Light-cone sum rules for baryonic form factors

Alexander Lenz — University of Regensburg

in collaboration with

V. Braun, R. Fries, N. Mahnke, A. Peters, G. Peters, A. Radyushkin, J. Rohrwild, E. Stein and M. Wittmann, QCDSF

Outline

Intro: The nucleon distribution amplitude (DA)

Form factors from Baryon DAs via LCSR

- **Compare: LCSR vs. QCD-SR vs. Perturbative approach**
- **Basic idea**
- **Example: Em form factors of the nucleon**
- **L.H.S. of the sum rule**
- **R.H.S. of the sum rule**
- **Combining L. & R.H.S. of the sum rule**

Current activities - including higher twist DAs:

- **Literature - Overview**
- **Determining the DA**
- **Nucleon form factors**
- **Decays of Baryons**

Outlook

The nucleon DA

- Definition: Distribution of quarks - virtuality up to μ - inside nucleon in longitudinal momentum fraction x_i

$$4\langle 0|\epsilon_{ijk} u^i_\alpha(a_1 z) u^j_\beta(a_2 z) d^k_\gamma(a_3 z)|N(P)\rangle = \int \mathcal{D}x e^{-iPz(\sum_i x_i a_i)} \sum \left(\Gamma_3^{\alpha\beta}\Gamma_4^\gamma\right) F(x_i)$$

with

$$\int \mathcal{D}x = \int_0^1 dx_1 \int_0^1 dx_2 \int_0^1 dx_3 \delta(1 - x_1 - x_2 - x_3)$$

  - universal non-perturbative input
  - DA$(\mu) = \int^{|k_\perp|<\mu} dk_\perp \Psi_{BS}$
- Expansion up to twist-6
  - e.g. twist 3: $\Phi_3 = V_1 - A_1 = 120 x_1 x_2 x_3 f_N + ...$
  - higher Fock states $\equiv$ higher twist
- Each twist expanded in conformal spin
  - Twist-3 up to NNL conformal spin
  - Twist 4,5,6 up to NL conformal spin

Sum rule approaches for the form factors

- $0.5\,\text{GeV}^2 < Q^2 < 2\,\text{GeV}^2$: QCD sum rules $\rightarrow$ vacuum condensates

$$T_\mu(P,q) = \int d^4x e^{-iPx} \int d^4y e^{-iP'y} \langle 0|T\{\eta(0) j_\mu(x) \bar{\eta}(y)\}|0\rangle$$

- $Q^2 = 0$
  - $B_1 \rightarrow B_1$: QCD sum rules $\rightarrow$ vacuum condensates in B.F.
  - $B_1 \rightarrow B_2$: LCSR $\rightarrow$ photon DA

$$T_\mu(P,q) = \int d^4x e^{-iPx} \langle 0|T\{\eta(0) \bar{\eta}(x)\}|0\rangle_F$$

- $1\,\text{GeV}^2 < Q^2 < 10\,\text{GeV}^2$: LCSR $\rightarrow$ baryon DA

$$T_\mu(P,q) = \int d^4x e^{-iPx} \langle 0|T\{\eta(0) j_\mu(x)\}|N(P)\rangle$$

- very, very large Q^2: Perturbation theory $\rightarrow$ baryon DA

$$F_1 \propto \int \Phi_3 T_H \Phi_3$$

Form factors from Baryon DAs via LCSR

To describe the transition of a baryon B to a baryon N via the current j_μ

$$B(P') \xrightarrow{j_\mu} N(P)\,, \qquad\qquad P' = P - q$$

Start with a correlation function

$$T_\mu(P,q) = \int d^4x e^{-ipx} \langle 0|T\{\eta(0) j_\mu(x)\}|N(P)\rangle$$

- Interpolating field η: “creating B from the vacuum”
  e.g. $\eta_{\rm CZ}(x) \;\; = \varepsilon^{ijk} \left[u^i(x)(C\not{z})\, u^j(x)\right] \;\; (\gamma_5 \not{z}) \;\; d^k_\delta(x)$ $\Rightarrow$ B = Proton
  or $\;\; \eta_{\rm Ioffe}(x) = \varepsilon^{ijk} \left[u^i(x)(C\gamma_\nu)\, u^j(x)\right] \, (\gamma_5 \gamma^\nu)\, d^k_\delta(x)$ $\Rightarrow$ B = Proton
- Current j_μ
  e.g. $j^{\rm em}_\mu(x) = e_u \bar{u}(x)\gamma_\mu u(x) + e_d \bar{d}(x)\gamma_\mu d(x)$ $\Rightarrow$ em form factors
  e.g. $j^{\rm weak}_\mu(x) = \bar{u}(x)\gamma_\mu(1-\gamma_5)d(x)$ $\Rightarrow$ weak decay

Now: Express T_μ in two different ways

Example: EM form factors of the Nucleon

- **Rosenbluth-formula** (1955) for elastic e^--N scattering (1 photon exchange)

$$\left(\frac{d\sigma}{d\Omega}\right) = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \left[\frac{G_E^2(Q^2)+\tau G_M^2(Q^2)}{1+\tau} + 2\tau G_M^2(Q^2)\tan^2\frac{\theta_e}{2}\right]$$

$$Q^2 = -q^2,\ \tau = \frac{Q^2}{4M^2c^2},\ \theta_e = \text{ scattering} - \text{angle of } e^-$$

- Electric $G_E(Q^2)$ and magnetic $G_M(Q^2)$ **Sachs form factors**
- Interpretation in **Breit frame**:
  - $G_E(Q^2)$ Fourier transform of electric charge distribution
  - $G_M(Q^2)$ Fourier transform of magnetization density
- Relation of Dirac and Pauli form factors to Sachs form factors

$$G_M(Q^2) = F_1(Q^2) + F_2(Q^2), \qquad G_E(Q^2) = F_1(Q^2) - \frac{Q^2}{4M^2}F_2(Q^2).$$

- $G_M^p(0) = \mu_p = 2.79,\ G_M^n(0) = \mu_n = -1.91.$
- Def.: $\langle P', s|j_\mu^{\rm em}|P\rangle = \bar{N}(P')\left[\gamma_\mu F_1 - i\frac{\sigma_{\mu\nu}q^\nu}{2m_p}F_2\right]N(P)$

L.H.S. of the sum rule

Inserting a full set of one-particle states in the correlation function we obtain

$$T_\mu(P,q) = \frac{1}{m_p^2 - (P')^2} \sum_s \langle 0|\eta_p|P',s\rangle\langle P',s|j_\mu^{\rm em}|P\rangle + \ldots$$

where the dots represent contributions of higher resonances.

The arising matrix elements read

- $\langle 0|\eta_{\rm CZ}|P\rangle = f_N Pz\!\!\!/ N(P)$ or $\langle 0|\eta_{\rm Ioffe}|P\rangle = \lambda_1 m_p N(P)$
  with the non-perturbative constants f_N, λ_1
- $\langle P',s|j_\mu^{\rm em}|P\rangle = \bar N(P') \left[\gamma_\mu F_1 - i\frac{\sigma_{\mu\nu}q^\nu}{2m_p} F_2\right] N(P)$

$\Rightarrow T_\mu = T_\mu(f_N$ or $\lambda_1, F_1, F_2)$

Which η to use?

Determine $f_N, \lambda_1, ...$

R.H.S. of the sum rule

Do all possible Wick-contractions in T_μ:

$$T_\mu(P,q) \propto \int d^4x e^{-ipx} \ldots\ \Gamma_1^{\alpha\beta}\Gamma_2^{\delta\gamma} 4\langle 0|\epsilon_{ijk} u_\alpha^i u_\beta^j d_\gamma^k|N(P)\rangle$$

and insert the Baryon DA

$$4\langle 0|\epsilon_{ijk} u_\alpha^i(a_1 z) u_\beta^j(a_2 z) d_\gamma^k(a_3 z)|N(P)\rangle = \sum \Gamma_3^{\alpha\beta}\Gamma_4^{\gamma} F(Pz)$$

with Dirac structures Γ_i and 24 distribution amplitudes $F(Pz)$.

$$F(Pz) = \int_0^1 dx_1 \int_0^1 dx_2 \int_0^1 dx_3 \delta(1-x_1-x_2-x_3) e^{-iPz(x_1a_1+x_2a_2+x_3a_3)} F(x_i)$$

- x_i: longitudinal momentum fraction carried by the quarks
- The DAs $F(x_i)$ are the universal non-perturbative input!
- DAs can be reduced to 8 non-perturbative parameters (NL CS)

$\Rightarrow T_\mu = T_\mu(f_N, \lambda_1, \lambda_2, V_1^d, A_1^u, f_1^d, f_1^u, f_2^d) \Rightarrow$ Determine $f_N, \lambda_1, \ldots$

Combining L.H.S. and R.H.S.

In order to combine the two expressions for T_μ we perform first a projection

$$\Rightarrow \Lambda_+ T_z = pz\,(m_p \mathcal{A}_1^{\rm em} + \not{q}_\perp \mathcal{B}_1^{\rm em})\,N^+(P)$$

with $z^2 = 0 = qz; p_\mu = P_\mu - z_\mu m_p^2/(2Pz); \Lambda^+ = \not{p}\not{z}/(2pz); \Lambda^+ N = N^+$

$$\mathcal{B}_1^{\rm em} = \frac{\lambda_1 F_2^{\rm em}}{m_p^2 - P'^2} = -2e_d \int_0^1 \frac{dx_3}{(q - x_3 P)^2} \int_0^{1-x_3} dx_1 120 x_1 x_2 x_3 \delta(1 - x_1 - x_2 - x_3) f_N + \ldots$$

To supress the contributions of higher resonances we perform a Borel trafo

$$F_2^{\rm em} = 2e_d \frac{1}{\lambda_1} \int_{x_0}^1 \frac{dx}{x} \int_0^{1-x} dx_1 120 x_1 x_2 x_3 \delta(1 - x_1 - x_2 - x_3) f_N e^{-\frac{(1-x)Q^2 - x^2 m_N^2}{x M_B^2}} + \ldots$$

Current activities - including higher twist DAs I

- **The nucleon DA**
  - up to twist 6, Braun, Fries, Mahnke, Stein, 2000
  - x^2-corrections to V_1, Braun, A.L., Mahnke, Stein, 2001
  - reestimate of non-perturbative parameters, Braun, A.L., Wittmann, 2006
  - x^2-correct. to A_1, T_1, Huang, Wang, 2004, Braun, A.L., Wittmann, 2006; A.L., 2007
  - Lattice determination, QCDSF 2008; Göckeler, Kaltenbrunner, A.L., Schäfer, Warkentin, to appear

- **LCSR for form factors of the nucleon**
  - em ff, η_{CZ}, Braun, A.L., Mahnke, Stein, 2001
  - em ff, isospin conserving $\eta_{Im.}$, A.L., Wittmann, Stein, 2003
  - em, weak ff , $\eta_{CZ}, \eta_{Im.}, \eta_{Ioffe}$;, Braun, A.L., Wittmann, 2006
  - scalar ff, η_{CZ}, Z. Wang, Wan, Yang, 2006
  - axial, induced pseudoscalar ff, η_{CZ}, Z. Wang, Wan, Yang, 2006
  - scalar ff, general η, Aliev, Savci, 2006
  - isovector, isoscalar, axialvector ff, general η, Aliev, Savci, 2007
  - em ff, general η, Aliev, Azizi, Ozpineci, Savci, 2008

Current activities - including higher twist DAs II

- **LCSR for transition form factors**
  - $\Lambda_b \to p\, l\bar{\nu}$, Huang, Wang, 2004
  - N $\to \Delta$, Braun, A.L., Peters, Radyushkin, 2005
  - $n \to p$, Braun, A.L., Wittmann, 2006
  - $N \to N + \pi$, Braun, Ivanov, A.L., Peters, 2006; Braun, Ivanov, Peters, 2007
  - $\Lambda_c \to \Lambda\, l\bar{\nu}$, Huang, Wang, 2006
  - $\Sigma \to$ N, η_{Ioffe}, Z. Wang, 2006
  - N $\to \Delta$ axial part, Aliev, Azizi, Ozpineci, 2007
  - $\Lambda_b \to \Lambda + \gamma$, $\Lambda_b \to \Lambda + l^+ l^-$, Wang, Li, Lu, 2008
- **Different DAs**
  - $N + \pi$, Braun, Ivanov, A.L., Peters, 2006
  - Axial Λ-DAs of leading conformal spin, Huang, Wang, 2006

Determining the Nucleon DA up to twist 6 I

$$4\langle 0|\,\varepsilon^{ijk}u_\alpha^i(a_1x)u_\beta^j(a_2x)d_\gamma^k(a_3x)\,|P\rangle =$$

$$\mathcal{S}_1 M C_{\alpha\beta}\left(\gamma_5 N\right)_\gamma + \mathcal{S}_2 M^2 C_{\alpha\beta}\left(\not{x}\gamma_5 N\right)_\gamma\, \mathcal{P}_1 M\left(\gamma_5 C\right)_{\alpha\beta} N_\gamma + \mathcal{P}_2 M^2\left(\gamma_5 C\right)_{\alpha\beta}\left(\not{x} N\right)_\gamma$$

$$+\left(\mathcal{V}_1 + \frac{x^2 m_N^2}{4}\mathcal{V}_1^M\right)\left(\not{P}C\right)_{\alpha\beta}\left(\gamma_5 N\right)_\gamma + \mathcal{V}_2 M\left(\not{P}C\right)_{\alpha\beta}\left(\not{x}\gamma_5 N\right)_\gamma + \mathcal{V}_3 M\left(\gamma_\mu C\right)_{\alpha\beta}\left(\gamma^\mu\gamma_5 N\right)_\gamma$$

$$+\mathcal{V}_4 M^2\left(\not{x}C\right)_{\alpha\beta}\left(\gamma_5 N\right)_\gamma + \mathcal{V}_5 M^2\left(\gamma_\mu C\right)_{\alpha\beta}\left(i\sigma^{\mu\nu}x_\nu\gamma_5 N\right)_\gamma + \mathcal{V}_6 M^3\left(\not{x}C\right)_{\alpha\beta}\left(\not{x}\gamma_5 N\right)_\gamma$$

$$+\left(\mathcal{A}_1 + \frac{x^2 m_N^2}{4}\mathcal{A}_1^M\right)\left(\not{P}\gamma_5 C\right)_{\alpha\beta} N_\gamma + \mathcal{A}_2 M\left(\not{P}\gamma_5 C\right)_{\alpha\beta}\left(\not{x}N\right)_\gamma + \mathcal{A}_3 M\left(\gamma_\mu\gamma_5 C\right)_{\alpha\beta}\left(\gamma^\mu N\right)_\gamma$$

$$+\mathcal{A}_4 M^2\left(\not{x}\gamma_5 C\right)_{\alpha\beta} N_\gamma + \mathcal{A}_5 M^2\left(\gamma_\mu\gamma_5 C\right)_{\alpha\beta}\left(i\sigma^{\mu\nu}x_\nu N\right)_\gamma + \mathcal{A}_6 M^3\left(\not{x}\gamma_5 C\right)_{\alpha\beta}\left(\not{x}N\right)_\gamma$$

$$+\left(\mathcal{T}_1 + \frac{x^2 m_N^2}{4}\mathcal{T}_1^M\right)\left(i\sigma_{\mu P}C\right)_{\alpha\beta}\left(\gamma^\mu\gamma_5 N\right)_\gamma + \mathcal{T}_2 M\left(i\sigma_{xP}C\right)_{\alpha\beta}\left(\gamma_5 N\right)_\gamma + \mathcal{T}_3 M\left(\sigma_{\mu\nu}C\right)_{\alpha\beta}\left(\sigma^{\mu\nu}\gamma_5 N\right)_\gamma$$

$$+\mathcal{T}_4 M\left(P^\nu\sigma_{\mu\nu}C\right)_{\alpha\beta}\left(\sigma^{\mu\varrho}x_\varrho\gamma_5 N\right)_\gamma + \mathcal{T}_5 M^2\left(x^\nu i\sigma_{\mu\nu}C\right)_{\alpha\beta}\left(\gamma^\mu\gamma_5 N\right)_\gamma + \mathcal{T}_6 M^2\left(i\sigma_{xP}C\right)_{\alpha\beta}\left(\not{x}\gamma_5 N\right)_\gamma$$

$$+\mathcal{T}_7 M^2\left(\sigma_{\mu\nu}C\right)_{\alpha\beta}\left(\sigma^{\mu\nu}\,\not{x}\gamma_5 N\right)_\gamma + \mathcal{T}_8 M^3\left(x^\nu\sigma_{\mu\nu}C\right)_{\alpha\beta}\left(\sigma^{\mu\varrho}x_\varrho\gamma_5 N\right)_\gamma$$

BFMS 2000

- The 24 functions $\mathcal{F}^{(i)} = \mathcal{S}_i, \mathcal{P}_i, \mathcal{A}_i, \mathcal{V}_i, \mathcal{T}_i$ can be related to **8 LCDAs** of twist-3 to twist-6.
- In leading conformal spin we have 3 parameters: $\lambda_1, \lambda_2, f_N$
- in NL conformal spin we have 5 parameters: $V_1^d, A_1^u, f_1^d, f_1^u, f_2^d$
- $\mathcal{V}_1^M$: BLMS 2001
- $\mathcal{A}_1^M, \mathcal{T}_1^M$: Huang, Wang 2004; BLW 2006.

Determining the Nucleon DA up to twist 6 II

Definition of the non-perturbative parameters

$$\langle 0|\varepsilon^{ijk}\left[u^i(0)(C\not z)\,u^j(0)\right]\quad(\gamma_5\not z)\;\;d^k_\delta(0)|P\rangle = f_N pz \not z N(P)$$

$$\langle 0|\varepsilon^{ijk}\left[u^i(0)(C\gamma_\mu)\,u^j(0)\right]\quad(\gamma_5\gamma^\mu)\;\;d^k_\delta(0)|P\rangle = \lambda_1 m_N N(P)$$

$$\langle 0|\varepsilon^{ijk}\left[u^i(0)(C\sigma_{\mu\nu})\,u^j(0)\right]\quad(\gamma_5\sigma^{\mu\nu})\;\;d^k_\delta(0)|P\rangle = \lambda_2 m_N N(P)$$

$$\langle 0|\varepsilon^{ijk}\left[u^i(0)(C\not z)\,u^j(0)\right]\quad(\gamma_5\not z)\;\;(iz\vec{D}d^k_\delta)(0)|P\rangle = f_N V_1^d (pz)^2\not z N(P)$$

$$\langle 0|\varepsilon^{ijk}\left[u^i(0)(C\not z)\,\gamma_5 iz\overleftrightarrow{D}\,u^j(0)\right]\quad\not z\;\;d^k_\delta)(0)|P\rangle = -f_N A_1^u (pz)^2\not z N(P)$$

$$\langle 0|\,\varepsilon^{ijk}\left[u^i(0)C\gamma_\mu u^j(0)\right]\not z\gamma_5\gamma^\mu(iz\overrightarrow{D}d^k)(0)\,|P\rangle = \lambda_1 f_1^d (pz) M\not z N(P)\,,$$

$$\langle 0|\,\varepsilon^{ijk}\left[u^i(0)C\sigma_{\mu\nu}u^j(0)\right]\not z\gamma_5\sigma^{\mu\nu}(iz\overrightarrow{D}d^k)(0)\,|P\rangle = \lambda_2 f_2^d (pz) M\not z N(P)\,,$$

$$\langle 0|\,\varepsilon^{ijk}\left[u^i(0)C\gamma_\mu\gamma_5 iz\overleftrightarrow{D}\,u^j(0)\right]\not z\gamma^\mu d^k(0)\,|P\rangle = \lambda_1 f_1^u (pz) M\not z N(P)\,,$$

Determining the Nucleon DA up to twist 6 III

- **Leading twist:** leading conformal spin f_N, next-to leading c.s. V_1^d, A_1^u
  - QCD SR: Chernyak, Zhitnitsky 1984; King, Sachrajda 1987; Gari,Stefanis 1987; Chernyak, Ogloblin, Zhitnitsky 1988,1989;

    $f_N = (5.0 \pm 0.5) \cdot 10^{-3}\text{GeV}^2 \qquad A_1^u = 0.38 \pm 0.15 \qquad V_1^d = 0.23 \pm 0.03$
  - Lattice: Martinelli, Sachrajda 1989; QCDSF 2008

    $f_N = (3.2 \pm 0.1) \cdot 10^{-3}\text{GeV}^2 \qquad A_1^u = 0.10 \pm 0.01 \qquad V_1^d = 0.30 \pm 0.01$
  - Asymptotic: $A_1^u = 0$ $V_1^d = 1/3$
  - LCSR: BLW 2006 $A_1^u = 0.13$ $V_1^d = 0.30$
  - Phenomenology: Bolz, Kroll 1996 $A_1^u = 0.071$ $V_1^d = 0.31$

Determining the Nucleon DA up to twist 6 IV

Moments of the leading twist DA: $\Phi_3 = V_1 - A_1$

$$\Phi^{lmn} := \int_0^1 dx_1 \int_0^1 dx_2 \int_0^1 dx_3 \delta(1 - x_1 - x_2 - x_3) x_1^l x_2^m x_3^n \Phi_3(x_1, x_2, x_3)$$

	Asy	$QCD - SR$	COZ	KS	BK	BLW	$Latt.$
Φ^{100}	$\frac{1}{3} \approx 0.333$	$0.560(60)$	0.579	0.55	$\frac{8}{21} \approx 0.38$	0.415	$0.3999(13)$
Φ^{010}	$\frac{1}{3} \approx 0.333$	$0.192(12)$	0.192	0.21	$\frac{13}{42} \approx 0.31$	0.285	$0.2986(22)$
Φ^{001}	$\frac{1}{3} \approx 0.333$	$0.229(29)$	0.229	0.24	$\frac{13}{42} \approx 0.31$	0.300	$0.3015(9)$
Φ^{200}	$\frac{1}{7} \approx 0.143$	$0.350(70)$	0.369	0.35	$\frac{5}{28} \approx 0.18^\star$	0.225	$0.1832(26)$
Φ^{020}	$\frac{1}{7} \approx 0.143$	$0.084(19)$	0.068	0.09	$\frac{1}{8} \approx 0.13^\star$	0.122	$0.1497(67)$
Φ^{002}	$\frac{1}{7} \approx 0.143$	$0.109(19)$	0.089	0.12	$\frac{1}{8} \approx 0.13^\star$	0.132	$0.1392(42)$
Φ^{011}	$\frac{2}{21} \approx 0.095$	$-0.030(30)$	0.027	0.02	$\frac{1}{12} \approx 0.08^\star$	0.071	$0.0473(55)$
Φ^{101}	$\frac{2}{21} \approx 0.095$	$0.102(12)$	0.113	0.10	$\frac{17}{168} \approx 0.10^\star$	0.097	$0.1151(21)$
Φ^{110}	$\frac{2}{21} \approx 0.095$	$0.090(10)$	0.097	0.10	$\frac{8}{21} \approx 0.10^\star$	0.093	$0.1016(34)$

Göckeler, Kaltenbrunner, A.L., Schäfer, Warkentin, to appear

Determining the Nucleon DA up to twist 6 V

- **Higher twist**
  - leading conformal spin: λ_1, λ_2
    - QCD SR: BFMS 2000, BLW 2006

$$\lambda_1 = -(2.7 \pm 0.9) \cdot 10^{-2}\text{GeV}^2 \qquad \lambda_2 = (5.4 \pm 1.9) \cdot 10^{-2}\text{GeV}^2$$

    - Lattice: QCDSF 2008

$$\lambda_1 = -(2.0 \pm 0.1) \cdot 10^{-2}\text{GeV}^2 \qquad \lambda_2 = (3.9 \pm 0.1) \cdot 10^{-2}\text{GeV}^2$$

  - next-to-leading conformal spin: f_1^d, f_1^u, f_2^d

Method	f_1^d	f_1^u	f_2^d	authors
QCD SR	0.40 ± 0.05	0.07 ± 0.05	0.22 ± 0.05	BFMS 2000, BLW 2006
LCSR	0.33	0.09	0.25	BLW 2006
asymptotic	0.30	0.10	$4/15$	

LCSR for the nucleon form factors

- EM - form factors using η_{CZ}: BLMS 2001
  - Higher twist is important
- EM - form factors using isospin conserving η_{IM}: LWS 2004
  - η_{CZ} leads to unphysical isospin violating effects
- EM and weak form factors, compare different ηs: BLW 2006
  - surprisingly good description of data

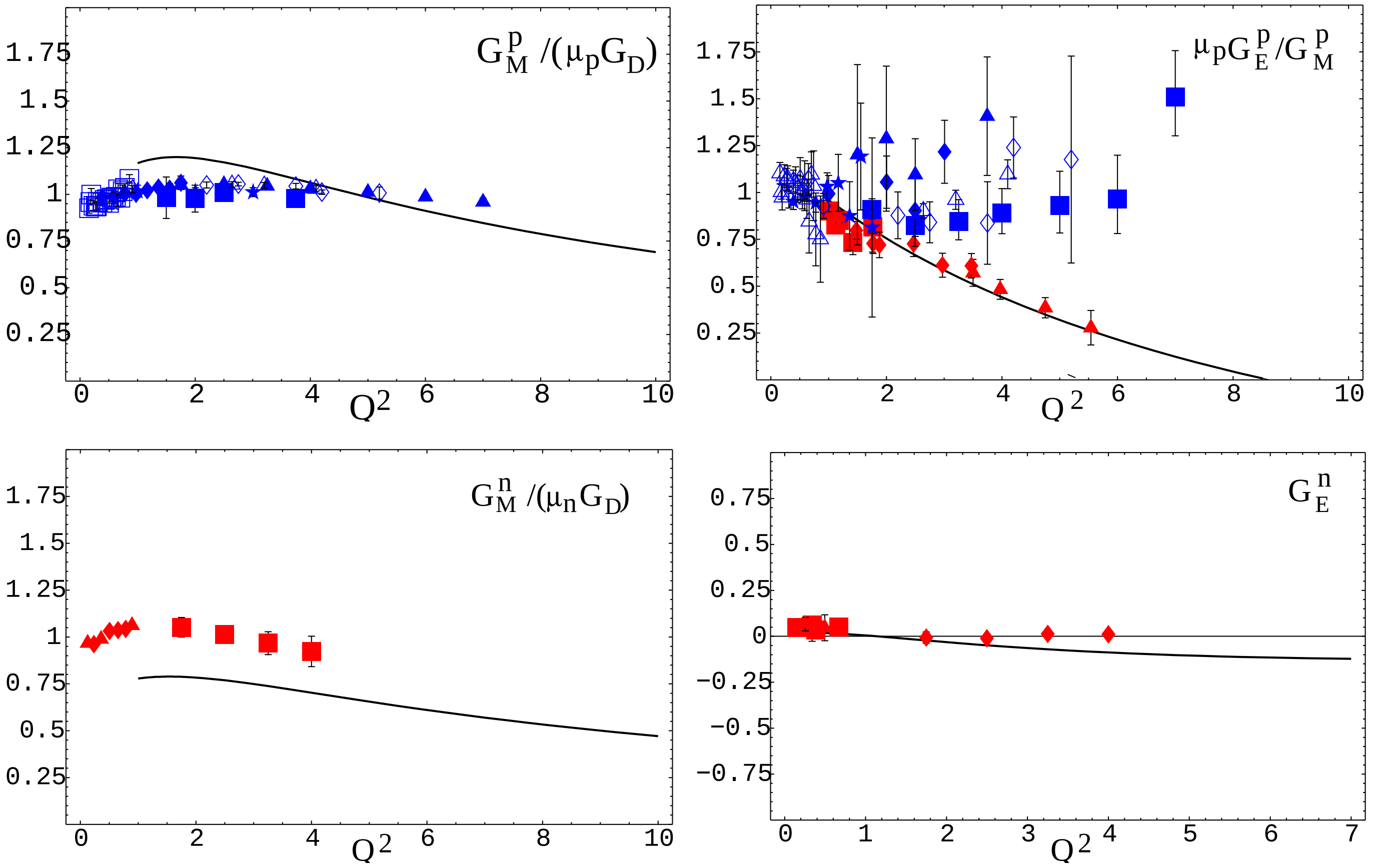
$\Rightarrow$ η_{Ioffe} seems to be the best choice

- EM form factor of the nucleon - general η: Aliev, Azizi, Ozpineci, Savci 2008
  - no x^2 corrections included
  - different Dirac structures used

* $\Rightarrow$ use η_{Ioffe} to compare experiment and LCSR
* FF depend on 5 Parameters $\lambda_1/f_N, A_1^u, V_1^d, f_1^d, f_1^u$

Nucleon electromagnetic form factors

$$\langle N(P')|j_\mu^{\rm em}(0)|N(P)\rangle = \bar{N}(P')\left[\gamma_\mu F_1(Q^2) - i\frac{\sigma_{\mu\nu}q^\nu}{2m_N}F_2(Q^2)\right]N(P)$$



proton

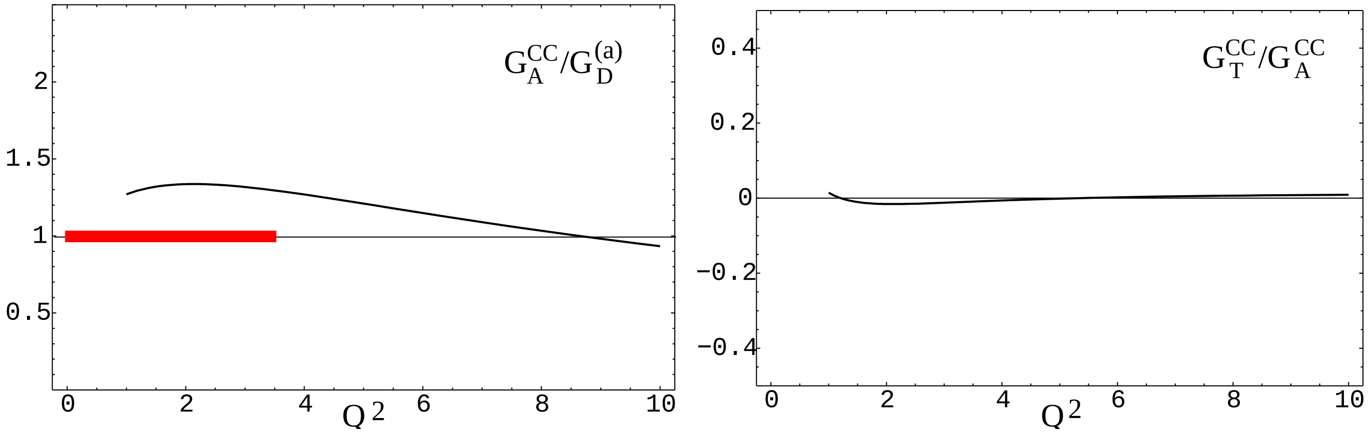
neutron

- Leading order LCSR, BLW distribution amplitudes

Braun, Lenz, Wittmann; PRD73 (2006) 094019

Nucleon axial vector form factors

$$\langle N(P')|A_\mu(0)|N(P)\rangle = \bar{N}(P')\left[\gamma_\mu G_A(Q^2) - \frac{q_\mu}{2m_N}G_P(Q^2) - i\frac{\sigma_{\mu\nu}q^\nu}{2m_N}G_T(Q^2)\right]\gamma_5 N(P)$$



charged current

- **Leading order LCSR, BLW distribution amplitudes**

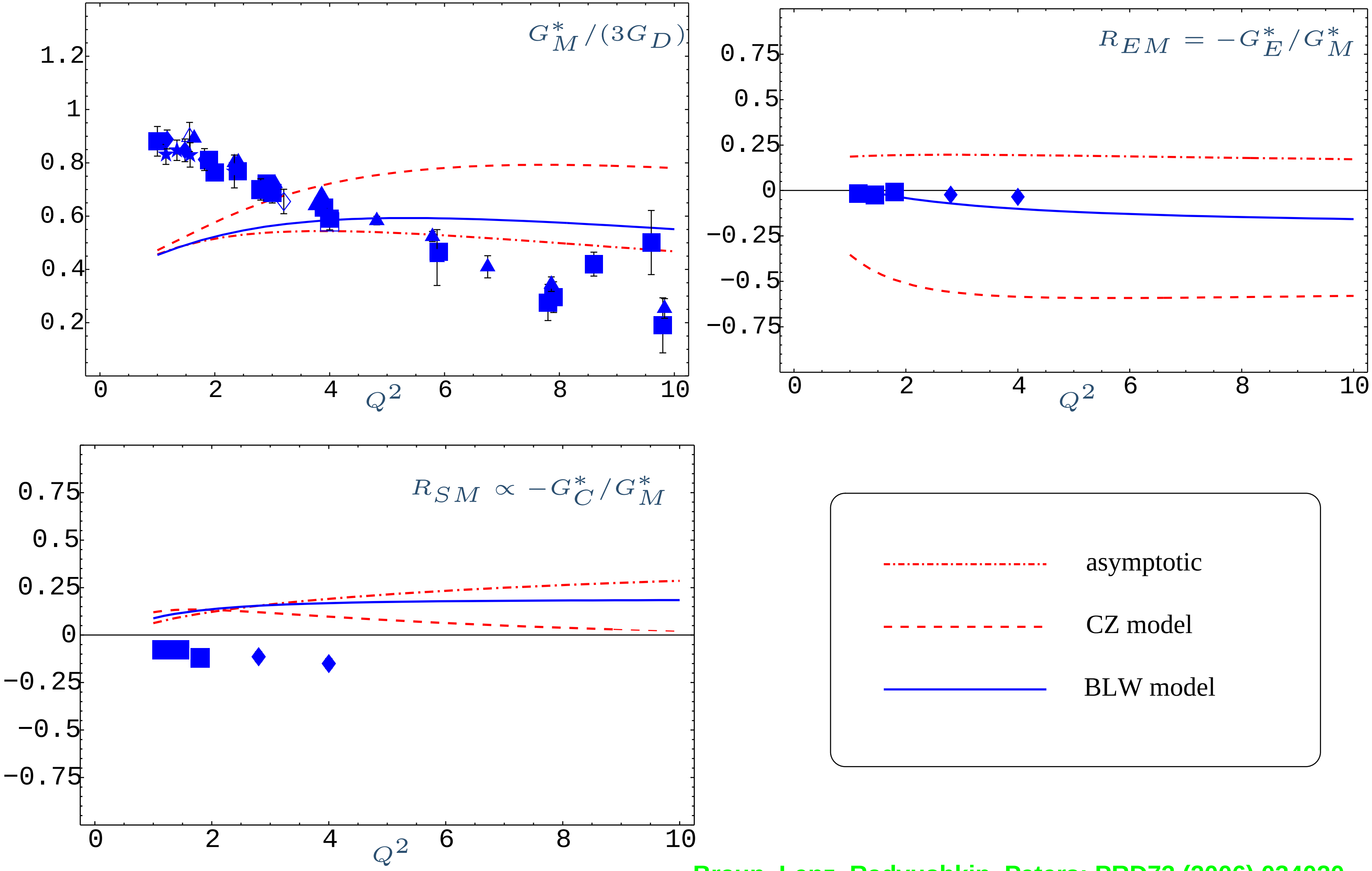
Braun, Lenz, Wittmann; PRD73 (2006) 094019

LCSR for transitions

- Huang, Wang, 2004: $\Lambda_b \to pl\nu$
  - Interpolating field: $\eta_{\Lambda_b} = \epsilon_{ijk} u^i C \not{z} d^j \cdot \gamma_5 \not{z} b^k$ vs. $\eta_{\Lambda_b} = \epsilon_{ijk} u^i C \not{z} d^j \cdot \gamma_5 \not{z} h_v^k$
  - Determine f_Λ from QCD-SR
  - HQET $\approx$ 1/10 QCD!
- BLPR 2005: N $\to \Delta$
  - Disentangle N $\to N^*$ (spin 1/2)
  - Interpolating field: $\eta_\Delta = \epsilon_{ijk} \left(2u^i C \gamma_\mu d^j \cdot \not{z} u^k + u^i C \gamma_\mu u^j \cdot \not{z} d^k \right)$
- BLW 2006: $n \to p$
- Huang, Wang, 2006: $\Lambda_c \to \Lambda l\nu$
  - Determine Λ-DA up to twist-6 and leading conformal spin
  - Interpolating field: $\eta_{\Lambda_c} = \epsilon_{ijk} u^i C \gamma_5 \not{z} d^j \cdot \not{z} c^k$
  - only tw-3 agrees with experiment
- Wang, 2006: $\Sigma \to$ N
  - Interpolating field: $\eta_\Sigma = \epsilon_{ijk} d^i C \gamma_\mu d^j \cdot \gamma_5 \gamma^\mu s^k$
  - Wang compared results for $Q^2 = 0$ with the data!

$N\Delta\gamma$ transition form factors

- **magnetic, electric and quadrupole form factors exist:**



Braun, Lenz, Radyushkin, Peters; PRD73 (2006) 034020

Outlook

- Nucleon DA
  - α_s corrections to LCSR for form factors of the nucleon,
    Compare LCSR to experiment and fit the non-perturbative parameters
    Passek-Kumericki, Peters, in progress
  - Lattice determination of the non-perturbative parameters
    Göckeler, Kaltenbrunner, A.L., Schäfer, Warkentin, to appear
- Decay of heavy baryons
  - LCSR for $\Lambda_b \to p\, l \bar{\nu}$
    A.L., Rohrwild, in progress
  - LCSR for $\Lambda_b \to \Lambda_c\, l + l$
    A.L., Rohrwild, in progress