Meson screening masses at finite temperature with Highly Improved Staggered Quarks

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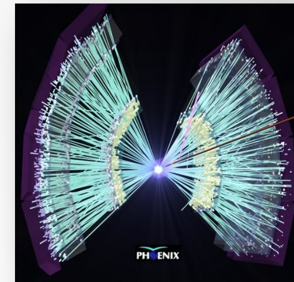
Introduction



In-medium properties of hadronic excitations in hot QCD matter

➡ Heavy-Ion Collision Experiments at RHIC and LHC

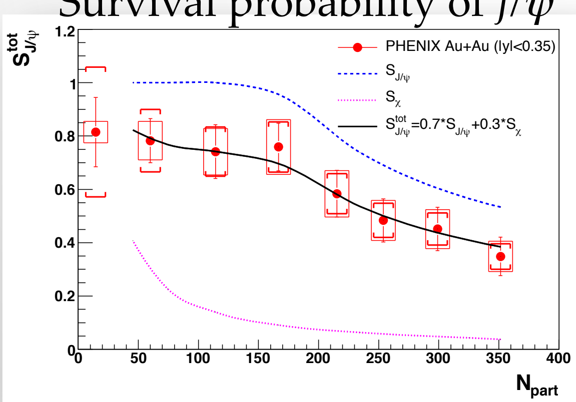
<u>Charmonium</u>

purely created after collision: direct probe in HIC experiments

e.g. dissociation of J/ψ at high temperature

➡ direct signal that Quark-Gluon plasma is created Matsui and Satz (1986)

Survival probability of J/ψ



Gunji et al. 2007

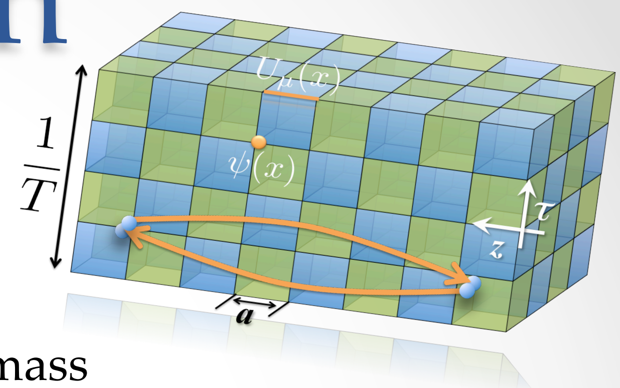
in PHENIX experiment at RHIC…

Suppression of survival probability of J/ψ

Understanding suppression of hadronic excitation in QGP

Theoretical understanding of meson thermal properties: indispensable

Introduction



Lattice QCD at finite temperature

Direct investigation of hadronic excitation: Difficult

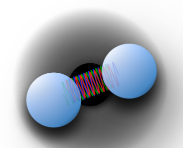
Meson correlation function to spatial direction: Screening mass

$$G(z,T) = \int dxdy \int_0^{1/T} d\tau \langle \bar{q}\Gamma q(x,y,z,\tau)\bar{q}\Gamma q(0,0,0,0)\rangle \xrightarrow{z\to\infty} Ae^{-M_\Gamma z}$$

$$\Rightarrow \quad G(z,T) = \int_0^\infty \frac{2d\omega}{\omega} \int_{-\infty}^{\infty} dp_z e^{iP_z z} \underline{\sigma(\omega, p_z, T)}$$

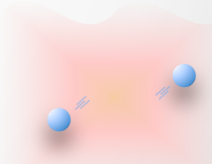
Spectral function

in thermal medium…



at $T \sim 0$, hadron structure: pole mass at $T = 0$: $M(T) \sim m_0$

at $T \sim T_c$, sensitive to quark structure: bound states broaden



at $T \to \infty$, free meson with two quark propagators

which have the lowest Matsubara mode: $M_{\text{free}} = 2\sqrt{(\pi T)^2 + m_q^2}$

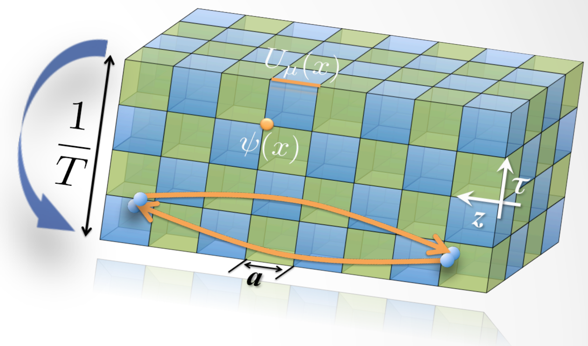
Meson screening mass at finite T

<u>Boundary Condition to temporal direction</u>:

Investigation of hadronic modification due to thermal effect

Anti-periodic BC: $q(\vec{x}, 1/T) = -q(\vec{x}, 0)$

Periodic BC: $q(\vec{x}, 1/T) = q(\vec{x}, 0)$



at low T: bosonic bound state ➡ no discrepancy

at high T: difference due to Matsubara mode

$$\Rightarrow M(T) \to \begin{cases} 2\sqrt{(\pi T)^2 + m_q^2} & \text{for APB} \\ 2m_q & \text{for PB} \end{cases}$$

probe of temporal broadening ➡ width of the spectral function

<u>Screening mass in lattice QCD simulations</u>

in p4 action for light and charm sector (2011)

➡ in this study: in HISQ action for charmonium,

open-charm and strangeness sectors

Highly Improved Staggered Quarks

HISQ action   Bazavov et al. (2011)

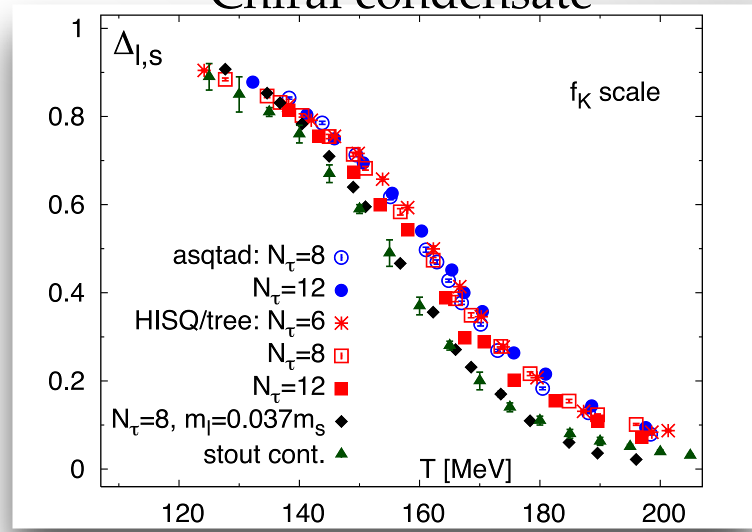
Reduction of the taste violation

Control the cutoff effects

Bulk thermal properties: investigated
Hot-QCD Coll. (2011)

abundant statistics with widely T range: utilizable

Chiral condensate



Lattice setup

2+1 flavor QCD (charm quenched)

$m_l/m_s = 0.05$ (m_π~160 MeV, m_K~504 MeV)

48^3x48 or 64 at $T = 0$

48^3x12, β = 6.664—7.280 (T = 138—245 MeV, 15 points)

N_τ=10, 8, 6, 4 at β = 7.280, N_s/N_τ=4 (T = 297—743 MeV)

scale: f_k input

meson propagators: point and wall sources (5000—10000 traj.)

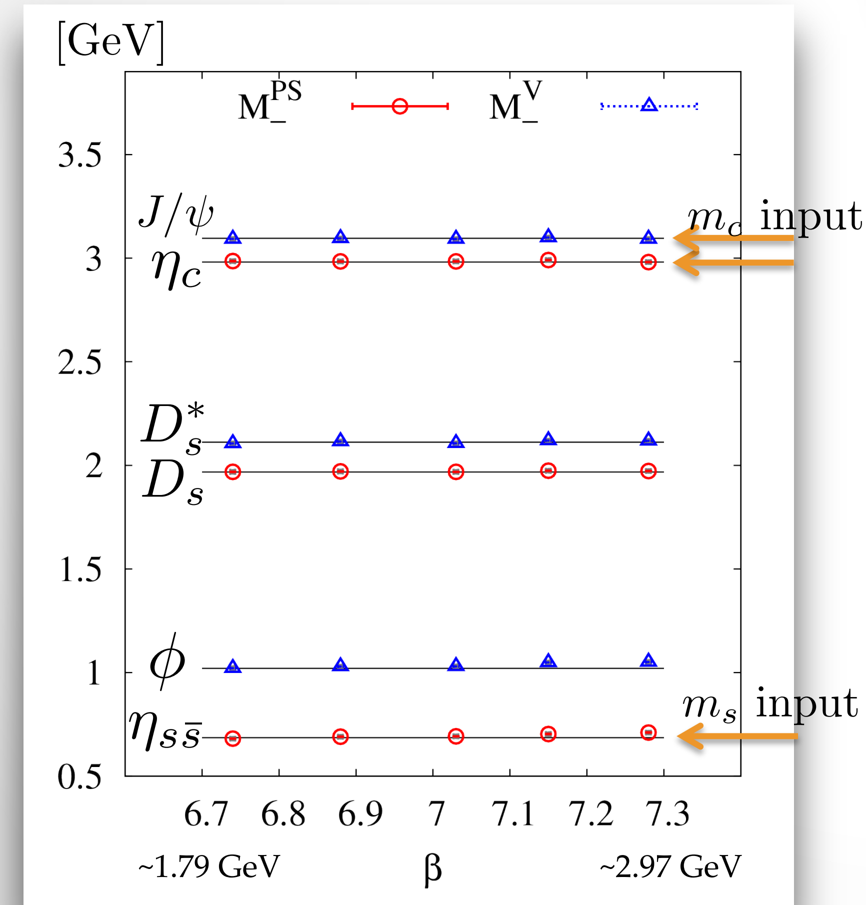
Meson spectrum at $T = 0$

Staggered meson propagators:

ground states with negative parity

$$M_{-}^{\mathrm{PS}},\ M_{-}^{\mathrm{V}}$$

	S		PS		AV		V	
Γ	$\gamma_4\gamma_5$	1	γ_5	γ_4	$\gamma_i\gamma_4$	$\gamma_i\gamma_5$	γ_i	$\gamma_j\gamma_k$
J^{PC}	0^{-+}	0^{++}	0^{-+}	0^{+-}	1^{--}	1^{++}	1^{--}	1^{+-}
$s\bar{s}$	$\eta_{s\bar{s}}$		$\eta_{s\bar{s}}$	$-$	ϕ		ϕ	
$s\bar{c}$	D_s	D_{s0}^*	D_s	D_{s0}^*	D_s^*	D_{s1}	D_s^*	D_{s1}
$c\bar{c}$	η_c	χ_{c0}	η_c	$-$	J/ψ	χ_{c1}	J/ψ	h_c



Determination of quark mass at $T = 0$

Strange-quark mass:

$$m_{\eta_{\bar{s}s}} = \sqrt{2m_K^2 - m_\pi^2}$$ Hot-QCD (2011)

Charm-quark mass:

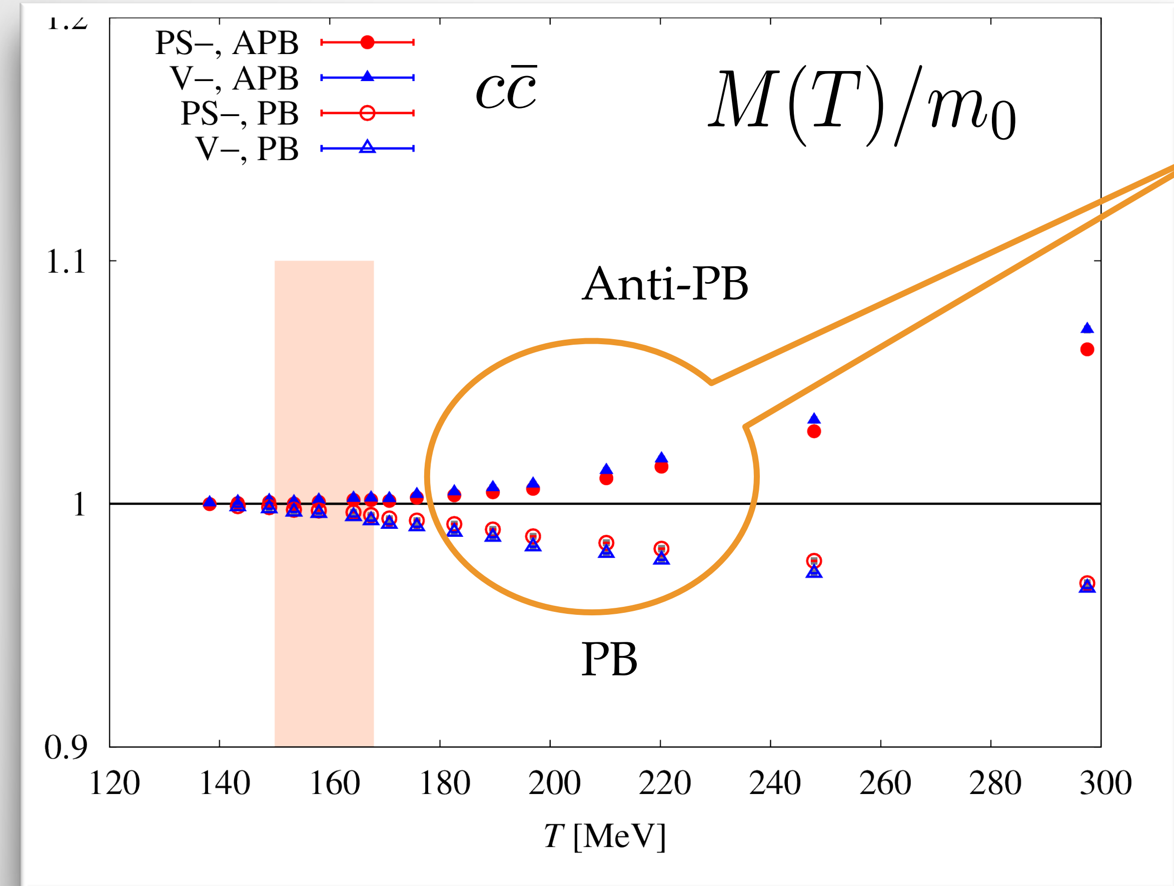
$$\frac{1}{4}m_{\eta_c} + \frac{3}{4}m_{J/\psi}$$

No significant β dependence:

➡ well improvement of the cutoff effect in HISQ action

Charmonium screening mass

Screening mass divided by pole mass at $T = 0$



at low T: $M(T)/m_0 = 1$

at T ~ 200—220 MeV:

APB: increases
PB: decreases

at high T:

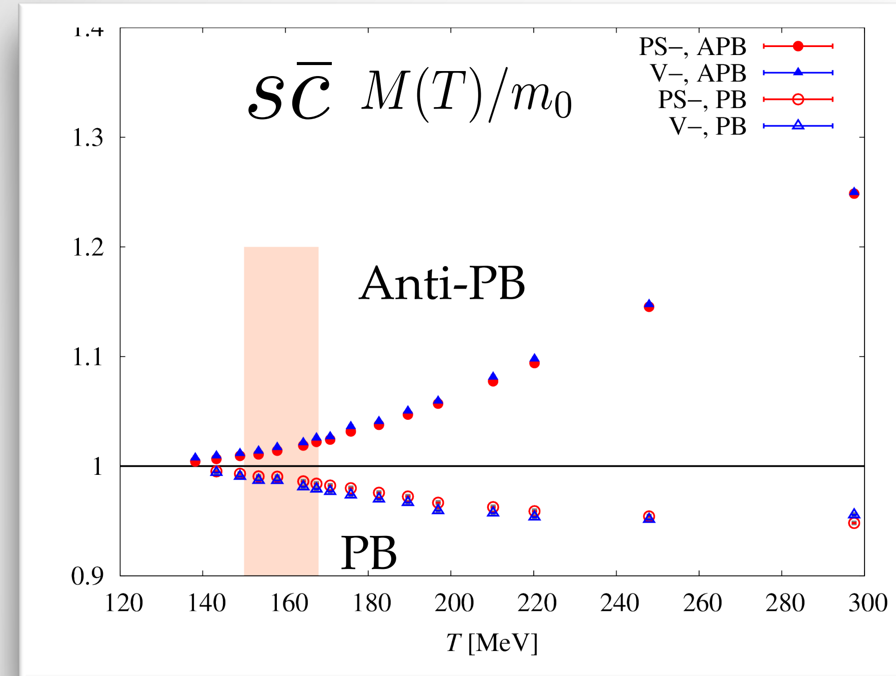
$$M^{\mathrm{APB}} \sim 2\sqrt{(\pi T)^2 + m_c^2}$$

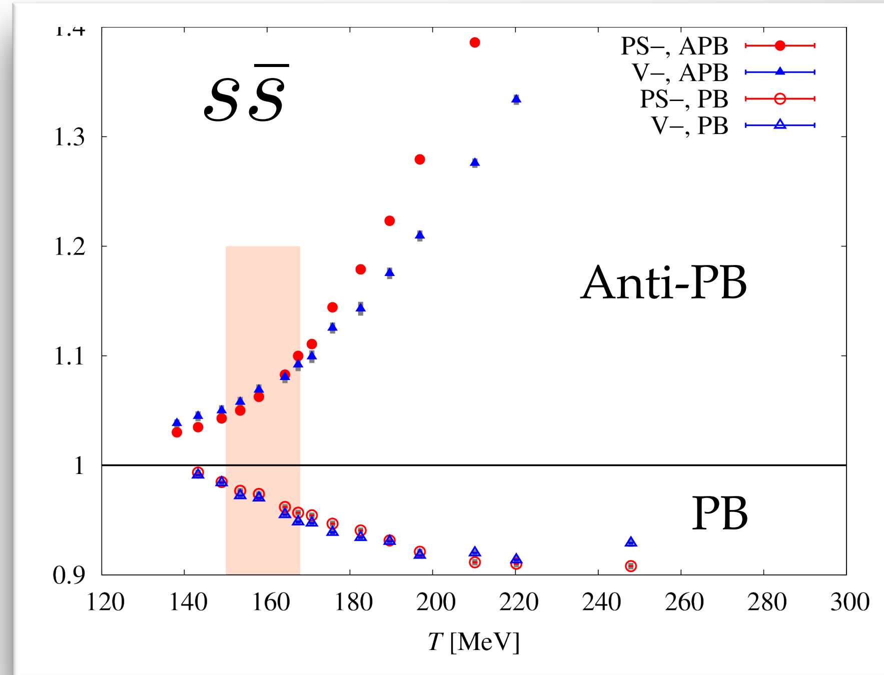
$$M^{\mathrm{PB}} \sim 2m_c$$

$\eta_c, J/\psi$ survive at $T < 1.3T_c$

and modified at $T > 1.3$—$1.4T_c$

Open-charm and strangeness





at $T \sim 160$ MeV:

discrepancy btw APB and PB

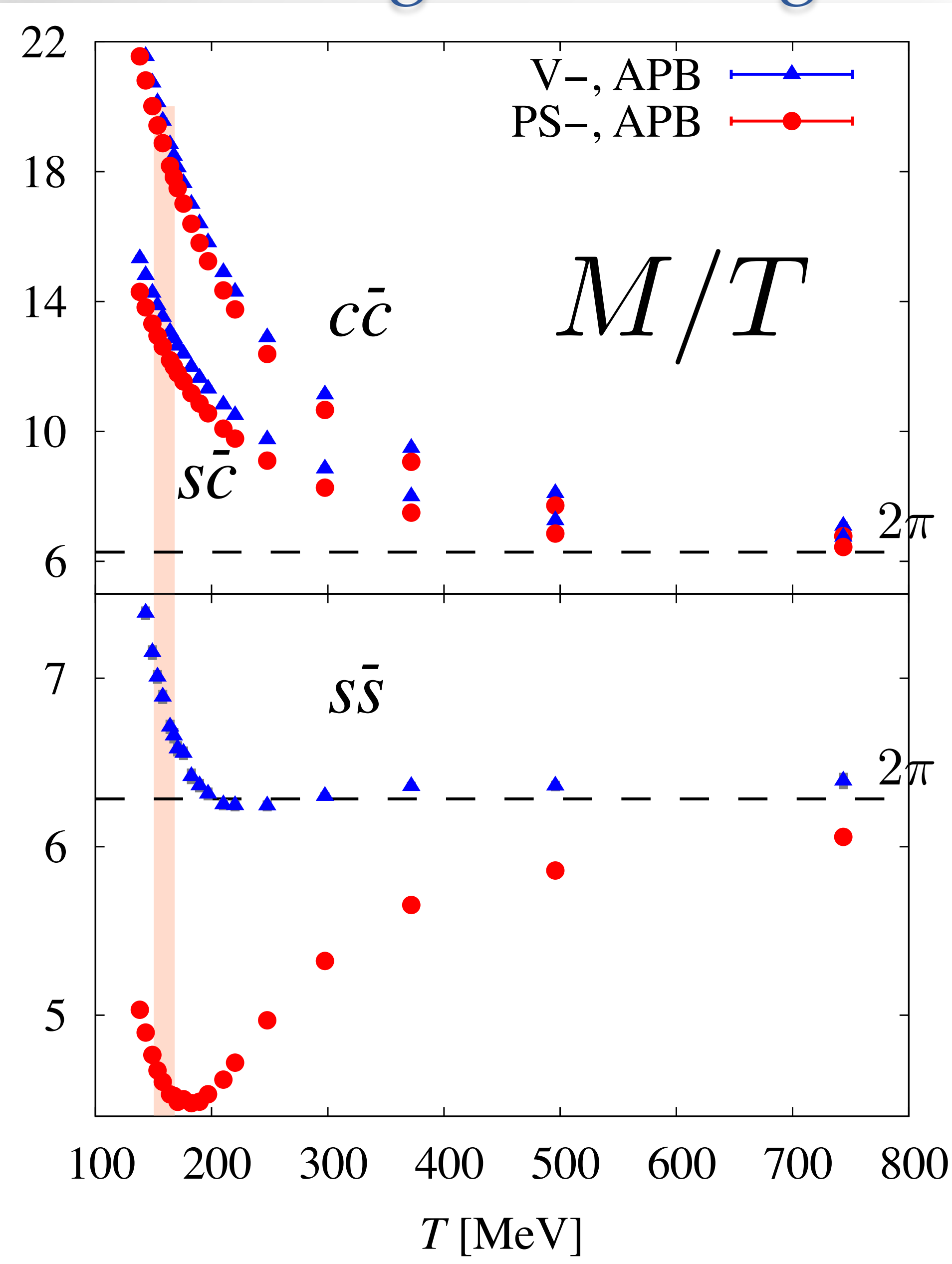
even at $T < 140$ MeV:

discrepancy btw APB and PB

➡ D_s, D_s^* modified at $T > T_c$

$(\eta_{s\bar{s}}), \; \phi$ significant modification at $T < 0.8T_c$

Screening mass at high T vs. thermal perturbation



with T increasing…

$c\bar{c}, \ s\bar{c}$

M/T decreases and converges to 2π

$s\bar{s}$

Significant T dependent slightly above T_c

Convergence to 2π

PS: from below

V: from above

- Thermal perturbation Laine et al 2004
  all channel converges and described by

$$M_{\text{weak}} = 2\pi T(1 + g^2 \times \begin{cases} 0.022(N_f = 0) \\ 0.033(N_f = 3) \end{cases})$$

on lattice: no convergence

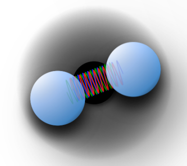
similar results in p4 (2011)

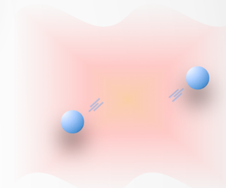
precise investigations at high T: future

Summary

Meson screening masses in Highly Improved Staggered Quarks

for charmonium, open-charm and strangeness





at low T: corresponding to pole mass at $T = 0$

at high T: convergence to $2\sqrt{(\pi T)^2 + m_q^2}$ with Anti-periodic BC

$2m_q$ with periodic BC

Modification due to thermal medium

$\eta_c, \;\; J/\psi$ survive at $T \sim 1.3\, T_c$

D_s, D_s^* modified at $T \sim T_c$

$(\eta_{s\bar{s}}), \;\; \phi$ significant modification even at $T < 0.8\, T_c$

Comparison with thermal perturbation: $s\bar{s}$ V— is similar, but PS— is not

→ no convergence: precise investigation at higher T

Buck up slides

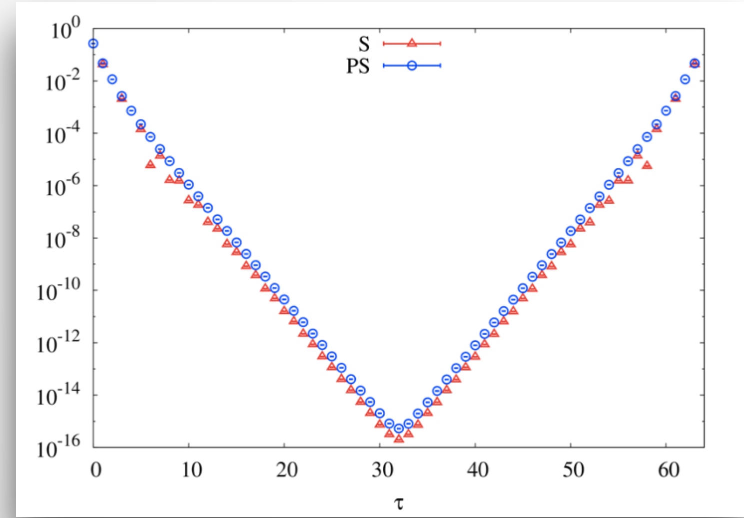
Meson correlators in staggered action

Staggered propagator: mixture of parities

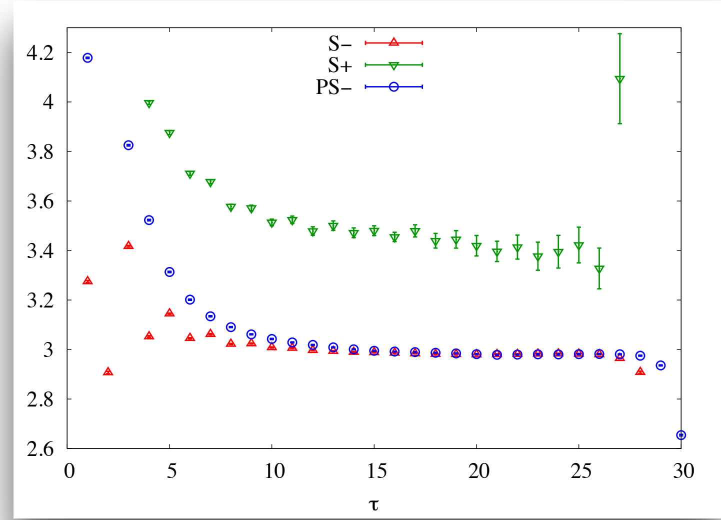
$$C(\tau) = A_{\rm NO} e^{-m_- \tau} - (-)^\tau A_{\rm O} e^{-m_+ \tau}$$

	S		PS		AV		V	
J^{PC}	0^{-+}	0^{++}	0^{-+}	0^{+-}	1^{--}	1^{++}	1^{--}	1^{+-}
$c\bar{c}$	η_c	χ_{c0}	η_c	$-$	J/ψ	χ_{c1}	J/ψ	h_c

Meson propagator



Effective masses



0^{++}

0^{-+}

$48^3 \times 64, \;\; \beta = 7.280$

Artifacts due to the staggered action: well suppressed at large distance

HISQ: well improvement for the hadronic propagators