hep-lat 0912.0167

DESY 09-196
Edinburgh 2009/20
LTH 853
TUM-T39-11-11

Lattice Investigations of Nucleon Structure at Light Quark Masses

M. Göckeler[a], Ph. Hägler[b], R. Horsley[c], Y. Nakamura[a], D. Pleiter[d], P. E. L. Rakow[e], A. Schäfer[a], G. Schierholz[a,f], H. Stüben[g], J. M. Zanotti[*c]

[a] *Institut für Theoretische Physik, Universität Regensburg, 93040 Regensburg, Germany*
[b] *Institut für Theoretische Physik T39, TU München, 85747 Garching, Germany*
[c] *School of Physics and Astronomy, University of Edinburgh, Edinburgh EH9 3JZ, UK*
[d] *John von Neumann Institute NIC / DESY Zeuthen, 15738 Zeuthen, Germany*
[e] *Theoretical Physics Division, Department of Mathematical Sciences, University of Liverpool, Liverpool L69 3BX, UK*
[f] *Deutsches Elektronen-Synchrotron DESY, 22603 Hamburg, Germany*
[g] *Konrad-Zuse-Zentrum für Informationstechnik Berlin, 14195 Berlin, Germany*
E-mail: jzanotti@ph.ed.ac.uk

QCDSF/UKQCD Collaboration

Lattice simulations of hadronic structure are now reaching a level where they are able to not only complement, but also provide guidance to current and forthcoming experimental programmes at, e.g. Jefferson Lab, COMPASS/CERN and FAIR/GSI. By considering new simulations at low quark masses and on large volumes, we review the recent progress that has been made in this exciting area by the QCDSF/UKQCD collaboration. In particular, results obtained close to the physical point for several quantities, including electromagnetic form factors and moments of ordinary parton distribution functions, show some indication of approaching their phenomenological values.

The XXVII International Symposium on Lattice Field Theory - LAT2009
July 26-31 2009
Peking University, Beijing, China

[*]Speaker.

© Copyright owned by the author(s) under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike Licence.

arXiv:0912.0167v1 [hep-lat] 1 Dec 2009

Figure 1: Nucleon mass as a function of m_π^2 for three different values of β. The scale is set using $r_0 = 0.467$ fm and the physical mass is indicated by the cross.

1. Introduction

Much of our knowledge about hadronic structure in terms of quark and gluon degrees of freedom has been obtained from high energy scattering experiments. However, there are still many unresolved issues in hadronic physics that need to be addressed, from both an experimental and theoretical perspective. This is one of the main motivations of the 12 GeV Jefferson Lab upgrade which aims to [1]: search for exotic mesons; study the role of hidden flavours in the nucleon; map out the spin and flavour dependence of the valence parton distribution functions; explore nuclear medium effecs; and measure the generalised parton distribution functions of the nucleon. It is imperative that these and other exciting experimental efforts, such as those at COMPASS/CERN and FAIR/GSI, are matched by modern lattice simulations. See recent lattice reviews [2, 3, 4, 5] for latest developments.

In this talk we present the latest results from the QCDSF/UKQCD Collaboration for electromagnetic (EM) form factors, $\langle x \rangle_q$, $\langle x \rangle_{\Delta q}$, g_A and g_T. Simulations are performed with the Wilson gauge action and two flavours of $\mathcal{O}(a)$-improved Wilson fermions. Four values of $\beta = 5.20, 5.25, 5.29, 5.40$, corresponding to lattice spacings in the range $0.1 < a < 0.07$ fm, allow for the approach to the continuum limit to be assessed, while a range of lattice volumes ($1.1 < L < 3.2$ fm) enable us to search for finite size effects in our simulations. A key feature of the new results presented here is the control we are now able to achieve over the approach to the chiral limit. This is made possible by several new simulations with pion masses reaching as low as 170 MeV, which are summarised in Fig. 1.

larger than $m_\pi > 300$ MeV. While the new results below $m_\pi < 300$ MeV are showing signs of upward curvature, as predicted from chiral perturbation theory [7, 8, 9], it is not yet clear whether this is enough to reach the experimental value. Of course, at such light quark masses, finite volume effects are expected to suppress the nucleon charge radii [9], and the results from three different volumes at $m_\pi^2 \approx 0.09$ GeV^2 indicate that this is indeed the case, although the effect appears to be rather small at this pion mass.

Results for the isovector anomalous magnetic moment, κ_v, are shown in Fig. 3 and the results are seen to be slowly increasing towards the experimental value as the pion mass is decreased. Closer to the chiral limit, the results are starting to exhibit stronger chiral behaviour, once again as predicted by χPT [7, 8, 9]. Here finite volume effects are also expected to suppress the magnetic moment [8], so the fact that our results on a finite volume are not increasing fast enough to agree perfectly with experiment is not totally unexpected.

3. Moments of Structure Functions

In this section we discuss our latest findings for the nucleon's axial charge, g_A, tensor charge, g_T, and spin-independent and spin-dependent quark momentum fractions, $\langle x \rangle_q$ and $\langle x \rangle_{\Delta q}$. All operators in this section have been renormalised nonperturbatively using the Rome-Southampton method [10].

3.1 Axial Charge, g_A

The axial coupling constant of the nucleon is important as it governs neutron β-decay and also provides a quantitative measure of spontaneous chiral symmetry breaking. It is also related to the first moment of the helicity dependent quark distribution functions, $g_A = \Delta u - \Delta d$. It has been studied theoretically as well as experimentally for many years and its value, $g_A = 1.2695(29)$, is known to very high accuracy. Hence it is an important quantity to study on the lattice, and since it is relatively clean to calculate (zero momentum, isovector), it serves as useful yardstick for lattice simulations of nucleon structure.

The axial charge is defined as the value of the isovector axial form factor at zero momentum transfer and is determined by the forward matrix element

$$\langle p, s | A_\mu^{u-d} | p, s \rangle = 2 g_A s_\mu \ , \tag{3.1}$$

where $A_\mu = \bar{q} \gamma_\mu \gamma_5 q$, p is the nucleon momentum, and s_μ is a spin vector with $s^2 = -M_N^2$.

g_A has been studied in-depth for many years by the QCDSF/UKQCD [11], LHP [12] and RBC/UKQCD [13] collaborations and has been shown to suffer from large finite size effects. Such effects are also seen in our new results at lighter pion masses as seen in Fig. 4 where we show those results for where we have more than one volume available at a fixed pion mass. Here we normalise the finite volume results for the axial charge, $g_A(L)$, with the result obtained from the largest available volume for that choice of (β, κ), $g_A(\infty)$.

Another way to visualise our results is to consider the ratio g_A / f_π, as shown in Fig. 5. A good reason for considering this ratio is that the common renormalisation constant, Z_A, cancels in the ratio. It is also a natural ratio to consider in the context of the Goldberger-Treiman relation,

Acknowledgements

The numerical calculations have been performed on the APE1000 and apeNEXT at NIC/DESY (Zeuthen, Germany), the IBM BlueGeneL at EPCC (Edinburgh, UK), the BlueGeneL and P at NIC (Jülich, Germany) and the SGI Altix 4700 at LRZ (Munich, Germany). Some of the configurations at the small pion mass have been generated on the BlueGene/L at KEK by the Kanazawa group as part of the DIK research programme. We thank all institutions. This work has been supported in part by the EU Integrated Infrastructure Initiative Hadron Physics (I3HP) under contract RII3-CT-2004-506078 and by the DFG under contracts FOR 465 (Forschergruppe Gitter-Hadronen-Phänomenologie) and SFB/TR 55 (Hadron Physics from Lattice QCD). PH is supported by the DFG under the Emmy-Noether program. JZ is supported through the UK's *STFC Advanced Fellowship Programme* under contract number ST/F009658/1.

References

[1] http://www.jlab.org/

[2] K. Orginos, PoS **LAT2006** (2006) 018.

[3] P. Hägler, PoS **LAT2007** (2007) 013 [arXiv:0711.0819 [hep-lat]].

[4] J. M. Zanotti, PoS **LAT2008** (2008) 007 [arXiv:0812.3845 [hep-lat]].

[5] D. Renner, PoS **LAT2009** (2009) 018.

[6] J. Arrington, C. D. Roberts and J. M. Zanotti, J. Phys. G **34** (2007) S23 [arXiv:nucl-th/0611050].

[7] M. Göckeler *et al.* [QCDSF], Phys. Rev. D **71** (2005) 034508 [arXiv:hep-lat/0303019].

[8] R. D. Young *et al.*, Phys. Rev. D **71** (2005) 014001 [arXiv:hep-lat/0406001].

[9] T. Hemmert, PoS **LAT2009** (2009) 146.

[10] G. Martinelli *et al.*, Nucl. Phys. B **445**, 81 (1995) [arXiv:hep-lat/9411010]; M. Göckeler *et al.*, Nucl. Phys. B **544**, 699 (1999) [arXiv:hep-lat/9807044]; M. Göckeler *et al.*, in preparation.

[11] A. Ali Khan *et al.*, Phys. Rev. D **74** (2006) 094508 [arXiv:hep-lat/0603028].

[12] R. G. Edwards *et al.* [LHPC], Phys. Rev. Lett. **96** (2006) 052001 [arXiv:hep-lat/0510062].

[13] T. Yamazaki *et al.* [RBC/UKQCD], Phys. Rev. Lett. **100** (2008) 171602 [arXiv:0801.4016 [hep-lat]].

[14] G. Colangelo, S. Dürr and C. Haefeli, Nucl. Phys. B **721**, 136 (2005) [arXiv:hep-lat/0503014].

[15] M. Göckeler *et al.* [QCDSF/UKQCD Collaboration], Phys. Lett. B **627**, 113 (2005) [arXiv:hep-lat/0507001].

[16] H. W. Lin *et al.*, Phys. Rev. D **78** (2008) 014505 [arXiv:0802.0863 [hep-lat]].

[17] S. Ohta and T. Yamazaki [RBC/UKQCD] PoS **LAT2008** (2008) 168 [arXiv:0810.0045 [hep-lat]].

[18] A. D. Martin *et al.*, Eur. Phys. J. C **23**, 73 (2002) [arXiv:hep-ph/0110215]; Eur. Phys. J. C **28**, 455 (2003) [arXiv:hep-ph/0211080].

[19] W. Detmold *et al.*, Phys. Rev. Lett. **87** (2001) 172001 [arXiv:hep-lat/0103006].

[20] G. S. Bali, S. Collins and A. Schaefer, arXiv:0910.3970 [hep-lat]; PoS **LAT2008** (2008) 161 [arXiv:0811.0807 [hep-lat]].

[21] W. Detmold, W. Melnitchouk and A. W. Thomas, Mod. Phys. Lett. A **18**, 2681 (2003) [arXiv:hep-lat/0310003].

[22] W. Detmold and C. J. D. Lin, Phys. Rev. D **71** (2005) 054510 [arXiv:hep-lat/0501007].