Physical Nucleon Form Factors from Lattice QCD

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Abstract. We explore the possibility of extrapolating state of the art lattice QCD calculations of nucleon electromagnetic form factors to the physical regime. We find that the lattice results can be reproduced using the Light Front Cloudy Bag Model by letting its parameters be analytic functions of the quark mass. We then use the model to extrapolate the lattice result to the physical value of the pion mass, thereby allowing us to study how the predicted zero in $G_E(Q^2)/G_M(Q^2)$ for proton varies as a function of quark mass.

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INTRODUCTION

The recent measurements of the ratio of the electric and magnetic form factors of the proton, G_E/G_M, using recoil polarization method [1, 2] have revealed a dramatic decrease with Q^2. This contradicted the earlier measurements based on the Rosenbluth separation method, which in turn heated theoretical discussions of the problem. To resolve this contradiction we need direct guidance from the first principle QCD calculations, which leaves us with lattice QCD simulations as the only choice for such rigorous calculations. The recent simulations of nucleon electromagnetic form factors presented by QCDSF Collaboration provide us with such data over a wide range of values of momentum transfer [3]. Several lattice spacings were chosen in this calculation with the smallest being around 0.05 fm ($\beta = 6.4$) and at present these are the state of the art. The quark masses used in the simulations correspond to pion masses in the range $(0.6, 1.2)$ GeV. Therefore one needs to parametrize the form factors as a function of pion mass and extrapolate to the physical value before comparing these lattice results with the experimental data. There is no model independent way to respect the constraints of chiral symmetry over the range of Q^2 and m_π required by the QCDSF data. In performing this extrapolations we first wish to use the lattice data to investigate whether a particular quark model is capable of describing the properties of the nucleon in this additional dimension of varying m_π. Then, having confirmed that, we use the model to extrapolate to the physical pion mass. For this purposes we consider in this work the light front cloudy bag model (LFCBM) [4], which was developed as a means of preserving the successes of the original cloudy bag model [5], while ensuring covariance in order to deal unambiguously with modern high energy experiments. The light-front dynamics is employed to maintain Poincaré invariance and one pion-loop corrections are added to incorporate significant pion cloud effects (particularly in the neutron electric form factor and magnetic moments) as well as the leading non-analytic behavior imposed by chiral symmetry. The LFCBM is defined by its four parameters: β and γ that describe the nucleon wave function, M, the constituent quark mass and Λ, which parametrizes the relativistic πN form factor. These parameters are chosen in LFCBM so to best reproduce the experimental data.

FITTING THE QCDSF FORM FACTORS AND EXTRAPOLATING TO THE PHYSICAL PION MASS.

We use data produced by the QCDSF Collaboration [3] and employ the LFCBM to calculate the corresponding form factors, varying the model parameters to find the best-fit to the different sets of lattice data obtained for different values of the current quark mass, m_q. The behavior of the fitting parameters is then represented by a polynomial function of the quark mass m_q. This polynomial fit in m_q, or equivalently in pion mass squared, m_π^2, can then be used to extrapolate the values of the fitting parameters to the physical pion mass. Nucleon form factors for the physical pion mass are then calculated using the extrapolated values for the model parameters. To obtain the fits to the lattice data we vary constituent quark mass M and nucleon wave function parameter γ as to obtain the minimum of χ^2 function for the deviation between lattice data and LFCBM calculations. The model is insensitive to the variations of the other two parameters β and Λ at the lattice pion masses, so we fixed them to the values defined in LFCBM. The resulting fits are in good agreement with data.[1] We use the extrapolated values of γ and M to calculate the nucleon electric and magnetic form factors using the physical pion and nucleon masses. The resulting plot for the ratio G_E/G_M vs. Q^2 for the proton is shown in Figure 1, which shows that our results are in more or less good agreement with the experimental data in the low-Q^2 region, but yield a slightly lower value of Q^2 for the zero cross-over point than that extrapolated from experiment [12]. A new analysis that includes an estimate of all of the effects of two photon exchange yields a zero-crossing value that is somewhat closer to ours [13] but future data will resolve this unambiguously.

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[1] Please reffer to [6] for corresponding plots of G_E and G_M for proton and neutron.

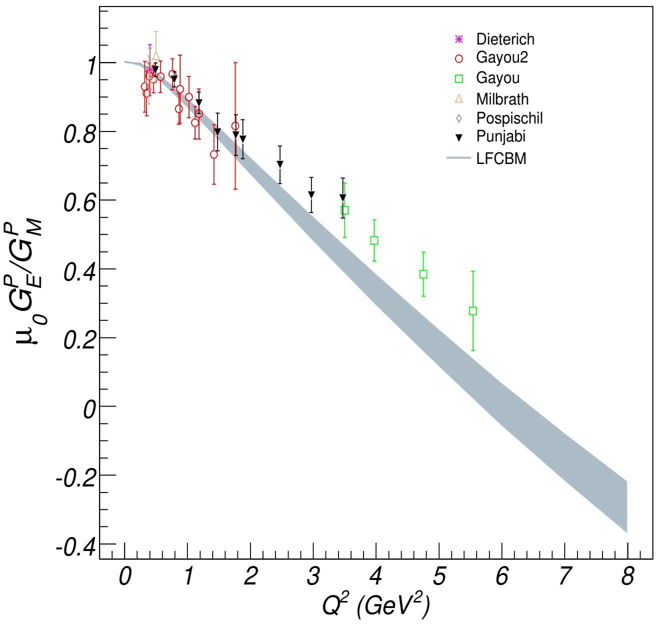

FIGURE 1. (Color Online)R$_p$, the ratio $\mu_p G_p^E/G_p^M$. Comparison of extrapolated calculations for the ratio of proton form factors, $\mu_0 G_E/G_M$, for lattice spacing $a = 0.26\ GeV^{-1}$ with the data. The experimental points used are taken from Refs.: Dieterich [7], Gayou2 [8], Gayou [2], Milbrath [9], Pospischil [10] and Punjabi [11]

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