VIII International Workshop on Charm Physics

From J/ψ to LHCb Pentaquark

(a constituent quark model description)

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Outline

- ✓ Motivation
- ✓ The model: constituent quarks,
  coupled channels
  $^3P_0$ model
- ✓ Results
- ✓ Conclusions

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Volume 8, number 3 PHYSICS LETTERS 1 February

A SCHEMATIC MODEL OF BARYONS AND MESONS *

M. GELL-MANN
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Received 4 January 1964

If we assume that the strong interactions of baryons and mesons are correctly described in terms of the broken "eightfold way" [1-3], we are tempted to look for some fundamental explanation of the situation. A highly promised approach is the purely dynamical "bootstrap" model for all the strongly interacting particles within which one may try to derive isotopic spin and strangeness conservation and broken eightfold symmetry from self-consistency alone [4]. Of course, with only strong interactions, the orientation of the asymmetry in the unitary space cannot be specified; one hopes that in some way the selection of specific components of the F-spin by electromagnetism and the weak interactions determines the choice of isotopic spin and hypercharge directions.

Even if we consider the scattering amplitudes of strongly interacting particles on the mass shell only and treat the matrix elements of the weak, electromagnetic, and gravitational interactions by means of dispersion theory, there are still meaningful and important questions regarding the algebraic properties of these interactions that have so far been discussed only by abstracting the properties from a formal field theory model based on fundamental entities [3] from which the baryons and mesons are built up.

If these entities were octets, we might expect the underlying symmetry group to be SU(8) instead of SU(3); it is therefore tempting to try to use unitary triplets as fundamental objects. A unitary triplet t consists of an isotopic singlet s of electric charge z (in units of e) and an isotopic doublet (u, d) with charges z+1 and z respectively. The anti-triplet $\bar{t}$ has, of course, the opposite signs of the charges. Complete symmetry among the members of the triplet gives the exact eightfold way, while a mass difference, for example, between the isotopic doublet and singlet gives the first-order violation.

ber $n_t - n_{\bar{t}}$ would be zero for all known baryons and mesons. The most interesting example of such a model is one in which the triplet has spin $\frac{1}{2}$ and $z = -1$, so that the four particles d^-, s^-, u^0 and b^0 exhibit a parallel with the leptons.

A simpler and more elegant scheme can be constructed if we allow non-integral values for the charges. We can dispense entirely with the basic baryon b if we assign to the triplet t the following properties: spin $\frac{1}{2}$, $z = -\frac{1}{3}$, and baryon number $\frac{1}{3}$. We then refer to the members $u^{\frac{2}{3}}$, $d^{-\frac{1}{3}}$, and $s^{-\frac{1}{3}}$ of the triplet as "quarks" [6] q and the members of the anti-triplet as anti-quarks $\bar{q}$. Baryons can now be constructed from quarks by using the combinations $(q\,q\,q)$, $(q\,q\,q\,q\,\bar{q})$, etc., while mesons are made out of $(q\,\bar{q})$, $(q\,q\,\bar{q}\,\bar{q})$, etc. It is assuming that the lowest baryon configuration $(q\,q\,q)$ gives just the representations **1**, **8**, and **10** that have been observed, while the lowest meson configuration $(q\,\bar{q})$ similarly gives just **1** and **8**.

A formal mathematical model based on field theory can be built up for the quarks exactly as for p, n, Λ in the old Sakata model, for example [3] with all strong interactions ascribed to a neutral vector meson field interacting symmetrically with the three particles. Within such a framework, the electromagnetic current (in units of e) is just

$$i\{\tfrac{2}{3}\,\bar{u}\,\gamma_\alpha\,u - \tfrac{1}{3}\,\bar{d}\,\gamma_\alpha\,d - \tfrac{1}{3}\,\bar{s}\,\gamma_\alpha\,s\}$$

or $\mathscr{F}_{3\alpha} + \mathscr{F}_{8\alpha}/\sqrt{3}$ in the notation of ref. [3]. For the weak current, we can take over from the Sakata model the form suggested by Gell-Mann and Lévy namely $i\,\bar{p}\,\gamma_\alpha(1+\gamma_5)(n\cos\theta + \Lambda\sin\theta)$, which gives in the quark scheme the expression ***

$$i\,\bar{u}\,\gamma_\alpha(1+\gamma_5)(d\cos\theta + s\sin\theta)$$

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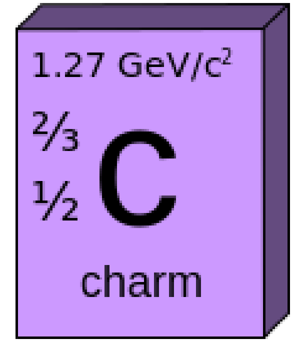
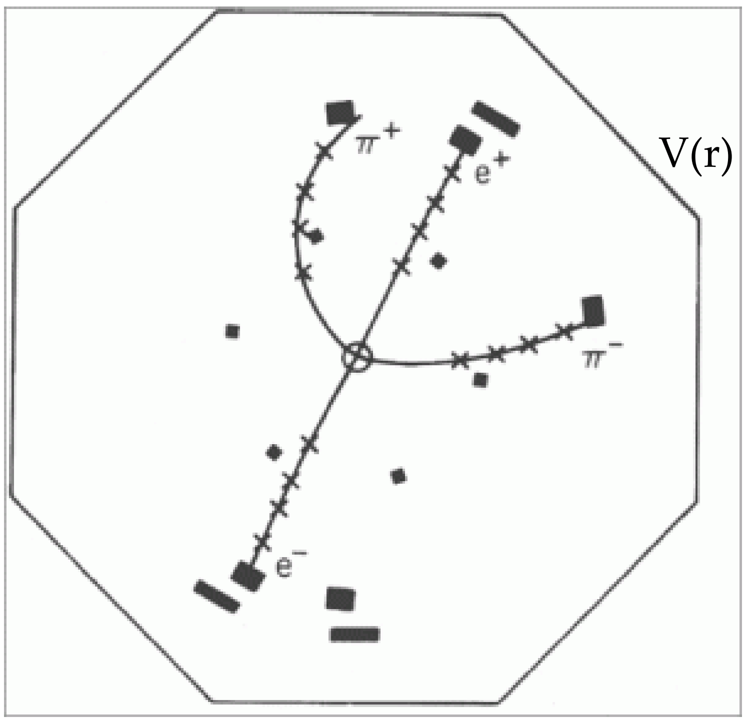
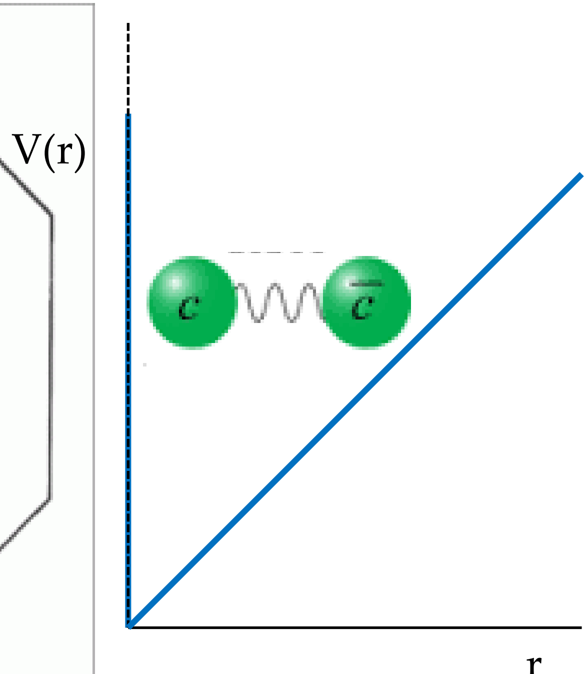
$$i\,\bar{u}\,\gamma_\alpha(1+\gamma_5)(d \cos\theta + s \sin\theta)$$

Charm sector

1974 $q\bar{q}$







Charmonium

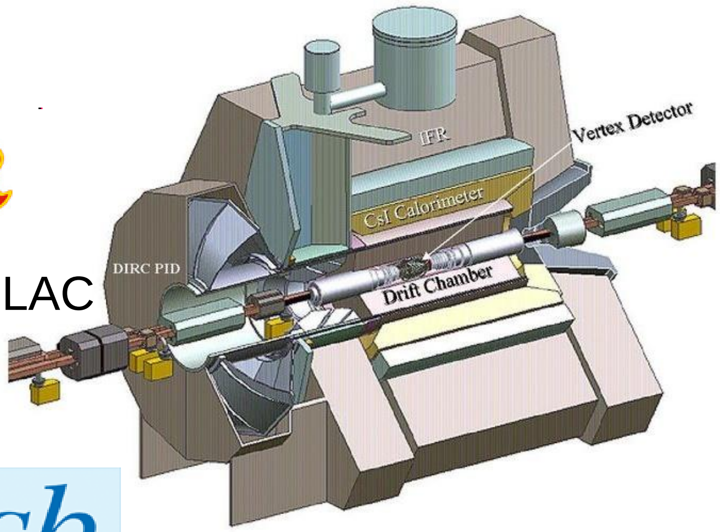
	exp	qm
J/ ψ	3097	3007
ψ(2S)	3770	3680
ψ(3S)	4040	4080
ψ(4S)	4415	4500

B-Factories

BABAR

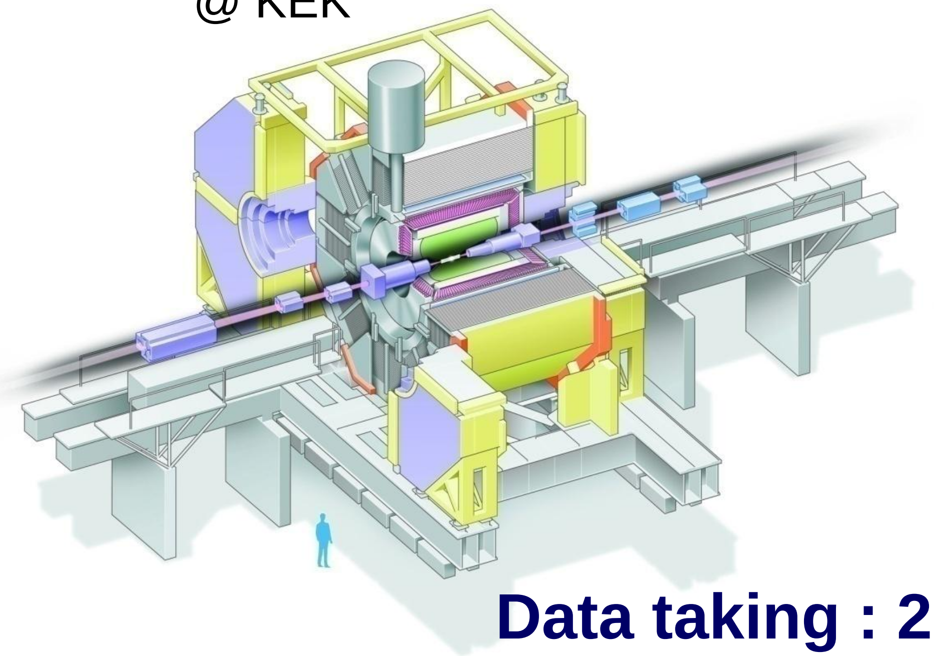
Collaboration Home Page

@ SLAC

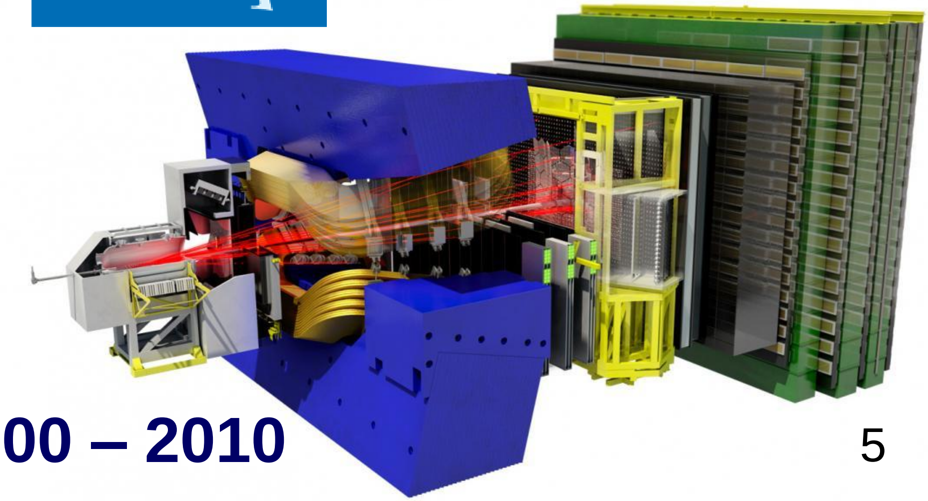


BELLE

@ KEK



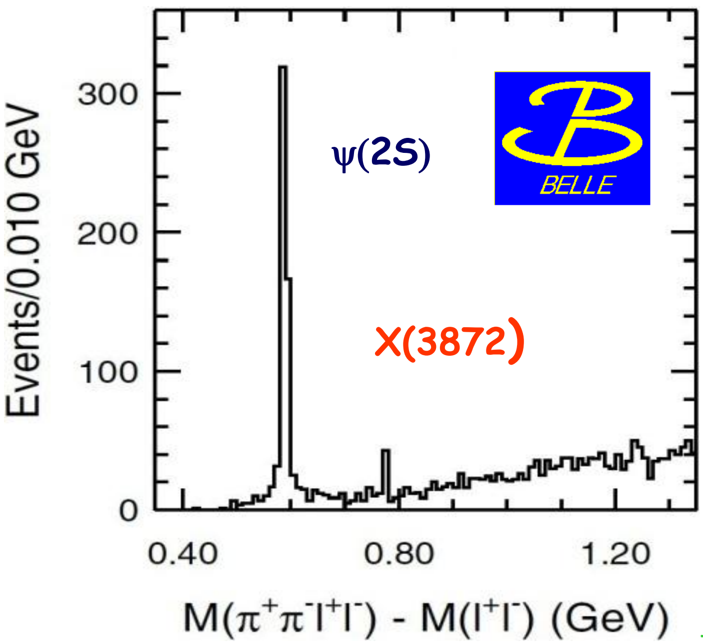
LHCb



Data taking : 2000 – 2010

2003 $q\bar{q}\, q\bar{q}$

X(3872) was observed in



$$B^+ \to X(3872)K^+ \to J/\Psi\pi^+\pi^-$$

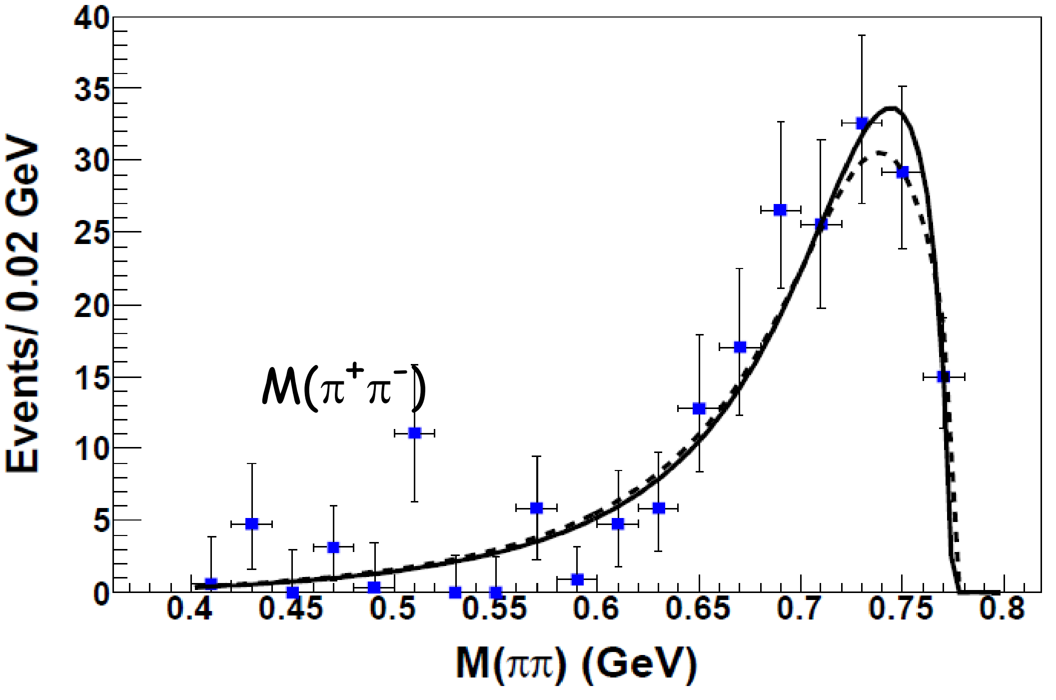
$$M = 3871.63 \pm 0.19\ MeV$$

$$\Gamma < 1.2\ MeV\ (90\%\ CL)$$

Mass close to $D^{*0}D^0$ threshold

$$\delta m = -0.9 \pm 0.34\ MeV$$

$X(3872) \rightarrow J/\psi\ \pi^+ \pi^-$



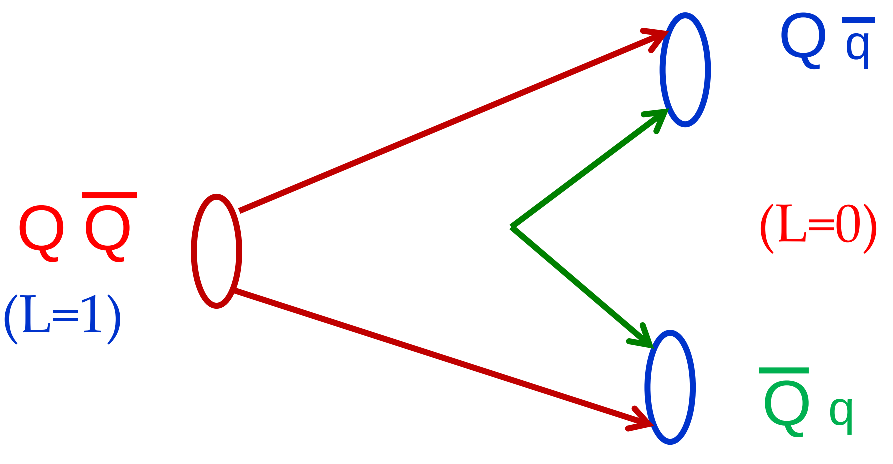
$\pi^+\pi^-$ pair is produced via ρ^0

X(3872) is observed in isospin-violating mode

$$R = \frac{\Gamma(X(3872) \rightarrow \pi^+\pi^-\pi^0 J/\psi)}{\Gamma(X(3872) \rightarrow \pi^+\pi^- J/\psi)} = 0.8 \pm 0.3$$

X (3872) is not very likely to be charmonium state

$J^{PC} = 1^{++}$ X(3872) (D* D threshold)



Two almost degenerated states → Coupled channel

Two different scenarios:

Strong coupling

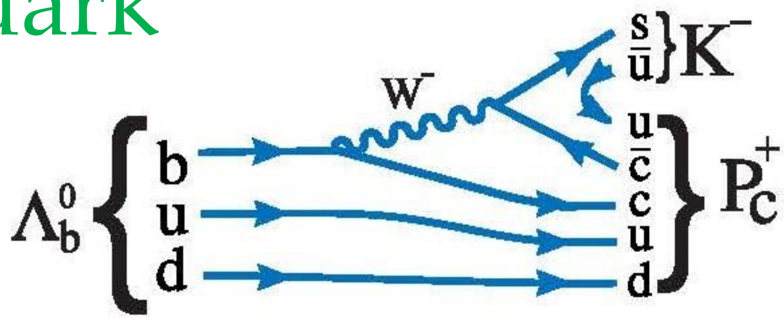
a) The coupling shifts substantially the energy of the two quark state (mass shift)
b) If strong enough it may create new extra states (XYZ states)

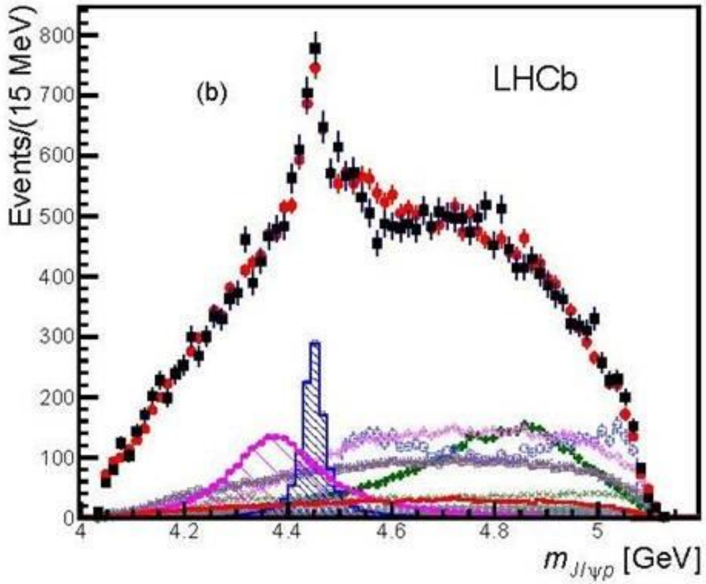
Weak coupling

a) The coupling shifts slightly the energy of the two quark state
b) No extra states (but some threshold effects are possibles)

2015 LHCb Pentaquark

$$\Lambda_b^0 \to J/\psi K^- p$$





$$M_{P_c(4380)} = 4380 \pm 8 \pm 29 \text{ MeV},$$
$$M_{P_c(4450)} = 4449.8 \pm 1.7 \pm 2.5 \text{ MeV}$$

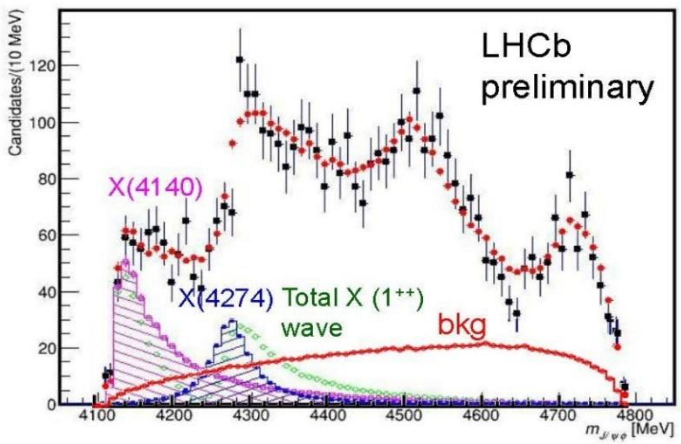
$$\Gamma_{P_c(4380)} = 205 \pm 18 \pm 86 \text{ MeV},$$
$$\Gamma_{P_c(4450)} = 39 \pm 5 \pm 19 \text{ MeV}.$$

The preferred spin-parity quantum numbers of of $P_c(4380)$ and $P_c(4450)$ are $3/2^{\mp}$ and $5/2^{\pm}$, respectively.

PhysRevLett.115.072001

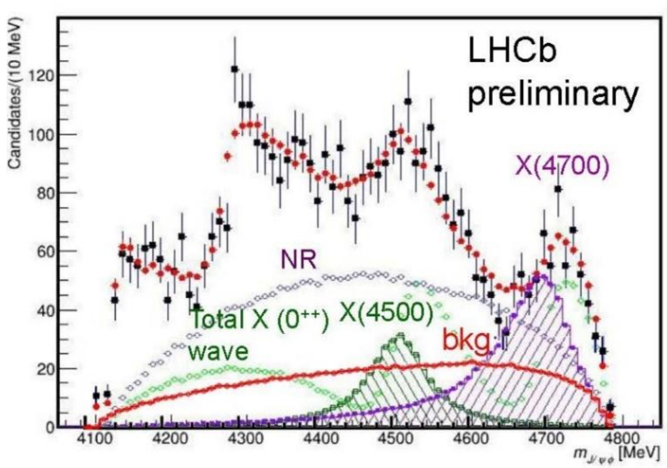
2016 what else?

X(1⁺⁺)



Contri-bution	sign. or Ref.	M_0 MeV	Γ_0 MeV	Fit results F.F. %
All $X(1^+)$				$16\pm3\ ^{+\ 6}_{-\ 2}$
$X(4140)$	8.4σ	$4146.5\pm4.5\ ^{+4.6}_{-2.8}$	$83\pm21\ ^{+21}_{-14}$	$13\pm3.2\ ^{+4.8}_{-2.0}$
ave.		4146.9 ± 2.3	17.8 ± 6.8	
$X(4274)$	6.0σ	$4273.3\pm8.3\ ^{+17.2}_{-\ 3.6}$	$56\pm11\ ^{+8}_{-11}$	$7.1\pm2.5\ ^{+3.5}_{-2.4}$
CDF		$4274.4\ ^{+8.4}_{-6.7}\pm1.9$	$32\ ^{+22}_{-15}\pm8$	
CMS		$4313.8\pm5.3\pm7.3$	$38\ ^{+30}_{-15}\pm16$	

X(0⁺⁺)



Contri-bution	sign.	M_0 MeV	Γ_0 MeV	Fit results F.F. %
All $X(0^+)$				$28\pm\ 5\ ^{+7}_{-7}$
$NR_{J/\psi\phi}$	6.4σ			$46\pm11\ ^{+11}_{-21}$
$X(4500)$	6.1σ	$4506\pm11\ ^{+12}_{-15}$	$92\pm21\ ^{+21}_{-20}$	$6.6\pm2.4\ ^{+3.5}_{-2.3}$
$X(4700)$	5.6σ	$4704\pm10\ ^{+14}_{-24}$	$120\pm31\ ^{+42}_{-33}$	$12\pm\ 5\ ^{+\ 9}_{-\ 5}$

Theoretical Ingredients

- ✓Two body model: Constituent Quark Model
- ✓Coupled channel model: RGM
- ✓Coupling : Pair Creation Model ($^3P_0$)

The constituent quark model

QCD lagrangian

- Asymptotic freedom
- Confinement
- (approximate) Chiral Symmetry

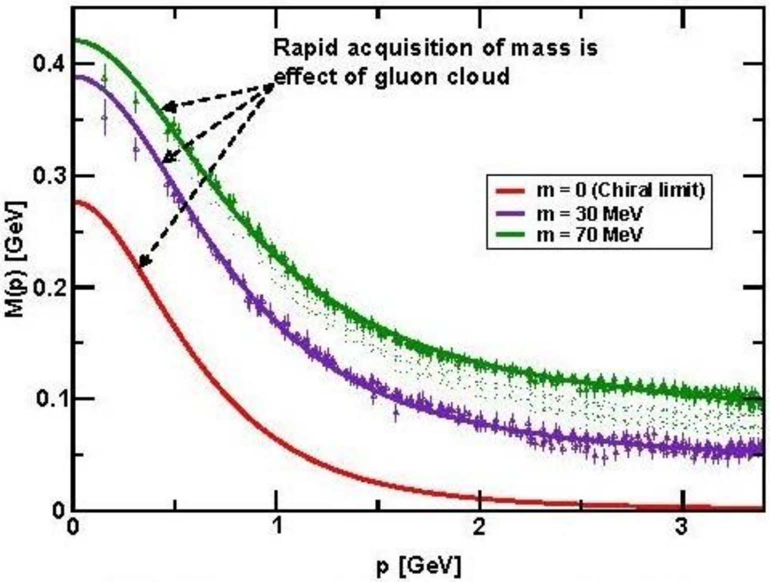
Chiral Symmetry is spontaneously broken at low momenta

$$M(q^2) = m_q F(q^2) = m_q \left[\frac{\Lambda^2}{\Lambda^2 + q^2} \right]^{1/2}$$

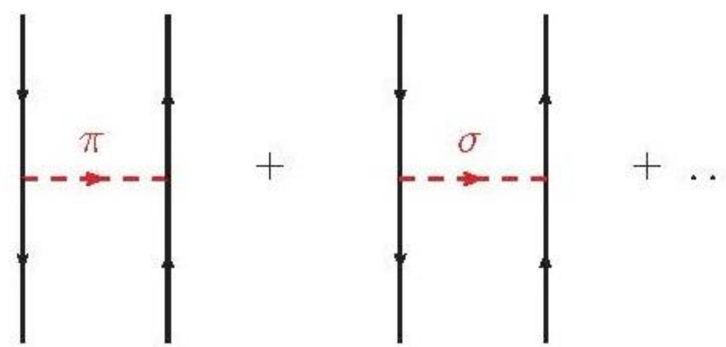
$$L_{eff} = \overline{\psi}(i\gamma_\mu \partial^\mu - M(q^2) U^{\gamma_5})\psi$$

Pseudo-Goldstone Bosons ($\vec{\pi}$, K_i and η_8)

$$U^{\gamma_5} = \exp(i\pi^a \lambda^a \gamma_5 / f_\pi) \sim 1 + \frac{i}{f_\pi}\gamma^5 \lambda^a \pi^a - \frac{1}{2f_\pi^2}\pi^a \pi^a + \dots$$



C.D. Roberts, arXiv:1109.6325v1 [nucl-th]



This interaction is not relevant for heavy quarks but is important for molecules

The constituent quark model

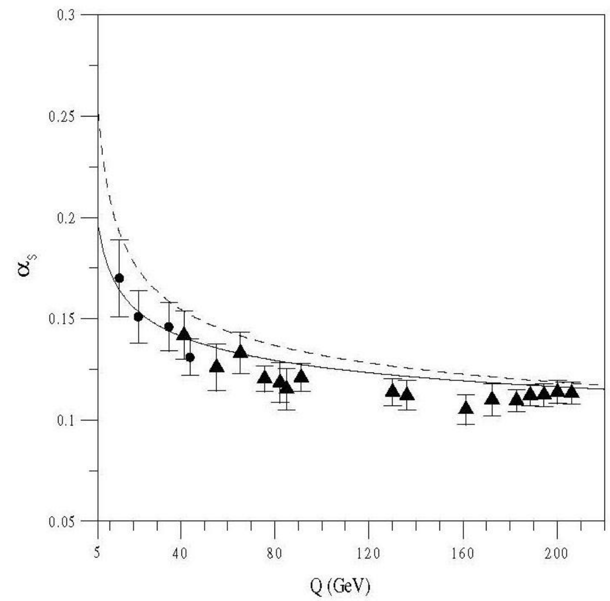
One Gluon Exchange

The OGE is a standard color Fermi-Breit interaction obtained from the vertex:

$$\mathcal{L}_{qqg} = i\sqrt{4\pi\alpha_s}\,\bar{\psi}\gamma_\mu G_c^\mu \lambda^c \psi$$

Effective scale dependent strong coupling constant:

$$\alpha_s(\mu) = \frac{\alpha_0}{\ln\left(\frac{\mu^2+\mu_0^2}{\Lambda_0^2}\right)}$$



Confinement

LINEAR SCREENED POTENTIAL

$$V_{CON}(r) = \left[-a_c(1-e^{-\mu_c r}) + \Delta\right](\vec{\lambda}_i \cdot \vec{\lambda}_j)$$

- *Flavor independent*
- $r \to 0 \quad \Rightarrow \quad V_{CON}(r) \to (-a_c\mu_c r + \Delta)(\vec{\lambda}_i \cdot \vec{\lambda}_j) \quad \Rightarrow$ *Linear.*
- $r \to \infty \quad \Rightarrow \quad V_{CON}(r) \to (-a_c + \Delta)(\vec{\lambda}_i \cdot \vec{\lambda}_j) \quad \Rightarrow$ *Threshold.*

- N-N interaction
  - F. Fernández, A. Valcarce, U. Straub, A. Faessler. J. Phys. G19, 2013 (1993)
  - A. Valcarce, A. Faessler, F. Fernández. Phys. Lett. B345, 367 (1995)
  - D.R. Entem, F. Fernández, A. Valcarce. Phys. Rev. C62 034002 (2000)
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- Baryon spectrum
  - H. Garcilazo, A. Valcarce, F. Fernández. Phys. Rev. C 64, 058201, (2001)
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  - J. Segovia, A. M. Yasser, D. R. Entem, F. Fernandez Phys. Rev D. 78 114033 (2008)

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  - A. Valcarce, H. Garcilazo, F. Fernandez, P.Gonzalez Rep. Prog. Phys. 68 965 (2005)
  - J. Segovia, D. R. Entem, F. Fernandez, Int. Jour. Mod. Phys. E 22 1330026 (2013)

Solving the two body problem

To found the quark-antiquark bound states we solve the Schrödinger equation using the Gaussian Expansion Method

$$R_\alpha(r) = \sum_{n=1}^{n_{max}} b_n^\alpha \phi_{nl}^G(r)$$

The coeficients b_n and the eigenenergy E are determined from the Rayleigh-Ritz variational principle

$$\sum_{n=1}^{n_{max}} \left[(T_{n'n}^\alpha - EN_{n'n}^\alpha) b_n^\alpha + \sum_{\alpha'} V_{n'n}^{\alpha\alpha'} b_n^{\alpha'} = 0 \right]$$

Results for the 1^{--} sector

(nL)	States	QM	Exp.
(1S)	J/ψ	3096	$3096{,}916 \pm 0{,}011$
(2S)	$\psi(2S)$	3703	$3686{,}09 \pm 0{,}04$
(1D)	$\psi(3770)$	3796	$3772 \pm 1{,}1$
(3S)	$\psi(4040)$	4097	4039 ± 1
(2D)	$\psi(4160)$	4153	4153 ± 3
(4S)	$Y(4360)$	4389	4361 ± 9
(3D)	$\psi(4415)$	4426	4421 ± 4
(5S)	$X(4630)$	4614	4634^{+9}_{-11}
(4D)	$Y(4660)$	4641	4664 ± 12

Masses in MeV of $J^{PC} = 1^{--}$ $c\bar{c}$ mesons (nL) refers to the dominant partial wave and QM denotes the results of the model.

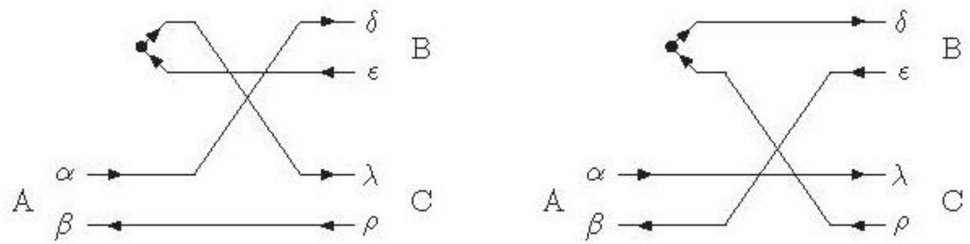
Coupling the states of two and four quarks ($^3P_0$ model)

The $^3P_0$ interaction Hamiltonian:

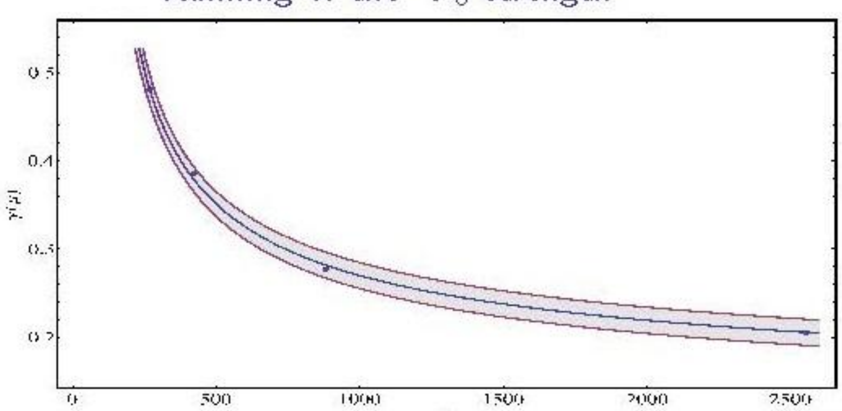
$$\mathcal{H}_I = \sqrt{3}\, g_s \int d^3x\, \bar{\psi}(\vec{x})\, \psi(\vec{x}), \text{ with } \gamma = g_s/2m$$

$$T = -\sqrt{3} \sum_{\mu,\nu} \int d^3p_\mu d^3p_\nu \delta^{(3)}(\vec{p}_\mu + \vec{p}_\nu) \frac{\sqrt{2^5\pi}\, g_s}{2m_\mu} \left[\mathcal{Y}_1 \left(\frac{\vec{p}_\mu - \vec{p}_\nu}{2} \right) \otimes \left(\frac{1}{2}\frac{1}{2} \right) 1 \right]_0 a^\dagger_\mu(\vec{p}_\mu) b^\dagger_\nu(\vec{p}_\nu)$$

Diagrams that contribute:



Running of the $^3P_0$ strength



$$\gamma(\mu) = \frac{\gamma_0}{\log\left(\mu/\mu_\gamma\right)}$$

- $\gamma_0 = 0.81 \pm 0.02$.
- $\mu_\gamma = 49.84 \pm 2.58\,\text{MeV}$.
- Solid line is the fit.
- Shaded area $\Rightarrow$ 90% C.L.

Solving the coupled channel problem

$$|\Psi\rangle = \sum_\alpha c_\alpha |\psi_\alpha\rangle + \sum_\beta \chi_\beta(P) |\phi_A \phi_B \beta\rangle$$

$$\begin{aligned} c_\alpha M_\alpha + \sum_\beta \int h_{\alpha\beta}(P) \chi_\beta(P) P^2 dP &= E c_\alpha \\ \sum_{\beta'} \int H^{M_1,M_2}_{\beta'\beta}(P',P) \chi_{\beta'}(P') P'^2 dP' + \sum_\alpha c_\alpha h_{\beta\alpha}(P) &= E \chi_\beta(P) \end{aligned}$$

$$\langle \phi_{M_1} \phi_{M_2} \beta | T | \psi_\alpha \rangle = P\, h_{\beta\alpha}(P)\, \delta^{(3)}(\vec{P}_{\rm cm})$$

$$\sum_{\beta'} \int \left(H^{M_1,M_2}_{\beta'\beta}(P',P) + V^{eff}_{\beta'\beta}(P',P) \right) \chi_{\beta'}(P') P'^2 dP' = E \chi_\beta(P)$$

$$V^{eff}_{\beta'\beta}(P',P) = \sum_\alpha \frac{h_{\beta'\alpha}(P') h_{\alpha\beta}(P)}{E - M_\alpha}$$

$$T^{\beta\beta'}(P,P',E) = V_T^{\beta\beta'}(P,P',E) + \sum_{\beta''}\int dP''P''^2 \; V_T^{\beta\beta''}(P,P'',E)\frac{1}{E-E_{\beta''}(P'')}T^{\beta''\beta'}(P'',P,E)$$

$V_T^{\beta\beta'}(p,p',E) = V^{\beta\beta'}(p,p') + V_{\beta'\beta}^{eff}(p,p')$, $V^{\beta\beta'}$ is the RGM potential and $V_{\beta'\beta}^{eff}(P',P)$ the coupling to intermediate $c\bar{c}$ states.

$$T^{\beta\beta'}(P,P',E) = T_V^{\beta\beta'}(P,P',E) + \sum_{\alpha,\alpha'}\phi^{\beta,\alpha'}(P',E)\Delta_{\alpha'\alpha}(E)^{-1}\phi^{\alpha,\beta'}(P',E)$$

$$\Delta_{\alpha'\alpha}(E) = \left((E-M_\alpha)\delta^{\alpha',\alpha} + \mathcal{G}^{\alpha',\alpha}(E)\right)$$

Resonances will appear as poles of the T matrix namely as zeros of the propagator of the mixed state.

$$|\Delta_{\alpha'\alpha}(E)| = \left|(\overline{E}-M_\alpha)\delta^{\alpha',\alpha} + \mathcal{G}^{\alpha',\alpha}(\overline{E})\right| = 0$$

$M\ (MeV)$	$c\bar{c}(1^3P_1)$	$c\bar{c}(2^3P_1)$	D^0D^{*0}	$D^{\pm}D^{*\mp}$	Assignment
3942	0 %	88 %	4 %	8 %	$\rightarrow X(3940)$
3871	0 %	7 %	83 %	10 %	$\rightarrow X(3872)$
3484	97 %	0 %	1,5 %	1,5 %	$\rightarrow \chi_{c1}(3510)$

γ	E_{bind}	$c\bar{c}(2^3P_1)$	D^0D^{*0}	$D^{\pm}D^{*\mp}$	$J/\psi\rho$	$J/\psi\omega$
0,231	−0,60	12,40	79,24	7,46	0,49	0,40
0,226	−0,25	8,00	86,61	4,58	0,53	0,29

$$R_1 = \frac{\Gamma(X(3872) \to \pi^+\pi^-\pi^0 J/\psi)}{\Gamma(X(3872) \to \pi^+\pi^- J/\psi)} = 0.8 \pm 0.3$$

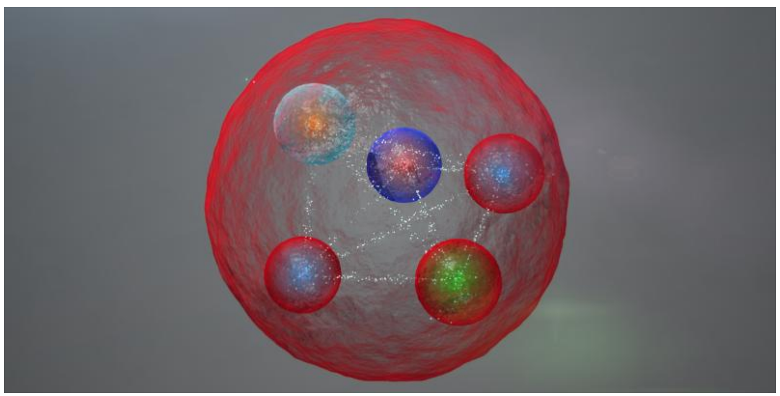
E_{bind} (MeV)	$\Gamma_{\pi^+\pi^- J/\psi}$	$\Gamma_{\pi^+\pi^-\pi^0 J/\psi}$	R_1
−0,60	27,61	14,40	0,52
−0,25	24,18	10,64	0,44

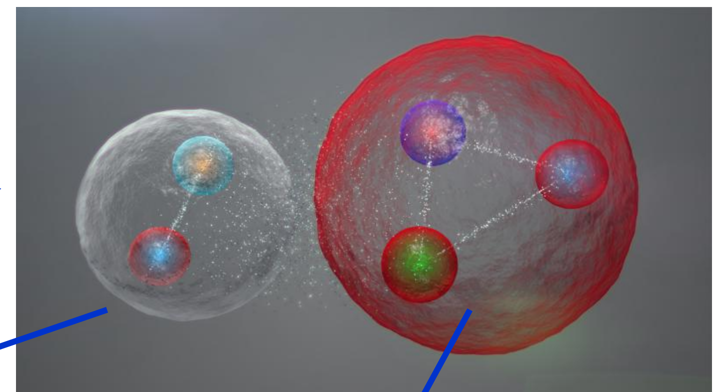
J. Phys. G 40 085107 (2013)

Pentaquark $P_c(4380)$, $P_c(4450)$

$D\Sigma^*_c$ threshold

$D^*\Sigma_c$ threshold

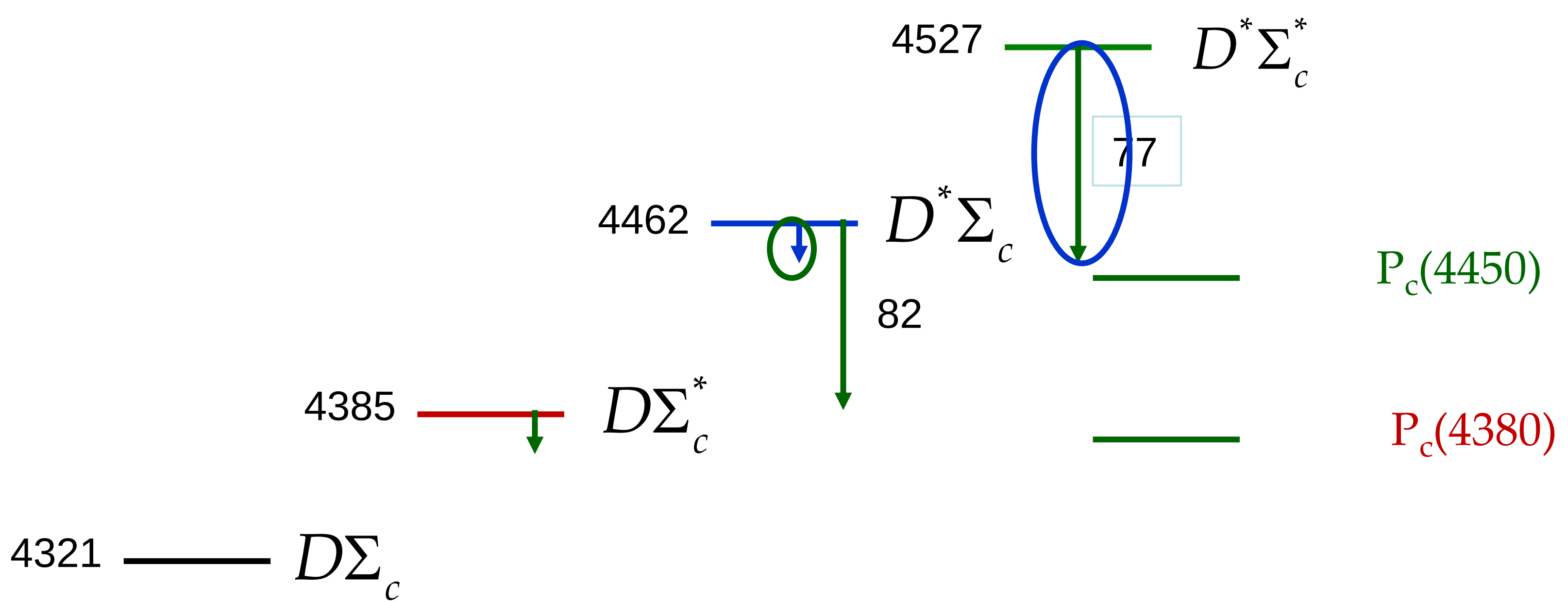




$$R_\alpha(r) = \sum_{n=1}^{n_{max}} b_n^\alpha \phi_{nl}^G(r)$$

$$\psi(\vec{p}_i) = \prod_{i=1}^{3} \left[\frac{b^2}{\pi}\right]^{\frac{3}{4}} e^{-\frac{b^2 p_i^2}{2}},$$

The compositeness problem



The parity problem

negative parity ⟶ S-waves molecules

positive parity ⟶ P-waves molecules (centrifugal barrier)

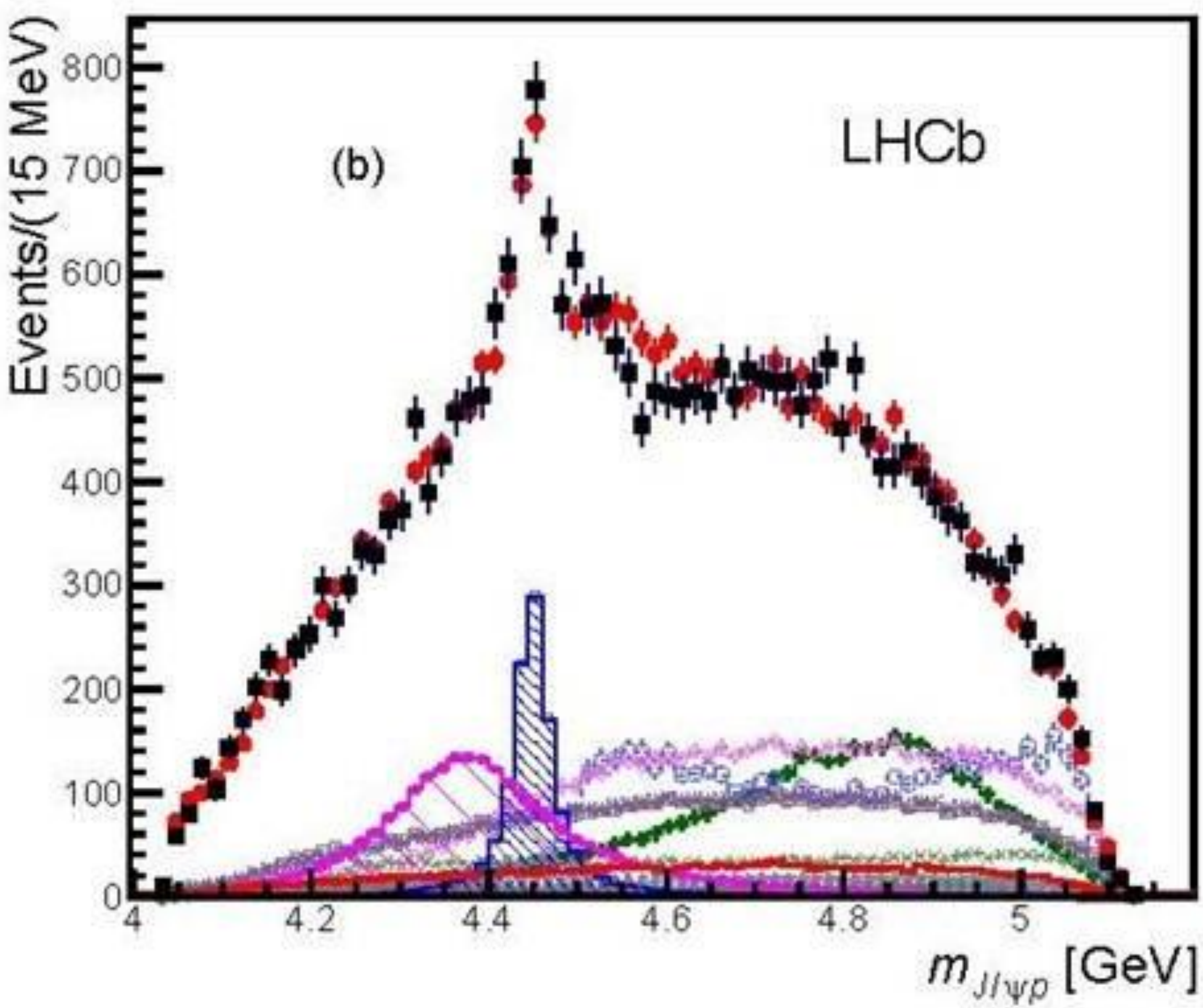
Residual interacction !!!!! (model)

Pentaquark

$P_c(4380)$, $P_c(4450)$

Molecule	J^P	I	$Mass(MeV/c^2)$	$B_E(MeV$
$\bar{D}\Sigma_c$	$\frac{1}{2}^-$	$\frac{1}{2}$	4320.782	0.765
$\bar{D}\Sigma_c^*$	$\frac{3}{2}^-$	$\frac{1}{2}$	4384.993	0.993
$\bar{D}^*\Sigma_c$	$\frac{1}{2}^-$	$\frac{1}{2}$	4458.894	3.796
$\bar{D}^*\Sigma_c$	$\frac{3}{2}^-$	$\frac{1}{2}$	4461.284	1.406
$\bar{D}^*\Sigma_c$	$\frac{3}{2}^+$	$\frac{1}{2}$	4462.677	0.013
$\bar{D}^*\Sigma_c^*$	$\frac{1}{2}^-$	$\frac{1}{2}$	4519.792	7.338
$\bar{D}^*\Sigma_c^*$	$\frac{3}{2}^-$	$\frac{1}{2}$	4523.275	3.855
$\bar{D}^*\Sigma_c^*$	$\frac{5}{2}^-$	$\frac{1}{2}$	4524.552	2.578
$\bar{D}^*\Sigma_c^*$	$\frac{5}{2}^+$	$\frac{1}{2}$	4526.165	0.965

Molecule	J^P	I	Width $J/\psi p$	Width $\bar{D}^*\Lambda_c$
$\bar{D}\Sigma_c$	$\frac{1}{2}^-$	$\frac{1}{2}$	2.394	1.109
$\bar{D}\Sigma_c^*$	$\frac{3}{2}^-$	$\frac{1}{2}$	10.046	14.688
$\bar{D}^*\Sigma_c$	$\frac{1}{2}^-$	$\frac{1}{2}$	5.294	63.576
$\bar{D}^*\Sigma_c$	$\frac{3}{2}^-$	$\frac{1}{2}$	0.794	21.198
$\bar{D}^*\Sigma_c$	$\frac{3}{2}^+$	$\frac{1}{2}$	0.214	6.292
$\bar{D}^*\Sigma_c^*$	$\frac{1}{2}^-$	$\frac{1}{2}$	0.893	9.954
$\bar{D}^*\Sigma_c^*$	$\frac{3}{2}^-$	$\frac{1}{2}$	22.901	4.050
$\bar{D}^*\Sigma_c^*$	$\frac{5}{2}^-$	$\frac{1}{2}$	0.053	3.048
$\bar{D}^*\Sigma_c^*$	$\frac{5}{2}^+$	$\frac{1}{2}$	0.051	0.845


Events/(15 MeV)
800
700
600
500
400
300
200
100
0
(b)
LHCb
4
4.2
4.4
4.6
4.8
5
$m_{J/\psi p}$ [GeV]

New LHCb resonances

Contribution	sign. or Ref.	M_0 MeV	Γ_0 MeV
All $X(1^+)$			
$X(4140)$	8.4σ	$4146.5\pm4.5\,^{+4.6}_{-2.8}$	$83\pm21\,^{+21}_{-14}$
ave.		4146.9 ± 2.3	17.8 ± 6.8
$X(4274)$	6.0σ	$4273.3\pm8.3\,^{+17.2}_{-3.6}$	$56\pm11\,^{+8}_{-11}$
CDF		$4274.4\,^{+8.4}_{-6.7}\pm1.9$	$32\,^{+22}_{-15}\pm8$
CMS		$4313.8\pm5.3\pm7.3$	$38\,^{+30}_{-15}\pm16$

Contribution	sign.	M_0 MeV	Γ_0 MeV
All $X(0^+)$			
$NR_{J/\psi\phi}$	6.4σ		
$X(4500)$	6.1σ	$4506\pm11\,^{+12}_{-15}$	$92\pm21\,^{+21}_{-20}$
$X(4700)$	5.6σ	$4704\pm10\,^{+14}_{-24}$	$120\pm31\,^{+42}_{-33}$

Quark model predictions

State	J^{PC}	nL	Mass (MeV/c^2)	Width (MeV)	Exp. (MeV/c^2)
χ_{c0}	0^{++}	$3P$	4261.7		
		$4P$	4497.7	115.40	$4506\pm11^{+12}_{-15}$
		$5P$	4697.6	122.02	$4704\pm10^{+14}_{-24}$
		$6P$	4855.6		
χ_{c1}	1^{++}	$3P$	4271.5	29.80	4273.3 ± 8.3
		$4P$	4520.8		

What about the X(4140)?

Looking for the X(4140)

Coupling channel calculation for the $J^{PC}=1^{++}$ channel

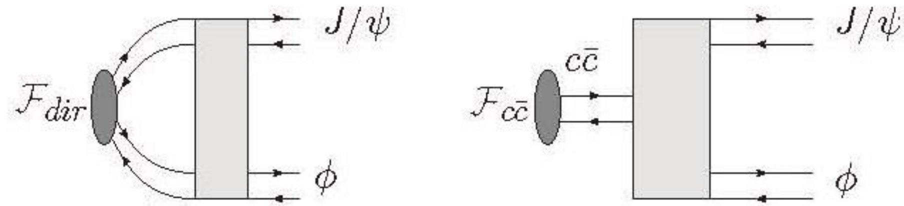
We include: DsDs, D*sD*s, DsD*s, J/ψϕ components

Mass	Width	$\mathcal{P}_{c\bar{c}}$	$\mathcal{P}_{D_sD_s^*}$	$\mathcal{P}_{D_s^*D_s^*}$	$\mathcal{P}_{J/\psi\phi}$
4242.4	25.9	48.7	43.5	5.0	2.7

Any signal of X(4140)

As we do not find any signal for the X(4140), neither bound nor virtual, we analysed the line shapes of the J/ψφ channel

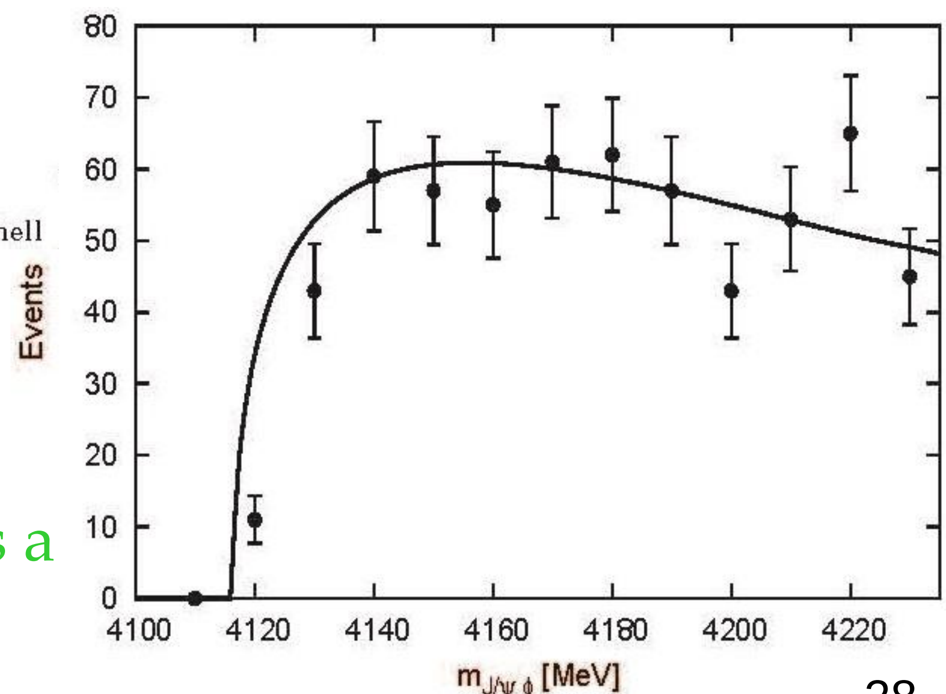
$$\frac{dB(J/\psi\phi)}{dE} = \mathcal{B}\, k\, \left|\mathcal{M}_{\rm point} + \mathcal{M}_{c\bar c}\right|^2 \Theta(E)$$



$$\mathcal{M}^{\beta}_{\rm point}(E) = \mathcal{F}_{\rm point} \times$$
$$\times \left(1 - \sum_{\beta'} \int dP\, T^{\beta\beta'}(E;k,P) \frac{2\mu P^2}{P^2 - k^2}\right)_{\rm on-shell}$$

$$\mathcal{M}^{\beta}_{c\bar c} = -\mathcal{F}_{c\bar c} \sum_{\alpha\alpha'} \Phi_{\alpha'\beta}(E;k)\, \Delta_{\alpha'\alpha}(E)^{-1}$$

the X(4140) signal appears as a threshold cusp.



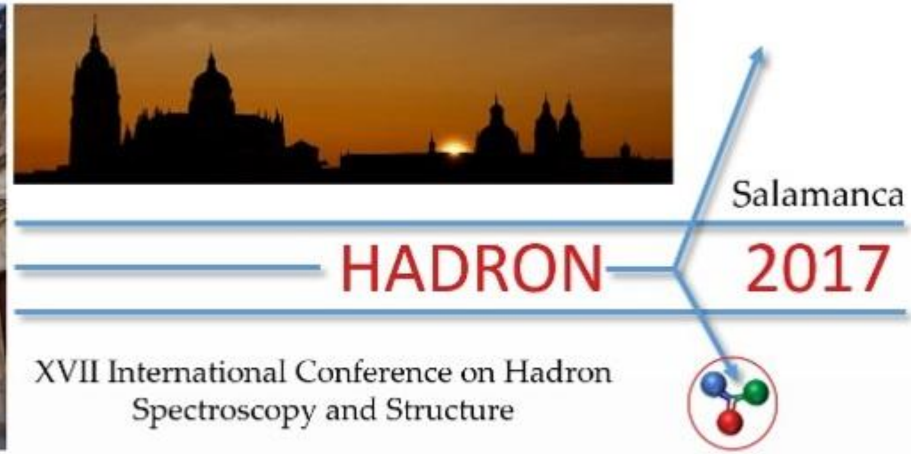
Conclusions

1. The heavy quark sector shows a rich phenomenology including two, (three), four and five body problems depending of the dynamics.

2. A constituent quark model plus a coupled channels calculation can account for this phenomenology from the J/ψ to the recently pentaquarks signals (and beyond)

Thanks for your attention

VIII International Workshop on Charm Physics



XVII INTERNATIONAL CONFERENCE ON HADRON SPECTROSCOPY AND STRUCTURE

September 25th-29th 2017

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Backup slides

OPEN CHARM MESONS

State	Mass	$\mathcal{P}[q\bar{q}\,(^3P_0)]$	$\mathcal{P}[DK(S-wave)]$
$D^*_{s0}(2317)$	2323.7	66.3%	33.7%

State	Mass	Width	$\mathcal{P}[q\bar{q}\,(^1P_1)]$	$\mathcal{P}[q\bar{q}\,(^3P_1)]$	$\mathcal{P}[D^*K(S)]$	$\mathcal{P}[D^*K(D)]$
$D_{s1}(2460)$	2484.0	0.00	12.9%	32.8%	54.3%	-
$D_{s1}(2536)$	2562.1	0.22	34.4%	15.8%	49.8%	-
$D_{s1}(2460)$	2484.0	0.00	12.1%	33.6%	54.1%	0.2%
$D_{s1}(2536)$	2535.2	0.56	31.9%	14.5%	16.8%	36.8%

$$\Gamma(D_{s1}(2536)^+) = \Gamma(D^{*0}K^+) + \Gamma(D^{*+}K^0)$$

$$R_1 = \frac{\Gamma(D_{s1}(2536)^+ \to D^{*0}K^+)}{\Gamma(D_{s1}(2536)^+ \to D^{*+}K^0)}$$

$$R_2 = \frac{\Gamma_S(D_{s1}(2536)^+ \to D^{*+}K^0)}{\Gamma(D_{s1}(2536)^+ \to D^{*+}K^0)}$$

	This work	Experiment
Γ (MeV)	0.56	$0.92 \pm 0.03 \pm 0.04$
R_1	1.15	1.18 ± 0.16
R_2	0.52	$0.72 \pm 0.05 \pm 0.01$