Study the charmonium-like states within the unitary chiral approach

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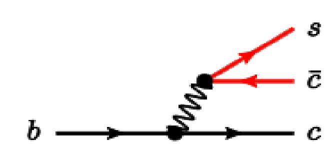
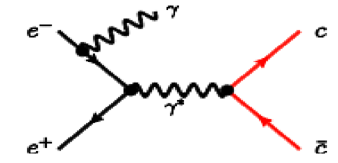
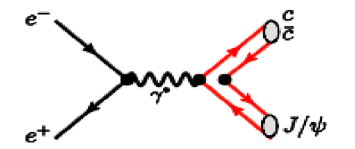
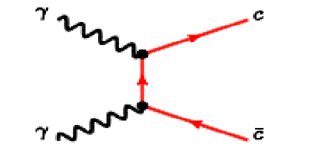
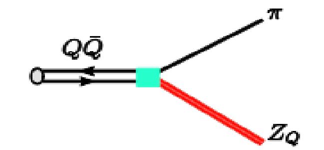
outline

- Motivation
- LHCb: $B^+ \to J/\psi \varphi K^+$
- BESIII: $e^+e^- \to \gamma J/\psi \varphi$
- LHCb: $B^+ \to J/\psi \omega K^+$
- Summary

Charmonium-like states

				
$X(3872)$	$Y(4008)$	$X(3940)$	$X(3915)$	$Z_c(3885)$
$Y(3940)$	$Y(4260)$	$X(4160)$	$Z(3930)$	$Z_c(3900)$
$Z^+(4430)$	$Y(4220)$		$X(4350)$	$Z_c(4020)$
$Z^+(4050)$	$Y(4320)$			$Z_c(4025)$
$Z^+(4250)$	$Y(4360)$			$Z_b(10610)$
$Y(4140)$	$Y(4390)$			$Z_b(10650)$
$Y(4274)$	$Y(4630)$			
$Z^+(4200)$	$Y(4660)$			
$Z^+(4240)$				
$X(3823)$				
$X_c(3250)$				
$P_c(4380)$				
$P_c(4450)$				

H.X.Chen,W. Chen,X.Liu, S.L. Zhu, Phys.Rept. 639 (2016) 1-121

X(4140)

- 2009, CDF Colla. PRL 102, 242002

  Evidence for $X(4140)$ with sig. 3.8 σ in $B^+ \to J/\psi\phi K^+$

  mass : $4143.0 \pm 2.9(\mathrm{stat}) \pm 1.2(\mathrm{syst})$ MeV

  width : $11.7^{+8.3}_{-5.0}(\mathrm{stat}) \pm 3.7(\mathrm{syst})$ MeV

- 2017, LHCb Colla., PRL 118, 022003

  3 fb^{-1} pp-bar collision data, $X(4140)$ with sig. >5 σ in $B^+ \to J/\psi\phi K^+$, $J^{PC}=1^{++}$, with sig. >4 σ

  mass : $4146.5 \pm 4.5^{+4.6}_{-2.8}$ MeV

  width : $83 \pm 21^{+21}_{-14}$ MeV

- 2010, Belle Colla., PRL 104, 112004

  825 fb^{-1} $\Upsilon(nS)$ data, no evidence for $X(4140)$, But evidence X(4350): with sig. 3.2 σ in $\gamma\gamma \to J/\psi\phi$

  mass: $4350.6^{+4.6}_{-5.1}(\mathrm{stat}) \pm 0.7(\mathrm{syst})$

  width: $13^{+18}_{-9}(\mathrm{stat}) \pm 4(\mathrm{syst})$

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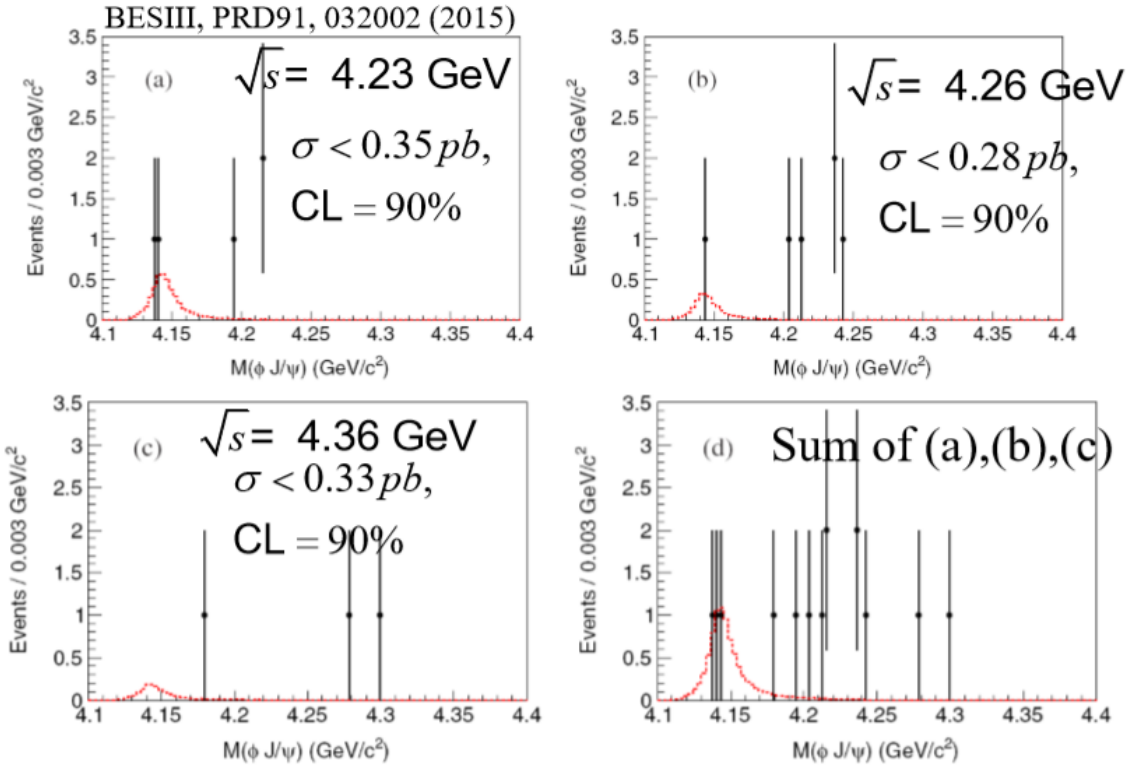
Silde of R.G. Ping, 2018.3.31
第一届强子与重味物理理论与实验联合研讨会@兰州

X(4140)

Search for the Y(4140) via $e^+e^- \to \gamma\phi J/\psi$ at $\sqrt{s}=$ 4.23, 4.26 and 4.36 Ge



Silde of R.G. Ping, 2018.3.31
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$$\frac{\sigma(e^+e^- \to \gamma Y(4140))}{\sigma(e^+e^- \to \gamma X(3872))} \sim 0.1 \text{ at } \sqrt{s} = 4.23, 4.26 \text{ GeV}$$

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BESIII

PHYSICAL REVIEW D **91**, 032002 (2015)

Search for the $Y(4140)$ via $e^+e^- \to \gamma\phi J/\psi$ at $\sqrt{s} = 4.23$, 4.26 and 4.36 GeV

Using data samples collected at center-of-mass energies $\sqrt{s} = 4.23$, 4.26, and 4.36 GeV with the BESIII detector operating at the BEPCII storage ring, we search for the production of the charmoniumlike state $Y(4140)$ through a radiative transition followed by its decay to $\phi J/\psi$. No significant signal is observed and upper limits on $\sigma[e^+e^- \to \gamma Y(4140)] \cdot \mathcal{B}(Y(4140) \to \phi J/\psi)$ at the 90% confidence level are estimated as 0.35, 0.28, and 0.33 pb at $\sqrt{s} = 4.23$, 4.26, and 4.36 GeV, respectively.

BESIII

PHYSICAL REVIEW D **91,** 032002 (2015)

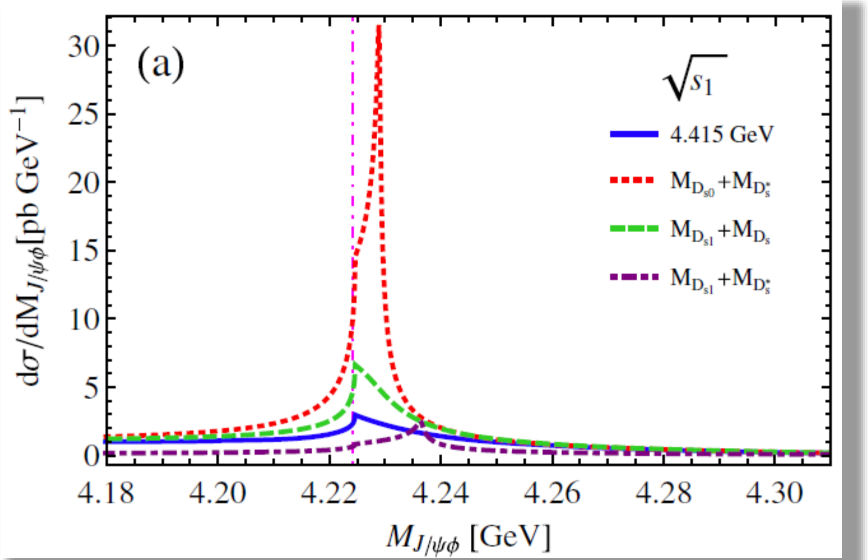
Search for the $Y(4140)$ via $e^+e^- \to \gamma\phi J/\psi$ at $\sqrt{s} = 4.23$, 4.26 and 4.36 GeV

Using data samples collected at center-of-mass energies $\sqrt{s} = 4.23$, 4.26, and 4.36 GeV with the BESIII detector operating at the BEPCII storage ring, we search for the production of the charmoniumlike state $Y(4140)$ through a radiative transition followed by its decay to $\phi J/\psi$. No significant signal is observed and upper limits on $\sigma[e^+e^- \to \gamma Y(4140)] \cdot \mathcal{B}(Y(4140) \to \phi J/\psi)$ at the 90% confidence level are estimated as 0.35, 0.28, and 0.33 pb at $\sqrt{s} = 4.23$, 4.26, and 4.36 GeV, respectively.

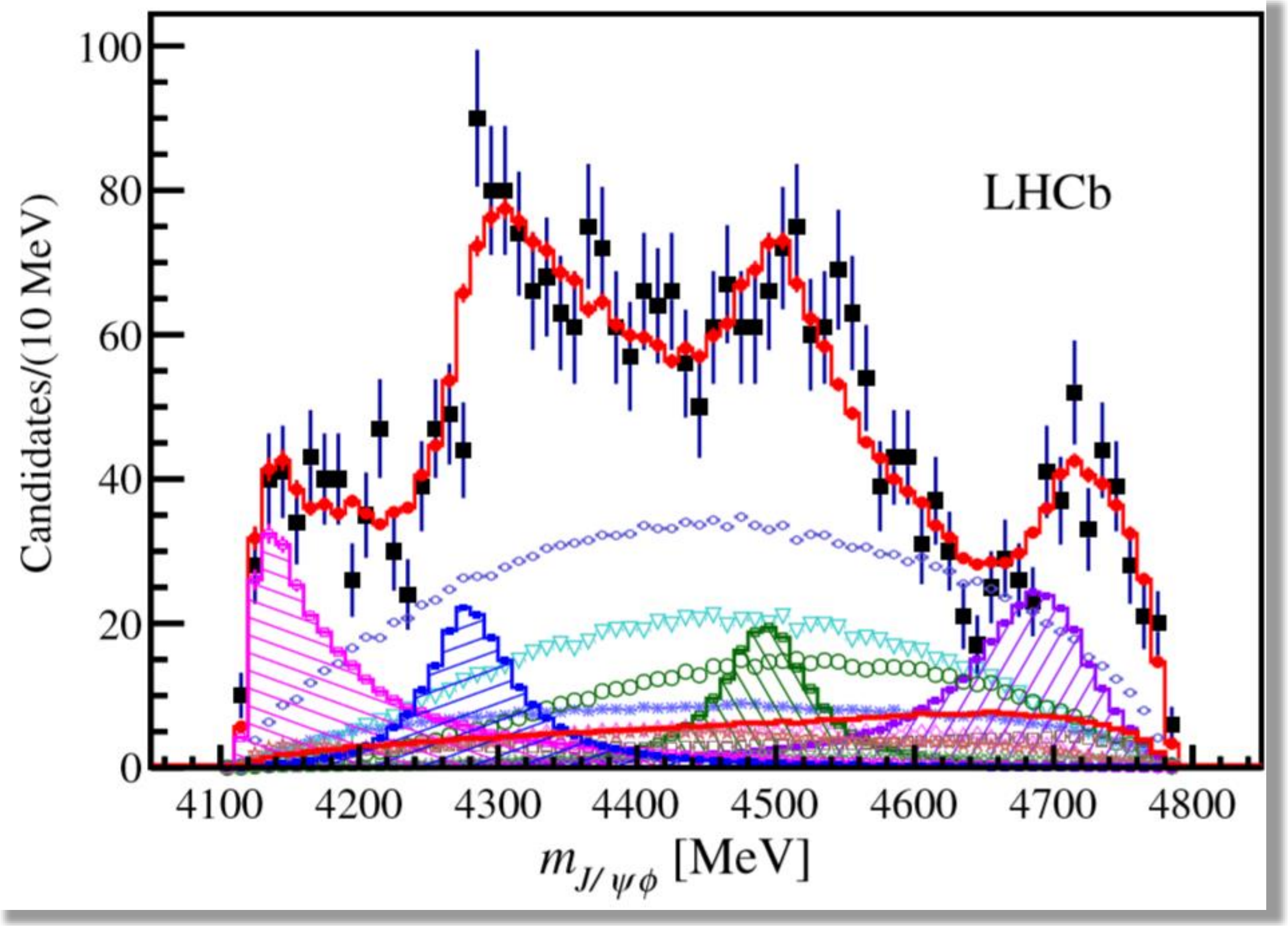
PHYSICAL REVIEW D **93,** 054032 (2016)

Searching for charmoniumlike states with hidden $s\bar{s}$

Xiao-Hai Liu[1,*] and Makoto Oka[1,2,†]



The LHCb measurement



$$B^+ \to J/\psi\phi K^+$$

4 X states are observed.

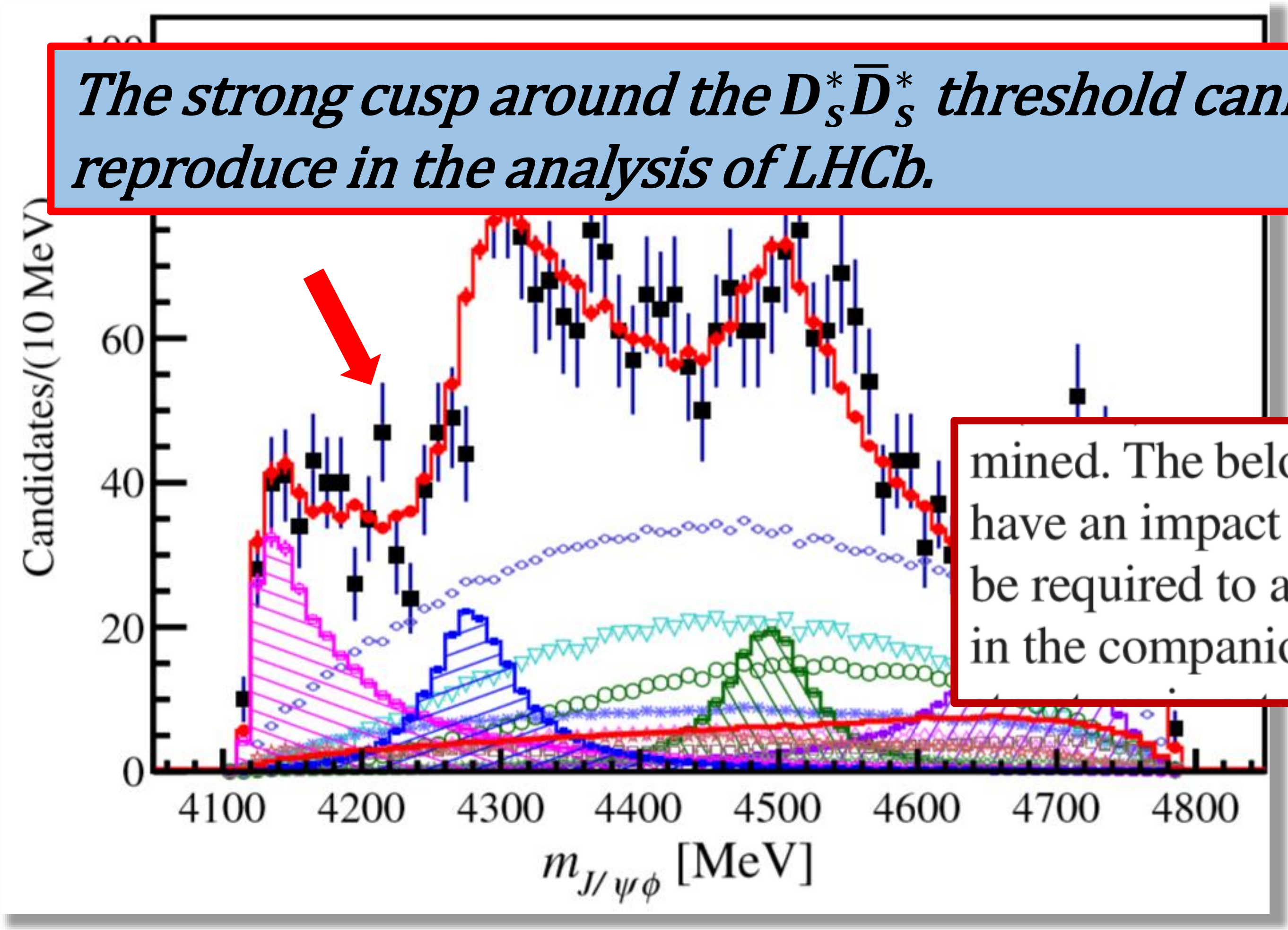
X(4140): $J^{PC}=1^{++}$

Width=83±21 MeV

J^{PC}	$X(4140)$	$X(4274)$	$X(4500)$	$X(4700)$
0^{++}	10.3σ	7.8σ	Preferred	Preferred
0^{-+}	12.5σ	7.0σ	8.1σ	8.2σ
1^{++}	Preferred	Preferred	$\mathbf{5.2\sigma}$	$\mathbf{4.9\sigma}$
1^{-+}	10.4σ	$\mathbf{6.4\sigma}$	6.5σ	8.3σ
2^{++}	$\mathbf{7.6\sigma}$	7.2σ	5.6σ	6.8σ
2^{-+}	9.6σ	$\mathbf{6.4\sigma}$	6.5σ	6.3σ

PRD95,2017,PRL118,2017

The LHCb measurement



The strong cusp around the $D_s^*\bar{D}_s^*$ threshold cannot be reproduce in the analysis of LHCb.

$B^+ \to J/\psi\phi K^+$

...states are observed.

X(4140): $J^{PC}=1^{++}$

Width=83±21 MeV

mined. The below-$J/\psi\phi$-threshold $D_s^{\pm}D_s^{*\mp}$ cusp [9,18] may have an impact on the $X(4140)$ structure, but more data will be required to address this issue, as discussed in more detail in the companion article [30]. The existence of the $X(4274)$

2^{++}	**7.6σ**	7.2σ	5.6σ	6.8σ
2^{-+}	9.6σ	**6.4σ**	6.5σ	6.3σ

PRD95,2017,PRL118,2017

The large width of X(4140)

Experiment	N_B	Mass (MeV)	Width (MeV)	σ	Fraction (%)
CDF [1]	58	$4143.0 \pm 2.9 \pm 1.2$	$11.7^{+8.3}_{-5.0} \pm 3.7$	3.8	
Belle [19]	*325*	*4143.0 fixed*	*11.7 fixed*	*1.9*	
CDF [26]	*115*	$4143.4^{+2.9}_{-3.0} \pm 0.6$	$15.3^{+10.4}_{-6.1} \pm 2.5$	*5.0*	$15 \pm 4 \pm 2$
LHCb [21]	346	4143.4 fixed	15.3 fixed	1.4	<7
CMS [23]	2480	$4148.0 \pm 2.4 \pm 6.3$	$28^{+15}_{-11} \pm 19$	5.0	10 ± 3
D0 [24]	215	$4159.0 \pm 4.3 \pm 6.6$	$19.9 \pm 12.6^{+1.0}_{-8.0}$	3.1	$21 \pm 8 \pm 4$
BABAR [22]	189	4143.4 fixed	15.3 fixed	1.6	<13
D0 [25]		$4152.5 \pm 1.7^{+6.2}_{-5.4}$	$16.3 \pm 5.6 \pm 11.4$	4.7–5.7	
Average		4147.1 ± 2.4	15.7 ± 6.3		

PRL118,2017

$X(4140)$ $I^G(J^{PC}) = 0^+(1^{++})$

Seen by AALTONEN 2009AH, ABAZOV 2014A, CHATRCHYAN 2014M, AAIJ 2017C in $B^+ \to XK^+$, $X \to J/\psi\phi$, and by ABAZOV 2015M separately in both prompt (4.7 σ) and non-prompt (5.6 σ) production in $p\,\overline{p} \to J/\psi\phi +$ anything. Not seen by SHEN 2010 in $\gamma\,\gamma \to J/\psi\phi$ and ABLIKIM 2015 in $e^+ e^- \to \gamma J/\psi\phi$ at $\sqrt{s}$ = 4.23, 4.26, 4.36 GeV.

$X(4140)$ MASS	4146.8 ± 2.5 MeV (S = 1.1)
$X(4140)$ WIDTH	19^{+8}_{-7} MeV (S = 1.4)

PDG2017

The large width of X(4140)

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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
D0 [25]		$4152.5 \pm 1.7^{+6.2}_{-5.4}$	$16.3 \pm 5.6 \pm 11.4$	4.7–5.7	
Average		4147.1 ± 2.4	15.7 ± 6.3		

The deduced width of X(4140), 83±21 MeV, larger than the former experimental measurements, and also the average of the PDG.

PRL118,2017

$X(4140)$ $I^G(J^{PC}) = 0^+(1^{++})$

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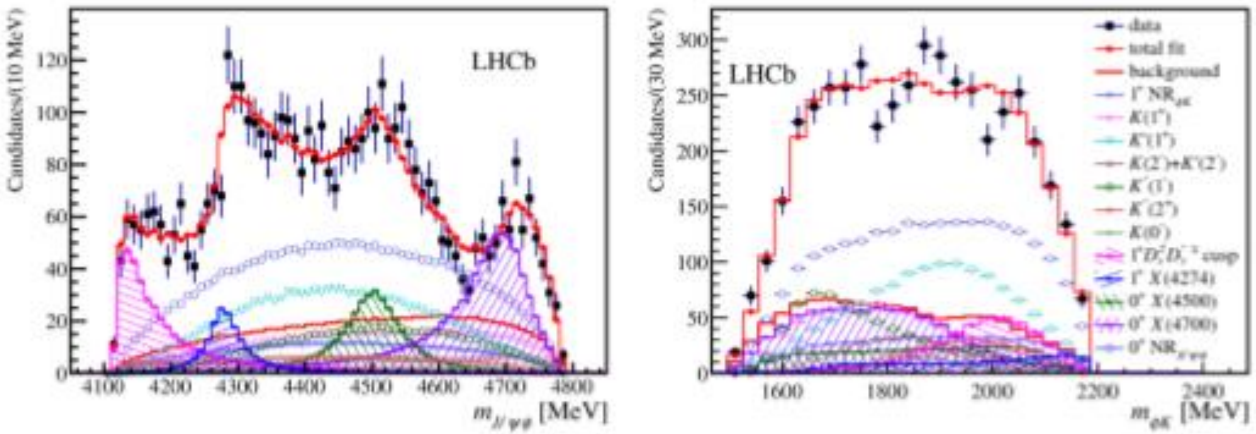
$X(4140)$ WIDTH	19^{+8}_{-7} MeV (S = 1.4)

PDG2017

Exotic states in $B^+ \to J/\psi\phi K^+$

- LHCb perform full 6D amplitude analysis

LHCb-PAPER-2016-018
PRL 118 (2017)022003
LHCb-PAPER-2016-019
PRD 95 (2017) 012002



Silde of Y.N.Gao, 2018.3.31
第一届强子与重味物理理论与实验联合研讨会@兰州

- 4 peaks are observed with X(4140) wider than CDF/DO/CMS

State	Signif	J^{PC}	M [MeV]	Γ [MeV]
X(4140)	8.4σ	1^{++}	$4160 \pm 4^{+5}_{-3}$	$83 \pm 21^{+21}_{-14}$
X(4274)	5.8σ	1^{++}	$4273 \pm 8^{+17}_{-4}$	$56 \pm 11^{+8}_{-11}$
X(4500)	6.1σ	0^{++}	$4506 \pm 11^{+12}_{-15}$	$92 \pm 21^{+21}_{-20}$
X(4700)	5.6σ	0^{++}	$4704 \pm 10^{+14}_{-24}$	$120 \pm 31^{+42}_{-33}$

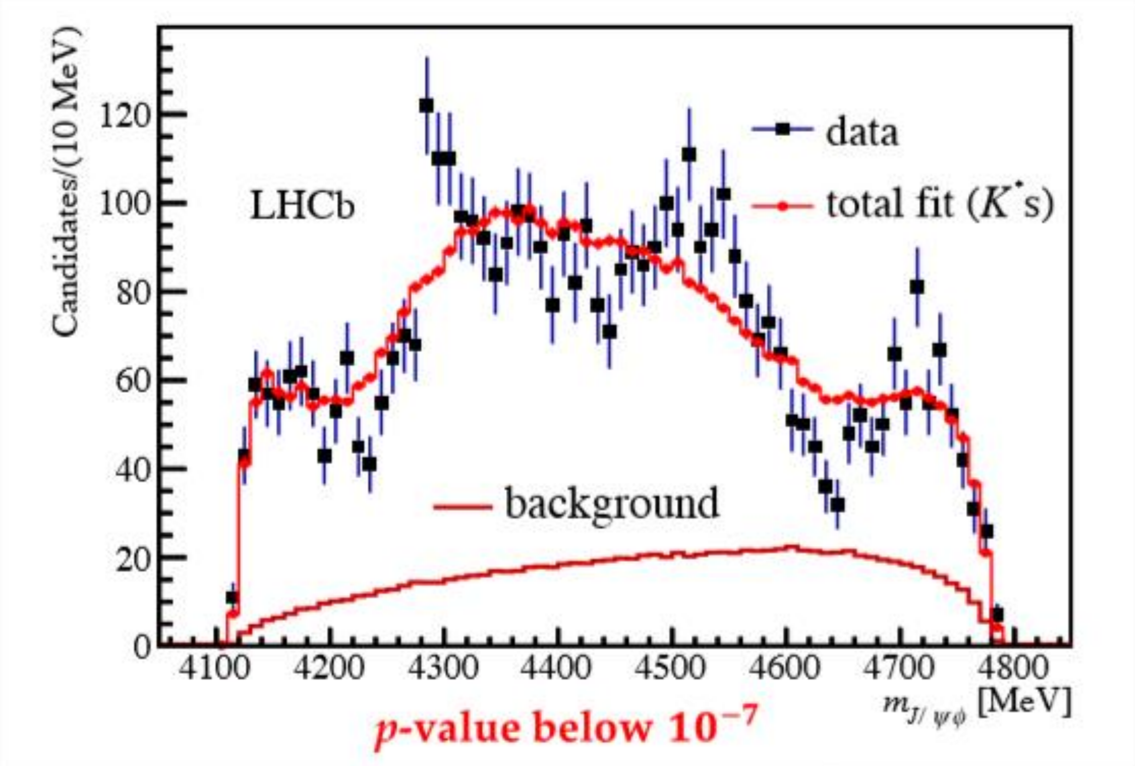
Significant larger at LHCb
$\Gamma_{avg}^{CDF/D0/CMS} = 15.7 \pm 6.3$ MeV

Amplitude analysis of $B^+ \to J/\psi\phi K^+$ decays

PRD 95, 012002
PRL 118, 022003

K^*'s-only hypothesis fit:

- $M_{\phi K}$ and $M_{J/\psi K}$ can be described by model
- $M_{J/\psi\phi}$ is not described by fit



p-value below 10^{-7}

→ non-K^* resonances needed:

- $Z^+ \to J/\psi K^+$ - does not lead to significant improvements
- $X \to J/\psi\phi$

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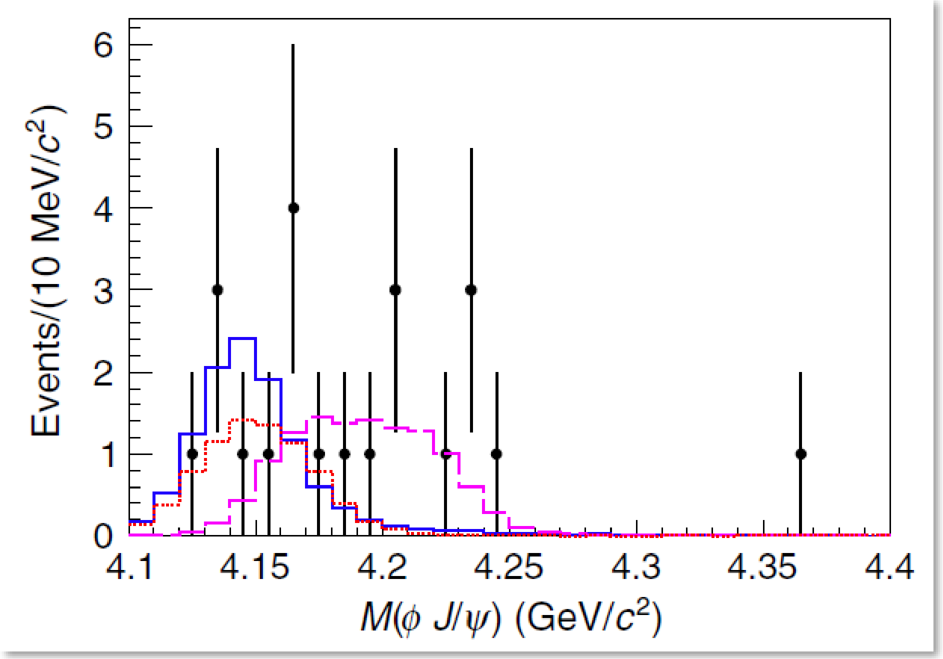
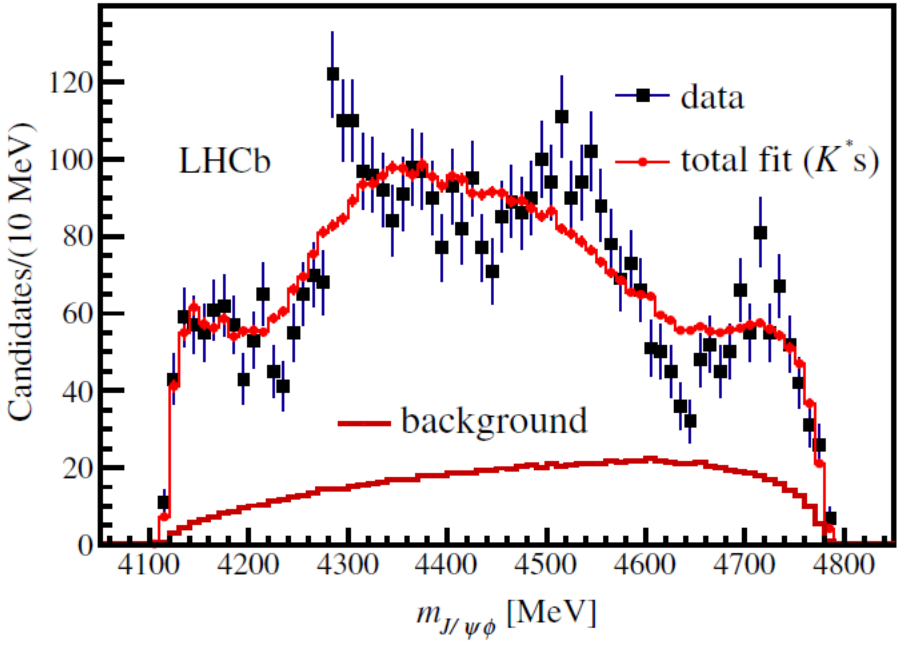
BESIII

Observation of $e^+e^- \to \phi\chi_{c1}$ and $\phi\chi_{c2}$ at $\sqrt{s} = 4.600\ \mathrm{GeV}$

M. Ablikim *et al.* (BESIII Collaboration)
Phys. Rev. D **97**, 032008 – Published 12 February 2018

second systematic. No significant signals are observed for $e^+e^- \to \phi\chi_{c0}$ and $e^+e^- \to \gamma X(4140)$ and upper limits on the Born cross sections at 90% C.L. are provided at $\sqrt{s} = 4.600$ GeV.





X(4140)

- Many explanantions:

➢ **Molecular state:**

X. Liu, S.L. Zhu, PRD80(2009), G.J. Ding,EPJC64(2009),J.R. Zhang, M.Q.Huang,JPG37(2010),

➢ **Tetraquark:**

F.Stancu,JPG37(2010),Z.G.Wang,IJMPA30(2015)

➢ **Hybrid state:**

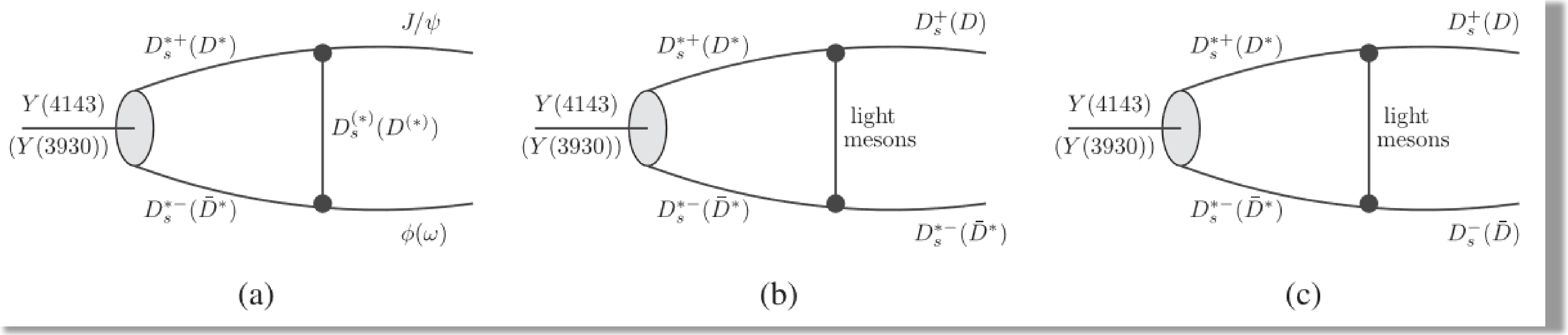
Mahajan,PLB679(2009),Z.G.Wang,EPJC63(2009)

➢ **Rescattering effect:**

X. Liu,PLB680(2009)

X(4140) as the $D_s^*\overline{D}_s^*$ molecule

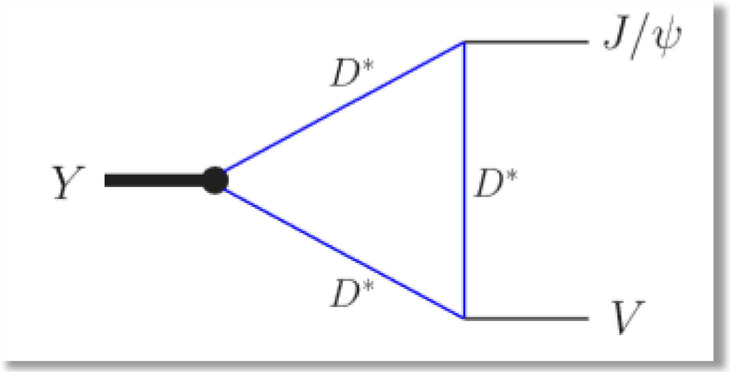
- **Meson exchange model,** X. Liu, S.L. Zhu, PRD80(2009)



- **The X(4140) is predicted to be** $J^{PC}=0^{++},2^{++}$

X(4140) as the $D_s^* \bar{D}_s^*$ molecule

- **The meson-exchange potentials generated by the Lagrangian of heavy hadron chiral perturbation theory**



$$\mathcal{L}_{D^*D^*J_\psi} = i g_{D^*D^*J_\psi} J_\psi^\mu (D_{\mu i}^{*\dagger} \overleftrightarrow{\partial}_\nu D_i^{*\nu} + D_{\nu i}^{*\dagger} \overleftrightarrow{\partial}^\nu D_{\mu i}^* - D_i^{*\dagger\nu} \overleftrightarrow{\partial}_\mu D_{\nu i}^*),$$

$$\mathcal{L}_{D^*D^*V} = i g_{D^*D^*V} V_{ij}^\mu D_{\nu i}^{*\dagger} \overleftrightarrow{\partial}_\mu D_j^{*\nu} + 4 i f_{D^*D^*V} (\partial^\mu V_{ij}^\nu - \partial^\nu V_{ij}^\mu) D_{\mu i}^* D_j^{*\dagger\nu}$$

- **The X(4140) with $J^{PC}=0^{++},2^{++}$**

  T. Branz, et. al, PRD80(2009)

X(4140) as the $D_s^*\bar{D}_s^*$ molecule

- Vector meson exchange, Bethe-Salpeter quations

  X.Z.Chen, X.F.lv, R.B.Shi, X.R.Guo, 1512.06483
- η exchange, M. Karliner, NPA954(2016)
- QCD sum rules

  J.R. Zhang, M.Q.Huang,JPG37(2010),

  ZGWang, EPJC63(2009),

  ZGWang, YF.Tian,IJMPA30(2015)
- η, ϕ, σ exchange,G.J.Ding,EPJC64(2009)

$D_s^* \bar{D}_s^*$ molecule

PHYSICAL REVIEW D **80,** 114013 (2009)

$Y(3940)$, $Z(3930)$, and the $X(4160)$ as dynamically generated resonances from the vector-vector interaction

R. Molina[1] and E. Oset[1]

[1]*Departamento de Física Teórica and IFIC, Centro Mixto Universidad de Valencia-CSIC, Institutos de Investigación de Paterna, Apartado 22085, 46071 Valencia, Spain*

(Received 24 July 2009; revised manuscript received 28 October 2009; published 15 December 2009)

- **Vector-vector exchange within local hidden gauge approach**

$D^*\bar{D}^*(4017)$, $D_s^*\bar{D}_s^*(4225)$, $K^*\bar{K}^*(1783)$,

$\rho\rho(1551)$, $\omega\omega(1565)$,

$\phi\phi(2039)$, $J/\psi J/\psi(6194)$, $\omega J/\psi(3880)$,

$\phi J/\psi(4116)$, $\omega\phi(1802)$,

TABLE V. Couplings g_i in units of MeV for $I = 0$, $J = 2$ (second pole).

$\sqrt{s_{\rm pole}} = 4169 + i66$, $I^G[J^{PC}] = 0^+[2^{++}]$

$D^*\bar{D}^*$	$D_s^*\bar{D}_s^*$	$K^*\bar{K}^*$	$\rho\rho$	$\omega\omega$
$1225 - i490$	$18927 - i5524$	$-82 + i30$	$70 + i20$	$3 - i2441$

$\phi\phi$	$J/\psi J/\psi$	$\omega J/\psi$	$\phi J/\psi$	$\omega\phi$
$1257 + i2866$	$2681 + i940$	$-866 + i2752$	$-2617 - i5151$	$1012 + i1522$

$D_s^*\bar{D}_s^*$ molecule

PHYSICAL REVIEW D **80,** 114013 (2009)

$Y(3940)$, $Z(3930)$, and the $X(4160)$ as dynamically generated resonances from the vector-vector interaction

$X(4160)$ $I^G(J^{PC}) = ?^?(?^{??})$

Seen by PAKHLOV 2008 in $e^+ e^- \to J/\psi X$, $X \to D^* \bar{D}^*$

(Re

- **Vector-**

$X(4160)$ MASS	4156^{+29}_{-25} MeV
$X(4160)$ WIDTH	139^{+110}_{-60} MeV

$D^*\bar{D}^*(4017)$, $D_s^*\bar{D}_s^*(4225)$, $K^*\bar{K}^*(1783)$, $\rho\rho(1551)$, $\omega\omega(1565)$,

$\phi\phi(2039)$, $J/\psi J/\psi(6194)$, $\omega J/\psi(3880)$, $\phi J/\psi(4116)$, $\omega\phi(1802)$,

pole).

$\sqrt{s_{pole}} = 4169 + i66$, $I^G[J^{PC}] = 0^+[2^{++}]$

$D^*\bar{D}^*$	$D_s^*\bar{D}_s^*$	$K^*\bar{K}^*$	$\rho\rho$	$\omega\omega$
$1225 - i490$	$18\,927 - i5524$	$-82 + i30$	$70 + i20$	$3 - i2441$
$\phi\phi$	$J/\psi J/\psi$	$\omega J/\psi$	$\phi J/\psi$	$\omega\phi$
$1257 + i2866$	$2681 + i940$	$-866 + i2752$	$-2617 - i5151$	$1012 + i1522$

$D_s^*\bar{D}_s^*$ molecule

PHYSICAL REVIEW D **80,** 114013 (2009)

$Y(3940)$, $Z(3930)$, and the $X(4160)$ as dynamically generated resonances from the vector-vector interaction

The $D_s^*\bar{D}_s^*$ molecule with 2^{++} was associated to the X(4160), not the X(4140).

- **Vector-vector exchange within local hidden gauge approach**

$D^*\bar{D}^*(4017)$, $D_s^*\bar{D}_s^*(4225)$, $K^*\bar{K}^*(1783)$,
$\rho\rho(1551)$, $\omega\omega(1565)$,

$\phi\phi(2039)$, $J/\psi J/\psi(6194)$, $\omega J/\psi(3880)$,
$\phi J/\psi(4116)$, $\omega\phi(1802)$,

TABLE V. Couplings g_i in units of MeV for $I = 0$, $J = 2$ (second pole).

$\sqrt{s_{\rm pole}} = 4169 + i66$, $I^G[J^{PC}] = 0^+[2^{++}]$				
$D^*\bar{D}^*$	$D_s^*\bar{D}_s^*$	$K^*\bar{K}^*$	$\rho\rho$	$\omega\omega$
$1225 - i490$	$18\,927 - i5524$	$-82 + i30$	$70 + i20$	$3 - i2441$
$\phi\phi$	$J/\psi J/\psi$	$\omega J/\psi$	$\phi J/\psi$	$\omega\phi$
$1257 + i2866$	$2681 + i940$	$-866 + i2752$	$-2617 - i5151$	$1012 + i1522$

$D_s^*\bar{D}_s^*$ molecule, X(4160)

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Nuclear Physics A 966 (2017) 135–157

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Understanding close-lying exotic charmonia states within QCD sum rules

A. Martínez Torres [a], K.P. Khemchandani [b,c,*], J.M. Dias [a], F.S. Navarra [a], M. Nielsen [a]

The comparison made above hints a possible $D_s^*\bar{D}_s^*$ molecule-like nature with quantum numbers $J^{PC} = 2^{++}$ for $X(4160)$. However, our work also implies the existence of a $J^{PC} = 0^{++}$

$D_s^* \bar{D}_s^*$ molecule, X(4140) or X(4160)

- **The quantum numbers of X(4140) established to be 0+(1++)**

J^{PC}	$X(4140)$	$X(4274)$	$X(4500)$	$X(4700)$
0^{++}	10.3σ	7.8σ	Preferred	Preferred
0^{-+}	12.5σ	7.0σ	8.1σ	8.2σ
1^{++}	Preferred	Preferred	$\mathbf{5.2\sigma}$	$\mathbf{4.9\sigma}$
1^{-+}	10.4σ	$\mathbf{6.4\sigma}$	6.5σ	8.3σ
2^{++}	$\mathbf{7.6\sigma}$	7.2σ	5.6σ	6.8σ
2^{-+}	9.6σ	$\mathbf{6.4\sigma}$	6.5σ	6.3σ

PRD95,2017,PRL118,2017

$X(4140)$ $I^G(J^{PC}) = 0^+(1^{++})$

Seen by AALTONEN 2009AH, ABAZOV 2014A, CHATRCHYAN 2014M, AAIJ 2017C in $B^+ \to XK^+$, $X \to J/\psi\phi$, and by ABAZOV 2015M separately in both prompt (4.7 σ) and non-prompt (5.6 σ) production in $p\bar{p} \to J/\psi\phi +$ anything. Not seen by SHEN 2010 in $\gamma\gamma \to J/\psi\phi$ and ABLIKIM 2015 in $e^+ e^- \to \gamma J/\psi\phi$ at $\sqrt{s}$ = 4.23, 4.26, 4.36 GeV.

$X(4140)$ MASS	4146.8 ± 2.5 MeV (S = 1.1)
$X(4140)$ WIDTH	19^{+8}_{-7} MeV (S = 1.4)

PDG2017

$D_s^*\bar{D}_s^*$ molecule, X(4140) or X(4160)

- The quantum numbers of X(4140) established to be 0+(1++)

J^{PC}	$X(4140)$	$X(4274)$	$X(4500)$	$X(4700)$
0^{++}	10.3σ	7.8σ	Preferred	Preferred
0^{-+}	12.5σ	7.0σ	8.1σ	8.2σ
1^{++}	Preferred	Preferred	5.2σ	4.9σ
1^{-+}	[illegible]	[illegible]	[illegible]	[illegible]

PRD95,2017,PRL118,2017

The association of the $D_s^*\bar{D}_s^*$ molecule with 0^{++}/ 2^{++} to X(4140) can no longer be supported, and the association of the $D_s^*\bar{D}_s^*$ molecule to X(4160) has much weight.

Seen by AALTONEN 2009AH, ABAZOV 2014A, CHATRCHYAN 2014M, AAIJ 2017C in $B^+ \to XK^+$, $X \to J/\psi\phi$, and by ABAZOV 2015M separately in both prompt (4.7 σ) and non-prompt (5.6 σ) production in $p\,\bar{p} \to J/\psi\phi +$ anything. Not seen by SHEN 2010 in $\gamma\,\gamma \to J/\psi\phi$ and ABLIKIM 2015 in $e^+\,e^- \to \gamma J/\psi\phi$ at $\sqrt{s}$ = 4.23, 4.26, 4.36 GeV.

$X(4140)$ MASS	4146.8 ± 2.5 MeV (S = 1.1)
$X(4140)$ WIDTH	19^{+8}_{-7} MeV (S = 1.4)

PDG2017

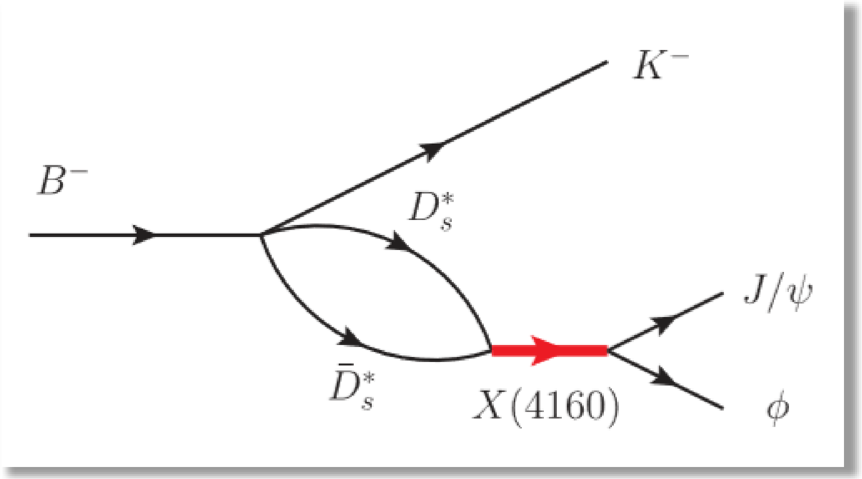
How is the molecule like?

- It decays into a heavy quarkonium plus a light meson with nozero isospin, for instance, Zc, Zb.
- For the molecular states that couple to several hadron-hadron channels, one can find a strong and unexpected cusp in one of the weakly coupled channels at the threshold of the channels corresponding to the main component of the molecular state.
- Dai,Dias,Oset,EPJC78(2018)
- Ewang,JJXie,LSGeng,Oset,PRD97(2019);1806.05113
- Dai,GYWang,Xchen,Ewang,DMLi,Oset,1808.10371

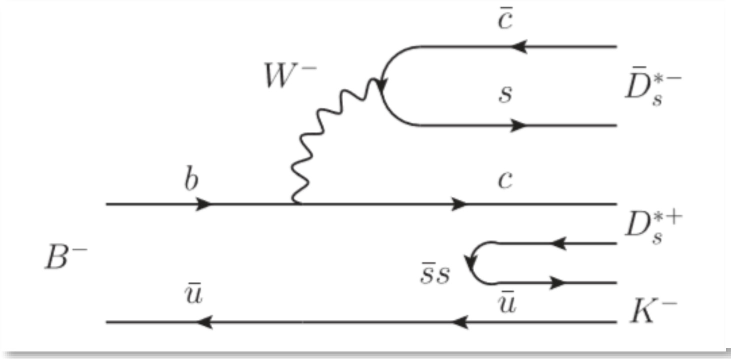
LHCb: $B^+ \to J/\psi \phi K^+$

PRD97(2018)014017

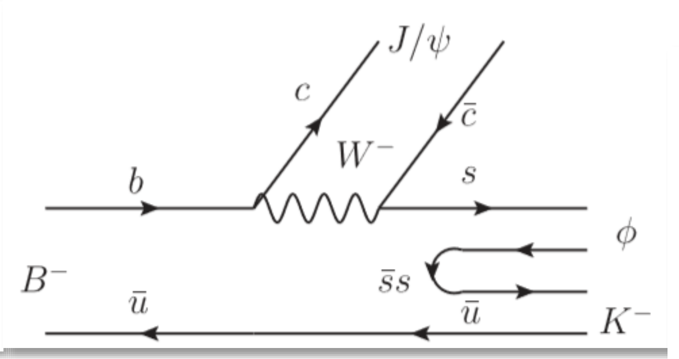
The reaction of $B^- \to J/\psi\, \phi K^-$



- The internal conversion is suppressed by color factors with respect to the external emission.
- The mechanism with the J/ψϕ intermediate state instead of $D_s^* \bar{D}_s^*$ would involve the extra factor $g_{J/\psi\phi} / g_{D_s^* \bar{D}_s^*}$, and can be safely neglected.



External emission



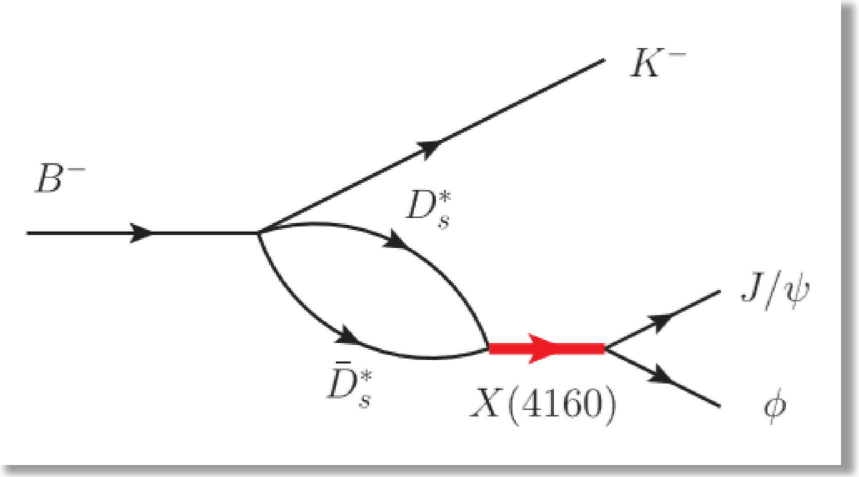
Internal conversion

TABLE V. Couplings g_i in units of MeV for $I = 0$, $J = 2$ (second pole).

$\sqrt{s_{\rm pole}} = 4169 + i66$, $I^G[J^{PC}] = 0^+[2^{++}]$

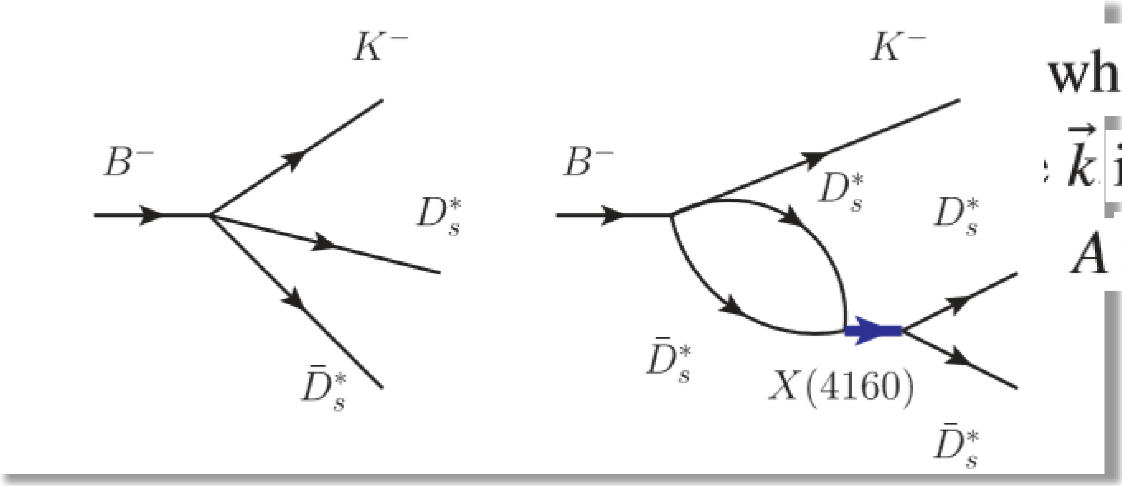
$D^*\bar{D}^*$	$D_s^*\bar{D}_s^*$	$K^*\bar{K}^*$	$\rho\rho$	$\omega\omega$
$1225 - i490$	$18\,927 - i5524$	$-82 + i30$	$70 + i20$	$3 - i2441$
$\phi\phi$	$J/\psi J/\psi$	$\omega J/\psi$	$\phi J/\psi$	$\omega\phi$
$1257 + i2866$	$2681 + i940$	$-866 + i2752$	$-2617 - i5151$	$1012 + i1522$

The reaction of $B^- \to J/\psi\,\phi K^-$



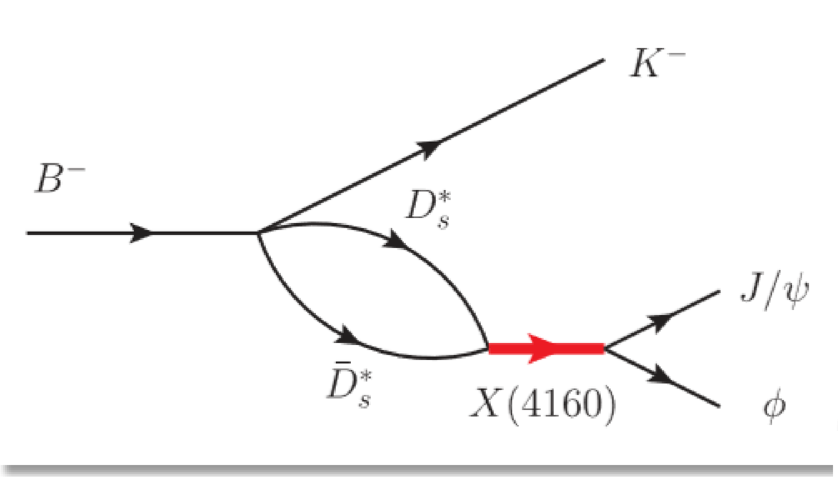
The X(4160) is JPC=2⁺⁺ state with L=0 in $D_s^*\bar{D}_s^*$.
We need a D-wave in the K⁻ to match the angular momentum in the reaction.

$$t^{\rm tree}_{B^-\to K^- D_s^*\bar{D}_s^*} = A\left(\vec{\epsilon}\cdot\vec{k}\vec{\epsilon}'\cdot\vec{k} - \frac{1}{3}\vec{k}^2\vec{\epsilon}\cdot\vec{\epsilon}'\right),$$



where $\vec{\epsilon}$, $\vec{\epsilon}'$ are the polarization vectors of D_s^* and $\vec{D}_s^*$,
$\vec{k}$ is the K^- momentum in the $D_s^*\bar{D}_s^*$ rest frame,
A is an unknown factor that will be fitted to the data.

The reaction of $B^- \to J/\psi\,\phi K^-$

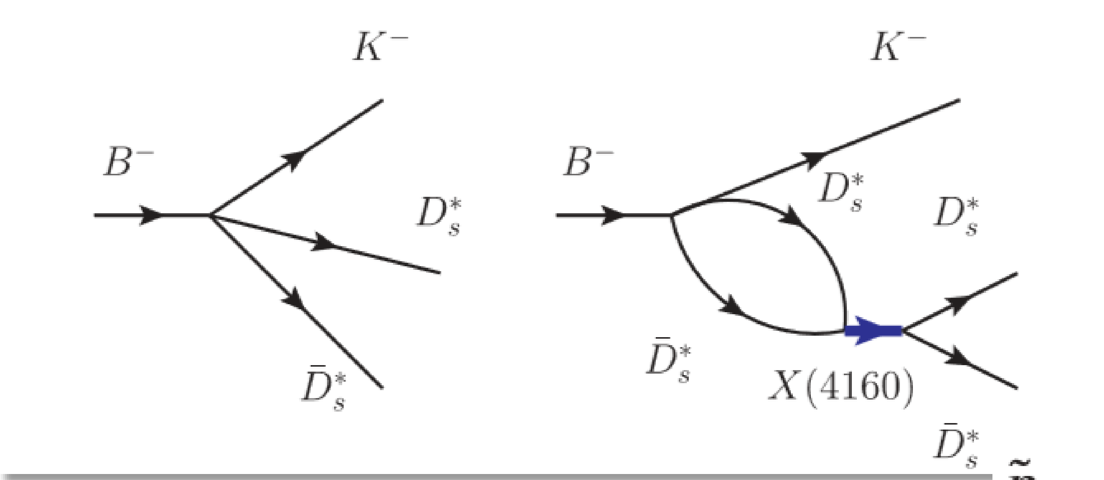


The X(4160) is JPC=2⁺⁺ state with L=0 in $D_s^*\bar{D}_s^*$. We need a D-wave in the K- to match the angular momentum in the reaction.

$$t^{\text{tree}}_{B^-\to K^- D_s^*\bar{D}_s^*} = A\left(\vec{\epsilon}\cdot\vec{k}\vec{\epsilon}'\cdot\vec{k} - \frac{1}{3}\vec{k}^2\vec{\epsilon}\cdot\vec{\epsilon}'\right),$$

The sum over polarizations of $|t|^2$ is

$$\sum_{\text{pol}}|t^{\text{tree}}_{B^-\to K^- D_s^*\bar{D}_s^*}|^2 = \frac{2}{3}|\vec{k}|^4,$$

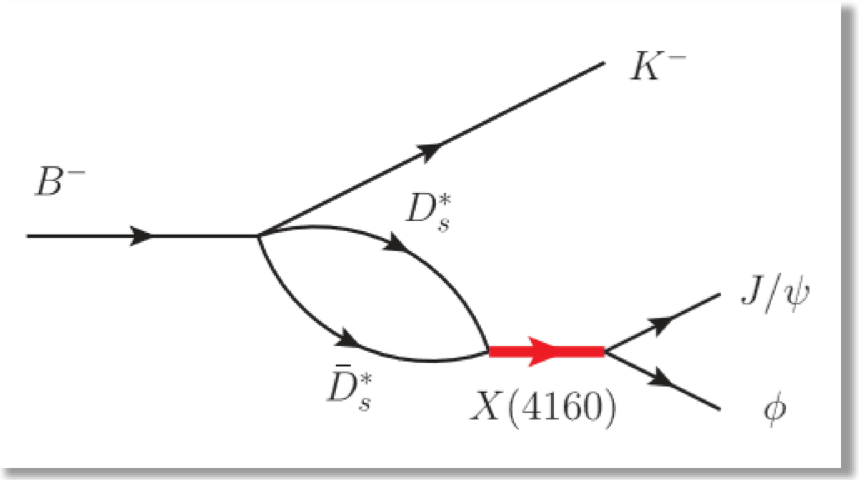


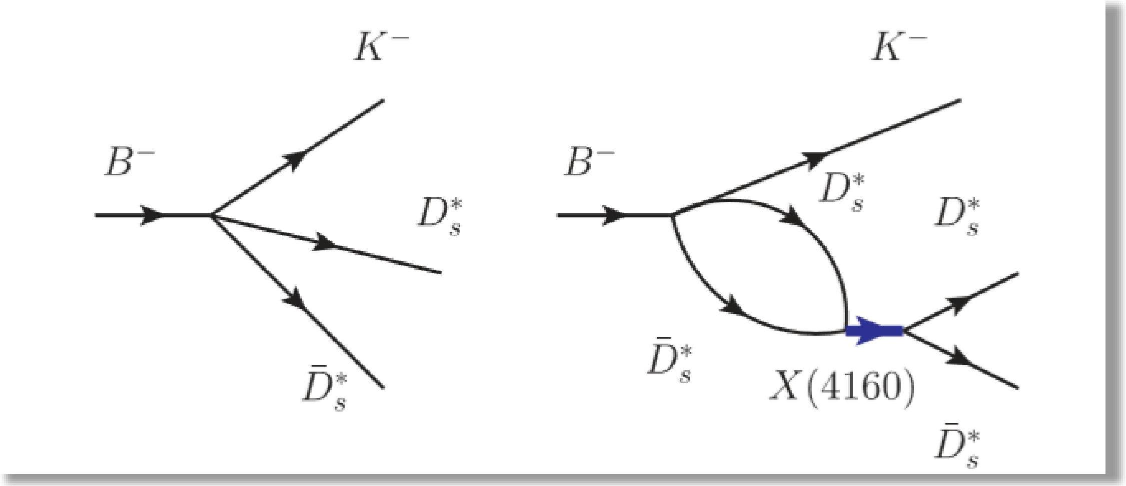
$$\frac{d\Gamma}{dM_{\text{inv}}(D_s^*\bar{D}_s^*)} = \frac{1}{(2\pi)^3}\frac{1}{4M_{B^-}^2}\frac{2}{3}|\vec{k}|^4|\vec{k}'||\tilde{p}_{D_s^*}||A|^2$$

$\vec{k}'$ the K^- momentum in the B^- rest frame

$\tilde{p}_{D_s^*}$ the D_s^* momentum in the $D_s^*\bar{D}_s^*$ rest frame.

The reaction of $B^- \to J/\psi\,\phi K^-$





$$\frac{d\Gamma}{dM_{\rm inv}(D_s^*\bar{D}_s^*)} = \frac{1}{(2\pi)^3}\frac{1}{4M_{B^-}^2}\frac{2}{3}|\vec{k}|^4|\vec{k}'|\tilde{p}_{D_s^*}|A|^2,$$

For the mass distribution of J/ψϕ

$$A \to A \times G_{D_s^*\bar{D}_s^*}(M_{\rm inv}(J/\psi\phi)) \times t_{D_s^*\bar{D}_s^* \to J/\psi\phi}(M_{\rm inv}(J/\psi\phi)),$$

For the mass distribution of $D_s^*\bar{D}_s^*$

$$A \to A[1 + G_{D_s^*\bar{D}_s^*}(M_{\rm inv}(D_s^*\bar{D}_s^*)) \times t_{D_s^*\bar{D}_s^* \to D_s^*\bar{D}_s^*}(M_{\rm inv}(D_s^*\bar{D}_s^*))].$$

The contribution of X(4160)

- G is the loop function, with the cut off method,

$$G_l = \int \frac{d^3q}{(2\pi)^3} \frac{M_l}{2\omega_l(q)E_l(q)} \frac{1}{k^0 + p^0 - q^0 - E_l(q) + i\epsilon}$$

$$D^*\bar{D}^*(4017), \quad D_s^*\bar{D}_s^*(4225), \quad K^*\bar{K}^*(1783), \quad \rho\rho(1551), \quad \omega\omega(1565),$$

$$\phi\phi(2039), \quad J/\psi J/\psi(6194), \quad \omega J/\psi(3880), \quad \phi J/\psi(4116), \quad \omega\phi(1802),$$

- The transition amplitudes are,

$$t_{D_s^*\bar{D}_s^* \to D_s^*\bar{D}_s^*} = \frac{g^2_{D_s^*\bar{D}_s^*}}{M^2_{\text{inv}}(D_s^*\bar{D}_s^*) - M_X^2 + iM_X\Gamma_X},$$

$$t_{D_s^*\bar{D}_s^* \to J/\psi\phi} = \frac{g_{D_s^*\bar{D}_s^*} g_{J/\psi\phi}}{M^2_{\text{inv}}(J/\psi\phi) - M_X^2 + iM_X\Gamma_X},$$

TABLE V. Couplings g_i in units of MeV for $I = 0$, $J = 2$ (second pole).

$\sqrt{s_{\text{pole}}} = 4169 + i66$, $I^G[J^{PC}] = 0^+[2^{++}]$

$D^*\bar{D}^*$	$D_s^*\bar{D}_s^*$	$K^*\bar{K}^*$	$\rho\rho$	$\omega\omega$
$1225 - i490$	$18\,927 - i5524$	$-82 + i30$	$70 + i20$	$3 - i2441$

$\phi\phi$	$J/\psi J/\psi$	$\omega J/\psi$	$\phi J/\psi$	$\omega\phi$
$1257 + i2866$	$2681 + i940$	$-866 + i2752$	$-2617 - i5151$	$1012 + i1522$

The contribution of X(4160)

- **G is the loop function, with the cut off method,**

$$G_l = \int \frac{d^3q}{(2\pi)^3} \frac{M_l}{2\omega_l(q)E_l(q)} \frac{1}{k^0 + p^0 - q^0 - E_l(q) + i\epsilon}$$

$D^*\bar{D}^*(4017)$, $D_s^*\bar{D}_s^*(4225)$, $K^*\bar{K}^*(1783)$, $\rho\rho(1551)$, $\omega\omega(1565)$,

$\phi\phi(2039)$, $J/\psi J/\psi(6194)$, $\omega J/\psi(3880)$, $\phi J/\psi(4116)$, $\omega\phi(1802)$,

- **The transition amplitudes are,**

$$t_{D_s^*\bar{D}_s^* \to D_s^*\bar{D}_s^*} = \frac{g^2_{D_s^*\bar{D}_s^*}}{M^2_{\rm inv}(D_s^*\bar{D}_s^*) - M_X^2 + iM_X\Gamma_X},$$

$$t_{D_s^*\bar{D}_s^* \to J/\psi\phi} = \frac{g_{D_s^*\bar{D}_s^*} g_{J/\psi\phi}}{M^2_{\rm inv}(J/\psi\phi) - M_X^2 + iM_X\Gamma_X},$$

$$\Gamma_X = \Gamma_0 + \Gamma_{J/\psi\phi} + \Gamma_{D_s^*\bar{D}_s^*},$$

with Γ_0 accounting for the channels of Ref. [23] not explicitly considered here (we shall fit that to the data as discussed above), and

Flatté effect

$$\Gamma_{J/\psi\phi} = \frac{|g_{J/\psi\phi}|^2}{8\pi M_X^2} \tilde{p}_\phi,$$

$$\Gamma_{D_s^*\bar{D}_s^*} = \frac{|g_{D_s^*\bar{D}_s^*}|^2}{8\pi M_X^2} \tilde{p}_{D_s^*} \Theta(M_{\rm inv}(D_s^*\bar{D}_s^*) - 2M_{D_s^*}).$$

The contribution of X(4140)

- **Since X(4140) is 1^{++}, the kaon should be in P-wave, and the operator for P-wave is,**

$$(\vec{\epsilon}_{J/\psi} \times \vec{\epsilon}_{\phi}) \cdot \vec{k}, \quad \Longleftrightarrow \quad t^{\text{tree}}_{B^- \to K^- D_s^* \bar{D}_s^*} = A\left(\vec{\epsilon} \cdot \vec{k}\vec{\epsilon}' \cdot \vec{k} - \frac{1}{3}\vec{k}^2\vec{\epsilon} \cdot \vec{\epsilon}'\right),$$

$$\frac{d\Gamma}{dM_{\text{inv}}(D_s^* \bar{D}_s^*)} = \frac{1}{(2\pi)^3}\frac{1}{4M_{B^-}^2}\frac{2}{3}|\vec{k}|^4|\vec{k}'|\tilde{p}_{D_s^*}|A|^2,$$

The substitution:

$$M_{\text{inv}}(D_s^* \bar{D}_s^*) \to M_{\text{inv}}(J/\psi\phi),$$

$$\frac{2}{3}|\vec{k}|^4 \to 2|\vec{k}|^2, \qquad \tilde{p}_{D_s^*} \to \tilde{p}_{\phi},$$

$$A \to \frac{BM^4_{X(4140)}}{M^2_{\text{inv}}(J/\psi\phi) - M^2_{X(4140)} + iM_{X(4140)}\Gamma_{X(4140)}}$$

with B a parameter to be fitted to the data.

$$M_{X(4140)} = 4132 \text{ MeV},$$

Results

- **We fit the data from threshold up to about 4250 MeV.**
- **13 data, chi^2/dof=15.3/(13-3)**

$$\Gamma_0 = 65.0 \pm 7.1 \text{ MeV} \quad (\text{at } 68\% \text{ confidence level}),$$

$$\Gamma_{J/\psi\phi} \simeq 22.0 \text{ MeV}$$

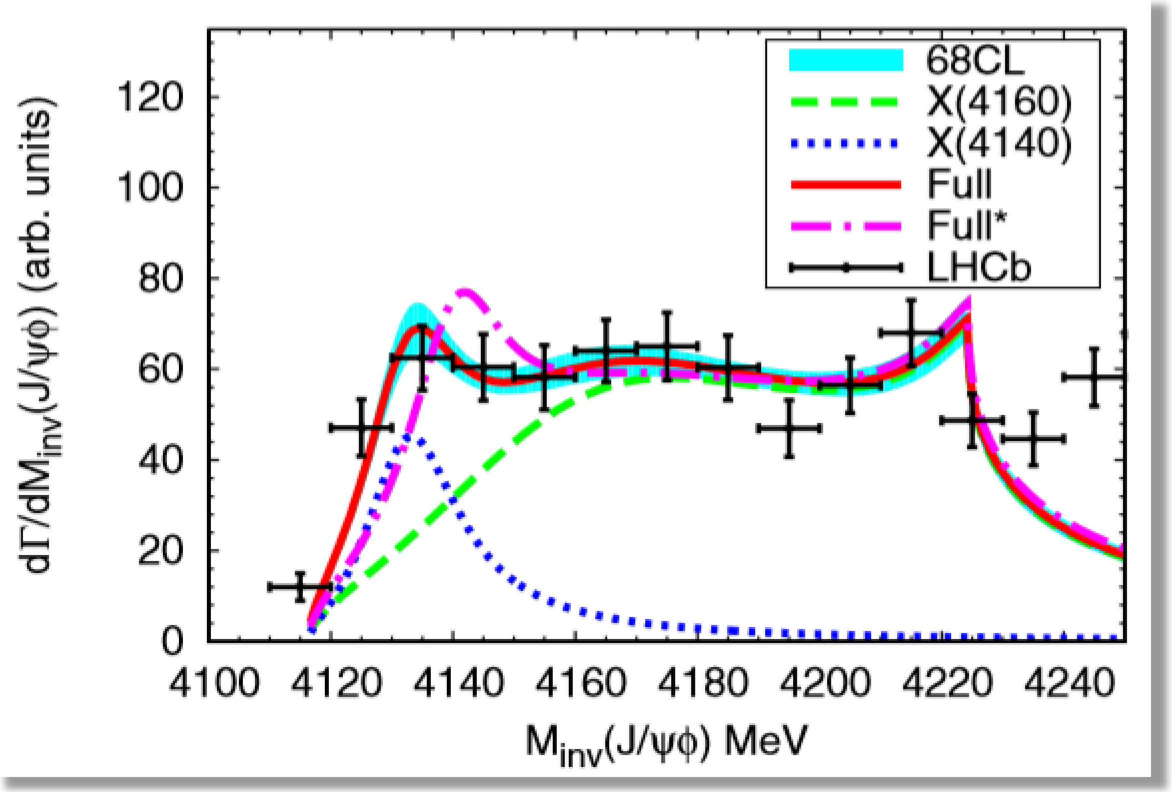
$$\Gamma_{X(4160)} \simeq 87.0 \pm 7.1 \text{ MeV}$$

$X(4160)$ $\quad I^G(J^{PC}) = ?^?(?^{??})$

Seen by PAKHLOV 2008 in $e^+ e^- \to J/\psi X$, $X \to D^* \overline{D}^*$

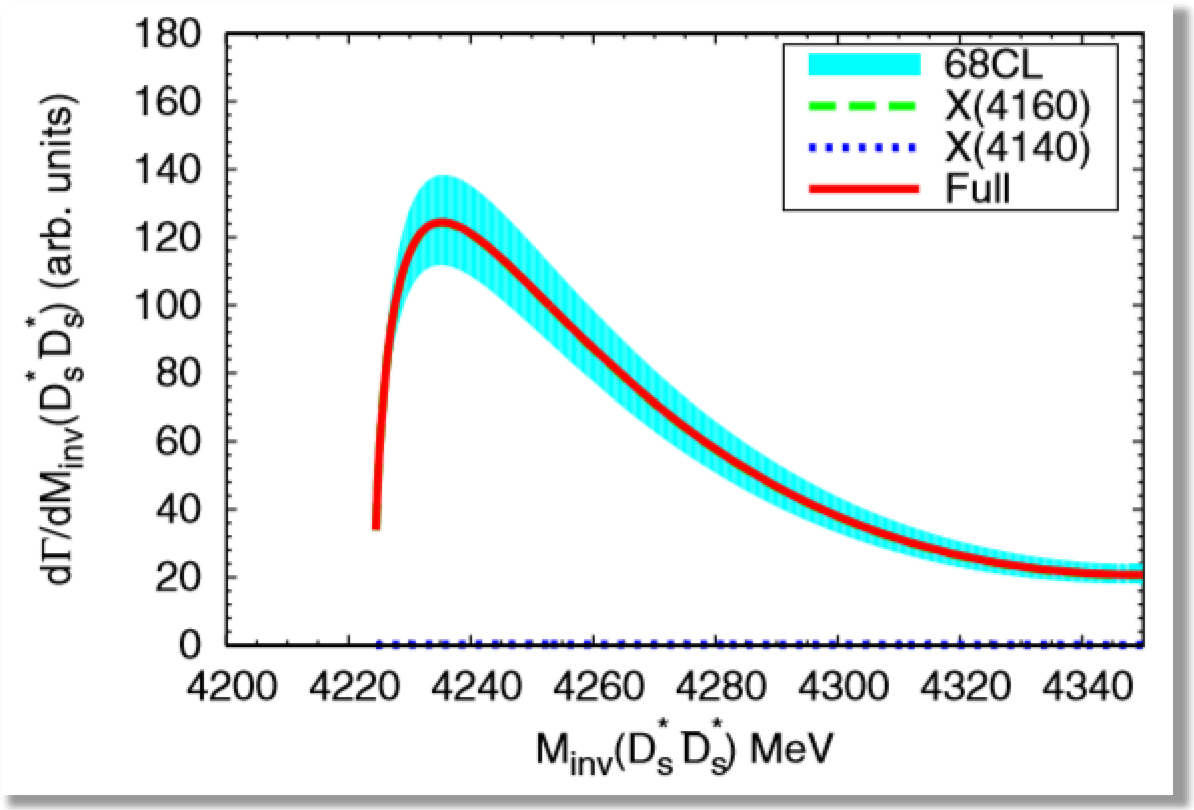
$X(4160)$ MASS	4156^{+29}_{-25} MeV
$X(4160)$ WIDTH	139^{+110}_{-60} MeV

Results



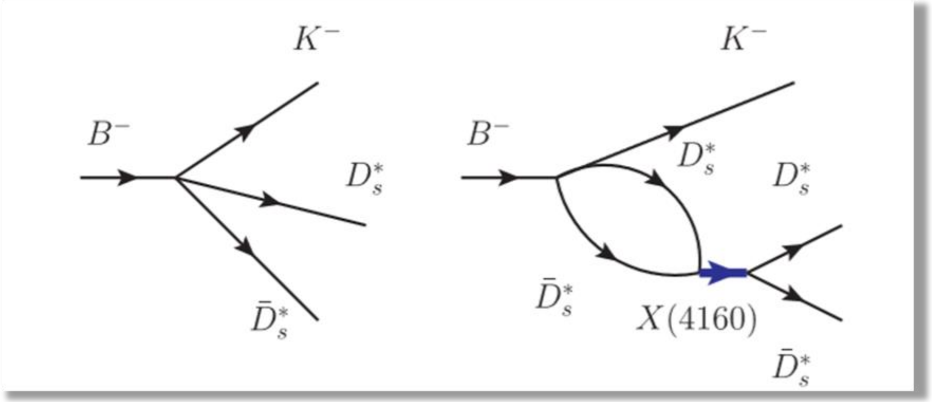
- The Flatte effect is visable, as a sharp fall down of the invariant mass distribution above the $D_s^* \overline{D}_s^*$ threshold.
- The lower part of the spectrum can be obtain from the contribution of X(4160)(2++) and X(4140)(1++, 19 MeV) resonances.
- The cusp of the distribution at the $D_s^* \overline{D}_s^*$ threshold, cannot be accommodated by a Breit-Wigner amplitude, and it indicates that the resonance in that region is tied to the $D_s^* \overline{D}_s^*$ channel.

Results



$$B^- \rightarrow K^- D_s^* \bar{D}_s^*$$

- **There is a peak close to the threshold, which should not be misidentified with a new state, but it is the reflection of the X(4160).**
- **The strength of the peak is the twice of the one of the X(4140).**



$B^{\pm}$

$I(J^P) = \frac{1}{2}(0^-)$

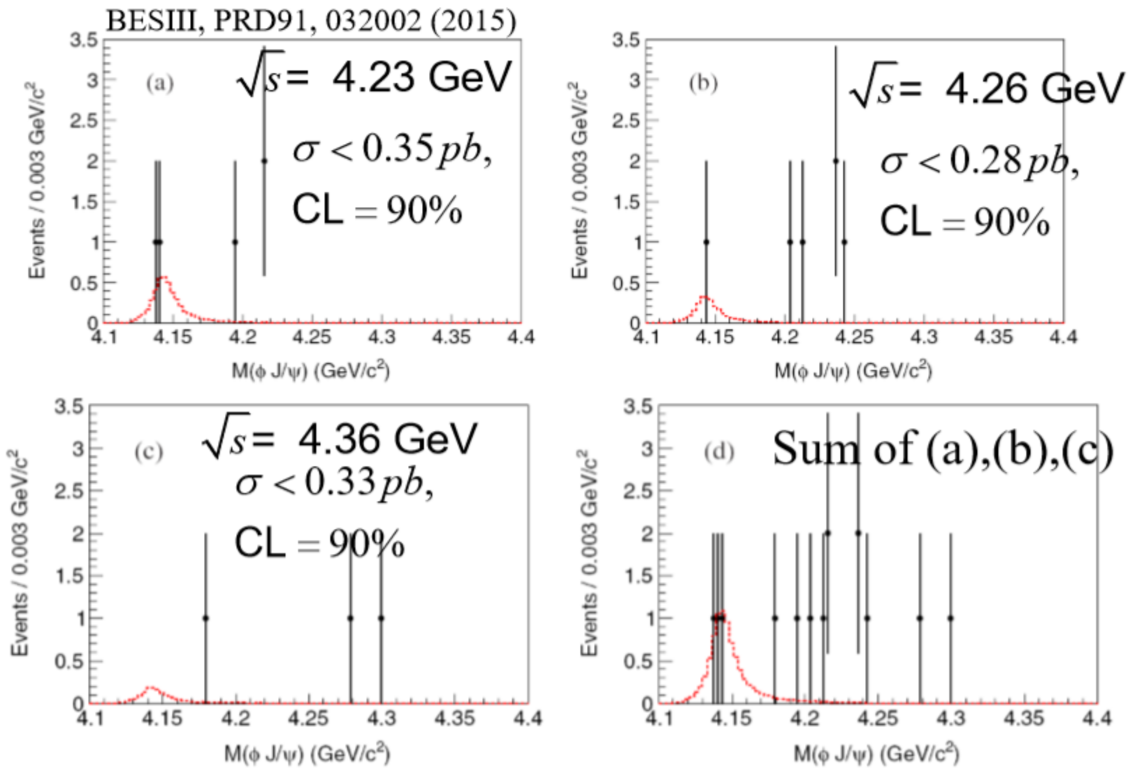
Γ_{169}	$\overline{D}^*(2007)^0 D_{s1}(2536)^+ \times$ B$(D_{s1}(2536)^+ \to D^*(2007)^0 K^+)$	$(5.5 \pm 1.6) \times 10^{-4}$	
Γ_{196}	$D^*(2010)^- D^*(2010)^+ K^+$	$(1.32 \pm 0.18) \times 10^{-3}$	
Γ_{210}	$D_s^+ \overline{K}^0$	$< 8 \times 10^{-4}$	CL=90%
Γ_{211}	$D_s^{*+} \overline{K}^0$	$< 9 \times 10^{-4}$	CL=90%

BESIII: $e^+e^-\to\gamma J/\psi\phi$

arxiv:1806.05113

X(4140)

Search for the Y(4140) via $e^+e^- \to \gamma\phi J/\psi$ at $\sqrt{s}$= 4.23, 4.26 and 4.36 Ge



Silde of R.G. Ping, 2018.3.31
第一届强子与重味物理理论与实验联合研讨会@兰州

$$\frac{\sigma(e^+e^- \to \gamma Y(4140))}{\sigma(e^+e^- \to \gamma X(3872))} \sim 0.1 \text{ at } \sqrt{s} = 4.23, 4.26 \text{ GeV}$$

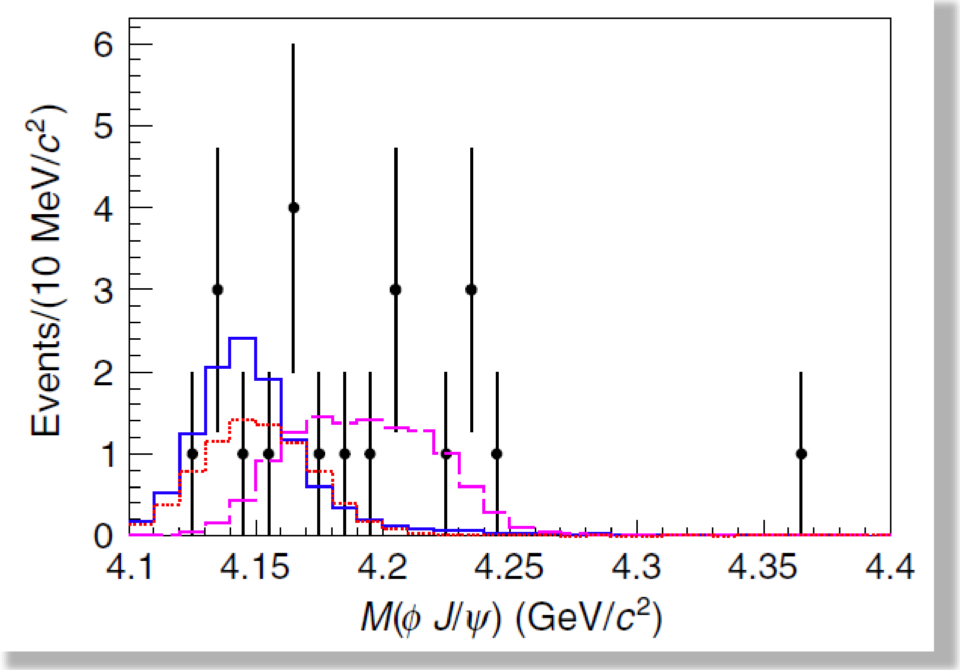
13

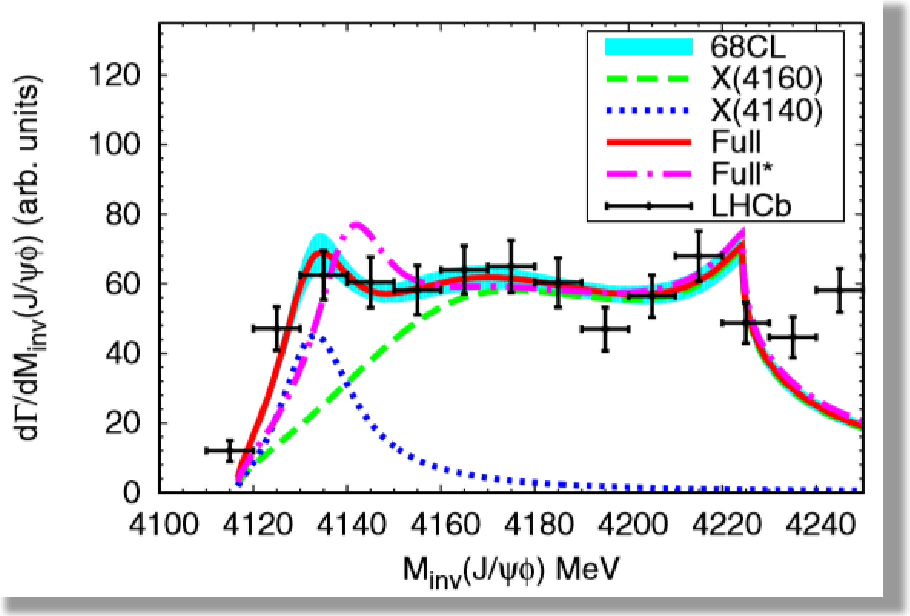
BESIII

Observation of $e^+e^- \to \phi\chi_{c1}$ and $\phi\chi_{c2}$ at $\sqrt{s} = 4.600$ GeV

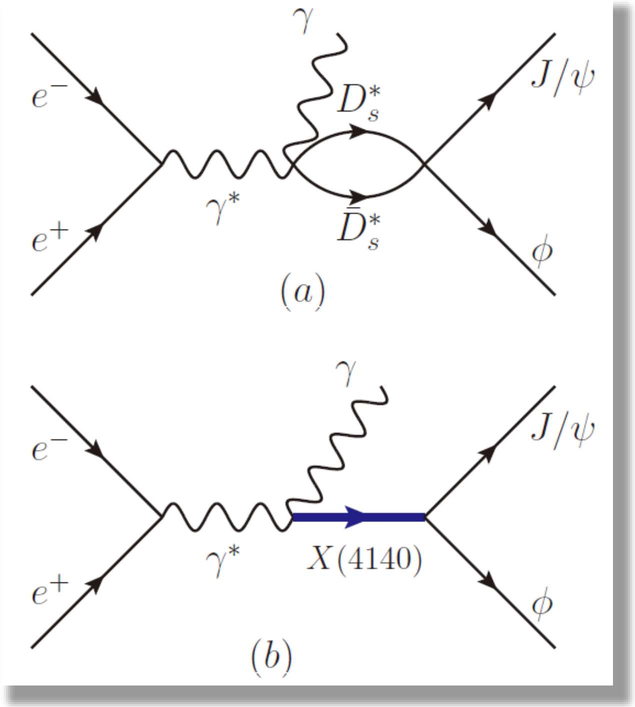
M. Ablikim *et al.* (BESIII Collaboration)
Phys. Rev. D **97**, 032008 – Published 12 February 2018

second systematic. No significant signals are observed for $e^+e^- \to \phi\chi_{c0}$ and $e^+e^- \to \gamma X(4140)$ and upper limits on the Born cross sections at 90% C.L. are provided at $\sqrt{s} = 4.600$ GeV.





The mechanism for J/ψφ production



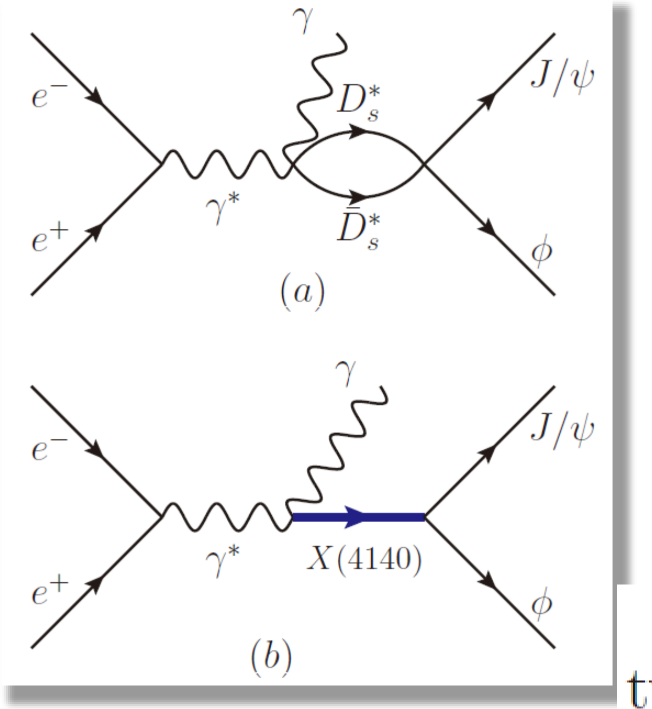
$$\tilde{\mathcal{M}}^{(a)}_{J/\psi\phi} = A \times G_{D_s^*\bar{D}_s^*} t_{D_s^*\bar{D}_s^*,J/\psi\phi} \times \mathcal{P}^{(a)} = \mathcal{M}^{(a)}_{J/\psi\phi} \times \mathcal{P}^{(a)},$$

$$\mathcal{P}^{(a)} = \left[\frac{1}{2}\left(\epsilon_{1i}\epsilon_{2j} + \epsilon_{1j}\epsilon_{2i}\right) - \frac{1}{3}\vec{\epsilon}_1 \cdot \vec{\epsilon}_2 \delta_{ij}\right] \times \left[\frac{1}{2}\left(\epsilon_{\phi i}\epsilon_{J/\psi j} + \epsilon_{\phi j}\epsilon_{J/\psi i}\right) - \frac{1}{3}\vec{\epsilon}_\phi \cdot \vec{\epsilon}_{J/\psi}\delta_{ij}\right]$$

$$t_{D_s^*\bar{D}_s^*,J/\psi\phi} = \frac{g_{D_s^*\bar{D}_s^*} g_{J/\psi\phi}}{M^2_{\text{inv}}(J/\psi\phi) - M^2_{X_1} + i\Gamma_{X_1}M_{X_1}},$$

$$g_{D_s^*\bar{D}_s^*} = (18927 - 5524i)\ \text{MeV}$$
$$g_{J/\psi\phi} = (-2617 - 5151i)\ \text{MeV}$$

The mechanism for J/ψφ production

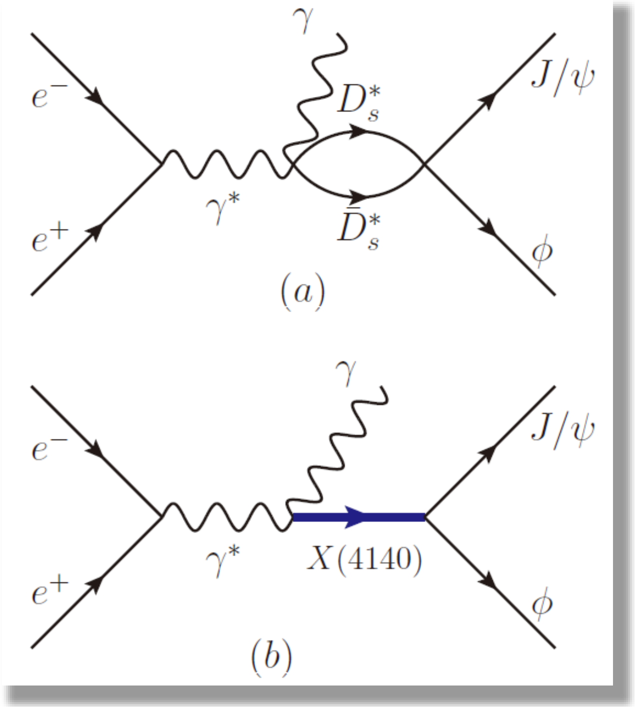


$$\tilde{\mathcal{M}}^{(b)}_{J/\psi\phi} = \frac{BM^2_{X_2} \times \mathcal{P}^{(b)}}{M^2_{\rm inv}(J/\psi\phi) - M^2_{X_2} + iM_{X_2}\Gamma_{X_2}} = \mathcal{M}^{(b)}_{J/\psi\phi} \times \mathcal{P}^{(b)},$$

$$\mathcal{P}^{(b)} = \sum_{\rm pol} [(\vec{\epsilon}_1 \times \vec{\epsilon}_2) \cdot \vec{\epsilon}_{X_2}] [\vec{\epsilon}_{X_2} \cdot (\vec{\epsilon}_\phi \times \vec{\epsilon}_{J/\psi})] = (\vec{\epsilon}_1 \times \vec{\epsilon}_2) \cdot (\vec{\epsilon}_\phi \times \vec{\epsilon}_{J/\psi}),$$

In the present work, the only relevant thing is that the two structures $\mathcal{P}^{(a)}$ and $\mathcal{P}^{(b)}$ do not interfere, and there are no momenta involved, unlike in the decay $B^- \to J/\psi\phi K$ [4].

The mechanism for J/ψφ production

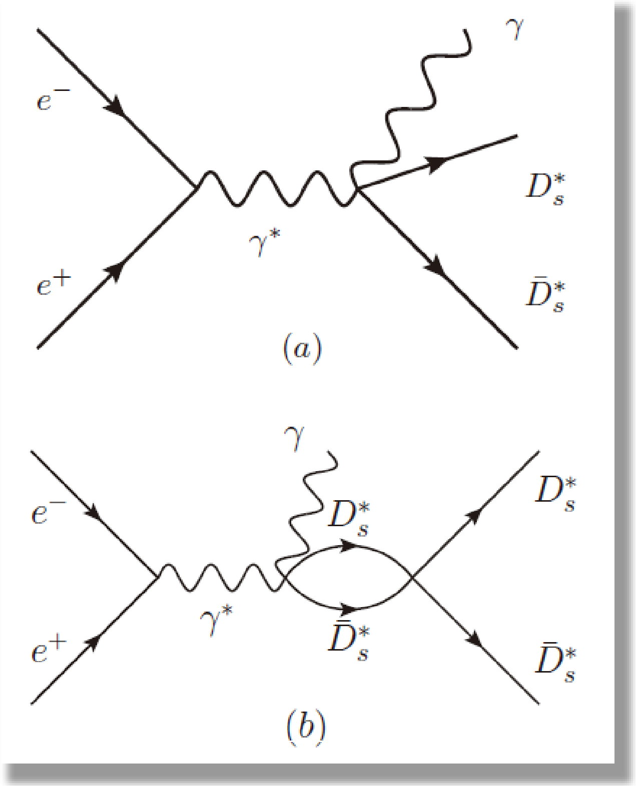


$$\frac{d\Gamma}{dM_{\text{inv}}(J/\psi\phi)} = \frac{1}{(2\pi)^3}\frac{1}{4s}k'\tilde{p}_\phi\left[|\mathcal{M}^{(a)}_{J/\psi\phi}|^2 + |\mathcal{M}^{(b)}_{J/\psi\phi}|^2\right]$$

$$k' = \frac{\lambda^{1/2}\left(s, 0, M^2_{\text{inv}}(J/\psi\phi)\right)}{2\sqrt{s}}$$

$$\tilde{p}_\phi = \frac{\lambda^{1/2}(M^2_{\text{inv}}(J/\psi\phi), m^2_{J/\psi}, m^2_\phi)}{2M_{\text{inv}}(J/\psi\phi)}$$

The mechanism for $D_s^*D_s^*$ production

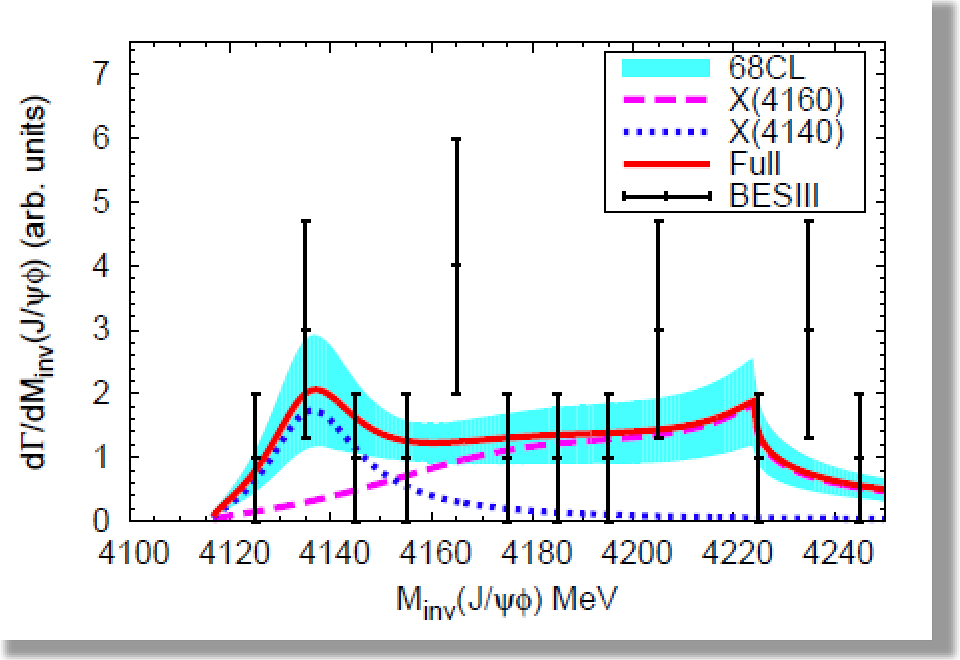


$$\frac{d\Gamma}{dM_{\rm inv}(D_s^*\bar{D}_s^*)} = \frac{1}{(2\pi)^3}\frac{1}{4s}k'\tilde{p}_{D_s^*}|\mathcal{M}_{D_s^*\bar{D}_s^*}|^2,$$

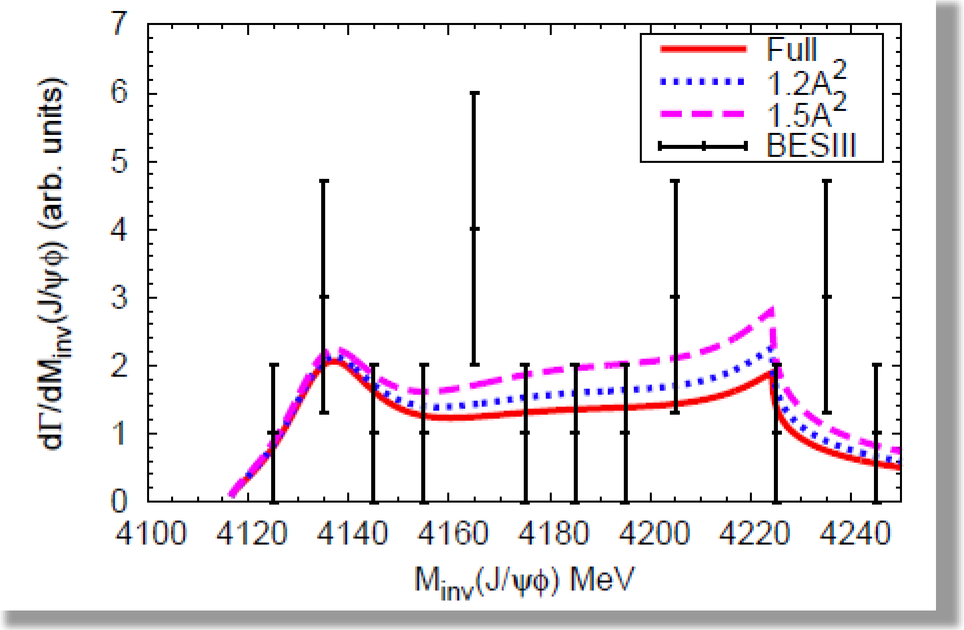
$$\begin{aligned}\mathcal{M}_{D_s^*\bar{D}_s^*} &= A\left[T^{\rm tree} + T^{X(4160)}\right] \\ &= A\left[1 + G_{D_s^*\bar{D}_s^*}\left(M_{\rm inv}(D_s^*\bar{D}_s^*)\right)\right. \\ &\quad \left.\times t_{D_s^*\bar{D}_s^*,D_s^*\bar{D}_s^*}\left(M_{\rm inv}(D_s^*\bar{D}_s^*)\right)\right]\end{aligned}$$

$$t_{D_s^*\bar{D}_s^*,D_s^*\bar{D}_s^*} = \frac{g^2_{D_s^*\bar{D}_s^*}}{M^2_{\rm inv}(D_s^*\bar{D}_s^*) - M^2_{X_1} + i\Gamma_{X_1}M_{X_1}}$$

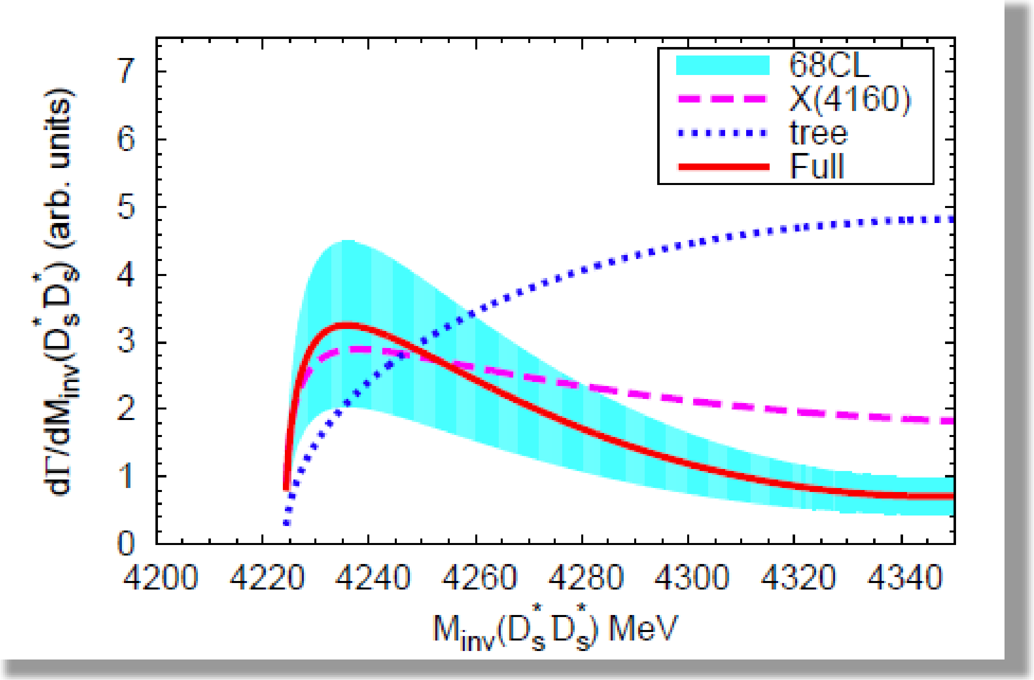
Results



68CL
X(4160)
X(4140)
Full
BESIII
dΓ/dM_inv(J/ψφ) (arb. units)
M_inv(J/ψφ) MeV



Full
1.2A2
1.5A2
BESIII
dΓ/dM_inv(J/ψφ) (arb. units)
M_inv(J/ψφ) MeV



68CL
X(4160)
tree
Full
$d\Gamma/dM_{inv}(D_s^* D_s^*)$ (arb. units)
0
1
2
3
4
5
6
7
4200
4220
4240
4260
4280
4300
4320
4340
$M_{inv}(D_s^* D_s^*)$ MeV

LHCb: $B^+ \to J/\psi \omega K^+$

arxiv:1808.10373

LHCb thesis 2014-243

χ_{c0}(2P)

X(3872)

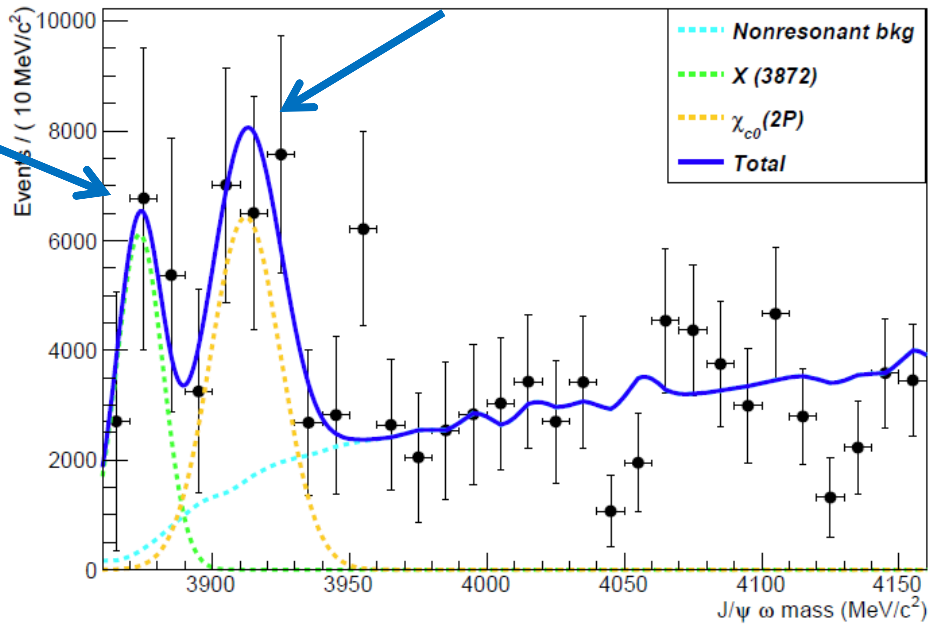
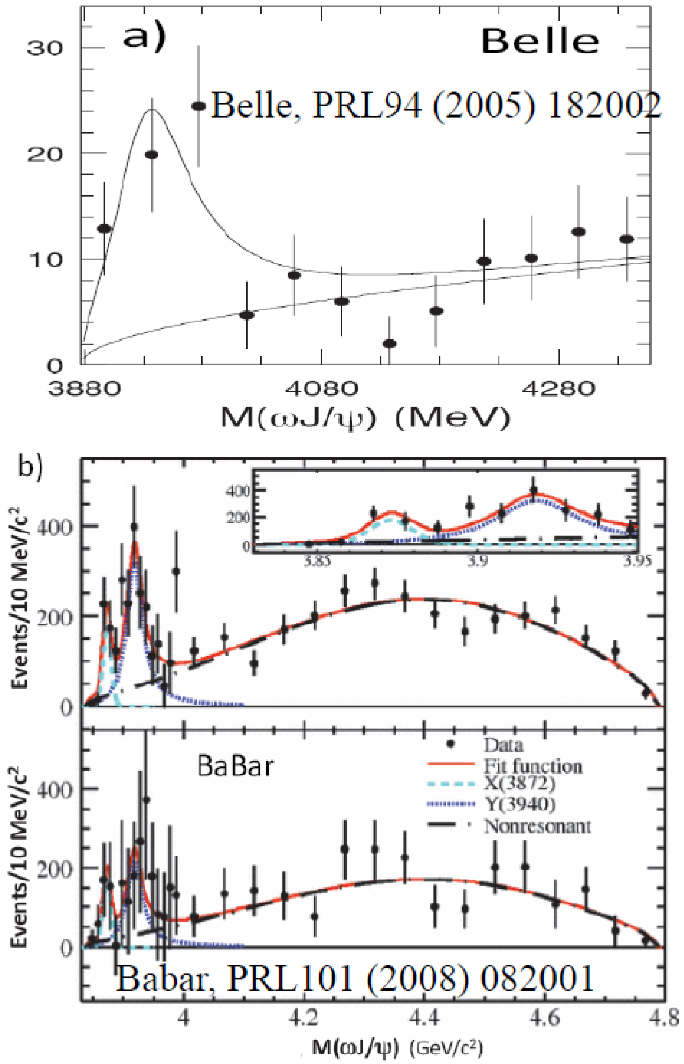


Figure 4.1: Fitted $J/\psi\ \omega$ efficiency-corrected invariant mass distribution.

χ_{c0}(2P)： X(3915)
Is X(3915) the χ_{c0}(2P)?
HXChen, Phys.Rept. 639 (2016)
Phys.Rev. D69 (2004) 094019

X(3915)

- $X(3915)$ in $B \to K\omega J/\psi$ observed by Belle and Babar



Belle: S-wave Breit-Wigner

$$M = 3943 \pm 17 \text{ MeV}$$
$$\Gamma = 87 \pm 24 \text{ MeV}$$

Babar:

$$M = 3919 \pm 4 \text{ MeV}$$
$$\Gamma = 31 \pm 11 \text{ MeV}$$

Weighted average:

$$M = 3920 \pm 4 \text{ MeV}$$
$$\Gamma = 41 \pm 10 \text{ MeV}.$$

16

D*D* molecule states,X(3940),X(3930)

PHYSICAL REVIEW D **80**, 114013 (2009)

$Y(3940)$, $Z(3930)$, and the $X(4160)$ as dynamically generated resonances from the vector-vector interaction

R. Molina[1] and E. Oset[1]

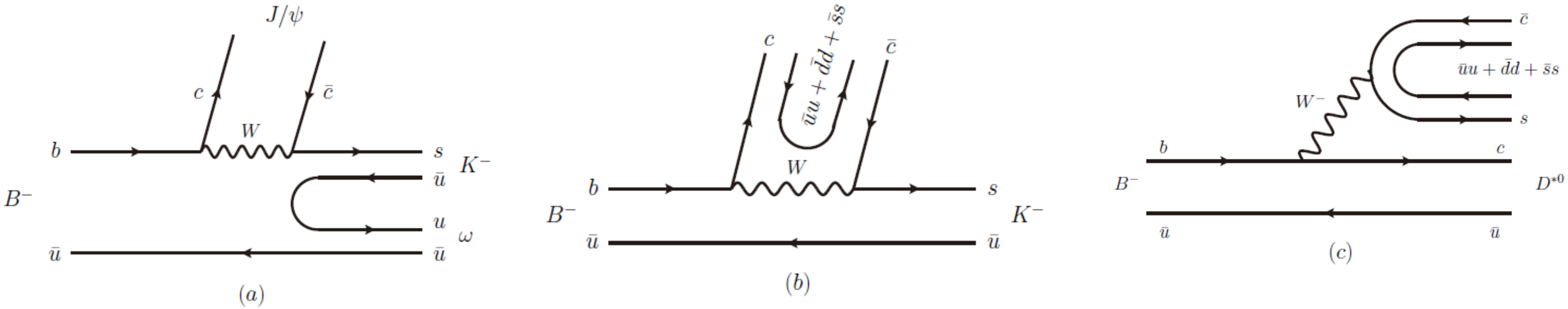
TABLE II. Couplings g_i in units of MeV for $I = 0$, $J = 0$.

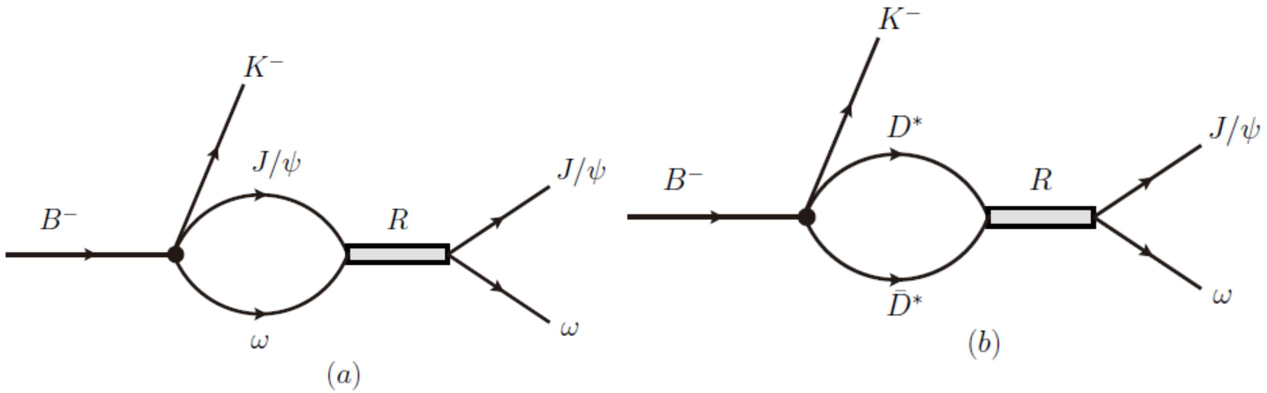
$\sqrt{s_{pole}} = 3943 + i7.4$, $I^G[J^{PC}] = 0^+[0^{++}]$				
$D^*\bar{D}^*$	$D_s^*\bar{D}_s^*$	$K^*\bar{K}^*$	$\rho\rho$	$\omega\omega$
$18\,810 - i682$	$8426 + i1933$	$10 - i11$	$-22 + i47$	$1348 + i234$
$\phi\phi$	$J/\psi J/\psi$	$\omega J/\psi$	$\phi J/\psi$	$\omega\phi$
$-1000 - i150$	$417 + i64$	$-1429 - i216$	$889 + i196$	$-215 - i107$

E IV. Couplings g_i in units of MeV for $I = 0$, $J = 2$.

$\sqrt{s_{pole}} = 3922 + i26$, $I^G[J^{PC}] = 0^+[2^{++}]$				
$D^*\bar{D}^*$	$D_s^*\bar{D}_s^*$	$K^*\bar{K}^*$	$\rho\rho$	$\omega\omega$
$21\,100 - i1802$	$1633 + i6797$	$42 + i14$	$-75 + i37$	$1558 + i1821$
$\phi\phi$	$J/\psi J/\psi$	$\omega J/\psi$	$\phi J/\psi$	$\omega\phi$
$-904 - i1783$	$1783 + i197$	$-2558 - i2289$	$918 + i2921$	$91 - i784$

The reaction





$$|H\rangle = \left|(D^{*0}\bar{D}^{*0} + D^{*+}\bar{D}^{*-} + D_s^{*+}\bar{D}_s^{*-} + 3\,C\,D^{*0}\bar{D}^{*0})K^-\right\rangle$$
$$= \left|\,\left[(1+3\,C)D^{*0}\bar{D}^{*0} + D^{*+}\bar{D}^{*-} + D_s^{*+}\bar{D}_s^{*-}\right]K^-\right\rangle .$$

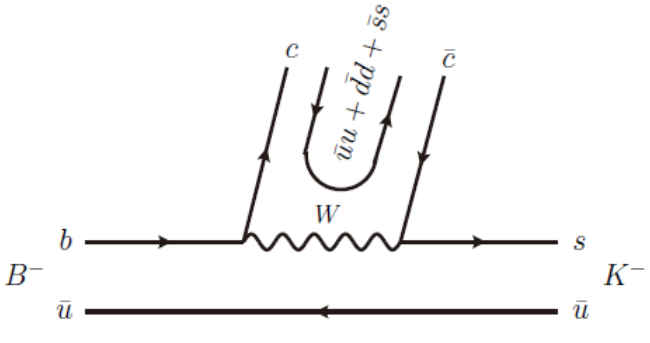
Tree level

$$|H\rangle = |(D^{*0}\bar{D}^{*0} + D^{*+}\bar{D}^{*-} + D_s^{*+}\bar{D}_s^{*-} + 3\,C\,D^{*0}\bar{D}^{*0})K^-\rangle$$
$$= |\,[(1+3\,C)D^{*0}\bar{D}^{*0} + D^{*+}\bar{D}^{*-} + D_s^{*+}\bar{D}_s^{*-}]\,K^-\rangle\,.$$

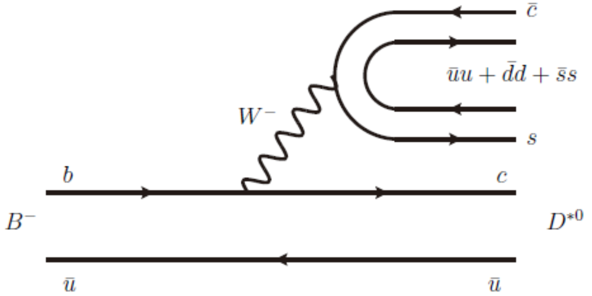
$$t^{tree}_{B^-\to K^- D^{*0}\bar{D}^{*0}} = \Big[A\,|\vec{k}_{\rm av}|^2\,\vec{\epsilon}\cdot\vec{\epsilon}\,' + B\,(\vec{\epsilon}\cdot\vec{k}\vec{\epsilon}\,'\cdot\vec{k} - \frac{1}{3}|\vec{k}|^2\,\vec{\epsilon}\cdot\vec{\epsilon}\,')\Big]\,(1+3\,C)\,,$$

$$t^{tree}_{B^-\to K^- D^{*+}D^{*-}} = A\,|\vec{k}_{\rm av}|^2\,\vec{\epsilon}\cdot\vec{\epsilon}\,' + B\,(\vec{\epsilon}\cdot\vec{k}\vec{\epsilon}\,'\cdot\vec{k} - \frac{1}{3}|\vec{k}|^2\,\vec{\epsilon}\cdot\vec{\epsilon}\,')\,,$$

$$t^{tree}_{B^-\to K^- D_s^{*+}D_s^{*-}} = A\,|\vec{k}_{\rm av}|^2\,\vec{\epsilon}\cdot\vec{\epsilon}\,' + B\,(\vec{\epsilon}\cdot\vec{k}\vec{\epsilon}\,'\cdot\vec{k} - \frac{1}{3}|\vec{k}|^2\,\vec{\epsilon}\cdot\vec{\epsilon}\,')\,,$$



(b)



(c)

Final state interaction

$$t_1 = G_{D^{*0}\bar{D}^{*0}}(M_{\rm inv})\, t^{I}_{D^{*0}\bar{D}^{*0}\to J/\psi\omega}(1+3\,C)$$
$$+\, G_{D^{*+}D^{*-}}(M_{\rm inv})\, t^{I}_{D^{*+}D^{*-}\to J/\psi\omega}$$
$$+\, G_{D_s^{*+}D_s^{*-}}(M_{\rm inv})\, t^{I}_{D_s^{*+}D_s^{*-}\to J/\psi\omega}\,,$$

$$t_2 = G_{D^{*0}\bar{D}^{*0}}(M_{\rm inv})\, t^{II}_{D^{*0}\bar{D}^{*0}\to J/\psi\omega}(1+3\,C)$$
$$+\, G_{D^{*+}D^{*-}}(M_{\rm inv})\, t^{II}_{D^{*+}D^{*-}\to J/\psi\omega}$$
$$+\, G_{D_s^{*+}D_s^{*-}}(M_{\rm inv})\, t^{II}_{D_s^{*+}D_s^{*-}\to J/\psi\omega}\,,$$

$$\frac{d\Gamma}{dM_{\rm inv}^{J/\psi\omega}} = \frac{1}{(2\pi)^3}\frac{1}{4M_B^2}k'\tilde{p}_\omega \times \left(3|A|^2|\vec{k}_{\rm av}|^4|t_1|^2 + \frac{2}{3}|B|^2|\vec{k}|^4|t_2|^2\right)$$

$$t^{i}_{D^{*0}\bar{D}^{*0},\,J/\psi\omega} = \frac{\frac{1}{\sqrt{2}}g^{(i)}_{R,\,D^*\bar{D}^*}\; g^{(i)}_{R,\,J/\psi\omega}}{M^2_{\rm inv} - M^2_{R_i} + iM_{R_i}\Gamma_{R_i}}\,,$$

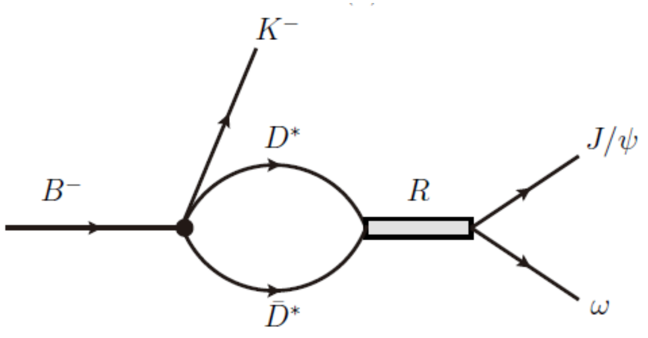
$$t^{i}_{D^{*+}D^{*-},\,J/\psi\omega} = \frac{\frac{1}{\sqrt{2}}g^{(i)}_{R,\,D^*D^*}\; g^{(i)}_{R,\,J/\psi\omega}}{M^2_{\rm inv} - M^2_{R_i} + iM_{R_i}\Gamma_{R_i}}\,,$$

$$t^{i}_{D_s^{*+}D_s^{*-},\,J/\psi\omega} = \frac{g^{(i)}_{R,\,D_s^{*+}D_s^{*-}}\; g^{(i)}_{R,\,J/\psi\omega}}{M^2_{\rm inv} - M^2_{R_i} + iM_{R_i}\Gamma_{R_i}}\,,$$

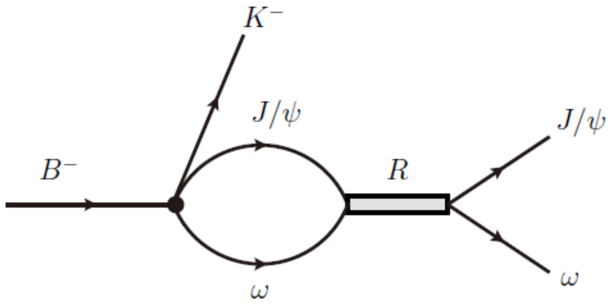
$$\Gamma_{R_i} = \Gamma_0^{(i)} + \Gamma^{(i)}_{J/\psi\omega} + \Gamma^{(i)}_{D^*\bar{D}^*}\,,$$

$$\Gamma^{(i)}_{J/\psi\omega} = \frac{|g^{i}_{R,\,J/\psi\omega}|^2}{8\pi M^2_{R_i}}\,\tilde{p}_\omega, \qquad \Gamma^{(i)}_{D^*\bar{D}^*} = \frac{|g^{i}_{R,\,D^*\bar{D}^*}|^2}{8\pi M^2_{R_i}}\,\tilde{p}_{D^*}\Theta(M_{\rm inv} - 2M_{D^*}),$$

$$\Gamma_0^{(i)} = \Gamma_{R_i} - \Gamma^{(i)}_{J/\psi\omega}(M_{\rm inv}^{J/\psi\omega} = M_{R_i}).$$

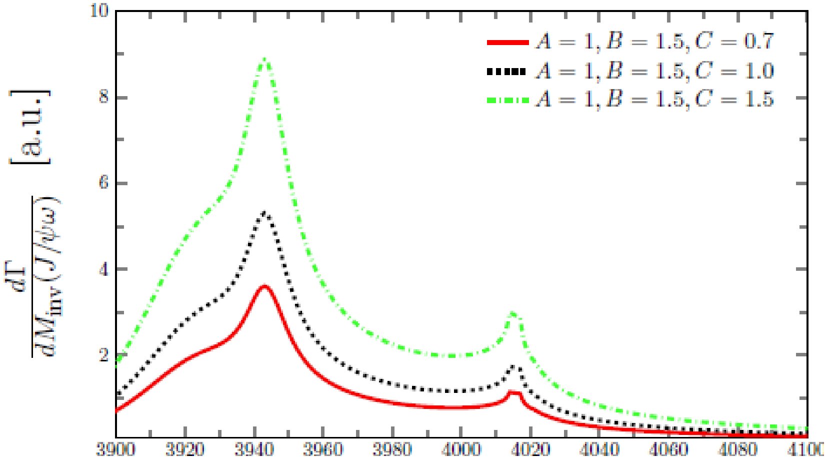


(b)

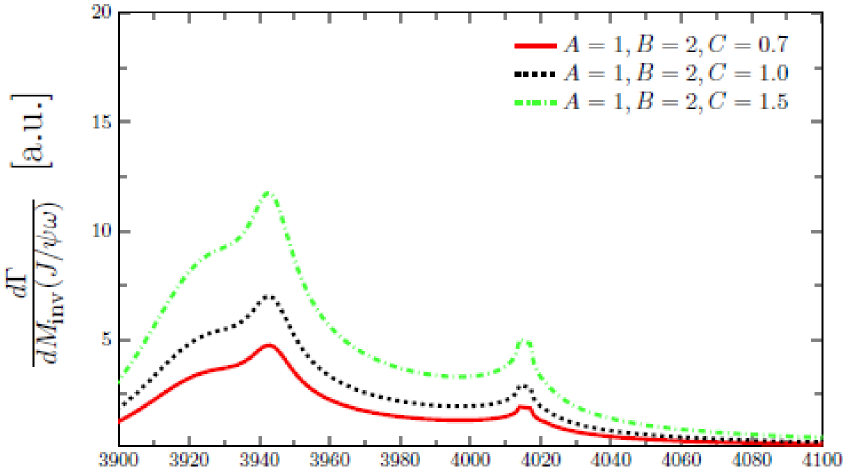


(a)

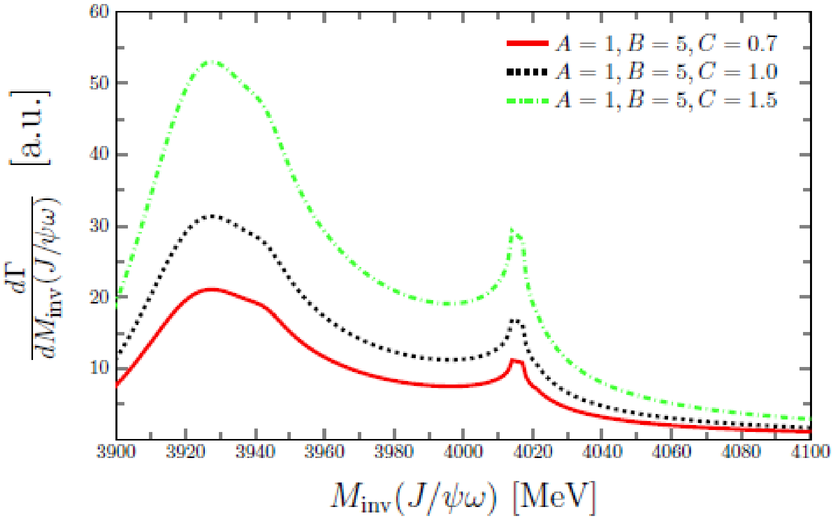
Results



$A=1, B=1.5, C=0.7$
$A=1, B=1.5, C=1.0$
$A=1, B=1.5, C=1.5$
$\frac{d\Gamma}{dM_{\rm inv}(J/\psi\omega)}$ [a.u.]

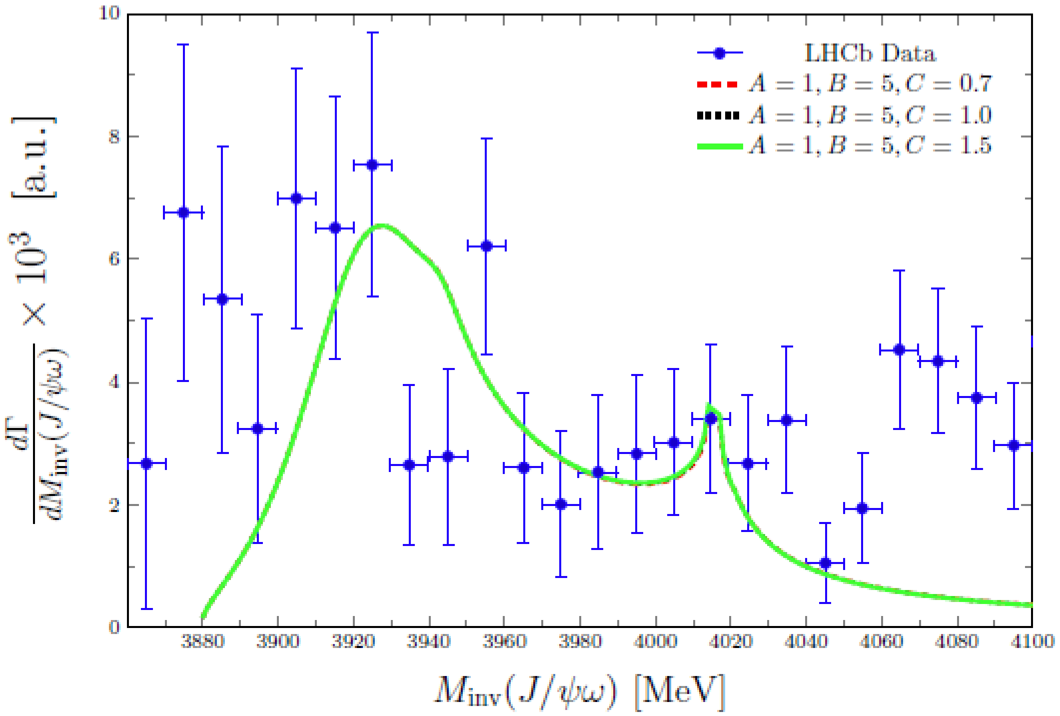


$A=1, B=2, C=0.7$
$A=1, B=2, C=1.0$
$A=1, B=2, C=1.5$
$\frac{d\Gamma}{dM_{\rm inv}(J/\psi\omega)}$ [a.u.]



$A=1, B=5, C=0.7$
$A=1, B=5, C=1.0$
$A=1, B=5, C=1.5$
$\frac{d\Gamma}{dM_{\rm inv}(J/\psi\omega)}$ [a.u.]
$M_{\rm inv}(J/\psi\omega)$ [MeV]

Results


LHCb Data
$A = 1, B = 5, C = 0.7$
$A = 1, B = 5, C = 1.0$
$A = 1, B = 5, C = 1.5$
$\frac{d\Gamma}{dM_{\rm inv}(J/\psi\omega)} \times 10^3$ [a.u.]
$M_{\rm inv}(J/\psi\omega)$ [MeV]
0
2
4
6
8
10
3880
3900
3920
3940
3960
3980
4000
4020
4040
4060
4080
4100

Summary

- The X(4140) deduced from the $B^+ \to J/\psi\phi K^+$ by LHCb has a large width 83±21 MeV vs. 19MeV of PDG.
- Many explanations of X(4140): molecular state, hybrid state, tetraquark state.
- X(4140) as the $D_s^*\bar{D}_s^*$ molecule, with JPC=0^{++}, 2^{++}, in contrast with the recent experimental measurement, PDG(1^{++}).
- X(4160) as the $D_s^*\bar{D}_s^*$ molecule, with JPC=2^{++}, large couplings to $D_s^*\bar{D}_s^*$, J/ψϕ channels.

Summary

- **Taking into account the contribution of X(4160) and X(4140), the lower part of the spectrum can be well reproduced.**
- **The cusp of the distribution at the $D_s^* \bar{D}_s^*$ threshold, cannot be accommodated by a Breit-Wigner amplitude, and it indicates that the resonance in that region is tied to the $D_s^* \bar{D}_s^*$ channel.**
- **We predict the $D_s^* \bar{D}_s^*$ distribution for $B^- \to K^- D_s^* \bar{D}_s^*$ reaction. There is a peak close to the threshold, and it is the reflection of the X(4160).**

Summary

- We analysed the process of $e^+e^- \to \gamma J/\psi\phi$, by considering the contributions of the molecular state X(4160), and the X(4140) state.
- Our results show that some structures can be associated to the X(4160) and X(4140) states.
- The reflection effect of X(4160) is clear in the Ds*Ds* distribution, which should not be misidentified as a new resonance.
- We strongly call for a measurment with high precise.

Summary

- We have presented a theoretical interpretation on the $B^+ \to J/\psi\omega K^+$ reaction in the range of $J/\psi\omega$ invariant mass 3930-4050 MeV, and found that two resonances X(3940) and X(3930), strongly coupled to D*D* in JPC=0++ and 2++, give rise to a strong cusp at D*D* threshold, which is supported by LHCb measurement.
- Our work should serve as a motivation to improve the statistic.

Thanks for your attention!