Light flavor-singlet pseudoscalar in J/ψ radiative decay

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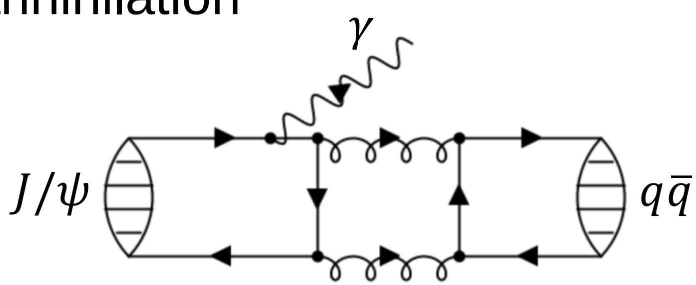
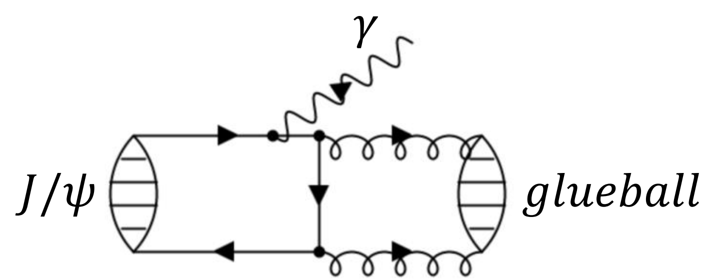
Outlines

- Motivation
- Methodology
- Preliminary results
- Summary

I. Motivation

- The radiative decays of J/ψ is thought of a good hunting ground for glueballs (and hybrids) due to the abundance of gluons in $c\bar{c}$ annihilation





- Naïve α_s power counting expects:

$$\frac{\Gamma(J/\psi \to \gamma G)}{\Gamma\big(J/\psi \to \gamma(q\bar{q})\big)} \propto \frac{1}{\alpha_s^2}$$

- Therefore, the production rate of $q\bar{q}$ mesons is relatively suppressed in comparison with that of glueballs.

I. Motivation

- Quenched lattice QCD studies predict large production ratios of the scalar and the tensor glueballs:
  - $Br(J/\psi \to \gamma G_{0^+}) = 3.8(9) \times 10^{-3}$, L.-C. Gui et al., PRL 110 (2013) 021601
  - $Br(J/\psi \to \gamma G_{2^+}) = 1.1(2) \times 10^{-2}$, Y.-B. Yang et al., PRL 111 (2013) 091601

- In order to check the possible suppression, it is intriguing to calculate the partial width $\Gamma\big(J/\psi \to \gamma(q\bar{q})\big)$ from lattice QCD.

- The decay $J/\psi \to \gamma\eta^{(\prime)}$ can be a good starting point, since $\eta^{(\prime)}$ is relatively stable in comparison to other light flavor singlet mesons.

- For two flavor gauge configuration, the isoscalar light pseudoscalar η is considered.

I. A. Configuration

- We generated $N_f = 2$ gauge configurations on an anisotropic lattice:

N_{conf}	a_s	$L^3 \times T$	ξ_f	m_π	a_t^{-1}
500	0.1517 fm	$16^3 \times 128$	5.30	349.2 Mev	6894 MeV

  - The fermion anisotropic ratio ξ_f is measured by dispersion relation on π.
  - The lattice spacing a_t^{-1} is measured by relationship between light flavor pseudoscalar (π) and vector (ρ) particles: $m_\rho^2 - m_\pi^2 = 0.5682\ \mathrm{GeV}^2$.

- Since glueballs and disconnected insertion need large statistics, such an anisotropic lattice is an optimal choice.
- Generated $\sim 70{,}000$ trajectories now, used 500 of them

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II. Methodology

- The general radiative decay width of an initial particle i to a final particle f is:

$$\Gamma(i \to \gamma f) = \int \mathrm{d}\Omega_q \frac{1}{32\pi^2} \frac{|\vec{q}|}{m_i^2} \frac{1}{2J_i + 1} \times \sum_{r_i, r_f, r_\gamma} \left| M_{r_i, r_f, r_\gamma} \right|^2$$

- The transition amplitude is:

$$M_{r_i, r_f, r_\gamma} = \epsilon_\mu^*(\vec{q}, r_\gamma) \langle f(\vec{p}_f, r_f) | j_{em}^\mu(0) | i(\vec{p}_i, r_i) \rangle$$

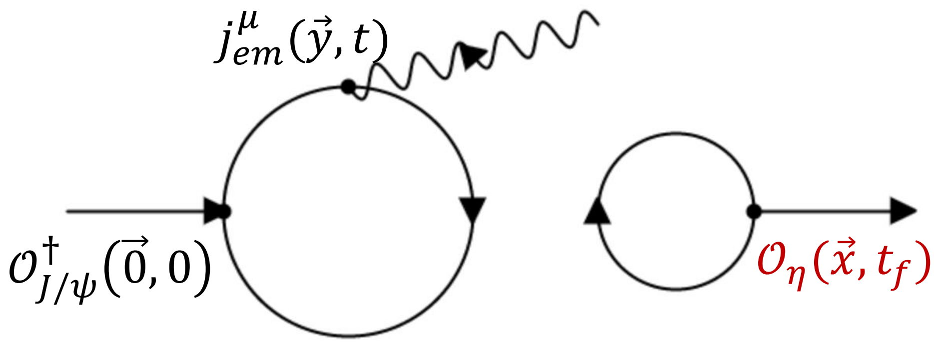
- Apply the multipole decomposition:

$$\langle f(\vec{p}_f, r_f) | j_{em}^\mu(0) | i(\vec{p}_i, r_i) \rangle = \sum_k \alpha_k^\mu(p_i, p_f) F_k^2(Q^2)$$

- The matrix element can be derived from 3-point function:

$$\Gamma^{(3)\mu}(\vec{p}_f, \vec{q}; t_f, t) = \sum_{\vec{x}, \vec{y}} e^{-i\vec{p}_f \cdot \vec{x}} e^{-i\vec{q} \cdot \vec{y}} \left\langle O_\eta(\vec{x}, t_f) j_{em}^\mu(\vec{y}, t) O_{J/\psi}^\dagger(\vec{0}, 0) \right\rangle$$

II. Methodology



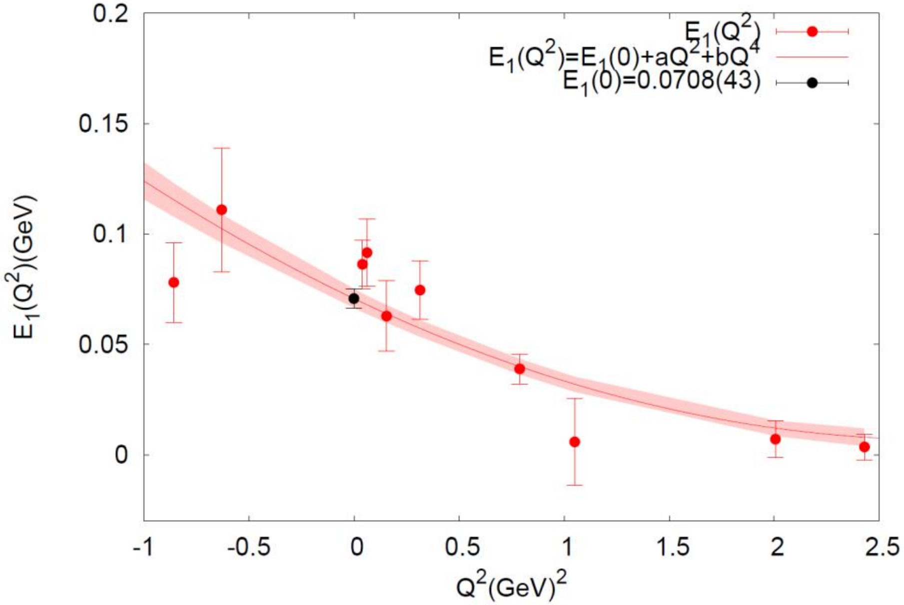
- One of the key points of this calculation is to tackle with the light quark loop relevant to the η meson. This can be done by applying the distillation method (M. Peardon et al., PRD 80 (2009) 054506)

- Left part of the diagram is something like 2-point function between J/ψ and electromagnetic current j^{μ}_{em}, which should be much simpler than the light quark loop

II. A. Previous work

- Once we get the good SNR of η, we can do the similar calculation as L.-C. Gui et al., PRL 110 (2013) 021601

- This paper calculated $J/\psi \rightarrow \gamma G_{0^+}$
- Include
  - calculating 3-point function
  - extracting form factors



II. Methodology

- At first, we check the 2-point functions of different interpolation operators for η:

$$\mathcal{O}_\Gamma = \frac{1}{\sqrt{2}}\left(\bar{u}\Gamma u + \bar{d}\Gamma d\right), \qquad \Gamma = \mathrm{i}\gamma_5, \gamma_4\gamma_5, \gamma_4\gamma_5\gamma_i\nabla_i$$

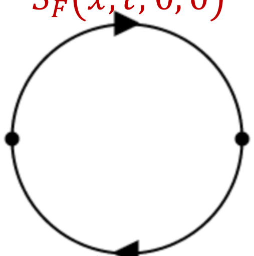
$$\text{where } \nabla_i = \frac{1}{2}\left(U_i(x)\delta_{x+i,y} - U_i^\dagger(x-i)\delta_{x-i,y}\right)$$

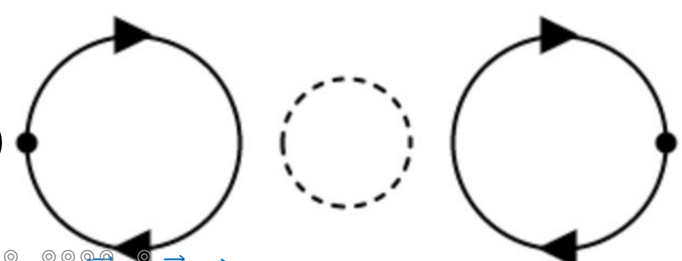
- And we have the 2-point function:

$$C_2(t) = \sum_{\vec{x}}\langle \mathcal{O}_\Gamma(\vec{x},t)\mathcal{O}_\Gamma^\dagger(\vec{0},0)\rangle = C(t) + 2D(t)$$

$$C(t) = -\sum_{\vec{x}}\langle \mathrm{Tr}\left[\Gamma S_F(\vec{x},t;\vec{0},0)\Gamma S_F(\vec{0},0;\vec{x},t)\right]\rangle$$

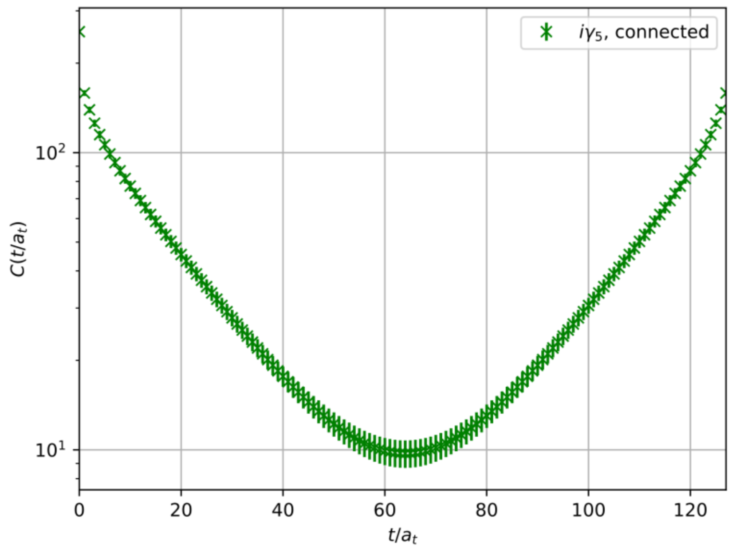
$$D(t) = \sum_{\vec{x}}\langle \mathrm{Tr}[\Gamma S_F(\vec{x},t;\vec{x},t)]\mathrm{Tr}\left[\Gamma S_F(\vec{0},0;\vec{0},0)\right]\rangle$$

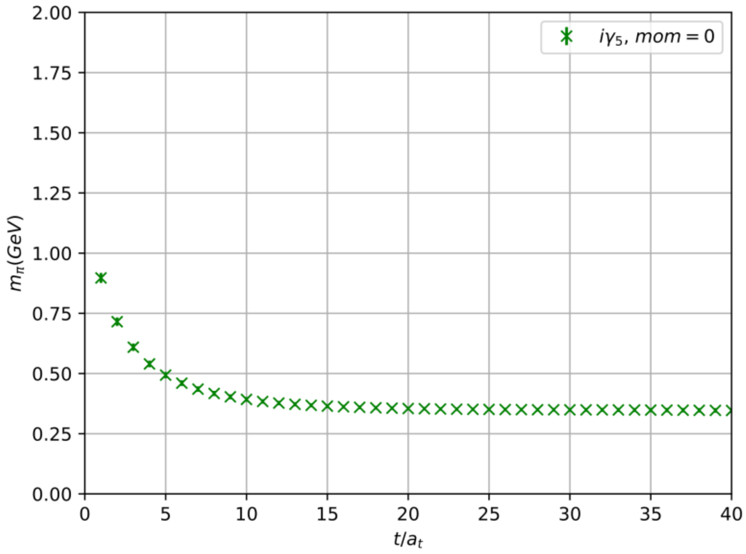




II. B. Distillation

- We use 70 eigenvectors to construct the perambulators and elementals for distillation method.
- The 2-point function for π generated by distillation method using only 10 configurations.





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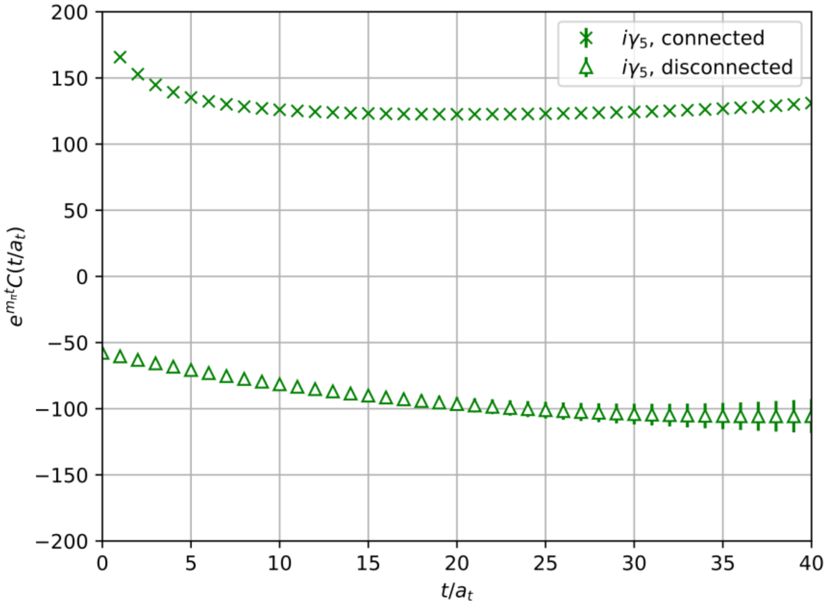
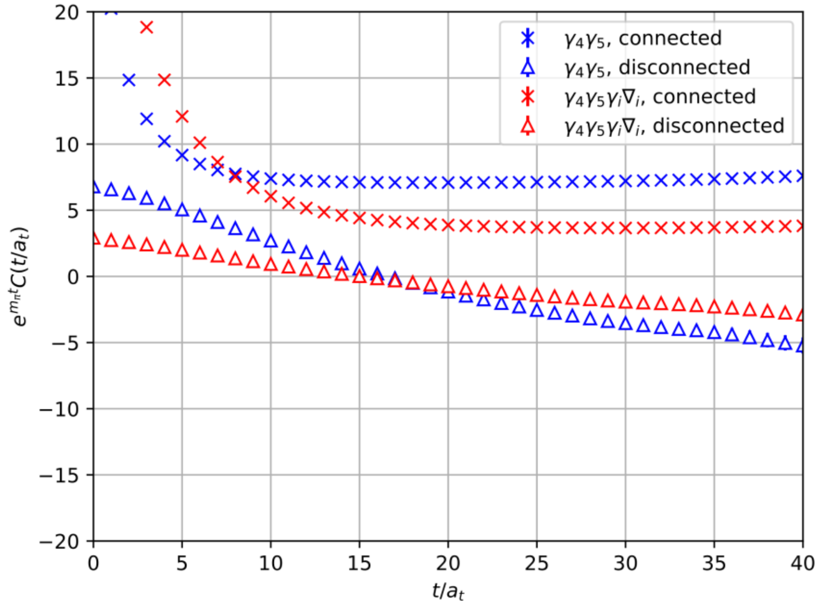
III. A. 2-point function

- Connected and disconnected part of the 2-point functions with zero momentum, multiplied by $e^{m_\pi t}$:

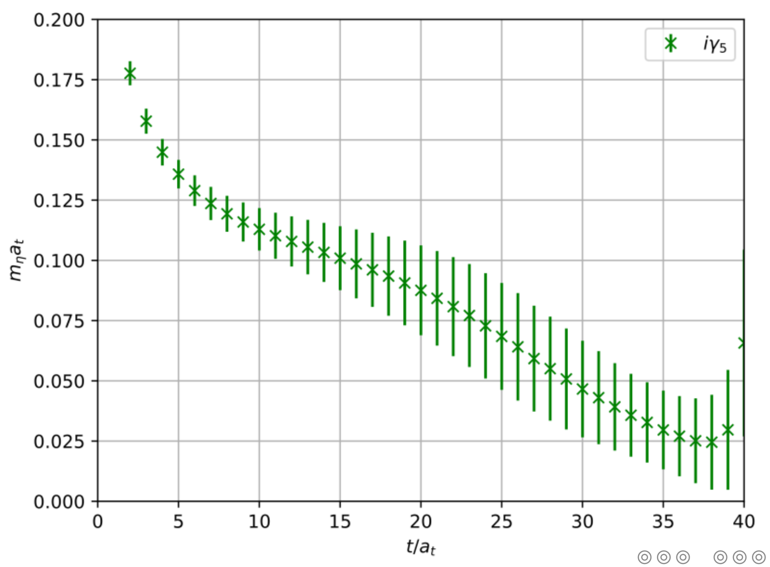


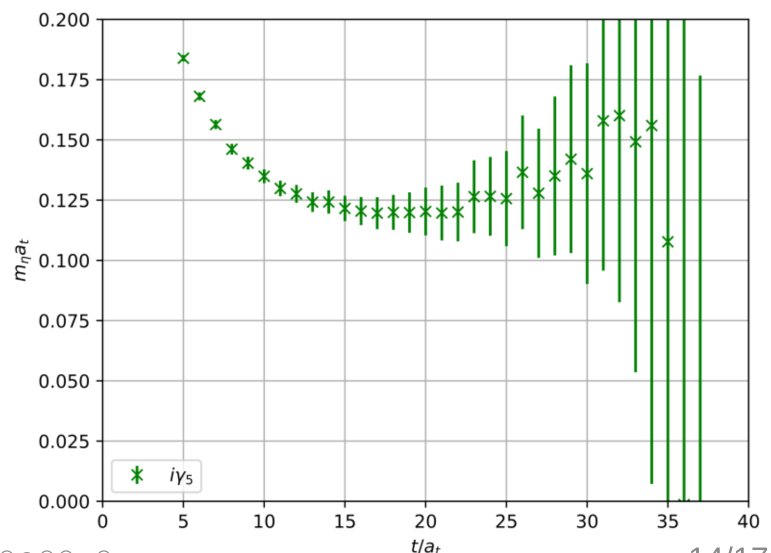


- Both connected and disconnected parts have good SNRs
- Orders of magnitude of the two parts are similar

III. B. Finite volume effect

- For $\Gamma = i\gamma_5$, the 2-point function of zero momentum has an extra constant at large t
- The constant is related to the topological charge (S. Aoki et al., PRD 76 (2007) 054508; G. Bali et al., PRD 91 (2015) 014503)
- We use $C_2(t+1) - C_2(t)$ instead of $C_2(t)$ to solve the effective mass

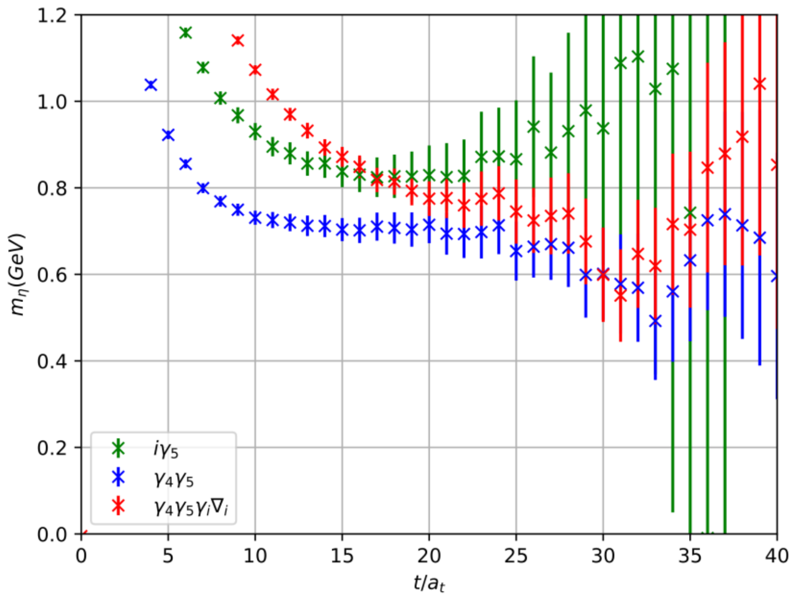




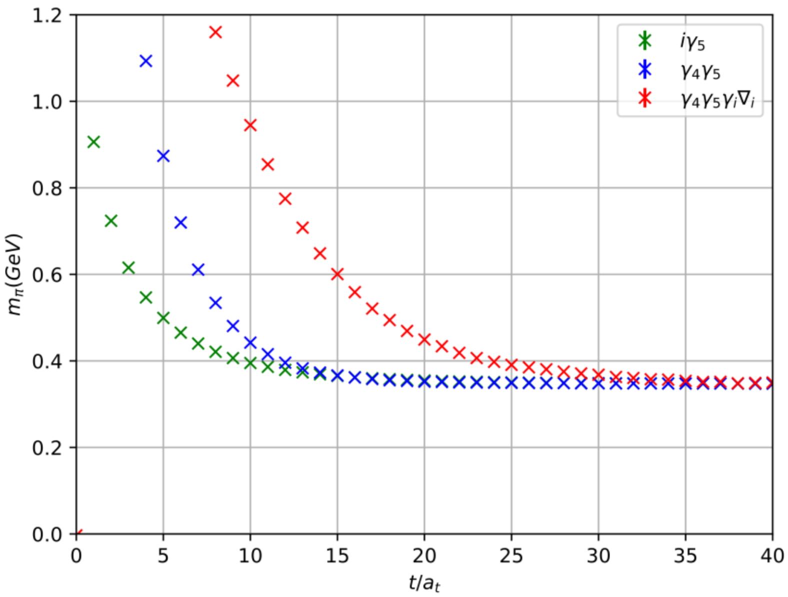
III. C. Effective mass plateaus

- For η with zero momentum, and π with zero momentum for comparison

Use $C + 2D$ as 2-point function

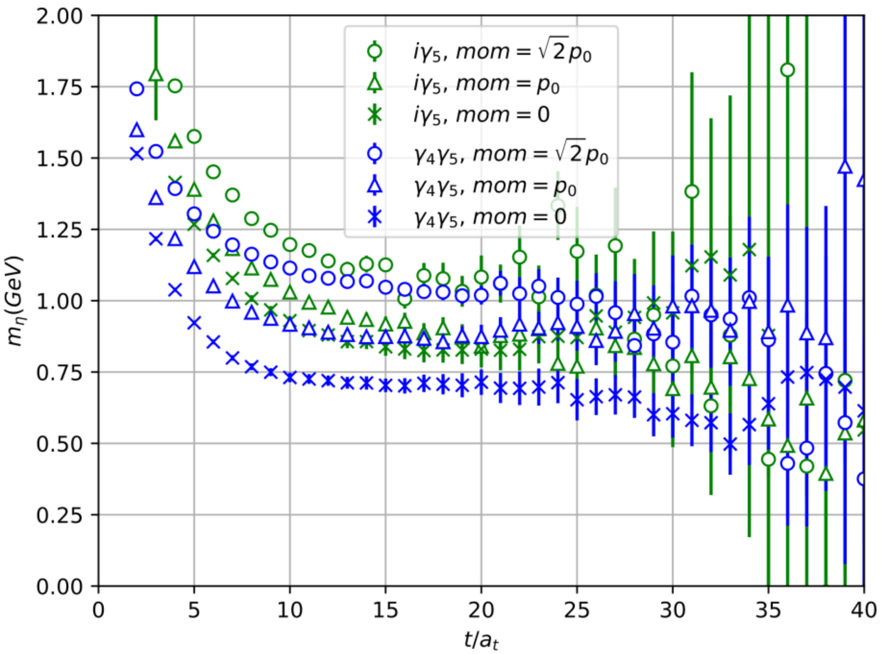


Use C as 2-point function



III. D. Non-zero momentum

- For the on-shell photon ($q^2 = \left(p_i - p_f\right)^2 = 0$) , $|\vec{q}| = \frac{m_{J/\psi}^2 - m_\pi^2}{2m_{J/\psi}}$ can be derived for center-of-mass frame, so the momentum of η should be at least $\sim 1.4\mathrm{GeV}$
- $p_0 = \frac{2\pi}{L_s a_s} \approx 511\mathrm{MeV}$, $\left|\vec{p}_\eta\right|$ should reach $\sqrt{8}p_0$
- At least we need $\vec{n}_p = (2,2,0)$
- Plateaus with momentum match!



IV. Summary

- We do get disconnected parts with good signals for different operators
- We do get a higher plateaus after we sum the two parts up, which means π in both parts canceled
- We see plateaus for η with different momentums, but need improved SNRs
- Can do variation analysis on these different operators

- In progress
  - Variation analysis will be applied on more operators
  - Solving eigensystems and calculating perambulators on ~ 5000 configurations by using chroma and primme
  - Porting the tensor contraction code to python

Appendix. A. Finite volume effect

$$\langle \rho(x)\rho(0)\rangle_Q \to \frac{1}{V_4}\left(\frac{Q^2}{V_4} - \chi_t - \frac{c_4}{2\chi_t V_4}\right) + \cdots$$

Topological charge $\rho(x) \approx \frac{C_{1pt}(x)}{\alpha a^4}$

$$\left\langle C_2^{\eta}\left(t, \vec{p} = \vec{0}\right)\right\rangle_Q \to \frac{3\alpha^2 a^5}{T}\left(\chi_t - \frac{Q^4}{V_4}\right)$$

From G. Bali et al., PRD 91 (2015) 014503

Appendix. B. Lattice spacing a_s

$q\bar{q}$	m_V (GeV)	m_{PS} (GeV)	$m_V^2 - m_{PS}^2$ (GeV^2)
$n\bar{n}$	0.775	0.140	0.581
$\bar{s}n$	0.896	0.494	0.559
$\bar{s}s$	1.020	0.686	0.570
$\bar{c}n$	2.010	1.870	0.543
$\bar{c}s$	2.112	1.968	0.588