Deciphering XYZ

(PANDA oriented)

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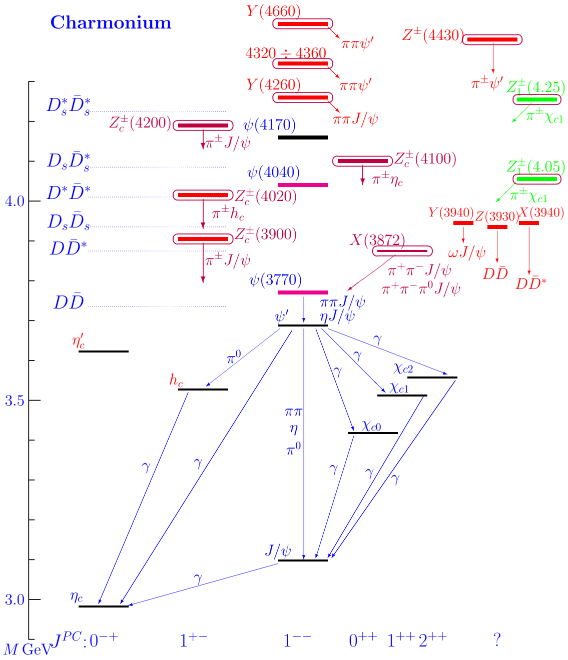
Charmonium



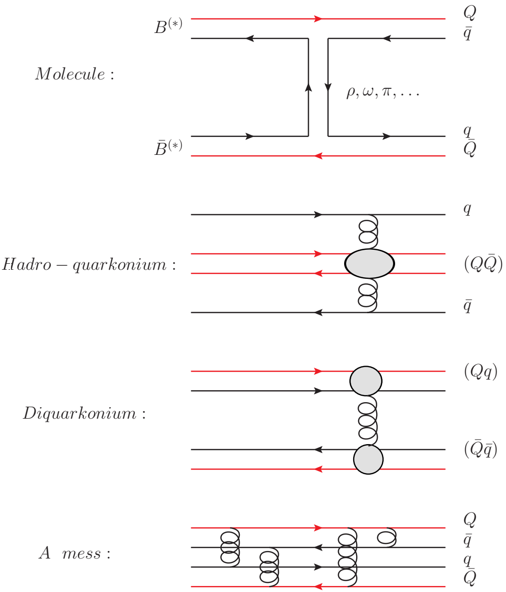
$Y(4660)$
$\pi\pi\psi'$
$Z^{\pm}(4430)$
$4320 \div 4360$
$\pi\pi\psi'$
$\pi^{\pm}\psi'$
$Z_1^{\pm}(4.25)$
$Y(4260)$
$\pi\pi J/\psi$
$\pi^{\pm}\chi_{c1}$
$D_s^*\bar{D}_s^*$
$Z_c^{\pm}(4200)$
$\pi^{\pm}J/\psi$
$\psi(4170)$
$D_s\bar{D}_s^*$
$Z_c^{\pm}(4100)$
$\pi^{\pm}\eta_c$
$\psi(4040)$
$Z_1^{\pm}(4.05)$
$\pi^{\pm}\chi_{c1}$
$D^*\bar{D}^*$
$Z_c^{\pm}(4020)$
4.0
$\pi^{\pm}h_c$
$Y(3940)$
$Z(3930)$
$X(3940)$
$D_s\bar{D}_s$
$Z_c^{\pm}(3900)$
$D\bar{D}^*$
$X(3872)$
$\omega J/\psi$
$\pi^{\pm}J/\psi$
$\pi^+\pi^-J/\psi$
$D\bar{D}$
$\psi(3770)$
$\pi^+\pi^-\pi^0 J/\psi$
$D\bar{D}^*$
$D\bar{D}$
$\pi\pi J/\psi$
ψ'
$\eta J/\psi$
η_c'
γ
π^0
γ
χ_{c2}
h_c
γ
χ_{c1}
3.5
$\pi\pi$
η
π^0
χ_{c0}
γ
γ
γ
γ
γ
J/ψ
γ
3.0
η_c
M GeV
J^{PC}: 0^{-+}
1^{+-}
1^{--}
0^{++}
1^{++}
2^{++}
?

The exotic menu

Exotic: not fitting the template Mesons = $(q\tilde{q})$, Baryons = (qqq).

- Charmonium-like
  - $X(3872)$ $(D^0 D^{*0})$, $\to J/\psi\rho$ *and* $J/\psi\omega$, isospin badly broken,
  - $Z_c^{\pm,0}(3900)$ (DD^*), $\to J/\psi\pi$,
  - $Z_c^{\pm}(4020)$, $(D^*\bar{D}^*)$, $\to h_c\pi^{\pm}$,
  - $Z_1^{\pm}(4050)$, $Z_2^{\pm}(4250)$ $\to \chi_{c1}\pi^{\pm}$,
  - $Z_c^{\pm}(4100)$ $\to \eta_c\pi^{\pm}$,
  - $Z_c^{\pm}(4200)$ $\to J/\psi\pi^{\pm}$,
  - $Z^{\pm}(4430)$, $\to \psi(2S)\pi^{\pm}$,
  - $Y(4260)$[4220] $\to J/\psi\pi\pi, h_c\pi\pi$ (almost no open charm),
  - $Y(4360) \to \psi(2S)\pi\pi, h_c\pi\pi$ (almost no open charm),
  - Pentaquark(s):
    $P_c(4380)$, $P_c(4440)$, $P_c(4457)$, $P_c(4312)$ $\to J/\psi p$
- Bottomonium-like
  - $Z_b^{\pm,0}(10610)$, (BB^*), $\to \Upsilon(nS)\pi$ $(n = 1, 2, 3)$, $h_b(kP)\pi$ $(k = 1, 2)$,
  - $Z_b^{\pm,0}(10650)$, $(B^*\bar{B}^*)$, $\to \Upsilon(nS)\pi$ $(n = 1, 2, 3)$, $h_b(kP)\pi$ $(k = 1, 2)$

What is inside?



Likely all are present simultaneously.
Dominant — different in different particles.

Recall: deuteron — mostly a *pn* molecule, and about 5% - a mess.

Molecules

- Must be very close to the threshold. At binding/excitation energy δ, the characteristic size

$$r \sim 1/\sqrt{M\delta} \approx \begin{cases} 4.5\,\mathrm{fm}\sqrt{\frac{1\,\mathrm{MeV}}{\delta}} & \text{charmonium} - \text{like} \\ 2.8\,\mathrm{fm}\sqrt{\frac{1\,\mathrm{MeV}}{\delta}} & \text{bottomonium} - \text{like} \end{cases}$$

- A clear-cut example: $Z_b(10610) = Z_b$, $Z_b(10650) = Z_b'$

  $M(Z_b) = 10607.2 \pm 2.0$ MeV [$M(BB^*) = 10604.1 \pm 0.3$ MeV],

  $M(Z_b') = 10652.2 \pm 1.5$ MeV [$M(B^*\bar{B}^*) = 10649.7 \pm 0.6$ MeV]

$$Z_b \sim \frac{B^*\bar{B} - \bar{B}^*B}{\sqrt{2}}, \qquad Z_b' \sim B^*\bar{B}^*$$

- Produced in $\Upsilon(5S) \to Z_b^{(\prime)}\pi$.
  Observed in $Z_b^{(\prime)} \to \Upsilon(1,2,3S)\pi$ and $Z_b^{(\prime)} \to h_b(1,2P)\pi$.
  Also $Z_b \to B^*\bar{B} + c.c.$, $Z_b' \to B^*\bar{B}^*$.
- In charmonium-like sector: $X(3872)$, $Z_c(3900)$, $Z_c(4020)$.

Heavy Quark Spin Symmetry (HQSS) and Molecules

- HQ spin-dependent interaction of heavy Q

$$H_s = -\frac{\vec{\sigma} \cdot \vec{B}}{2\, M_Q} \sim \frac{\Lambda_{QCD}^2}{M_Q} \ll \Lambda_{QCD}$$

- E.g. $\Upsilon(2S) \to \Upsilon(1S)\eta$ requires $b\bar{b}$ spin rotation (Ampl. $\propto (\vec{p}_\eta \cdot [vec\Upsilon_2 \times \vec{\Upsilon}_1]))$:

$$\Gamma[\Upsilon(2S) \to \Upsilon(1S)\eta] \sim 10^{-3}\, \Gamma[\Upsilon(2S) \to \Upsilon(1S)\pi\pi]$$

- In a widely separated $B^{(*)}\bar{B}^{(*)}$ pair the spin of b is not correlated with the spin of $\bar{b}$. Rather

$$H_{spin} = \mu\, (\vec{s}_b \cdot \vec{s}_{\bar{q}}) + \mu\, (\vec{s}_{\bar{b}} \cdot \vec{s}_q), \quad \mu = M(B^*) - M(B) \approx 45\,\mathrm{MeV}$$

- The spin of the $b\bar{b}$ pair (S_H) is mixed. In the $J^{PC} = 1^{+-}$ state:

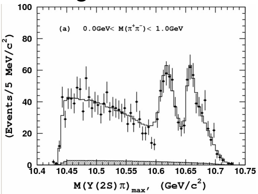
$$B^*\bar{B} - \bar{B}^*B \sim 0_H^- \otimes 1_L^- + 1_H^- \otimes 0_L^- \qquad B^*\bar{B}^* \sim 0_H^- \otimes 1_L^- - 1_H^- \otimes 0_L^-$$

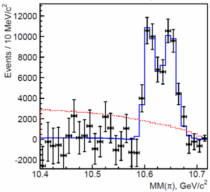
Spin structure of $Z_b^{(\prime)}$

- If the $H \otimes L$ spin composition of pairs of free mesons is retained in Z_b and Z_b',

$$Z_b \sim 0_H^- \otimes 1_L^- + 1_H^- \otimes 0_L^- \qquad Z_b' \sim 0_H^- \otimes 1_L^- - 1_H^- \otimes 0_L^- \ ,$$

  then
  - $M(Z_b') - M(Z_b) \approx M(B^*) - M(B) \approx 45\,\text{MeV}$, $\Gamma(Z_b') \approx \Gamma(Z_b)$, in particular $\Gamma(Z_b') \to B^* \bar{B} + c.c.$ should be small;
  - $A[Z_b' \to \Upsilon(nS)\,\pi] \approx -A[Z_b \to \Upsilon(nS)\,\pi]$, $\quad A[Z_b' \to h_b(kP)\,\pi] \approx +A[Z_b \to h_b(kP)\,\pi]$;
  - $A[\Upsilon(5S) \to Z_b'\,\pi] \approx -A[\Upsilon(5S) \to Z_b\,\pi]$;
  - Definite and opposite sign of interference of Z_b and Z_b' in the $\pi\pi$ cascades from $\Upsilon(5S)$ to ortho- and para- states of $b\bar{b}$
- Well agrees with the data. In fact surprisingly well.





S wave molecules related by HQSS, Charmonium-like.

- $J^{PC} = 1^{+1}$ $Z_c(3900) \sim D\bar{D}^* - \bar{D}D^* \sim 0_H^- \otimes 1_L^- + 1_H^- \otimes 0_L^-$
- $J^{PC} = 1^{+1}$ $Z_c(4020) \sim D^*\bar{D}^* \sim\sim 0_H^- \otimes 1_L^- + 1_H^- \otimes 0_L^-$
- Other diagonal states of the Hamiltonian H_s with $PC = ++$:

$$X_{c2}: \quad 1^-(2^+): \quad \left(1_H^- \otimes 1_L^-\right)\big|_{J=2}, \quad D^*\bar{D}^*;$$

$$X_{c1}: \quad 1^-(1^+): \quad \left(1_H^- \otimes 1_L^-\right)\big|_{J=1}, \quad D^*\bar{D} + \bar{D}^*D;$$

$$X'_{c0}: \quad 1^-(0^+): \quad \frac{\sqrt{3}}{2}\left(0_H^- \otimes 0_L^-\right) + \frac{1}{2}\left(1_H^- \otimes 1_L^-\right)\big|_{J=0}, \quad D^*\bar{D}^*;$$

$$X_{c0}: \quad 1^-(0^+): \quad \frac{1}{2}\left(0_H^- \otimes 0_L^-\right) - \frac{\sqrt{3}}{2}\left(1_H^- \otimes 1_L^-\right)\big|_{J=0}, \quad D\bar{D};$$

- In charmonium-like sector in fact $X_{c1} = X(3872) \sim D^0\bar{D}^{*0} + \bar{D}^0D^{*0}$ (mixture of $I = 0$ and $I = 1$.)
- The interaction depends on S_L: V_0, V_1. Generally $V_0 \neq V_1$. However $X(3872)$ and X_{c2} are pure $S_L = 1 \Rightarrow$ Existence of $X(3872)$ implies existence of $J^{PC} = 2^{++}$ resonance at the $D^{*0}\bar{D}^{*0}$ threshold, 4013.7 MeV. Could be broad, >10 MeV.May be testable by PANDA.

Molecules at PANDA

- A caveat for studies of molecules in $p\bar{p}$ — only $I = 0$ states have a chance to be produced in a short-distance process ($p\bar{p}$, B decays, etc...)
- Molecules are spatially BIG. For charmonium-like

$$r \sim 1/\sqrt{M\,\delta} \approx 4.5\,\mathrm{fm}\sqrt{\frac{1\,\mathrm{MeV}}{\delta}}$$

- The overlap with a short-distance source ($|\psi(0)|^2$) is small $\Rightarrow$ small rate
- $X(3872)$ is produced in short-distance processes due to mixing with compact charmonium $c\bar{c}$
- The mixing is possible only in the $I = 0$ isotopic state.
- $\Rightarrow$ The prospects of producing molecules at PANDA depend on *i* $I = 0$ content and *ii* the mixing with $c\bar{c}$.
- $X(3872)$ appears to be OK. Its 2^{++} partner near 4013.7 MeV depends on the mixing with 2^{++} charmonium.
- Othe states — exploratory.

A side remark on diquarkonium $[Qq][\bar{Q}\bar{q}]$

- Driving idea: in antisymmetric $[Qq]$ attraction, in symmetric $\{Qq\}$ repulsion. Inspired by Coulomb-like one gluon exchange.
- However generally there are transitions $[Qq][\bar{Q}\bar{q}] \leftrightarrow \{Qq\}\{\bar{Q}\bar{q}\}$
- One gluon exchange in $Q(1)\bar{Q}(2)q(3)\bar{q}(4)$ in terms of $c_{ij} = \alpha_s/r_{ij}$:

$$V \begin{pmatrix} [Qq][\bar{Q}\bar{q}] \\ \{Qq\}\{\bar{Q}\bar{q}\} \end{pmatrix} = -\frac{1}{4} \begin{pmatrix} \frac{N_c^2-1}{N_c} r + \frac{N_c+1}{N_c} t & \sqrt{N_c^2-1}\, s \\ \sqrt{N_c^2-1}\, s & \frac{N_c^2-1}{N_c} r - \frac{N_c-1}{N_c} t \end{pmatrix} \begin{pmatrix} [Qq][\bar{Q}\bar{q}] \\ \{Qq\}\{\bar{Q}\bar{q}\} \end{pmatrix}$$

N_c - number of colors, $r = c_{12} + c_{34} + c_{14} + c_{23}$,
$s = c_{12} + c_{34} - c_{14} - c_{23}$, $t = 2c_{13} + 2c_{24} - c_{12} - c_{14} - c_{23} - c_{34}$

- s — attraction between the diquarks (zero overall color), t — attraction/repulsion within $[Qq]/\{Qq\}$, r — mixing $[Qq][\bar{Q}\bar{q}] \leftrightarrow \{Qq\}\{\bar{Q}\bar{q}\}$
- difference attraction - repulsion within $[Qq]/Qq \propto 2N_c/N_c = 2$; mixing term $\propto \sqrt{N_c^2-1} = O(N_c) \Rightarrow$ parametrically mixing $\gg$ difference.
- There is no parameter that would keep diquarks color antysymmetric in a $Q\bar{Q}q\bar{q}$ system!

Hadro-charmonium

No obvious nearby threshold

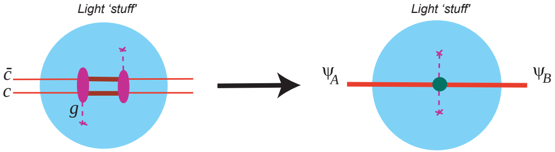
- $Z_1^{\pm}(4050)$, $Z_2^{\pm}(4250)$ $\rightarrow \chi_{c1}\pi^{\pm}$ (status unclear),
- $Z_c^{\pm}(4100)$ $\rightarrow \eta_c\pi^{\pm}$,
- $Z_c^{\pm}(4200)$ $\rightarrow J/\psi\pi^{\pm}$,
- $Z^{\pm}(4430)$, $\rightarrow \psi(2S)\pi^{\pm}$,

Still under discussion [$D_1\left(\frac{3}{2}^{+}\right)\bar{D}$ nearby threshold but S wave in e^+e^- forbidden by HQSS]:

- $Y(4260)$[4220] $\rightarrow J/\psi\pi\pi, h_c\pi\pi$ (almost no open charm),
- $Y(4360) \rightarrow \psi(2S)\pi\pi, h_c\pi\pi$ (almost no open charm)

To me these all look like 'a charmonium stuck in a light hadron'. At least this can explain why a specific charmonium state e.g. J/ψ, or ψ', or η_c appears in the decay.

Here's what I mean:



A van der Waals type interaction due to chromo-polarizability

$$\langle B|H_{eff}|A\rangle = -\frac{1}{2}\,\alpha_{AB}\,\vec{E}^a \cdot \vec{E}^a \qquad \mathrm{Chromo-polarizability}:\ \alpha_{AB}$$

$|\alpha_{\psi' J/\psi}| \approx 2\,GeV^{-3}$ is known from $\psi' \to \pi\pi\, J/\psi$. Schwartz inequality $\alpha_{J/\psi}\alpha_{\psi'} \geq \alpha^2_{\psi' J/\psi}$.

$$\langle X|\vec{E}^a \cdot \vec{E}^a\,|X\rangle \geq \langle X|\vec{E}^a \cdot \vec{E}^a - \vec{B}^a \cdot \vec{B}^a|X\rangle = -\frac{1}{2}\langle X|(F^a_{\mu\nu})^2|X\rangle = \frac{32\pi^2}{9}\,M_X^2$$

X=(Light hadron) $\Rightarrow$ strong interaction with heavier hadronic states made of light quarks and gluons.

E.g. J/ψ binding potential in heavy nuclei $V < -27\,\mathrm{MeV}$.

If charmonium-light hadron interaction is described by potential $V(x)$, the low-energy theorem implies that

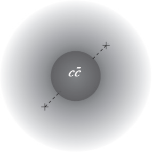
$$\int V(x)\, d^3x \leq -\frac{8\pi^2}{9}\, \alpha^{(\psi)}\, M_X$$

The existence of bound state depends on relation between the mass M_X and the size of the hadron R:

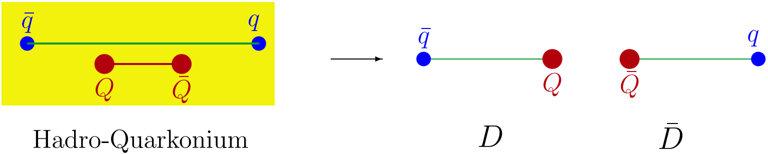
$$\alpha^{(\psi)}\, \frac{M_X \bar{M}}{R} \geq O(1)$$

($\bar{M} = M_X M_\psi/(M_X + M_\psi)$ - reduced mass.)
If with excitation R grows slower than M_X then binding necessarily occurs at sufficiently high excitation. E.g. in bag model $R \propto M^{1/3}$.
Linear Regge trajectories: $R \propto M$ and a better analysis is needed. In a holographic model with linear Regge behavior binding necessarily occurs at a high excitation.

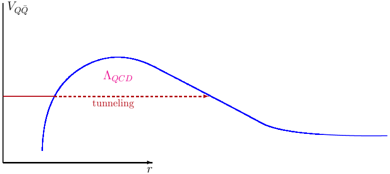
(S. Dubynskiy, A. Gorsky, M.B.V.)



Decay to open heavy flavor requires reconnection of the couplings



Born-Oppenheimer potential between heavy:



The tunneling momentum $|p_Q| = \sqrt{M_Q\,(V_{Q\bar{Q}} - E)} \sim \sqrt{M_Q\,\Lambda_{QCD}} \Rightarrow$

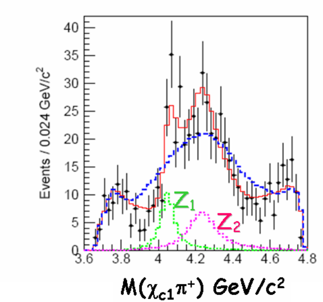
$$\Gamma(\to \text{open flavor}) \propto \exp(-\sqrt{M_Q/\Lambda_{QCD}})$$

If such interpretation of Y's and Z's has anything to do with reality, there should be:

- bound states of J/ψ and/or ψ' with light nuclei and with baryonic resonances, i.e. baryo-charmonium decaying to e.g. pJ/ψ (+ pions) $\Rightarrow$ pentaquarks
- resonances containing χ_{cJ} charmonium, i.e. in χ_{cJ}+pion(s) $Z_1^{\pm}(4050)$, $Z_2^{\pm}(4250)$ $\quad \to \chi_{c1}\pi^{\pm}$
- decays (moderately suppressed) into non-preferred charmonium states, e.g. $Y(4260) \to \pi\pi\psi'$, or $Y(4.36) \to \pi\pi J/\psi$
- Contain compact charmonium inside $\Rightarrow$ can be produced in hard processes: B decays, $p\bar{p}$, LHC, ...

$Z_1(4050)$, $Z_2(4250)$

Belle 08: $Z^+_{1,2} \to \pi^+ \chi_{c1}$. (Observed in $B \to K\pi^+\chi_{c1}$)



Z_1 : $M \approx 4.05\,$GeV, $\Gamma \approx 80\,$MeV. Z_2 : $M \approx 4.25\,$GeV, $\Gamma \approx 180\,$MeV.

Notice: $Z(4430) - Z_2(4250) \approx \psi' - \chi_{c1} \approx 180\,$MeV.

Could it be that they have the same hosting light-meson resonance?

However $\Gamma_{Z_2} \approx 4\,\Gamma_{Z(4430)}$ (???)

Neither Z_1 nor Z_2 confirmed by BaBaR or any other.

$Z_c(4100)$, $Z_c(4200)$

- Belle 2014: $B^0 \to J/\psi\pi^- K^+$ resonance in $J/\psi\pi^-$ (6.2σ), $Z_c(4200)$, $M = 4196^{+35}_{-32}$ MeV, $\Gamma = 370^{+170}_{-150}$ MeV, $\mathcal{B}[B^0 \to Z_c(4200)^- K^+ \to J/\psi\pi^- K^+] \approx 2.2 \times 10^{-5}$, $J^P = 1^+$ preferred.
- LHCb 2018: $B^0 \to \eta_c\pi^- K^+$ resonance in $\eta_c\pi^-$ ($> 3\sigma$), $Z_c(4100)$, $M = 4096 \pm 20^{+18}_{-22}$ MeV, $\Gamma = 152 \pm 58^{+60}_{-35}$ MeV $\mathcal{B}[B^0 \to Z_c(4100)^- K^+ \to \eta_c\pi^- K^+] \approx 1.9 \times 10^{-5}$, $J^P = 0^+$ preferred

Strongly suggests: $Z_c(4100)$ = η_c embedded in S wave in an 'excited pion' $I^G(J^P) = 1^-(0^-)$, $Z_c(4200)$ = J/ψ embedded in the same 'excited pion' $I^G(J^P) = 1^-(0^-)$. Expected:

- The same embeddings — HQSS partners, like η_c and J/ψ $\Rightarrow$

$$M[Z_c(4200)] - M[Z_c(4100)] \approx M(J/\psi) - M(\eta_c) = 112\,\mathrm{MeV}$$

- $\Gamma[Z_c(4100) \to \eta_c\pi] \approx \Gamma[Z_c(4200) \to J/\psi\pi]$
- $$\frac{\mathcal{B}[B^0 \to Z_c(4100)^- K^+]}{\mathcal{B}[B^0 \to Z_c(4200)^- K^+]} \approx \left.\frac{\mathcal{B}[B^0 \to \eta_c\pi^- K^+]}{\mathcal{B}[B^0 \to J/\psi\pi^- K^+]}\right|_{M(c\bar{c}\pi)\approx M(Z_c)}$$

HQSS breaking processes

Leading HQSS breaking — M1 chromomagnetic interaction

$$H_{M1} = -\frac{1}{2m_c}\,(t_c^a - t_{\bar{c}}^a)\,\left(\vec{\Delta}\cdot\vec{B}^a\right)$$

$\vec{\Delta} = \vec{s}_1 - \vec{s}_2$ spin operator: $\langle {}^1S_0|\Delta|{}^3S_1\rangle = \langle {}^3S_1|\Delta|{}^1S_0\rangle \Rightarrow$ same coefficient C in the HQSS breaking amplitudes:

$$A[Z_c(4100) \to J/\psi\rho] = C\,(\vec{\psi}\cdot\vec{\rho})\,; \quad A[Z_c(4200) \to \eta_c\rho] = C\,(\vec{Z}\cdot\vec{\rho})$$

Implies

$$\Gamma[Z_c(4100) \to J/\psi\rho] \approx 3\,\Gamma[Z_c(4200) \to \eta_c\rho]$$

HQSS breaking in charmonium $\sim$ 10% in the rate ($\psi' \to J/\psi\eta$ vs. $\psi' \to J/\psi\pi\pi$)

Other related processes

- Same embedding — the same admixture of excited states $\eta_c(2S)$, $\psi(2S) \Rightarrow$

$$\Gamma[Z_c(4100) \to \eta_c(2S)\pi] \approx \Gamma[Z_c(4200) \to \psi(2S)\pi]$$

- Orbitally excited. P and G conservation allows only $Z_c(4100) \to \chi_{c1}\pi$ and $Z_c(4200) \to h_c\pi$

$$\frac{\Gamma[Z_c(4200) \to h_c\pi]}{\Gamma[Z_c(4100) \to \chi_{c1}\pi]} \approx \left(\frac{p_2}{p_1}\right)^3 \approx 1.5$$

(P wave decays. Thus the kinematical difference is more important than in the previous.) Both processes are suppressed by both HQSS and the (orbital) excitation.

Acsessible at PANDA:

Molecules (due to mixing with quarkonium):

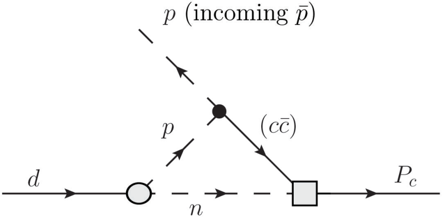
- $X(3872)$
- $X_{c2}(4013)$ (?)
- Other X_{cJ} (??), esp. isosinglet. Not readily accessible in e^+e^-, but can appear in $\bar{p}p$.

Hadro-charmonium:

- $I = 1$ neutral components
  - $Z^0(4050)$, $Z^0(4250)$ $\rightarrow \chi_{c1}\pi^0$,
  - $Z_c^0(4100)$ $\rightarrow \eta_c\pi^0$,
  - $Z_c^0(4200)$ $\rightarrow J/\psi\pi^0$,
  - $Z^0(4430)$, $\rightarrow \psi(2S)\pi^0$
- $I = 1$ charged components can be available with a deuterium target, $\bar{p}n \rightarrow Z_c^-$.
- $I = 0$ mixing with $c\bar{c}$ or 'direct'
  - $Y(4260)$[4220] $\rightarrow J/\psi\pi\pi$, $h_c\pi\pi$ (almost no open charm),
  - $Y(4360) \rightarrow \psi(2S)\pi\pi$, $h_c\pi\pi$ (almost no open charm)

Hidden-charm pentaquarks at PANDA

Deuterium target: $\bar{p} + d \to P_c$



Simultaneously for d at rest and p at rest $\bar{p} + d \to Pc$ and $\bar{p} + p \to (c\bar{c})$:
$M_{P_c} = M_0$

$$M_0^2 = 2m_{(c\bar{c})}^2 + m_N^2$$

$M_0 = 4.48\,\mathrm{GeV}$ for $(c\bar{c}) = J/\psi$ and $M_0 = 4.33\,\mathrm{GeV}$ for $(c\bar{c}) = \eta_c$.
Compare with $P_c(4450)$.
No need to consider short distance structure in deuteron.
BW max cross section: $\sigma(\bar{p} + d) \to P_c \approx Br[P_c \to \bar{p} + d] \times 2 \times 10^{-27}\mathrm{cm}^2$
$Br[P_c \to \bar{p} + d] \approx 0.5 \times 10^{-6}\, Br[P_c \to (c\bar{c}) + n]\, \Gamma[(c\bar{c}) \to p\bar{p}]/(1\mathrm{keV})$
$\sim 10^{-7}\, Br(P_c \to J/\psi + n)$ for J/ψ, $\sim 2.5 \times 10^{-5}\, Br(P_c \to \eta_c + n)$ for η_c

Conclusions

- It looks like we (somewhat) understand charmonium and bottomonium below open flavor threshold. The atomic physics of quarkonium.
- What happens above the threshold — mostly puzzles.
- Molecules, hadroquarkonium, . . . — Hadronic chemistry.
- Hybrids — $c\bar{c}$ plus gluonic excitations. Nowhere to be seen . . .
- At least $O(10)$ extremely interesting tasks (with known, or 'sighted' resonances) for $\bar{p}p$ at PANDA.
- More possibilities (charged states) if $\bar{p}n$ could be studied using deuterium target.
- Pentaquarks can possibly be studied in $\bar{p}d$.