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Physics Update

Michael Kohl

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

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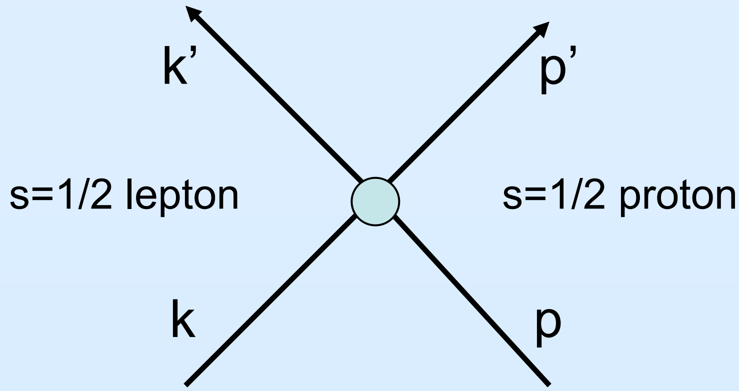
Elastic ep Scattering Beyond OPE



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

Kinematical invariants :

$$Q^2 = -(p-p')^2$$
$$\nu = K \cdot P = (s-u)/4$$

Next-to Born approximation:

$$T^{non-flip}_{h'\lambda'_N, h\lambda_N} = \frac{e^2}{Q^2} \bar{u}(k',h')\gamma_\mu u(k,h)$$

$(m_e = 0)$

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

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 ~α^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!

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

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

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

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

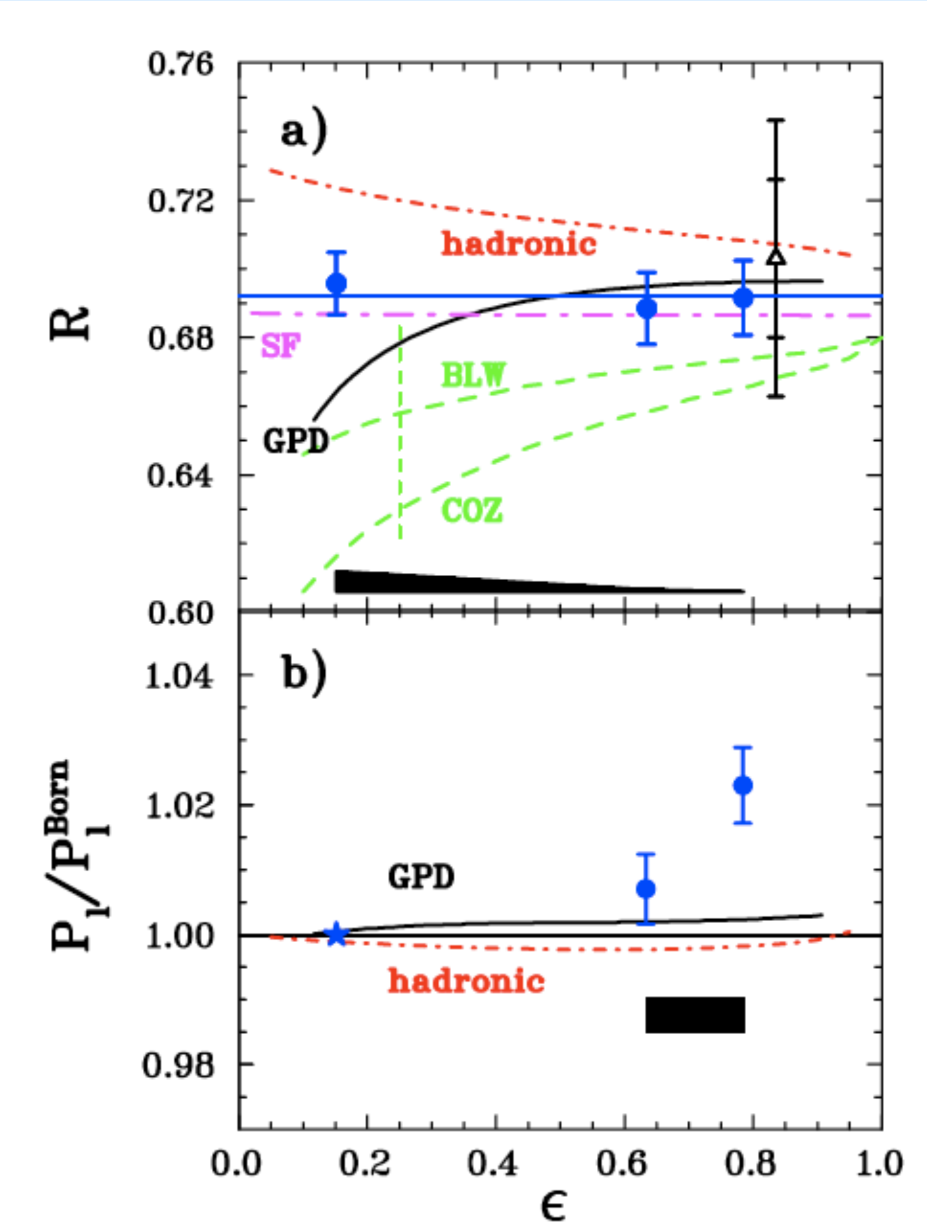
Born Approximation | **Beyond Born Approximation**

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

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

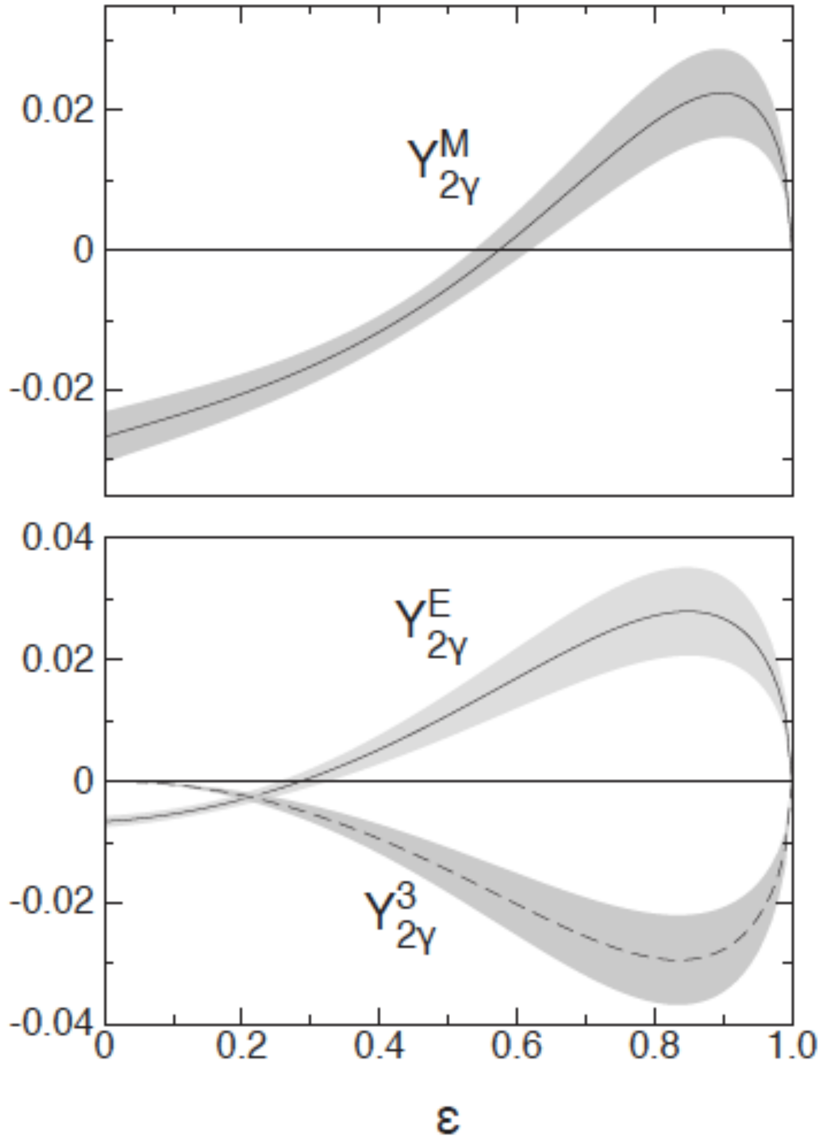
➔ no effect in P_t/P_l
➔ some effect in P_l

Expect larger effect in e+/e-!

M. Meziane et al., hep-ph/1012.0339v1
submitted to PRL

Empirical extraction of TPE amplitudes

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



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

$$Y_{2\gamma}^{M}(\nu, Q^2) \equiv \mathcal{R}\left(\frac{\delta \tilde{G}_M}{G_M}\right), \quad Y_{2\gamma}^{E}(\nu, Q^2) \equiv \mathcal{R}\left(\frac{\delta \tilde{G}_E}{G_M}\right),$$

$$Y_{2\gamma}^{3}(\nu, Q^2) \equiv \frac{\nu}{M^2}\mathcal{R}\left(\frac{\tilde{F}_3}{G_M}\right), \qquad (3)$$

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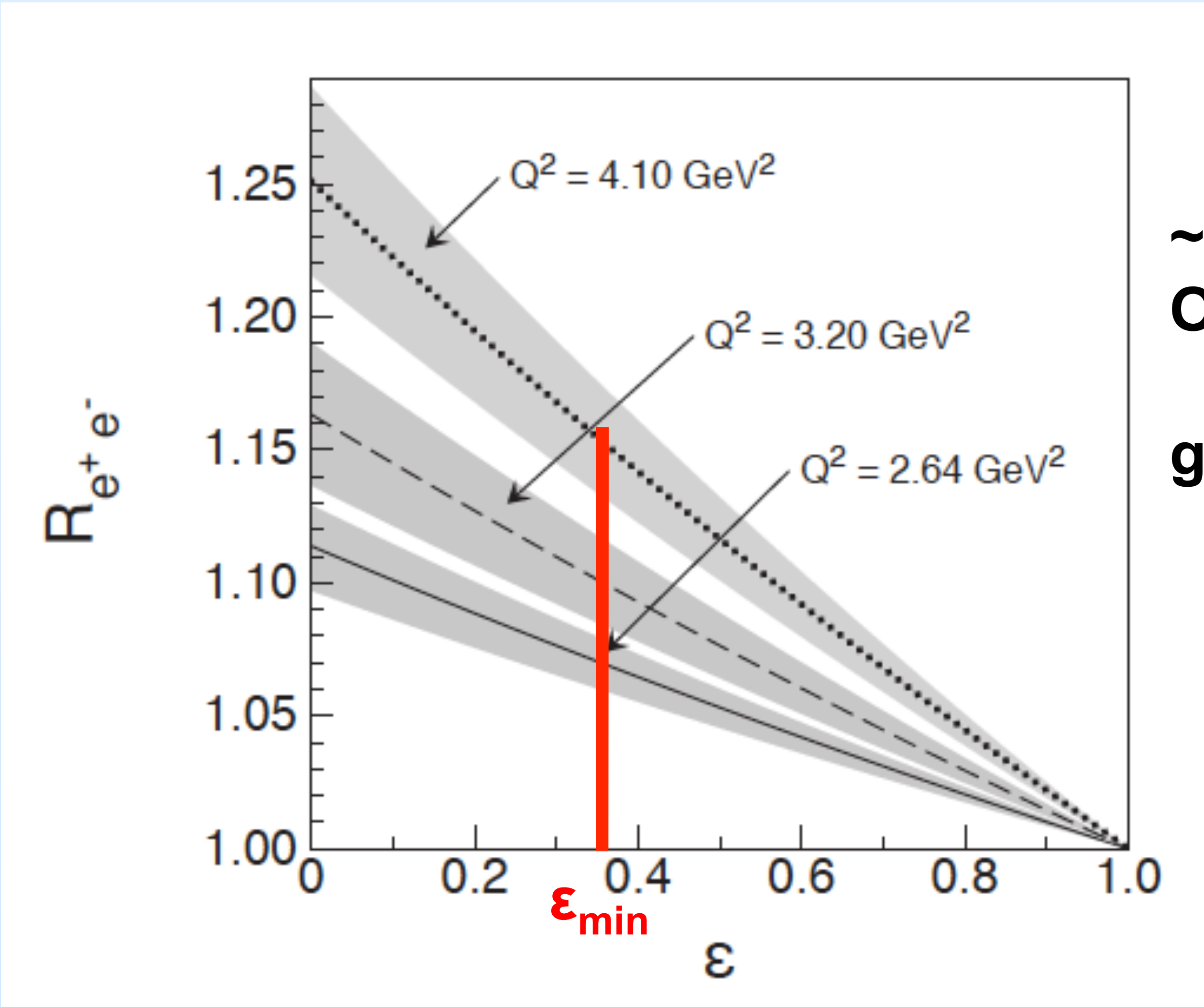
J. Guttmann, N. Kivel, M. Meziane, and M. Vanderhaeghen, hep-ph/1012.0564v1



~6% effect for OLYMPUS@2.0GeV

grows with Q^2!

From the TDR (2009):

~6% effect on R

E_0 [GeV]	θ_e	$p_{e'}$ [GeV/c]	θ_p	p_p [GeV/c]	Q^2 [(GeV/c)^2]	ϵ	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 1.2: Kinematics for 2.0 GeV beam energy and count estimate per 8° bin for 500 h at $2 \cdot 10^{33}$ / (cm^{2}s).

40k events = 1% stat. precision

Unfortunately, Q^2 is not quite at 2.5 (GeV/c)^2
(at E=2.3 GeV it would be! – price is a factor ~2 in rate)

From the Letter of Intent (2007):

E_0 [GeV]	θ_e	$p_{e'}$ [GeV/c]	θ_p	p_p [GeV/c]	Q^2 [(GeV/c)^2]	ϵ	Counts
4.5	**24**	**3.18**	**39.1**	**4.01**	**2.5**	**0.867**	**437082**
	32	**2.60**	**31.0**	**3.41**	**3.6**	**0.751**	**60093**
	40	**2.12**	**25.4**	**2.91**	**4.5**	**0.625**	**14427**
	48	1.74	21.2	2.51	5.2	0.505	4986
	56	1.44	18.0	2.19	5.7	0.402	2195
	64	1.22	15.5	1.94	6.2	0.318	1138
	72	1.04	13.5	1.74	6.5	0.250	662
3.0	**24**	**2.35**	**48.3**	**3.15**	**1.2**	**0.892**	**5594080**
	32	**2.02**	**39.7**	**2.80**	**1.8**	**0.800**	**860732**
	40	**1.72**	**33.2**	**2.48**	**2.4**	**0.691**	**207325**
	48	**1.46**	**28.2**	**2.20**	**2.9**	**0.581**	**69017**
	56	**1.24**	**24.2**	**1.97**	**3.3**	**0.477**	**28964**
	64	1.07	20.9	1.78	3.6	0.387	14356
	72	0.93	18.2	1.62	3.9	0.311	8029
2.3	**24**	**1.90**	**53.7**	**2.68**	**0.8**	**0.901**	**23563000**
	32	**1.68**	**45.3**	**2.44**	**1.2**	**0.820**	**4158760**
	40	**1.46**	**38.5**	**2.21**	**1.6**	**0.723**	**1056590**
	48	**1.27**	**33.1**	**2.00**	**1.9**	**0.620**	**355293**
	56	**1.10**	**28.6**	**1.81**	**2.2**	**0.519**	**147671**
	64	**0.97**	**24.9**	**1.66**	**2.5**	**0.428**	**71950**
	72	0.85	21.8	1.53	2.7	0.348	39498

Table 3: Kinematics for three beam energies and count estimate per 8° bin for 1000 h at $2 \cdot 10^{33}$ / (cm^{2}s). For the higher beam energy the backward lepton angle acceptance is limited by the forward proton angle > 23°. Bold face corresponds to kinematics within the acceptance of the current BLAST detector configuration.

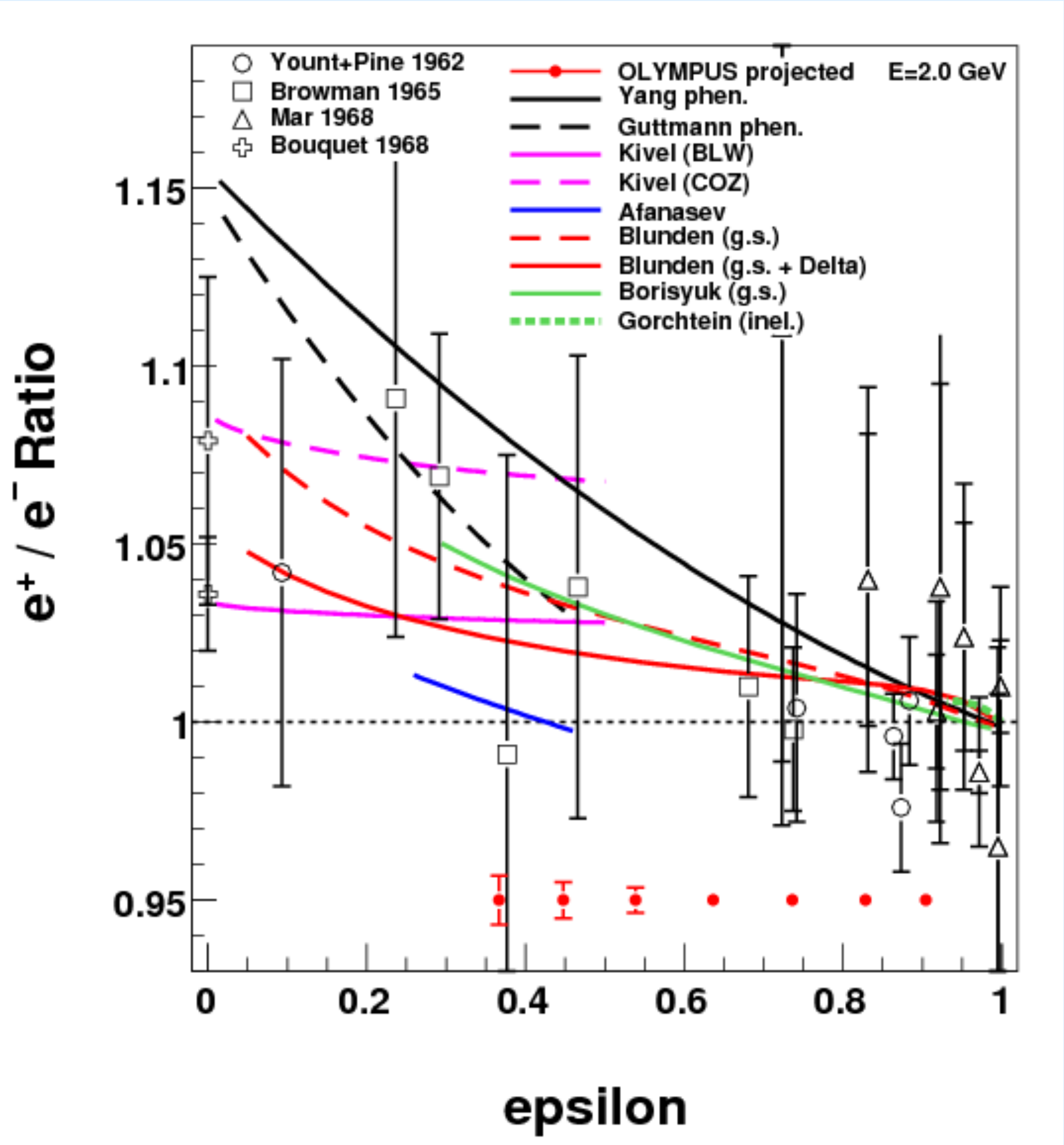
~5% effect on R
75% of the rate

~10% effect on R
9% of the rate

40k events = 1% stat. precision

2x more at 2 GeV

Projected Results for OLYMPUS



Data from 1960's

Many theoretical predictions with little constraint

OLYMPUS:

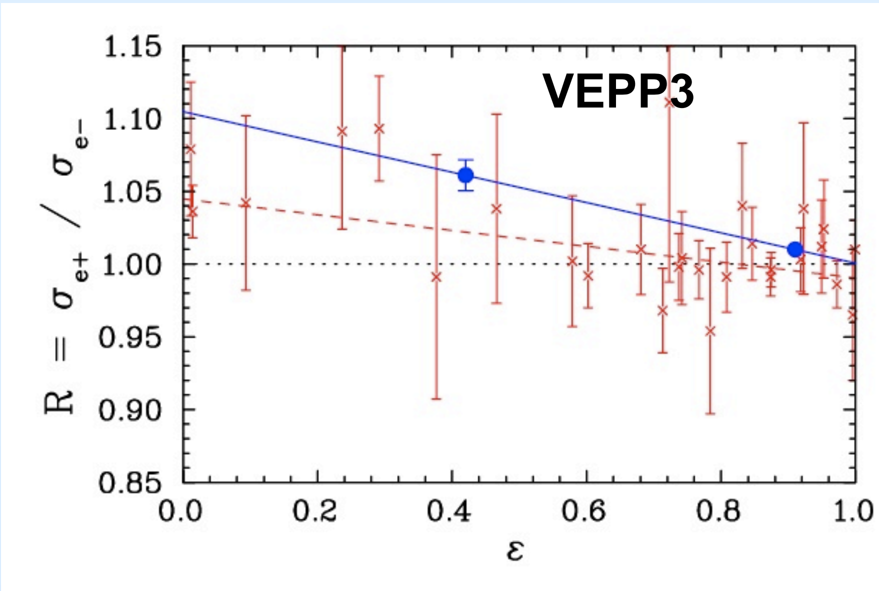
E= 2 GeV

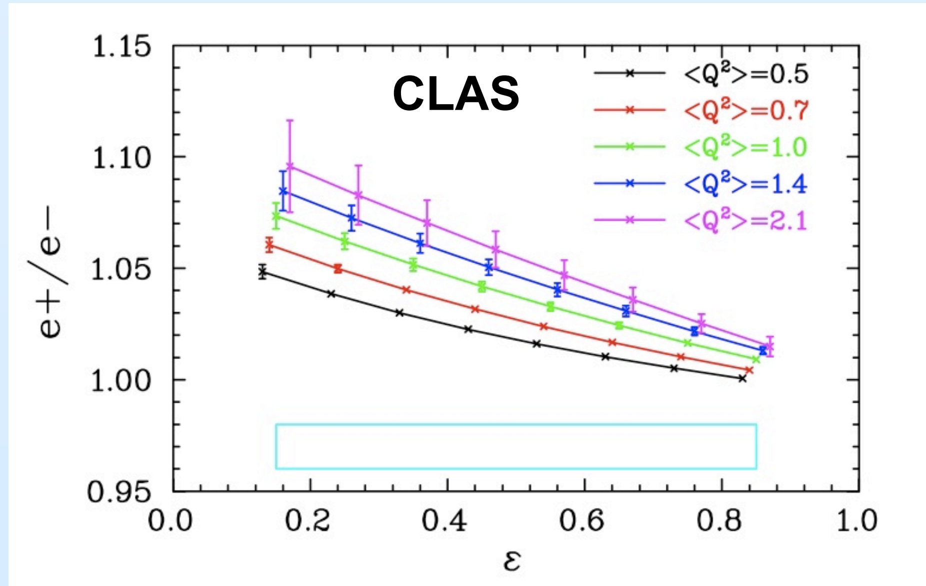
<1% projected uncertainties

500h @ $2x10^{33}$ / cm^2s

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 (now firmly scheduled)**	
	Novosibirsk/VEPP-3	**storage ring / intern. target – 2009 (preliminary result: large effect)**
	OLYMPUS@DESY	**storage ring / intern. target – 2012**

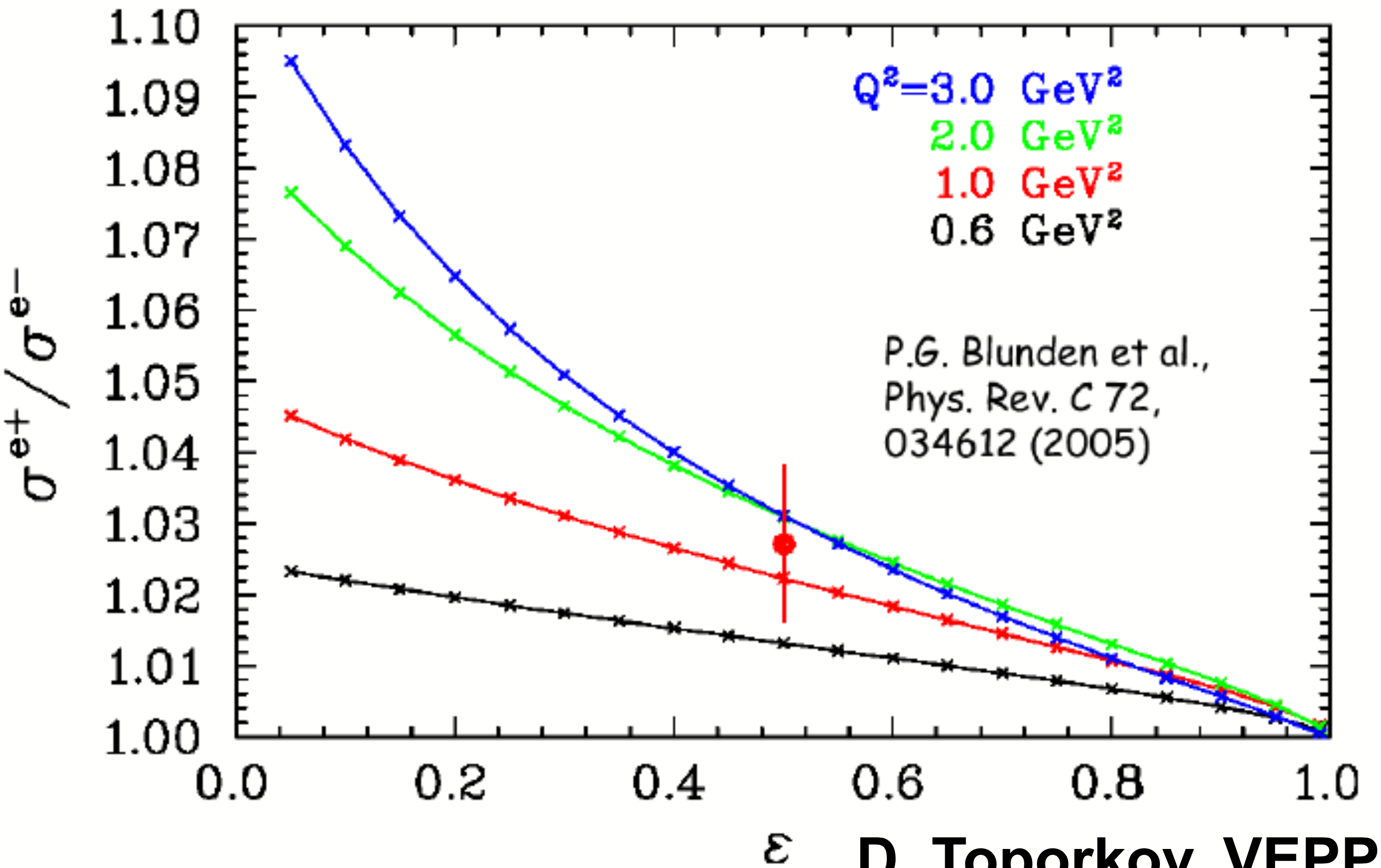
SSA: **PR05-15 (Hall A, trans. pol target); MAMI-A4 (trans. pol. beam)**

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

(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

CLAS TPE – 2γ effects in ep scattering

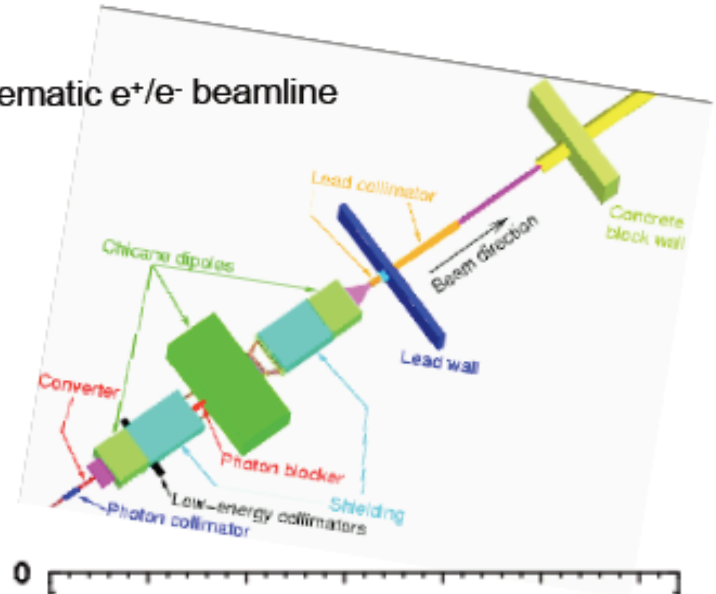
2γ contributions are expected to be the a major factor in explaining the discrepancy in the ratio G_E^p/G_M^p observed for using the Rosenbluth technique or the polarization transfer technique.

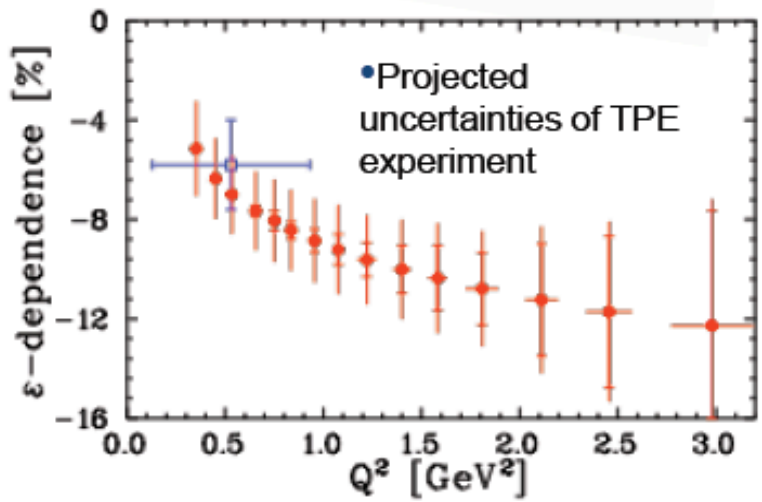
2γ effects are exposed in comparing e^-p and e^+p elastic scattering cross sections. The 1γ/2γ interference term $\delta_{2\gamma}$ has opposite sign resulting in a measureable difference from unity for the ratio

$$= \frac{\sigma(e^+)}{\sigma(e^-)} \approx 1 - 2\delta_{2\gamma}.$$

Experiment is currently taking production data. It uses an intense photon beam and converts it to a beam of equal mixture of e^+ and e^- directed onto a LH2 target. The scattered leptons and proton are detected in CLAS.

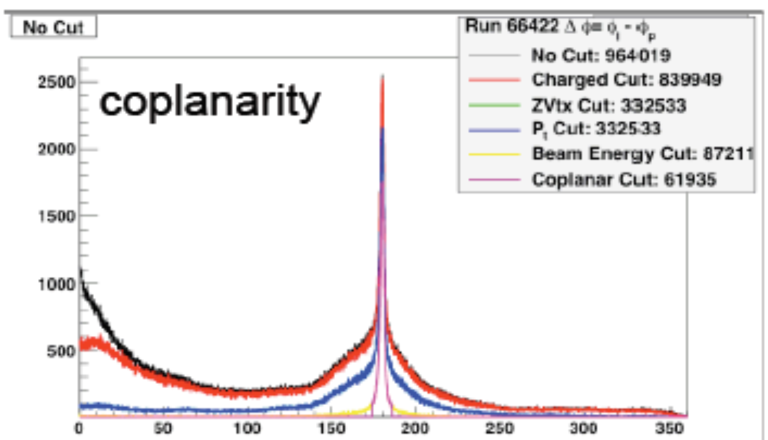
Schematic e^+/e^- beamline



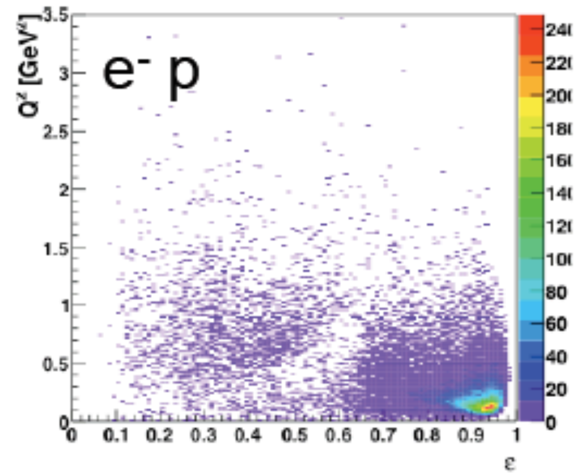


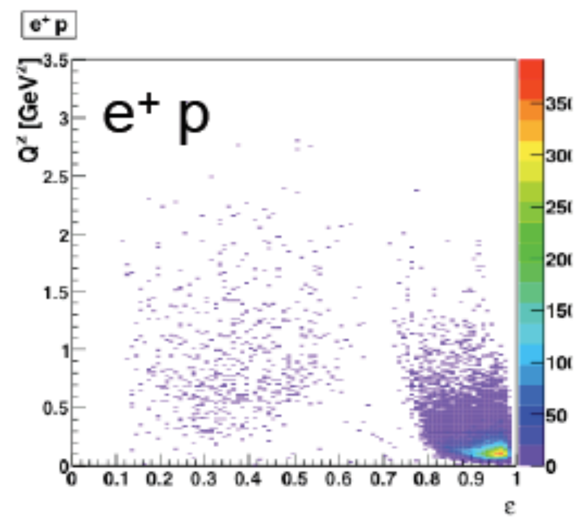
CLAS TPE - Experimental Progress

- e^+/e^- Chicane tuned
- Achieved luminosity within a factor of two of simulations
- 10^7 elastic events as of December.
- Identify elastic events by:
  - coplanarity,
  - zero total transverse momentum,
  - beam energy matching (angle/mom)
- Reduce systematic errors by:
  - Identical simultaneous beams
  - Reversing torus field
  - Reversing chicane field
  - Taking triple ratios



One hour of data …





L. Cardman, PAC37, Jan. 2011