# Charmonium coupling to charmed mesons

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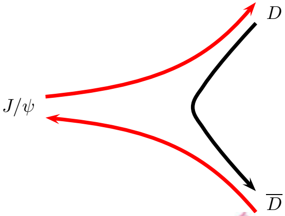
# Outline

# History and motivation

- Preferred coupling $\phi \to K\overline{K}$ led Zweig to propose quarks ("aces").
- $\phi \to K\overline{K}$ large and $\phi \to \pi$'s small formalized as OZI rule or A-Z rule.
- 1974: $J/\psi$ and $\psi'$ discovered and found even more narrow than expected. States above the threshold broad, and decay mainly into $D^{(\star)}\overline{D}^{(\star)}$.

- OZI rule working better than expected by asymptotic freedom of QCD.
- Confirmed in the $\Upsilon$ spectrum.
- Important to study $\phi \to K\overline{K}$, $\psi \to D\overline{D}$, $\Upsilon \to B\overline{B}$, ...
- 

Related topics

## Spin forces in charmonium

- The absorptive part of $(c\bar{c}) \to (c\bar{q}) + (\bar{c}q) \Rightarrow$ decay.
- Dispersive part is more delicate: energy dependence, off-shell dependence.
- Could be important, especially near the threshold
- For instance, it was predicted that $\eta_c'$ should be higher than naively predicted in potential model.
- $\eta_c'$ was not seen in the $p\bar{p}$ formation experiment at Fermilab, looking too low in the mass range,
- It was eventually seen in $B$ factories.

Related topics

## molecules or multiquarks vs. charmonium

Recurrent issue, from the very beginning of charmonium physics.

- At the end of 1974 (published in 1975), Iwazaki proposed that $J/\psi = (c\bar{c})$ but $\psi' = (c\bar{c}\, q\bar{q})$,
- At that time, Regge trajectories were well studied, and within the quark model, the orbital excitations were more commonly discussed than the radial ones,
- In 1976, Okun and Voloshin suggested $D^{(\star)}\overline{D}^{(\star)}$ molecules
- In 1976, De Rujula, Georgi and Glashow also noticed intriguing branching ratios of $\psi(4.03)$ into $D\overline{D}$, $D^\star\overline{D} + \mathrm{c.c.}$ and $D^\star\overline{D}^\star$, and concluded it is a $D^\star\overline{D}^\star$ molecule.
  *"Be not ashamed of mistakes . . . "* (Confucius)
- However, Le Yaouanc et al., and independently, Eichten et al., explained that the pattern of branching ratios was due to the node structure of $(c\bar{c})$.

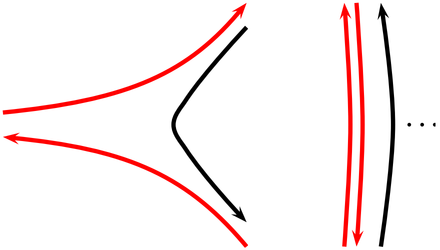
Related topics

## molecules or multiquarks vs. charmonium-2

- In 1991, Törnqvist proposed $D^\star\overline{D} + \mathrm{c.c.}$ molecules based on pion-exchange.
- See, also, Manohar, Ericson and Karl, Voloshin, Braaten, Swanson, etc., for contributions to this model,
- So when the $X(3872)$ was found, it was greeted as a success of the molecular model,
- But recent results on $X(3872)$ hardly explained in this approach, as $X \to \gamma\psi(2S)/X \to \gamma\psi(1S)$
- Likely X(3872) is a coherent mixture of $(c\bar{c})$ and $(D^\star\overline{D} + \mathrm{c.c.}$, and one needs the $(c\bar{c}) \leftrightarrow (c\bar{q}) + (\bar{c}q)$,
- Note that this model also exhibits attractive forces for $D^\star\overline{D}^\star$ and for some $D^{(\star)}D^{(\star)}$ configurations with charm $= +2$.

## Related topics
# Heavy quarks and nuclear physics

- Pion-exchange binds other hadrons containing heavy quarks,
- In particular $(ccq)+(ccq)$, hence a whole Mendeleev table of nuclei made of charmed baryons to be expected,
- Charmonium binding to nuclei. $(c\bar{c}) \to (c\bar{q}) + (\bar{c}q)$ has the same topology as $(\bar{c}cq\ldots) \to (\bar{c}cq\ldots)$. Hence it is somewhat a crossed channel of $J/\psi$(or $\eta_c-$)–nucleus.



Related topics

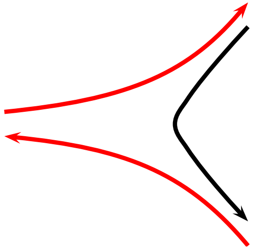
# Charmonium decay

The systematics is far from being fully understood. But some pattern emerges:

- OZI rule. States below the open charm sector are narrow.
- OZI rule in the light sector, $\phi + X$ vs. $\omega + X$,
- $(\psi' \to X)/(J/\psi \to X)$ about the same for most final states $X$, except for a tendency to slightly larger multiplicity in $\psi'$
- and the famous $\rho\pi$ puzzle, here for years ($J/\psi \to \rho\pi$ large, $\psi' \to \rho\pi \simeq 0$)
- *"Even if you do not find a solution, the question remains."* (Confucius)
- Solution perhaps in the role of virtual $D^{(\star)}\overline{D}^{(\star)}$ (Qiang Zhao et al.)
- Probably very subtle $(D\overline{D})$ interplay for some decays.

Theory
# Quark models with pair creation

- Quark models with pair creation



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- $^3\mathrm{P}_0$ model, i.e., pair created with *vacuum* quantum numbers,
- A variant is the Cornell model (Eichten et al.)
- Successful for decay of higher charmonium
- Not fully convincing for mass splittings (See Barnes and Swanson)

# QCD sum rules

- Duality principle: in the past $s$-channel vs./ $t$-channel, more recently hadrons vs. quarks, short distance vs. large distance,
- QCD sum rules, since 32 years, with an impressive amount of results,
- For charmonium–charmed-mesons, first series of works by the Sao Paulo team, M. Nielsen et al.
- $J/\psi - D - \overline{D}$ and $J/\psi - D - \overline{D}^{\star}$ with various types of offshellness,
- Now resumed by a Beijing-Montpellier-Lyon-SaoPaulo collaboration,
- Towards a systematics.

QCD sum rules

## Ongoing work

### Collaboration

Ze-kun Guo, Qiang Zhao, Yuan-Jiang Zhang, Xiao-Hai Liu (IHEP), S. Narison (Montpellier), M. Nielsen (Sao Paulo) and collaborators, JMR + a coming thesis student (Lyon)

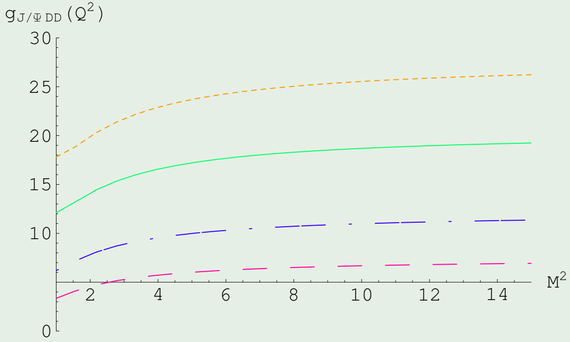
### Activity

- Visit of QZ + YG + YZ at Lyon in March 2010,
- Visit QZ at Montpellier and talk at QCD10
- Visit JMR to Beijing, and talk at Charm2010
- Two meetings with our Brazilian collaborators

### Aims

- Compare variants of QCD sum rules, in particular LC-QCD
- # twists vs. power counting,
- Analyse stability with respect to the LR-SR transition,
- Higher-order terms in the SR part,

## Example




Here $Q^2 = 0$, 1, 3, and 5, $\mathrm{GeV}^2$

Dozens of similar plots to be analysed before the results can be validated.

# Conclusions

- Charm physics on the forefront of QCD
- Charmonium–charmed meson coupling directly linked to results from BES and B factories
- Slow but significant progress from our collaboration,