RIKEN Accel. Prog. Rep. 49 (2016)

High-precision calculation of the strange nucleon electromagnetic form factors†

J. Green,*1 S. Meinel,*2,*3 M. Engelhardt,*4 S. Krieg,*5,*6 J. Laeuchli,*7 J. Negele,*8 K. Orginos,*9,*10 A. Pochinsky,*8 and S. Syritsyn*2

The nucleon electromagnetic form factors describe how electric charge and current are distributed inside protons and neutrons. Protons and neutrons primarily contain up and down quarks, but virtual strange-anti-strange quark pairs also give minute contributions to the form factors. Isolating these contributions has been a long-standing challenge for experiment and theory. The strange electromagnetic form factors, G_E^s and G_M^s, can be accessed in elastic electron-proton scattering by analyzing the small parity-violating effects arising from Z-boson exchange. The available experimental results, which focus on momentum transfers Q^2 in the vicinity of $0.2\,\mathrm{GeV}^2$, are consistent with zero but constrain the relative contribution of the strange quarks to be within a few percent[1].

Ab-initio calculations of G_E^s and G_M^s are possible using lattice QCD. This is a formidable task because it requires the computation of quark-disconnected diagrams, which are very noisy. The noise originates both from the gauge-field fluctuations of the QCD path integral, and from the stochastic methods needed to evaluate the disconnected quark loops. In this work, we performed a lattice QCD calculation of the strange nucleon electromagnetic form factors using a novel variance reduction method called *hierarchical probing*[2]. Our lattice results for G_E^s and G_M^s, along with model-independent fits using the z expansion, are shown in Fig. 1. This is the first time that both G_E^s and G_M^s are resolved from zero with high significance. In addition, our calculation was performed in a larger lattice volume and at a closer-to-physical light-quark mass (corresponding to $m_\pi = 317$ MeV) than previous work.

From the z-expansion fits of the Q^2-dependence, we determined the strange electric and magnetic charge radii $(r^2_{E,M})^s \equiv -6\,\mathrm{d}G^s_{E,M}/\mathrm{d}Q^2|_{Q^2=0}$, and the strange magnetic moment $\mu^s \equiv G_M^s(0)\,\mu_N$ (where μ_N is the nuclear magneton). We also performed simple extrapolations of these quantities to the physical pion mass, obtaining

$$
\begin{aligned}
(r_E^2)^s &= -0.0067(10)(17)(15)\,\mathrm{fm}^2,\\
(r_M^2)^s &= -0.018(6)(5)(5)\,\mathrm{fm}^2,\\
\mu^s &= -0.022(4)(4)(6)\,\mu_N.
\end{aligned}
$$

The first two uncertainties given here originate from the statistical and systematic uncertainties in the lattice QCD calculation itself, and the last uncertainty results from the extrapolation to the physical point. For comparison, a global analysis of parity-violating asymmetry data for elastic electron-proton scattering gives $\mu^s = -0.26(26)\,\mu_N$[1], which is consistent with our result but has a much larger uncertainty.

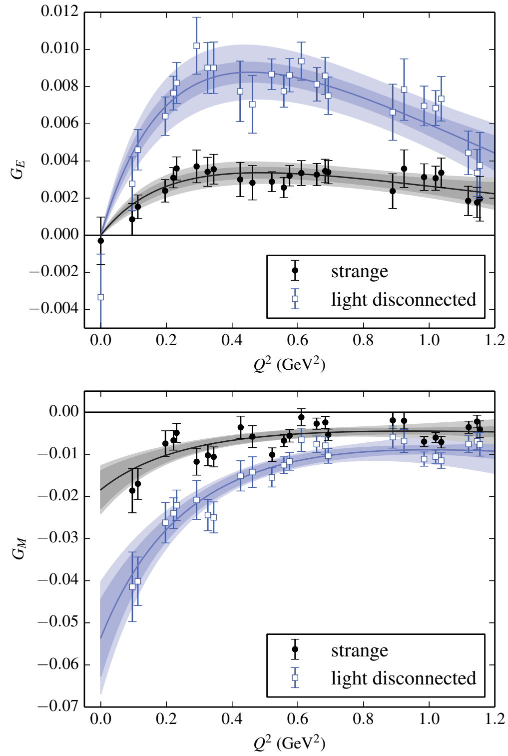

Fig. 1. Strange-quark and disconnected light-quark electric and magnetic form factors of the nucleon, for a light-quark mass corresponding to $m_\pi = 317$ MeV.

† Condensed from the article in Phys. Rev. D **92**, 031501 (2015)

*1 Institut für Kernphysik, Johannes Gutenberg-Universität Mainz
*2 RIKEN Nishina Center
*3 Department of Physics, University of Arizona
*4 Department of Physics, New Mexico State University
*5 Bergische Universität Wuppertal
*6 IAS, Jülich Supercomputing Centre, Forschungszentrum Jülich
*7 Department of Computer Science, College of William and Mary
*8 Center for Theoretical Physics, Massachusetts Institute of Technology
*9 Physics Department, College of William and Mary
*10 Thomas Jefferson National Accelerator Facility

References

1) R. González-Jiménez, J. A. Caballero, and T. W. Donnelly, Phys. Rev. D **90**, 033002 (2014).
2) A. Stathopoulos, J. Laeuchli, and K. Orginos, SIAM J. Sci. Comput. **35(5)**, S299–S322 (2013).