LATTICE CALCULATION OF BARYON MASSES USING CLOVER FERMION ACTION

D.G. RICHARDS
Jefferson Laboratory, 12000 Jefferson Avenue, Newport News, VA 23606, USA

M. GÖCKELER, P.E.L. RAKOW
Institut für Theoretische Physik, Universität Regensburg, D-93040 Regensburg, Germany

D. PLEITER, G. SCHIERHOLZ
Deutsches Elektronen-Synchrotron DESY, John von Neumann Institute for Computing NIC/Deutsches Elektronen-Synchrotron DESY, D-15738 Zeuthen, Germany

R. HORSLEY, C.M. MAYNARD
Department of Physics & Astronomy, University of Edinburgh, Edinburgh EH9 3JZ, Scotland, UK

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 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 rôle of excited glue, and the existence of "molecular" states. Recently, several calculations of the masses of lowest-lying nucleon states have appeared, using a variety of fermion actions. [1,2,3,6] In this talk, I describe a calculation of the mass of the lowest-lying negative-parity state using an $\mathcal{O}(a)$-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. [4,5] 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:

$$N_1^{1/2+} = \epsilon_{ijk}(u_i^T C\gamma_5 d_j)u_k,$$
$$N_2^{1/2+} = \epsilon_{ijk}(u_i^T C d_j)\gamma_5 u_k. \tag{1}$$

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 postive-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 χ^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 positive- and negative-parity correlators of N_1. For the chiral extrapolation of the masses, we adopt the ansatz

$$(am_X)^2 = (aM_X)^2 + b_2(am_\pi)^2 \tag{2}$$

where X is either $N^{1/2+}$ or $N^{1/2-}$. The leading non-analytic term in the quenched approximation is linear in m_π, [7] but our data are insensitive to this term, and indeed 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.

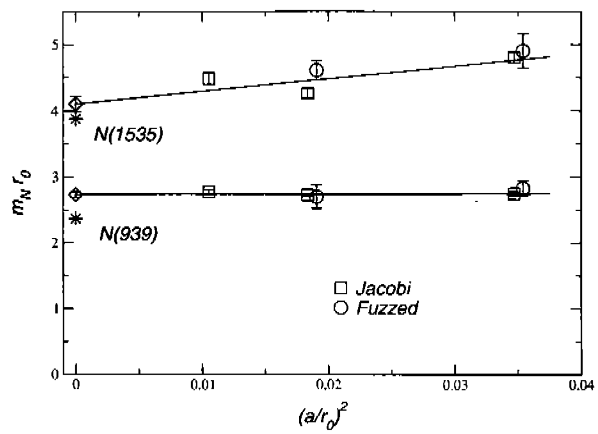

Figure 1. Masses of nucleon and its parity parnter in units of r_0^{-1} where $r_0 \sim 0.5$ fm.

The nature of the Roper, the first nucleon excitation, has long been debated in both the experimental and theory communities. In Figure 2, we show the effective masses of the positive- and negative-parity correlators constructed from N_1, and of the positive-parity correlator constructed using N_2 for a quark mass around that of the strange; it is clear that the latter mass is much higher than that of the Roper. The ordering of the masses at each quark mass is also shown in the figure, revealing a mass splitting between the radial excitation and its parity partner comparable to that between the parity partner and the nucleon, in accord with other lattice calculations. [1,2,3]

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, further precise calculations will require the full panoply of lattice technology, such the use of anisotropic lattice. [2,8] Such lattice calculations will provide the vital theoretical complement to the experimental programme at Jefferson Laboratory and elsewhere.