Internal structure of the nucleon inspired by AdS/QCD correspondence

Sabrina Cotogno
Vrije Universiteit van Amsterdam and Nikhef
Summary

Part I – Ingredients
Parton Distributions
Light-Front Wave Functions (LFWFs)
AdS/QCD correspondence

Part II - Recipe
LFWFs inspired by AdS/QCD

Part III - Phenomenology

Conclusions
Part I – Understanding the nucleon structure

How? → High energy processes → Soft nonperturbative part + Hard perturbative part

Deep Inelastic Scattering

\[ ep \rightarrow eX \]

PDFs

Elastic Scattering

\[ ep \rightarrow ep \]

FFs

Semi-Inclusive DIS

\[ ep \rightarrow ehX \]

TMDs

Sabrina Cotogno

VU Amsterdam/Nikhef

February 2, 2015
Part I – Understanding the nucleon structure

How? → High energy processes → Soft nonperturbative part + Hard perturbative part

**Deep Inelastic Scattering**

\[ ep \rightarrow eX \]

- PDFs
- TMDs

**Elastic Scattering**

\[ ep \rightarrow ep \]

- FFs

**Semi-Inclusive DIS**

\[ ep \rightarrow ehX \]

- Knowledge of all the parton distributions → Tomography of the proton

Sabrina Cotogno  
VU Amsterdam/Nikhef  
February 2, 2015
Part I – Fock-state expansion and Light Front quantization

Goal: evaluate hadronic matrix elements in which the proton state appears.
Fock state expansion of the proton state.

\[ |P\rangle = \psi_{qqq} |qqq\rangle + \psi_{qqg} |qqgg\rangle + \psi_{qqqg} |qqqq\rangle + \ldots \]

\[ |P, \Lambda\rangle = \sum_{N, \beta} \int \left[ \frac{dx}{\sqrt{x}} \right] \left[ d^2k_\perp \right] \Psi_{N, \beta}^\Lambda (r_1, \ldots, r_N) |N, \beta; \tilde{k}_1, \ldots, \tilde{k}_N\rangle \]

Sabrina Cotogno
VU Amsterdam/Nikhef
February 2, 2015
Part I – Fock-state expansion and Light Front quantization

Goal: evaluate hadronic matrix elements in which the proton state appears.
Fock state expansion of the proton state.

\[ |P\rangle = \psi_{qqq} |qqq\rangle + \psi_{qqqg} |qqqg\rangle + \psi_{qqqq\bar{q}} |qqqq\bar{q}\rangle + \ldots \]

\[ |P, \Lambda\rangle = \sum_{N, \beta} \int \left[ \frac{dx}{\sqrt{x}} \right] \left[ d^2 k_\perp \right] \Psi^\Lambda_{N, \beta} (r_1, \cdots, r_N) |N, \beta; \tilde{k}_1, \ldots, \tilde{k}_N\rangle \]

Convenient formalism → Light Cone quantization

\[ x^+ = \frac{1}{\sqrt{2}} (x^0 + x^3) ; \quad x^- = \frac{1}{\sqrt{2}} (x^0 - x^3) \]
Part I – LFWFs Overlap representations

\[ |P, \Lambda\rangle = \sum_{N, \beta} \int \left[ \frac{dx}{\sqrt{x}} \right]_N \left[ d^2 k_\perp \right]_N \Psi^\Lambda_{N, \beta} (r_1, \cdots, r_N) |N, \beta; \tilde{k}_1, \cdots, \tilde{k}_N \rangle \]

**Light-front Wave Functions**

\( \psi_N \rightarrow \) Probability amplitude to find the N-th state inside the proton
Part I – LFWFs Overlap representations

\[ |P, \Lambda \rangle = \sum_{N, \beta} \int \left[ \frac{dx}{\sqrt{x}} \right] N \left[ d^2 k_\perp \right] N \Psi^\Lambda_{N, \beta} (r_1, \cdots, r_N) \left| N, \beta; \tilde{k}_1, \ldots, \tilde{k}_N \right\]

\( \psi_N \rightarrow \) Probability amplitude to find the N-th state inside the proton

Once they are known, the LFWFs allow us to model all the parton distributions.

When possible, the probabilistic interpretation is evident, e.g.

PDF \( \rightarrow \)

\[ f_{1q}^\Lambda (x) = \frac{1}{2} \sum_\beta \int \frac{d^2 k_\perp}{16\pi^3} \left| \psi^\Lambda_\beta (x, k_\perp) \right|^2 \]
Problem:
The LFWFs are highly non perturbative objects → No easy way to access them.
Possible approach: Duality.
Problem:
The LFWFs are highly non perturbative objects → No easy way to access them.
Possible approach: Duality.

Non gravitational dual field theory → Supersymmetric conformal Theory
Part I – Applicability to QCD

• Massless quarks and constant coupling:

\[ \mathcal{L}_{QCD} = \bar{\psi}_i (i \gamma^\mu D_\mu)_{ij} \psi_j - \frac{1}{4} G^a_{\mu\nu} G^{\mu\nu}_a \]

Inclusion of confinement (bottom-up approach):

• Modifications of AdS metric → Insertion of a dilaton field in order to simulate confinement:

\[ S = \int d^4 x dz \sqrt{|g|} e^{\varphi(z)} \left( g^{MN} \partial_M \Phi(x, z) \partial_N \Phi(x, z) - \mu^2 \Phi^2(x, z) \right) \]

\[ \varphi(z) = \lambda z^2 \]

\[ e^{\varphi(z)} \rightarrow 1 \quad z \rightarrow 0 \]

Soft-wall model

\[ \text{AdS}_5 \] metric
Part II – LFWFs derivation from AdS/QCD

Meson form factor

\[
\int d^4x \int dz \sqrt{g} \ A^M(x, z) \Phi^*_P(x, z) \mathrel{\overrightarrow{\partial}}_M \Phi(x, z)
\]

\[
(2\pi) \delta^{(4)}(P' - P - q) \epsilon_\mu (P' + P)^\mu F(q^2)
\]
Part II – LFWFs derivation from AdS/QCD

Meson form factor

\[ \int d^4x \int d\zeta \sqrt{g} \ A^M (x, \zeta) \Phi^*_P (x, \zeta) \left\langle \partial_M \Phi (x, \zeta) \right\rangle \]

\( (2\pi) \delta^{(4)} (P' - P - q) \epsilon_\mu (P' + P)^\mu F (q^2) \)

\[ Q^2 F(Q^2) \]

\[ Q^2 [\text{GeV}^2] \]

\[ 0 \quad 5 \quad 10 \quad 15 \quad 20 \quad 25 \quad 30 \]

\[ 0.0 \quad 0.2 \quad 0.4 \quad 0.6 \quad 0.8 \quad 1.0 \]

Sabrina Cotogno
VU Amsterdam/Nikhef
February 2, 2015
Part III – Nucleon wave function

Quark-diquark model for the nucleon

Phenomenological parameters

\[
\varphi^{(i)}(x, k_\perp) = N_q^{(i)} 4\pi \sqrt{\log \left( \frac{1}{x} \right)} \frac{x^{a_q(i)} (1 - x)^{b_q(i)}}{\kappa (1 - x)} \exp \left\{ -\frac{k_\perp^2}{2\kappa^2} \log \left( \frac{1}{x} \right) \right\}.
\]

Procedure:
- Fitting the experimental data of flavor separated form factors,
- Fitting the PDFs parametrizations,
- Using the fitted parameters to obtain predictions for TMDs.
Summary, Conclusions and outlooks

• Importance of the LFWFs to model parton distributions.
• Need for a model which provides the hadronic LFWF.
• LFWFs inspired by AdS/QCD correspondence.
Summary, Conclusions and outlooks

• Importance of the LFWFs to model parton distributions.
• Need for a model which provides the hadronic LFWF.
• LFWFs inspired by AdS/QCD correspondence.

• Pure AdS/QCD correspondence provides LFWFs which have a rigid form.
• No reasonable description of the pion.
• Phenomenological changes are needed in order to describe the nucleon.
Summary, Conclusions and outlooks

- Importance of the LFWFs to model parton distributions.
- Need for a model which provides the hadronic LFWF.
- LFWFs inspired by AdS/QCD correspondence.

- Pure AdS/QCD correspondence provides LFWFs which have a rigid form.
- No reasonable description of the pion.
- Phenomenological changes are needed in order to describe the nucleon.

- Phenomenological LFWF for the pion (in progress).
- Improvement of nucleon TMDs analysis, including QCD evolution.
- Analysis of other parton distributions.