I NUOVI ADRONI: MOLECOLE O TETRAQUARKS?

IFAE - Roma, 8 Aprile 2010

Chiara Sabelli

Univ. Roma Sapienza & INFN Roma

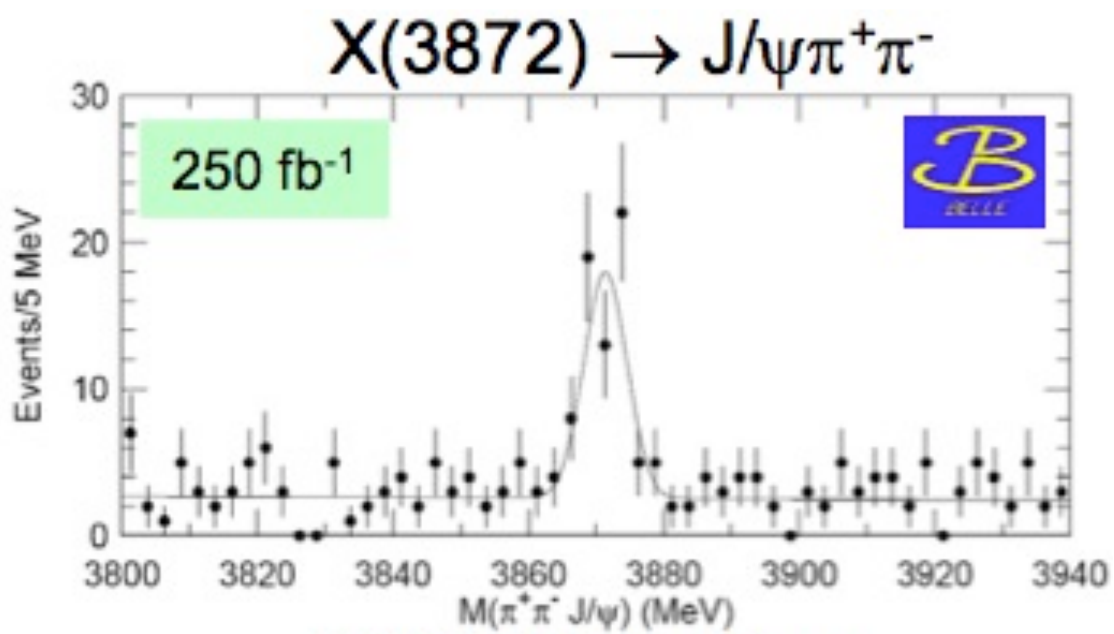
X(3872)

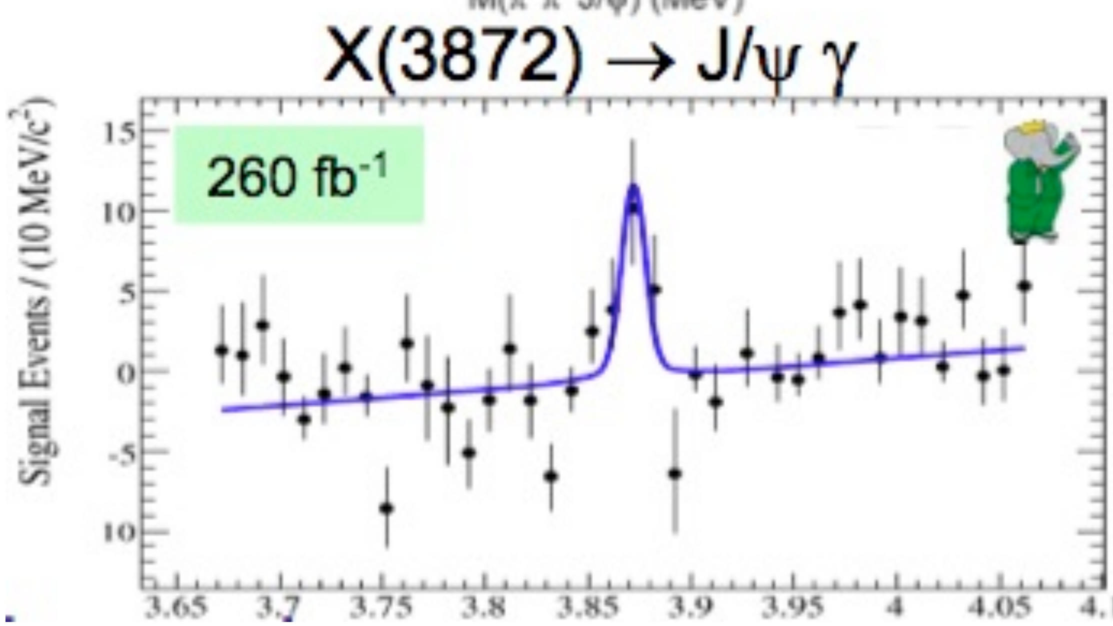
Phys. Rev. Lett. 103 (2009) 162001
arXiv:0906.0882 [hep-ph]

La scoperta

Agosto 2003:

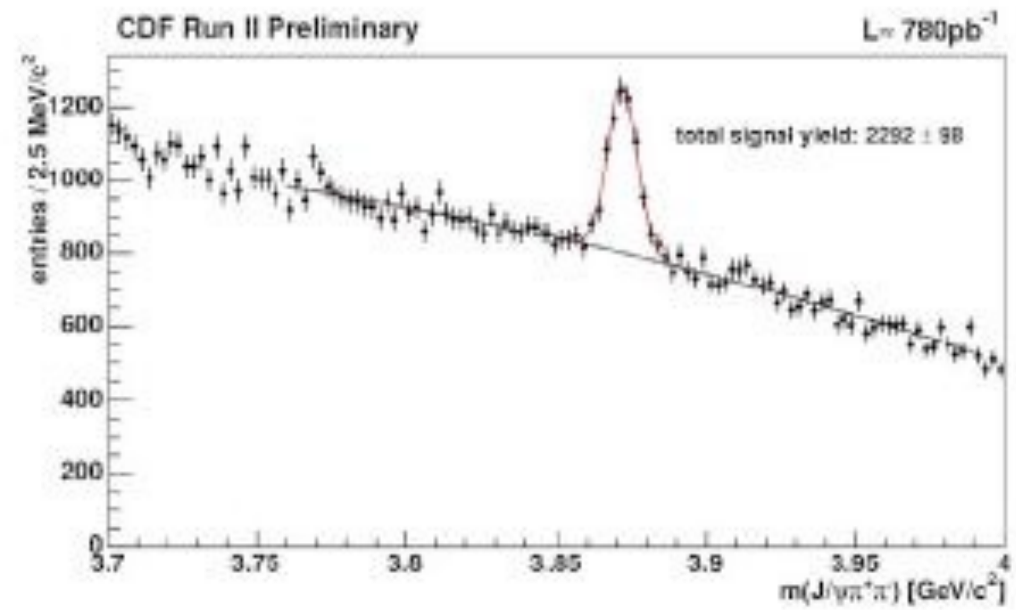
$B^\pm \to K^\pm J/\psi\ \pi^+\pi^-$

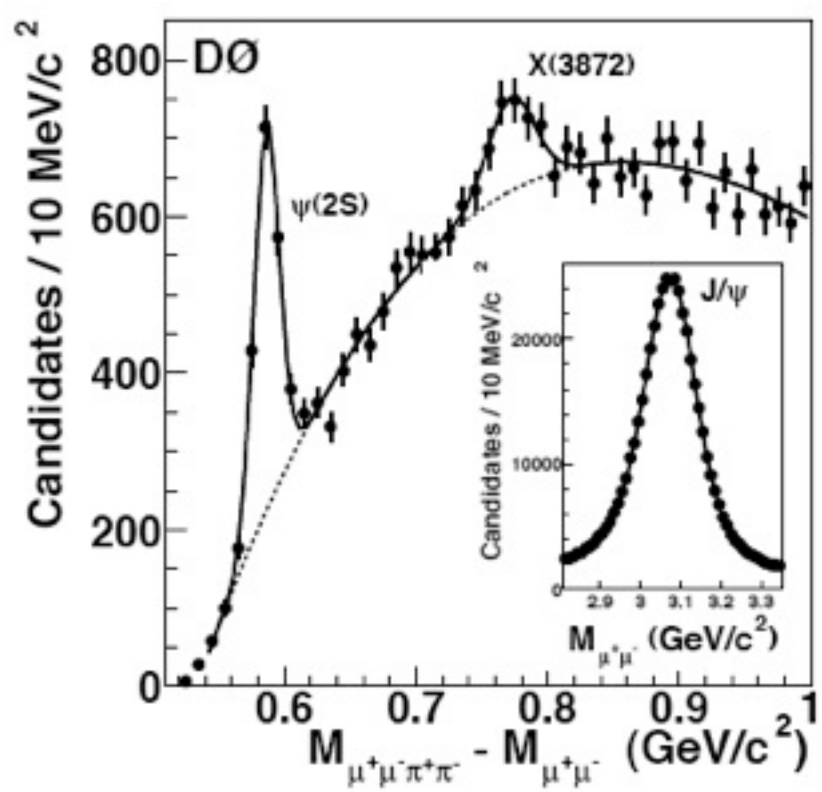




Settembre 2003:

$p\bar{p} \to J/\psi\ \pi^+\pi^-$





La scoperta

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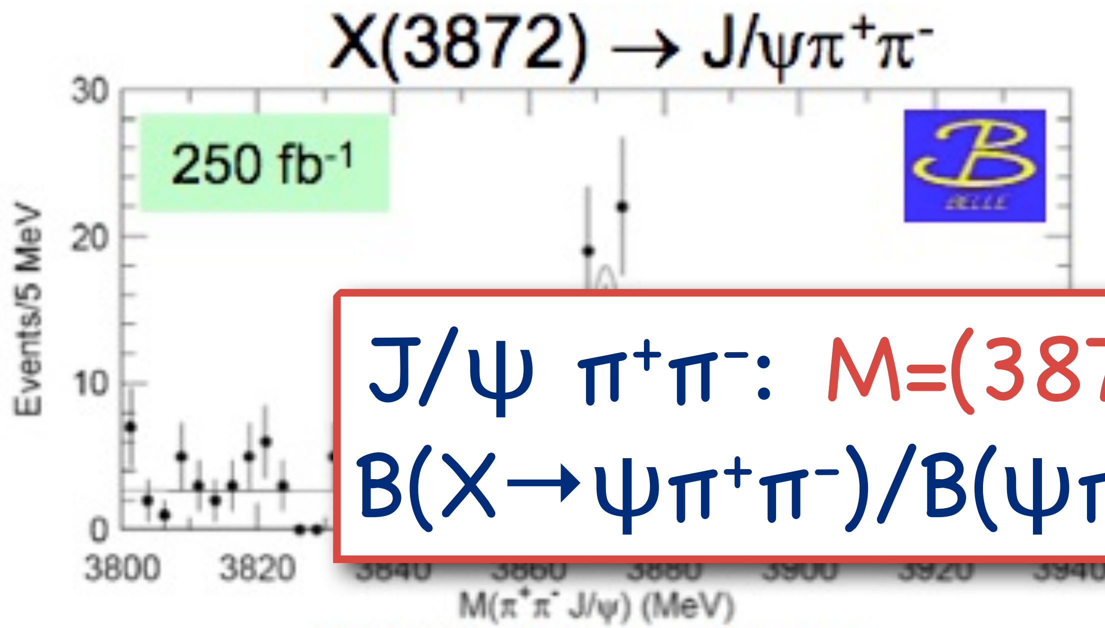
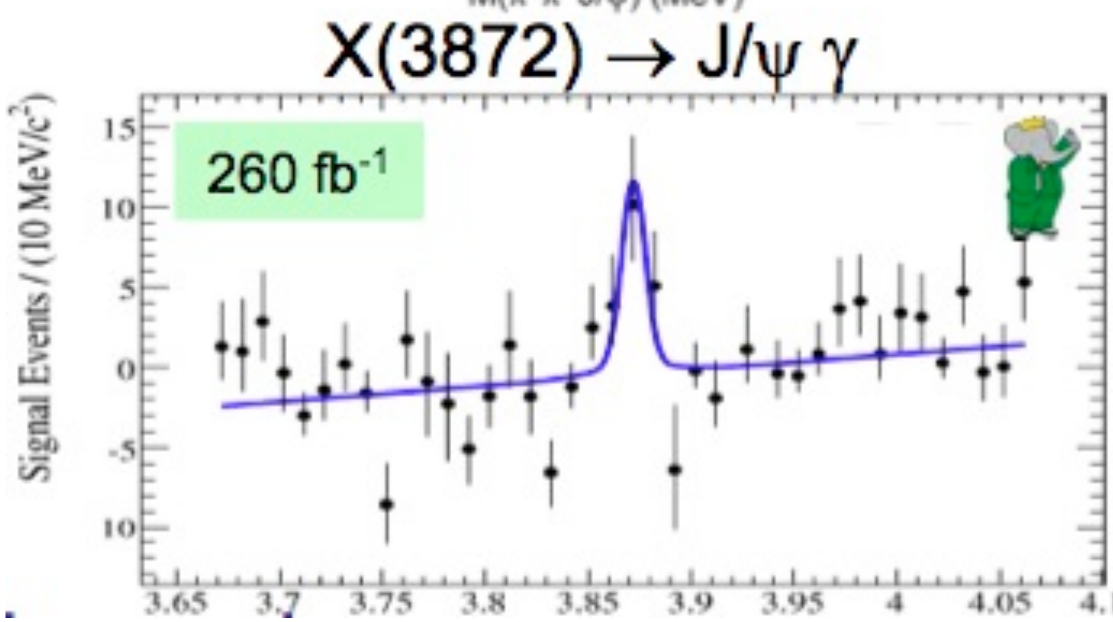
$B^{\pm} \rightarrow K^{\pm} J/\psi\ \pi^+\pi^-$





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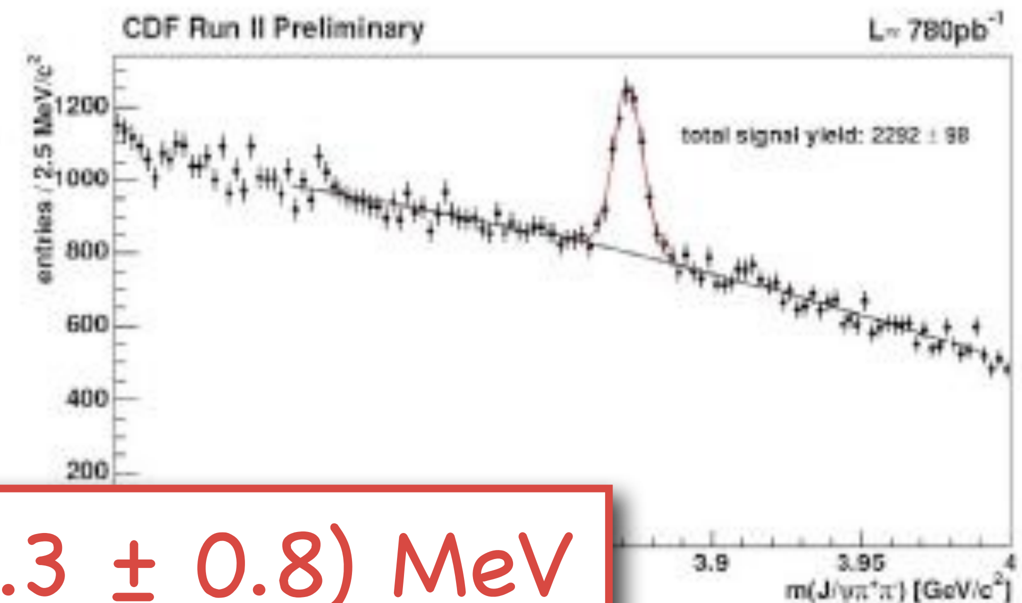
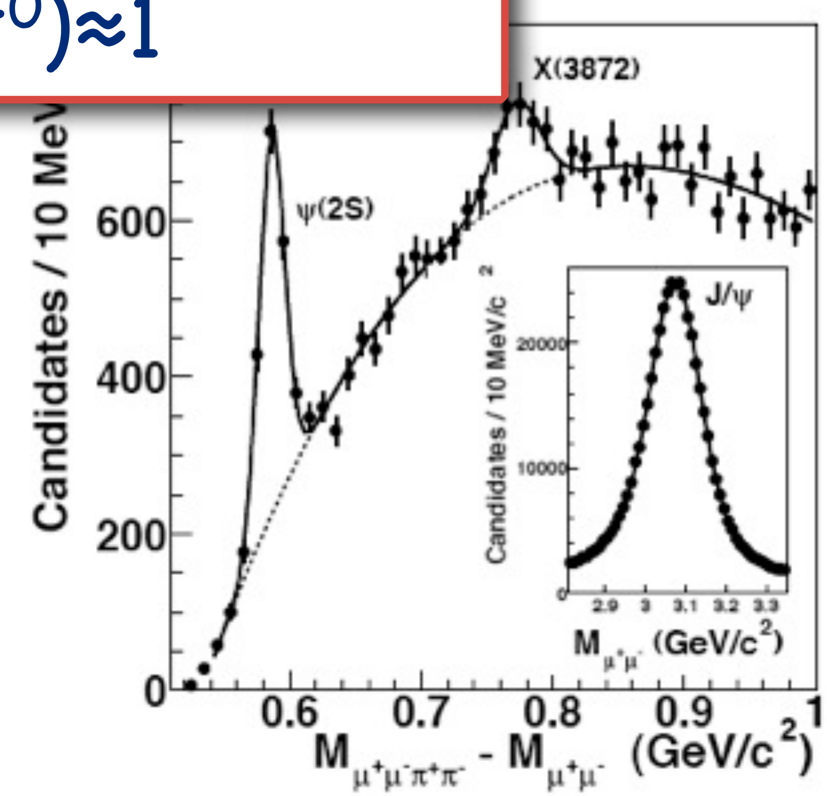


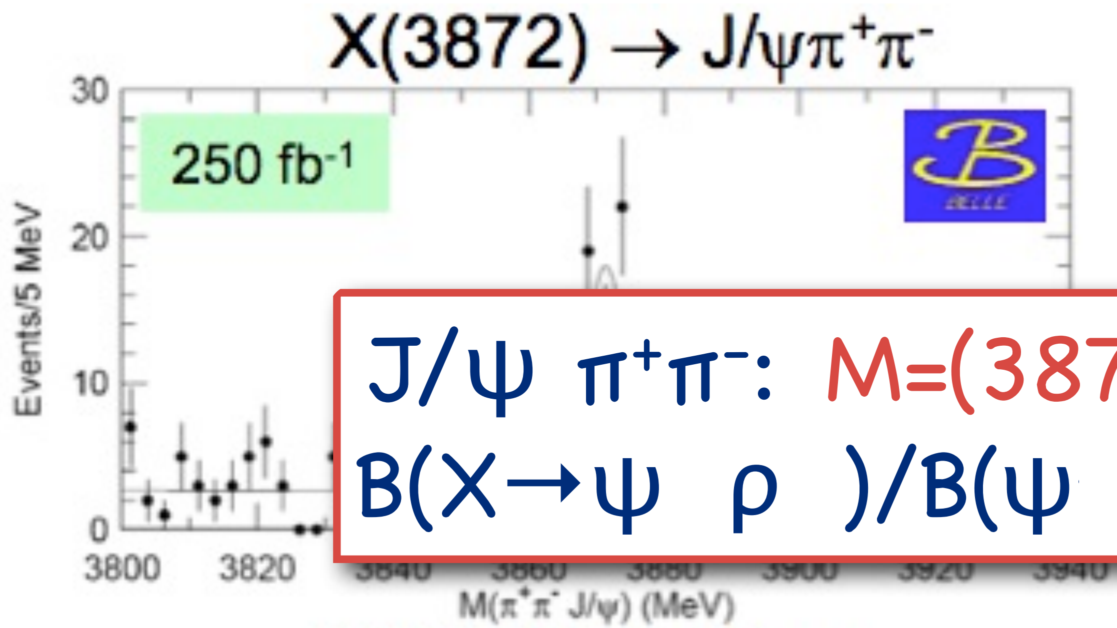


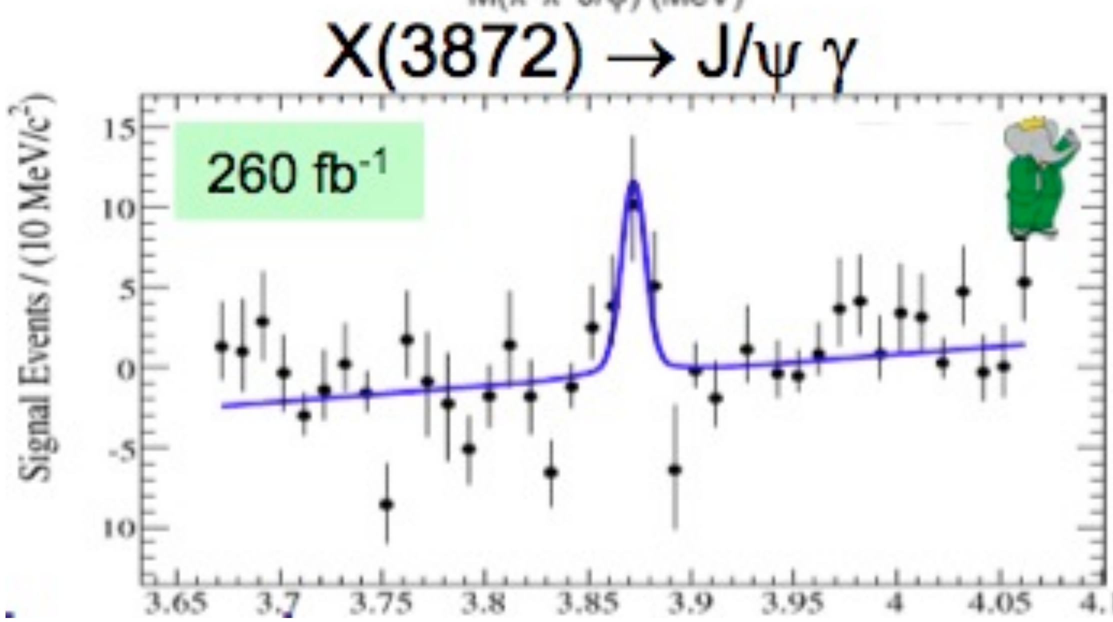
$J/\psi\ \pi^+\pi^-$: $M = (3872.3 \pm 0.8)$ MeV

$B(X \rightarrow \psi\pi^+\pi^-)/B(\psi\pi^+\pi^-\pi^0) \approx 1$

La scoperta

Agosto 2003:
$B^{\pm} \to K^{\pm} J/\psi\ \pi^+\pi^-$





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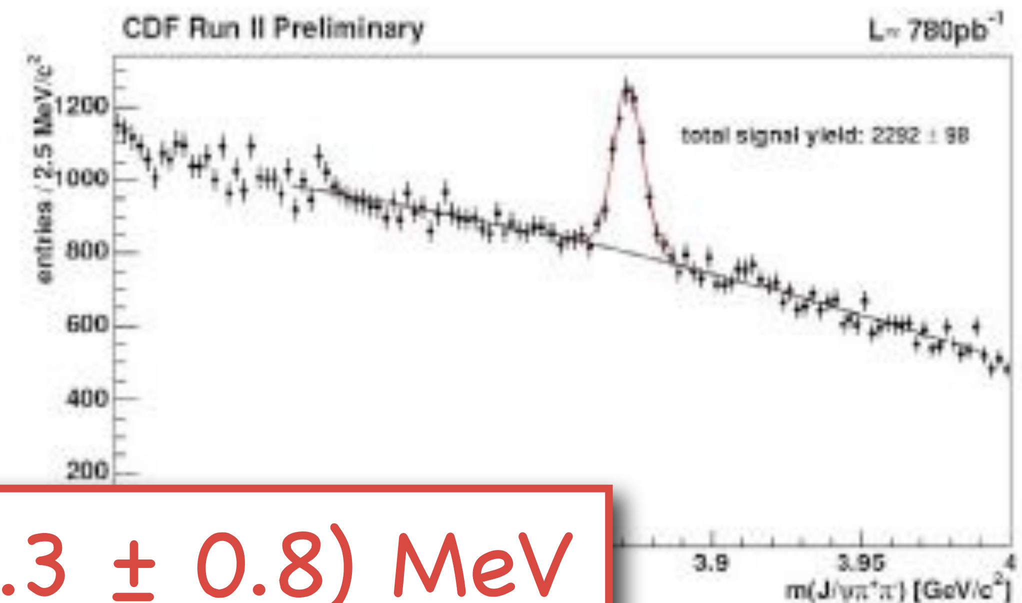
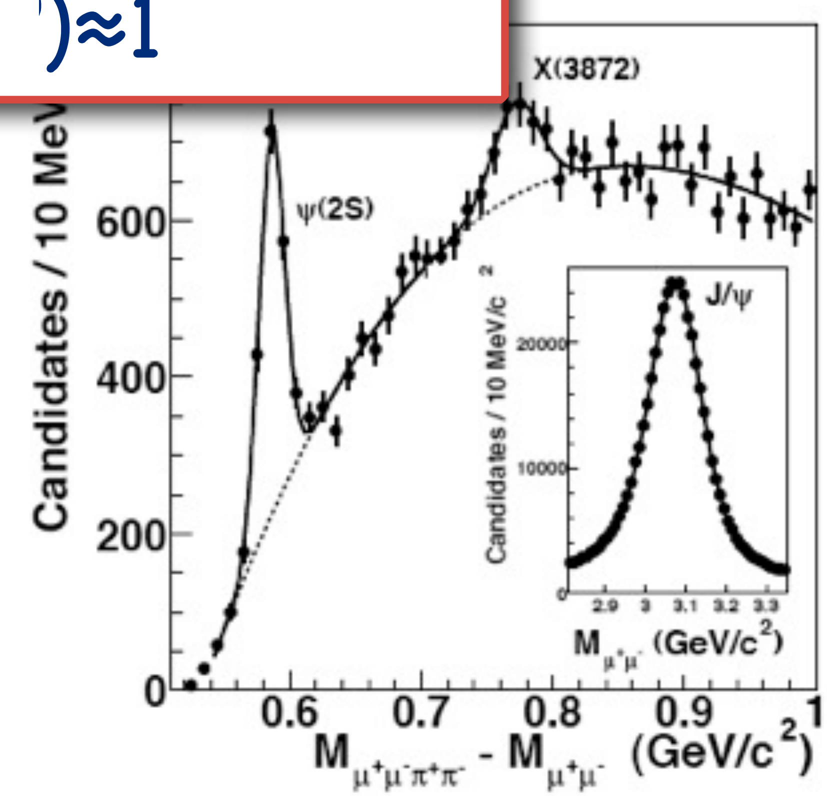
$p\bar{p} \to J/\psi\ \pi^+\pi^-$



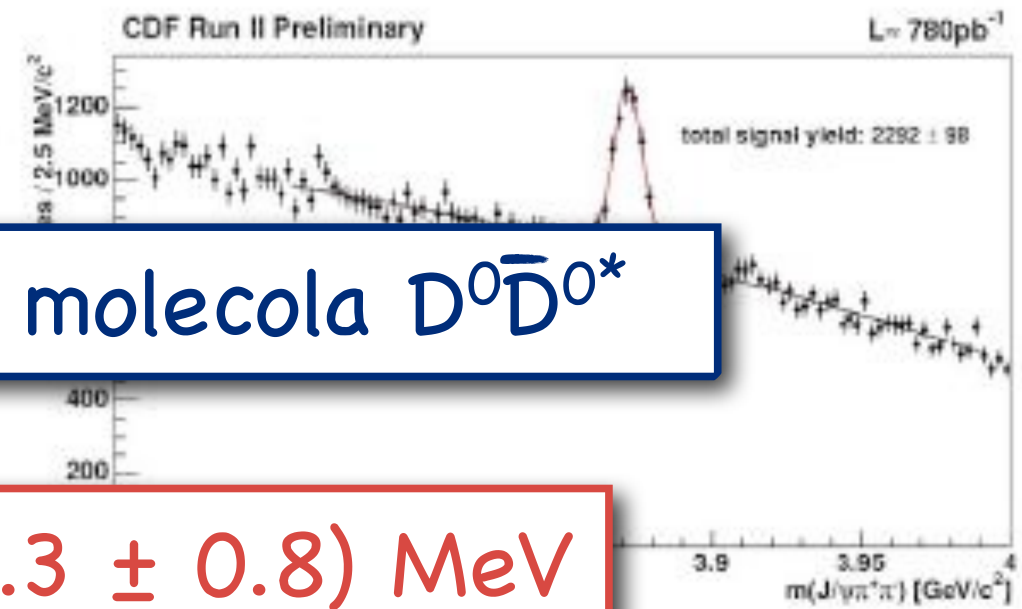


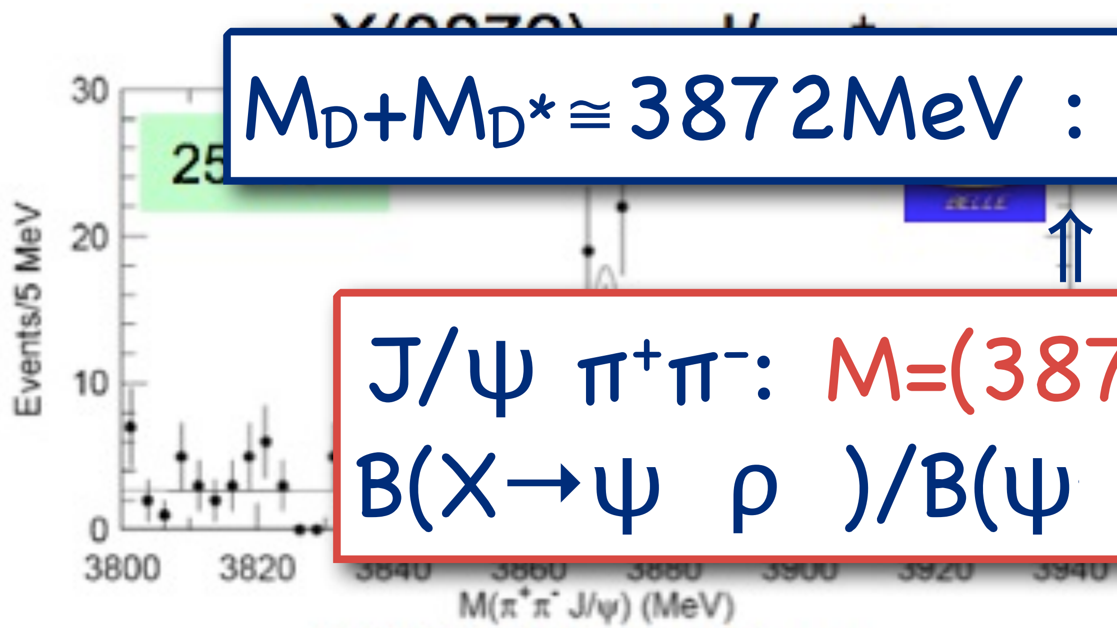
$J/\psi\ \pi^+\pi^-$: $M=(3872.3 \pm 0.8)$ MeV
$B(X\to\psi\ \ \rho\ \ )/B(\psi\ \ \omega\ \ ) \approx 1$

La scoperta

Agosto 2003:
$B^{\pm} \to K^{\pm}\, J/\psi\ \pi^+\pi^-$

Settembre 2003:
$p\bar{p} \to J/\psi\ \pi^+\pi^-$

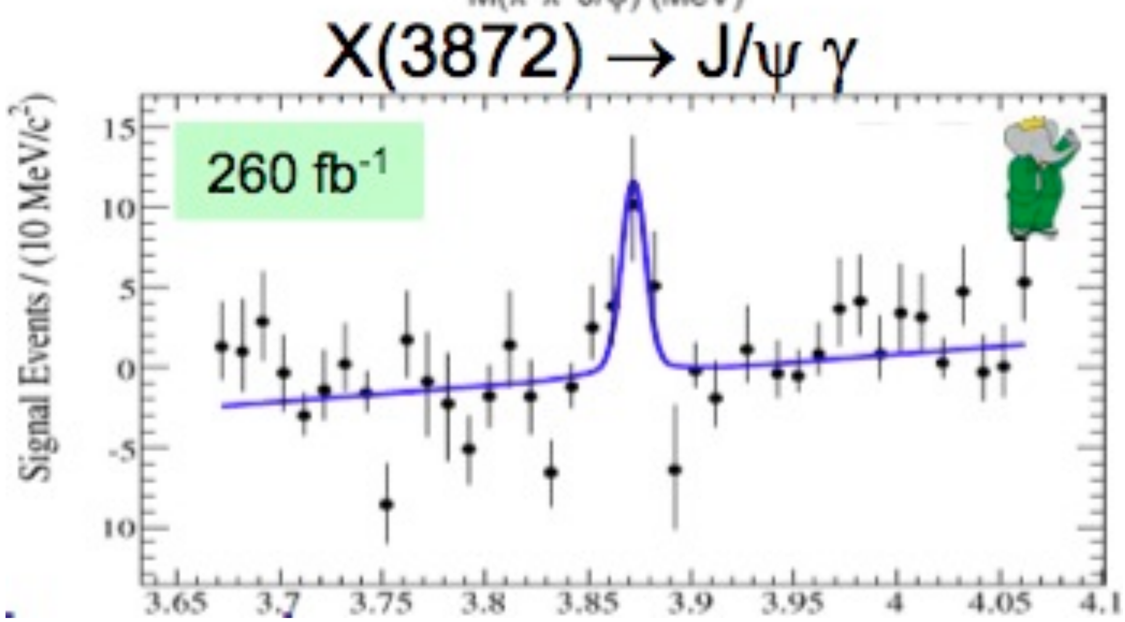


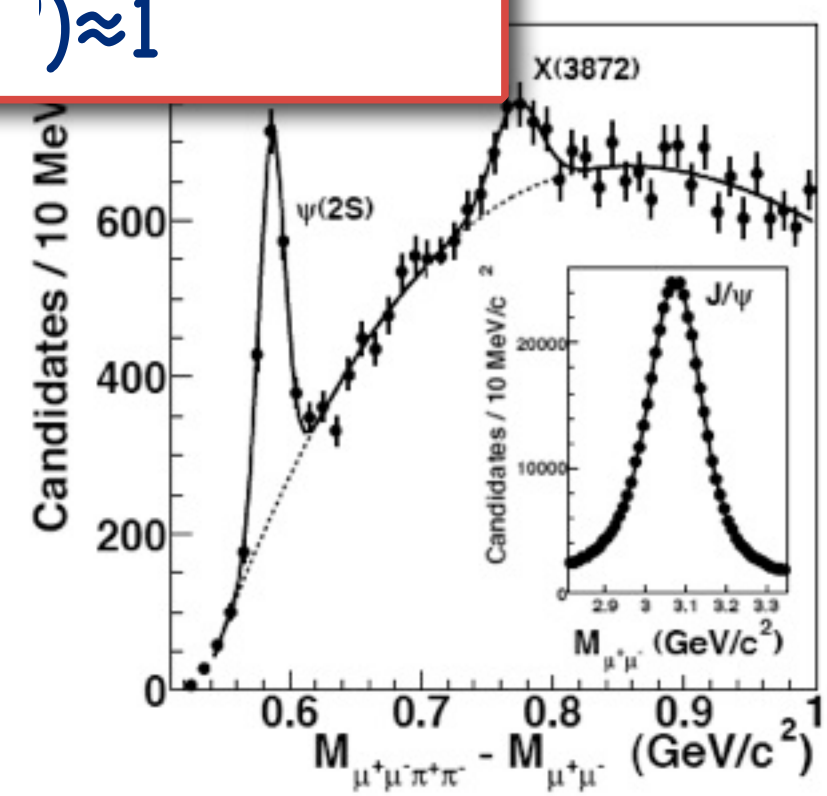


$M_D + M_{D^*} \cong 3872$MeV : X molecola $D^0\bar{D}^{0*}$

⇑

$J/\psi\ \pi^+\pi^-$: M=(3872.3 ± 0.8) MeV
B(X→ψ ρ)/B(ψ ω)≈1





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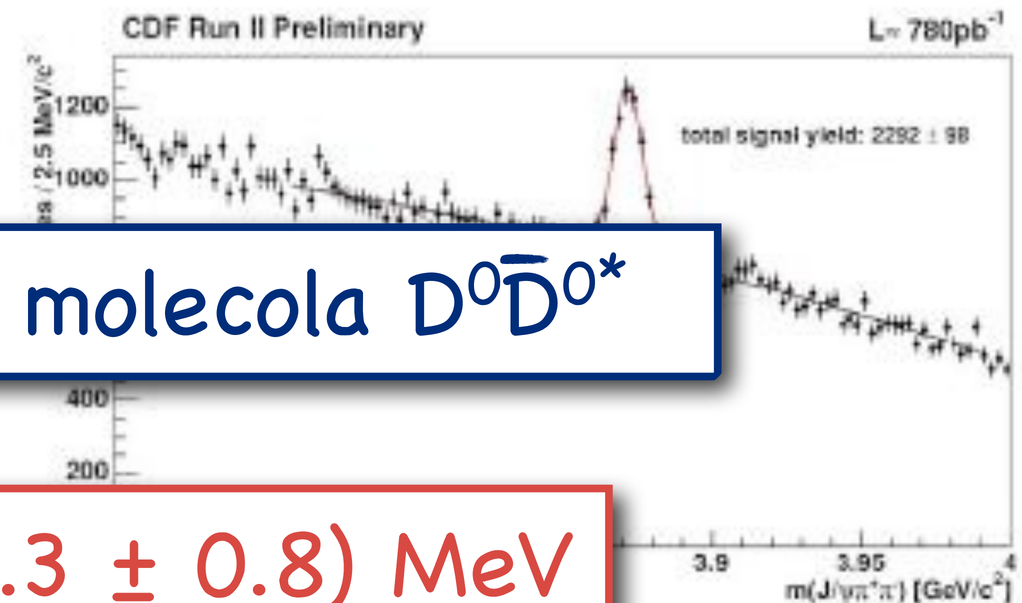
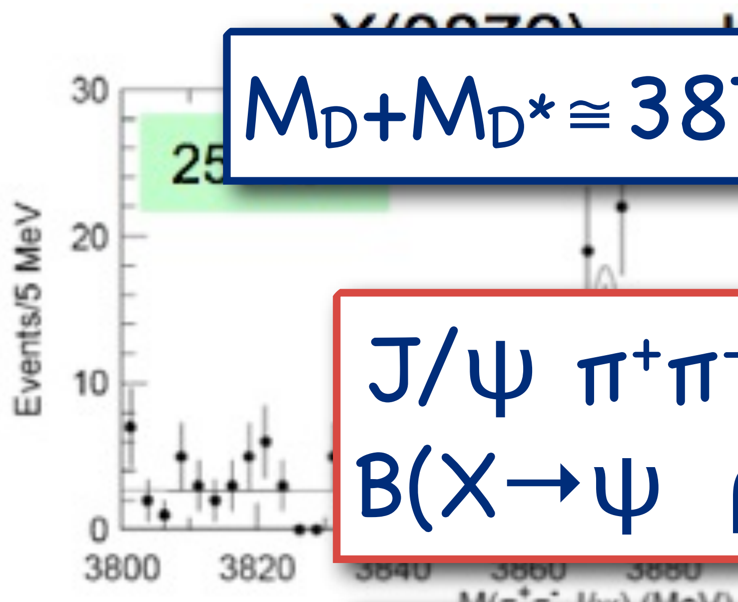
$p\bar{p} \to J/\psi\ \pi^+\pi^-$



Agosto 2003:

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



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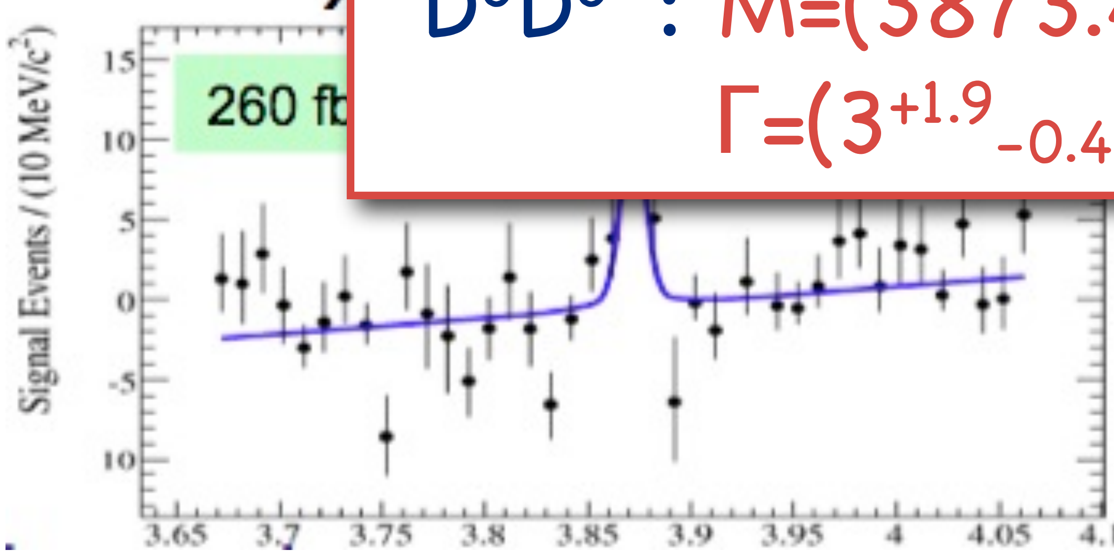
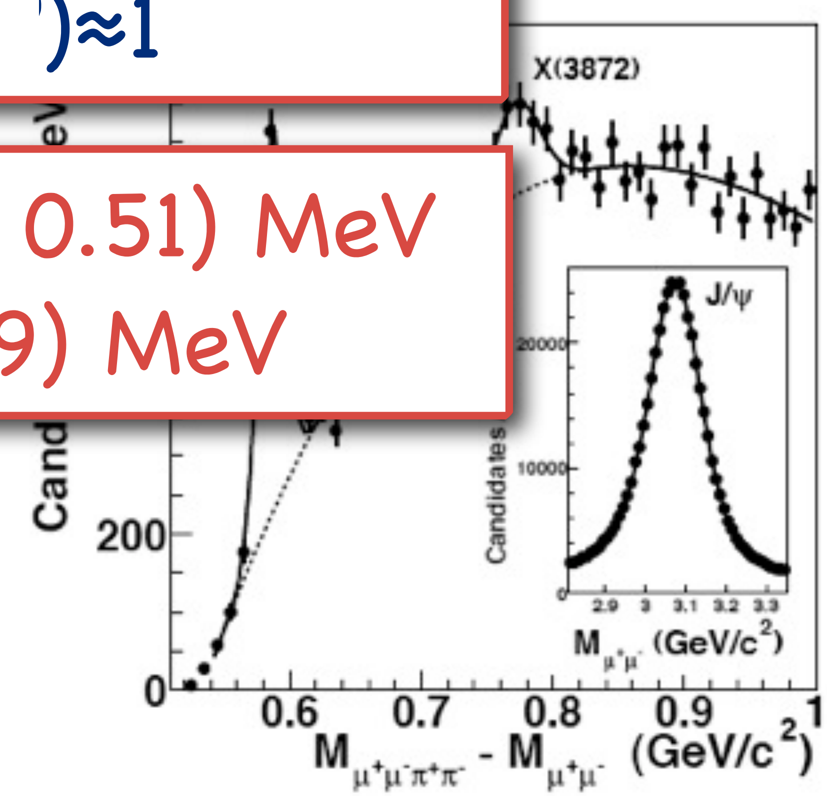
$J/\psi\ \pi^+\pi^-$: $M = (3872.3 \pm 0.8)$ MeV

$B(X \to \psi\ \rho\ )/B(\psi\ \ \omega\ \ ) \approx 1$

$\bar{D}^0 D^{0*}$: $M = (3873.49 \pm 0.51)$ MeV

$\Gamma = (3^{+1.9}_{-0.4} \pm 0.9)$ MeV

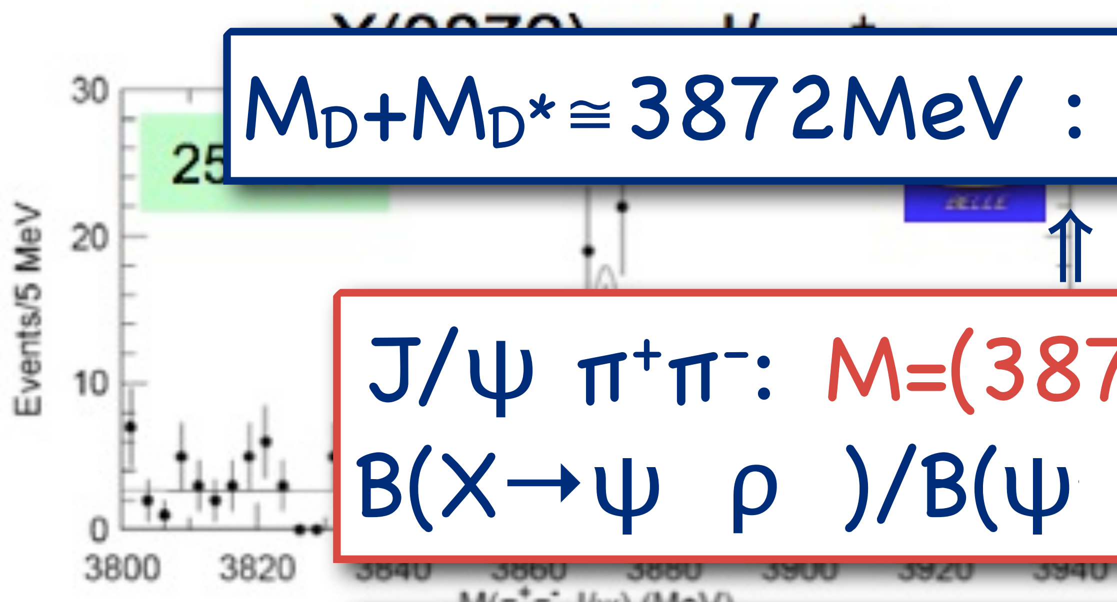


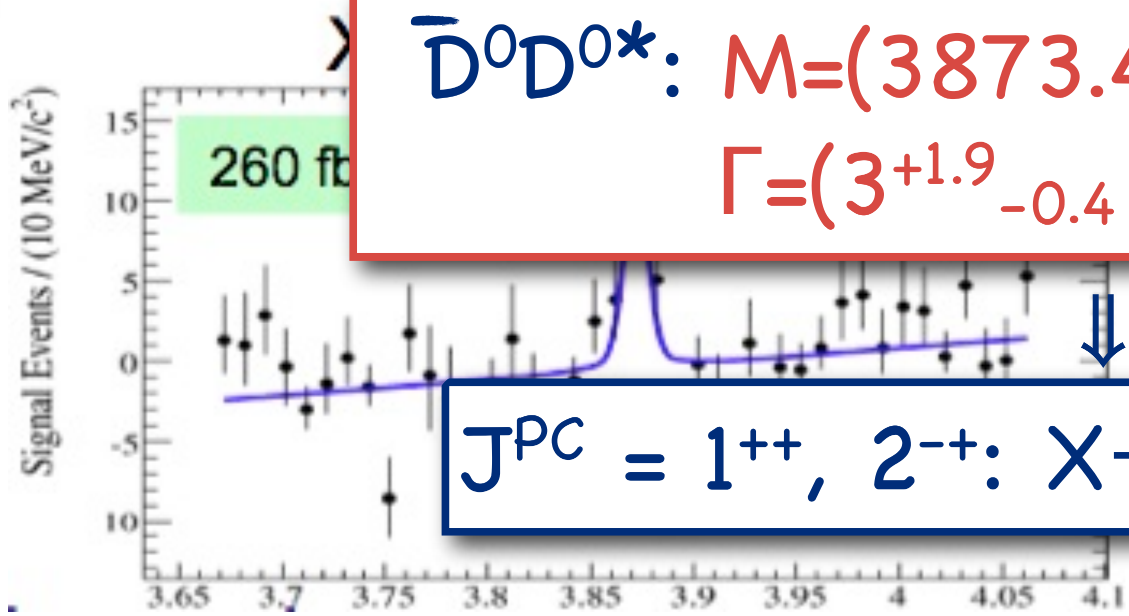


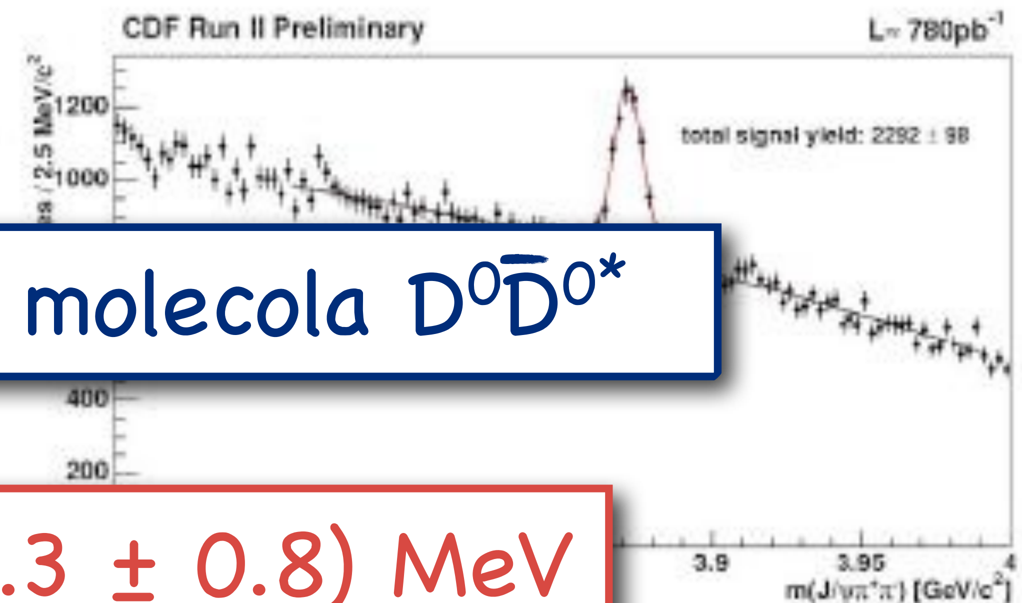
La scoperta

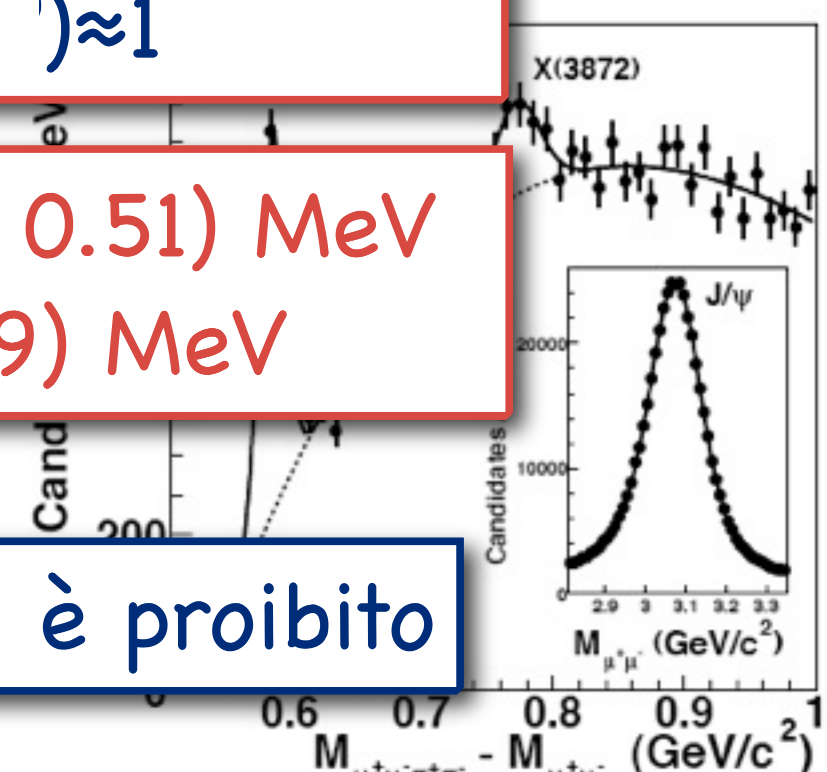
Settembre 2003:
$p\bar{p} \to J/\psi\ \pi^+\pi^-$

Agosto 2003:
$B^\pm \to K^\pm J/\psi\ \pi^+\pi^-$









$M_D + M_{D^*} \cong 3872\,\text{MeV}$: X molecola $D^0\bar{D}^{0*}$

⇑

$J/\psi\ \pi^+\pi^-$: $M = (3872.3 \pm 0.8)$ MeV
$B(X \to \psi\ \ \rho\ \ )/B(\psi\ \ \ \omega\ \ \ ') \approx 1$

$\bar{D}^0 D^{0*}$: $M = (3873.49 \pm 0.51)$ MeV
$\Gamma = (3^{+1.9}_{-0.4} \pm 0.9)$ MeV

⇓

$J^{PC} = 1^{++}, 2^{-+}$: $X \to D\bar{D}$ è proibito

X come molecola

- Se la X ha $J^{PC} = 1^{++}$: molecola in onda s con fdo:

$$|X\rangle = \frac{|D^0\bar{D}^{0*}\rangle + |\bar{D}^0 D^{0*}\rangle}{\sqrt{2}}$$

- Energia di legame:

$$E_B = M_X - M_D - M_{D^*} = (-0.49 \pm 1.6)\,\mathrm{MeV}$$

$$\Downarrow$$

Può uno stato così debolmente legato essere prodotto prompt in $p\bar{p}$?

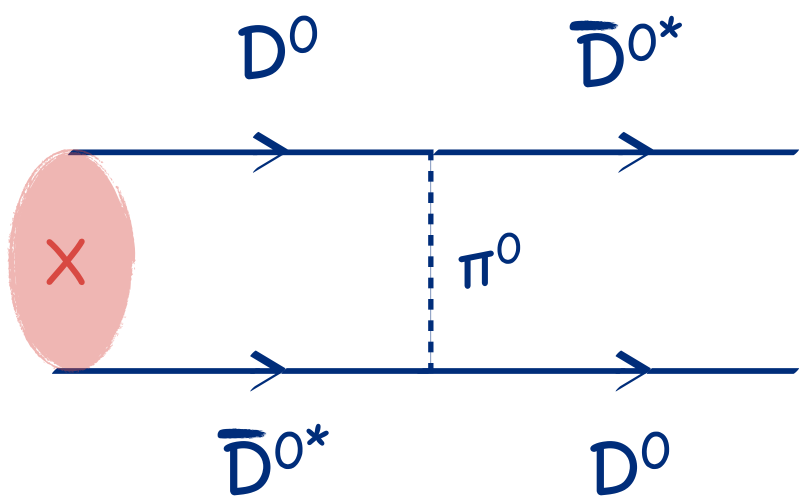
$p\bar{p} \to X(3872)$ @ CDF

$$33 \text{ nb} < \sigma(p\bar{p} \to X(3872) + \text{All})_{\text{prompt}} < 72 \text{ nb}$$

Phys. Rev. Lett. 98, 132002 (2007).
Phys. Rev. D80, 031103 (2009).
Phys. Rev. Lett. 79, 572 (1997).

$p\bar{p} \to X(3872)$

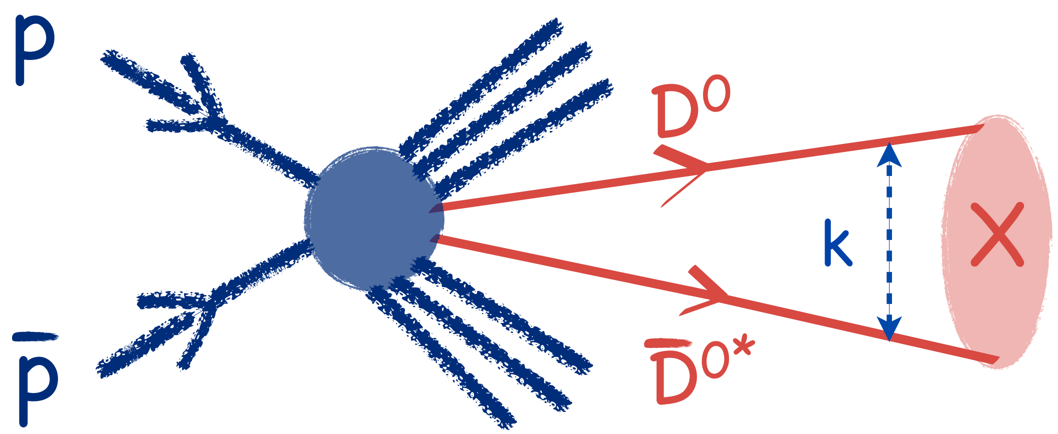
- I mesoni D interagiscono scambiando π^0



(1) $r_0 \simeq 6\, fm \quad \Rightarrow \quad \Delta k \sim 1/2r_0 \simeq 15 \text{ MeV}$

(2) $k_0 = \dfrac{\sqrt{\lambda(m_X^2, m_D^2, m_{D^*}^2)}}{2m_X} \simeq 30 \text{ MeV}$

$p\bar{p} \rightarrow X(3872)$



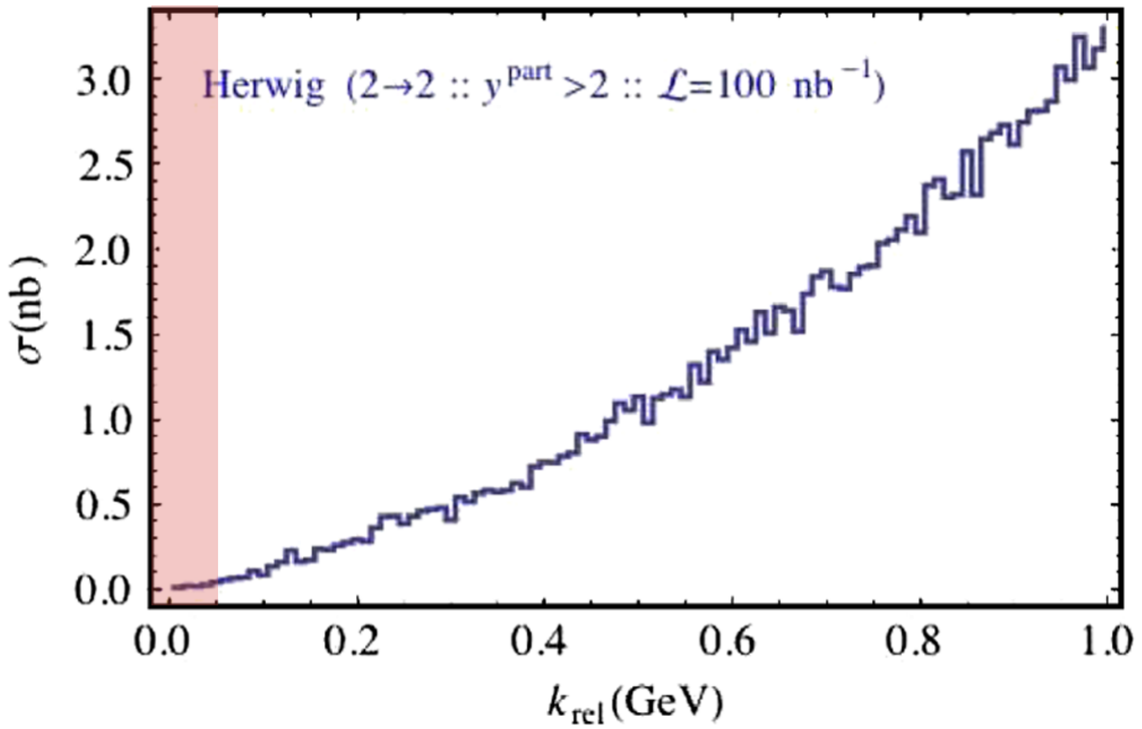
$$\mathcal{R}: \; 0 \leq k \leq k_0 + \Delta k$$

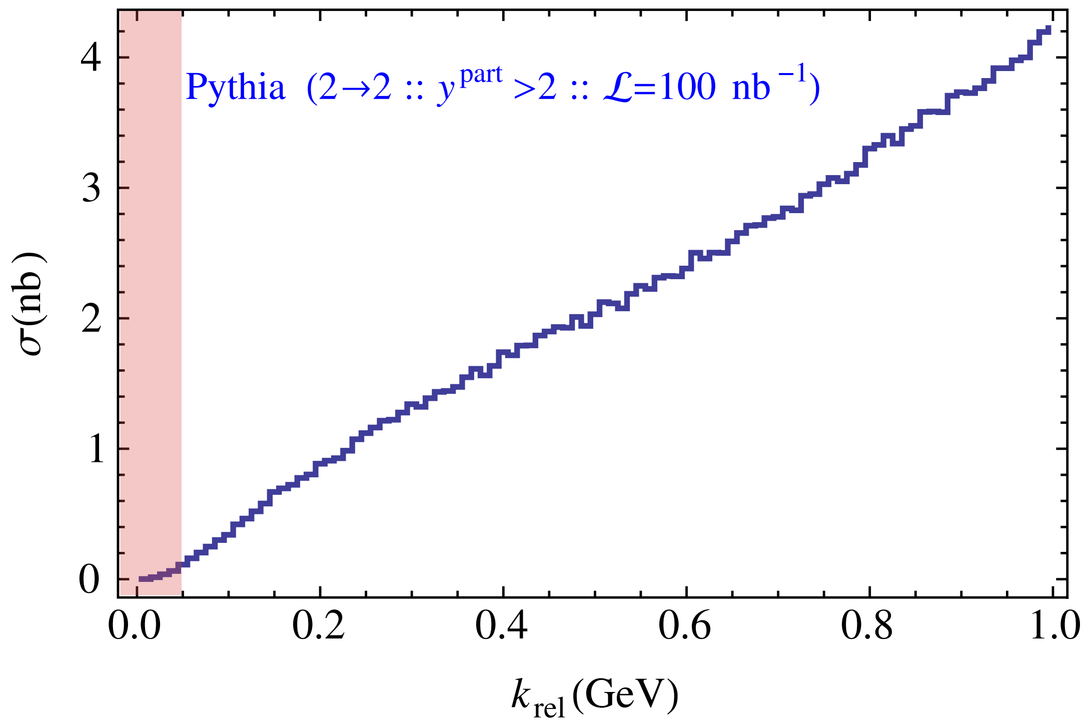
$$\sigma(p\bar{p} \rightarrow X(3872)) \leq \int_{\mathcal{R}} d^3\mathbf{k} |\langle D\bar{D}^*(\mathbf{k})|p\bar{p}\rangle|^2$$

Disuguaglianza di Schwartz

MC: Herwig Pythia

$p\bar{p} \to X(3872)$ con Pythia e Herwig





$$\sigma(p\bar{p} \to X(3872) + \mathrm{All})^{\mathrm{max}}_{\mathrm{th}} \simeq 0.085 \ \mathrm{nb}$$

$$\frac{\sigma^{\mathrm{min}}_{\mathrm{exp}}}{\sigma^{\mathrm{max}}_{\mathrm{th}}} \simeq 300$$

E il dibattito continua ...

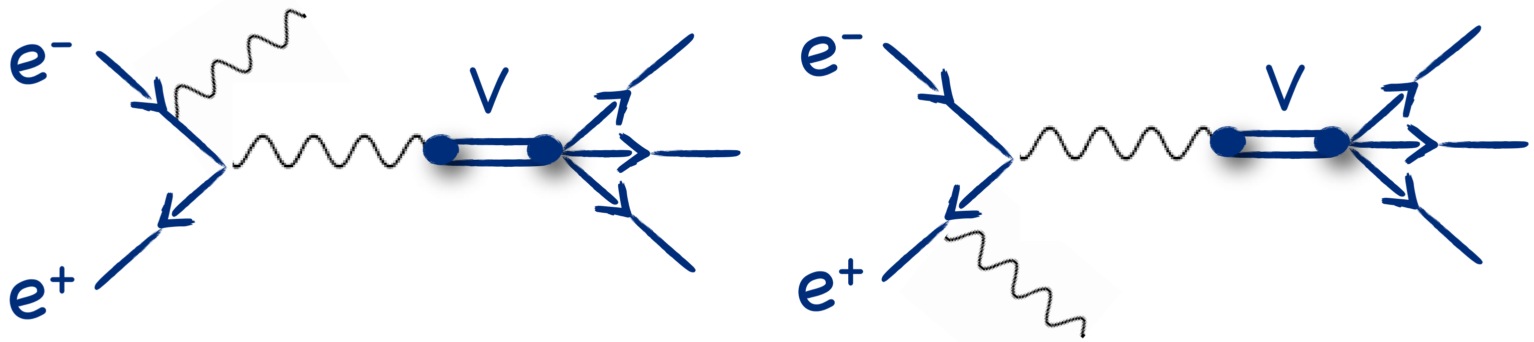
arXiv:0911.2016 & arXiv:0912.5064 / Phys.Lett.B684:228-230,2010

Y: stati esotici 1^{--}

arXiv:0911.2178 [hep-ph]
In stampa su Phys. Rev. Lett.

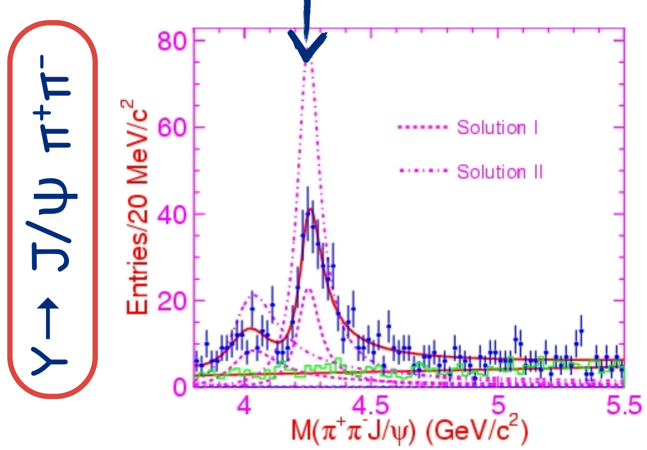
Stati 1^{--} : Y(4260), Y(4350), Y(4660) and Y(4630)

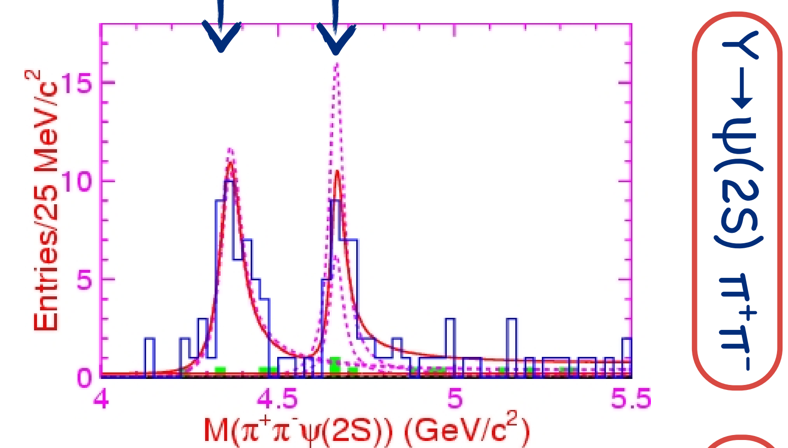
- Alle B-factories: riduzione dell'energia del c.o.m. via ISR

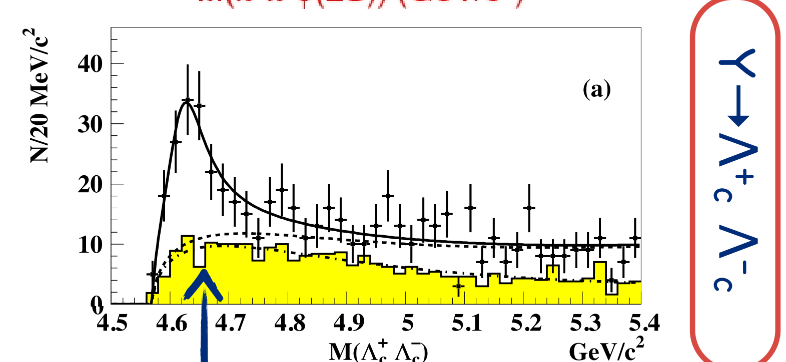


$e^+e^- \to Y\ \gamma_{ISR}$

- Y(4260) — Y(4350) Y(4660)



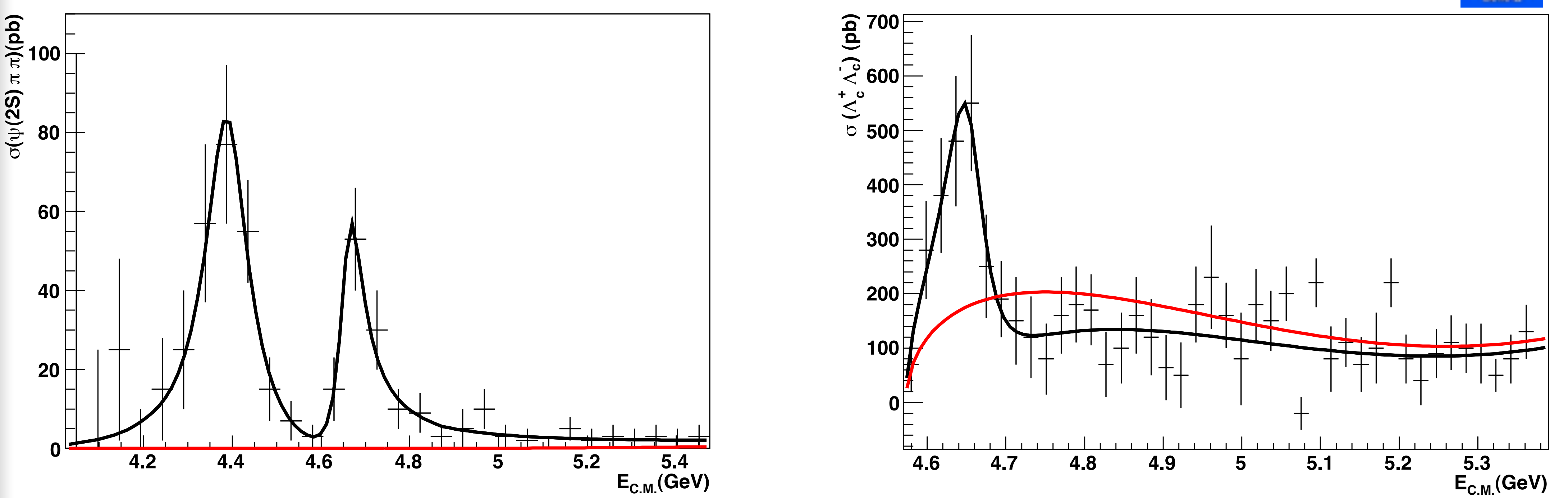




Y(4630)

Y(4630) ≡ Y(4660) ≡ Y_B

Nuova analisi dei dati di Belle nei canali $\psi(2S)\,\pi^+\pi^-$ e $\Lambda^+_c\,\Lambda^-_c$

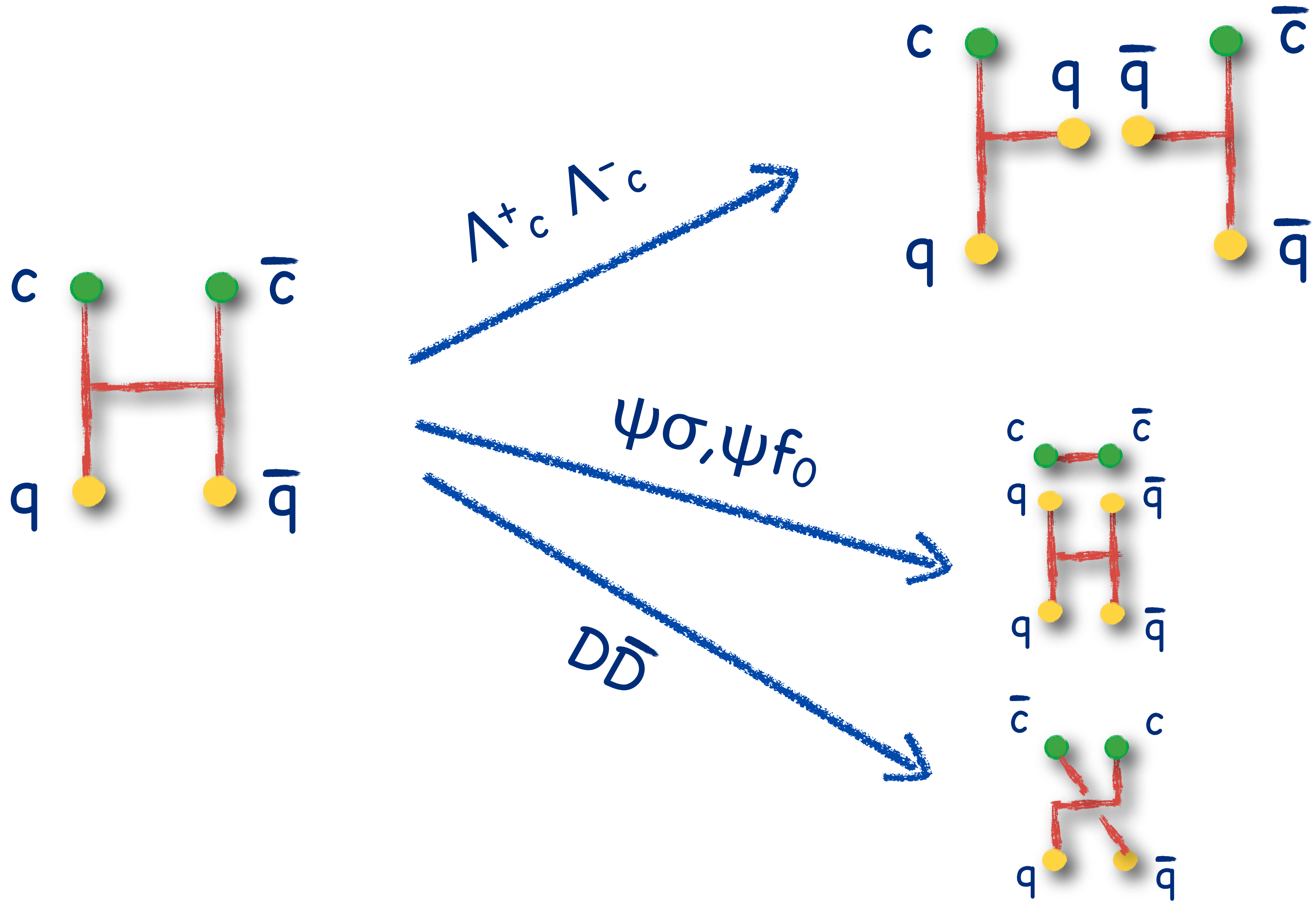


$$M_{Y_B} = (4660.7 \pm 8.7)\mathrm{MeV}$$

$$\frac{\mathcal{B}(Y_B \to \Lambda_c^+\Lambda_c^-)}{\mathcal{B}(Y_B \to \psi(2S)\pi^+\pi^-)} = 117 \pm 44 \qquad \frac{\mathcal{B}(Y_B \to J/\psi\pi^+\pi^-)}{\mathcal{B}(Y_B \to \psi(2S)\pi^+\pi^-)} < 0.46$$

Barionio

- Una struttura $[cq][\bar{c}\bar{q}]$ è in grado di spiegare la forte dominanza del canale barionico



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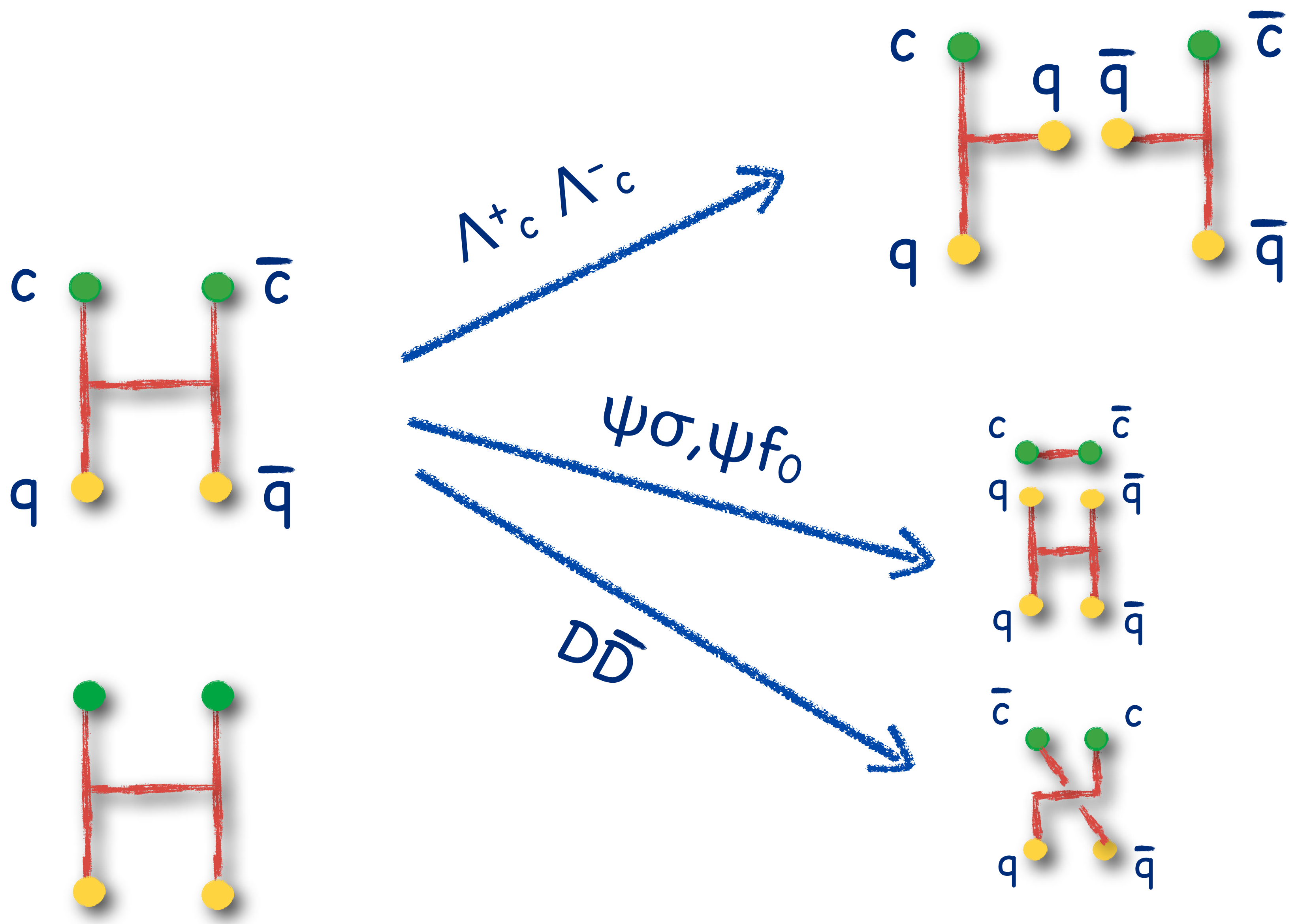

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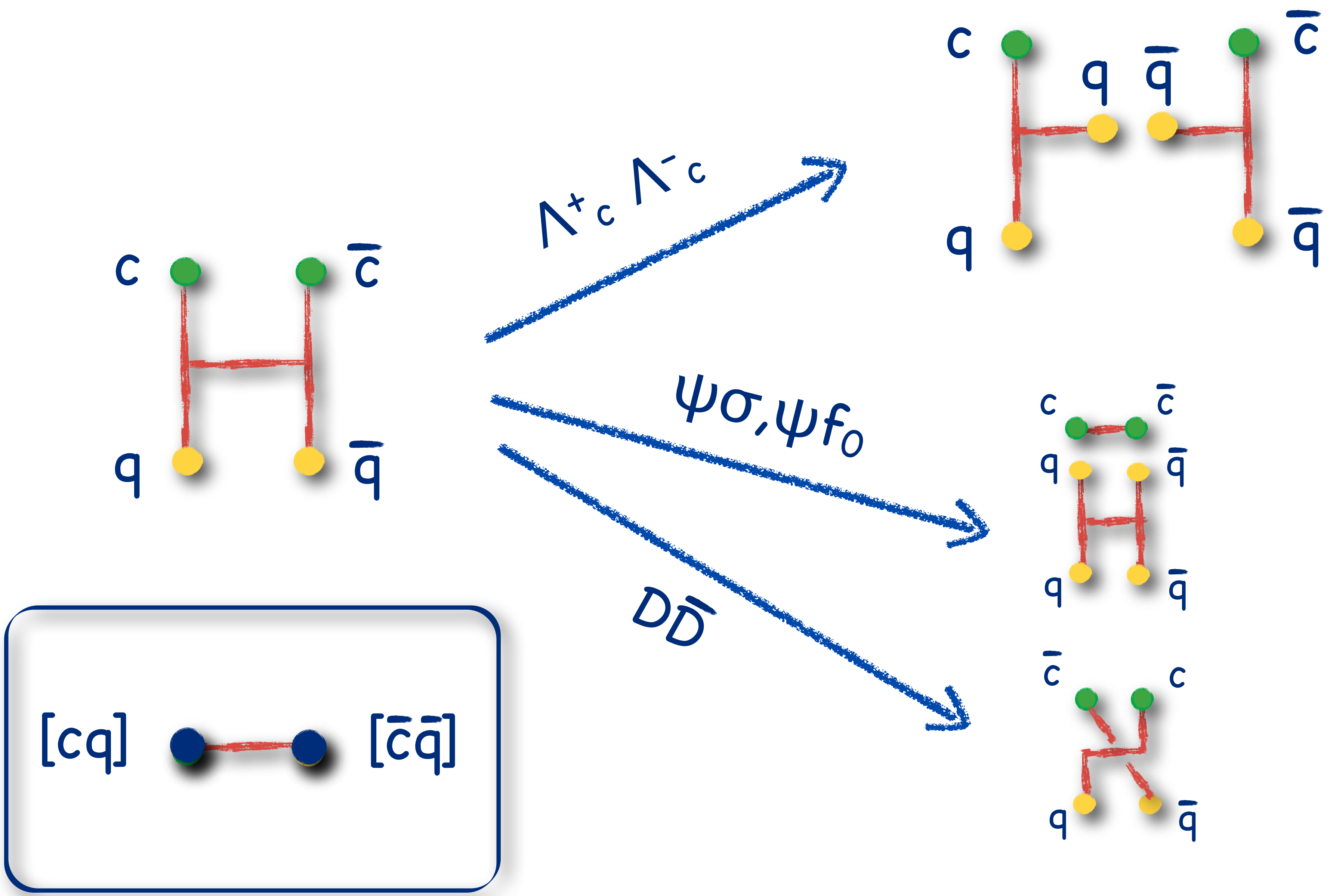
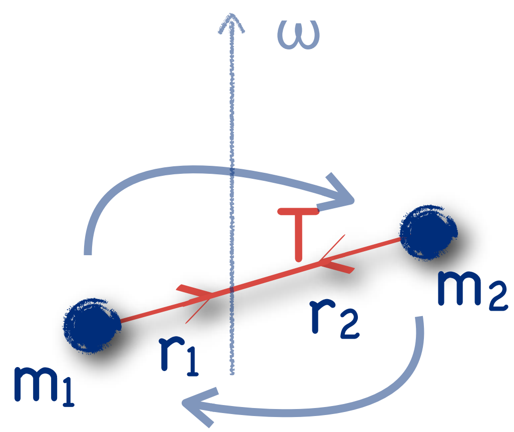


Lo spettro: stringa rotante relativistica



$$dE^* = T dr \rightarrow dE = \frac{T}{\omega} \frac{dv}{\sqrt{1-v^2}}$$

$$dL = \omega dI = \frac{v^2}{\omega} dE = \frac{T}{\omega^2} \frac{v^2\, dv}{\sqrt{1-v^2}}$$

T=σ/2π, σ=1.1 GeV^2
dalle traiettorie di Regge

$m_1=m_2=M$, $M>>T/\omega$ →

$$E = 2M + \frac{3L^{2/3}T^{2/3}}{(4M)^{1/3}}$$

n_r	L	M_{th}(MeV)	
0	1	4340	← Y(4350)
0	3	4850	
1	1	4700	← Y(4660)

Back Up

$p\bar{p} \to X(3872)$ @ CDFII

[arXiv:hep-ex/0612053]
[arXiv:0905.1982 [hep-ex]]
Phys. Rev. Lett. 79, 572 (1997)

- $$\frac{\sigma(p\bar{p} \to X(3872) + \text{All})_{\text{prompt}} \times \mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-))}{\sigma(p\bar{p} \to \psi(2S) + \text{All})_{\text{prompt}}} \simeq (4.6 \pm 0.1)\%$$

con: $p_\perp > 5\ \text{GeV}, |y| < 1$

- $\sigma(p\bar{p} \to \psi(2S) + \text{All})_{\text{prompt}} = (67 \pm 9)\ \text{nb}$ with: $(p_\perp > 5\ \text{GeV}, |y| < 0.6)$

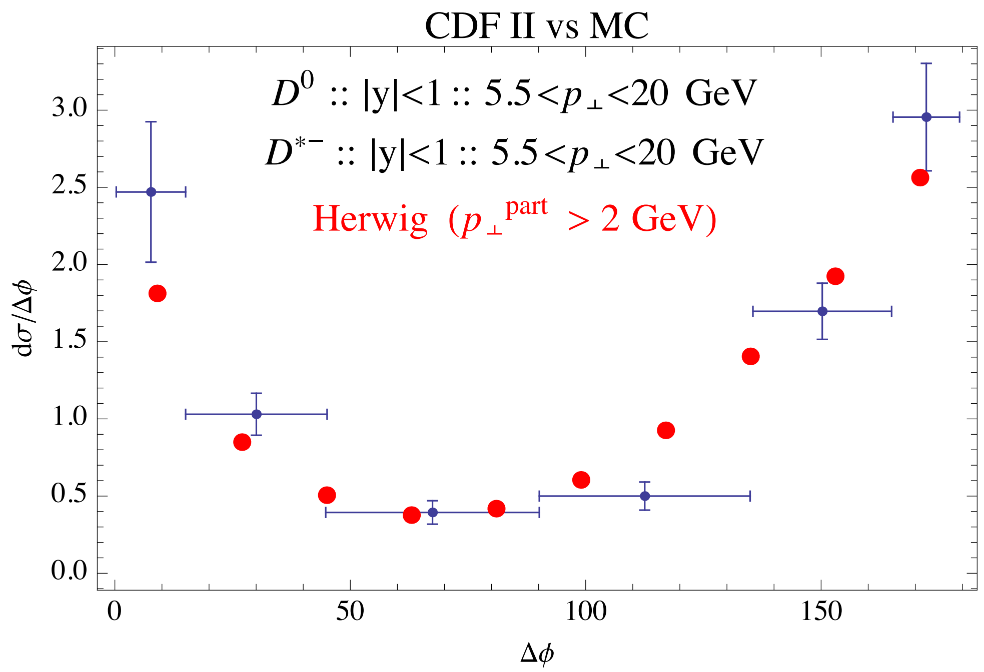
- Assumendo la stessa distribuzione in rapidità e $p_\perp$ per X e $\psi(2S)$:

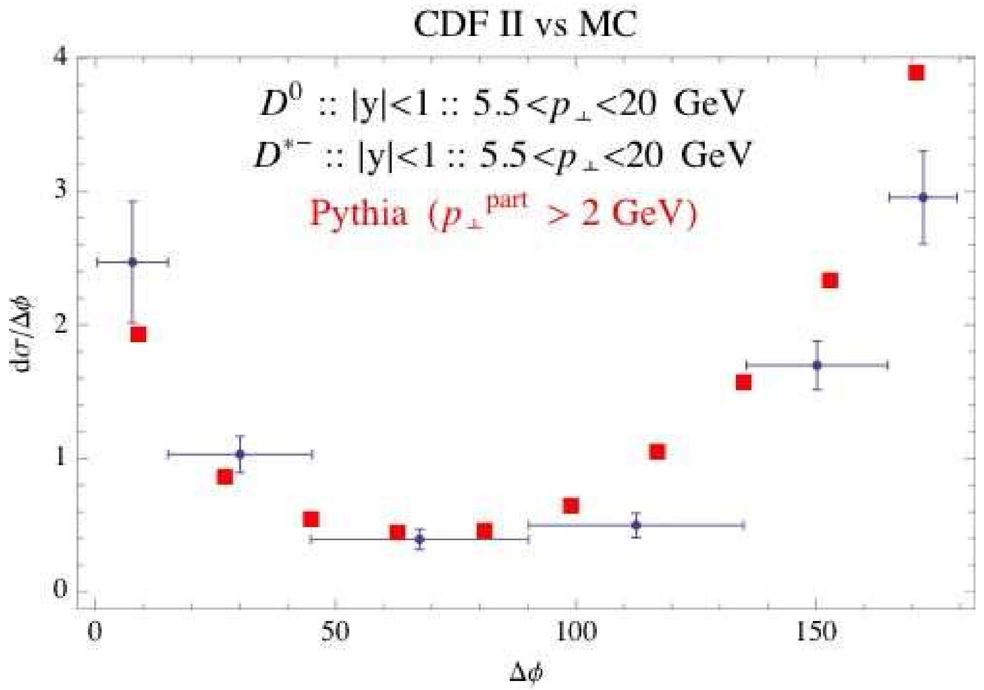
$$\sigma(p\bar{p} \to X(3872) + \text{All})_{\text{prompt}}\, \mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-) \simeq (3.1 \pm 0.7)\text{nb}$$

- Inoltre: $0.042 < \mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-) < 0.093$

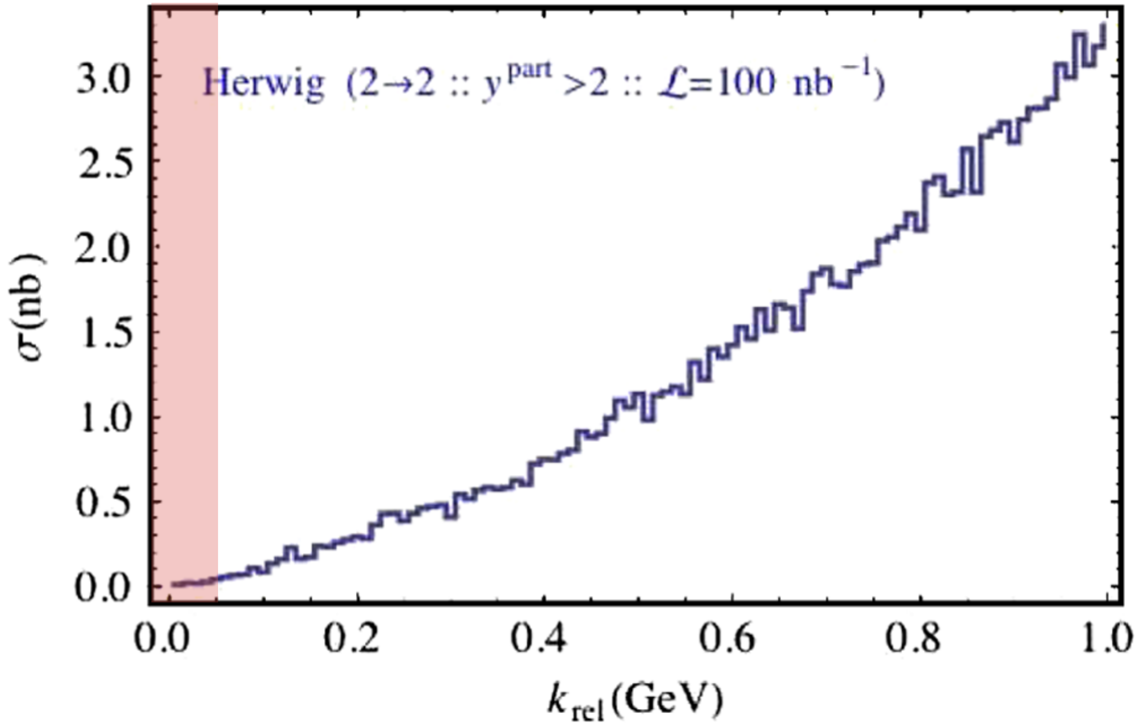
$$\Rightarrow \quad 33\ \text{nb} < \sigma(p\bar{p} \to X(3872) + \text{All})_{\text{prompt}} < 72\ \text{nb}$$

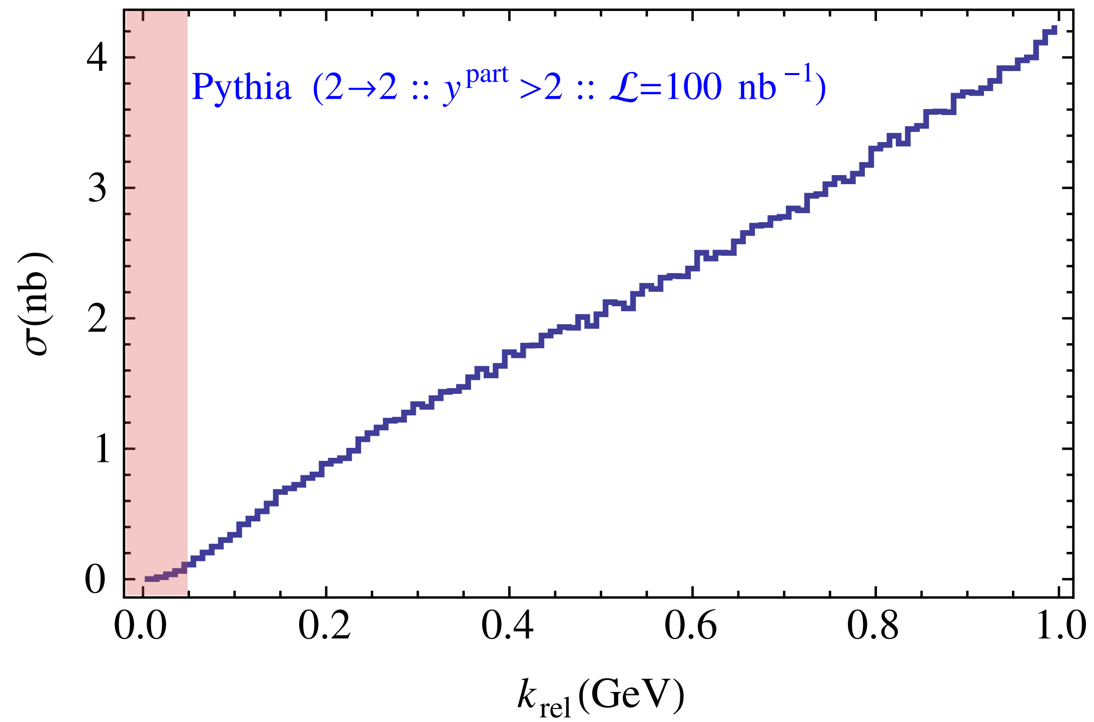
Tuning del MC sui dati





$p\bar{p} \to X(3872)$ con Pythia e Herwig





55×10^9 eventi :: $p_\perp^{part} > 2$ GeV :: $|y^{part}| < 6$
Tagli sui mesoni finali D tali che $p_\perp^X > 5$ GeV and $|y^{part}| < 0.6$

$$\sigma(p\bar{p} \to X(3872) + \mathrm{All})^{\mathrm{max}}_{\mathrm{th}} \simeq 0.085\ \mathrm{nb}$$

$$\sigma(p\bar{p} \to X(3872) + \mathrm{All})^{\mathrm{max}}_{\mathrm{th}} \simeq 3\ \mathrm{nb}$$

k fino a ~200 MeV

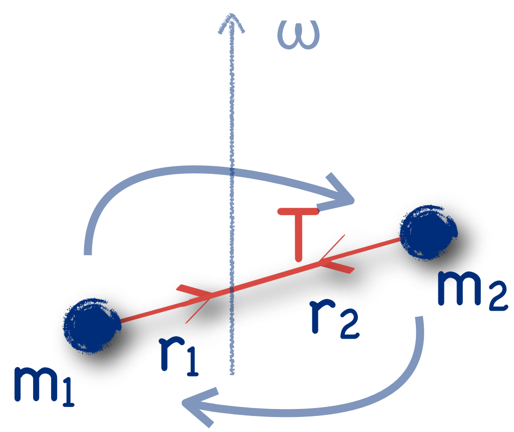
Decadimenti della X

$\Gamma(2^3P_1 \to \psi\gamma)/\Gamma(2^3P_1 \to \psi\pi\pi) \sim 40$
$\Gamma(X \to \psi\gamma)/\Gamma(X \to \psi\pi\pi) \sim 0.1$

$B(X \to \psi\rho)/B(X \to \psi\omega) \sim 1$

B Decay mode	X decay mode	PBF($\times 10^5$)	B_{fit}	R_{fit}
$XK^{\pm}$	$X \to J/\psi\pi\pi$	0.82±0.09 [101, 102]	$[0.035, 0.075]$	N/A
[illegible]	[illegible] $J/\psi\pi\pi$	0.53±0.13 [101, 102]	–	N/A
[illegible]	[illegible] $D^{*0}D^0$	13±3 [99, 103]	$[0.54, 0.8]$	$[3.9, 18.9]$
[illegible]	[illegible] $D^{*0}D^0$	13±3 [99, 103]	–	–
XK	$X \to \chi_c(1P)\gamma$	[95]	–	–
XK	$X \to J/\psi\gamma$	[104]	$[0.0075, 0.0195]$	$[0.19, 0.32]$
XK	$X \to \psi(2S)\gamma$	[104]	$[0.03, 0.09]$	$[0.75, 1.55]$
XK	$X \to \gamma\gamma$	[105]	< 0.00[illegible]	[illegible]
XK	$X \to J/\psi\eta$	[106]	< 0.098	< 1.9
XK	$X \to J/\psi\pi\pi\pi^0$	[107]	$[0.015, 0.08]$	$[0.45, 1.44]$
XK^*	$X \to J/\psi\pi\pi$	[102]	–	–

Lo spettro: stringa rotante relativistica



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$$dL = \omega dI = \frac{v^2}{\omega} dE = \frac{T}{\omega^2} \frac{v^2 \, dv}{\sqrt{1-v^2}}$$

$T = \sigma/2\pi$, $\sigma = 1.1$ GeV^2
dalle Regge trajectories

$m_1 = m_2 = M$, $M >> T/\omega$ ⟶

$$E = 2M + \frac{3L^{2/3}T^{2/3}}{(4M)^{1/3}}$$

$c\bar{c}$

$$L = 1 \begin{cases} M^{th}_{\chi_{cJ}} = 3517\,\text{MeV} \\ M^{exp}_{\chi_{cJ}} = 3525\,\text{MeV} \end{cases}$$

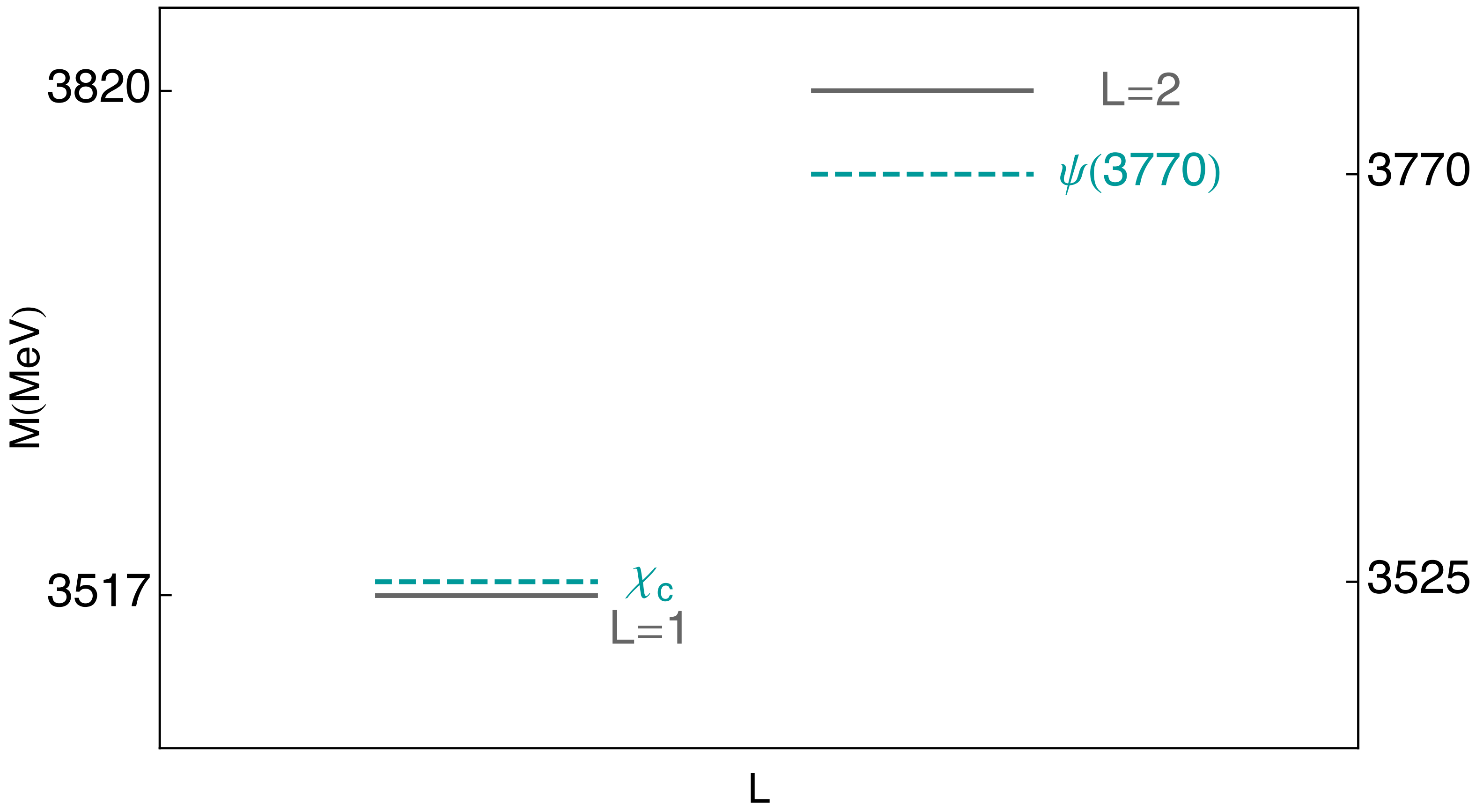
$$L = 2 \begin{cases} M^{th}_{\psi'} = 3820\,\text{MeV} \\ M^{exp}_{\psi'} = 3770\,\text{MeV} \end{cases}$$

$[cq][\bar{c}\bar{q}]$

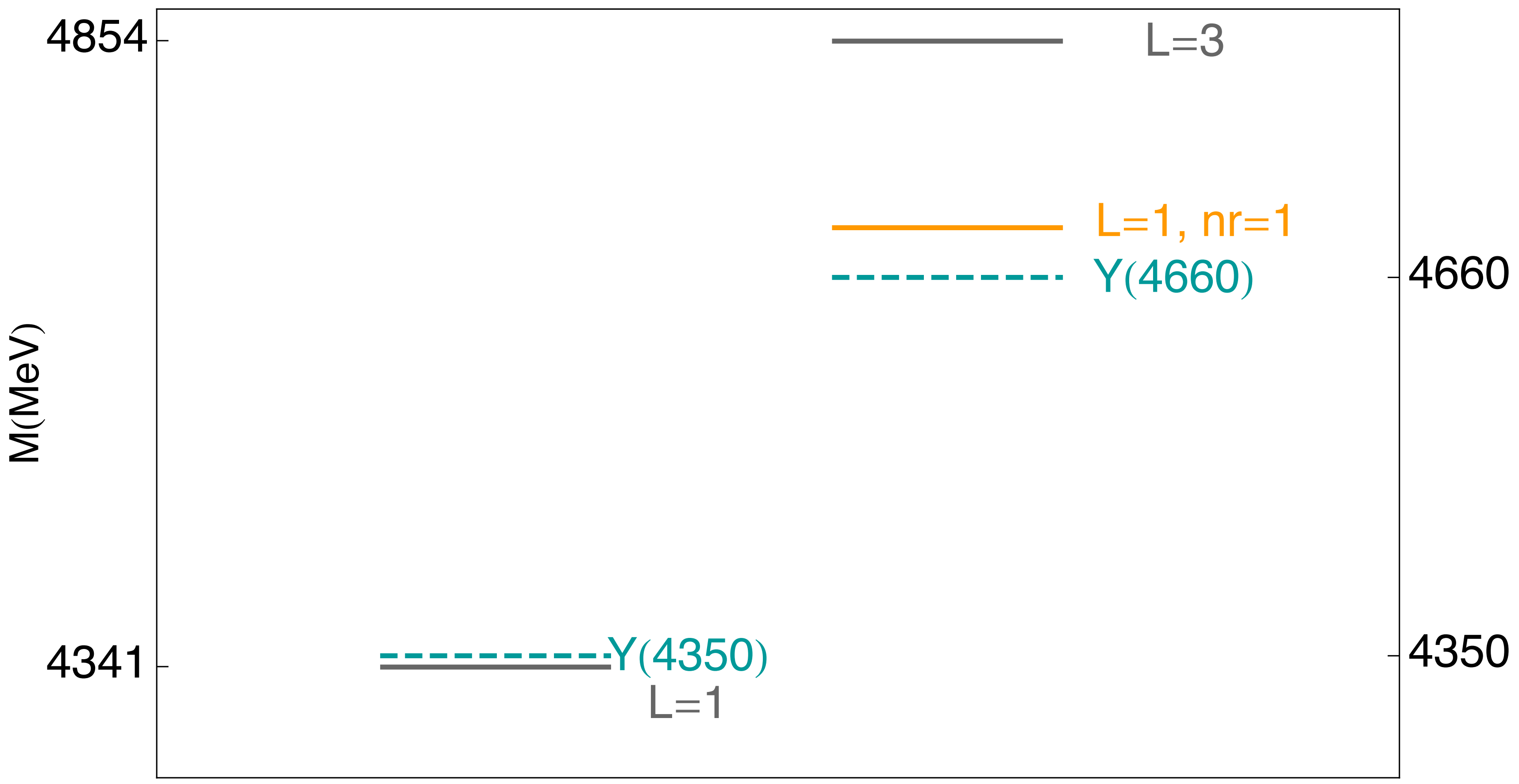
$$L = 1 \begin{cases} M^{th} = 4340\,\text{MeV} \\ M^{exp} = 4350\,\text{MeV} \end{cases}$$

?! $$L = 3 \begin{cases} M^{th} = 4850\,\text{MeV} \\ M^{exp} = 4660\,\text{MeV} \end{cases}$$

Stringa su charmonio

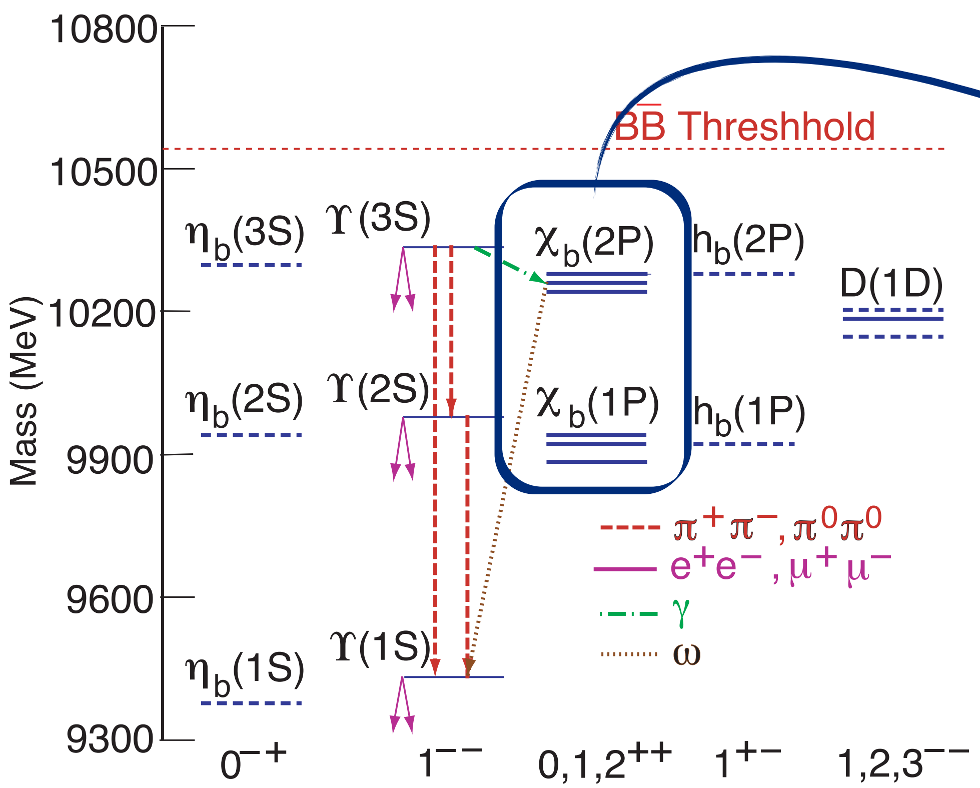


Stringa sulle Y



Eccitazioni radiali

- La dominanza del decadimento in $\psi(2S)\pi^+\pi^-$ suggerisce che il sistema sia eccitato radialmente



$$\Delta M = M_{\chi_b(2P)} - M_{\chi_b(1P)} \simeq 360\text{MeV}$$

$$E(n_r, L) = 2M + \frac{3L^{2/3}T^{2/3}}{(4M)^{1/3}} + n_r\Delta M$$

n_r	L	M_{th}(MeV)	
0	1	4340	⟵ Y(4350)
0	3	4850	
1	1	4700	⟵ Y(4660)

- Il rapporto B(J/ψ)/B(ψ(2S)) puo' essere spiegato con un integrale di sovrapposizione delle fdo radiali ?

$$\int \psi_{c\bar{c}}^*(r)\ \psi_{[cq][\bar{c}\bar{q}]}(r)$$