LHC injector complex Upgrade

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scenarios for the luminosity upgrade

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Phase 0: steps to reach ultimate performance no hardware changes:

1) collide beams only in IP1 and IP5 with alternating H-V crossing
2) increase N_b up to the beam-beam limit ⇒ $L = 2.3 \times 10^{34}$ cm^{-2} s^{-1}
3) increase the dipole field from 8.33 to 9 T ⇒ $E_{max} = 7.54$ TeV

The ultimate dipole field of 9 T corresponds to a beam current limited by cryogenics and/or by beam dump/machine protection considerations.

Phase 1: steps to reach maximum performance with IR and RF changes:

1) modify the insertion quadrupoles and/or layout ⇒ $\beta^* = 0.25$ m
2) increase crossing angle θ_c by $\sqrt{2}$ ⇒ $\theta_c = 445\ \mu$rad
3) increase N_b up to ultimate luminosity ⇒ $L = 3.3 \times 10^{34}$ cm^{-2}s^{-1}
4) halve σ_z with high harmonic RF system ⇒ $L = 4.6 \times 10^{34}$ cm^{-2}s^{-1}
   - new RF system in LHC providing an accelerating voltage of 43MV at 1.2GHz
   - a power of about 11MW/beam ⇒ large estimated cost
   - a longitudinal beam emittance reduced to 1.78 eVs
   - horizontal Intra-Beam Scattering (IBS) growth time will decrease by about $\sqrt{2}$
5) double the no. of bunches n_b (increasing θ_c) ⇒ $L = 9.2 \times 10^{34}$ cm^{-2}s^{-1}
   (exceeding ultimate beam intensity ⇒)
   - upgrade LHC cryogenics, collimation and beam dump systems
   - upgrade the electronics of beam position monitors
   - possibly upgrade the SPS RF system and other equipments in the injector chain

luminosity and energy upgrade

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Phase 2: steps to reach maximum performance with major hardware changes in particular in the injector chain:

- Staged improvement with the aim of injecting into the LHC at 1 TeV
  - ➲ each stage should contribute to the increase of the luminosity
- ⇨ SPS+ option (2015 ÷ 2017)
  - ➲ beam luminosity should increase
  - ➲ first step in view of an LHC energy upgrade
  - The normalized acceptance doubles in LHC, this should allow doubling the beam intensity by doubling N_b and ε_n (at constant beam-beam parameter $\Delta Q_{bb} \propto N_b/\varepsilon_n$) and the LHC peak luminosity (long range beam-beam compensation schemes mandatory)
  - LHC energy swing is reduced by a factor of 2 ⇨ the SC transient phenomena should be smaller and the turnaround time to fill LHC should decrease
  - interesting alternative ⇨ compact low-field booster rings in the LHC tunnel (LER option)

present views on injector upgrade

- Present bottle-neck of the injector complex
  - The SPS (capture loss, longitudinal stability)
  - The BPS (space charge)

a PS (at 50 GeV) and a LINAC4 at 160 MeV turns out to be the best choice for the first improvement of the injector chain

  - the right move towards the (high-priority) LHC performance upgrade
  - an interesting alternative is to develop new fast pulsing SC magnets (for a superconducting PS+ option)

- The 1TeV injector remains the long-term strategic objective

factorization of the luminosity gain

- factor of 2.3 on L at the ultimate beam intensity (I = 0.58 → 0.86 A)
- factor of 2 on L from new low-β (β^* = 0.5 → 0.25 m)
  - ☹ $T_{turnaround}$ = 10h → $\int L dt$ = 3 × nominal = 200 fb^{-1} per year
- factor of 2 on L doubling the number of bunches (may be impossible due to e-cloud) or increasing bunch intensity and bunch length
  - ☹ $T_{turnaround}$ = 10h → $\int L dt$ = 6 × nominal = 400 fb^{-1} per year

Consolidation of injectors and completion of LHC
Linac 4 & PS2/PS+
later a new SPS & transfer lines injecting in LHC at 1 TeV/c

- factor of 1.4 in $\int L dt$ for shorter $T_{turnaround}$ = 5 h
- factor of 2 on L (2 × bunch intensity, 2 × emittance)

☺ $L = 10^{35}$ $cm^{-2}s^{-1}$ AND $\int L dt$ = 9 × nominal = 600 fb^{-1} per year