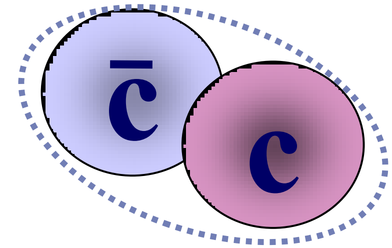
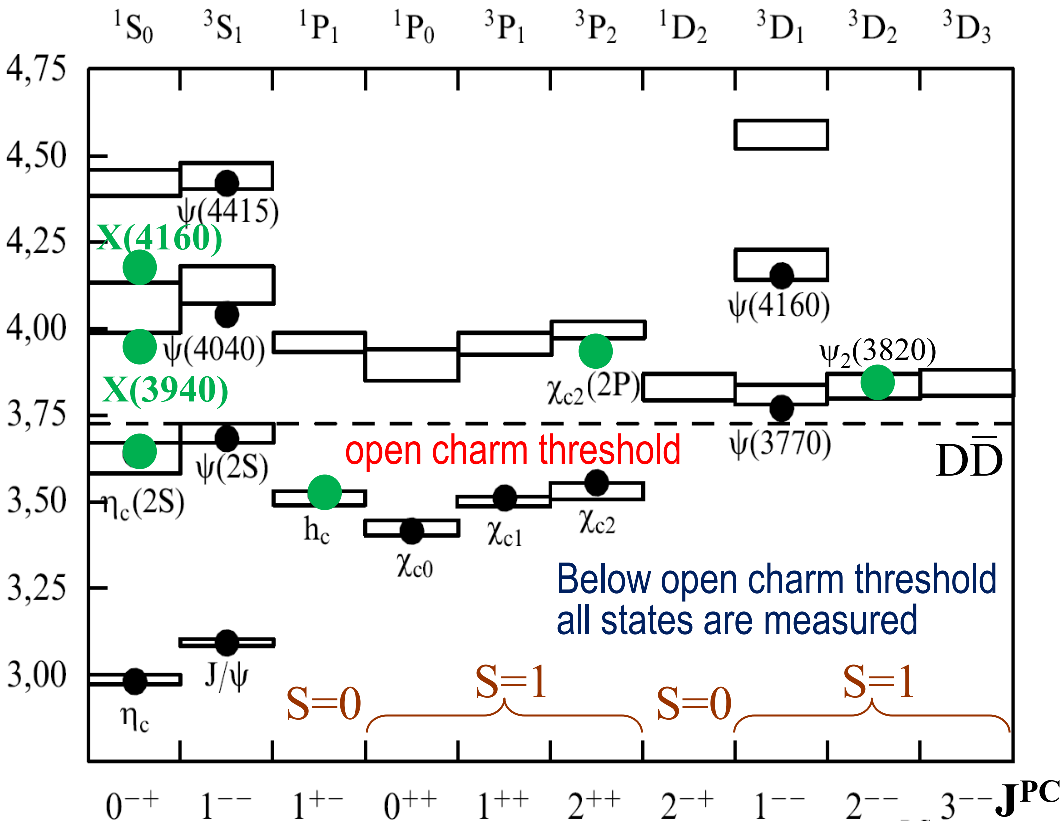
Charmonium and charmoniumlike states: present and future

Galina Pakhlova

ICPPA, October 7, 2015, Moscow, Russia

Charmonium in standard quark model



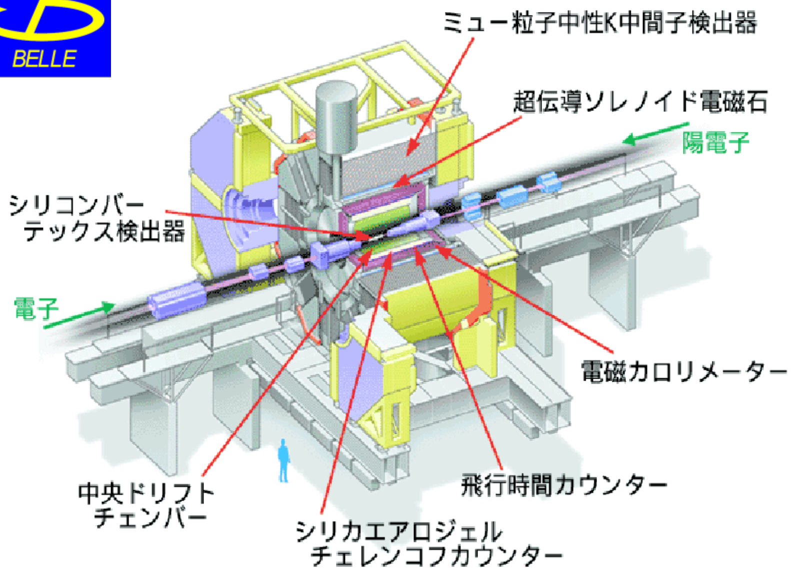


$(n+1)^{(2S+1)}L_J$

- n radial quantum number
- S total spin of quark-antiquark
- L relative orbital ang. mom.
  - L = 0, 1, 2 ... corresponds to S, P, D...
- J = S + L
- $P = (-1)^{L+1}$ parity
- $C = (-1)^{L+S}$ charge conj.

1974 -1980 Discovery of **10 standard charmonium states**
1980-2002 … nothing
2002-2013 Discovery of **6 standard charmonium states**

B factories

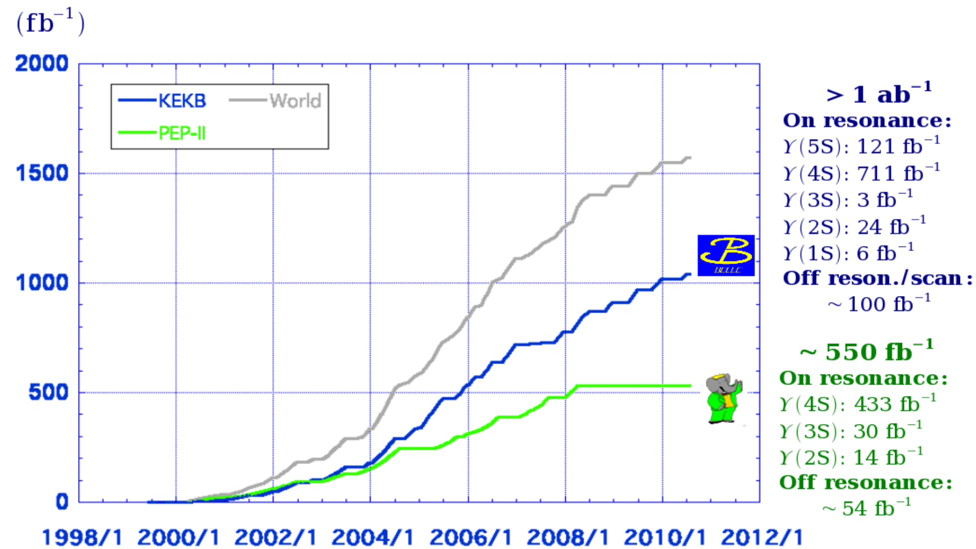


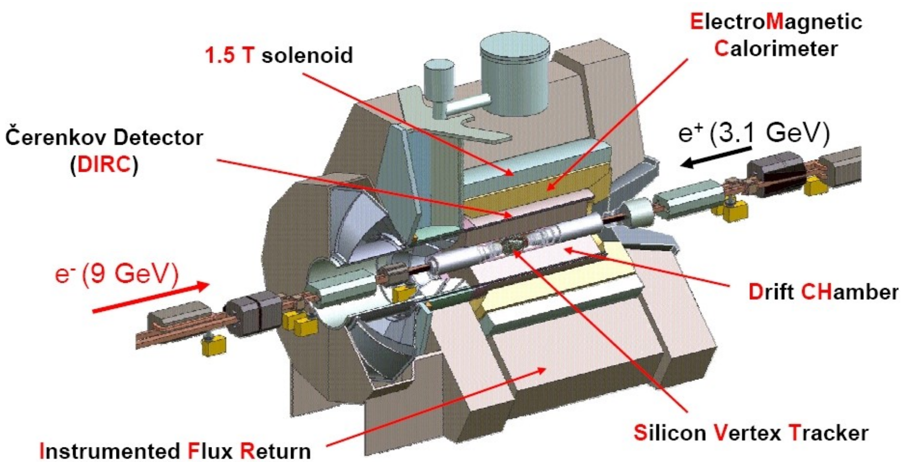
Belle: 8 GeV (e^-) × 3.5 GeV (e^+)

designed luminosity: $10.0 \times 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$

achieved $21.2 \times 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (>2 times larger!)

Luminosity at B factories





Belle completed data taking in 2010
to start SuperKEKB/Belle II upgrade

Charm factories

BESIII
Symmetric e^+e^- collider
$e^+e^- \to J/\psi$, $\psi(2S)$, $\psi(3770)$, etc
scan 2.0 - 4.6 GeV
$L \sim 10^{33}/\mathrm{cm}^2/\mathrm{s}$

LHC

pp collider

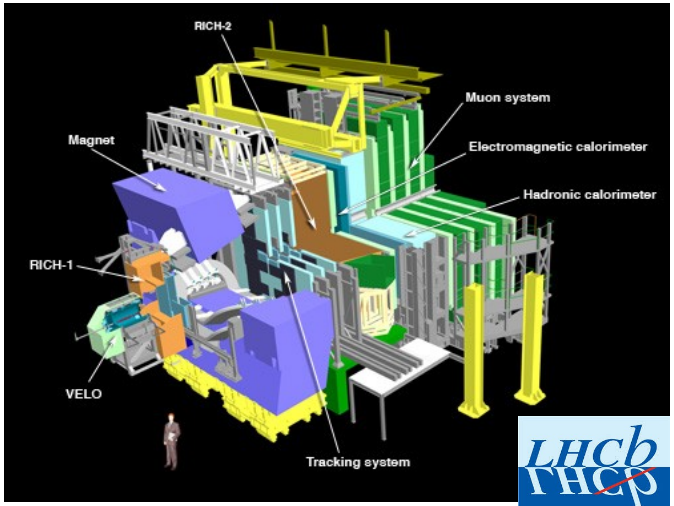
$E \sim 7$ TeV: $L \sim 5\,\mathrm{fb}^{-1}$ per experiment
$E \sim 8$ TeV: $L \sim 20\,\mathrm{fb}^{-1}$ per experiment

LHCb $E \sim 7$-8 TeV: $L \sim 3\,\mathrm{fb}^{-1}$

Tevatron

$p\bar{p}$ collider
$E \sim 1.8$ TeV: $L \sim 4\,\mathrm{fb}^{-1}$ per experiment

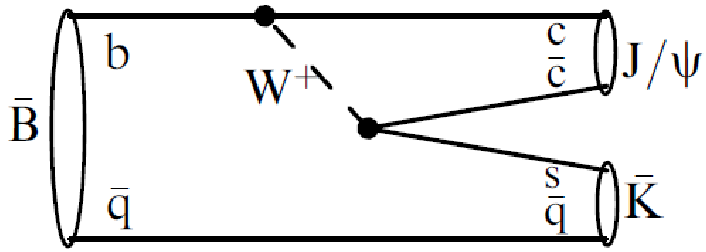
Charmonium
Prompt production
B meson decays



Charmonium
Prompt production
Beauty hadrons decays

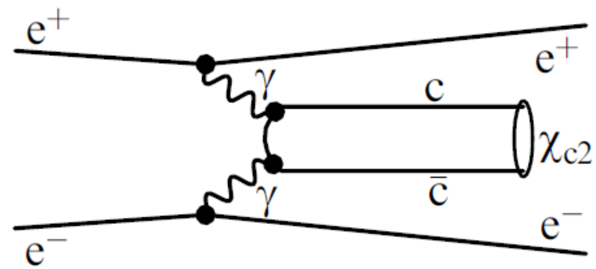
Charmonium production at B factories

B decays



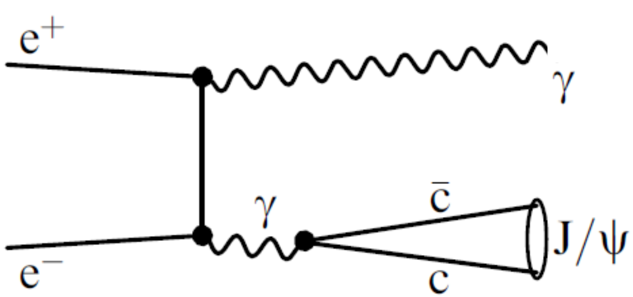
Any quantum numbers are possible, can be measured in angular analysis (Dalitz plot)

γγ fusion



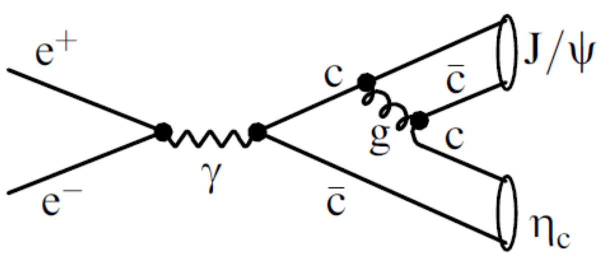
$J^{PC} = 0^{\pm+}, 2^{\pm+}$

e^+e^- annihilation with ISR



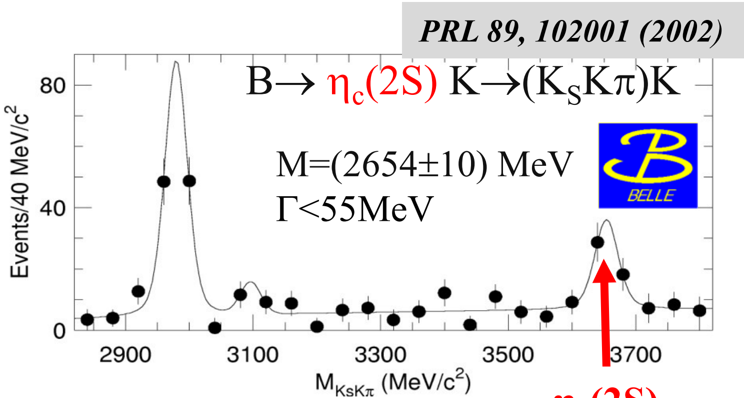
$J^{PC} = 1^{--}$

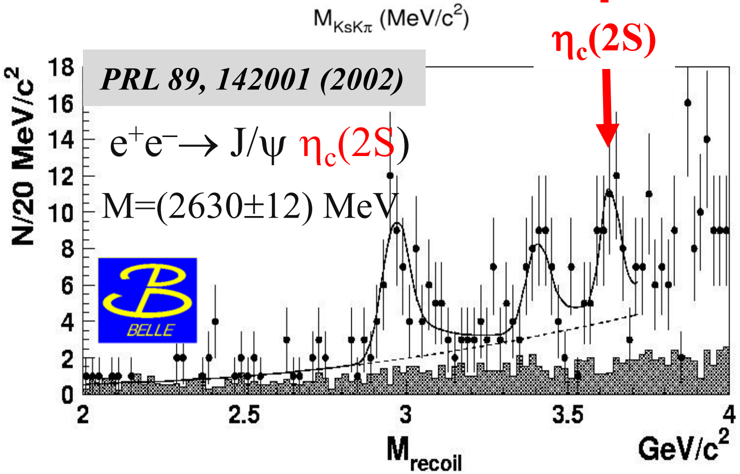
double charmonium production



in association with J/ψ only $J^{PC} = 0^{\pm+}$ seen

Observation of $\eta_c(2S)$ and h_c



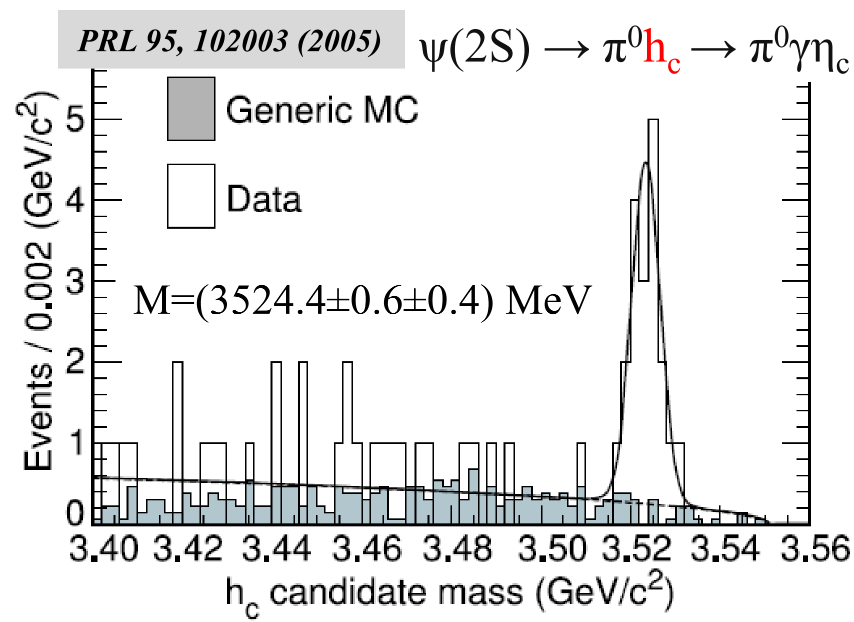


- $\eta_c(2S)$ first observed by Belle in B decays and in double charmonium production. Confirmed by CLEO, BaBar&Belle in $\gamma\gamma$
- h_c first observed by CLEO

For both $\eta_c(2S)$ and h_c the properties are in good agreement with the potential model expectations

- mass, total width, decays modes, $\gamma\gamma$-width

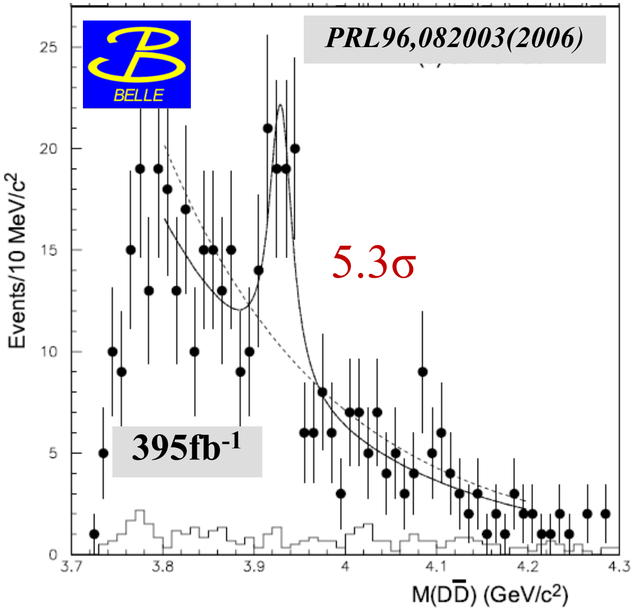
Charmonium table below DD threshold is completed!



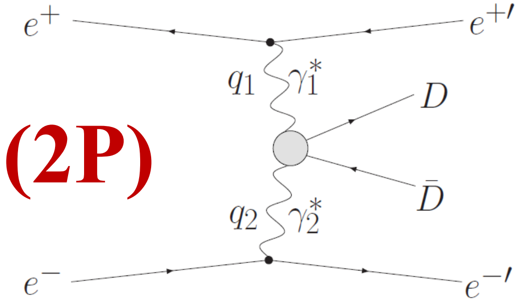
To be done

η_c : new decay modes, absolute BR measurements, improve mass, total width and $\Gamma_{\gamma\gamma}$

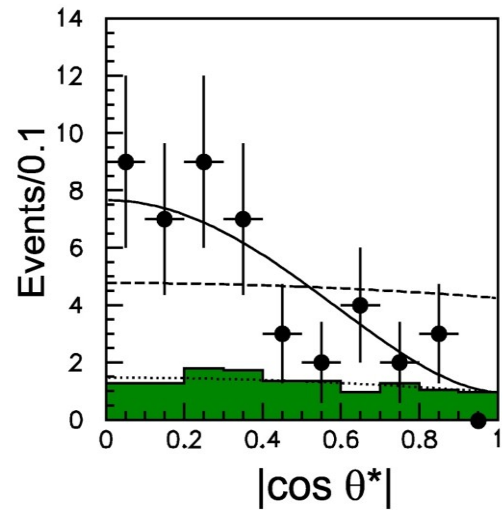
h_c : search in three body B decays: $B \to h_c K\pi$…



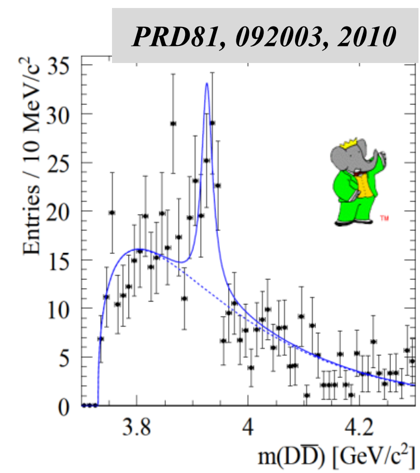
$\gamma\gamma \rightarrow Z(3940) = \chi_{c2}(2P)$



Helicity distribution favors J=2



Confirmed by BaBar



Decay mode, helicity distribution, $\Gamma_{\gamma\gamma}$ width prove out:

$Z(3940) = \chi_{c2}(2P) = 2^3P_2$

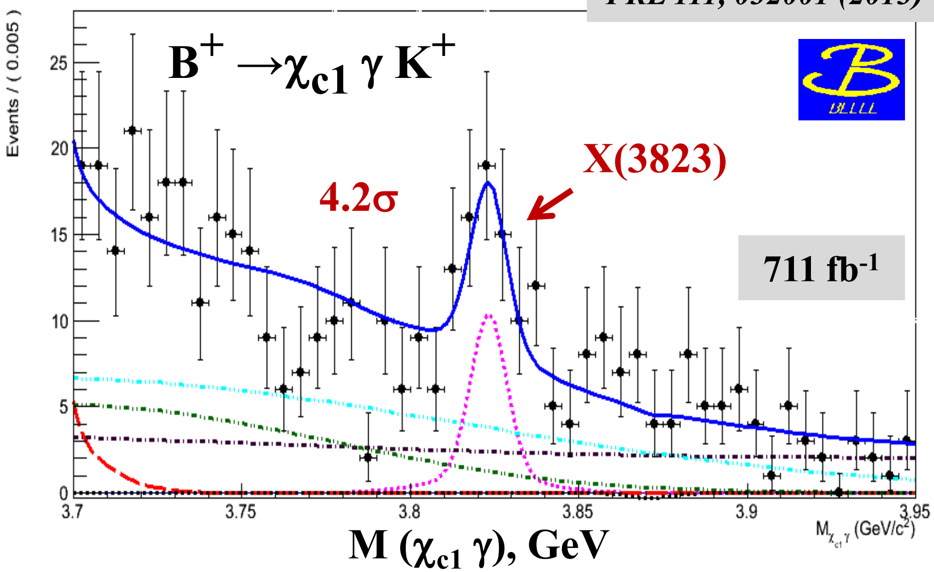
Mass is ~50-100 MэB/c^2 lighter than expected

To be done

Improve parameters, search in multi-body B decays

Exp.	Process	Luminosity (fb^{-1})	Mass (MeV/c^2)	Width (MeV)	Spin J^{PC}	$\Gamma_{\gamma\gamma}(\chi_{c2}(2P)) \times \mathcal{B}(\chi_{c2}(2P) \rightarrow D\bar{D})$ (keV)
Belle	$\gamma\gamma \rightarrow D\bar{D}$	395	$3929 \pm 5 \pm 2$	$29 \pm 10 \pm 2$	2^{++}	$0.18 \pm 0.05 \pm 0.03$
BABAR	$\gamma\gamma \rightarrow D\bar{D}$	384	$3926.7 \pm 2.7 \pm 1.1$	$21.3 \pm 6.8 \pm 3.6$	2^{++}	$0.24 \pm 0.05 \pm 0.04$

PRL 111, 032001 (2013)



X(3823) = $\psi(1^3D_2)$

X(3823)→$\chi_{c1}\gamma$ ⟹ C = –

1^{--}	**1^{+-}**	**2^{--}**	**3^{--}**
Ψ(3770)	**$h_c(2P)$**	**ψ_2**	**$\psi_3 \to DD$**

decay to DD is forbidden due to unnatural spin-parity → small Γ

decay to $\chi_{c1}\gamma$ should be prominent (E1)

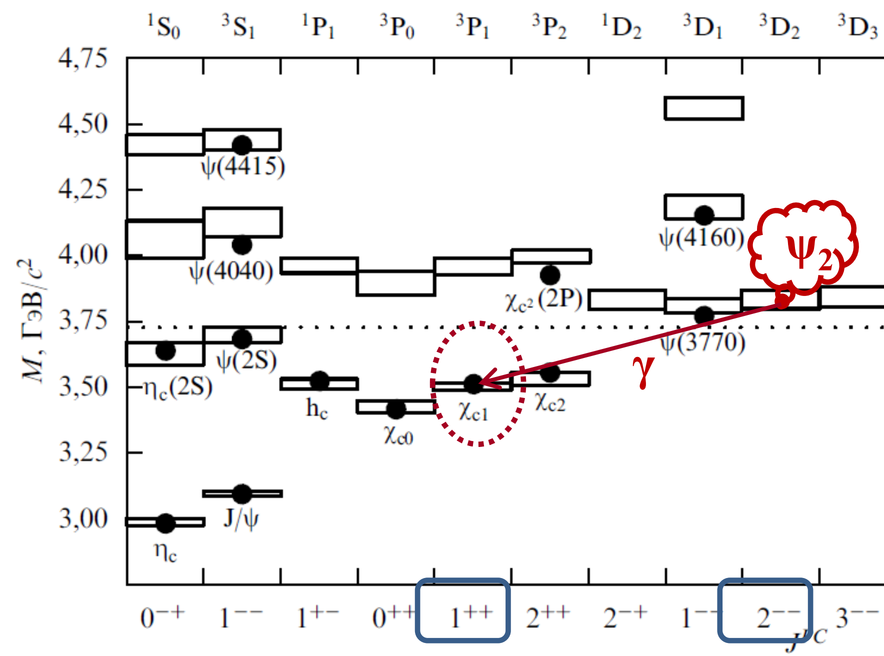
$\Gamma(\chi_{c1}\gamma) \sim O(10KeV)$ is typical for charmonium

Confirmed by BESIII, 6.2σ

ArXiv:1503.08203

M = 3823.5 ± 2.8 MeV

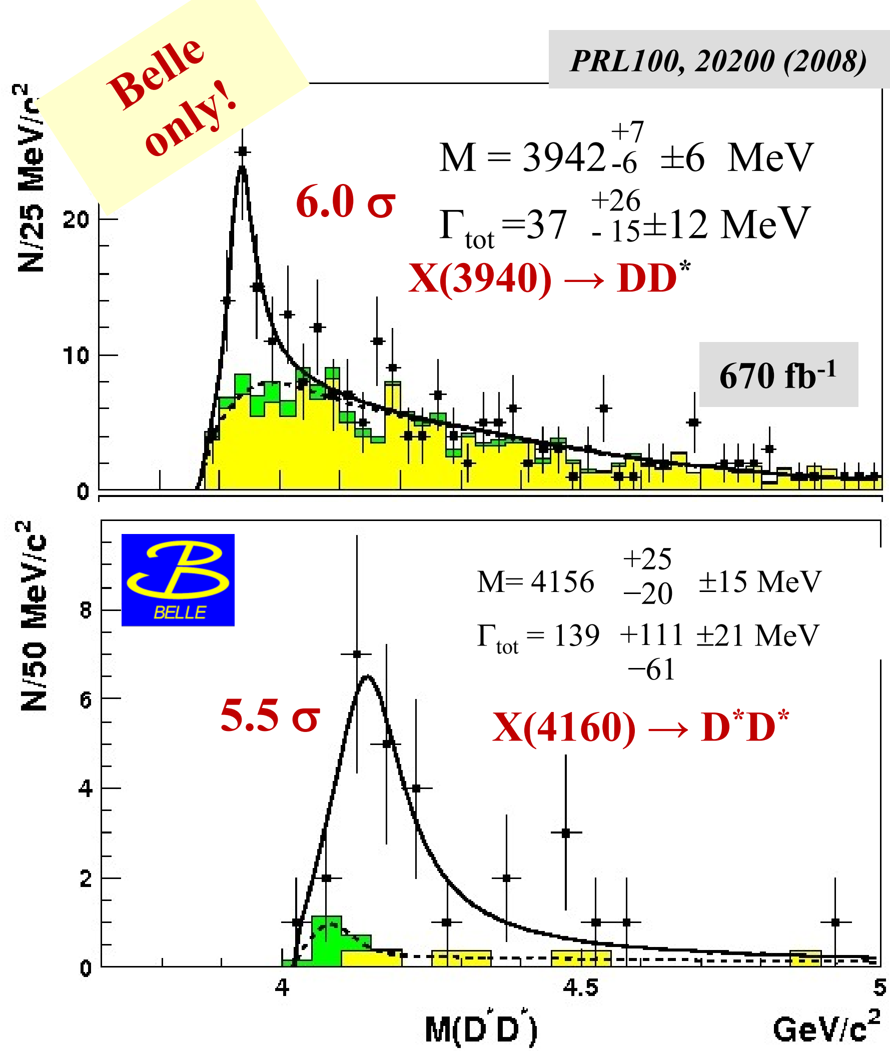
Γ = 4 ± 6 MeV, < 14 MeV @90%CL

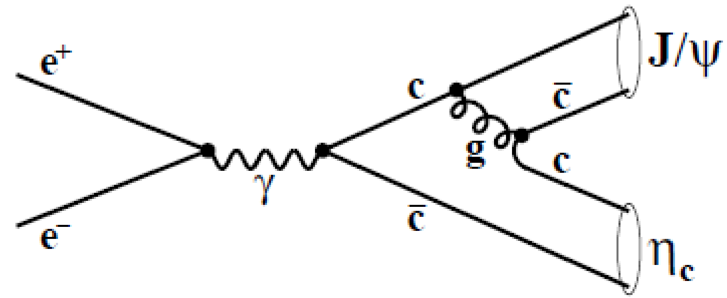


To be done

- Critical prove at Belle II
- To measure X(3823) decays to $J/\psi\pi^+\pi^-$ and $\chi_{c2}\gamma$ final states and to compare with theoretical predictions for $\psi(1^3D_2)$

Observation mode with two gammas in the final state is difficult for LHCb





X(3940) & X(4160) in $e^+e^- \to J/\psi\, D^*D^{(*)}$

$J^{PC}=0^{-+}$

$X(3940) = 3^1S_0 = \eta_c(3S)$

$X(4160) = 4^1S_0 = \eta_c(4S)$

Decays to open charm like standard charmonium

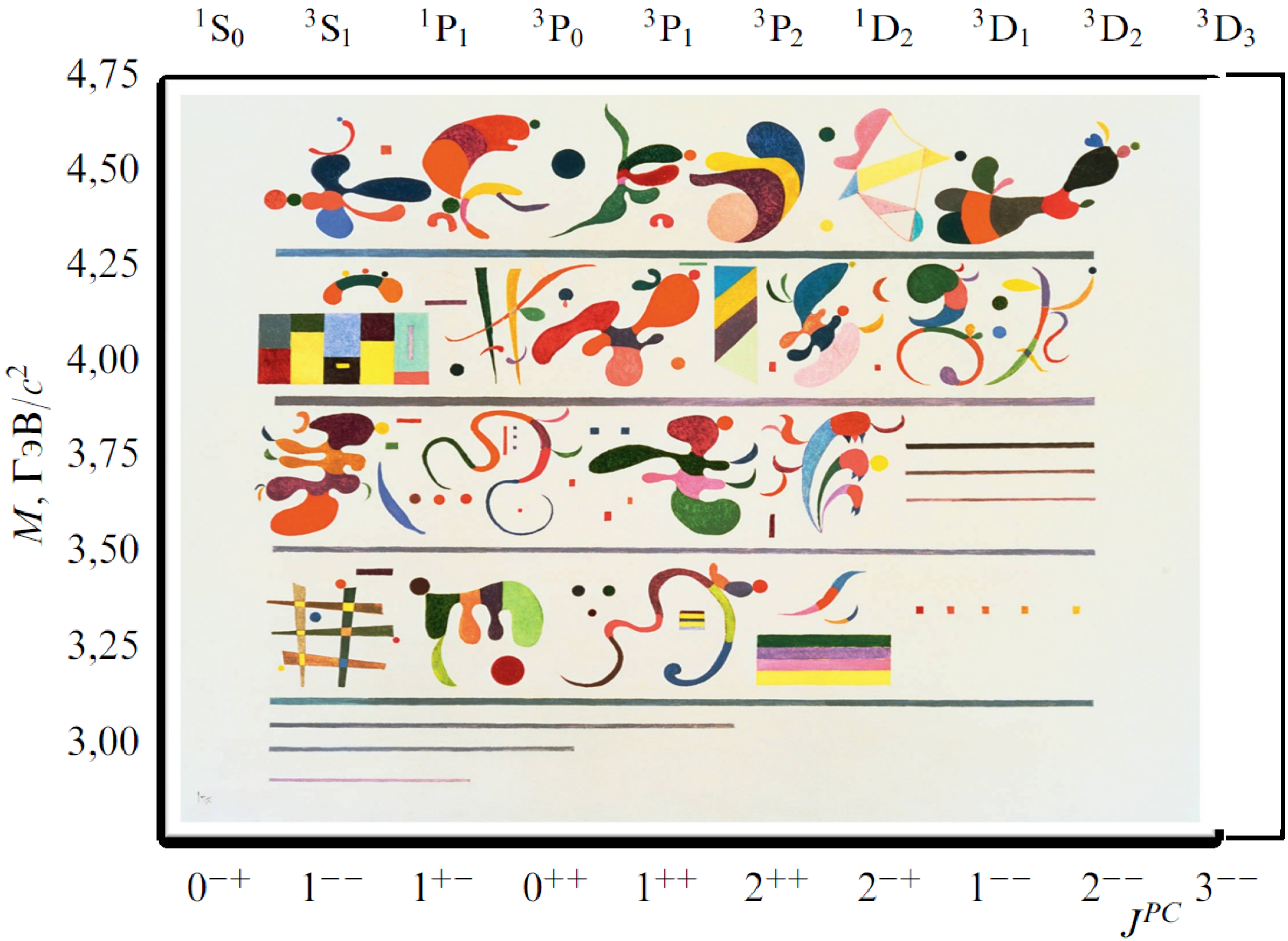
Mass of X(3940) &X(4160) are ~100-150 (250-300) MeV lower than the masses predicted by the potential models for $\eta_c(3S)$ and $\eta_c(4S)$

Theory probably needs more elaborate models to take into account charmonia couplings to meson pairs

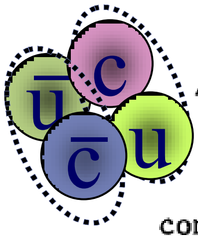
To be done

- Angular analysis for solid identification
- Search in B decays

New charmoniumlike spectroscopy



Exotic charmoniumlike states



Volume 8, number 3 PHYSICS LETTERS 1 February 1964

February 1964

A SCHEMATIC MODEL OF BARYONS AND MESONS *

M. GELL-MANN
California Institute of Technology, Pasadena, California

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

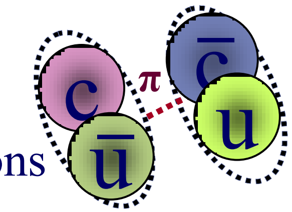
Multiquark states

Tetraquark

tightly bound four-quark state

Molecular state

two loosely bound charm mesons



Hydronic molecules and the charmonium atom

M. B. Voloshin and L. B. Okun'
Institute of Theoretical and Experimental Physics

March 1976

(February 16, 1976)
Pis'ma Zh. Eksp. Teor. Fiz. **23**, No. 6, 369–372 (20 March 1976)

We consider the possible existence of levels in a system consisting of a charmed particle and a charmed antiparticle; these levels result from exchange of ordinary mesons (ω,ρ,ε,ϕ, etc.). An interpretation of the resonances in e^+e^- annihilation in the region 3.9–4.8 GeV is proposed.

Molecular Charmonium: A New Spectroscopy?*

A. De Rújula, Howard Georgi,† and S. L. Glashow
Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 02138

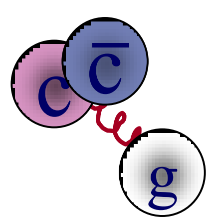
(Received 23 November 1976)

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.

November 1976

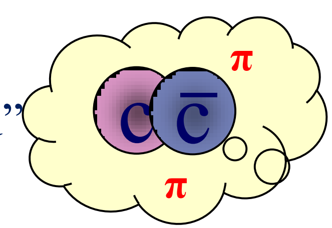
Charmonium hybrids

States with excited gluonic degrees of freedom

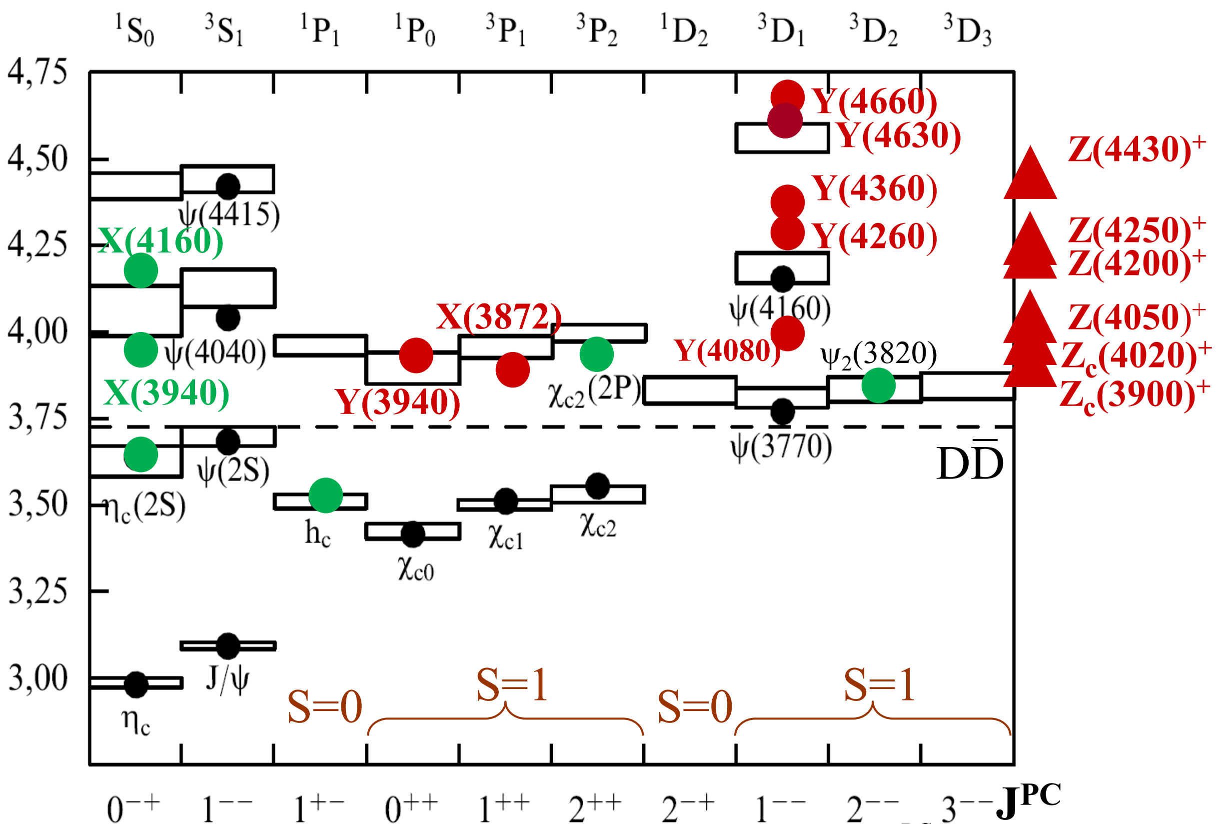


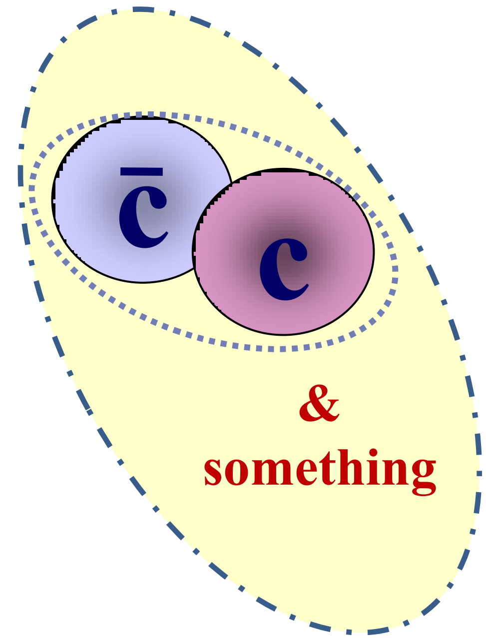
Hadro-charmonium

Specific charmonium state "coated" by excited light-hadron matter



Charmonium & Charmoniumlike states

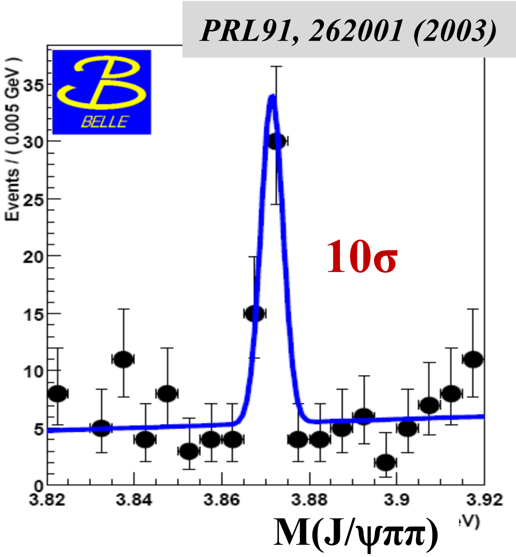




2002-2013 Discovery of **6 standard charmonium states**

2002-2015 Discovery of **13(+4?) exotic charmonium states**

All of them above open charm threshold



X(3872)

M_X close to D^0D^{*0} threshold

$M = 3871.68 \pm 0.17$ MeV

not clear below or above:

$\Delta m = -0.11 \pm 0.22$ MeV

surprisingly narrow:

$\Gamma_{tot} < 1.2$ MeV at 90% CL

$J^{PC} = 1^{++}$ finally established

Belle topcited: 1000+

First observed by Belle in

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

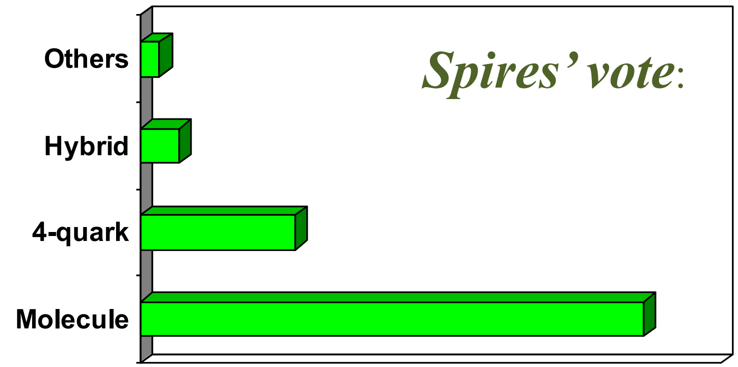
Confirmed:

BaBar, LHCb, CMS, ATLAS, CDF

<u>Hadronic collisions</u>: produced mostly promptly; only 0.263±0.023±0.016 from B-decays (CMS)

Known decays	BR relative to $J/\psi\rho$ mode	Comments
$J/\psi\rho$	1	isospin violation
$J/\psi\omega$	0.8 ± 0.3	isospin violation
$J/\psi\gamma$	0.21 ± 0.06	Belle&Babar good agreement
$\psi(2S)\gamma$	0.50 ± 0.15	Belle&Babar disagreement LHCb confirms BaBar
D^0D^{*0}	~10	dominant mode

X(3872) interpretations



Conventional charmonium χ_{c1} (2P) ($J^{PC}=1^{++}$)

Problems:

- $\Gamma(\chi_{c1}(2P) \to J/\psi\gamma)/\Gamma(\chi_{c1}(2P) \to J/\psi\pi\pi) \sim 30$, **measured < 0.2**
- ~ 100MeV heavier then expected

D^0D^{*0} molecular state: (the most popular)

- $M_X \sim M_{D0} + M_{D^*0}$ is not accidental
- $J^{PC}=1^{++}$ (D^0D^{*0} in S-wave)
- DD^* decay
- Small rate for decay into $J/\psi\gamma$ is expected

Tetraquark (cq)(cq):

+ 3 states (cu)(cu), (cd)(cu), (cd)(cd) with a few MeV mass splitting

Problems:

no evidence of neither neutral doublet nor charged partner yet

Problems:

- too large $X(3872) \to \psi(2S)\gamma$
- too small binding energy: D^0 and D^{*0} too far in space to be produced in high energy pp collisions

Possible solution:

Mixture of P-wave charmonium level χ_{c1}(2P) and S-wave DD^{*0} molecule

X(3872): to be done

Search for X(3872) partners decays	Comments
$\chi_{c1}\,\gamma$ $\chi_{c2}\,\gamma$	Forbidden by C-parity conservation C-odd partners: tetraquark, molecule UL : $<$ 1/4 from $J/\psi\ \pi^+\pi^-$
$J/\psi\ \eta$	C-odd partners: tetraquark UL : $<$ 1/2 from $J/\psi\ \pi^+\pi^-$
$\eta_c\,\eta$ $\eta_c\,\pi^0$ $\eta_c\,\pi^+\pi^-$ $\eta_c\,\omega$	Search for other X-like molecular states UL : $\sim J/\psi\ \pi^+\pi$

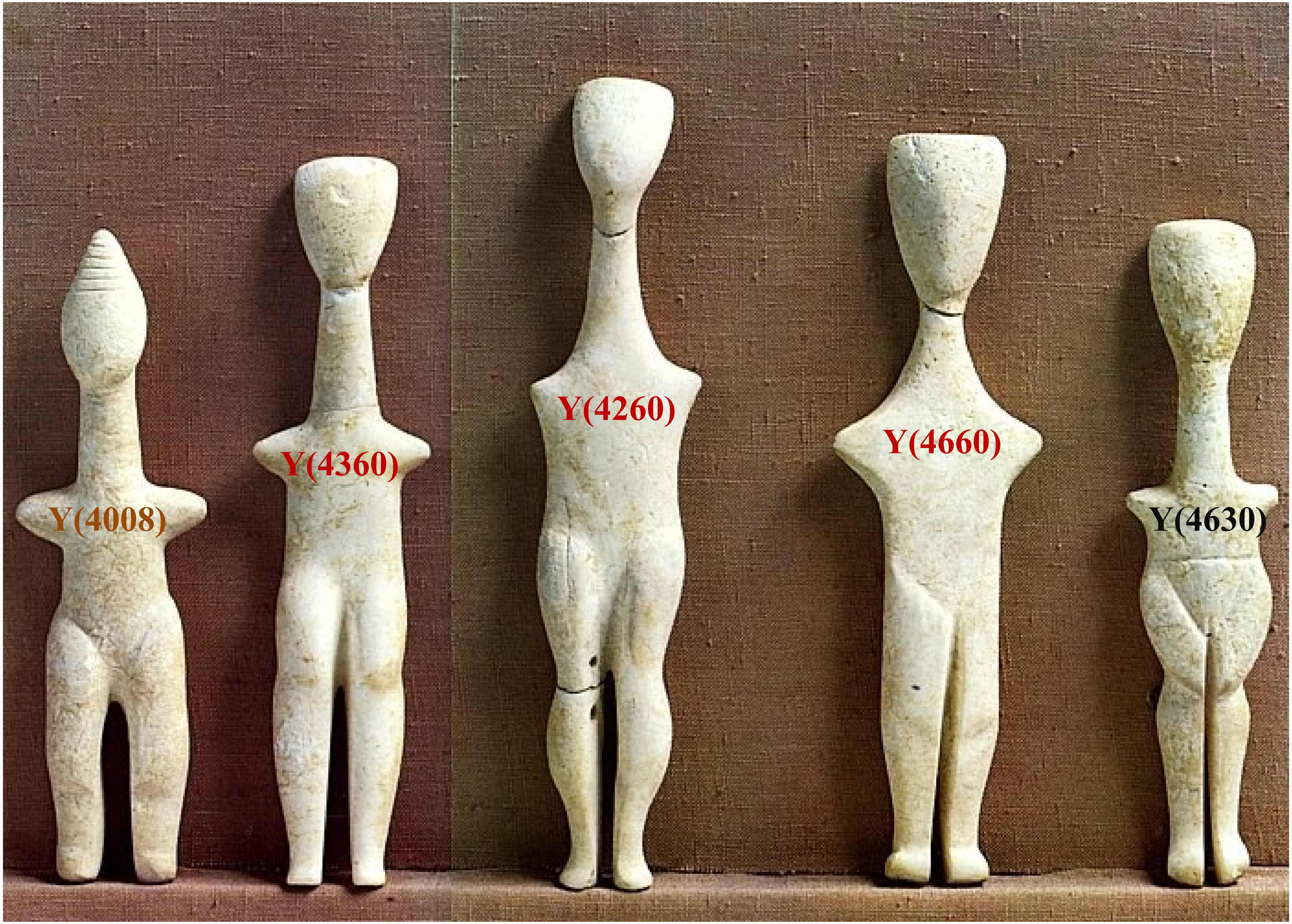
○ Detailed pattern of X(3872) to charmonium transitions (radiative and hadronic) with significantly improved accuracy

○ Search for partners of X(3872)
molecules with $J^{PC} = 0^{++}, 1^{+-}, 2^{++}\ldots$

○ Measurements of absolute BR of $B \to KX(3872)$

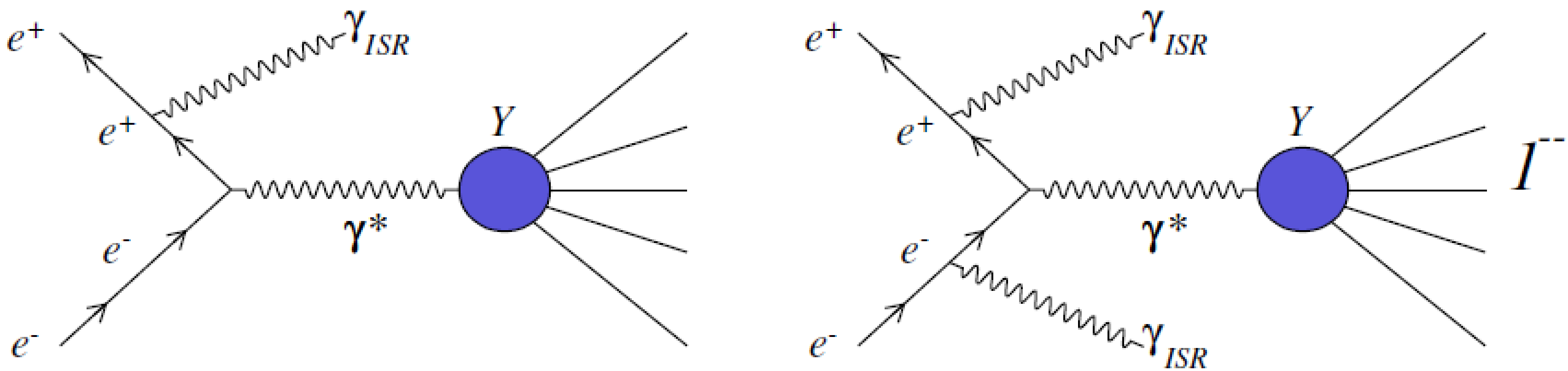
○ Measurements of line shape of X(3872) decaying to DD^* at threshold and to $J/\psi\pi^+\pi^-$ to clarify nature of X(3872): virtual or bound state ***Yu.S.Kalashnikova, A.V.Nefediev PRD80, 074004 (2009)***

○ Measurements of the total width of X(3872)



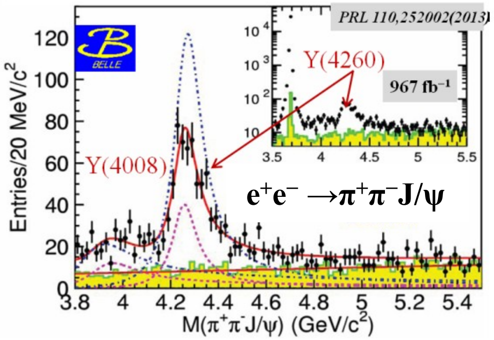
Vector states

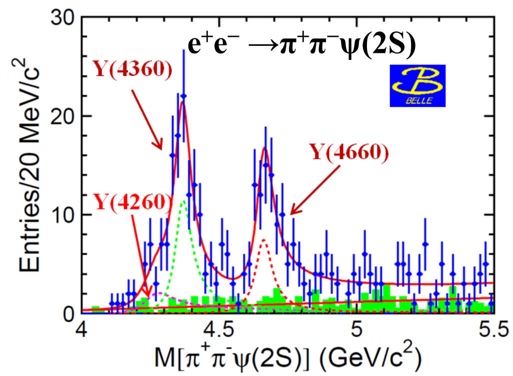
Vector states in e⁺e⁻ annihilation with ISR

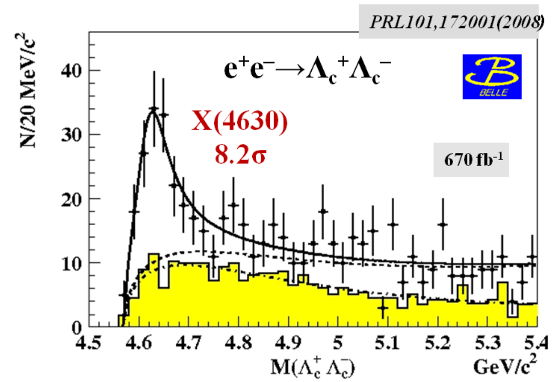


$Y(4008)$	3891 ± 42	255 ± 42	1^{--}	$e^+e^- \to (\pi^+\pi^- J/\psi)$	Belle [1046, 1094] (7.4)	2007	NC!
$Y(4260)$	4250 ± 9	108 ± 12	1^{--}	$e^+e^- \to (\pi\pi J/\psi)$	BaBar [1104, 1105] (8), CLEO [1106, 1107] (11) Belle [1046, 1094] (15), BES III [1045] (np)	2005	Ok
				$e^+e^- \to (f_0(980) J/\psi)$	BaBar [1105] (np), Belle [1046] (np)	2012	Ok
				$e^+e^- \to (\pi^- Z_c(3900)^+)$	BES III [1045] (8), Belle [1046] (5.2)	2013	Ok
				$e^+e^- \to (\gamma X(3872))$	BES III [1108] (5.3)	2013	NC!
$Y(4360)$	4354 ± 11	78 ± 16	1^{--}	$e^+e^- \to (\pi^+\pi^- \psi(2S))$	Belle [1110] (8), BaBar [1111] (np)	2007	Ok
$X(4630)$	4634^{+9}_{-11}	92^{+41}_{-32}	1^{--}	$e^+e^- \to (\Lambda_c^+ \bar{\Lambda}_c^-)$	Belle [1116] (8.2)	2007	NC!
$Y(4660)$	4665 ± 10	53 ± 14	1^{--}	$e^+e^- \to (\pi^+\pi^- \psi(2S))$	Belle [1110] (5.8), BaBar [1111] (5)	2007	Ok

10th anniversary of Y family discovery

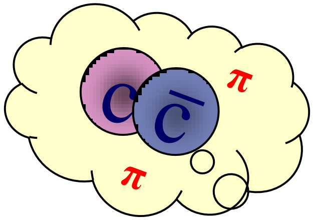






It seems that up to now we have not found an ISR state that has more than one decay mode

Open question: nature of Yfamily

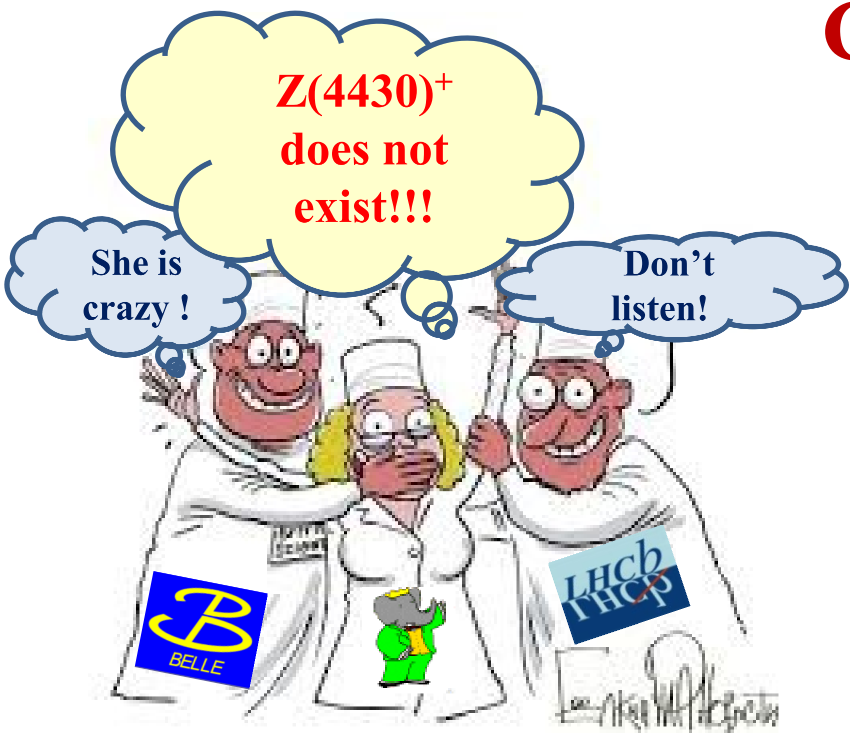


__**To be done**__

- Improve accuracy
- Confirm Y(4008)
- Confirm X(4630) found by Belle only
- Resolve X(4630) &Y(4660) puzzle
- Search for other final states: χ_{c1} , χ_{c2} ,η_c, X(3872) + and/or other light hadrons
  - Up to now only J/ψ, ψ(2S) + ππ, η


Z (4430)$^{\pm}$
Z(4050)$^{\pm}$ & Z(4250)$^{\pm}$
Z(4200) $^{\pm}$ et al
or
exotic only
$\bar{u}$ c d $\bar{c}$

Charged charmoniumlike states at Belle



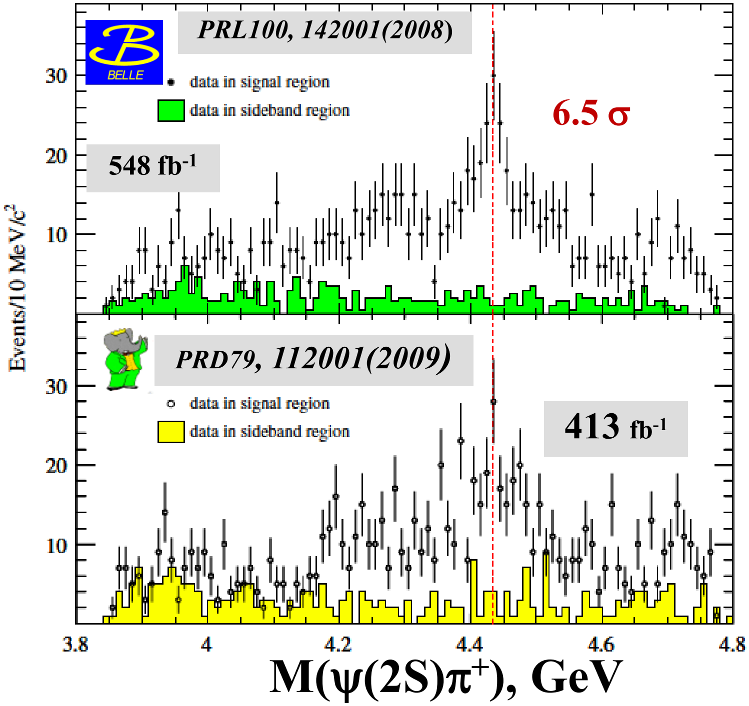
Charged Z_c^+ states cannot be conventional charmonium or hybrid

From four states found by Belle in B decays only $Z(4430)^+$ is confirmed (by LHCb)

Two states are found by Belle in e^+e^- annihilation + five more by BESIII

$Z(4430)^+$	4458 ± 15	166^{+37}_{-32}	1^{+-}	$B^0 \to K^-(\pi^+\psi(2S))$	Belle [1112, 1113] (6.4), BaBar [1114] (2.4) LHCb [1115] (13.9)	2007	Ok
				$\bar{B}^0 \to K^-(\pi^+J/\psi)$	Belle [1103] (4.0)	2014	NC!
$Z(4050)^+$	4051^{+24}_{-43}	82^{+51}_{-55}	$??+$	$\bar{B}^0 \to K^-(\pi^+\chi_{c1})$	Belle [1096] (5.0), BaBar [1097] (1.1)	2008	NC!
$Z(4200)^+$	4196^{+35}_{-30}	370^{+99}_{-110}	1^{+-}	$\bar{B}^0 \to K^-(\pi^+J/\psi)$	Belle [1103] (7.2)	2014	NC!
$Z(4250)^+$	4248^{+185}_{-45}	177^{+321}_{-72}	$??+$	$\bar{B}^0 \to K^-(\pi^+\chi_{c1})$	Belle [1096] (5.0), BaBar [1097] (2.0)	2008	NC!

More details: Kirill Chilikin, "Charged charmoniumlike states at Belle", 6.10.2015 ICPPA



$B \to Z^+_c K^-$

$Z(4430)^+$: three different analysis, $J^P = 1^+$

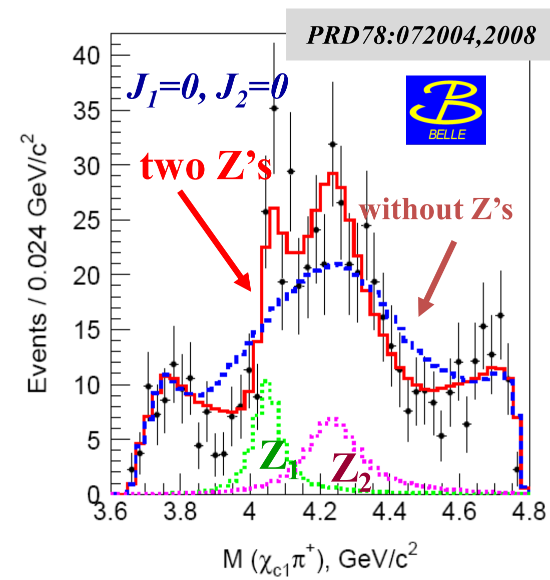
- Fit to $M(\psi(2S)\pi^+)$ with $K^*(890)$&$K^*(1430)$ veto
- Dalitz analysis
- Full amplitude analysis to obtain spin-parity

Mass values are the same, width depends on method

$Z(4050)^+$ & $Z(4050)^+$

in $\chi_{c1}\pi^+$ final state

- Daliz analysis



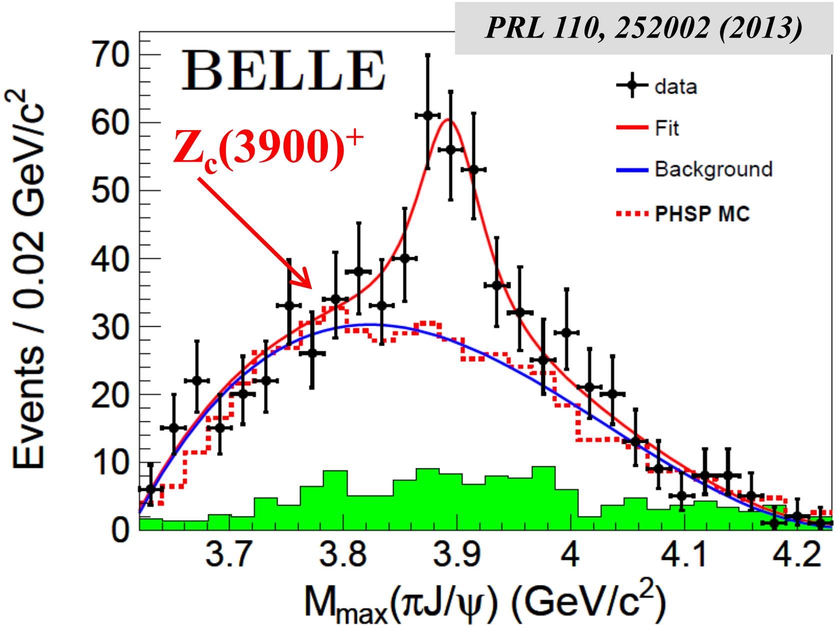
$Z_c(4200)^+$ in $J/\psi\ \pi^+$ final state, $J^P=1^+$

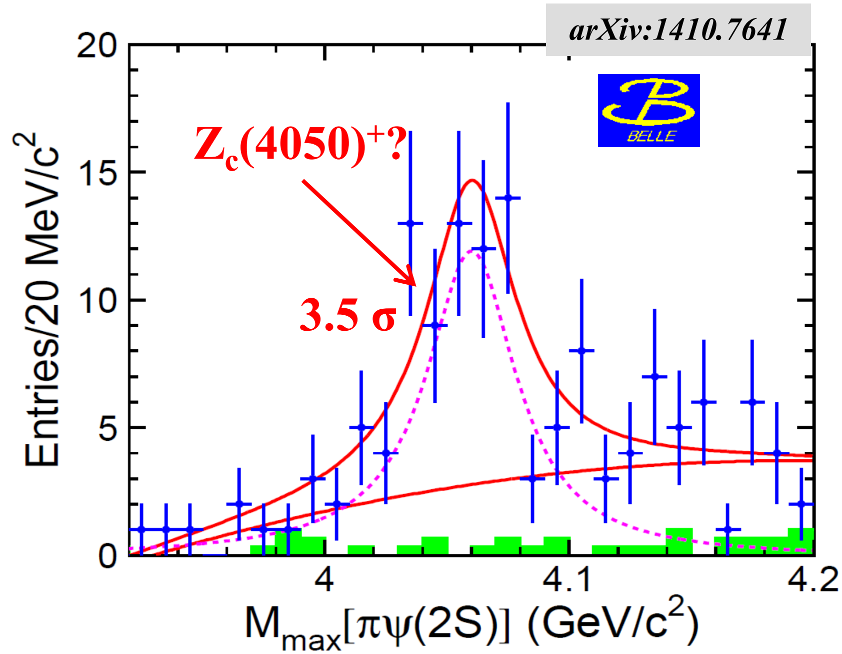
- 4D-fit: Dalitz + angular variables
- New decay mode $Z_c(4430)^+ \to J/\psi\ \pi$
  - order of magnitude suppressed (to $\psi(2S)\pi$) despite larger phase space

BaBar does not confirm Belle, but also does not rule it out!

More details: Kirill Chilikin, "Charged charmoniumlike states at Belle", 6.10.2015 ICPPA

Z_c family in e^+e^- annihilation





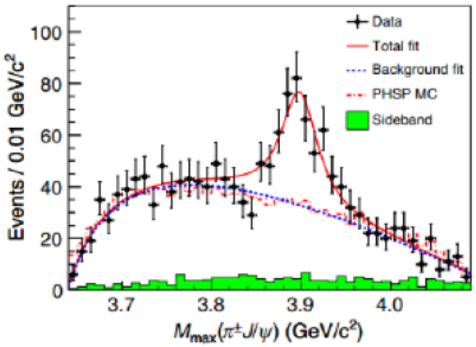
$J/\psi\pi$ mass from Y(4260) peaking at DD^* threshold

New signal in $Y(4360) \rightarrow \pi^- Z(4050)^+$
Belle only

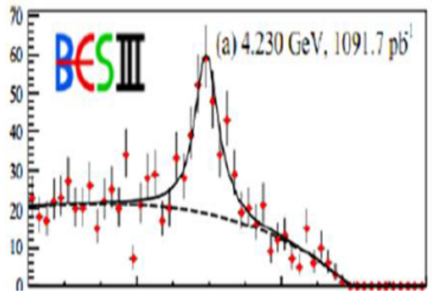
Only one charged state from the long BESIII list is confirmed by Belle (due to limited statistic)
$\mathbf{Z_c(3900)^+ \rightarrow J/\psi\pi^+}$, $Z_c(3900)^0 \rightarrow J/\psi\pi^0$, $Z_c(3885)^+ \rightarrow DD^*$, $Z_c(4020)^+ \rightarrow \pi^+ h_c$, $Z_c(4020)^0 \rightarrow \pi^0 h_c$, $Z_c(4025)^+ \rightarrow D^*D^*$

To be done
Confirm (or not) the BESIII & Belle charmoniumlike states & to look for new structures in $\pi\psi(2S)$ et al using ISR

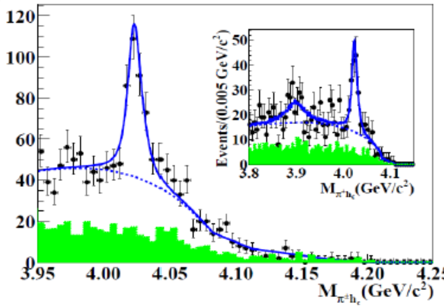
Overview of Z_c states



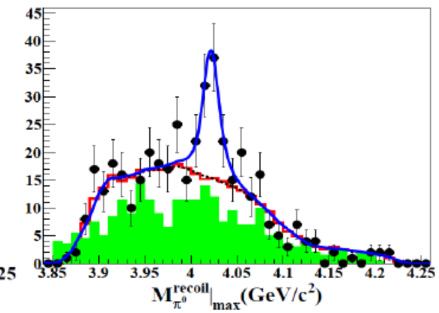
$e^+e^- \rightarrow \pi^-\pi^+J/\psi$



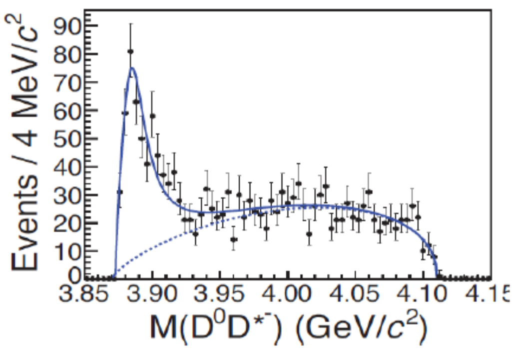
$e^+e^- \rightarrow \pi^0\pi^0J/\psi$



$e^+e^- \rightarrow \pi^-\pi^+h_c$



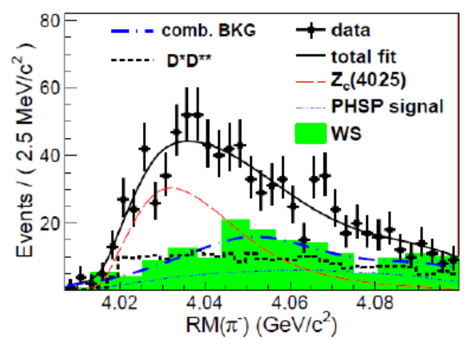
$e^+e^- \rightarrow \pi^0\pi^0h_c$



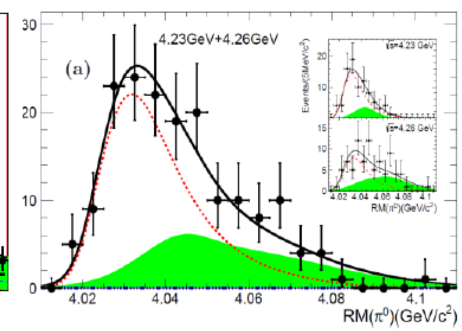
$e^+e^- \rightarrow \pi^{\pm}(D\bar{D}^*)^{-/+}$

Preliminary

soon…



$e^+e^- \rightarrow \pi^{\pm}(D^*\bar{D}^*)^{-/+}$



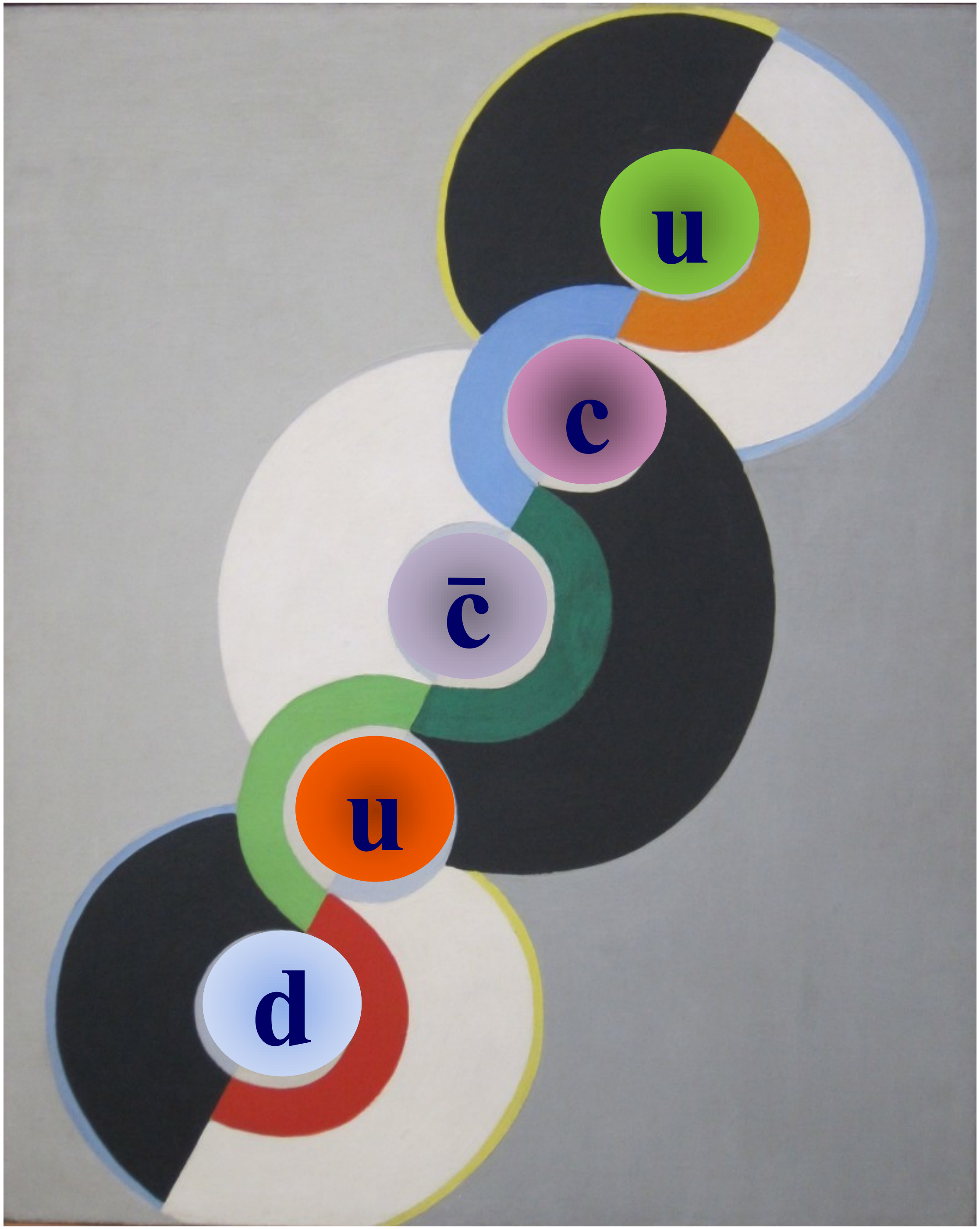
$e^+e^- \rightarrow \pi^0(D^*\bar{D}^*)^0$

$Z_c(3900)^{\pm}$?

$Z_c(3900)^0$?

$Z_c(4020)^{\pm}$?

$Z_c(4020)^0$?

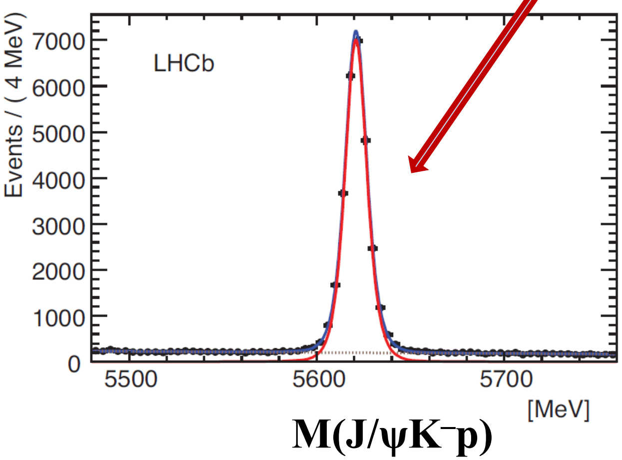


Pentaquark?
Charmoniumlike?

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

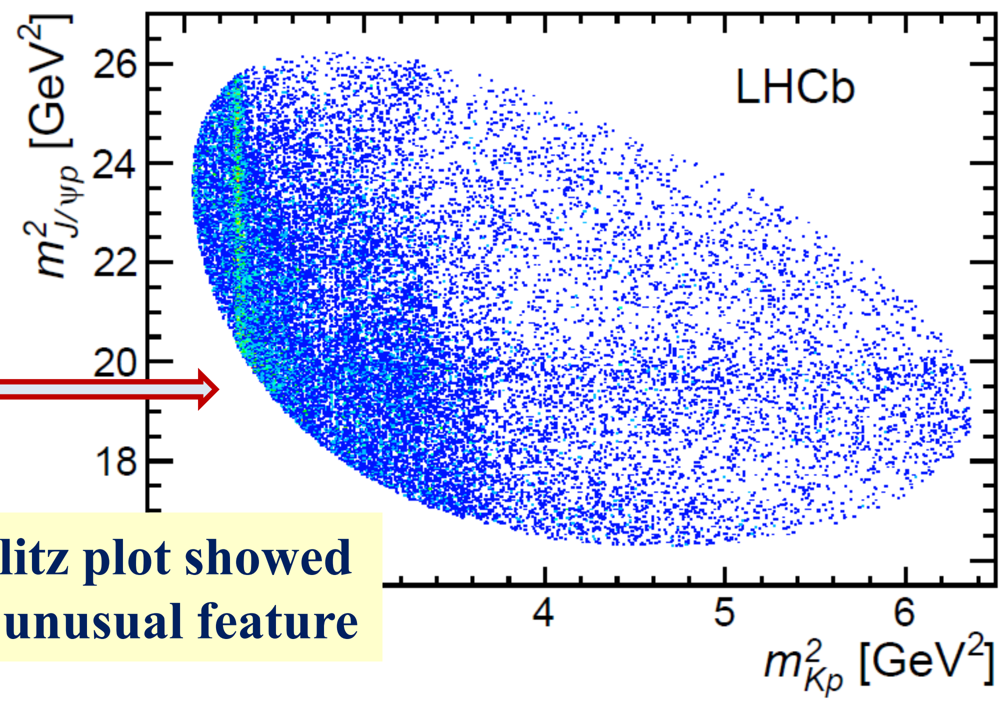
LHCb: search for background for $B^0 \to J/\psi K^- K^+$

Large signal found



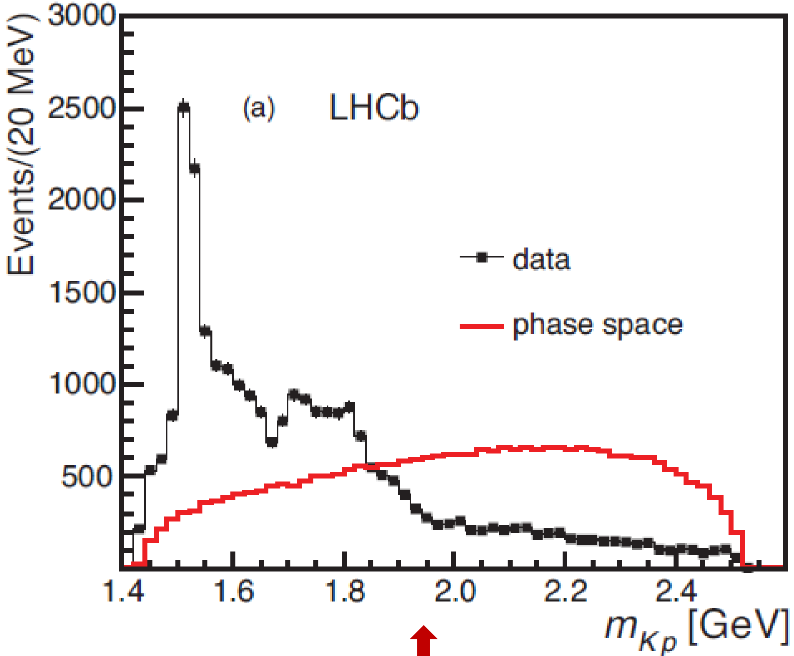
$\Lambda^{(*)}$ …

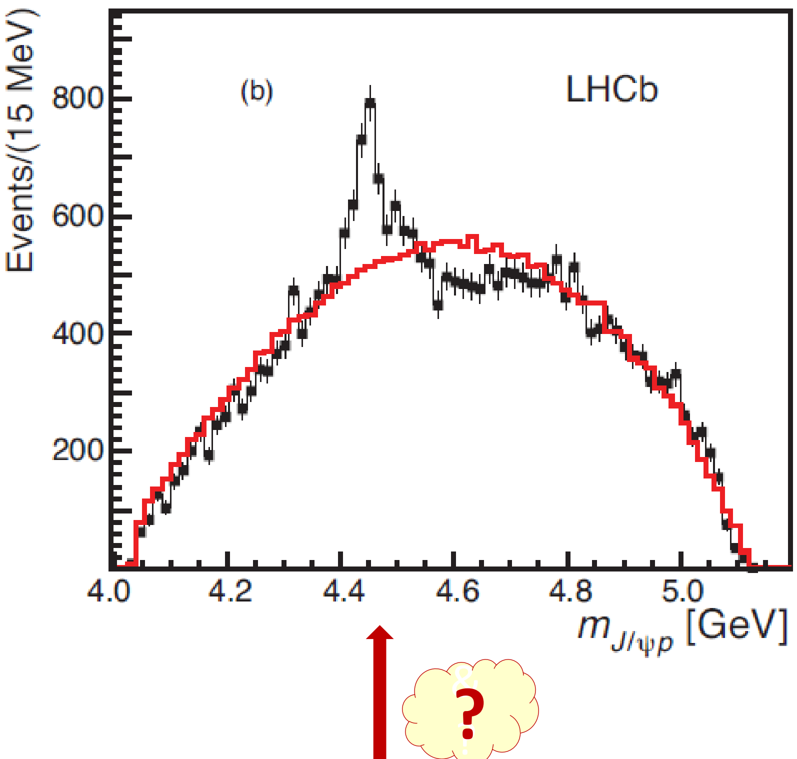
ArXiv:1507.03414

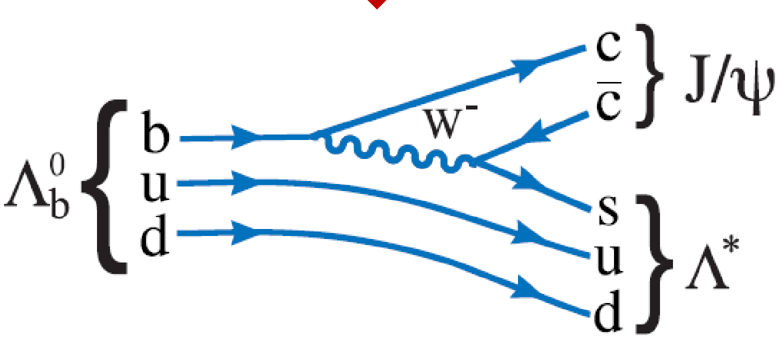


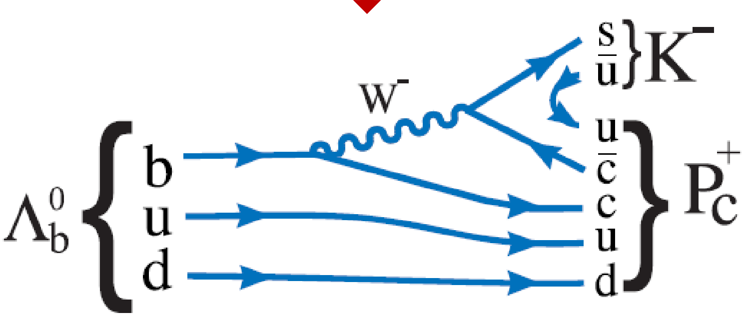
Dalitz plot showed an unusual feature

Projections







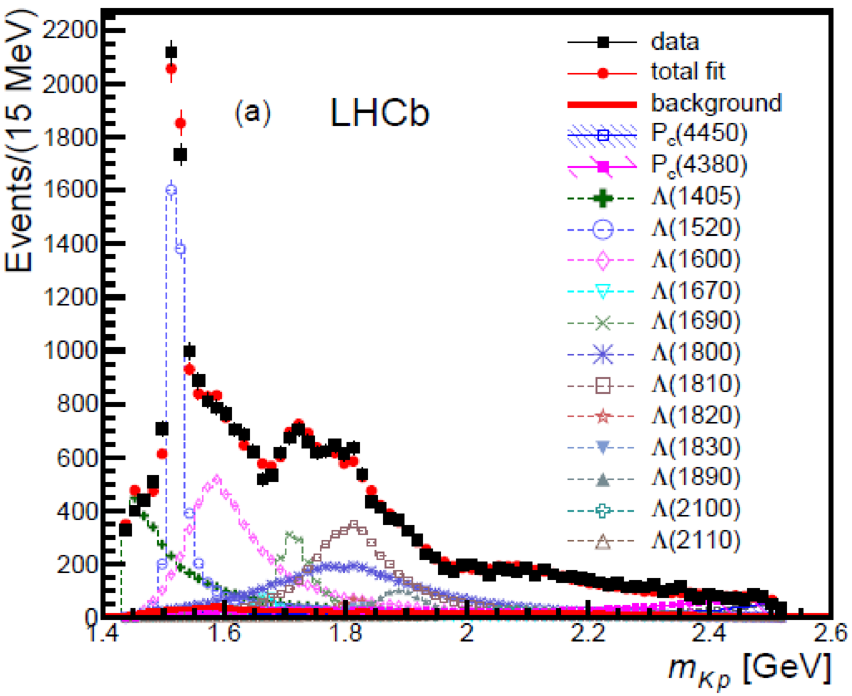


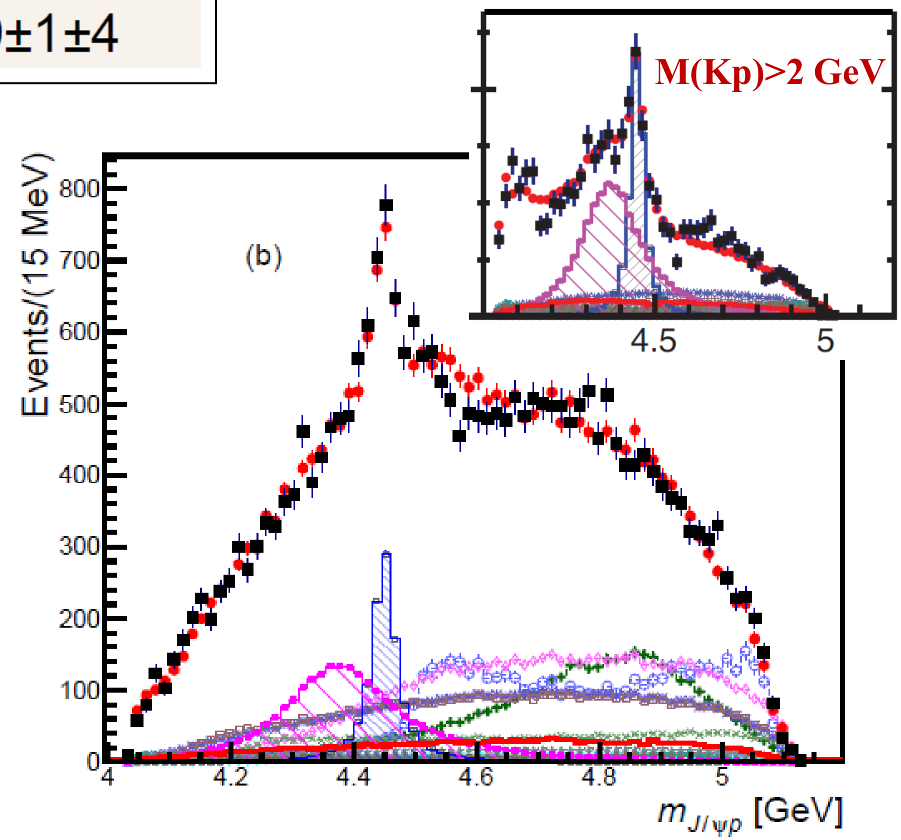
Fit results

Mass (MeV)	Width (MeV)	Fit fraction (%)
4380±8±29	205±18±86	8.4±0.7±4.2
4449.8±1.7±2.5	39±5±19	4.1±0.5±1.1
Λ(1405)		15±1±6
Λ(1520)		19±1±4

Models

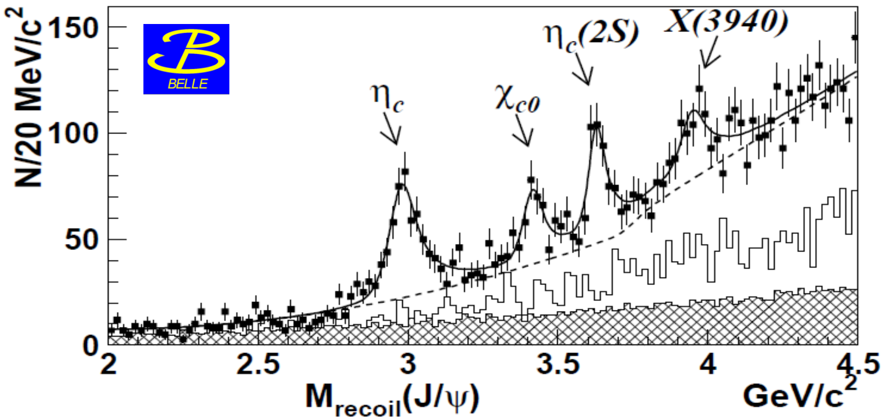
- Tightly bound quarks
- Hadroquarkonium
- Rescattering
- Molecules

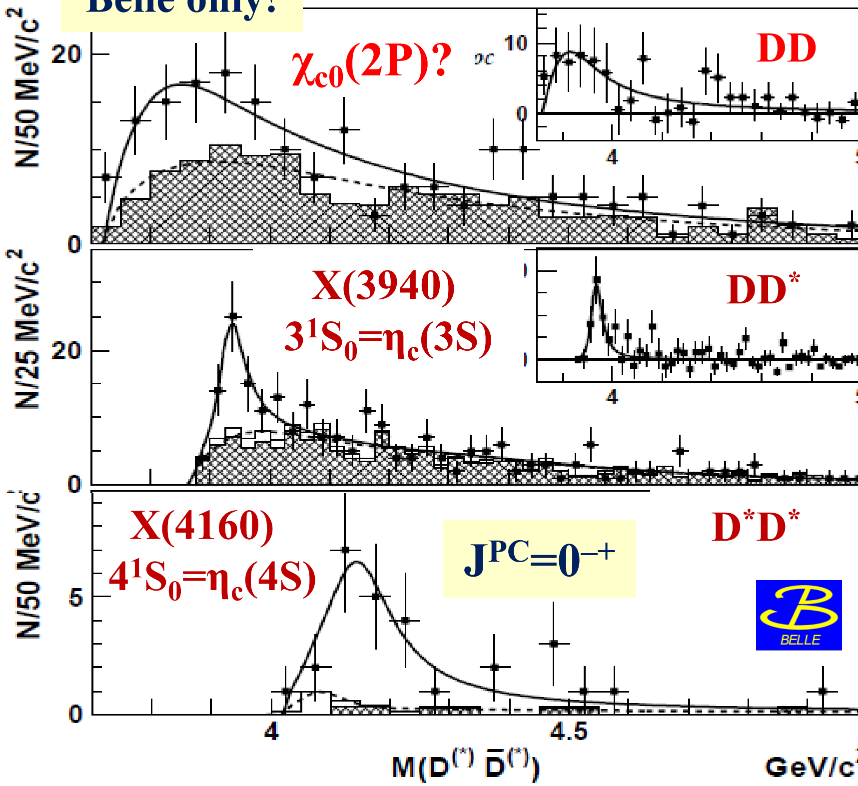




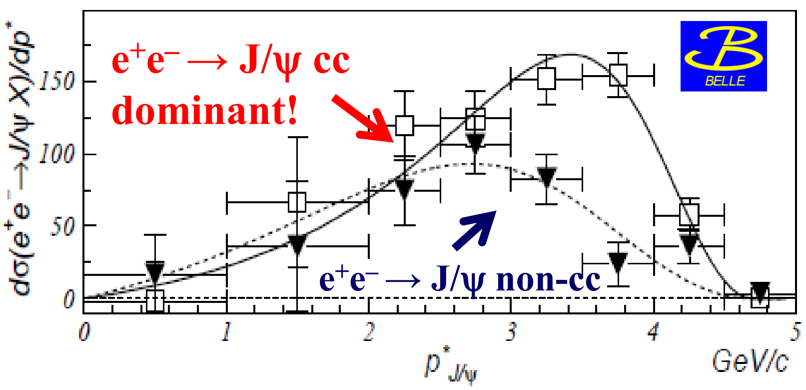

Exotic?
Standard?

Charmonium double production





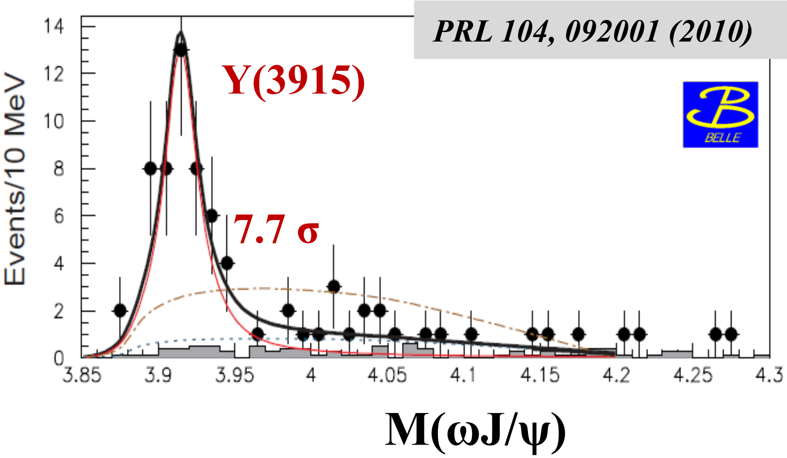
J/ψ production study with/without additional charm



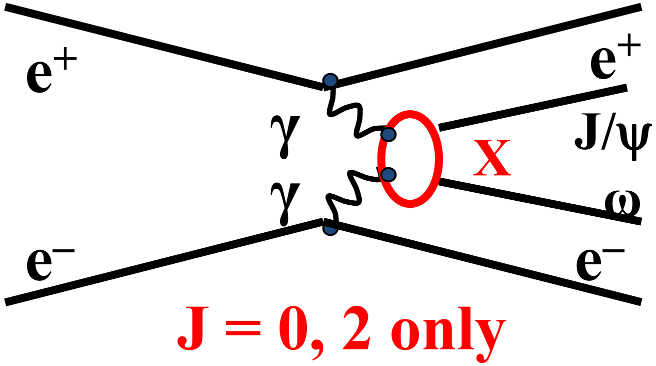
$\sigma(e^+e^- \to J/\psi$ cc), pb	$0.74\pm0.08^{+0.09}_{-0.08}$
$\sigma(e^+e^- \to J/\psi$ non-cc), pb	$0.43\pm0.09\pm0.09$

To be done

- Angular analysis for solid identification $\eta_c(3S)$, $\eta_c(4S)$, χ_{c0} . Search in B decays.
- Search for new states in $e^+e^-\to J/\psi D^{(*)}D^{(*)}\pi$ and in $e^+e^-\to\chi_{c1}\, D^{(*)}D^{(*)}$
- Production: reconstruction of the exclusive final states
- Production studies with other charmonium states (e.g. $\psi(2S)$, χ_{c1})



Y(3940) & Y(3915)



Confirmed by BaBar, prefer $J^P=0^+$

$Y(3915)$	3918.4 ± 1.9	20 ± 5	$0/2^{?+}$	$B \to K(\omega J/\psi)$	Belle [1088] (8), BaBar [1038, 1089] (19)	2004	Ok
				$e^+e^- \to e^+e^-(\omega J/\psi)$	Belle [1090] (7.7), BaBar [1091] (7.6)	2009	Ok
$X(4350)$	$4350.6^{+4.6}_{-5.1}$	13^{+18}_{-10}	$0/2^{?+}$	$e^+e^- \to e^+e^-(\phi J/\psi)$	Belle [1109] (3.2)	2009	NC!

PDG: **Y(3940) = Y(3915)=χ_{c0}(2P)**

Theory ☹

○ χ_{c0}(2P) production in two body B decays is suppressed

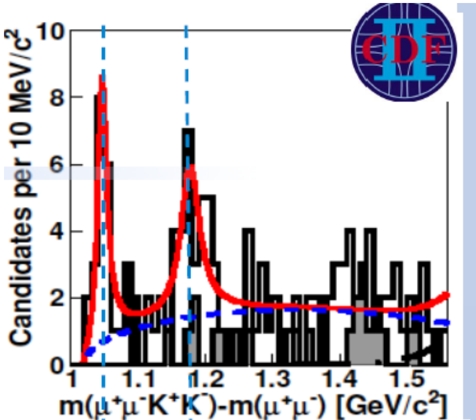
○ χ_{c0}(2P) → DD should be dominant, but not seen

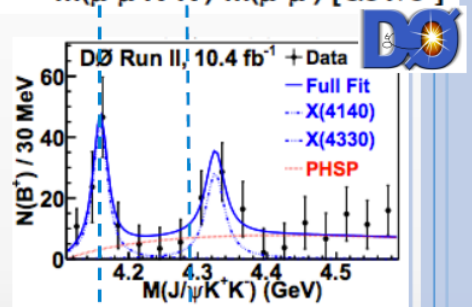
○ a better candidate for χ_{c0}(2P) seen in $e^+e^- \to J/\psi DD$

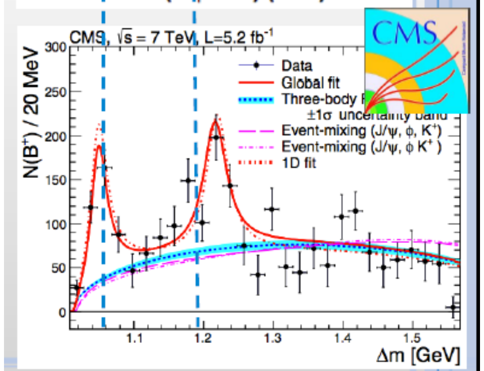
To be done

○ (Not) confirm that Y(3940) = Y(3915) = χ_{c0}(2P)

Seach for tetraquark

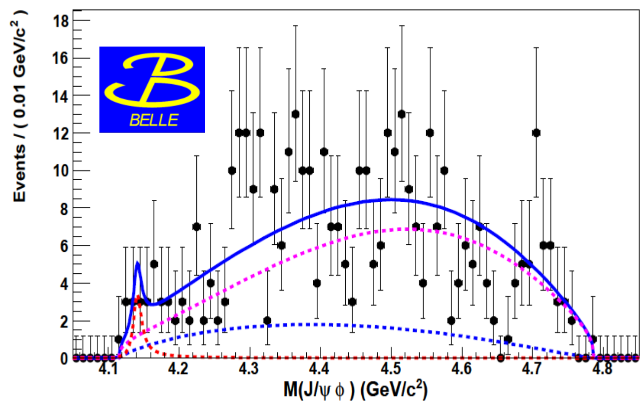




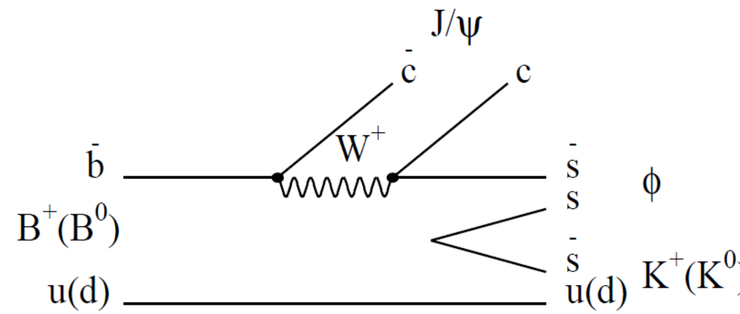


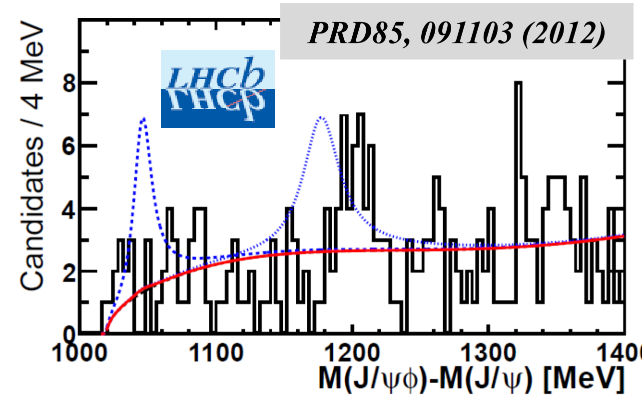
Y(4140) & Y(4274)

narrow peak at threshold and one more nearby



Belle: low momentum kaon detection efficiency is small. 50X more data should help



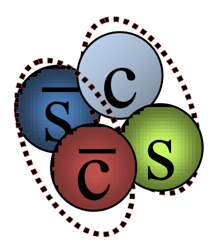


CDF, D0, CMS: **YES!**

Belle & LHCb: **NO!**

To be (not) confirmed

$Y(4140)$	4145.8 ± 2.6	18 ± 8	$?^{?+}$	$B^+ \to K^+(\phi J/\psi)$	CDF [1098] (5.0), Belle [1099] (1.9), LHCb [1100] (1.4), CMS [1101] (>5) D0 [1102] (3.1)	2009	NC!
$Y(4274)$	4293 ± 20	35 ± 16	$?^{?+}$	$B^+ \to K^+(\phi J/\psi)$	CDF [1098] (3.1), LHCb [1100] (1.0), CMS [1101] (>3), D0 [1102] (np)	2011	NC!



In conclusion

Conclusion

About two dozens of charmoniumlike states was found recently and this list continues to increase

<u>In future we expect</u>

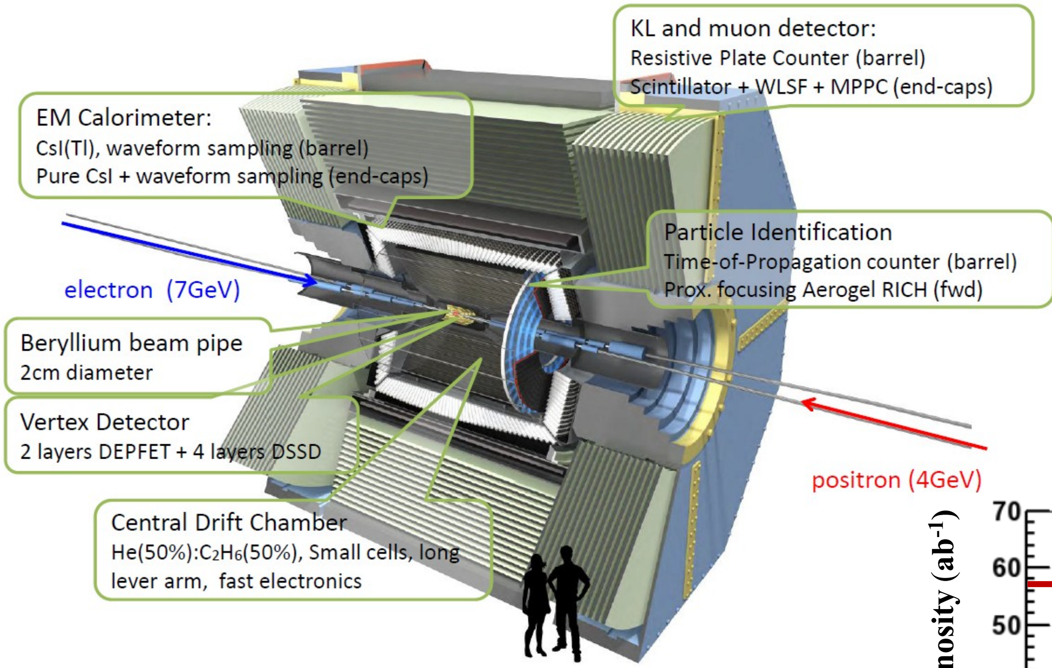
- Precise measurements of known charmonium and charmoniumlike states
- Search for new charmonium and charmoniumlike states above open charm threshold
- Many opportunities for analysis on exotic hadron physics
- A lot of surprises

<u>The most perspective processes</u>

- $B \to K\ X_{cc}$
- Double charmonium production
- Processes with ISR
- Processes with $\gamma\gamma$ fusion

Backup

Belle II Detector



Belle/KEKB recorded ~1000 fb^{-1}

Now change units to ab^{-1}

SuperKEKB luminosity profile