Early Separation Scheme for the LHC upgrade

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Abstract

In this work the current status of the Early Separation Scheme are reported, giving details on the performance of the scheme and the technological requirements.

INTRODUCTION

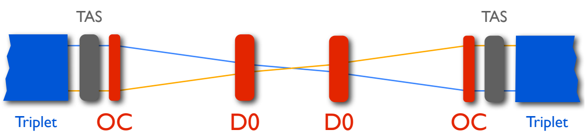

Figure 1: The Early Separation Scheme

The Early Separation Scheme (ESS, Fig. 1, [1]) is a possible player in the Phase II Luminosity Upgrade Scenario. It consists of two dipoles per each side of each experiment: the D0 (close to the IP) and the OC (between the D0 and the triplet). There are several roads for the upgrade [2]: all are a different combination of the same elements

- more beam current
- lower β^*
- reduction of the full crossing angle (θ_c) at the IP

The reduction of the θ_c for boosting the luminosity enters in competition with the beam-beam (BB) effect: the ESS, the Crab Cavities and Wire Compensation are the three hardware proposals to solve this issue.

The ESS aims to reduce the θ_c by means of a local bump correction (Fig. 2) decoupling the crossing angle at the IP to the beam separation in the triplet. In addition, a possible dynamic change of θ_c (luminosity leveling) can be taken into account for reducing the multiplicity in the detector and the cryogenics' heat load, optimizing the overall integrated luminosity performance.

Two important parameters are used to describe the ESS: the inner beam separation (IS) and the outer beam separation (OS):

- the IS is the beam separation expressed in σ between the IP an the D0: it is proportional to the θ_c
- the OS is the average beam separation expressed in σ after the OC: it is proportional to the angle between the beams just after the OC.

The ESS has to come together a stronger focusing at the IP and this introduces an interplay between the hourglass

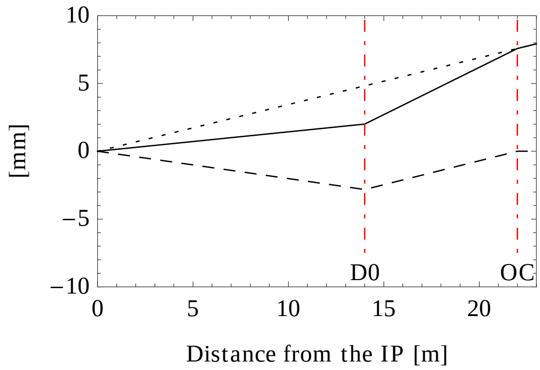

Figure 2: The closed orbit (solid line) of the beam on the right side of the IP as sum of the two bumps: the internal bump (dashed line) and the external bump (dotted line). We are assuming an internal separation of 5 σ and an external separation of 12 σ with a $\beta^* = 15$ cm.

factor (F_{HG}) and the geometrical factor (F_G). The overall loss factor due to both contributions (F_{HG+G}) is given by the following integral

$$\int_{-\infty}^{\infty} \frac{e^{-\frac{1}{2}z^2\left(\frac{\cos(\theta_c)+1}{\sigma_z^2} - \frac{(\cos(\theta_c)-1)\beta^*}{\epsilon(z^2+\beta^{*2})}\right)} (\sec(\theta_c)+1)\,\beta^{*2}}{2\sqrt{\pi}\sigma_z\,(z^2+\beta^{*2})}\, dz \quad (1)$$

where z is the longitudinal coordinate in the machine reference frame, θ_c is the full crossing angle, ϵ the natural beam emittance and the other symbols have their usual meaning. By numerical integration of the Eq. 1 it is possible

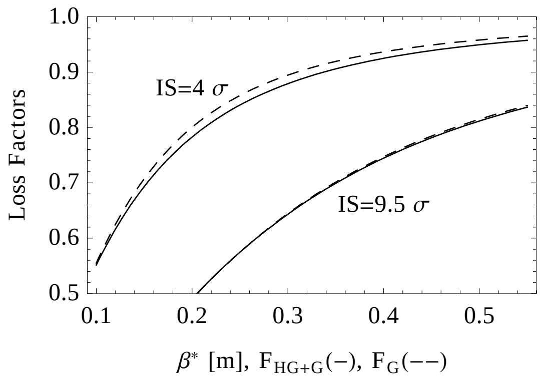

Figure 3: Comparison, considering σ_z and ϵ_n of the nominal LHC, between the F_G (dashed line) and the F_{HG+G} (full line): the inner separation of 4 σ and 9.5 σ are shown.

to observe that, considering σ_z and ϵ_n of the nominal LHC beam, the $F_{HG+G} \approx F_G$ for an IS bigger than 4 σ (Fig. 3). This is due to a partial compensation between the hourglass effect and geometrical effect: due to the bigger transversal σ in the luminous region tails, the crossing angle will have a reduced impact.

The lower reachable β^* is given by the available magnet technology and, for the chromaticity point of view, by the correction strength of the LHC arc sextupoles. The minimum β^* considered in the following is 15 cm: this is within the possibilities of Nb_3Sn triplet considering an aperture of 150 mm, a gradient of $170\ \frac{\mathrm{T}}{\mathrm{m}}$, a distance from the IP of 23 m, first and second order chromaticity corrected [3].

PERFORMANCE SCENARIOS

In Fig. 4 we show the losses due to the the geometrical and hourglass factor as a function of the internal separation of the two beams.

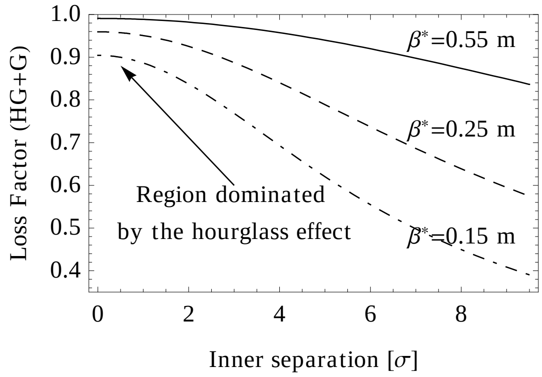

Figure 4: Loss factor (geometrical effect and hourglass effect) as function of the inner separation between the beams.

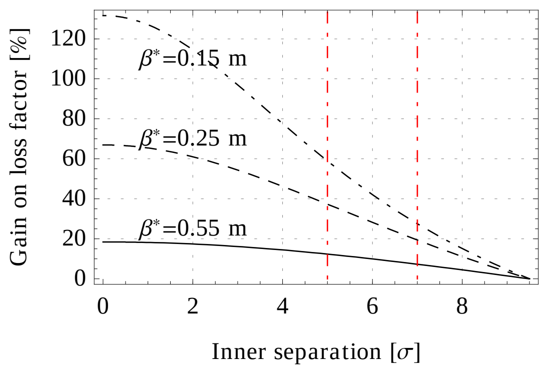

Figure 5: Relative gain on the overall loss factor (geometrical effect and hourglass effect) as function of the inner separation between the beams.

In Fig. 5 the relative gain on the loss factor is presented: the gain is referred to the situation with an IS of 9.5 σ. This means that, with a $\beta^* = 15$ cm we have a gain of 30% with an IS of 7 σ and 60% with an IS of 5 σ.

INTEGRATED FIELD REQUESTED

The integrated field requested for the D0 and the OC depends on several variables:

- the D0 position
- the OC position
- the β^*
- the inner and outer beams separation

Assuming $\beta^* = 15$ cm, an IS of $5\ \sigma$ and an OS of $12\ \sigma$ we need about 13 Tm for a dipole at 14 m from the IP (2 m length, starting at 13 m from the IP) and we need 8 Tm for the OC (Fig. 6).

A possible hardware solution with a D0 at 7 m is already proposed [4]. Given the detector constraints and the energy deposition issues, a 30 cm aperture magnet is considered. In that condition the performance is limited by the stress on the coil: Nb-Ti coils at 1.9 K can deliver the required 7 Tm in a 2 m long cryostat starting at 6.8 m from the IP. The power deposition peak is manageable even without shielding blocks. The total heat load of 74 W is a small fraction of that of a single triplet.

A D0 positioned at 14 m would be much less invasive for the detectors, but will require a higher magnetic field (Fig. 6) and it increases the number of parasitic encounters.

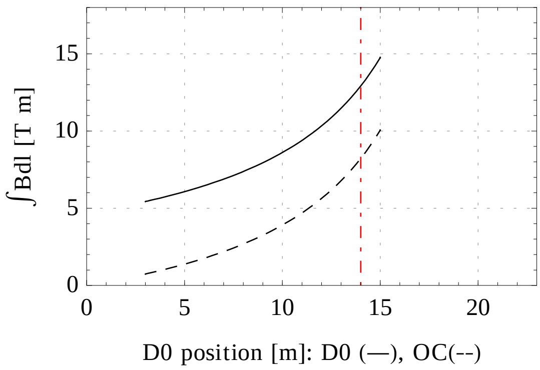

Figure 6: Assuming OC at 22 m, $\beta^* = 0.15$ m, IS $= 5\ \sigma$ and OS $= 12\ \sigma$.

THE IMPACT ON BEAM-BEAM EFFECT

The beam-beam effect is a key aspect for ESS. With a D0 at 14 m, $3-4$ encounters will be at reduced separation. With an IS of $7\ \sigma$ (Fig. 7) the BB separation pattern does not change from the nominal one: we move the $7\ \sigma$ encounters that are in the triplets in the nominal scheme near the IP (since the phase advance on each side of the IP is negligible the different order of the parasitic encounters does not play any role). The cost to pay is an increase of $3\ \sigma$ in the triplet aperture.

All plots are done using the nominal IR optics layout: changing the triplet length or the D1 position will have an impact on the number of parasitic encounters.

Reducing the IS to $5\ \sigma$ the BB separation pattern gets worser than the nominal (Fig. 8). The results of the BB experiment in SPS during the 2008 show that few encounters at reduced distance have an important effect on the beam

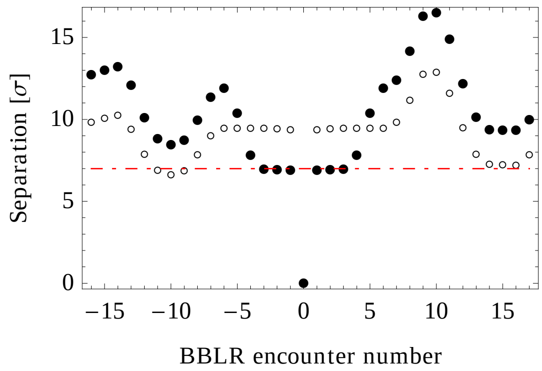

Figure 7: Assuming an IS of 7 σ and an OS of 12 σ. New separation (●), nominal separation (○) for comparison.

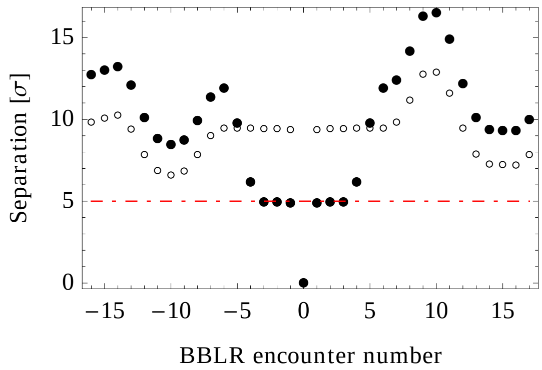

Figure 8: Assuming an IS of 5 σ and an OS of 12 σ. New separation (●), nominal separation (○) for comparison.

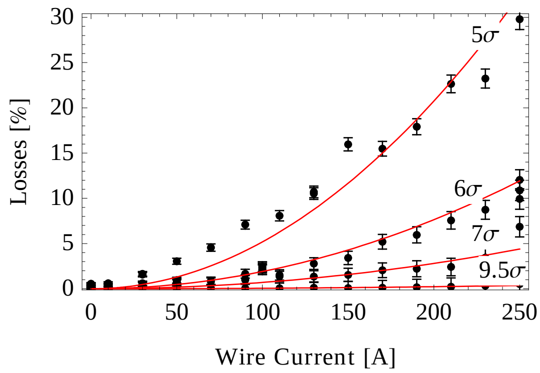

Figure 9: Experimental results in SPS: current wire scan at different separation beam-wire.

lifetime; moreover we have observed that the losses depend strongly on the working tunes.

A part the BB separation pattern, the BB interaction depends on the beam current: in the LHC Phase II Upgrade all scenarios go beyond the nominal bunch current ($N_b = 1.15\ 10^{11}$) and even beyond the LHC ultimate current ($N_b = 1.7\ 10^{11}$). The luminosity leveling can be beneficial even in that respect (Figg. 10-11): since the IS is reduced during the run, the minimum crossing angle is reached only when the beam current is decreased. The luminosity leveling will allow even to go beyond the ultimate

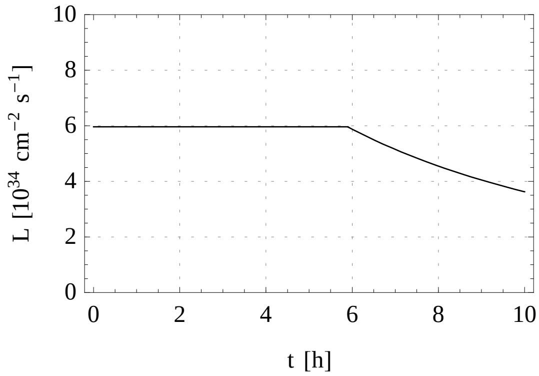

Figure 10: Luminosity leveling considering $\beta^* = 0.15$ m, $\mathrm{N} = 2.5\ 10^{11}$, $\mathrm{n_b} = 2808$, leveling from 12 to 5 σ (the maximum total HO tune shift is $7\ 10^{-3}$).

bunch current without overcoming the head-on tune shift limit (but keeping in mind that, at the moment, the maximum N_b reached in SPS for LHC beam time structure is $\approx 1.2\ 10^{11}$ ppb).

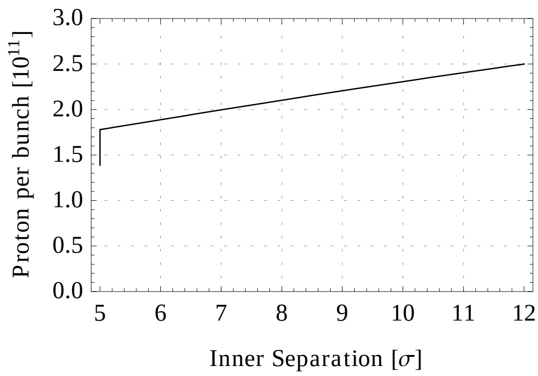

Figure 11: Beam current as function of the IS during the luminosity leveling showed in Fig. 10.

CONCLUSION

Positioning the D0 at 14 m has a significant impact on the required integrated field (13 Tm D0 + 8 Tm OC) and the energy heat load (to be investigated) can be a major problem. A D0 with 7 σ separation at $\beta = 0.15$ m provides a gain of 30% on the F factor with an impact similar to the nominal LHC scheme but with the need of 12 σ separation in the triplet. The 5 σ solution can present seriuos problems from the beam lifetime (SPS results are not encouraging but the luminosity leveling can be beneficial even for the beam-beam effect): other experiments in SPS at higher energy (to have a better beam lifetime) will be proposed in 2009.

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