Nucleon-Nucleon Scattiering Parameters in the Limit of SU(3) Flavor Symmetry

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Parameters

L	T	beta	b(fm)	L(fm)	T(fm)	m_π	m_π L	m_π T	Ncfg	Nsrc
24	48	6.1	0.145	3.4	6.7	806.5(0.3)(0)(8.9)	14.3	28.5	3822	96
32	48	6.1	0.145	4.5	6.7	806.9(0.3)(0.5)(8.9)	19.0	28.5	3050	72
48	64	6.1	0.145	6.7	9.0	806.7(0.3)(0)(8.9)	28.5	38.0	1905	54

errors:(statistical)(fit systematic)(lattice spacing)

Three ensembles of isotropic gauge-field configurations, generated with a tadpole-improved Lüscher-Weisz gauge action and a clover fermion action [15], are used in this work and have been used previously to calculate the lowest-lying levels of the s-shell nuclei and hypernuclei [13]. This particular lattice-action setup follows closely the anisotropic clover action of the ensembles generated by the JLab group that we have used in our previous calculations [4, 11, 16–19]. The parameter tuning and scaling properties of this action will be discussed elsewhere [20]. One level of stout smearing [21] with $\rho = 0.125$ and tadpole-improved tree-level clover coefficient $c_{SW} = 1.2493$ are used in the gauge-field generation. Studies [20, 22, 23] of the partially-conserved axial-current (PCAC) relation in the Schrödinger functional indicate that this choice is consistent with vanishing $\mathcal{O}(b)$ violations, leading to discretization effects that are essentially $\mathcal{O}(b^2)$. The parameters of the ensembles are listed in Table I, and further details will be presented elsewhere [20]. As two-nucleon systems are

Nucleon operator

$$\mathcal{B}_N^{ijk}(\mathbf{p},t;x_0) = \sum_{\mathbf{x}} e^{i\mathbf{p}\cdot\mathbf{x}} S_i^{(f_1),i'}(\mathbf{x},t;x_0) S_j^{(f_2),j'}(\mathbf{x},t;x_0) S_k^{(f_3),k'}(\mathbf{x},t;x_0) b^{(N)}_{i'j'k'} \quad , \qquad (1)$$

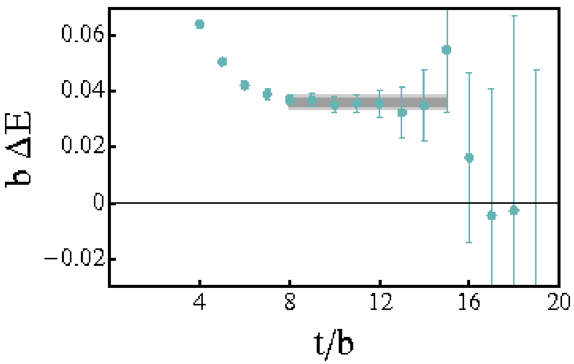
where $S^{(f)}$ is a quark propagator of flavor f, and the indices are combined spin-color indices running over $i = 1, \ldots, N_c N_s$.[1] The choice of the f_i and the tensor $b^{(N)}$ depend on the

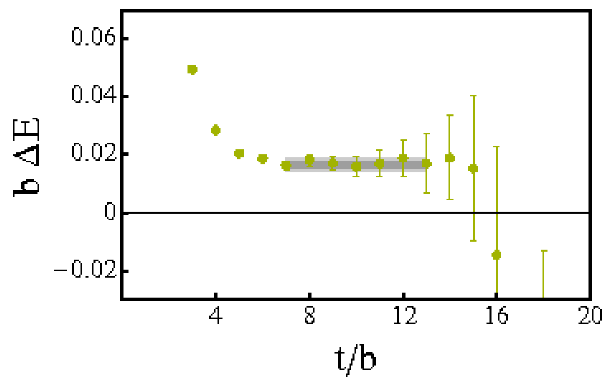
$$m_\pi = 805.9(0.6)(0.4)(8.9)\,MeV$$

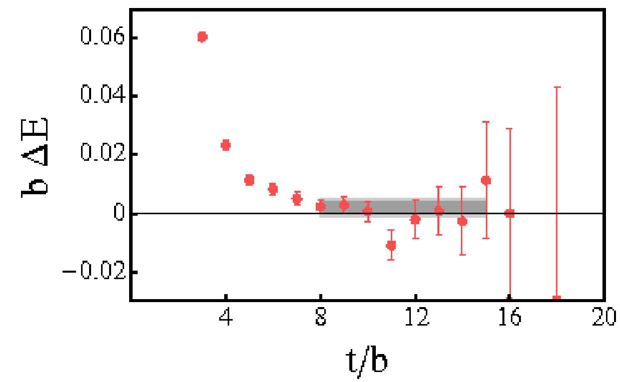
$$m_N = 1.635(0)(0)(18)\,GeV$$

NN scattering in 1S0 channel

Effective mass of the first excited state







L=3.4fm L=4.5 fm L=6.7fm

Volume effects are observed in the smallest volume

The binding energy in the infinite volume is taken from the binding energy in the largest volume

Lowest-lying continuum states in 1S0

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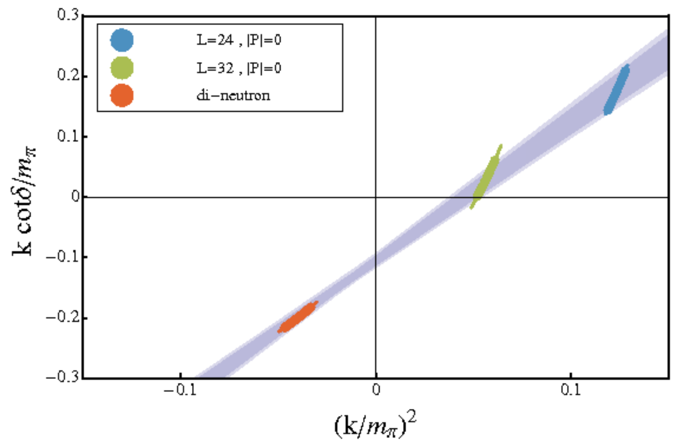
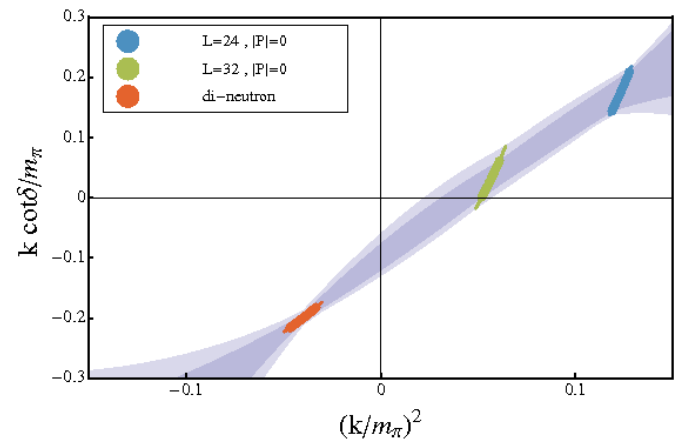
	ΔE b	|k|/mπ	kcotδ / mπ
24^3x48	0.0358(13)(16)	0.3506(64)(78)	0.175(+.034 -0.031)(+0.043 -0.036)
32^3x48	0.0165(13)(22)	0.2373(92)(96)	0.030(+0.031 -0.028)(+0.057 -0.046)

binding energy
Bnn = 15.9(2.7)(2.7)(0.2) MeV
from 3.4 fm, 4.5 fm, 6.7 fm

K cot delta in 1S0 channel





2-parameter fit 3-parameter fit

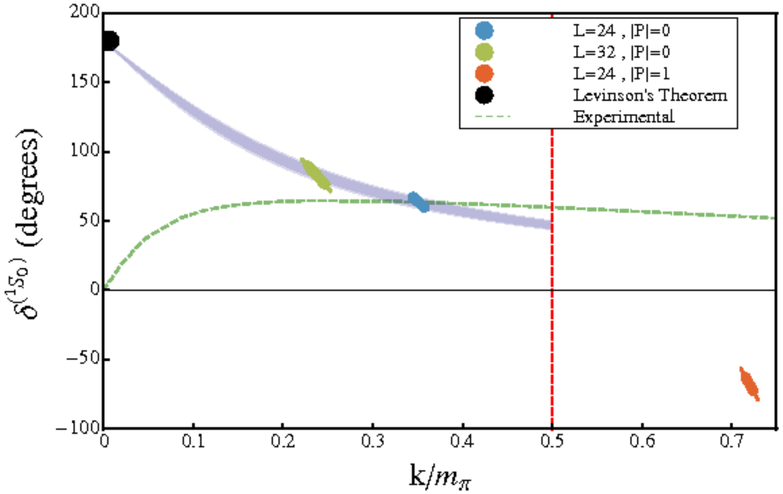
$$k\cot\delta = -\frac{1}{a} + \frac{1}{2} r|k|^2 + P|k|^4 + O(|k|^6)$$

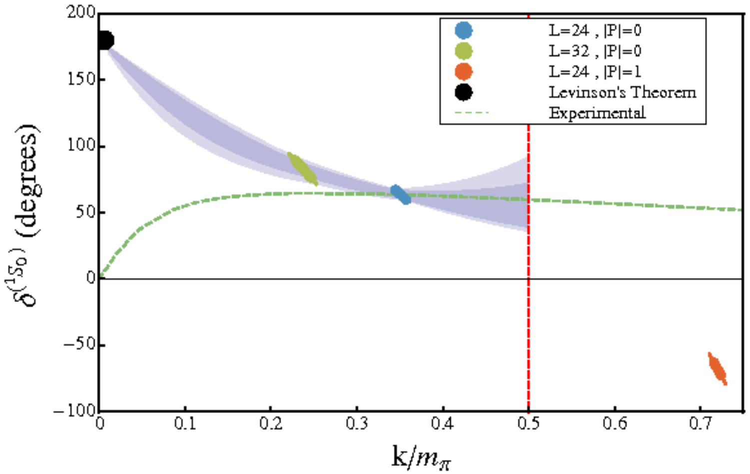
$$a({}^1S_0) = 2.33^{+0.19+0.27}_{-0.17-0.20}\ fm \qquad r({}^1S_0) = 1.130^{+0.071+0.059}_{-0.077-0.063}\ fm$$

P: consistent with zero $$P m_\pi^3 = -1^{+4+5}_{-5-8}$$

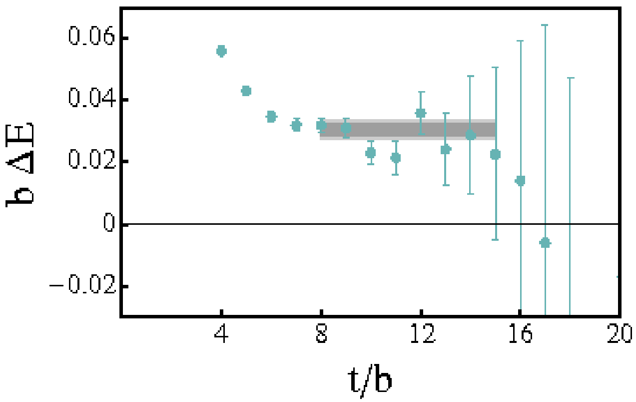
cf. exp.: a_nn = -18.9 +/- 0.4 fm r_nn = 2.75 +/- 0.11 fm
a_np = -23.740 +/- 0.020 fm r_np = 2.77 +/- 0.05 fm

Phase shift in 1S0 channel

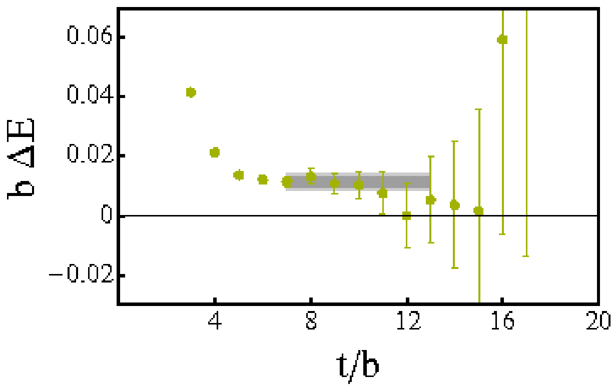




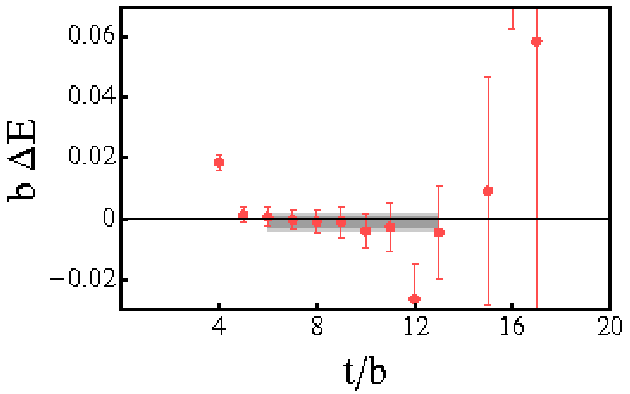
NN scattering in 3S1 channel



L=3.4fm



L=4.5 fm



L=6.7fm

Lowest-lying continuum states in 3S1

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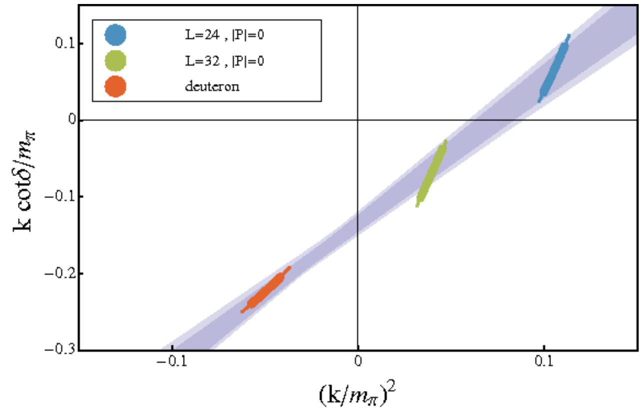
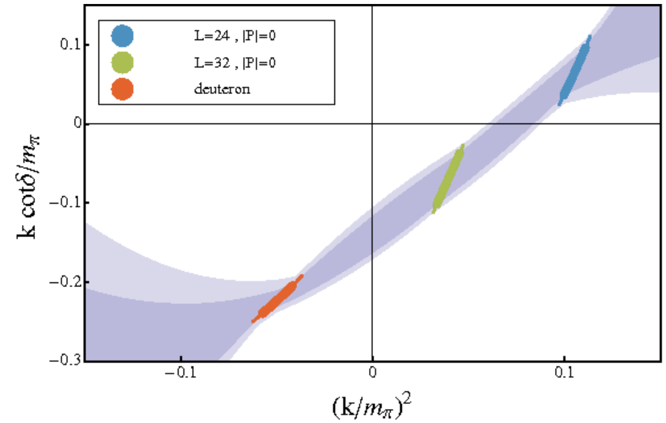
	ΔE_b	$|k|/m_\pi$	$k\cot\delta / m_\pi$
24^3x48	0.0306(16)(23)	0.324(8)(12)	0.065(+.031 -0.029)(+0.47 -0.40)
32^3x48	0.0115(17)(23)	0.198(15)(19)	-0.069(32)(43)

binding energy
Bnn = 19.5(3.6)(3.1)(0.2) MeV
from 3.4 fm, 4.5 fm, 6.7 fm

K cot delta in 3S1 channel



2-parameter fit



3-parameter fit

$$k\cot\delta = -\frac{1}{a} + \frac{1}{2} r|k|^2 + P|k|^4 + O(|k|^6)$$

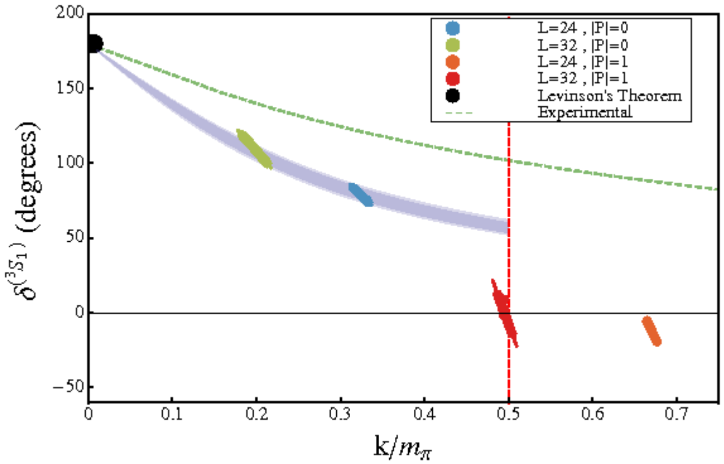
$$a(\,^3S_1) = 1.82^{+0.14+0.17}_{-0.13-0.12}\, fm \qquad r(\,^3S_1) = 0.906^{+0.068+0.068}_{-0.075-0.084}\, fm$$

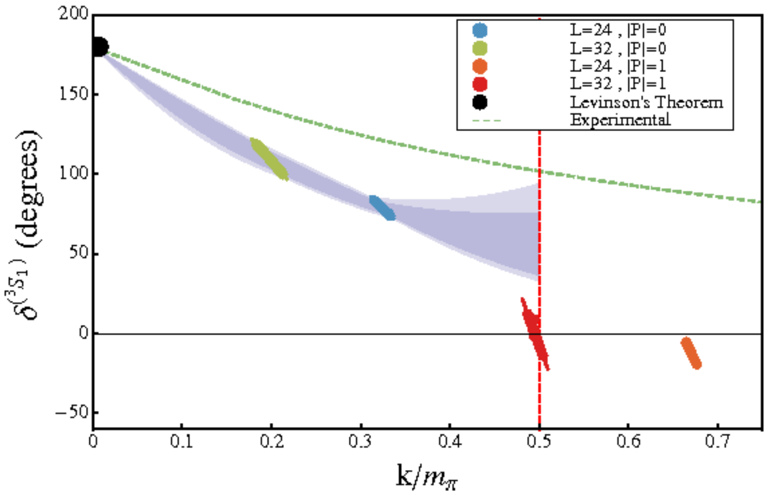
P: consistent with zero

$$P m_\pi^3 = 3^{+5+5}_{-6-6}$$

cf. exp.: a_np = 5.419 +/- 0.007 fm r_np = 1.753 +/- 0.008 fm

Phase shift in 3S1 channel





conclusions

- Low-energy NN scattering parameters at
  SU(3) symmetric point
  m_pi = 800 MeV

- Effective ranges are calculated for the first time
- Phase shifts change sign at higher momentum, indicating that the nuclear interactions have a repulsive core

$$a/r \sim 2.0$$

- Experimental values

  a/r ~ -8.7 (1S0), +3.1(3S1)

- Present work : performed at a single pion mass
  with one lattice spacing