Two-Photon Exchange Contribution to Elastic ep Scattering in a Non-local Field Formalism

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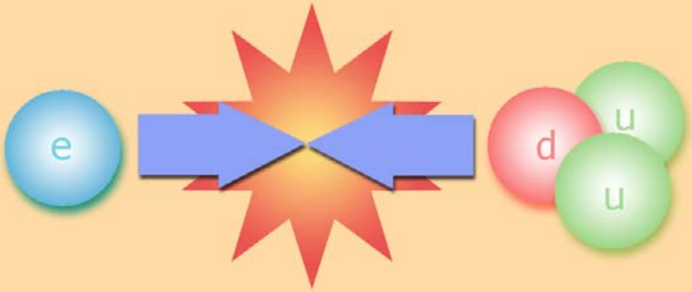
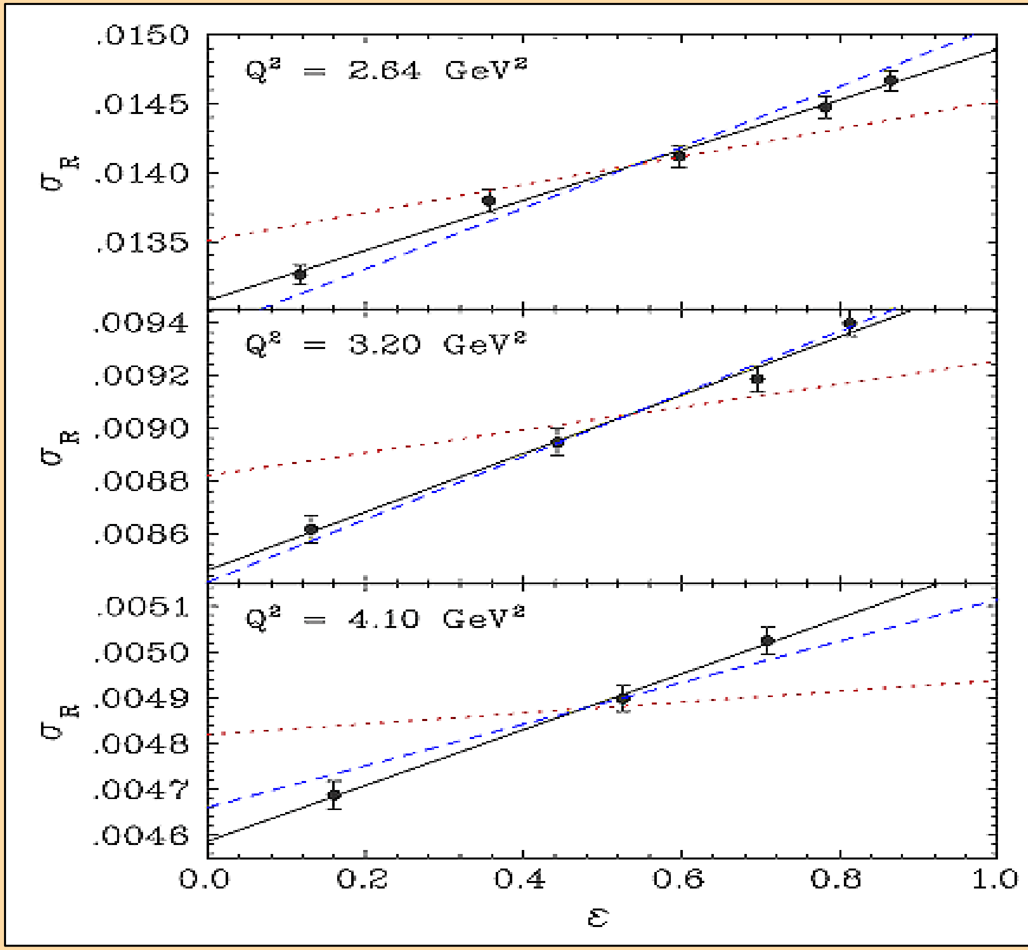
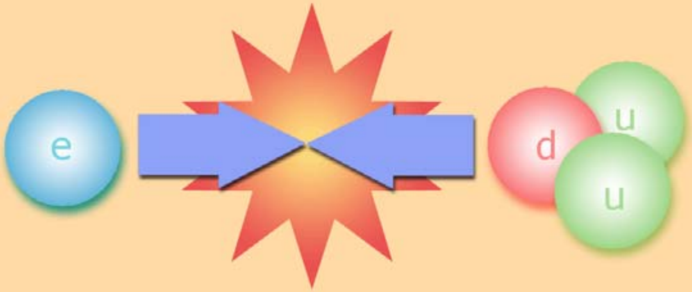
Experimental Disagreement



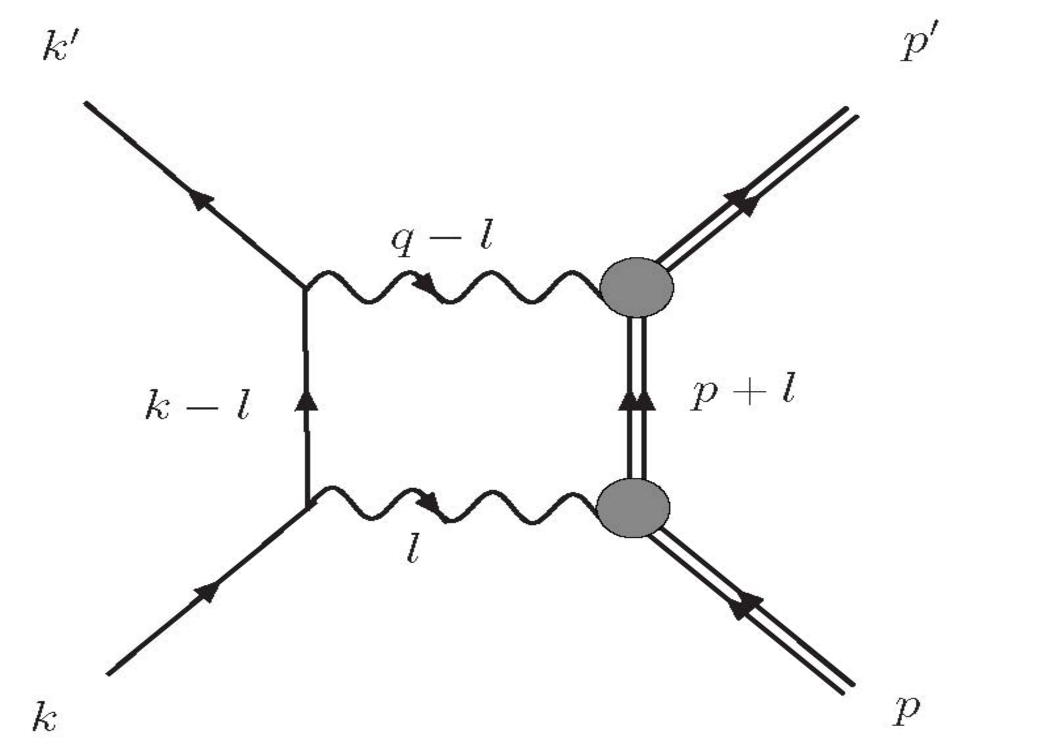
The observed trend in polarization transfer experiment is different from Rosenbluth separation.



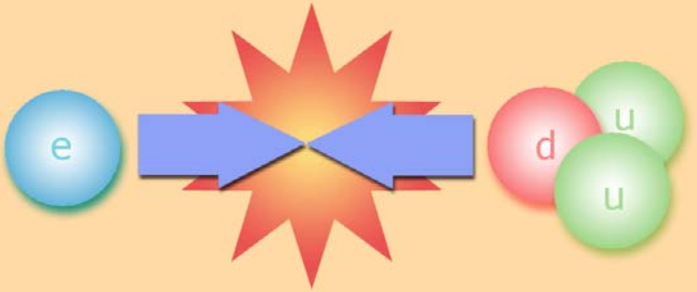
Two-photon Exchange



Two photon exchange diagrams have been proposed as a possible solution to this problem.

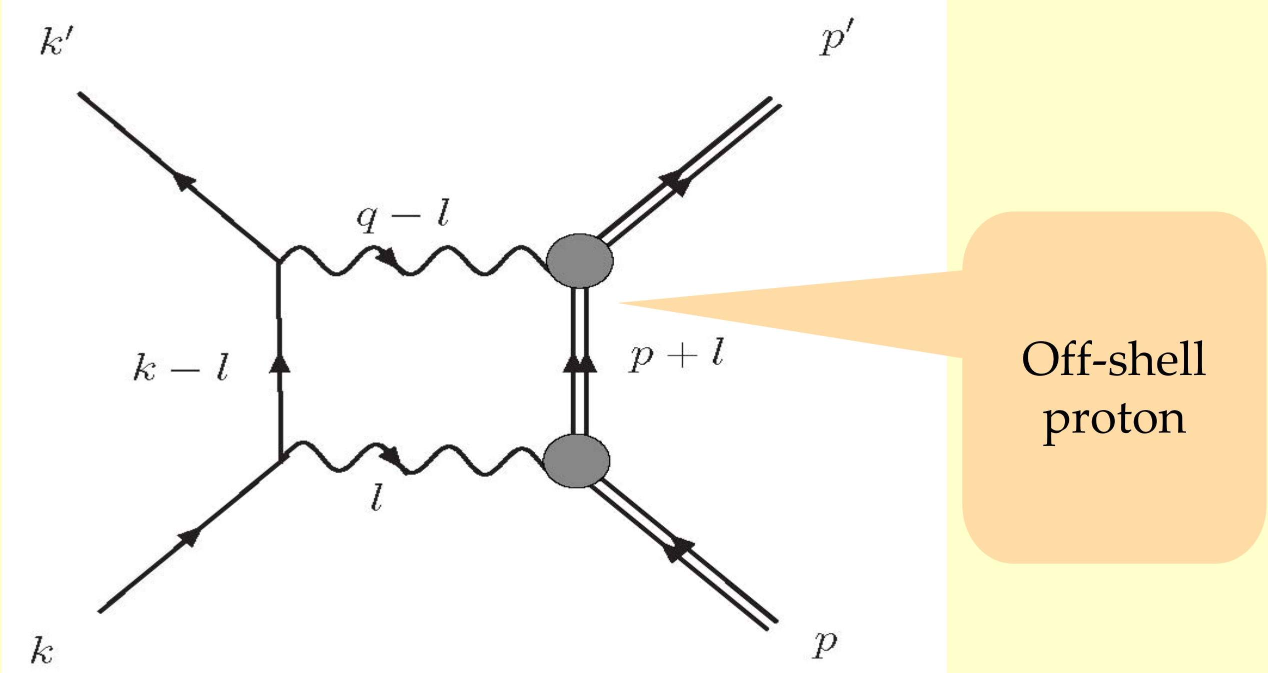


Two-photon Exchange

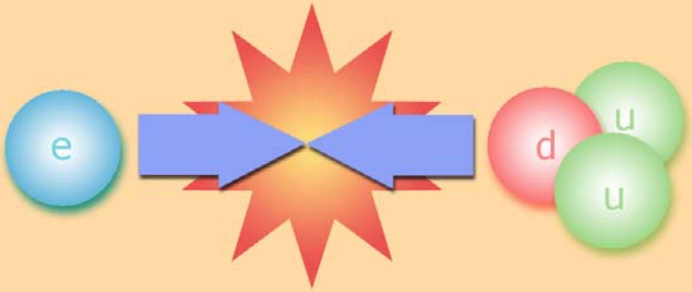


Since one of the proton line is off-shell, one needs a more general electromagnetic vertex and proton propagator. Else the Ward identity is not satisfied

$$q^{\mu}\Gamma_{\mu}(p', p) = S_F^{-1}(p') - S_F^{-1}(p)$$



Non-local Model



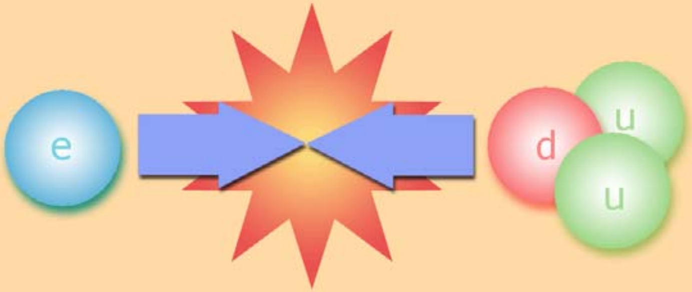
We construct a gauge invariant non-local model for the electromagnetic interaction of proton.

The scale of non-locality is equal to the scale of compositeness of hadrons.

The theory is appropriate for dealing with reactions below this momentum scale.

We include all operators up to dimension 5

Effective Non-local Action



$$\mathcal{L} = \overline{\psi}(i\tilde{\not{D}} - M_p)\psi + \frac{a'}{2M_p}\overline{\psi}\left(\sigma_{\mu\nu} f_2\left[\frac{\partial^2}{\Lambda^2}\right]F^{\mu\nu}\right)\psi + \frac{b'}{2M_p}\overline{\psi}(i\tilde{\not{D}} - M_p)^2\psi$$

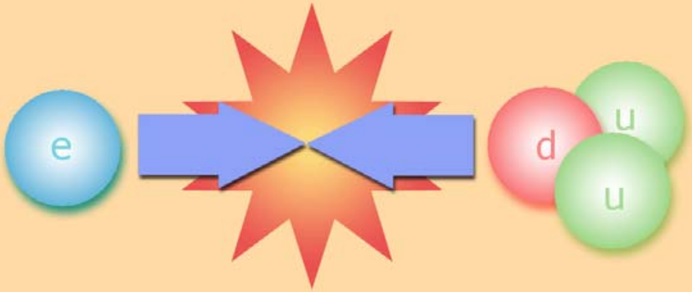
where

$$\mathrm{i}\tilde{\mathrm{D}} = \mathrm{i}\partial - \mathrm{e}\mathrm{f}_1\left[\frac{\partial^2}{\Lambda^2}\right]\mathrm{A}.$$

$\mathcal{L}$ is invariant under the non-local gauge transformations:

$$\delta A_\mu = -\partial_\mu \alpha(x);\ \psi \to e^{\mathrm{ief}_1\left[\frac{\partial^2}{\Lambda^2}\right]\alpha(x)}\psi;\ \overline{\psi} \to \overline{\psi}e^{-\mathrm{ief}_1\left[\frac{\partial^2}{\Lambda^2}\right]\alpha(x)}$$

Effective Non-local Action

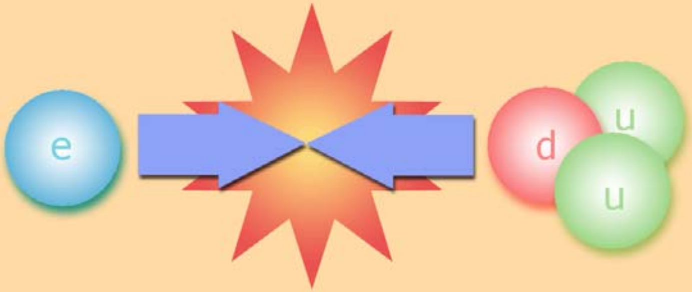


Higher dimensional operators will contribute at higher order in

$$(P^2 - M^2)/\Lambda^2$$

and hence are negligible if the proton is not too far off-shell

Effective Non-local Action

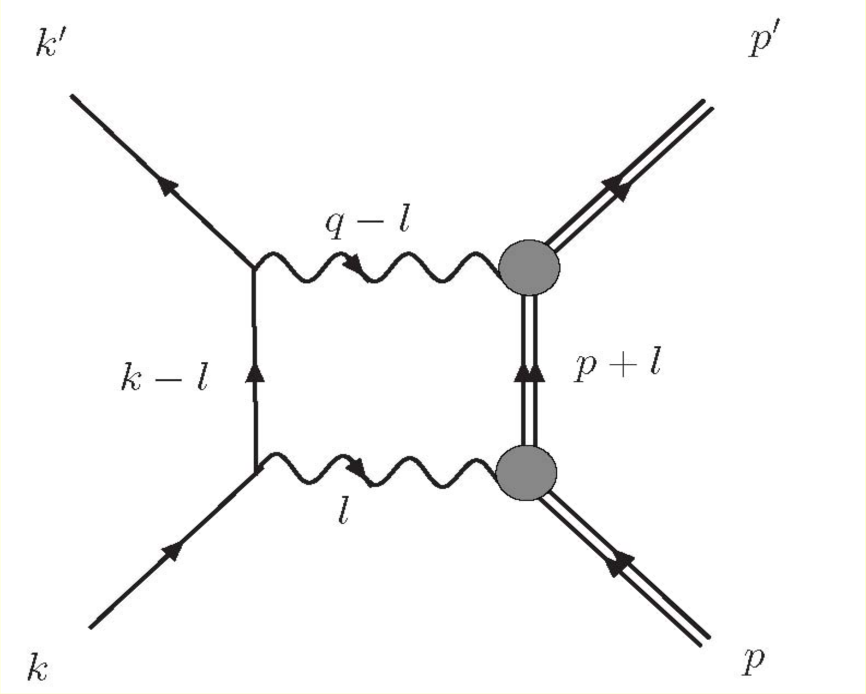


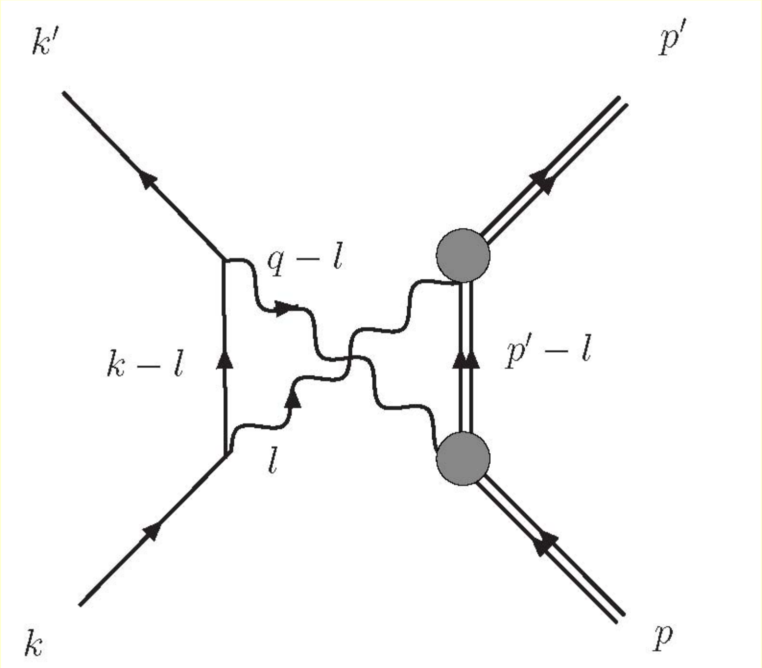
The model so far produces a spurious pole in the proton propagator. We therefore modify it further

$$L = \overline{\psi}\left(i\tilde{\not{D}} - M_p\right)\exp\left[\frac{b'}{2M_p}\left(i\tilde{\not{D}} - M_p\right)\right]\psi + \frac{\alpha'}{2M_p}\overline{\psi}\left(\sigma_{\mu\nu} f_2'\left[\frac{\partial^2}{\Lambda^2}\right]F^{\mu\nu}\right)\psi$$

After expanding the exponential, keeping terms upto $(b')^2$ and field transformation, we find only one extra term if we restrict to operators of dim≤ 5

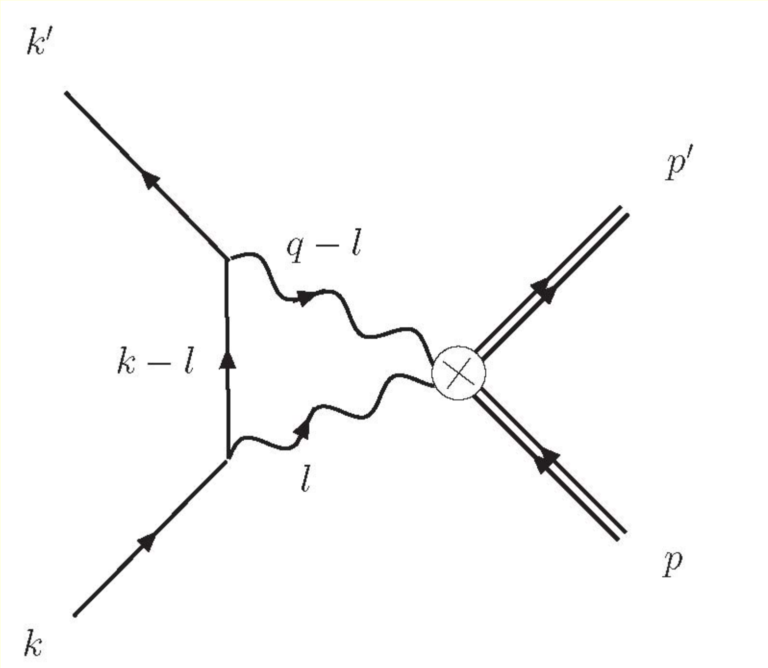
Feynman Diagrams



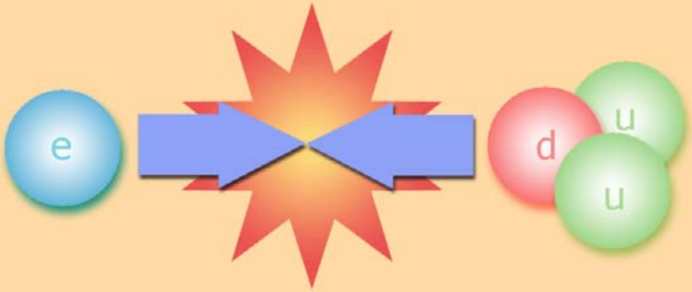


Feynman Diagrams

Order $(b')^2$



G_M and G_E

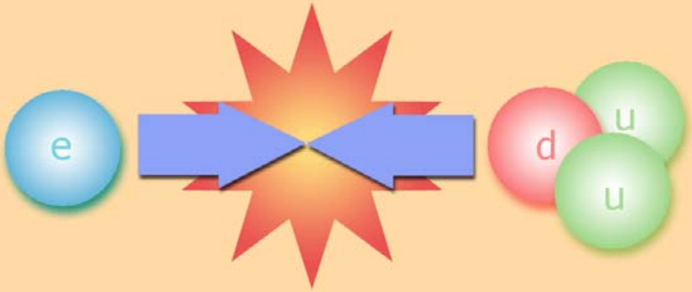


We need G_E and G_M both in the space-like region and time-like region.

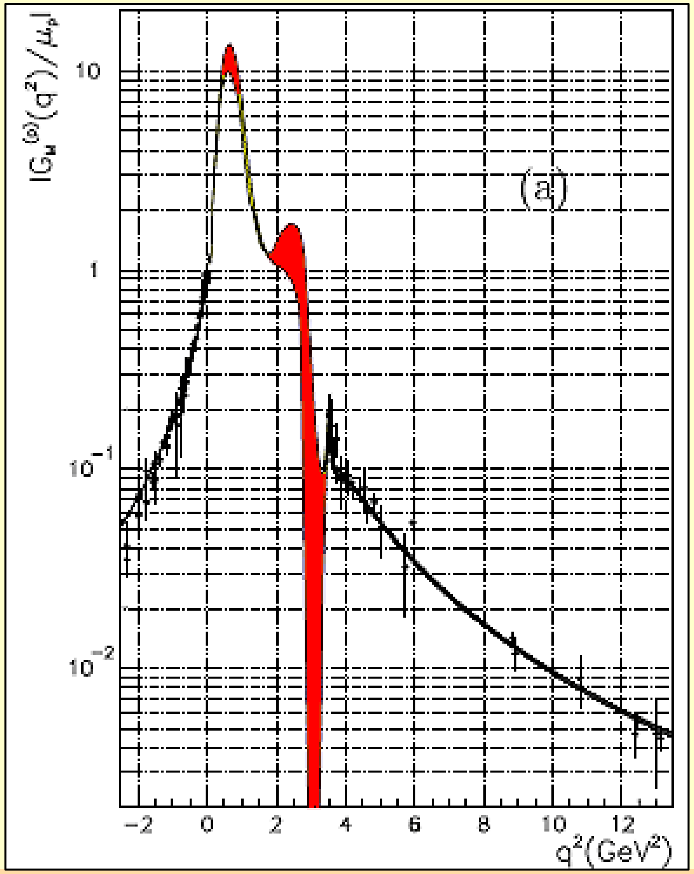
In the space-like region G_M is known reasonably well.
In the time-like region experimental data exists for $4M_P^2 < q^2 < 14$ GeV^2.
In the unphysical region G_M has been extracted by using the dispersion relations.

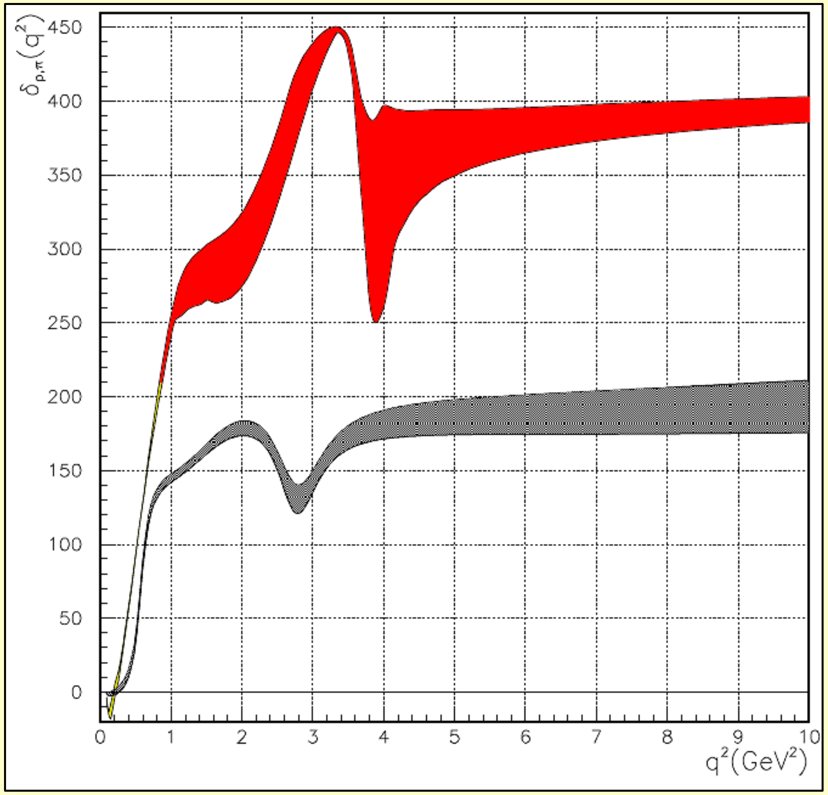
G_E is not known very well in the time-like region.
We use two different models for G_E

G_M



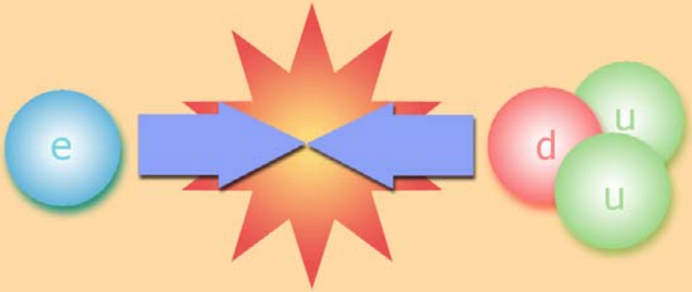
It shows two resonances at masses M ~ 770 MeV and M ~ 1600 MeV. The phase shows a large variation in the unphysical region.





Baldini et al 1999

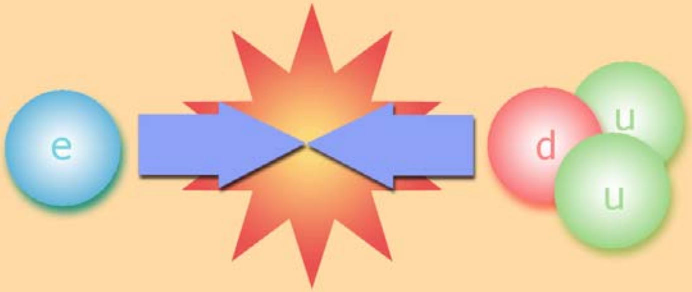
Model G_M and G_E

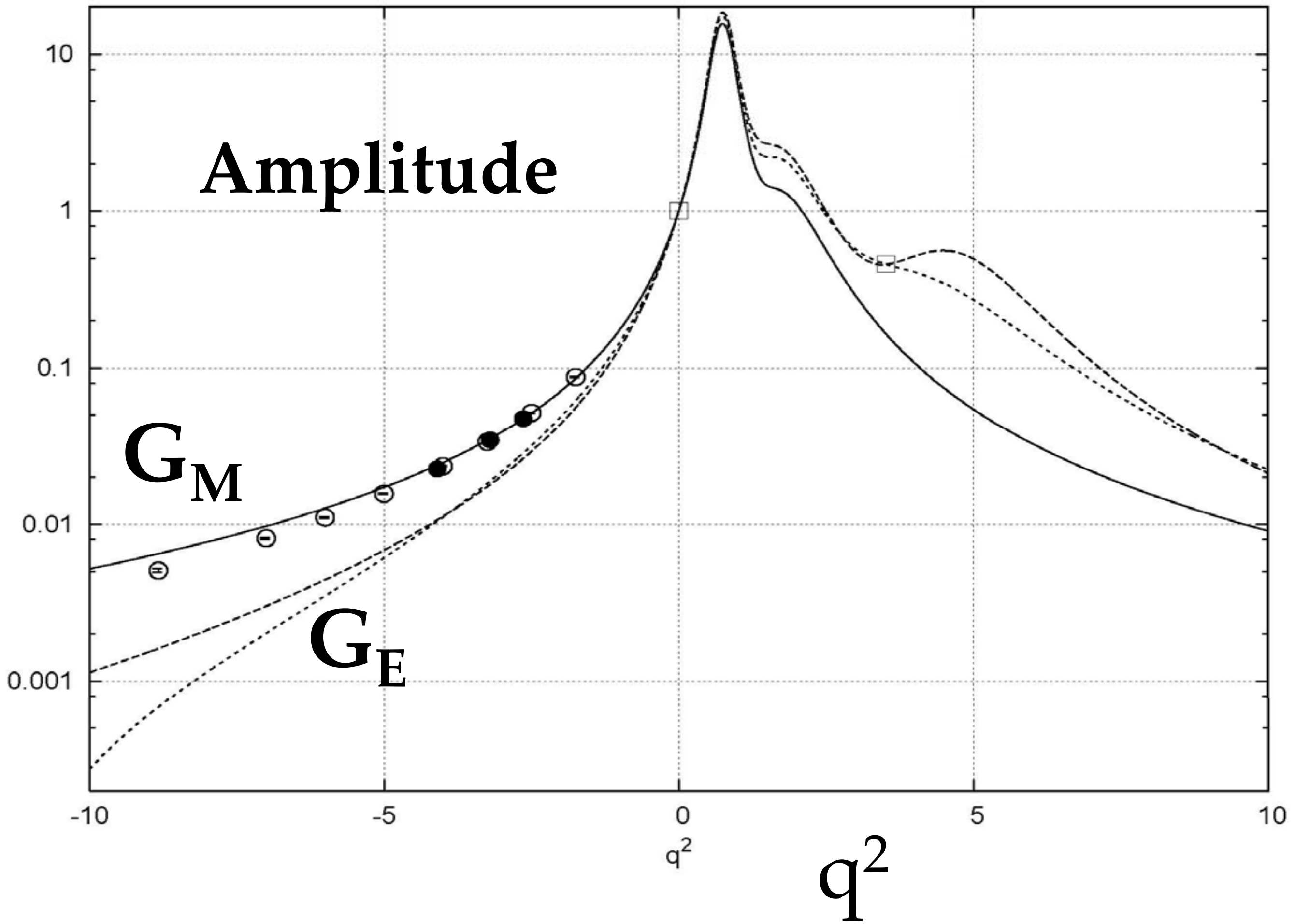


$$G_M(q^2) = \mu_p \sum_{a=1}^{4} \frac{A_a}{q^2 - m_a^2 + i m_a \Gamma_a}$$

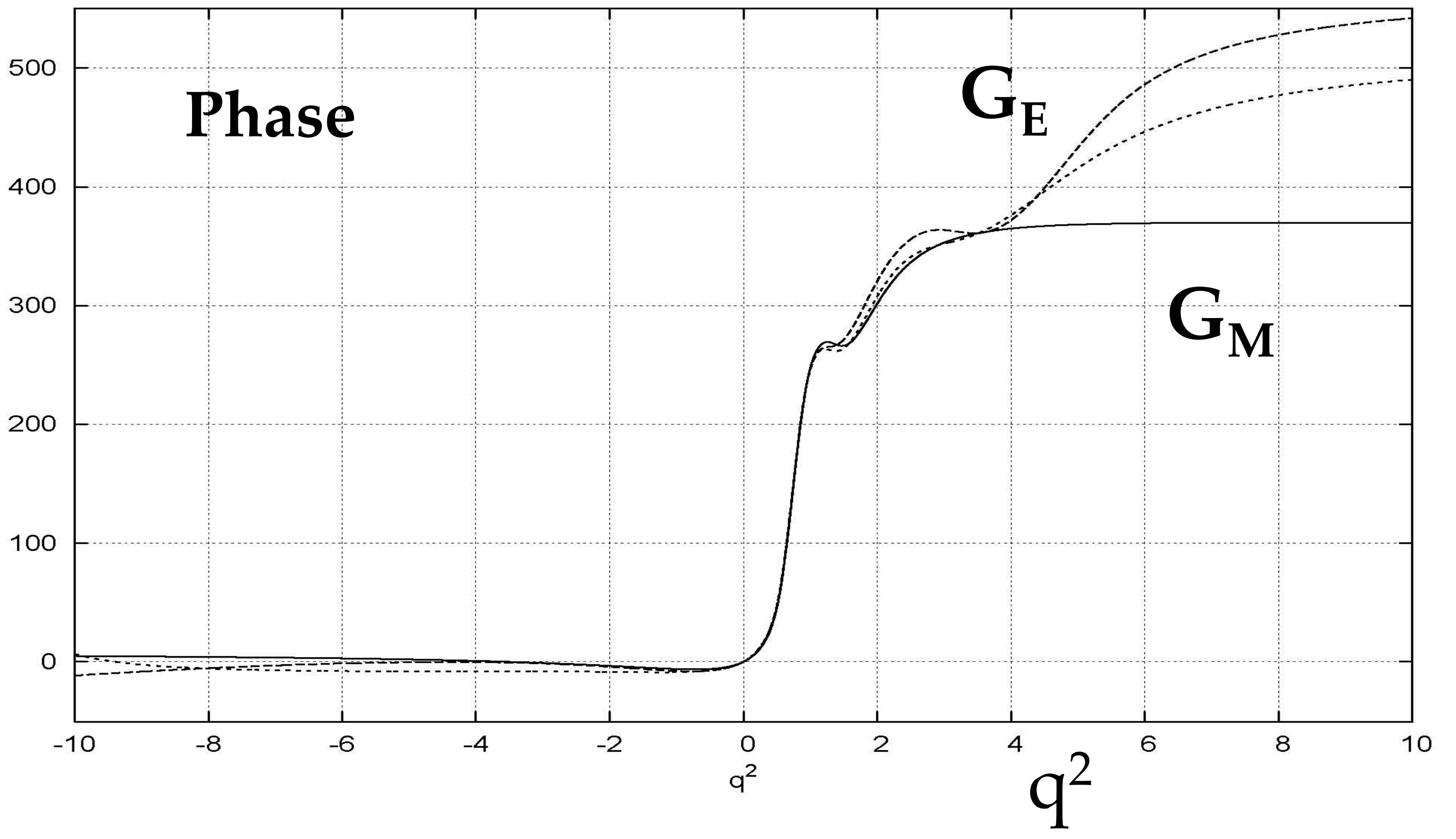
$$G_E(q^2) = \sum_{a=1}^{6} \frac{B_a}{q^2 - m_a^2 + i m_a \Gamma_a}$$

G_M , G_E (model)





G_M, G_E (model)



The calculation is performed using Feynman parametrization.

We are unable to do all the integrals analytically since the form factors are complex in the unphysical region.

We insert a small photon mass μ to regulate the infrared divergence. The infrared divergent μ dependence has to be removed.

Numerically we are not able to go below μ≈50 MeV. At this value of μ there are corrections to the log μ dependence of the infrared divergence

$$\sigma_R = (a_0 + a_1\mu^2) + (b_{IR} + b_1\mu^2)\ln(\mu^2)$$

where b_{IR} is the analytic result for IR divergence

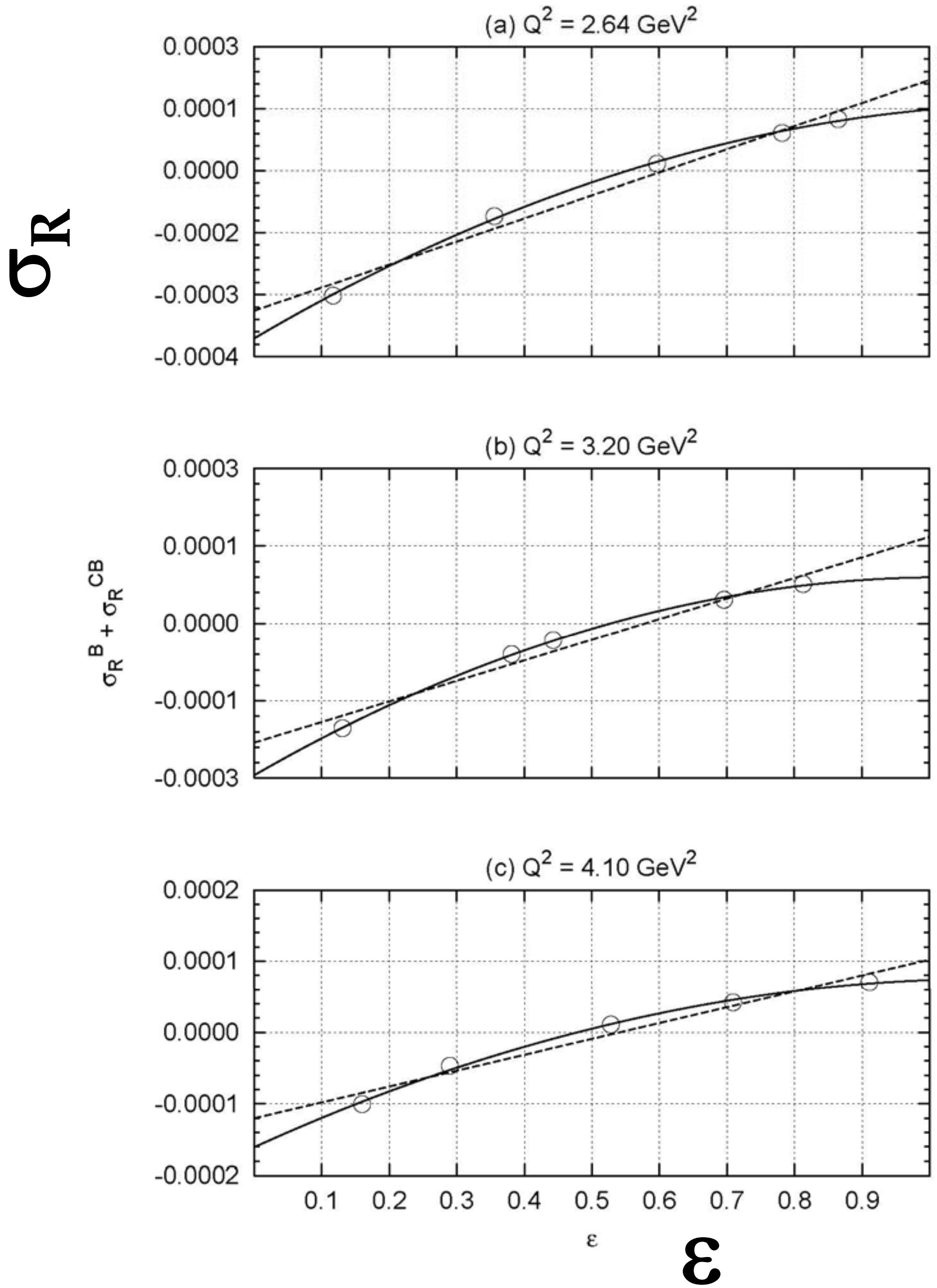
a_0 can be extracted from this fit, which gives the required two photon contribution

Results:

Reduced cross section (Box +Cross Box)

$$\frac{d\sigma}{d\Omega} = \frac{\sigma_{Mott}}{\varepsilon(1+\tau)}\sigma_R$$

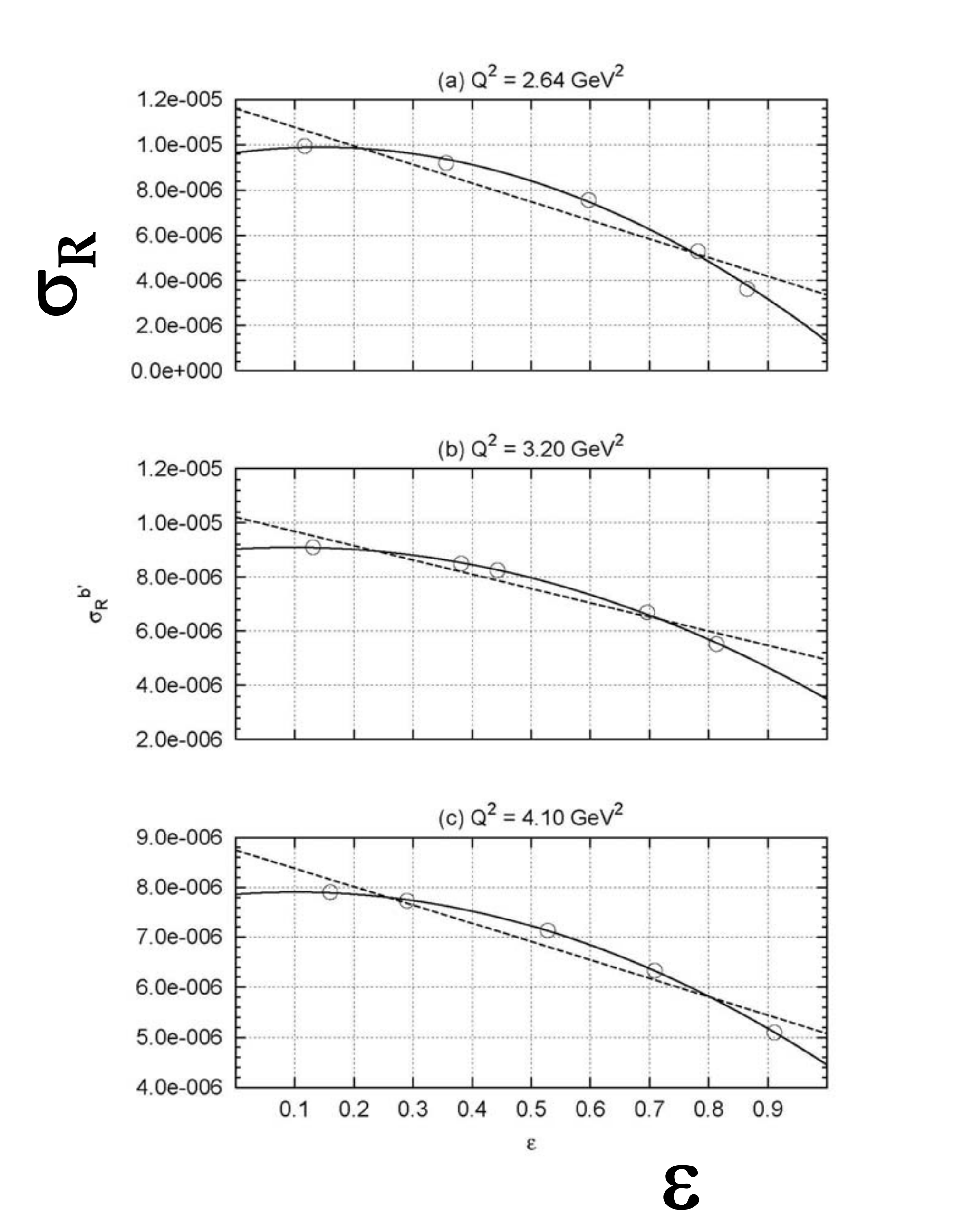
ε = photon long. polarization



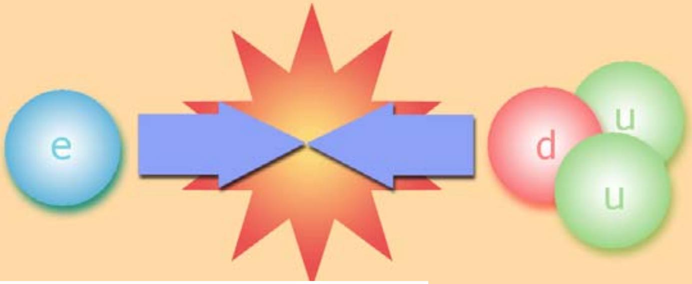
Results: Reduced cross section ($(b')^2$ diagram)

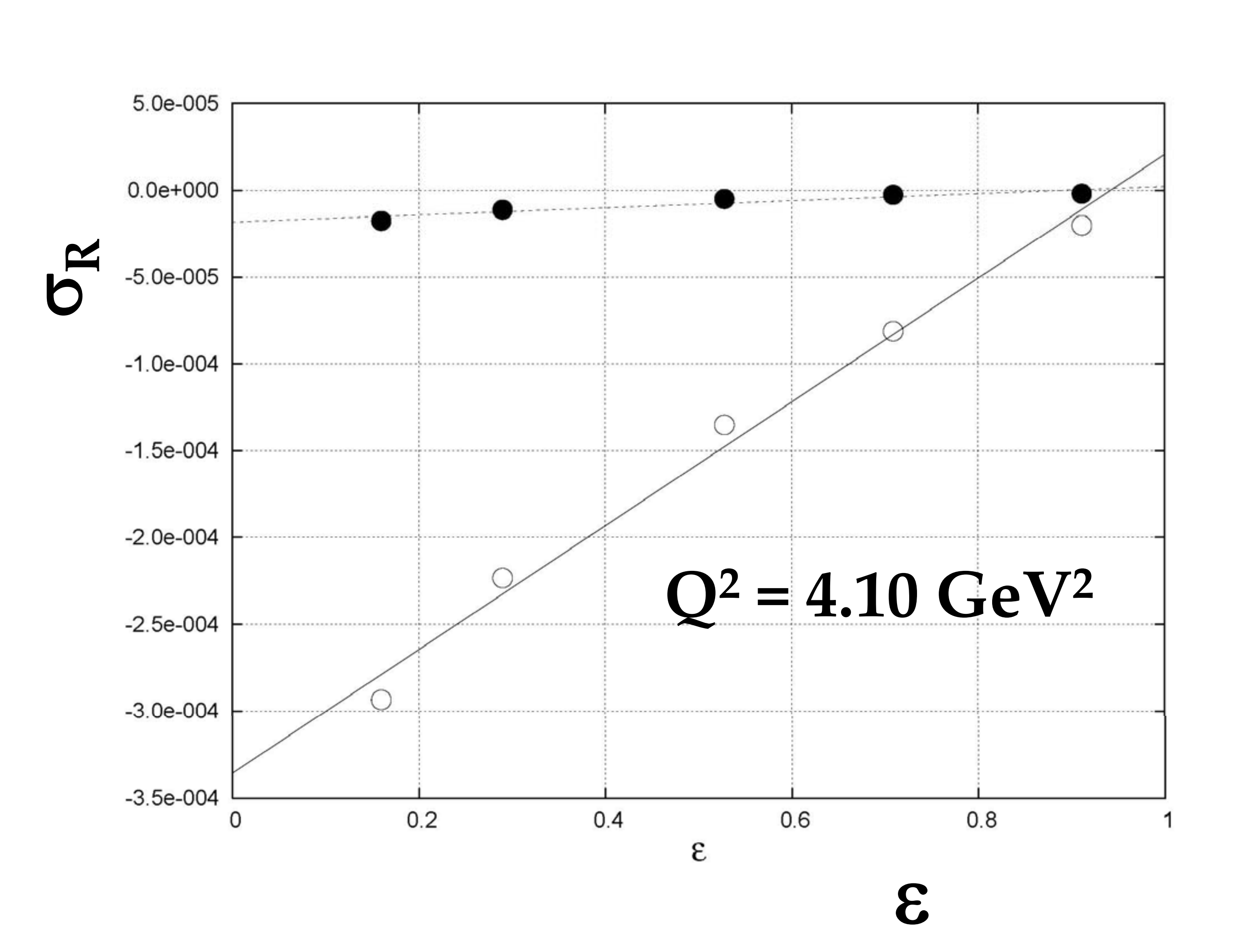
set b' = 1

This contribution turns out to be very small and in the direction opposite to that required for explaining the data

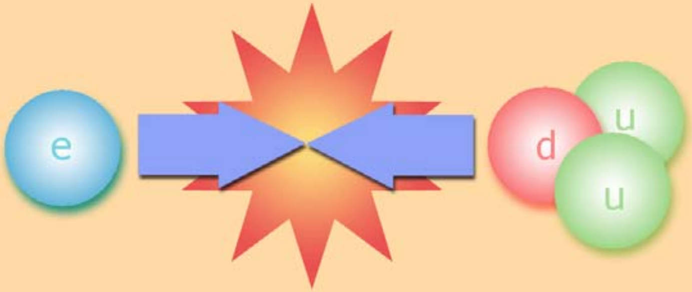


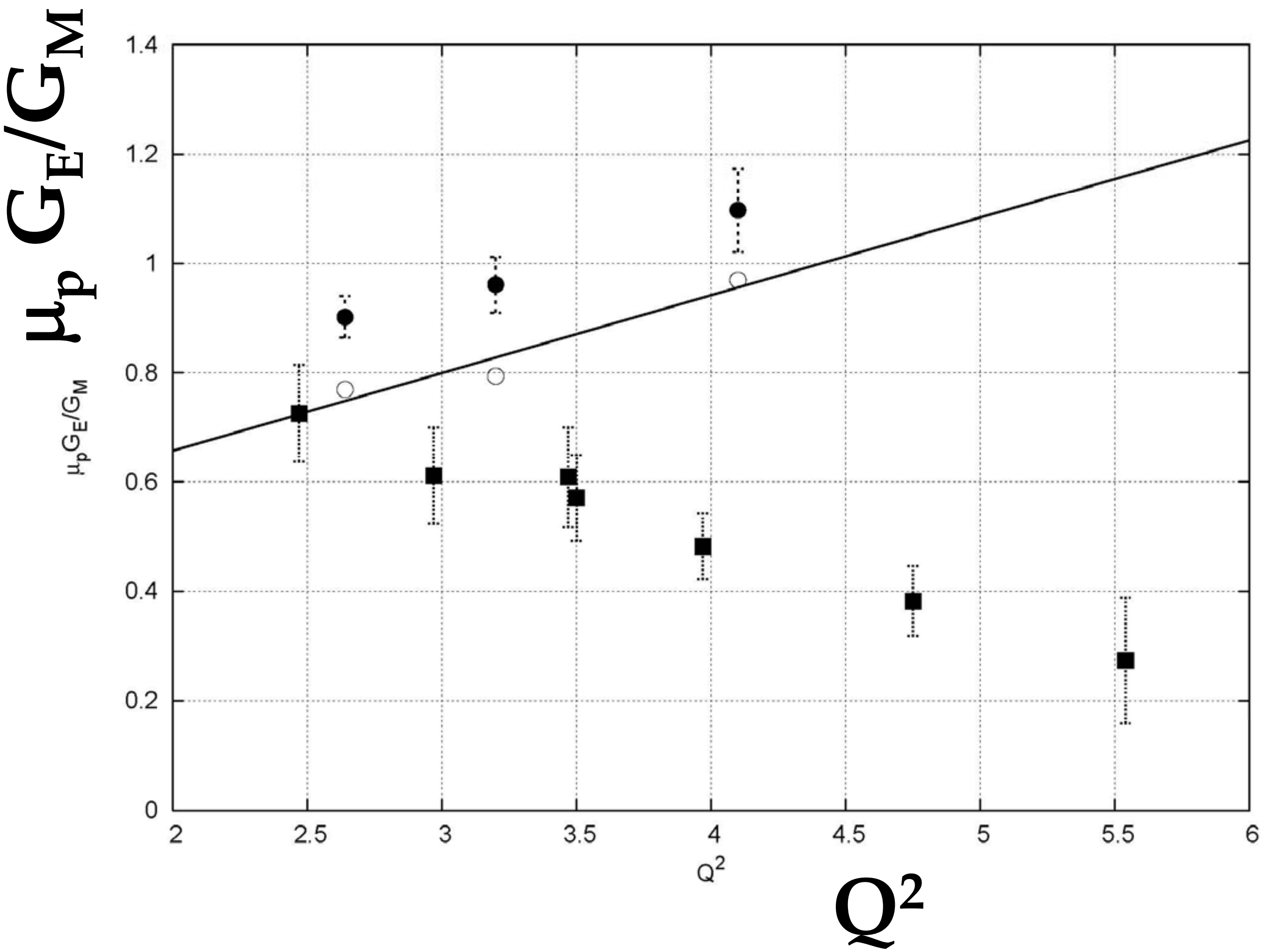
F_2-F_2 contribution



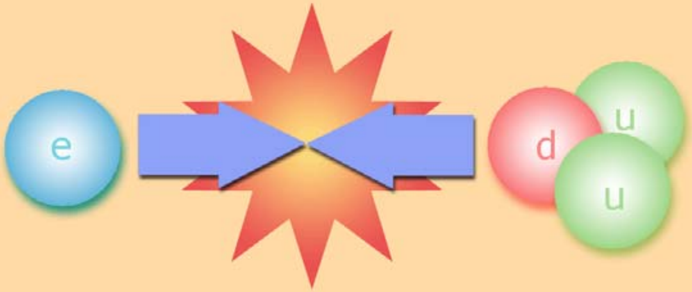


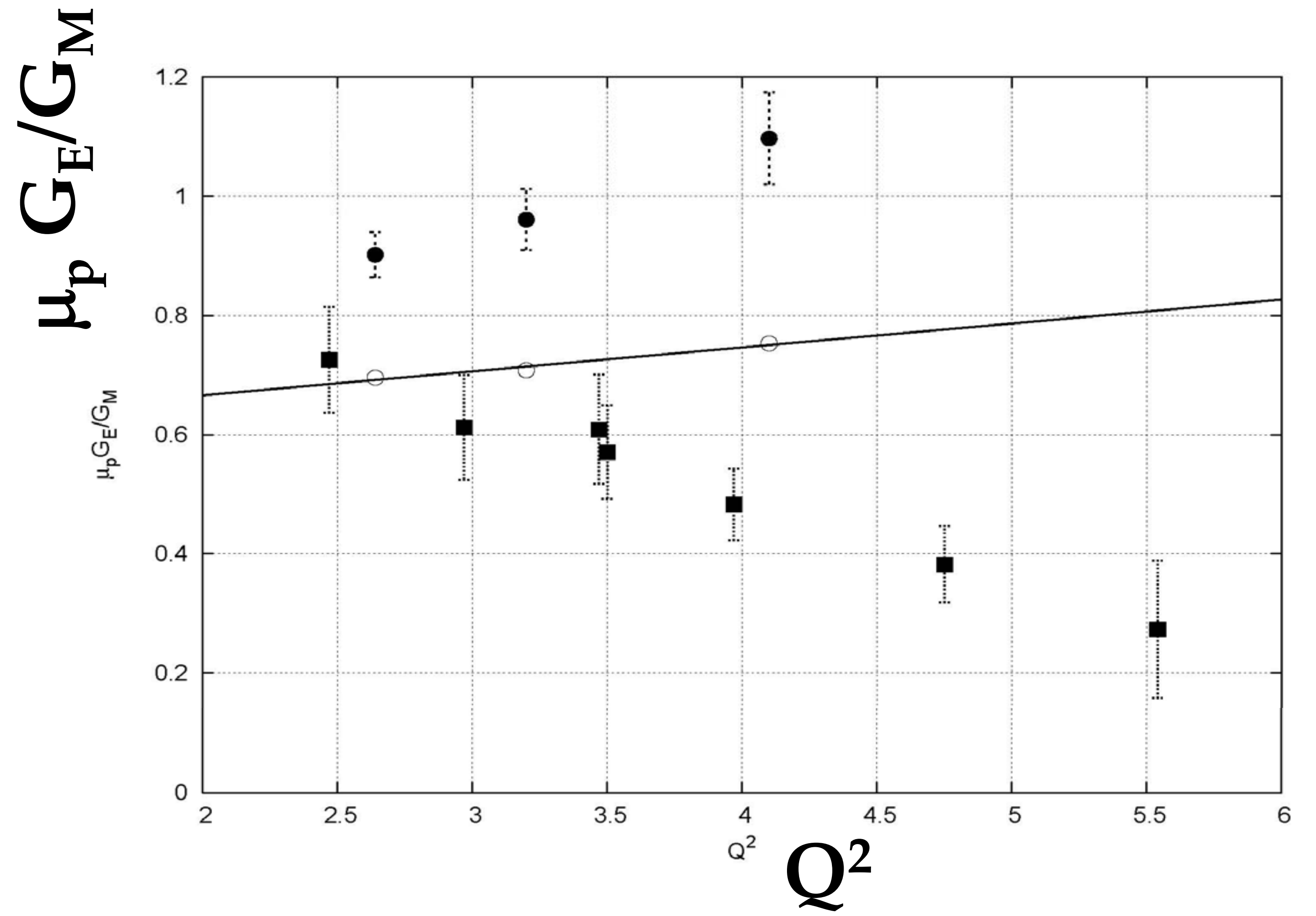
Results



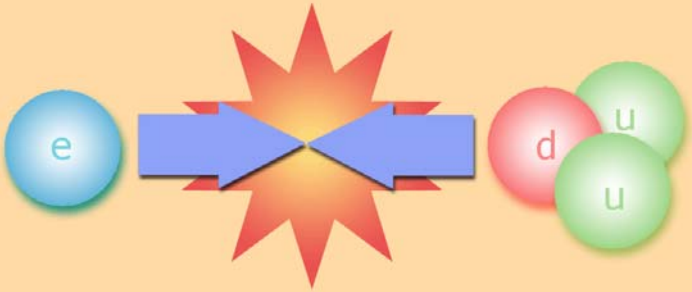


Results (with ε≤0.5)





Conclusions

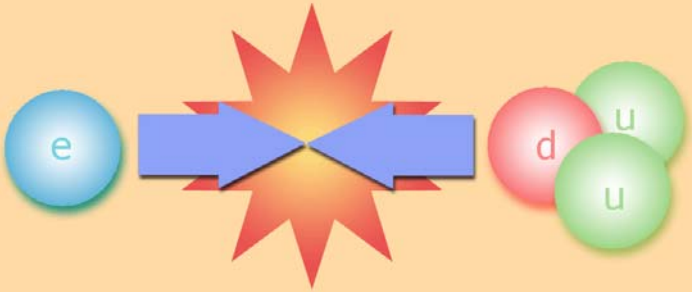


We have used a non-local model to compute the two photon exchange contributions.

The model preserves gauge invariance and can be used reliably as long as the proton is not too far off-shell.

It involves only one unknown parameter b‘ whose contribution is found to be small

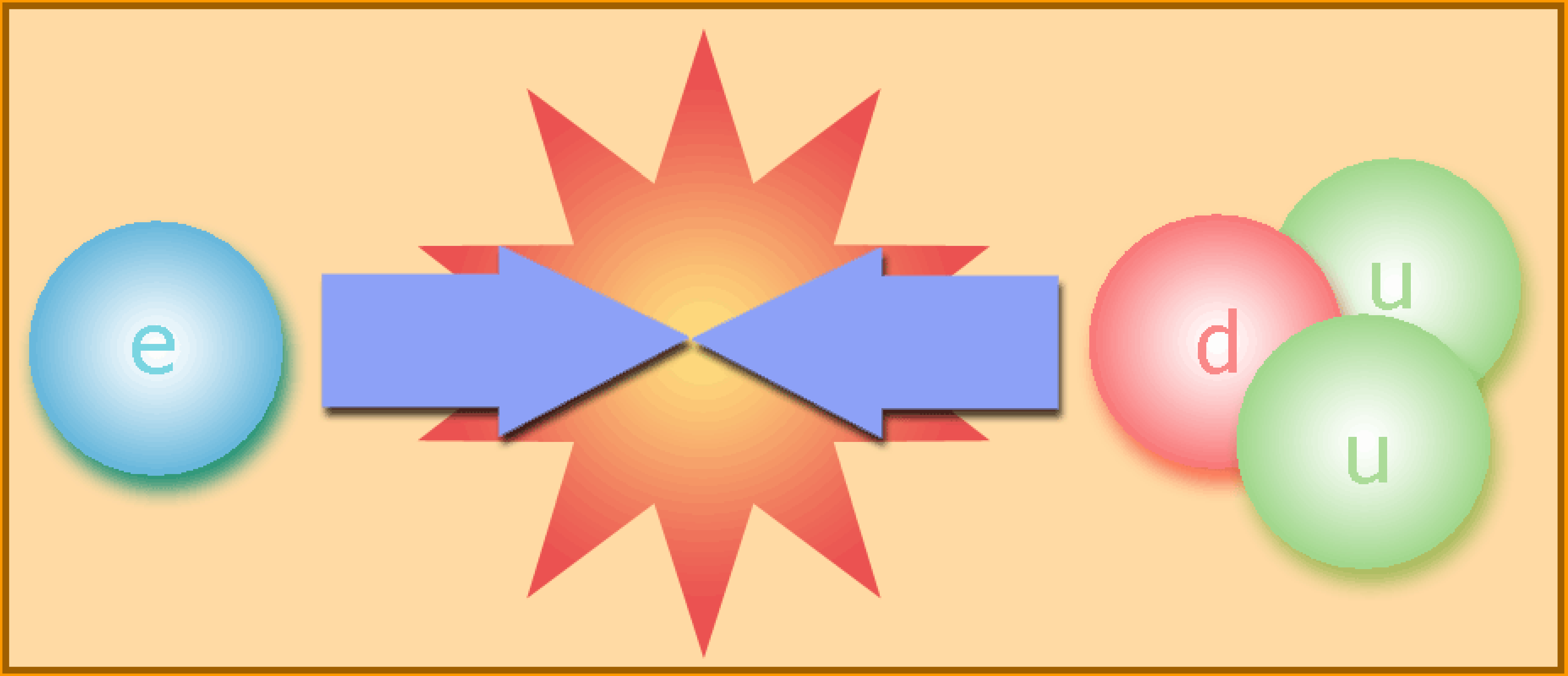
Conclusion



The ε dependence of σ_R is slightly non-linear. This trend is not seen in data but is still within the error bars.

The resulting two photon contribution explains about 70% of the discrepancy at $Q^2 = 2.64$ GeV^2, but only about 20% at $Q^2 = 4.10$ GeV^2

If we use only the results at $\varepsilon \leq 0.5$, then we are able to explain 50% of the difference at $Q^2 = 4.10$ GeV^2



Thank you