New Particles at BELLE

There is an impressive list of new particles in the charm sector discovered by BELLE in the last few years:

This talk covers only

X(3872)

X(3940)

Y(3940) → Phys. Rev. Lett. 94 (2005)

Σ_c(2800) → Phys. Rev. Lett. 94 (2005)

Not included in this talk

$\eta_c(3753)$ → Phys. Rev. Lett. 89 (2002)

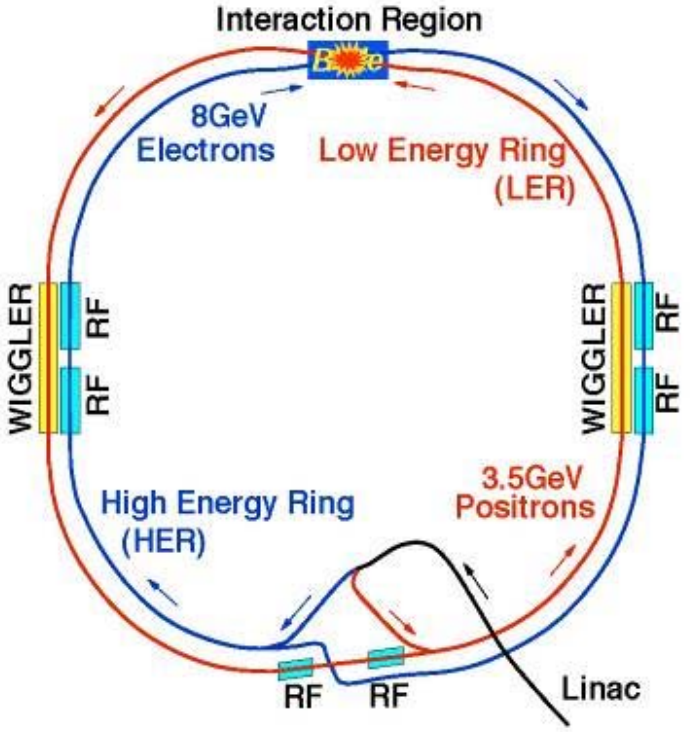
$D_0^*(2308)$, $D_1(2427)$ → Phys. Rev. D 69 (2004)

The Belle experiment: the KEKB collider

main aim:CPV studies using time-dependence of $B\overline{B}$ pair decays

boosted $e^+e^- \to \Upsilon(4S)$ using asymmetric e^+e^- storage rings:

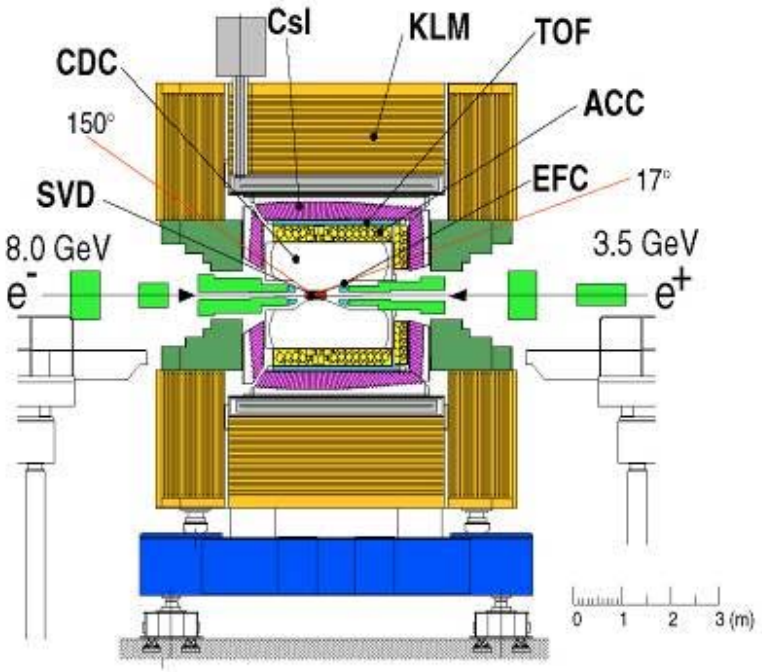
- $\sqrt{s} = 10.58\,\text{GeV} \equiv M(\Upsilon(4S))$
  $\longrightarrow B^+B^-$ and $B^0\overline{B}^0$ pairs
- also produces $q\bar{q}$, $c\bar{c}$, $\tau^+\tau^-$ ...
- peak performance:
  - $> 15 \times 10^{33}\,\text{cm}^{-2}\text{s}^{-1}$
  - $\text{cm}^{-2}\text{s}^{-1} \equiv \text{nb}^{-1}\text{s}^{-1}$, *cf.*
    $\sigma_{\Upsilon(4S)} \approx 1\,\text{nb}$, $\sigma_{c\bar{c}} \approx 1.3\,\text{nb}$
  - $> 1\,\text{fb}^{-1}/24\,\text{hours}$
- $\int dt\,\mathcal{L} > 350\,\text{fb}^{-1}$
- single collision point ...



The Belle experiment: detector

A general-purpose detector inside a 1.5 T superconducting solenoid

- 1.5 T solenoid
- 3-layer SVD, 50-layer CDC
- $\frac{\sigma_{p_T}}{p_T} = (0.19 p_T \oplus 0.3)\%$
- $\sigma_{xy} = \left(19 \oplus \frac{49}{p\beta \sin^{3/2}\theta}\right)\ \mu\text{m}$
- $\sigma_z = \left(28 \oplus \frac{41}{p\beta \sin^{5/2}\theta}\right)\ \mu\text{m}$
- $\frac{\sigma_E}{E} = \left(1.3 \oplus \frac{0.07}{E} \oplus \frac{0.8}{E^{1/4}}\right)\%$
- PID: $\begin{cases} \sigma_{\mathrm{d}E/\mathrm{d}x} = 6.9\% \\ \sigma_{TOF} = 95\,\text{ps} \\ \text{aerogel Čerenkov} \end{cases}$



+ ECAL, $\mathrm{d}E/\mathrm{d}x$ *etc.* for $e^{\pm}$ ID ...

+ the KLM (K^0_L and μ system) ...

$\epsilon(K^{\pm}) \approx 85\%$ for $\pi^{\pm}$ fake-rate $\lessapprox 10\%$ up to 3.5 GeV/c

Discovery of X(3872) $\rightarrow \pi^+ \pi^- J/\psi$

- **History**

Discovery by BELLE :

narrow $\pi^+\pi^-$ **J/**ψ mass peak

in excl. $B^- \rightarrow K^- \pi^+\pi^- J/\psi$ decays $\rightarrow$ Phys. Rev. Lett. 91, 262001 (2003)

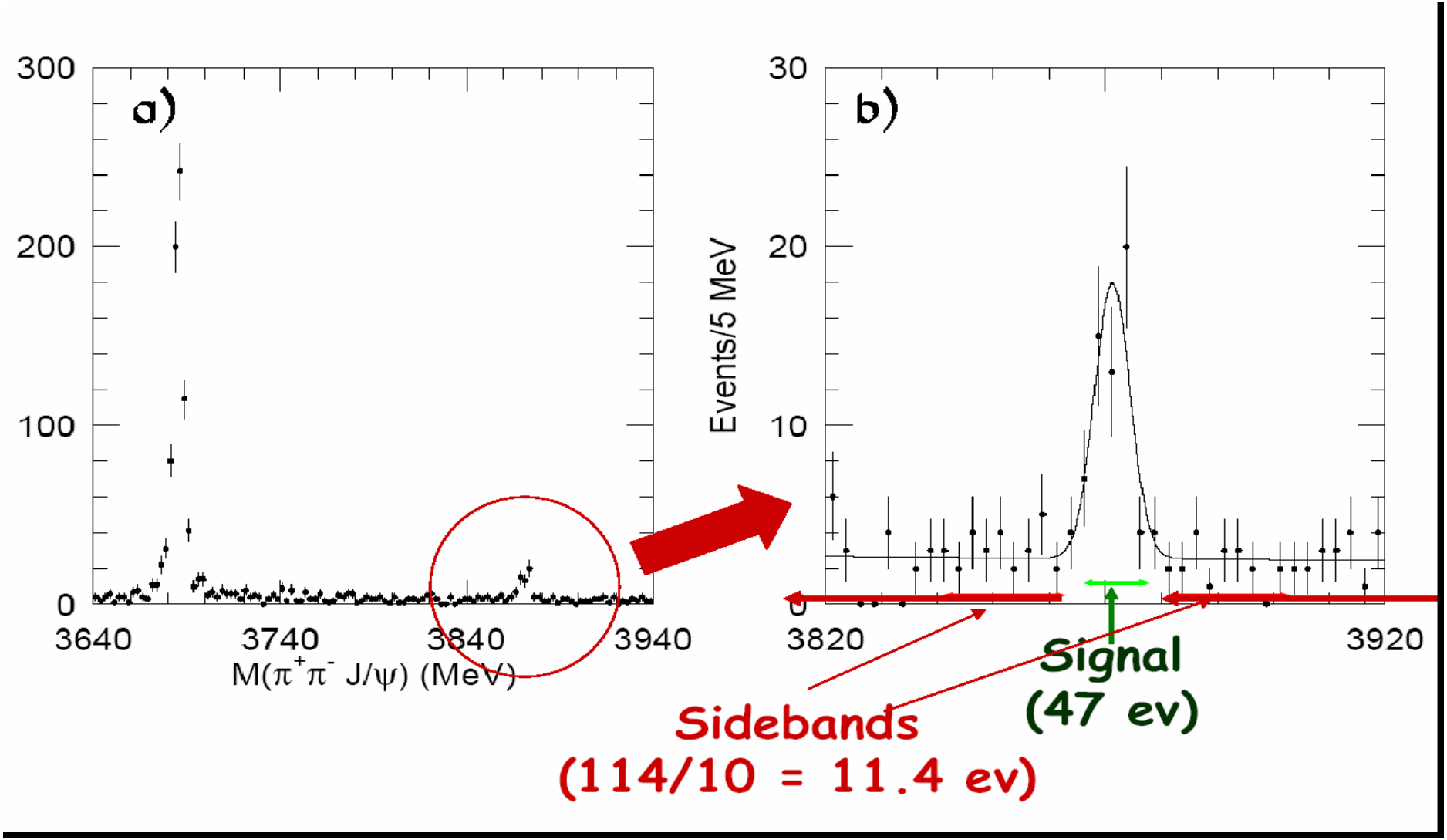
has been **confirmed** by CDF II, D0, BaBar

m, Γ **not** compatible with **charmonium** state

$m_{\pi+\pi-}$ peaks near upper kinematic limit as expected for $\rho \rightarrow \pi^+\pi^-$

but : charmonium decaying to $\rho J/\psi$ violates isospin $\rightarrow$ suppressed

X(3872) observation



Theoretical Explanation for X(3872)

- **What could it be?**

M_x = (3871.9 ± 0.5) MeV is within error equal to the $D^0\overline{D}^{*0}$ threshold (3871.3 ± 1) MeV

→ Speculation: X might be a molecule - like $D^0\overline{D}^{*0}$ bound state

Tornquist: $J^{PC} = 0^{-+}, 1^{++}$ C = +1

$\pi^+\pi^-$ J/ψ via ρ^0J/ψ intermediate state → $m_{\pi+\pi-}$ concentrated at high masses

Swanson: dynamical model for X as a $D^0\overline{D}^{*0}$ hadronic resonance

$J^{PC} = 1^{++}$ strongly favoured

$D^0\overline{D}^{*0}$ + appreciable admixture of ωJ/ψ + small ρJ/ψ

Decay X(3872) → γJ/ψ observation would unambiguously establish C = 1 for X

Study B → K γJ/ψ

256 fb^{-1} data sample (275 M $B\overline{B}$)

Selection: J/ψ, K^0 or $K^{\pm}$, γ P_{tab} > 40 MeV

to reduce continuum events ($e^+e^- \to q\overline{q}$, q ≠ b)

R2 < 0.4 (normalized Fox-Wolfram moment)

$|\cos\Theta_B| < 0.8$ Θ_B polar angle of B in cms

B → Kγ J/ψ are identified by

$$\Delta E \equiv E_B^{cms} - E_{beam}^{cms}$$

$$M_{cb} \equiv \sqrt{(E_{beam}^{cms})^2 - (P_B^{cms})^2}$$

Evidence for X(3872) → γJ/ψ

Constraint:

M_{bc} > 5.20 GeV

|ΔE| < 0.2 GeV

Signal Region:

5.2745 < M_{bc} < 5.2855 GeV

|ΔE| < 0.035 GeV

Prominent peak near 3510 MeV in M(γJ/ψ) is used for calibration (*from* $B \to K\chi_{c1}$, $\chi_{c1} \to \gamma J/\psi$)

The only significant B-meson signal is in the 3872 MeV bin (also for ΔE-distribution)

Simultaneous fit of M_{bc} and ΔE and background (ARGUS function for M_{bc} and first order polynominal for ΔE):

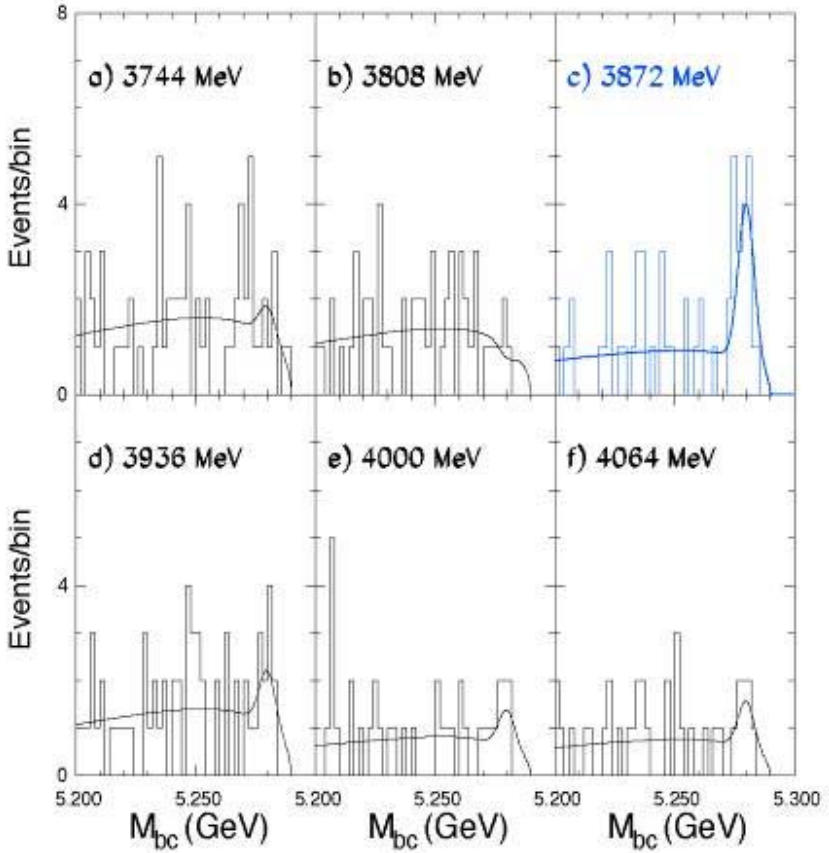
Signal yield: 13.6 ± 4.4 events,

Significance: 4.0 σ

- look for $B \to KX$ signal
  [both K^+ and K^0_S used]
- simultaneous binned-$\mathcal{L}$ fit:

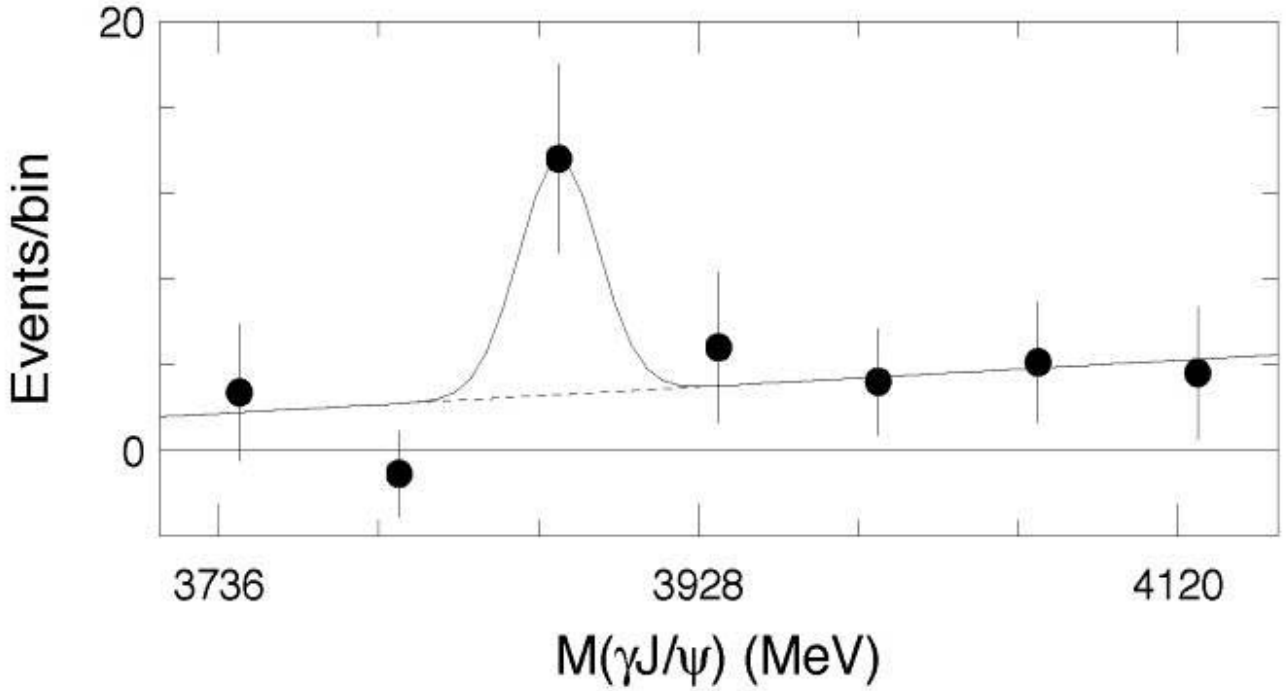
  M_{bc}: B-momentum signal

  ΔE: B-mass signal
- fit in bins of "X" mass
- $X \to \gamma J/\psi$ results $\longrightarrow$
  B-yield seen only in the
  $M(\gamma J/\psi) \sim 3872$ MeV bin



$C = +1$: observation of $X(3872) \to \gamma J/\psi$

both γ and J/ψ are 1^{--}: fixes $C = +1$



$$\frac{\Gamma(X \to \gamma J/\psi)}{\Gamma(X \to \pi^+\pi^- J/\psi)} = 0.14 \pm 0.05; \quad \text{signif.} > 4\sigma$$

$$\mathcal{B}(B \to K X) \times \mathcal{B}(X \to \gamma J/\psi) = (1.8 \pm 0.6 \pm 0.1) \times 10^{-6}$$

Evidence for X(3872) → $\pi^+\pi^-\pi^0$ J/ψ

X → $\pi^+\pi^-\pi^0$J/ψ

similar selection as above

π^0, $\gamma\gamma - fit : \chi^2 < 6, \quad p^{cms}_{\pi^0} > 180 MeV$

$|M(\pi^+\pi^- J/\psi) - m(\psi(2S))| > 3\sigma$

slightly different signal region

only significant B-meson signal in 3872 MeV bin (not shown)

M_{bc} distribution for various $\pi^+\pi^-\pi^0$ inv. mass bins:

only significant B meson signal for M($\pi^+\pi^-\pi^0$) > 750 MeV bin

the same for ΔE

Fit: 12.4 ± 4.1 events **Significance: 4.3 σ**

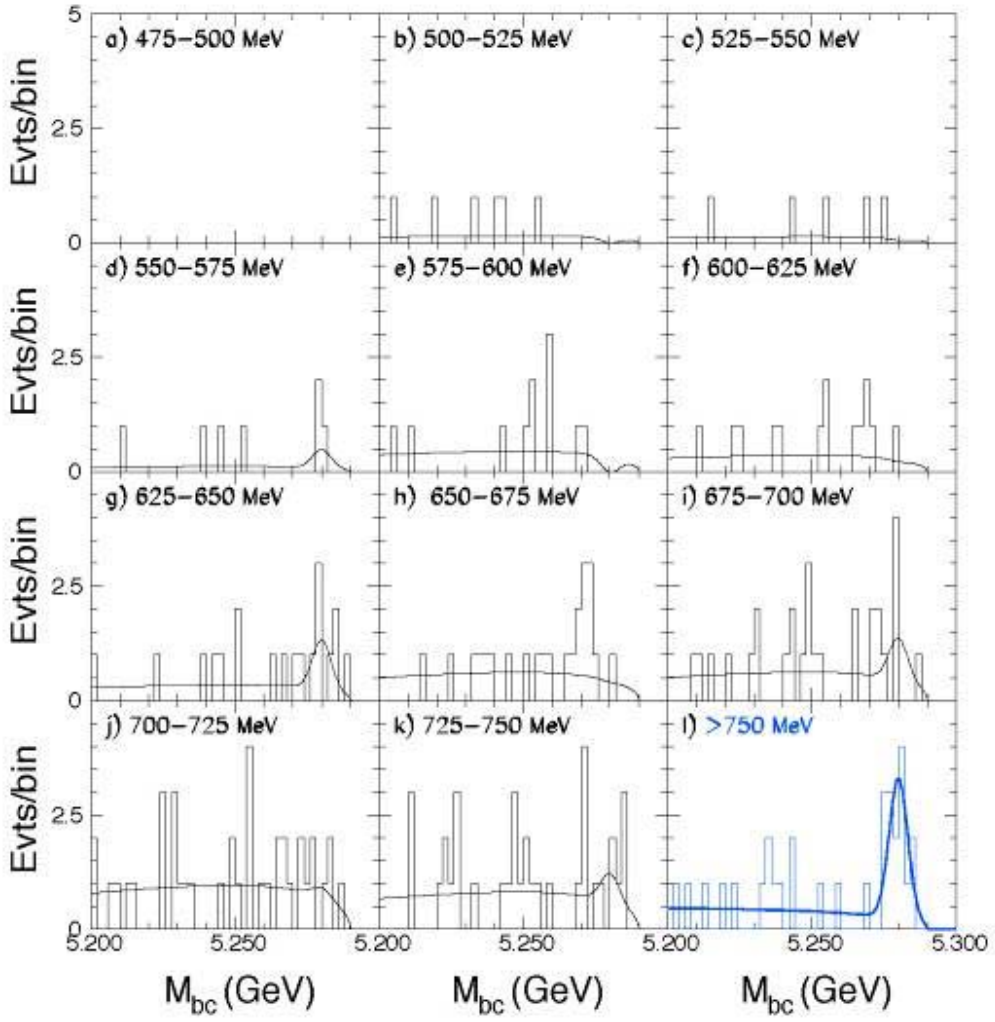
possible background B → K ω J/ψ fit: 0.75 ± 0.14 events

B → K$^-\pi^+\pi^-\pi^0$ J/ψ non res., use left and right side bound region

1.3 ± 1.0 events

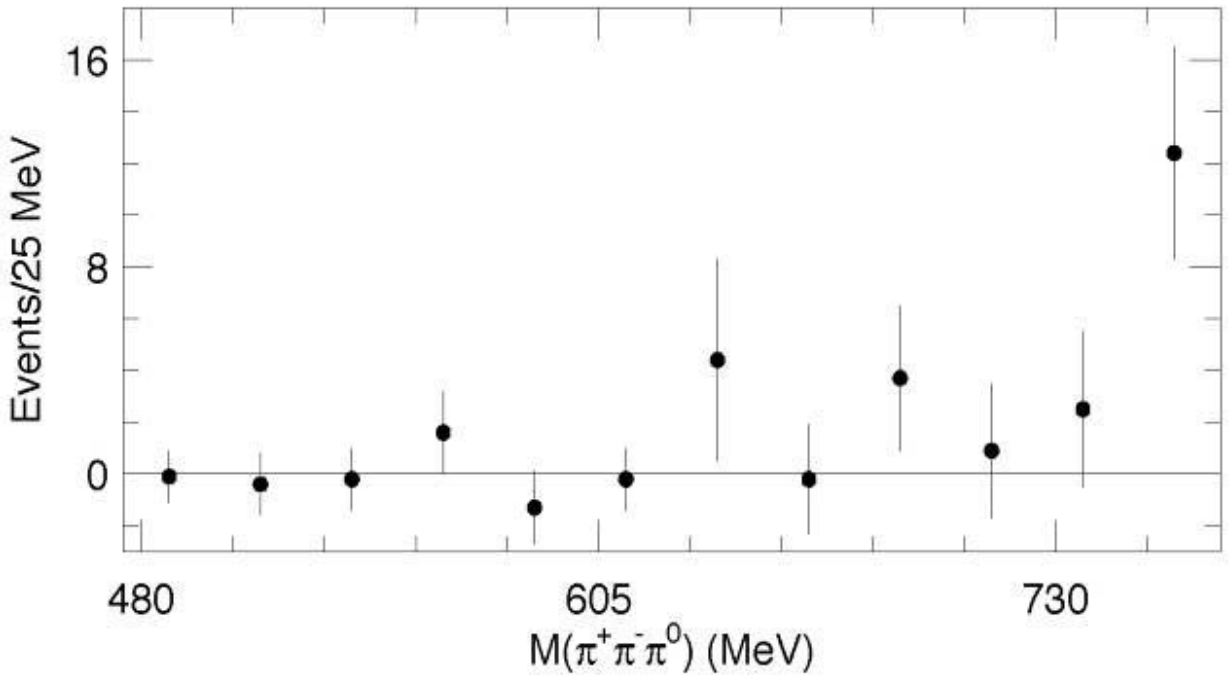
$$\frac{Br(X \to \pi^+\pi^-\pi^0 J/\psi)}{Br(X \to \pi^+\pi^- J/\psi)} = 1.0 \pm 0.4 \pm 0.3$$

$B \to KX,\ X \to \pi^+\pi^-\pi^0\psi$ M_{bc} fits in $M(\pi^+\pi^-\pi^0)$ bins



$C = +1$ (ii): sub-threshold $X(3872) \to \omega J/\psi$

significant yield in highest $M(\pi^+\pi^-\pi^0) \lesssim m_\omega$ bin only



$$\frac{\Gamma(X \to \pi^+\pi^-\pi^0 J/\psi)}{\Gamma(X \to \pi^+\pi^- J/\psi)} = 1.0 \pm 0.4 \pm 0.3; \quad \text{signif.} > 4.3\sigma \text{ for } \omega J/\psi$$

systematic $\ni$ limits on $Y(3940)$ feed-across, $\pi^+\pi^-\pi^0$ non-res; $M(3\pi)$ shape

$J^{PC} = 0^{-+}$: expect $\frac{d^2N}{d\cos\theta d\cos\psi} \propto \sin^2\theta \sin^2\psi$

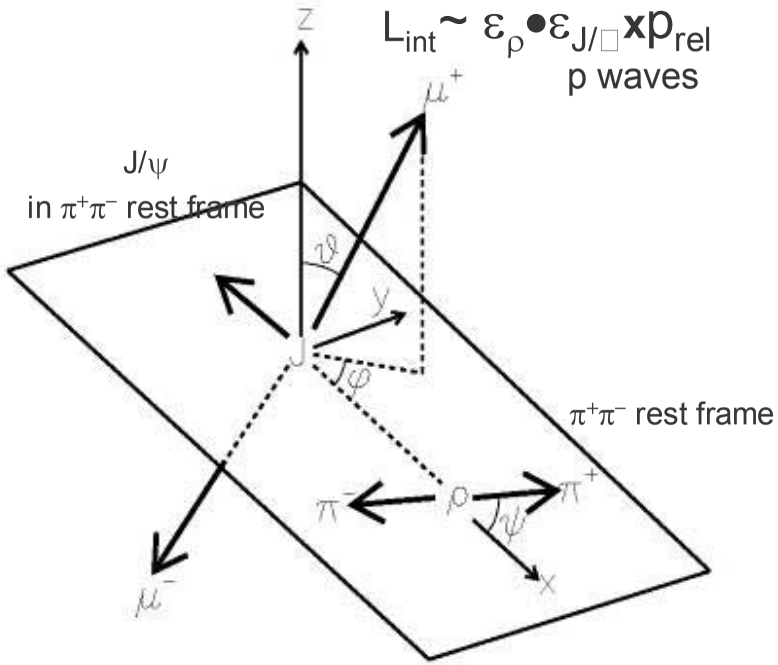
- exploit zeroes in predicted [J. Rosner, *PRD* **70**, 094023 (2004)] distribution
- exact for $p^*_\psi = p^*_\rho = 0$; histogram : MC $p^* \neq 0$; + scaled X-mass sidebands

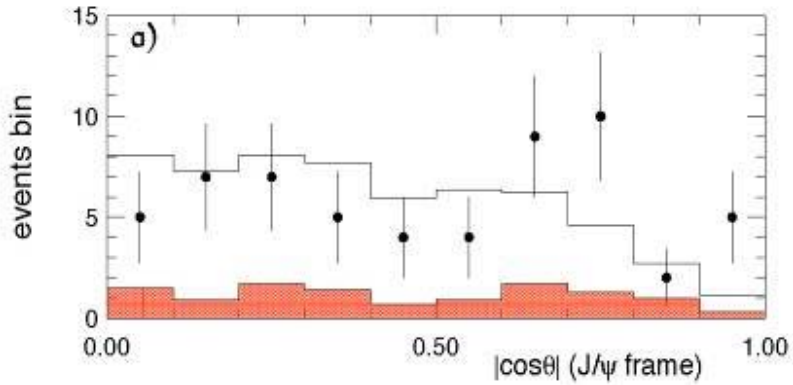
X(3872) → $\pi^+\pi^-$J/ψ

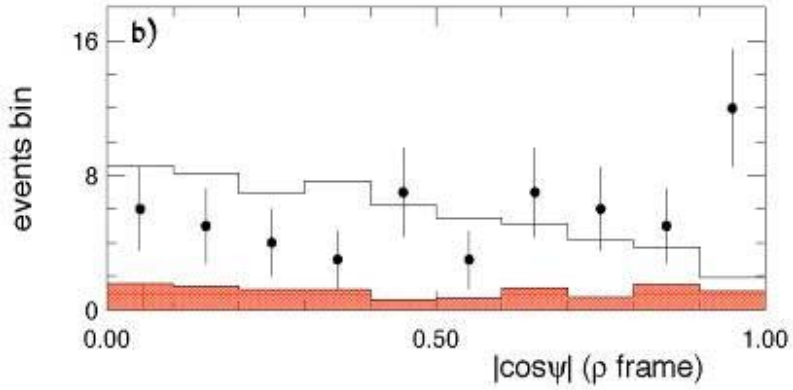
triple scalar product

$L_{int} \sim \varepsilon_\rho \bullet \varepsilon_{J/\square} \mathbf{x} p_{rel}$

p waves







Transversity analysis useful for decays to V + V

$\chi^2/d.o.f. = 17.7/9$ and $34.2/9$: DISFAVORED

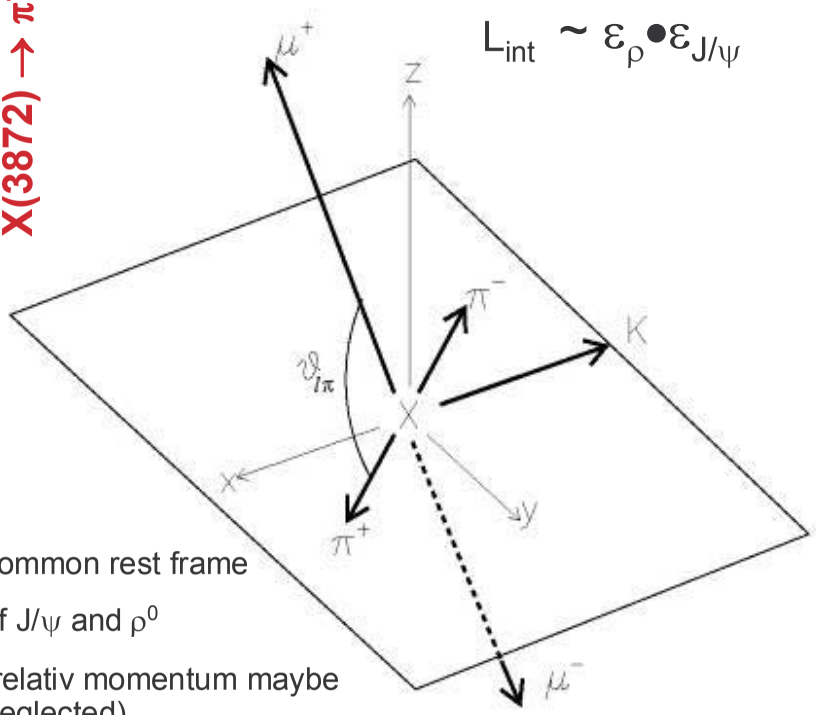
1-p = 4%, 0.01%

$J^{PC} = 0^{++}$: expect $\frac{dN}{d\cos\theta_{\ell\pi}} \propto \sin^2\theta_{\ell\pi}$

- ρ and J/ψ in S- or D-wave; ignoring D-wave $\longrightarrow$ $\sin^2$ dependence [Rosner]
- exact for $p^*_\psi = p^*_\rho = 0$; both ρ-frame and X-frame distributions shown

X(3872) → $\pi^+\pi^-$J/ψ

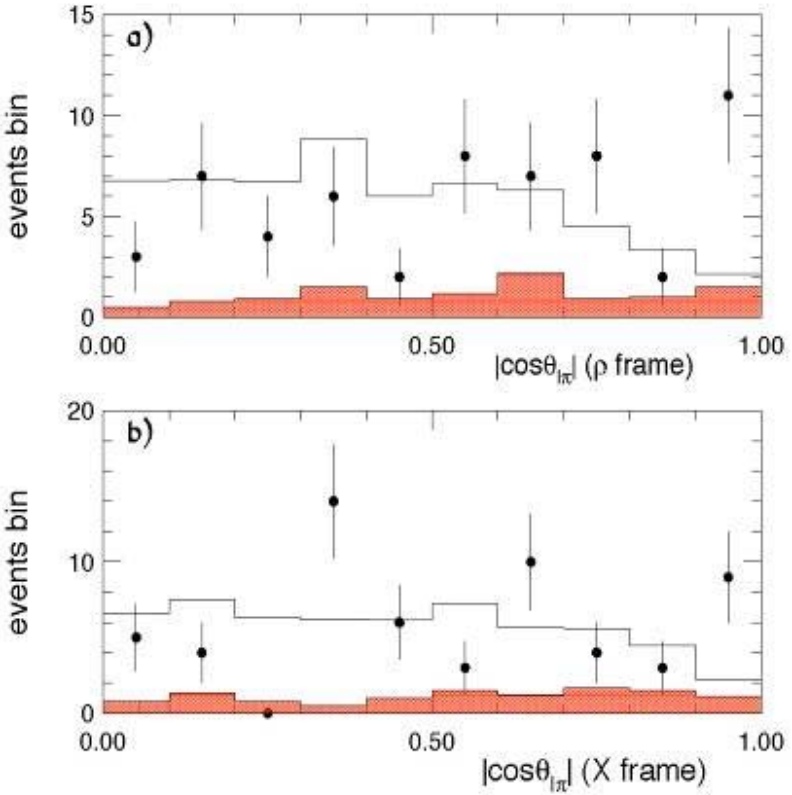
$L_{int} \sim \varepsilon_\rho \bullet \varepsilon_{J/\psi}$



common rest frame

of J/ψ and ρ^0

(relativ momentum maybe neglected)



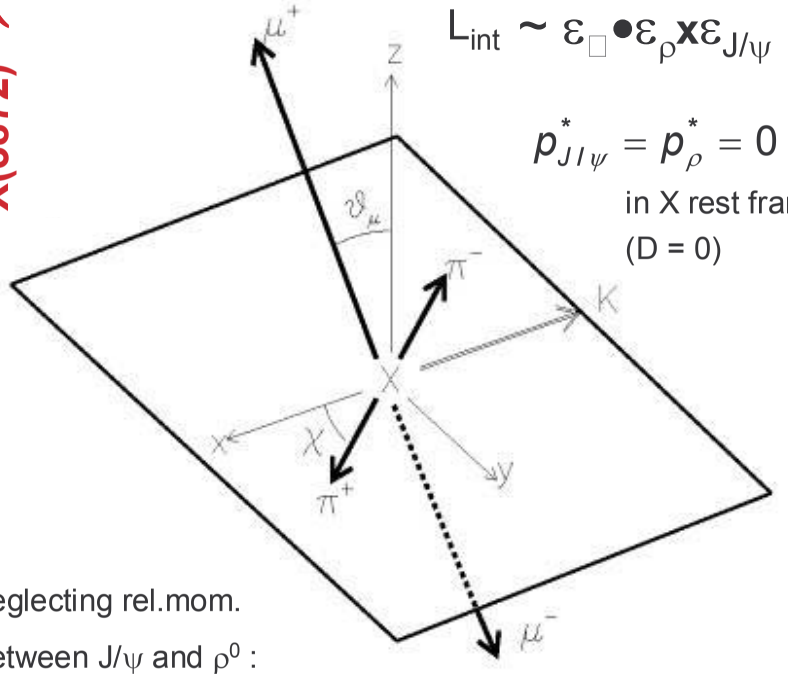
$\chi^2/d.o.f. = 31.0/9$ and $41.0/9$: DISFAVORED

1-p = 0.3%, 5×10^{-6} %

$J^{PC} = 1^{++}$: expect $\frac{d^2N}{d\cos\theta_\ell d\cos\chi} \propto \sin^2\theta_\ell \sin^2\chi$

X(3872) → $\pi^+\pi^- J/\psi$

- ρ and J/ψ in S- or D-wave; ignoring D-wave ⟶ $\sin^2\theta_\ell \sin^2\chi$ [Rosner]
- agreement for both θ_ℓ and χ; MC $p^* \neq 0$; + scaled X-mass sidebands



triple scalar product

$L_{int} \sim \varepsilon_{\square} \bullet \varepsilon_\rho \mathbf{x} \varepsilon_{J/\psi}$

$p^*_{J/\psi} = p^*_\rho = 0$

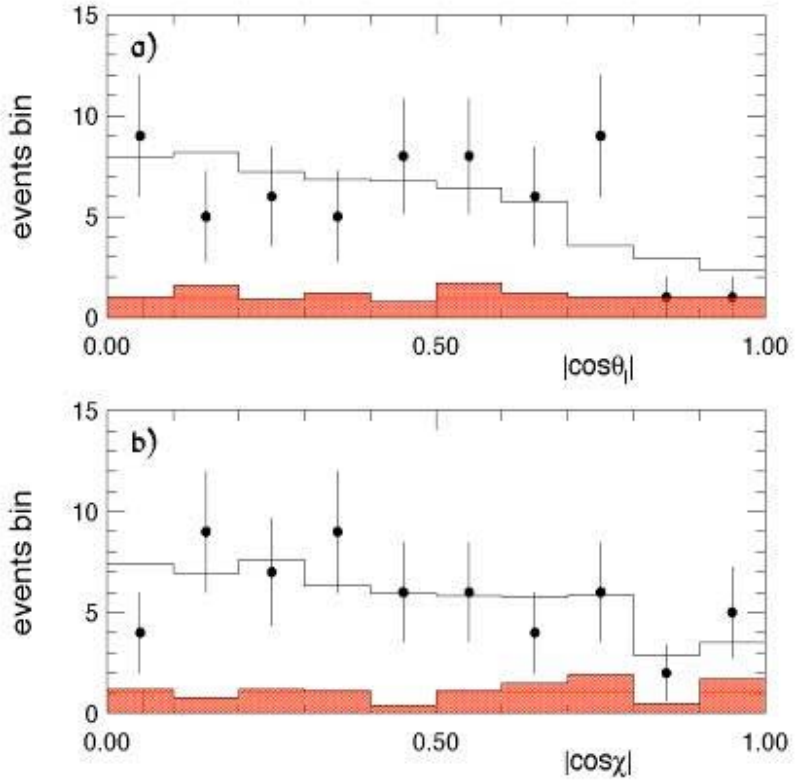
in X rest frame

(D = 0)

neglecting rel.mom.

between J/ψ and ρ^0 :

all are in same CMS



$\chi^2/d.o.f. = 11.4/9$ and $5.0/9$: ALLOWED

1-p = 75%, 16%

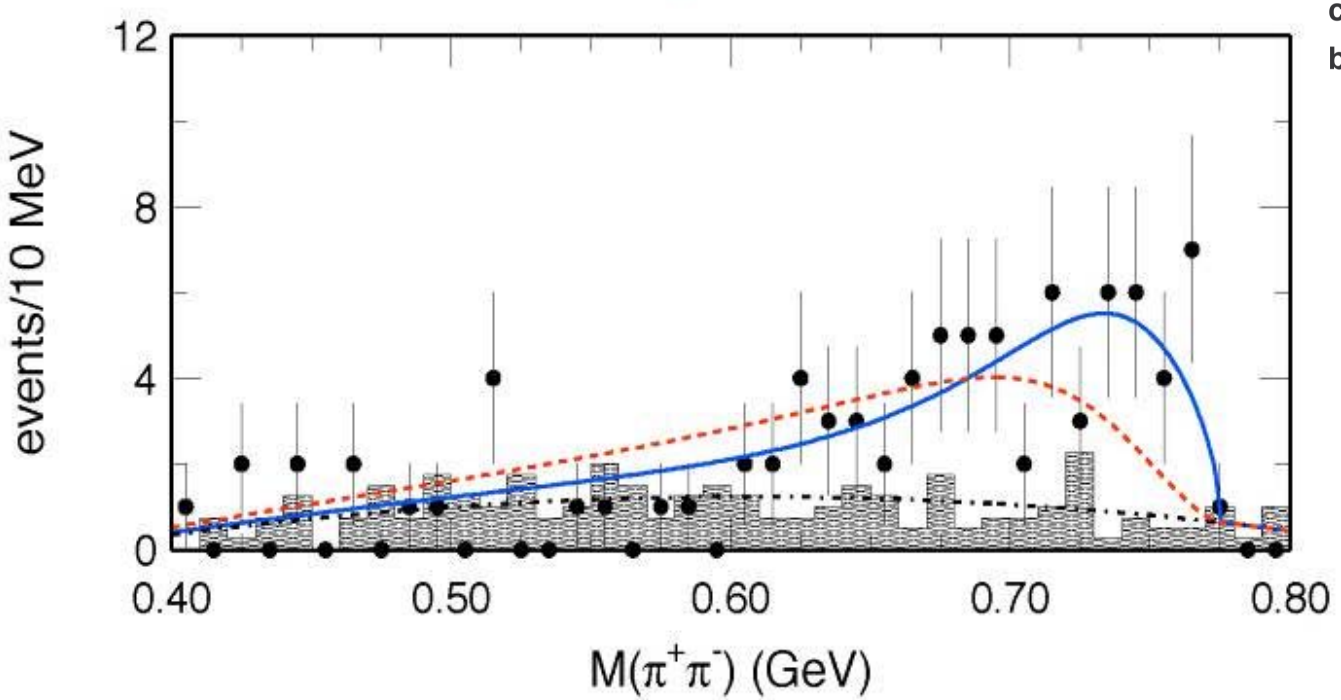
J^{++} versus J^{-+}: $M(\pi^+\pi^-)$ shape

J^{++}: ρ and J/ψ in S-wave, $\propto q^*_{J/\psi}$ at threshold [ignoring D-wave]

J^{-+}: ρ and J/ψ in P-wave, $\propto (q^*_{J/\psi})^3$ at threshold [ignoring F-wave]

centrifugal barrier !

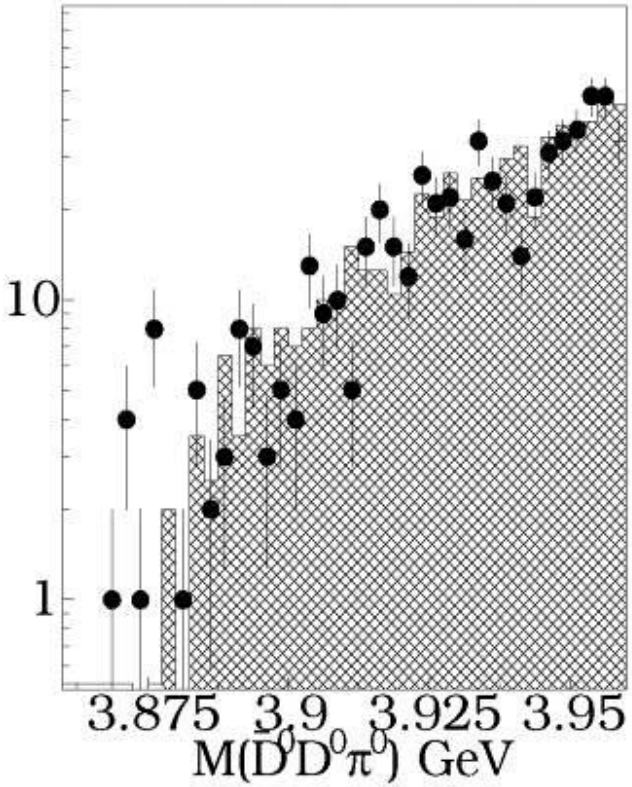
X(3872) → $\pi^+\pi^-$J/ψ



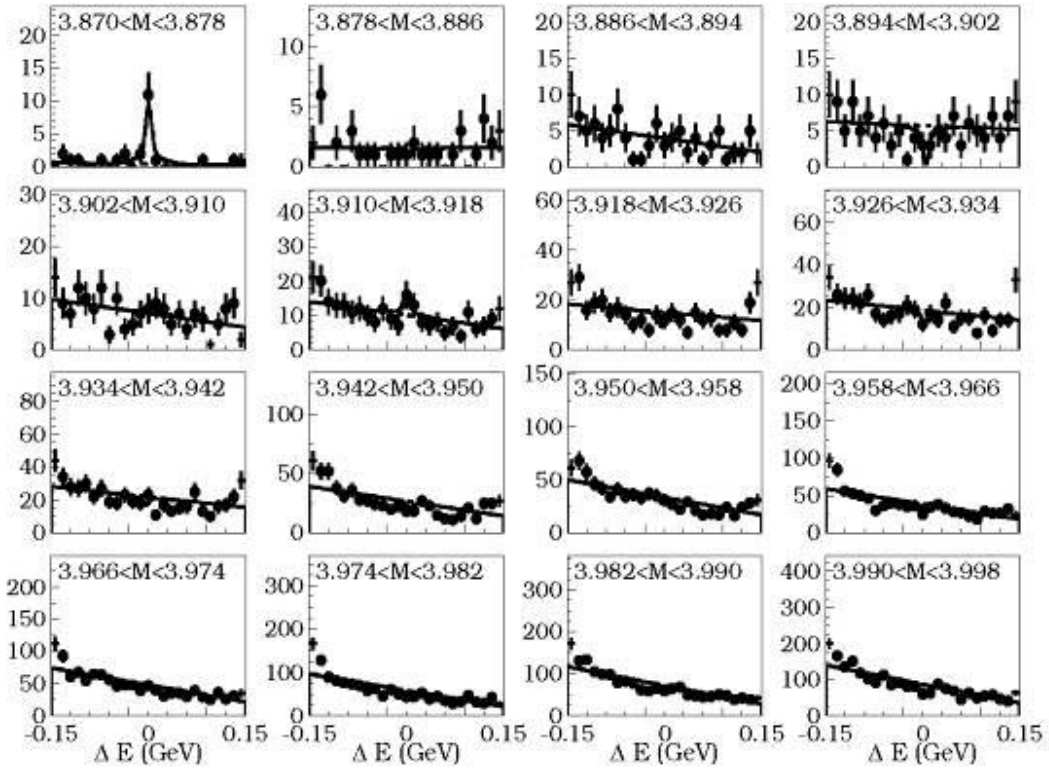
$\chi^2/d.o.f. = 43.1/39$ (28%) allowed *cf.* 71.0/39 (0.1%) disfavored

2^{++}?: evidence for $B \to K X$, $X(3872) \to D^0 \overline{D}{}^0 \pi^0$

$M(D\overline{D}\pi)$ distribution of . . .



. . . individual ΔE fits



3 pseudoscalars require D-wave

$2^{++} \Longrightarrow$ D-wave, so would be suppressed (small q);

$X \to D^0 \overline{D}{}^0 \pi^0$ disfavors 2^{++}: RESULTS PRELIMINARY

$X(3872)$

- 1^{++} consistent with data; all other J^{PC} disfavored by ≥ 1 test
- 1^{++} charmonium χ'_{c1} assignment is unlikely
  - potential model mass is wrong: 3953–3990 MeV
  - coupling to open charm doesn't help: +28 MeV
  - $\chi'_{c1} \to \pi^+\pi^- J/\psi$ is I-violating: $\mathcal{B} \sim 0.1\%$ *cf.* BaBar limit $> 4.3\%$
  - expected $\Gamma(\chi'_{c1}) \sim 11$ keV: but $\frac{\mathcal{B}(X\to\gamma\psi)}{\mathcal{B}(X\to\pi^+\pi^-\psi)} = 0.14 \pm 0.05$

    [guessing $\Gamma(\chi'_{c1} \to \pi^+\pi^- J/\psi) \sim \Gamma(\psi(2S) \to \pi^0 J/\psi) = (0.27 \pm 0.06)$ keV]

I-violating hadr.trans.: $\psi(2S) \to \pi 0\ J/\psi$

- observed properties all consistent with $X = D^0\overline{D}^{*0}$ bound state
  - mass within errors of $D^0\overline{D}^{*0}$ threshold: $(+0.6 \pm 1.1)$ MeV
  - $M(D^+D^{*-}) - M(D^0\overline{D}^{*0}) = 8.1$ MeV $\Longrightarrow$ I-violation is natural
  - Swanson's $|D^0\overline{D}^{*0}\rangle + \alpha|\omega J/\psi\rangle + \epsilon|\rho J/\psi\rangle \Longrightarrow$ decays are natural
  - low $\Gamma(X \to \gamma J/\psi)/\Gamma(X \to \pi^+\pi^- J/\psi)$ expected

[E.S. Swanson, *Phys. Lett.* **B 588**, 189 (2004); *Phys. Lett.* **B 598**, 197 (2004)]

X(3940)

Further analysis of the processes $e^+e^- \to J/\psi\, \eta_c(1S)\, (X_{c0}, \eta_c(2S), X)$

History: first observation of such processes by BELLE

Phys. Rev. Lett. 89, 142001 (2002)

Theoretical calculation $e^+e^- \to \gamma \to J/\psi\eta_c$ ~ 2fb << *measurement*

$\Rightarrow$ various speculations: glueball contribution ? etc.

For the first time seen:

$e^+e^- \to \psi(2S)(c\bar{c})_{res}$

X(3940) new charmonium state

Look for recoil to J/ψ and ψ(2S): $M_{recoil}(J/\psi) = \sqrt{(E_{cm} - E^*_{J/\psi})^2 - p^*_{J/\psi}}$ etc.

double charmonium

Study of the decay of reconstructed $\psi(2S) \to J/\psi\ \pi^+\pi^-$

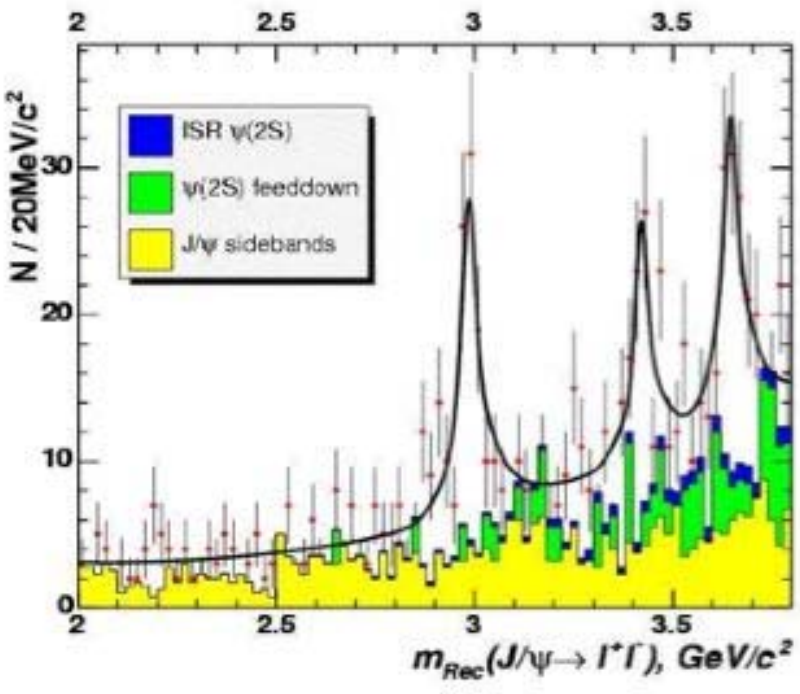
search for $e^+e^- \to \psi(2S)(c\bar{c})res$

look for recoil spectra

3 significant signals seen:

(BaBar gets consistent results)

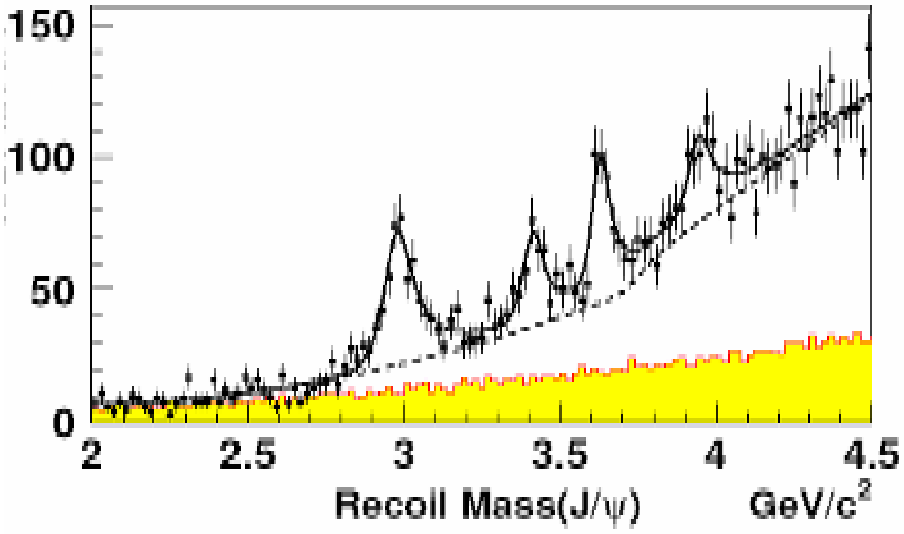
$\psi(c\bar{c})$	Belle (155 fb)
$\psi\eta_c$	$25.6 \pm 2.8 \pm 3.4$
$\psi\chi_{c0}$	$6.4 \pm 1.7 \pm 1.0$
$\psi\eta_c'$	$16.5 \pm 3.0 \pm 2.4$



$e^+e^- \to J/\psi\, X$

Using higher statistics (287 fb⁻)

extend analysis of recoil masses against J/ψ above DD threshold



Fit yields:

	N	M [GeV/c^2]	σ
η_c	471 ± 40	2.969 ± 0.006	∞
χ_{c0}	232 ± 37	3.406 ± 0.007	large
η_c'	350 ± 17	3.626 ± 0.006	HUGE
X	236 ± 71	3.937 ± 0.012	5.0

$\Gamma_X = 27 \pm 21$ MeV; < 95 MeV at 90% CL

no signal of X(3872)

$\Rightarrow$ **find new significant peak at M ~ 3.940 GeV/c²** $\to$ **"X(3940)"**

Fit: η_c, χ_{co}, $\eta_c(2S)$, X(3940) + background

$\to$ **M_X = (3.937 ± 0.012) GeV/c²**

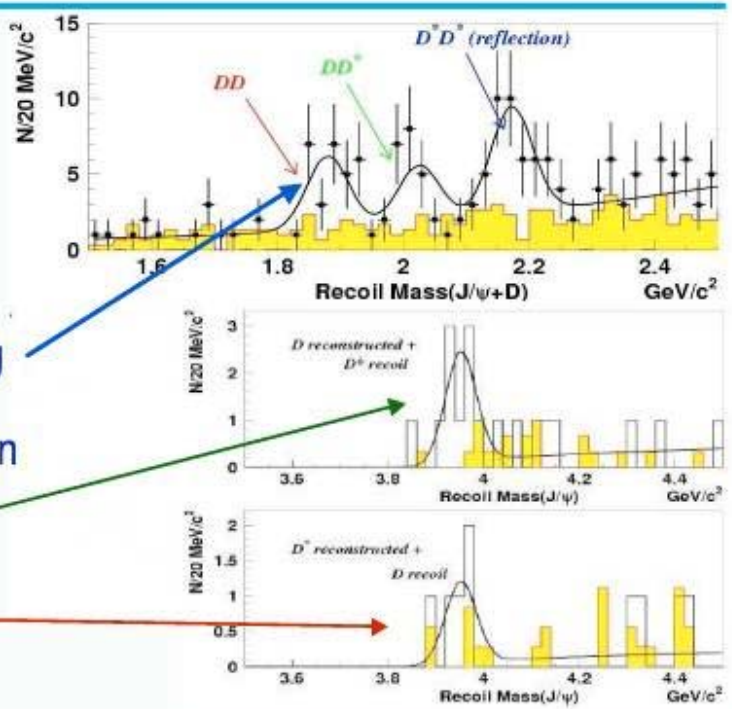
Γ compatible with 0 (< 95 MeV/c²) 90% CL <~ resolution (=32 MeV)

Search for X(3940) → DD(*)

- Idea: Reconstruct J/ψ and one D; Look for the second $D^{(*)}$ in the event at recoil mass against reconstructed (J/ψ D)
- Use only the cleanest $D^0 \to K^-\pi^+$ and $D^+ \to K^-\pi^+\pi^+$
- $e^+e^- \to J/\psi D^{(*)} D^{(*)}$ + nothing clearly seen
- Look at M_{recoil} (J/ψ) when

M_{recoil} (J/ψ D) ~ M(D*)
N=9.9±3.3 (4.5σ)

M_{recoil} (J/ψ D) ~ M(D)
N=4.1±2.2 (2.1σ)



P.Pakhlov (ITEP, Moscow)

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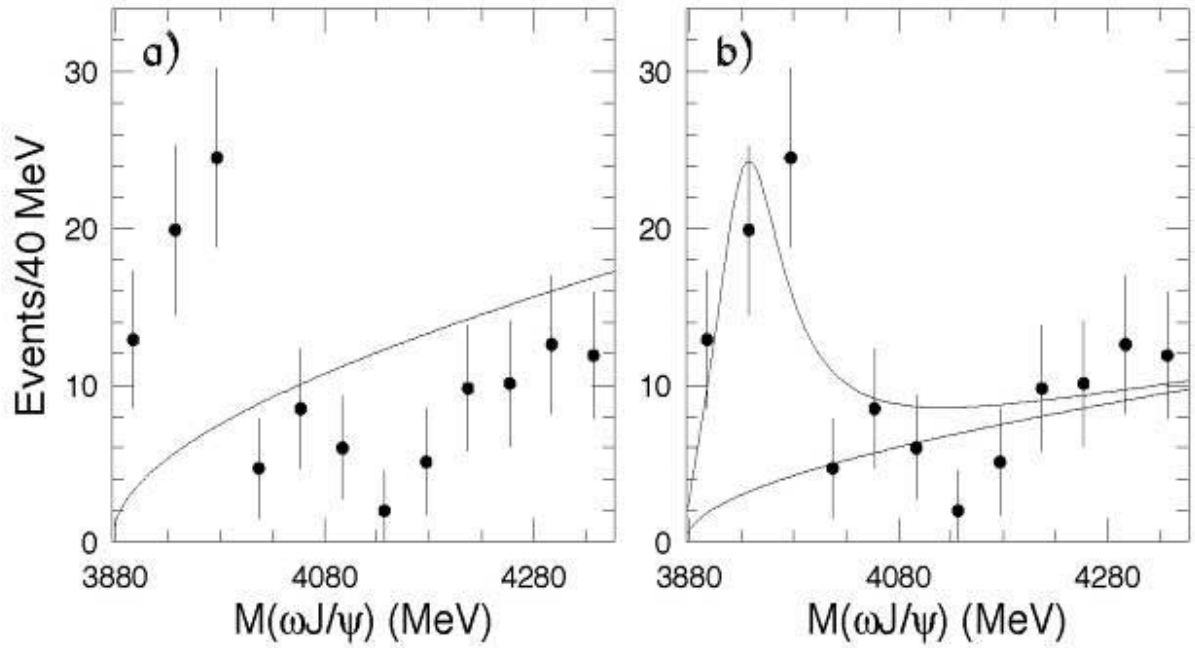
B → K$\omega J/\psi$ yields: enhancement at $M(\omega J/\psi)$ threshold



$M = (3943 \pm 11 \pm 13)$ MeV, $\Gamma = (87 \pm 22 \pm 26)$ MeV

fits with & without threshold Breit-Wigner: $\sqrt{-2\Delta \ln \mathcal{L}} = 8.1$ ("$8.1\,\sigma$")

Charmed baryon spectroscopy

light diquark in the environment of a heavy quark → test for theoretical models

PDG 2004: $\Lambda_c^+\pi^+\pi^-$ 4 excited charmed baryons observed

$\Lambda_c^+\pi$ $\Sigma_c(2455)$ ground state $\Sigma_c(2520)$

Aim : **find excitations of Σ_c**

Analysis: uses data sample 253 fb^{-1} at $\Upsilon(4S)$, Λ_c^+ *are reconstructed via* $pK^-\pi^+$

signal window around $m(\Lambda_c^+)$: ± 8 MeV/c^2

$x_p > 0.5$ for Λ_c^+ candidates $\quad x_p \equiv \frac{p^*}{p^*_{max}} \quad p^*_{max} \equiv \sqrt{E^{*2}_{beam} - M^2}$

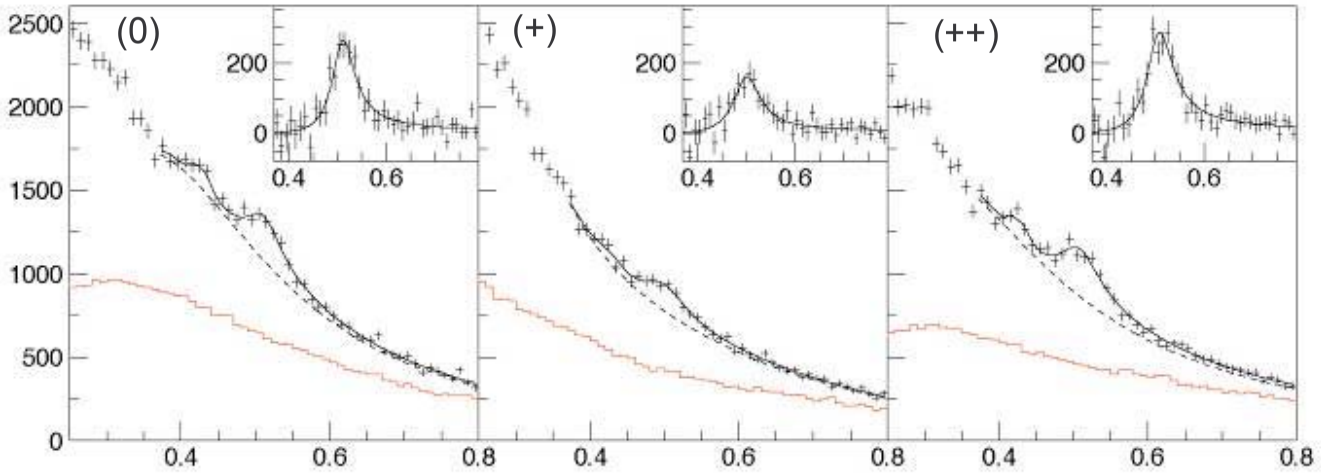
yield: (516 ± 2) x 10^{13} S/B = 2.3

combine Λ_c^+ with π, $x_p > 0.7$ $\cos\theta_{dec} > -0.4$

θ_{dec} = angle between (π in rest frame of $\Lambda_c^+\pi$) and boost direction of the $\Lambda_c^+\pi$ system in cms

$\Sigma_c(2800) \to \Lambda_c^+ \pi^{-,0,+}$: *PRL* **94**, 122002 (2005)

mass difference $M(\Lambda_c^+\pi) - M(\Lambda_c^+)$, GeV/$c^2$:



points:	data
histogram:	sidebands
curve:	signal fit (D-wave B-W)
dashed:	background $(1/\{C_0 + C_1 x + C_2 x^2 + C_3 x^3\})$
inset:	background-subtracted data

Note the $\Lambda_c(2880) \to \Lambda_c^+ \pi^+ \pi^-$ reflection ...

tentative identification: Σ_{c2}, $J^P = \frac{3}{2}^-$; Σ_{c1}, $J^P = \frac{3}{2}^-$ admixture

Charmed baryon spectroscopy

$\Sigma_c(2800)^0$ $\Sigma_c(2800)^+$ $\Sigma_c(2800)^{++}$ Isotriplet

Enhancement at $\Delta M \sim 0.43$ GeV for $\Delta M(\Lambda_c^+ \pi^-)$ and $\Delta M(\Lambda_c^+ \pi^+)$

$\rightarrow$ feed-down from decay $\Lambda_c(2880)+ \rightarrow \Lambda_c^+ \pi^+\pi^-$ observed by CLEO

next: study $\Lambda_c^+ \pi^+\pi^-$: clear peaks of $\Lambda_c(2800)^+$ and $\Lambda_c(2765)^+$ seen

consistent with observation of CLEO

Fit: Isotriplet + feed-down + combinatorial background

$\sigma(e^+e^- \rightarrow \Sigma_c(2800)X) \times Br(\Sigma_c(2800) \rightarrow \Lambda_c^+\pi)$ 2.04 (0), 2.6 (+), 2.36 (++) pb

Theoretical models

Σ_{c2} doublet with $J^p = 3/2^-$ and $5/2^-$ $\Sigma_{c2} \rightarrow \Lambda_c^+\pi$ mainly in D wave

$\Delta M = 500$ MeV/c^2 as measured $\Gamma \sim 15$ MeV smaller as measured

$\Sigma_{c2}(J^P = 3/2^-)$ can mix with $\Sigma_{c1}(J^P = 3/2^-)$ and would produce a wider physical state

Summary

- $X(3872)$ observ^n & updated measurement of properties
  - no natural charmonium candidate has been found
  - $X \to \gamma J/\psi$ and $\omega J/\psi$ observations fix $C = +1$
  - angular and $M(\pi^+\pi^-)$ distributions favour $J^{PC} = 1^{++}$
  - decays & properties consistent with $D^0\overline{D}^{*0}$, but not χ'_{c1}
- $e^+e^- \to \psi(2S)(c\bar{c})_{res}$ seen for the first time (now also BaBar)
- X(3940) new charmonium state
- $X(3940) \to DD^*$ (not the $X(3872)$, not the $Y(3940) \to \omega J/\psi$)

- $\Sigma_c(2800)$ triplet established

  tentative identification: Σ_{c2}, $J^P = 3/2^-$; Σ_{c1}, $J^P = 3/2^-$ admixture

SPARES ↓

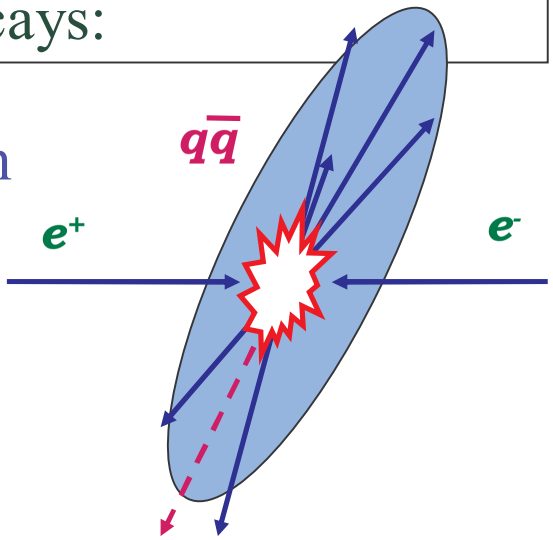
Continuum Suppression

Unwanted Background for B-Decays:

$e^+e^- \rightarrow q\bar{q}$ "continuum" (~3x $B\bar{B}$)

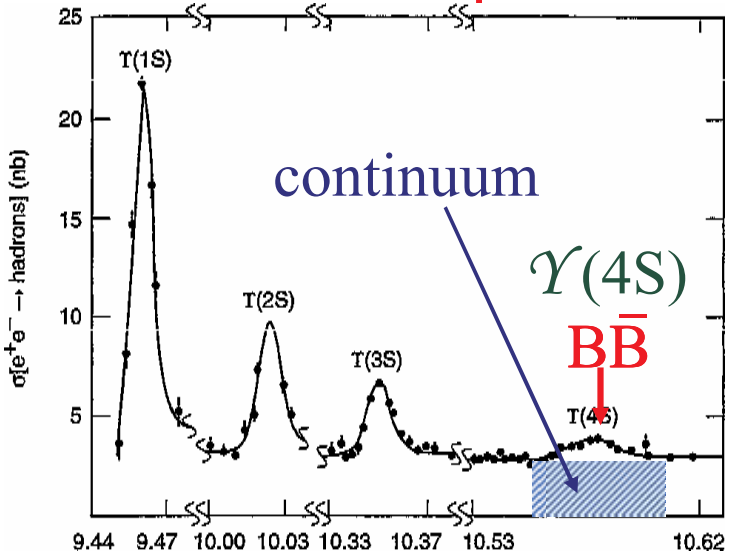
Continuum

Jet-like



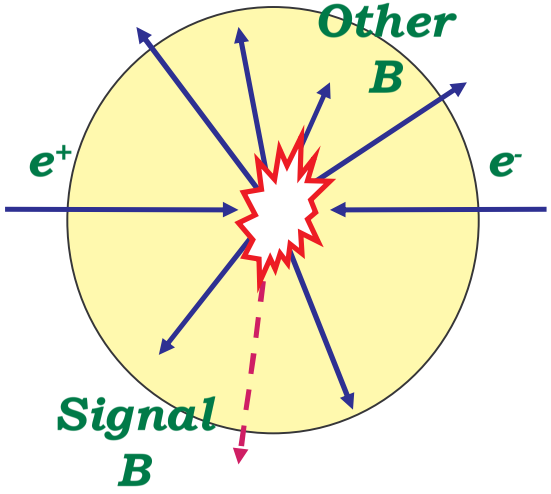
To suppress:

use event shape variables

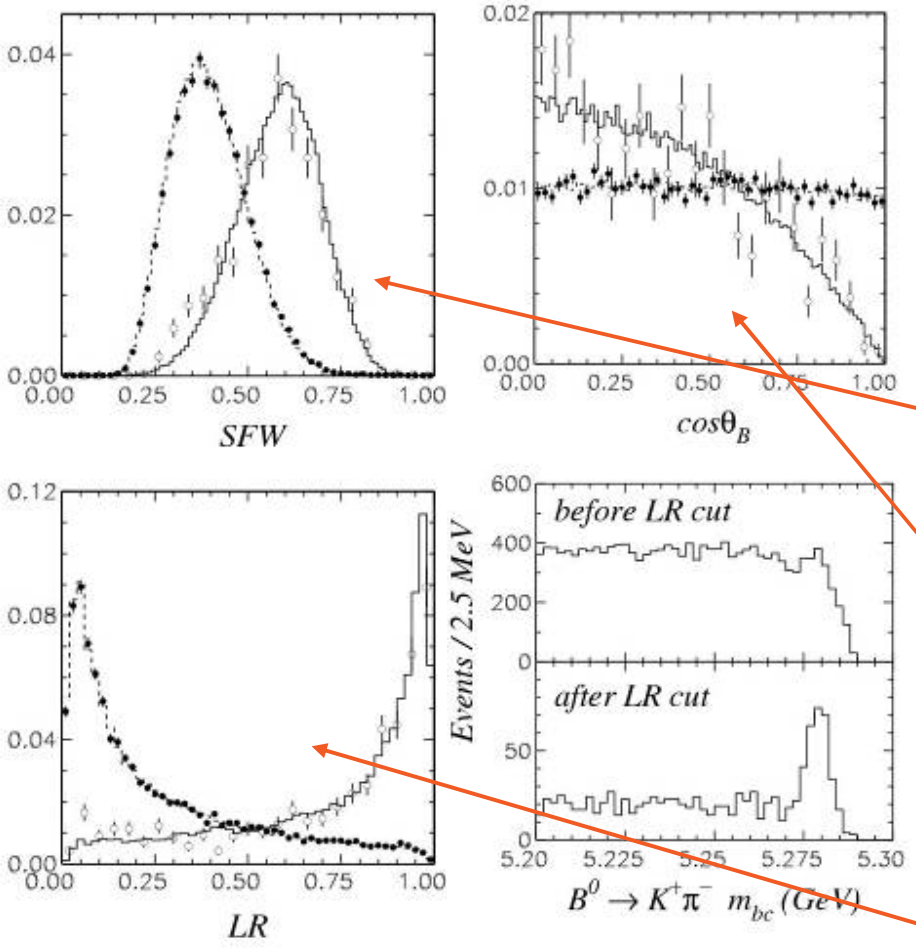


$B\bar{B}$

spheric



Continuum Suppression



To separate spherical BB events from jet-like continuum events, topological variables are used:

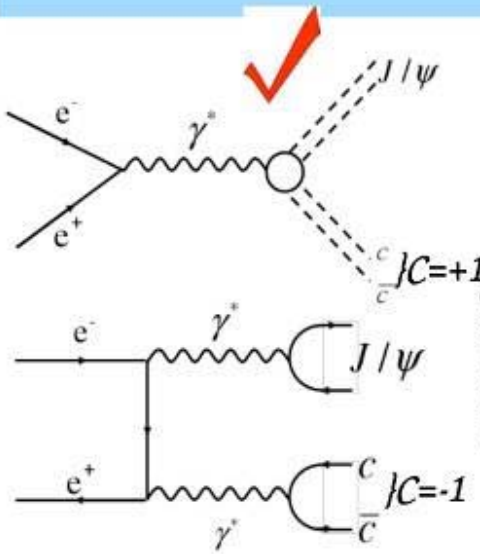
1) Second Fox-Wolfram moment
2) Super Fox-Wolfram (six modified Fox-Wolfram moments, Fisher discriminant)
3) Angle between B meson and beam axis direction
4) Angle between thrusts of selected B meson particles and all other particles in event

Likelihood ratio includes all info.

BaBar confirms $e^+e^- \to J/\psi\,(c\bar{c})_{res}$: J.Coleman @ Moriond QCD

Recoil Mass Spectrum

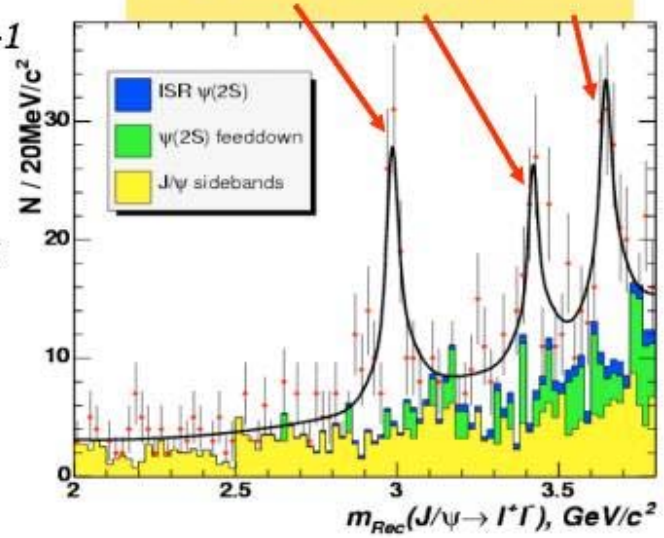
244 fb^{-1}



observe only C=+1 states

Observe

$\eta_c(1S)$ $\chi_c(1P)$ $\eta_c(2S)$



2004: $X(3872)$ charmonium exclusions

MESON 2004: "Search for a charmonium assignment for the $X(3872)$"
Int. J. Mod. Phys. **A20**, 240–249 (2005) [arXiv:hep-ex/0407033]

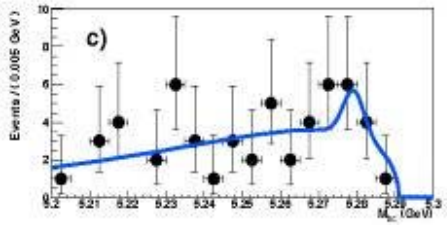
- X is narrow & $X \not\to D\overline{D}$ [R. Chistov *et al.*, *PRL* **93**, 051803 (2004)]
  $\longrightarrow$ disfavours natural $J^P = 0^+, 1^-, 2^+, \ldots$
- run through low-J charmonia with unnatural J^P:

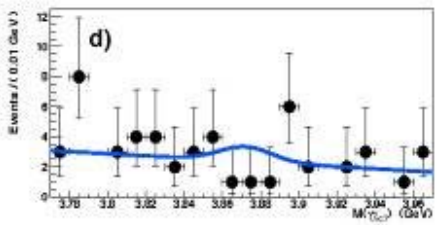
state	alias	J^{PC}	M_{pred}	Γ_{pred}	comment
1^3D_2	ψ_2	2^{--}	3838	0.7	Mass wrong; $\Gamma_{\gamma\chi_{c1}}$ too small
2^1P_1	h_c'	1^{+-}	3953	1.6	Ruled out by $\lvert\cos\theta_{J/\psi}\rvert$ distribution
1^3D_3	ψ_3	3^{--}	3849	4.8	M, Γ wrong; $\Gamma_{\gamma\chi_{c2}}$ too small; J too high
1^1D_2	η_{c2}	2^{-+}	3837	0.9	$\mathcal{B}(\pi^+\pi^- J/\psi)$ expected to be very small
2^3P_1	χ_{c1}'	1^{++}	3956	1.7	$\Gamma_{\gamma J/\psi}$ too small
3^1S_0	η_c''	0^{-+}	4060	~ 20	Mass and width are wrong

$$\frac{\Gamma(X \to \gamma\chi_{c1})}{\Gamma(X \to \pi\pi\psi)} < 0.89\ (90\%)$$

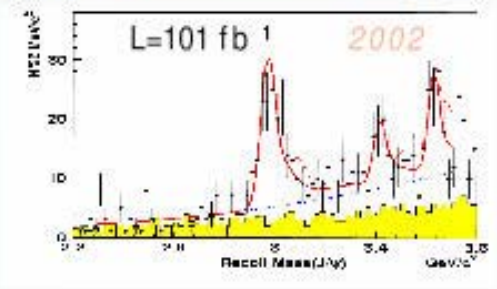
cf. ψ_2: > 1.6

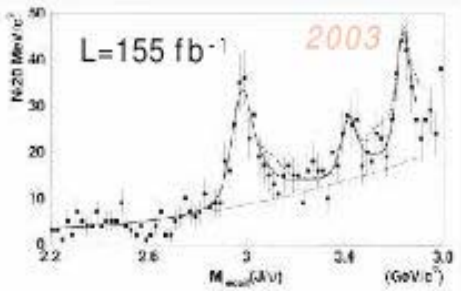
[potential / ψ' Wigner-Eckart]



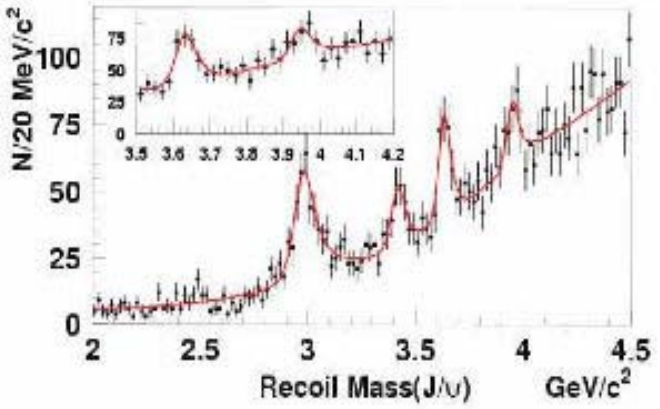


Recent update





Whole Belle data set collected by
July 2004 L=287 fb⁻¹



P.Pakhlov (ITEP, Moscow) 10

D_{sJ} confirmation: *PRL* **92**, 012002 (2004)

$D^*_{sJ}(2317) \to D_s\pi^0$

$M = 2317.2 \pm 0.5 \pm 0.9\,\text{MeV}$

confirming BaBar

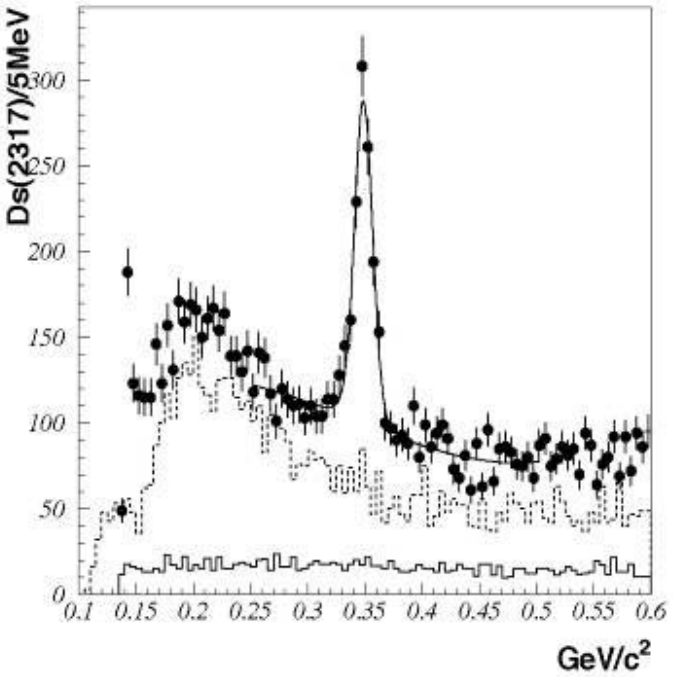
PRL **90**, 242001 (2003)

$D_{sJ}(2460) \to D^*_s\pi^0$

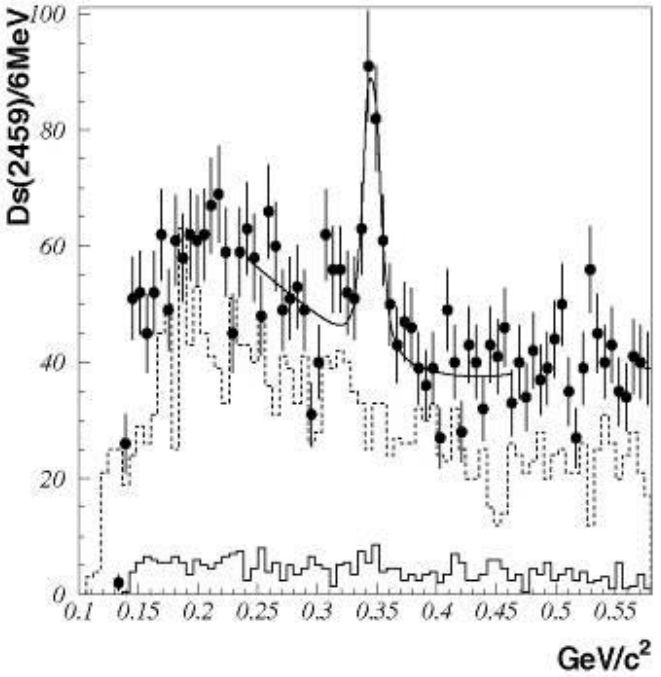
$M = 2456.5 \pm 1.3 \pm 1.3\,\text{MeV}$

confirming CLEO

PRD **68**, 032002 (2003)



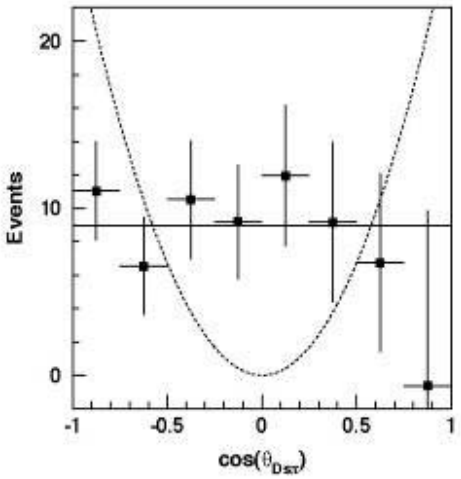
MC feed-down from $D^*_s\pi^0 \to D_s\pi^0$



fit to D^*_s-sideband subtracted dist^n

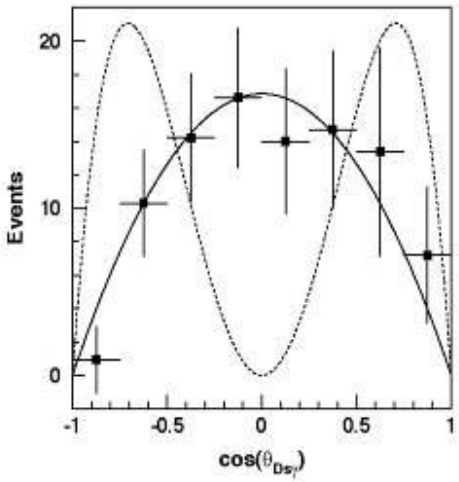
Updated $B \to \overline{D}^{(*)} D_{sJ}$: BELLE–CONF–0461

$D^*_{sJ}(2317) \to D_s \pi^0$



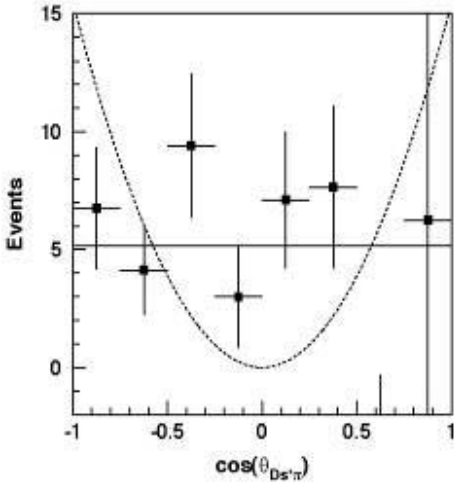
$J = 0$ favoured
$J = 1$ excluded

$D_{sJ}(2460) \to D_s \gamma$



$J = 1$ favoured
$J = 2$ excluded

$D_{sJ}(2460) \to D^*_s \pi^0$



S-wave favoured
D-wave disfavoured

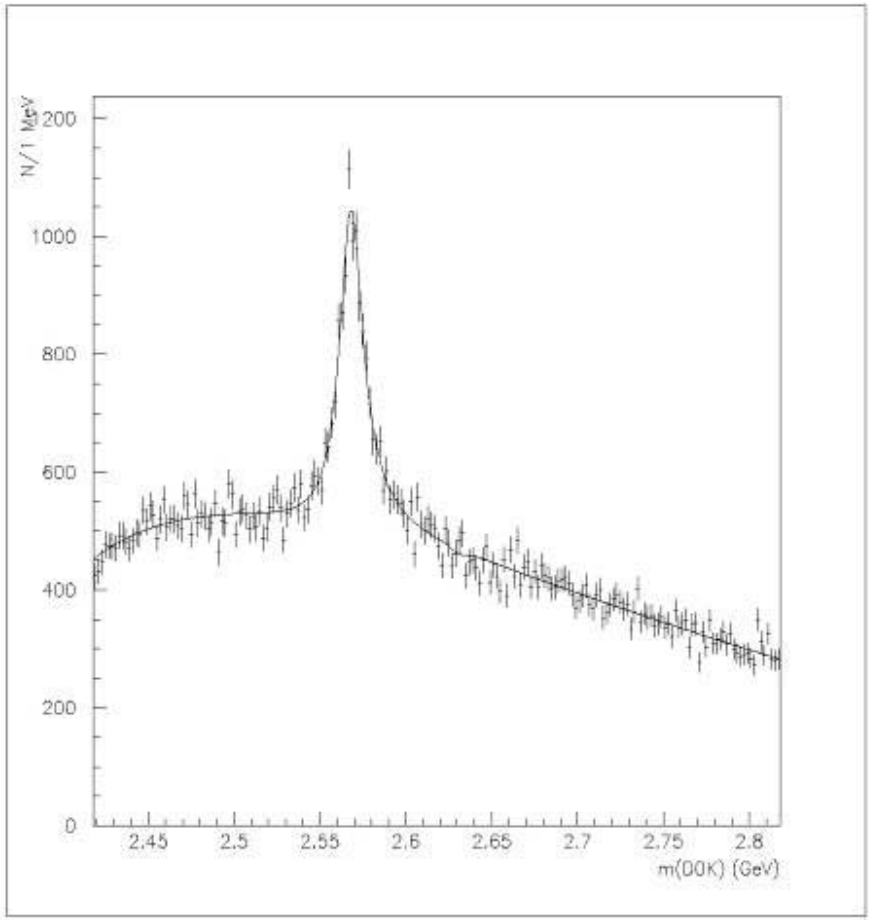
$B \to \overline{D}^* D_{sJ}(2460)$ also seen

$B \to \overline{D}^{(*)} D_{sJ}(2632)$ *not* seen

[the claimed SELEX state decaying $\to D_s \eta$, $D^0 K^+$]

$D_{sJ} \to D^0K^+$ search in continuum

- 155 fb^{-1}
- inclusive $p^*(D^0K^+) > 3.5\,GeV/c$
- $\mathcal{P}_{K/\pi} > 0.9$ cut on K^+
  suppress $D_1(2460)$ feed-down
- $|M(K\pi) - m_D|$ cut: 10 MeV
- fit $M(K^-\pi^+K^+) - M(K^-\pi^+)$:
  - in full range shown
  - 2573: relativistic B-W
  - bkgd: $(x - x_0)^a(x_1 - x)^b$
  - $\mathcal{G}(\Delta M_{SELEX}, \sigma_{SELEX})$
- $N_{2573} = 7292 \pm 164$
- $N_{2633} = -66 \pm 64$



$$\frac{\sigma(2633)\times\mathcal{B}(2633)}{\sigma(2573)\times\mathcal{B}(2573)} = (-0.93 \pm 1.08) \times 10^{-2};\ < 1.2 \times 10^{-2}\ (\text{stat}^l\ \text{only})$$

J^{PC} possibilities for X(3872)

- $J \leq 2$
- DD allowed & P-violating unlikely
  - signal for $X \rightarrow \gamma J/\psi$

➔ C=-1 ruled out

  - check of angular distributions

➔ rules out $1^{\pm -}, 0^{\pm +}, 2^{--}$

  - fits of $M_{\pi\pi}$

➔ 2^{-+} unlikely

  - $X(3872) = \chi_{c1}$'?

➔ unlikely, since mass and BR ratio way off theo. expect.

0^{--} *exotic* violates parity	0^{-+} (η_c'')	0^{++} DD allowed (χ_{c0}')	0^{+-} *exotic* DD allowed
1^{--} DD allowed $(\psi(3S))$	1^{-+} *exotic* DD allowed	1^{++} (χ_{c1}')	1^{+-} (h_c')
2^{--} (ψ_2)	2^{-+} (η_{c2})	2^{++} DD allowed (χ_{c2}')	2^{+-} *exotic* DD allowed