SR damping, IBS, and beam-beam simulations for HE-LHC

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Acknowledgments

- This work is based in big part on IBS model by V.Lebedev (Fermilab)
- Beam-beam simulations were carried out with Lifetrac code by D.Shatilov (BINP)

Outline

- Synchrotron radiation damping and excitation in HE-LHC
- Intra-beam scattering
- Luminosity evolution model
- Beam-beam simulation

LARP

Machine and beam parameters

Beam energy	16.5 TeV
Number of bunches	1404
Number of IPs	2
Bunch population	1.3×10^{11}
Initial normalized transverse emittance	3.75, 1.84 (x,y) μm
Initial momentum spread	0.9×10^{-4}
RF voltage	32 MV
Beta-function at IP	1.0, 0.43 (x,y) m
Full crossing angle	175 μrad

Parameters of synchrotron radiation

Synchrotron radiation integrals computed for LHC optics V6.5	I_2=0.002245 m^{-1}
	I_3=7.99×10^{-7} m^{-2}
	I_5=2.11 10^{-8} m^{-1}
Energy loss per turn	U_0=206.3 keV
SR power	P=67 kW
Emittance damping time	τ_x, τ_y=1.93 h
	τ_E=0.96 h
Normalized SR equilibrium emitance	ε_{x0}=0.01 μm
Equilibrium momentum spread	δ_0=3.4×10^{-6}

$$U_0 = \frac{C_\gamma}{2\pi} E^4 I_2$$

$$P = U_0 I_b N_b$$

$$\tau_{x,y} = \frac{E T_0}{U_0}$$

$$\tau_E = \frac{E T_0}{2 \cdot U_0}$$

$$\frac{d\varepsilon_x}{dt} = -\frac{\varepsilon_x}{\tau_x} + \frac{55}{48\sqrt{3}} \frac{\hbar c}{T_0} \frac{r_0}{mc^2} \gamma^5 I_5$$

Parameters of diffusion

IBS in smooth optics approximation, for full description see
http://lhc-commissioning.web.cern.ch/lhc-commissioning/presentations/2010/VL_LHC_LuminosityEvolution.pdf

Lattice parameters for LHC V6.5	Average βx=104.8 m
	Average βy=109.4 m
	Average Ax=2.29
Horizontal IBS emittance growth time	82 h
Longitudinal IBS emittance growth time	72 h
Lifetime due to scattering on residual gas	900 h

$$A_x = \frac{D_x^2 + \left(\beta_x D_x' + \alpha_x D_x\right)^2}{\beta_x}$$

$$\frac{d}{dt}\begin{pmatrix} \varepsilon_x \\ \varepsilon_y \\ \sigma_p^{\ 2} \end{pmatrix} = \frac{N r_0^{\ 2} c L_c}{4\sqrt{2}\beta^3\gamma^3\sigma_x\sigma_y\sigma_z\theta_\perp}\begin{pmatrix} \langle A_x \rangle_s \\ 0 \\ 1 \end{pmatrix}$$

Luminosity evolution model

Numerical solution of system of equations

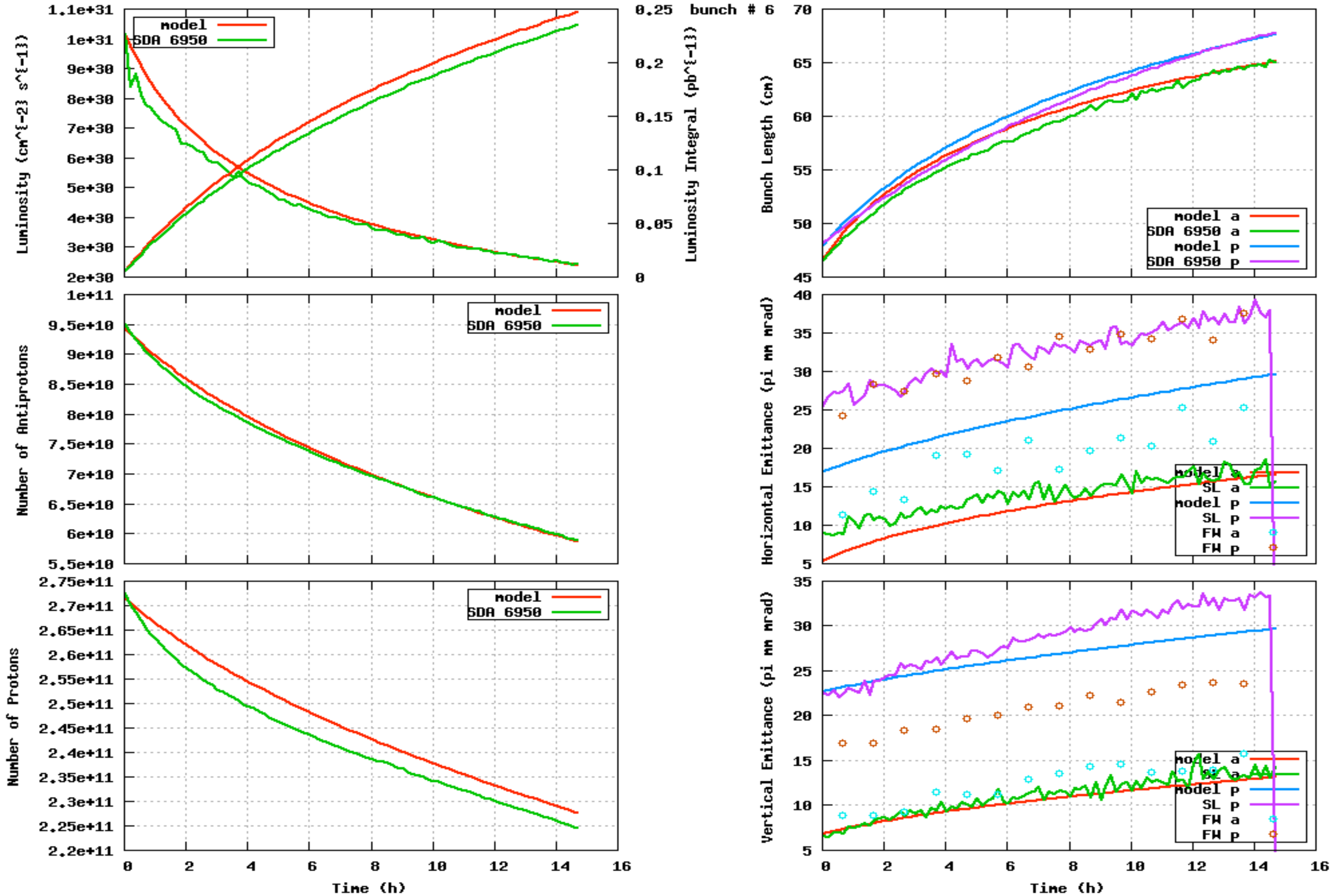
$$\frac{d\varepsilon_x}{dt} = -\frac{2\varepsilon_x}{\tau_{SRx}} + \frac{d\varepsilon_{xSR}}{dt} + \frac{d\varepsilon_{xIBS}}{dt} + \frac{d\varepsilon_{xBB}}{dt} + \frac{d\varepsilon_{xExt}}{dt}$$

$$\frac{d\varepsilon_y}{dt} = -\frac{2\varepsilon_y}{\tau_{SRy}} + \frac{d\varepsilon_{ySR}}{dt} + \frac{d\varepsilon_{yIBS}}{dt} + \frac{d\varepsilon_{yBB}}{dt} + \frac{d\varepsilon_{yExt}}{dt}$$

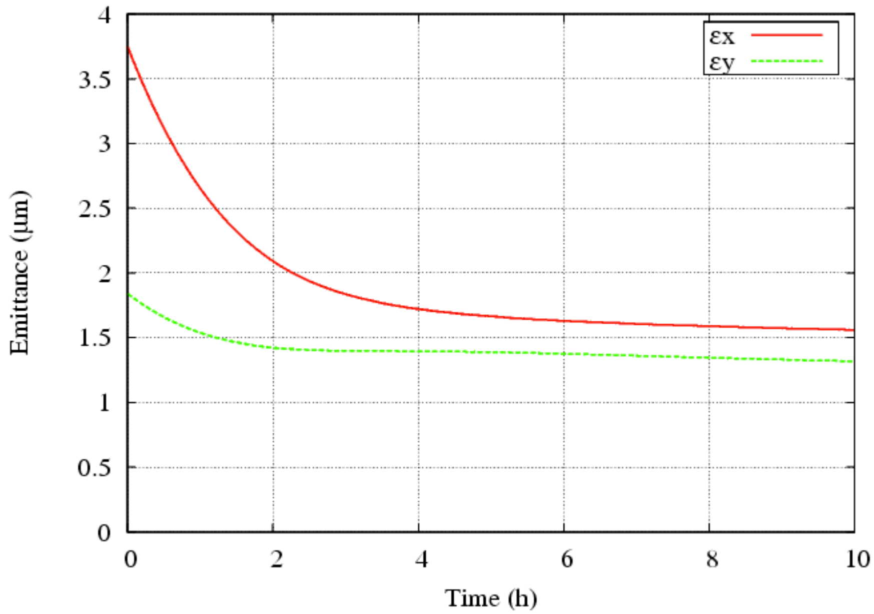
$$\frac{d\sigma_E^2}{dt} = -\frac{2\sigma_E^2}{\tau_{SRE}} + \frac{d\sigma_{SR}^2}{dt} + \frac{d\sigma_{IBS}^2}{dt} + \frac{d\sigma_{BB}^2}{dt}$$

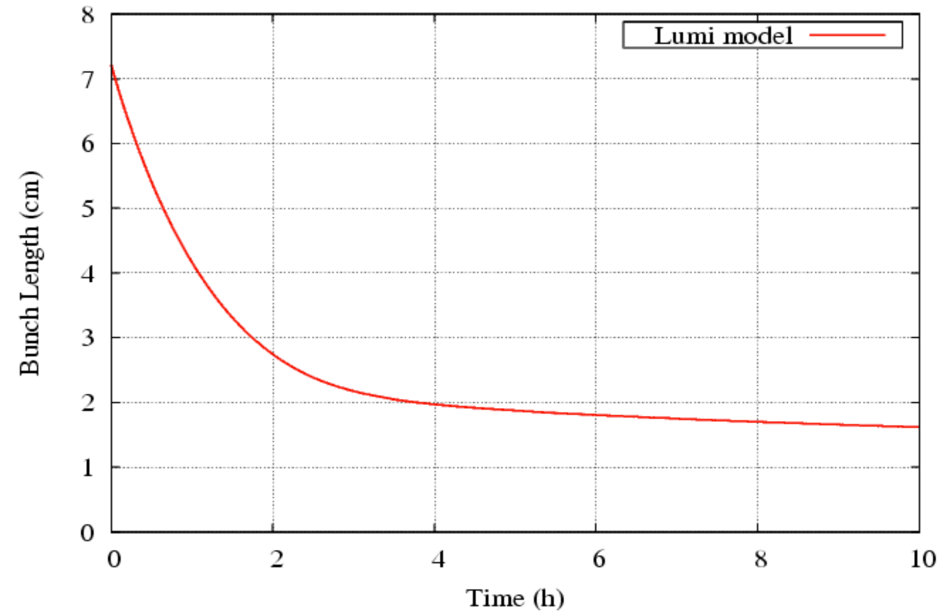
$$\frac{dN}{dt} = -N_{IP}\frac{L}{N_b}\sigma_{tot} - \frac{N}{\tau_{Ext}}$$

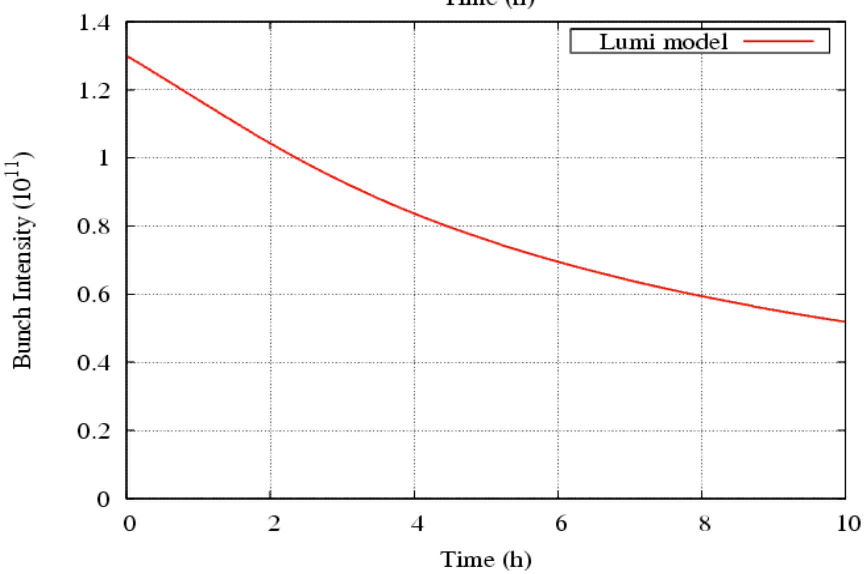
Luminosity evolution model example.
Tevatron store 6950 $L_0=3.5\times10^{32}$ $cm^{-2}s^{-1}$

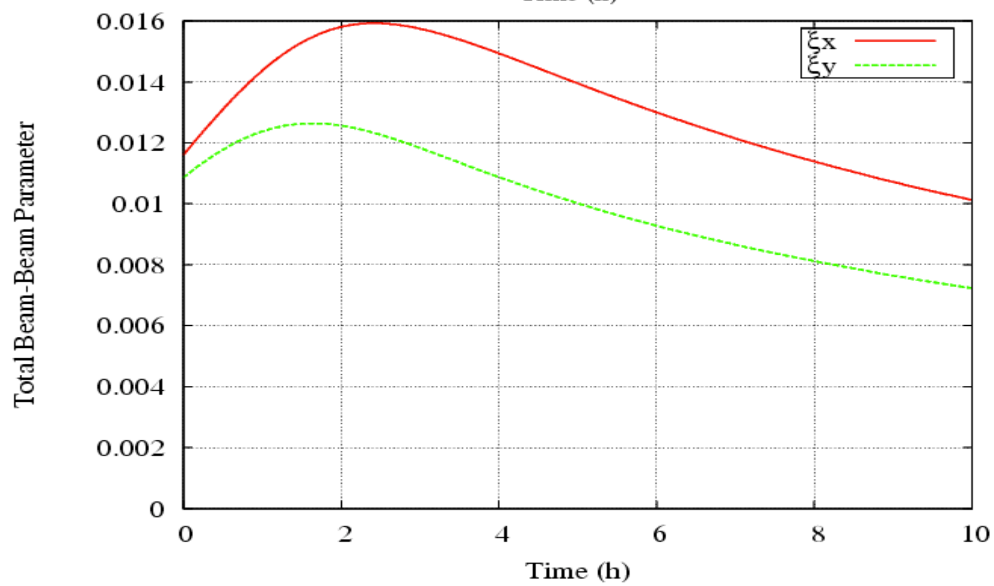


Evolution of beam parameters

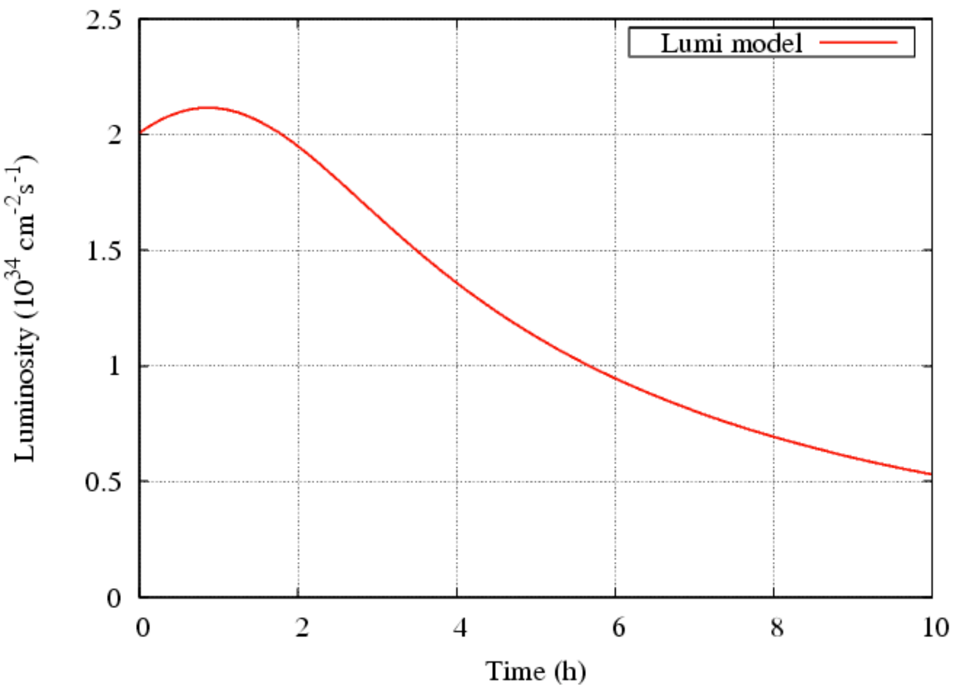


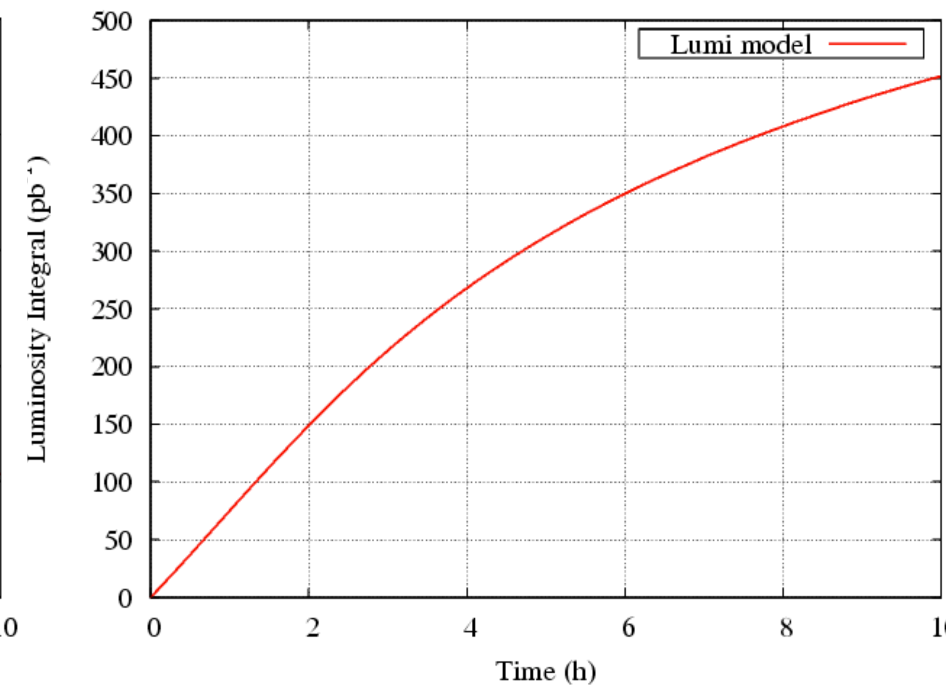






Luminosity and luminosity integral



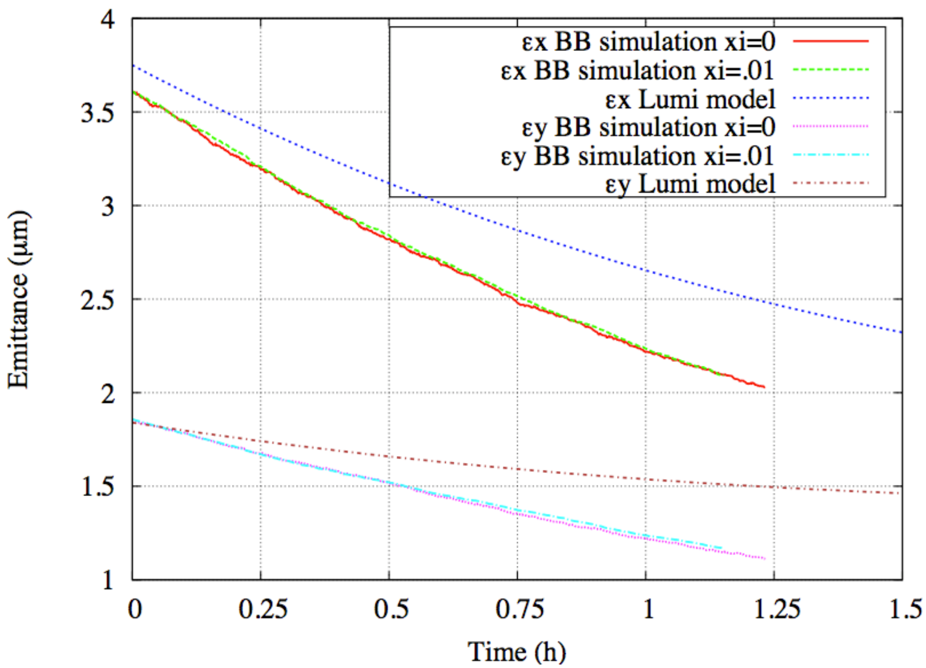


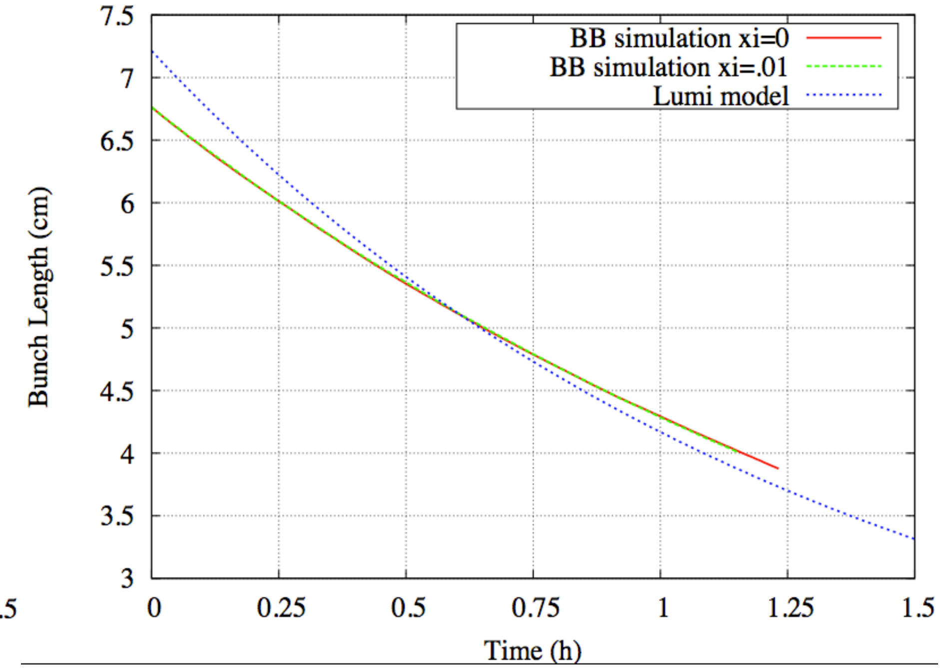
Lumi integral for 10h store = 450 pb^{-1}

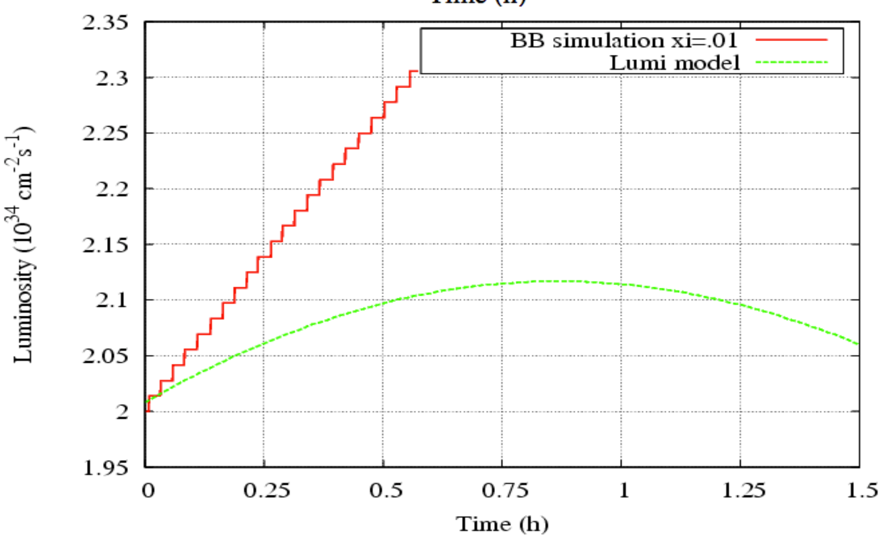
Beam-beam simulation

- Weak-strong, 5000 macro-particles, 6D
- 5×10^7 turns (1.23 h) – no long-range collisions only 2 main IPs
- SR damping and IBS rates once per turn
- No particle losses due to luminosity, no diffusion due to scattering at the IP

Beam-beam simulation results

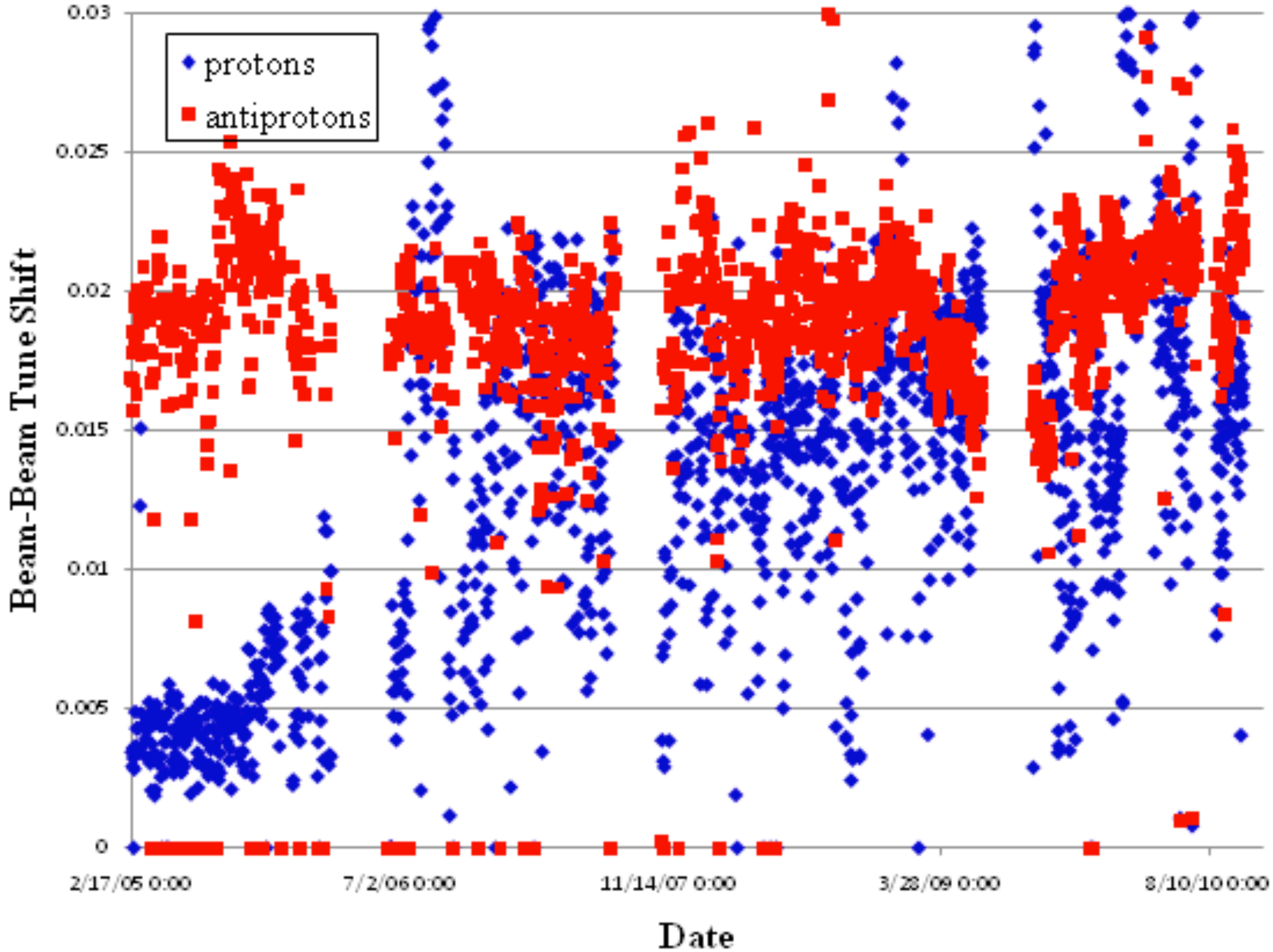






No particle losses at ξ=0.01

Tevatron beam-beam parameter



Lumi integral loss is ~5-7% up to ξ=0.025

Summary

- Synchrotron radiation damping is a significant effect for HE-LHC
- Luminosity evolution model with IBS and SR confirms that luminosity integral of 450 pb^{-1} is possible for 10 h store
- Simplified (no LR collisions) beam-beam simulation with IBS and SR predicts no losses. From Tevatron experience it is reasonable to expect ~5% loss of luminosity integral due to beam-beam.