Elastic Form Factors

Bogdan Wojtsekhowski, Jefferson Lab

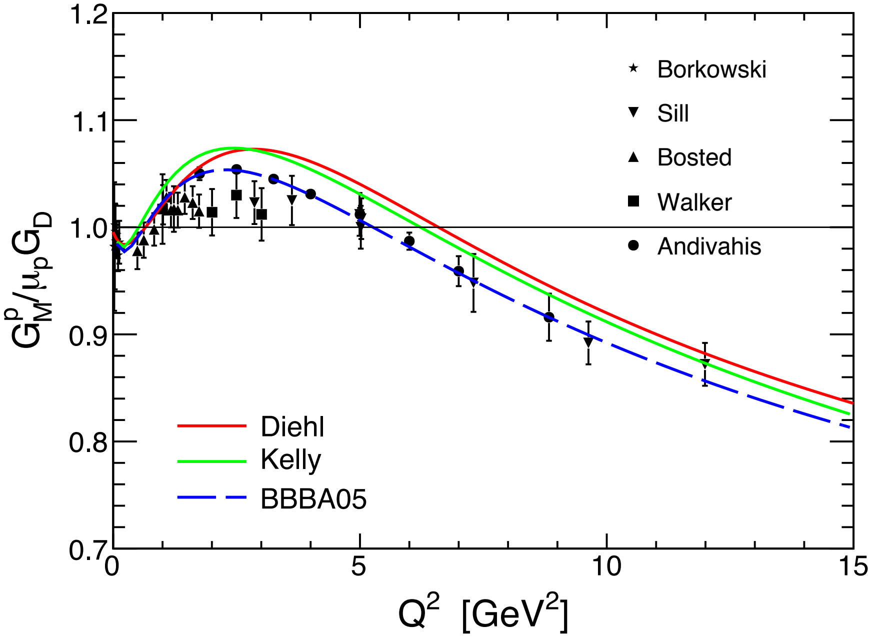
JLab past and current elastic form factor experiments

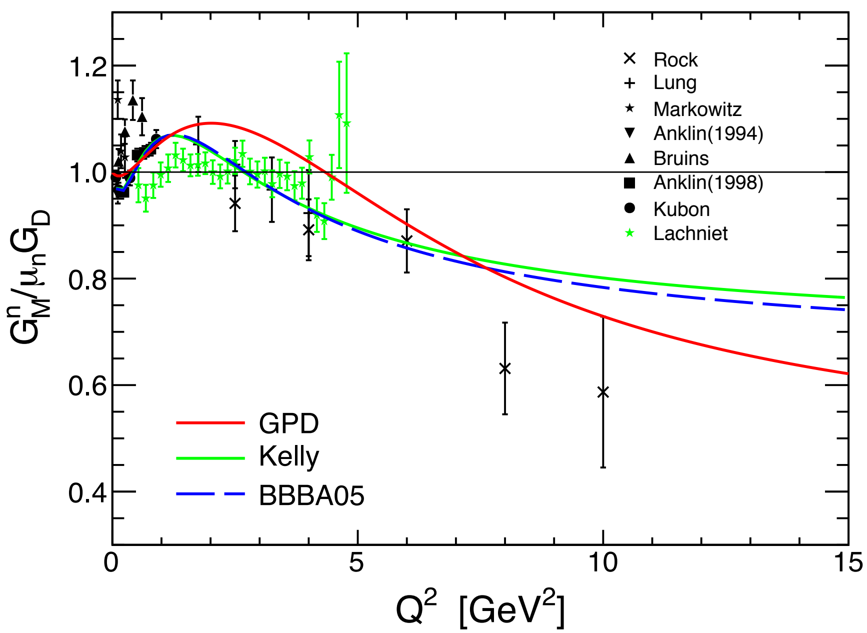
Diquarks in the nucleon

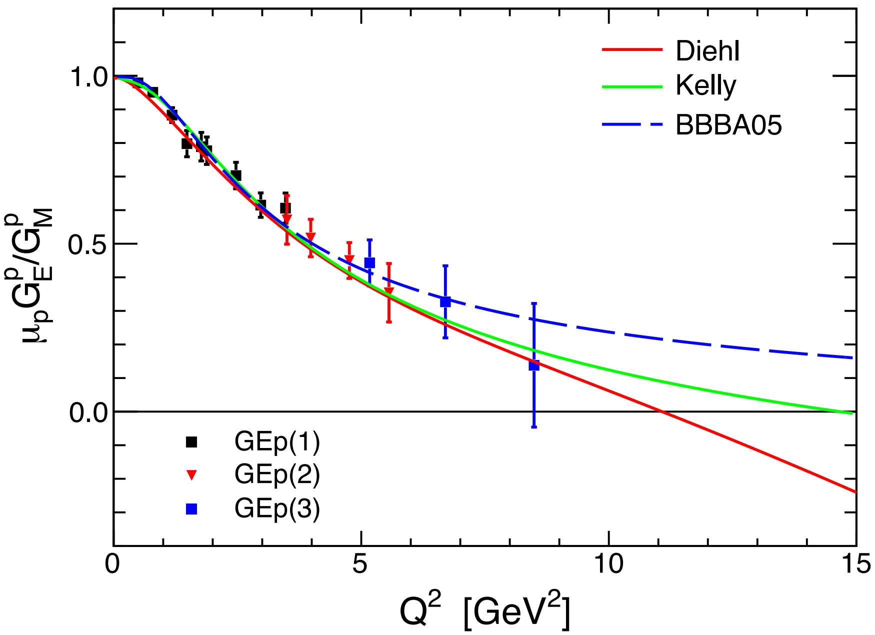
Direct evidence of diquark from the form factor flavor decomposition

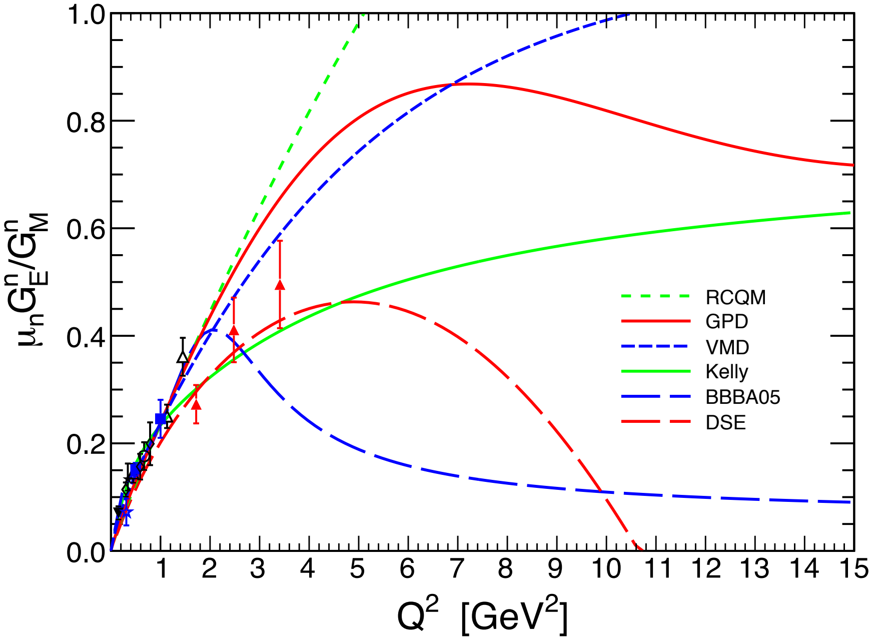
Does diquark have a role in the σ_L/σ_T "minimum" ?

Sachs Form Factors of the nucleon

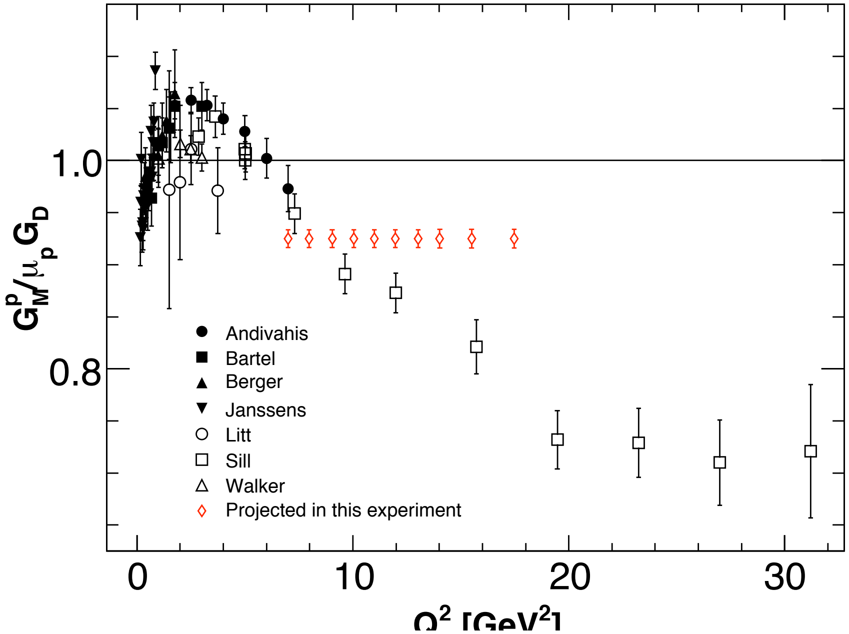


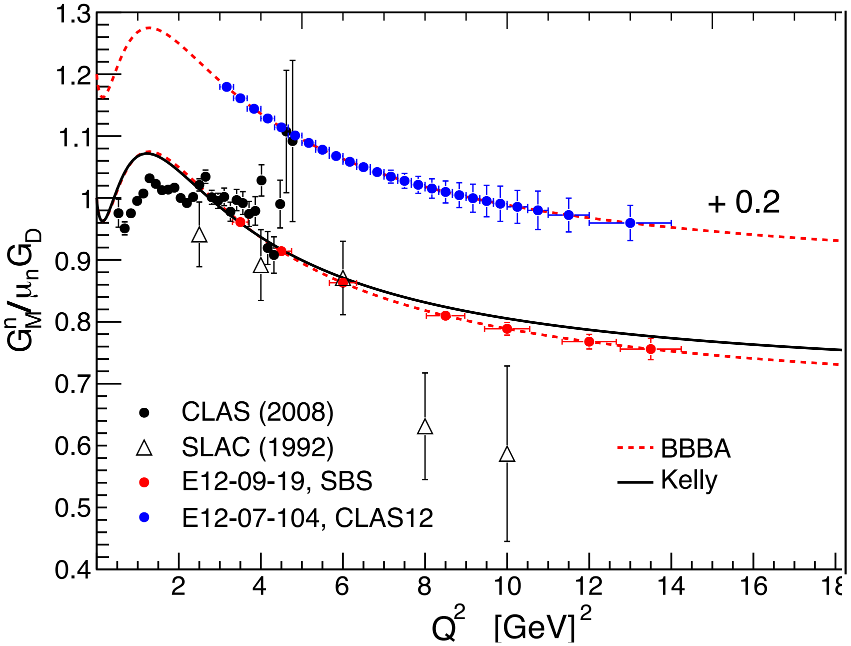


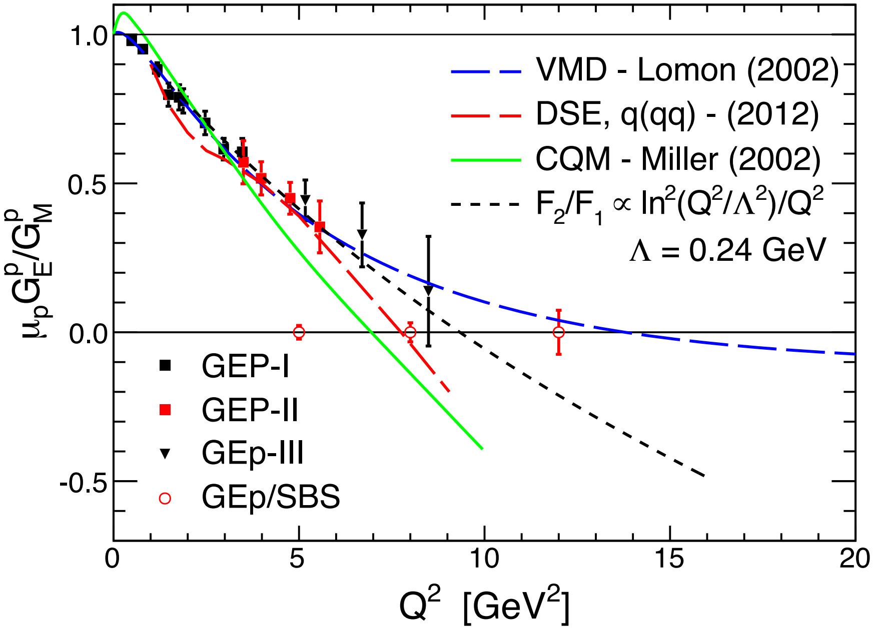


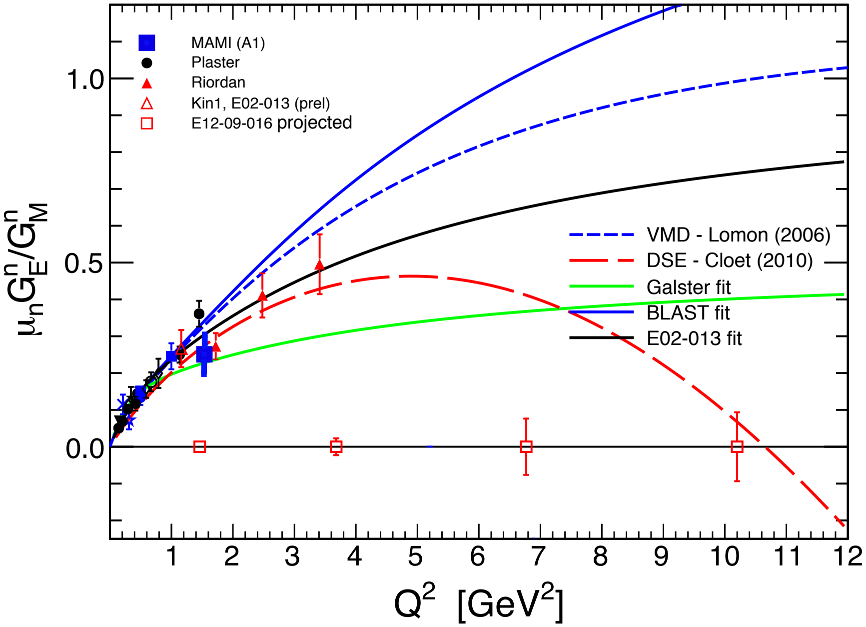


Sachs Form Factors, JLab plans



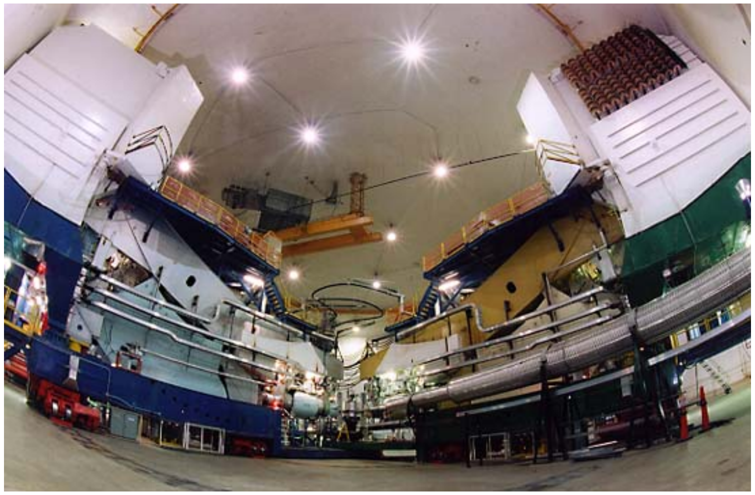




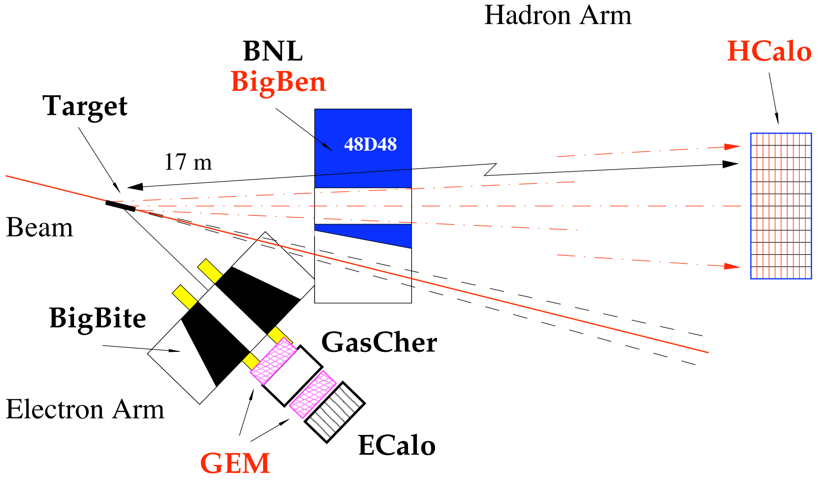


Hall A form factor experiments

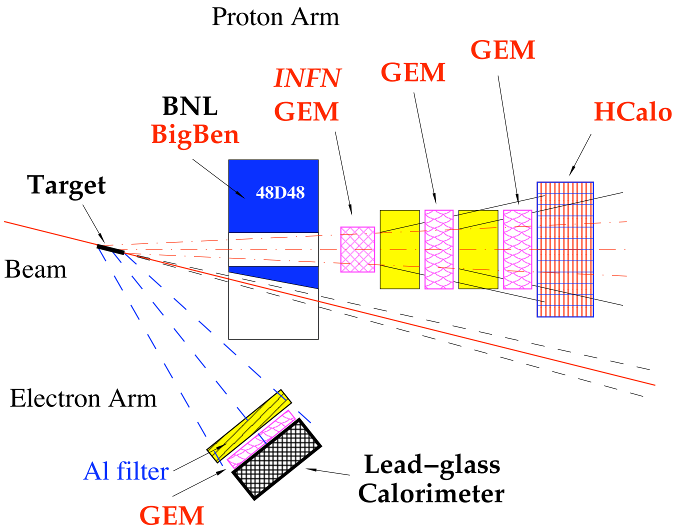
Proton magnetic form factor: E12-07-108



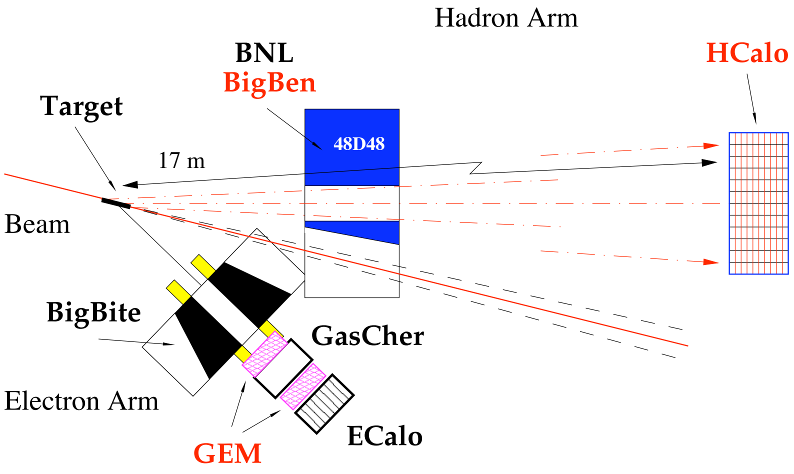
Neutron/proton form factors ratio: E12-09-019



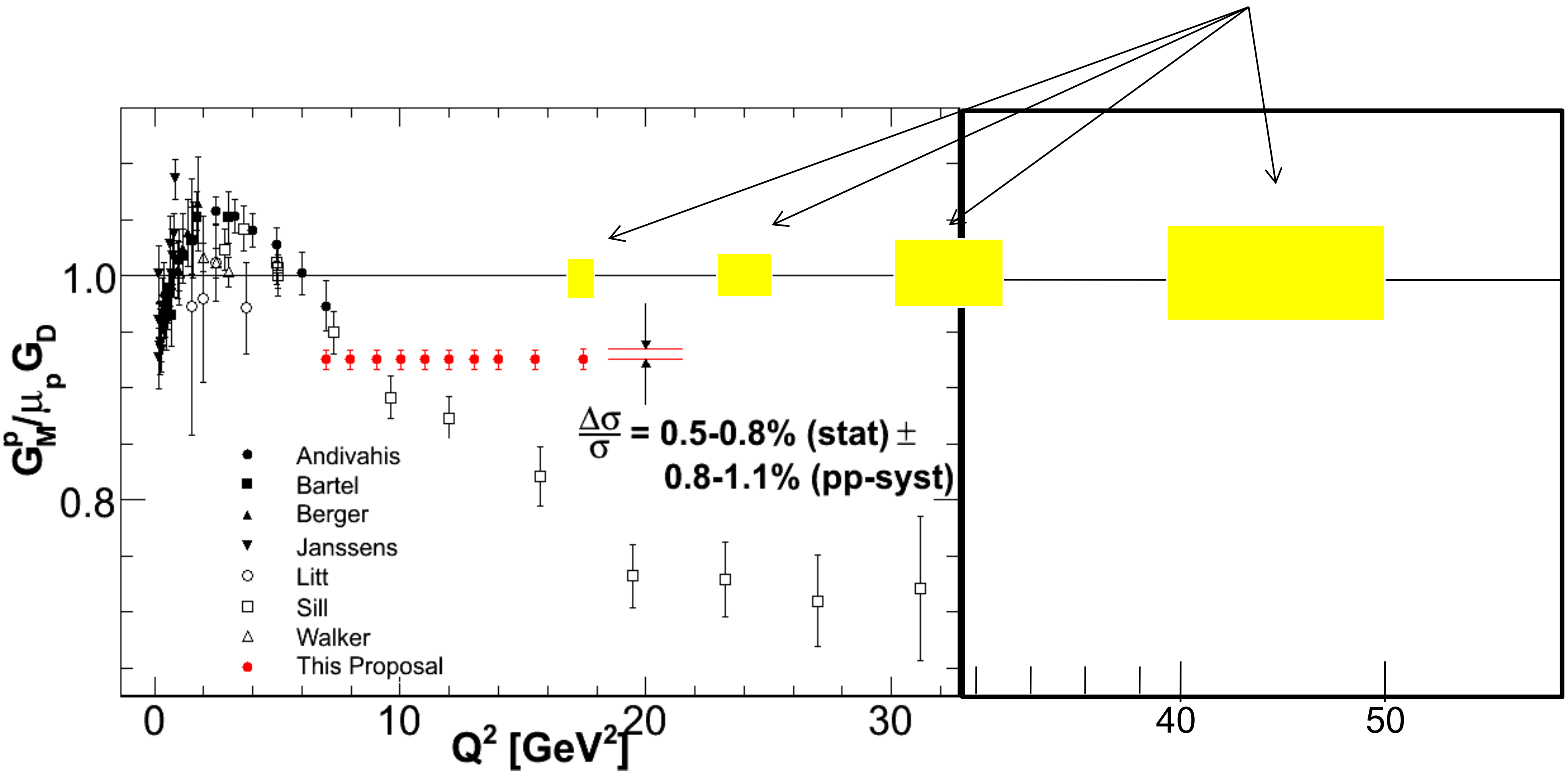
Proton form factors ratio, GEp(5): E12–07–109



Neutron form factors ratio, GEn(2):E12-09-016

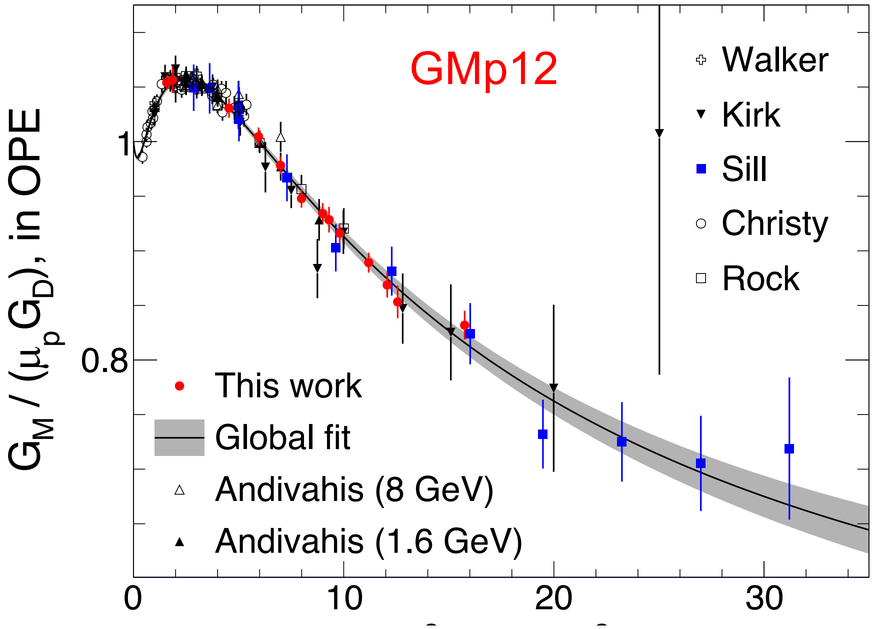


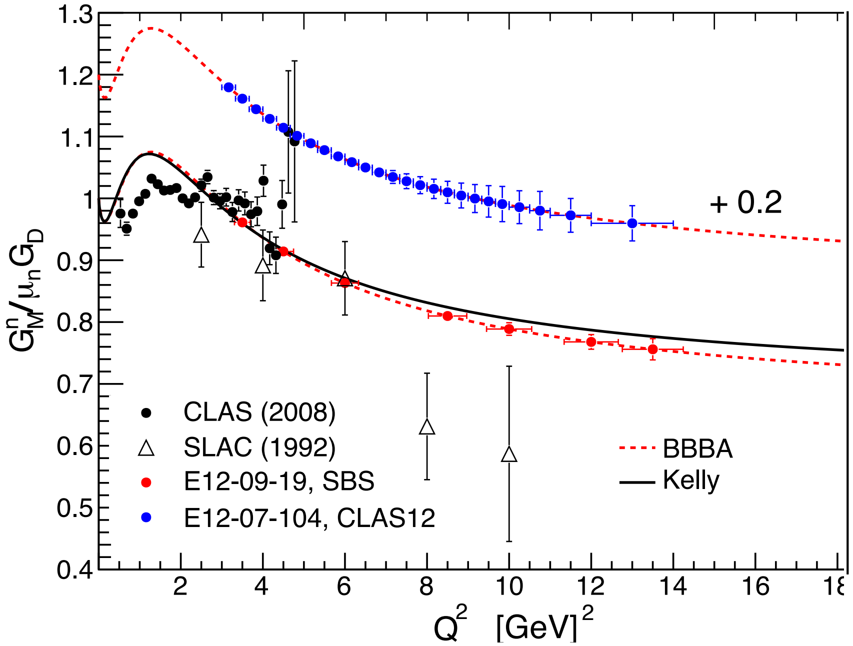
GMp Form Factor with EIC

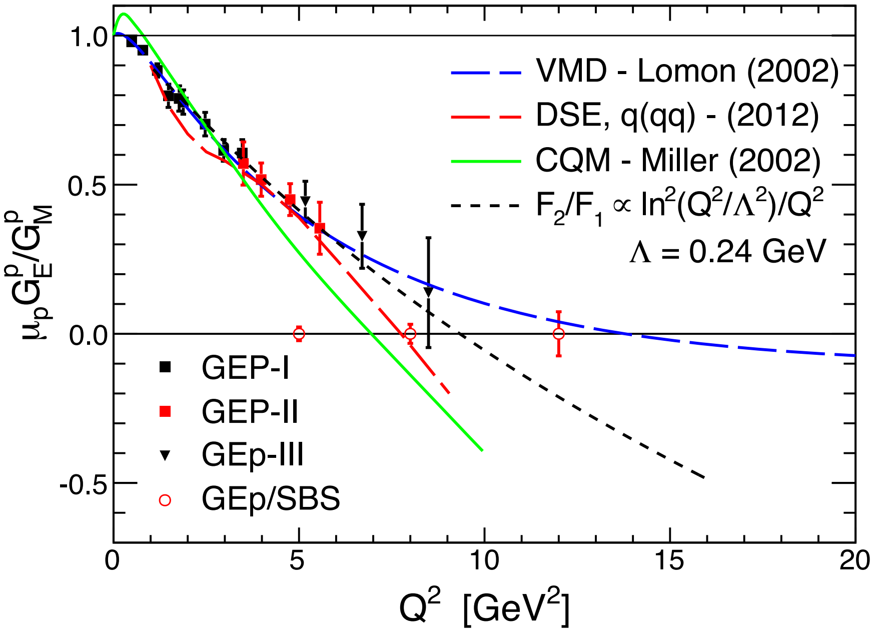


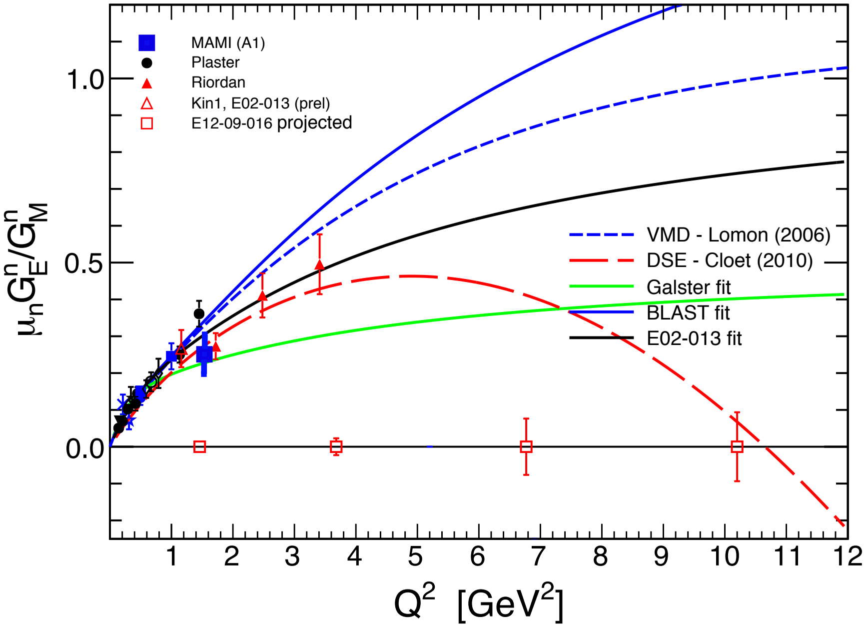
$$F_1(t) \approx G_M \sim \mu_p G_{Dipole} = \mu_p[1 + Q^2/0.71]^{-2}$$

Sachs Form Factors today

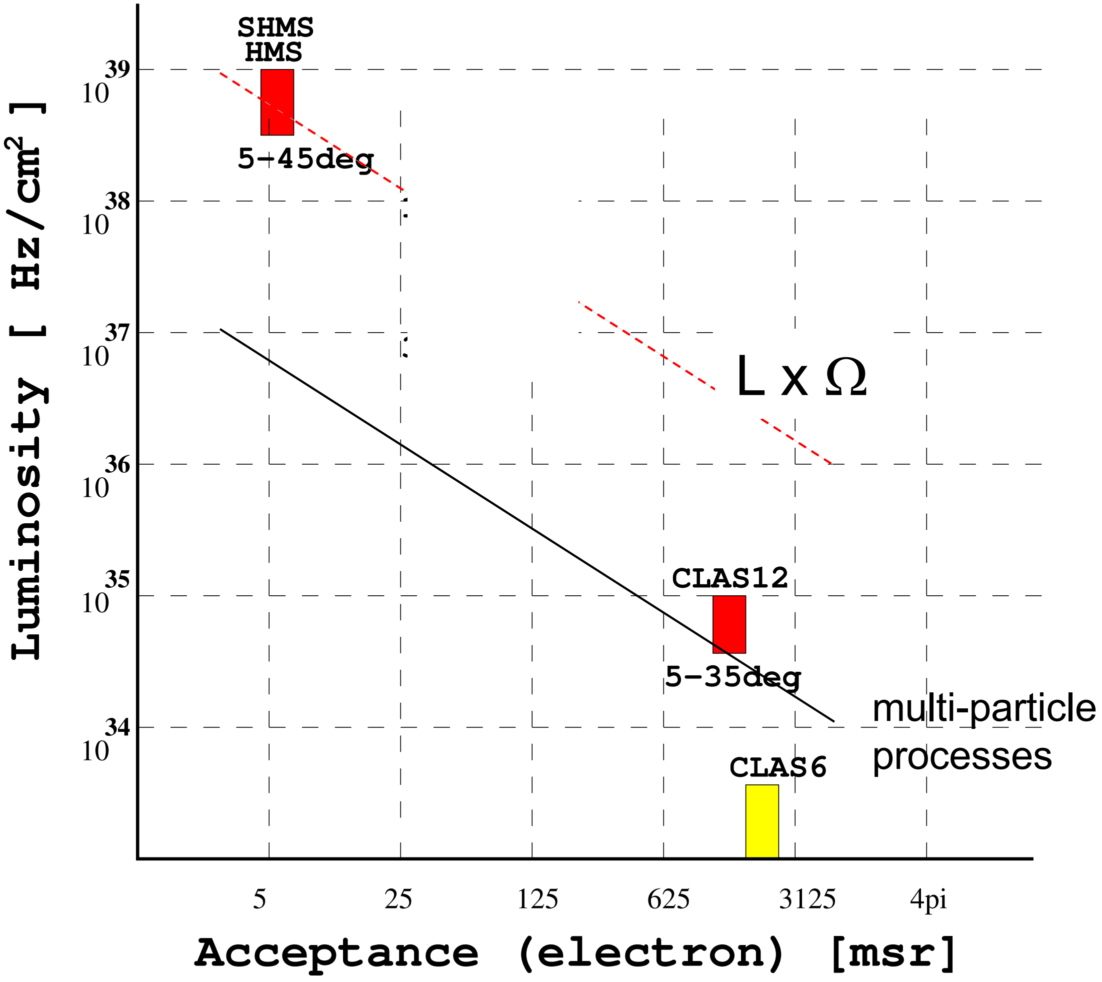








JLab detector landscape



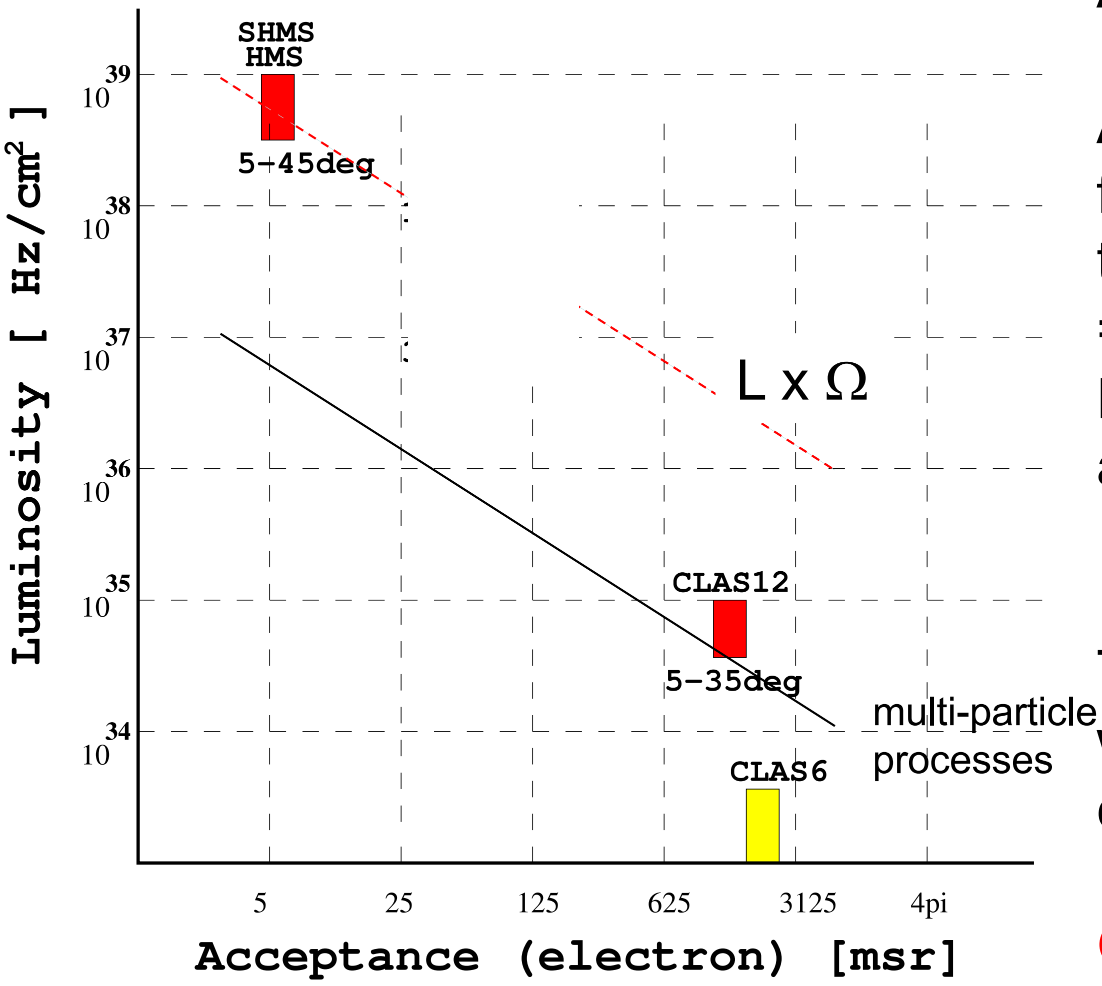
A range of 10^4 in luminosity.

A big range in solid angle:
from 5 msr (SHMS)
to about 1000 msr (CLAS12).

Polarized He-3 target operates at $L_{\text{electron-nucleon}}$ luminosity up to $1.8 \cdot 10^{37}$ Hz/cm^2 (+ the cell)

Beam intensity is limited by 5 μA in Hall B and D

JLab detector landscape



A range of 10^4 in luminosity.

A big range in solid angle:
from 5 msr (SHMS)
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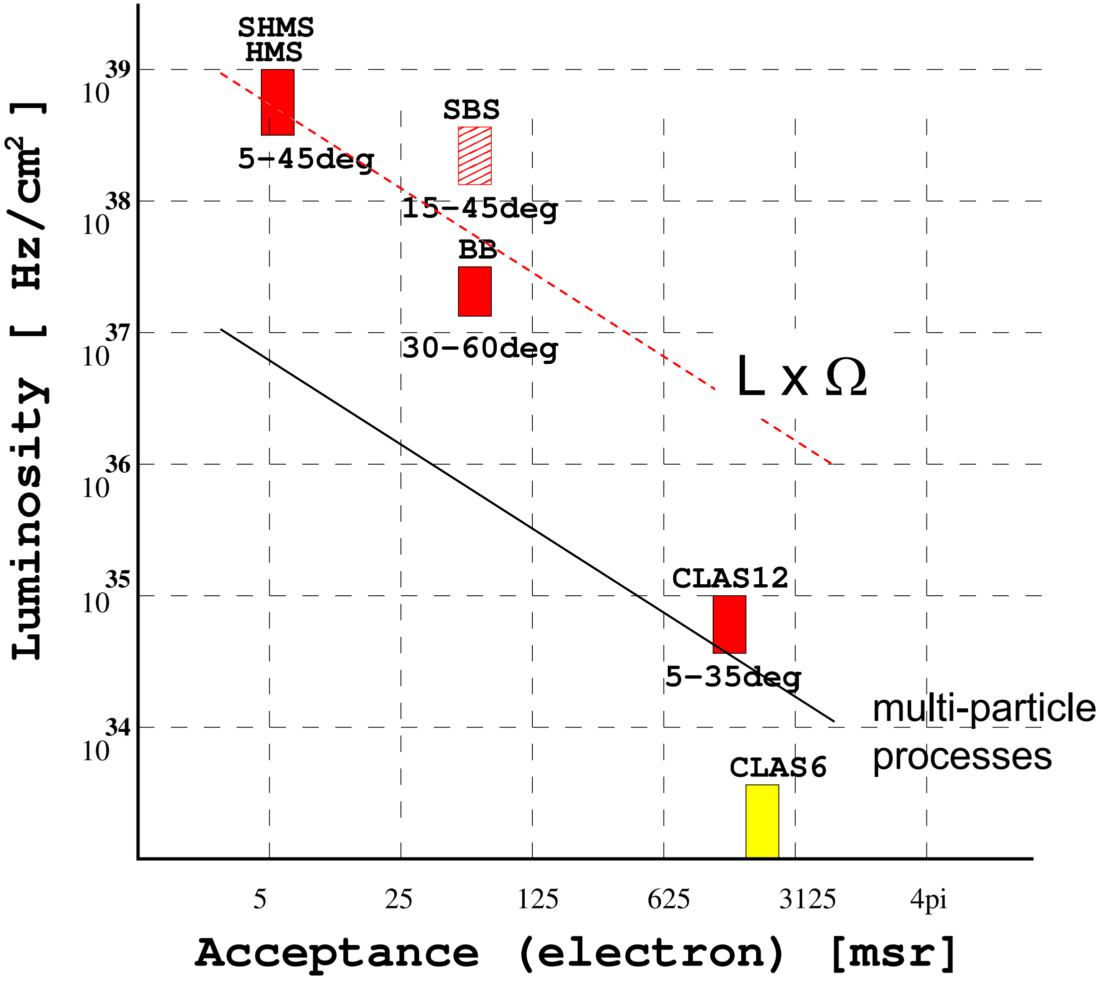
==========================

Polarized He-3 target operates at $L_{\text{electron-nucleon}}$ luminosity up to $1.8 \cdot 10^{37}$ Hz/cm^2 (+ the cell)

There is a need for a spectrometer with a solid angle of 100 msr capable of operating at 10^{38} Hz/cm^2

GEM tracking is the answer

JLab detector landscape



A range of 10^4 in luminosity.

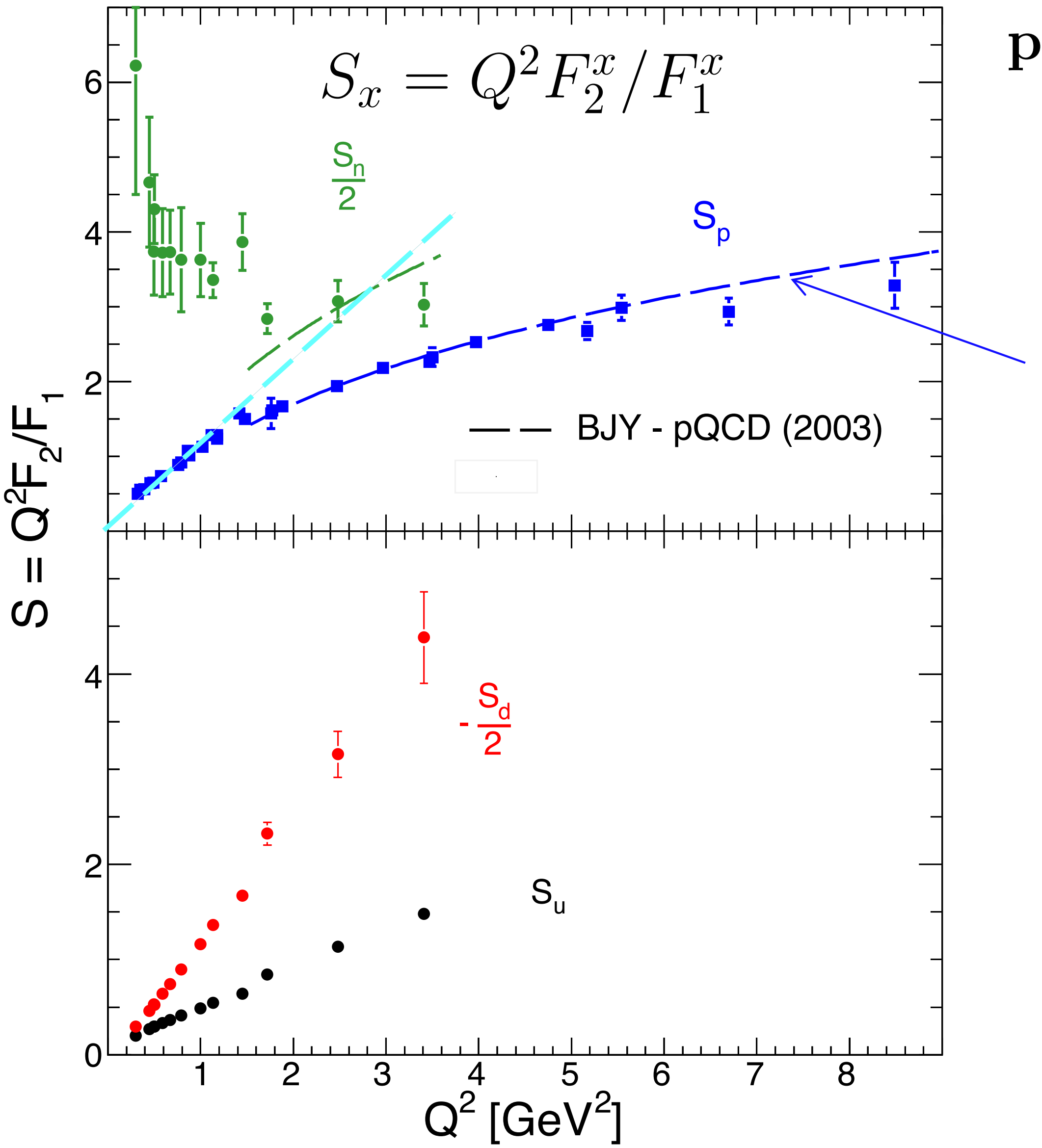
A big range in solid angle:
from 5 msr (SHMS)
to about 1000 msr (CLAS12).

The SBS is in the middle:
for solid angle (up to 70 msr)
and high luminosity capability.

In several A-rated experiments
SBS was found to be the best
match to the physics.

GEM allows a spectrometer
with open geometry (and large
acceptance) at high luminosity.

The goal is understanding of the nucleon



pQCD prediction for large Q^2:

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

pQCD updated prediction:

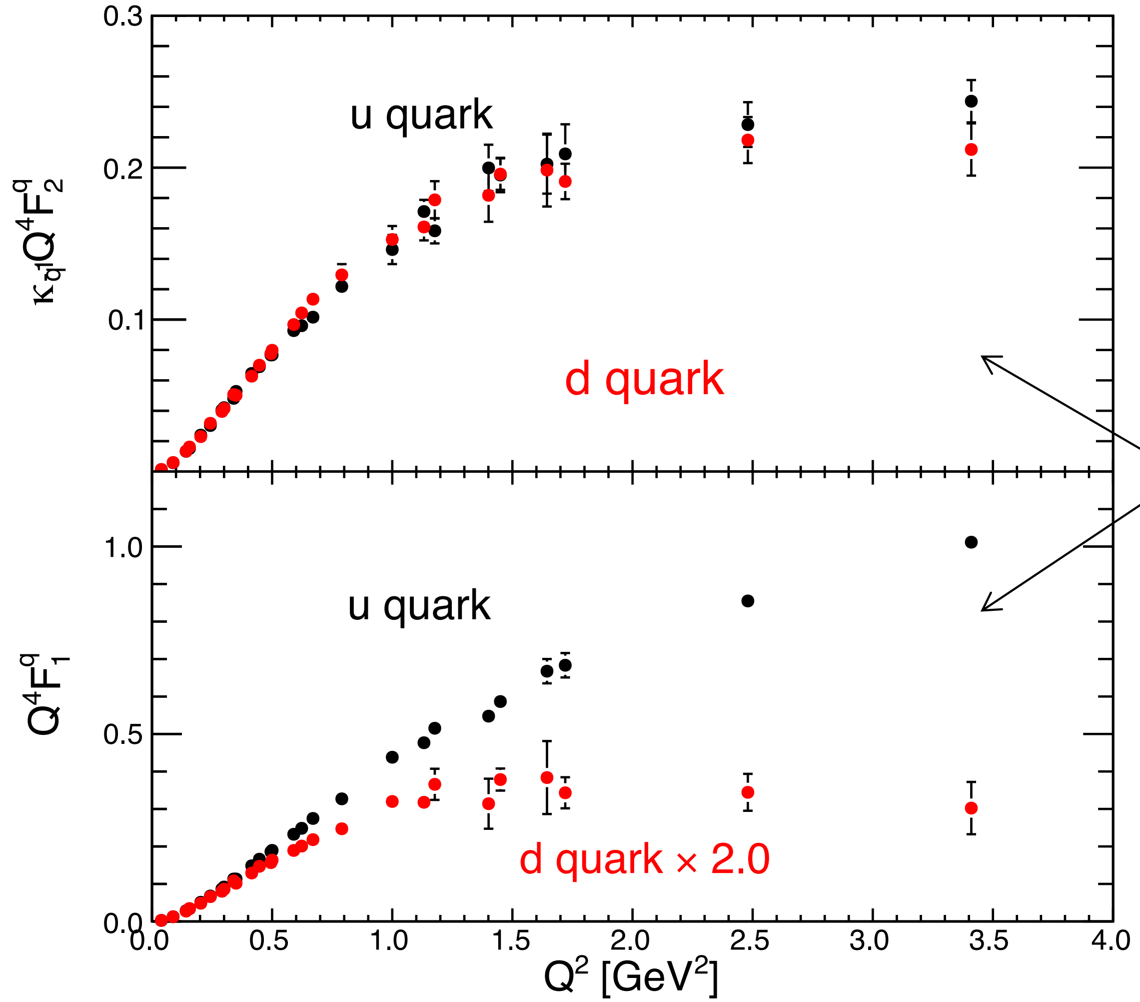
$$S \to \left[Q^2/\ln^2(Q^2/\Lambda^2)\right] F_2/F_1$$

Flavor separated contribution: The log scaling for the proton Form Factor ratio at a such low - 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)

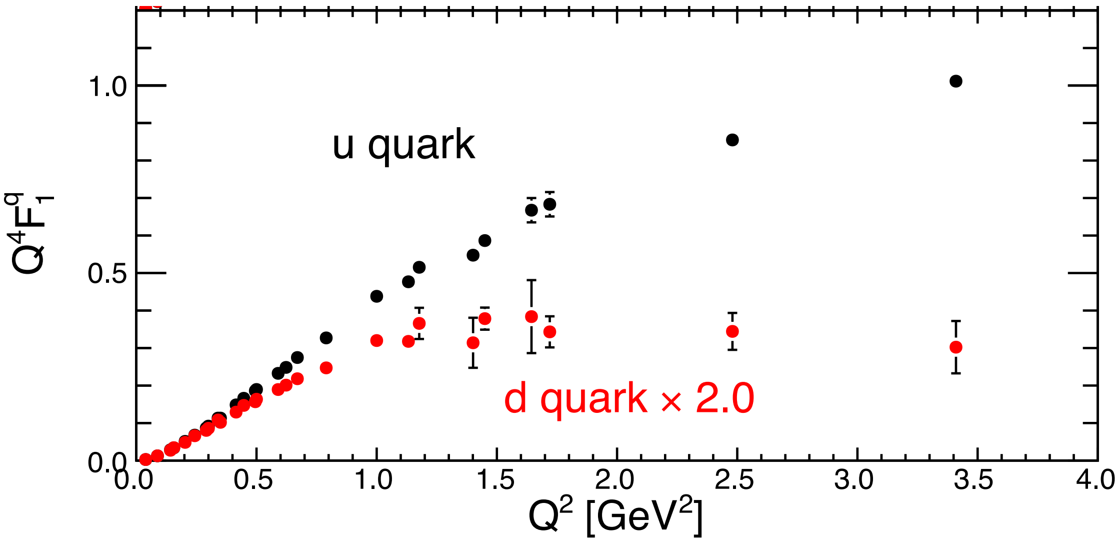
Eur.Phys.J. C73 (2013) 2397

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

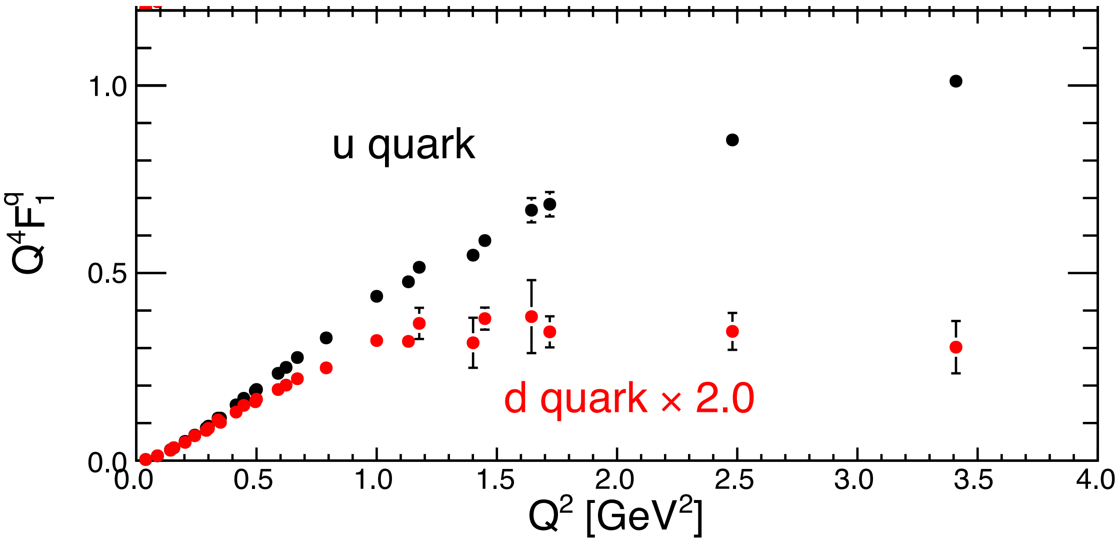
When the virtual photon of 3 GeV^2 interacts with the down quark the proton more likely falls apart than in the case of the up quark

The flavor disparity in the nucleon



The contribution of the down quark to the F_{1p} form factor at Q^2=3.4 GeV^2 is three times less than the contribution of the up quarks (corrected for the number of quarks and their charge).

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.

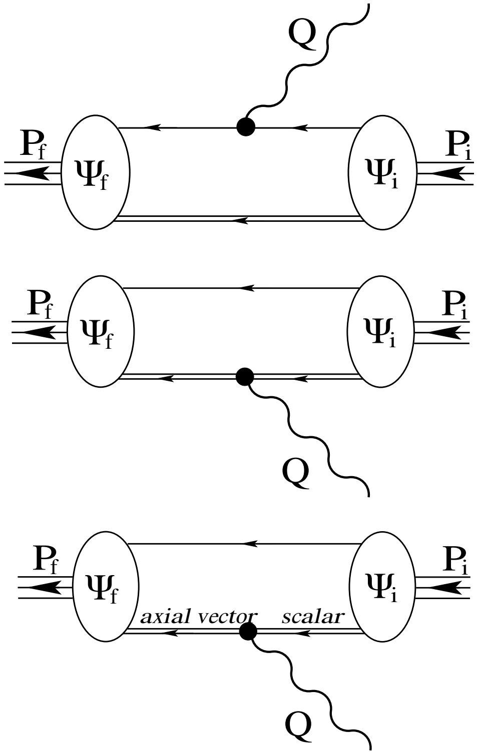
This may be interpreted as an indication of the up-up correlation. At high Q^2 a correlation usually enhances the high momentum component and the interaction cross section.

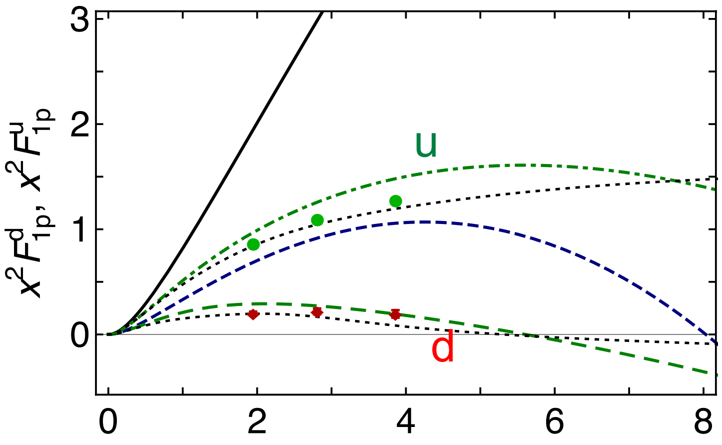
The relatively weak down quark contribution to the F_{1p} indicates a suppression of the up-down correlation or a mutual cancellation of different types of up-down correlations.

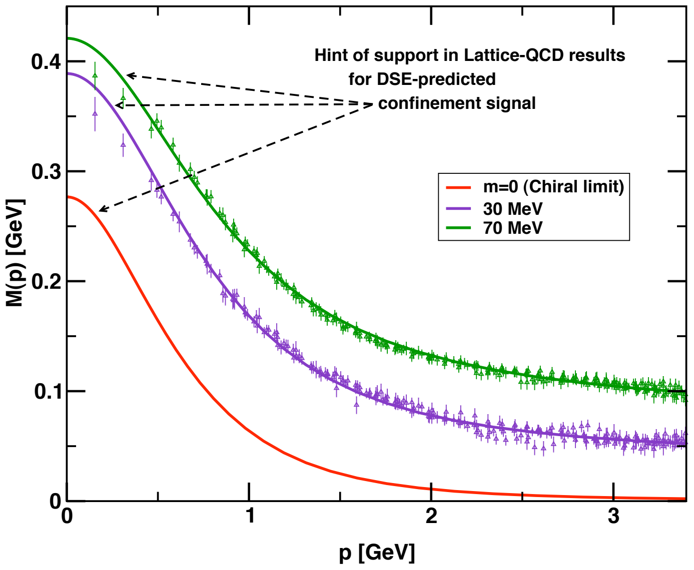
The goal is understanding of the nucleon

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, arXiv:0812.0416

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?

A singly represented quark has a wider distribution in the impact parameter space than the doubly represented quarks. Why is it wider?

What is the reason for the F2/F1 ratio to be constant?

F2 and F1 are originated by the same object.
There is no indication of the orbital moment.

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?

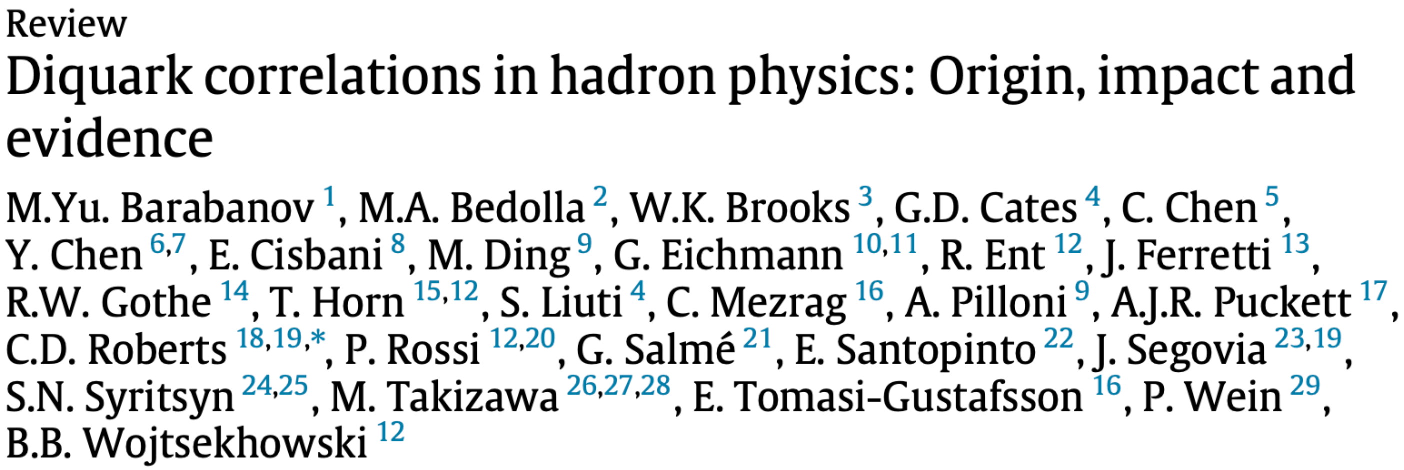
Diquarks are in the nucleon!
Expected (due to the baryon spectrum) since the 1960s (the problem of the missing resonances)

What is the reason for the F2/F1 ratio to be constant?

F2 and F1 are originated by the same object.

The goal is understanding of the nucleon

The Trento workshop in September 2019 led to a comprehensive review of the diquark physics and related experiments:



Review

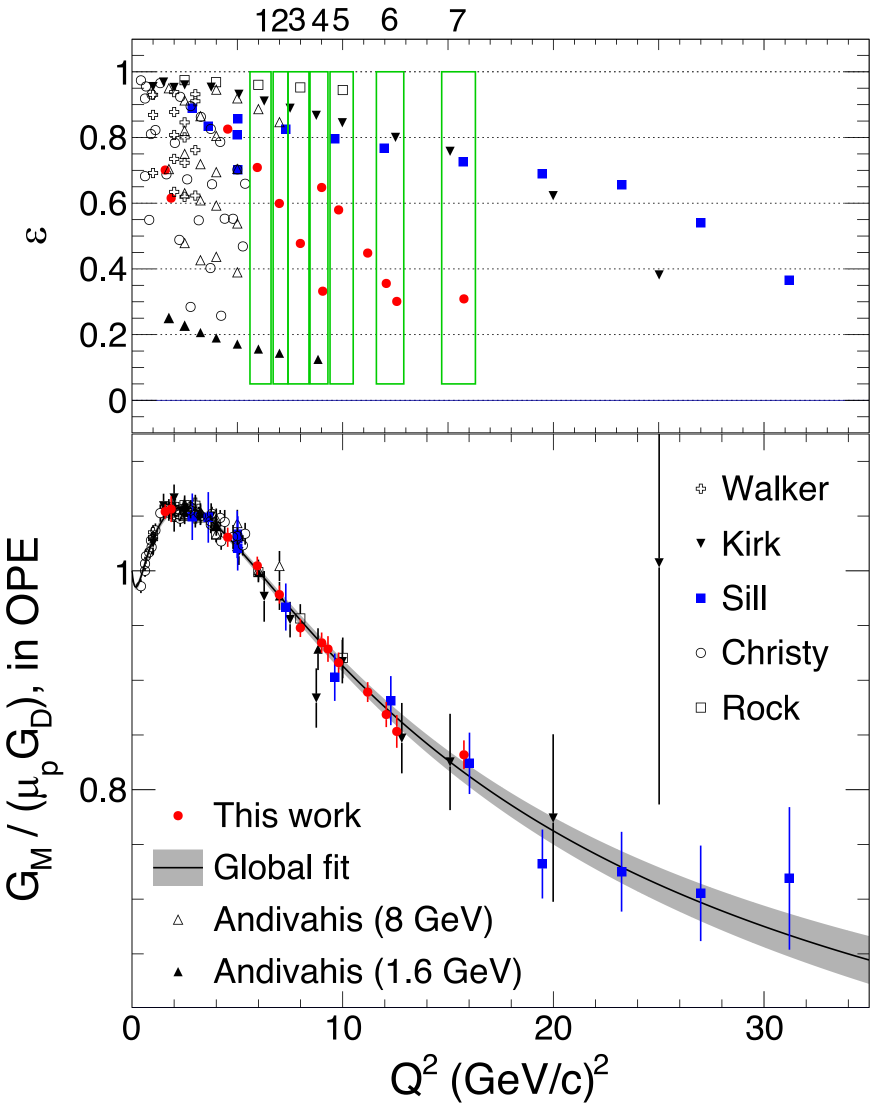
Diquark correlations in hadron physics: Origin, impact and evidence

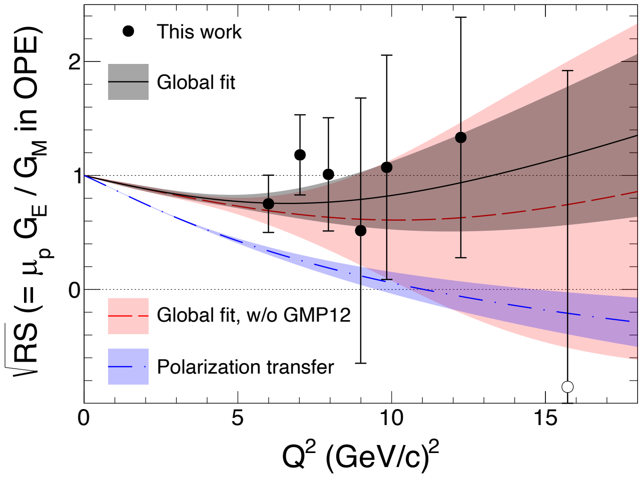
M.Yu. Barabanov [1], M.A. Bedolla [2], W.K. Brooks [3], G.D. Cates [4], C. Chen [5], Y. Chen [6,7], E. Cisbani [8], M. Ding [9], G. Eichmann [10,11], R. Ent [12], J. Ferretti [13], R.W. Gothe [14], T. Horn [15,12], S. Liuti [4], C. Mezrag [16], A. Pilloni [9], A.J.R. Puckett [17], C.D. Roberts [18,19,*], P. Rossi [12,20], G. Salmé [21], E. Santopinto [22], J. Segovia [23,19], S.N. Syritsyn [24,25], M. Takizawa [26,27,28], E. Tomasi-Gustafsson [16], P. Wein [29], B.B. Wojtsekhowski [12]

published in Progress in Particle and Nuclear Physics 116 (2021) 103835

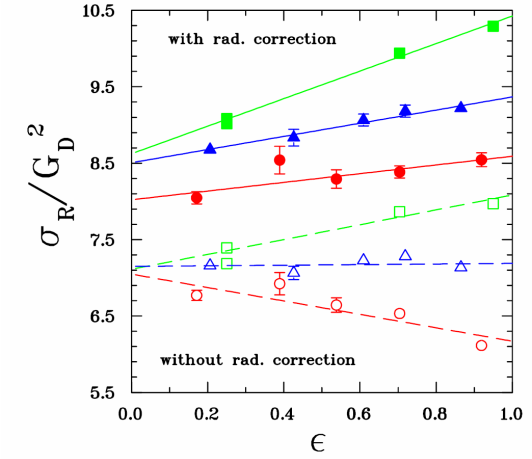
From the GMp12 experiment

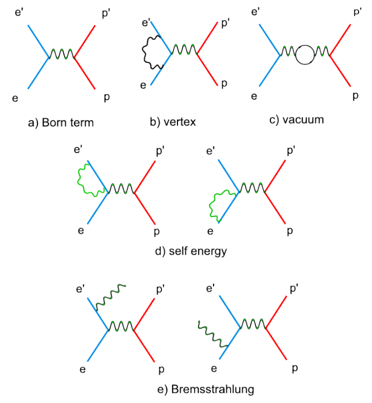
arXiv:2103.01842v2 [nucl-ex]





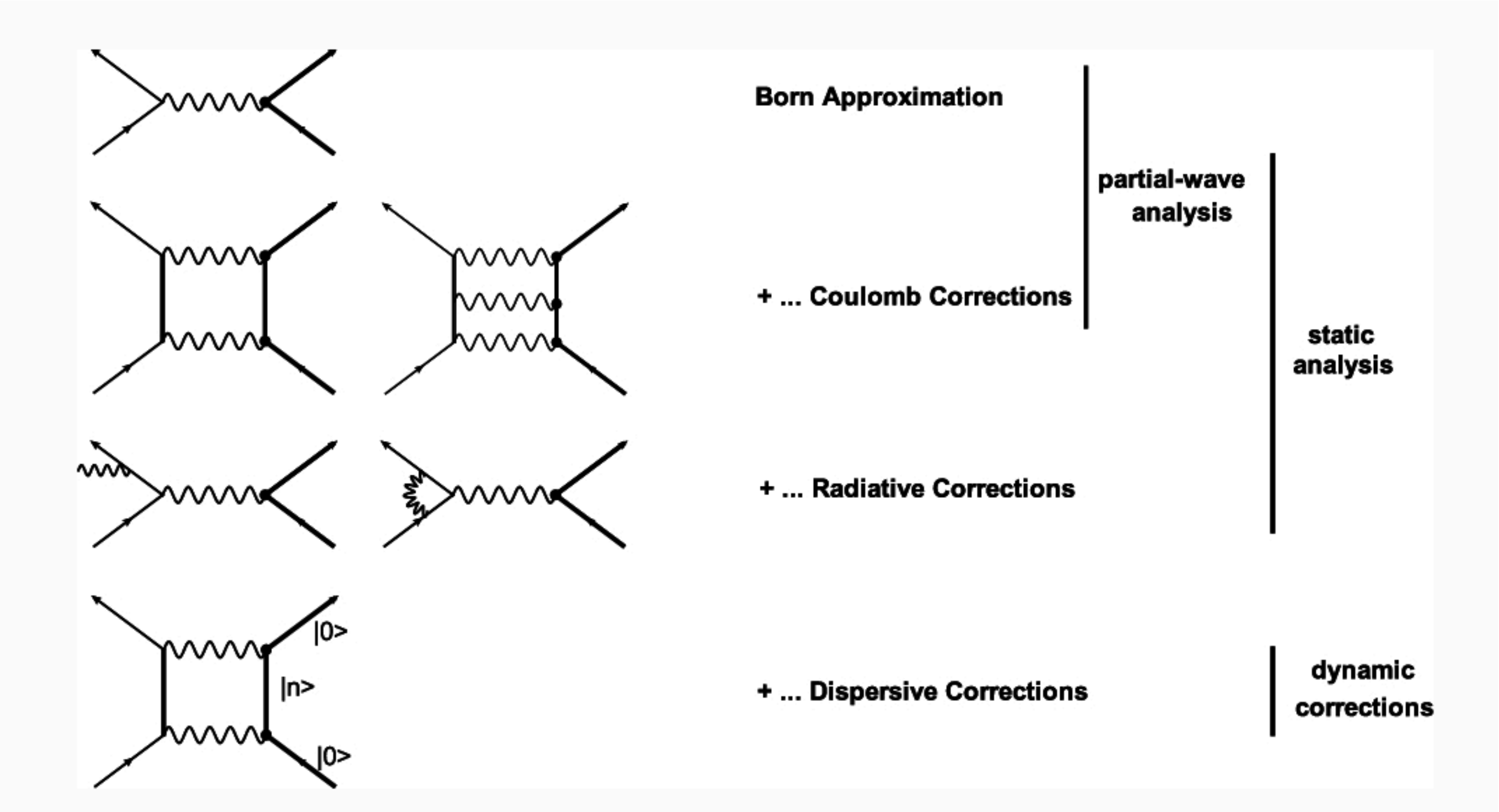
Important role of radiative corrections





http://www.scholarpedia.org/article/Nucleon_Form_factors

Diagrams


Born Approximation
+ ... Coulomb Corrections
+ ... Radiative Corrections
+ ... Dispersive Corrections
partial-wave analysis
static analysis
dynamic corrections
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Diffractive minimum

242 HOFSTADTER

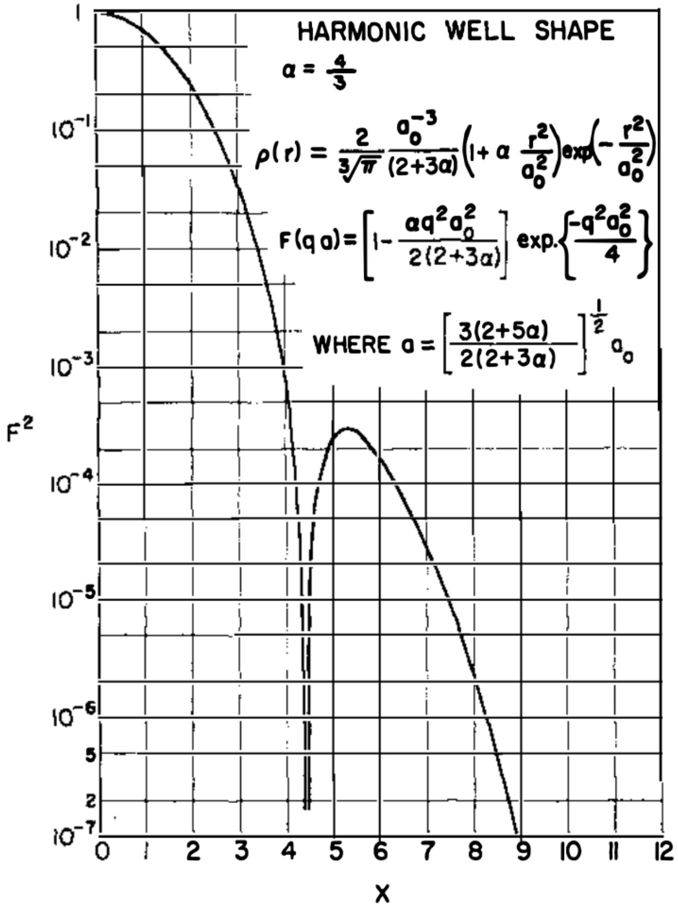


FIG. 2. Born approximation for the absolute square of the form factor associate the harmonic-well shape in the case, $\alpha = 4/3$, which is appropriate to carbon.

HOFSTADTER

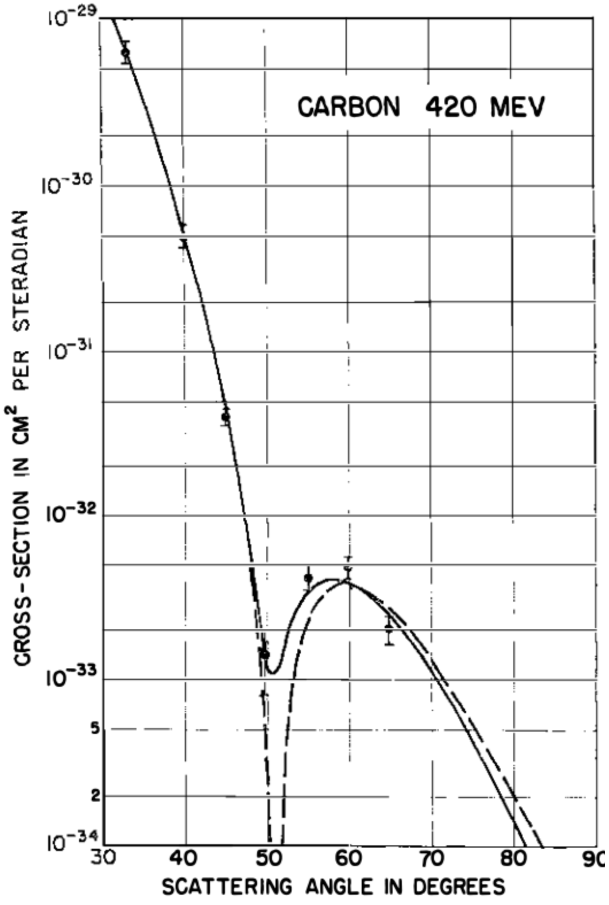


FIG. 4. Recent data in C^{12} observed by Sobottka & Hofstadter (10) at an i ctron energy of 420 Mev. Two theoretical curves are presented for comp e dashed curve is the Born approximation for a harmonic-well charge distr responding to Fig. 3 ($\alpha = 4/3$). The solid line is the accurate phase-shift calculation D. G. Ravenhall, which appears to fit the experimental points rather well.

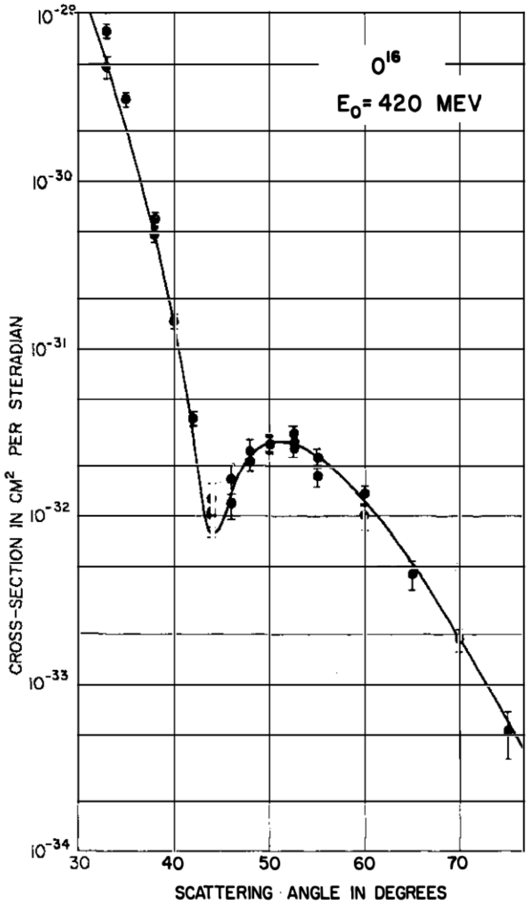
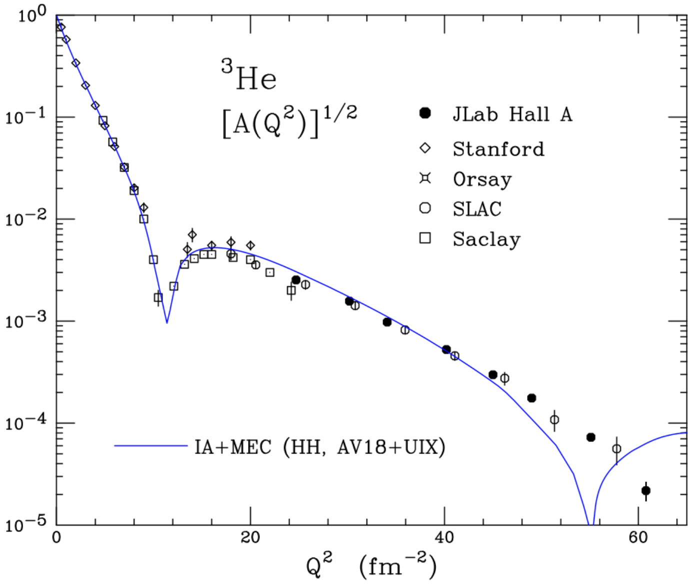
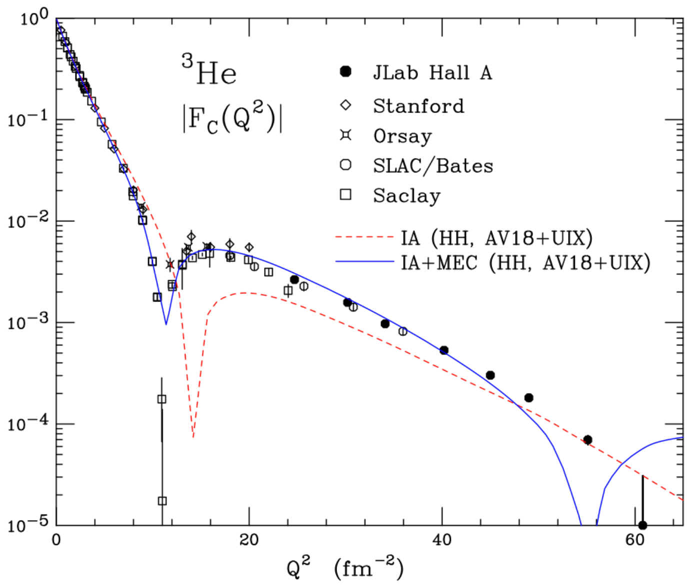


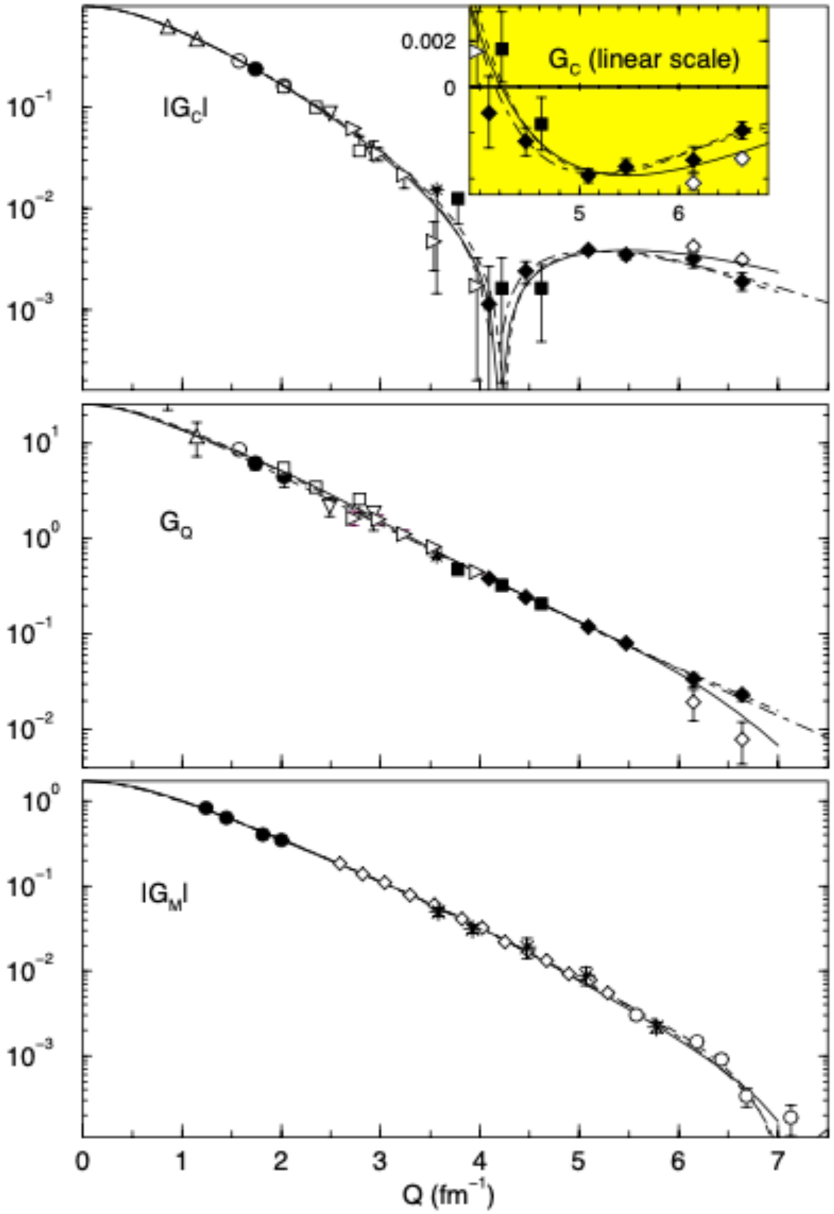
FIG. 17. New experimental data of Ehrenberg *et al.* (64) obtained at 420 Mev for the O^{16} nucleus. The figure also shows the exact calculations of D. G. Ravenhall for the harmonic-well model for which $\alpha = 2.0$ and $a_0 = 1.75 \times 10^{-13}$ cm.

Diffractive minimum

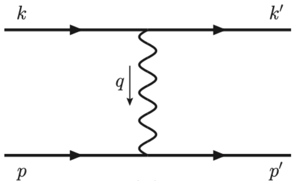




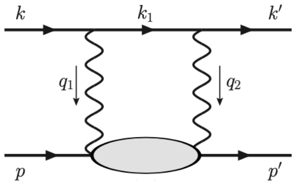
Diffractive minimum for Deuteron



Proton Charge Form Factor

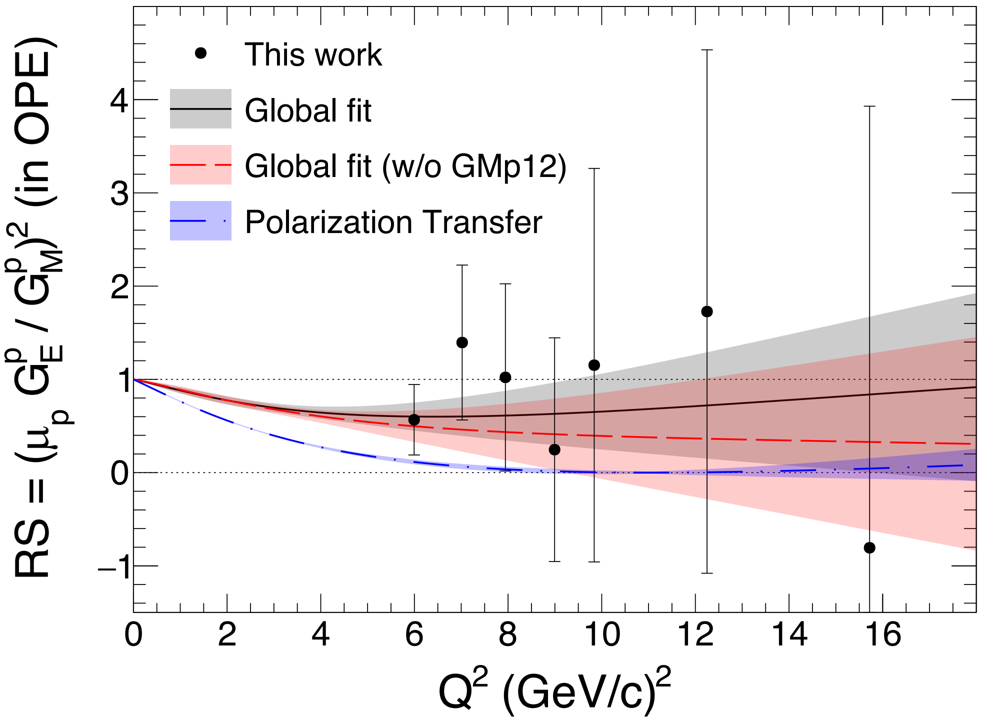


(a)



(b)

$$\sigma_R = \tau\, G_M^2(Q^2) + \varepsilon\, G_E^2(Q^2) = \sigma_T + \varepsilon\, \sigma_L$$
$$= G_M^2(Q^2)(\tau + \varepsilon\, RS(Q^2)/\mu_p^2),$$

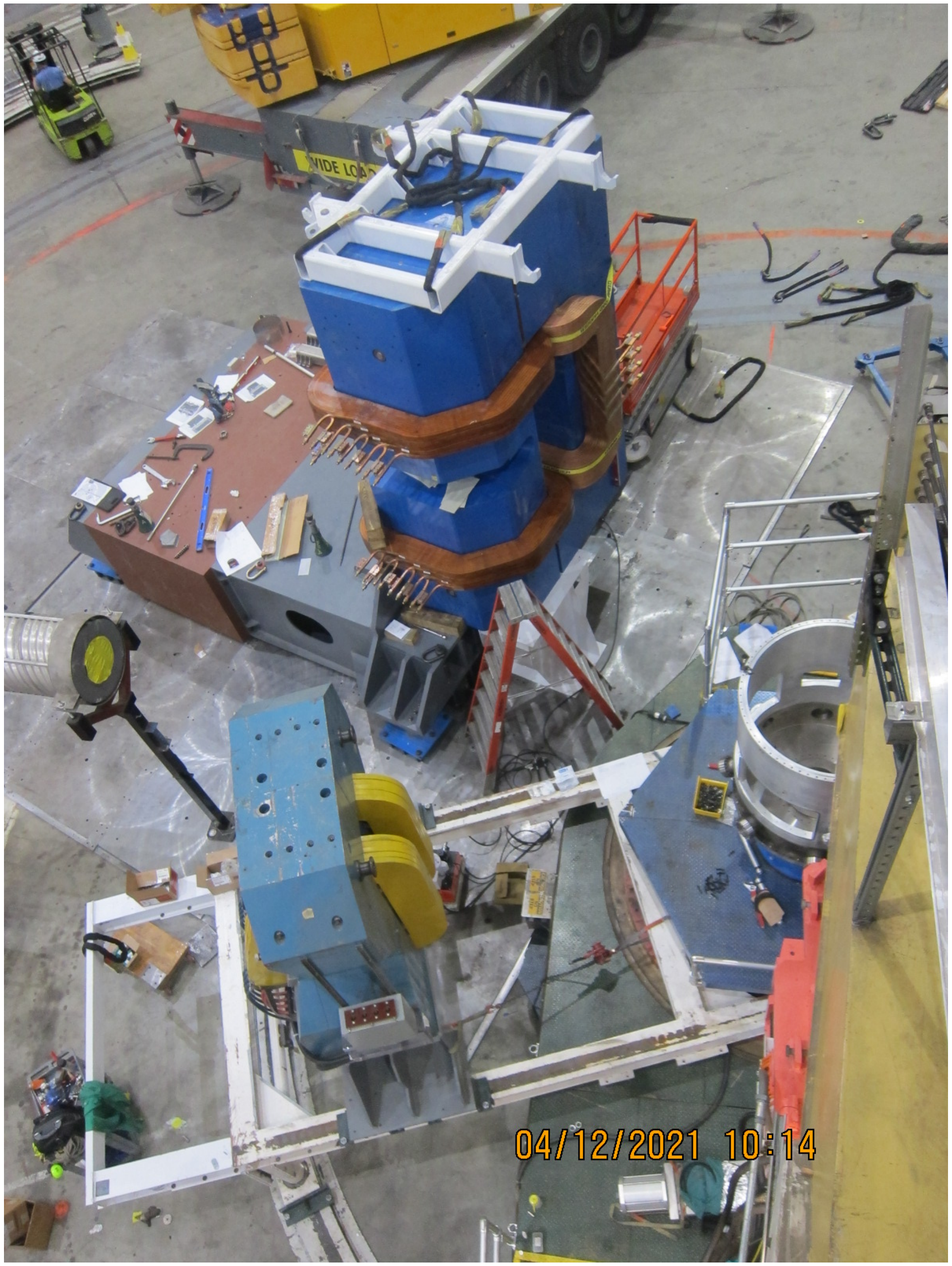


Fast moving quarks can not produce a sharp minimum.

Can a diquark lead to a “minimum” in the form factor? Yes, according to the DSE approach.

Can a diquark play a role in the two-photon exchange contribution?
Can one make calculation of the two-photon exchange contribution to e-p cross section in the DSE approach?

Summary



The JLab program on the nucleon elastic form factors with the Super Bigbite Spectrometer will start taking data in 2021.

The $F1_d/F1_u$ up to 12 GeV^2 will be one of the first results from the GMn run, then will be GEn, and finally GEp.

The last week magnets were assembled in Hall A.