

Charmonia in moving frames

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ABSTRACT

Lattice simulation of charmonium resonances with non-zero momentum provides additional information on the two-meson scattering matrices. However, the reduced rotational symmetry in a moving frame renders a number of states with different J^P in the same lattice irreducible representation. The identification of the J^P for these states is particularly important, since quarkonium spectra contain a number of states with different J^P in a relatively narrow energy region. Preliminary results concerning spin-identification are presented in relation to our study of charmonium resonances in flight on the $N_f=2+1$ CLS ensembles.

MOTIVATION FOR MOVING FRAMES

Experiments discovered a number of interesting and exotic hadrons in charmonium sector. Most of those appear near or above open flavor threshold. They have to be inferred from two-hadron scattering matrices. Simulation of the system with non-zero total momentum (i.e. moving frames) provides additional information on the relevant two-meson scattering matrices.

SCOPE OF STUDY

Charmonia in several moving frames are considered. In this presentation single-hadron approach is considered and only quark-antiquark operators are employed. The motivation is to identify J^P of “single-hadron” eigenstates. This will be helpful to spin-identify the narrow states when this study is extended to two-hadron scattering (see talks [2,3]).

THE CHALLENGE

The charmonium spectrum is dense (Fig.1). The purpose is to identify J^P of observed eigenstates. The reduced rotational symmetry in the moving frame renders a number of states with different J^P in the same irrep. Parity is also not a good quantum number in moving frames. The commonly used spin-identification (via degeneracies of energies from multiple irreps) may not be reliable since there are typically several charmonia with different J^{PC} in a narrow energy region. We follow a more reliable approach proposed in [1] (applied there for light mesons).

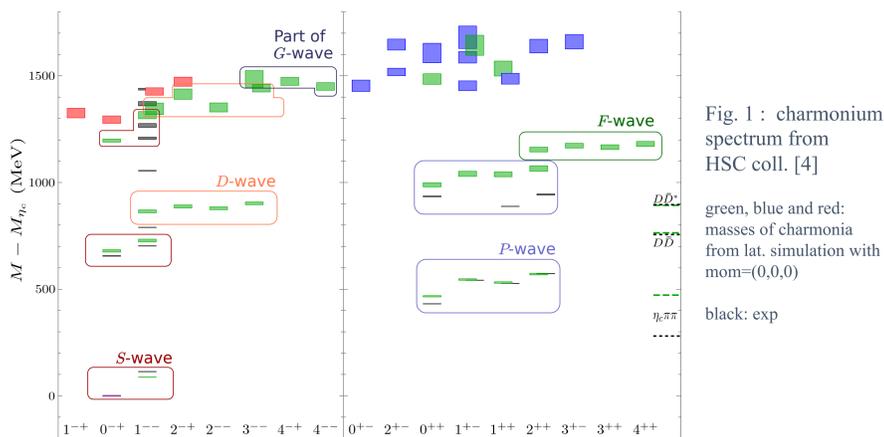


Fig. 1: charmonium spectrum from HSC coll. [4]

green, blue and red: masses of charmonia from lat. simulation with $\text{mom}=(0,0,0)$
black: exp

THE REDUCED ROTATIONAL SYMMETRY for $\text{mom}=(0,0,1)$

mom.	J^P	0^\pm	1^\pm	2^\pm	3^\pm
$(0,0,0)$	Λ^P	A_1^\pm	T_1^\pm	T_2^\pm, E^\pm	$T_{1,2}^\pm, A_2^\pm$
$(0,0,1)$	Λ	A_1	A_2	E_2	$B_{1,2}$

$\Lambda = \text{irrep.}$
 $\lambda = \text{helicity}$
 $\tilde{\eta} = P(-1)^J$

Note: spin J provides helicities $\lambda = -J, \dots, 0, \dots, +J$

B_1 and B_2 : contain $|\lambda|=2$; $J=0,1$ can not contribute; states with $J^P=2^\pm, 3^\pm$ can contribute

E_2 : contain $|\lambda|=1$; $J=0$ can not contribute; states with $J^P=1^\pm, 2^\pm, 3^\pm$ can contribute : challenging!

A_1 and A_2 : $|\lambda|=0$; all J can contribute; these irreps fortunately contain another handle $\eta=P(-1)^J$

A_1 : $|\lambda|=0, \eta=1=P(-1)^J$; states with $J^P=1^-, 3^-, 0^+, 2^+$ can contribute

A_2 : $|\lambda|=0, \eta=-1=P(-1)^J$; states with $J^P=1^+, 3^+, 0^-, 2^-$ can contribute

The additional handle for $c\bar{c}$ is C-parity. This is a good quantum num. also in moving frames.

SIMULATION

- CLS $N_f=2+1, V=24^3 \times 128, a \approx 0.085 \text{ fm}, m_\pi \approx 280 \text{ MeV}$, presently 130 conf. (“U101”)
- full distillation method with 90 eigenvectors

OPERATORS and SPIN-IDENTIFICATION

The operator construction and spin-identification follow approach of [1]

- First step: operators $O^{J,\lambda}$ with good continuum spin J and helicity λ are build from $O^{J,M}$

$$O^{J,\lambda}(\vec{p}) = \sum_M D_{M,\lambda}^{(J)*}(R) O^{J,M}(\vec{p}) \quad O^{J,M}(\vec{p}) = \sum_{m_1, m_2, \dots} CGs(m_1, m_2, m_3, \dots) \sum_{\vec{x}} e^{i\vec{p}\vec{x}} \bar{c}(\vec{x}, t) \Gamma_{m_1} D_{m_2} D_{m_3} \dots c(\vec{x}, t)$$

- Then these are subduced to irreps Λ and rows μ using subduction coefficients S from [1]. Such operators $O^{[J,\lambda]}_{\Lambda,\mu}$ were found to carry memory of continuum spin J of underlying state

$$O^{[J,\lambda]}_{\Lambda,\mu}(\vec{p}) = \sum_{\hat{\lambda}=\pm|\lambda|} S_{\Lambda,\mu}^{\hat{\eta},\hat{\lambda}} O^{J,\lambda}(\vec{p})$$

AN EXAMPLE OF PRELIMINARY RESULTS: $\text{mom}=(0,0,1), A_1$ irrep, $C=+1$

- Operators: - seven operators with continuum $J=0$: $O^{[J=0]}_{i=1,\dots,7}$
- five operators with continuum $J=2$: $O^{[J=2]}_{i=8,\dots,12}$

- States with $J^P=1^-, 3^-, 0^+, 2^+$ can contribute to A_1

- ✧ states with $J^P=1^-, 3^-$ and $C=+1$ have $m > 4.2 \text{ GeV}$ (Fig. 1)

- ✧ only states with $J^P=0^+, 2^+$ expected in region of interest $m < 4 \text{ GeV}$: verified in Figs below

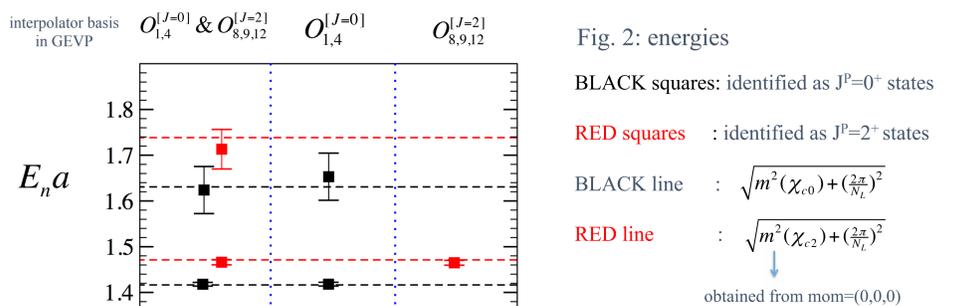


Fig. 2: energies

BLACK squares: identified as $J^P=0^+$ states

RED squares: identified as $J^P=2^+$ states

BLACK line: $\sqrt{m^2(\chi_{c0}) + (\frac{2\pi}{N_L})^2}$

RED line: $\sqrt{m^2(\chi_{c2}) + (\frac{2\pi}{N_L})^2}$

obtained from $\text{mom}=(0,0,0)$

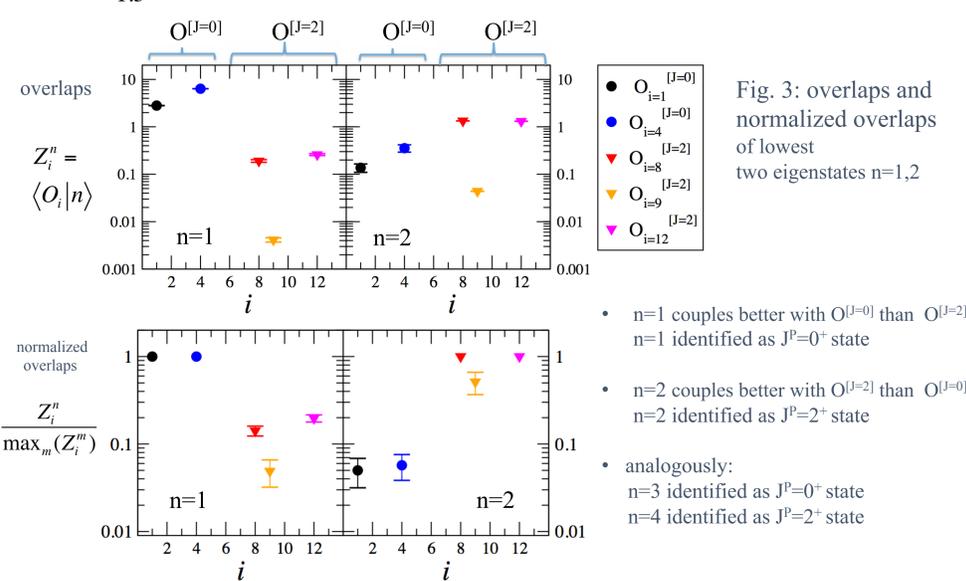


Fig. 3: overlaps and normalized overlaps of lowest two eigenstates $n=1,2$

- $n=1$ couples better with $O^{[J=0]}$ than $O^{[J=2]}$: $n=1$ identified as $J^P=0^+$ state

- $n=2$ couples better with $O^{[J=2]}$ than $O^{[J=0]}$: $n=2$ identified as $J^P=2^+$ state

- analogously: $n=3$ identified as $J^P=0^+$ state
 $n=4$ identified as $J^P=2^+$ state

CONCLUSIONS

The purpose was to identify J^P of observed charmonium eigenstates in moving frames. The applied approach successfully identified the spin-parities $J^P=0^+$ and $J^P=2^+$ of nearby charmonium states in irreducible representation A_1 for momentum $(0,0,1)$. It also worked well for other examples we considered. This will be helpful to spin-identify the narrow states when this study is extended to two-hadron scattering [2,3].

REFERENCES

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