observation of a narrow charmonium-like state in exclusive $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}J/\psi$ decays

Peter Klassen

November 30, 2015

HISKP

the belle experiment

motivation

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The experiment set out to show that in millions of collisions, the short-lived variety of K meson always decayed into two pi mesons, while the long-lived variety never did. But to their surprise, a "suspicious-looking hump" in the data showed an unexpected result . . .

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1972 Makoto Kobayashi and Toshihide Maskawa

propose a new scheme of weak interaction quark couplings. This scheme requires three families of quarks and permits a CP violating phase in the quark mixing matrix. At the time only three quarks (u,d and s) were known, although there was some preliminary evidence from Kiyoshi Niu's group at Nagoya of the fourth quark (the c)

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1981 Ikaros Bigi and A. Ichiro Sanda

show that in the KM picture CP violating effects are observable in the $B^0 - \bar{B}^0$ *system if the B lifetime is long and* $B^0 - \bar{B}^0$ *mixing is large. They propose specific ways to measure them.*

kekb the b-factory

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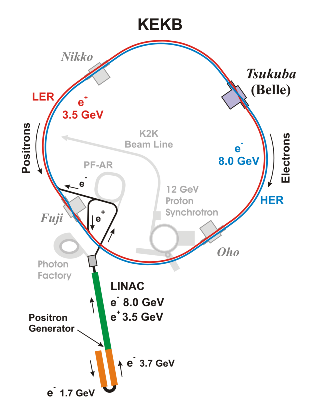
- asymmetric e^-e^+ collider
- $8\,\mathrm{GeV}$ e^- and $3.5\,\mathrm{GeV}$ e^+



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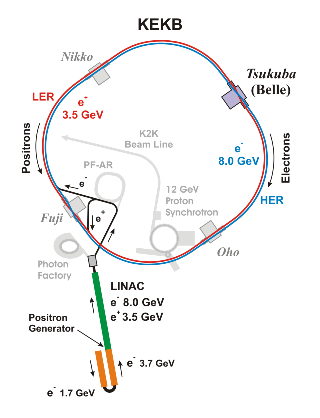

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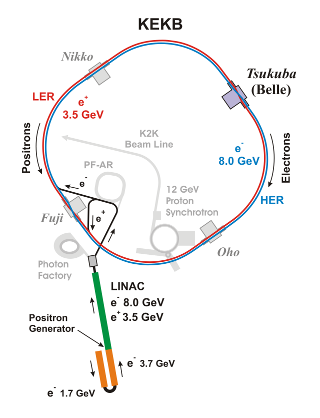
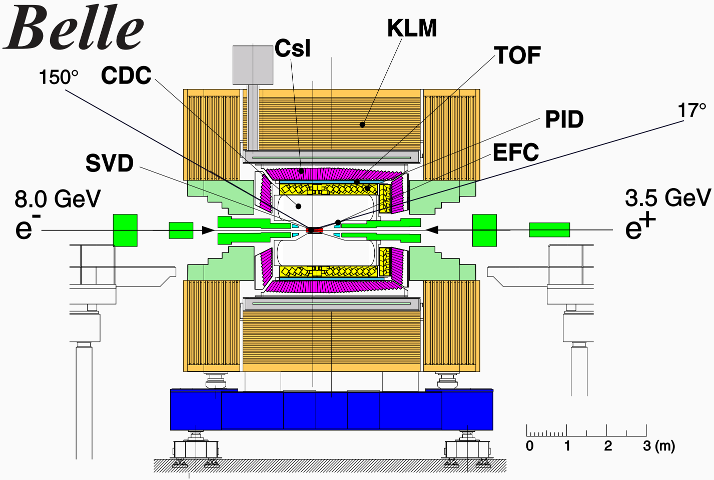
- 2009 luminosity world record of $2.1 \times 10^{34}\,\mathrm{cm}^{-1}\mathrm{s}^{-1}$
- Operation 12/1998 untill 06/2010



belle experiment



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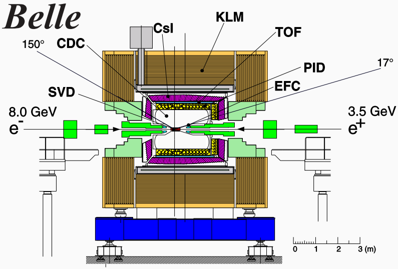

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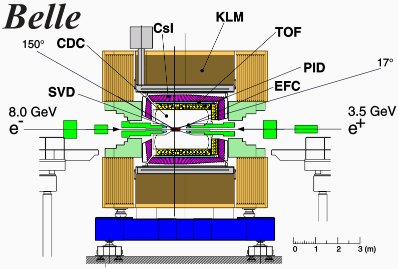
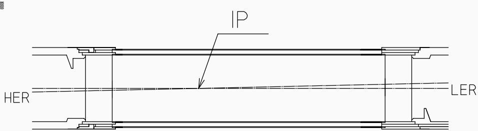
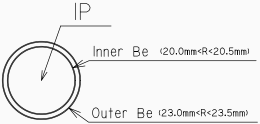


- beryllium pipe (low Z)
- He cooling system





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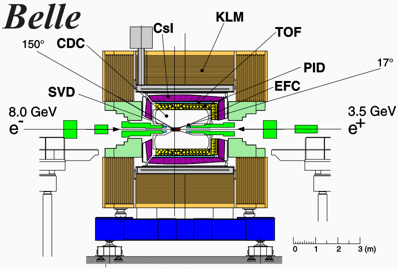
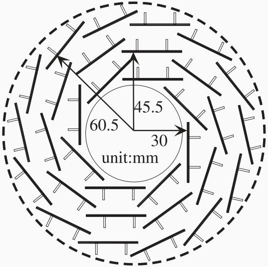


- equal modules
- 100 μm B vertex resolution

SVD endview



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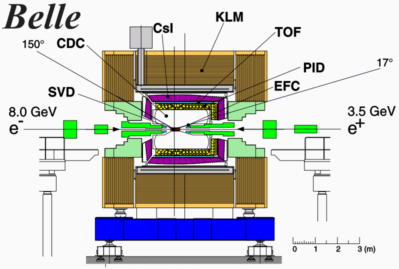
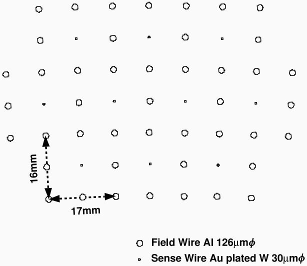


- PID via dE/dx
- 3.5 t wire tension
- up to 2.2 m length

BELLE Central Drift Chamber



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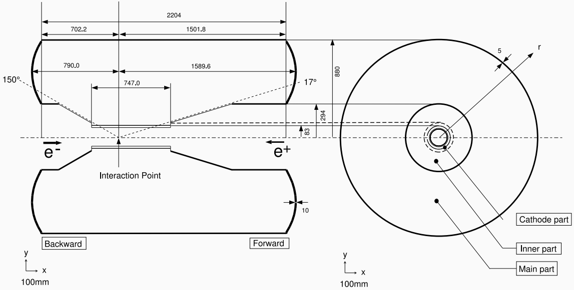

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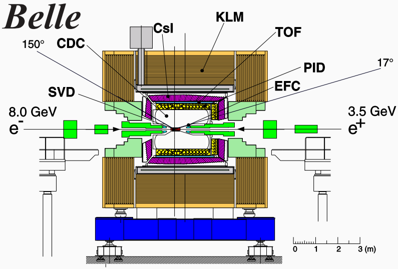
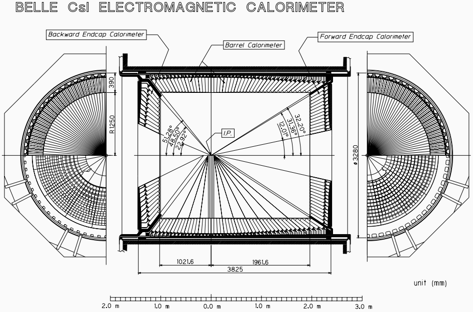


- 2.5 m inner diameter
- photodiode readout



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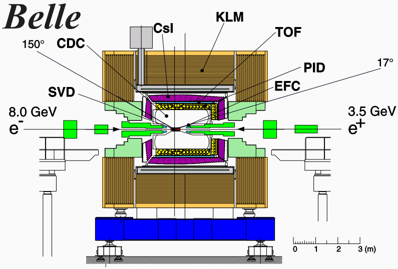
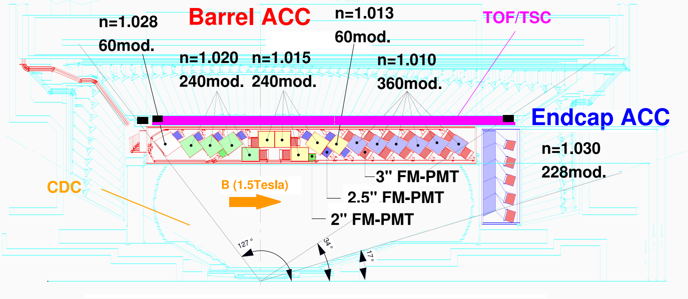


- aerogel cherenkov counter
- $1.01 \leq n \leq 1.03$



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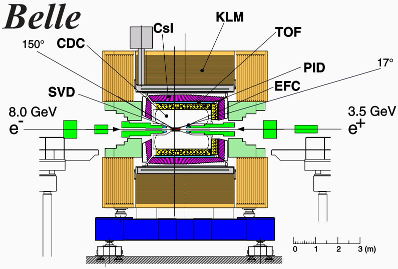
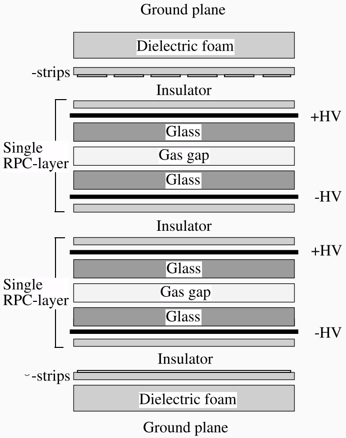


- 4.7 cm iron
- 3.7 cm sensitive area
- resistive plate countes



result

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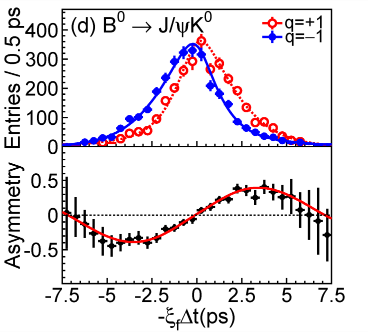
1998	*Beginning of KEKB accelerator operation. KEKB produces large samples of B mesons and will become the world's highest luminosity accelerator*
1999	*Beginning of Belle experimental operation*

2001 [HEP-EX/0107061]

. . . From the asymmetry in the distribution of the time intervals between the two B meson decay points, we determine $sin(2\phi_1) = 0.99 \pm 0.14(stat) \pm 0.06(syst)$*. We conclude that we have observed CP violation in the neutral B meson system.*



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- 8 years of planning and construction
- 2 years of measurement and analysis

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- “we need to do something else in the meantime, let’s do quarkonium physics”

quarkonium

remember?

simple quantum mechanical systems and its quantum numbers

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hydrogen:

n: $E_n^{Hyd} = -\frac{\alpha^2 mc^2}{2n^2} = \frac{-13.6\,\mathrm{eV}}{n^2}$

L: $\Delta E_{LS} \sim \alpha^2$

S: $\Delta E_{SS} \sim \alpha^2 \frac{\mu_n}{\mu_e}$

r: $r^H = 0.53 \times 10^5\,\mathrm{fm}$

$n = N + l + 1$

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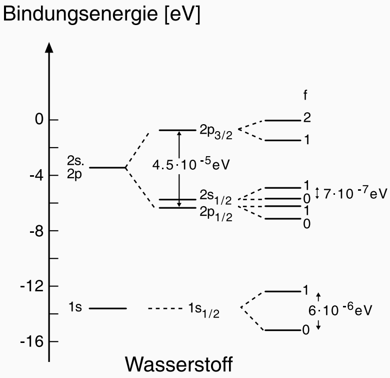

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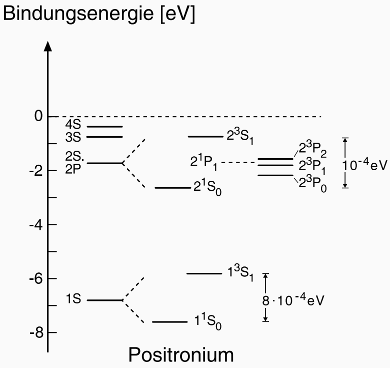

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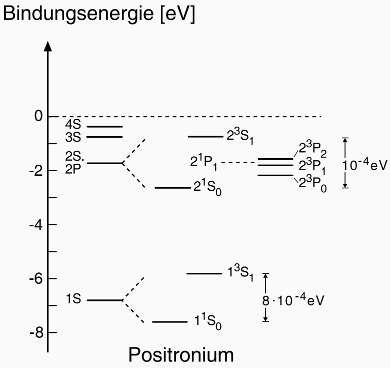

$n^{2S+1}L_J$

$|L - S| \leq J \leq |L + S|$

quarkonium

- $q\bar{q}$ state
- light qarkonia
  $\pi^0 = \frac{|u\bar{u}\rangle - |d\bar{d}\rangle}{\sqrt{2}}$
  $\eta \approx \frac{|u\bar{u}\rangle + |d\bar{d}\rangle - 2|s\bar{s}\rangle}{\sqrt{6}}$
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denoted:

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- if $S \neq 0$ $\chi_{c1}(1P)$
- if quantum numbers are not known $\mathrm{MeV/c^2}$ is given $X(3872)$ (as well for all light mesons (u,d,s))

why is quarkonium interesting?

- draw conclusion about underlying potential $V(r) = -\frac{4}{3}\frac{\alpha_S(r)\bar{h}c}{r} + kr$ from relative distances of energy levels
- roughly calculate, α_S, k, m_c,

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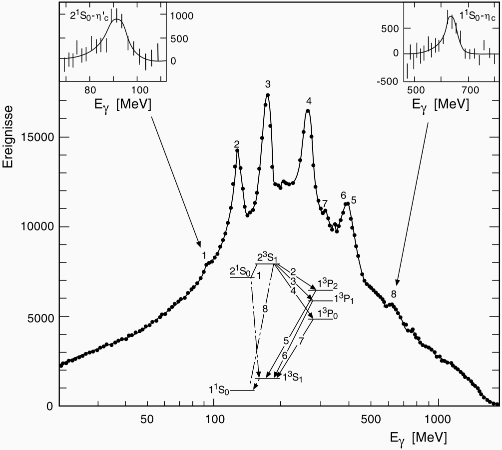

belle measurement

Abstract

We report the observation of a narrow charmonium-like state produced in the exclusive decay process $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}J/\psi$. This state, which decays into $\pi^{+}\pi^{-}J/\psi$, has a mass of $3872.0 \pm 0.6(stat) \pm 0.5(syst)\,\mathrm{MeV}$, a value that is very near the $m_D + m_{D*}$ mass threshold. The results are based on an analysis of 152M $B - B$ events collected at the $\Upsilon(4S)$ resonance in the Belle detector at the KEKB collider. The signal has a statistical significance that is in excess of 10σ.

analysis

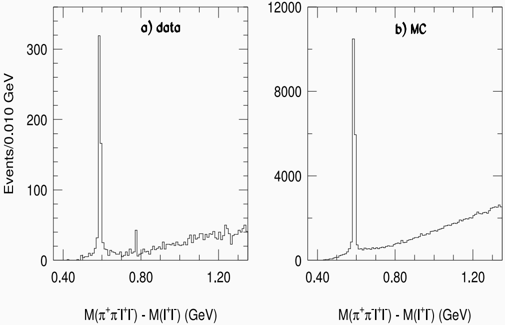

FIG. 1: Distribution of $M(\pi^+\pi^-\ell^+\ell^-) - M(\ell^+\ell^-)$ for selected events in the ΔE-$M_{\mathbf{bc}}$ signal region for **(a)** Belle data and **(b)** generic B-$\bar{B}$ MC events .

analysis

TABLE II: Results of the fits to the ψ' and $M = 3872$ MeV regions. The errors are statistical only.

Quantity	ψ' region	$M = 3872$ MeV region
Signal events	489 ± 23	35.7 ± 6.8
$M^{\text{meas}}_{\pi^+\pi^- J/\psi}$ peak	3685.5 ± 0.2 MeV	3871.5 ± 0.6 MeV
$\sigma_{M\pi^+\pi^- J/\psi}$	3.3 ± 0.2 MeV	2.5 ± 0.5 MeV

analysis

Candidate ($^3D_{c2}$) test: BR

$$\Gamma(^3D_{c2} \to \gamma\chi_{c1}) > 5 \times \Gamma(^3D_{c2} \to \pi^+\pi^- J/\psi)$$

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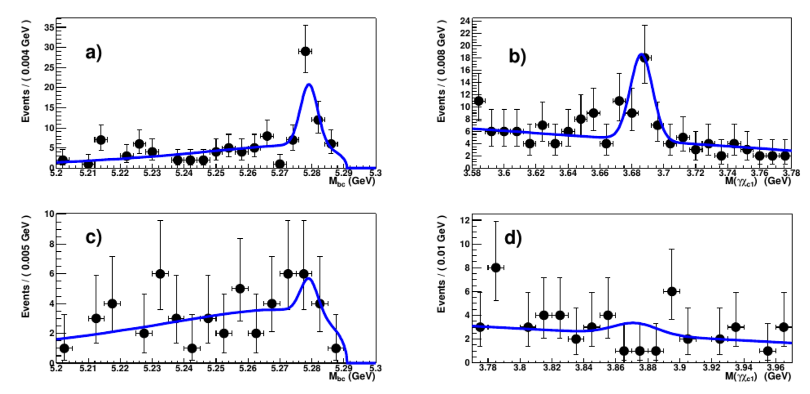

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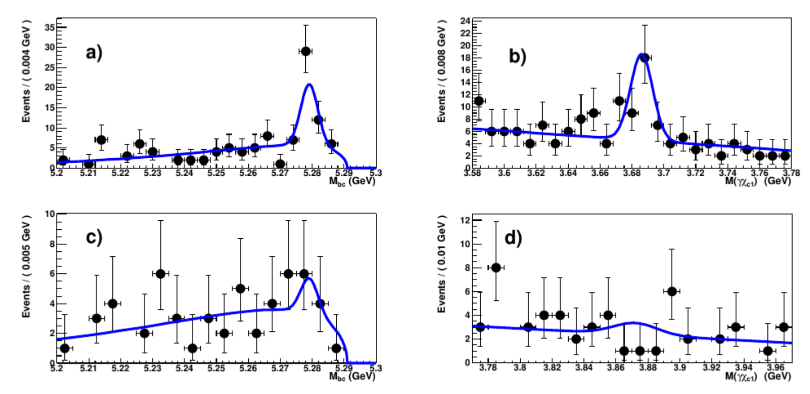
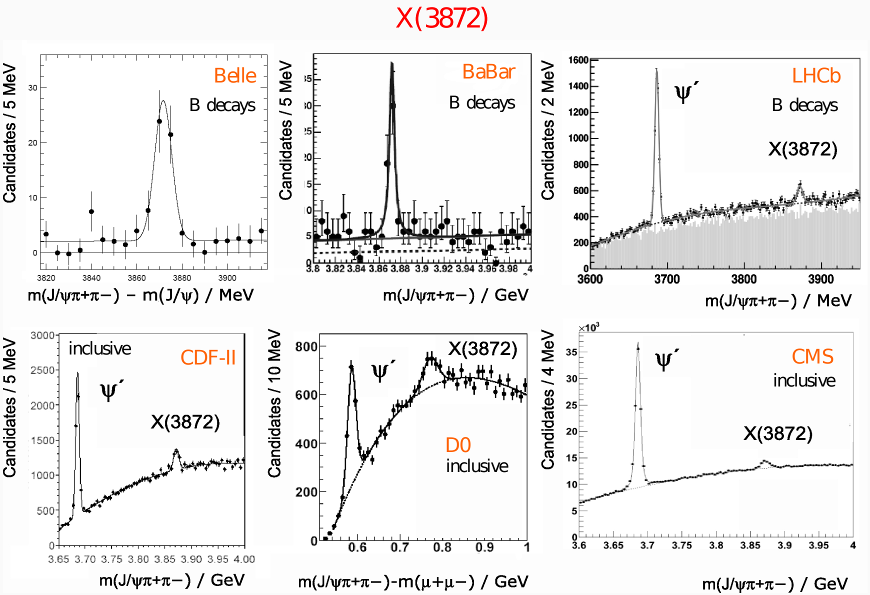


thus they named it X(3872)

xyz-states

x(3872) confirmed



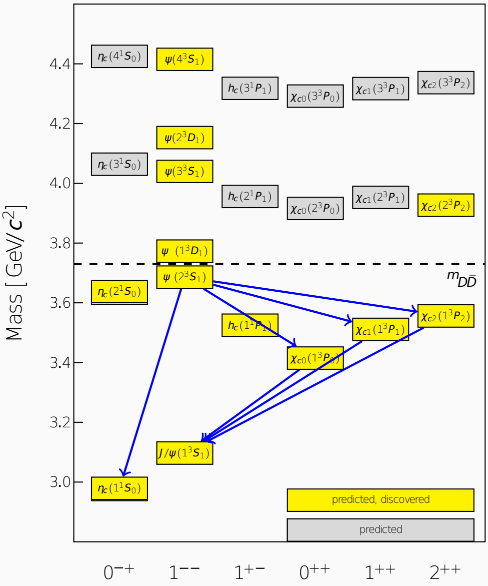
quantum numbers

LHCb,2013:

> *The quantum numbers of the X(3872) meson are determined to be $J^{PC} = 1^{++}$ based on angular correlations in $B^+ \to (3872)K^+$ decays, where $X(3872) \to \pi^+\pi^- J/\psi$ and $J/\psi \to \mu^+\mu^-$. The data correspond to $1.0\,\mathrm{fb}^{-1}$ of pp collisions collected by the LHCb detector. The only alternative assignment allowed by previous measurements $J^{PC} = 2^{-+}$ is rejected with a confidence level equivalent to more than 8 Gaussian standard deviations using a likelihood-ratio test in the full angular phase space. This result favors exotic explanations of the $X(3872)$ state.*

[hep:122245]

exotic



Mass [GeV/c^2]
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
$\eta_c(4^1S_0)$
$\psi(4^3S_1)$
$h_c(3^1P_1)$
$\chi_{c0}(3^3P_0)$
$\chi_{c1}(3^3P_1)$
$\chi_{c2}(3^3P_2)$
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$m_{D\bar{D}}$
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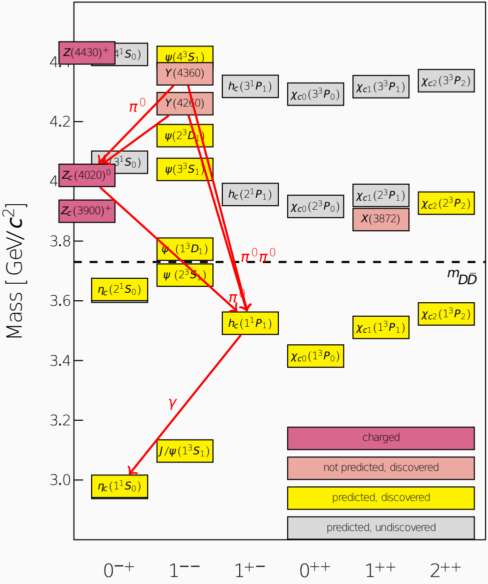
$\psi(2^3S_1)$
$\chi_{c2}(1^3P_2)$
$h_c(1^1P_1)$
$\chi_{c1}(1^3P_1)$
$\chi_{c0}(1^3P_0)$
$J/\psi(1^3S_1)$
$\eta_c(1^1S_0)$
predicted, discovered
predicted
0^{-+}
1^{--}
1^{+-}
0^{++}
1^{++}
2^{++}

exotic



Mass [GeV/c^2]
4.2
3.8
3.6
3.4
3.2
3.0
$Z(4430)^+$
$\psi(4^3S_1)$
$Y(4360)$
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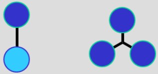
π^0
$h_c(3^1P_1)$
$\chi_{c0}(3^3P_0)$
$\chi_{c1}(3^3P_1)$
$\chi_{c2}(3^3P_2)$
$\psi(2^3D_1)$
$\psi(3^3S_1)$
$Z_c(4020)^0$
$Z_c(3900)^+$
$h_c(2^1P_1)$
$\chi_{c0}(2^3P_0)$
$\chi_{c1}(2^3P_1)$
$X(3872)$
$\chi_{c2}(2^3P_2)$
$\psi(1^3D_1)$
$\psi(2^3S_1)$
$\pi^0\pi^0$
$m_{D\bar{D}}$
$\eta_c(2^1S_0)$
π^0
$h_c(1^1P_1)$
$\chi_{c1}(1^3P_1)$
$\chi_{c2}(1^3P_2)$
$\chi_{c0}(1^3P_0)$
γ
$J/\psi(1^3S_1)$
$\eta_c(1^1S_0)$
charged
not predicted, discovered
predicted, discovered
predicted, undiscovered
0^{-+}
1^{--}
1^{+-}
0^{++}
1^{++}
2^{++}

qcd

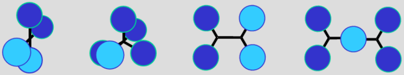
We know

mesons and baryons



QCD also allows

molecules/multi-quarks



hybrids

glueballs

and more

conclusion

- Belle Experiment observed CP violation in the neutral B Meson system (but not all asymmetry is explicable by that small CP violation)
- They(and others) analyzed bottomonium decays and found exotic states
- XYZ states are interesting, because they do not fit into the $q\bar{q}$ decay scheme