Holographic QCD

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Introduction

String theory provides new and very surprising methods to understand aspects of quantum gauge theories, one of these being the holographic correspondence, a conjecture which gives a relationship between strongly coupled quantum field theories and gravity in higher dimensions. This conjecture and its surprising properties have been applied in countless physics areas, from particle physics to condensed matter physics and have offered an extremely useful tool to investigate strongly coupled phenomena. In particular, holography has brought new insights into the strongly coupled regime of Yang-Mills theories, and it has been used for the computation of observables in a class of strongly coupled QCD-like models. Among the latter, a relevant example is the Witten-Sakai-Sugimoto model (WSS) [1, 2]. This is a top-down holographic model based on the duality between type IIA string theory with N_f pairs of $D8$ and $\overline{D8}$ probe branes in the background sourced by $N_c \gg 1$ $D4$-branes wrapped around a S^1 circle ($N_f \ll N_c$) and a strongly coupled large-N_c QCD-like theory with N_f massless quarks. This model displays many physical properties interesting for QCD, such as confinement and chiral symmetry breaking, and provides holographic description of mesons and baryons.

Nucleon spin structure in Holographic QCD

In recent publications, the Jefferson Lab collaborations E97-110 [3] and Hall A g_{2p} [4] have presented novel results on the behaviour of the *generalized nucleon spin polarizabilities* $\gamma_0(Q^2)$ and $\delta_{LT}(Q^2)$ - extracted from polarized inelastic lepton-nucleon scattering experiments - at very low energy-momentum transfer squared (namely $Q^2 \lesssim 0.2$ GeV^2). At low energies, where QCD is strongly correlated and perturbative tools are not available, it is widely expected that a sensible theoretical tool for extracting predictions on the above observables could be provided by Chiral Effective Field Theories (χEFT). However, experimental data from JLab show both qualitative and quantitative disagreement with the latter, especially for what concerns the low Q^2 behaviour of the longitudinal-transverse neutron spin polarizability $\delta_{LT}(Q^2)$. Motivated by these results and, in particular, by the data/predictions discrepancy, in my Master's thesis work, I have studied the above-mentioned observables by the means of the WSS model. Using holographic techniques, I have extended the analysis of the unpolarized WSS proton structure functions, already available in the literature, to the case of the polarized structure functions for both proton and neutron. These results, in fact, provide the first study of polarized lepton-hadron scattering in the low-energy regime within a QCD-like top-down holographic model. I have used these results to estimate the contribution of a class of spin 1/2 nucleon resonances (with both positive and negative parity) to $\delta_{LT}(Q^2)$ and $\gamma_0(Q^2)$. Finally, extrapolated the WSS parameters to fit QCD observables, in order to confront predictions with experimental data, I have studied through a numerical analysis the behaviour of $\delta_{LT}(Q^2)$ and $\gamma_0(Q^2)$ in the low-Q^2 regime. Despite being focused on a different class of contributions, the findings are in qualitative agreement with predictions from χEFT. This suggests that, in order to capture the features deduced from low-Q^2 polarized scattering experiments, the theoretical study of the nucleon spin structure has to be extended to other possible channels.

The PhD project

My PhD project is primarily focused on deepening the issues related to the study of the nucleon spin structure in Holographic QCD, and in particular, I envisage

- To improve the analysis, by the inclusion of the contributions of spin 3/2 resonances, such as the Δ. This purpose could be reached starting from the results in [5];
- To carry out a more "inclusive" alternative method of calculating polarized structure functions in the model, not based on the study of the nucleon resonance production but on the direct evaluation of the holographic electromagnetic currents two-point function;
- To extend the study of the nucleon spin polarizabilities with the introduction of the masses of quarks in the WSS model [6].

The holographic approach, keeping in mind the limitations of this kind of description for baryons in a strongly coupled large-N_c QCD-like theory, provides a useful tool to investigate the behaviour of the relevant observables and the realization of the proposed objectives will contribute to increase our current understanding of nucleon spin structure.

The expertise acquired within the WSS model will allow me, not only to study topics in the field of QCD physics, but also to approach problems, for instance, concerning physics beyond the Standard Model, in which the WSS and similar top-down models are taken as proposals for QCD-like dark sectors. This approach has already been considered by the String group at UniFi, with applications related with, for example, gravitational waves produced by cosmological phase transitions [7–9]. Holography offers the unique opportunity to study these phenomena, and the related equilibrium and out-of-equilibrium dynamics, in a fully non-perturbative context.

References

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