Charmonium-like states with $J^{PC} = 1^{++}$ using diquark-antidiquark operators

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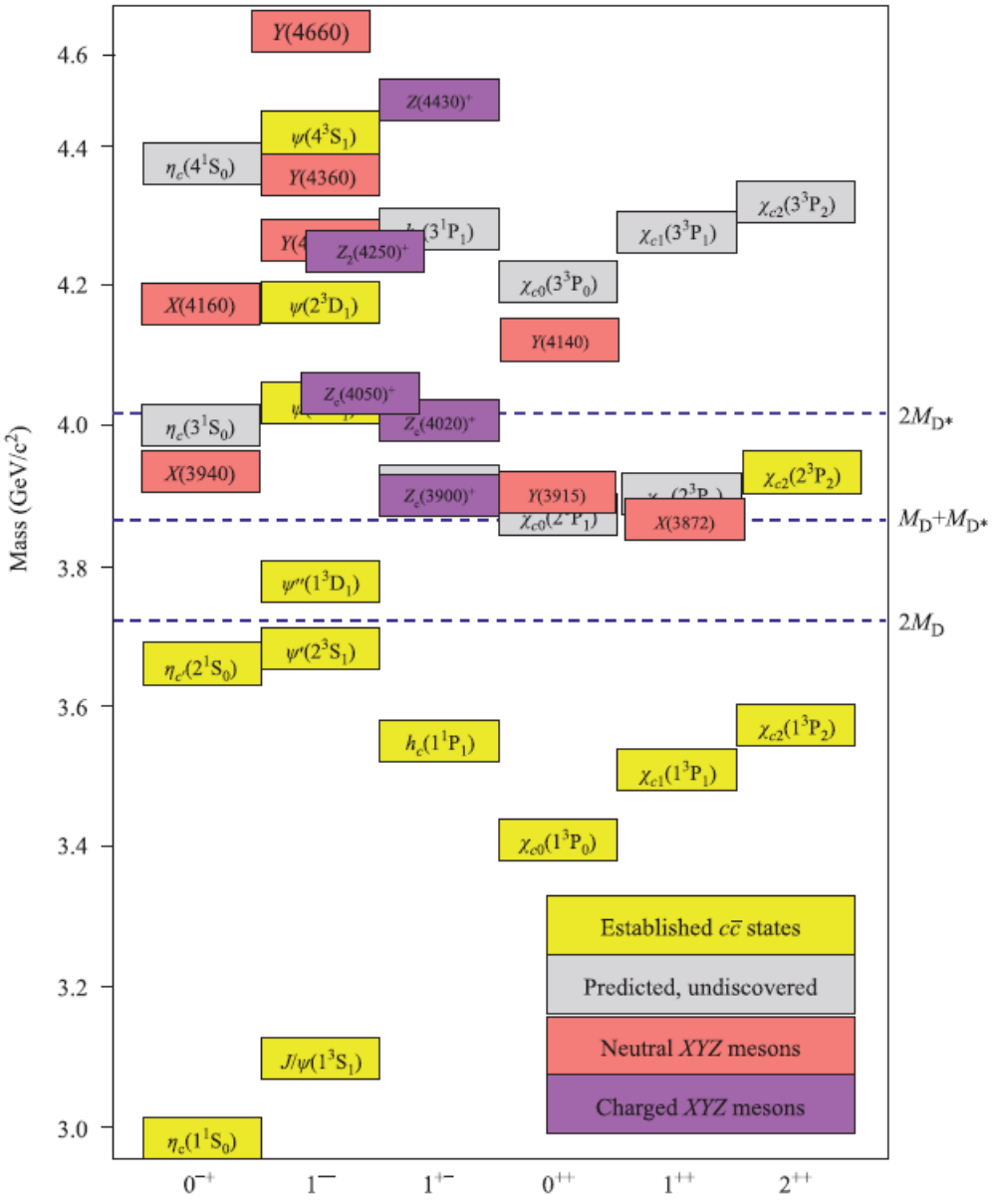
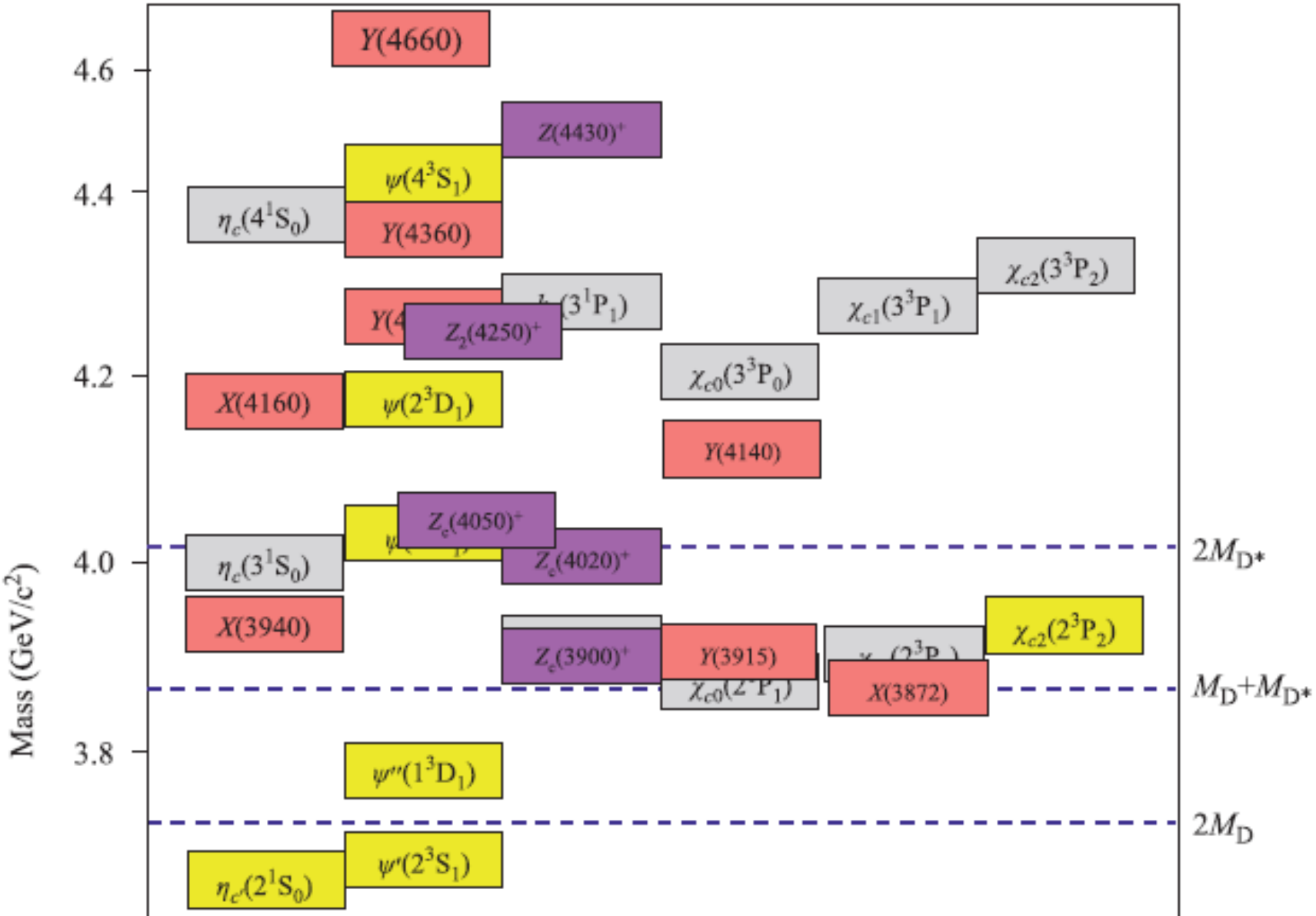
Motivation : The charmonium spectrum



Motivation : The charmonium spectrum



Lattice calculations in the past

- T-W. Chiu and T-H. Hsieh - 2008 (Phys.Lett. B646 (2007))
  quenched calculations using chiral fermions.
- G. Bali, et. al - 2011 (Phys.Rev. D84 (2011) 094506)
  Dynamical calculations with clover fermions.
- S. Prelovsek et. al. - 2013 (Phys.Rev.Lett. 111 (2013) 192001)
  First evidence from lattice for X(3872)
- S-H. Lee, et. al. (arXiv:1411.1389)
  2+1+1 HISQ lattices. Supports the measurement by S. Prelovsek, et. al.
- A long list of phenomenological calculations.

QCD spectrum from Lattice QCD

- Euclidean two point current-current correlation functions

$$C_{ji}(t_f - t_i) = \langle 0|O_j(t_f)\bar{O}_i(t_i)|0\rangle = \sum_n \frac{Z_i^{n*} Z_j^n}{2m_n} e^{-m_n(t_f - t_i)}$$

  where $O_j(t_f)$ and $\bar{O}_i(t_i)$ are the interpolators and $Z_j^n = \langle 0|O_j|n\rangle$.

- Interpolators $(O_j(t))$:

  $\bar{c}c$,
  $(\bar{c}q)_{1_c}(\bar{q}c)_{1_c}$, $(\bar{c}c)_{1_c}(\bar{q}q)_{1_c}$,
  $[\bar{c}\bar{q}]_{3_c}[cq]_{\bar{3}_c}$ and $[\bar{c}\bar{q}]_{\bar{6}_c}[cq]_{6_c}$.

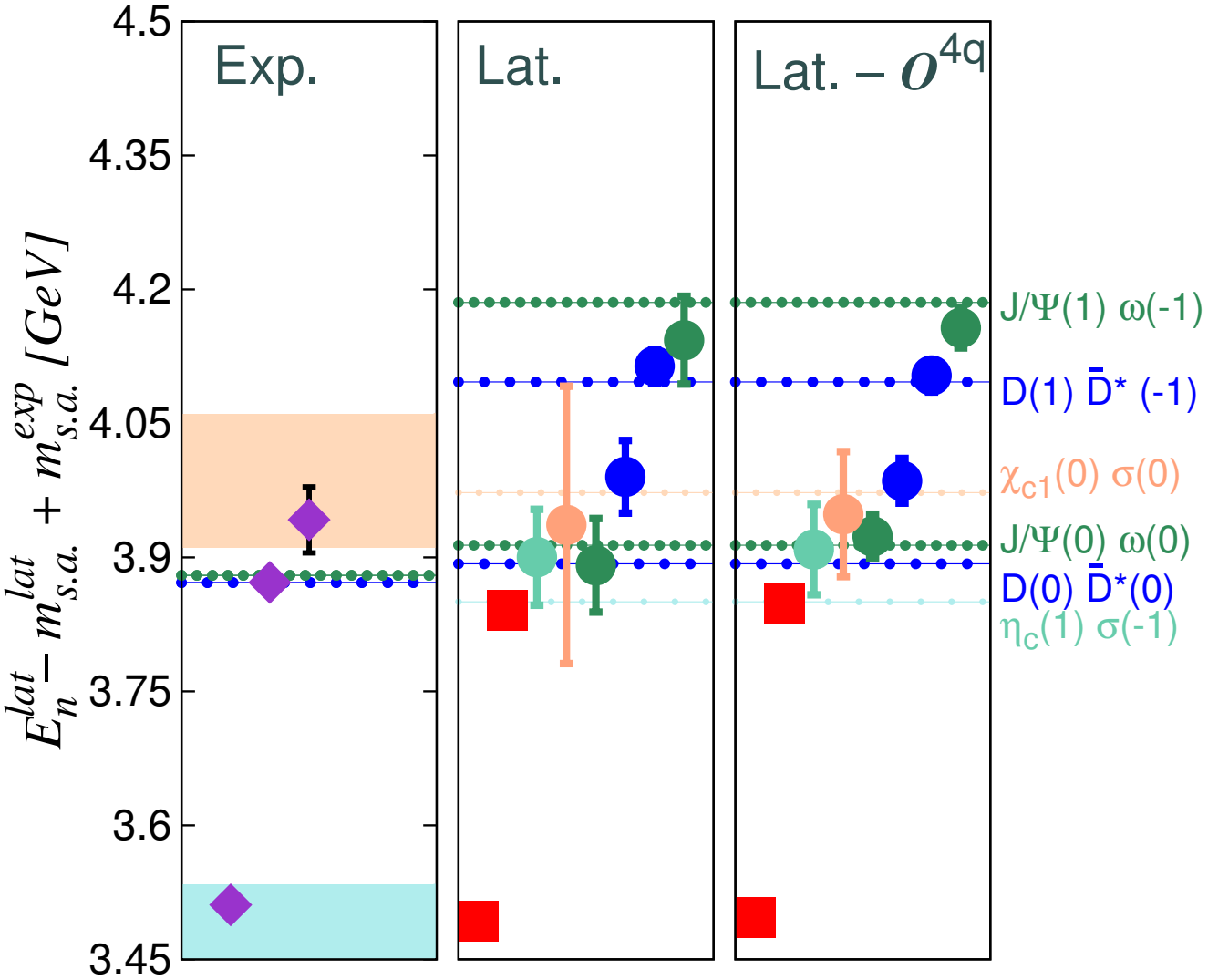
- Solve the generalized eigenvalue problem for $C_{ij}(t)$.

$$C_{ij}(t)v_j^{(n)}(t, t_0) = \lambda^{(n)}(t, t_0)C_{ij}(t_0)v_j^{(n)}(t, t_0)$$

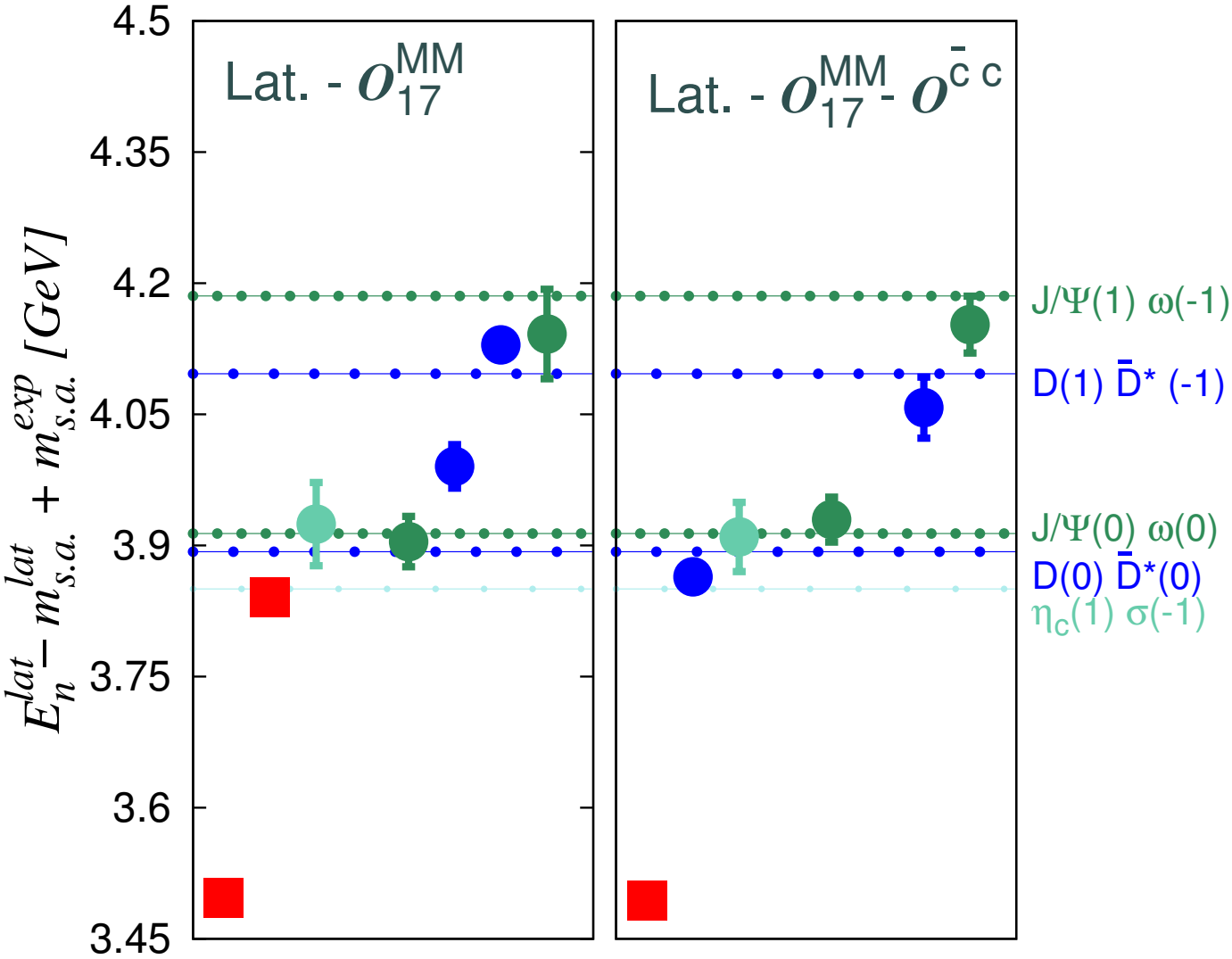
- Identification of the states based on a level counting method between spectra from different bases.

- Caution : The linear relation between interpolators by Fierz transformation.

Results : $I = 0$


Exp.
Lat.
Lat. – $\mathcal{O}^{4q}$
$E_n^{lat} - m_{s.a.}^{lat} + m_{s.a.}^{exp}$ [GeV]
4.5
4.35
4.2
4.05
3.9
3.75
3.6
3.45
J/Ψ(1) ω(-1)
D(1) D̄* (-1)
$\chi_{c1}(0)$ σ(0)
J/Ψ(0) ω(0)
D(0) D̄*(0)
$\eta_c(1)$ σ(-1)

Results : $I = 0$


Lat. - O_{17}^{MM}
Lat. - O_{17}^{MM} - $O^{\bar{c}\,c}$
$E_n^{lat} - m_{s.a.}^{lat} + m_{s.a.}^{exp}\ [GeV]$
4.5
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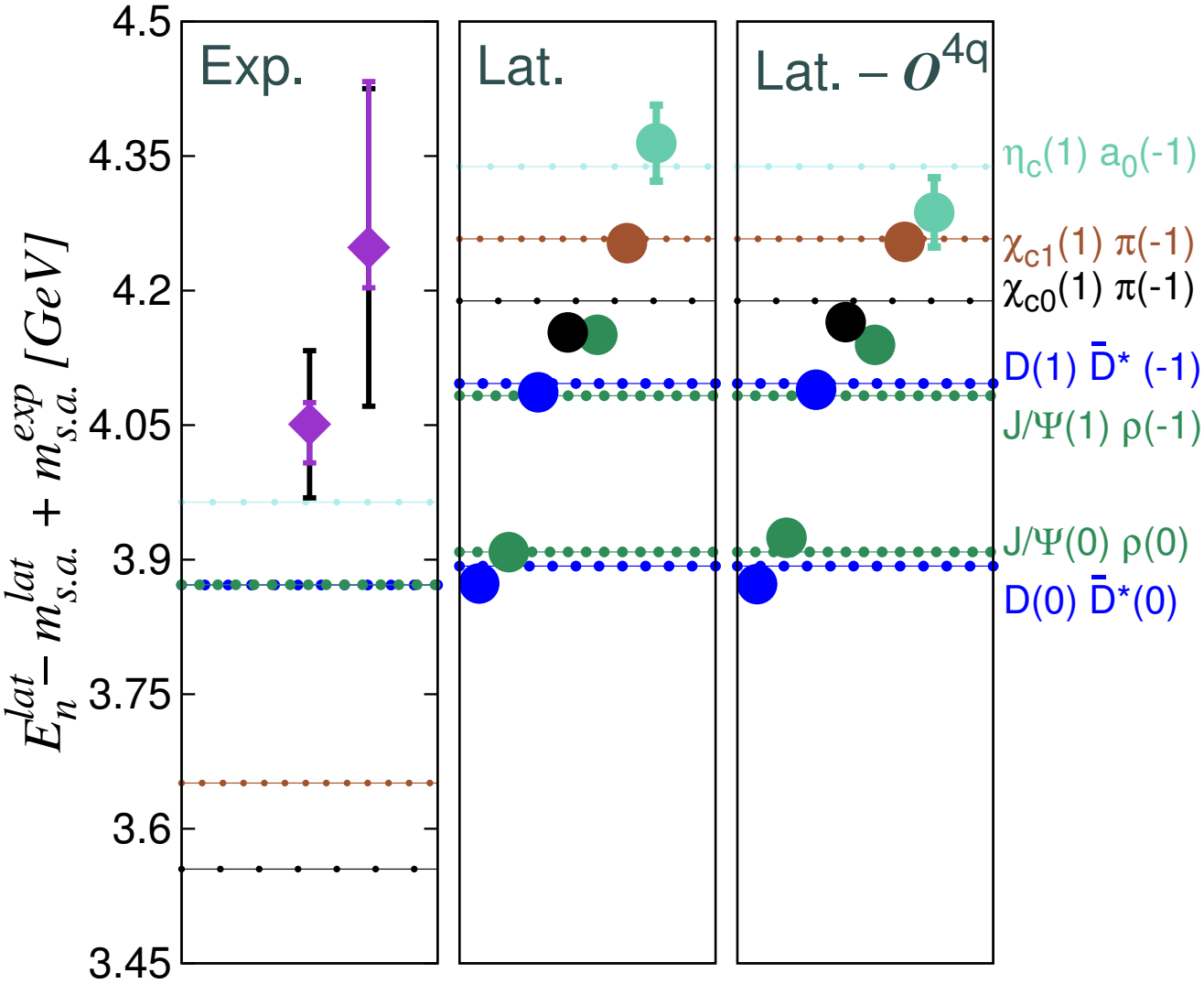
J/Ψ(1) ω(-1)
D(1) D̄* (-1)
J/Ψ(0) ω(0)
D(0) D̄*(0)
$\eta_c(1)$ σ(-1)

Results : $I = 1$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$\eta_c(1)$ $a_0(-1)$
$\chi_{c1}(1)$ $\pi(-1)$
$\chi_{c0}(1)$ $\pi(-1)$
D(1) $\bar{D}^*$ (-1)
J/Ψ(1) ρ(-1)
J/Ψ(0) ρ(0)
D(0) $\bar{D}^*(0)$

Summary

- Lattice computation of $J^{PC} = 1^{++}$ charmonium-like states.
- Main focus on a candidate for X(3872) in $I = 0$ and $I = 1$.
- Interpolators : $\bar{c}c$, $(\bar{c}q)_{1_c}(\bar{q}c)_{1_c}$, $(\bar{c}q)_{1_c}(\bar{q}q)_{1_c}$, $[\bar{c}\bar{q}]_{3_c}[cq]_{\bar{3}_c}$ and $[\bar{c}\bar{q}]_{\bar{6}_c}[cq]_{6_c}$.
- Extract spectra upto 4.3 GeV.
- Reproduce the lattice candidate for $X(3872)$.
  $[\bar{c}\bar{q}]_c[cq]_c$ observed to have no effect on the position of X(3872).
- No candidate for charge partner of X(3872) seen.