TPEX@DESY - Measuring Two-Photon Exchange at the DESY Test Beam Facility

Patrick Moran on behalf of the TPEX Collaboration

Background

Measurements of the proton form factor ratio yield dramatically different results depending on whether a Rosenbluth or a recoil polarization technique is used (Fig. 1).

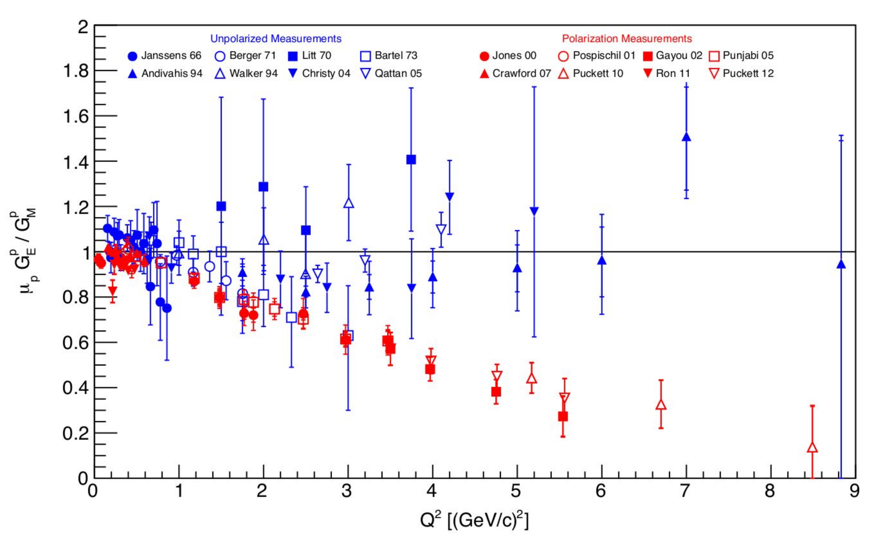

Figure 1. Proton form factor ratio measured using unpolarized (blue) and polarized (red) techniques.

The ep elastic cross section depends on higher order corrections to one photon exchange diagram. “Soft” two photon exchange approximation assumes that the momentum of one of the photons is negligible. “Hard” two photon exchange is difficult to calculate and is typically neglected in calculations. Hard TPE has been suggested as a cause of the form factor discrepancy (Afanasev et. al., 2017).

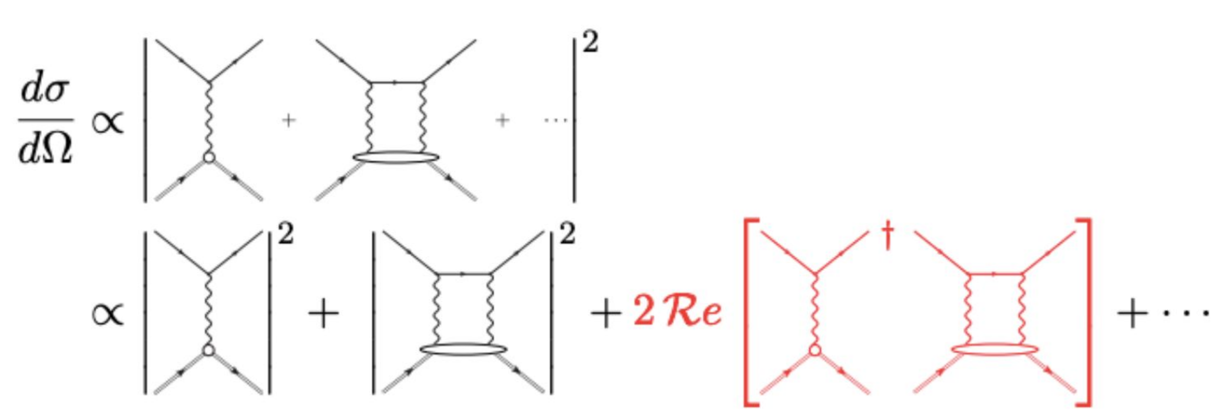

Figure 2. Feynman diagram expansion of elastic scattering cross section. Interference term shown in red.

The interference term in the cross section expansion changes sign between electron and positron scattering (Fig. 2). By measuring the ratio $R_{2\gamma}$ of the electron and positron scattering cross sections, we can determine the contribution of hard TPE.

Recent measurement by OLYMPUS (Fig. 3), VEPP-3, and CLAS have not resolved the form factor ratio discrepancy

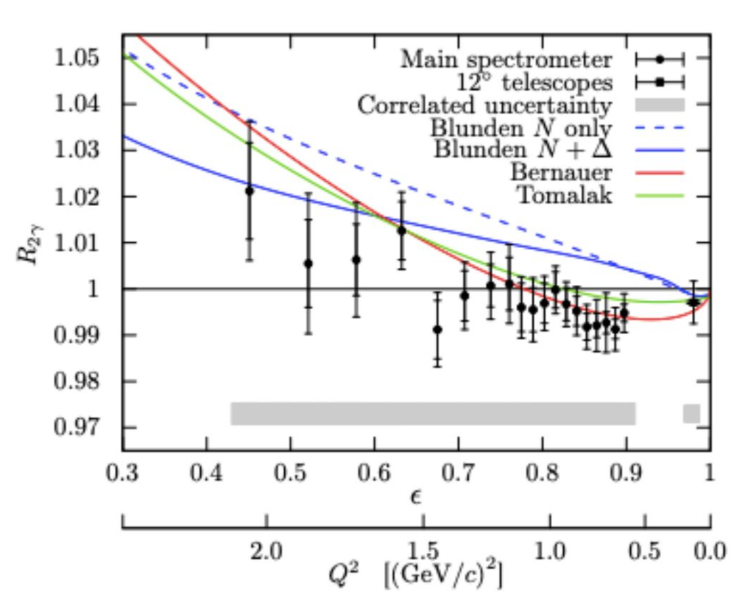

Figure 3. OLYMPUS results for $R_{2\gamma}$ (Henderson et. al., 2017)

DESY

The TPEX measurement requires a sufficiently high-intensity electron and positron beam of a few GeV. DESY in Hamburg, Germany is one of the only facilities in the world capable of providing this. TPEX would run at the DESY II synchrotron.

Beam specifications	
Beam energy	2.0-5.0 GeV
Electron current	60 nA
Positron current	30 nA
Bunch frequency	12.5 Hz

Liquid Hydrogen Target

20 cm long liquid hydrogen target. Areal density of 8.46×10^{-23} atoms·cm^{-2} will give roughly a factor of 200 increase in luminosity relative to OLYMPUS. This, together with the extracted beam currents, overcomes the decrease in cross section with higher energies, enabling measurements at higher Q^2.

Developed by collaborators at the University of Michigan together with MIT Bates and Creare, Inc.

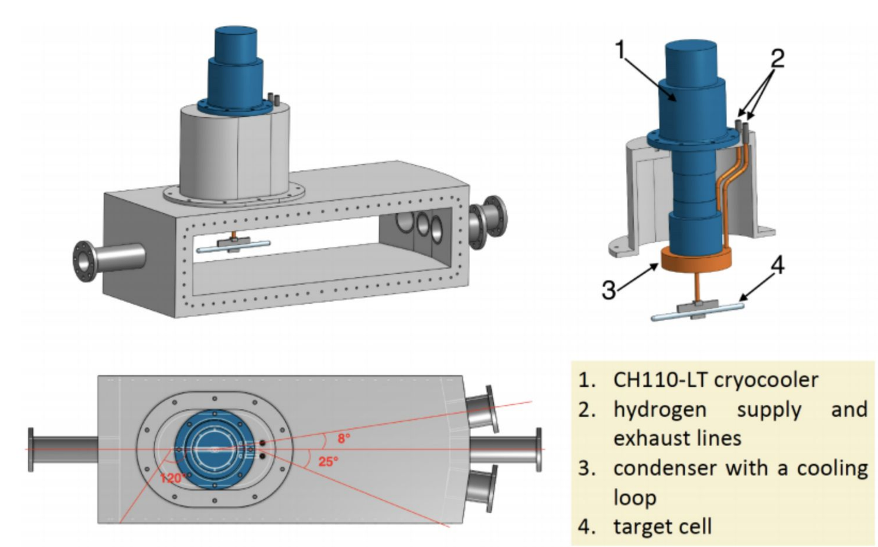

Figure 4. Conceptual design of the TPEX target chamber

Calorimeters

Ten 5x5 arrays of $PbWO_4$ crystals will be placed at ±30°, ±50°, ±70°, ±90°, ±110° at 1m from the target. A ceramic glass calorimeter alternative is also being explored.

Two triple GEM detectors in front of each calorimeter array can provide tracking for hit reconstruction and aiding particle identification. Developed by Hampton University collaborators.

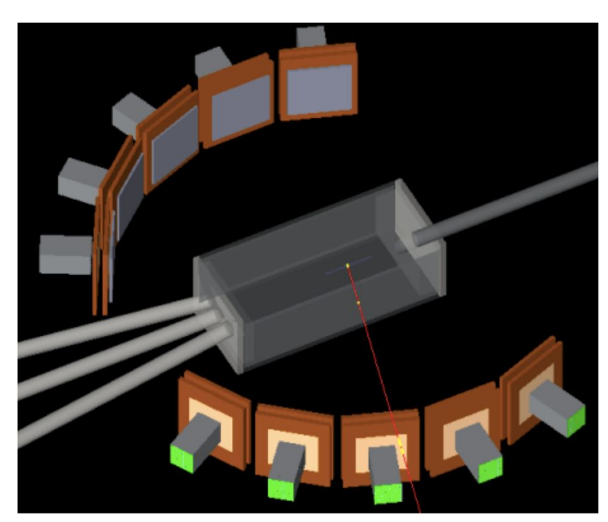

Figure 5. GEANT4 simulation of experimental set-up

Luminosity Monitors

Two quartz Cherenkov luminosity monitors will be placed 3m downstream from the target at ±8°. At this angle, Møller and Bhabha scattering are well-calculated using QCD, are insensitive to misalignments in beam and detector position and are four orders of magnitude higher in rate than elastic scattering. Developed by collaborators at George Washington University.

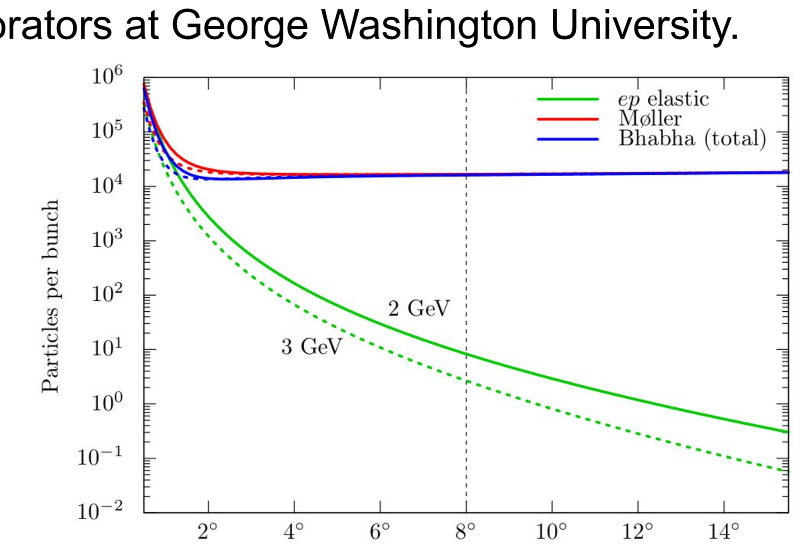

Figure 6. Rates for elastic, Moller and Bhabha scattering vs angle. Dashed line indicates the position of the monitors.

Fall 2019 Test Beam

Using a single 3x3 calorimeter array, data was taken to test the readout system. Overall agreement between simulation and data can be improved but initial results appear promising (Fig. 7). Future tests with 5x5 array planned for this Fall and beyond.

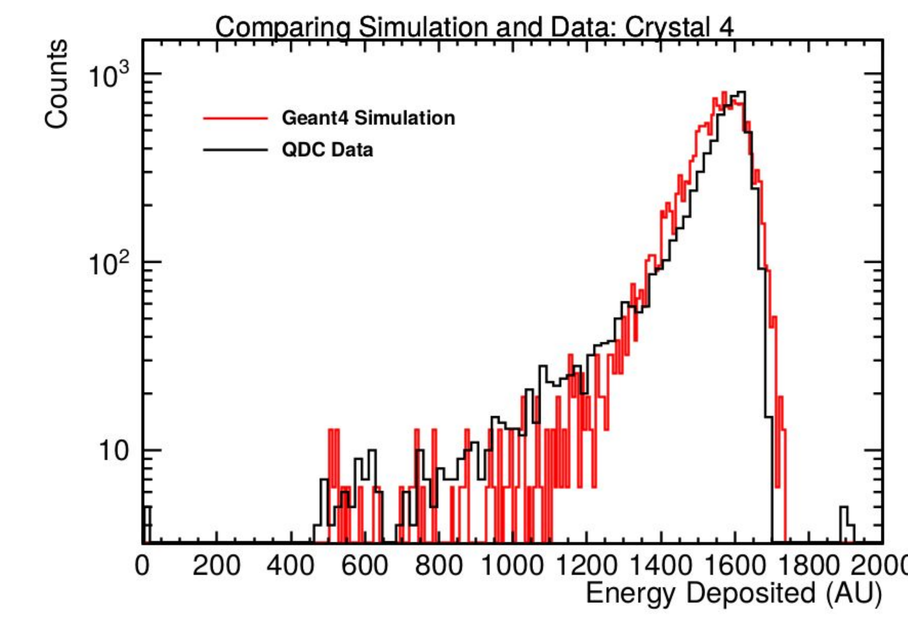

Figure 7. Fall 2019 test beam results. Comparison between GEANT4 simulation and data from QDCs

Physics Reach

The 3 GeV run will extend the form factor ratio measurement up to 4.57 (GeV/c)^2. This exceeds the reach of the OLYMPUS experiment of 2.3 (GeV/c)^2. The 2 GeV run will validate the OLYMPUS results and extend slightly up to 2.7 (GeV/c)^2. Higher energies are also possible in the future.

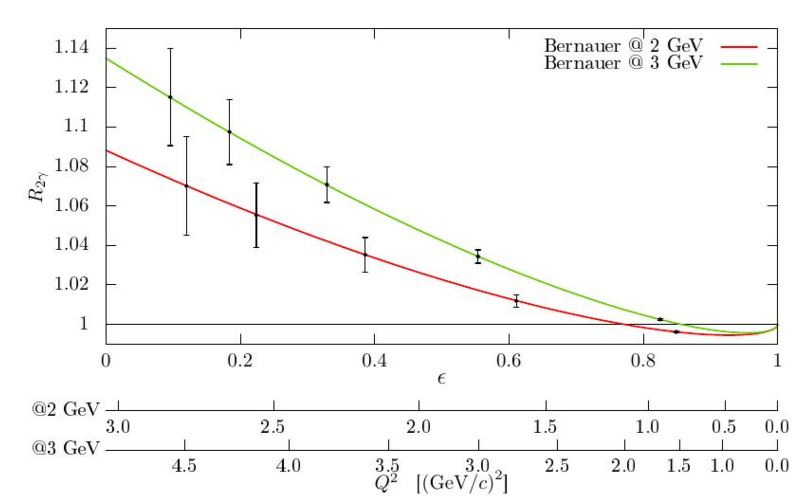

Figure 8. Projected magnitude of two-photon exchange assuming Bernauer’s calculations

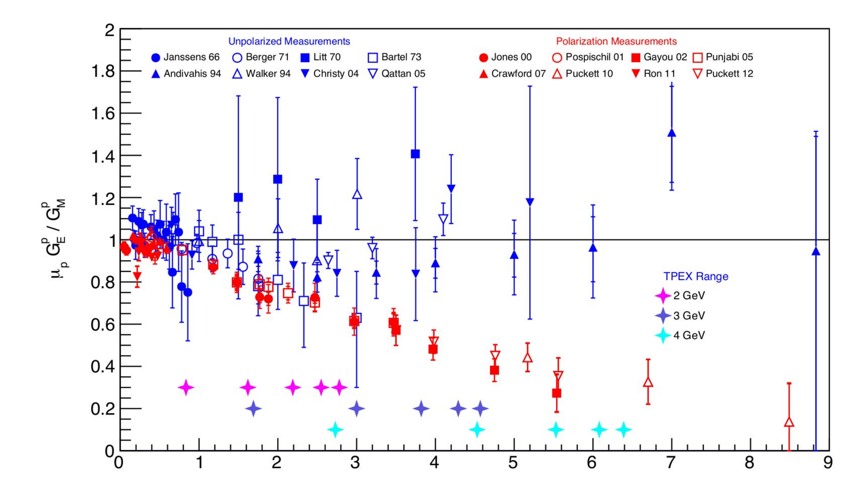

Figure 9. Q^2 range for TPEX overlaid on previous form factor ratio measurements

Collaborating Institutions

Arizona State University, Catholic University of America, Charles University, Deutsches Elektronen-Synchrotron, Friedrich Wilhelms Universität, George Washington University, Hampton University, Johannes Gutenberg Universität, Massachusetts Institute of Technology, Riken BNL Research Center, Stony Brook University, University of Glasgow, University of Michigan, University of Zagreb

References

- A. Afanasev, P. G. Blunden, D. Hasell, and B. A. Raue, Prog. Part. Nucl. Phys. 95, 245 (2017), 1703.03874.
- B. S. Henderson et al. (OLYMPUS), Phys. Rev. Lett. 118, 092501 (2017), 1611.04685.

Work supported by DOE Office of Science, DE-FG02-94ER40818