

# Hadron Spectroscopy at B-Factories.

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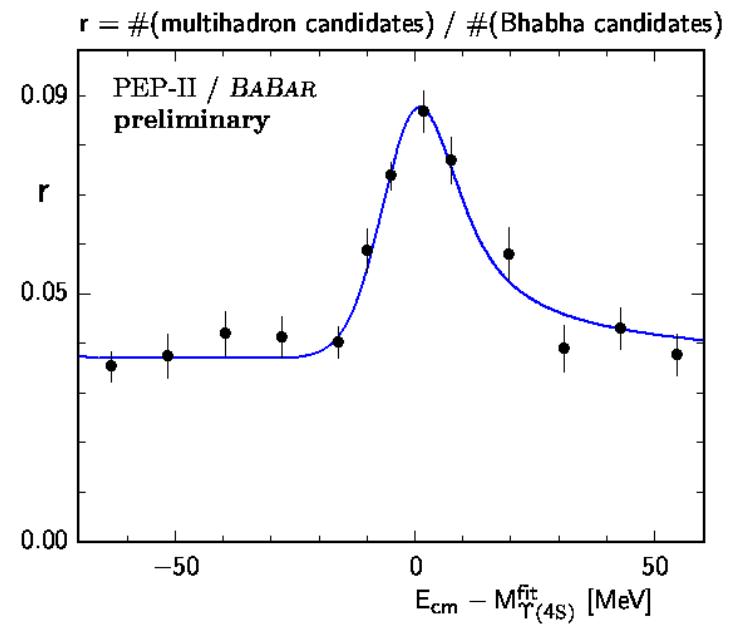
*Compass Workshop, Freiburg, March 20, 2007.*

- In the last few years light, charm and charmonium spectroscopy has received a new interest due to the discovery of new unexpected states.
- New results on Spectroscopy from B-factories are coming from:
  - B decays;
  - Charm decays;
  - Inclusive  $e^+e^-$  interactions;
  - $\gamma\gamma$  collisions;
  - Initial State Radiation;
- Important issue for spectroscopy: Exclusive or Semi-exclusive reactions.

# Spectroscopy at B-factories.

- At B-factories, the  $\Upsilon(4S)$  resonance sits on a consistent continuum background.
- Cross sections for different processes, at the  $\Upsilon(4S)$ :

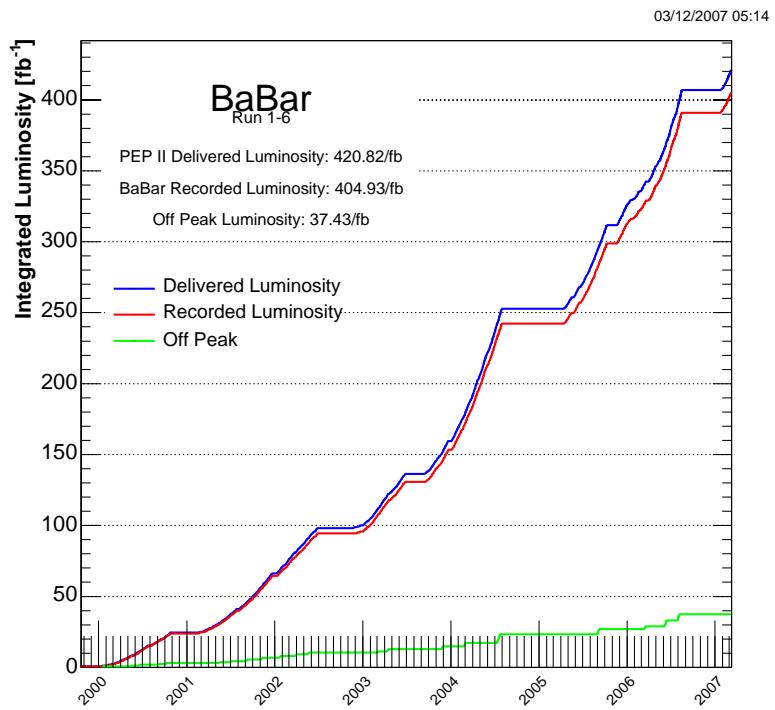
$e^+e^- \rightarrow$	$\sigma$ (nb)
$b\bar{b}$	1.05
$c\bar{c}$	1.30
$s\bar{s}$	0.35
$u\bar{u}$	1.39
$d\bar{d}$	0.35
$\tau^+\tau^-$	0.94
$\mu^+\mu^-$	1.16
$e^+e^-$	$\approx 40$



## Spectroscopy at B-factories.

- The power of B-factories for spectroscopy is based on:
  - Relatively small combinatorial in  $e^+e^-$  interactions.
  - Good tracking and vertexing.
  - Good Particle Identification.
  - Detection of all possible final states, with charged tracks and  $\gamma$ 's.
  - Very high statistics.

- Last week: BABAR:  $405\text{ fb}^{-1}$ , running up to the end of 2008.
- BELLE:  $700\text{ fb}^{-1}$



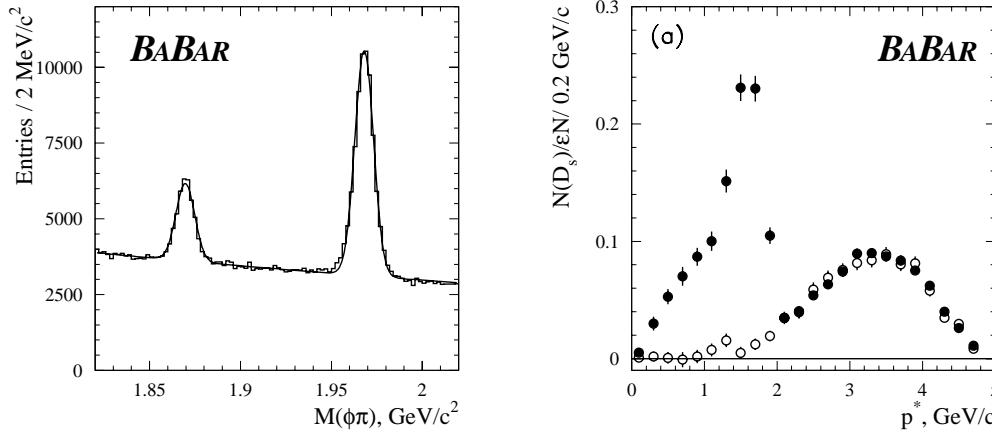
## Some New Results in Spectroscopy.

- Among the recent results in hadron spectroscopy from B-factories, I will focus on:
  - Charm spectrum;
  - Charmonium spectrum;
  - Light meson spectroscopy;
  - New inputs on the possible existence of gluonium, hybrid and multiquark states.
- **Not covered: high precision measurements and the discovery of many new charmed baryons.**

## Charm Spectroscopy at B-factories.

- Inclusive Charm Physics is performed on events selected from continuum  $e^+e^- \rightarrow \bar{c}c$
- Very high statistics samples of charmed mesons actually available.
- Example from BaBar: mass distribution and  $p^*$  momentum spectrum for  $D_s^+ \rightarrow \phi\pi^+$ . BABAR, hep-ex/0201041

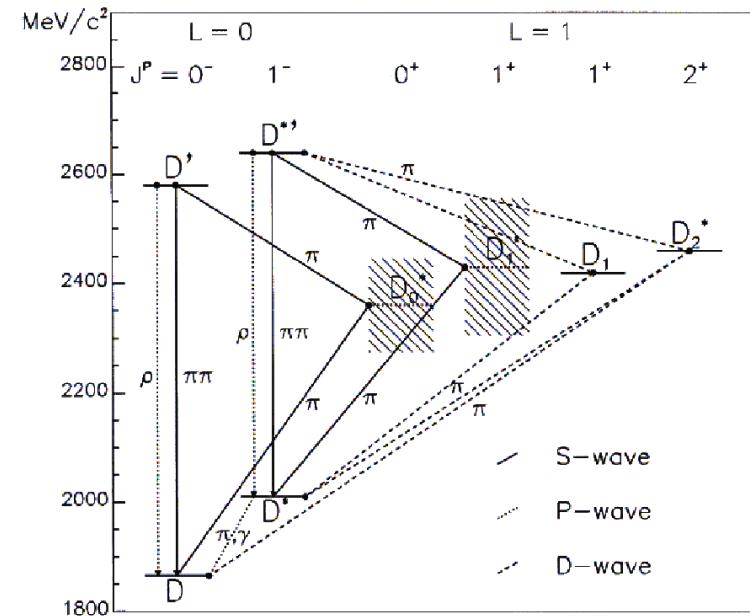
*Filled/open points: normalized on/off peak data.*



- By using inclusive continuum events combinatorial background is strongly reduced.
- Kinematical selection: the center of mass momentum ( $p^*$ ) > 2.5  $\text{GeV}/c$ .

## The charm spectrum.

- The recent discoveries in the charm spectrum put back into question the validity of the potential models.
- Therefore it is important to establish the complete spectrum of charm. The  $\bar{c}u/d$  spectrum.



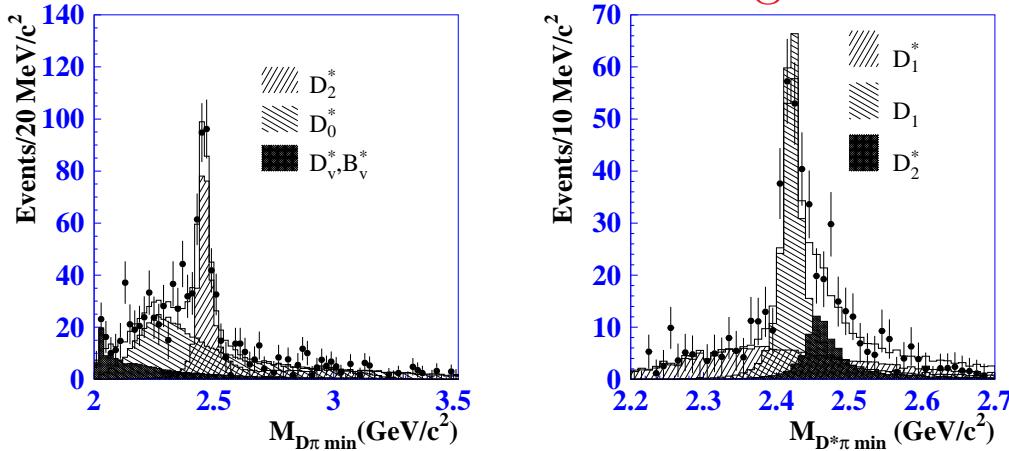
- Presence of very narrow and broad states.
- Radial excitations not yet seen.

## The broad states.

- BELLE experiment has studied the decays: [hep-ex/0307021](https://arxiv.org/abs/hep-ex/0307021)

$$B^- \rightarrow D^+ \pi^- \pi^-, \quad B^- \rightarrow D^{*+} \pi^- \pi^-$$

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



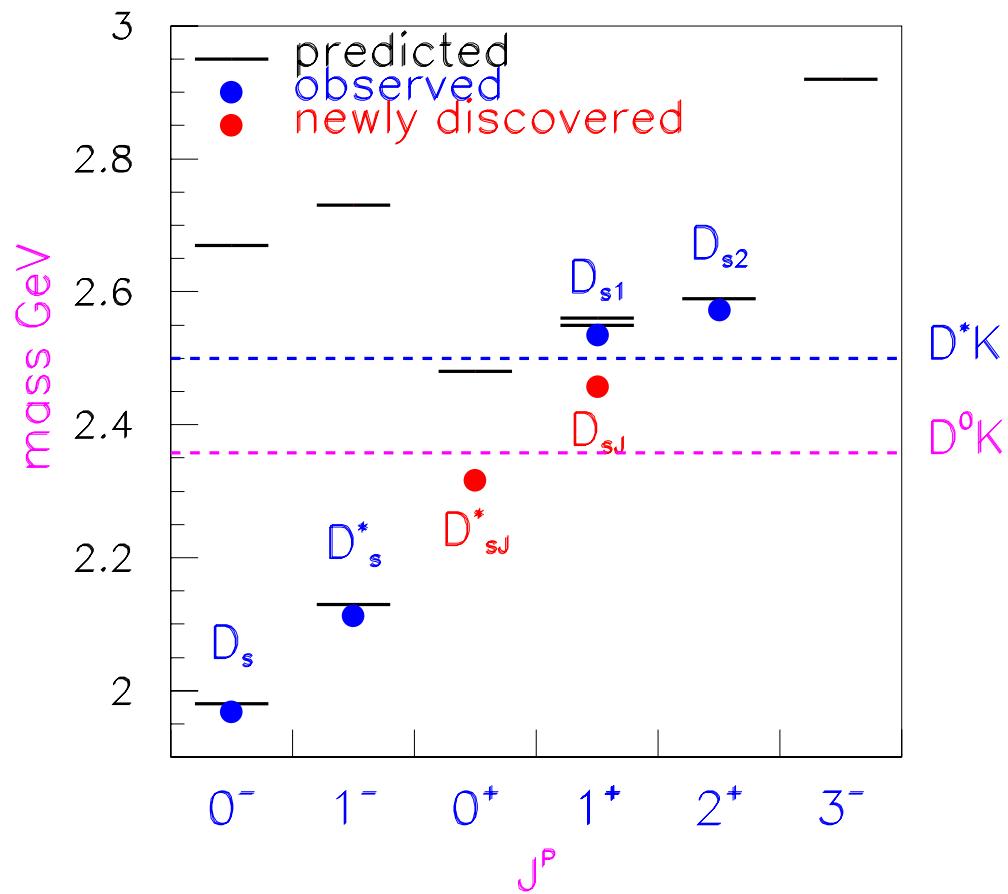
- Resulting parameters for the scalar and axial broad states:

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

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

## The $c\bar{s}$ charm spectrum.

- The  $\bar{c}s$  spectrum after the discovery of the  $D_{sJ}$  states.



## Charm Spectroscopy: $D_{sJ}$ states.

- Important to measure all possible decay modes.
- BaBar: upgrade of measurements with  $240 \text{ fb}^{-1}$ . [hep-ex/0604030](#)

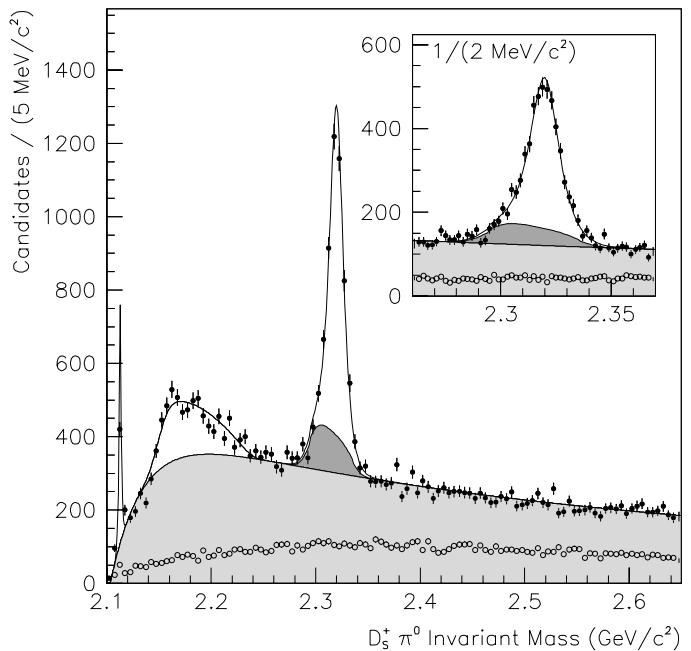
Decay Channel	$D_{sJ}^*(2317)^+$	$D_{sJ}(2460)^+$
$D_s^+ \pi^0$	Seen	Forbidden
$D_s^+ \gamma$	Forbidden	Seen
$D_s^+ \pi^0 \gamma$ (a)	Allowed	Allowed
$D_s^*(2112)^+ \pi^0$	Forbidden	Seen
$D_{sJ}^*(2317)^+ \gamma$	—	Allowed
$D_s^+ \pi^0 \pi^0$	Forbidden	Allowed
$D_s^+ \gamma \gamma$ (a)	Allowed	Allowed
$D_s^*(2112)^+ \gamma$	Allowed	Allowed
$D_s^+ \pi^+ \pi^-$	Forbidden	Seen

(a) Non-resonant only

## Charm Spectroscopy: $D_{sJ}$ states.

- A new measurement of the  $D_{sJ}^*(2317)^+$  mass:

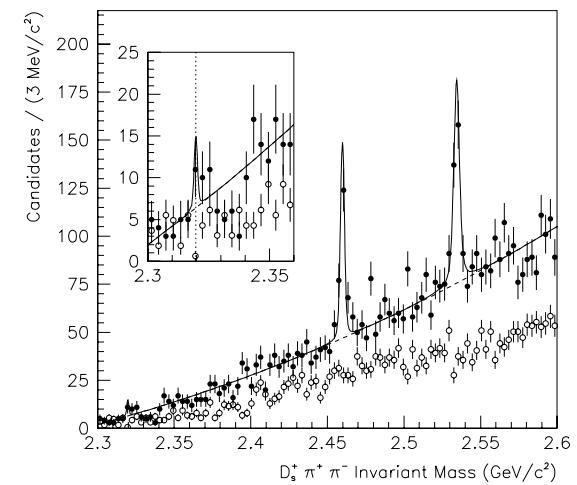
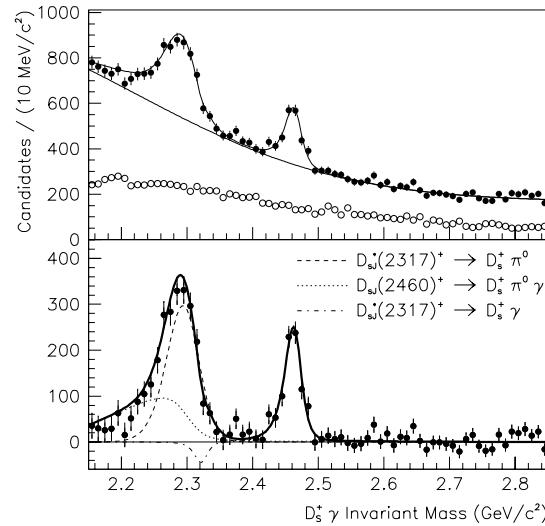
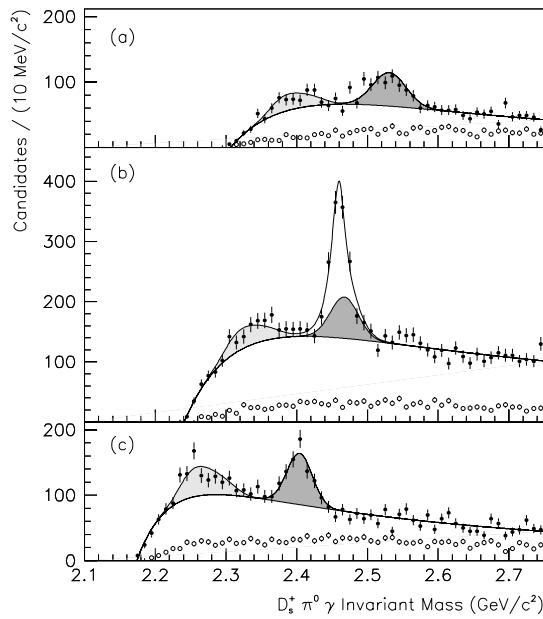
$$m(D_{sJ}^*(2317)^+) = 2319.6 \pm 0.2 \text{ (stat.)} \\ \pm 1.4 \text{ (syst.) MeV/c}^2$$



- Mass moves by  $\approx 2$  MeV: electromagnetic calorimeter calibration.
- Shaded is the reflection from  $D_{sJ}(2460)^+$ .

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

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



- The average of these results is:

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

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

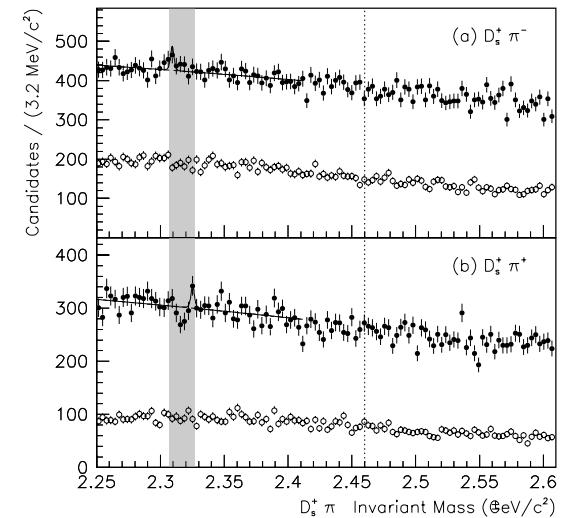
□ Branching fractions:

$$\frac{\mathcal{Br}(D_{sJ}(2460)^+ \rightarrow D_s^+ \gamma)}{\mathcal{Br}(D_{sJ}(2460)^+ \rightarrow D_s^+ \pi^0 \gamma)} = 0.337 \pm 0.036 \text{ (stat.)} \pm 0.038 \text{ (syst.)}, (0.62, 0.24, 0.47)$$

$$\frac{\mathcal{Br}(D_{sJ}(2460)^+ \rightarrow D_s^+ \pi^+ \pi^-)}{\mathcal{Br}(D_{sJ}(2460)^+ \rightarrow D_s^+ \pi^0 \gamma)} = 0.077 \pm 0.013 \text{ (stat.)} \pm 0.008 \text{ (syst.)}, (0.16, 0.20)$$

□ S. Godfrey

- A. Bardeen, E. Eichten, C. Hill
- P. Colangelo, F. De Fazio
- Search for  $m(D_{sJ}^*(2317)^+) \rightarrow D_s^+ \pi^\pm$ : no signal



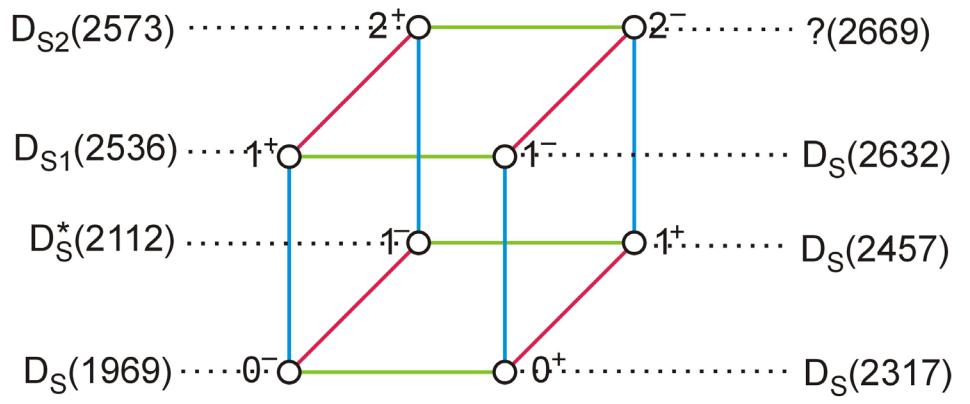
## The new $D_{sJ}$ states.

□ The new  $D_{sJ}$  states have been interpreted as:

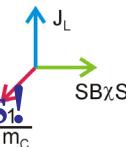
- The missing  $c\bar{s}$  states. For reasons still to understand potential models predict wrong masses.
- 4-quark states or molecules. In this cases other states should be found. Some of them could be narrow.
- The discovery of a new phenomenon such as Chiral Doubling? In this case again new states are expected to be found.

M. A. Nowak et al., hep-ph/0307102

W.A. Bardeen et al., hep-ph/0305049

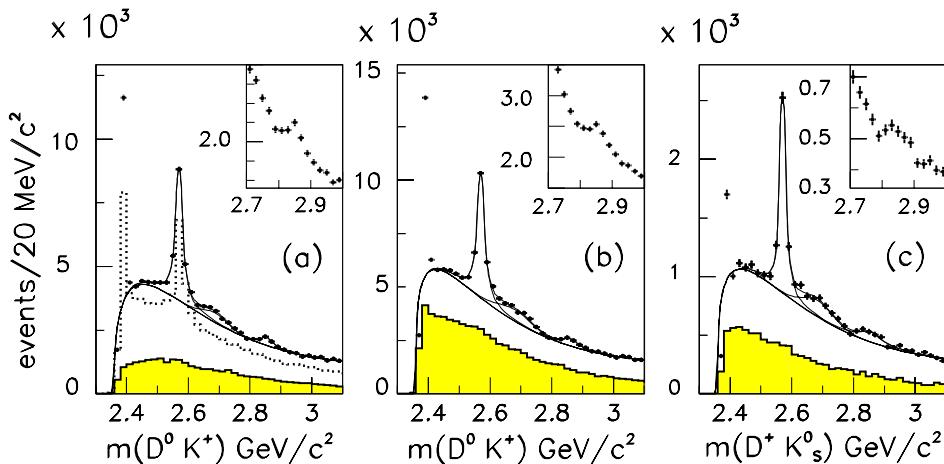


□ Are there still unexpected particles to be found? Yes!



## Still new $D_{sJ}$ states.

- BaBar: Observation of a new  $D_{sJ}$  at a mass of 2.86 GeV. [hep-ex/0607082](#)
- Study of three inclusive  $DK$  mass spectra.  $p^* > 3.5 \text{ GeV}/c$ .



$$m(D_{sJ}(2860)^+) = (2856.6 \pm 1.5 \pm 5.0) \text{ MeV}/c^2$$

- Parameters:

$$\Gamma(D_{sJ}(2860)^+) = (47 \pm 7 \pm 10) \text{ MeV}/c^2$$

- Presence also of a broad structure:

$$m(X(2690)^+) = (2688 \pm 4 \pm 3) \text{ MeV}/c^2$$

$$\Gamma(X(2690)^+) = (112 \pm 7 \pm 36) \text{ MeV}/c^2$$

## Still new $D_{sJ}$ states.

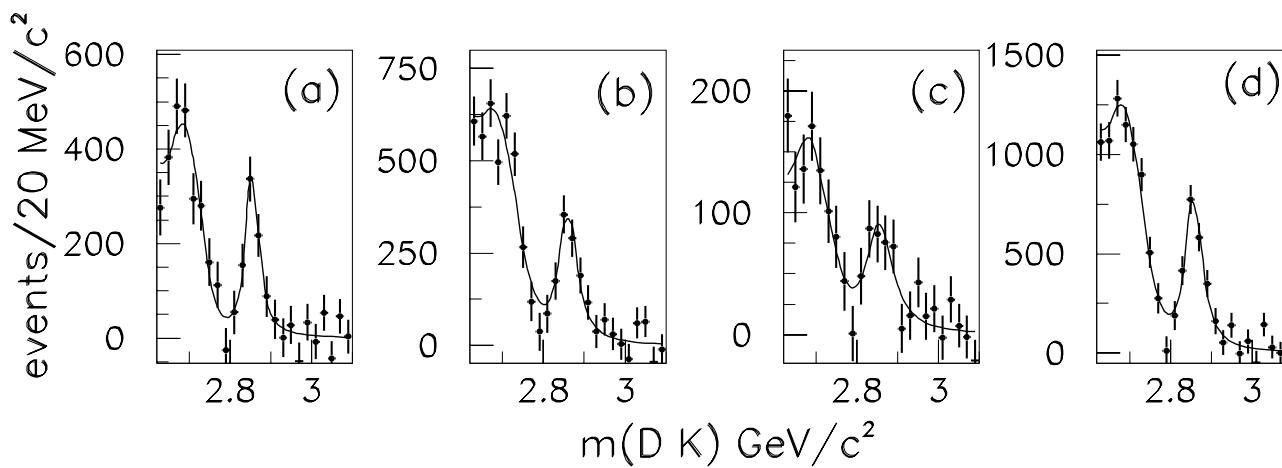
□ Final states:

$$(a) D_{K^-\pi^+}^0 K^+$$

$$(b) D_{K^-\pi^+\pi^0}^0 K^+$$

$$(c) D_{K^-\pi^+\pi^+}^+ K_S^0$$

□ After background subtraction:



## BELLE: charm spectrum from B decays.

- Study of  $B^+ \rightarrow \bar{D}^0 D^0 K^+$  hep-ex/0608031

- Observation of a resonance:

$$M = 2715 \pm 11^{+11}_{-14} \text{ MeV}/c^2$$

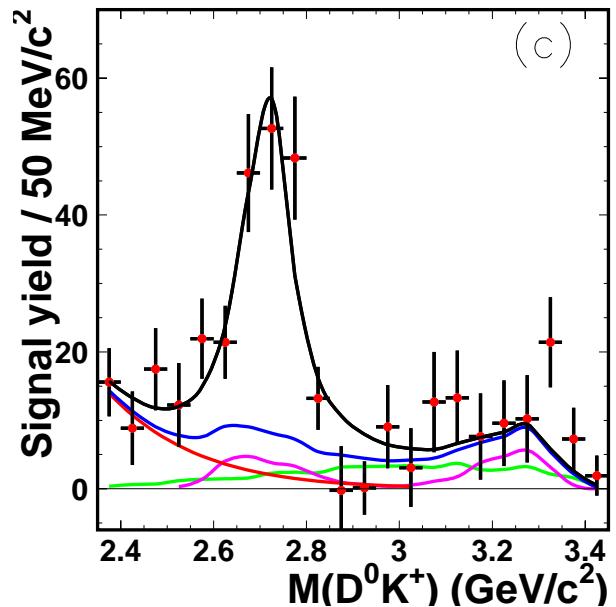
$$\Gamma = 115 \pm 20^{+36}_{-32} \text{ MeV}/c^2$$

Spin-parity:  $1^-$ .

- $D^0 K^+$  spectrum after background subtraction.

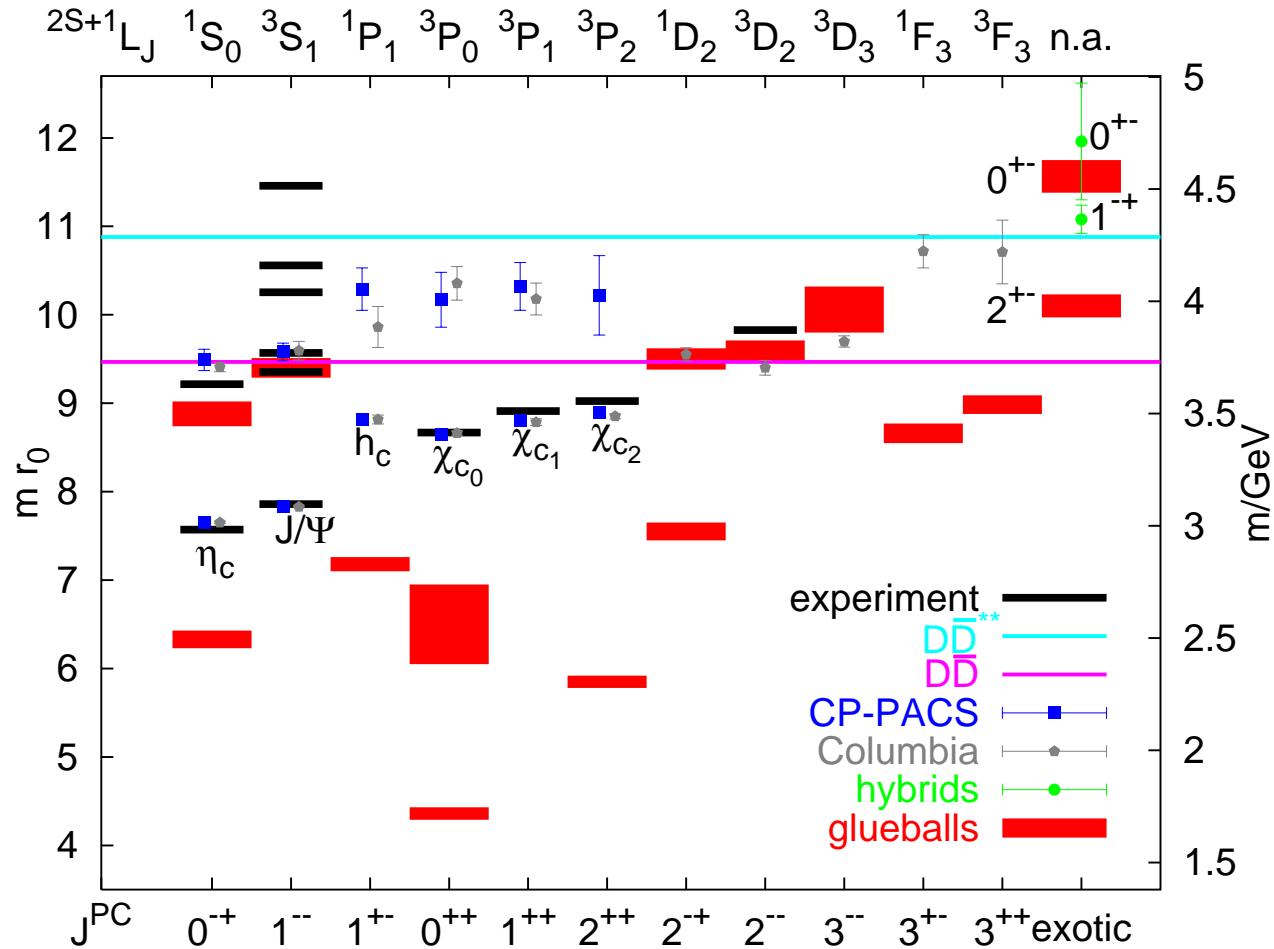
- The same state as seen by BaBar?

- Searching for  $D^* K$ ,  $D_s \eta$  and  $D_s \omega$  decays.



# The charmonium spectrum.

- It is important to establish the complete spectrum of charmonium.



- Several states still missing. Are there hybrid charmonium states?

## Charmonium hybrids.

- S. Godfrey: the existence of gluonium excitations in the hadron spectrum is one of the most important unanswered questions in hadron physics.
- Hybrid mesons  $\psi_g$  consists of  $\bar{c}cg$ .
- The flux tube model predicts 8 states between 4 and 4.2 GeV.
- Lattice QCD calculations predict the  $J^{PC} = 1^{-+}$  state between 4.04 and 4.4 GeV. The proximity of  $D^*D$  thresholds could make it narrow.
- Some hybrids can have exotic quantum numbers such as:

$$\psi_g(J^{PC} = 0^{+-}, 2^{+-}) \rightarrow J/\psi + (\pi^+ \pi^-), \eta, \eta'$$

$$\psi_g(J^{PC} = 1^{-+}) \rightarrow \eta_c + (\pi^+ \pi^-), \eta, \eta'$$

- Some of these states could be produced in B decays.
- Hybrid mesons with  $J^{PC} = 1^{--}$  could be looked for in  $e^+e^-$  annihilations via ISR.

## New Resonances

- Tentatively assigned to Charmonium states:

$h_c$	$1^1P_1$	CLEO	$\psi(2S) \rightarrow \pi^0 h_c (\rightarrow \gamma \eta_c)$
X(3943)	$\eta_c''(3^1S_0(c\bar{c}))?$	BELLE	recoil on $J/\psi$ in $e^+e^-$
Y(3940)	$\chi'_{c1}(2^3P_1(c\bar{c}))?$	BELLE	$B \rightarrow (J/\psi \omega)K$
Z(3930)	$\chi'_{c2}(2^3P_2(c\bar{c}))?$	BELLE	$\gamma\gamma \rightarrow D\bar{D}$

- Not Charmonium states?

X(3872)	BELLE	$J/\psi \pi^+ \pi^-$
Y(4260)	BaBar	$J/\psi \pi^+ \pi^-$

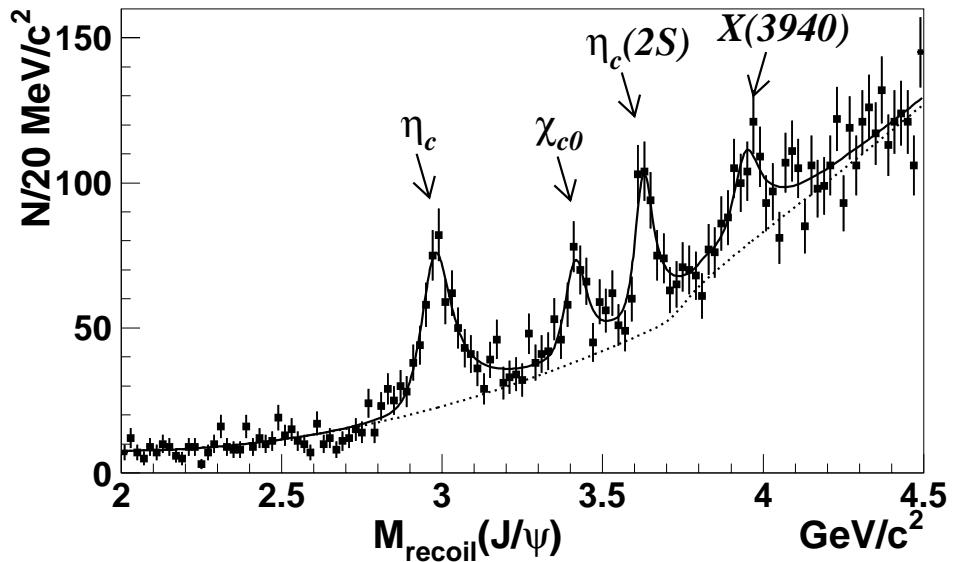
## Double $\bar{c}c$ .

- Observation by BELLE of an unexpected large rate for: ([hep-ex/0507019](#))

$$e^+ e^- \rightarrow J/\psi(\bar{c}c)$$

- Study of the missing mass to  $e^+ e^- \rightarrow J/\psi$  with  $J/\psi \rightarrow l^+ l^-$ .

$$m_{recoil} = \sqrt{(\sqrt{s} - E_{J/\psi}^*)^2 - p_{J/\psi}^{*2}}$$



- Observed peaks at the positions of:

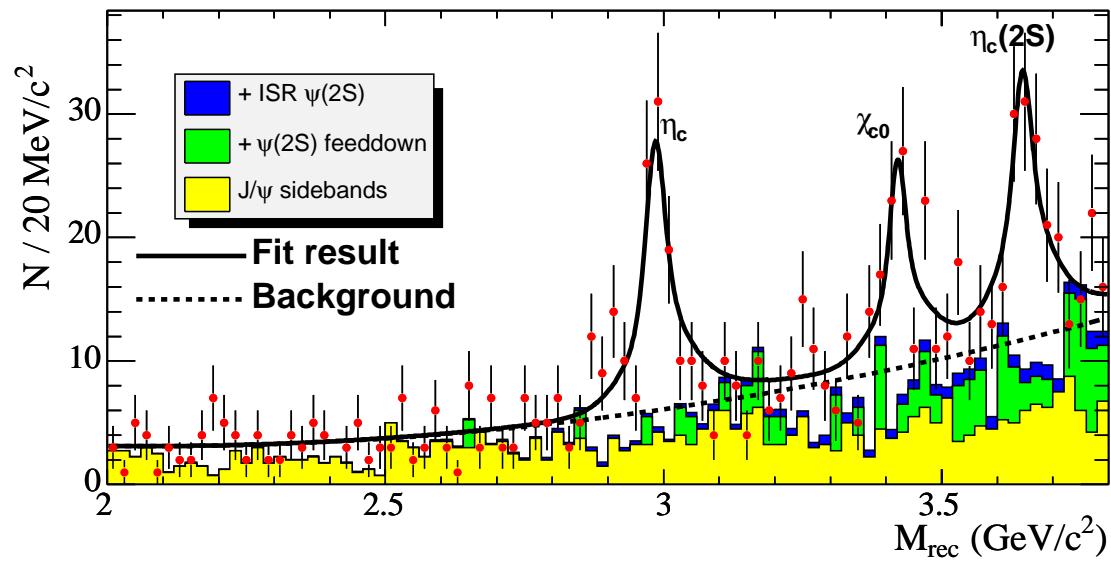
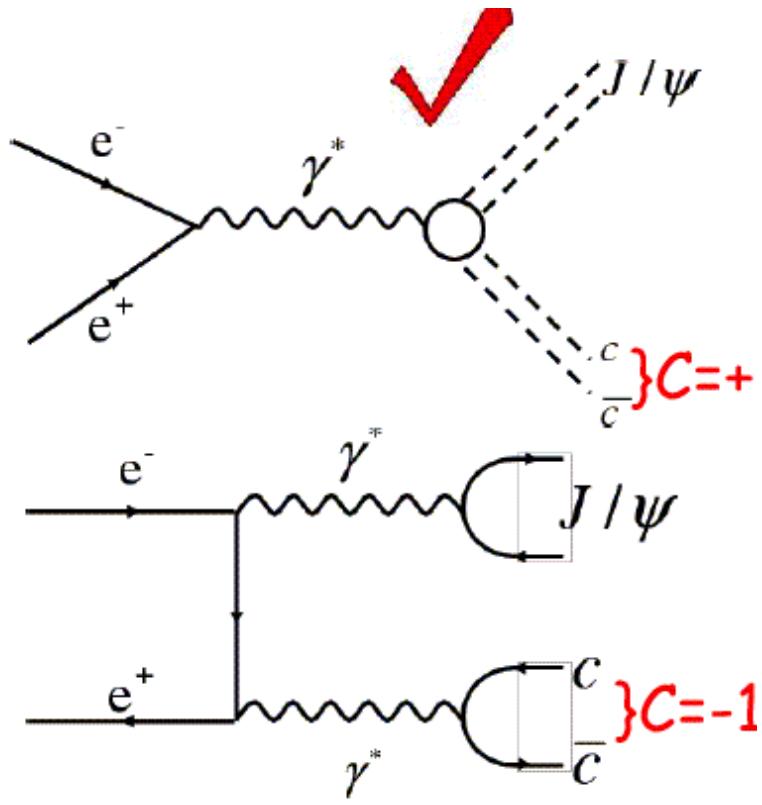
$\eta_c, \chi_{c0}, \eta_c(2S), X(3940)$

- $X(3940)$  unknown object.

$$M = 3943 \pm 6 \pm 6 \text{ MeV}$$

## Double $\bar{c}c$ .

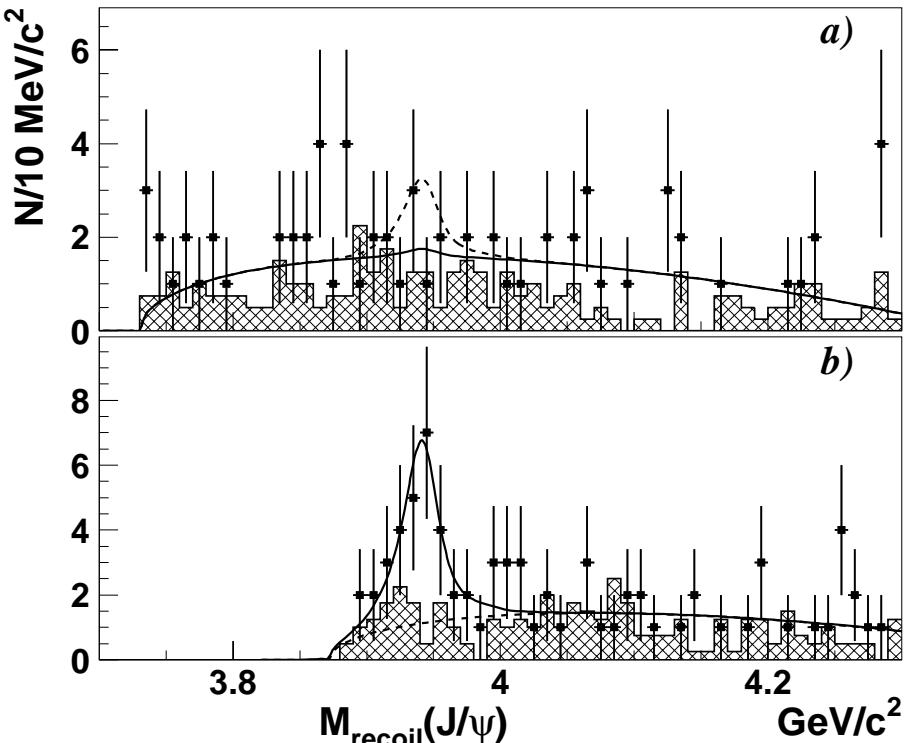
- Result confirmed by BaBar.
- Two diagrams are possible:



- Observed only  $C=+$  states.

## X(3943).

- Observed also  $X(3943) \rightarrow D\bar{D}^*$ , but not  $X(3943) \rightarrow D\bar{D}$ .



$$BR(X \rightarrow D\bar{D}^*) = 96^{+45}_{-32} \pm 22 \%$$

$$BR(X \rightarrow D\bar{D}^*) < 41 \% \text{ (90 \% CL);}$$

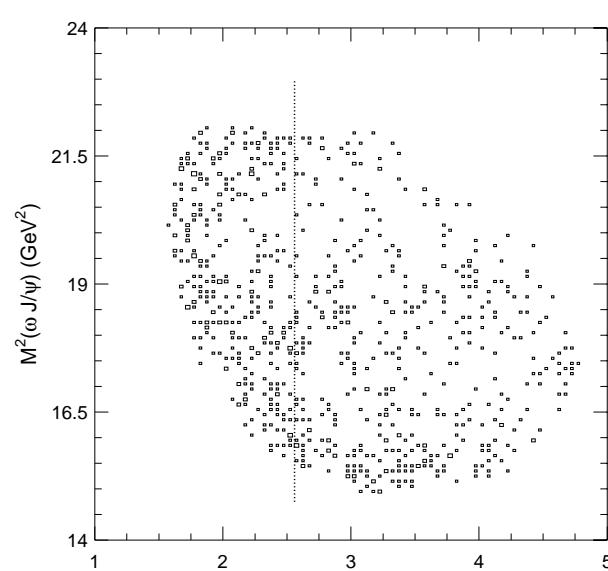
$$BR(X \rightarrow D\omega J/\psi) < 26 \% \text{ (90 \% CL);}$$

- Possibly  $3^1S_0(c\bar{c})\eta_c''$  state.
- Test  $\gamma\gamma \rightarrow D\bar{D}^*$ . (S. Godfrey, hep-ph/0605152)

# A threshold enhancement in $J/\psi\omega$ , $Y(3943)$ .

- BELLE has shown a threshold enhancement in  $J/\psi\omega$ :

BELLE, hep-ex/0408126



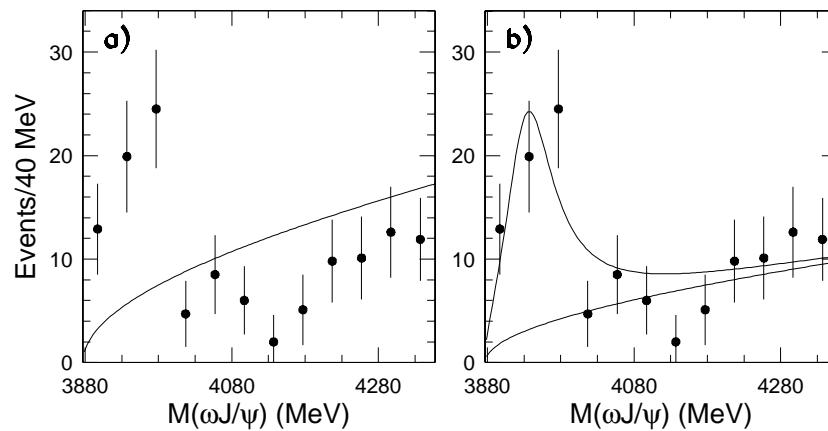
$$M = 3943 \pm 11 \pm 13 \text{ MeV}$$

$$\Gamma = 87 \pm 22 \pm 26 \text{ MeV}$$

- Not yet seen:  $Y \rightarrow D\bar{D}$ ,  $Y \rightarrow D\bar{D}^*$ .

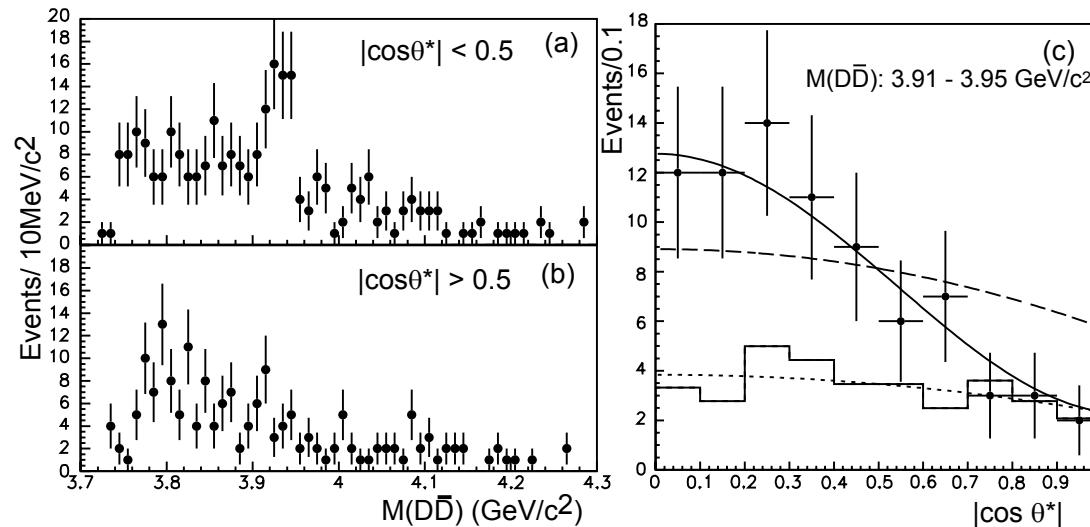
- Possibly:  $\chi'_{c1}(2^3P_1(c\bar{c}))$ .

- Test: see  $D\bar{D}^*$ , don't see  $D\bar{D}$  (Godfrey).



# Z(3930).

- Observation of  $Z(3939)$  by BELLE in  $\gamma\gamma$  collisions. (hep-ex/0512035)



$\gamma\gamma \rightarrow D\bar{D}$ :  $J^{PC} = 0^{++}, 2^{++}$ , angular distributions consistent with  $J=2$

$M = 3929 \pm 5 \pm 2$  MeV

$\Gamma = 29 \pm 10 \pm 2$  MeV

□ Probably  $\chi'_{c2}$  state ( $2^3P_2(c\bar{c})$ )

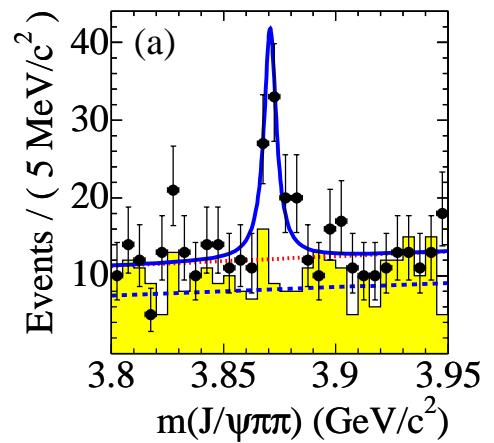
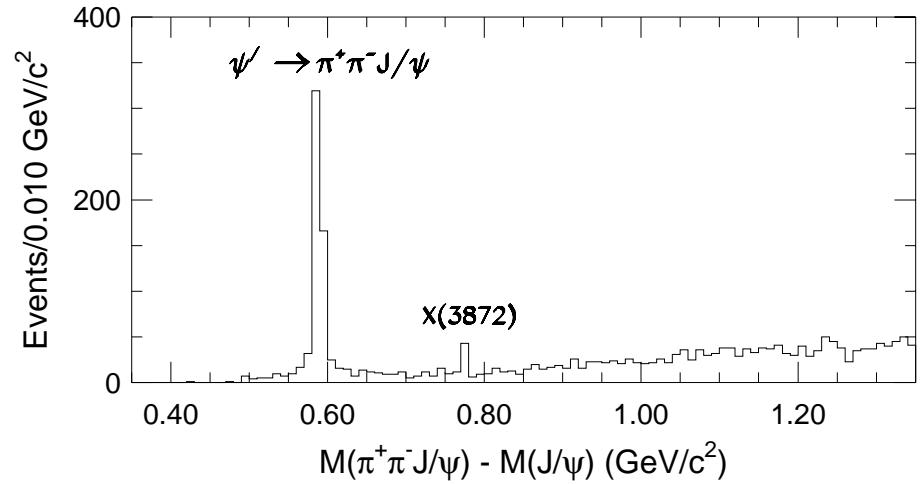
# X(3870).

- The  $J/\psi\pi^+\pi^-$  mass spectrum from BELLE in  $B^+ \rightarrow K^+ J/\psi\pi^+\pi^-$ :

hep-ex/0309032

- Confirmed by BaBar, CDF and D0.

(hep-ex/0507090)



# X(3870).

$M = 3871.9 \pm 5$  MeV,  $D\bar{D}^*$  threshold at  $3871.3 \pm 1$  MeV

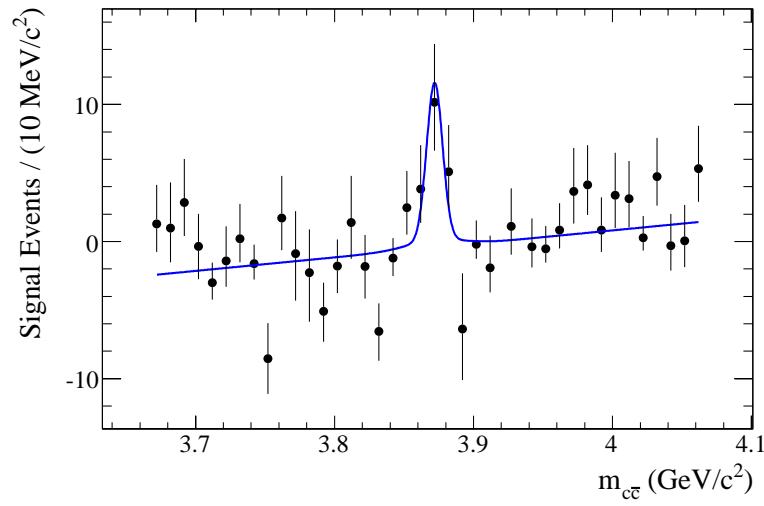
$\Gamma < 2.3$  MeV, 90 % CL

□ Di-pion mass distribution consistent with:  $X(3870) \rightarrow J/\psi\rho^0$ .

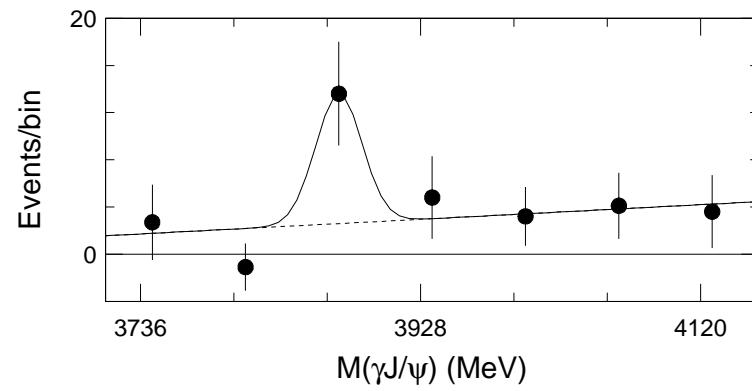
I=0, no evidence for a  $J/\psi\pi^-\pi^0$  decay mode (BaBar); hep-ex/0412051

□  $B \rightarrow KX(3870)(\rightarrow J/\psi\gamma)$ : C=+1. hep-ex/0607050, hep-ex/0505037

BaBar

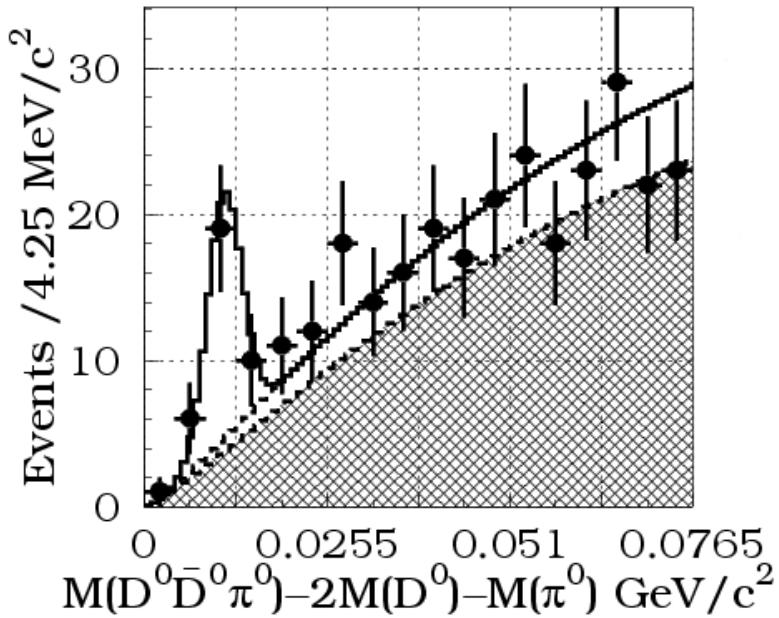


BELLE



X(3870).

- BELLE:  $B \rightarrow KX(3870)(\rightarrow D^0\bar{D}^0\pi^0)$ :  $J^P = 2^+$  disfavoured. hep-ex/0606055



- Angular analysis from BELLE and CDF: only  $J^{PC} = 1^{++}$  left.
- $\chi'_{c1}$  expected at a mass of  $\approx 3950$  MeV!
- X(3870) too light.

## X(3870) Interpretation.

- Diquark-antidiquark. Maiani et al (PRD71 014028 (2005)).

Expect 2 neutral and 2 charged states.

Expect:  $\Delta m = m(X_d) - m(X_u) \approx (7 \pm 2) \text{ MeV}$

Compare  $B^+ \rightarrow X(3870)K^+$  with  $B^0 \rightarrow X(3870)K^0$ .

BaBar:  $\Delta m = 2.7 \pm 1.3 \pm 0.2 \text{ MeV}$  (resolution 5.4 MeV).

- S-wave  $D^0\bar{D}^{*0}$  molecule. (Braaten, Kusunoki, PRD71 (2005) 074005)

$B^0 \rightarrow X(3870)K^0$  suppressed by a factor 10 wrt  $B^+ \rightarrow X(3870)K^+$

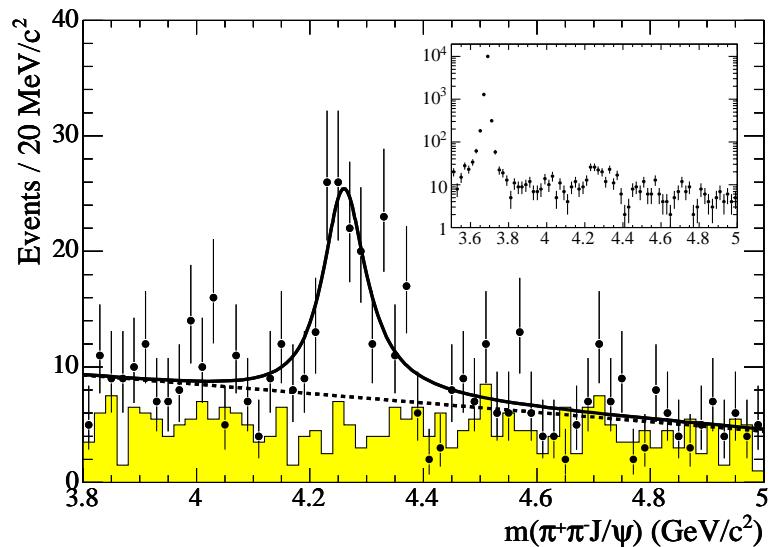
BaBar:  $R = B^0/B^+ = 0.5 \pm 0.3 \pm 0.05$

- Need more statistics!

# Y(4260).

- BaBar. Observation of a new resonance in ISR: ( $J^{PC} = 1^{--}$ ). [hep-ex/0506081](#)

$$e^+ e^- \rightarrow \gamma_{ISR} J/\psi \pi^+ \pi^-$$



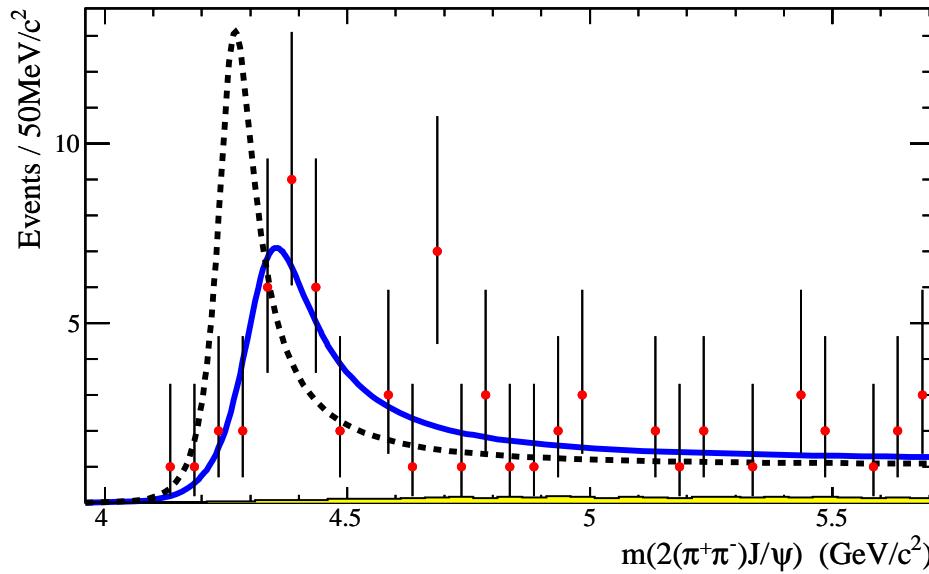
$$m = 4259 \pm 8 \text{ MeV}$$

$$\Gamma = 88 \pm 23 \text{ MeV}$$

- Confirmed by CLEO and BELLE.

# BaBar: Search for $Y(4260) \rightarrow \psi(2S)\pi^+\pi^-$ .

hep-ex/0610057



$$m = 4324 \pm 24 \text{ MeV}$$

$$\Gamma = 172 \pm 33 \text{ MeV}$$

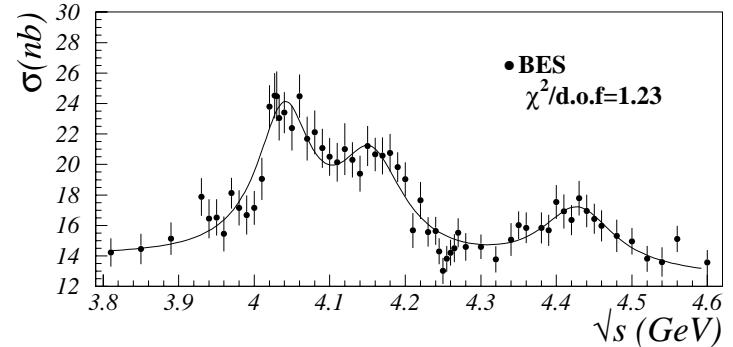
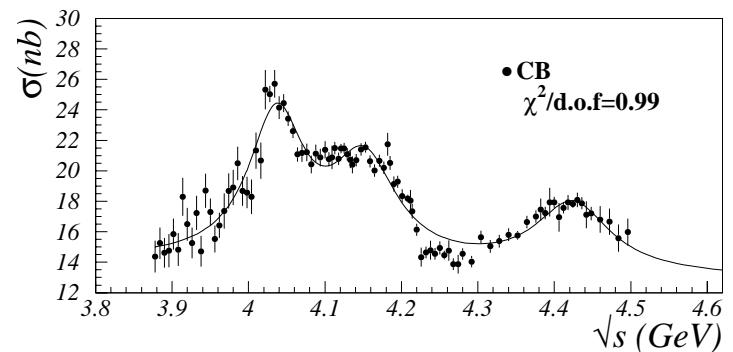
Mass shifted.

Cannot exclude being a new decay mode of  $Y(4260)$

## $c\bar{c}$ Meson?

- If  $J^{PC} = 1^{--}$ , it should be produced directly in  $e^+e^-$  collisions.

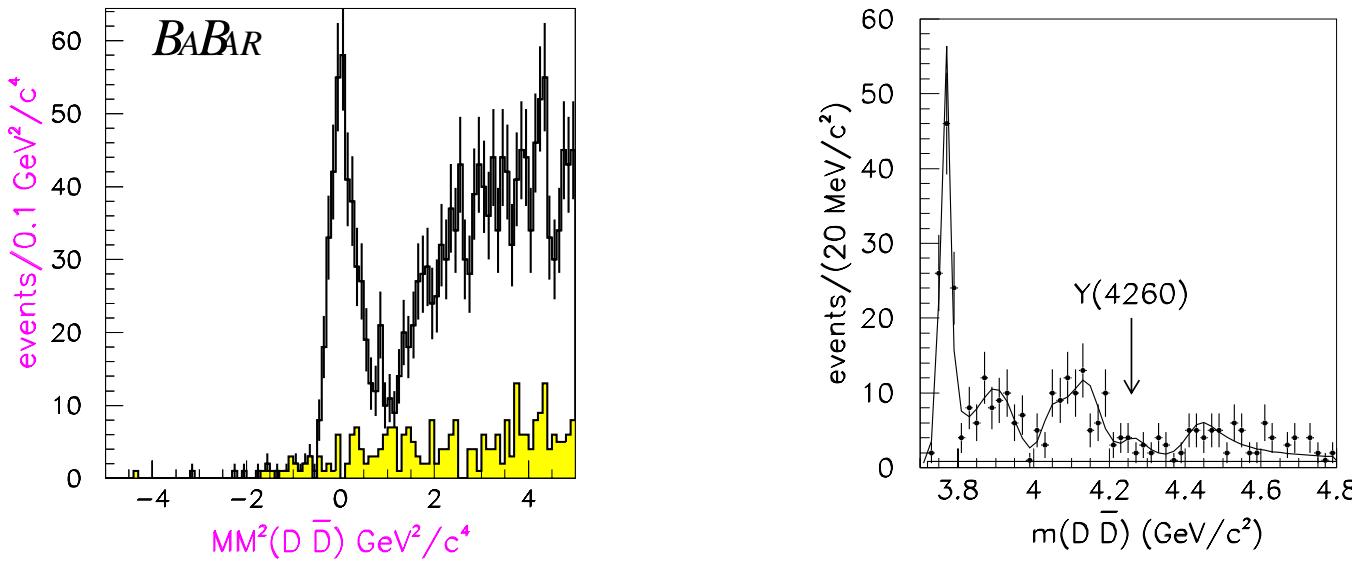
$$R(\sqrt{s}) = \sigma(e^+e^- \rightarrow \text{hadrons})/\sigma(e^+e^- \rightarrow \mu\mu)$$



- No signal.

## Search for $Y(4260) \rightarrow D\bar{D}$ .

- BaBar: Study of exclusive ISR production of  $D\bar{D}$ . [hep-ex/0607083](#)
- $\gamma_{ISR}$  reconstructed as missing particle.

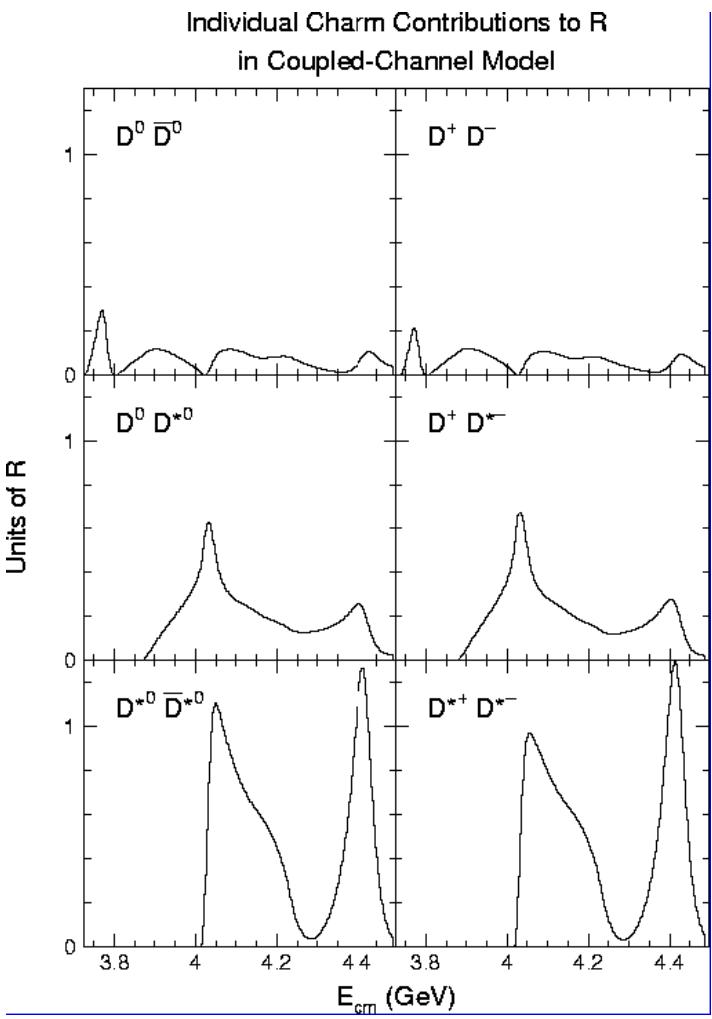


$$r = \frac{BR(Y(4260) \rightarrow D\bar{D})}{BR(Y(4260) \rightarrow J/\psi\pi^+\pi^-)} < 7.6 \quad 95\% c.l.$$

- $r \approx 500$  for  $\psi(3770)$ .
- Observation of structure around 3.9 GeV.

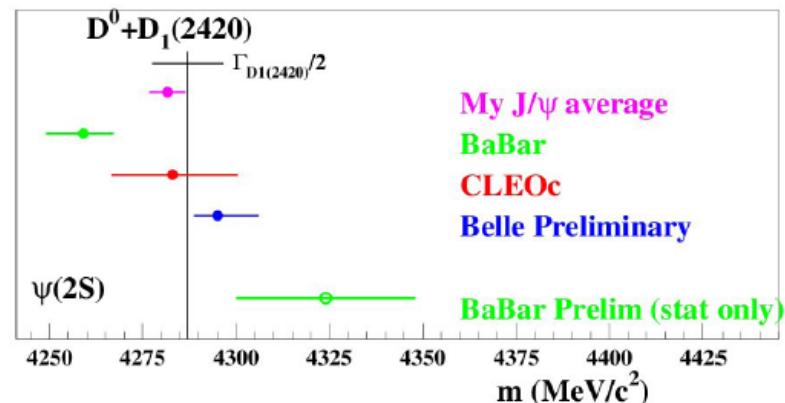
## Coupled channel model.

- Old coupled channel model from E. Eichten.
- Not all the visible structures are due to resonances.



# Y(4260)?

- Mass just at the threshold of  $D_1 D$ :



- Not a glueball. BaBar: no evidence for  $Y(4260) \rightarrow \phi\pi\pi$ .

Zhu, Phys.Lett. B625, 212(2005)

- TetraQuark?  $(cs)(\bar{c}\bar{s})$  predicts  $D_s^+ D_s^- \gg D\bar{D}$ . Search in progress.

L. Maiani et al., Phys.Rev.D72, 031502 (2005)

- An  $\omega\chi_{c1}$  Molecule? C. Yuan et al., Phys.Lett.B634,399 (2006)

- An Hybrid Meson? Suppressed  $D\bar{D}$ ,  $D\bar{D}^*$  decays.

- $Y \rightarrow \bar{D}D_1(2420)$  should dominate.

- Quenched Lattice QCD predicts:  $1^{--} : m = 4.38 \pm 0.15$  GeV.

## Light meson spectroscopy.

□ Several processes explored.

- $e^+e^-$  interactions;
- Charm decays;
- B decays;

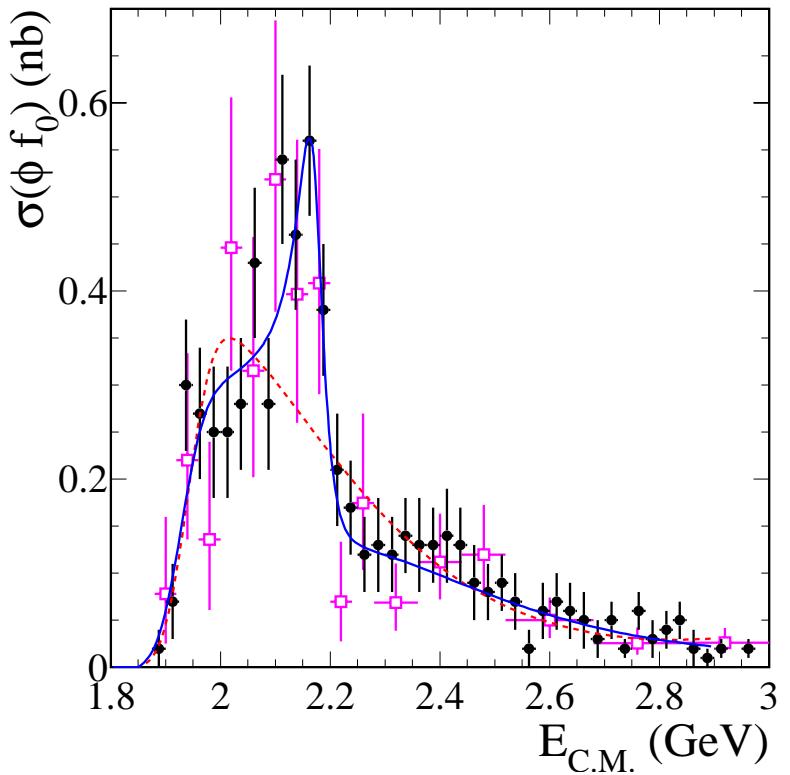
# BaBar: Observation of structure in ISR $\phi f_0$ .

hep-ex/0610018

$$e^+ e^- \rightarrow \gamma_{ISR} \phi(1020) f_0(980) (\rightarrow \pi\pi)$$

$m = 2175 \pm 18$  MeV

$\Gamma = 58 \pm 26$  MeV



## Scalar mesons.

I = 1/2	I = 1	I = 0
$k(800)$		$\sigma$
	$a_0(980)$	$f_0(980)$
		$f_0(1370)$
	$K_0^*(1430)$	$a_0(1490)$
		$f_0(1500)$
		$f_0(1700)$
	$K_0^*(1950)$	

□ Two nonets? 4-quark states? Gluonium?

□ Where is the scalar glueball?

□ Many proposals.

Narrow:  $f_0(1500)$ ,  $f_0(1700)$ .

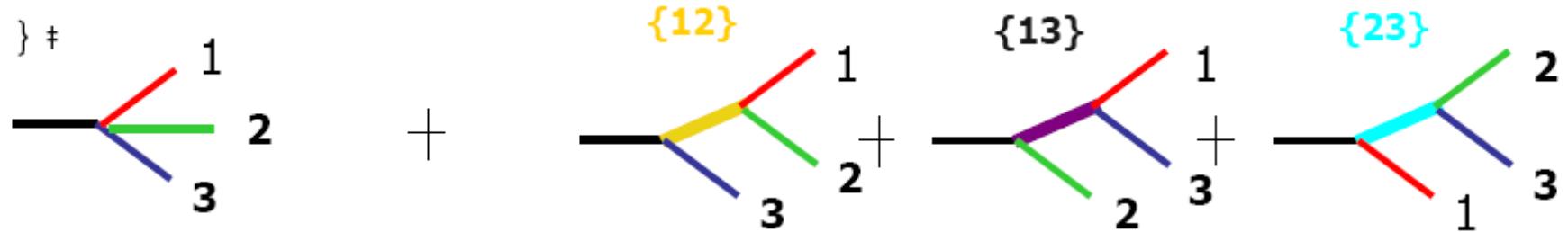
Wide:  $\sigma$ .

□ Information on some of these states, such as the existence of  $k(800)$  and  $\sigma$  can be extracted from existing data from charm decays.

□ Unlikely to produce gluonium in charm decays.

## Charm decays.

- Charmed mesons are produced with high statistics in B-factories.
- Some three-body charm decays can be very simple and produce useful information on scalar and vector mesons.



- In some cases decay channels can be switched off by physics.
- Examples:

$$D^+ \rightarrow K^- \pi^+ \pi^+, \quad D^+ \rightarrow \pi^+ \pi^+ \pi^-, \quad D_s^+ \rightarrow \pi^+ \pi^+ \pi^-$$

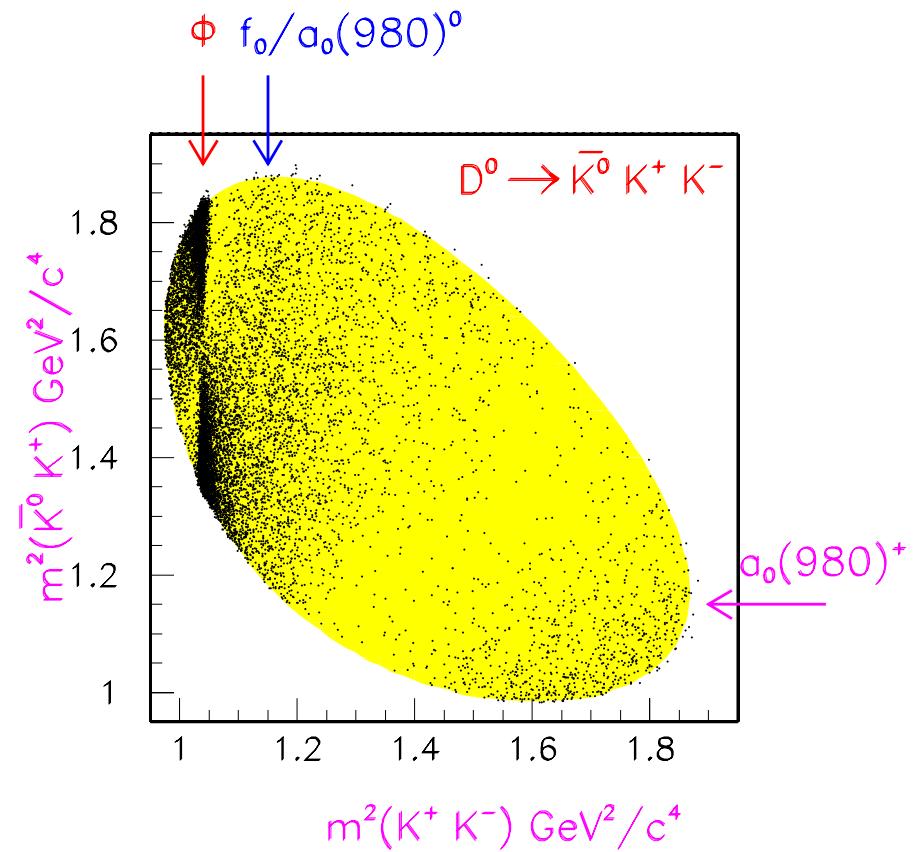
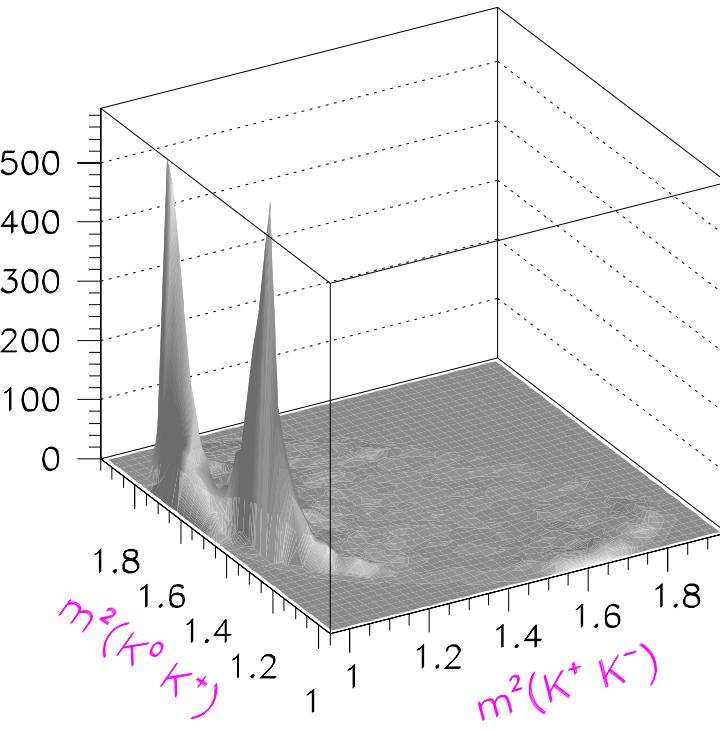
can give useful information on the structure of the S-wave in the  $K\pi$  and  $\pi\pi$  final states.

- D meson decay to resonances coupled to  $u\bar{u} + d\bar{d}$ ,  $D_s$  mesons to  $s\bar{s}$ .

# Dalitz plot Analysis of $D^0 \rightarrow \bar{K}^0 K^+ K^-$ .

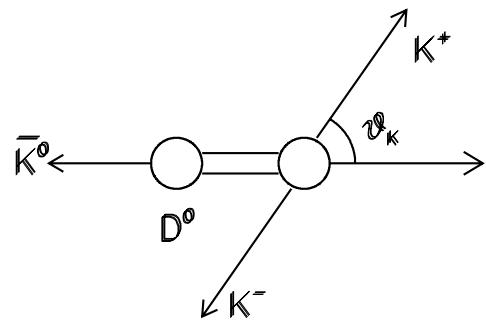
- 95  $fb^{-1}$ , 12541 events with a purity P=97.3 %

hep-ex/0507026



# Partial Wave Analysis of the $K^+K^-$ system.

- Assume, in the  $K^+K^-$  threshold region, a diagram:



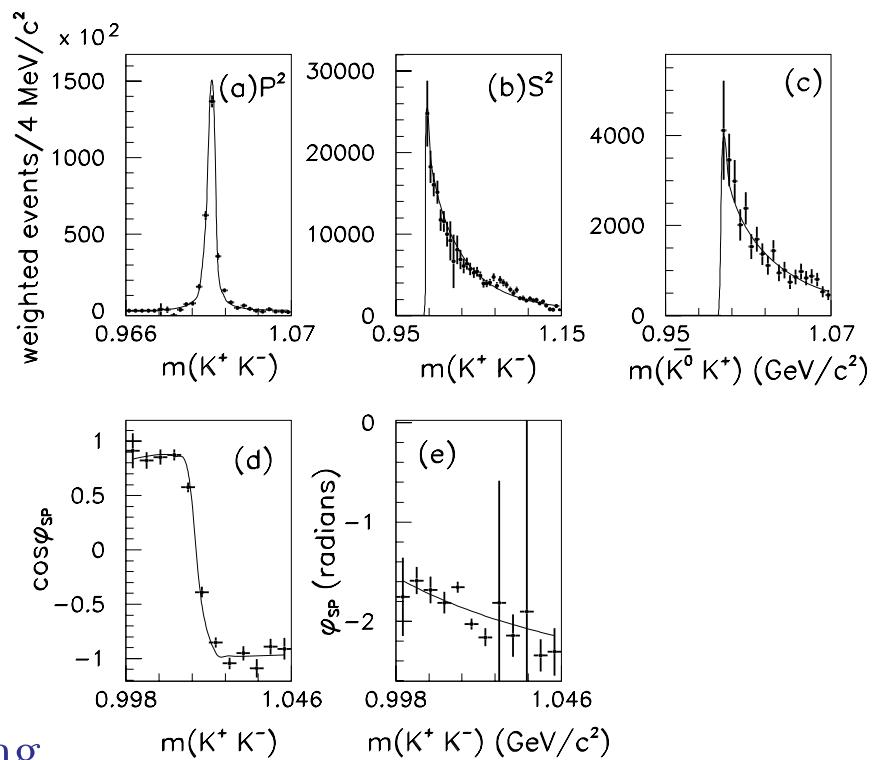
- S, P waves and relative phase can be extracted using:

$$\sqrt{4\pi}Y_0^0 = S^2 + P^2$$

$$\sqrt{4\pi}Y_1^0 = 2SP\cos\phi$$

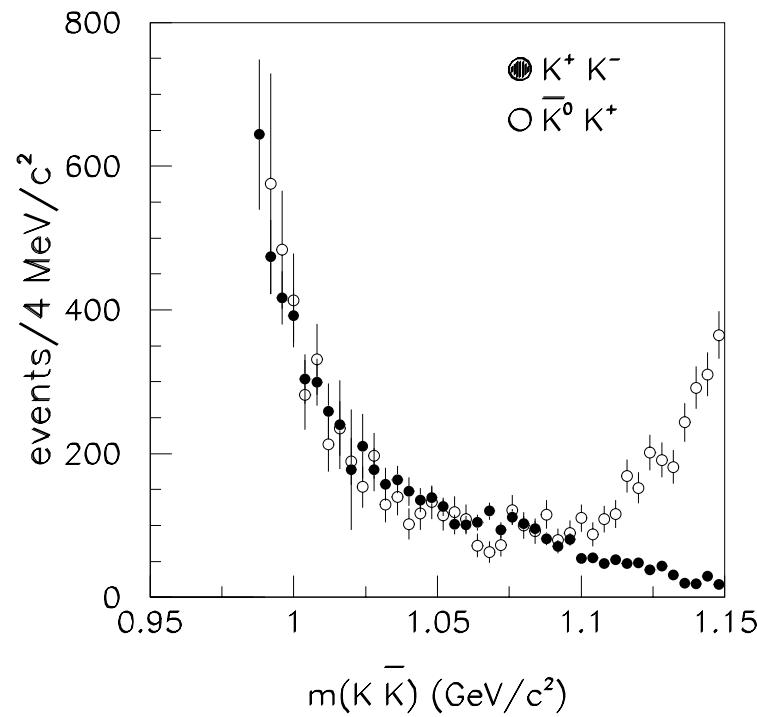
$$\sqrt{4\pi}Y_2^0 = 0.894P^2$$

- Correcting for phase space a simultaneous fit has been performed using also the  $\bar{K}^0K^+$  projection.



## Little $f_0(980)$ contribution.

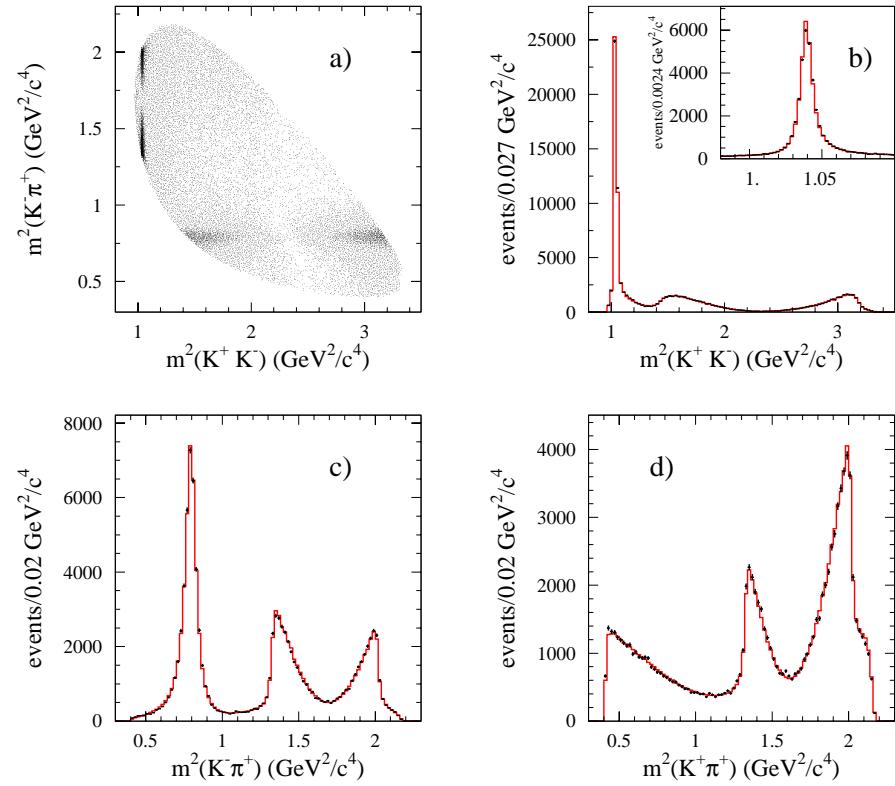
- Since  $f_0(980)$  has  $I=0$ , it cannot decay to  $\bar{K}^0 K^+$ .
- Therefore the  $\bar{K}^0 K^+$  projection contains only  $a_0(980)^+$ .
- Superposition of the two normalized projections, phase space corrected:



- Consistent with little  $f_0(980)$  contribution. Or similar  $KK$  projections for the two states.

# Dalitz plot analysis of $D_s^+ \rightarrow K^+ K^- \pi^+$ .

- Use high statistics  $D_s^+$  samples (100 K).
- Coupled analysis of  $D_s^+$  decays to:  $K^+ K^- \pi^+$ ,  $\pi^+ \pi^+ \pi^-$ ,  $K_S^0 K_S^0 \pi^+$



- Aim is to study the scalar mesons properties coupled to  $s\bar{s}$ .

## A new approach: MIPWA.

- A new method has been developed by E791 in the study of:



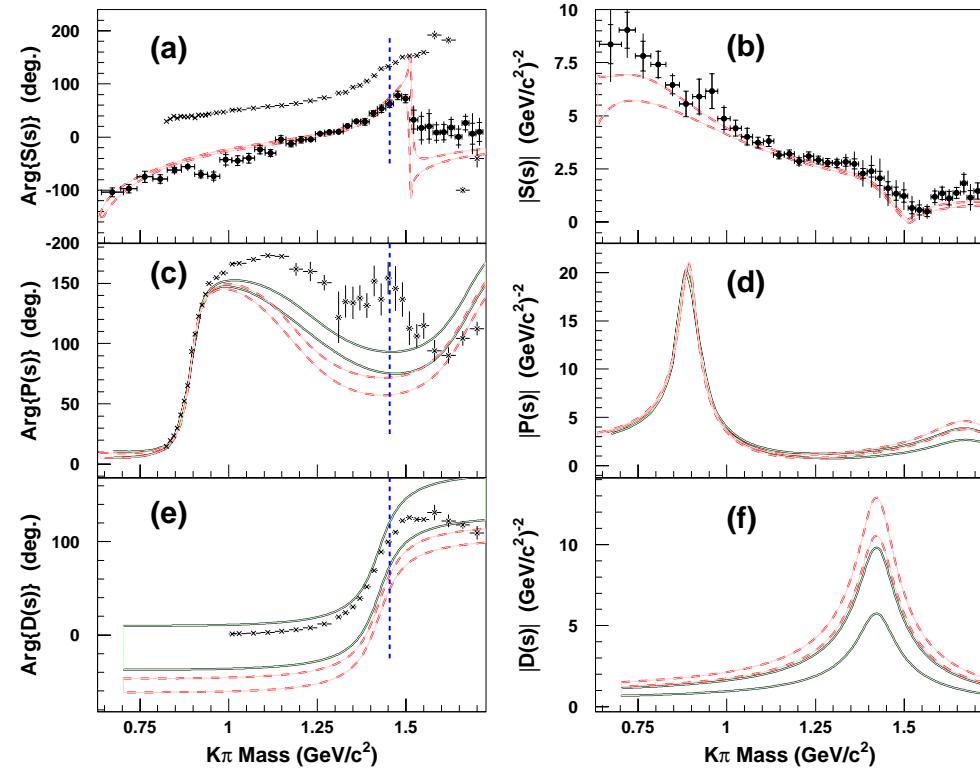
- Model Independent Partial Wave Analysis.
- In this case only one channel is open ( $K^- \pi^+$ ) but combinatorial problem.
- The scalar contribution is left free in the Dalitz plot analysis in terms of a complex number:

$$c_{m(K\pi)} e^{i\phi_{m(K\pi)}}$$

- The fit measures amplitude and phase as a function of the  $K\pi$  mass.

# Results.

- Fitted phase and amplitude.
- Comparison with LASS experiment: direct proof of the Watson theorem.



- 15 K events. Analyses in progress with 1M events.

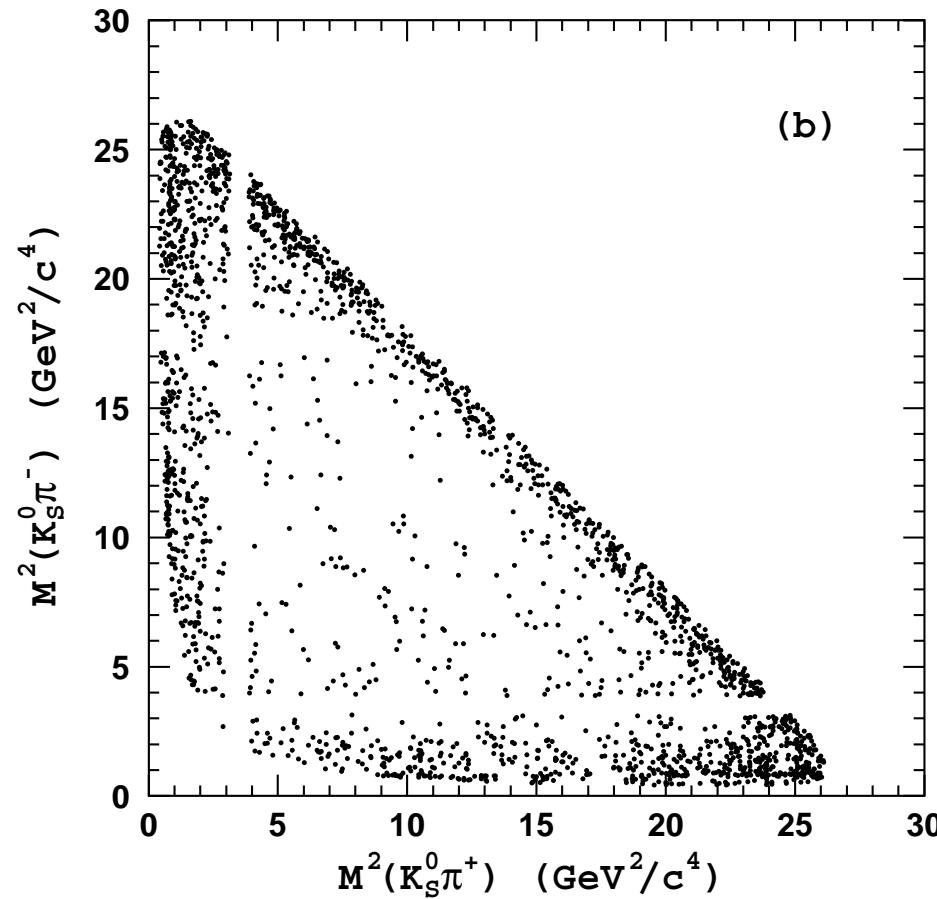
## Dalitz plot analysis in B decays.

- Many Dalitz analyses in B and charm decays are in progress.
- Some projections from:

- $B^0 \rightarrow K_S^0 \pi^+ \pi^-$
- $B^+ \rightarrow K^+ \pi^+ \pi^-$
- $B^+ \rightarrow K^+ K^+ K^-$
- $B^0 \rightarrow K_S^0 K^+ K^-$

## Dalitz plot analysis of $B^0 \rightarrow K_S^0 \pi^+ \pi^-$ .

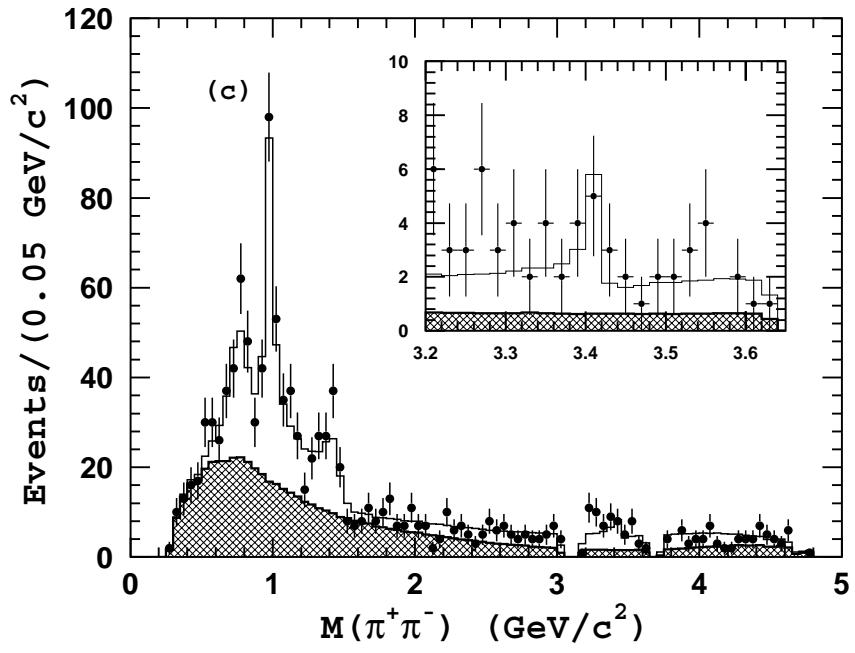
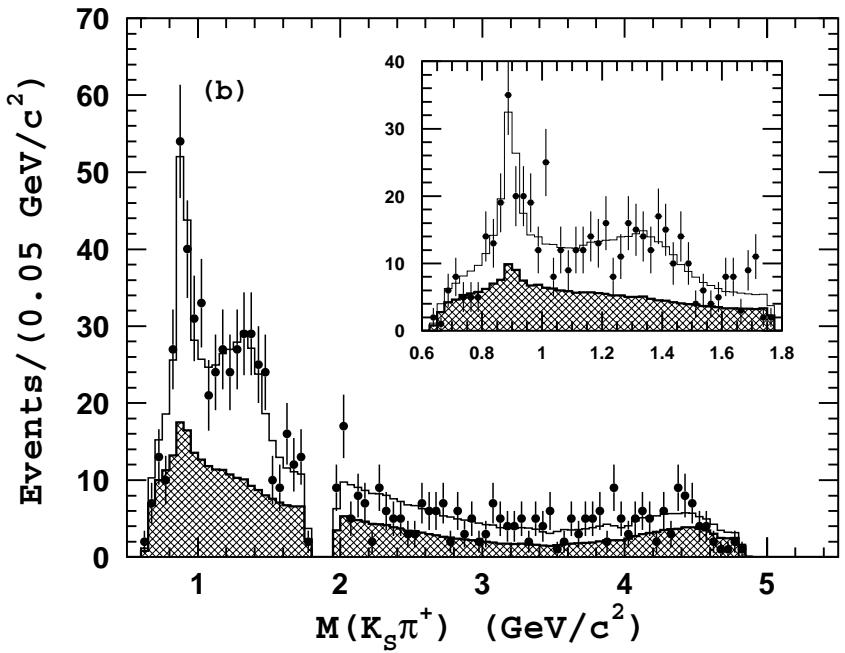
- Data from BELLE ( $357 fb^{-1}$ ): Dalitz plot.



- Cuts due to suppression of intermediate charm and charmonium decays.

# Dalitz plot analysis of $B^0 \rightarrow K_S^0 \pi^+ \pi^-$ .

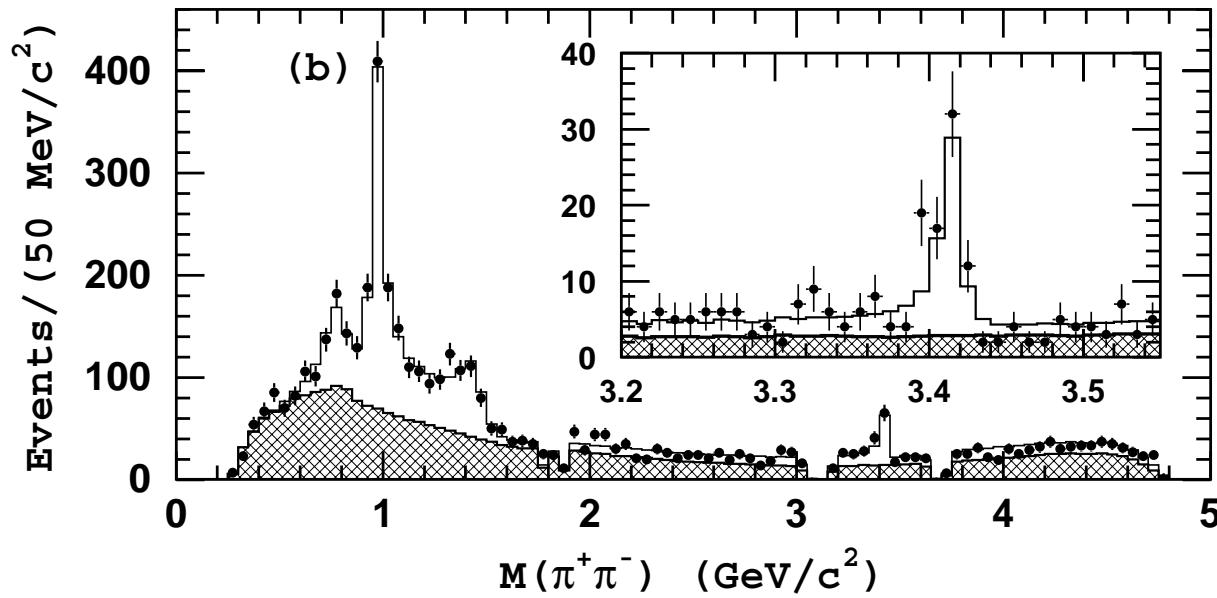
- $K_S^0 \pi^\pm$  and  $\pi^+ \pi^-$  mass spectra.



- Decays dominated by spin 0 and spin 1 resonances.
- Presence of  $K^*(890)$  and  $K_0^*(1430)$  resonances in  $K\pi$ .
- Presence of  $\rho(770)$  and  $f_0(980)$  and  $f_0(1300)$  resonances in  $\pi\pi$ .

## Dalitz plot analysis of $B^+ \rightarrow K^+\pi^+\pi^-$ .

- Data from BELLE ( $386 \text{ fb}^{-1}$ ) :  $\pi^+\pi^-$  projection. Similar features, presence of  $\rho(770)$  and  $f_0(980)$  and  $f_0(1300)$  resonances.

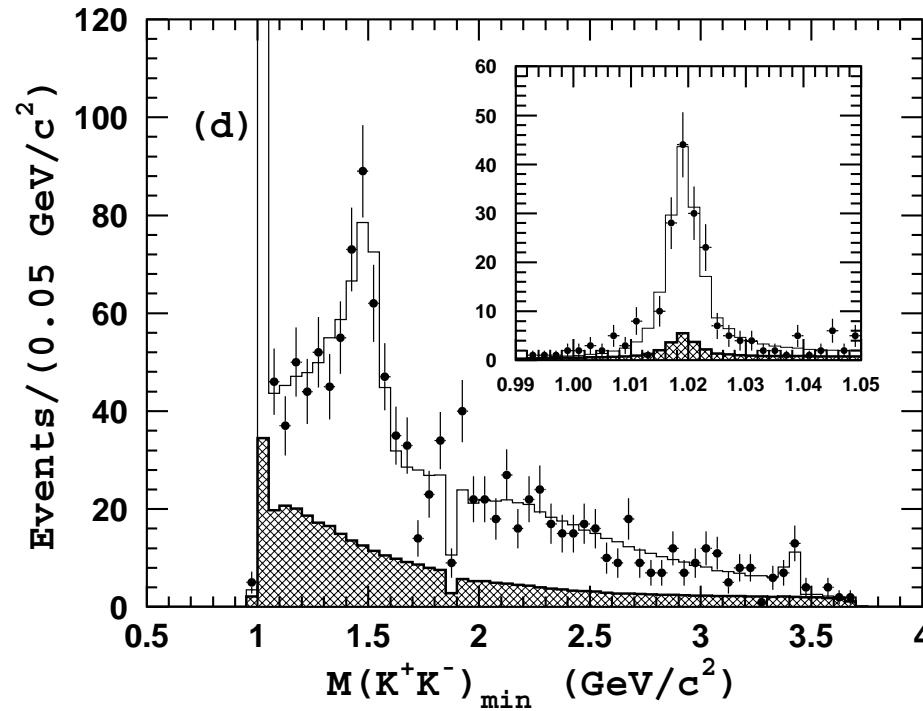


- Need for an extra  $K\pi$  S-wave. Using the  $\kappa(800)$  the fit improves but not possible to extract its parameters.

## Dalitz plot analysis of $B^+ \rightarrow K^+ K^+ K^-$ .

- Data from BELLE ( $140 \text{ fb}^{-1}$ ):  $K^+ K^-$  projection.

Garmash et al., PRD71,092003

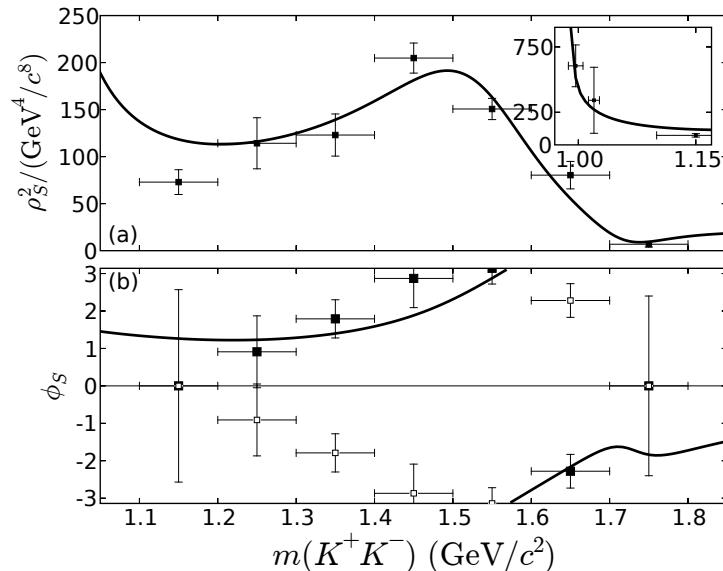
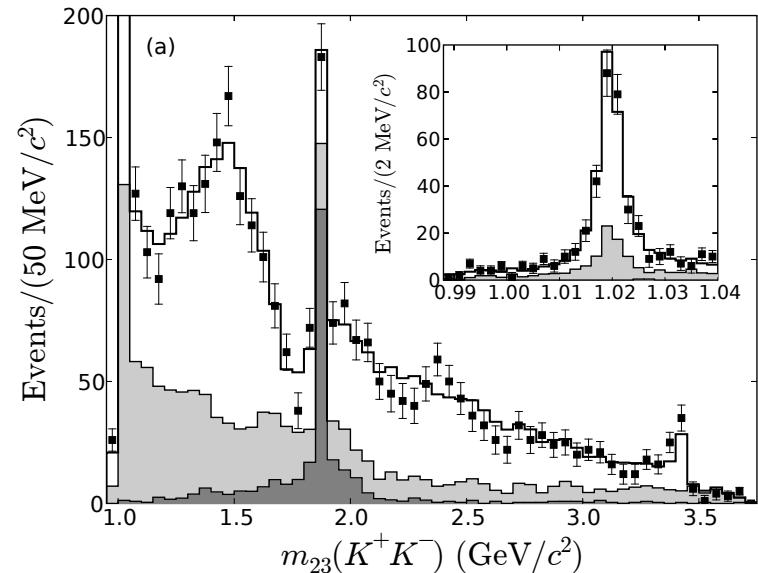


- Presence of  $f_0(1500)$ ? Analysis prefers a scalar resonance.
- If  $f_0(1500)$ , something wrong in its branching fractions.

# Dalitz plot analysis of $B^+ \rightarrow K^+ K^+ K^-$ .

- Data from BaBar ( $215 \text{ fb}^{-1}$ ):  $K^+ K^-$  projection.

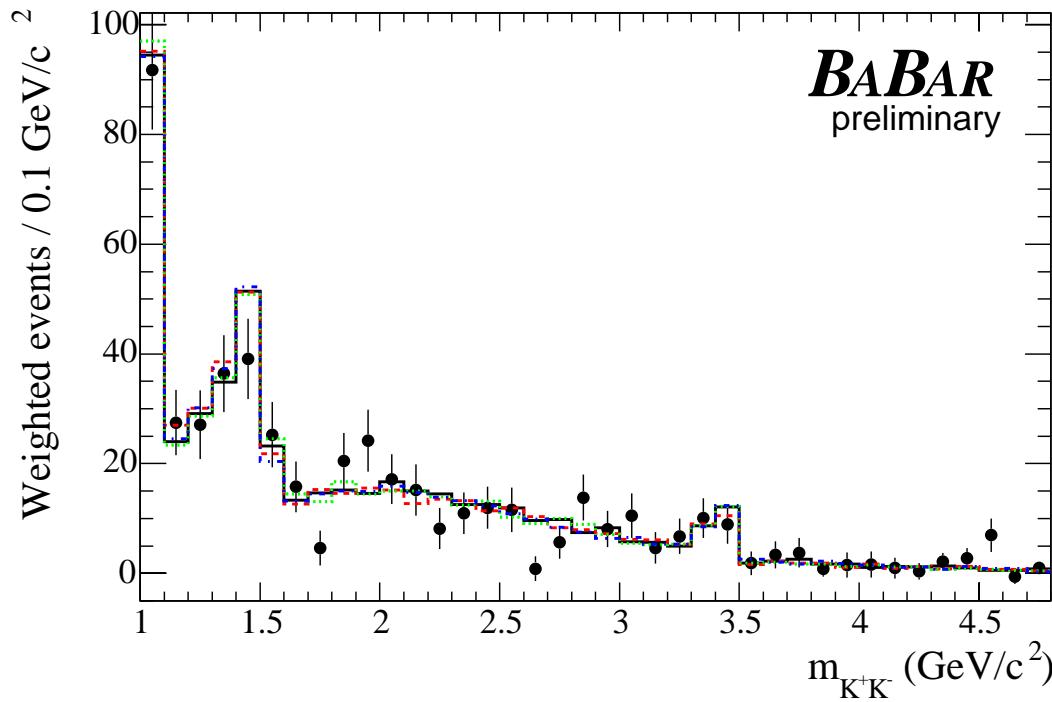
hep-ex/0605003



- Scalar resonance at a mass of 1.55 GeV.
- Presence of scalar resonance also at threshold.

## Dalitz plot analysis of $B^0 \rightarrow K_S^0 K^+ K^-$ .

- Data from BABAR ( $215 \text{ fb}^{-1}$ ):  $K^+ K^-$  projection.



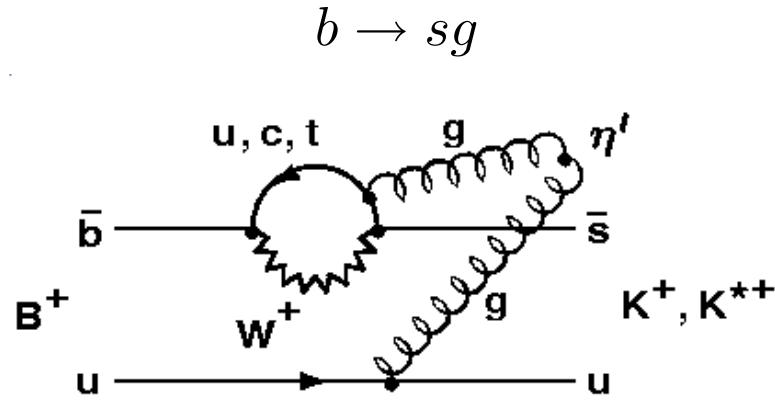
- Presence of  $f_0(1500)$ ? Analysis prefers a scalar resonance.

## Search for gluonium in B decays.

- The possibility of searching for gluonium in B decays has been suggested by the experimental measurement of a large decay rate for:

$$B \rightarrow \eta' X, \quad B \rightarrow \eta' K$$

- The diagram giving rise to these processes is:



- There are arguments in favour of a gluonic content of the  $\eta'$ , therefore gluonium states may be produced in B decays.

H. Fritzsch, Phys. Lett. B415 (1997) 83

P. Minkowski and W. Ochs hep-ph/0404194

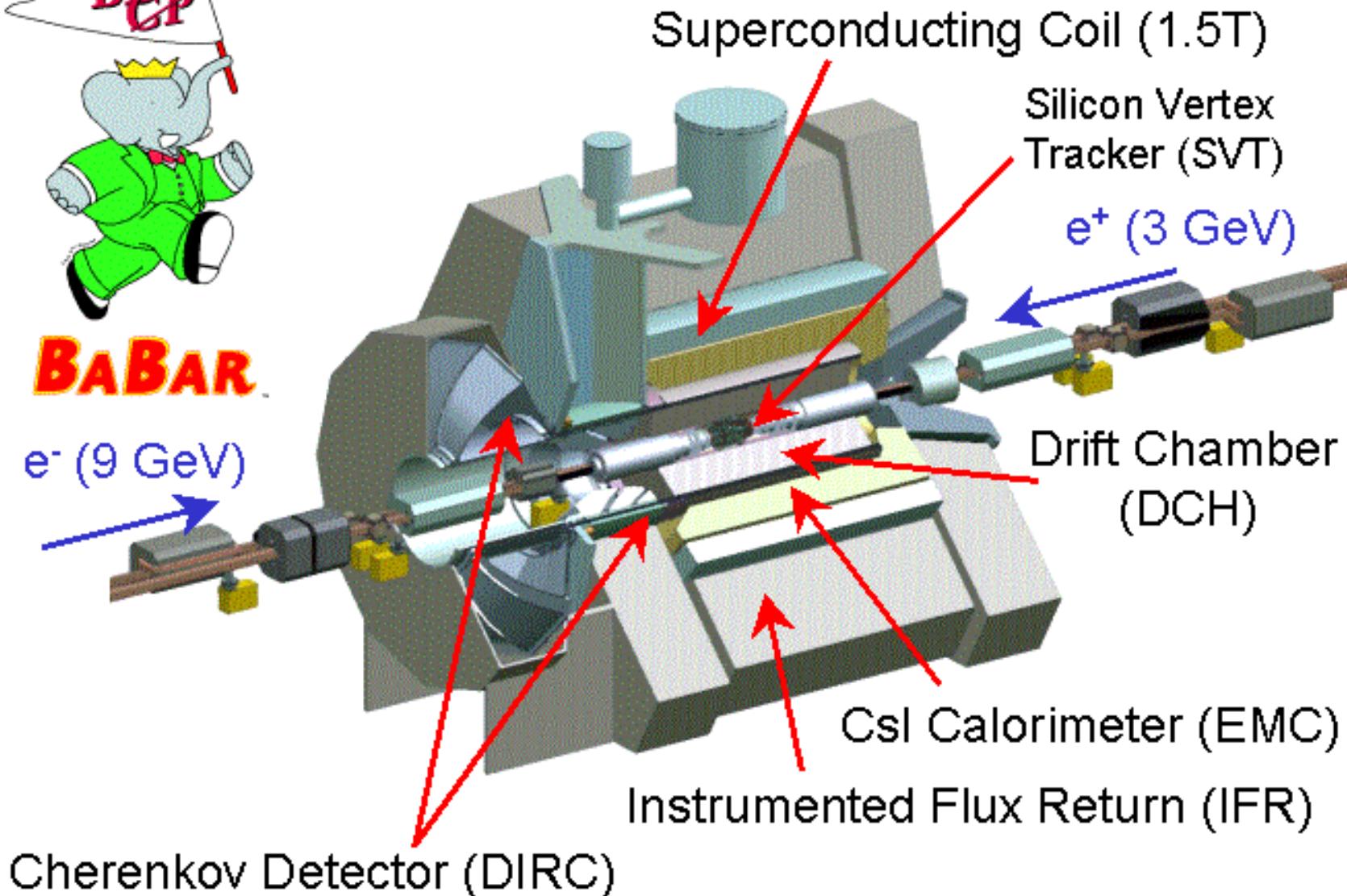
## Conclusions.

- Rich spectrum of new particles being discovered at B-factories.
- Not all of them can still be accommodated in the standard quark model.
- Potential models not able to describe well the resulting spectrum.
- Several analyses in progress.
- Search for other new states in progress.
- The data taking is continuing.

Backup slides.

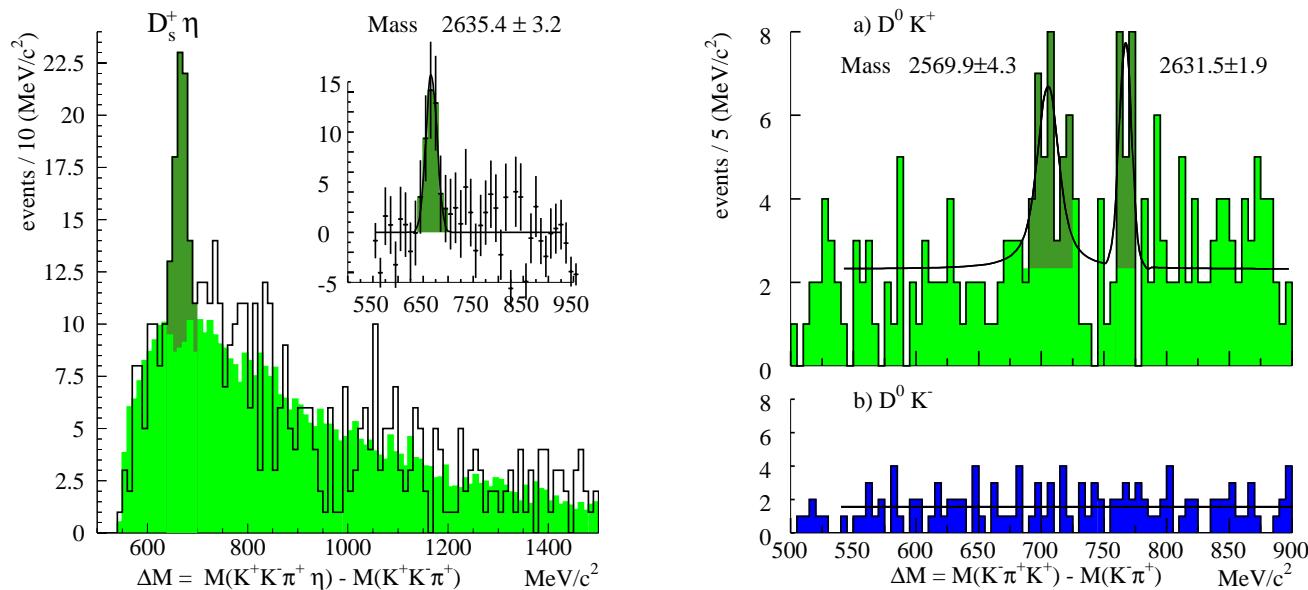


## BABAR Detector @ PEP-II



## Search for the SELEX state $D_s(2632)$ .

- SELEX experiment, at Fermilab, uses a 600 GeV/c hyperon beam on nuclei.
- Starting with a sample of 544  $D_s^+ \rightarrow K^+ K^- \pi^+$  events they claim for a structure in the  $D_s^+ \eta$  mass spectrum and  $D^0 K^+$  mass spectra:

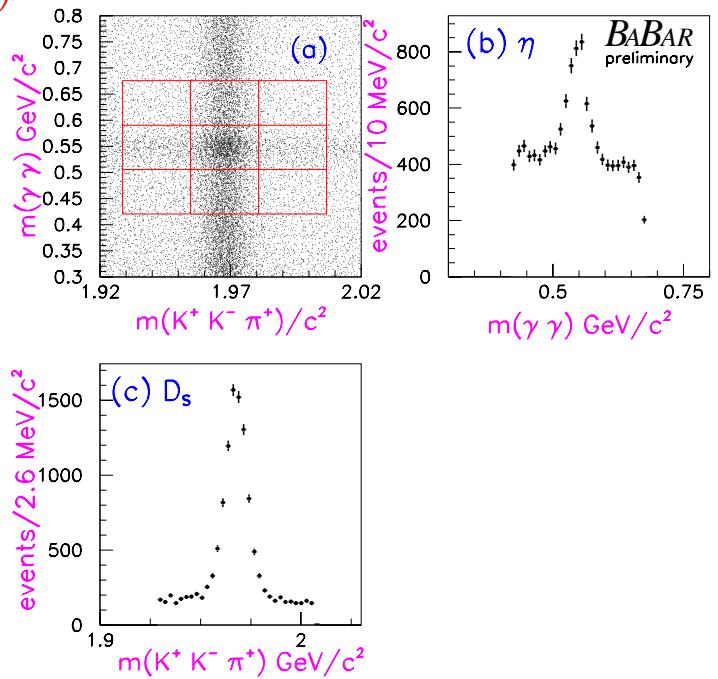


$$m(D_s(2632)) = 2635 \pm 3 \text{ MeV}$$

- 55 % of all the observed  $D_s^+$  are coming from the decay of this particle.

## BaBar Search for $D_s(2632)$ .

- BaBar experiment has used a sample of 196 000  $D_s^+$  events, and 3900  $\eta$ 's.
- The scatter diagram  $m(\gamma\gamma)$  vs.  $m(K^+K^-\pi^+)$  shows an excess of events in the  $D_s^+\eta$  region.



$$N(D_s^+\eta) = 1102 \pm 75$$

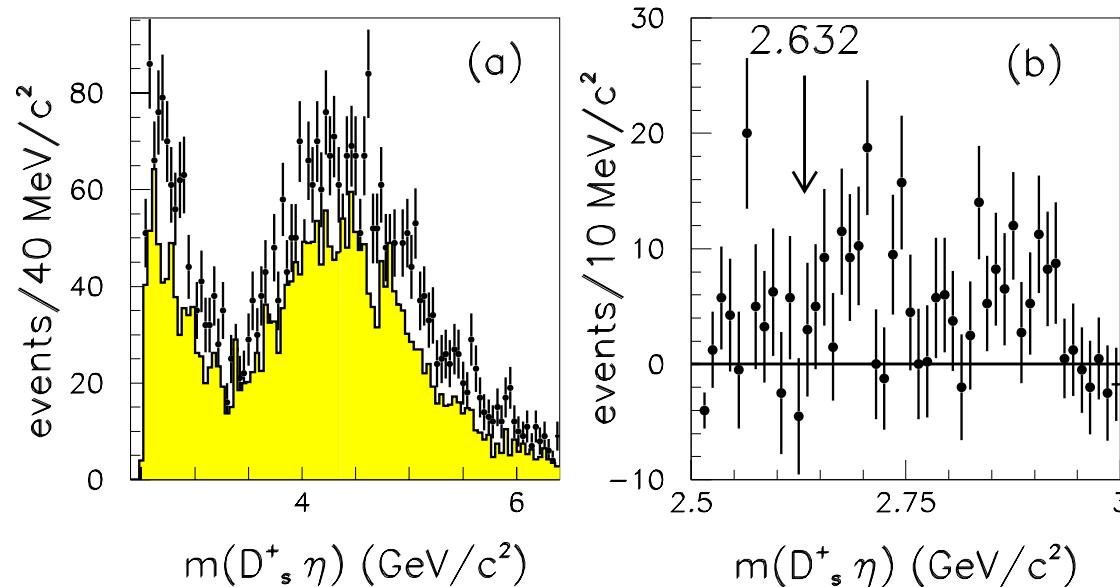
- Excess and masses computed using the 9 tiles method:

$$N = N_5 - 0.5 * (N_1 + N_3 + N_7 + N_9) + 0.25 * (N_2 + N_4 + N_6 + N_9)$$

where  $N_i$  are the events in each of the 9 tiles numbered from left to right and from bottom to top.

## BaBar Search for $D_s(2632)$ .

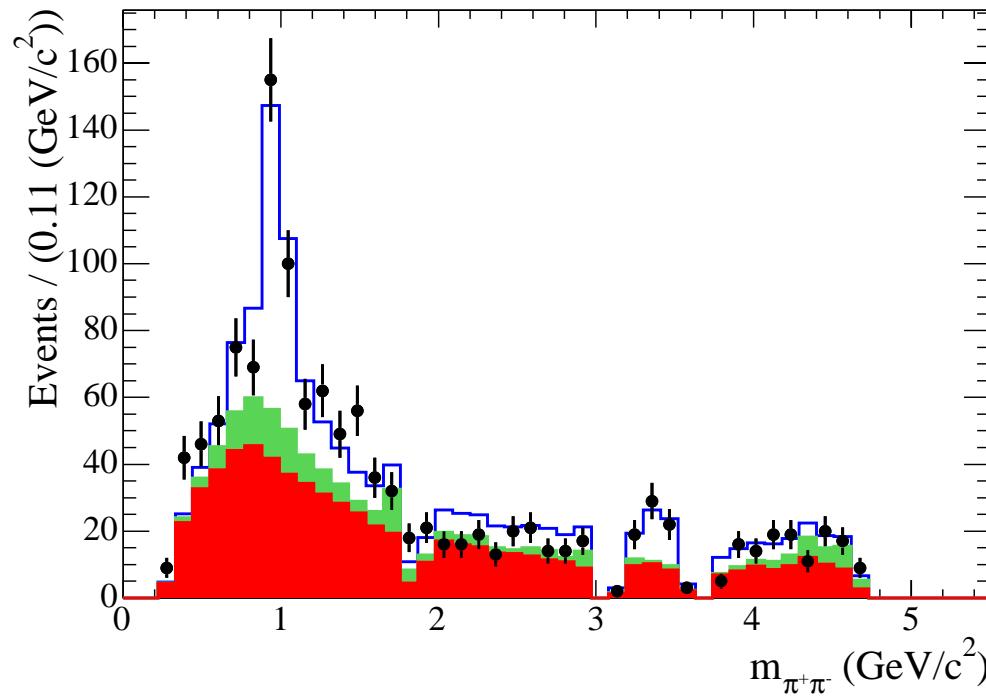
- The data show that a fraction of the  $D_s^+$  and  $\eta$  are in opposite jets (uncorrelated).
- The  $D_s^+ \eta$  mass spectrum does not show any signal in the  $D_s^+(2632)$  region.



- No signal also in  $DK$  or  $D^*K$  mass spectra.

## Dalitz plot analysis of $B^+ \rightarrow K^+\pi^+\pi^-$ .

- Data from BABAR ( $205\text{ fb}^{-1}$ ):  $\pi^+\pi^-$  projection. Similar features, presence of  $\rho(770)$  and  $f_0(980)$ .
- Not clear  $f_0(1300)$ .
- $K\pi$  S-wave parametrized according to the LASS fit to the S-wave  $K\pi$  data.



# The search for $h_c$ by CLEO.

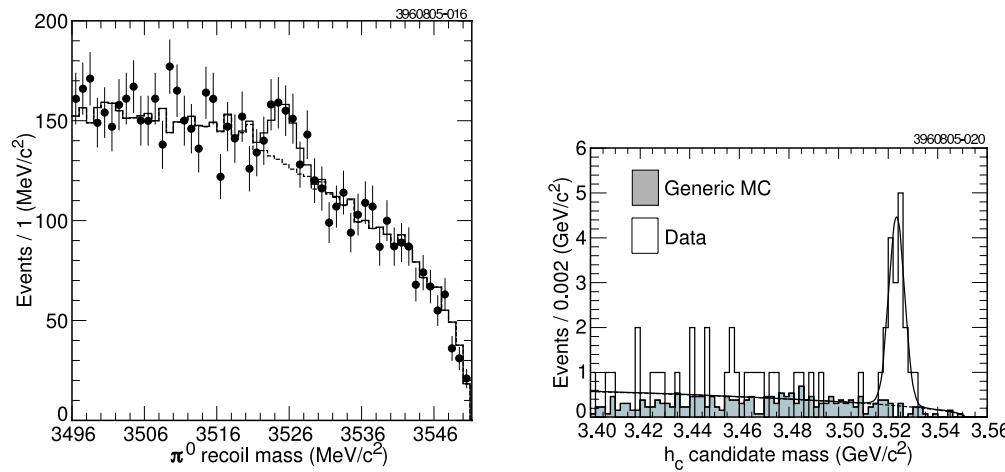
- CLEO experiment has searched for  $h_c$  using  $\approx 3 \times 10^6 \psi'(3686)$  decays.

hep-ex/0508037

$$\psi' \rightarrow \pi^0 h_c$$

$$\rightarrow \gamma \eta_c$$

- Two analyses have been performed inclusive, and exclusive (where the  $\eta_c$  has been reconstructed using many decay modes).



$$m = 3524.4 \pm 0.6 \quad \pm 0.4 \quad MeV$$