OLYMPUS Overview

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

- Motivation for experiment
- Outline of experiment
- Path forward to realization

An Experiment to Definitively Determine the Contributions of Multiple Photon Exchange in Elastic Lepton-Nucleon Scattering

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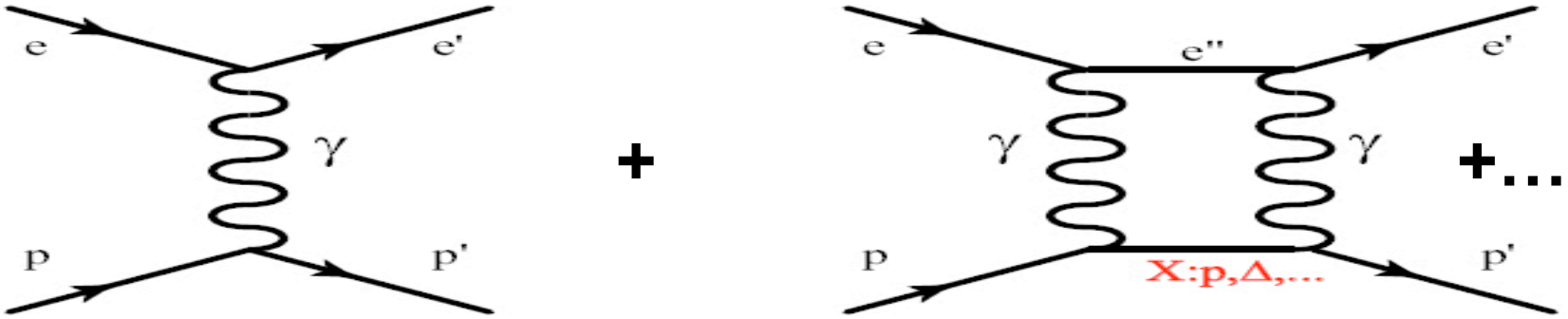
June 19, 2007

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

- Defined in the context of single photon exchange
- Fundamental observables describing the distribution of charge and magnetism in the proton and neutron
- Experimentally, data well described (to first order) 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 $Q^2 \gg 1$, $\sigma \sim \sigma_{Mott} G^2_D \sim Q^{-12}$
- FF determined by quark structure of proton
- Will be calculable in lattice QCD

Unpolarized Elastic e-N Scattering

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

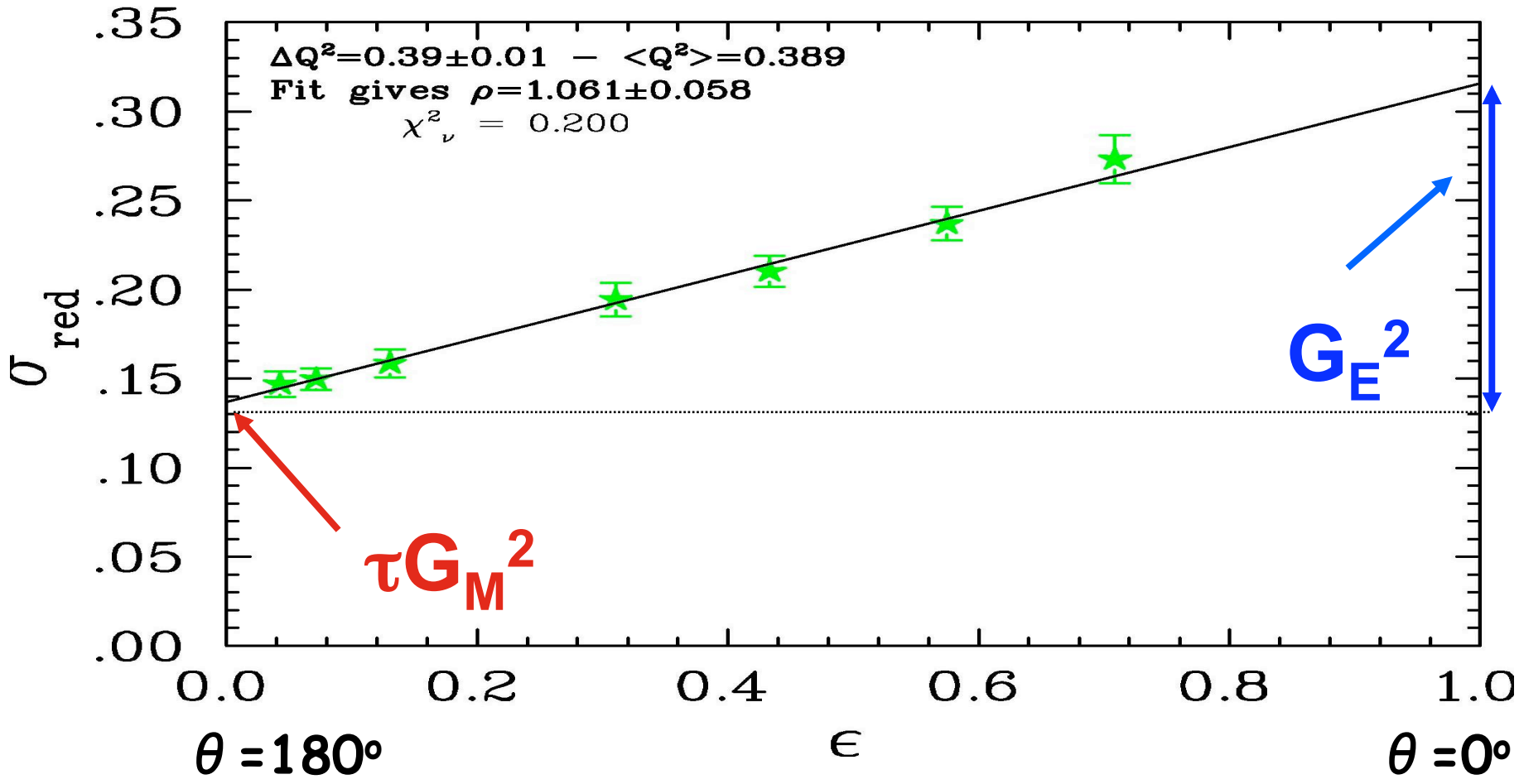
$$= \frac{G_E^2(Q^2) + \tau G_M^2(Q^2)}{1+\tau} + 2\tau G_M^2(Q^2)\tan^2\frac{\theta}{2}$$

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

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

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

Rosenbluth Separation



Polarization Measurements of Elastic FF

- Double polarization in elastic ep scattering:
  Recoil polarization or polarized target
  $^1H(\vec{e},e'\vec{p})$, $^1\vec{H}(\vec{e},e'p)$

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

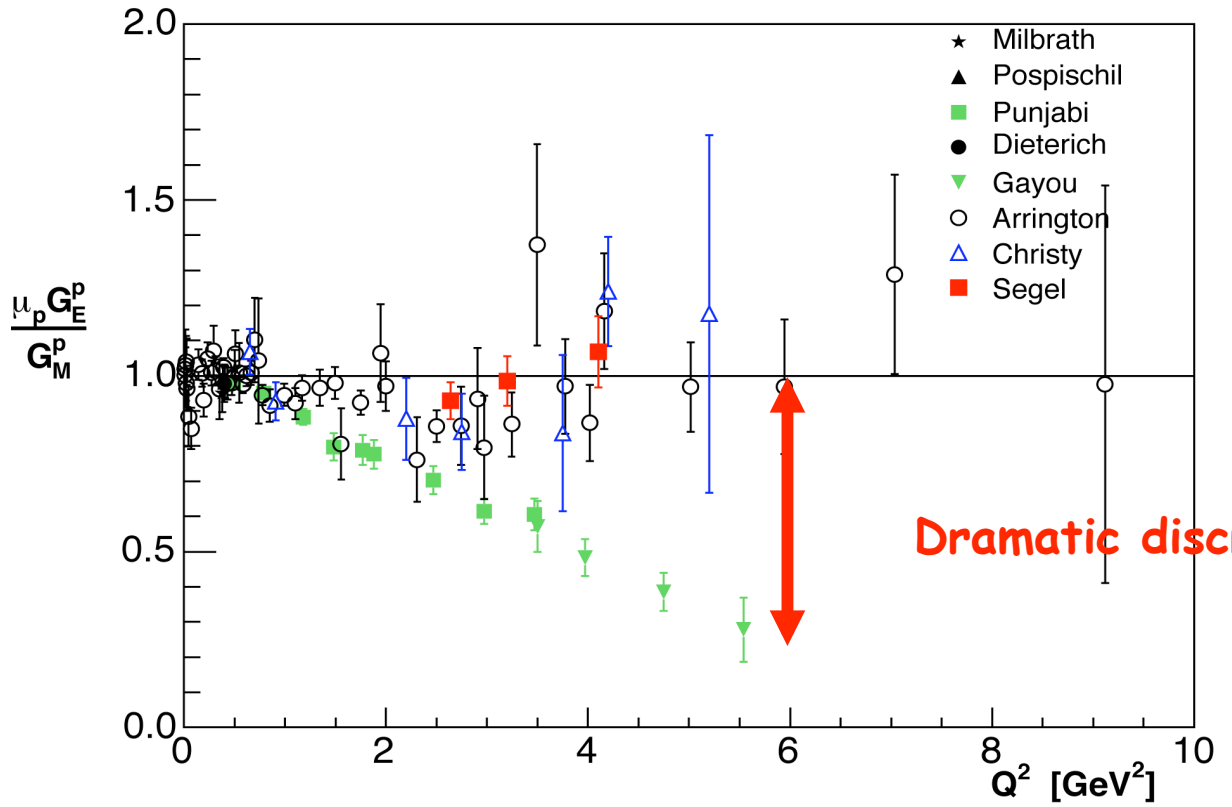
- Double spin asymmetry

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

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

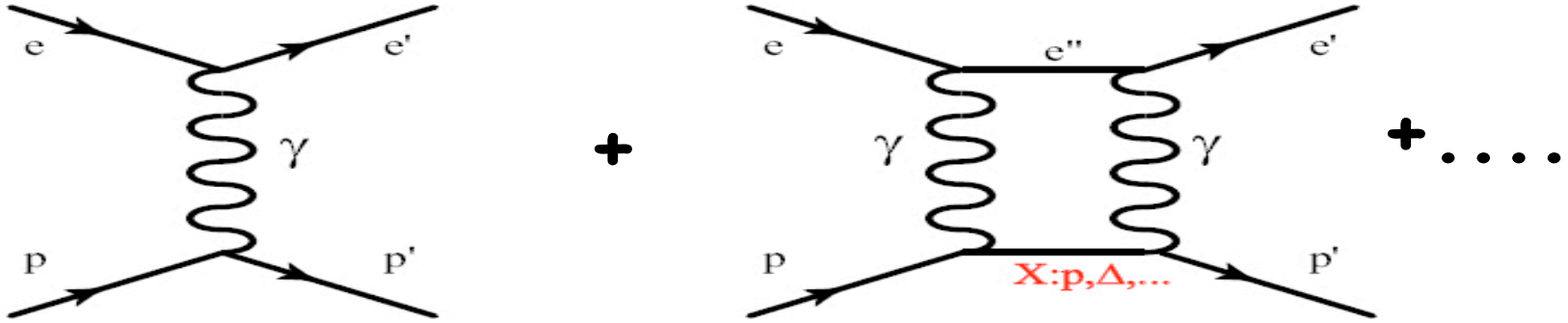
  independent of polarization or analyzing power

Proton Form Factor Ratio



- All Rosenbluth data from SLAC and Jlab in agreement.
- Dramatic discrepancy between Rosenbluth and recoil polarization technique

Calculation of Two Photon Exchange Effects



- P.A.M. Guichon and M. Vanderhaeghen, PRL91, 142303 (2003)
- P.G. Blunden, W. Melnitchouk, and J.A. Tjon, PRC72, 034612 (2005), PRL91, 142304 (2003)
- M.P. Rekalo and E. Tomasi-Gustafsson, EPJA22, 331 (2004)
- Y.C. Chen et al.,PRL93, 122301 (2004)
- A.V. Afanasev and N.P. Merenkov, PRD70, 073002 (2004)

Estimation of TPE Contribution

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

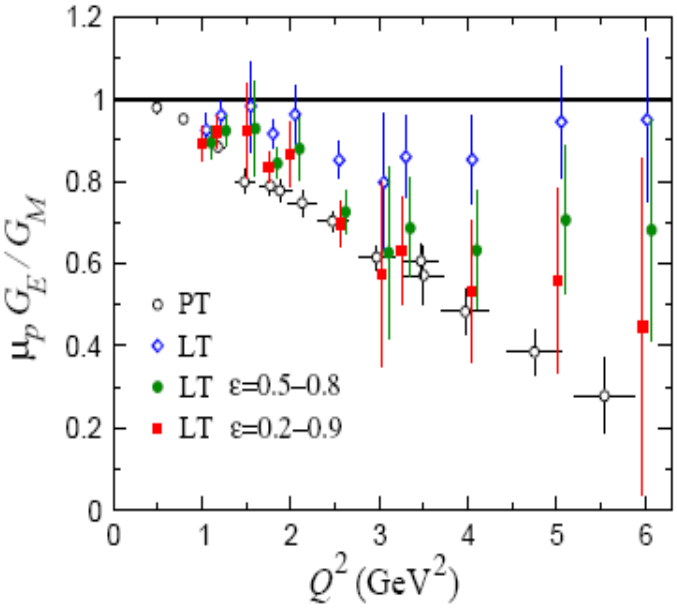


FIG. 5: The ratio of proton form factors $\mu_p G_E/G_M$ measured using LT separation (open diamonds) [2] and polarization transfer (PT) (open circles) [5]. The LT points corrected for 2γ exchange are shown assuming a linear slope for $\varepsilon = 0.2 - 0.9$ (filled squares) and $\varepsilon = 0.5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

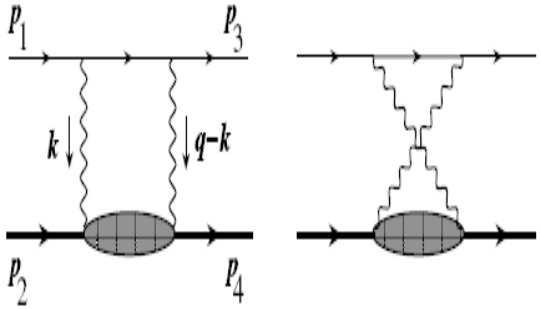
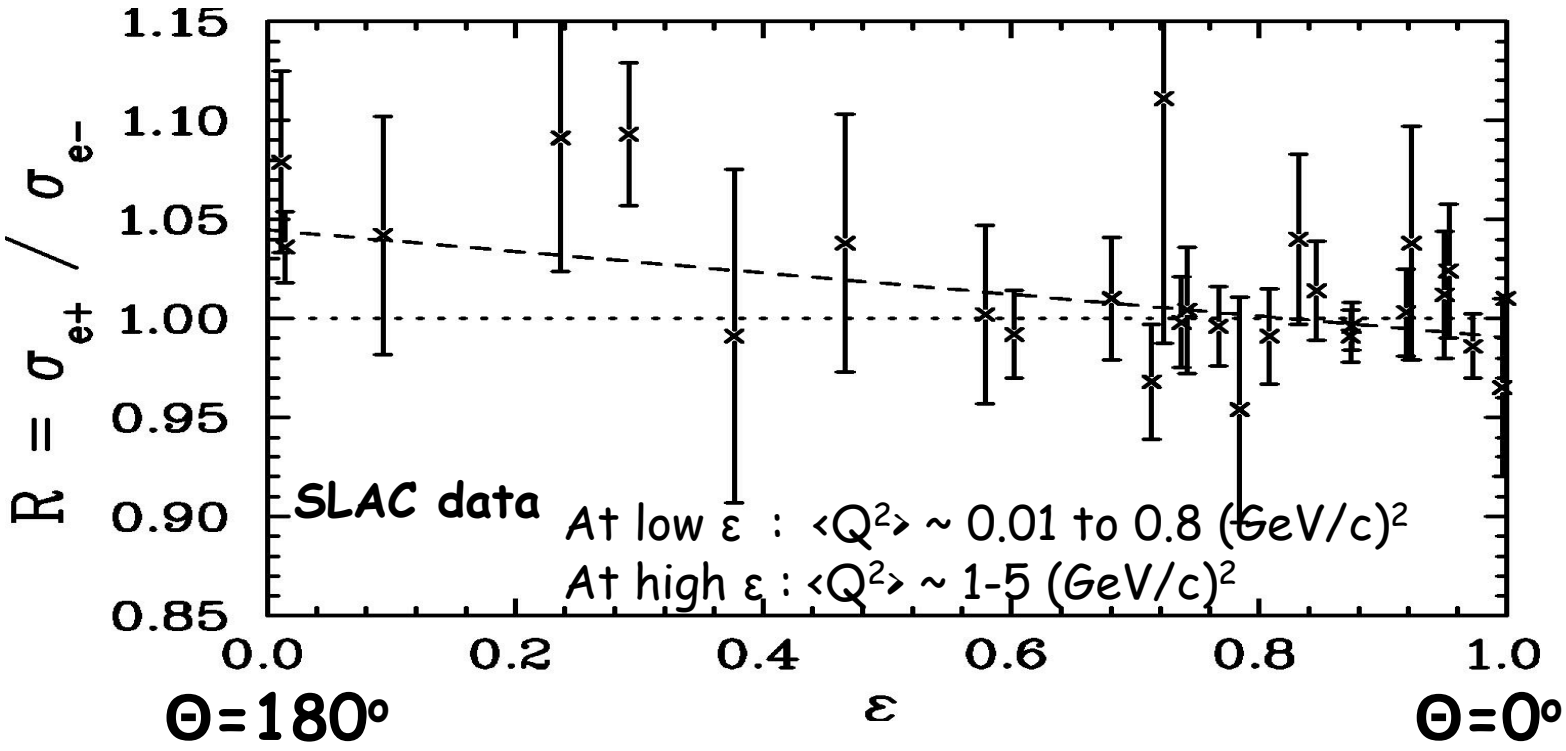


FIG. 1. Two-photon exchange box and crossed box diagrams for elastic electron-proton scattering.

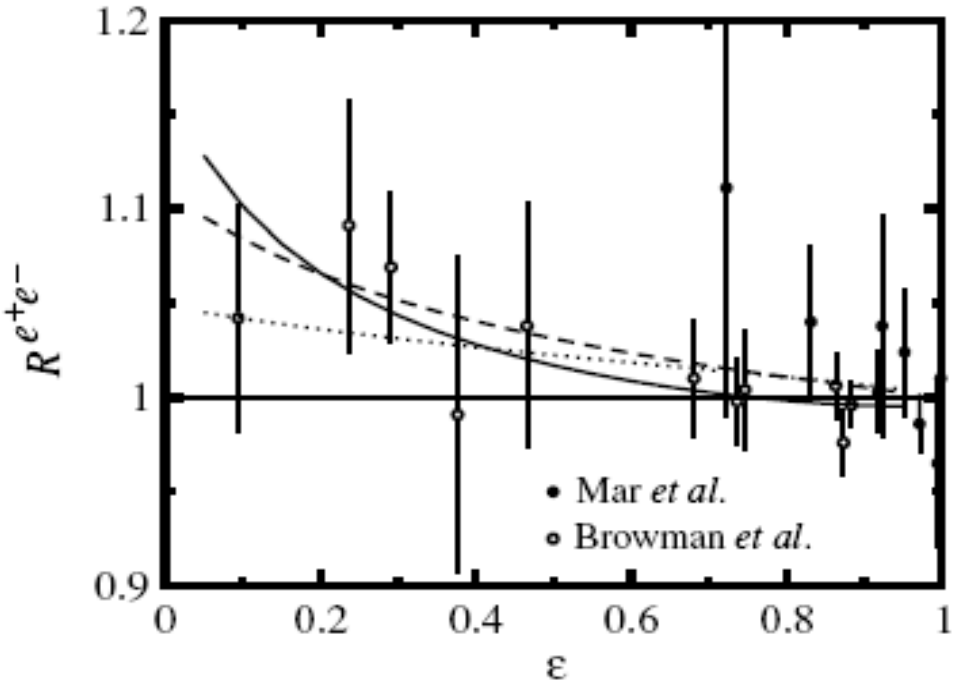
How do we verify that the TPE contribution interpretation is correct?

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

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



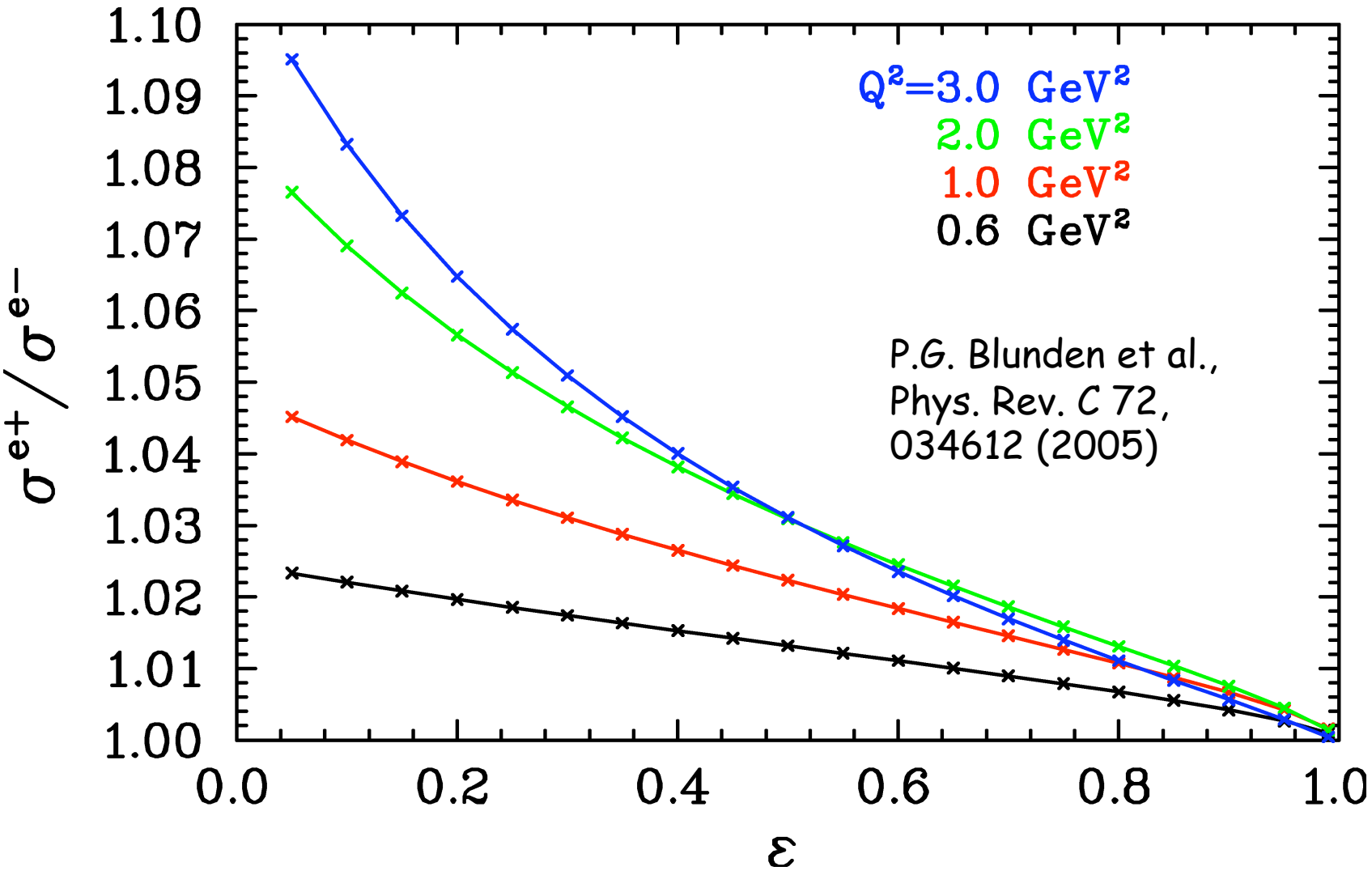
TPE Calculation comparison with e⁺p/e⁻p scattering data



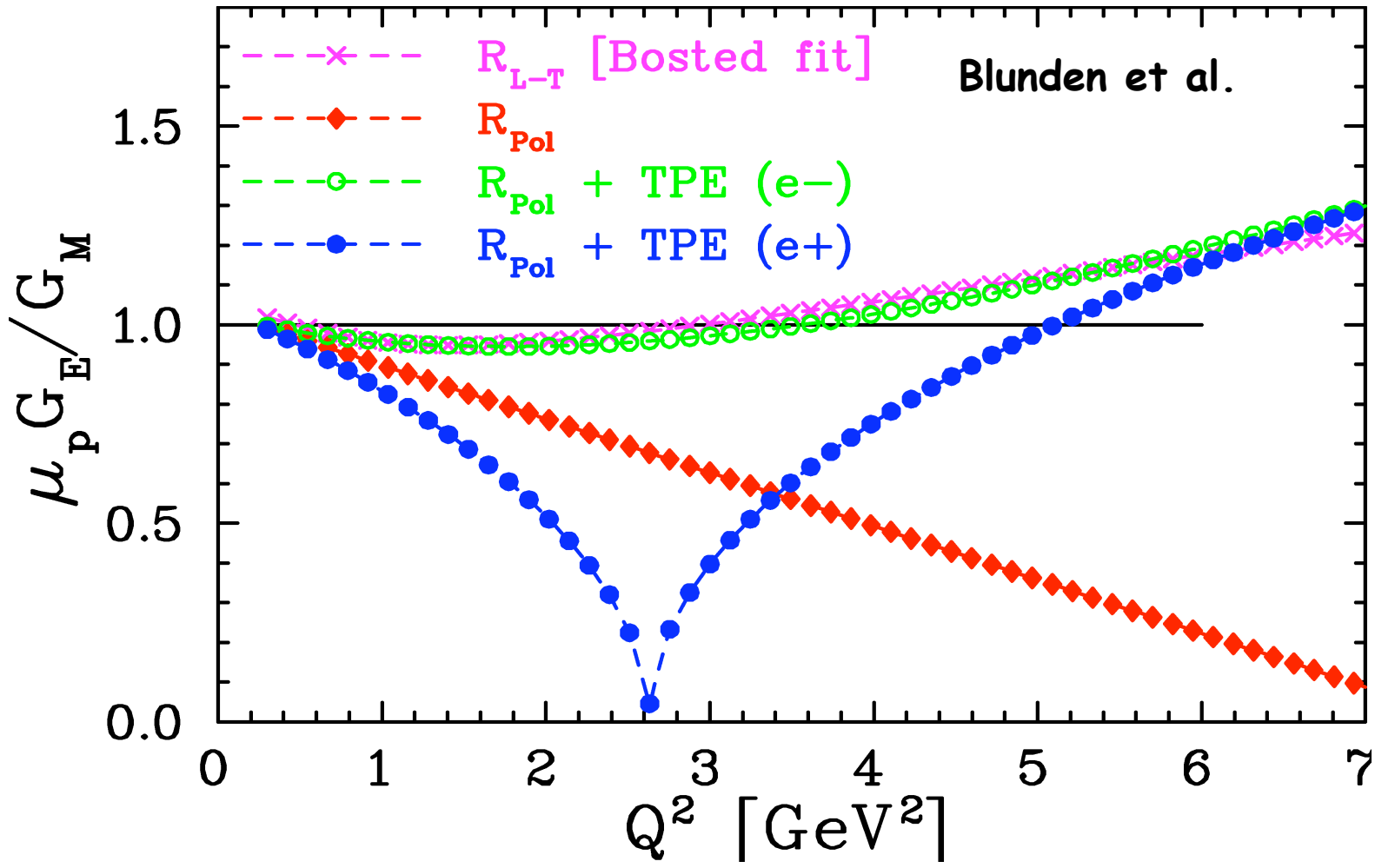
P.G. Blunden et al., Phys. Rev. C 72, 034612 (2005)

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 2γ 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



Proposed DESY 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 → L = 2x10^{33} / (cm^2s)
- Measure elastic e^+/e^- proton scattering to 1% precision at 2.3 to 4.5 GeV energies 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 from e^+ beam to e^- beam 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

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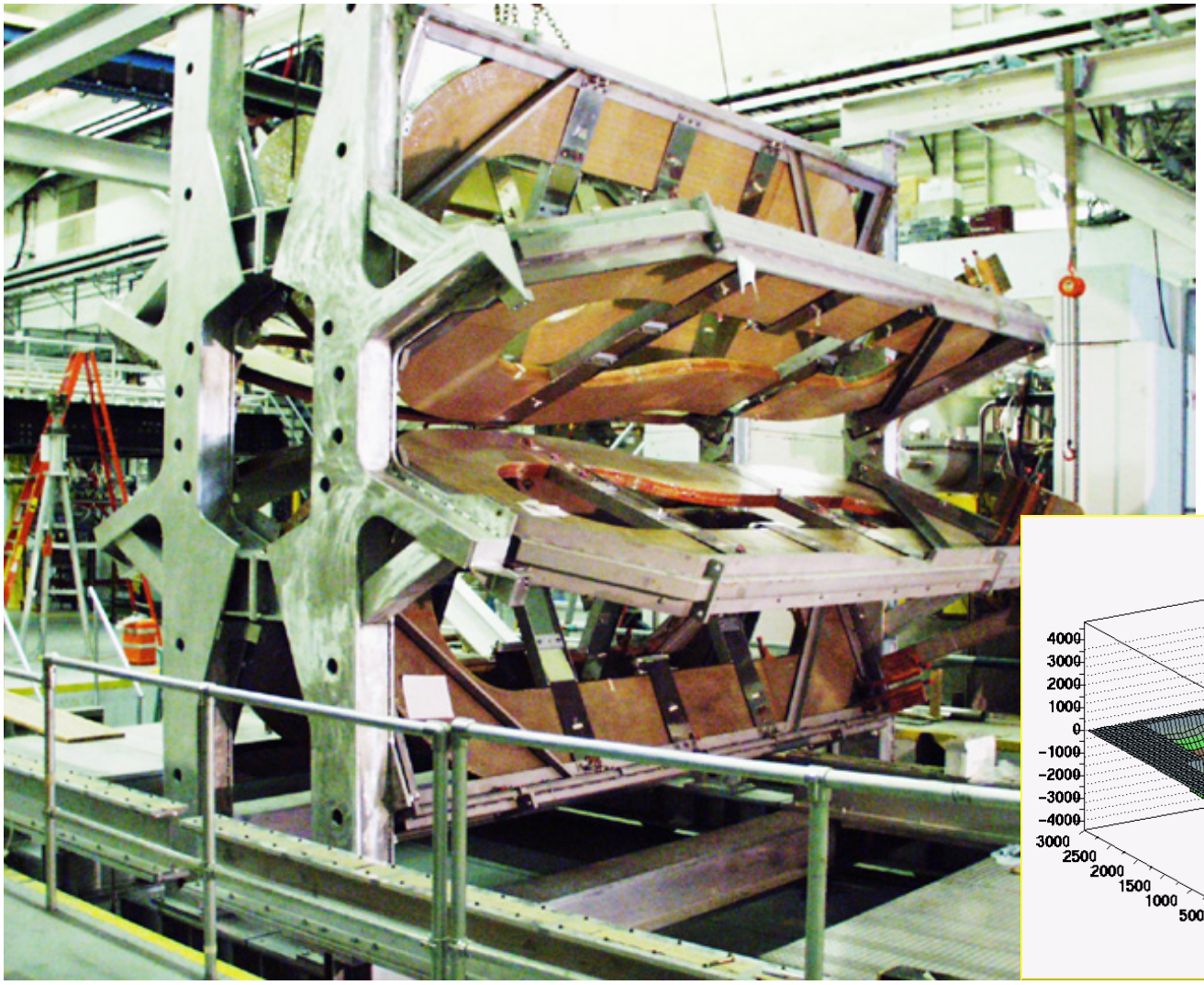
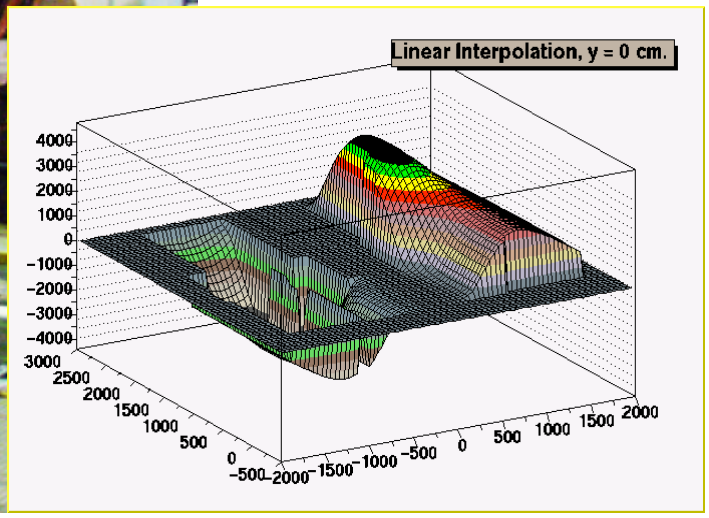
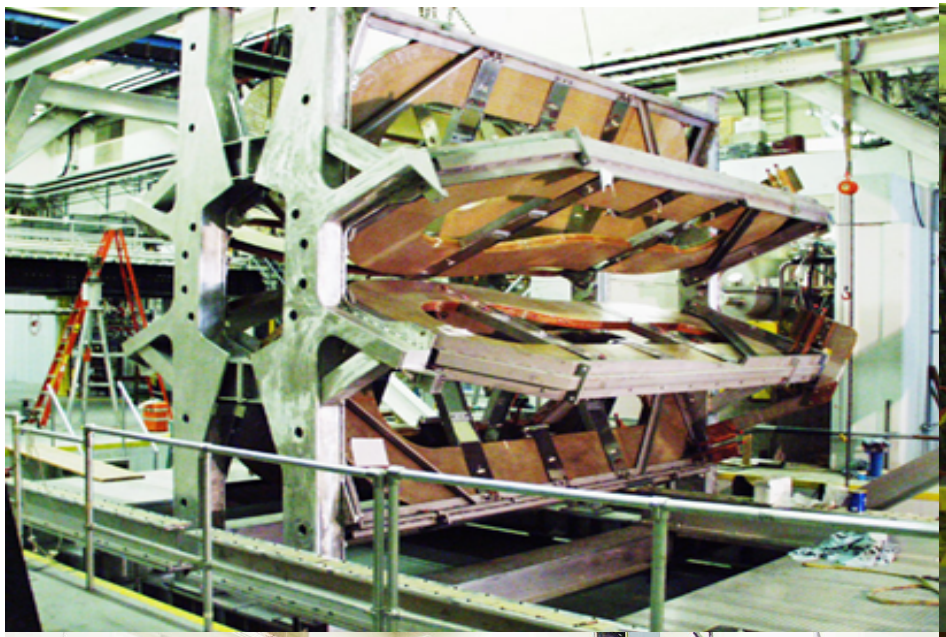
Bates Large Acceptance Spectrometer Toroid

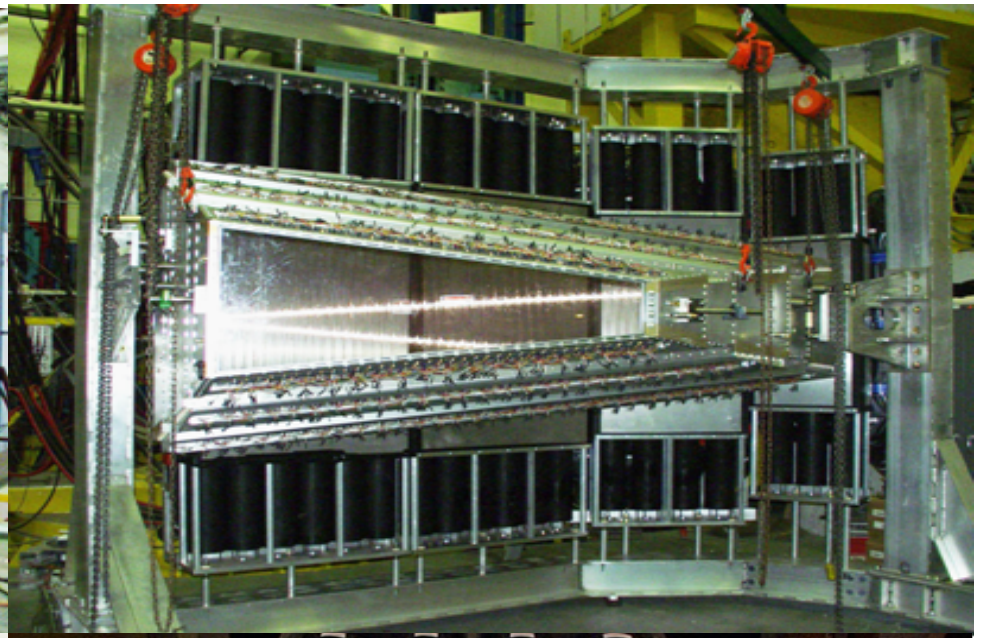


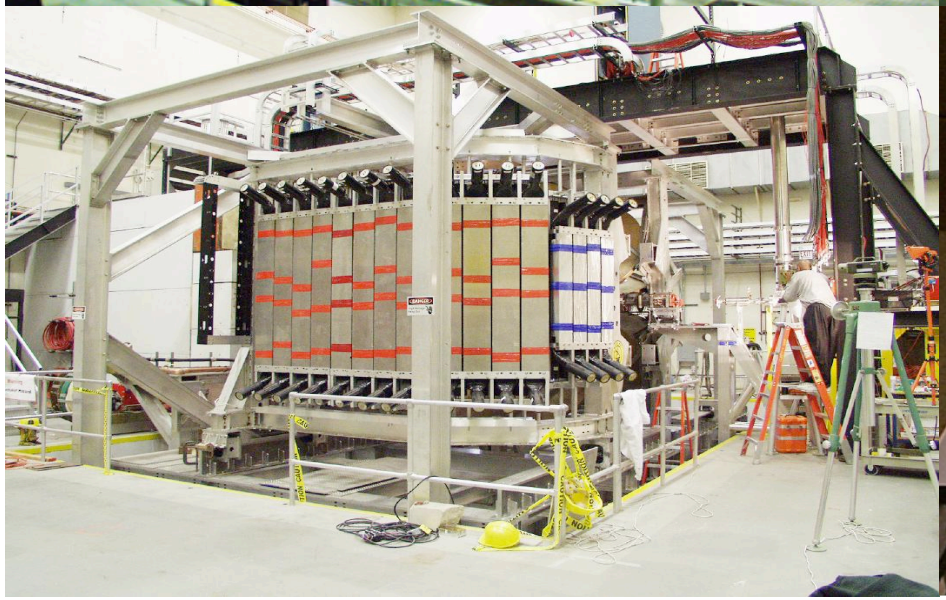
- 8 copper coils
  - 6730 A
  - 3700 G
- field mapped (3D)
  - coil position adjusted
  - ±1% of calculated
  - minimize target field
  - tracking



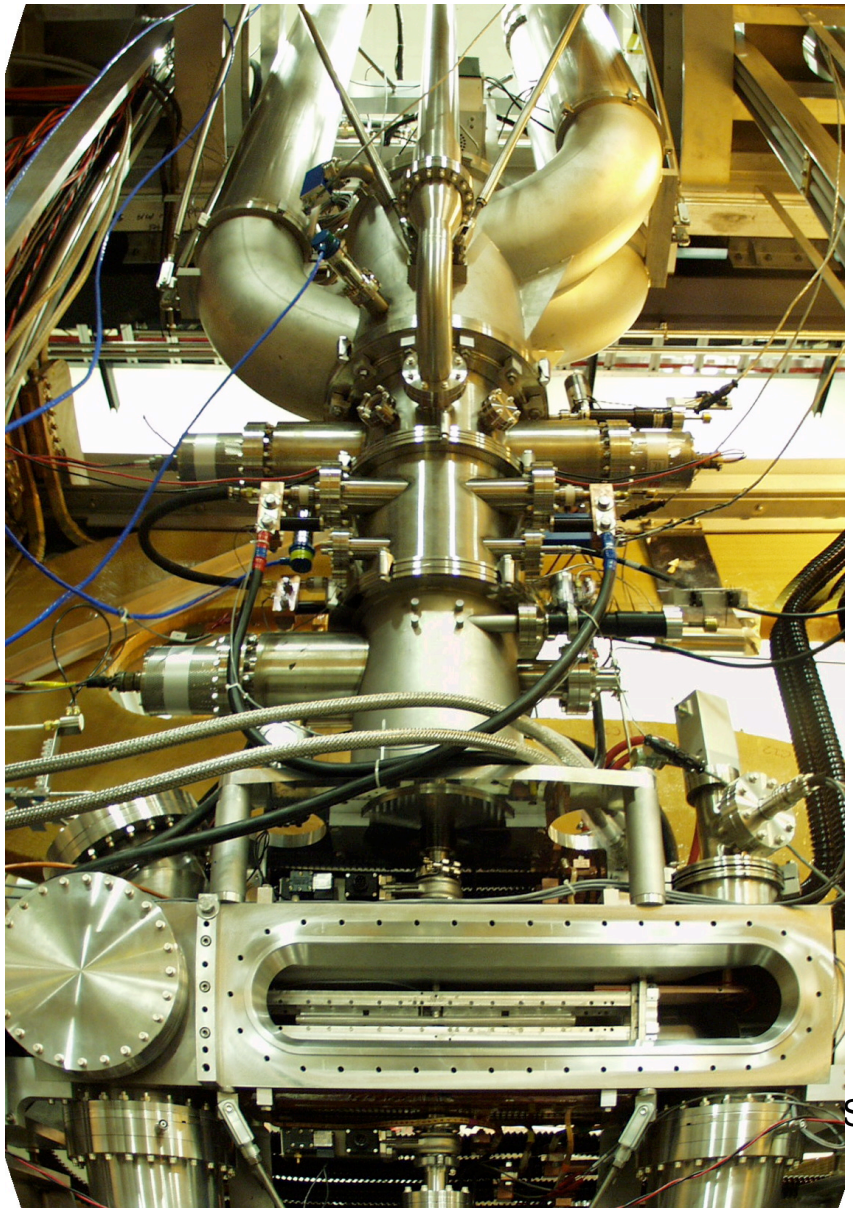
The BLAST Detector components



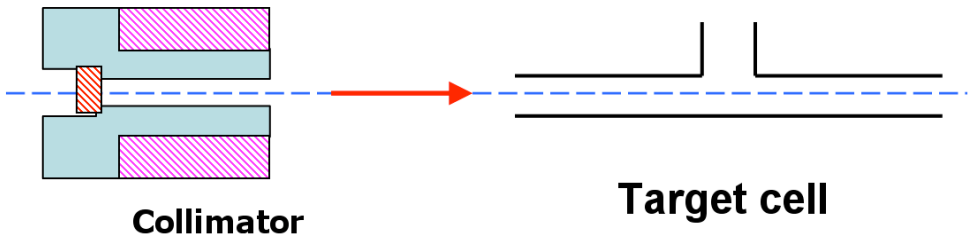




BLAST Target Performance

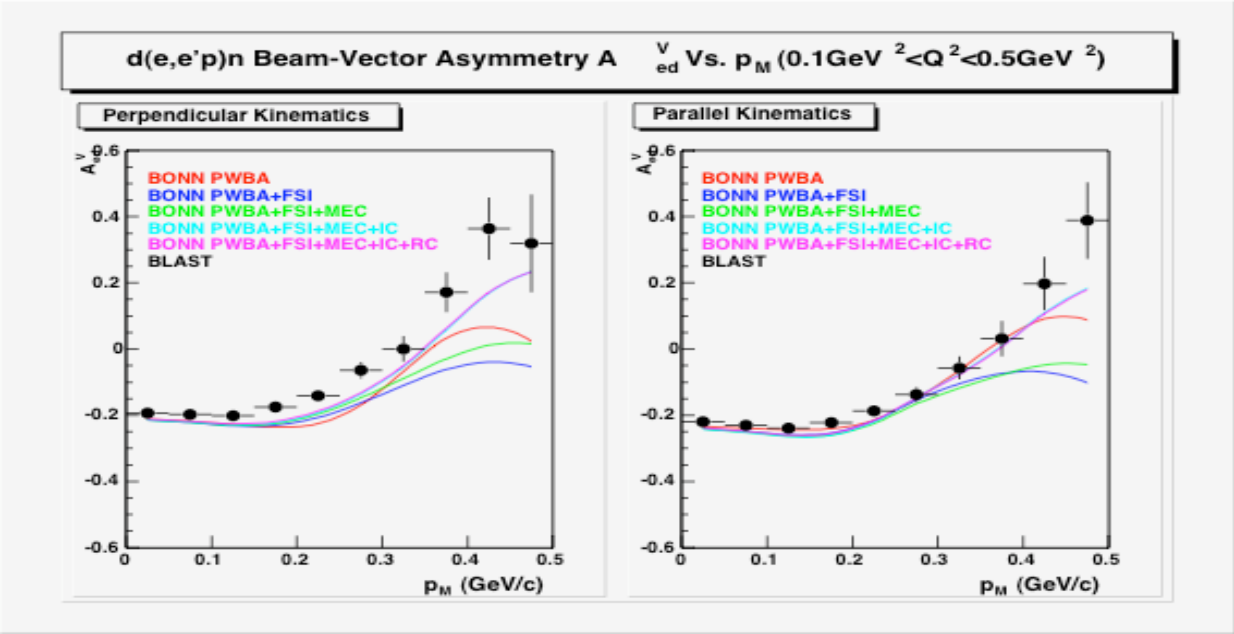


- Isotopically pure H or D atoms
  (Vector-) polarized H
  Vector- and tensor-polarized D
- Target thickness / luminosity
  $r=6\times10^{13}$ at/cm^2, $L=6\times10^{31}$/(cm^{2}s)
- Operated within BLAST B-field
  B_{max} = 3.8 kG
- Target polarization 70-80%
  P_z, P_{zz} from low Q^2 analysis

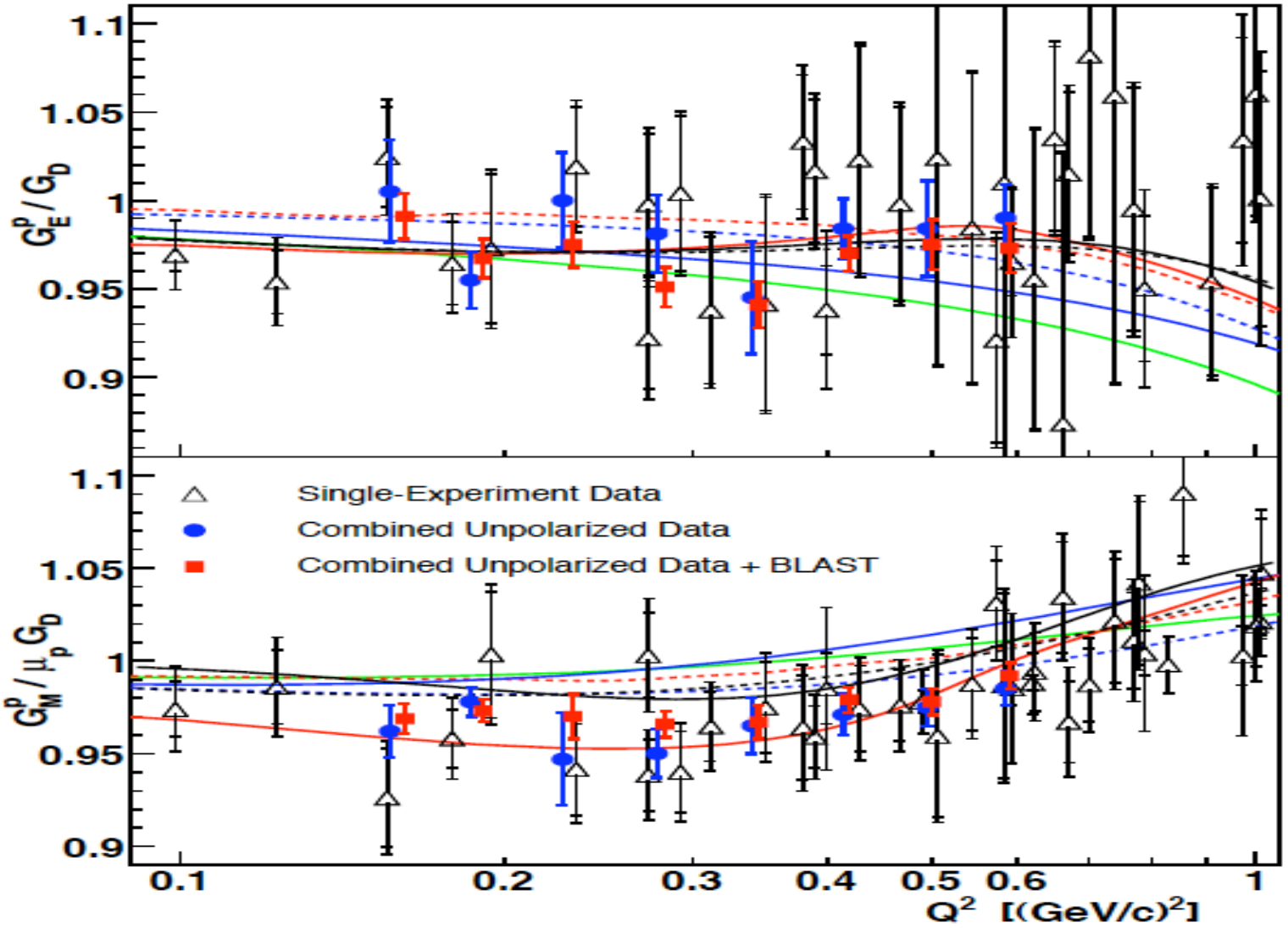


BLAST science highlights

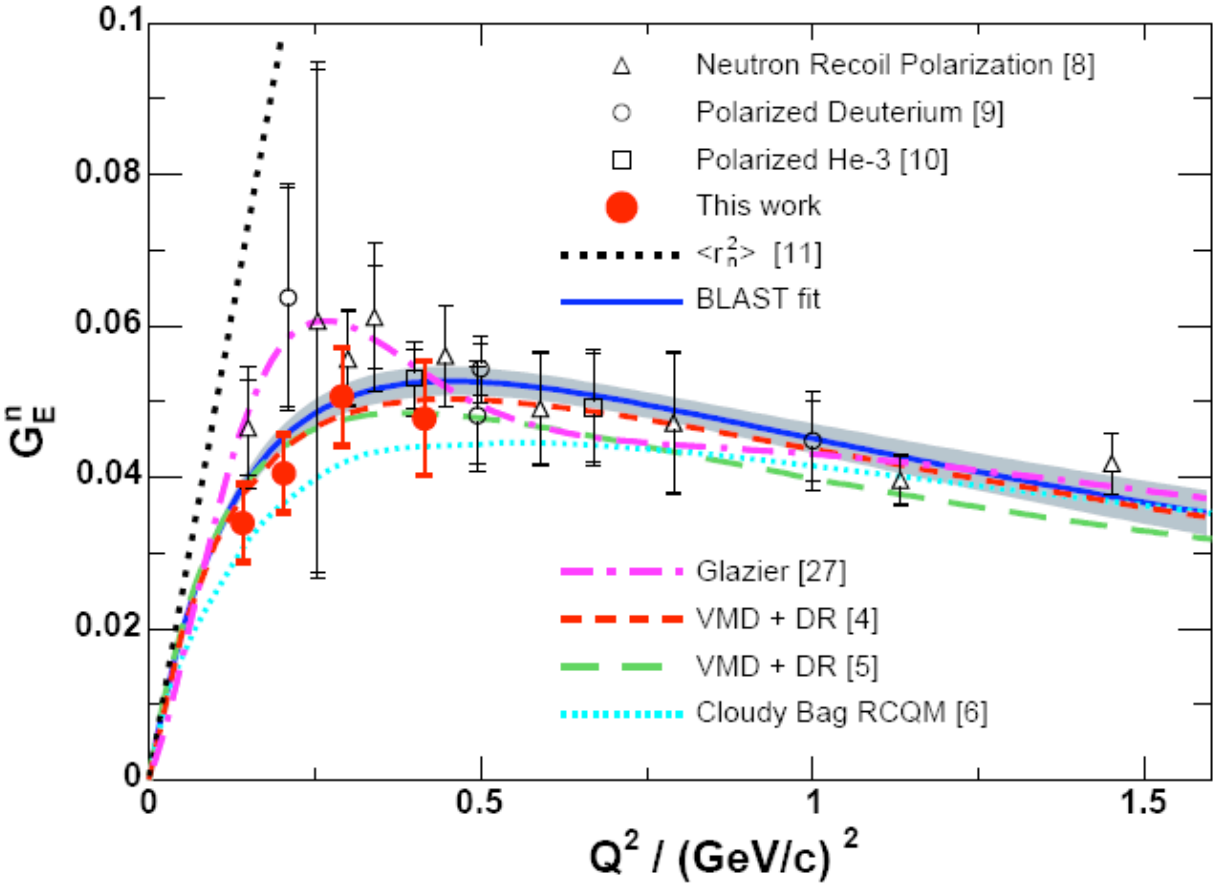
- BLAST constructed in 1999-2002
- BLAST commissioned in 2003
- BLAST took data in 2003-2005 on spin-dependent electron scattering from polarized hydrogen and deuterium at 850 MeV



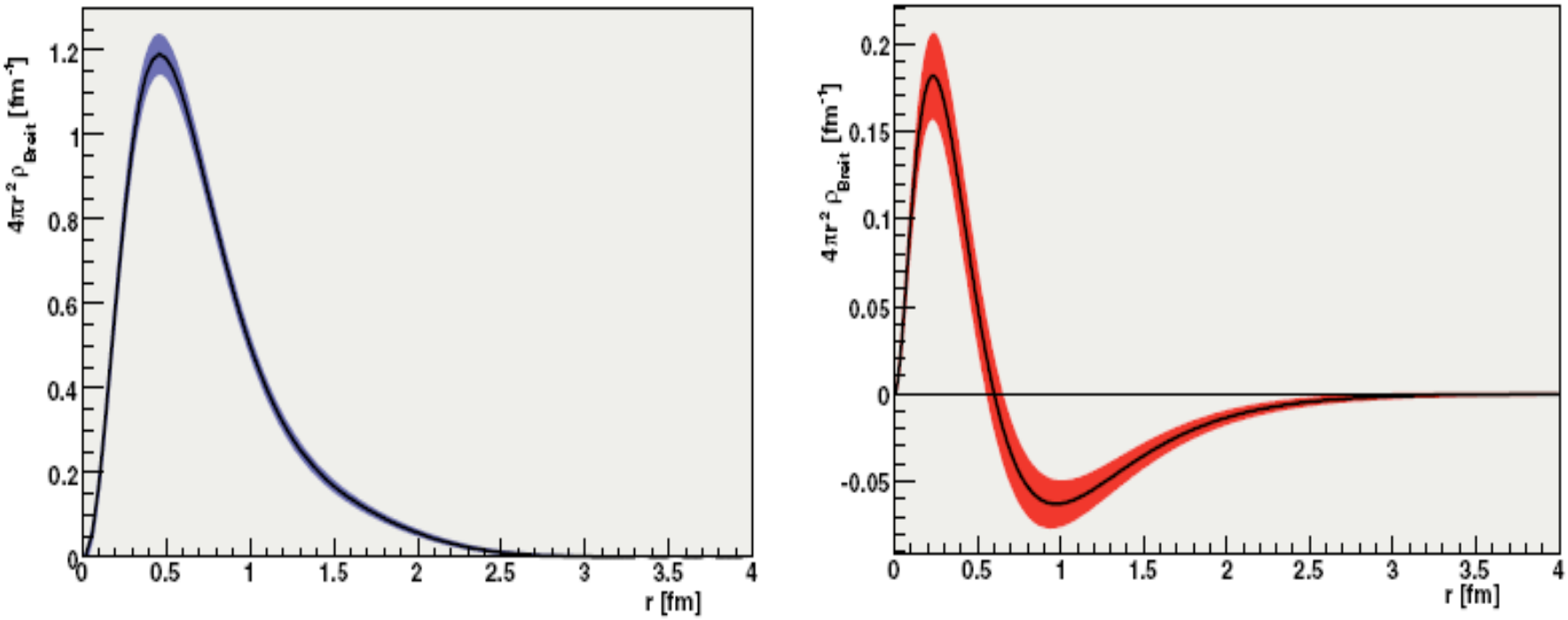
Extraction of G_E^p and G_M^p



World's G^n_E data from spin measurements

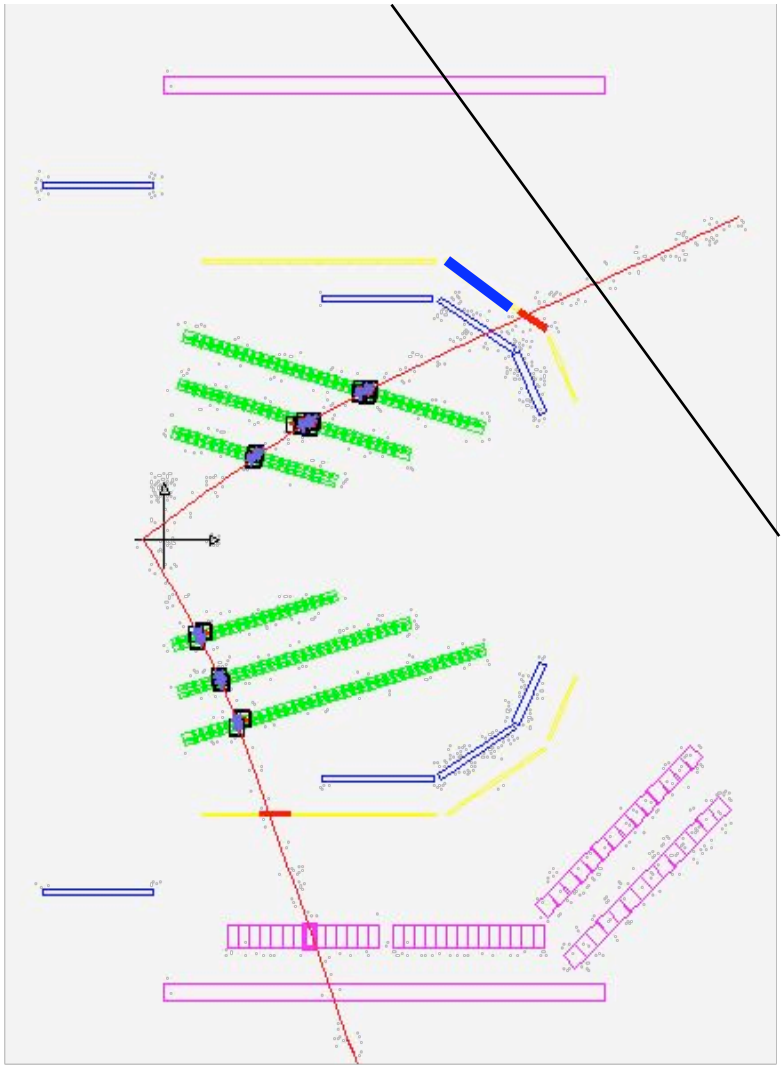


Spatial Distribution

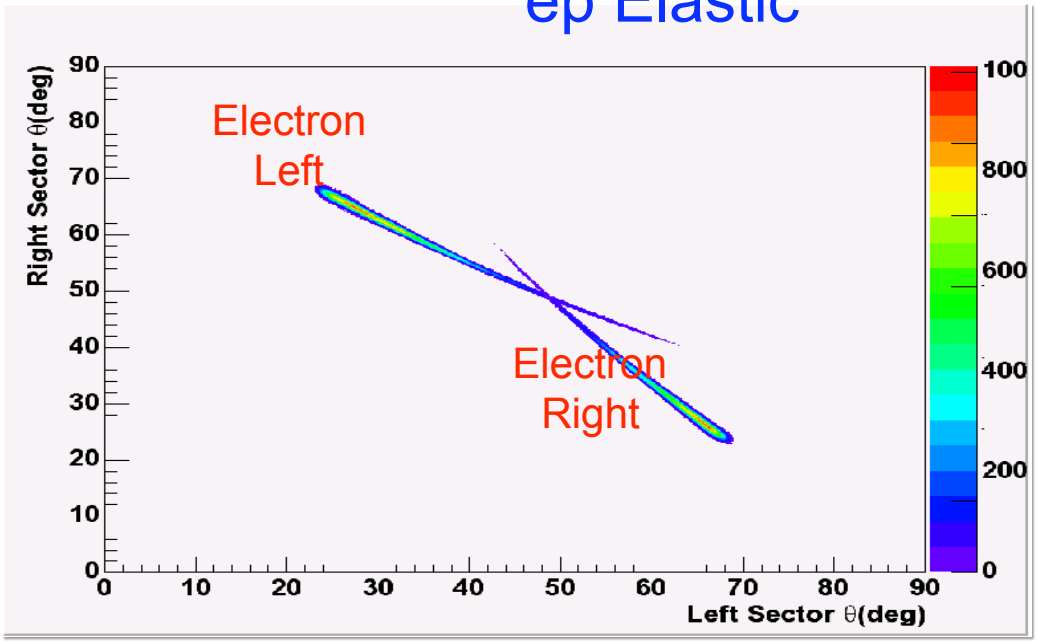


***The Frontiers of Nuclear Science*, p. 26, December 2007**
a long range plan for U.S. nuclear science

BLAST event reconstruction

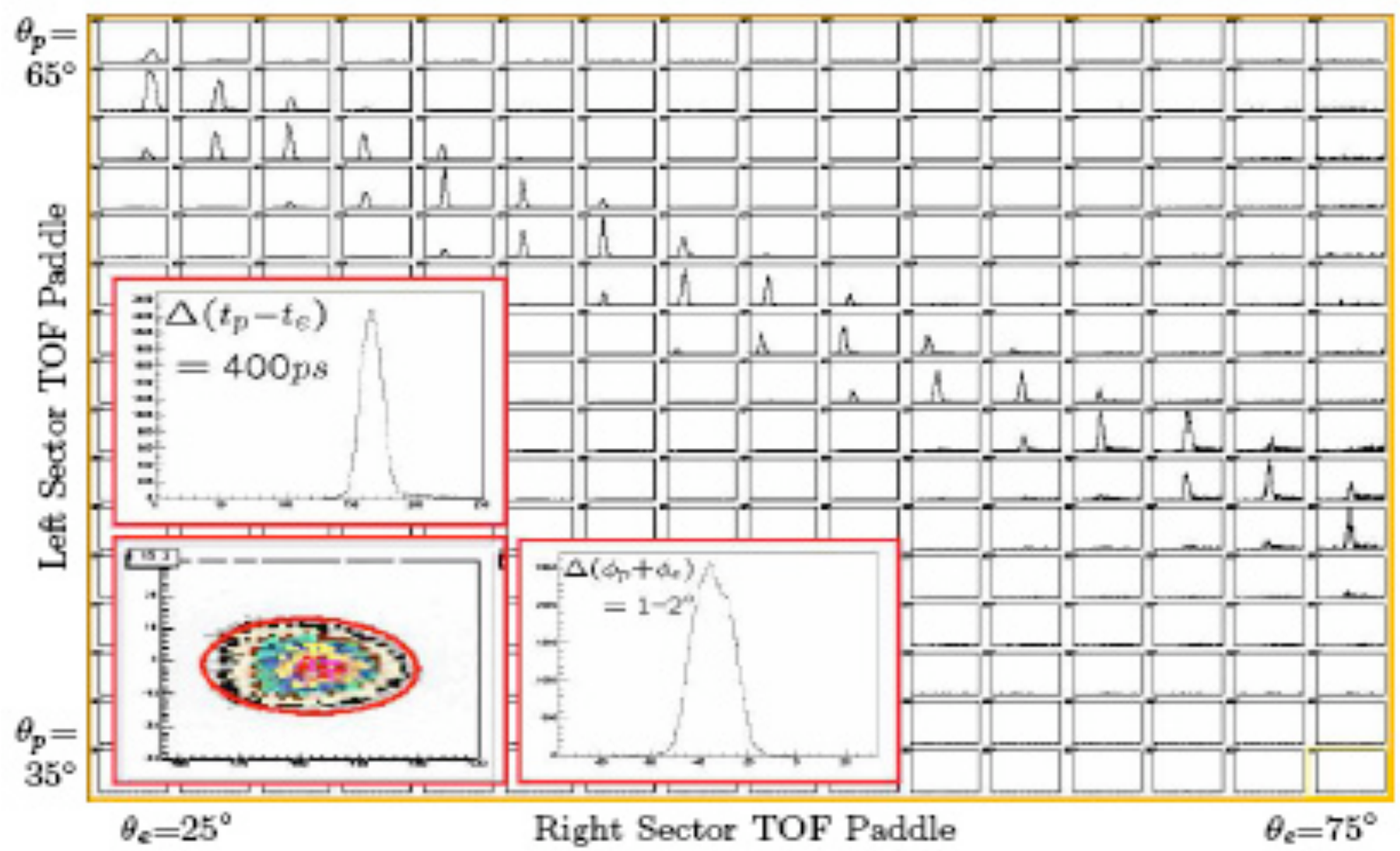


850 MeV energy

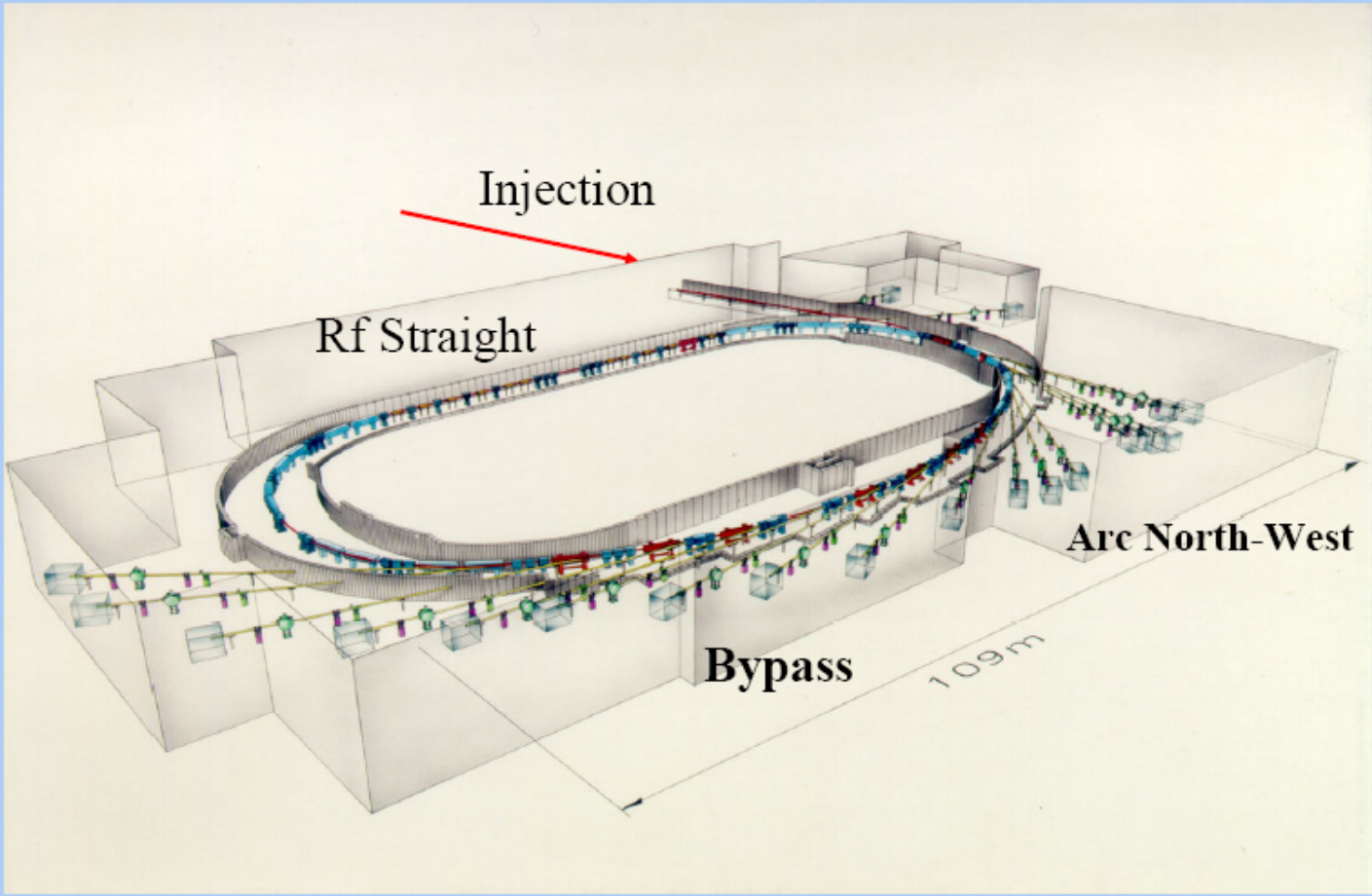


- Advantages of magnetic field:
  - suppression of background
  - 2-3% momentum resolution
- $\sigma_\theta = 0.5^o$ and $\sigma_\varphi = 0.5^o$

Elastic ep timing with BLAST



DORIS

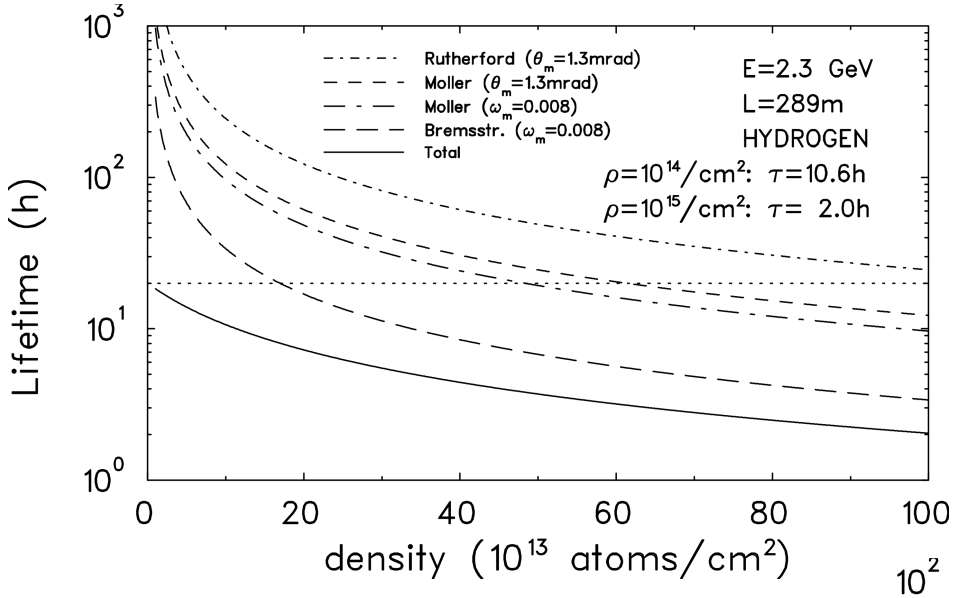


DORIS parameters

Positron energy:	4.45 GeV
RF frequency	500 MHz
Initial positron beam current (5 bunches):	120 mA
Circumference:	289.2 m
Number of buckets:	482
Number of bunches:	1 (for tests), 2 and 5
Bunch separation (minimum):	964 nsec (for tests), 480 nsec and 192 nsec
Horizontal positron beam emittance:	404 π nmrad
Coupling factor:	3%
Vertical positron beam emittance:	12 π nmrad
Positron beam energy spread (rms):	0.11%
Curvature radius of bending magnets:	12.1849 m
Magnetic field of bending magnets:	1.2182 T
Critical photon energy from bending magnets:	16.04 keV

Lifetime in DORIS vs. target thickness

C. Tschalär MIT



DORIS

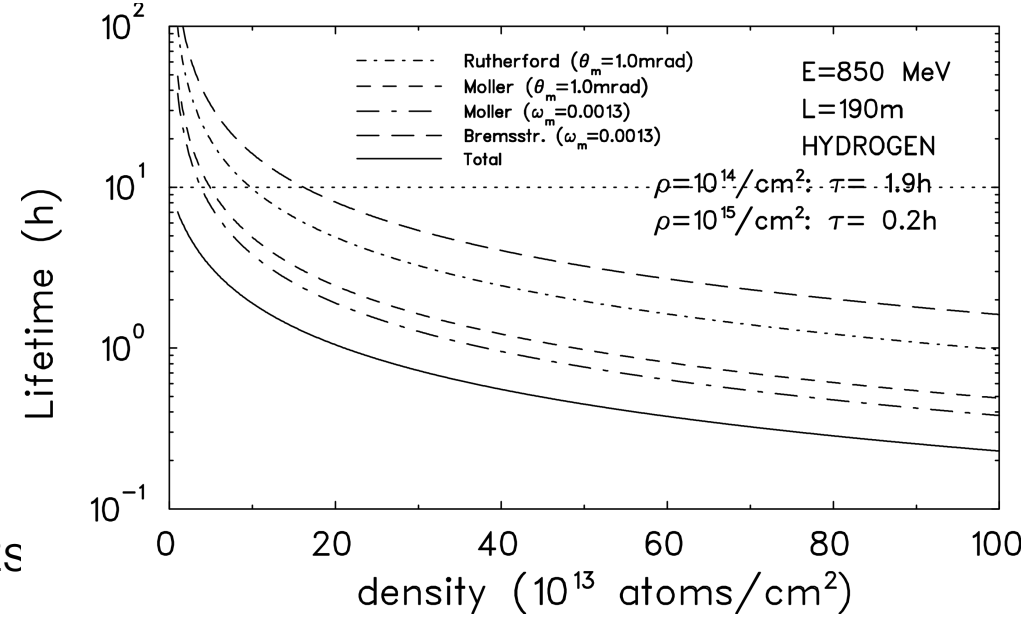
θ_m = 1.3 mrad

ω_m = 0.8%

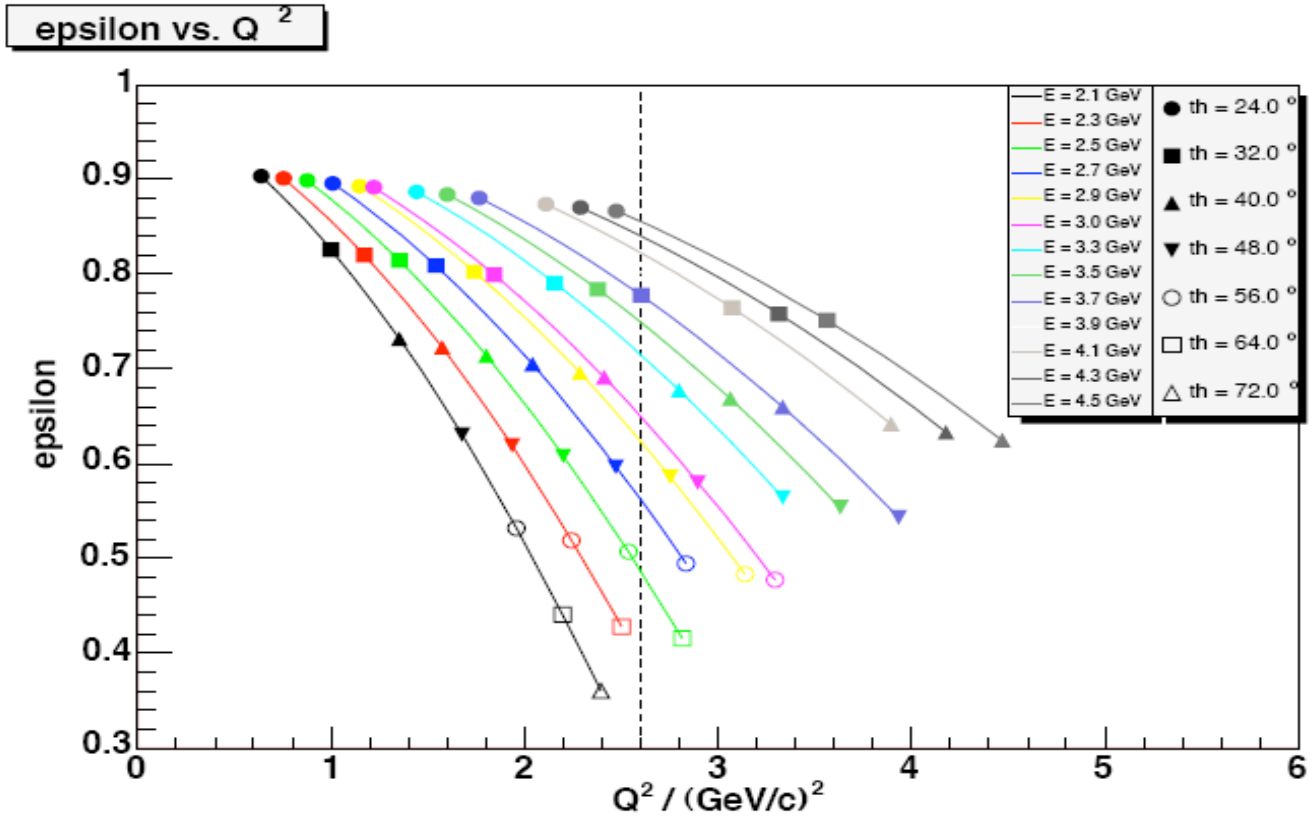
MIT SHR

θ_m = 1.0 mrad

ω_m = 0.13%



Acceptance with BLAST

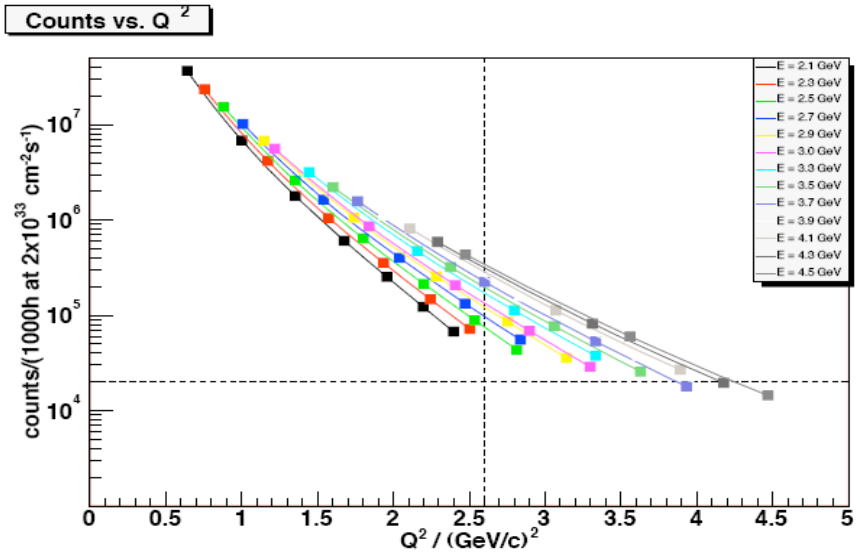


- Lowest epsilon ~0.4 only for E < 2.3 GeV
- At epsilon = 0.4, require E>2 GeV to maintain Q^2 > 2 $(GeV/c)^2$

Count rate estimate

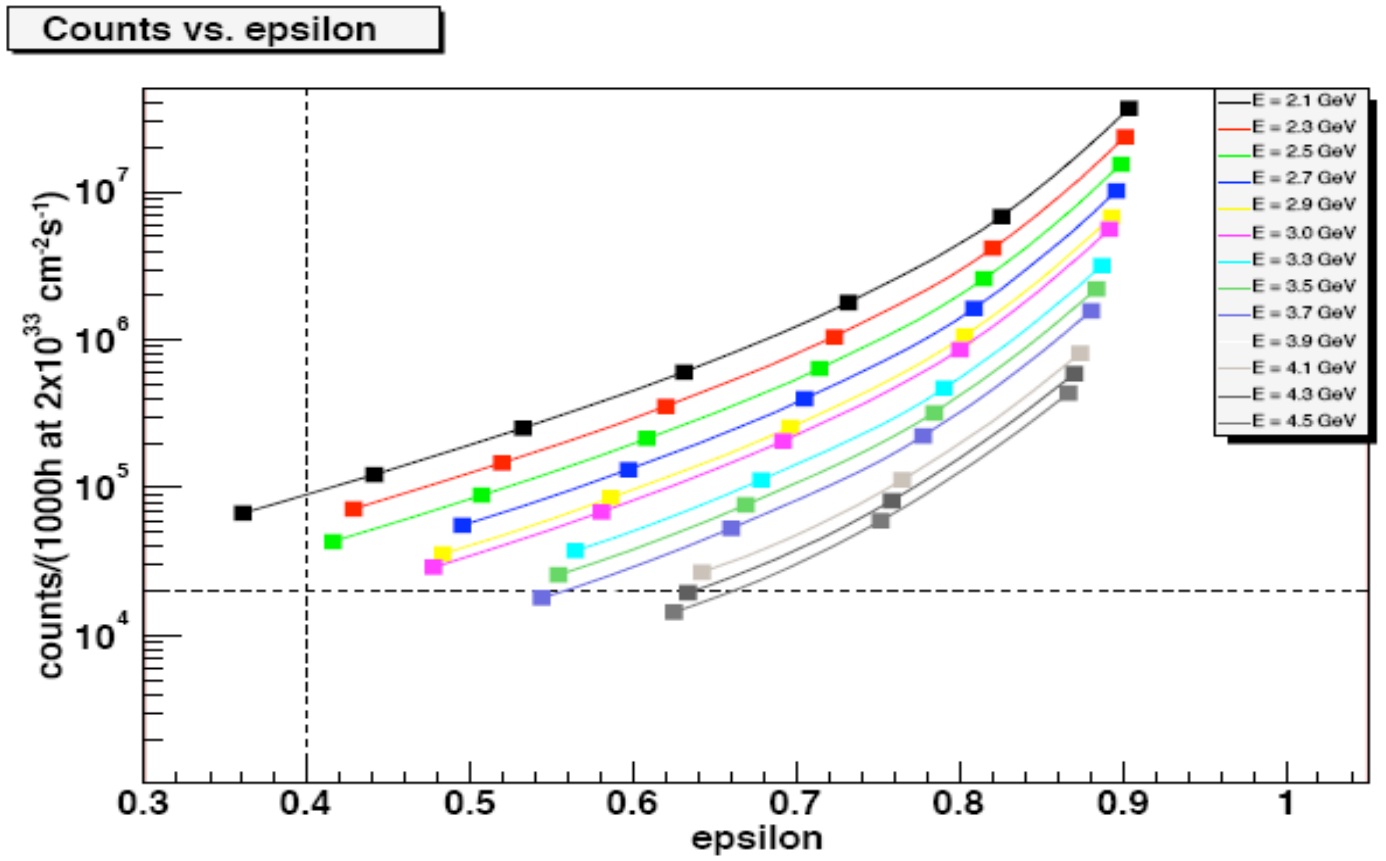
E_0 [GeV]	Q^2 [(GeV/c)^2]	θ_e	$p_{e'}$ [GeV/c]	ϵ	θ_p	p_p [GeV/c]
4.5	2.6	24.9°	3.114	0.86	38.0°	2.125
3.0	2.6	43.0°	1.614	0.65	31.2°	2.125
2.3	2.6	67.6°	0.914	0.39	23.4°	2.125

Table 2: Kinematics for three beam energies and $Q^2 = 2.6$ (GeV/c)^2.



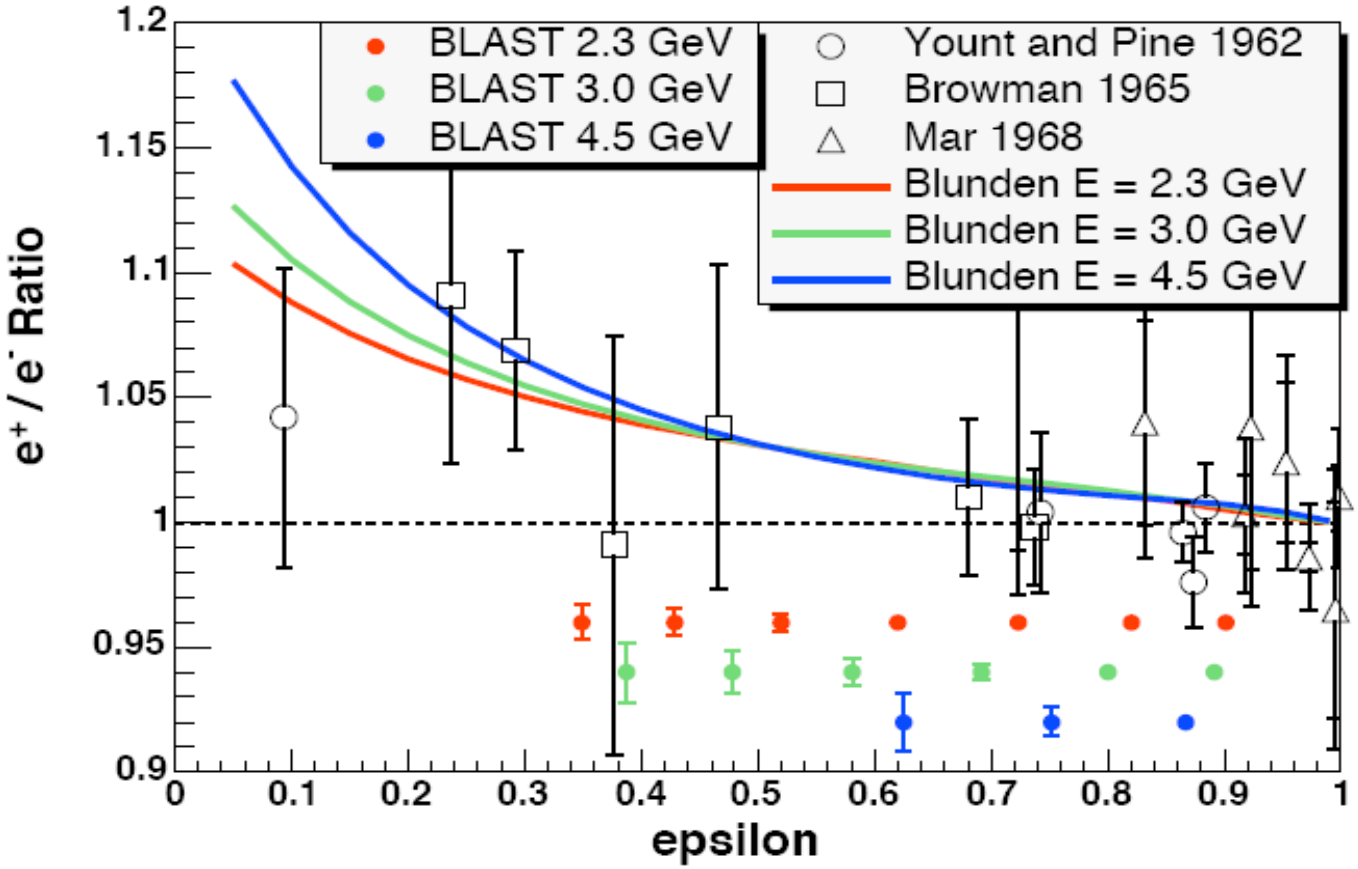
- **Sufficient counts at all angles and energies**
- **At Q^2 = 2.6 (GeV/c)^2 beam energies 2.3-4.5 GeV for Rosenbluth sepn.**

Count rate estimate



- **Sufficient counts at all angles and energies**
- **Epsilon = 0.4 achievable**

Projected results for DORIS experiment

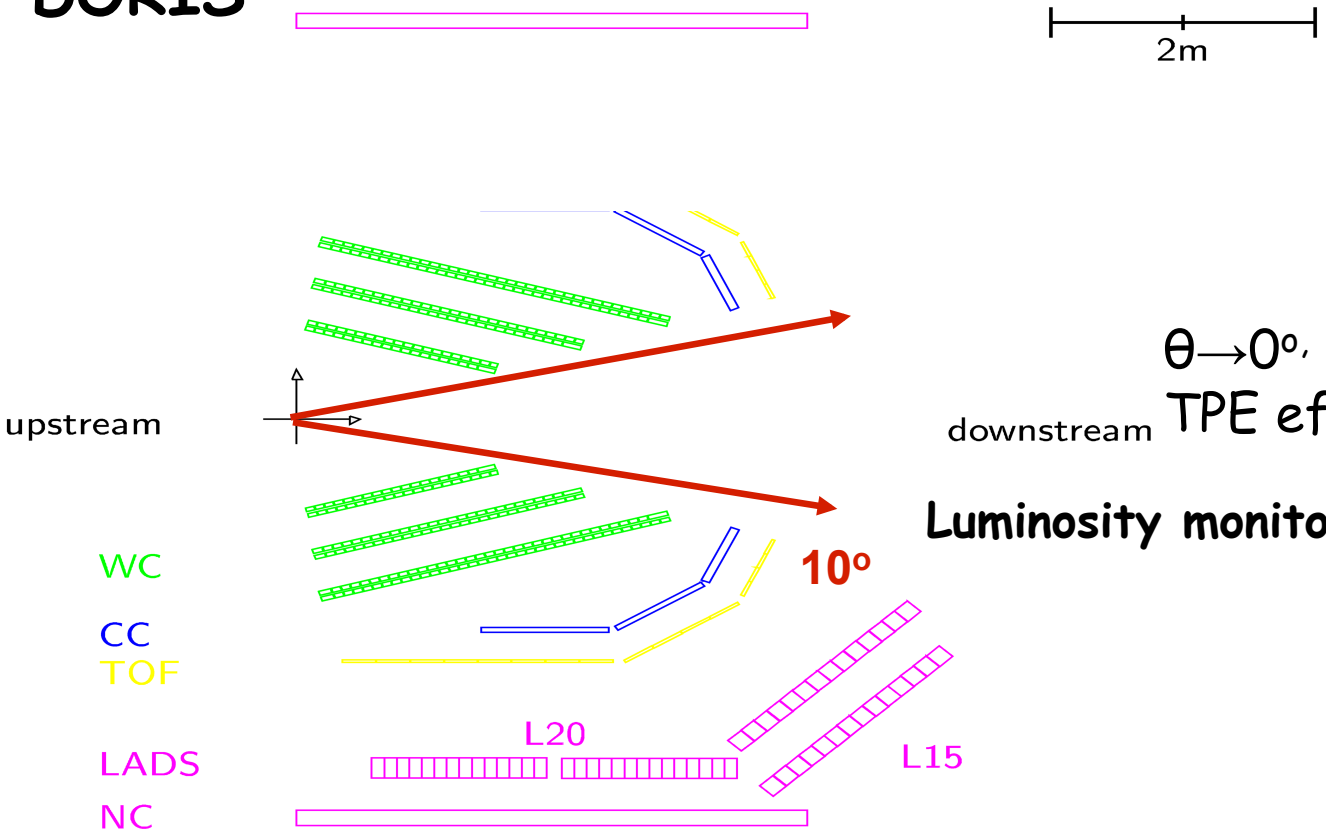


1000 hours each for e+ and e- assuming two (of eight) sectors instrumented and

Lumi = 2 x 10^{33} cm^{-2} s^{-1} – 100 mA on 3 x 10^{15} cm^{-2}

Control of systematics

BLAST @ DORIS



- Change BLAST polarity once a day
- Change between electrons and positrons regularly
- Left-right symmetry

Control of systematics

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

i = e+ or e-
j= pos/neg polarity of BLAST field

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

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

Ratio in single polarity j

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

Control of systematics

Super ratio:

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

Cycle of four states ij
Repeat cycle many times

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

Other experiments

- **JLab**

  Approved experiment to compare e^+p to e^-p elastic scattering using secondary beams and the CEBAF Large Acceptance Spectrometer. Challenging systematics. Expected to take data ~ 2011.

- **Novosibirsk**

  Similar experiment to DESY experiment has been considered. Positron currents are about an order of magnitude lower. No momentum measurement. Data taking ??

- **Parity violating electron scattering**

  Experiments at JLab and Mainz which measure transverse spin asymmetries are sensitive to two photon effects but not directly to the contribution which enters in G_E^p/G_M^p.

PRC64 (Nov. 2007) Report

- **Internal Target Experiment at DORIS**

  The PRC formed an external referee group to review the proposal of a possible new experiment at DORIS using the available MIT-BLAST detector and an unpolarized hydrogen gas target. The goal of the experiment is to determine the contribution of multiple photon exchange processes and to resolve the existing discrepancy in lepton-nucleon scattering data. Dedicated data taking for one month per year for several years would be sufficient to carry out the experiment. The external referees strongly support the physics case. The PRC thus recommends that the DESY management discuss this new experimental opportunity with the accelerator group.

Accelerators | Photon Science | Particle Physics

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April 11, 2008

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(Repesentative of Directors in Zeuthen)

Re.: OLYMPUS

Dear Richard,

Thank you for submitting a Letter of Intent for 'An Experiment to Definitely Determine the Contribution of Multiple Photon Exchange in Elastic Lepton-Nucleon Scattering'. The experiment, called OLYMPUS, will be re-using the existing detector of BLAST and is proposed to run at the DORIS accelerator at DESY in Hamburg. The PRC has reviewed the physics case and strongly supports it. First discussions with accelerator experts and within the directorate have revealed no technical show stoppers so far. Although many boundary conditions still need to be clarified, we encourage you to proceed towards forming a viable collaboration and writing a proposal which in turn will be reviewed by our scientific advisory bodies and the directorate. Some important topics need to be clarified as soon as possible like the size of the collaboration, in particular also the participation of German groups, expected funding, schedule of the experiment, support required from DESY, and possible running scenarios.

Please note that a stringent boundary condition for DESY is the running of PETRA in the next years. We will contact you again in June concerning possible running scenarios.

Looking forward to hearing from you,

with best regards

Prof. Dr. Albrecht Wagner

Prof. Dr. Rolf-Dieter Heuer

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

THE OLYMPUS COLLABORATION

June 23, 2008

THE OLYMPUS COLLABORATION

Arizona State University, USA
DESY, Hamburg, Germany
Hampton University, USA
INFN, Ferrara, Italy
INFN, Frascati, 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

Possible timeline

- Complete proposal by September 2008
- Submit funding requests to funding agencies ~ fall 2008
- Approval by DESY and funding ~ Spring 2009
- Install OLYMPUS target in DORIS ~ summer 2009 – test runs to optimize experiment design
- BLAST installation completed ~ spring 2010
- Take data 2010, 2011, 2012 at ~ 2 months/year
- Accelerated data taking schedule possible

Note that running time ≈ [lumi · acceptance]$^{-1}$

Funding

- Existing instrumentation:

  BLAST + detectors + internal gas target

  ~ $ 7 million
- Upgrades + new instrumentation + shipping – funds to be requested from individual group funding agencies
- DORIS operations – DESY ???

Summary

- The elastic form-factors of the proton are in question - the contribution of multiple photon exchange processes is essential to resolving the discrepancy.
- A definitive, precision comparison (~ 1%) of elastic electron -proton and positron-proton elastic scattering at 2.3 to 4.5 GeV at large angles (~ 60^0) can be carried out at DORIS using the available MIT-BLAST detector and an unpolarized hydrogen gas target.
- The physics case for the proposed experiment has been favorably reviewed by the DESY PRC. We should proceed to complete and submit a full proposal by the end of the summer.