Plans for the LHC Upgrade

contribution to the round table discussion

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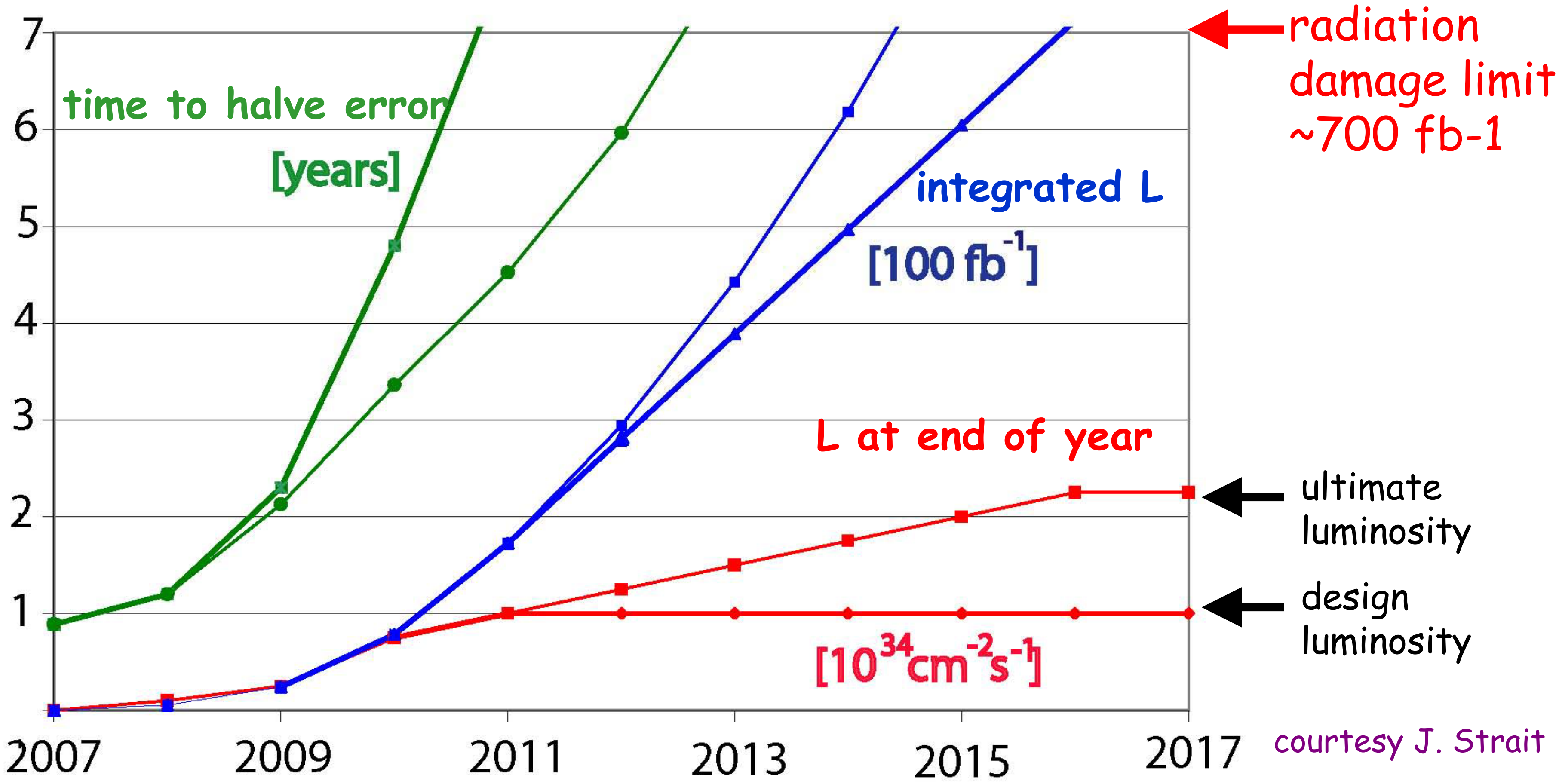
time scale of LHC upgrade



(1) ***life expectancy of LHC IR quadrupole magnets*** is estimated to be <10 years due to high radiation doses

(2) the ***statistical error halving time*** will exceed 5 years by 2011-2012

(3) therefore, it is reasonable to plan a ***machine luminosity upgrade based on new low-ß IR magnets before ~2014***

scenarios for the luminosity upgrade

- ultimate performance without hardware changes (phase 0)
- maximum performance with only IR changes (phase 1)
- maximum performance with 'major' hardware changes (phase 2)

Nominal LHC performance $\Rightarrow$
- beam-beam tune spread of 0.01
- $L = 10^{34}$ $cm^{-2}s^{-1}$ in Atlas and CMS
- Halo collisions in ALICE
- Low-luminosity in LHCb

Phase 0: steps to reach ultimate performance without 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 $\Rightarrow$ $L = 2.3 \times 10^{34}$ cm^{-2} s^{-1}
3) increase the dipole field from 8.33 to 9 T $\Rightarrow$ $E_{max} = 7.54$ TeV

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

scenarios for the luminosity upgrade

Phase 1: steps to reach maximum performance with only IR changes:

1) modify the SC insertion quadrupoles and/or layout $\Rightarrow$ $\beta^* = 0.25$ m
2) increase crossing angle θ_c by $\sqrt{2}$ $\Rightarrow$ $\theta_c = 445\ \mu$rad
3) increase N_b up to ultimate luminosity $\Rightarrow$ L = 3.3 $\times$ 10^{34} cm^{-2}s^{-1}
4) ~~halve σ_z with high harmonic RF system $\Rightarrow$ L = 4.6 $\times$ 10^{34} cm^{-2}s^{-1}~~
5) double the no. of bunches n_b (increasing θ_c) $\Rightarrow$ L = 9.2 $\times$ 10^{34} cm^{-2}s^{-1}

RF upgrade
RF upgrade

☹ step 4) is not cheap: it requires a new RF system in LHC providing

- an accelerating voltage of 43MV at 1.2GHz
- a power of about 11MW/beam $\Rightarrow$ estimated cost 56 MCHF
- a longitudinal beam emittance reduced to 1.78 eVs
- horizontal Intra-Beam Scattering (IBS) growth time will decrease by about $\sqrt{2}$

☹ operational consequences of step 5) ($\Rightarrow$ 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

Phase 2: steps to reach maximum performance with major hardware changes:

- equip the SPS with SC magnets, upgrade transfer lines to LHC and the injector chain, to inject into the LHC at 1 TeV (⇒ super-SPS option)
  - ⇒ beam luminosity should increase
  - ⇒ first step in view of an LHC energy upgrade
  - for a given mechanic and dynamic apertures at injection, this option can double the beam intensity (at constant beam-beam parameter $\Delta Q_{bb} \propto N_b/\varepsilon_n$) increasing the LHC peak luminosity by nearly a factor two, in conjunction with long range beam-beam compensation schemes
  - LHC energy swing is reduced by a factor 2, hence the SC transient phenomena should be smaller and the turnaround time to fill LHC should decrease
  - interesting alternative ⇒ cheap, compact low-field booster rings in the LHC tunnel
- install in LHC new dipoles with a operational field of 15 T considered a reasonable target for 2015 ÷ 2020 ⇒ beam energy around 12.5 TeV
  - ⇒ luminosity should increase with beam energy
  - ⇒ major upgrade in several LHC hardware components

general considerations

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

- Best possible investment for improvement
  - The linac (synergy with neutrino-physics needs)
  - The SPS (synergy with neutrino and flavour physics need ? - prerequisite for LHC energy upgrade)

however a SC- PS turns out to be the best choice for CERN especially if the PS magnet consolidation program is not a reliable long term solution

In addition, this is

- the right move towards the (high-priority) LHC performance upgrade (better SPS performance at low-energy)
- an opportunity to develop new fast pulsing SC magnets

- The 1TeV SC SPS should remain the strategic objective
- The benefit for LHC should be quantified as much as possible

factorization of the expected luminosity upgrade

- factor of 2.3 on L_0 at the ultimate beam intensity (I = 0.58 → 0.86 A)
- factor of 2 (or more ?) on L_0 from new low-ß (ß* = 0.5 → 0.25 m)
  - ☹ $T_{turnaround}$ = 10h → ∫Ldt = 3 × nominal = 200 fb^{-1} per year
- factor of 2 on L_0 doubling the number of bunches (may be impossible due to e-cloud) or increasing bunch intensity and bunch length
  - ☹ $T_{turnaround}$ = 10h → ∫Ldt = 6 × nominal = 400 fb^{-1} per year

A new SPS injecting in LHC at 1 TeV/c would yield

- factor of 1.4 in integrated luminosity for shorter $T_{turnaround}$ = 5 h
- factor of 2 on L_0 (2 × bunch intensity, 2 × emittance)

☺ $L_0 = 10^{35}\ cm^{-2}s^{-1}$ AND ∫Ldt = 9 × nominal = 600 fb^{-1} per year

open issues

1. evaluate all consequences of higher intensity operation
2. installation staging in the PS and SPS tunnel ➲ minimal duration of the shutdown
3. lattice design for the SC-PS and the SC-SPS
4. slow extraction design at 60 GeV and 1 TeV (respectively) within the space available
5. optimal extraction & injection channels (kickers and septa operating on more energetic particles within serious space occupancy constraints)
6. estimate of the expected loss ➲ optimize collimation and machine protection
7. design of SC transfer lines to the LHC
8. optimal design for the SC magnets for the super-SPS: nominal parameters should be proposed and a road map for the requested R & D presented.
9. cryogenic system: solution should be investigated for the needs and the installation of cryogenics in the SPS tunnel
10. RF systems: the optimal choice of the RF parameter is not yet available
11. impedance budget: reduce it possibly by an order of magnitude
12. pre-injector upgrade (linac 4 vs RCS/FFAG, booster upgrade)

foreseeing other uses of the super-SPS for neutrino or flavor physics

1. scenario to fill the whole super-SPS ring
2. upper value of the circulating intensity
3. optimal cycle duration
4. optimal bunch distance

Concluding remarks

A vigorous R & D programme is required on

- optics, beam control, machine protection, collimation
- high gradient high aperture SC quadrupoles
  - → Nb_3Sn SC wire and cable
  - → radiation-hard SC magnet design and prototyping
- RF-systems & crab-cavities
- SC fast ramping magnets
  - → low-loss NbTi SC wire and cable
  - → fast ramping SC magnet design and prototyping

Time-scale required 10 years

So START as soon as possible !