THE $Y(4230)$ AS A $D_1 D$ MOLECULE

June 22, 2023 | Leon von Detten | IAS-4/IKP-3

MESON 2023

in collaboration with Christoph Hanhart, Vadim Baru, Qian Wang, Daniel Winney and Qiang Zhao

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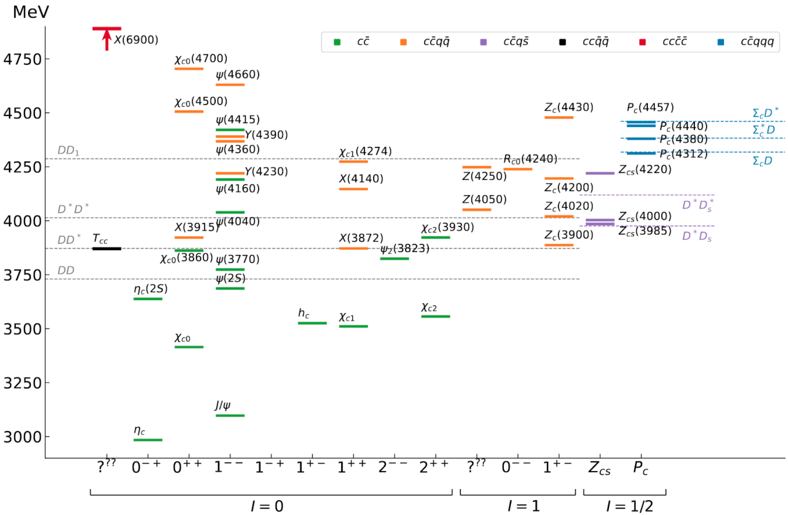
Motivation



JPAC, PPNP127(2022)103981

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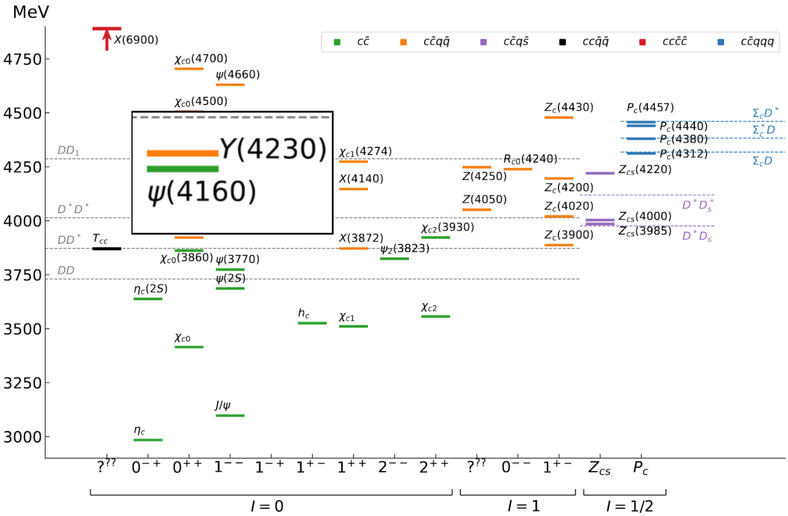
Motivation



JPAC, PPNP127(2022)103981

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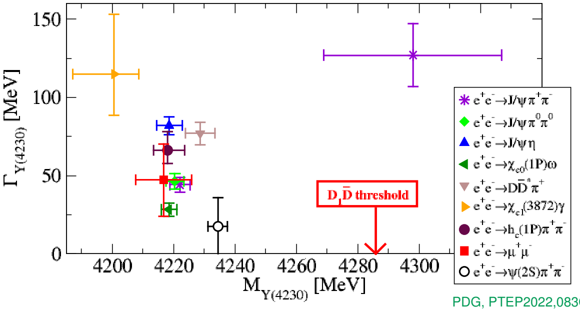
Motivation



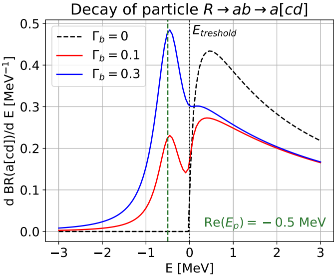
PDG, PTEP2022,083C01(2022)

- Why do mass and decay width scatter so much for different reactions?
- How big is the influence of the $D_1\bar{D}$ threshold ?
- Why $Y(4320)$ only seen in $e^+e^- \to J/\psi\pi\pi$?

Simultaneus fit of $D^0D^{*-}\pi^+, J/\psi\pi^+\pi^-, J/\psi K^+K^-, h_c\pi^+\pi^-, J/\psi\eta, \chi_{c0}\omega$ and $\chi_{c1}(3872)\gamma$ final states.

Postpone $\Psi(2s)\pi^+\pi^-$ for now

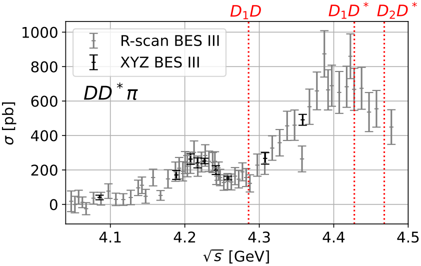
Hadronic Molecules

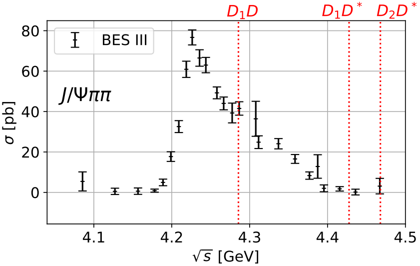


- Coupling to 2 hadron continuum maximal
  $\to$ Loop contributions at leading order
  $\to$ Possible imprint of threshold on lineshape

Braaten and Lu PRD76(2007)094028, Hanhart et al.,PRD81(2010)094028

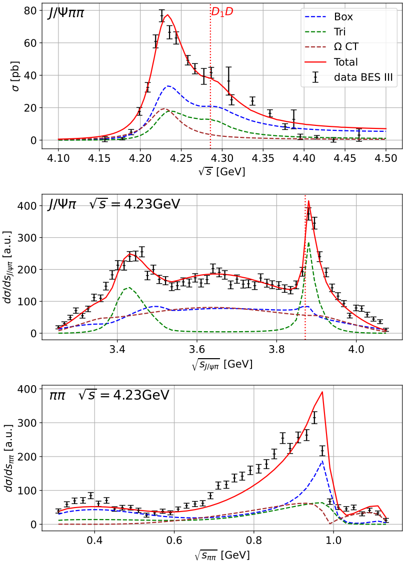
- $Y(4230) \to D_1\bar{D} \to [D^*\pi]\bar{D}$ main decay channel
- Also $D_1\bar{D}^*$ and $D_2\bar{D}^*$ 1^{--} bound states in molecular scenario

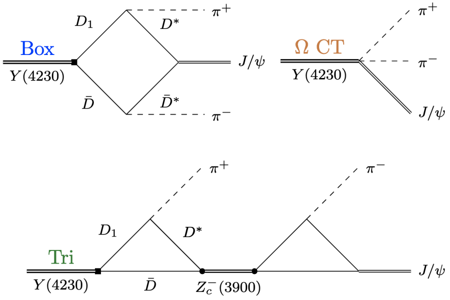




BES III,PRD106(2022)7,072001 BES III, PRL130(2023)12,1219011

$J/\psi\,\pi^+\pi^-$





+ different box and triangle topologies

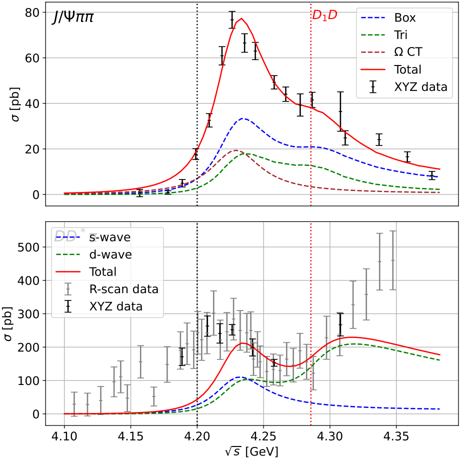
$\pi\pi/KK$ s-wave final state interaction approximate via coupled channel Omnés

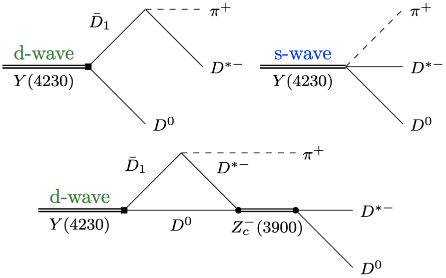
Full FSI: Chen at al., PRD99(2019)7,074016
Danilkin et al., PRD 102(2020)1,016019

BES III, PRL119(2017)7,072001

$D^{*-}D^0\pi^+$

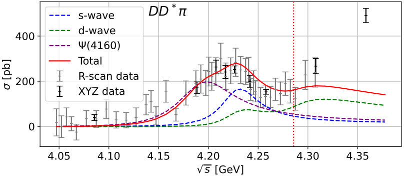
m_Y and Γ_Y fixed by $J/\psi\pi\pi$

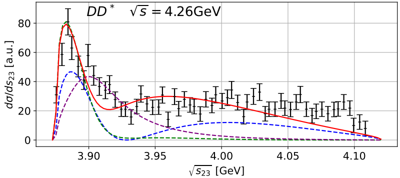


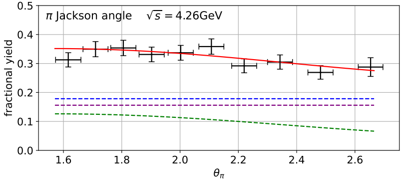


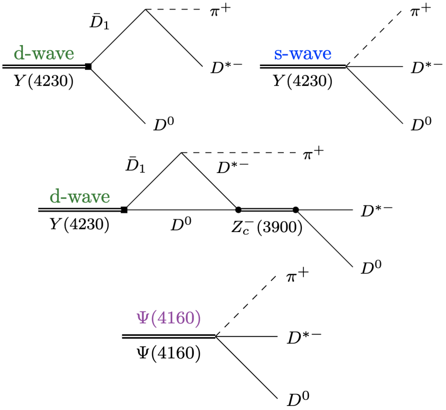
left flank of $D^*D\pi$ inconsistent with $J/\psi\pi\pi$ lineshape

$D^{*-} D^0 \pi^+$









Ψ(4160) with

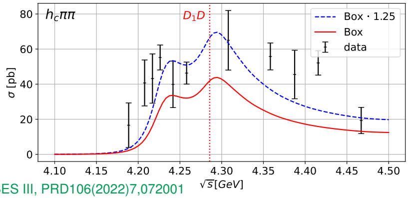
$m_\Psi = (4.191 \pm 0.005)$ GeV

$\Gamma_\Psi = (70 \pm 10)$ MeV

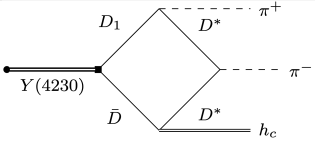
Thanks to Ryan Mitchell

BES III, PRD92(2015)9,092006 BES III, PRL112(2014)2,022001

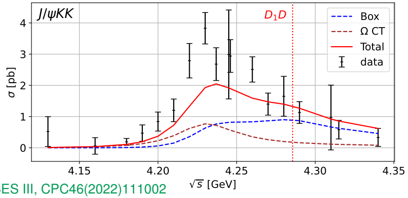
$h_c\pi^+\pi^-$ and $J/\psi K^+K^-$



BES III, PRD106(2022)7,072001

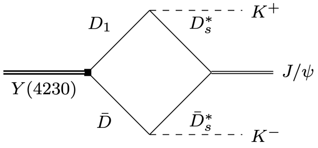


- No contact term due to HQSS
- Triangle requires $D_1\bar{D}^*$ coupling



BES III, CPC46(2022)111002

- FSI via $Y \to J/\psi\pi\pi \to J/\psi KK +$



Full coupled channel analysis will include complete $\{D, D^*\} \otimes \{D_1, D_2\}$ multiplet with SU(3) strangeness

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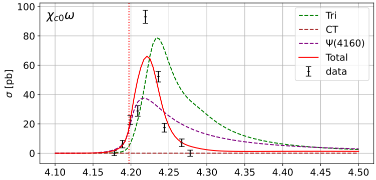
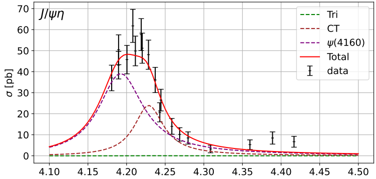
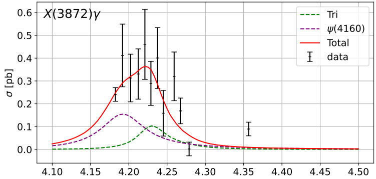
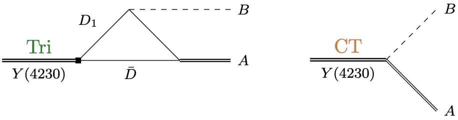
$\chi_{c0}\,\omega,\;\; J/\psi\,\eta$ and $X(3872)\gamma$







$Y(4230) \to AB$ two body decay



- Destructive interference needed to create narrow structure in $\chi_{c0}\omega$
- $J/\psi\eta$ described by $\Psi(4160)$ in-combination with either chiral contact term or triangle loop
- $Y \to X(3872)\gamma$ contact term subleading

exp. Data
BES III,PRD99(2019)9,091103
BES III,PRD102(2020)3,031101
BES III,PRL122(2019)23,232002

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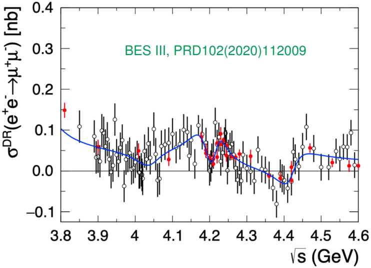
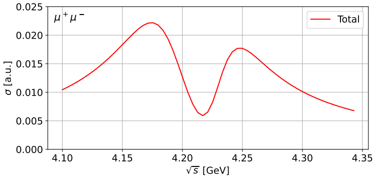
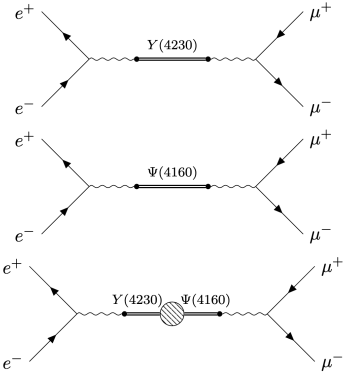
$\mu^+\mu^-$







- Only 1 free real parameter
- Reproduce destructive interference between $Y(4230)$ and $\Psi(4160)$ observed in data

Conclusion

Parameterize $Y(4230)$ as a hadronic molecule
$\longrightarrow$ coupling to two hadron continuum gets maximal

$$\sqrt{s_{\text{pole}}} = m - i\frac{\Gamma}{2} \longrightarrow m_{Y(4230)} \approx 4228\,\text{MeV}, \quad \Gamma_{Y(4230)} \approx 46\,\text{MeV}$$

- Able to describe the asymmetry observed in $J/\psi\pi\pi$ with a single pole
- Strong impact of $\bar{D}_1 D$ continuum in $D^{*-}D^0\pi^+$
- Inclusion of $\Psi(4160)$ allows to describe multiple final states with consistent parameters
  $\longrightarrow$ Fit determines in which channel $\Psi(4160)$ contributes

Single channel Breit-Wigner analysis should be avoided!

Outlook:

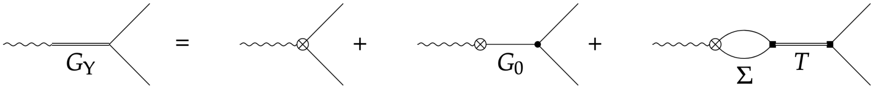
Coupled channel analysis with complete $\{D, D^*\} \otimes \{D_1, D_2\}$ multiplet and SU(3) strangeness

Appendix

Y(4230)

Parameterize Y(4230) as $D_1 D$ bound state

$$T = V - V\Sigma T$$



$$g_{\gamma D_1 D} G_Y = (c - \alpha G_0 y_0) \cdot (1 + \Sigma T) \qquad \text{with} \;\; \mathrm{disc} G_Y = 2iT^* \sigma G_Y$$

$J^{PC} = 1^{--}$ isosinglet wavefunction

$$|Y(4230)(\mathcal{C} = -1, I = 0)\rangle = -\frac{1}{2}\left(|D_1^+ D^-\rangle + |D^+ D_1^-\rangle + |D_1^0 \bar{D}^0\rangle + |D^0 \bar{D}_1^0\rangle\right)$$

Lagrangian constructed by imposing invariance under heavy-quark spin and chiral symmetry

$D^* D\pi$ parameterisation

$$i\mathcal{M}^{ij}_{D^* D\pi} = -i\bar{v}(k_1)\gamma^i u(k_2) G'_{\Upsilon} \left\{ A_S \delta^{ij} - A'_D \left(3p^i_\pi p^j_\pi - p^2_\pi \delta^{ij} \right) \right\} \epsilon^j_{D^*}$$

$$\begin{aligned}
G'_Y =& \frac{e^2 m_Y^2}{f_Y E^2} G_Y(E) \\
G_Y(E) =& \frac{1}{E - m_0 + \Sigma_{D_1 D}(-y^2 + 2g_1(E - m_0))} \\
G_Z(E) =& \frac{1}{E - m_0 + \Sigma_{D^* D}((E - m_0)g_2 - z^2)} \\
A'_D =& \frac{h_1^\pi y}{\sqrt{2}} \left[G_{D_1}(E_{D^*\pi}) - 2z^2 \mathcal{T}_1 G_Z(E_{D^* D}) \right] \\
A_s =& \alpha_1(\alpha_2 + s_{DD^*}) G_Z(s_{DD^*}) \omega_\pi
\end{aligned}$$

$J/\psi\pi\pi$ parameterisation

$$
\begin{aligned}
i\mathcal{M}^{ik} =& i\frac{1}{\sqrt{2}}\bar{v}(k_1)\gamma^i u(k_2)G_Y'' \Big[\quad \mathcal{M}_{\text{CT}}^{ik} + (\mathcal{M}^{\triangle})^{ik} \\
& - (3p_1^i p_1^j - \delta^{ij} p_1^2) \Big[\\
& C^{\text{I}} \left[q_{\text{I}}^k p_2^j - p_2^k q_{\text{I}}^j - \delta^{kj}(p_2 \cdot q_{\text{I}}) \right] \\
& + C^{\text{II}} \left[p_2^k q_{\text{II}}^j - \delta^{jk}(p_2 \cdot q_{\text{II}}) \right] \\
& + C^{\text{III}} p_2^j q_{\text{III}}^k \quad \Big] \quad \Big] \epsilon_{J/\psi}^k + \frac{1}{\sqrt{2}}(p_1 \leftrightarrow p_2)
\end{aligned}
$$

$$
\vec{\mathcal{M}}_{\text{CT}} = \Omega \vec{\mathcal{N}}
$$

match to ChPT expression

$$
\mathcal{M}_{\text{CT}}^{\pi\pi} = \Omega_{\pi\pi} \frac{2}{f_\pi^2} \sqrt{m_{mJ/\psi}} \left[c_1(s_{12} - m_\pi^2) + \frac{c_2}{2} \left\{ s_{12} + q^2 \left(1 - \frac{\sigma_{\pi\pi}^2}{3} \right) \right\} \right]
$$