Status of The OLYMPUS Experiment

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April 8, 2015
6th Workshop of the APS Topical Group on Hadron Physics

Contents

OLYMPUS: Using $\frac{\sigma(e^+p)}{\sigma(e^-p)}$ to determine the multiple-photon exchange contribution to elastic lepton-proton scattering

1. Motivation and Background
    - The proton form factor discrepancy
    - Higher order corrections
2. Experiment
    - Beam and Target
    - Detector
3. Analysis
    - Analysis process
    - Current status

Proton Form Factors

Electric and Magnetic Form Factors of the Proton: $G_{Ep}(Q^2)$ and $G_{Mp}(Q^2)$

- Characterize the influence of the E.M. fields of the proton on the lepton
- Related to the spatial current and charge distributions
- Experimentally found
  - Rosenbluth Separation Method
  - Polarization Measurements

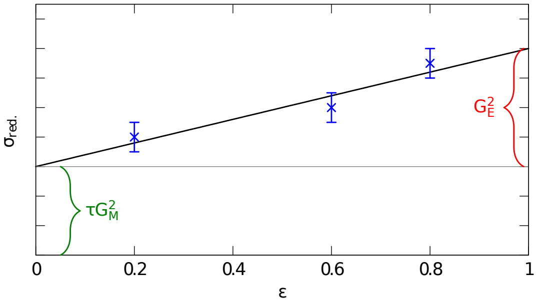
Rosenbluth

Rosenbluth Formula

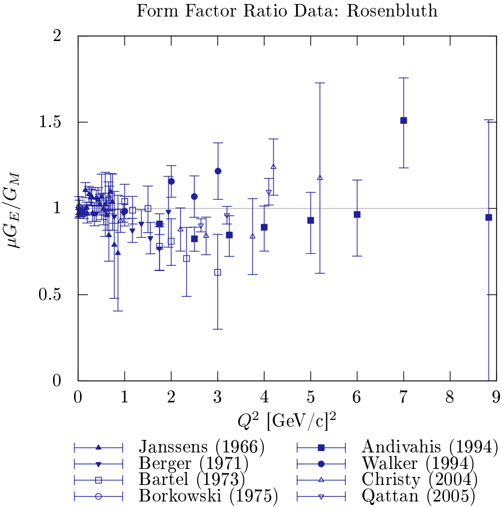
- Extension of Mott to include nucleon structure
- 1 γ exchange assumed

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \frac{\epsilon G_{Ep}^2(Q^2) + \tau G_{Mp}^2(Q^2)}{\epsilon(1+\tau)}$$

$$\tau = \frac{Q^2}{4M^2} \qquad \epsilon = \frac{1}{1+2(1+\tau)\tan^2\theta/2}$$



Rosenbluth Technique



$$\mu_p G_{Ep}/G_{Mp}(Q^2) \approx 1$$

Polarization Experiments

- Became possible to advent of highly polarized e^{-} beams
- From that G_{Ep}/G_{Mp} can be extracted

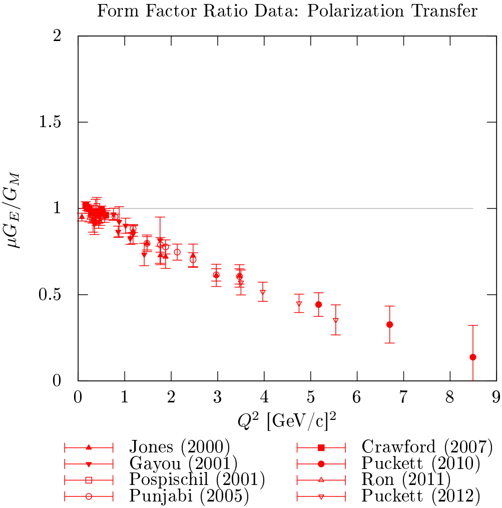
Asymmetry with Polarized Targets

- Longitudinally polarized leptons on polarized proton target
- Asymmetry is the ratio of the polarized to unpolarized cross section

Polarization Transfer

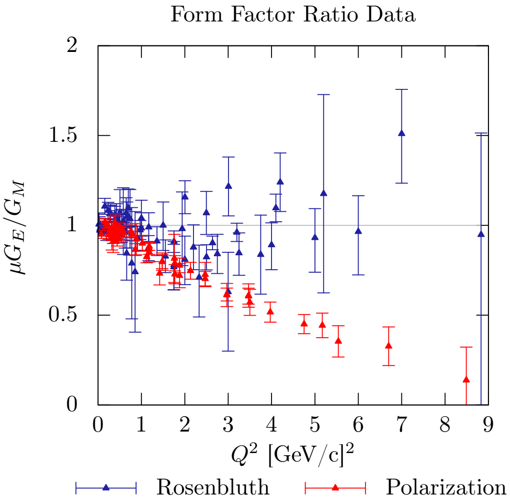
- Polarized lepton beams scattered on unpolarized proton target
- Recoil proton polarization measured

Polarization Experiments



$\mu_p G_{Ep}/G_{Mp}(Q^2)$
decreases with Q^2

Discrepancy

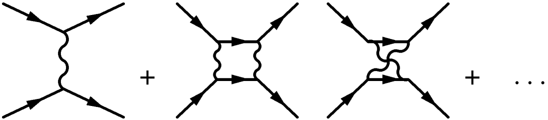


Different Results!

- Flaw in formalism or measurement?
- Possible culprit
  - Higher order contributions in cross section measurement

Two-Photon Exchange Effect in Elastic ep Scattering

- Significant multiple photon correction to Rosenbluth technique?
- The hard 2γ exchange is not included in usual radiative corrections



How to measure higher order contributions

With the 1γ assumption $e^- p$ and $e^+ p$ cross sections are identical

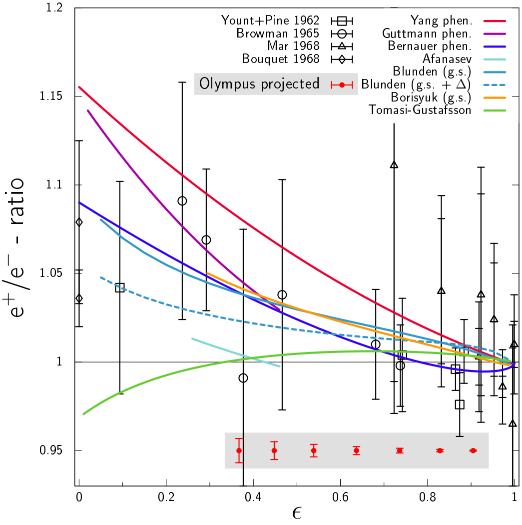
Interference term between $M_{1\gamma}$ and $M_{2\gamma}$ sensitive to lepton charge

$$\frac{d\sigma(e^\pm p)}{d\Omega} = |M_{1\gamma} \pm M_{2\gamma} + \ldots|^2$$
$$= |M_{1\gamma}|^2 \pm 2Re\{M^\dagger_{1\gamma} M_{2\gamma}\} + \ldots$$

Use positron-proton and electron-proton scattering

$$\frac{\sigma(e^+ p)}{\sigma(e^- p)} \approx 1 + 4\frac{Re\{M^\dagger_{1\gamma} M_{2\gamma}\}}{|M_{1\gamma}|^2}$$

Expected Results



The Experiment

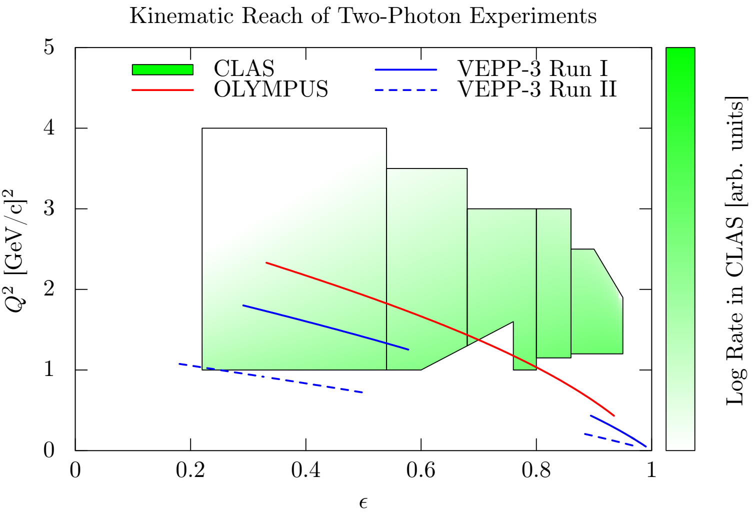
OLYMPUS Goal

Measure $\frac{\sigma(e^+p)}{\sigma(e^-p)}$ to within 1%
E = 2.0 GeV
$0.25 \leq Q^2 \leq 2.5\ (GeV/c)^2$
$0.35 \leq \epsilon \leq 0.98$

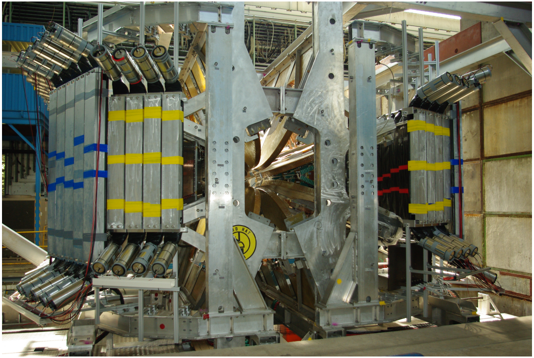
Other Experiments

- VEPP-3 Novosibirsk
  - E = 1.6 and 1 GeV
  - No magnetic field
  - I.A. Rachek, et al., Phys. Rev. Lett. 114, 062005 (2015)
- CLAS
  - $E < 5.5$ GeV
  - Large Q^2 and ϵ range
  - D. Adikaram, et al., Phys. Rev. Lett. 114, 062003 (2015)

Experiment Comparison



The Experiment



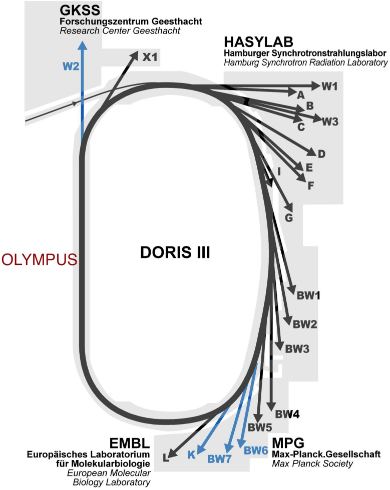
Beam: DORIS

DORIS III: Hamburg, Germany

- Positron and electron beams
- Energies up to 4.45 GeV
- Current up to 140 mA
- Primarily used as source of synchrotron radiation

OLYMPUS

- E = 2.01 GeV
- Current between 40 mA - 60 mA
- Switch beam species daily

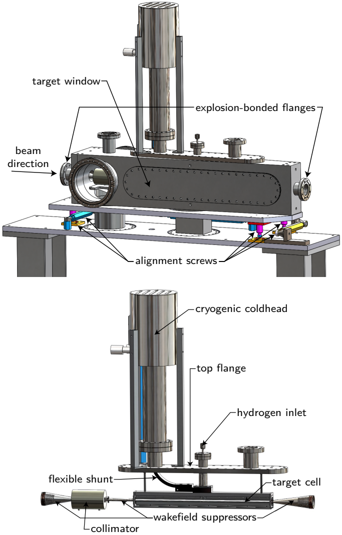


http://bilder.desy.de:9080/DESYmediabank

Target

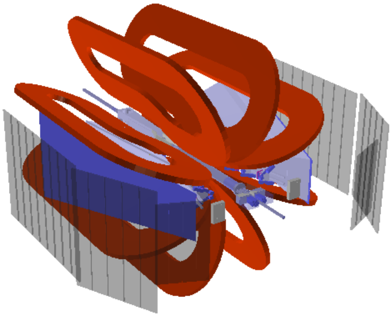
H_2 Target

- Internal design
  - Windowless, thin-walled
- Isotopically pure hydrogen gas
- Multistage pumping system
- Cryogenically cooled
- Density: 3×10^{15}atoms/cm^{-2}



J.C. Bernauer, et al., NIMA 755 (2014) 20-27

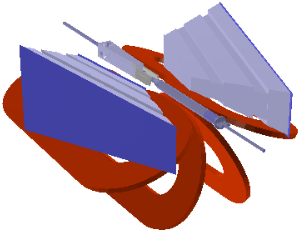
OLYMPUS Detector



- Large acceptance spectrometer
- 8-sector toroid magnet
- Left/right symmetric

R. Milner, et al., NIMA 741 (2014) 1-17

OLYMPUS Detector: Wire Chambers

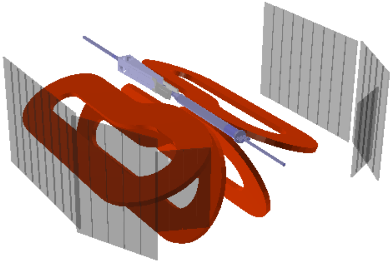


Wire Chambers

- Main tracking detectors:
  - Momentum
  - Scattering angles
- Define acceptance
  - 20°- 80° scattering angle
  - $\pm 15^\circ$ azimuthal angle

R. Milner, et al., NIMA 741 (2014) 1-17

OLYMPUS Detector: Time of Flight

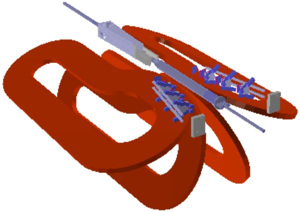


Time of Flight

- 36 scintillator bars
- Full acceptance of wire chambers
- Kinematic trigger

R. Milner, et al., NIMA 741 (2014) 1-17

OLYMPUS Detector: 12° Luminosity

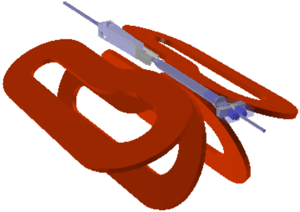


GEM and MWPC Telescopes

- Monitor forward angle elastic $e^{\pm}p$
- 12° scattering angle
- Gas electron multipliers
- Multi-wire proportional chambers

R. Milner, et al., NIMA 741 (2014) 1-17

OLYMPUS Detector: Symmetric Møller and Bhabha



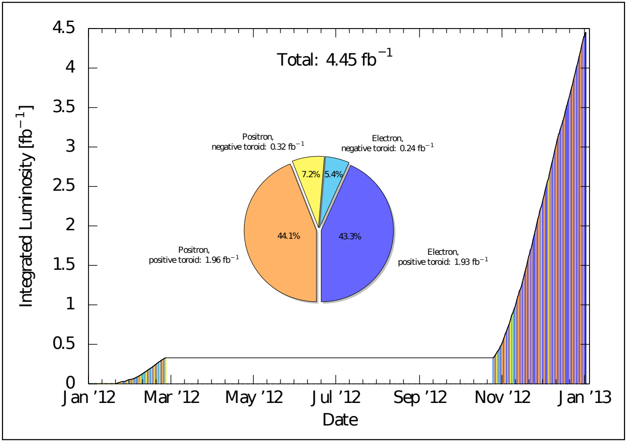
Møller and Bhabha Calorimeters

- Elastic e^-e^- (Møller), e^-e^+ (Bhabha) and pair annihilation
- 1.29° scattering angle

R. Milner, et al., NIMA 741 (2014) 1-17

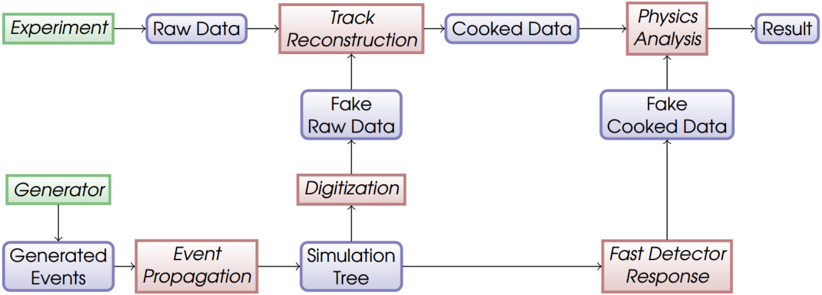
Data

- February 2012: 4 weeks
- October-January 2013: 9 weeks



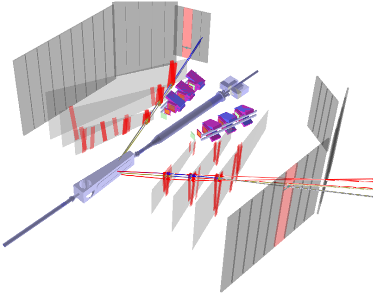
Analysis is underway

Analysis Strategy



Track Reconstruction

- Track Finding
  - Pattern matching: M. Dell'orso and L. Ristori[1]
  - Pattern library created with Geant4
- Elastic Arm Approach
  - Track reconstruction: M. Ohlsson and C. Peterson [2]
  - Deformable templates
  - Deterministic annealing
- Session E4 (Saturday)



[1] M. Dell'orso, L. Ristori, NIMA 287 (1990) 436-438

[2] M. Ohlsson, C. Peterson, Computer Physics Communications 71 (1992)

Luminosity

The relative luminosity between e^+p and e^-p is crucial for finding $\frac{\sigma(e^+p)}{\sigma(e^-p)}$ better than 1%

- 3 Luminosity Monitoring Systems
- Slow control: beam and target information
- Elastic $e^\pm p$ scattering at 12°
  - 2γ contribution assumed negligible here
- Symmetric Møller and Bhabha Calorimeters
  - Accounting for radiative corrections in analysis
- C. O'Connor talk in session B6 (Saturday)

OLYMPUS Radiative Corrections

We are measuring the $\frac{\sigma(e^+p)}{\sigma(e^-p)}$ to find the Hard 2 γ exchange contribution to elastic electron proton scattering.

Other radiative corrections distort ratio!

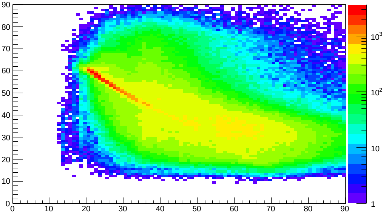
OLYMPUS radiative generator

- Monte Carlo
  - Coincidence measurement
  - Convolved with acceptances, efficiencies, and analysis cuts
  - Bremsstrahlung: no soft γ or peaking approximation
- Compares well with VEPP-3 ESEPP generator

Analysis Progress: Elastic Peak

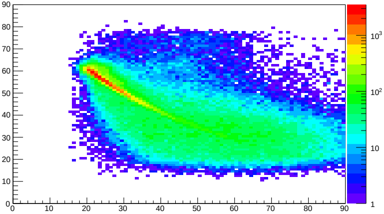
No Cuts

lepton vs proton theta



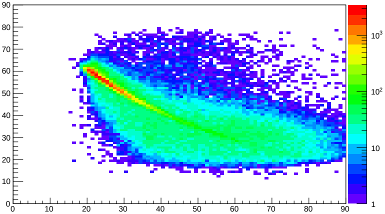
t_0

lepton vs proton theta



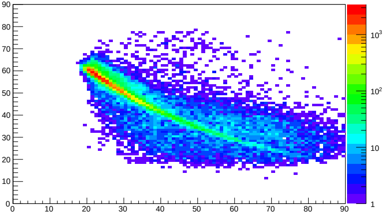
Event vertex position

lepton vs proton theta



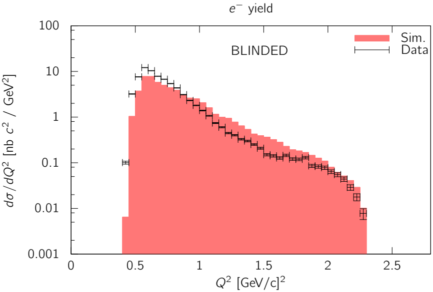
Coplanarity

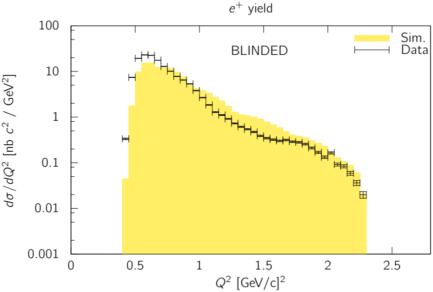
lepton vs proton theta



Electron and Positron Yields

Blinded!





Current Status

Analysis

- The analysis is still underway
- Preliminary result expected in May, 2015
- Final result in Fall 2015

Conclusions

Two-photon exchange is likely explanation for electromagnetic form-factor ratio discrepancy

- OLYMPUS will measure $\frac{\sigma(e^+p)}{\sigma(e^-p)}$
  - To within 1%
  - $0.25 \leq Q^2 \leq 2.5$ (GeV/c)^2 and $0.35 \leq \epsilon \leq 0.98$
- 4.45 fb^{-1} of data was taken in 2012
- Analysis is still ongoing
- Expect results soon!

Thanks!

The OLYMPUS Collaboration

Arizona State University
Deutsches Elektronen-Synchrotron, Hamburg
Hampton University
Istituto Nazionale di Fisica Nuleare, Bari, Ferrara, Rome
Massachusetts Institute of Technology
MIT-Bates Linear Accelerator Center
St. Petersburg Nuclear Physics Institute
University of Bonn
University of Glasgow
University of Mainz
University of New Hampshire
Yerevan Physics Institute

Author's work is supported by NSF Award 1306547

Extra Slides

What is a proton?

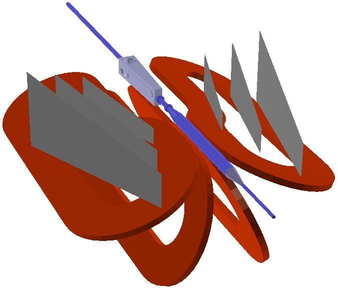
Internal Structure of the Proton

- Important for understanding fundamental properties of the proton
- Tests for QCD, nucleon-nucleon interactions
- Studied for over 50 years now

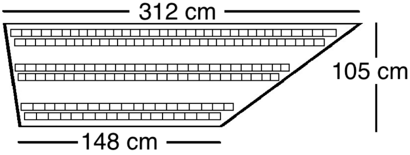
Probing the proton structure ($ep \rightarrow ep$)

- Using lepton scattering from proton to measure electromagnetic structure of proton
- QED is understood
- α_{em} perturbation is valid

OLYMPUS Detector: Wire Chambers

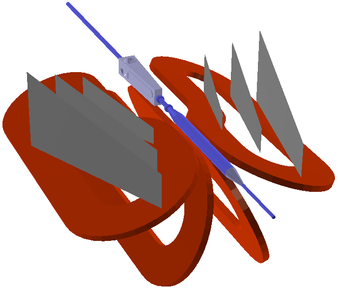


View of a sector from above

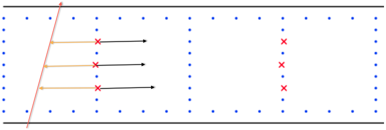


- 3 sensitive detector planes/sector (chambers)
- 2 wire cell layers/chamber
- Cell layers at 10° stereo angle

OLYMPUS Detector: Wire Chambers



Two cells side-by-side



- Staggered sense wires
  - 1mm
  - Left/right discernment

Radiative Corrections: Finding Hard 2γ exchange

Need to correct for large odd radiative corrections

Relevant Processes

- One-photon exchange
- Bremsstrahlung (4 processes)
- Self energy (4 processes)
- Vacuum polarization
- Vertex corrections (2 processes)
- Two-photon exchange (2 processes)

Plan

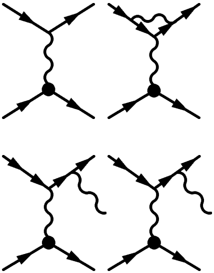
Monte Carlo

1. Generate events with radiative corrected cross section
2. Propagate through Geant4 simulation
   - Convolve with acceptance, efficiency, resolutions
3. Analyze like data
4. Compare to data

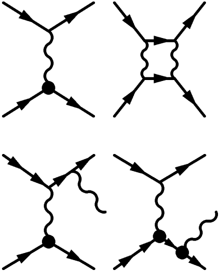
Radiative Corrections

Corrections order α^3

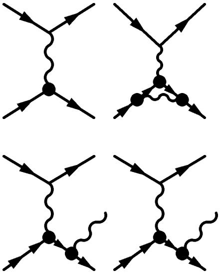
Large: Even



Odd

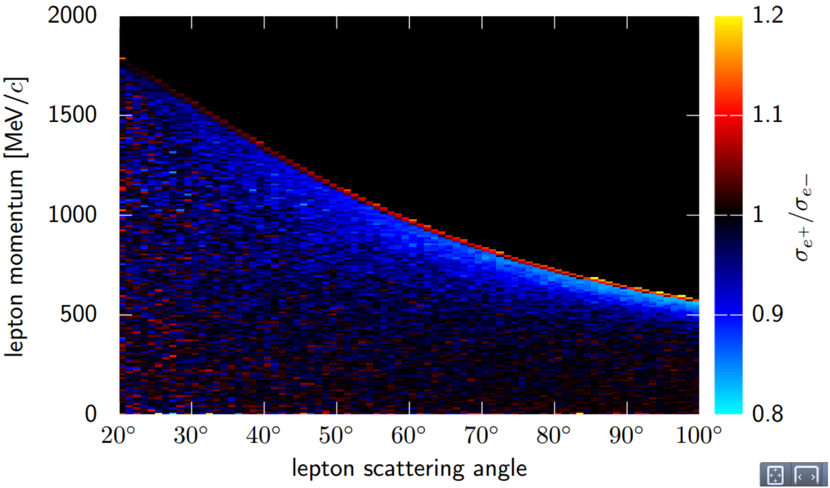


Negligible



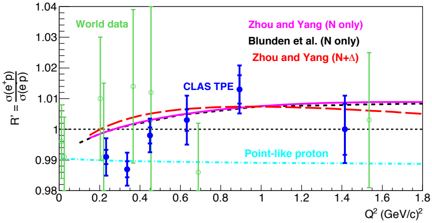
Correcting for odd terms results in hard two-photon exchange

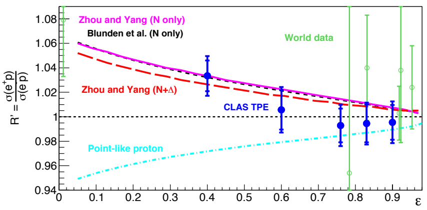
Radiative Generator

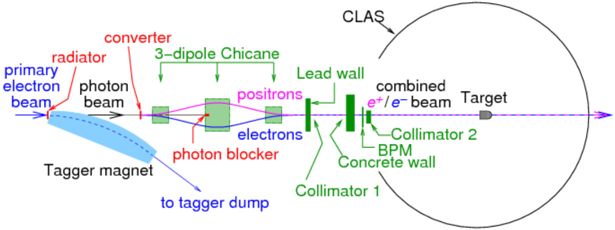


A. Schmidt, R. Russell, J. Bernauer

Other experiments: CLAS



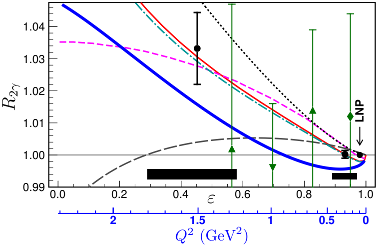




D. Adikaram, et al., Phys. Rev. Lett. 114, 062003 (2015)
M. Moteabbed, et al. Phys. Rev. C88 025210 (2013)

Other experiments: Novosibirsk VEPP-3

Run I



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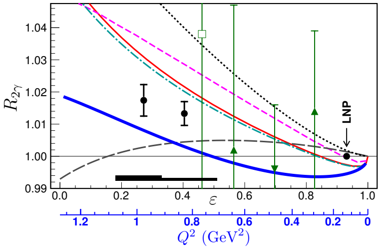
- W. Bartel, B. Dudelzak, H. Krehbiel, J. M. McElroy, R. J. Morrison, W. Schmidt, V. Walther, and G. Weber, Phys. Lett. 25B, 242 (1967).

Run II



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- J. Arrington and I. Sick, Phys. Rev. C 70, 028203 (2004).
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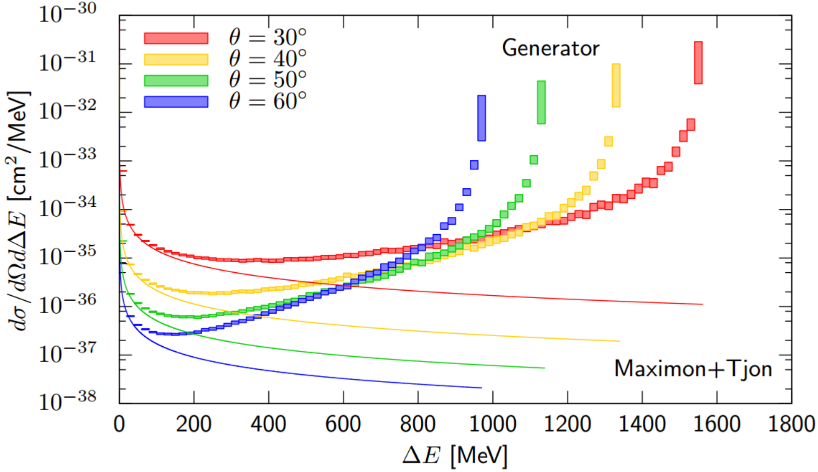
I.A. Rachek, et al., Phys. Rev. Lett. 114, 062005 (2015)

Radiative Generator



A. Schmidt, R. Russell, J. Bernauer