The OLYMPUS Experiment at DESY

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Abstract. The OLYMPUS experiment, which is currently being prepared for running at DESY in 2012, plans to measure the ratio of unpolarized positron-proton and electron-proton elastic scattering cross sections to quantify the effect of two-photon exchange. This effect is widely considered to be responsible for the discrepancy between measurements of the proton electric to magnetic form factor ratio with the Rosenbluth and polarization transfer methods. The experiment uses intense beams of electrons and positrons stored in the DORIS ring at 2.0 GeV, an unpolarized internal hydrogen target and the previous BLAST detector from the MIT-Bates Linear Accelerator Center with modest upgrades. In this contribution, the physics case for OLYMPUS is reviewed and the current status of the project is reported.

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The foundation of all lepton scattering experiments is based on the core assumption that the nature of the interaction between leptons and hadrons is well known and can be described in terms of one-photon exchange. This allows to interpret measured cross sections and polarization observables in terms of form factors to characterize the structure of hadronic systems [1, 2]. In this framework, the structure of the proton and other strongly interacting systems has been studied for many years. However, for about a decade meanwhile, there has been an outstanding discrepancy between measurements of the elastic electric form factor of the proton (in units of the magnetic form factor) between results from two experimental methods, those of the Rosenbluth method which uses unpolarized cross sections [3], and those of proton recoil polarization which uses the amount of polarization transferred to the recoiling proton as a sensitive probe to determine the proton's electric-to-magnetic form factor ratio [4, 5].

Theorists have suggested that neglected higher orders in the Born Approximation corresponding to the exchange of two or more photons present the main explanation for this discrepancy. The structure of the electromagnetic probe introduces three independent TPE amplitudes with real and imaginary parts [6]. While the imaginary parts give rise to small single-spin asymmetries, which can be measured with transversely polarized electron beam [7] or transversely polarized target, only the real parts of the two-photon exchange amplitude are relevant for proton form factor extractions. Contrary to standard radiative corrections [8], the exchange of two hard photons involves knowledge of hadronic structure and is therefore model-dependent. Calculations have been carried out e.g. in hadronic [9, 10], or partonic frameworks of generalized parton distributions and perturbative QCD [11, 12]. In these model frameworks, the effect of two-photon exchange (TPE) generally accounts for about half of the discrepancy found in elastic form factor measurements. In addition, the TPE amplitudes have been constrained in phenomenological fits [13, 14]. The TPE effects are expected to modify the angular dependence of cross sections and of double polarization observables. For a satisfactory understanding of TPE effects it is essential to verify them experimentally. The most stringent way to probe TPE is to compare the e^+p and e^-p unpolarized elastic scattering cross sections. The ratio of both cross sections will be unity if one-photon exchange is exact. As a result of the interference between the one- and two-photon amplitudes, which depends on the sign of the lepton charge, the deviation of the ratio from one directly quantifies the TPE amplitude in units of the single-photon exchange amplitude. This effect is expected to increase with the scattering angle, corresponding to a decrease of the virtual photon polarization ε, and to increase with the four-momentum transfer squared Q^2, in order to explain the form factor discrepancy. The effect vanishes in the limit of $\varepsilon \rightarrow 1$. Previous measurements of the ratio were carried out in the 1960's without showing significant evidence for an effect [15], as displayed in the r.h.s. of Fig. 1. Most of these data were however measured either at low Q^2 or at large ε, where the effect is also expected to be small.

The OLYMPUS experiment [16, 17] aims to precisely measure the ratio of elastic e^+p and e^-p scattering cross sections to better than 1% total error for a beam energy of 2 GeV and a wide range of scattering angles. In the kinematic region covered by OLYMPUS the cross section ratio is expected to deviate from unity by as much as 5-10%, if the form factor discrepancy between Rosenbluth and recoil polarization measurements is caused by two-photon exchange. The OLYMPUS experiment will

- run at the DORIS storage ring at DESY, Hamburg, Germany, which provides both electron and positron beams in excess of 100 mA at 2 GeV,
- detect scattered leptons and recoiling protons from an internal, unpolarized, isotopically pure hydrogen gas target of $3 \cdot 10^{15}$ atoms/s, corresponding to a luminosity of $2 \cdot 10^{33}/(\mathrm{cm}^2\mathrm{s})$,
- reuse the previous BLAST apparatus with modest upgrades from the MIT-Bates Linear Accelerator Center [18, 19, 20], a toroidal spectrometer with excellent tracking capability over a wide range of scattering angles of $\approx 20^\circ - 80^\circ$ and $\pm 15^\circ$ out of plane,
- and redundantly measure the relative luminosity of electron and positron beams and both toroidal magnet polarities using forward-angle elastic ep and symmetric Moller/Bhabha scattering.

Preparations of the OLYMPUS experiment have begun upon approval in 2010 after securing the required funding from the US agencies DOE and NSF, DESY and the German agency DFG. The BLAST detector was transferred from MIT and reassembled at DESY in a park position. In summer 2011 it was brought into final position in the DORIS storage ring. The new internal hydrogen gas target has been designed and constructed at MIT with a 60 cm long target cell made by INFN Ferrara. The target was first commissioned in a test run in February 2011, while the improved final version of the cryogenically cooled target and vacuum system has gone into stable operation in August 2011. The experiment is now commissioned in parallel with the regular DORIS synchrotron operation, with several dedicated beamtests before the first production data taking begin of 2012.

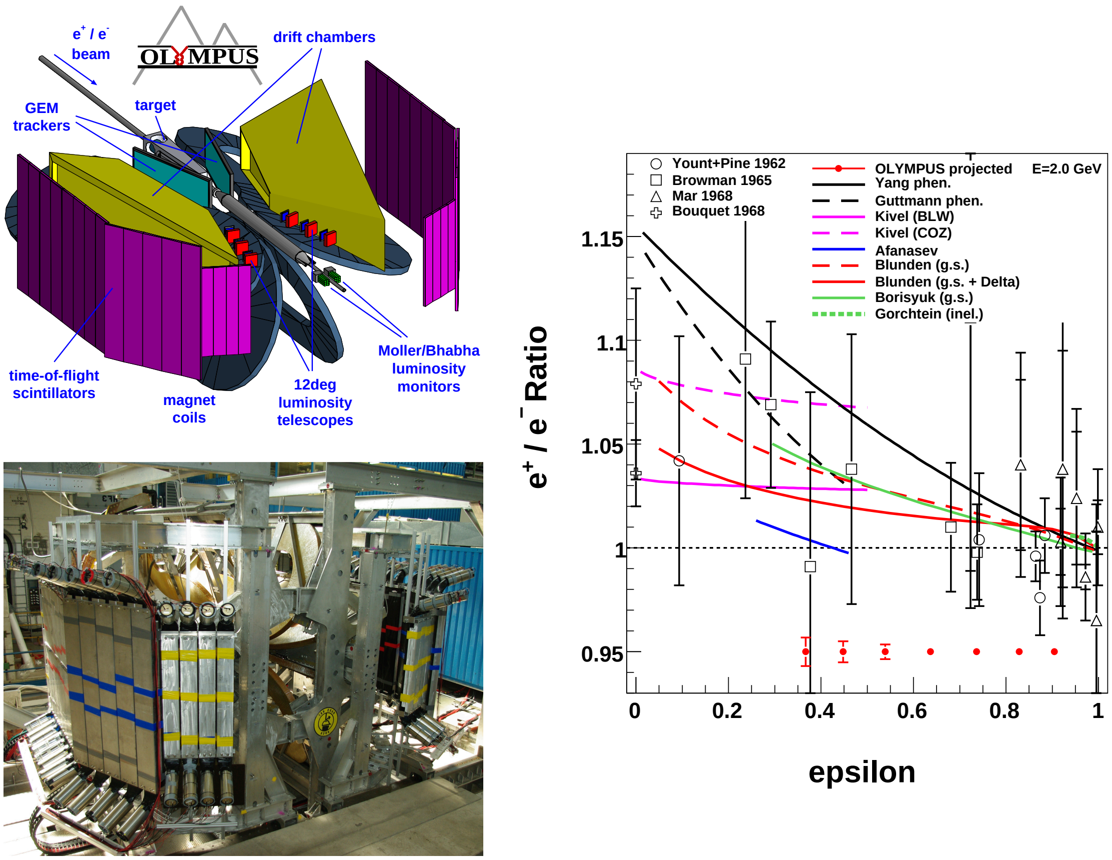

FIGURE 1. *Left:* Design and reality of the OLYMPUS experiment with components labeled in the figure. The photo was taken shortly before the installation into the DORIS ring. *Right:* Projected precision of OLYMPUS for the e^+p to e^-p cross section ratio along with previous data [15] and theoretical predictions [9, 10, 11, 12, 13, 14].

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. The four-momentum transfer region near $Q^2 = 2.5$ (GeV/c)^2 is of particular interest, where the most complete experimental data set of cross sections and polarization observables exists [5, 14].

The layout of OLYMPUS is shown on the l.h.s. of Fig 1. Of the original BLAST setup [18], the toroidal magnet, the wire chambers (WC) and the time-of-flight scintillators (TOF) are used. Forward-angle elastic scattering luminosity monitoring systems have been constructed at Hampton University (GEM detector telescopes) and Petersburg Nuclear Physics Institute (multi-wire proportional chambers, MWPC). In addition, a symmetric Moller/Bhabha monitoring system has been developed at Mainz University. Figure 1 (r.h.s.) 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 [15] and various theoretical expectations [9, 10, 11, 12, 13, 14]. 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 $\varepsilon = 0.37$.

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