The OLYMPUS Experiment at DESY

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Abstract. Recent determinations of the proton electric to magnetic elastic form factor ratio from polarization transfer measurements at Jefferson Lab indicate an unexpected and dramatic discrepancy with the elastic form factor ratio obtained using the Rosenbluth separation technique in unpolarized cross section measurements. This discrepancy has been explained as the effect of two-photon exchange beyond the usual one-photon exchange approximation in the calculation of the elastic electron-proton scattering cross section. The OLYMPUS experiment at DESY, Hamburg, Germany has been proposed to definitively determine the effect of two-photon exchange in elastic lepton-proton scattering by precisely measuring the ratio of positron-proton to electron-proton elastic unpolarized cross sections.

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INTRODUCTION

The observed decline of the proton electric-to-magnetic form factor ratio from polarization transfer data [1] is in dramatic disagreement with extractions of this ratio from unpolarized cross section data based on the Rosenbluth separation method [2]. Both methods use the single photon exchange assumption including standard radiative corrections [3].

Exchange of two hard photons, which had previously been neglected, is widely considered as the best candidate to explain the observed discrepancy [4, 5, 6, 7]. Most of our understanding on the structure of the proton and atomic nuclei, however, is based upon lepton scattering analyzed in terms of the single photon approximation, hence it essential to precisely quantify the effect from the exchange of two and more photons.

Contrary to standard radiative corrections of the lepton arm, which are calculable based on pure QED principles, calculations of the two-photon exchange amplitude are always dependent on a model used to describe the intermediate off-shell hadronic state between the two photon vertices. Such model descriptions have been carried out e.g. in hadronic [4], or partonic frameworks linked to generalized parton distributions [5]. Also the importance of higher-order radiative effects, not necessarily through two or more photons, has been emphasized [6]. While most calculations tend to remove the discrepancy in the form factor data, different model assumptions generally do not lead to a consistent determination of the size of the two-photon exchange amplitude.

For a satisfactory solution for the concurrent interpretation issue of lepton scattering experiments, it is essential to definitively verify the contribution of multiple photon exchange. Importantly, it is the real part of this amplitude that matters for proton form factor extractions. While the imaginary part generally occurs in small single-spin asymmetries such as with transversely polarized electron beam, transversely polarized pro-

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ton target and in induced transverse recoil polarization, the real part of the two-photon exchange amplitude can manifest itself indirectly in a modified, linear or non-linear dependence on the virtual photon polarization ε of the elastic cross section or polarization transfer.

However, the only stringent observable that directly probes the size of the two-photon exchange amplitude is the difference of unpolarized elastic electron-proton and positron-proton cross sections. Experimentally, it is more advantageous to focus on the ratio of such cross sections. To leading order, the interference of the single and two-photon amplitudes yield a contribution $\propto \alpha^3$ ($\alpha = 1/137$) to the cross section. This interference effect is odd in the number of lepton vertices and therefore changes its sign with the interchange of electron and positron probes. In the presence of two-photon exchange, the e^+/e^- cross section ratio will deviate from unity. This effect is expected to be angular dependent, to be larger at large scattering angles or small value of virtual photon polarization ε, and to increase with Q^2, in order to explain the form factor discrepancy. Existing measurements of the ratio were carried out in the 1960's without showing significant evidence for an effect [8], as displayed in the r.h.s. of Fig. 1; however these data were measured either at low Q^2 or at large ε, where the effect is also expected to be small.

PROPOSED EXPERIMENT

The OLYMPUS experiment has been proposed at the storage DORIS at DESY [9]. It aims to precisely measure the ratio of elastic e^+p and e^-p scattering cross sections to better than 1% total error in a kinematic region where the ratio is expected to deviate from 1 on the order 5-10%, if two-photon exchange is indeed responsible for the form factor discrepancy between Rosenbluth and recoil polarization measurements. OLYMPUS has been designed to minimize systematic and statistical uncertainties

- by running the experiment at the DORIS storage ring at DESY, Hamburg, Germany, which provides both electron and positron beams, each with currents of > 100 mA,
- by scattering leptons from an internal, unpolarized, isotopically pure, essentially background-free hydrogen gas target, resulting in a luminosity of $2 \cdot 10^{33}/(\mathrm{cm}^2\mathrm{s})$,
- by deploying the available symmetric, large acceptance detector BLAST from MIT-Bates Linear Accelerator Center [10, 11, 12], which features a toroidal magnetic field with arbitrary polarity and excellent charged particle tracking capability over a wide range of scattering angles of $\approx 20^\circ - 80^\circ$ and $\pm 15^\circ$ out of plane,
- and by carefully measuring the relative luminosity of OLYMPUS between electron and positron running and alternating magnet polarities based on small-angle elastic scattering.

OLYMPUS has been proposed at DESY in summer 2008 and was conditionally approved by the DESY Physics Research Committee (PRC) in October 2008, provided that appropriate funding can be secured. The current schedule sees the BLAST setup transferred to DESY in 2010 and remounted at DORIS by mid 2011. Assembly and commissioning can be carried out simultaneously with regular synchrotron operations of DORIS. The internal target will be installed early in 2011 and commissioned during DORIS synchrotron operations. A total of three months of production running at a beam energy of 2.0 GeV and a luminosity of $L = 2 \cdot 10^{33}$ /(cm^{2}s) (500 h at 100 mA in each beam species) is required to provide the statistical accuracy of $< 1\%$ up to $Q^2 \leq 2.2$ (GeV/c)^2. Commissioning of the experiment at the standard operating energy of 4.5 GeV will provide an additional precise measurement of the cross section ratio at a large value of $\varepsilon \approx 0.9$ at a similar value of Q^2 in a fraction of the time, which will allow to infer a Rosenbluth-like separation of the e^+p cross section by assuming the known e^-p cross section. In the present scenario, production running of OLYMPUS will be completed by end of 2012. It should be noted that besides OLYMPUS, there are two proposals for experiments to measure the same cross section ratio, yet at slightly different kinematics (generally lower in Q^2) with different techniques and systematics, at the VEPP-3 storage ring in Novosibirsk [13] (scheduled for fall 2009) and at Jefferson Lab [14] (scheduled for end of 2011).

The schematic layout of OLYMPUS is shown on the l.h.s. of Figure 1. Of the original BLAST setup [10], the toroidal magnet (not shown), wire chambers (WC) and time-of-flight scintillators (TOF) will be used. Both tracks of the scattered lepton and recoiling proton will be measured in coincidence by the BLAST detector. The left-right symmetry of the detector with respect to the beam axis effectively doubles the acceptance for coincident lepton-proton events, i.e. two redundant experiments are carried out simulataneously.

The BLAST wire chambers embedded in the horizontal octants of the toroid provide three tracking points of the curved track in the region of maximum magnetic field. The tracking capability will be enhanced with an additional tracking point close to the target where only little magnetic field is present. One GEM (Gas Electron Multiplier) chamber (GC) will be built in each sector for this purpose. The additional near-target tracking point will decouple the determination of scattering angle and vertex location from the momentum reconstruction and will result in improved track resolution, more powerful background suppression and a simplified analysis scheme.

The internal target will be newly built, with a storage tube of ≈ 60 cm length and ellipical cross section, optimized for DORIS beam parameters. Also, a new vacuum scattering chamber will be built allowing access to more forward scattering angles than in the previous geometry of BLAST. Much of the BLAST trigger and data acquisition system can be no longer maintained and will be replaced as well.

In order to control the systematic uncertainties to the percent level, the relative luminosity of the experiment in a cycle of four combinations of beam species and magnet polarity will be measured precisely based on small-angle elastic scattering. The lepton is detected at a forward angle of $\approx 10^\circ$ in coincidence with the recoil proton accepted by the BLAST detector. The kinematics corresponds to low $Q^2 \approx 0.12$ (GeV/c)^2 and large $\varepsilon \approx 0.98$ at 2.0 GeV beam energy, where the cross section is well known and where the two-photon exchange effect is expected to be negligible. The e^+p and e^-p cross sections are hence expected to be equal and the ratio of count rates becomes a monitor of the respective luminosity ratio. With the given luminosity of $2 \cdot 10^{33}$ / (cm^{2}s) the statistical error of this monitor is better than 1% in one hour at 4.5 GeV, with even a factor 20 higher counting statistics at 2.0 GeV. It is anticipated that the beam will be switched between positrons and electrons and the magnet polarity be reversed of the order once per day or every two days. By cycling through four states, the detection efficiencies for lepton and proton detection cancel out exactly. This way, about 100 random cycles through the four running states will reduce any systematics, that are associated with slowly varying control parameters such as detector efficiencies or field drifts, by an order of magnitude. The systematic error of the cross section ratio in one cycle only needs to be better than 10% if a total systematic error of 1% is the set goal.

For the detection of electrons or positrons at forward angle, a GEM tracking telescope based on three tracking planes will be constructed for each sector. Each tracking plane will be built as a 10×10 cm^2 triple-GEM detector with stereo-strip readout, following a design similar to that of the GEM detectors used at COMPASS [15] and recently realized in a prototype at MIT [16]. The spatial resolution of better than 100 μm will allow to reconstruct the lepton vertex at the extended target with a similar resolution as is possible for the recoil proton measured with BLAST.

The r.h.s. of Figure 1 shows the projected statistical uncertainties for the e^+p to e^-p cross section ratio at a beam energy of 2.0 GeV as a function of virtual photon polarization along with previous data [8] and one example theoretical expectation [4]. The systematic uncertainties of the ratio are expected to be less than 1%.

To summarize, the proposed OLYMPUS experiment at the lepton storage ring DORIS at DESY will provide a definitive determination of the two-photon exchange effect by precisely measuring the e^+p / e^-p unpolarized cross section ratio up to $Q^2 = 2.2$ (GeV/c)^2 and virtual photon polarization down to $\varepsilon = 0.37$.

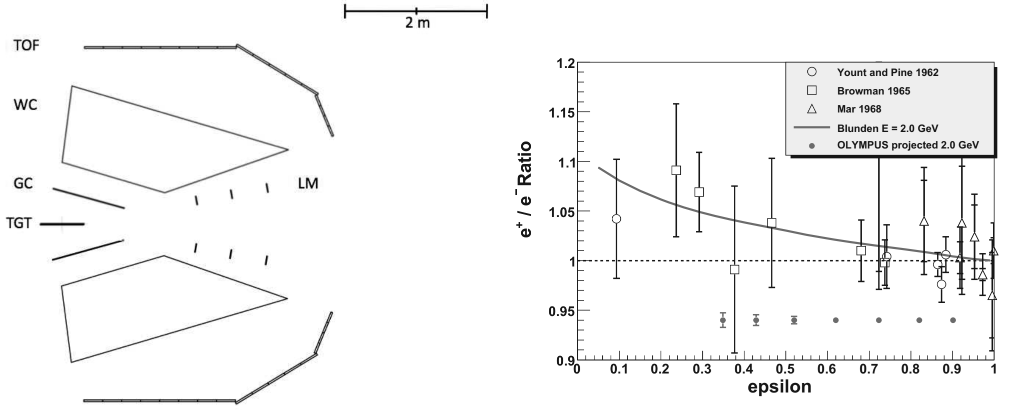

FIGURE 1. Left: Schematic layout of the OLYMPUS experiment, with the beam coming from the left passing through the extended internal target. The displayed components are Time-of-Flight Scintillators (TOF), Wire Chambers (WC), Gas Electron Multiplier Chambers (GC), Luminosity Monitors (LM) and Target (TGT). Right: Projected precision of OLYMPUS for the e^+p to e^-p cross section ratio along with previous data [8] and a theoretical prediction [4].

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