CAS September 2010, Varna, Bulgaria

Luminosity optimization for a Higher-Energy LHC

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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Abstract

First thoughts on a higher-energy LHC ("HE-LHC") with about **16.5 TeV beam energy** and 20-T dipole magnets have recently taken shape. In this poster we sketch in particular the proposed principal parameters and luminosity optimization schemes for both round and flat beams.

Motivation

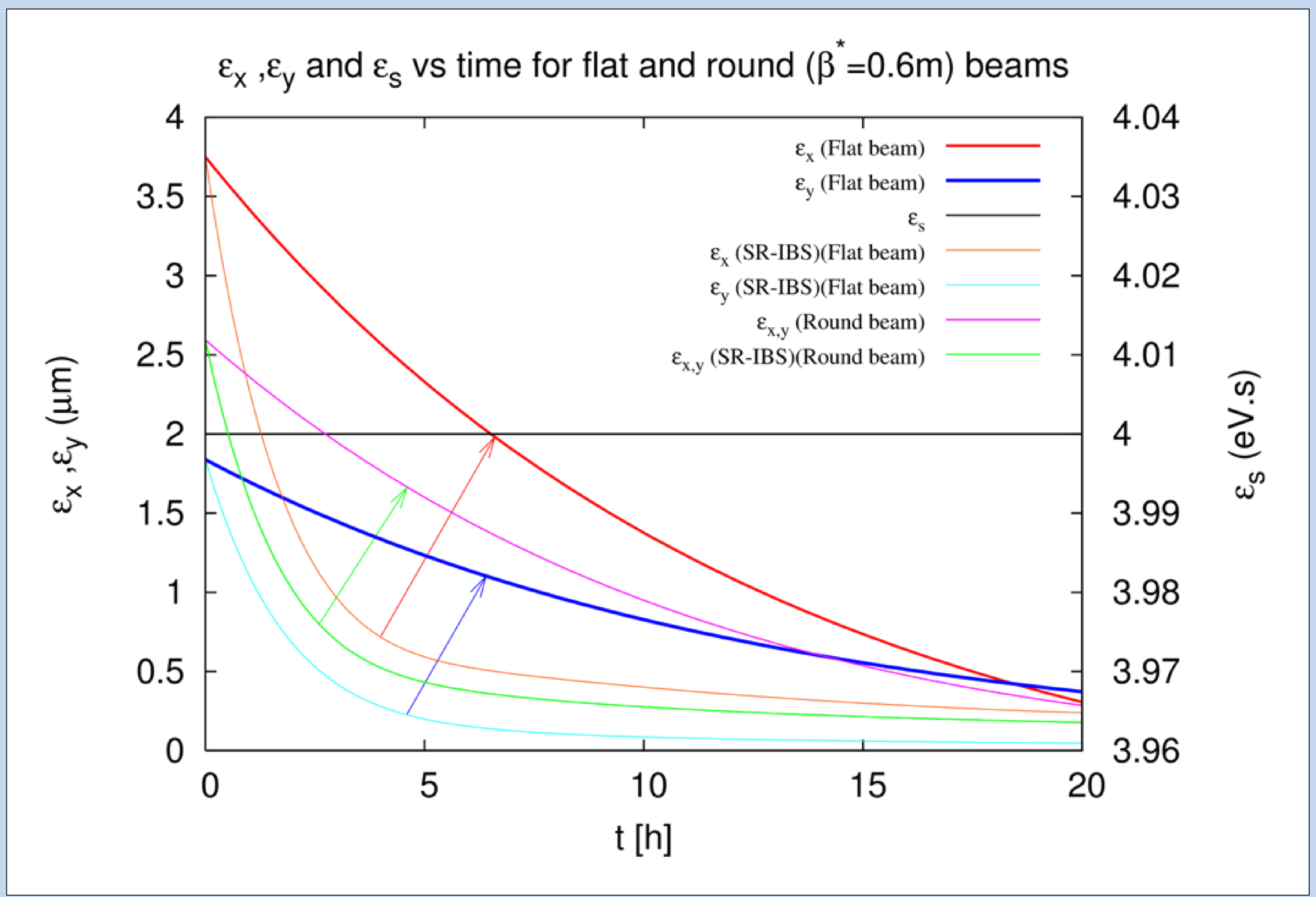
Since the beam energy is the main parameter to raise the discovery potential of the LHC, it is important to study approaches and scenarios for an LHC energy upgrade. A large R&D effort on SC magnets is still required to achieve - in industrial production - the high magnetic fields needed to increase the LHC beam energy by a factor two or more, but the current state and recent progress with Nb_3Sn, Nb_3Al and HTS materials look encouraging. Since the synchrotron radiation (SR) increases with the fourth power of the energy, machine protection and cryogenics are also challenging issues.

Main parameters	Nominal LHC	HE-LHC (Flat)	HE-LHC (Round)
Energy [TeV]	7	16.5	
Bending field [T]	8.33	19.62	
Injection Energy [TeV]	0.450	~1.0	
Number of bunches	2808	1404	
Bunch population [$\cdot 10^{11}$ ppb]	1.15	1.29	1.30
Initial normalized transverse emittance [μm]	3.75	3.75 (x), 1.84 (y)	2.59
Initial normalized long. emittance [eV· s]	2.5	4.0	
Initial/maximum tune shift x,y (*#IPs)	0.01	0.01	
β^*_x, β^*_y [m]	0.55	1.0, 0.43	0.6
RF voltage [MV]	16	32	
rms bunch length [cm]	7.55	6.5	
rms momentum spread [$\cdot 10^{-4}$]	1.13	0.9	
Stored energy per beam [MJ]	334	478.5	480.7
SR power per ring [kW]	3.6	65.7	66.0
Dipole SR heat load dW/ds [W/m/aperture]	0.16	2.8	2.8
SR energy loss per turn [keV]	6.7	201.3	
Longitudinal SR emittance damping time [h]	12.9	0.98	
Transversal SR emittance damping time [h]	25.8	1.97	
Initial horizontal IBS emittance rising time [h]	80	~80	~60
Initial vertical IBS emittance rising time [h] (= $\kappa_c^{-1}\tau_x$)	~400	398 (κ_c=0.2)	~300
Initial long. IBS emittance rising time [h]	61	~64	~68
Crossing angle [μrad]	285 (9.5$\sigma_{x,y}$)	175.2 (12$\sigma_{x,y}$)	188.1 (12$\sigma_{x,y}$)
Peak luminosity [$\cdot 10^{34}$ cm^{-2} s^{-1}]	1.0	2.0	
Initial rate of events per crossing	19	76	
Beam life time [h]	46	12.6	
Optimum running time [h]	15.2	10.4	
Integrated luminosity after t_r [fb^{-1}] (t_{TA}=5h)	0.41	0.50	0.51
Optimum avg. Int. luminosity per day [fb^{-1}]	**0.47**	**0.78**	**0.79**

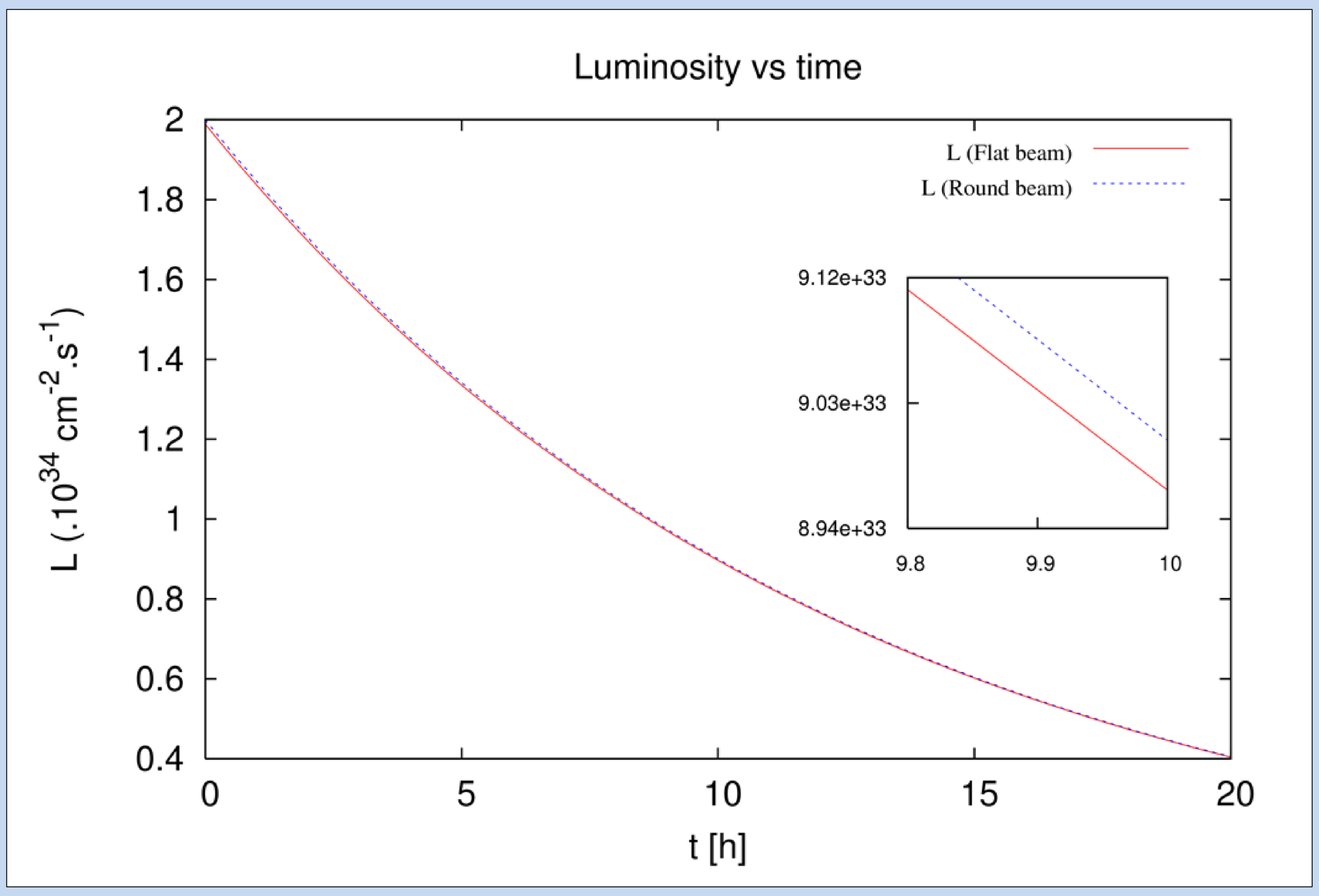
Initial parameters are set so that we consider an **initial luminosity of 2.0·10^{34} cm^{-2}s^{-1}** as well as an initial beam-beam tune shift value of **$\Delta Q_{x,y}$= 0.01**. The latter condition is maintained for the whole physics store, which gives us the emittances values to which we have to inject noise **(blow up)**.

$$\Delta Q_{round} = \frac{\beta^* \cdot r_p \cdot N_b}{4\pi\gamma\sigma\sqrt{\sigma_z^2 \cdot \left(\frac{\theta_c}{2}\right)^2 + \sigma^2}} \quad ; \quad L = \frac{N_b^2 \cdot n_b \cdot f_{rev}}{4\pi\beta^*\varepsilon} \cdot F_G(\theta_c, \varepsilon, \beta^*, \sigma_z)$$

$$\frac{dN_b}{dt} = -\frac{\sigma_{tot} \cdot L \cdot n_{IP}}{n_b} \quad ; \quad \left(\frac{d\varepsilon}{dt}\right)_{round} = \frac{\varepsilon}{\tau_{IBS}} - \frac{\varepsilon}{\tau_{SR}} + \left(\frac{\Delta\varepsilon}{\Delta t}\right)_{noise}$$



Evolution of the three HE-LHC emittances during a physics store for flat and round beams with controlled blow up compared with the natural transverse emittance evolution due to radiation damping and IBS only, which would lead to an **excessive tune shift**. Constant longitudinal emittance and crossing angle are considered. The arrows point out the controlled blow up.



Time evolution of the HE-LHC luminosity including emittance variation with controlled transverse and longitudinal blow up and proton burn off for a constant crossing angle.

- The luminosity is almost independent of a variation in the crossing angle and of a variation in the longitudinal emittance. Both can, therefore, be kept constant (the latter by controlled longitudinal noise injection)
- To fulfill the tune shift condition controlled blow up is required throughout the physics store and SR-IBS equilibrium is never reached

Conclusions

- Round and flat beams give a similar performance
- High integrated luminosity values (~0.8 fb^{-1} per day, 1.7 x nominal)
- Transverse emittance control (blow up) needed during the whole run
- Heat loads are close to the limit of the present cryogenics cooling capacity
- Higher tune shift options are being studied