The OLYMPUS Experiment

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The OLYMPUS Experiment
Elastic scattering cross section ratio:

\[
\frac{e^+ p \rightarrow e^+ p}{e^- p \rightarrow e^- p}
\]
The important points:

1. Motivation:
   - Why the discrepancy calls for a measurement of $\sigma_{e^+p}/\sigma_{e^-p}$

2. Experiment:
   - The advantages OLYMPUS has in making this measurement

3. Analysis:
   - How to guarantee an accurate result
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Elastic scattering kinematics are fixed by two parameters.

1. Beam energy
2. Scattering angle

Momentum transfer to the proton ($q$)
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1. Beam energy
2. Scattering angle

Momentum transfer to the proton ($q$)

Theory

1. $Q^2 = -q_\mu q^\mu$

2. $\epsilon = \left[ 1 + 2 \left( 1 + \frac{Q^2}{4m_p^2} \right) \tan^2 \frac{\theta}{2} \right]^{-1}$
Elastic scattering kinematics are fixed by two parameters.
The two form factor extraction methods disagree.
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$\sigma_{e^+p}/\sigma_{e^-p}$ is sensitive to two-photon exchange.

\[ |^2 = \pm 2 \text{Re} \left\{ \left( \begin{array}{c} R \end{array} \right) \gamma \right\} + \ldots \]

\[ R_{2\gamma} \equiv \frac{\sigma_{e^+p}}{\sigma_{e^-p}} \approx 1 + \frac{4\text{Re} \{ M_{2\gamma} M_{1\gamma} \}}{|M_{1\gamma}|^2} \]
A few percent effect is large enough to resolve the discrepancy.
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Previous world data are inadequate.
New $\sigma_{e^+p}/\sigma_{e^-p}$ experiments will have better kinematic reach.
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Advantage I: High luminosity

- OLYMPUS
- DORIS storage ring

Alternate $e^- \leftrightarrow e^+$ daily
Advantage I: High luminosity

DORIS storage ring

$e^+ \text{ injection from DESY}$

OLYMPUS

$\text{Alternate } e^- \leftrightarrow e^+ \text{ daily}$
Advantage I: High luminosity

Alternate $e^- \leftrightarrow e^+$ daily

Typical current: 50–70 mA
Advantage I: High luminosity

- Alternate $e^- \leftrightarrow e^+$ daily
- Typical current: 50–70 mA
- Windowless hydrogen target
Advantage I: High luminosity

- Alternate $e^- \leftrightarrow e^+$ daily
- Typical current: 50–70 mA
- Windowless hydrogen target
- $2 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$
- Over 4 fb$^{-1}$ recorded!
Advantage II: large acceptance spectrometer
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Advantage III: redundant luminosity monitors

1. Slow-control
2. Forward tracking telescopes
3. Symmetric Møller Bhabha Calorimeters
Advantage III: redundant luminosity monitors
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3. Analysis:
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Simulation is critical to our analysis.

Differences between $e^-$ and $e^+$ running:

- Lepton curvature direction
  - Acceptance
  - Efficiency ($\theta$)
- Radiative corrections
  - Soft $2\gamma$ correction
  - Bremsstrahlung

Simulate with Monte Carlo!
Simulated data is analyzed with the same software.

\[
R_{2\gamma} = \frac{N_{e^+p}^{\text{exp.}}}{\sigma_{e^+p}^{\text{sim.}} \mathcal{L}_{e^+p}} \times \frac{\sigma_{e^-p}^{\text{sim.}} \mathcal{L}_{e^-p}}{N_{e^-p}^{\text{exp.}}}
\]
Analysis steps

1. Produce simulated data
   1. Generate
   2. Propagate
   3. Digitize

2. Track the experimental and simulated data

3. Select elastic events

4. Estimate background

5. Form ratio
Elastic selection: leptons at 27°

Counts

Non-coplanarity of track pairs

PRELIMINARY

All pairs

$ep$ pairs

Final pairs

Counts

Non-coplanarity of track pairs
Elastic selection: leptons at 44°
Yields

Cross section \([\text{nbc}^2/\text{GeV}^2]\)

\[Q^2 [\text{GeV}/c]^2\]

PRELIMINARY

- \(e^- \text{ Sim.}\)
- \(e^- \text{ Data}\)

- \(e^+ \text{ Sim.}\)
- \(e^+ \text{ Data}\)
We can test our simulation without biasing the result.

1. **Lepton-averaged cross section ratio:**

\[ \frac{\bar{\sigma}^{\text{exp.}}}{\bar{\sigma}^{\text{sim.}}} \equiv \frac{\sigma^{\text{exp.}}_{e^+ p} + \sigma^{\text{exp.}}_{e^- p}}{\sigma^{\text{sim.}}_{e^+ p} + \sigma^{\text{sim.}}_{e^- p}} \]

2. **Left/right ratio:**

\[ \frac{R_L}{R_R} \equiv \left( \frac{\sigma^{\text{exp.}}}{\sigma^{\text{sim.}}} \right)_L \bigg/ \left( \frac{\sigma^{\text{exp.}}}{\sigma^{\text{sim.}}} \right)_R \]
Lepton-averaged cross section is limited by knowledge of the form factors.

Projected OLYMPUS stat., 3.1 fb$^{-1}$

**Form Factor models**
- Dipole
- Bernauer ±1σ
- Kelly
- Arrington
Left/right comparisons can reveal deviations.

PRELIMINARY without simulation

courtesy of J.C. Bernauer
We exploit redundancy to control our systematics.

- **Acceptance**
  - Lepton-averaged cross section
  - Left-right ratio

- **Luminosity**
  - Two independent monitors

- **Radiative corrections / form factors**
  - Simulate multiple corrections, form factor models

- **Tracking efficiency**
  - Two independent track-reconstruction algorithms

- **Event selection / background subtraction**
  - Multiple independent analyses

Results will be released when we are confident in all of our systematic checks.
OLYMPUS will make a strong statement about two-photon exchange.
In summary...

$\sigma_{e^+p}/\sigma_{e^-p}$ will say if two-photon exchange causes the form factor discrepancy.
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- OLYMPUS has advantages:
  - Excellent statistics
  - Large acceptance
  - Redundant luminosity monitors
In summary...

- \( \sigma_{e^+p}/\sigma_{e^-p} \) will say if two-photon exchange causes the form factor discrepancy.
- OLYMPUS has advantages:
  - Excellent statistics
  - Large acceptance
  - Redundant luminosity monitors
- Redundancy helps us guard against systematics.
In summary...

- $\sigma_{e^+p}/\sigma_{e^-p}$ will say if two-photon exchange causes the form factor discrepancy.
- OLYMPUS has advantages:
  - Excellent statistics
  - Large acceptance
  - Redundant luminosity monitors
- Redundancy helps us guard against systematics.
- Expect results soon.
Back-up slides
12° telescopes: luminosity results

Luminosity: 12° telescopes / slow control

Left telescope

Right telescope

Run

$\mu_{e^-} = 0.9778$

$\mu_{e^+} = 0.9784$

$\mu_{e^-} = 0.9853$

$\mu_{e^+} = 0.9843$