NEW RESULTS ON THE EARLY SEPARATION SCHEME

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Abstract

A new strategy of luminosity leveling using the early separation scheme is proposed. It increases rather than decreases the integrated luminosity to levels above those presently predicted for the LHC luminosity upgrade. The multiplicity is kept under control at about 100.

INTRODUCTION

The principle of the early separation scheme is to decouple the crossing angle at the IP from the required beam separation in the common part by means of small dipoles included deep inside the detectors (figure 1) [1]. To avoid an intrusion in the inner detector, this ideal scheme may only be considered for 50 ns bunch spacing. For the nominal spacing of 25 ns, a residual crossing angle must be maintained to weaken the few long range interactions occurring just before and after the separator dipoles (D0). A detailed description can be found in [1].
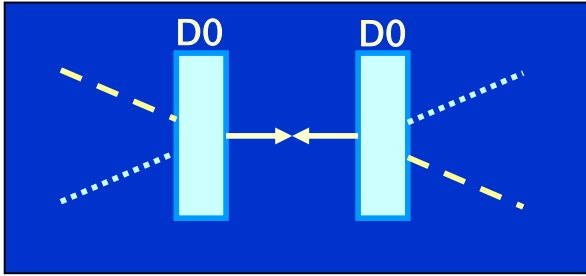

Figure 1: ideal full early separation

LAYOUT AND MAGNETIC FIELD

The required magnetic field integral depends on the D0 position chosen to be between two long range encounters. Table 1 gives possible positions for the dipole center of gravity versus bunch spacing and beam-beam tolerance. The 1.9 m position is inside the inner detector and impossible. The 18.8 m position is too close to the triplet and would require an unrealistic D0 field integral. The positions at 3.8 m and 5.6 m are favored, the first one allowing ideal early separation for a 50 ns spacing. For these positions, the required field integral is in the range 5 to 8 Tm, depending on the exact position and value of the β^* function.

Table 1: Possible dipole positions

		25 ns	*50 ns*
Full separation	early	~~1.9 m~~	3.8 m
Partial	1LR @ 5σ	5.6 m	11.25 m
early sep.	2LRs	9.4 m	~~18.8 m~~

OUTCOME OF BEAM-BEAM STUDIES

Even though including this dipole inside the detectors does not appear impossible, there is a strong reluctance and fear that the calorimetry would be strongly disturbed. This was an incentive to investigate in simulation and experimentally the consequence of the long-range beam-beam interactions at a reduced distance that would occur with partial early separation if the D0 dipole would be relocated farther away from the IP. Experiments were conducted at RHIC and in the SPS in 2007. Their results are discussed in [2], with the following outcome: Experiments have shown that a certain number of long-range encounters at a reduced distance (5σ) can be tolerated. However, their exact number is not yet clear (4 to 8?) and requires further dedicated experiments at RHIC.

It would be premature to draw firm conclusions. However it becomes possible to investigate positions that would be less stressing for the detectors.

PEAK LUMINOSITY

The machine performance is estimated for the ultimate bunch charge of $1.7\ 10^{11}$ protons and the nominal position of the triplet (l*=23 m). The results are given in Table 2 for various configurations and 25 ns or 50 ns bunch spacing.

Table 2: Peak luminosity in 10^{34} cm^{-2}s^{-1} versus scenarios

Bunch spacing	25 ns	50 ns
No early separation β*=25 cm	3.1	1.7
Full early separation β*=14 cm	-	4.9
Partial early sep. β*=14 cm	5.8	3.1
Partial early sep. β*=14 cm + electron lens	~7	
Partial early sep. β*=14 cm + crab cavities	9.8	

It is assumed that the long-range compensation by the electron lens allows reducing the beam separation at the first parasitic crossing to 3 σ. Decreasing the IP to triplet distance to 13 m instead of 23 m increases all figures by about 20%.

LUMINOSITY WITH LEVELING

The luminosity lifetime is dominated by the proton burning. It is of the order of 3.5 hours at $10\ 10^{34}$ cm^{-2}s^{-1},

inversely proportional to the luminosity and proportional to the bunch charge. This apparently is an advantage when increasing performance by increasing the beam current and a handicap when increasing the performance by stronger focusing. This deficiency may however be circumvented by luminosity leveling. The early separation scheme lends itself to a very simple leveling strategy by adjusting the crossing angle. The angle bump is produced by the D0 dipoles and closed by an orbit corrector in front of each triplet [3]. The beam trajectory is therefore unchanged except in the experimental straight section, suppressing any basic optical side-effect and making it operationally extremely simple. Two issues have nevertheless to be considered: i) the modulation of the longitudinal extent of the luminous region, initially decreased by about a factor of 2; ii) the consequence of a large Piwinski angle, up to 3.5. The latter is a common issue to both upgrade paths and requires dedicated studies. Depending on the leveling scenario chosen, the luminosity can be kept up to 8 hours at a moderate cost in integrated luminosity (~20%).

After this initial study of leveling [3], it was realized that the leveling by the crossing angle includes a special provision that may be used if the machine would accept a larger bunch charge: indeed, an initially larger crossing angle reduces both the luminosity and the head-on beam-beam tune shift, unlike leveling with the β^* function. This opens the door to a new optimization where the bunch charge and hence the luminosity can be increased thanks to leveling.
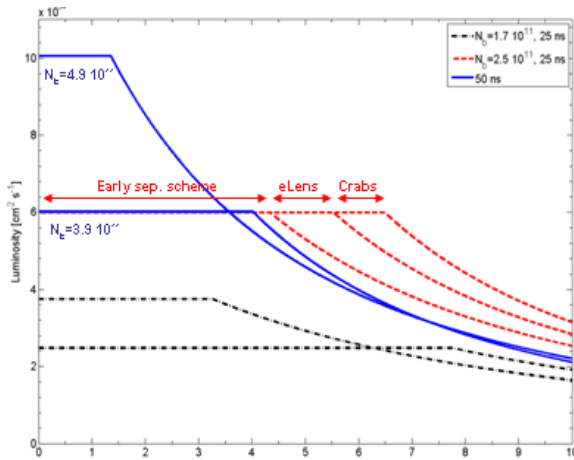

Figure 2: Luminosity [10^{34}] with leveling and HV crossings versus time [hour]: 1) Nb=1.7 10^{11} , p 2) Nb=2.5 10^{11} , p 3) 50 ns spacing and Nb= 4.9 10^{11}p

Examples are given on figure 2 where HV crossing is assumed. The two lower dotted curves show leveling without increase of the bunch charge beyond its ultimate value [3]. The dotted (red) intermediate curves show leveling with a bunch charge increased to 2.5 10^{11} proton, the assumed limit for 25 ns bunch spacing. The early separation scheme alone allows a constant luminosity of 6

10^{34} cm^{-2}s^{-1} for 4 hours followed by the natural decay. The availability of weak crab crossing supplementing the early separation scheme extends the luminosity plateau by another 3 hours while the availability of electron lens compensation would allow an extension by 1 hour. Altogether, the performance in terms of integrated luminosity is increased by almost two with respect to the Valencia scenarios while the maximum pile-up and energy deposition are decreased by a factor of 3 to reach about 110. The plain (blue) curves show that similar results can be obtained with the same hardware and a bunch spacing of 50 ns if the bunch charge is increased to the level assumed in the LPA option [4].

RISETIME OF PERFORMANCE

As already mentioned, an upgrade based on stronger focusing rather than increased beam current suffers from faster luminosity decay. The general experience is that handling large currents is always more difficult and less efficient. It is however difficult to be quantitative. Using an approach by V. Shiltsev [5] based on a statistical analysis of accelerator performance, a scenario of performance increase in time was built for either increasing the beam current or decreasing the β^* function, without taking into account the new leveling option described just above. Figure 3 shows that a strategy with lower beam current should yield about 20% more integrated luminosity with a much steeper rise. Given the many hypotheses, another cautious interpretation could be that 20% is the threshold of significance for integrated luminosity estimates.
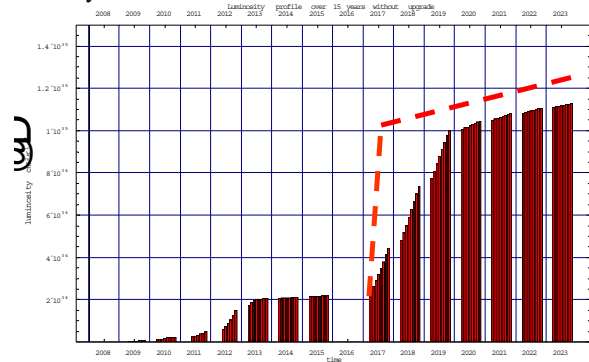

Figure 3: Luminosity [2 10^{34}/division] versus time [1 year/division]1) plain: beam current increase 2) dotted: increased focusing

CONCLUSION

The native luminosity leveling associated to the early separation scheme alleviates a serious defect of the LHC upgrade phase 2 related to a too fast decay of the luminosity with time. Indeed the leveling applies not only to the luminosity but as well to the beam-beam tune shift. The initially lower tune shift allows for more beam current. Hence leveling thru the collision angle opens the possibility of increasing significantly the integrated

luminosity. It then becomes possible to propose a scenario with a constant luminosity of $6 \cdot 10^{34}$ cm^{-2}s^{-1} for 4.5 hours to 6.5 hours depending on the availability of "adds-on " (electron lens, weak crab crossing). The multiplicity is significantly reduced to less than 120.

An issue for future study is the consequence of a large Piwinski angle. It should be noted that all advantages of the above solution can be provided by a local crab crossing scheme alone, would the presence of D0 inside the detectors be an overwhelming problem. This technically very challenging solution deserves as well feasibility investigations.

REFERENCES

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