Recent Results on Insertion Design for the LHC Luminosity Upgrade

Highlights

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for the HHH-CARE Collaboration

Highlights on Following Issues

1- A global approach to insertion design: beam physics, magnet technology, energy deposition

a→ ***Investigation on the potential of NbTi & Nb_3Sn triplets for performance improvement and for the full LHC upgrade ($L/L_0 \approx 10$)***

2- Minimizing the geometrical luminosity loss factor

a→ ***"Flat" beams***

b→ ***D0 early separation scheme***

3- Other solutions for the insertion

a→ ***Long NbTi*** *triplets at low gradient*

b→ ***Dipole-first insertions***

1- A Global Approach

The present LHC insertion has been pushed for maximum performance. Hence any upgrade must necessarily pass "qualitative barriers"…

- ***Focusing barrier*** (larger magnet gradient and aperture, closer to IP, correction of possibly larger optical aberrations)
- ***Beam-beam barrier*** (maximize useful head-on and minimize perturbing long-range interactions)
- ***Energy deposition barrier*** (instant energy deposition, heat removal, radiation lifetime and activation issues)

…**simultaneously**, with a **large interplay between the barriers'parameters**.

Investigation of quadrupole first solutions: Model (J.P. Koutchouk/CERN)

Global model of an insertion

- ***Beam optics*** *(linear optics, optics aberrations)*
- ***Beam dynamics*** *(long-range beam-beam effect)*
- ***Performance*** $L\left(N_b, k_b, \beta^*, F\left(\sigma_s, \beta^*, \theta_c\left(\beta^*, N_b k_b, l_{LR}, BBLR\right)\right)\right)$
- ***Magnet parameters*** *(gradient, length, aperture, sc. margins)*

$$\phi_{coil}\left(\phi_{beam}\left(\sigma_{beam}\left(\beta^*, dispersion(\theta_c)\right)\right), \theta_c, l^*, l_{triplet}, tol, co\right), w_{CB}, w_{BS}, w_{shield}\right)$$

- ***Peak power deposition*** $\hat{P}\left(L, l_{triplet}, G_Q, \phi_{beam}, \sigma_{beam}, \theta_c, \phi_{coil}\right)$

Using scaling laws to explore the parameter space 10^6 faster.

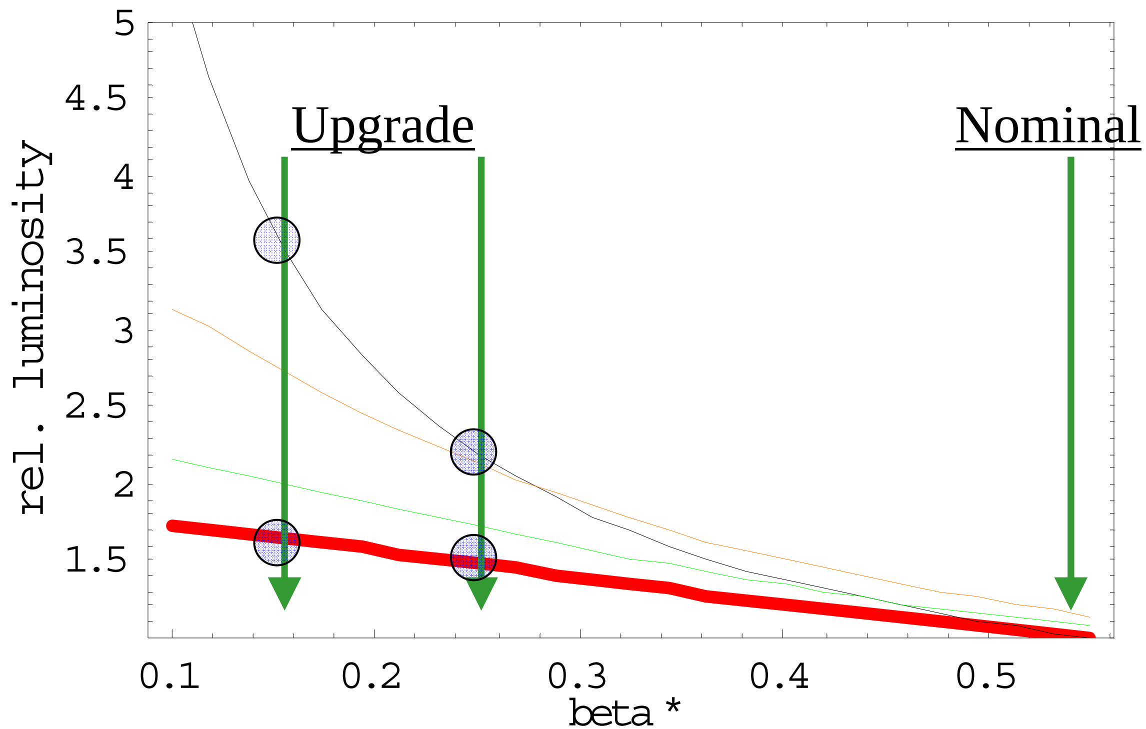
Investigation of Quadrupole first solutions: Results (J.P. Koutchouk/CERN)

- ***The Nb-Ti technology appears limited to the vicinity of the nominal performance. Larger aperture NbTi triplets would allow a luminosity improvement by 65% for a beam current halfed.***

- ***The most promising solution appears to be:***
  - **Nb_3Sn** ***technology with a triplet similar to nominal***
  - **19 m *from IP*** *(23),* **100 mm *coil aperture*** *(70)*
  - ***Peak heat deposition to be reduced by a*** **few units** ***at L/L_0=10***
  - ***Performance:*** **L/L0 = 6 → 11**

- ***The global model will be further improved in collaboration, especially for the heat deposition scaling laws (US/LARP)***

2- Minimizing the geometrical loss factor



Luminosity increase vs beta*:

1. no Xing angle,
2. nominal Xing and bunch length,
3. BBLR?,
4. Bunch length/2

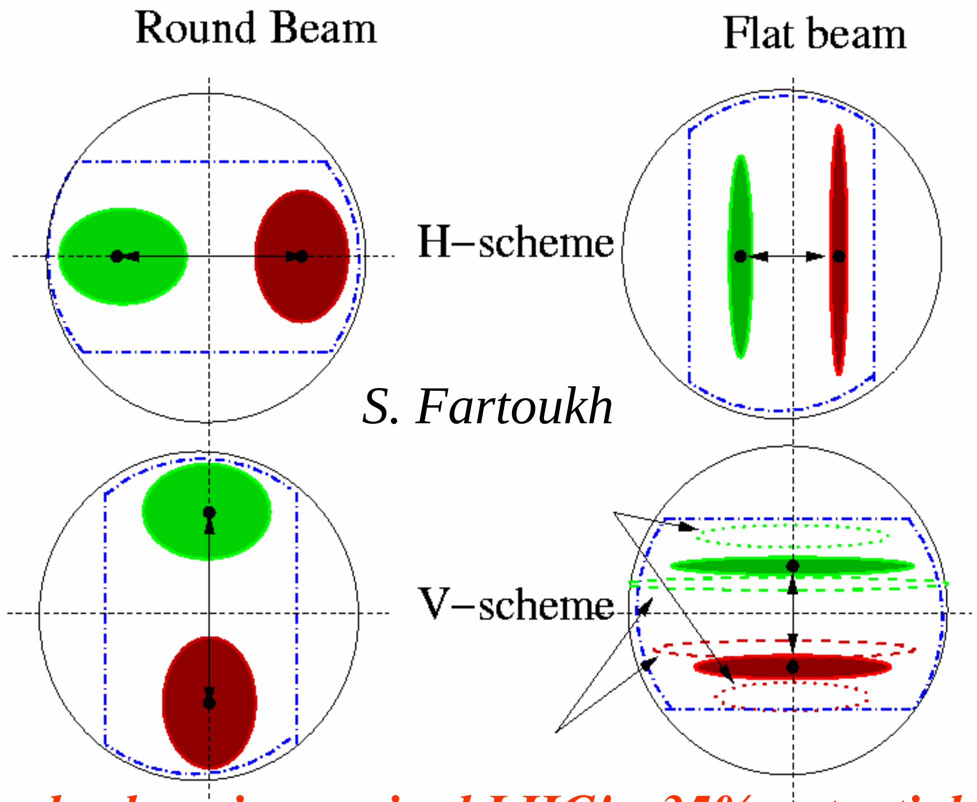
Pushing the low-β makes sense if simultaneously the impact of the luminosity geometrical loss factor is acted upon.

Flat Beams (T. Sen/US-LARP, S. Fartoukh/CERN)

***Basic Idea:* Create with focusing a non unit beam aspect ratio and separate the beams in the plane where the size is minimum:**

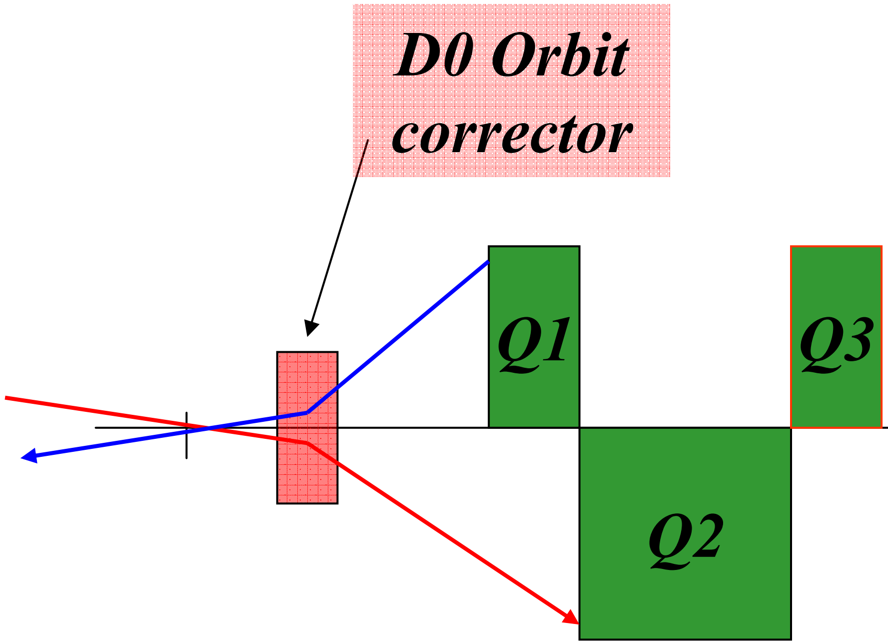
- ***the "elliptical" aperture is better used***
- ***the Xing angle constant in "σ" decreases in "μrad"→***

$$\frac{1}{\sqrt{1+\left(\frac{\theta_c \sigma_s}{2\sqrt{\langle\beta\rangle\varepsilon}}\right)^2}}$$



Can be done in nominal LHC! ~35% potential luminosity increase to be confirmed (larger tune spread), likely with long-range b-b compensation.

Early separation scheme (J.P. Koutchouk/CERN)



Principle: reduce or *__cancel__* *the Xing angle at the IP and gain ~50% in luminosity or more.*

__Issues:__ ***where can the dipole be installed? which angle→ LR beam-beam studies, requirements on the dipole: transparency, magnetic confinement, heat deposition & rad. resistance…***

G. Sterbini, student from U. La Sapienza ←

Low-gradient long NbTi quadrupole solutions

(O. Bruning/CERN)

As a fall-back of dipole-first and combined-function studies, a *"different "* quad-first solution emerged, with challenges radically different from a Nb_3Sn solution:

- *Weak gradients: 47 → 70 T/m*
- *Large coil aperture: 143mm → 212 mm*
- *peak field well within NbTi capabilities*
- *Large β_{max}=18 km*
- *Very long triplet ~100 m*
- *Local chromaticity correction probably required*

Performance level to be evaluated

Dipole first Insertions

A full insertion layout was optically designed (O. Bruning/CERN). ***A new optical matching toolkit was developed*** (R. de Maria/CERN)

Challenges:

- ***Separation dipole D1: Conceptual studies*** (R. Gupta/US-LARP, P. McIntyre/US-LARP)
- ***Local chromaticity correction:*** P. Raimondi/INFN

The advantage of this solution is primarily a reduced requirement on the quadrupole aperture.

Conclusions

- ***Several other fields moving ahead: Beam-beam compensation, large crossing angle with Crab cavities…***
- ***The CARE-HHH Arcidosso workshop gave a*** **boost** ***to LHC upgrade studies and a meeting opportunity to develop collaborations. The US/LARP Chicago meeting as well.***
- ***There is a variety of research lines to increase the LHC luminosity by ~10 with different challenges.***
- ***The advancement of the studies should allow soon a ranking of solutions and topics by potential and feasibility to focus the effort.***