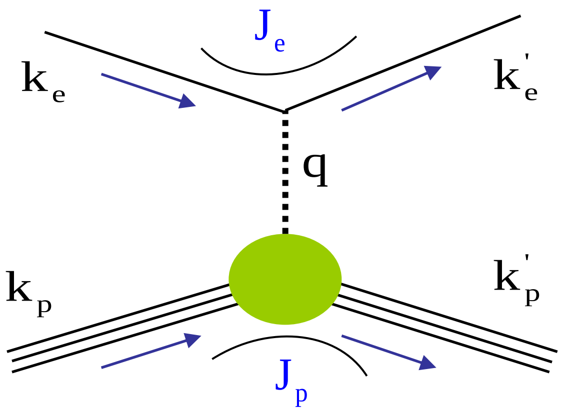
Эксперимент OLYMPUS
и
форм факторы протона

С.Белостоцкий

FF definition and observables



In plane wave Born (OPE) approximation e-p scattering invariant amplitude

$$M_{\mu\nu} \sim \underbrace{e_e \cdot \bar{u}(k_e')\gamma^\mu u(k_e)}_{J_e} \cdot \underbrace{\left(-\frac{1}{q^2}\right)}_{\gamma} \cdot \underbrace{e_p \bar{u}(k_p')\left[F_1(Q^2)\gamma^\mu + \frac{1}{2M_p}F_2(Q^2)i\sigma^{\mu\nu}q_\nu\right]u(k_p)}_{J_p}$$

Unpolarized cross section

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega_{Mott}} \frac{1}{\varepsilon(1+\tau)}\left[\varepsilon G_E^2(Q^2) + \tau G_M^2(Q^2)\right], \quad \tau = \frac{Q^2}{4M_p},$$

photon polarization $\varepsilon = \dfrac{1}{1+2(1+\tau)\tan^2(\theta_e/2)}, \quad 0 < \varepsilon < 1.$

under study for decades

$$\sigma_r = \varepsilon G_E^2(Q^2) + \tau G_M^2(Q^2)$$

Theoretical interpretation

VMD-based models (Lomon, Bijker)

Relativistic constituent quark (rCQM), G.A. Miller, many others

Behavior of G_{Ep}/G_{Mp} at intermediate Q^2 related to u/d ratio at small distances (Miller et al.)

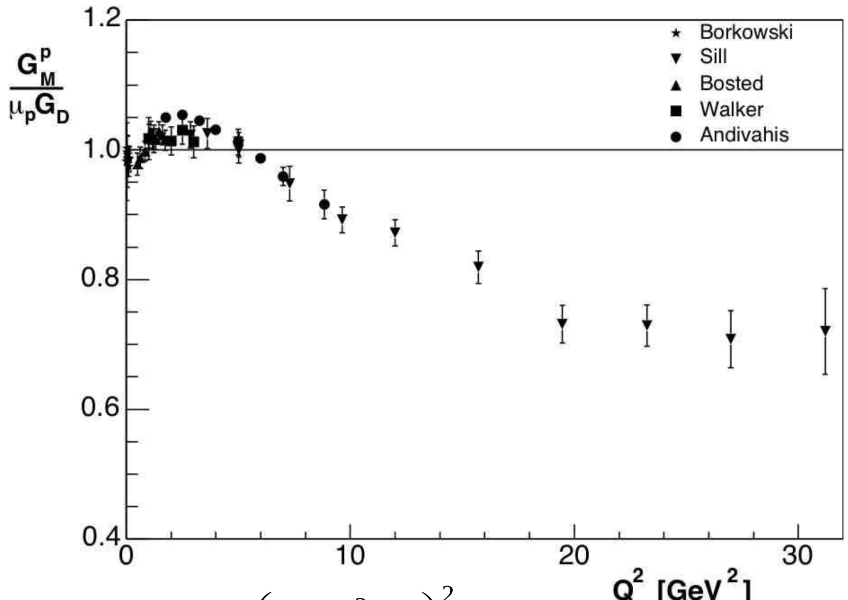
Lattice QCD models

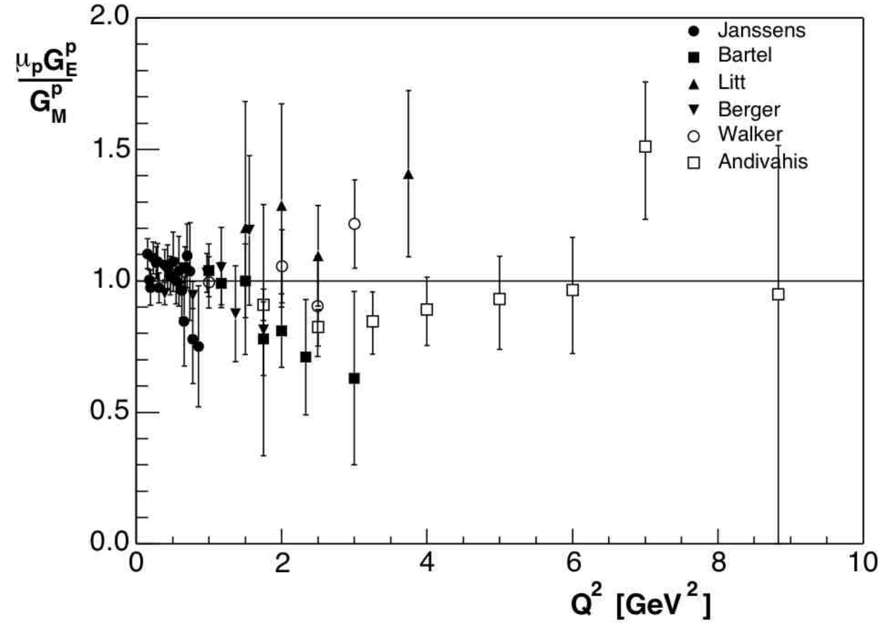
Dyson-Schwinger equations, as continuum approach to QCD (Roberts, Cloet et al.).

Flavor separation for "dressed" quarks in nucleon

Extraction of FFs from unpolarized e-p elastic scattering

Direct measurements $G_M(Q^2)$ Rosenbluth separation $G_E(Q^2)$





$$G_D(Q^2) = \left(\frac{\Lambda^2}{\Lambda^2 + Q^2}\right)^2, \quad Q^2 = |\vec{q}|^2$$

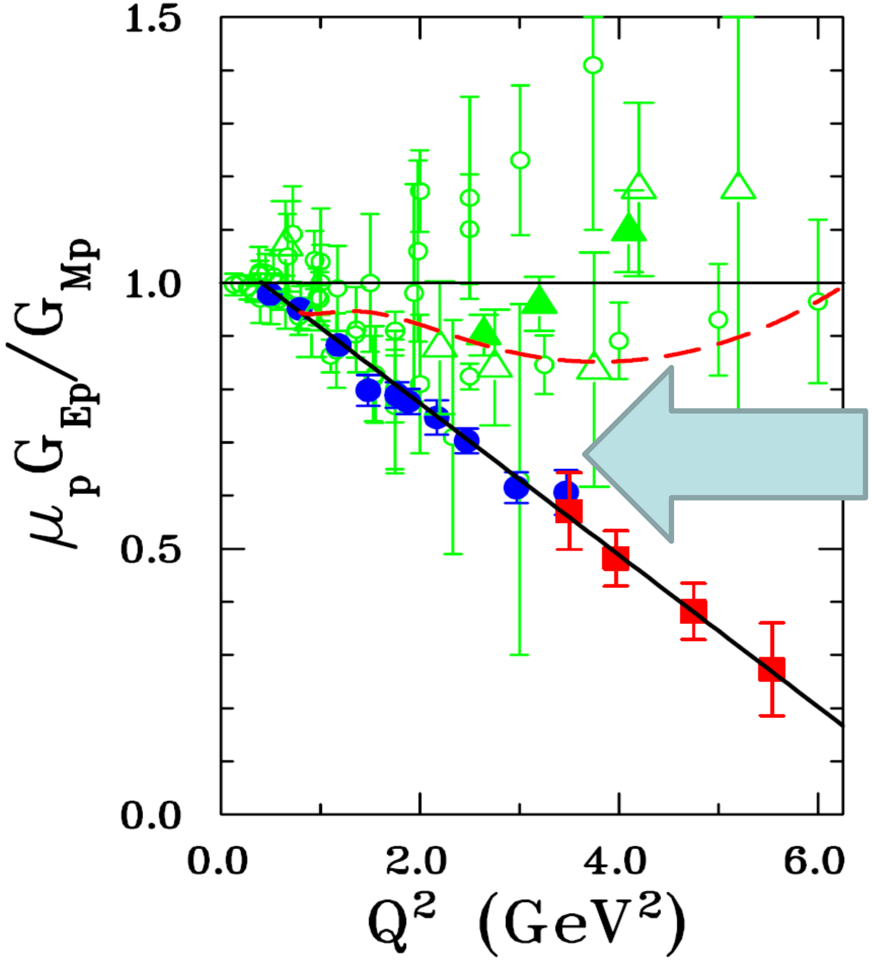
with $\Lambda = 0.84\,\mathrm{GeV}$

not ideal but acceptable parameterization

It was commonly accepted that

$$\frac{\mu_p G_E^2(Q^2)}{G_M^2(Q^2)} = 1$$

JLAB measurements of recoil proton polarization



Direct measurements:

$P_{\parallel}$ along recoil proton momentum,

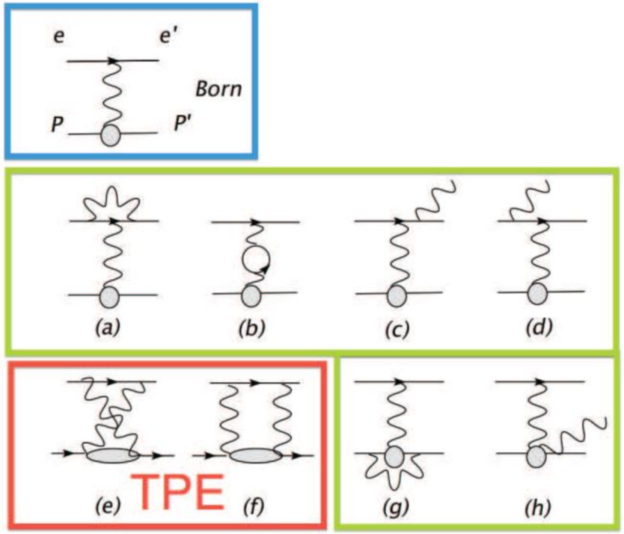
$P_{\perp}$ perp. to recoil proton momentum in scat. plane

$$\frac{\mu G_E(Q^2)}{G_M(Q^2)} = \mu \frac{P_{\perp}}{P_{\parallel}} \cdot \sqrt{\frac{\tau(1+\varepsilon)}{2\varepsilon}}$$

Polarized JLAB measurements

$$\frac{\mu_p G_E(Q^2)}{G_M(Q^2)} = ???$$

Two photon exchange TPE and beam charge asymmetry



Most likely explanation

Second order corrections affect **strongly** $\mu_p G_E(Q^2)/G_M(Q^2)$ extracted from unpolarized experiments

keeping intact polarized data

Beam charge asymmetry sensitive to TPE:

$$\frac{\sigma^{e^+p}(\theta_e)}{\sigma^{e^-p}(\theta_e)} = 1 + \frac{4M_{Born}(\theta_e)\,\mathrm{Re}(M^*_{2\gamma}(\theta_e))}{|M_{Born}(\theta_e)|^2} + QED_{cor}$$

must be measured

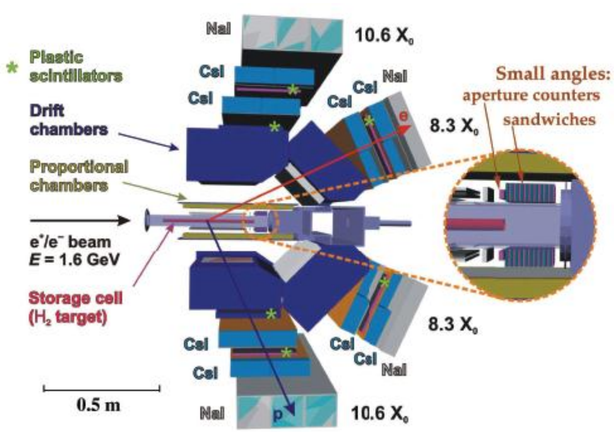
TPE or some other explanations ???

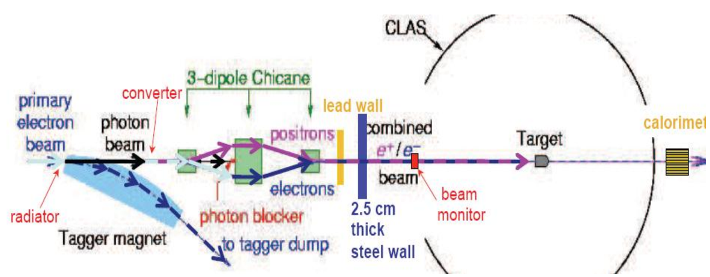
Are the RC corrections applied to cross section data accurate enough?
Bystritskiy, Kuraev, and Tomasi-Gustafsson answer no, based on structure function calculation, which leaves no room for measurable two-photon effects.

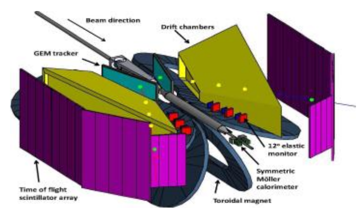
Others see the discrepancy as mostly explainable in terms of two-photon effect. For example Afanasev, Brodsky, Carlson, Chen and Vanderhaeghen; Arrington; Blunden, Melnitchouk and Tjon; Borysyuk and Kobushkin; Guttmann, Kivel, Meziane and Vanderhaeghen; and others.

Experiment

SPIN2012 29







CLAS-JLAB

OLYMPUS

VEPP-3 Novosibirsk

OLYMPUS collaboration

- Arizona State University, USA
- DESY, Hamburg, Germany
- Hampton University, USA
- INFN Bari, Ferrara, and Rome, Italy
- MIT and MIT-Bates, USA
- Petersburg Nuclear Physics Institute, Russia
- University of Bonn, Germany
- University of Glasgow, United Kingdom
- University of Mainz, Germany
- University of New Hampshire, USA
- Yerevan Physics Institute, Armenia

Российские участники

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А.Киселев
О.Миклухо
Ю.Нарышкин

Отдел трековых детекторов

А.Крившич, В Андреев, Е.Иванов,...

Лаборатория радиоэлектроники

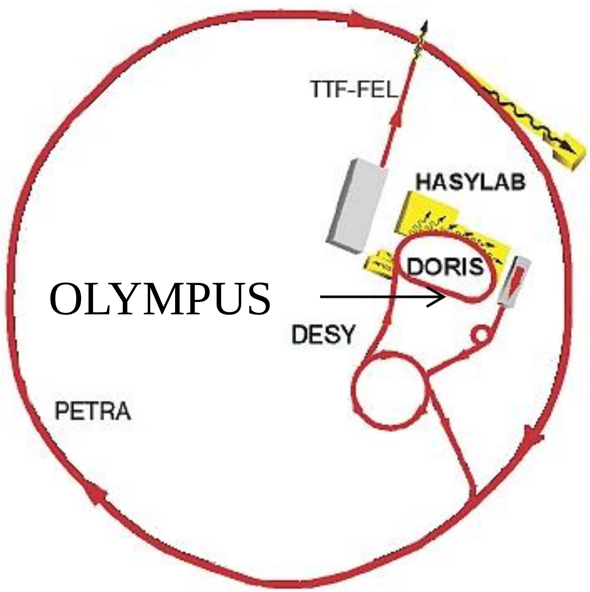
Л.Уваров

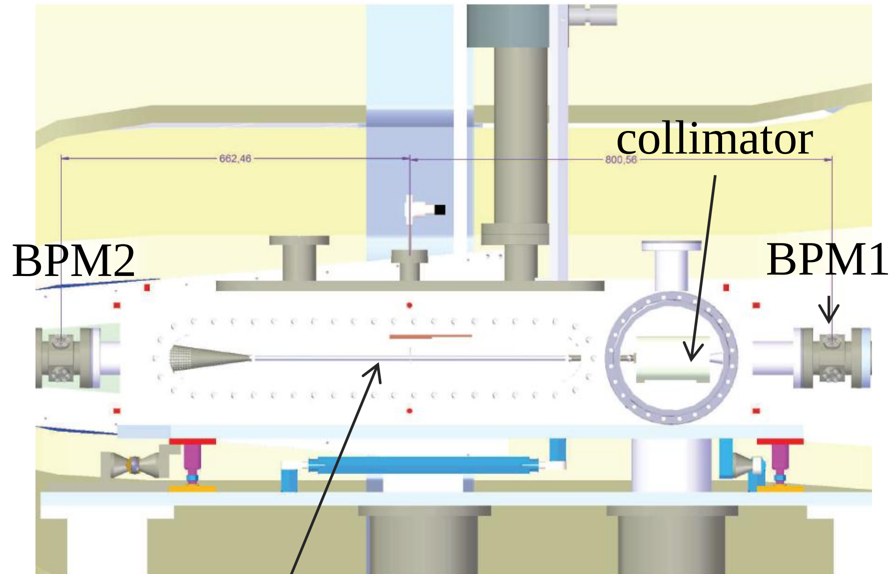
Воронежский государственный университет (студенты)

К.Суворов, К.Байбуз

OLYMPUS at DORIS, DESY

Study of $e^{+}p, e^{-}p$ elastic scattering in identical conditions @ 2 GeV





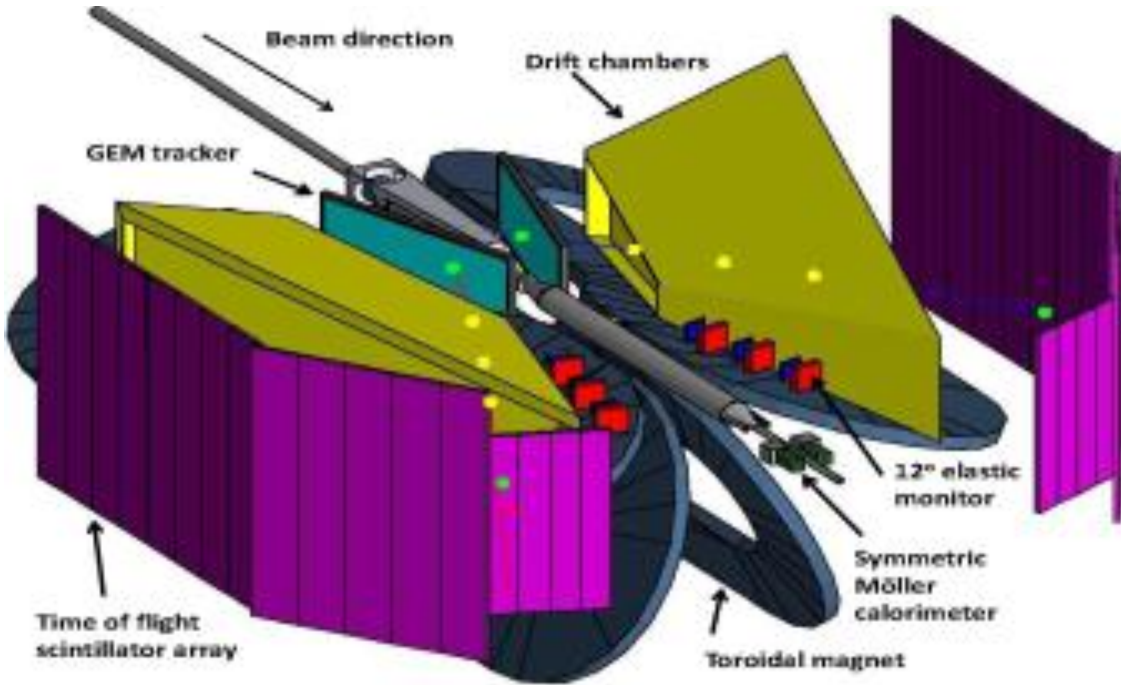
Hydrogen target region

Doris storage ring 2-4.5 GeV
2 GeV $\mathbf{e^{+}, e^{-}}$ beams, **100 mA**, change daily,
Beam energy stability **0.5 MeV**
Beam position **0.1mm**
quasi **continuous** beam (“topup” mode)

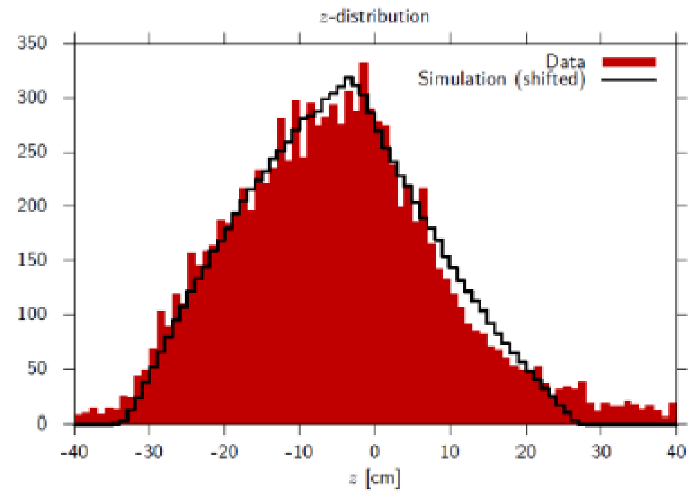
Target cell elliptical 9x16mm**2.
length 60mm, $\mathbf{8 \cdot 10^{15}\ atoms \cdot cm^{-2}}$
Beam sizes 0.6x0.1mm**2

$\text{Luminosity} = 2 \cdot 10^{33}\,\text{cm}^{-2}\text{s}^{-1}$

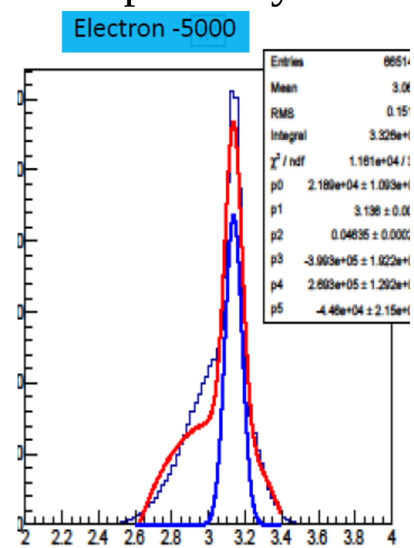
Olympus detector



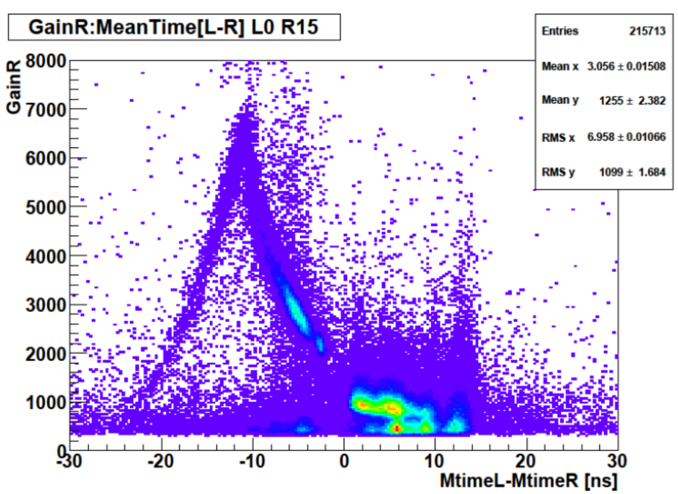
Positron vertex distribution



co-planarity



ep elastic event selection:
TOF correlation,
energy deposit in TOF counters,
ep vertices correlation,
co-planarity requirement,
angular/momentum
kinematic correlations

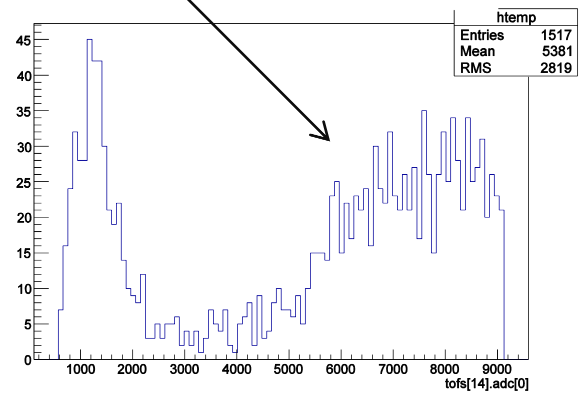


12 deg. Luminosity monitor

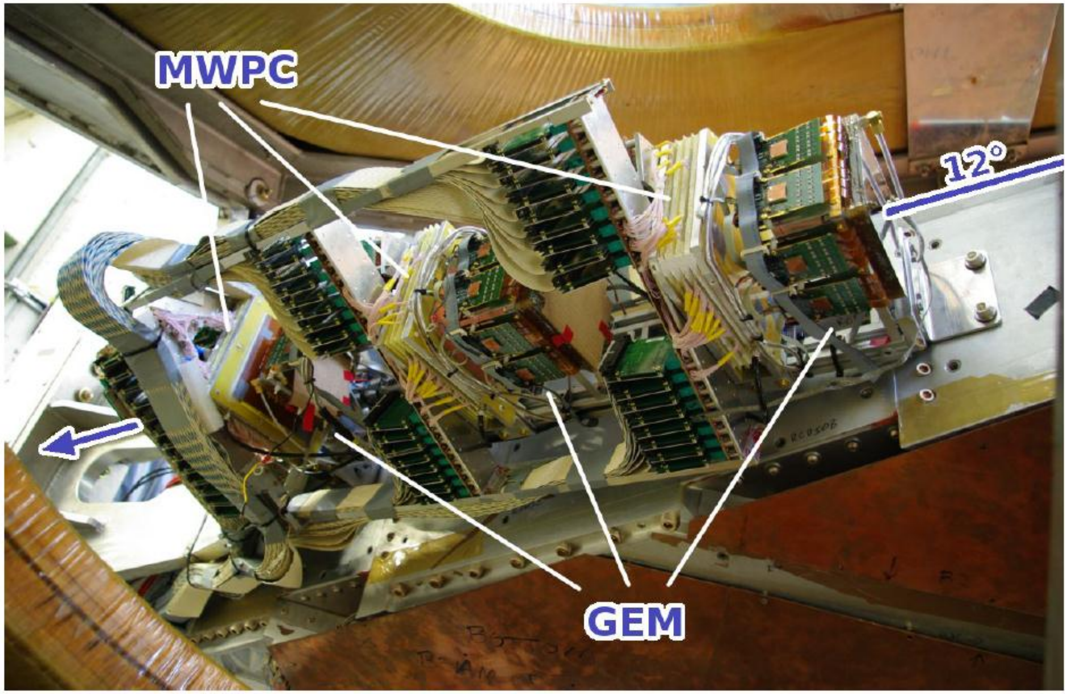
e^+p / e^-p **ratio must be 1 as TPE expected to be small at low Q**2**

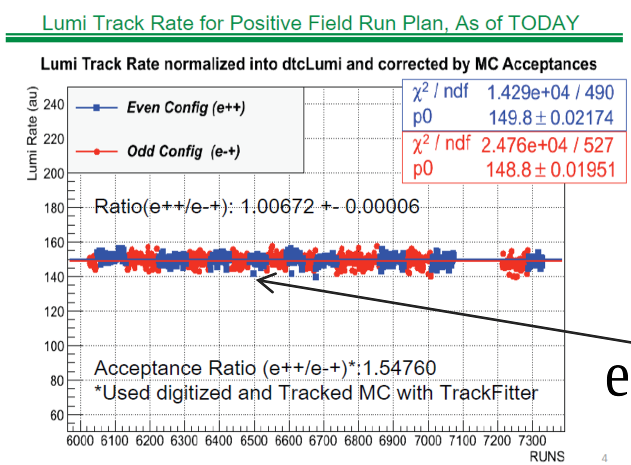
Sci. counters SiPMs, MWPCs, PNPI readout, GEMs

Energy deposit in TOF scintillation bar
for **recoil protons** in coincidence with 12 deg. leptons



Target density measurement
Good agreement with MC

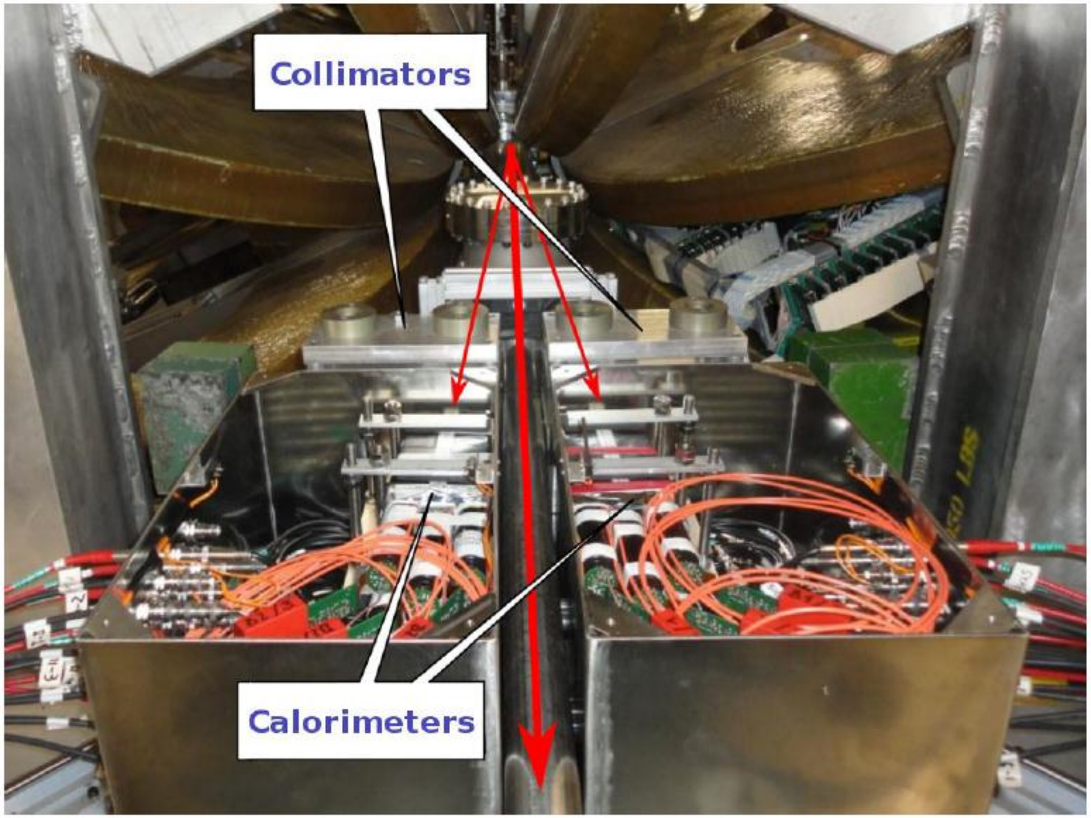


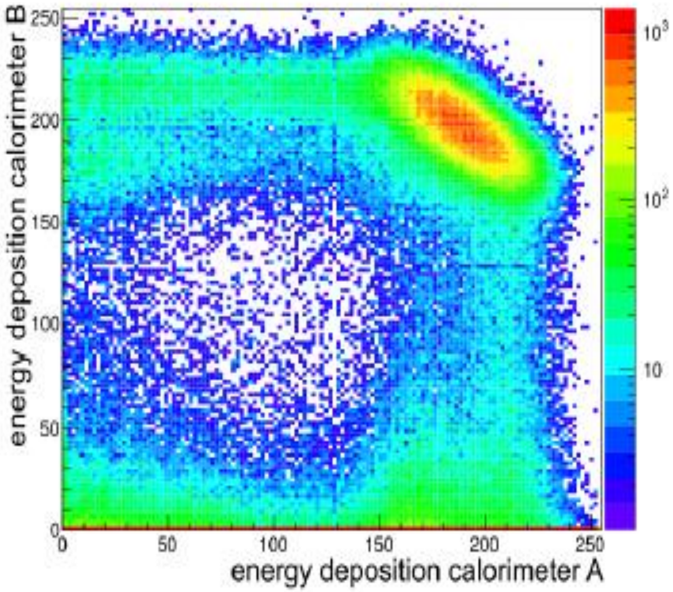


$e^+p / e^-p = 1.0067 \pm 0.0008$ close to unity

Symmetric Meoller /Bhabha monitor

$$\text{at } 2\,\text{GeV} \qquad \theta_{\text{symm.}}(e^-e^-, e^+e^-) = 1.3\,\text{deg.}$$

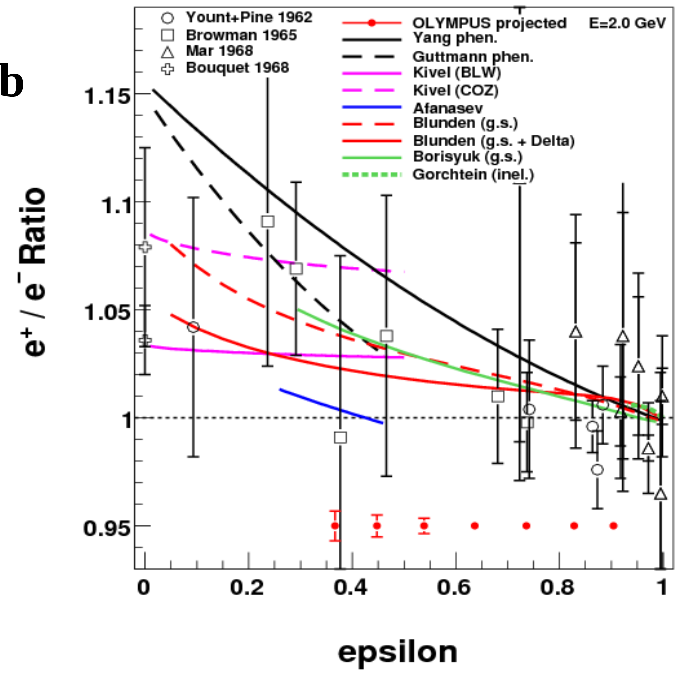




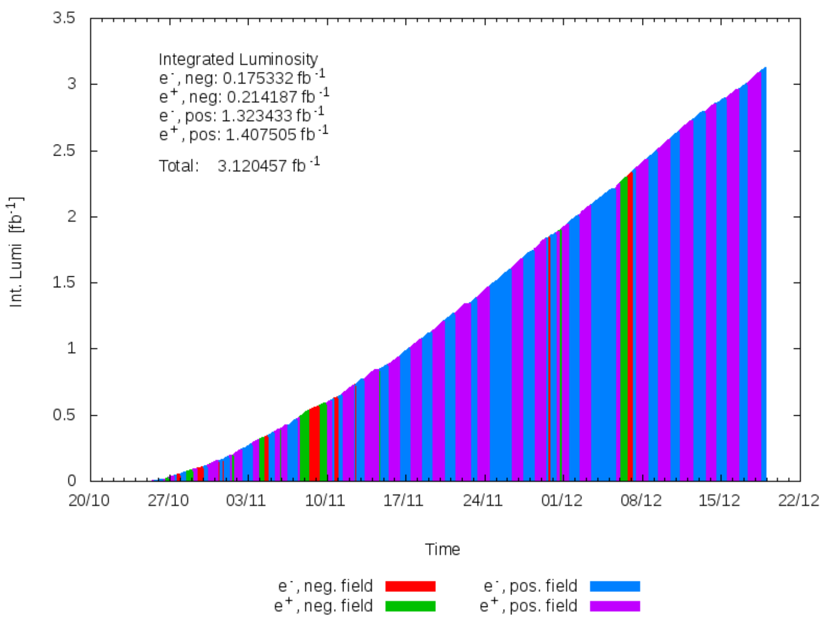
Data taking

Two period of data taking in 2012 Febr and Oct.-Nov.Dec.-Janu 2.
Doris full stop in 2013

Planned for 3.6 1/fb



accumulated by December 18



Outlook

2013 Survey, upgrade of geometrical file for MC
Toroid field mapping
Setup disassembly

Data analysis:
Finalize tracking
Dedicated computer (available)
Two analysis groups: MIT and PNPI
cross-check

2014 Data analysis, consensus, publication

“Experimental and theoretical aspects of the proton form factors”

symposium 9-13 July 2012, St.Petersburg, Gatchina,
Petersburg Nuclear Physics Institute (PNPI)

- *Multi-photon effects in charge lepton proton scattering;*
- *Form factors in QCD. Lattice calculations;*
- *Beam charge asymmetry in electron/positron proton elastic scattering:*
  overview of current experiments and data analysis;
- *Proton form factors and recoil proton polarization experiments;*
- *Proton structure at large momentum transfer;*
- *Charge lepton proton elastic scattering at low momentum transfer, proton radius;*
- *Form factors in time-like region.*

http://hepd.pnpi.spb.ru/hepd/olympus_2012/

BACKUP SLIDES

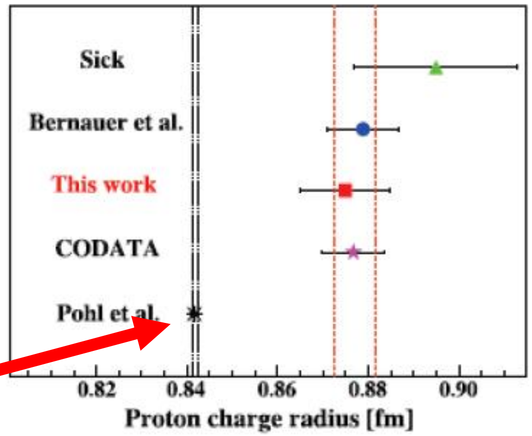
Proton Charge Radius Puzzle

Mainz

JLab

Mostly Hydrogen
Lamb shift

Muonic Hydrogen
Lamb shift

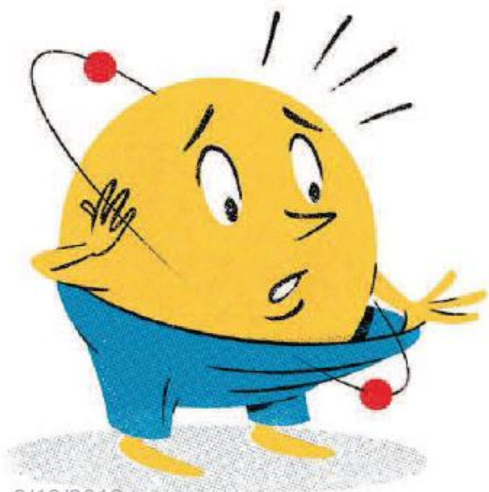


The figure is from X. Zhan et al., PLB 705, 59 (2011)

Connection to radius of the proton:

$$F(q^2) = 1 - \frac{1}{6}\frac{q^2 <r^2>}{\hbar^2} + $$

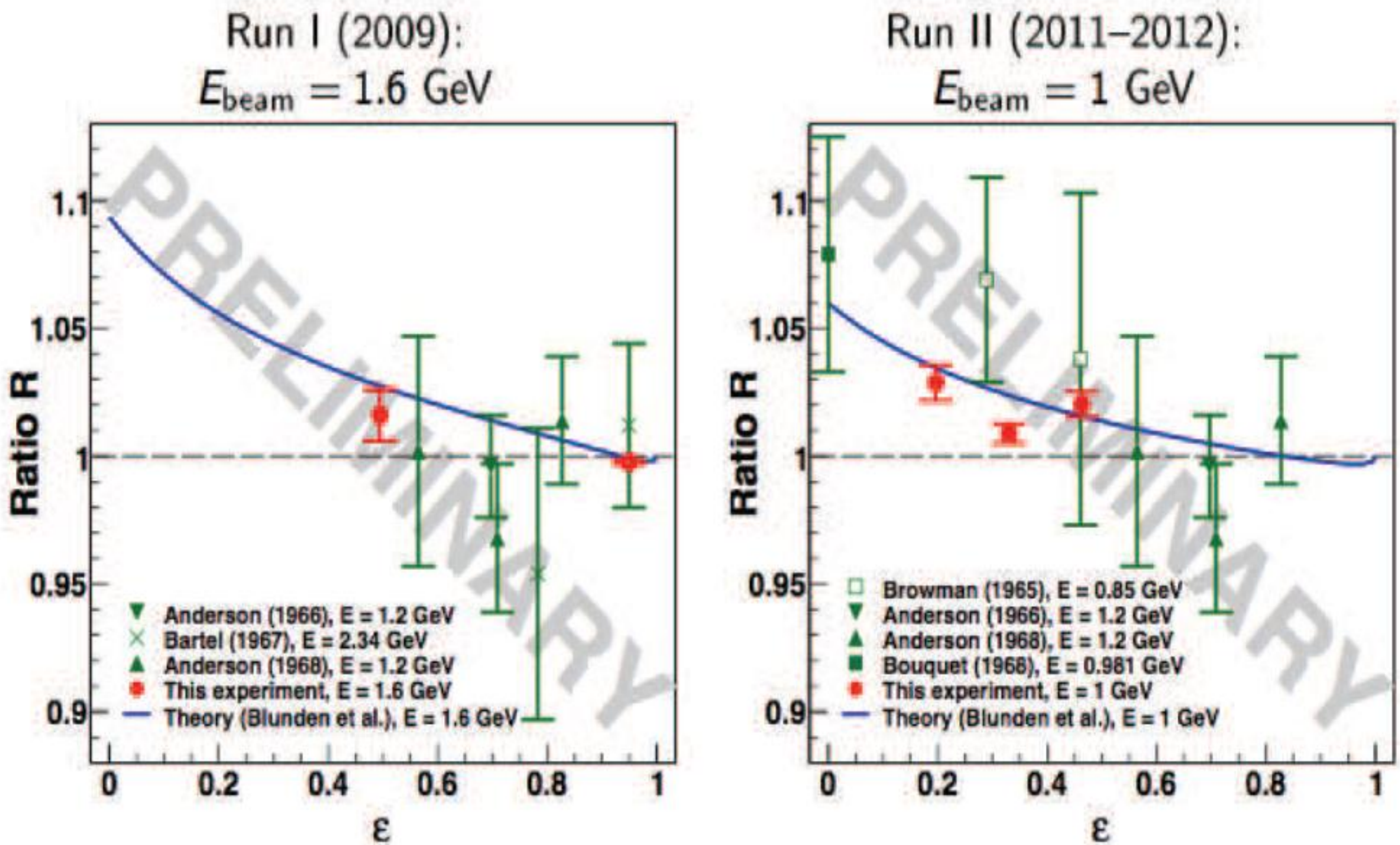
$$<r^2> = -6\hbar^2 \frac{dF(q^2)}{dq^2}\Big|_{q^2}$$



The New York Times, July 13, 2010.

It went from 0.8768±0.0069 fm to 0.8418±0.0007 fm
"For a Proton, a Little Off the Top (or Side) Could Be Big Trouble"

VEPP-3 Preliminary Results



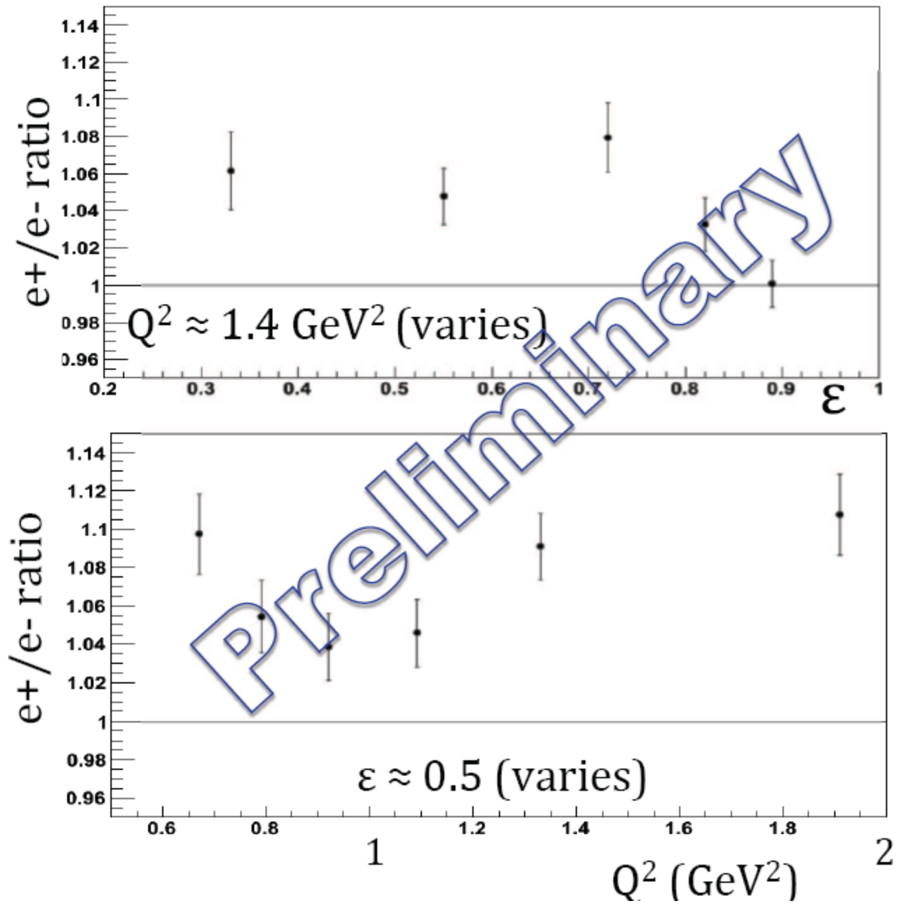
Theory: Blunden et al, Phys. Rev. C 72, 034612 (2005)

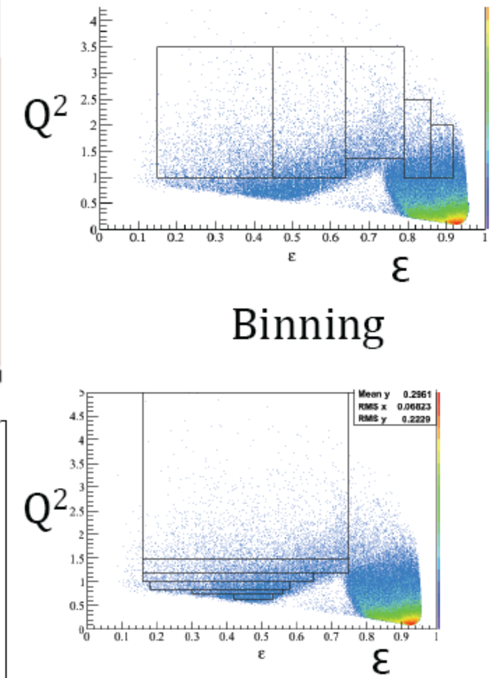
Radiative corrections have been applied.

Systematic error 0.3% (not shown)

CLAS-JLAB preliminary

Preliminary Results





75% of data
No acceptance corrections
No radiative corrections

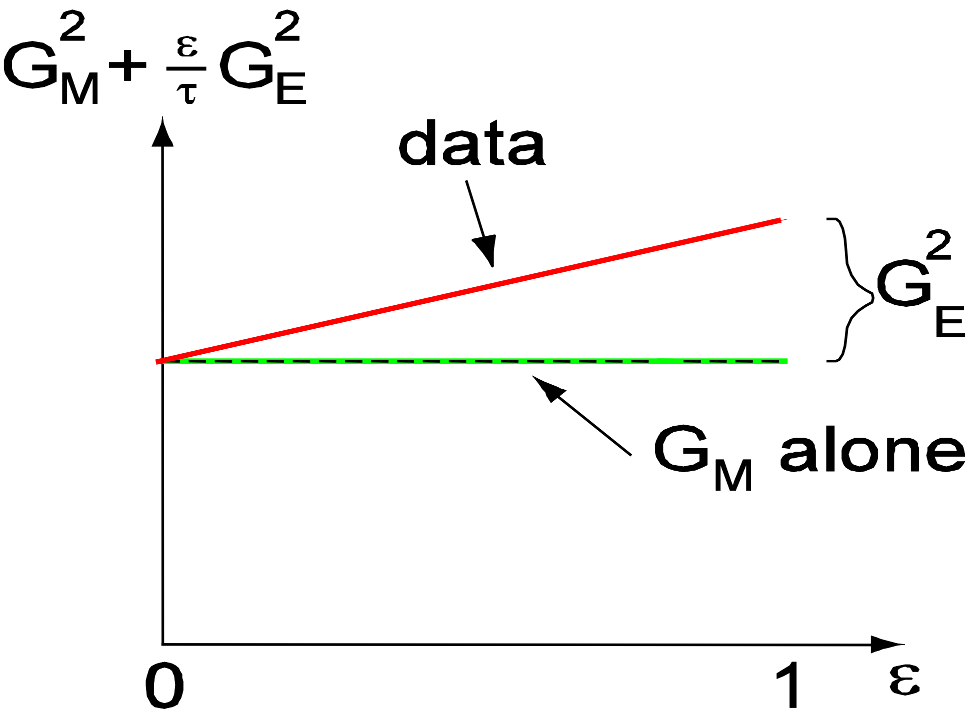
Rosenbluth separation (L-T separation)

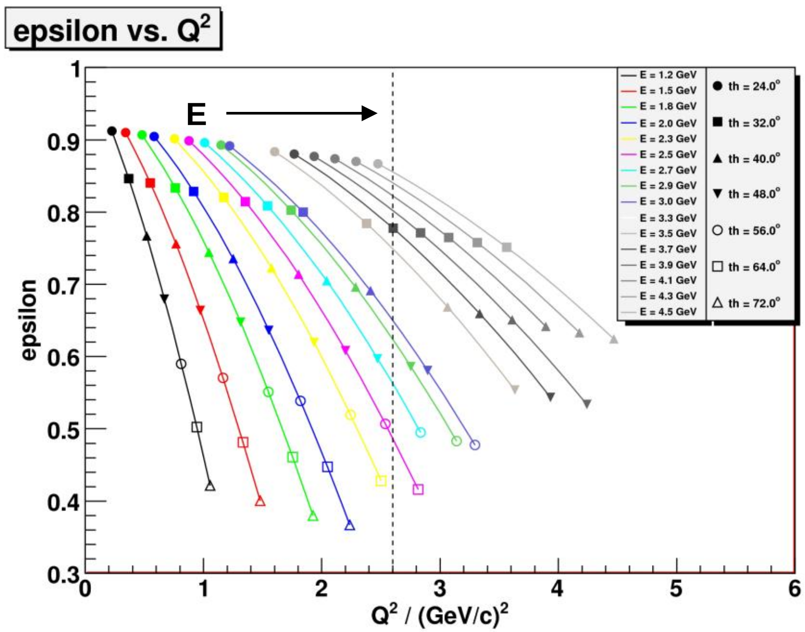
$$\sigma_r = \varepsilon G_E^2(Q^2) + \tau G_M^2(Q^2)$$

$$\textit{scan} \quad \varepsilon = \frac{1}{1+2(1+\tau)\tan^2(\theta_e/2)} \quad \textit{at fixed} \quad \tau = \frac{Q^2}{4M_p}$$

$$Q^2 = -q^2 = 4E_e E_e' \sin^2\frac{\theta_e}{2} \qquad E_e \searrow, (E_e' \searrow), \theta_e \to 2\pi, \varepsilon \to 0$$

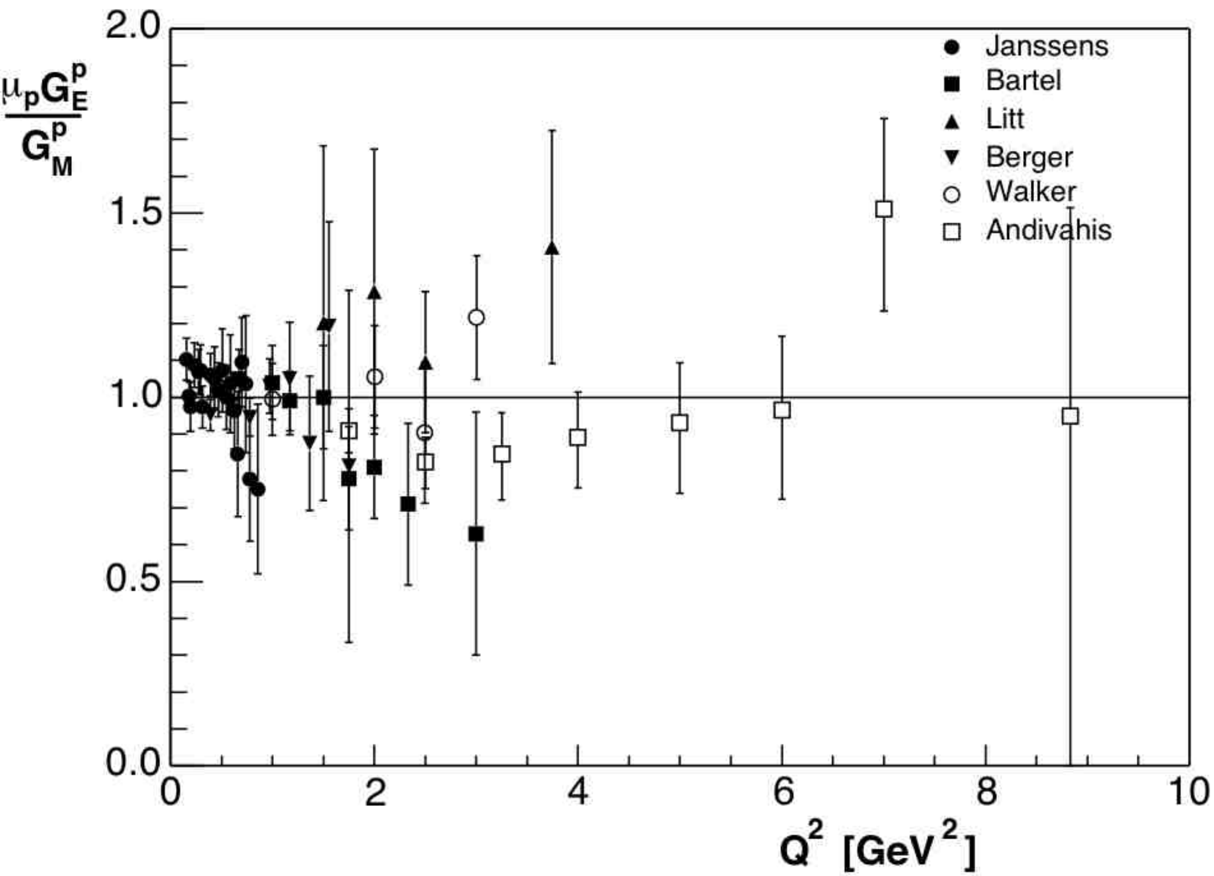
$$\textit{scalar photon fraction} \to 1$$





Extraction of FFs from Unpolarized Elastic e-p Scattering

Proton electric form factor



Under study

$$\sigma_r = \varepsilon G_E^2(Q^2) + \tau G_M^2(Q^2)$$

Note that $0 < \varepsilon < 1$

while $0 < \tau \equiv \frac{Q^2}{2M_p} < 15$

$\Rightarrow$ *problems to extract* $G_E^2(Q^2)$ *at high* Q^2

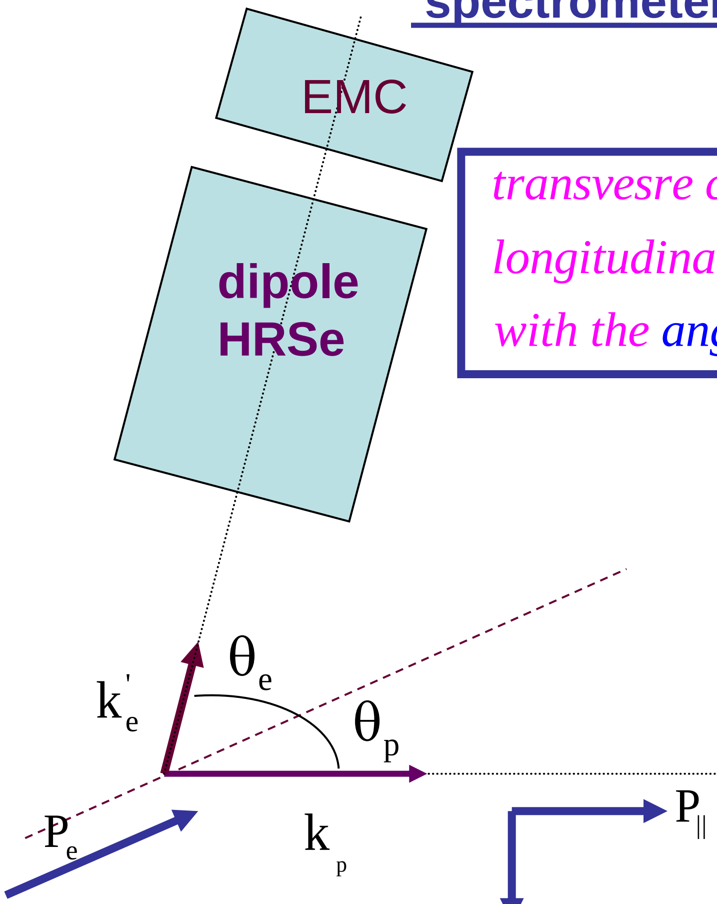
Additional problem $\rightarrow$ *cross section normalization uncertainty (included in error bars)*

JLAB Polarization Transfer experiment

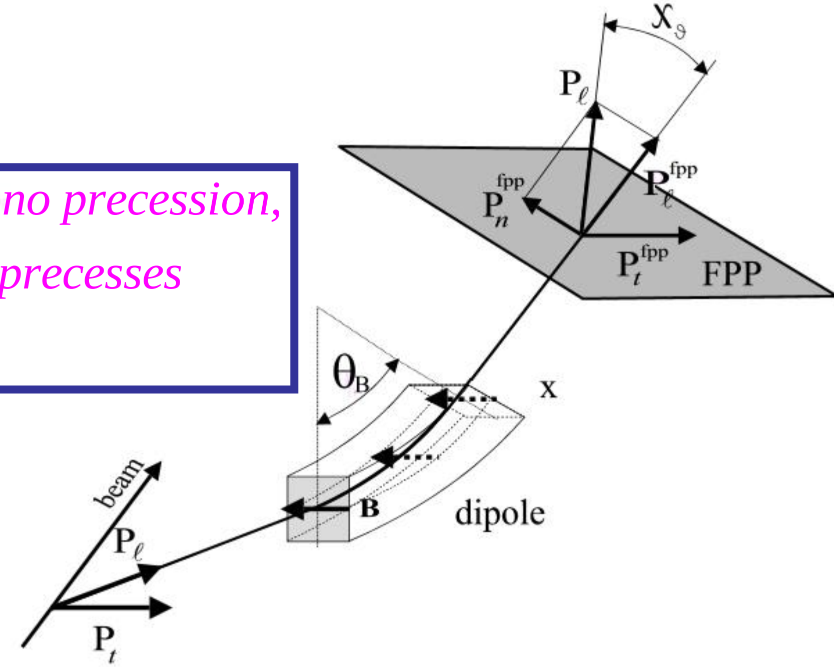
(V.Punjabi, C.F.Perdrisat, et al. Phys.Rev. C71, 2005)

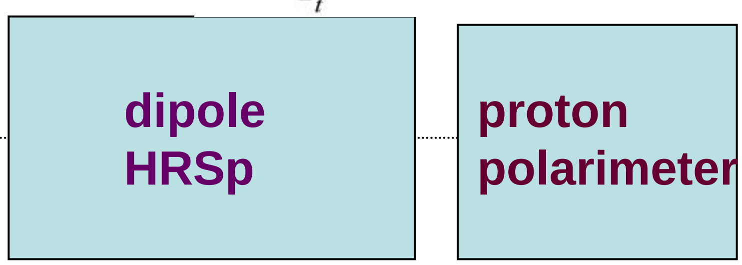
$$\frac{G_E^2(Q^2)}{G_M^2(Q^2)} = -\frac{P_\perp}{P_\parallel}\cdot\frac{E_e + E_e^{'}}{2M_p}\tan(\theta_e/2)$$

JLAB Hall A two-arm spectrometer (top view)



transvesre component $P_\perp$ *no precession,*
longitudinal component $P_\parallel$ *precesses*
with the angle $=\gamma(\mu_p - 1)\Theta_B$





Polarized e-beam
P_e ~0.4-0.6,
0.934-4.091 GeV,
5-15 μA.

Vertical bending
Θ_B=45 deg.

JLAB Polarization Transfer Results

(V.Punjabi, C.F.Perdrisat, et al. Phys.Rev. C71, 2005)

disagreement with LT separation results

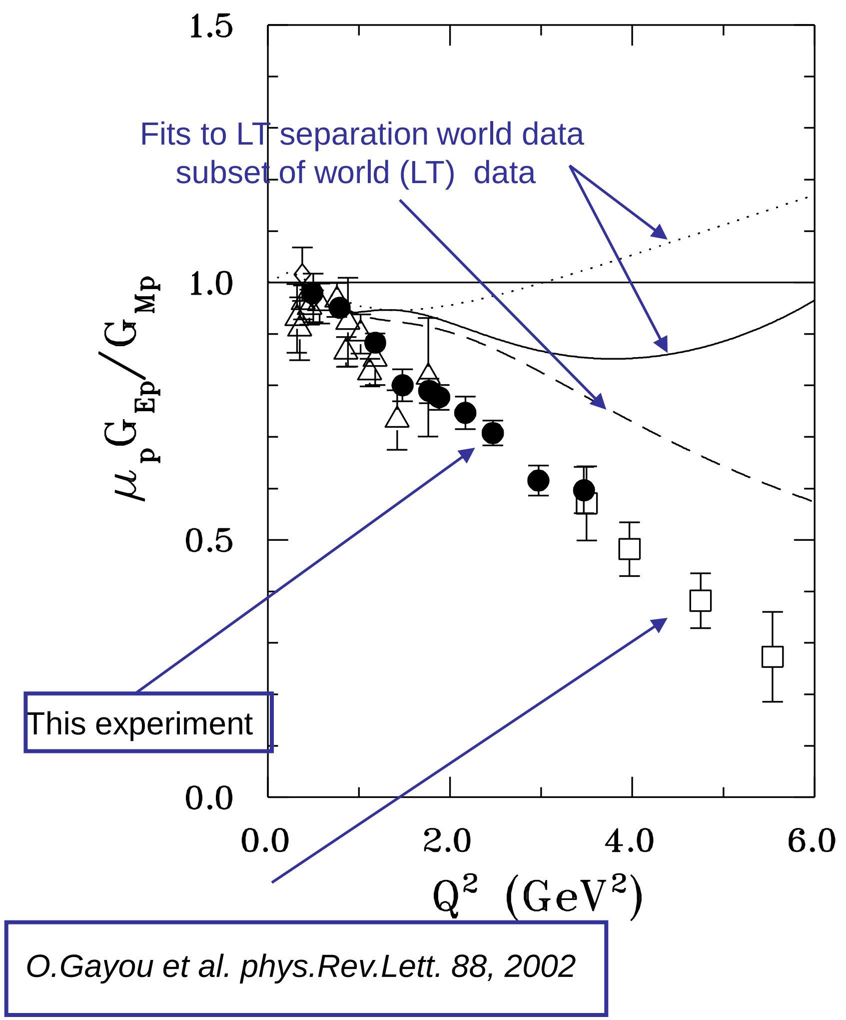


TABLE VI: The ratio $\mu_p G_{Ep}/G_{Mp} \pm$ statistical uncertainty (1σ). Δ_{sys} is the systematic uncertainty from Table VII. $\overline{Q}^2$ and $\overline{\chi}_\theta$ are the weighted average four momentum transfer squared and spin precession angle, respectively. ΔQ^2 is half the Q^2 acceptance. The last column P_t/P_ℓ is the ratio of measured polarization components at the target, the relative uncertainty is the same as for $\mu_p G_{Ep}/G_{Mp}$.

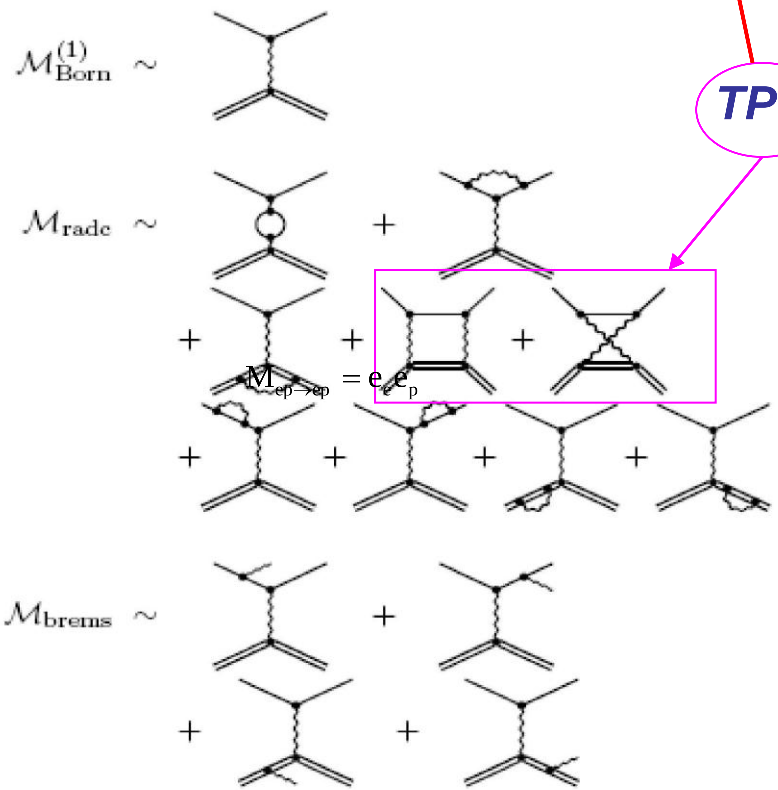
$\overline{Q}^2 \pm \Delta Q^2$ (GeV^2)	$\overline{\chi}_\theta$ (deg)	$\mu_p G_{Ep}/G_{Mp}$ (± stat. uncert.)	Δ_{sys}	P_t/P_ℓ
0.49±.04	105	0.979 ± 0.016	0.006	-0.822
0.79±.02	118	0.951 ± 0.012	0.010	-0.527
1.18±.07	136	0.883 ± 0.013	0.018	-0.492
1.48±.11	150	0.798 ± 0.029	0.026	-0.422
1.77±.12	164	0.789 ± 0.024	0.035	-0.381
1.88±.13	168	0.777 ± 0.024	0.033	-0.368
2.13±.15	181	0.747 ± 0.032	0.034	-0.329
2.47±.17	196	0.703 ± 0.023	0.033	-0.284
2.97±.20	218	0.615 ± 0.029	0.021	-0.224
3.47±.20	239	0.606 ± 0.042	0.014	-0.198

Radiative Corrections & TPE graphs

Contribution from two photon exchange diagram not taken into account in traditional analysis may be an explanation

$$\left|M_{ep\to ep}\right|^2 = e_e^2 e_p^2 \left[\left|M_{Born}\right|^2 + 2e_e e_p M_{Born}\, \mathrm{Re}\left(M^*_{2\gamma}\right) + 2e_e e_p \left(M_{e-bremm} M^*_{p-bremm}\right)\right]$$

TPE



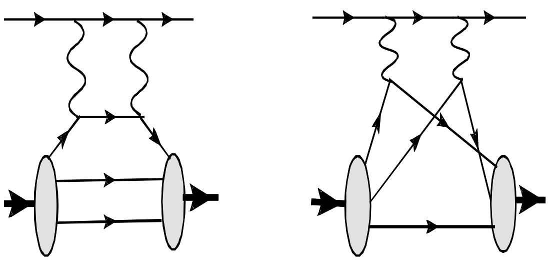
$$2e_e e_p M_{Born}\, \mathrm{Im}\left(M^*_{2\gamma}\right) \sim P_{transverse}$$

perpendicular to the production plane, not related neither beam nor target helicity (spontanious)

another indication of TPE

small, not measured yet

Charge asymmetry & TPE graph theoretical calculations



Charge asymmetry

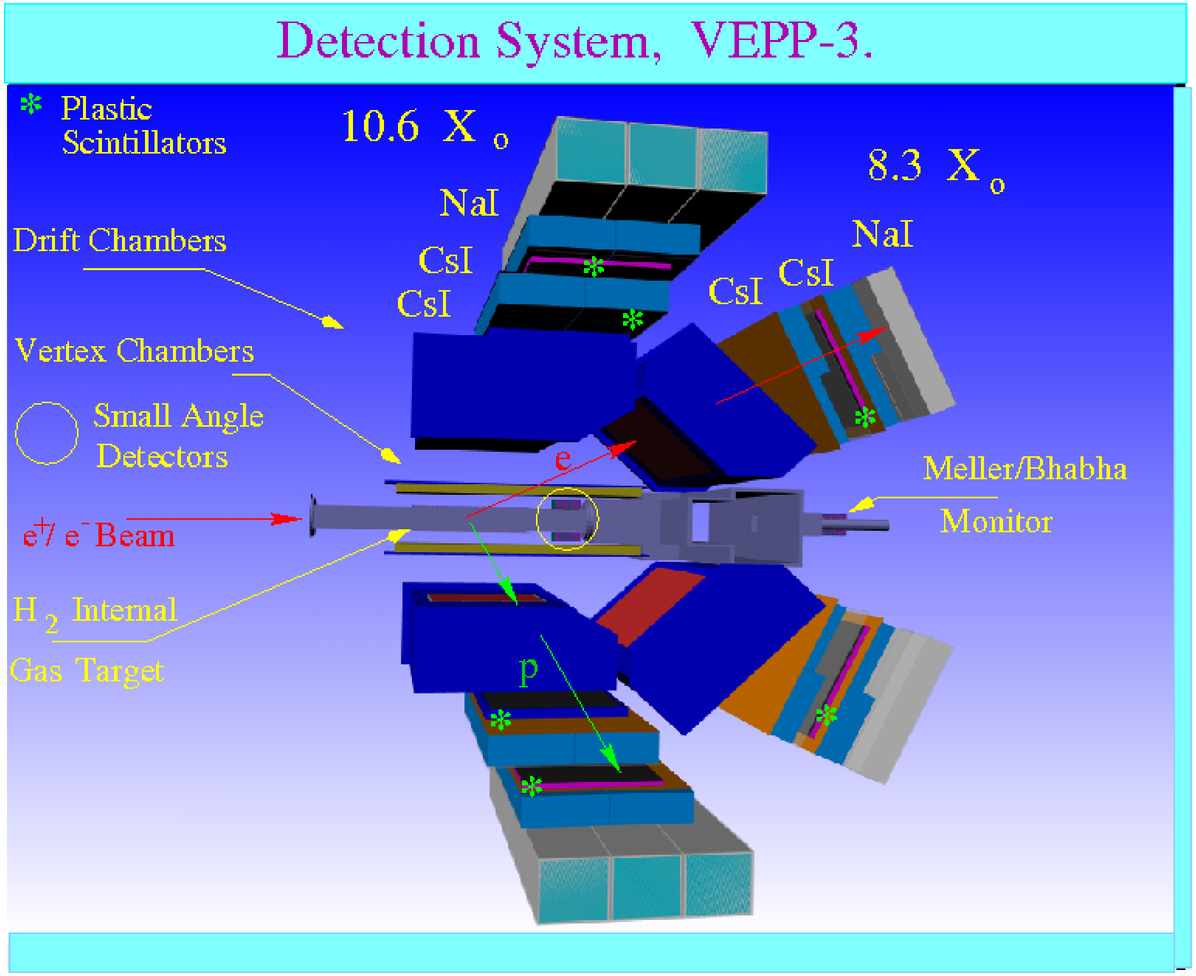
$$\frac{\sigma^+}{\sigma^-} \simeq \frac{\left|M_{Born}\right|^2 + 2e_e e_p M_{Born}\ \mathrm{Re}(M^*_{2\gamma}) + 2e_e e_p\ \mathrm{Re}(M_{e-bremstr} M^*_{p-bremstr})}{\left|M_{Born}\right|^2 - 2e_e e_p M_{Born}\ \mathrm{Re}(M^*_{2\gamma}) - 2e_e e_p\ \mathrm{Re}(M_{e-bremstr} M^*_{p-bremstr})}$$

Intermediate state contributions → model dependent calculations

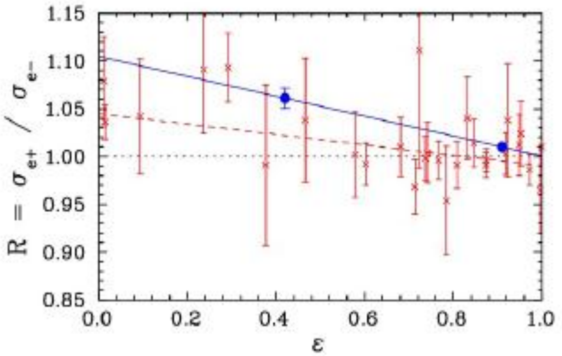
- *P.A.M. Guichon and M. Vanderhaeghen, PRL91, 142303 (2003)*
- *P.G. Blunden, W. Melnitchouk, and J.A. Tjon,*
  PRC72, 034612 (2005), PRL91, 142304 (2003)
- *M.P. Rekalo and E. Tomasi-Gustafsson, EPJA22, 331 (2004)*
- *Y.C. Chen et al.,PRL93, 122301 (2004)*
- *A.V. Afanasev and N.P. Merenkov, PRD70,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

VEPP-3 experiment

E_e=1.6 GeV (up to 2 GeV)
electron current ~ 30mA, positron current limited to ~ 9mA
HERMES type gas target 10^{15} atoms/cm^2, L≈10^{31}cm^{-2}s



Planned for 2009-11



JLAB Polarization Transfer Results

Hall B, CLAS spectrometer,
primary 5.7Gev e-beam 1μA→ γ-beam → e+e- beam 250 pA→ thick hydrogen target→L=1.3x10^{33} cm^{-2}sec^{-1}
Major challenge hard background conditions related to e+e- production target