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The D0 Run IIb luminosity measurement

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ABSTRACT

An assessment of the recorded integrated luminosity is presented for data collected with the D0 detector at the Fermilab Tevatron Collider from June 2006 to September 2011 (Run IIb). In addition, a measurement of the effective cross-section for inelastic interactions, also referred to as the luminosity constant, is reported. This measurement incorporates new features that lead to a substantial improvement in the precision of the result. A luminosity constant of $\sigma_{LM} = 48.3 \pm 1.9 \pm 0.6$ mb is obtained, where the first uncertainty is due to the accuracy of the inelastic cross-section used by both CDF and D0, and the second uncertainty is due to D0 sources. The recorded luminosity for the highest E_T jet trigger is $\mathcal{L}_{\rm rec} = 9.2 \pm 0.4$ fb^{-1}, with a relative uncertainty of 4.3%.

1. Introduction

An essential ingredient in cross-section measurements is the integrated luminosity, $\mathcal{L}$, used to normalize the data sample. At D0, the instantaneous luminosity, L, is derived from hit rates produced from inelastic proton–antiproton collisions registered in a dedicated detector system. Measured hit rates are converted to luminosity using a normalization procedure based on the total inelastic cross-section, and the geometric acceptance and efficiency of the dedicated detector system for registering inelastic events. The measurement of the effective cross-section for inelastic interactions, and the assessed recorded integrated luminosity for data collected with the D0 detector at the Fermilab Tevatron Collider from June 2006 to September 2011 are reported. Luminosity L varied during that period in the range $(5-420)\ \mu\text{b}^{-1}\ \text{s}^{-1}$ (equivalent to $(5-420)\times 10^{30}\ \text{cm}^{-2}\ \text{s}^{-1}$). In this luminosity range, the average number of inelastic proton–antiproton interactions per crossing ranges from 0.18 to 14.8 requiring an accurate treatment of multiple interactions.

In this note, a short description of the detector used for the instantaneous luminosity measurement and of the data samples used for this study is followed by a review of the luminosity measurement technique. The following sections describe the backgrounds that affect the luminosity measurement, the calculation of the detector acceptance, and the calculation of the luminosity constant and its uncertainty. In Appendices, the luminosity measurement technique and the background removal are described in more detail.

1.1. Luminosity monitor detector

The Luminosity Monitor (LM) [1,2] consists of two arrays of scintillation counters mounted on the D0 end-cap calorimeter cryostats as indicated in Fig. 1. In the description of the D0 detector a right-handed coordinate system is used. The z-axis is along the proton beam direction. The angles ϕ and θ are the azimuthal and polar angles, respectively. The r coordinate denotes the perpendicular distance from the z-axis.

From the perspective of the proton beam, the upstream LM array is called the "north" LM and the downstream array is called the "south" LM. Each array has 24 wedge-shaped scintillation counters with fine-mesh photomultiplier tube (PMT) readout. The PMT signals are amplified on the detector and are carried on low-loss cables to the LM VME electronics where the charge and the

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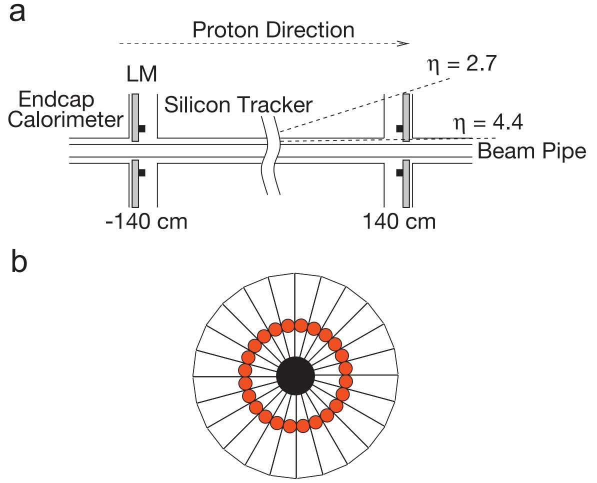

Fig. 1. The Luminosity Monitor layout. In (a) and (b) the solid dots represent the location of the PMTs: (a) $r-z$ view of the two arrays and (b) $r-\phi$ view of one array.

timing of PMT signals are measured. Coverage is provided over the pseudorapidity interval of $2.7<|\eta|<4.4$, where $\eta=-\ln[\tan(\theta/2)]$.

The LM electronics identify in-time hits that are within ± 6.4 ns of the nominal time-of-flight from the center of the D0 detector to the LM. This window is about three times the width of the time distribution for in-time hits. Halo particles typically produce hits that are ~ 9 ns early in one of the detectors. A luminosity coincidence is identified when there is at least one in-time hit in both the north and the south LM detector arrays. Since beam crossings with many early hits from beam halo interactions can lead to luminosity measurement errors, a "halo veto" is applied when there are six or more early hits in one or both detector arrays. The beam crossings that do not trigger the halo veto are called "live crossings".[3]

1.2. Data samples

The data sample that D0 recorded during Run II of the Fermilab Tevatron Collider is split in two periods: (i) data collected between April 2002 and February 2006 (Run IIa), and (ii) data collected from June 2006 to September 2011 (Run IIb). A major difference between the two periods is the addition of an inner silicon layer [3] to the D0 Silicon Microstrip Tracker [4] (SMT) during the 2006 shutdown. Other differences between the two periods include removal of a forward silicon disk on each end of the SMT and introduction of a new beryllium beam pipe with a flange near the LM. The readout system of the LM detector was upgraded between Runs IIa and IIb to reduce the electronic noise [5].

The data from the LM detector information includes measurements of the arrival time and pulse height information for each of the 48 LM counters. In addition, the LM electronics allow the accumulation of histograms of quantities calculated by the LM electronics for calibration and monitoring purposes. These histograms are accumulated at the beam crossing rate with no deadtime.

The Fermilab Tevatron Collider has 1113 possible radio frequency (RF) buckets. The minimal spacing between RF buckets where particles can be placed is one "tick" and corresponds to a gap of 132 ns. One turn of the Tevatron consists of 159 ticks, 36 of which generally contain beam. The ticks that actually contain particles are called "beam bunches", and the collision of proton and anti-proton bunches is called a "beam crossing" or "bunch crossing". The beam bunches are arranged in 3 evenly spaced "bunch trains", separated by a 2.5 μs abort gap, and within each bunch train there are 12 beam bunches, each separated by 396 ns. Ticks that do not contain beam are referred to as "empty ticks".

[3] The definition of live crossings in this context is with respect to the luminosity measurement and not the D0 trigger system.

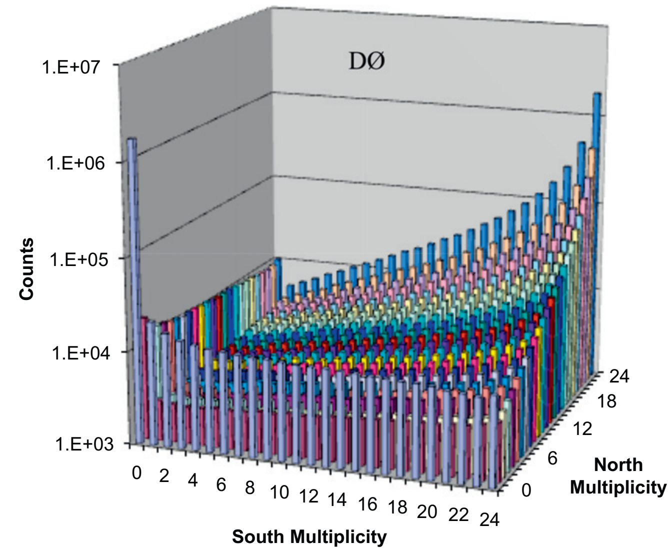

Fig. 2. The 2D multiplicity distribution for live crossings, after background subtraction, collected with the histogramming feature of the LM electronics.

The LM electronics can accumulate two-dimensional (2D) distributions of the multiplicity of in-time hits for the north and south LM detectors. Fig. 2 shows an example distribution accumulated at a luminosity of 63 $\mu b^{-1}\,s^{-1}$ after background subtraction (see Section 3). Three distinct components can be identified: (i) empty crossings with no LM hits, (ii) single-sided interactions where only one side has hits, and (iii) double-sided interactions where both sides have hits.

In this study extensive use is made of these 2D multiplicity distributions since they increase the number of events available for study by three orders of magnitude compared to an earlier analysis [6] (Run IIa) and provide the ability to measure the multiplicity distributions for a single bunch crossing, instead of averaging over 36 bunch crossings. Consequently, rigorous background subtraction techniques can be applied. In addition, data are now acquired over a short period of time (~ 8 min total) such that the typical change in luminosity while the sample is acquired is less than 1%. For contrast, the Run IIa analysis includes $\sim 1\%$ statistical errors due to the measurement being based in low statistics data samples (on the order of $\sim 10\,000$ beam crossings).

Histogram data samples were acquired over a period ranging from August 2008 to January 2009 for a variety of luminosities. In total, 35 such datasets were used for this study.

2. The D0 luminosity measurement

The D0 luminosity measurement is performed by counting the rate of north–south coincidences in the LM detectors using

$$L=\frac{1}{\sigma_{LM}}\frac{dN}{dt} \quad (1)$$

where σ_{LM} is the effective inelastic cross-section for north–south coincidences as seen by the LM. We refer to the quantity σ_{LM} as the "luminosity constant". The effective inelastic cross-section is derived from the total inelastic cross-section, σ_{inel}, and adjusted for the LM system geometric acceptance and the efficiency for registering inelastic events. The inelastic cross-section has been