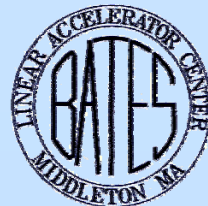
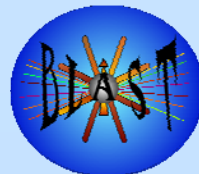


DIS2011, Newport News, April 11-15, 2011

The OLYMPUS Experiment at DESY

Michael Kohl

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

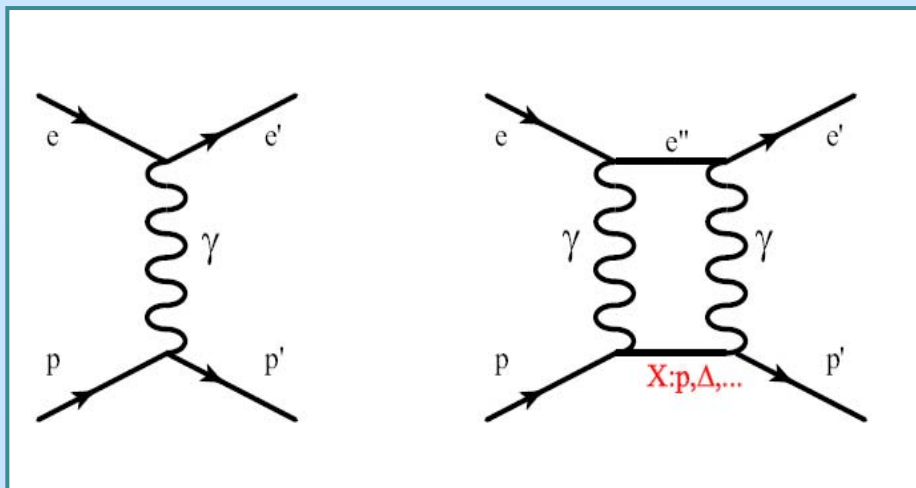


* Supported by NSF grants PHY-0855473 and 0959521, and DOE Early Career Award DE-SC0003884

The OLYMPUS Experiment

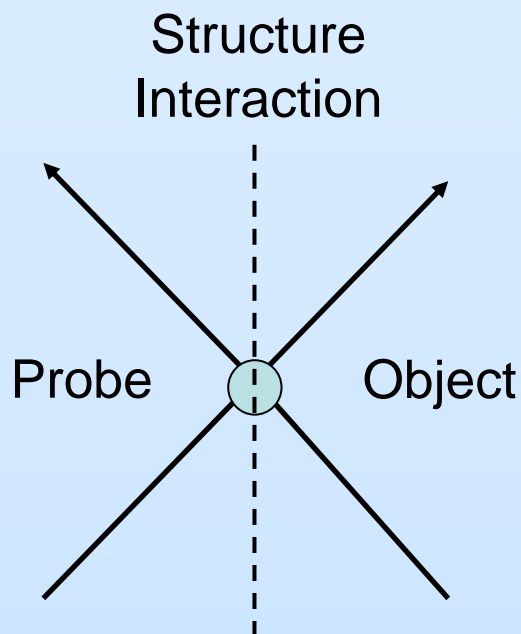
- Review of the physics case – two-photon exchange
- The limit of one-photon exchange:
 - What is $G^p_E(Q^2) \Leftrightarrow$ proton charge distribution?
 - What is the nature of lepton scattering?
- Description of the OLYMPUS experiment
- Status and timeline

OLYMPUS



OLYMPUS @ DESY

Hadronic Structure and EW Interaction

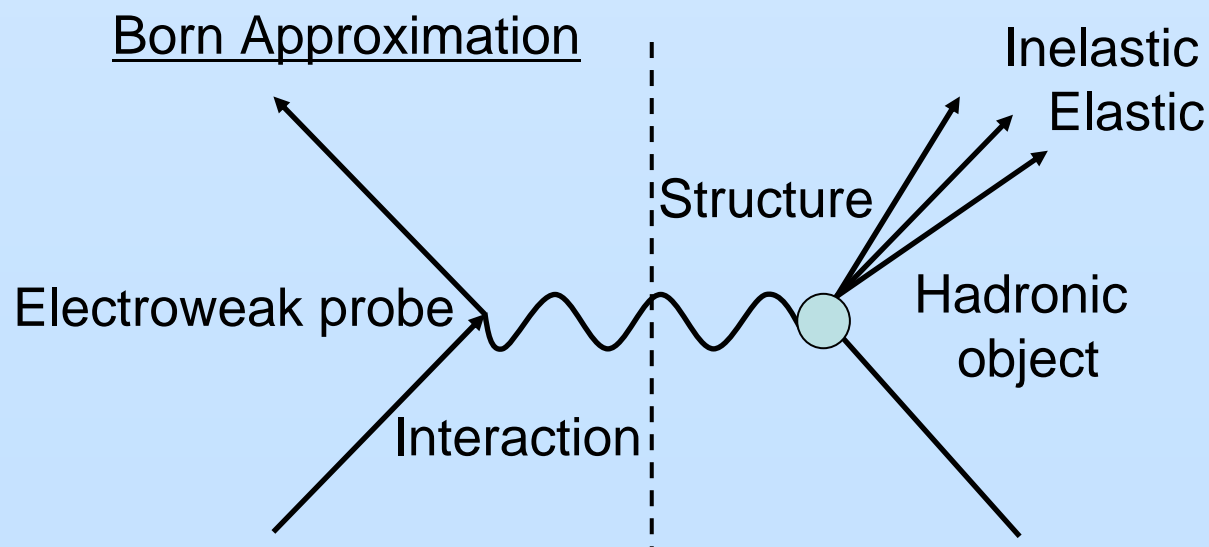
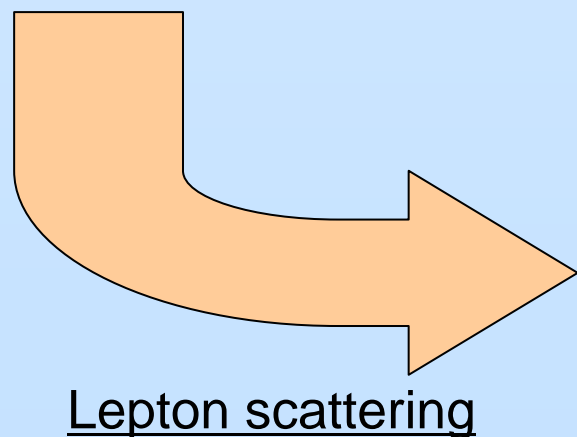


Factorization!

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

→ **Interference!**

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

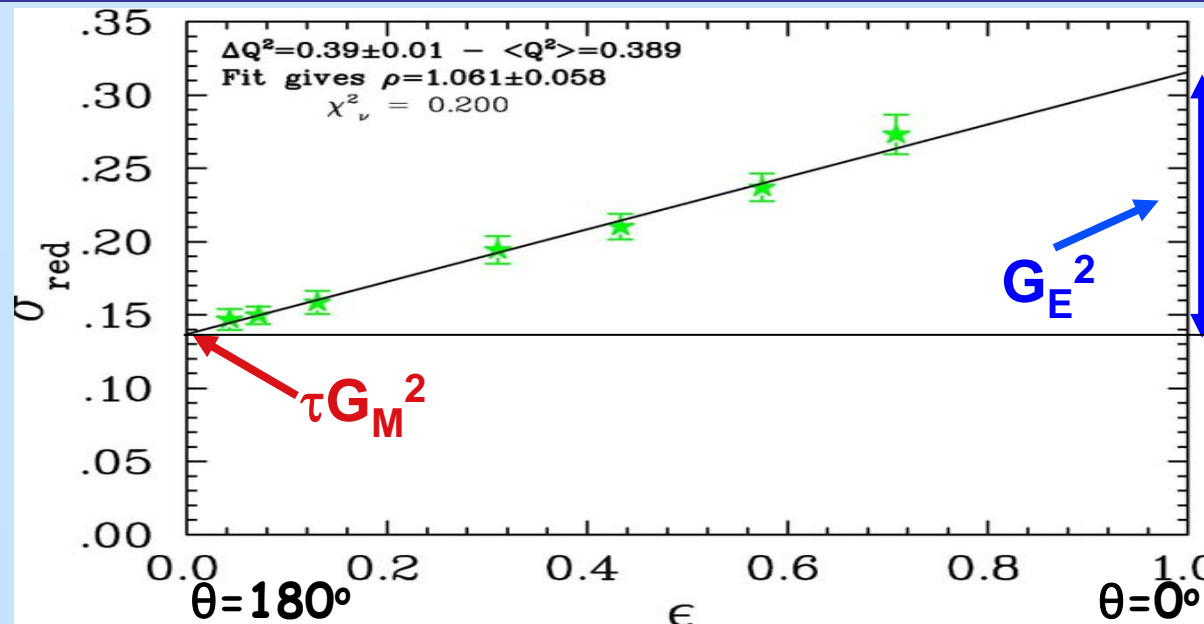


One-Photon Exchange Approximation

Form Factors from Rosenbluth Method

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

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



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

→ Determine

$$\begin{aligned} &|G_E|, |G_M|, \\ &|G_E/G_M| \end{aligned}$$

Nucleon Form Factors and Polarization

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

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

- Polarized cross section

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

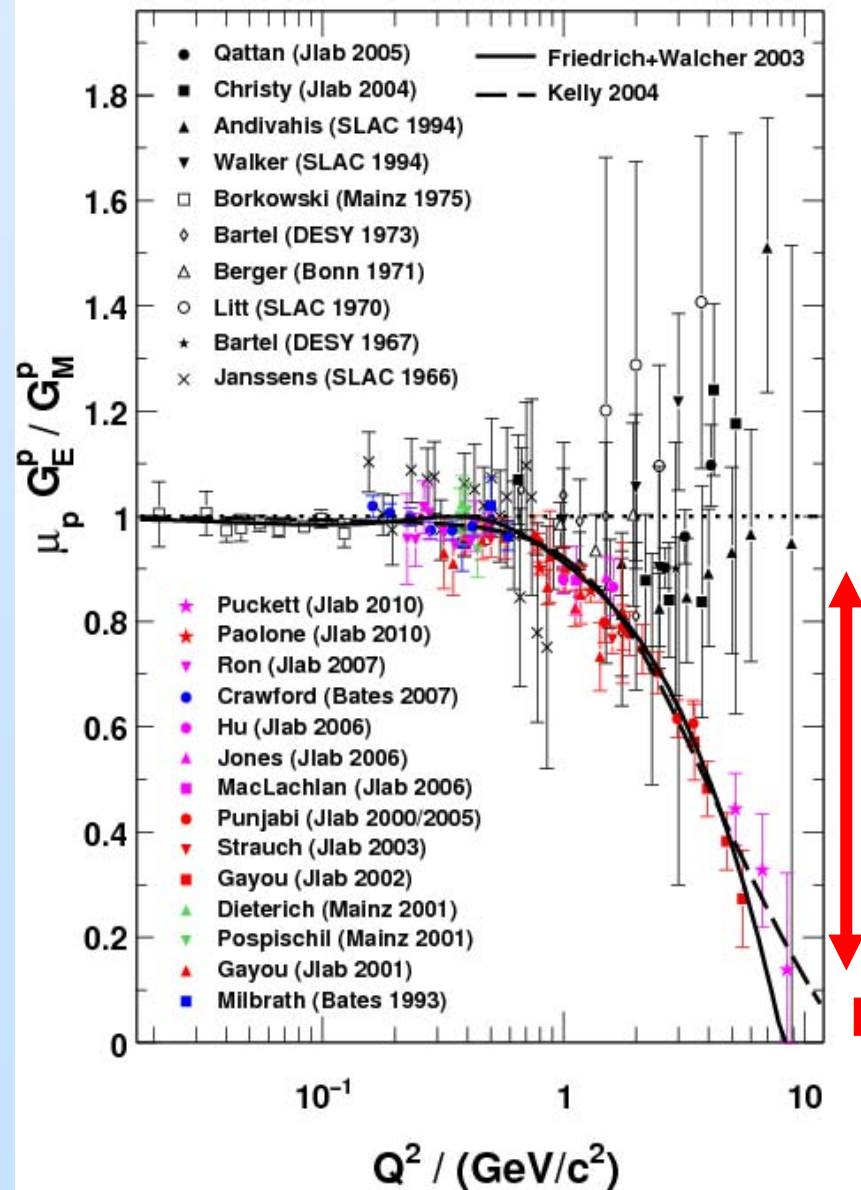
- Double spin asymmetry = spin correlation

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

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

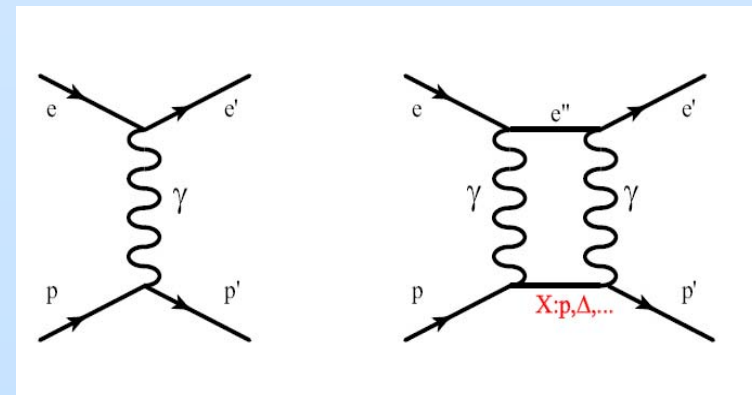
independent of polarization or analyzing power

Proton Form Factor Ratio



Jefferson Lab 2000–

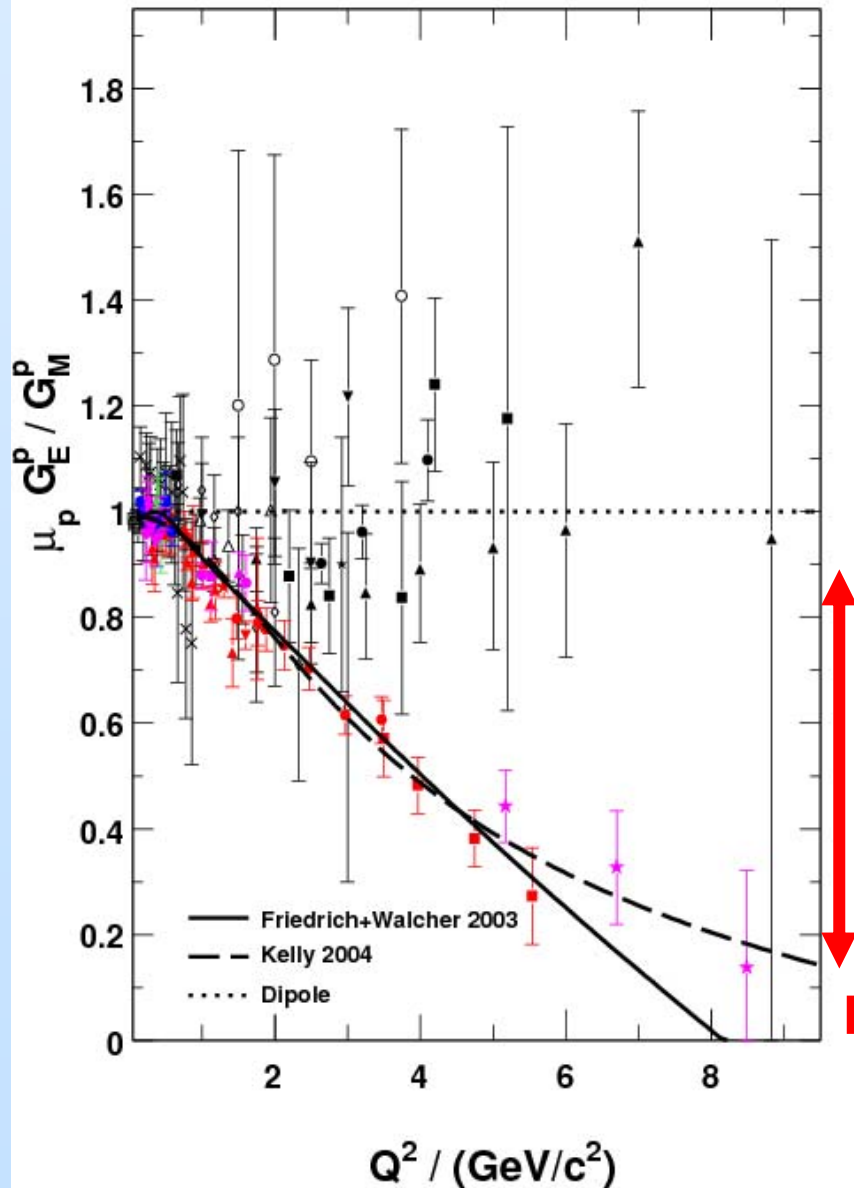
- All Rosenbluth data from SLAC and Jlab in agreement
- Dramatic discrepancy between Rosenbluth and recoil polarization technique
- Multi-photon exchange considered best candidate



Dramatic discrepancy!

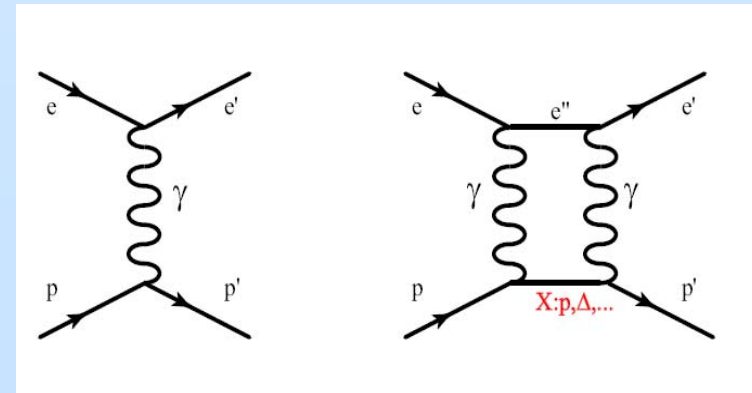
>800 citations

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!

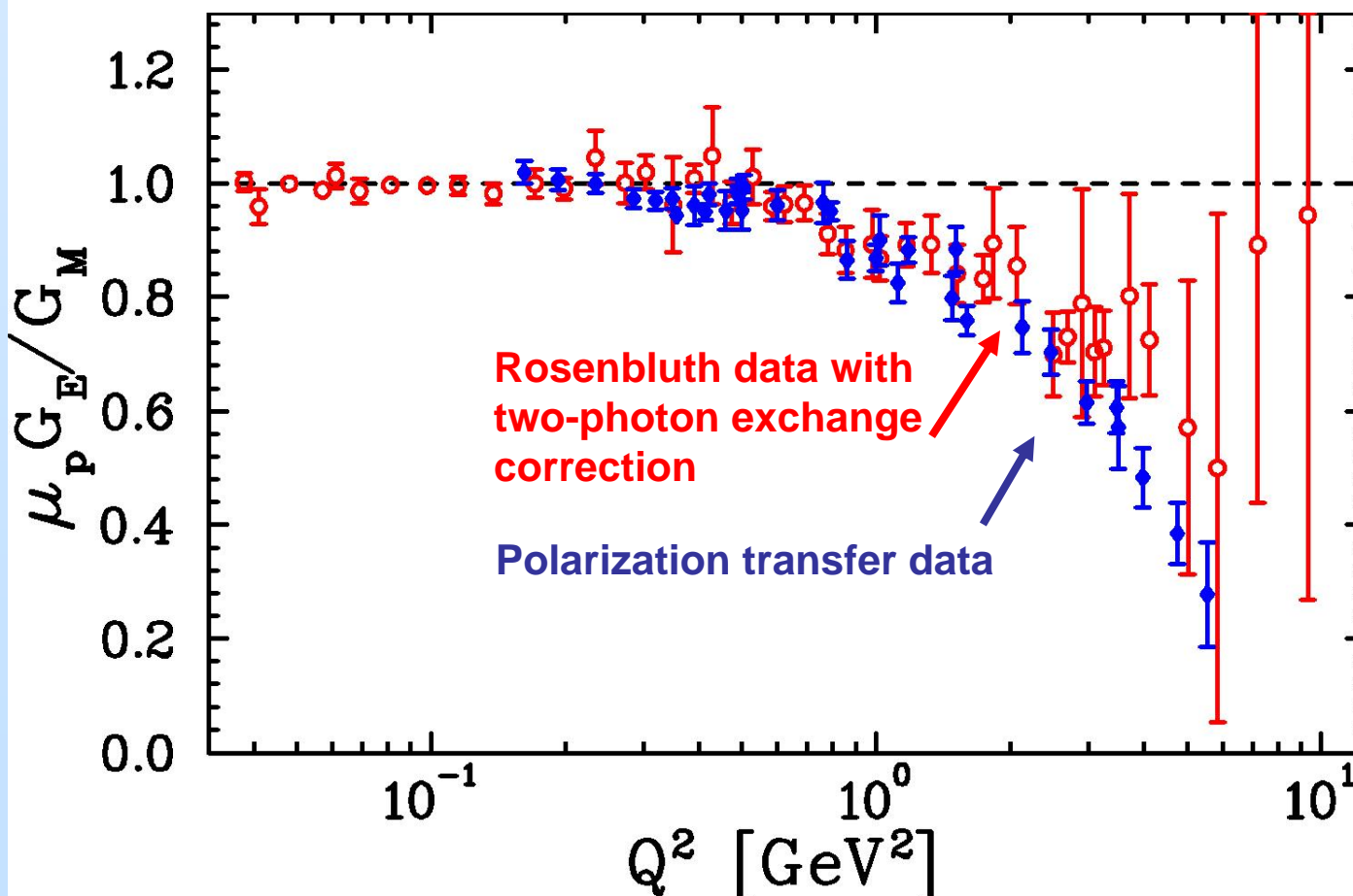
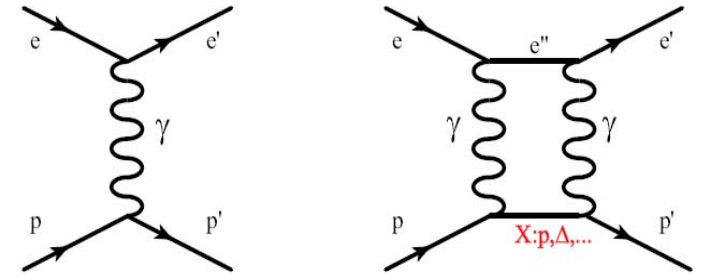
>800 citations

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

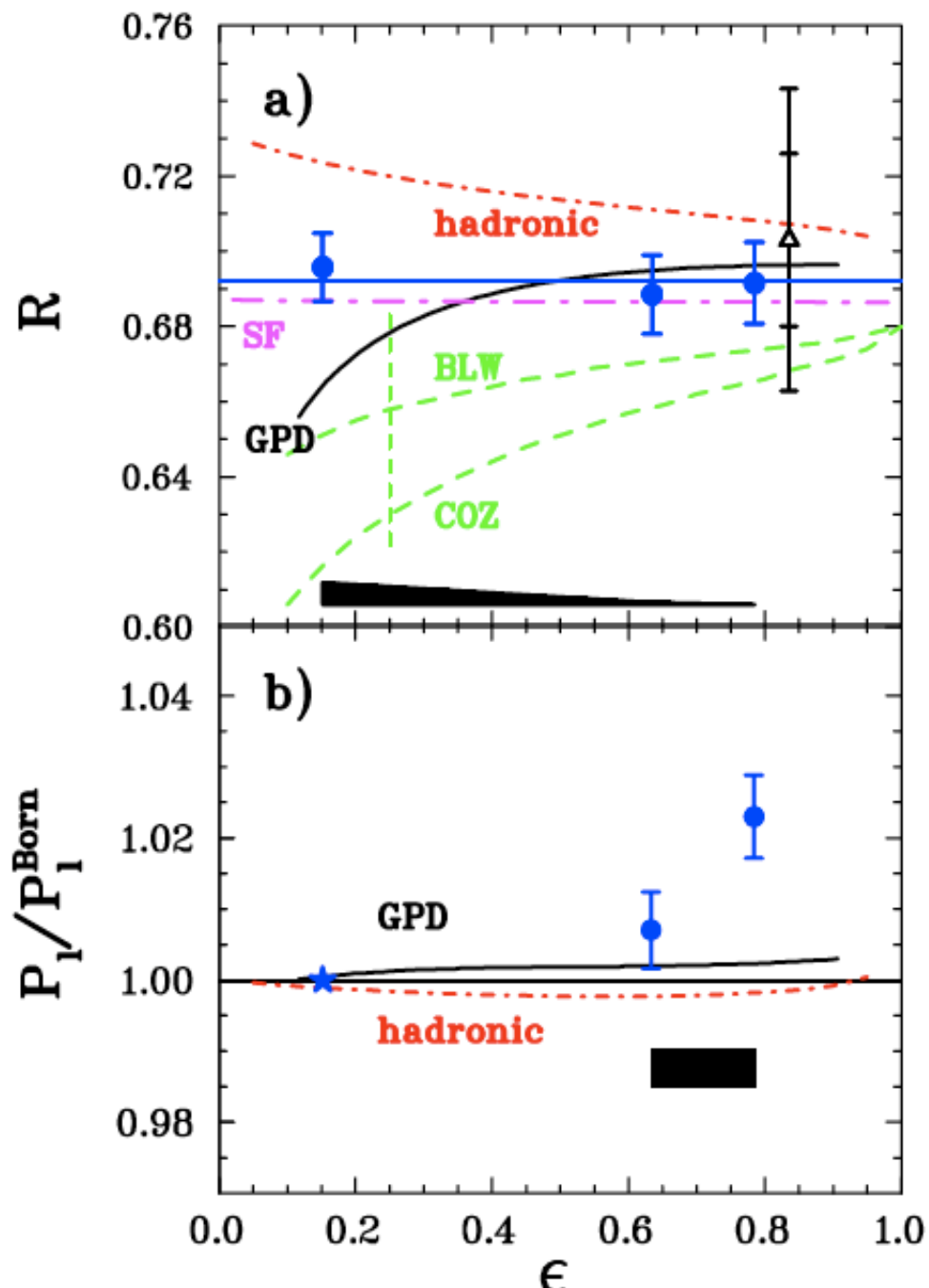
$P_t = -\sqrt{\frac{2\varepsilon(1-\varepsilon)}{\tau}} \frac{G_M^2}{d\sigma_{red}} \left\{ R + \right.$ $P_l = \sqrt{(1+\varepsilon)(1-\varepsilon)} \frac{G_M^2}{d\sigma_{red}} \left\{ 1 + 2 \frac{\Re(\delta\tilde{G}_M)}{G_M} + \frac{2}{1+\varepsilon} \varepsilon Y_{2\gamma} \right\}$ $\frac{P_t}{P_l} = -\sqrt{\frac{2\varepsilon}{(1+\varepsilon)\tau}} \left\{ R - \right.$	$\left. R \frac{\Re(\delta\tilde{G}_M)}{G_M} + \frac{\Re(\delta\tilde{G}_E)}{G_M} + Y_{2\gamma} \right\}$ $\left. 2 \frac{\Re(\delta\tilde{G}_M)}{G_M} + \frac{2}{1+\varepsilon} \varepsilon Y_{2\gamma} \right\}$ $\left. R \frac{\Re(\delta\tilde{G}_M)}{G_M} + \frac{\Re(\delta\tilde{G}_E)}{G_M} + 2 \left(1 - R \frac{2\varepsilon}{1+\varepsilon} \right) Y_{2\gamma} \right\}$	<p>E04-019 (Two-gamma)</p>
$d\sigma_{red} / G_M^2 = 1 + \frac{\varepsilon R^2}{\tau} + 2 \frac{\Re(\delta\tilde{G}_M)}{G_M} + 2R \frac{\varepsilon \Re(\delta\tilde{G}_E)}{\tau G_M} + 2 \left(1 + \frac{R}{\tau} \right) \varepsilon Y_{2\gamma}$ $\Re(\tilde{G}_E) = G_E(Q^2) + \Re(\delta\tilde{G}_E(Q^2, \varepsilon))$ $\Re(\tilde{G}_M) = G_M(Q^2) + \Re(\delta\tilde{G}_M(Q^2, \varepsilon))$ $R = G_E / G_M \quad Y_{2\gamma} = 0 + \sqrt{\frac{\tau(1+\tau)(1+\varepsilon)}{1-\varepsilon}} \frac{\Re(\tilde{F}_3(Q^2, \varepsilon))}{G_M}$ <p>Born Approximation</p>	$\left. 2 \frac{\Re(\delta\tilde{G}_M)}{G_M} + 2R \frac{\varepsilon \Re(\delta\tilde{G}_E)}{\tau G_M} + 2 \left(1 + \frac{R}{\tau} \right) \varepsilon Y_{2\gamma} \right\}$ $\left. \Re(\delta\tilde{G}_E(Q^2, \varepsilon)) \right\}$ $\left. \Re(\delta\tilde{G}_M(Q^2, \varepsilon)) \right\}$ $\left. \frac{\Re(\tilde{F}_3(Q^2, \varepsilon))}{G_M} \right\}$ <p>Beyond Born Approximation</p>	<p>e⁺/e⁻ x-section ratio CLAS, VEPP3, OLYMPUS</p> <p>Rosenbluth non-linearity E05-017</p>

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
 $Q^2 = 2.5 \text{ (GeV/c)}^2$

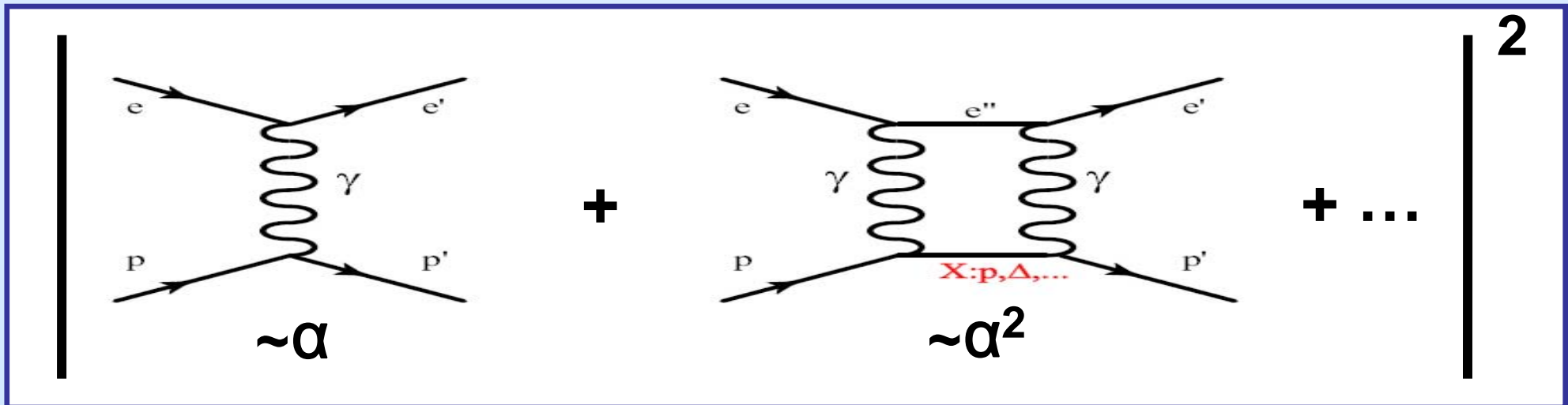
G_E/G_M from P_t/P_l constant vs. ϵ

- 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



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

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

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

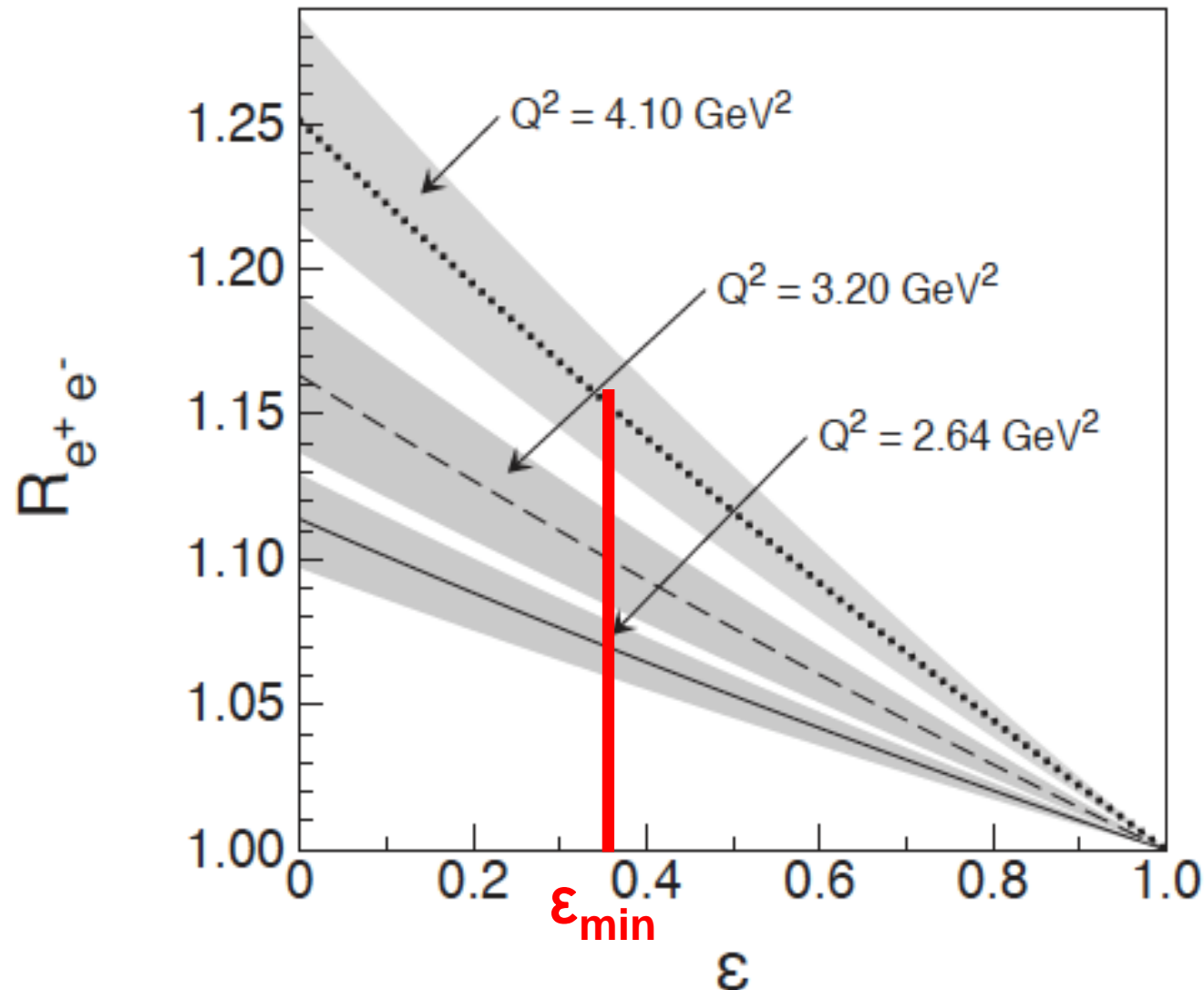
$$\sigma(\text{positron-proton}) = (1\gamma)^2\alpha^2 + (1\gamma)(2\gamma)\alpha^3 + ..$$

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

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

Empirical Extraction of TPE Amplitudes

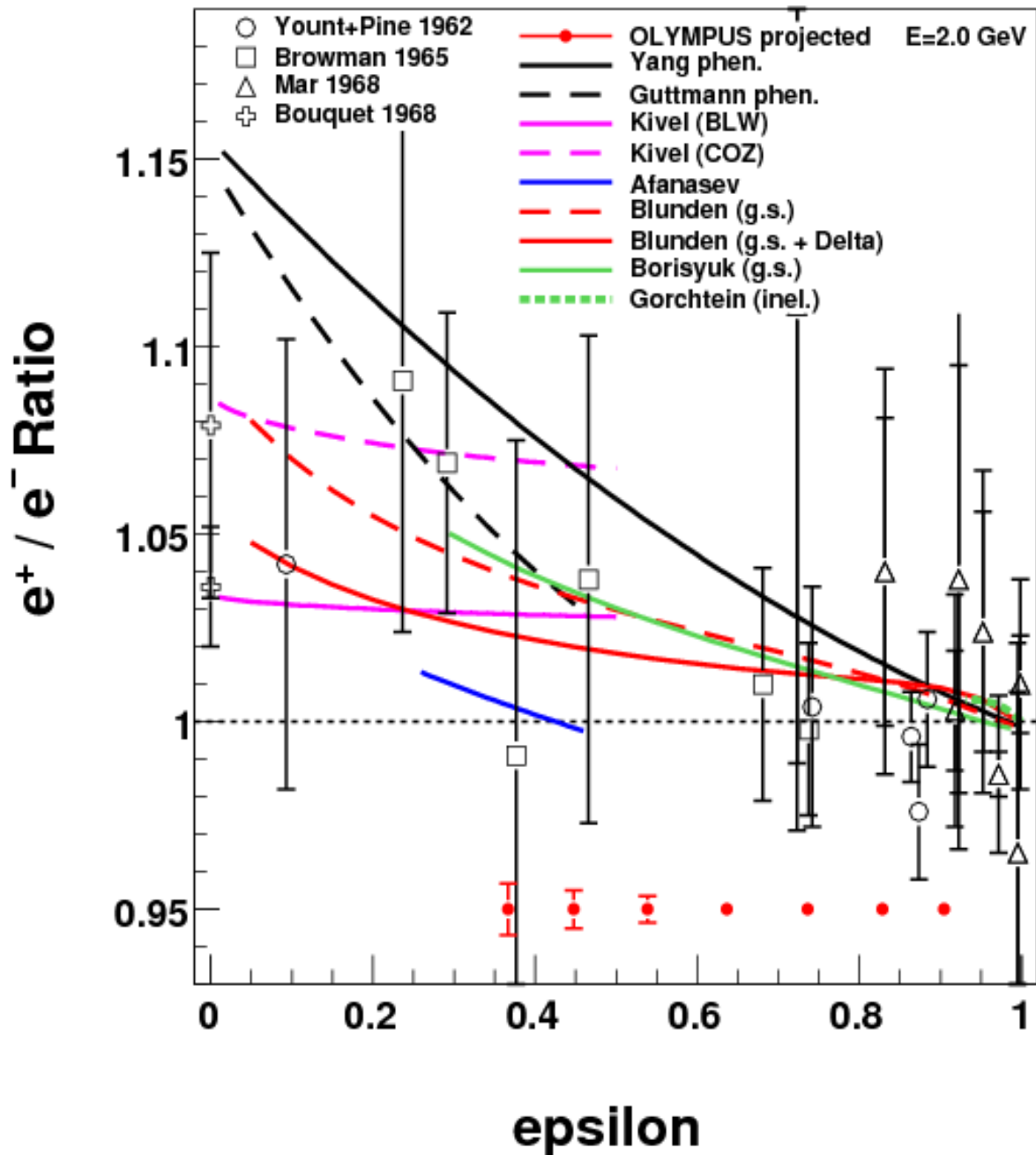
J. Guttman, N. Kivel, M. Meziane, and M. Vanderhaeghen, hep-ph/1012.0564v1



**~6% effect for
OLYMPUS@2.0GeV**

grows with Q^2 !

Projected Results for OLYMPUS



OLYMPUS

Data from 1960's

Many theoretical predictions
with little constraint

OLYMPUS:

$E = 2$ GeV, $\epsilon = 0.37-0.9$

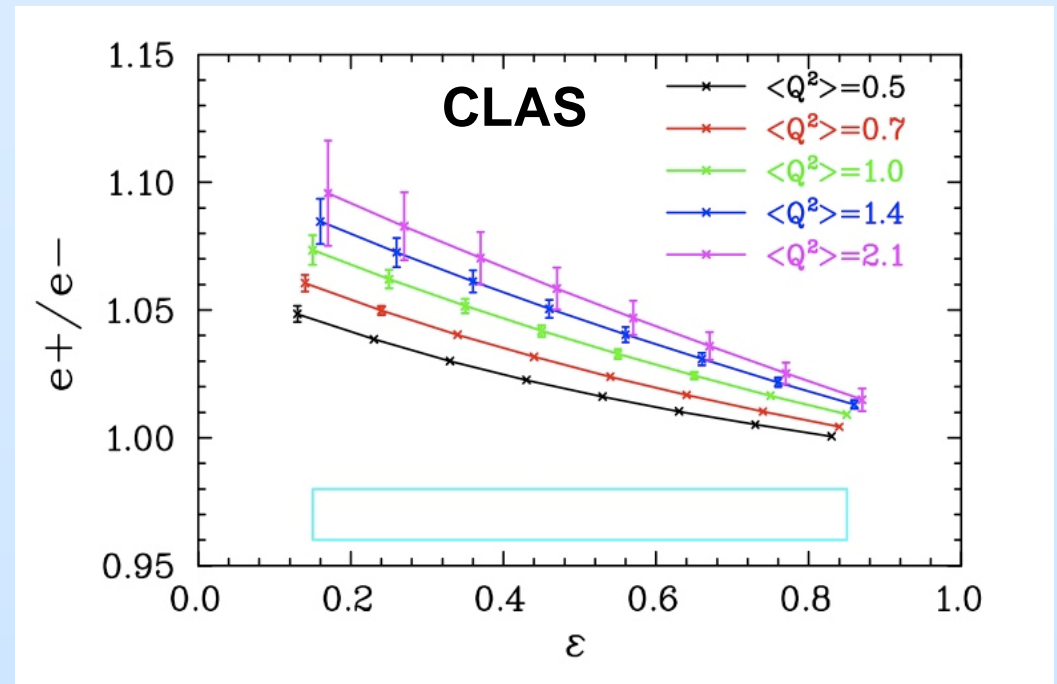
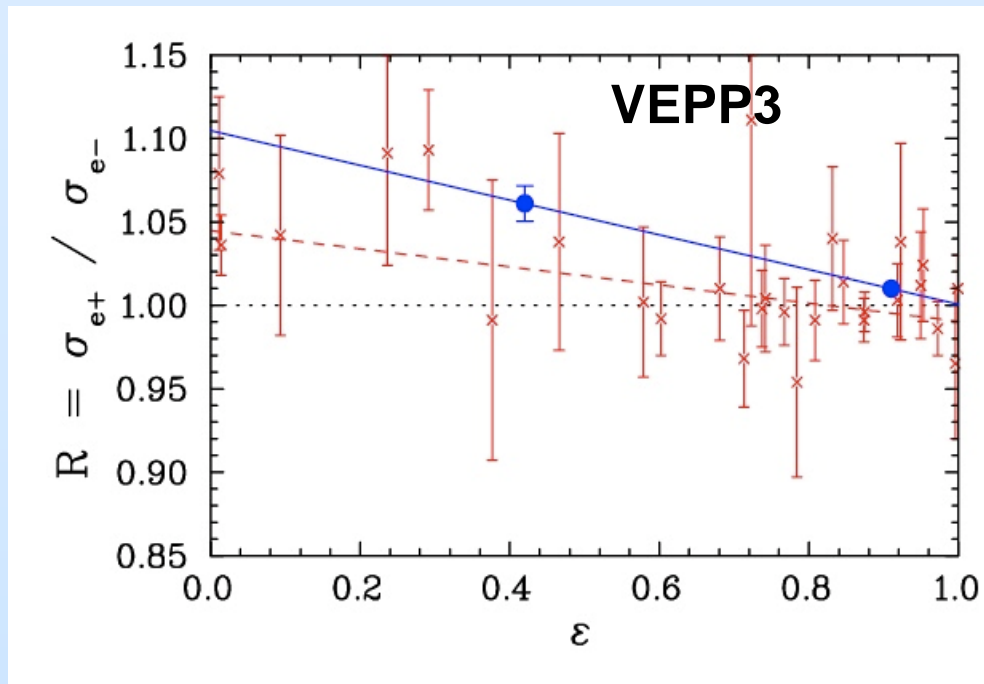
$Q^2 = 0.6-2.2$ (GeV/c)²

<1% projected uncertainties

500h @ 2×10^{33} / cm²s e+,e-

to be run in 2012

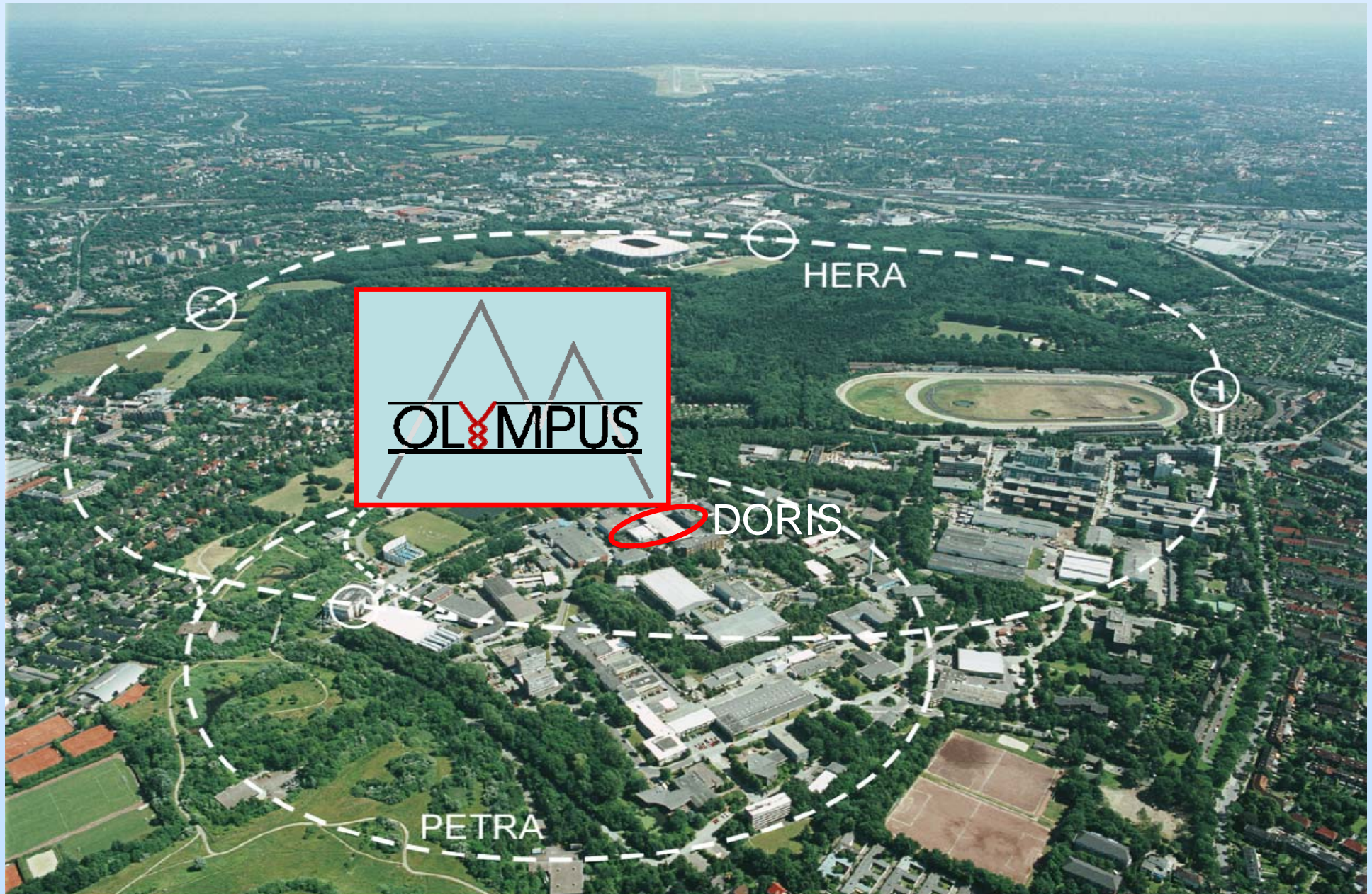
Other Experiments to Verify TPE



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

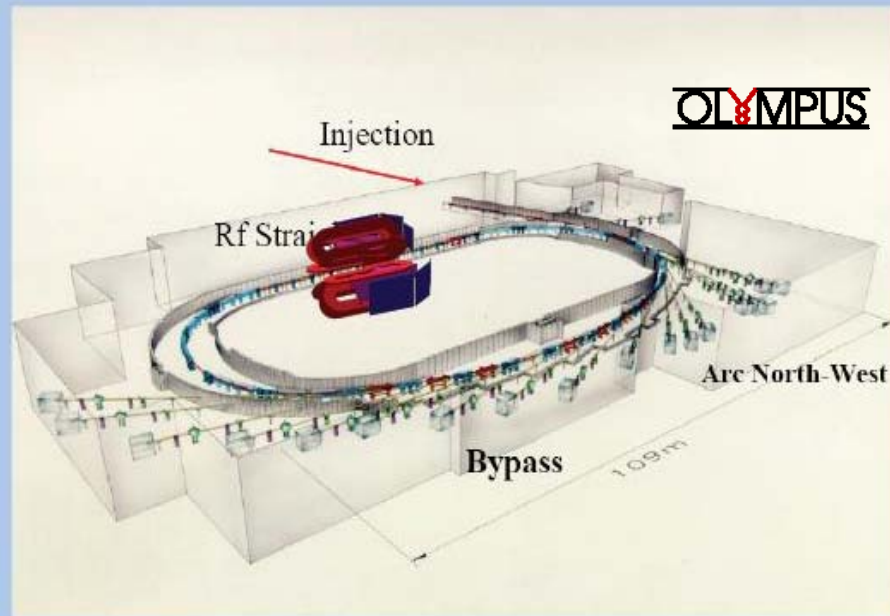
OLYMPUS @ DESY



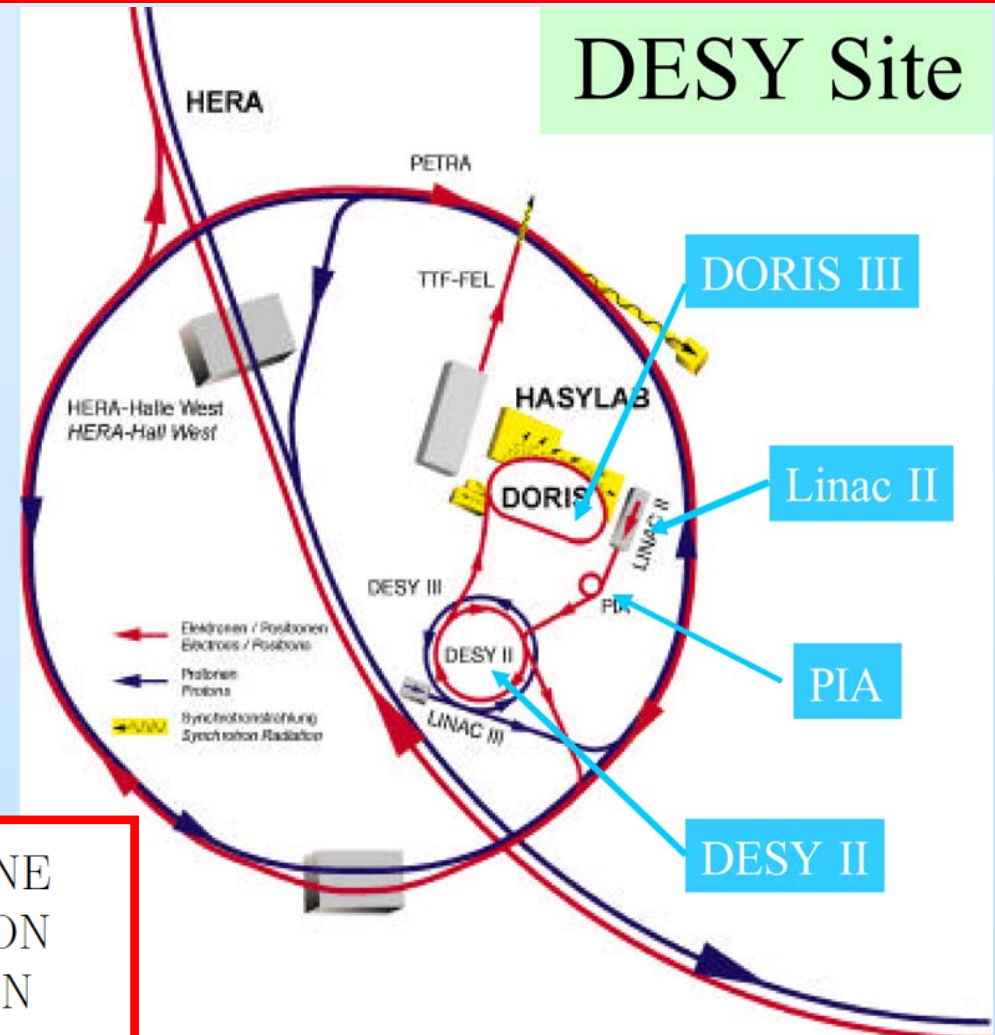
OLYMPUS @ DESY



DORIS



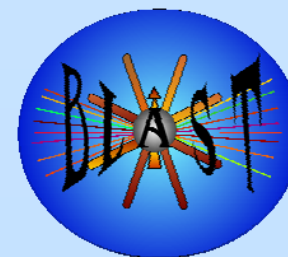
DESY Site



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

THE OLYMPUS COLLABORATION

September 9, 2008



OLYMPUS

OLYMPUS @ DESY

pOsitron-proton and
eLectron-proton elastic scattering to test the
hYpothesis of

Multi-

Photon exchange

Using

DoriS

OLYMPUS

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)
 3×10^{15} at/cm² @ 100 mA \rightarrow $L = 2 \times 10^{33}$ / (cm²s)
 - 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 Q²
Symmetric Moller/Bhabha scattering
- **Measure ratio of positron-proton to electron-proton unpolarized elastic scattering to 1% stat.+sys.**

Collaboration Organization

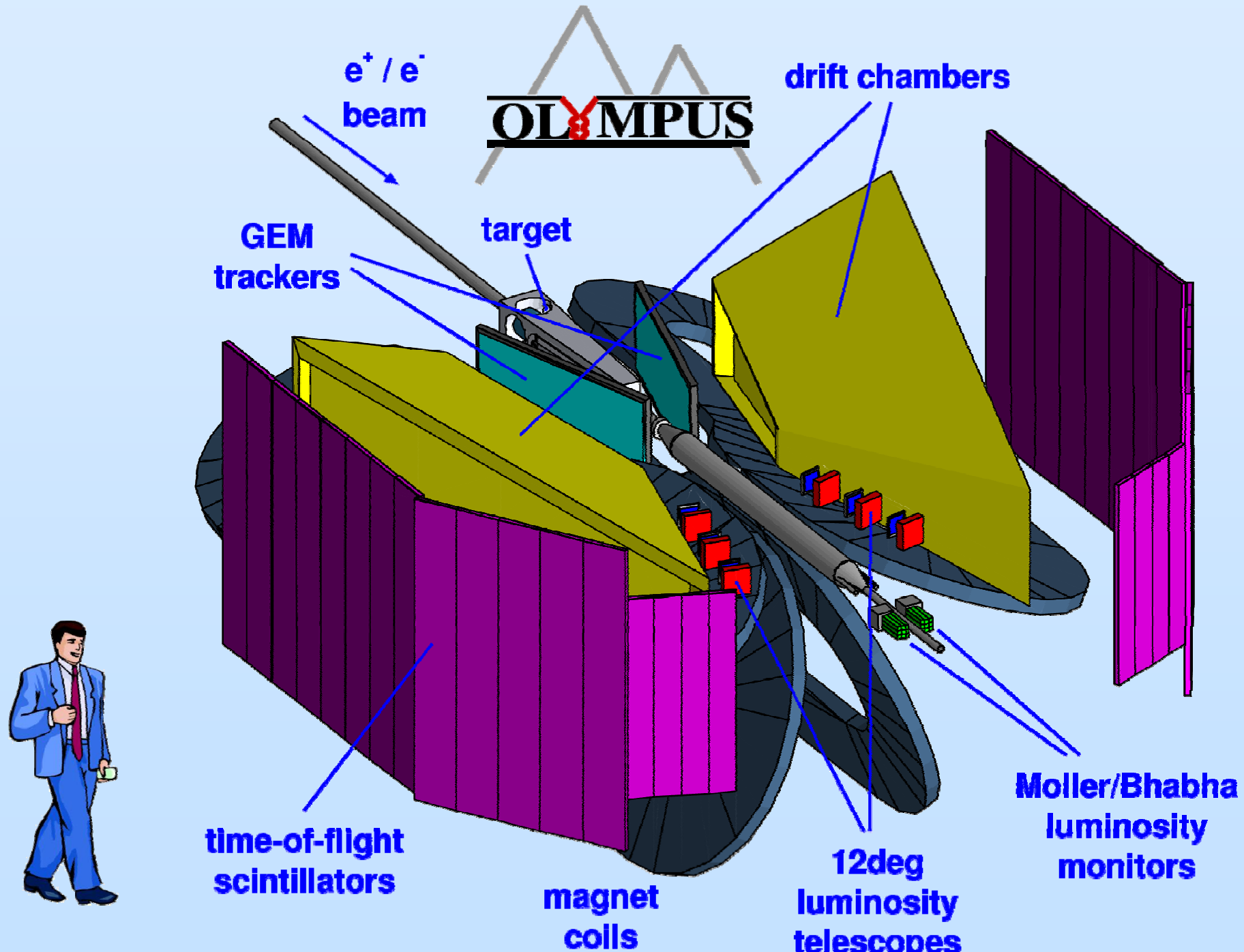
- Nov 2006 – Idea first formulated (D. Hasell, M.K., R. Milner)
- Jun 2007 – Letter of Intent
- Sept 2008 – Full Proposal
- Technical review Sept 2009, funded and officially approved since Jan 2010
- Several collaboration meetings since technical review
 - Nov 30–Dec 1, 2009 Feb 23–24, 2010 Apr 26–27, 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)



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
 - ◆ Constructed 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



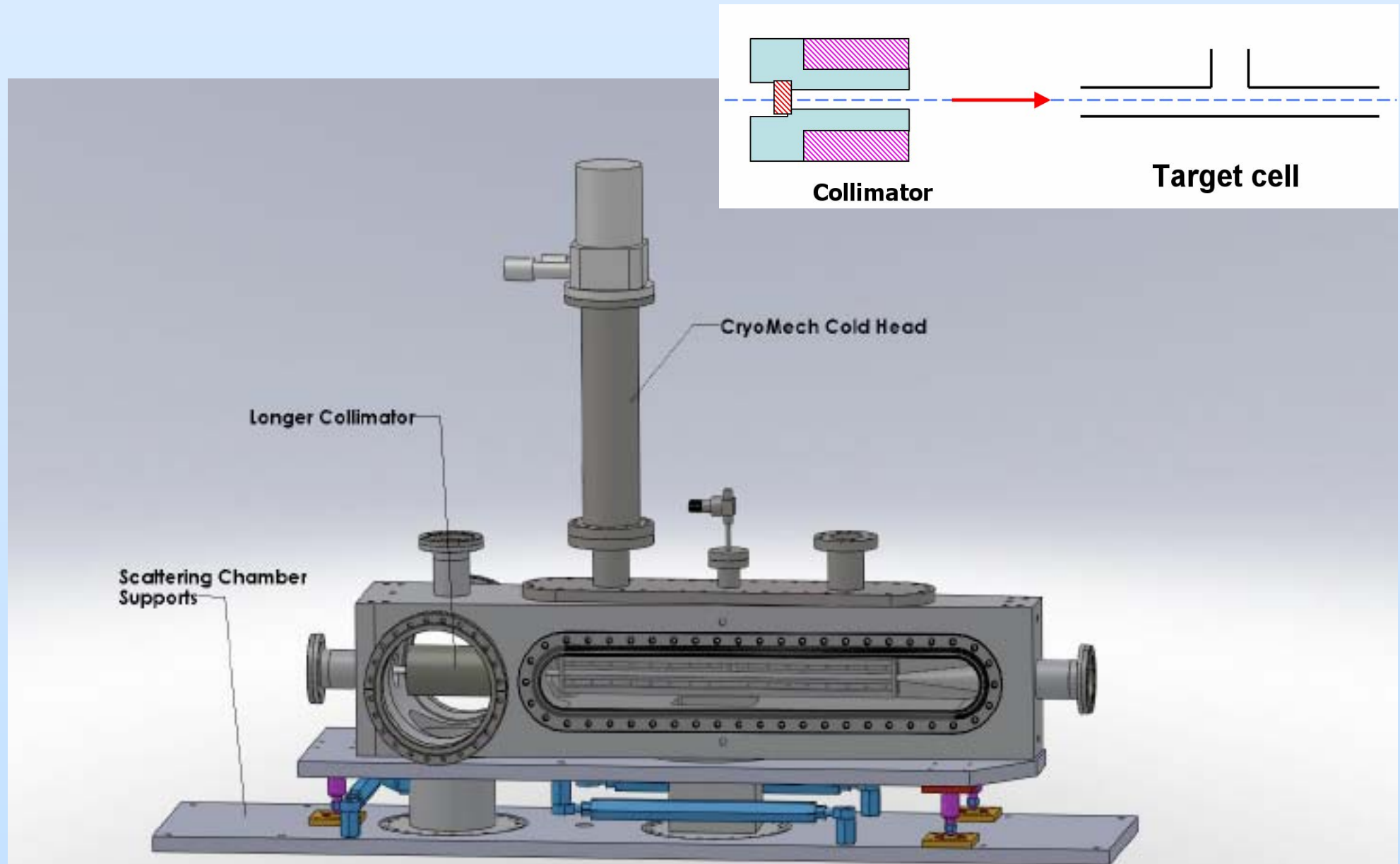
August 2010

OLYMPUS: BLAST@DESY/DORIS



September 2010

Target and Vacuum System



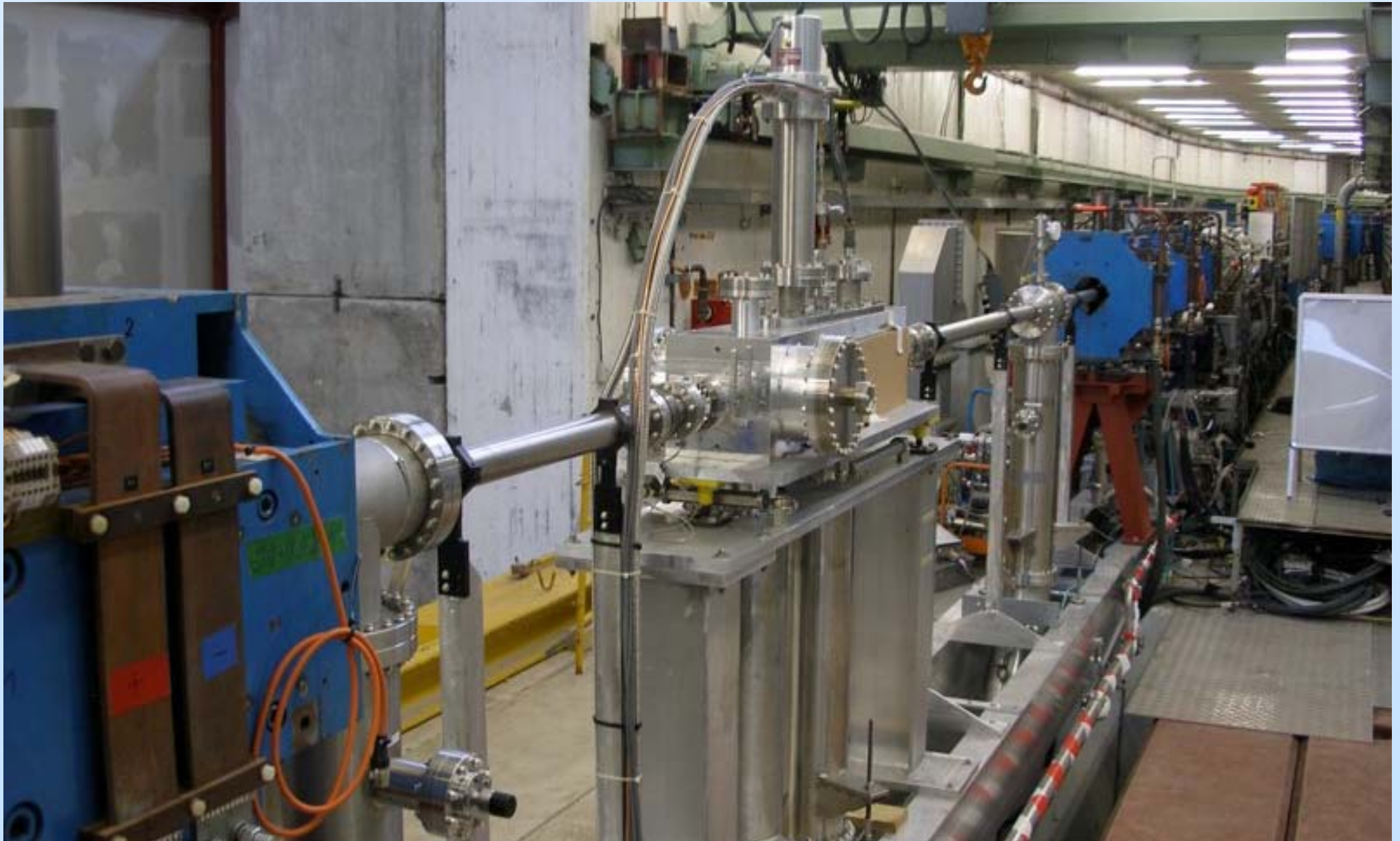
Designed until summer 2010

Target and Vacuum System



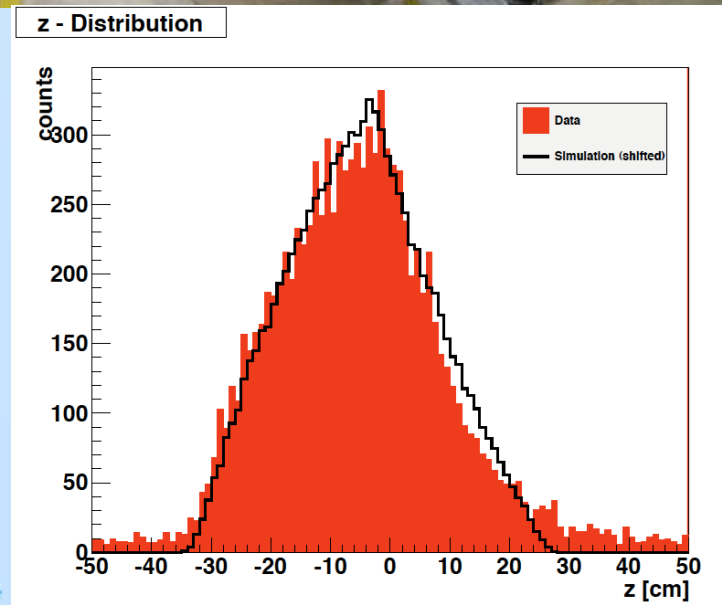
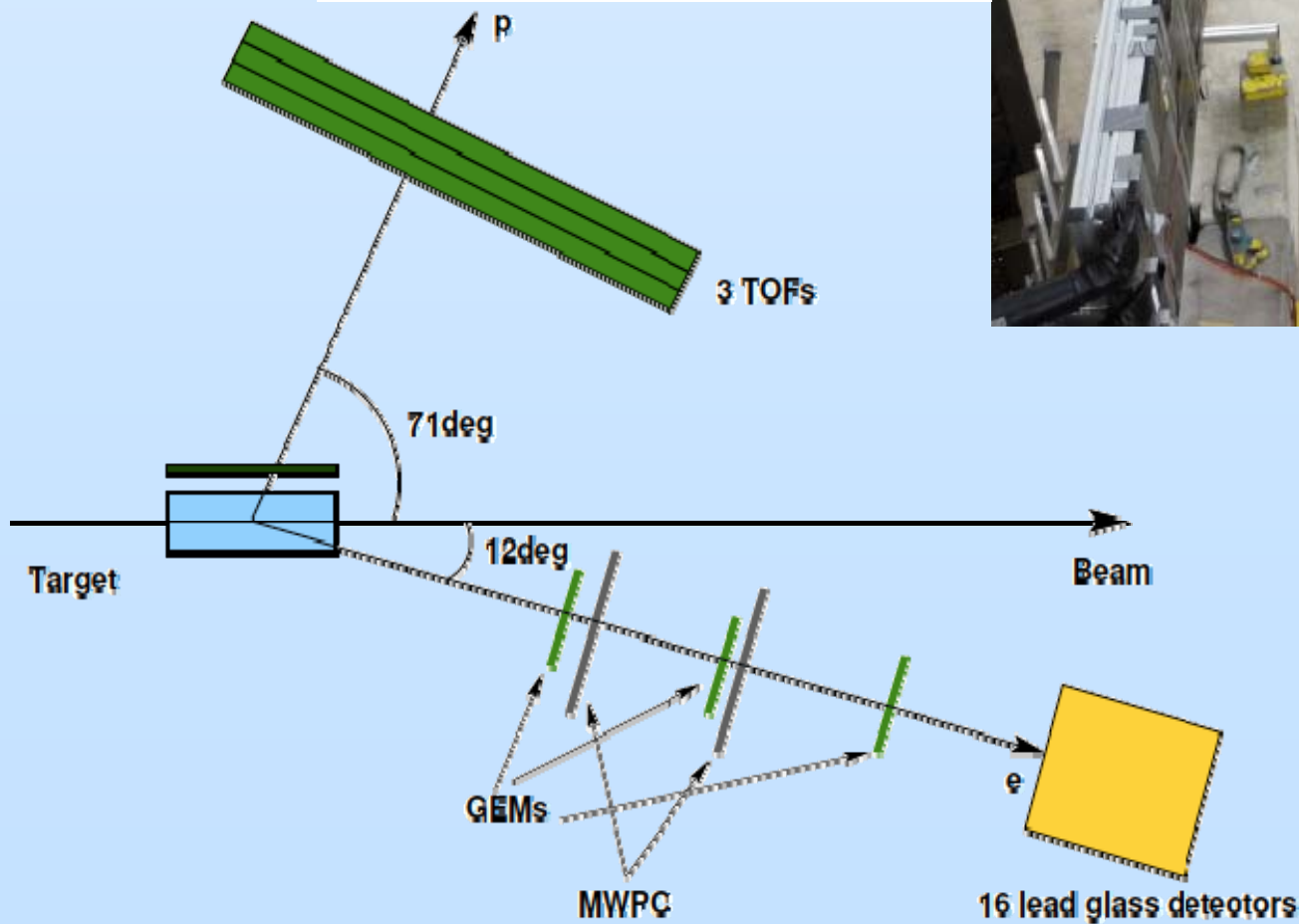
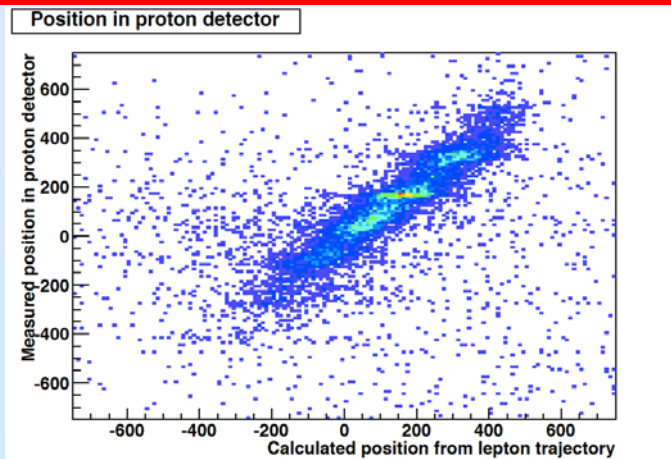
Target chamber machined by October 2010

Target and Vacuum System



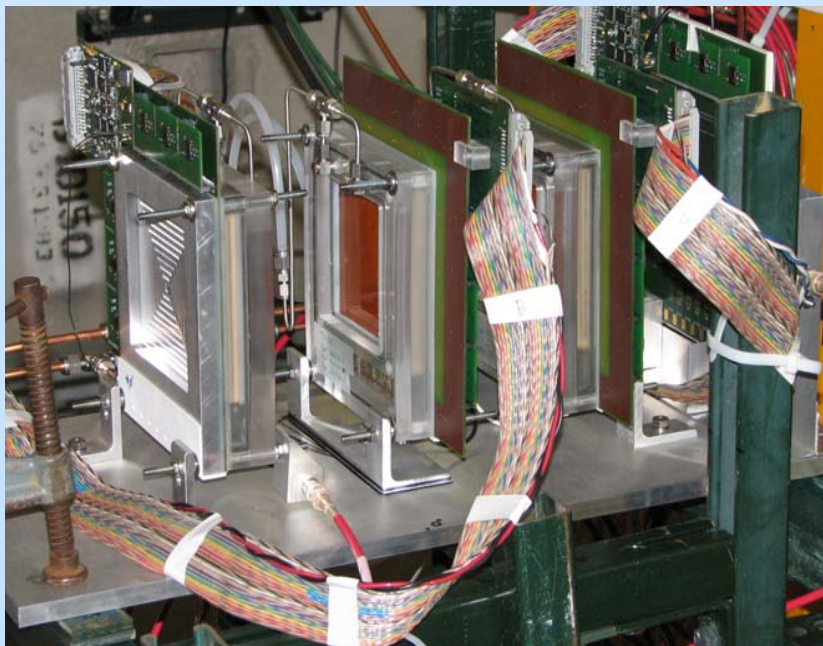
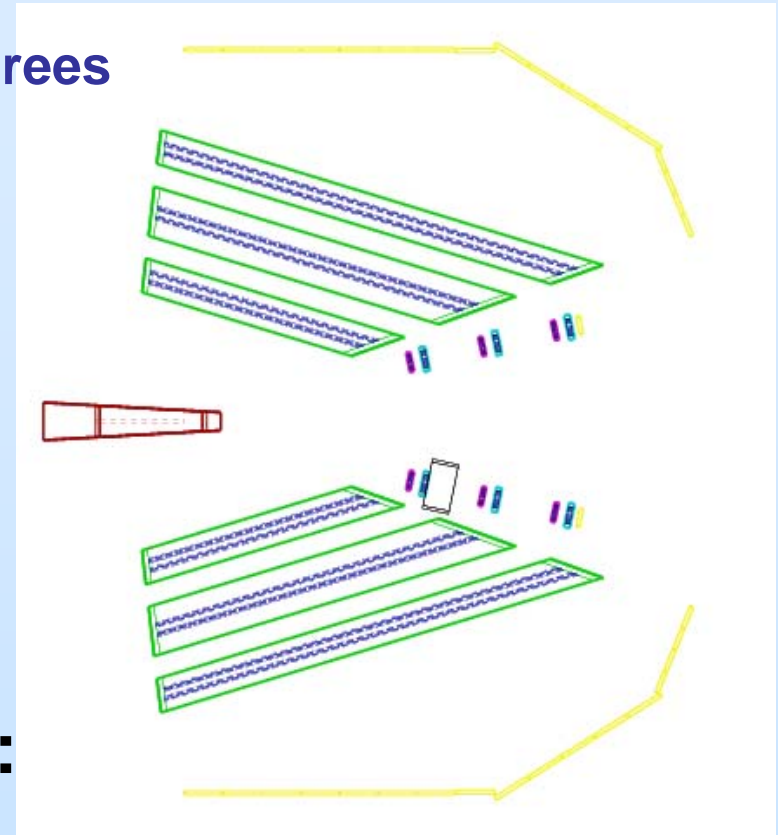
Installed in DORIS in January 2011

DORIS Test Experiment in Feb 2011



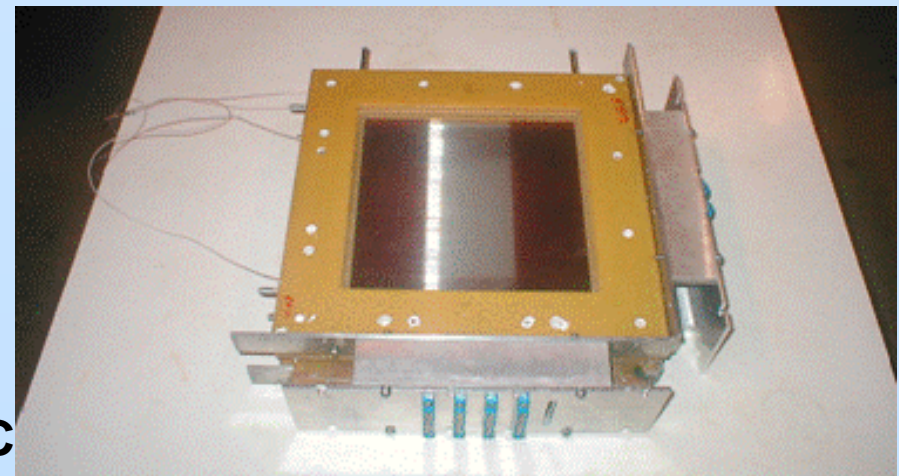
Luminosity Monitors: GEM + MWPC

- 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

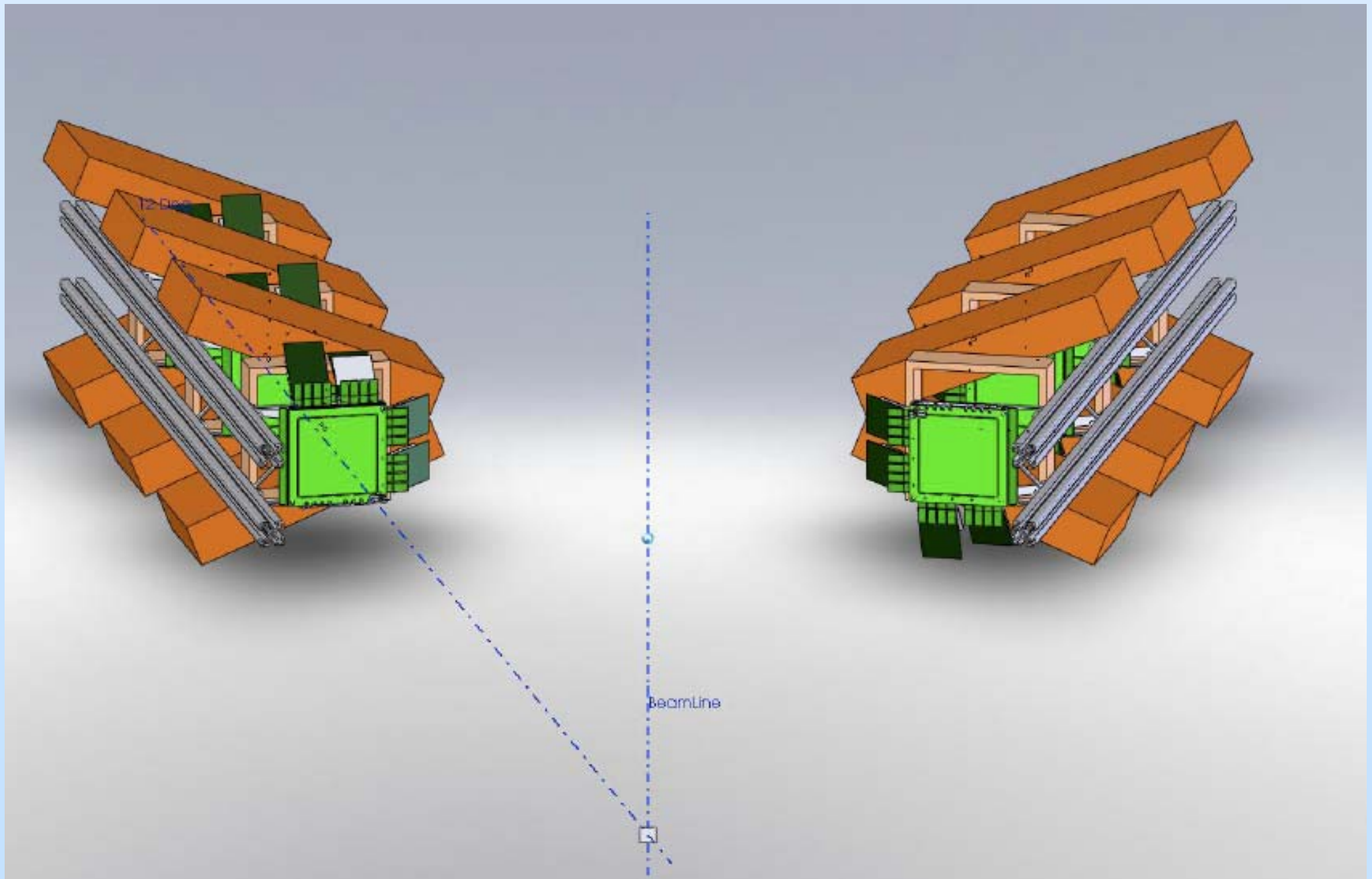
Proposed version included in OLYMPUS TDR Sept. 2009

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 $\theta_e = 12^\circ$. 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 cm² at ~290 cm distance (rearmost plane)
- Three GEM layers with ~0.1 mm resolution with ~50 cm gaps

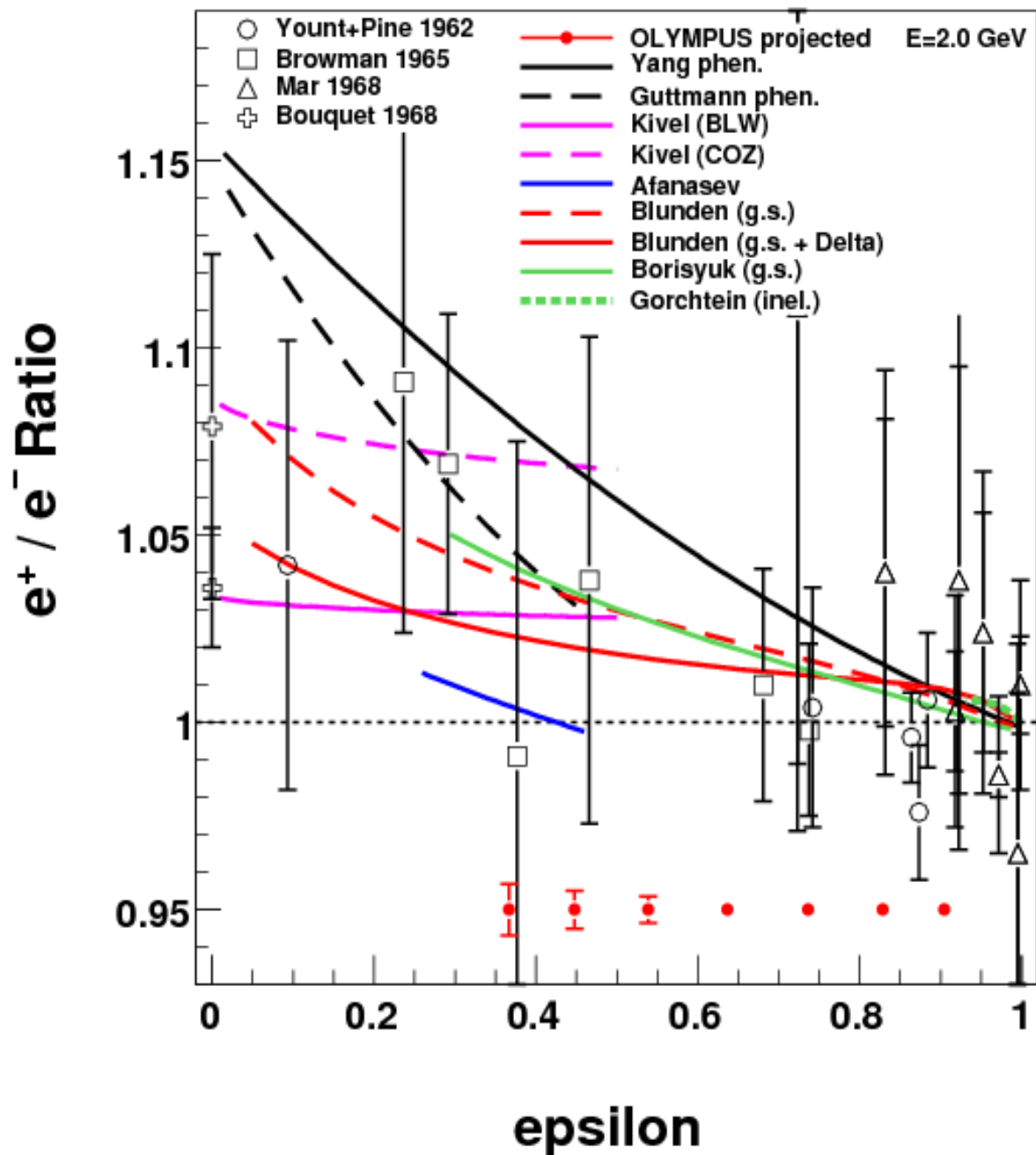
Luminosity Monitors: GEM + MWPC



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
- The logo for the OLYMPUS experiment, featuring the word "OLYMPUS" in a stylized font with a red lightning bolt symbol integrated into the letter "Y".
- Take data in two running blocks beginning and end 2012

Projected Results for OLYMPUS



OLYMPUS

Data from 1960's

Many theoretical predictions
with little constraint

OLYMPUS:

$E = 2$ GeV, $\epsilon = 0.37-0.9$

$Q^2 = 0.6-2.2$ (GeV/c)²

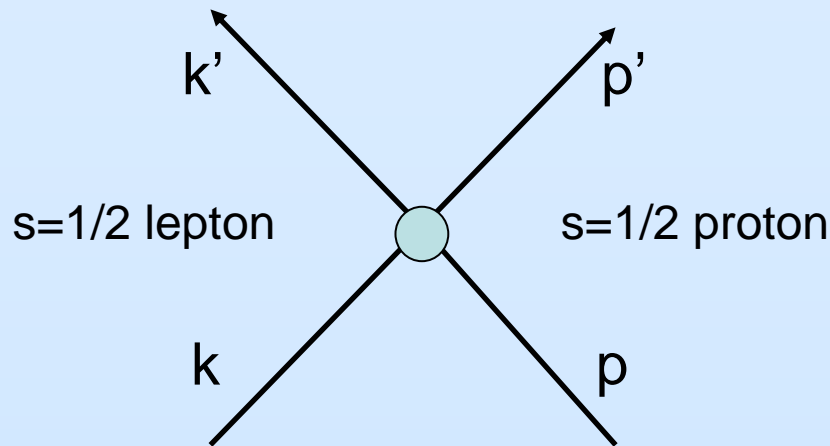
<1% projected uncertainties

500h @ 2×10^{33} / cm²s e^+, e^-

to be run in 2012

Backup slides – OLYMPUS

Elastic ep Scattering Beyond OPE



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

Kinematical invariants :

$$Q^2 = -(p - p')^2$$

$$\nu = K \cdot P = (s - u)/4$$

Next-to Born approximation:

$$T_{h' \lambda'_N, h \lambda_N}^{non-flip} = \frac{e^2}{Q^2} \bar{u}(k', h') \gamma_\mu u(k, h)$$

$$(m_e = 0) \quad \times \quad \bar{u}(p', \lambda'_N) \left(\tilde{G}_M \gamma^\mu - \tilde{F}_2 \frac{P^\mu}{M} + \tilde{F}_3 \frac{\gamma \cdot K P^\mu}{M^2} \right) u(p, \lambda_N)$$

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 $\sim \alpha^3$

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

$$\tilde{F}_2(\nu, Q^2) = F_2(Q^2) + \delta \tilde{F}_2$$

$$\tilde{F}_3(\nu, Q^2) = 0 + \delta \tilde{F}_3$$

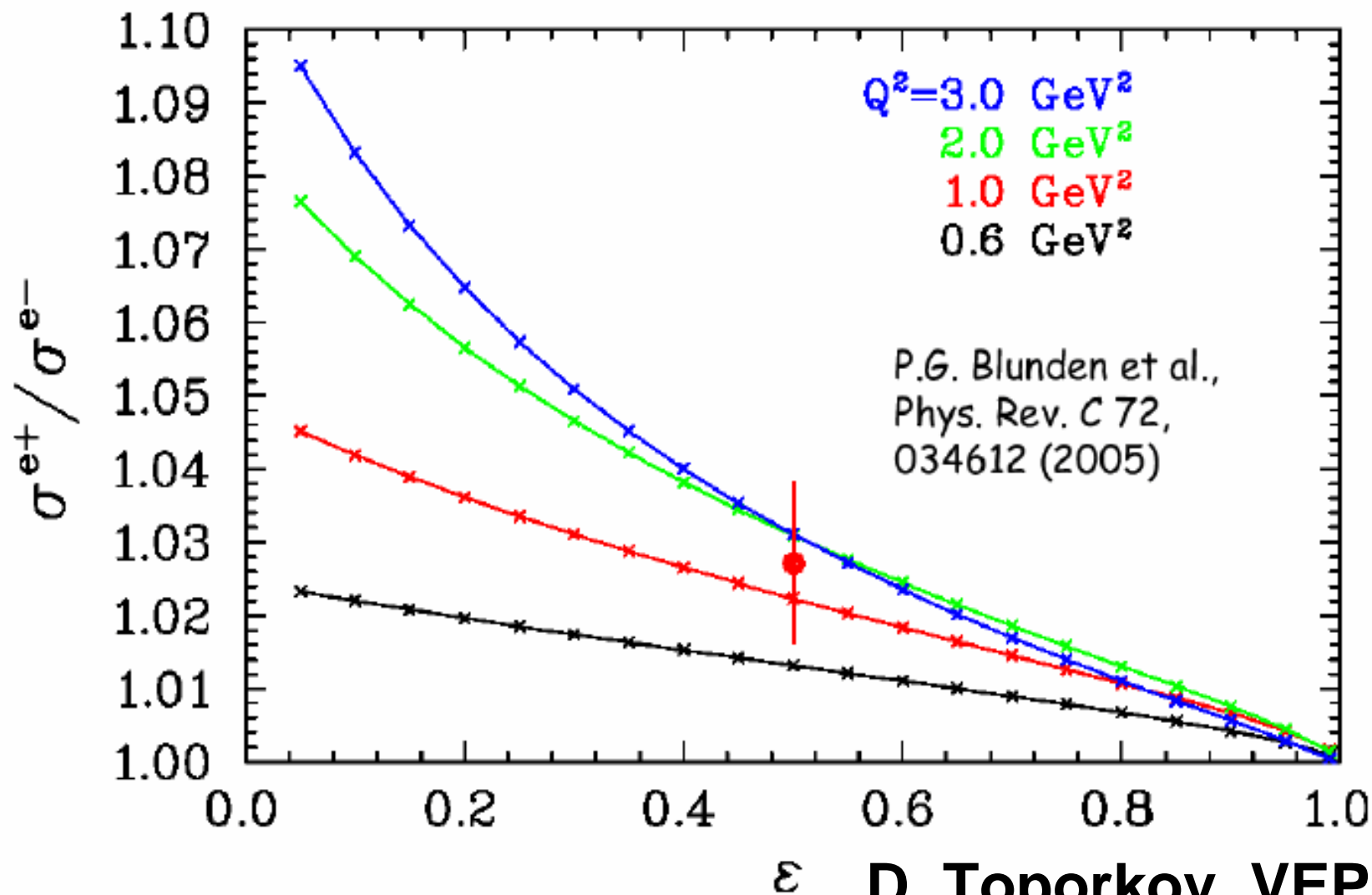
$$\tilde{G}_E \equiv \tilde{G}_M - (1 + \tau) \tilde{F}_2$$

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

New amplitudes are complex!

(Unofficial) Novosibirsk Information

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



Control of Systematics

$$N_{ij} = L_{ij} \sigma_i \kappa_{ij}^p \kappa_{ij}^l$$

$i = e^+ \text{ or } e^-$

$j = \text{pos/neg polarity}$

Geometric **proton** efficiency: $\kappa_{e^+j}^p = \kappa_{e^-j}^p$

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

Ratio in single
polarity j

Geometric **lepton**
efficiency: $\kappa_{e^++}^l = \kappa_{e--}^l$ and $\kappa_{e^+-}^l = \kappa_{e^-+}^l$

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