The OLYMPUS Experiment at DESY

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The OLYMPUS Experiment

- Review of the physics case – two-photon exchange

- The limit of one-photon exchange:
  - What is $G^p_E (Q^2) \leftrightarrow$ proton charge distribution?
  - What is the nature of lepton scattering?

- Description of the OLYMPUS experiment

- Status and timeline
Hadronic Structure and EW Interaction

Lepton scattering → Utilize spin dependence of electromagnetic interaction to achieve high precision

|Form factor|^2 = \frac{\sigma(\text{structured object})}{\sigma(\text{pointlike object})}

→ Interference!

Born Approximation

Inelastic Elastic

Hadronic object

Electroweak probe

Interaction

Structure
In One-photon exchange approximation, elastic form factors are observables of elastic electron-nucleon scattering.

\[
\frac{d\sigma}{d\Omega} = S_0 = A(Q^2) + B(Q^2) \tan^2 \frac{\theta}{2}
\]

\[
= \frac{G_E^2(Q^2) + \tau G_M^2(Q^2)}{1 + \tau} + 2\tau G_M^2(Q^2) \tan^2 \frac{\theta}{2}
\]

\[
= \frac{\epsilon G_E^2 + \tau G_M^2}{\epsilon (1 + \tau)}, \quad \epsilon = \left[1 + 2(1 + \tau) \tan^2 \frac{\theta}{2}\right]^{-1}
\]

\[
\sigma_{\text{red}} = \epsilon G_E^2 + \tau G_M^2
\]

\[\rightarrow\text{Determine } |G_E|, |G_M|, \quad |G_E/G_M|\]
Double polarization in elastic $ep$ scattering:
Recoil polarization or (vector) polarized target

$^1H(e,e'p), \quad ^1H(e,e'p)$

Polarized cross section

$$\sigma = \sigma_0 \left( 1 + P_e \vec{P}_p \cdot \vec{A} \right)$$

Double spin asymmetry = spin correlation

$$-\sigma_0 \vec{P}_p \cdot \vec{A} = \sqrt{2\tau\epsilon(1-\epsilon)} G_E G_M \sin \theta^* \cos \phi^* + \tau \sqrt{1-\epsilon^2} G_M^2 \cos \theta^*$$

Asymmetry ratio (“Super ratio”)

$$\frac{P_\perp}{P_\parallel} = \frac{A_\perp}{A_\parallel} \propto \frac{G_E}{G_M}$$

independent of polarization or analyzing power
All Rosenbluth data from SLAC and Jlab in agreement

Dramatic discrepancy between Rosenbluth and recoil polarization technique

Multi-photon exchange considered best candidate

Jefferson Lab 2000–

Dramatic discrepancy!

>800 citations
Jefferson Lab 2000–

- All Rosenbluth data from SLAC and Jlab in agreement
- Dramatic discrepancy between Rosenbluth and recoil polarization technique
- Multi-photon exchange considered best candidate

Dramatic discrepancy!

>800 citations
Two-Photon Exchange: Exp. Evidence

Two-photon exchange theoretically suggested

TPE can explain form factor discrepancy
J. Arrington, W. Melnitchouk, J.A. Tjon,
Observables involving real part of TPE

\[ P_t = -\sqrt{\frac{2\varepsilon(1-\varepsilon)}{\tau}} \frac{G_M^2}{d\sigma_{\text{red}}} \left\{ R + \frac{\Re(\delta G_M)}{G_M} + \frac{\Re(\delta G_E)}{G_M} + Y_{2\gamma} \right\} \]

\[ P_t = \sqrt{(1+\varepsilon)(1-\varepsilon)} \frac{G_M^2}{d\sigma_{\text{red}}} \left\{ 1 + 2 \frac{\Re(\delta G_M)}{G_M} + \frac{2}{1+\varepsilon} \varepsilon Y_{2\gamma} \right\} \]

\[ \frac{P_t}{P_t} = -\sqrt{\frac{2\varepsilon}{(1+\varepsilon)\tau}} \left\{ R - \frac{\Re(\delta G_M)}{G_M} + \frac{\Re(\delta G_E)}{G_M} + 2 \left( 1 - R \frac{2\varepsilon}{1+\varepsilon} \right) Y_{2\gamma} \right\} \]

\[ \frac{d\sigma_{\text{red}}}{G_M^2} = 1 + \frac{\varepsilon R^2}{\tau} + 2 \frac{\Re(\delta G_M)}{G_M} + 2R \frac{\varepsilon R(\delta G_E)}{\tau G_M} + 2 \left( 1 + \frac{R}{\tau} \right) \varepsilon Y_{2\gamma} \]

\[ \Re(\widetilde{G}_E) = G_E(Q^2) + \Re(\delta G_E(Q^2, \varepsilon)) \]

\[ \Re(\widetilde{G}_M) = G_M(Q^2) + \Re(\delta G_M(Q^2, \varepsilon)) \]

\[ R = G_E / G_M \quad Y_{2\gamma} = 0 + \sqrt{\frac{\tau(1+\tau)(1+\varepsilon)}{1-\varepsilon} \frac{\Re(\widetilde{F}_3(Q^2, \varepsilon))}{G_M}} \]

Born Approximation

Beyond Born Approximation


E04-019 (Two-gamma)

e^+e^- x-section ratio
CLAS, VEPP3, OLYMPUS
Rosenbluth non-linearity E05-017

Slide idea: L. Pentchev
Jlab – Hall C
$Q^2 = 2.5 \text{(GeV/c)}^2$

$G_E/G_M$ from $P_t/P_I$ constant vs. $\epsilon$

⇒ no effect in $P_t/P_I$
⇒ some effect in $P_I$

Expect larger effect in e+/e-!

M. Meziane et al., hep-ph/1012.0339v2
Lepton-Proton Elastic Scattering

\[ \sigma = (1\gamma)^2 \alpha^2 + (1\gamma)(2\gamma)\alpha^3 + \ldots \]

\[ e^- \leftrightarrow e^+ \Rightarrow \alpha \leftrightarrow -\alpha \]

\[ \sigma(\text{electron-proton}) = (1\gamma)^2 \alpha^2 - (1\gamma)(2\gamma)\alpha^3 + \ldots \]

\[ \sigma(\text{positron-proton}) = (1\gamma)^2 \alpha^2 + (1\gamma)(2\gamma)\alpha^3 + \ldots \]

\[ \frac{\sigma(e^+p)}{\sigma(e^-p)} = 1 + (2\alpha) \frac{2\gamma}{1\gamma} \]

\( \sigma \)-ratio to deviate from 1 due to interference of \( 1\gamma \) and \( 2\gamma \) proportional to TPE
Empirical Extraction of TPE Amplitudes

J. Guttmann, N. Kivel, M. Meziane, and M. Vanderhaeghen, hep-ph/1012.0564v1

~6% effect for OLYMPUS@2.0GeV grows with $Q^2$!
Projected Results for OLYMPUS

Data from 1960’s

Many theoretical predictions with little constraint

OLYMPUS:
E = 2 GeV, ε = 0.37-0.9
Q^2 = 0.6-2.2 (GeV/c)^2
<1% projected uncertainties
500h @ 2x10^{33} / cm^2s e+,e- to be run in 2012
Other Experiments to Verify TPE

Experiment proposals to verify hypothesis:

**e+/e- ratio:**
- Novosibirsk/VEPP-3: storage ring / intern. target – 2009 (preliminary result: sizable effect)
- OLYMPUS@DESY: storage ring / intern. target – 2012

**SSA:**
- PR05-15 (Hall A, trans. pol target); MAMI-A4 (trans. pol. beam)

**ε-dependence:**
- PR04-019 (polarized), PR05-017 (unpolarized)
OLYMPUS @ DESY
A PROPOSAL TO DEFINITIVELY DETERMINE THE CONTRIBUTION OF MULTIPLE PHOTON EXCHANGE IN ELASTIC LEPTON-NUCLEON SCATTERING

THE OLYMPUS COLLABORATION

September 9, 2008
OLYMPUS @ DESY

pOsitron-proton and eLectron-proton elastic scattering to test the hypothesis of Multi-
Photon exchange Using DoriS

2007 – Letter of Intent
2008 – Full proposal
2009/10 – Funding and Approval
2010/11 – Transfer of BLAST detector Installation and commissioning

2012 – OLYMPUS Running
Proposed Experiment

- Electrons/positrons (100mA) in multi-GeV storage ring DORIS at DESY, Hamburg, Germany

- Unpolarized internal hydrogen target (buffer system) 3x10^{15} at/cm^2 @ 100 mA → L = 2x10^{33} / (cm^2s)

- Large acceptance detector for e-p in coincidence BLAST detector from MIT-Bates available

- Redundant monitoring of luminosity Pressure, temperature, flow, current measurements Small-angle elastic scattering at high epsilon / low Q^2 Symmetric Moller/Bhabha scattering

- Measure ratio of positron-proton to electron-proton unpolarized elastic scattering to 1% stat.+sys.
Collaboration Organization

- Jun 2007 – Letter of Intent
- Sept 2008 – Full Proposal
- Technical review Sept 2009, funded and officially approved since Jan 2010
- Several collaboration meetings since technical review
  Nov 30–Dec 1, 2009    Feb 23–24, 2010    Apr 26–27, 2010

- Elected management of OLYMPUS at Dec 2009 meeting:
  Spokesman: Richard Milner (MIT)
  Deputy spokesman: Reinhard Beck (U. Bonn)
  Technical coordinator: Douglas Hasell (MIT)
  Project manager: Uwe Schneekloth (DESY)

- Appointed coordinators:
  Tracking – D. Hasell (MIT)
  Scintillators – I. Lehmann (U. Glasgow)
  Luminosity Monitor – M. Kohl (Hampton U.)
  Symmetric Moller Monitor – F. Maas (U. Mainz)
  Target – R. Milner (MIT)
  Data Acquisition – C. Funke (U. Bonn)
  Slow Controls – A. Izotov (PNPI)
Institutional Responsibilities

- **Arizona State University**: TOF support, particle identification, magnetic shielding
- **DESY**: Modifications to DORIS accelerator and beamline, toroid support, infrastructure, installation
- **Hampton University**: GEM luminosity monitor, simulations
- **INFN Bari**: GEM electronics
- **INFN Ferrara**: Target
- **INFN Rome**: GEM electronics
- **MIT**: BLAST spectrometer, wire chambers, tracking upgrade, target and vacuum system, transportation to DESY, simulations
- **Petersburg Nuclear Physics Institute**: Slow controls, MWPC luminosity monitor
- **University of Bonn**: Trigger and data acquisition
- **University of Glasgow**: Particle Identification, TOF scintillators
- **University of Kentucky**: Simulations
- **University of Mainz**: Trigger, DAQ, Symmetric Moller monitor
- **University of New Hampshire**: TOF scintillators
- **Yerevan Physics Institute**: Removal of ARGUS, TOF system
The Proposed OLYMPUS Detector
Preparation of OLYMPUS

- **Transfer of detector**
  - ARGUS removed; BLAST disassembled and shipped (May-July 2010)
  - OLYMPUS assembly at DESY started in June 2010, complete by August 2011

- **Target and vacuum system**
  - New target chamber designed, machined from solid aluminum
  - Target cells constructed by INFN Ferrara
  - Control system development started in May 2010
  - Contructed and tested by Nov. 2010, shipped and installed in Jan. 2011
  - Test experiment successful in Feb. 2011; reinstall in DORIS in May 2011

- **Drift Chambers**
  - Rewired drift chambers at DESY in summer 2010, to be installed May 2011

- **TOFs**
  - TOFs tested and calibrated at Bates in January 2010
  - Supports redesigned, coordinated by U. Glasgow, to be installed in May 2011

- **Luminosity Monitoring**
  - 12-degree elastic scattering telescopes (Hampton & PNPI), well advanced
  - Symmetric Moller/Bhabha monitors (U. Mainz)
  - Test of all elements at DESY testbeam facility in May 2011

- **DAQ**
  - U. Bonn coordinating, system brought into operation at DESY in summer 2010

- “ROLLING-IN” of final OLYMPUS detector into DORIS in August 2011
Target and Vacuum System

Designed until summer 2010
Target and Vacuum System

Target chamber machined by October 2010
Target and Vacuum System

Installed in DORIS in January 2011
DORIS Test Experiment in Feb 2011
Luminosity Monitors: GEM + MWPC

- Forward elastic scattering of lepton at 12 degrees in coincidence with proton in main detector
- Two GEM + MWPC telescopes with interleaved elements operated independently
- Scintillator for triggering and timing
- High redundancy – alignment, efficiency
  Two independent groups (Hampton, PNPI)

Prototypes: GEM, MWPC
Luminosity Monitors – Basic Properties

- Two symmetric GEM telescopes at 12°
- Two-photon effect negligible at high-ε / low-Q^2
- Sub-percent (relative) luminosity measurement per hour at 2.0 GeV, per day at 4.5 GeV
- 1.2 msr = 10 x 10 cm^2 at ~290 cm distance (rearmost plane)
- Three GEM layers with ~0.1 mm resolution with ~50 cm gaps

Table 4.1: Kinematics and count rates of the luminosity control measurement for beam energies of 2.0 and 4.5 GeV at θ_e = 12°. The assumed solid angle is 1.2 msr determined by the area of rearmost tracking plane farthest from the target.
Luminosity Monitors: GEM + MWPC
Summary

The limits of OPE have been reached with available today’s precision
- Nucleon elastic form factors, particularly $G_{Ep}$ under doubt

The TPE hypothesis is suited to remove form factor discrepancy, however calculations of TPE are model-dependent

Experimental probes: Real part of TPE –
- $\epsilon$-dependence of polarization transfer
- $\epsilon$-nonlinearity of cross sections
- Comparison of positron and electron scattering

Need both positron and electron beams for a definitive test of TPE
OLYMPUS, CLAS, VEPP-3

Install OLYMPUS experiment in DORIS IR in August 2011 (“rolling-in”)
Commissioning of OLYMPUS August – December 2011

Take data in two running blocks beginning and end 2012
Projected Results for OLYMPUS

Data from 1960’s
Many theoretical predictions with little constraint

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Elastic ep Scattering Beyond OPE

Kinematical invariants:
\[ P \equiv \frac{p + p'}{2}, \quad K \equiv \frac{k + k'}{2} \]

\[ Q^2 = -(p - p')^2 \]
\[ \nu = K \cdot P = (s - u)/4 \]

Next-to Born approximation:
\[ T_{h'\chi'_N, h\chi_N}^{m_{\text{e}} = 0} = \frac{e^2}{Q^2} \bar{u}(k', h') \gamma_{\mu} u(k, h) \]
\[ \times \bar{u}(p', \chi'_N) \left( \tilde{G}_M \gamma^{\mu} - \tilde{F}_2 \frac{P_{\mu}}{M} + \tilde{F}_3 \frac{\gamma \cdot K P_{\mu}}{M^2} \right) u(p, \chi_N) \]

The T-matrix still factorizes, however a new response term \( F_3 \) is generated by TPE.

Born-amplitudes are modified in presence of TPE; modifications \( \sim \alpha^3 \)

\[ \tilde{G}_M (\nu, Q^2) = G_M (Q^2) + \delta \tilde{G}_M \]
\[ \tilde{F}_2 (\nu, Q^2) = F_2 (Q^2) + \delta \tilde{F}_2 \]
\[ \tilde{F}_3 (\nu, Q^2) = 0 + \delta \tilde{F}_3 \]

\[ \tilde{G}_E \equiv \tilde{G}_M - (1 + \tau) \tilde{F}_2 \]
\[ \tilde{G}_E (\nu, Q^2) = G_E (Q^2) + \delta \tilde{G}_E \]

New amplitudes are complex!
Preliminary result for $R_{e^+/e^-}$ in comparison with calculations of P.G. Blunden et al.

$\varepsilon = 0.50 \quad Q^2 = 1.43 \text{ GeV}^2$
Control of Systematics

\[ N_{ij} = L_{ij} \sigma_i \kappa^p_{ij} \kappa^l_{ij} \]

\( i = e^+ \text{ or } e^- \)

\( j = \text{pos/neg polarity} \)

Geometric proton efficiency: \( \kappa^p_{e^+j} = \kappa^p_{e^-j} \)

\[
\frac{N_{e^+j} / L_{e^+j}}{N_{e^-j} / L_{e^-j}} = \frac{\sigma_{e^+}}{\sigma_{e^-}} \cdot \frac{\kappa^l_{e^+j}}{\kappa^l_{e^-j}}
\]

Geometric lepton efficiency:

\( \kappa^l_{e^{++}} = \kappa^l_{e^{--}} \) and \( \kappa^l_{e^{+-}} = \kappa^l_{e^{-+}} \)
Control of Systematics

Super ratio:

\[
\left[ \frac{N_{e^{++}}}{L_{e^{++}}} \cdot \frac{N_{e^{+-}}}{L_{e^{+-}}} \right]^{\frac{1}{2}} = \frac{\sigma_{e^+}}{\sigma_{e^-}}
\]

Cycle of four states $ij$
Repeat cycle many times

- Change between electrons and positrons every other day
- Change BLAST polarity every other day
- Left-right symmetry