The Variation of CDF/D0 Luminosity Ratio with Time

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Abstract

The two detectors installed at Tevatron, CDF and D0, have different luminosity due to optical function distortion at both IPs. This ratio also changes with time. The study we are taking out is to investigate this phenomenon and try to explain it with hourglass effects, beam separation at IP and crossing angle effects, etc. The measured data are also included in the analysis, and give out a predict luminosity ratio change with time. The results are mostly agree with our observation, but still some other effects we don't understand very clear yet.

Introduction

There are two detectors, CDF and D0, installed at Tevatron. The designed luminosities for both detectors are the same, but since the actual optical function varies from ideal value, they have different luminosity. At the same time, we also observed that the luminosity ratio varying with time, Fig. 1. This paper is to investigate some possible reasons that could cause such effects, and estimate the effects by using measured data.

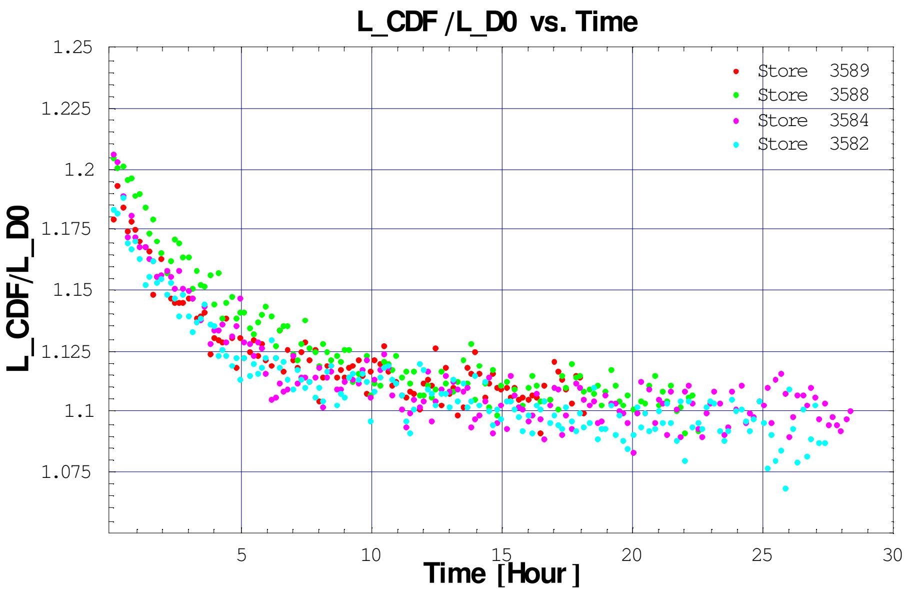

Fig. 1: CDF/D0 Luminosity ratio vs. Time (Store 3589/3588/3584/3582)

The luminosity [1] in Tevatron can be written in [1]. Here we assume that $\beta_x^* = \beta_y^*$, $\sigma_z = \sqrt{\sigma_{z,p}^2 + \sigma_{z,\bar{p}}^2}$, f_0 is the circulation frequency of beam, B is the bunch number in each beam, N is bunch population, ε is the beam emittance. The subscript (p, $\bar{p}$), (x, y) indicates beam type and plane.

$$L = \frac{3\pi f_0 B N_p N_{\bar{p}} \gamma}{\beta^* \sqrt{\varepsilon_x^p + \varepsilon_x^{\bar{p}}} \sqrt{\varepsilon_y^p + \varepsilon_y^{\bar{p}}}} H\left(\frac{\beta^*}{\sigma_z}\right) \qquad [1]$$

where:

$$H\left(\frac{\beta^*}{\sigma_z}\right) = \sqrt{\pi}\left(\frac{\beta^*}{\sigma_z}\right) e^{\left(\frac{\beta^*}{\sigma_z}\right)^2} \left[1 - \frac{2}{\sqrt{\pi}} \int_0^{\frac{\beta^*}{\sigma_z}} e^{-t^2} dt\right]$$

Since we are investigating luminosity ratio depending on time [2], we only care about those parameter that their time dependencies are different for both IPs [2].

$$\frac{L_{CDF}}{L_{D0}} = \frac{\beta_{D0}^* \sqrt{\varepsilon_{x,D0}^p + \varepsilon_{x,D0}^{\bar{p}}} \sqrt{\varepsilon_{y,D0}^p + \varepsilon_{y,D0}^{\bar{p}}}}{\beta_{CDF}^* \sqrt{\varepsilon_{x,CDF}^p + \varepsilon_{x,CDF}^{\bar{p}}} \sqrt{\varepsilon_{y,CDF}^p + \varepsilon_{y,CDF}^{\bar{p}}}} \frac{H\left(\frac{\beta_{CDF}^*}{\sigma_z}\right)}{H\left(\frac{\beta_{D0}^*}{\sigma_z}\right)} \qquad [2]$$

Hourglass effect

CDF and D0 luminosity ratio due to hourglass effects has been analyzed independently by V. Shiltsev and V. Lebedev [2] by using an empirical formula [3]. The results show that hourglass effect can only contribute part of the variation. We have to investigate other effects.

$$H\left(\frac{\beta^*}{\sigma_z}\right) = \left(\frac{1}{\sqrt[3]{1 + 1.3 * (\sigma_z / \beta^*)^2}}\right) \qquad [3]$$

Before going further in the investigation, the hourglass effect has been estimated by using more precise formula [1] instead of [3]. From the beta functions reported by CDF/D0 [3], I have chosen $\beta_x^* = \beta_y^*$, $\beta_{CDF}^* = 0.25\text{m}$, $\beta_{D0}^* = 0.36\text{m}$ in the calculation. By using measured bunch length, the hourglass effect has been calculated and shown in Fig. 2. The measured luminosity ratios are also shown in same plot for comparison. The difference between formula [1] and [3] is shown in Fig. [3].

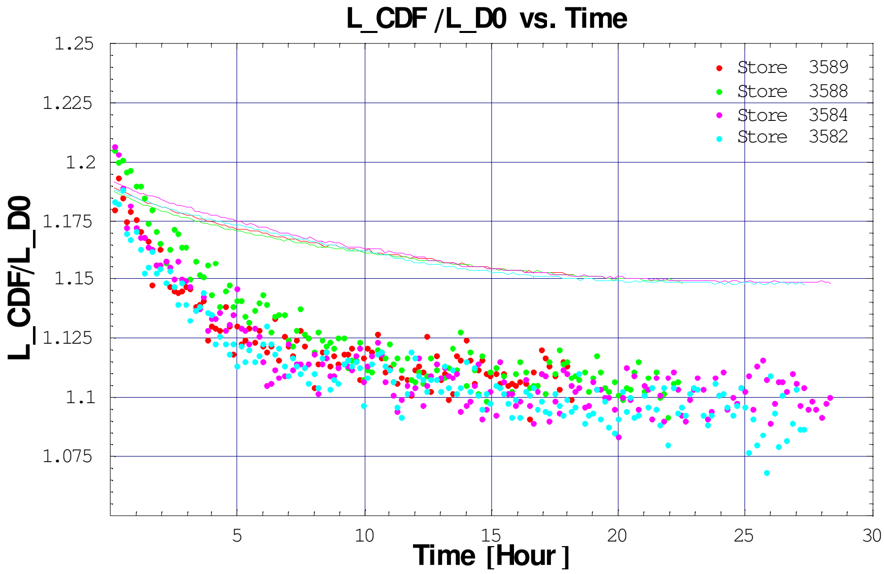

Fig. 2: Measured luminosity ratio comparison with hourglass effect
Dots are measured value. Lines are calculated value

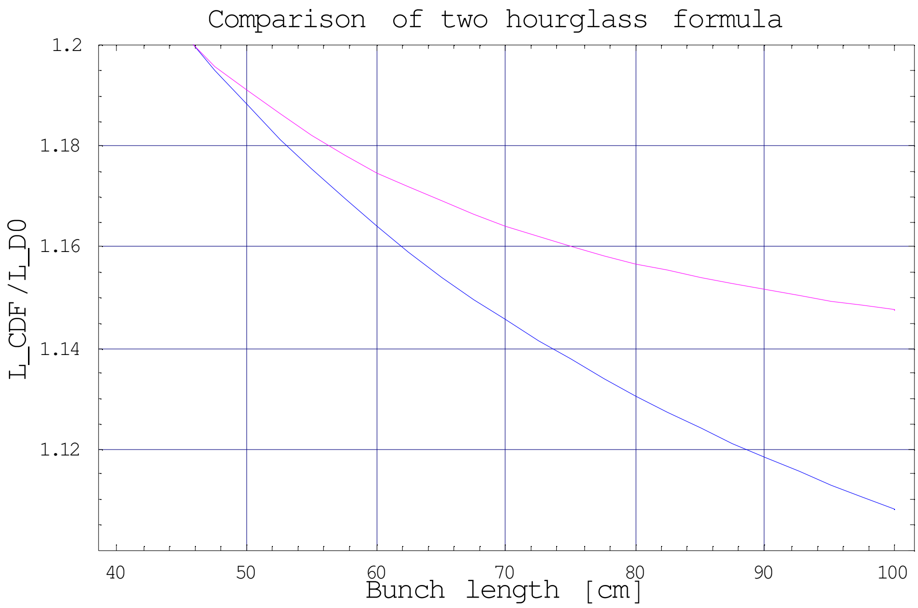

Fig. 3: Comparison of two hourglass formulas
Pink trace is result formula [3]. Blue trace is result from formula [1]

Effective emittance effect

From Fig. 2, it's obviously that hourglass effect cannot fully explain the measured ratio change, there must be some other reasons. Formula [2] tells us that if beam emittance varying with time is different for CDF and D0, it also can contribute to the ratio variation. As we know that beam emittance is varying with time but same everywhere, so the possible way to make them differ at both IPs is crossing angle and separation which cause effective emittance differ.

Suppose that proton and pbar are separated by 2Δ at IP, the luminosity can be written as [4]. Assume: $\Delta_{CDF}=0$, $\Delta_{D0}=20\mu m$, $\beta^*=35cm$, emittance at beginning of store $\varepsilon(0)=20\pi$ [mm.mrad], end of store $\varepsilon(f)=42\pi$ [mm.mrad], then: $L_{CDF}/L_{D0}(0)=1.09$, $L_{CDF}/L_{D0}(f)=1.04$.

$$\begin{aligned} L &= \left(\int_{-\infty}^{\infty} \frac{N_p}{\sqrt{2\pi}\sigma_x} e^{-\frac{(x-\Delta)^2}{2\sigma_x^2}} \times \frac{N_{\bar{p}}}{\sqrt{2\pi}\sigma_x} e^{-\frac{(x+\Delta)^2}{2\sigma_x^2}} dx \right) \times \cdots \\ &= e^{-\left(\frac{\Delta}{\sigma_x}\right)^2} \left(\int_{-\infty}^{\infty} \frac{N_p}{\sqrt{2\pi}\sigma_x} e^{-\frac{x^2}{2\sigma_x^2}} \times \frac{N_{\bar{p}}}{\sqrt{2\pi}\sigma_x} e^{-\frac{x^2}{2\sigma_x^2}} dx \right) \times \cdots = e^{-\left(\frac{\Delta}{\sigma_x}\right)^2} \cdot L_0 \end{aligned} \qquad [4]$$

Another possible scenario is proton and pbar collide with an angle θ at IP, the effective emittance with crossing angle be expressed in [5]:

$$\begin{aligned} \sqrt{\beta\varepsilon_{eff}(t)} &= \sqrt{\beta\varepsilon(t) + \left(\frac{\sigma_z(t)}{2}\theta\right)^2} \\ &= \sqrt{1+g(t)} \times \sqrt{\beta\varepsilon(t)} \end{aligned} \qquad [5]$$

where, we let $\left(\frac{\sigma_z(t)}{2}\theta\right)^2 = g(t) \times \beta\varepsilon(t)$

The luminosity ratio then be written as:

$$\frac{L_{CDF}}{L_{D0}}(t) = \sqrt{\frac{1+g_{D0}(t)}{1+g_{CDF}(t)}}$$

Assume: $\theta_{CDF}=50mrad$, $\theta_{D0}=0$, $\beta^*=35cm$, emittance at beginning of store $\varepsilon(0)=20\pi$ [mm.mrad], end of store $\varepsilon(f)=42\pi$ [mm.mrad], bunch length at beginning of the store $\sigma(0)=45cm$, end of the store $\sigma(f)=81cm$, then: $L_{CDF}/L_{D0}(0)=0.95$, $L_{CDF}/L_{D0}(f)=0.93$.

Background and Calibration

When we combine all the effects above, the result is still some kind of away from measurement, although it's not very big. Is there any measured fake luminosity coming from background? Fig. 4 shows measured data from 4 recent stores. We can see there is no clear dependency between luminosity ratio and background.

How about luminosity monitor's calibration for both detectors? If they are off by ~1%, it will also contribute a roughly same amount percentage luminosity ratio variation during a store.

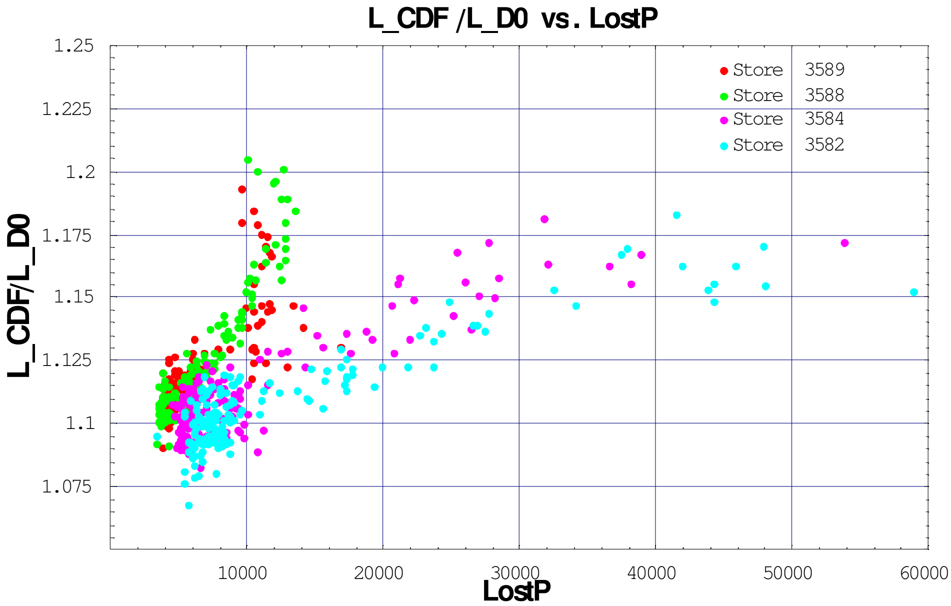

Fig. 4: Luminosity ratio vs. background

Summary

The CDF/D0 luminosity ratio varying with time has been investigated; most part of the variation can be explained by the combination of hourglass effect, crossing angle effect and beam separation at IP. The ratio dependent on background is not very clear. The two detectors calibration might be not the same.

References

[1] Michael J. Syphers, "Accelerator Physics Discussion Group Presentations", Beams-doc-871-v4
[2] Tevatron minutes, June 25, 2004
[3] Tevatron minutes, May 21, 2004