Comparison of different source calculations in two-nucleon channel at large quark mass

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Outline

- Introduction
- Important condition of direct calculation of nuclei
- Simulation parameters
- Preliminary result of $N_f = 0$ $m_\pi = 0.8$ GeV
- Summary and future work

Introduction

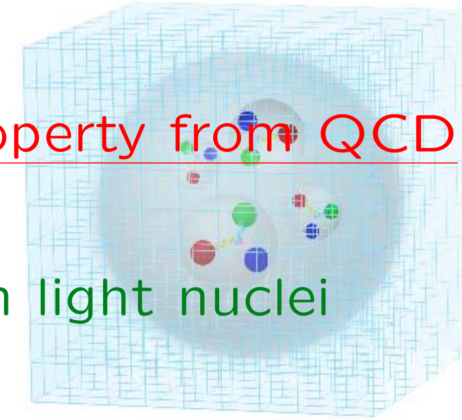


figure from Irie-san

Final goal: Qunantitave understanding of nucleus property from QCD

Lattice calculation of light nuclei started at 2009

Current purpose: Reproduce binding energy of known light nuclei

Direct calculation of NN binding energy

Exponential source

PACS-CS, $N_f = 0$ $m_\pi = 0.8$ GeV [PRD84:054506(2011)]
TY *et al.*, $N_f = 2 + 1$ $m_\pi = 0.5$ GeV [PRD86:074514(2012)]
TY *et al.*, $N_f = 2 + 1$ $m_\pi = 0.3$ GeV [PRD92:014501(2015)]

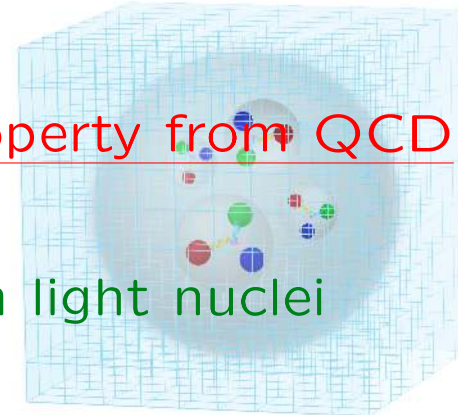
Gaussian source

'12 NPLQCD, '15 CalLat $N_f = 3$ $m_\pi = 0.81$ GeV; '15 NPLQCD $N_f = 2 + 1$ $m_\pi = 0.45$ GeV

Direct calculations have been carried out exponential or Gaussian source

'16 HALQCD : Large dependence of binding energy on source operator

Introduction



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Final goal: Qunantitave understanding of nucleus property from QCD

Lattice calculation of light nuclei started at 2009

Current purpose: Reproduce binding energy of known light nuclei

Direct calculation of NN binding energy

Direct calculations have been carried out exponential or Gaussian source

'16 HALQCD : Large dependence of binding energy on source operator

Comparison of exponential and wall sources

Wall source is known to need longest time for plateau.

$\rightarrow$ Hard to satisfy important condition of direct calculation

Purpose

Examine source dependence in high precision calculation,

where important condition is satsified

Important condition of direct calculation

Traditional method in lattice QCD (NN channel)

nucleon correlation function

$$C_N(t) \;=\; \langle 0|N(t)\overline{N}(0)|0\rangle = \sum_n \langle 0|N|n\rangle\langle n|\overline{N}|0\rangle e^{-E_n^N t} \xrightarrow[t \geq t_N \gg 1]{} A_0^N\, e^{-m_N t}$$

NN correlation function

$$C_{NN}(t) \;=\; \langle 0|O_{NN}(t)\overline{O}_{NN}(0)|0\rangle = \sum_n \langle 0|O_{NN}|n\rangle\langle n|\overline{O}_{NN}|0\rangle e^{-E_n t}$$

$$\xrightarrow[t \geq t_{NN} \gg 1]{} A_0\, e^{-E_{NN} t}$$

Ratio of correlation functions

$$R(t) = \frac{C_{NN}(t)}{(C_N(t))^2} \xrightarrow[t \geq t_R \gg 1]{} A_0'\, e^{-\Delta E t}, \qquad \Delta E = E_{NN} - 2m_N$$

$\boxed{\text{Important condition: } t_R \geq t_N, t_{NN}}$

i.e. $C_N(t)$ and $C_{NN}(t)$ are written by each ground state in $t \geq t_R$

Simulation parameter

High precison calculation in $N_f = 0$ $m_\pi = 0.8$ GeV

Iwasaki gauge ($\beta = 2.416$, $a^{-1} = 1.541$ GeV) + tadpole imporved Wilson fermion actions

same action as '02 CP-PACS, PRD81:111504(R)(2010); PRD84:054506(2011)

Comparison exponential and wall sources in NN $^3S_1$ channel

point sink (each N with $p = 0$)

L	T	source	N_{meas}
16	64	Exp	*12,544,000
		Wall	*4,467,200
20	64	Exp	5,504,000
		Wall	8,960,000
32	64	Exp	3,200,000
		Wall	4,473,600

*updated from lattice 2016

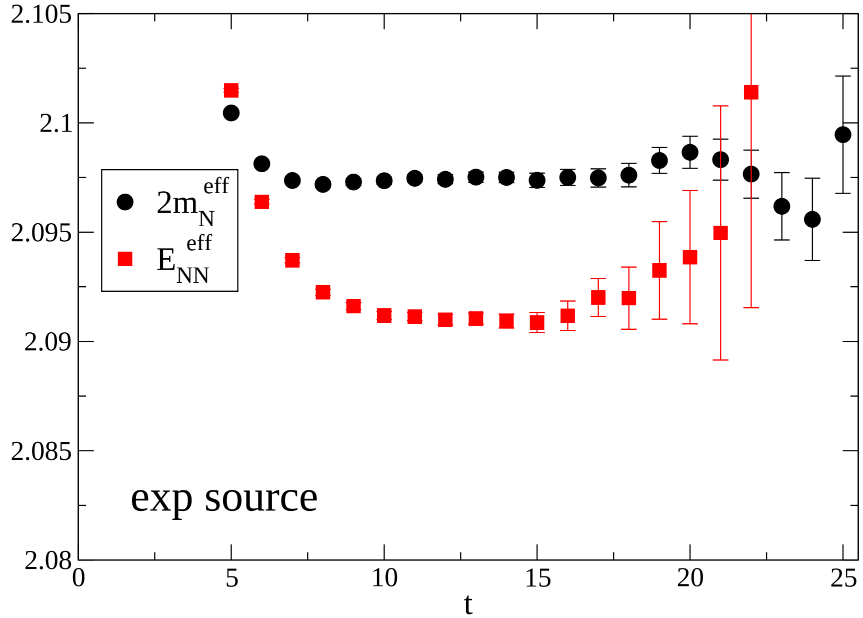
All results are preliminary.

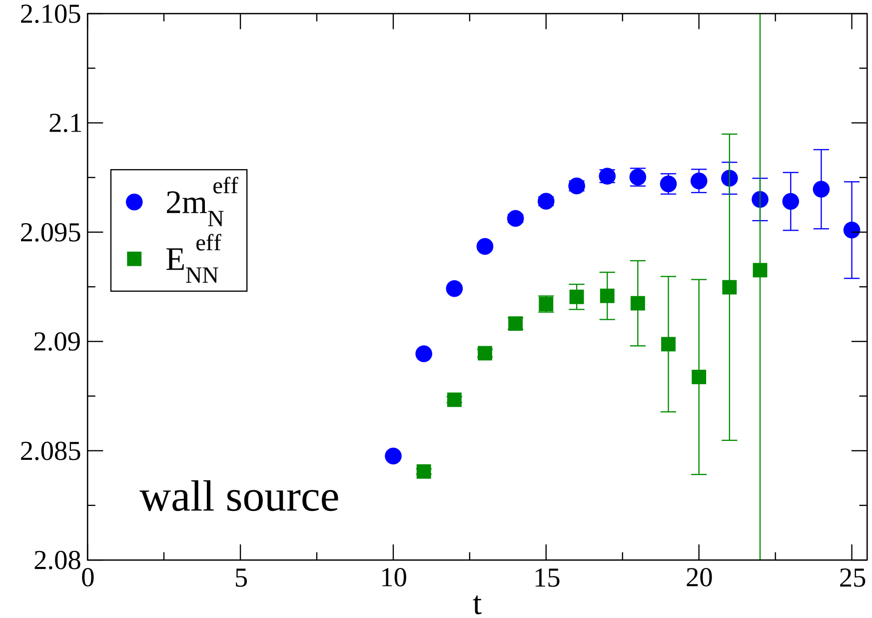
Computational resources (HPCI System Research Project: hp160124)

COMA and HA-PACS(U. of Tsukuba), FX10 and Reedbush (U. of Tokyo), Tatara (Kyushu U.), FX100 and CX400(Nagoya U.), OFP(JCAHPC)

$R(t) = C_{NN}(t)/(C_N(t))^2$ in $L = 20$

Effective $2m_N$ and E_{NN}





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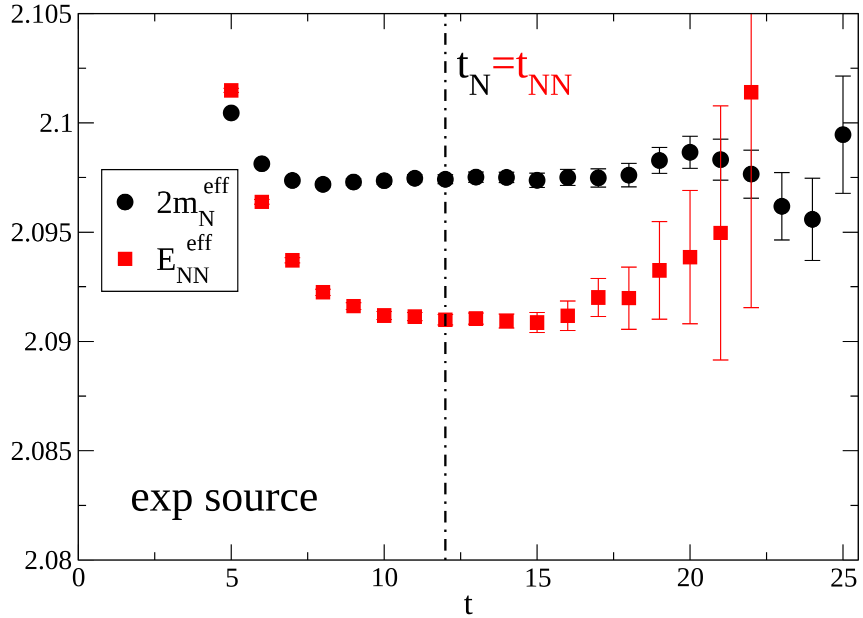
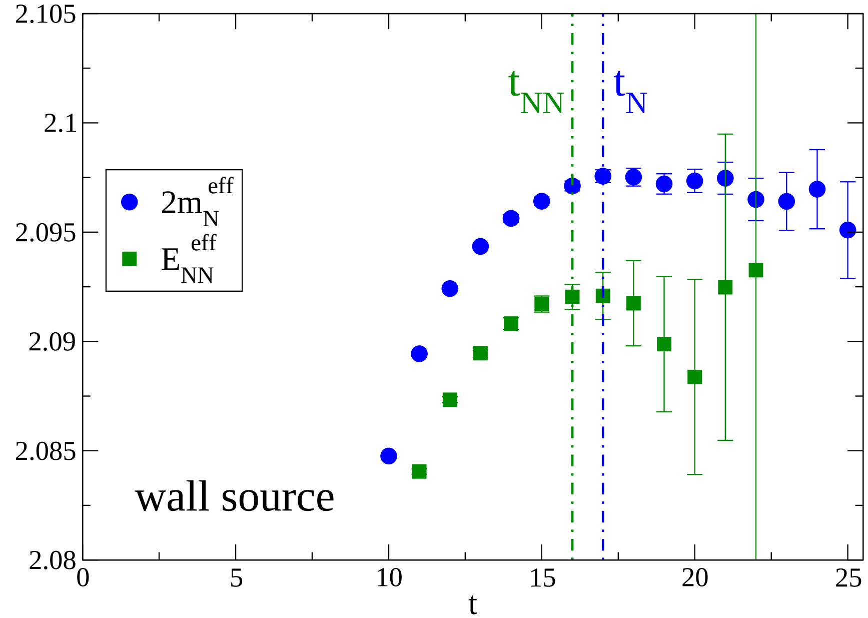


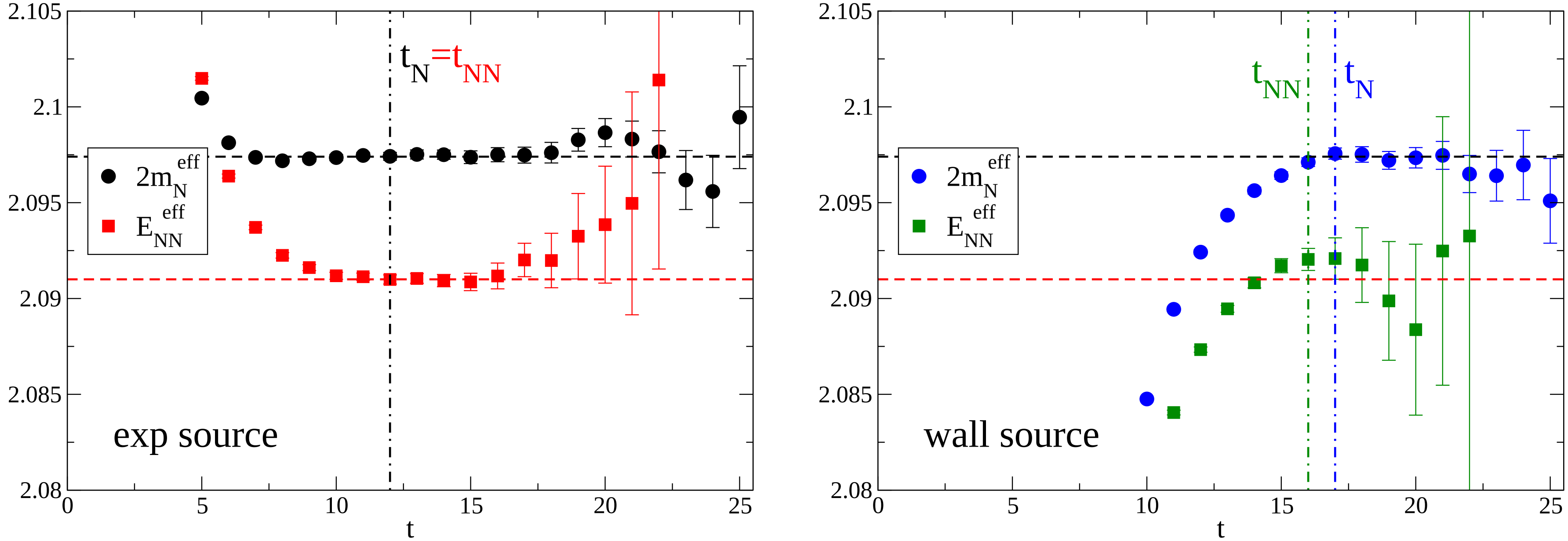


$t_N \sim t_{NN} \sim 12$

$t_{NN} \sim 16, \ t_N \sim 17$

$R(t) = C_{NN}(t)/(C_N(t))^2$ in $L = 20$

Effective $2m_N$ and E_{NN}



$t_N \sim t_{NN} \sim 12$

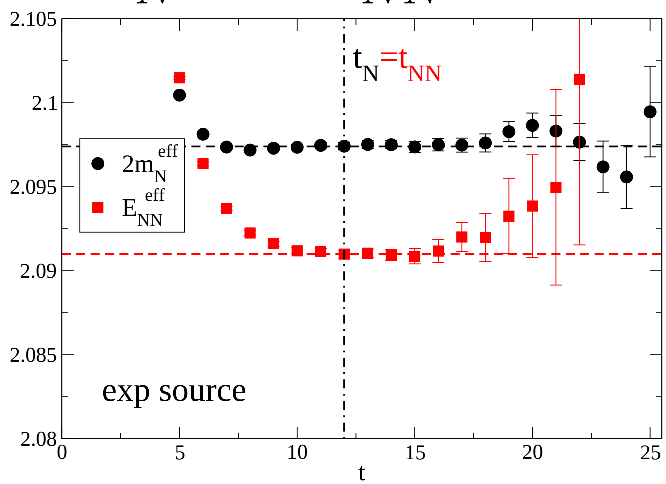
$t_{NN} \sim 16, \;\; t_N \sim 17$

dashed lines determined from exponential source

consistent with each other in plateau region

$R(t) = C_{NN}(t)/(C_N(t))^2$ in $L = 20$

Effective $2m_N$ and E_{NN}



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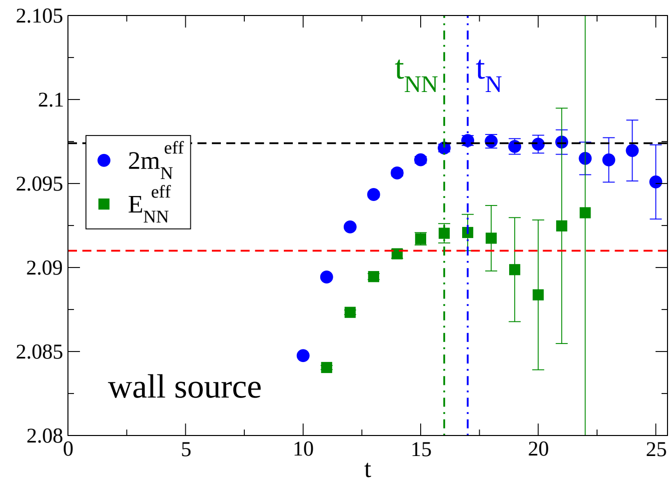

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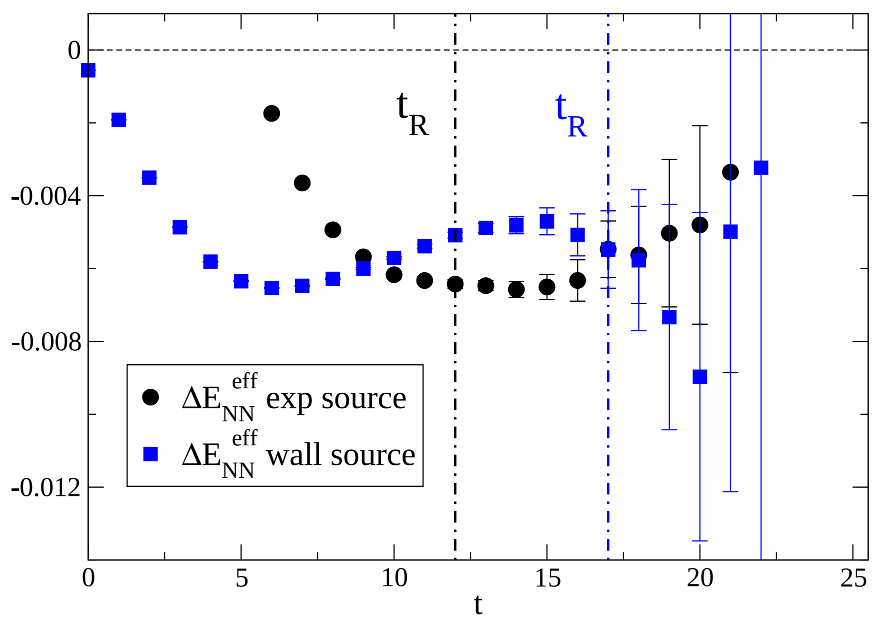


Effective $\Delta E_{NN} = E_{NN} - 2m_N$

exp: reasonable plateau in $t \gtrsim t_{N,NN}$

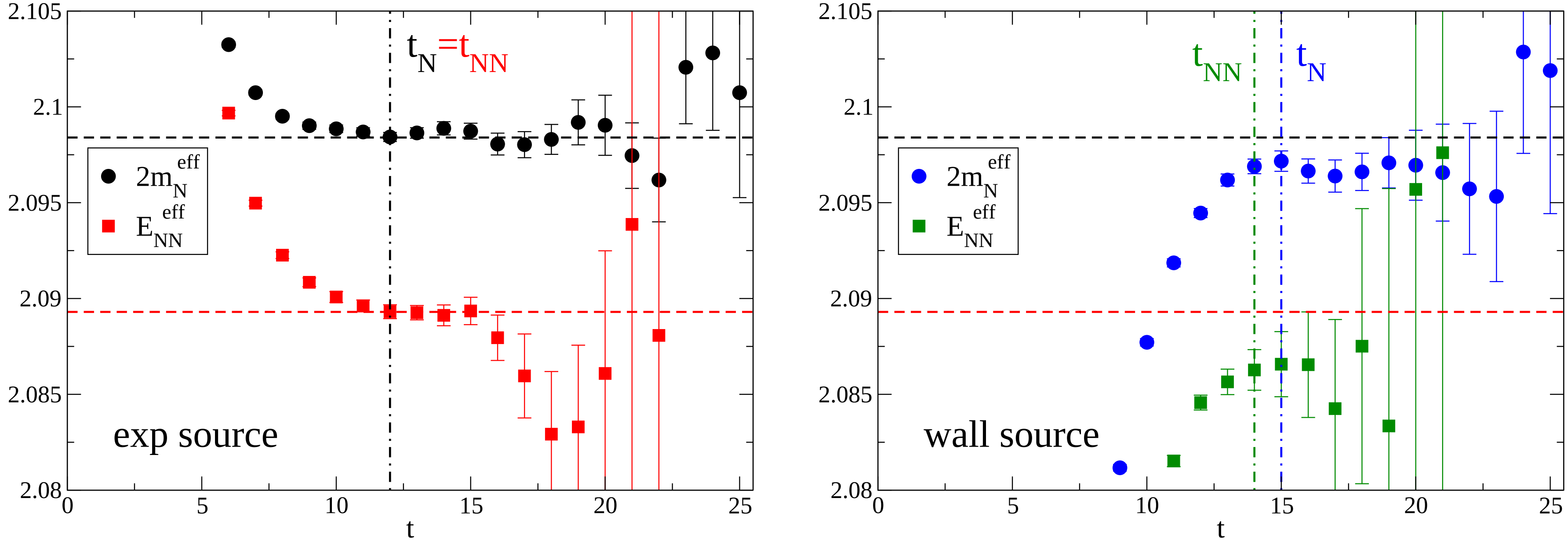
wall: non-monotonic behavior

consistent with exp in $t \gtrsim t_N$

with large error

$R(t) = C_{NN}(t)/(C_N(t))^2$ in $L = 16$

Effective $2m_N$ and E_{NN}



$t_N \sim t_{NN} \sim 12$ $\qquad$ $t_{NN} \sim 14$, $t_N \sim 15$

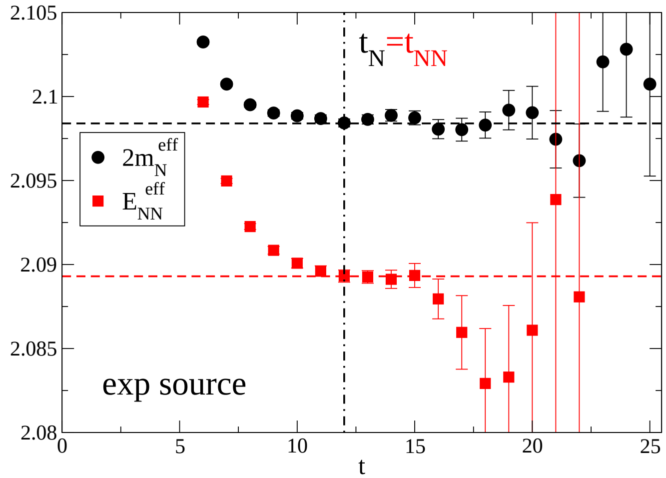
dashed lines determined from exponential source

reasonably consistent with each other in plateau region

wall data: little smaller than exp data due to statistics, probably

$R(t) = C_{NN}(t)/(C_N(t))^2$ in $L = 16$

Effective $2m_N$ and E_{NN}



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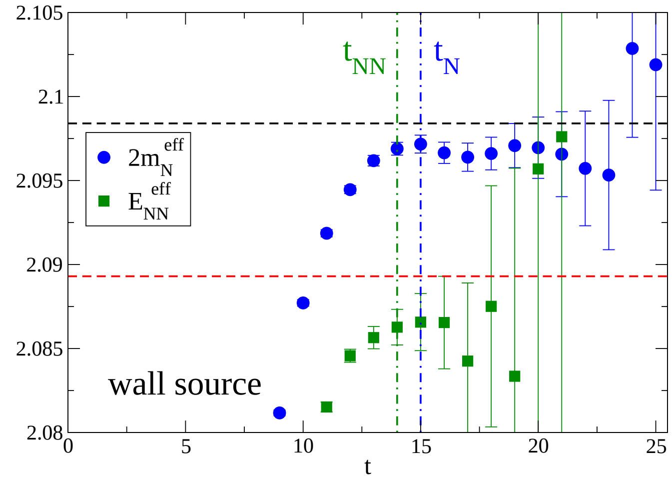
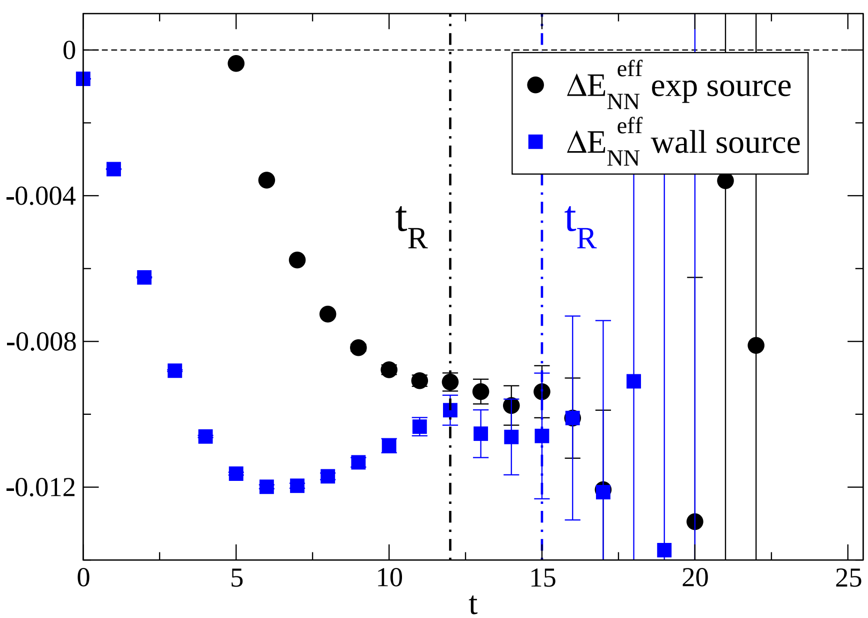


$t_{NN} \sim 14$, $t_N \sim 15$



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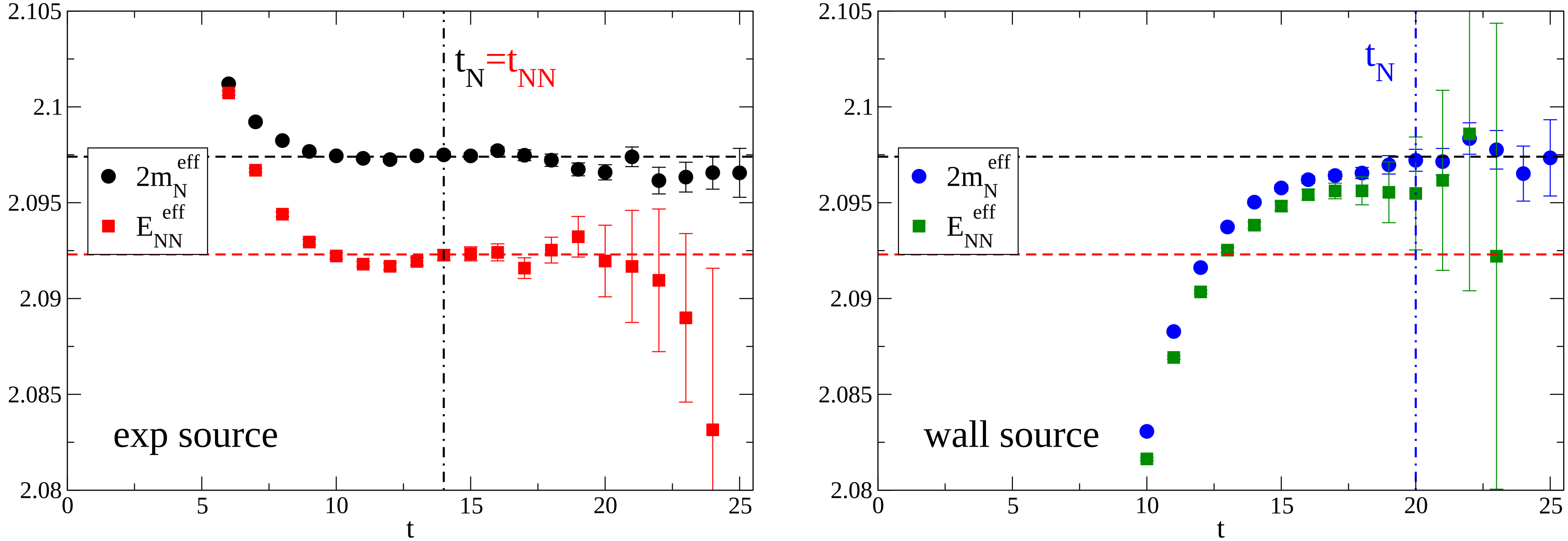
with large error

$R(t) = C_{NN}(t)/(C_N(t))^2$ in $L = 32$

Effective $2m_N$ and E_{NN}



$t_N \sim t_{NN} \sim 14$ $\qquad$ $t_{NN} \approx 20, \ t_N \sim 20$

dashed lines determined from exponential source

hard to obtain consistent E_{NN} in this statistics

wall source

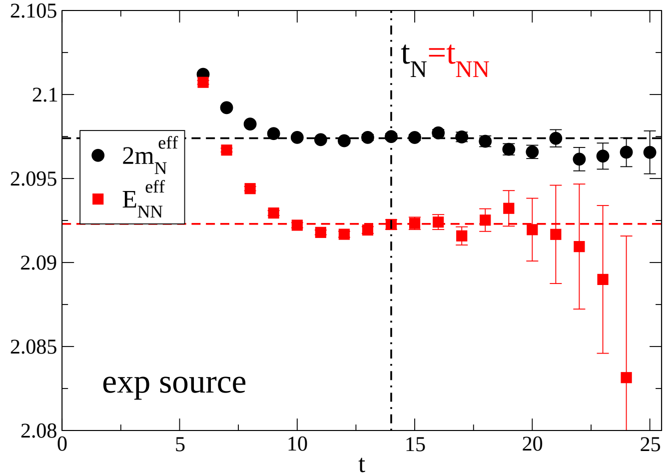
overlap to scattering state becomes larger as volume increases.

$\rightarrow$ need longer t to reach plateau

$\rightarrow$ assume $t_{NN} = 20$ in this study

$R(t) = C_{NN}(t)/(C_N(t))^2$ in $L = 32$

Effective $2m_N$ and E_{NN}



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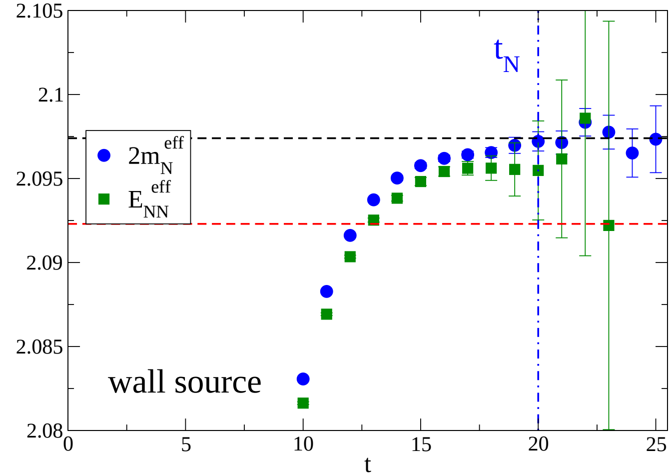

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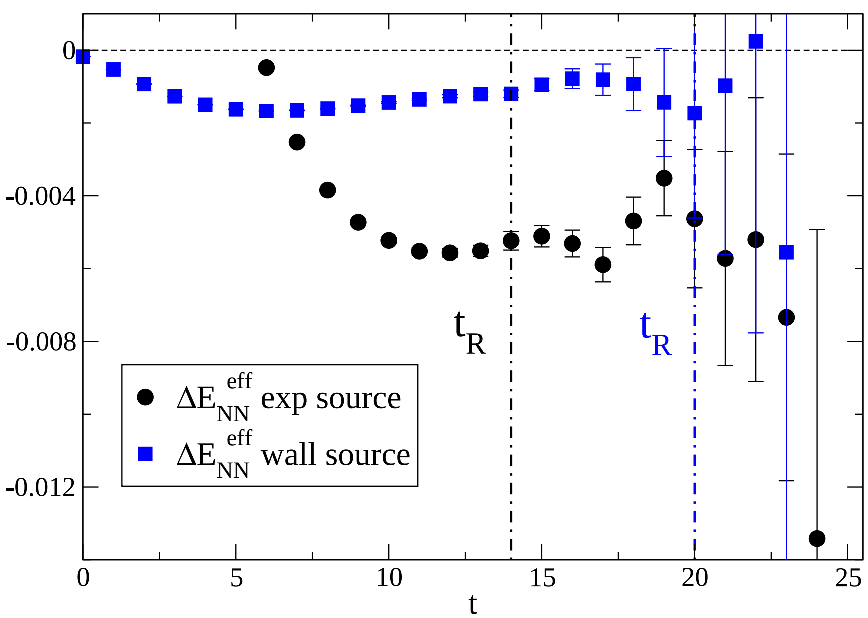

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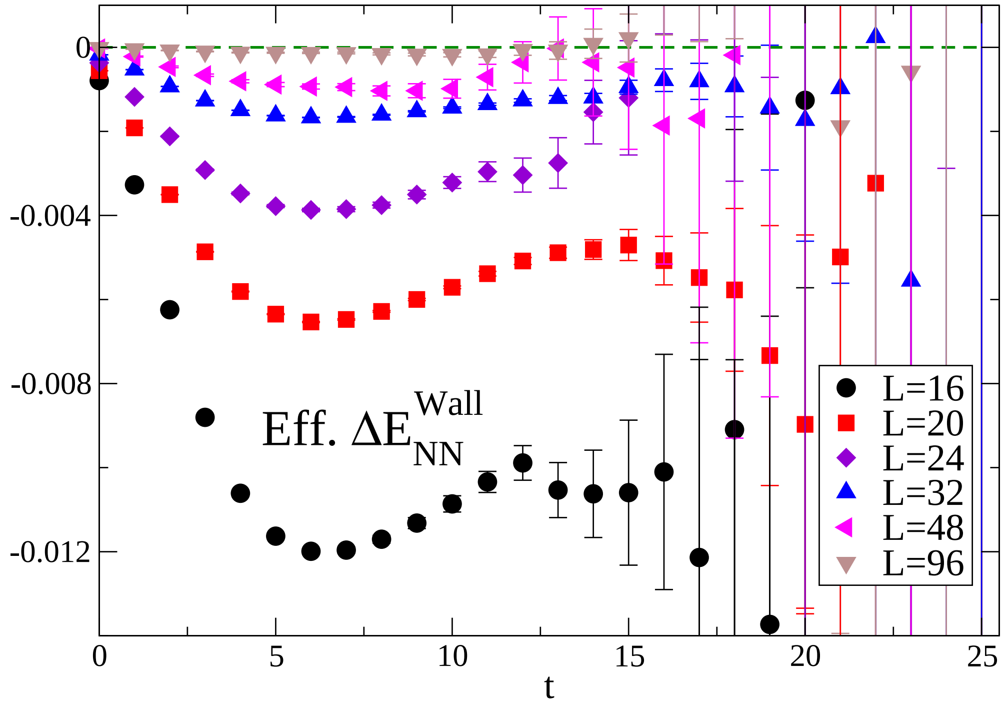
Volume dependence of wall source

Preliminary result + pilot study of PRD84:054506(2011): $N_f = 0$ $m_\pi = 0.8$ GeV



Clear volume dependence + bowl like structure in small t

$\Leftarrow$ mistaken as plateau in large volume if statistics is not enough

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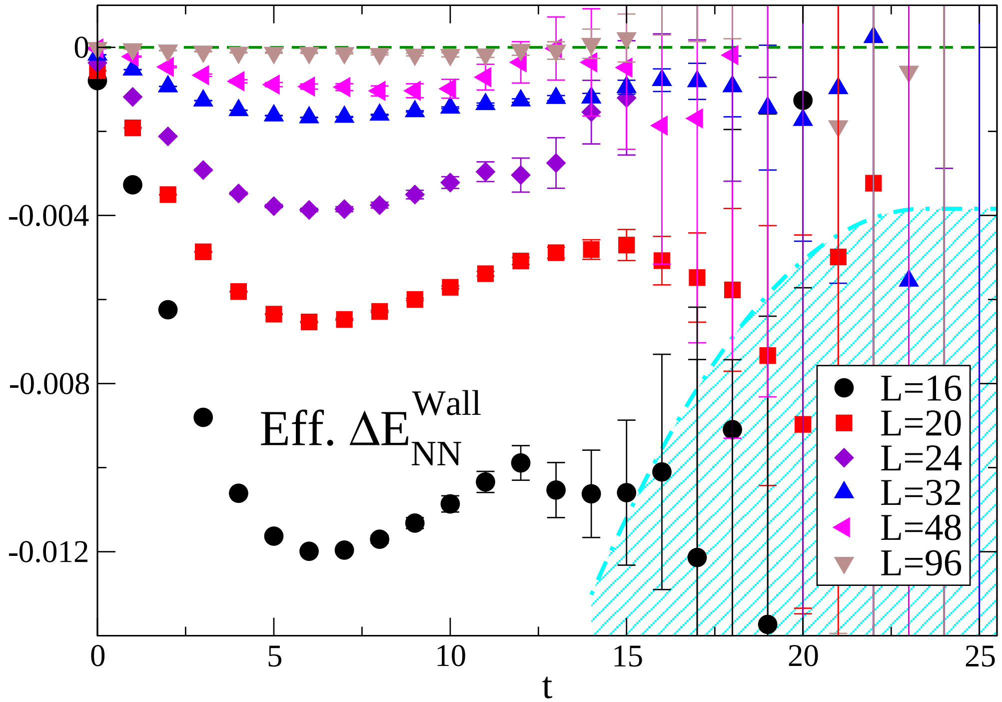

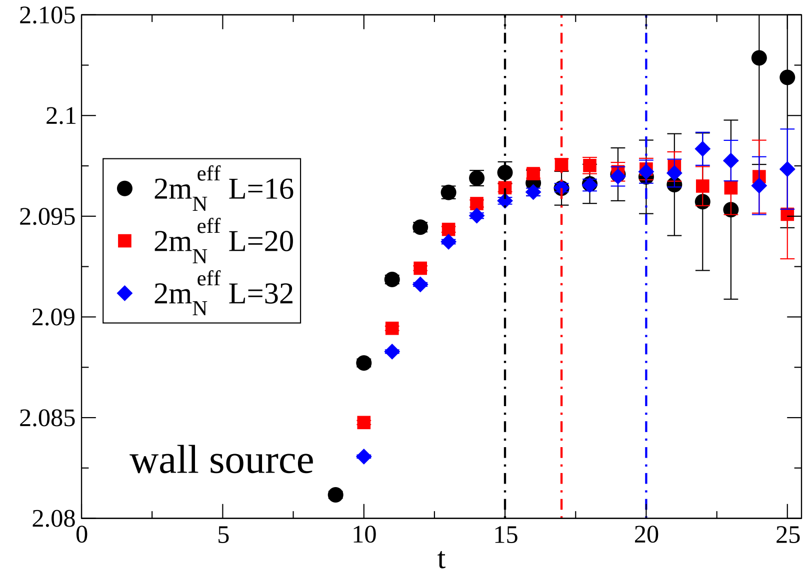

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Plateau of ΔE_{NN} is expected to be obtained in shaded region.

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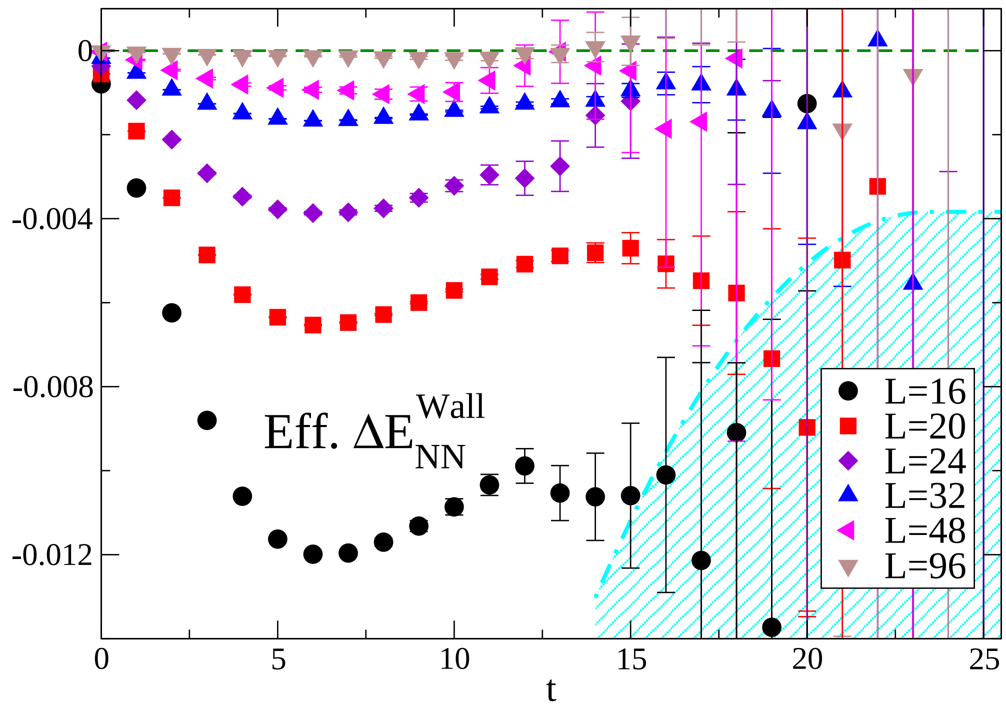

Clear volume dependence + bowl like structure in small t

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Plateau of ΔE_{NN} is expected to be obtained in shaded region.

Positive effective ΔE_{NN} might be obtained in large volume.

$\rightarrow$ overlap to scattering state becomes larger with volume

and $\Delta E_{NN}^{\text{scat}} > 0$ when bound state exists.

Summary and future work

Comparison of exponential and wall sources in NN ^{3}S$_1$
from high precision calculation in $N_f = 0$ $m_\pi = 0.8$ GeV

Important condition of direct calculation
Plateau of ΔE_{NN} should be obtained from region
where C_N and C_{NN} are dominated by each ground state.
Two sources give consistent ΔE_{NN}, while wall source has larger error.

Wall source

- hard to obtain plateau for $2m_N$, E_{NN}, and ΔE_{NN}

much harder in larger volume due to scattering state contribution

- bowl like behavior of effective ΔE_{NN} in small t

possibility to be mistaken as a plateau in poor statistics

Need further investigations

consistency check of exponential and wall sources in large volume
more sophisticated analysis (GEVP)
observing effective $\Delta E_{NN} > 0$ in wall source, $\cdots$