Excited state analysis in the quasi-PDF matrix elements

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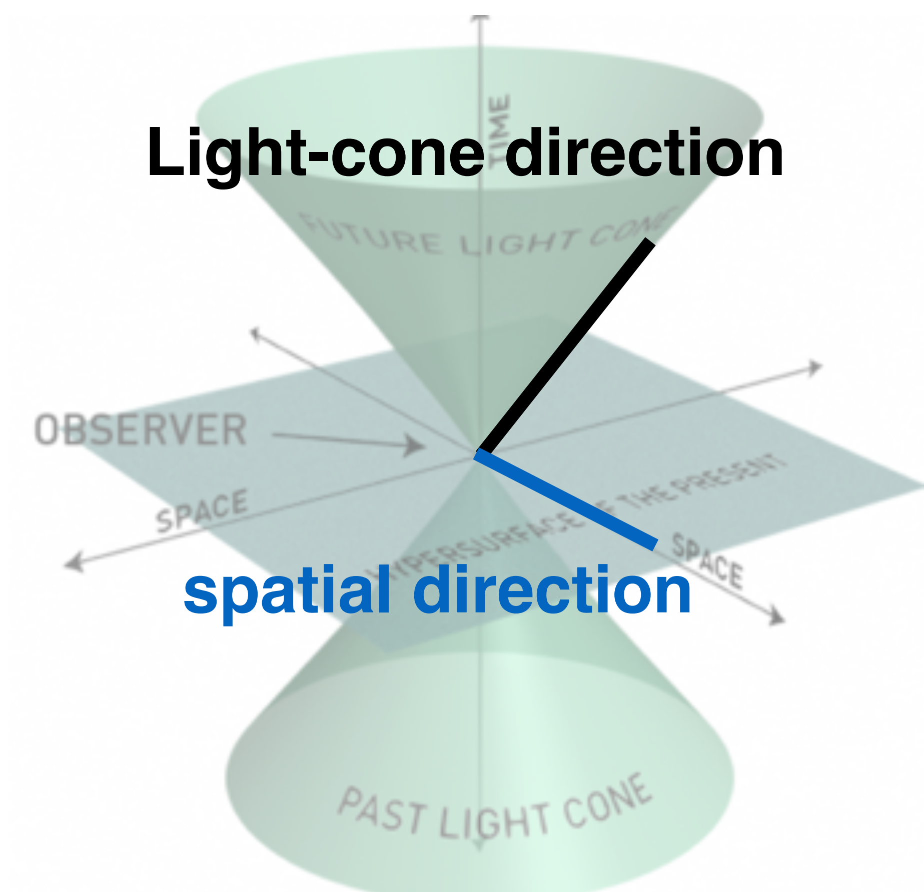
Large momentum effective theory

The light-cone PDF is defined by

$$q(x,\mu^2) = \int \frac{d\xi^-}{4\pi} e^{-ix\xi^- P^+} \langle P|\overline{\psi}(\xi^-)\gamma^+ \times \exp\left(-ig\int_0^{\xi^-} d\eta^- A^+(\eta^-)\right)\psi(0)|P\rangle$$

quasi-PDF



When nucleon is boosted:

- The axial gauge conditions become the light-cone one,

*and the **FT** of the **RI/MOM renormalized quasi-PDF**,*

$$\langle P|\bar{\psi}(z)\gamma_t U_z(z,0)\psi(0)|P\rangle^R_{p^2=\mu_R^2, p_z=p_z^R}$$

X. Ji, PRL 110 (2013) 262002, 1305.1539
X. Ji. SCPMA 57 (2014) 1407, 1404.6680

becomes the light-cone PDF up to perturbative matching.

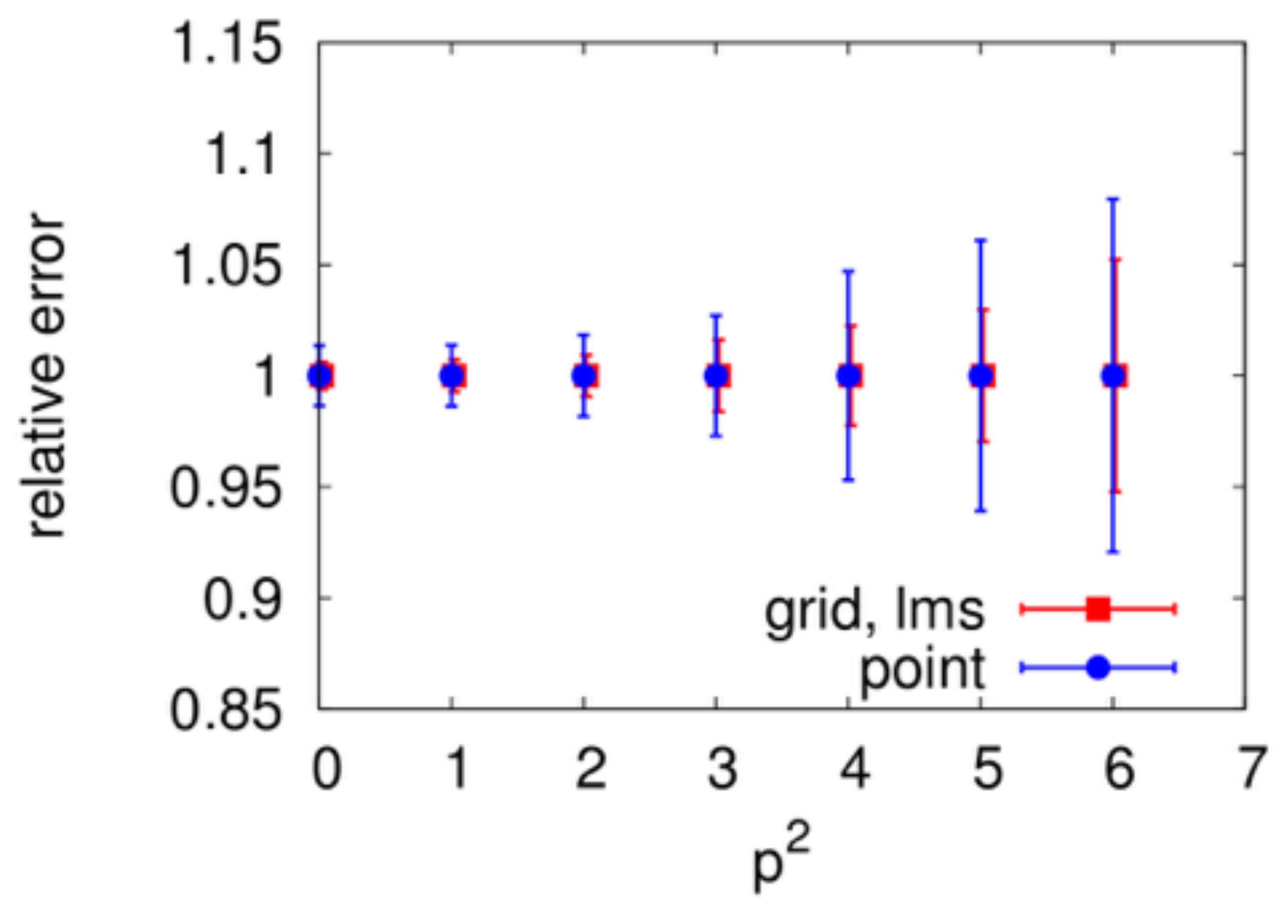
Large momentum…

Really possible?

- The expectation value of a moving hadron decays as $\sim e^{-Et}$, where $E=\sqrt{(m^2+p^2)}$.

- Its statistical uncertainty decays as $\sim e^{-m_0 t}$, where $m_0 \propto m_\pi$ and $m_0 \leq m$.

- Seems to be hopeless to reach large momentum as required by LaMET.

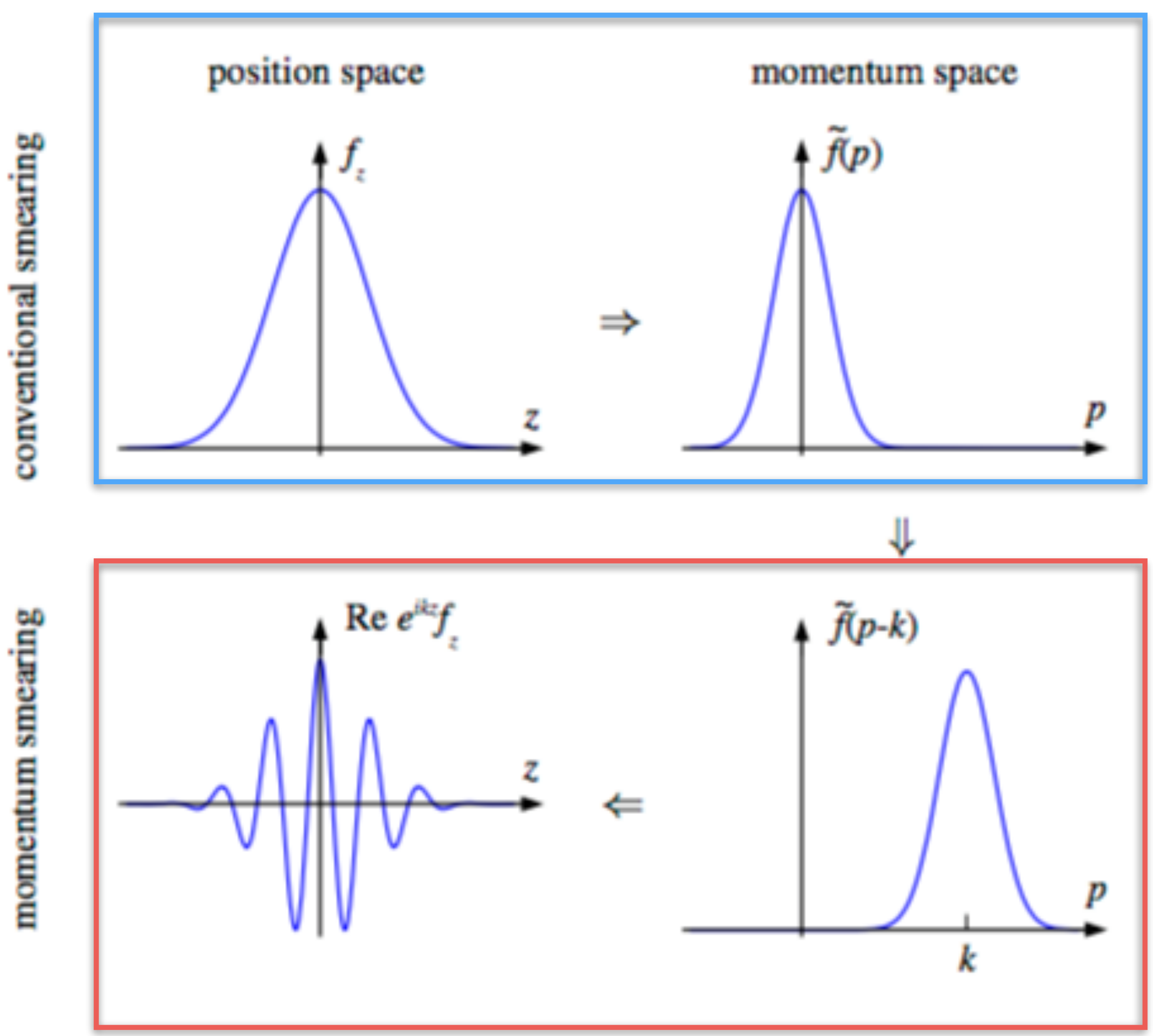


An example from: YBY, et al., χQCD collaboration, PRD93 (2016) 034503, 1509.04616

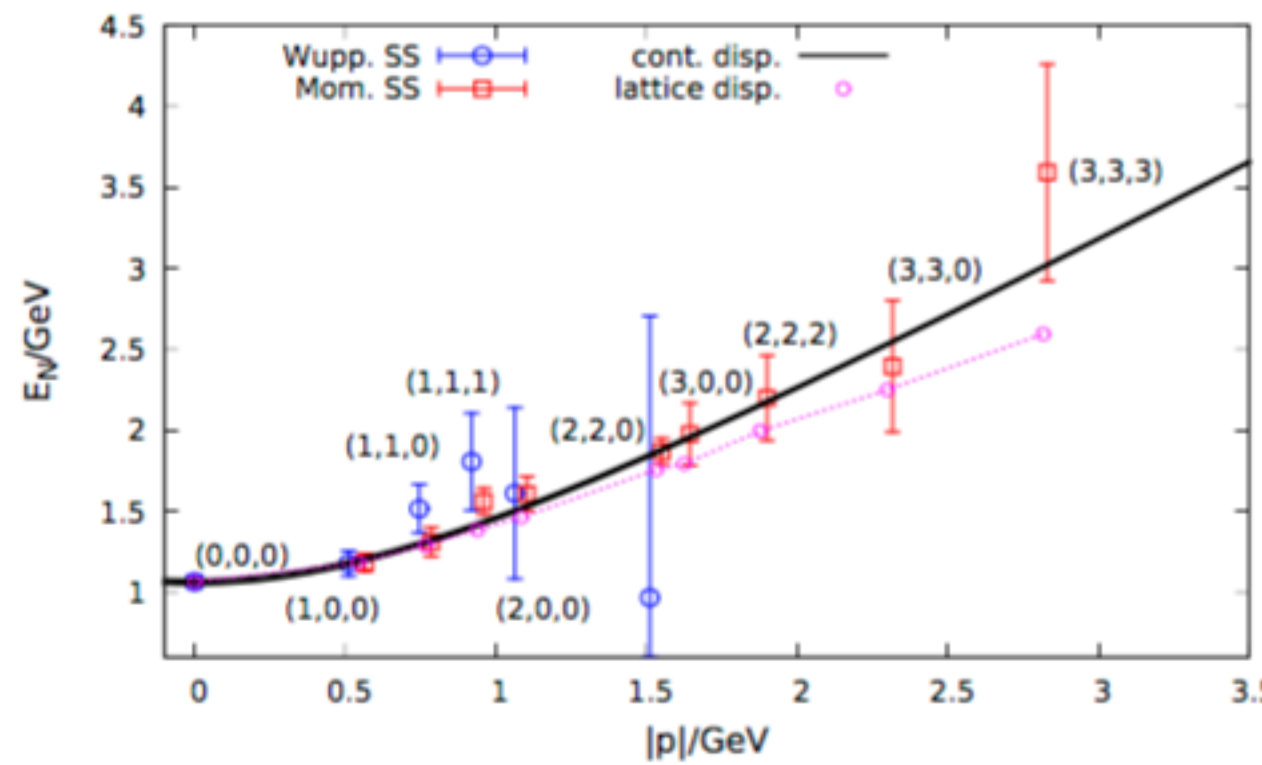
Momentum smearing

in 2pt

Wuppertal (Gaussian) Smearing



Momentum Smearing

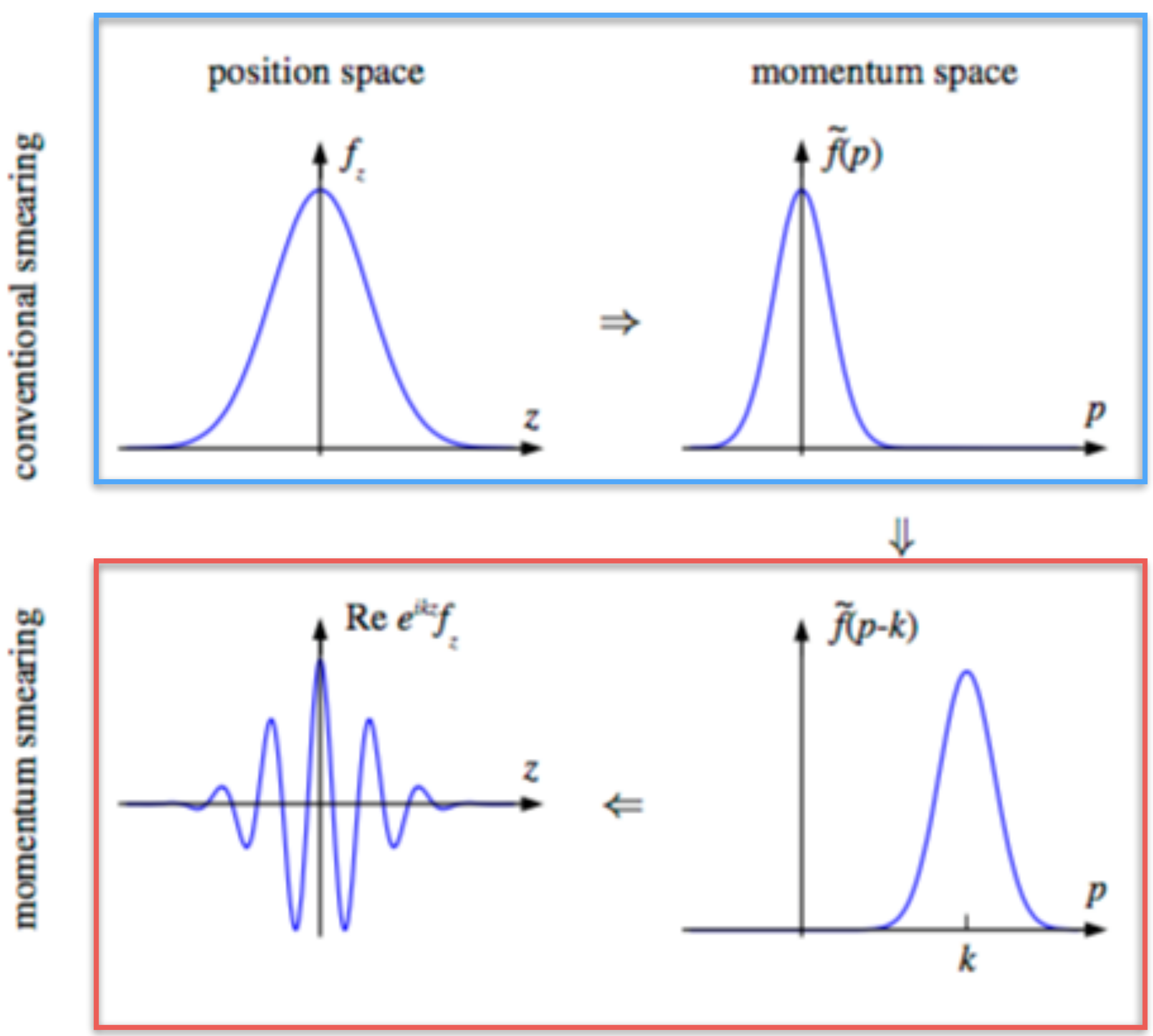


Momentum smearing can provide much better signal in 2pt!

G. Bali, et al., PRD93 (2016) 094515, 1602.05525

Momentum smearing

Wuppertal (Gaussian) Smearing

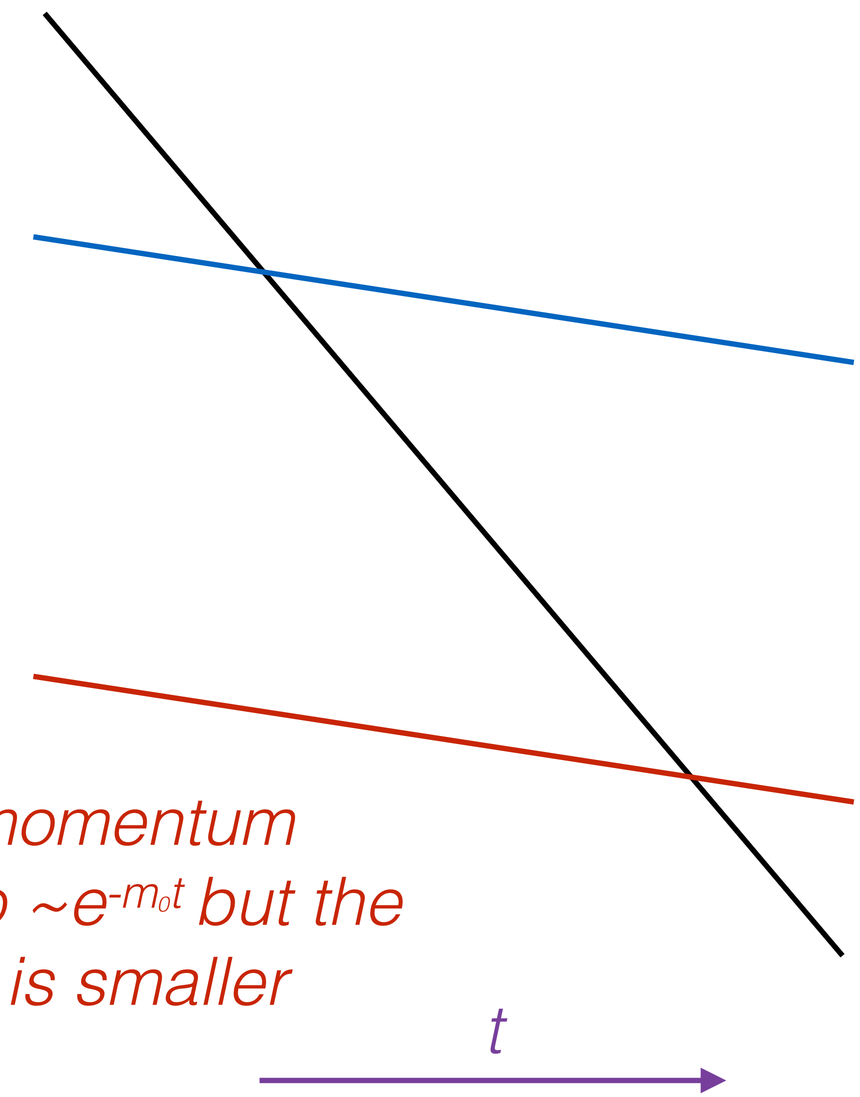


Momentum Smearing

Why?

The expectation value of the 2pt with momentum, $\sim e^{-Et}$

The statistical uncertainty with momentum smearing, $\sim e^{-m_0 t}$



That with momentum smearing, also $\sim e^{-m_0 t}$ but the coefficient is smaller

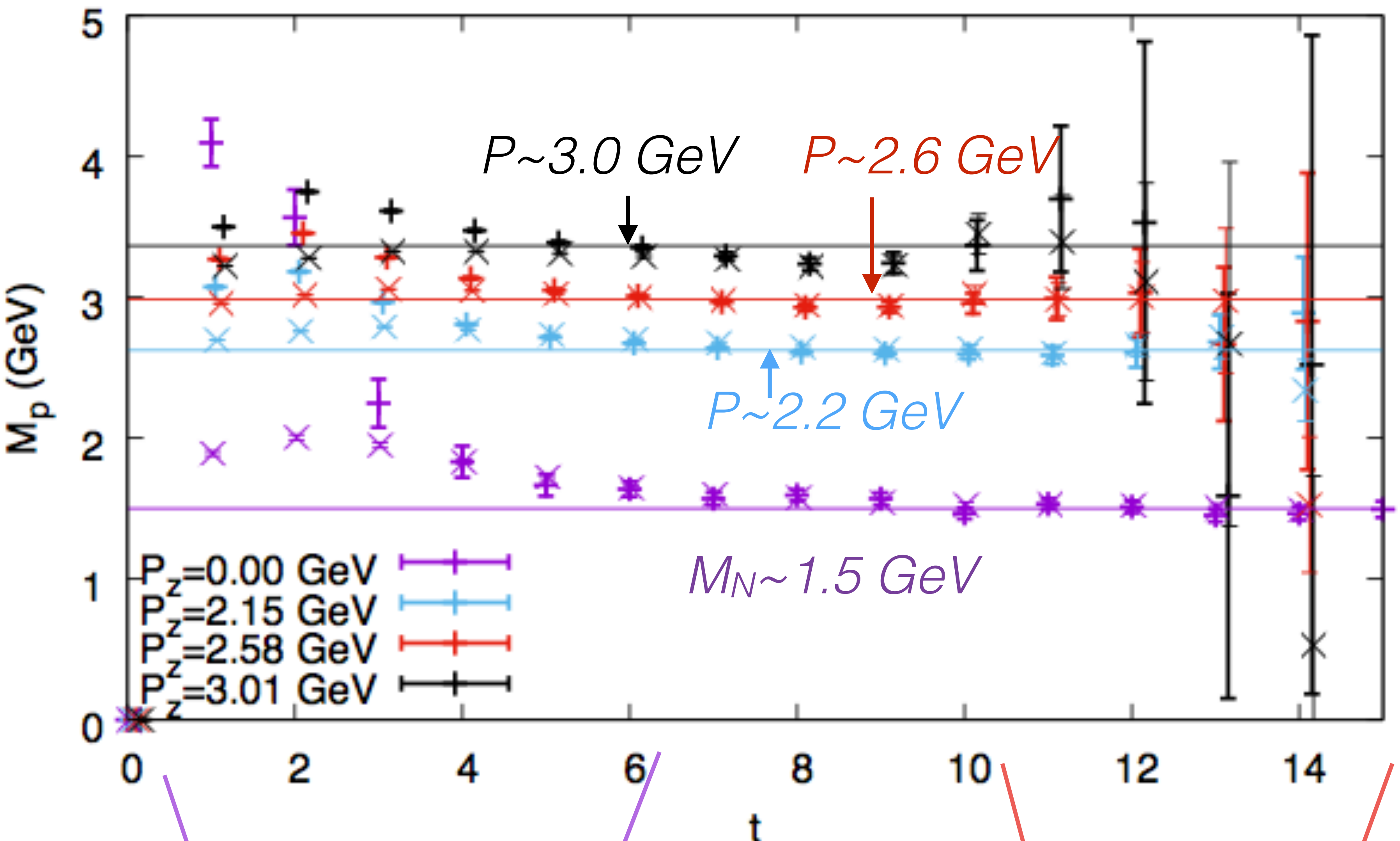
t

The momentum smearing is not a magic. Just effectively gain some statistics.

2pt

a09m310

- m_π~670 MeV, m_π^{sea}~310 MeV, a=0.09 fm;
- L^3xT = 32^3x96;
- 1 step HYP smearing on everything.
- 1152 measurements=(288 configurations) x (4 sources/configuration);



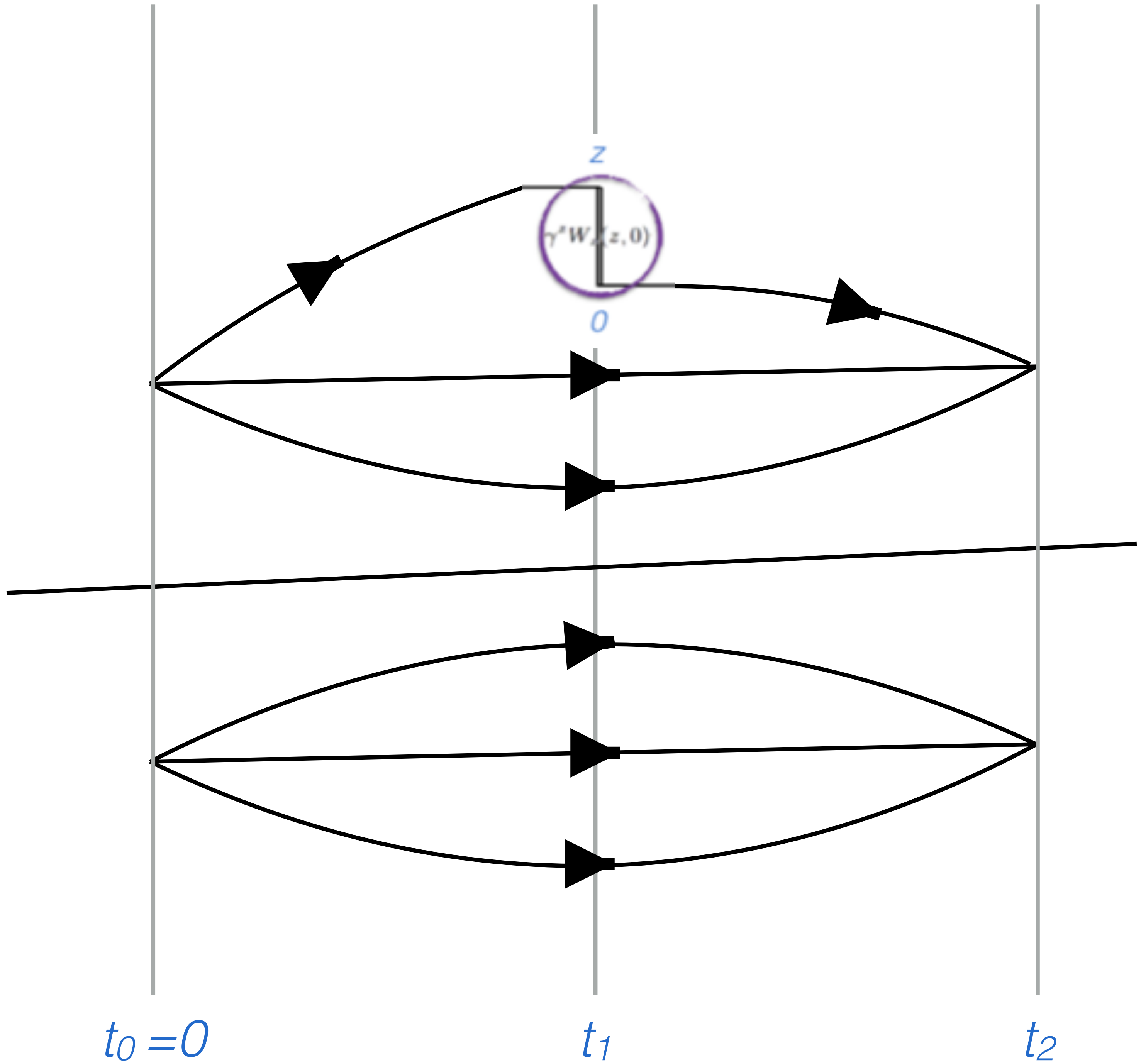
+: smeared src. to smeared sink

x: smeared src. to point sink

The signals with P≠0 are much better than that with P=0, at small t

The condition is reversed at large t

Quasi-PDF matrix element

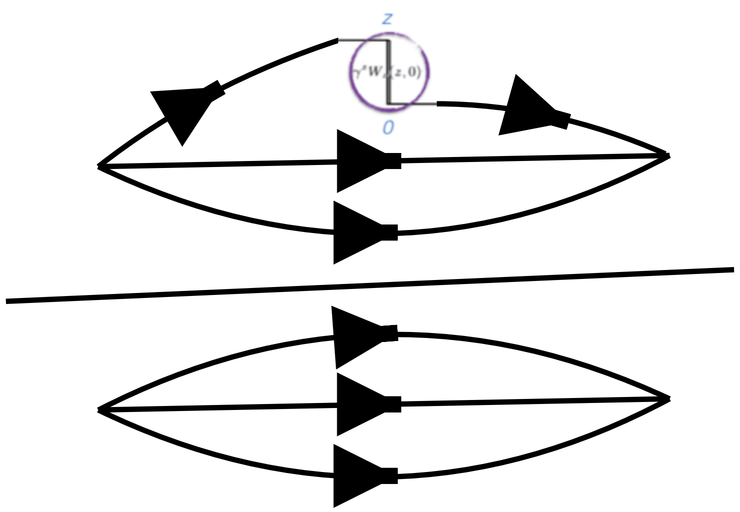


In practical, the following ratio is calculated on the lattice:

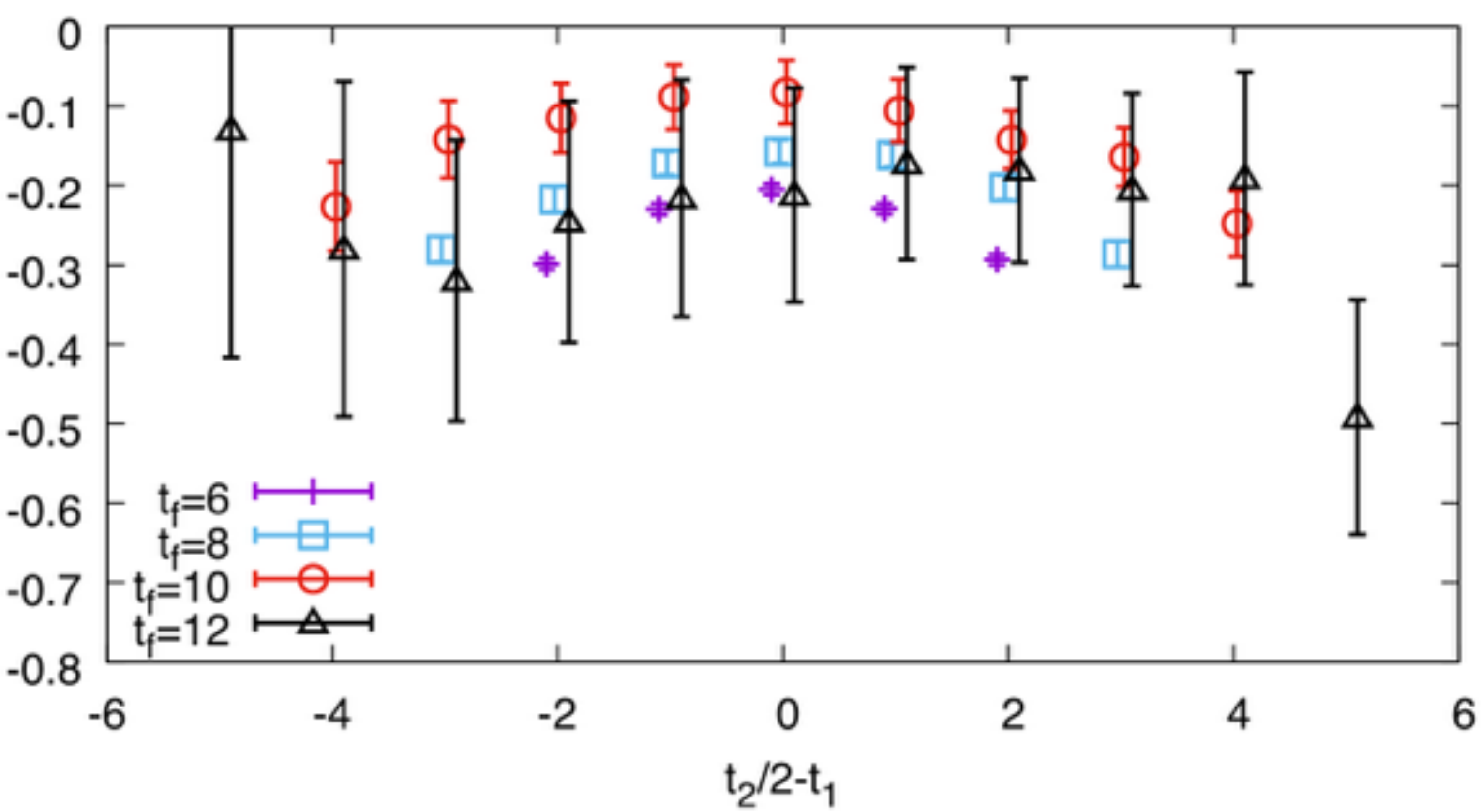
$$= \tilde{h}(z, P_z) + C_1(e^{-\Delta m t_1} + e^{-\Delta m(t_2 - t_1)}) + C_2 e^{-\Delta m t_2}$$

where the $C_{1,2}$ terms correspond to the excited state contaminations vanishing in the $t_2 \gg t_1 \gg 0$ limit.

Quasi-PDF matrix element



$$
= \tilde{h}(z, P_z) + C_1\left(e^{-\Delta m t_1} + e^{-\Delta m (t_2 - t_1)}\right) + C_2 e^{-\Delta m t_2}
$$

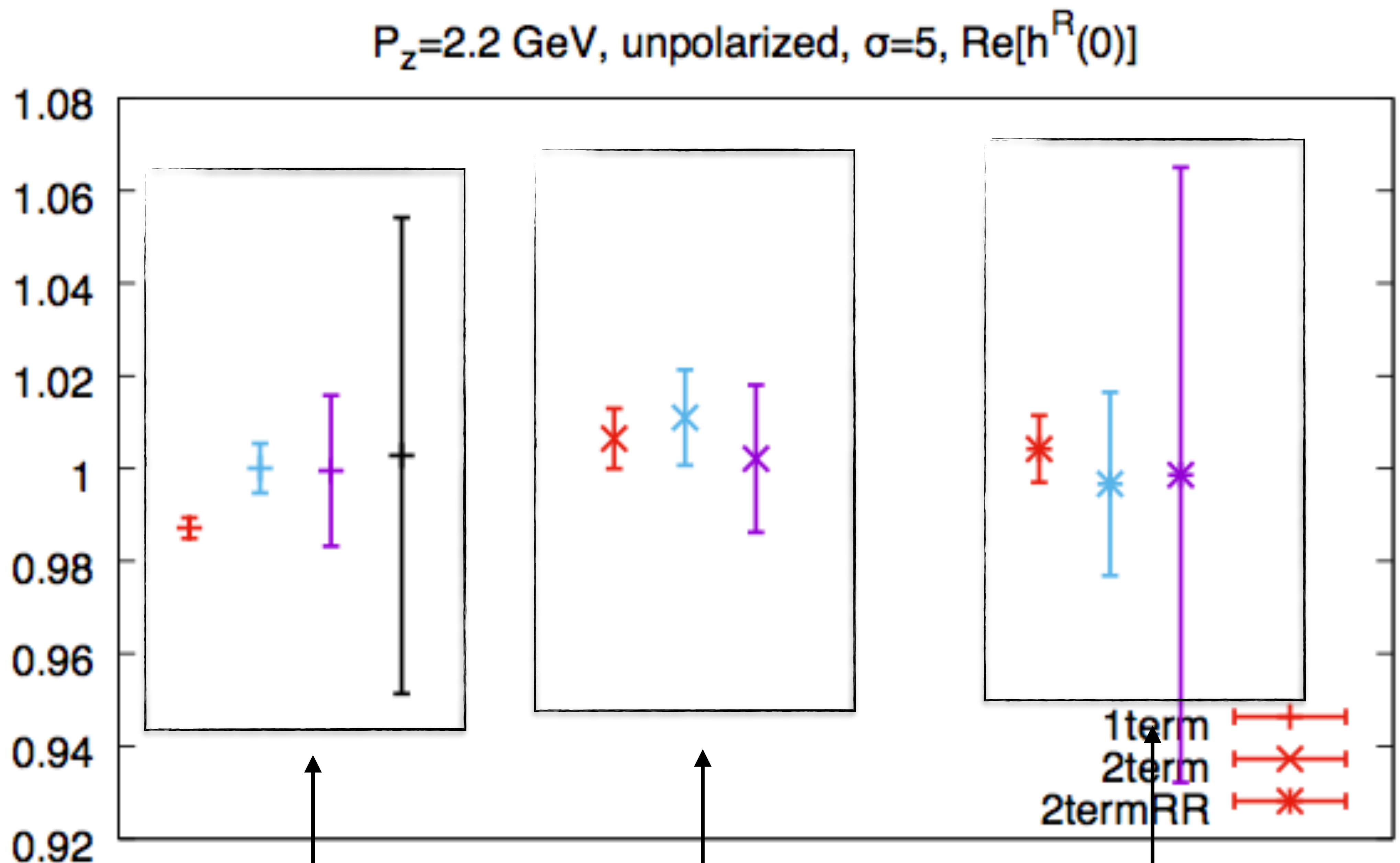


1-term fit: A constant fit around $t_1 \sim t_2/2$

2-term fit: drop the contribution from the C_2 term

2-termRR fit: including all the terms

The fit results of the ME

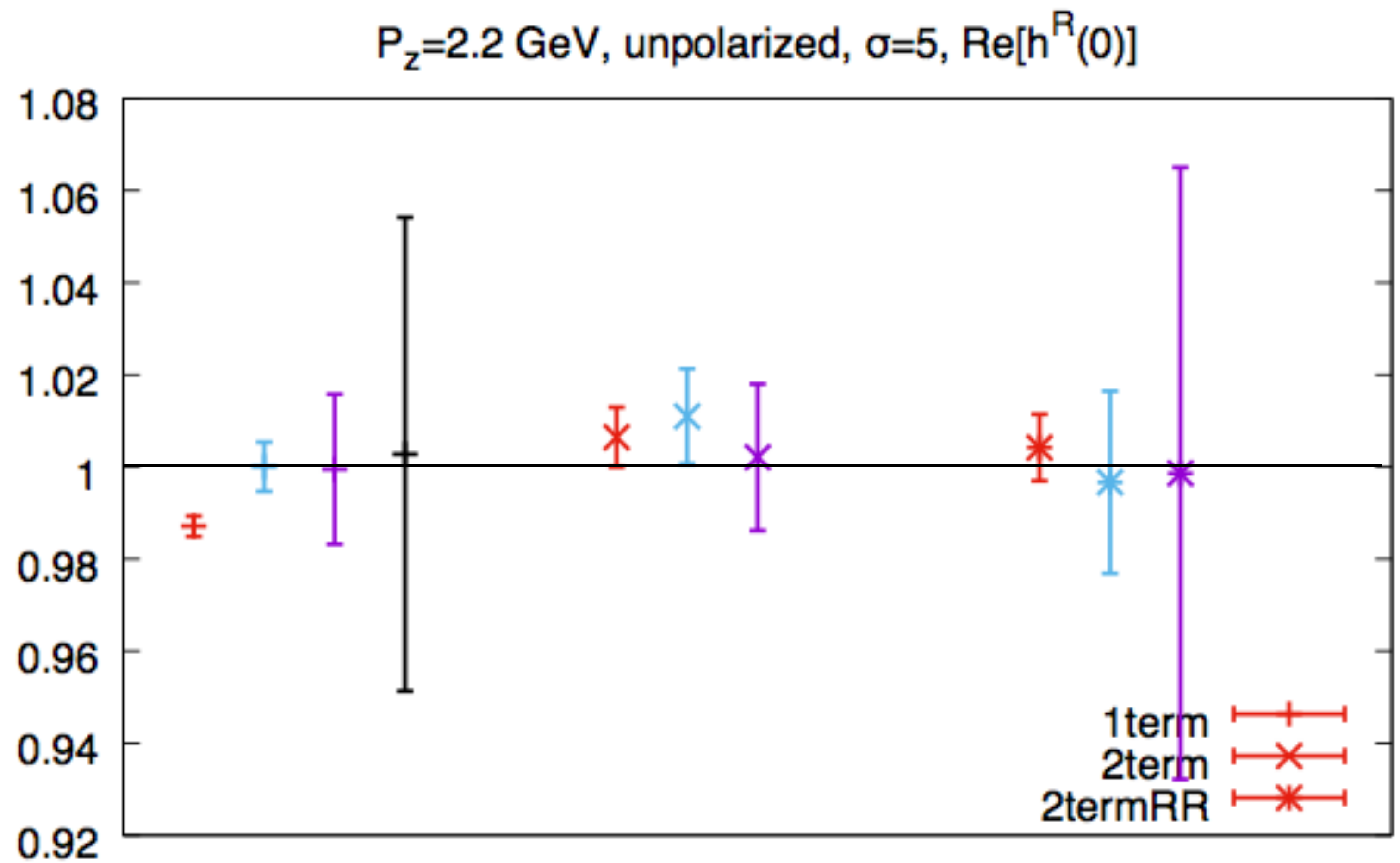


1-term fit at t_{sep}=6/8/10/12

two-two fit from t_{sep}=6/8/10 to t_{sep}=12, without C_2 term

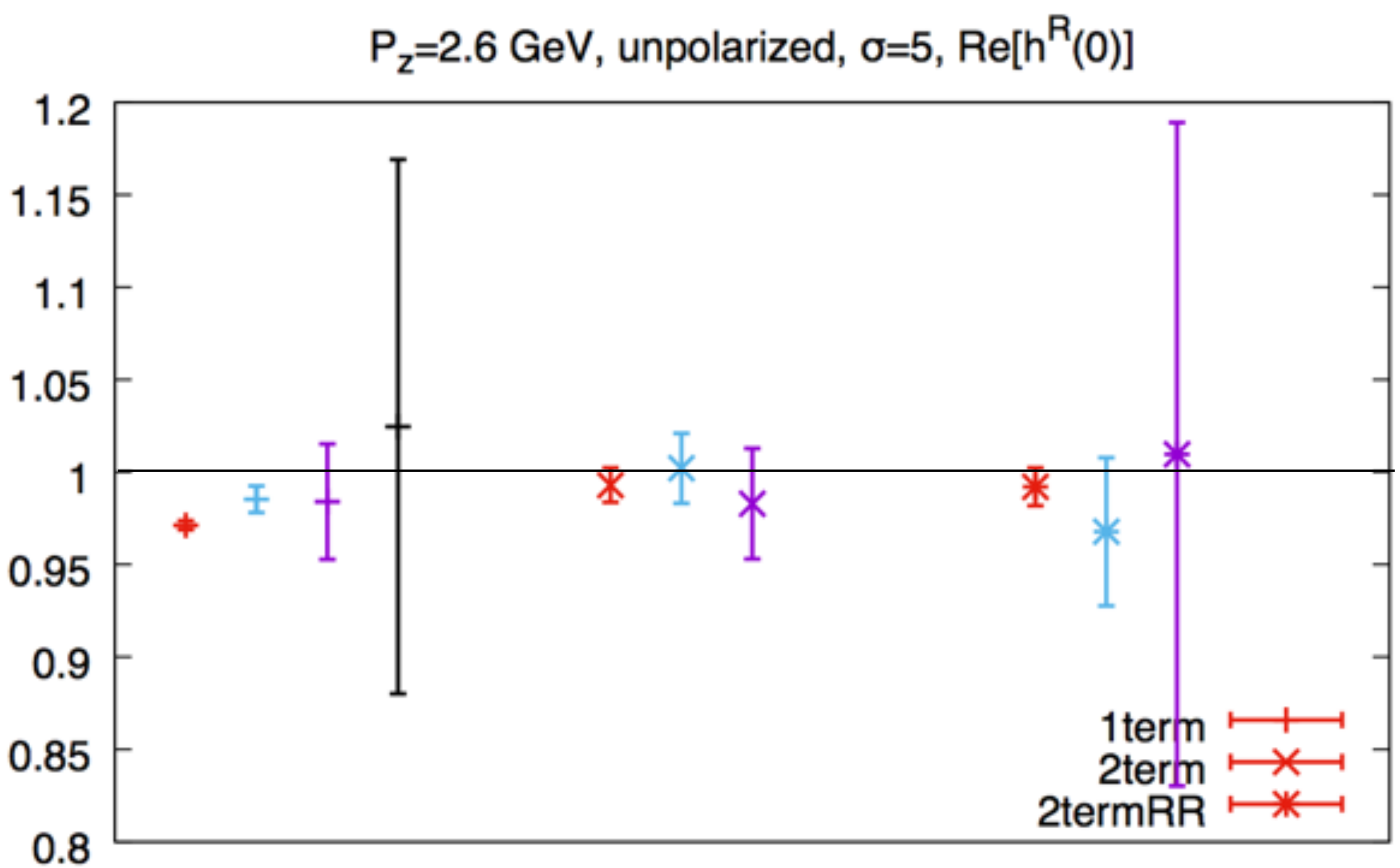
two-twoRR fit from t_{sep}=6/8/10 to t_{sep}=12 **with C_2 term**

z=0, unpolarized



Three groups for three types of the fits

Different colors for different minimum separations.



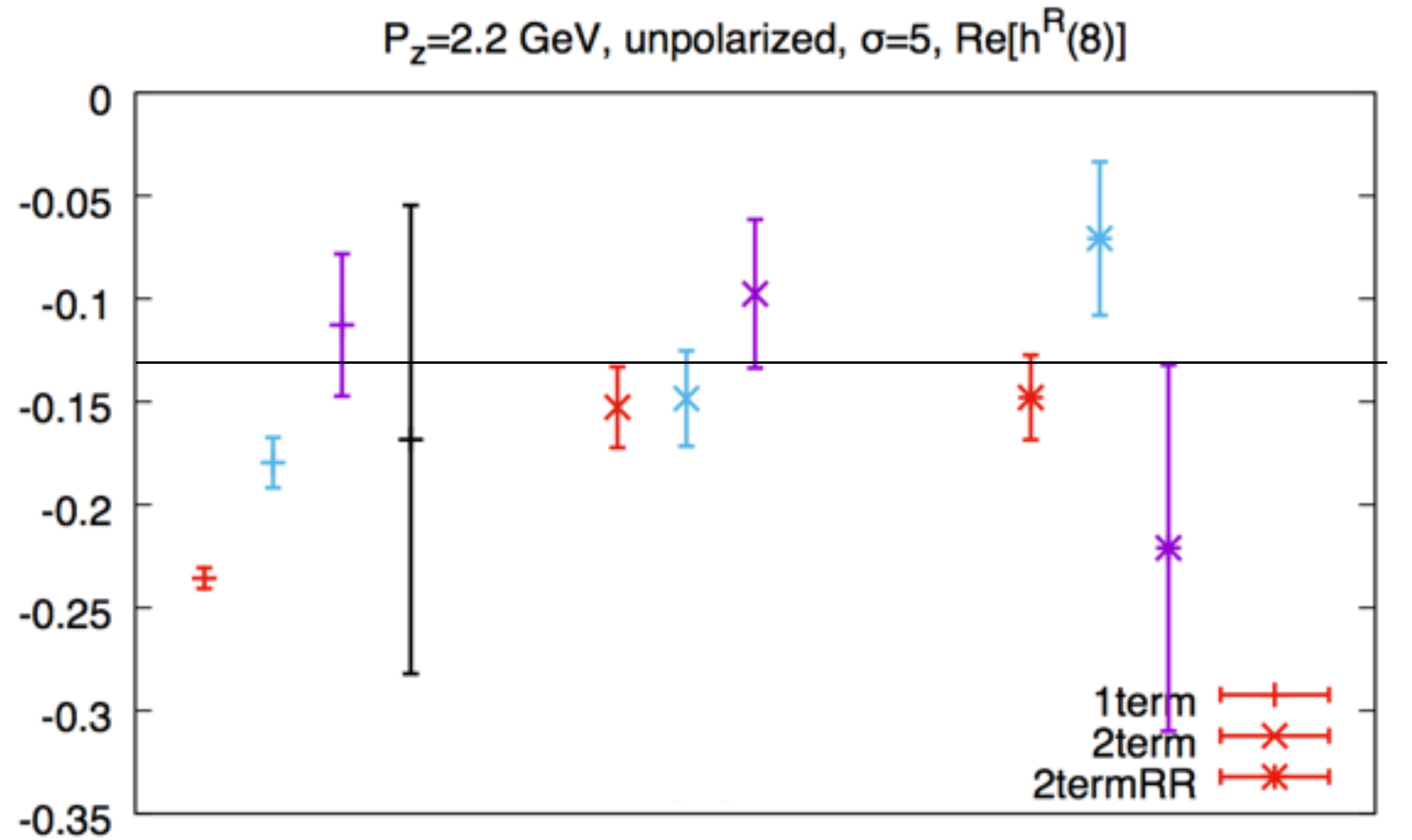
The results with different P_z are consistent with the same normalization at z=0.

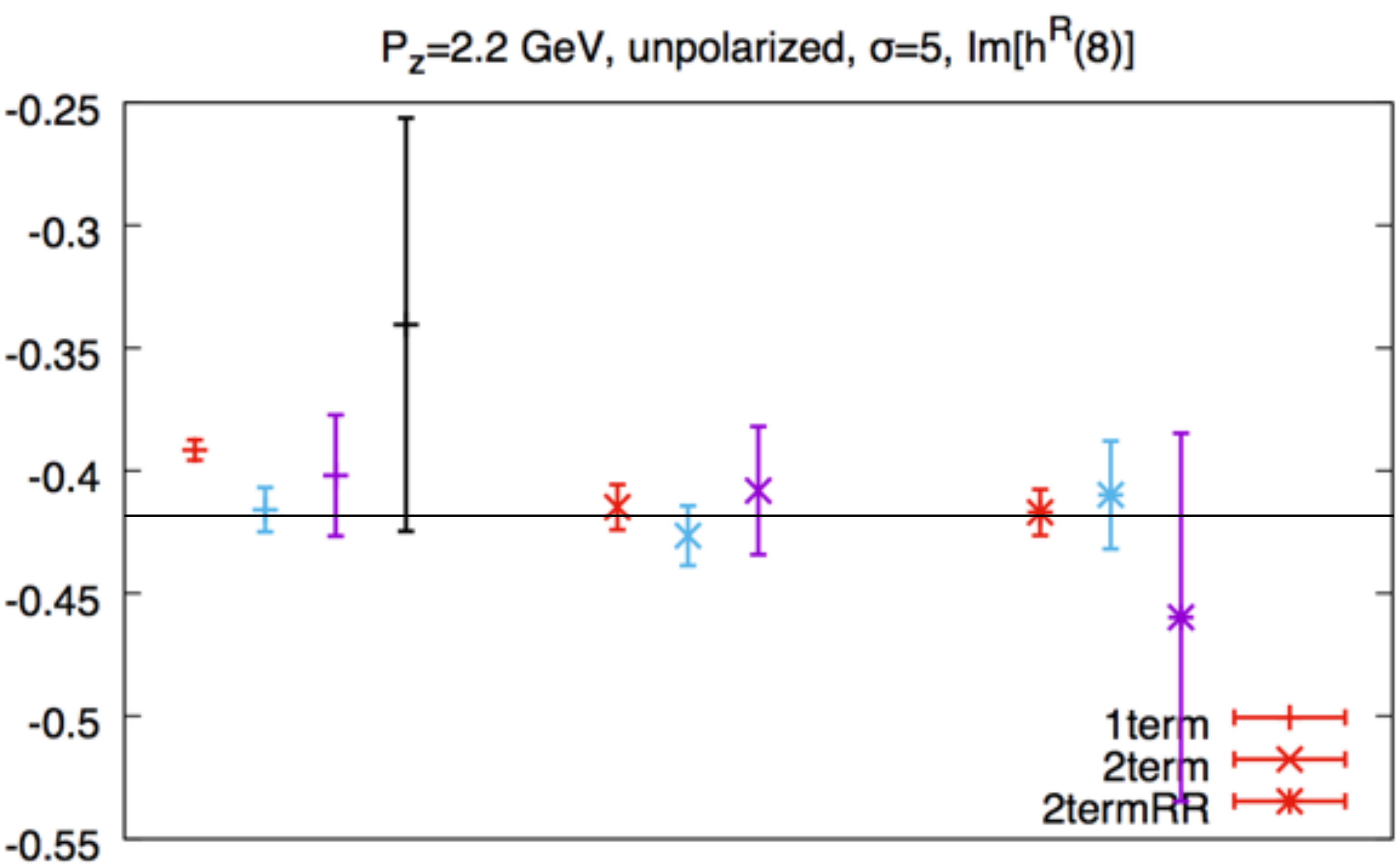
The horizontal line with the same value are placed to guide your eyes.

Pz=2.2 GeV, z=8, unpolarized

Three groups for three types of the fits

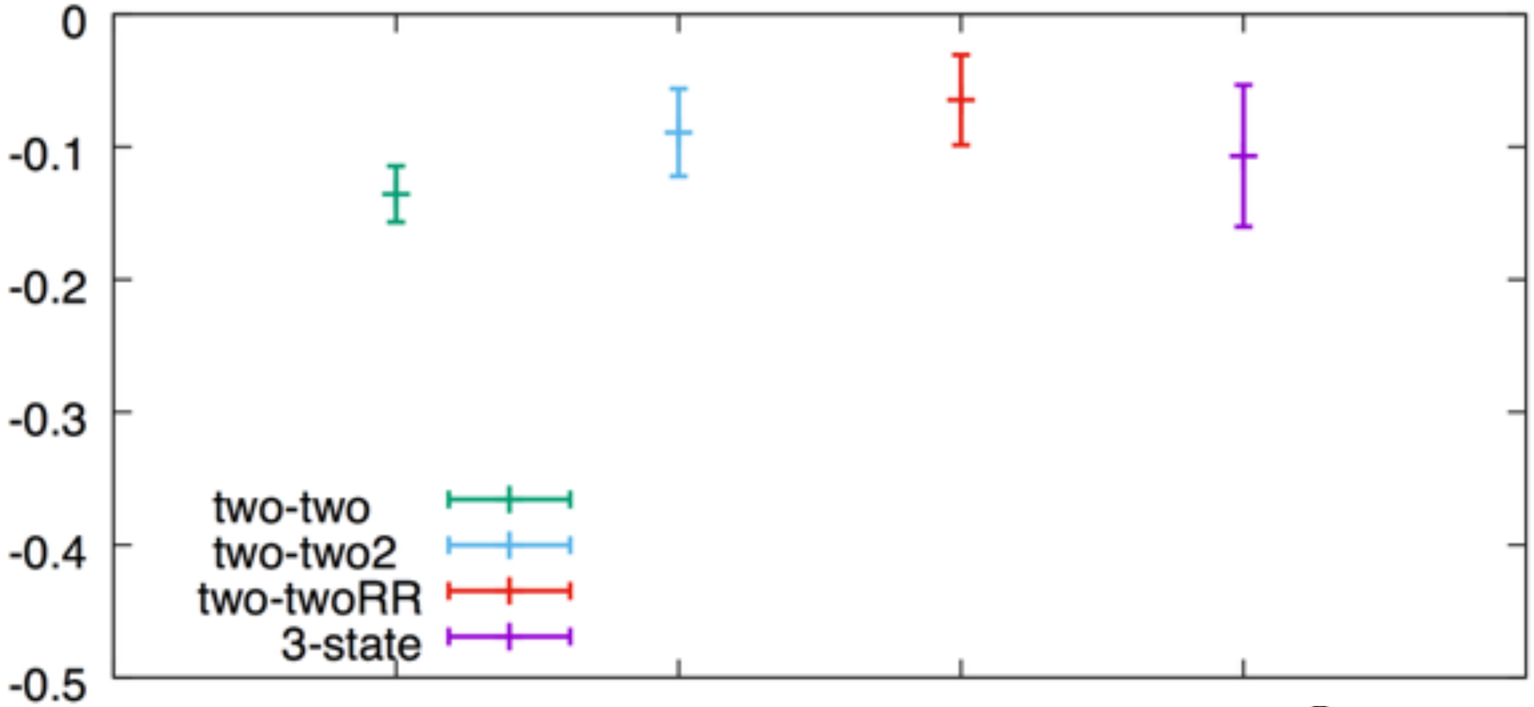
Different colors for different minimum separations.





At z=8, the fits for the imaginal part have good agreement but the real part require more statistics at large t_{sep} to get a solid conclusion.

Two-state fit vs. three-state fit

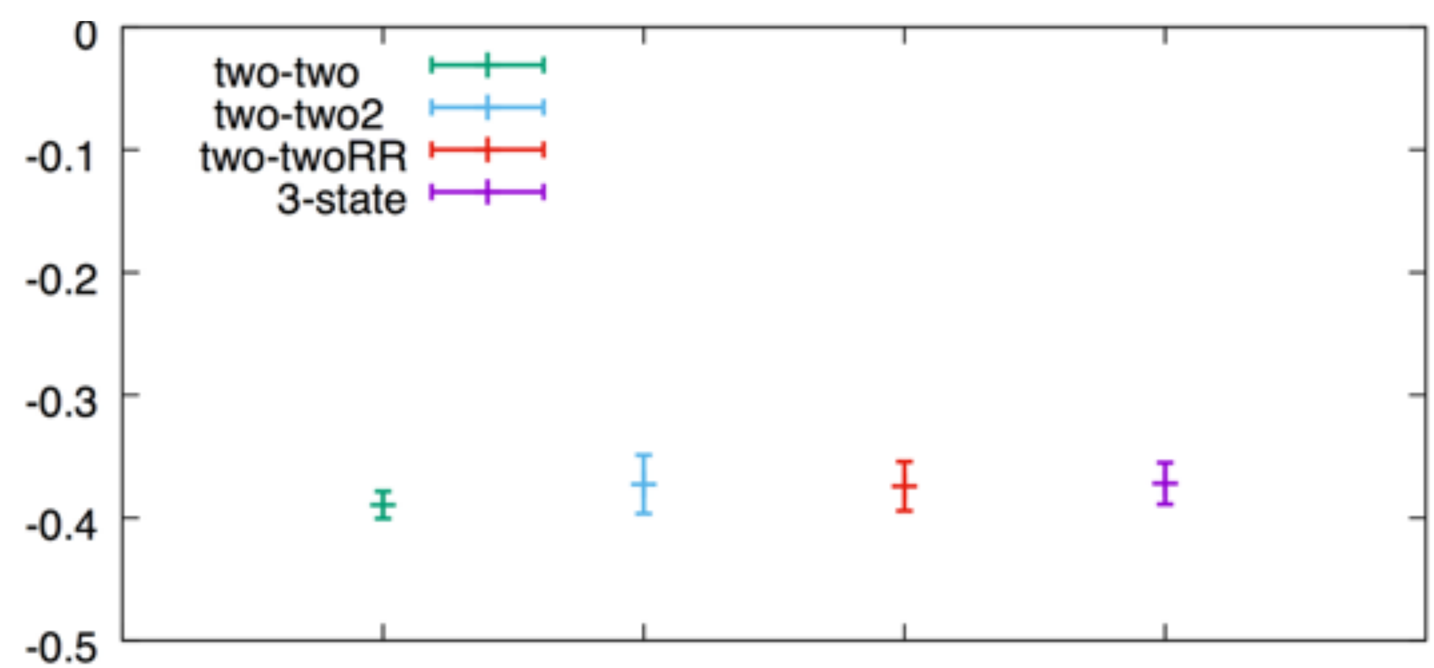


Two-Two: t_2=8, 10, 12, without RR

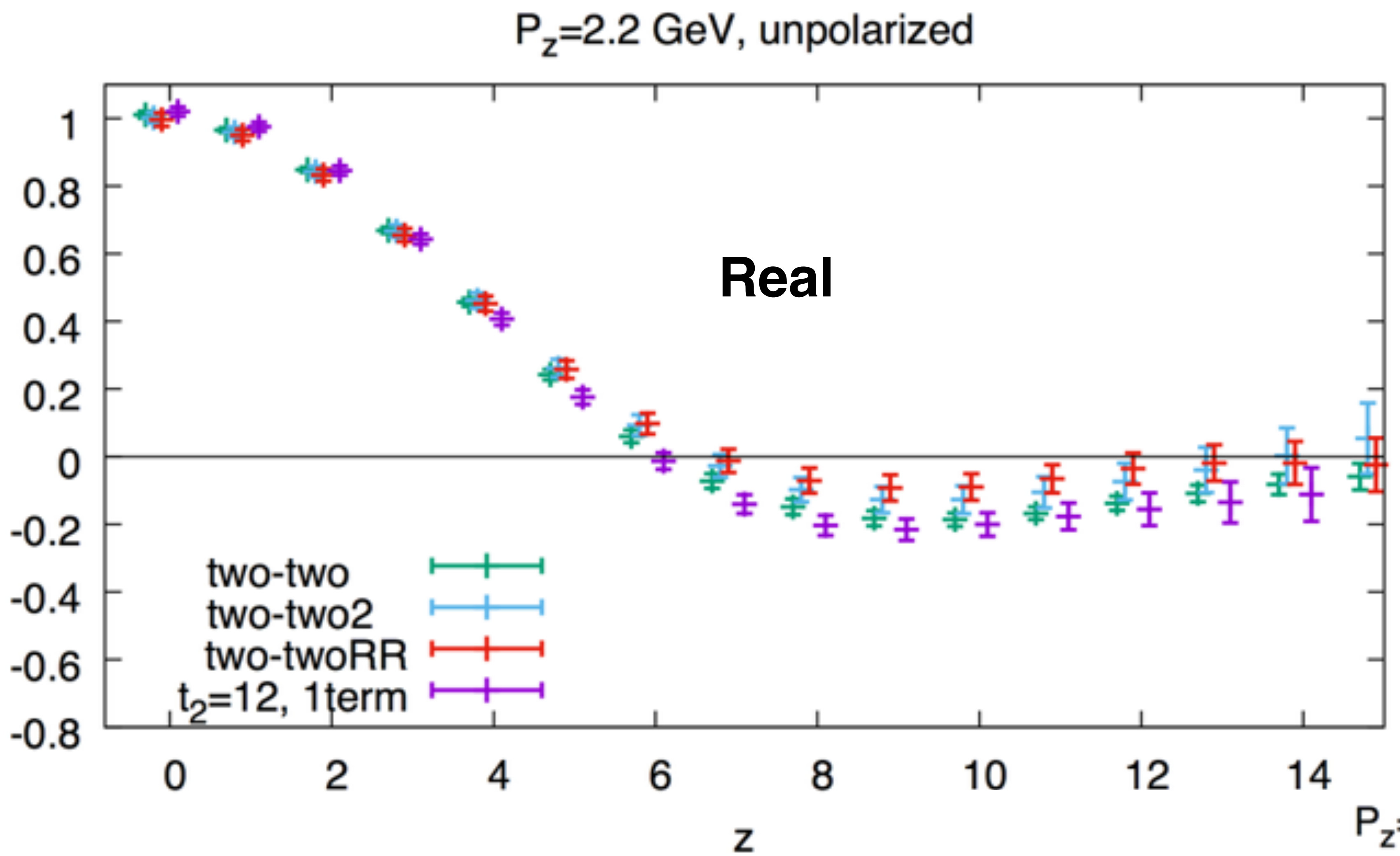
Two-Two2: t_2=10, 12, without RR

Two-TwoRR: t_2=8, 10, 12, with RR

t_2=6, 8, 10, 12, 3-state fit



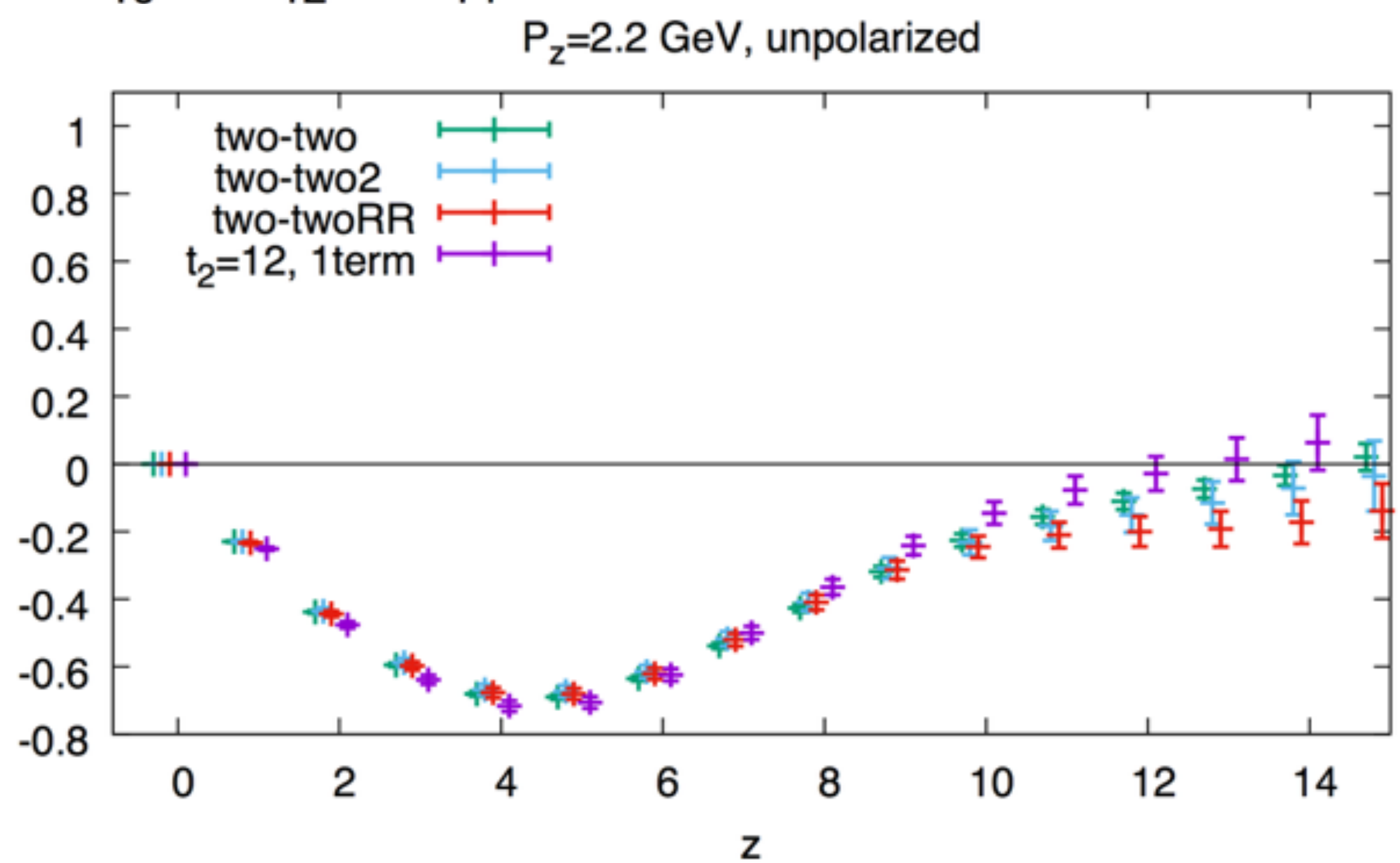
Ruizi. Li, et al., LP^3 collaboration, in preparation



Two-Two: t_2=8, 10, 12, without RR

Two-Two2: t_2=10, 12, without RR

Two-TwoRR: t_2=8, 10, 12, with RR



16x statistics for t_2=12, 1-state fit

The large statistics result with t=12 agrees with that based on two-state fits ones using smaller separations!

Summary

- The momentum smearing allow us to achieve good signal for the matrix elements with large hadron momentum, at small source-sink separation.
- The multi-state fit can provide a good subtraction on the excited state contamination with smaller source-sink separations.
- The production with another smearing size are ongoing to confirm the multi-state fit results.