Measuring Luminosity at OLYMPUS

Dmitry Khaneft[1] *and OLYMPUS Collaboration*[1]

[1]Johannes Gutenberg-Universitä Mainz, Mainz, Germany

DOI: will be assigned

The OLYMPUS experiment [1] seeks to provide a high-precision measurement (<1% error) of the positron-proton versus electron-proton elastic scattering cross-section ratio. This requires fine control of all systematic uncertainties, including the calculation of the luminosity. For this purpose, multiple independent subsystems were operated alongside the main spectrometer during data taking to allow for empirical determination of the luminosity as a function of time. An approximate value is computed based on the parameters of the lepton beam and gaseous target, while small-angle elastic scatters of known cross-section are counted by two sets of ionization-based detector systems. The most precise value comes from counting coincidences of high-rate (pure QED) lepton-lepton scatters using a pair of calorimetric lead fluoride Cherenkov detectors.

1 Introduction

The OLYMPUS experiment was equipped with an eight-coil toroidal magnet and detectors located in two horizontal sectors on both sides of the beamline (see Fig. 1). Each side consisted of drift chambers for particle tracking and a set of time-of-flight scintillator bars for triggering and measurements of energy deposition, particle position, and timing. Two luminosity monitors were used: symmetric Møller/Bhabha (SYMB) calorimeters at $\theta = 1.291°$ and detector telescopes at $12°$ in both sectors, each consisting of three gas electron multiplier (GEM) detectors interleaved with three multi-wire proportional chambers (MWPCs). In additional the luminosity could be measured using the slow control system.

2 Slow control system

The slow control system (see Fig. 2a) was used to control the gas feed to the target [2]. Together with the beam current measurements and the detector live time the slow control system allowed for a luminosity measurement using the following equation:

$$\mathcal{L} = I \cdot \rho \cdot \Delta t,$$

where I is the beam current, ρ is the target density, and Δt is the measurement time. Although the slow control was not precise enough (±15% absolute and ±3% relative uncertainty) for the cross-section ratio determination, it made possible an on-line luminosity measurement that proved useful during the data taking period.

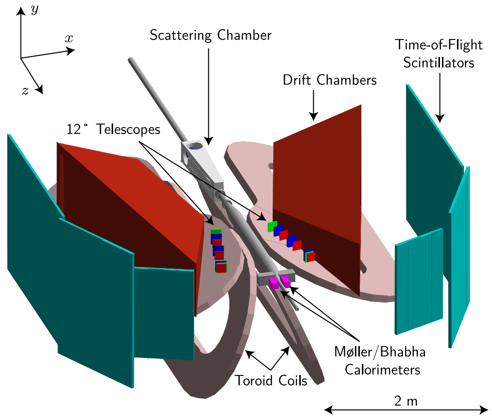
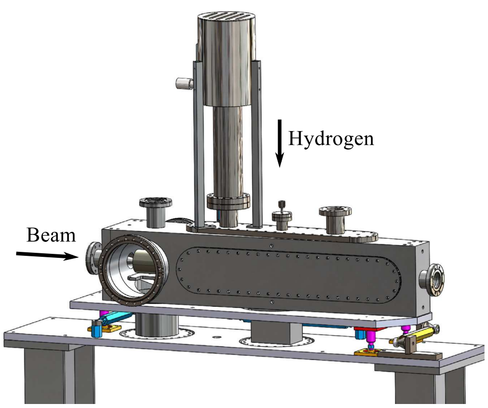
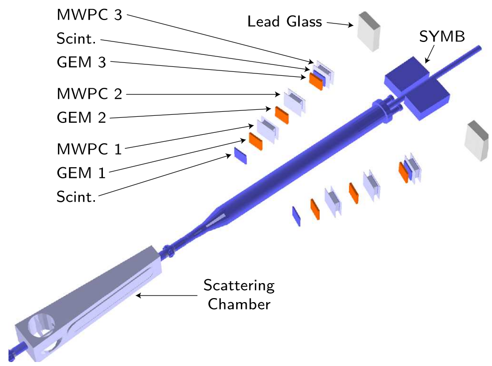


Figure 1: A solid-model representation of the OLYMPUS detector with the top four magnet coils removed to show the instrumented horizontal sectors



(a)



(b)

Figure 2: CAD model of the OLYMPUS scattering chamber (a) and the layout of the $\theta = 12°$ luminosity monitors and the symmetric Møller/Bhabha calorimeters (b).

3 12° monitors

The 12° luminosity monitors (see Fig. 2b) measured elastic lepton-proton scattering in coincidence with the recoil proton detected in drift chambers. With a designed statistical precision of less than 1% per hour of data taking it is capable to measure the electron-proton to positron-proton elastic scattering cross-section ratio, as well as serve as a cross check for other luminosity monitors.

Fig. 3a and Fig. 3b show lepton reconstructed vertex and scattering angle. One can see that acceptance is similar for opposite beam charge and toroid polarity combinations but because the most of data were taken using positive magnet polarity a correction using a Monte Carlo simulation has to be performed.

Fig. 3c and Fig. 3d show lepton reconstructed vertex and scattering angle together with corresponding Monte Carlo simulations, for a positive magnet polarity. The Monte Carlo results reproduce the data very well with only a small difference in scaling.

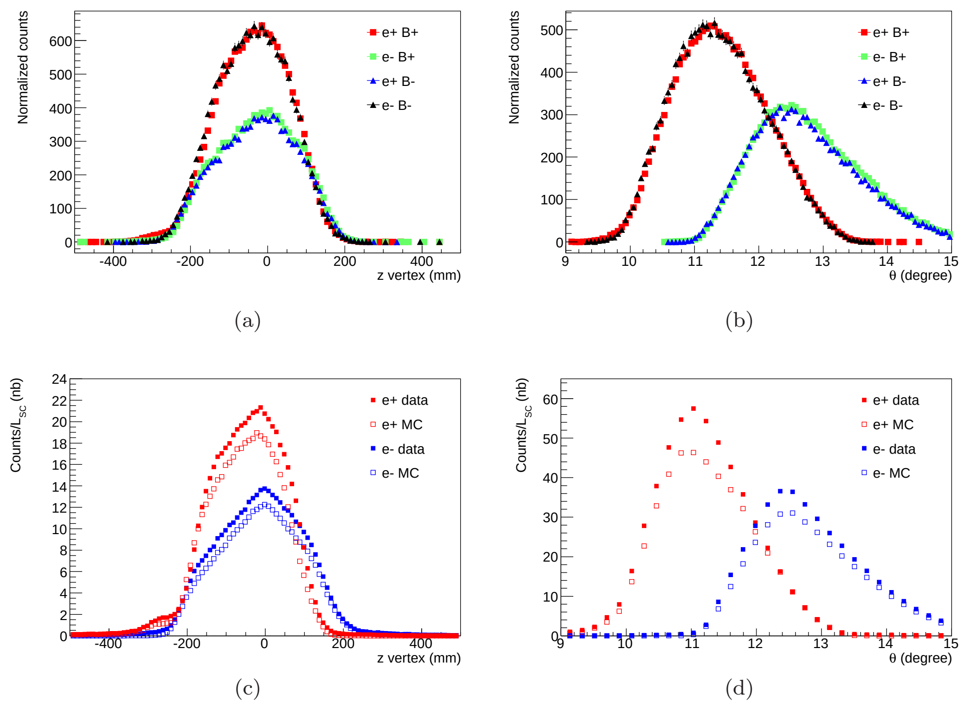


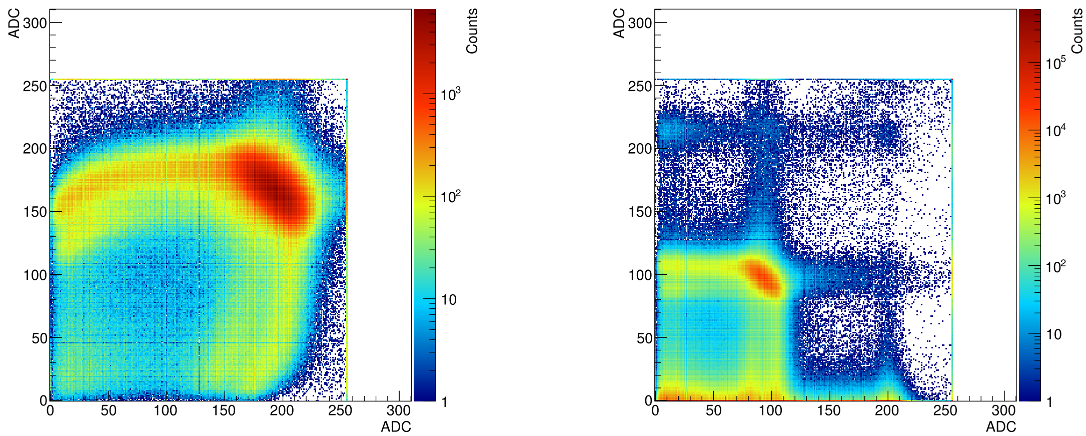
Figure 3: Lepton reconstructed vertex (a,c) and scattering angle (b,d).

4 Symmetric Møller/Bhabha monitor

Symmetric Møller/Bhabha monitor was designed for a high precision luminosity measurements. It detected lepton pairs from symmetric ($\theta = 1.29^\circ$ for a beam energy of 2 GeV) Møller/Bhabha scattering. High event rates made possible to measure a luminosity on the timescale of minutes.

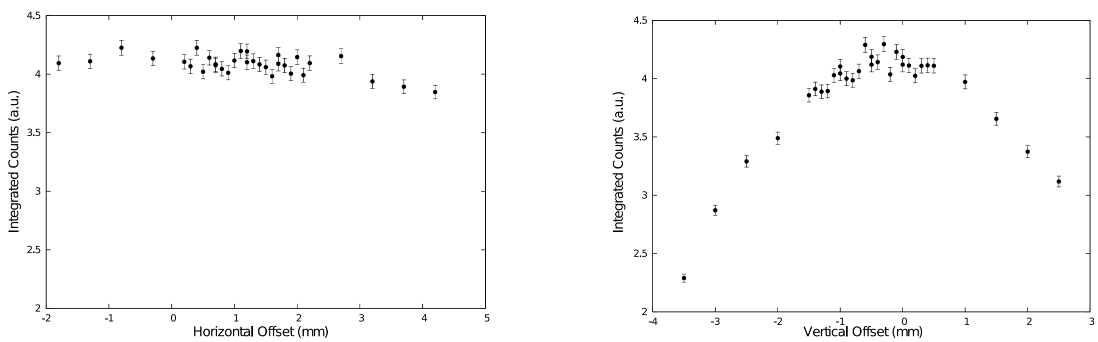
Fig. 4a shows SYMB signal in the coincidence (central crystal in both detectors should had the highest signal amplitude, i.e., contained the center of the electromagnetic shower) mode. Møller/Bhabha events can be seen as a red ellipse in the top right corner. Lines going out of the ellipse correspond to events when one of the leptons lost part of it's energy due to a collision with a collimator. Fig. 4b shows the data taken in the Master/Slave (central crystal in one of the detectors should have the highest signal amplitude) mode. In this mode electronics allowed to detect leptons from lepton-proton elastic scattering that can be seen as a yellow area at the right bottom edge of the figure.

As Møller/Bhabha cross-sections strongly depend on a scattering angle, it is crucial to know the exact position of detectors in respect to the target, as well as the offset and slope of the beam. Monte Carlo simulation (see Fig. 5a and Fig. 5b) shows counts dependency from



(a) (b)

Figure 4: Typical signal of the SYMB in the coincidence mode (a) and Master/Slave mode (b).



(a) (b)

Figure 5: Counts dependency from horizontal (a) and vertical (b) beam offsets.

horizontal and vertical beam offsets. It can be seen that the SYMB detector is very sensitive to the vertical beam offset, while changing horizontal position has much smaller effect.

References

[1] R. Milner, D. Hasell, M. Kohl, U. Schneekloth, N. Akopov, et al. The OLYMPUS experiment. *Nuclear Instruments and Methods in Physics Research Section A*, 741:1–17, 2014.

[2] J. C. Bernauer, V. Carassiti, G. Ciullo, et al. The OLYMPUS internal hydrogen target. *Nuclear Instruments and Methods in Physics Research Section A*, 755:20–27, 2014.