


Observation of New Narrow Charmonium State



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for the Belle Collaboration

Weak Interactions and Neutrinos
October 8, 2003



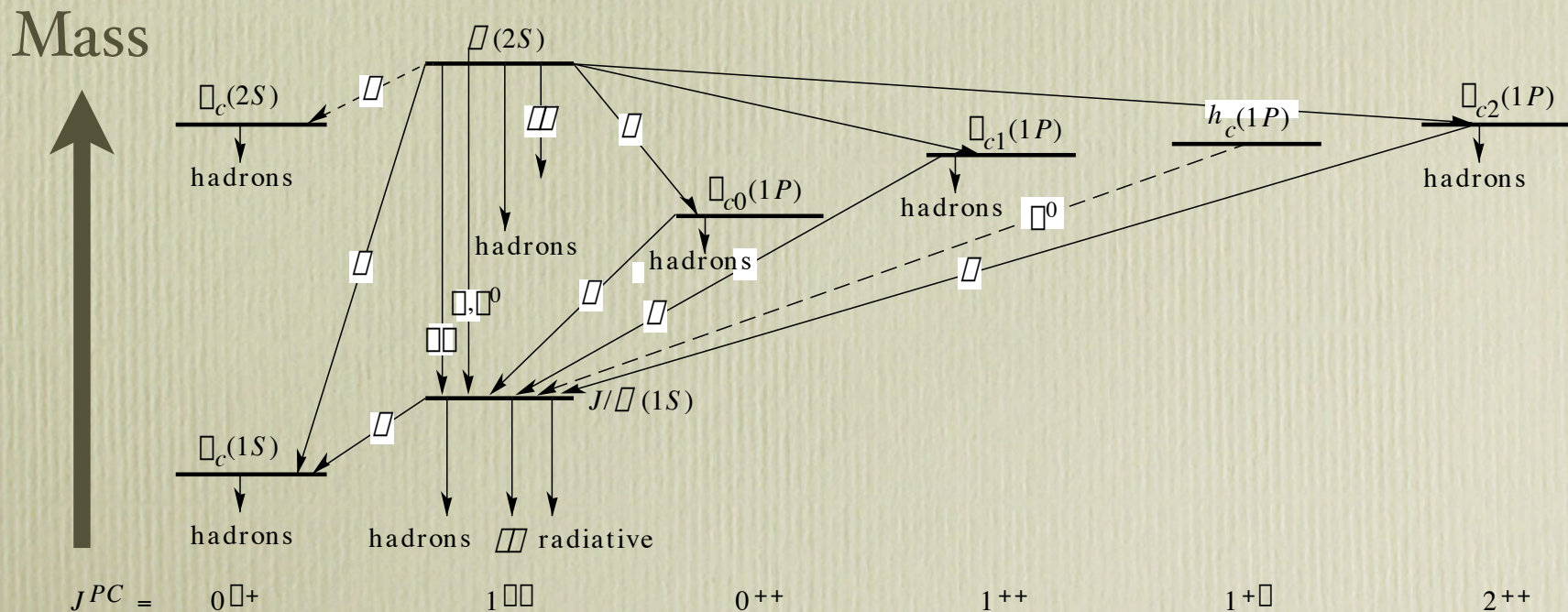
Charmonium Spectroscopy

- Many as-yet unobserved but expected $c\bar{c}$ states:

E.g., $n = 1$: $^1P_1 (h_c)$, $^1D_{c2}$, $^3D_{c3,2,1}$

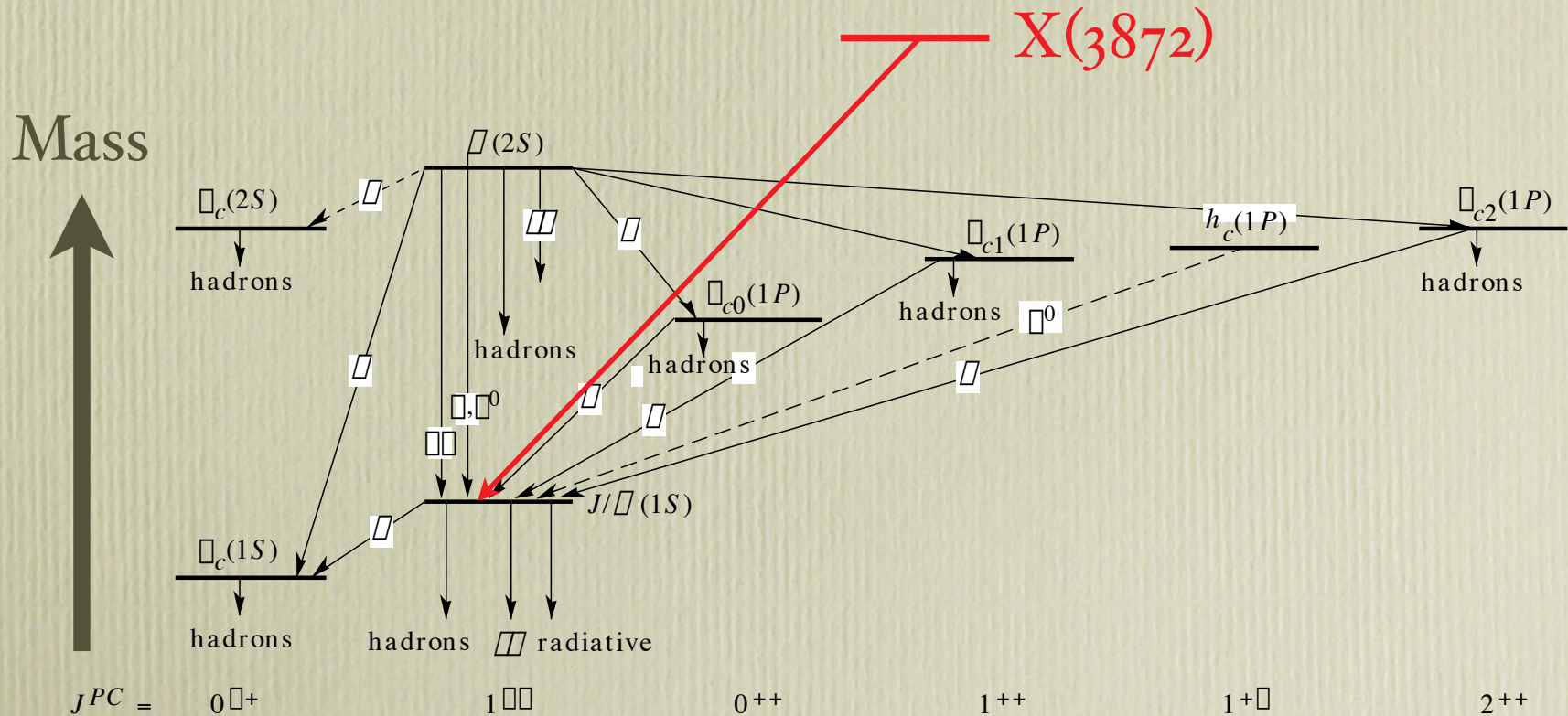
- Could be produced in B decays, then decay to $\pi\pi J/\psi$

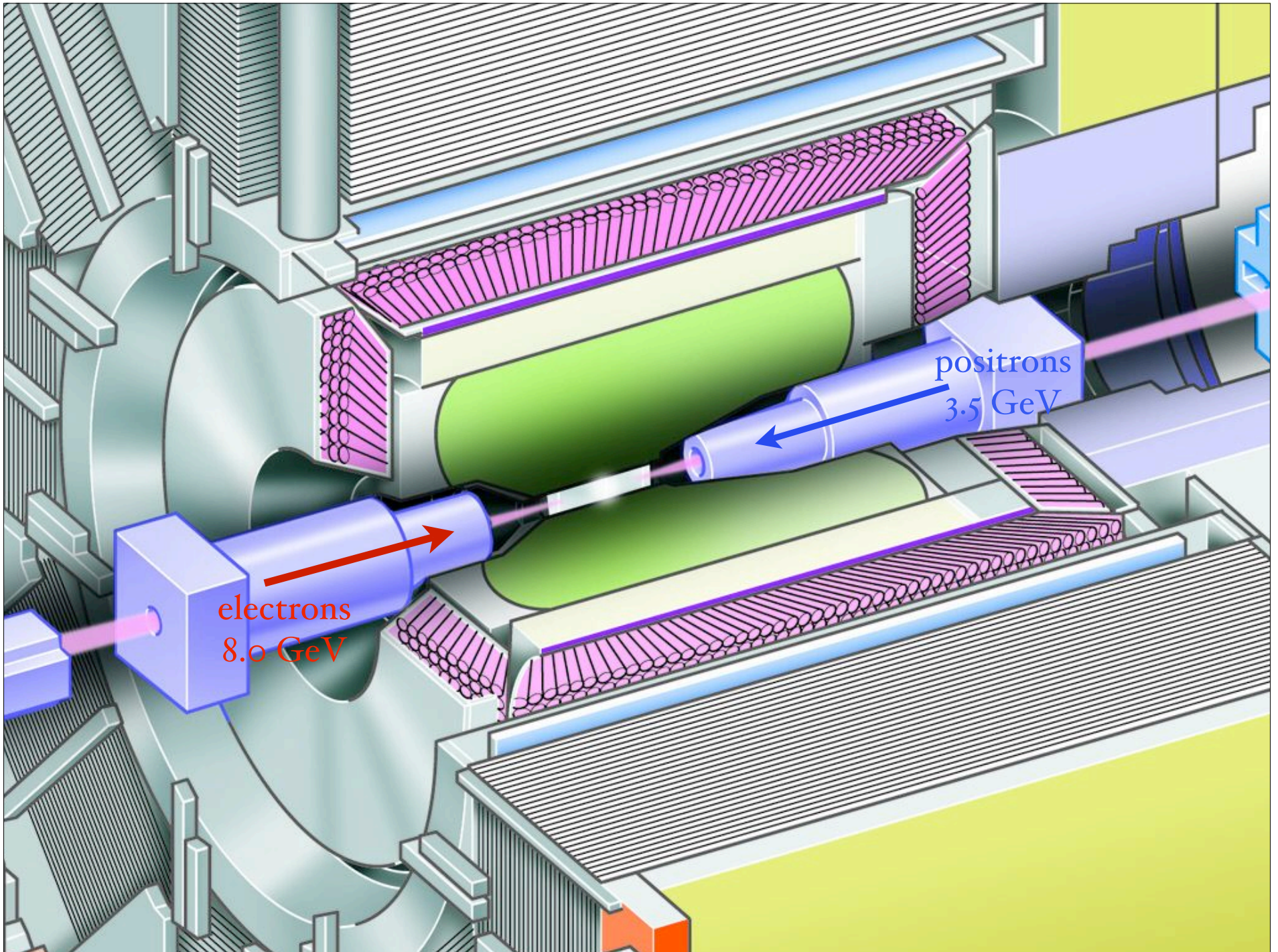
Eichten, Lane, Quigg, PRL **89**, 102001 (2002)





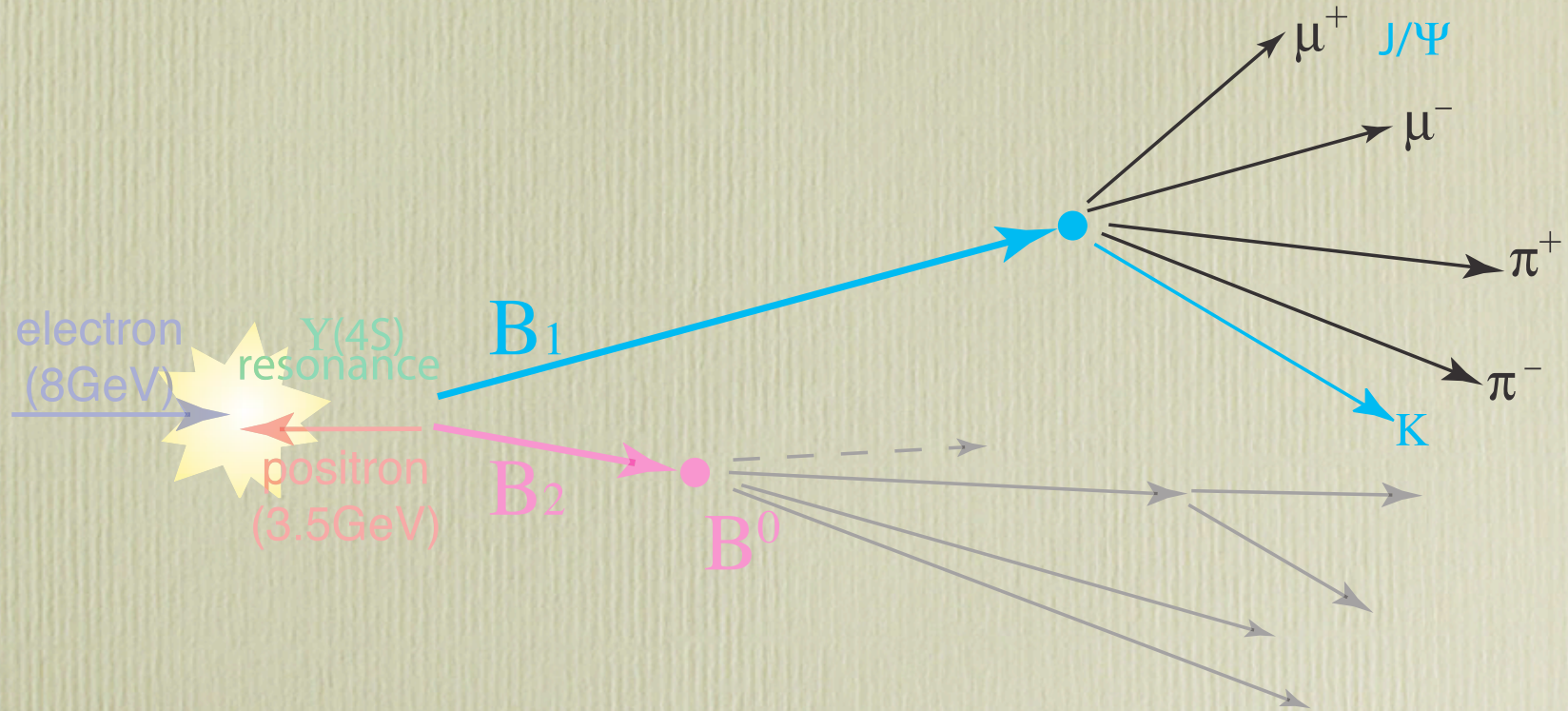
Charmonium Spectroscopy





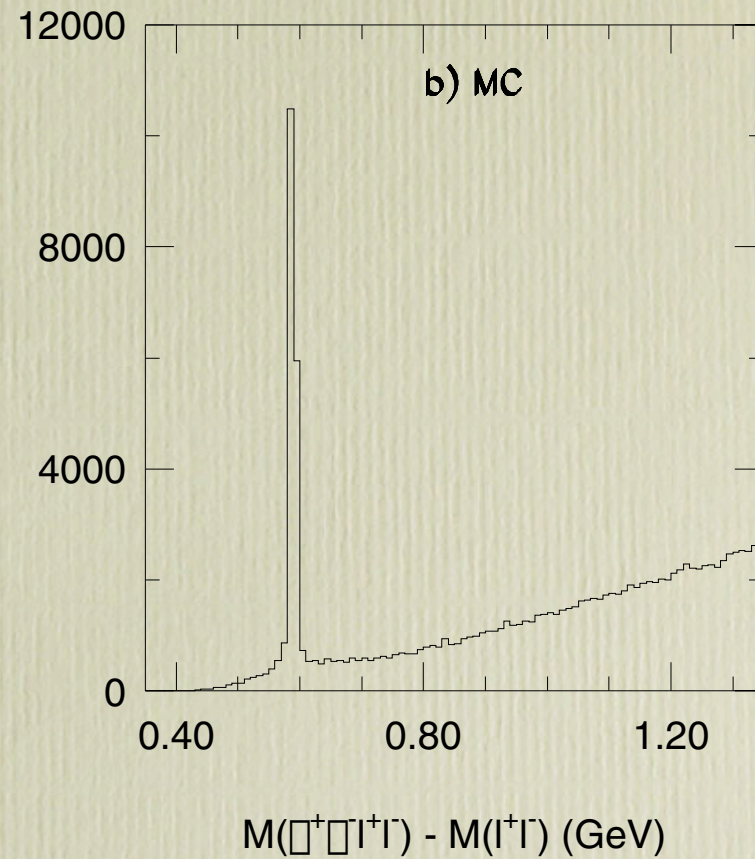
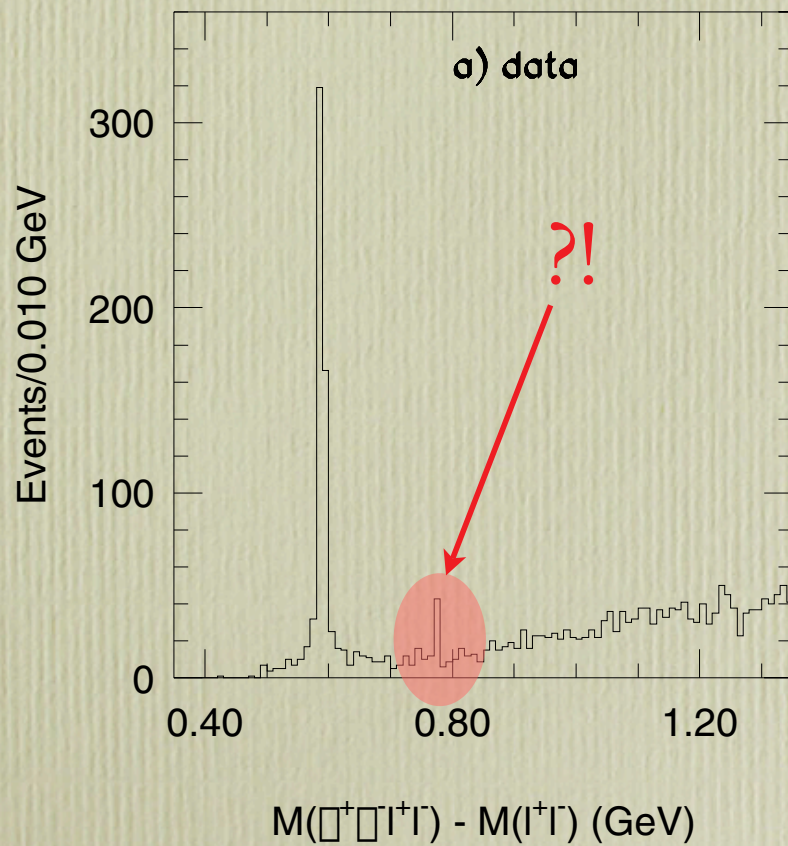


B-Meson Decay



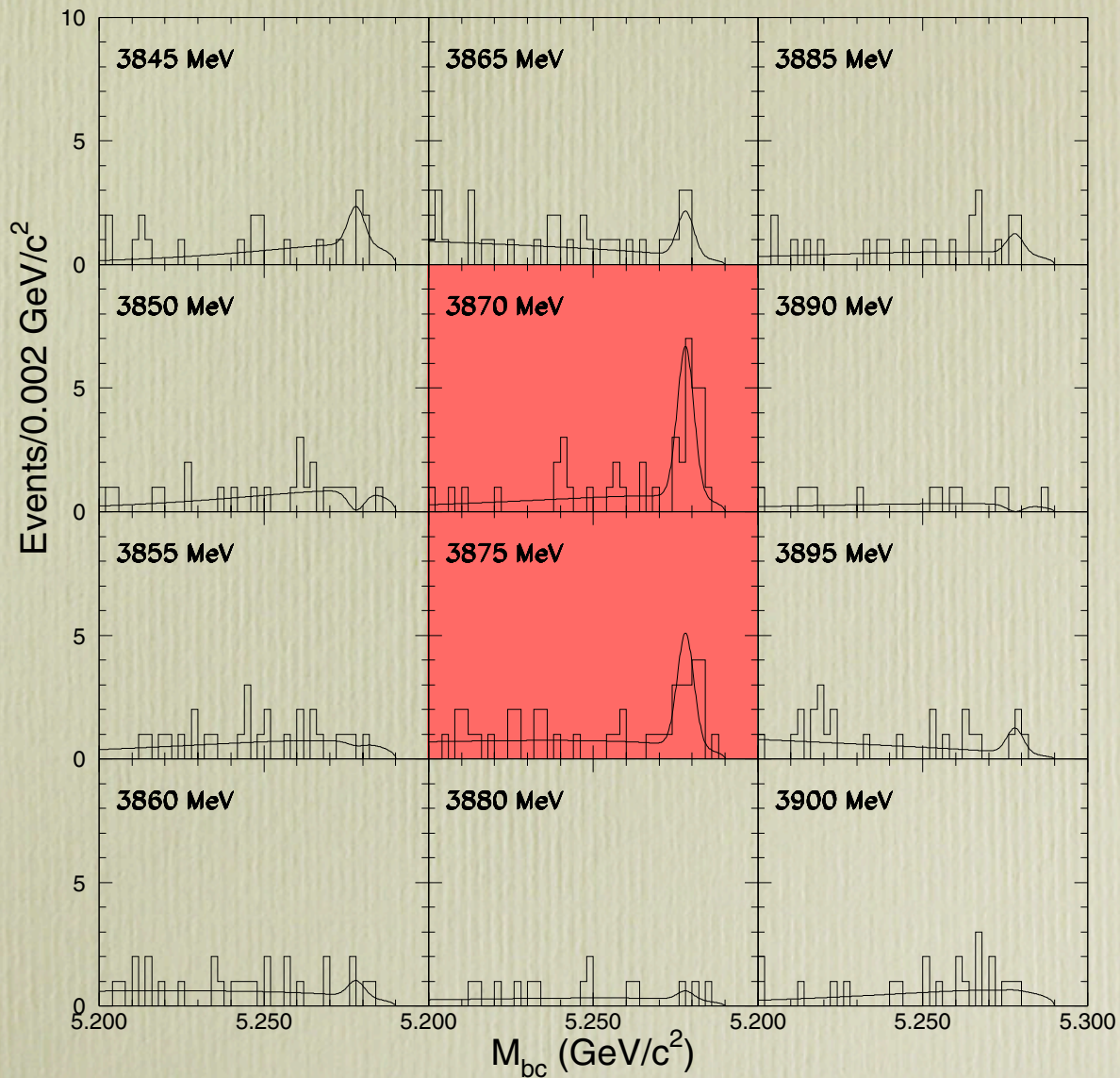


$$B^{\pm} \rightarrow K^{\pm} X \rightarrow K^{\pm} (\pi^{+} \pi^{-} J/\psi)$$





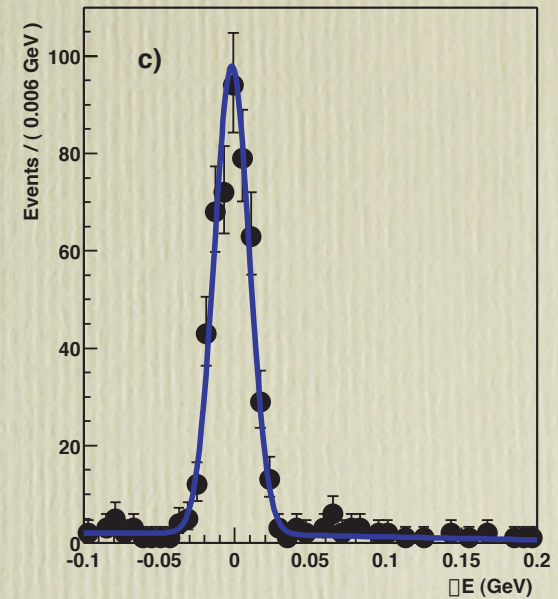
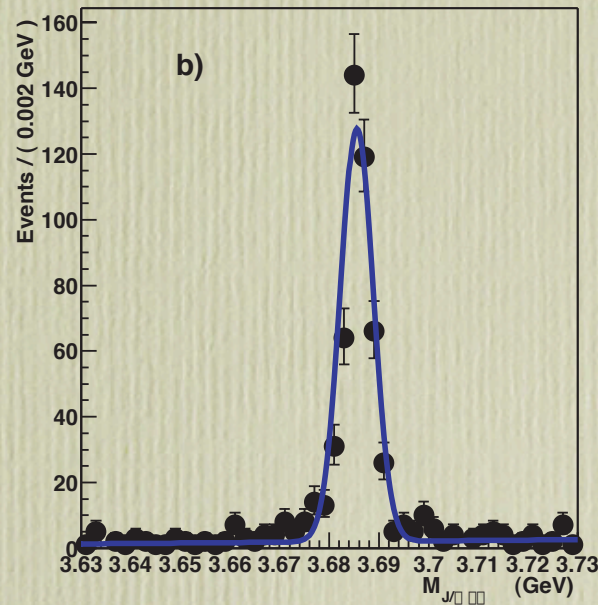
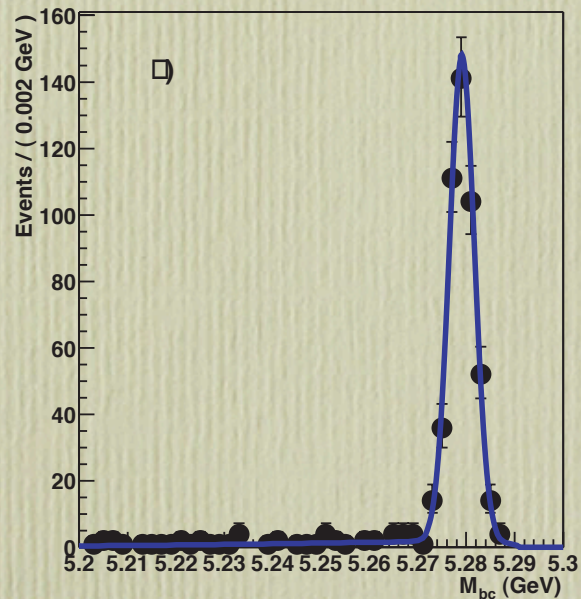
m_{bc} Fits for $3845 < M_X < 3900$





$$B^{\pm} \rightarrow K^{\pm} \psi' \rightarrow K^{\pm} (\pi^{+} \pi^{-} J/\psi)$$

Unbinned maximum likelihood fit:

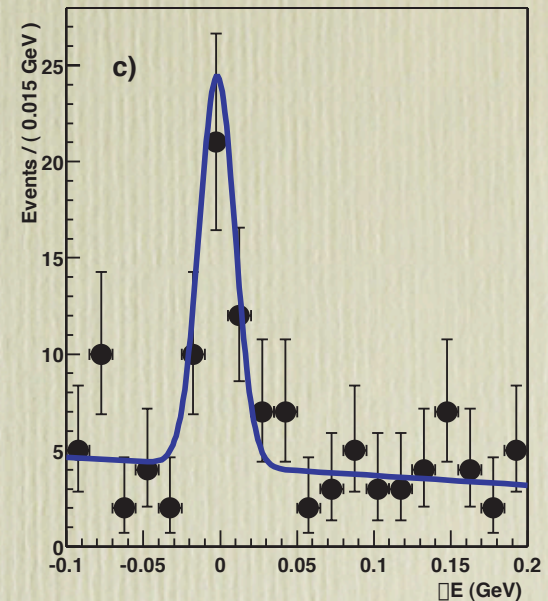
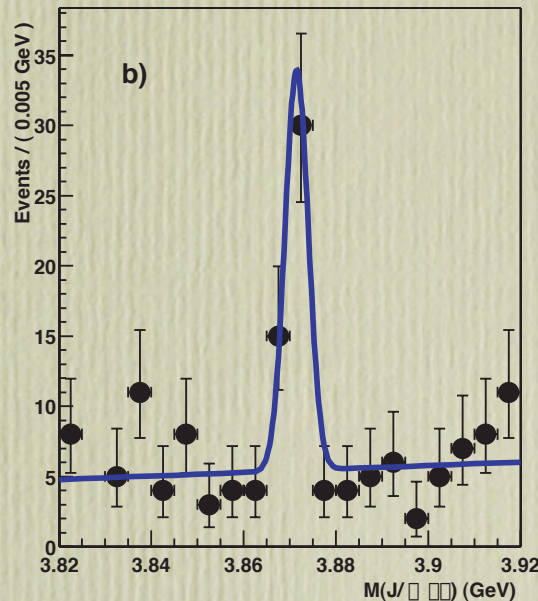
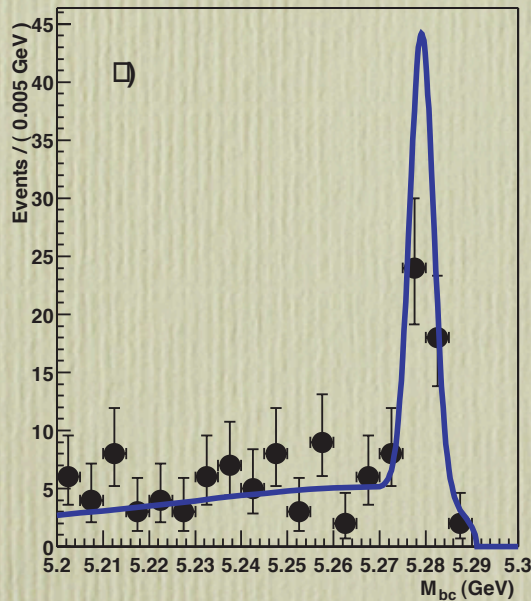


$$\begin{aligned} N &= 494 \pm 23 \text{ events} & M_{J/\psi \pi \pi} &= 3685.5 \pm 0.2 \text{ MeV} \\ M_{bc} &= 5279.1 \pm 0.1 \text{ MeV} & \sigma_{J/\psi \pi \pi} &= 3.3 \pm 0.2 \text{ MeV} \\ \Delta E &= -2.0 \pm 0.4 \text{ MeV} \end{aligned}$$



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

Unbinned maximum likelihood fit:



$$N = 35.7 \pm 6.8 \text{ events}$$

$$M_{J/\psi \pi \pi} = 3871.5 \pm 0.6 \text{ MeV}$$

$$M_{bc} = 5279.1 \text{ MeV (fixed)}$$

$$\sigma_{J/\psi \pi \pi} = 2.5 \pm 0.5 \text{ MeV}$$

$$\Delta E = -2.0 \text{ MeV (fixed)}$$

$$S = 10.3 \sigma$$



$X(3872)$ Parameters

- Adjust fitted $M(X)$ upward by 0.5 MeV to account for observed $M(\psi')$ shift from PDG value
- Refit with resolution-broadened Breit-Wigner

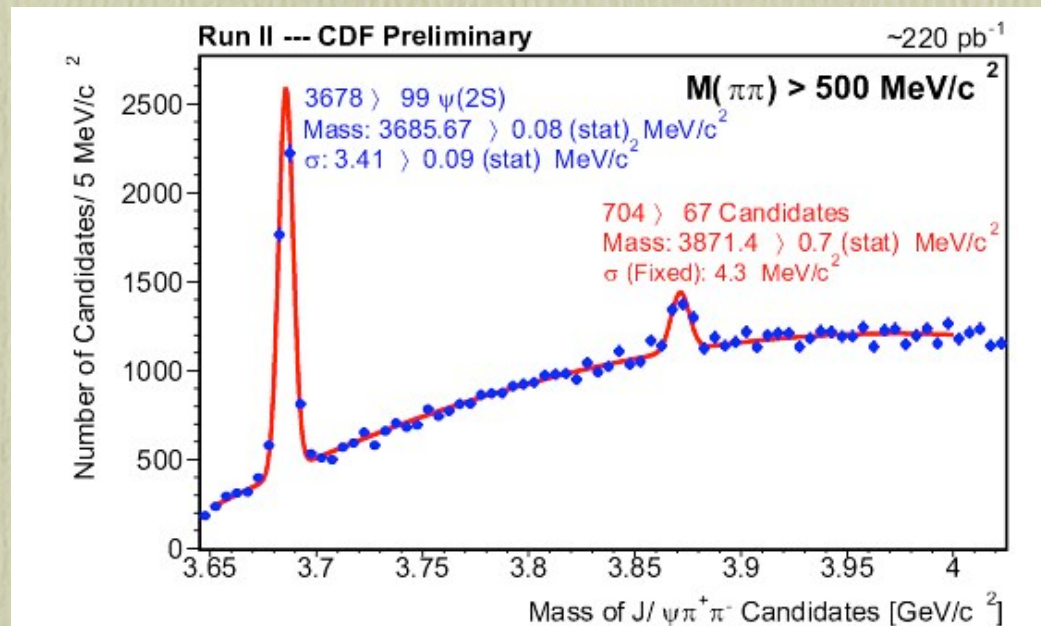
$$M_X = 3872.0 \pm 0.6 \text{ (stat)} \pm 0.5 \text{ (syst)} \text{ MeV}$$

$$\Gamma_X < 2.3 \text{ MeV (90\% C.L.)}$$

$$\mathcal{S} = 10.3 \sigma$$



X(3872) confirmed by CDF



Source: Fermilab Today (October 2)

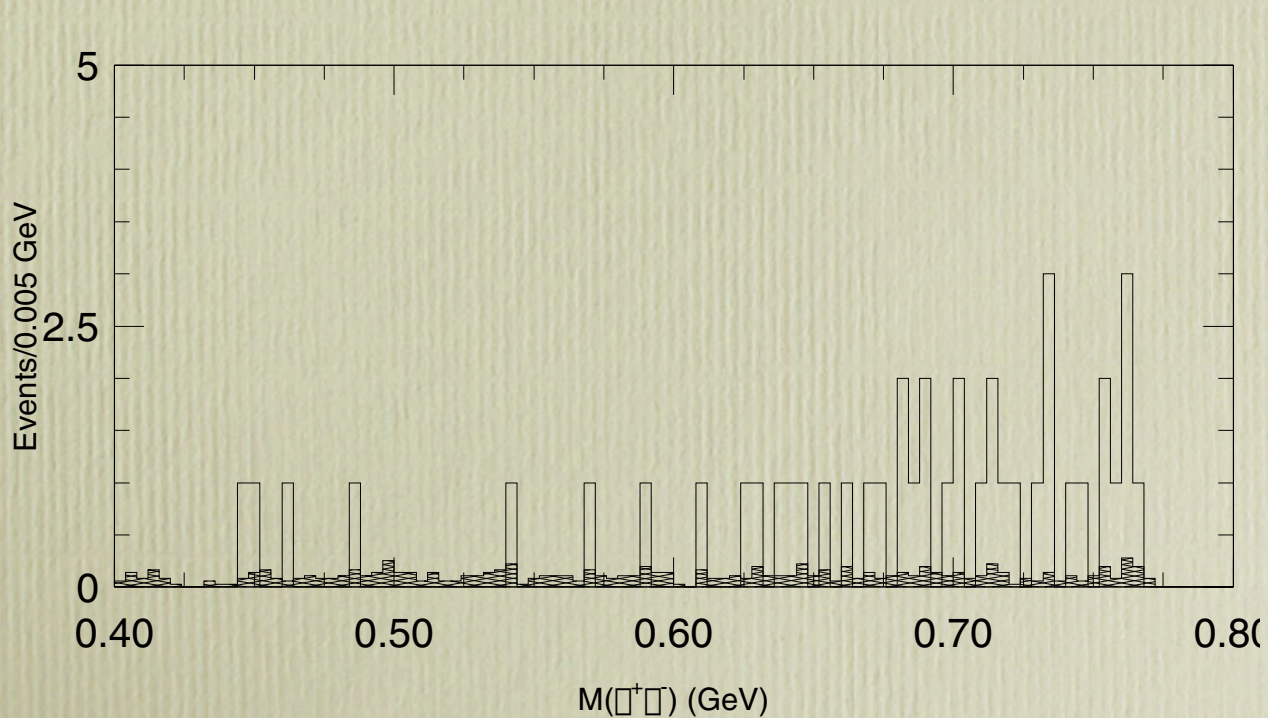


X(3872) Production/Decay

$$\frac{\mathcal{B}(B^+ \rightarrow K^+ X) \cdot \mathcal{B}(X \rightarrow \pi^+ \pi^- J/\psi)}{\mathcal{B}(B^+ \rightarrow K^+ \psi') \cdot \mathcal{B}(\psi' \rightarrow \pi^+ \pi^- J/\psi)} = 0.063 \pm 0.012 \pm 0.007$$

(stat) (syst)

- Looks like $B^\pm \rightarrow K^\pm X$

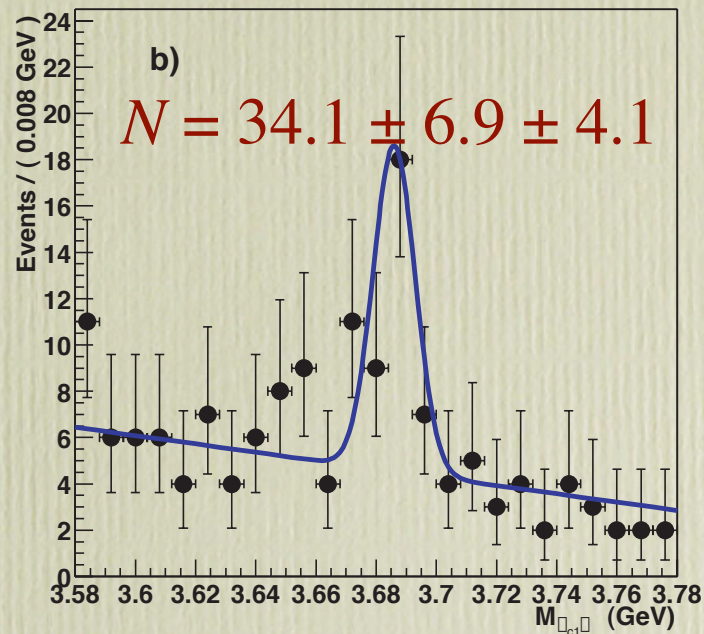
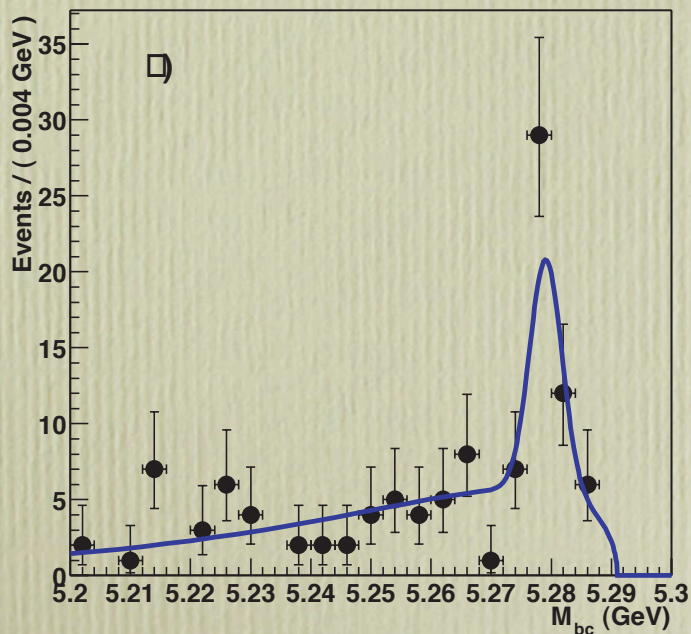


$\rho J/\psi$
 $l^+ l^-$
 $\pi^+ \pi^-$



Is it the $^3D_{c2}$ Charmonium State?

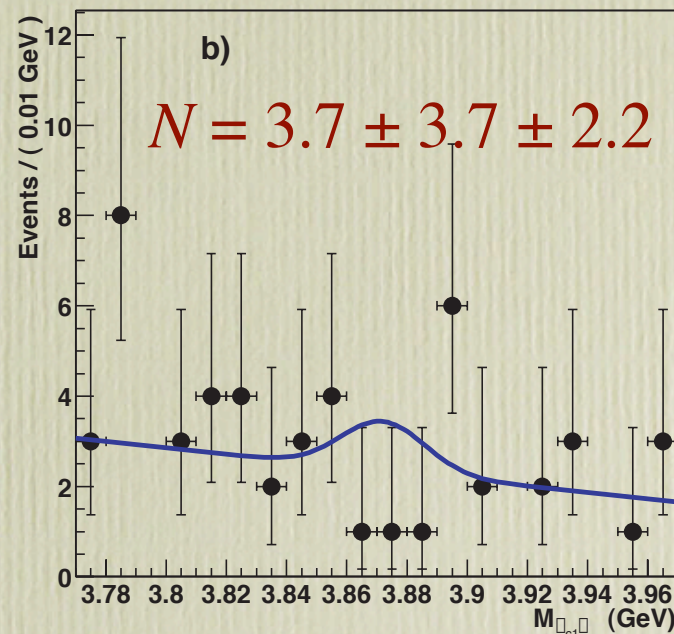
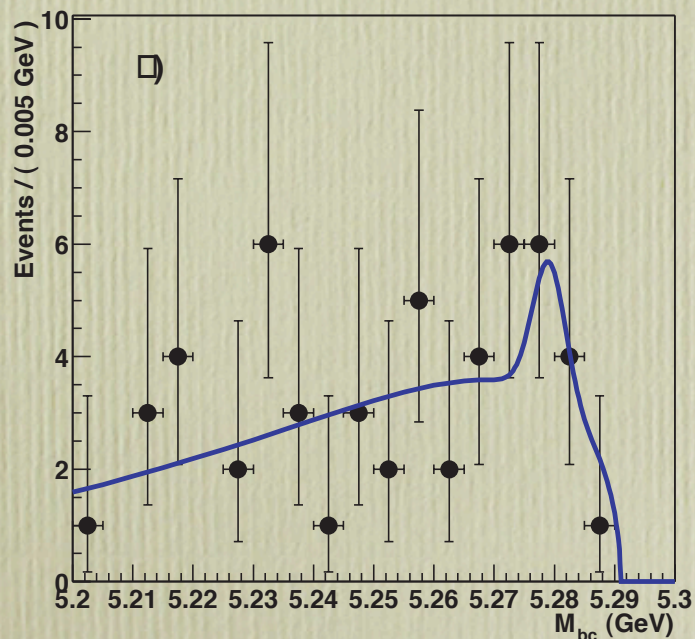
- $^3D_{c2} \rightarrow \gamma \chi_{c1}$ is allowed $E1$ transition \Rightarrow
expect $\Gamma(^3D_{c2} \rightarrow \gamma \chi_{c1}) > 5 \times \Gamma(^3D_{c2} \rightarrow \pi^+ \pi^- J/\psi)$
Eichten, Lane, Quigg in PRL **89**, 162002 (2002)
- Unbinned max \mathcal{L} fit to M_{bc} and $M_{\chi_{c1} \gamma}$ in the ψ' region





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Eichten, Lane, Quigg in PRL **89**, 162002 (2002)
- Unbinned max \mathcal{L} fit to M_{bc} and $M_{\chi_{c1} \gamma}$ in the X region

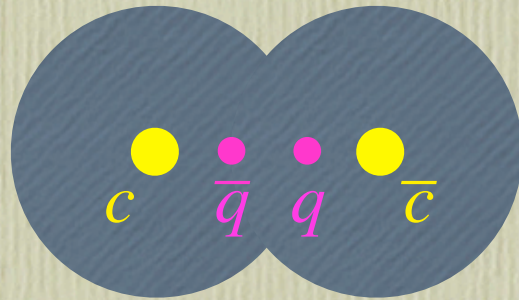


- $\Gamma(X \rightarrow \gamma \chi_{c1}) < 0.89 \times \Gamma(X \rightarrow \pi^+ \pi^- J/\psi)$ (90% CL)



A DD^* Molecular Resonance?

$$M(X) = 3872.0 \pm 0.6 \text{ (stat)} \pm 0.5 \text{ (syst)} \text{ MeV}$$
$$M(D^0 \bar{D}^{*0}) = 3871.3 \pm 0.5 \text{ MeV}$$



“Loose binding”

Discussed in literature since 1975, e.g.,

M. Bander, G.L. Shaw, P. Thomas, PRL 36, 695 (1976)

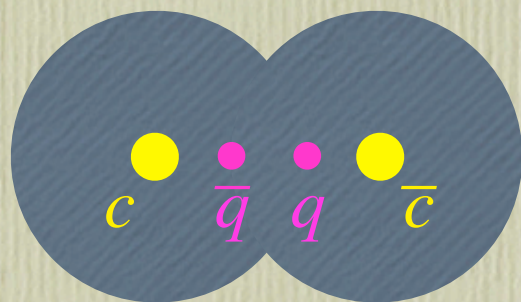
M.B. Voloshin, L.B. Okun, JETP Lett. 23, (1976), Pisma Zh.Eksp.Teor.Fiz.23, 369 (1976)

A.De Rujula, H.Georgi, S.L.Glashow, PRL 38 (1977)



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Törnqvist: One-pion exchange can provide deuterium-like binding for $(Q\bar{q})(\bar{Q}q)$!

Nils Törnqvist, Phys. Rev. Lett. **67** (1992) 556; Z. Phys. **C61** (1994) 526; hep-ph/0308277

“Deusons”

$D\bar{D}^*$	$J^{PC} = 0^{-+}, 1^{++}$	3870 MeV
$D^*\bar{D}^*$	$0^{++}, 0^{-+}, 1^{+-}, 2^{++}$	4015 MeV
$B\bar{B}^*$	$0^{-+}, 1^{++}$	10545-10562
$B^*\bar{B}^*$	$0^{++}, 0^{-+}, 1^{+-}, 2^{++}$	10582-10608



Conclusions

- Observation of new charmonium resonance $X(3872)$ in $B^+ \rightarrow K^+(\pi^+\pi^- J/\psi)$
 - ★ $M = 3872.0 \pm 0.6 \pm 0.5$ MeV
 - ★ $\Gamma < 2.3$ MeV (90% CL)
 - ★ 10.3σ significance
 - ★ Appears to decay preferentially to $\rho J/\psi$
 - ★ Unlikely to be $^3D_{c2}$
 - ★ Molecular $D^0 \bar{D}^{*0}$??
 - “If [this is] supported by the data, it would open up a completely new spectroscopy.” – Törnqvist