

The properties of sea quark in baryons

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Krabi, 2015.7.7-11

I. Introduction

II. Dbar-ubar asymmetry in proton

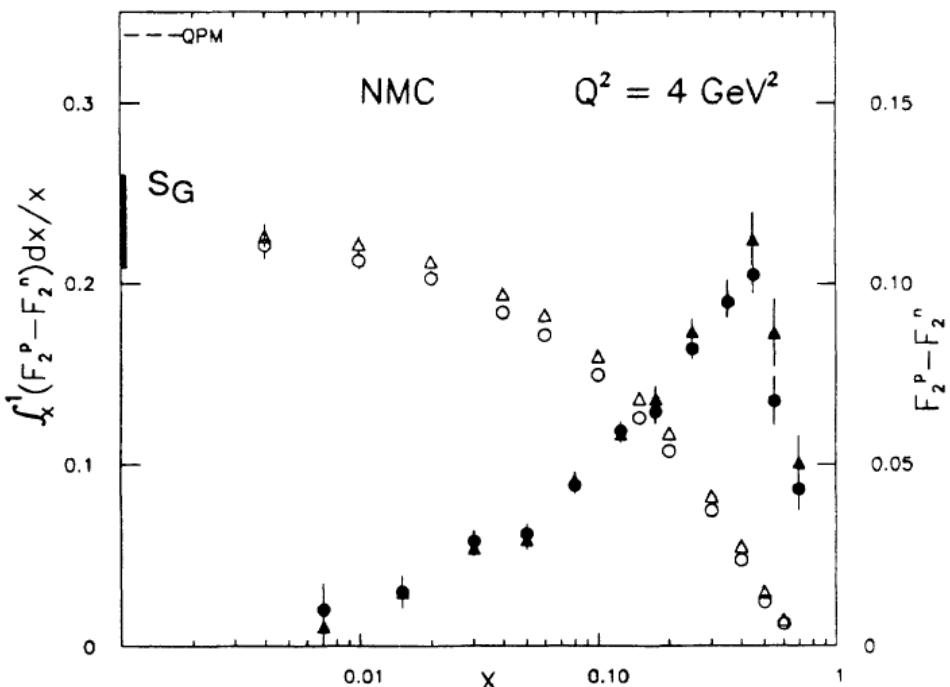
III. Magnetic form factor of u quark in Σ

IV. Summary

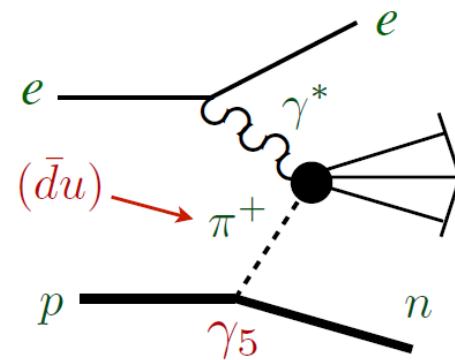
Introduction

Gottfried sum rule (GSR):

$$\int_0^1 [F_2^p(x) - F_2^n(x)] \frac{dx}{x} = \frac{1}{3} - \frac{2}{3} \int_0^1 [\bar{d}_p(x) - \bar{u}_p(x)] dx$$



→ Sullivan process



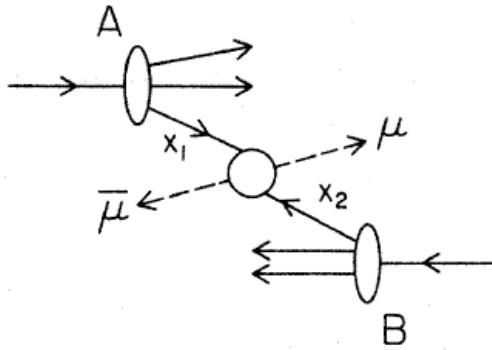
$$S_G = 0.235 \pm 0.026$$

$$\int_0^1 [\bar{d}_p(x) - \bar{u}_p(x)] dx = 0.147 \pm 0.039$$

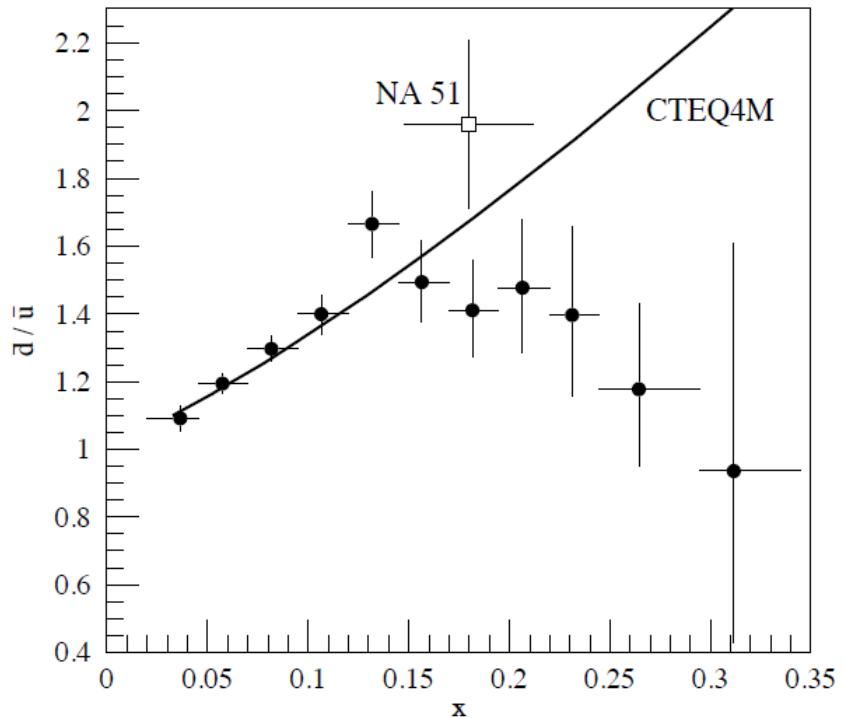
New Muon Collaboration, PRD 50, 1 (1994)

Introduction

→ Drell-Yan process



$$\frac{d^2\sigma}{dx_b dx_t} = \frac{4\pi\alpha^2}{9Q^2} \sum_q e_q^2 (q(x_b)\bar{q}(x_t) + \bar{q}(x_b)q(x_t))$$



Fermilab E866, PRL 80, 3715 (1998)

$$\frac{\sigma^{pd}}{2\sigma^{pp}} \approx \frac{1}{2} \left(1 + \frac{\bar{d}(x_t)}{\bar{u}(x_t)} \right) \rightarrow \int_0^1 dx (\bar{d} - \bar{u}) = 0.118 \pm 0.012$$

Introduction

Spin puzzle

The Ellis-Jaffe sum-rule is expressed as

$$\begin{aligned} \int_0^1 dx g_1^{p(n)}(x, Q^2) &= C^{\text{ns}}(1, a_s(Q^2))(\pm \frac{1}{12}|g_A| + \frac{1}{36}a_8) \\ &\quad + C^{\text{s}}(1, a_s(Q^2)) \exp\left(\int_{a_s(\mu^2)}^{a_s(Q^2)} da'_s \frac{\gamma^s(a'_s)}{\beta(a'_s)}\right) \frac{1}{9}a_0(\mu^2) \end{aligned}$$

$$\begin{aligned} |g_A|s_\sigma &= 2\langle p, s | J_\sigma^{5,3} | p, s \rangle = (\Delta u - \Delta d)s_\sigma, \\ a_8s_\sigma &= 2\sqrt{3}\langle p, s | J_\sigma^{5,8} | p, s \rangle = (\Delta u + \Delta d - 2\Delta s)s_\sigma, \\ a_0(\mu^2)s_\sigma &= \langle p, s | J_\sigma^5 | p, s \rangle = (\Delta u + \Delta d + \Delta s)s_\sigma = \Delta\Sigma(\mu^2)s_\sigma \end{aligned}$$

Introduction

$$\int_0^1 dx g_1^{p(n)}(x, Q^2) = \left[1 - \left(\frac{\alpha_s}{\pi} \right) - 3.5833 \left(\frac{\alpha_s}{\pi} \right)^2 - 20.2153 \left(\frac{\alpha_s}{\pi} \right)^3 \right] (\pm \frac{1}{12} |g_A| + \frac{1}{36} a_8) \\ + \left[1 - 0.333333 \left(\frac{\alpha_s}{\pi} \right) - 0.54959 \left(\frac{\alpha_s}{\pi} \right)^2 - 4.44725 \left(\frac{\alpha_s}{\pi} \right)^3 \right] \frac{1}{9} \hat{a}_0$$

At NLO, $\Gamma_1^N(Q^2) = \frac{1}{9} \left(1 - \frac{\alpha_s(Q^2)}{\pi} + \mathcal{O}(\alpha_s^2) \right) \left(a_0(Q^2) + \frac{1}{4} a_8 \right)$

COMPASS result:

$$\Gamma_1^N(Q^2 = 3(\text{GeV}/c)^2) = 0.050 \pm 0.003 \text{ (stat.)} \pm 0.003 \text{ (evol.)} \pm 0.005 \text{ (syst.)}$$

Hyperon beta decay: $a_8 = 0.585 \pm 0.025$

$$a_0(Q^2 = 3(\text{GeV}/c)^2) = 0.35 \pm 0.03 \text{ (stat.)} \pm 0.05 \text{ (syst.)}$$

Introduction

<i>uuds</i> ground state	<i>uuds P</i> –state
$[31]_{FS}[211]_F[22]_S$ (-16)	$[4]_{FS}[22]_F[22]_S$ (-28)
$[31]_{FS}[211]_F[31]_S$ (-40/3)	$[4]_{FS}[31]_F[31]_S$ (-64/3)
$[31]_{FS}[22]_F[31]_S$ (-28/3)	$[31]_{FS}[211]_F[22]_S$ (-16)
$[31]_{FS}[31]_F[22]_S$ (-8)	$[31]_{FS}[211]_F[31]_S$ (-40/3)
$[31]_{FS}[31]_F[31]_S$ (-16/3)	$[31]_{FS}[22]_F[31]_S$ (-28/3)
$[31]_{FS}[31]_F[4]_S$ (0)	$[31]_{FS}[31]_F[22]_S$ (-8)
$[31]_{FS}[4]_F[31]_S$ (+8/3)	$[4]_{FS}[4]_F[4]_S$ (-8)
	$[22]_{FS}[211]_F[31]_S$ (-16/3)
	$[31]_{FS}[31]_F[31]_S$ (-16/3)
	$[22]_{FS}[22]_F[22]_S$ (4)
	$[211]_{FS}[211]_F[22]_S$ (0)
	$[31]_{FS}[31]_F[4]_S$ (0)
	$[211]_{FS}[211]_F[31]_S$ (8/3)
	$[22]_{FS}[31]_F[31]_S$ (8/3)
	$[31]_{FS}[4]_F[31]_S$ (8/3)
	$[22]_{FS}[22]_F[4]_S$ (4)
	$[211]_{FS}[22]_F[31]_S$ (20/3)
	$[211]_{FS}[211]_F[4]_S$ (8)
	$[211]_{FS}[31]_F[22]_S$ (8)
	$[22]_{FS}[4]_F[22]_S$ (8)
	$[211]_{FS}[31]_F[31]_S$ (32/3)

negative strange magnetic moment for the configurations on the left side

positive strange magnetic moment for the configurations on the right side

positive strange magnetic moments for the diquark-diquark-antistrange quark configuration

negative strange magnetic moments for the {ud}{ussbar} configuration

B.S. Zou and D.O. Riska, PRL95(2005)072001

Dbar-ubar asymmetry

Generalized parton distribution function:

$$\begin{aligned} F^q &= \frac{1}{2} \int \frac{dz^-}{2\pi} e^{ixP^+z^-} \langle p' | \bar{q}(-\frac{1}{2}z) \gamma^+ q(\frac{1}{2}z) | p \rangle \Big|_{z^+=0, \mathbf{z}=0} \\ &= \frac{1}{2P^+} \left[H^q(x, \xi, t) \bar{u}(p') \gamma^+ u(p) + E^q(x, \xi, t) \bar{u}(p') \frac{i\sigma^{+\alpha} \Delta_\alpha}{2m} u(p) \right] \end{aligned}$$

Forward limit: $H^q(x, 0, 0) = q(x)$

Zero-th order moments, Dirac form factor, Pauli Form factor:

$$\int_{-1}^1 dx H^q(x, \xi, t) = F_1^q(t), \quad \int_{-1}^1 dx E^q(x, \xi, t) = F_2^q(t)$$

First moments:

$$\int_{-1}^1 dx x H^q(x, \xi, t) = A_{2,0}^q(t) + (-2\xi)^2 C_{2,0}^q(t) \quad \int_{-1}^1 dx x E^q(x, \xi, t) = B_{2,0}^q(t) - (-2\xi)^2 C_{2,0}^q(t)$$

Dbar-ubar asymmetry

Theoretical research:

Parameterization method:

M. Guidal, M.V. Polyakov, A.V. Radyushkin, M. Vanderhaegen, Phys. Rev. D72(2005)054013

Quark models:

Bag model: X. Ji, W. Melnitchouk, X. Song, Phys. Rev. D56(1997)5511

Cloudy bag mode: B. Pasquini, S. Boffi, Nucl.Phys.A782(2007)86

Constituent quark model: S. Scopetta, V. Vento, Phys. Rev. D69(2004)094004

Light-front bag model: H. Choi, C.R. Ji, L.S. Kisslinger, Phys. Rev. D64(2001)093006

Betha-Salpeter approach: B.C. Tiburzi, G.A. Miller, Phys. Rev. D65(2002)074009

NJL model: H. Mineo, S.N. Yang, C.Y. Cheung, W. Bentz, Phys. Rev. C72(2005)025202

Color glass condensate model: K. Goeke, V. Guzey, M. Siddidov, Eur. Phys. J. C56(2008)203

Experiments:

ZEUS and H1: $10^{-4} < x < 0.02$

EIC: Up to $x = 0.3$

HERMES: $0.02 < x < 0.3$

JLab 12 GeV: $0.1 < x < 0.7$

COMPASS: $0.006 < x < 0.3$

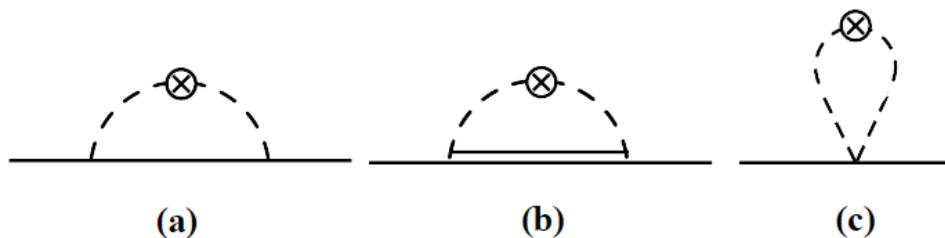
Dbar-ubar asymmetry

Relativistic Lagrangian:

$$\begin{aligned}\mathcal{L}_{rel} = & \text{Tr} [\bar{B} (i \not{D} - M_0) B] - D \text{Tr}(B \gamma^\mu \gamma^5 \{A_\mu, B\}) - F \text{Tr}(B \gamma^\mu \gamma^5 [A_\mu, B]) \\ & \bar{T}_\mu (i \gamma^{\mu\nu\alpha} D_\alpha - M_D \gamma^{\mu\nu}) T_\nu + \mathcal{C} (\bar{T}_\mu (g^{\mu\nu} - Z \gamma^\mu \gamma^\nu) A_\mu B + h.c.),\end{aligned}$$

Heavy baryon Lagrangian:

$$\begin{aligned}\mathcal{L}_v = & i \text{Tr} \bar{B}_v (v \cdot \mathcal{D}) B_v + 2D \text{Tr} \bar{B}_v S_v^\mu \{A_\mu, B_v\} + 2F \text{Tr} \bar{B}_v S_v^\mu [A_\mu, B_v] \\ & - i \bar{T}_v^\mu (v \cdot \mathcal{D} - \Delta) T_{v\mu} + \mathcal{C} (\bar{T}_v^\mu A_\mu B_v + \bar{B}_v A_\mu T_v^\mu),\end{aligned}$$



Dbar-ubar asymmetry

The convolution form:

$$q(x) = Z_2 q_0(x) + \left(f_i \otimes q_i \right) (x)$$

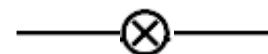
$$1 - Z_2 = \int_0^1 dy \sum_i f_i(y)$$

$$\bar{d} - \bar{u} = (f_{\pi^+ n} + f_{\pi^+ \Delta^0} - f_{\pi^- \Delta^{++}} + f_{\pi(\text{bub})}) \otimes \bar{q}_v^\pi$$

$$f \otimes q = \int_0^1 dy \int_0^1 dz \delta(x - yz) f(y) q(z), \text{ with } y = k^+ / p^+$$

y is the light-cone fraction of the proton's momentum (p) carried by pion (k).

Tree level contribution is zero



Dbar-ubar asymmetry

Pion momentum distribution in nucleon:

$$f_{\pi^+ n}(y) = 4M \left(\frac{g_A}{2f_\pi} \right)^2 \int \frac{d^4 k}{(2\pi)^4} \bar{u}(p) (\not{k}\gamma_5) \frac{i(\not{p} - \not{k} + M)}{D_N} (\gamma_5 \not{k}) u(p) \frac{i}{D_\pi} \frac{i}{D_\pi} 2k^+ \delta(k^+ - yp^+)$$

$$f_{\pi^+ n}(y) = 2 \left[f_N^{(\text{on})}(y) + f_N^{(\delta)}(y) \right]$$

On-shell (nucleon pole) contribution:

$$f_N^{(\text{on})}(y) = \frac{g_A^2 M^2}{(4\pi f_\pi)^2} \int d\mathbf{k}_\perp^2 \frac{y (k_\perp^2 + y^2 M^2)}{(1-y)^2 D_{\pi N}^2}$$

$$D_{\pi N} = -[\mathbf{k}_\perp^2 + yM^2 + (1-y)m_\pi^2]/(1-y)$$

Off-shell contribution:

$$f_N^{(\delta)}(y) = \frac{g_A^2}{4(4\pi f_\pi)^2} \int d\mathbf{k}_\perp^2 \log \frac{\Omega_\pi}{\mu^2} \delta(y)$$

Dbar-ubar asymmetry

Delta intermediate state:

$$f_{\pi^+ \Delta^0}(y) = f_\Delta^{(\text{on})}(y) + f_\Delta^{(\text{end-pt})}(y) + f_\Delta^{(\delta)}(y)$$

On-shell (Delta pole) contribution:

$$\begin{aligned} f_\Delta^{(\text{on})}(y) &= C_\Delta \int dk_\perp^2 \frac{y (\overline{M}^2 - m_\pi^2)}{1 - y} \\ &\times \left[\frac{(\overline{M}^2 - m_\pi^2)(\Delta^2 - m_\pi^2)}{D_{\pi\Delta}^2} - \frac{3(\Delta^2 - m_\pi^2) + 4MM_\Delta}{D_{\pi\Delta}} \right] \end{aligned}$$

End-point singularity at $y=1$:

$$\begin{aligned} f_\Delta^{(\text{end-pt})}(y) &= C_\Delta \int dk_\perp^2 \delta(1 - y) \\ &\times \left\{ \left[\Omega_\Delta - 2(\Delta^2 - m_\pi^2) - 6MM_\Delta \right] \log \frac{\Omega_\Delta}{\mu^2} - \Omega_\Delta \right\} \end{aligned}$$

Dbar-ubar asymmetry

Off-shell contribution:

$$\begin{aligned} f_{\Delta}^{(\delta)}(y) &= C_{\Delta} \int dk_{\perp}^2 \delta(y) \\ &\times \left\{ \left[3(\Omega_{\pi} + m_{\pi}^2) + \overline{M}^2 \right] \log \frac{\Omega_{\pi}}{\mu^2} - 3\Omega_{\pi} \right\} \end{aligned}$$

Bubble diagram: $f_{\pi(\text{bub})}(y) = -\frac{2}{g_A^2} f_N^{(\delta)}(y)$

In the HB limit:

$$\tilde{f}_{\Delta}^{(\text{on})}(y) = \frac{8g_{\pi N \Delta}^2 M^2}{9(4\pi)^2} \int dk_{\perp}^2 \frac{y(\Delta^2 - m_{\pi}^2 - \tilde{D}_{\pi \Delta})}{\tilde{D}_{\pi \Delta}^2}$$

$$\tilde{f}_{\Delta}^{(\delta)}(y) = \frac{2g_{\pi N \Delta}^2}{9(4\pi)^2} \int dk_{\perp}^2 \delta(y) \log \frac{\Omega_{\pi}}{\mu^2}$$

$$f(y) \ (m \ll M) = \tilde{f}(y)$$

Dbar-ubar asymmetry

LNA behavior:

$$(\overline{D} - \overline{U})_{\text{LNA}} = \frac{3g_A^2 + 1}{2(4\pi f_\pi)^2} m_\pi^2 \log m_\pi^2 - \frac{g_{\pi N\Delta}^2}{12\pi^2} J_1$$

$$J_1 = (m_\pi^2 - 2\Delta^2) \log m_\pi^2 + 2\Delta r \log [(\Delta - r)/(\Delta + r)]$$

$$\Delta \equiv M_\Delta - M \quad r = \sqrt{\Delta^2 - m_\pi^2}$$

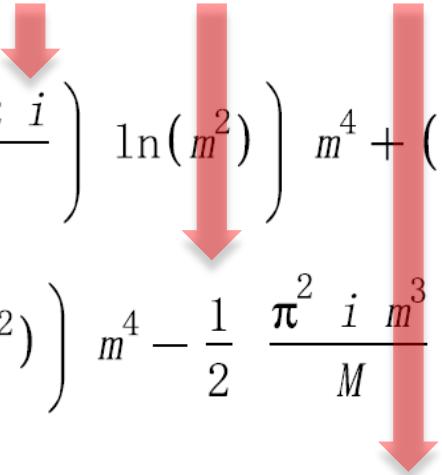
Sullivan approach (on-shell component):

$$(\overline{D} - \overline{U})_{\text{LNA}}^{(\text{Sul})} = \left[\frac{2g_A^2}{(4\pi f_\pi)^2} - \frac{g_{\pi N\Delta}^2}{9\pi^2} \right] m_\pi^2 \log m_\pi^2$$

Dbar-ubar asymmetry

General regulator: $F(t, u) \equiv F[k^2, (p-k)^2] = \left(\frac{\Lambda_t - m^2}{\Lambda_t - t} \right) \cdot \left(\frac{\Lambda_u - M^2}{\Lambda_u - u} \right) = \frac{a}{d_N} \frac{b}{d_\pi}$

$$f_{n\pi^+}(y) = \frac{-i \cdot (F + D)^2}{4f^2} \cdot \int \frac{d^4k}{(2\pi)^4} \left(\frac{4(p \cdot k)}{D_\pi^2} + \frac{8M^2}{D_\pi D_N} + \frac{8M^2m^2}{D_\pi^2 D_N} \right) \cdot F^2(t, u) \cdot y \cdot \delta\left(y - \frac{k^+}{p^+}\right)$$



$$\left(\left(-\frac{\pi i}{\Lambda_t} - \frac{9\pi i M^2}{a^2} - \frac{3\pi i}{a} \right) \ln(m^2) \right) m^4 + (-\pi i \ln(m^2)) m^2$$

$$\left(\left(\frac{3}{2} \frac{\pi i M^2}{a^2} - \frac{1}{4} \frac{\pi i}{M^2} \right) \ln(m^2) \right) m^4 - \frac{1}{2} \frac{\pi^2 i m^3}{M} + \left(\frac{1}{2} \pi i \ln(m^2) \right) m^2$$

$$\left(\left(\frac{3\pi i M^2}{a^2} + \frac{\pi i}{\Lambda_t} - \frac{1}{2} \frac{\pi i}{M^2} \right) \ln(m^2) \right) m^4 - \frac{3}{4} \frac{\pi^2 i m^3}{M} + \left(\frac{1}{2} \pi i \ln(m^2) \right) m^2$$

Dbar-ubar asymmetry

Non-analytic term with DR:

First term: $-\pi i \cdot \ln(m^2) m^2$

Second term: $\left(-\frac{1}{4} \frac{\pi i \ln(m^2)}{M^2} \right) m^4 - \frac{1}{2} \frac{\pi^2 i m^3}{M} + \left(\frac{1}{2} \pi i \ln(m^2) \right) m^2$

Third term: $\left(-\frac{1}{2} \frac{\pi i \ln(m^2)}{M^2} \right) m^4 - \frac{3}{4} \frac{\pi^2 i m^3}{M} + \left(\frac{1}{2} \pi i \ln(m^2) \right) m^2$

Same as that with form factor when $\Lambda_t \Lambda_u a b \Rightarrow \infty$

LNA is the same as that with form factor at **finite** Λ .

Dbar-ubar asymmetry

The constituent building blocks of the nucleon and the pion U and D [Gluck et at]:

$$p = UUD \quad \pi^+ = U\bar{D}$$

$$f^p(x, Q^2) = \int_x^1 \frac{dy}{y} [U^p(y) + D^p(y)] f_c \left(\frac{x}{y}, Q^2 \right)$$

$$f^\pi(x, Q^2) = \int_x^1 \frac{dy}{y} [U^{\pi^+}(y) + \bar{D}^{\pi^+}(y)] f_c \left(\frac{x}{y}, Q^2 \right)$$

$$f = v, \bar{q}, g$$

$$\frac{v^\pi(n, \mu^2)}{v^p(n, \mu^2)} = \frac{\bar{q}^\pi(n, \mu^2)}{\bar{q}^p(n, \mu^2)} = \frac{g^\pi(n, \mu^2)}{g^p(n, \mu^2)}$$

$$\int_0^1 xv^\pi(x, Q^2) dx = \int_0^1 xv^p(x, Q^2) dx$$

Dbar-ubar asymmetry

Pionic parton distribution function :

$$x v^\pi(x, Q^2) = N x^a (1 + A\sqrt{x} + Bx)(1 - x)^D$$

$$N = 1.212 + 0.498 s + 0.009 s^2$$

$$a = 0.517 - 0.020 s$$

$$A = -0.037 - 0.578 s$$

$$B = 0.241 + 0.251 s$$

$$D = 0.383 + 0.624 s .$$

$$s \equiv \ln \frac{\ln [Q^2/(0.204 \text{ GeV})^2]}{\ln [0.26/(0.204 \text{ GeV})^2]}$$

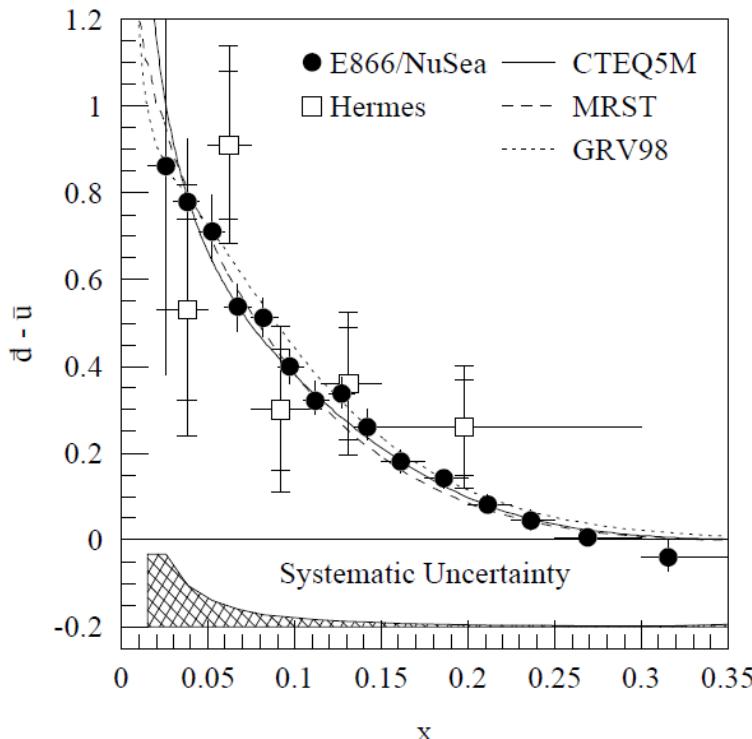
valid for $0.5 \lesssim Q^2 \lesssim 10^5 \text{ GeV}^2$ and $10^{-5} \lesssim x < 1$

Dbar-ubar asymmetry

Input: valence quark distribution function in pion [Gluck, 99]

$$\bar{d}_{\pi^+, v}(x, Q^2 = 1 \text{ GeV}^2) = \frac{0.869(1-x)^{0.73}(1-0.57x^{0.5}+0.53x)}{x^{0.456}}$$

For μ ranging between 0.1 and 1 GeV, Λ is fixed by matching the dbar-ubar integral extracted from the E866 Drell-Yan data over the measured x range:

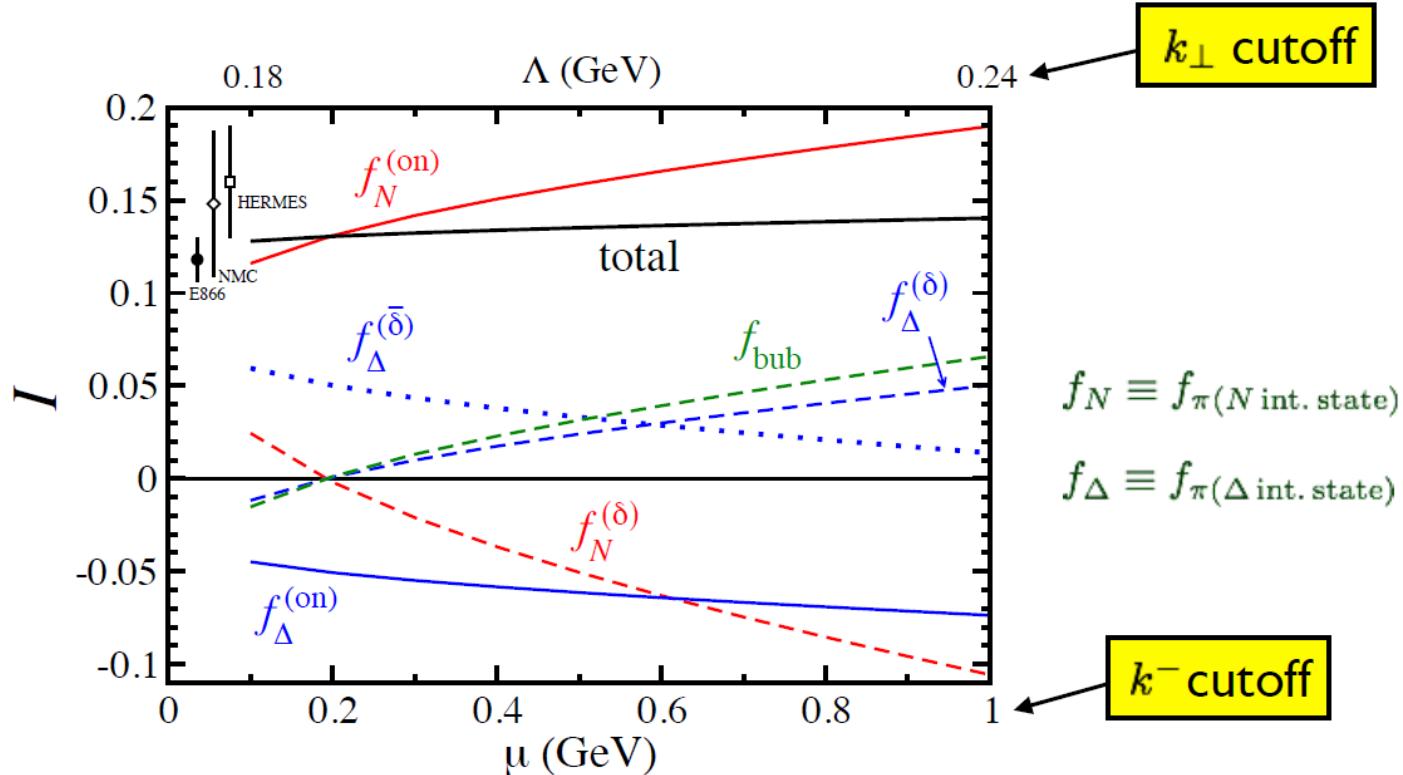


$$\int_{0.015}^{0.35} dx (\bar{d} - \bar{u}) = 0.0803(11)$$

R. S. Towell *et al.*, Phys. Rev. D 64, 052002 (2001)

Dbar-ubar asymmetry

Integrated asymmetry $I = \int_0^1 dx (\bar{d} - \bar{u})(x)$

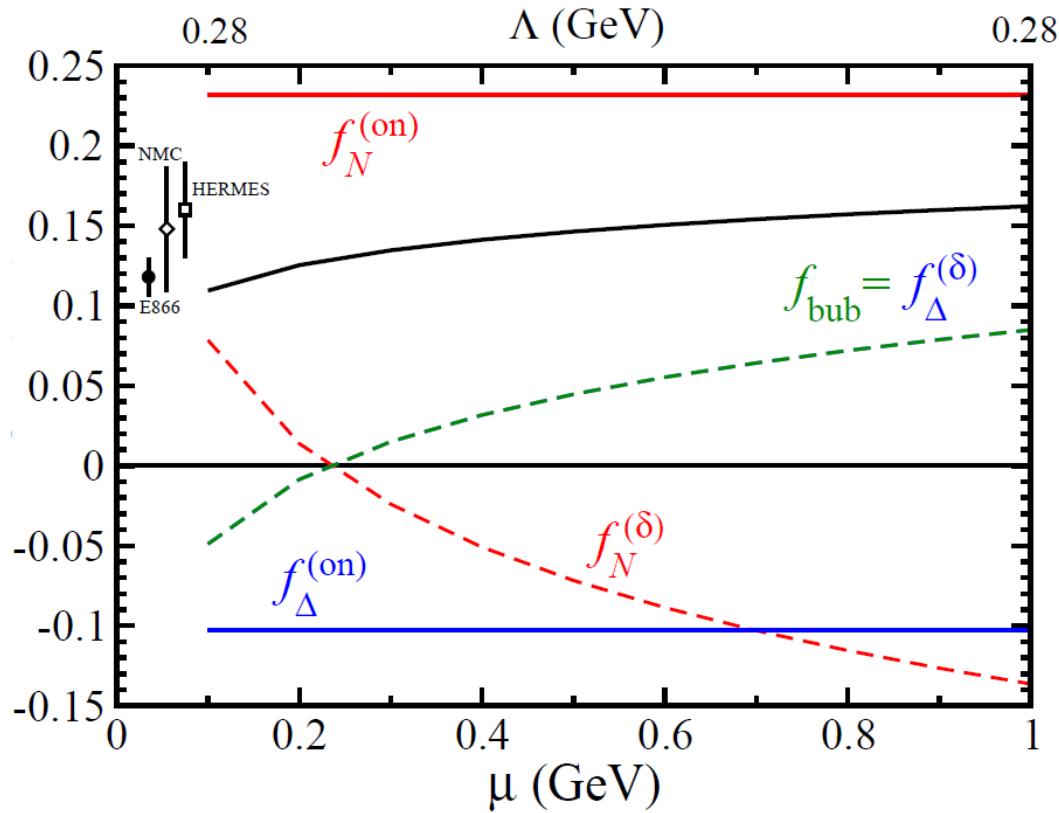


→ N on-shell contribution \approx total!

...

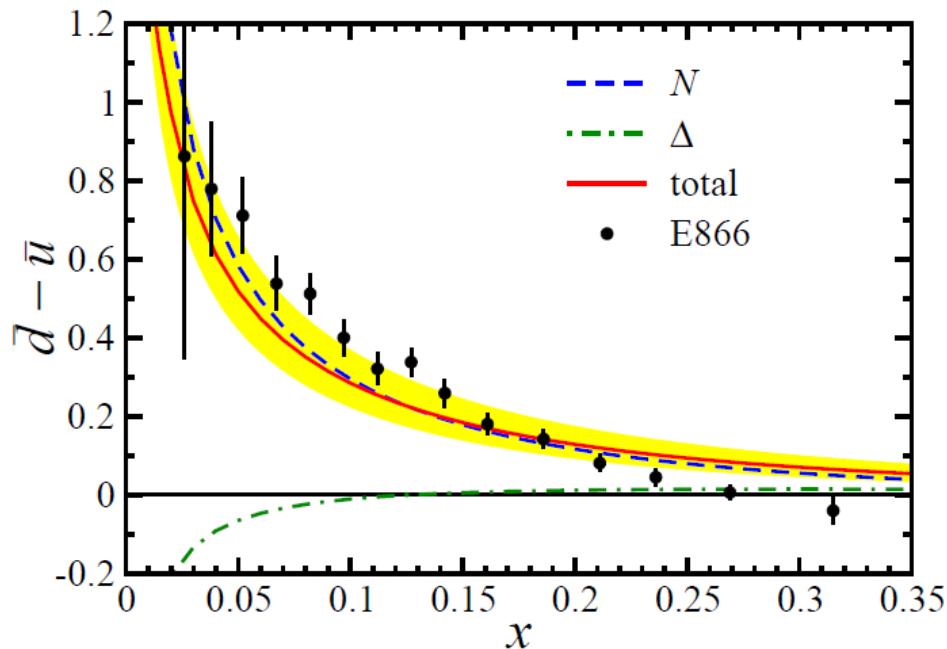
Y.Salamu, W.Melnitchouk,C.R.Ji,P.Wang, Phys. Rev. Lett. 114 (2015) 122001

Dbar-ubar asymmetry



HB limit is comparable with the relativistic case.

Dbar-ubar asymmetry



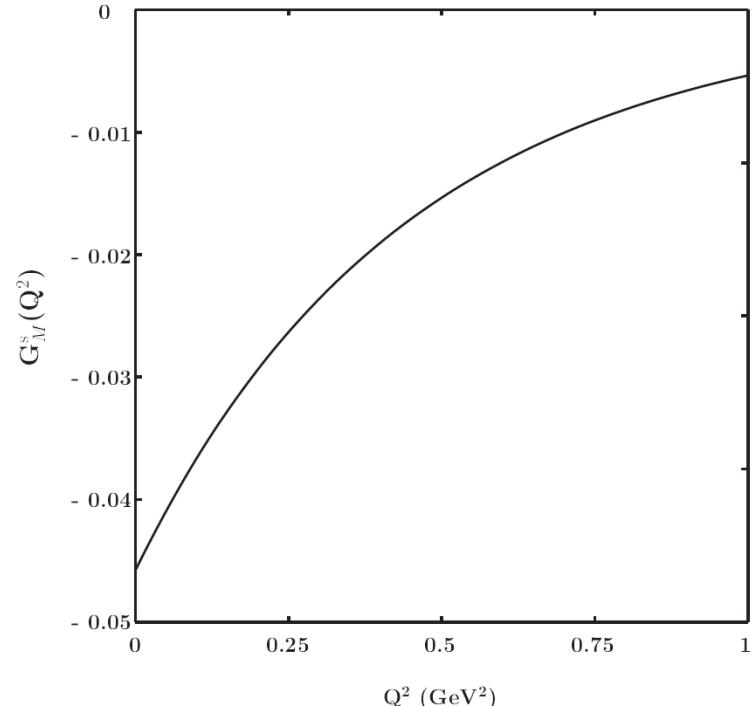
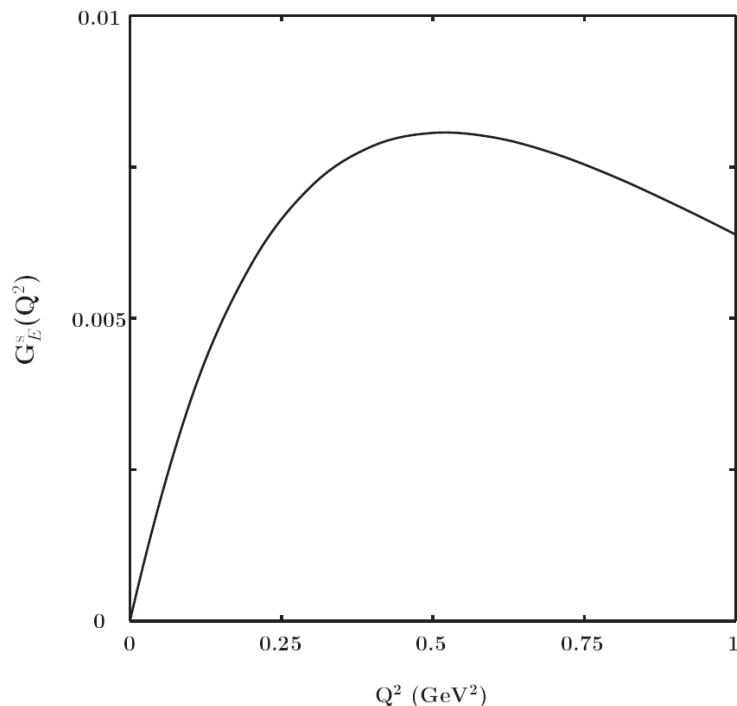
Y.Salamu, W.Melnitchouk,C.R.Ji,P.Wang,
Phys. Rev. Lett. 114 (2015) 122001

FIG. 3: Flavor asymmetry $\bar{d} - \bar{u}$ from the N and Δ intermediate states, and the total, for cutoffs $\mu = 0.3$ GeV and $\Lambda = 0.2$ GeV, compared with the asymmetry extracted at leading order from the E866 Drell-Yan data [4] at $Q^2 = 54$ GeV 2 . The band indicates the uncertainty on the total distribution from the cutoff parameters (for μ between 0.1 and 1 GeV) and from the empirical $\bar{D} - \bar{U}$ normalization.

u/d quark in Σ^-/Σ^+

Strange quark contribution to the form factor

$$\langle B(p') | J_\mu | B(p) \rangle = \bar{u}(p') \left\{ v_\mu G_E(Q^2) + \frac{i \epsilon_{\mu\nu\alpha\beta} v^\alpha S_v^\beta q^\nu}{m_N} G_M(Q^2) \right\} u(p)$$



V. Lyubovitskij, P. Wang, T. Gutsche, A. Faessler, Phys. Rev. C 66 (2002) 055204

u/d quark in Σ^-/Σ^+

Approach	μ^s (n.m.)	$\langle r^2 \rangle_E^s$ (fm 2)	$\langle r^2 \rangle_M^s$ (fm 2)	ρ^s	$\rho^s + \mu_p \mu^s$
QCD equalities [7]	-0.75 ± 0.30				
Lattice QCD [8]	-0.16 ± 0.18				
Lattice QCD [9]	-0.36 ± 0.20	-0.16 ± 0.06		2.02 ± 0.75	1 ± 0.75
Lattice QCD [10]	-0.28 ± 0.10				
HBChPT [12]	0.18 ± 0.34	0.05 ± 0.09	-0.14		
Poles [13]	-0.31 ± 0.09	0.14 ± 0.07		-2.1	-2.97
Poles [14]	-0.185 ± 0.075	0.14 ± 0.06		-2.93	-3.60
Poles [15]	-0.24 ± 0.03				
Kaon loop [16]	-0.355 ± 0.045	-0.0297 ± 0.0026			
Kaon loop + VMD [17]	-0.28 ± 0.04	-0.0425 ± 0.0026			
Skyrme model [19]	-0.13	-0.11		1.64	1.27
NJL soliton model [20]	0.10 ± 0.15	-0.15 ± 0.05		3.06	2.92
χ QSM [21]	0.115	-0.095	0.073		
CBM [22]	0.37				
CQM [23]	~ -0.05				
CQM [24]	-0.046		~ 0.02		
PCQM	-0.048 ± 0.012	-0.011 ± 0.003	-0.024 ± 0.003	0.17 ± 0.04	0.05

u/d quark in Σ^-/Σ^+

At $Q^2 = 0.1$ GeV 2

$$G_M^s(0.1) = 0.37 \pm 0.20 \pm 0.26 \pm 0.07 \quad \text{SAMPLE 2004}$$

$$G_M^s(0.1) = 0.23 \pm 0.36 \pm 0.40 \quad \text{SAMPLE 2005}$$

$$G_E^s(0.109) + 0.09G_M^s(0.109) = 0.007 \pm 0.011 \pm 0.006 \quad \text{HAPPEX-II 2007}$$

At $Q^2 = 0.23$ GeV 2

$$G_E^s(0.23) + 0.225G_M^s(0.23) = 0.039 \pm 0.034 \quad \text{PAV4 2004}$$

$$G_E^s(0.23) + 0.26G_M^s(0.23) = -0.12 \pm 0.11 \pm 0.11 \quad \text{PAV4 2009}$$

$$G_E^s(0.23) + 0.224G_M^s(0.23) = 0.020 \pm 0.029 \pm 0.016 \quad \text{PAV4 2009}$$

At $Q^2 = 0.477$ GeV 2

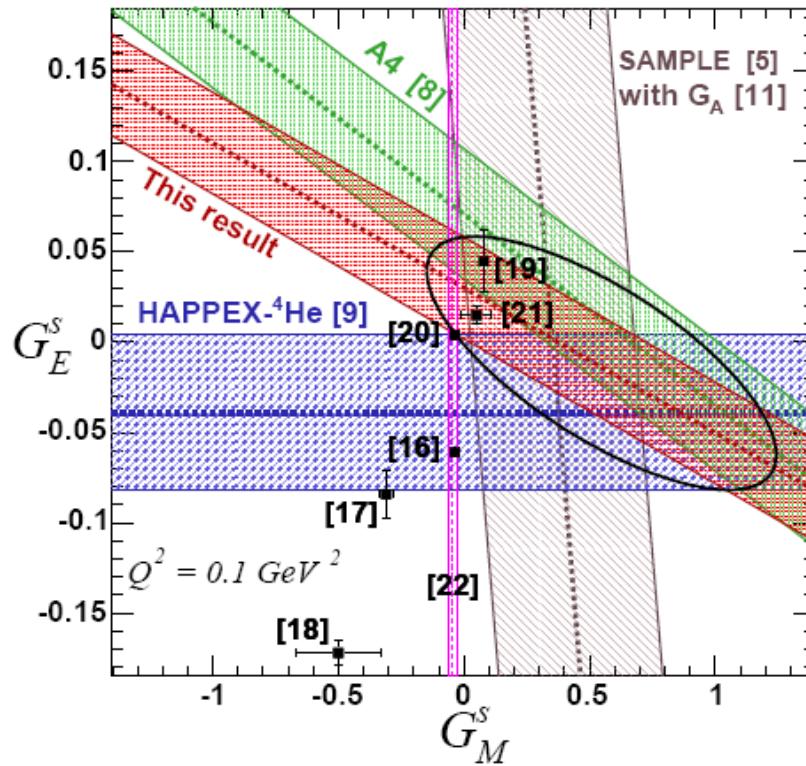
$$G_E^s(0.477) + 0.392G_M^s(0.477) = 0.014 \pm 0.020 \pm 0.010 \quad \text{HAPPEX-I 2004}$$

At $Q^2 = 0.62$ GeV 2

$$G_E^s(0.62) + 0.517G_M^s(0.62) = 0.003 \pm 0.010 \pm 0.004 \pm 0.009 \quad \text{HAPPEX-III 2012}$$

u/d quark in Σ^-/Σ^+

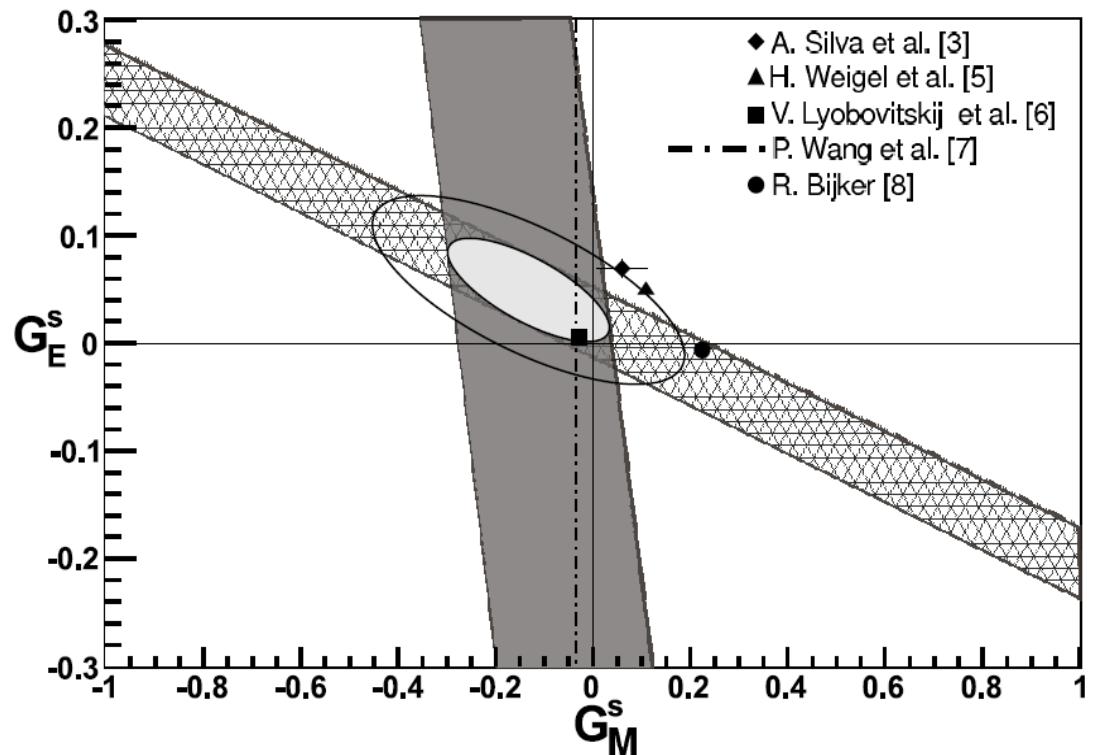
HAPPEX Collaboration
Phys. Lett. B635 (2006) 275



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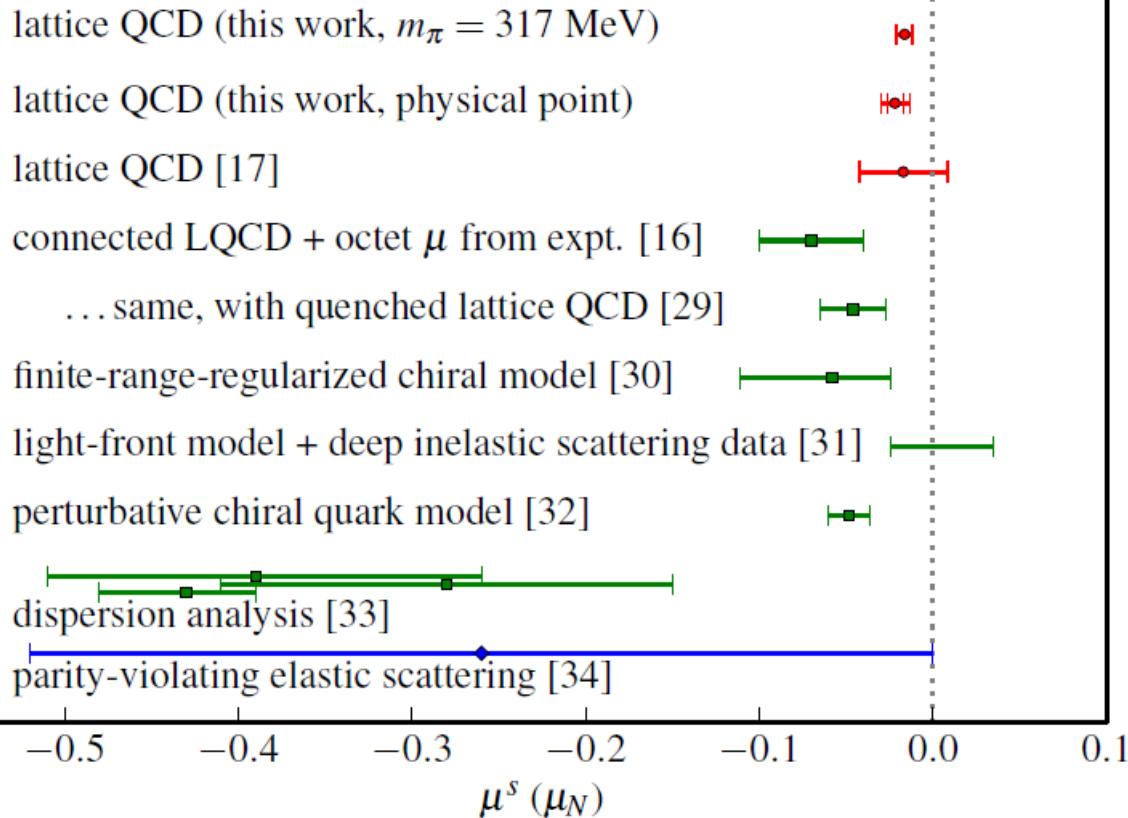
u/d quark in Σ^-/Σ^+

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u/d quark in Σ^-/Σ^+



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S. Syritsyn, arXiv:1505.01803 [hep-lat].

$$(r_E^2)^s = -0.0067(10)(17)(15) \text{ fm}^2,$$

$$(r_M^2)^s = -0.018(6)(5)(5) \text{ fm}^2,$$

$$\mu^s = -0.022(4)(4)(6) \mu_N,$$

PCQM	-0.011 +/- 0.003
	-0.024 +/- 0.003
	-0.048 +/- 0.012

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u/d quark in Σ^-/Σ^+

Strange form factors in Chiral effective field theory ??

“The quantity one wishes to predict – the strangeness vector current matrix element – is the same quantity one needs to know in order to make a prediction.”

ChEFT + FRR

The contribution of diagram a:

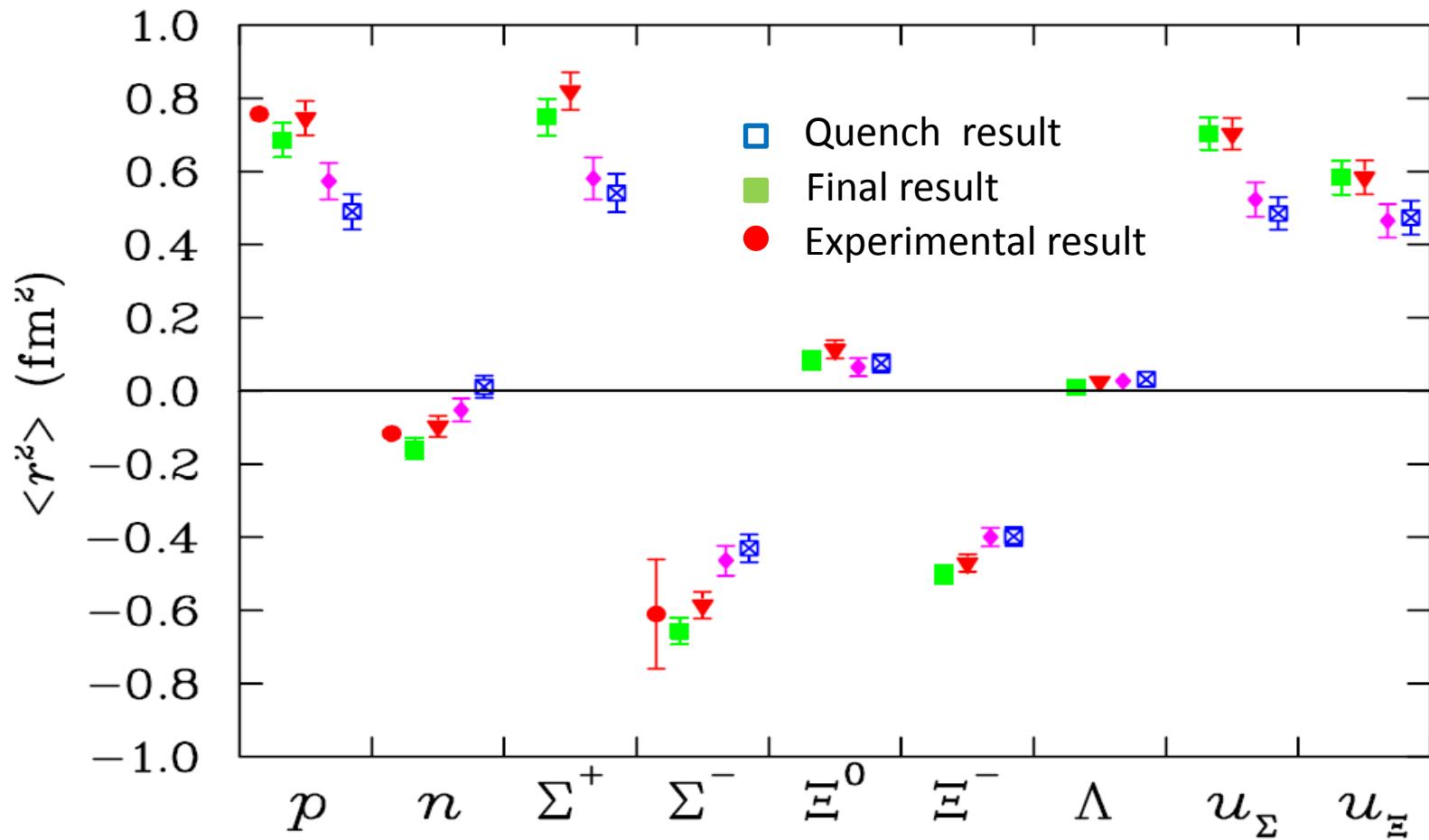


$$G_M^{p(1a)} = \frac{m_N(D+F)^2}{8\pi^3 f_\pi^2} I_{1\pi}^{NN} + \frac{m_N(D+3F)^2 I_{1K}^{N\Lambda} + 3m_N(D-F)^2 I_{1K}^{N\Sigma}}{48\pi^3 f_\pi^2}$$

$$G_M^{n(1a)} = -\frac{m_N(D+F)^2}{8\pi^3 f_\pi^2} I_{1\pi}^{NN} + \frac{m_N(D-F)^2}{8\pi^3 f_\pi^2} I_{1K}^{N\Sigma}.$$

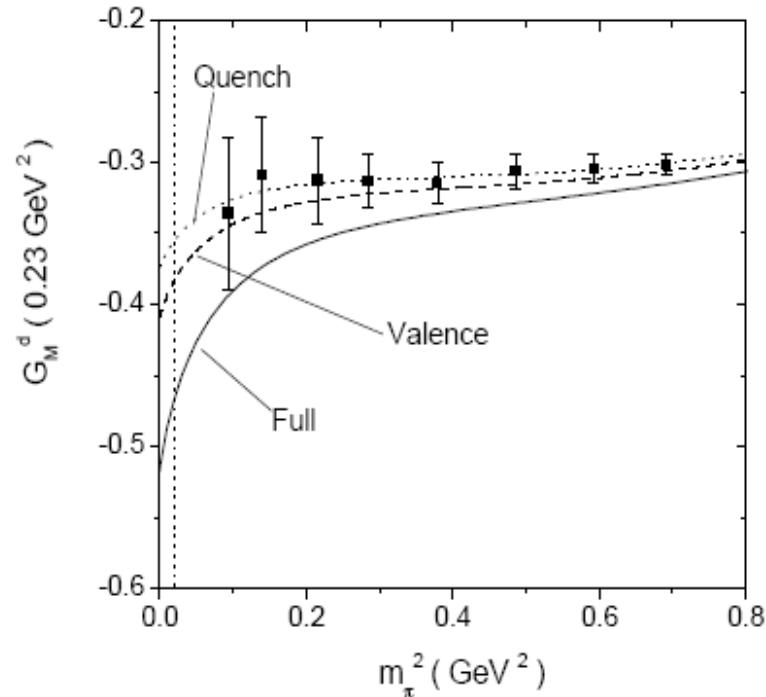
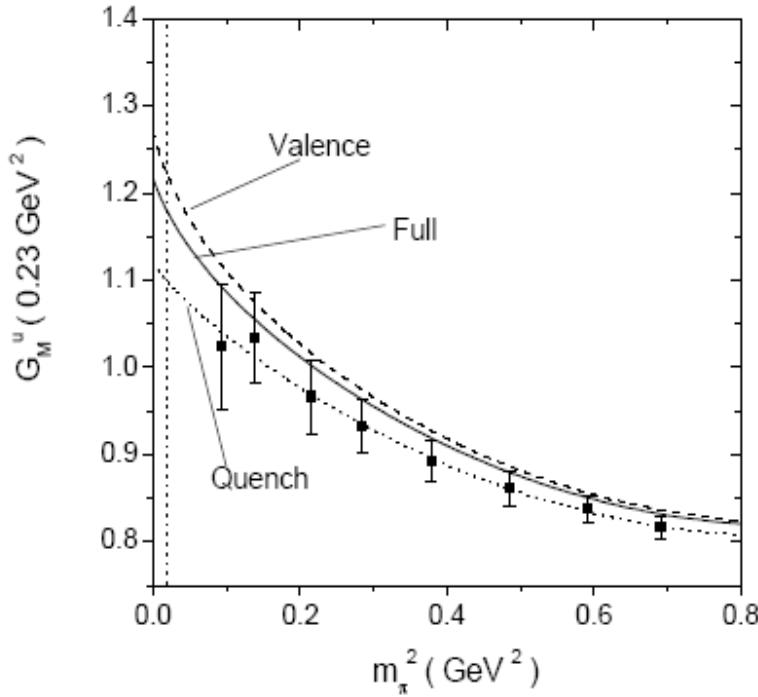
$$I_{1j}^{\alpha\beta} = \int d\vec{k} \frac{k_y^2 u(\vec{k} + \vec{q}/2) u(\vec{k} - \vec{q}/2) (\omega_j(\vec{k} + \vec{q}/2) + \omega_j(\vec{k} - \vec{q}/2) + \delta^{\alpha\beta})}{A_j^{\alpha\beta}}$$

Baryon octet charge radii:



D. B. Leinweber, S. Boinepalli, A.W. Thomas, P. Wang, et al, Phys. Rev. Lett. 97 (2006) 022001
P. Wang, D. B. Leinweber, A. W. Thomas, R. Young, Phys. Rev. D 79 (2009) 094001

Strange magnetic form factor:



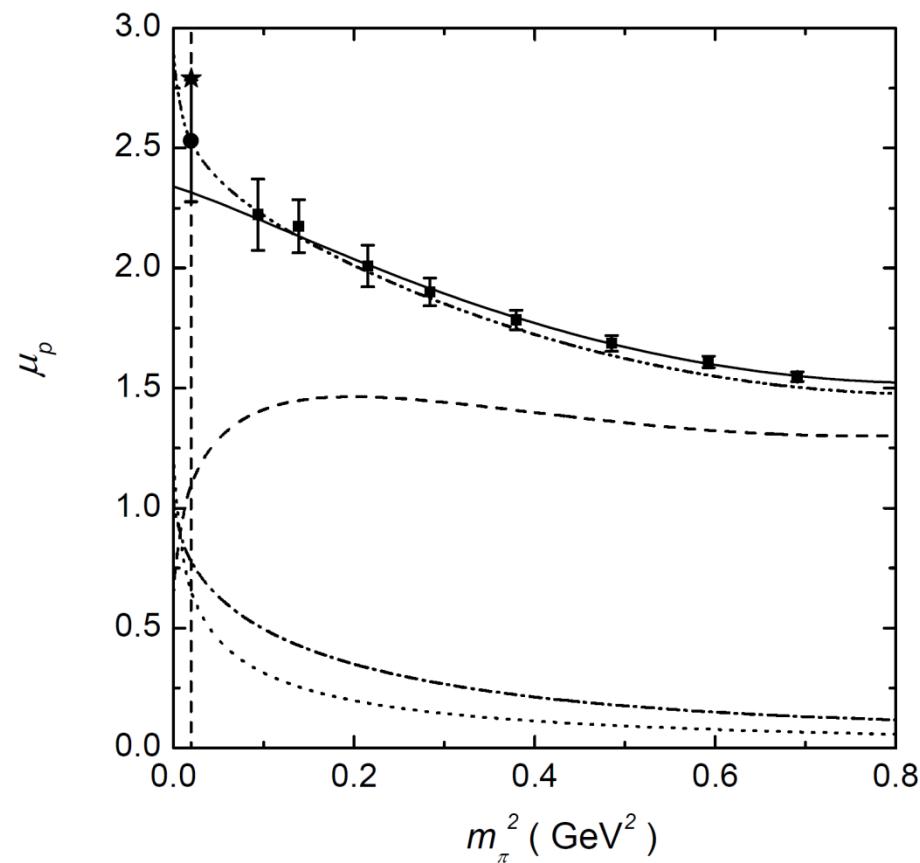
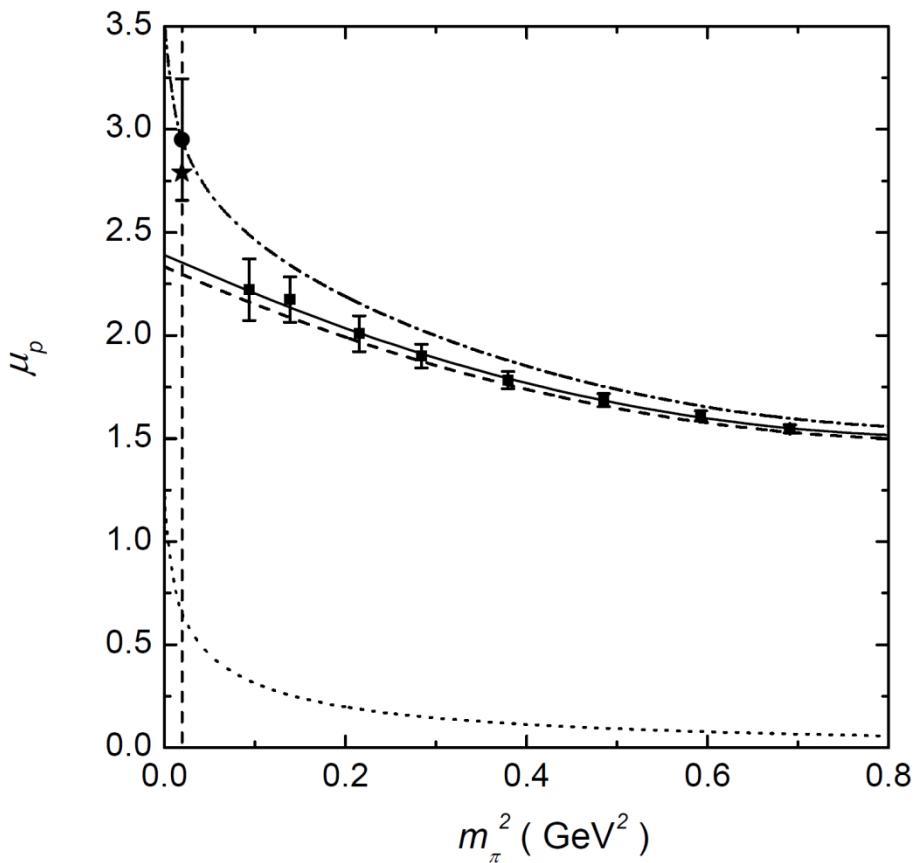
$$G_M^s = -0.034 \pm 0.021$$

TABLE II: The strange magnetic form factor at different Q^2 . Uncertainties reflect the range of Λ considered herein.

Q^2 (GeV^2)	0	0.1	0.23	0.477	0.62
$G_M^s(Q^2)$	$-0.058^{+0.034}_{-0.053}$	$-0.052^{+0.031}_{-0.051}$	$-0.046^{+0.029}_{-0.048}$	$-0.038^{+0.024}_{-0.040}$	$-0.035^{+0.023}_{-0.040}$

P. Wang, D. B. Leinweber, A. W. Thomas and R. D. Young, Phys. Rev. C 79 (2009) 065202
 P. Wang, D. B. Leinweber and A. W. Thomas, Phys. Rev. D 89 (2014) 033008

Chiral extrapolation of proton magnetic moment at LO and NLO



P. Wang, D. B. Leinweber, A. W. Thomas and R. D. Young, Phys. Rev. D 86 (2012) 94038

u/d quark in Σ^-/Σ^+

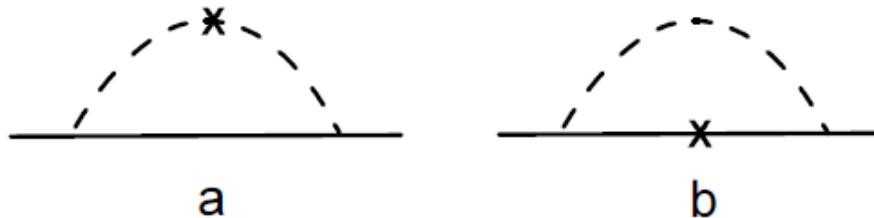


FIG. 1: Feynmann diagrams for the calculation of the magnetic form factor of the Σ^+ . Diagrams a and b correspond to the leading- and next-to-leading-order diagrams, respectively.

Leading order contribution: $G_{\Sigma^+}^{d(1a)} = P_{\pi^+\Sigma^0} + P_{\pi^+\Lambda} + P_{\pi^+\Sigma^{*0}}$

Octet intermediate state:

$$P_{\pi^+\Sigma^0} = -\frac{m_\Sigma F^2}{12 \pi^3 f_\pi^2} \int d^3 k \frac{k^2 u_1 u_2}{\omega_1^2 \omega_2^2} \quad P_{\pi^+\Lambda} = \frac{D^2}{3F^2} P_{\pi^+\Sigma^0}$$

Decuplet intermediate state:

$$P_{\pi^+\Sigma^{*0}} = \frac{m_\Sigma C^2}{432 \pi^3 f_\pi^2} \int d^3 k \frac{k^2 u_1 u_2 (1 + \Delta/(\omega_1 + \omega_2))}{\omega_1 \omega_2 (\omega_1 + \Delta) (\omega_2 + \Delta)}$$

u/d quark in Σ^-/Σ^+

Next to Leading order contribution: $G_{\Sigma^+}^{d(1b)} = P_{\Sigma^0} \cdot \mu_{\Sigma^0}^d + P_{\Sigma^{*0}} \cdot \mu_{\Sigma^{*0}}^d + P_{\Sigma^{*0}\Sigma^0(\Lambda)} \cdot \mu^d$

Octet intermediate state: $P_{\Sigma^0} = \frac{F^2}{16\pi^3 f_\pi^2} \int d^3k \frac{k^2 u_k^2}{\omega_k^3}$

Decuplet intermediate state: $P_{\Sigma^{*0}} = -\frac{5\mathcal{C}^2}{864\pi^3 f_\pi^2} \int d^3k \frac{k^2 u_k^2}{\omega_k(\omega_k + \Delta)^2}$

Octet-decuplet transition: $P_{\Sigma^{*0}\Sigma^0(\Lambda)} = -\frac{(D - F)\mathcal{C}}{36\pi^3 f_\pi^2} \int d^3k \frac{k^2 u_k^2}{\omega_k^2(\omega_k + \Delta)}$

Tree level: $\mu_{\Sigma^0}^d = \frac{2}{3}\mu_{\Sigma^{*0}}^d = \frac{2}{3}\mu_d \quad \mu_{\Sigma^0\Sigma^{*0}}^d = \frac{\sqrt{3}}{3}\mu_{\Lambda\Sigma^{*0}}^d = \frac{\sqrt{2}}{3}\mu_d$

u/d quark in Σ^-/Σ^+

TABLE I: d quark contributions to the magnetic moment of the Σ^+ in unit of μ_N at different Λ .

Λ (GeV)	0.6	0.7	0.8	0.9	1.0
LO	-0.21	-0.27	-0.34	-0.42	-0.49
NLO	-0.017	-0.025	-0.035	-0.045	-0.057
$G_{\Sigma^+}^d$	-0.22	-0.30	-0.38	-0.46	-0.55

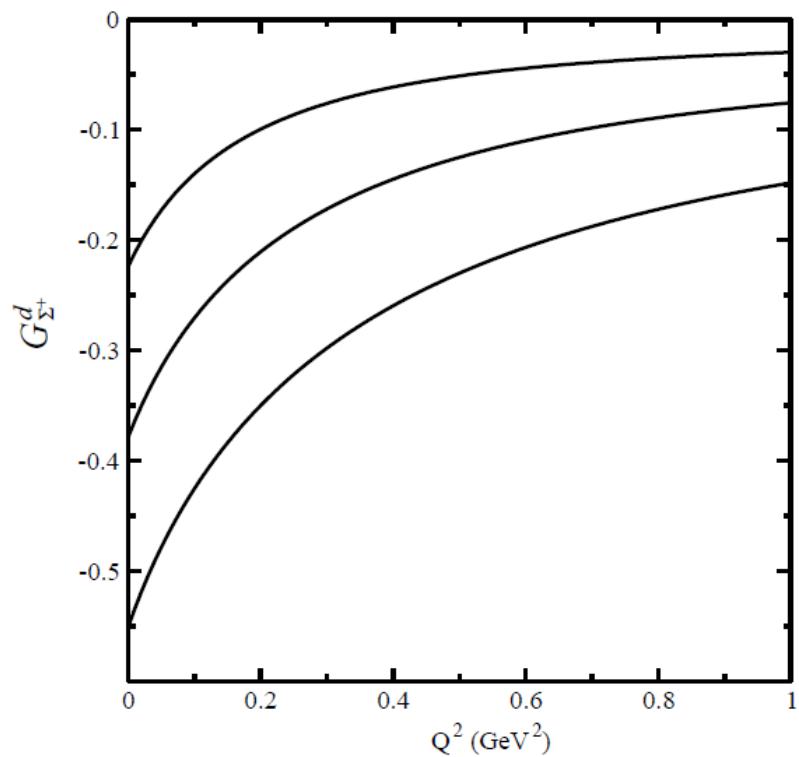
$$u_k = \frac{1}{(1 + k^2/\Lambda^2)^2} \quad \Lambda = 0.8 \pm 0.2 \text{ GeV}$$

Magnetic moment : $-0.38^{+0.16}_{-0.17} \mu_N$

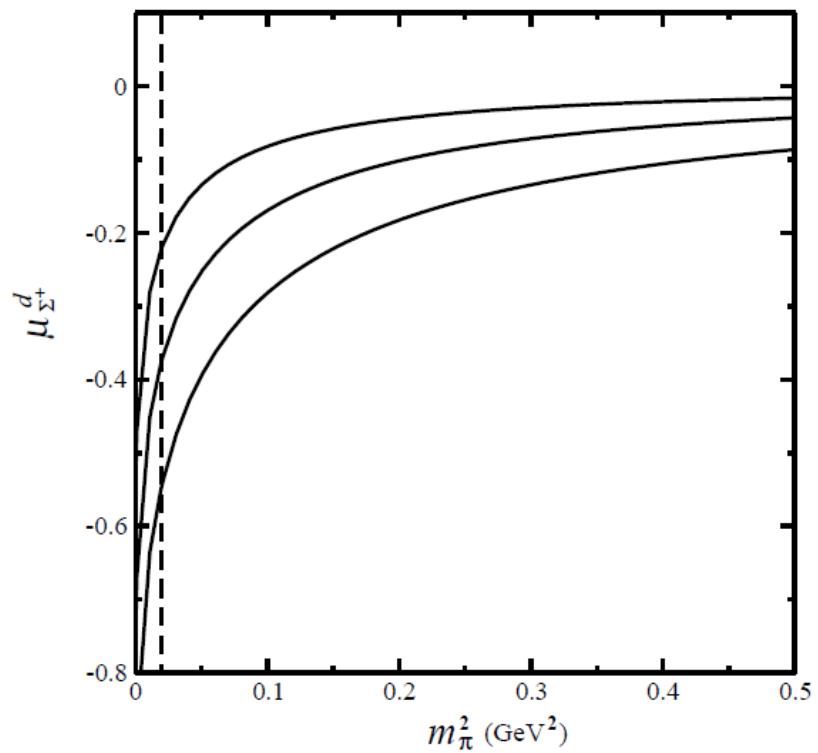
7 times larger than the strange magnetic moment of the nucleon.

P. Wang, D. B. Leinweber and A. W. Thomas, arXiv:1504.06392.

u/d quark in Σ^-/Σ^+



$Q^2 < 0.2 \text{ GeV}^2$
G is larger than 0.2



pion mass 300-400 MeV
magnetic moment around 0.2

P. Wang, D. B. Leinweber and A. W. Thomas, arXiv:1504.06392.

Summary

- We compute the $\bar{d} - \bar{u}$ asymmetry in the proton within relativistic and heavy baryon effective field theory Including both nucleon and baryon intermediate states.
- In addition to the distribution at nonzero x , we also estimate the correction to the integrated asymmetry arising at $x = 0$, which have not been accounted for in previous empirical analyses.
- Without attempting to fine-tune the parameters, the overall agreement between the calculation and experiment is very good.
- We propose the pure sea-quark contributions to the magnetic form factors of baryons, $G_{\Sigma^-}^u$ and $G_{\Sigma^+}^d$ as priority observables for the examination of sea-quark contributions to baryon structure, both in present lattice QCD simulations and possible future experimental measurement.
- It is about seven times larger than the strange magnetic moment of the nucleon found in the same approach. Including quark charge factors, the u-quark contribution to the Σ - magnetic moment exceeds the strange quark contribution to the nucleon magnetic moment by a factor of 14.

The End