New Resonances and Spectroscopy (Belle)

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On behalf of the
Belle Collaboration

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MESON2006

- Introduction - Belle experiment
- $X(3782)$ properties
- $Y(3940)$
- $X(3940)$
- $Z(3930)$ - χ'_{c2} candidate
- New charm-strange baryons in $\Lambda_c^+ K^- \pi^+$ channel
- Summary

The Belle experiment

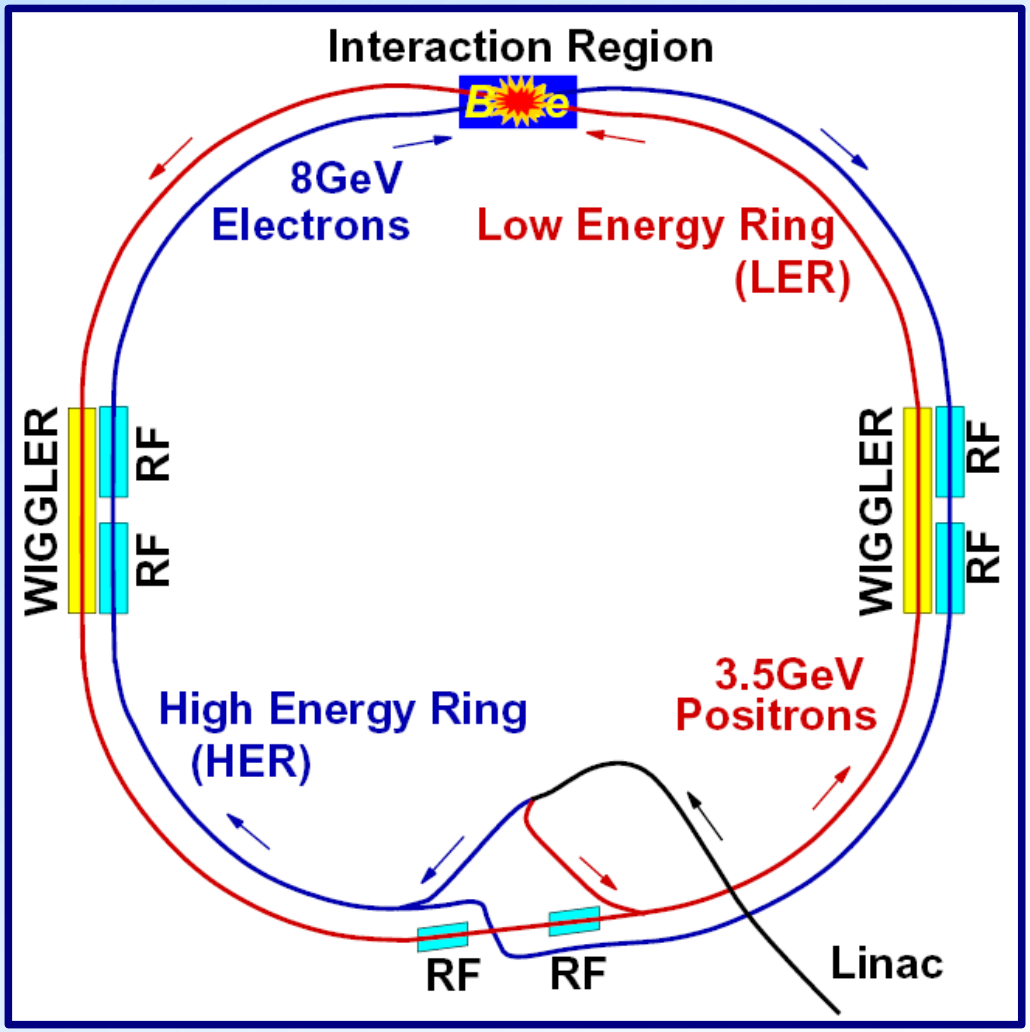
Excellent performance:

Main goal is to study CPV by measuring time-dependence of $B\bar{B}$ pair decays

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

- $\sqrt{s} = 10.58\,\text{GeV} \equiv M(\Upsilon(4S))c^2$
  $\to B^+B^-$ and $B^0\bar{B}^0$
- also produces $q\bar{q}, c\bar{c}, \tau^+\tau^-$ ...
  - $\sigma_{\Upsilon(4S)} \sim 1\,\text{nb}, \sigma_{c\bar{c}} \sim 1.3\,\text{nb}$
- peak performance:
  - $> 16 \times 10^{33}\,\text{cm}^{-2}\,\text{s}^{-1}$
    $(10^{33}\,\text{cm}^{-2}\,\text{s}^{-1} = \text{nb}^{-1}\,\text{s}^{-1})$
  - $> 1.2\,\text{fb}^{-1}/\text{day}$

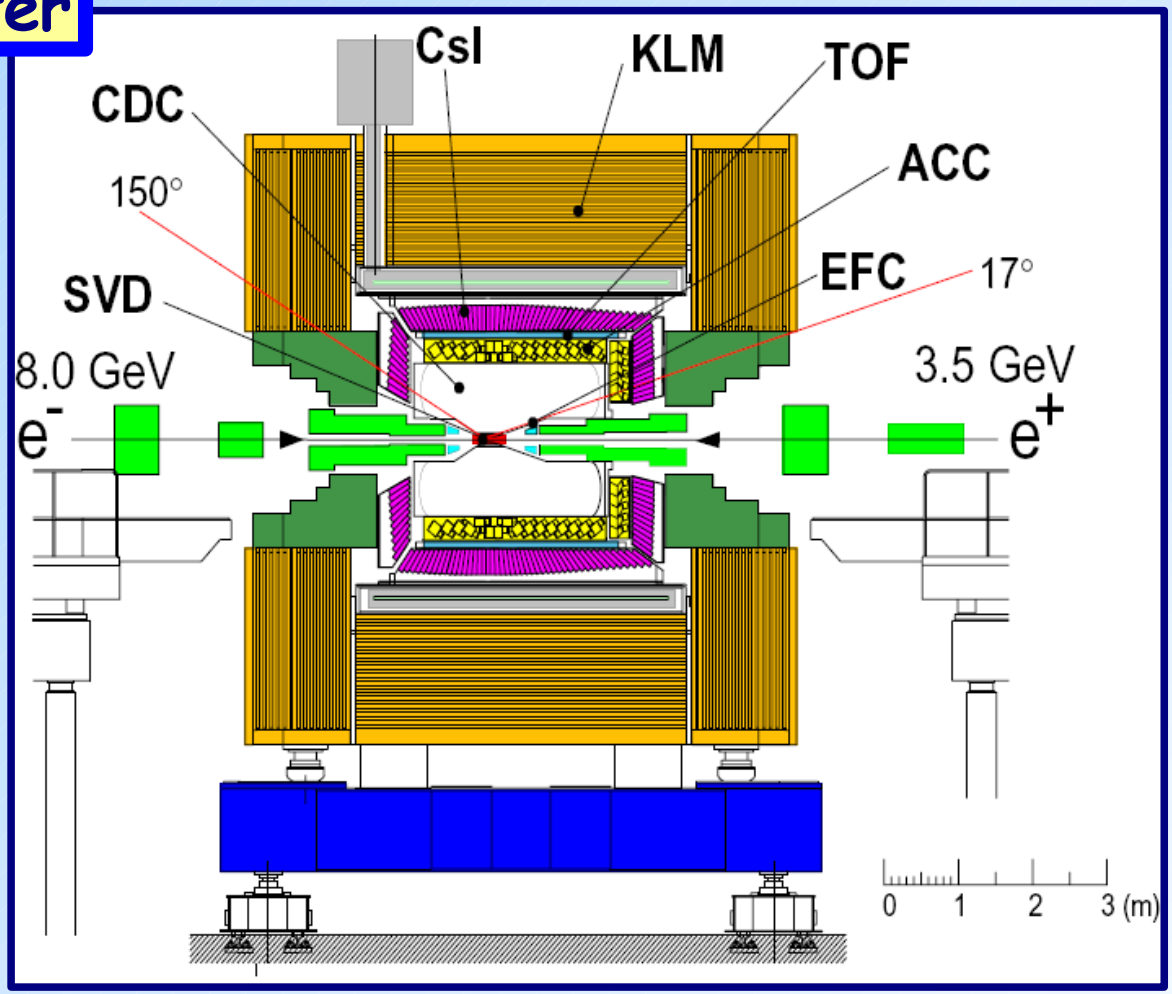
- $\int dt\,\mathcal{L} > 600\,\text{fb}^{-1}$
- single collision point ...



The Belle spectrometer

- 1.5 T solenoid
- 3(4)-layer SVD, 50-layer CDC

- $\frac{\sigma_{p_T}}{p_T} = (0.19 p_T \oplus 0.3)\%$
- $\sigma_{xy} = (19 \oplus \frac{49}{p\beta \sin^{3/2}\theta})\mu m$
- $\sigma_z = (28 \oplus \frac{41}{p\beta \sin^{5/2}\theta})\mu m$
- $\frac{\sigma_E}{E} = (1.3 \oplus \frac{0.07}{E} \oplus \frac{0.8}{E^{1/4}})\%$



- PID:
  - $\sigma_{dE/dx} = 6.9\%$
  - $\sigma_{TOF} = 95\,ps$
  - aerogel Čerenkov
  - +ECAL, dE/dx etc. for $e^{\pm}$ ID ...
  - +KLM (K^0_L and μ system) ...

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

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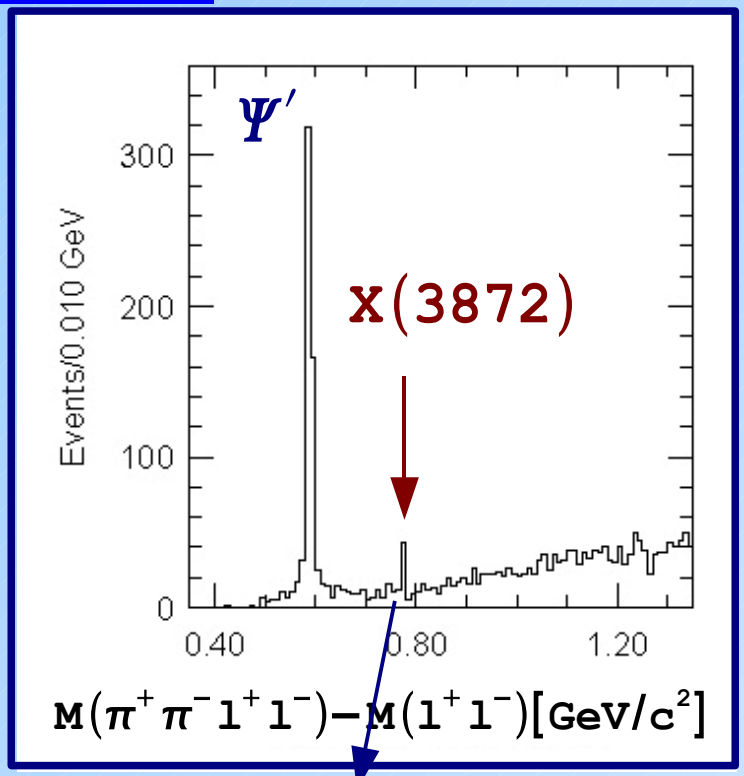
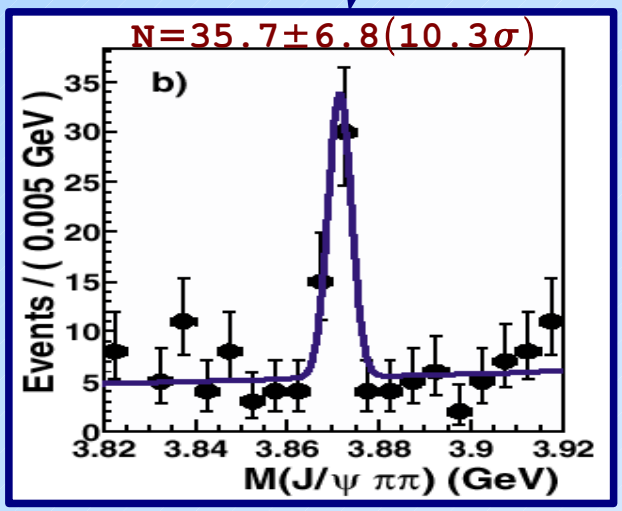
X(3872) : observation

PRL 91, 262001 (2003)

~152M $B\bar{B}$ pairs





- observed in the decay channel

$$B^{\pm} \to J/\Psi \pi^+ \pi^- K^{\pm}$$

New state properties:

- $M_{X(3872)} = (3872.0 \pm 0.6 \pm 0.5)\ \mathrm{MeV}/c^2$
- $\Gamma_{X(3872)} < 2.3\ \mathrm{MeV}$ @ 90% C.L.
- $\mathrm{Br}(B \to XK) \times \mathrm{Br}(X \to J/\Psi \pi^+ \pi^-) = (1.31 \pm 0.24 \pm 0.13) \times 10^{-5}$

- initial expectation: charmonium state, disfavored by subsequent observations
- possible alternative - $D\bar{D}^*$ molecule

M.Bander, G.L.Shaw and P.Thomas, Phys. Rev. Lett. **36**, 695 (1976) ...
S.Godfrey and J.Napolitano, Rev. Mod. Phys. **71**, 1411 (1999)

- next: - search for decay modes
  - determination of J^{PC}

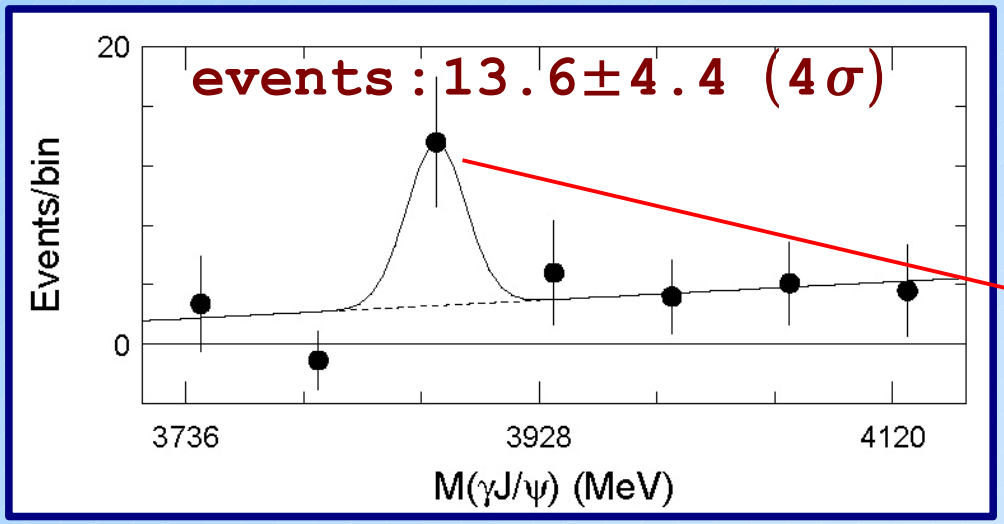
$X(3872): \gamma J/\Psi$

hep-ex/0505037 (2005)

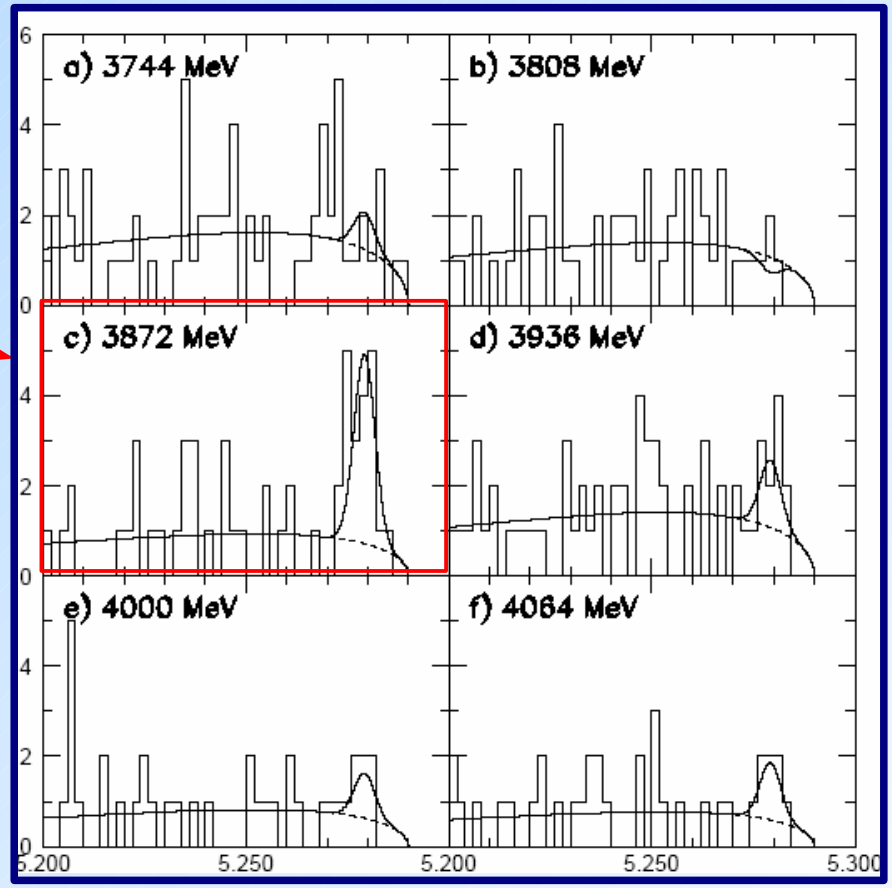
~275M $B\bar{B}$ pairs

$B^{\pm} \to X(\gamma J/\Psi) K^{\pm}$

No. of B's in bins of $M(\gamma J/\Psi)$



Fit M_{BC} in bins of $M(\gamma J/\Psi)$



- strong evidence for $X \to \gamma J/\Psi$

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

- ratio expected much larger and mass is to small for χ'_{c1} interpretation

$C(X(3872)) = +1$

$$M_{BC} = \sqrt{E^2_{beam} - \left(\sum_i \vec{p}_i\right)^2}$$

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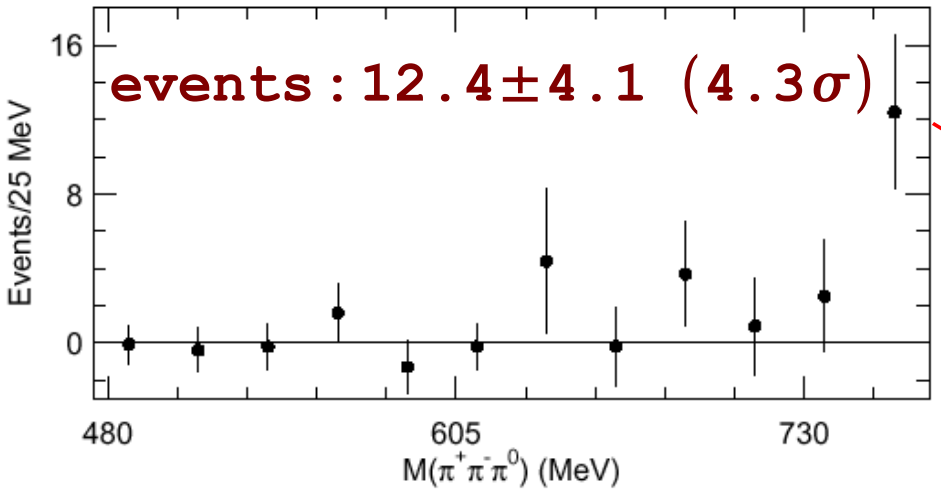
$X(3872): \pi^+\pi^-\pi^0 J/\Psi$

$B^\pm \to \pi^+\pi^-\pi^0 J/\Psi K^\pm$

hep-ex/0505037 (2005)

~275M $B\bar{B}$ pairs

No. of B's in bins of $\pi^+\pi^-\pi^0$

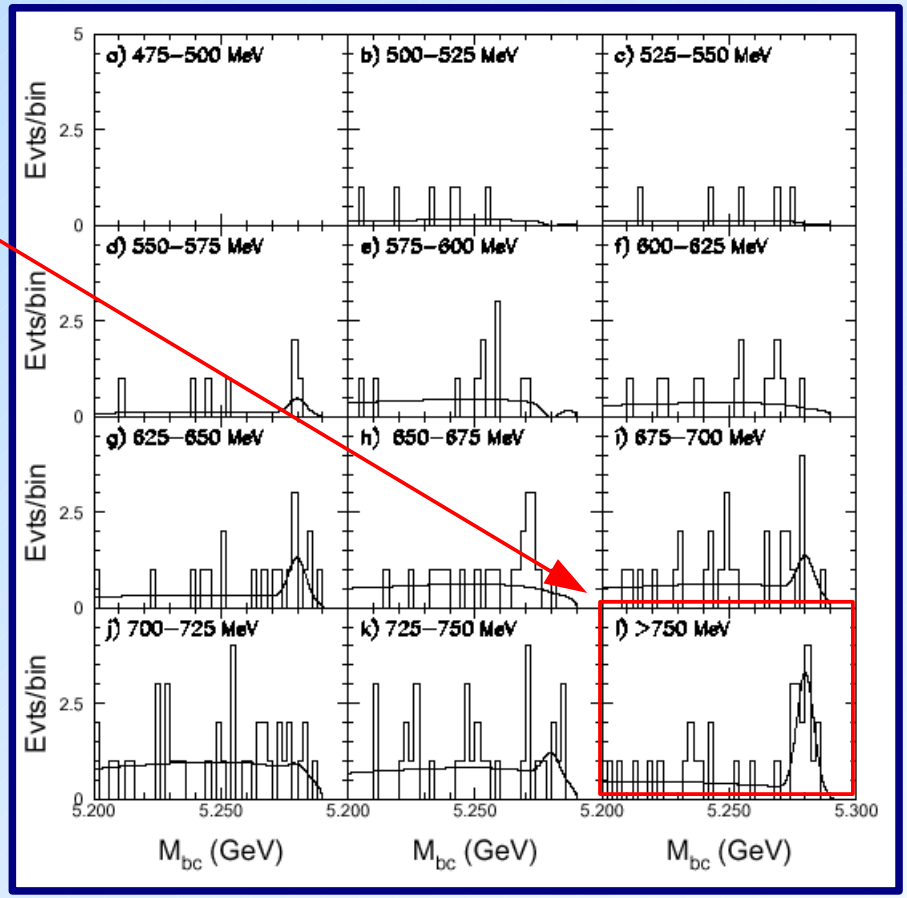


- **dominated by sub-threshold decay $X \to \omega J/\Psi$**

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

$M(J/\Psi\pi^+\pi^-\pi^0)$ around $M(X)$

Fit M_{BC} in bins of $\pi^+\pi^-\pi^0$



Large isospin violation:

- hard to accommodate in charmonium interpretation
- natural consequence in $D\bar{D}^*$ molecule model

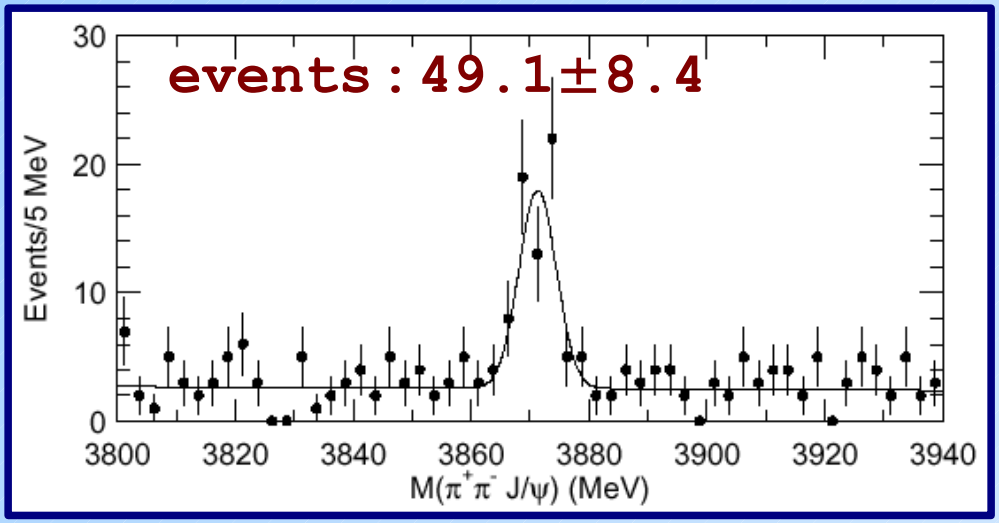
N.A. Törnqvist, Phys. Lett. B **590**, 209 (2004)
E.S. Swanson, Phys. Lett. B **588**, 189 (2004)

X(3872) : J^{PC}- angular distributions

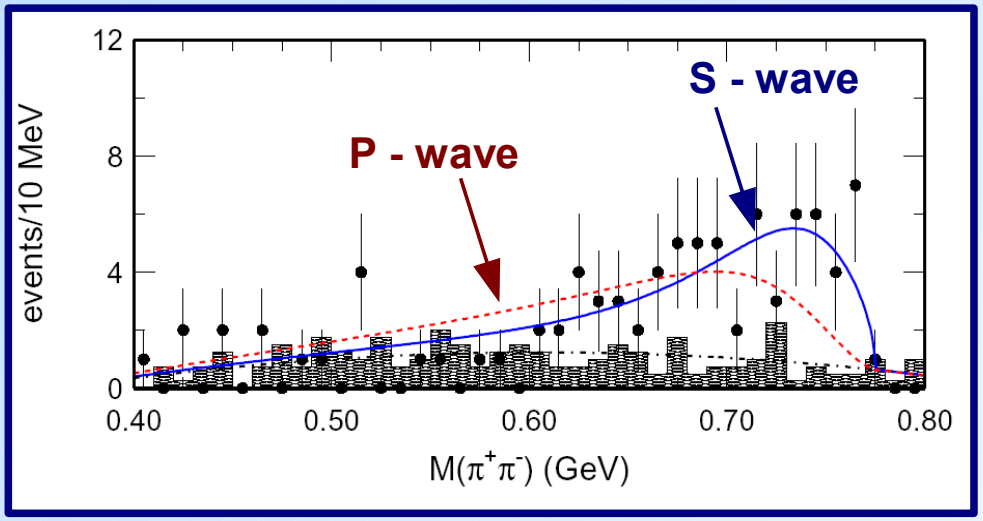
hep-ex/0505038 (2005)

~275M $B\bar{B}$ pairs

$B^{\pm} \to X(J/\Psi \pi^+ \pi^-) K^{\pm}$



$X \to J/\Psi \rho$



Angular distribution study:

- signal region ± 5MeV/c^2
- 58 events – 11.4±1.1 background
- S/N ~ 4

- J/Ψ and ρ in relative S - wave
  $\chi^2/ndf = 43/39$
- J/Ψ and ρ in relative P - wave
  $\chi^2/ndf = 71/39$

J^{++} favored over J^{-+}

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X(3872) : J^{PC}- angular distributions

hep-ex/0505038 (2005)

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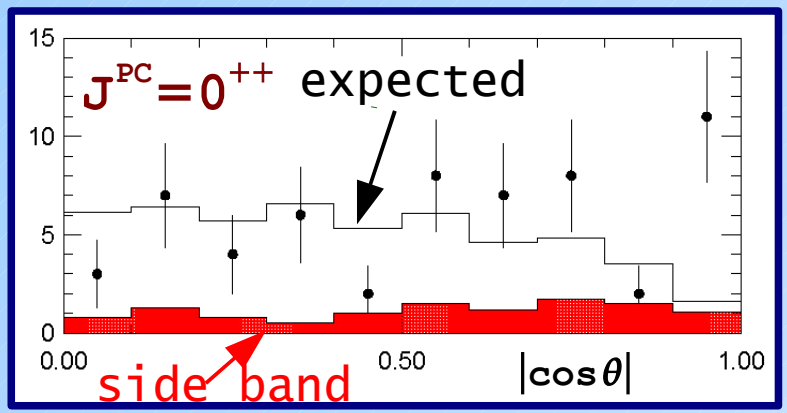
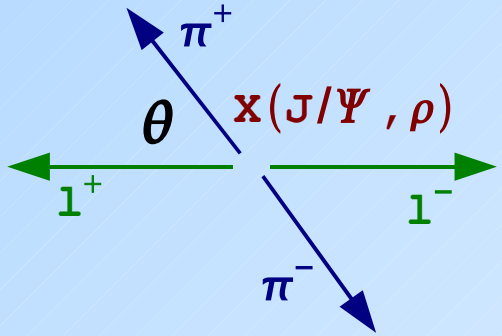
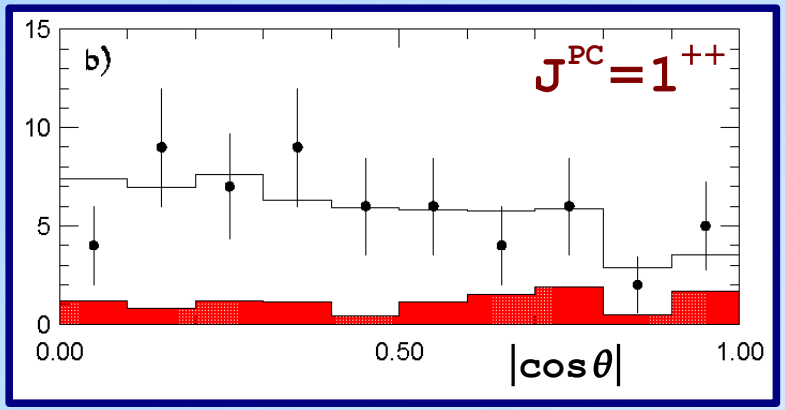
$B^{\pm} \to X(J/\Psi \pi^+ \pi^-) K^{\pm}$

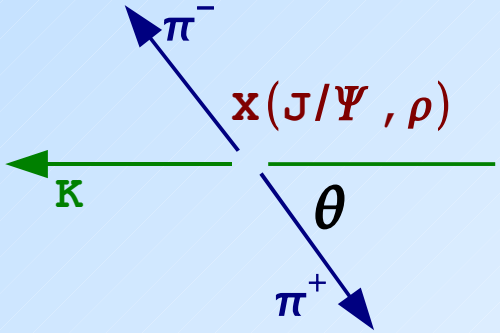
examples:





- poor agreement
  $\chi^2/ndf=31/9$
- $J^{PC}=0^{++}$ disfavored





- good agreement
  $\chi^2/ndf=5/6$

J.L.Rosner, Phys. Rev. D **70**, 094023 (2004)
D.V.Bugg, Phys. Rev. D **71**, 016006 (2005)

similar angular distributions for other J^{PC} were tested:

remaining possibilities: $J^{PC} = 1^{++}$ or 2^{++}

$X(3872): D^0\bar{D}^0\pi^0,\ D^0\bar{D}^{*0}$

Preliminary

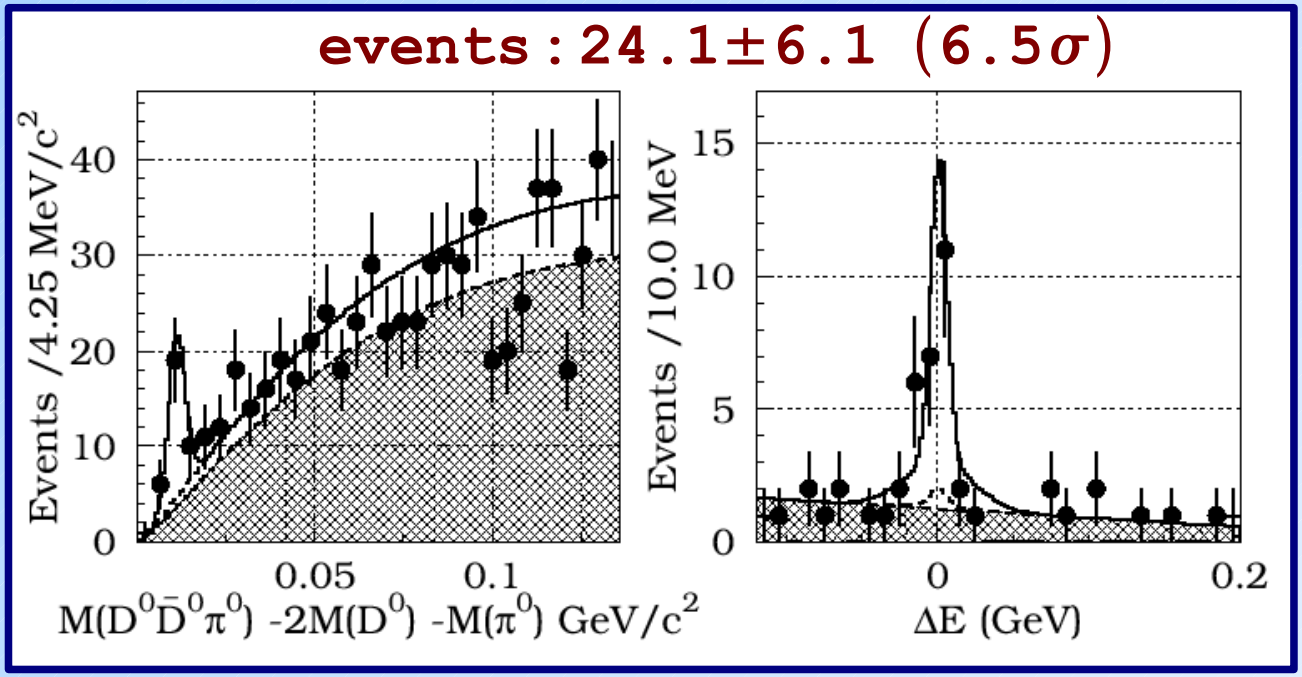
~447M $B\bar{B}$ pairs

$B \to X(D^0\bar{D}^0\pi^0)K$

- near-threshold $D^0\bar{D}^0\pi^0$ invariant mass enhancement observed

  $M = 3875.4 \pm 0.7 \pm 0.4 \pm 1.0\ \mathrm{MeV}/c^2$

- $D^0\bar{D}^{*0}$ and $D^0\bar{D}^0\pi^0$ can not be distinguished



$Br(B \to D^0\bar{D}^0\pi^0 K) = (1.27 \pm 0.31 \pm 0.21) \times 10^{-4}$

expected to be suppressed for near-threshold decays

If this is X(3872): $J^{PC} = 1^{++}$ is favored over $J^{PC} = 2^{++}$

$\rightarrow$ $D^0\bar{D}^{*0}$ bound state

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$Y(3940)$: observation

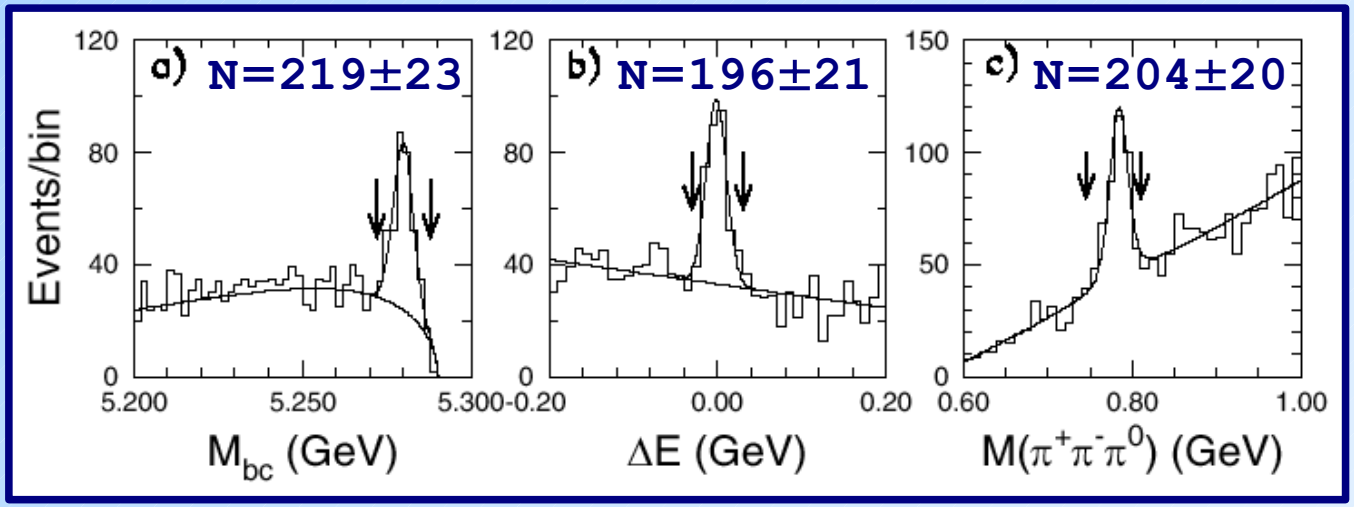
$B \to Y(J/\Psi\,\omega)K$

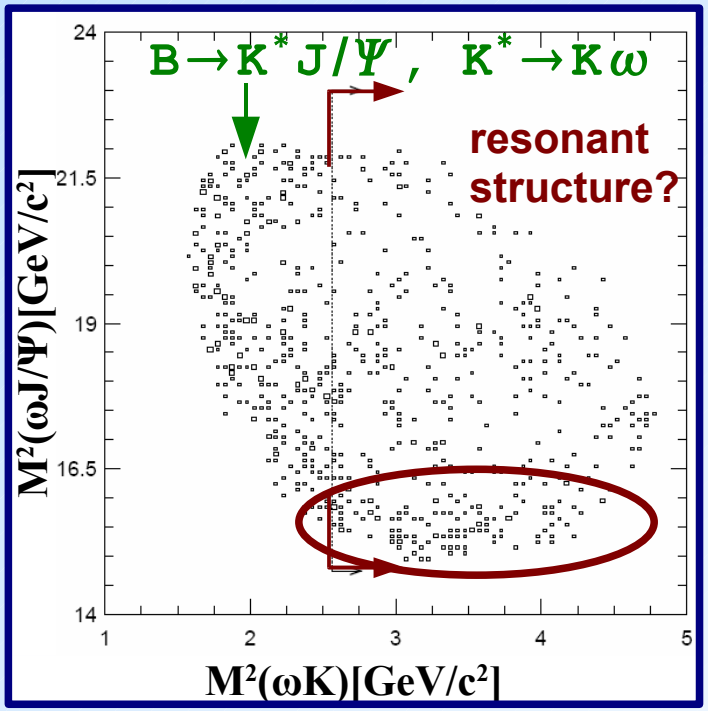
PRL 94, 182002 (2005)

~275M $B\bar{B}$ pairs

- study decays $B \to \pi^+\pi^-\pi^0 J/\Psi K$
- require $M(\omega K) < 1.6\,GeV/c^2$ to avoid strange meson resonances

$B \to J/\Psi\,\omega K$ signal:





Dalitz plot for $B \to K\omega J/\Psi$

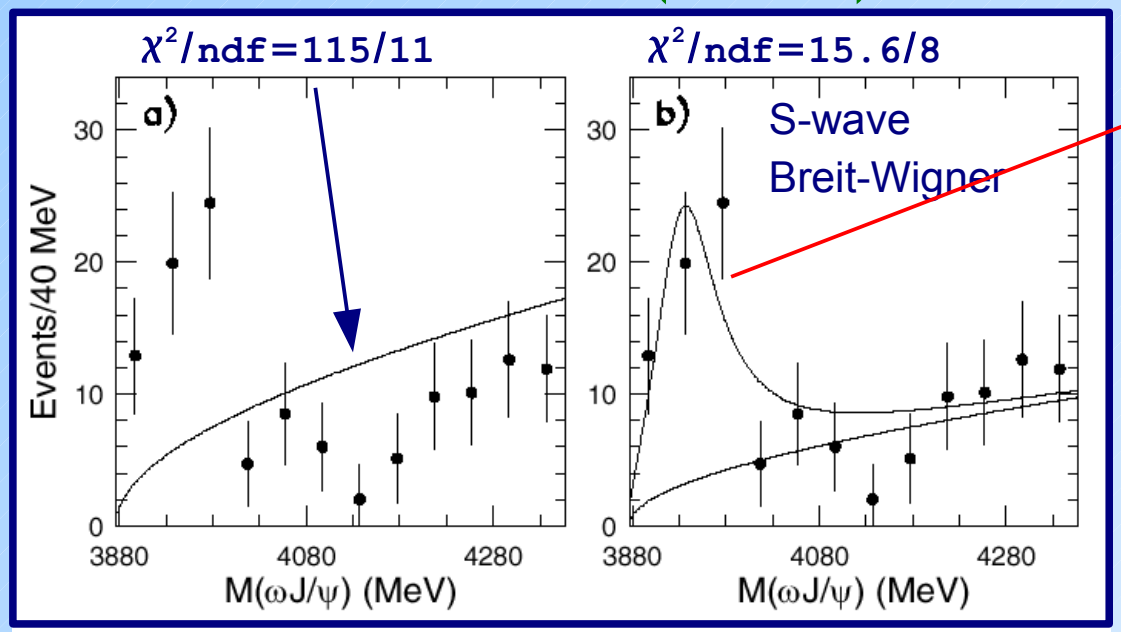
$Y(3940)$: observation

$B \to Y(J/\Psi\omega)K$

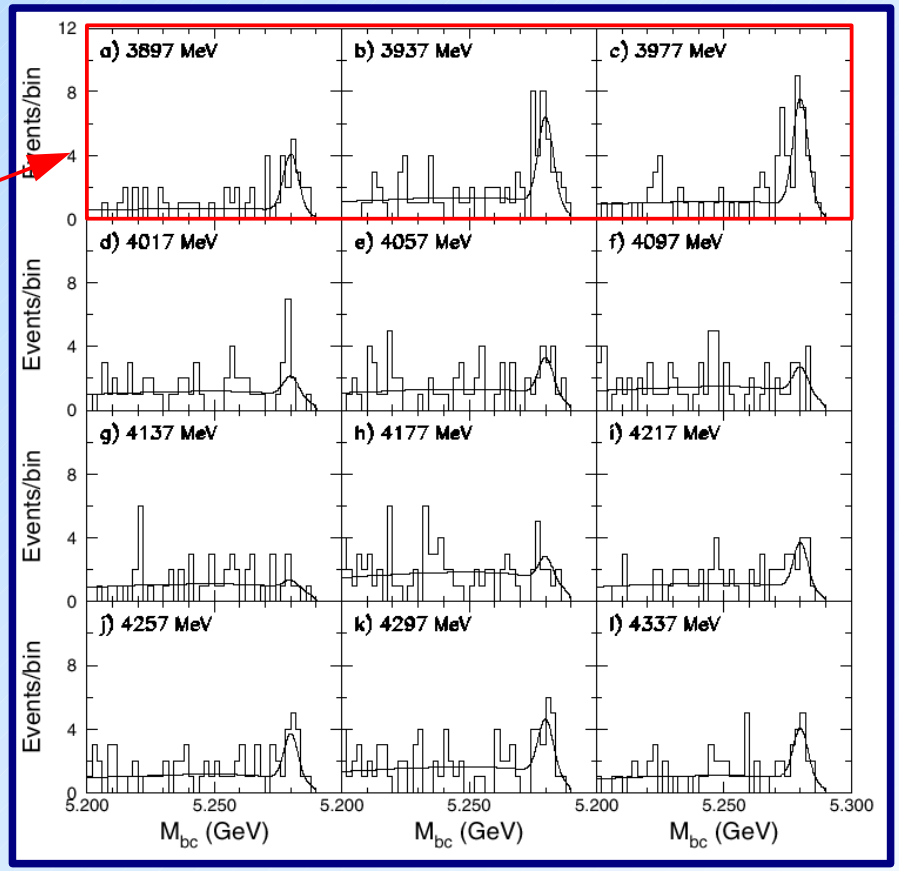
PRL 94, 182002 (2005)

~275M $B\bar{B}$ pairs

No. of B's in bins of $M(\omega J/\Psi)$



Fit M_{BC} in bins of $M(\omega J/\Psi)$



- significant deviation from phase-space (8.1 σ)
- 58 ± 11 events

Resonance properties:

- $M_{Y(3940)} = (3943 \pm 11 \pm 13)\,MeV/c^2$
- $\Gamma_{Y(3940)} = 87 \pm 22 \pm 26\,MeV$

$c\bar{c}c\bar{c}$: update & X(3940)

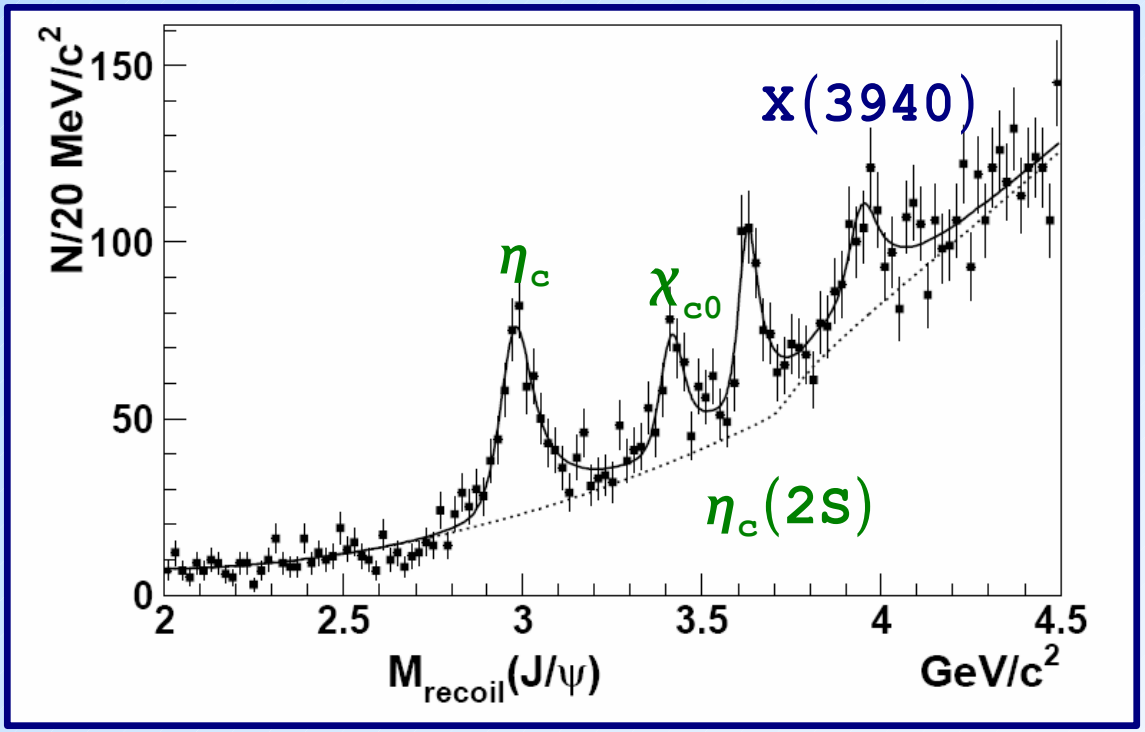
hep-ex/0507019 (2005)

$\sim 357\,fb^{-1}$

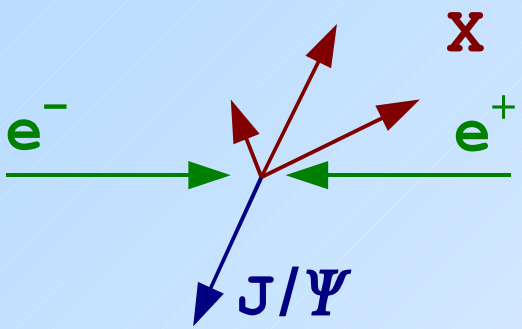
Recoil mass:

- reconstruct $J/\Psi \to l^+ l^-$
- calculate mass of the system recoiling from J/Ψ

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



$$e^+ e^- \to J/\Psi\, c\bar{c}$$



New state properties:

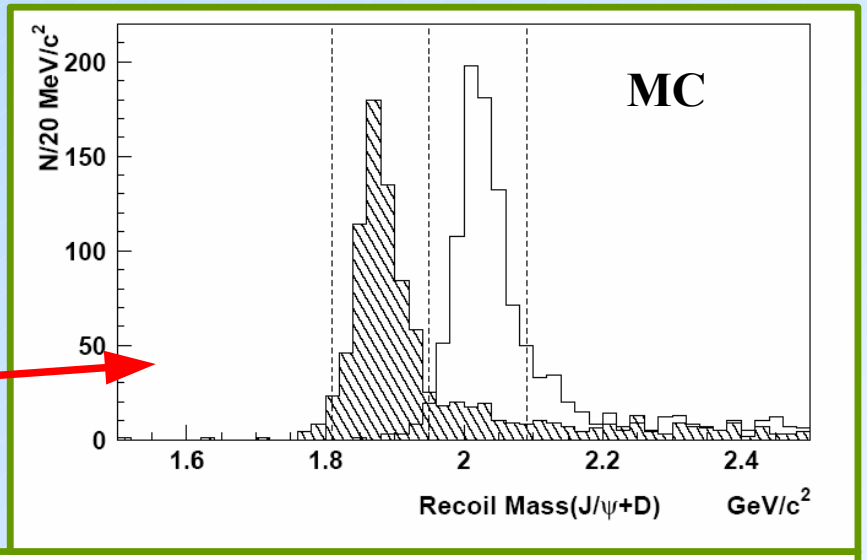
- significance 5.0σ
- $M_{X(3940)} = (3.943 \pm 0.006 \pm 0.006)\,GeV/c^2$
- $\Gamma_{X(3940)} < 52\,MeV$ @ 90% C.L.
- $\sigma_{Born} \times Br_{>2} = (10.6 \pm 2.5 \pm 2.4)\,pb$

$c\bar{c}c\bar{c}$: $X(3940) \to D\bar{D}^{(*)}$

hep-ex/0507019 (2005)

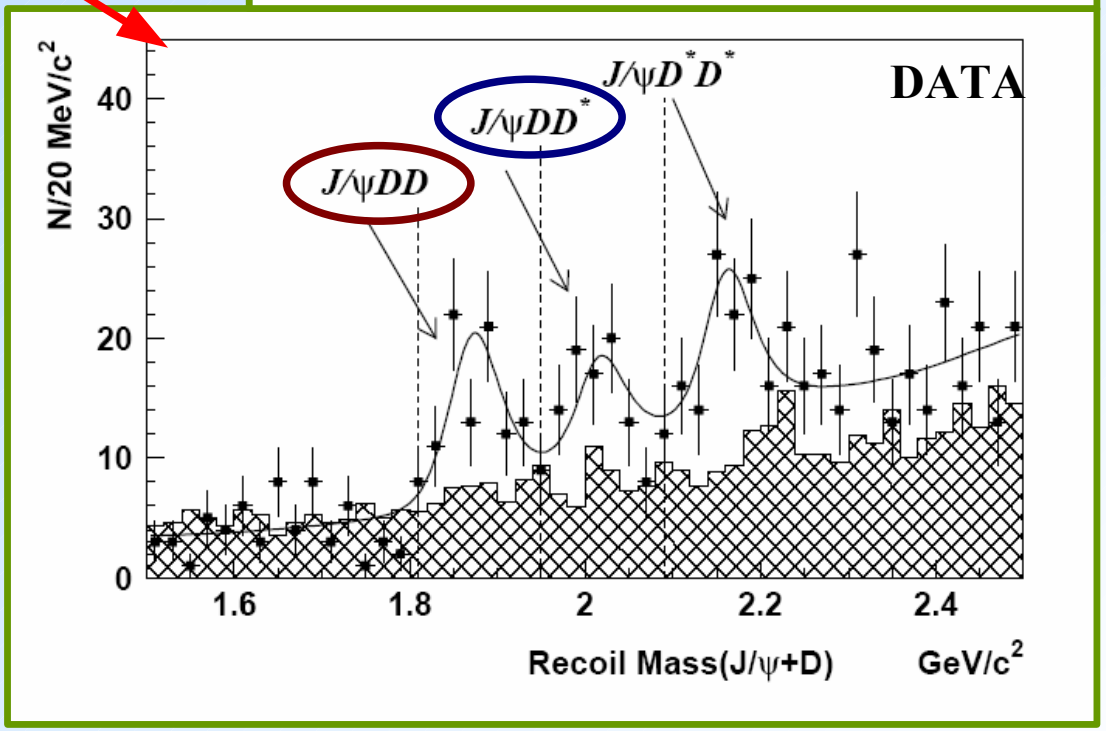
$\sim 357\,fb^{-1}$

- reconstruct additional D^0 or D^+
- calculate $M_{rec}(J/\Psi + D)$
- D and D^* clearly separated in MC and data $(\sim 2.5\sigma)$



$N(J/\Psi D\bar{D}) = 86 \pm 17 \ (5.1\sigma)$

$N(J/\Psi D^*\bar{D}) = 55 \pm 18 \ (3.3\sigma)$



- requiring $M_{rec}(J/\Psi + D) = M(D^{(*)})$ improves resolution on $M_{rec}(J/\Psi)$ by factor 2.5

$c\bar{c}c\bar{c}$: $X(3940)\to D\bar{D}^{(*)}$

hep-ex/0507019 (2005)

$\sim 357\,fb^{-1}$

- reconstruct additional D^0 or D^+
- for $M_{rec}(J/\Psi+D)=M(D^{(*)})$ recalculate $M_{rec}(J/\Psi)$

- clear peak for $X(3940)\to D^*\bar{D}$
- $N=24.5\pm6.9(5.0\sigma)$

$Br(X(3940)\to D^*\bar{D})=(96^{+45}_{-32}\pm22)\%$

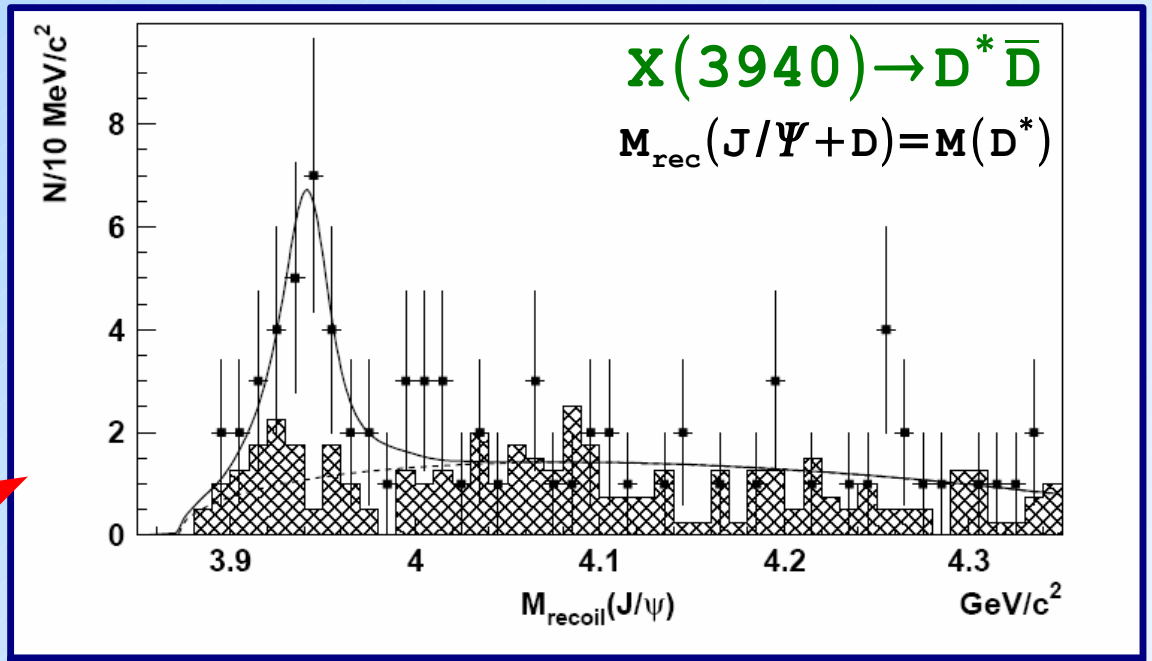
- no signal: $X(3940)\to D\bar{D}$
- $N=0.2^{+4.4}_{-3.5}(<8.1)$

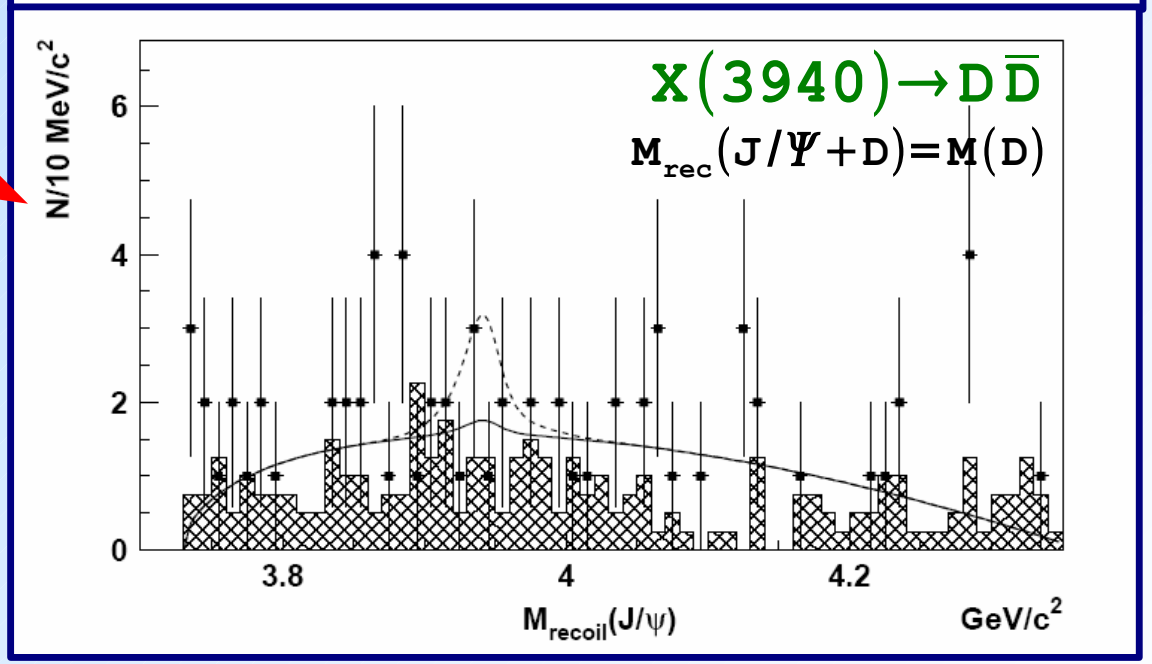
$Br(X(3940)\to D\bar{D})<41\%@90\%C.L.$

$Br(X(3940)\to J/\Psi\omega)<26\%@90\%C.L.$

strong evidence for

$X(3940)\neq Y(3940)$





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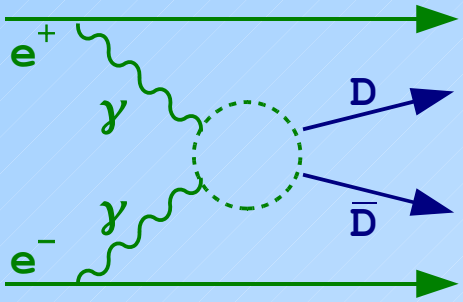
Z(3930) : observation

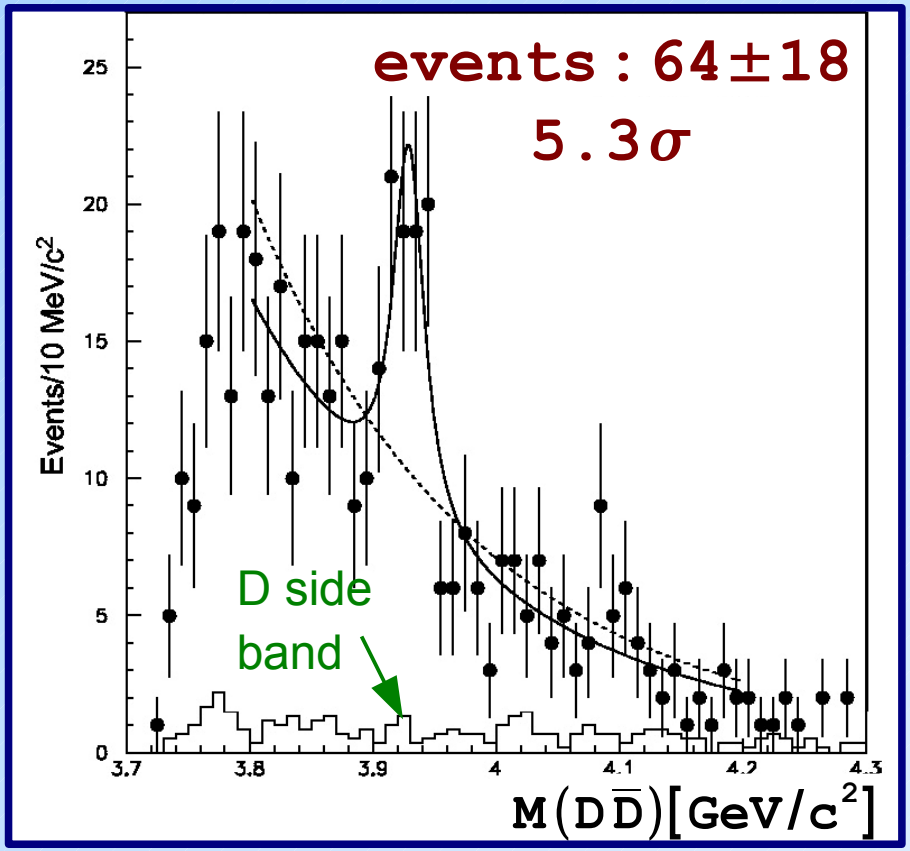
PRL 96, 082003 (2006)

$\sim 395\,fb^{-1}$

$\gamma\gamma \to D\bar{D}$



- un-tagged
- $D^0 \to K\pi$, $K\pi\pi^0$, $K3\pi$
  $D^+ \to K\pi\pi$
- $p_t(D\bar{D}) < 0.05\,GeV/c^2$



New state properties:

- $M_{Z(3930)} = (3929 \pm 5 \pm 2)\,MeV/c^2$
- $\Gamma_{Z(3930)} = 29 \pm 10 \pm 2\,MeV$

$Z(3930)$: χ'_{c2} candidate

PRL 96, 082003 (2006)

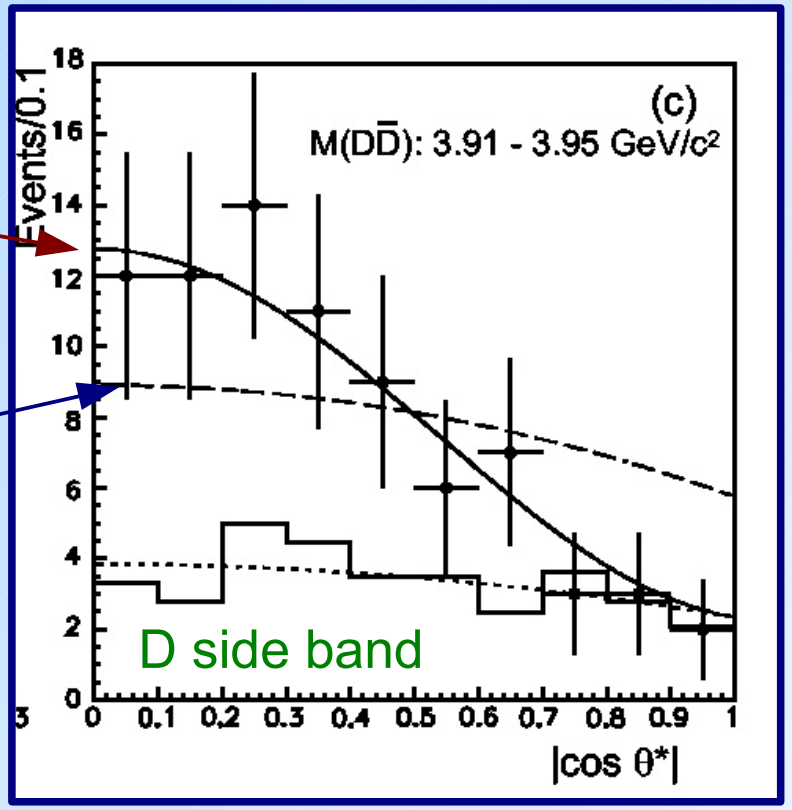
$\sim 395\,fb^{-1}$

$\gamma\gamma \to D\bar{D}$

θ^* : D, beam axis in $\gamma\gamma$ frame

- J=2 expectation
  $\chi^2/nof = 1.9/9$
- J=0 expectation
  $\chi^2/nof = 23.4/9$

acceptance corrected



$\Gamma_{\gamma\gamma}(Z)\,Br(Z \to D\bar{D}) =$
$(0.18 \pm 0.05 \pm 0.03)\,keV$

Mass, angular distributions and $\Gamma_{\gamma\gamma} Br(\to D\bar{D})$ are all consistent with:

χ'_{c2} - 2^3P_2 charmonium state

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

$\Xi_{cx}(2980)^+$, $\Xi_{cx}(3077)^+$

Preliminary

$\sim 460\,fb^{-1}$

- new exited charm-strange baryons
- observed decay: $\Xi_{cx}(2980) \to \Lambda_c^+ K^- \pi^+$, $\Lambda_c^+ \to p K^- \pi^+$
- c and s taken by different final state particle
- require $p^* > 3.0\,GeV/c$ to suppress combinatorial background

$\Xi_{cx}(3077)^+$:

$N = 326 \pm 39.6 (9.7\sigma)$

$M = (3076.7 \pm 0.9 \pm 0.5)\,MeV/c^2$

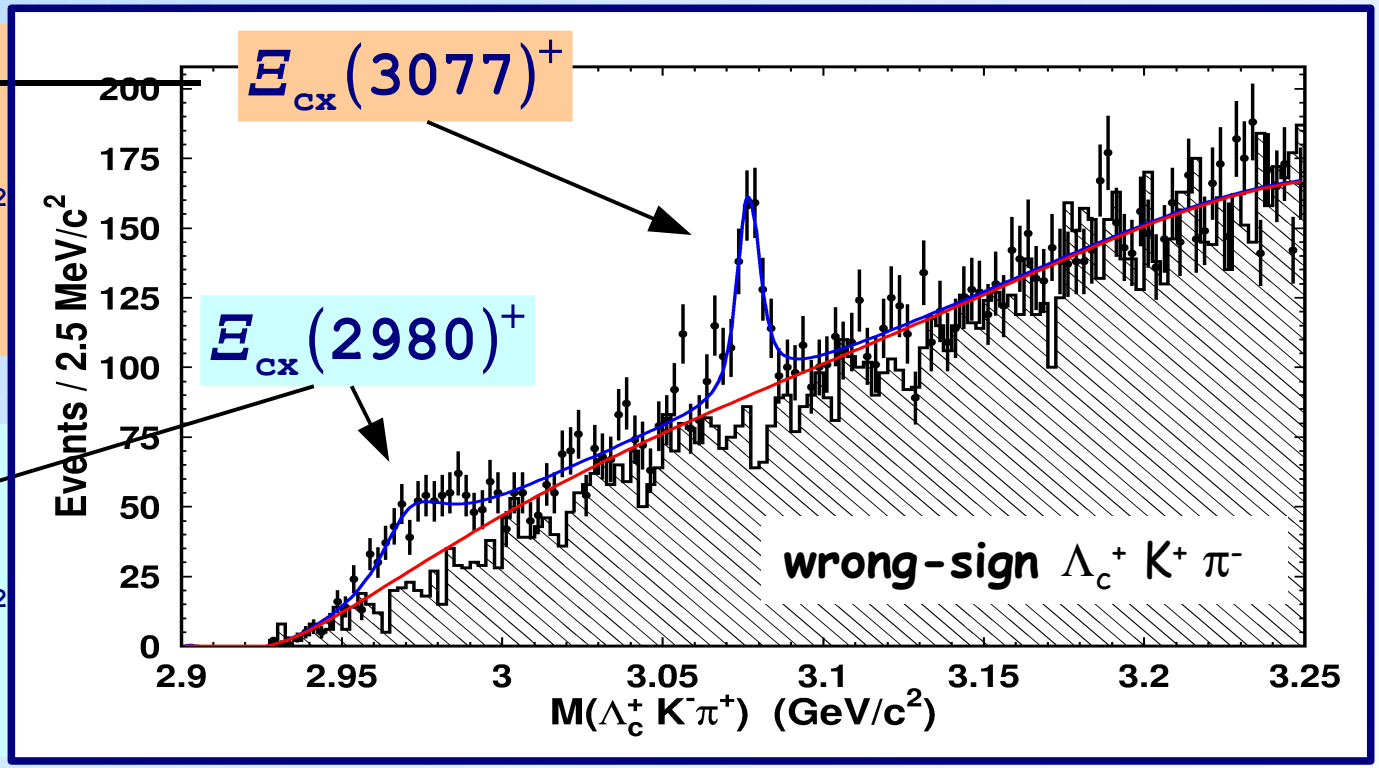
$\Gamma = (6.2 \pm 1.2 \pm 0.8)\,MeV$

$\Xi_{cx}(2980)^+$:

$N = 405.3 \pm 50.7 (6.3\sigma)$

$M = (2978.5 \pm 2.1 \pm 2.0)\,MeV/c^2$

$\Gamma = (43.5 \pm 7.5 \pm 7.9)\,MeV$

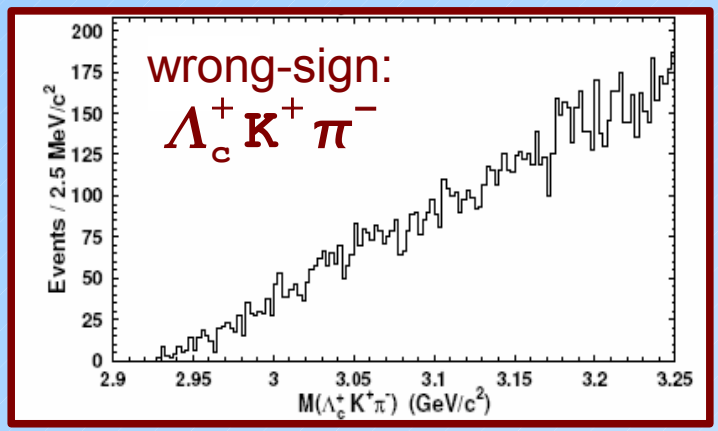


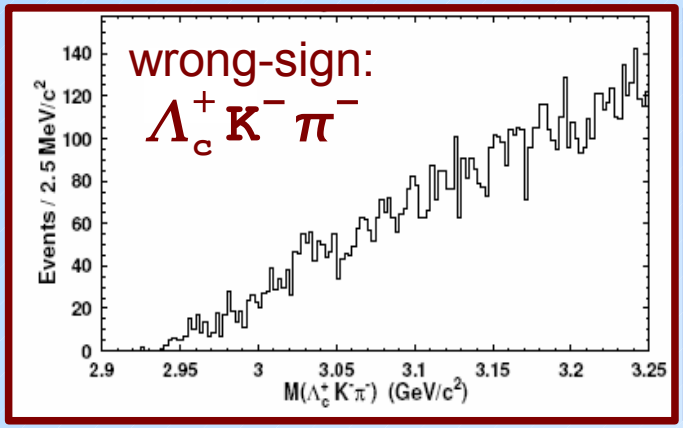
$\Xi_{cx}(2980)^+$, $\Xi_{cx}(3077)^+$

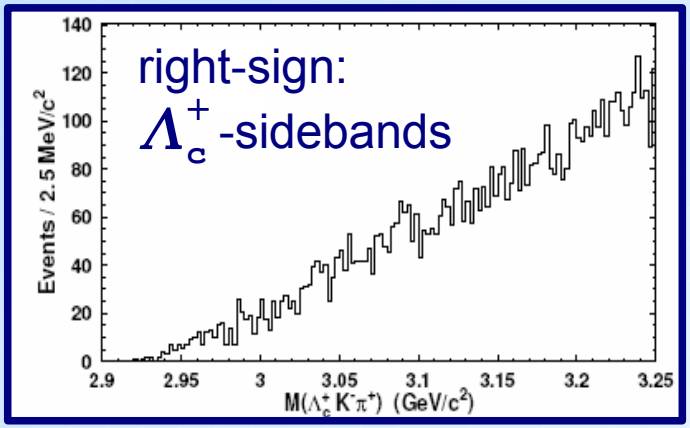
Preliminary

$\sim 460\,fb^{-1}$

- wrong-sign and sideband check:







Check for reflections due to $K-\pi$ misidentification:

$\Lambda_c(2593)^+$, $\Lambda_c(2625)^+$, $\Lambda_c(2765)^+$, $\Lambda_c(2880)^+ \to \Lambda_c^+ \pi^+ \pi^-$

(verified with MC simulation)

Check stability against:

- PID criteria
- Λ_c^+ mass selection window
- p^* requirement ...

$\Xi_{cx}(2980)^0$, $\Xi_{cx}(3077)^0$

Preliminary

$\sim 460\,fb^{-1}$

- search for neutral isospin partners
- observed decay:
  $\Xi_{cx}(2980)^0 \to \Lambda_c^+ K_S^0 \pi^-$
- tighter requirement
  $p^* > 3.5\,GeV/c$

$\Xi_{cx}(3077)^0$:

$N = 67.1 \pm 19.9 (5.1\sigma)$

$M = (3082.8 \pm 1.8 \pm 1.5)\,MeV/c^2$

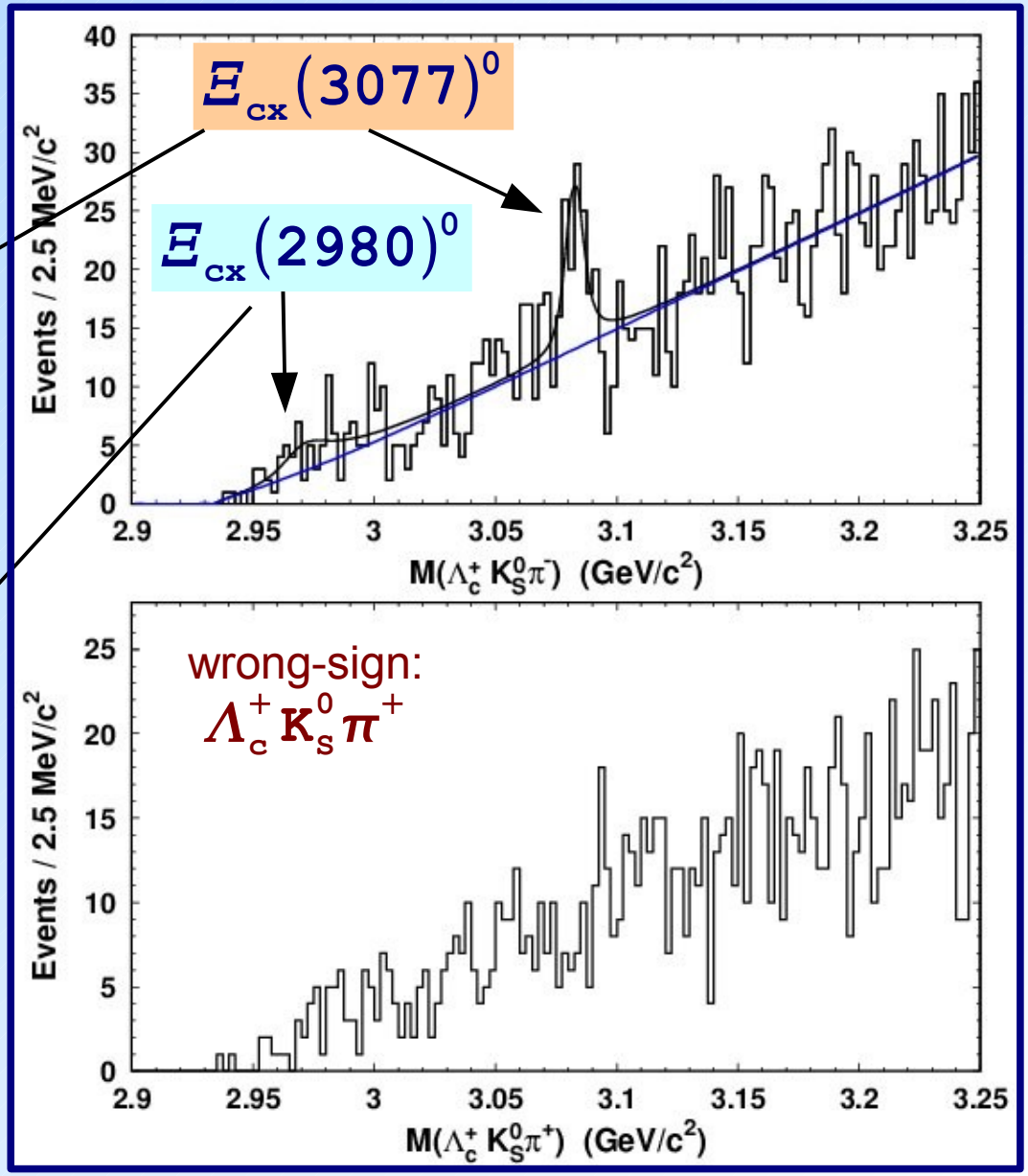
$\Gamma = (5.2 \pm 3.1 \pm 1.8)\,MeV$

$\Xi_{cx}(2980)^0$:

$N = 42.3 \pm 23.8 (2.0\sigma)$

$M = (2977.1 \pm 8.8 \pm 3.5)\,MeV/c^2$

$\Gamma = 43.5\,MeV$ (FIXED)



Search for $\Xi_{cc}(3519)^+$

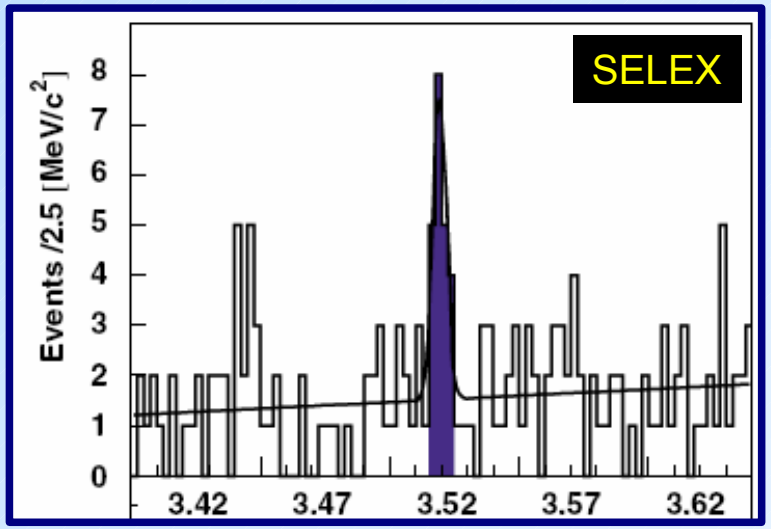
Preliminary

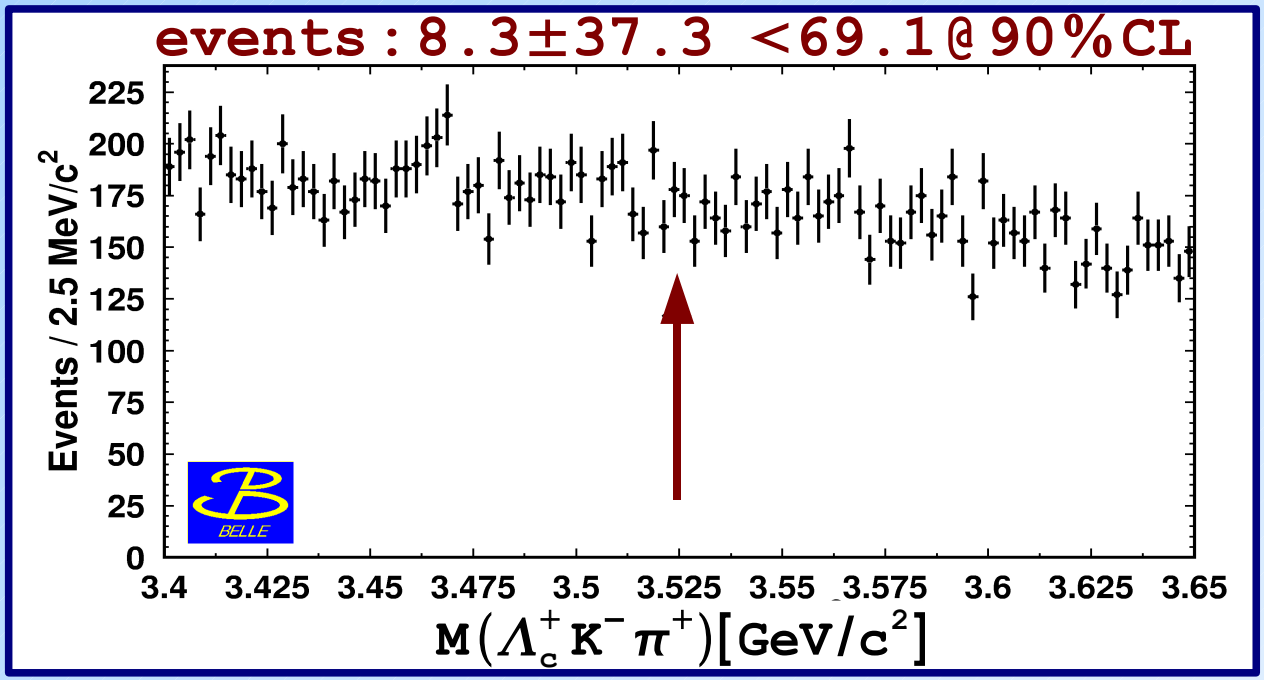
$\sim 460\,fb^{-1}$

- observed by SELEX in the same decay channel:

$$\Xi_{cc}(3519)^+ \to \Lambda_c^+ K^- \pi^+$$

PRL 89, 112001 (2002)





- $p^* > 2.5\,GeV/c$ only for Λ_c^+
- no signal observed:

- $\Lambda_c^+ \to p K^- \pi^+$

  $N = 835360 \pm 13748$

$$\frac{\sigma(\Xi_{cc}(3519)^+) \times Br(\Xi_{cc}(3519)^+ \to \Lambda_c^+ K^- \pi^+)}{\sigma(\Lambda_c^+)} < 1.5 \times 10^{-4} \ @90\%CL$$

Summary

- Properties of $X(3872)$ have been studied:
  favorable interpretation $D^0\bar{D}^{*0}$ molecule
- $Y(3940)$: analysis of more data is needed to study its properties

- $X(3940)$: a new state found in double charm production

  $$X(3940) \neq Y(3940)$$

- A candidate for χ'_{c2} observed in $\gamma\gamma \to D\bar{D}$ reaction

- New charmed baryons found in the final state $\Lambda_c^+ K^- \pi^+$
  No evidence for SELEX $\Xi_{cc}(3519)^+$

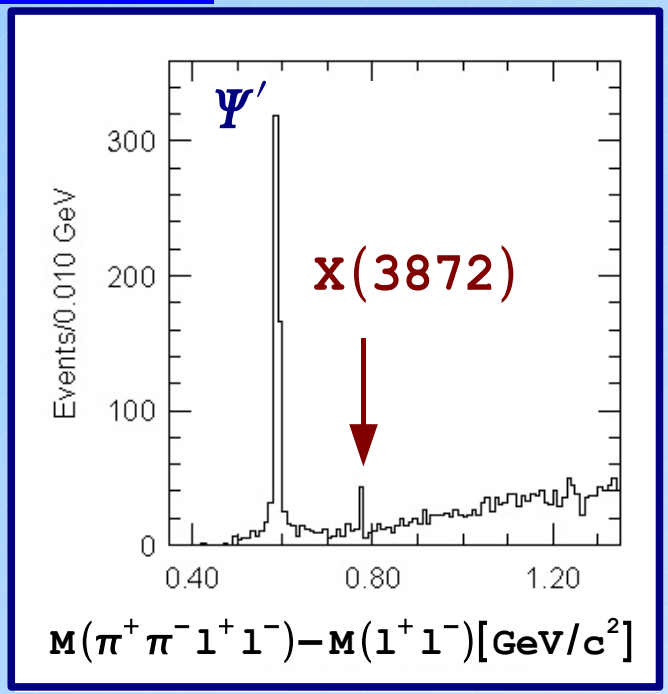
Many new resonances were observed at Belle in recent years and with new data pouring in continuously a search for new ones will continue.
For topics not covered in this talk see http://belle.kek.jp

BACKUP SLIDES

X(3872) : observation

PRL 91, 262001 (2003)

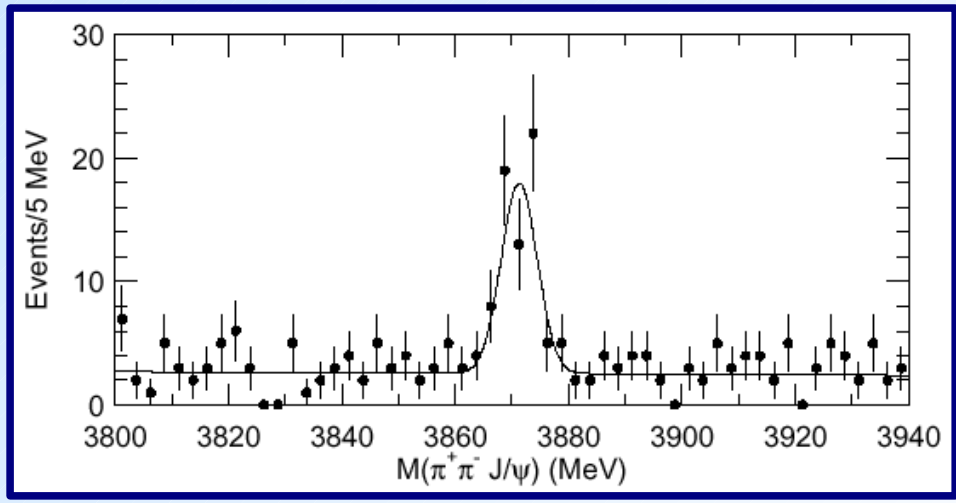
~152M $B\bar{B}$ pairs



$B^{\pm} \to J/\Psi \pi^+ \pi^- K^{\pm}$

- initial expectation: unobserved charmonium state
- disfavored by subsequent observations
- possible alternatives: - DD molecule
  - qqg ...
- → study properties

update:



hep-ex/0505038 (2005)

~275M $B\bar{B}$ pairs

New state properties:

- $M_{X(3872)} = (3872.0 \pm 0.6 \pm 0.5)\,MeV/c^2$
- $\Gamma_{X(3872)} < 2.3\,MeV$ @ 90% C.L.
- $Br(B \to XK) \times Br(X \to J/\Psi \pi^+ \pi^-) = (1.31 \pm 0.24 \pm 0.13) \times 10^{-5}$
- $M(\pi\pi)$ is consistent with ρ^0

$c\bar{c}c\bar{c}$: further study

PRD 70, 071102(R) (2004)

$\sim 155\,fb^{-1}$

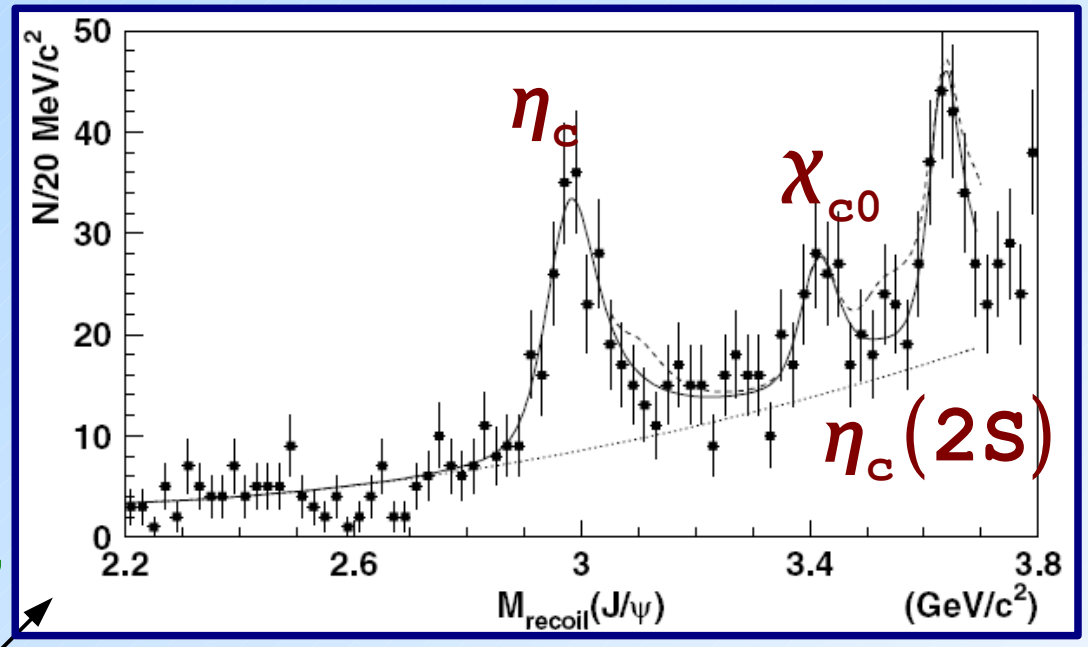
Alternative interpretations proposed:

- contribution from $2\gamma^*$ process
- charmonium + glueball
- misinterpretation of peaks – M_{rec} shift

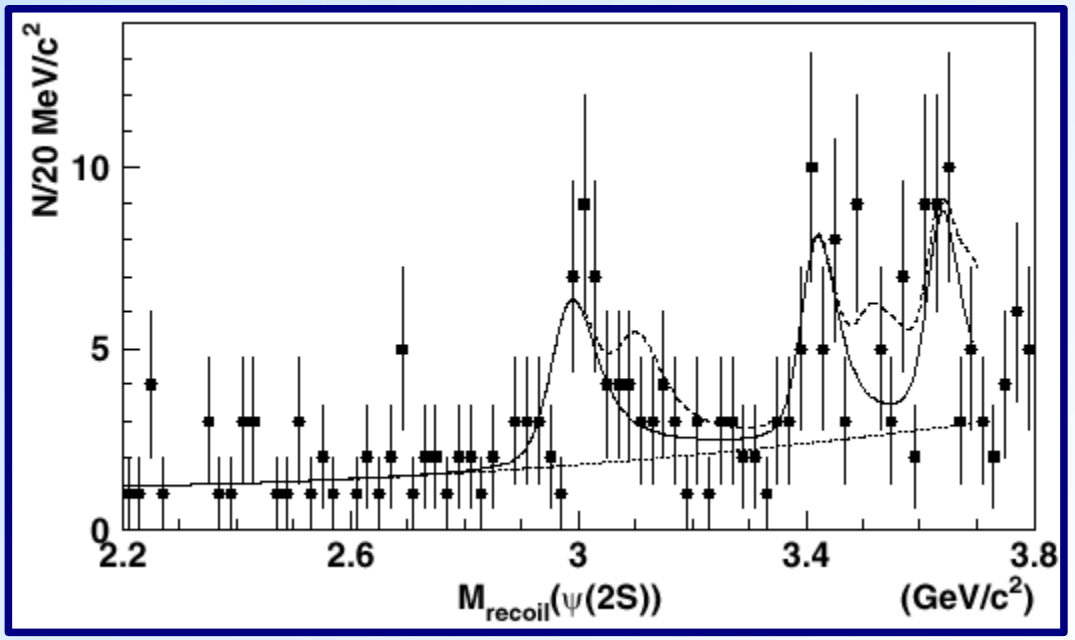
NO - everything consistent with:

$$e^+e^- \to \gamma^* \to J/\Psi\,\eta_c$$

($\partial N/\partial\theta_{pr.}\,\partial\theta_{hel.}$, M_{rec} bias $< \sim 3\,MeV/c^2$,
3 events fully-reconstructed)



$(c\bar{c})_{res}$	N	M [GeV/c^2]	Signif.	$\sigma_{Born} \times \mathcal{B}_{>2}$ [fb]
η_c	235 ± 26	2.972 ± 0.007	10.7	$25.6 \pm 2.8 \pm 3.4$
J/ψ	-14 ± 20	fixed	···	<9.1 at 90% CL
χ_{c0}	89 ± 24	3.407 ± 0.011	3.8	$6.4 \pm 1.7 \pm 1.0$
$\chi_{c1} + \chi_{c2}$	10 ± 27	fixed	···	<5.3 at 90% CL
$\eta_c(2S)$	164 ± 30	3.630 ± 0.008	6.0	$16.5 \pm 3.0 \pm 2.4$
$\psi(2S)$	-26 ± 29	fixed	···	<13.3 at 90% CL



- observation of $e^+e^- \to \gamma^* \to \Psi(2S)\eta_c$

$c\bar{c}c\bar{c}$: recoil mass spectrum

PRL 89, 142001 (2002)

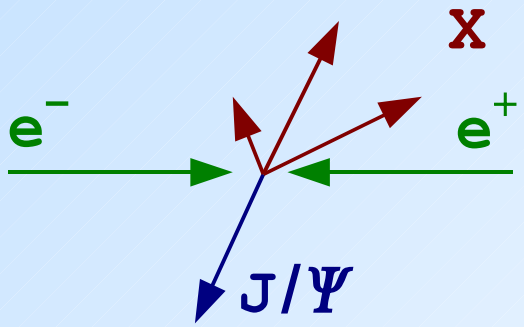
$\sim 46\,fb^{-1}$

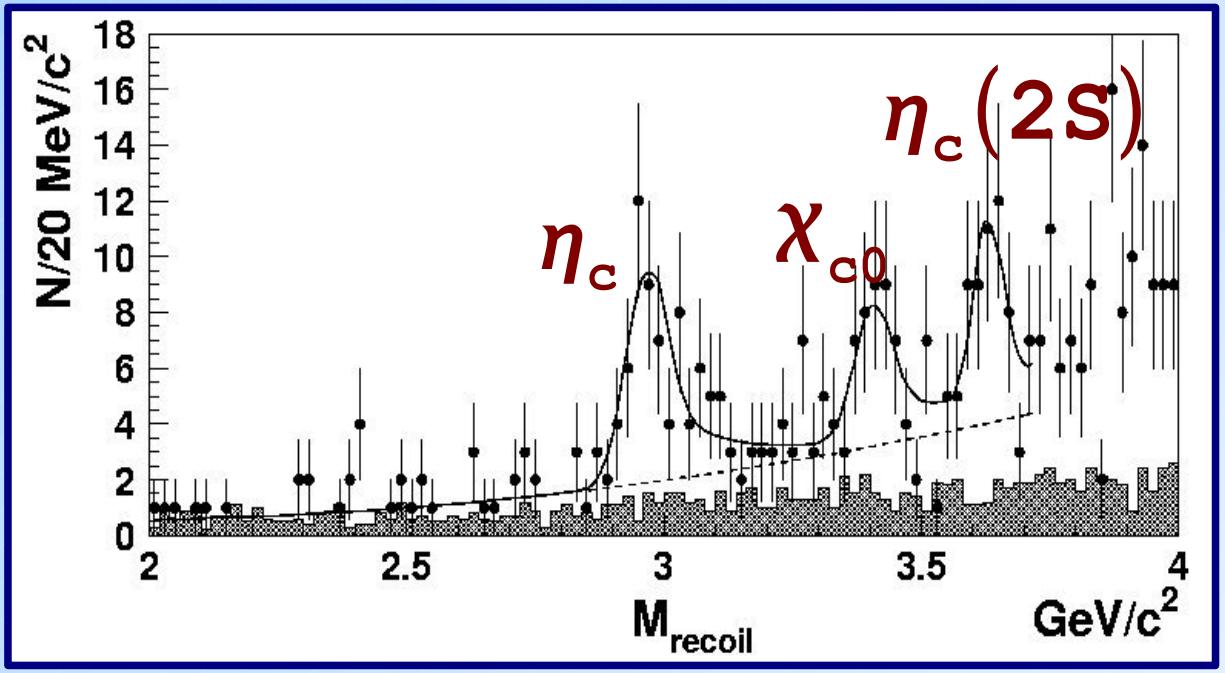
Recoil mass:

- reconstruct $J/\Psi \to l^+ l^-$
- calculate mass of the system recoiling from J/Ψ

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

$e^+e^- \to J/\Psi\, c\bar{c}$



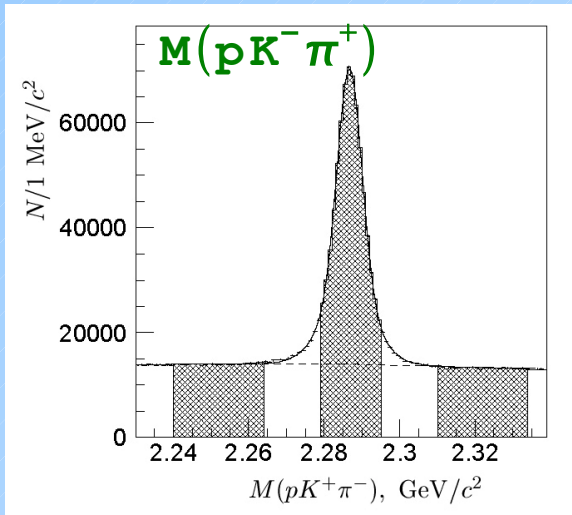


- first observation in 2002

$\Sigma_c(2800)$ isotriplet

PRL 94, 122002 (2005)

$\sim 280\,fb^{-1}$



$\Sigma_c(2800) \to \Lambda_c^+ \pi$

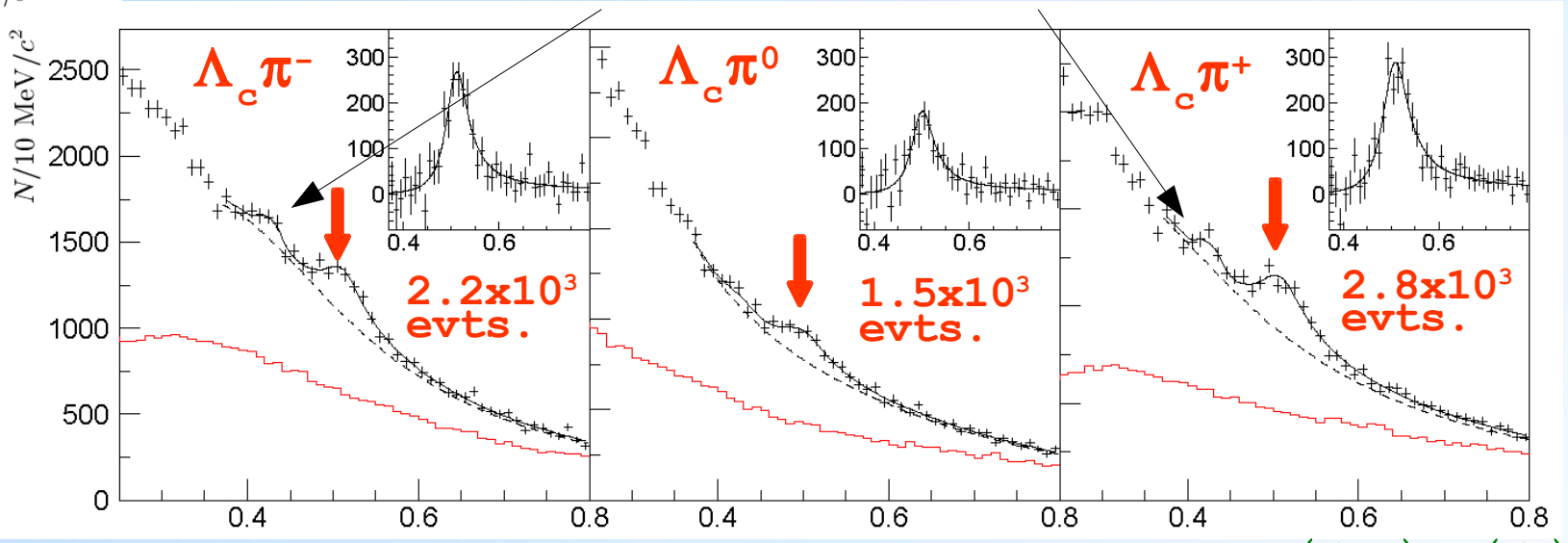
$\hookrightarrow pK^-\pi^+$

- tentatively identified as Σ_{c2}, $J^P = 3/2^-$

  (prediction: $\Delta M \sim 500\,MeV/c^2$, $\Gamma \sim 15\,MeV$)
- larger Γ (mixing with $\Sigma_{c1}(J^P = 3/2^-)$?)

- add π
- require: $x_p(\Lambda_c^+\pi) > 0.7$

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

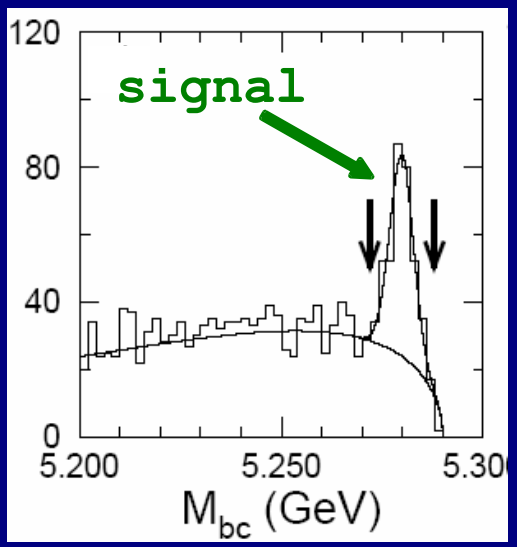


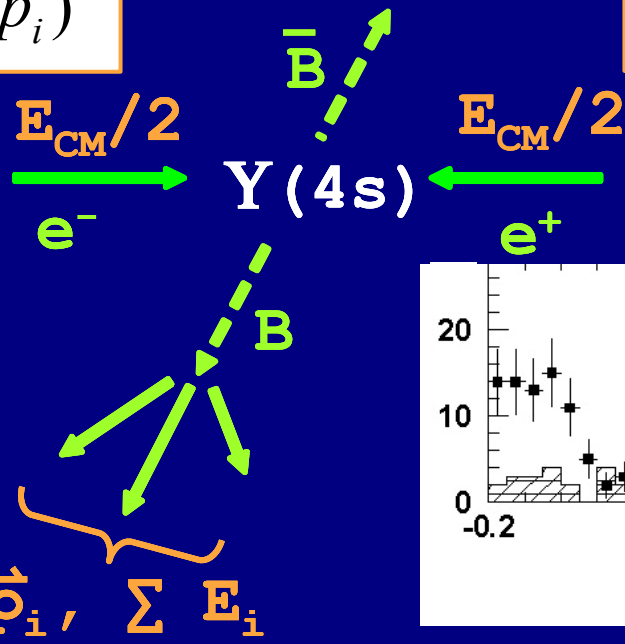
$M_{\Sigma_c(2800)} - M_{\Lambda_c}(MeV/c^2) =$	$515.4^{+3.2+2.1}_{-3.1-6.0}$	$505.4^{+5.8+12.4}_{-4.6-2.0}$	$514.5^{+3.4+2.8}_{-3.1-4.9}$
$\Gamma_{\Sigma_c(2800)}(MeV) =$	61^{+18+22}_{-13-13}	62^{+37+52}_{-23-38}	75^{+18+12}_{-13-11}

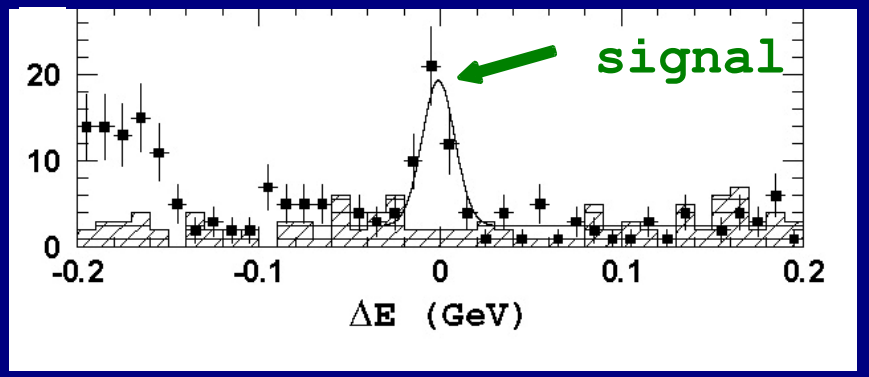
Belle experimental environment

$$M_{bc} = \sqrt{(E_{CM}/2)^2 - (\sum \vec{p}_i)^2}$$

$$\Delta E \equiv \sum E_i - E_{CM}/2$$







Off reson. data:
continuum only
On reson. data:
$B\bar{B}$ (spherical) separated from continuum (jet shaped) on basis of topological variables

e.g. angle between B direction and beam axis