# Hadronic Properties of Higher Excited Charmed Mesons

张爱林

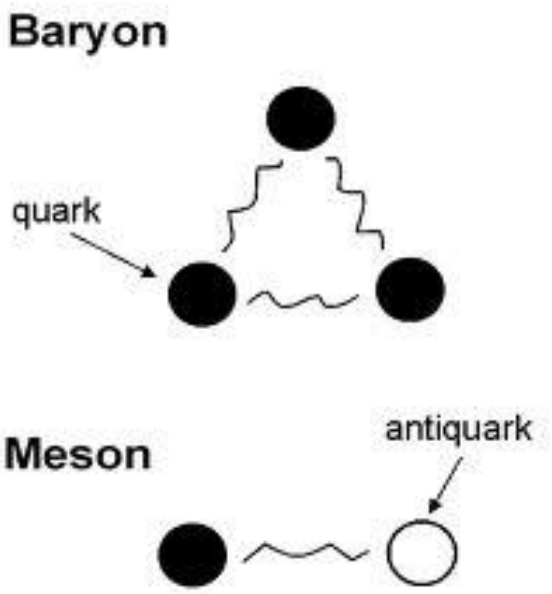
上海大学

# Outline

- 1. Introduction
- 2. Higher excited charmed mesons
- 3. Conclusions and discussions

# 1. Introduction

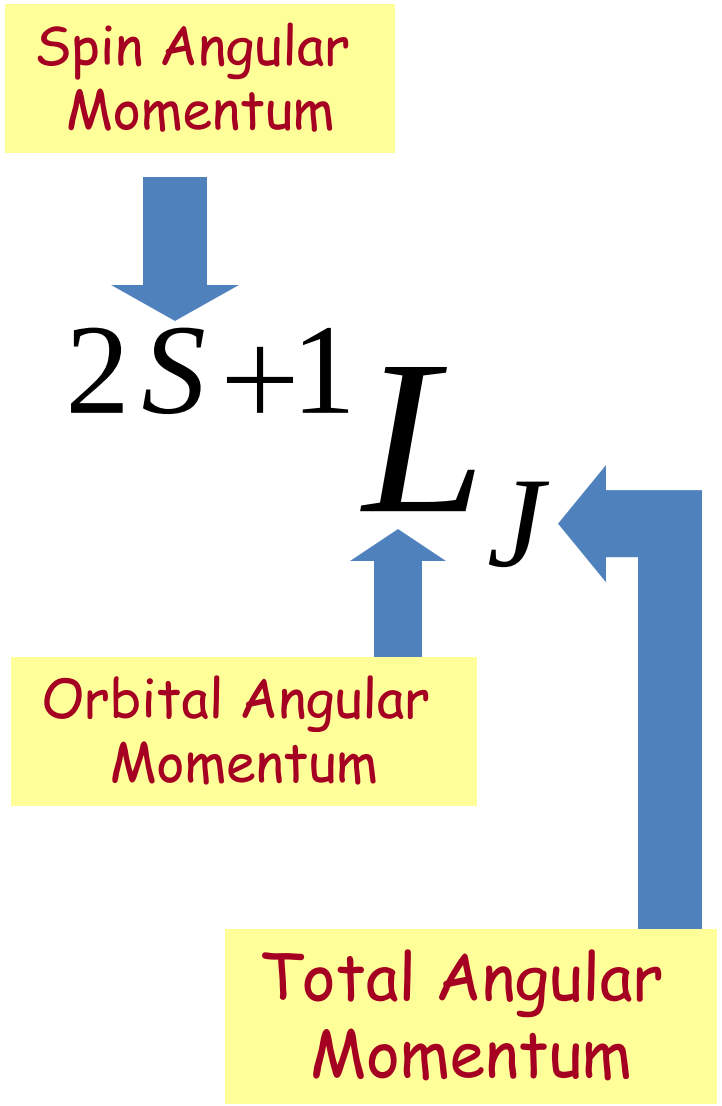
## Charmed mesons




Mesons are often denoted by $n^{2S+1}L_J$(similar to hydrogen atom) with quantum numbers $J^{PC}$, or $J^P$ .

n: radial excited numbers
P: parity
C: charge conjugate
(only neutral mesons have definite C)

**Heavy-light systems:**
**Interactions,**
**Heavy quark symmetry,**
**Chiral symmetry**




**natural parity**

$$J^P = 0^+, 1^-, 2^+, \cdots$$

$$P = (-1)^J$$

**unnatural parity**

$$J^P = 0^-, 1^+, 2^-, \cdots$$

# Two kinds of classification schemes of $D_s$, $^{2S+1}L_J$ or the $j^P$ eigenstates

**Nonrelativistic:**

$$n^{2S+1}L_J$$

$$\left|J = L, j_q = L + \frac{1}{2}\right\rangle = \sqrt{\frac{J+1}{2J+1}}|J = L, S = 0\rangle + \sqrt{\frac{J}{2J+1}}|J = L, S = 1\rangle$$

**Heavy quark symmetric:**

$$nj^P$$

$$\left|J = L, j_q = L - \frac{1}{2}\right\rangle = -\sqrt{\frac{J}{2J+1}}|J = L, S = 0\rangle + \sqrt{\frac{J+1}{2J+1}}|J = L, S = 1\rangle.$$

# Physical states may not be the $^{2S+1}L_J$ or the $j^P$ eigenstates! Mixing!

$$\begin{bmatrix} Q^{c\bar{q}}_{\text{low}} \\ Q^{c\bar{q}}_{\text{high}} \end{bmatrix} \simeq \begin{bmatrix} \cos\theta^{c\bar{q}}_{nL} & \sin\theta^{c\bar{q}}_{nL} \\ -\sin\theta^{c\bar{q}}_{nL} & \cos\theta^{c\bar{q}}_{nL} \end{bmatrix} \begin{bmatrix} n\,{}^1L_L \\ n\,{}^3L_L \end{bmatrix}$$

$$\theta^{c\bar{u}}_{1P} \simeq -41^0, \quad \theta^{c\bar{u}}_{1D} \simeq -39^0, \quad \theta^{c\bar{s}}_{1P} \simeq -44^0, \quad \theta^{c\bar{s}}_{1D} \simeq -39^0$$

Phys.Rev.D32,189(1985)

$$\theta_P = \tan^{-1}(-1/\sqrt{2}) \simeq -35.3^\circ \qquad \theta_D = -\tan^{-1}(\sqrt{2/3}) = -39.2^\circ$$

## ♢ Heavy quark symmetry

$$SU(2N_f)$$

Vanishing hyperfine splitting effects, degenerate spin multiplets

Ground state: $j^P = \frac{1}{2}^-$

Doublet: $J^P = (0^-, 1^-)(^1S_0, \, ^3S_1)$

The first excited states(a P-wave excitation): $j^P = \frac{1}{2}^+$ or $\frac{3}{2}^+$

Two doublets: $J^P = (0^+, 1^+)$ and $J^P = (1^+, 2^+)$

## ♢ Light quark chiral symmetry

$SU(2)_L \times SU(2)_R$ (1994), $SU(3)_L \times SU(3)_R$ (2003)

Parity degeneracy

$j^P = \frac{1}{2}^-$ multiplet degenerate with $j^P = \frac{1}{2}^+$ multiplet

$(0^+, 1^+)$ degenerate with $(0^-, 1^-)$

Chiral symmetry breaking

elevating $(0^+, 1^+)$ while depressing $(0^-, 1^-)$

Mass splitting between these parity partners(the even and odd parity multiplets)

$$\Delta M = g_\pi f_\pi$$

where $g_\pi$ is the $0^+ \to 0^- \pi$ coupling constant, and $\Delta M(\infty) \approx 338$ MeV

# References:


**Relativized quark model**

S. Godfrey and N.Isgur, Phys. Rev. D32, 189(1985) GI

S. Godfrey and R. Kokoski, Phys. Rev. D43,1679(1991)

F.E. Close and E.S. Swanson, Phys. Rev. D72, 094004(2005)

S. Godfrey and K. Moats, Phys. Rev. D93,034035(2016) GM

**Heavy quark symmetry theory**

E.J. Eichten, C.T. Hill and C. Quigg, Phys. Rev. Lett. 71, 4116(1993)

Zhi-Gang Wang, Phys. Rev. D 88, 114003(2013)

Bing Chen, Xiang Liu and Ailin Zhang, Phys. Rev.D92,034005(2016)

**Chiral quark model**

M.Di Pierro and E. Eichten, Phys. Rev. D64, 114004(2001)

Xian-Hui Zhong and Qiang Zhao, Phys. Phys. Rev. D78, 014029(2008); D81, 014031(2010)

Li-Ye Xiao and Xian-Hui Zhong, Phys. Rev. D 90, 074029(2014)

**Constituent quark model**
**(heavy quark symmetry + light quark chiral symmetry)**

M.A. Nowak, M. Rho and I. Zahed , Phys. Rev. D48, 4730(1993)
W.A. Bardeen and C.T. Hill, Phys. Rev. D49, 409(1994)
W.A. Bardeen, E.J. Eichten and C.T. Hill, Phys. Rev. D68, 054024(2003)
P. Colangelo, et al., Phys. Rev. D86, 054024(2012)

**Mass loaded flux tube model**

T.J. Allen, T. Coleman, M.G. Olsson and S. Veleli, Phys. Rev. D69, 074010(2004)
Hong-Yun Shan and Ailin Zhang, Chin. Phys. C34, 16(2010).
Bing Chen, Deng-Xia Wang and Ailin Zhang, Phys. Rev. D80, 071502(R)(2009)

**Coupled channels model**

Eef van Beveren and George Rupp, Phys. Rev. Lett. 91, 012003(2003)
Yu.A. Simonov and J.A. Tjon, Phys. Rev. D70, 114013(2004)
Eef van Beveren and George Rupp, Phys. Rev. Lett. 97, 202001(2006)

**Lattice QCD**

J. Hein, et al., Phys. Rev. D62, 074503(2000)
A. Dougall, et al., UKQCD, Phys.Lett. B. B569, 41 (2003)
C. Daniel Mohler and R. M. Woloshyn, Phys. Rev. D84, 054505 (2011)

## $^3P_0$ model

Bo Zhang, Xiang Liu, Wei-Zhen Deng and Shi-Lin Zhu, Eur.Phys.J. C50, 617(2007)

Zhi-Feng Sun, Jie-Sheng Yu, Xiang Liu, and Takayuki Matsuki, Phys. Rev. D 82, 111501(R)(2010)

De-Min Li and Bing Ma, Phys. Rev. D 81, 014021(2010)

Ling Yuan, Bing Chen and Ailin Zhang, arXiv:1203.0370

Jing Ge, Dan-Dan Ye and Ailin Zhang, Eur.Phys.J. C75, 178(2015)

Ze Zhao, Yu Tian and Ailin Zhang, arXiv: 1610.08202

**Other models**

Yu.S. Kalashnikova, A.V. Nefediev and Yu. A. Simonov, Phys. Rev. D64, 014037(2001)

Ailin Zhang, Phys. Rev. D72 , 017902(2005)

J. Erdmenger, N. Evans and J. Grosse, JHEP 0701, 098(2007)

Ailin Zhang, Nucl.Phys. A856, 88(2011)

Bing Chen, Ling Yuan, and Ailin Zhang, Phys. Rev. D83, 114025(2011)

A. M. Badalian and B. L. G. Bakke, Phys. Rev. D 84, 034006(2011)

**Review**

P. Colangelo, F. De Fazio and R. Ferrandes, Mod. Phys. Lett. A19, 2083(2004)

E.S. Swanson, Phys. Rept. 429, 243(2006)

J.L. Rosner, J. Phys. G34, S127(2007)

Shi-Lin Zhu, Int. J. Mod. Phys. E17, 28(2008)

Hua-Xing Chen, et al., arXiv: 1609.08928

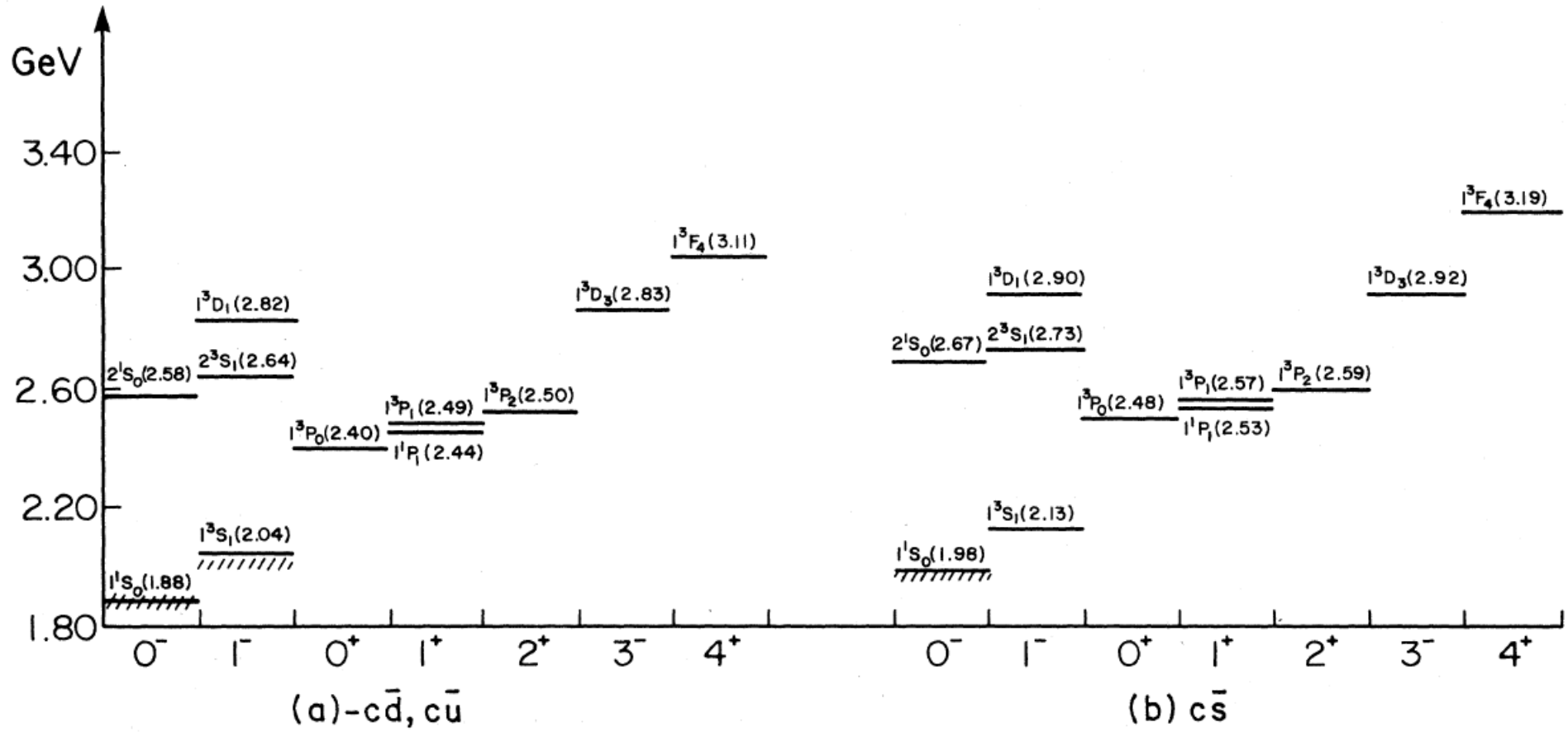
# Theoretical prediction of the charmed mesons spectrum

PHYSICAL REVIEW D VOLUME 32, NUMBER 1 1 JULY 1985

## Mesons in a relativized quark model with chromodynamics

Stephen Godfrey and Nathan Isgur

We show that mesons—from the $\pi$ to the $\Upsilon$—can be described in a unified quark model with chromodynamics. The key ingredient of the model is a universal one-gluon-exchange-plus-linear-confinement potential motivated by QCD, but it is crucial to the success of the description to take into account relativistic effects. The spectroscopic results of the model are supported by an extensive analysis of strong, electromagnetic, and weak meson couplings.




Phys.Rev.D32,189(1985)

# Theoretical prediction of the charmed mesons spectroscopy

PHYSICAL REVIEW D **93,** 034035 (2016)

## Properties of excited charm and charm-strange mesons

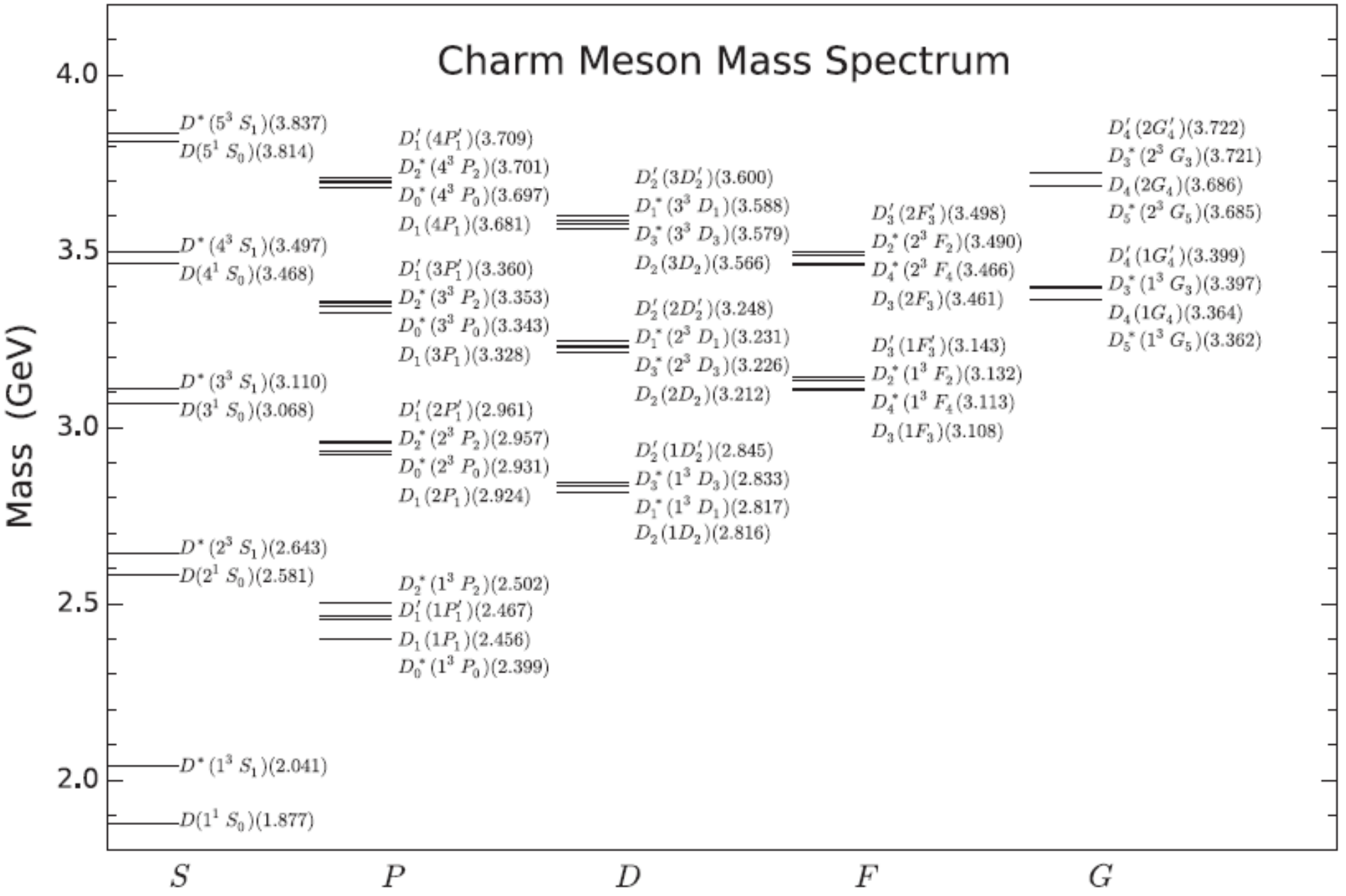
Stephen Godfrey* and Kenneth Moats

*Department of Physics, Ottawa-Carleton Institute for Physics, Carleton University, Ottawa, Ontario K1S 5B6, Canada*

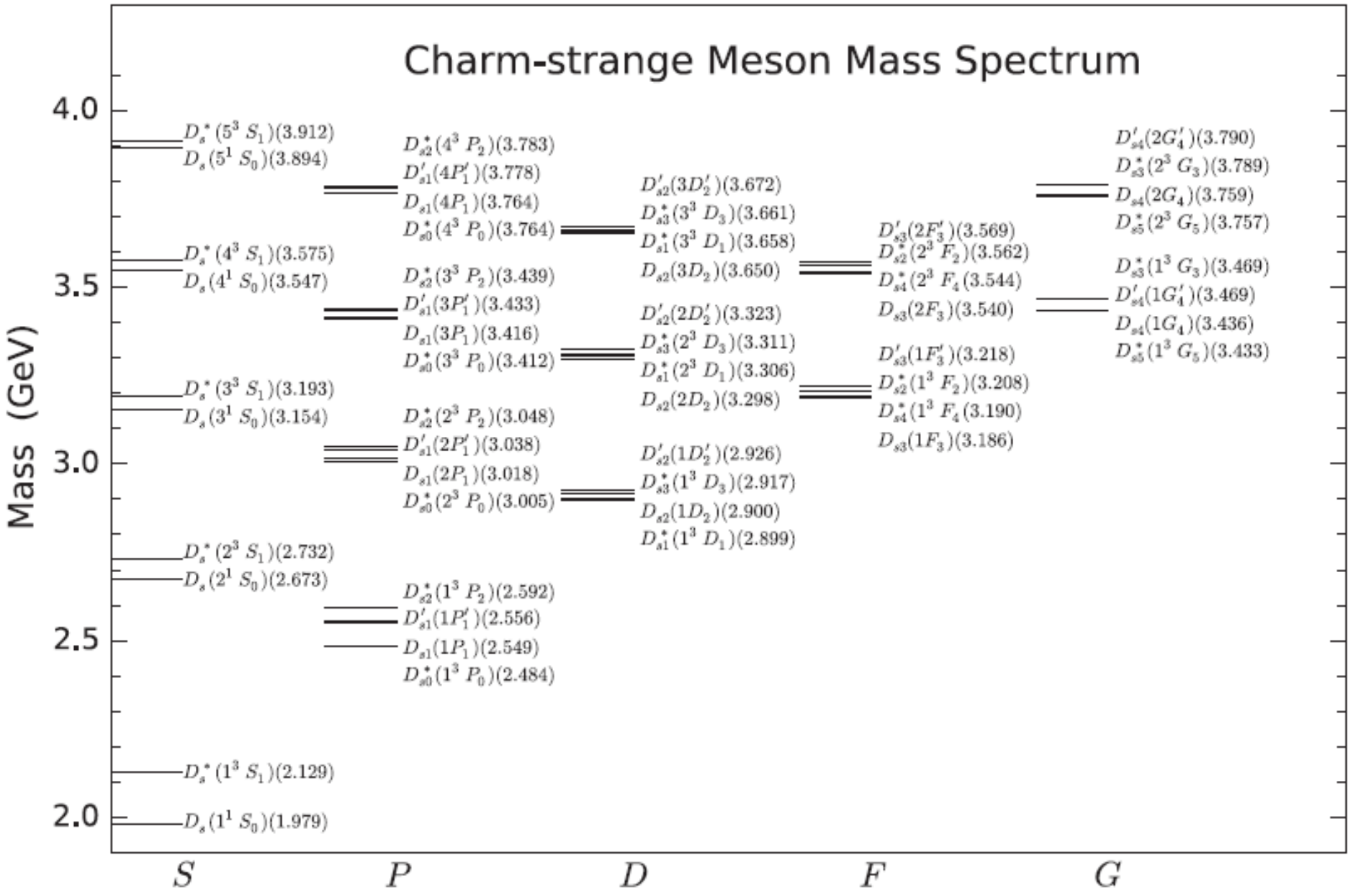
(Received 2 December 2015; published 23 February 2016)

We calculate the properties of excited charm and charm-strange mesons. We use the relativized quark model to calculate their masses and wave functions that are used to calculate radiative transition partial widths and the $^3P_0$ quark-pair-creation model to calculate their strong decay widths. We use these results to make quark model spectroscopic assignments for recently observed charm and charm-strange mesons. In particular, we find that the properties of the $D_J(2550)^0$ and $D_J^*(2600)^0$ are consistent with those of the $2^1S_0(c\bar{u})$ and the $2^3S_1(c\bar{u})$ states respectively, and the $D_1^*(2760)^0$, $D_3^*(2760)^-$, and $D_J(2750)^0$ with those of the $1^3D_1(c\bar{u})$, $1^3D_3(d\bar{c})$, and $1D_2(c\bar{u})$ states respectively. We tentatively identify the $D_J^*(3000)^0$ as the $1^3F_4(c\bar{u})$ and favor the $D_J(3000)^0$ to be the $3^1S_0(c\bar{u})$ although we do not rule out the $1F_3$ and $1F_3'$ assignment. For the recently observed charm-strange mesons we identify the $D_{s1}^*(2709)^{\pm}$, $D_{s1}^*(2860)^-$, and $D_{s3}^*(2860)^-$ as the $2^3S_1(c\bar{s})$, $1^3D_1(s\bar{c})$, and $1^3D_3(s\bar{c})$ states respectively and suggest that the $D_{sJ}(3044)^{\pm}$ is most likely the $D_{s1}(2P_1')$ or $D_{s1}(2P_1)$ state although it might be the $D_{s2}^*(2^3P_2)$ with the $DK$ final state too small to be observed with current statistics. Based on the predicted properties of excited states, that they do not have too large a total width and that they have a reasonable branching ratio to simple final states, we suggest states that should be able to be found in the near future. We expect that the tables of properties summarizing our results will be useful for interpreting future observations of charm and charm-strange mesons.

DOI: 10.1103/PhysRevD.93.034035




Phys.Rev.D93,034035(2016)




Phys.Rev.D93,034035(2016)

## Mixing between the orbital D-wave $|1^-\rangle$ and the first radial S-wave $|1^-\rangle$

$$|(SD)_1\rangle_L = cos\theta|2^3S_1\rangle - sin\theta|1^3D_1\rangle$$
$$|(SD)_1\rangle_R = sin\theta|2^3S_1\rangle + cos\theta|1^3D_1\rangle,$$

## Mixing between orbital P-wave

$$P = {}^1P_1 \cos\theta_{nP} + {}^3P_1 \sin\theta_{nP}$$
$$P' = -{}^1P_1 \sin\theta_{nP} + {}^3P_1 \cos\theta_{nP}$$

# Mixing between orbital D-wave

$$\left|J = L, j_q = L + \frac{1}{2}\right\rangle = \sqrt{\frac{J+1}{2J+1}}|J = L, S = 0\rangle + \sqrt{\frac{J}{2J+1}}|J = L, S = 1\rangle$$

$$\left|J = L, j_q = L - \frac{1}{2}\right\rangle = -\sqrt{\frac{J}{2J+1}}|J = L, S = 0\rangle + \sqrt{\frac{J+1}{2J+1}}|J = L, S = 1\rangle.$$

$$\theta_D = -\tan^{-1}(\sqrt{2/3}) = -39.2^\circ$$

**Radiative transitions are sensitive to the $^3L_L$ – $^1L_L$ mixing angle!**

# S-wave and P-wave D is believed established

| $c\bar{u},\ c\bar{d}$ | $J^P$ | $j^P$ | $n^{2S+1}L_J$ | GI | GM |
|---|---|---|---|---|---|
| $D$ | $0^-$ | $\frac{1}{2}^-$ | $1^1S_0$ | 1.98 | 1.877 |
| $D^*$ | $1^-$ | $\frac{1}{2}^-$ | $1^3S_1$ | 2.13 | 2.041 |
| $D_0^*(2400)$ | $0^+$ | $\frac{1}{2}^+$ | $1^3P_0$ | 2.48 | 2.399 |
| $D_1(2420)$ | $1^+$ | $(\frac{3}{2}^+)$ | $1^3P_1$ | 2.57 | 2.456 |
| $D_1'(2430)$ | $1^+$ | $(\frac{1}{2}^+)$ | $1^1P_1$ | 2.53 | 2.467 |
| $D_2^*(2460)$ | $2^+$ | $\frac{3}{2}^+$ | $1^3P_2$ | 2.59 | 2.502 |

**Higher excited D have been observed**

# S-wave and P-wave $D_s$ is believed established

| $c\bar{s}$ | $J^P$ | $j^P$ | $n^{2S+1}L_J$ | GI | GM |
|---|---|---|---|---|---|
| $D_s$ | $0^-$ | $\frac{1}{2}^-$ | $1^1S_0$ | 1.98 | 1.979 |
| $D_s^*$ | $1^-$ | $\frac{1}{2}^-$ | $1^3S_1$ | 2.13 | 2.129 |
| $D_{s0}^*(2317)$ | $0^+$ | $\frac{1}{2}^+$ | $1^3P_0$ | 2.48 | 2.484 |
| $D_{s1}(2536)^{\pm}$ | $1^+$ | $(\frac{3}{2}^+)$ | $1^3P_1$ | 2.57 | 2.549 |
| $D_{s1}(2460)^{\pm}$ | $1^+$ | $(\frac{1}{2}^+)$ | $1^1P_1$ | 2.53 | 2.556 |
| $D_{s2}(2573)^{\pm}$ | $2^+$ | $\frac{3}{2}^+$ | $1^3P_2$ | 2.59 | 2.592 |

**Higher excited $D_s$ have also been observed**

# 2. Higher excited charmed mesons

## D mesons

- D(2550) $2^1S_0(c\bar{q})$

**Observed in inclusive $e^+e^-$ and pp collisions by BaBar and LHCb collaborations**

$$e^+e^- \to c\bar{c} \to D^{(*)}\pi X,$$

$$pp \to D^+\pi^- X,\ pp \to D^0\pi^+ X,\ pp \to D^{*+}\pi^- X,$$

Mass : $2564 \pm 20$ MeV ;

Decay width : $135 \pm 17$ MeV ;

## ♢ $D^*(2600)$

$2^3S_1(c\overline{q})$

$$e^+e^- \to c\bar{c} \to D^{(*)}\pi X,$$

$$pp \to D^+\pi^- X,\ pp \to D^0\pi^+ X,\ pp \to D^{*+}\pi^- X,$$

Mass: $2622 \pm 12$ MeV;

Decay width: $104 \pm 20$ MeV;

**$\Gamma(D^+\pi^-)/\Gamma(D^{*+}\pi^-)$** **$\Gamma_2/\Gamma_5$**

| *VALUE* | *EVTS* | *DOCUMENT ID* | *TECN* | *COMMENT* |
|---|---|---|---|---|
| **0.32±0.02±0.09** | 76k | DEL-AMO-SA...10P | BABR | $e^+e^- \to D^{(*)+}\pi^- X$ |

## ♢ D(2750)

$1^1D_2$ or a $1^3D_2$

$$e^+e^- \to c\bar{c} \to D^{(\star)}\pi X,$$

$$pp \to D^+\pi^- X,\ pp \to D^0\pi^+ X,\ pp \to D^{*+}\pi^- X,$$

Mass : $2763 \pm 4$ MeV ;

Decay width : $65 \pm 5$ MeV ;

## ♢ $D^*_1(2760)$

$1^3D_1(c\bar{q})$

$$e^+e^- \to c\bar{c} \to D^{(\star)}\pi X,$$

$$pp \to D^+\pi^- X,\ pp \to D^0\pi^+ X,\ pp \to D^{*+}\pi^- X,$$

**Observed also in exclusive B decay by LHCb collaboration**

$$B^- \to D^+K^-\pi^-$$

Mass : $2781 \pm 18 \pm 11 \pm 6$ MeV ;

Decay width : $177 \pm 32 \pm 20 \pm 7$ MeV ;

♢ $D^*_3(2760)$ $1^3D_3(c\bar{q})$

$$e^+e^- \to c\bar{c} \to D^{(*)}\pi X,$$

$$pp \to D^+\pi^- X,\ pp \to D^0\pi^+ X,\ pp \to D^{*+}\pi^- X,$$

**Observed also in exclusive B decay by LHCb collaboration**

$$B^0 \to \bar{D}^0\pi^+\pi^-$$

Mass : $2798 \pm 7 \pm 1 \pm 7$ MeV ;

Decay width : $105 \pm 18 \pm 6 \pm 23$ MeV ;

## ♢ D(3000)

$$e^+e^- \to c\bar{c} \to D^{(\star)}\pi X,$$

$$pp \to D^+\pi^- X,\ pp \to D^0\pi^+ X,\ pp \to D^{*+}\pi^- X,$$

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

Mass : 2971.8 ± 8.7 MeV ;

Decay width : 188.1 ± 44.8 MeV ;

**2P, 3S, and 1F**

## ♢ $D^*(3000)$

$$e^+e^- \to c\bar{c} \to D^{(*)}\pi X,$$

$$pp \to D^+\pi^- X,\ pp \to D^0\pi^+ X,\ pp \to D^{*+}\pi^- X,$$

$$D^0\pi^+$$

Mass : 3008.1 ± 4.0 MeV ;

Decay width : 110.5 ± 11.5 MeV ;

**2P, 3S, and 1F**

| $c\bar{u},\ c\bar{d}$ | $J^P$ | $j^P$ | $n^{2S+1}L_J$ | GI | GM |
|---|---|---|---|---|---|
| $D_1^*(2760)?$ | $1^-$ | $\frac{3}{2}^-$ | $1^3D_1$ | 2.82 | 2.817 |
| $D(2750)?$ | $2^-$ | $(\frac{5}{2}^-)$ | $1^3D_2$ | - | 2.816 |
| $D(2750)?$ | $2^-$ | $(\frac{3}{2}^-)$ | $1^1D_2$ | - | 2.845 |
| $D_3^*(2760)?$ | $3^-$ | $\frac{5}{2}^-$ | $1^3D_3$ | 2.83 | 2.833 |
| $D(2550)?$ | $0^-$ | $\frac{1}{2}^-$ | $2^1S_0$ | 2.58 | 2.581 |
| $D^*(2600)?$ | $1^-$ | $\frac{1}{2}^-$ | $2^3S_1$ | 2.64 | 2.643 |
| ? | $0^+$ | $\frac{1}{2}^+$ | $2^3P_0$ | - | 2.931 |
| ? | $1^+$ | $(\frac{3}{2}^+)$ | $2^3P_1$ | - | 2.924 |
| ? | $1^+$ | $(\frac{1}{2}^+)$ | $2^1P_1$ | - | 2.961 |
| ? | $2^+$ | $\frac{3}{2}^+$ | $2^3P_2$ | - | 2.957 |

# $D_s$ mesons

- $D_s(2650?)$

## ♢ $D^*_{s1}(2700)$

$2^3S_1(c\bar{s})$

$D_{s1}(2700)^{\pm}$ was first observed by Belle(K. Abe, *et al.*, Belle Collaboration, hep-ex/0608031) in

$$B^+ \to \bar{D}^0 D_{sJ} \to \bar{D}^0 D^0 K^+$$

with $M = 2715 \pm 11^{+11}_{-14}$ and $\Gamma = 115 \pm 20^{36}_{-32}$ MeV. The mass and the decay width change a little in their published version(J. Brodzicka *et al.*, Belle Collaboration, Phys. Rev. Lett. **100**, 092001 (2008))

Mass: $2708.3^{+4}_{-3.4}$ MeV;

Decay width: $120 \pm 11$ MeV;

Branching ratio: $\Gamma(D^* K)/\Gamma(D K) = 0.91 \pm 0.13 \pm 0.12$.

- $D_s(2850?)$

# $D^*_{s1}(2860)$

$1^3D_1(s\bar{c})$

$$e^+e^- \to D^0K^+X, \qquad D^0 \to K^-\pi^+, \tag{1}$$

$$e^+e^- \to D^0K^+X, \qquad D^0 \to K^-\pi^+\pi^0, \tag{2}$$

$$e^+e^- \to D^+K^0_SX, \qquad D^+ \to K^-\pi^+\pi^+, \qquad K^0_S \to \pi^+\pi^-. \tag{3}$$

Mass: $2859 \pm 12 \pm 24$ MeV;

Decay width: $159 \pm 23 \pm 77$ MeV;

**$\Gamma(D^*K)/\Gamma(DK)$** **$\Gamma_4/\Gamma_1$**

| VALUE | EVTS | DOCUMENT ID | TECN | COMMENT |
|---|---|---|---|---|
| **1.10±0.15±0.19** | 3122 | [1] AUBERT | 09AR BABR | $e^+e^- \to D^{(*)}KX$ |

[1] From the average of the corresponding ratios with $D^{(*)0}K^+$ and $D^{(*)+}K^0_S$.

**$\Gamma(D^{*0}K^+)/\Gamma(D^0K^+)$** **$\Gamma_5/\Gamma_2$**

| VALUE | EVTS | DOCUMENT ID | TECN | COMMENT |
|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |
| $1.04 \pm 0.17 \pm 0.20$ | 2241 | [1] AUBERT | 09AR BABR | $e^+e^- \to D^{(*)}KX$ |

[1] From the $D^{*0}K^+$ and $D^0K^+$, where $D^{*0} \to D^0\pi^0$.

**$\Gamma(D^{*+}K^0_S)/\Gamma(D^+K^0_S)$** **$\Gamma_6/\Gamma_3$**

| VALUE | EVTS | DOCUMENT ID | TECN | COMMENT |
|---|---|---|---|---|

## ♢ $D^*_{s3}(2860)$ $1^3D_3(s\bar{c})$

$$e^+e^- \to D^0K^+X, \quad D^0 \to K^-\pi^+, \tag{1}$$

$$e^+e^- \to D^0K^+X, \quad D^0 \to K^-\pi^+\pi^0, \tag{2}$$

$$e^+e^- \to D^+K^0_SX, \quad D^+ \to K^-\pi^+\pi^+, \quad K^0_S \to \pi^+\pi^-. \tag{3}$$

Mass: $2860.5 \pm 2.6 \pm 6.5$MeV;

Decay width: $53 \pm 7 \pm 7$MeV;

## ♢ $D_{sJ}(3040)$

$$e^+e^- \to D^{*0}K^+X$$
$$e^+e^- \to D^{*+}K^0_S X$$
$$e^+e^- \to D^{*+}K^0_S X$$
$$e^+e^- \to D^{*+}K^0_S X$$
$$e^+e^- \to D^{*+}K^0_S X$$

**BaBar**

$$\text{Mass}: \ 4044 \pm 8^{+30}_{-5} \ \text{MeV};$$

$$\text{Decay width}: \ 239 \pm 35^{+46}_{-42} \ \text{MeV};$$

| $c\bar{s}$ | $J^P$ | $j^P$ | $n^{2S+1}L_J$ | GI | GM |
|---|---|---|---|---|---|
| $D^*_{s1}(2860)?$ | $1^-$ | $\frac{3}{2}^-$ | $1^3D_1$ | 2.90 | 2.899 |
| ? | $2^-$ | $(\frac{5}{2}^-)$ | $1^3D_2$ | - | 2.900 |
| ? | $2^-$ | $(\frac{3}{2}^-)$ | $1^1D_2$ | - | 2.926 |
| $D^*_{s3}(2860)?$ | $3^-$ | $\frac{5}{2}^-$ | $1^3D_3$ | 2.92 | 2.917 |
| ? | $0^-$ | $\frac{1}{2}^-$ | $2^1S_0$ | 2.67 | 2.673 |
| $D*_{s1}(2700)?$ | $1^-$ | $\frac{1}{2}^-$ | $2^3S_1$ | 2.73 | 2.732 |
| ? | $0^+$ | $\frac{1}{2}^+$ | $2^3P_0$ | - | 3.005 |
| ? | $1^+$ | $(\frac{3}{2}^+)$ | $2^3P_1$ | - | 3.018 |
| ? | $1^+$ | $(\frac{1}{2}^+)$ | $2^1P_1$ | - | 3.038 |
| ? | $2^+$ | $\frac{3}{2}^+$ | $2^3P_2$ | - | 3.048 |

## ♢ $D^*(2760)$

**Observed in inclusive $e^+e^-$ and pp collisions by BaBar and LHCb collaborations**

$$e^+e^- \to c\bar{c} \to D^{(*)}\pi X,$$

$$pp \to D^+\pi^- X,\ pp \to D^0\pi^+ X,\ pp \to D^{*+}\pi^- X,$$

Mass: $2763.3 \pm 2.3 \pm 2.3\,\mathrm{MeV}$;

Decay width: $60.9 \pm 5.1 \pm 3.6\,\mathrm{MeV}$;

**$D^*(2760)$ produced in inclusive $e^+e^-$ and pp collisions is found to consist of $D^*_1(2760)$ and $D^*_3(2760)$**

## ◊ $D^*_{sJ}(2860)$

$$e^+e^- \to D^0K^+X, \qquad D^0 \to K^-\pi^+, \tag{1}$$

$$e^+e^- \to D^0K^+X, \qquad D^0 \to K^-\pi^+\pi^0, \tag{2}$$

$$e^+e^- \to D^+K^0_SX, \qquad D^+ \to K^-\pi^+\pi^+, \qquad K^0_S \to \pi^+\pi^-. \tag{3}$$

$D_{sJ}(2860)$ was first reported by BaBar(B. Aubert, *et al.*, BaBar Collaboration, Phys. Rev. Lett. **97**, 222001 (2006)) in

$$D_{sJ}(2860) \to D^0K^+ \ , \ D^+K^0_s$$

with $M = 2856.6 \pm 1.5(stat) \pm 5.0(syst)$ and $\Gamma = 48 \pm 7(stat) \pm 10(syst)$ MeV

**$D^*_{sJ}(2860)$ produced in inclusive $e^+e^-$ and pp collisions is found to consist of $D^*_{s1}(2860)$ and $D^*_{s3}(2860)$**

## ♢ $D_s(2632)$

A new surprisingly narrow charmed strange meson, $D_{sJ}(2632)^+$, was reported by SELEX(A. Evdokimov et al, SELEX Collaboration, Phys. Rev. Lett. **93**, 242001(2004)) in

$$D_{sJ}^+(2632) \to D_s^+\eta \ , \ D^0K^+$$

with $M = 2632.5 \pm 1.7(stat) \pm 5.0(syst)$ and $\Gamma < 17$ MeV with $90\%$ confidence level

# 3. Conclusions and discussions

**1, It is believed that S-wave and P-wave charmed resonances have been established**

**2, The 1D,1F,2S and 2P charmed resonances have been observed**

**3, The mixing of $^3L_L$ – $^1L_L$ have to be studied in detail**

**4, Experiment by BaBar, Belle and LHCb required**

谢谢！