

Nucleon isovector axial charge in 2+1-flavor domain-wall QCD with physical mass

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RBC and UKQCD have been generating **2+1-flavor dynamical DWF** ensembles with **good chiral and flavor symmetries**. We have been at **physical mass** for a while now, with a range of momentum cuts off, 1-3 GeV, and volumes $m_\pi L \sim 4$ and producing **a lot of good physics in pion, kaon, and $(g - 2)_\mu$** .

In nucleon: RBC observed puzzling and persistent deficit in the isovector axial charge, g_A , while vector-current form factors are well-behaved, and low structure-function moments are trending toward experiments, at heavier than physical mass.

This year LHP+RBC are ready to report our joint nucleon-structure studies at physical mass using the **RBC+UKQCD “48I” ensemble at $a^{-1} = 1.730(4)$ GeV**. This effort is driven by Tom Blum, Michael Engelhardt, Jeremy Green, Taku Izubuchi, Chulwoo Jung, Christos Kallidonis, Meifeng Lin, John Negele, Hiroshi Oki, Andrew Pochinsky, **Sergey Syritsyn**, Jun-Sik Yoo, (and SO,) using ANL ALCC Mira.

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On the lattice, with appropriate nucleon operator, for example, $N = \epsilon_{abc}(u_a^T C \gamma_5 d_b) u_c$, ratio of two- and three-point correlators such as $\frac{C_{3\text{pt}}^{\Gamma,O}(t_{\text{sink}}, t)}{C_{2\text{pt}}(t_{\text{sink}})}$ with

$$C_{2\text{pt}}(t_{\text{sink}}) = \sum_{\alpha,\beta} \left(\frac{1 + \gamma_t}{2} \right)_{\alpha\beta} \langle N_\beta(t_{\text{sink}}) \bar{N}_\alpha(0) \rangle,$$

$$C_{3\text{pt}}^{\Gamma,O}(t_{\text{sink}}, t) = \sum_{\alpha,\beta} \Gamma_{\alpha\beta} \langle N_\beta(t_{\text{sink}}) O(t) \bar{N}_\alpha(0) \rangle,$$

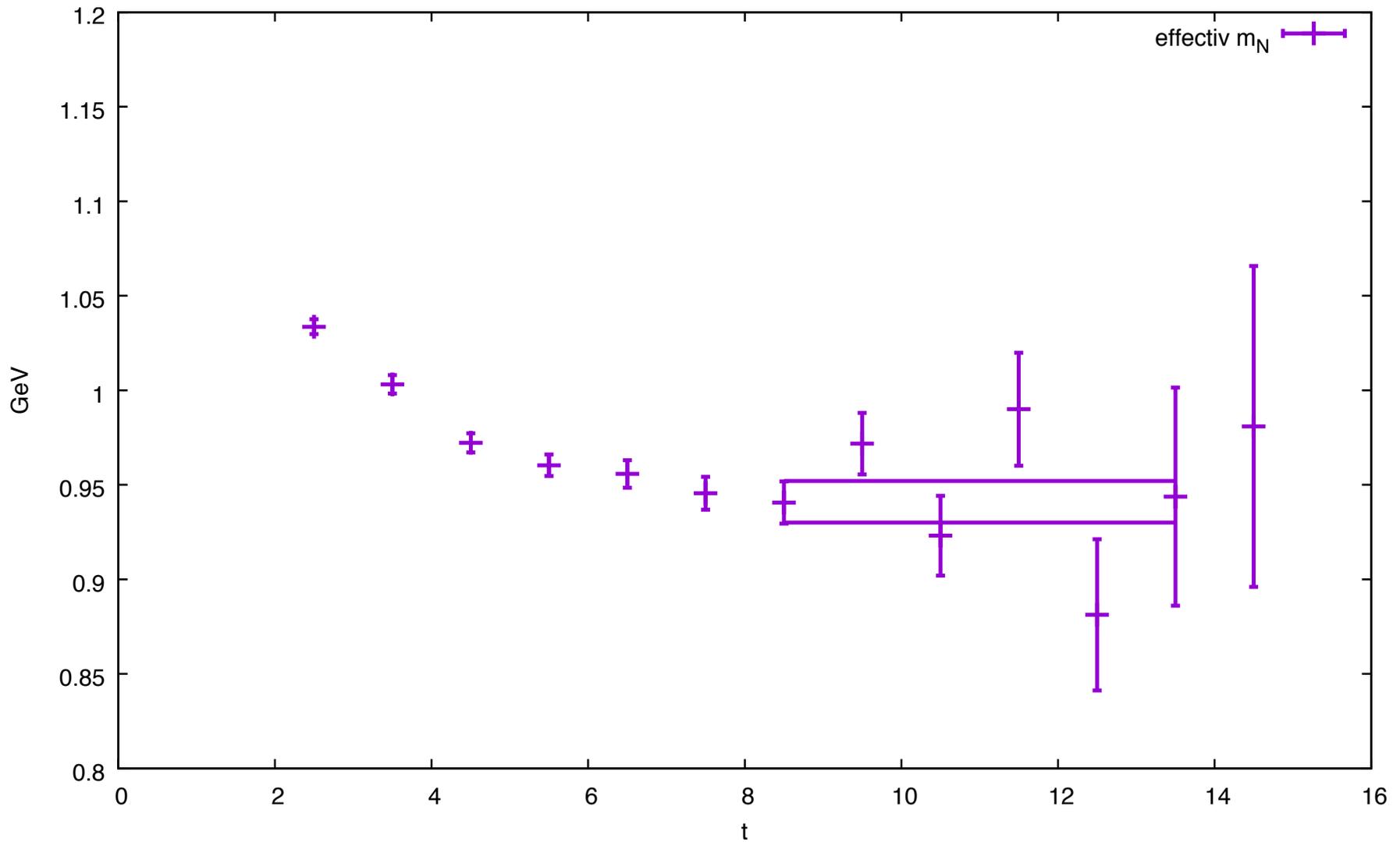
give a plateau in t for a lattice bare value $\langle O \rangle$ for the relevant observable, with appropriate spin ($\Gamma = (1 + \gamma_t)/2$ or $(1 + \gamma_t)i\gamma_5\gamma_k/2$) or momentum-transfer (if any) projections.

Here I report results for isovector quark bilinears: vector charge g_V , $O = \bar{q}\gamma_t q$, axial charge g_A , $O = \bar{q}\gamma_5\gamma_z q$, transversity, g_T , $O = \bar{q}\gamma_5\gamma_z\gamma_t q$, and scalar “charge,” g_S , $O = \bar{q}q$, from RBC+UKQCD “48I” ensemble:

- with Iwasaki gauge action at $\beta = 2.13$, $a^{-1} = 1.730(4)$ GeV, and pion mass of about 139.2(4) MeV,
- 130 configurations at trajectory (620-980)/20 and (990-2160)/10
 - except 1050, 1070, 1150, 1170, 1250, 1270, and 1470,
- each deflated with 2000 low-lying eigenvalues,
- each with 130 AMA sloppy calculations unbiased by 4 precision ones.

with similar Gaussian smearing as in earlier RBC studies.

Nucleon mass:



our mass estimate is $m_N = 941(11)$ MeV.

We set source-sink separations of $T = 8, 9, 10, 11,$ and 12 lattice units, or $(0.9-1.4)$ fm.

Previous RBC and RBC+UKQCD calculations addressed a few important sources of systematics:

- Spatial volume, which we cannot address with RBC+UKQCD 48I and 64I where $m_\pi L \sim 4$;

But we can study well the dependences on

- time separation between nucleon source and sink, and
- quark mass, in a sense, at the lighter, physical mass.

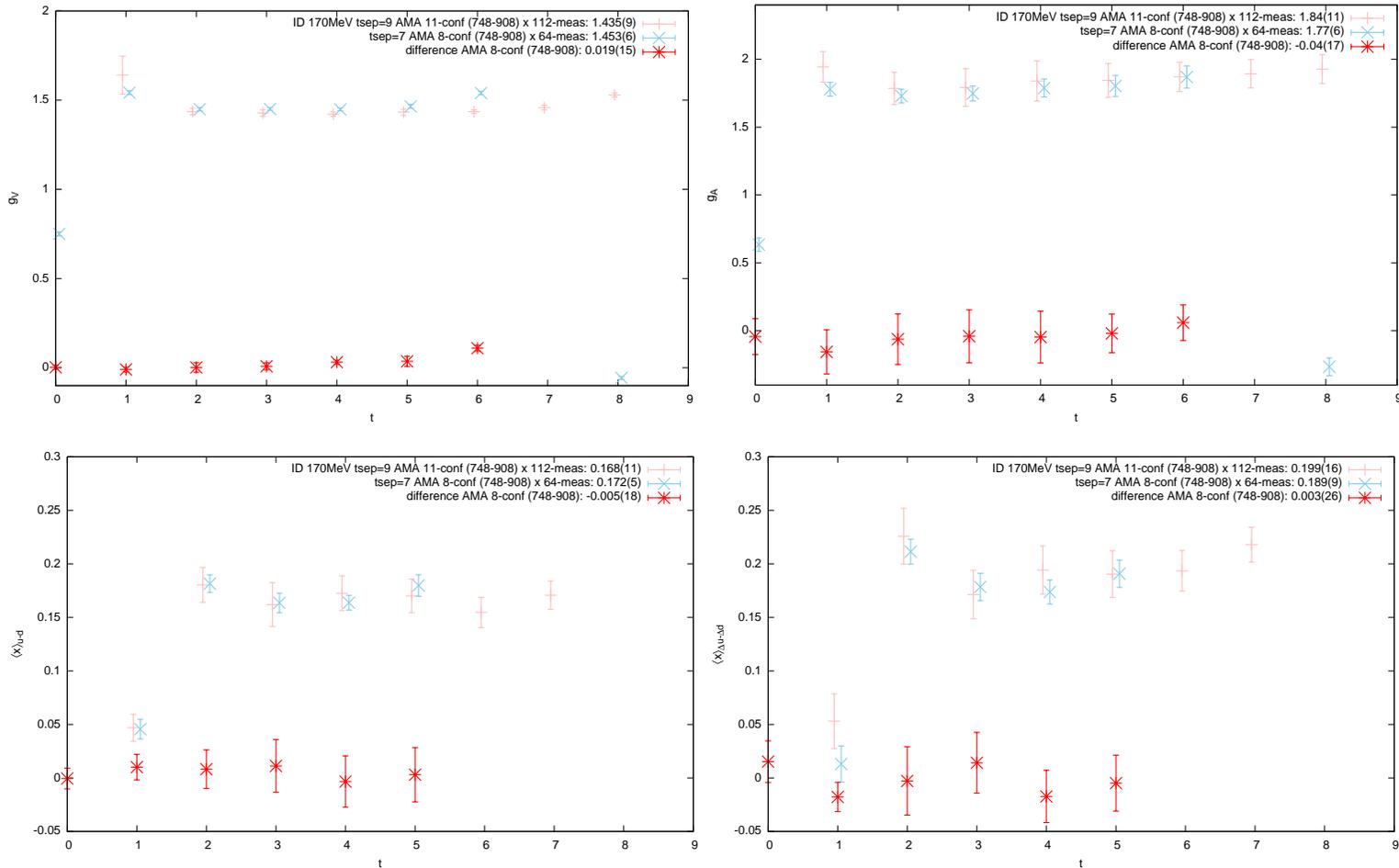
No source or sink is purely ground state: $e^{-E_0 t}|0\rangle + A_1 e^{-E_1 t}|1\rangle + \dots$ resulting in dependence on $T = t_{\text{sink}} - t_{\text{source}}$,

$$\langle 0|O|0\rangle + A_1 e^{-(E_1 - E_0)T} \langle 1|O|0\rangle + \dots$$

Any conserved charge, $O = Q$, $[H, Q] = 0$, is insensitive because $\langle 1|Q|0\rangle = 0$.

- g_V is clean, up to $O(a^2)$,
- g_A similarly does not suffer so much, indeed we never detected this systematics,
- structure function moments are not protected, so we saw the problem.
- Energy spectrum (E_n) is defined by the action.
- We can adjust source smearing (A_n) to optimize $A_1 e^{-(E_1 - E_0)T}$.

Indeed no excited-state contamination was seen in our 170-MeV calculations.

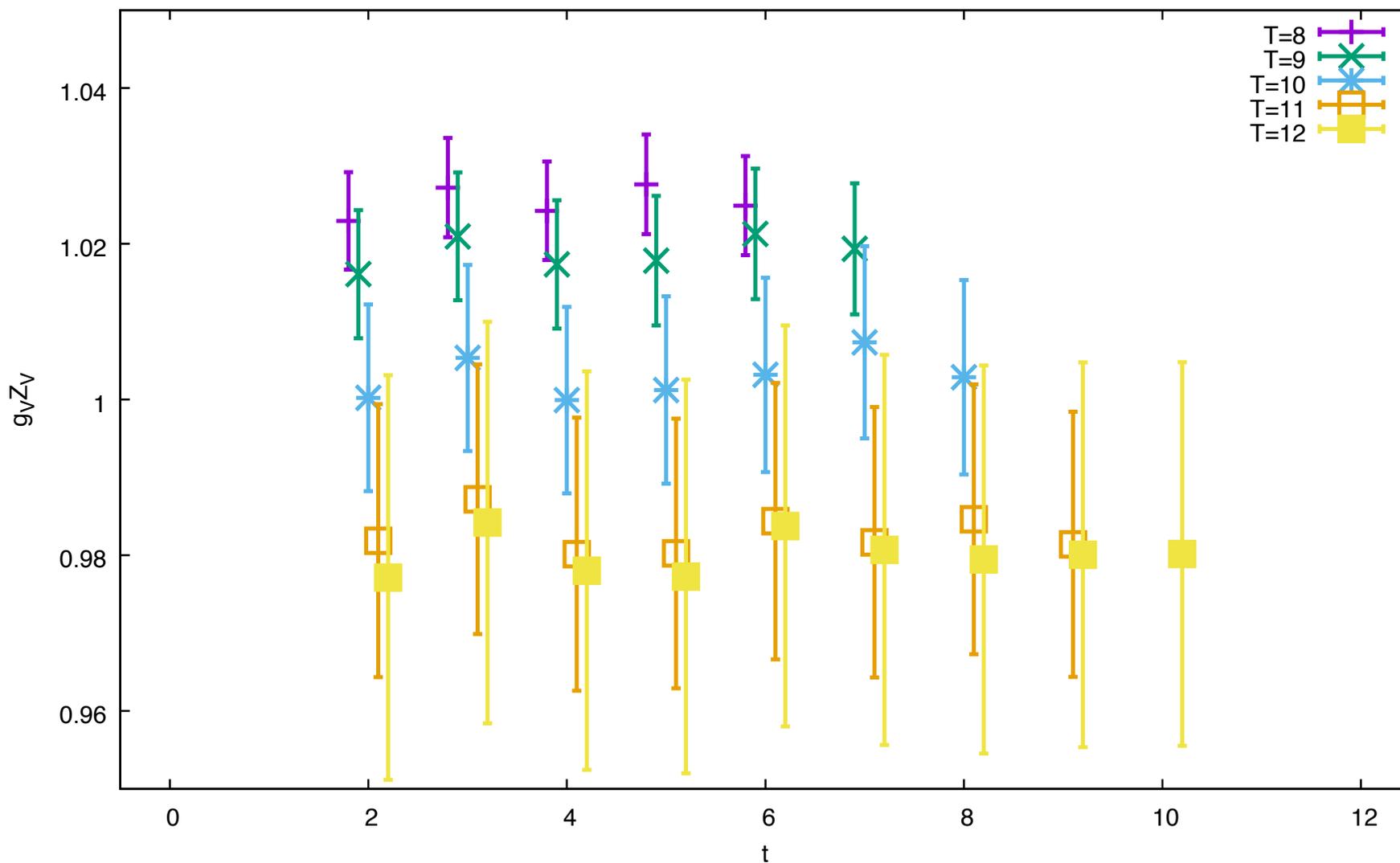


When compared with the same configurations, the difference is always consistent with 0.

$A_1 \langle 1|O|0 \rangle \sim 0$ for any observable we look at: A_1 is negligible for these small $\langle 1|O|0 \rangle$.

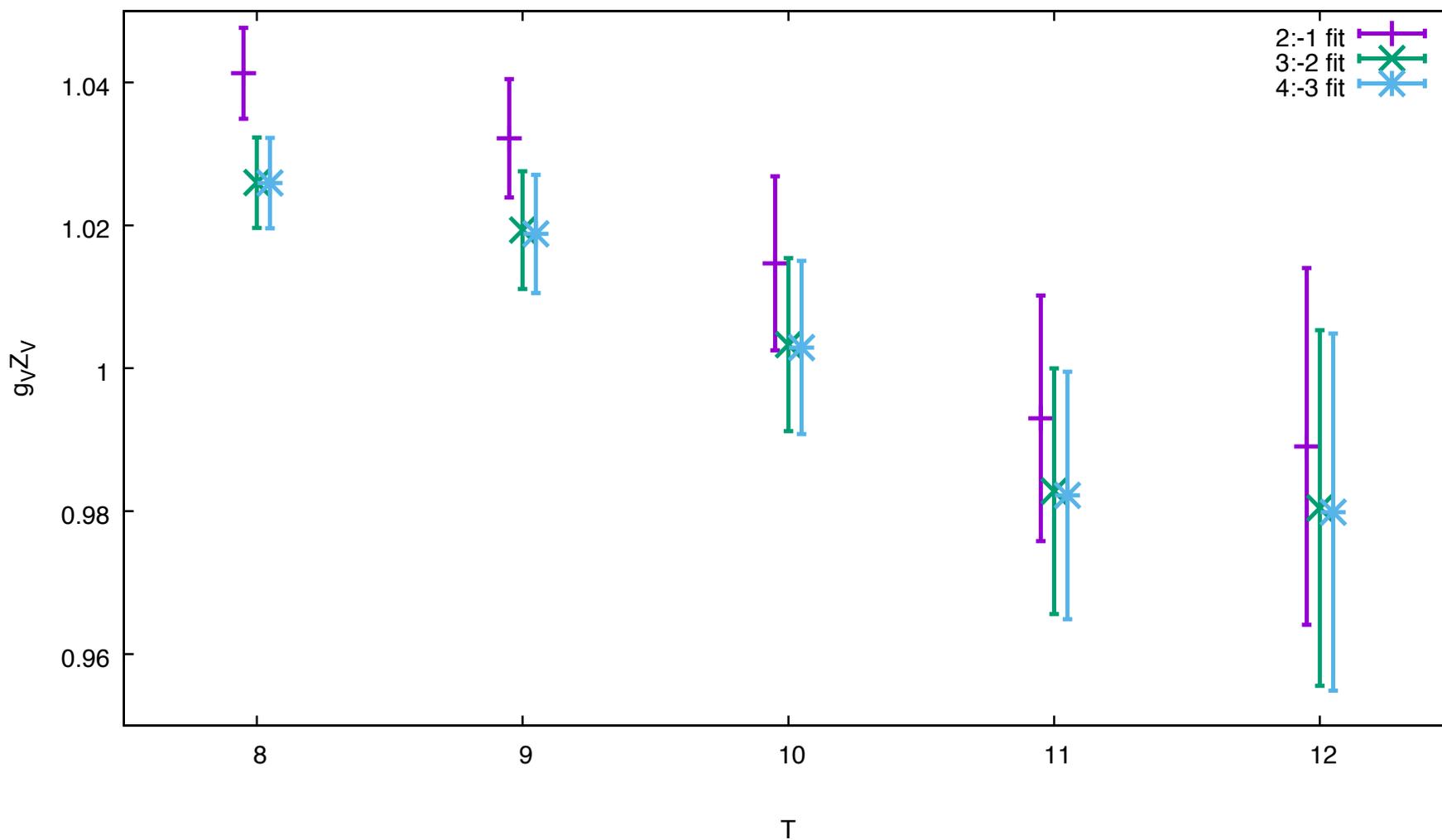
However, with 48I we planned to characterize the excited-state contamination by $T = 8, 9, 10, 11,$ and 12 .

Isvector vector charge, g_V , renormalized with meson-sector $Z_V^{\text{meson}} = 0.71076(25)$:



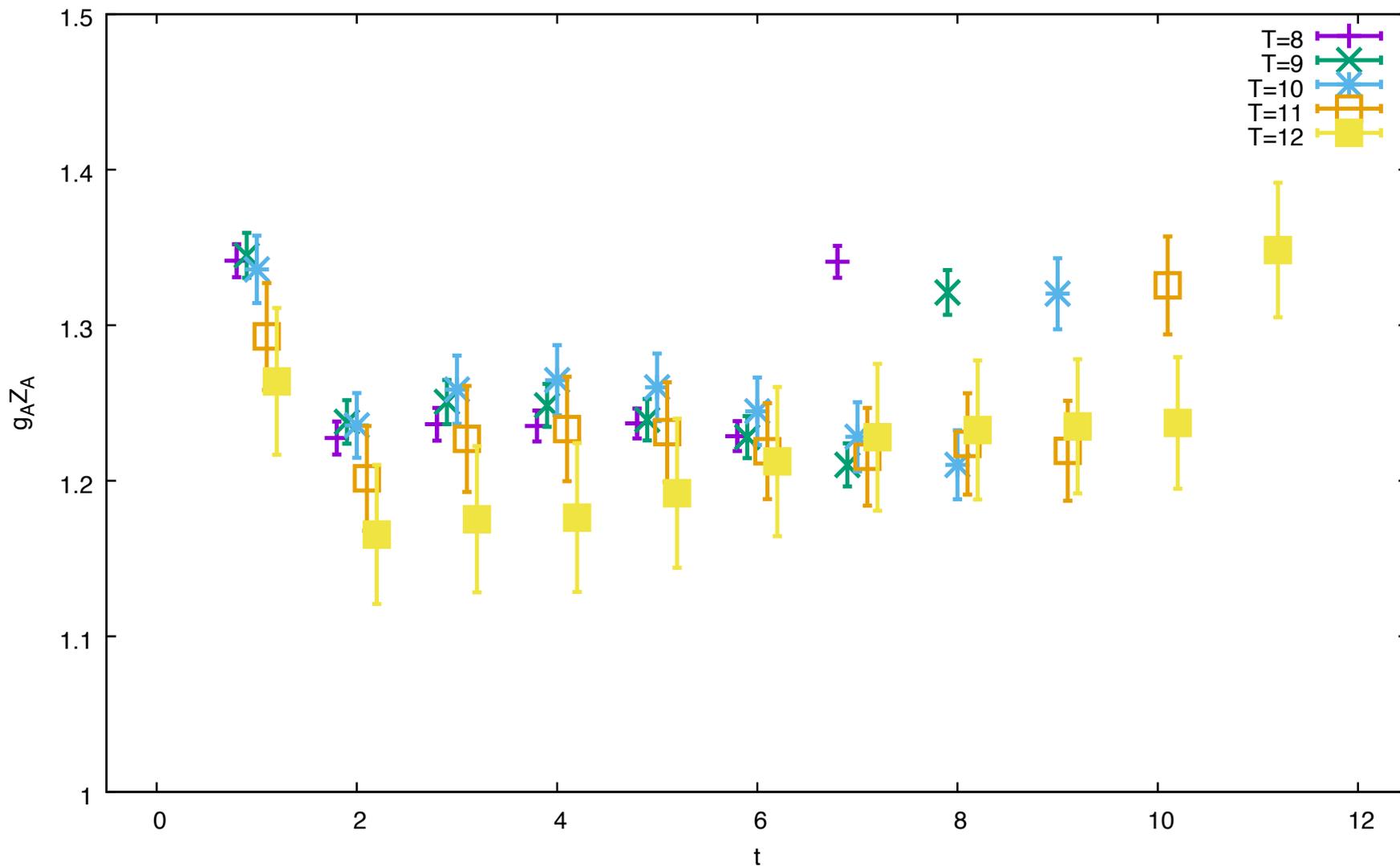
Sub-percent-level statistical accuracy, but there appears $O(a^2)$ systematics, at a couple of percent, as expected.

Isovector vector charge, g_V , renormalized with meson-sector $Z_V^{\text{meson}} = 0.71076(25)$:



We may be losing the signal at as early as $T = 10$ or 1.1 fm: 9-11 slope appears steeper than 8-9.

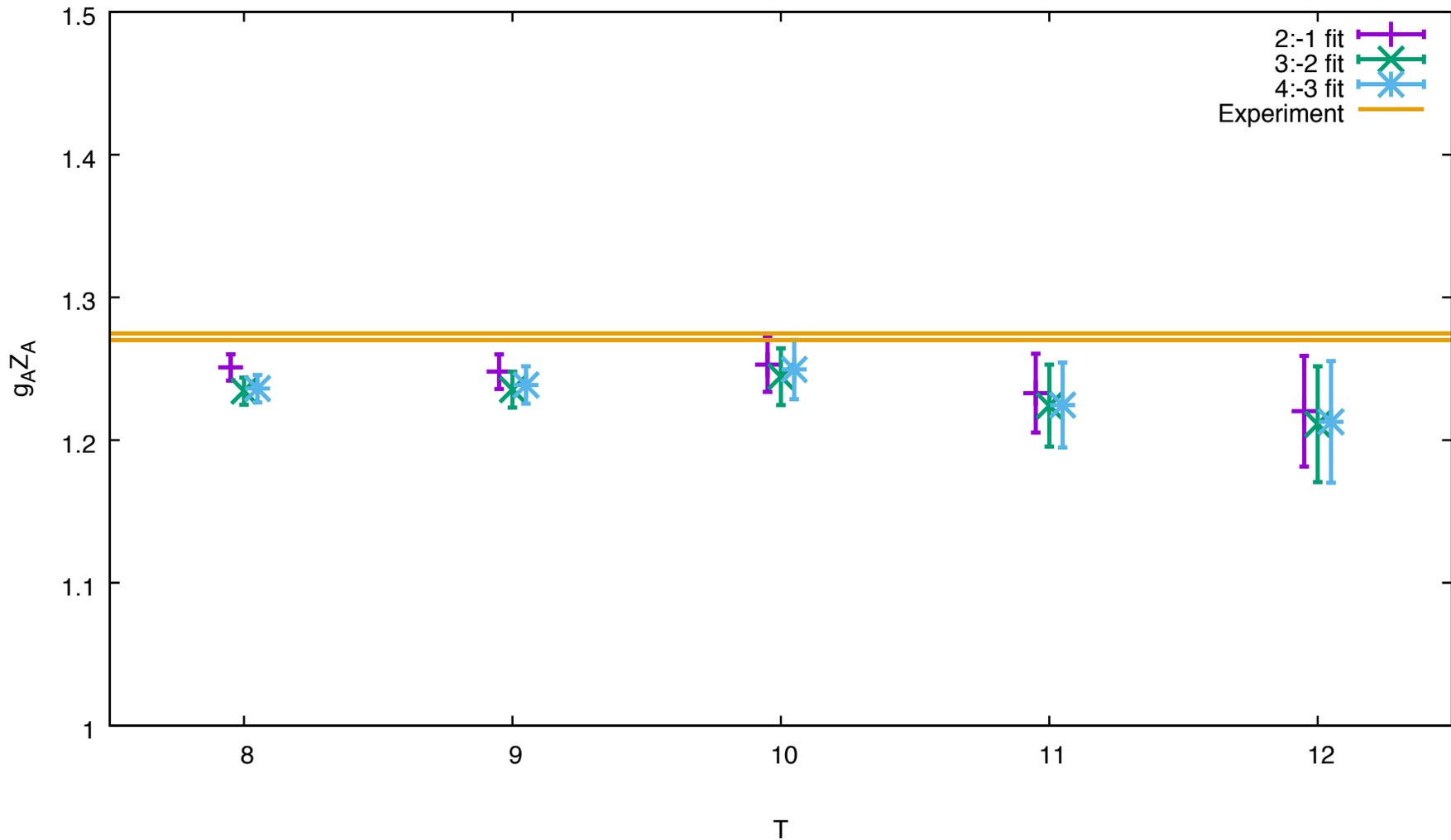
Isvector axialvector charge, g_A , renormalized with meson-sector $Z_A^{\text{meson}} = 0.71191(5)$:



No dependence on source-sink separation, T , is seen.

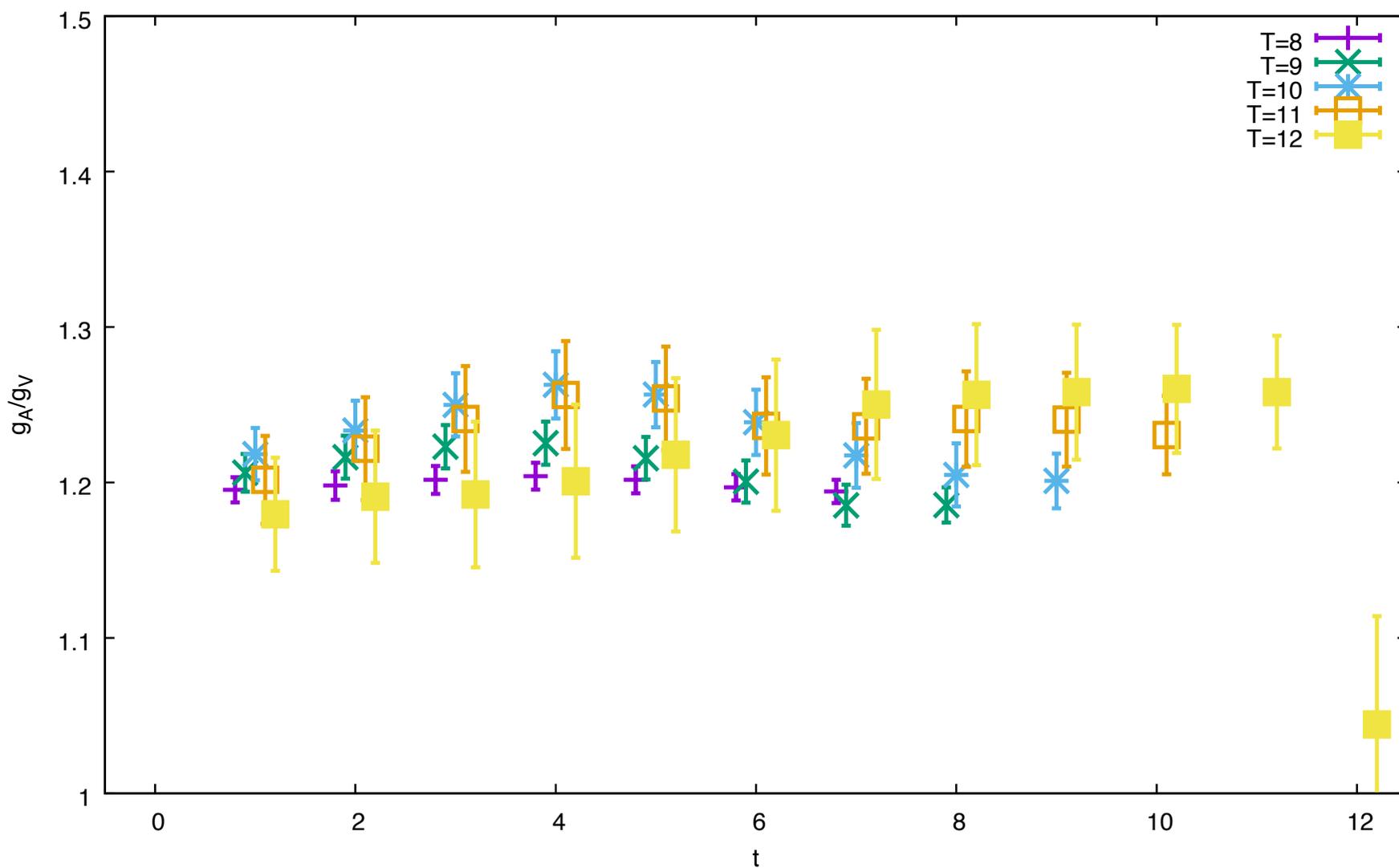
Percent-level statistical accuracy, but not quite in agreement with g_A/g_V in the following either.

Isovector axialvector charge, g_A , renormalized with meson-sector $Z_A^{\text{meson}} = 0.71191(5)$:



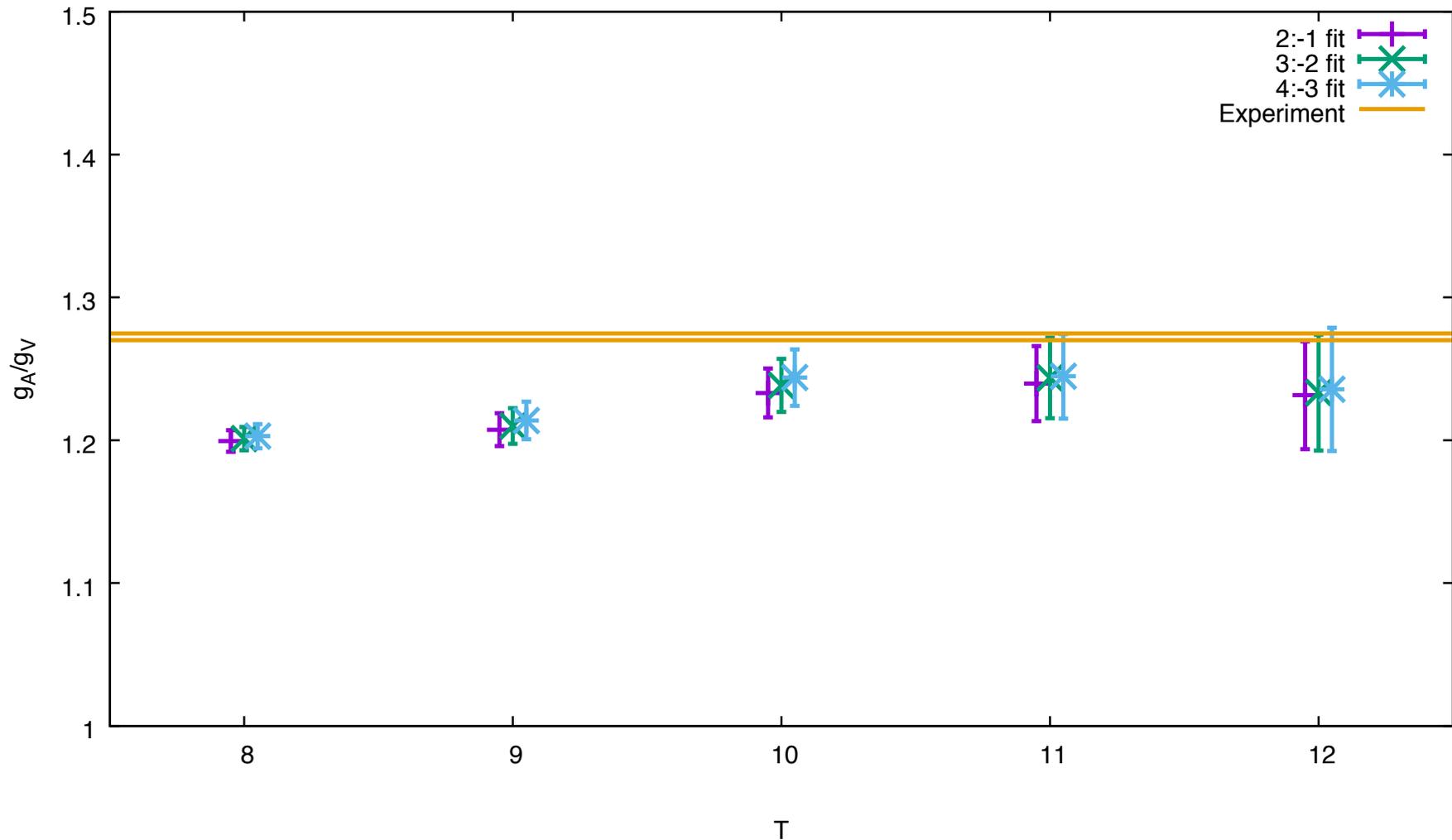
No dependence on source-sink separation, T , is seen.

Isvector axialvector to vector charge ratio, g_A/g_V :



Percent-level statistical accuracy, but we do not yet know how $O(a^2)$ systematics are here.

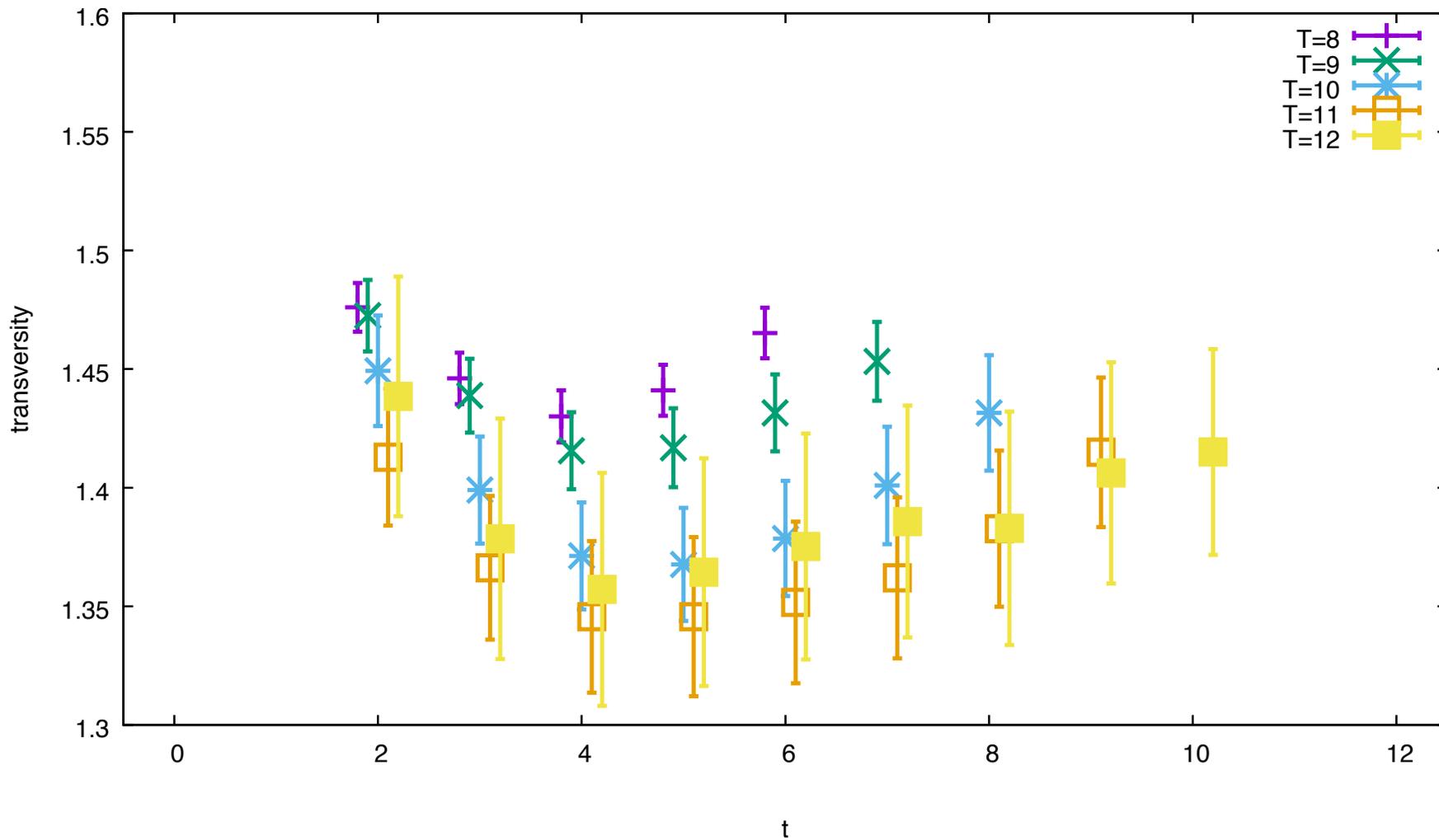
Isovector axialvector to vector charge ratio, g_A/g_V :



Not quite the same as $g_A Z_A$ in the above.

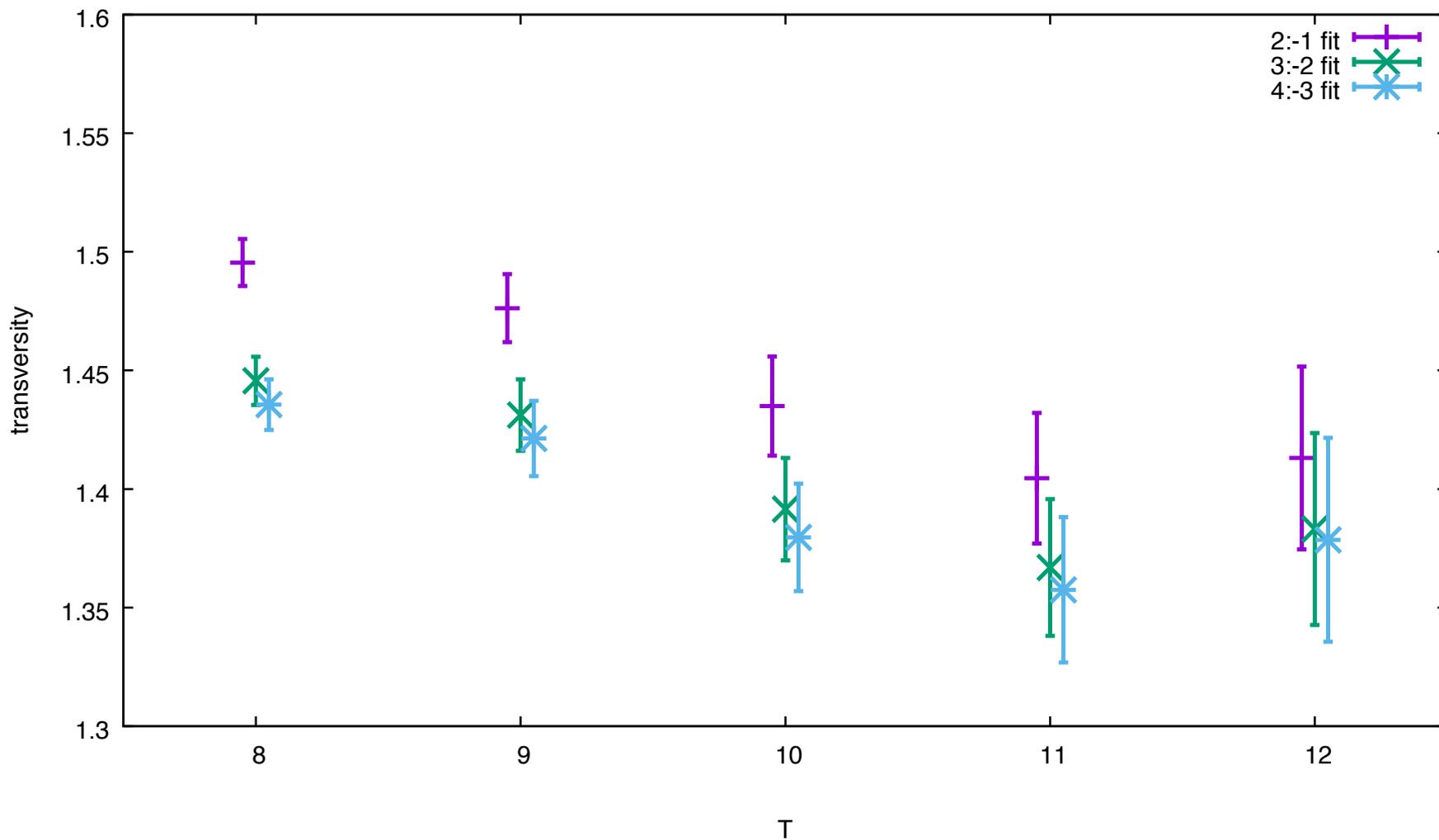
We may be losing the signal at as early as $T = 10$ or 1.1 fm: 9-10 slope appears steeper than 8-9.

Isvector transversity, bare:



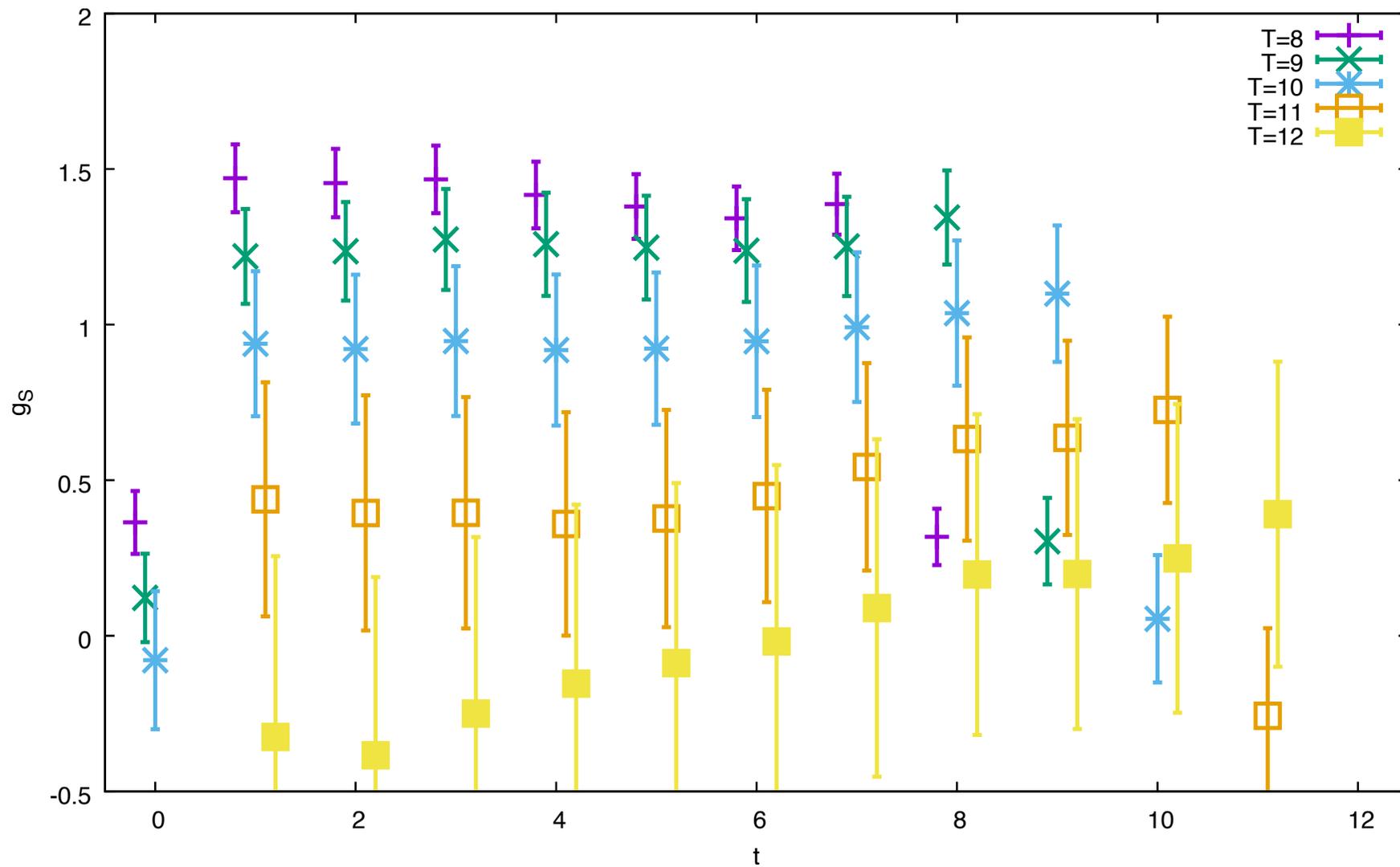
Clear dependence on source-sink separation, T .

Isvector transversity, bare:



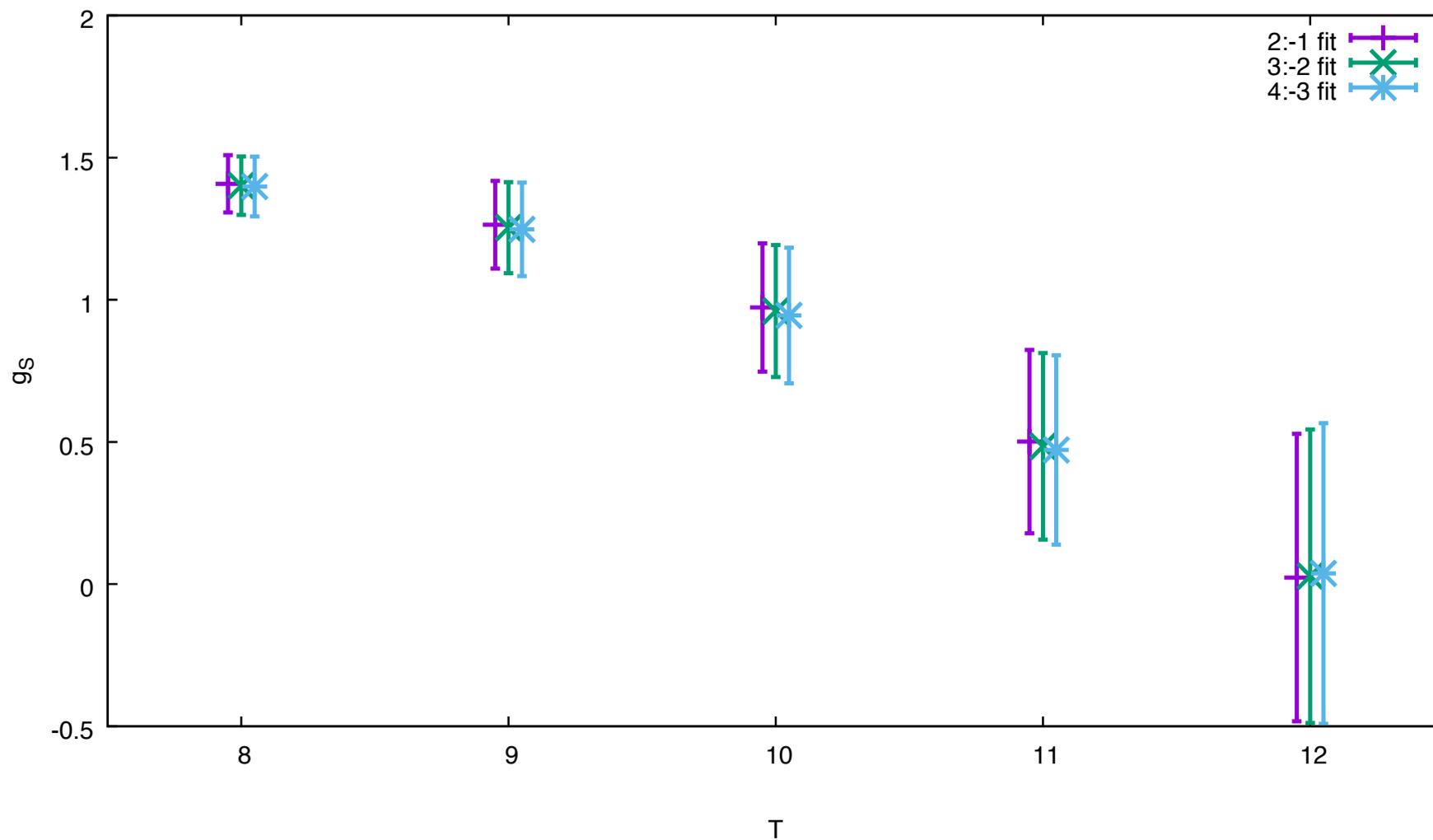
We may be losing the signal at as early as $T = 10$ or 1.1 fm: 9-11 slope appears steeper than 8-9.
We are yet to work out the renormalization, Z_T .

Isvector scalar "charge," g_S , bare:



Clear dependence on source-sink separation, T .

Isovector scalar “charge,” g_S , bare:



We know the renormalization, $Z_S = 1/Z_m$.

We may be losing the signal at as early as $T = 10$ or 1.1 fm: 9-11 slope appears steeper than 8-9.

Summary

Nucleon “charges” from RBC+UKQCD 2+1-flavor dynamical DWF ensemble at physical mass, 48I:
 $a^{-1} = 1.730(4)$ GeV, 130 configurations, 2000 eigenvalues, 130/4 AMA samples each, $T = 8, 9, 10, 11, 12$.

Nucleon mass: 941(11) MeV.

Vector charge: sub-percent-level statistical accuracy,

- expected $O(a^2)$ systematics is seen,
- we would need another coupling, such as in 64I, to understand and control this.

Axial charge: percent-level statistical accuracy,

- no dependence on source-sink separation, T , is seen,
- $g_A Z_A$ and g_A/g_V do not quite agree well,
- $O(a^2)$ systematics yet to be understood or controlled, we would need another coupling, such as in 64I.

Signals in transversity and scalar “charge” with dependence on source-sink separation, T , are seen.

We may be losing the signals as early as $T = 10$, or 1.1 fm:

- steeper slopes at later T ,
- so we are yet to understand $O(a^2)$ or excited-state systematics.

Shorter T such as 7 and 6 would help, as well as another coupling such as in a finer 64I.