New Meson States.

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on behaf of the BaBar Collaboration

□ Summary:

- Introduction.
- New Charm States.
- New Charmonium States.
- Conclusions.

Hadron 2007, October 8, 2007

Introduction.

□ Charm and Charmonium spectroscopy have made considerable and unexpected progress in the last few years.

□ This is due to the large data sets being collected by several experiments, in particular:

□ e^+e^- interactions at the $\Upsilon(4S)$ energy:

BaBar, BELLE, CLEO

□ Integrated luminosities. BaBar: 477 fb^{-1}, BELLE: 709 fb^{-1}.

□ $e^+e^- \rightarrow charmonium$:

CLEO-c, BES-II

□ $\bar{p}p$ colliders:

CDF, D0

Charm and Charmonium Spectroscopy.

□ Charm spectroscopy is studied in:

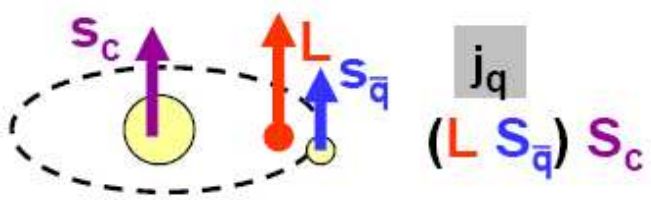
- inclusive $e^+e^- \to \bar{c}c$ interactions (all spins allowed);
- B decays (higher spins suppressed).

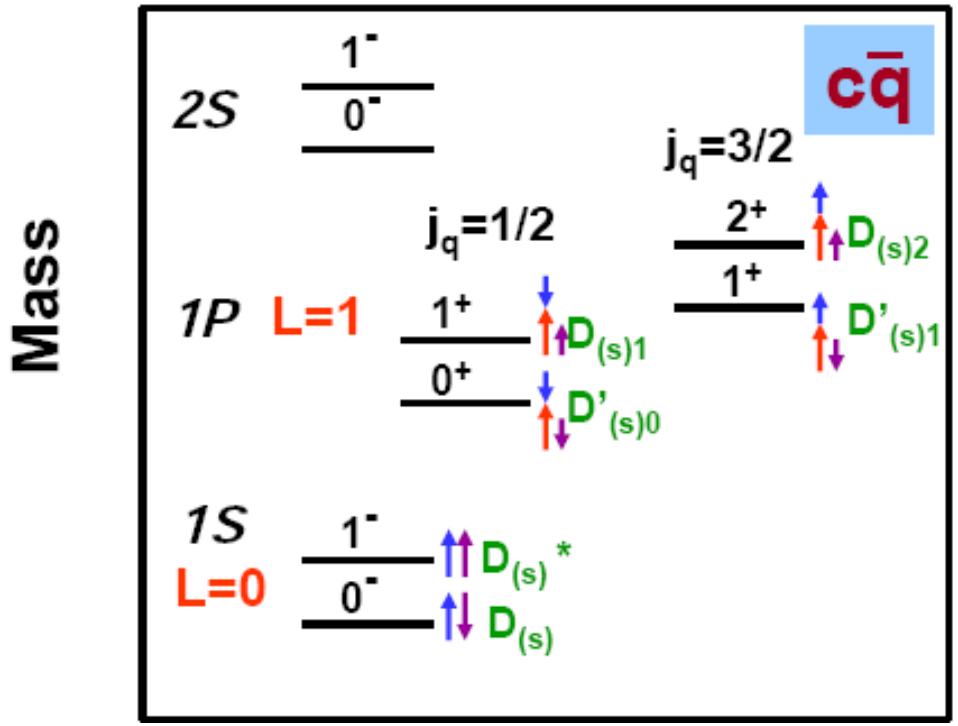
□ Charmonium spectroscopy is studied in:

- B decays;
- Initial-State-Radiations reactions $e^+e^- \to \gamma_{ISR}X$(only $J^{PC} = 1^{--}$);
- Double $c\bar{c}$ ($e^+e^- \to J/\psi X$). C(X)=+;
- Two photon interactions $\gamma\gamma \to X$: $J_X \neq 1$;

The charm spectrum.

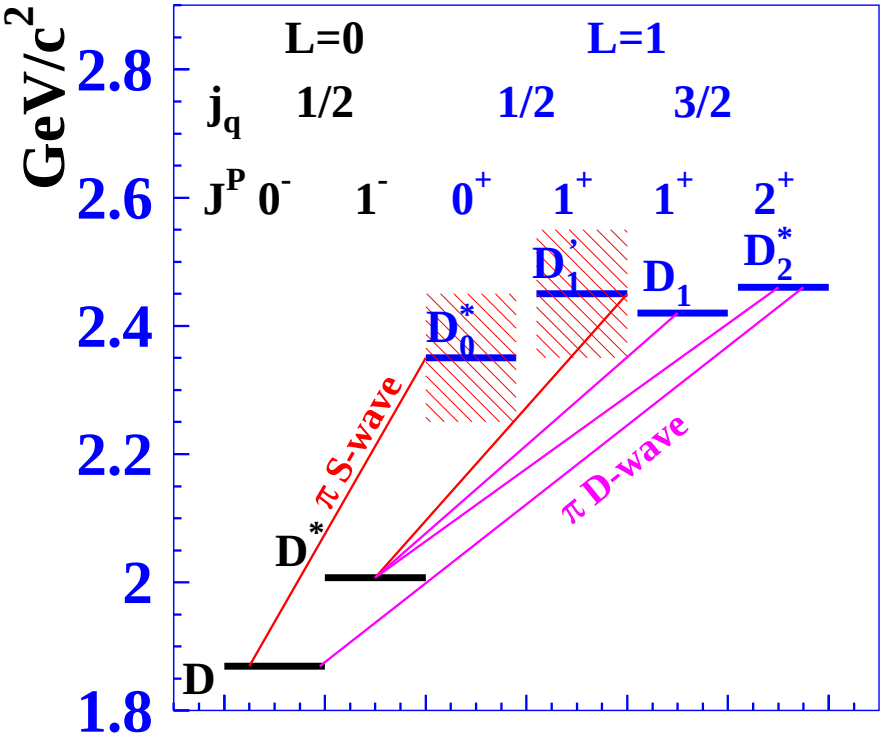
- Expected mass splitting.
- Separated $D_{(s)}$ meson-spin doublets: $(0^-, 1^-)$, $(0^+, 1^+)$, $(1^+, 2^+)$.





The spectroscopy of the $c(\bar{u}/\bar{d})$ states.

- Theory and experiment are in agreement.



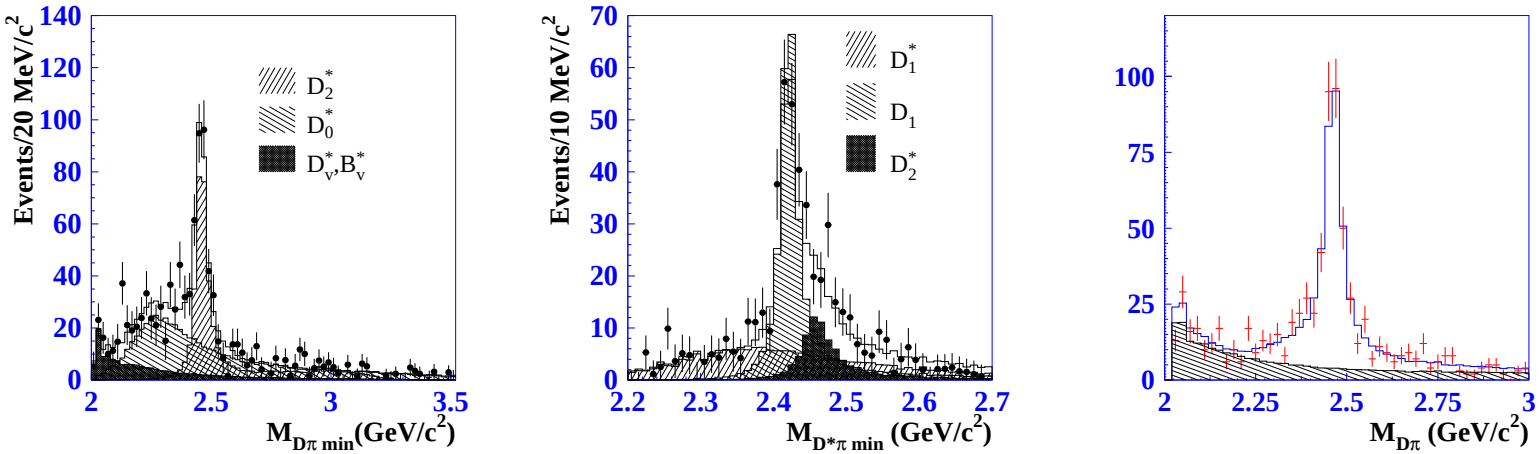
- Expect narrow and wide states. Wide resonances difficult to isolate.

Recent results.

- BELLE experiment has studied the decays: hep-ex/0307021,hep-ex/0611054

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

- Dalitz plot analysis of the B mesons three-body and four-body decays. Fitted projections on the $D\pi$ and $D^*\pi$ masses.



- Resulting parameters for the scalar and axial broad states:

$$D_0^{*0} : m = 2308 \pm 17 \pm 15 \pm 28 \quad MeV/c^2, \quad \Gamma = 276 \pm 21 \pm 18 \pm 60 \quad MeV$$

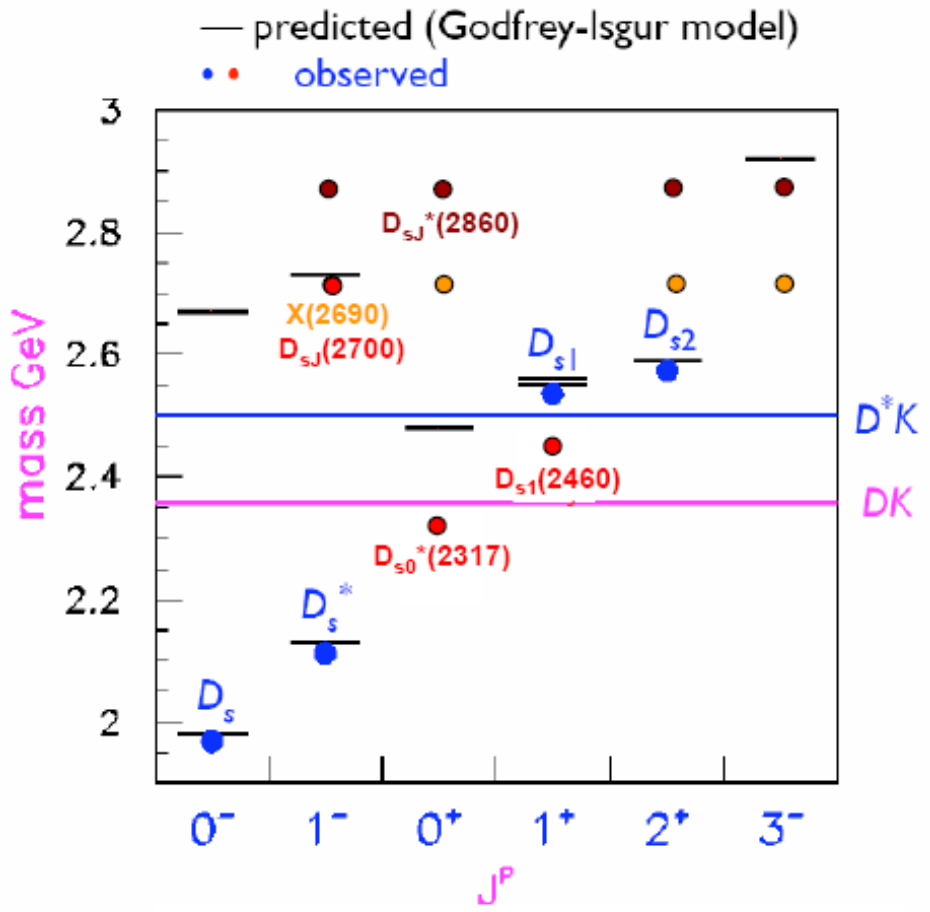
$$D_1 : m = 2427 \pm 26 \pm 20 \pm 15 \quad MeV/c^2, \quad \Gamma = 384^{+107}_{-75} \pm 24 \pm 70 \quad MeV$$

- Parameters of the D_2^{*0} state:

$$D_2^{*0} : m = 2465.7 \pm 1.8 \pm 0.8 \pm^{1.2}_{4.7} \quad MeV/c^2, \quad \Gamma = 49.7 \pm 3.8 \pm 4.1 \pm 4.9 \quad MeV$$

Charm Spectroscopy: D_{sJ}^{+} states.

□ The discovery of the new D_{sJ} states has brought into question potential models.



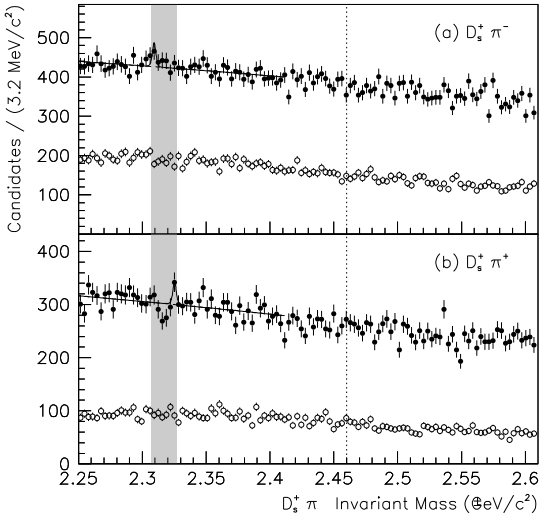
Charm Spectroscopy: D_{sJ} states.

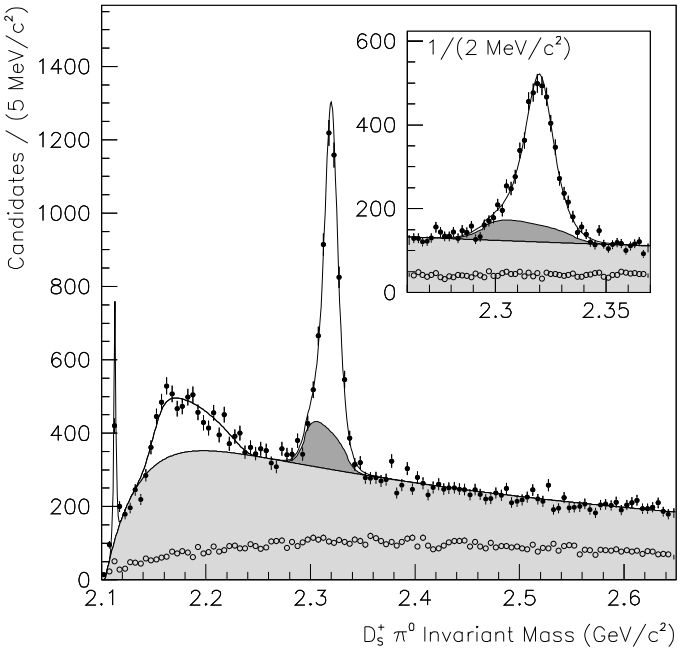
- BaBar: upgrade of measurements with 240 fb^{-1}. hep-ex/0604030
- A new measurement of the $D^*_{sJ}(2317)^+$ mass:

$m(D^*_{sJ}(2317)^+) = (2319.6 \pm 0.2 \pm 1.4) MeV/c^2$

- Shaded is the reflection from $D_{sJ}(2460)^+$.
- Search for $m(D^*_{sJ}(2317)^+) \to D_s^+ \pi^\pm$:

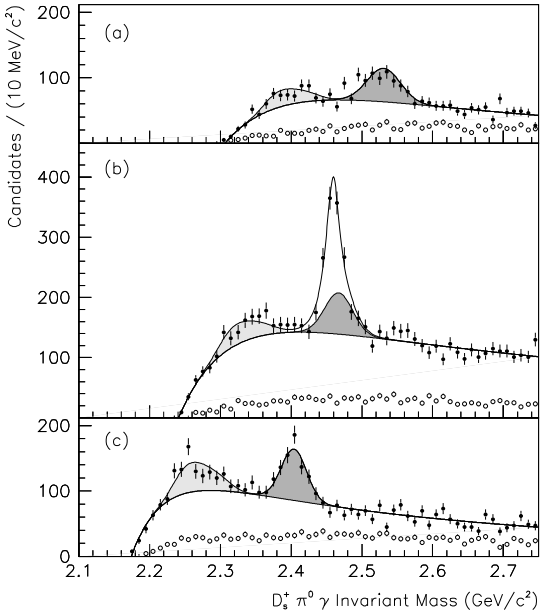
No signal: probably not 4-quark states.

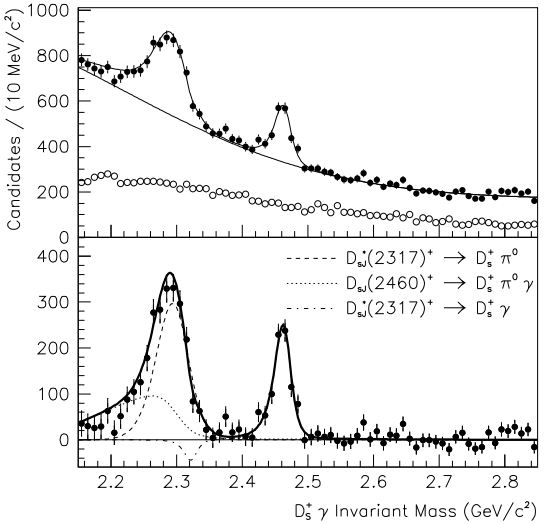


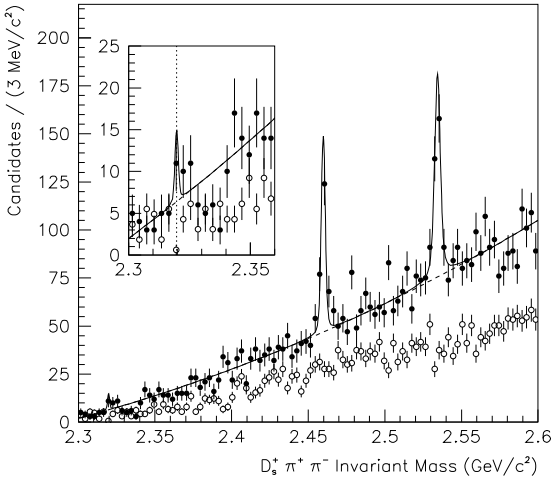


Charm Spectroscopy: $D_{sJ}(2460)^+$.

□ BaBar: new measurements of the $D_{sJ}(2460)^+$ has been obtained from $D_s^+\pi^0\gamma$, $D_s^+\gamma$, and $D_s^+\pi^+\pi^-$ decays.







□ The average of these results is:

$$m(D_{sJ}(2460)^+) \quad = \quad (2460.1 \pm 0.2 \pm 0.8)\ MeV/c^2 \qquad (1)$$

Summary on $D_{sJ}^*(2317)^+$ and $D_{sJ}(2460)^+$.

□ Discovered 4 years ago in $e^+e^- \to c\bar{c}$ events, observed in B decays.

□ $D_{sJ}^*(2317)^+$ and $D_{sJ}(2460)^+$ very well estabished and known experimentally:

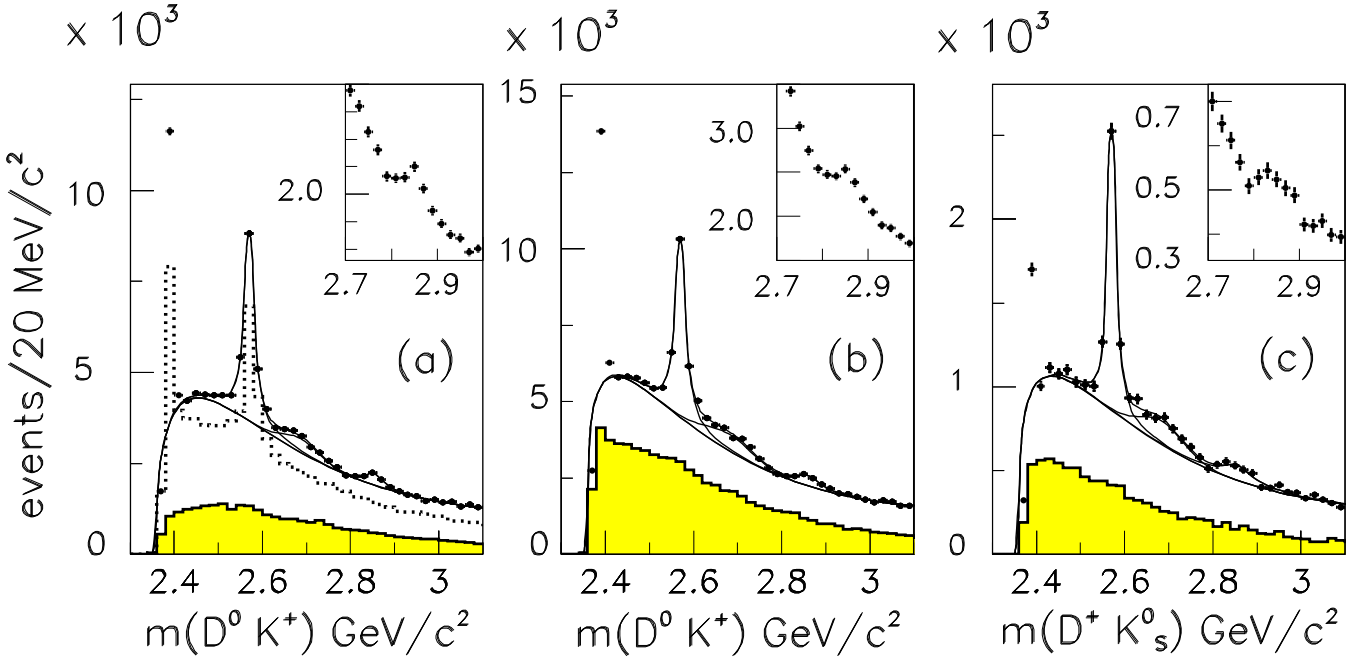
- Mass and widths;
- $J^P : 0^+$ for $D_{sJ}^*(2317)^+$ and $J^P : 1^+$ for $D_{sJ}(2460)^+$.
- decay modes and branching fractions.

□ Interpretation of these states still unclear.

- Identification of these states as the 0^+ and 1^+ $c\bar{s}$ states: strong difficulties within the potential model
- Other possibilities: 4-quark states? DK molecules? $D\pi$ atom? Chiral symmetry?

A new state: $D_{sJ}(2860)$.

□ BaBar. Study of continuum $e^+e^- \to D^0(\to K^-\pi^+, K^-\pi^+\pi^0)X$ and $e^+e^- \to D^+K^0_S X$.



□ New state at 2860 MeV/c^2.

□ Bump at 2690 MeV/c^2.

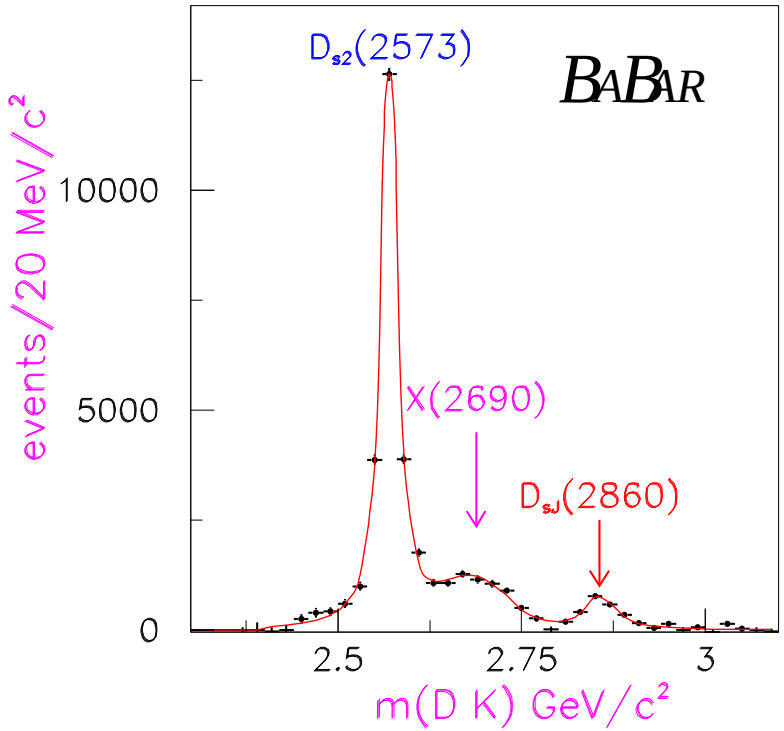
A new state: $D_{sJ}(2860)$.

- Background subtracted sum of the three modes.
- Precision measurement of the $D^*_{s2}(2573)$ parameters:

$M(D^*_{s2}(2573)) = (2572.2 \pm 0.3 \pm 1.0) MeV/c^2$
$\Gamma(D^*_{s2}(2573)) = (27.1 \pm 0.6 \pm 5.6) MeV$

$M(D^*_{sJ}(2860)) = (2856.6 \pm 1.5 \pm 5.0) MeV/c^2$
$\Gamma(D^*_{sJ}(2860) = (47 \pm 7 \pm 10) MeV$

- Final state is DK, i.e. two pseudoscalars. Therefore: $J^P = 0^+, 1^-, 2^+, 3^-, ...$



Interpretation?

- Radial excitation of $D^*_{s0}(2317)$? hep-ph/0606110
- $c\bar{s}$ with JP= 3-? hep-ph/0607245
- $c\bar{s}$ with JP= 0+? hep-ph/0608139

□ Another structure at 2690 MeV/c^2?

$$M(X(2690)) = (2688 \pm 4 \pm 3) \quad MeV/c^2$$

$$\Gamma(X(2690)) = (112 \pm 7 \pm 36) \quad MeV$$

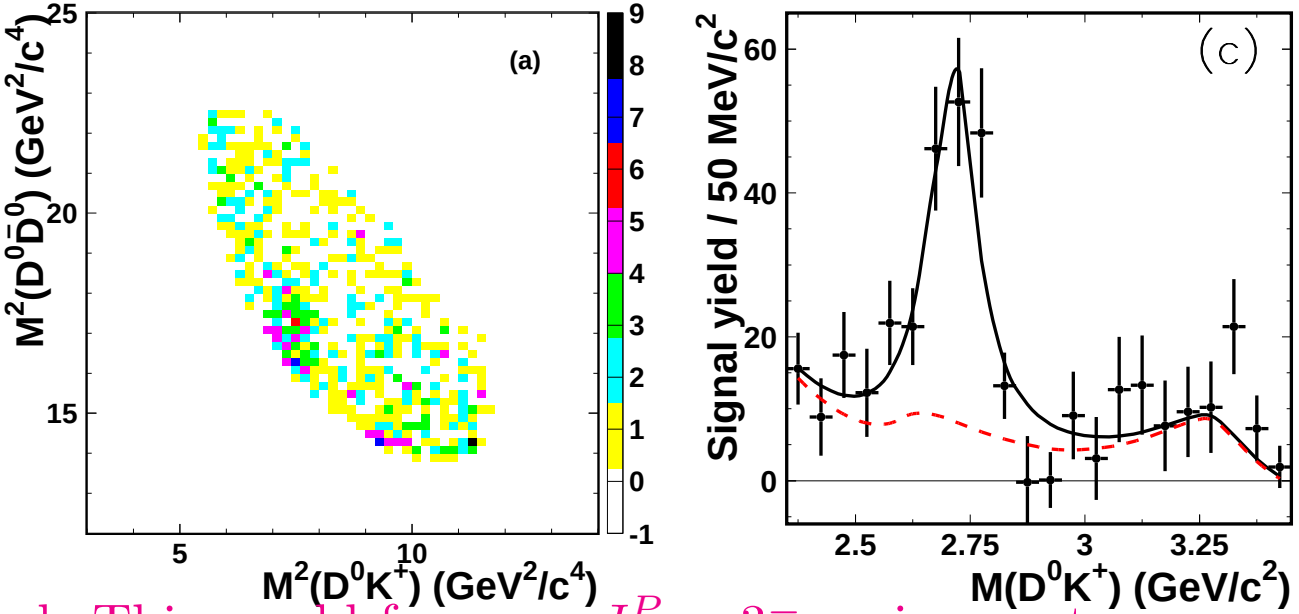
□ Needs confirmation by other experiments.

A new state: $D_{sJ}(2700)$.

□ BELLE: Study of $B^+ \to D^0 \bar{D}^0 K^+$. Observation of a new D_s meson with $J^P = 1^-$. Dalitz plot and $D^0 K^+$ mass.

$M = 2708 \pm 9^{+11}_{-10}$ MeV/c^2

$\Gamma = 108 \pm 23^{+36}_{-31}$ MeV

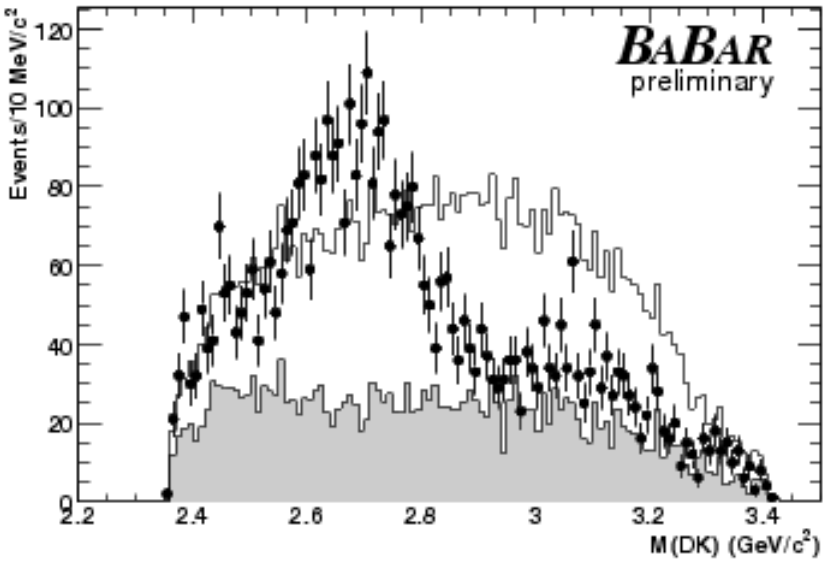


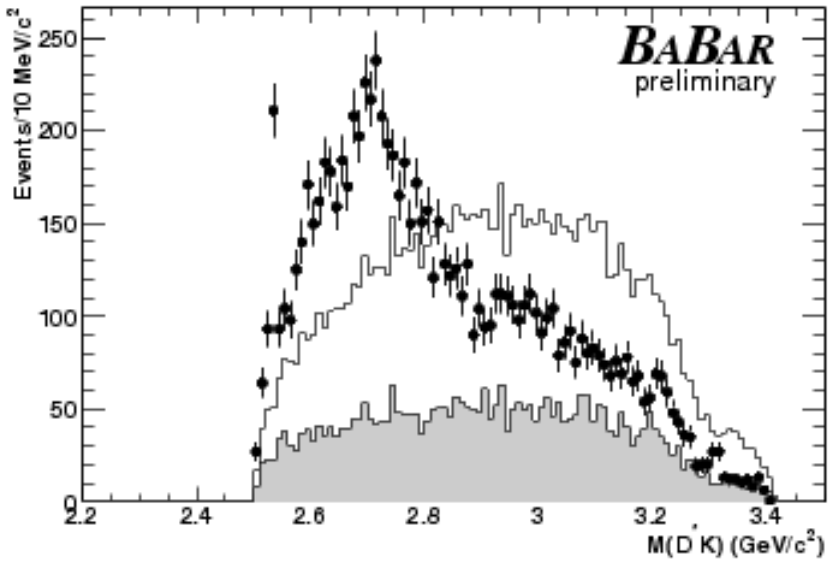
□ X(2690)=$D_{sJ}(2700)$?

□ No $D_{sJ}(2860)$ observed. This would favour a $J^P = 3^-$ assignment (suppressed in B decays).

$D_{sJ}(2700)$.

- BaBar: Study of $B \to D^{(*)}\bar{D}^{(*)}K$ (22 modes).
- Observation of resonances in DK and D^*K. Dalitz analysis in progress.





Charmonium spectroscopy: the new zoology.

- X(3872).
- The 1^- family: Y(4260) and others.
- The 3940 family.
- Z(4430): an exotic charged state?

X(3872).

- Decays:

$X(3872) \to J/\psi\pi\pi$ (original observation by BELLE), possibly $J/\psi\rho$

$\mathcal{B}(X(3872) \to J/\psi\rho) \approx \mathcal{B}(X(3872) \to J/\psi\omega)$

$X(3872) \to J/\psi\gamma$, $\frac{\mathcal{B}(X(3872)\to J/\psi\gamma)}{\mathcal{B}(X(3872)\to J/\psi\pi^+\pi^-)} = 0.19 \pm 0.07$

- $J^{PC} = 1^{++}$ favoured.
- Production in B decays only so far. BaBar:

$$\sigma(e^+e^- \to X(3872)X) \times \mathcal{B}(X(3872) \to \gamma J/\psi) \times \mathcal{B}(X \to (N_{ch} > 2)) < 5.1 fb$$

at 90% C.L.

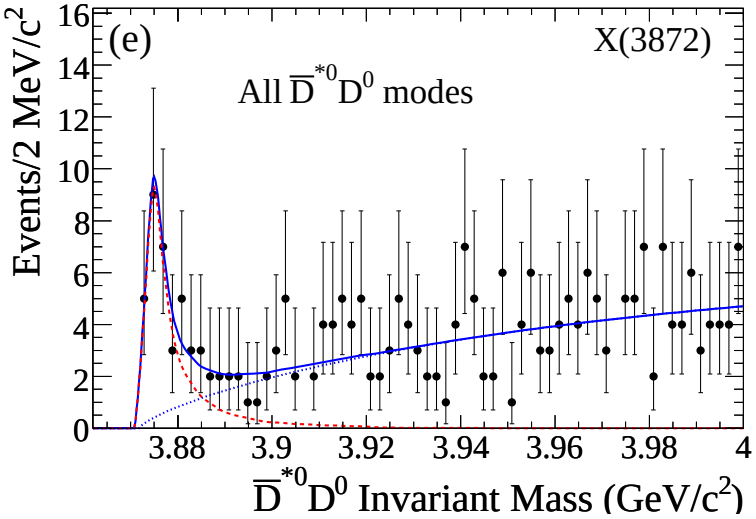
- Not matching any predicted state.
- Above the $D\bar{D}$ threshold. Should have large width but it is narrow.
- Charmonium decay to $J/\psi\rho$ highly suppressed because isospin violation.

$X(3872) \to D^* \bar{D}.$

- BELLE observes $X(3872) \to D^0 \bar{D}^0 \pi^0$.
- BABAR observes $X(3872) \to D^* \bar{D}.$ (BABAR-PUB-07/049)

$$m = 3875.1 \pm 1.1 \pm 0.5 \quad MeV/c^2$$

$$\Gamma = 3.0^{+4.6}_{-2.3} \pm 0.9 \quad MeV$$

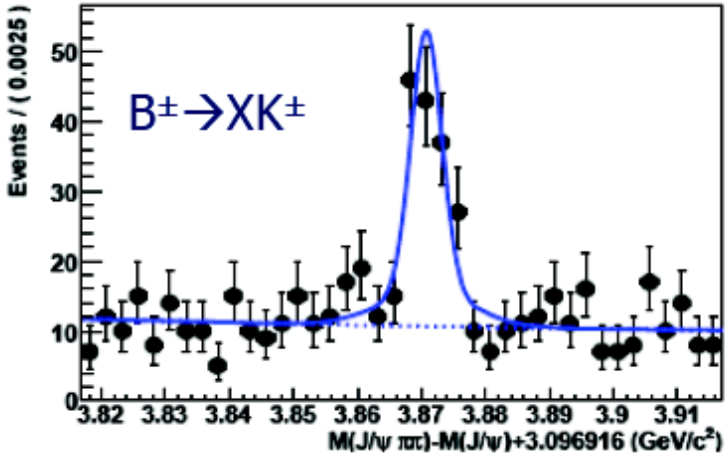


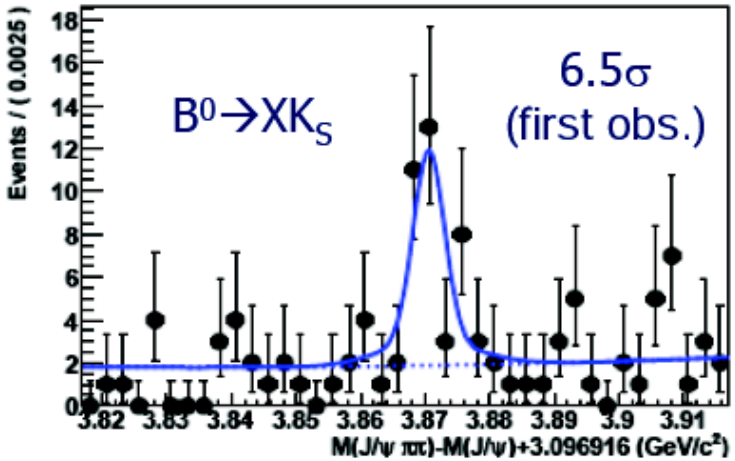
- Poor agreement in mass between $J/\psi\pi\pi$ and $D^*\bar{D}$ modes, $\approx 3\sigma$. However, presence of a threshold in $D^*\bar{D}$.

$X(3872)$ Production.

□ New results from BELLE. Observation of $X(3872)$ in B^+ and B^0 decays.

(BELLE-CONF-0711)





□ Consistent with no mass difference:

$$\Delta m = (0.22 \pm 0.9 \pm 0.27) MeV/c^2$$

□ Consistent with no rate difference:

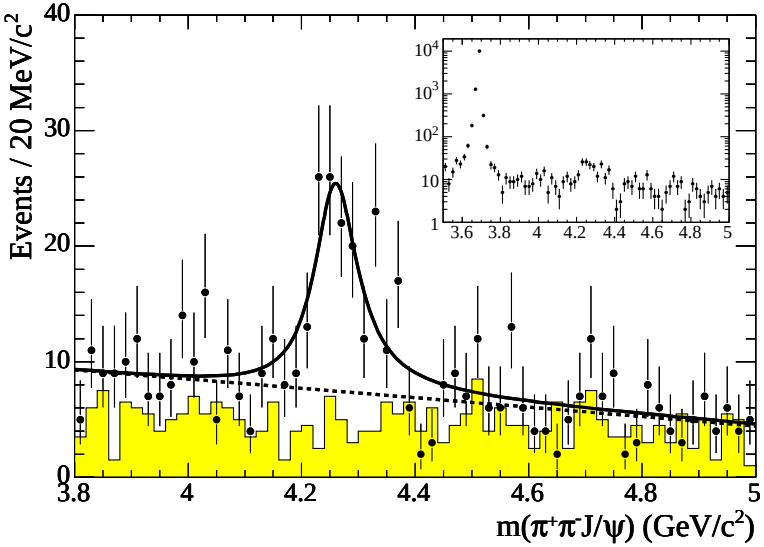
$$\frac{\mathcal{B}(B^+ \to X(3872)K^+, X(3872) \to J/\psi\pi^+\pi^-)}{\mathcal{B}(B^0 \to X(3872)K^0_S, X(3872) \to J/\psi\pi^+\pi^-)} = 0.94 \pm 0.24 \pm 0.10$$

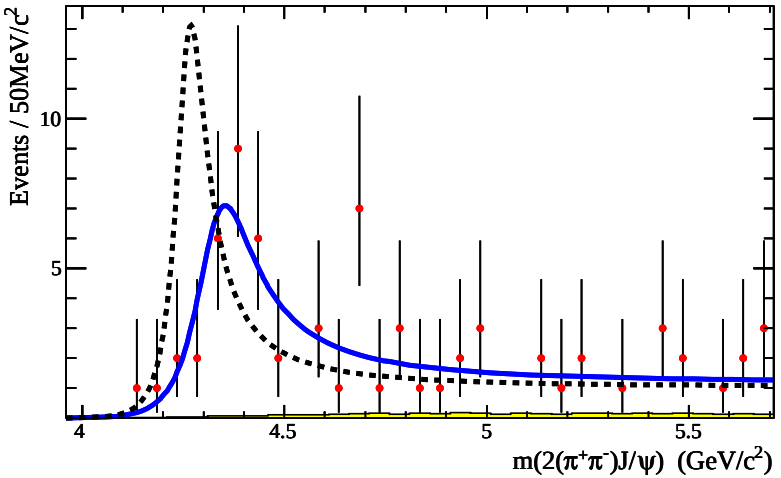
The $J^P = 1^-$ family.

□ BaBar: observation of $Y(4260)$ in ISR events: $J^P = 1^-$.(PRL 95, 142001 (2005))

$$e^+e^- \to \gamma_{ISR} Y(4260)(\to J/\psi\pi^+\pi^-)$$

$$M(Y) = 4259 \pm 8^{+2}_{-6} \quad MeV/c^2, \quad \Gamma(Y) = 88 \pm 23^{+6}_{-4} \; MeV$$





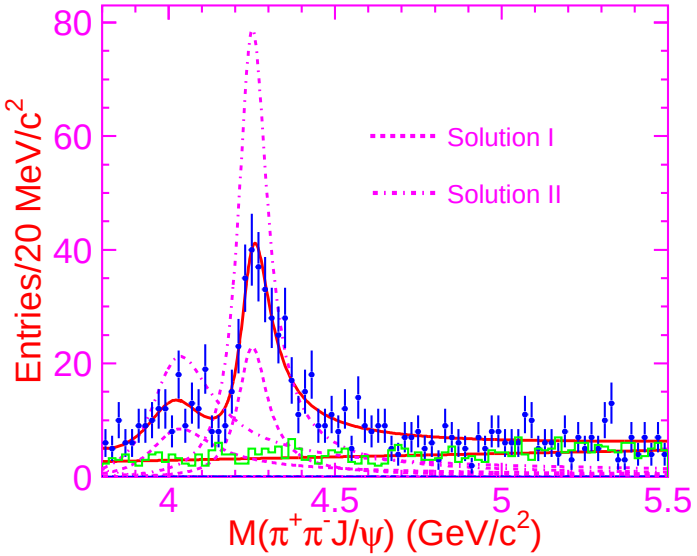
□ BaBar, yet another state (Y(4350)):(PRL 98, 1212001 (2007))

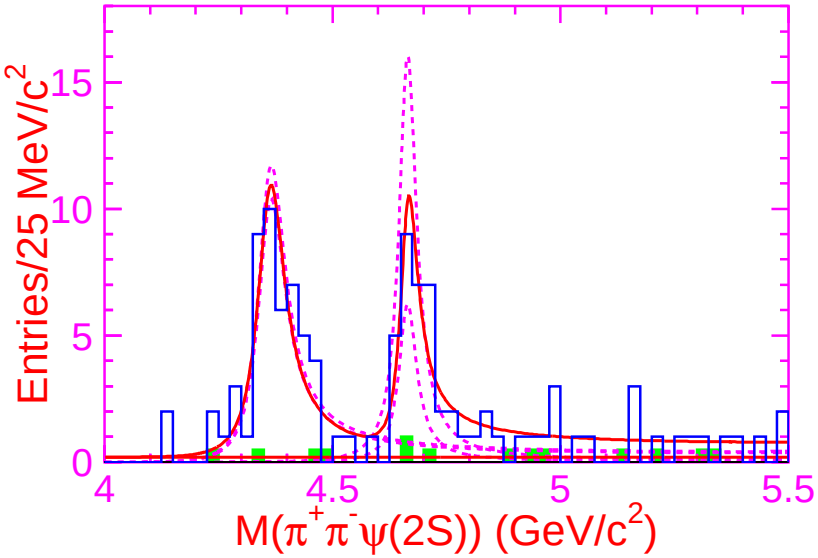
$$e^+e^- \to \gamma_{ISR} Y(4350)(\to \psi(2S)\pi^+\pi^-)$$

$$M(Y) = 4324 \pm 24 \quad MeV/c^2, \quad \Gamma(Y) = 172 \pm 33 \; MeV$$

The $J^P = 1^-$ family.

- New information from BELLE.





- Confirms BaBar findings.

$$M(Y) = 4247 \pm 12^{+17}_{-26} \quad MeV/c^2, \quad \Gamma(Y) = 108 \pm 19^{+8}_{-10} \ MeV$$

$$M(Y) = 4361 \pm 9 \pm 9 \quad MeV/c^2, \quad \Gamma(Y) = 74 \pm 15 \pm 15 \ MeV$$

- Claim/Evidence for further states:

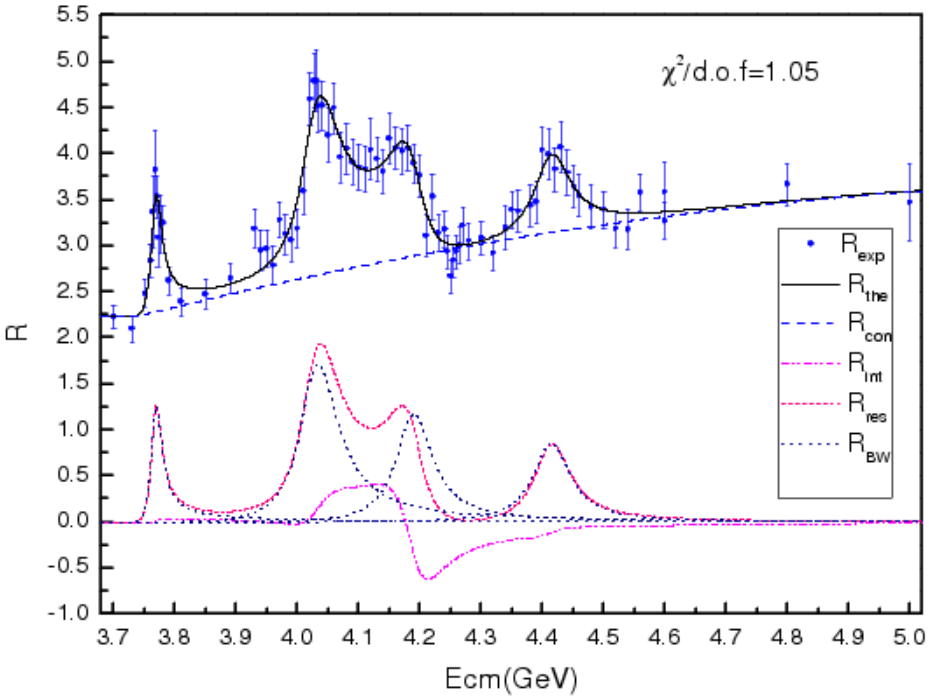
$$M(?) = 4008 \pm 40^{+72}_{-28} \ MeV/c^2, \qquad \Gamma = 226 \pm 44^{+87}_{-79} \ MeV$$

$$M(Y) = 4664 \pm 11 \pm 5 \ MeV/c^2, \qquad \Gamma = 48 \pm 15 \pm 3 \ MeV$$

Search for Y's $D^{(*)}\bar{D}^{(*)}$ decays.

□ BES fit of the R measurement. Include interferences among the different states.

$\psi(3770)$	$\psi(4040)$	$\psi(4160)$	$\psi(4415)$
3771.4±1.8	4038.5±4.6	4191.6±6.0	4415.2±7.5
25.4±6.5	81.2±14.4	72.7±15.1	73.3±21.2

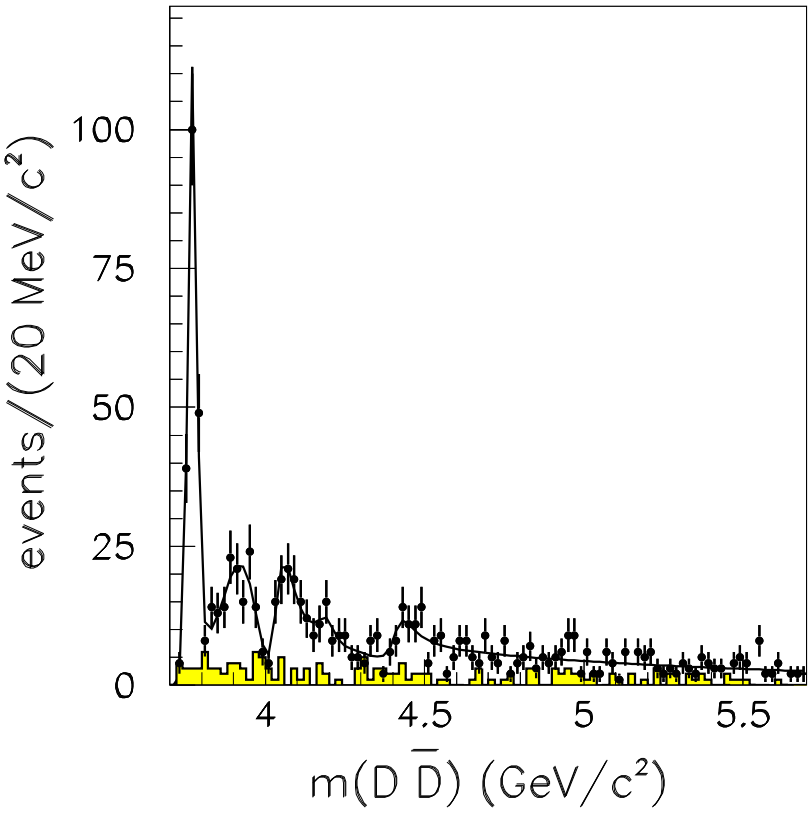


□ No evidence for Y's here.

New information from ISR.

- BABAR (New Result): study of $e^+e^- \to \gamma_{ISR} D\bar{D}$.
- No evidence for $Y(4260)$.

$$\frac{\mathcal{B}(Y(4260)\to D\bar{D})}{\mathcal{B}(Y(4260)\to J/\psi\pi^+\pi^-)} < 1.0 \quad 90\% C.L.$$

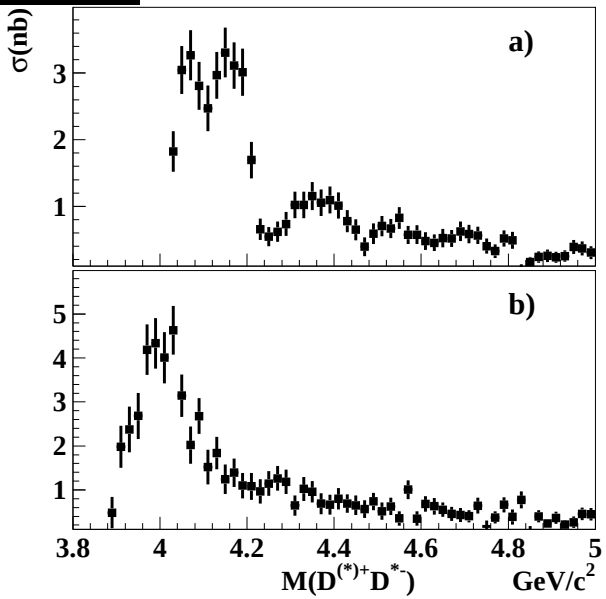


- Observation of structure in the 3.9 GeV region: expected from the coupled channel model of Eichten et al.

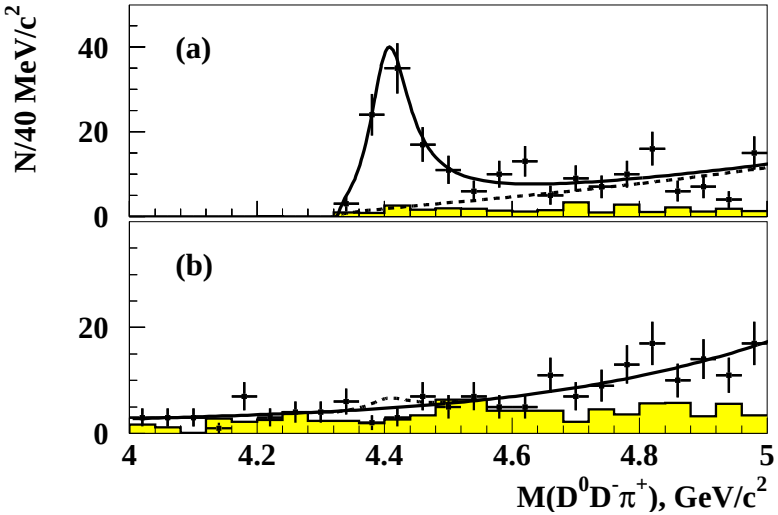
E. Eichten et al., Phys. Rev. **D21**, 203 (1980)

New information from ISR.

- BELLE: study of $e^+e^- \to \gamma_{ISR} D^{(*)} \bar{D}^{(*)}$.



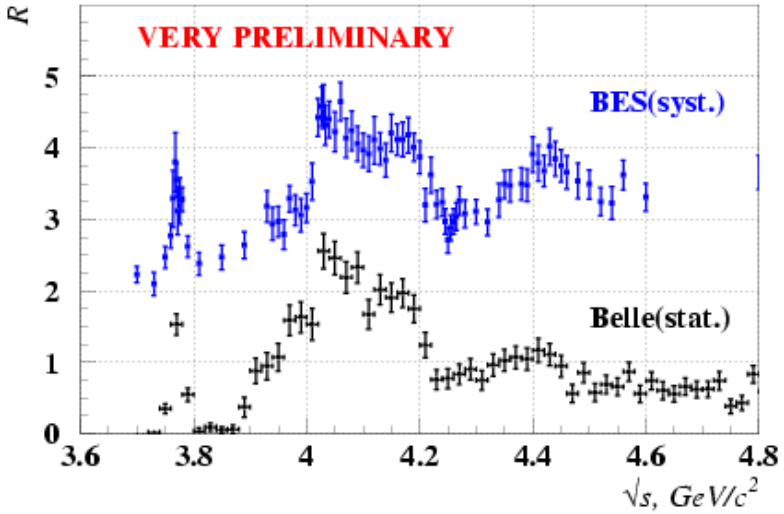
- BELLE: observation of $\psi(4415) \to DD_2^*$.

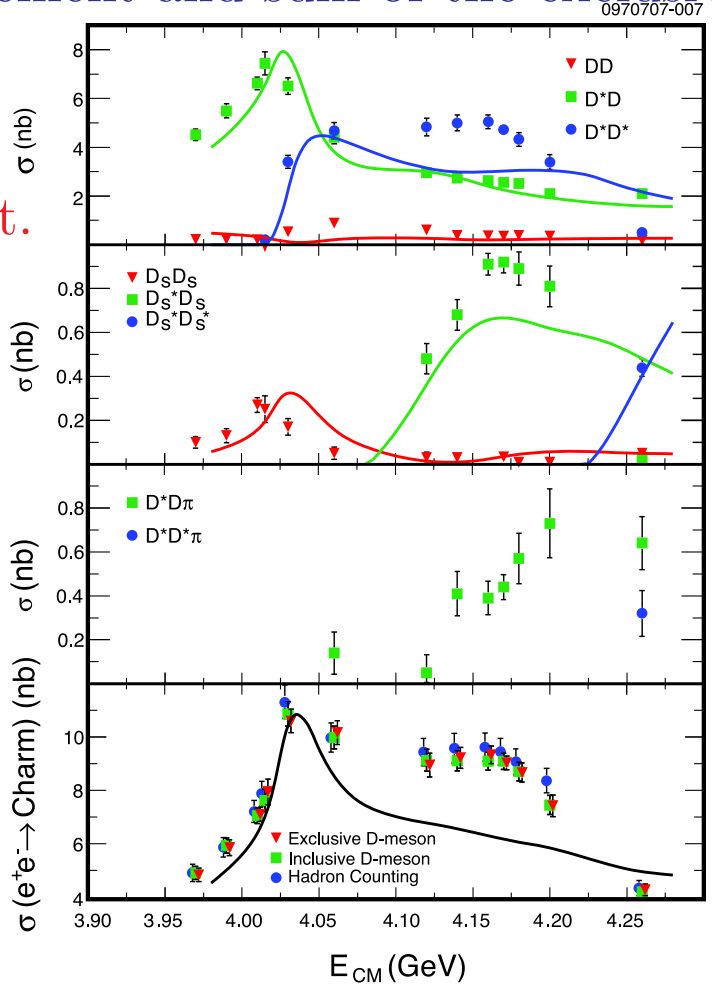


New information from ISR.

□ BELLE: Comparison between R measurement and sum of the exclusive measurements: good agreement.

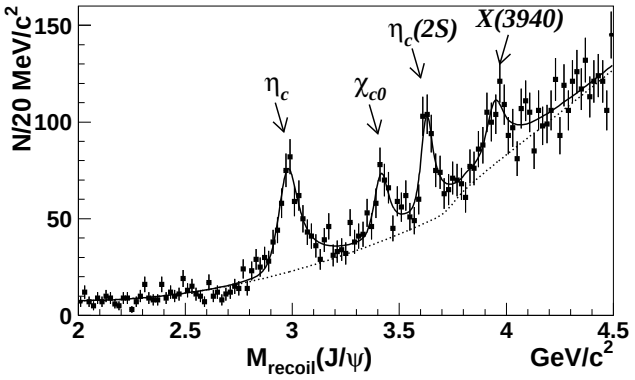
□ Upgraded coupled channel model on CLEO-c measurements: no good agreement.

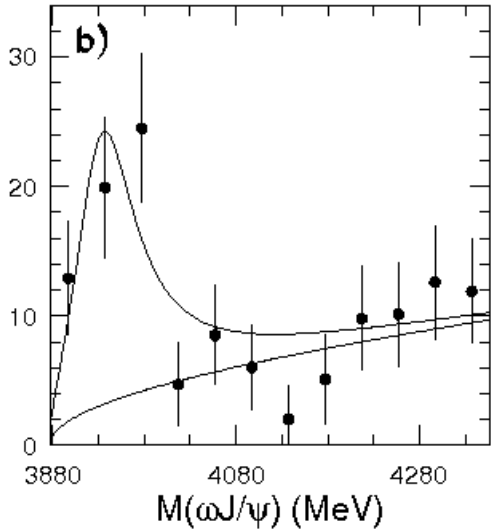


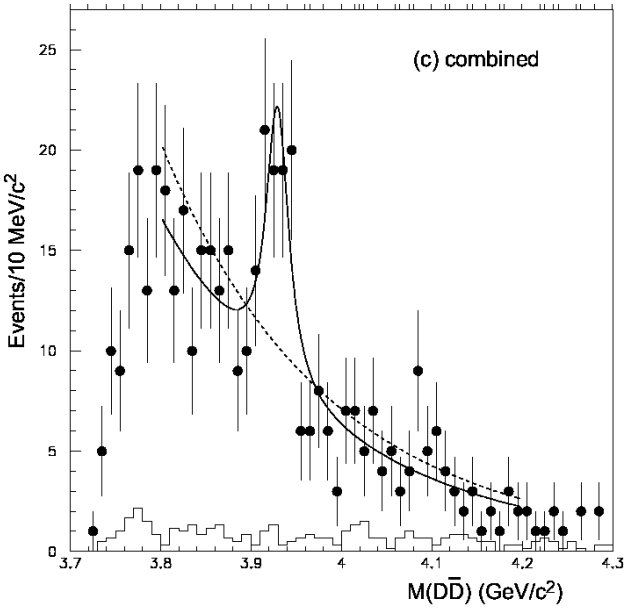


The X(3940) family.

- Results from BELLE.







	Observed in	J^{PC}?	M (MeV/c^2)	Γ (MeV)
X	$e^+e^- \to J/\psi X$	$0^{-+}, 1^{++}$	3943 ± 8	< 39
Y	$B \to YK(Y \to J/\psi\omega)$	$1^{++}, ..$	3943 ± 17	87 ± 34
Z	$\gamma\gamma \to Z(Z \to D\bar{D})$	2^{++}	3929 ± 5	29 ± 10

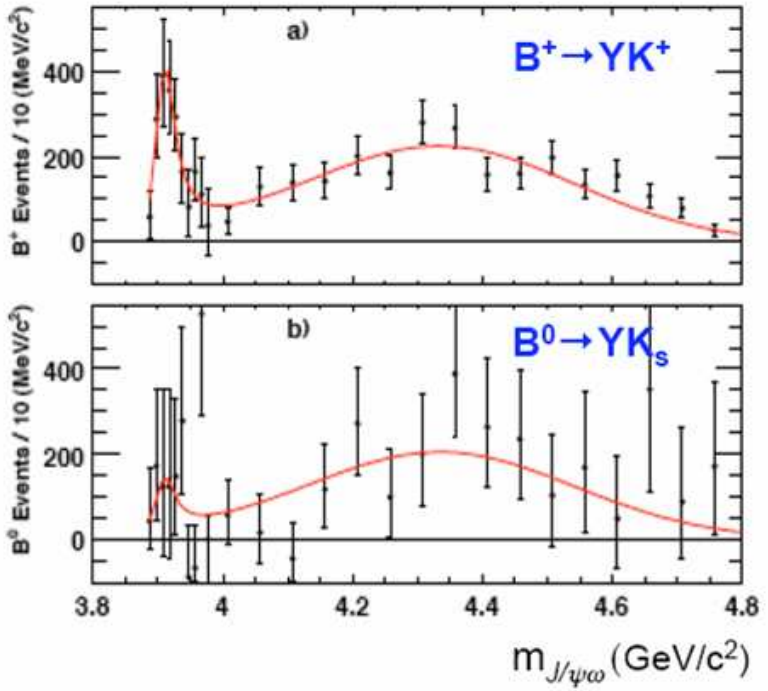
More on Y(3940).

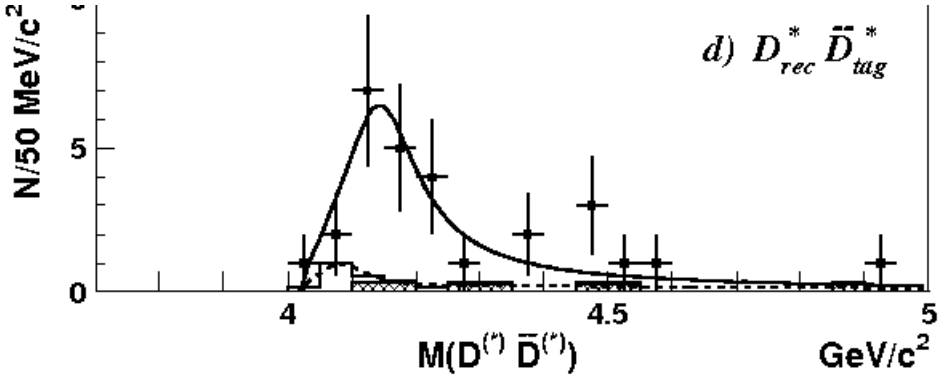
- BaBar: confirmation of $Y(3940) \to J/\psi\omega$ in $B \to J/\psi\omega K$.

$M = 3914.3^{+3.8}_{-3.4} \pm 1.6\ MeV/c^2, \quad \Gamma = 33^{+12}_{-8} \pm 6\ MeV$

- $X(3940)$ the same as $Y(3940)$?
- BELLE: Study of $e^+e^- \to J/\psi D^{(*)}\bar{D}^{(*)}$.
- Confirmation of $X(3940) \to D^*\bar{D}$.

Further evidence for a new state
in the $D^*\bar{D}^*$ mass spectrum: $\eta_c(3S)$?

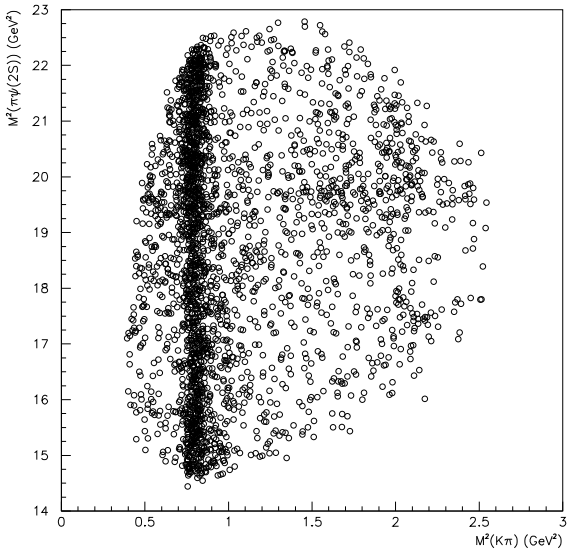


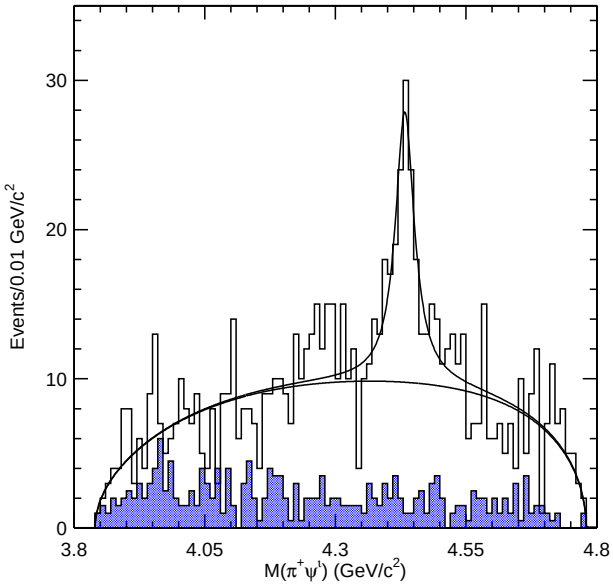


$M = 4156^{+25}_{-20} \pm 15\ MeV/c^2, \quad \Gamma = 37^{+111}_{-61} \pm 21\ MeV$

A new exotic charged state Z(4430)?

- BELLE: Study of $B \to \psi(2S)K\pi$. hep-ex/0708.1790





- K^*'s removed. Narrow structure in $\psi(2S)\pi^{\pm}$.

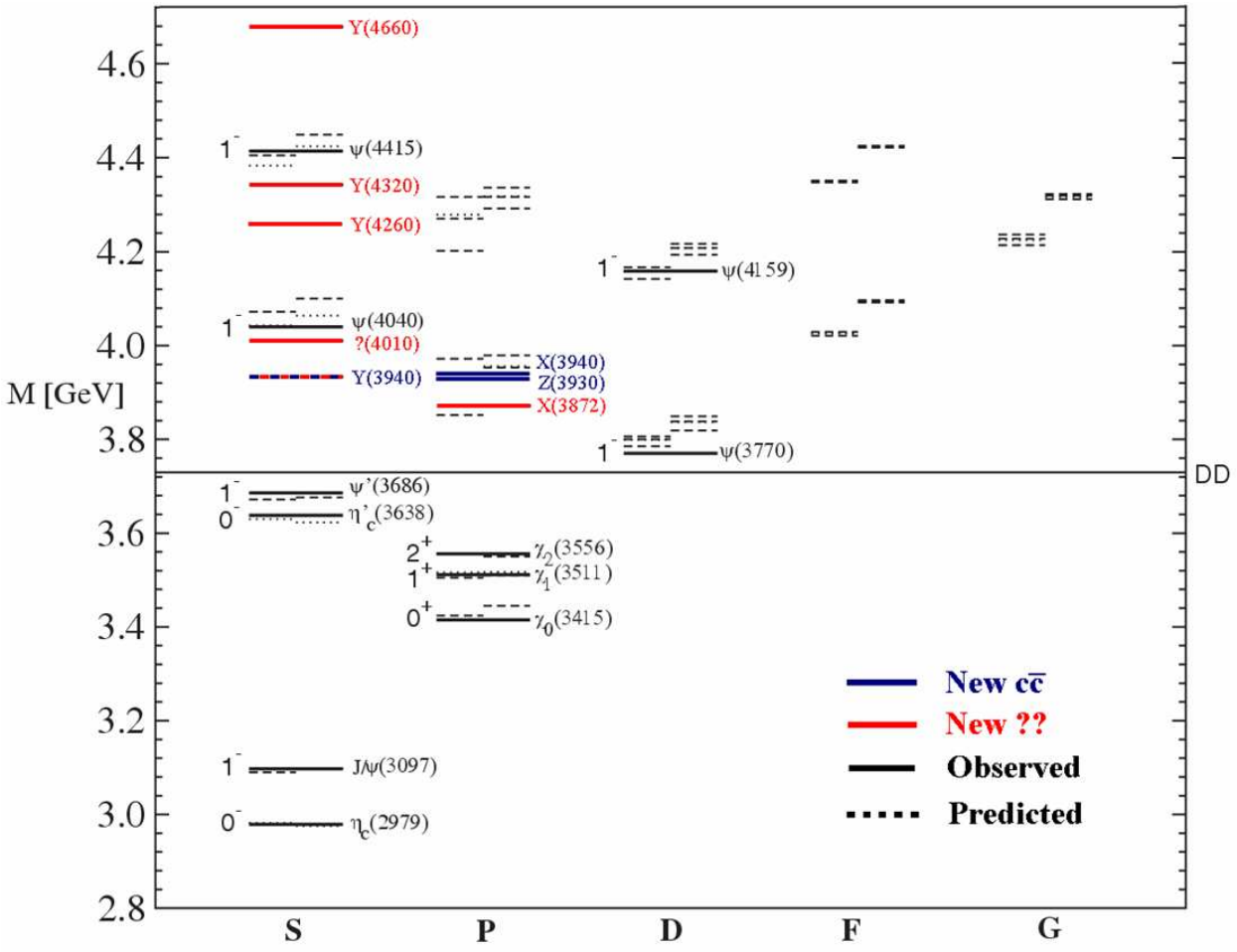
$M = 4433 \pm 4 \pm 1\ MeV/c^2$

$\Gamma = 44^{+17+30}_{-13-11}\ MeV$

- If true: first observation of an exotic state.
- On an analysis of such a relevance: why not a full Dalitz analysis?

Summary on the charmonium spectrum.

- Large number of new experimental results.
- Many states waiting for a classification.



Conclusions.

- B-factories have produced a large mess of unexpected new states.
- Potential models are in troubles in trying to explain the available data.
- Are we close to the start of a new spectroscopy?
- Several possibilities:
  - Hybrids $q\bar{q}g$;
  - Tetraquarks; $(qq')\overline{(qq')}$
  - Molecules: $(q\bar{q})(q'\bar{q}')$
- Need of new clean and high statistics data from many sources to clarify the situation.
- Super-B's, $\tau - charm$ factories, LHCB?