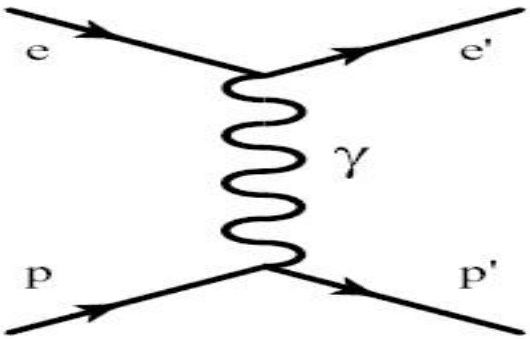
# OLYMPUS Overview

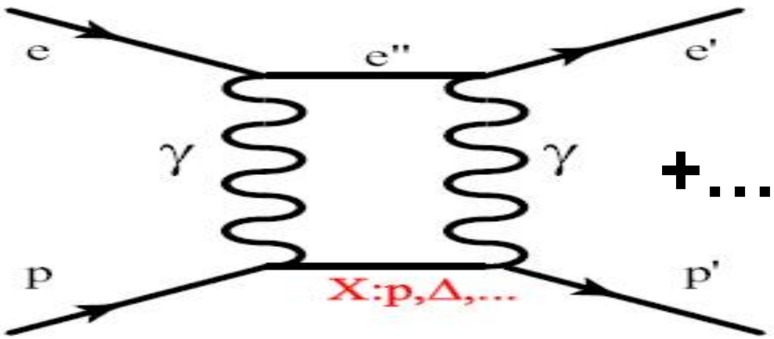
## http://web.mit.edu/OLYMPUS/

- Scientific motivation
- Overview of the experiment
- Expected results
- Collaboration, costs, schedule

# Elastic Electron Scattering from Proton




**+**




**+…**

## Dirac, Pauli FF

$$\langle N(P')|J^{\mu}_{\rm EM}(0)|N(P)\rangle =$$
$$\bar{u}(P')\left[\gamma^{\mu}F_1^N(Q^2)+i\sigma^{\mu\nu}\frac{q_\nu}{2M}F_2^N(Q^2)\right]u(P)$$

## Sachs FF

$$G_E = F_1 - \tau F_2; \quad G_M = F_1 + F_2, \quad \tau = \frac{Q^2}{4M^2}$$

# Nucleon elastic form factors

- Fundamental observables describing the distribution of charge and magnetism in the proton and neutron
- Defined in the context of single photon exchange
- Experimentally, data well described by an exponential spatial fall off of nucleon's charge and magnetism ~ $e^{-\mu r}$

  => dipole form factor

  $$G_D(Q^2) \sim (1 + Q^2/0.71)^{-2}$$
- At $Q^2 >> 1$, $\sigma \sim \sigma_{Mott}\, G^2_D \sim Q^{-12}$
- FF determined by quark structure of proton
- Will be calculable in lattice QCD

# Unpolarized Elastic e-N Scattering

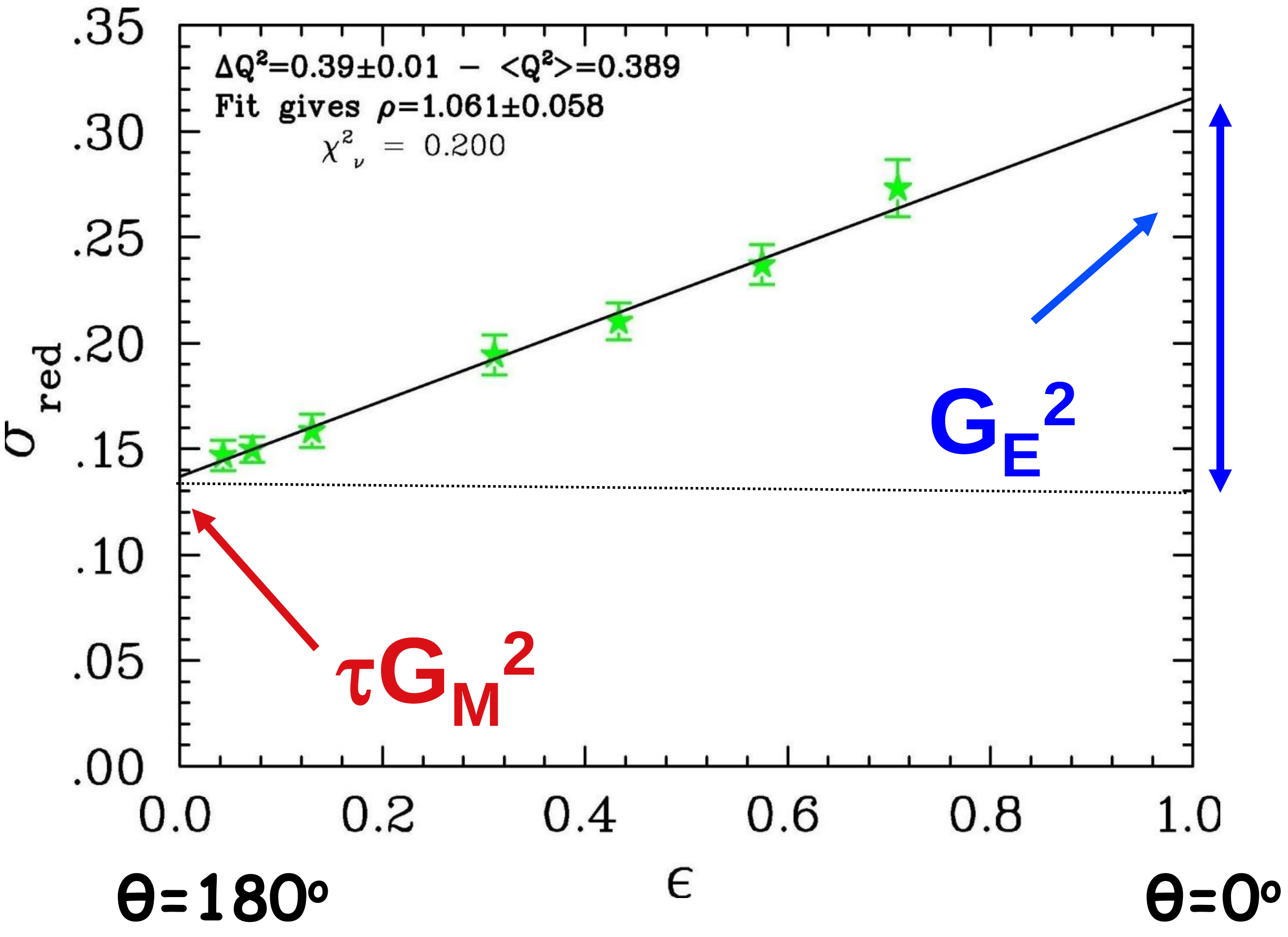
$$\frac{d\sigma/d\Omega}{(d\sigma/d\Omega)_{Mott}} = \frac{\sigma}{\sigma_0} = A(Q^2) + B(Q^2)\tan^2\frac{\theta}{2}$$
$$= \frac{G_E^2(Q^2) + \tau G_M^2(Q^2)}{1+\tau} + 2\tau G_M^2(Q^2)\tan^2\frac{\theta}{2}$$

**For ~ 50 years unpolarized cross section measurements have determined the elastic FF $G^p_E$ and $G^p_M$ using the Rosenbluth separation**

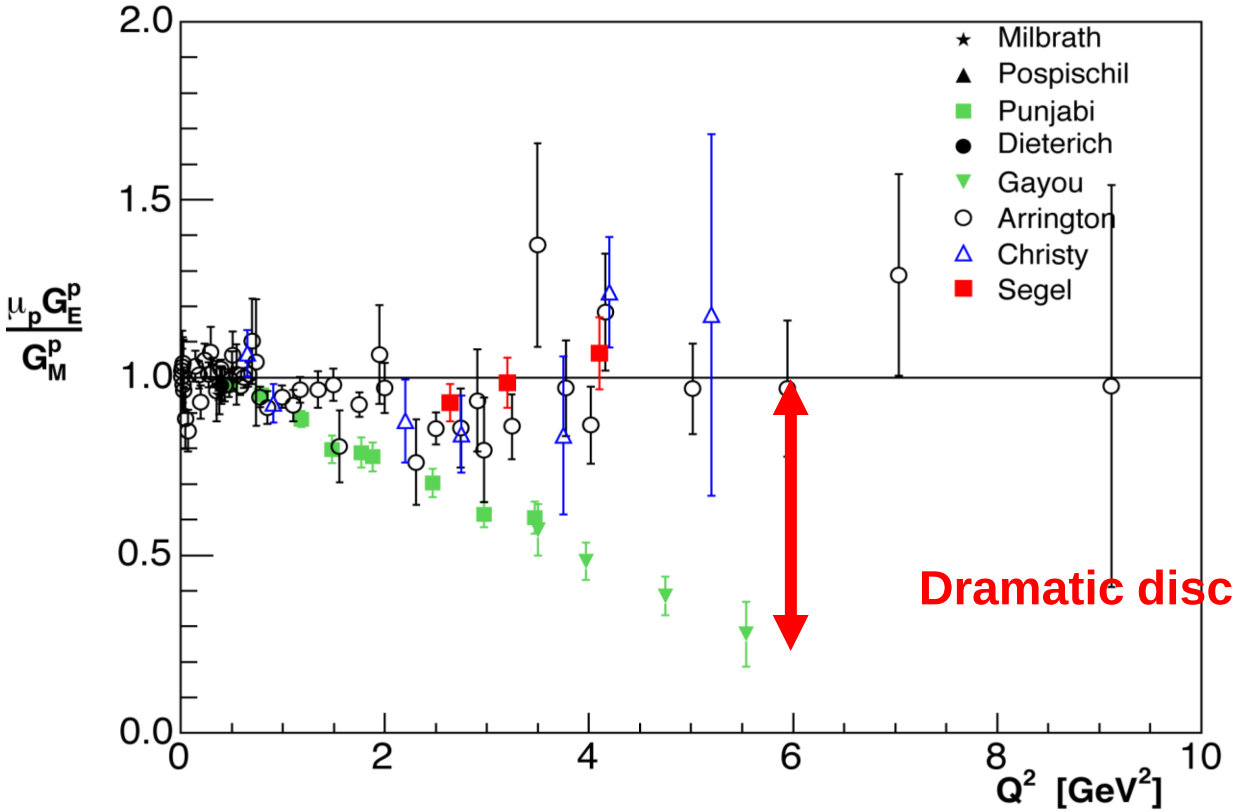
$\sigma_{red} = d\sigma/d\Omega\ [\varepsilon(1+\tau)/\sigma_{Mott}] = \tau G_M^2 + \varepsilon G_E^2$

$\tau = Q^2/4M^2$ $\varepsilon = [\ 1 + 2(1+\tau)\tan^2 \theta/2\ ]^{-1}$

# Rosenbluth Separation



# Proton Form Factor Ratio




Jefferson Lab

- **All Rosenbluth data from SLAC and Jlab in agreement.**
- **Dramatic discrepancy between Rosenbluth and recoil polarization technique**
- **Interpreted as evidence for two photon exchange**

# Calculation of Two Photon Exchange (TPE) Effects

- **P.A.M. Guichon and M. Vanderhaeghen, PRL91, 142303 (2003).**
- **P.G. Blunden, W. Melnitchouk, and J.A. Tjon,  Phys. Rev. C72, 034612 (2005), Phys. Rev. Lett. 91, 142304 (2003).**
- **M.P. Rekalo and E. Tomasi-Gustafsson, Eur. Phys. Jour. A22, 331 (2004).**
- **Y.C. Chen *et al.*,Phys. Rev. Lett. 93, 122301 (2004).**
- **A.V. Afanasev and N.P. Merenkov, Phys. Rev. D70, 073002 (2004).**
- **A.V. Afanasev *et al.,* Phys. Rev. D72, 013008 (2005).**
- **Y.C. Chen *et al.,* Phys. Rev. C 72, 034612 (2005).**
- **S. Kondratyuk *et al*., Phys. Rev. Lett. 95, 172503 (2005).**
- **M. Gorchtein, Phys. Lett. B644, 322 (2007).**
- **D. Borisyuk and A. Kobushkin, Phys. Rev. C 78, 025208 (2008).**
- **N. Kivel and M. Vanderhaeghen, hep-ph/0905-0282v1.**

# Estimation of TPE Contribution

P.G. Blunden et al.,
Phys. Rev. C 72, 034612
(2005)

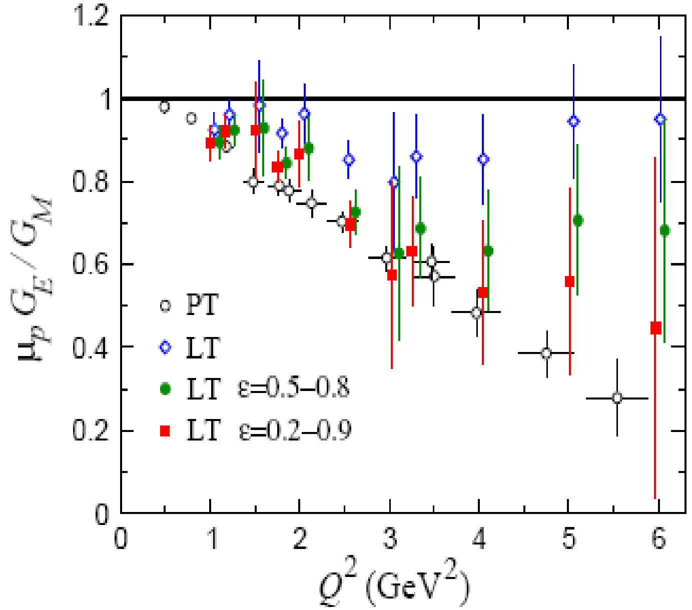
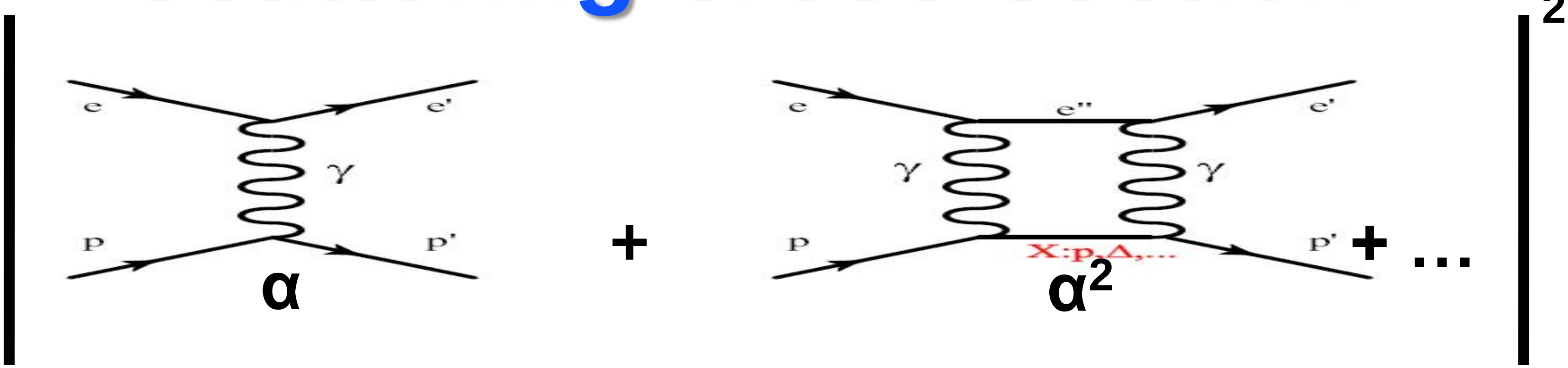



FIG. 5: The ratio of proton form factors $\mu_p G_E/G_M$ measured using LT separation (open diamonds) [2] and polarization transfer (PT) (open circles) [5]. The LT points corrected for $2\gamma$ exchange are shown assuming a linear slope for $\varepsilon = 0.2 - 0.9$ (filled squares) and $\varepsilon = 0.5 - 0.8$ (filled circles) (offset for clarity).

**Only experiment can definitively resolve the contributions beyond single photon exchange**

# Lepton-proton elastic scattering cross-section




$$\sigma = (1\gamma)^2\alpha^2 + (1\gamma)(2\gamma)\alpha^3 + .....$$

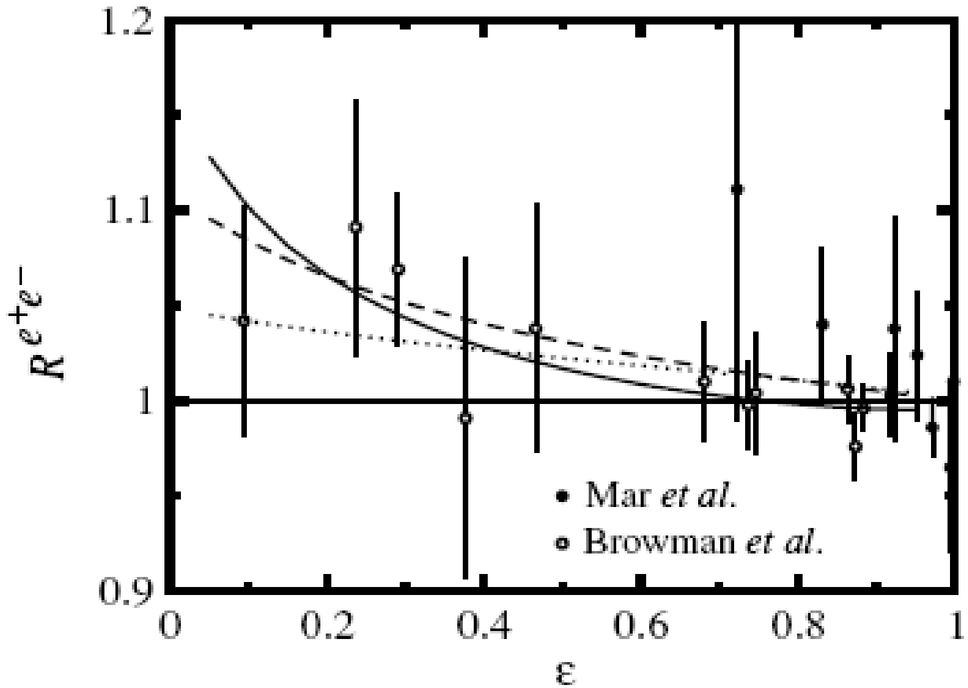
$$e^- \Longleftrightarrow e^+ \Rightarrow \alpha \Longleftrightarrow -\alpha$$

$$\sigma(\text{electron-proton}) = (1\gamma)^2\alpha^2 - (1\gamma)(2\gamma)\alpha^3 + ..$$

$$\sigma(\text{positron-proton}) = (1\gamma)^2\alpha^2 + (1\gamma)(2\gamma)\alpha^3 + ..$$

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

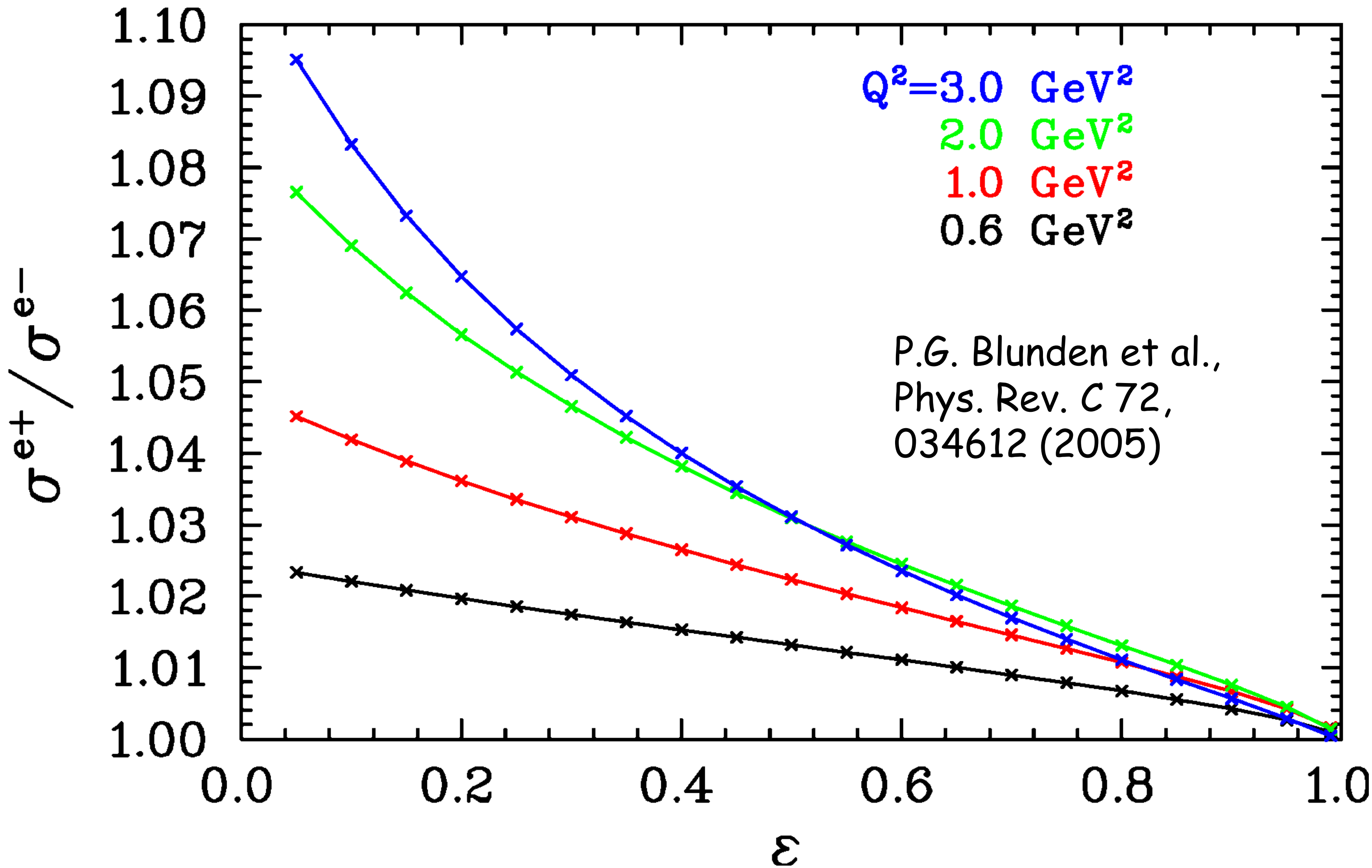
# TPE calculation comparison with $e^+p/e^-p$ scattering data



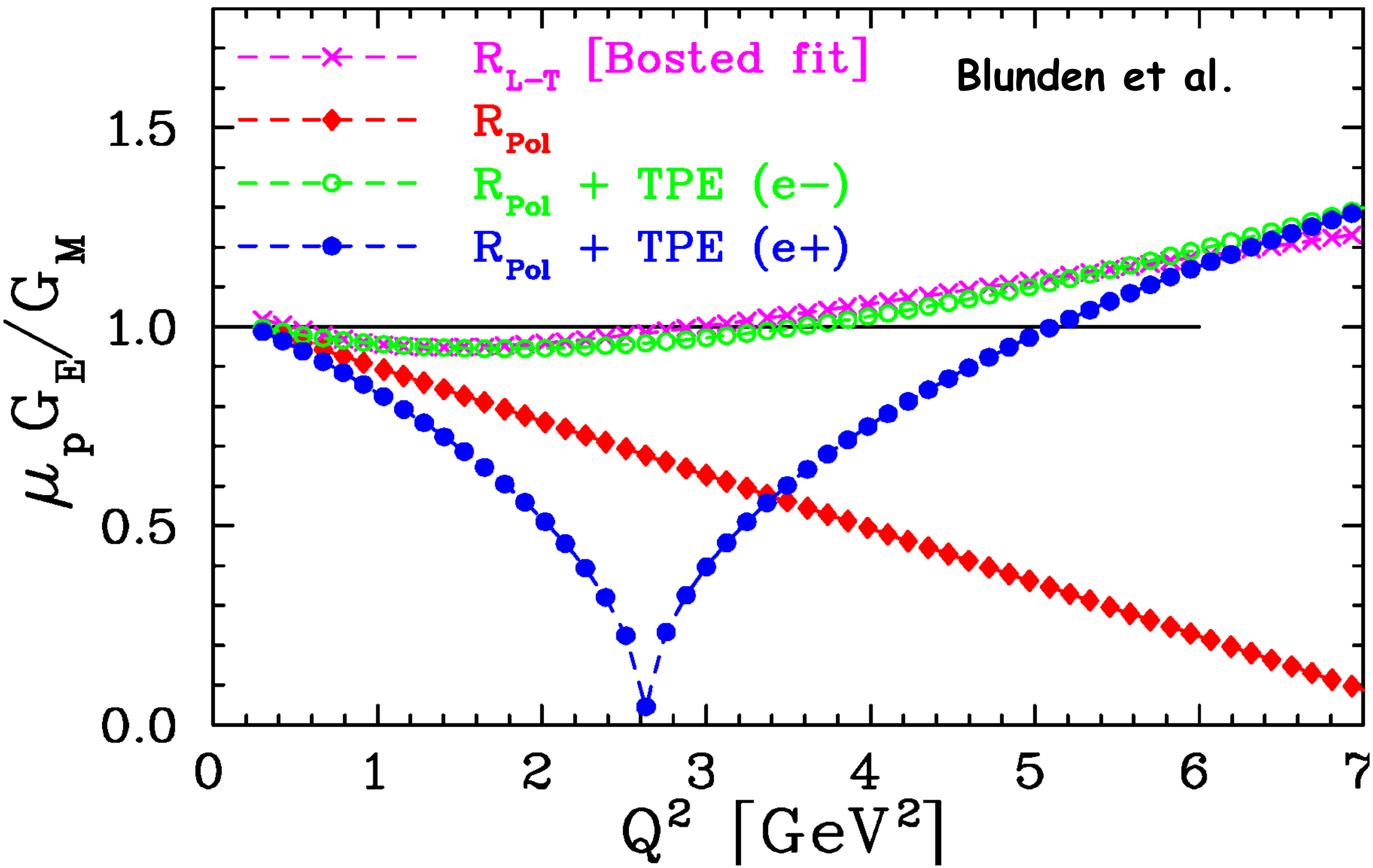

P.G. Blunden et al., Phys. Rev. C 72, 034612 (2005)

FIG. 7. Ratio of elastic $e^+p$ to $e^-p$ cross sections. The data are from SLAC [31,32], with $Q^2$ ranging from 0.01 to 5 GeV$^2$. The results of the $2\gamma$ exchange calculations are shown by the curves for $Q^2 = 1$ (dotted), 3 (dashed), and 6 GeV$^2$ (solid).

# $e^{+}p/e^{-}p$ cross section ratio



# Proton form factor ratio



# The OLYMPUS Experiment

- Electrons/positrons (100mA) in multi-GeV storage ring DORIS at DESY, Hamburg, Germany
- Unpolarized internal hydrogen target (like HERMES) 3 x $10^{15}$ at/$cm^2$ @ 100 mA $\rightarrow$ L = $2 \times 10^{33}$ / ($cm^2$s)
- Measure elastic $e^+/e^-$ proton scattering to 1% precision at 2 GeV energy with ε range from 0.4 to 1 at high $Q^2$ ~ 2-3 $(GeV/c)^2$ using the existing Bates Large Acceptance Spectrometer Toroid
- Experiment requires switching both the lepton sign and the direction of the BLAST magnetic field, both on timescale of ≤ 1 day.
- Redundant monitoring of luminosity, pressure, temperature, flow, current measurements - small-angle elastic scattering at high ε and low $Q^2$

# THE OLYMPUS COLLABORATION


Arizona State University, USA
DESY,Hamburg, Germany
Hampton University, USA
INFN, Bari, Italy
INFN, Ferrara, Italy
INFN, Rome, Italy
Massachusetts Institute of Technology, USA
St. Petersburg Nuclear Physics Institute, Russia
Universität Bonn, Germany
University of Colorado, USA
Universität Erlangen-Nürnberg, Germany
University of Glasgow, United Kingdom
University of Kentucky, USA
Universität Mainz, Germany
University of New Hampshire,USA
Yerevan Physics Institute, Armenia

# OLYMPUS kinematics

| $E_0$ [GeV] | $\theta_e$ | $p_{e'}$ [GeV/c] | $\theta_p$ | $p_p$ [GeV/c] | $Q^2$ [(GeV/c)$^2$] | $\epsilon$ | Counts |
|---|---|---|---|---|---|---|---|
| 2.0 | 24 | 1.69 | 56.4 | 2.45 | 0.6 | 0.905 | 22613100 |
| | 32 | 1.51 | 48.1 | 2.26 | 0.9 | 0.828 | 4321570 |
| | 40 | 1.46 | 41.3 | 2.07 | 1.2 | 0.736 | 1141960 |
| | 48 | 1.27 | 35.7 | 1.89 | 1.6 | 0.636 | 389822 |
| | 56 | 1.10 | 31.0 | 1.73 | 1.8 | 0.538 | 162355 |
| | 64 | 0.97 | 27.1 | 1.59 | 2.0 | 0.447 | 78744 |
| | 72 | 0.85 | 23.8 | 1.47 | 2.2 | 0.367 | 42954 |

Table 1.3: Kinematics for 2.0 GeV beam energy and count estimate per $8^\circ$ bin for 500 h at $2 \cdot 10^{33}$ / (cm$^2$s).

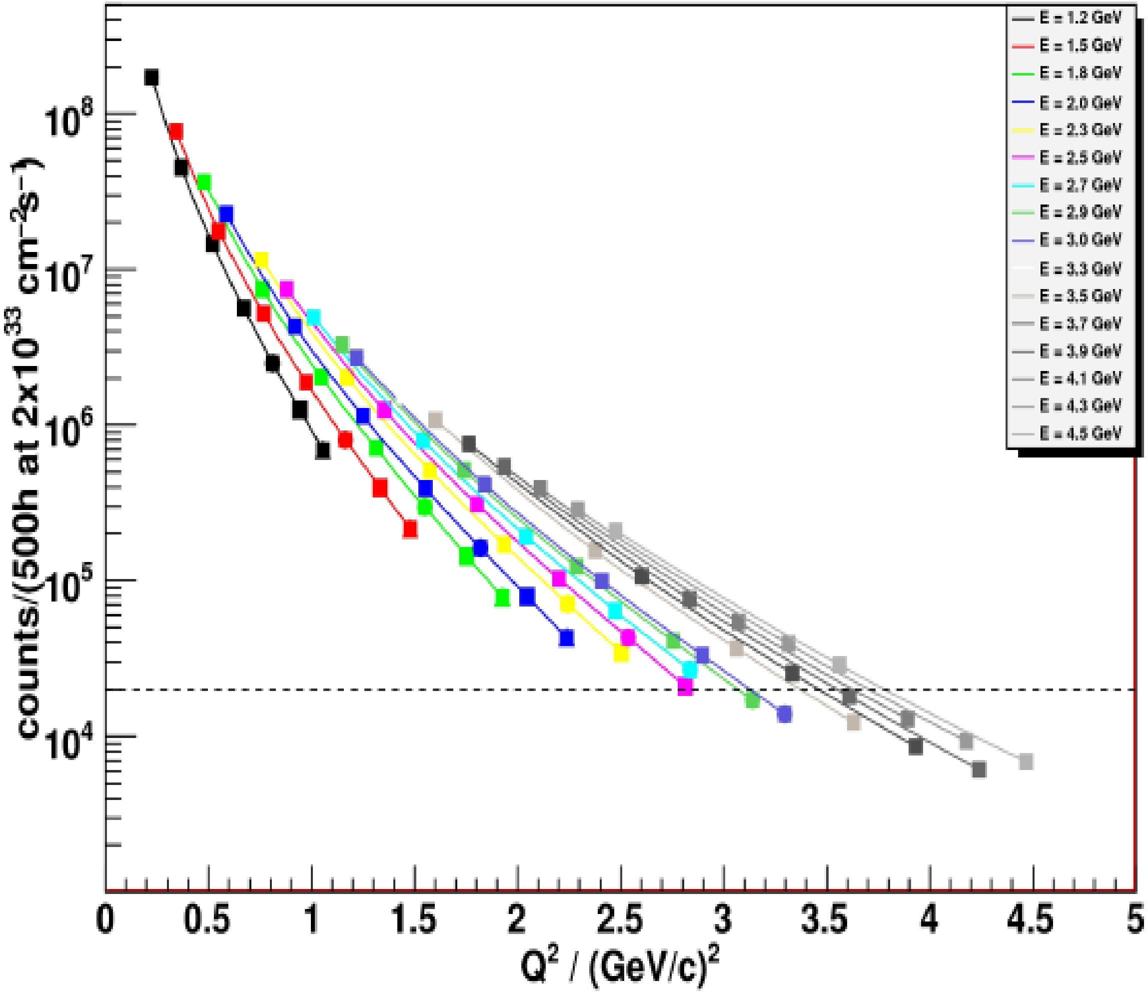



Figure 1.10: Expected distribution of counts per marked angle bin for the BLAST detector for various beam energies, as a function of $Q^2$. The assumed luminosity is $2 \cdot 10^{33}/(\mathrm{cm}^2\mathrm{s}) \times$ 500 hours.

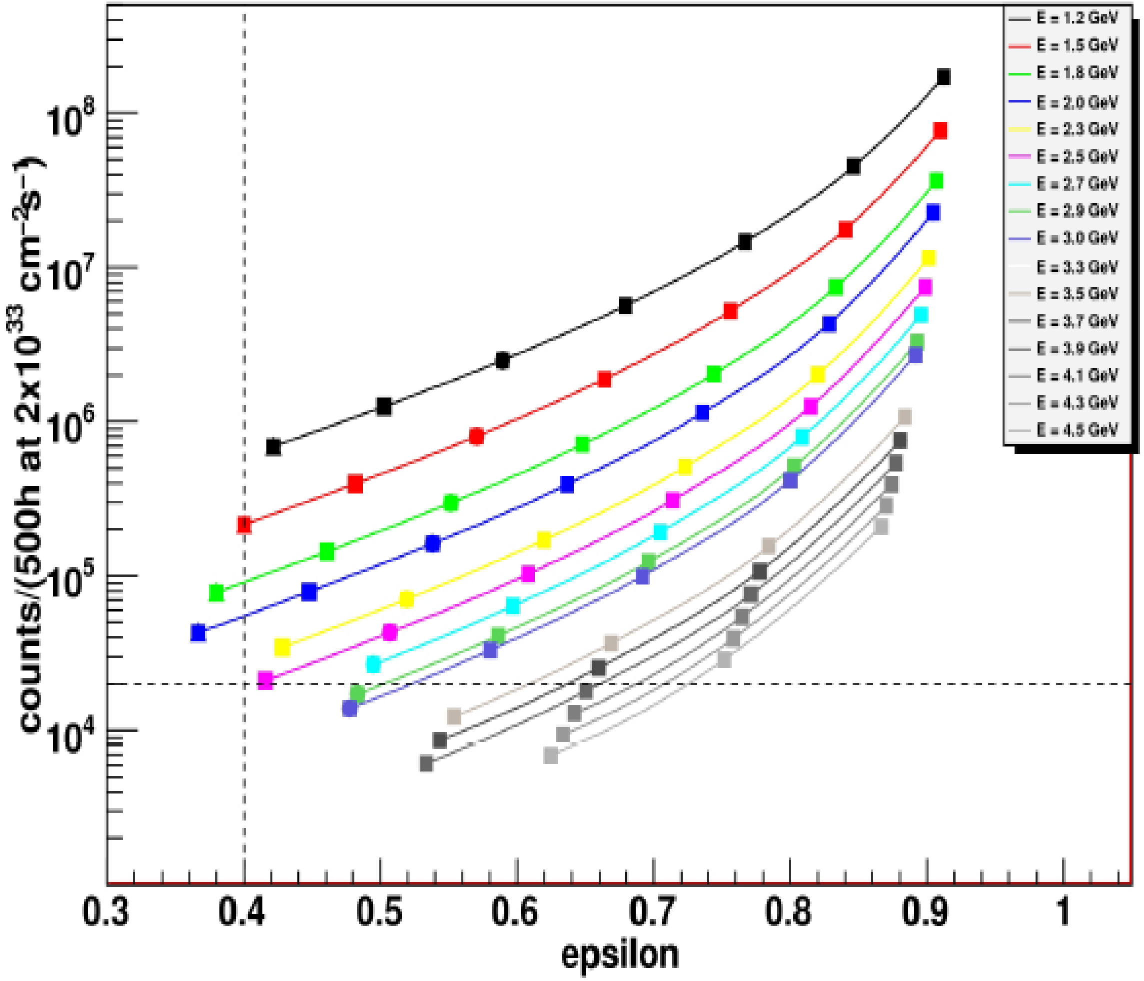
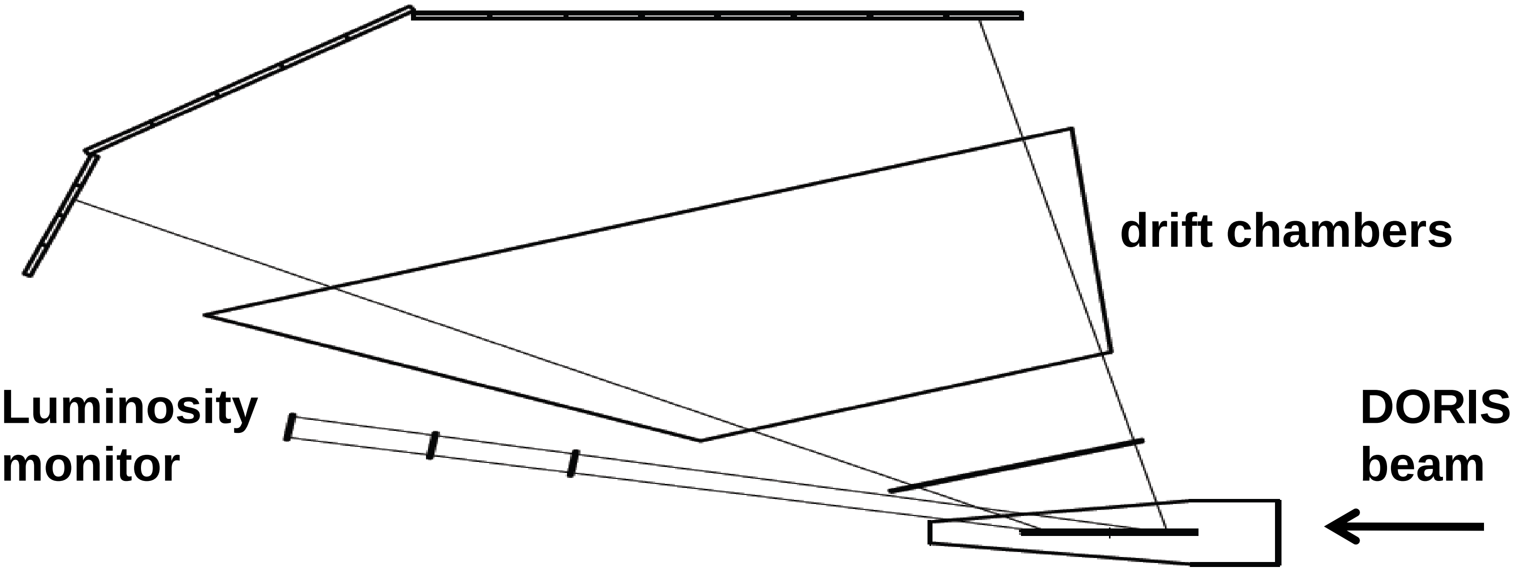



Figure 1.11: Expected distribution of counts per marked angle bin for the BLAST detector for various beam energies, as a function of $\epsilon$. The assumed luminosity is $2 \cdot 10^{33}/(\mathrm{cm}^2\mathrm{s}) \times$ 500 hours.

# Luminosity Monitor



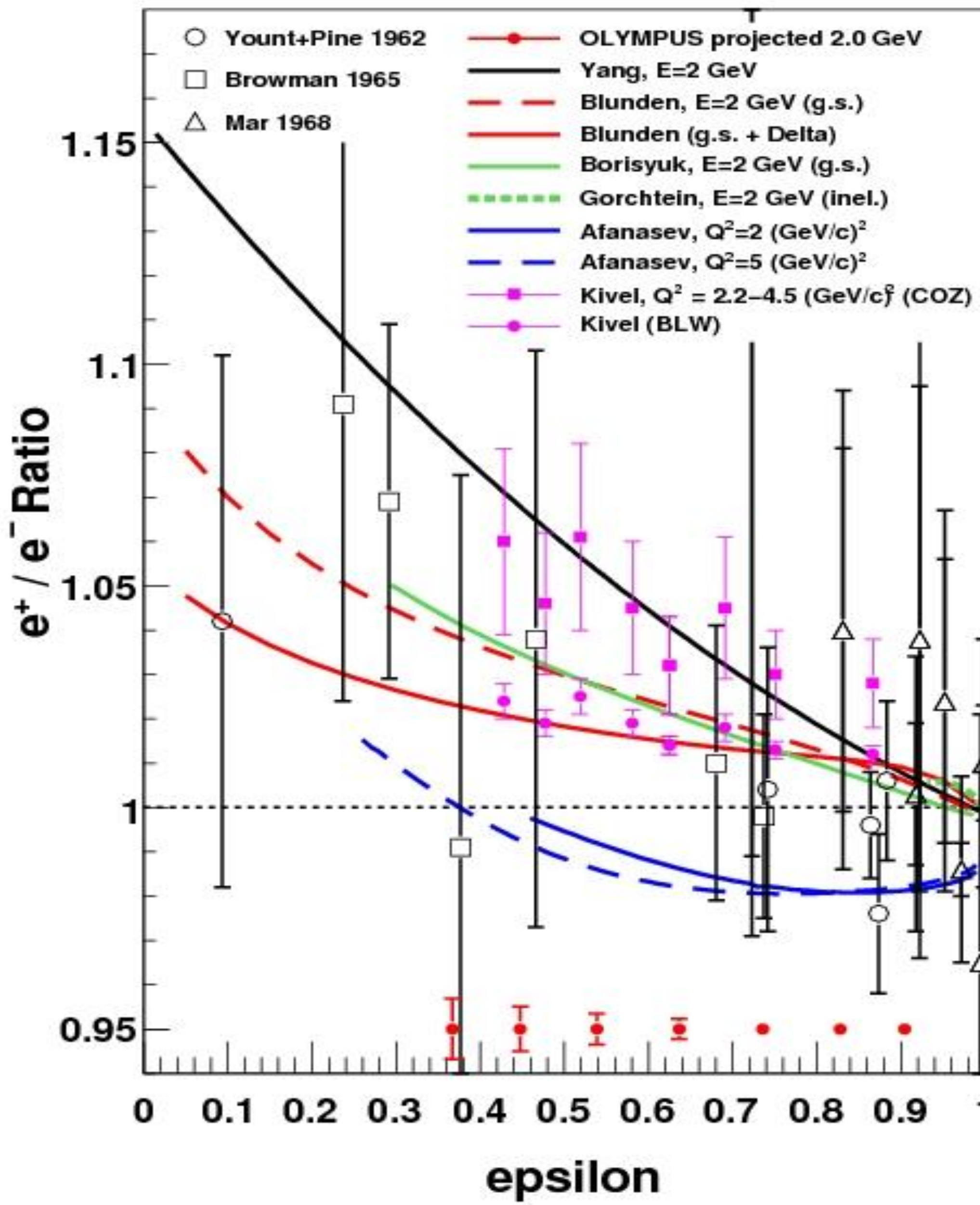

| $E_0$ [GeV] | $Q^2$ [(GeV/c)$^2$] | $p_{e'}$ [GeV/c] | $\epsilon$ | $\theta_p$ | $p_p$ [MeV/c] | Rate [h$^{-1}$] |
|---|---|---|---|---|---|---|
| 4.5 | 0.801 | 4.073 | 0.9736 | 58.7° | 992 | 1846 |
| 2.0 | 0.167 | 1.911 | 0.9774 | 71.8° | 418 | 49792 |

Table 4.1: Kinematics and count rates of the luminosity control measurement for beam energies of 2.0 and 4.5 GeV at $\theta_e = 12°$. The assumed solid angle is 1.2 msr determined by the area of rearmost tracking plane farthest from the target.

# Projected OLYMPUS uncertainties

- Luminosity = 2 x $10^{33}$ $cm^{-2}$ $s^{-1}$
- 500 hours each for e+ and e-
- 2 GeV energy

**M. Kohl**



# Control of systematics

**The ratio of positron to electron cross sections can be determined by forming the super ratio :**

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

- **Change between electrons and positrons ~ 1 per day**
- **Change BLAST polarity ~ 1 per day**
- **Left-right symmetry provides additional redundancy – two identical experiments simultaneously taking data**

# Schedule

- OLYMPUS proposal approved by DESY in December 2008, conditional upon the necessary funding being realized.
- Requests submitted to funding agencies:

  December 2008 (Germany) and January 2009 (US)

  Fall 2009 (Italy, Russia, and U.K.)
- Hope for a green light from DOE in the near future
- Remove ARGUS experiment in Fall 2009
- Ship BLAST/OLYMPUS detector and OLYMPUS target in summer/fall 2010
- Modify DORIS beamline and install OLYMPUS target in DORIS in winter 2010/11 shutdown.
- Install complete OLYMPUS experiment in summer 2011
- Commission in fall 2011
- Take data in 2012

# OLYMPUS Collaboration

- 57 collaborators from 16 institutions
- The OLYMPUS collaboration is built from
  - the core of the BLAST collaboration
  - key expertise from HERMES
  - strong hadron physics groups in Europe
  - key DESY staff
- 12 FTE years of engineering are available to design, construct, and install the experiment.
- In the years 2010-12, 16.6 Physicist FTE years p.a. are committed, i.e. 49.8 FTE years in total.
- 14 graduate students are committed to OLYMPUS.
- In place already 13.6/16.6 Physicist FTE years p.a.

  10/14 Ph.D. students

  7.5/12 FTE years of engineering
- The collaboration is providing in-kind contributions to the removal of ARGUS and the modifications to DORIS.

| Institute Faculty | Physicist FTE | Ph.D. Student | Engineer FTE | Fraction Requested |
|---|---|---|---|---|
| **ASU:** | | | | |
| Alarcon | 0.3 | 1 | | |
| **DESY:** | | | | |
| Brinker, Holler, Schneekloth | 2 | | 3 | |
| **Hampton:** | | | | |
| Kohl | 1.5 | 1 | | |
| **Italian Groups:** | | | | |
| Cisbani, DeLeo, Ferretti Dalpiaz | | | | |
| Frullani, Garibaldi, Lenisa, Nappi | 2 | 2 | 3 | 2 Ph.D. stud. |
| **MIT:** | | | | |
| Matthews, Milner, Redwine | 3 | 2 | 1.5 | 1.5 Engineers |
| **St. Petersburg:** | | | | |
| Belostotski, Miklukho, Naryshkin | 1 | 1 | 3 | 3 Engineers |
| **U. Bonn:** | | | | |
| Beck, Klein, Schmieden | 2 | 1 | 0.5 | 1 p.d. |
| **U. Colorado:** | | | | |
| Kinney | 0.2 | | | |
| **U. Erlangen-Nürnberg:** | | | | |
| Steffens | 0.1 | | | |
| **U. Glasgow:** | | | | |
| Kaiser,Rosner | 1.3 | 1 | 0.5 | 1 p.d., 1 Ph.D. stud. |
| **U. Kentucky:** | | | | |
| Crawford | | 1 | | |
| **U. Mainz:** | | | | |
| Denig, Maas, Von Harrach | 1.9 | 1 | 0.5 | 1 p.d., 1 Ph.D. stud. |
| **U. New Hampshire** | | | | |
| Calarco | 0.5 | 1 | | |
| **Yerevan** | | | | |
| Akopov, Avetisyan, | | | | |
| Elbakian, Marukyan | 0.8 | 2 | | |
| Total | 16.6 | 14 | 12 | |

Table 8.1: Personnel committed to the OLYMPUS experiment by institution.

## 8.2 Institutional responsibilities

The responsibilities of each institution are listed as follows:

**Arizona State University:** TOF support, particle identification, magnetic shielding
**DESY:** Modifications to DORIS accelerator and beamline, toroid support, infrastructure, installation
**Hampton University:** Luminosity monitor, simulations
**INFN, Bari:** GEM electronics
**INFN, Ferrara:** Target
**INFN, Rome:** GEM electronics
**MIT:** BLAST spectrometer, wire chambers, tracking upgrade, target, transportation to DESY, simulations
**St. Petersburg Nuclear Physics Institute:** Removal of ARGUS, slow controls, simulations
**Universität Bonn:** Trigger and data acquisition
**University of Colorado:** Wire chambers
**Universität Erlangen-Nürnberg:** Target
**University of Glasgow:** Data acquisition, particle identification
**University of Kentucky:** Simulations
**Universität Mainz:** Trigger, data acquisition, GEM detectors
**University of New Hampshire:** TOF scintillators
**Yerevan:** Removal of ARGUS, TOF system

# Costs

- > M€ 3.6 of existing equipment is provided from the U.S.
- k€ 872 is requested from DOE for the tracking upgrade, the target, and shipping to DESY.
- k€ 89.3 is requested from NSF for the luminosity monitor.
- k€ 751 is requested by Univ. of Bonn, Erlangen and Mainz from BMBF for electronics and DAQ.
- The total operating cost is estimated at k€ 634 over the lifetime of OLYMPUS => k€ 4.2 per Physicist Ph.D. per year over three years.

# Summary

- The OLYMPUS experiment is proposed to definitively answer a fundamental question of great current interest in physics.

  `The biggest surprise of all!' – Elliot Leader, SPIN 2008
- The OLYMPUS collaboration with DESY has developed a detailed design of the experiment and a plan to install, commission and carry out the experiment by the end of 2012.
- The OLYMPUS design and necessary resources (personnel and costs) and schedule are described in the OLYMPUS TDR draft.
- We seek the endorsement of the review committee to proceed with realizing the experiment.

# Back up slides

# Other Experiments

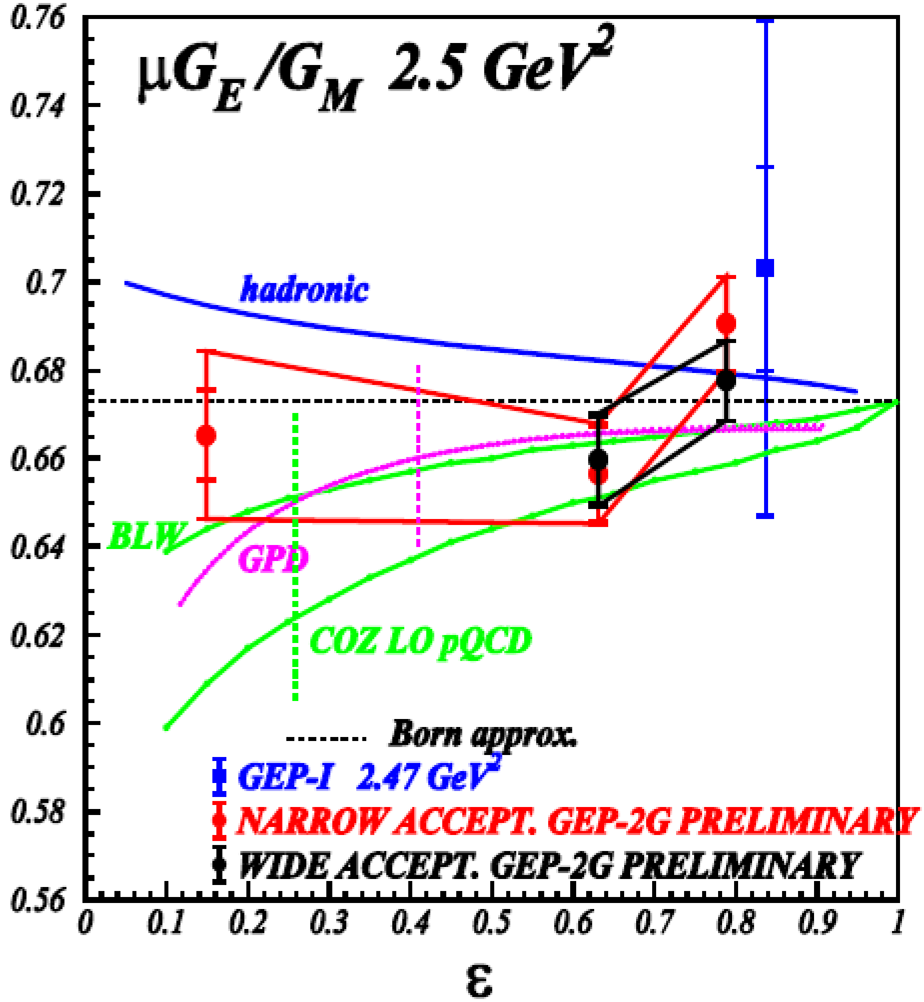
There are two other experiments proposed to measure the cross section ratio:

- **CLAS/PR04-116**
  - secondary e+/e- beam generated via bremsstrahlung
  - reconstruct beam energy
  - high statistics at low $Q^2$
  - very different systematic uncertainties to OLYMPUS
- **Novosibirsk/VEPP-3**
  - like OLYMPUS storage ring with internal target
  - positron beam current ≈ 10 mA
  - non-magnetic detector

There are other JLab experiments which measure other observables sensitive to multi photon contributions:

- **Single spin asymmetries: PR05-15 (Hall A)**
  - sensitive to imaginary amplitude
- **$\varepsilon$-dependence: PR04-119 (polarized), PR05-017 (unpolarized)**
  - weak sensitivity to multi photon contributions

# Preliminary results on form factor ratio




**L. Pentchev**
**JLab Users Meeting**
**June 2009**

**No evidence for effects beyond single photon exchange!**