Fundamental Symmetries, Precision Probes of the Standard Model and Lattice QCD

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There are a number of potentially high impact nuclear physics experiments underway or planned which will probe the limits of the Standard Model (SM) through precision tests of its fundamental symmetries. The interpretation of these experiments and their relation to Beyond the Standard Model (BSM) physics requires a solution of QCD in the low-energy regime. The US lattice QCD community has developed the theory, technology and computational tools to perform many of these needed calculations with control over all systematic errors. Applications of lattice QCD related to fundamental symmetries include precision beta-decay of neutrons, hadronic parity violation, EDMs of the neutron, nuclei and atoms, and neutrinoless double beta-decay. In this brief executive summary, we provide examples of deliverables relevant to the fundamental symmetry program, estimated by the U.S. lattice QCD community in a number of reports and white papers. These examples are an integral part of the broader Computational Nuclear Physics initiative, highlighted in the recent Computational Nuclear Physics white paper.

I. EXCECUTIVE SUMMARY

The interpretation of fundamental symmetries tests performed using hadrons and nuclei requires understanding the hadron or nucleus used as a "laboratory". This in turn requires solving non-perturbative dynamics at several scales, from hadrons to few- and many-body nuclei, with a range of techniques spanning from lattice QCD to nuclear many-body methods. These efforts, essential to maximize the impact of fundamental symmetry and precision Standard Model tests, are an integral part of the Computational Nuclear Physics initiative [1]. Within this broader framework, one can identify a number of symmetry tests for which lattice QCD calculations are expected to have very high impact.

The U.S. lattice QCD community has been periodically carrying out an assessment of what it can deliver that would impact experiments in the areas of fundamental symmetries and Beyond the Standard Model physics [2–4]. As discussed in the Computational Nuclear Physics white paper [1], progress can be accelerated significantly by a coordinated effort between experiment, theory and computational physics. The future computational needs required to reach these goals are set out in the "recommendations and requests" of the Computational Nuclear Physics white paper. To assess the current state-of-the-field, a meeting of all U.S. collaborations working in this area was held in Washington D.C. during Septemter 18-19, 2014. Based on a review of the status of current results, algorithms, previous detailed reports and the rate of progress over the last two years, they concluded that a cohesive collaborative effort under the "recommendations and requests" of the Computational Nuclear Physics is poised to provide the following estimates over the next three years:

1. The nucleon axial charge, g_A, to 4% precision

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2. Nucleon isovector charges g_S and g_T with 10% precision. Precision measurements of the Fierz interference term and decay correlations in neutron and nuclear beta-decays require $g_{S,T}$ to constrain novel scalar and tensor interactions at the TeV scale.

3. Nucleon isoscalar charge g_T to 20%. This gives the contribution to the neutron EDM from the quark EDM.

4. Nucleon sigma term and scalar matrix elements at the 20% level. This will impact our interpretation of direct dark matter detection experiments and mu-to-e conversion experiments by reducing the uncertainty associated to scalar mediators (e.g. SM Higgs, extended Higgs sector, squarks).

5. First results for the neutron EDM due to the Theta-term; the development of methods to calculate quark chromo EDM and quantifications of the systematic error.

6. Matrix elements for novel experiments such as $N\overline{N}$ oscillations, dark matter direct detection, and proton decay.

7. Determine the Isospin 2 contribution to hadronic parity violation in the two-nucleon system at the 25% level, which will also improve our understanding of the Isoscalar contribution; Make a first determination of the Isospin 1 parity violation with all systematics quantified, an extension of the work of J. Wasem, PRC85 022501 (2012), relevant to the NPDGamma results.

With the anticipated increase in computing power due to the next generation of leadership class computers that will become available during the period 2016-2018, the 7 year goal of the community is to reduce the above errors by a factor of 2. These examples are drawn from the Computational Nuclear Physics white paper [1], the 2009 ExaScale report [2] and the recent USQCD white papers on projected lattice QCD computations relevant to the US fundamental symmetry and precision tests of the Standard Model physics program [3, 4]. There are now several lattice QCD collaborations working towards these efforts.

Ultimately, progress in our understanding of this important physics, and its relation to the Standard Model and beyond, will require a coordinated effort between experiment, theory and computational physics. The future computational needs required to reach these goals are set out in the “recommendations and requests” of the Computational Nuclear Physics white paper [1].

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