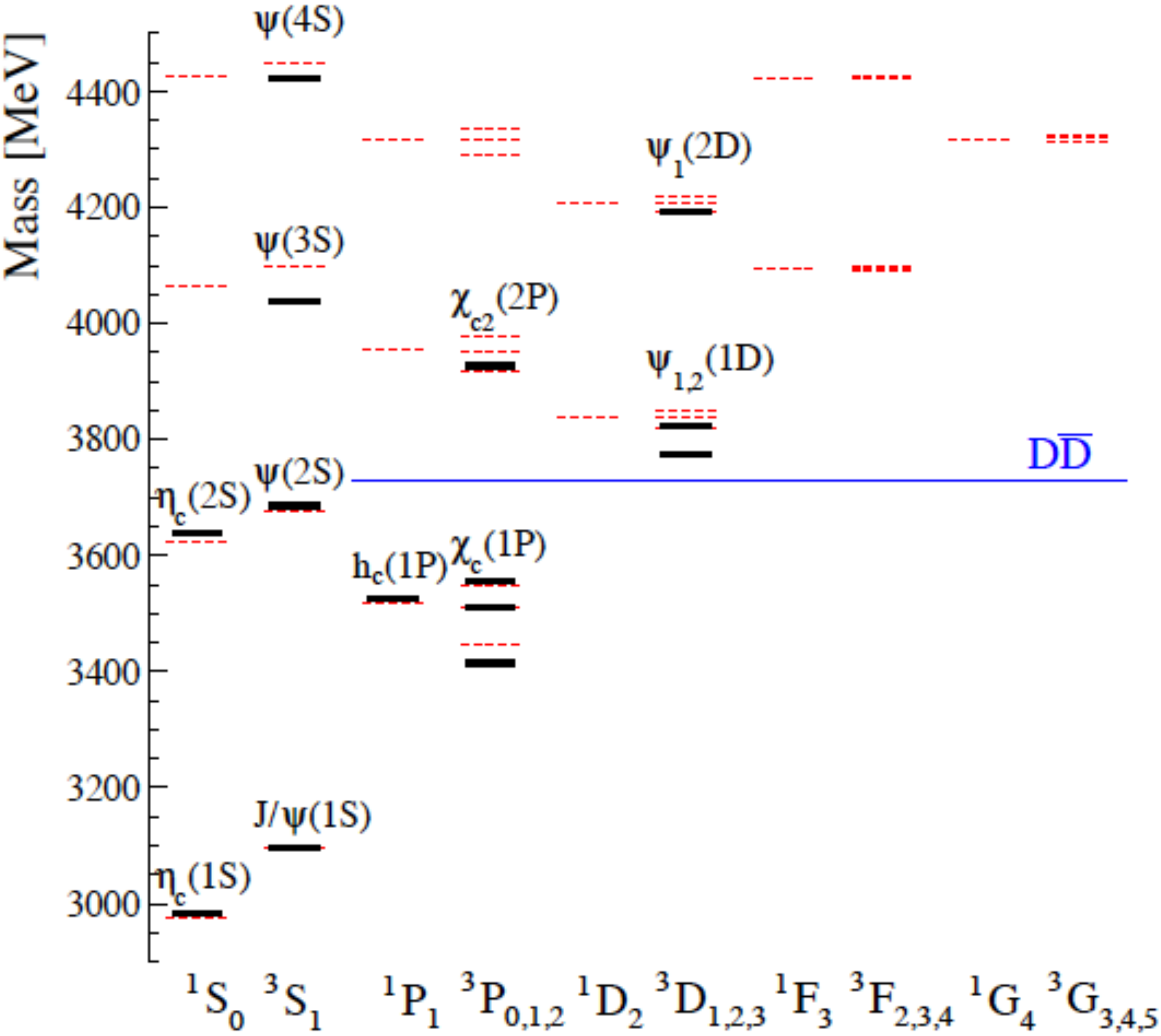
Ciężkie kwarki,
stany wielokwarkowe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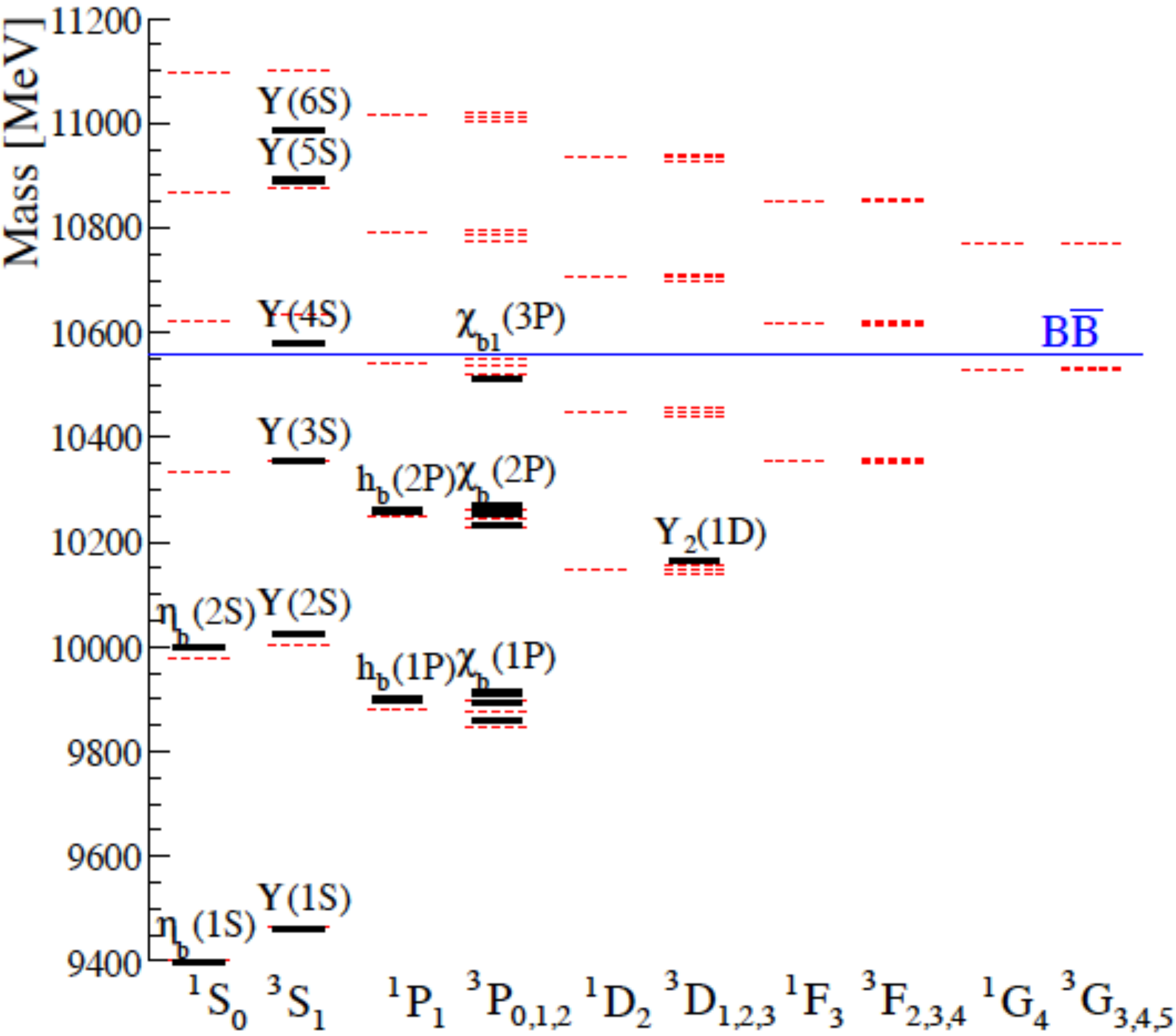
4200
4000
3800
3600
3400
3200
3000
ψ(4S)
ψ(3S)
ψ(2S)
J/ψ(1S)
η_c(2S)
η_c(1S)
h_c(1P)
χ_c(1P)
χ_{c2}(2P)
ψ_1(2D)
$\psi_{1,2}$(1D)
$D\overline{D}$
$^1S_0$
$^3S_1$
$^1P_1$
$^3P_{0,1,2}$
$^1D_2$
$^3D_{1,2,3}$
$^1F_3$
$^3F_{2,3,4}$
$^1G_4$
$^3G_{3,4,5}$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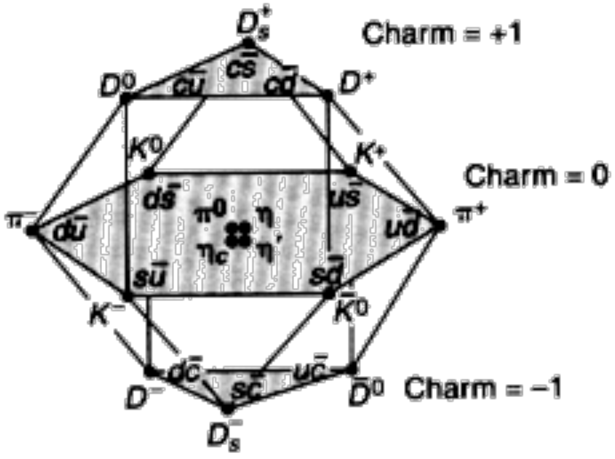
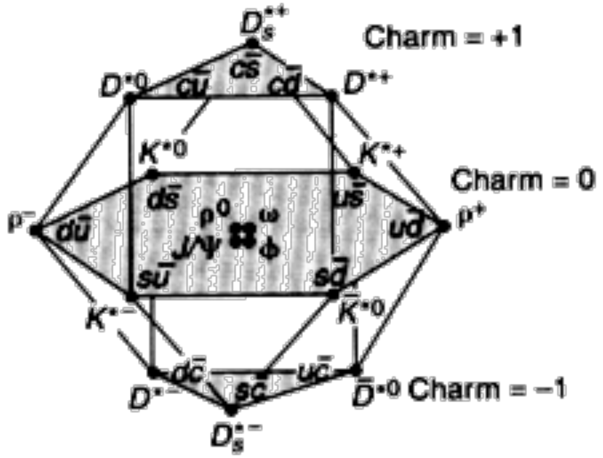
10000
9800
9600
9400
Υ(6S)
Υ(5S)
Υ(4S)
Υ(3S)
Υ(2S)
Υ(1S)
η_b(2S)
η_b(1S)
χ_{b1}(3P)
h_b(2P)
χ_b(2P)
h_b(1P)
χ_b(1P)
Υ_2(1D)
$B\bar{B}$
$^1S_0$
$^3S_1$
$^1P_1$
$^3P_{0,1,2}$
$^1D_2$
$^3D_{1,2,3}$
$^1F_3$
$^3F_{2,3,4}$
$^1G_4$
$^3G_{3,4,5}$



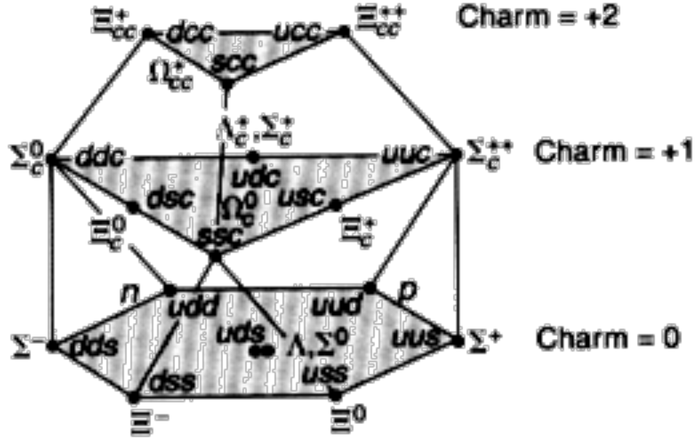
0^- Mesons

(a)



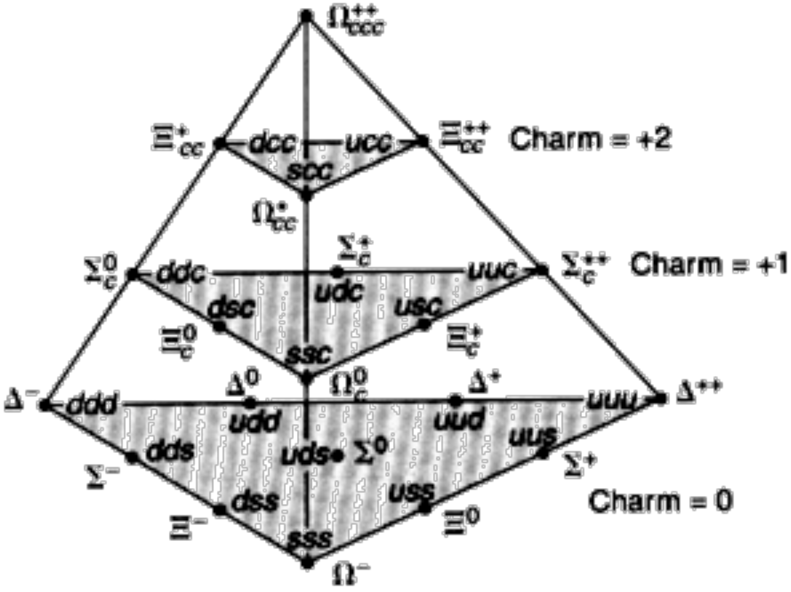
1^- Mesons

(b)



$\frac{1}{2}^+$ Baryons

(c)



$\frac{3}{2}^+$ Baryons

(d)

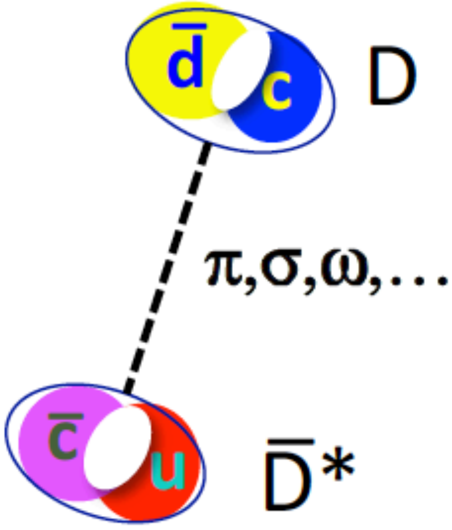
particle	quark content	J^P	$I : I_3$	$\mathcal{S}$	$\mathcal{C}$	$\mathcal{B}$	M (MeV)	$c\tau$ (μm)
D^+	$c\bar{d}$	0^-	$1/2 : \ \ 1/2$	0	1	0	1869.6	312
D^0	$c\bar{u}$	0^-	$1/2 : -1/2$	0	1	0	1864.8	123
D^{*+}	$c\bar{d}$	1^-	$1/2 : \ \ 1/2$	0	1	0	2010.3	~ 0
D^{*0}	$c\bar{u}$	1^-	$1/2 : -1/2$	0	1	0	2007.0	~ 0
D_s^+	$c\bar{s}$	0^-	$0 : 0$	1	1	0	1968.3	150
Λ_c^+	cud	$(1/2)^+$	$0 : 0$	0	1	0	2286.5	60
Σ_c^{++}	cuu	$(1/2)^+$	$1 : \ \ 1$	0	1	0	2454.0	~ 0
Σ_c^+	cud	$(1/2)^+$	$1 : \ \ 0$	0	1	0	2452.9	~ 0
Σ_c^0	cdd	$(1/2)^+$	$1 : -1$	0	1	0	2453.8	~ 0
$\bar{B}^0$	$b\bar{d}$	0^-	$1/2 : \ \ 1/2$	0	0	-1	5279.6	455
B^-	$b\bar{u}$	0^-	$1/2 : -1/2$	0	0	-1	5279.3	491
$\bar{B}^{*0}$	$b\bar{d}$	1^-	$1/2 : \ \ 1/2$	0	0	-1	5325.2	~ 0
B^{*-}	$b\bar{u}$	1^-	$1/2 : -1/2$	0	0	-1	5325.2	~ 0
$\bar{B}_s^0$	$b\bar{s}$	0^-	$0 : 0$	1	0	-1	5366.8	453
Λ_b	bud	$(1/2)^+$	$0 : 0$	0	0	-1	5619.5	435

Pentaquark

H-dibaryon

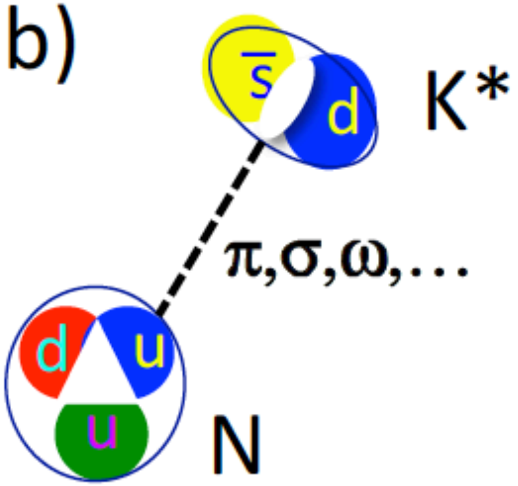
Tetraquark

a)



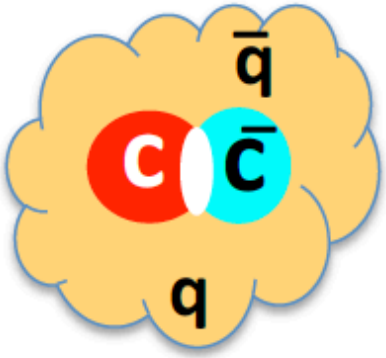
meson-antimeson molecule

b)



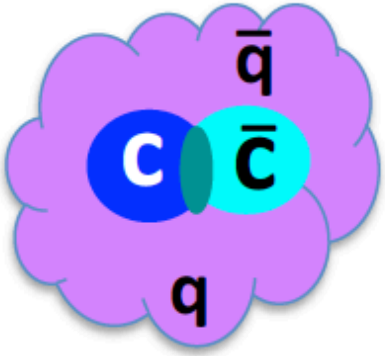
meson-baryon molecule

c)



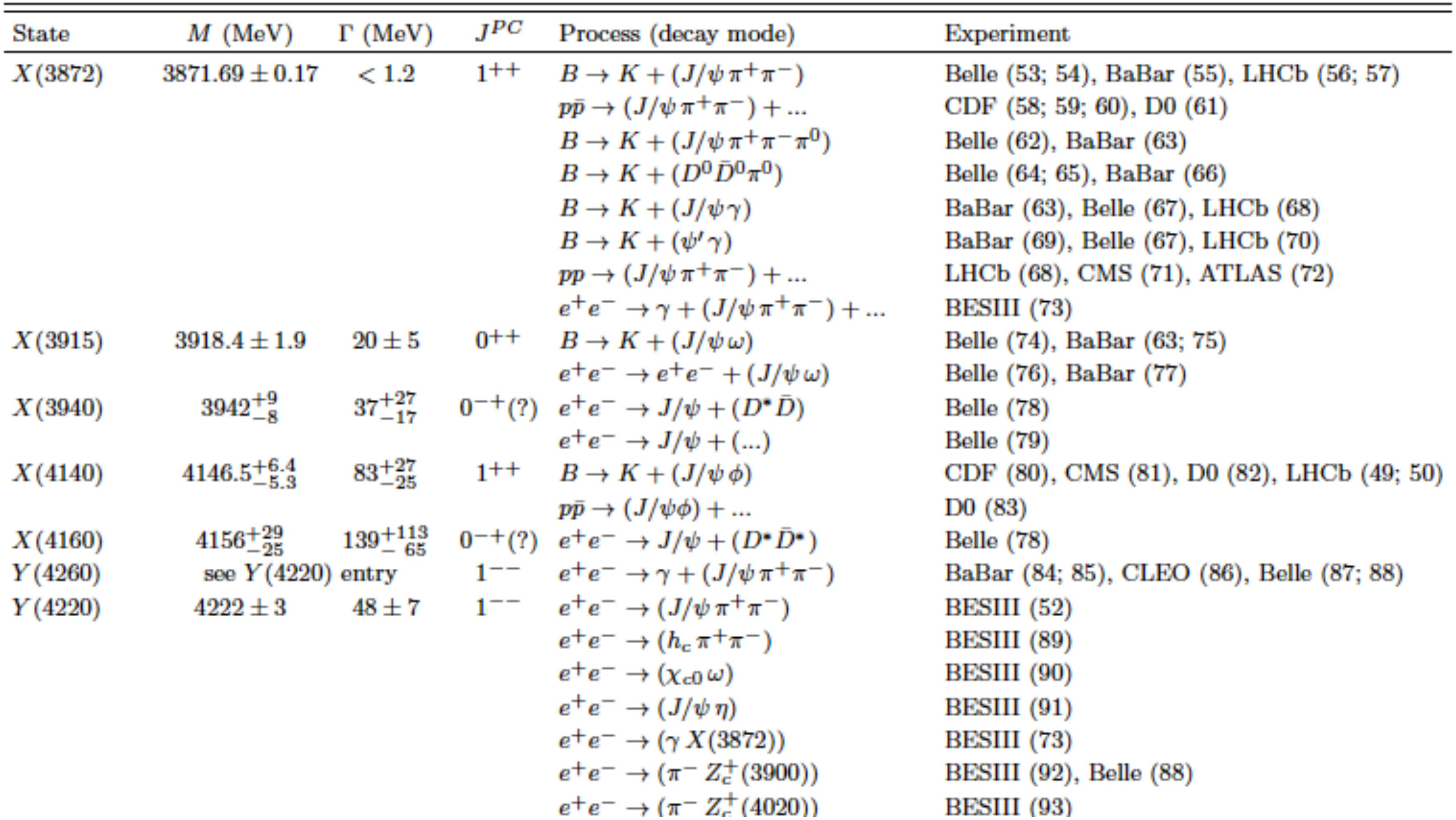
hadrocharmonium

d)



adjoint charmonium

Nonstandard hadrons with hidden charm or beauty



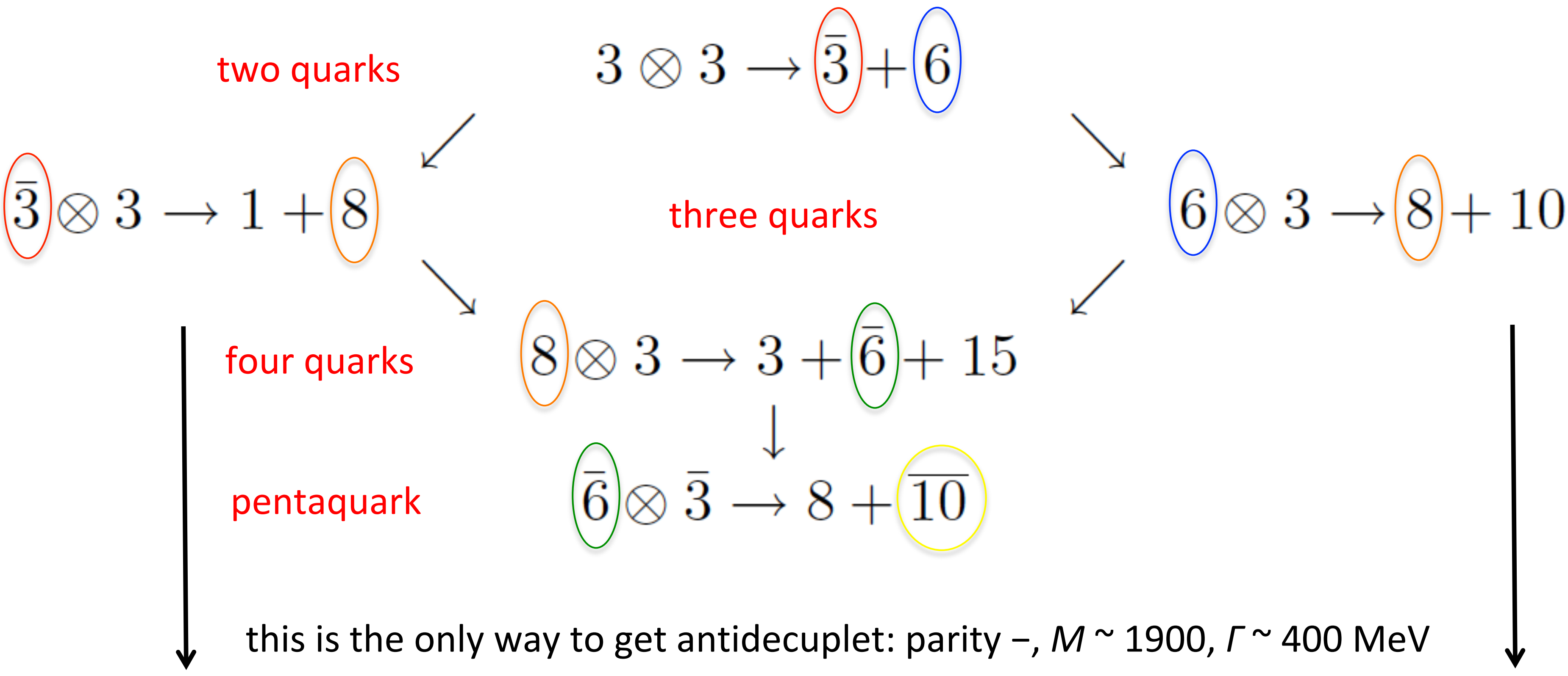
State	M (MeV)	Γ (MeV)	J^{PC}	Process (decay mode)	Experiment
$X(3872)$	3871.69 ± 0.17	< 1.2	1^{++}	$B \to K + (J/\psi\, \pi^+\pi^-)$	Belle (53; 54), BaBar (55), LHCb (56; 57)
				$p\bar{p} \to (J/\psi\, \pi^+\pi^-) + ...$	CDF (58; 59; 60), D0 (61)
				$B \to K + (J/\psi\, \pi^+\pi^-\pi^0)$	Belle (62), BaBar (63)
				$B \to K + (D^0 \bar{D}^0 \pi^0)$	Belle (64; 65), BaBar (66)
				$B \to K + (J/\psi \gamma)$	BaBar (63), Belle (67), LHCb (68)
				$B \to K + (\psi' \gamma)$	BaBar (69), Belle (67), LHCb (70)
				$pp \to (J/\psi\, \pi^+\pi^-) + ...$	LHCb (68), CMS (71), ATLAS (72)
				$e^+e^- \to \gamma + (J/\psi\, \pi^+\pi^-) + ...$	BESIII (73)
$X(3915)$	3918.4 ± 1.9	20 ± 5	0^{++}	$B \to K + (J/\psi\, \omega)$	Belle (74), BaBar (63; 75)
				$e^+e^- \to e^+e^- + (J/\psi\, \omega)$	Belle (76), BaBar (77)
$X(3940)$	3942^{+9}_{-8}	37^{+27}_{-17}	$0^{-+}(?)$	$e^+e^- \to J/\psi + (D^* \bar{D})$	Belle (78)
				$e^+e^- \to J/\psi + (...)$	Belle (79)
$X(4140)$	$4146.5^{+6.4}_{-5.3}$	83^{+27}_{-25}	1^{++}	$B \to K + (J/\psi\, \phi)$	CDF (80), CMS (81), D0 (82), LHCb (49; 50)
				$p\bar{p} \to (J/\psi \phi) + ...$	D0 (83)
$X(4160)$	4156^{+29}_{-25}	$139^{+113}_{-\ 65}$	$0^{-+}(?)$	$e^+e^- \to J/\psi + (D^* \bar{D}^*)$	Belle (78)
$Y(4260)$	see $Y(4220)$ entry		1^{--}	$e^+e^- \to \gamma + (J/\psi\, \pi^+\pi^-)$	BaBar (84; 85), CLEO (86), Belle (87; 88)
$Y(4220)$	4222 ± 3	48 ± 7	1^{--}	$e^+e^- \to (J/\psi\, \pi^+\pi^-)$	BESIII (52)
				$e^+e^- \to (h_c\, \pi^+\pi^-)$	BESIII (89)
				$e^+e^- \to (\chi_{c0}\, \omega)$	BESIII (90)
				$e^+e^- \to (J/\psi\, \eta)$	BESIII (91)
				$e^+e^- \to (\gamma\, X(3872))$	BESIII (73)
				$e^+e^- \to (\pi^-\, Z_c^+(3900))$	BESIII (92), Belle (88)
				$e^+e^- \to (\pi^-\, Z_c^+(4020))$	BESIII (93)

$X(4274)$	$4273^{+19}_{-\ 9}$	56^{+14}_{-16}	1^{++}	$B \to K + (J/\psi\,\phi)$	CDF (94), CMS (81), LHCb (49; 50)
$X(4350)$	$4350.6^{+4.6}_{-5.1}$	$13.3^{+18.4}_{-10.0}$	$(0/2)^{++}$	$e^+e^- \to e^+e^- + (J/\psi\,\phi)$	Belle (95)
$Y(4360)$	4341 ± 8	102 ± 9	1^{--}	$e^+e^- \to \gamma + (\psi'\,\pi^+\pi^-)$	BaBar (96; 97), Belle (98; 99)
				$e^+e^- \to (J/\psi\,\pi^+\pi^-)$	BESIII (52)
$Y(4390)$	4392 ± 6	140 ± 16	1^{--}	$e^+e^- \to (h_c\,\pi^+\pi^-)$	BESIII (89)
$X(4500)$	4506^{+16}_{-19}	92^{+30}_{-21}	0^{++}	$B \to K + (J/\psi\,\phi)$	LHCb (49; 50)
$X(4700)$	4704^{+17}_{-26}	120^{+52}_{-45}	0^{++}	$B \to K + (J/\psi\,\phi)$	LHCb (49; 50)
$Y(4660)$	4643 ± 9	72 ± 11	1^{--}	$e^+e^- \to \gamma + (\psi'\,\pi^+\pi^-)$	Belle (98; 99), BaBar (96; 97)
				$e^+e^- \to \gamma + (\Lambda_c^+\Lambda_c^-)$	Belle (100)
$Z_c^{+,0}(3900)$	3886.6 ± 2.4	28.1 ± 2.6	1^{+-}	$e^+e^- \to \pi^{-,0} + (J/\psi\,\pi^{+,0})$	BESIII (92; 101), Belle (88)
				$e^+e^- \to \pi^{-,0} + (D\bar{D}^*)^{+,0}$	BESIII (102; 103)
$Z_c^{+,0}(4020)$	4024.1 ± 1.9	13 ± 5	$1^{+-}(?)$	$e^+e- \to \pi^{-,0} + (h_c\,\pi^{+,0})$	BESIII (93; 104)
				$e^+e^- \to \pi^{-,0} + (D^*\bar{D}^*)^{+,0}$	BESIII (105; 106)
$Z^+(4050)$	4051^{+24}_{-43}	82^{+51}_{-55}	$?^{?+}$	$B \to K + (\chi_{c1}\,\pi^+)$	Belle (107), BaBar (108)
$Z^+(4200)$	4196^{+35}_{-32}	$370^{+\ 99}_{-149}$	1^+	$B \to K + (J/\psi\,\pi^+)$	Belle (51)
				$B \to K + (\psi'\pi^+)$	LHCb (46)
$Z^+(4250)$	$4248^{+185}_{-\ 45}$	$177^{+321}_{-\ 72}$	$?^{?+}$	$B \to K + (\chi_{c1}\,\pi^+)$	Belle (107), BaBar (108)
$Z^+(4430)$	4477 ± 20	181 ± 31	1^+	$B \to K + (\psi'\,\pi^+)$	Belle (45; 109; 110), LHCb (46; 111)
				$B \to K + (J\psi\,\pi^+)$	Belle (51)
$P_c^+(4380)$	4380 ± 30	205 ± 88	$(\frac{3}{2}/\frac{5}{2})^\mp$	$\Lambda_b^+ \to K + (J/\psi\,p)$	LHCb (47)
$P_c^+(4450)$	4450 ± 3	39 ± 20	$(\frac{5}{2}/\frac{3}{2})^\pm$	$\Lambda_b^+ \to K + (J/\psi\,p)$	LHCb (47)
$Y_b(10860)$	$10891.1^{+3.4}_{-3.8}$	$53.7^{+7.2}_{-7.8}$	1^{--}	$e^+e^- \to (\Upsilon(nS)\,\pi^+\pi^-)$	Belle (112; 113)
$Z_b^{+,0}(10610)$	10607.2 ± 2.0	18.4 ± 2.4	1^{+-}	$Y_b(10860) \to \pi^{-,0} + (\Upsilon(nS)\,\pi^{+,0})$	Belle (114; 115; 116)
				$Y_b(10860) \to \pi^- + (h_b(nP)\,\pi^+)$	Belle (114)
				$Y_b(10860) \to \pi^- + (B\bar{B}^*)^+$	Belle (117)
$Z_b^+(10650)$	10652.2 ± 1.5	11.5 ± 2.2	1^{+-}	$Y_b(10860) \to \pi^- + (\Upsilon(nS)\,\pi^+)$	Belle (114; 115)
				$Y_b(10860) \to \pi^- + (h_b(nP)\,\pi^+)$	Belle (114)
				$Y_b(10860) \to \pi^- + (B^*\bar{B}^*)^+$	Belle (117)

Pentaquarks

Pentaquarks in the Quark Model

M. Gell-Mann Phys. Rev. 125 (1962)



two quarks

$$3 \otimes 3 \rightarrow \bar{3} + 6$$

$$\bar{3} \otimes 3 \rightarrow 1 + 8$$

three quarks

$$6 \otimes 3 \rightarrow 8 + 10$$

four quarks

$$8 \otimes 3 \rightarrow 3 + \bar{6} + 15$$

$$\downarrow$$

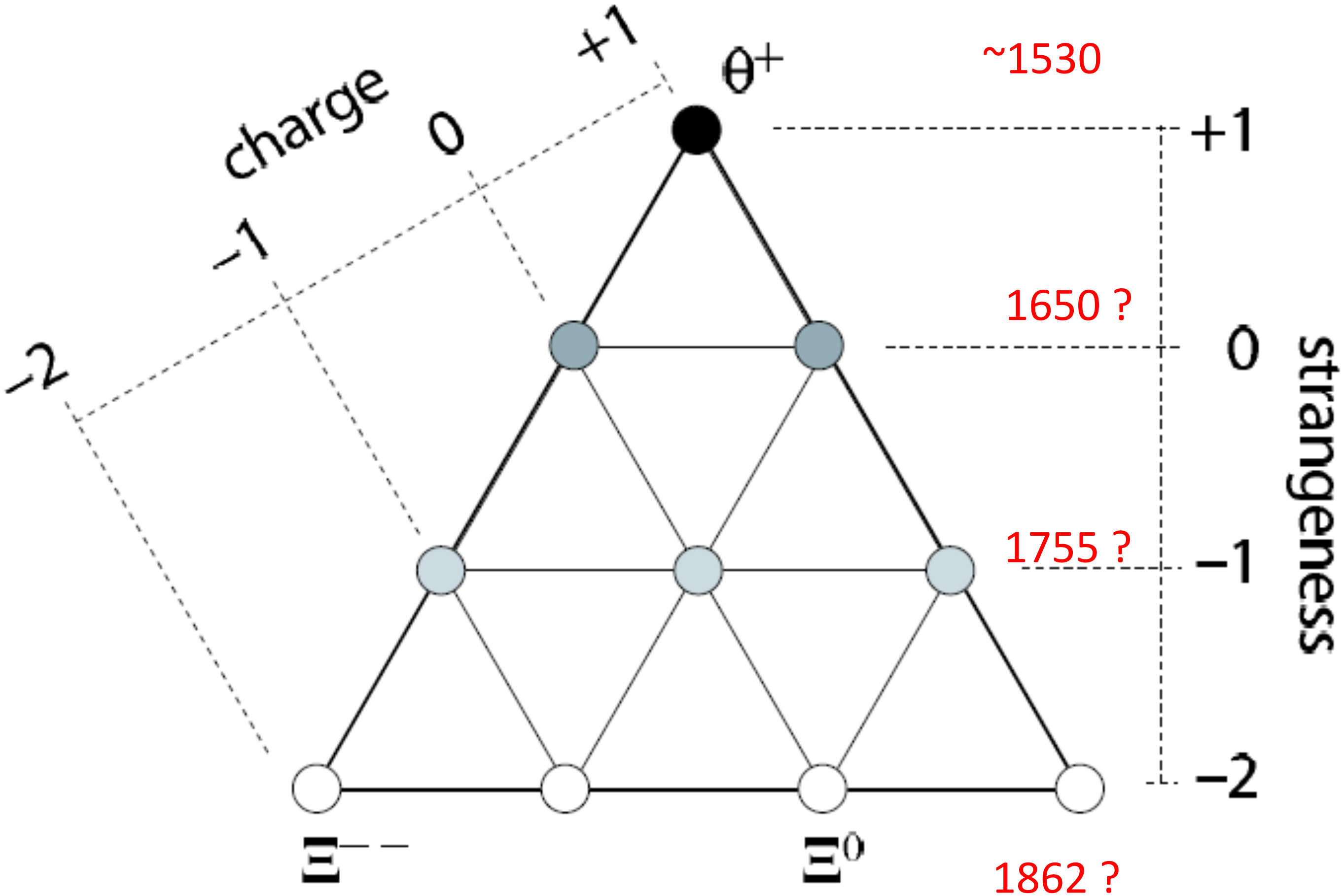
pentaquark

$$\bar{6} \otimes \bar{3} \rightarrow 8 + \overline{10}$$

this is the only way to get antidecuplet: parity –, *M* ~ 1900, *Γ* ~ 400 MeV

$1 + 8$ some of these reps. may be not allowed by other symms. $8 + 10 + 27 + 35$

Θ^+: uudd$\bar{s}$



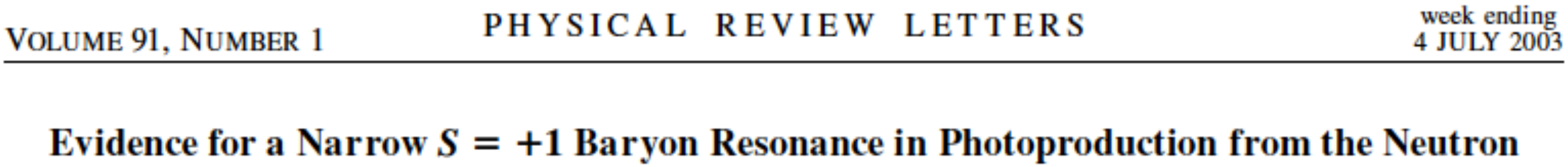
~1530

1650 ?

1755 ?

1862 ?

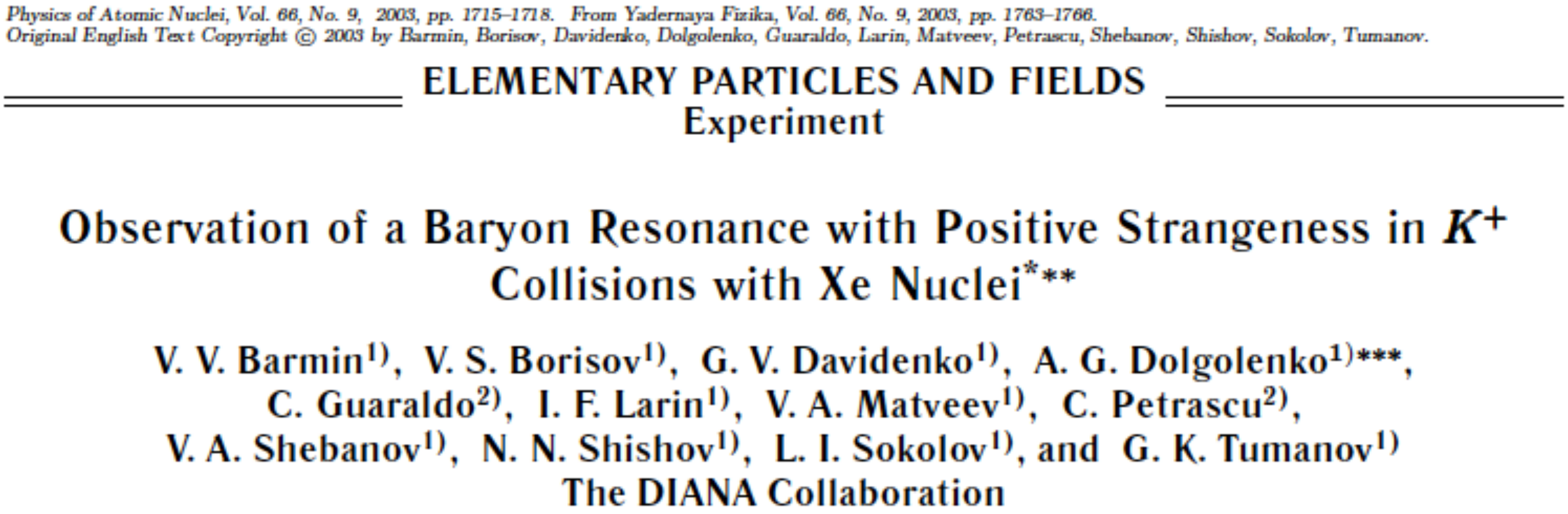
2003



VOLUME 91, NUMBER 1 PHYSICAL REVIEW LETTERS week ending 4 JULY 2003

Evidence for a Narrow $S = +1$ Baryon Resonance in Photoproduction from the Neutron

LEPS Collaboration



Physics of Atomic Nuclei, Vol. 66, No. 9, 2003, pp. 1715–1718. From Yadernaya Fizika, Vol. 66, No. 9, 2003, pp. 1763–1766.

ELEMENTARY PARTICLES AND FIELDS
Experiment

Observation of a Baryon Resonance with Positive Strangeness in K^+ Collisions with Xe Nuclei*,**

V. V. Barmin1), V. S. Borisov1), G. V. Davidenko1), A. G. Dolgolenko1)***,
C. Guaraldo2), I. F. Larin1), V. A. Matveev1), C. Petrascu2),
V. A. Shebanov1), N. N. Shishov1), L. I. Sokolov1), and G. K. Tumanov1)
The DIANA Collaboration

July 2003

NEW YORK TIMES **INTERNATIONAL** TUESDAY, JULY 1, 2003

A Subatomic Discovery Emerges From Experiments in Jap

By KENNETH CHANG

Slamming high-energy particles of light into carbon atoms, physicists have unexpectedly produced a new type of subatomic particle.

Protons and neutrons, the building blocks of atoms, are made of smaller particles known as quarks, which come in six varieties. A proton, for example, consists of three quarks — two so-called up quarks and one down quark. Physicists know of slews of particles containing two or three quarks.

Now they believe they know of a particle containing five quarks that perhaps could have been common in the very early universe. (No one

the experiments, Dr. Takashi Nakano, of the Research Center for Nuclear Physics at Osaka University, and told Dr. Nakano that he should look through the data for signs of five-quark particles.

"Dimitri Diakonov was very confident of that," Dr. Nakano said. Dr. Nakano and his collaborators looked, and they found a peak in their graphs corresponding to the mass of the five-quark particle that Dr. Diakonov had predicted. "He was right," Dr. Nakano said. "Actually, I was very surprised."

Dr. Kenneth H. Hicks, a professor of physics at Ohio University and another member of the Spring-

would consist of two up quarks, two down quarks and one known as an anti-strange quark.

The findings will be reported Friday in the journal Physical Review Lette

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USA TODAY · TUESDAY, JULY 1, 2003 · 7D

Physics team goes where no quark has gone before

Quarks

Five alive!

Scientists find fleeting form of basic matter

JOHN MANGELS
Plain Dealer Science Writer

Teams of scientists in Japan and the United States have confirmed the existence of a previously unknown kind of matter, a strange, fleeting subatomic particle that has been the object of a 30-year search.

One of the scientists likens the discovery to finding a new animal that doesn't fit the typical classifications of mammals or reptiles. The researchers say it's too soon to know what impact their finding will have, but they speculate that it may add to the basic understanding of how the universe was formed and how the particles that compose all matter interact.

The newly identified particle, dubbed a "pentaquark" because of its five ingredients, likely existed in the fractions of a second after the Big Bang, as the universe began to organize from the fiery chaos of free-floating elementary particles into the familiar components of atoms.

Pentaquarks also probably flicker in and out of being today, the short-lived product of billiard-ball-like collisions between cosmic rays and atoms in deep space or Earth's upper atmosphere.

SEE PARTICLE | A7

PARTICLE

FROM A1

Scientists find unknown form of basic matter

Scientists had to duplicate those conditions in the lab by firing powerful energy beams into targets of carbon or hydrogen atoms. Even then, it took months for them to analyze the data, recognize what they had done, and convince themselves it wasn't a false conclusion. Their findings will be published in Physical Review Letters, a prominent physics journal, later this month.

When he first saw the computer tracing that was the signature of the new category of particle, "I thought it was some mistake," said Ohio University physics Professor Ken Hicks, who was a collaborator in the Japanese experiments and headed similar work at the U.S. Department of Energy's Thomas Jefferson National Accelerator Facility in Virginia.

His Japanese colleague had a similar reaction. "It must be

To reach this Plain Dealer reporter:
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HIGH-ENERGY PHYSICS

Evidence for 'Pentaquark' Particle Sets Theorists Re-Joyce-ing

Newcomers. Jolted by collisions, quarks inside atomic nuclei recombined into bursts of particles that appear to include exotic five-quark specimens.

www.sciencemag.org SCIENCE VOL 301 11 JULY 2003

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News

New five-quark states found at CERN

Figure 1

Only a few months after the first burst of excitement over the appearance at several laboratories of what seems to be a new five-quark particle, evidence has been found for a different five-quark state that appears to be closely related.

The constituent quark model of hadrons that was invented in the 1960s has been very successful in describing the known baryons as composites of three valence quarks. Quantum chromodynamics (QCD), the theory of strong interactions, does not forbid baryons containing more than three quarks. In fact, such states were proposed a long time ago but no good candidates were found by experiments until recently. The search was revived by the theorists Dmitri Diakonov, Victor Petrov and Maxim Polyakov. They predicted that the masses of the lightest pentaquark (4q,qbar) baryon multiplet, an antidecuplet (see figure 1), were rather small and that the width of its lightest member was expected to be very narrow (Diakonov et al. 1997). Recent evidence for this state, named Θ^+, has opened up a new chapter in baryon spectroscopy that will help to elucidate QCD in the non-perturbative regime (CERN Courier September 2003 p5). The Θ^+ is a manifestly exotic baryon, that is, it cannot be composed of three quarks. This is also the case for the other two corner members of the antidecuplet depicted in figure 1. The latter have a strangeness of $S = -2$, a charge of $Q = -2, +1$, and form members of an isospin quartet of Ξ states.

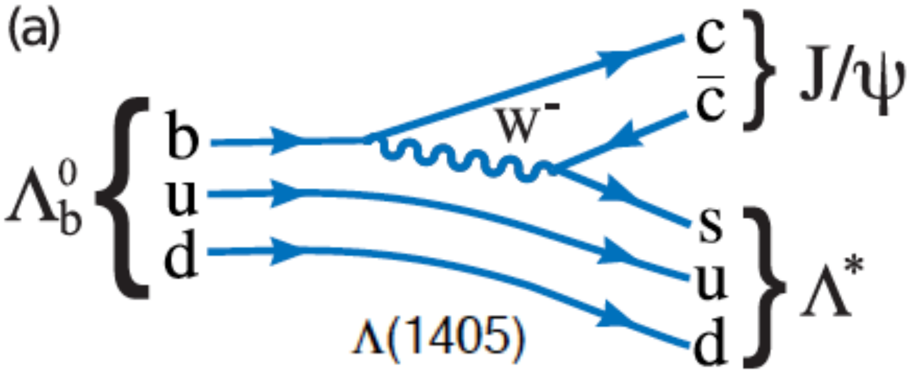
Figure 2

Experiment NA49 at the CERN Super Proton Synchrotron has searched for the Ξ^{--} and the Ξ states in proton-proton collisions at a beam energy of 158 GeV (Alt et al. 2003). Tracks of particles produced in the reactions are recorded by the detector's four large time-projection chambers. Their high resolution allows for a precise reconstruction of the particle trajectories and momenta as well as their identification via the measurement of the energy loss in the chamber gas. The reconstruction of secondary decay vertices makes possible the observation of the complex decay chains of the pentaquark states. After suppression of the overwhelming background by suitable selection cuts, the summed $\Xi\pi$ mass distribution shows a narrow peak of 5.6 standard deviations at a mass of 1.862 ± 0.002 GeV/c^2 (see figure 2). The true width of the peak must be smaller than the observed full width at half maximum of 0.017 GeV/c^2, which is consistent with the resolution of the detector.

In fact, peaks are seen at the same mass in the individual $\Xi^-\pi^-$ and $\Xi^-\pi^+$ mass distributions, as well as in those of the antiparticles. No signal has been found yet for the Θ^+, for which the background in the potentially

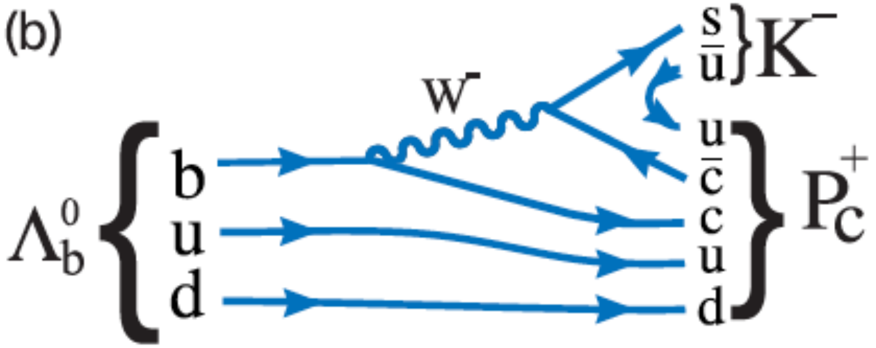
c-cbar pentakwark

Produkcja stanu $K^- + J/\psi + p$



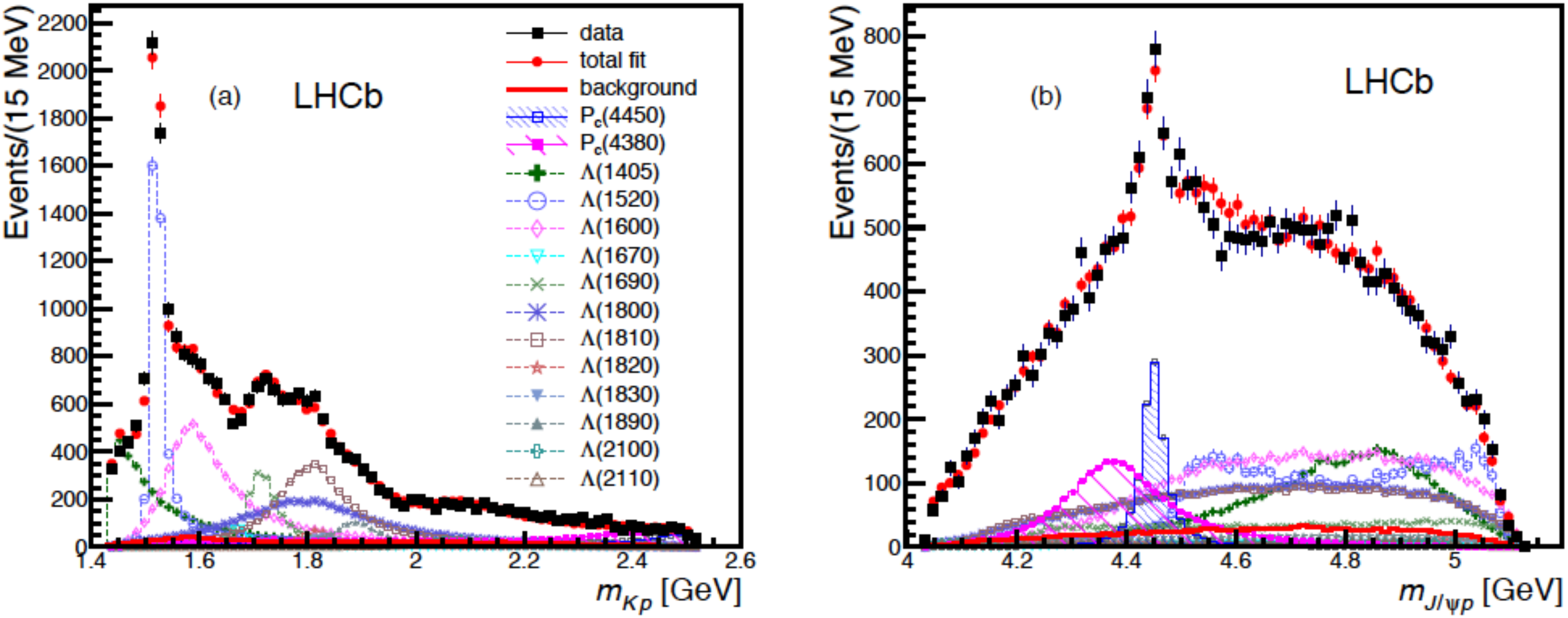
Λ(1405)
Λ(1520)
Λ(1600)
Λ(1670)
Λ(1690)
Λ(1800)
Λ(1810)
Λ(1820)
Λ(1830)
Λ(1890)
Λ(2100)
Λ(2110)

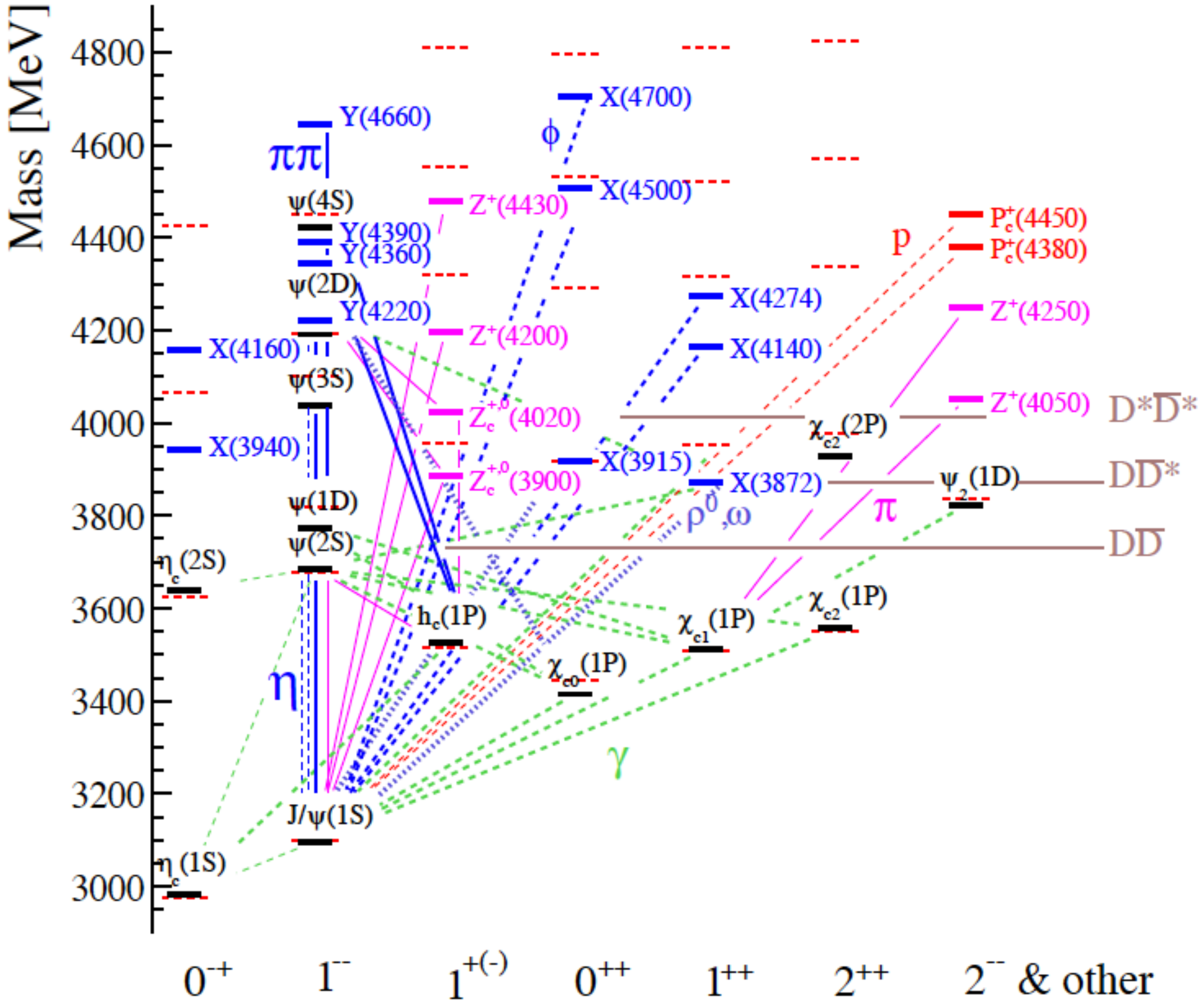
$$\Lambda^* \to K^- p$$

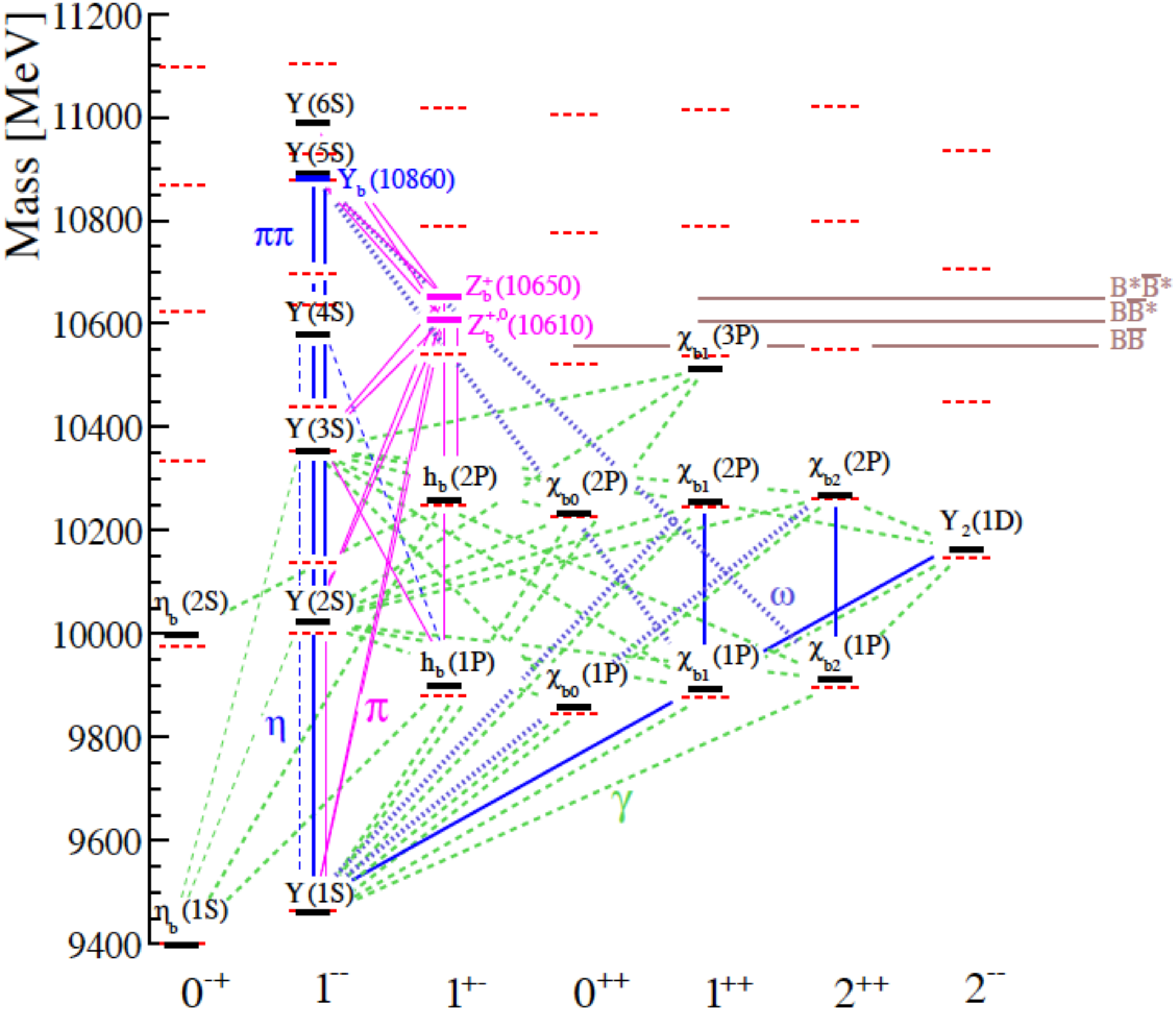


$P_c(4450)$
$P_c(4380)$

$$P_c^+ \to J/\psi\, p$$


(a)
LHCb
data
total fit
background
$P_c(4450)$
$P_c(4380)$
$\Lambda(1405)$
$\Lambda(1520)$
$\Lambda(1600)$
$\Lambda(1670)$
$\Lambda(1690)$
$\Lambda(1800)$
$\Lambda(1810)$
$\Lambda(1820)$
$\Lambda(1830)$
$\Lambda(1890)$
$\Lambda(2100)$
$\Lambda(2110)$
Events/(15 MeV)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
1.4
1.6
1.8
2
2.2
2.4
2.6
m_{Kp} [GeV]
(b)
LHCb
Events/(15 MeV)
0
100
200
300
400
500
600
700
800
4
4.2
4.4
4.6
4.8
5
$m_{J/\psi p}$ [GeV]


Mass [MeV]
4800
4600
4400
4200
4000
3800
3600
3400
3200
3000
Y(4660)
$\pi\pi$
$\psi(4S)$
Y(4390)
Y(4360)
$\psi(2D)$
Y(4220)
X(4160)
$\psi(3S)$
X(3940)
$\psi(1D)$
$\psi(2S)$
$\eta_c(2S)$
η
$J/\psi(1S)$
$\eta_c(1S)$
$Z^+(4430)$
$Z^+(4200)$
$Z_c^{+,0}(4020)$
$Z_c^{+,0}(3900)$
$h_c(1P)$
ϕ
X(4700)
X(4500)
X(3915)
$\chi_{c0}(1P)$
X(4274)
X(4140)
X(3872)
ρ^0,ω
$\chi_{c1}(1P)$
γ
$\chi_{c2}(2P)$
$\chi_{c2}(1P)$
$\psi_2(1D)$
π
p
$P_c^+(4450)$
$P_c^+(4380)$
$Z^+(4250)$
$Z^+(4050)$
$D^*\overline{D}^*$
$D\overline{D}^*$
$D\overline{D}$
0^{-+}
1^{--}
$1^{+(-)}$
0^{++}
1^{++}
2^{++}
2^{--} & other


Mass [MeV]
11200
11000
10800
10600
10400
10200
10000
9800
9600
9400
Υ(6S)
Υ(5S)
Υ_b(10860)
ππ
Z_b^+(10650)
$Z_b^{+,0}$(10610)
Υ(4S)
χ_{b1}(3P)
$B^*\bar{B}^*$
$B\bar{B}^*$
$B\bar{B}$
Υ(3S)
h_b(2P)
χ_{b0}(2P)
χ_{b1}(2P)
χ_{b2}(2P)
Υ_2(1D)
η_b(2S)
Υ(2S)
ω
h_b(1P)
χ_{b0}(1P)
χ_{b1}(1P)
χ_{b2}(1P)
η
π
γ
Υ(1S)
η_b(1S)
0^{-+}
1^{--}
1^{+-}
0^{++}
1^{++}
2^{++}
2^{--}