g_A

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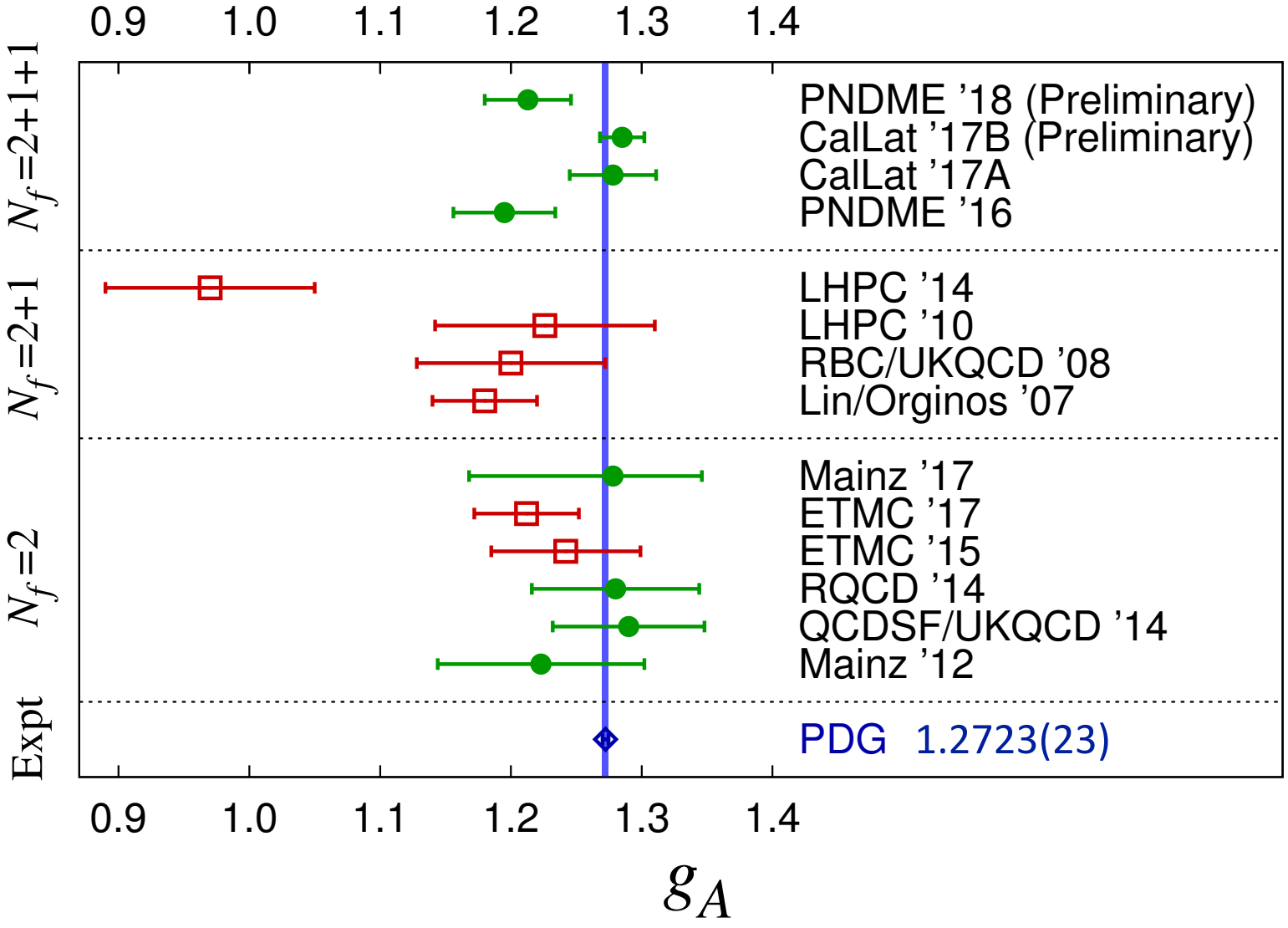
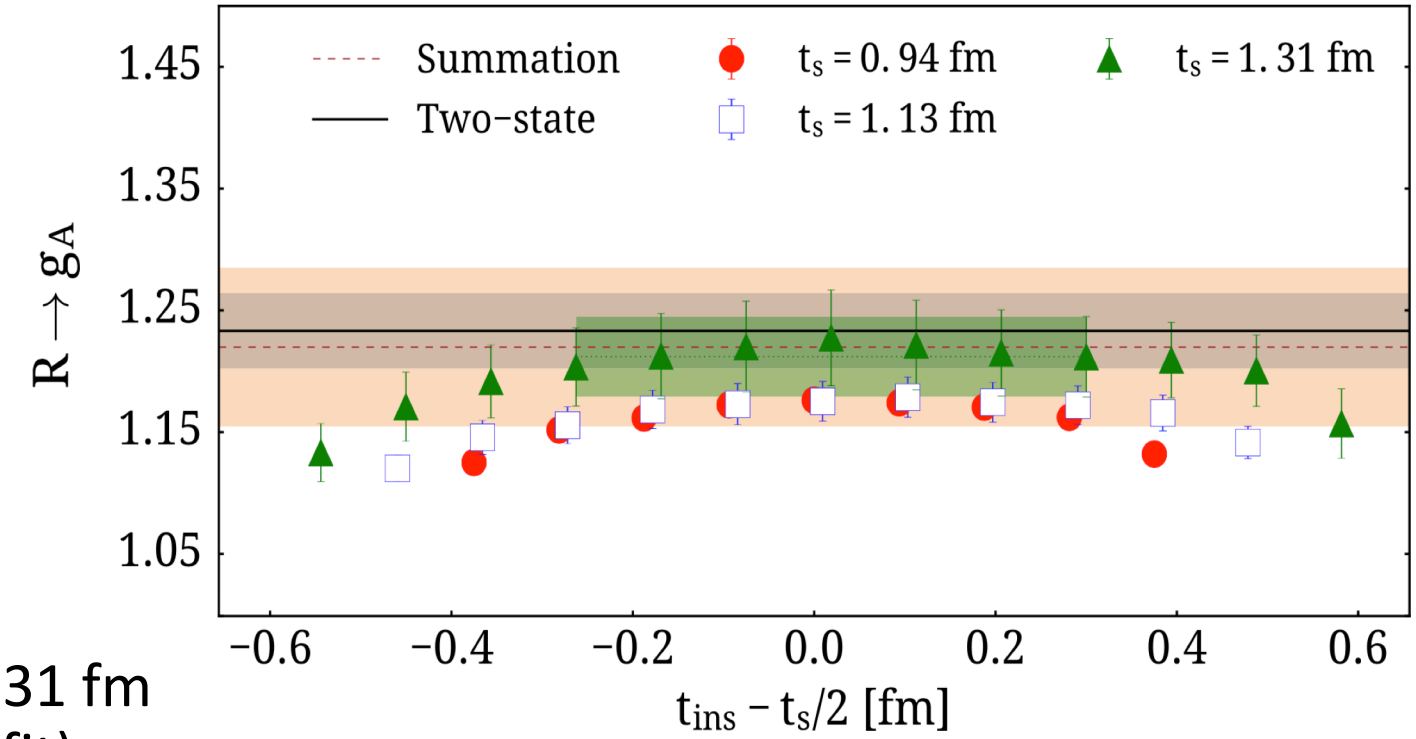
Current Status - g_A



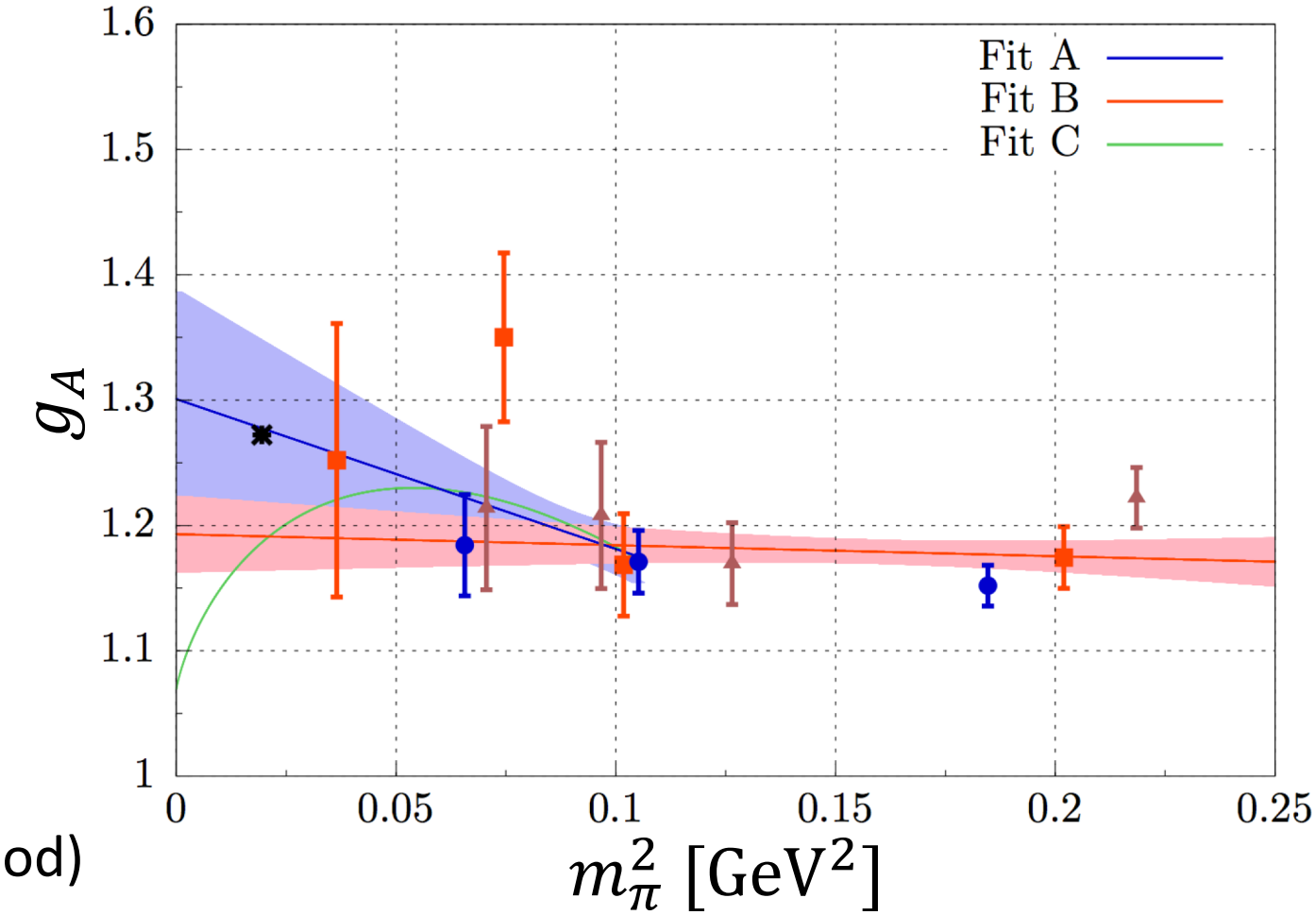
ETMC '17 (PRD 96, 054507, 2017)

- **Lattice**
  - TMF, N_f=2
  - a = 0.094 fm
  - m_π = 130 MeV
  - $m_\pi L$ = 3.0
- **Measurement/Analysis**
  - APE-smeared links
  - Fixed-sink method
  - *Plateau method* at t_{sep} = 1.31 fm (compared with Two-state fit)
  - NPR
  - Single lattice spacing at physical pion mass



Mainz ’17 (arXiv:1705.06186)

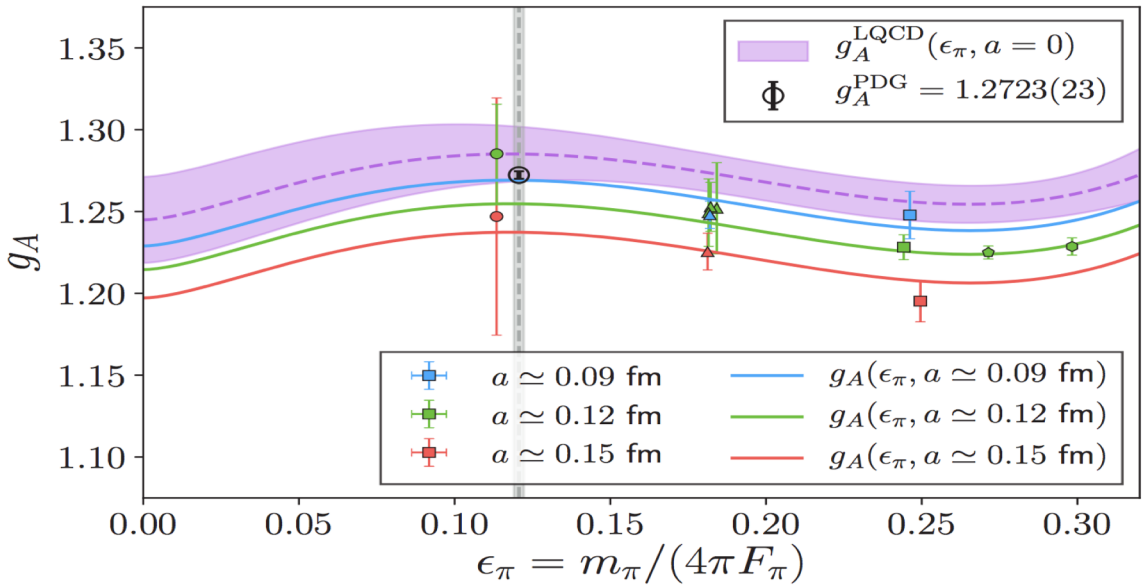
- **Lattices**
  - CLS, N_f=2
  - a = 0.050, 0.063 and 0.079 fm
  - m_π = 190 – 473 MeV, $m_\pi L \gtrsim 4$
- **Measurement/Analysis**
  - APE-smeared links
  - Fixed-sink method
  - O(a)-improved axial current
  - *Two-state fit* with assumption of the N$\pi\pi$ dominant excited-state (compared with summation method)
  - NPR
  - No a-dependence, central value from linear fit in m_π^2 for m_π < 330MeV

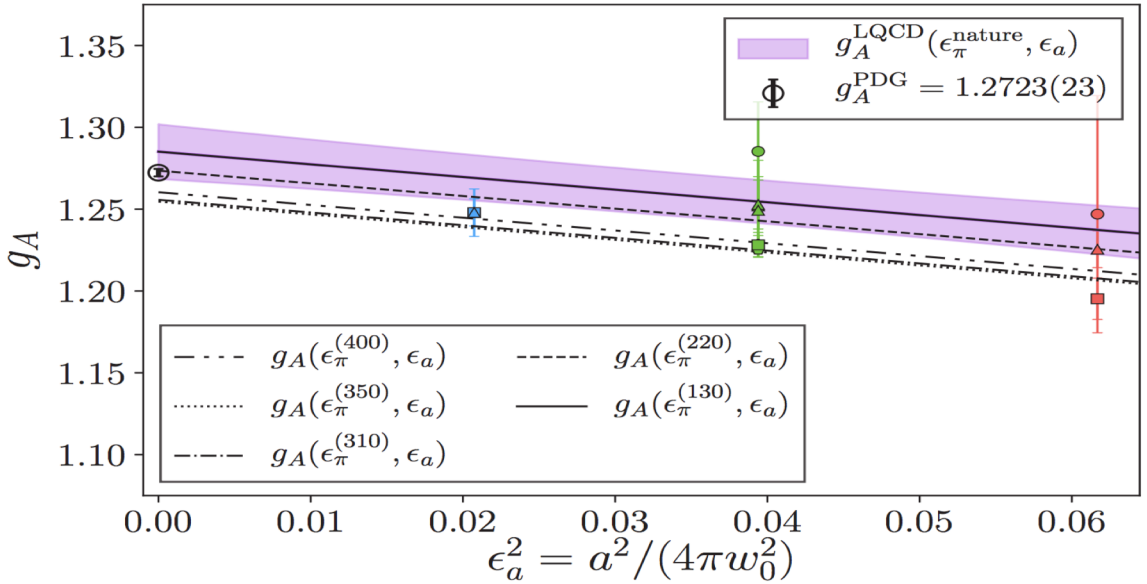


CalLat '17 (EPJ WoC **175**, 01008, 2018)

- **Lattices**
  - DWF-on-HISQ, N_f=2+1+1
  - a = 0.09, 0.12 and 0.15 fm
  - m_π = 130 – 400 MeV
- **Measurement/Analysis**
  - Gradient-flowed links
  - Feynman-Hellmann-inspired current-at-all-timeslices method
  - Summation method + two-state fit
  - g_A/g_V with Z_A/Z_V=1, $Z_V g_V$=1
  - (a, m_π, L) extrapolation:

$$g_A = g_0 - \epsilon_\pi^2[(g_0 + 2g_0^3)\ln\epsilon_\pi^2 - c_2] + g_0 c_3 \epsilon_\pi^3$$
$$+ a_2\epsilon_a^2 + c_4\epsilon_\pi^4 + b_4\epsilon_a^2\epsilon_\pi^2 + a_4\epsilon_a^4$$
$$+(8/3)\,\epsilon_\pi^2\,[g_0^3 F_1(m_\pi L) + g_0 F_3(m_\pi L)]$$

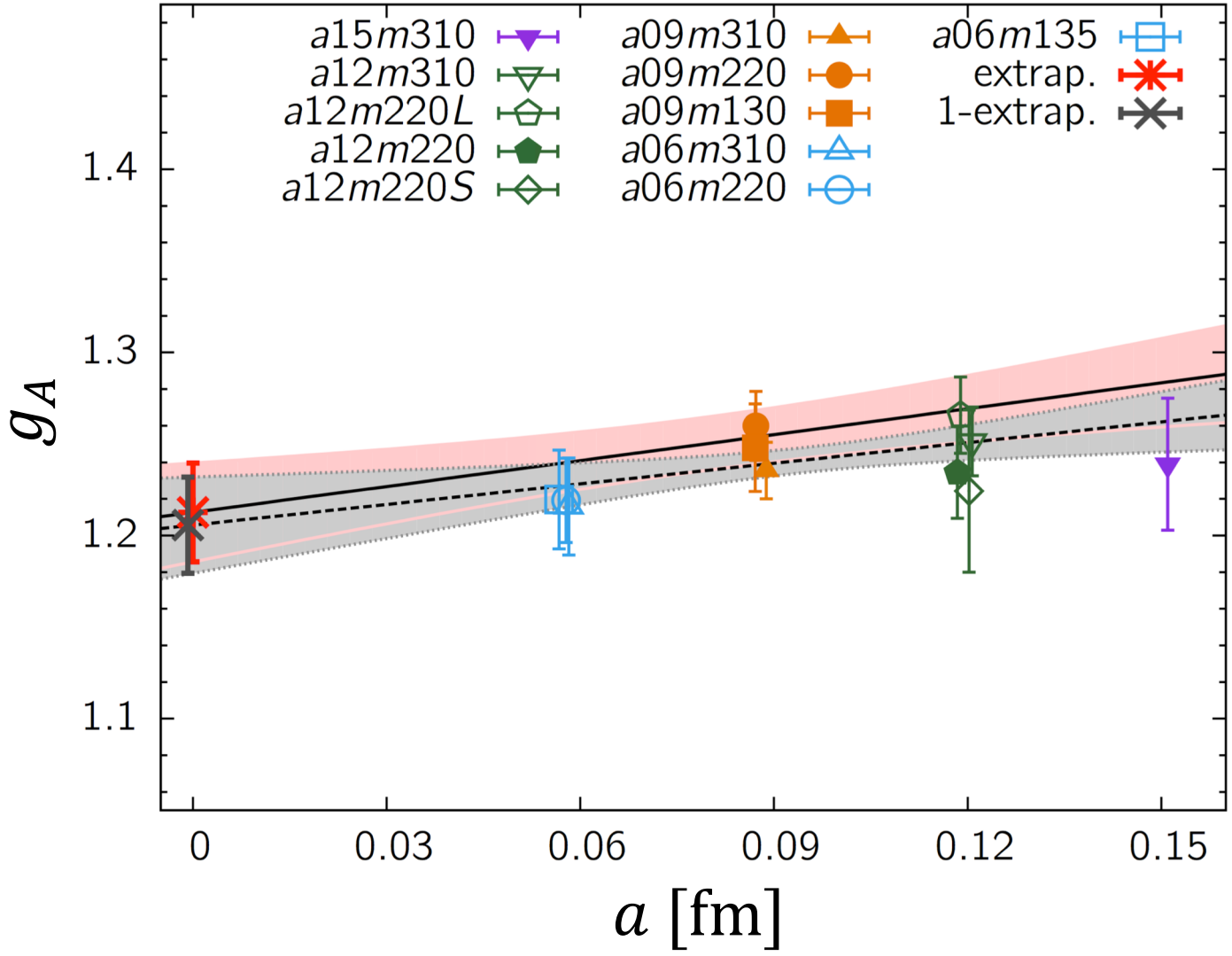




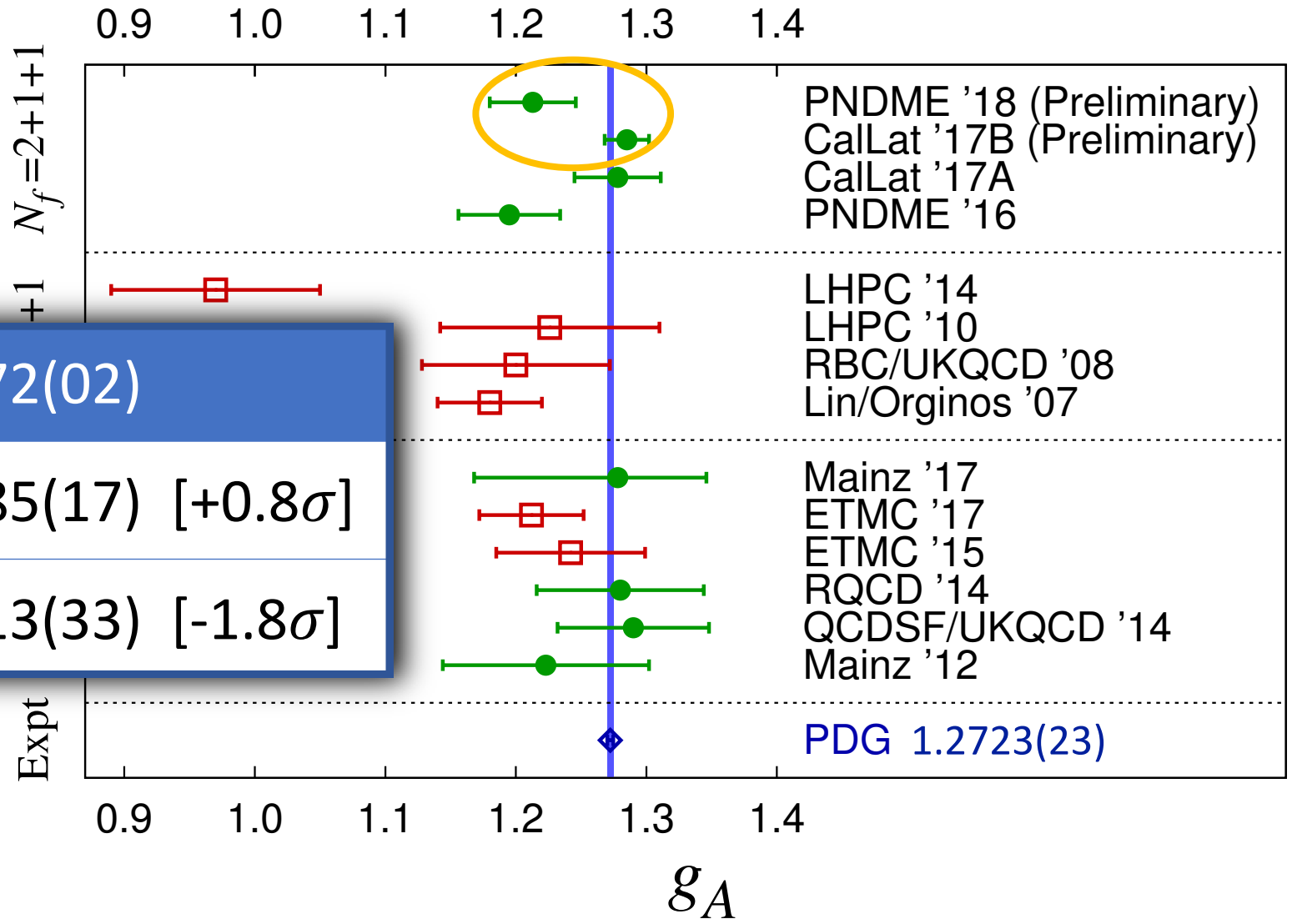
PNDME '18 (Preliminary)

- **Lattices**
  - Clover-on-HISQ, N_f=2+1+1
  - a = 0.06, 0.09, 0.12 and 0.15 fm
  - m_π = 130 – 320 MeV
- **Measurement/Analysis**
  - HYP-smeared links
  - Fixed-sink-method
  - 3-state fit for excited state
  - NPR
  - (a, m_π, L) extrapolation:

$$g_A = c_1 + c_2 a + c_3 m_\pi^2 + c_3' m_\pi^2 \ln\left(m_\pi/m_\rho\right)^2 + c_4 m_\pi^2 e^{-m_\pi L}$$



g_A Comparison between CalLat and PNDME



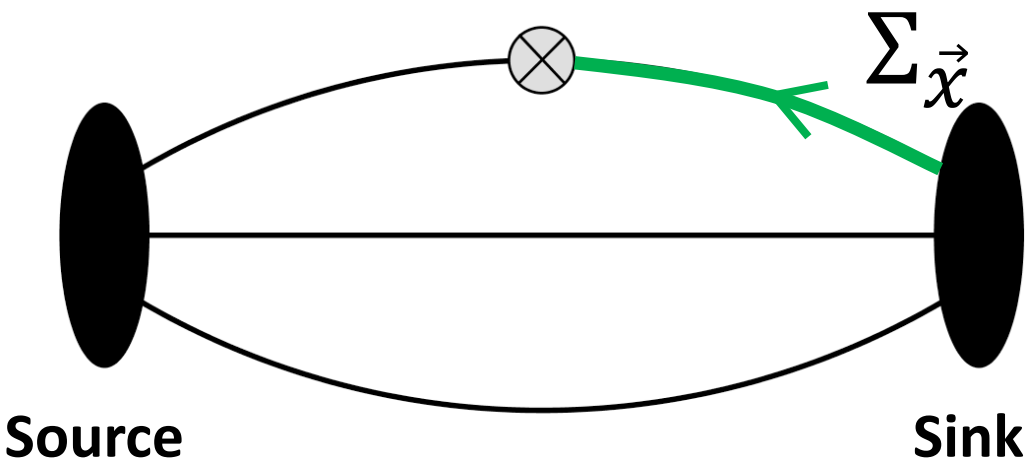
PDG	1.272(02)	
CalLat '17B	1.285(17)	[+0.8σ]
PNDME '18	1.213(33)	[-1.8σ]

CalLat vs PNDME

	PNDME	**CalLat**
Sequential source position in C_{3pt}	At sink All $\vec{p}$ & γ, *single* t_{sep}	At current (at all t) Single $\vec{p}$ & γ, *all* t_{sep}
Excited State	three-state fit t_{sep} = 0.9 – 1.5 fm	Summation method + two-state fit t_{sep} = 0.5 – 1.5 fm
Renormalization	NPR	$\mathrm{Z_A/Z_V} = 1$
Leading $(\mathbf{a}, \boldsymbol{m_\pi})$	a , m_π^2	$(a/w_0)^2$, $(m_\pi/F_\pi)^2$

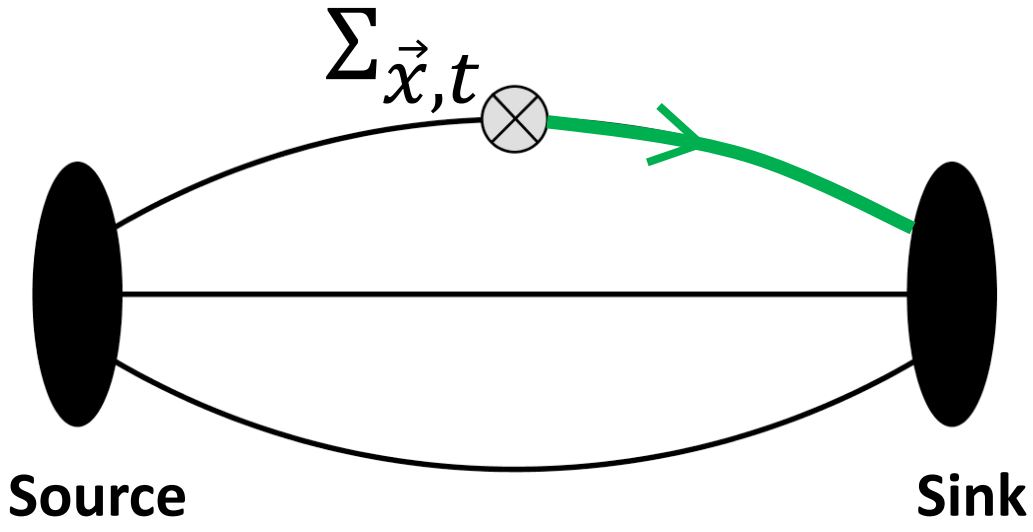
Fixed-sink method

- Fixed sink timeslice, momentum, projection
- Sequential prop from sink
- Any operator insertions with any momenta can be obtained by contraction
- Need sequential prop for each t_{sep}



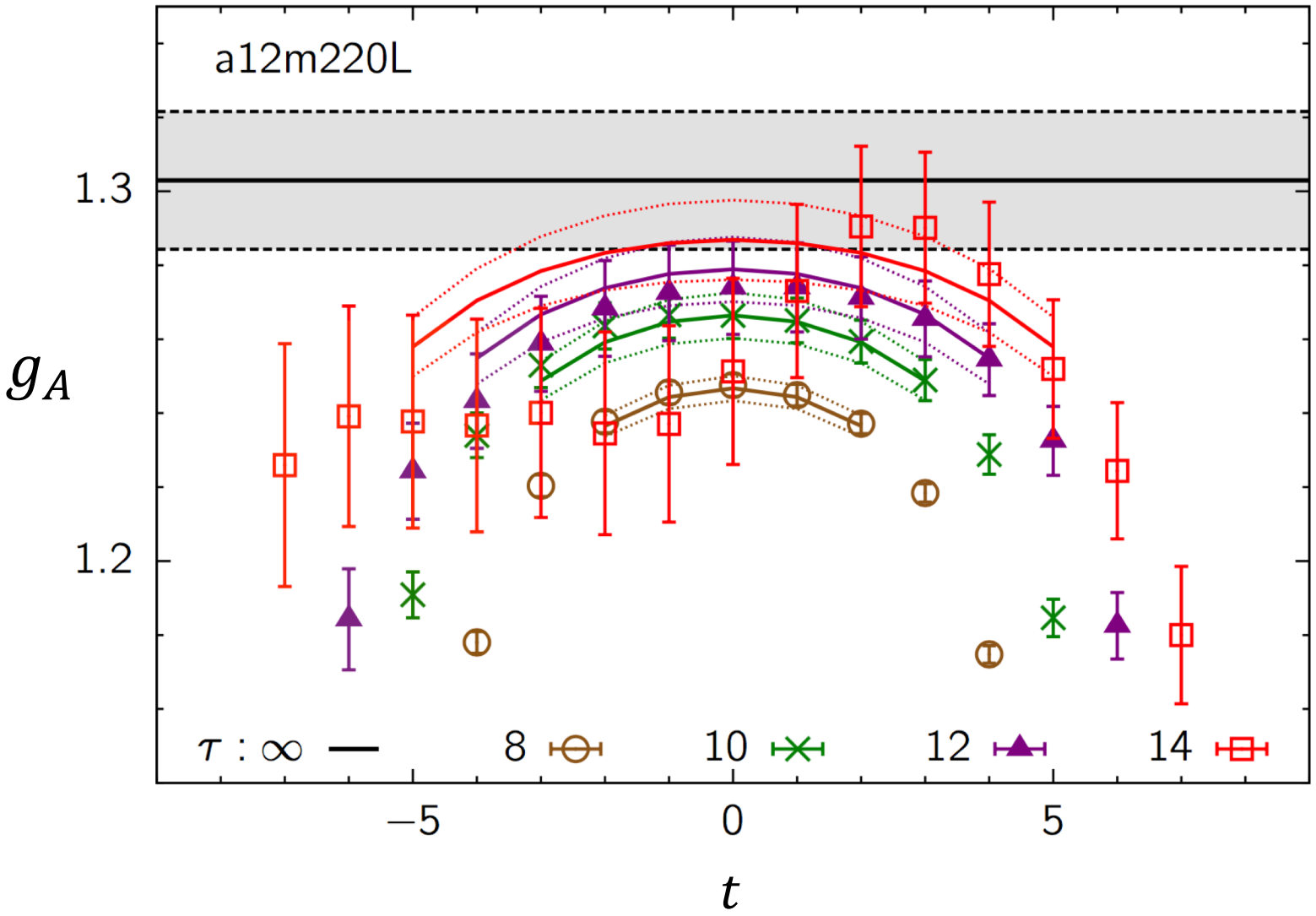
Current-at-all-timeslices

- Current inserted at all lattice space-time
- Sequential prop from current insertion
- Any sink timeslices obtained by contraction
- Need sequential propagator calculation for each current (A, V) and momentum



Excited States - PNDME

- 3-state fit with $t_{sep} \approx 0.9 - 1.5$ fm
- Data at $t_{sep} = 14a$ are noisy



Excited States - CalLat

- Remove excited states by 2-point difference in **summation method**:

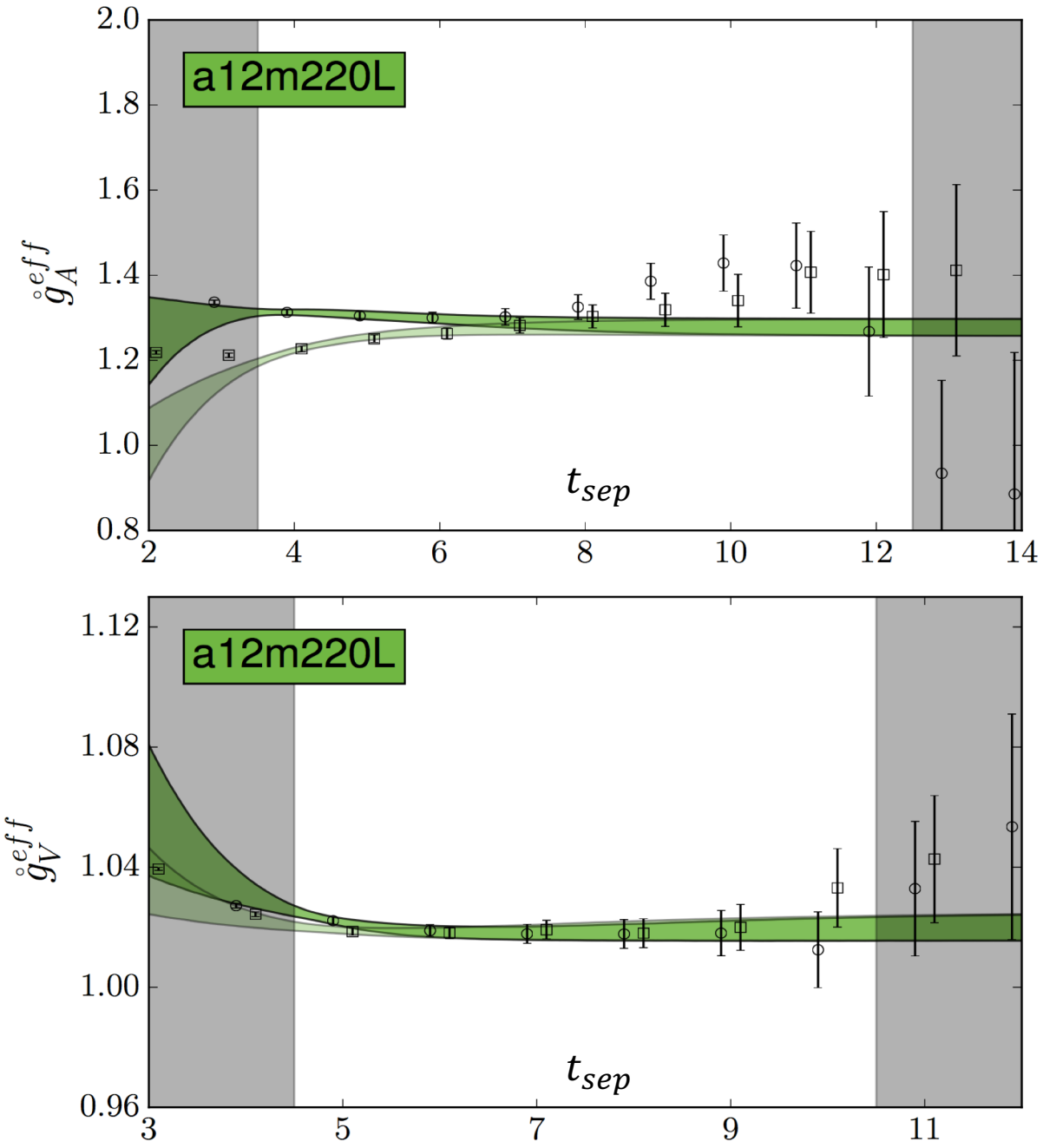
$$g_{A,V}^{\mathrm{eff}}(t_{sep}) = \frac{N_{3\mathrm{pt}}(t_{sep}+1)}{C_{2\mathrm{pt}}(t_{sep}+1)} - \frac{N_{3\mathrm{pt}}(t_{sep})}{C_{2\mathrm{pt}}(t_{sep})}$$

Usual summation method:

$$\sum_{t=1}^{t_{sep}-1} \frac{C_{3\mathrm{pt}}(t_{sep},t)}{C_{2\mathrm{pt}}(t_{sep})} = Const + t_{sep} g_A + \cdots$$

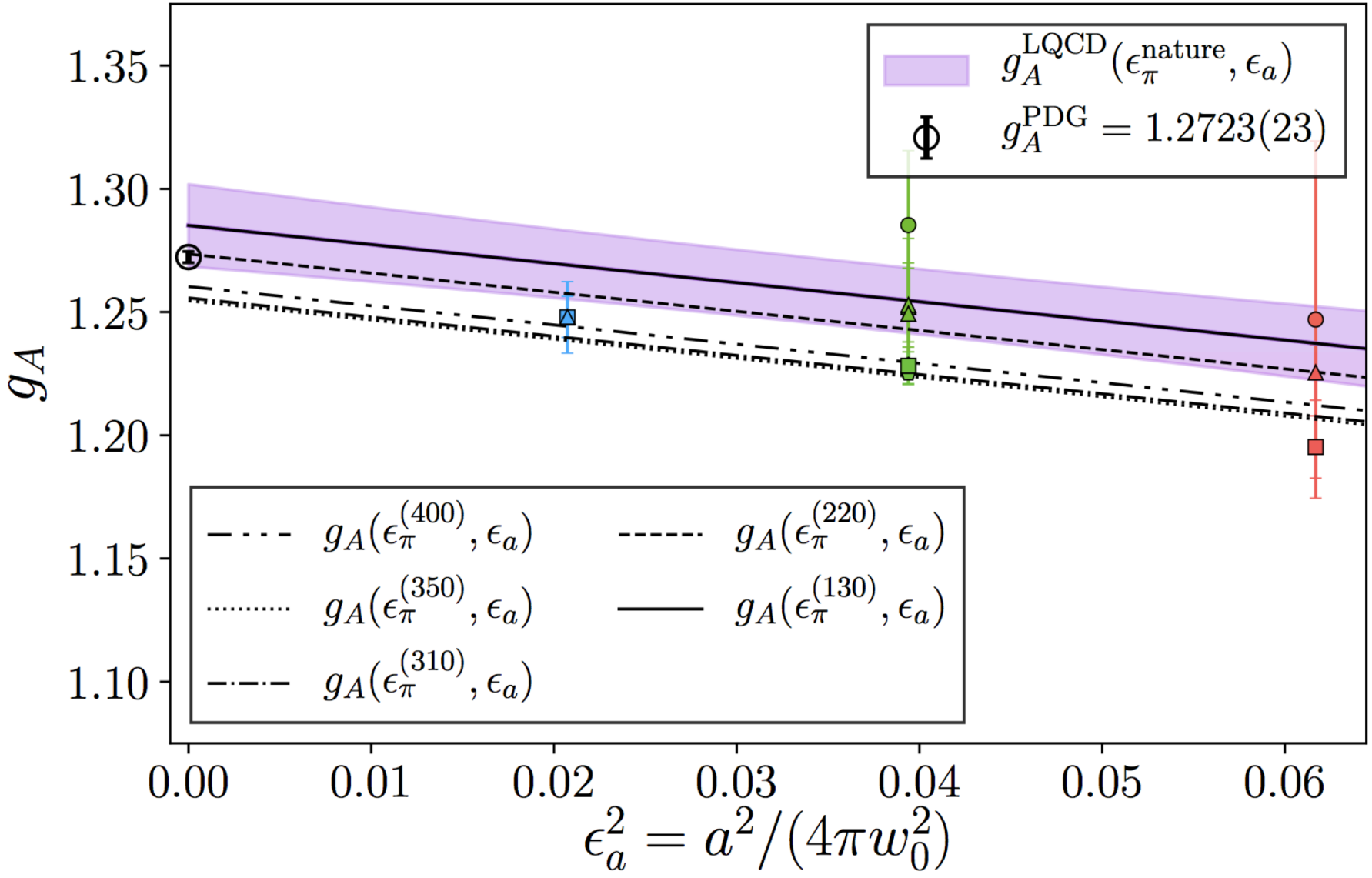
- Remove remaining excited state by two-state fit to $g_{A,V}^{\mathrm{eff}}$ with

$$t_{sep} \approx 0.5 - 1.5 \text{ fm}$$



Continuum extrapolation - CalLat

- Upward trend in a^2
- $g_A = 1.285(17)$

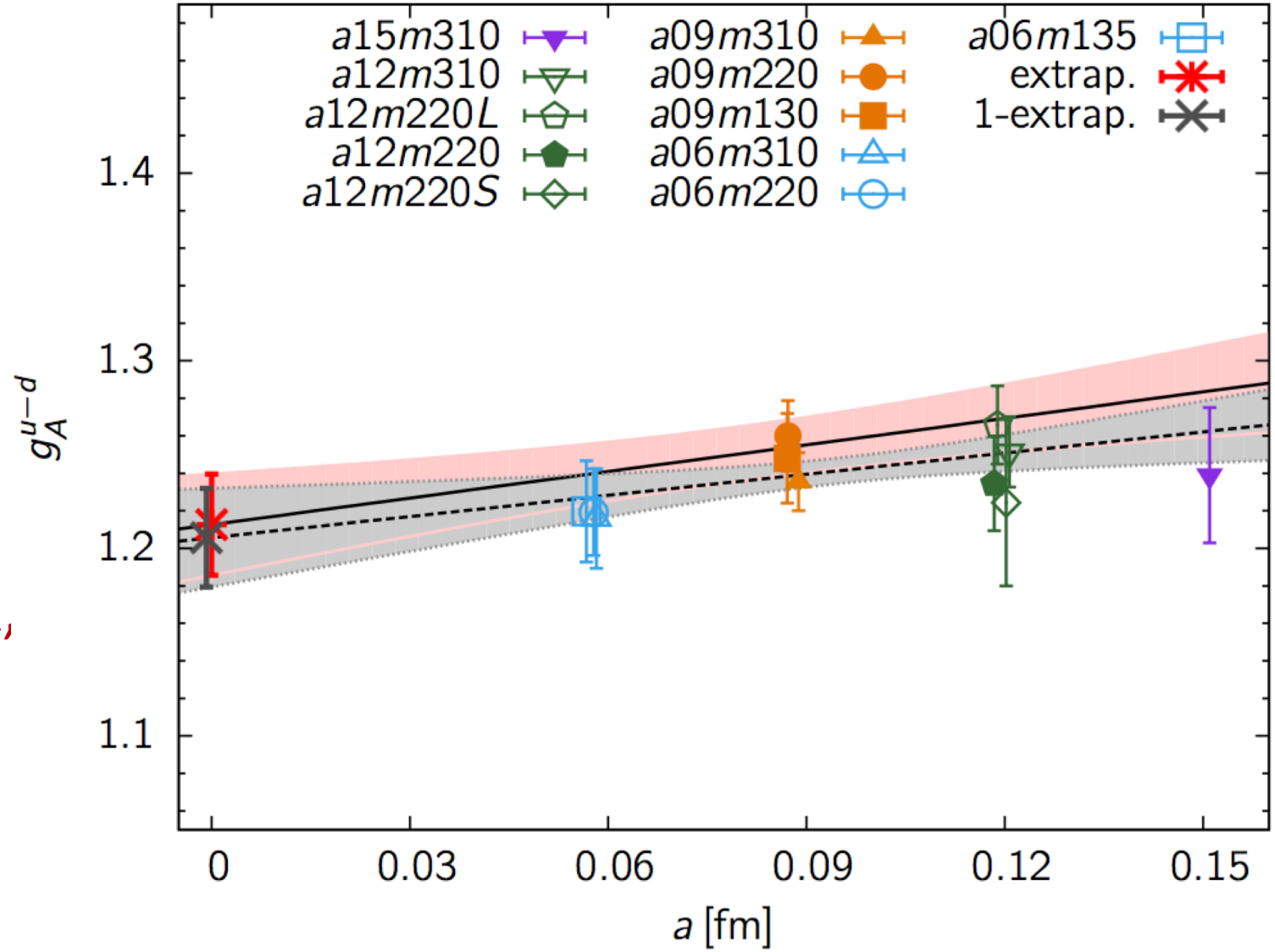


Continuum extrapolation - PNDME

- Downward trend in a
- $g_A = 1.213(33)$

- Largely driven by $a \sim 0.06$ fm points

➢ Without $a \sim 0.06$ fm, $g_A = 1.238(49)$

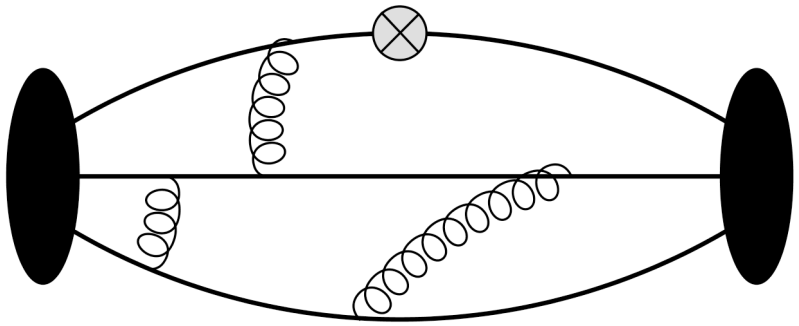


Flavor-diagonal g_A^u, g_A^d, and g_A^s

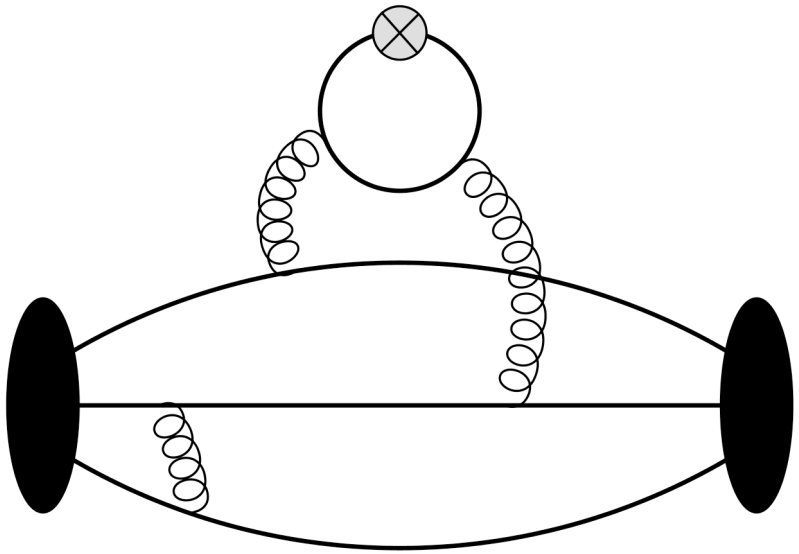
- Proton spin decomposition

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + \Delta G$$

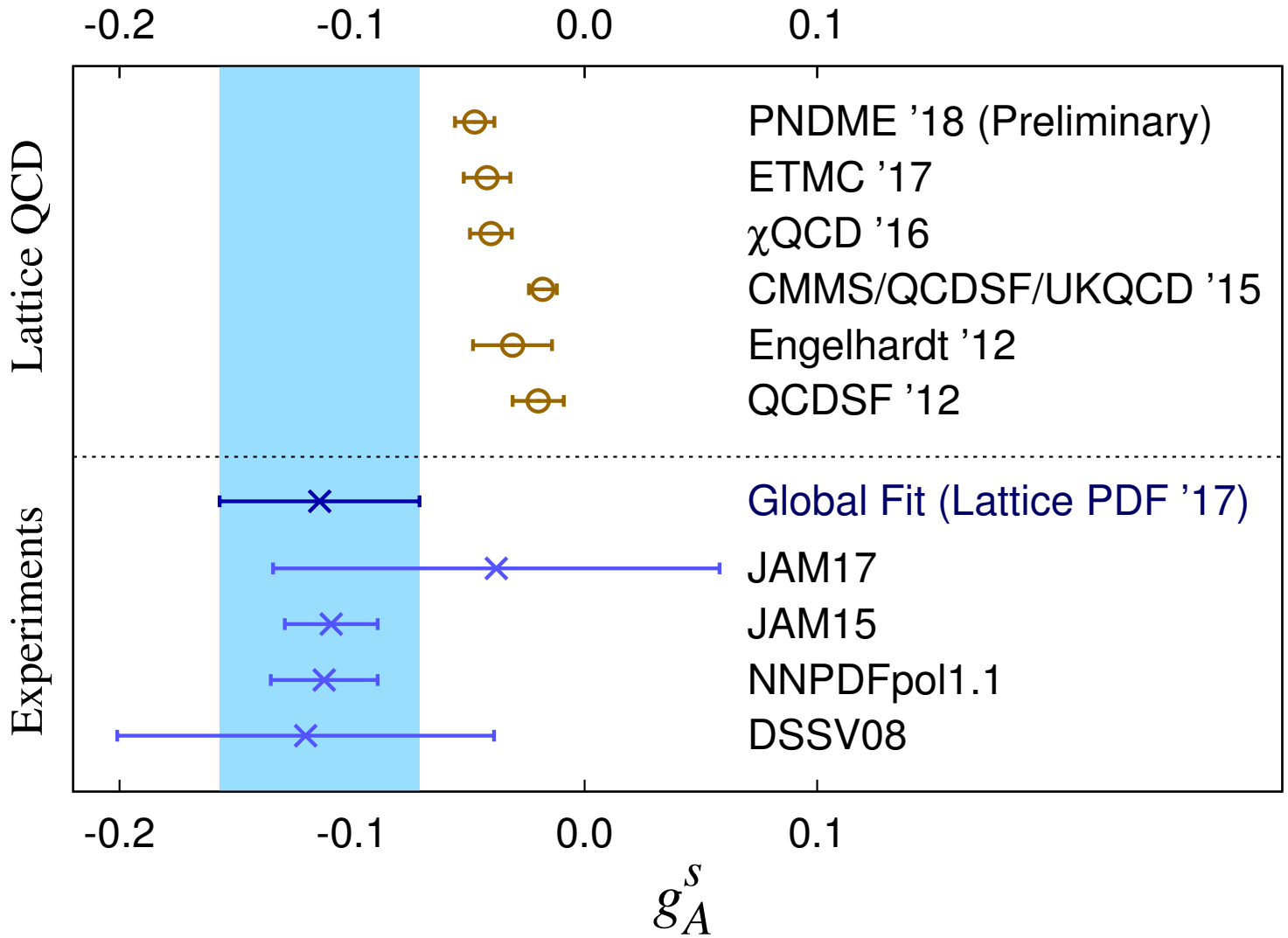
$$\Delta\Sigma = g_A^u + g_A^d + g_A^s + \cdots$$



- Need evaluation of quark-line **connected** & **disconnected** diagrams

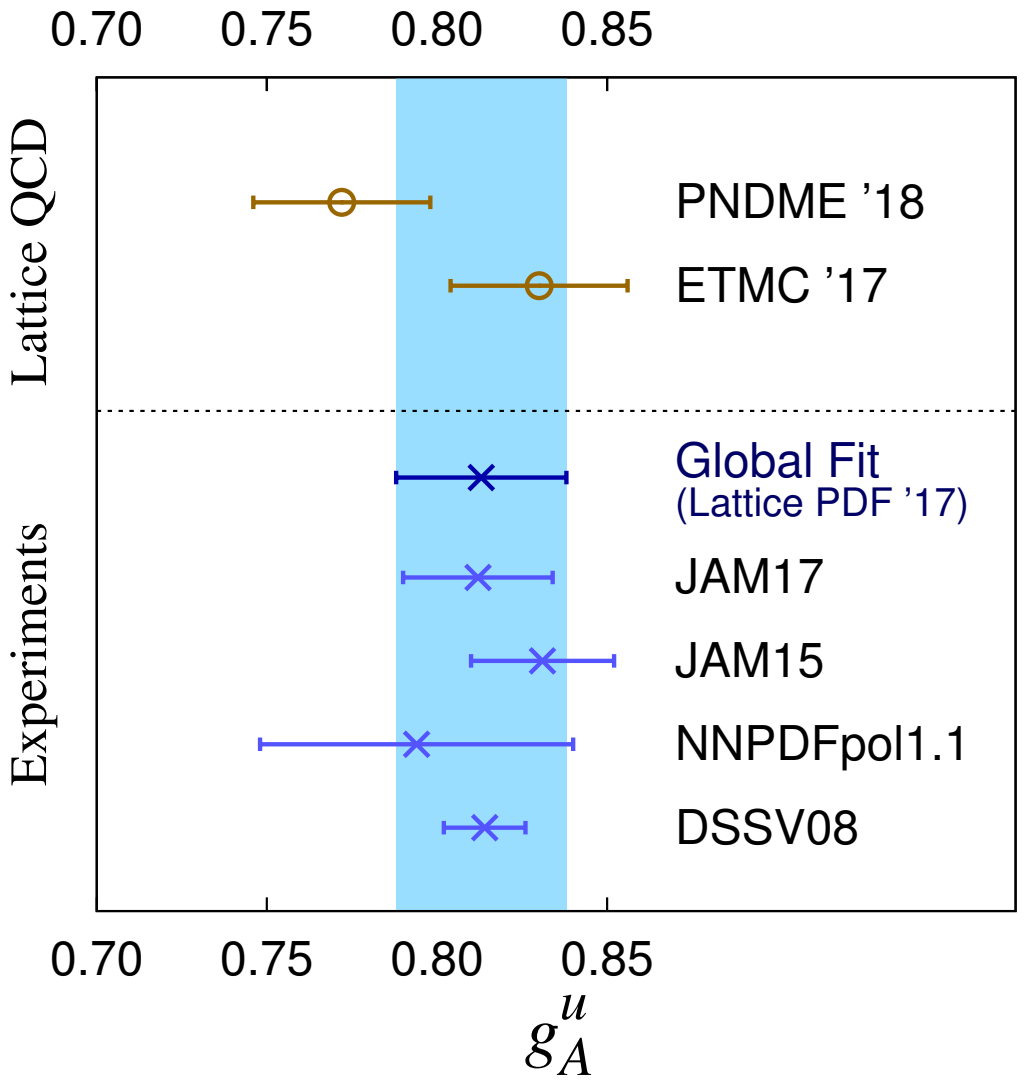


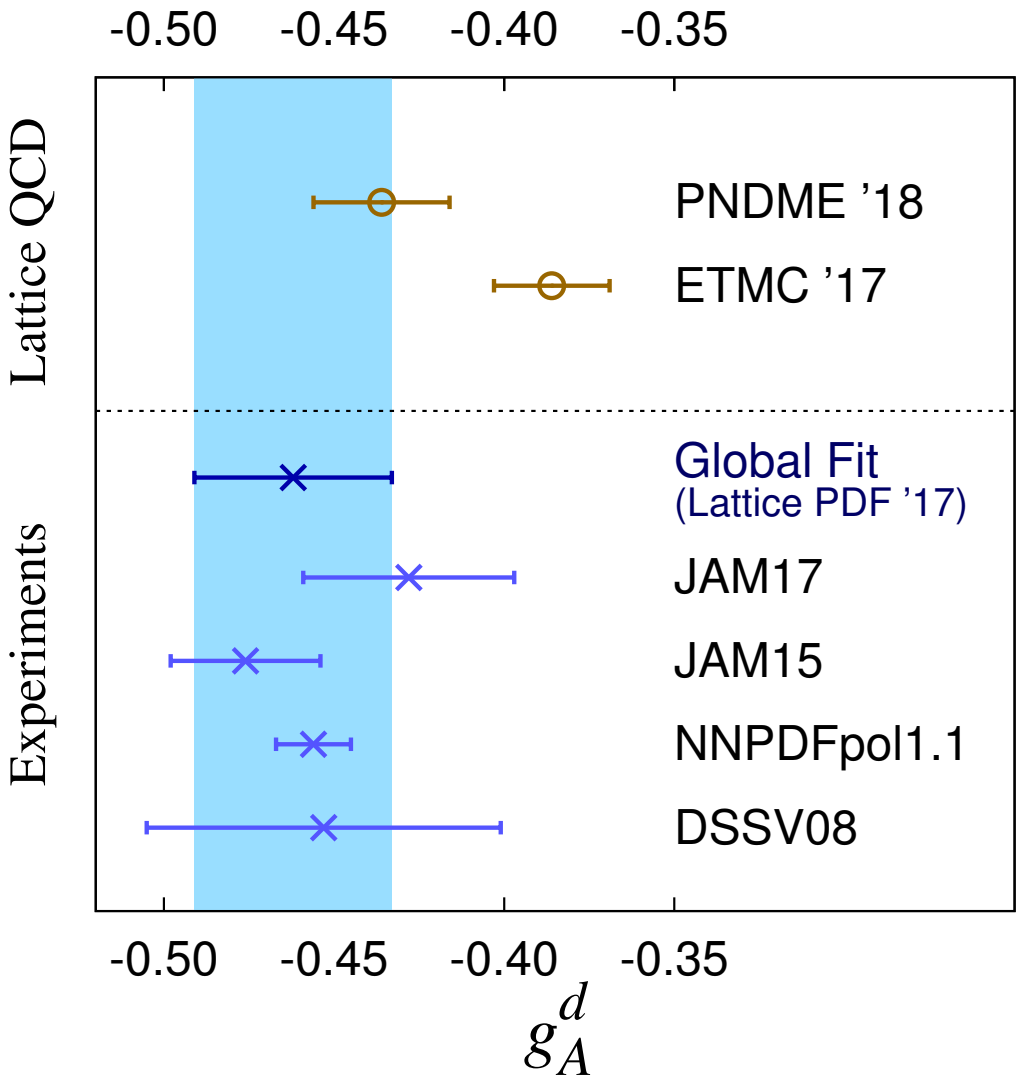
Current Status - g_A^s



Lattice PDF '17 White paper: arXiv:1711.07916, H. Lin, E. Nocera, F. Olness, K. Orginos, J. Rojo, *et al*.

Current Status - g_A^u and g_A^d





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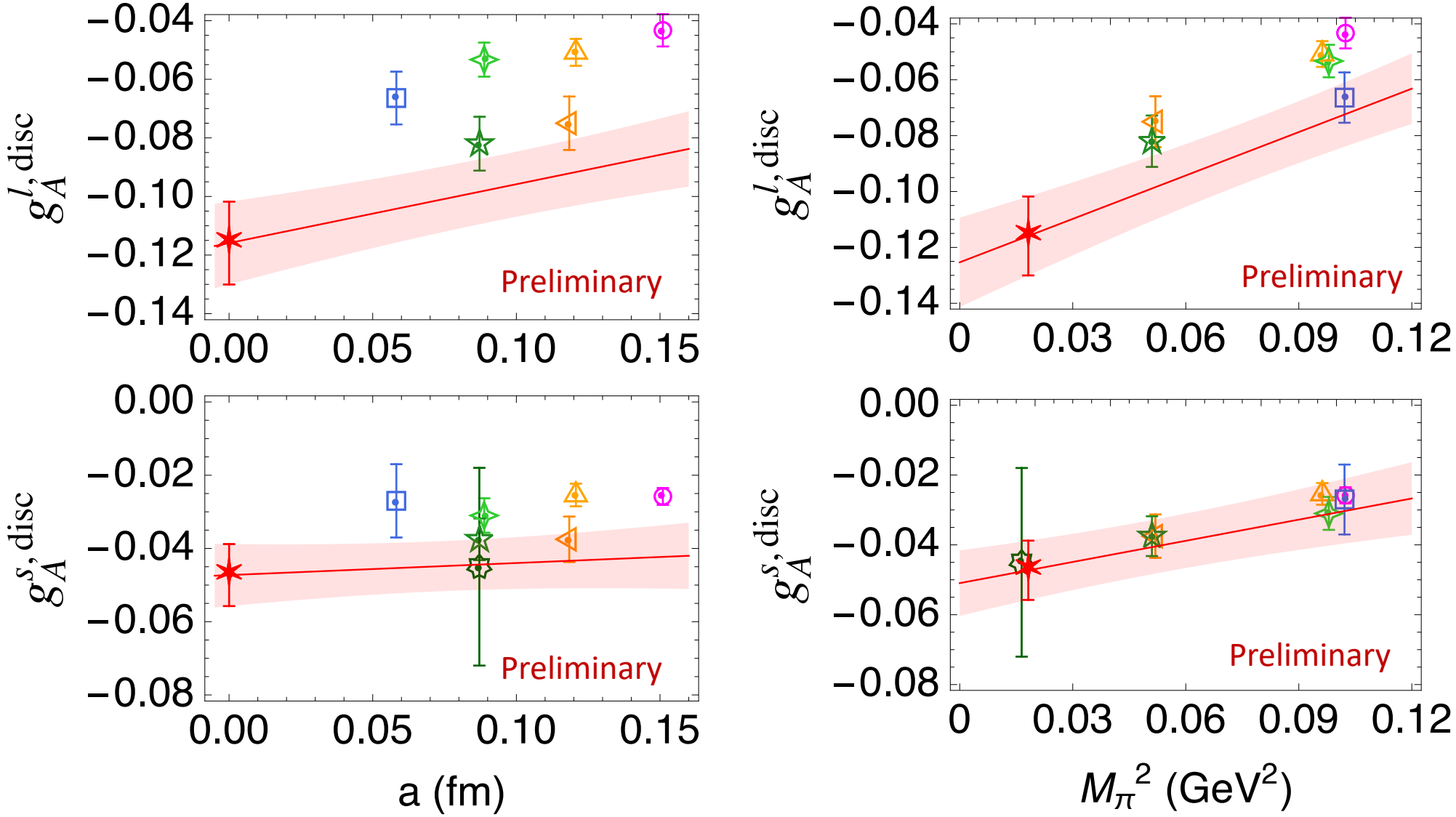
Disconnected contribution: PNDME



Conclusion

- g_A: CalLat provides most precise lattice QCD estimate based on fits with small t_{sep} and exact $Z_A/Z_V = 1$
- Difference between PNDME and CalLat comes mostly from difference in a-extrapolation with results at $a \sim 0.06$ fm

- $g_A^{u,d}$: PNDME show a significant dependence on a and m_π. The larger negative disconnected contribution reduces the contribution of quarks to the proton spin:

$$\frac{1}{2}\Sigma = 0.201(18) \quad \text{[ETMC '17]}$$

$$\frac{1}{2}\Sigma = 0.144(17) \quad \text{[PNDME '18 (preliminary)]}$$