Spin Sum Rules and Polarizabilities

Dieter Drechsel

Institut für Kernphysik , Universität Mainz

JLab Workshop, March 2009

- D.D., B. Pasquini, M. Vanderhaeghen, Phys. Rept. **378**, 99 (2003)
- D.D. and L. Tiator, Ann. Rev. Nucl. Part. Sci. **54**, 69 (2004)
- S.E. Kuhn, J.-P. Chen, E. Leader, arXiv:0812.3535 [hep-ph] (2009)
- X. Ji and J.J. Osborne, J. Phys. G **27, 127 (2001)**

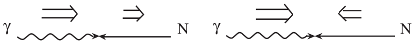
Table of Contents

Introduction

- GDH sum rule: special case of several relations connecting real and virtual Compton scattering (RCS/VCS) to inclusive photo/electroproduction. **VCS$\equiv$ VVCS**
- Based on universal principles: causality, unitarity, gauge invariance, crossing symmetry.
- Unique testing ground to study internal degrees of freedom that hold the system together.
- At small photon virtuality: information about long-range phenomena, effective degrees of freedom due to interplay of quarks and mesons (Goldstone bosons, resonances).
- At larger virtualities: the primary degrees of freedom (quarks and gluons) become visible.
- Need better understanding of transition
  coherent $\leftrightarrow$ incoherent processes
  generalized spin polarizabilities $\leftrightarrow$ higher twists
- Recent experiments have collected a large body of precise and solid data and prepared the ground for theoretical activities: Chiral Perturbation, Lattice Gauge, perturbative QCD

Gerasimov-Drell-Hearn-Hosada-Yamamoto sum rule

Unsubtracted dispersion relation relating the anomalous magnetic moment κ to spin-dependent inclusive cross sections $(\sigma_P - \sigma_A)$ for real photons with parallel/antiparallel spin w.r.t. target spin S



$$\frac{\pi e^2 \kappa^2}{M^2} S = \int_{\nu_0}^{\infty} \frac{d\nu}{\nu} \left(\sigma_P(\nu) - \sigma_A(\nu)\right) \qquad (1)$$

♡ Finite $\kappa \rightarrow$ particle has (spin-dependent) excitation spectrum $\rightarrow$ particle has spatial extension, size and shape $\Rightarrow$ HADRONIC PHYSICS.

Discovery of large κ_p by Stern and collaborators (1933) rang up the curtain for hadronic physics.

♣ LHS $> 0 \rightarrow$ photon prefers absorption with parallel spins. Leads to excited state with spin $S = 3/2$, ruled out for absorption on single quark ($\neq DIS$).

Gyromagnetic Moment and Convergence of GDH Integral

Relation between magnetic moment $\vec{\mu}$ and spin vector $\vec{S}$:

$$\vec{\mu} = \frac{eg}{2M}\,(Q+\kappa)\,\vec{S}\ , \qquad (2)$$

gyromagnetic ratio $g = 2$ for particles of any spin.

♢ Value $g = 2$ required for well-behaved scattering amplitude at high energy (Weinberg, 1970).

♠ Large a.m.m. of nucleon shows its composite structure, described by unitarity corrections from pion loops and low-energy resonance effects. Such spatially extended phenomena should fade out with increasing energy.

♣ Therefore, GDH integral Eq. (1) should saturate at sufficiently large energies, unsubtracted dispersion relation should exist.

♡ In a completely supersymmetric, high-energy world, all GDH integrals would vanish, all particles would be “truly elementary” pointlike objects .

Finite value of κ in real world: measure of broken supersymmetry.

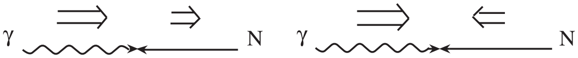
Forward RCS and Polarizability

Forward Compton amplitude:

$$T(\nu,\, \theta = 0) = \vec{\varepsilon}'^{*} \cdot \vec{\varepsilon}\, f(\nu) + i\, \vec{\sigma} \cdot (\vec{\varepsilon}'^{*} \times \vec{\varepsilon})\, g(\nu) \qquad (3)$$

Invariance under photon crossing ($\varepsilon'^{*} \leftrightarrow \varepsilon$ and $\nu \rightarrow -\nu$) requires that $f(\nu)$ even and $g(\nu)$ odd function of ν.

Amplitudes f and g measured by double-polarization experiment:



Parallel spins: excited state has spin $3/2$, transition requires a correlated 3-quark system.
Opposite spins: excited state has spin $1/2$, process can take place on single quark.

$$f(\nu) = (T_{1/2} + T_{3/2})/2\,, \quad g(\nu) = (T_{1/2} - T_{3/2})/2 \qquad (4)$$

Optical Theorem

Scattering amplitudes $T_{1/2}$ and $T_{3/2}$ related to helicity-dependent absorption cross sections $\sigma_A = \sigma_{1/2}$ and $\sigma_P = \sigma_{3/2}$.
Total and helicity dependent cross sections:

$$\begin{aligned} \sigma_T &= \frac{1}{2}\left(\sigma_{1/2} + \sigma_{3/2}\right), \\ \sigma_{TT} &= \frac{1}{2}\left(\sigma_{1/2} - \sigma_{3/2}\right) \end{aligned} \tag{5}$$

Unitarity $\Rightarrow$ optical theorem

$$\begin{aligned} \mathrm{Im}\, f(\nu) &= \frac{\nu}{8\pi}(\sigma_{1/2}(\nu) + \sigma_{3/2}(\nu)) = \frac{\nu}{4\pi}\,\sigma_T(\nu)\,, \\ \mathrm{Im}\, g(\nu) &= \frac{\nu}{8\pi}(\sigma_{1/2}(\nu) - \sigma_{3/2}(\nu)) = \frac{\nu}{4\pi}\,\sigma_{TT}(\nu) \end{aligned} \tag{6}$$

Dispersion Relations and LET

Subtracted DR for $f(\nu)$, unsubtracted DR for $g(\nu)$:

$$\mathrm{Re}\, f(\nu) = f(0) + \frac{\nu^2}{2\pi^2}\,\mathcal{P}\int_{\nu_0}^{\infty} \frac{\sigma_T(\nu')}{\nu'^2 - \nu^2}\, d\nu' \,, \tag{7}$$

$$\mathrm{Re}\, g(\nu) = \frac{\nu}{4\pi^2}\,\mathcal{P}\int_{\nu_0}^{\infty} \frac{\sigma_{1/2}(\nu') - \sigma_{3/2}(\nu')}{\nu'^2 - \nu^2}\, \nu' d\nu' \,. \tag{8}$$

Below pion production, $\nu < \nu_0$: amplitudes $f(\nu)$ and $g(\nu)$ are real, can be expanded in Taylor series and compared to low-energy theorem (Low, Gell-Mann & Goldberger, 1954),

$$f(\nu) = -\frac{e^2\, e_N^2}{4\pi M} + (\alpha + \beta)\,\nu^2 + \mathcal{O}(\nu^4)\,, \tag{9}$$

$$g(\nu) = -\frac{e^2 \kappa_N^2}{8\pi M^2}\,\nu + \gamma_0 \nu^3 + \mathcal{O}(\nu^5)\,. \tag{10}$$

Leading term in Eq. (8) yields GDH sum rule,
higher order terms express (forward) polarizabilities by integrals over absorption spectrum.

Sum Rules

- Baldin sum rule
  Compare $\mathcal{O}(\nu^2)$ of Eq. (7) to LET, Eq. (9):

$$\alpha + \beta = \frac{1}{2\pi^2} \int_{\nu_0}^{\infty} \frac{\sigma_T(\nu)}{\nu^2} \, d\nu \qquad (11)$$

- Gerasimov-Drell-Hearn sum rule
  Compare $\mathcal{O}(\nu)$ of Eq. (8) to LET, Eq. (10):

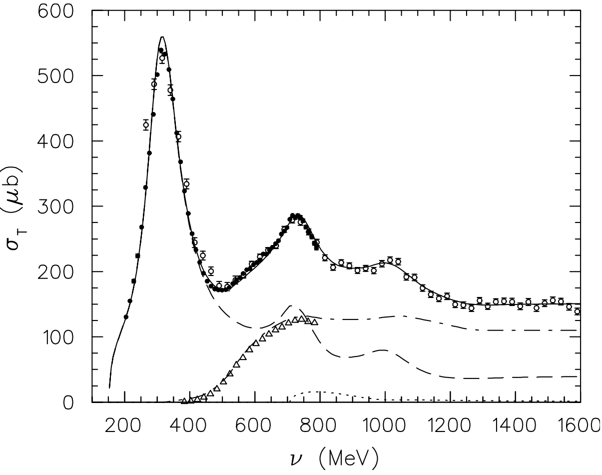
$$\frac{\pi e^2 \kappa_N^2}{2M^2} = \int_{\nu_0}^{\infty} \frac{\sigma_{3/2}(\nu) - \sigma_{1/2}(\nu)}{\nu} \, d\nu \equiv I_{GDH} \qquad (12)$$

- (Gell-Mann)-Goldberger-Thirring sum rule
  Compare $\mathcal{O}(\nu^3)$ Eq. (8) to LET, Eq. (10):

$$\gamma_0 = -\frac{1}{4\pi^2} \int_{\nu_0}^{\infty} \frac{\sigma_{3/2}(\nu) - \sigma_{1/2}(\nu)}{\nu^3} \, d\nu \qquad (13)$$

- Higher terms of power series yield quadrupole polarizability, $\mathcal{O}(\nu^5)$, and so on.

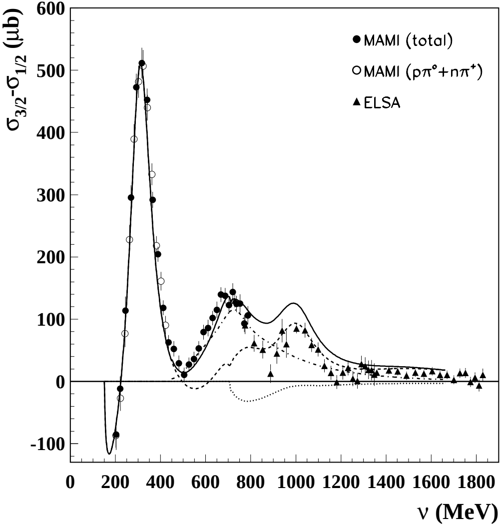
Total Photoabsorption $\sigma_T(\nu)$



phenomena from low to high lab energy ν:

- ♠ non-resonant S-wave π^+ (E_{0+})
- ♠ P_{33} resonance (M_{1+}/E_{1+})
- ♠ D_{13} resonance (E_{2-}/M_{2-})
  S_{11} resonance (E_{0+})
- ♠ F_{15} resonance (E_{3-}/M_{3-})
  D_{33} resonance (E_{2-}/M_{2-})
  S_{31} resonance (E_{0+})
  P_{13} resonance (E_{1+}, M_{1+})
- ♠ $>$ 500 MeV: $\pi\pi$ channels
- ♠ $>$ 700 MeV: η channel
- ♠ $>$ 2 GeV constant absorption
  slight increase in Regge region
  from soft pomeron exchange

Helicity Dependent Photoabsorption $\sigma_{3/2} - \sigma_{1/2}$ for proton



phenomena from low to high lab energy ν:

♠ non-resonant S-wave π^+ $(-|E_{0+}|^2)$

♠ P_{33} resonance $(+|M_{1+}|^2 + \ldots)$

♠ D_{13} resonance $(+|E_{2-}|^2 + \ldots)$
S_{11} resonance $(-|E_{0+}|^2)$

♠ F_{15} resonance $(+|E_{3-}|^2 + \ldots)$
D_{33} resonance $(+|E_{2-}|^2 + \ldots)$
S_{31} resonance $(-|E_{0+}|^2)$
P_{13} resonance $(-|E_{1+}|^2 + \ldots)$

♠ $\pi\pi$ channels positive

♠ η channel negative

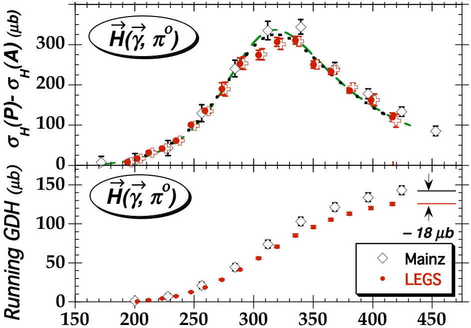
♠ > 2 GeV small negative contribution from Regge tail for $\nu \to \infty$ "helicity blind" (?)

GDH and FSP for proton

energy [GeV]	Ref.	$I^p_{GDH}[\mu\text{b}]$	γ^p_0 $[10^{-4}\ \text{fm}^4]$
$\nu_0 - 0.2$	MAID/SAID	-27.5 ± 3	0.90 ± 0.05
$0.2 - 0.8$	Ahrens 2001	$226 \pm 5 \pm 12$	$-1.87 \pm 0.08 \pm 0.10$
$0.8 - 2.9$	Dutz 2004	$27.5 \pm 2.0 \pm 1.2$	-0.03
total		$226 \pm 6 \pm 12$	$-1.00 \pm 0.08 \pm 0.11$
sum rule		204	–

♣ Regge tail above 2.9 GeV $(-14 \pm 2)\mu$b (Bianchi, Thomas,Simula)

♣ Hoblit (2009) measure smaller (γ, π^0) near $\Delta(1232)$: $(-18 \pm 6)\mu$b

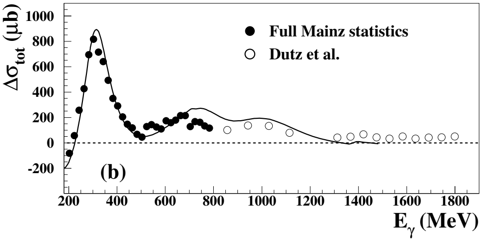


GDH for neutron

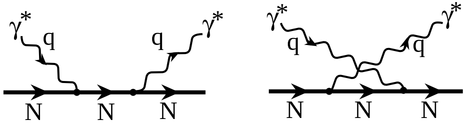
energy [GeV]	Ref.	$I^n_{GDH}[\mu b]$
$\nu_0 - 0.2$	MAID/SAID	-30 ± 3
$0.2 - 0.8$	Ahrens 2006	$181 \pm 21 \pm 30$
$0.8 - 1.8$	Dutz 2004	$+34 \pm 5 \pm 5$
> 1.8	Regge tail	$+30 \pm 10$
total		$215 \pm 22 \pm 34$
sum rule		234

♣ $\gamma + d \rightarrow p + n$ 20 μb ?

♣ $>$ 1.8 GeV
positive integrand
Regge tail of 30 μb ?
(Bianchi, Thomas, Simula)

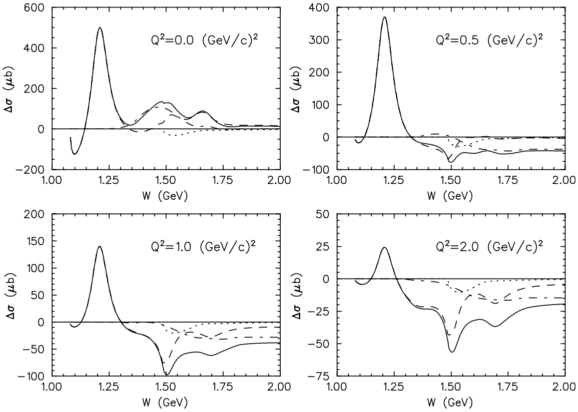


Inclusive Electroproduction and Virtual Compton Scattering



- Inclusive electroproduction cross section
  $\sigma(\nu,\ Q^2) = \sigma_T + \epsilon\,\sigma_L - hP_x\sqrt{2\epsilon(1-\epsilon)}\,\sigma_{LT} - hP_z\sqrt{1-\epsilon^2}\,\sigma_{TT}$
  momentum transfer $Q^2 = 4EE^{'}\sin^2\frac{\theta}{2}$, energy transfer $\nu = E_e - E_e'$,
  ϵ transverse photon pol., h electron helicity, $P_{x,z}$ target polarization
- Scattering amplitude
  $T(\nu,\ Q^2,\ \theta = 0)$
  $=(\vec{\varepsilon}'^{*}\cdot\vec{\varepsilon})\,f_T + f_L - i\vec{\sigma}\cdot(\vec{\varepsilon}'^{*}\times\vec{\varepsilon})g_{TT} - i(\vec{\varepsilon}'^{*}-\vec{\varepsilon})\cdot(\vec{\sigma}\times\vec{q})g_{LT}$
- Crossing symmetry
  Invariance under $\vec{\varepsilon}'^{*}\leftrightarrow\vec{\varepsilon}$, $\vec{q}\rightarrow-\vec{q}$, $\nu\rightarrow-\nu$
  g_{TT} odd and g_{LT} even function of ν.
- Optical theorem
  $\mathrm{Im}\,\{f_T, f_L, g_{TT}, g_{LT}\} = \frac{K_H}{4\,\pi}\{\sigma_T, \sigma_L, \sigma_{TT}, \sigma_{LT}\}$
  K_H="equivalent photon energy"

Helicity Difference $\Delta\sigma = \sigma_{3/2}(W, Q^2) - \sigma_{1/2}(W, Q^2)$



$W = \sqrt{2M\nu - M^2 - Q^2}$ total hadronic c.m. energy

with increasing Q^2:

π S-wave @ thr.
rapid decrease

$\Delta(1232)$ drops faster
than dipole f.f.

2nd and 3rd resonance
regions change sign
near $Q^2 = 0.2\mathrm{GeV}^2$

above $Q^2 = 2\mathrm{GeV}^2$
resonance structures
wash out, DIS regime

Spin-flip Cross Sections, Nucleon Spin Structure Functions, Asymmetries

cross sections and nucleon structure functions g_1 and g_2

Note: nucleon structure functions contain elastic and inelastic parts!

$$\sigma_{TT} = \frac{\pi\, e^2}{M\, K}\,(g_1 - \gamma^2\, g_2), \quad \sigma_{LT} = \frac{\pi\, e^2}{M\, K}\,\gamma(g_1 + g_2), \quad \gamma = Q/\nu$$

Asymmetries and helicity amplitudes

Experiments measure asymmetries for longitudinal electron polarization and target polarization longitudinal ($A_{||}$) and transverse ($A_\perp$) $\Rightarrow g_1,\, g_2$

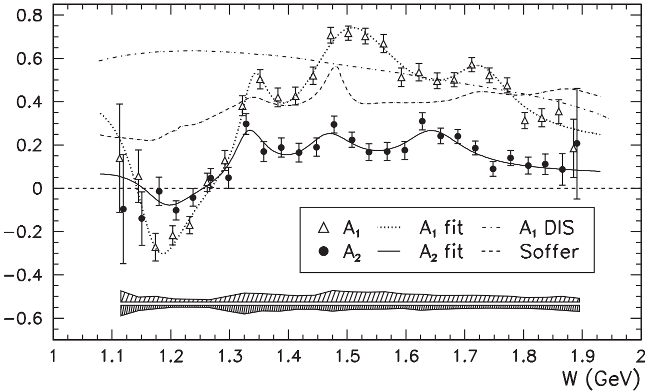
Resonance physics: Introduce polarization w.r.t. virtual photon.

$$A_1 \sim \sigma_{TT} \sim g_1 - \gamma^2\, g_2 \sim |A_{1/2}|^2 - |A_{3/2}|^2$$
$$A_2 \sim \sigma_{LT} \sim g_1 + g_2 \sim S^*_{1/2} A_{1/2}$$

HELICITY AMPLITUDES $A_{3/2}$, $A_{1/2}$, $S_{1/2}$ characterize resonance structure.

JLab Hall A, B, and C collaborations have provided new and precise information on both DIS and resonance structure

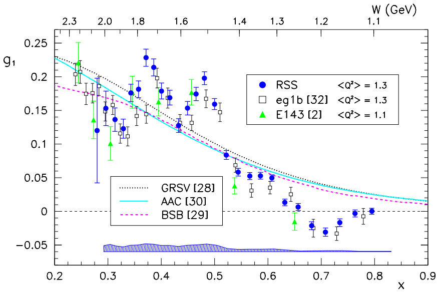
Asymmetries $A_1 \sim \sigma_{TT}$ and $A_2 \sim \sigma_{LT}$

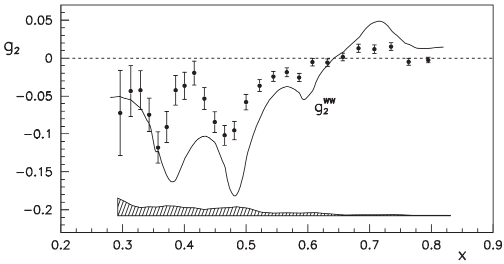


RSS/Hall C, Wesselmann et al., PRL (2007)
$Q^2 \approx 1.33 \mathrm{GeV}^2$

σ_{TT} dominant, σ_{LT} suppressed
distinct resonance structures $\neq$ DIS
$P_{33}(1232)$, 2nd resonance region (1500), 3rd resonance region (1700)
indication of peak near 1350 MeV (Roper? mostly 2-pion?)

Spin Structure Functions





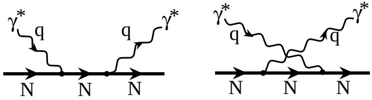
RSS/Hall C, CLAS, and SLAC data; see also new CLAS data (Bosted 2009)

g_1: fluctuations about DIS extrapolation as before
g_2: WW approximation right structure but differs in size
$\sigma_{LT} \sim g_1 + g_2$ suppressed

distinct resonance structures, importance of higher twists (convergence?)
$P_{33}(1232)$, 2nd resonance region (1500), 3rd resonance region (1700)
indication of peak near 1350 MeV (Roper? mostly 2-pion?)

Dispersion Relations and VCS Sum Rules I

Born terms



$$g_{TT}^{\text{Born}}(\nu,\ Q^2) = -\frac{e^2\,\nu}{8\pi M^2}\left(F_P^2 + \frac{Q^2}{\nu^2-\nu_B^2+i\varepsilon}\,G_M^2\right)$$

$$g_{LT}^{\text{Born}}(\nu,\ Q^2) = \frac{e^2\,Q}{8\pi M^2}\left(F_D F_P - \frac{Q^2}{\nu^2-\nu_B^2+i\varepsilon}\,G_E G_M\right)$$

form factors Dirac: $F_D(Q^2)$, Pauli: $F_D(Q^2)$, Sachs: $G_E(Q^2)$ and $G_M(Q^2)$

pole positions: $\nu = \pm\nu_B = \pm Q^2/2M$.

RCS vs. VCS

Real photon in limit $Q^2 \to 0 \Rightarrow F_P \to \kappa_N,\ F_D \to e_N$
Pole terms vanish, Born terms real $\Leftrightarrow$ real photon not absorbed by nucleon.
Taylor series $g(\nu) = g_{TT}(\nu, Q^2 = 0)$ converges for $\nu < \nu_0$

Virtual photon absorbed by nucleon $(e + N \to e' + N')$.
Pole at ν_B yields complex amplitude, fulfills dispersion relation by itself.
$g_{TT}(\nu, Q^2) - g_{TT}^{\text{pole}}(\nu, Q^2)$ is real for $\nu < \nu_\pi(Q^2) = \nu_0 + \nu_B(Q^2)$,
can be expanded in power series up to $\nu = \nu_\pi(Q^2)$ and

can be evaluated by dispersion integral over (polarized) electroproduction.

Dispersion Relations and VCS Sum Rules II

g_{TT}, odd power series for $\nu < \nu_\pi(Q^2)$

$$g_{TT}^{\rm non-pole}(\nu,\ Q^2) = \frac{\nu}{2\pi^2}\,\mathcal{P}\int_{\nu_\pi}^{\infty} \frac{K(\nu',Q^2)\,\sigma_{TT}(\nu',Q^2)}{\nu'^2-\nu^2}\,d\nu'$$
$$\Rightarrow \frac{e^2}{2\,\pi\,M^2}\,I_{TT}(Q^2)\,\nu + \gamma_{TT}(Q^2)\,\nu^3 + \mathcal{O}(\nu^5)$$

generalized GDH integral, $I_{TT}(0) = -\kappa_N^2/4$

generalized spin (dipole) polarizability, $\gamma_{TT}(0) = \gamma_0$

g_{LT}, even power series for $\nu < \nu_\pi(Q^2)$

$$g_{LT}^{\rm non-pole}(\nu,\ Q^2) = \frac{1}{2\pi^2}\,\mathcal{P}\int_{\nu_\pi}^{\infty} \frac{\nu'\,K(\nu',Q^2)\,\sigma_{LT}(\nu',Q^2)}{\nu'^2-\nu^2}\,d\nu'$$
$$= \frac{e^2 Q}{2\,\pi\,M^2}\,I_{LT}(Q^2) + Q\delta_{LT}(Q^2)\,\nu^2 + \mathcal{O}(\nu^4)$$

longitudinal-transverse analog of generalized GDH integral
longitudinal-transverse analog of generalized spin polarizability

I_{LT} and $\delta_{LT}(0) = \delta_0$ obtained by extrapolation $Q^2 \to 0$.

Integrals and Sum Rules

integrals

$$I_{1,2}(Q^2) = \frac{2\,M^2}{Q^2} \int_0^1 dx\, g_{1,2}\,(x,\ Q^2) = \frac{2\,M^2}{Q^2}\, \Gamma_{1,2}(Q^2)$$

limit $Q^2 \to \infty$

$$\Gamma_1(Q^2) = \tilde{\Gamma}_1(Q^2) + \mathcal{O}\left(\frac{M^2}{Q^2}\right)\ ,\quad \Gamma_2(Q^2) = \mathcal{O}\left(\frac{M^4}{Q^4}\right)$$

Bjorken sum rule, QCD prediction for isovector integral

confirmed within 10%

$$\tilde{\Gamma}_1^p(Q^2) - \tilde{\Gamma}_1^n(Q^2) = \frac{1}{6}\, g_A \left\{1 - \frac{\alpha_s(Q^2)}{\pi} + \mathcal{O}\left(\alpha_s^2\right)\right\}$$

$$\approx 0.18\ \text{@}\ Q^2 = 5\,\mathrm{GeV}^2$$

Burkhard-Cottingham sum rule

$I_2(Q^2) = 0 \Rightarrow \Gamma_2(Q^2) = 0$ (elastic and inelastic !)

Burkhard-Cottingham sum rule

"Superconvergence relation", assuming convergent dispersion relation for $g_2(\nu)$ and $\nu\, g_2(\nu)$. *If these integrals converge* $\Rightarrow$

$$\frac{M^2}{\pi\, e^2} \int_{\nu_\pi}^{\infty} \frac{K(\nu, Q^2)}{\nu^2+Q^2} \left\{ -\sigma_{TT}(\nu,\ Q^2) + \frac{\nu}{Q}\,\sigma_{LT}(\nu,\ Q^2) \right\} d\nu$$

$$= I_2^{\rm inel}(Q^2) = -I_2^{\rm el}(Q^2) = \frac{1}{4}\ F_P(Q^2)(F_D(Q^2) + F_P(Q^2))$$

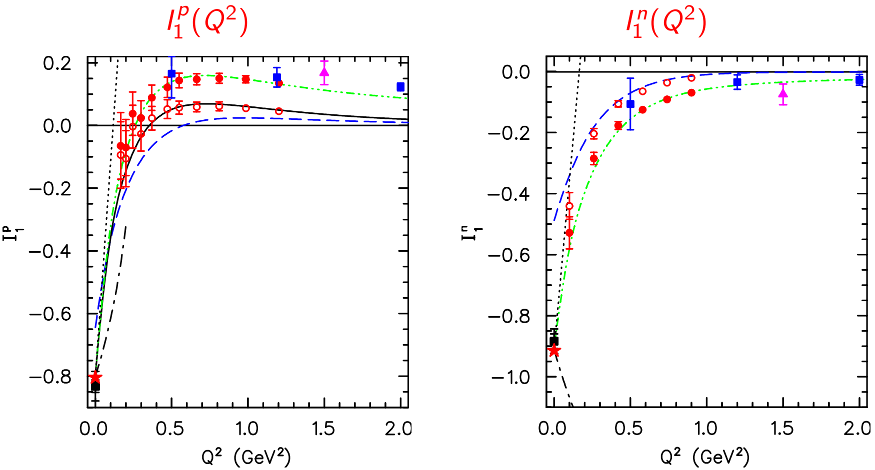
Integral over excitation spectrum is fully determined by electric and magnetic ground state form factors F_D and F_P.

BC integral converges in QED and perturbative QCD. It also follows from Wandzura-Wilczek relation. Does it converge in strong QCD?

In limit $Q^2 \to \infty, \quad I_2^{\rm inel}(Q^2) = -I_2^{\rm el}(Q^2) = \mathcal{O}\left(\frac{M^{10}}{Q^{10}}\right)$

$$I_1^{\rm inel}(0) = -\frac{1}{4}\kappa_N^2, \quad I_2^{\rm inel}(0) = \frac{1}{4}(e_N + \kappa_N)\kappa_N$$
$$I_{TT}^{\rm inel}(0) = -\frac{1}{4}\kappa_N^2, \quad I_{LT}^{\rm inel}(0) = \frac{1}{4}e_N\kappa_N$$

GDH-like Integrals



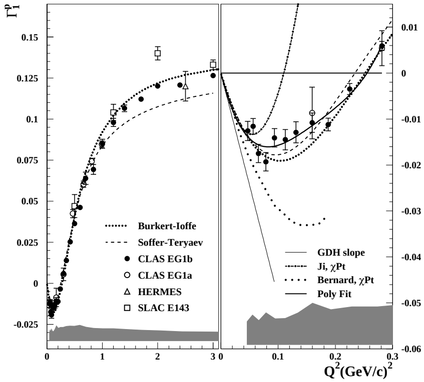
data: JLab CLAS and E94-010 (circles, open: $W < 2GeV$, solid: plus DIS)
SLAC (diamonds), HERMES (triangles)

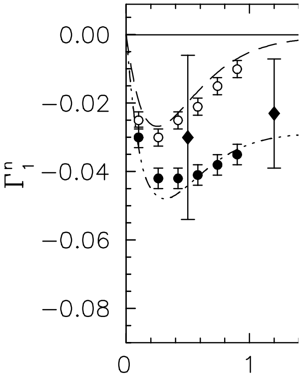
lines: 1-pion (– – –), 2-pion added (——), Burkert-Ioffe (–··–··–)

Kao 2003 (.....), Bernard 2003 (– · – · –)

First Moments of Spin Structure Function g_1

$\Gamma_1^p(Q^2) = \frac{Q^2}{2M^2} I_1^p(Q^2)$ $\Gamma_1^n(Q^2) = \frac{Q^2}{2M^2} I_1^n(Q^2)$



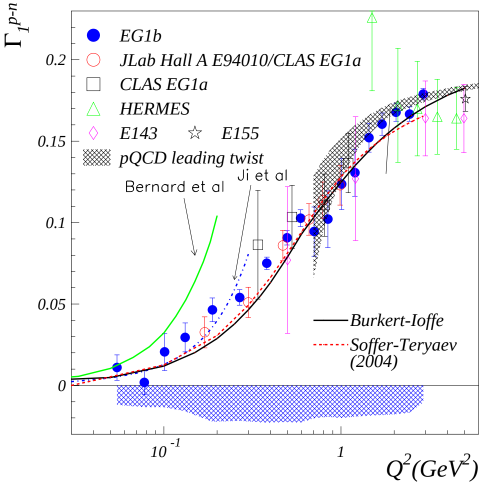


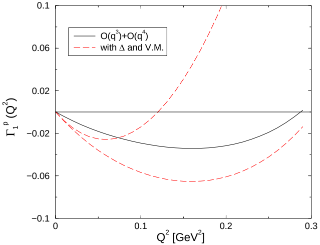
data: CLAS (circles), SLAC (diamonds)
HERMES (triangles)
lines: Burkert-Ioffe (.....), Soffer-Teryaev (- - -)
Bernard 2003 (. . .), Ji 2000 (– · – · –)

data: E94-010 (circles)
SLAC (diamonds)
lines: Burkert-Ioffe (–··–··–)
MAID one-pion (– – –)

Isovector Moment and ChPT

$\Gamma_1^p - \Gamma_1^n$ $\Gamma_1^p(Q^2)$





loop corrections $f(Q^2/m_\pi^2)$
vector mesons (and $\Delta(1232)$) effects are large and model-dependent
predictions at $Q^2 = 0.1\mathrm{GeV}^2$ differ by large factor

Q^6 and 2-loop ...

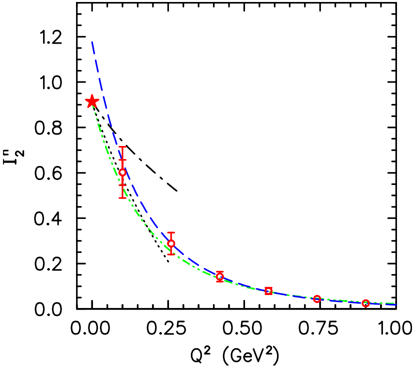
$$\Gamma_1^{p-n} = \frac{(\kappa_n^2 - \kappa_p^2)Q^2}{8M^2} + 0.62\frac{Q^4}{M^4} - 0.77\frac{Q^6}{M^6} + \ldots$$

Ji et al.: HBChPT $\mathcal{O}(p^4)$

Bernard et al.: Lorentz inv. BChPT $\mathcal{O}(p^4)$

The Burkhardt-Cottingham Sum Rule: $I_2^{\rm inel} = -I_2^{\rm el}$???

$I_2^{n,\rm inel}(Q^2)$



data: E94-010

$*$ BC sum rule at $Q^2 = 0$

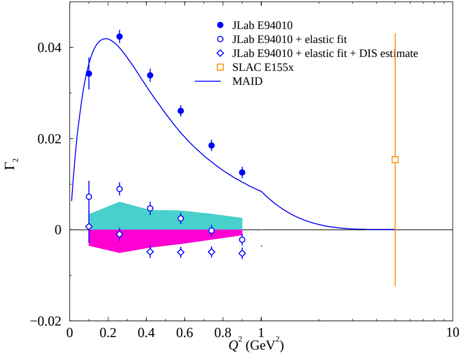
lines: BC sum rule (–·–·–)

MAID one-pion (– – –)

Bernard 2003 (· · ··)

Kao 2003 ($- \cdot - \cdot -$)

$\Gamma_2^n(Q^2)$



data solid circles: E94-010

(inelastic contribution $W < 2$GeV)

open circles: elastic contribution added

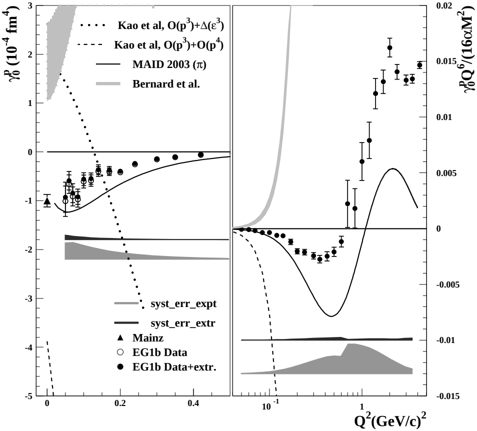
diamonds: DIS added

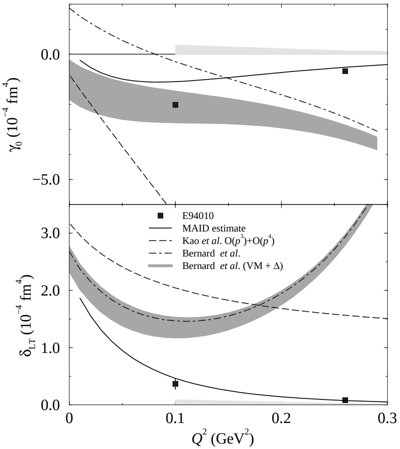
line: MAID one-pion ——

K. Slifer et al, arXiv: 0812.0031 $\Rightarrow \Gamma_2^p(1.33) = 0.0003 \pm 0.0007 \pm 0.0041$

Generalized Spin Polarizabilities

$\gamma_{TT}^{p}(Q^2)$ $\frac{Q^6}{16\alpha M^2}\gamma_{TT}^{p}(Q^2)$ $\gamma_{TT}^{n}(Q^2)$ **and** $\delta_{LT}^{n}(Q^2)$





data: EG1b/CLAS (circles), Mainz (triangle)

lines: MAID one-pion (——)

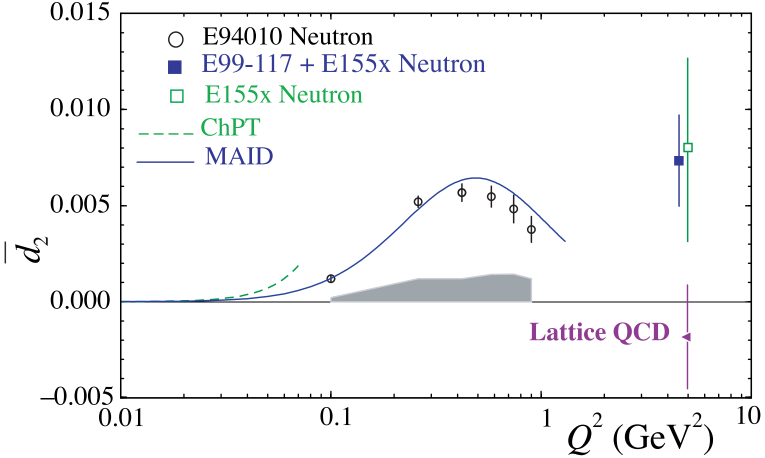
Kao (- - - - , · · · ·), Bernard (shaded)

data: E 94-010

lines: MAID one-pion (——)

Kao (– – –), Bernard (– · – · –)

Twist-3 d_2



surprising agreement with MAID, looked even nicer in yesterday's talk of P. Savignon!