Hadron Structure from GPDs and Lattice QCD ◇

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Since the mid '90s, generalized parton distributions (GPDs) have proven to play a vital role for the understanding of the structure of hadrons in terms of quark and gluon degrees of freedom. Based on the complete set of leading twist helicity dependent, independent and helicity flip GPDs, we performed an analytical investigation of the longitudinal and transverse quark spin structure of the nucleon. We presented results for transverse quark spin densities in impact parameter ($b_\perp$-)space, improved bounds on GPDs and equation-of-motion relations between twist-2 and twist-3 GPDs [1]. Although the measurement of GPDs in experiments like DVCS is a highly important and promising long term goal, lattice QCD simulations represent to this day the only systematic approach to obtain directly the lowest moments of the full set of quark GPDs. In the framework of the UKQCD/QCDSF collaborations we performed first lattice calculations of the generalized transversity H_T and numerically investigated the Soffer bound $2|\delta q(x)| \leq q(x) + \Delta q(x)$ which relates the quark transversity $\delta q(x)$ to the polarized $\Delta q(x)$ and unpolarized $q(x)$ distribution functions [2].

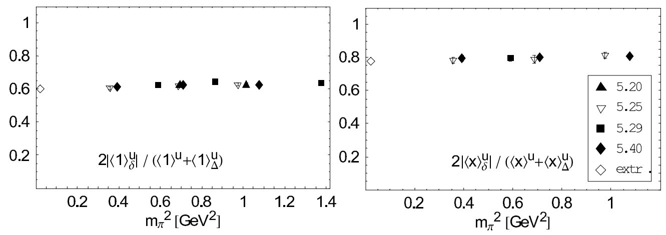

Fig. 1: Lattice results for the lowest two moments of the Soffer bound for up quarks

Our simulations indicate that for the pion masses available the Soffer bound is saturated by 60 to 80% (see Fig. 1), which is a promising result with respect to the proposed measurement of double spin asymmetries (PAX) at FAIR/GSI.

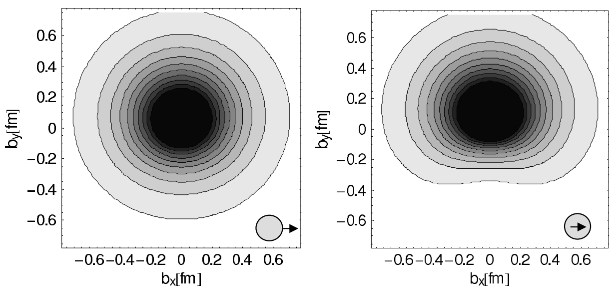

Fig. 2: Transverse spin densities of up quarks in the nucleon. The inner arrow denotes the quark transverse spin, the outer arrow the nucleon transverse spin

Preliminary results from lattice QCD calculations on transverse spin densities of quarks in the nucleon [3] show a complex interplay of spin and coordinate space degrees of freedom (Fig. 2), and the strongly distorted densities could provide an intuitive mechanism for single spin asymmetries like the Sivers asymmetry. In addition to a first investigation of GPDs of the pion in lattice QCD [4] in collaboration with UKQCD/QCDSF, we also started a concentrated effort to study the pion mass and lattice volume dependence of the axial vector coupling constant g_A of the nucleon. Promising preliminary results for this fundamental quantity based on chiral perturbation theory calculations in the small scale expansion [5] have been presented in [6] (see LHS of Fig. 3). In particular the volume dependence observed in the lattice calculation compares very favorably to results from ChPT [7].

In the framework of the LHPC/MILC collaborations, we continued the extraction and investigation of moments of GPDs from lattice simulations based on a hybrid approach of domain-wall valence and improved staggered sea quarks, which allows to reach (to this date) lowest pion masses of $m_\pi \approx 350$ MeV in nucleon structure calculations.

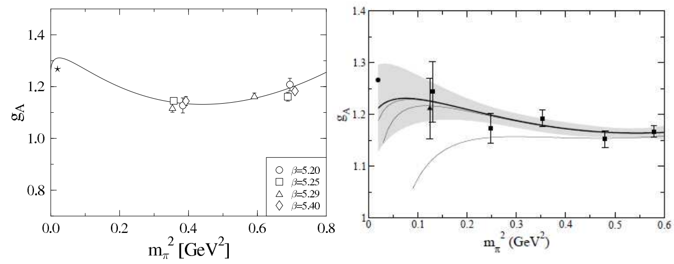

Fig. 3: Results for g_A vs m_π^2 from UKQCD/QCDSF (left) and LHPC/MILC (right) compared to ChPT

As a first step towards a complete anaylsis of a large number of hadron structure observables, we presented an ivestigation of g_A based on six datasets with pion masses ranging from 796 to 352 MeV in volumes of $(2.5\text{ fm})^3$ and $(3.5\text{ fm})^3$ [8]. Chiral extrapolation of our results to the physical pion mass yields a value for g_A which is in agreement with experiment within errors (RHS of Fig. 3). At the same time, our results indicate that finite volume effects are small in volumes $\geq (2.5\text{ fm})^3$ for our lowest pion masses.

References

[1] M. Diehl and P. Hägler, Eur.Phys.J. **C44** (2005) 87, arXiv:hep-ph/0504175
[2] M. Göckeler *et al.*, QCDSF Collaboration, Phys.Lett. **B627** (2005) 113, arXiv:hep-lat/0507001
[3] M. Diehl *et al.*, QCDSF Collaboration, arXiv:hep-ph/0511032
[4] D. Brömmel *et al.*, PoS **LAT2005** (2005) 360, arXiv:hep-lat/0509133
[5] T. R. Hemmert, M. Procura and W. Weise, Phys.Rev. **D68** (2003) 075009, arXiv:hep-lat/0303002
[6] A. A. Khan *et al.*, PoS **LAT2005** (2005) 349, arXiv:hep-lat/0510061
[7] Ph. Hägler, T. R. Hemmert and T. Wollenweber, 106
[8] R. G. Edwards *et al.*, LHPC Collaboration, Phys.Rev.Lett. **96** (2006) 052001, arXiv:hep-lat/0510062

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