Leveling with angle

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[1, *LHC Project Note 403*]

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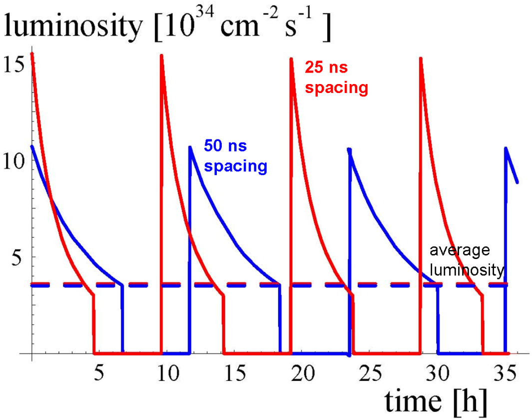
Outline

A LHC Luminosity Upgrade perspective.



Courtesy of W. Scandale and F. Zimmermann
[2, *"Two scenarios for the LHC Luminosity Upgrade"*]

WHY to level the luminosity?

Since...

"Experiments prefer more constant luminosity, less pile up at the start of run, higher luminosity at end."

[2, *"Two scenarios for the LHC Luminosity Upgrade"*]

and from the machine perspective, there is the energy deposition issue: 1.8 kW of debris at nominal luminosity.

...it is already proposed to level the luminosity...

- squeezing β^*
- varying the bunch length.

[2, *"Two scenarios for the LHC Luminosity Upgrade"*]

HOW to level the luminosity?

Here we proposed...

- to vary the θ_c for leveling the luminosity using the Early Separation Scheme.

[3, "An Early Beam Separation Scheme for the LHC Luminosity Upgrade"]

It should be a very **clean** and very **flexible** control system.

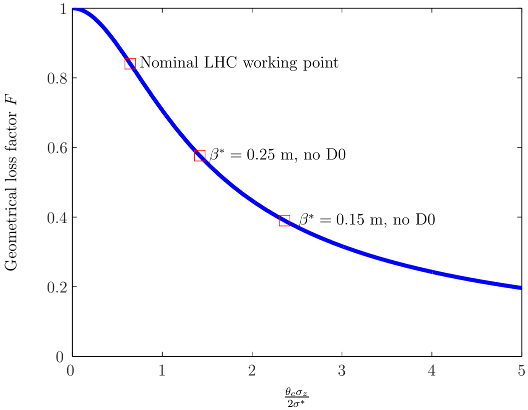
- NO chromaticity correction variation
- NO closed orbit variation around the machine
- NO sextupoles feed-down
- NO spurious dispersion at the IP.

But...

We need to install dipoles in the detector area.

Why varying the θ_c...

$$L(\theta_c) = N_b^2 \frac{f_{rev} n_b}{4\pi} \frac{F(\theta_c)}{\sigma^{*2}} \quad \text{where} \quad F(\theta_c) \approx \frac{1}{\sqrt{1 + \left(\frac{\theta_c \sigma_z}{2\ \sigma^*}\right)^2}}$$



The model of luminosity we used.

We implemented the following three processes

- the protons burning

$$\dot{N}_b(t) = -\frac{\sigma\ n_{exp}}{n_b} L(t)$$

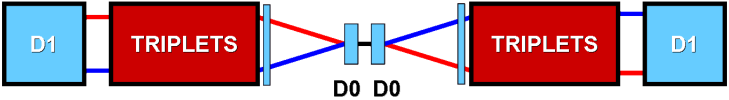
- the intra beam scattering [4, "Handbook of Accelerator Physics and Engineering"]

$$\dot{\epsilon}(t) = \frac{1}{\tau_{IBS}} \frac{N_b(t)}{N_{IBS}} \epsilon(t)$$

- the rest gas scattering [4, "Handbook of Accelerator Physics and Engineering"].

$$\dot{N}_b(t) = -\frac{n_b}{\tau_{RGS} N_{RGS} n_{RGS}} {N_b}^2(t)$$

The numerical values of the constants are obtained from [5, "LHC Luminosity and Energy Upgrade"].



- θ_1 is the kick provided by the dipole at the position l_1 from the IP
- θ_2 is the kick provided by the orbit corrector at the position l_2 from the IP.
  The beams angle after the orbit corrector is θ_{tripl}.

A simple geometrical approach...

$$\theta_1 = atan\left(\frac{l_2\ tan(\frac{\theta_{tripl}}{2}) - l_1\ tan(\frac{\theta_c}{2})}{l_2 - l_1}\right) - \frac{\theta_c}{2}$$

$$\theta_2 = \frac{\theta_{tripl}}{2} - \frac{\theta_c}{2} - \theta_1$$

The dynamic range of the θ_c

Lower limit...

- encounters at reduced distance
- position of the dipoles

Upper limit...

- synchro-betatron coupling (to be investigated)
- strength of dipoles

Assumptions...

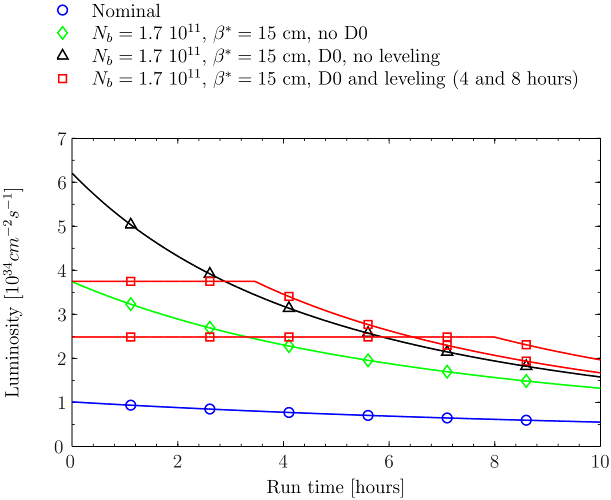
Machine performance.

- $\beta^* = 15$ cm
- ultimate LHC current (25 ns, $N_b = 1.7\ 10^{11}$)

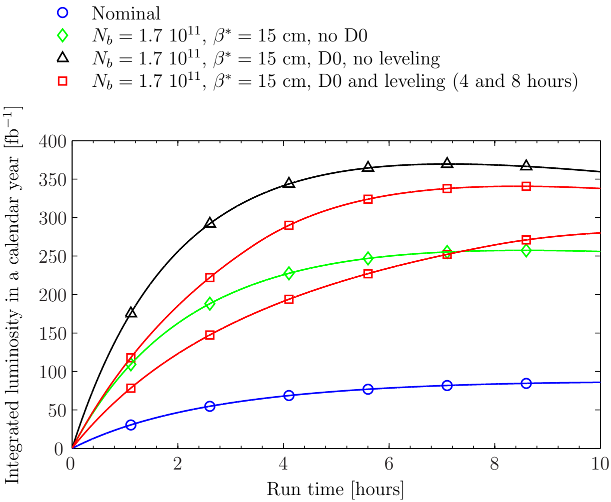
Early separation scheme.

- D0 at 6 m from the IP
- orbit corrector at 19 m from the IP.

The instantaneous luminosity.



The integrated luminosity.



General consideration

The leveling has a "moderate analytical cost" in term of integrated luminosity. To compute the integrated luminosity we considered an optimization based on 5 hours turn-around-time and 200 days per year.

		Peak L [10^{34} cm^{-2} s^{-1}]	Integrated L [fb^{-1}]
Nominal scenario		1.01	86.37
$\beta^* = 0.15$ m	no D0	3.74	257.37
$\beta^* = 0.15$ m	D0, no leveling	6.20	369.65
$\beta^* = 0.15$ m	D0 and leveling	3.75	340.70

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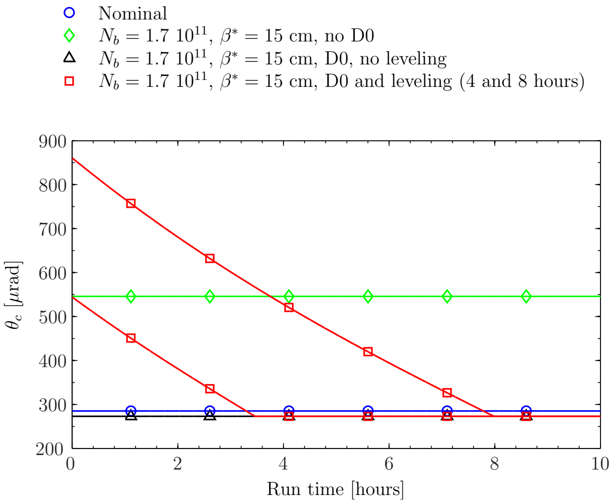
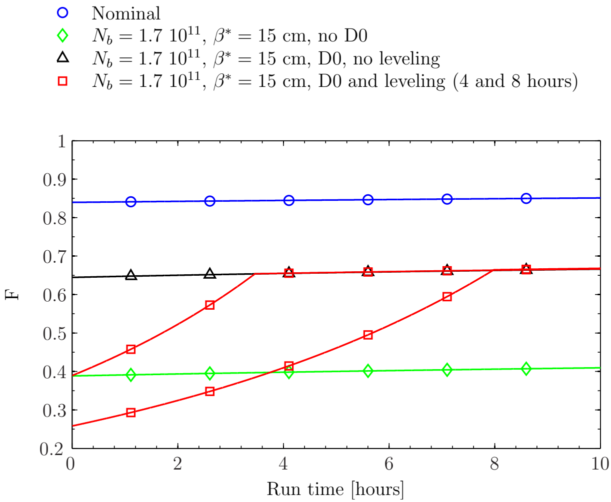
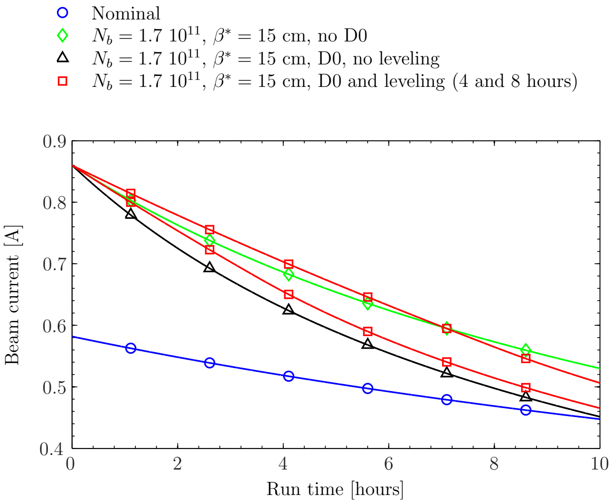
The crossing angle.



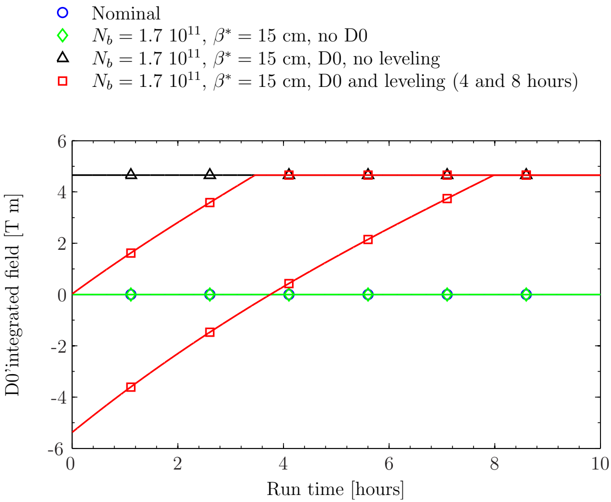
The geometrical loss factor.



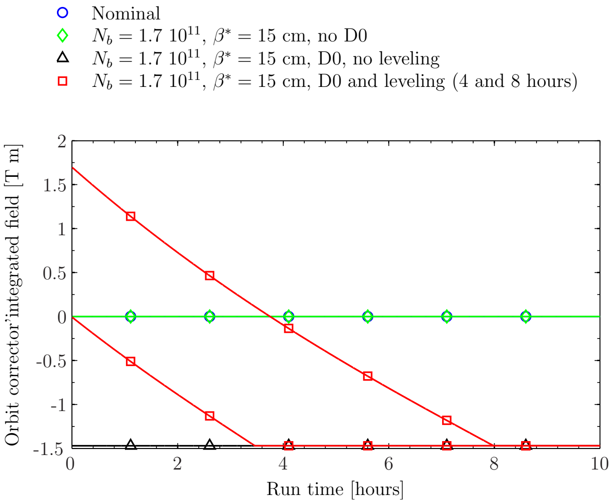
The beam current.



The dipole working condition.



The orbit corrector working condition.



Possible side effects.

We focus on

- the distance between the beams
- the longitudinal size of the luminous region

$$\sigma_{lum} = \frac{\sigma_z}{\sqrt{2}} F$$

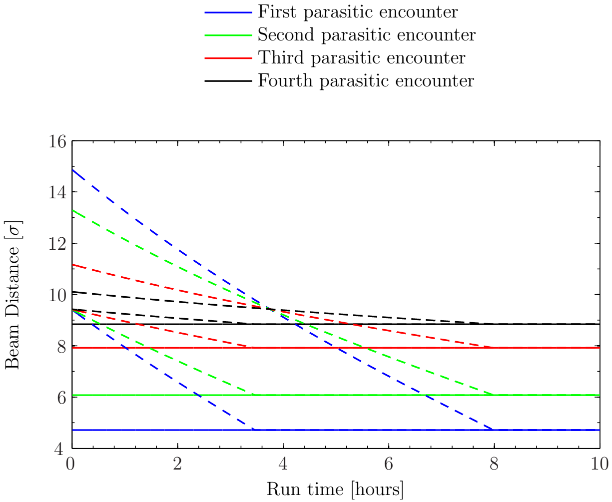
[2, *"Two scenarios for the LHC Luminosity Upgrade"*]

- the tune shift due to head-on collisions

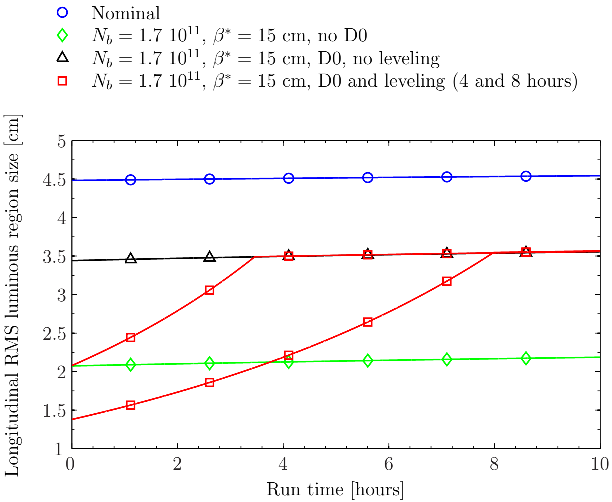
$$\Delta Q = \frac{N_b r_p}{4\pi\epsilon_n} F$$

[5, "LHC Luminosity and Energy Upgrade"].

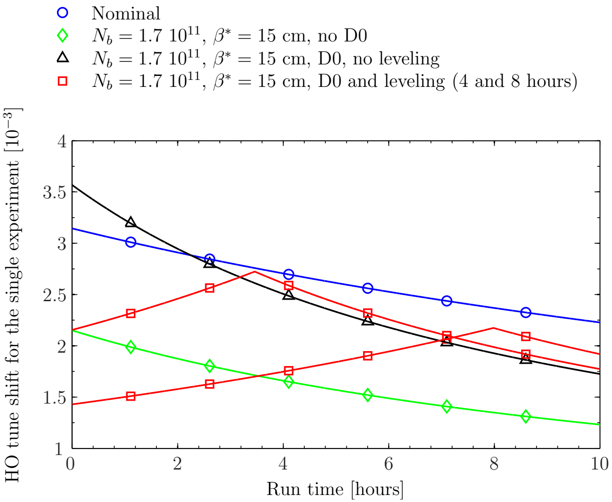
Distance between the beams



The longitudinal size of the luminous region.



The tune shift due to head-on collisions.



Summary

- Leveling using the θ_c fully compatible with the Early Separation Scheme (and/or Crab Cavities).

Pros

- Increase of integrated luminosity with a reduced peak luminosity increase
- Clean to implement
- With flexibility: reduced separation when the beam current is decreased.

Cons

- Dipoles in the detectors
- Variation in the luminous region longitudinal size
- BB effect to understand better.

References

- G. Sterbini and J.-P. Koutchouk, *"A Luminosity Leveling Method for LHC Luminosity Upgrade using an Early Separation Scheme"*, LHC-Project-note-403, May 2007.
- F. Zimmermann and W. Scandale, *"Two scenarios for the LHC Luminosity Upgrade"*, PAF/POFPA meeting, 13 February 2007, CERN.
- J.-P. Koutchouk and G. Sterbini, *"An Early Beam Separation Scheme for the LHC Luminosity Upgrade"*, EPAC06 Proceedings, Edinburgh.
- A.W. Chao and M. Tigner, *"Handbook of Accelerator Physics and Engineering"*, World Scientific Publishing Co. Pte. Ltd. , 2006.
- O. Brüning and al., *"LHC Luminosity and Energy Upgrade: a Feasibility Study"*, LHC Project Report 626, December 2002, Geneva.