PRECISION TEST OF THE WEAK NUCLEAR FORCE

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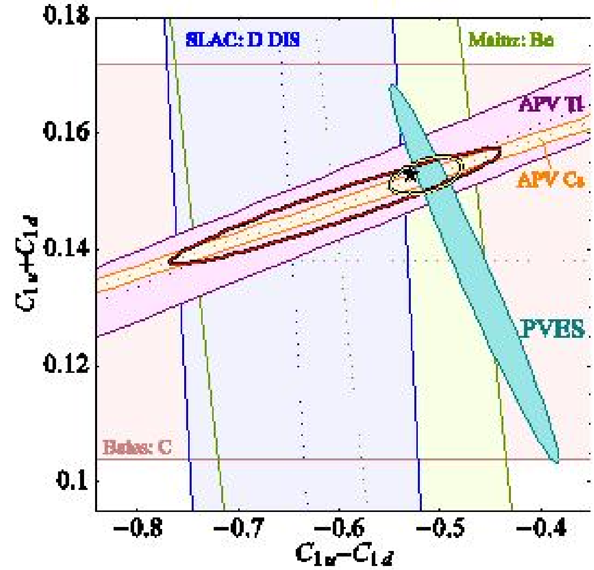
INTRODUCTION

The Standard Model has been enormously successful at describing experiments in nuclear and particle physics. The search for new physical phenomena beyond the Standard Model is driven by two complementary experimental strategies. The first is to build high-energy colliders, such as the Large Hadron Collider (LHC) at CERN, which aim to excite a new form of matter from the vacuum. The second, more subtle approach is to perform precision measurements at moderate energies, where an observed discrepancy is a signature of such new forms of matter. Here we show that the latest measurements of the electroweak force severely constrain the possibility of physics beyond the Standard Model to the TeV (10^{12} electronvolts) energy scale.

ELECTROWEAK INTERACTION

The Standard Model is built upon three generations of fundamental fermions, each consisting of a set of quarks (e.g., the up and down quarks which compose the nuclei of which we are made) and leptons (e.g., the electron and its neutrino). Within this framework, the strong force between the quarks is carried by the exchange of virtual gluons, while the unified theory of electricity, magnetism and the weak force (the electroweak theory) involves the exchange of the massless photon and three heavy vector bosons, the $W^{\pm}$ and the Z^0 (the neutral current), which were discovered at CERN in 1983. After three decades of experimental tests, the only indication of vulnerability in the Standard Model lies in the recent discovery of neutrino oscillations (1).

In high-energy collider experiments, Z^0 bosons can be produced in large abundance. These high-statistics measurements allow a precise determination of the production rates of these bosons. The Standard Model predicts a precise relation between these observed production rates and the "strength" of the weak nuclear force (or static interaction). For our purposes, we can parametrize the weak force between an electron and either and up or a down quark by the "charge" parameters, C_{1u} and C_{1d}.



These parameters are analogous to the product of charges, Q_1Q_2, used in calculating (for example) the Coulomb force in electrostatics.

While these weak charge parameters, C_{1q}, can be precisely inferred from collider measurements, there is significantly less precision known from measuring the static interaction directly. The most precise direct measurements come from atomic parity violation, particularly Cesium (2). The summary of all previous knowledge at the 95% confidence level is shown by the red ellipse. Excellent agreement is observed with the prediction of the Standard Model (black star).

RESULTS

There has been recent experimental progress in parity-violating electron scattering (PVES) from nuclear targets. In these experiments, an asymmetry is measured between the scattering cross sections of left- and right-hand polarized electron beams. This parity-violating asymmetry directly isolates the weak interaction. The principal motivation of these measurements has to been to use the weak force to isolate the strange quark charge and current distributions of the nucleon.

Using the same experimental asymmetries employed to probe the strange quark content of the nucleon (3), we also find significant constraint on the weak charge parameters. The teal ellipse in the figure shows the net constraint obtained from an ensemble of recent nuclear PVES measurements. The observed improvement is primarily driven by the G0 and HAPPEX measurements performed at Jefferson Lab (4,5), where the combined kinematic coverage and experimental precision are paramount in this analysis. Further, as most of these measurements are on a proton target, we obtain an essentially orthogonal constraint to the Cesium measurement. Combining the PVES measurements with the earlier results yields a factor of 5 improvement in the experimental determination of the weak charges, as shown by the gold ellipse.

The combined result is in excellent agreement with the Standard Model prediction. The improvement in precision places tight constraints on the strength of forces arising from sources beyond the Standard Model. In particular, the lower-bound on the relevant mass scale of new physics is raised to 0.9 TeV (6).

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