FUNDAMENTAL INTERACTIONS IN NUCLEI

FINAL PROGRESS REPORT

MICHAEL J. RAMSEY-MUSOLF

UNIVERSITY OF CONNECTICUT
STORRS, CT 06269

MARCH 2003

DOE Patent Clearance Granted
MP Dvorscak
Mark P Dvorscak
(630) 252-2393
E-mail mark.dvorscak@ch.doe.gov
Office of Intellectual Property Law
DOE Chicago Operations Office
9-29-03
Date

PREPARED FOR

THE U.S. DEPARTMENT OF ENERGY
AWARD NO. DE-FG0200ER41146

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Final Report: Fundamental Interactions in Nuclei
PI: M.J. Ramsey-Musolf

The research supported by this grant was carried out in four areas: (a) physics beyond the Standard Model (SM) (b) fundamental symmetries (c) the interpretation of precision electroweak measurements (d) topics in hadron structure. Three Ph.D. students (S. Puglia, A. Kurylov, and G. Sacco) were supported, two of which completed their Ph.D. degrees (S. Puglia in 4/01 and A. Kurylov in 8/02). Both Dr. Puglia and Dr. Kurylov have obtained post-doctoral positions in nuclear theory (S. Puglia at Ohio State and A. Kurylov at Caltech). Mr. Sacco continues his Ph.D. dissertation research. Support was provided for one post-doc (G. Prezeau). The PI also served as an informal advisor to a University of Washington Ph.D. student (C.-P. Liu).

The primary projects are results of the research supported under this grant are summarized below:

Physics Beyond the Standard Model

A study of possible effects of parity-conserving, time-reversal violating interactions in atomic electric dipole moments was completed. The results indicate that constraints from atomic EDM measurements on such P-even, T-odd interactions are considerably weaker than those obtained from either the electron or neutron EDM's. A program to compute the effects of supersymmetric electroweak radiative corrections to a variety of low-energy precision electroweak observables was undertaken. Three publications have resulted so far. In the study of charged current reactions, we found that the implications of low-energy data appear to conflict with generic features of the spectrum of SUSY particles implied by flavor-blind models of SUSY-breaking mediation. In the neutral current sector, we showed that a comparison of parity-violating ee and ep scattering could test the viability of SUSY dark matter (R-parity). Third, we computed SUSY radiative correction effects in deep inelastic neutrino-nucleus scattering to determine if the recently reported NuTeV anomaly could be explained by SUSY. Our results indicate that SUSY contributions generate the opposite sign effect from what is needed to account for the NuTeV anomaly.

1. "Constraints on T-Odd, P-Even Interactions from Electric Dipole Moments, Revisited", A. Kurylov, G.C. McLaughlin, and M.J. Ramsey-Musolf, *Phys. Rev. D* **63**: 076007 (2001).
2. "Charged Current Universality in the MSSM", A. Kurylov and M.J. Ramsey-Musolf, *Phys. Rev. Lett.* **88**: 071804 (2002).
3. "Probing Supersymmetry with Parity-Violating Electron Scattering", A. Kurylov, M.J. Ramsey-Musolf, and S. Su, [hep-ph/0303026] (2003).

4. "Supersymmetric Effects in Deep Inelastic Neutrino-Nucleus Scattering", A. Kurylov, M.J. Ramsey-Musolf, and S. Su, [hep-ph/0301208] (2003).

Fundamental Symmetries

In collaboration with W. Haxton and C.-P. Liu (U. of W. PhD student, now a post-doc at TRIUMF), the PI completed an analysis of the anapole moments of heavy nuclei. This analysis provides the most complete two-body computation of the nuclear anapole moment for cesium, which has been measured in atomic parity violation by the Boulder group. The results confirm earlier, one-body treatments that suggest the cesium results are inconsistent with the constraints placed by other hadronic PV experiments on the PV nucleon-nucleon interaction. A reformulation of the hadronic PV problem using effective field theory was also undertaken in collaboration with B. Holstein, U. van Kolck, S.-L. Zhu, and C. Maekawa. The latter project is nearing completion. Third, study of neutrinoless $\beta\beta$ -decay from the standpoint of effective field theory was undertaken in collaboration with P. Vogel and G. Prezeau. The latter project is also nearing completion and a manuscript is in preparation.

1. "Nuclear Anapole Moments", W.C. Haxton, C.P. Liu, and M.J. Ramsey-Musolf, Phys. Rev. C **65**: 045502 (2002).
2. "Anapole Moment and Other Constraints on the Strangeness Conserving Hadronic Weak Interaction", W.C. Haxton, C.P. Liu, and M.J. Ramsey-Musolf, Phys. Rev. Lett. **86**: 5247 (2001).

Interpretation of Precision Electroweak Measurements

Several projects were undertaken. A study of the weak charge of the proton, which will be measured in PV elastic electron scattering at the Jefferson Lab was carried out. We showed that the QCD-related theoretical uncertainties are considerably smaller than the proposed experimental precision, making this observable a theoretically clean probe of new physics. We also showed now the proton and electron weak charges (the latter being measured at SLAC) provide complementary information on physics beyond the SM.

M. Wise and I analyzed the hadronic light-by-light contribution to the muon anomalous magnetic moment in chiral perturbation theory. We computed all the leading and sub-leading large logarithmic contributions and identified the low-energy constants that must be determined from other experiments. We argued that there exists an uncertainty associated with the overall magnetic moment low-energy constant that should increase the theoretical uncertainty beyond the level quoted for model computations.

Two studies relevant to the program to study strange quarks with PV electron scattering were carried out. In one, we computed the effects of PV NN interactions on the axial response in quasielastic eD scattering. The latter was measured by the SAMPLE collaboration and used, in conjunction with the elastic ep asymmetry measurement, to

separate the axial vector and strange magnetic form factors. We showed that contaminations from PV NN interactions are considerably smaller than the precision with which the two form factors are determined experimentally. A third project is related to the planned determination of the N to Δ axial vector form factor by the G0 collaboration. We computed the relevant electroweak radiative corrections and quantified the level of theoretical uncertainty associated with non-perturbative strong interaction effects in the radiative corrections. We also identified the dependence of the inelastic asymmetry on a new, presently unknown low-energy constant that must be determined by an independent measurement in order to reduce the theoretical uncertainty to an acceptable level.

Two studies of electroweak radiative corrections relevant to low-energy neutrino reactions were carried out. The first corrected errors in previously published work that is relevant to the analysis SNO measurements. In the second, we showed identified a universality among radiative corrections to a variety of low-energy neutrino reactions, including deuterium breakup, inverse β -decay, and the pp reaction in the sun.

1. "The Weak Charge of the Proton and New Physics", J. Erler, A. Kurylov, and M.J. Ramsey-Musolf, [hep-ph/0302149] (2003).
2. "Hadronic Parity-Violation and Inelastic Electron-Deuteron Scattering", C.-P. Liu, G. Prezeau, and M.J. Ramsey-Musolf, [nucl-th/0212041] (2002), to appear in Phys. Rev. C.
3. "Radiative Corrections to Low-Energy Neutrino Reactions", A. Kurylov, M.J. Ramsey-Musolf, and P. Vogel, [hep-ph/0211306] (2002), to appear in Phys. Rev. C.
4. "The Nucleon's Mirror Image: Revealing the Strange and Unexpected", R.D. McKeown and M.J. Ramsey-Musolf, [hep-ph/0203011] (2002).
5. "Hadronic Light-by-Light Contribution to Muon g-2 in Chiral Perturbation Theory", M.J. Ramsey-Musolf and Mark. B. Wise, Phys. Rev. Lett. **89**, 041601 (2002).
6. "Radiative Corrections in Neutrino-Deuteron Disintegration", A. Kurylov, M.J. Ramsey-Musolf, and P. Vogel, Phys. Rev. **C65**: 055501 (2002).
7. "Electroweak Radiative Corrections to Parity Violating Electroexcitation of the Delta", Shi-lin Zhu, C.M. Maekawa, G. Sacco, B.R. Holstein, and M.J. Ramsey-Musolf, Phys. Rev. **D65**: 033001 (2002).

Hadron Structure

1. "What Do We Know About the Strange Magnetic Radius?", H.-W. Hammer, S.J. Puglia, M. J. Ramsey-Musolf, and Shi-lin Zhu, [hep-ph/0206301] (2002).
2. "The Off-diagonal Goldberger-Treiman Relation and Its Discrepancy", Shi-lin Zhu, and M.J. Ramsey-Musolf, Phys. Rev. **D66**: 076008 (2002).
3. "Recoil Order Chiral Corrections to Baryon Octet Axial Currents and Large Nc QCD", Shi-lin Zhu, G. Sacco, and M.J. Ramsey-Musolf, Phys. Rev. **D66**: 034021 (2002).
4. "Parity Violating Photoproduction of the π^+ on the Delta Resonance", Shi-lin Zhu, C.M. Maekawa, B.R. Holstein, and M.J. Ramsey-Musolf, Phys. Rev. Lett. **87**, 201802 (2001).
5. "Subleading Corrections to Parity Violating Pion Photoproduction", Shi-lin Zhu, S.J. Puglia, B.R. Holstein, and M.J. Ramsey-Musolf, Phys. Rev. **C64**: 035502 (2001).
6. "Recoil Order Chiral Corrections to Baryon Octet Axial Currents, Shi-lin Zhu, S.J. Puglia, and M.J. Ramsey-Musolf, Phys. Rev. **D63**: 034002 (2001).