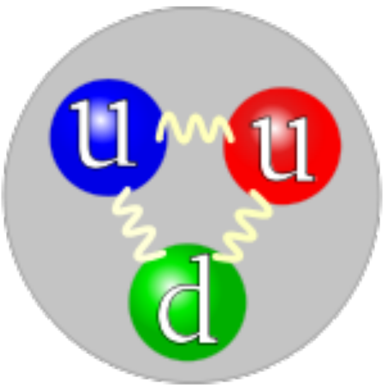
Jefferson Lab
Thomas Jefferson National Accelerator Facility

Flavor composition of the nucleon EMFFs

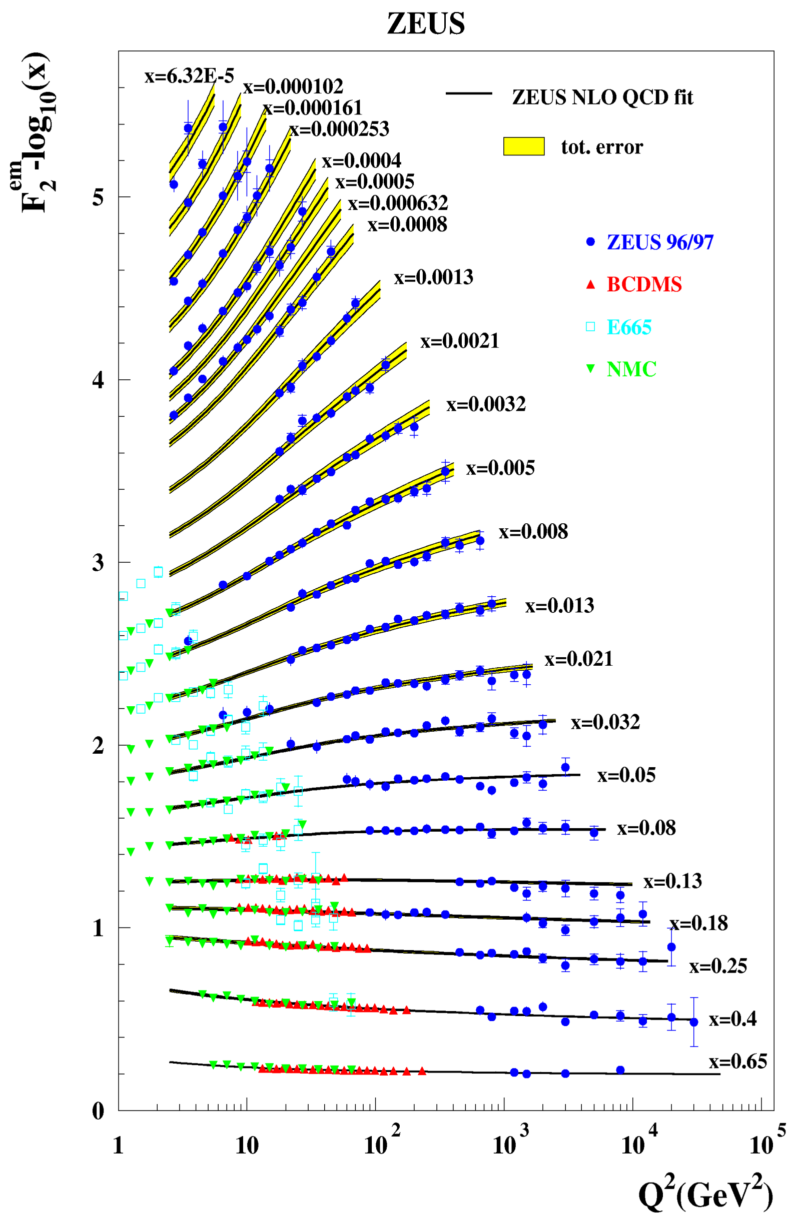
Bogdan Wojtsekhowski, Jefferson Lab

Nucleon constituents



1) valence quarks
2) gluons
3) $q\bar{q}$ pairs
4) meson cloud

Unpolarized and polarized structure functions



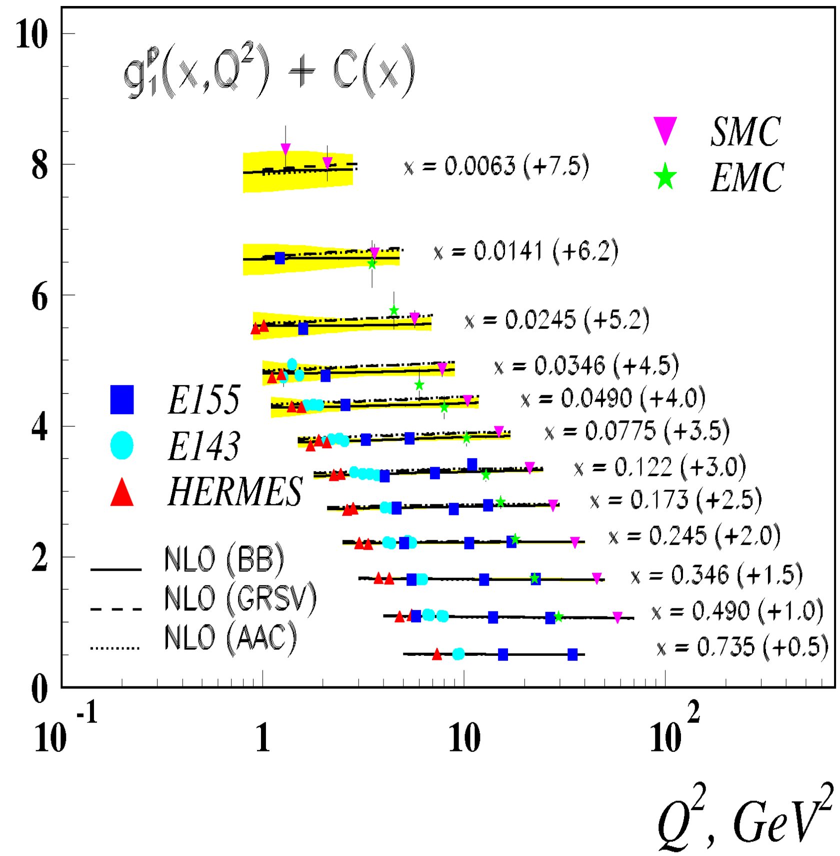
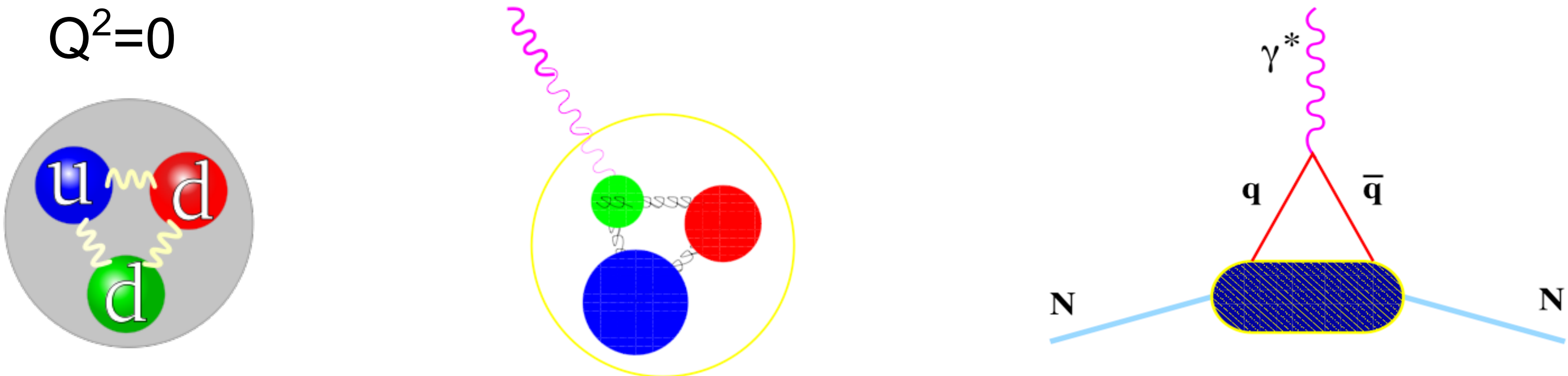
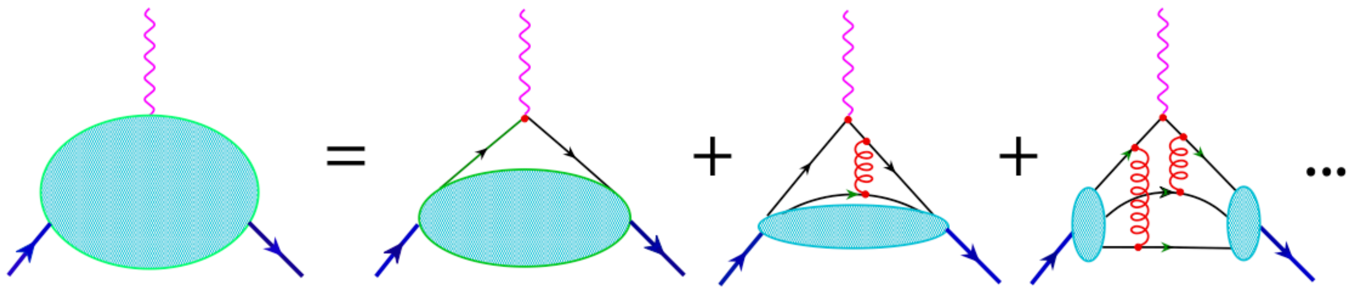


Figure 7: The polarized structure function g_1^p as function of Q^2 in intervals of x. The error bars shown are the statistical and systematic uncertainties added in quadrature. The data are well described by our QCD NLO curves (solid lines), ISET=3, and its fully correlated 1σ error bands calculated by Gaussian error propagation (shaded area). The values of $C(x)$ are given in parentheses. Also shown are the QCD NLO curves obtained by AAC (dashed lines) [15] and GRSV (dashed–dotted lines) [16] for comparison.

Photon-nucleon interaction

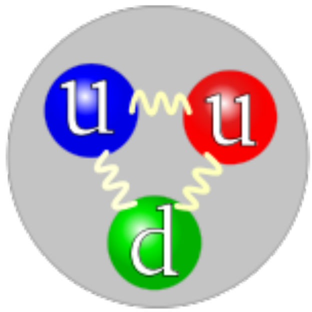


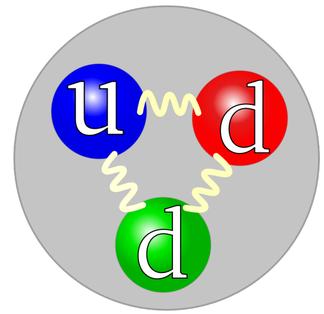


What are the dominant degrees of freedom in gamma-nucleon interaction?

pQCD:2-gluon exchange? q-qbar? q-2q? constituent quarks?

The proton and the neutron



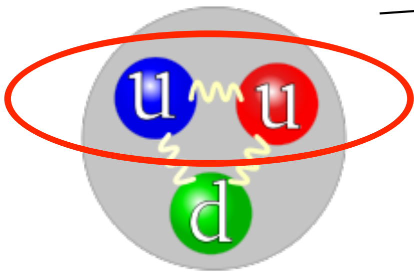


$$F_{1p} = \frac{+2}{3} F_{1u} + \frac{-1}{2} F_{1d}$$

$$F_{1n} = \frac{-1}{3} F_{1u} + \frac{+2}{2} F_{1d}$$

Assuming the charge symmetry and zero strangeness contribution

The goal is understanding of the nucleon



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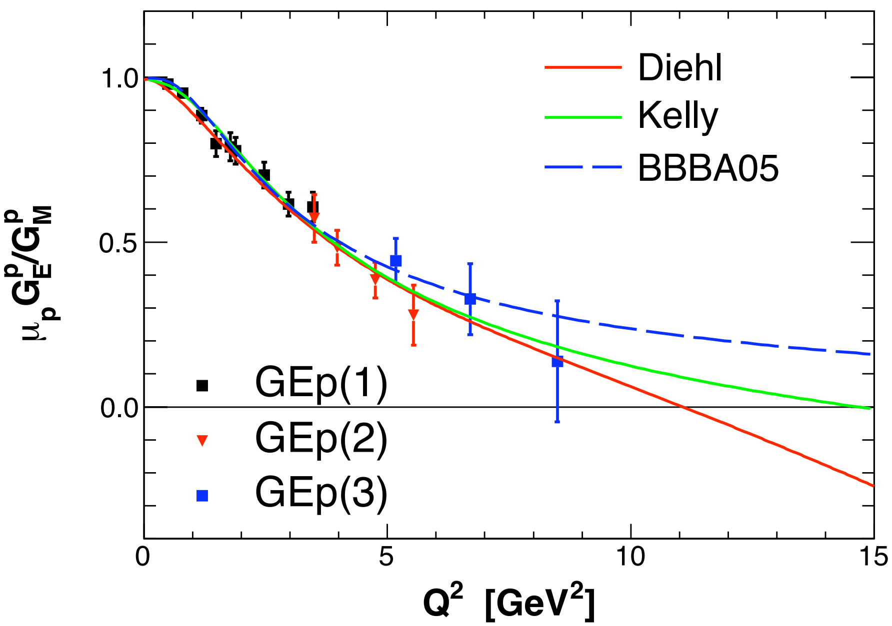
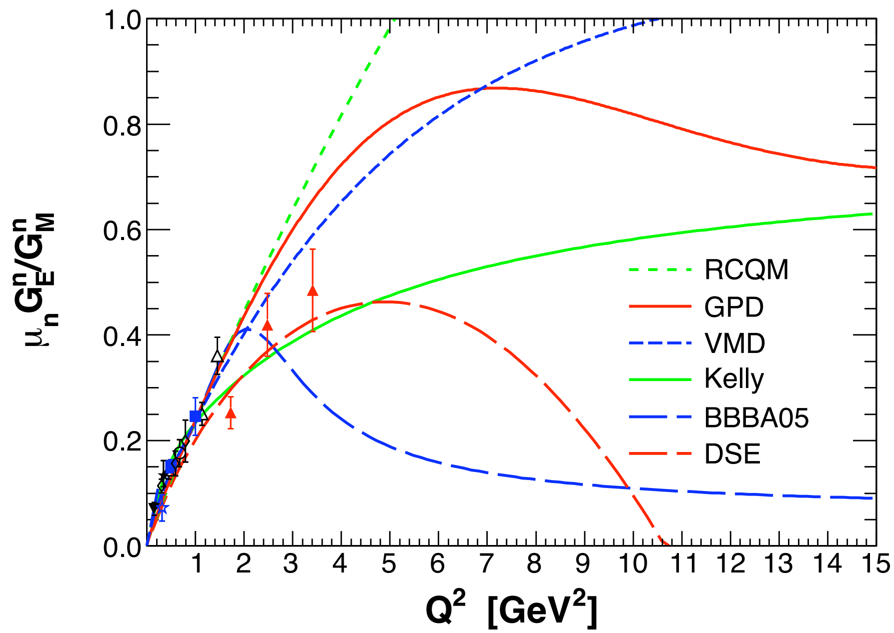
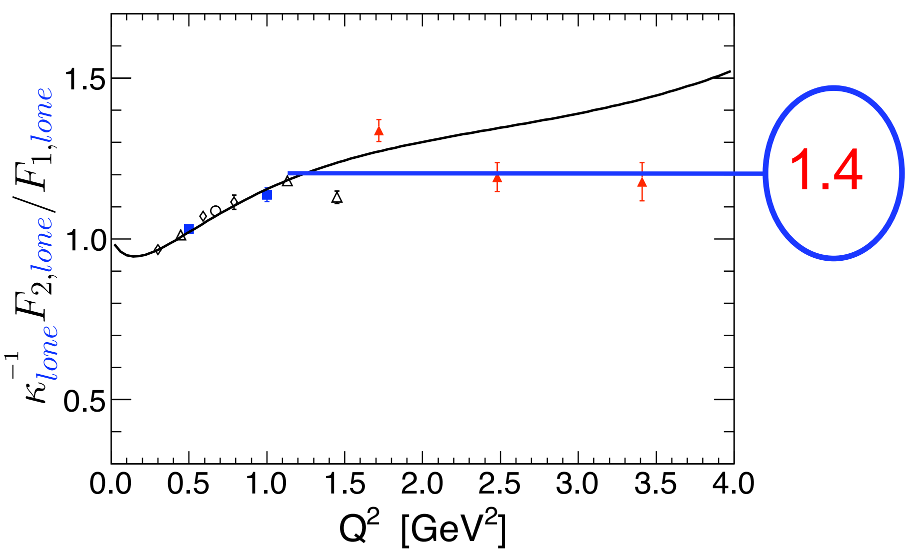


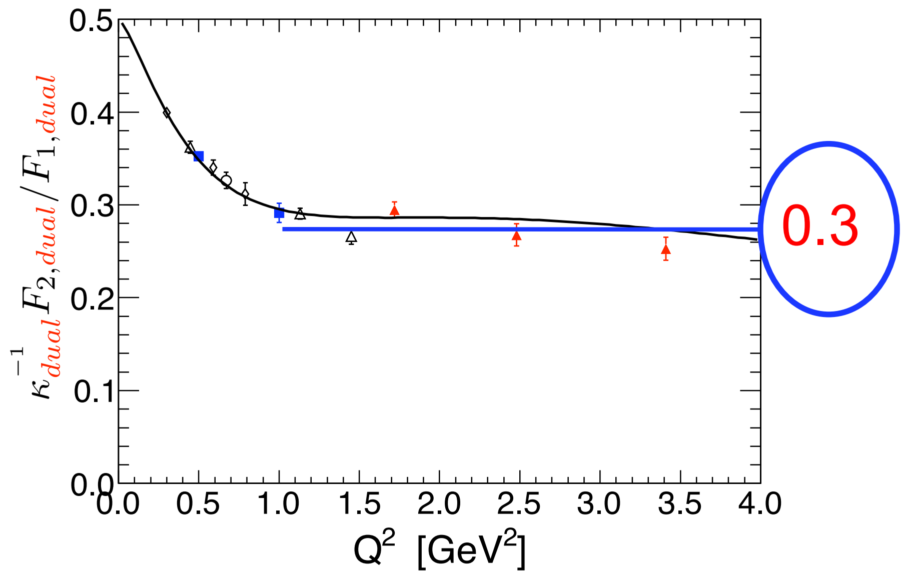


The goal is understanding of the nucleon

$$F_1^u = 2\,F_{1p} + F_{1n}, \quad F_1^d = 2\,F_{1n} + F_{1p}$$

Results of JLab GEn experiment, 2006





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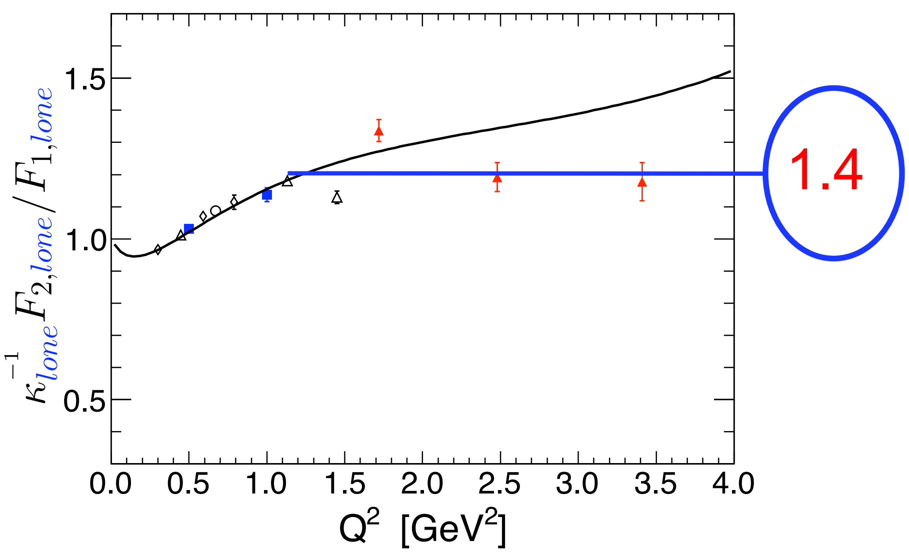
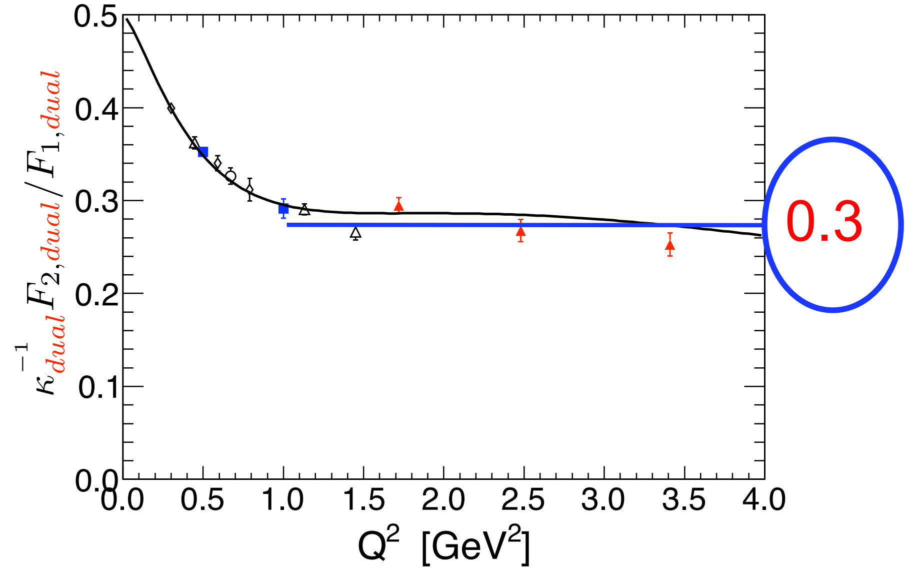
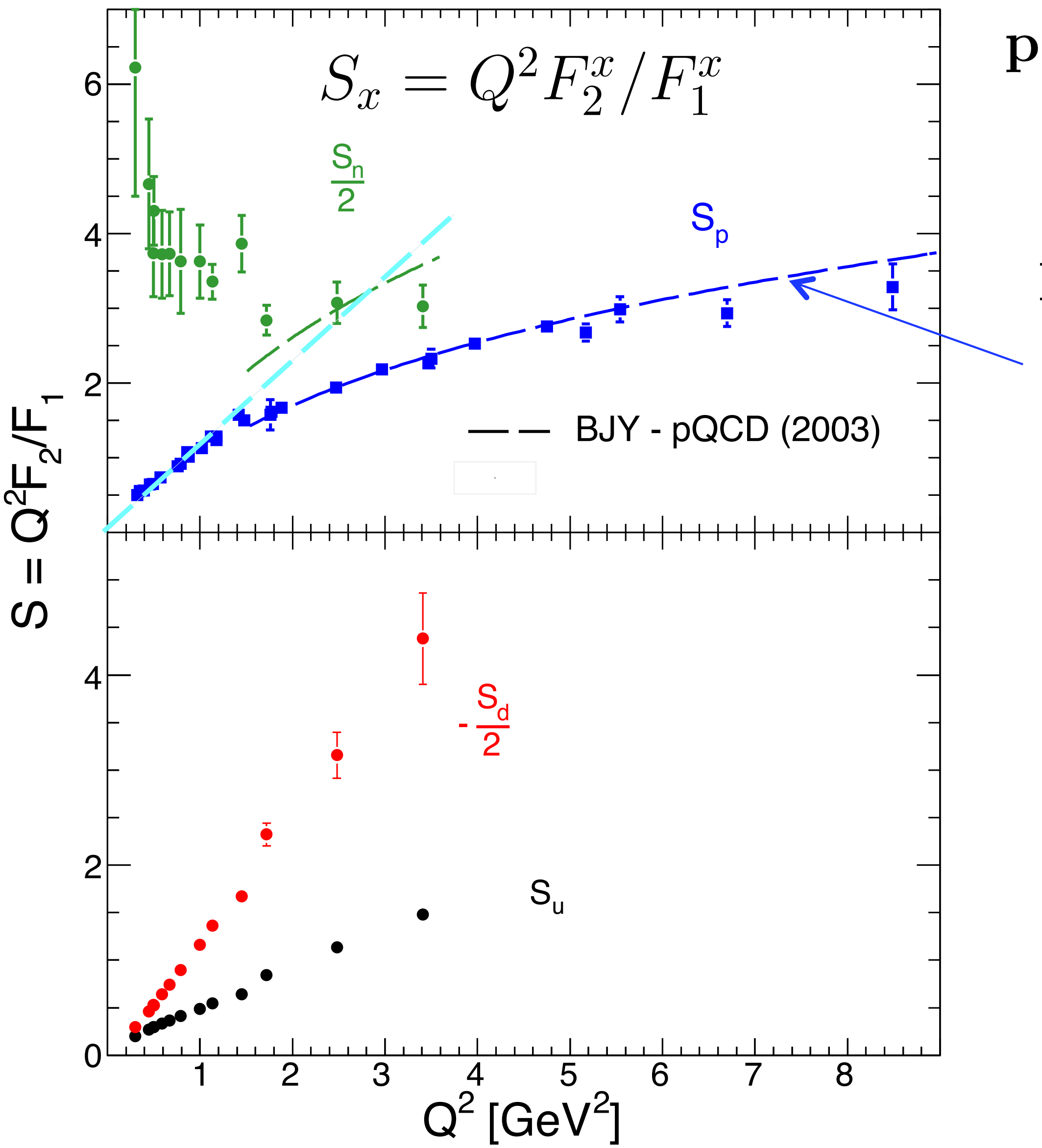




Is it due to a diquark configuration?

The goal is understanding of the nucleon



pQCD prediction for large Q^2:

$$S \to Q^2 F_2/F_1$$

pQCD updated prediction:

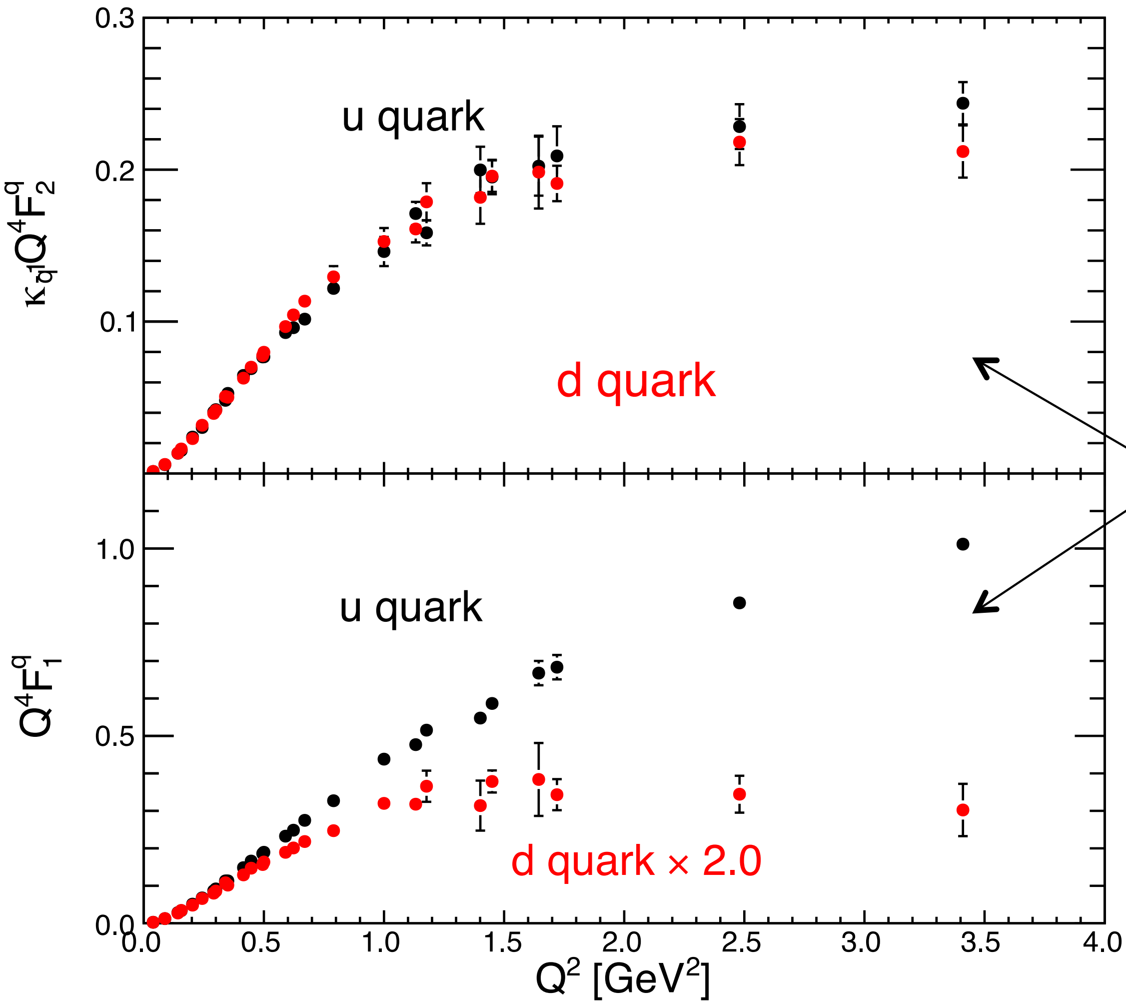
$$S \to \left[Q^2/\ln^2(Q^2/\Lambda^2)\right] F_2/F_1$$

Flavor separated contribution: The log scaling for the proton Form Factor ratio at few GeV^2 may be "accidental".

The lines for individual flavor are straight! unlikely accidental

Cates, Jager, Riordan, BW
Physical Review Letters, 106, 252003 (2011)

The flavor disparity in the nucleon



CJRW (u/d with new GEn data)

Phys. Rev. Lett. 106 (2011)

Qattan, Arrington (2-γ effects)

Phys.Rev. C86 (2012) 065210

M.Diehl and P.Kroll (GPDs)

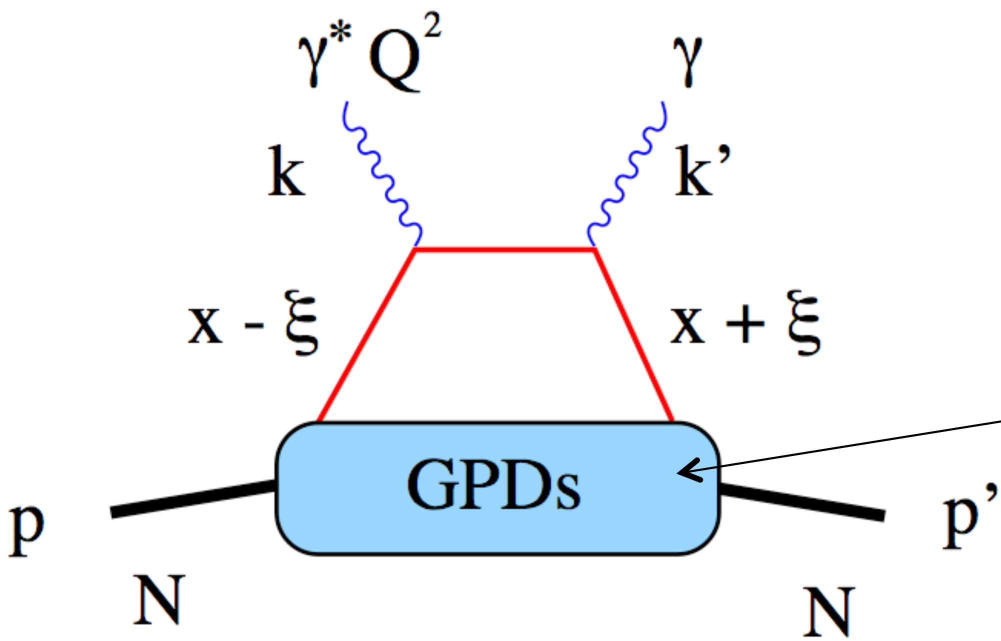
Eur.Phys.J. C73 (2013) 2397

Using the D&K table of F^u, F^d

The down quark contribution to the F_1 proton form factor is strongly suppressed at high Q^2

When the virtual photon of 3 GeV^2 interacts with the d-quark the proton more likely falls apart than in the case of the u-quark

The scheme for flavor disparity



Handbag diagram

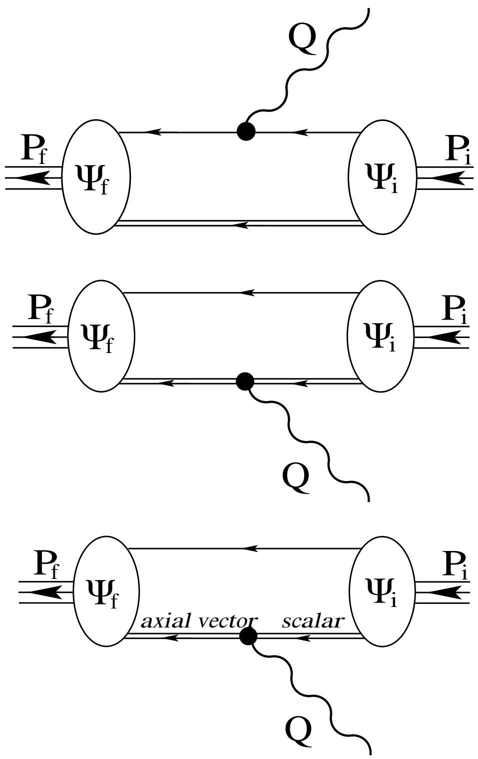
After γ^*-q interaction the momentum should be shared with other quarks:

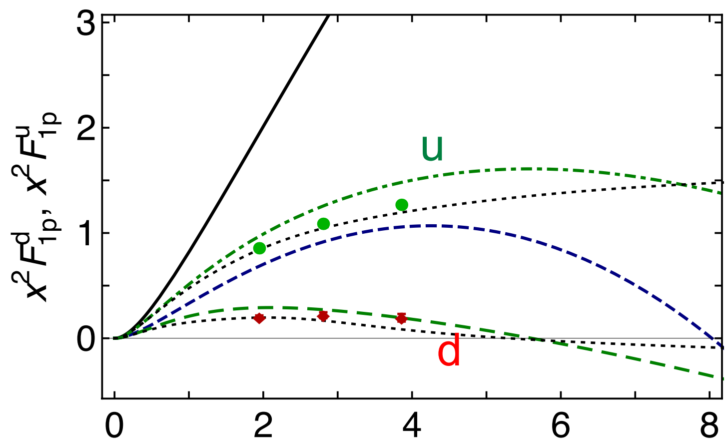
and the u-u pair is less likely to do it than the u-d pair.

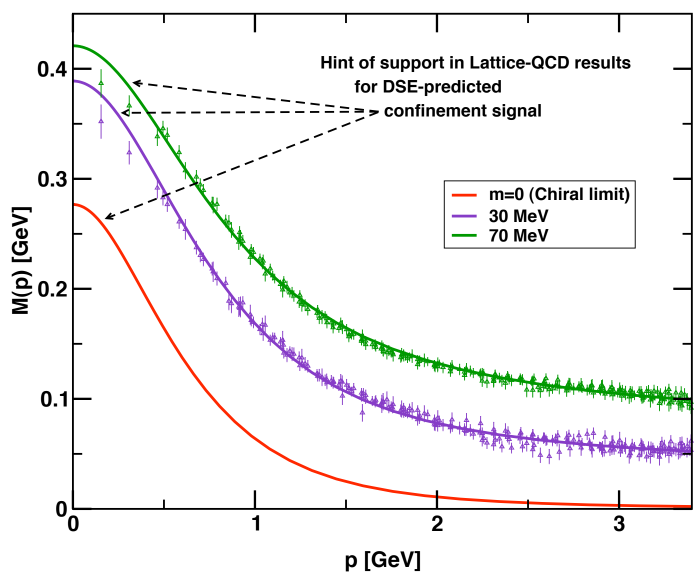
The goal is understanding of the nucleon

Nucleon and Roper electromagnetic elastic and transition form factors

Wilson, Cloet, Chang, Roberts, PRC 85, 025205 (2012)





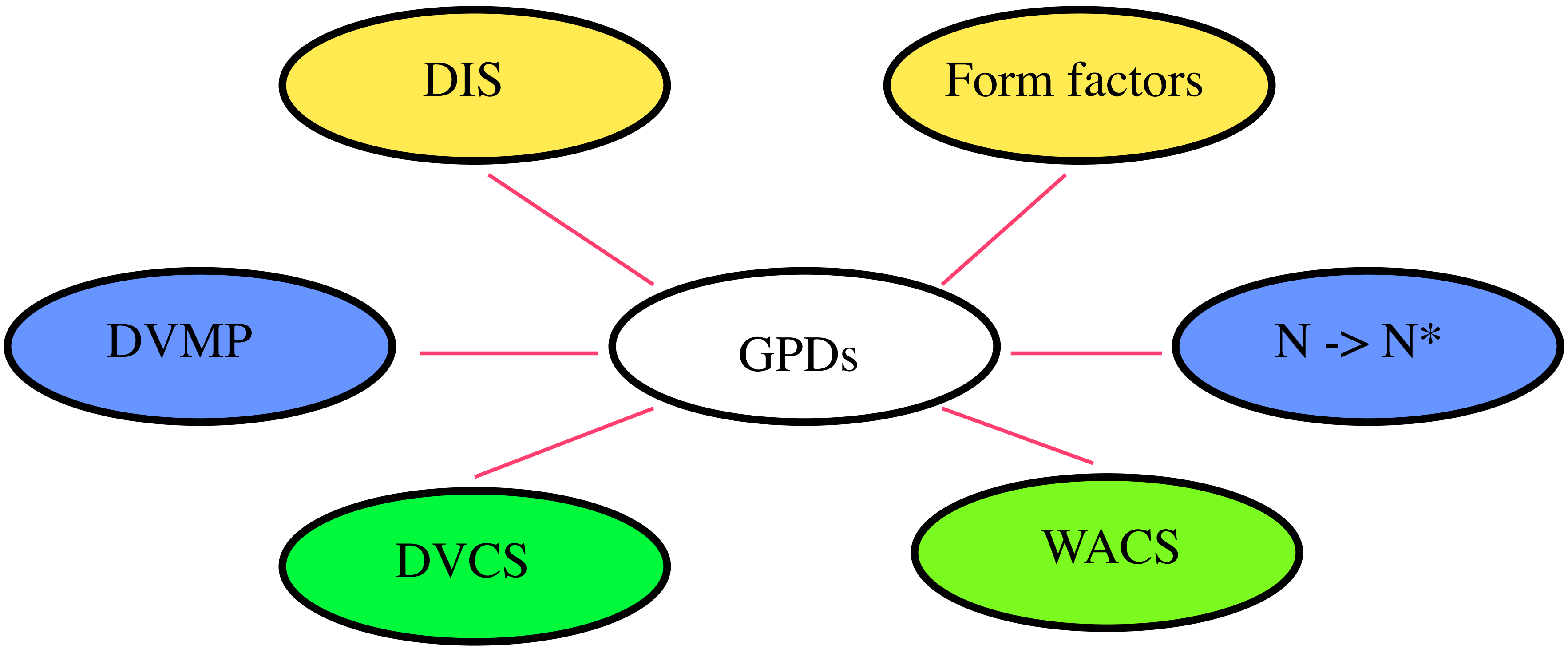


QCD based prediction:

Interplay between the [qq] and {qq} diquarks creates a zero crossing

Cloet, Eichmann, El-Bennich, Klahn and C. D. Roberts, Few Body Syst. 46 (2009) 1-36.

Unification of nucleon structure within GPDs



x ξ t

Elastic eN form factors within GPDs

$$F_1(t) = \sum_q e_q \int dx H_q(x,t)$$

Muller, Ji, Radyushkin

$$q(x, \mathrm{b}) = \int \frac{d^2q}{(2\pi)^2} e^{i\,\mathrm{q}\cdot\mathrm{b}} H_q(x, t = -\mathrm{q}^2)$$

M.Burkardt

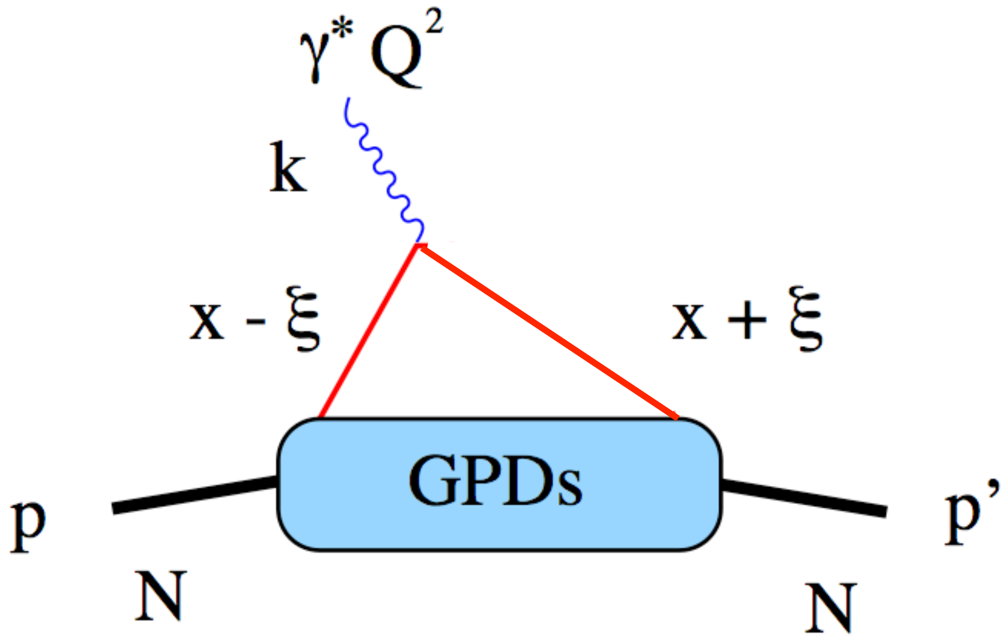
P.Kroll: u/d segregation

$$\rho(b) \equiv \sum_q e_q \int dx\; q(x, \mathrm{b}) = \int d^2q F_1(\mathrm{q}^2) e^{i\,\mathrm{q}\cdot\mathrm{b}}$$

$$\rho(b) = \int_0^\infty \frac{Q \cdot dQ}{2\pi} J_0(Qb) \frac{G_E(Q^2) + \tau G_M(Q^2)}{1+\tau}$$

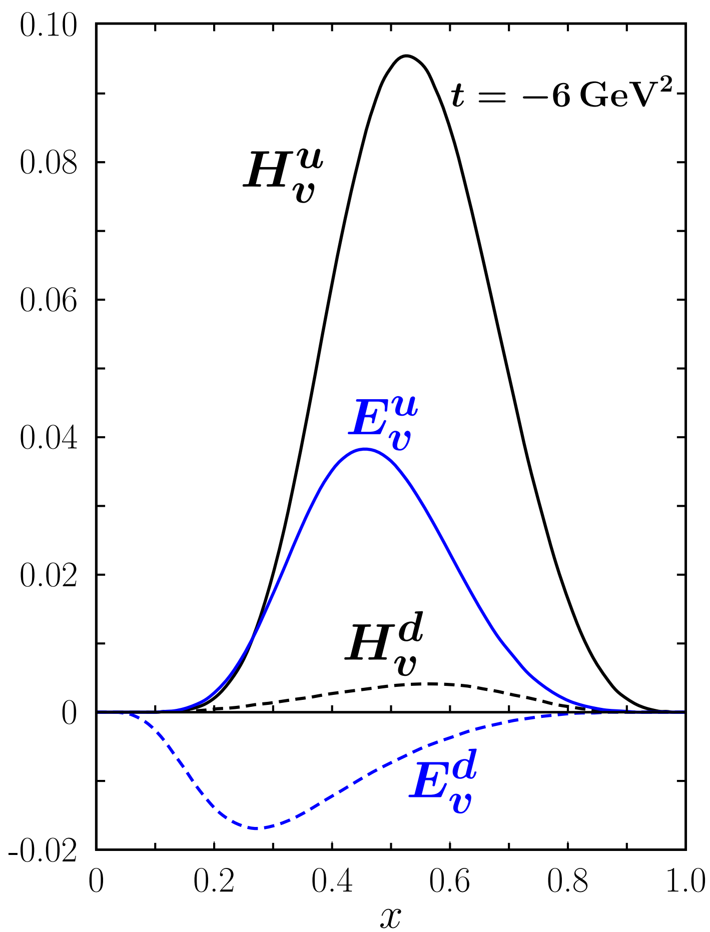
G.Miller

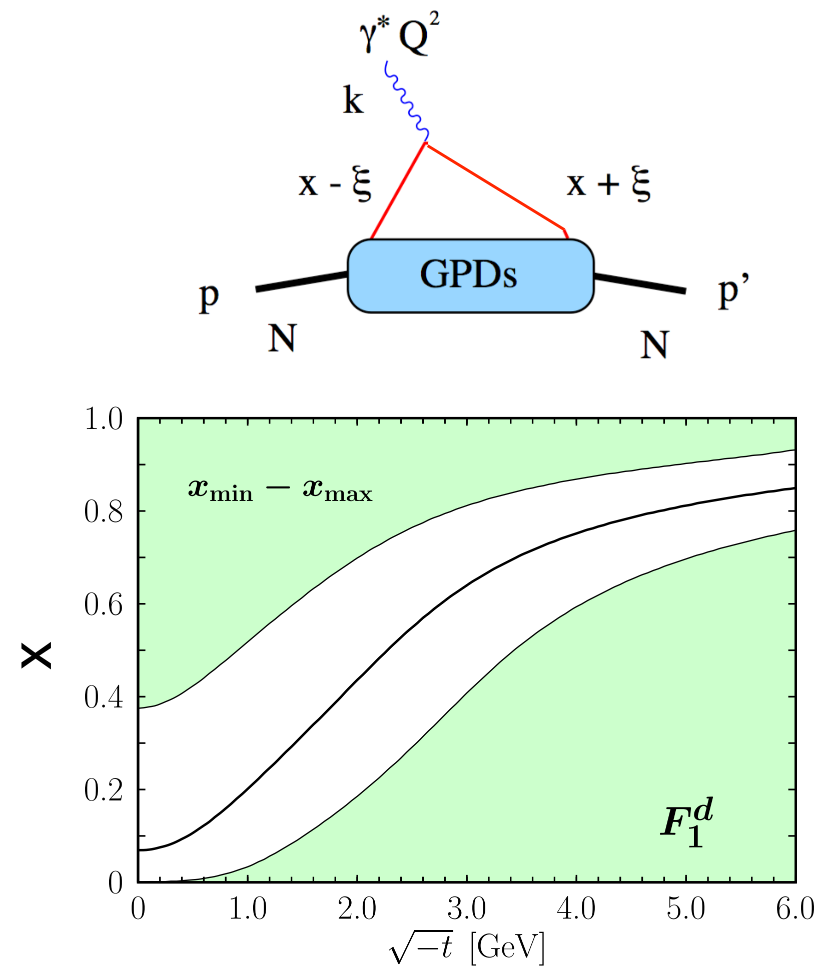
Leading quark in the GPD-based phenomenology for elastic electron-nucleon scattering



Electromagnetic Form Factors and GPDs

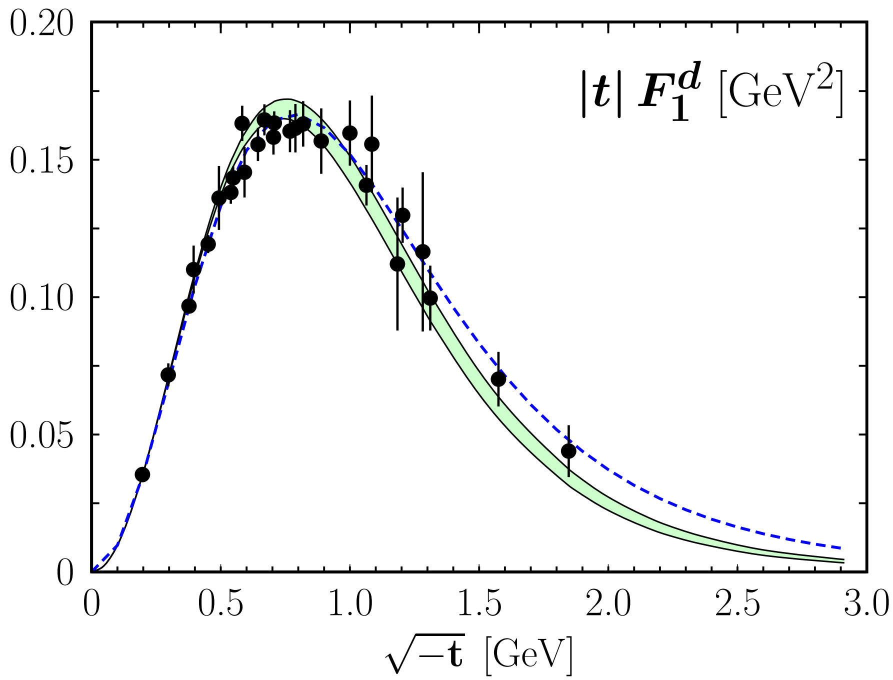
M.Diehl and P.Kroll, Eur.Phys.J. C73 (2013) 2397

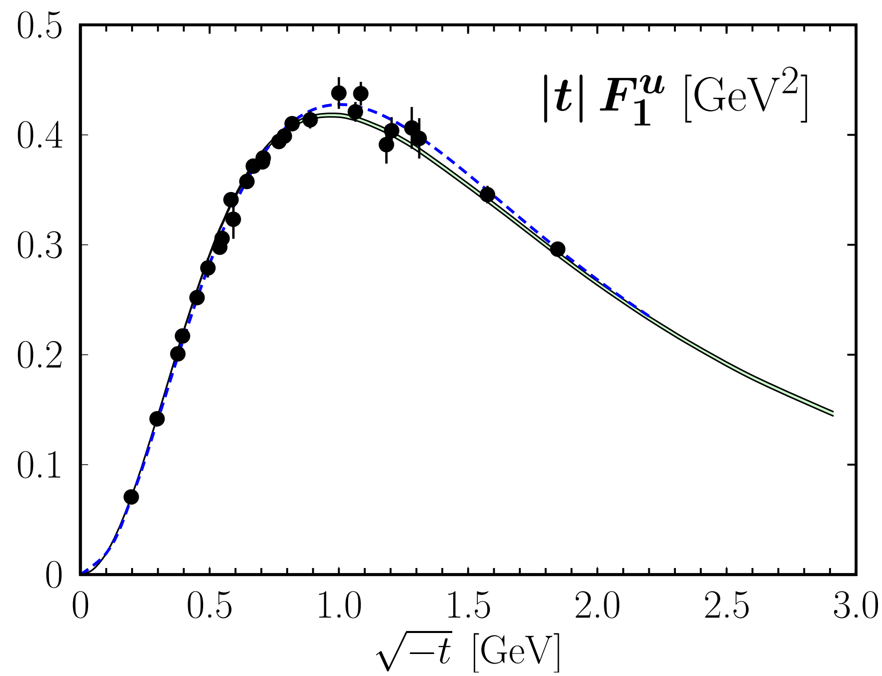




Electromagnetic Form Factors from the GPD models

M.Diehl and P.Kroll, Eur.Phys.J. C73 (2013) 2397



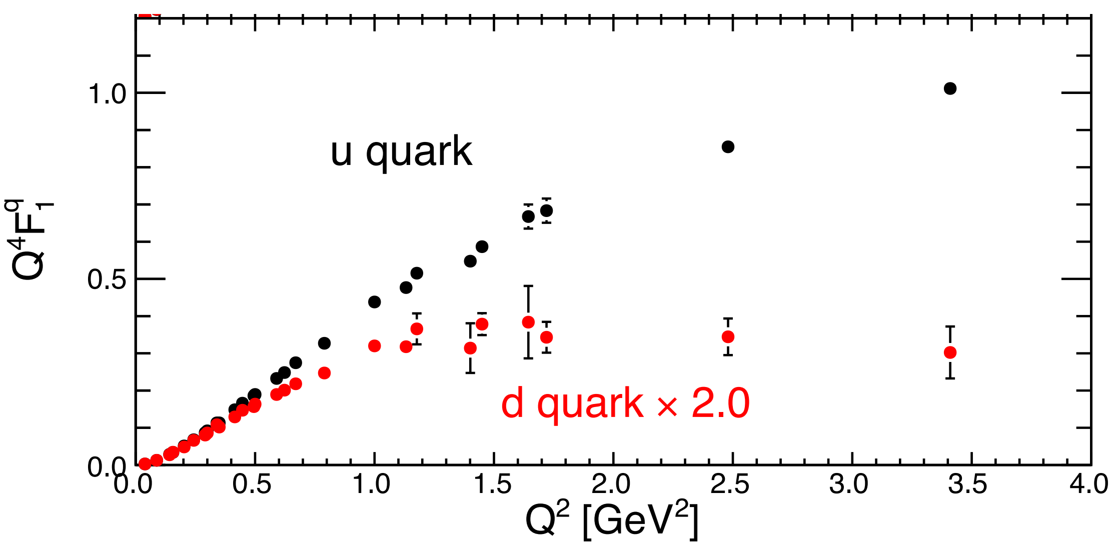


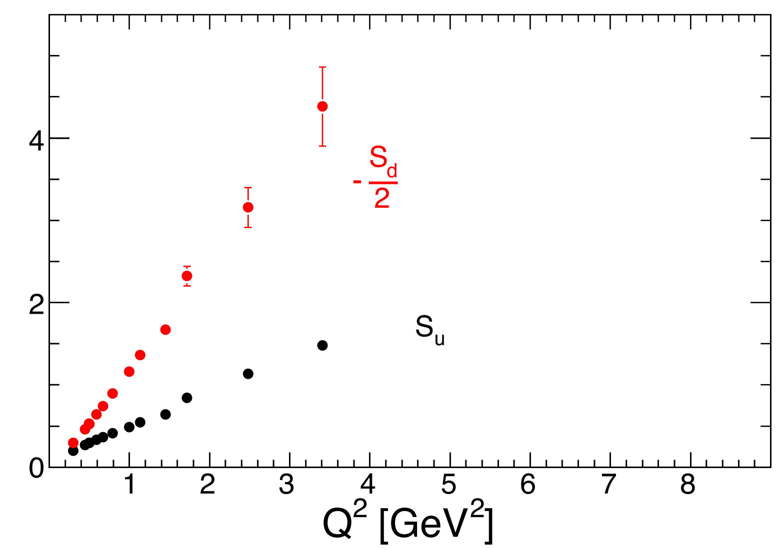
$F_1{}^d$ is always positive.

The observed difference between Fu and Fd Q^2 dependences in the nucleon

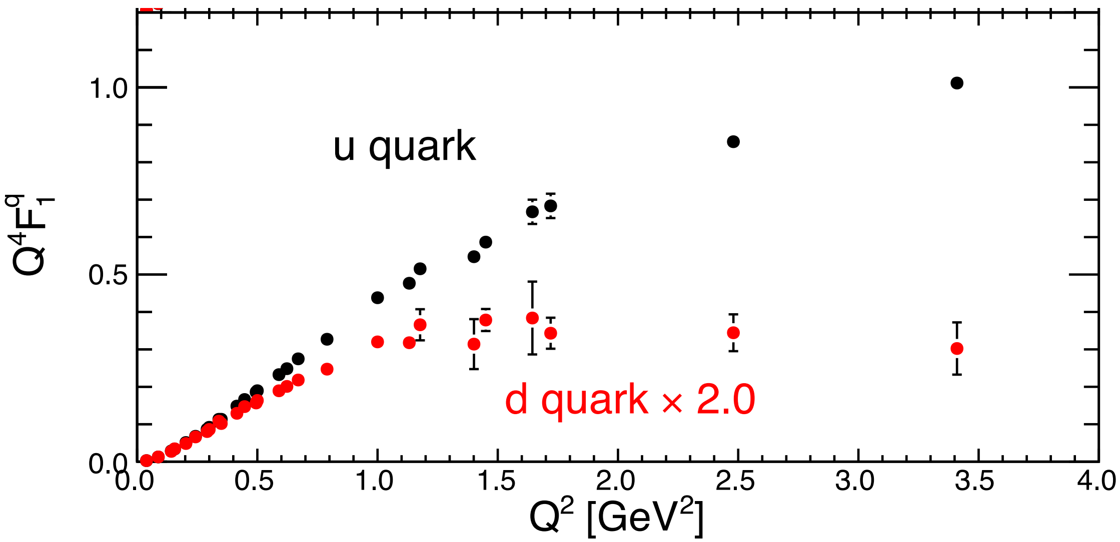
What is the nature of this result: a strong reduction of the d-quark contribution with increase of Q^2?

What is the reason for the F_2/F_1 ratio to be constant?





The flavor disparity in the nucleon



The experiment suggests that the probability of proton survival after absorption of a massive virtual photon is much higher when the photon interacts with an up quark, which is doubly represented in the proton.

This may be interpreted as an indication of the up-up correlation. At high Q^2 a correlation usually enhances the high momentum component and the interaction cross section.

The relatively weak down quark contribution to the F_{1p} indicates a suppression of the up-down correlation or a mutual cancellation of different types of up-down correlations.

The goal is understanding of the nucleon

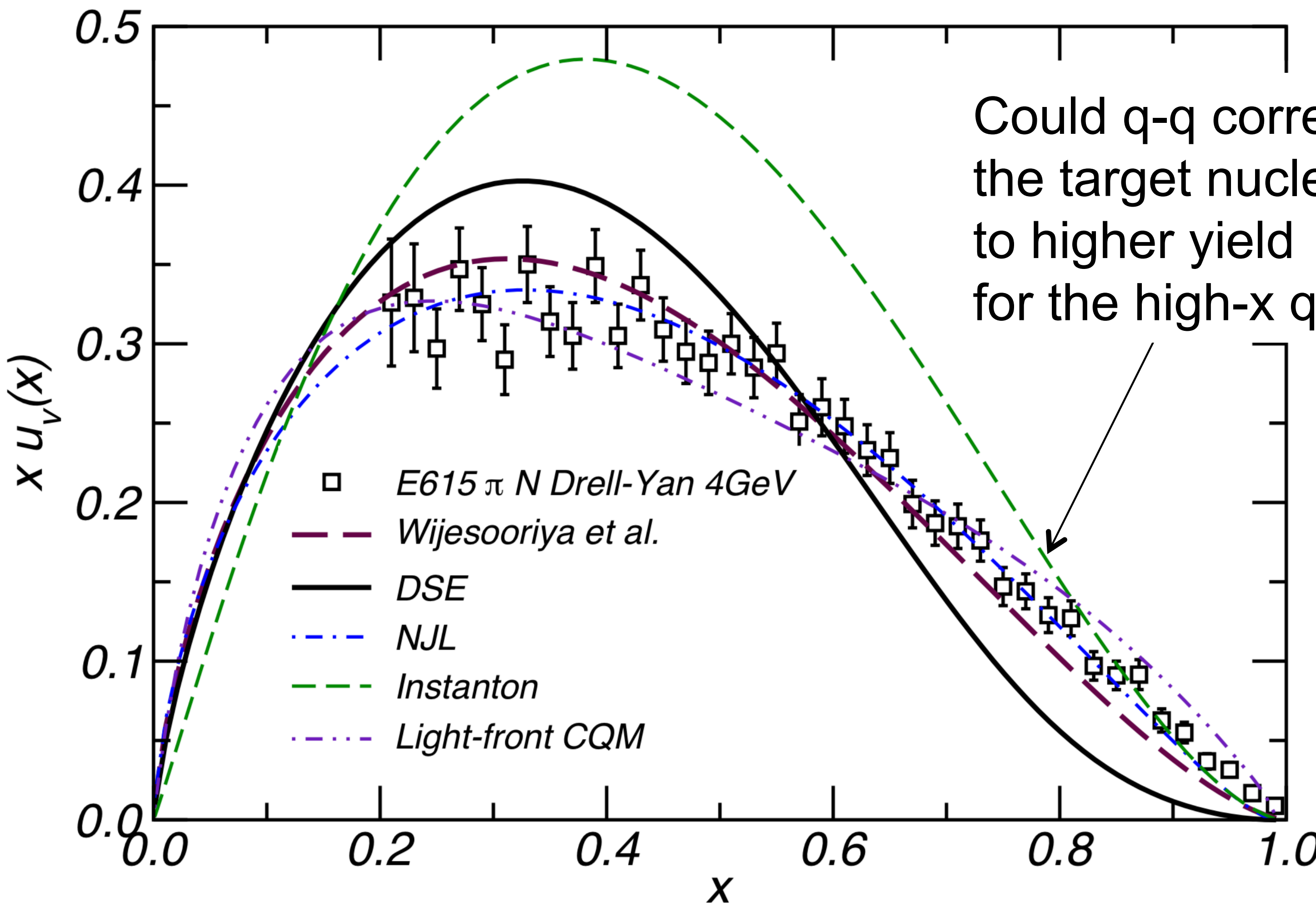
What is the nature of the result: a strong reduction of the d-quark contribution with increase of Q^2?

Diquarks are in the nucleon!
Expected (due to the baryon spectrum) since the 1960s (the problem of the missing resonances)

What is the reason for the F_2/F_1 ratio to be constant?

F_2 and F_1 are originated by the same object.

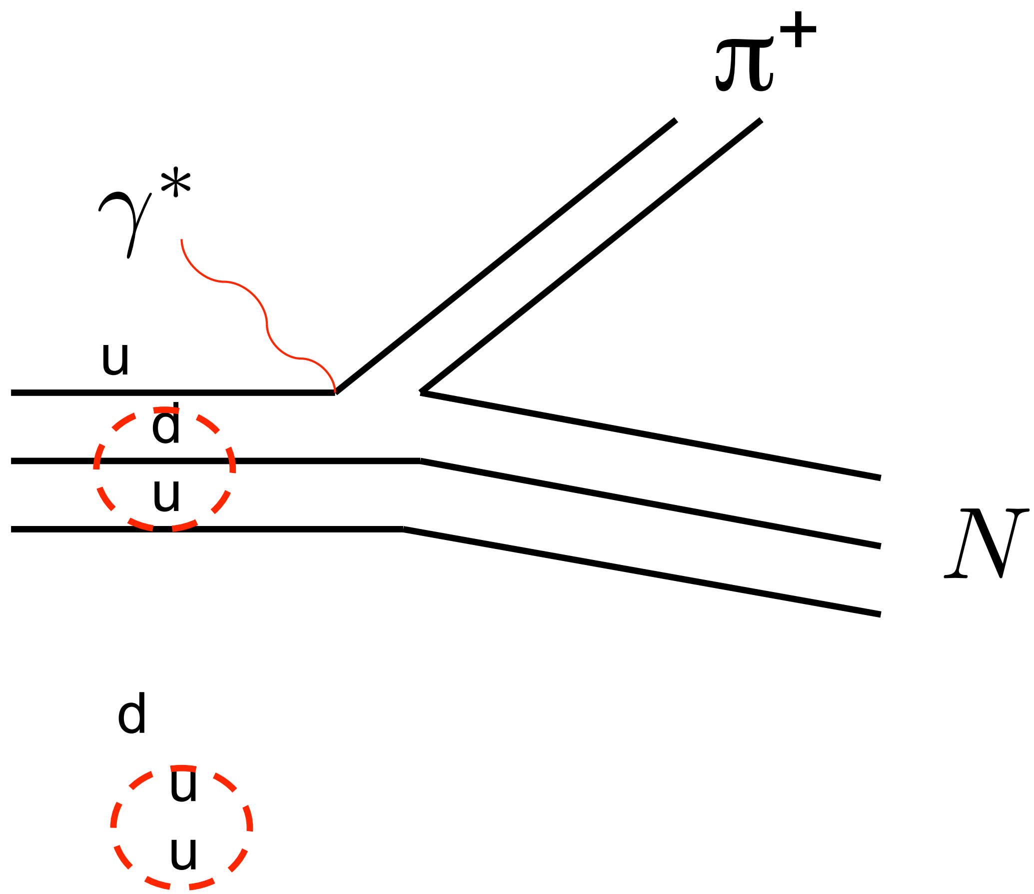
Are diquarks visible in Drell-Yan?



Could q-q correlation in the target nucleon lead to higher yield for the high-x quarks?

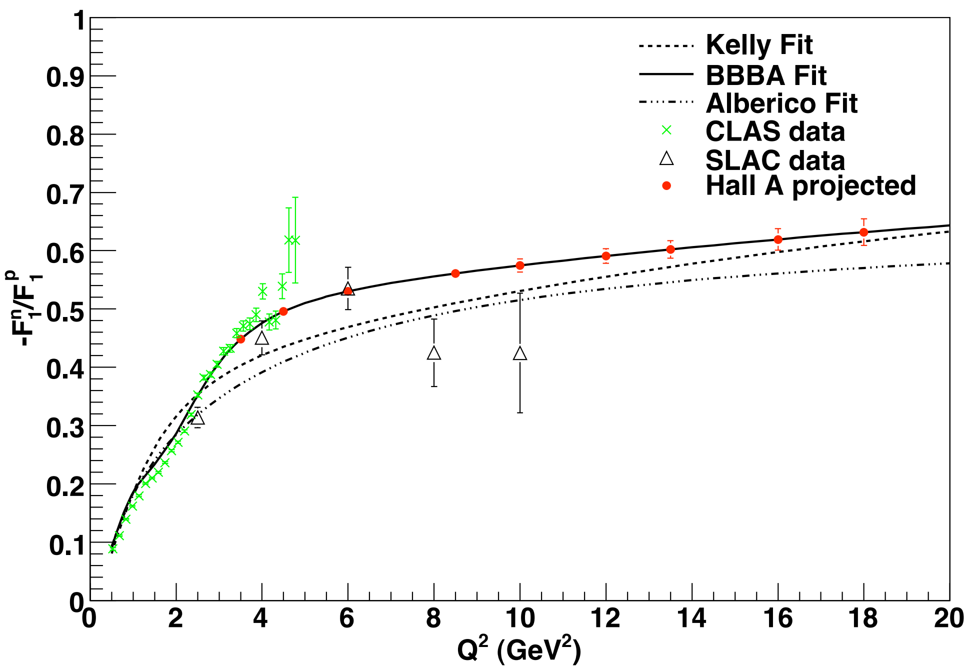
Are diquarks visible in the π^+/π^- ratio?

$$H(e, e'\pi N)$$



In the wide angle regime
down quark contribution
expected to be reduced
and negative pion yield drops

Upcoming GMn/GMp experiment

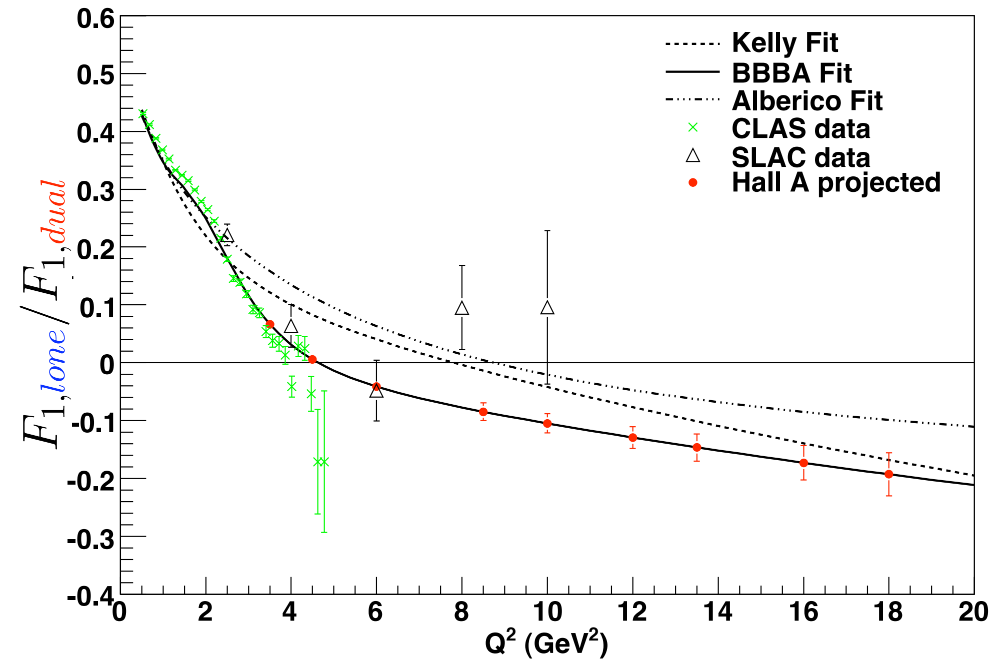


GPD model (Guidal etal):

$$F_1^u(t) = \int_0^1 dx u_v(x) e^{-t\alpha' \ln x},$$

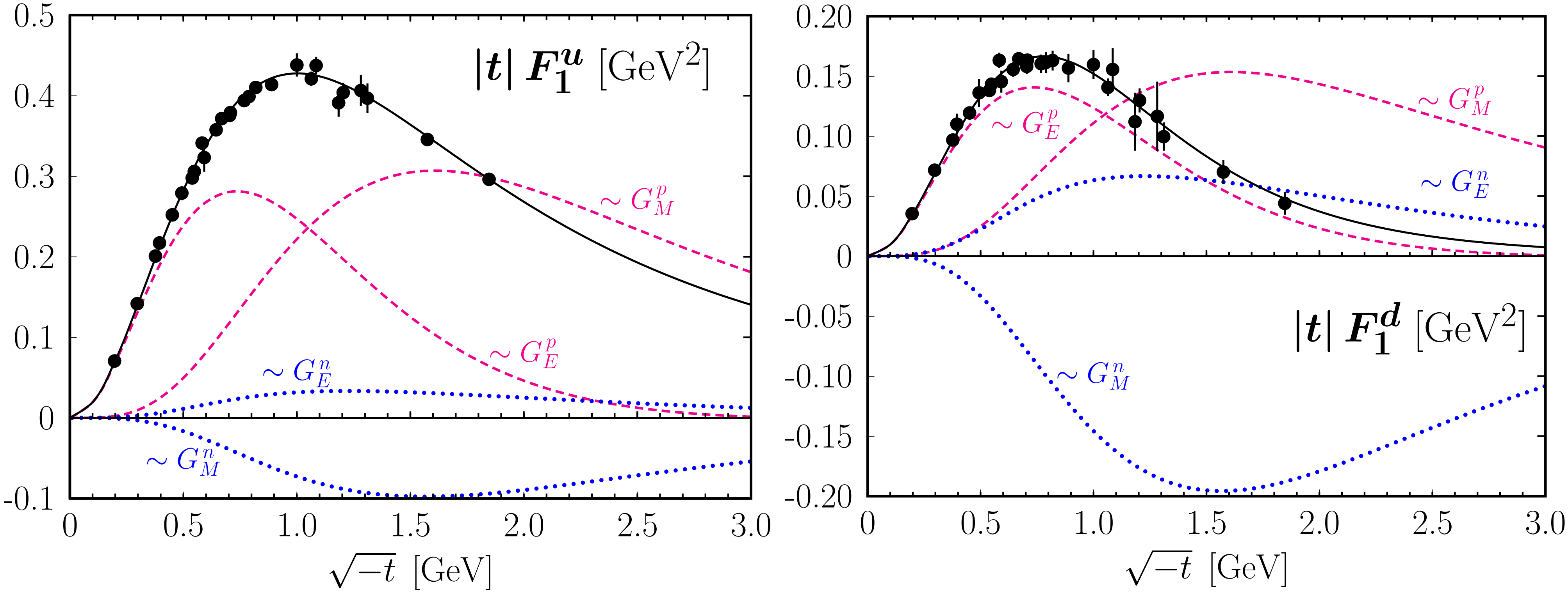
$$F_1^d(t) = \int_0^1 dx d_v(x) e^{-t\alpha' \ln x}.$$

If the experiment find $F_1^d < 0$.
It will present an interesting challenge to such a model.



F_1 decomposition at very large Q^2

$$F_1 = \frac{G_E + \tau G_M}{1+\tau} \quad F_2 = -\frac{G_E - G_M}{1+\tau}$$



M.Diehl and P.Kroll, Eur.Phys.J. C73 (2013) 2397

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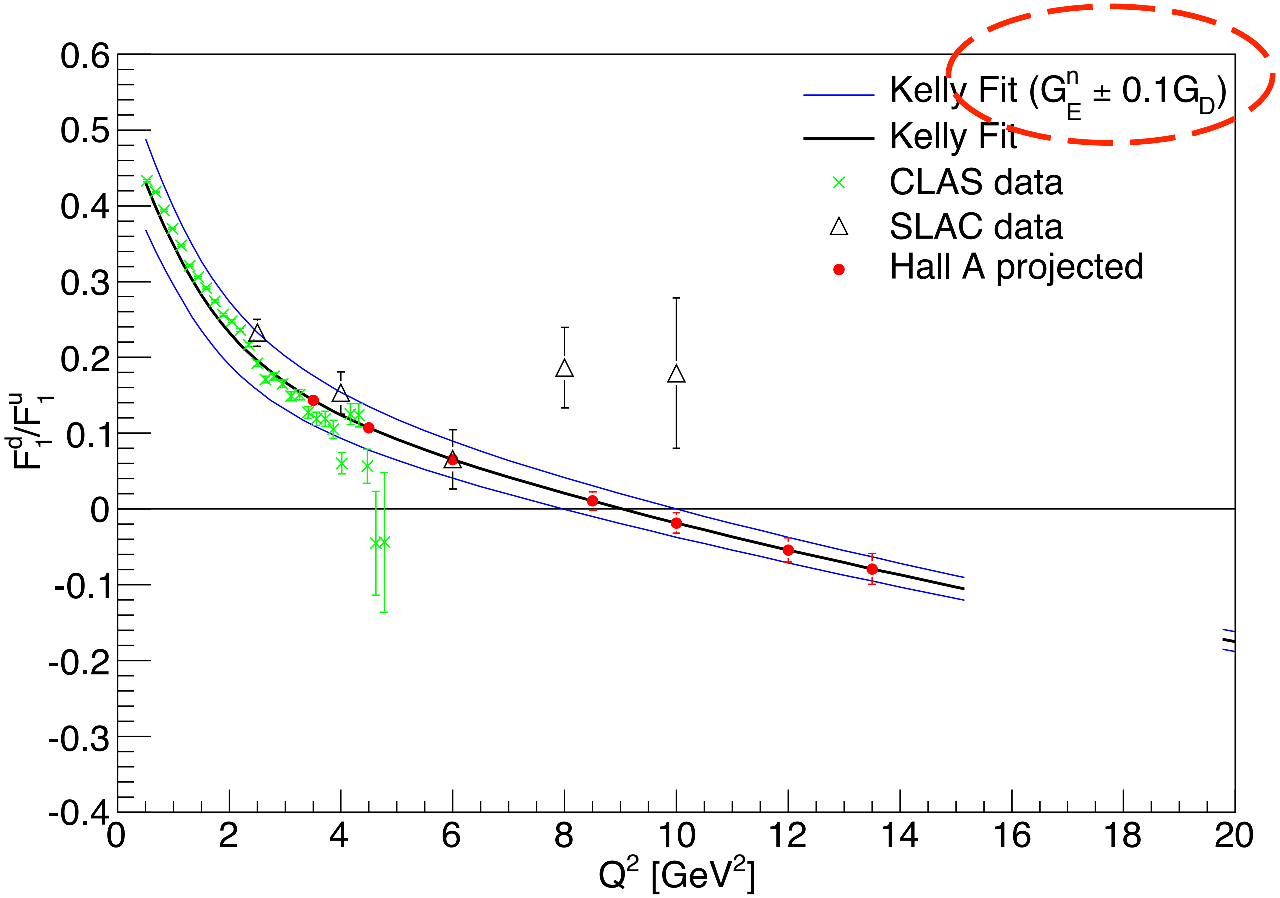
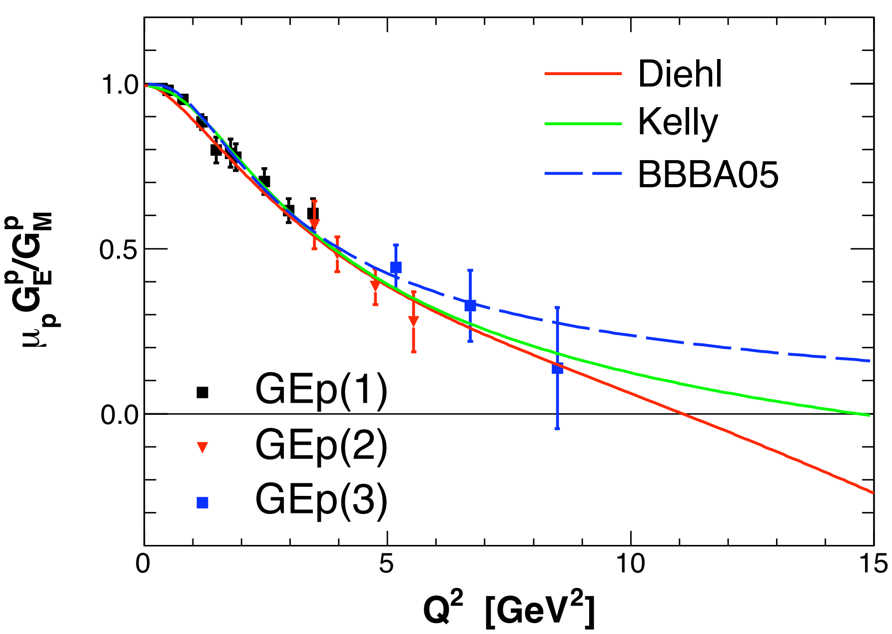
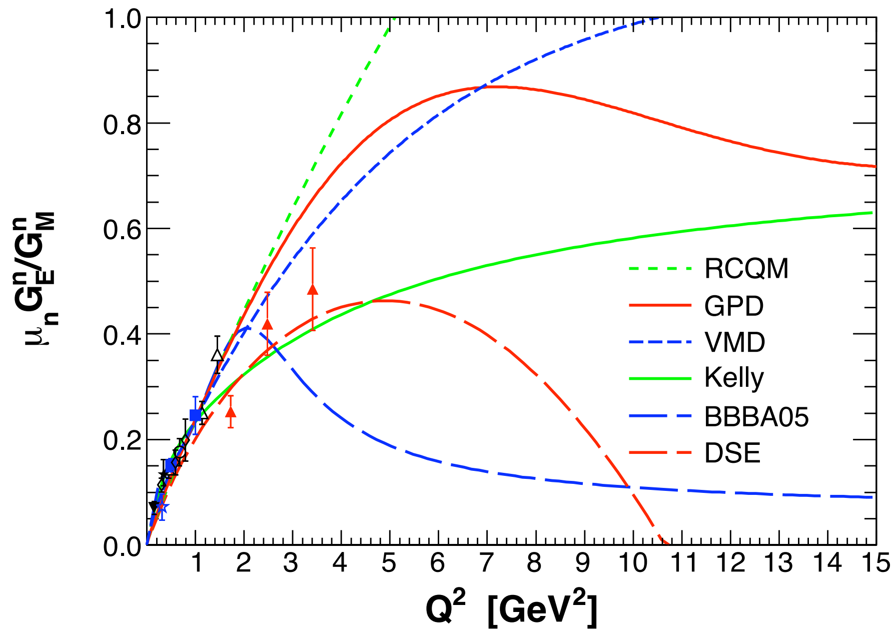


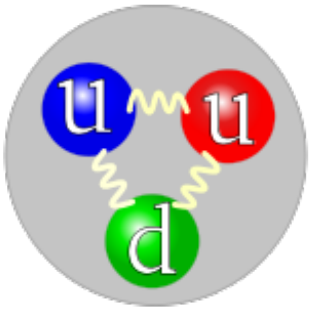
The strangeness form factors and impact on decomposition of EMFFs

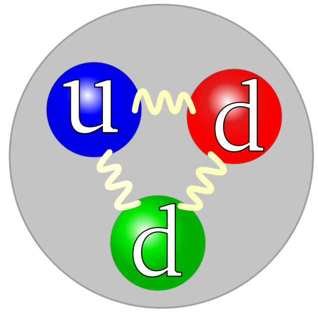




At 3 GeV^2 the GEp and GEn are similar ~ 0.4-0.5 of G_D

sFF data and projections



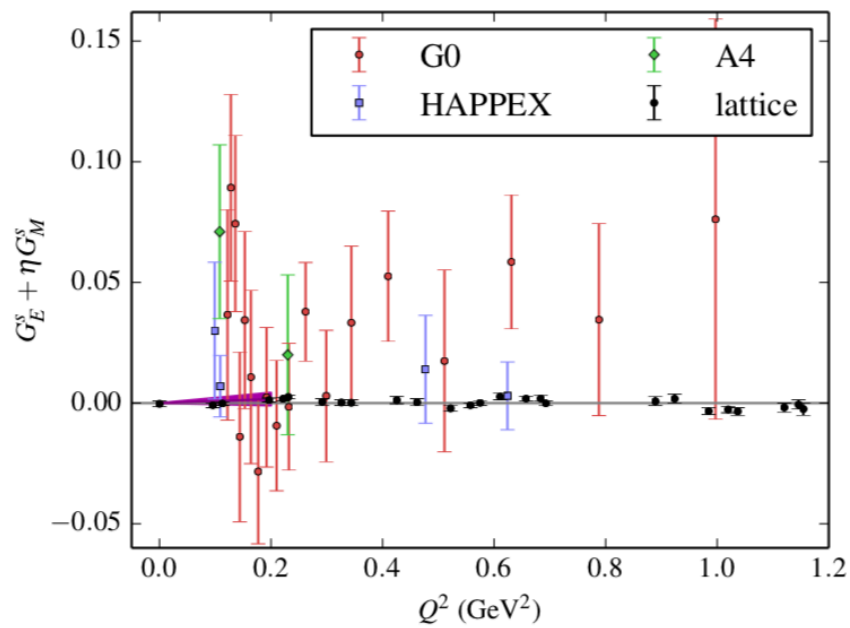


Expectations for
the strangeness FF

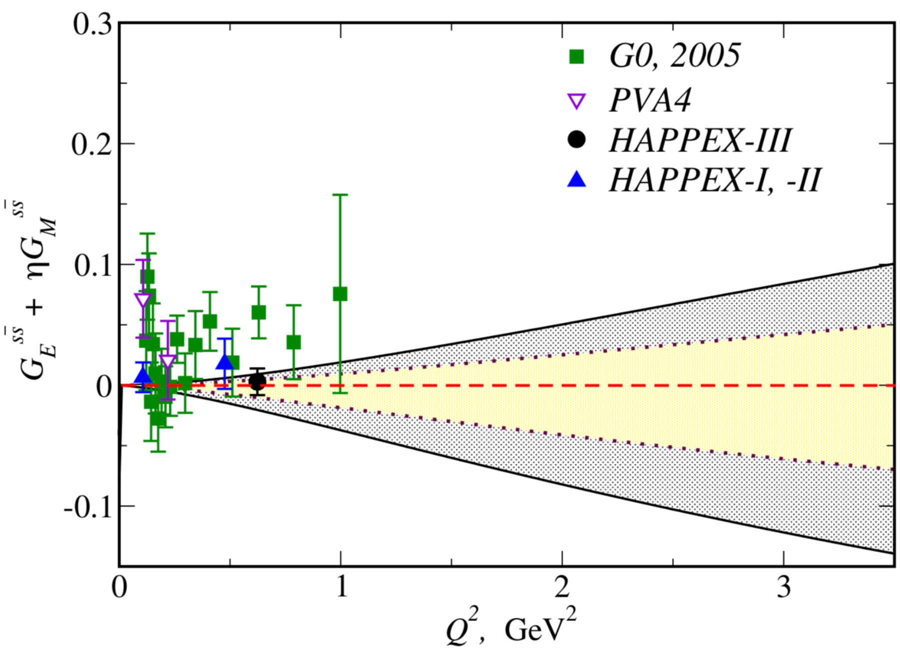
G_D at 3 GeV^2 is 0.037

$G_s/G_D \sim 1$ is not excluded

J.Green etal, 2015



T.Hobbs & J.Miller, 2018

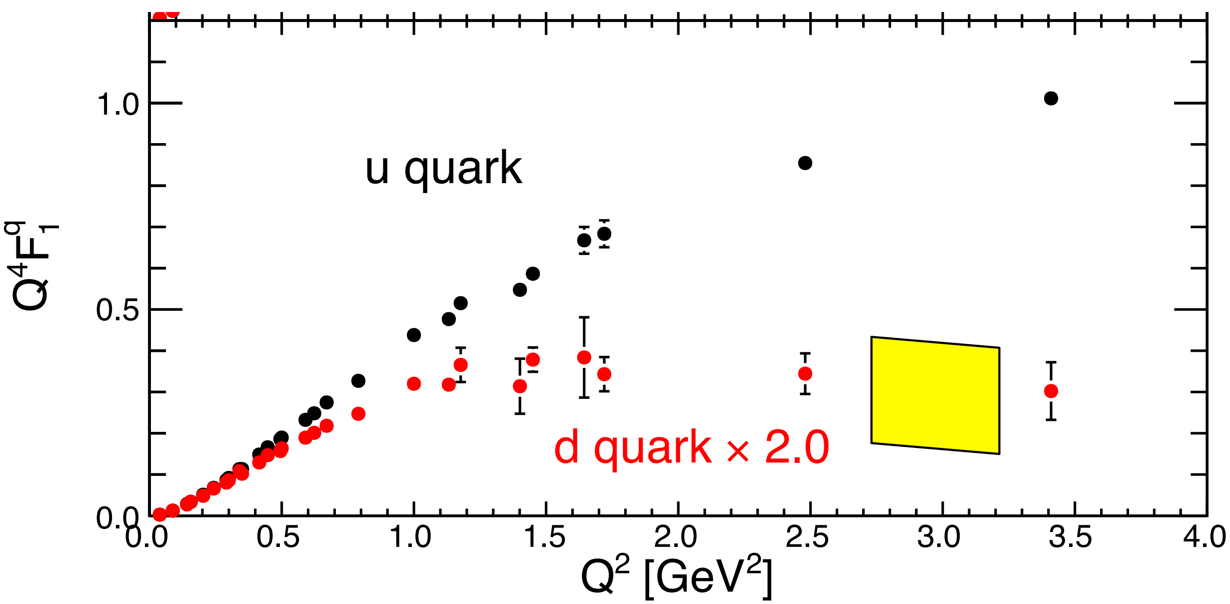


Electromagnetic Form Factors

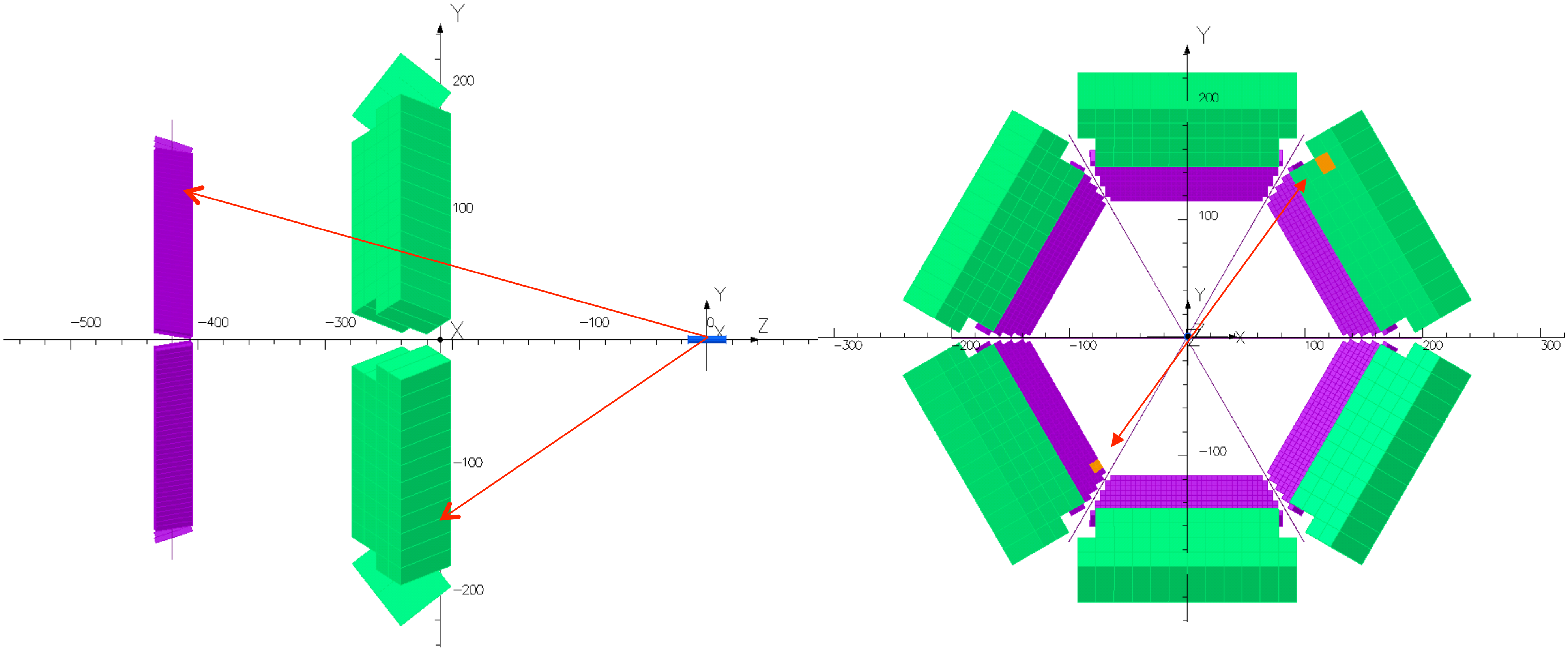
$$F_{1p} = e_u\, F_1^u \;+\; e_d\, F_1^d \;+\; e_s\, F_1^s$$

$$F_{1n} = e_u\, F_1^d \;+\; e_d\, F_1^u \;+\; e_s\, F_1^s$$

$$F_1^u = 2\, F_{1p} \;+\; F_{1n} - \tfrac{1}{3} F_1^s, \quad F_1^d = 2\, F_{1n} \;+\; F_{1p} - \tfrac{1}{3} F_1^s$$



Coincidence parity experiment

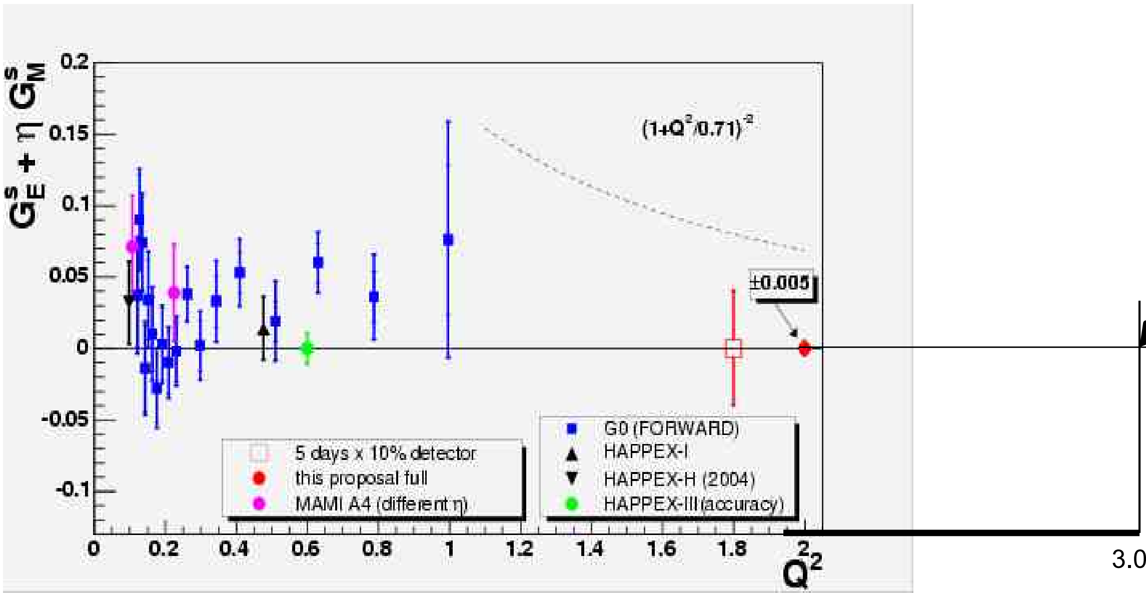


The apparatus can re-use two calorimeters from the GEp/SBS experiment.

Coincidence is needed for selecting of the elastic scattering process.

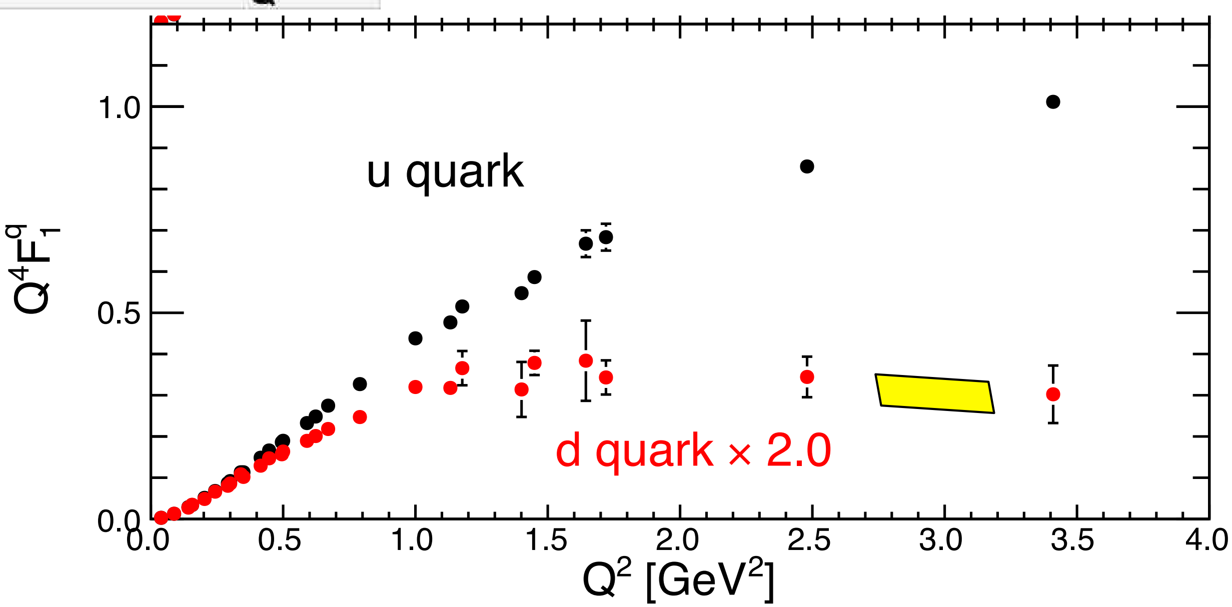
Coincidence parity experiment

Strangeness Form factor



projected precision
at Q^2 = 3 GeV^2

$\Delta G^s/G_D = 0.05$



Summary

- Flavor decomposition of the nucleon Form Factors revealed significant change in the up and down quarks' contributions to the F_1 form factor at Q^2 above 1-1.5 GeV^2.

- Diquarks are a natural interpretation of the observed drop in F_1^d/F_1^u ratio with Q^2 in the range 1.5 - 3 GeV^2.

- GMn 12-GeV experiment with the Super Bigbite spectrometer will soon (2021) take data => F_1^d/F_1^u.

- Uncertainty of the strangeness contribution to u,d FF is a dominant one, but sFF can be measured at Q^2 of 3 GeV^2.