



A novel technique for determining luminosity in electron-scattering/positron-scattering experiments from multi-interaction events

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ABSTRACT

The OLYMPUS experiment measured the cross-section ratio of positron–proton elastic scattering relative to electron–proton elastic scattering to look for evidence of hard two-photon exchange. To make this measurement, the experiment alternated between electron beam and positron beam running modes, with the relative integrated luminosities of the two running modes providing the crucial normalization. For this reason, OLYMPUS had several redundant luminosity monitoring systems, including a pair of electromagnetic calorimeters positioned downstream from the target to detect symmetric Møller and Bhabha scattering from atomic electrons in the hydrogen gas target. Though this system was designed to monitor the rate of events with single Møller/Bhabha interactions, we found that a more accurate determination of relative luminosity could be made by additionally considering the rate of events with both a Møller/Bhabha interaction and a concurrent elastic ep interaction. This method was improved by small corrections for the variance of the current within bunches in the storage ring and for the probability of three interactions occurring within a bunch. After accounting for systematic effects, we estimate that the method is accurate in determining the relative luminosity to within 0.36%. This precise technique can be employed in future electron–proton and positron–proton scattering experiments to monitor relative luminosity between different running modes.

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1. Introduction

The OLYMPUS experiment [1] measured the ratio of positron–proton to electron–proton elastic scattering cross-sections for a 2.01 GeV beam energy over a range of scattering angles [2]. The analysis depended on the accurate (better than 1%) determination of the relative integrated luminosity between positron-beam running mode and electron-beam running mode. Three luminosity monitoring systems were implemented for the experiment, of which one was a pair of Symmetric Møller/Bhabha (SYMB) calorimeters, designed to use the rate of symmetric scattering from the atomic electrons in the hydrogen target to extract luminosity [3]. Since the Møller and Bhabha scattering cross-sections can be calculated precisely using quantum electrodynamics, this method was expected to have high performance. Møller and Bhabha calorimeters had previously been used successfully for luminosity monitoring with the HERMES experiment [4].

Unfortunately, this method turned out to be ill-suited for the needs of OLYMPUS. Whereas HERMES typically needed the relative luminosity

between running modes with two different beam or target polarization states using the same beam species, OLYMPUS required the relative luminosity between running modes with different beam species. Since the Møller and Bhabha differential cross-sections have different angular dependences close to the symmetric angle, this method required control of the calorimeter acceptance to a better degree than was possible, even with sophisticated simulations. We estimated the accuracy of the relative luminosity determination from SYMB to be on the order of 4%.

Nevertheless, we developed an alternate method to determine the relative luminosity from the SYMB data, achieving an accuracy of 0.36% by comparing the rate of symmetric Møller/Bhabha events to the rate of a specific type of multi-interaction event (MIE). In this specific type of MIE, a symmetric Møller/Bhabha interaction occurs simultaneous to an elastic lepton–proton scattering event in which the lepton enters one of the two calorimeters. While the rate of Møller/Bhabha events scales with luminosity, the MIE rate scales with luminosity squared, and by taking a ratio, the luminosity can be recovered. This MIE method has

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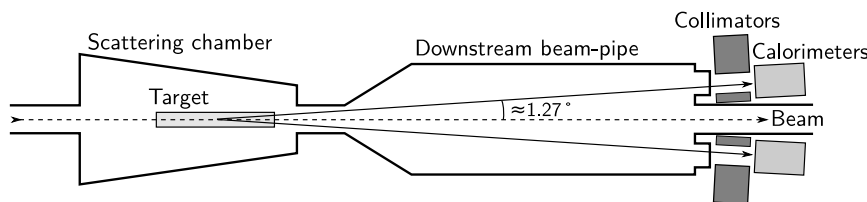


Fig. 1. The SYMB calorimeters were positioned approximately 3 m downstream from the target, on either side of the beamline, as seen in this schematic (not to scale).

Table 1
Relevant geometric parameters for the OLYMPUS SYMB calorimeters.

Parameter	Value
Distance from target to upstream face of collimator	2992 mm
Distance from target to upstream face of calorimeter	3117 mm
Collimator thickness	100 mm
Radius of collimator aperture	10.25 mm
Angle to center of left collimator aperture	1.32°
Angle to center of right collimator aperture	1.28°
Orientation of left collimator aperture	1.30°
Orientation of right collimator aperture	1.22°
Møller–Bhabha symmetric angle	1.27°

three principal advantages that make it robust against many systematic effects:

1. The important quantity is a ratio of rates rather than a single rate, canceling some systematics,
2. The ratio is nearly the same in both electron and positron modes,
3. There is a reduced burden on acceptance simulations.

In this paper, we present a derivation of the MIE method, estimate its associated systematic accuracy for OLYMPUS, and discuss how it might be useful for luminosity monitoring in future experiments.

2. The OLYMPUS experiment

The OLYMPUS experiment collected data at the DORIS storage ring, at DESY, Hamburg, in 2012. DORIS was capable of storing both electron and positron beams, and, in OLYMPUS, the beam species was switched approximately once per day. Determining the relative integrated luminosity of the data from the two different beam species was crucial for the OLYMPUS measurement.

OLYMPUS operated with a fixed hydrogen gas target. The SYMBs were positioned approximately 3 m downstream from the target, at an approximate scattering angle of 1.27°. This corresponded to the symmetric angle for Møller and Bhabha scattering at the beam energy of 2.01 GeV. The two calorimeters were placed on either side of the beam line in order to detect both final state leptons in coincidence. Fig. 1 shows a schematic of calorimeter placement relative to the target and beamline. Relevant distances and angles, determined from the OLYMPUS optical survey, are given in Table 1.

There were two other luminosity monitoring systems in OLYMPUS in addition to the SYMBs. The first was a pair of forward tracking telescopes, which monitored the rate of forward lepton–proton scattering. This method of determining luminosity was relative to the asymmetry, if any, between the electron–proton and positron–proton cross-sections – such as that caused by hard two-photon exchange (TPE) – at the forward scattering angle. However, given a luminosity determination from the SYMBs, the forward tracking telescopes could make a determination of hard TPE. This determination was reported in the OLYMPUS results [2]. The second system was the OLYMPUS slow control system, which recorded the beam current in the storage ring, the flow rate of hydrogen to the target, and the target temperature, which could be combined into a luminosity determination. This method was only accurate to the order of 3%, but had the advantage that it could be made online during data taking, without any simulation or track reconstruction.

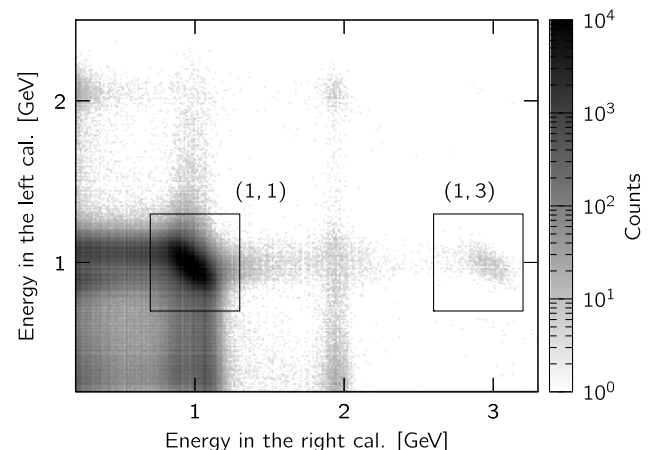


Fig. 2. Luminosity can be extracted from the ratio of (1, 3) MIE events (in the right box) to single (1, 1) Møller/Bhabha events (in the left box).

The SYMB data were digitized using fast histogramming cards, whose acquisition time was less than the ≈ 100 ns bunch separation time at DORIS. The system was dead-time free. The cards provided two-dimensional histograms, in which one axis corresponded to the energy deposited in the left calorimeter and the other axis corresponded to the energy of the right calorimeter. Each fill of the histogram corresponded to one beam bunch passing through the target. The SYMB data consisted of three histograms, one triggered on the left calorimeter, one triggered on the right calorimeter, and one triggered on left–right coincidences. The three histograms had different dynamic ranges. The dynamic range of the coincidence histogram was optimized to cover the energy range of symmetric Møller/Bhabha events. The left- and right-triggered histograms, which were intended as diagnostics, had larger dynamic ranges to cover forward-going elastic ep events. By chance, the dynamic range of the left-triggered histogram was large enough to include events of more than 3 GeV, permitting the analysis discussed in this work. The left-triggered histogram for a subset of data is shown in Fig. 2. There are several dense areas – signal peaks – that correspond to specific processes. The most prominent is due to symmetric Møller and Bhabha scattering, which deposits approximately 1 GeV in both the left and the right calorimeters.

3. Derivation

In this derivation, we consider three types of events of interest. In symmetric Møller/Bhabha events, denoted ee , 1 GeV of energy is deposited in each calorimeter. We denote elastic lepton–proton interactions in which the lepton deposits 2 GeV in the left calorimeter with $ep \rightarrow L$. We denote elastic lepton–proton interactions in which the lepton deposits 2 GeV in the right calorimeter with $ep \rightarrow R$. Since the energy depositions in GeV are approximately integer values, we will use a coordinate system (L, R) to label signal peaks. For example, peak (1, 3) refers to the signal peak with 1 GeV deposited in the left and 3 GeV deposited in the right.

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