Crab cavity IR optics design with $\theta = 8$mrad *

R. Tomás, R. de Maria, F. Zimmermann, CERN, Geneva, Switzerland;
R. Calaga, BNL, Upton, NY 11973, USA

Abstract

Crab cavities have a large transverse radius that makes their allocation in the IR a complicated task. This paper describes an IR optics design with enough separation between the two beams to fit these cavities. To make this possible a crossing angle of 8mrad at the IP is used.

INTRODUCTION

The use of crab cavities in the LHC upgrade was first proposed in [?]. Since then two have been the most relevant concerns of using crab cavities: space and phase noise of the RF fields. The space problem is due to the fact that crab cavities operating at 400MHz have a large radius and also, when large voltages are required, long free straight sections are needed for these cavities. In view of this limitation two scenarios are considered:

1st Large crossing angle, enough to fit the cavities in the IR.

2nd Small crossing angle with crab cavities placed somewhere else in the ring and hence leaving an uncorrected crabbed orbit around the accelerator.

This paper focuses on the 1st scenario.

LUMINOSITY SCOPE

Fig **??** shows the achievable luminosity as function of the beta at the IP. The red curve corresponds to the nominal crossing scheme, which foresees an increase of the crossing angle as the beta* decreases. The green curve corresponds to the ideal case of a zero crossing angle, and the blue curve shows the luminosity of the crab cavity option with 400MHz and $\theta = 8$mrad. This curve is lower than the zero crossing angle because part of the bunch experiences the non-linear deflection of the crab cavity. The luminosity ratio is shown in Fig **??** for different cases.

IR OPTICS & LAYOUT

Fig. **??** shows the optics and layout of the crab cavity option ($\beta^* = 0.25$m and $\beta_{peak} \approx 9.5$km). Note that an extra dipole and two quadrupoles have been added at either side of the IP to be able to produce the 8mrad crossing angle scheme shown in Fig. **??**. The large separation of the two beams is mandatory to fit the 0.53m radius crab cavities. The free straight sections at about 100m from the IPs are dedicated for the crab cavities. The available longitudinal space is approximately 25m per ring and per IR side. The precise allocation of the crab cavities is shown in Fig **??**.

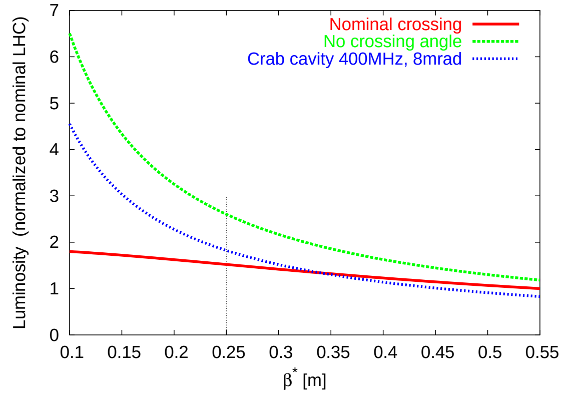

Figure 1: Luminosity scope of the crab cavity option.

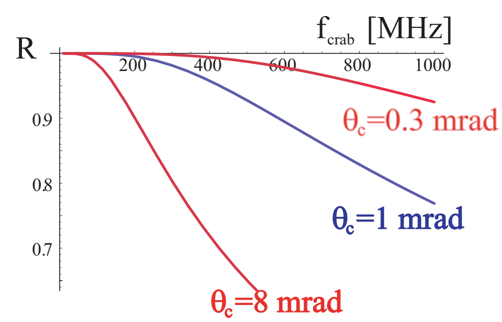

Figure 2: Luminosity ratio between ideal head on collisions and collisions using crab cavities versus frequency and for various crossing angles.

The requirements of the magnets in the IR are shown in Table **??**. Of all the magnets QX2 has the maximum required aperture with a value of 63mm. The gradient in all triplet quadrupoles is 200T/m. Therefore existing technology (NbTi) is enough to manufacture these magnets. There exists only a minor difficulty in the construction of these magnets, which is the fact that the two QX1 flare with the 8mrad angle, Fig. **??**.

The maximum magnetic field in the dipoles is 8.6T which is as well within the limits of NbTi.

The optics model in MADX format can be downloaded from the web [?] as described in [?].

CHROMATICITY

The natural chromaticities of this option are (Q'_x, Q'_y)=(-208.2, -203.3). We can compare these values to those of the nominal LHC (Q'_x, Q'_y)=(-136.0, -131.5). The lattice sex-

* This work was partly performed under the auspices of the US Department of Energy

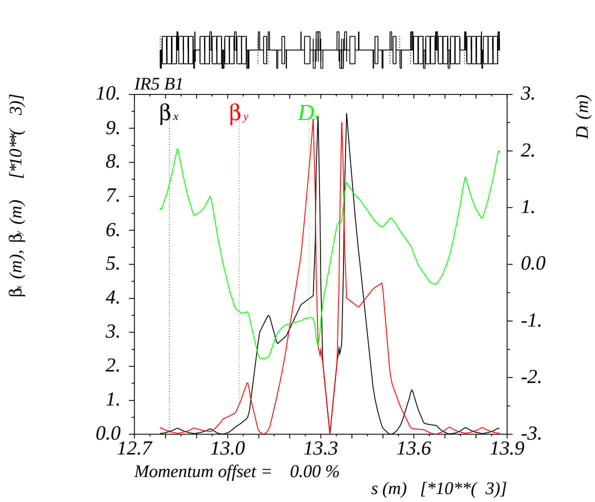

Figure 3: Optics and layout of the crab cavity option.

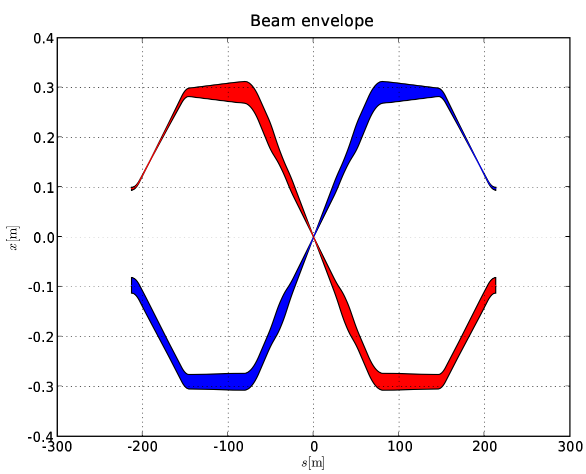

Figure 4: Beam envelope showing the IR crossing scheme.

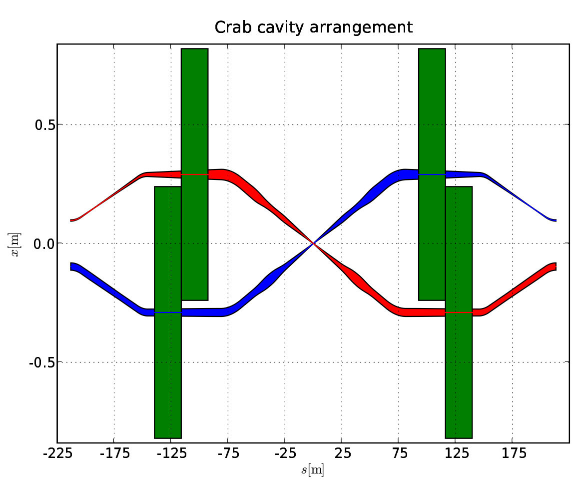

Figure 5: Crab cavity allocation in the IR.

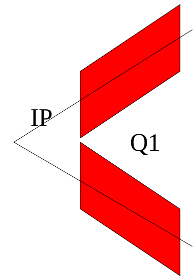

Figure 6: Illustrating sketch of the first triplet quadrupole, QX1.

Magnet	Aperture	Gradient/Field	Length [m]
QX1	46 mm	200 T/m	6.3
QX2	63 mm	200 T/m	5.5
QX3	63 mm	200 T/m	5.5
BXA	59 mm	5.3 T	17.6
BXB	39 mm	8.6 T	9.0
BXC	42 mm	8.2 T	9.45

Table 1: Description of the different magnets in the IR.

tupoles are used to correct the extra 70 units of chromaticity and also to minimize the second order chromaticity. Fig **??** shows the tunes versus relative momentum deviation after correction of 1st and 2nd order chromatics. The required maximum strength of the lattice sextupoles was about 70% of the available strength. This leaves a reasonable margin for operation. However the large third order chromaticity that remains uncorrected could limit the energy acceptance and make machine operation difficult.

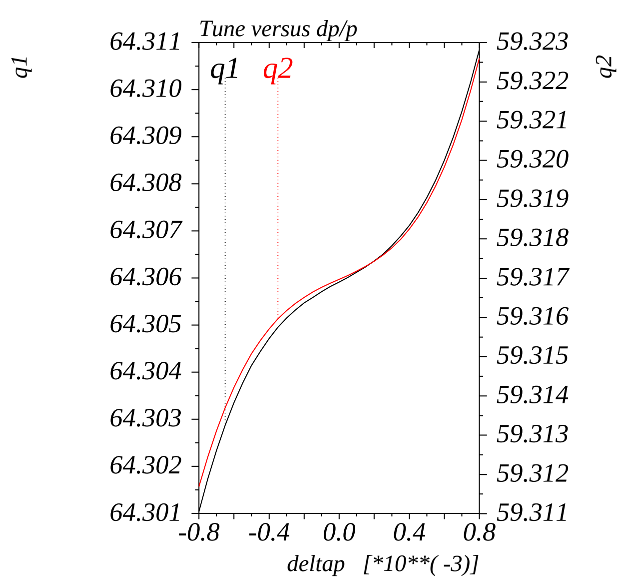

Figure 7: Tune versus relative momuntum deviation.

Case	Dip err	Quad err	Both	Both/10
Crab cavity	1.5	7.0	1.5	12.5
T. Sen Quad first			4.5	14.0

Table 2: Dynamic aperture of different magnetic error configurations and cases.

PARTICLE STABILITY

The large betas at the triplet make particle stability a serious concern for almost all the LHC IR upgrade options. We have computed the dynamic aperture for a collection of error configurations and for both the crab cavity case and another quadrupole first option. The magnetic errors are taken equal to the measured errors of the LHC magnets. We choose to compute the dynamic aperture for errors either in the dipole or the quadrupole, for errors in both magnet types and for the latter with a factor of 10 reduction in all multipolar errors. The results are shown in Table **??**. It is obvious that the large dipoles used in this option dominate the dynamic aperture, which is too small to be acceptable. However if errors are reduced by a factor of 10 a reasonable value for the dynamic aperture is obtained. This is the case also for another quadrupole first option with identical β^* and L^*, for which the 4.5 sigmas of dynamic aperture are too few and a factor about 10 in the reduction of the multipolar errors is required as well. The dynamic aperture problem is even more severe for other IR options [**?**, **?**]

It is therefore necessary to develop means to improve the magnetic quality of the IR magnets and/or to find efficient correction schemes using dedicated multipole coils for the LHC IR upgrade.

CONCLUSION

An IR design with 8mrad crossing that allocates enough space for crab cavities has been presented. The luminosity is increased by a factor of 2 (with respect to the nominal LHC) only from optics considerations. This option has the advantage of having a negligible long-range beam-beam effect. However it also has the disadvantage of strongly relying on the well functioning of the crab cavities. For example, the luminosity of this crossing scheme goes down by a factor of 25 if crab cavities are not used.

ACKNOWLEDGMENTS

We thank R. Gupta, T. Hayes, T. Risselada, T. Sen and J. Tuckmantel for fruitful discussions.

REFERENCES

[1] F. Zimmermann and U. Dorda, “Progress of beam-beam compensation schemes” Proceedings of LHC-LUMI-05.

[2] http://care-hhh.web.cern.ch/care-hhh/SuperLHC_IRoptics/IRoptics.html

[3] R. Tomás, R. de Maria, F. Ruggiero and F. Zimmermann, “LHC upgrade IR optics web repository” these proceedings.

[4] O. Bruning et al, “Low-gradient triplet magnets” these proceedings.

[5] R. de Maria et al, “Dipole fi rst with chromaticity issues” these proceedings.