THE UNIVERSITY OF TOKYO

Flavor physics at B factories and hadron machines

Part 12: advances in hadron spectroscopy

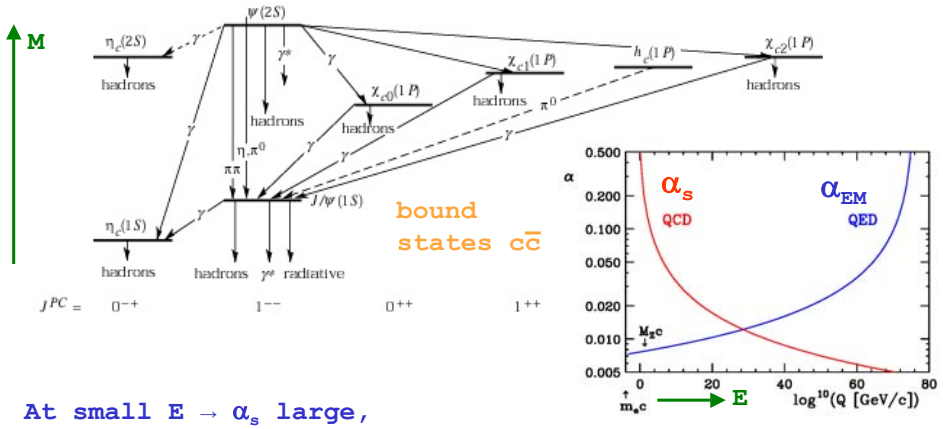
Peter Križan

University of Ljubljana and J. Stefan Institute

Contents

Introduction

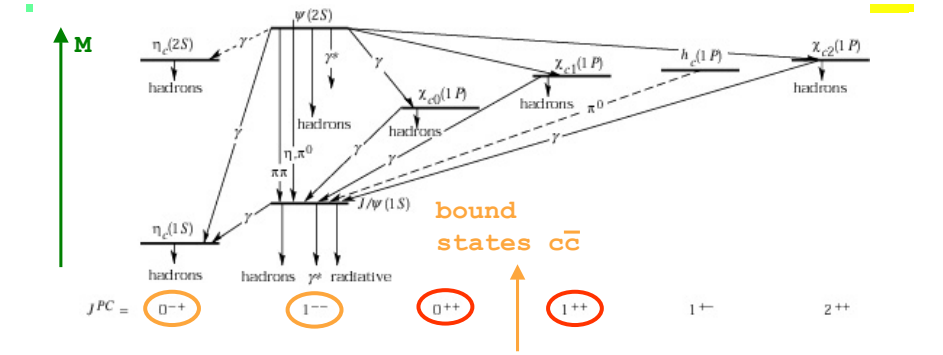
quark and anti-quark are bound by the strong force → mesons



At small E → α_s large,
Perturb. calculation does not work →models

Ljana

Introduction

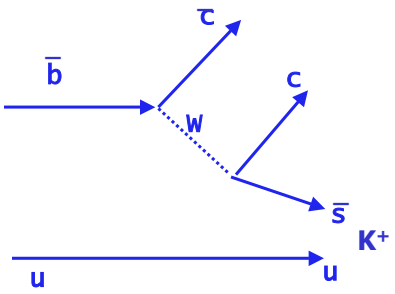


Checking the properties of predicted states =>
Understanding of strong force

meson spin: ½ ⊕ ½ → J = 0,1; L=1 → J = 0,1,1,2

parity (P): $(-1)\ (-1)^L = (-1)^{L+1}$

Search for missing charmonium states



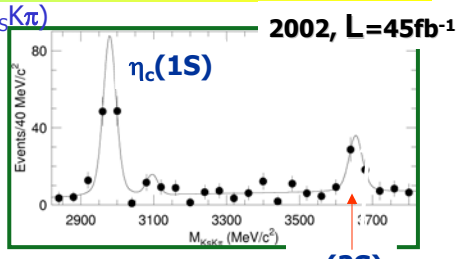
Charmonium production in B decays: accompanied with a kaon, e.g. $B^+ \to J/\psi\, K^+$

Look for missing charmonium states in $B^+ \to K^+ X$ decays

with X= some exclusive final state

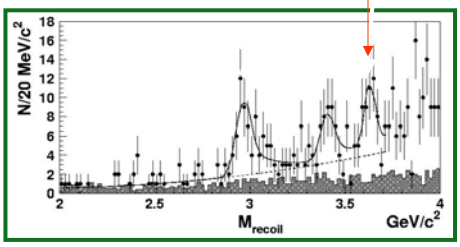
Discovery of $\eta_c(2S)$

First: $B \to K K_S K\pi$ (because $\eta_c(1S) \to K_S K\pi$)
→observation
Confirmed
•by Belle in e^+e^- annihilation (inclusive)
•by CLEO & BaBar in $\gamma\gamma$
⇒ PDG'05 full listing



$M = 3.638 \pm 0.005$ GeV/c²
$\Gamma = 14 \pm 7$ MeV/c²
$\Gamma_{\gamma\gamma}(\eta'_c) * B(\eta'_c \to K_S K^+\pi^-) / \Gamma\gamma\gamma(\eta_c) * B(\eta_c \to K_S K^+\pi^-) = 0.18 \pm 0.05 \pm 0.02$

the properties are in reasonable agreement with the expectations



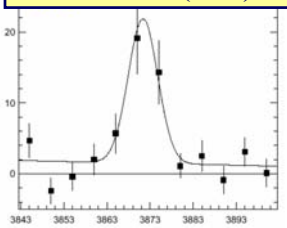
X(3872)

Belle observed a new state decaying into $J/\psi\ \pi^+\pi^-$

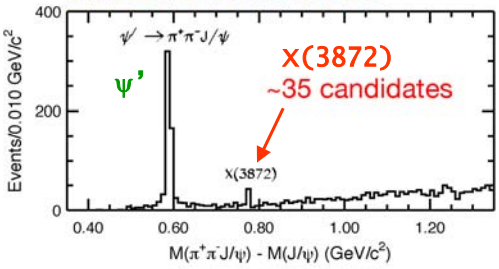
$B^+ \to K^+ X(3872)$

35±7 events
M=3872.0±0.8 MeV
Γ<2.3MeV (90%)

$X(3872) \to J/\psi\ \pi^+\pi^-$
$J/\psi \to l^+l^-$

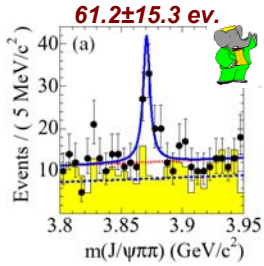


Belle, PRL 91 (2003) 262001
Mass 3872.0 ± 0.6 ± 0.5 MeV

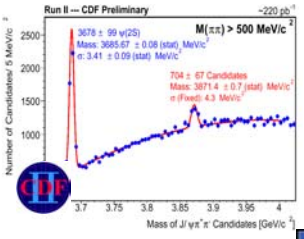


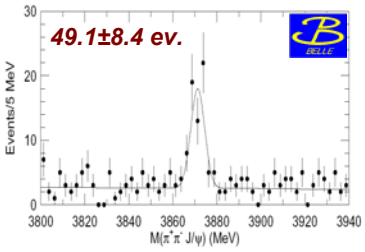
$M(J/\psi\ \pi^+\pi^-) - M(J/\psi)$ [GeV]

Confirmed by CDF,D0,BaBar

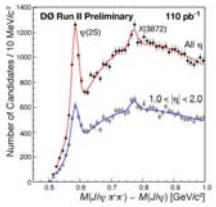


- Well established and included into PDG'05





- Not assigned yet to any charmonium state

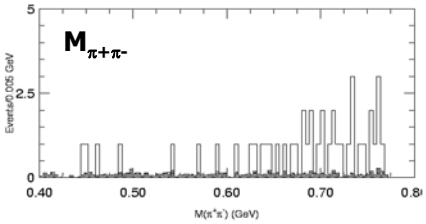


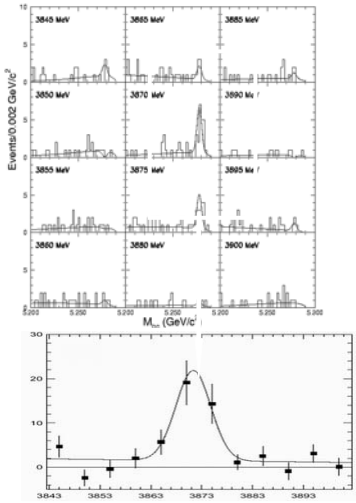
X(3872)

2003, L=140fb^{-1}

- Observed in $B^+ \to (J/\psi\pi\pi)K^+$
- $M_X = (3872.0 \pm 0.6 \pm 0.5)\,MeV/c^2$

  $M_X \approx M_D + M_{D^*}$
- $\Gamma < 2.3\,MeV/c^2$ at 90% CL
- Surprisingly: $M_{\pi^+\pi^-}$ tends to peak around limit ($J/\psi\,\rho$ is isospin violating decay)



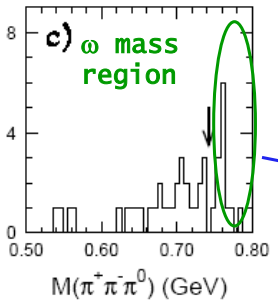


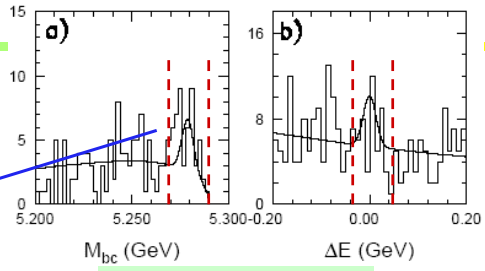
X(3872): more decays

Search for

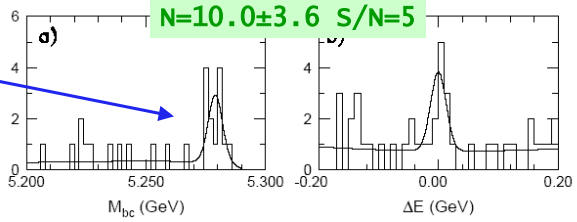
$B^+ \to K^+ X(3872)$

$\hookrightarrow J/\psi\ \pi^+\pi^-\pi^0$





N=10.0±3.6 S/N=5



$\Gamma(\omega\,J/\psi)/\Gamma(J/\psi\ \pi^+\pi^-) = 0.8 \pm 0.3 \pm 0.1$

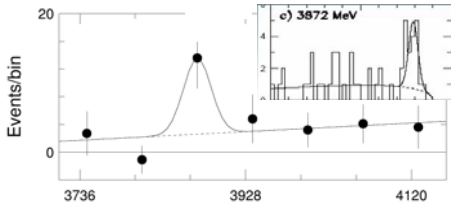
in accordance with $D\bar{D}^*$ molecule model

Swanson, PLB 588,189(2004)

X(3872): new decays

No.of B→J/ψγ K in bins of M(γJ/ψ)

2005, L=256fb^{-1}



13.6±4.4 ev. (4σ)

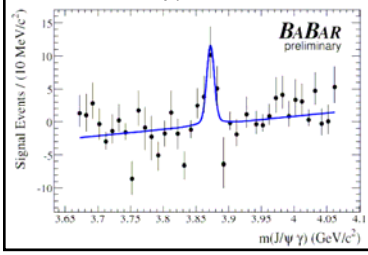
X(3872) → J/ψγ

Use B→χ_{c1}K as a reference

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

No.of B→J/ψγ K in bins of M(γJ/ψ)

2005, L=288fb^{-1}



$$B[B \to KX(3872), X(3872) \to J/\psi\gamma] = (3.4 \pm 1.0 \pm 0.3) \times 10^{-6}$$

BaBar confirms X(3872) → J/ψγ

C(X(3872))=+1

X(3872): new decays

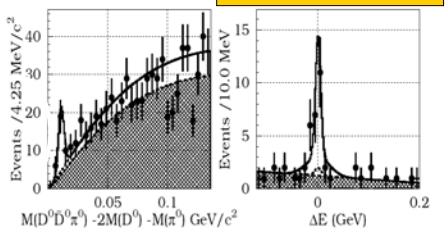
X(3872)→D^{0}D^{0}π^0

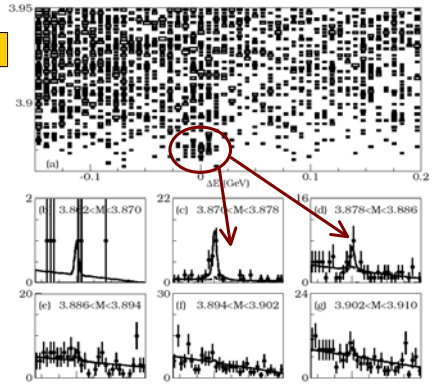
2005, L=256fb^{-1}

B→D^{0}D^{0}π^0 K signal region

M(D^{0}D^{0}π^0): enhancement at M$_X$

N=24±6 6.4σ





$$\frac{B(X \to D^0 D^0 \pi^0)}{B(X \to J/\psi\pi^+\pi^-)} = 3.0 \pm 1.0$$

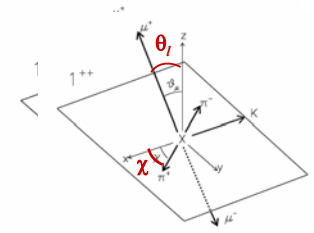
Spin =2 or greater disfavored: d-, f- … wave around threshold

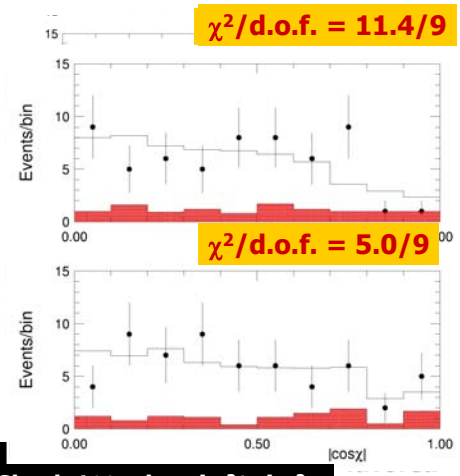
M=3875.4±0.7±0.4±0.1 MeV

Angular analysis

5 particles in the final state ($B \to ll\pi\pi K$) – 1 conservation law = 4 independent vectors = 6 independent angular distributions

Examine J^{PC} hypothesis one by one, choosing the most distinctive angular distribution for each





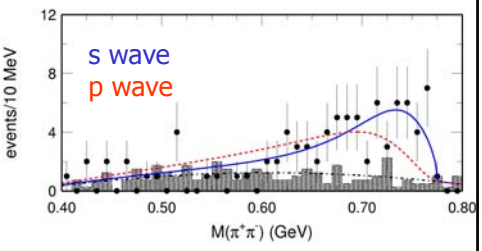
2005, $L=256fb^{-1}$

Check 1^{++} : $d\Gamma \sim \sin^2\theta \sin^2\chi$

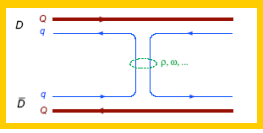
X(3872) quantum numbers

- New decay modes ⇒ C=+1, J≤1
- Angular analysis ⇒ J≠0
- M(ππ) shape favors s-wave ⇒ P=+1

2005, $L=256fb^{-1}$



Quantum numbers are fixed $J^{PC}=1^{++}$ corresponds to χ_{c1}', but
- $\chi_{c1}' \to J/\psi\gamma$ should be much stronger than $\chi_{c1}' \to J/\psi\pi\pi$ (measured ratio ~0.15, expected ~ 30)
- ~100MeV/c^2 lighter than expected.
Possible interpretion: D^0D^{*0} molecule:
- Large isospin violation expected
- $J^{PC}=1^{++}$ predicted

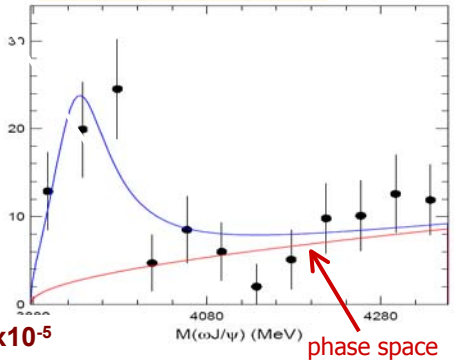


Y(3940)

$B \to J/\psi\omega K$ signal is scanned in bins of $M(J/\psi\omega)$:
broad enhancement around threshold

2004, $L=253fb^{-1}$

M=3940±11 MeV/c²
Γ=92±24 MeV/c²



Threshold effect or particle?
-The mass is well above DD* threshold and decay to J/ψω should not be dominant if Y=charmonium
cc-gluon hybrid?
- Large B(J/ψ , ψ′ + light hadrons), decays to DD(*) are suppressed, expected width is ~100MeV/c².
- However according to lattice QCD M ~ 4.5 GeV/c².

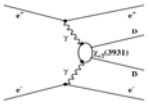
$B(B \to YK) \times B(Y \to J/\psi\omega) = (7.1 \pm 1.3 \pm 3.1) \times 10^{-5}$

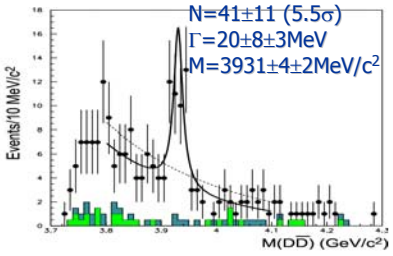
χ_{c2}' in $\gamma\gamma$ production

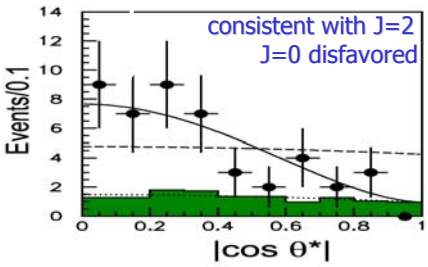
Peak at $M_{DD} \sim 3.930$ GeV/c² in selected $\gamma\gamma$ events
p_t distribution consistent with $\gamma\gamma$ production

2005, $L=395fb^{-1}$

Helicity distribution favors spin = 2
J=0 disfavored $\chi^2/dof = 23.4/9$





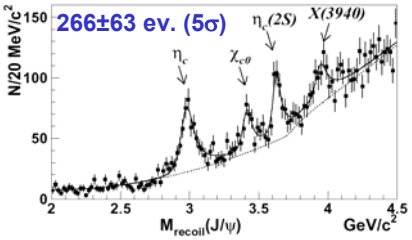


The observed state is χ_{c2}'

$(2J+1)\Gamma\gamma\gamma \times B(Z \to DD) = (1.13 \pm 0.30)$keV

X(3940) in ee annihilation

2005, L=357fb^{-1}

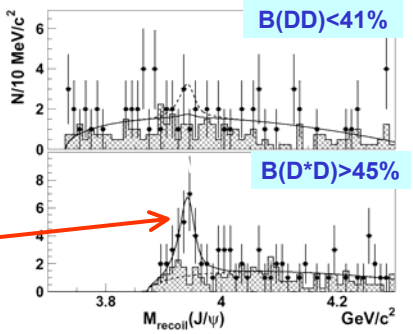


Reconstruct $J/\psi \to ll$
Form $M_{recoil}(J/\psi) \equiv M_X$

- Reconstruct J/ψ + D
- Refit $M_{recoil}(J/\psi) \to M_{D(*)}$

From X(3940) → D*D:
M = (3943 ± 6 ± 6) MeV
Γ < 52 MeV at 90%CL

24.5±6.9 ev.
5σ

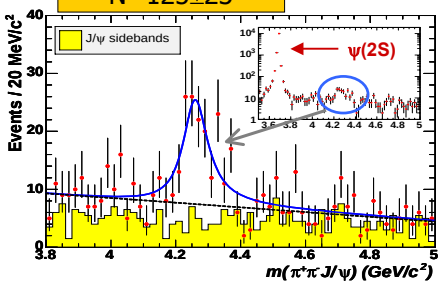


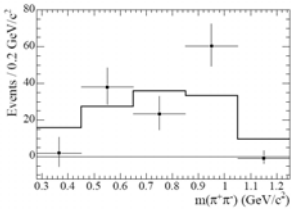
Possible interpretation: $\eta_c(3S)$?

Y(4260) in $e^+e^- \to \gamma$ X (radiation return)

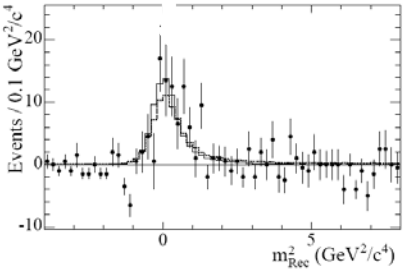
2005, L=357fb^{-1}

N=125±23



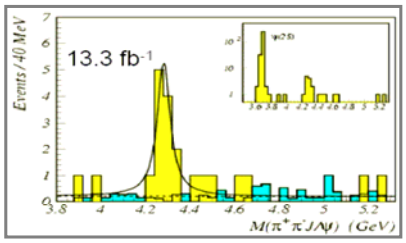


- Observed in ISR events in ($J/\psi\pi\pi$) mass spectra
- M_Y=4260 MeV/c^2
- Γ = 90MeV/c^2
- Recoil mass ($J/\psi\pi\pi$) is consistent with ISR expectations



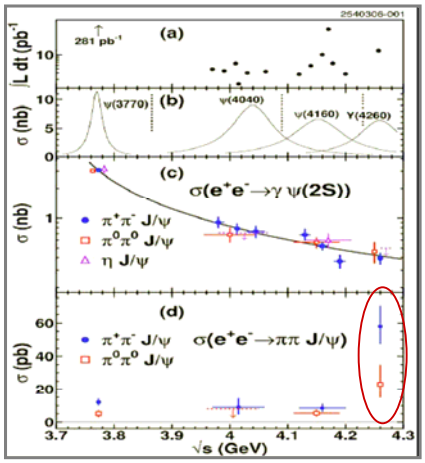
Y(4260) at CLEO

Confirmed by CLEO-III: **L=13.3fb^{-1}**



- $\sigma(ee \to J/\psi\pi^+\pi^-) = 58 \pm 11 \pm 4$ pb 11 σ
- $\sigma(ee \to J/\psi\pi^0\pi^0) = 23 \pm 11 \pm 1$ pb 5.1 σ
- $\sigma(ee \to J/\psi\pi^+\pi^-) = 9 \pm 9/5 \pm 1$ pb 3.7 σ

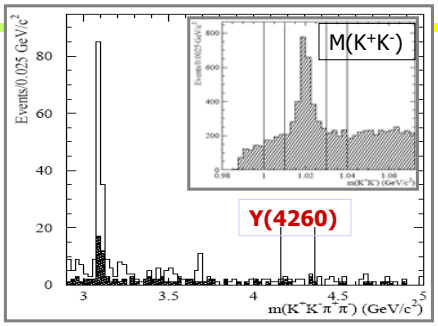
... and by CLEO-c scan:



Y(4260): other final states

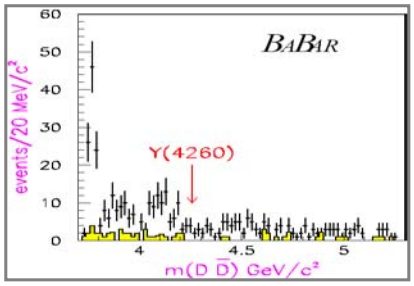
Y(4260) → ππφ: no signal

$$\Gamma_{ee}^{Y} \times B(Y(4260) \to \pi^+\pi^-\phi) < 0.4\,\text{eV}\,@\,90\%\,\text{CL}$$



Y(4260) → pp̄: nothing seen

$$\frac{B(Y(4260) \to p\bar{p})}{B(Y(4260) \to \pi^+\pi^- J/\psi)} < 0.13\,@\,90\%\,\text{CL}$$



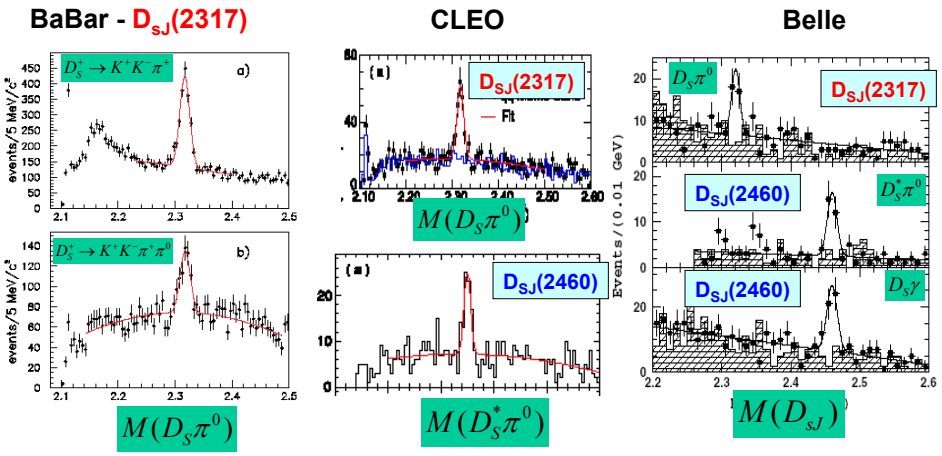
Not found in Y(4260) → D$\bar{D}$

$$\frac{B(Y(4260) \to D\bar{D})}{B(Y(4260) \to \pi^+\pi^- J/\psi)} < 7.6\,@\,95\%\,\text{CL}$$

New charmonia, summary

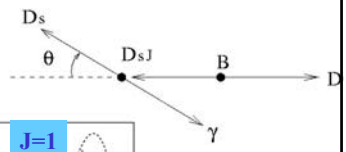
State	Mass (MeV)	Width (MeV)	Decay mode(s)	J^{PC}
X(3872)	3871.2 ± 0.6	<2.3 @ 90% CL	$\pi^+\pi^- J/\psi$ $\gamma J/\psi$ $D^0D^0\pi^0$	1^{++} I=0
X(3940)	3943 ± 9	<52 @ 90% CL	D^*D Not DD or $\omega J/\psi$	0^{-+} ?
Y(3940)	3943 ± 17	87 ± 34	$\omega J/\psi$	C=+ 1 I=0
Z(3930)	3929 ± 6	29 ± 10	DD	2^{++}
Y(4260)	$4259\ ^{+8}_{-10}$	$88\ ^{+24}_{-23}$	$\pi^+\pi^- J/\psi$, $\pi^0\pi^0 J/\psi$ Not $\pi^+\pi^-\phi$, DD, pp	1^{--} I=0

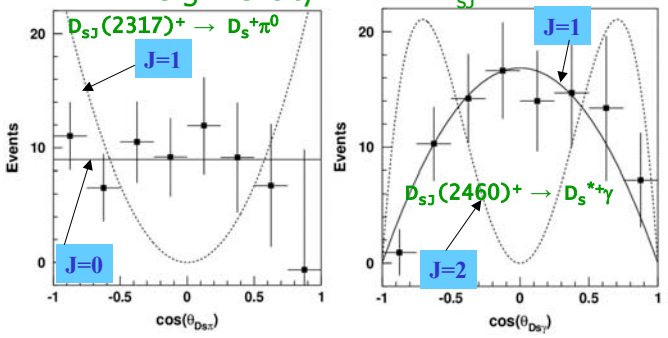
$D_{sJ}(2317)$ and $D_{sJ}(2460)$ mesons



D_{sJ} mesons

Properties studied
e.g. helicity in $B \to DD_{sJ}$



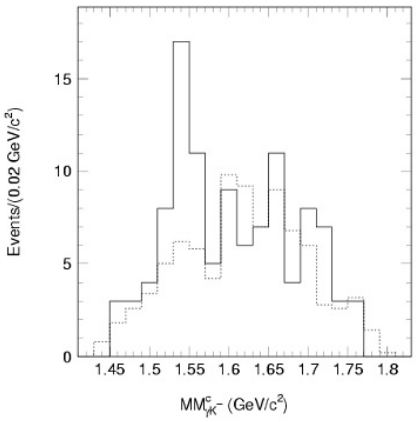


Properties in accordance with lowest level P states $J^P=0^+,1^+$
Masses lower than expected from models!

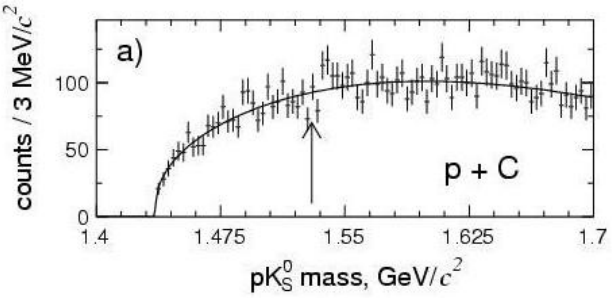
Pentaquarks

Pentaquark discovery in 2003 of a state θ^+ at 1.520 GeV which decays into
nK^+, $uud\bar{d}s$, was immediately confirmed by 10 experiments
statistical significance of individual expts is not high ~5-6 σ

Discovery by LEPS ->



HERA-B: no evidence for θ^+



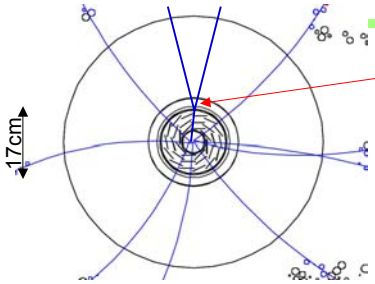
However many experiments DO NOT see pentaquarks

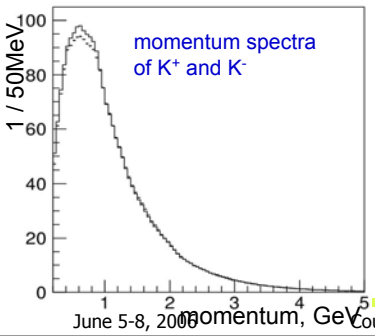
$\Rightarrow$ Situation IS NOT clear yet

$\Rightarrow$Experiments which do not see θ^+ pentaquark are mainly at HIGH energy
->While pentaquarks are seen mainly at LOW energies

$\Rightarrow$ Need for a high statistics experiment at LOW energy

Belle: Search for pentaquarks using kaon interactions in the detector material

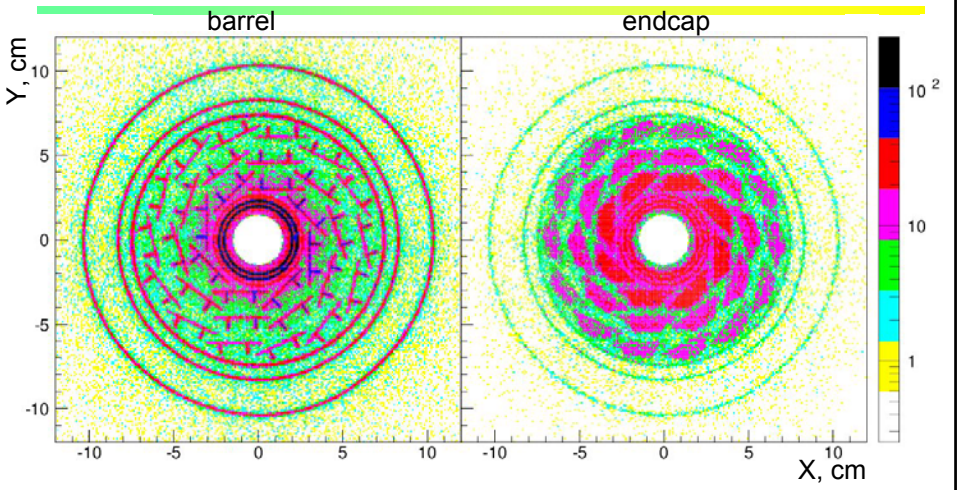




- Small fraction of kaons interacts in the detector material. Select secondary pK pairs to search for the pentaquarks.
- Momentum spectrum of the projectile is soft.
  $\Rightarrow$ low energy regime, similar to most experiments which observed pentaquark.
- Projectile is not reconstructed.
  $\Rightarrow$ K_S flavor is not fixed.
  $\Rightarrow$ can not distinguish between elastic and inelastic scattering.

- Secondary pK pairs selection:
  - p, $K^{\pm}$ do not originate from e^+e^- interaction point, identified using dE/dx, TOF and Cherenkov info
  - $K_S \rightarrow \pi^+\pi^-$ detached vertex, momentum is not pointing to e^+e^- interaction point
  - detached common pK vertex

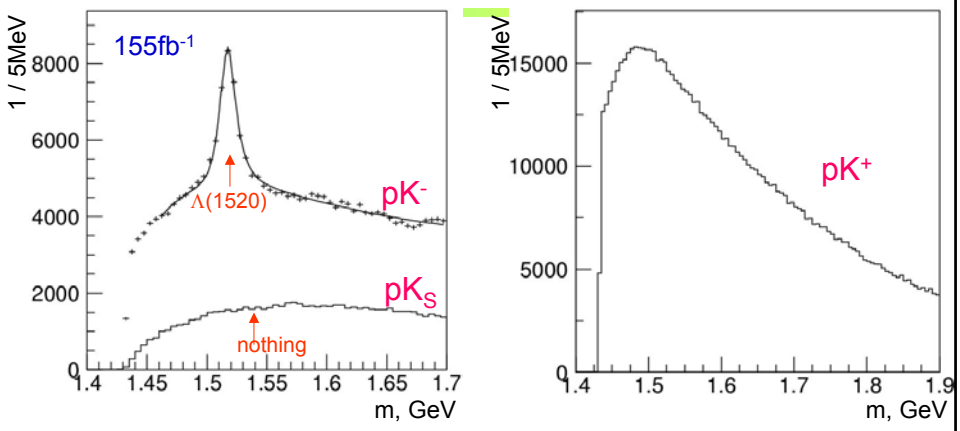
XY Distribution of Secondary pK^- Vertices in Data



"Strange particle tomography" of the detector.

$\Rightarrow$ Selected pK vertices originate from nuclear interactions.

Mass Spectra of Secondary pK Pairs



Fit M(pK^-) to D-wave BW $\oplus$ resolution function + threshold function.

$\Rightarrow$ **Λ(1520) yield is 15519±412 events**

M=1518.5±.2MeV in agreement with PDG'02 value 1519.5±1.0MeV

Summary

- New states renewed the interest in low energy QCD:
  - Great interest: ~800 references to "New charmonium" papers
- Still a lot of work to be done:
  - Study more carefully their properties experimentally
  - More theoretical ideas
- And hope for new discoveries in the nearest future

Charmonium spectroscopy