^{-1}$.

Conclusions

Table 1 summarises the results of the present study. For the considered working points the estimated luminosity for one IP and for two IPs collisions is given (second and third columns, respectively). In the case of 2-IPs it is also shown the horizontal phase advance between the IPs where the maximum luminosity is achieved. The normalised beam size blow up due to the beam-beam interaction is reported in the vertical and horizontal plane for the 2-IPs case (fourth and fifth columns respectively).

Table 1. *Predicted values of luminosity with one IP and two IPs, for the best ΔQ_x between them, and normalised beam sizes for each working point.*

WP	L_{2IP} $(10^{30} cm^{-2}s^{-1})$	L_{1IP} $(10^{30} cm^{-2}s^{-1})$	σ_y / σ_{y0} (2IP)	σ_x / σ_{x0} (2IP)
(5.15;5.21) $\Delta Q_x = 0.31$	2.24	2.20	1.05	1.12
(5.16; 5.21) $\Delta Q_x = 0.3$	1.80	1.64	1.49	1.33
(5.11; 5.21) $\Delta Q_x = 0$	2.47	2.24	1.03	0.94
(5.145; 5.09) $\Delta Q_x = 0.01$	2.37	2.20	1.44	1.00
(5.10; 5.14) $\Delta Q_x = 0$	2.43	2.34	1.14	0.94
(5.52; 5.59) $\Delta Q_x = 0$	1.90	2.50	1.71	1.03

In our opinion:

1) The best point for the two IPs is (5.15; 5.21) since it has high luminosity and short tails (even shorter than in the case of a single IP). Besides, $\Delta Q_x = 0.31$ between the IPs is not far from the actual one of $\Delta Q_x = .24$. So it will not require major lattice modifications.
2) The working point (5.16; 5.21) provides lower luminosities but, even more important, long horizontal tails reaching the machine dynamic aperture in case of two IPs can be observed. For this reason we expect short lifetime for this point.
3) (5.11; 5.21) seems to give good luminosity in both 1IP and 2-IPs collisions. However, the point is close to the resonance $2Q_x - Q_y = 5$ which limits the dynamic aperture and makes more difficult the coupling correction.
4) (5.145; 5.09) is the point which is worth to try: the luminosity is good and the tails are well within the dynamic apertures. The only disadvantage is that the maximum luminosity is reached with the phase advance difference close to zero and some lattice modifications are necessary to fulfill this condition.
5) The same conclusion as in 4) can be applied to the point (5.10; 5.14).
6) The point (5.52; 5.59) is good for single IP collisions. Moreover, this is one of the few points on the tunes diagram where the design luminosity of $L = 4.3 \cdot 10^{30} cm^{-2} s^{-1}$ is achieved with the beam-beam code. However, for the optimal ΔQ_x in this case a 70% vertical size blow up is observed in the code output when colliding with two IPs. We have also to underline that being close to the half-integer the point can be a challenge for the machine optics.

References

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