V.Balagura, ITEP (Moscow), Belle Collaboration

Spectroscopy and New States at B factories

or X, Y, Z ...

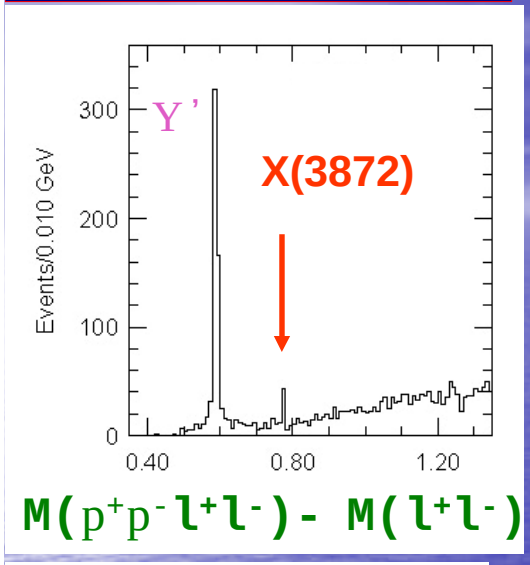
Outline

- X(3872) – quantum numbers
- γ ? Y(4260) ? $\pi^+\pi^-$ J/ψ
- $\gamma\gamma$? Z(3930) ? $D\bar{D}$
- B ? K Y(3940) ? K (ω J/ψ)
- e^+e^- ? J/ψ X(3940)? J/ψ ($D\bar{D}^*$)
- Summary

X(3872)

Observed by Belle in $B^{\pm}$? $K^{\pm}$ p^+p^-J/ψ

152M BB,PRL91,262001(2003)



Confirmed by CDF, D0, BaBar,

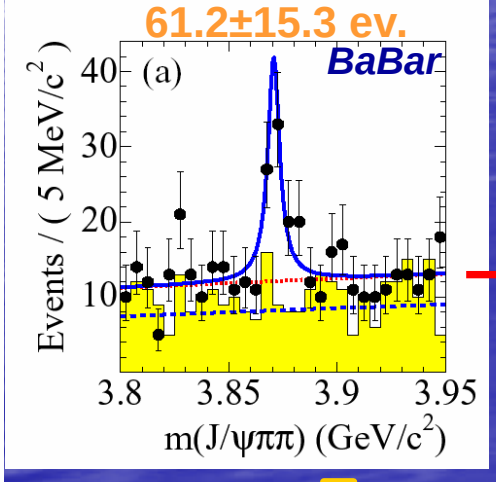
world average: M=3871.9±0.5 MeV/c²

charmonium, $D\bar{D}^*$, tetraquarks...?

E.S.Swanson,PLB588,189(2004)
L.Maiani et al.,PRD71,014028(2005)

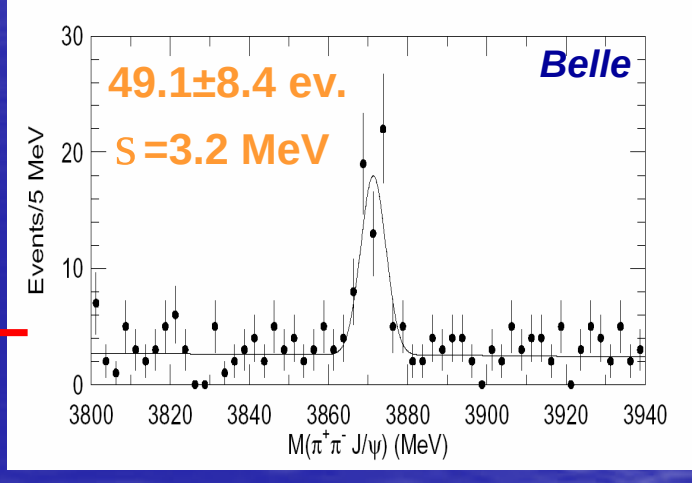
Updates

no. of B's in M($p\bar{p}J/\psi$) bins



Br(B?XK) Br(X?p^+p^-J/ψ) =

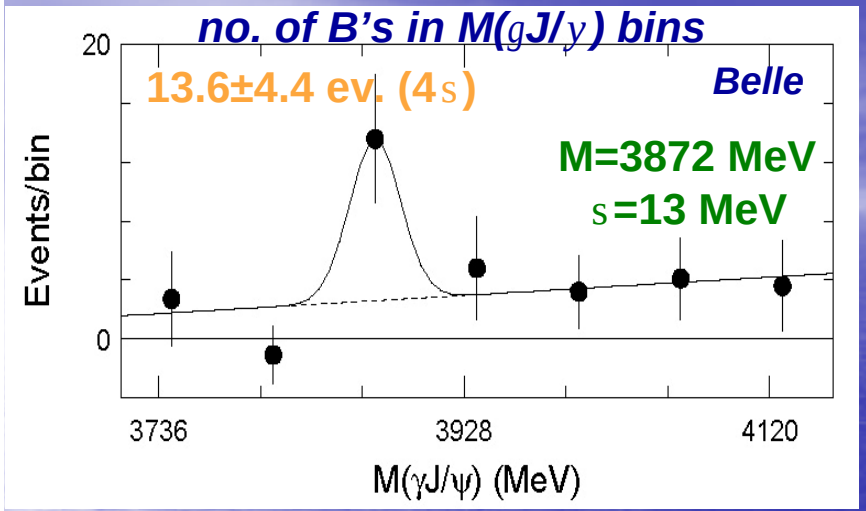
(1.01±0.25±0.10)x10⁻⁵
(1.31±0.24±0.13)x10⁻⁵



BaBar, 232M $B\bar{B}$ (hep-ex/0507090)

Belle, 275M $B\bar{B}$ (hep-ex/0505038)

X(3872)



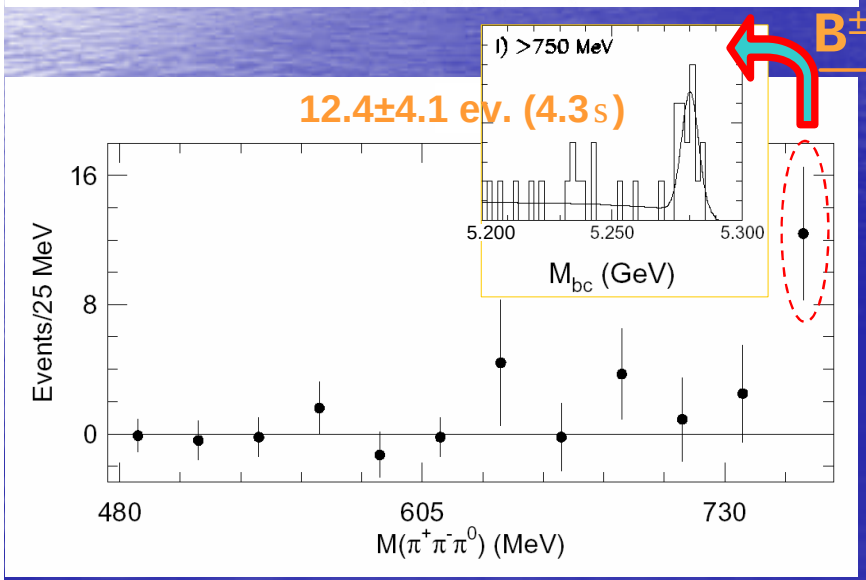
$B^{\pm} \to K^{\pm} \gamma J/\psi$

Belle, 275M $B\bar{B}$, hep-ex/0505037

$B^{\pm} \to K^{\pm} \chi_{c1}(\gamma J/\psi)$ calibration mode, π^0 veto

$$\frac{Br(X \to \gamma J/\psi)}{Br(X \to \pi^+\pi^- J/\psi)} = 0.14 \pm 0.05$$

C(X(3872))=+1



$B^{\pm} \to K^{\pm} \omega_{virtual} J/\psi$, $\omega_{virtual} \to \pi^+\pi^-\pi^0$

$$\frac{Br(X \to \pi^+\pi^-\pi^0 J/\psi)}{Br(X \to \pi^+\pi^- J/\psi)} = 1.0 \pm 0.4 \pm 0.3$$

Further evidence for **C(X(3872))=+1**

If 3π come from ω, 2π – from ρ:

→ **large isospin violation, difficult to explain if X=$c\bar{c}$ state**

X(3872)

M($\pi^+\pi^-$) from $B^\pm$? $K^\pm \pi^+\pi^- J/\psi$

Belle, 275M $B\bar{B}$, hep-ex/0505038

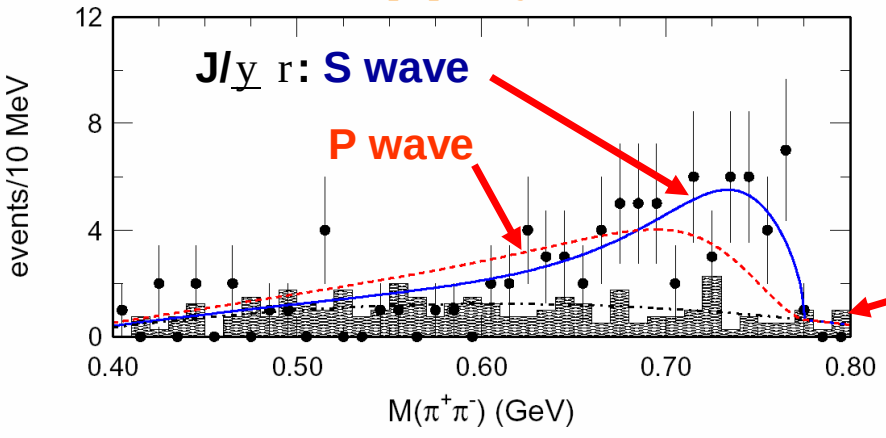
For C=+1: if P=+1 L({$\pi^+\pi^-$}, J/ψ)=0,2,…

P=-1 L({$\pi^+\pi^-$}, J/ψ)=1,3,…

M($\pi^+\pi^-$) upper boundary is modulated by q^{2L+1} centrifugal barrier.

S,P waves should dominate

no. of ev. in $\pi^+\pi^- J/\psi$ signal region



S wave: c^2/dof=43.1/39 (CL=28%)

P wave: c^2/dof=71.0/39 (CL=0.1%)

parameterized X(3872) side band determined bgr.

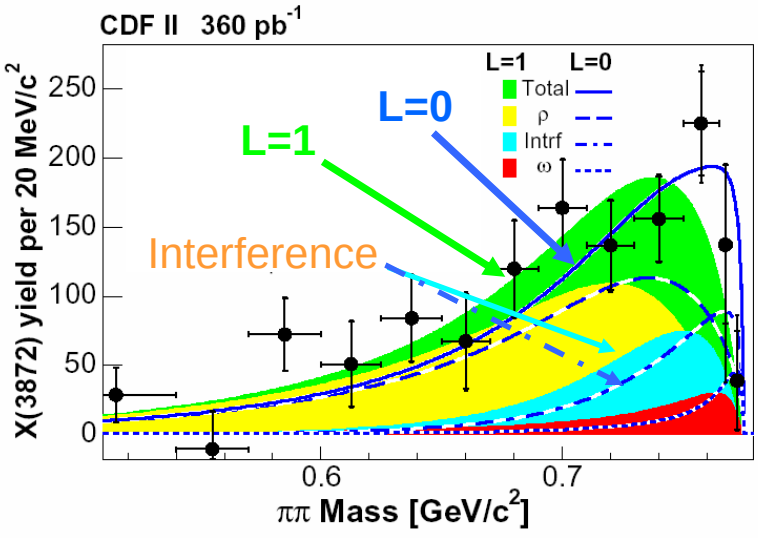
P(X(3872))=+1

J^{PC}(X(3872))=0^{++}, 1^{++}, 2^{++} ?

X(3872)

M(p^+p^-) in CDF, hep-ex/0512074

no. X(3872) in M(pp) bins



Differences with Belle

1. Description of X(3872), ρ resonances in addition to Breit-Wigner term (BW) include Blatt-Weisskopf factors: $f_L(k)$xBW

$$f_{L=0}(k)=1, \quad f_{L=1}(k)=\frac{1}{1+R^2k^2}$$

R is the radius of interaction for the meson.

2. B(ω? $\pi^+\pi^-$) is small but its contribution can be enhanced by ρ-ω interference seen in e^+e^-? $\pi^+\pi^-$. Relative phase in the fit is set to 95°, ratio B(X? J/ψω)/ B(X? J/ψρ)=1 is taken from Belle.

Fit probability:

L=0: 19%

L=1: 53%

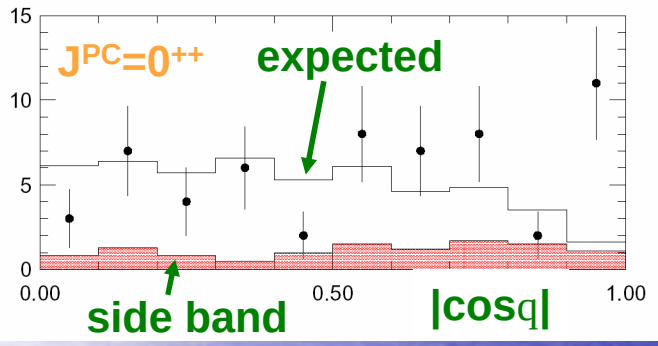
P(X(3872))=-1 is not ruled out

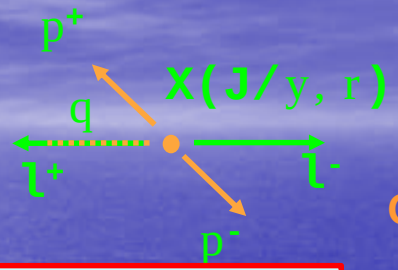
X(3872)

Angular distributions in $B^{\pm} \to K^{\pm} \pi^+\pi^- J/\psi$

Belle, hep-ex/0505038

0^{++} (S, D waves) *is disfavored*

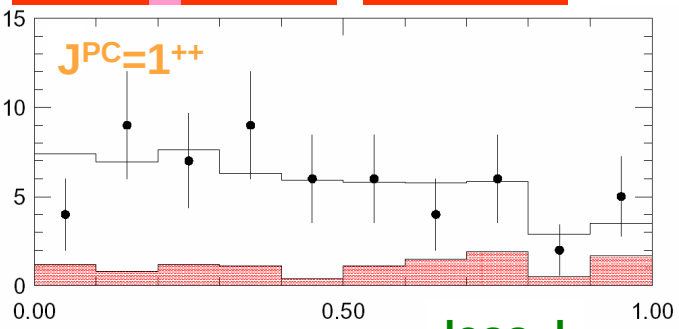


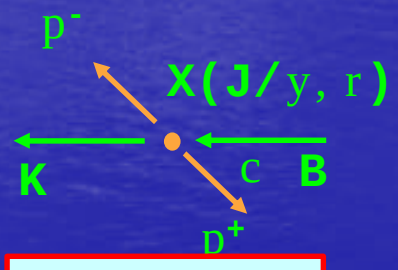


$\chi^2/dof=31/9$

Opposite parity 0^{-+} (P wave) has been also ruled out

1^{++} (S, D waves) *is favored*





$\chi^2/dof=5/9$

If P(X)=+1:

$J^{PC}= 0^{++}, 1^{++}, 2^{++}$?

2^{++} is not seriously challenged by angular distribution tests

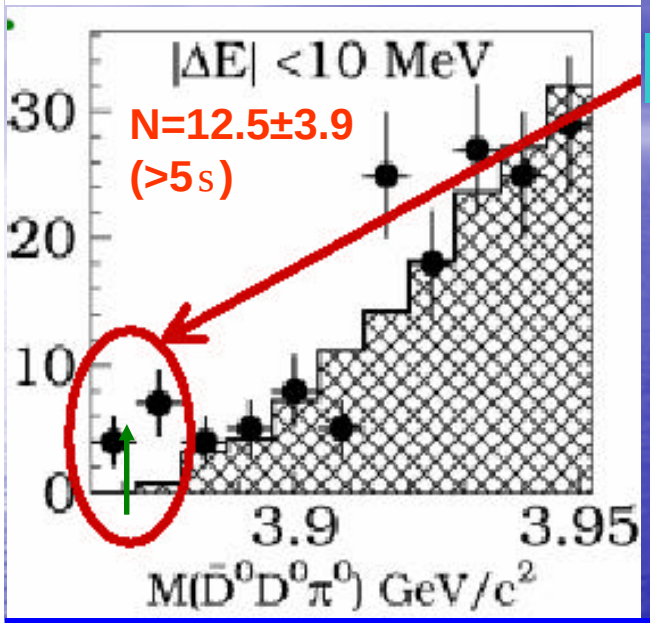
X(3872)

B? KX(…), X(3872)? $D^0\bar{D}^0p^0/KD^0\bar{D}^{*0}$

Belle, preliminary

preliminary

$M(D^0\bar{D}^0p^0)$ in B signal region



$M(D^0\bar{D}^0p^0) \sim M(X)$

$Br(B \to K\,X)Br(X \to D\bar{D}p) = (1.6\pm0.4\pm0.3)$ …

$Br(X \to D\bar{D}p)/Br(X \to p^+p^-J/\psi) = 12\pm5$

2^{++} is rather unlikely
(at least one D wave near threshold)

If P(X)=+1:

$J^{PC}(X(3872)) = 1^{++}$

ψ'_{c1} has 1^{++}, but $\psi'_{c1} \to \gamma J/\psi$ decay should be *much stronger* than *isospin violating decay* $\psi' \to pp J/\psi$. Experimentally the ratio is 0.14±0.05.
In addition potential models predict $M(\psi'_{c1}) = 3953\sim3990$ MeV

Possible interpretation: $X(3872) = D^0\bar{D}^{*0}$ molecule

X(3872)

X(3872) from neutral B: $B^0 ? K^0_S \pi^+\pi^- J/\psi$

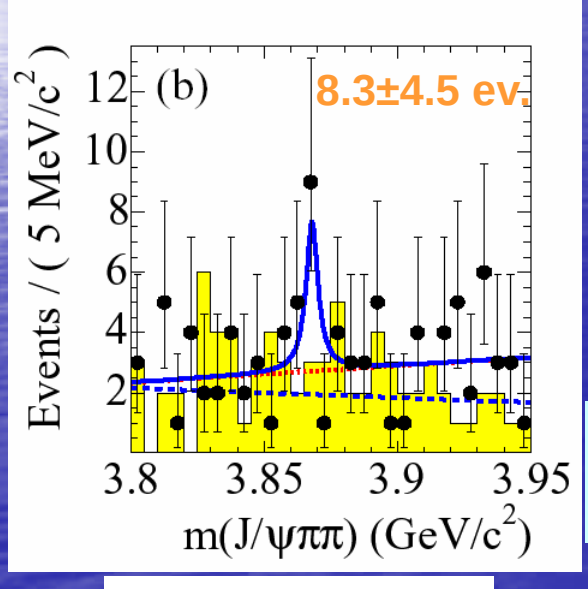
BaBar, 232M $B\bar{B}$, hep-ex/0507090

If X(3872)=$D^0\bar{D}^{*0}$ S wave molecule

factorization, heavy-quark and isospin symmetry ⇒

$$\frac{B(B^0 \to K^0 X(3872))}{B(B^- \to K^- X(3872))} \approx \frac{1}{10}$$

Another interpretation: X(3872) is a mixture of $X_u=(cu)(\bar{cu})$ and $X_d=(cd)(\bar{cd})$ tetraquarks. The production rates from B^0 and B^- can vary depending on the mixing angle.



2.5σ significance

$$0.13 < \frac{B(B^0 \to K^0 X(3872))}{B(B^- \to K^- X(3872))} < 1.10 \quad \text{at } 90\%\ \text{CL}$$

Mass shift: 2.7±1.3±0.2 MeV

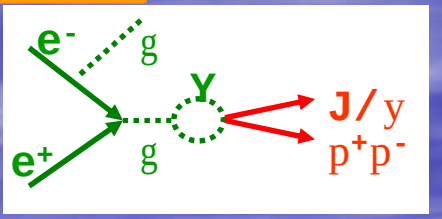
Γ< 4.1 / 2.1 MeV (BaBar / Belle) at 90%CL

If B^0 decays dominantly to tetraquark X_u and B^- to X_d or vice versa: R=1 and mass difference ~(7±2) MeV

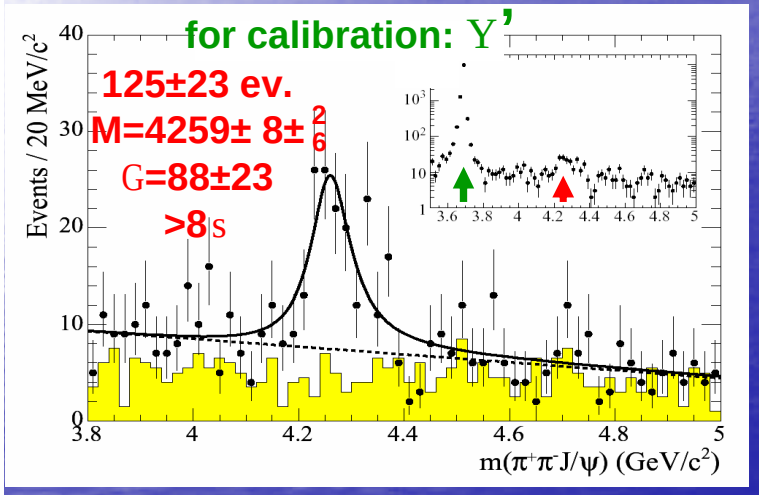
Y(4260)

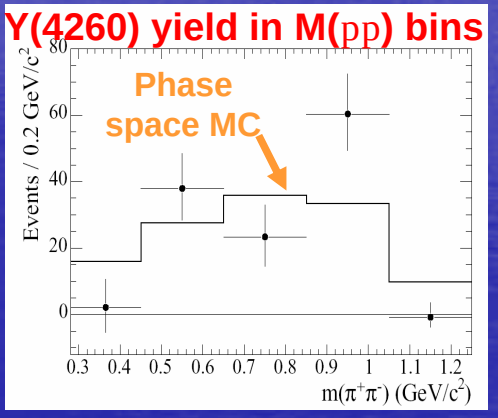
e^+e^-? g_{ISR}Y(4260) ? g_{ISR} p^+p^- J/y

Search for e^+e^-? g_{ISR}X(3872) ? g_{ISR} p^+p^- J/y (allowed only for $J^{PC}=1^{--}$): $G_{ee}B(X(3872)?\ p^+p^-\ J/y)<6.2$ eV @ 90%CL, BaBar,89 fb^{-1}, *PRD71, 052001 (2005)*



Scan of the charmonium mass range (BaBar, 211 fb^{-1}, hep-ex/0506081)





ISR production is confirmed by g_{ISR} reconstruction and M_{rec} distribution

$J^{PC}(Y(4260))=1^{--}$

$G(Y?\ e^+e^-)B(Y?\ p^+p^-J/y)=5.5\pm1.0^{0.8}_{0.7}$ eV

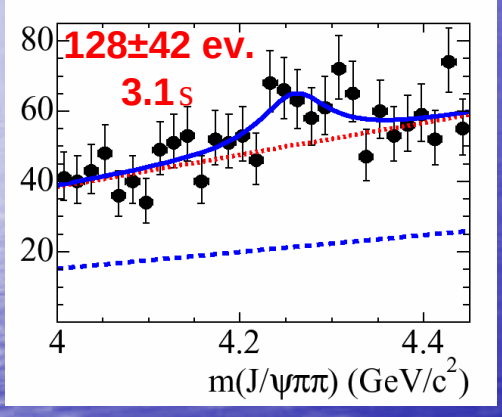
(Single resonance hypothesis)

Y(4260)

Other results on Y(4260) from BaBar

$B^- \to K^- p^+ p^- J/\psi$

232M $B\bar{B}$, hep-ex/0507090

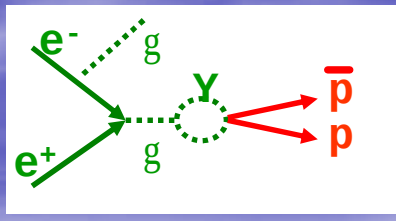


$K_1(1270)$? $K^- p^+ p^-$ veto

$B(B^- \to K^- Y(4260)) \times B(Y \to p^+ p^- J/\psi) =$

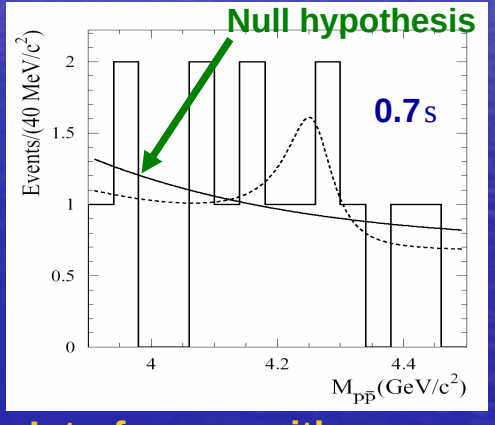
$(1.2 \ldots 2.9) \times 10^{-5}$ at 90% CL

$e^+e^- \to p\bar{p}$ study with ISR



232 fb^{-1}, hep-ex/0512023

Y(4260) range



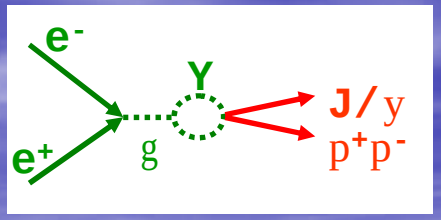
Interference with nonresonant $e^+e^- \to p\bar{p}$ process is included

$B(Y \to p\bar{p})/B(Y \to p^+ p^- J/\psi) < 13\%$ @90% CL

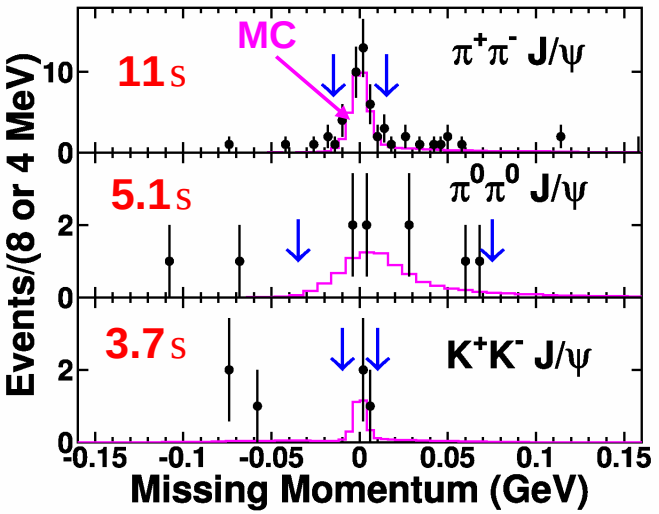
Y(4260)

Direct production e^+e^-? Y(4260) ? $p^+p^- J/\psi$ at CLEO

Scan over the range vs=3.97 … 4.26 GeV: hep-ex/0602034

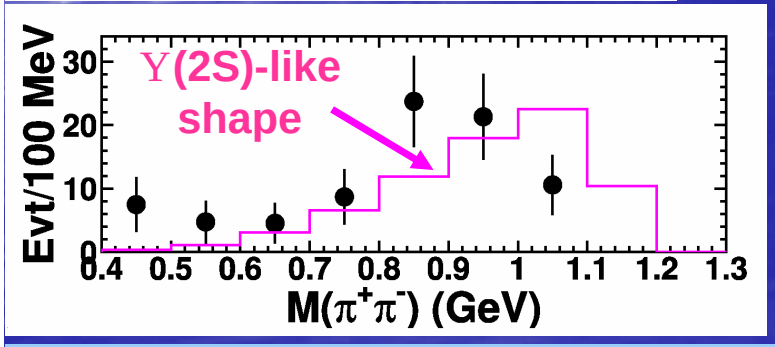


vs=4.26 GeV



N_{sig}, ev	N_{bgr}, ev	s, pb
37	2.4	58^{+12}_{-11}
Disfavors $c_{cJ}r^0$ molecule		
8	0.3	23^{+12}_{-8}
3	0.07	9^{+9}_{-5}

Plus a lot of upper limits for other channels



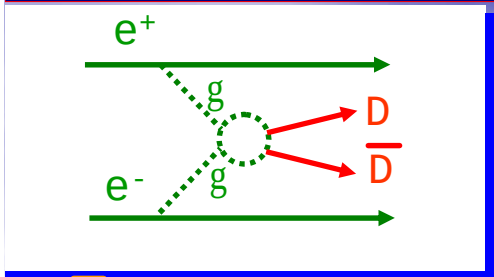
No signals for y(4040), y(4160)? p^+p^-J/ψ, B<0.4%

Strange if y(4040)= y(3S), Y(4260)= y(4S)

Z(3930)

$\gamma\gamma$? Z(3930) ? $D\bar{D}$

Belle, 395 fb^{-1}, hep-ex/0512035

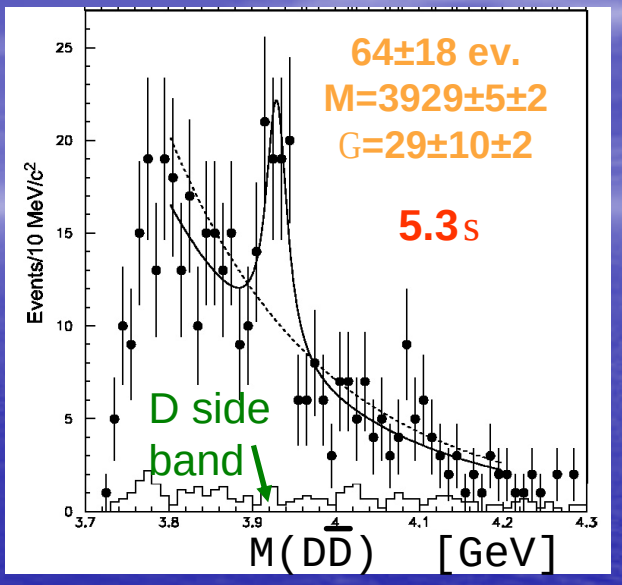


e+,e- are not reconstructed,

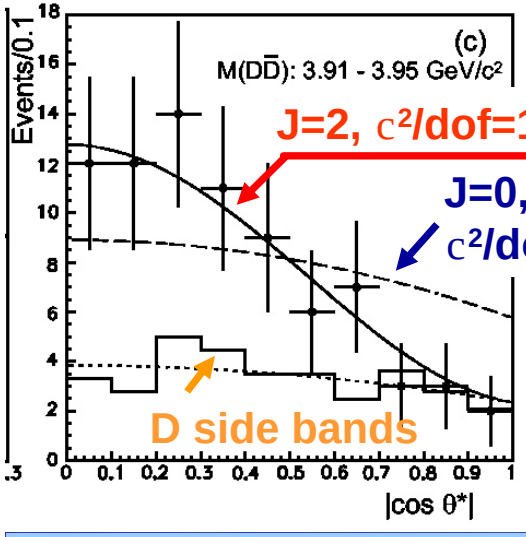
$P_t(D\bar{D})<50$ MeV

$D^0\bar{D}^0$? (K^-p^+), ($K^-p^+p^0$, K^-3p^+)

D^+D^- ? ($K^-p^+p^+$) ($K^-p^+p^+$)



q*: (D, beam axis) in $\gamma\gamma$ frame



accept. corrected

$$\Gamma_{\gamma\gamma}(Z)Br(Z \to D\bar{D}) =$$

$$0.18 \pm 0.05(stat.) \pm 0.03(syst.)\ keV$$

$Z = c_{c2}'$

2^3P_2 $c\bar{c}$

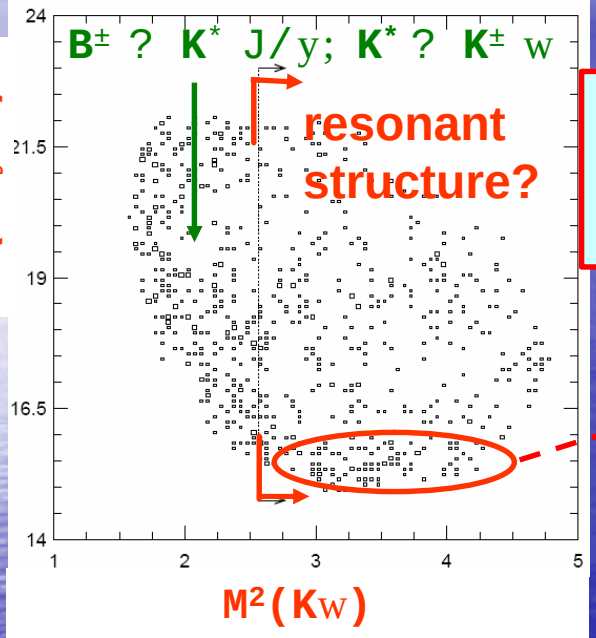
S.Godfrey,N.Isgur,PRD32,189 (1985)
C.R.Münz,Nucl.Phys.A609,364 (1996)

Y(3940)

B ? KY(3940) ? KwJ/y

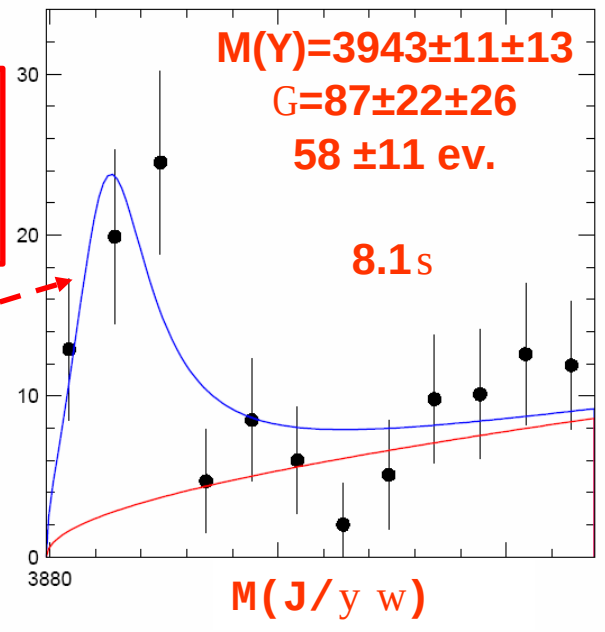
Belle, 275M $B\bar{B}$, PRL94, 182002 (2005)

Dalitz plot



B(B?YK)x B(Y?wJ/y)= $(7.1\pm1.3\pm3.1)\times10^{-5}$

No. of B's in bins of M(wJ/y)



$c\bar{c}$ charmonium above open charm threshold should dominantly decay to $D\bar{D}^{(*)}$.

$c\bar{c}$-gluon hybrid?

Large B(J/y or y' + light hadrons), decays to $D\bar{D}^{(*)}$ are suppressed, expected width is similar.
However according to lattice QCD M ~ 4.3 - 4.5 GeV

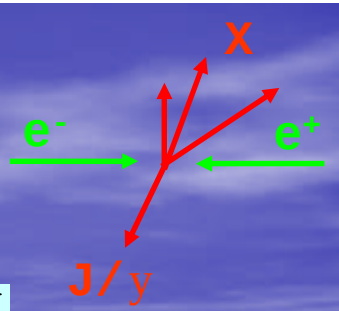
F.E.Close,P.R.Page, Nucl.Phys.B443,233(1995)

C.Banner et al., PRD56,7039(1997)
Z.-H. Mei, X.-Q.Luo, Int.J.Mod.Phys.A18, 5713 (2003)

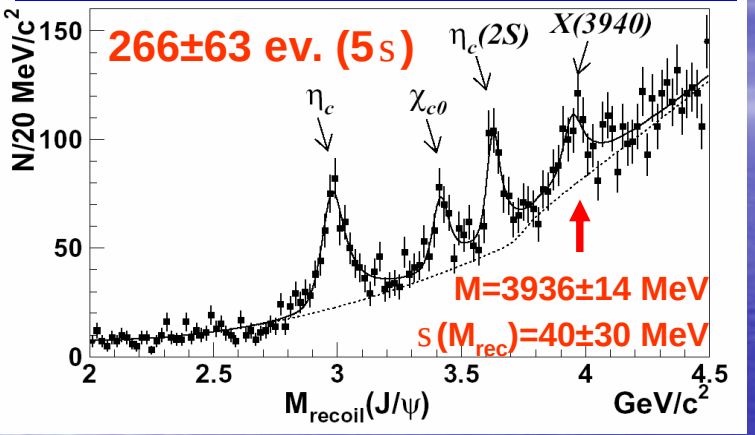
X(3940)

e^+e^- ? X(3940) J/ψ

Belle, 357 fb^{-1}, hep-ex/0507019



First, reconstruct J/ψ ? l^+l^- only



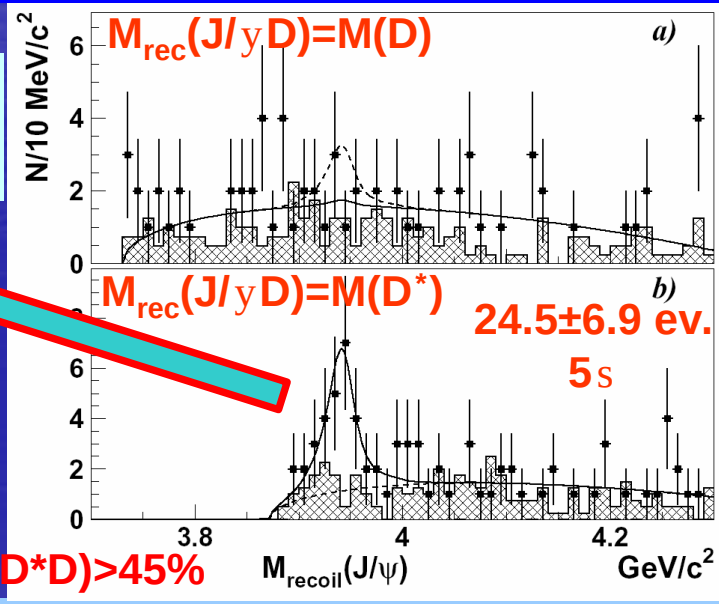
recoil mass (mass of X):

$$M_{rec} = \sqrt{(E_{cms} - E^*_{J/\psi})^2 - p^{*\,2}_{J/\psi}}$$

X(3940) ? $D^{(*)}\bar{D}$?

Second, reconstruct J/ψ ? l^+l^- *and D*.

Constrain M_{rec}(J/ψD)=M($D^{(*)}$): σ_{rec}~10 MeV.



From X(3940) ? $D^*\bar{D}$:
M = (3943 ± 6 ± 6) MeV
Γ < 52 MeV at 90%CL

X(3940) ? J/ψ ω?

B($D\bar{D}$)<41%
@90%CL

Third, reconstruct J/ψ ? l^+l^-, ω? $\pi^+\pi^-\pi^0$
and require M_{rec}(J/ψω)=M(J/ψ): no signal!

B(J/ψ ω)<26% → ***X(3940)?Y(3940) !***

Possible interpretation: X(3940) = η_c(3S) ?

B(D*D)>45%

Summary

- **B factories are great sources of charm & $c\bar{c}$ states**
- **Recent discoveries have shown that there are many puzzles in this field.**