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Improved Determination of Hadron Matrix Elements using the Variational Method

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Abstract

Utilising lattice QCD to calculate nucleon matrix elements has had a huge impact on the knowledge of the structure of nucleons. From the comparison to experimental data, to the new insights into the structure of nucleons, the practices of lattice QCD has cemented itself as a fundamental field for particle physics. Some key contributions to the understanding of nucleon structure lattice QCD can provide are parameters needed for the *beyond standard model* (BSM) extensions, understanding the size of the nucleons via the charge radii and the decomposition of the spin and angular momentum of the quarks and gluons within the nucleon.

But the extraction of hadron matrix elements in lattice QCD using the standard two- and three-point correlator functions demands careful attention to systematic uncertainties. Although other systematics including discretisation, renormalisation and chiral extrapolation effects need to be analysed, one of the most recent and emerging sources of systematic error is contamination from excited-states.

This thesis applies the variational method to calculate the axial vector current g_A, the scalar current g_S, the tensor current g_T and the quark momentum fraction $\langle x \rangle$ of the nucleon and we compare the results to the more commonly used summation and two-exponential fit methods. Proceeding with the same comparison of methods, we extend the calculation to non-zero momentum transfer to access the vector form factors for both the proton and neutron, as well as the iso-vector combination of the axial and induced pseudoscalar form factors for the proton. The results demonstrate how excited-states affect the extraction of nucleon matrix elements and in the process discovering that the variational approach offers a more efficient and robust method for the determination of nucleon matrix elements.

Through this demonstration of how excited-states impact lattice QCD calculation and how we can use methods to suppress these excited-states, we can hope to achieve higher and higher precision determinations of nucleon matrix elements form lattice QCD which will aid in our understanding of the structure of nucleons.

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Jack Dragos

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