Charm and Charmonium Spectroscopy at BaBar.

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on behaf of the BaBar Collaboration

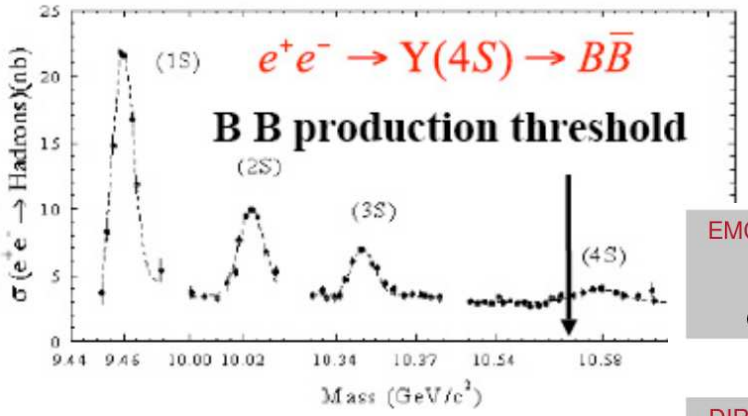
□ Summary:

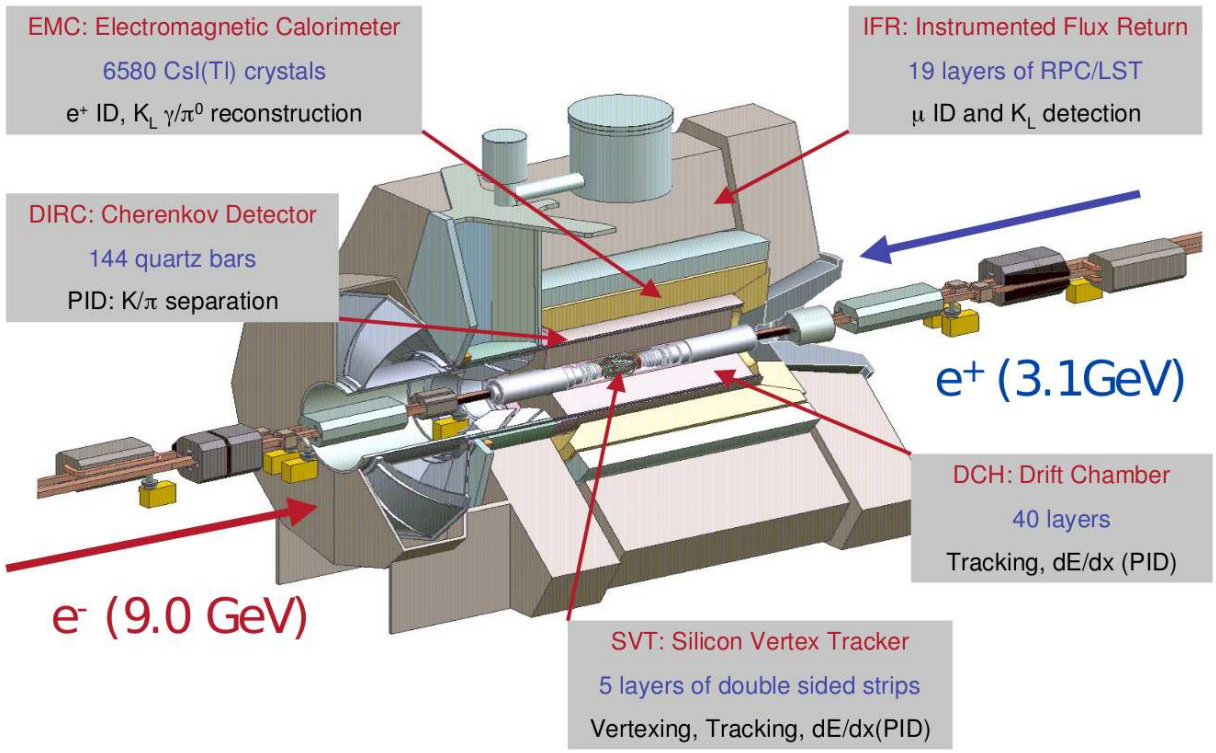
- The BaBar Experiment.
- Recent results on new Charm States.
- Recent Results on new Charmonium States.
- Conclusions.

Meson2008, Krakow, Poland, June 6-10, 2008

The BaBar experiment.

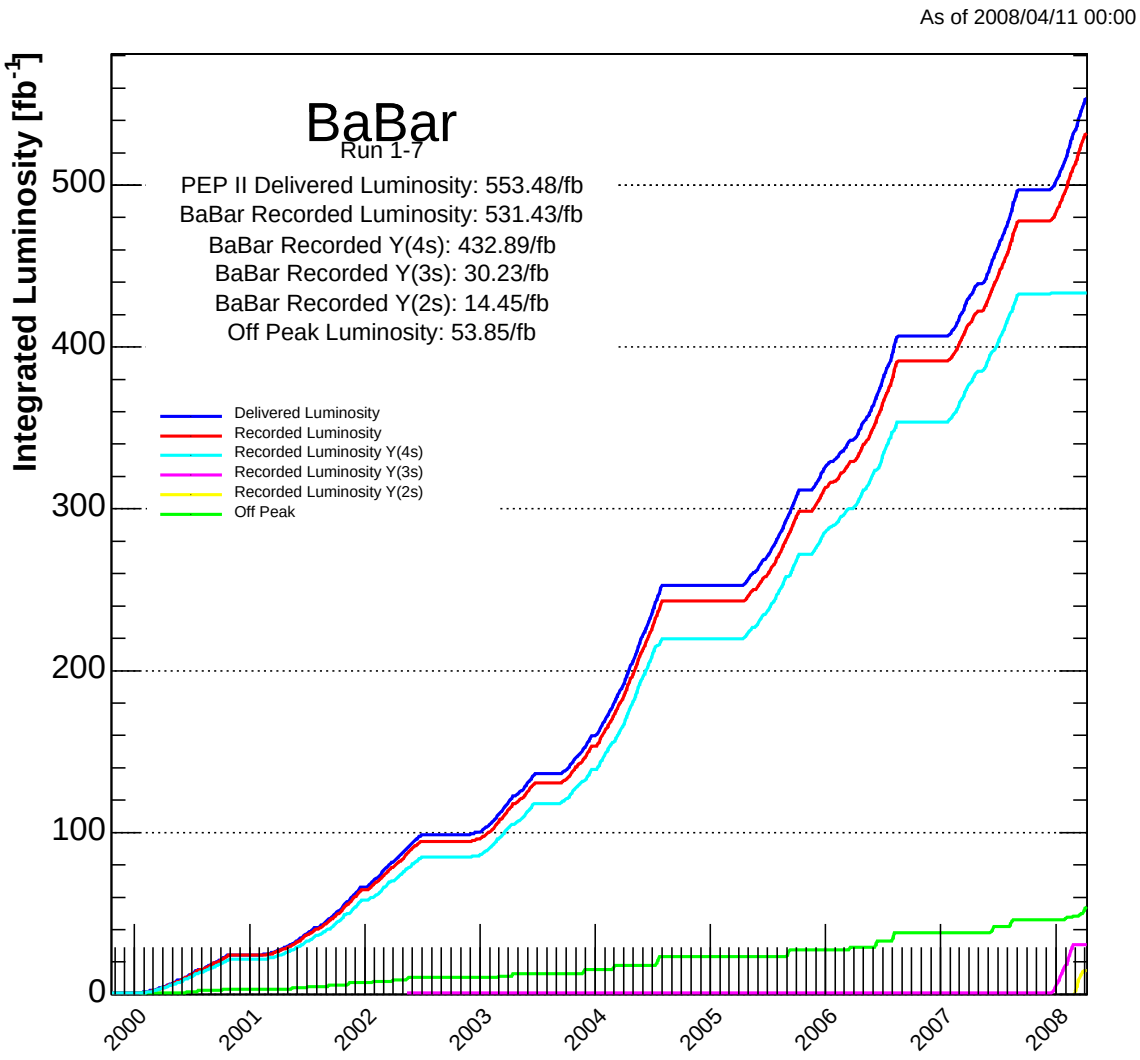
- Study of e^+e^- at the $\Upsilon(4S)$ energy: 10.58 GeV at PEPII, SLAC.





Data Collected.

- $\Upsilon(4S)$: 432.9 fb^{-1}
- $\Upsilon(3S)$: 30.2 fb^{-1}
- $\Upsilon(2S)$: 14.5 fb^{-1}
- OffPeak+Scan above $Y(4S)$: 53.9 fb^{-1}
- The largest world samples on $\Upsilon(3S)$ and $\Upsilon(2S)$.
- Data-taking ended in april 2008.

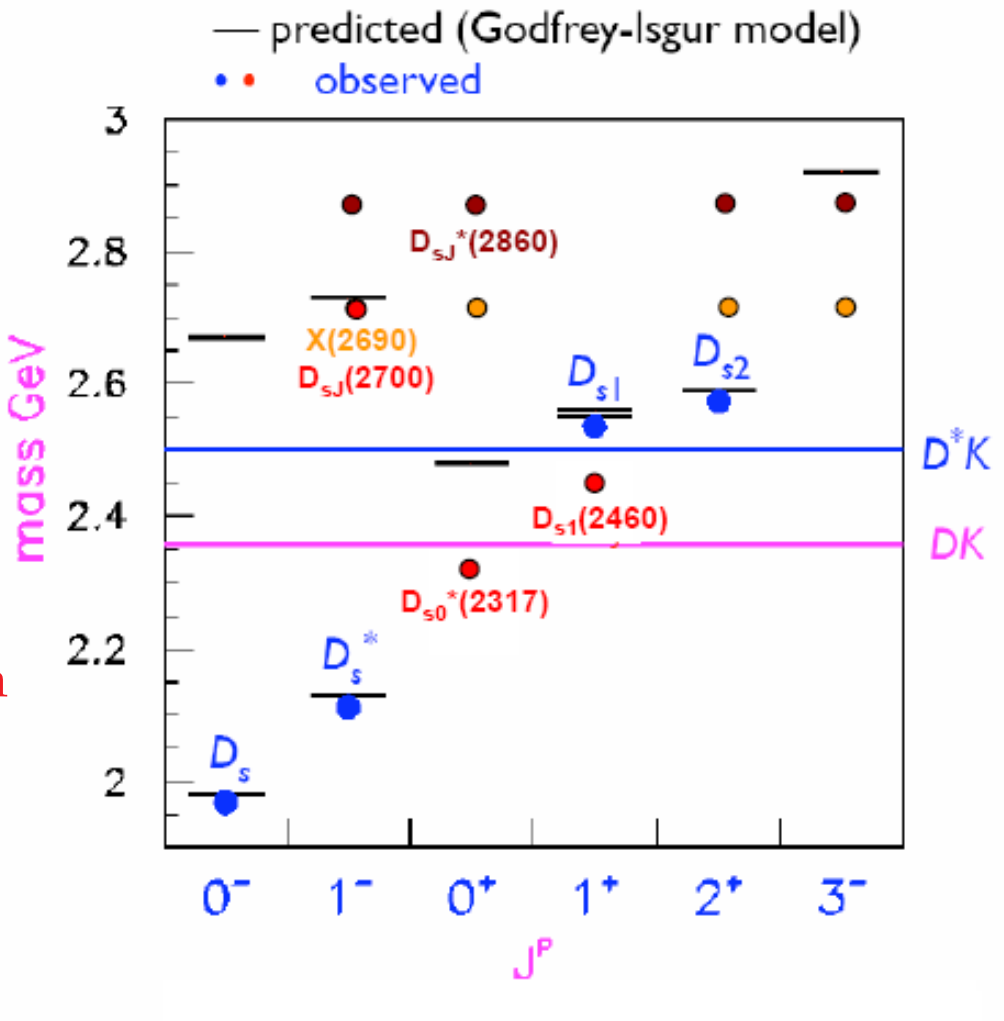


Charm Spectroscopy.

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

□ Mass positions of $D^*_{sJ}(2317)^+$ and $D_{sJ}(2460)^+$ very much lower than expected and below the DK and D^*K thresholds respectively.

□ Need new experimental information to disentangle different models.



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

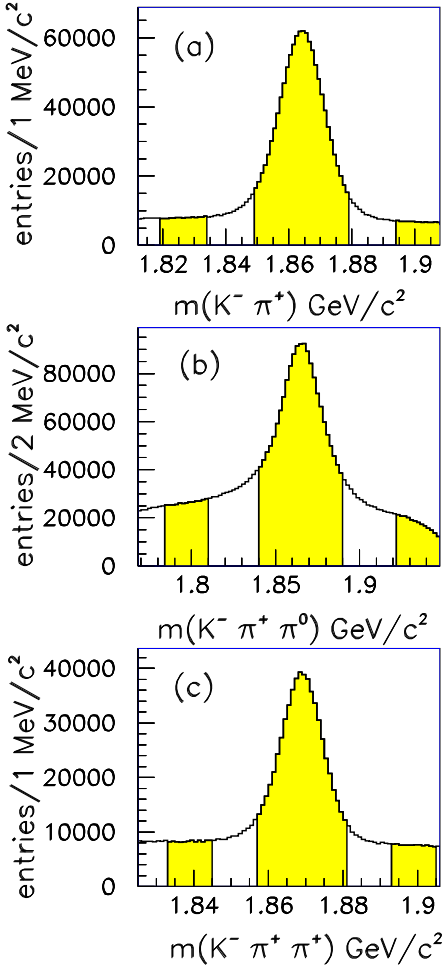
□ Looking to very small cross sections in the study of continuum (240 fb^{-1}).

$e^+e^- \to D^0(\to K^-\pi^+, K^-\pi^+\pi^0)K^+X$

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

□ $N_{D^0\to K^-\pi^+}$ = 950,000, $N_{D^0\to K^-\pi^+\pi^0}$= 790,000 and $N_{D^+\to K^-\pi^+\pi^+}$=430,000 events.

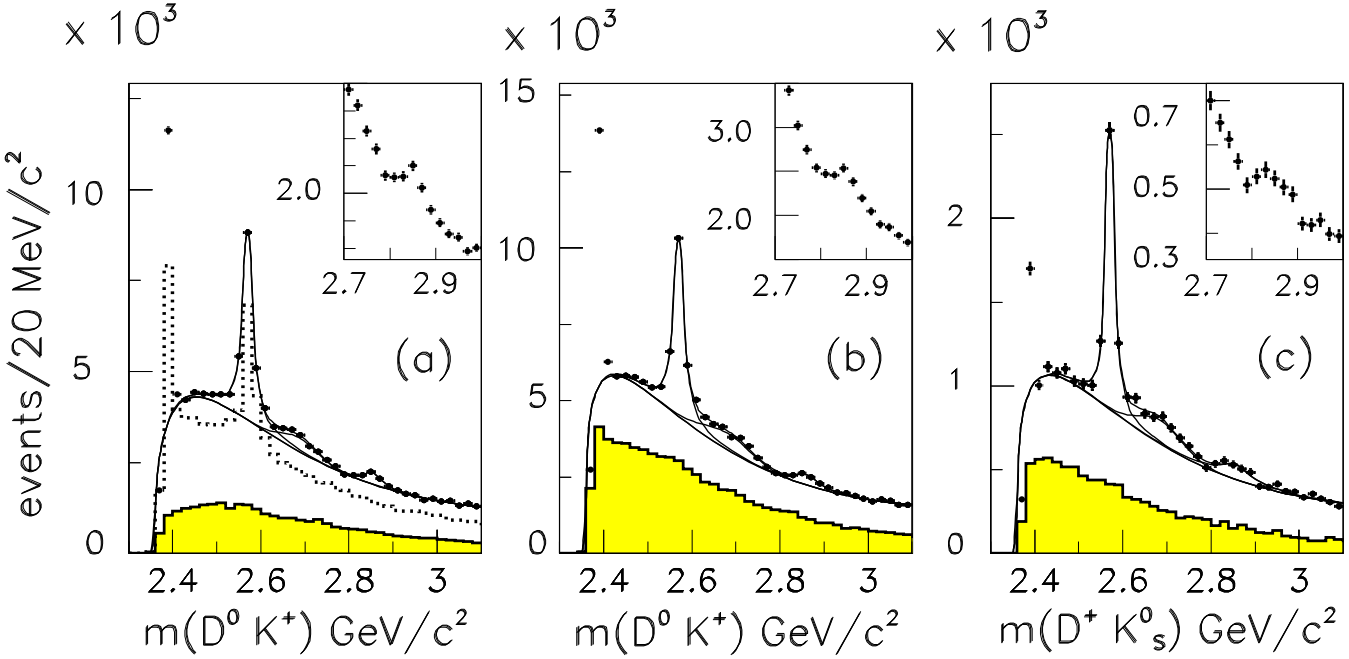
□ Require the center of mass momentum $p^*(DK) > 3.5$ GeV/c.



Phys.Rev.Lett. 97 (2006) 222001

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

- The three DK mass spectra show similar features.



- Narrow reflection at threshold due to $D_{s1}(2536)^+$.
- Signal of $D^*_{s2}(2573)$.
- Bump at 2690 MeV/c^2.
- New state at 2860 MeV/c^2.
- No signal for these new structures in sidebands or Monte Carlo.

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

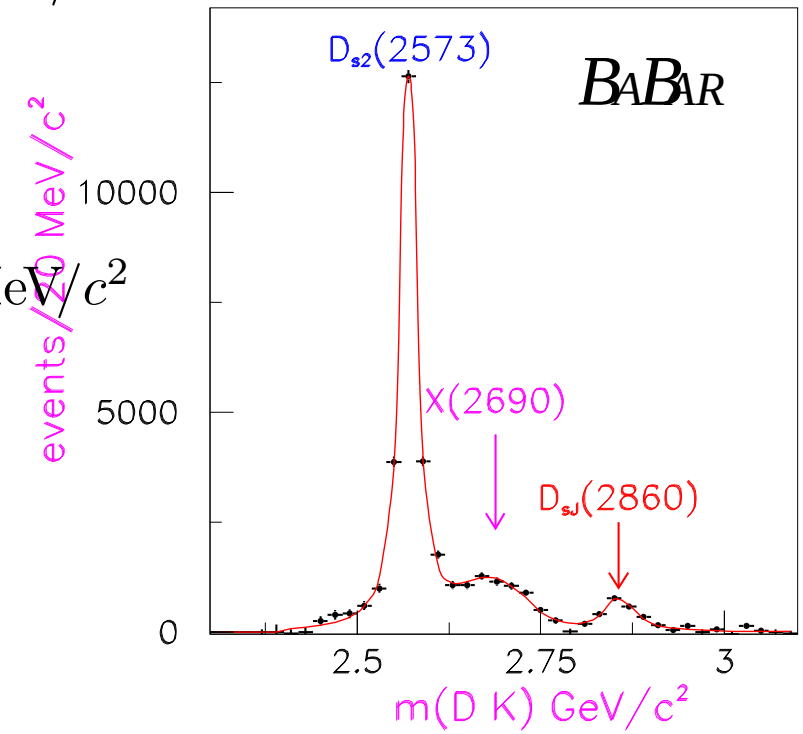
- Parameters of the new state.

$M(D^*_{sJ}(2860)) = (2856.6 \pm 1.5 \pm 5.0)$ 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 $J^P = 3^-$? hep-ph/0607245
- $c\bar{s}$ with $J^P = 0^+$? hep-ph/0608139

□ The possible observation of the decay to D^*K would solve the problem.

□ Another resonance at 2690 MeV/c^2?

$M(X(2690)) = (2688 \pm 4 \pm 3)$ MeV/c^2, $\Gamma(X(2690)) = (112 \pm 7 \pm 36)$ MeV

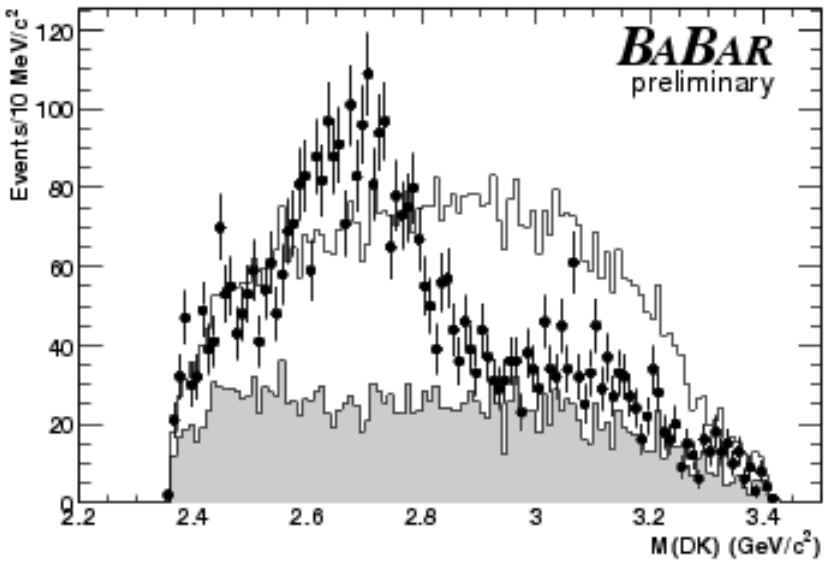
□ Resonance with $J = 1$ simultaneously observed by BELLE in the study of $B^+ \to D^0 \bar{D}^0 K^+$. arXiv:0707.3491

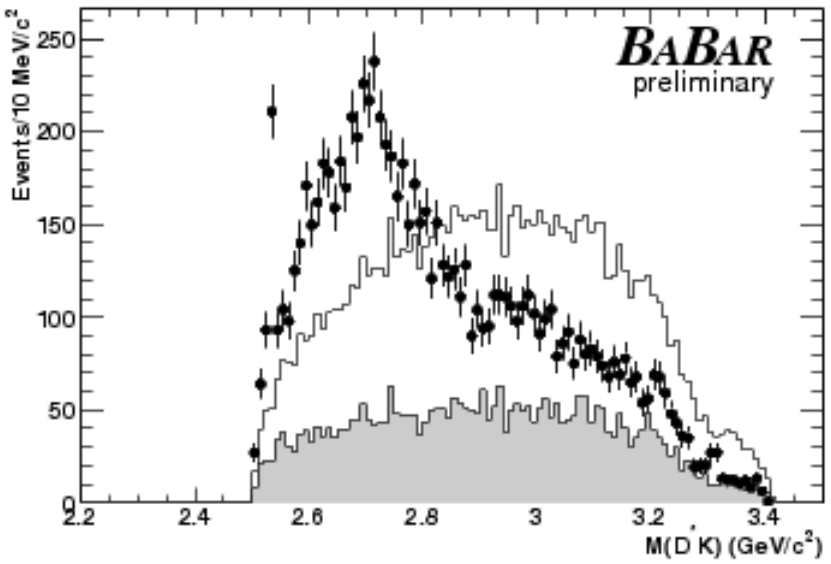
$M = (2708 \pm 9^{+11}_{-10})$ MeV/c^2, $\Gamma = (108 \pm 23^{+36}_{-31})$ MeV

□ Most likely the same state.

$D_{sJ}(2700)$.

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

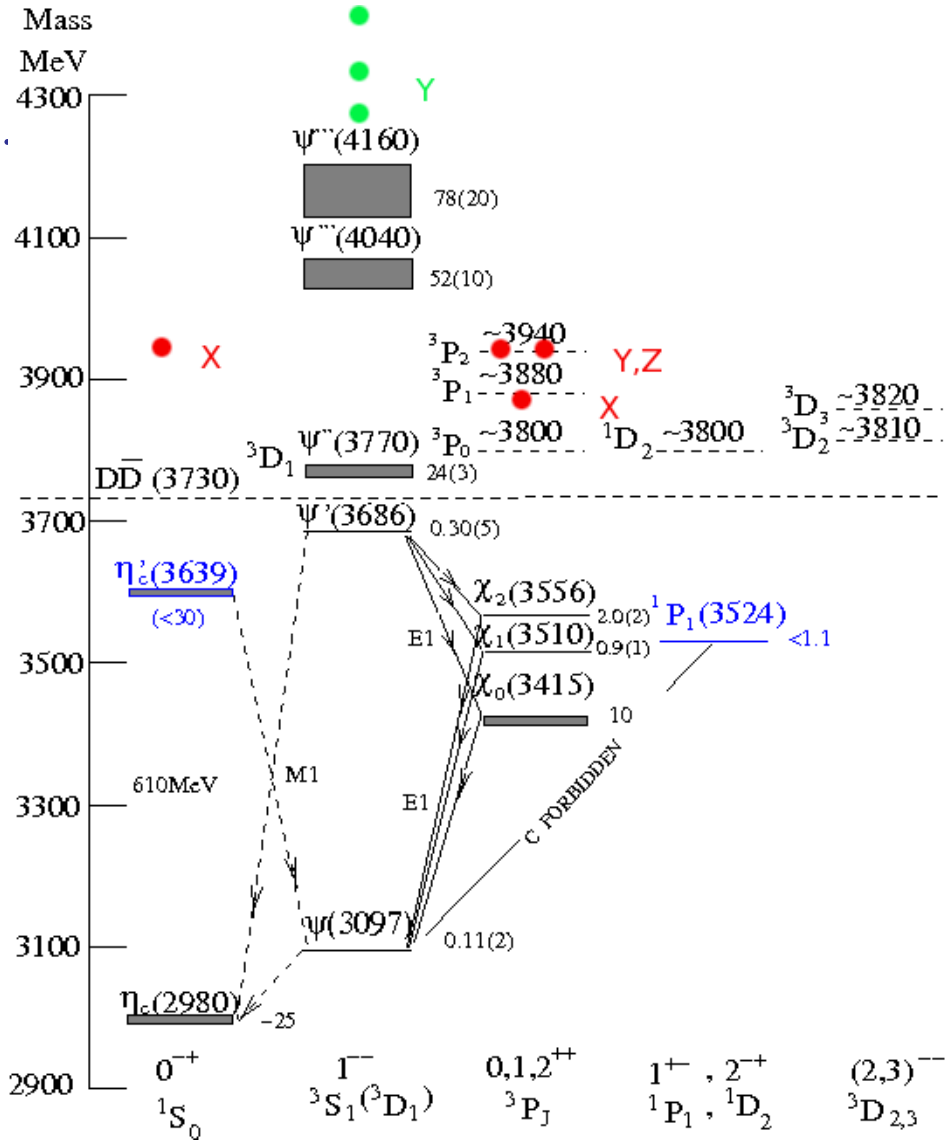




- No signal of $D^*_{sJ}(2860)$ in B decays. This would favour $J^P = 3^-$ (suppressed in B decays).

Charmonium spectroscopy.

- In the past few years many new charmonium states have been discovered.
- At moment we do not have a clear picture.
- Several states do not fit in the quark model.
- Presence of exotic states?



Charmonium spectroscopy: X(3872).

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

$m_X = 3871.4 \pm 0.6 \quad \text{MeV}/c^2, \qquad \Gamma_X < 2.3 \quad \text{MeV} \quad @90\% \quad C.L.(PDG)$

□ $J^{PC} = 1^{++}$ favoured.

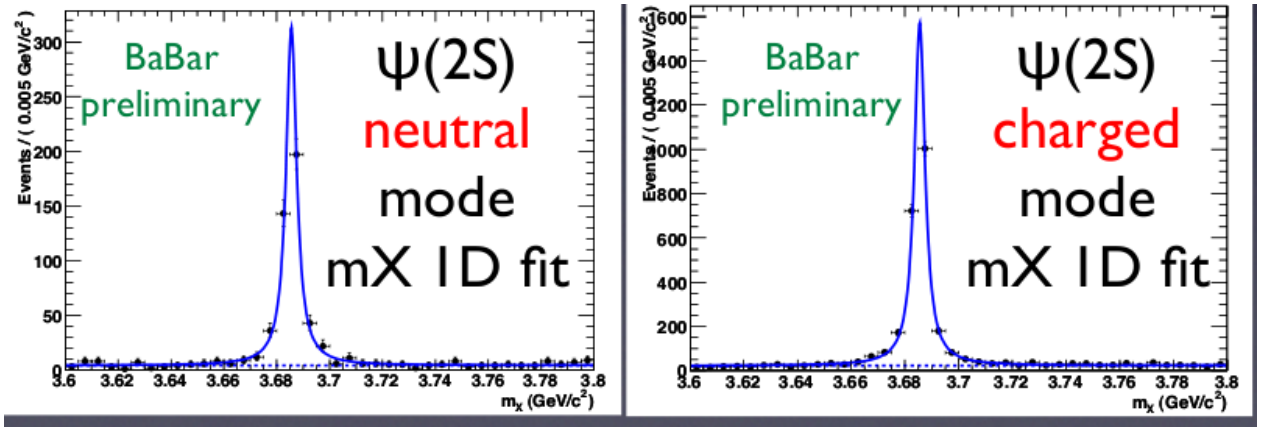
□ Not matching any predicted state.

□ Above the $D\bar{D}$ threshold. Should have large width but it is narrow.

□ Tetraquark model expects different rates and mass difference between $B^0 \to K^0 X$ and $B^+ \to K^+ X$.

New results on X(3872) from BaBar.

- Full statistics: 413 fb^{-1}: arXiv:0803.2838
- Use $B \to \psi(2S)K$ as control sample to correct the $\psi\pi^+\pi^-$ mass.



- $\psi(2S)$ mass:

$B^+ : m = 3685.52 \pm 0.07, \quad B^0 : m = 3685.54 \pm 0.16 \quad \text{MeV}/c^2$

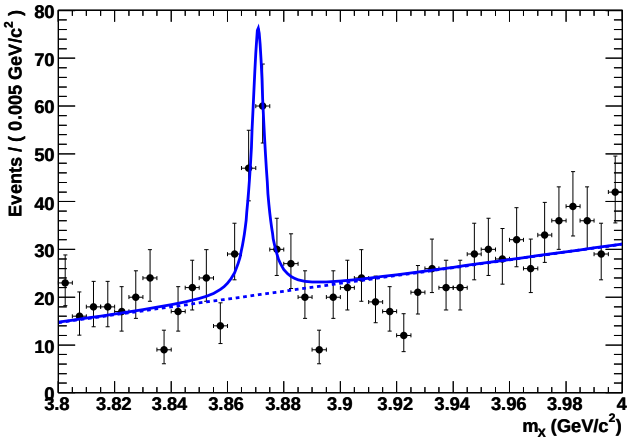
PDG: $m = 3686.09 \pm 0.04 \quad \text{MeV}/c^2$

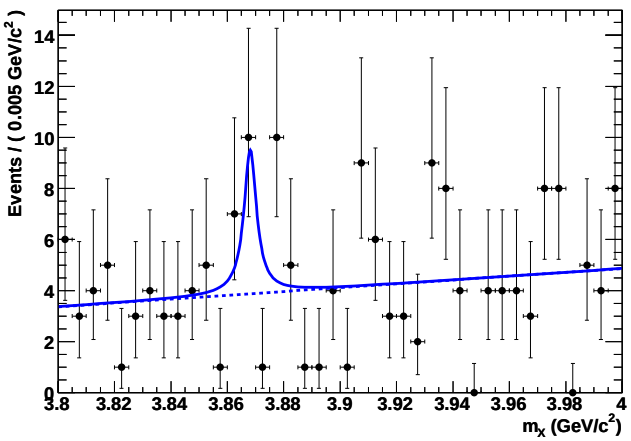
$R = B^0/B^+ = 0.81 \pm 0.05 \pm 0.01,$

PDG: $R = 0.96 \pm 0.11$

New results on X(3872) from BaBar.

$B^+ \to J/\psi\pi^+\pi^- K^+$ $\qquad$ $B^0 \to J/\psi\pi^+\pi^- K^0_S$





- We measure:

$$R(X) = \frac{\mathcal{B}(B^0 \to X^0 K^0)}{\mathcal{B}(B^+ \to X^0 K^+)} = 0.41 \pm 0.24 \pm 0.05 \quad \text{(BELLE: } 0.94 \pm 0.24 \pm 0.10\text{)}$$

- Mass for the charged mode:

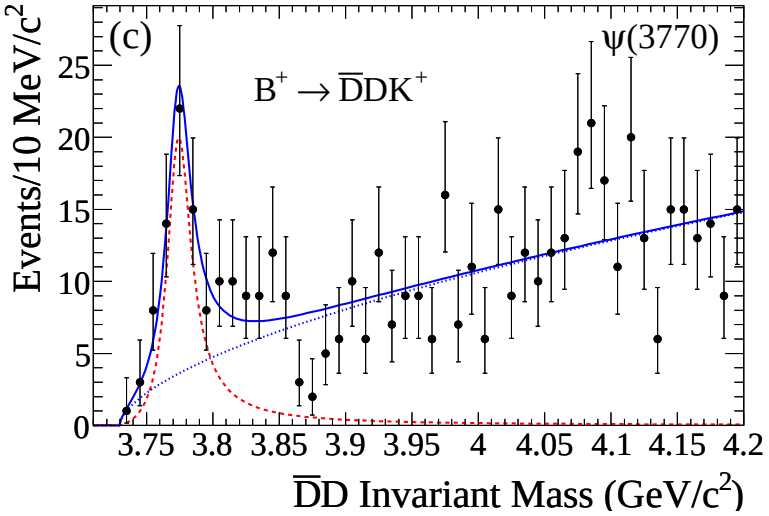
$$(3871.4 \pm 0.6 \pm 0.1) \quad \text{MeV}/c^2, \quad \Gamma < 3.3 \quad \text{MeV} \quad 90\% \quad CL$$

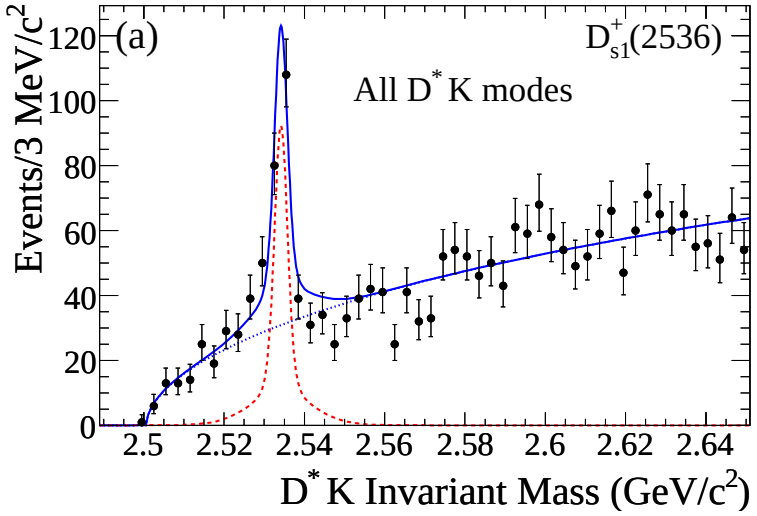
- Mass difference:

$$\Delta m = (2.7 \pm 1.6 \pm 0.4) \quad \text{MeV}/c^2, \quad \text{(BELLE: } 0.22 \pm 0.90 \pm 0.27\text{)}$$

Study of $B \to D^{(*)}\bar{D}^{(*)}K$ in BaBar.

- Observation of $B \to \psi(4770)K$, $\psi(3770) \to D\bar{D}$. Phys. Rev. D77, 011102 (2008)
- Observation of $B \to D_{s1}\bar{D}$, $D_{s1} \to D^*K$.



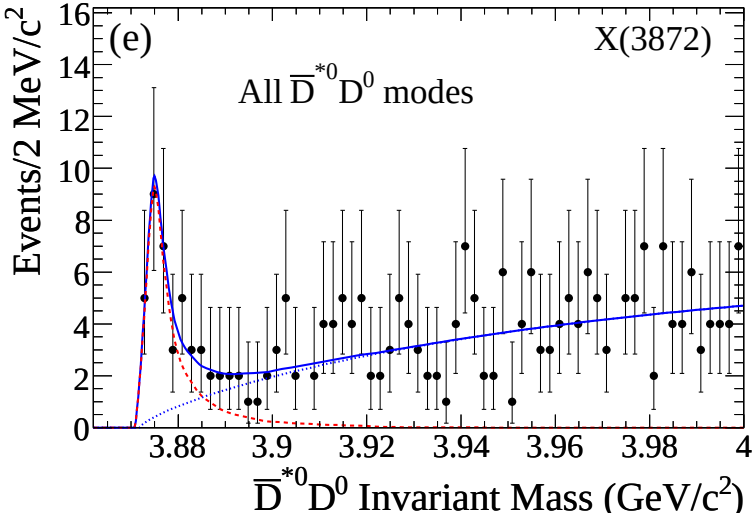


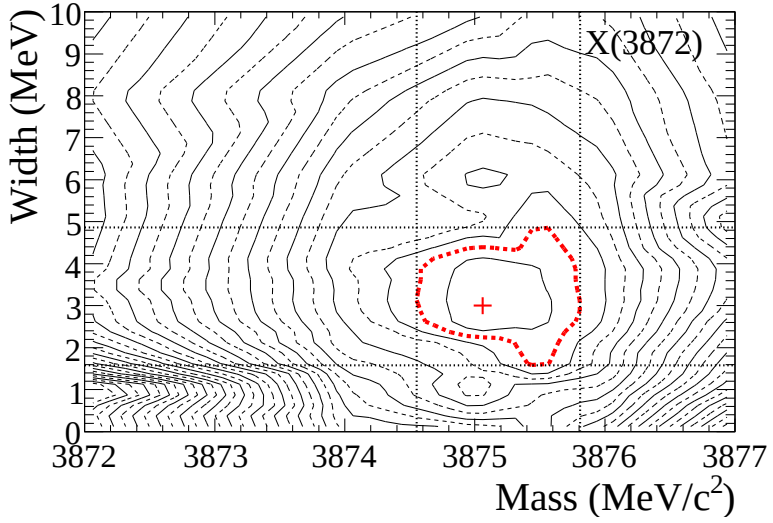
Study of $B \to D^{(*)}\bar{D}^{(*)}K$ in BaBar.

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

$$m = 3875.1^{+0.7}_{-0.5} \pm 0.5 \quad \text{MeV}/c^2$$

$$\Gamma = 3.0^{+1.9}_{-1.4} \pm 0.9 \quad \text{MeV}$$





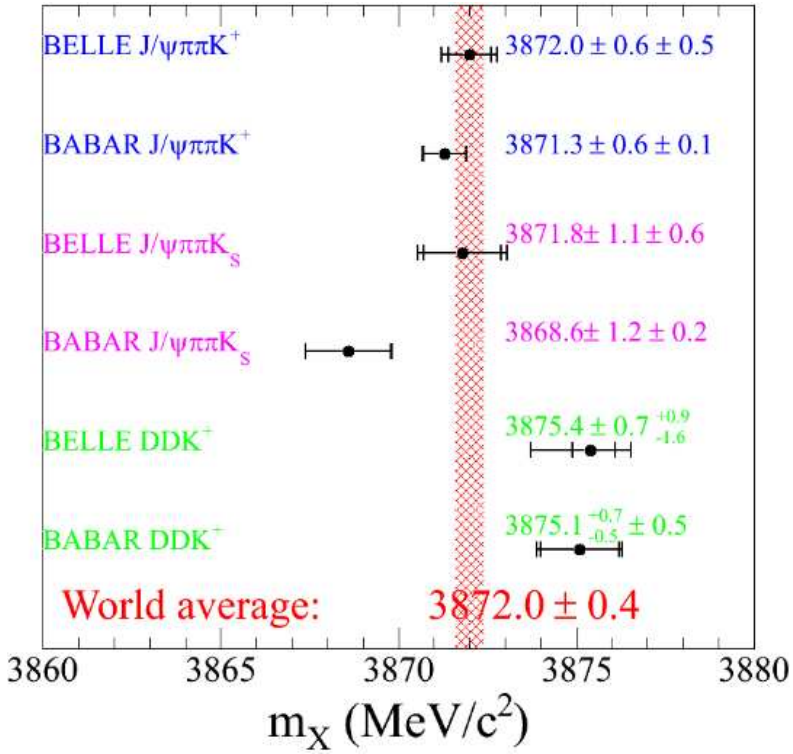
- Problem with threshold. Fit with 90 different PDFs.

$X(3872)$ Mass.

□ Poor agreement in mass between $J/\psi\pi\pi$ and $D^*\bar{D}$ modes, $\approx 3\sigma$. Different states?

□ However, presence of a threshold in $D^*\bar{D}$.

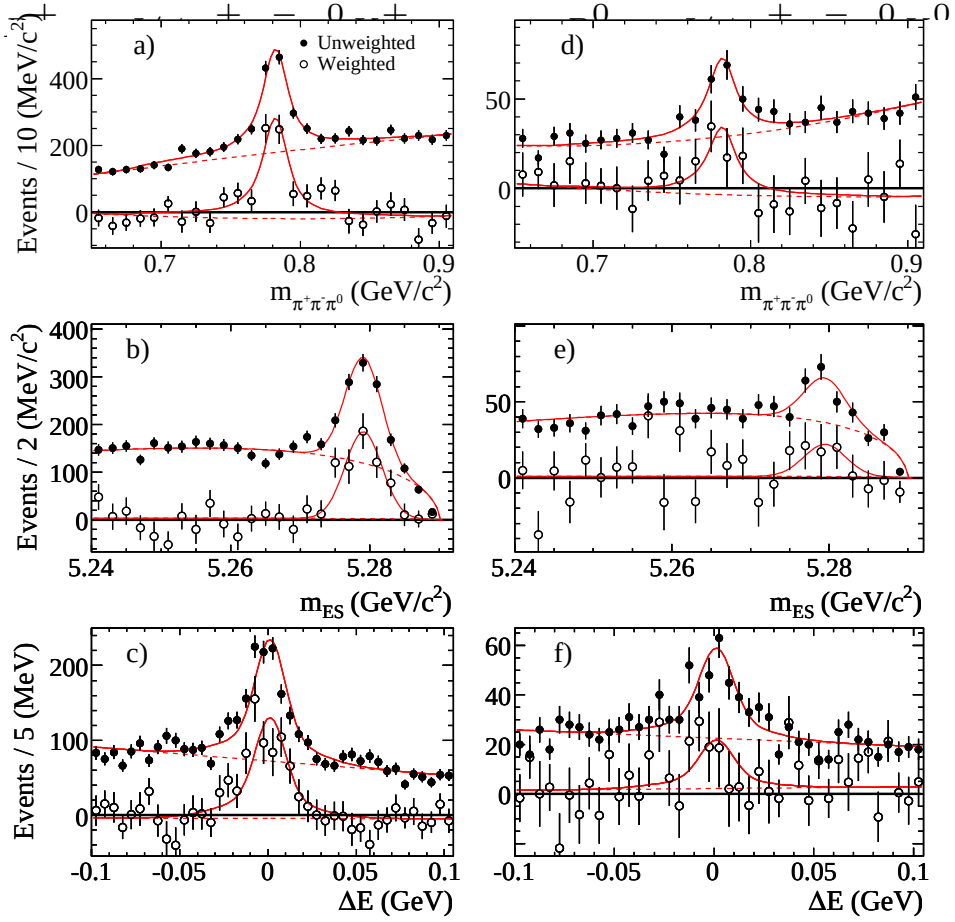
W. Dunwoodie and V. Ziegler (PRL100, (2008)062006): if $\Gamma = 3$MeV, expected behavior.



Study of $X(3980) \to J/\psi\omega$ in BaBar.

- Broad structure at threshold observed by BELLE in $B \to J/\psi\omega K$.
- BaBar analysis. Weight the events by the ω angular distributions.

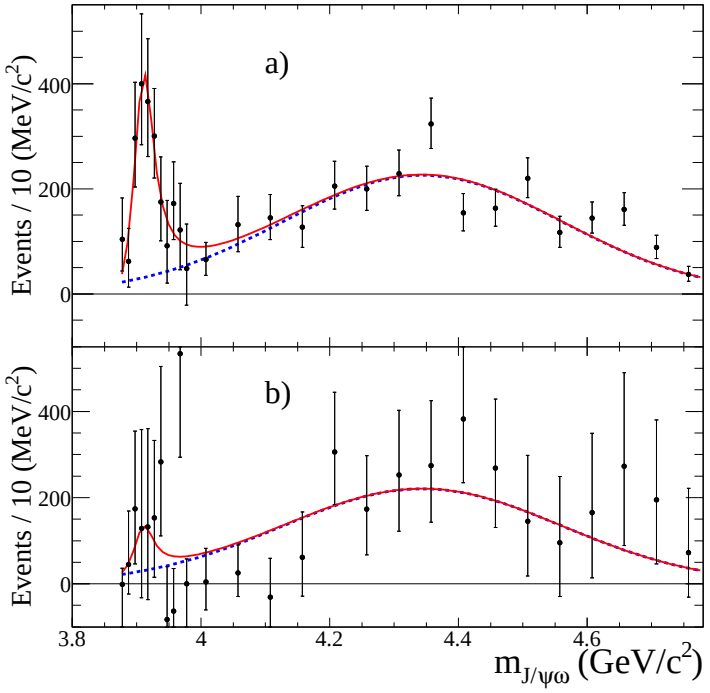
($w_i = \frac{5}{2}(1 - 3\cos^2\theta_h^i)$) where θ_h is the angle between the π^+ and π^0 directions in the $\pi^+\pi^-$ rest frame.



arXiv:0711.2047

Study of $X(3980) \to J/\psi\omega$ in BaBar.

- Fit the ΔE yields as function of $J/\psi\omega$ mass.



$$M(Y) = 3914.6^{+3.8}_{-3.4} \pm 1.9 \quad \text{MeV}/c^2, \qquad \Gamma = 33^{+12}_{-8} \pm 5 \quad \text{MeV}$$

- 30 MeV lower in mass and narrower width wrt Belle:

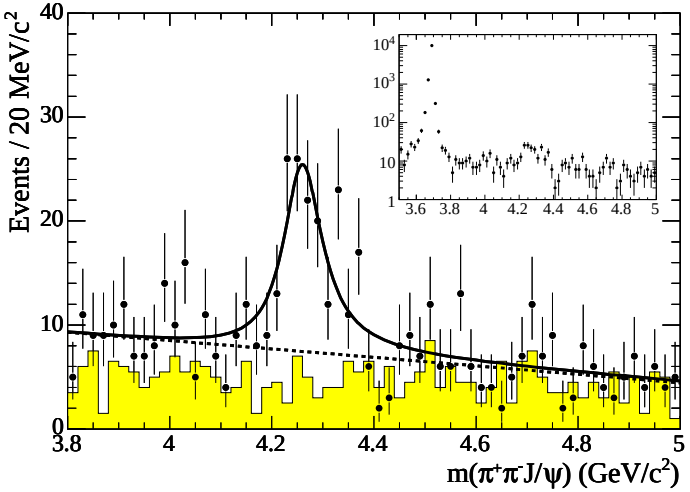
$$m = 3943 \pm 17 \quad \text{MeV}/c^2, \qquad \Gamma = 87 \pm 34 \quad \text{MeV}$$

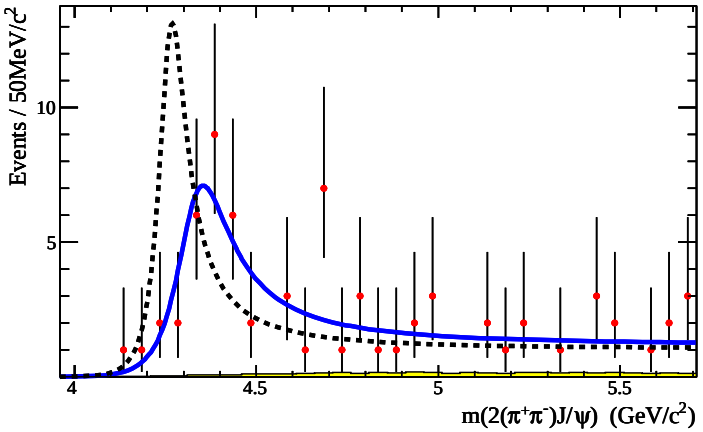
The $J^P = 1^-$ family.

- 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))

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

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

- Confirmed by BELLE. Observe further structure in the $\psi(2S)\pi^+\pi^-$ mass at:

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

Study of the exclusive ISR production of $D\bar{D}$ in BaBar.

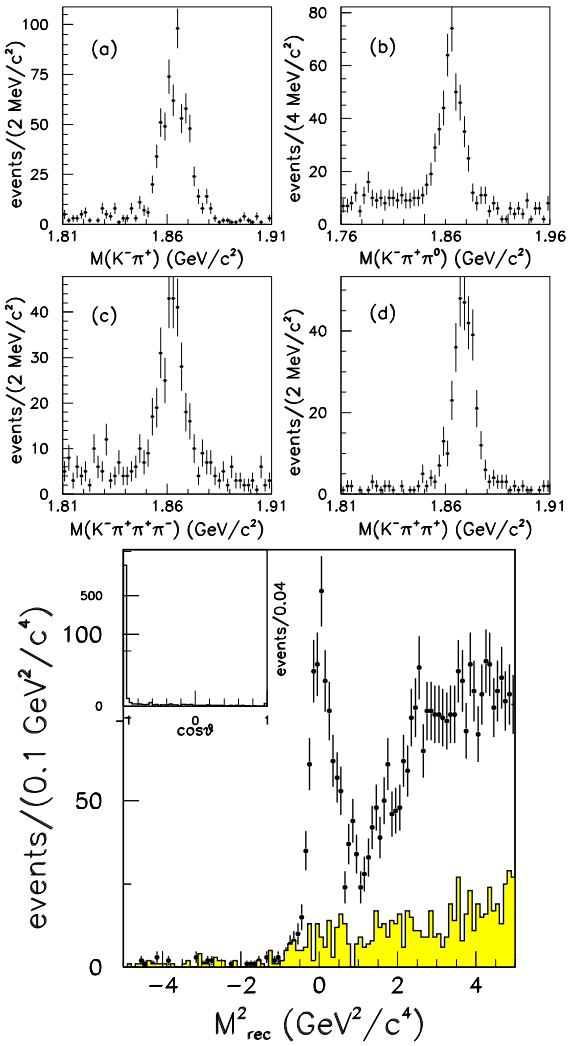
- Study of $e^+e^- \to \gamma_{ISR} D\bar{D}$. arXiv:0710.1371
- D^0 reconstructed as:

$D^0 \to K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^+\pi^-.$

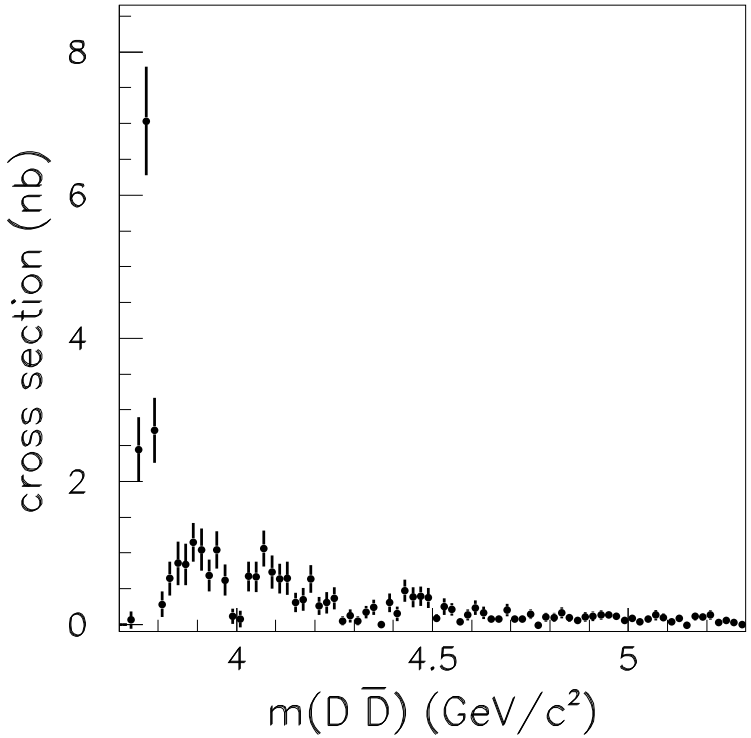
D^+ reconstructed as:

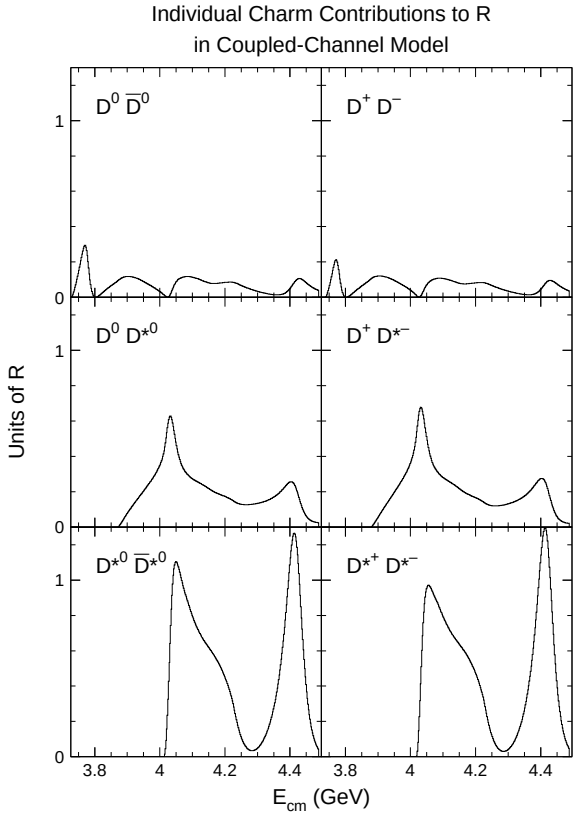
$D^+ \to K^-\pi^+\pi^+, K^0_S\pi^+.$

- ISR photon reconstructed as missing mass.



Measurement of the $D\bar{D}$ cross section.



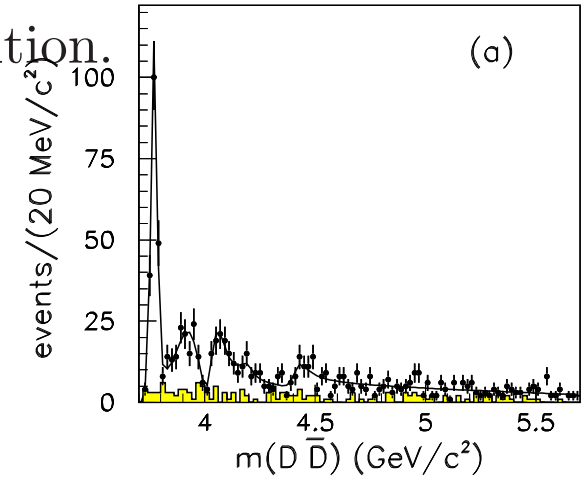


□ Observation of structure in the 3.9 GeV region: expected from the coupled channel model of Eichten et al.

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

Limit on $Y(4260) \to D\bar{D}$.

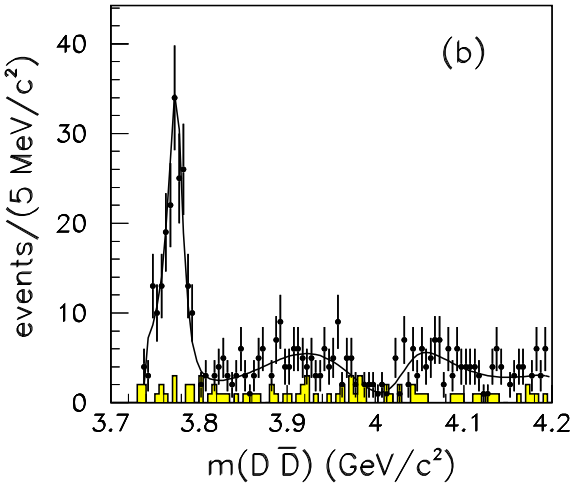
- Fit to the $D\bar{D}$ mass spectrum with interfering spin-1 Breit-Wigner.
- Interference required with non-resonant contribution.
- The 3.9 GeV effect represented by a Gaussian.



- $\psi(3770)$ parameters.

$m = (3778.8 \pm 1.9_{stat} \pm 0.9_{syst})$ MeV/c^2

$\Gamma = (23.5 \pm 3.7_{stat} \pm 0.9_{syst})$ MeV

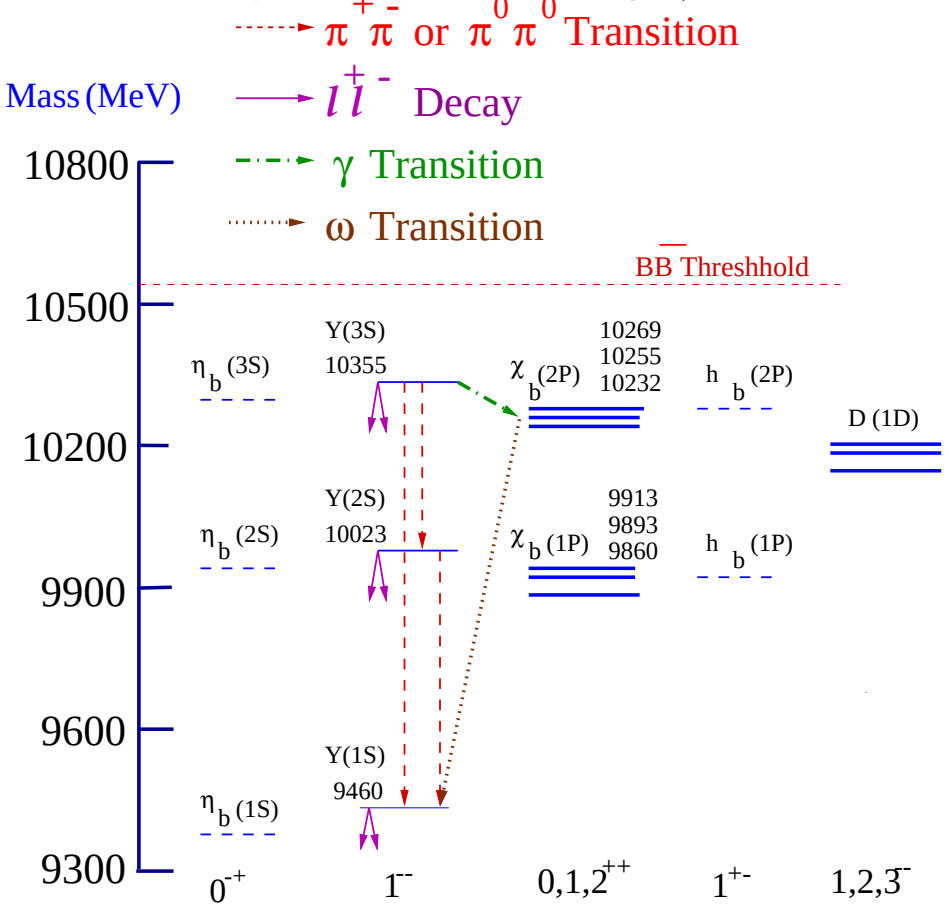


- We compute a limit:

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

The bottomonium spectrum.

- ≈ 100 M events at the $\Upsilon(2S)$ and at the $\Upsilon(3S)$
- Analysis in progress. It may lead to the discovery on the missing η_b and h_b.
- Spectrum still to be fully exploited.



Conclusions.

- Spectroscopy is reserving many new surprises.
- Several new charmed and charmonium states discovered in the last few years.
- Many newly discovered states in the charm and charmonium sectors are waiting for a classification in the quark model.
- New information is needed. Several analyses going on in BaBar.

- B-factories have produced a large mess of unexpected new states.
- Potential models are in trouble in trying to explain the available data.
- Some theorists suggest that we may be close to the start of a new spectroscopy.