X, Y, and Z states

Relativistische Schwerionenphysik - Seminar

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Content

1) Theoretical models beyond constituent quark model

2) Experiments and production channels

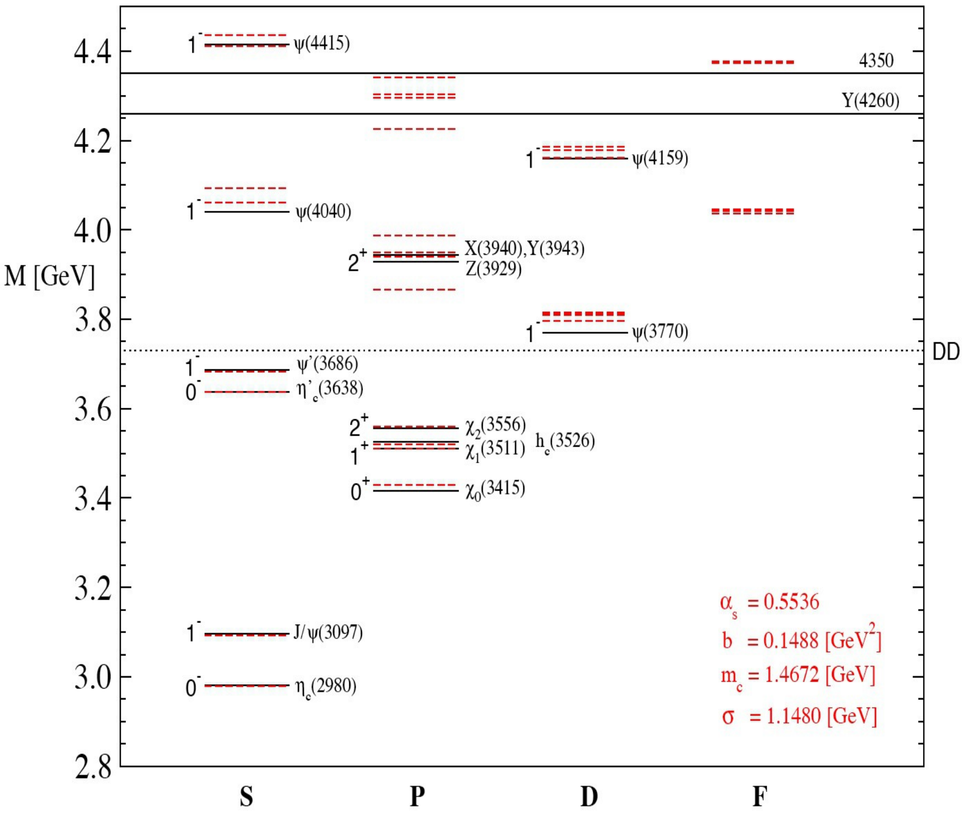
3) The X(3872) state

4) Other XYZ states

5) Conclusion

Charmonium spectroscopy

- Measurement of $c\bar{c}$ spectrum
- Theoretical calculations of $c\bar{c}$ states using potential model
- Models based on interactions described by the QCD
- (Confinement, gluon exchange)
- Successful description of low level charmonium states
- Models predict possible existance of exotic states



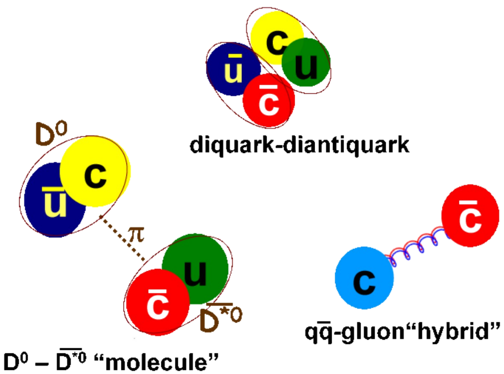
arXiv:hep-ph/0608103v1

Constituent quark model

- So far only hadrons containing $q\bar{q}$ or qqq have been observed
- QCD does not forbid other configurations
- Many quark potential models predict existance of additional quark states
- Search for exotic states as gluonballs and pentaquarks still unsuccessful

Exotic quark models

- Molecular state
- Tetraquark
- Hybrid mesons



arXiv:0801.3867v1 [hep-ph]

Molecular Charmonium: A New Spectroscopy?*

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Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 02138
(Received 23 November 1976)

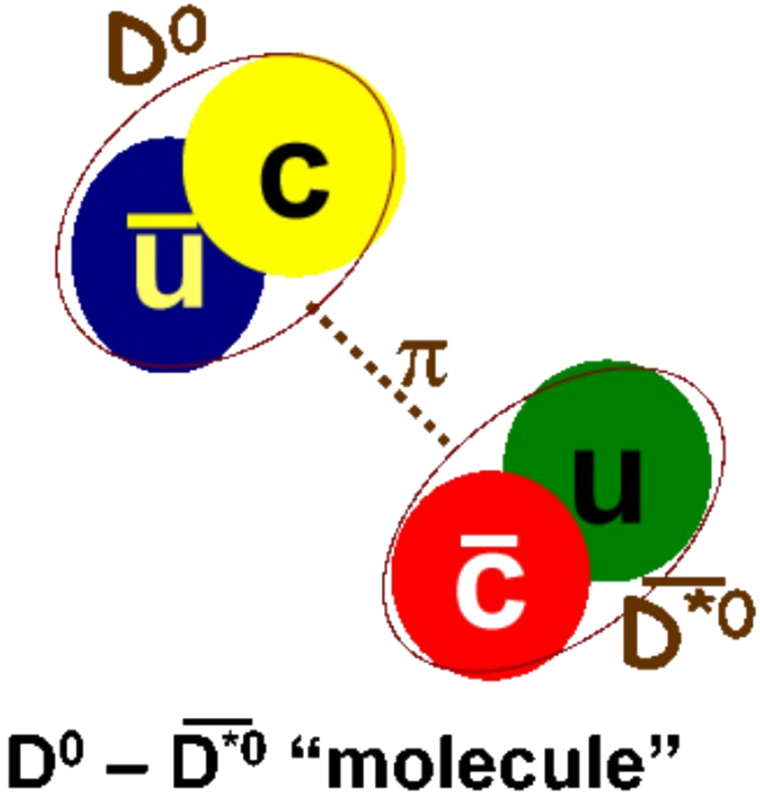
Recent data compel us to interpret several peaks in the cross section of e^-e^+ annihilation into hadrons as being due to the production of four-quark molecules, i.e., resonances between two charmed mesons. A rich spectroscopy of such states is predicted and may be studied in e^-e^+ annihilation.

Properties of recently discovered charmed particles,[1] D^0, D^+, D^{*0}, and D^{*+}, are in good agreement with a simple picture of hadrons as bound states of quarks in a color gauge theory.[2] The model of mesons as quark-antiquark bound states (and baryons as three-quark bound states) with long-range spin-independent binding and short-range spin-dependent color gluon exchange adequately describes many features of normal hadron spectroscopy.[2,3] Moreover, it has correctly predicted the qualitative behavior of the charmonium states and of charmed hadrons themselves.[2] This Letter is focused on one remaining striking and generally unexpected feature of charmed-meson production in e^-e^+ annihilation. Much data in which D mesons are seen are taken at a peak in the annihilation cross section, at $\sqrt{s} = 4.028$ GeV, where the yield of charmed mesons was expected to be, and indeed is, high. Analysis of the recoil-mass spectrum against detected D^0's indicates that $\sigma(\bar{D}^0D^0)$, $\sigma(\bar{D}^0D^{*0}+\bar{D}^{*0}D^0)$, and $\sigma(\bar{D}^{*0}D^{*0})$ are in the ratios 1: ~8: ~11 at this energy.[4,5] Estimates of charmed-meson masses reveal that the available decay energies are ~300, ~160, and ~18 MeV, respectively. It is remarkable that the $\bar{D}^{*0}D^{*0}$ mode, with so little phase

317

Molecular state

- Two (charmed) mesons bound to a molecular state
- Quark/color interaction at short ranges
- Pion exchange at long range

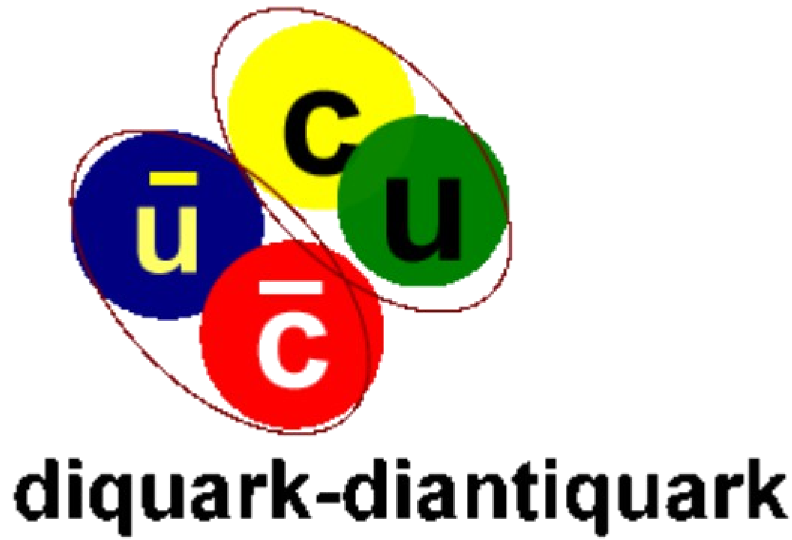


Tetraquark

- Tight bound state of diquark diantiquark configuration

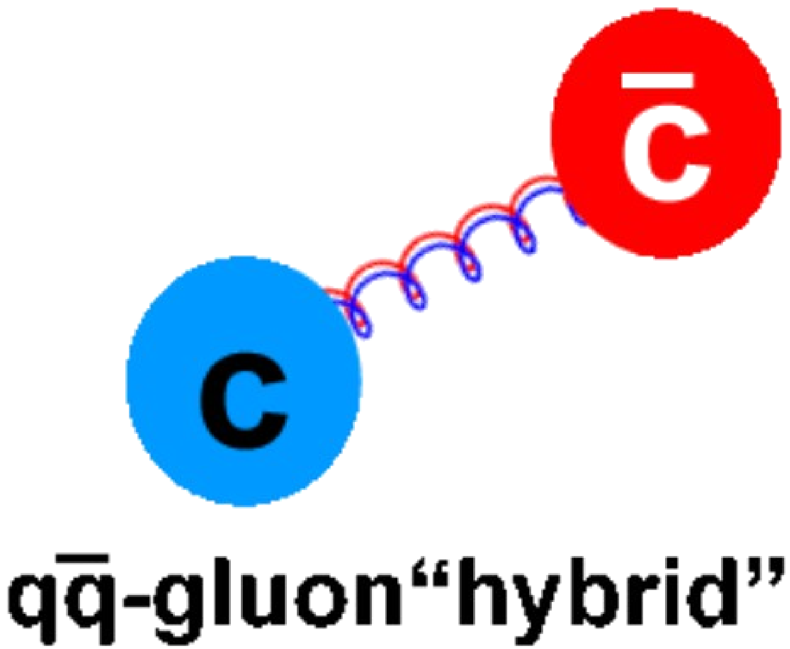
  Difference to normal charmonium:

- Existance of multiplets with nonzero charge or strangeness: $[cu\overline{cd}]$, $[cd\overline{cs}]$



Hybrid mesons

- Additional excited gluon described by flux tube model
- Possibility to form exotic quantum numbers which are not allowed in normal $q\bar{q}$:
- $J^{PC} = 0^{+-}, 1^{-+}, 2^{+-}$
- Predicted mass > 4.2 GeV/c^2



Colliders types & experiments for spectroscopy

<u>B-factories</u>

- High luminosity e^+e^- colliders at Y(4S) energy

- Designed to measure CP violation but because of high rates also excellent for spectroscopy

<u>Hadron colliders</u>

- High energy pp colliders

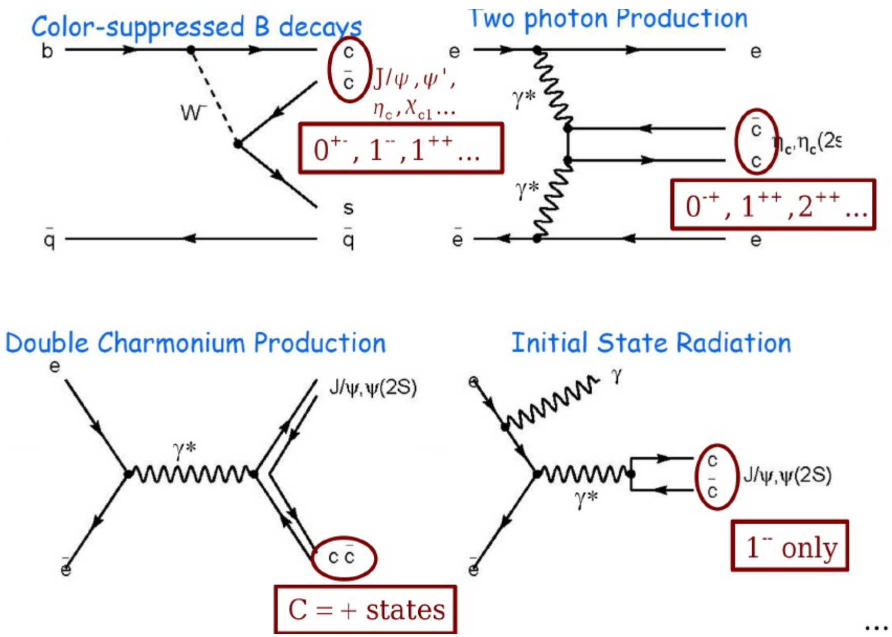
- Great phase space range of particle production

BES III

CLEO

Charmonium production in e^+e^- colliders

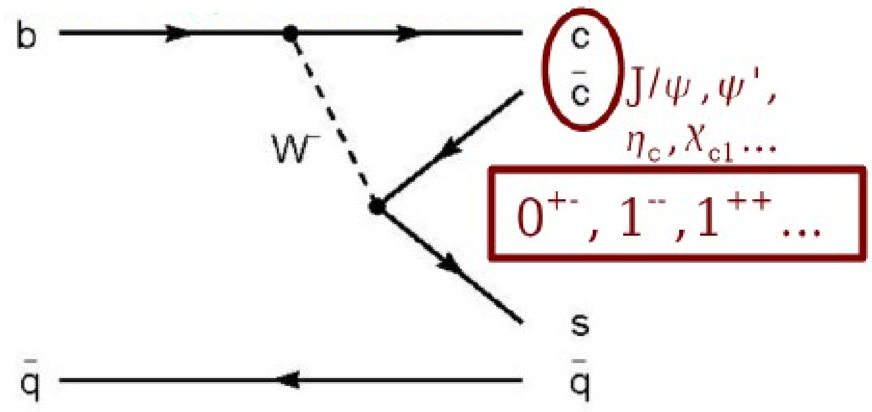
- Weak B decays
- Initial state radiation
- Charmonium with J/Ψ
- Photon-photon collisions



Roman Mizuk, ITEP Seminar, 18 Nov 2009

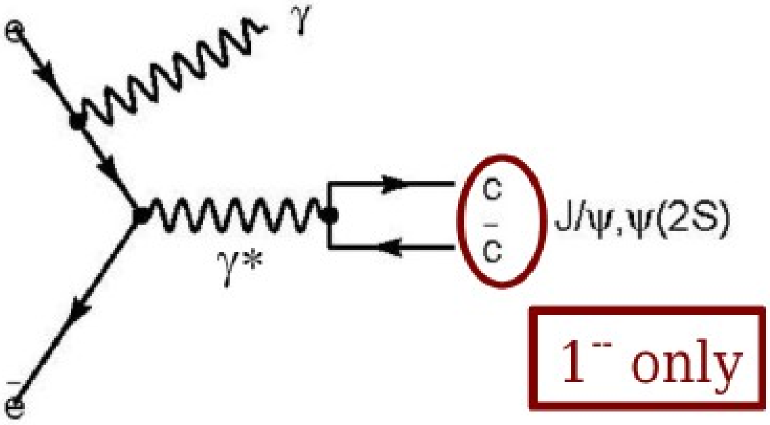
Weak B decays

- Beauty decays weak to charm
- B -> K + X($c\bar{c}$) with branching ratio 10^{-3}
- At Belle η_c(2S) was discovered using this decay channel (Phys. Rev. Lett. 89:102001)



Initial state radiation

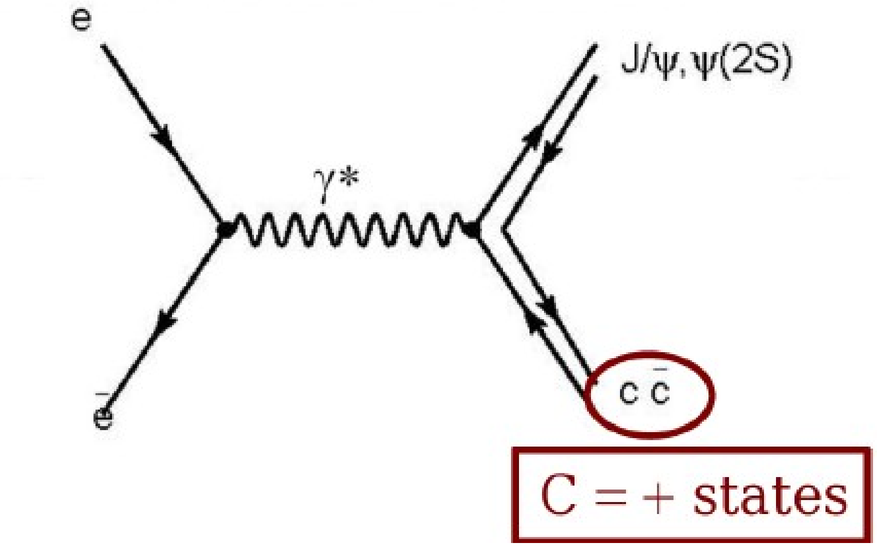
- Gamma ray radiated from e^+ or e^- before interaction
- Can reduce cm energy of the e+e- system to be in charmonium mass range
- Because of photon, charmonium has to be 1^{--} state



Charmonium with J/Ψ

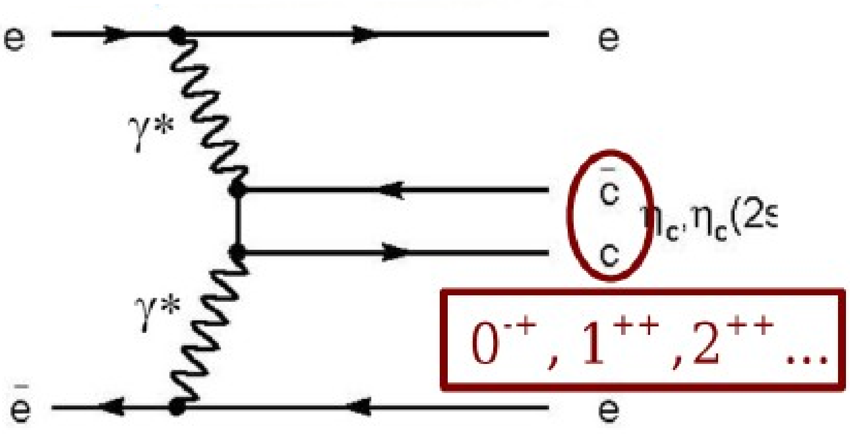
- Production of J/Ψ and other X($c\bar{c}$) state

- C-parity conservation implies positive C-parity for X



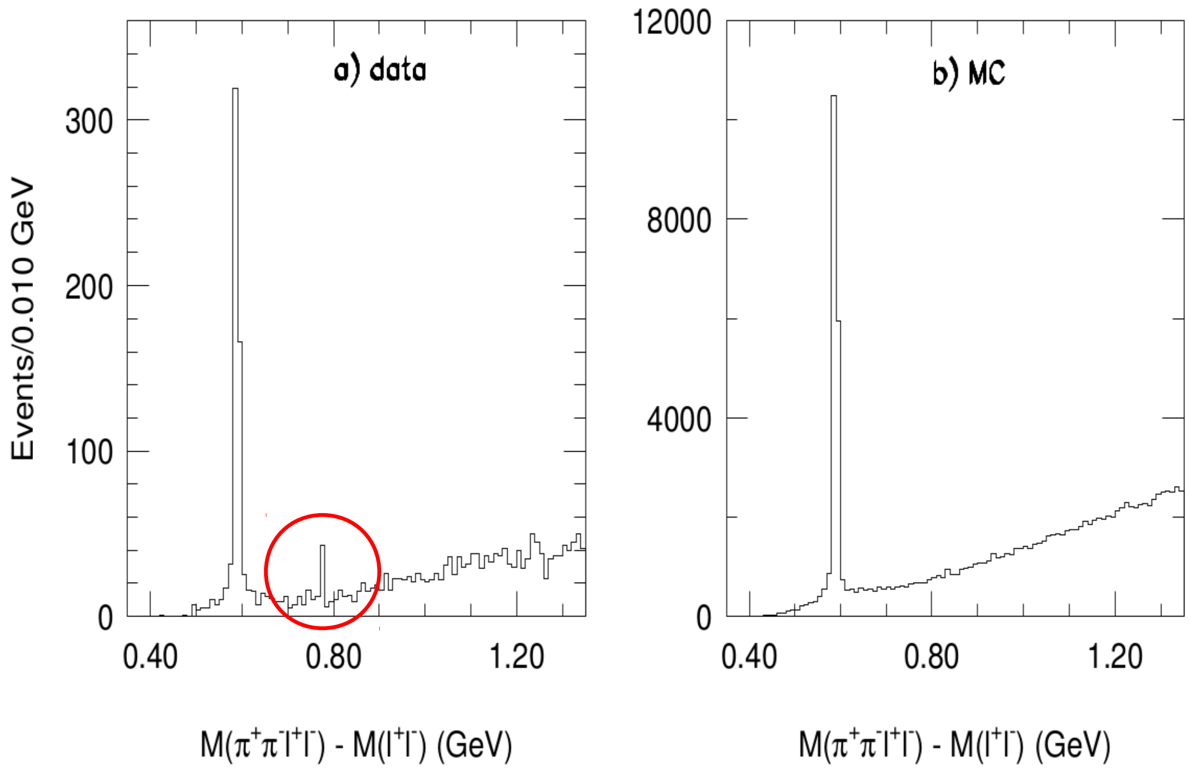
Photon-photon collisions

- Interaction of photons radiated by the e^+ and the e^-
- Final state measured with e^+ and e^-
- $\eta_c(2S)$ confirmation via photon-photon collisions at CLEO
  (Phys. Rev. Lett. 92:142001)



X (3872) – The beginning

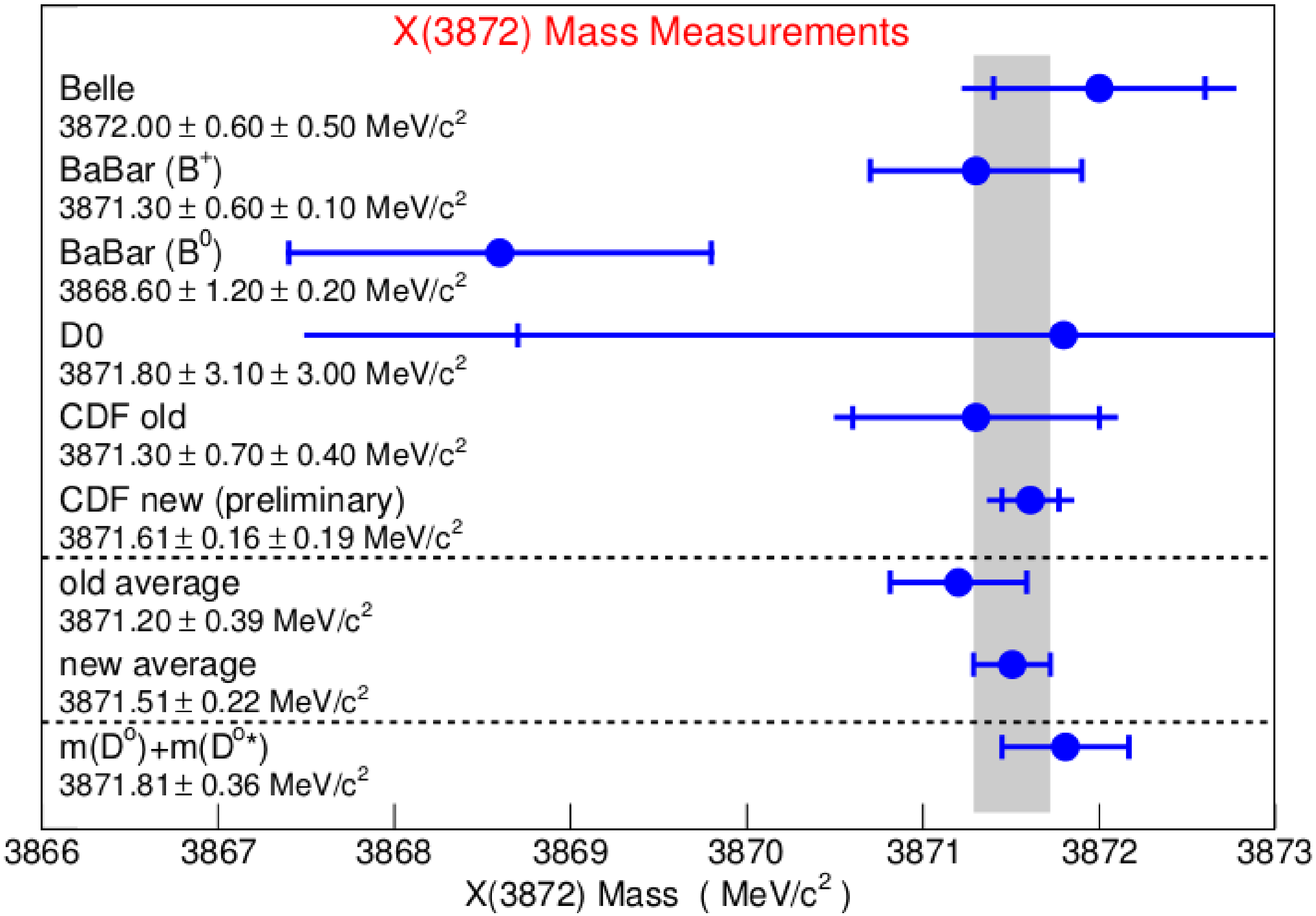
- Belle studied the decay $B^+ \rightarrow K^+ \pi^+ \pi^- J/\psi$ and found a new narrow resonance at 3872 MeV/c^2 (10.3σ)
- Confimation by other experiments (CDF, D0, BaBar, CMS, LHCb)



X (3872) – different decay channels

- $B \rightarrow K (\pi^{+} \pi^{-} J/\psi)$
- Belle, BaBar
- $p\bar{p}/pp \rightarrow (\pi^{+} \pi^{-} J/\psi)$
- CDF, D0 / LHCb, CMS
- $B \rightarrow K (\omega J/\psi)$
- Belle, BaBar
- $B \rightarrow K (\gamma J/\psi)$
- Belle, BaBar
- $B \rightarrow K (\gamma \psi(2S))$
- Belle, BaBar

X (3872) – mass measurements

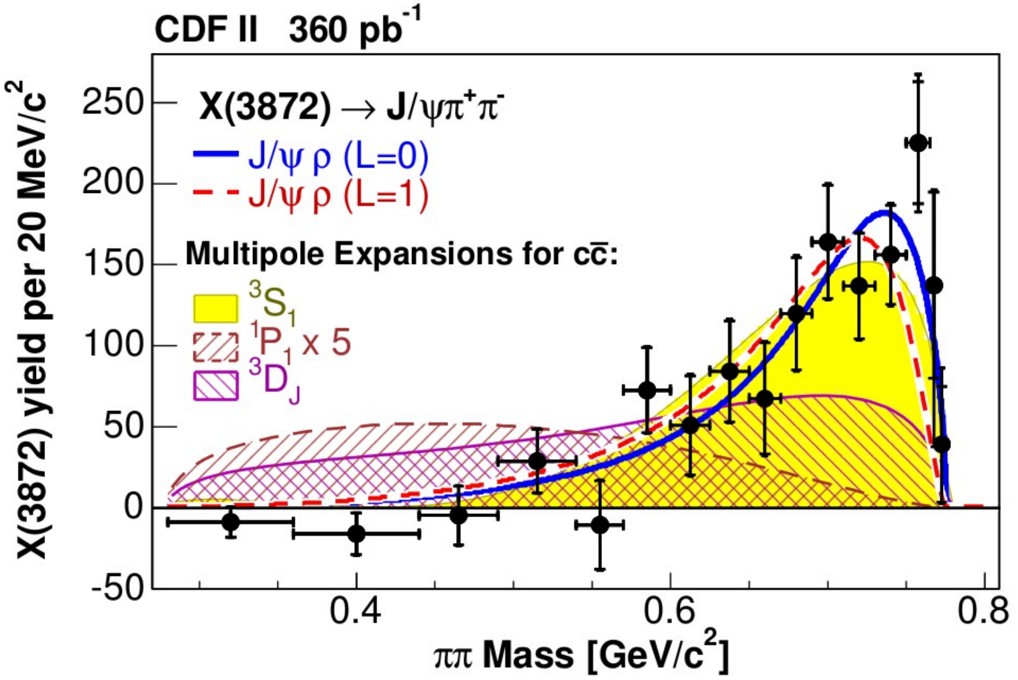


arXiv:0906.4996

X (3872) – quantum numbers

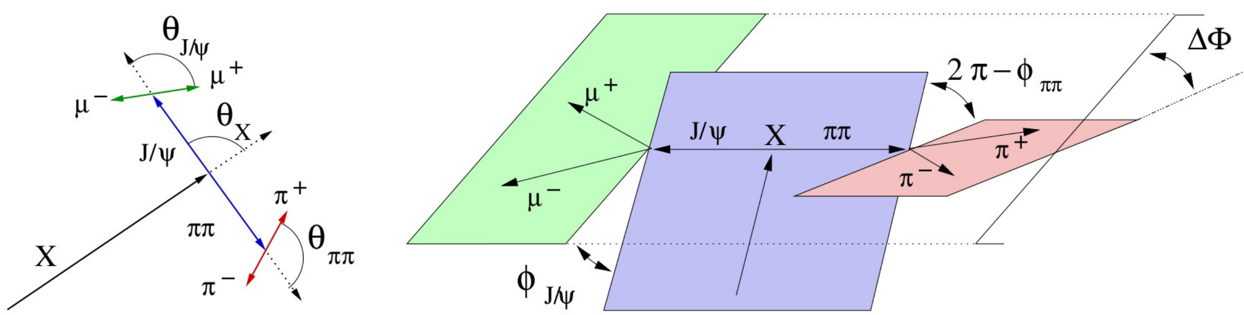
- The decay X(3872)->γ J/ψ indicates C=+ for X(3872)

- Dipion spectrum shows resemblance with ρ meson in CDF (arXiv:hep-ex/0512074v1)



X (3872) – quantum numbers

- Extensive angular measurement from CDF lead to:
  $J^{PC} = 1^{++}$ or 2^{-+} (arXiv:hep-ex/0612053v2)
- Confirmation by Belle and BaBar
- LHCb recently published 5D angular correlation measurement excluding 2^{-+} by 8.4σ (arXiv:1302.6269v1 [hep-ex])



X (3872) possible interpretation

- Decay to $\rho J/\psi$ would violate isospin if X(3872) is charmonium

- Tetraquark hypothesis predict charged isospin partner states, not observed so far

- Close to the $D^0 D^{0*}$ theshold (3871.81 +/- 0.36 MeV/c^2) hints to molecule hypothesis

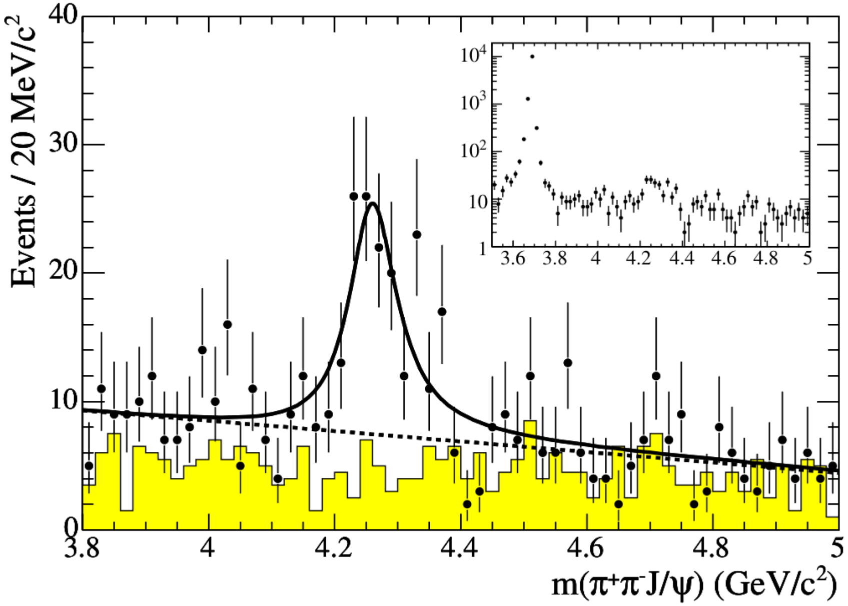
Y (4260) vector state 1^{--}

Discovered by BaBar via InitialStateRadiation:

$e^+e^- \rightarrow \gamma_{ISR} (\pi^+ \pi^- J/\psi)$

- Confirmed by Belle and CLEO
- Mass does not fit predictions for regular charmonium state

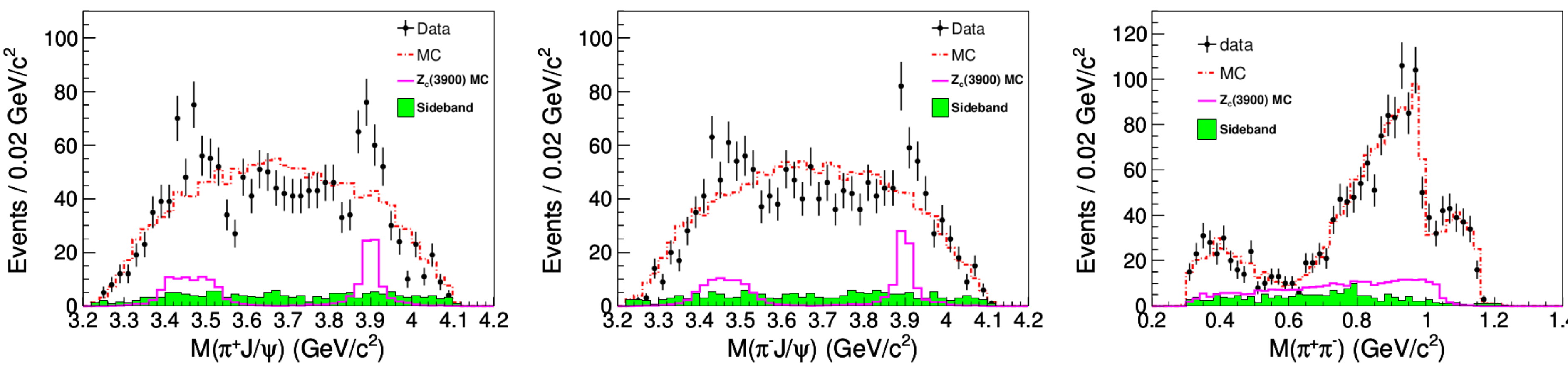
- Recently substructure found in the Y(4260) resonance



$Z_c(3900)^{\pm}$ charged exotic

- BESIII measured at cm energy Y(4260)
- Peak in the projection in the mass of $J/\psi + \pi^-$ and $J/\psi + \pi^+$
- Combined spectrum gives peak at 3900 MeV/c^2 (>8σ)
  (Reflection at ~3500 MeV/c^2)

arXiv:1303.5949v2 [hep-ex]

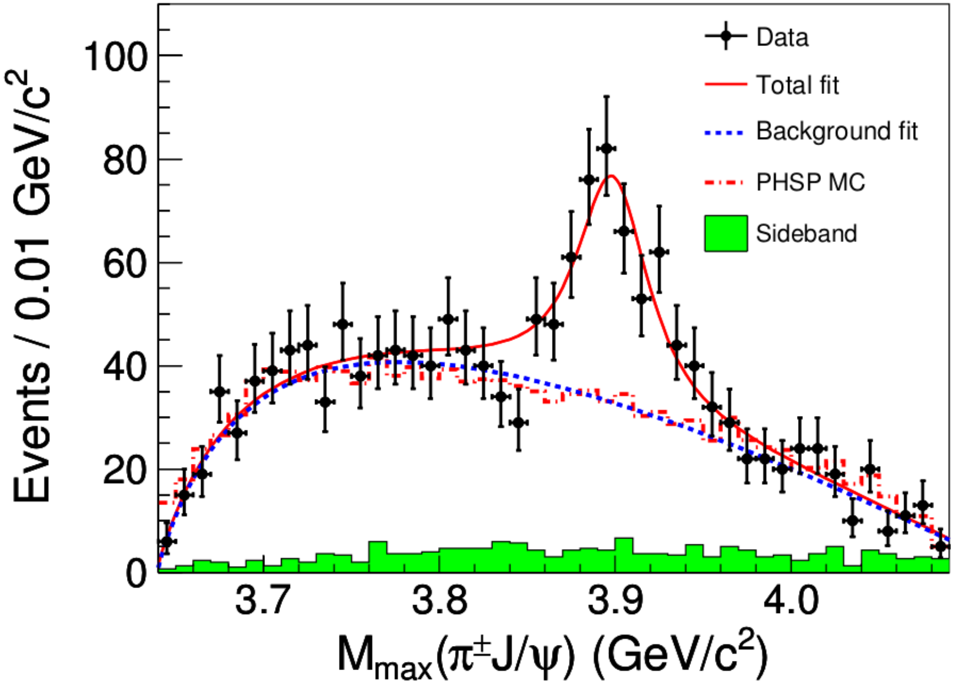


$Z_c(3900)^{\pm}$ charged exotic

- Also peak around 3900 MeV visible at Belle (5.2σ)
  (arXiv:1304.0121v2 [hep-ex])

  <u>Possible interpretation:</u>

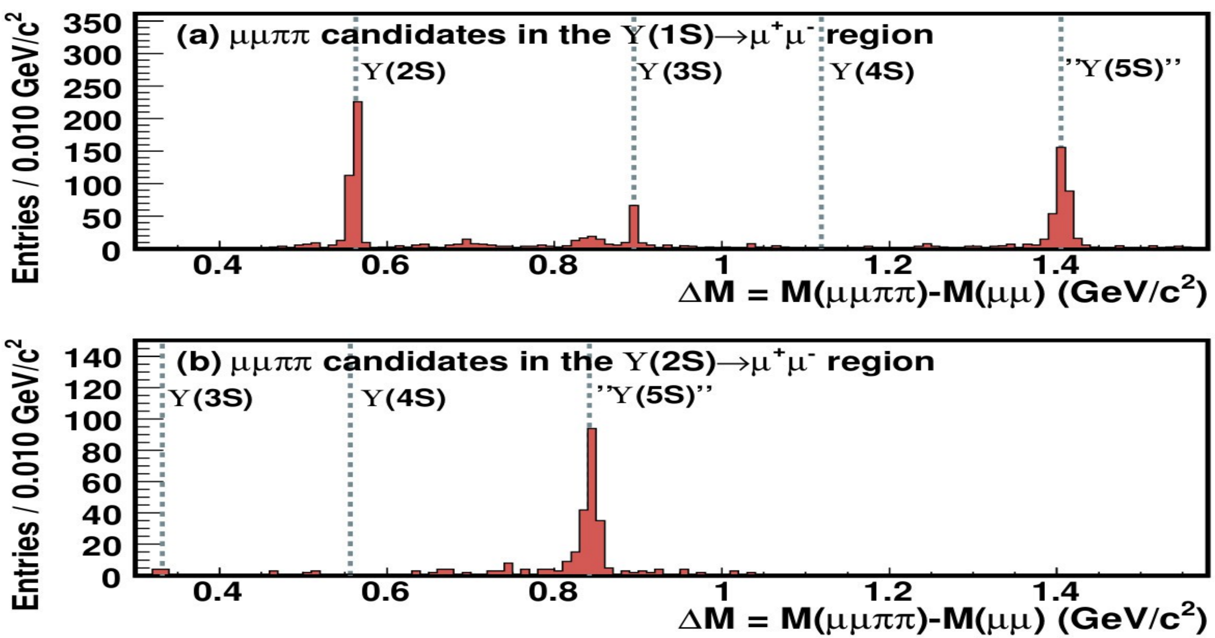
  Tetraquark or molecule structure because of nonzero charge



Hint of beauty exotics

- Anomalous $\Upsilon(2S)\pi^+\pi^-$ and $\Upsilon(1S)\pi^+\pi^-$ production from $\Upsilon(5S)$ transition
- Much larger partial width than expected:
- $\Gamma(\text{“}\Upsilon(5S)\text{”} \rightarrow \pi + \pi - \Upsilon(1S)) = (590 \pm 100)$ keV/c2
- $\Gamma(\text{“}\Upsilon(5S)\text{”} \rightarrow \pi + \pi - \Upsilon(2S)) = (850 \pm 175)$ keV/c2
- $\Gamma(\text{“}\Upsilon(5S)\text{”} \rightarrow \pi + \pi - \Upsilon(3S)) = (520 \pm 220)$ keV/c2
- $\Upsilon(4S) \rightarrow \pi + \pi - \Upsilon(2S)$ (1.8 ± 0.4) keV
- $\Upsilon(4S) \rightarrow \pi + \pi - \Upsilon(1S)$ (1.7 ± 0.5) keV

Possible $Y_b(10888)$ next to $\Upsilon(5S)$?



arXiv:0710.2577v5 [hep-ex]

XYZ states

State	m (MeV)	Γ (MeV)	J^{PC}	Process (mode)	Experiment (#σ)	Year	Status
$X(3872)$	3871.68 ± 0.17	< 1.2	$1^{++}/2^{-+}$	$B \to K(\pi^+\pi^- J/\psi)$	Belle [36,37] (12.8), BABAR [38] (8.6)	2003	OK
				$p\bar{p} \to (\pi^+\pi^- J/\psi) + ...$	CDF [39–41] (np), D0 [42] (5.2)		
				$B \to K(\omega J/\psi)$	Belle [43] (4.3), BABAR [23] (4.0)		
				$B \to K(D^{*0}\overline{D}^0)$	Belle [44,45] (6.4), BABAR [46] (4.9)		
				$B \to K(\gamma J/\psi)$	Belle [47] (4.0), BABAR [48,49] (3.6)		
				$B \to K(\gamma\psi(2S))$	BABAR [49] (3.5), Belle [47] (0.4)		
				$pp \to (\pi^+\pi^- J/\psi) + ...$	LHCb [50] (np)		
$X(3915)$	3917.4 ± 2.7	28^{+10}_{-9}	$0/2^{?+}$	$B \to K(\omega J/\psi)$	Belle [51] (8.1), BABAR [52] (19)	2004	OK
				$e^+e^- \to e^+e^-(\omega J/\psi)$	Belle [53] (7.7), BABAR [23] (np)		
$X(3940)$	3942^{+9}_{-8}	37^{+27}_{-17}	$?^{?+}$	$e^+e^- \to J/\psi(D\overline{D}^*)$	Belle [54] (6.0)	2007	NC!
				$e^+e^- \to J/\psi(...)$	Belle [20] (5.0)		
$G(3900)$	3943 ± 21	52 ± 11	1^{--}	$e^+e^- \to \gamma(D\overline{D})$	BABAR [55] (np), Belle [56] (np)	2007	OK
$Y(4008)$	4008^{+121}_{-49}	226 ± 97	1^{--}	$e^+e^- \to \gamma(\pi^+\pi^- J/\psi)$	Belle [57] (7.4)	2007	NC!
$Z_1(4050)^+$	4051^{+24}_{-43}	82^{+51}_{-55}	?	$B \to K(\pi^+\chi_{c1}(1P))$	Belle [58] (5.0), BABAR [59] (1.1)	2008	NC!
$Y(4140)$	4143.4 ± 3.0	15^{+11}_{-7}	$?^{?+}$	$B \to K(\phi J/\psi)$	CDF [60,61] (5.0)	2009	NC!
$X(4160)$	4156^{+29}_{-25}	139^{+113}_{-65}	$?^{?+}$	$e^+e^- \to J/\psi(D\overline{D}^*)$	Belle [54] (5.5)	2007	NC!
$Z_2(4250)^+$	4248^{+185}_{-45}	177^{+321}_{-72}	?	$B \to K(\pi^+\chi_{c1}(1P))$	Belle [58] (5.0), BABAR [59] (2.0)	2008	NC!
$Y(4260)$	4263^{+8}_{-9}	95 ± 14	1^{--}	$e^+e^- \to \gamma(\pi^+\pi^- J/\psi)$	BABAR [62,63] (8.0)	2005	OK
					CLEO [64] (5.4), Belle [57] (15)		
				$e^+e^- \to (\pi^+\pi^- J/\psi)$	CLEO [65] (11)		
				$e^+e^- \to (\pi^0\pi^0 J/\psi)$	CLEO [65] (5.1)		
$Y(4274)$	$4274.4^{+8.4}_{-6.7}$	32^{+22}_{-15}	$?^{?+}$	$B \to K(\phi J/\psi)$	CDF [61] (3.1)	2010	NC!
$X(4350)$	$4350.6^{+4.6}_{-5.1}$	$13.3^{+18.4}_{-10.0}$	$0/2^{++}$	$e^+e^- \to e^+e^-(\phi J/\psi)$	Belle [66] (3.2)	2009	NC!
$Y(4360)$	4361 ± 13	74 ± 18	1^{--}	$e^+e^- \to \gamma(\pi^+\pi^-\psi(2S))$	BABAR [67] (np), Belle [68] (8.0)	2007	OK
$Z(4430)^+$	4443^{+24}_{-18}	107^{+113}_{-71}	?	$B \to K(\pi^+\psi(2S))$	Belle [69,70] (6.4), BABAR [71] (2.4)	2007	NC!
$X(4630)$	4634^{+9}_{-11}	92^{+41}_{-32}	1^{--}	$e^+e^- \to \gamma(\Lambda_c^+\Lambda_c^-)$	Belle [72] (8.2)	2007	NC!
$Y(4660)$	4664 ± 12	48 ± 15	1^{--}	$e^+e^- \to \gamma(\pi^+\pi^-\psi(2S))$	Belle [68] (5.8)	2007	NC!
$Z_b(10610)^+$	10607.2 ± 2.0	18.4 ± 2.4	1^+	$\Upsilon(5S) \to \pi^-(\pi^+[b\bar{b}])$	Belle [73,74] (16)	2011	NC!
$Z_b(10650)^+$	10652.2 ± 1.5	11.5 ± 2.2	1^+	$\Upsilon(5S) \to \pi^-(\pi^+[b\bar{b}])$	Belle [73,74] (16)	2011	NC!
$Y_b(10888)$	10888.4 ± 3.0	$30.7^{+8.9}_{-7.7}$	1^{--}	$e^+e^- \to (\pi^+\pi^-\Upsilon(nS))$	Belle [75,76] (2.0)	2010	NC!

J. Beringer et al. (PDG), PR D86, 010001 (2012)

The grain of salt: Pentaquark

- LEPS, Japan measured narrow state in the nK+ decay channel at 1540 MeV in 2003 with 4.6 sigma
- Interpretation: Pentaquark $\Theta^{+}(uudd\bar{s})$
- Pentaquark with similar mass (1530 MeV) and width predicted by Diakonov et al. in 1997
- "confirmed" by other experiments although with questionable results (mass variation, cut optimization)
- Big experiments with great statistics measure NULL (CLAS, BELLE)
- Pentaquark(s) discarded for now

Summary & Conclusion

- Different theoretical approaches predict exotic quark states, which have not been identified until now
- Spectroscopic measurement in the heavy quarkonium range reveal new states
- High statistics and independent experiments needed to identify new states and exotic quark structures