A pilot study of 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 important[1)] 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). Before jumping into the calculation of the three point functions the values of some optimization parameters needs to be fixed. One of them is the smearing function of the quark fields which enter in the interpolation operator of the proton. The smearing parameter is tuned so that the ground state proton reasonably dominates the two point correlation function of the proton operator. As a bi-product of such a computation, the low energy constants of the proton decay can be extracted with almost no additional computational cost.

One of the low energy constants α is defined as

$$\langle 0|(u^T C P_L d) P_R u(0)|p\rangle = \alpha P_R u_p, \qquad (1)$$

where u and d in the left hand side are u and d quark operators. $P_{L(R)}$ is left (right) handed projection operator to Dirac spinor. The proton p to vacuum matrix element defines the low energy constant α appearing in the right hand side, where u_p denotes the Dirac spinor of the proton at rest.

Figure 1 shows a ratio of the two point functions relevant to the computation of α, which is extracted from the asymptotic plateau of this figure. Hokusai supercomputer at RIKEN has been used to obtain the results. The figure compares two different lattice volumes 64^4 and 96^4. It shows a good plateau and show consistency between two different volumes.

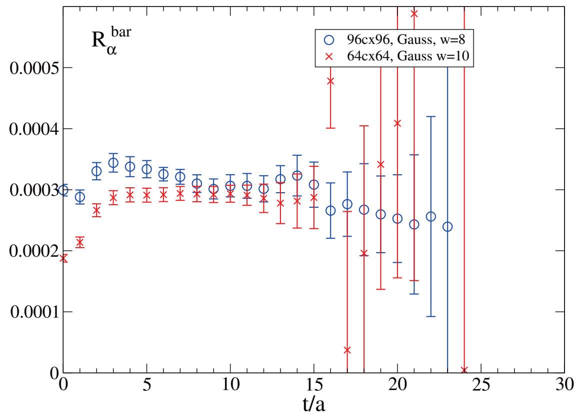

Fig. 1. Local computation $\alpha(t)$ with t being the time separation of the source and sink operators. A low energy constant α is extracted from the asymptotic plateau.

We need several further steps to obtain α in the physical unit (GeV^3) 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 renormalization[4)] can be applied to solve the mixing and at the same time to obtain the totally renormalized operator in the $\overline{\mathrm{MS}}$ scheme. Finally the lattice cutoff cubed $1/a^3$ needs to be multiplied.

This pilot study has shown that we have reasonably a good signal for the low energy constant at the physical quark mass. It gives a confidence to obtain a good signal for the relevant matrix element as the signal/noise ratio of the low energy constant and the relevant matrix element are of similar size in the previous computations. We therefore plan to calculate the three point functions for the proton decay matrix elements on Hokusai in next fiscal year.

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