An exotic vector charmonium and its leptonic decay width

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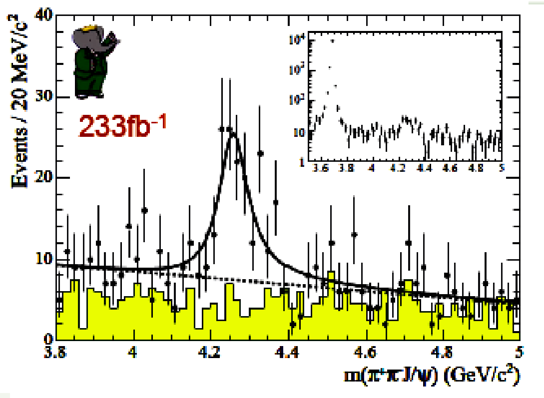
XYZ Workshop @ IHEP
Beijing, May 10, 2013

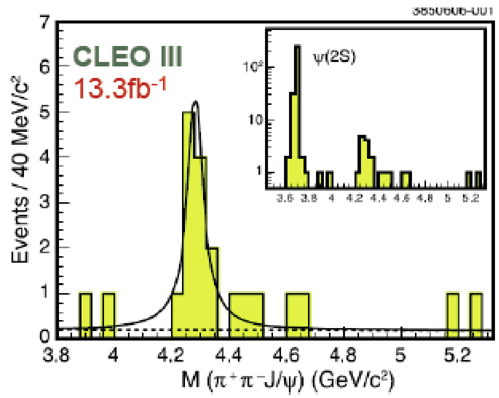
Outline

I. Experimental status of Y(4260)
II. The existence of an exotic vector charmonium in quenched LQCD
III. The leptonic decay width of this state
IV. Phenomenological implications
V. Conclusion

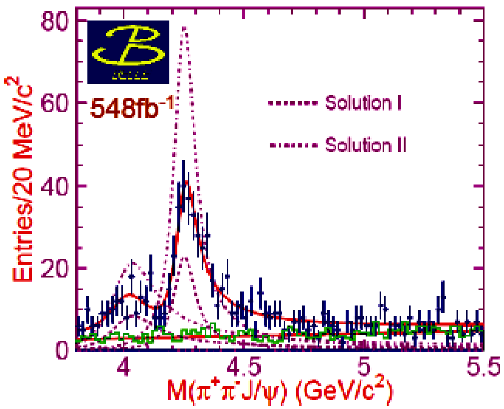
I.Experimental status of Y(4260)



BaBar,PRL95,142001(05)



CLEO-III,PRD74,
091104(R)(2006)



Belle,PRL99,182004(07)

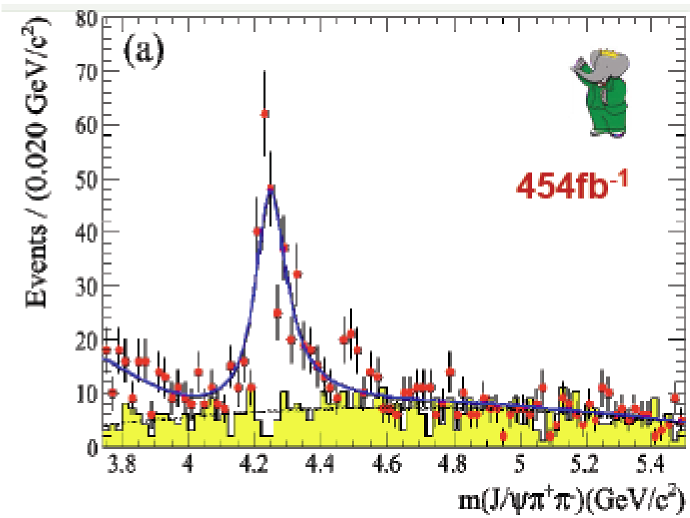
1. Observed in the initial state radiation process

$$e^+e^- \to \gamma_{ISR} X$$
$$X \to J/\psi\pi^+\pi^-$$
$$J/\psi \to l^+l^-$$

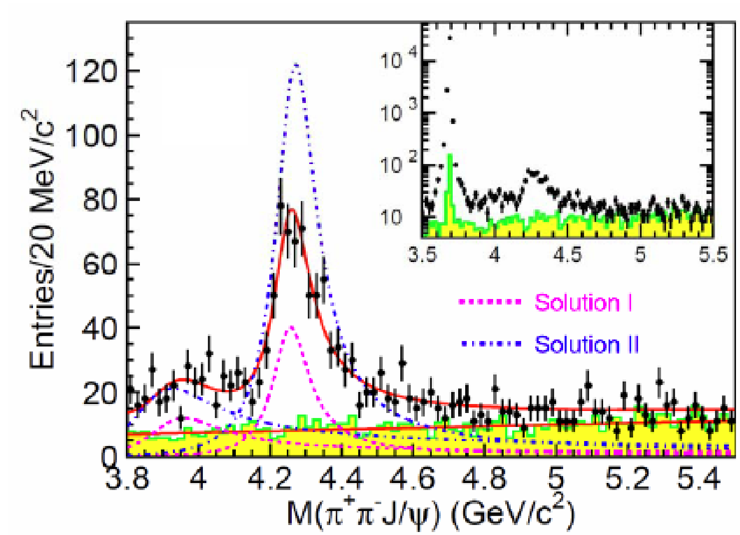
2. The resonance parameter (PDG2012)

$$M_X = 4263(8) MeV$$
$$\Gamma_X = 95(14) MeV$$

3. Update ISR $\pi^+\pi^- J/\psi$ analysis from BABAR and Belle

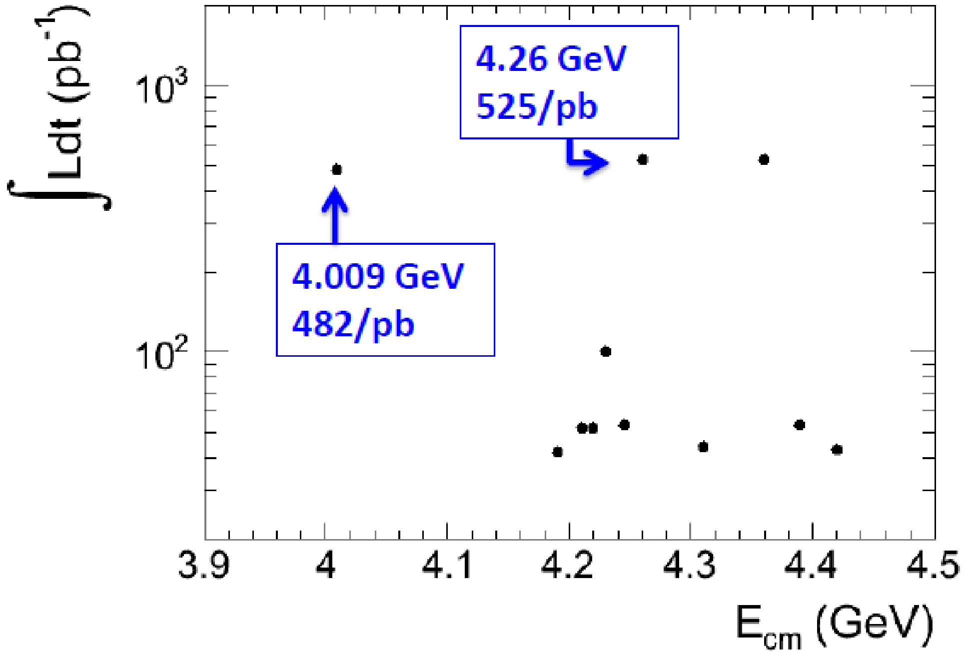


BaBar,PRD86(R),051102(2012)



Belle, QWG2013 talk

XYZ programs at BESIII

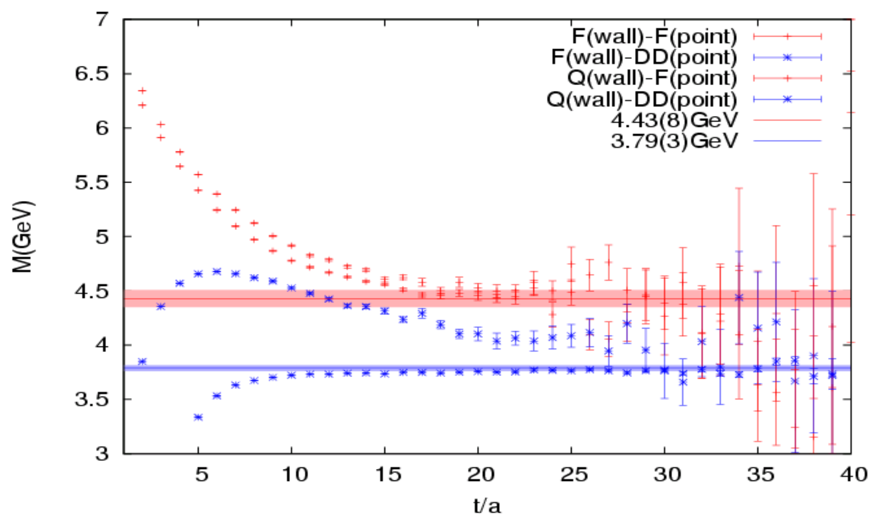


- More in the future
- 2/fb near Y(4260) peak by this June!
- 2/fb on ψ(4160)
- Scan over 3.8 – 4.6 GeV
- …

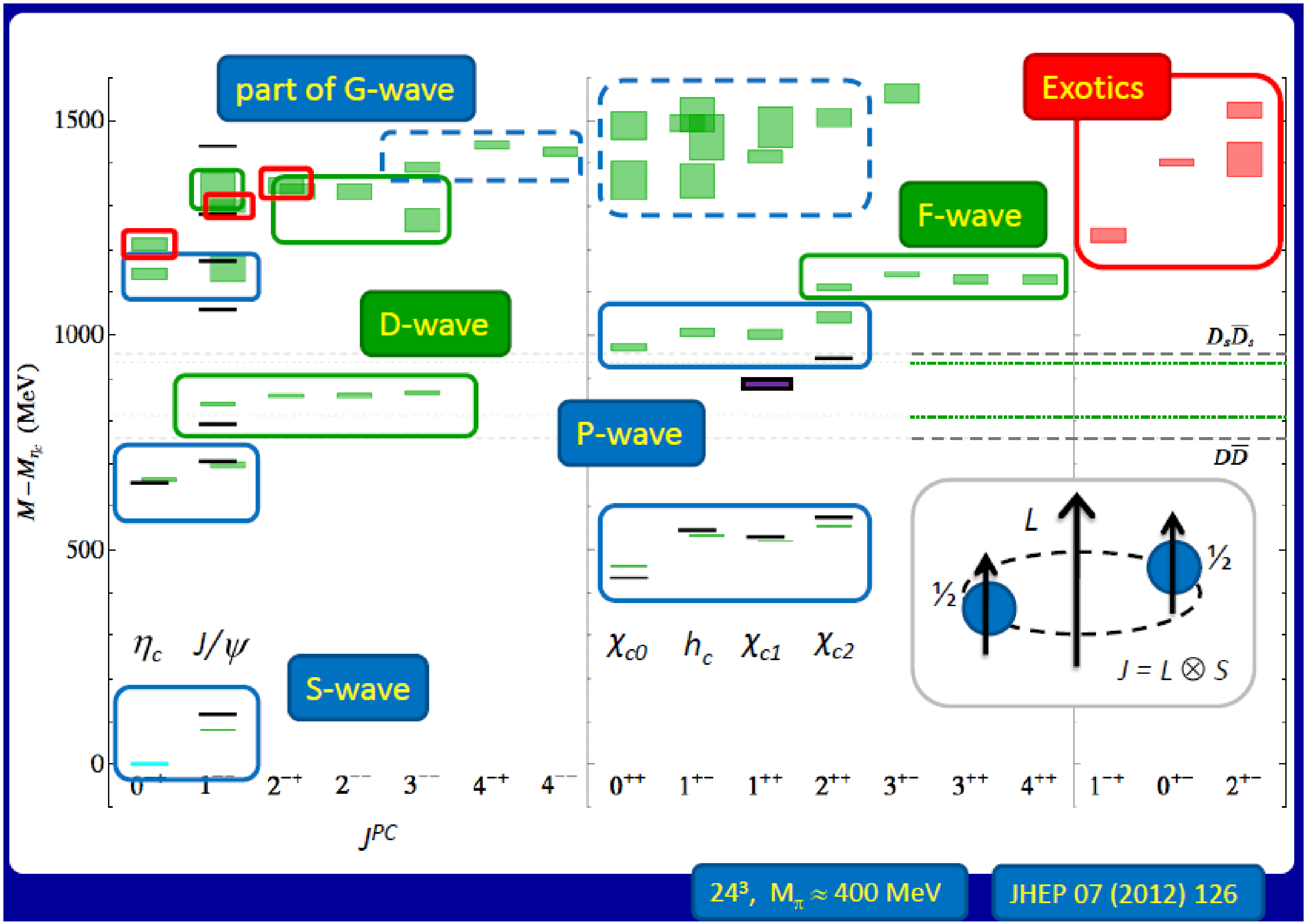
Energy	Luminosity (pb^{-1})
E_{cm}=4.009 GeV	482
E_{cm}=4.26 GeV	525

II. The existence of an exotic vector charmonium in the quenched LQCD

- 1-+ is an exotic quantum number in quark model.
- The mass of 1-+ hybrid charmonium was predicted to be 4.1~4.3 GeV from lattice QCD study.
- In 2-+ channel, we found a hybrid-like interpolation field operator couples most to a higher state with a mass 4.43(8) GeV, rather than the conventional 2-+ charmonium eta_c2, whose mass is predicted to be 3.80(3) GeV.



Latest charmonium spectrum from lattice QCD



1 1^{--} hybrid-like interpolation field operator

$$\overline{\psi}^{a}\gamma_5\psi^{b}B_i^{ab}$$

Nonrelativistic decomposition

$$q = e^{\frac{\gamma\cdot D}{2m}}\begin{pmatrix}\psi\\ \chi\end{pmatrix} = \left[1+\frac{\gamma\cdot D}{2m}+\frac{\gamma\cdot\vec{D}\,\gamma\cdot D}{8m^2}O(1/m^3)\right]\begin{pmatrix}\psi\\ \chi\end{pmatrix}$$
$$= \begin{pmatrix}\psi\\ \chi\end{pmatrix}+\frac{i}{2m}\begin{pmatrix}-\sigma\cdot\vec{D}\chi\\ \sigma\cdot\vec{D}\psi\end{pmatrix}+\frac{(\vec{D}^2+\sigma\cdot B)}{8m^2}\begin{pmatrix}\psi\\ \chi\end{pmatrix}+O(1/m^3),$$
$$\bar{q} = \begin{pmatrix}\psi^\dagger & -\chi^\dagger\end{pmatrix}e^{-\frac{\gamma\cdot\overleftarrow{D}}{2m}} = \begin{pmatrix}\psi^\dagger & -\chi^\dagger\end{pmatrix}+\frac{i}{2m}\begin{pmatrix}\chi^\dagger\sigma\cdot\overleftarrow{D}^\dagger & \psi^\dagger\sigma\cdot\overleftarrow{D}^\dagger\end{pmatrix}$$
$$+\frac{(\overleftarrow{D}^2+\sigma\cdot B)}{8m^2}\begin{pmatrix}\psi^\dagger & -\chi^\dagger\end{pmatrix}+O(1/m^3),$$

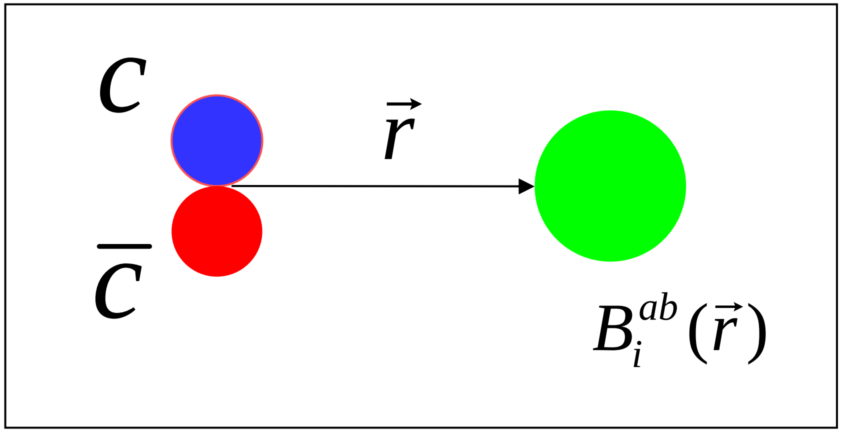
0^{-+}	$\overline{\psi}\gamma_5\psi$	$\chi^{+}\varphi$
1^{--}	$\overline{\psi}\gamma_i\psi$	$\chi^{+}\sigma_i\varphi$
$1^{--}{}_H$	$\overline{\psi}^{a}\gamma_5\psi^{b}B_i^{ab}$	$\chi^{a+}\varphi^{b}B_i^{ab}$

$$O_i^{(H)} \equiv \bar{c}^a\gamma_5 c^b B_i^{ab} \to \chi^{a\dagger}\phi^b B_i^{ab} + O(\frac{1}{m_c}),$$ → **c-cbar spin singlet**

$$O_i^{(M)} \equiv \bar{c}^a\gamma_i c^a \to \chi^{a\dagger}\sigma_i\phi^a + O(\frac{1}{m_c}).$$ → **c-cbar spin triplet**

2. Spatially extended interpolation field operator for the vector charmonium-like state

In the Coulomb gauge, $$O(\vec{r}) = (\bar{c}^{a}\gamma_5 c^{b})(0)B_i^{ab}(\vec{r})$$



This is equivalent to giave a c-cbar center of mass motion, which describes the recoil of the c-cbar against additional degrees of freedom.

Intuitively, the coupling of this kind of operators to conventional vector charmonia can be suppressed from two aspects:

a) spin states of the c-cbar (spin flipping is suppressed by the heavy quark mass.

b) center-of-mass motion (to the leading order of NR, there is no cneter-of-mass motions for conventional charmonia.)

3. The two-point functions calculated on the lattice

We introduce the following wall-source operator

$$O_i^{(W)}(\tau) = \sum_{\mathbf{y},\mathbf{z}} \bar{c}^a(\mathbf{y},\tau)\gamma_5 B_i^{ab}(\mathbf{z},\tau)c^b(\mathbf{z},\tau).$$

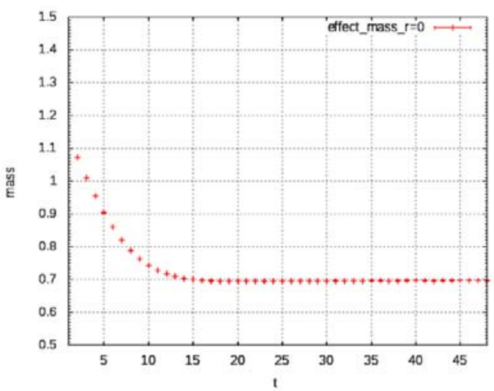
and calculate the following two-point functions

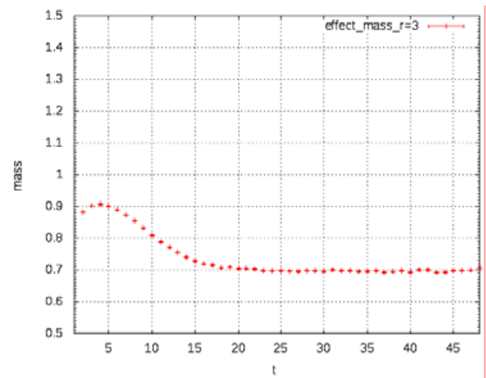
$$C(r,t) = \left\langle O(\vec{r},t) O^{(w)^+}(0) \right\rangle = \sum_i W_i(r) e^{-m_i t}$$

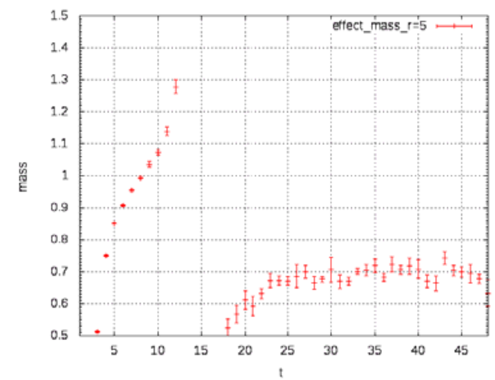
where Wi(r) is the spectral weight of the i-th state, which varies with respect to r, and thereafter can be interpreted as the Coulomb BS wave function versus the distance between the c-cbar and B field.

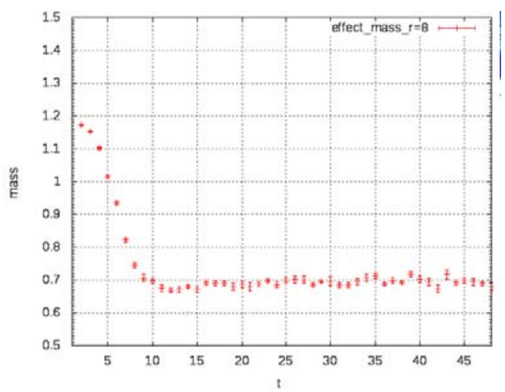
Effective mass plots for different r

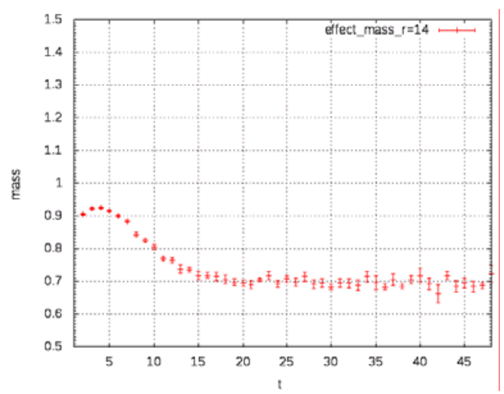
$$m_{eff}(r,t) = \ln \frac{C(r,t)}{C(r,t+1)}$$

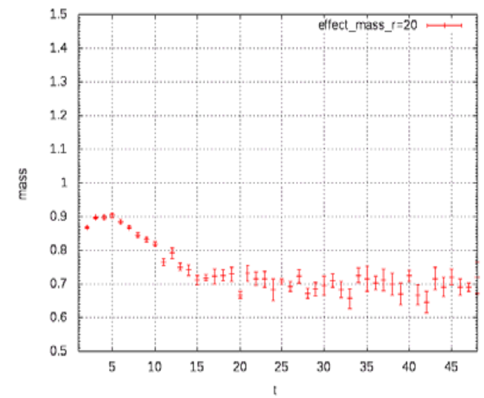








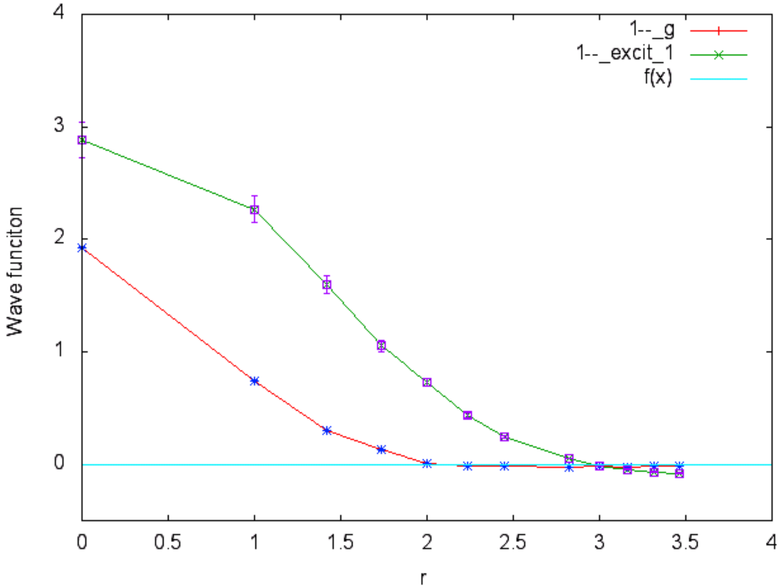




The two-point functions with different r can be fit jointly with the same spectrum.

$$C(r,t)=\left\langle O(\vec{r},t)O^{(w)+}(0)\right\rangle=\sum_i W_i(r)e^{-m_i t}$$

2-mass term fit

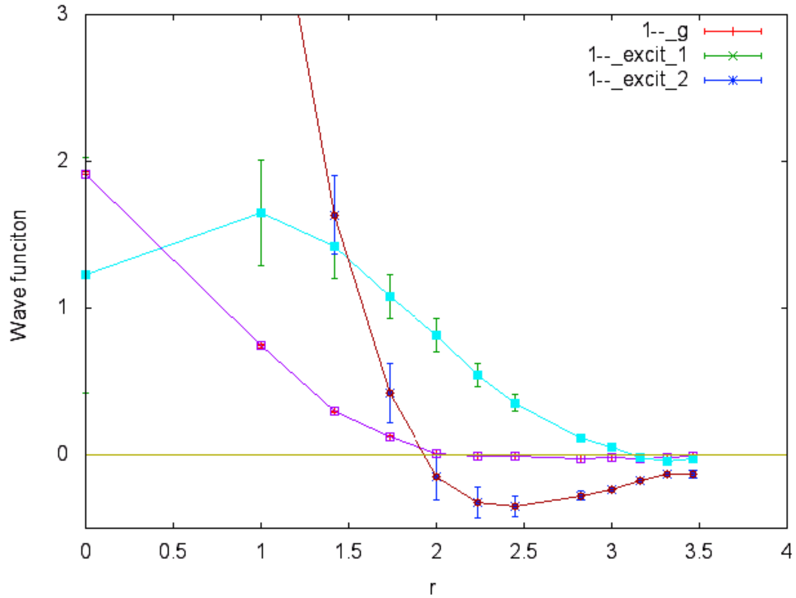


$$m_1=3.076(4)GeV$$

$$m_2=4.275(18)GeV$$

X(4260)???

3-mass term fit



$$m_1=3.072(9)GeV$$

$$m_2=4.311(44)GeV$$

$$m_3=4.932(88)GeV$$

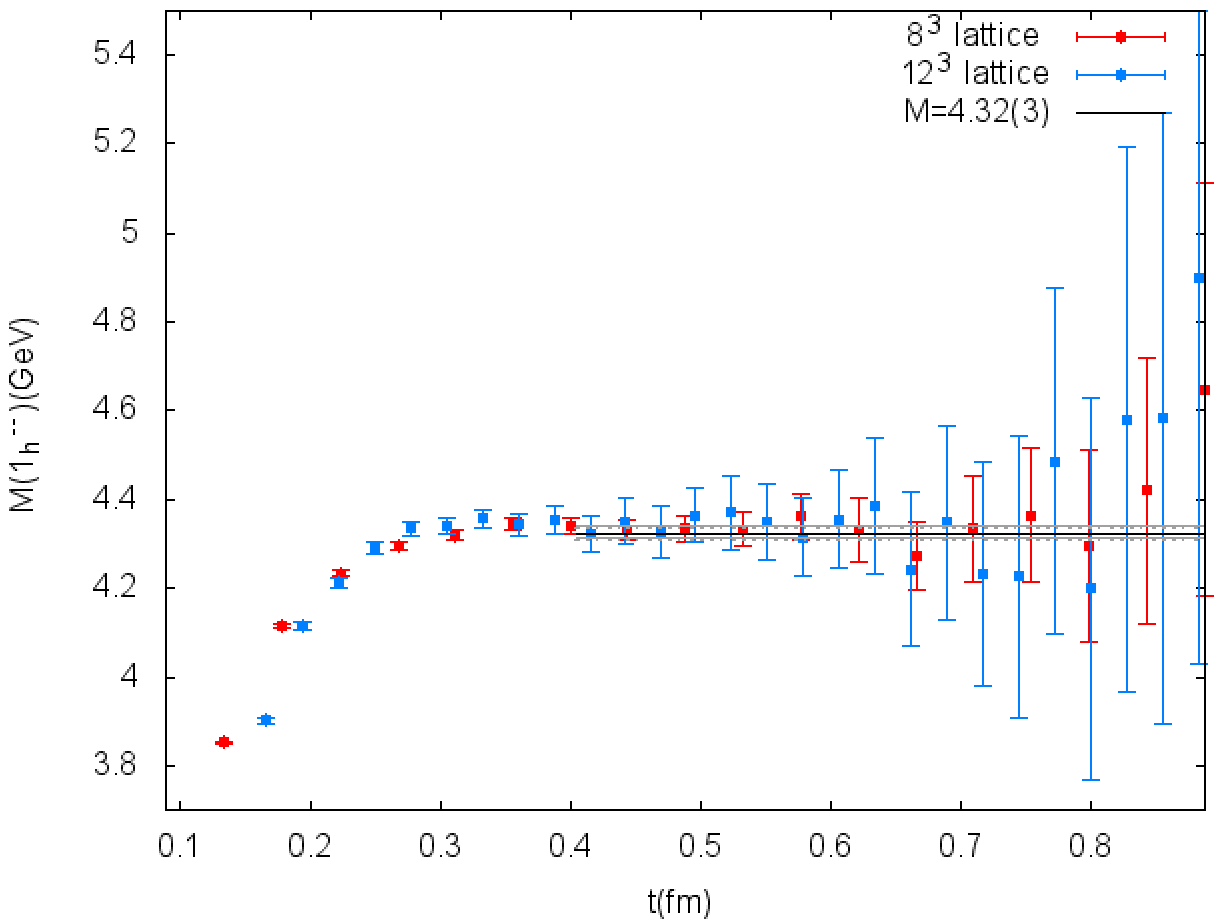
It is obviously seen that

1. The spectral weight of J/psi (and actually other conventional vector charmonia) damps more rapidly with the increment of r;
2. The small deviation of the J/psi mass from the original value 3.097 can be understood as the small contamination of higher conventional charmonia;
3. The different behaviors of the spectral weight can be applied to eliminate the conventional states. In other words, we can linearly combine them to obtain an optimal two-point function

$$C_{optimal}(t) = C(r_1, t) + \omega C(r_2, t)$$

which is dominated by the exotic vector charmonium. The optimal parameter omega can be determined numerically by requesting the plateau lasting as long as enough.

Linearly combine the correlation functions with different r we can eliminate the conventional vector charmonium and get a relatively clean signal of the exotic vector meson.



III. The leptonic decay width of the exotic vector charmonium

1. The leptonic decay width of this exotic vector chamonium is an important quantity, which can shed light on the nature of Y(4260).

$$\boxed{\Gamma(Y(4260)\to e^+e^-)\Gamma(Y(4260)\to J/\psi\pi^+\pi^-)/\Gamma_{tot}=5.8eV}$$

2. The leptonic decay constant of the exotic state can be calculated directly in lattice QCD.

The decay constant of a vector meson is defined as

$$\boxed{\langle 0|\bar{q}\gamma_\mu q|V(\vec{p},r)\rangle = m_V f_V \varepsilon_\mu(\vec{p},r)}$$

where the matrix element on the left can be derived by calculate the two point function

$$\sum_{\vec{x}}\langle 0|\bar{q}\gamma_\mu q(\vec{x},t)O^{(w)}(0)|0\rangle = \sum_{i,r}\frac{1}{2M_i}\langle 0|\bar{q}\gamma_\mu q|V_i,r\rangle\langle V_i,r|O^{(w)}|0\rangle e^{-M_i t}$$

β	$M(J/\psi)$(GeV)	$f_{J/\psi}$ (MeV)	$M(Y)$(GeV)	f_Y (MeV)
2.4	3.076(4)	428(7)	4.43(7)	32(20)
2.8	3.082(1)	378(6)	4.40(7)	31(11)
Exp.	3.097	407(5)	$\cdots$	$\cdots$

Using the formula

$$\Gamma(V_{c\bar{c}} \to e^+e^-) = \frac{16\pi}{27}\alpha_{\mathrm{QED}}^2 \frac{f_V^2}{M_V}$$

One can predict the leptonic decay width of the exotic vector charmonium

$$\boxed{\Gamma(Y \to e^+e^-) \approx 25(20)\,\mathrm{eV}}$$

(*preliminary*)

IV. Phenomenological implications

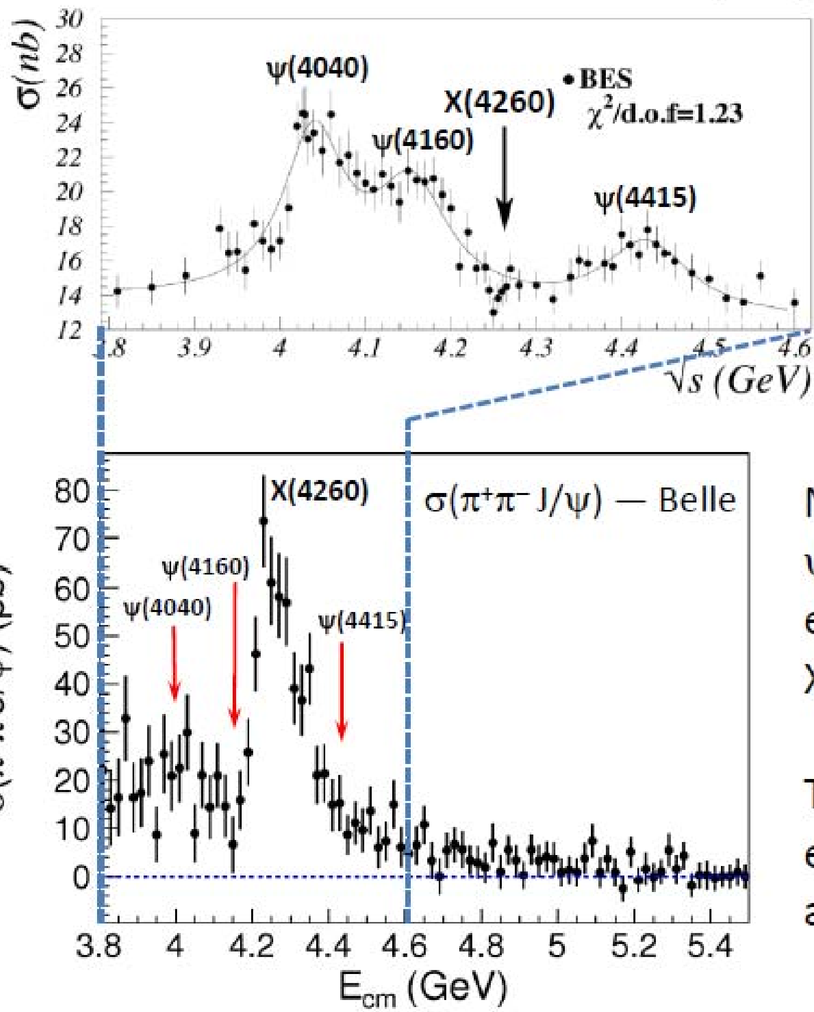
1. Both quenched and unquenched studies on charmonium spectrum show that there may be an exotic vector charmonium state around M~4.3 GeV.
2. For the first time, the leptonic decay width of this state is predicted to be 25(20) eV, which is roughly two order of magnitude smaller than that of the conventional vector charmonia.

	$\Gamma(e^+e^-)$(keV)	$\Gamma(J/\psi\pi^+\pi^-)$ (keV)
J/ψ	5.55(14)	$\cdots$
ψ'	2.35(4)	~ 100
$\psi(4040)$	0.86(7)	< 320
$\psi(4415)$	0.58(7)	$\cdots$
$\psi(3770)$	0.262(18)	~ 50
$\psi(4160)$	0.83(7)	< 310

$$\boxed{\begin{aligned}&\Gamma(V\to e^+e^-)\propto f_V^2\\&\langle 0|\bar{q}\gamma_\mu q|V(\vec{p},r)\rangle = m_V f_V \varepsilon_\mu(\vec{p},r)\end{aligned}}$$

$$\boxed{\Gamma(Y(4260)\to e^+e^-)\Gamma(Y(4260)\to J/\psi\pi^+\pi^-)/\Gamma_{tot} = 5.8eV}$$

K. Seth, QWG2013



Note that **all** 1^{--} states ψ(4040,4160,4415) are strongly excited in $\sigma(e^+e^- \to \gamma^* \to \text{hadrons})$, but X(4260) 1^{--} is not at all excited.

Note that **none** of the 1^{--} states ψ(4040,4160,4415) are appreciably excited in $\sigma(\pi^+\pi^- J/\psi)$, but X(4260) is strongly excited

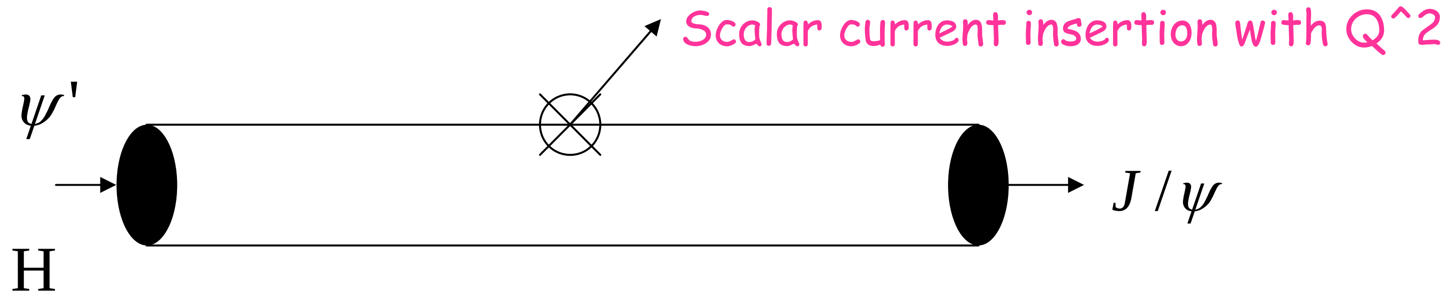
This “orthogonality” in preferential excitation is extremely interesting and provocative

3. If this exotic vector charmonium corresponds to Y(4260), then the branch ratio of $\pi^+\pi^- J/\psi$ decay mode is roughly 20-30%.

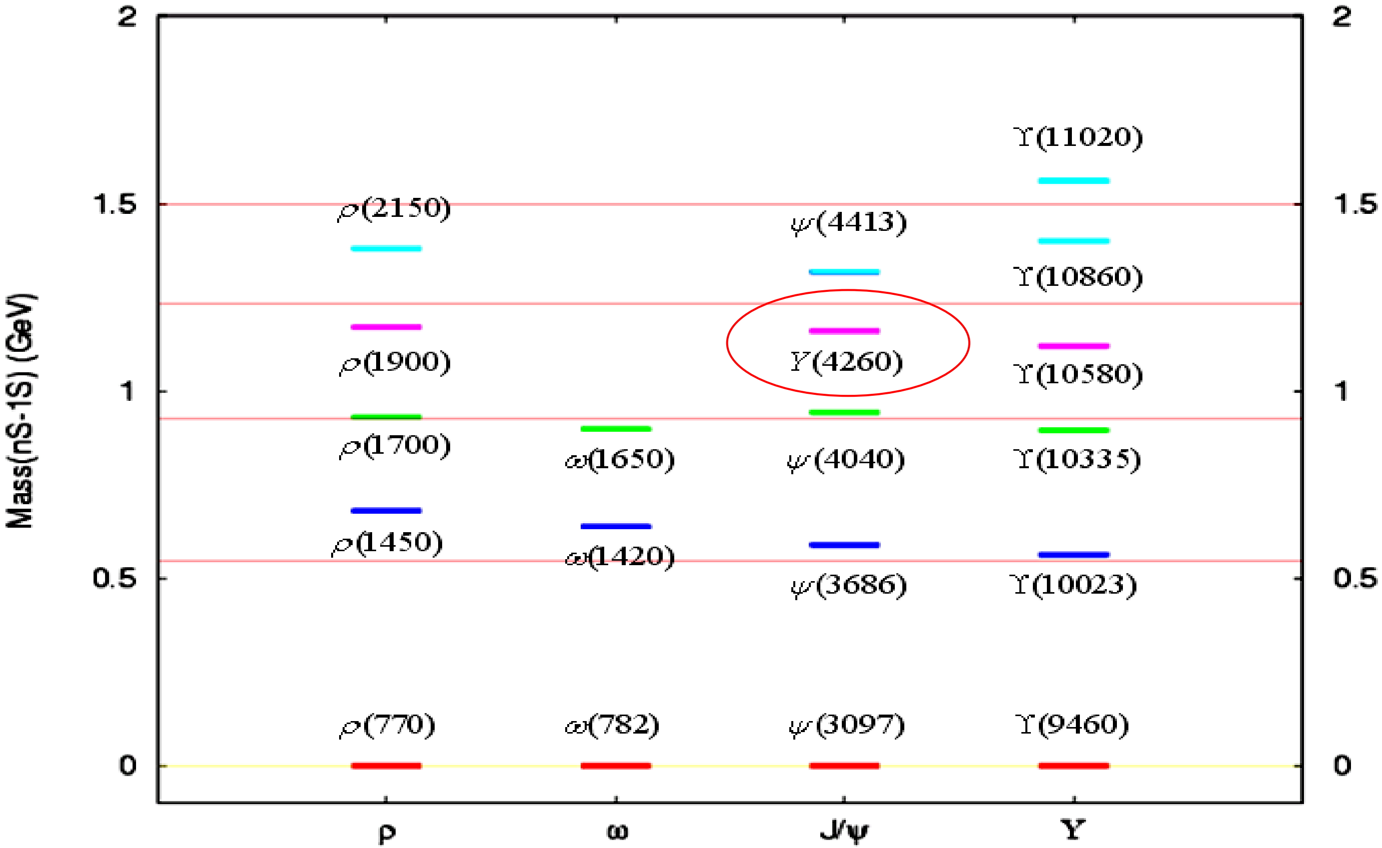
4. We are calculating the ratio

$$\frac{g(\psi' \to J/\psi X)}{g(H \to J/\psi X)}$$

where X stands for scalar objects.



5. If we take a look into the vector meson spectrum, we can see that, for both light and heavy quarks, the spectra have similar tower structure.



5. **Are there two vector states around 4.26 GeV, of which one is the conventional 4S state, and the other is the exotic vector state observed in lattice calculations?**

IV. Conclusion

1. No firm conclusion can be drawn at present.
2. For comments

Thanks!