LATTICE CALCULATION OF BARYON MASSES USING THE CLOVER FERMION ACTION

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We present a calculation of the lowest-lying baryon masses in the quenched approximation to QCD. The calculations are performed using a non-perturbatively improved clover fermion action, and a splitting is found between the masses of the nucleon and its parity partner. An analysis of the mass of the first radial excitation of the nucleon finds a value considerably larger than that of the parity partner of the nucleon, and thus little evidence for the Roper resonance as a simple three-quark state.

1 Introduction

The calculation of the excited nucleon spectrum provides a theatre to explore many of the central questions in hadronic physics, including the applicability of the quark model, the role of excited glue, and the existence of “molecular” states. Recently, several lattice calculations of the masses of lowest-lying nucleon states have appeared, using a variety of fermion actions. In this talk, I describe a calculation of the mass of the lowest-lying negative-parity state using an $O(a)$-improved clover fermion action. By using a variety of volumes and lattice spacings, we are able to estimate finite-volume and finite-lattice-spacing effects; further details of this calculation are provided in earlier papers. For a subset of our lattices, we also determine the mass of the first radial excitation of the nucleon.
2 Calculational Details

There are two interpolating operators that we will consider in our measurement of the low-lying $J = 1/2$ nucleon spectrum:

\[
N_{1/2^+} = \epsilon_{ijk}(u_i^T C \gamma_5 d_j)u_k, \\
N_{2/2^+} = \epsilon_{ijk}(u_i^T C d_j)\gamma_5 u_k.
\]

These operators have an overlap with particles of both positive and negative parity; on a lattice periodic or anti-periodic in time, the best delineation that can be achieved is that of a forward-propagating positive-parity state, and a backward-propagating negative-parity one.

The “diquark” piece of $N_1$ couples upper, or large, spinor components whilst that of $N_2$ couples an upper and a lower spinor component and hence vanishes in the non-relativistic limit. Thus we expect $N_1$ to have a better overlap with the positive-parity ground state than $N_2$. The expectation is that $N_2$ couples primarily to the lightest radial excitation of the nucleon, which experimentally is the so-called Roper resonance $N^*(1440)$.

The calculation is performed in the quenched approximation to QCD, using the the standard Wilson gluon action and the non-perturbatively improved “clover” fermion action. The quark propagators are computed using both local and smeared sources. Where possible, errors on the fitted masses are computed using a bootstrap procedure, but simple uncorrelated $\chi^2$ fits are employed in the chiral extrapolations.

3 Results

The masses of the nucleon and its parity partner are obtained from four-parameter fits to the two-point correlators of $N_1$. For the chiral extrapolation of the masses, we adopt the ansatz

\[
(a m_X)^2 = (a M_X)^2 + b_2 (a m_\pi)^2
\]

where $X$ is either $N^{1/2^+}$ or $N^{1/2^-}$. The leading non-analytic term in the quenched approximation is linear in $m_\pi$, but results for $a M_X$ are insensitive to this term, and indeed in the case of $N^{1/2^+}$ we find a coefficient whose central value differs in sign from that predicted.

In order to compare our data to experiment, we show in Figure 1 the masses of the nucleon and its parity partner at each lattice spacing; we find good consistency between the lattice calculation and the physical values, despite systematic uncertainties due to the chiral extrapolation, finite-volume and the use of the quenched approximation.
Figure 1. Masses of nucleon and its parity partner in units of $r_0^{-1}$ where $r_0 \sim 0.5$ fm. The labels “Jacobi” and “Fuzzed” refer to two different nucleon smearing techniques used to improve the signal for the ground-state masses.

The nature of the Roper, the first nucleon excitation, has long been debated. In Figure 2, we show the effective masses of the positive- and negative-parity states constructed from $N_1$, and of the positive-parity state constructed using $N_2$ for a quark mass around that of the strange; it is clear that the latter mass is considerably higher than that of the negative-parity state, and therefore much heavier than the Roper (1440). The ordering of the masses at each quark mass is also shown in the figure, revealing a mass splitting between the radial excitation and the nucleon parity partner comparable to that between the parity partner and the nucleon, in accord with other lattice calculations.

4 Conclusions

We have seen that the low-lying excited nucleon spectrum is accessible to lattice calculation, and that lattice calculations are already providing valuable insight, most notably through the lack of evidence for the Roper resonance as a naive three-quark state. Increasingly energetic excitations are subject to increasing statistical noise, and thus further precise calculations will require the full panoply of lattice technology, such as the use of anisotropic lattices. Such lattice calculations will provide the vital theoretical complement to the experimental programme at Jefferson Laboratory and elsewhere.
Figure 2. The left-hand plot shows the effective masses of the positive-parity states using $N_1$ (circles) and $N_2$ (bursts), and negative-parity using $N_1$ (diamonds). The right-hand plot shows the corresponding fitted masses at $(a/r_0)^2 \sim 0.02$, the middle points in Figure 1.

Acknowledgements

This work was supported in part by DOE contract DE-AC05-84ER40150 under which the Southeastern Universities Research Association (SURA) operates the Thomas Jefferson National Accelerator Facility, by EP-SRC grant GR/K41663, and PPARC grants GR/L29927, GR/L56336 and PPA/P/S/1998/00255. MG acknowledges financial support from the DFG (Schwerpunkt “Elektromagnetische Sonden”).

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