DIS2011, Newport News, April 11-15, 2011

The OLYMPUS Experiment at DESY

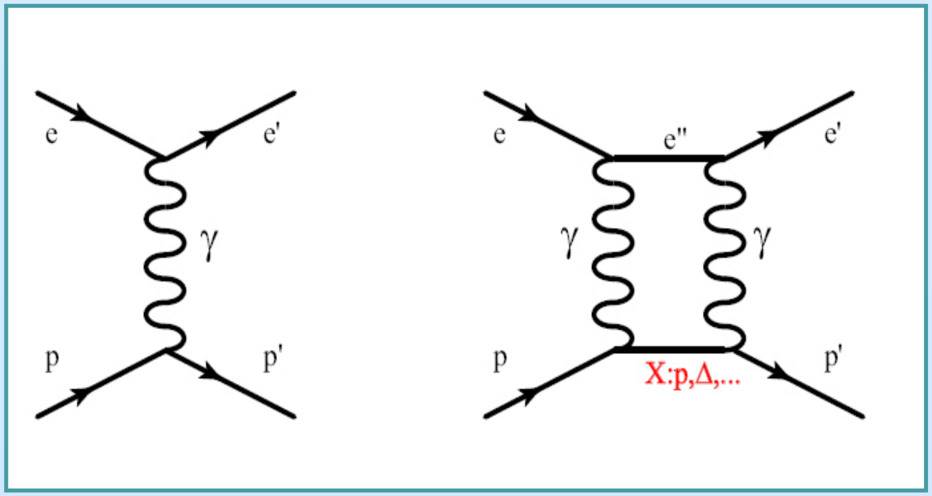
Michael Kohl

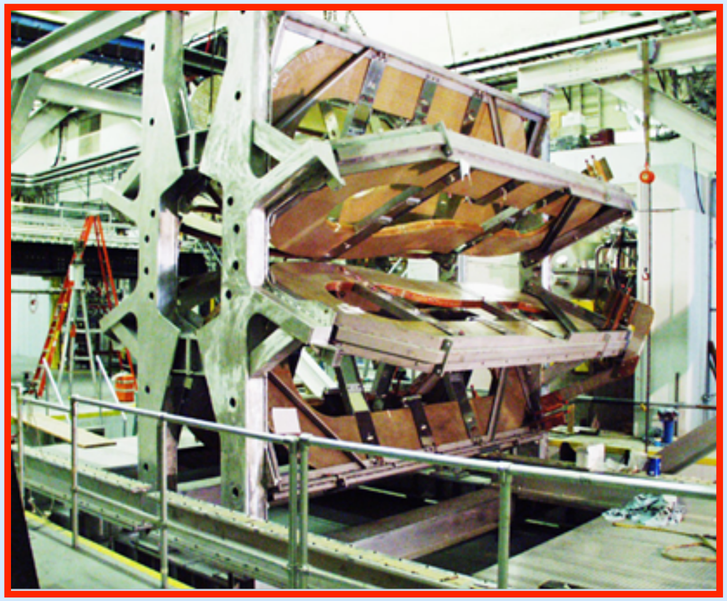
Hampton University, Hampton, VA 23668
Jefferson Laboratory, Newport News, VA 23606

* Supported by NSF grants PHY-0855473 and 0959521, and DOE Early Career Award DE-SC0003884

The OLYMPUS Experiment

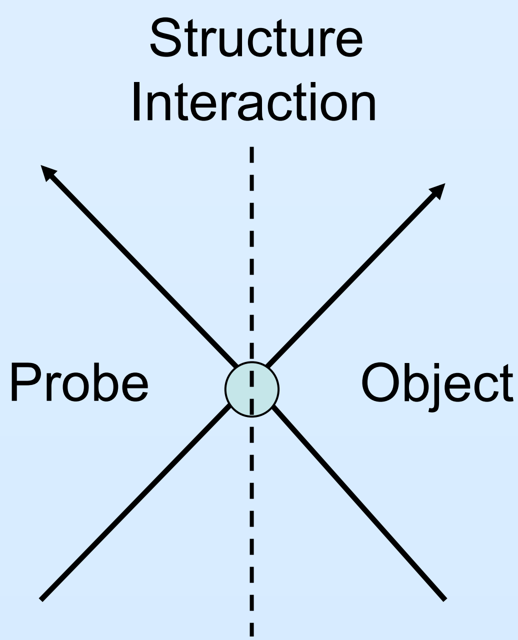
- **Review of the physics case – two-photon exchange**
- **The limit of one-photon exchange:**
  - **What is $G^p_E(Q^2)$ ⇔ proton charge distribution?**
  - **What is the nature of lepton scattering?**
- **Description of the OLYMPUS experiment**
- **Status and timeline**





OLYMPUS @ DESY

Hadronic Structure and EW Interaction

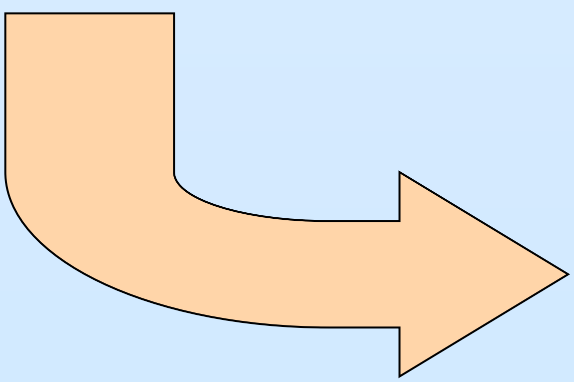


Factorization!

$$|\text{Form factor}|^2 = \frac{\sigma(\text{structured object})}{\sigma(\text{pointlike object})}$$

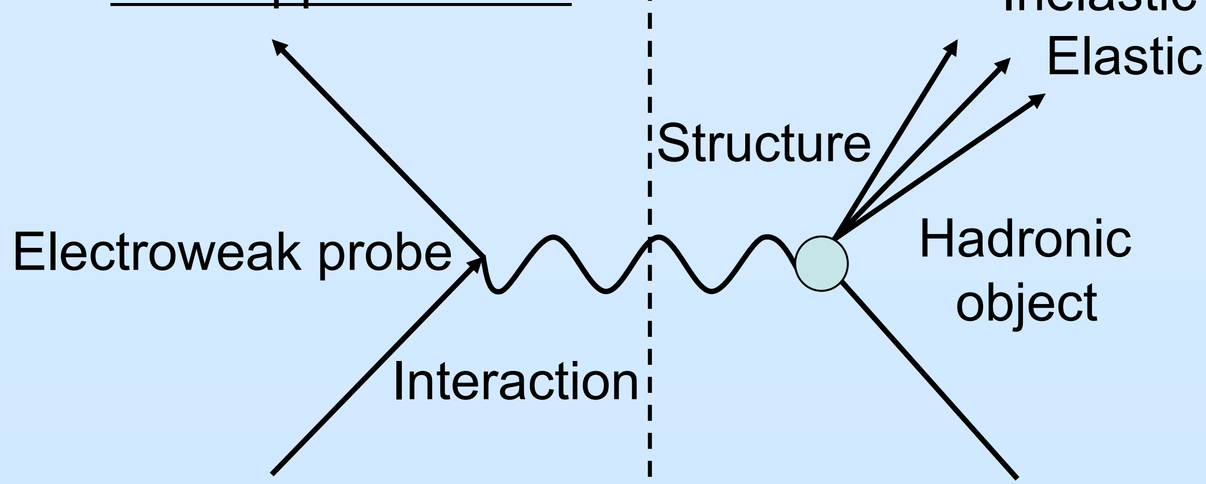
→ **Interference!**

→ **Utilize spin dependence of electromagnetic interaction to achieve high precision**



Lepton scattering

Born Approximation



One-Photon Exchange Approximation

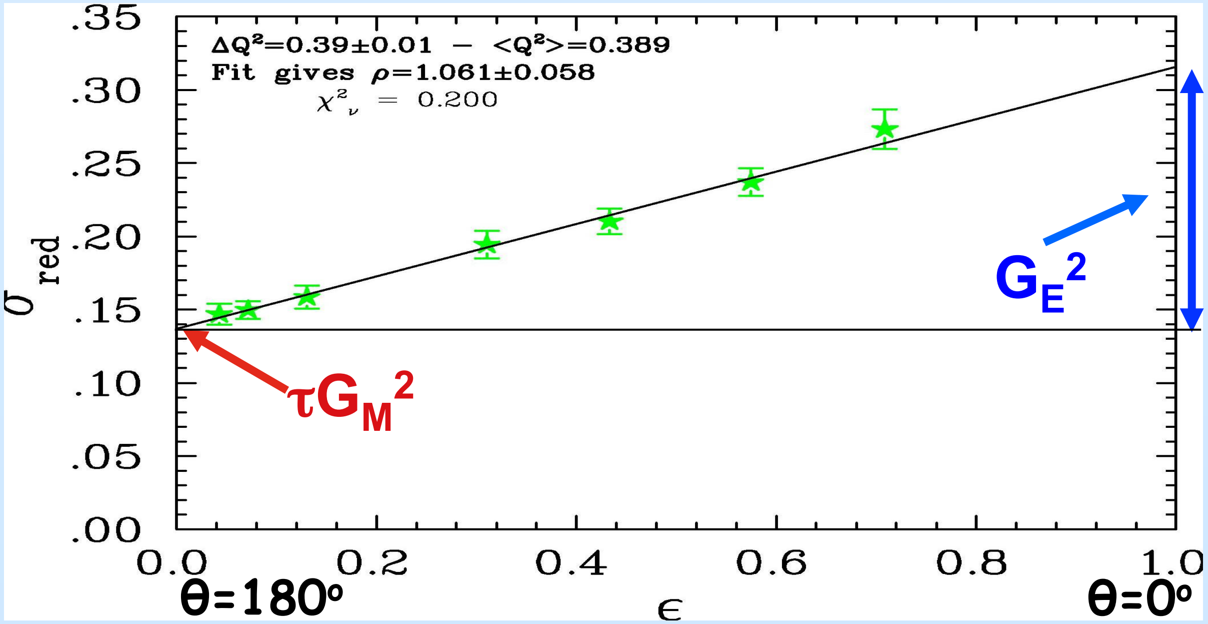
Form Factors from Rosenbluth Method

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

$$\frac{d\sigma/d\Omega}{(d\sigma/d\Omega)_{Mott}} = S_0 = A(Q^2) + B(Q^2)\tan^2\frac{\theta}{2}$$

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

$$= \frac{\epsilon G_E^2 + \tau G_M^2}{\epsilon(1+\tau)}, \qquad \epsilon = \left[1 + 2(1+\tau)\tan^2\frac{\theta}{2}\right]^{-1}$$



$\sigma_{red} = \varepsilon G_E^2 + \tau G_M^2$

➔Determine

$|G_E|$, $|G_M|$, $|G_E/G_M|$

Nucleon Form Factors and Polarization

- **Double polarization in elastic ep scattering:**
  Recoil polarization or (vector) polarized target

  $^1H(\vec{e},e'\vec{p})$, $^1\vec{H}(\vec{e},e'p)$

- **Polarized cross section**

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

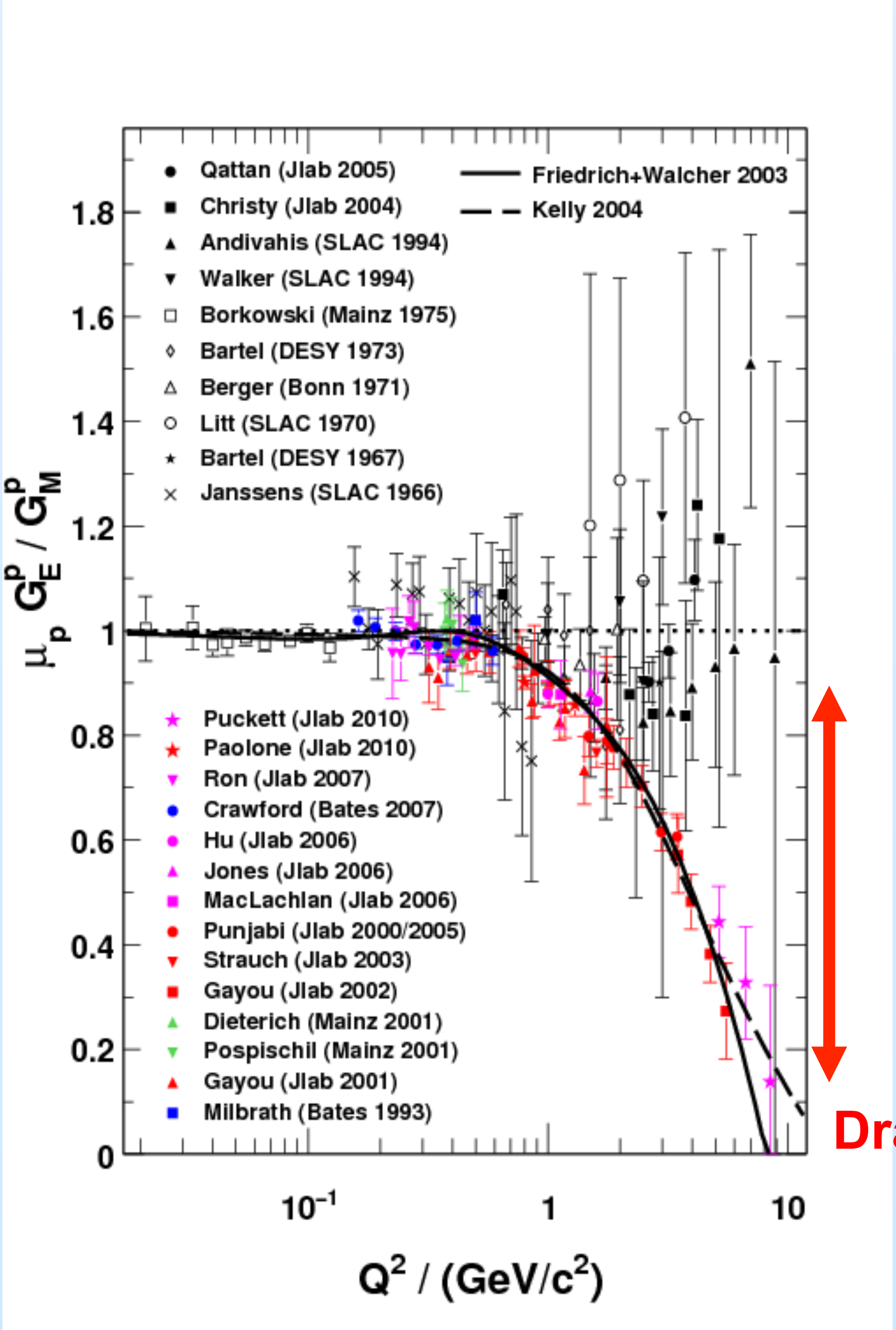
- **Double spin asymmetry = spin correlation**

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

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

  independent of polarization or analyzing power

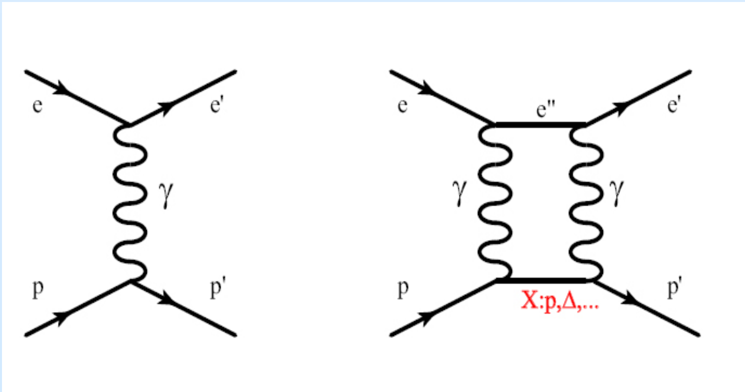
Proton Form Factor Ratio



Dramatic discrepancy!

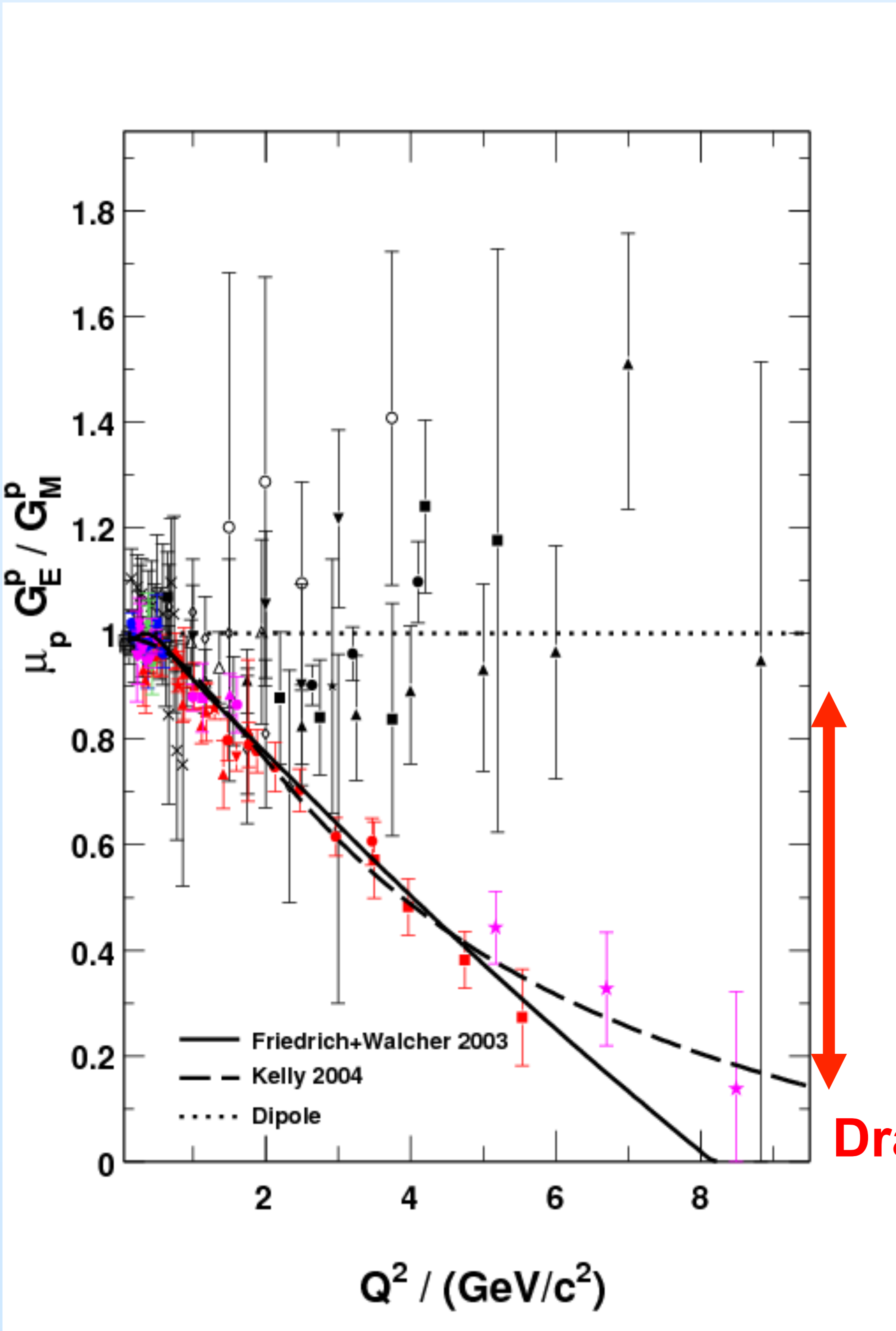
Jefferson Lab 2000–

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



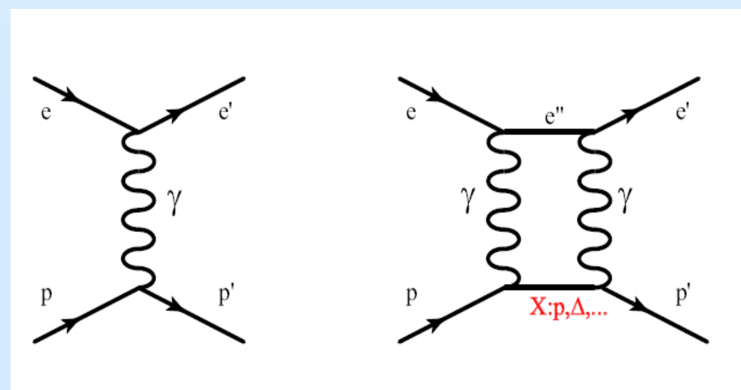
>800 citations

Proton Form Factor Ratio



Jefferson Lab 2000–

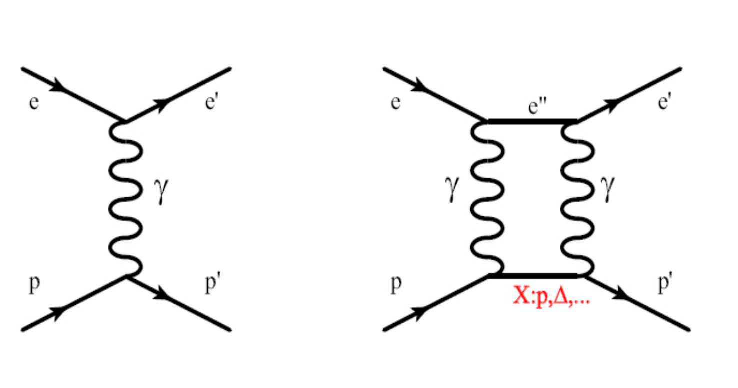
- All Rosenbluth data from SLAC and Jlab in agreement
- Dramatic discrepancy between Rosenbluth and recoil polarization technique
- Multi-photon exchange considered best candidate



Dramatic discrepancy!

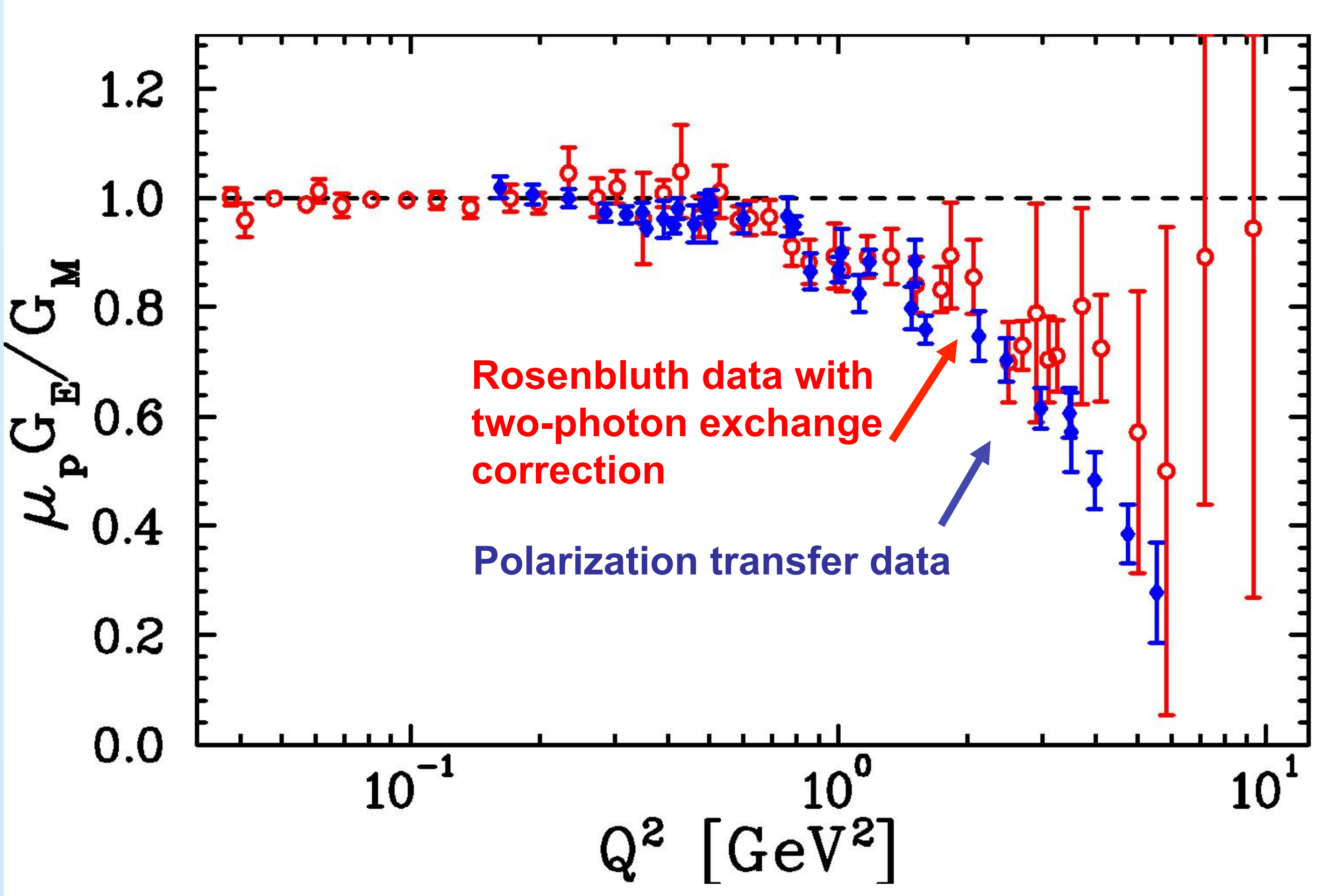
>800 citations

Two-Photon Exchange: Exp. Evidence



Two-photon exchange theoretically suggested

TPE can explain form factor discrepancy
J. Arrington, W. Melnitchouk, J.A. Tjon,
Phys. Rev. C 76 (2007) 035205



Observables involving real part of TPE

$$P_t = -\sqrt{\frac{2\varepsilon(1-\varepsilon)}{\tau}}\frac{G_M^2}{d\sigma_{red}}\left\{R + R\frac{\Re\left(\delta\tilde{G}_M\right)}{G_M} + \frac{\Re\left(\delta\tilde{G}_E\right)}{G_M} + Y_{2\gamma}\right\}$$

$$P_l = \sqrt{(1+\varepsilon)(1-\varepsilon)}\frac{G_M^2}{d\sigma_{red}}\left\{1 + 2\frac{\Re(\delta\tilde{G}_M)}{G_M} + \frac{2}{1+\varepsilon}\varepsilon Y_{2\gamma}\right\}$$

$$\frac{P_t}{P_l} = -\sqrt{\frac{2\varepsilon}{(1+\varepsilon)\tau}}\left\{R - R\frac{\Re\left(\delta\tilde{G}_M\right)}{G_M} + \frac{\Re\left(\delta\tilde{G}_E\right)}{G_M} + 2\left(1 - R\frac{2\varepsilon}{1+\varepsilon}\right)Y_{2\gamma}\right\}$$

E04-019
(Two-gamma)

$$d\sigma_{red}/G_M^2 = 1 + \frac{\varepsilon R^2}{\tau} + 2\frac{\Re(\delta\tilde{G}_M)}{G_M} + 2R\frac{\varepsilon\Re(\delta\tilde{G}_E)}{\tau G_M} + 2\left(1+\frac{R}{\tau}\right)\varepsilon Y_{2\gamma}$$

e^+/e^- x-section ratio
CLAS,VEPP3,OLYMPUS

Rosenbluth non-linearity
E05-017

$$\Re(\tilde{G}_E) = G_E(Q^2) + \Re(\delta\tilde{G}_E(Q^2,\varepsilon))$$

$$\Re(\tilde{G}_M) = G_M(Q^2) + \Re(\delta\tilde{G}_M(Q^2,\varepsilon))$$

$$R = G_E/G_M \qquad Y_{2\gamma} = 0 + \sqrt{\frac{\tau(1+\tau)(1+\varepsilon)}{1-\varepsilon}}\frac{\Re(\tilde{F}_3(Q^2,\varepsilon))}{G_M}$$

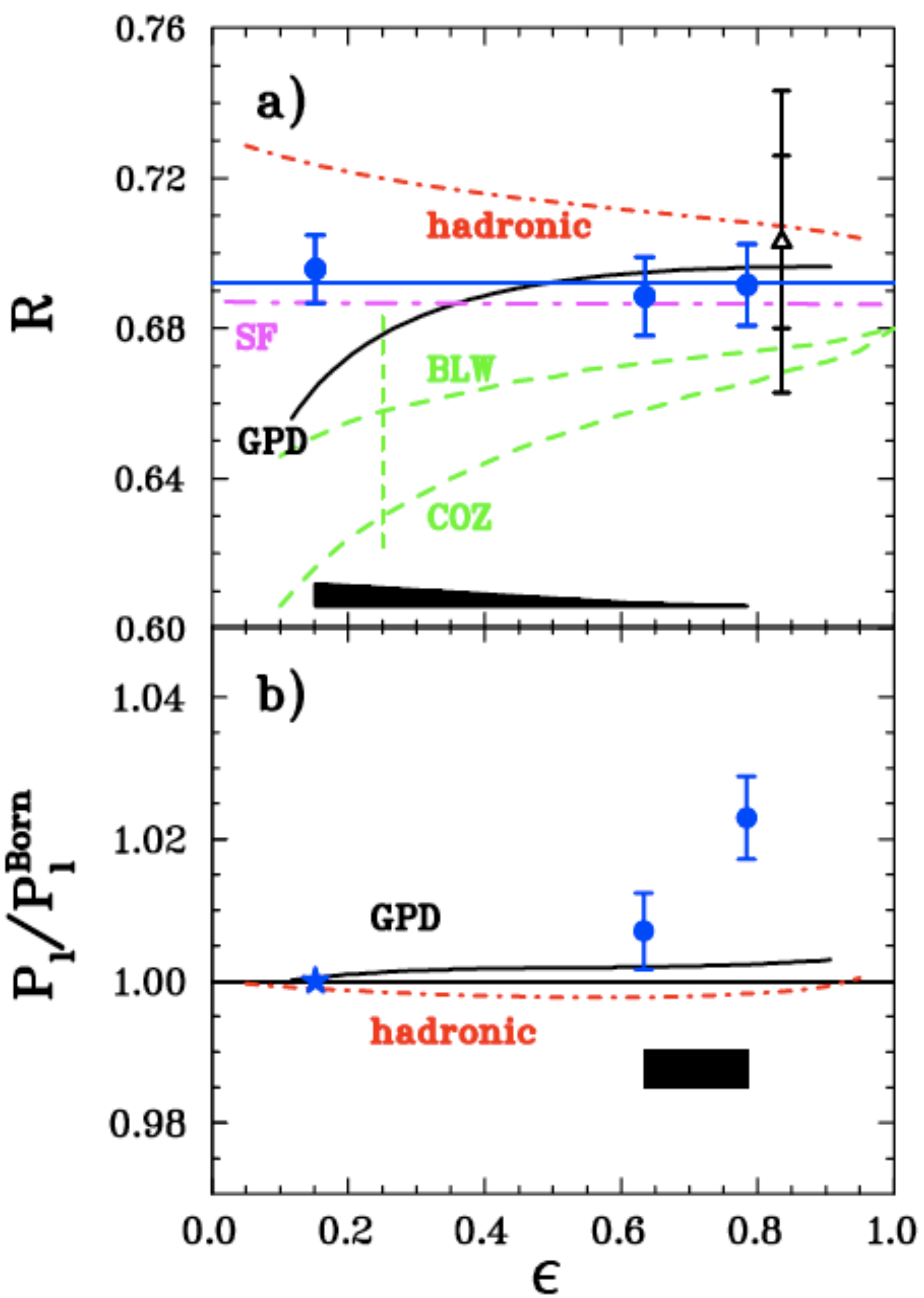
Born Approximation | **Beyond Born Approximation**

P.A.M. Guichon and M.Vanderhaeghen, Phys.Rev.Lett. 91, 142303 (2003)

M.P. Rekalo and E. Tomasi-Gustafsson, E.P.J. A 22, 331 (2004)

Slide idea:
L. Pentchev

Jefferson Lab E04-019 (Two-gamma)



Jlab – Hall C

Q^2 = 2.5 $(GeV/c)^2$

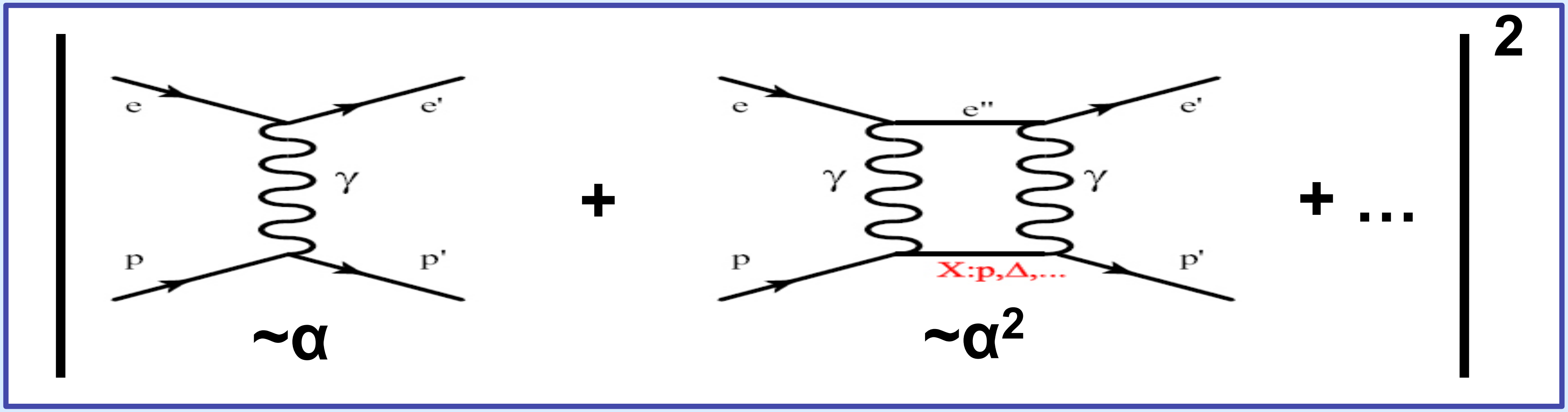
G_E/G_M from P_t/P_l constant vs. ε

- ➔ **no effect in P_t/P_l**
- ➔ **some effect in P_l**

Expect larger effect in e+/e-!

M. Meziane et al., hep-ph/1012.0339v2
Phys. Rev. Lett. 106, 132501 (2011)

Lepton-Proton Elastic Scattering



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

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

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

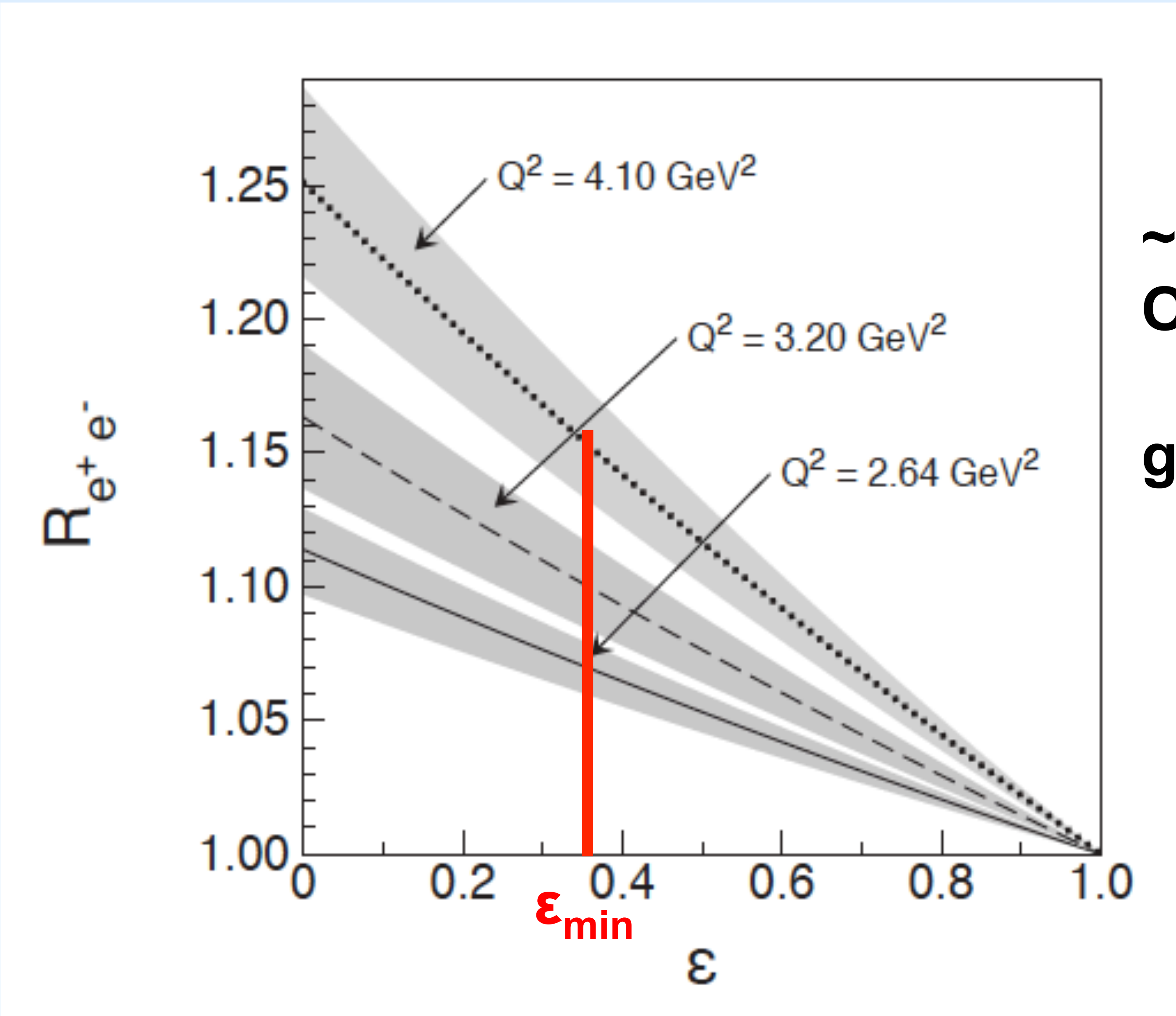
$$\sigma(\text{positron-proton}) = (1\gamma)^2\alpha^2 + (1\gamma)(2\gamma)\alpha^3 + ..$$

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

σ-ratio to deviate from 1 due to interference of 1γ and 2γ proportional to TPE

Empirical Extraction of TPE Amplitudes

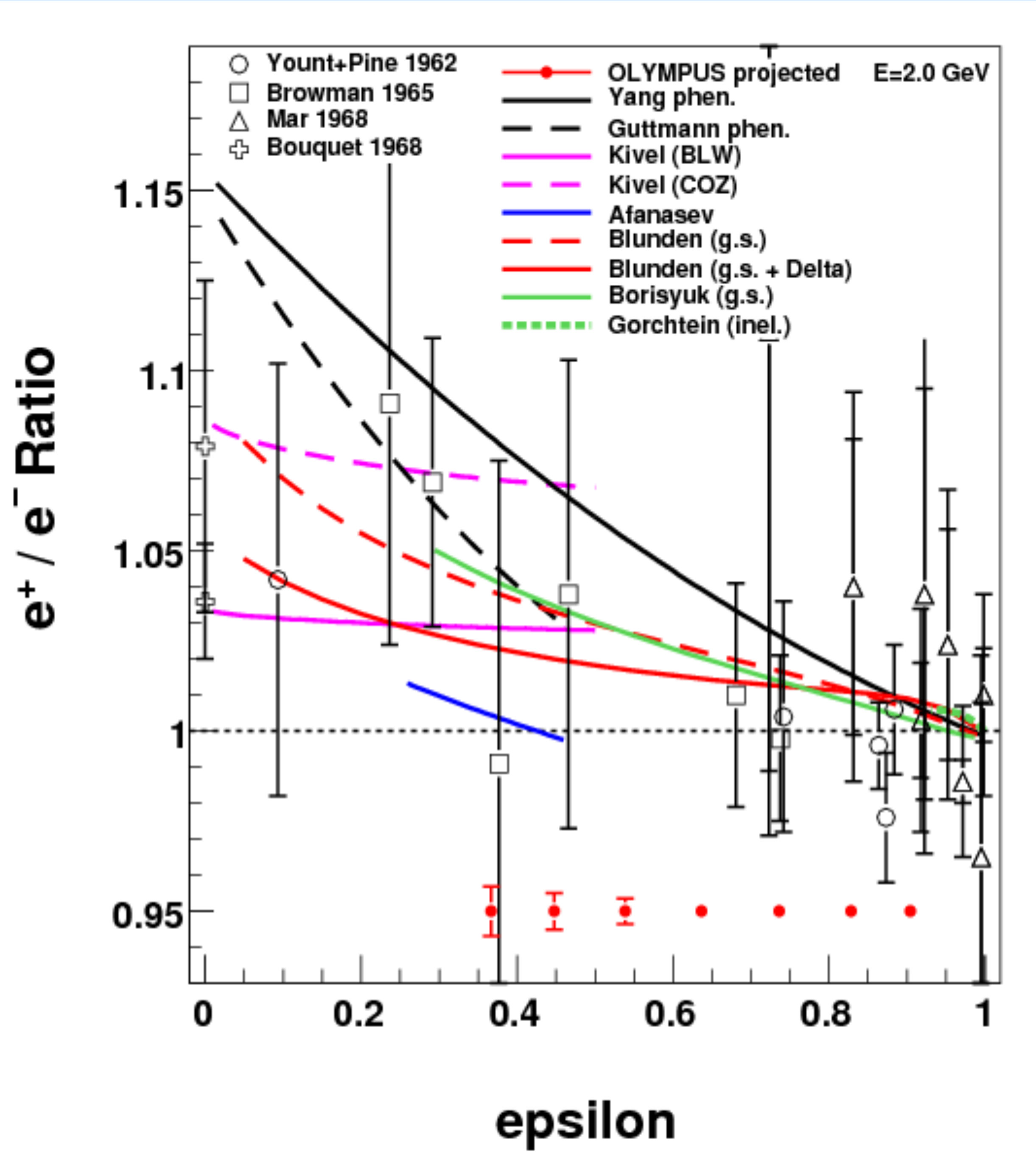
J. Guttmann, N. Kivel, M. Meziane, and M. Vanderhaeghen, hep-ph/1012.0564v1

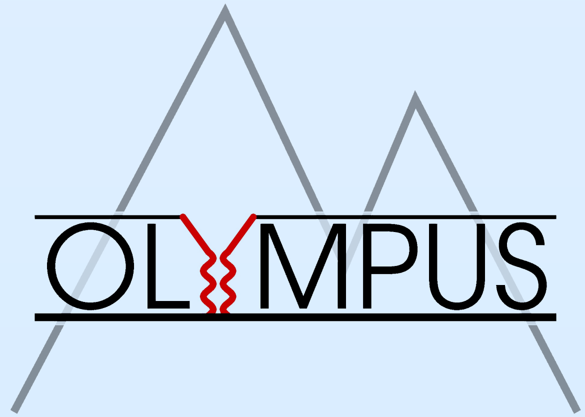


~6% effect for OLYMPUS@2.0GeV

grows with Q^2!

Projected Results for OLYMPUS





Data from 1960's

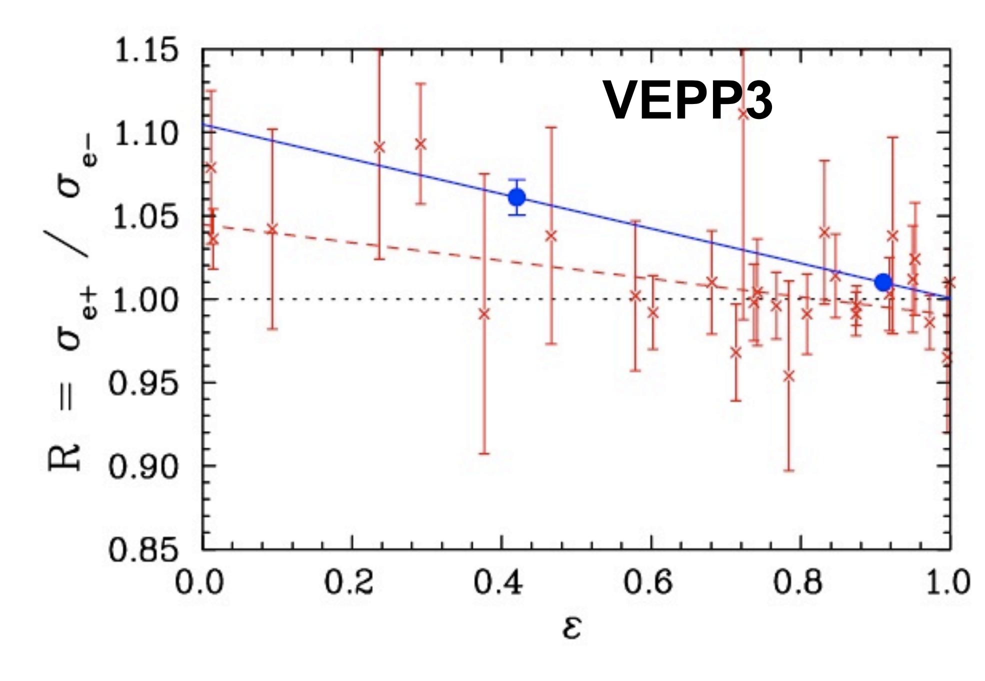
Many theoretical predictions with little constraint

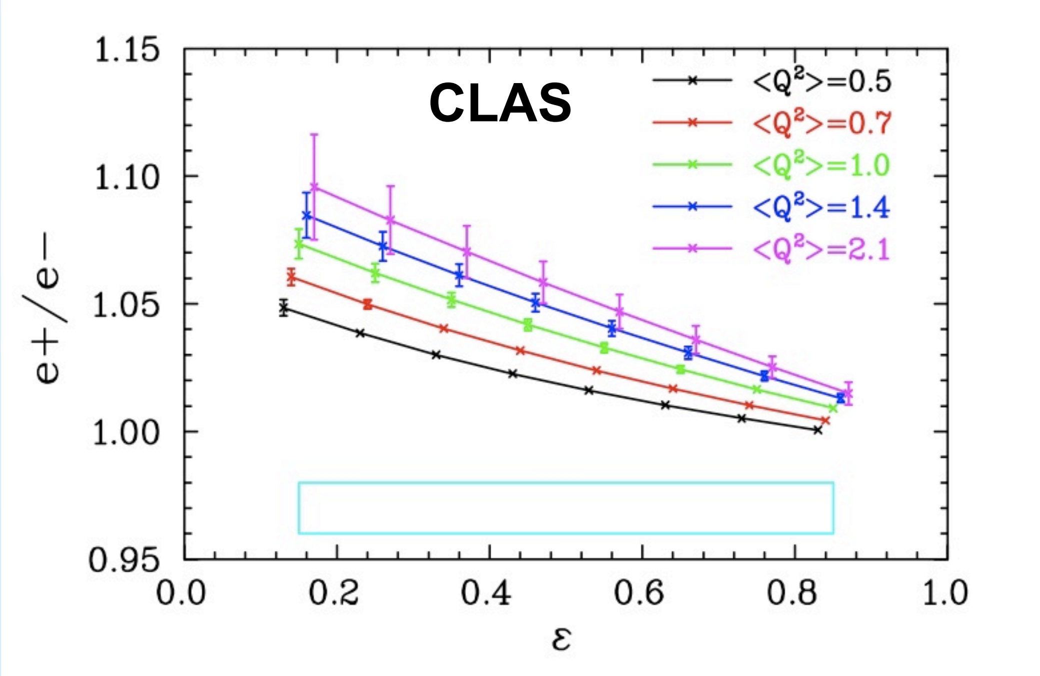
OLYMPUS:

- **E = 2 GeV, ε = 0.37-0.9**
- **Q^2 = 0.6-2.2 $(GeV/c)^2$**
- **<1% projected uncertainties**
- **500h @ $2x10^{33} / cm^2s$ e+,e-**

to be run in 2012

Other Experiments to Verify TPE





Experiment proposals to verify hypothesis:

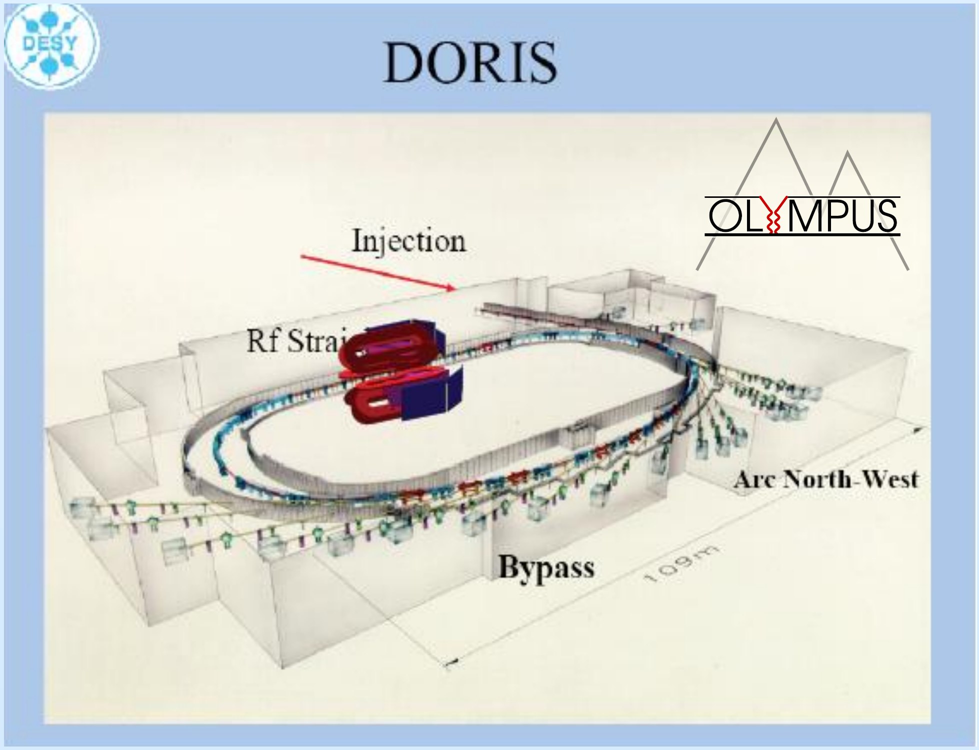
e+/e- ratio:	**CLAS/PR04-116**	**secondary e+/e- beam/ext. target – 2010/11 (completed in Feb. 2011)**
	Novosibirsk/VEPP-3	**storage ring / intern. target – 2009 (preliminary result: sizable effect)**
	OLYMPUS@DESY	**storage ring / intern. target – 2012**

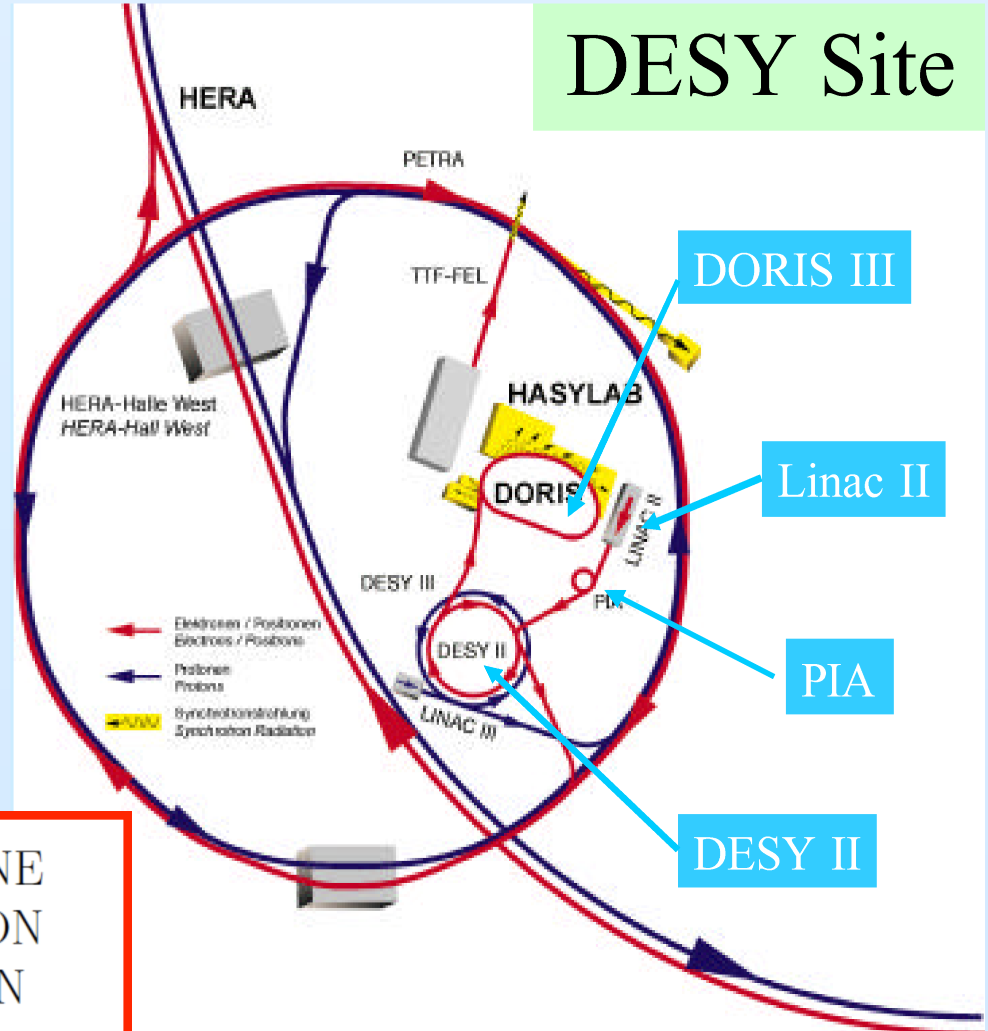
SSA: **PR05-15 (Hall A, trans. pol target); MAMI-A4 (trans. pol. beam)**

ε-dependence: **PR04-019 (polarized), PR05-017 (unpolarized)**

OLYMPUS @ DESY

OLYMPUS @ DESY





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

THE OLYMPUS COLLABORATION

September 9, 2008

BLAST → OLYMPUS

OLYMPUS @ DESY

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

2007 – Letter of Intent
2008 – Full proposal
2009/10 – Funding and Approval
2010/11 – Transfer of BLAST detector
Installation and commissioning

2012 – OLYMPUS Running

Proposed Experiment

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

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

Collaboration Organization

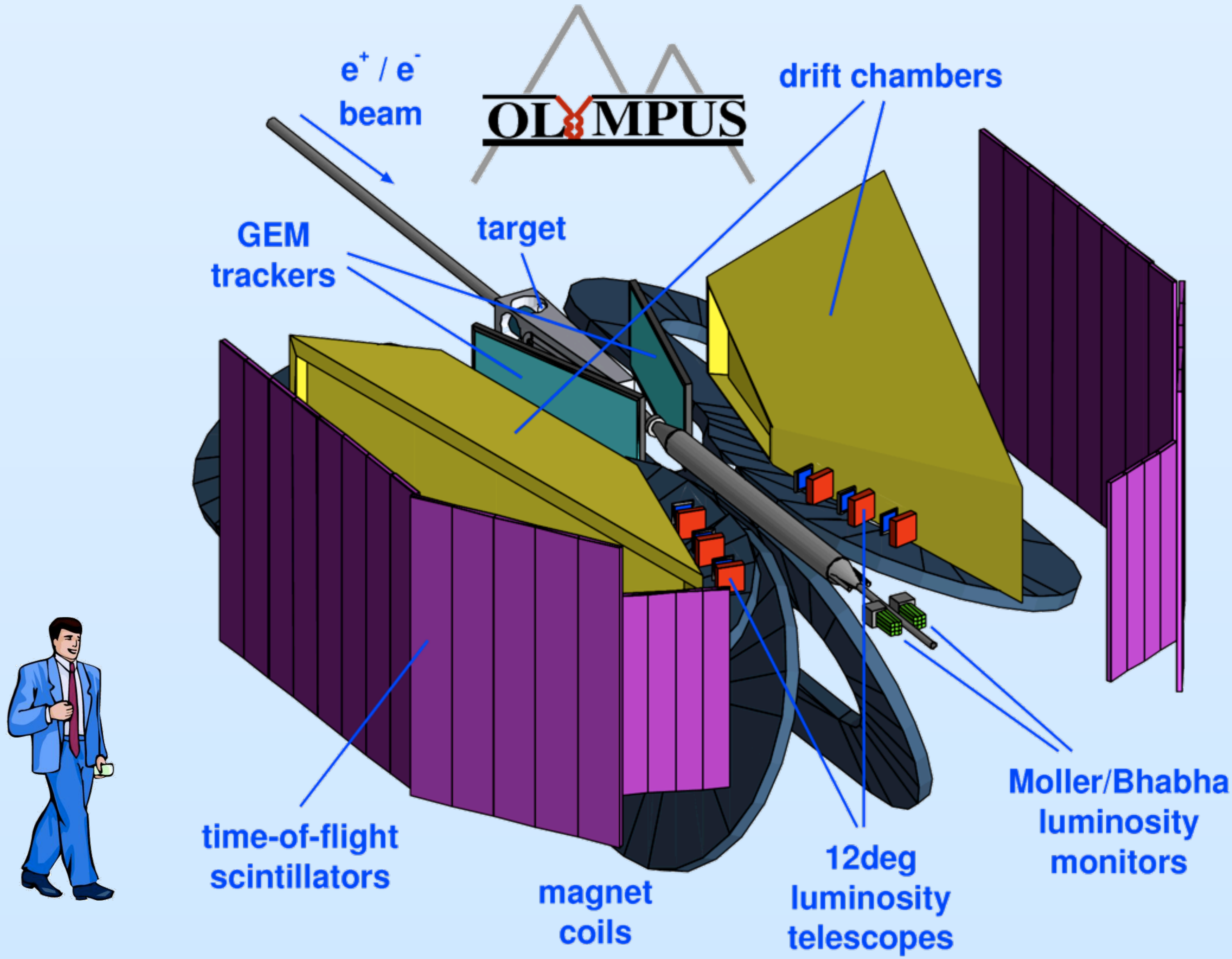
- Nov 2006 – Idea first formulated (D. Hasell, M.K., R. Milner)
- Jun 2007 – Letter of Intent
- Sept 2008 – Full Proposal
- Technical review Sept 2009, funded and officially approved since Jan 2010
- Several collaboration meetings since technical review
  Nov 30–Dec 1, 2009 Feb 23–24, 2010 Apr 26–27, 2010
  Jun 28–29, 2010 Aug 30–31, 2010 Nov 1–2, 2010 Jan 24 – 25, 2011
- Elected management of OLYMPUS at Dec 2009 meeting:
  Spokesman: Richard Milner (MIT)
  Deputy spokesman: Reinhard Beck (U. Bonn)
  Technical coordinator: Douglas Hasell (MIT)
  Project manager: Uwe Schneekloth (DESY)
- Appointed coordinators:
  Tracking – D. Hasell (MIT)
  Scintillators – I. Lehmann (U. Glasgow)
  Luminosity Monitor – M. Kohl (Hampton U.)
  Symmetric Moller Monitor – F. Maas (U. Mainz)
  Target – R. Milner (MIT)
  Data Acquisition – C. Funke (U. Bonn)
  Slow Controls – A. Izotov (PNPI)

OLYMPUS

Institutional Responsibilities

- **Arizona State University:** TOF support, particle identification, magnetic shielding
- **DESY:** Modifications to DORIS accelerator and beamline, toroid support, infrastructure, installation
- **Hampton University:** GEM luminosity monitor, simulations
- **INFN Bari:** GEM electronics
- **INFN Ferrara:** Target
- **INFN Rome:** GEM electronics
- **MIT:** BLAST spectrometer, wire chambers, tracking upgrade, target and vacuum system, transportation to DESY, simulations
- **Petersburg Nuclear Physics Institute:** Slow controls, MWPC luminosity monitor
- **University of Bonn:** Trigger and data acquisition
- **University of Glasgow**: Particle Identification, TOF scintillators
- **University of Kentucky:** Simulations
- **University of Mainz:** Trigger, DAQ, Symmetric Moller monitor
- **University of New Hampshire:** TOF scintillators
- **Yerevan Physics Institute:** Removal of ARGUS, TOF system

The Proposed OLYMPUS Detector



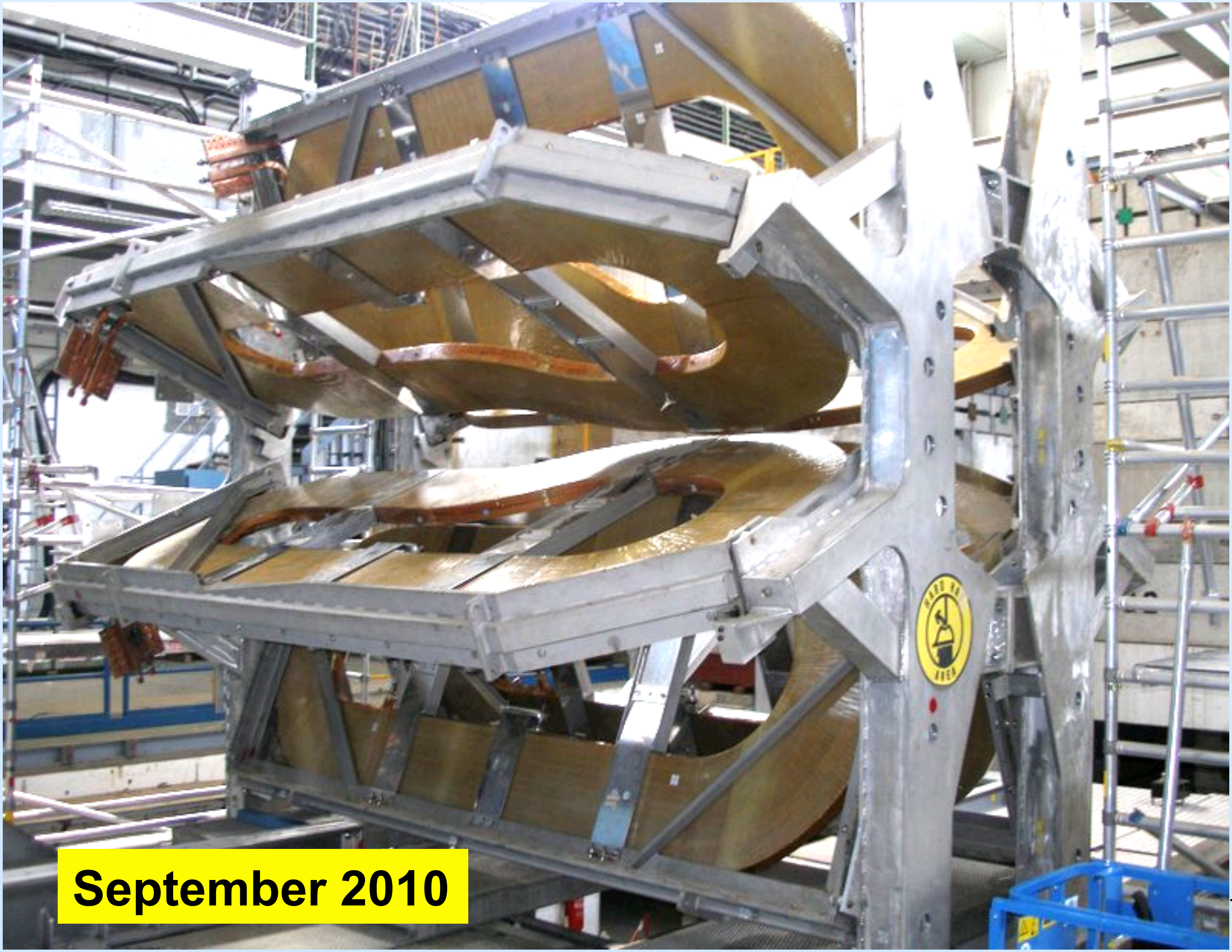
Preparation of OLYMPUS

- Transfer of detector
  - ARGUS removed; BLAST disassembled and shipped (May-July 2010)
  - OLYMPUS assembly at DESY started in June 2010, complete by August 2011
- Target and vacuum system
  - New target chamber designed, machined from solid aluminum
  - Target cells constructed by INFN Ferrara
  - Control system development started in May 2010
  - Contructed and tested by Nov. 2010, shipped and installed in Jan. 2011
  - Test experiment successful in Feb. 2011; reinstall in DORIS in May 2011
- Drift Chambers
  - Rewired drift chambers at DESY in summer 2010, to be installed May 2011
- TOFs
  - TOFs tested and calibrated at Bates in January 2010
  - Supports redesigned, coordinated by U. Glasgow, to be installed in May 2011
- Luminosity Monitoring
  - 12-degree elastic scattering telescopes (Hampton & PNPI), well advanced
  - Symmetric Moller/Bhabha monitors (U. Mainz)
  - Test of all elements at DESY testbeam facility in May 2011
- DAQ
  - U. Bonn coordinating, system brought into operation at DESY in summer 2010

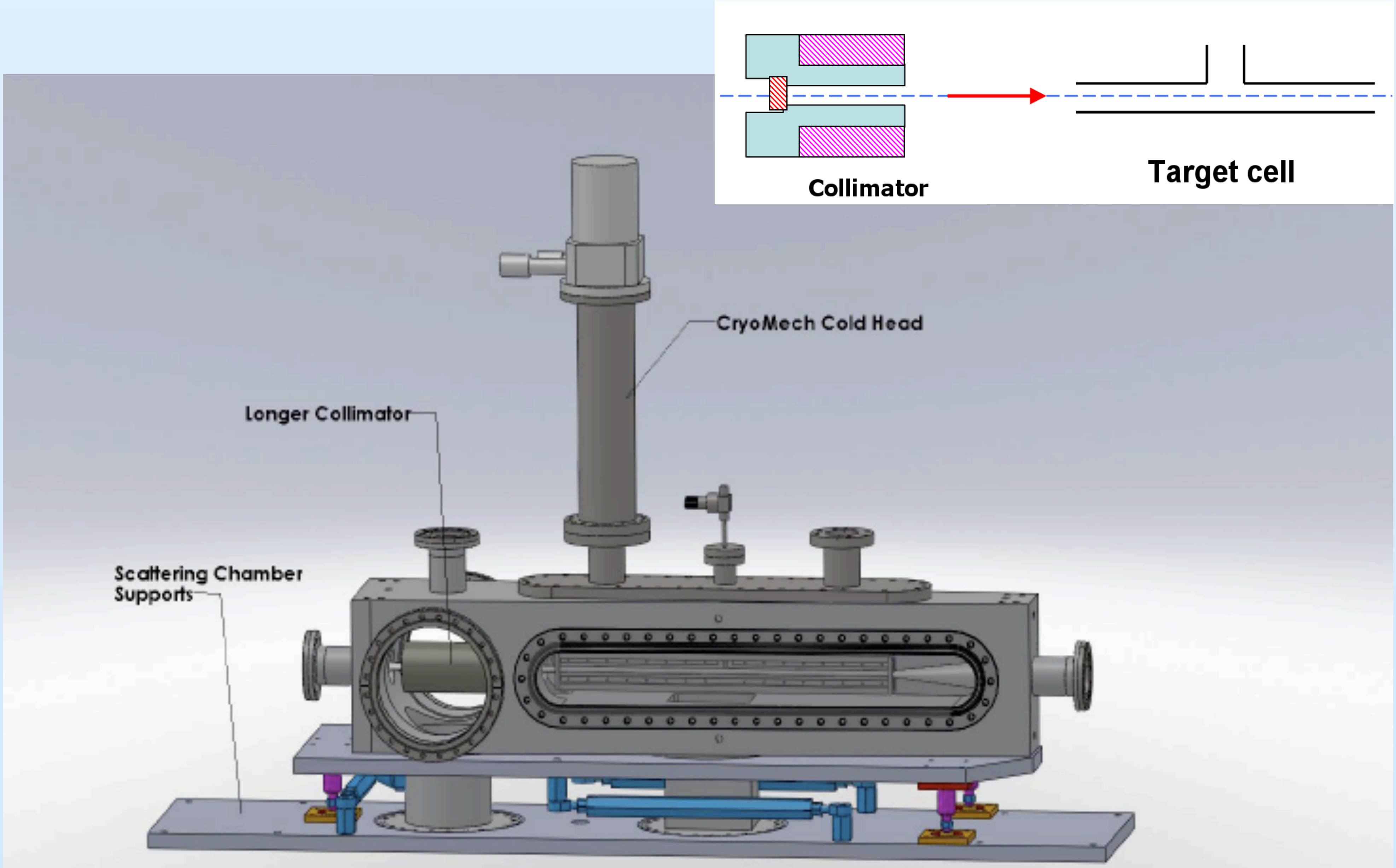
- **“ROLLING-IN” of final OLYMPUS detector into DORIS in August 2011**

OLYMPUS: BLAST@DESY/DORIS

OLYMPUS: BLAST@DESY/DORIS



Target and Vacuum System

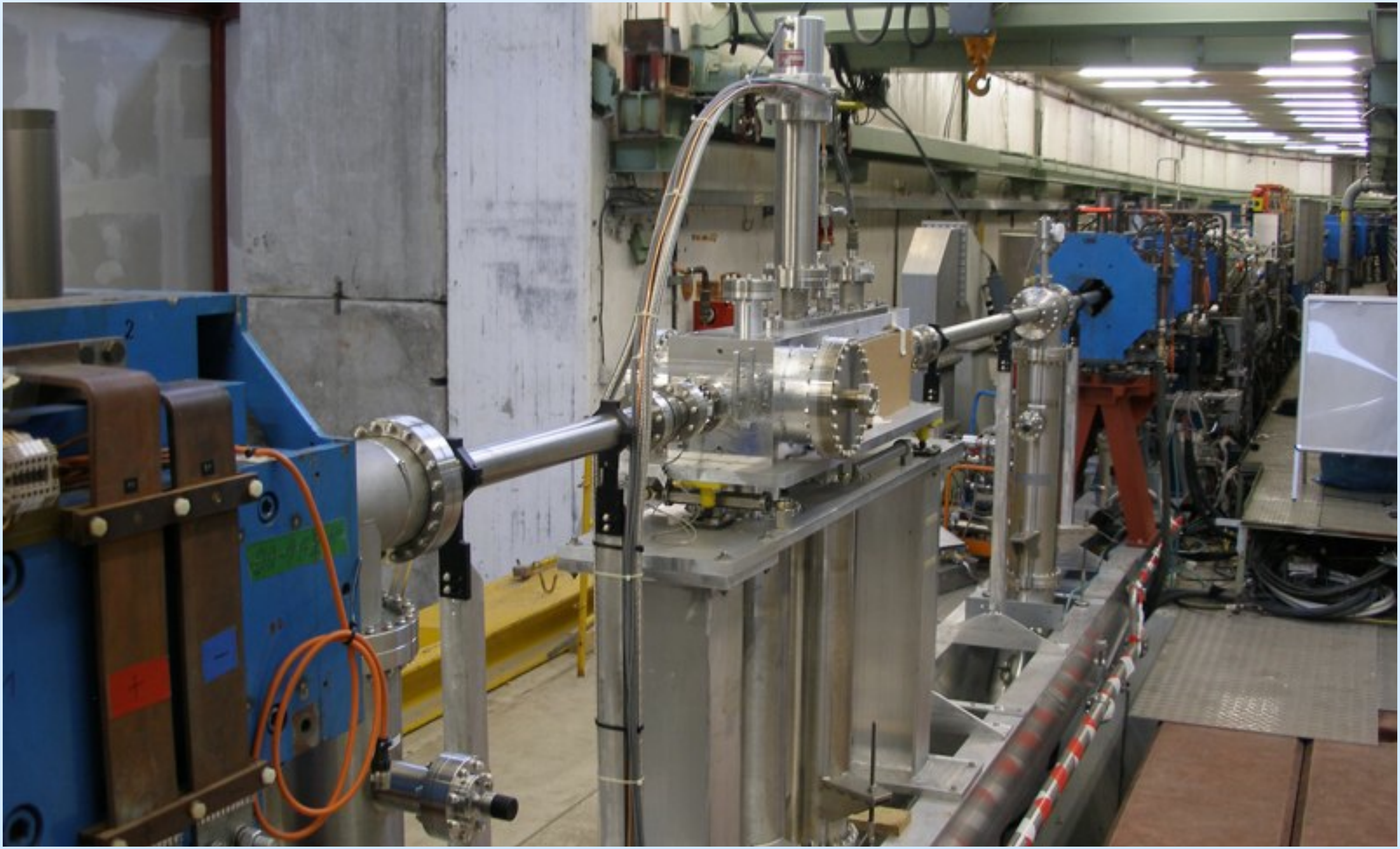


Designed until summer 2010

Target and Vacuum System

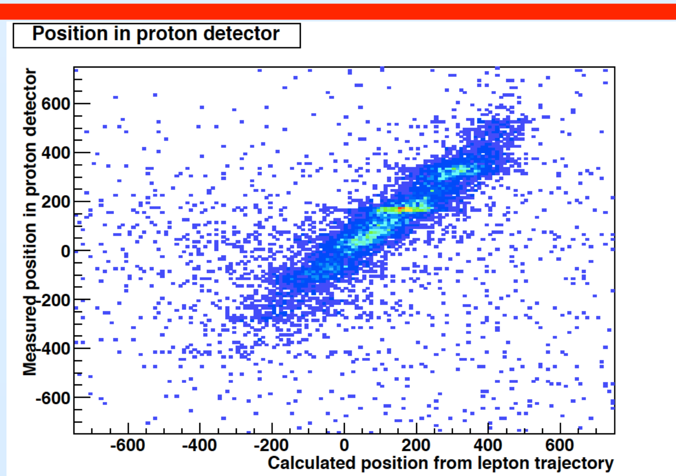
Target chamber machined by October 2010

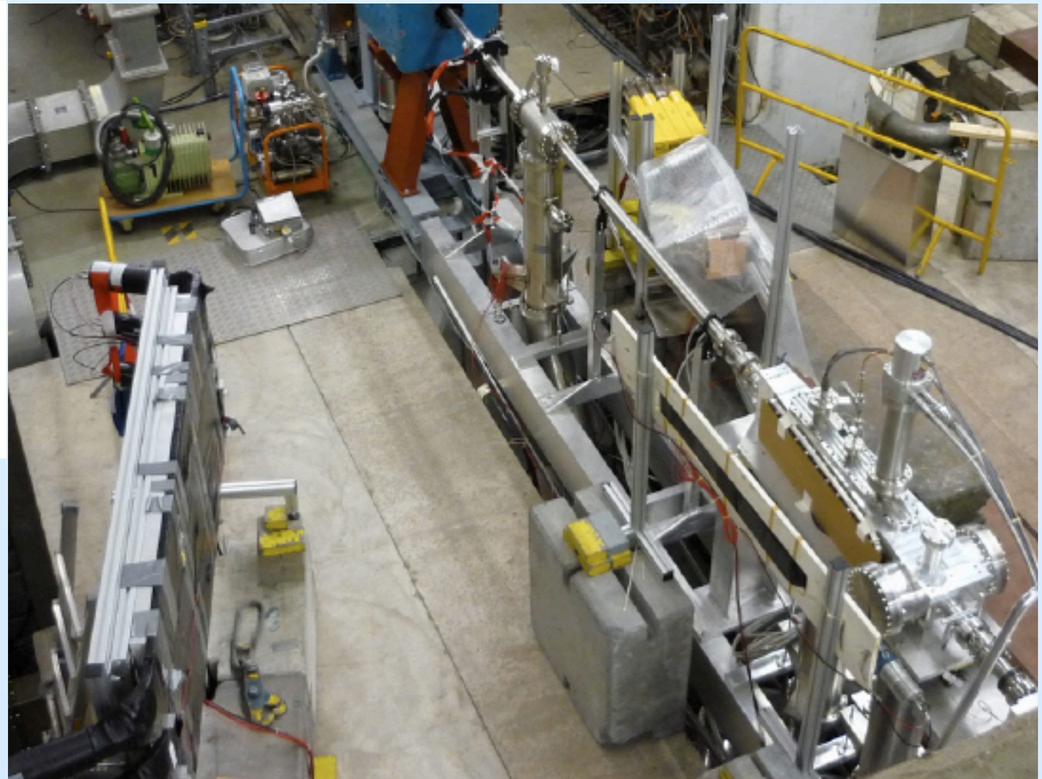
Target and Vacuum System

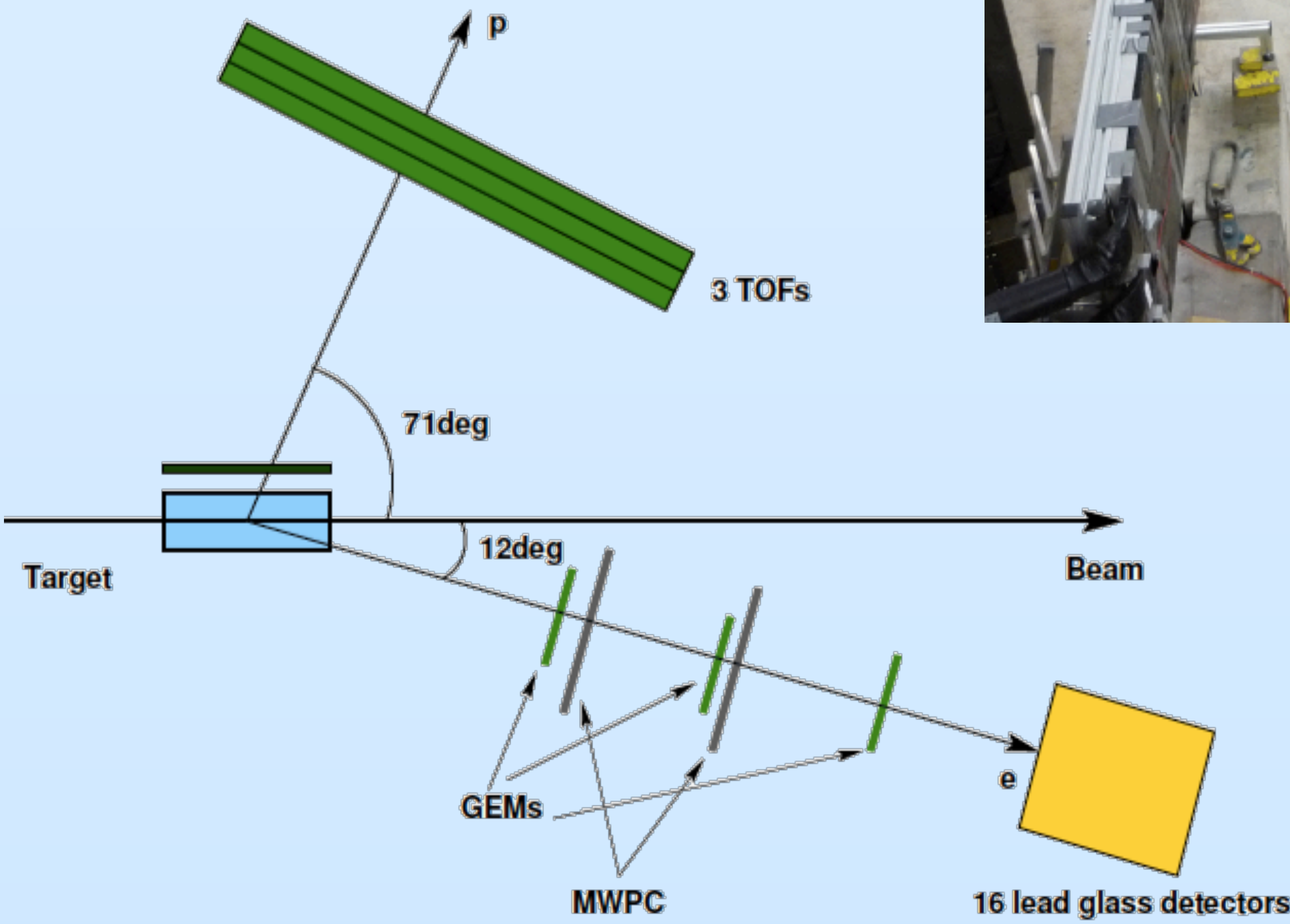


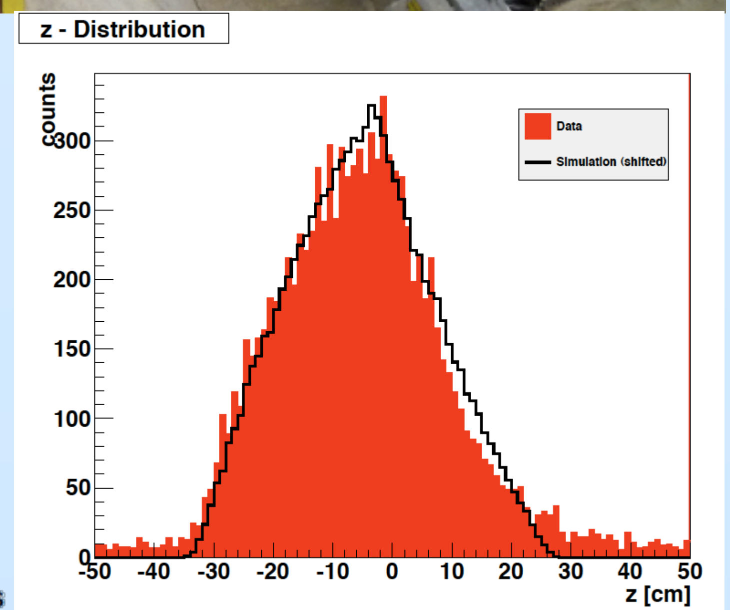
Installed in DORIS in January 2011

DORIS Test Experiment in Feb 2011



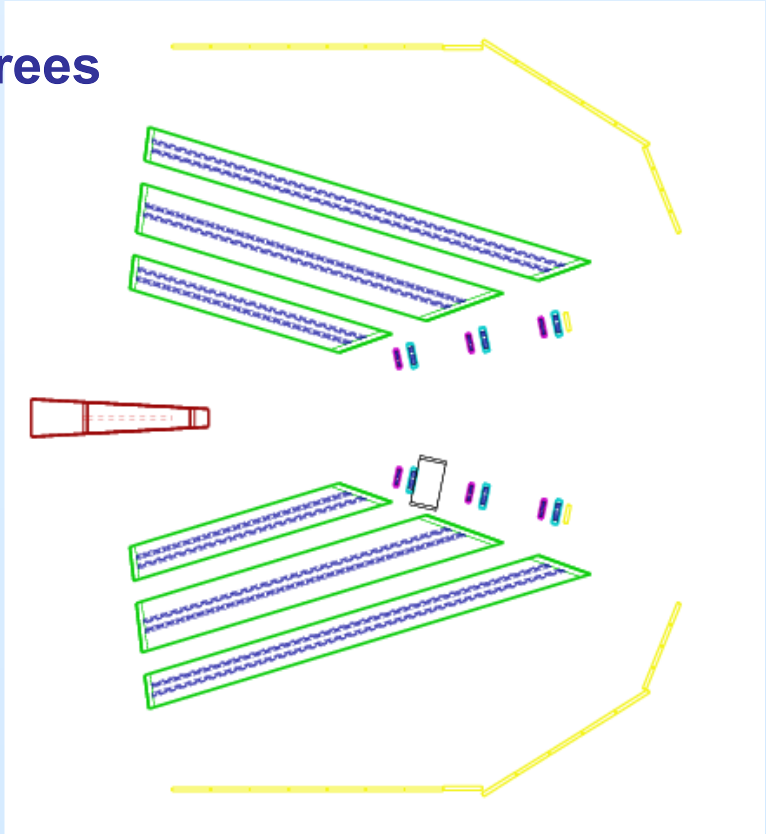






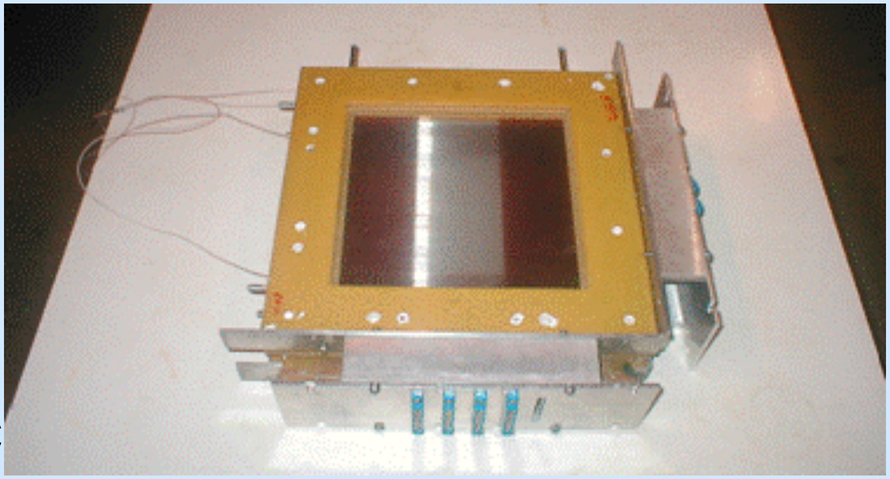
Luminosity Monitors: GEM + MWPC

- Forward elastic scattering of lepton at 12 degrees in coincidence with proton in main detector
- Two GEM + MWPC telescopes with interleaved elements operated independently
- Scintillator for triggering and timing
- High redundancy – alignment, efficiency
  Two independent groups (Hampton, PNPI)



Prototypes:

GEM



MWPC

Luminosity Monitors – Basic Properties

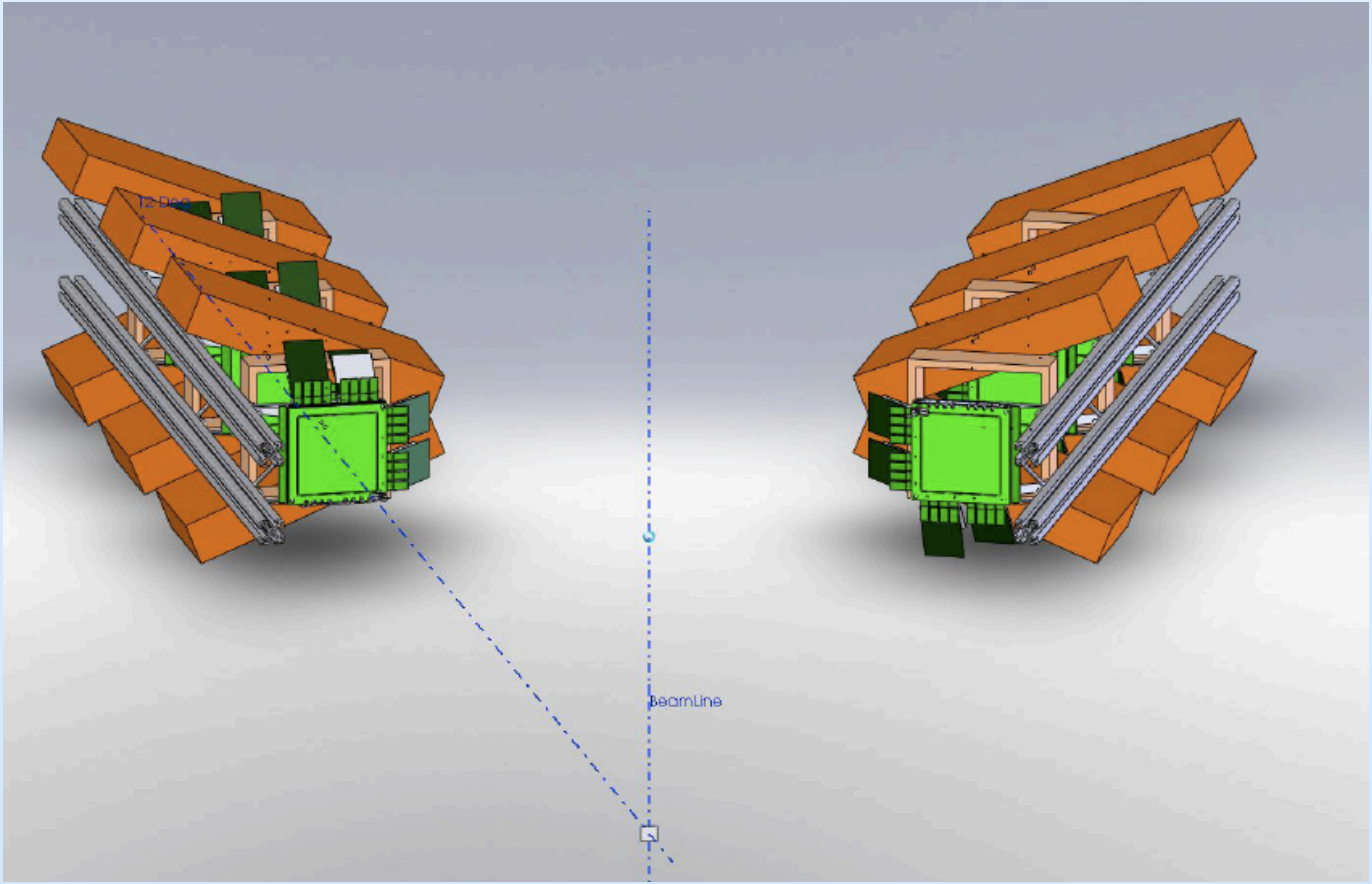
Proposed version included in OLYMPUS TDR Sept. 2009

E_0 [GeV]	Q^2 [(GeV/c)^2]	$p_{e'}$ [GeV/c]	ϵ	θ_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.

- **Two symmetric GEM telescopes at 12°**
- **Two-photon effect negligible at high-ε / low-Q^2**
- **Sub-percent (relative) luminosity measurement**
  per hour at 2.0 GeV, per day at 4.5 GeV
- **1.2 msr = 10 x 10 cm^2 at ~290 cm distance (rearmost plane)**
- **Three GEM layers with ~0.1 mm resolution with ~50 cm gaps**

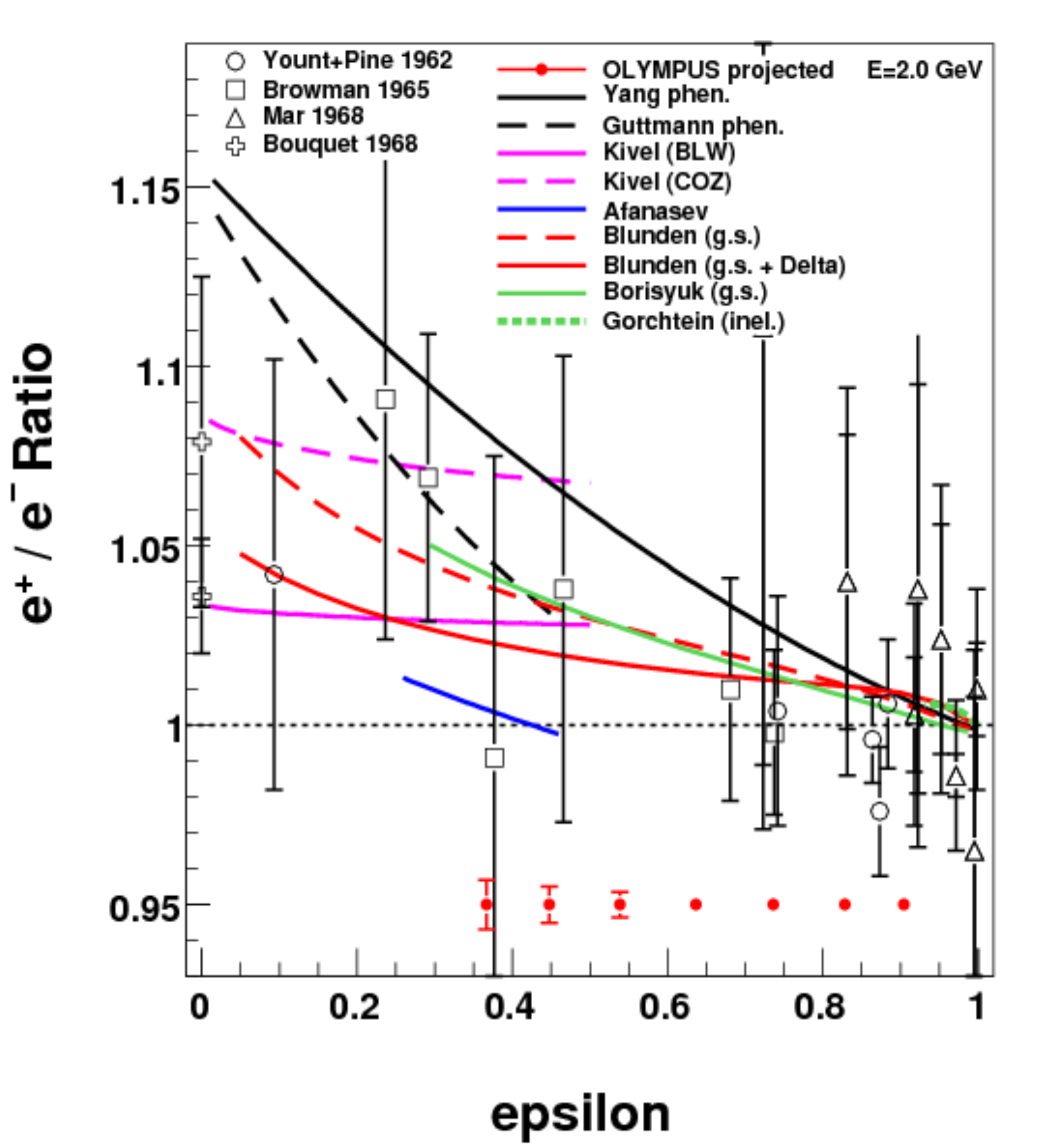
Luminosity Monitors: GEM + MWPC



Summary

- The limits of OPE have been reached with available today's precision
  ➔ Nucleon elastic form factors, particularly G_E^p under doubt
- The TPE hypothesis is suited to remove form factor discrepancy, however calculations of TPE are model-dependent
- Experimental probes: Real part of TPE –
  - ε-dependence of polarization transfer
  - ε-nonlinearity of cross sections
  - Comparison of positron and electron scattering
- Need both positron and electron beams for a definitive test of TPE
  OLYMPUS, CLAS, VEPP-3
- Install OLYMPUS experiment in DORIS IR in August 2011 ("rolling-in")
- Commissioning of OLYMPUS August – December 2011
- Take data in two running blocks beginning and end 2012

Projected Results for OLYMPUS



Data from 1960's

Many theoretical predictions with little constraint

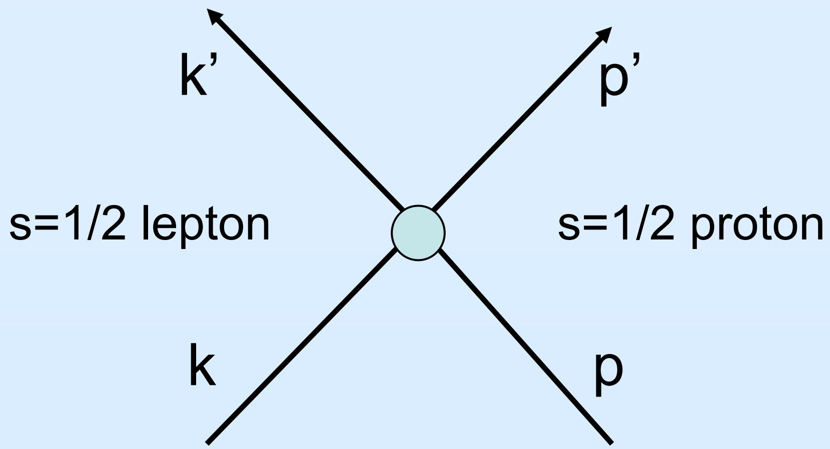
OLYMPUS:

E = 2 GeV, ε = 0.37-0.9
Q^2 = 0.6-2.2 $(GeV/c)^2$
<1% projected uncertainties
500h @ $2x10^{33}$ / cm^2s e+,e-

to be run in 2012

Backup slides – OLYMPUS

Elastic ep Scattering Beyond OPE



$$P \equiv \frac{p+p'}{2}, \qquad K \equiv \frac{k+k'}{2}$$

Kinematical invariants :

$$\begin{aligned} Q^2 &= -(p-p')^2 \\ \nu &= K \cdot P = (s-u)/4 \end{aligned}$$

Next-to Born approximation:

$$\begin{aligned} T^{non-flip}_{h'\lambda'_N, h\lambda_N} &= \frac{e^2}{Q^2} \bar{u}(k', h') \gamma_\mu u(k, h) \\ &\times \bar{u}(p', \lambda'_N) \left(\tilde{G}_M \gamma^\mu - \tilde{F}_2 \frac{P^\mu}{M} + \tilde{F}_3 \frac{\gamma . K P^\mu}{M^2} \right) u(p, \lambda_N) \end{aligned}$$

($m_e = 0$)

The T-matrix still factorizes, however a new response term F_3 is generated by TPE
Born-amplitudes are modified in presence of TPE; modifications ~α^3

$$\begin{aligned} \tilde{G}_M(\nu, Q^2) &= G_M(Q^2) + \delta\tilde{G}_M \\ \tilde{F}_2(\nu, Q^2) &= F_2(Q^2) + \delta\tilde{F}_2 \\ \tilde{F}_3(\nu, Q^2) &= 0 + \delta\tilde{F}_3 \end{aligned}$$

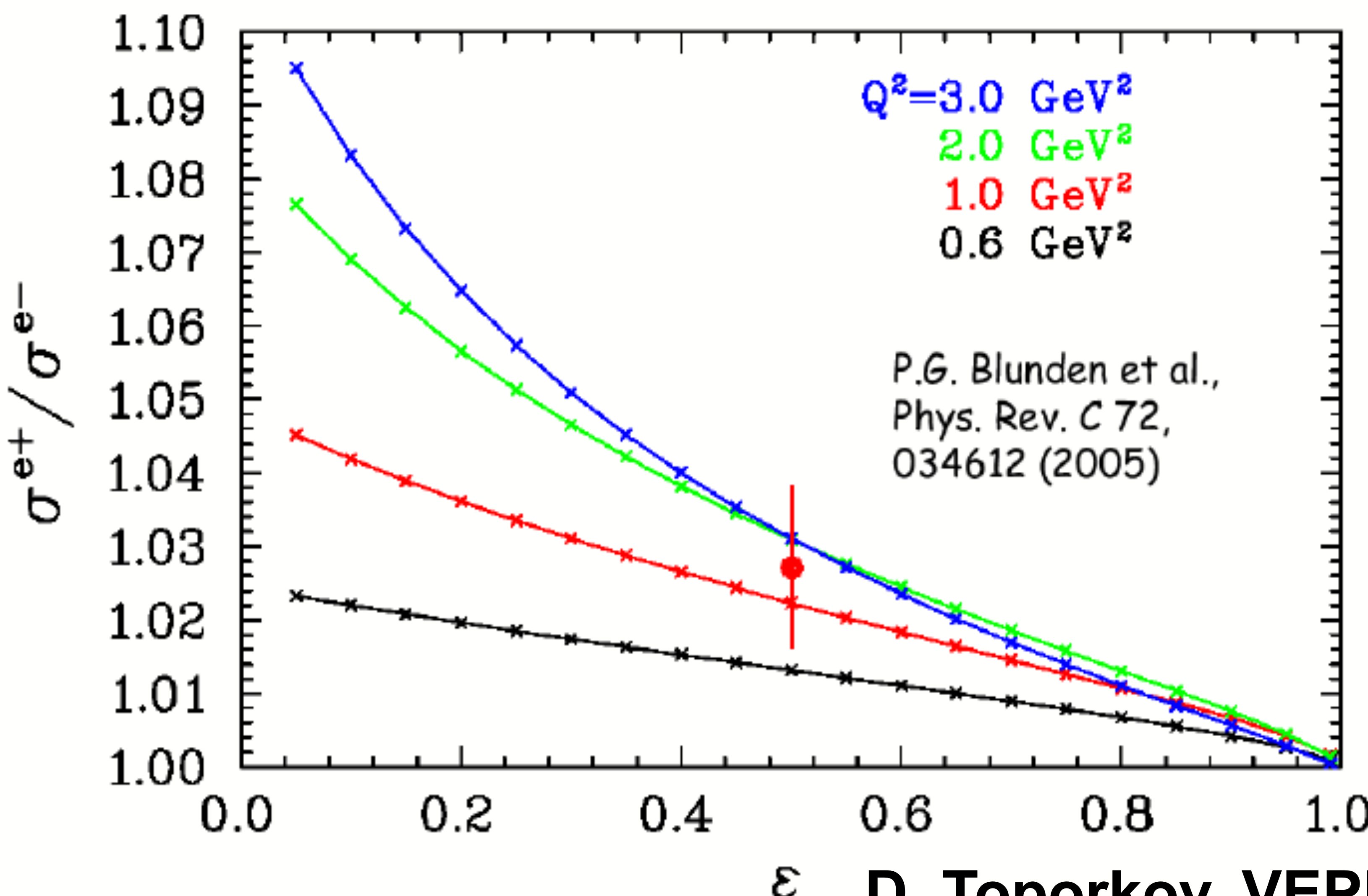
$$\tilde{G}_E \equiv \tilde{G}_M - (1+\tau)\, \tilde{F}_2$$

$$\tilde{G}_E(\nu, Q^2) = G_E(Q^2) + \delta\tilde{G}_E$$

New amplitudes are complex!

(Unofficial) Novosibirsk Information

Preliminary result for $R^{e+/e-}$ in comparison with calculations of P.G. Blunden et al.
ε=0.50 Q^2=1.43 GeV^2



D. Toporkov, VEPP-3

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:

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

Cycle of four states ij
Repeat cycle many times

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