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 chamonia with different J^{PC} in a narrow energy region. We follow a more reliable approach proposed in [1] (applied there for light mesons).

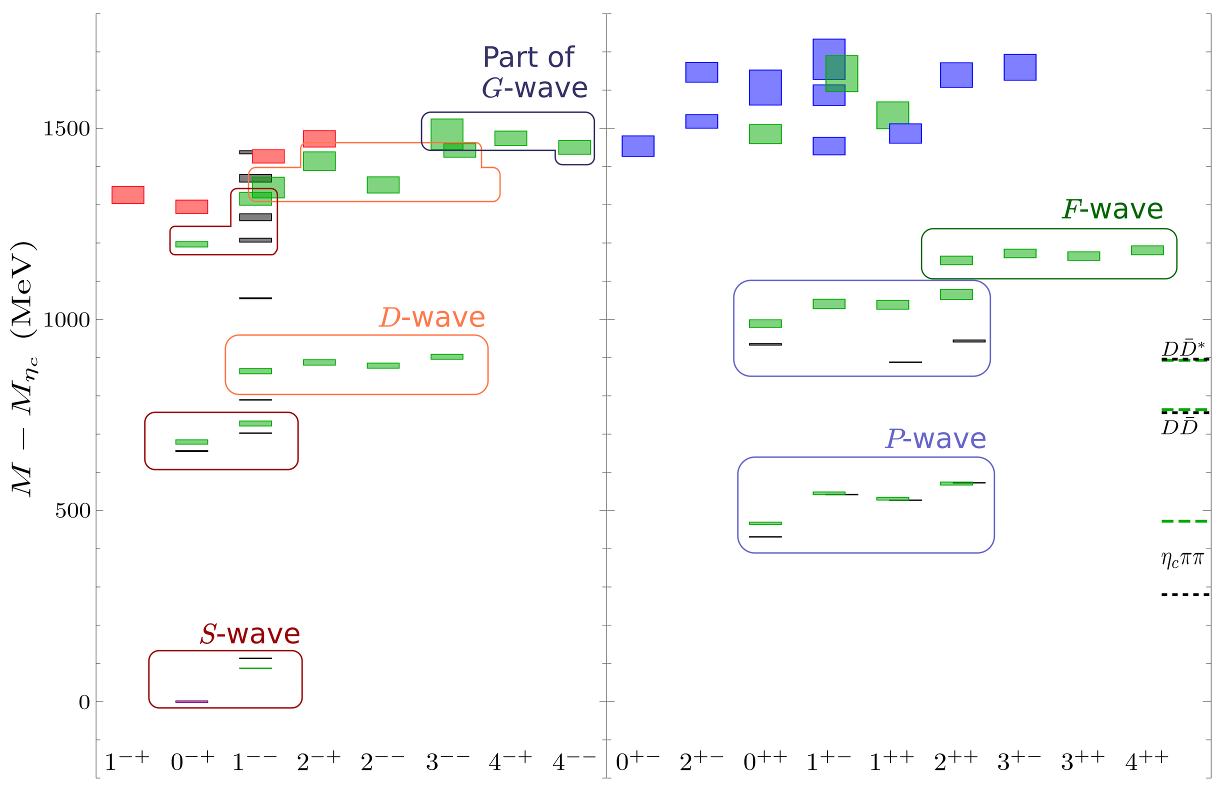

Fig. 1 : charmonium spectrum from HSC coll. [4]

green, blue and red: masses of charmonia from lat. simulation with mom=(0,0,0)

black: exp

THE REDUCED ROTATIONAL SYMMETRY for mom=(0,0,1)

mom. (0,0,0)	J^P Λ^P	$0^\pm$ $A_1^\pm$		$1^\pm$ $T_1^\pm$	$2^\pm$ $T_2^\pm, E^\pm$	$3^\pm$ $T_{1,2}^\pm, A_2^\pm$
mom. (0,0,1)	$\lvert\lambda\rvert^{\tilde\eta}$ Λ	0^+ A_1	0^- A_2	1 E_2	2 $B_{1,2}$	3 E_2

Λ = irrep.

λ=helicity

$\tilde\eta = P(-1)^J$

Note: spin J provides helicities λ= -J, ..,0,..,+J

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

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

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

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

A_2: |λ|=0, η=-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 x 128, a ≈ 0.085 fm, m_π ≈ 280 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 $O^{J,M}$

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

- 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

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

AN EXAMPLE OF PRELIMINARY RESULTS: mom=(0,0,1), A_1 irrep, C=+1

- ➢ Operators: - seven operators with continuum J=0: $O^{[J=0]}_{i=1,..,7}$
  - five operators with continuum J=2: $O^{[J=2]}_{i=8,..,12}$
- ➢ 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 GeV (Fig. 1)
- ✧ only states with $J^P=0+,2^+$ expected in region of interest m<4 GeV : verified in Figs below

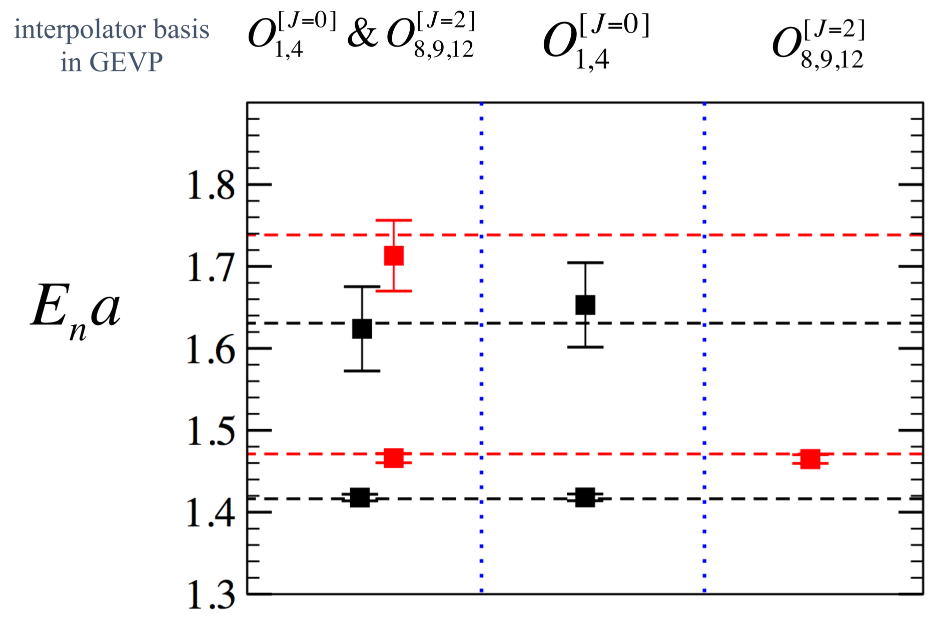

Fig. 2: energies

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 mom=(0,0,0)

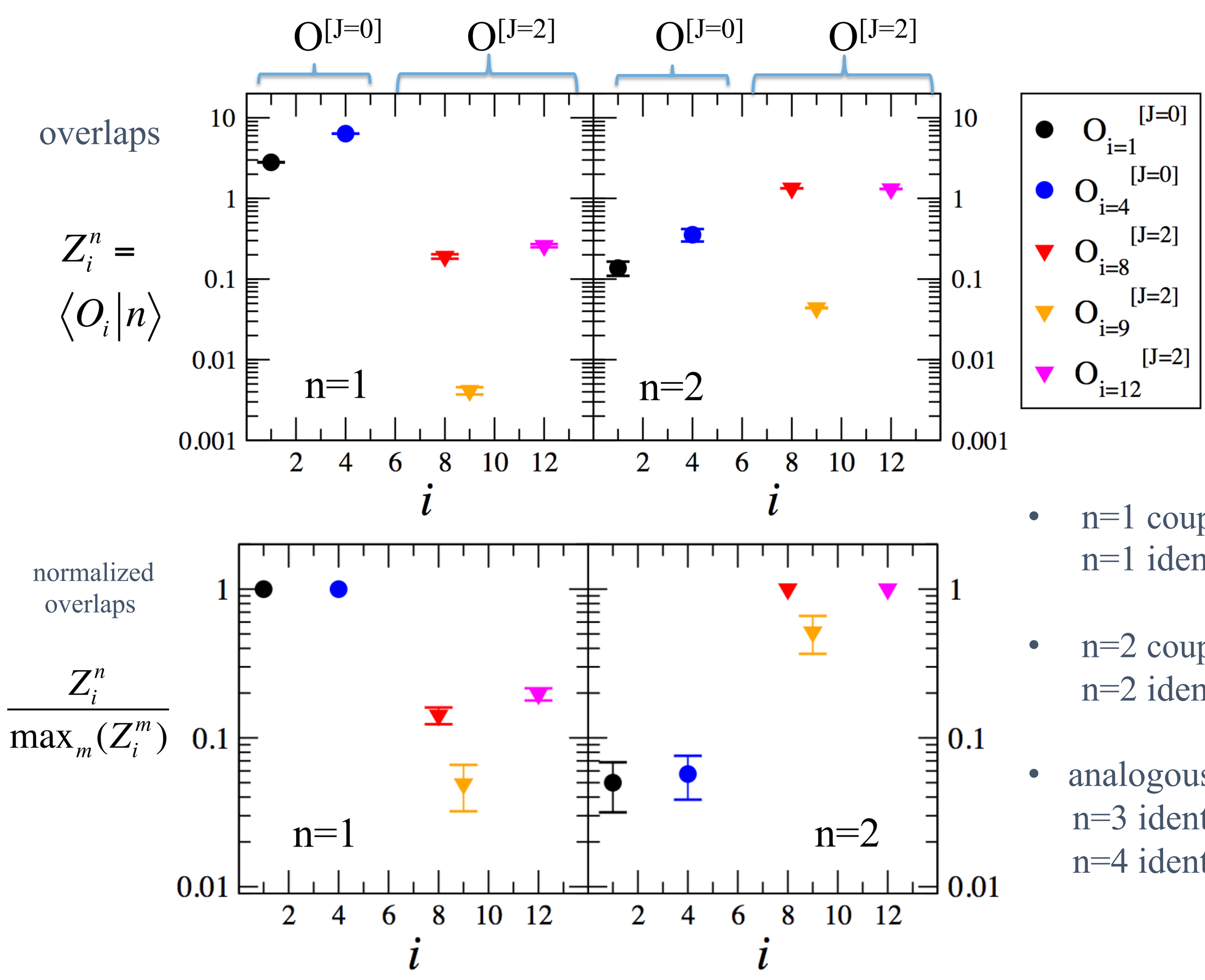

Fig. 3: overlaps and normalized overlaps of lowest two eigenstates n=1,2

- 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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