Toward Baryon Distributions Amplitudes

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Chapter 1:
Dyson-Schwinger equations

Dyson-Schwinger Equations in a nutshell

- Dyson-Schwinger equations relate Green (Schwinger) functions among each other.
- One get in the case of QCD, an infinite system $\rightarrow$ truncations are required.
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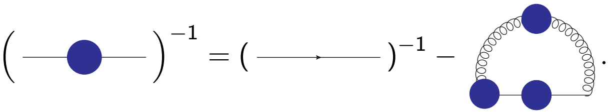
Truncating the DSEs yields an non-perturbative approximation of QCD Schwinger functions.

The Gap Equation

- The gap equation for the quark propagator $S(q)$:



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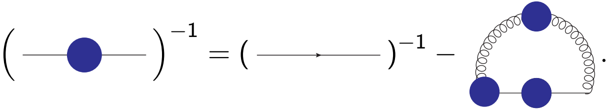
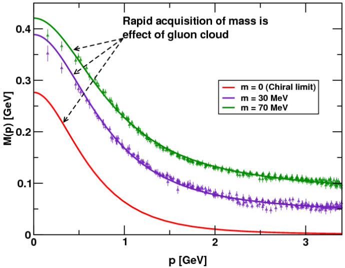


- It has successfully described the quark mass behaviour:



- $S(q)^{-1} = i\not{q}A(q^2) + B(q^2)$
- Non-perturbative description of the quark mass
- Dynamical mass generation
- Figure from Bashir *et al.* (2012)

Baryon and Diquarks

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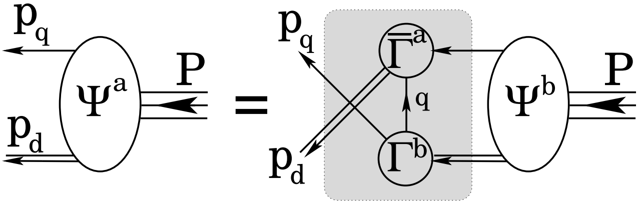

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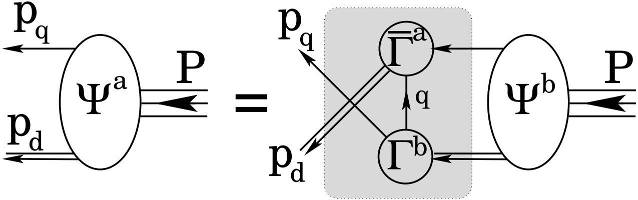

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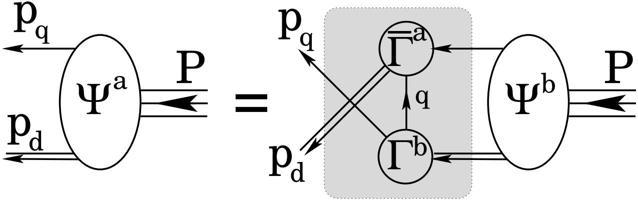

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  - Scalar diquarks,
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- Can we understand the nucleon structure in terms of quark-diquarks correlations?

Chapter 2:
Baryon Distribution Amplitudes

CM, J. Segovia, L. Chang, C.D. Roberts

Hadrons seen as Fock States

- Lightfront quantization allows to expand hadrons on a Fock basis:

$$|P,\pi\rangle \propto \sum_\beta \Psi_\beta^{q\bar{q}}|q\bar{q}\rangle + \sum_\beta \Psi_\beta^{q\bar{q},q\bar{q}}|q\bar{q},q\bar{q}\rangle + \dots$$

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- Non-perturbative physics is contained in the N-particles Lightfront-Wave Functions (LFWF) Ψ^N
- Schematically a distribution amplitude φ is related to the LFWF through:

$$\varphi(x) \propto \int \frac{\mathrm{d}^2 k_\perp}{(2\pi)^2}\Psi(x,k_\perp)$$

S. Brodsky and G. Lepage, PRD 22, (1980)

Nucleon Distribution Amplitudes

- 3 bodies matrix element:

$$\langle 0|\epsilon^{ijk} u_\alpha^i(z_1) u_\beta^j(z_2) d_\gamma^k(z_3)|P\rangle$$

Nucleon Distribution Amplitudes

- 3 bodies matrix element expanded at leading twist:

$$\langle 0|\epsilon^{ijk} u^i_\alpha(z_1) u^j_\beta(z_2) d^k_\gamma(z_3)|P\rangle = \frac{1}{4}\Big[\left(\not{p}C\right)_{\alpha\beta}\left(\gamma_5 N^+\right)_\gamma V(z_i^-) + \left(\not{p}\gamma_5 C\right)_{\alpha\beta}\left(N^+\right)_\gamma A(z_i^-) - \left(ip^\mu \sigma_{\mu\nu} C\right)_{\alpha\beta}\left(\gamma^\nu \gamma_5 N^+\right)_\gamma T(z_i^-)\Big]$$

V. Chernyak and I. Zhitnitsky, Nucl. Phys. B 246, (1984)

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- Isospin symmetry:

$$2T(x_1,x_2,x_3) = \varphi(x_1,x_3,x_2) + \varphi(x_2,x_3,x_1)$$

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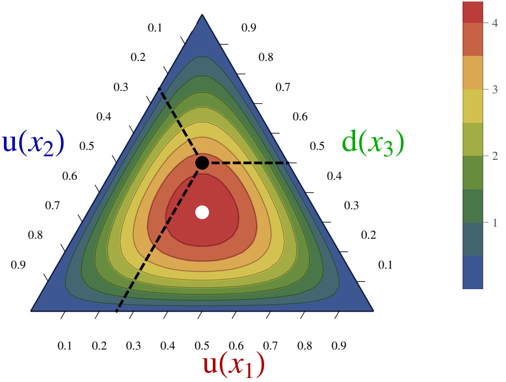
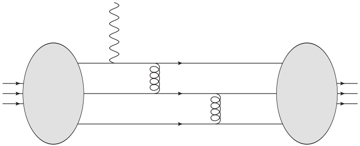


Form Factors: Nucleon case



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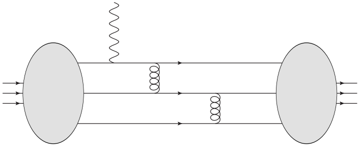

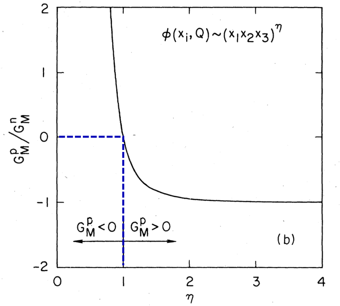

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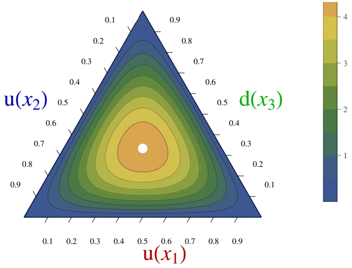

$\eta = 1$

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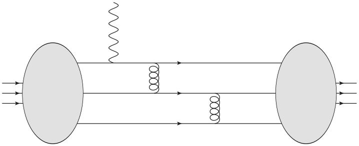
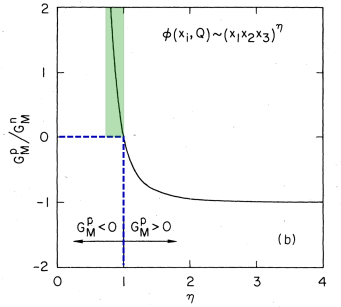
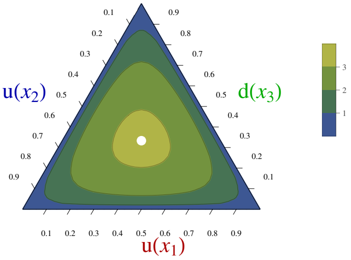
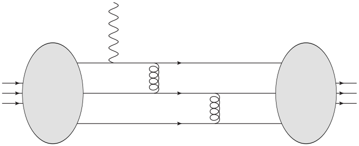


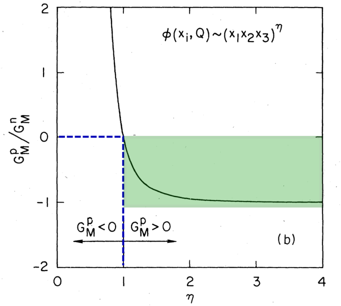


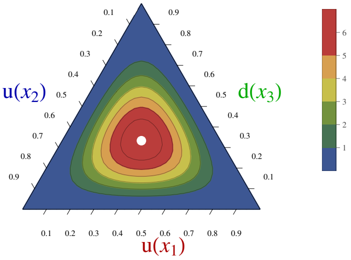


$\eta = 0.5$

S. Brodsky and G. Lepage, PRD 22, (1980)







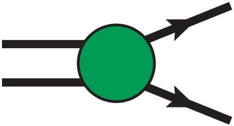
$\eta = 2$

S. Brodsky and G. Lepage, PRD 22, (1980)

Some previous studies of DA

- QCD Sum Rules
  - V. Chernyak and I. Zhitnitsky, Nucl. Phys. B 246 (1984)
- Relativistic quark model
  - Z. Dziembowski, PRD 37 (1988)
- Scalar diquark clustering
  - Z. Dziembowski and J. Franklin, PRD 42 (1990)
- Phenomenological fit
  - J. Bolz and P. Kroll, Z. Phys. A 356 (1996)
- Lightcone quark model
  - B. Pasquini *et al.*, PRD 80 (2009)
- Lightcone sum rules
  - I. Anikin *et al.*, PRD 88 (2013)
- Lattice Mellin moment computation
  - G. Bali *et al.*, JHEP 2016 02

- Algebraic parametrisation inspired by the results obtained from DSEs and Faddeev equations.
- It is based on Nakanishi representation, which is completely general.
- We also assume the dynamical diquark correlations, both scalar and AV, and compare in the end with Lattice QCD one.
- This is a work in progress, an update of the previous baryon PDA work (which was suffering some issues)



At all order of perturbation theory, one can write (Euclidean space):

$$\Gamma(k,P) = \mathcal{N}\int_0^\infty \mathrm{d}\gamma \int_{-1}^{1} \mathrm{d}z \frac{\rho_n(\gamma,z)}{(\gamma + (k+\frac{z}{2}P)^2)^n}$$

We use a "simpler" version of the latter as follow:

$$\tilde{\Gamma}(q,P) = \mathcal{N}\int_{-1}^{1} \mathrm{d}z \frac{\rho_n(z)}{(\Lambda^2 + (q+\frac{z}{2}P)^2)^n}$$

Nucleon Distribution Amplitude

- Operator point of view for every DA (and at every twist):

$$\langle 0|\epsilon^{ijk}\left(u_{\uparrow}^{i}(z_1)C\not{n}u_{\downarrow}^{j}(z_2)\right)\not{n}d_{\uparrow}^{k}(z_3)|P,\lambda\rangle \rightarrow \varphi(x_1,x_2,x_3),$$

Braun *et al.*, Nucl.Phys. B589 (2000)

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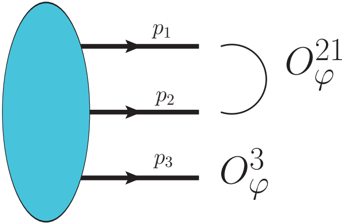

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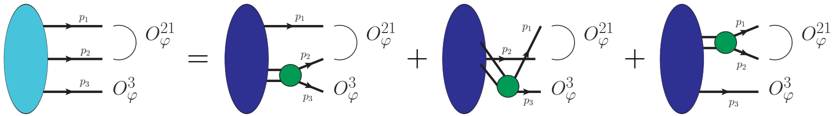

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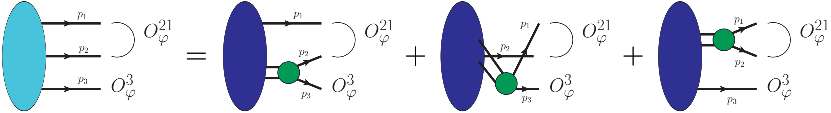

- The operator then selects the relevant component of the wave function.

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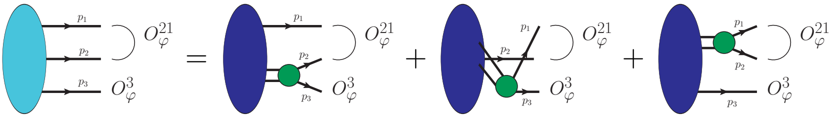
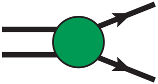


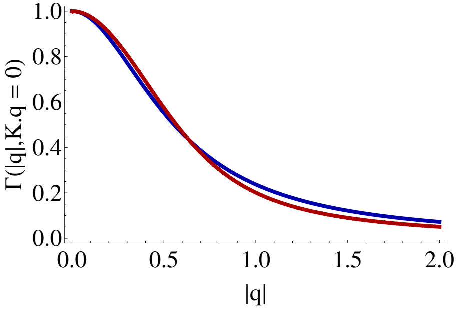
- The operator then selects the relevant component of the wave function.
- Our ingredients are:
  - Perturbative-like quark and diquark propagator
  - Nakanishi based diquark Bethe-Salpeter-like amplitude (green disks)
  - Nakanishi based quark-diquark amplitude (dark blue ellipses)

The model used:



$$= \mathcal{N} \int_{-1}^{1} \mathrm{d}z \frac{(1-z^2)}{(\Lambda^2 + (q + \frac{z}{2}P)^2)}$$

Comparable to scalar diquark amplitude previously used:

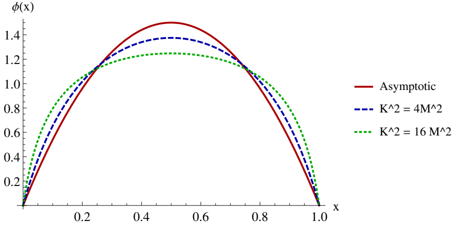


red curve from Segovia *et al.*,Few Body Syst. 55 (2014) 1185-1222

Diquark DA

$$\phi(x) \propto 1 - \frac{M^2}{K^2}\frac{\ln\left[1+\frac{K^2}{M^2}x(1-x)\right]}{x(1-x)}$$

Scalar diquark



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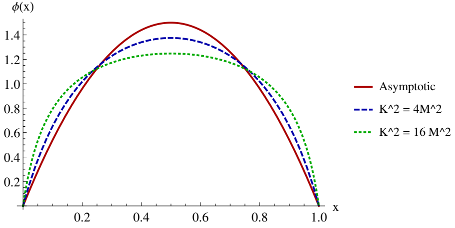
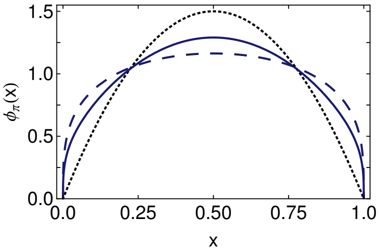


Pion



Pion figure from L. Chang *et al.*, PRL 110 (2013)

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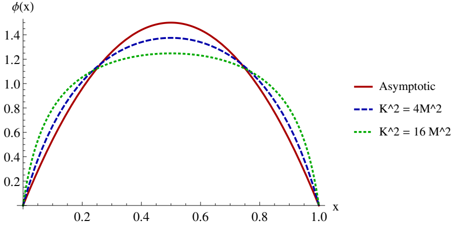

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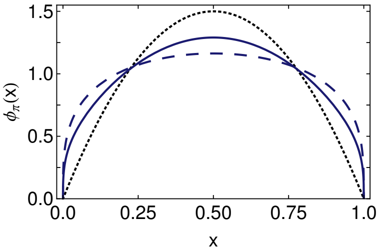
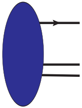


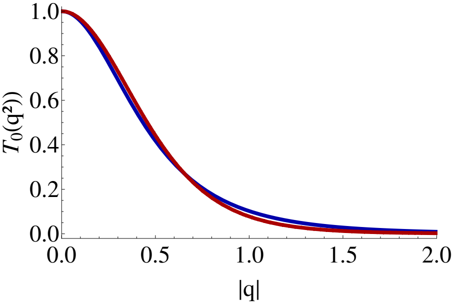
Pion figure from L. Chang *et al.*, PRL 110 (2013)

- This results provide a broad and concave meson DA parametrisation
- The endpoint behaviour remains linear



$$= \mathcal{N} \int_{-1}^{1} \mathrm{d}z \frac{(1-z^2)\tilde{\rho}(z)}{(\Lambda^2 + (q - \frac{1+3z}{6} P)^2)^3}$$

Preliminary estimations of the parameters through comparison to Chebychev moments:



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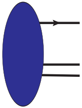

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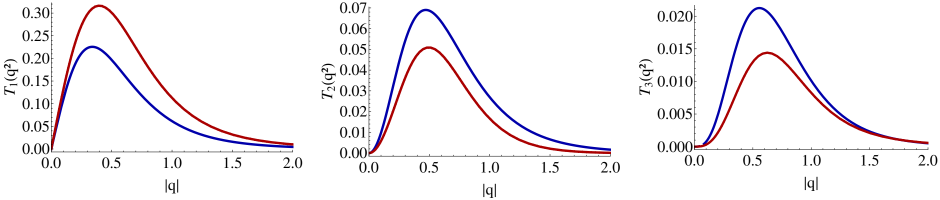

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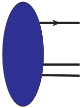
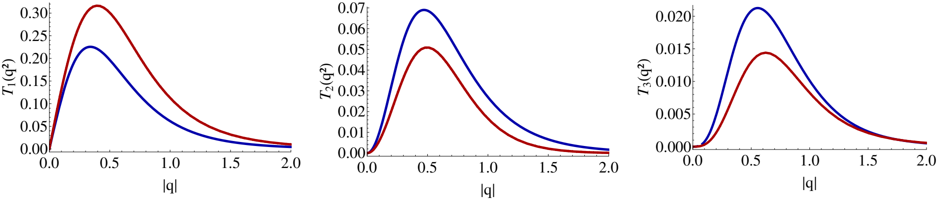
Nucleon Quark-Diquark Amplitude



$$= \mathcal{N} \int_{-1}^{1} \mathrm{d}z \frac{(1-z^2)\tilde{\rho}(z)}{(\Lambda^2 + (q - \frac{1+3z}{6}P)^2)^3}$$

Preliminary estimations of the parameters through comparison to Chebychev moments:



red curves from Segovia *et al.*,

There are still some works necessary to improve the comparison of higher Chebychev moments

- We do not compute the PDA directly but Mellin moments of it:

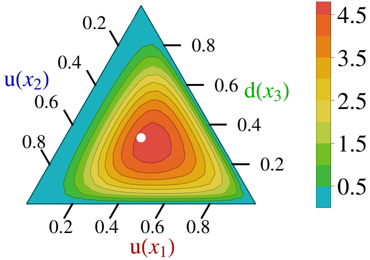
$$\langle x_1^m x_2^n \rangle = \int_0^1 \mathrm{d}x_1 \int_0^{1-x_1} \mathrm{d}x_2 \; x_1^m x_2^n \varphi(x_1, x_2, 1 - x_1 - x_2)$$

- For a general moment $\langle x_1^m x_2^n \rangle$, we change the variable in such a way to right down our moments as:

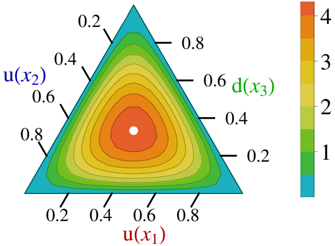
$$\langle x_1^m x_2^n \rangle = \int_0^1 \mathrm{d}\alpha \int_0^{1-\alpha} \mathrm{d}\beta \; \alpha^m \beta^n f(\alpha, \beta)$$

- f is a complicated function involving the integration on 6 parameters
- Uniqueness of the Mellin moments of continuous functions allows us to identify f and φ

Preliminary Results



Nucleon DA
(Scalar Diquark only)

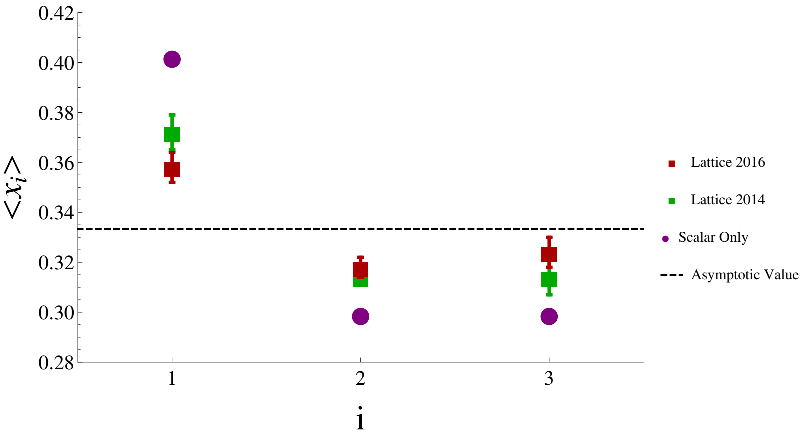


Asymptotic DA

- Nucleon DA is skewed compared to the asymptotic one
- These properties are consequences of our quark-diquark picture

Comparison with lattice

$$< x_i >_\varphi = \int \mathcal{D}x \; x_i \varphi(x_1, x_2, x_3)$$



Lattice data from V.Braun *et al*, PRD 89 (2014)

G. Bali *et al.*, JHEP 2016 02

Summary

Summary

Baryon PDA

- **DSE compatible** framework for Baryon PDAs.
- Simple Nakanishi representation works for the nucleon PDA.
- Preliminary results assuming a scalar diquarks

For the Future

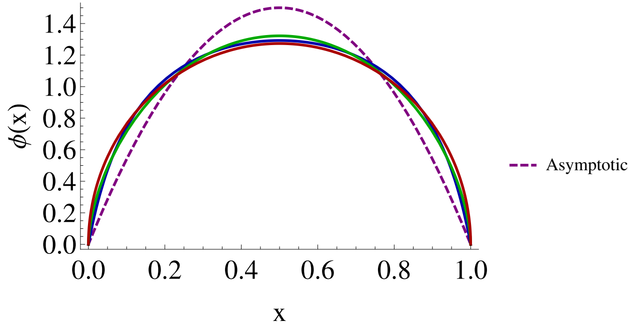
- **Priority** : calculation of AV diquark part
- Improvement of our various components (ie propagators and amplitudes)
- Calculation of the Dirac form factor.

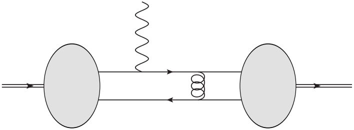
Addendum:
Meson Form Factors and beyond

$n = -1$ Mellin Moment

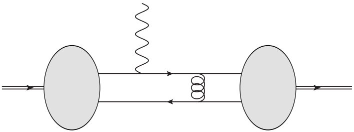
$$\langle x^{-1} \rangle = \int_0^1 \mathrm{d}x \frac{\varphi(x)}{1-x} \qquad \phi_{\ln}(x) \propto 1 - \frac{\ln\left[1 + \kappa x(1-x)\right]}{\kappa x(1-x)}$$

	$x(1-x)$	$\phi_{\ln}(x)$	$(x(1-x))^{\nu}$	$\sqrt{x(1-x)}$
$\langle x^{-1} \rangle$	3	3.41	3.66	4
$\frac{\langle x^{-1} \rangle}{\langle x^{-1} \rangle_{As}}$	1	1.14	1.22	1.33





$$Q^2F(Q^2) = \mathcal{N}\int [\mathrm{d}x_i][\mathrm{d}y_i]\varphi(x,\zeta_x^2)\,T(x,y,Q^2,\zeta_x^2,\zeta_y^2)\varphi(y,\zeta_y^2)$$



$$Q^2F(Q^2) = \mathcal{N}\int [\mathrm{d}x_i][\mathrm{d}y_i]\varphi(x,\zeta_x^2)T(x,y,Q^2,\zeta_x^2,\zeta_y^2)\varphi(y,\zeta_y^2)$$

- LO Kernel and NLO kernels are known
- $T_0 \propto \frac{\alpha_S(\mu_R^2)}{(1-x)(1-y)}$
- $T_1 \propto \frac{\alpha_s^2(\mu_R^2)}{(1-x)(1-y)}(f_{UV}(\mu_R^2) + f_{IR}(\zeta^2) + f_{finite})$

R Field *et al.*, NPB 186 429 (1981)
F. Dittes and A. Radyushkin, YF 34 529 (1981)
B. Melic *et al.*, PRD 60 074004 (1999)

- The UV scale dependent term behaves like:

$$f_{UV}(\mu_R^2) \propto \beta_0 \left(5/3 - \ln((1-x)(1-y)) + \ln\left(\frac{\mu_R^2}{Q^2}\right)\right)$$

- Here I take two examples:
  - the standard choice of $\zeta_x^2 = \zeta_y^2 = \mu^2 = Q^2/4$
  - the regularised BLM-PMC scale $\zeta_x^2 = \zeta_y^2 = \mu^2 = e^{-5/3}Q^2/4$

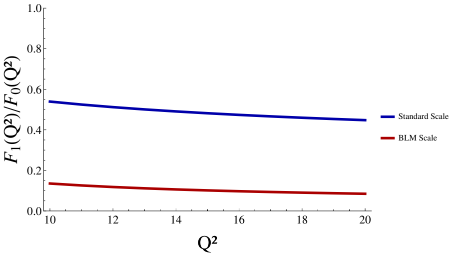
S. Brodsky *et al.*, PRD 28 228 (1983)
S. Brodsky and L. Di Giustino, PRD 86 085026 (2011)

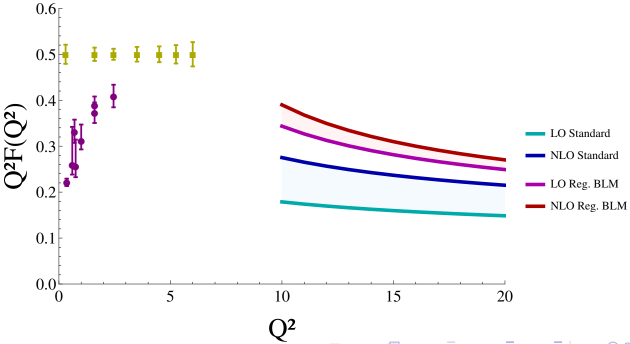
- Take the PDA model coming from the scalar diquark:

$$\phi(x) \propto 1 - \frac{\ln\left[1 + \kappa x(1-x)\right]}{\kappa x(1-x)}$$

κ is fitted to the lattice Mellin Moment

Pion FF


1.0
0.8
0.6
0.4
0.2
0.0
10
12
14
16
18
20
$F_1(Q^2)/F_0(Q^2)$
Q^2
Standard Scale
BLM Scale


0.6
0.5
0.4
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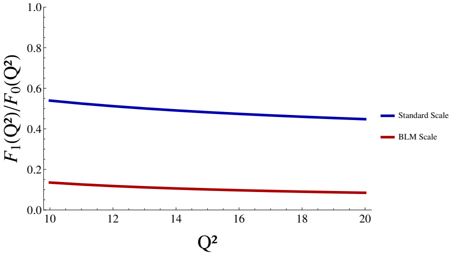
0.1
0.0
0
5
10
15
20
$Q^2F(Q^2)$
Q^2
LO Standard
NLO Standard
LO Reg. BLM
NLO Reg. BLM

Pion FF



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$F_1(Q^2)/F_0(Q^2)$
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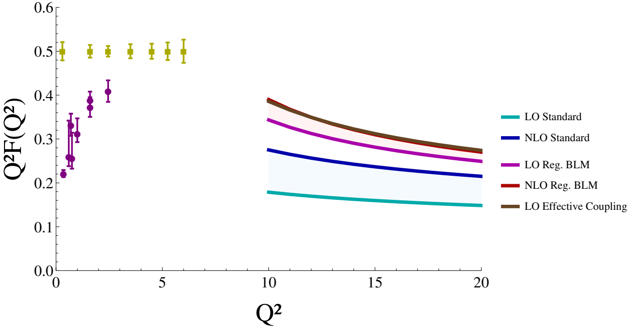
14
16
18
20
Q^2
Standard Scale
BLM Scale



0.6
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0.0
$Q^2F(Q^2)$
0
5
10
15
20
Q^2
LO Standard
NLO Standard
LO Reg. BLM
NLO Reg. BLM
LO Effective Coupling

- The UV scale dependent term behaves like:

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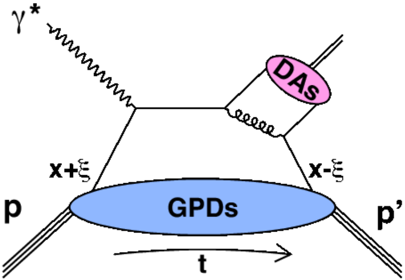
S. Brodsky *et al.*, PRD 28 228 (1983)
S. Brodsky and L. Di Giustino, PRD 86 085026 (2011)

- BLM scale reduces significantly the impact of the NLO corrections and increase dramatically the LO one.

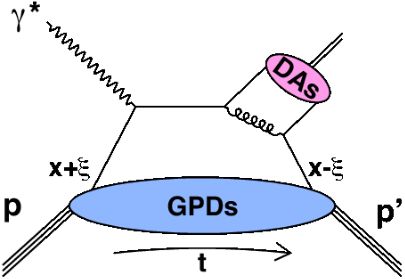
DVMP



- LO Transition Form Factor $\propto \langle x^{-1} \rangle$
- At NLO : $g_{UV} \propto \beta_0 \left(5/3 - \ln((1-u)(1-v)) + \ln\left(\frac{\mu_R^2}{Q^2}\right)\right)$
- Shape effects are also magnified

D. Müller *et al.*, Nucl.Phys. B884 (2014) 438-546

DVMP



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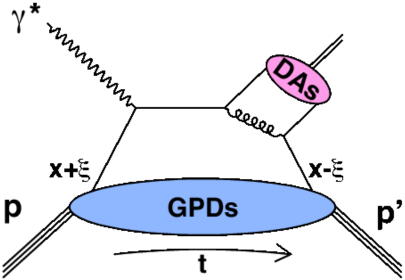
Bottom Line

A good knowledge of the PDA is a key point to perform reliable extraction of GPDs though DVMP

DVMP



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Optimism

This workshop shows that we are on good tracks to achieve it

Thank you for your attention

Back up slides