Radiative Corrections and Charge Asymmetry in $e\pm p$ elastic scattering

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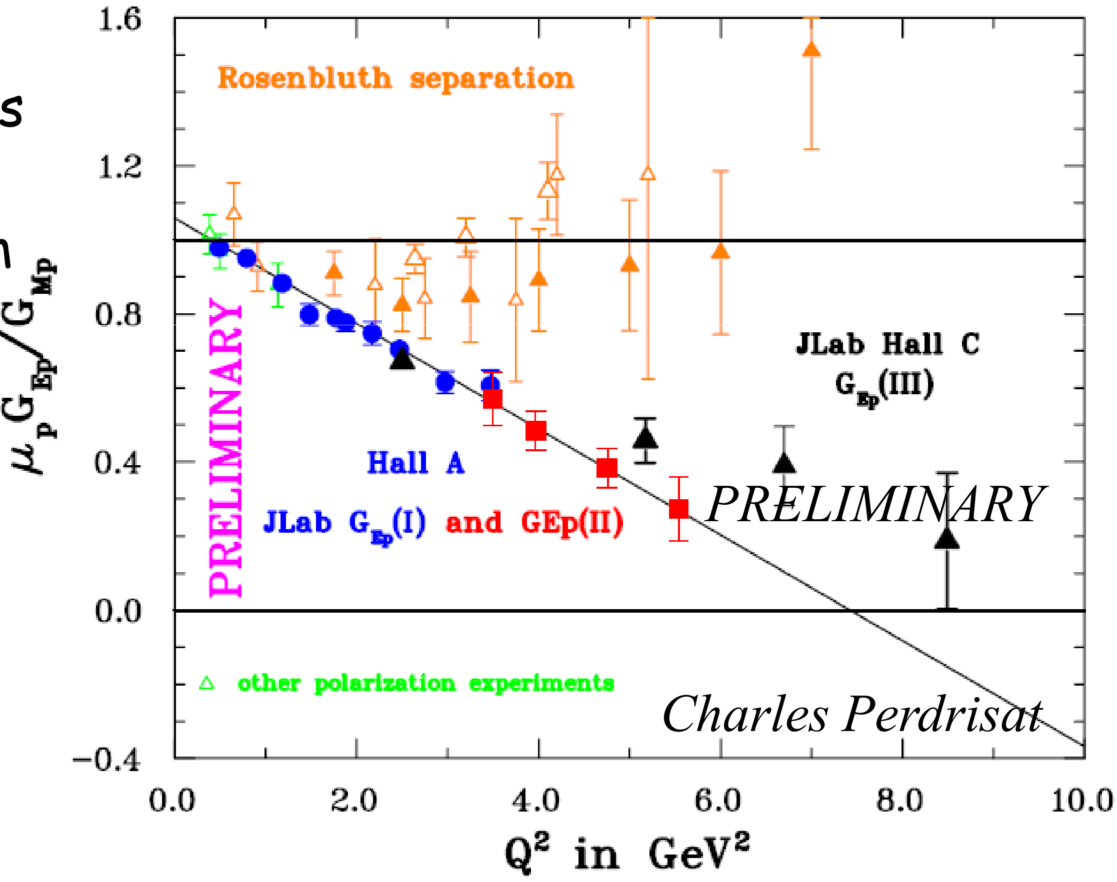
Polarization experiments GEP -Jlab

A.I. Akhiezer and M.P. Rekalo, 1967

Space-like region

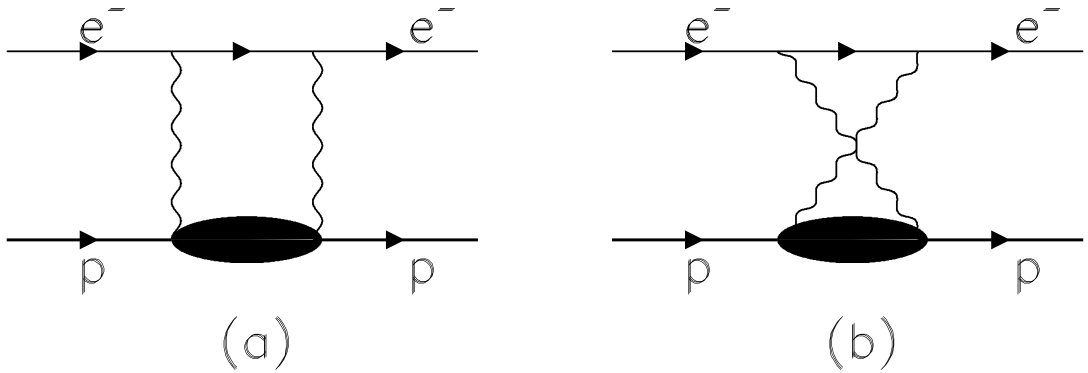
1) "standard" dipole function for the nucleon magnetic FFs GMp and GMn
2) linear deviation from the dipole function for the electric proton FF GEp
3) ***contradiction between polarized and unpolarized measurements***



Two photon exchange

- The calculation of the box amplitude requires the description of intermediate nucleon excitation and of their FFs at any Q^2

- Different calculations give quantitatively different results



Theory not enough constrained!

Model independent statements

How to proceed?

Our Suggestion:

- Search for model independent statements
- Exact calculation in frame of QED ($p \sim \mu$)
- Prove that QED box is upper limit of QCD box diagram

Our Conclusion

- Two photon contribution is negligible (real part)
- Radiative corrections are huge: take into account higher order effects (Structure Functions method)

E.A. Kuraev, Yu. Bystritsky, V. Bytev, E. T.-G. , (2006-2008)

Model independent statements

In presence of 2γ exchange :

- Non linearity in the Rosenbluth fit
- charge asymmetry in the crossed channel (and/or odd powers of cos θ)
- Non vanishing odd polarization observables

- Different cross section for electron/positron - proton elastic(inelastic) scattering

M. P. Rekalo, E. T.-G. , EPJA (2004), Nucl. Phys. A (2003)

Electron/Positron scattering

$$\frac{d\sigma^{e^\pm h \to e^\pm h}}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \left[A(Q^2) + B(Q^2)\tan^2\frac{\theta}{2}\right]$$

Born approximation

$$\left|M^{\pm}\right|^2 = \left|\pm M_{1\gamma}\right|^2 = \left|M_{1\gamma}\right|^2$$

2γ exchange:

$$\left|M^{\pm}\right|^2 = \left|\pm M_{1\gamma} + M_{2\gamma}\right|^2 = \left|M_{1\gamma}\right|^2 \pm 2\,\mathrm{Re}\, M_{1\gamma} M^*_{2\gamma} + \cancel{\left|M_{2\gamma}\right|^2}$$

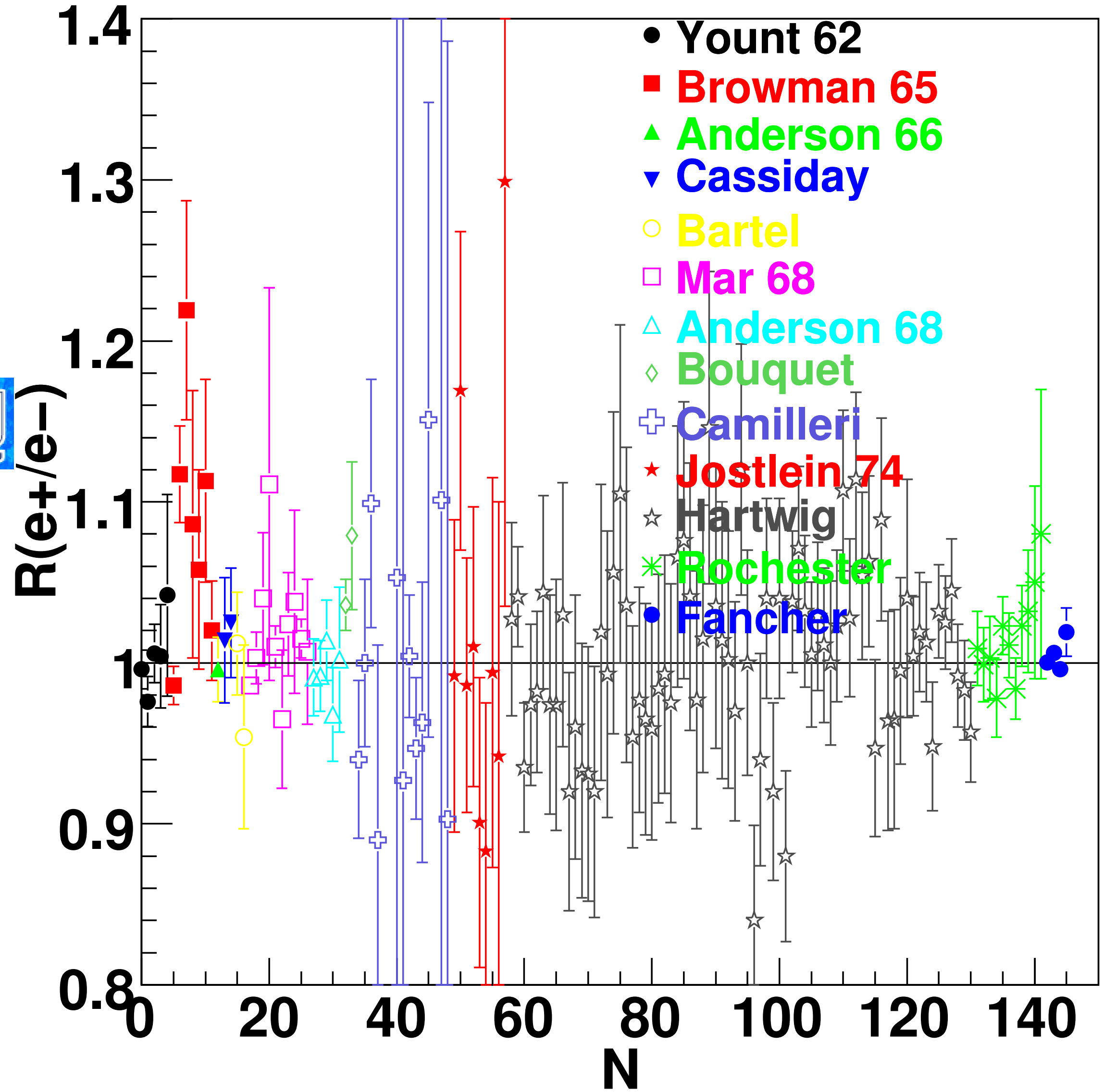
Asymmetry

$$A = \frac{\sigma(e^+p) - \sigma(e^-p)}{\sigma(e^+p) + \sigma(e^-p)} = \frac{2\,\mathrm{Re}\, M_{1\gamma} M_{2\gamma}}{\left|M_{1\gamma}\right|^2}$$

The effect is enhanced in the ratio

$$R = \frac{\sigma(e^+p)}{\sigma(e^-p)} = \frac{1+A}{1-A} \cong 1 + \frac{4\,\mathrm{Re}(M_{1\gamma} M^*{}_{2\gamma})}{\left|M_{1\gamma}\right|^2}$$

World data e+e- scattering



Fitting with a constant

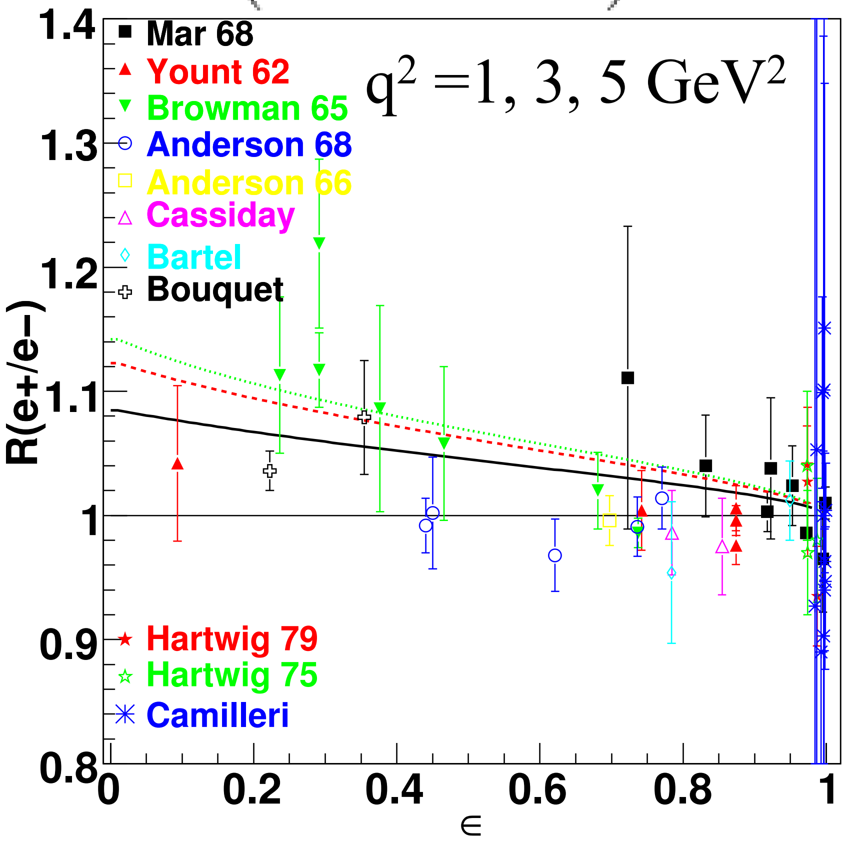
R=0.997

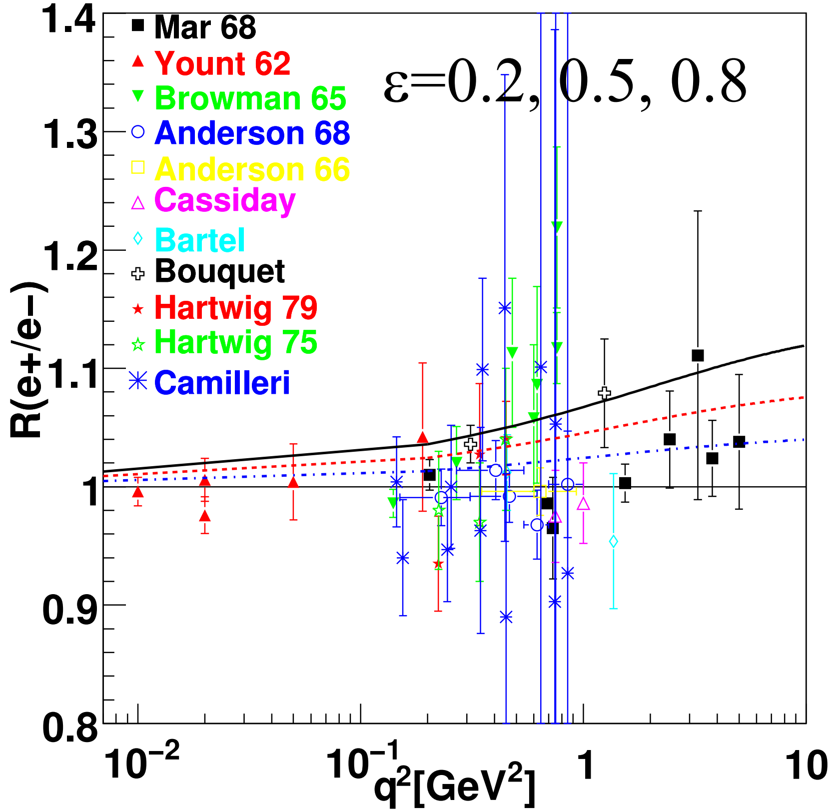
DR=0.003

$\chi^2 = 1.03$

Elastic scattering

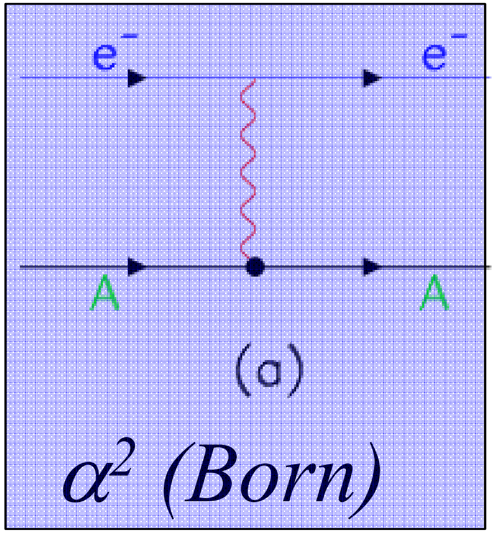
$$R = \frac{\sigma(e^+h \to e^+h)}{\sigma(e^-h \to e^-h)} = \frac{1 + A^{odd}}{1 - A^{odd}}$$

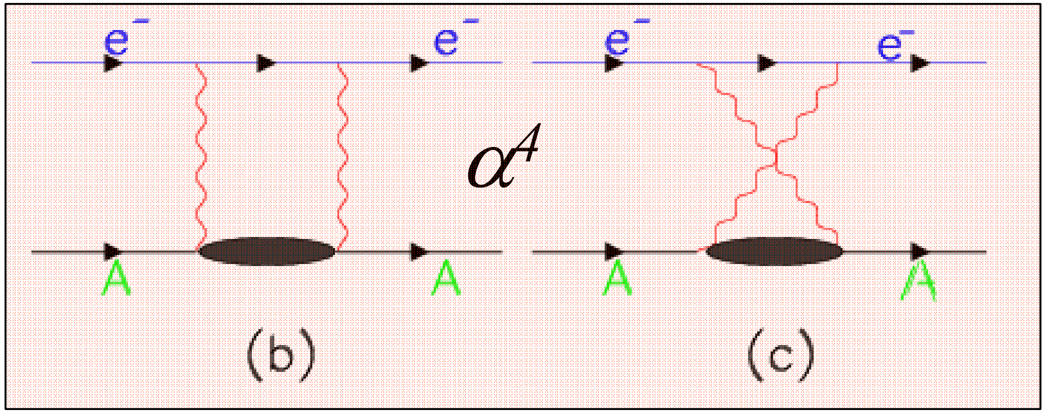


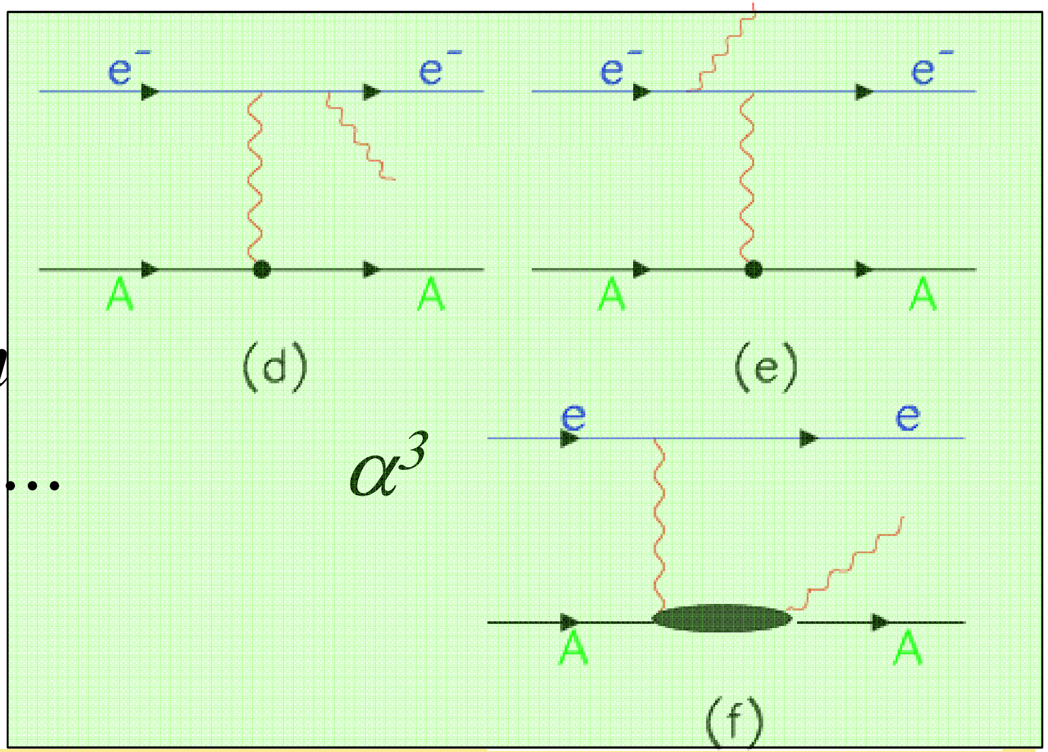


$$R = (-0.071 \pm 0.016)\,\varepsilon + (1.058 \pm 0.014)$$

Radiative corrections(first order)







+vertex corrections

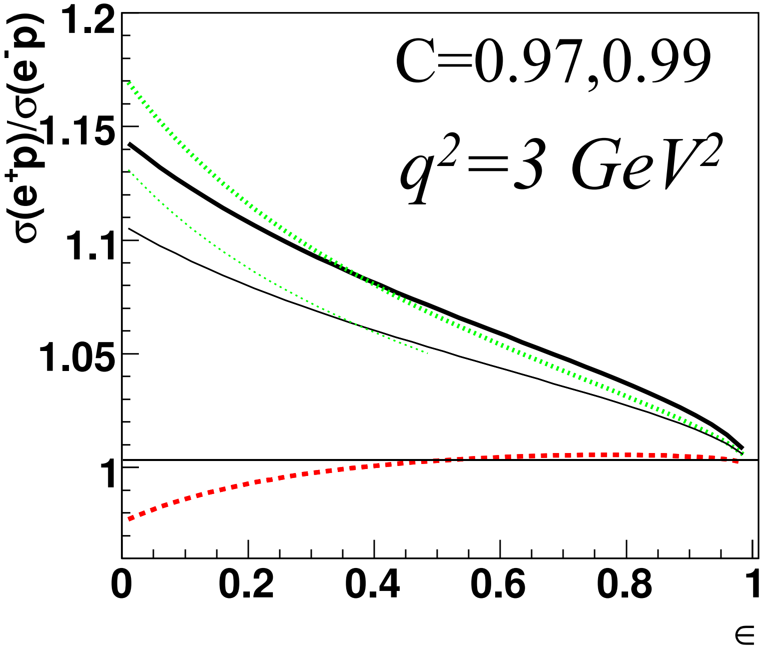
+ real proton emission

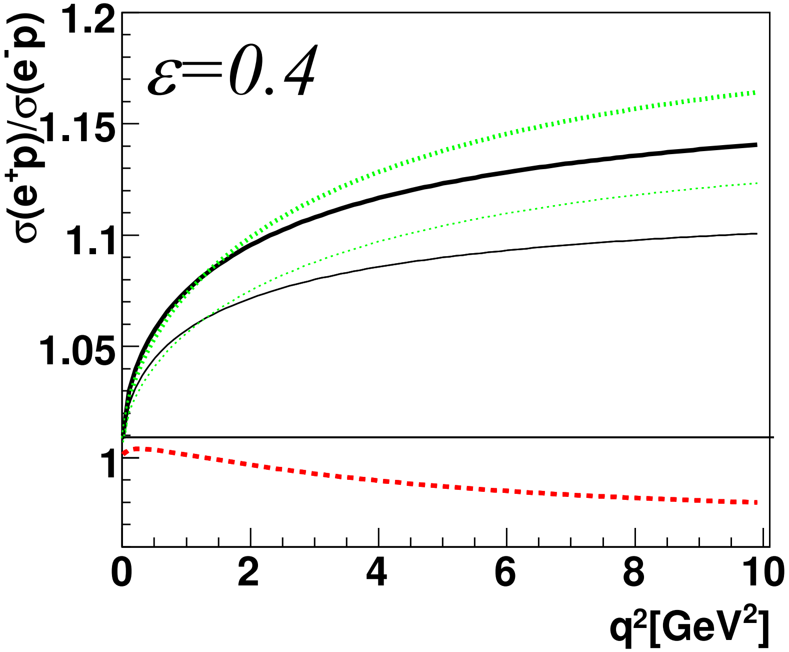
+vacuum polarization...

Interference !

Electron/Positron scattering

E.A. Kuraev, V.V.Bytev, S.Bakmaev and E.T-G, PRC 78, 015295 (2008).





Soft photon emission **2γ exchange**

$$A^{odd} = \frac{d\sigma^{e+p} - d\sigma^{e^-p}}{2d\sigma^B} =$$

$$= \frac{2\alpha}{\pi}\left[\boxed{\ln\frac{1}{\rho}\ln\frac{(2\Delta E)^2}{ME}}\ \boxed{-\ln x\ln\rho + \mathrm{Li}_2\left(1-\frac{1}{\rho x}\right) - \mathrm{Li}_2\left(1-\frac{\rho}{x}\right)}\right],$$

$$\rho = \left(1-\frac{Q^2}{s}\right)^{-1} = 1 + 2E/M\sin^2(\theta/2),\ x = \frac{\sqrt{1+\tau}+\sqrt{\tau}}{\sqrt{1+\tau}-\sqrt{\tau}},$$

Comparison Experiment-Theory

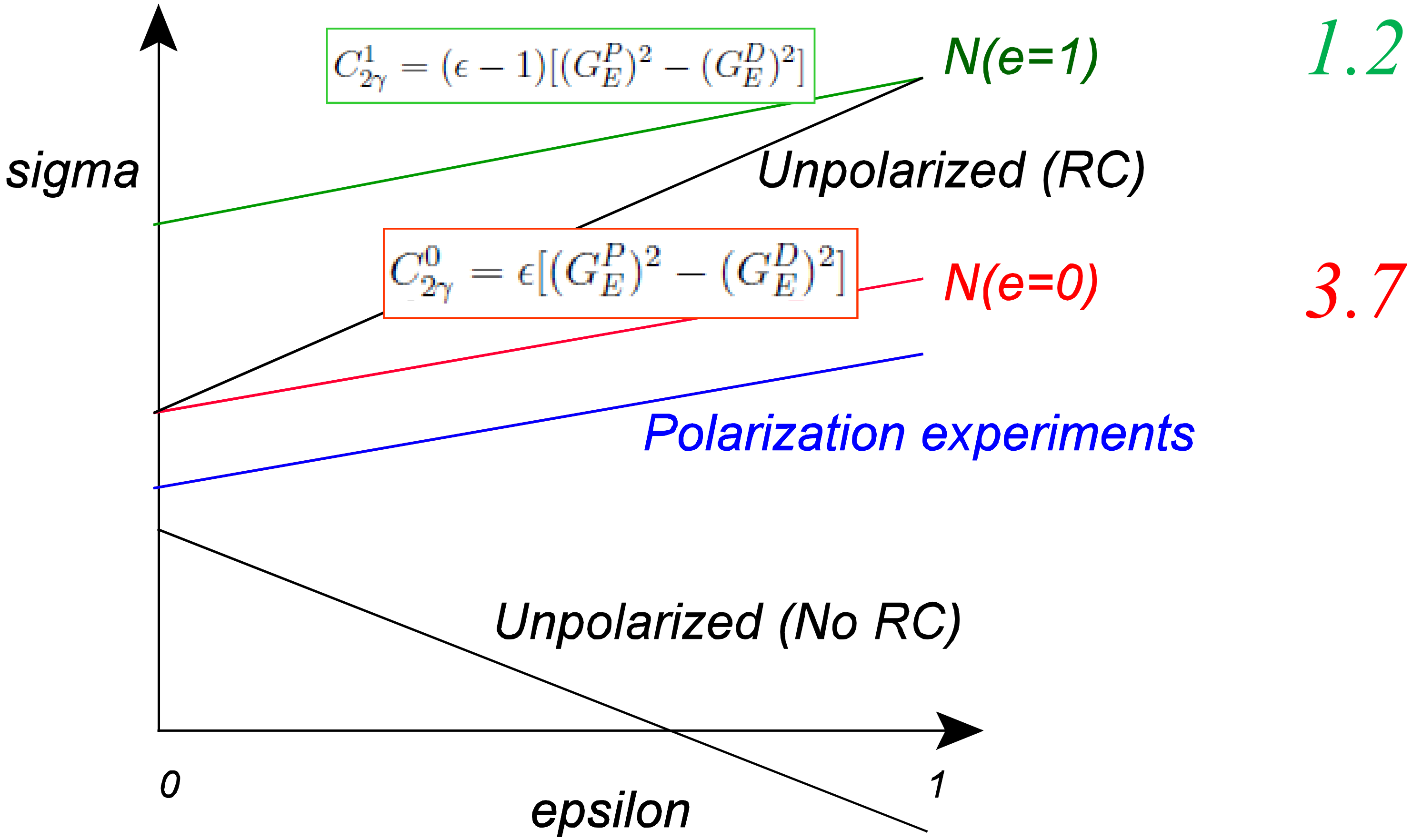
$$D(Q^2, \epsilon, \Delta E) = \frac{R_i^{raw} - R^{th}(Q^2, \epsilon, \Delta E)}{R^{th}(Q^2, \epsilon, \Delta E)},$$

Ref.	Q^2 [GeV^2]	ϵ	T	N	$< R \pm \Delta R >$	$< D \pm \Delta D >$	χ^2	χ^2_1	χ^2_0
[25]	1.2÷3.3	0.1÷0.87	H	5	0.994 ± 0.008	-0.007 ± 0.008	3.1	3.1	3.1
[23]	0.27÷0.76	0.29÷0.68	H	6	1.024 ± 0.015	0.007 ± 0.010	11.6	10.1	4.2
[26]	0.64	0.70	H	1	0.996 ± 0.020	$0. \pm 0.020$	0.09	2.87	1.13
[29]	0.85, 0.78	0.75, 1	H	2	0.981 ± 0.026	-0.003 ± 0.026	0.02	3.7	1.94
[27]	0.45, 1.37	0.95, 0.78,	H	2	0.998 ± 0.028	-0.008 ± 0.028	1.01	1.10	1.79
[31]	0.20÷ 0.85	0.44÷ 0.77	H	5	0.992 ± 0.012	-0.006 ± 0.012	2.68	0.67	7.17
[30]	0.2÷5	0.72÷0.99	H	8	0.993 ± 0.005	-0.010 ± 0.005	11.6	137.3	9.2
[32]	0.31, 1.24	0.	H	2	1.038 ± 0.015	0.009 ± 0.017	0.42	6.16	11.1
[34]	0.14÷ 0.75	0.98 ÷1	H	15	0.973 ± 0.020	-0.028 ± 0.020	14.9	12.9	14.8
[36]	0.22÷ 0.45	0.97÷ 0.99	H	3	0.992 ± 0.030	-0.009 ± 0.030	0.96	1.21	0.96
[38]	0.22÷O.45	0.97÷ 0.98	C,Al	3	1.005 ± 0.023	0.003 ± 0.023	4.49	5.56	4.57
					Total			χ^2/ndf	
				52	0.996 ± 0.004	-0.007 ± 0.003	1.0	3.7	1.2

Comparison Data-Theory

$$R_{0,1} = \frac{\sigma^+}{\sigma^-} = \frac{\sigma^B + C_{2\gamma}^{0,1}}{\sigma^B - C_{2\gamma}^{0,1}}, \quad A_{0,1} = \frac{C_{2\gamma}^{0,1}}{\sigma^B},$$

$$\chi^2_{0,1}(Q^2,\epsilon,\Delta E) = \frac{(R_i - R_{0,1})^2 (Q^2,\epsilon,\Delta E)}{\Delta R_i^2 (Q^2,\epsilon,\Delta E)},$$

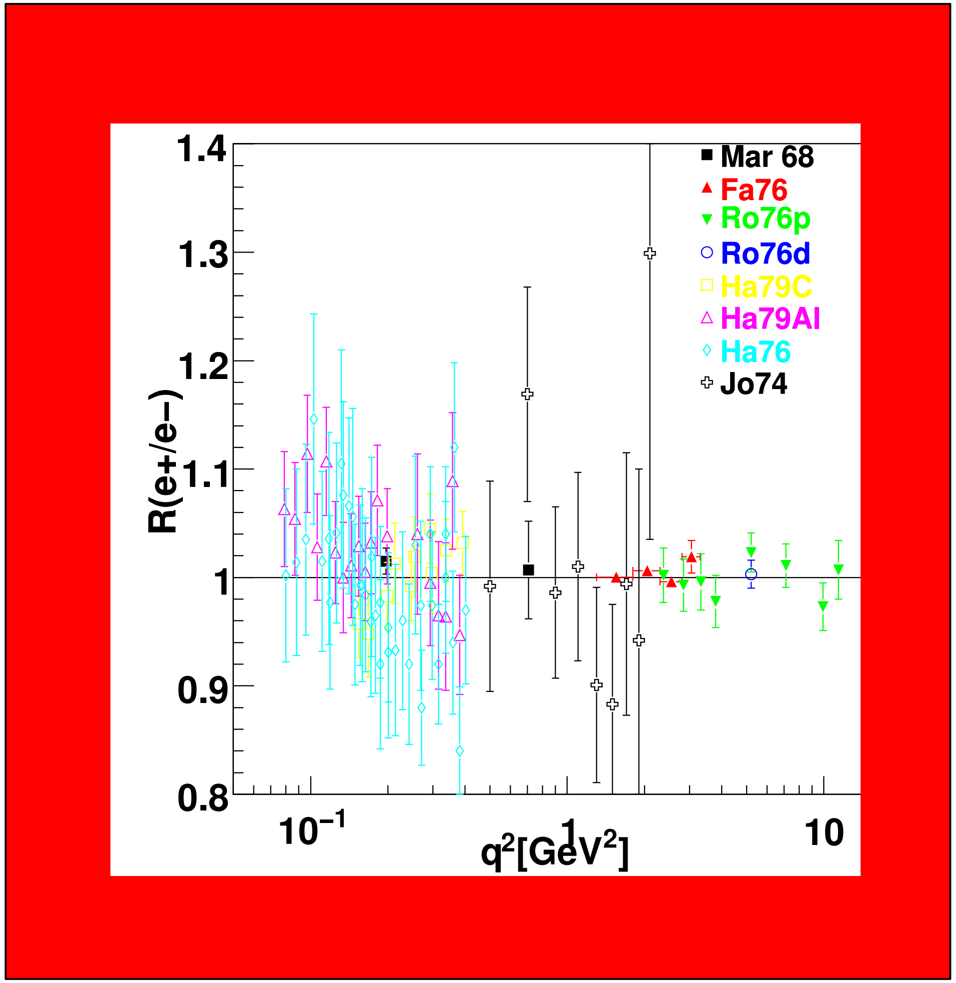


Inelastic e+e- scattering

$$R = 1.002 \pm 0.002$$

$$R = (-0.0009 \pm 0.001)q^2 + (1.005 \pm 0.003)$$

$$\chi^2 = 0.84$$

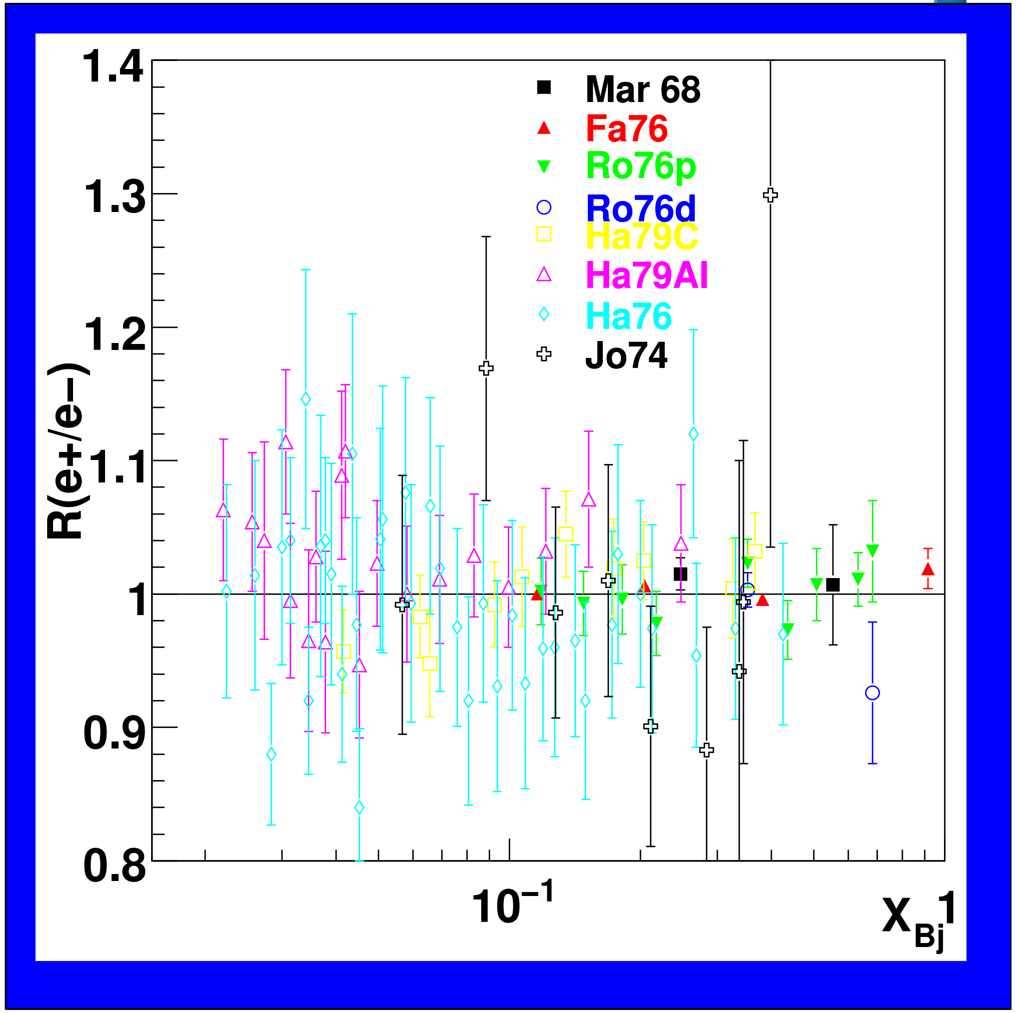


Inelastic e+e- scattering

$$R=1.002\pm0.002$$

$$R=(0.005 \pm 0.014)X_{Bj} + (1.002 \pm 0.004)$$

$$\chi^2=0.84$$



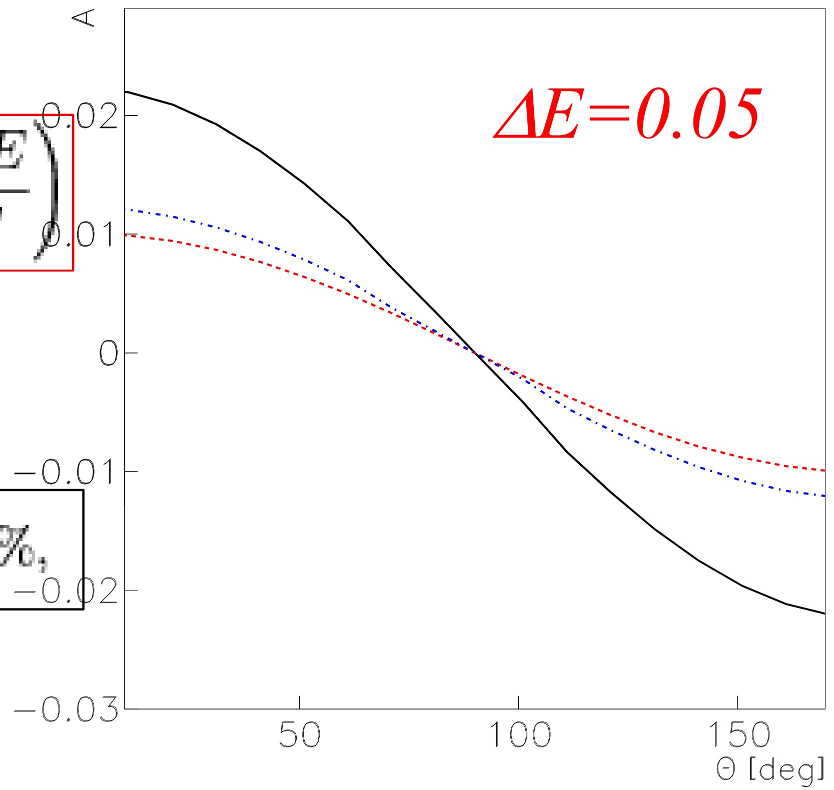
$$x_{Bj} = Q^2/(2M\nu)$$

$$\nu = E - E' = (W^2 - M^2 + q^2)/(2M)$$

Structure Function method

$$e^+ + e^- \to p + \bar{p} + \gamma$$

$$A^{soft}(E) \simeq \frac{2\alpha}{\pi}\left(\ln\frac{1+\beta c}{1-\beta c}\ln\frac{\Delta E}{E}\right)$$

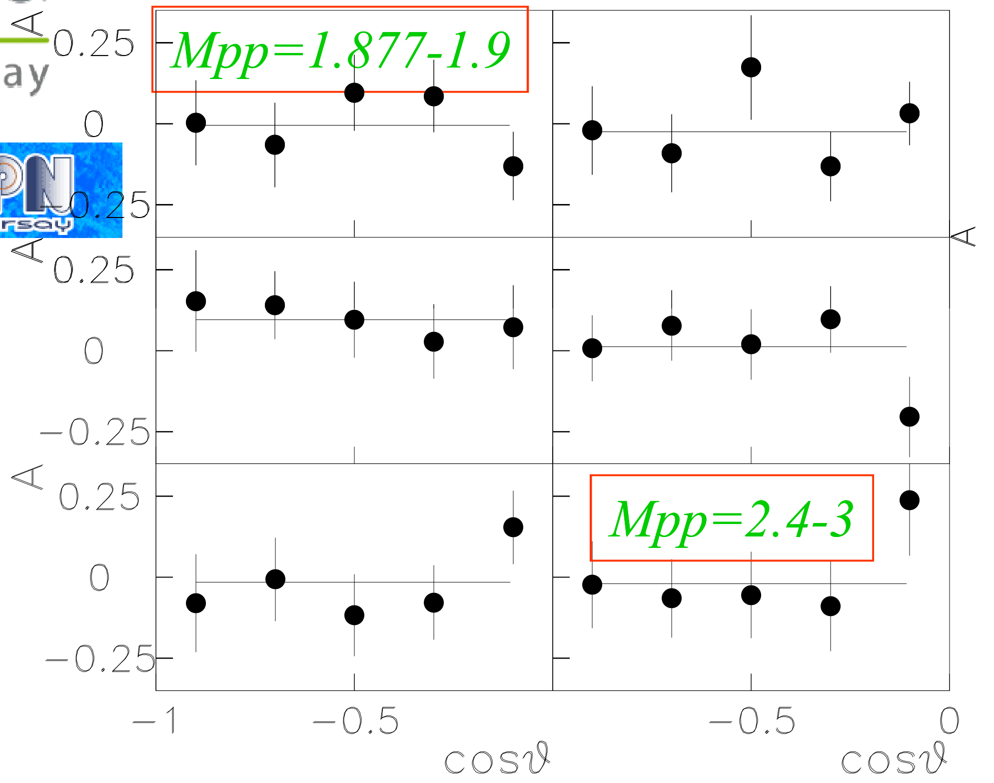


$$A^{tot} = A^{soft} + A^{hard} = \frac{2\alpha}{\pi}\psi(c,\beta),\ |A^{tot}| \le 2\%,$$

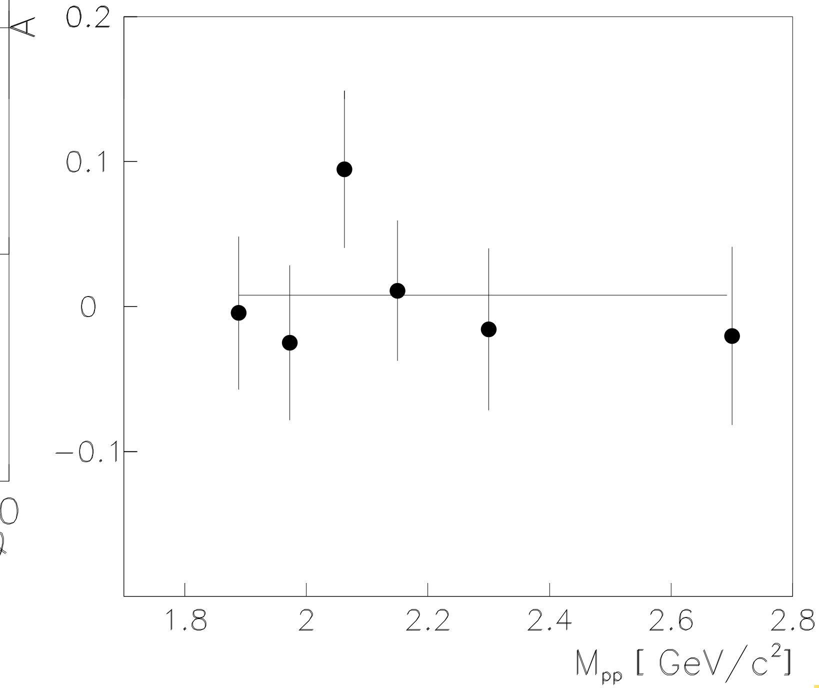
$$\frac{d\sigma}{d\Omega}(c) \pm \frac{d\sigma}{d\Omega}(-c) \sim \int dx_1 \mathcal{D}(x_1,L)\mathcal{D}(x_2,L)dx_2\left(1+\frac{\alpha}{\pi}K\right)$$

$$\frac{d\sigma}{d\Omega}(c) + \frac{d\sigma}{d\Omega}(-c) = 2\frac{d\sigma_0}{d\Omega}\left[1+\frac{\alpha}{\pi}\left(\frac{3}{2}L - 2(L-1)\ln\frac{\Delta E}{E} + \frac{\pi^2}{3} - 2\right)\right],\ L = \ln\frac{t}{m^2},$$

BABAR



$A=0.01\pm0.02$



Conclusions

- Determination of the *validity of one photon exchange approximation:* basic question for deriving information on the hadron structure

- in annihilation processes all information is contained in *a precise measurement of the angular distribution*

- Comparison of *scattering* and *annihilation* channels: model independent statements

- *No evidence of two photon exchange* (real part) in the data.

- Precise calculation of radiative corrections