Proton decay matrix elements at physical quark mass

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Proton decay is a smoking-gun signal of the physics beyond the standard model (BSM). Grand unified theory (GUT) is the most natural origin of such an event if observed. Despite no clear signal of the supersymmetry or any BSM phenomena at LHC, the idea of unifying the known fundamental interactions is still attractive. Estimate of the QCD contribution of the proton decay matrix element is needed to test GUTs against the proton lifetime bound obtained in the experiment. Also a reliable estimate of the matrix elements is desirable for planning the future generation proton decay detectors.

The proton decay matrix elements are obtained by numerical computation using lattice QCD. So far, the $2+1$ flavor computations have provided the matrix elements with extrapolation to the physical ud quark mass from the results at unphysically large masses. This procedure yields one of the largest systematic uncertainties. Settling this systematics is important1) and possible using current lattice gauge field ensembles generated at the physical point.

We use gauge field configurations of $2+1$ flavor QCD generated with non-perturbatively $O(a)$-improved Wilson fermions by the PACS collaboration.2) As pointed in the previous works (see *e.g.*3)), computations using the three-point functions are mandatory to obtain the matrix elements of a proton decaying into a pseudoscalar (and an anti lepton). Last year we reported on the optimization of the parameters of smearing function of the quarks for interpolating operators of proton and mesons. Using this we are extending the computation for the three-point functions. Figure 1 shows the ratio of the three and two-point functions for proton decay form factor W_0 for $p \to \pi^0$ via LL operator $(\epsilon_{ijk}(u_i^T C P_L d_j) P_L u_k)$, for three different momentum values $\vec{p} = 2\pi/64 * \vec{n_p}$. From the plateau we will obtain the form factor that we are after. Comparison of the two different source-sink separation t_s is performed, and they show consistent results in the middle. In this study we use 64^4 lattice at the physical point mass. Last year we present a result of low energy constant α computed on 64^4 and 96^4 volumes. As the results from two volumes are consistent, we expect 64^4 is also good for the form factors.

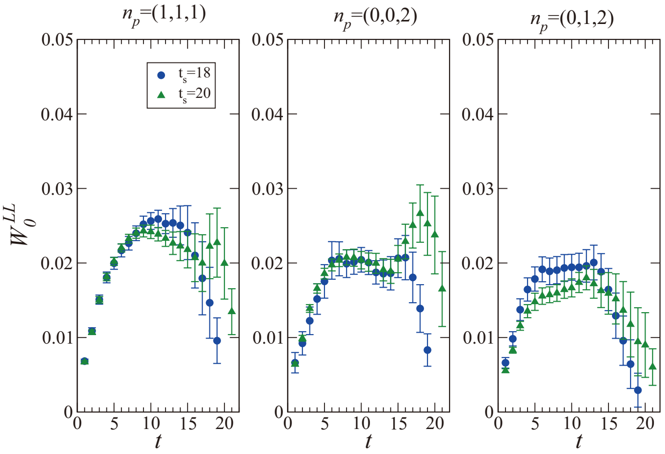

Fig. 1. Time dependence of the ratio of three and two-point functions for proton decay form factor W_0 for $p \to \pi^0$ via LL operator $(\epsilon_{ijk}(u_i^T C P_L d_j) P_L u_k)$. The middle points should converge to the form factor in the asymptotic limit of large source-sink separation t_s, thus develops a plateau.

We need several further steps to obtain the from factors in the physical unit (GeV^2) and renormalized in a convenient renormalization scheme for phenomenological use. For the renormalization one needs to solve the operator mixing due to an explicit chiral symmetry breaking of the Wilson fermion formulation. The non-perturbative renormalization4) can be applied to solve the mixing and at the same time to obtain the totally renormalized operator in the $\overline{\text{MS}}$ scheme. The use of RI/SMOM schemes5) are under investigation. Finally the lattice cutoff squared $1/a^2$ needs to be multiplied.

This study has shown that we have reasonably a good signal for the form factors and the low energy constants (last year) at the physical quark masses. With a full statistics and a supplemental mass dependence analysis, as well as with a completion of the operator renormalization, this work provides results of proton decay matrix elements with no systematic error from chiral extrapolation for the first time. There is another on-going project6) to calculate the same matrix elements with domain-wall fermions with very coarse lattice but with a better control of chiral symmetry. These two studies are complementary to each other and together will bring us to the final goal of estimating the proton decay matrix elements for pseudo-scalar final states with direct simulation at the physical point.

References
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