Properties of the X(3872)

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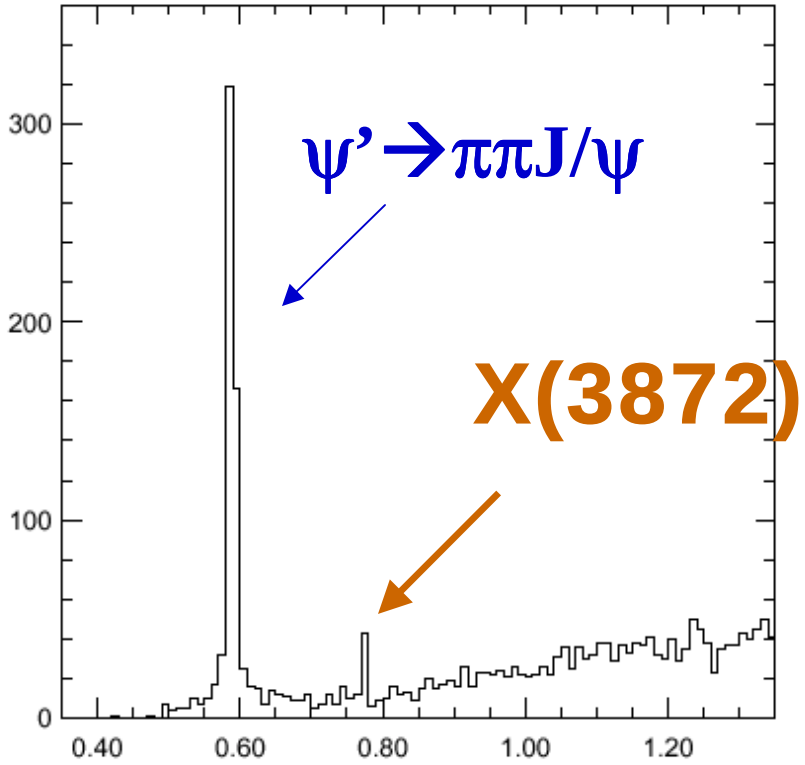
(For the  Belle Collaboration)

Lake Louise Winter Institute, Feb19, 2004

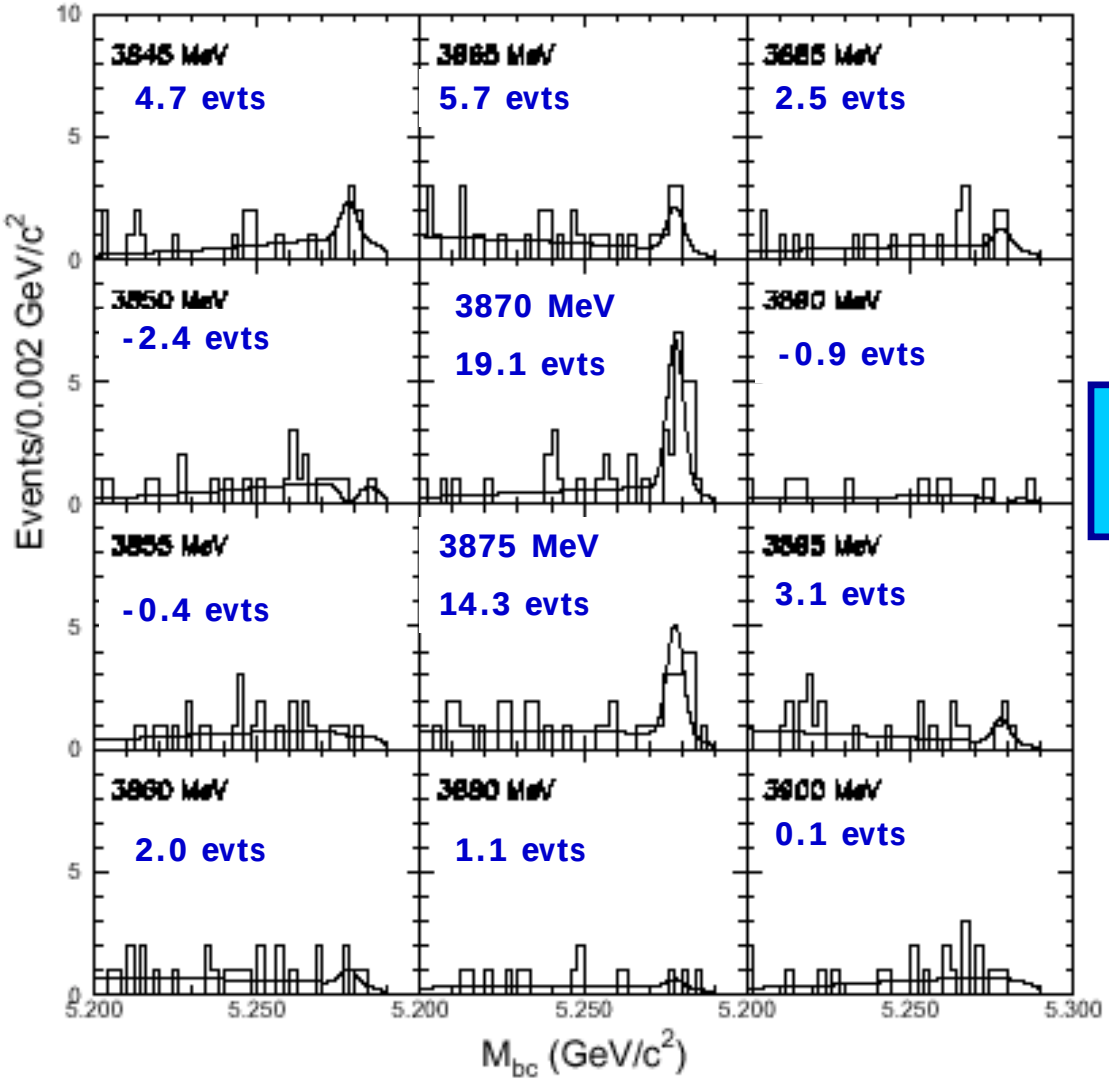
Look at $B^{\pm} \rightarrow K^{\pm}\pi^{+}\pi^{-}J/\psi$

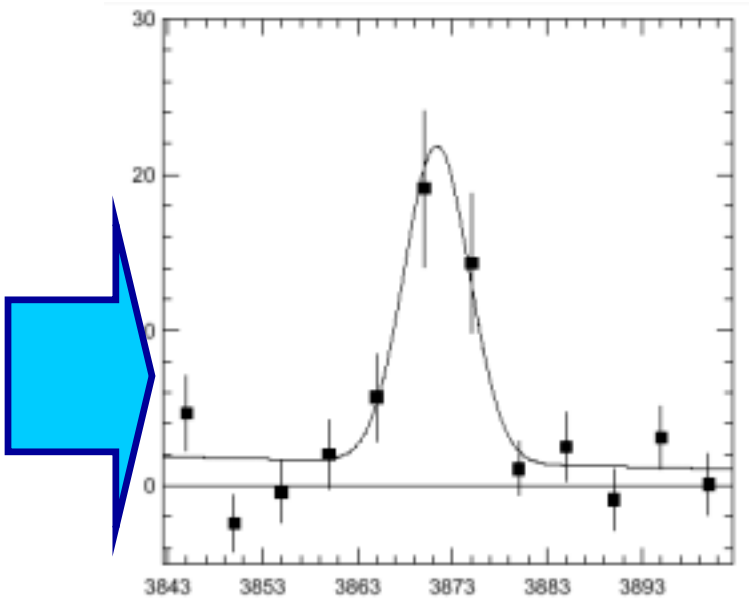
140 fb^{-1} from Belle
(152M $\Upsilon(4S) \rightarrow BB$ decays)



$M(\pi^{+}\pi^{-} J/\psi) - M(J/\psi)$

M_{bc} for 5 MeV $M(\pi\pi J/\psi)$ bins



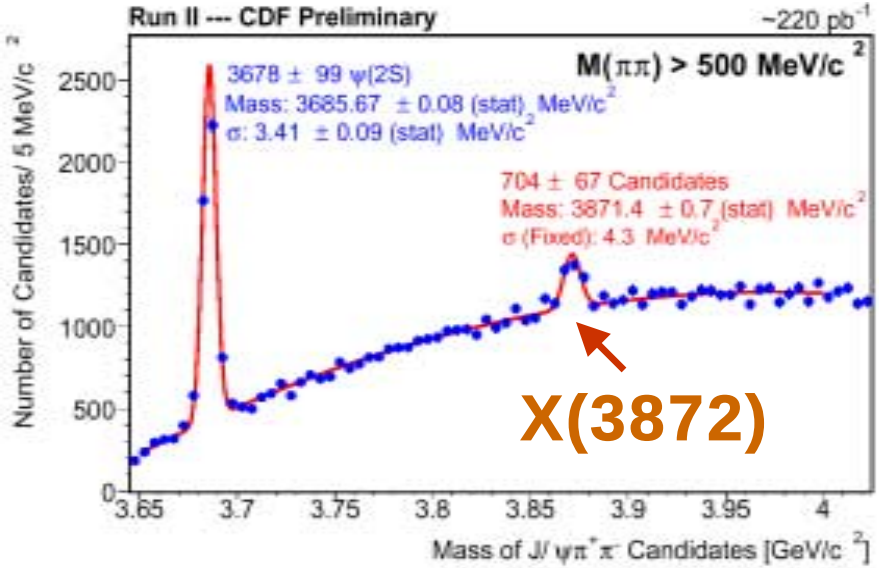


$M_X = 3872 \pm 0.6 \pm 0.5$ MeV

$\Gamma_{tot} < 2.3$ MeV (90%CL)

Confirmed by CDF & D0

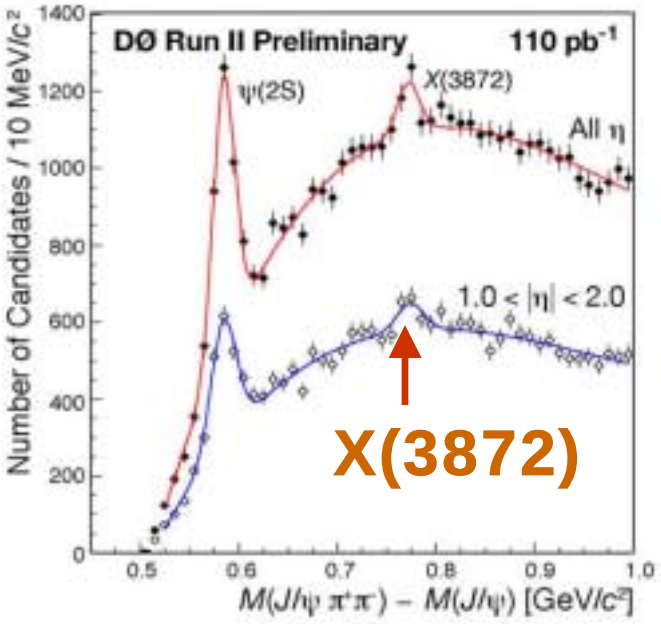
CDF



G.Bauer, talk at QWG03

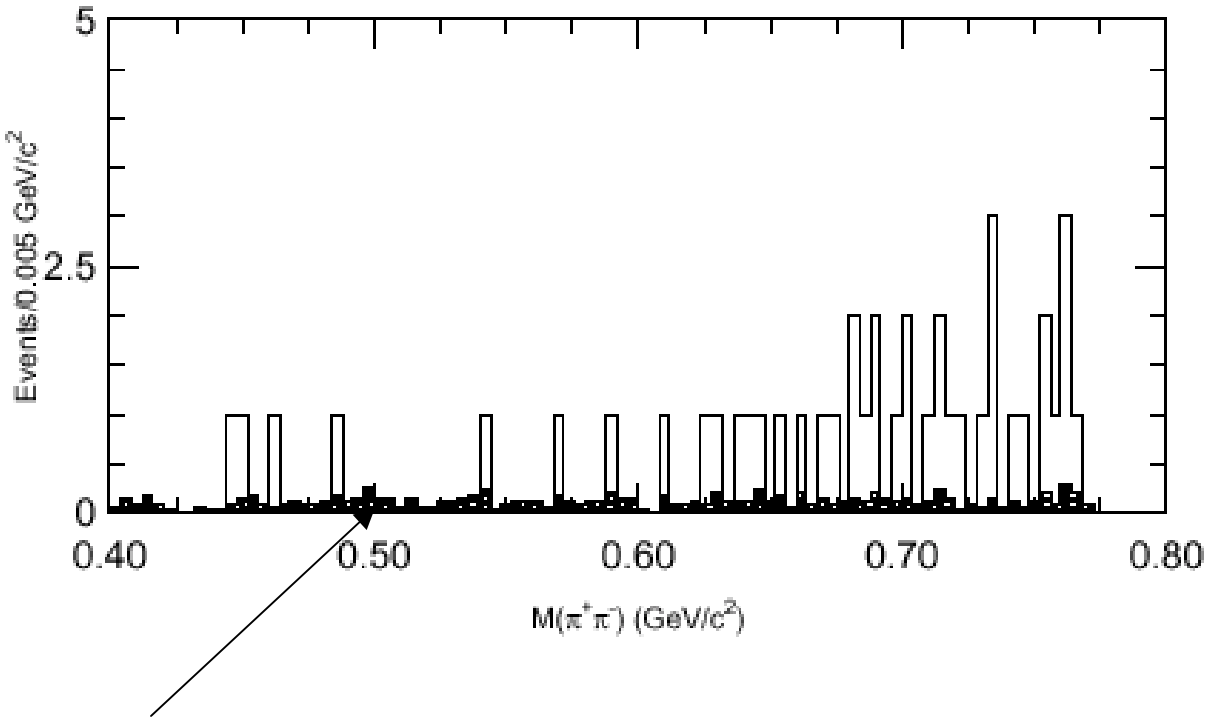
hep-ex/031202

D0



Fermilab Today, 12/18/03

$M_{\pi+\pi-}$ tends to peak near limit



background estimated from M_{bc}-ΔE sidebands

What could it be?

- **Decays to $\pi^+\pi^-$ J/ψ**
  - **contains $c\bar{c}$ quarks (charmonium?)**
- **Above $D\bar{D}$ threshold, but narrow**
  - **X(3872)→$D\bar{D}$ forbidden or suppressed**
- **Produced in exclusive B→KX(3872) decays**
  - **high J values unlikely**

Allowed J^{PC} for a 0^{++} $\pi\pi$ system

L	J^{PC}	$c\bar{c}$?	$D\bar{D}$?	comment
0	1^{--}	$\psi'/\psi(3770)$	allowed	
1	0^{+-}	no	forbidden	possibility (exotic)
1	1^{+-}	h_c' (2^1P_1)	forbidden	possibility
1	2^{+-}	no	forbidden	exotic
2	1^{--}	$\psi'/\psi(3770)$	allowed	
2	2^{--}	ψ_2 (1^3D_2)	forbidden	possibility
2	3^{--}	$\eta_{c2}(1^3D_3)$	suppressed?	possibility?
3	2^{+-}	no	forbidden	possibility (exotic)
3	3^{+-}	$^1F_3$	forbidden	possible??
3	4^{+-}	no	forbidden	possibility? (exotic)

Allowed J^{PC} for a 1^{--} $\pi\pi$ system

L	J^{PC}	$c\bar{c}$?	$D\bar{D}$?	comment
0	0^{++}	χ'_{c0} (2^3P_0)	allowed	
0	1^{++}	χ'_{c1} (2^3P_1)	forbidden	possibility
0	2^{++}	χ'_{c2} (2^3P_2)	allowed	
1	0^{-+}	η''_c $(3^1S_0$	forbidden	possibility
1	1^{-+}	no	forbidden	possibility (exotic)
1	2^{-+}	η_{c2} (1^1D_2)	forbidden	possiibility
1	3^{-+}	no	forbidden	possibility (exotic)
2	0^{++}	χ'_{c0} (2^3P_0)	allowed	
2	1^{++}	χ'_{c1} (2^3P_1)	forbidden	possibility
2	2^{++}	χ'_{c2} (2^3P_2)	allowed	
2	3^{++}	1^3F_3	forbidden	possibility
2	4^{++}	1^3F_4	suppressed?	possibility?
3	1^{-+}	no	forbidden	possibility (exotic)
3	2^{-+}	η_{c2} (1^1D_2)	forbidden	possibility??
3	3^{-+}	no	forbidden	possibility (exotic)
3	4^{-+}	1^1G_4	forbidden	possibility?
3	5^{-+}	no	forbidden	possibility (exotic)

reject $D\bar{D}$-allowed states

&disregard J=3 or higher

$\pi\pi$ is spin 0

L	J^{PC}	name
1	0^{+-}	exotic
1	1^{+-}	h_c'
1	2^{+-}	exotic
2	2^{--}	ψ_2
2	3^{--}	ψ_3

$X \rightarrow \pi^0\pi^0 J/\psi \approx \frac{1}{2}\, X \rightarrow \pi^+\pi^- J/\psi$

$\pi\pi$ is spin 1 (ρ)

L	J^{PC}	name
0	1^{++}	χ_{c1}'
1	0^{-+}	η_c''
1	1^{-+}	exotic
2	2^{-+}	η_{c2}

$X \rightarrow \pi^0\pi^0 J/\psi = 0$

Charmonium possibilities

For these, $X \to \pi\pi J/\psi$ violates isospin (unlikely for charmonium)

$\pi\pi$ is spin 0

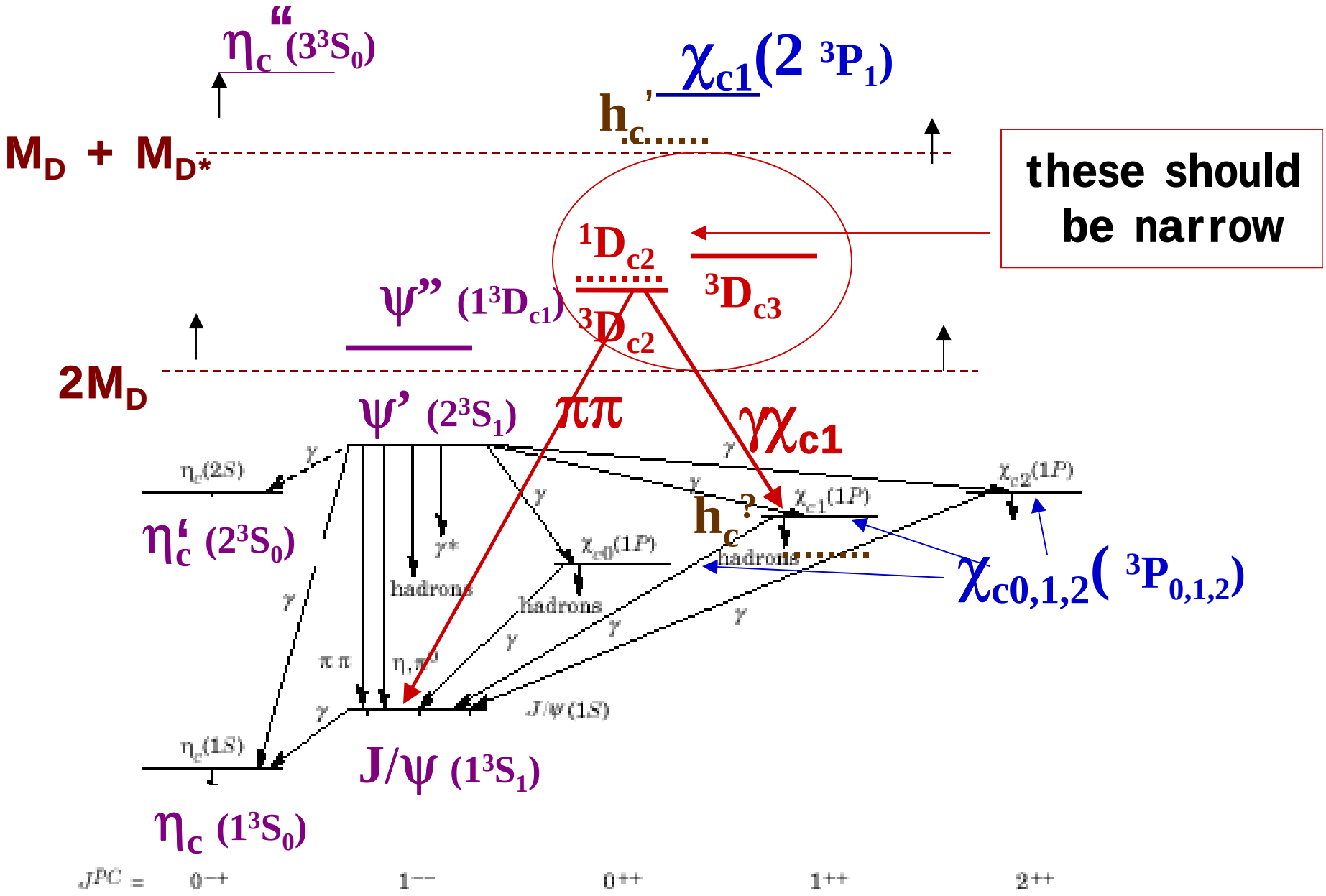
J^{PC}	name
1^{+-}	h_c'
2^{-+}	ψ_2
3^{--}	ψ_3

$X \to \pi^0\pi^0 J/\psi \approx \frac{1}{2}\, X \to \pi^+\pi^- J/\psi$

$\pi\pi$ is spin 1 (ρ)

J^{PC}	name
1^{++}	χ_{c1}'
0^{-+}	η_c''
2^{-+}	η_{c2}

$X \to \pi^0\pi^0 J/\psi = 0$


η_c “(3^3S_0)
$\chi_{c1}(2\ ^3P_1)$
h_c’……
$M_D + M_{D^*}$
these should be narrow
$^1D_{c2}$
$^3D_{c3}$
ψ” (1^3D_{c1})
$^3D_{c2}$
$2M_D$
ψ’ (2^3S_1)
$\pi\pi$
$\gamma\chi_{c1}$
$\eta_c(2S)$
η_c‘ (2^3S_0)
h_c ?
$\chi_{c2}(1P)$
$\chi_{c1}(1P)$
$\chi_{c0}(1P)$
hadrons
hadrons
hadrons
$\chi_{c0,1,2}(\ ^3P_{0,1,2})$
$\pi\ \pi$
η,π^0
$J/\psi(1S)$
$\eta_c(1S)$
J/ψ (1^3S_1)
η_c (1^3S_0)
J^{PC} = 0−+ 1−− 0++ 1++ 2++

First consider D-wave states (ψ_2 or ψ_3)

Wigner-Eckart:

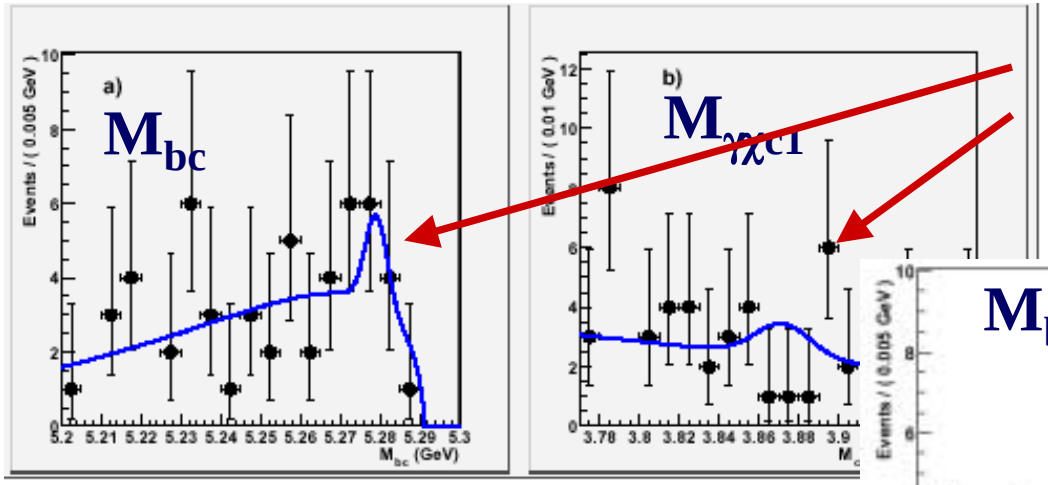
$$\Gamma(\psi_2 \to \pi^+\pi^- J/\psi) = \Gamma(\psi_3 \to \pi^+\pi^- J/\psi) = \Gamma(\psi'' \to \pi^+\pi- J/\psi)$$

CLEO: < 55keV (90% CL)
BESII: 85 ± 35 keV (new)

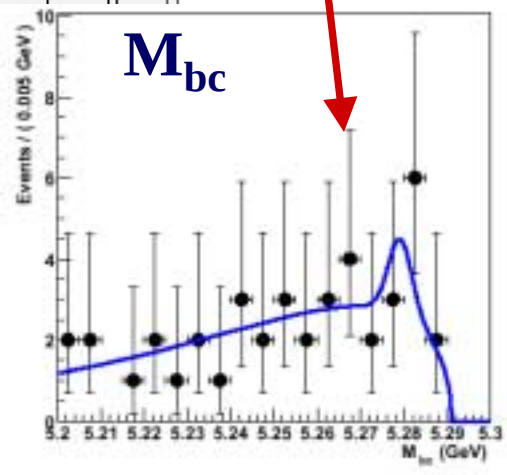
$$\Gamma(\psi_2 \to \gamma\chi_{c1}) = 360\ (207)\ \text{keV} \quad >2\ \Gamma(\pi+\pi-J/\psi)$$
$$\Gamma(\psi_3 \to \gamma\chi_{c2}) = 370\ (299)\ \text{keV} \quad >3\ \Gamma(\pi+\pi-J/\psi)$$

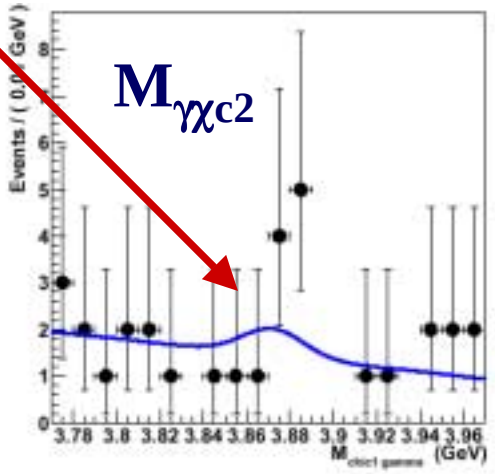
Barnes & Godfrey hep-ph/0311162 (Eichten, Lane Quigg hep-ph/0401210)

Look for $X(3872) \to \gamma\chi_{c1}$ ($\gamma\chi_{c2}$)



No signals !!





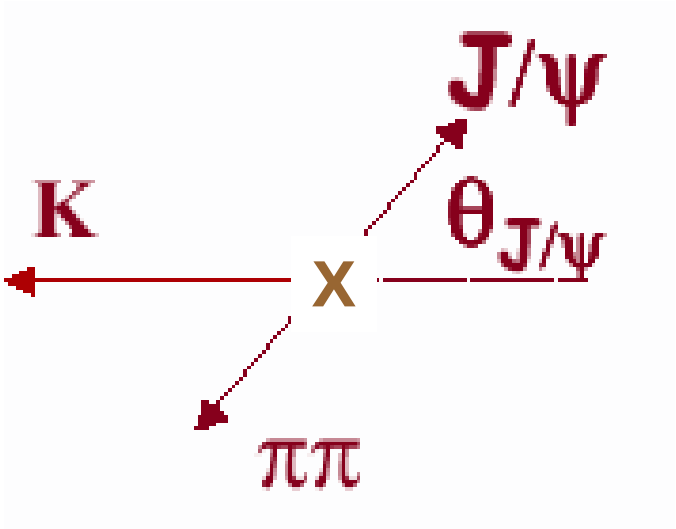
$$\frac{\Gamma(X \to \gamma\chi_{c1})}{\Gamma(X \to \pi^+\pi^- J/\psi)} < 0.9$$

$$\frac{\Gamma(X \to \gamma\chi_{c2})}{\Gamma(X \to \pi^+\pi^- J/\psi)} < 1.1$$

Contrary to expectations for charmonium D states

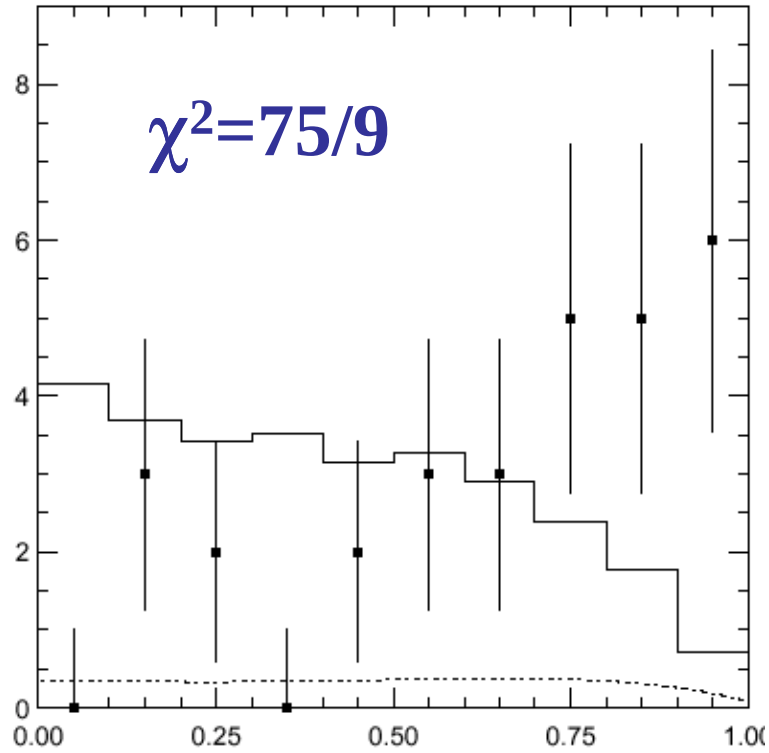
What about (1^{+-}) h_c'

Look at J/ψ angular distribution:



For 1^{+-} expect: $dN/d\cos\theta_{J/\psi} \propto \sin^2\theta$

Fit to 1^{+-}



1^{+-} (h_c') is ruled out!

What about C=+1 charmonium?

- $\pi^+\pi^-$ system would be a ρ
  - consistent with M($\pi^+\pi^-$) dist
- X→ $\pi^+\pi^-$ J/ψ would violate isospin
  - should be strongly suppressed
- Candidates: $0^{-+}(\eta_c'')$; $1^{++}(\chi_{c1}')$; $2^{-+}(\eta_{c2})$
  - η_c'' should be wide; M≈ψ(3S) (4030MeV)
  - $\Gamma(\chi_{c1}' \to \gamma\, J/\psi) >> \Gamma(\chi_{c1}' \to \pi\pi J/\psi)$
  - Br($\eta_{c2} \to \pi\pi J/\psi$) should be very small

Is the X(3872) = the 2^3P_1 ?

Look for X(3872)→γ J/ψ

allowed E1 transition

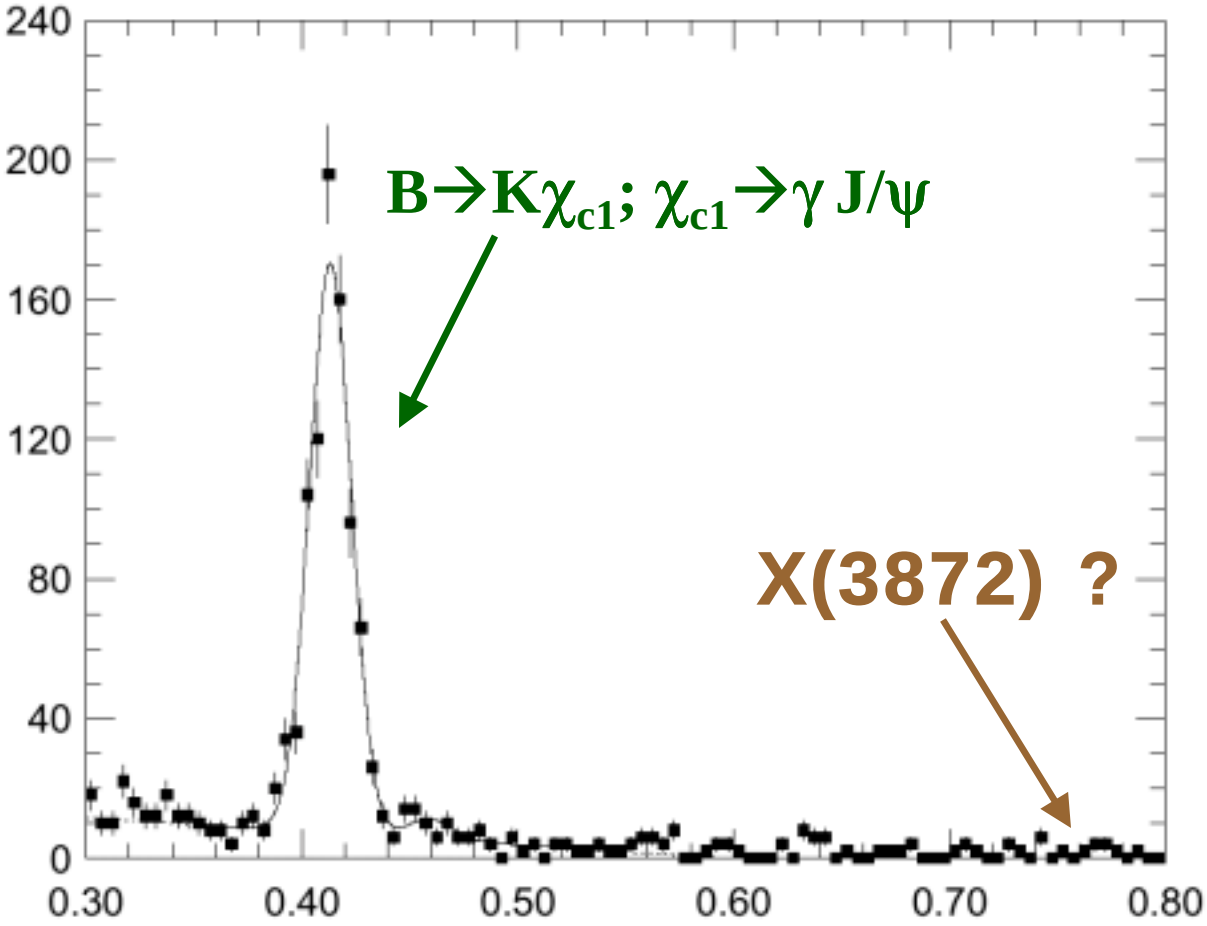
Expectation:

Barnes, Godfrey hep-ph/0311162

$$\frac{\Gamma(2^3P_1 \rightarrow \gamma\, J/\psi) \sim 11 \text{ keV}}{\Gamma(2^3P_1 \rightarrow \pi\pi J/\psi) \sim \Gamma(\psi' \rightarrow \pi^o\, J/\psi) \sim 0\ (0.3 \text{ keV})} \sim 30$$

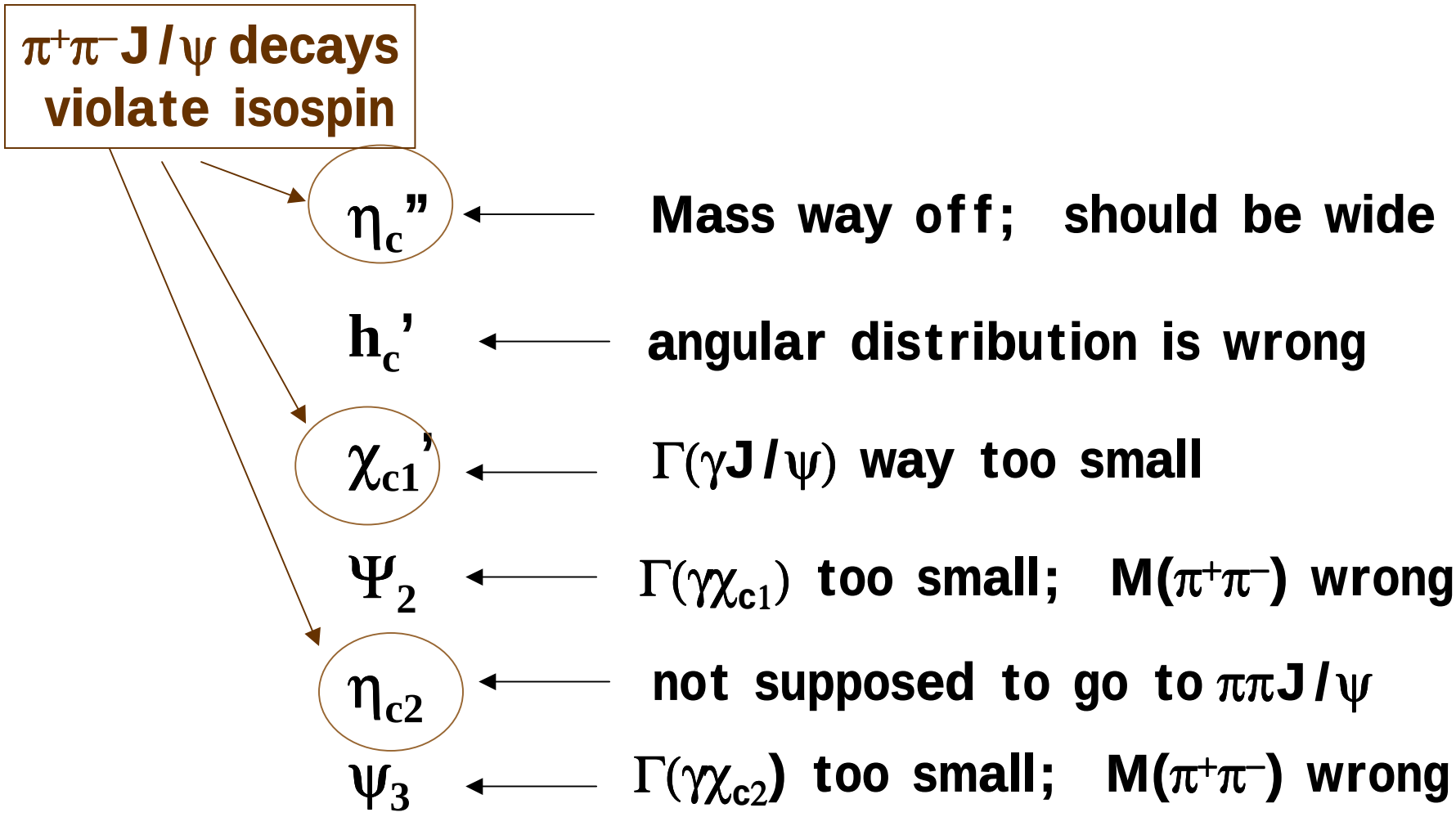
isospin violating

M(γ J/ψ)



$$\frac{Br(X \to \gamma\, J/\psi)}{Br(X \to \pi^+\pi^- J/\psi)} < 0.4$$

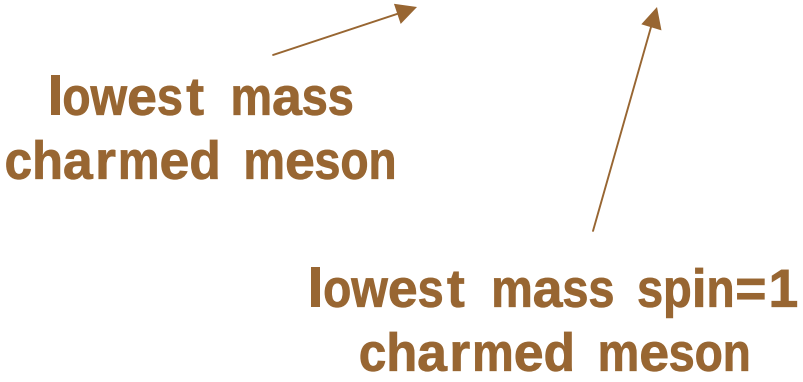
still no good $c\bar{c}$ candidates)



Curious fact

$$M_X = 3872 \pm 0.6 \pm 0.5 \text{ MeV}$$

$$M_{D0} + M_{D0^*} = 3871.2 \pm 1.0 \text{ MeV}$$



X(3872) is very near DD* threshold.
Is it somehow related to that?

Summary

- If it is a $c\bar{c}$ charmonium state, theory needs a lot of work

- If it's something else, what is it?

  - Angular analyses

  - Search for $X \rightarrow \pi^0\pi^0 J/\psi$

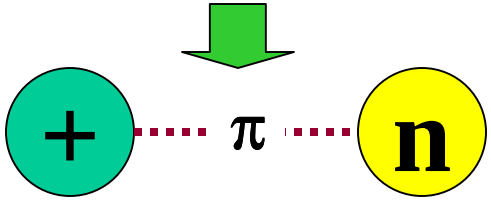
In Progress

$h\bar{h}$ bound states (hadronium)??

There is lots of literature about this possibility

deuteron:

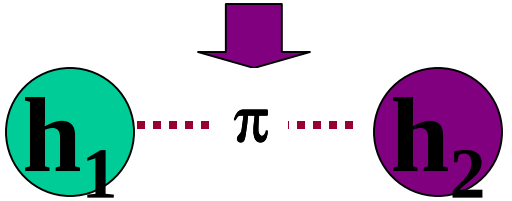
attractive nuclear force



loosely bound
3-q color
singlets with
$M_d = m_p + m_n - \varepsilon$

hadronium:

attractive force??



loosely bound
3-q or $q\text{-}\bar{q}$ color
singlets with
$M_b = m_{h1} + m_{h2} - \delta$

hadronic molecules

a new spectroscopy?

DeRujula, Georgi,Glashow, PRL 38, 317 (1977)

X(3872)??