Nucleon isovector couplings from 2+1 flavor lattice QCD at the physical point

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Previous results

The PACS collaboration performed realistic lattice QCD simulations using the PACS10 conf.

PACS10 conf.

- stout-smeared $\mathcal{O}(a)$ improved Wilson action
- Iwasaki gauge action

K.-I. Ishikawa *et al.*, PRD99 014504 (2019).

- $m_\pi = 135$MeV
- $L^3\,T = 128^4$, $aL \sim 10.8\mathrm{fm}$
- $a^{-1} \approx 2.3$[GeV]

Achievement

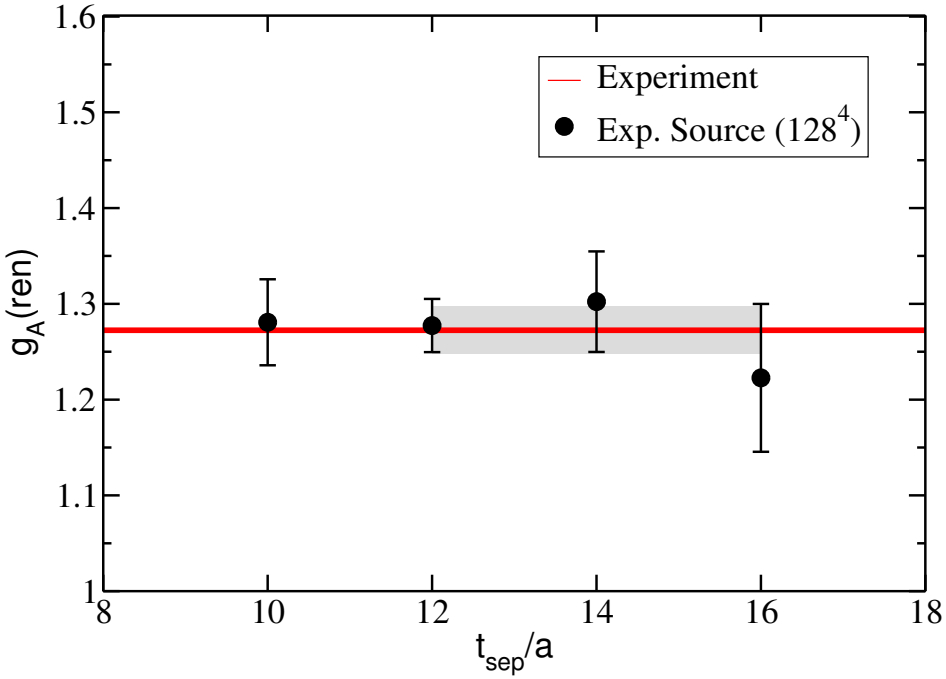
a few-percent determination of the axial-vector coupling and proton charge radius

- $g_A = 1.273(24)_{\mathrm{stat}}(5)_{\mathrm{sys}}(9)_{\mathrm{ren}}$
- $\sqrt{\langle r_E^2 \rangle} = 0.858(13)_{\mathrm{stat}}(35)_{\mathrm{sys}}$

E. Shintani *et al.*, PRD 99 014510(2019).

Previous results

We had computed nucleon 2pt and 3pt correlators using the all-mode-averaging (AMA) technique with the 4 different source-sink separations ($t_{\rm sep}$).



source	$N_{\rm conf}$	$t_{\rm sep}/a$	# of meas.
Exp	20	10	2560
		12	5120
		14	6400
		16	10240

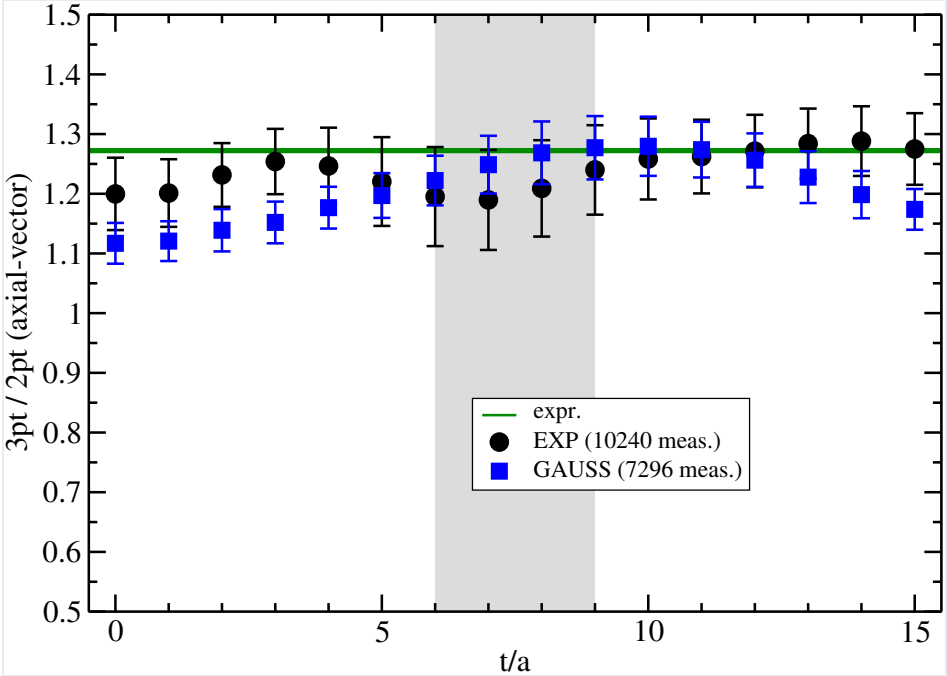
our next goal

- 1%-level precison on g_A and $\sqrt{\langle r^2 \rangle_E}$
- accurate determination of g_S and g_T

Update of g_A

Using the gauge-covariant Gauss-smeared source, the statistical errors can be efficiently reduced.

g_A with $t_{\rm sep}/a = 16$ as an example



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Exp	20	10	2560
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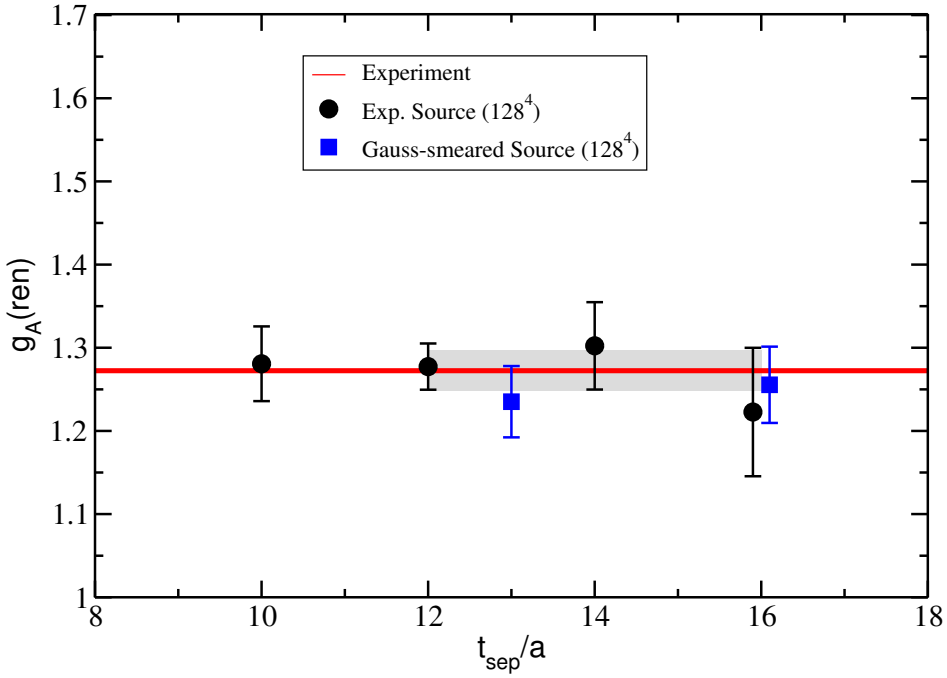
		16	10240
Gauss	16	13	1024
	19	16	7296

5-6 times lower cost than the case of the Exp source.



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Gauss	16	13	1024
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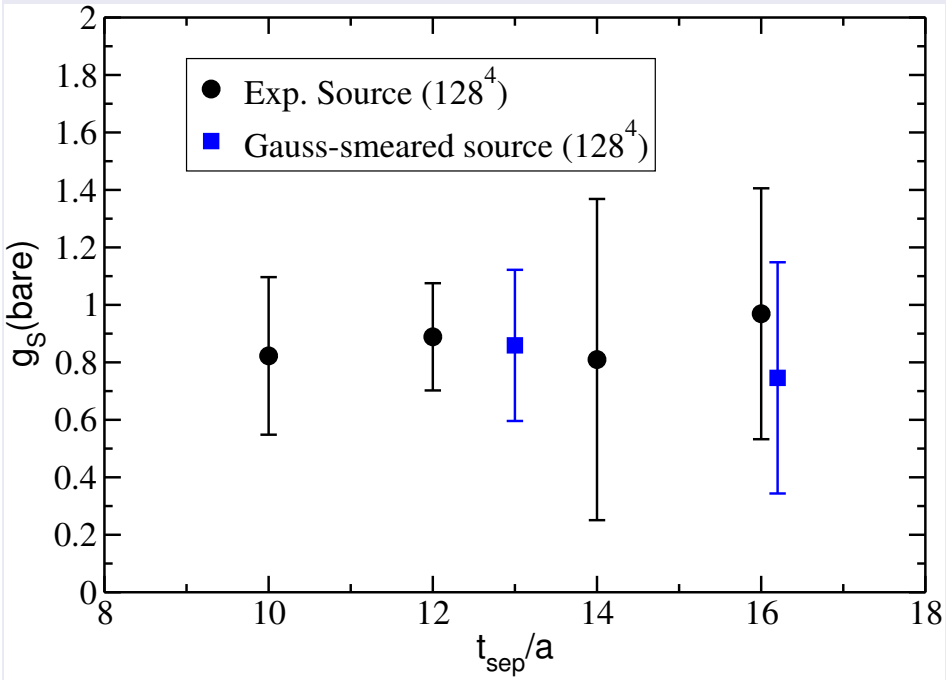
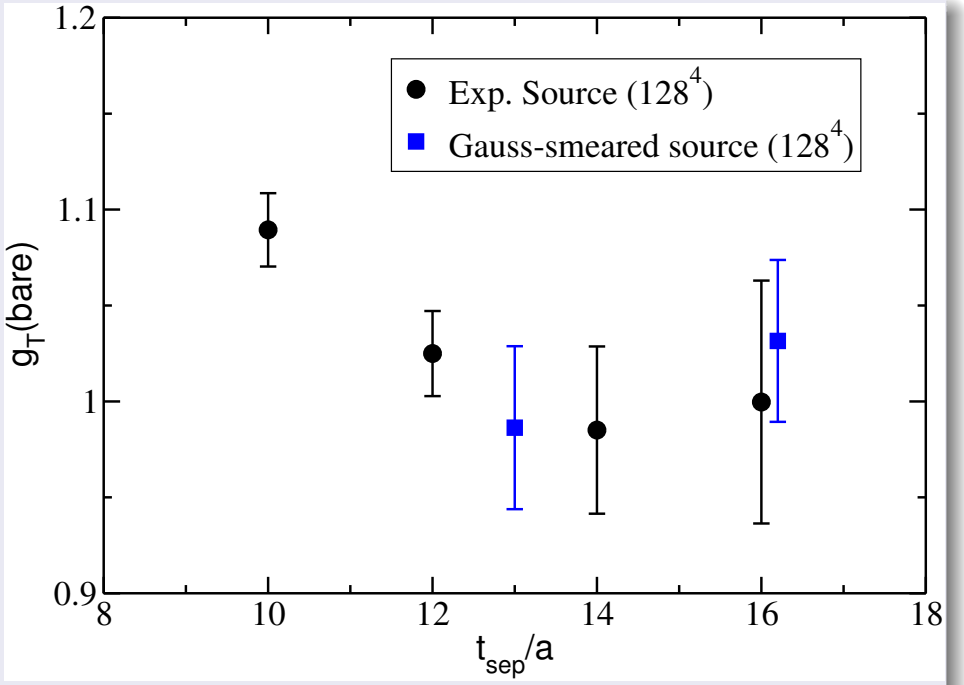
- A few %-level precision on g_A with $t_{\rm sep}/a = 16$ will be easily achieved
- Combined with the result obtained with $t_{\rm sep}/a = 13$, our final result of g_A will be able to reach 1%-level precision.
- Analysis on $\langle r_E^2 \rangle$ is now in progress.

Determination of bare couplings g_S and g_T

We also measured bare coupling constants in the tensor and scalar channels with the several different source-sink separations.



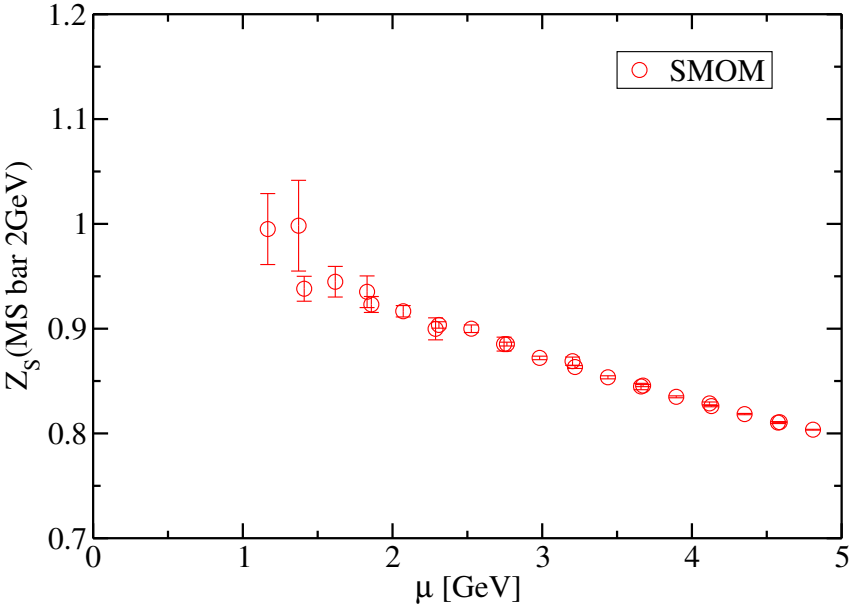


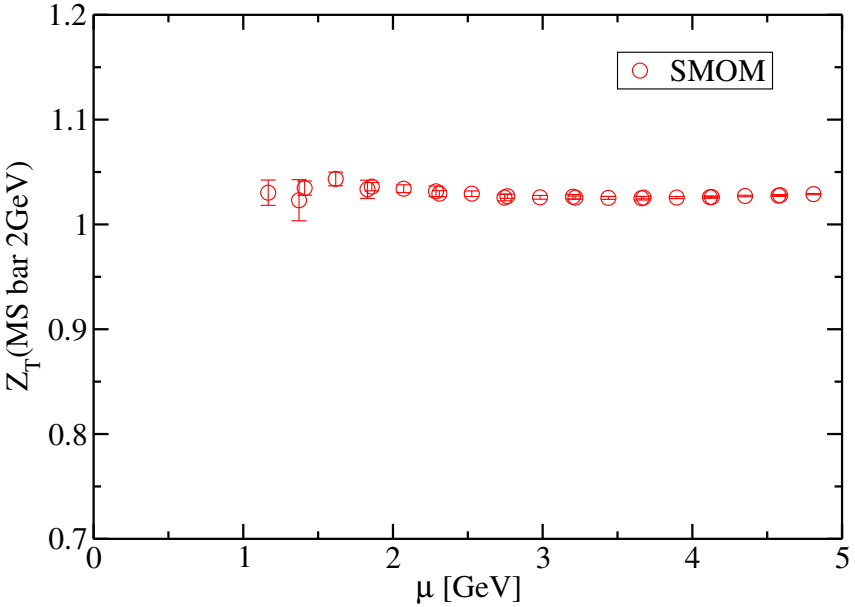
The systematic uncertainties stemming from the excited state contamination are enough small for $t_{\rm sep}/a \geq 12$

To be compared with the other simulations or experiments, the renormalization constants are required.

Renormalization

- calculate the renormalization constants in the RI/SMOM scheme at the scale of μ ($1 < \mu < 5$ [GeV]).
- then convert it into the $\overline{\mathrm{MS}}$ scheme at the scale of 2GeV.
- The scale dependence in $Z_\Gamma^{\overline{\mathrm{MS}}}$(2GeV) is observed in both cases.





- lattice artifact (the power function of μ) at large μ
- non-perturbative effect (e.g. $\frac{\langle A^2 \rangle}{\mu^2}$) at small μ [1]

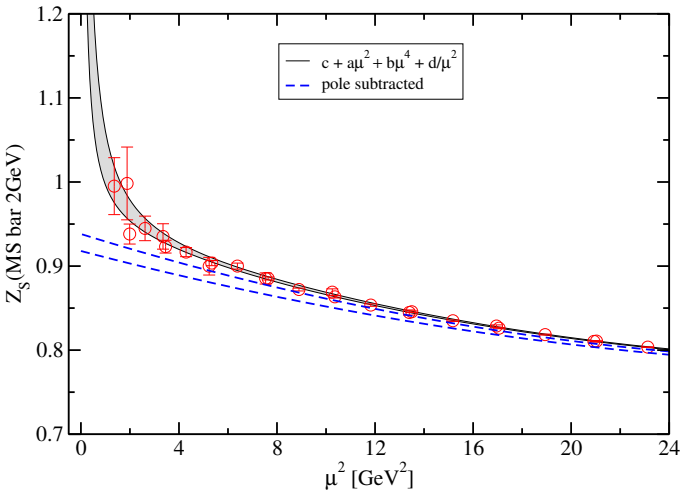
[1] Ph. Boucaud *et al.*, PRD74 034505 (2006).

Residual scale dependence

To eliminate the residual scale dependence, we performed two types of the fits [2]

$$Z_\Gamma^{\overline{\rm MS}}(2{\rm GeV},\mu) = \begin{cases} \frac{c_{-1}}{\mu^2} + c_0 + c_1\mu + c_2\mu^2 & \text{pole} + \text{power} \\ \frac{c_{-1}}{\mu^2} + c_0 + c_2\mu^2 + c_4\mu^4 & \text{pole} + \text{even power} \end{cases} \tag{1}$$

with c_0 being the μ-independent value of Z.



$$Z_S^{\overline{\rm MS}}(2{\rm GeV}) = 1.00 \pm 0.02_{\rm stat} \pm 0.06_{\rm sys}$$
$$Z_T^{\overline{\rm MS}}(2{\rm GeV}) = 1.05 \pm 0.01_{\rm stat} \pm 0.02_{\rm sys}$$

The difference between the results from two types of the fits is treated as the systematic uncertainty.

[2] pole + even power N. Hasan *et al.*, arXiv:1903.06487 [hep-lat].

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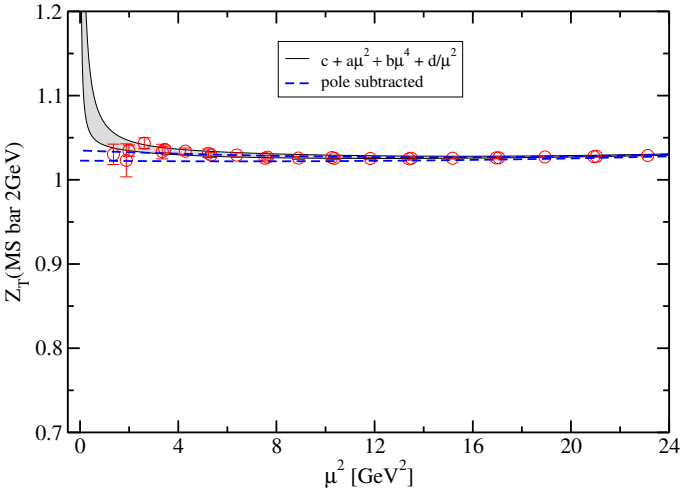

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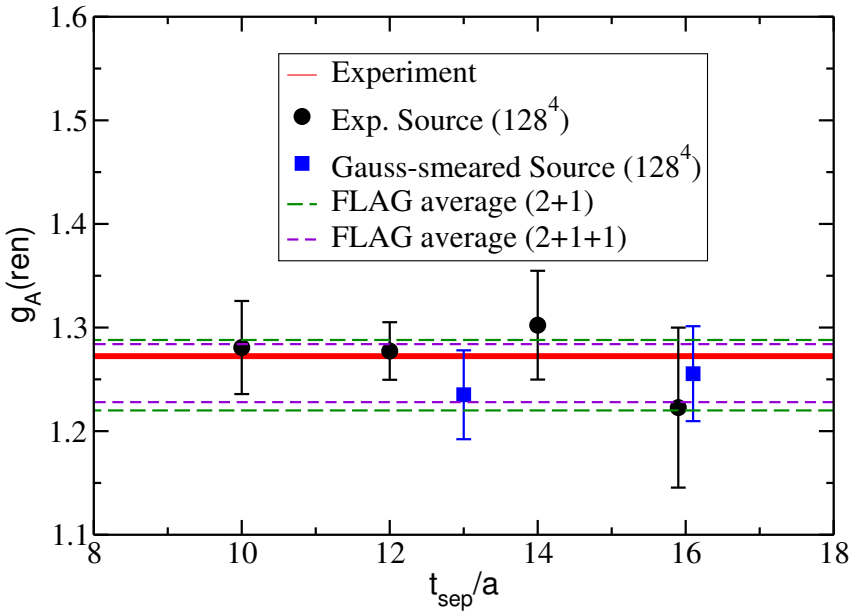
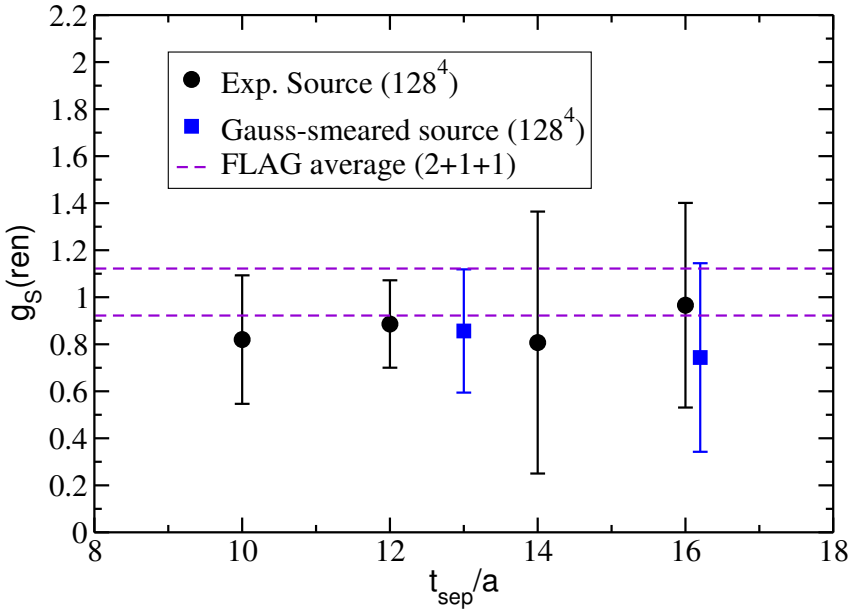
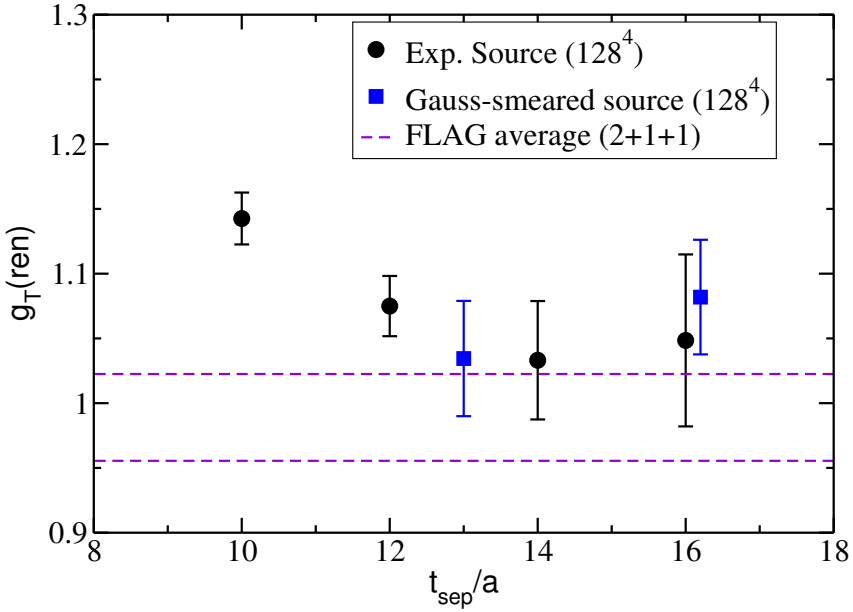
Renormalized coupling constants

We finally obtain renormalized coupling constants g_S, g_T which are consistent with the FLAG average values, while the axial-vector coupling g_A is in good agreement with the experiment.







Summary

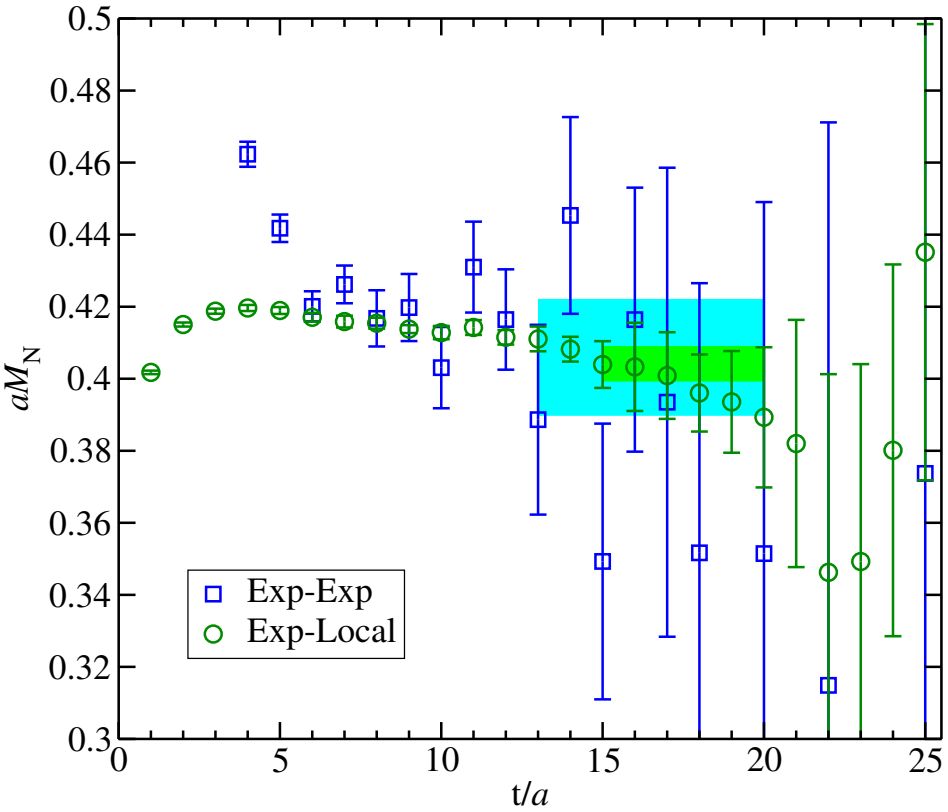
We reported the recent progress on the nucleon iso-vector couplings.

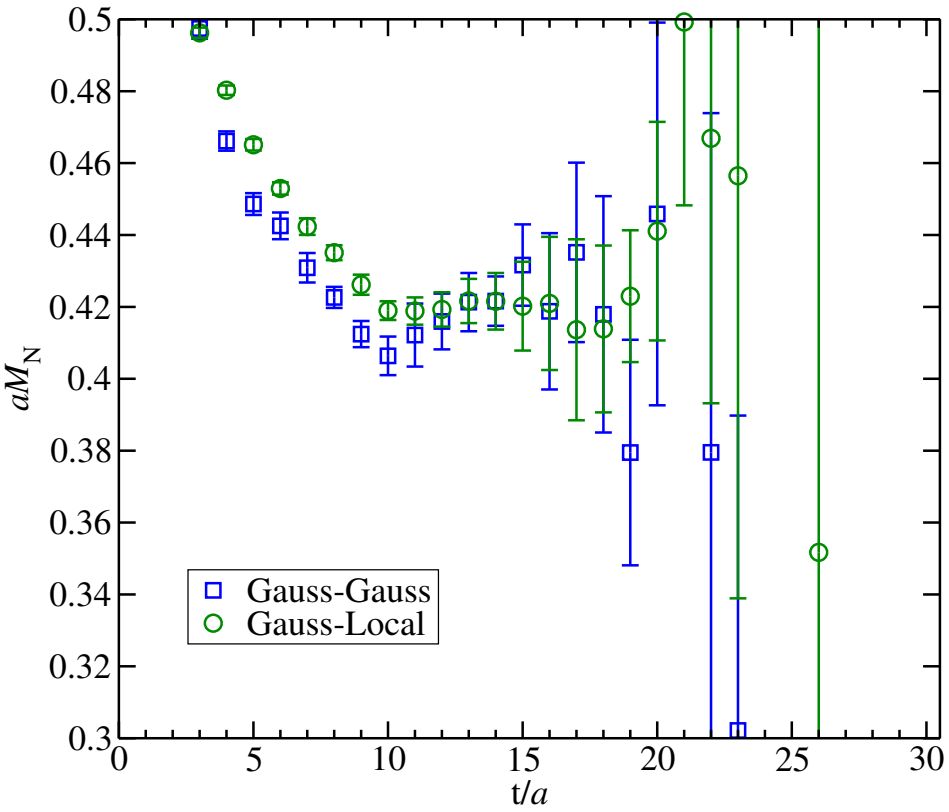
- Using the Gauss-smeared source, the statistical errors are efficiently reduced.
  - A few % precision on g_A with $t_{\rm sep}/a = 16$ will be easily achieved.
  - Combining the results with $t_{\rm sep}/a = 13, 16$, our final result of g_A will be able to reach 1%-level precision.
- We measured the bare couplings in the scalar and tensor channels with different source-sink separations.
  - $\rightarrow$ Excited state contamination is well under control.
  - We also non-perturbatively estimated the renormalization constants for the scalar and tensor current using the RI/SMOM scheme.
    - $\rightarrow$ We obtain the renormalized g_A, g_S, g_T which are consistent with the recent FLAG averages (2019).
    - g_S 54%(stat),6%(sys) uncertainties
    - g_T 4%(stat),2%(sys) uncertainties

    with $t_{\rm sep}/a = 16$, using the Gauss-smeared source.
- (Future work) Measurements on 160^4 lattice with a different lattice spacing $\rightarrow$Free from systematic errors, lattice artifact, chiral extrapolation, and finite volume effect.

BACKUP

effective mass





insertion time dependence in the scalar and tensor channels