On the Luminosity Lifetimes, Emittance Growth Rates.... Intra-Beam Scattering at 980 GeV, for Protons.

Relevant Machine/Beam Parameters
Lorentz boost γ = 1045. (980 GeV)
Average $\beta_{x,\,y}$ function ~ 71.5 m.
Average Dispersion D_x ~ 2.84 m.
Transverse Coupling κ ~ 0.3 ?
Revolution Frequency f = 47713 Hz

Proton Beam
# of protons/per bunch ~ 1.70 to 2.30 e^{11}
Typical Bunch Length σ_τ = 2.1 ns.
$\delta P/P \sim 1.4\ 10^{-4}$
Transverse Emittance (x,y) ~ 25 pi mm mRad (95%)
(From Flying Wire)
Effective Transverse Emittance ~ 16 to 19 pi mm mRad
(From Luminosity measurements)

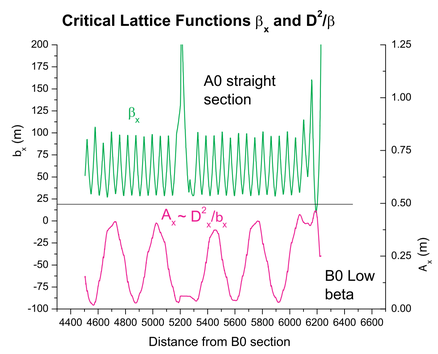
$$\begin{bmatrix} d\epsilon_x/dt \\ d\epsilon_y/dt \end{bmatrix} \approx \frac{L_c\, N_0\, r_0^2\, Ax_{av}}{4\,\sqrt{2.}\,\gamma^3\,\sigma_\tau\,\sigma_x\,\sigma_y\,\sqrt{\theta_x^2+\theta_y^2}} \begin{bmatrix} 1-\kappa \\ \kappa \end{bmatrix}$$

where

$$A_x = \frac{D_x^2 \;+\; (dD_x/ds\,\beta_x \;+\; \alpha_x\,D_x)^2}{\beta_x}$$

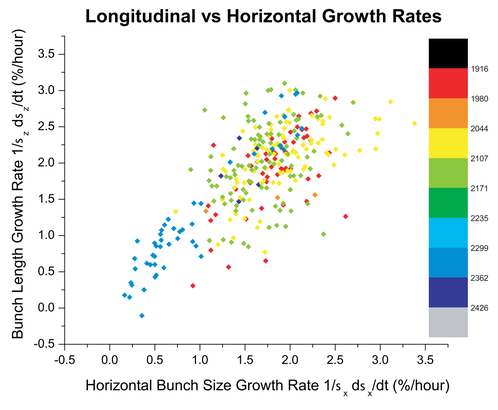
Likewise, longitudinally,

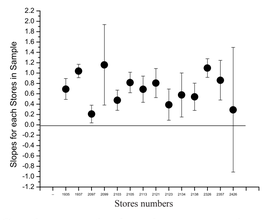
$$r_{\epsilon,z} = \frac{d\epsilon_s}{\epsilon_s\,dt} = \frac{L_c\, N_0\, r_0^2\, \Gamma_s^2}{4\,\sqrt{2.}\,\gamma^3\,\sigma_\tau\,\sigma_x\,\sigma_y\,\sqrt{\theta_x^2+\theta_y^2}}$$



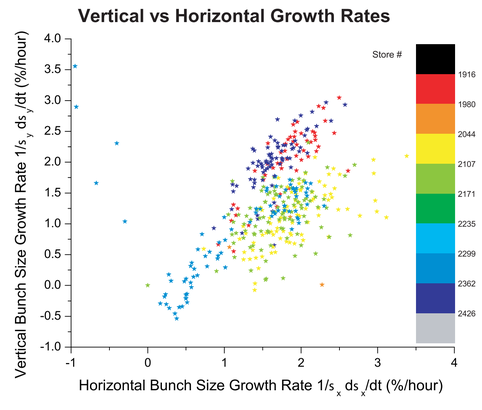
Observations: Correlations between Longitudinal and Transverse, at Synchrotron Light Monitor.

Data Selection : Proton Lifetime due to non HEP collisions (beam lossese due to unknown causes) ~> 70 hours
Synchrotron Light bunch sizes (rms) must have "physically " valid values , between 300 and 700 microns, corresponding to reasonable emittances. Growth rate fits performed on the raw data rejects points that are at ~ 5 σ off the average curve.





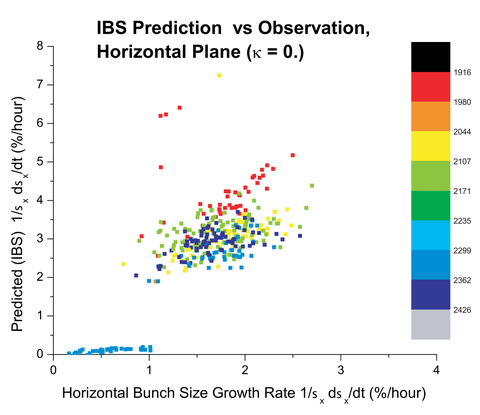
Such correlation between bunch size growth rates in different planes shown here and below can almost be established with any single store. Shown above are the result of simple linear fits performed on th data shown on the left, for each store, individually

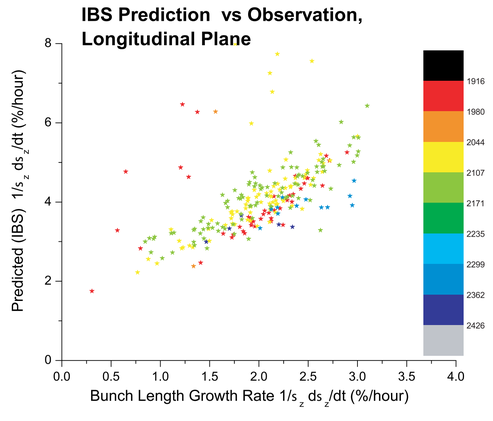


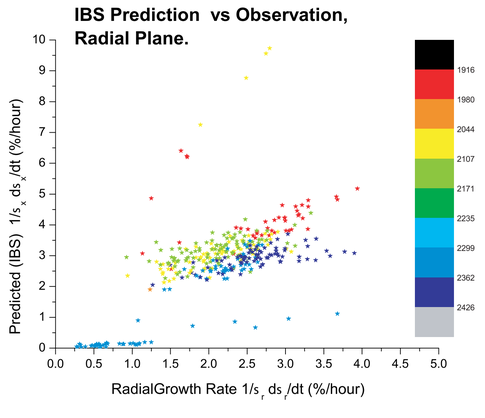
While the relationship between the horizontal and longitudinal emittance growth rates was anticipated, the correlation between the growth rates in the horizontal and vertical planes is troublesome. We have other indications coming from direct lattice measurement that the Tevatron has a rather strong betatron coupling factor. Thus, bunches are expanding in all 3 planes at the rate of ~ 2 to 3 percent per hour, at the beginning of the store. These rate slowly go down as the bunch becomes more diffuse.

Direct Comparison between Intra-Beam Scattering predictions and the measured growth rates

Whle the measured growth rates $1/\sigma\ d\sigma/dt$ *are independent of an overall scale factor in the bunch size, the predicted IBS rate do depend critically on the absolute value of these bunch size and thereby the emittances. Here, we use the Flying Wires, the Synchroton Light Monitor and the Sample Bunch Display to compute the IBS growth rates.*







Conclusion: Despite a few obviously wrong emittance measurements, there is a clear correlation between predicted and observed growth rates. The uncertainties are relatively large (~50%). Yet, this work gives us confidence in the model predicting the luminosity lifetime at higher luminosity, which is expected to be ~ 6 hours.

PAC 2003, TPPB062, May 13, 2003

Fermi National Accelerator Laboratory
A Department of Energy National Laboratory Managed by Universities Research Association