Evidence for a new $SU(4)$ symmetry with $J = 2$ mesons

Markus Pak
Karl-Franzens-Universität Graz

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in collaboration with: M. Denissenya (Graz), L. Glozman (Graz)

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Outline

Based on a recent publication: **M. Denissenya, L. Glozman, M. Pak**
Phys. Rev. D 91, 11, 114512; hep-lat/1505.03285

1. **Quasi-zero mode removal and spin-1 meson spectrum:**
   Evidence for a new $SU(4)$ symmetry, which contains $SU(2)_L \times SU(2)_R$ and $U(1)_A$ as subgroups

2. **Is $SU(4)$ also applicable to higher spin mesons?**
   Spin-2 degeneracy patterns w.r.t. chiral and $SU(4)$ symmetry

3. **Lattice Setup and Meson Spectroscopy**

4. **Results**
   Eigenvalues of correlation matrix and effective masses of spin-2 mesons (after quasi-zero mode removal) give clear evidence for $SU(4)$

5. **Conclusions and Outlook**

- Leonid Glozman's talk (tomorrow 15:00, „vacuum structure and confinement") more about $SU(4)$

Quasi-zero mode removal

M. Denissenya, L. Glozman, C. B. Lang, M. Pak, M. Schröck

- We remove the quasi-zero modes from the quark propagator via the prescription:

$$S_k(x,y) = S_{\mathrm{FULL}}(x,y) - \sum_{i=1}^{k} \frac{1}{\lambda_i} v_i(x) v_i^\dagger(y)$$

- **Banks-Casher:** chiral condensate is connected with density of quasi-zero modes

- Only a very small number of eigenvalues removed (10-30 out of millions)

- What happens with the spin-1 meson spectrum after removing the chiral condensate?

    - Hadrons survive $\longrightarrow$ **confinement stays intact**

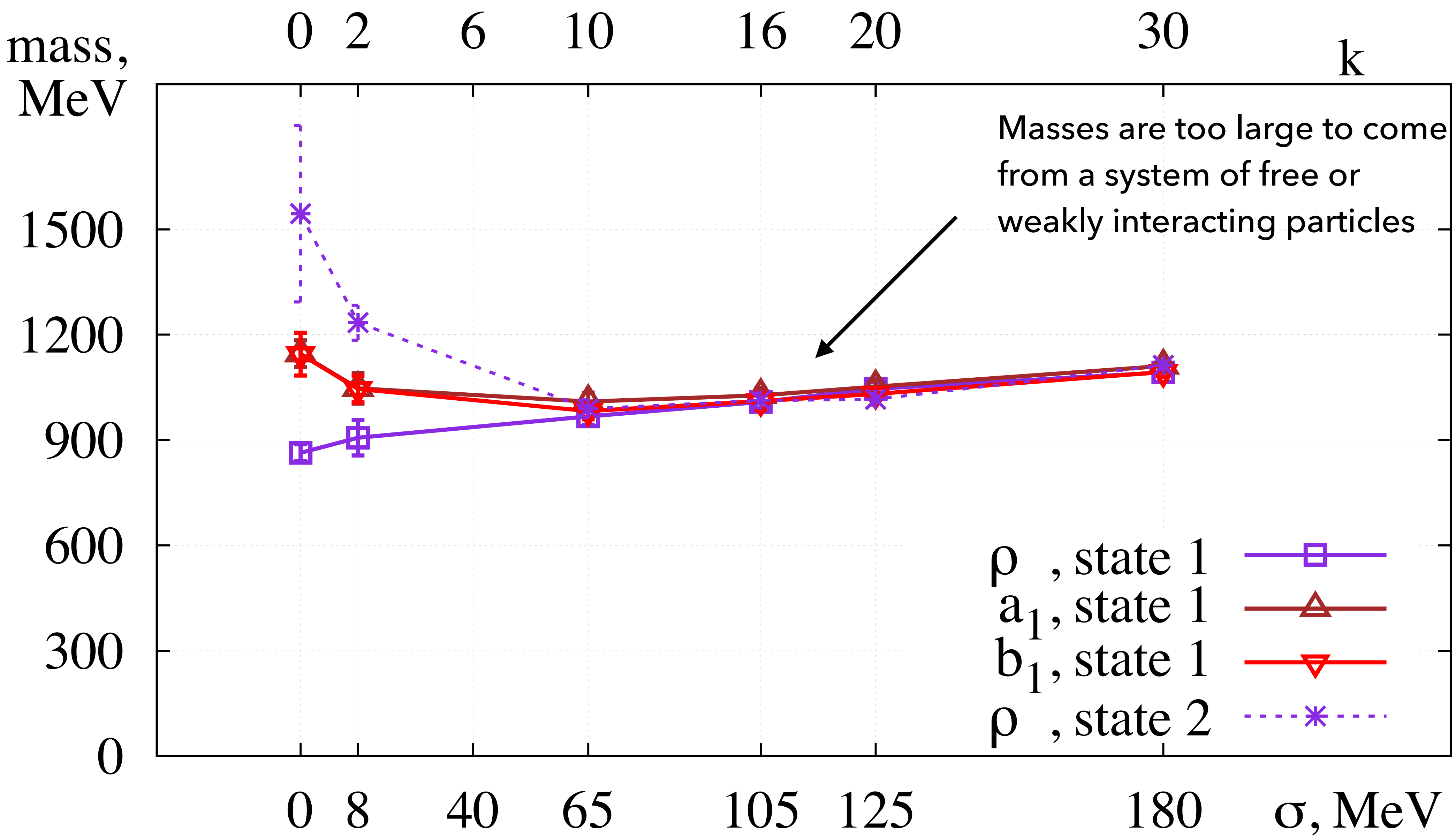
    - Chiral symmtry is restored $\longrightarrow$ parity partners become mass degenerate

- but...

$J = 1$ meson spectrum after quasi-zero mode removal

All iso-vector states become mass degenerate

Higher symmetry than chiral symmetry is observed



M Denissenya, L. Glozman, C. B. Lang; Phys. Rev. D91 (2015) 3, 034505

- All iso-vectors and **all iso-scalars** become mass degenerate

$SU(4)$ - symmetry

L. Glozman; Eur. Phys. J. A51 (2015) 3, 034505

L. Glozman, M. Pak; Phys. Rev. D92 (2015) 1, 016001

- **Not** a symmetry of the QCD Lagrangian; **emerges** after quasi zero-mode removal
- The fundamental vector is $\Psi = \begin{pmatrix} u \\ d \end{pmatrix}$ with $\Psi \rightarrow \Psi' = e^{i\boldsymbol{\epsilon}\cdot\boldsymbol{T}/2}\Psi \equiv W\,\Psi$

$$\begin{pmatrix} u'_L \\ u'_R \\ d'_L \\ d'_R \end{pmatrix} = \begin{pmatrix} * & * & * & * \\ * & * & * & * \\ * & * & * & * \\ * & * & * & * \end{pmatrix} \begin{pmatrix} u_L \\ u_R \\ d_L \\ d_R \end{pmatrix}$$

Not only u and d quarks mix, but also the left- and right-handed components

- All states of given J except one isoscalar state become mass degenerate via $SU(4)$
- Has non-trivial consequences: implies that interaction of quarks with color-magnetic field is absent after quasi-zero mode removal

Chiral symmetry predictions for spin-2 mesons

- Classification of states in the (I_L, I_R) irreps of $SU(2)_L \times SU(2)_R \times \mathcal{C}_i$

$(0,0)$		$\omega_2(0,2^{--})$		$f_2(0,2^{++})$	
$(1/2,1/2)_a$	$U_A(1)$	$\pi_2(1,2^{-+})$	$\overset{SU_A(2)}{\longleftrightarrow}$	$f_2'(0,2^{++})$	$U_A(1)$
$(1/2,1/2)_b$		$a_2'(1,2^{++})$	$\overset{SU_A(2)}{\longleftrightarrow}$	$\eta_2(0,2^{-+})$	
$(1,0)\oplus(0,1)$		$a_2(1,2^{++})$	$\overset{SU_A(2)}{\longleftrightarrow}$	$\rho_2(1,2^{--})$	

- Predictions from $SU(2)_L \times SU(2)_R \times U(1)_A$:

$$\pi_2 \longleftrightarrow f_2' \longleftrightarrow a_2' \longleftrightarrow \eta_2$$

$$a_2 \longleftrightarrow \rho_2$$

- No degeneracy between these two multiplets
- **Not all iso-vectors are mass degenerate**
- No constraints on masses of $\omega_2(0,2^{--})$ and $f_2(0,2^{++})$

$SU(4)$ symmetry predictions for spin-2 mesons

$SU(4)$

$(0,0)$	$\omega_2(0,2^{--})$	$f_2(0,2^{++})$
$(1/2,1/2)_a$	$\pi_2(1,2^{-+})$	$f_2'(0,2^{++})$
$(1/2,1/2)_b$	$a_2'(1,2^{++})$	$\eta_2(0,2^{-+})$
$(1,0)\oplus(0,1)$	$a_2(1,2^{++})$	$\rho_2(1,2^{--})$

- Predictions from $SU(4)$:

$$f_2 \longleftrightarrow \pi_2 \longleftrightarrow f_2' \longleftrightarrow a_2' \longleftrightarrow \eta_2 \longleftrightarrow a_2 \longleftrightarrow \rho_2$$

  - **All iso-vectors have to be mass degenerate**
  - No constraints on mass of $\omega_2(0,2^{--})$

Lattice Setup and Meson Spectroscopy

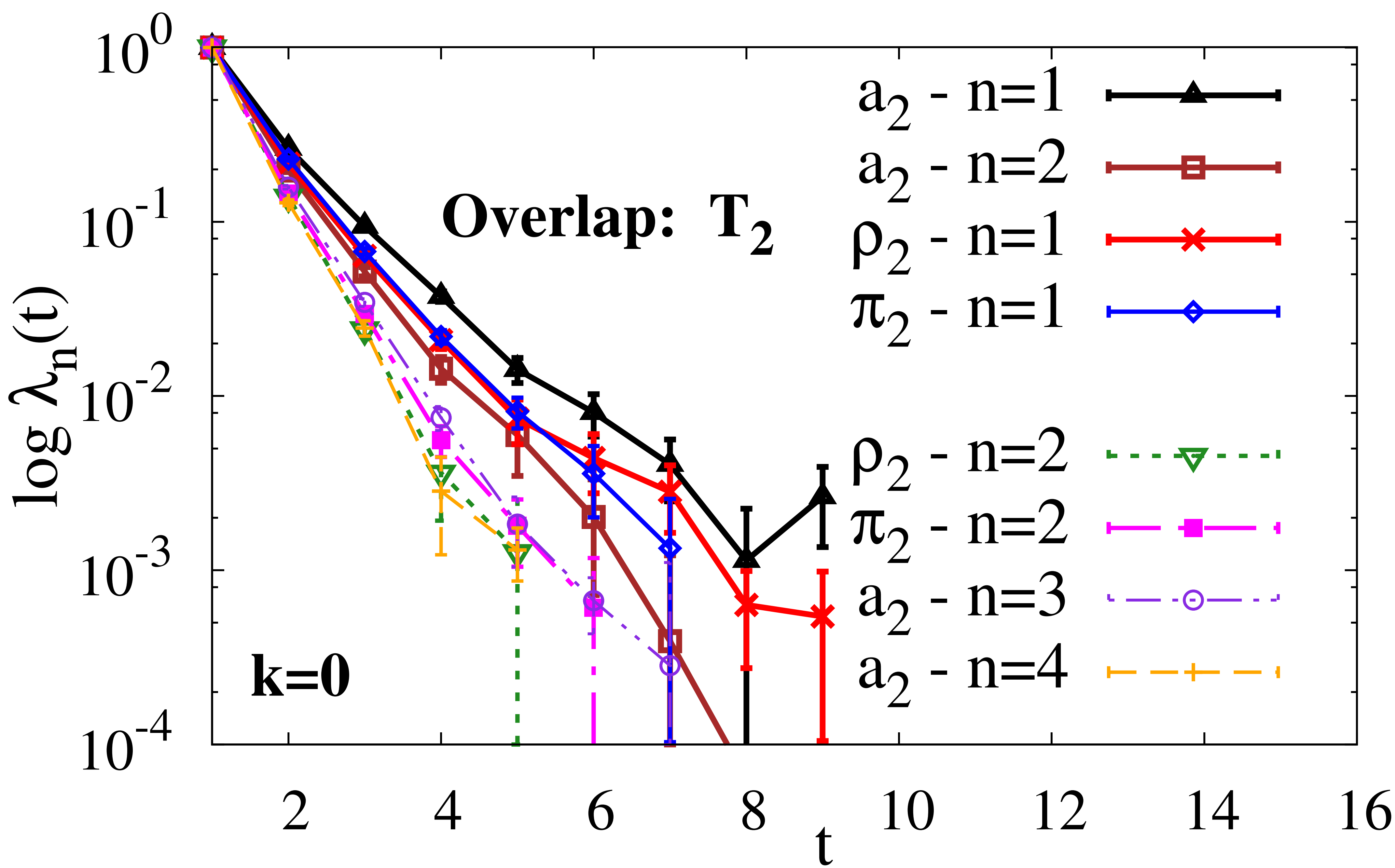
- Two-flavor dynamical Overlap configurations from JLQCD on $16^3 \times 32$ lattice with $a = 0.118\,\mathrm{fm}$ S. Aoki et. al (2008)
- Pion mass $M_\pi = 289(2)\mathrm{MeV}$
- Topological sector fixed to $Q_T = 0$
- 83 gauge configurations
- Jacobi smeared and derivative based quark propagators with different smearing widths
- Spectroscopy via the variational method $C_{ij}(t) = \langle O_i(t)\overline{O}_j(0)\rangle$

$$C(t)\vec{v} = \lambda_n(t)C(n_0)\vec{v} \qquad \lambda_n(t) \sim e^{-m_n t}$$

- $SU(4)$ **symmetry, if** $\lambda_{a_2} = \lambda_{a_2'} = \lambda_{\rho_2} = \lambda_{\pi_2}$

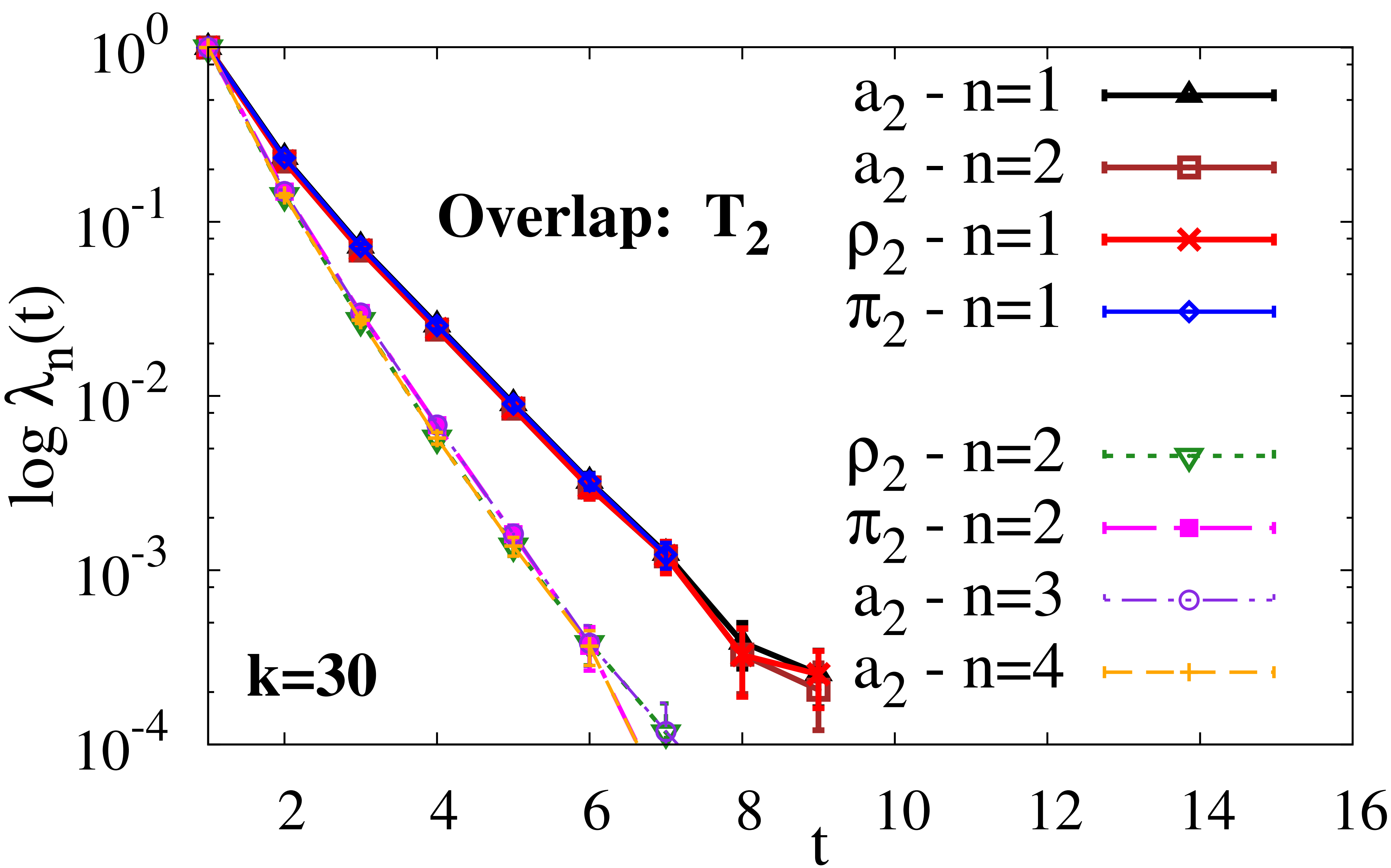
Results: $J = 2$ Correlators

- Before chiral symmetry restoration:

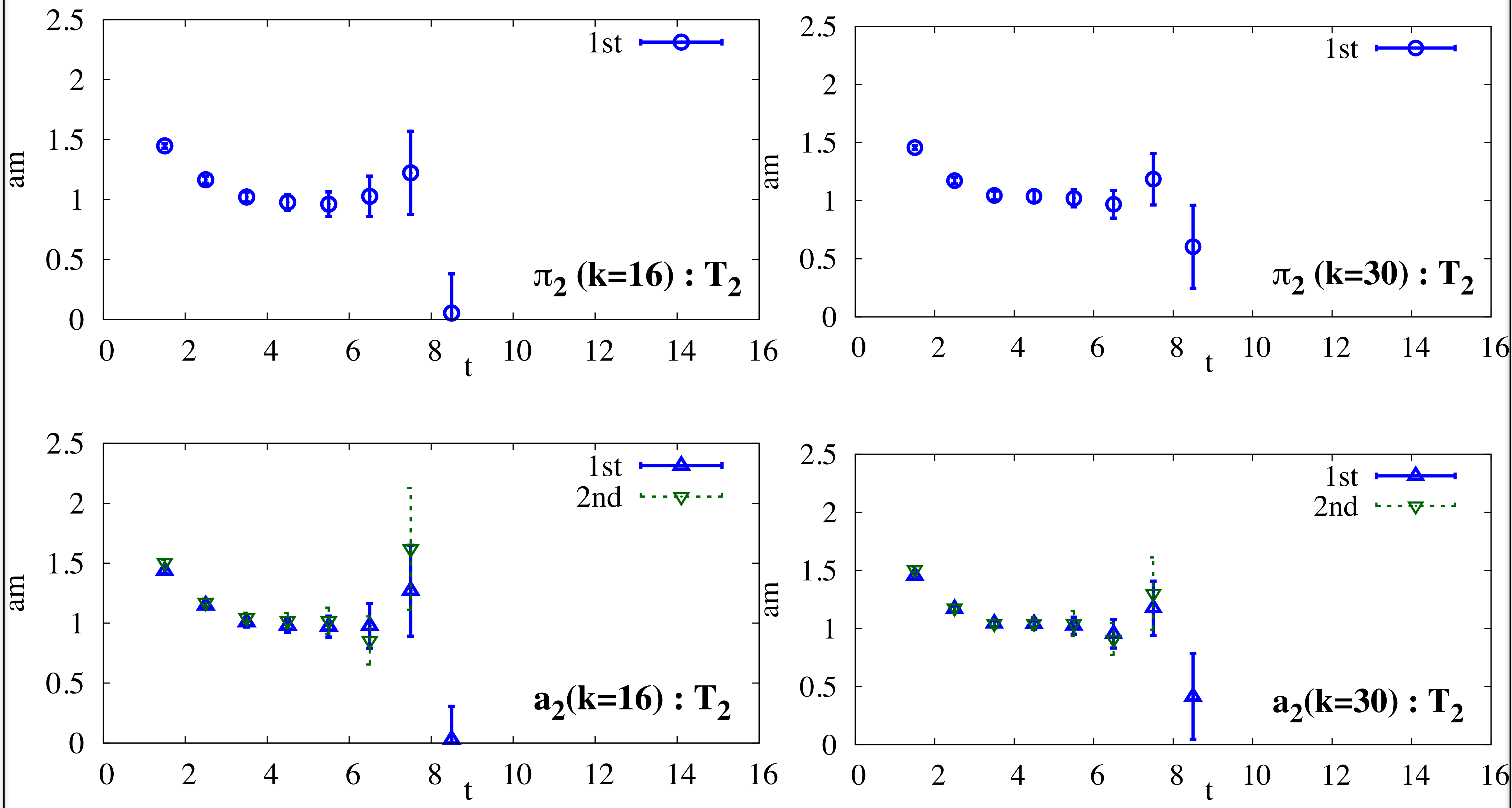


Results: $J = 2$ Correlators

- After chiral symmetry restoration:

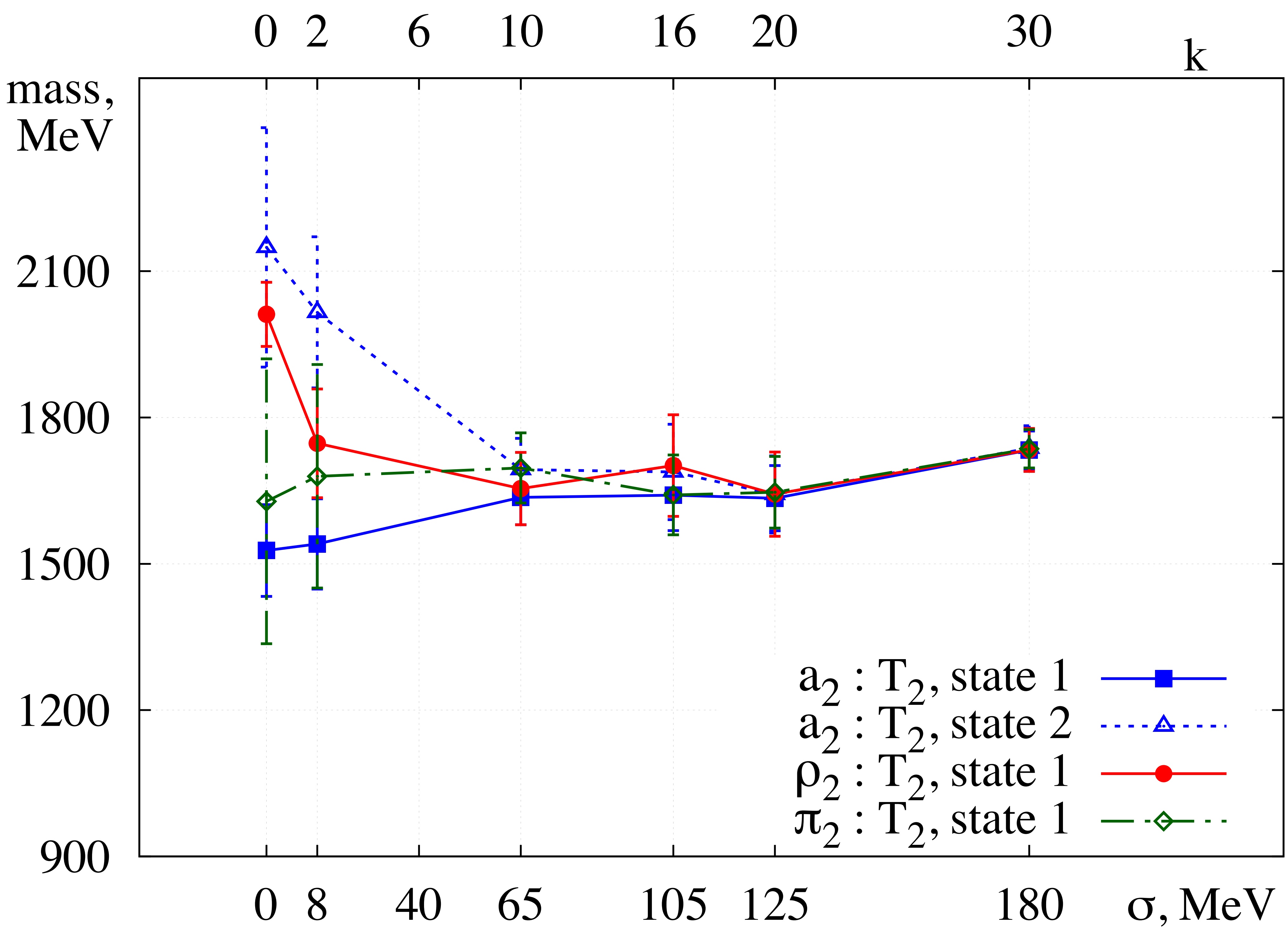


Results: $J=2$ Effective masses after quasi-zero mode removal



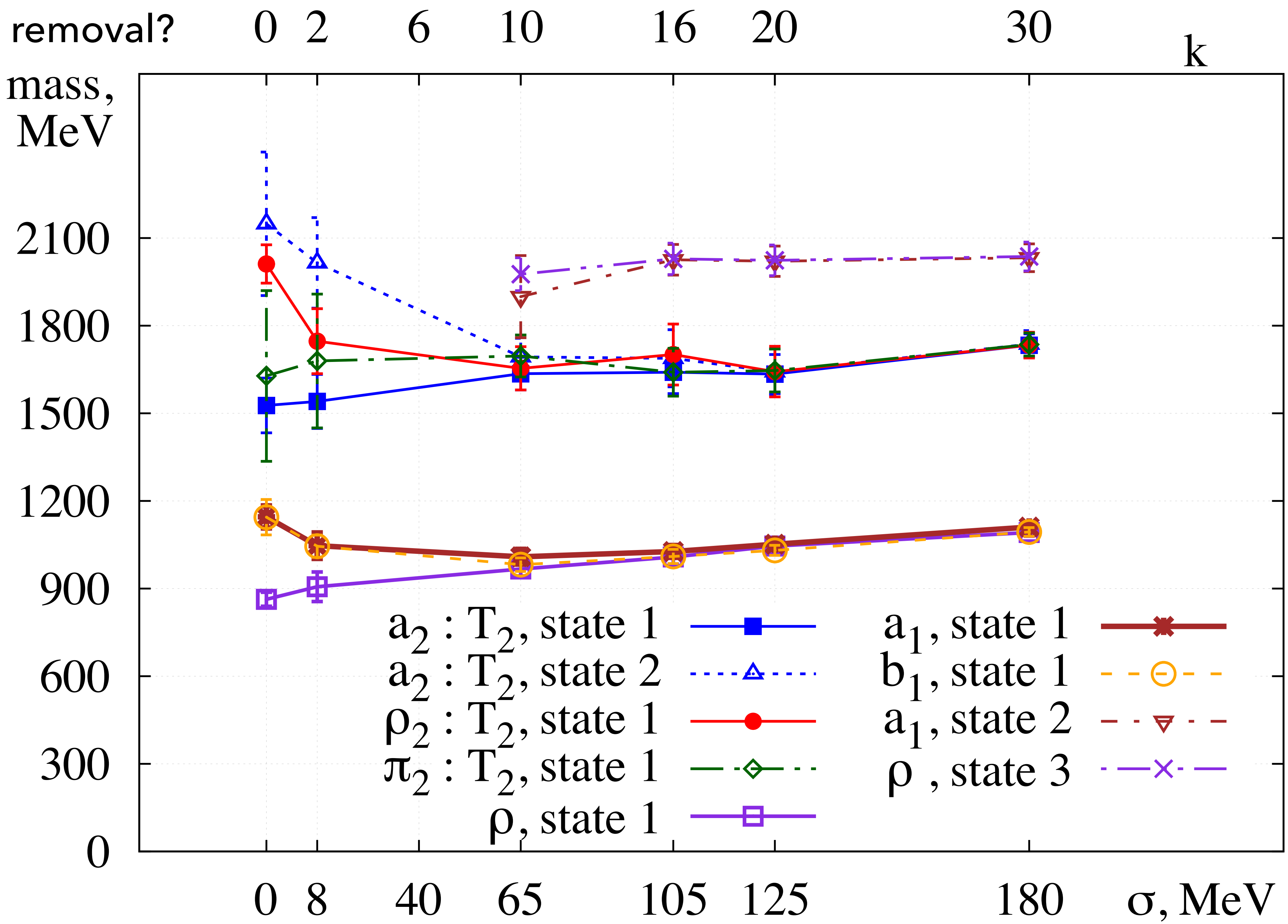
- States exist ⟶ confinement persists ⟶ masses can be extracted

Evolution of $J = 2$ meson masses after quasi-zero mode removal



Higher symmetry?

- Degeneracy of **ground state spin-2 mesons** with **excited spin-1 mesons** after quasi-zero mode removal?



- No evidence for an even higher degeneracy, but for a precise statement repeat calcuation on **larger volumes**

Summary and Conclusions

- Spin-2 mesons also show emergent $SU(4)$ degeneracy pattern after quasi-zero mode removal
- We expect, that this is general and $SU(4)$ applies for all $J \geq 1$ mesons
- Allows for a simple energy quantization law
- Predicts the absence of the interaction of quarks with the color-magnetic field after quasi-zero mode removal
- Currently baryons are considered $\longrightarrow$ also show $SU(4)$ degeneracy
- Larger volumes are considered to probe a possible higher symmetry

- More about $SU(4)$ in Leonid Glozman's talk (tomorrow 15:00 in „vacuum structure and confinement“)