N3LOW Pictures

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Abstract

Pictures of the new low-momentum chiral EFT potential of Entem and Machleidt, called "N3LOW", which has a sharp cutoff at relative momenta of 400 MeV. The potential is compared to N^3LO potentials with higher (and smoother) cutoffs in their original form and evolved to lower momenta using a smoothly regulated renormalization group ("$V_{\mathrm{low}\,k}$") and with the similarity renormalization group.

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I. BACKGROUND

Most N^3LO chiral effective field theory nucleon-nucleon (NN) potentials have smooth cutoffs with cutoff parameters (in the relative momentum) around 500–600 MeV. A cutoff of this order is desirable to minimize the truncation error in the EFT. The regulators used are not sharp, which means that there are substantial components of the potential at still higher momenta.

By evolving such potentials to lower momenta using renormalization group techniques [2–7], significant improvements in convergence in few- and many-body systems have been found. The question arises whether similar improvements could be achieved simply by developing an N^3LO potential with a lower cutoff. Since a smooth cutoff also distorts observables below the cutoff, one would want to use a sharper cutoff than usual.

An N^3LO chiral potential with a sharp cutoff at about 400 MeV has recently been fitted by Entem and Machleidt and applied in Ref. [1]. Here we look at some pictures of this potential, comparing with other bare N^3LO potentials and with evolved potentials.

First, we note the quality of the phase shifts in Figs. 1 and 2. In the S waves, the N3LOW and N^3LO (500 MeV) [8] phase shifts agree until almost 300 MeV. This is better agreement than one would expect from chiral power counting with the low cutoff in N3LOW, which implies that there is fine-tuning that may distort the power counting. We note that for any of these initial potentials, the phase shifts for evolved SRG potentials will be the same as the original phase shifts, since the transformations are unitary.

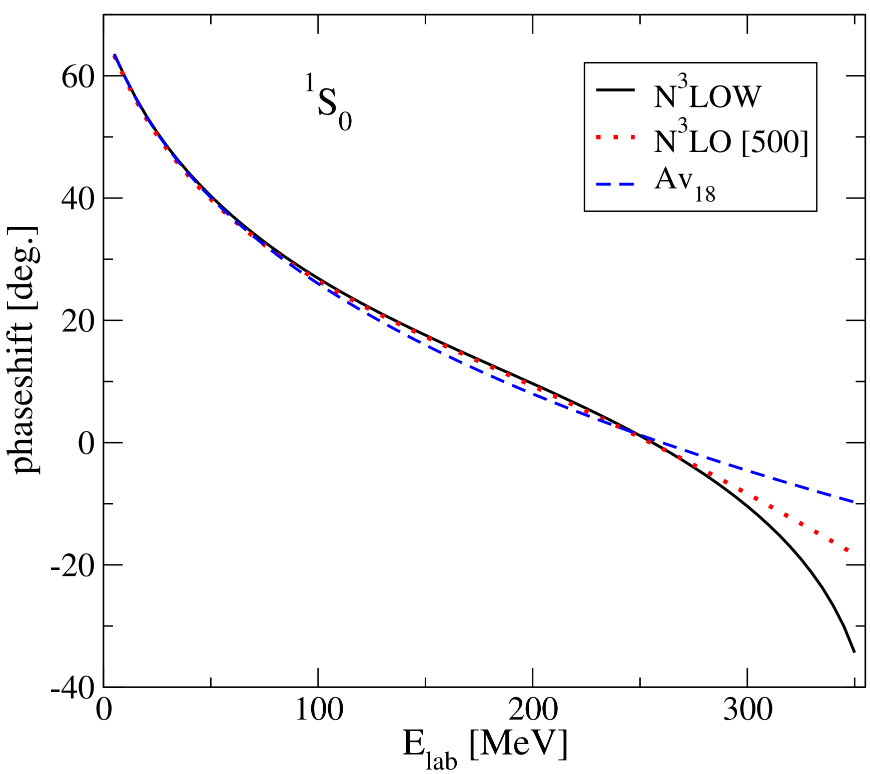


FIG. 1: $^1S_0$ phase shifts for the N^3LOW potential compared to the N^3LO potential with 500 MeV cutoff and the AV18 potential.

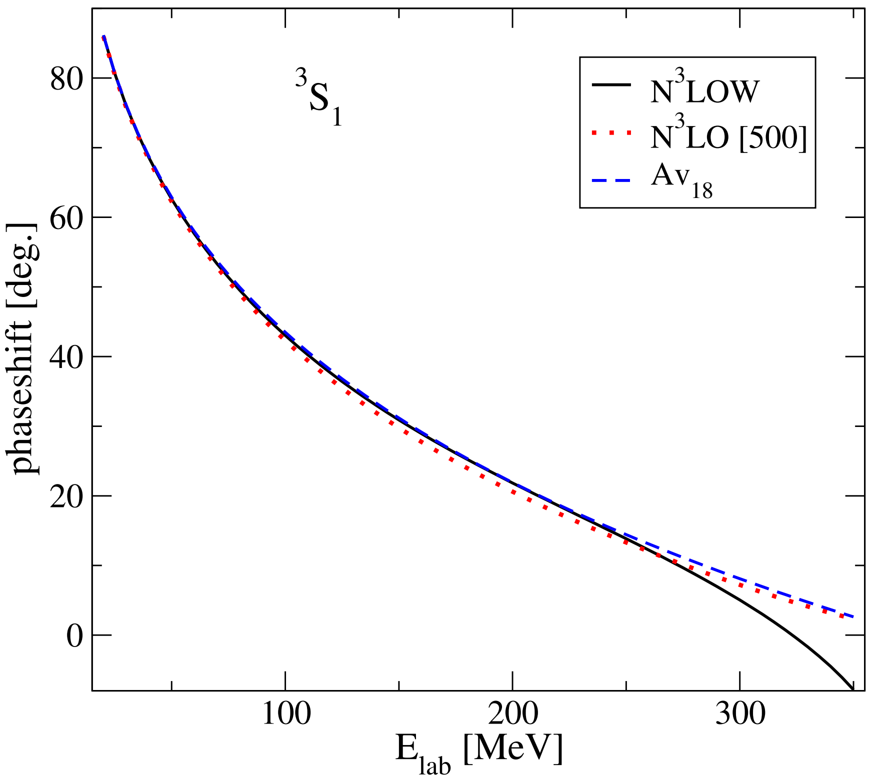


FIG. 2: $^3S_1$ phase shifts for the N^3LOW potential compared to the N^3LO potential with 500 MeV cutoff and the AV18 potential.

II. PLOTS OF $V(k, k')$ IN VARIOUS PARTIAL WAVES

In each case, there is both a color contour plot and a surface plot of the momentum space potential $V(k, k')$ in the specified partial wave. The potential is in units of fm. The plots were created in MATLAB.

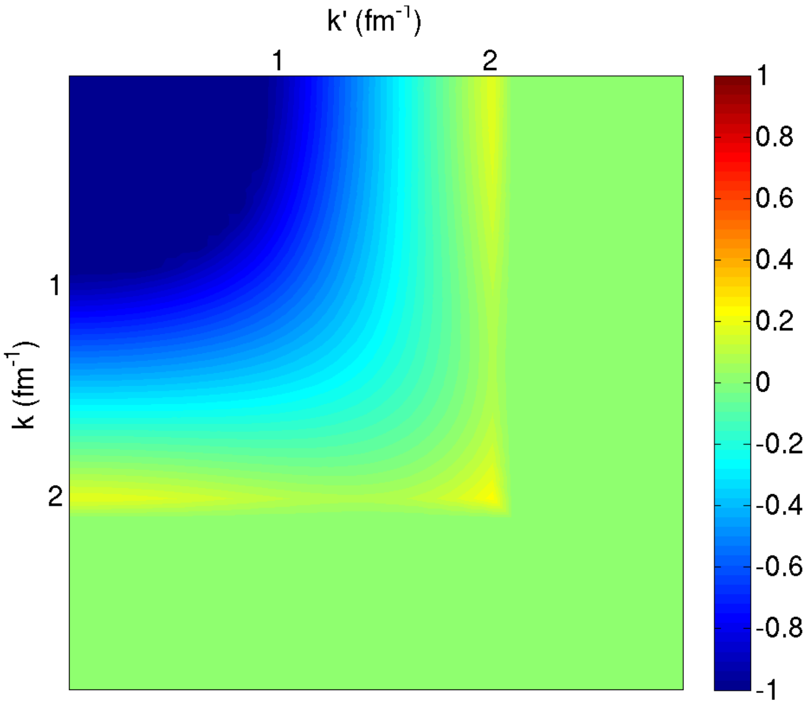


FIG. 3: $^1S_0$ N^{3}LOW potential.

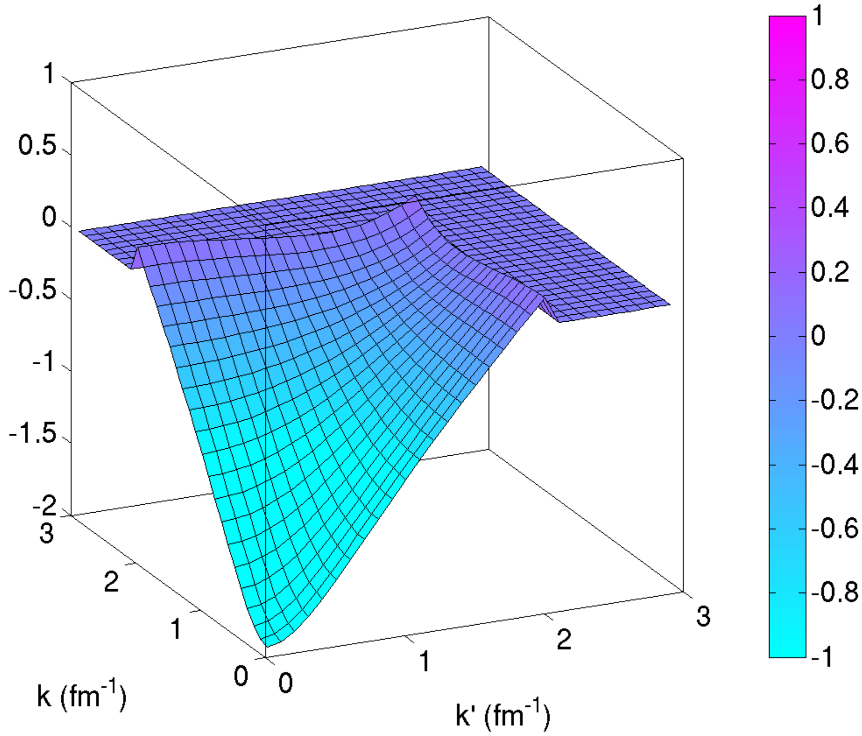


FIG. 4: $^1S_0$ N^{3}LOW potential.

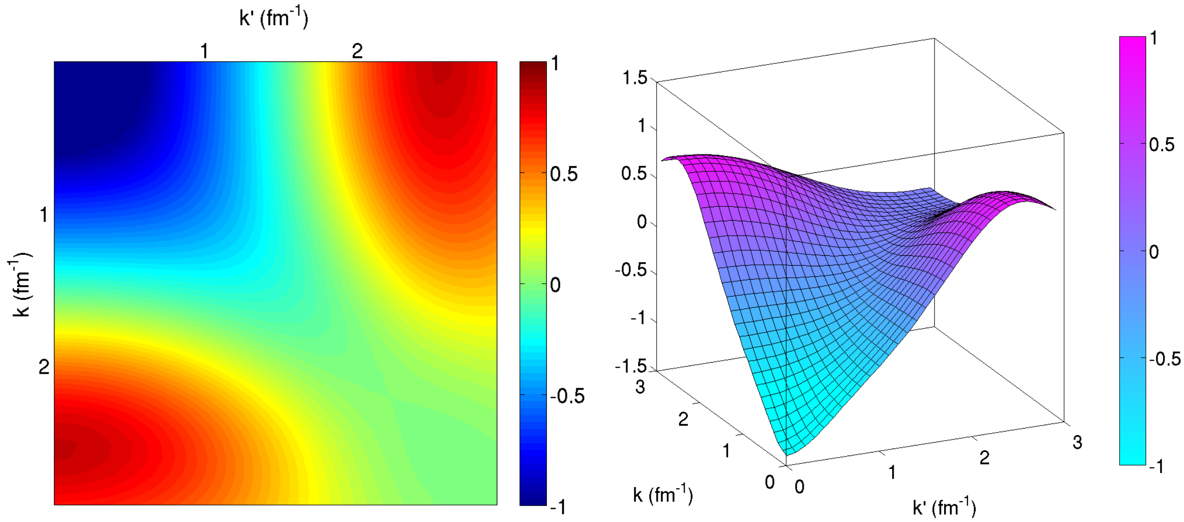


FIG. 5: $^3S_1$ N^{3}LO 500 MeV potential.

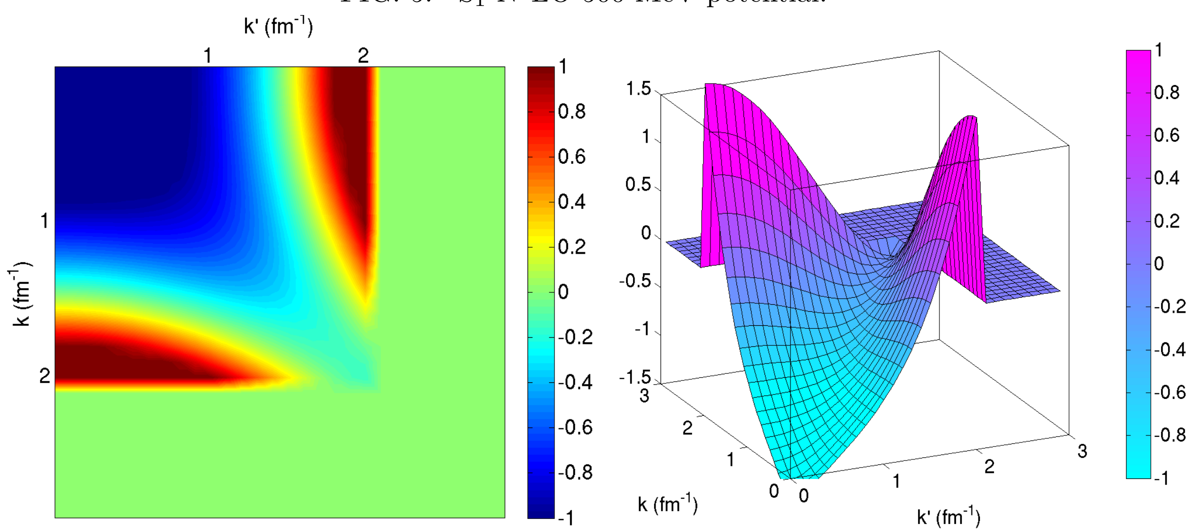


FIG. 6: $^3S_1$ N^{3}LOW potential.

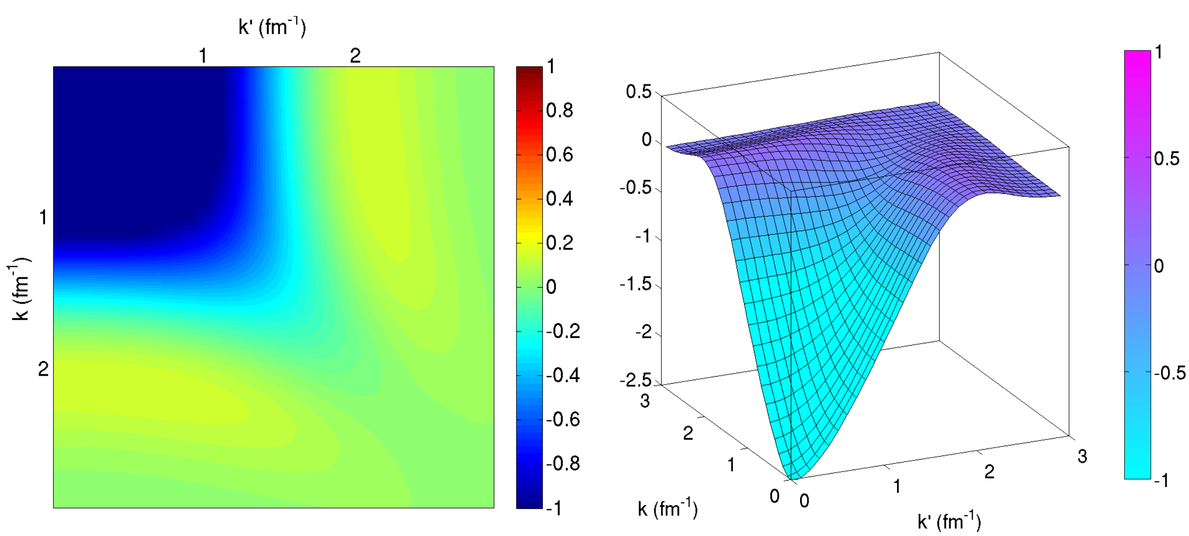


FIG. 7: $^3S_1$ N^{3}LO 500 MeV potential evolved by the SRG to $\lambda = 2\,\mathrm{fm}^{-1}$.

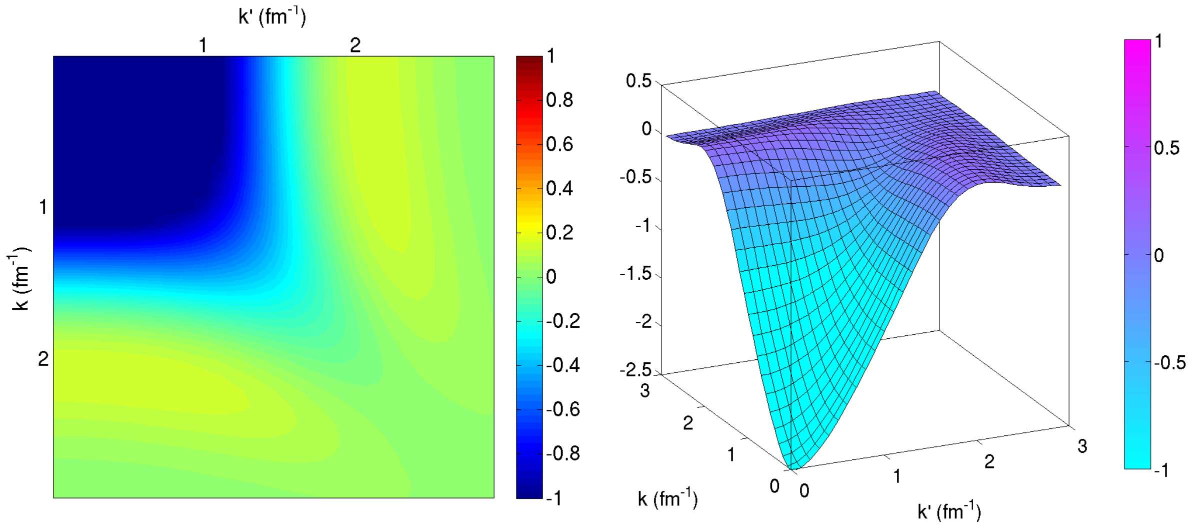


FIG. 8: ${}^3\mathrm{S}_1$ N^{3}LO 500 MeV potential evolved by the SRG to $\lambda = 2\,\mathrm{fm}^{-1}$.

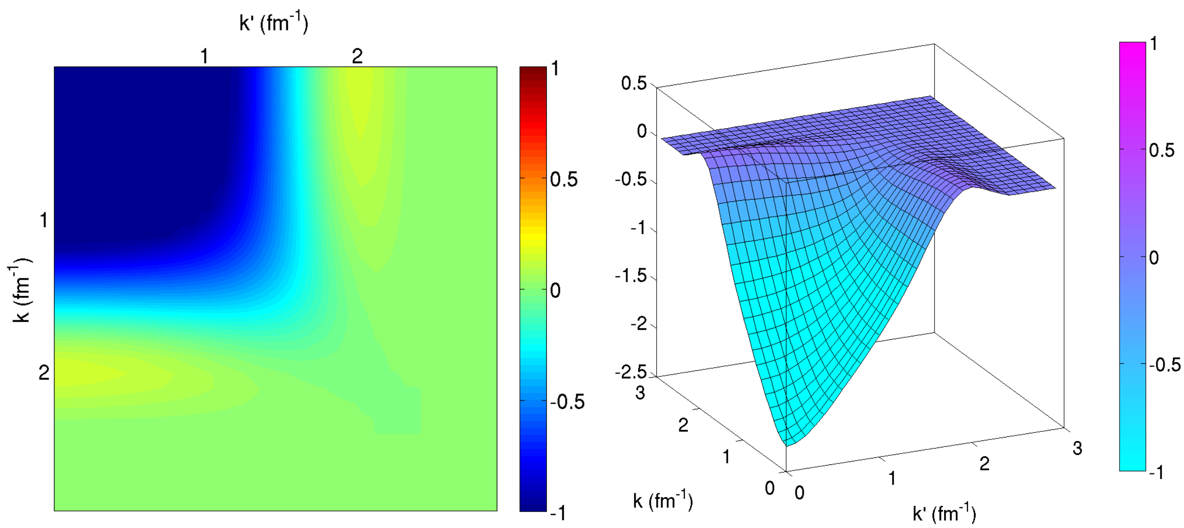


FIG. 9: ${}^3\mathrm{S}_1$ $V_{\mathrm{low}k}$ $\Lambda = 2\,\mathrm{fm}^{-1}$, $n_{\mathrm{exp}} = 4$ from N^{3}LO 500 MeV potential.

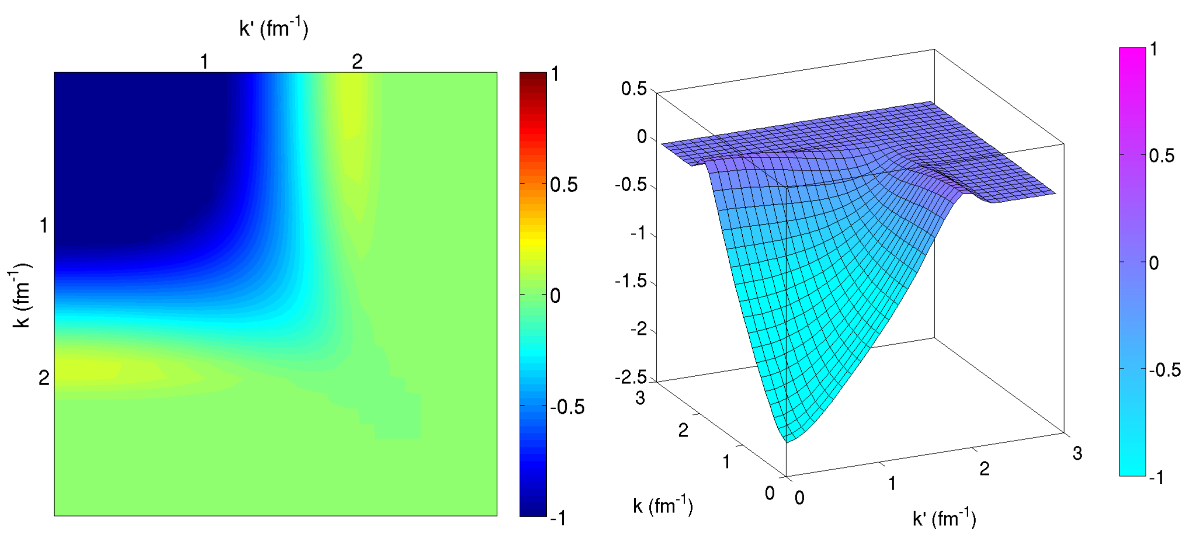


FIG. 10: ${}^3\mathrm{S}_1$ $V_{\mathrm{low}k}$ $\Lambda = 2\,\mathrm{fm}^{-1}$, $n_{\mathrm{exp}} = 8$ from N^{3}LO 500 MeV potential.

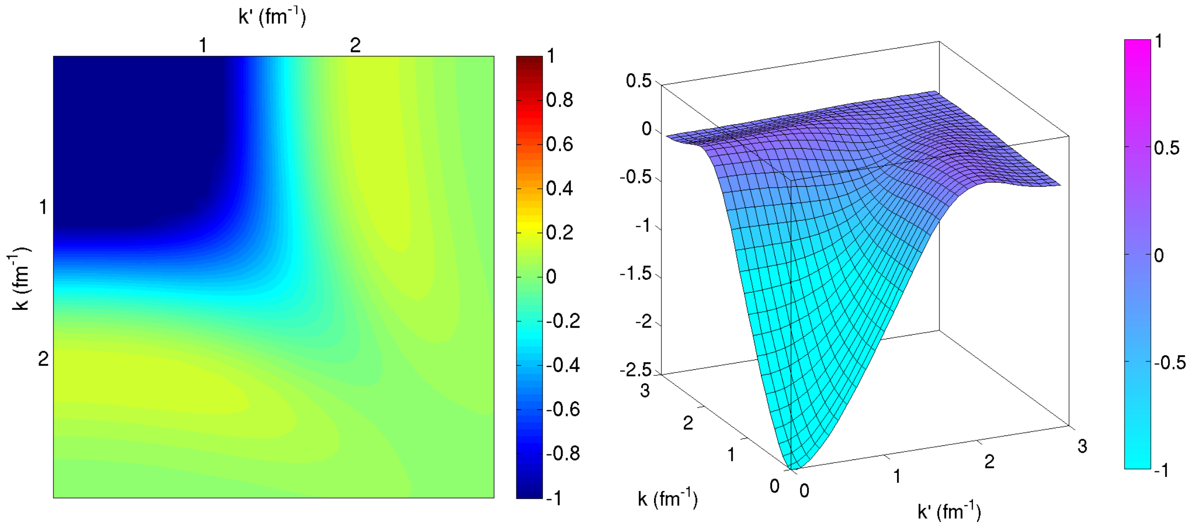


FIG. 11: $^3S_1$ N^{3}LO 500 MeV potential evolved by the SRG to $\lambda = 2\,\mathrm{fm}^{-1}$.

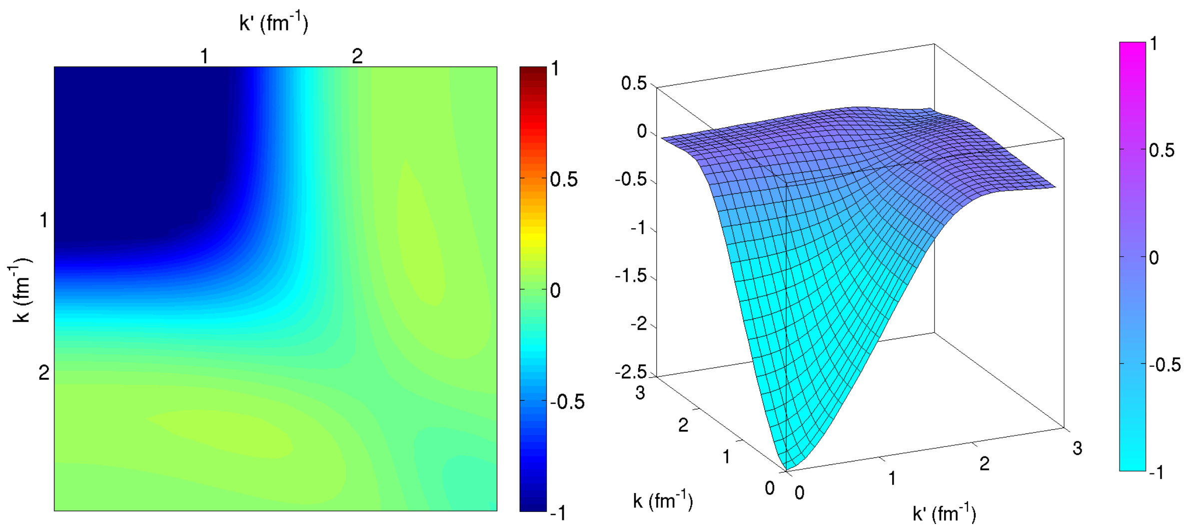


FIG. 12: $^3S_1$ N^{3}LO 600 MeV potential evolved by the SRG to $\lambda = 2\,\mathrm{fm}^{-1}$.

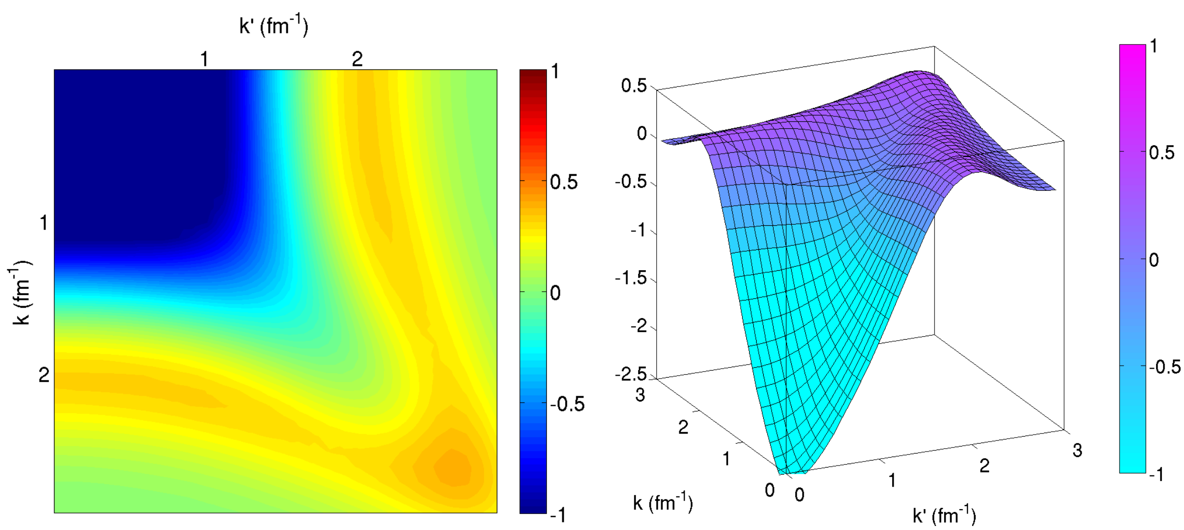


FIG. 13: $^3S_1$ N^{3}LO 550/600 MeV potential evolved by the SRG to $\lambda = 2\,\mathrm{fm}^{-1}$.

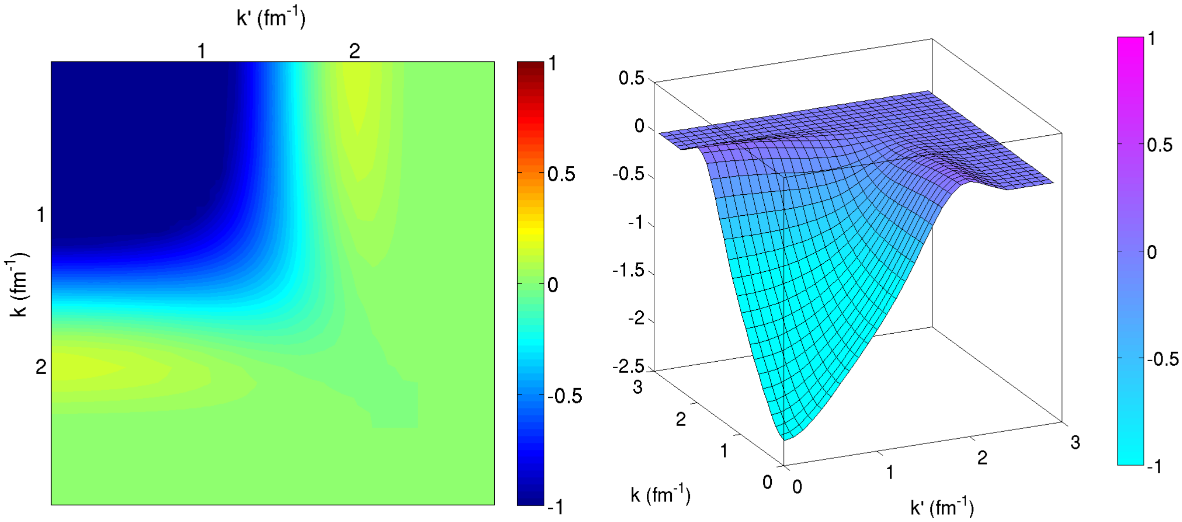


FIG. 14: ^{3}S$_1$ $V_{\mathrm{low}k}$ $\Lambda = 2\,\mathrm{fm}^{-1}$, $n_{\mathrm{exp}} = 4$ from N^{3}LO 500 MeV potential.

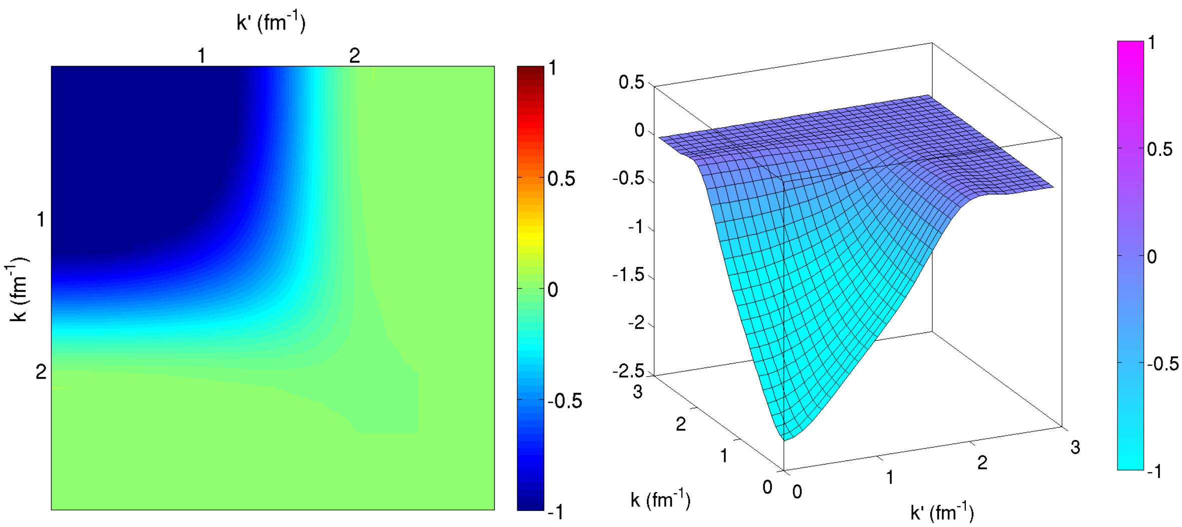


FIG. 15: ^{3}S$_1$ $V_{\mathrm{low}k}$ $\Lambda = 2\,\mathrm{fm}^{-1}$, $n_{\mathrm{exp}} = 4$ from N^{3}LO 600 MeV potential.

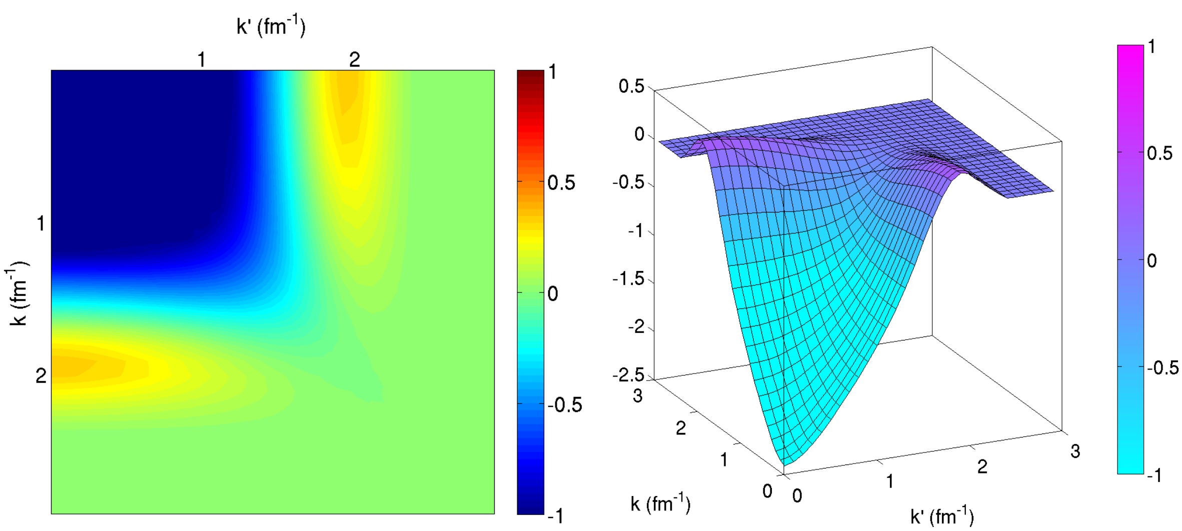


FIG. 16: ^{3}S$_1$ $V_{\mathrm{low}k}$ $\Lambda = 2\,\mathrm{fm}^{-1}$, $n_{\mathrm{exp}} = 4$ from N^{3}LO 550/600 MeV potential.

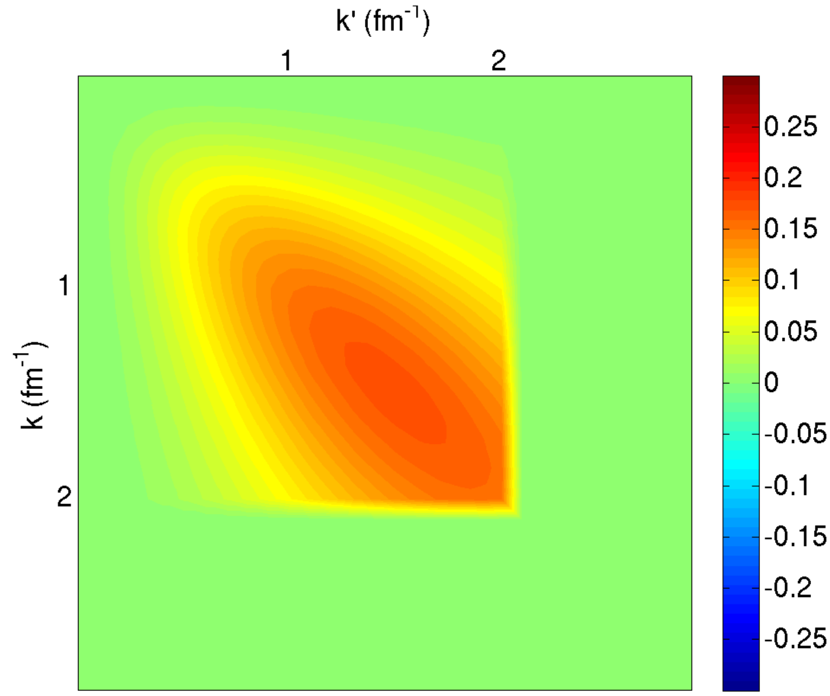


FIG. 17: $^{3}D_{1}$ $N^{3}LOW$ potential.

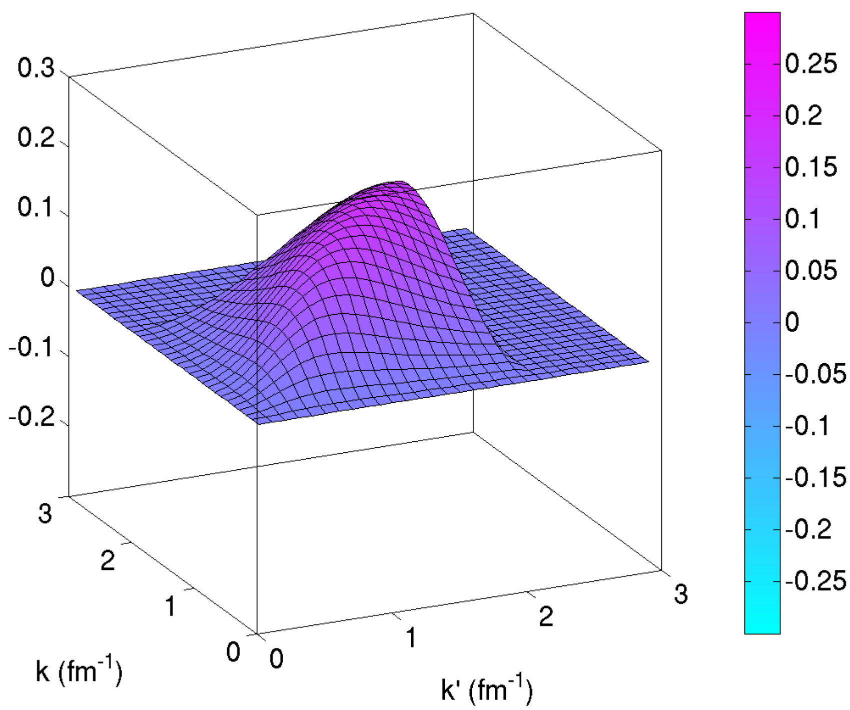


FIG. 18: $^{3}D_{1}$ $N^{3}LOW$ potential.

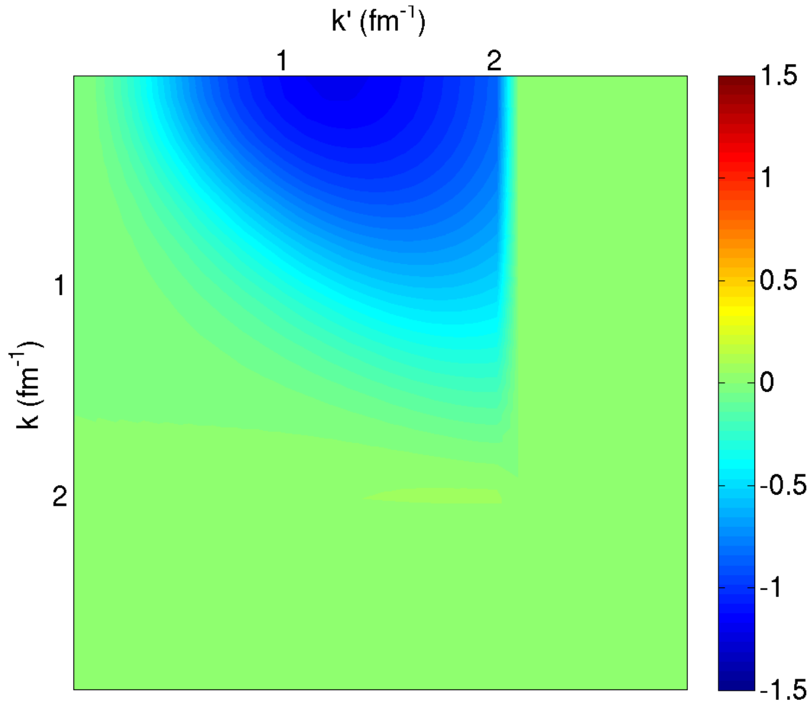


FIG. 19: $^3S_1$–$^3D_1$ N^{3}LOW potential.

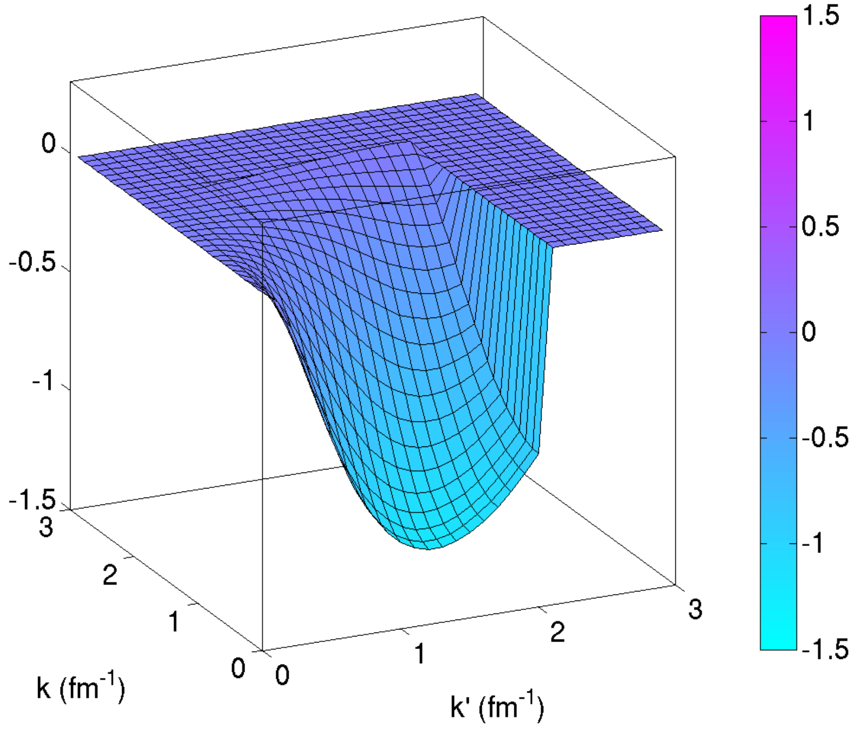
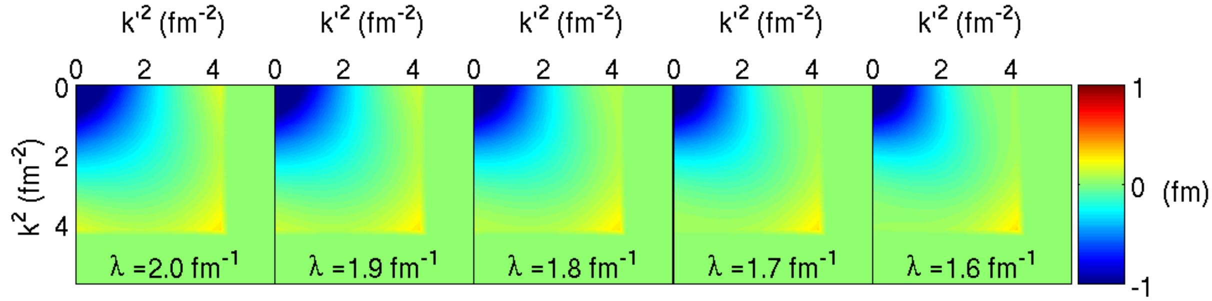


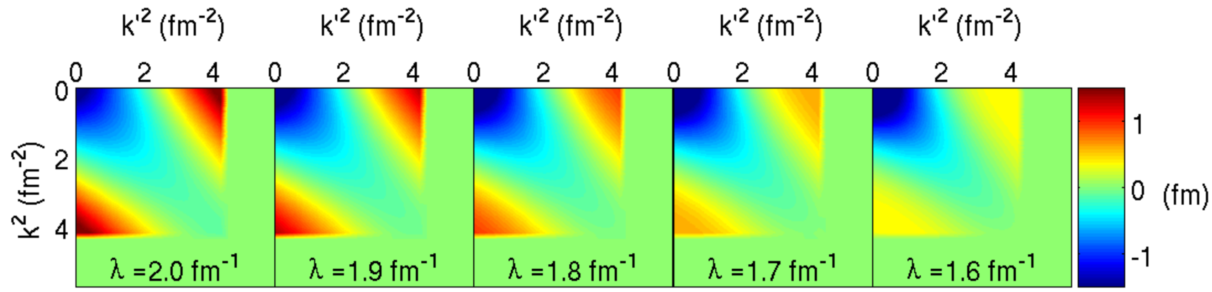
FIG. 20: $^3S_1$–$^3D_1$ N^{3}LOW potential.

III. EVOLUTION WITH THE SRG

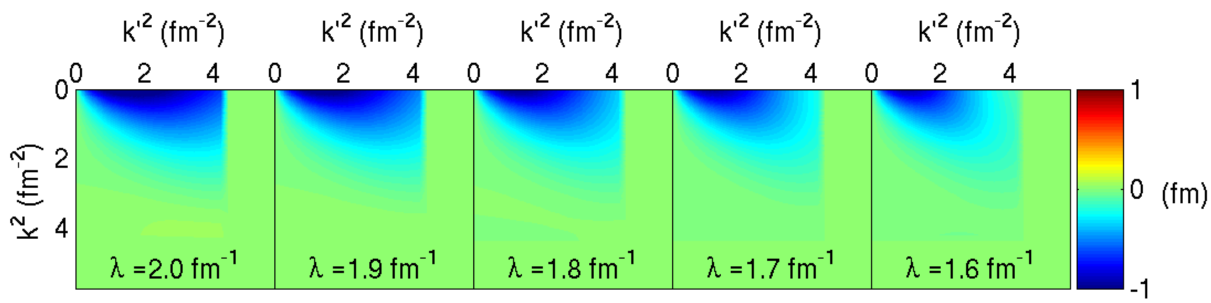
Here we show the SRG evolution of the N3LOW potential as contour plots. (The notation "potential #13" is automatically generated by MATLAB and is the assigned number for this potential.) The range of flow parameter λ is only from $2.0\,\mathrm{fm}^{-1}$ to $1.6\,\mathrm{fm}^{-1}$, yet significant softening of the off diagonal matrix elements is clearly observed. This is most evident in the $^3\mathrm{S}_1$ partial wave.



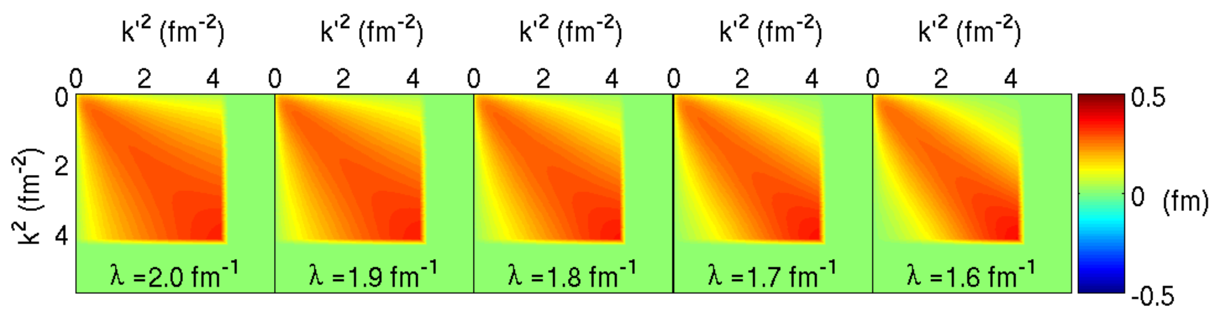
1S0 potential #13



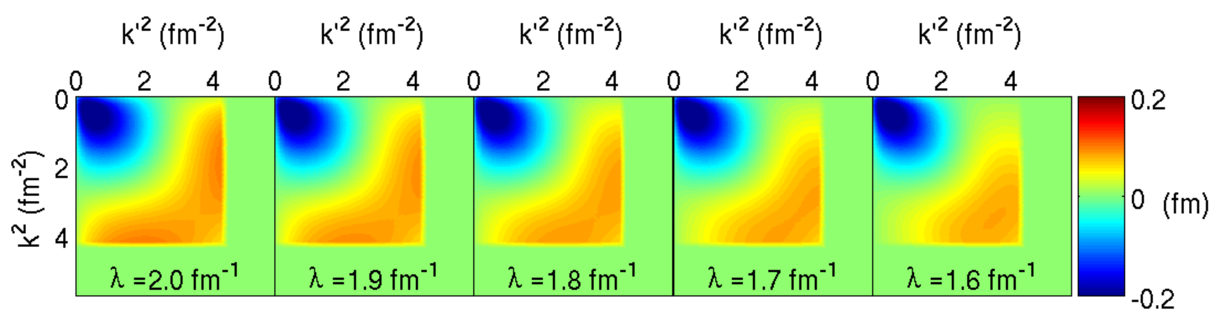
3S1 potential #13



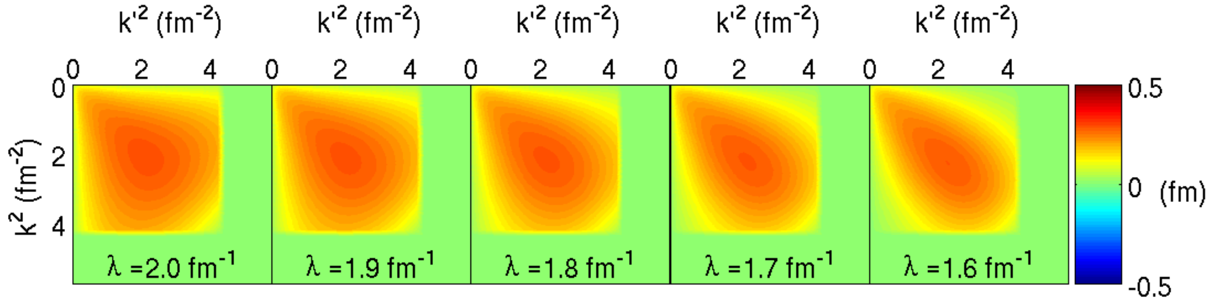
3S1-3D1 potential #13



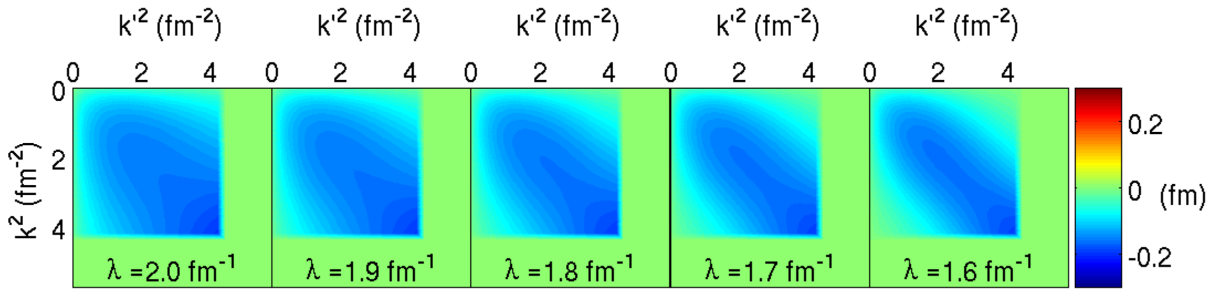
1P1 potential #13



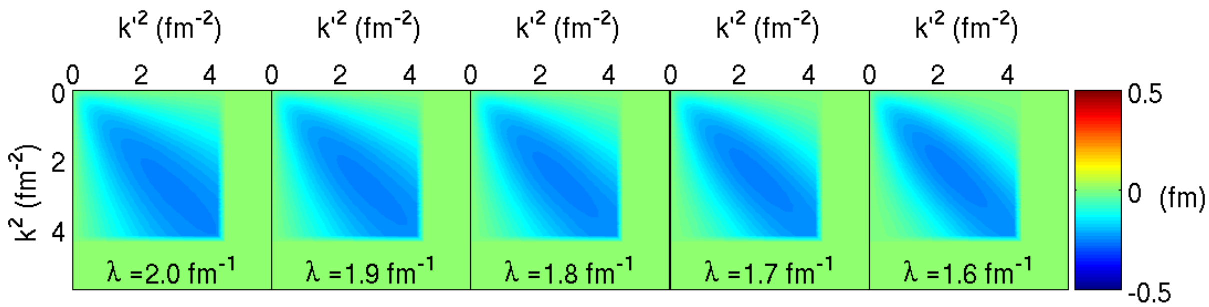
3P0 potential #13



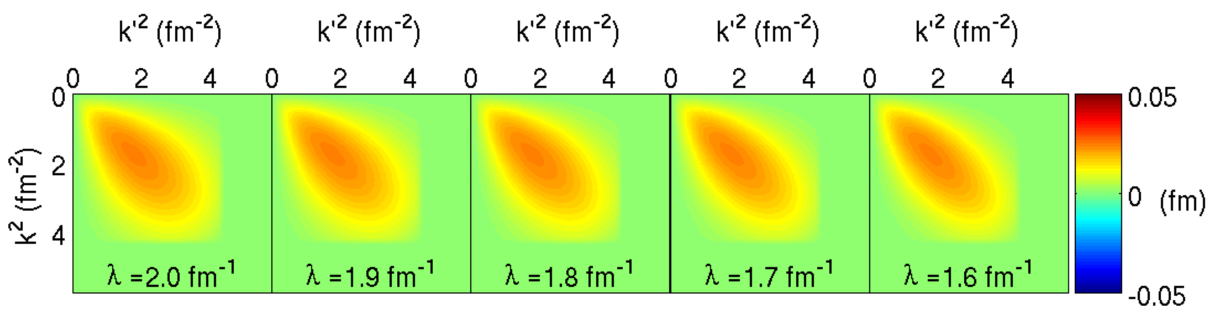
3P1 potential #13



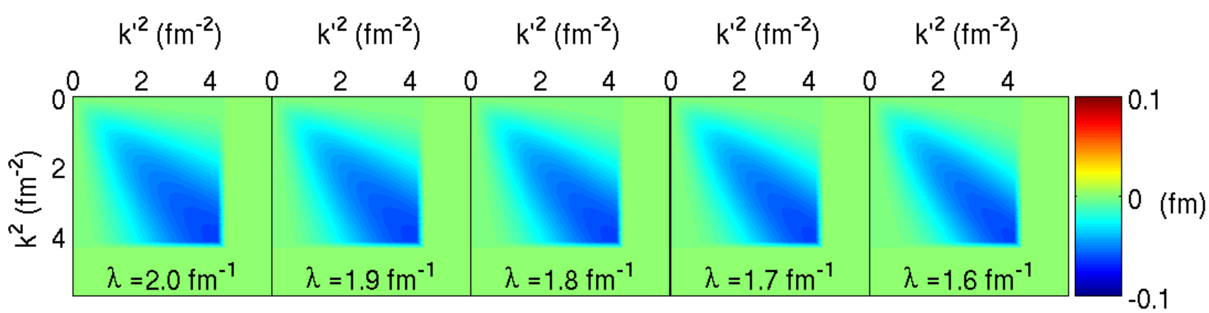
3P2 potential #13



3D2 potential #13



3F3 potential #13



3G4 potential #13

IV. CONVERGENCE

In Fig. 21, the ground-state energy of the triton in a harmonic oscillator basis is shown as a function of the oscillator parameter b for different size spaces (specified by $N_{\rm max}$). This is a variational calculation, so the best estimate is the lowest energy. The bare N3LOW potential is in the upper left and then the results from evolving the potential with the SRG to $\lambda = 2.0$, 1.8, and 1.6 fm^{-1}. The improvement in convergence is evident. Note the converged energy depends on λ, because only the NN interaction is included.

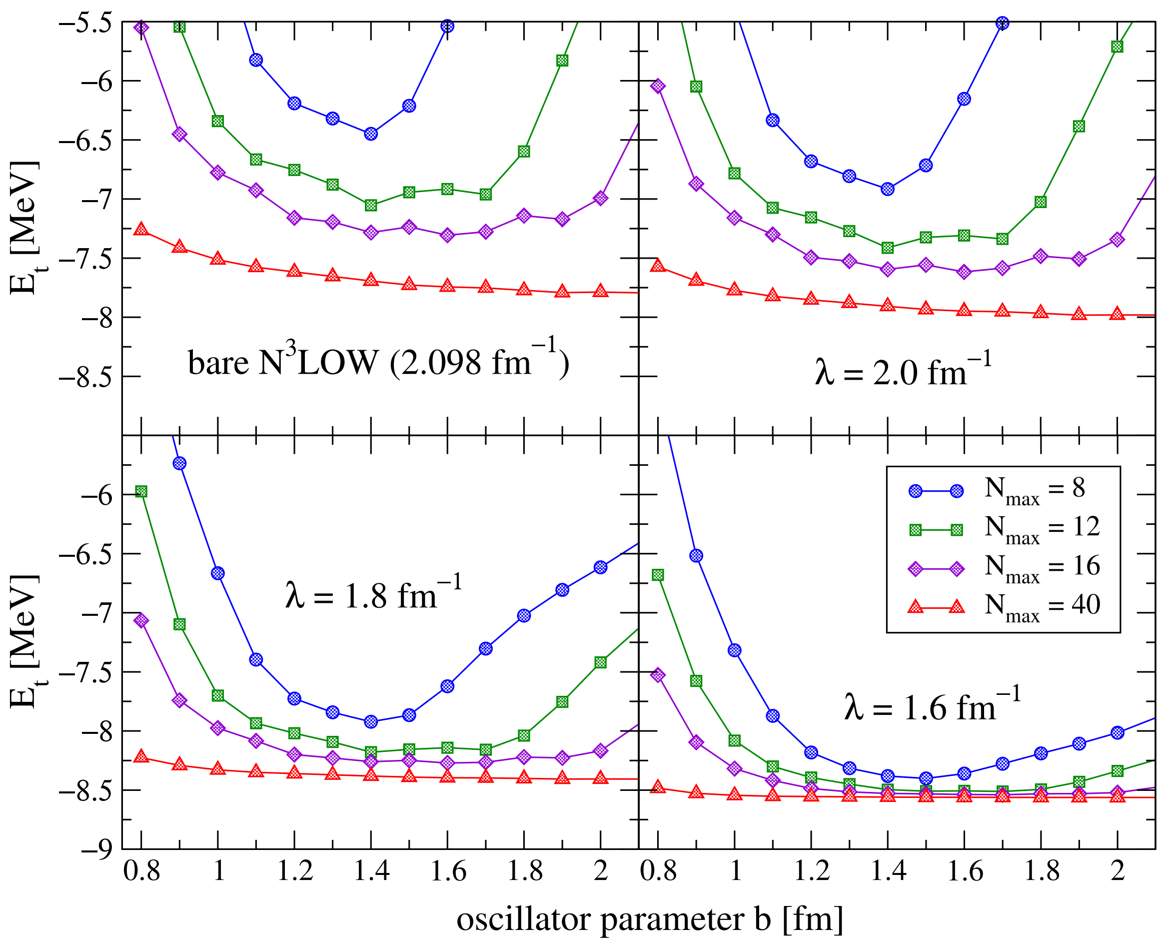


FIG. 21: Convergence of the triton ground-state energy calculated in a harmonic oscillator basis as a function of the oscillator parameter, for different size spaces.

Acknowledgments

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