0.5 set

Light Cone Sum Rules for Baryon Form Factors

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in collaboration with

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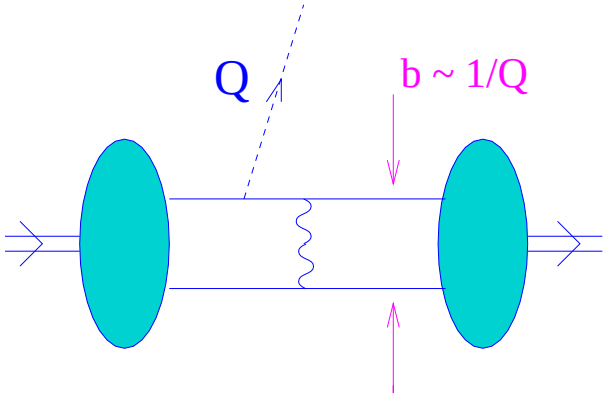
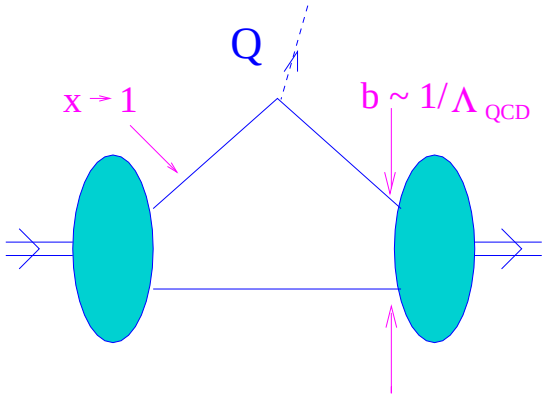
Soft vs. Hard





Hard rescattering:

Small b

Average $0 < x < 1$

Soft (Feynman):

Average b

Large $x \longrightarrow 1$

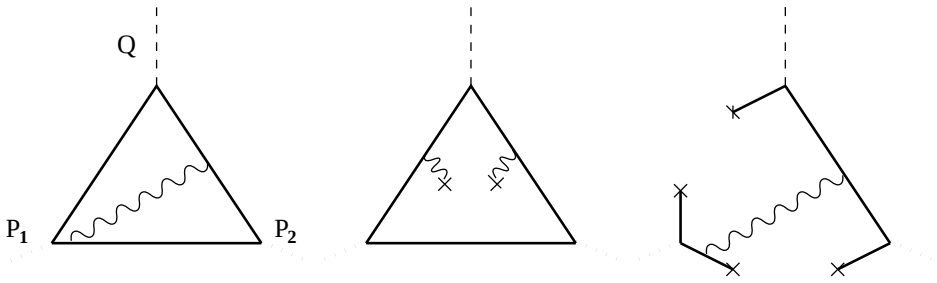
- **Dominance of hard rescattering is only true for simplest reactions**
- **Soft constributions enter at the same power in** $1/Q^2$ **as higher-twist hard contributions**
- **Separation of soft and hard contributions is nontrivial and not unique**

- **Estimates of soft terms require a nonperturbative approach that would be explicitly consistent with perturbative QCD factorization:** **LCSR**

Why Light-Cone Sum Rules?

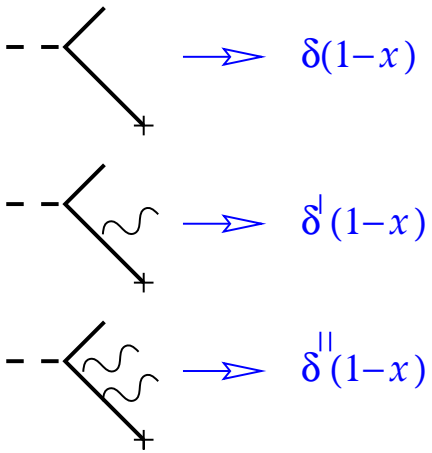
QCD Sum Rules

Nesterenko, Radyushkin '82; Ioffe, Smilga '82



$$= \left(\frac{1}{Q^4} + \frac{\alpha_s(Q)}{Q^2}\right) + \text{const} \cdot \left\langle \frac{\alpha_s}{\pi} G^2 \right\rangle + Q^2 \cdot \langle \bar{q} q \rangle^2 + \ldots$$

- Power counting in Q^2 is not consistent with OPE ?



Expansion goes in derivatives of the delta-function!

Sum of all orders: ⟶ ***const (1-x)***

$\Rightarrow$ Need resummation of the OPE to all orders

◇ new technique

Light-Cone Sum Rules

Balitsky, Braun, Kolesnichenko '86 – '89

Braun, Filyanov '89

Chernyak, Zhitnitsky '90

◇ large momentum transfer to light meson in final state

SVZ Sum Rules	Light-Cone Sum Rules
• Short-distance Expansion	• LC-Expansion
• Local operators	• Light-ray operators
• Parameter: Dimension	• Parameter: twist
	• Conformal expansion
• Vacuum Condensates	• Hadron Distribution amplitudes

◇ Mean-field-approach (SVZ) vs. the expansion in rapidly varying background fields (LCSR)

♡

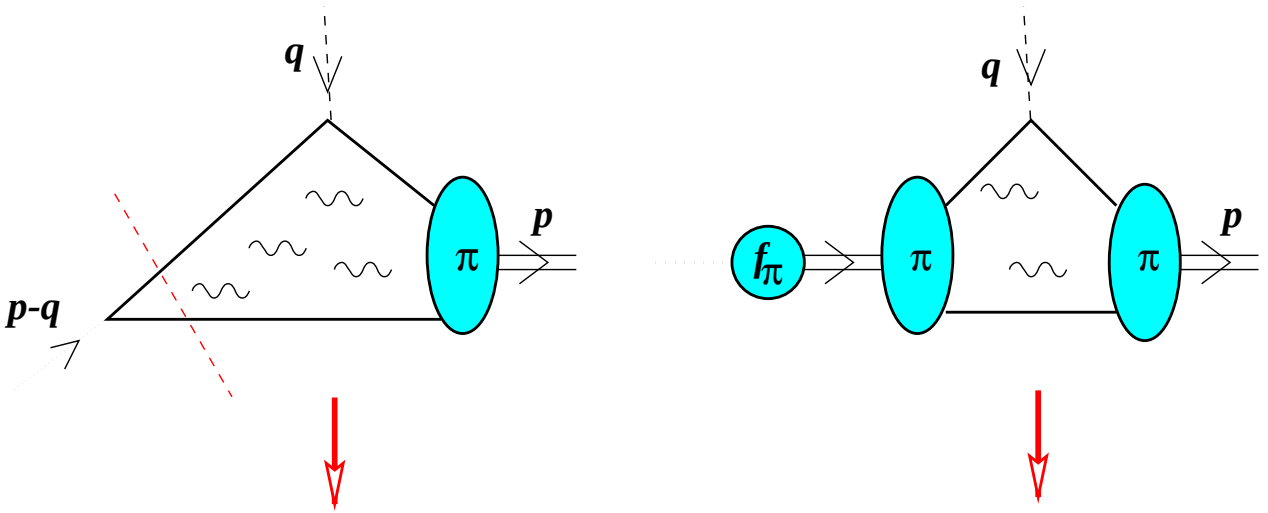
Premium: Consistent with the expansion in powers of large momentum (mass)

reviews: *V. Braun, hep-ph/9801222;* *Khodjamirian, Rückl, hep-ph/9801443*

detailed comparison of SVZ/light-cone sum rules: *P. Ball, V. Braun, PRD* **55** *(1997) 5561*

Example: Light-Cone Sum Rule for the Pion Form Factor

duality:



$$\int_0^{s_0} ds\, \frac{\mathrm{Disc}_{(p-q)^2} T(p,q)}{s-(p-q)^2} \overset{p^2\sim -1\mathrm{GeV}^2}{=} f_\pi \cdot \frac{1}{m_\pi^2-(p-q)^2} \cdot F_\pi(Q^2)$$

- $T(p,q)$ **is calculated in terms of pion wave functions of increasing twist**
- **No condensates!**
- **Dispersion relation in one variable**

Braun, Halperin, '94

Braun, Khodjamirian, Maul, '99

Study Case: asymptotic distribution amplitude

Expanding the sum rule at $Q^2 \gg s_0$

$$F_\pi(Q^2) = \frac{3\alpha_s C_F}{2\pi Q^2}\int_0^{s_0} ds\, e^{-s/M^2} + \frac{6}{Q^4}\int_0^{s_0} ds\, s\, e^{-s/M^2}\left\{1 - \frac{\alpha_s C_F}{4\pi}\left[10 - \frac{\pi^2}{3} + \ln^2\frac{Q^2}{s}\right]\right\} + \dots$$

The leading term: $\int_0^{s_0} ds\, e^{-s/M^2} \to 4\pi^2 f_\pi^2$

$$F_\pi^{\rm as}(Q^2) \longrightarrow \frac{8\pi\alpha_s f_\pi^2}{Q^2} = \frac{8\pi\alpha_s f_\pi^2}{9Q^2}\left|\int_0^1 du \frac{\varphi_\pi(u)}{\bar u}\right|^2$$

Soft-hard separation with explicit momentum-fraction cutoff:

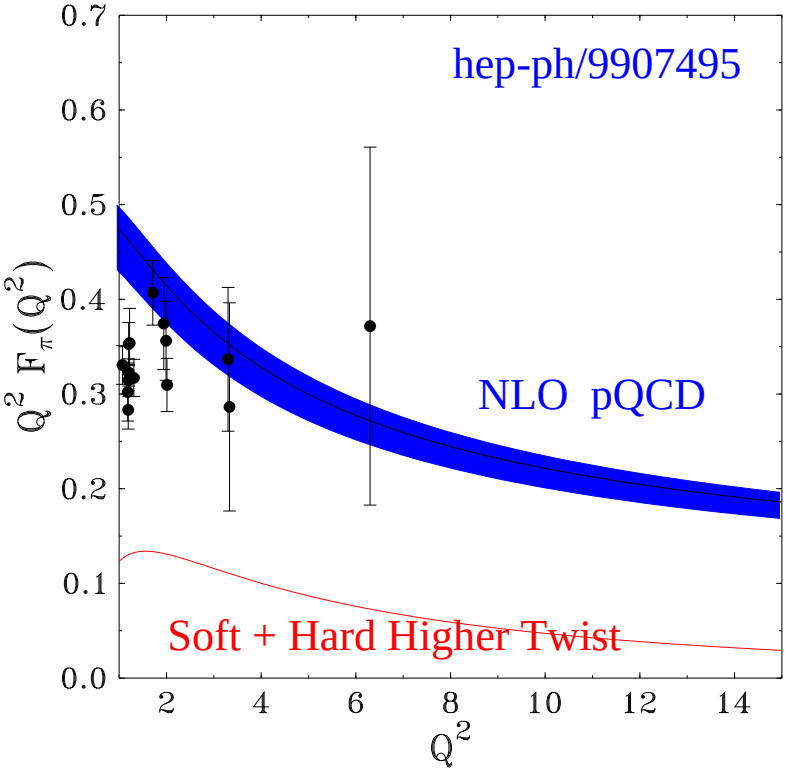
$$\int_0^1 du = \int_0^{u_0} du + \int_{u_0}^1 du; \qquad u_0 = 1 - s_0/Q^2$$

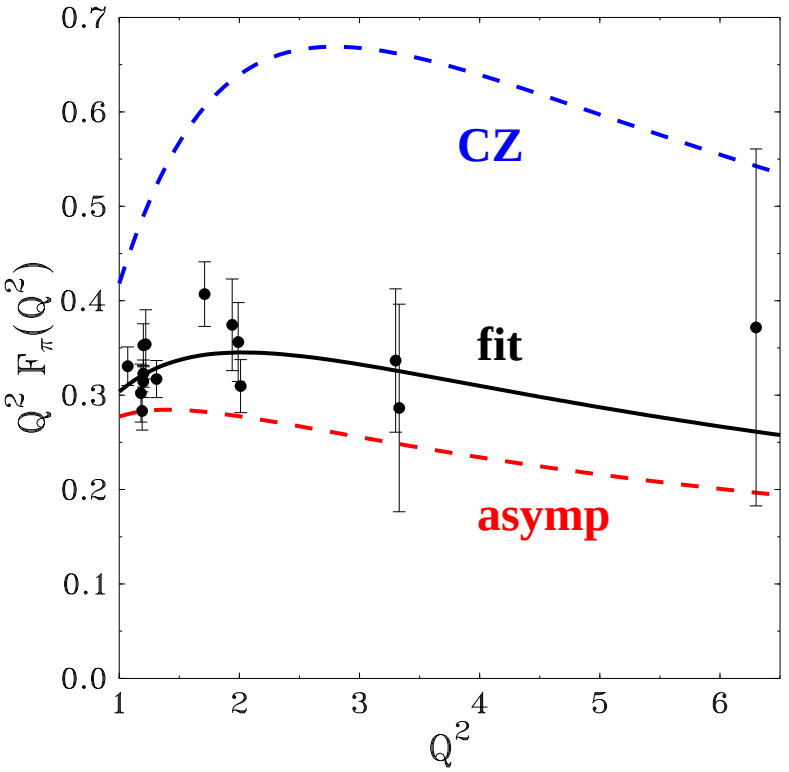
$$F_\pi^{\rm hard}(Q^2) = \frac{3\alpha_s C_F}{2\pi Q^2} s_0\left\{1 - \frac{s_0}{Q^2}\left[\frac{13}{2} - \frac{\pi^2}{6} + \ln\frac{Q^2}{s_0}\ln\frac{\mu^2}{s_0} + \ln\frac{\mu^2}{s_0} + 2\ln\frac{Q^2}{s_0}\right]\right\}$$

$$F_\pi^{\rm soft}(Q^2) = \frac{3s_0^2}{Q^4} + \frac{3\alpha_s C_F}{4\pi Q^4} s_0^2\left\{\frac{5}{2} + \ln^2\frac{\mu^2}{s_0} - \ln^2\frac{Q^2}{\mu^2} + 2\ln\frac{\mu^2}{s_0} + 3\ln\frac{Q^2}{s_0}\right\}$$

Lessons to be learnt

♡ **LCSR are fully consistent with pQCD:**





- **Observe a complicated interplay of soft and hard contributions;**

  perturbation theory might be rescued by the cancellation between soft and hard higher-twist corrections

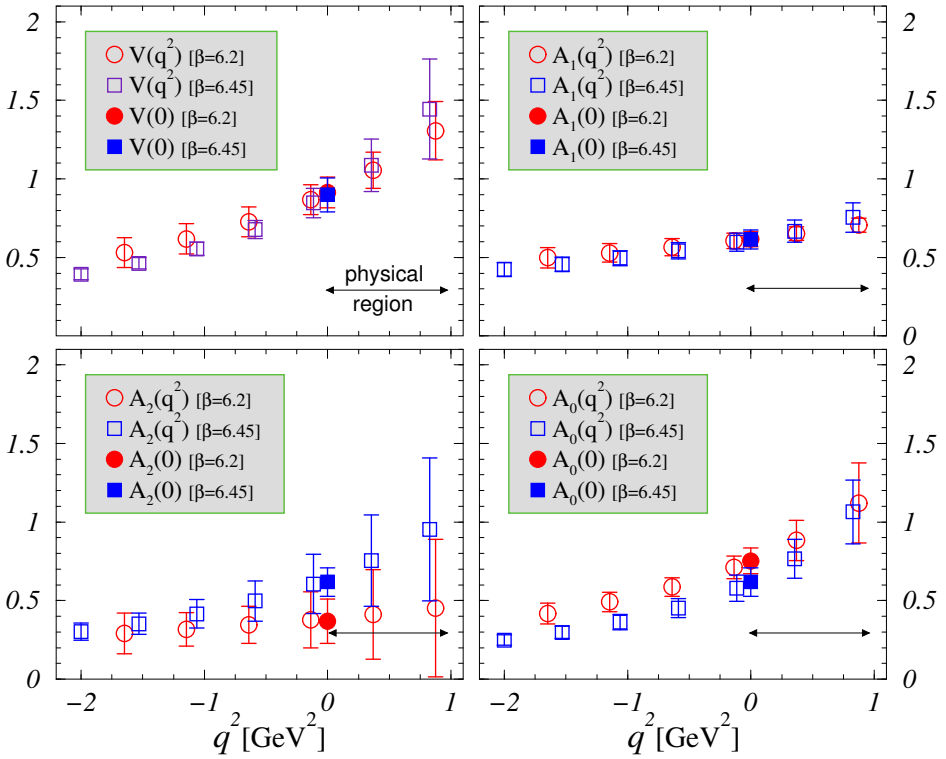
- **Further theoretical progress possible**

LCSR for Heavy meson decays

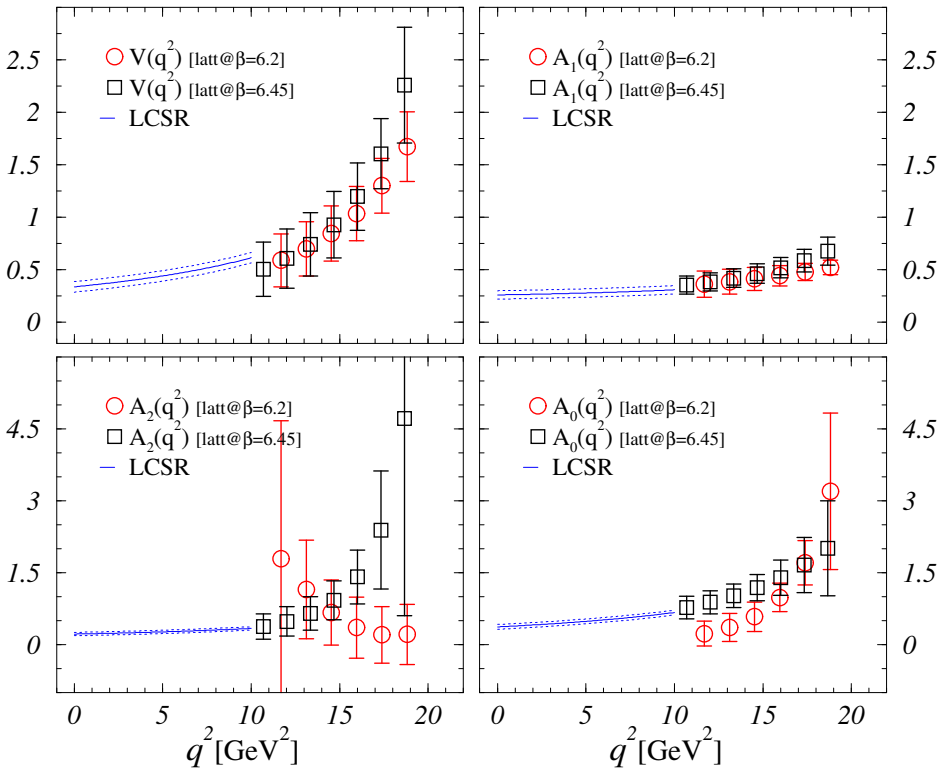
Lattice calculations: **A. Abada *et al.*, hep-lat/0209116**

LCSR: **P. Ball, V. Braun, PRD 58 (1998) 094016**

$D \to K^* l \nu_l$

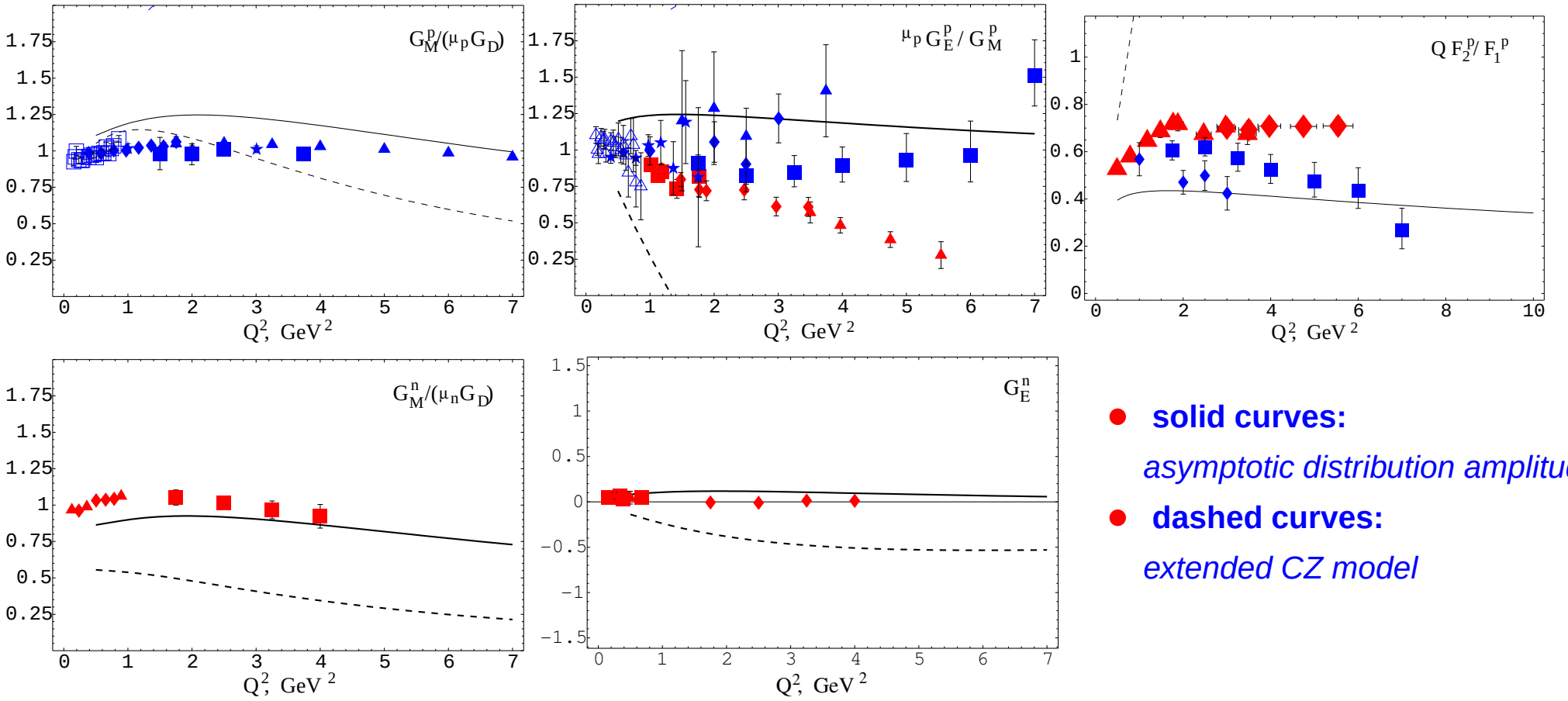


$B \to \rho l \nu_l$



Nucleon electromagnetic form factors

- **Tree-level light-cone sum rules:**

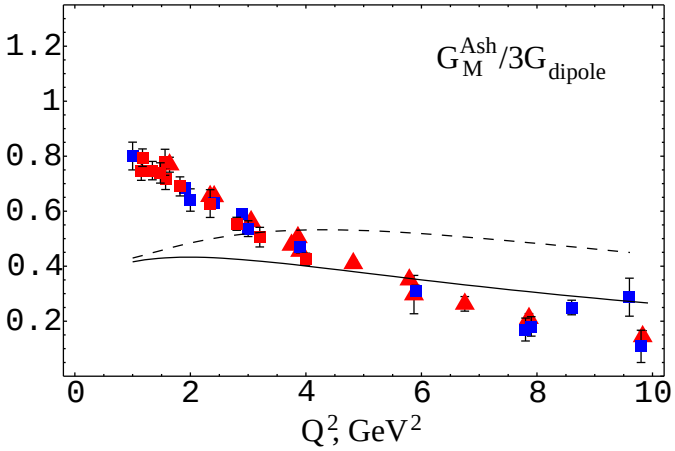


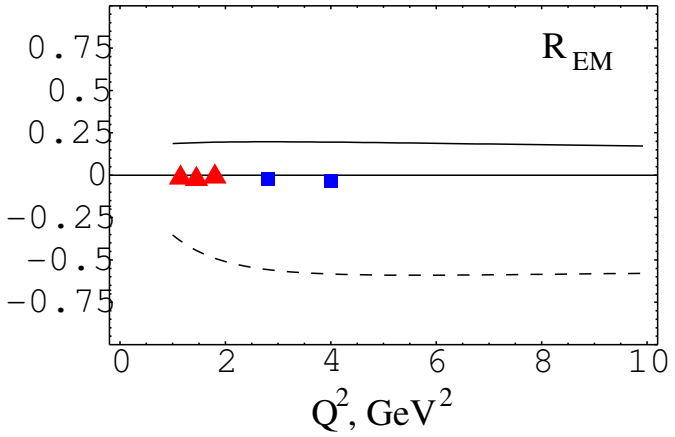
- **solid curves:**
  asymptotic distribution amplitudes
- **dashed curves:**
  extended CZ model

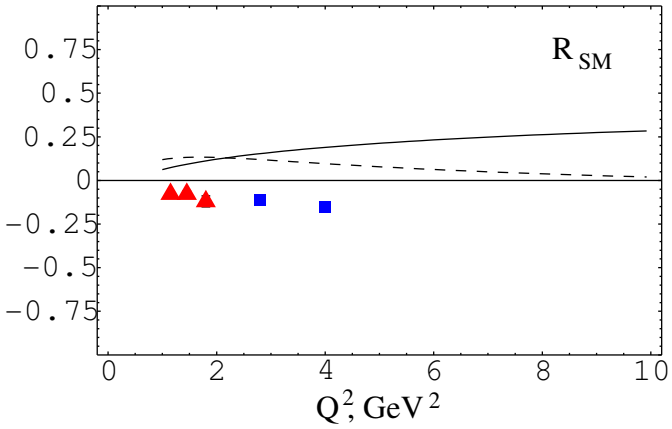
V. Braun, A. Lenz, M. Wittmann
paper in preparation

$N\Delta\gamma$ transition form factors

- **Tree-level light-cone sum rules:**







- **solid curves:** *asymptotic distribution amplitudes*
- **dashed curves:** *extended CZ model*

V. Braun, A. Lenz, G. Peters, A. Radyushkin

paper in preparation

Electroproduction of soft pions

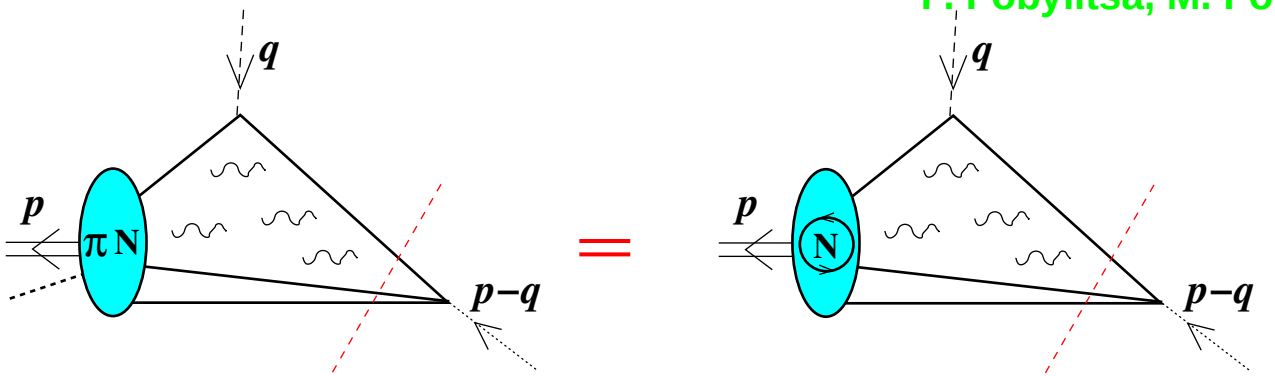
- $Q^2 \to \infty$ **does not commute with the chiral limit** $m_\pi \to 0$: $Q^2 \ll \Lambda^3/m_\pi$ **vs.** $Q^2 \gg \Lambda^3/m_\pi$

at the threshold

$$\langle N\pi(P-q)|j_\mu^{\rm em}|N(P)\rangle = \frac{i}{f_\pi}\bar N(P-q)\left[\gamma_\mu\gamma_5 G_A^{\pi N}(Q^2) - \frac{1}{2m}\gamma_5 q_\mu G_P^{\pi N}(Q^2)\right] N(P)$$

chiral rotation:

P. Pobylitsa, M. Polyakov, M. Strikman '01



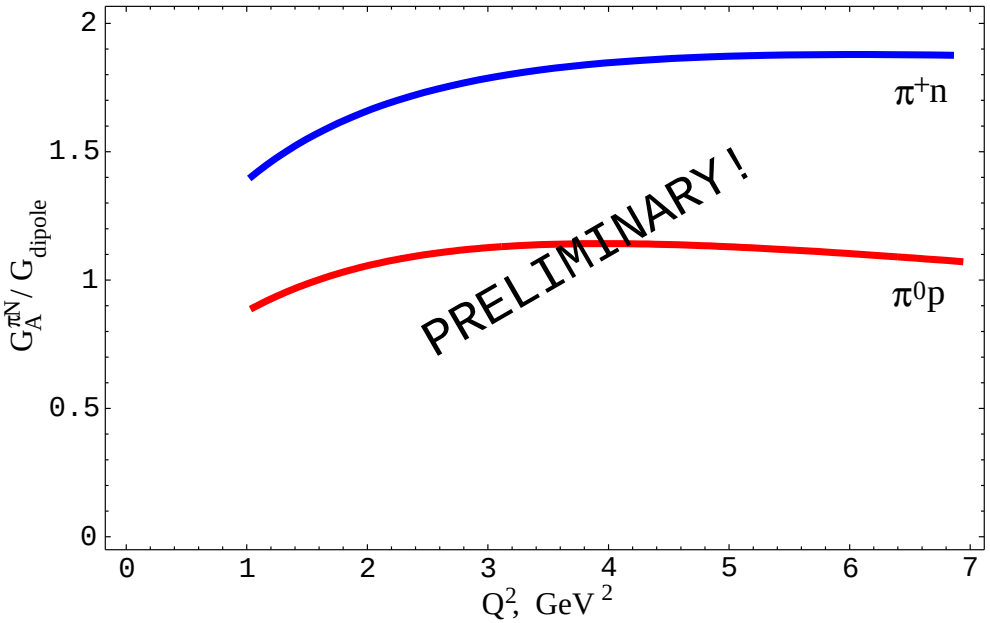
$$|p\uparrow\rangle = \frac{\phi_s(x)}{\sqrt{6}}|2u_\uparrow d_\downarrow u_\uparrow - u_\uparrow u_\downarrow d_\uparrow - d_\uparrow u_\downarrow u_\uparrow\rangle + \frac{\phi_s(x)}{\sqrt{2}}|u_\uparrow u_\downarrow d_\uparrow - d_\uparrow u_\downarrow u_\uparrow\rangle$$

$$|p\uparrow\pi^0\rangle = \frac{\phi_s(x)}{2\sqrt{6}f_\pi}|6u_\uparrow d_\downarrow u_\uparrow + u_\uparrow u_\downarrow d_\uparrow + d_\uparrow u_\downarrow u_\uparrow\rangle - \frac{\phi_s(x)}{2\sqrt{2}f_\pi}|u_\uparrow u_\downarrow d_\uparrow - d_\uparrow u_\downarrow u_\uparrow\rangle$$

$$|n\uparrow\pi^+\rangle = \frac{\phi_s(x)}{\sqrt{12}f_\pi}|2u_\uparrow d_\downarrow u_\uparrow - 3u_\uparrow u_\downarrow d_\uparrow - 3d_\uparrow u_\downarrow u_\uparrow\rangle - \frac{\phi_s(x)}{2f_\pi}|u_\uparrow u_\downarrow d_\uparrow - d_\uparrow u_\downarrow u_\uparrow\rangle$$

V. Braun, A. Lenz, A. Peters *work in progress*

- **Tree-level light-cone sum rules, preliminary:**



- **solid curves:** *asymptotic distribution amplitudes*

V. Braun, A. Lenz, A. Peters; work in progress

Outlook

- Light-cone sum rules offer
  - Rigorous approach to factorization of hard and soft (end-point) contributions
  - Nonperturbative model for soft terms, based on QCD duality and OPE
- General formalism is well established
  - Considerably more complex for baryons than for mesons
- Leading-order (tree-level) sum rules have been derived for a large variety of baryon form factors and seem to have 30% accuracy
- NLO baryon sum rules in progress; time scale 1–2 years
- Combination of LCSR and soft-pion techniques offers unique opportunities
- Long-term goal: information on nucleon distribution amplitide, in particular average momentum fraction carried by the three valence quarks to 5-7% precision

	$u^\uparrow$	$u^\downarrow$	$d^\uparrow$
asymptotic	33%	33%	33%
CZ model	58%	19%	23%