X(3872) at Belle

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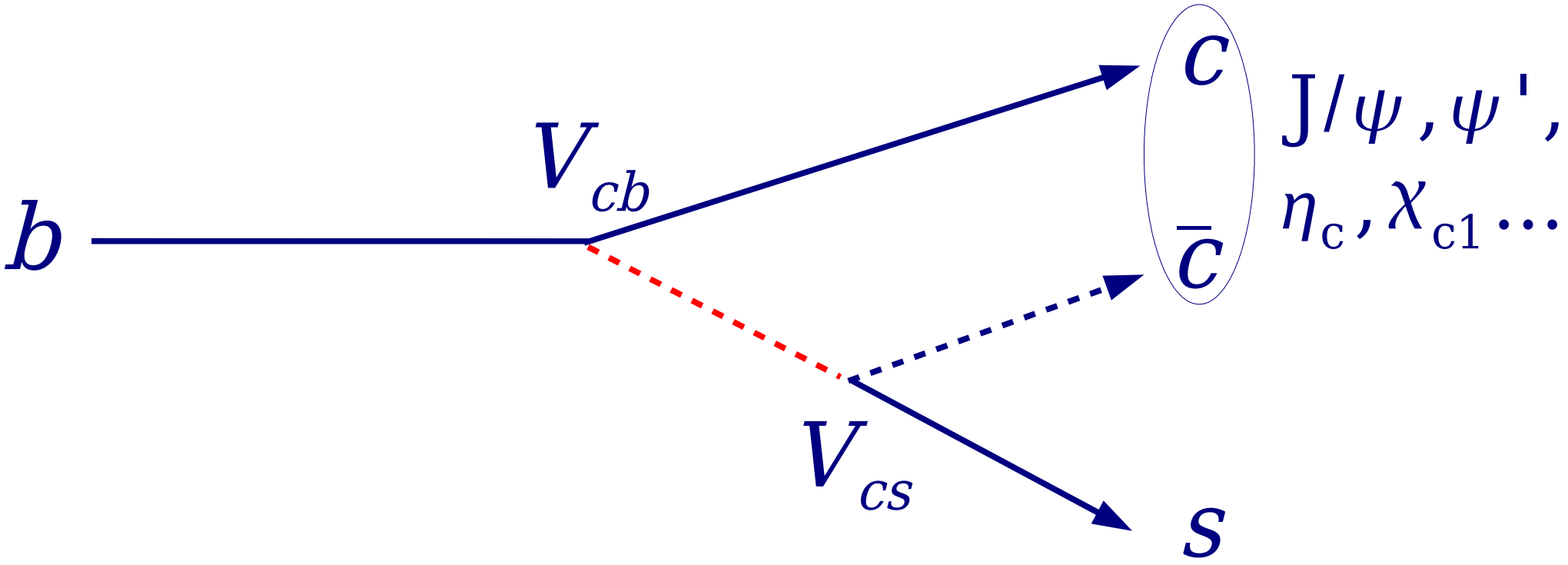
KEK

BES-Belle-CLEO-Babar 2007 Joint Workshop
on Charm Physics
Beijing, Nov 26th, 2007

$b \to c\bar{c}s$ is a dominant process



Brs$\sim 10^{-2}$ (inclusive)

B mesons are a good source for charm,
charmonium and other $c\bar{c}$ states
good place to carry out spectroscopy studies

An example : reconstruct $B \to K K_S K^- \pi^+$

PRL89 , 102001(2002)

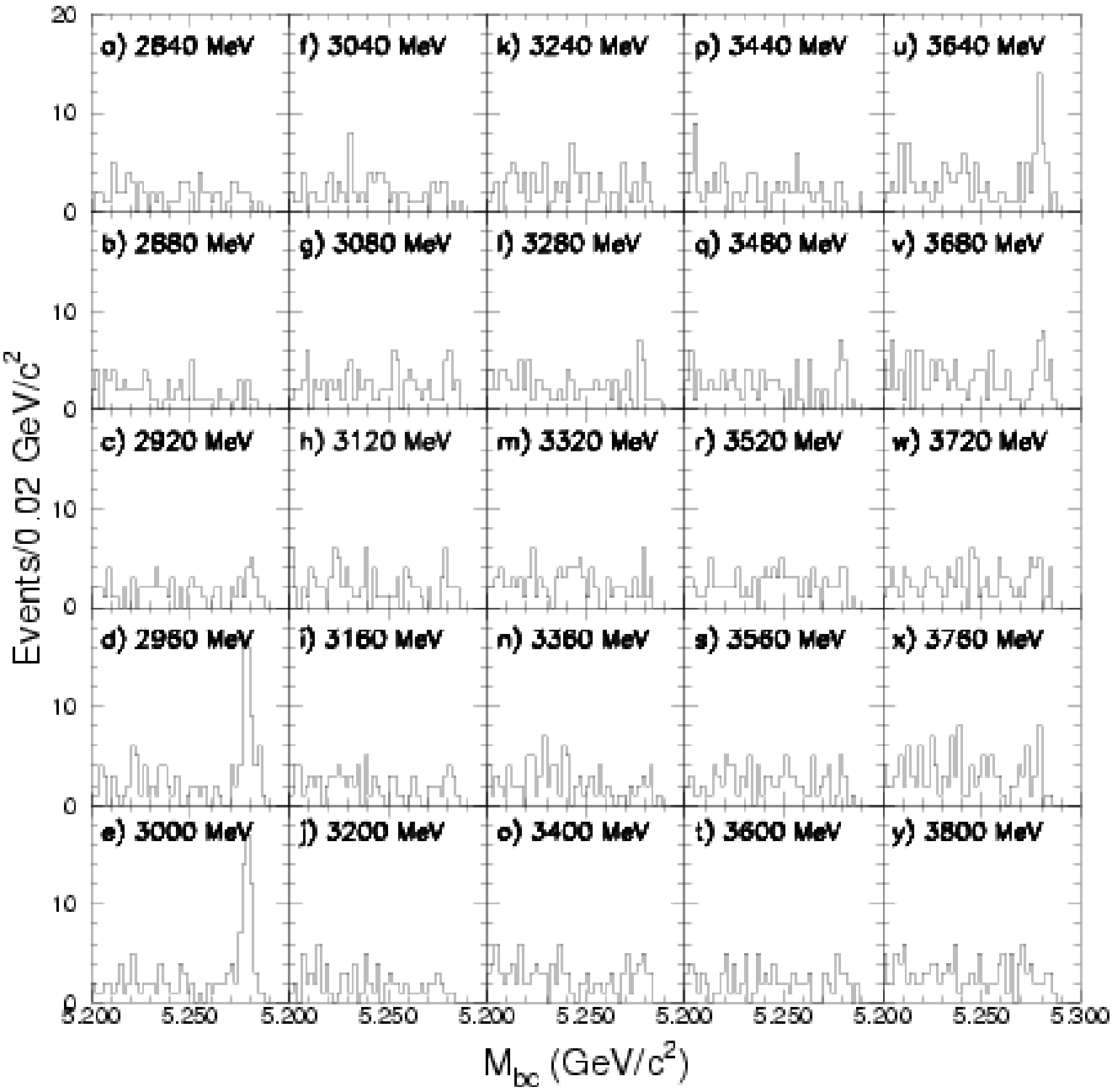
Beam − constrained mass :

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

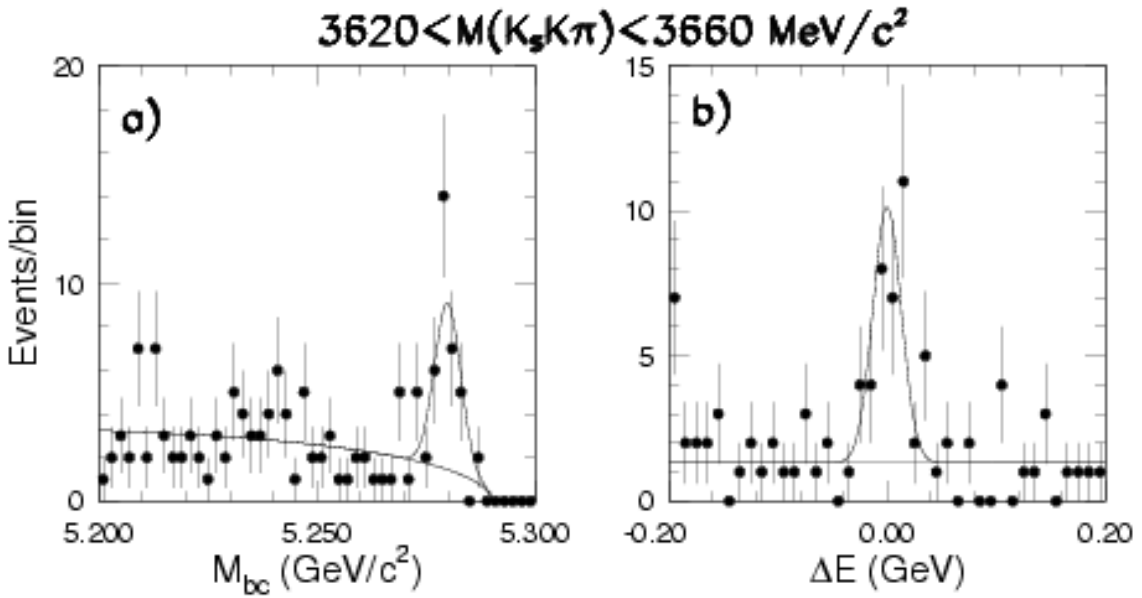
Energy difference :

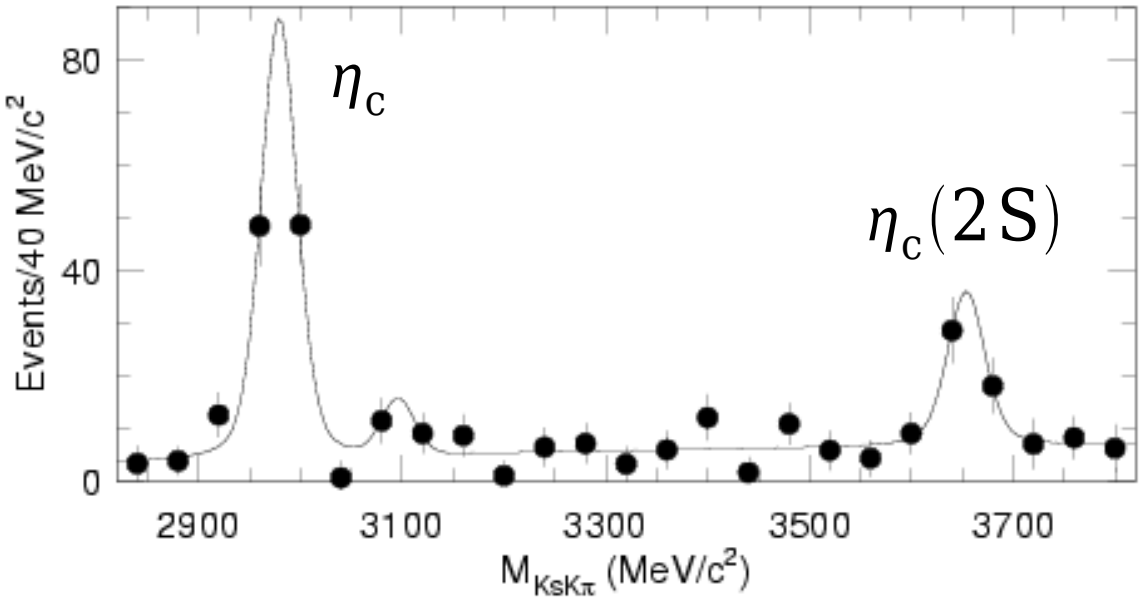
$$\Delta E = \sum E_i - (E_{CM}/2)$$

Fit M_{bc} in bins of $K_S K^- \pi^+$ invariant mass of $40\,MeV/c^2$



$B \to K K_S K^- \pi^+$ to see $\eta_c(2S)$





significance $> 6\sigma$

$M = 3654 \pm 6 \pm 8$ MeV/c^2

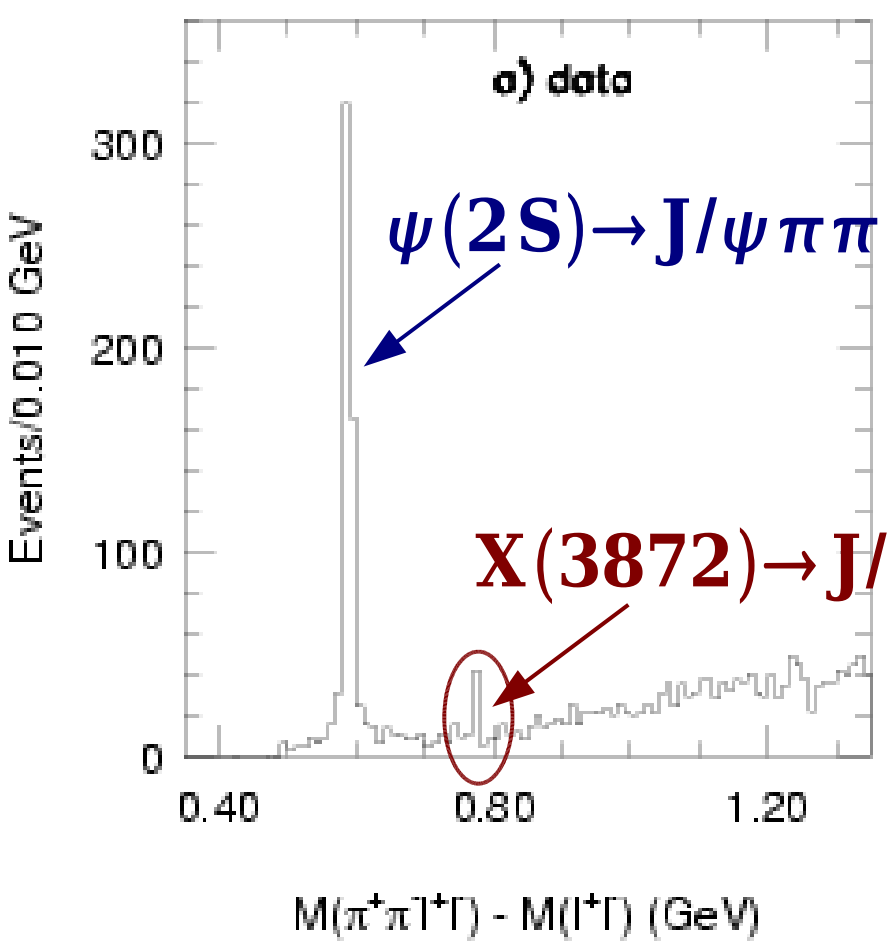
$\Gamma < 55$ MeV/c^2

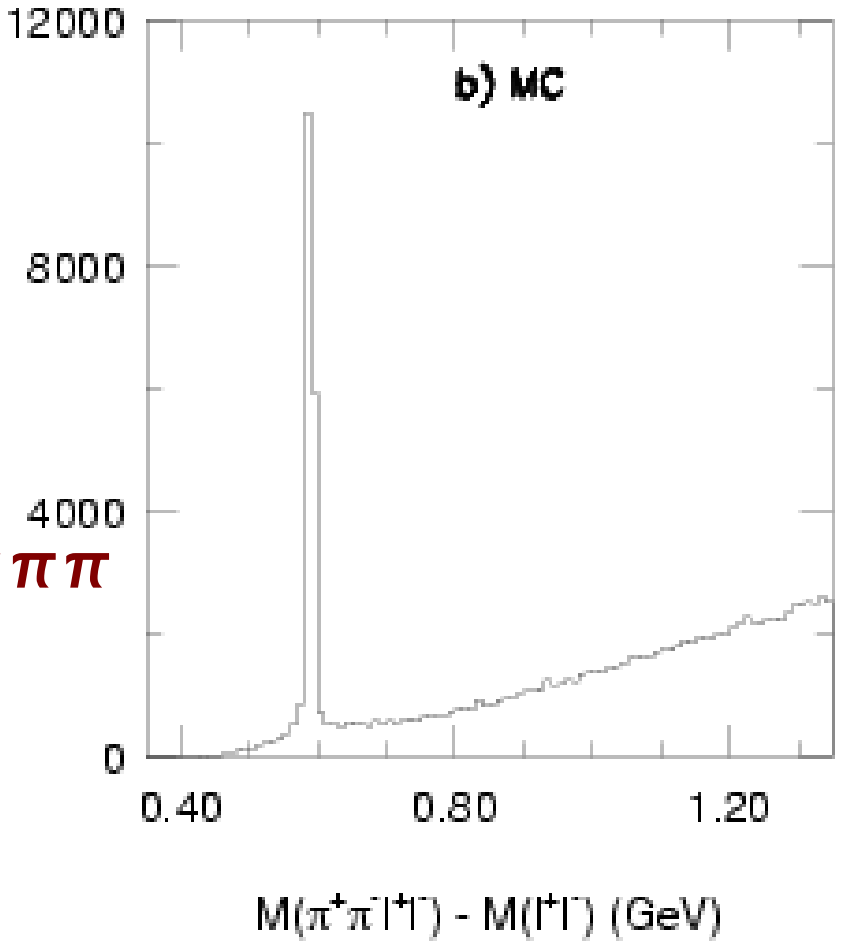
PRL89, 102001(2002)

X(3872) first observation

S.K.Choi , S.Olsen et al
PRL91 , 262001 (2003)

$B \to K \pi^+ \pi^- J/\psi$ using $140\,fb^{-1}$





$N = 35.7 \pm 6.8$

significance $10.3\,\sigma$

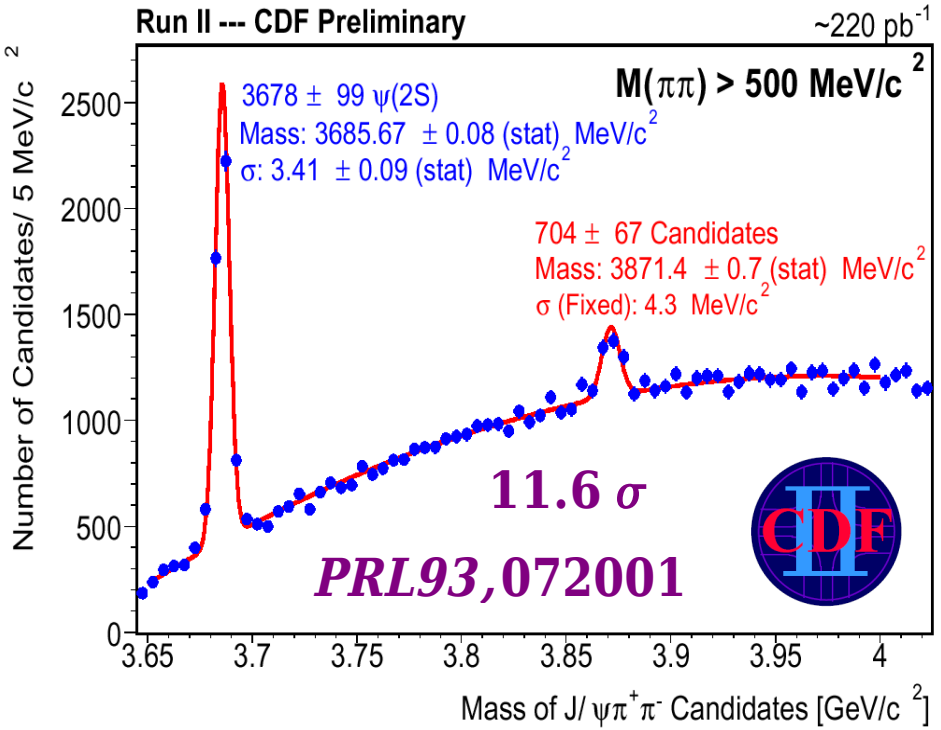
$(3872 \pm 0.6 \pm 0.5)\ MeV/c^2 \sim m_{D^0} + m_{D^{*0}}$

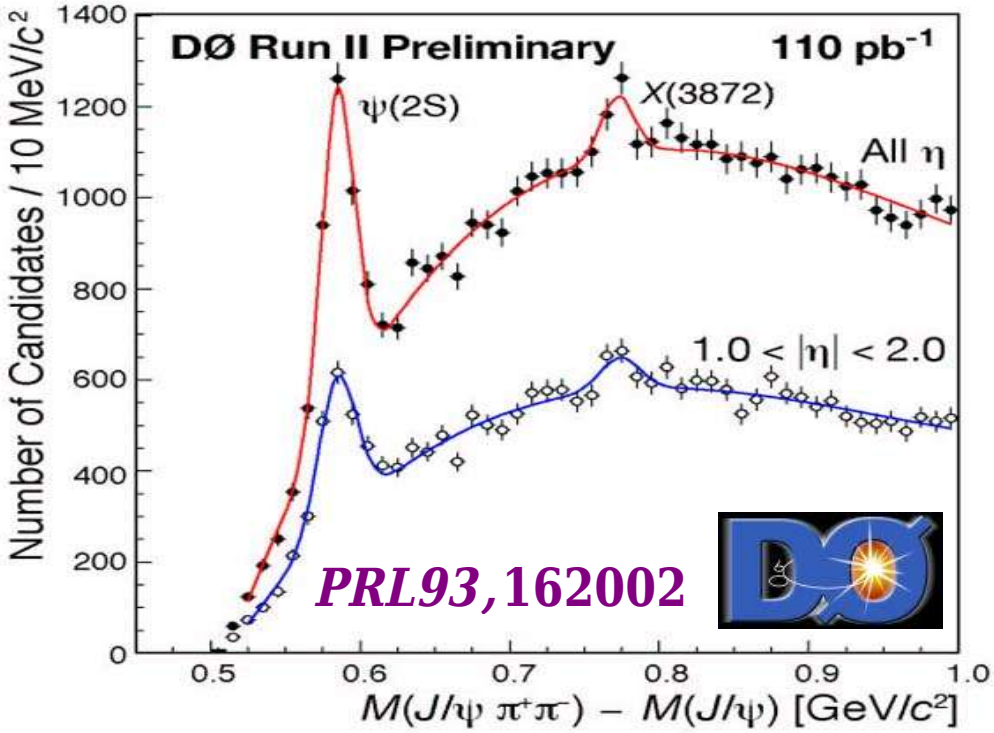
$[m_{D^0} + m_{D^{*0}} = (3871.55 \pm 0.44)\ MeV/c^2]$

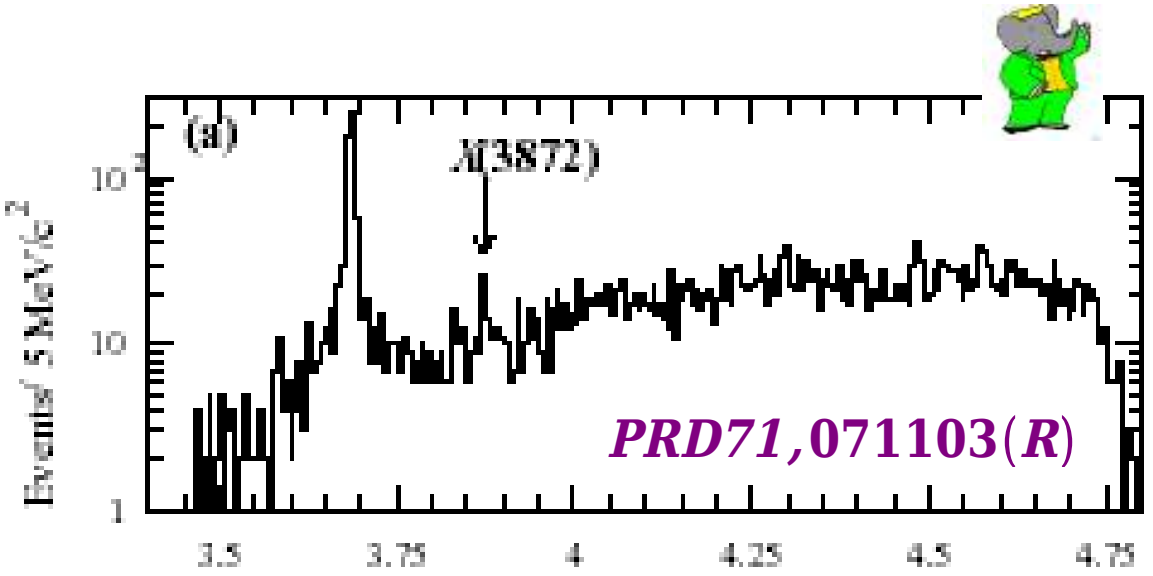
$\Gamma < 2.3\ MeV$

X is narrow and doesn't decay to $D\bar{D}$ [PRL93, 051803 (2004)]

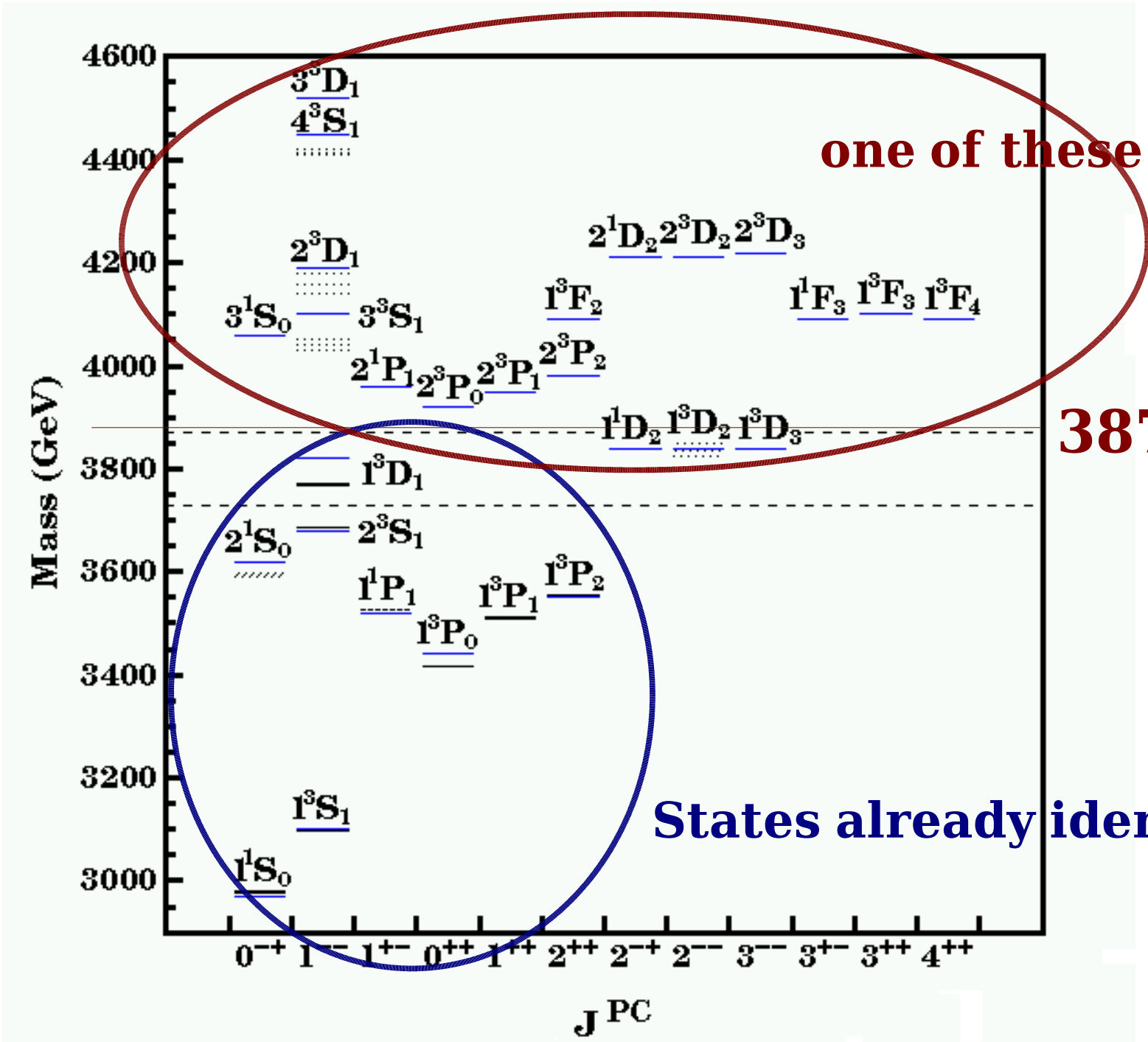
X(3872) confirmed by 3 other experiments







Is it a $c\bar{c}$ meson ?



one of these states ?

3872 MeV

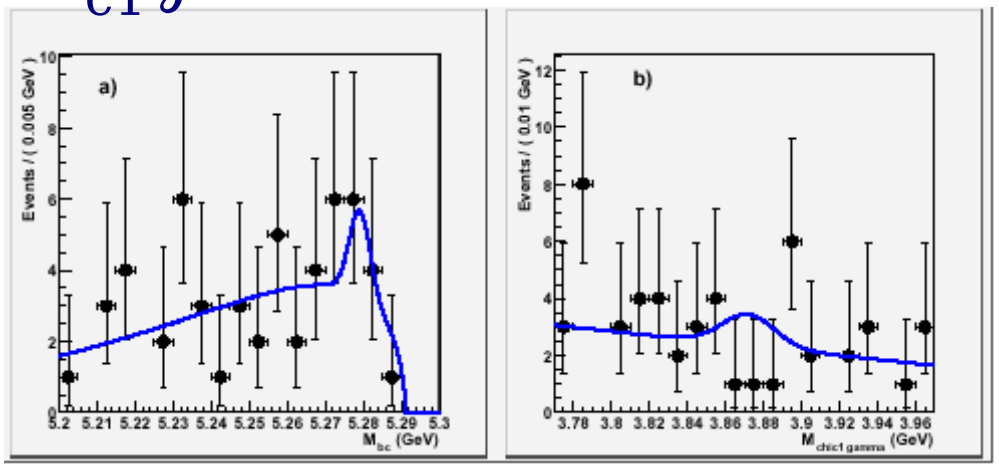
States already identified

Non observation of $X(3872) \to \chi_{cJ}\gamma$ decays

PRL91,262001(2003)

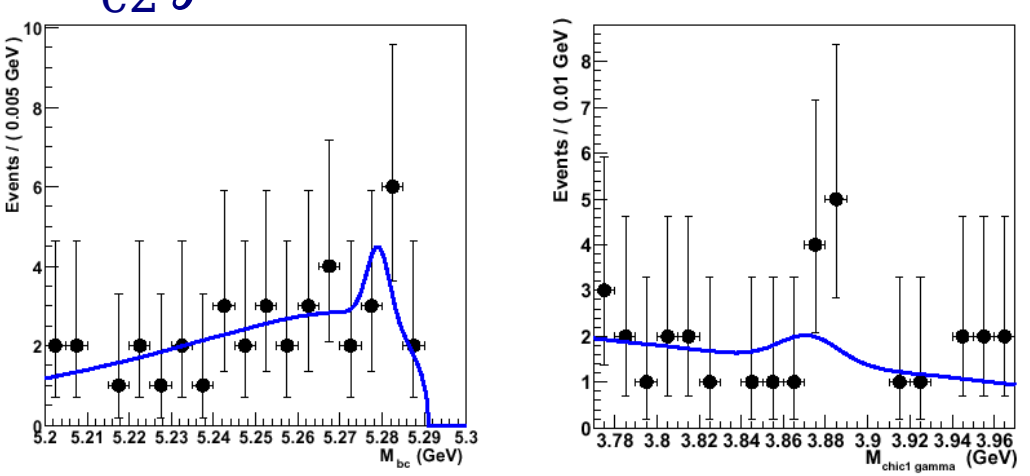
The radiative decays to $\chi_{cJ}\gamma$ expected to be large for some charmonium states... but not found

$\chi_{c1}\gamma K$



M_{bc} $M(\chi_{c1}\gamma)$

$\chi_{c2}\gamma K$



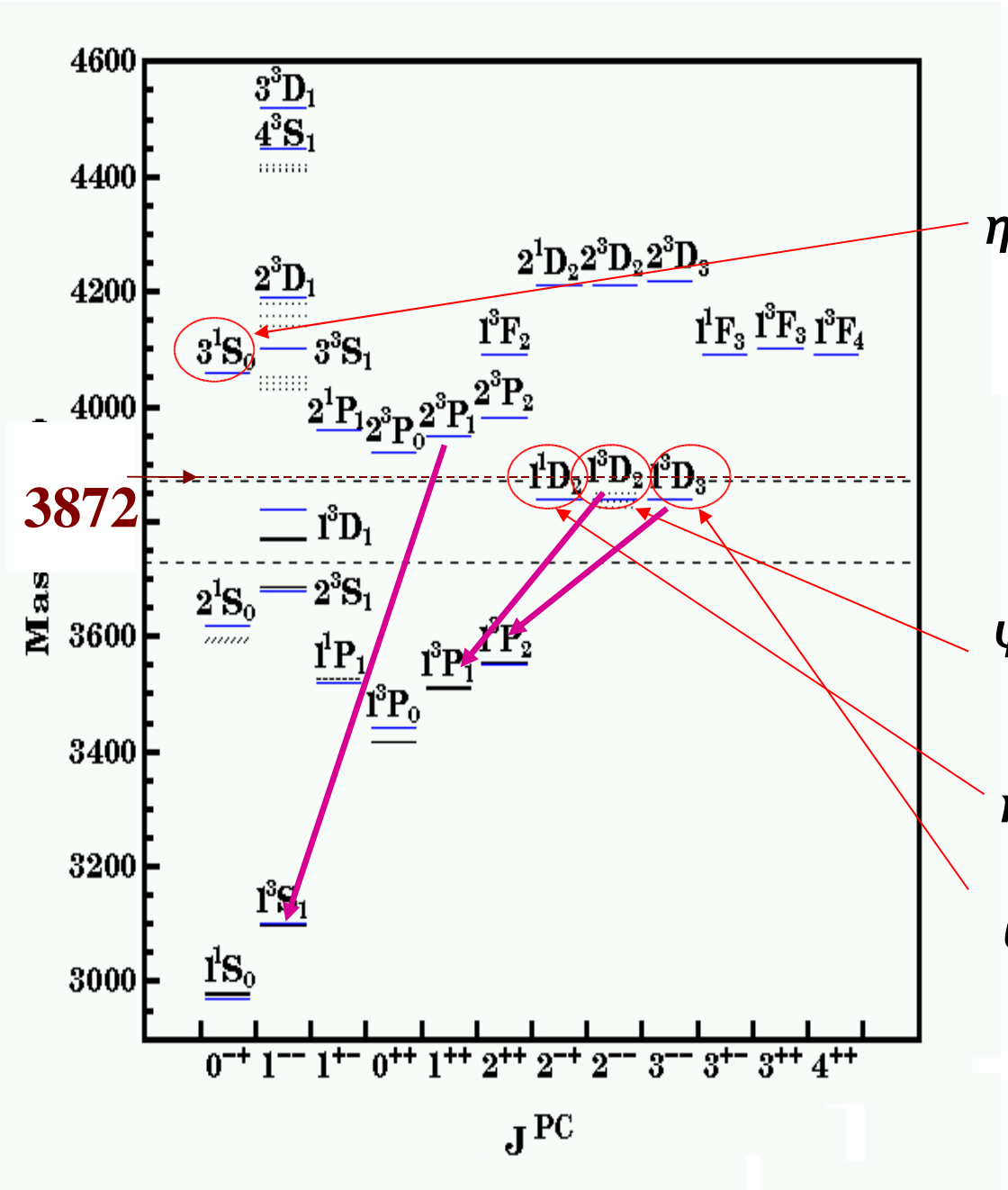
M_{bc} $M(\chi_{c2}\gamma)$

$B(X \to \chi_{c1}\gamma)/B(X \to J\psi\pi^+\pi^-) < 0.9$ at 90% CL $X \equiv \psi_2$ expect > 1.6

[potential/ψ'' Wigner-Eckart]

$B(X \to \chi_{c2}\gamma)/B(X \to J\psi\pi^+\pi^-) < 1.1$ at 90% CL $X \equiv \psi_3$ expect > 3.5

$c\bar{c}$ assignment ?



hep-ex/0407033

η_c'' **M too low and** Γ **too small**

ψ_2 $\Gamma(\gamma\chi_{c1})$ **too small**
$M(\pi^+\pi^-)$ **wrong**

η_{c2} $\pi\pi\eta_c$ **should dominate**

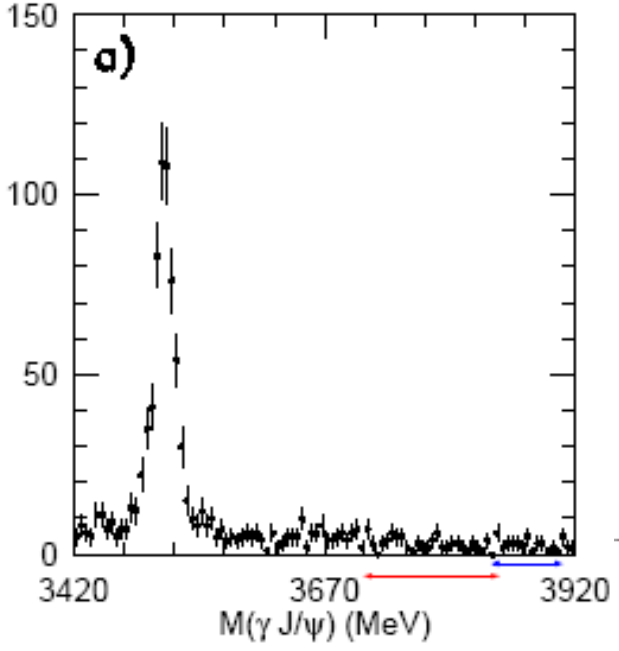
ψ_3 $\Gamma(\gamma\chi_{c2}\&\&D\bar{D})$ **too small**

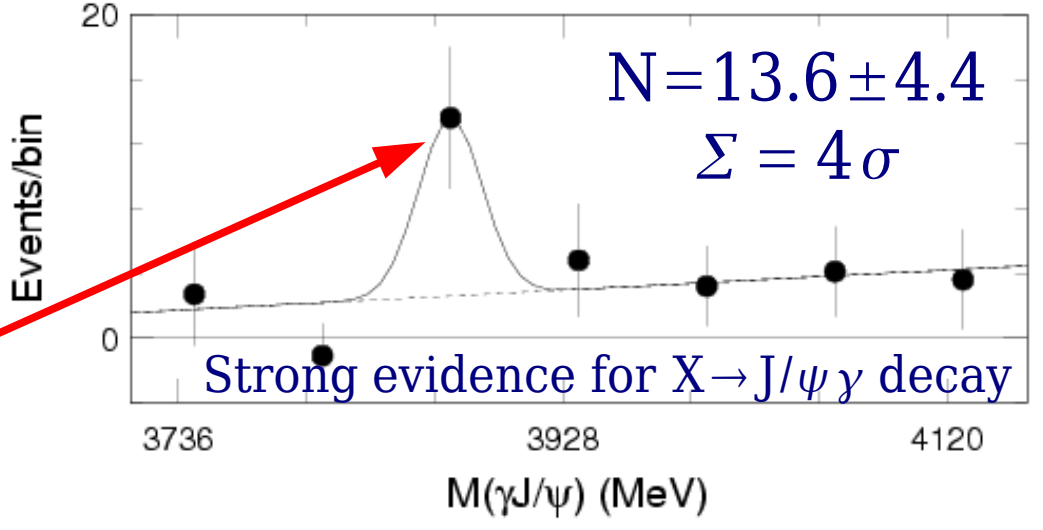
Evidence for $X(3872) \to J/\psi\gamma$

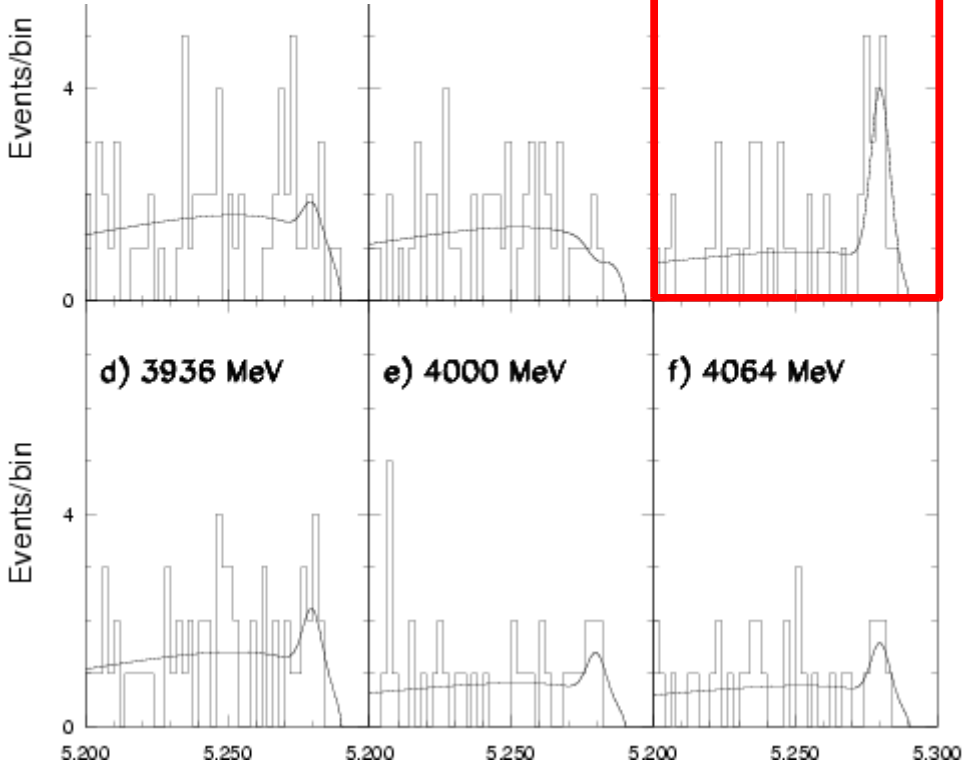
***hep-ex*/0505037**
($256\ fb^{-1}$)

Look for $B^+ \to XK^+$ where $X \to J/\psi\gamma$

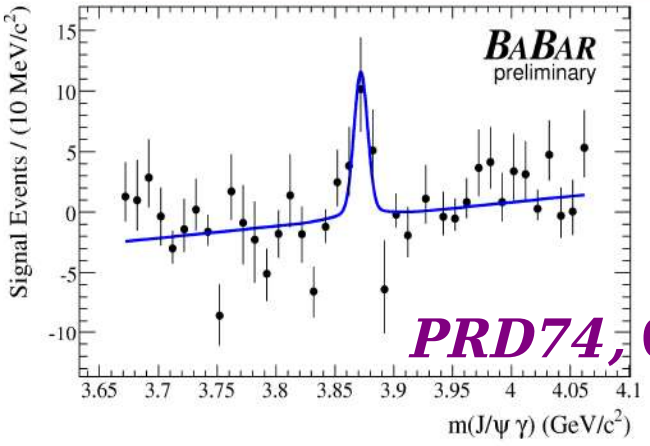
$\chi_{c_1} \to J/\psi\gamma$ as calibration mode







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



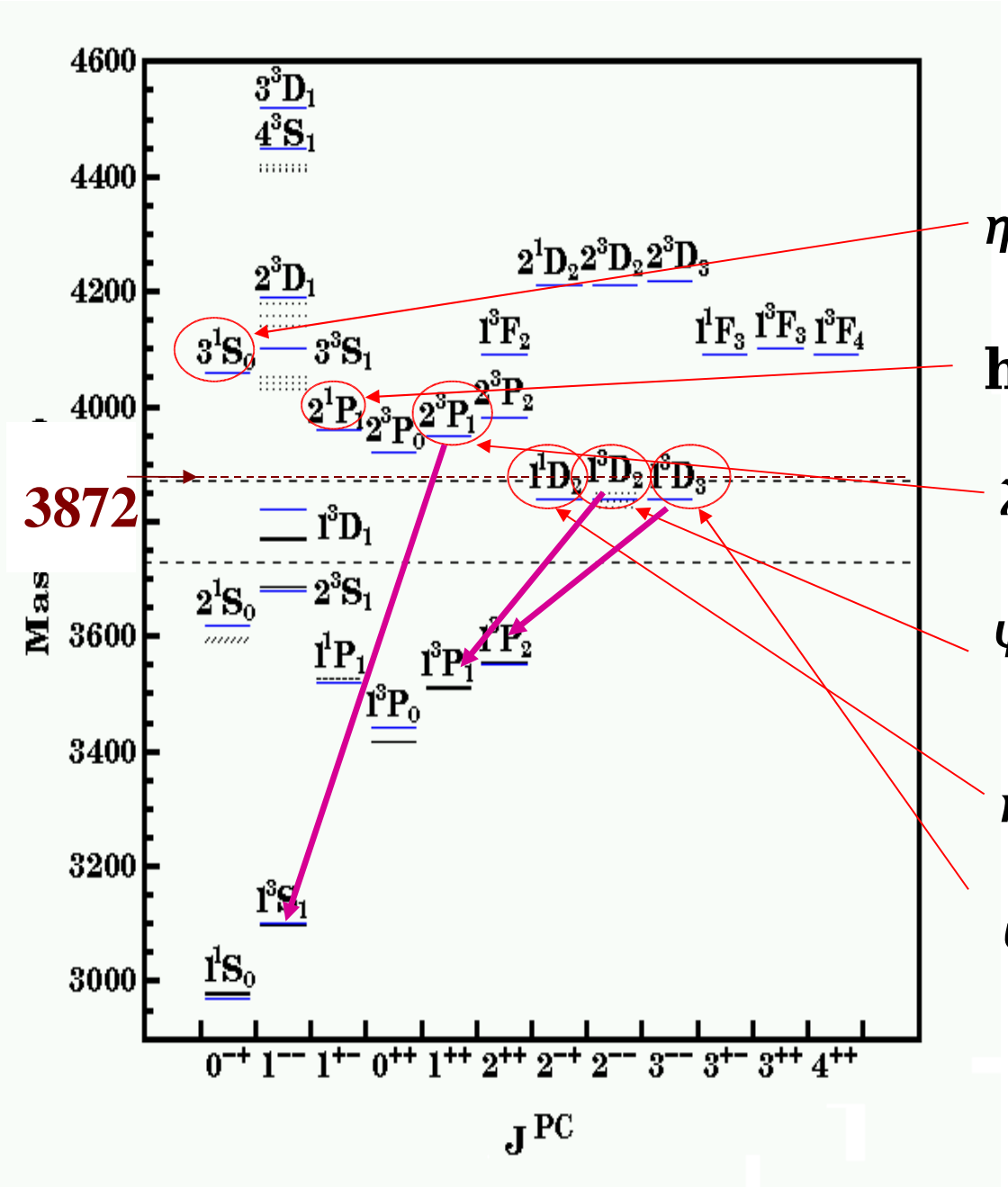
$B^+ \to X(\to J/\psi\gamma)K^+$

$\Sigma = 3.4\sigma$

***PRD74*, 071101 (2006)**

→ C-parity positive !

No obvious $c\bar{c}$ assignment



hep-ex/0407033

η_c'' **M too low and** Γ **too small**

h_c' **angular dist rules out** 1^{+-}

χ_{c1}' $\Gamma(\gamma J/\psi)$ **way too small**

ψ_2 $\Gamma(\gamma\chi_{c1})$ **too small**
$M(\pi^+\pi^-)$ **wrong**

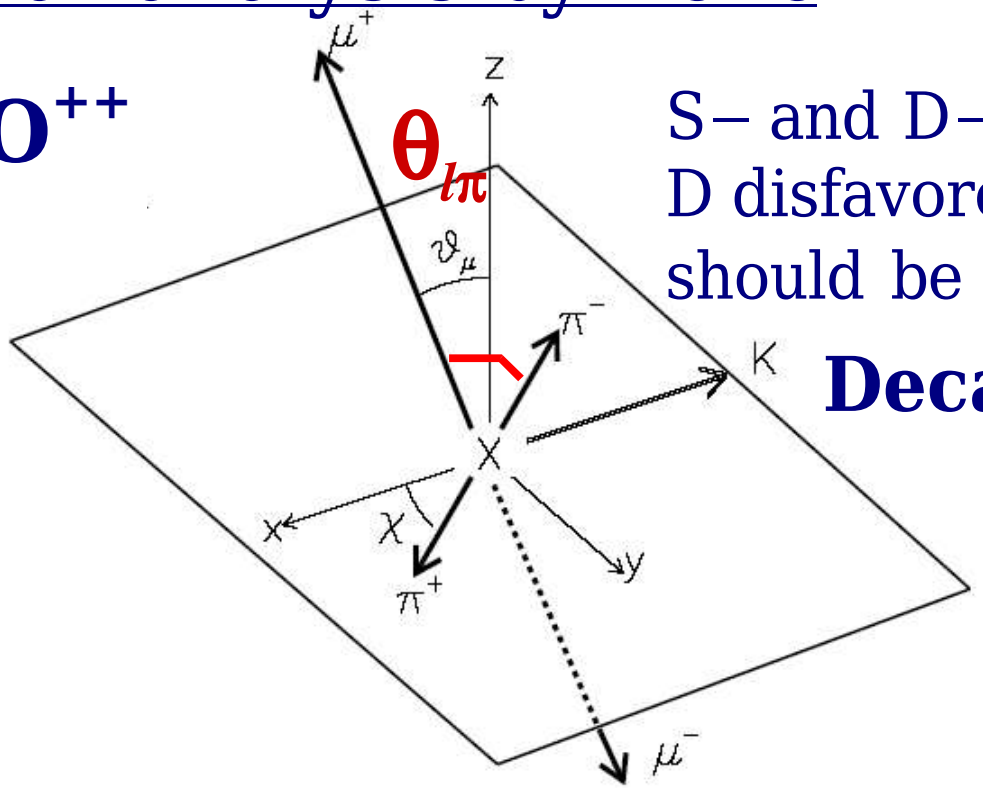
η_{c2} $\pi\pi\eta_c$ **should dominate**

ψ_3 $\Gamma(\gamma\chi_{c2}\&\&D\bar{D})$ **too small**

Angular analysis by Belle

hep-ex/0505038

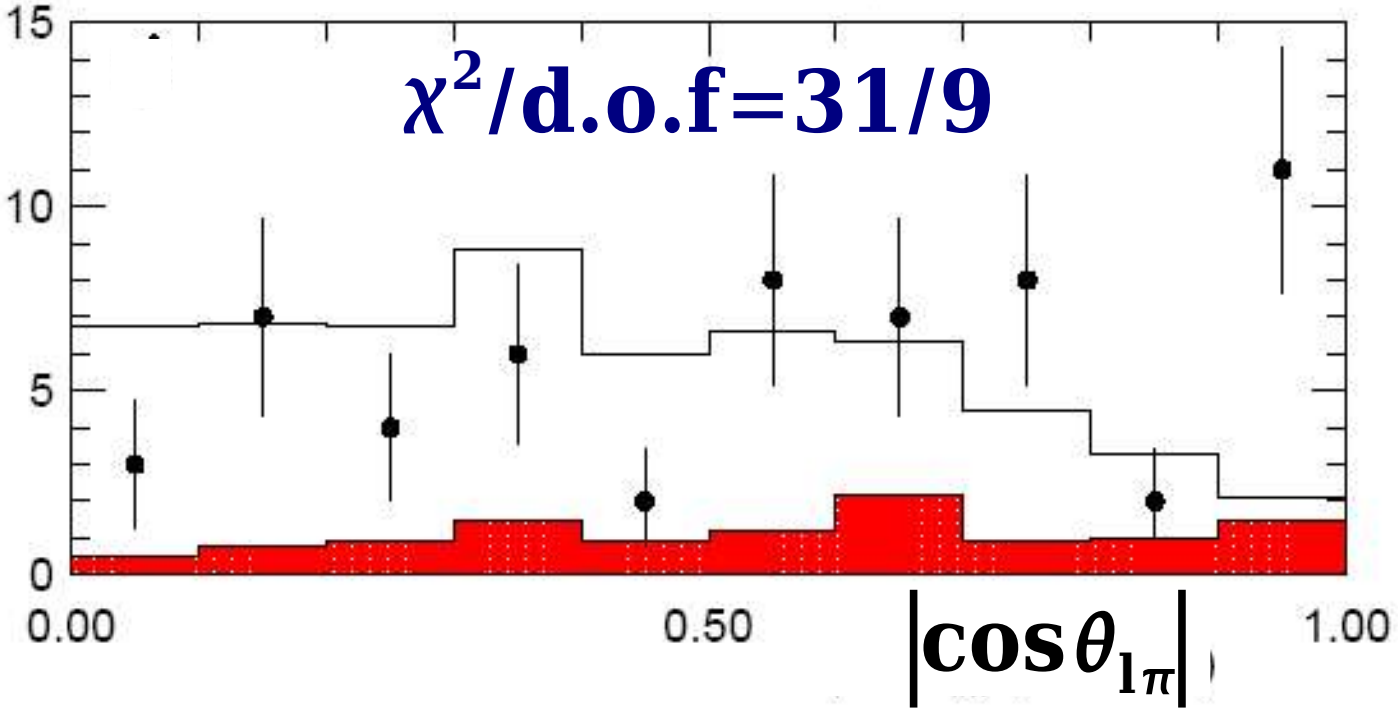
$J^{PC}=O^{++}$



S− and D−waves possible but D disfavored by $M(\pi\pi)$ and should be suppressed by phase space

Decay amplitude $\propto (\vec{\epsilon}_{J/\psi}.\vec{\epsilon}_{\rho})$

$$\frac{dN}{d(\cos\theta_{l\pi})} \propto \sin^2\theta_{l\pi}$$

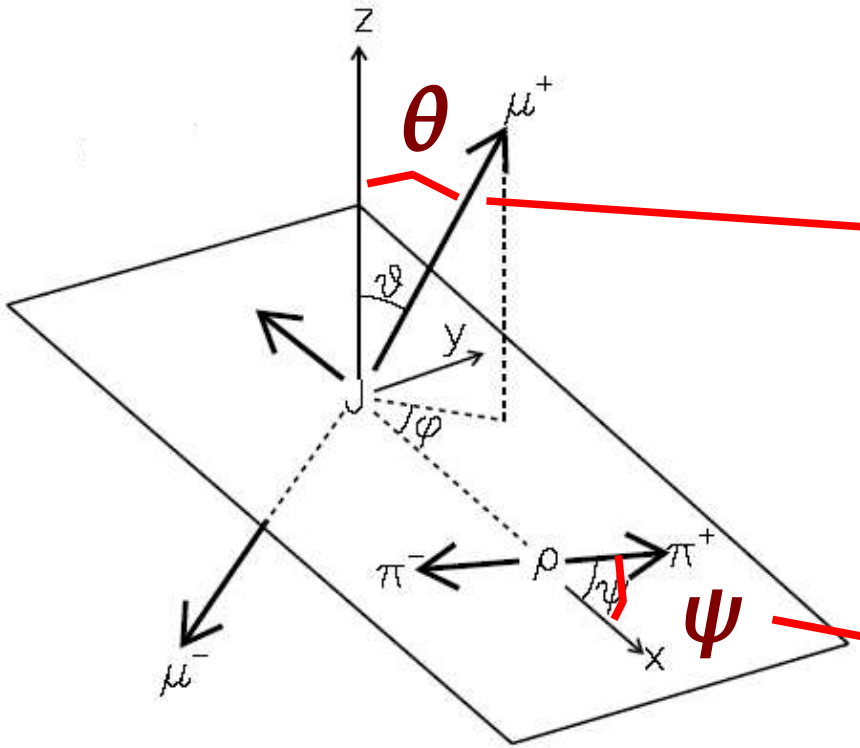


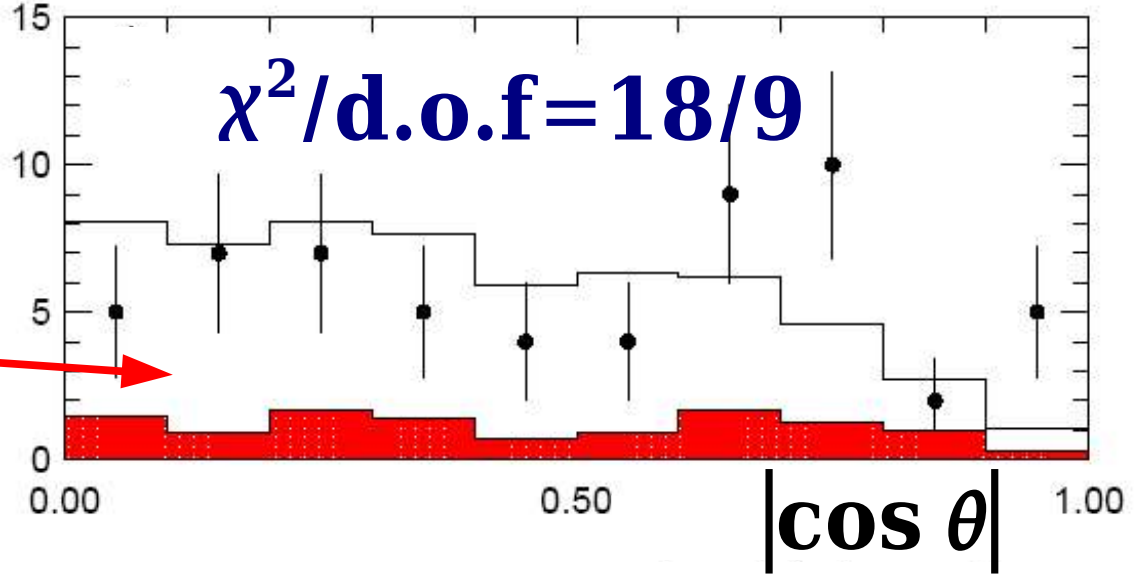
disfavours 0^{++}

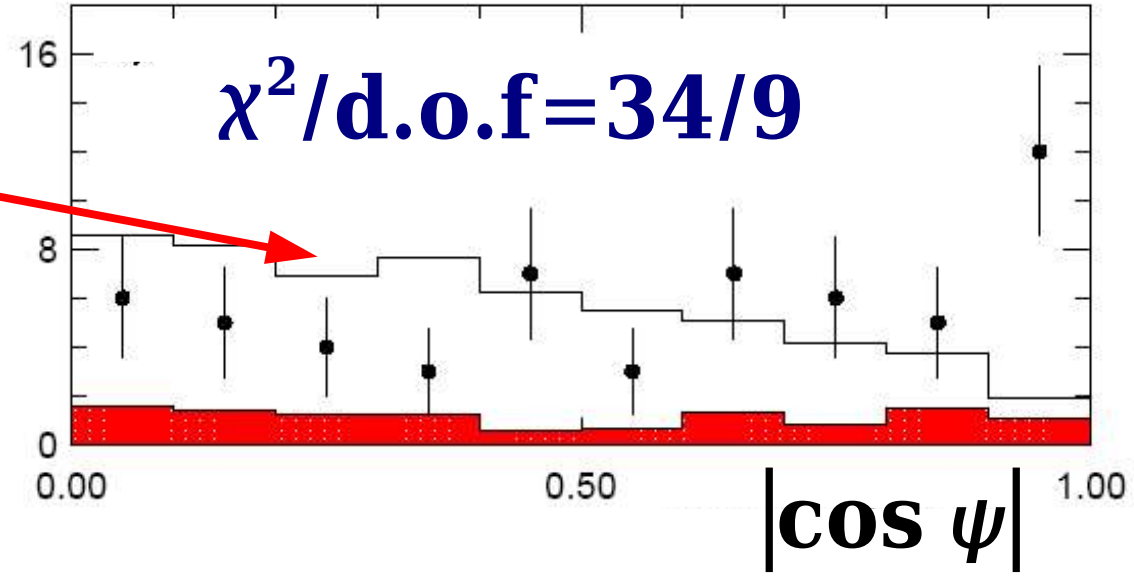
$J^{PC}=O^{-+}$

$$\text{Decay amplitude} \propto \vec{p}_{J/\psi}.(\vec{\epsilon}_{J/\psi}\times\vec{\epsilon}_{\rho})$$

$$\frac{d^2N}{d(\cos\theta)d(\cos\psi)} \propto \sin^2\theta\sin^2\psi$$



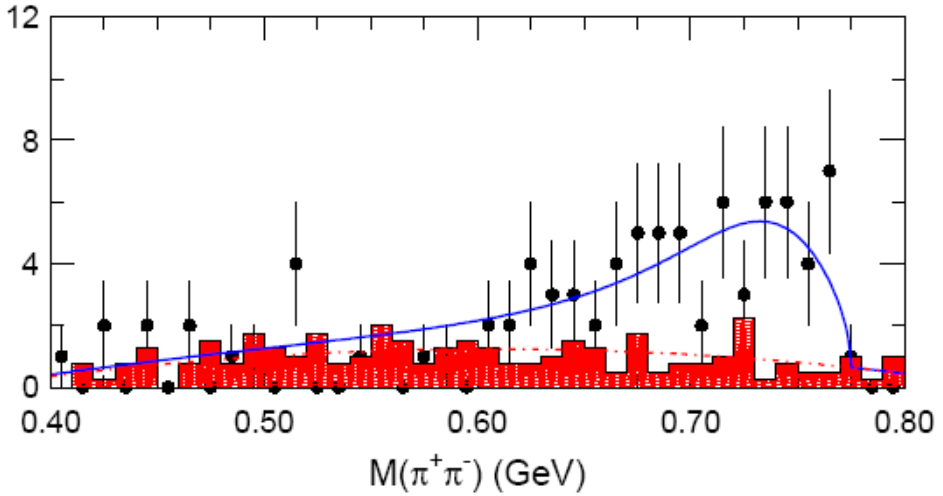


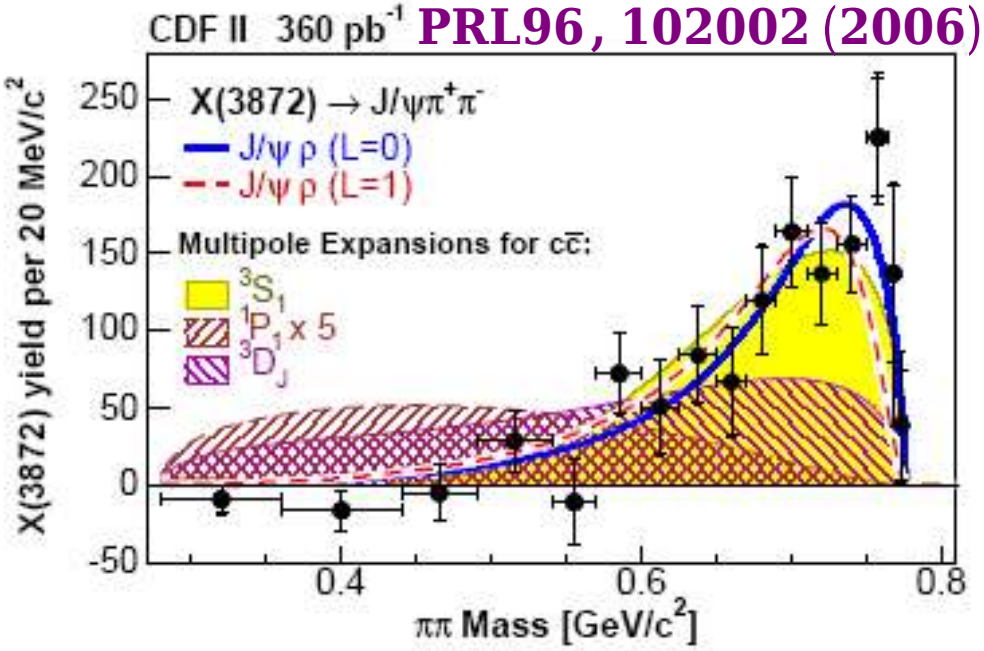


disfavours 0^{-+}

$M_{\pi\pi}$ looks like a ρ

concentration → high $M(\pi^+\pi^-)$ favouring $X(3872) \to \rho\, J/\psi$
and hence $C = +1$





PRL96, 102002 (2006)

see also angular analysis
[**PRL98, 132002 (2007)**]

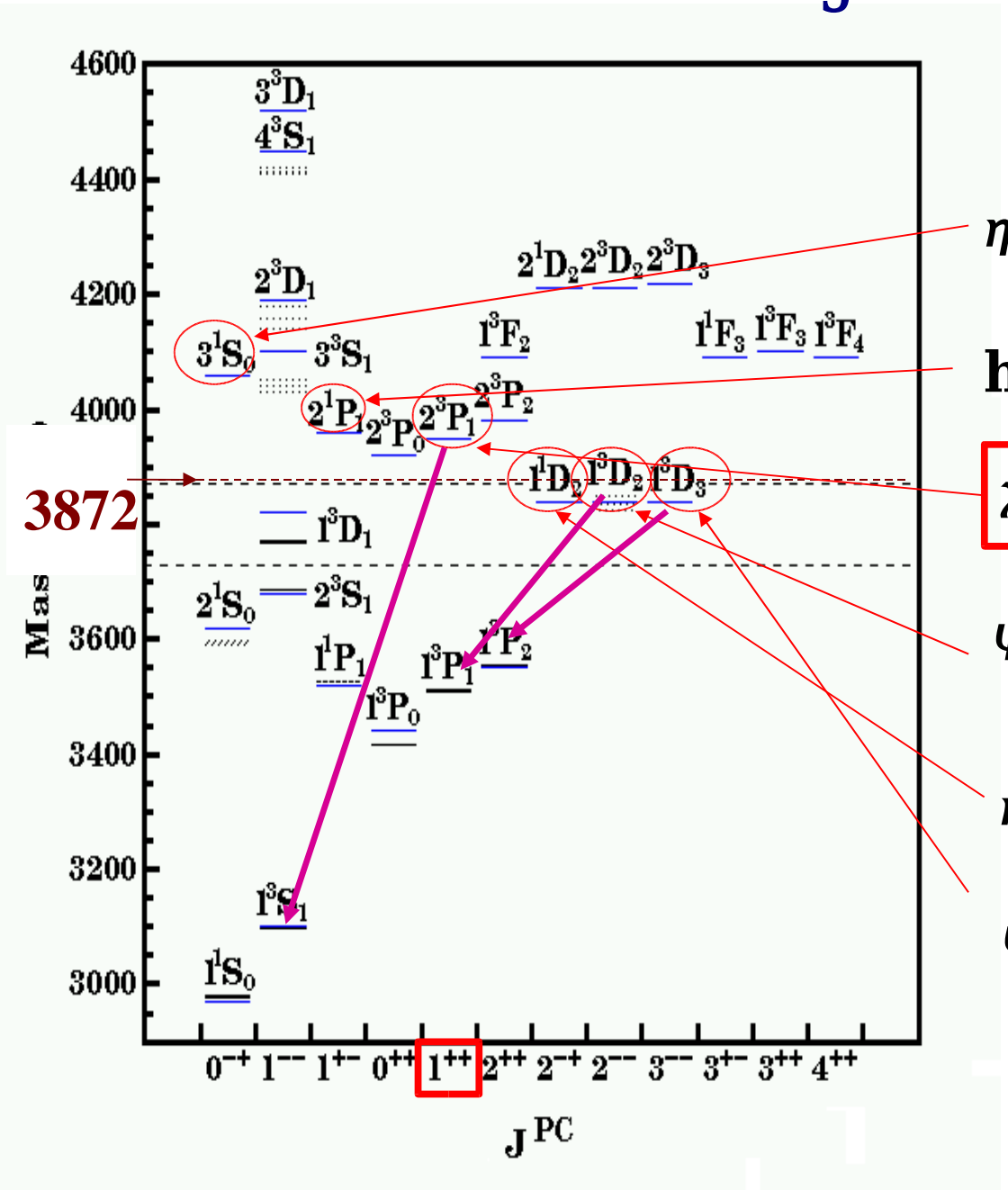
rules out h_c', ψ_J …

reinforces $X(3872) \to \rho\, J/\psi$ $(L=0)$,
$J^{PC} = 1^{++}$ interpretation

puts $L=1$, $J^{PC}=2^{-+}$ possibility back
in play: η_{c2}… but
$\Gamma(\eta_{c2} \to \pi^+\pi^-\eta_c)$ sh^d be $\gg \Gamma(\eta_{c2} \to \pi^+\pi^- J/\psi)$

No obvious $c\bar{c}$ assignment

if $J^{PC} = 1^{++}$



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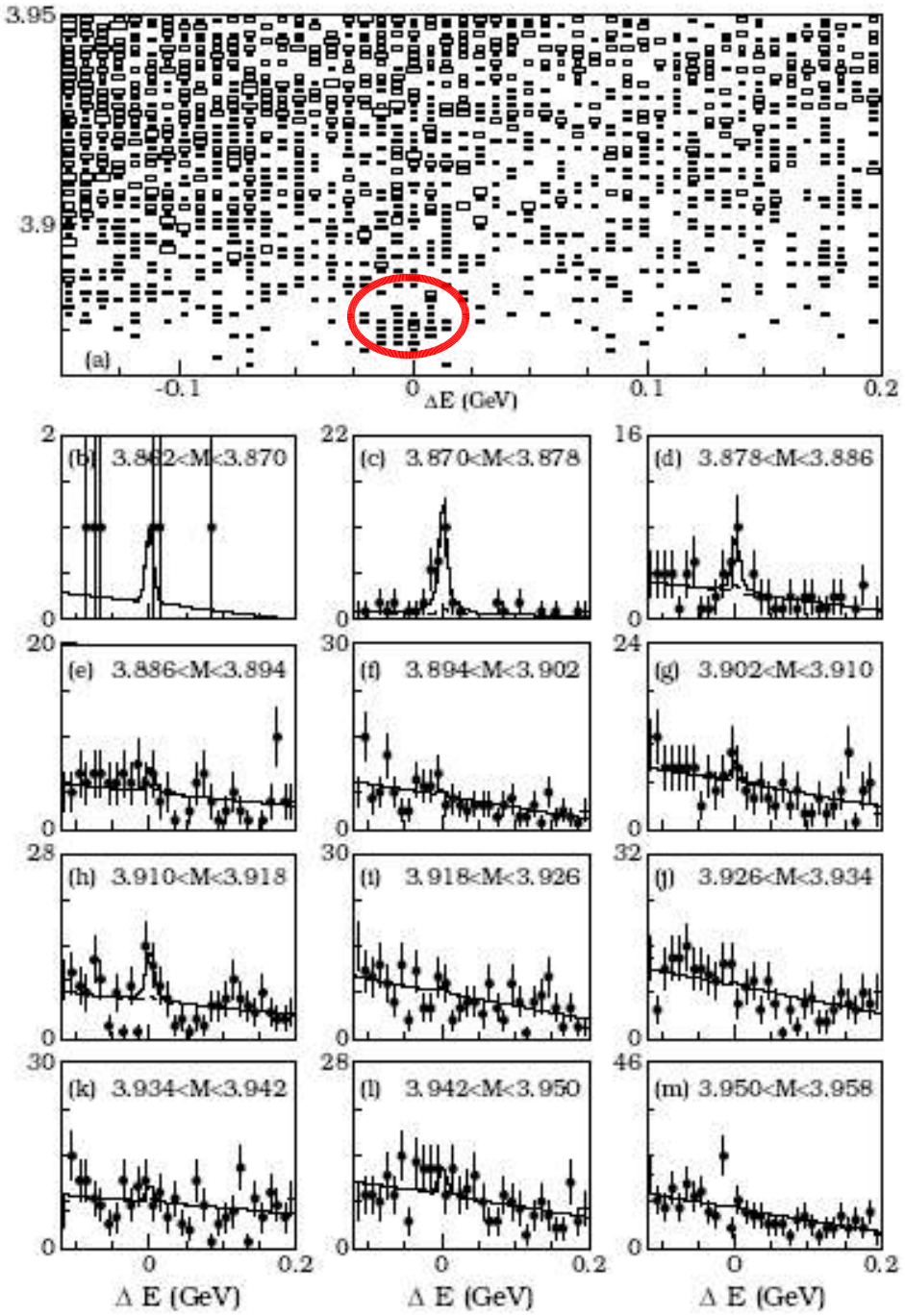
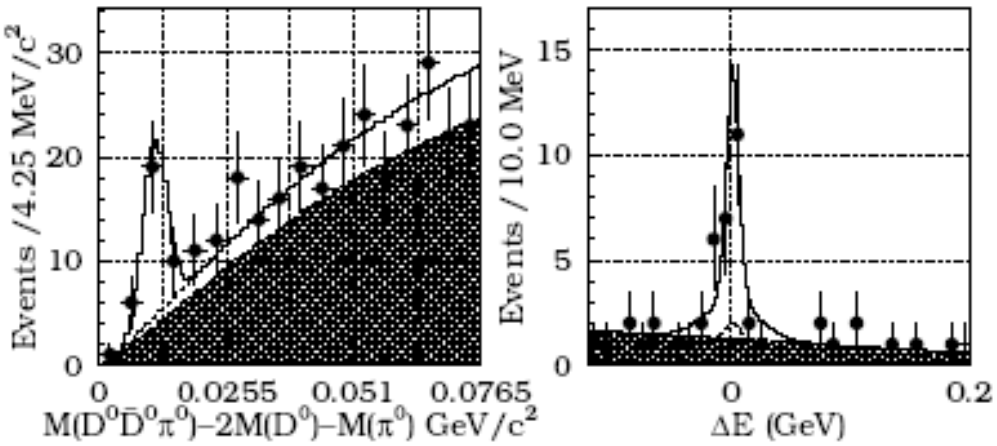
threshold enhancement in $D^0\bar{D}^0\pi^0$ PRL97, 162002 (2006)



$\Sigma = 6.4\sigma$



$$M = (3875.4 \pm 0.7^{+1.2}_{-2.0})\ \mathrm{MeV/c^2}$$

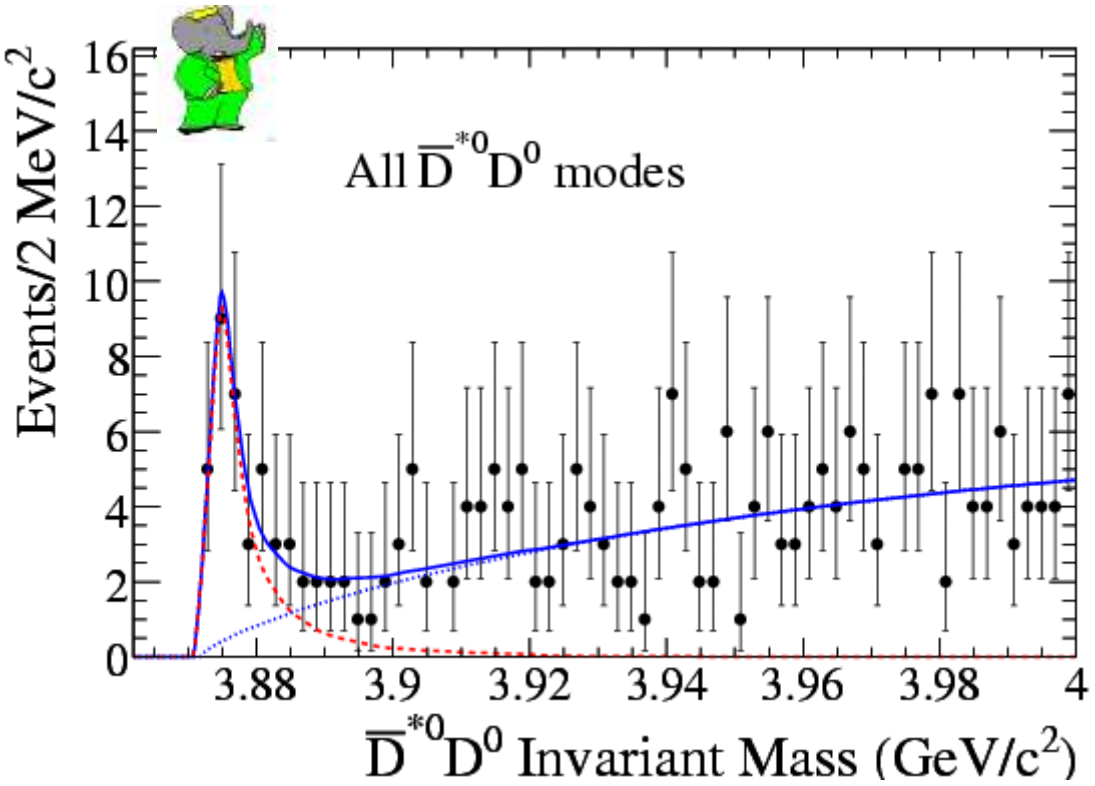
$$BR(B \to XK) \times BR(X \to D^0\bar{D}^0\pi^0) = (1.27 \pm 0.31^{+0.22}_{-0.39}) \times 10^{-4}$$

$$\frac{BR(X \to D^0\bar{D}^0\pi^0)}{BR(X \to J/\psi\,\pi^+\pi^-)} \sim 10$$

$X \to D^0\bar{D}^{*0}/D^0\bar{D}^0\pi^0$ expected to be strongly suppressed for J=2

…and BaBar this summer

hep-ex/0708.1565



$\Sigma = 4.9\sigma$

$D^{*0} \to D^0\pi^0$, $D^0\gamma$

$$M = (3875.1^{+0.7}_{-0.5} \pm 0.5)\ \mathrm{MeV}/c^2$$

$$\Gamma = (3.0^{+1.9}_{-1.4} \pm 0.9)\ \mathrm{MeV}/c^2$$

$$BR(B^0 \to XK^0) \times BR(X \to \bar{D}^{*0}D^0) = (2.22 \pm 1.05 \pm 0.42) \times 10^{-4}$$
$$BR(B^+ \to XK^+) \times BR(X \to \bar{D}^{*0}D^0) = (1.67 \pm 0.36 \pm 0.47) \times 10^{-4}$$

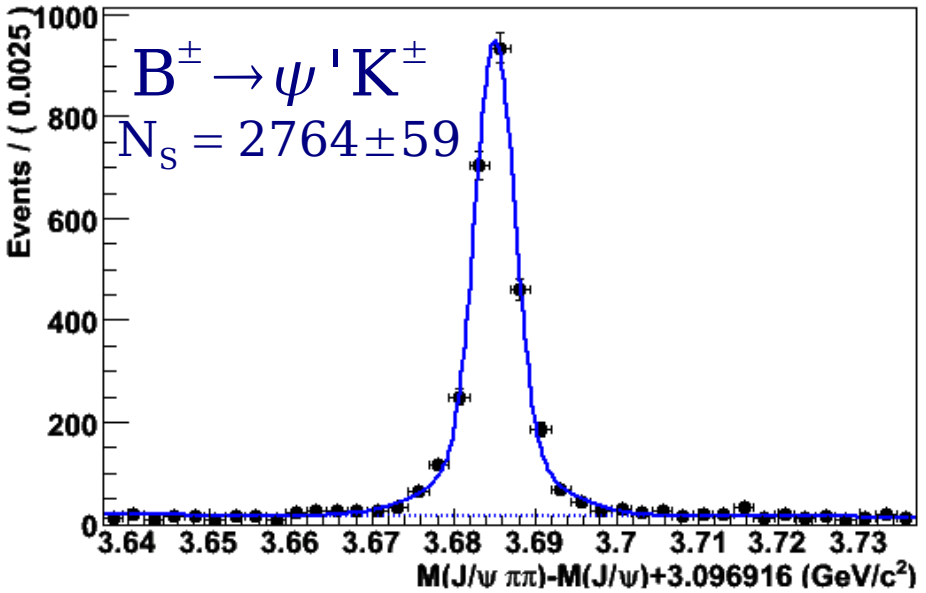
M_X differs in $D^0\bar{D}^0\pi^0$ and $J/\psi\pi^+\pi^-$ decays ? $(\sim 4\sigma)$

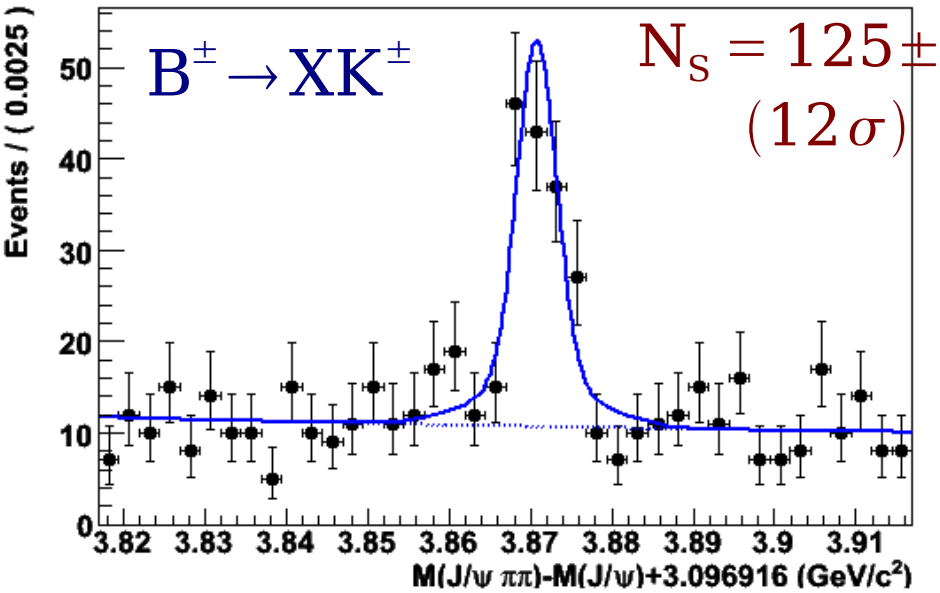
Summer 2007: update with 605 fb^{-1}

Flow of the analysis:

- $B \to \psi' K$ and $B \to X(3872) K$ are reconstructed
  at the same time $(\psi'/X(3872) \to J/\psi \pi^+ \pi^-,\ J/\psi \to \mu^+ \mu^-,\ e^+ e^-)$
  = utilize ψ' as a control sample as much as possible
  (detector resolution)
- Require $M_{\pi\pi} > (M_{J/\psi\pi\pi}(M_{J/\psi} + 0.2\,GeV/c^2))$, efficient
  to reduce combinatorial background
- Look at Delta $M = M_{l^+l^-\pi\pi} - M_{l^+l^-}$ distribution for B candidates
  $(|\Delta E| < 30\,MeV$ and $M_{bc} > 5.27\,GeV/c^2)$
- Enough stat to look at $X(3872)$ in both B modes separately

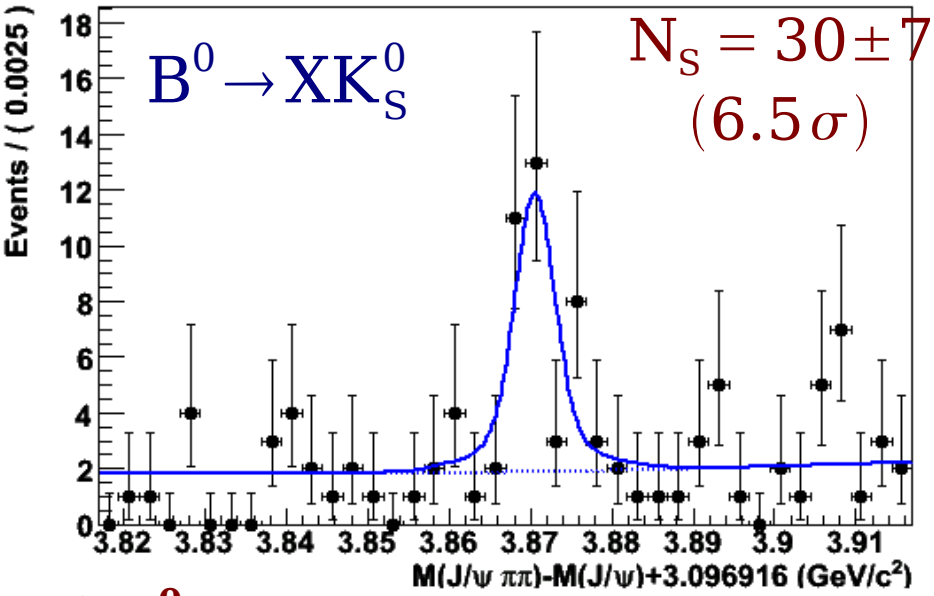
$B^{\pm} \to X(3872) K^{\pm}$ and $B^0 \to X(3872) K^0_S$





distributions for ψ' and $X(3872)$ are fitted simultaneously:

detector resolution effect is automatically calibrated by ψ'



First observation of $B^0 \to X(3872) K^0_S$

$B^{\pm} \to X(3872) K^{\pm}$ and $B^{0} \to X(3872) K^{0}$

- $$R = \frac{BR(B^{0} \to X(3872) K^{0})}{BR(B^{\pm} \to X(3872) K^{\pm})} = 0.94 \pm 0.24 \pm 0.10$$

  charged and neutral B mesons decay into X(3872) with comparable branching fraction

- $$\delta M_{X} = M(X \text{ from } B^{\pm}) - M(X \text{ from } B^{0})$$
  $$= (0.22 \pm 0.90 \pm 0.27)\ \text{MeV}/c^{2}$$

  No mass splitting signature

Possible interpretations...

- four-quark model

(*L.Maiani et al, arXiv:*0707.3354)

$X_u = [cu][\bar{c}\bar{u}] = X$ state decaying into $D^0\bar{D}^0\pi^0 = X(3876)$

$X_d = [cd][\bar{c}\bar{d}] = X$ state decaying into $J/\psi\pi^+\pi^- = X(3872)$

(finding the charged partner is critical)

- molecule model ($D^{*0}\bar{D}^0$ bound state)

M_X close to the $D^{*0}\bar{D}^0$ threshold

1^{++}, favors $D\bar{D}\pi^0$ decay over $J/\psi\pi\pi$ over $J/\psi\gamma$

(*E.Braaten et al, arXiv:*0710.5482)

(line shapes of the X depends on its decay channel, different in B^+ or B^0 decays)

- ....

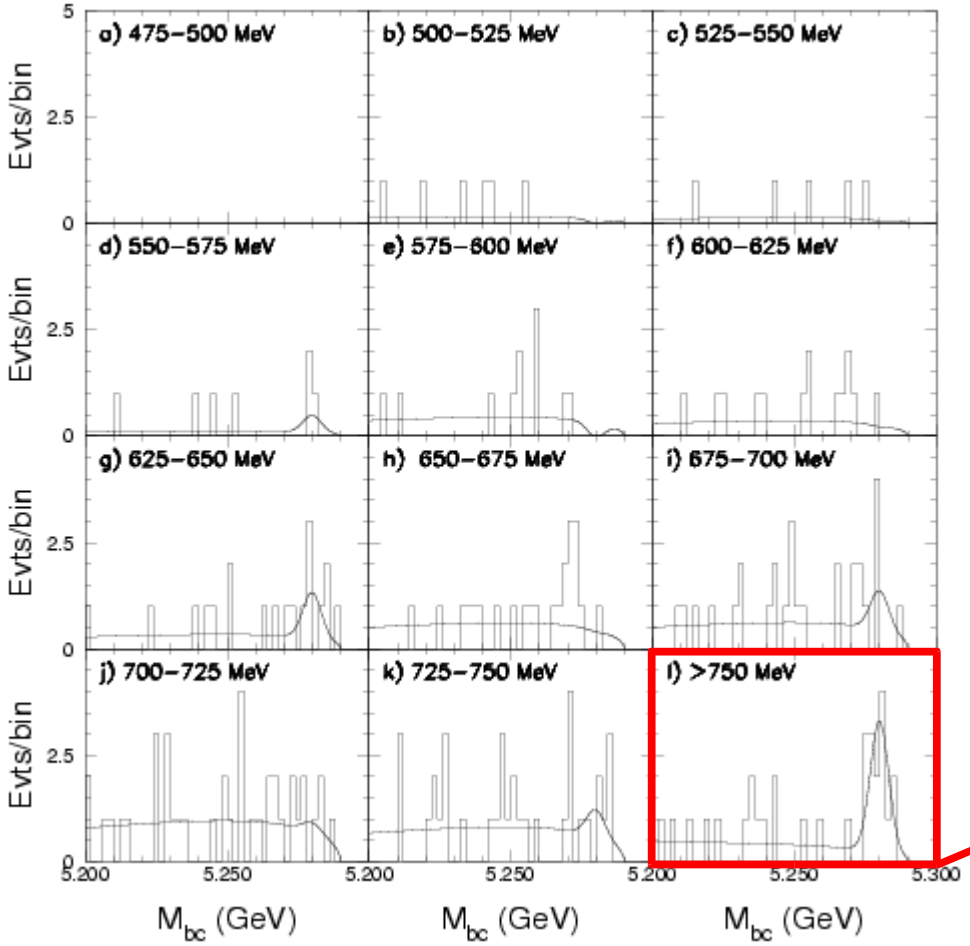
Conclusions

- narrow and right above $m_{D^0}+m_{D^{*0}}$
- seen in $D^0\overline{D}^0\pi^0$, $J/\psi\,\pi^+\pi^-$, $J/\psi\,\omega$, $J/\psi\,\gamma$
- $C=+1$ well established
- $J^{PC}=1^{++}$ seems likely
- no charmonium candidate
- so what is it ? tetraquark , molecule , ... ?
- need more experimental inputs

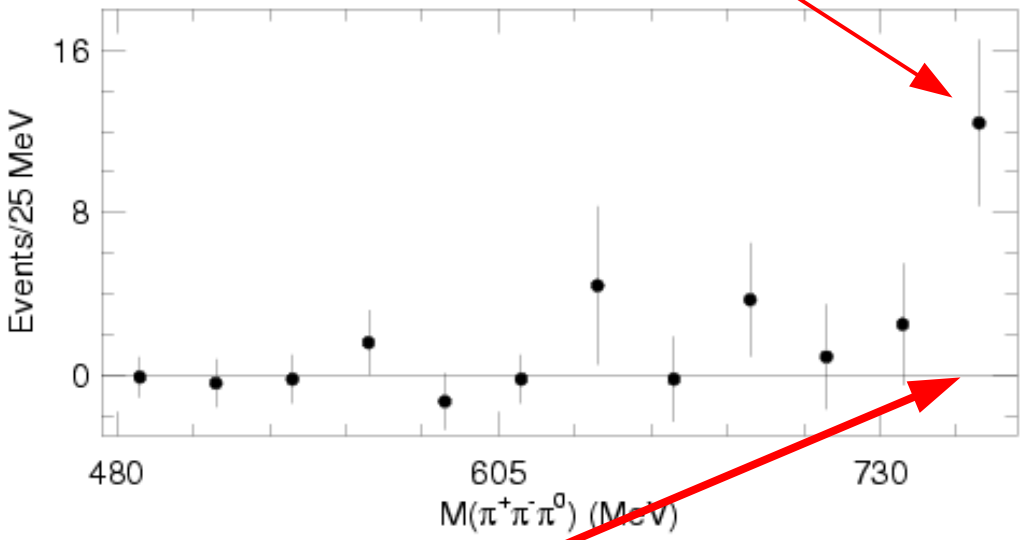
(updates , precise measurements , new decays...)

- ...and suggestions from theorists !

Evidence for $X(3872) \to \pi\pi\pi^0 J/\psi$ hep−ex/0505037 (256 fb^{-1})



virtual $\omega(782)$ *?*



$N = 12.1 \pm 4.1$

Backgrounds $= 2.1 \pm 1.0$

significance 4.3σ

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

for $M(\pi^+\pi^-\pi^0) > 750$ MeV/c^2

Large isospin violation