Hall C Users Meeting 2009, Jefferson Lab, January 30-31, 2009

OLYMPUS – A proposal to definitively determine the contribution of multiple photon exchange in elastic lepton-nucleon scattering

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BLAST

LINEAR ACCELERATOR CENTER BATES MIDDLETON MA

Jefferson Lab

HAMPTON UNIVERSITY The Standard of Excellence, An Education for Life

Overview

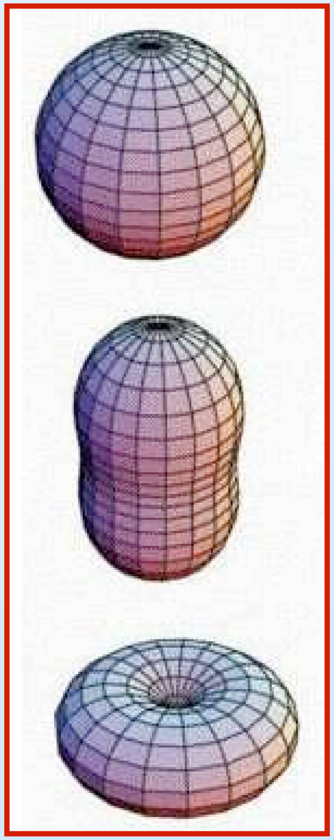
- Introduction
- Motivation from previous data
- Description of the proposed experiment
- Summary

Nucleon Elastic Form Factors …

- Fundamental quantities
- Defined in context of single-photon exchange

- Describe internal structure of the nucleons
- Related to spatial distribution of charge and magnetism

- Rigorous tests of nucleon models
- Determined by quark structure of the nucleon
- Ultimately calculable by Lattice-QCD
- Input to nuclear structure and
  parity violation experiments



50 years of ever increasing activity

- Tremendous progress in experiment and theory
  over last decade
- New techniques / polarization experiments
- Unexpected results

Nucleon Elastic Form Factors

- General definition of the nucleon form factor

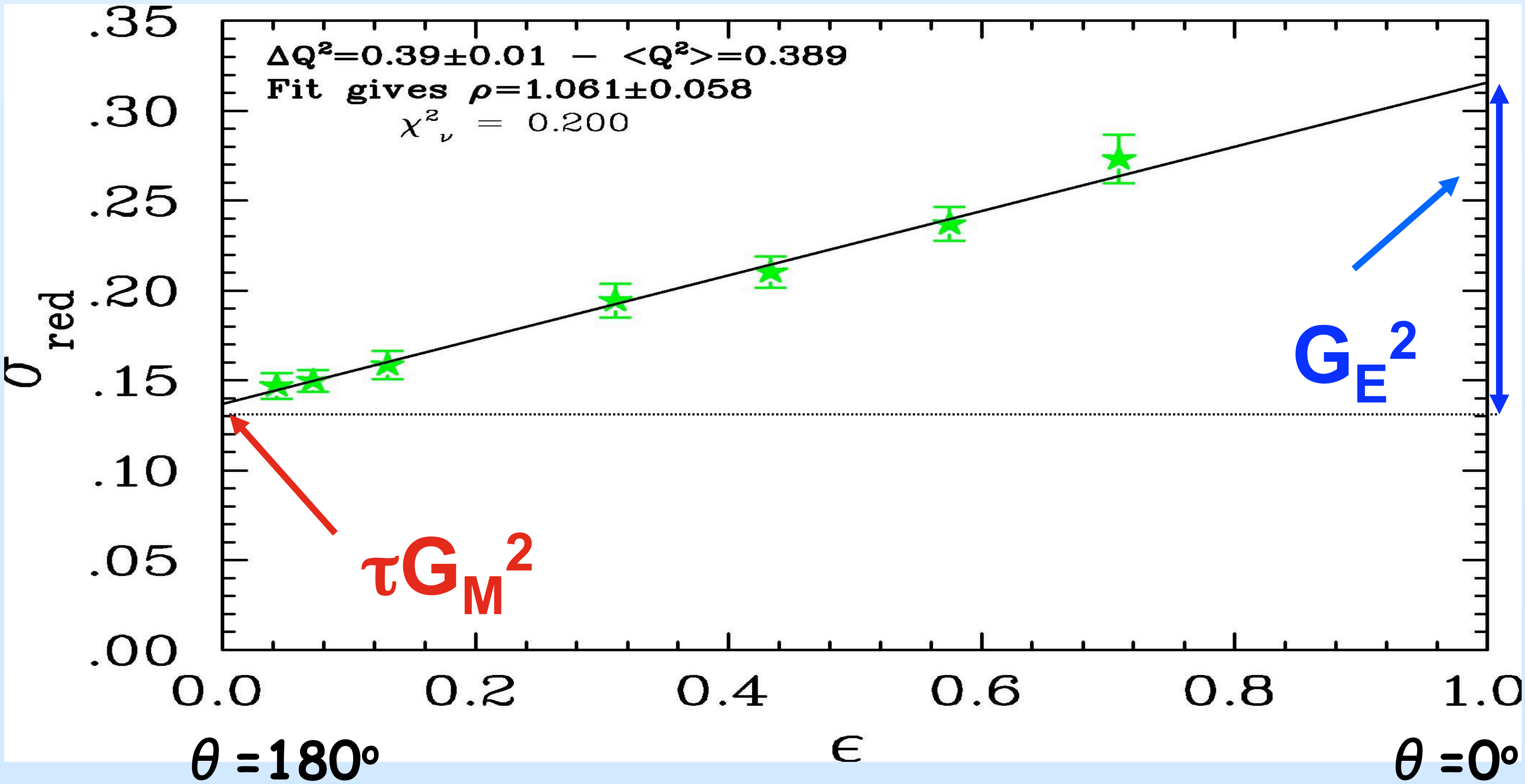
$$\langle N(P')|J^{\mu}_{\rm EM}(0)|N(P)\rangle =$$
$$\bar{u}(P')\left[\gamma^{\mu}F_1^N(Q^2) + i\sigma^{\mu\nu}\frac{q_\nu}{2M}F_2^N(Q^2)\right]u(P)$$

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

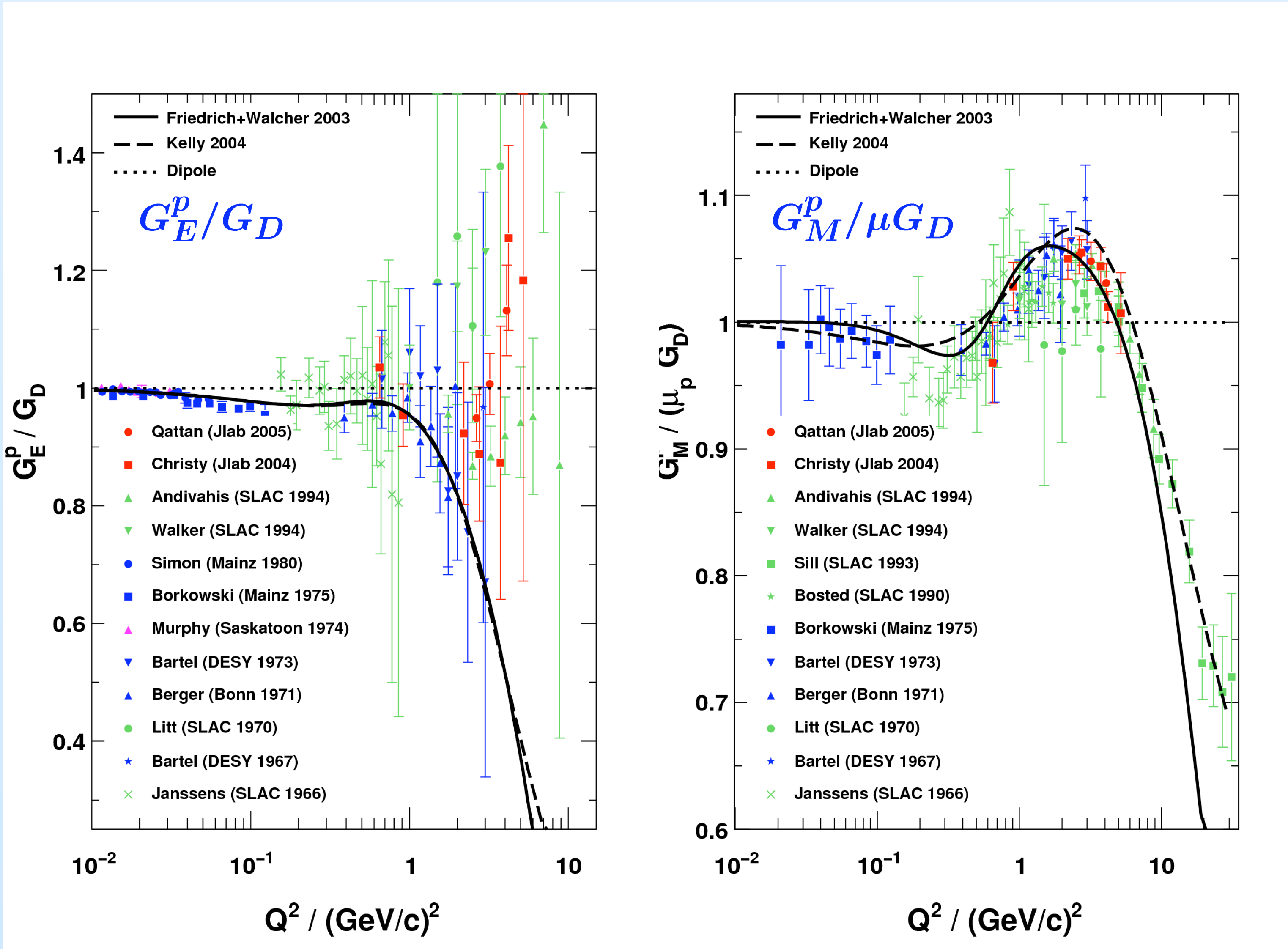
- In One-photon exchange approximation above form factors are observables of **elastic electron-nucleon** scattering

$$\frac{d\sigma/d\Omega}{(d\sigma/d\Omega)_{Mott}} = S_0 = A(Q^2) + B(Q^2)\tan^2\frac{\theta}{2}$$
$$= \frac{G_E^2(Q^2) + \tau G_M^2(Q^2)}{1+\tau} + 2\tau G_M^2(Q^2)\tan^2\frac{\theta}{2}$$
$$= \frac{\epsilon\, G_E^2 + \tau G_M^2}{\epsilon\,(1+\tau)}, \qquad \epsilon = \left[1 + 2(1+\tau)\tan^2\frac{\theta}{2}\right]^{-1}$$

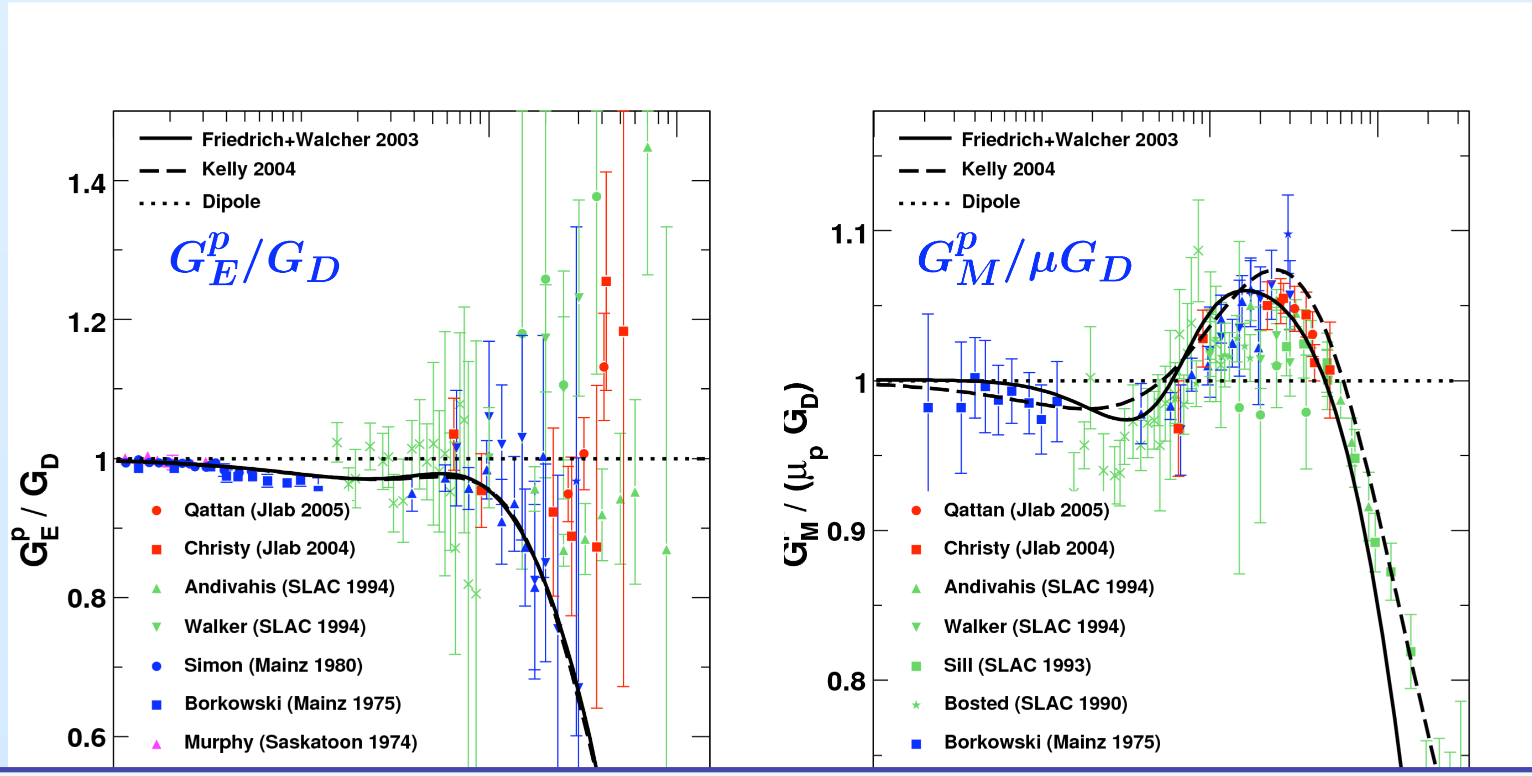
Rosenbluth Separation



G^p_E and G^p_M from Unpolarized Data



G^p_E and G^p_M from Unpolarized Data



- $G(Q^2) \overset{\text{Fourier}}{\longleftrightarrow} \rho(r)$ **charge and magnetization density**
- **Dipole form factor** $G_D = \frac{1}{\left(1+\frac{Q^2}{0.71}\right)^2} \quad \leftrightarrow \quad \rho_D(r) = \rho_0\, e^{-\sqrt{0.71}r}$
- $G_E^p \approx G_M^p/\mu_p \approx G_M^n/\mu_n \approx G_D$ **within 5% for Q^2 < 10 (GeV/c)^2**

Nucleon Form Factors and Polarization

- Double polarization in elastic/quasielastic **ep** or **en** scattering:
  Recoil polarization or (vector) polarized target
  $^{1,2}H(\vec{e},e'\vec{p})$, $^{1,2}\vec{H}(\vec{e},e'p)$, $^{2}H(\vec{e},e'\vec{n})$, $^{2}\vec{H}(\vec{e},e'n)$, $^{3}\vec{He}(\vec{e},e'n)$,

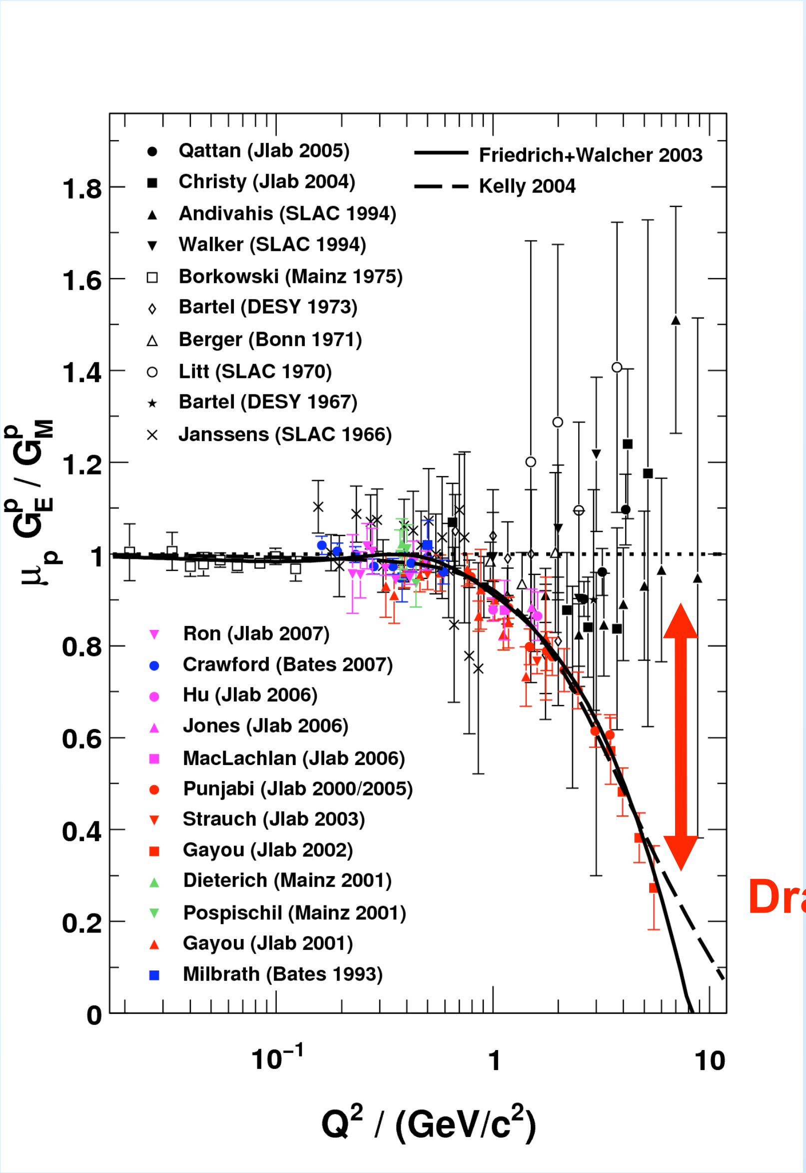
- Polarized cross section
  $$\sigma = \sigma_0 \left(1 + P_e \vec{P}_p \cdot \vec{A}\right)$$

- 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") $\dfrac{P_\perp}{P_\parallel} = \dfrac{A_\perp}{A_\parallel} \propto \dfrac{G_E}{G_M}$

  independent of polarization or analyzing power

Proton Form Factor Ratio

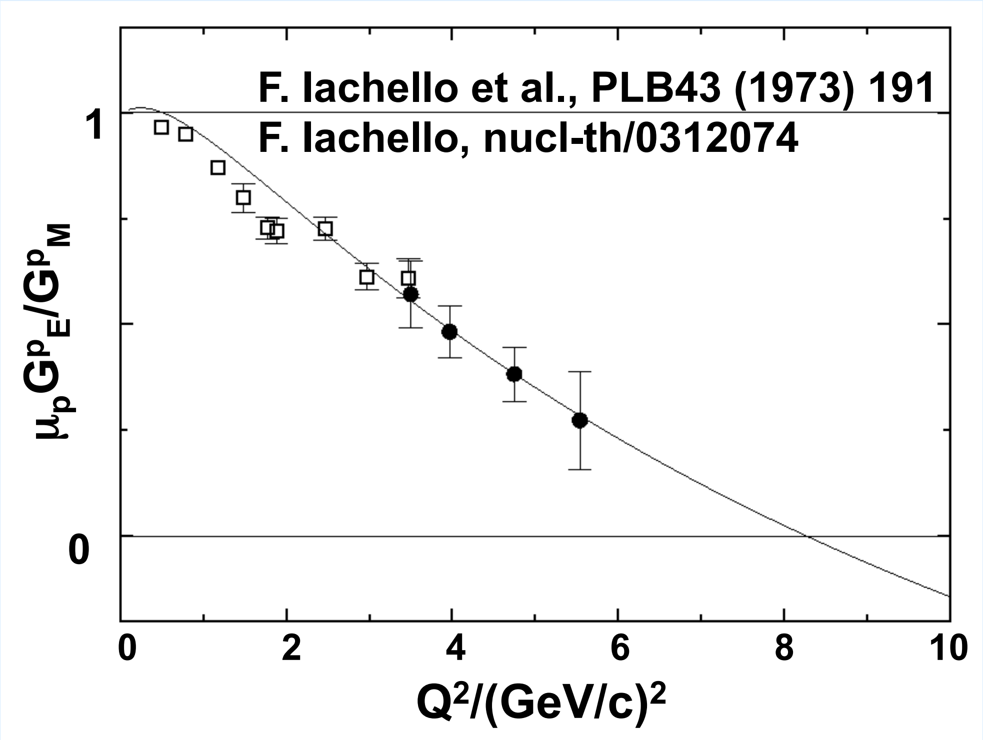


Jefferson Lab

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

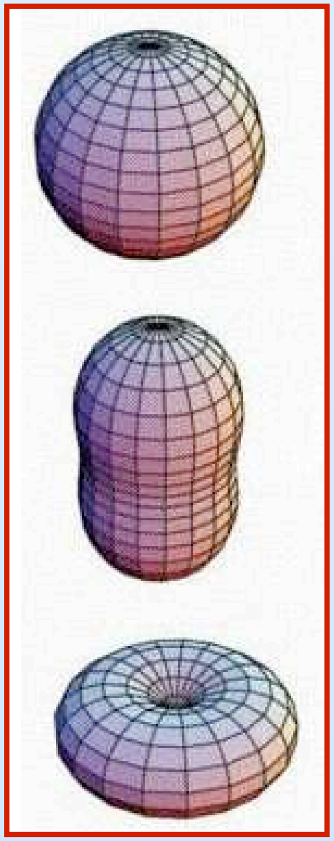
Dramatic discrepancy!

Proton Form Factor Ratio



Iachello 1973:

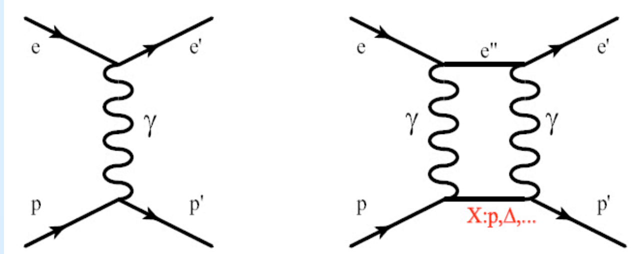
Drop of the ratio already suggested by VMD



A.V. Belitsky et al., PRL91 (2003) 092003
G. Miller and M. Frank, PRC65 (2002) 065205
S. Brodsky et al., PRD69 (2004) 076001
Quark angular momentum
Helicity non-conservation

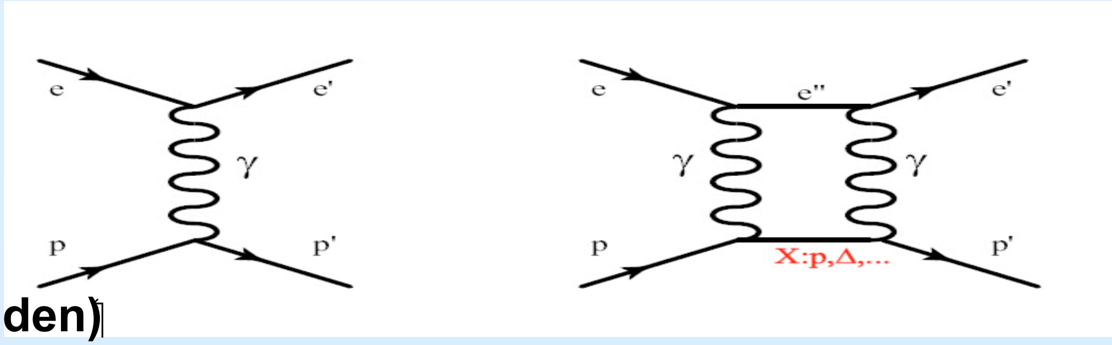
Two-Photon Exchange

Two-photon exchange theoretically suggested

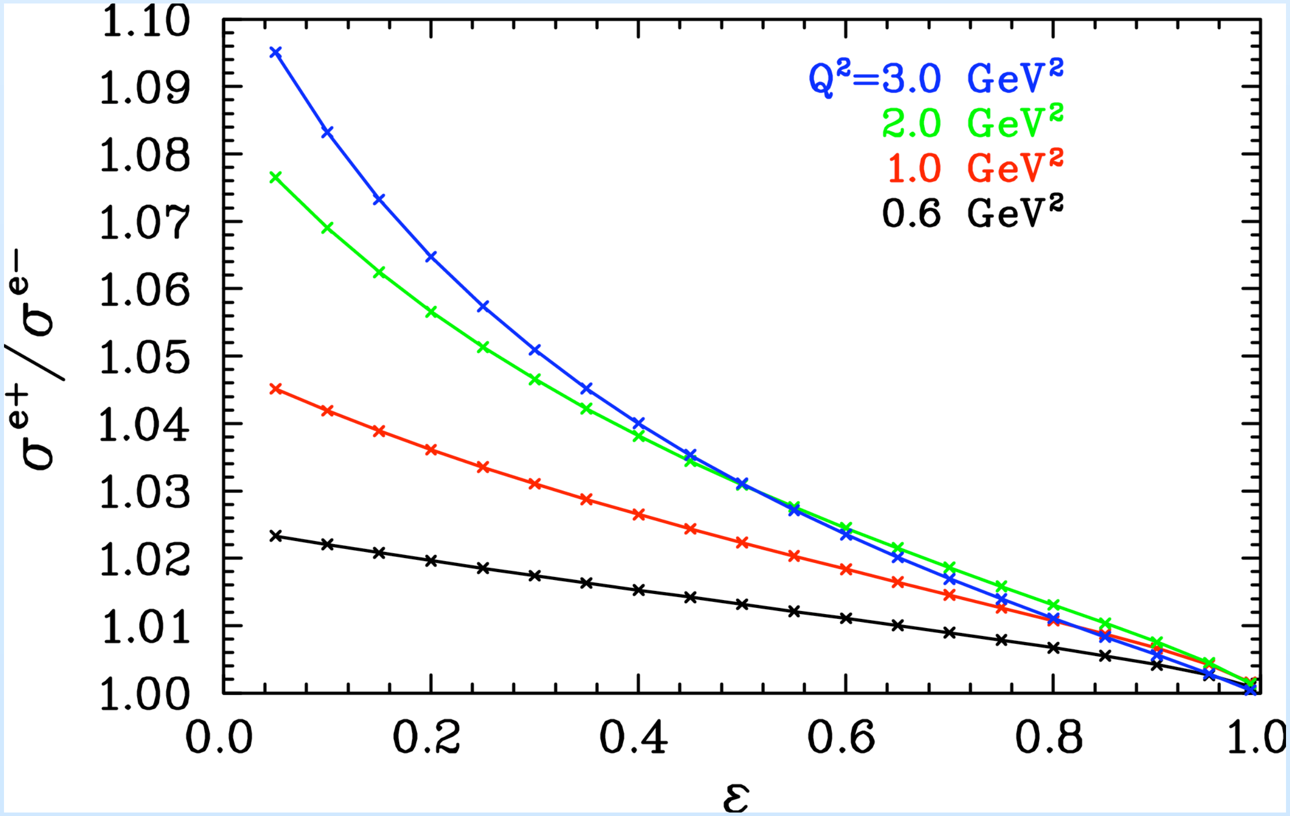


- P.A.M. Guichon and M. Vanderhaeghen, PRL91 (2003) 142303: Formalism … effect could be large on x-sec, small on asym.
- P.G. Blunden, W. Melnitchouk, and J.A. Tjon, PRC72 (2005) 034612, PRL91 (2003) 142304: Nucl. theory … elastic=half
- ➡ S. Kondratyuk, P. G. Blunden, W. Melnitchouk, and J. A. Tjon, PRL95 (2005) 172503; S. Kondratyuk, P.G. Blunden, PRC75 (2007) 038201: Resonances
- M.P. Rekalo and E. Tomasi-Gustafsson, EPJA22 (2004) 331: General features, epsilon (non-) linearity
- Y.-C. Chen, A. Afanasev, S.J. Brodsky, C.E. Carlson, M. Vanderhaeghen, PRL93 (2004) 122301: Partonic calculation at high Q^2 in agreement
- A.V. Afanasev and N.P. Merenkov, PRD70 (2004) 073002: SSA and large logarithms
- ➡ A.V. Afanasev, S.J. Brodsky, C.E. Carlson, Y.C.Chen, M. Vanderhaeghen, PRD72 (2005) 013008: GPD/high Q^2, small effect on asym., nonlinear Rosenbl., induced P
- ➡ Y.M. Bystritskiy, E.A. Kuraev, E. Tomasi-Gustafsson, PRC75 (2007) 015207: TPE small, higher-order radiative effects responsible
- ➡ D. Borisyuk, A. Kobushkin, PRC78 (2008) 025208: Dispersion approach – TPE small!
- M. Kuhn, H. Weigel, EPJA38 (2008) 295: TPE in Skyrme model (assuming 100%)
- D.Y. Chen , H.Q. Zhou, Y.B. Dong, PRC78 (2008) 045208: TPE and timelike form factors
- M. Gorchtein, C.J. Horowitz, arXiv:0811.0614 [hep-ph]: gamma-Z box and PV

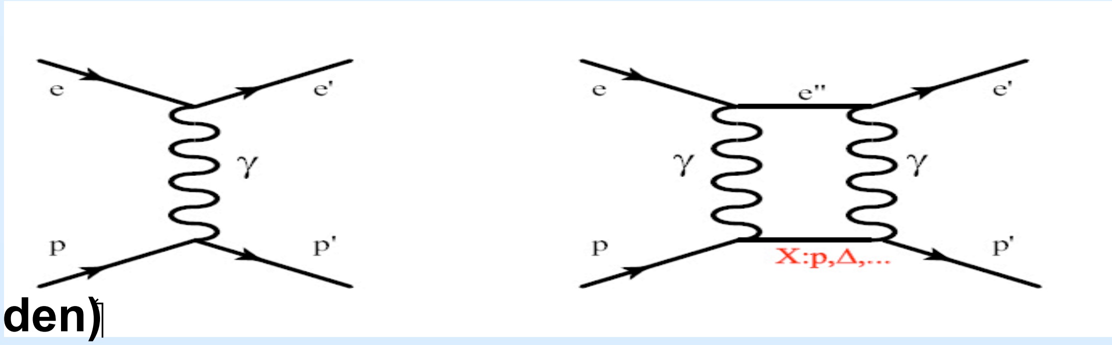
Two-photon exchange



Elastic electron-proton to positron-proton ratio (P. Blunden)



Two-photon exchange



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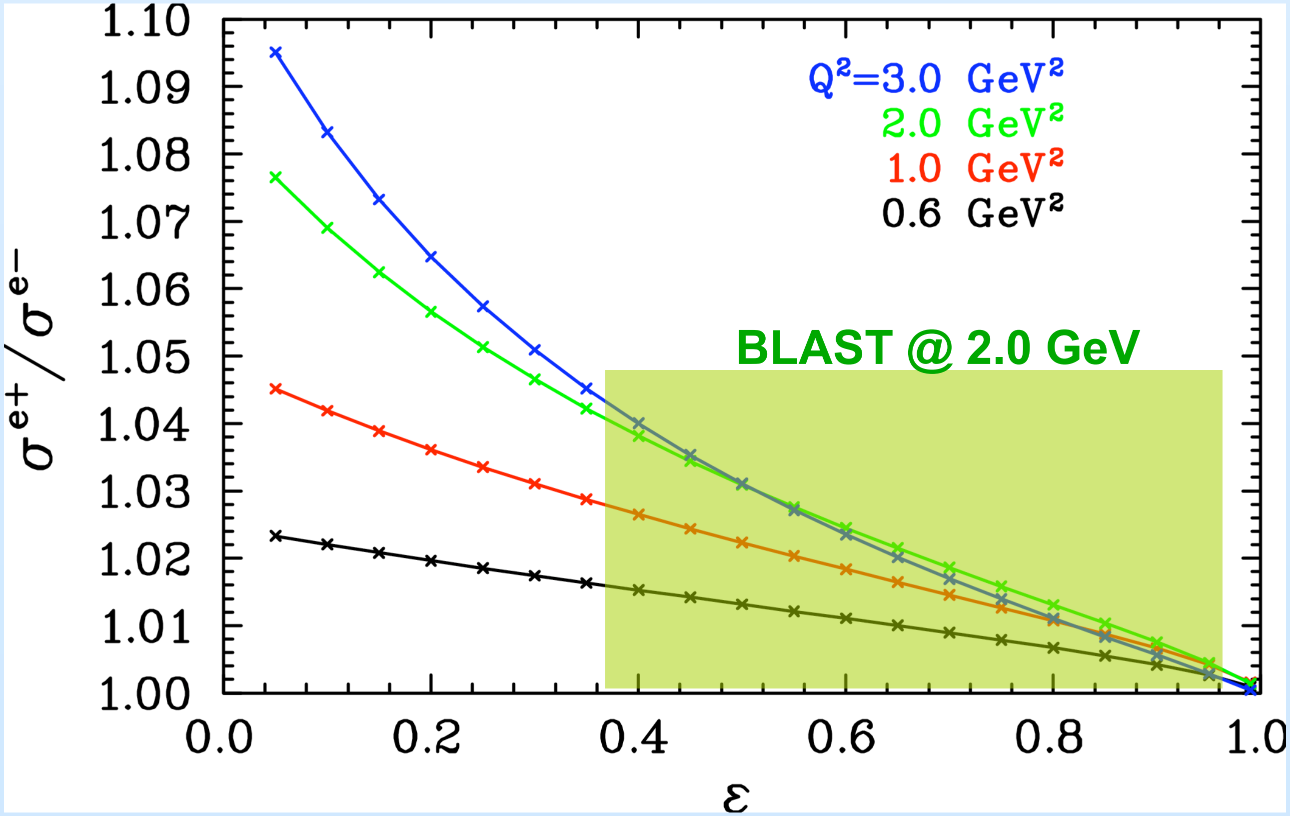
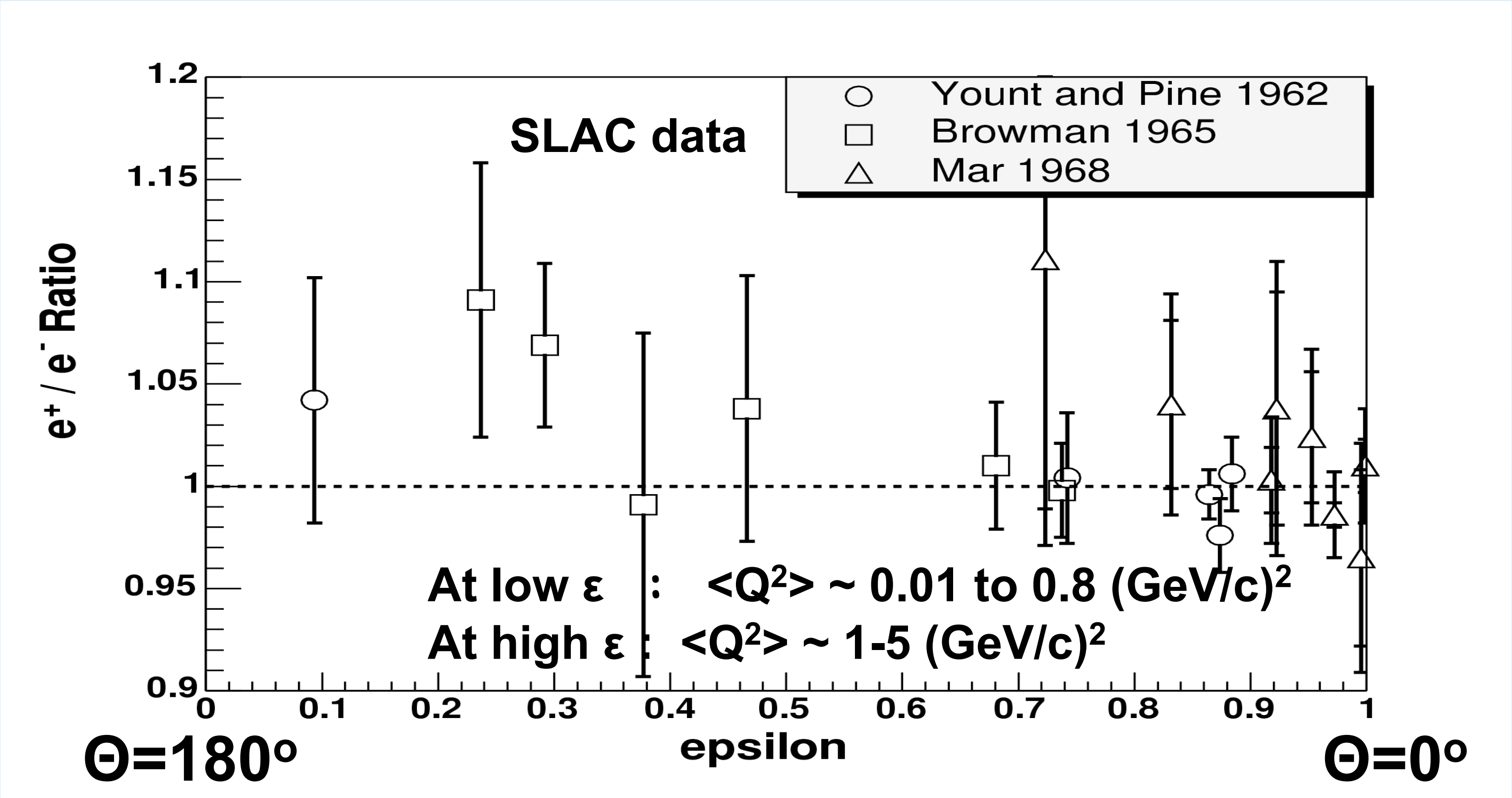


Experiments to Verify 2γ Exchange

Precision comparison of positron-proton and electron-proton elastic scattering over a sizable ε range at $Q^2 \sim$ 2-3 $(GeV/c)^2$

J. Arrington, PRC 69 (2004) 032201(R)



Two-photon exchange

DORIS

HERA

DESY Site

A PROPOSAL TO DEFINITIVELY DETERMINE THE CONTRIBUTION OF MULTIPLE PHOTON EXCHANGE IN ELASTIC LEPTON-NUCLEON SCATTERING

THE OLYMPUS COLLABORATION

September 9, 2008

Argonne National Laboratory   Arizona State University

J. Calarco
University of New Hampshire

June 19, 2007

Abstract

OLYMPUS

pOsitron-proton and

eLectron-proton elastic scattering to test the

hYpothesis of

Multi-

Photon exchange

Using

DoriS

2008 – Full proposal
2009/10 – Transfer of BLAST
2011/12 – OLYMPUS Running

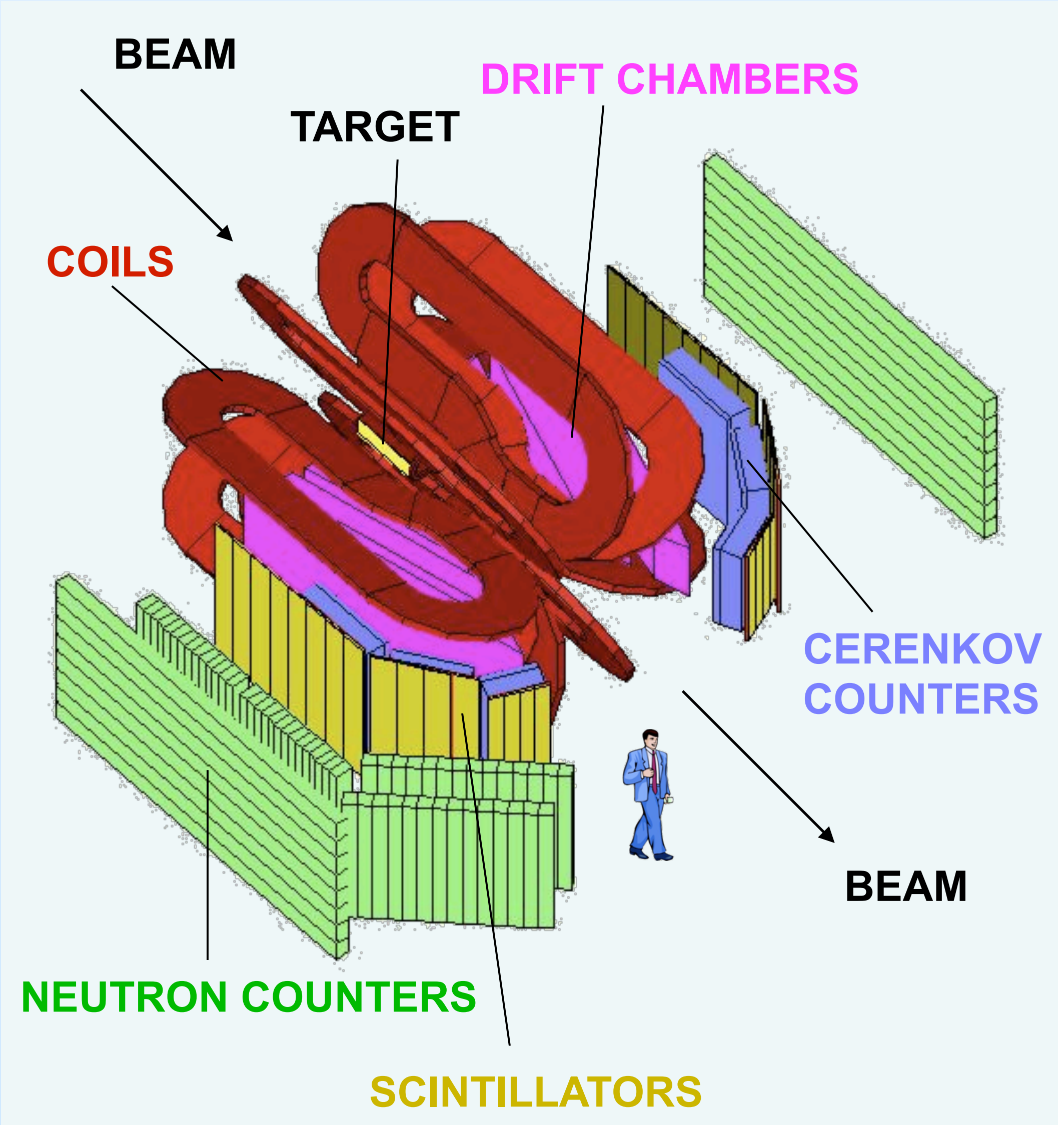
Proposed Experiment

- Electrons/positrons (100mA) in multi-GeV storage ring
  DORIS at DESY, Hamburg, Germany
- Unpolarized internal hydrogen target (buffer system)
  3×10^{15} at/cm^2 @ 100 mA $\rightarrow$ $L = 2 \times 10^{33}$ / (cm^{2}s)
- Redundant monitoring of luminosity
  pressure, temperature, flow, current measurements
  small-angle elastic scattering at high epsilon / low Q^2
- Large acceptance detector for e-p in coincidence
  BLAST detector from MIT-Bates available

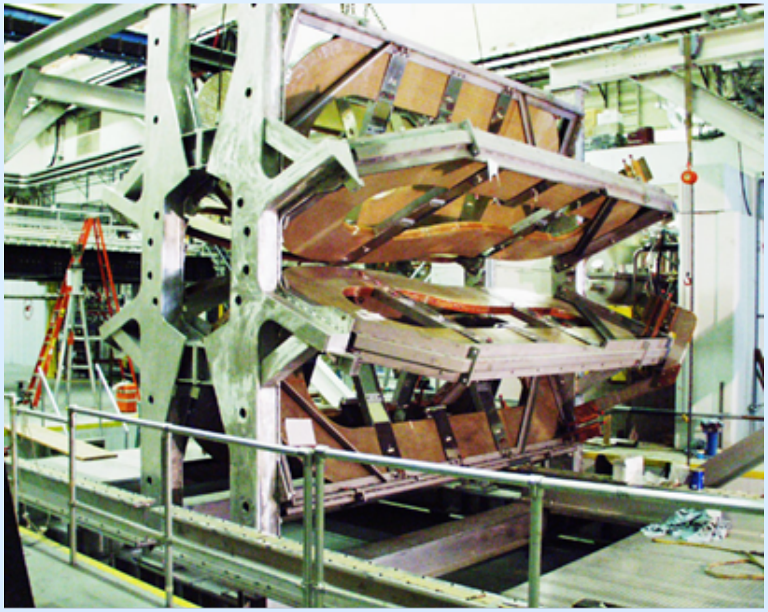
- Measure ratio of positron-proton to electron-proton unpolarized elastic scattering to 1% stat.+sys.

The BLAST Detector

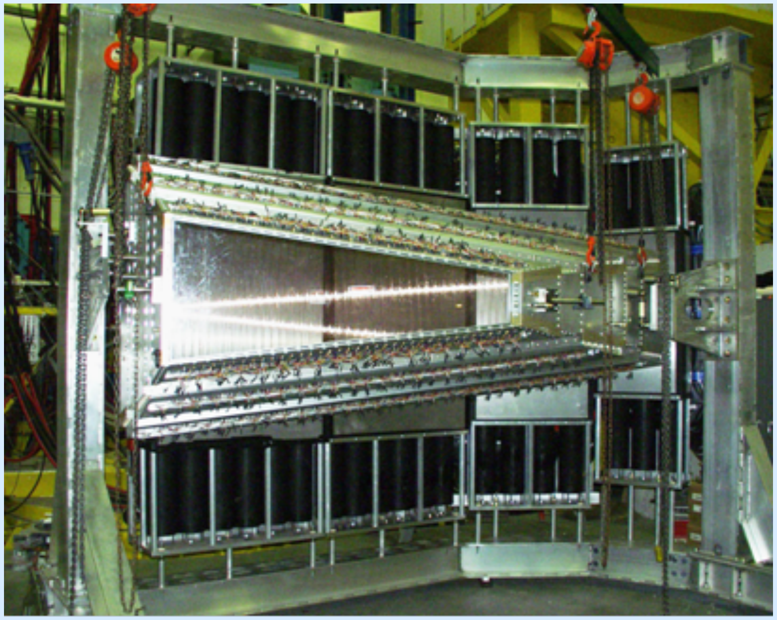
- **Left-right symmetric**
- **Large acceptance:**
  $0.1 < Q^2/(GeV/c)^2 < 0.8$
  $20^o < \theta < 80^o$, $-15^o < \phi < 15^o$
- **COILS** $B_{max} = 3.8$ kG
- **DRIFT CHAMBERS**
  Tracking, PID (charge)
  $\delta p/p=3\%$, $\delta\theta = 0.5^o$
- **CERENKOV COUNTERS**
  e/π separation
- **SCINTILLATORS**
  Trigger, ToF, PID (π/p)
- **NEUTRON COUNTERS**
  Neutron tracking (ToF)



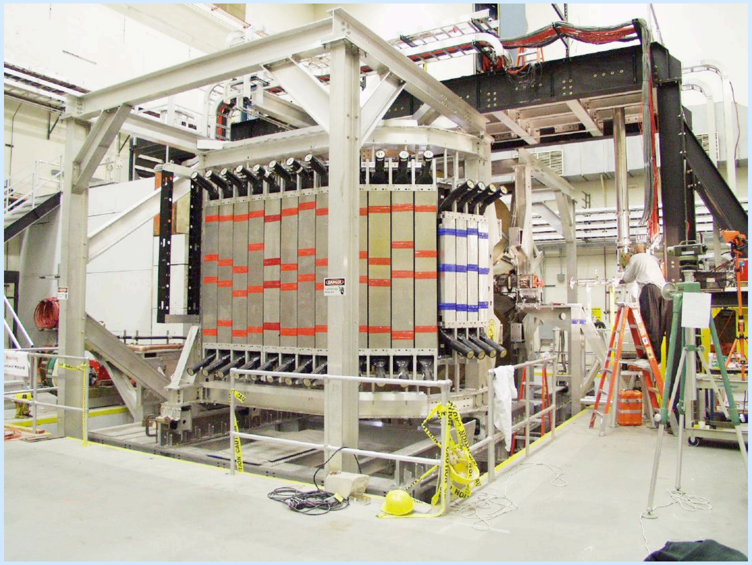
The BLAST Detector



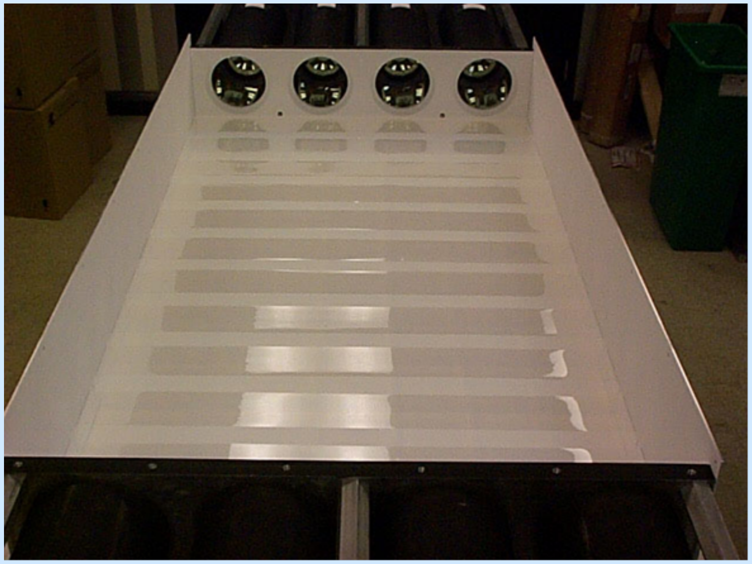
Bates



MIT



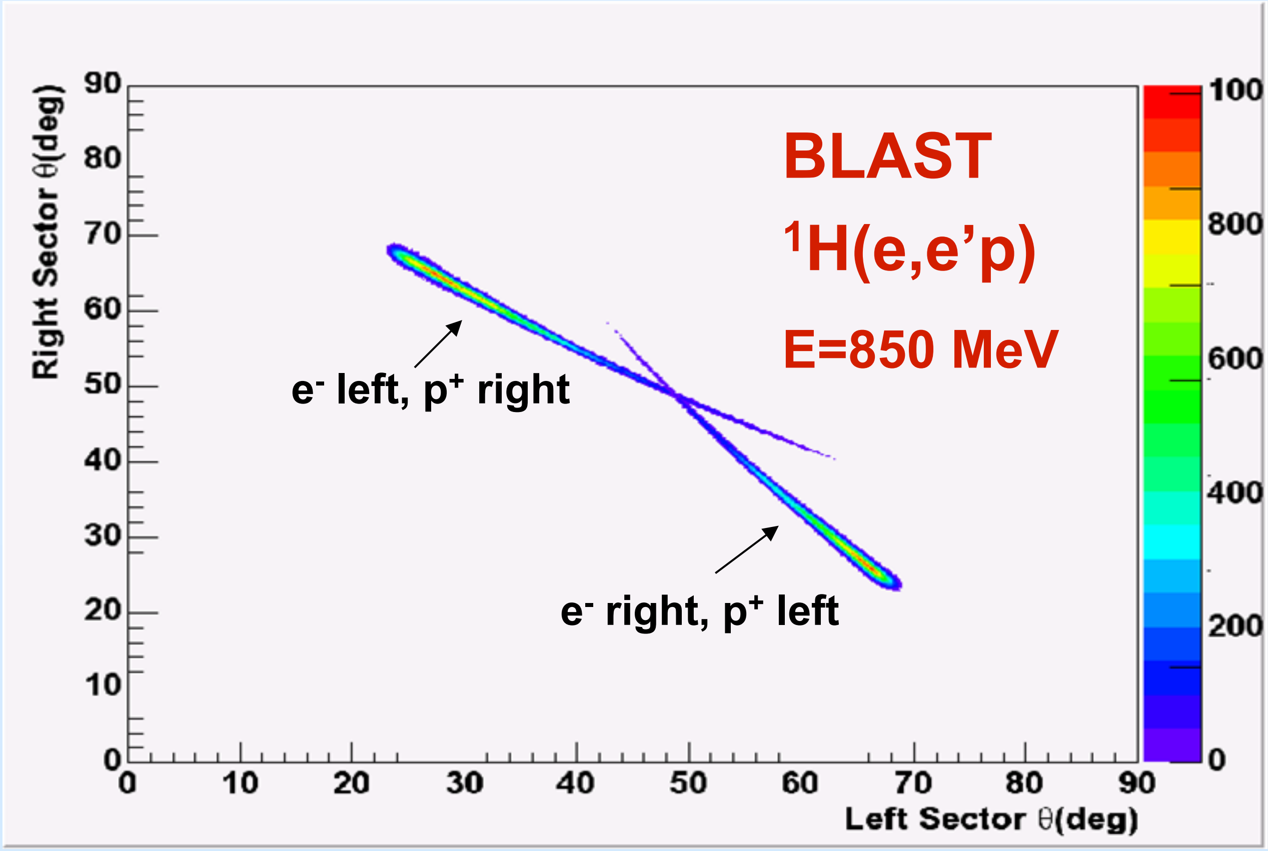
UNH

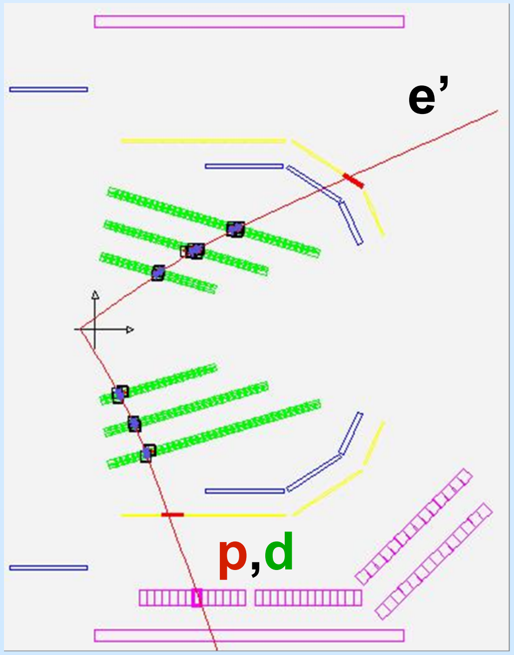


ASU

Identification of Elastic Events

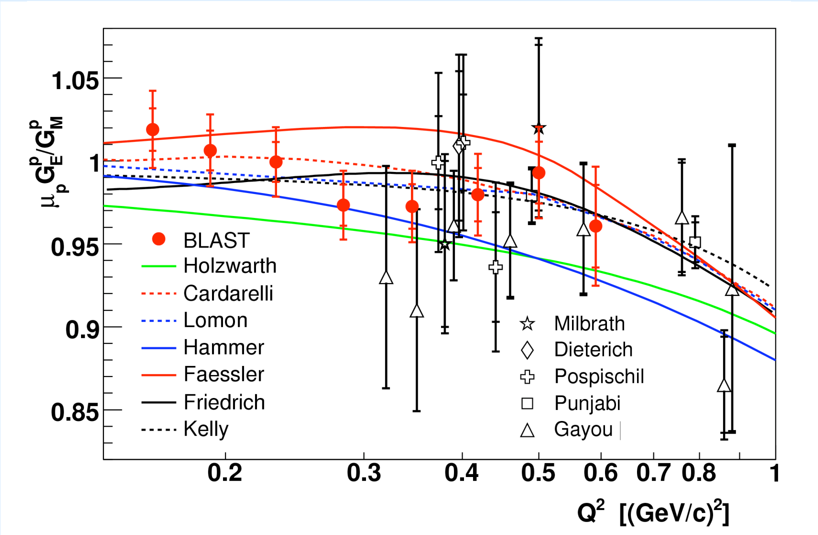
- Charge +/-
- Coplanarity
- Kinematics
- Timing

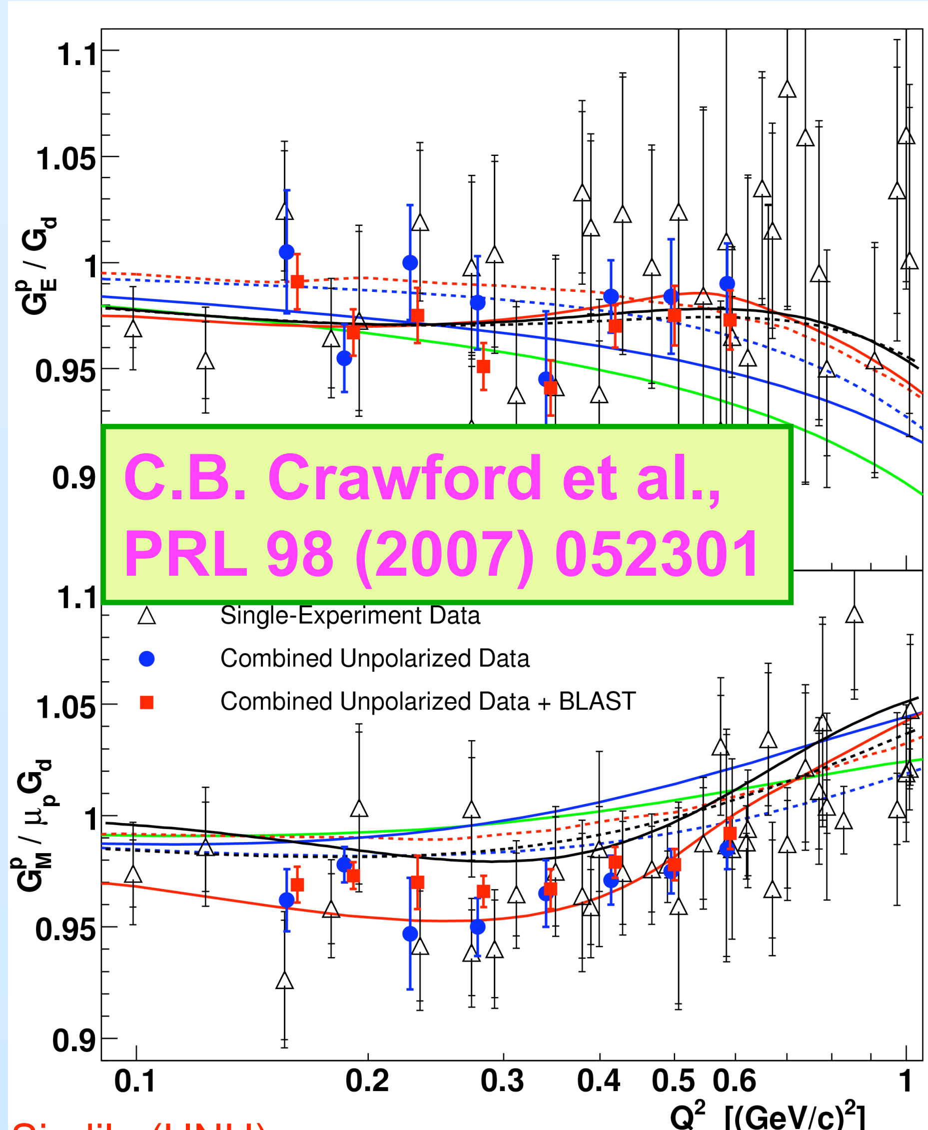




- Advantages of magnetic field:
  - suppression of background
  - 2-3% momentum resolution
- $\sigma_\theta = 0.5^o$ and $\sigma_\varphi = 0.5^o$

Proton Form Factor Ratio $\mu_p G^p_E / G^p_M$ *



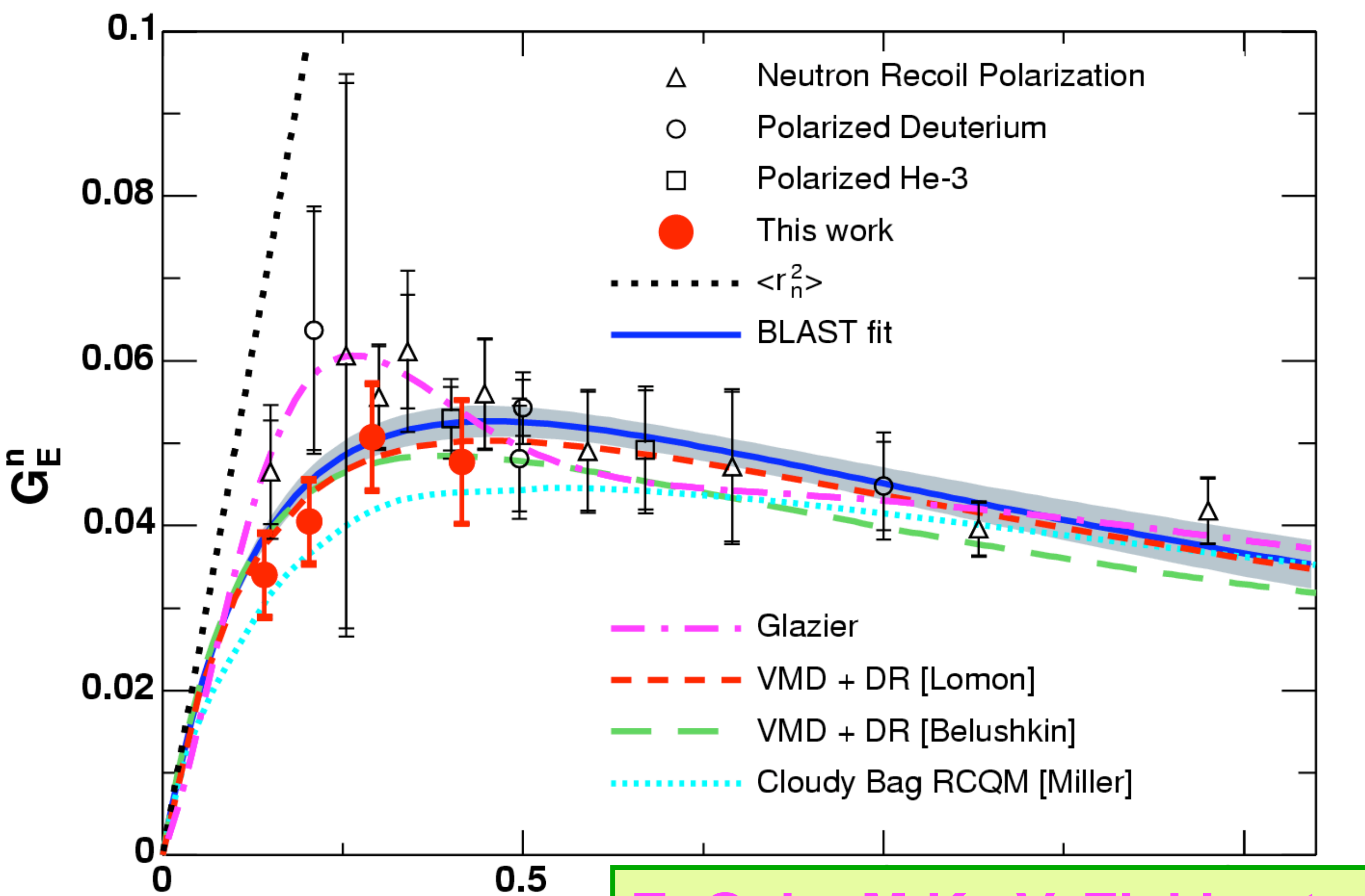


C.B. Crawford et al., PRL 98 (2007) 052301

- **Impact of BLAST data combined with cross sections on separation of G^p_E and G^p_M**
- **Errors factor ~2 smaller**
- **Reduced correlation**
- **Deviation from dipole at low Q^2!**

*Ph.D. work of C. Crawford (MIT) and A. Sindile (UNH)

Neutron Electric Form Factor G^n_E*



E. Geis, M.K., V. Ziskin et al., PRL 101 (2008) 042501

*Ph.D. work of V. Ziskin (MIT) and E.

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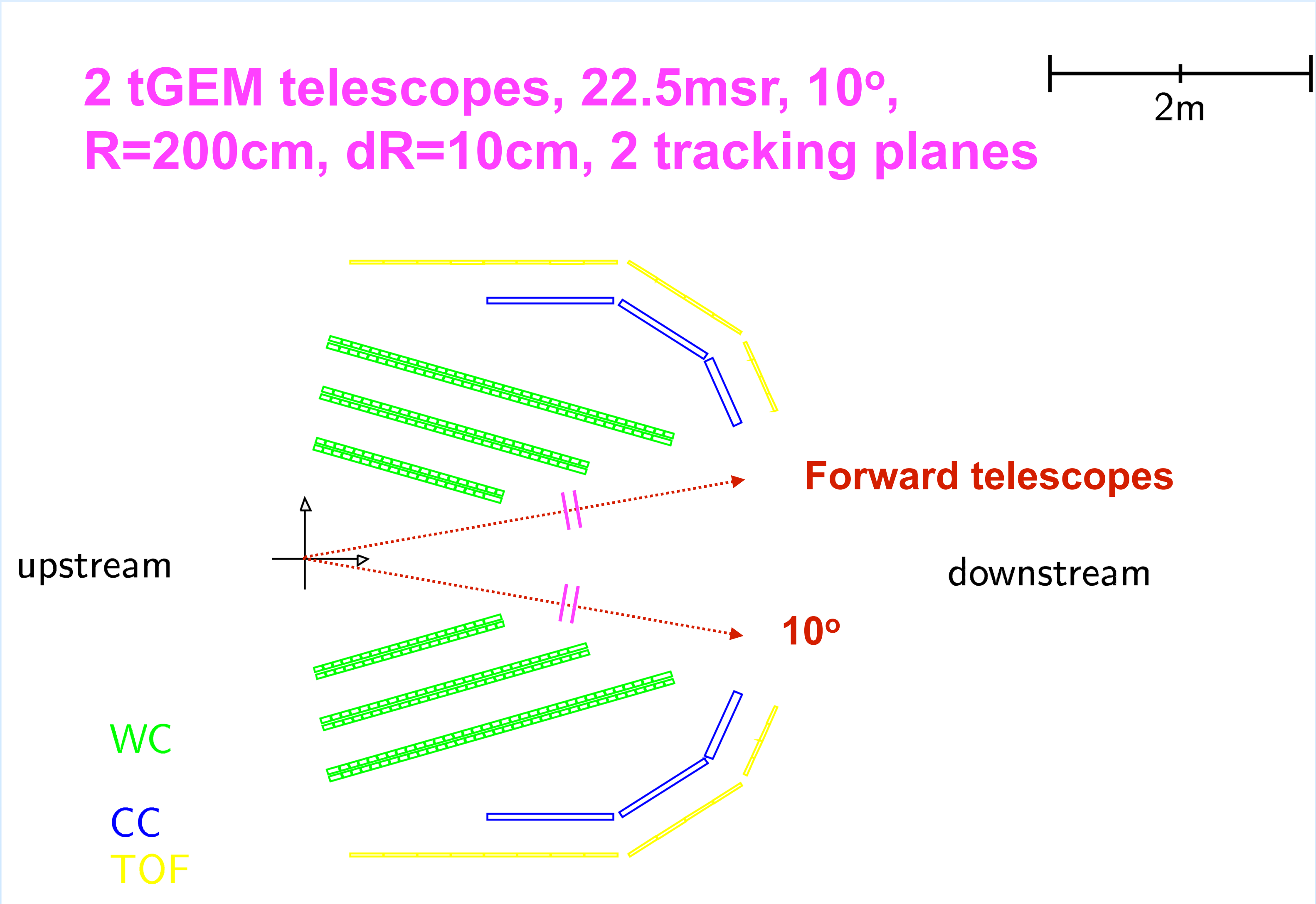
Luminosity Monitors: Telescopes



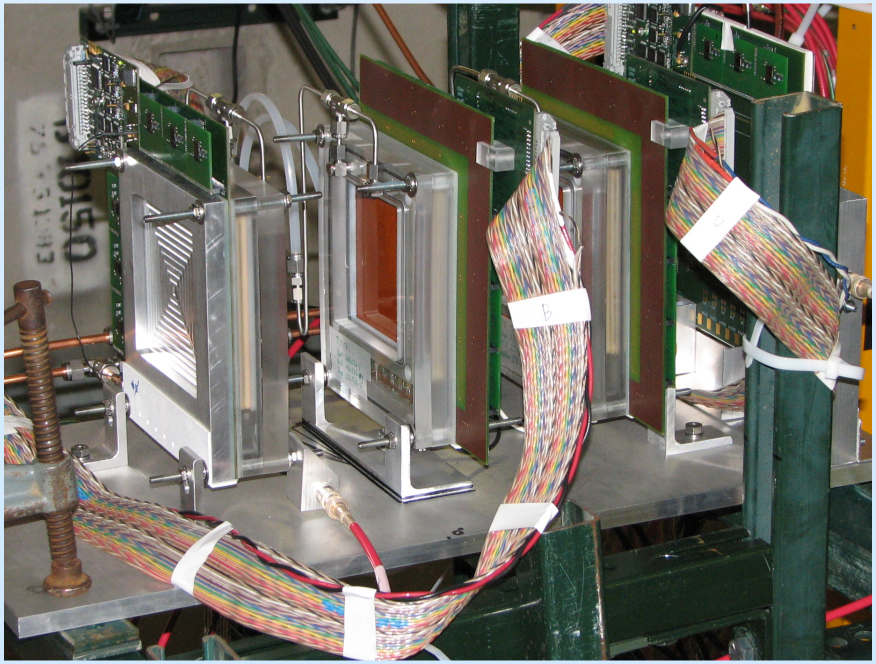
Forward Elastic Luminosity Monitor

- Forward angle electron/positron telescopes or trackers with good angular and vertex resolution
- Coincidence with proton in BLAST
- High rate capability

GEM technology

MIT protoype:

Telescope of 3 Triple GEM prototypes (10×10 cm^2) using TechEtch foils



F. Simon et al., Nucl. Instr. and Meth. A 598 (2009) 432

Control of Systematics

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

i = e+ or e-
j= pos/neg polarity

Geometric proton efficiency: $\kappa^p_{\mathrm{e}+j} = \kappa^p_{\mathrm{e}-j}$

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

Ratio in single polarity j

Geometric lepton efficiency: $\kappa^l_{\mathrm{e}+\,+} = \kappa^l_{\mathrm{e}-\,-}$ and $\kappa^l_{\mathrm{e}+\,-} = \kappa^l_{\mathrm{e}-\,+}$

Control of Systematics

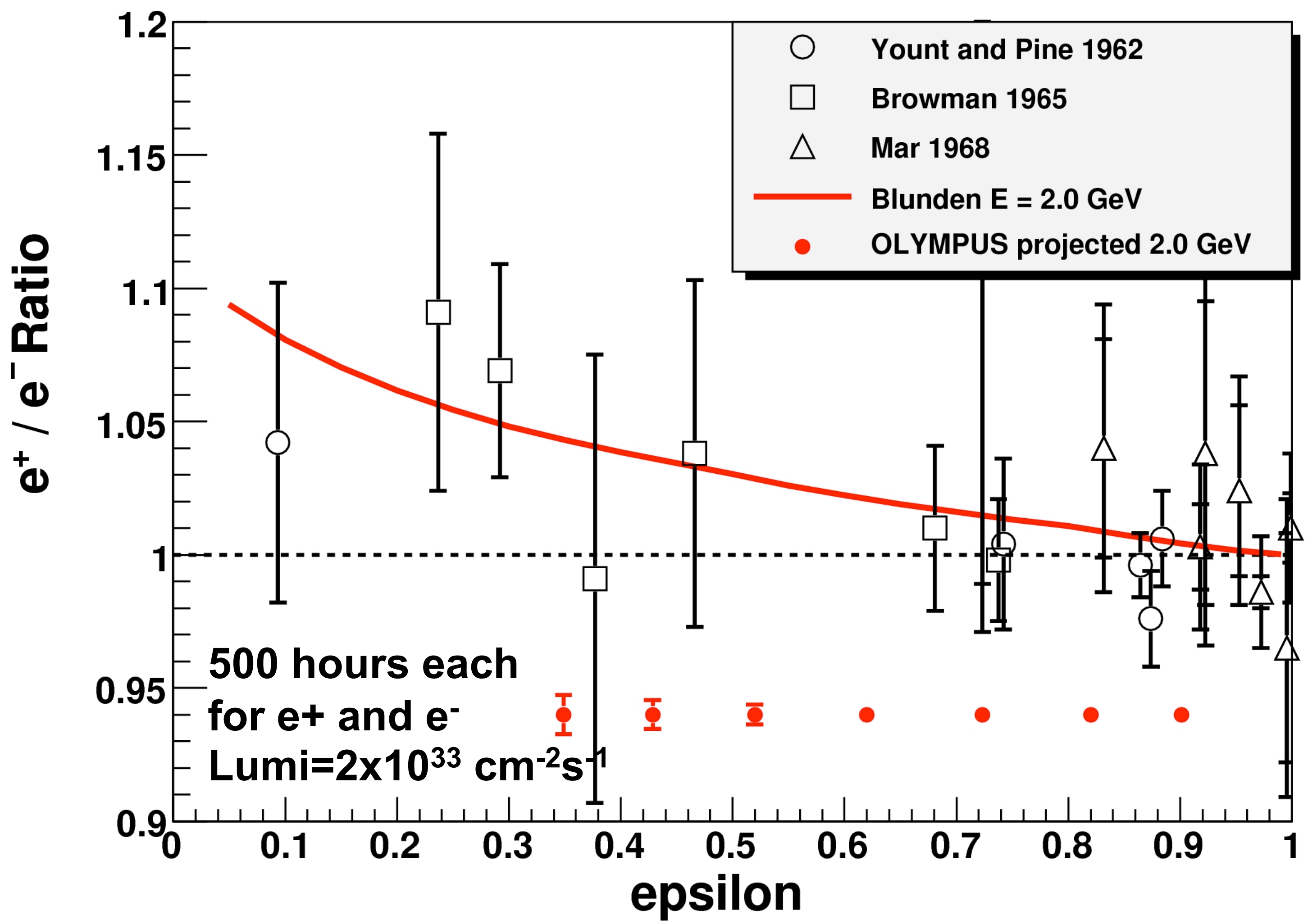
Super ratio:

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

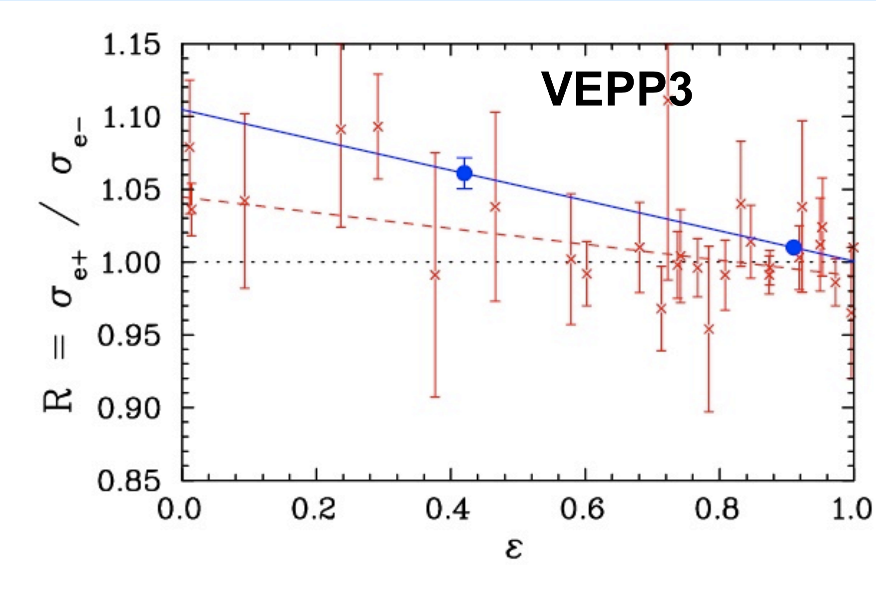
Cycle of four states ij
Repeat cycle many times

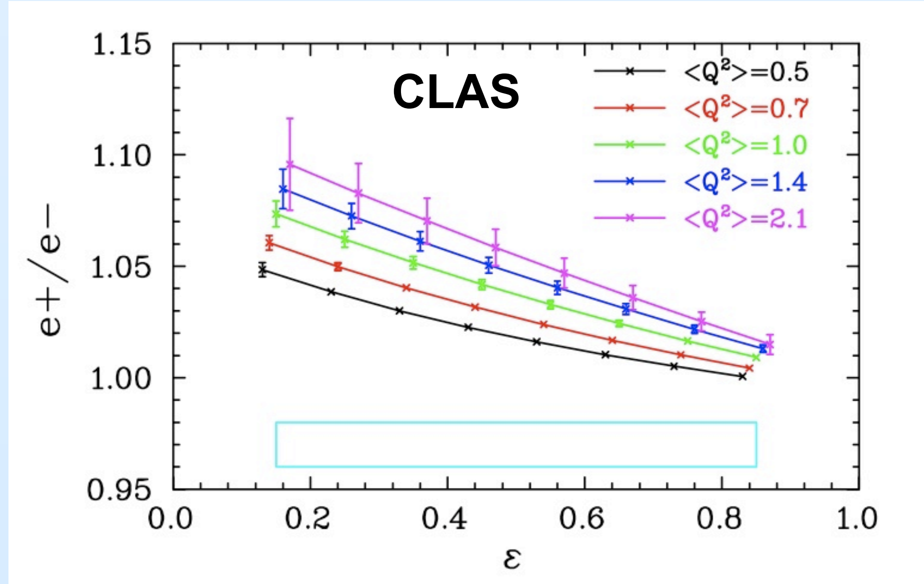
- Change between electrons and positrons every other day
- Change BLAST polarity every other day
- Left-right symmetry

Projected Results for OLYMPUS



Experiments to Verify 2γ Exchange





Experiment proposals to verify hypothesis:

e+/e- ratio:	**CLAS/PR04-116**	**secondary e+/e- beam**
	Novosibirsk/VEPP-3	**storage ring / internal target**
	BLAST@DORIS/DESY	**storage ring / internal target**
SSA:	**PR05-15 (Hall A)**	
ε-dependence:	**PR04-119 (polarized), PR05-017 (unpolarized)**	

Summary

- Significant effect theoretically predicted, size uncertain
- Convinced from feasibility of proposed experiment (2006)
- Contacted DESY, idea presented to PRC in May 2007
- Submitted letter of intent in June 2007
- Presented to DOE at MIT review in July 2007
- Intern. collaboration (~50 scientists, 11 inst.), April 2008
- Submitted full proposal on invitation by DESY (Sep 2008)

Next steps:

Fund raising in the US and in Europe (2009)

Transfer of BLAST detector (2009-2010)

Construction of new components (2009-2011)

Running 3 months in 2011 and 2012 (DORIS shutdown)

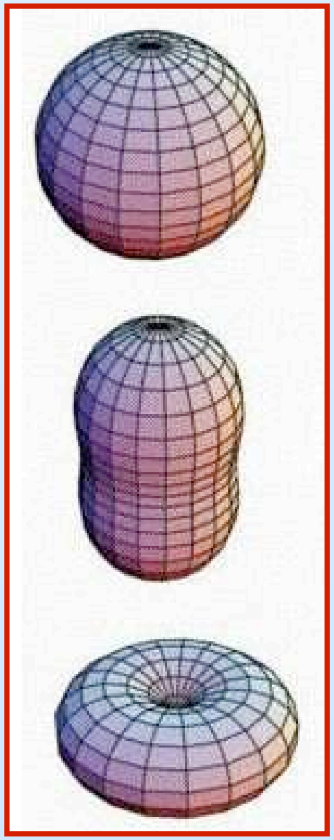
Interpreting Electron Scattering …

"[…] most of what we know and everything we believe about hadron structure […]" (W. Turchinetz)

"The electromagnetic probe is well understood, hence …" (a common phrase in many articles)

The elastic form factors characterize the simplest process in nuclear physics, namely elastic scattering (straightforward, one should think)

If we don't understand the form factors and elastic scattering, we will not have understood anything (my take on the importance of OLYMPUS)



Science = Replacing belief by knowledge