Some rare decays of $\psi(3770)$

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Outline

History

Observation of a Resonance in e^+e^- Annihilation Just above Charm Threshold

G. J. Feldman, J. M. Feller, A. Fong, G. Hanson, J. A. Jaros, B. P. Kwan, P. Lecomte, A. M. Litke, R. J. Madaras, J. F. Martin, T. S. Mast, D. H. Miller, S. I. Parker, M. L. Perl, I. Peruzzi,[a] M. Piccolo,[a] T. P. Pun, M. T. Ronan, R. R. Ross, B. Sadoulet, T. G. Trippe, V. Vuillemin, and D. E. Yount

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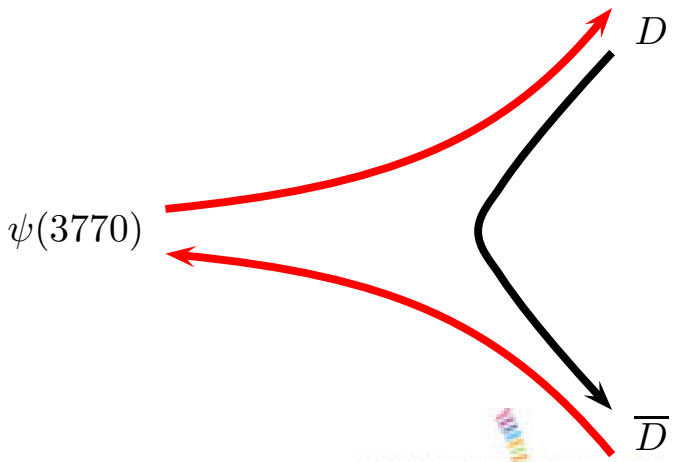
We observe a resonance in the total cross section for hadron production in e^+e^- annihilation at a mass of 3772 ± 6 MeV/c^2 having a total width of 28 ± 5 MeV/c^2 and a partial width to electron pairs of 370 ± 90 eV/c^2.

History and motivation

- J/ψ narrow since its $D\bar{D}$ decay is forbidden,
- ψ', $\psi(3770)$ and higher ψ decay mainly into $D^{(*)}\bar{D}^{(*)}$ (OZI rule)
- non-$D\bar{D}$ decay of $\psi(3770)$ seen and studied,
- already in the 70s, $\psi(3770) \to e^+e^-$ much debated ($S-D$ mixing, and origin of this mixing: quark tensor forces or mixing through $D^{(*)}\bar{D}^{(*)}$)

- J/ψ decay and non $D\bar{D}$ decay of ψ' usually rather similar,
- with noticeable exceptions, such as $\rho\pi$
- interesting to study how $\psi(3770)$ behaves on this respect,



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Structure of the $\psi(3770)$

- In the simplest version of the quark model, S-D mixing induced by tensor forces,
- Analogous to S-D mixing in the deuteron,
- This results into coupled equations,
- Sometimes approximated by a simple mixing scheme

$$\psi(3770) = a|^3D_1\rangle + b_1|^3S_1, n = 1\rangle + b_2|^3S_1, n = 2\rangle + \cdots$$

- b_2 favoured by the vicinity of $\psi(3770)$ and ψ',
- b_1 favoured by the node structure.

Related topics

Molecular charmonium

- $D^{(*)}\bar{D}^{(*)}$ have been proposed since the beginning of charmonium physics,
- renewed activity with the discovery of $X(3872)$, Y, Z states, and their analogues in the b sector,
- conversely, renewed interest for $D^{(*)}\bar{D}^{(*)}$ admixtures into states which are mainly $c\bar{c}$,
- in particular, $\psi(3770)$ now becomes

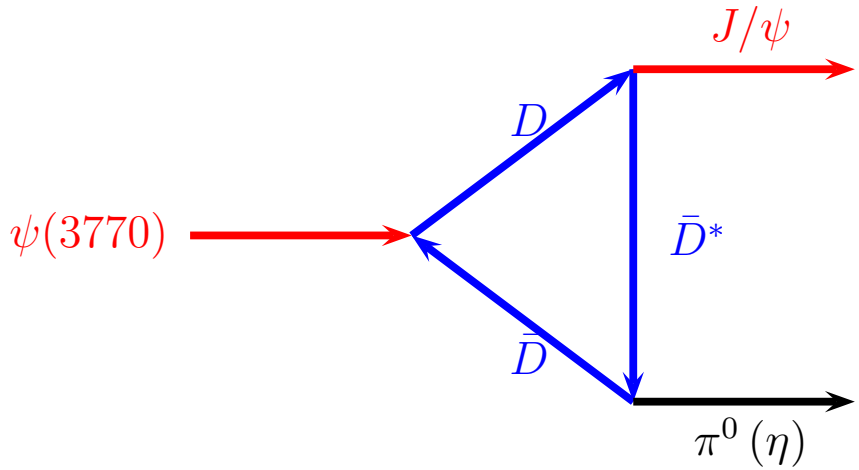
$$\psi(3770) = a|^3D_1\rangle + \sum_n b_n|^3S_1, n\rangle + \sum_i c_i|D_i^{(*)}\bar{D}_i^{(*)}\rangle + \cdots$$

with sum over spin and flavour excitations of D

$\psi(3770)$ decay

- CLEO $R(\text{non}D\bar{D})$ consistent with 0 and certainly less than 7%
- BES $R \sim 15\%$
- Zhi-Guo He, Ying Fan, and Kuang-Ta Chao: about 5% in an elaborate NRQCD
- Yuan-Jiang Zhang, Gang Li, and Qiang Zhao and Xiang Liu, Bo Zhang, Xue-Qian Li suggested a contribution of $D\bar{D}$ to non-$D\bar{D}$ decay.
- applied here to $\psi(3770) \to J\psi + \pi^0$
- Exp. $R(\psi(3770) \to J\psi\eta = (9 \pm 4) \times 10^{-4}$
- from $eta - \pi^0$ mixing alone, one would expect $R(\psi(3770) \to J\psi\pi^0\ 10^{-6}$
- aim: meson loop effect

Mechanism



- Coupling described by effective Lagrangians,

$$\begin{aligned}
\mathcal{L}_{\psi'' DD} &= -ig_{\psi'' DD}\psi''^{\mu} D_i^{\dagger} \overleftrightarrow{\partial_\mu} D_i \ , \\
\mathcal{L}_{\psi DD^*} &= g_{\psi DD^*}\epsilon_{\mu\nu\alpha\beta}\partial^\mu \psi_n^\nu \{D_i^{*\beta\dagger} \overleftrightarrow{\partial^\alpha} D_i - D_i^{\dagger} \overleftrightarrow{\partial^\alpha} D_i^{*\beta}\} \ , \\
\mathcal{L}_{D^* D\pi} &= -ig_{D^* DP}\left(D^i \partial^\mu P_{ij} D_\mu^{*j\dagger} - D_\mu^{*i}\partial^\mu P_{ij} D^{j\dagger}\right) \ ,
\end{aligned}$$

- and, the most demanding, a careful study of the form factors at each vertex.

QCD SR

- The form factors were studied with QCD SR
- analysis of the dependence upon the usual parameters of QCD SR (threshold, quark masses, masses involved in the Borel transform, etc.)
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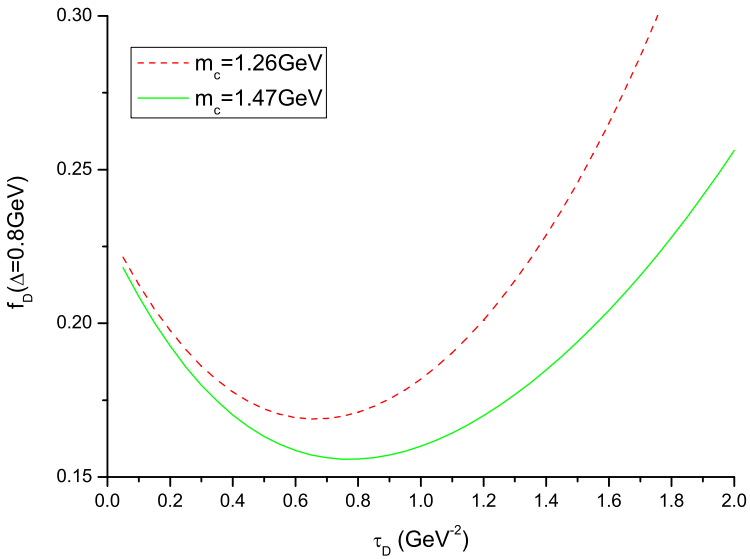

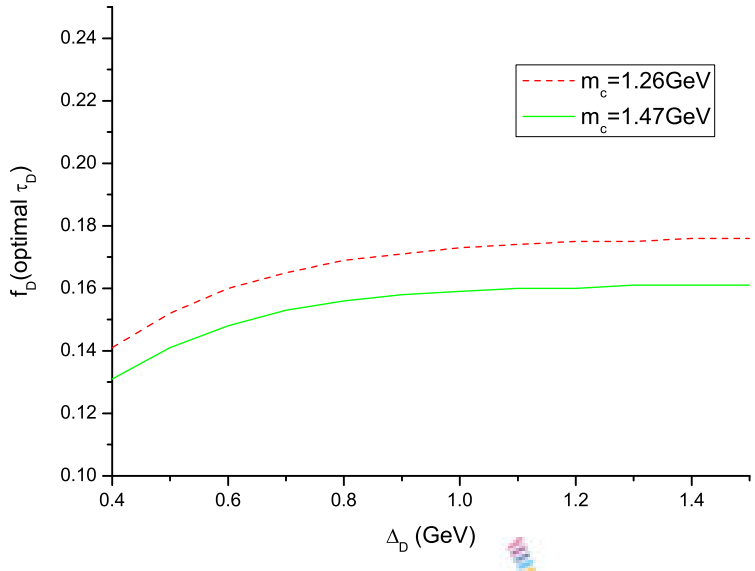

Isospin violation

- Masses in the loop
- $g(\psi(3770)D^+D^-)$ and $g(\psi(3770)D^0\bar{D}^0)$, to account for the observed branching ratios. But the error bar are large.
- With the largest effect here, one can reach

$$R \sim 5 \times 10^{-5}$$

- isospin violation in $J\psi \to D\bar{D}^*$ remains open

Conclusions and outlook

- This paper will be published shortly
- Isospin violation very important in charmonium
  - $\psi' \to J/\psi + \pi$ in the early days of charmonium
  - $X(3872)$
- Physics of $\psi(3770)$ very rich
- Role of hadron loops: hot issue
- Many projects in heavy quark physics for this collaboration: X, Y, Z states, other exotics
- Develop expertise in QCD SR
- *"Care your weakness and develop your skills"* (Confucius)