

Status of XYZ states

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MEIREI WORKSHOP, Incheon INHA University, Oct 25, 2016

QCD: theory of the strong interaction

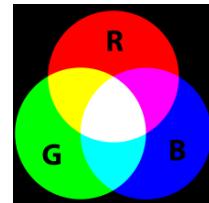
QED: electric charge is a simple scalar (singlet)

QCD: quark “charges” are triplets; the three varieties of “charge” obey combination rules that closely match those that govern our eyes’ perception of color

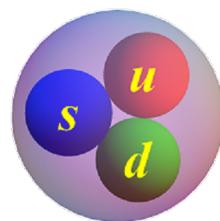
Quantum Electro Dynamics → Quantum **Chromo** Dynamics

only “white” particles are observable

3 **primary** colors → **white**

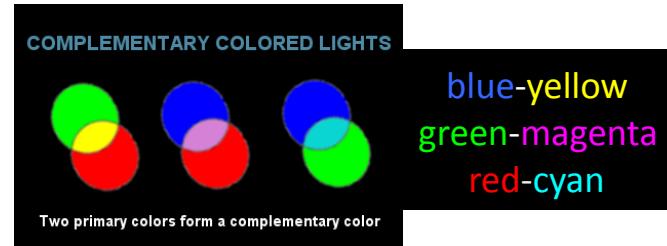


$\Lambda = (uds)$

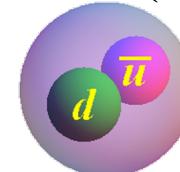


Baryons are **red-blue-green** triplets

color + complementary color → **white**



$\pi^- = (d\bar{u})$



Mesons are **color-anticolor** pairs

QCD has other color-singlet combinations:

“Multiquark Particles:” other possible “white” combinations of quarks

Pentaquark:

S=+1 Baryon



diquark-diquark-antiquark

H-diBaryon

tightly bound
6-quark state



diquark-diquark-diquark

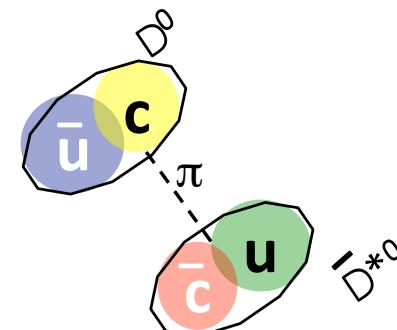
Tetraquark mesons:

tightly bound
diquark-diantiquark

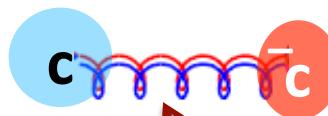


diquark-diantiquark

loosely bound
meson-antimeson
“molecule”

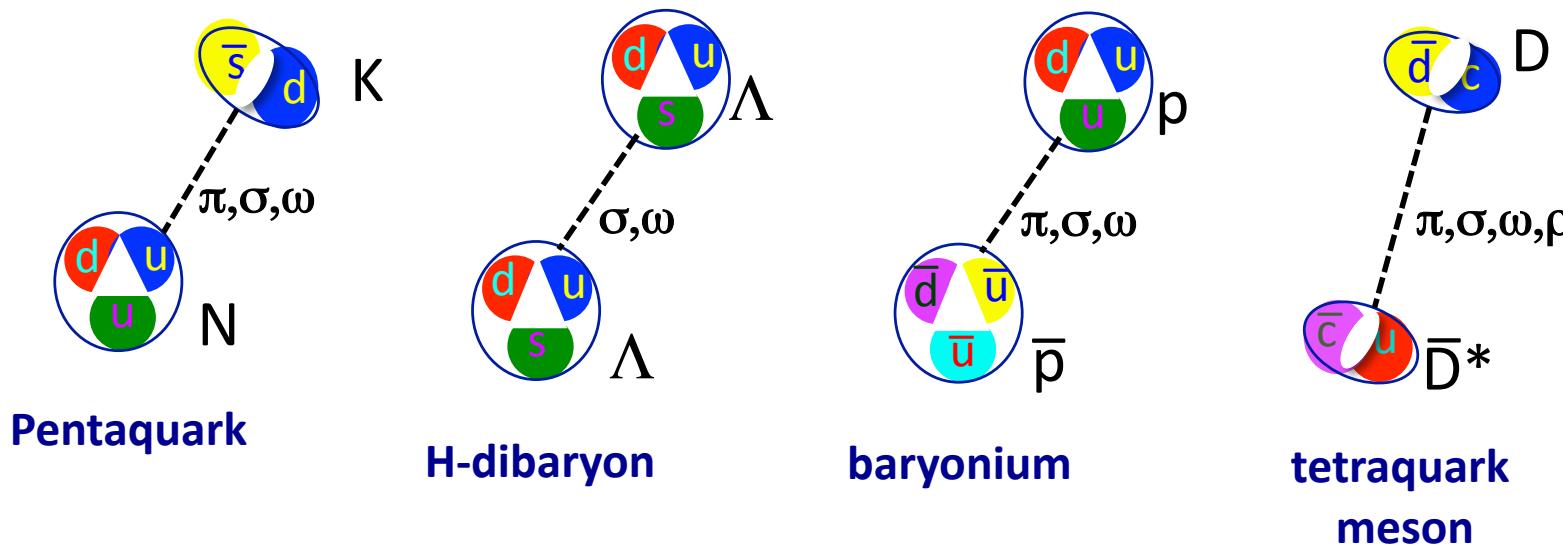


$\bar{q}q$ -gluon hybrid mesons



gluon: the QCD equivalent of QED's photon

multiquark states from “molecules”



Nuclear-physics style “exotic” hadrons

Candidates of XYZ & pentaquark states

State	M (MeV)	Γ (MeV)	J^{PC}	Process (decay mode)	Experiment
$X(3872)$	3871.68 ± 0.17	< 1.2	1^{++}	$B \rightarrow K + (J/\psi \pi^+ \pi^-)$ $p\bar{p} \rightarrow (J/\psi \pi^+ \pi^-) + \dots$ $B \rightarrow K + (J/\psi \pi^+ \pi^- \pi^0)$ $B \rightarrow K + (D^0 \bar{D}^0 \pi^0)$ $B \rightarrow K + (J/\psi \gamma)$ $B \rightarrow K + (\psi' \gamma)$ $pp \rightarrow (J/\psi \pi^+ \pi^-) + \dots$	Belle, BaBar, LHCb CDF, D0 Belle, BaBar Belle , BaBar BaBar, Belle , LHCb BaBar, Belle , LHCb LHCb, CMS Atlas
$X(3915)$	3917.4 ± 2.7	28_{-9}^{+10}	0^{++}	$B \rightarrow K + (J/\psi \omega)$ $e^+ e^- \rightarrow e^+ e^- + (J/\psi \omega)$	Belle , BaBar Belle , BaBar
$\chi_{c2}(2P)$	3927.2 ± 2.6	24 ± 6	2^{++}	$e^+ e^- \rightarrow e^+ e^- + (D\bar{D})$	Belle , BaBar
$X(3940)$	3942_{-8}^{+9}	37_{-17}^{+27}	$0(?)^{- (?)} +$	$e^+ e^- \rightarrow J/\psi + (D^* \bar{D})$ $e^+ e^- \rightarrow J/\psi + (\dots)$	Belle Belle
$G(3900)$	3943 ± 21	52 ± 11	1^{--}	$e^+ e^- \rightarrow \gamma + (D\bar{D})$	BaBar, Belle
$Y(4008)$	4008_{-49}^{+121}	226 ± 97	$1^{--} 1^{++?}$	$e^+ e^- \rightarrow \gamma + (J/\psi \pi^+ \pi^-)$	Belle
$Y(4140)$	$4146.5_{-5.3}^{+6.4}$	$83_{-25}^{+30} 9$	1^{++}	$B \rightarrow K + (J/\psi \phi)$	CDF, CMS, LHCb
$X(4160)$	4156_{-25}^{+29}	139_{-65}^{+113}	$0(?)^{- (?)} +$	$e^+ e^- \rightarrow J/\psi + (D^* \bar{D})$	Belle
$Y(4260)$	4263_{-9}^{+8}	95 ± 14	1^{--}	$e^+ e^- \rightarrow \gamma + (J/\psi \pi^+ \pi^-)$	BaBar, CLEO, Belle
			$1^{++?}$	$e^+ e^- \rightarrow (J/\psi \pi^+ \pi^-)$ $e^+ e^- \rightarrow (J/\psi \pi^0 \pi^0)$	CLEO, BESIII CLEO, BESIII
$Y(4274)$	4273_{-9}^{+19}	56 ± 16	1^{++}	$B \rightarrow K + (J/\psi \phi)$	CDF, CMS, LHCb
$X(4350)$	$4350.6_{-5.1}^{+4.6}$	$13.3_{-10.0}^{+18.4}$	$0/2^{++}$	$e^+ e^- \rightarrow e^+ e^- (J/\psi \phi)$	Belle
$Y(4360)$	4361 ± 13	74 ± 18	1^{--}	$e^+ e^- \rightarrow \gamma + (\psi' \pi^+ \pi^-)$	BaBar, Belle
$X(4630)$	4634_{-11}^{+9}	92_{-32}^{+41}	1^{--}	$e^+ e^- \rightarrow \gamma (\Lambda_c^+ \Lambda_c^-)$	Belle
$Y(4660)$	4664 ± 12	48 ± 15	$1^{--} 1^{+}$	$e^+ e^- \rightarrow \gamma + (\psi' \pi^+ \pi^-)$	Belle
$Z_c^+(3900)$	3890 ± 3	33 ± 10	1^{+-}	$Y(4260) \rightarrow \pi^- + (J/\psi \pi^+)$ $Y(4260) \rightarrow \pi^- + (D\bar{D}^*)^+$	BESIII, Belle
$Z_c^+(4020)$	4024 ± 2	10 ± 3	$1(?)^{+ (?)} -$	$Y(4260) \rightarrow \pi^- + (h_c \pi^+)$ $Y(4260) \rightarrow \pi^- + (D^* \bar{D}^*)^+$	BESIII BESIII
$Z_1^+(4050)$	4051_{-43}^{+24}	82_{-55}^{+51}	$?^{?+}$	$B \rightarrow K + (\chi_{c1} \pi^+)$	Belle, BaBar
$Z_1^+(4200)$	4196_{-32}^{+35}	370_{-149}^{+99}	1^{+-}	$B \rightarrow K + (J/\psi \pi^+)$	Belle, LHCb
$Z_2^+(4250)$	4248_{-45}^{+185}	177_{-72}^{+321}	$?^{?+}$	$B \rightarrow K + (\chi_{c1} \pi^+)$	Belle, BaBar
$Z^+(4430)$	4477 ± 20	181 ± 31	1^{+-}	$B \rightarrow K + (\psi' \pi^+)$ $B \rightarrow K + (J/\psi \pi^+)$	Belle
$P_c^+(4380)$	4380 ± 30	205 ± 88	$(3/2)^-$	$\Lambda_b^+ \rightarrow K + (J/\psi p)$	LHCb
$P_c^+(4450)$	4449.8 ± 3.0	39 ± 20	$(5/2)^+$	$\Lambda_b^+ \rightarrow K + (J/\psi p)$	LHCb
$Y_b(10890)$	10888.4 ± 3.0	$30.7_{-7.7}^{+8.9}$	1^{--}	$e^+ e^- \rightarrow (\Upsilon(nS) \pi^+ \pi^-)$	Belle
$Z_b^+(10610)$	10607.2 ± 2.0	18.4 ± 2.4	1^{+-}	$"\Upsilon(5S)" \rightarrow \pi^- + (\Upsilon(nS) \pi^+), n = 1, 2, 3$ $"\Upsilon(5S)" \rightarrow \pi^- + (h_b(nP) \pi^+), n = 1, 2$ $"\Upsilon(5S)" \rightarrow \pi^- + (BB^*)^+, n = 1, 2$	Belle Belle Belle
$Z_b^0(10610)$	10609 ± 6		1^{+-}	$"\Upsilon(5S)\Upsilon' \rightarrow \pi^0 + (\Upsilon(nS) \pi^0), n = 1, 2, 3$	Belle
$Z_b^+(10650)$	10652.2 ± 1.5	11.5 ± 2.2	1^{+-}	$"\Upsilon(5S)" \rightarrow \pi^- + (\Upsilon(nS) \pi^+), n = 1, 2, 3$ $"\Upsilon(5S)" \rightarrow \pi^- + (h_b(nP) \pi^+), n = 1, 2$ $"\Upsilon(5S)" \rightarrow \pi^- + (B^* \bar{B}^*)^+, n = 1, 2$	Belle Belle Belle
$X(5568)$	5568 ± 3	22 ± 8	$??$	$pp \rightarrow \pi^+ Bs + X$	D0
$X(4500)$	4506 ± 19	92 ± 30	0^{++}	$B^+ \rightarrow K^+(\phi J/\psi)$	LHCb
$X(4700)$	4704 ± 22	120 ± 49	0^{++}	$B^+ \rightarrow K^+(\phi J/\psi)$	LHCb

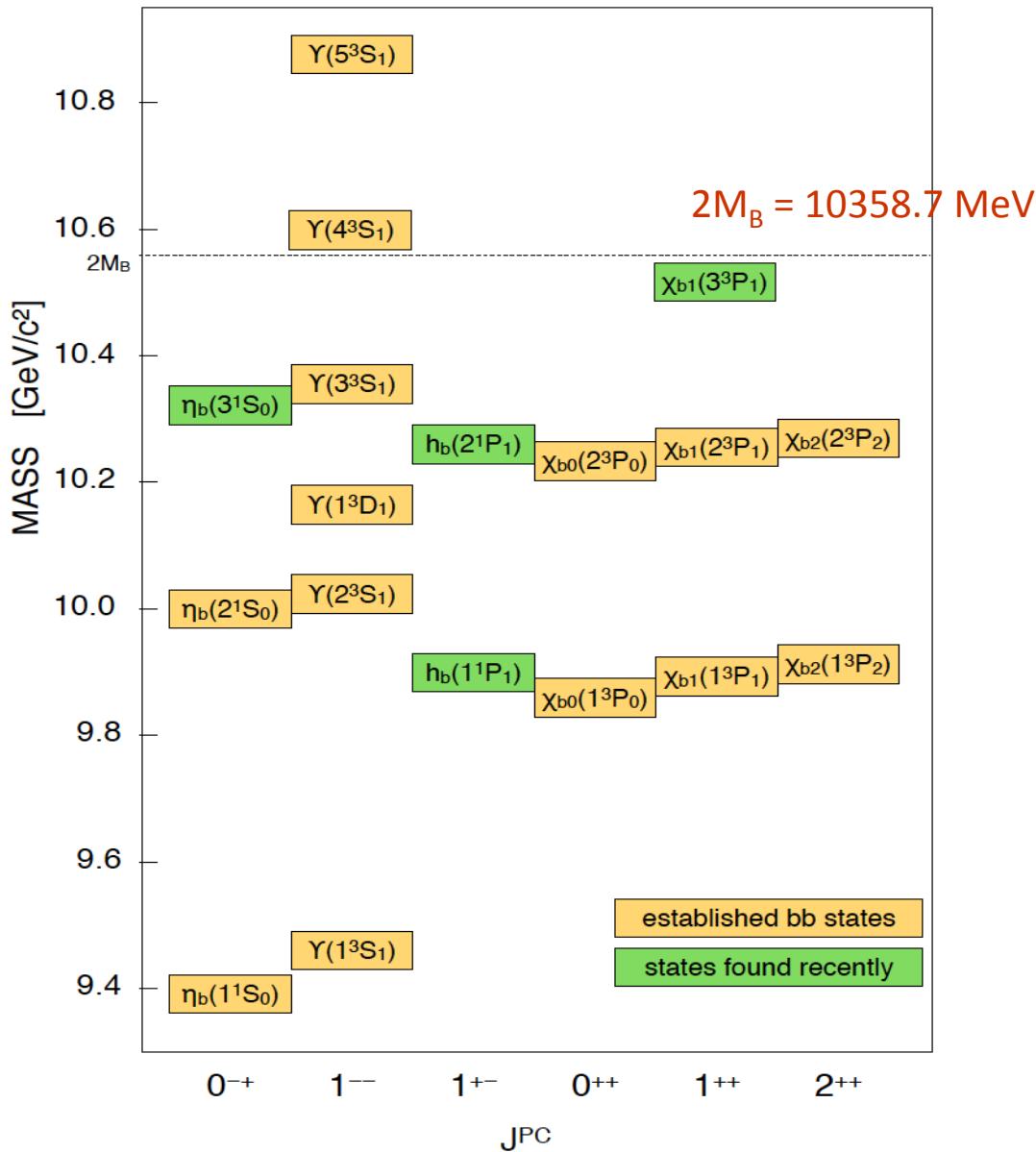
From S.Olsen

5
This year

The Charged $Z_b(10610)$ and $Z_b(10650)$

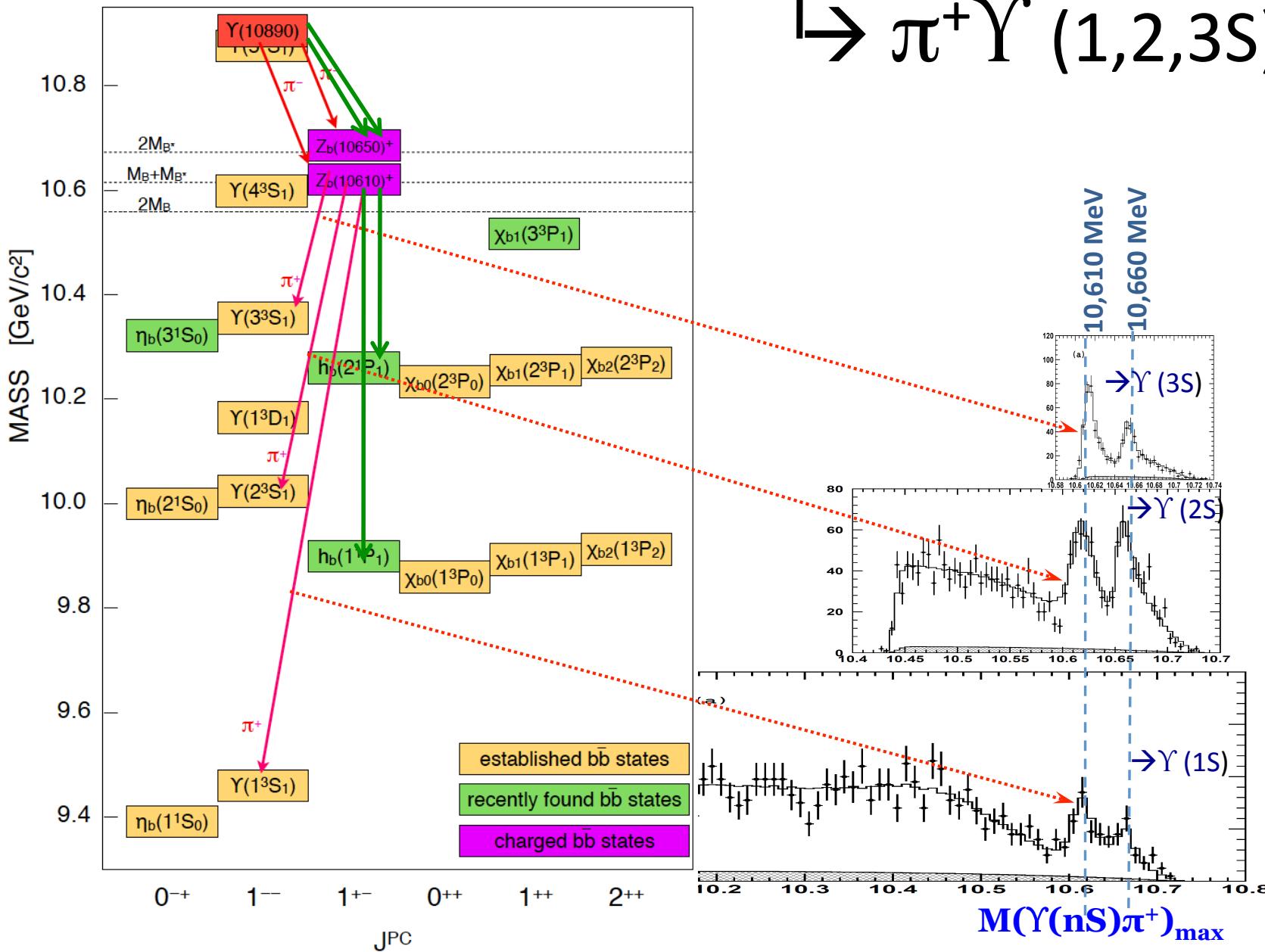
- Observation of $Y(4260) \rightarrow$ Search for bb analog of Y
- Observing huge rate of “ $Y(5S) \rightarrow \pi\pi Y(1,2,3)$ ” and $Y(5S)$ mass offset
- Observation of $Z_b^+(10610)$ and $Z_b^+(10650)$ (abbreviation: Z_{b1} and Z_{b2})
- Search for cc analog of $Z_b \rightarrow$ Observation of many Z_c 's including $Z_c(3900)$, $Z_c(3885)$, etc.

“bottomonium” $b\bar{b}$ mesons



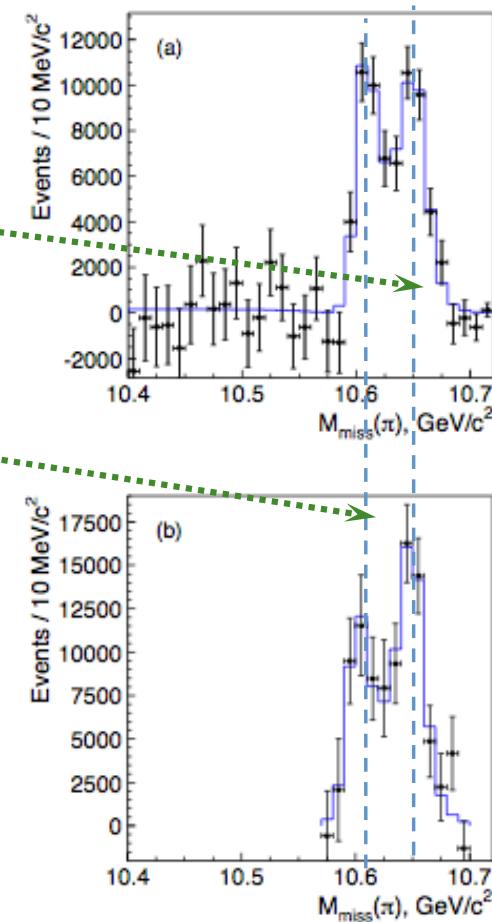
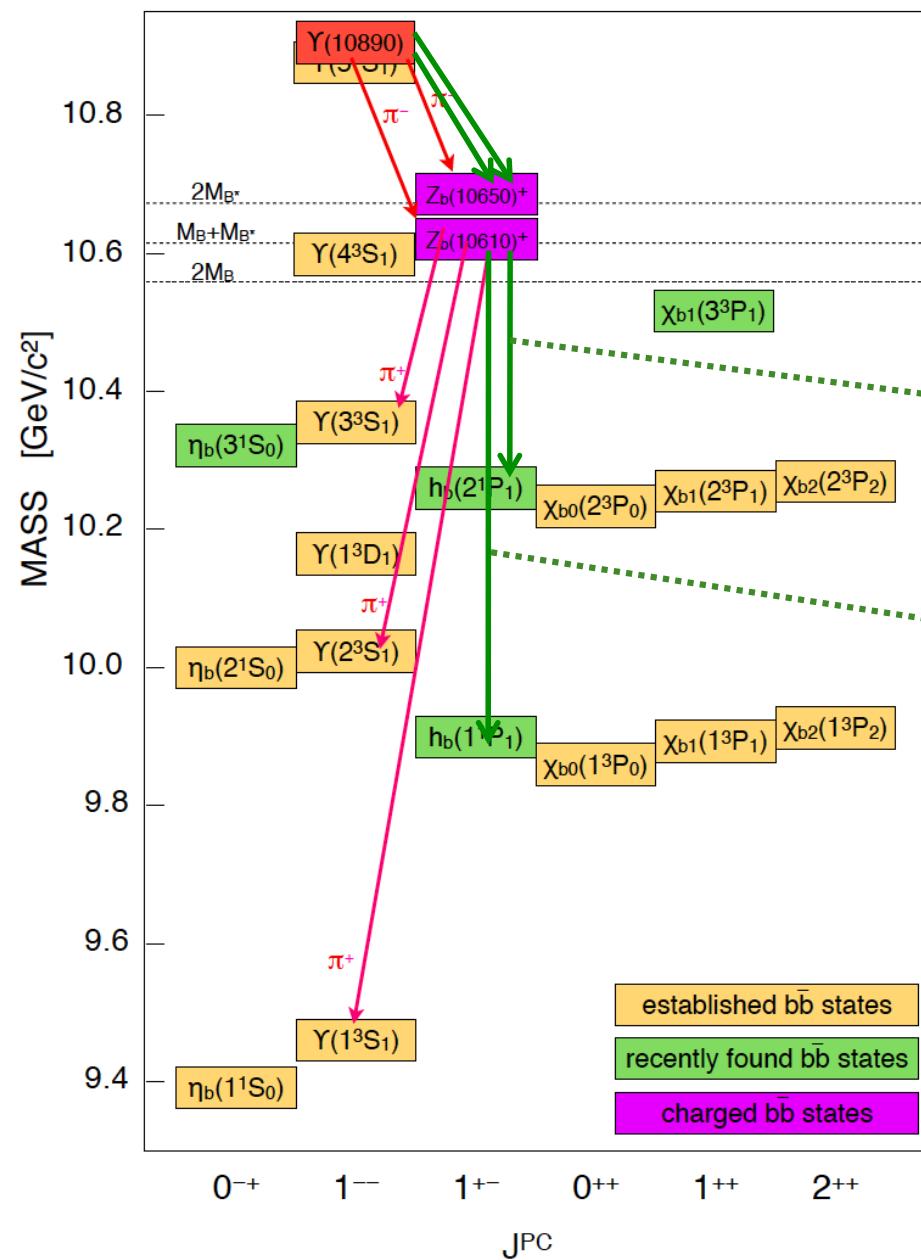


“ $\Upsilon(5S)$ ” $\rightarrow \pi^- Z_{b1,2}^+ \rightarrow \pi^+ \Upsilon(1,2,3S)$





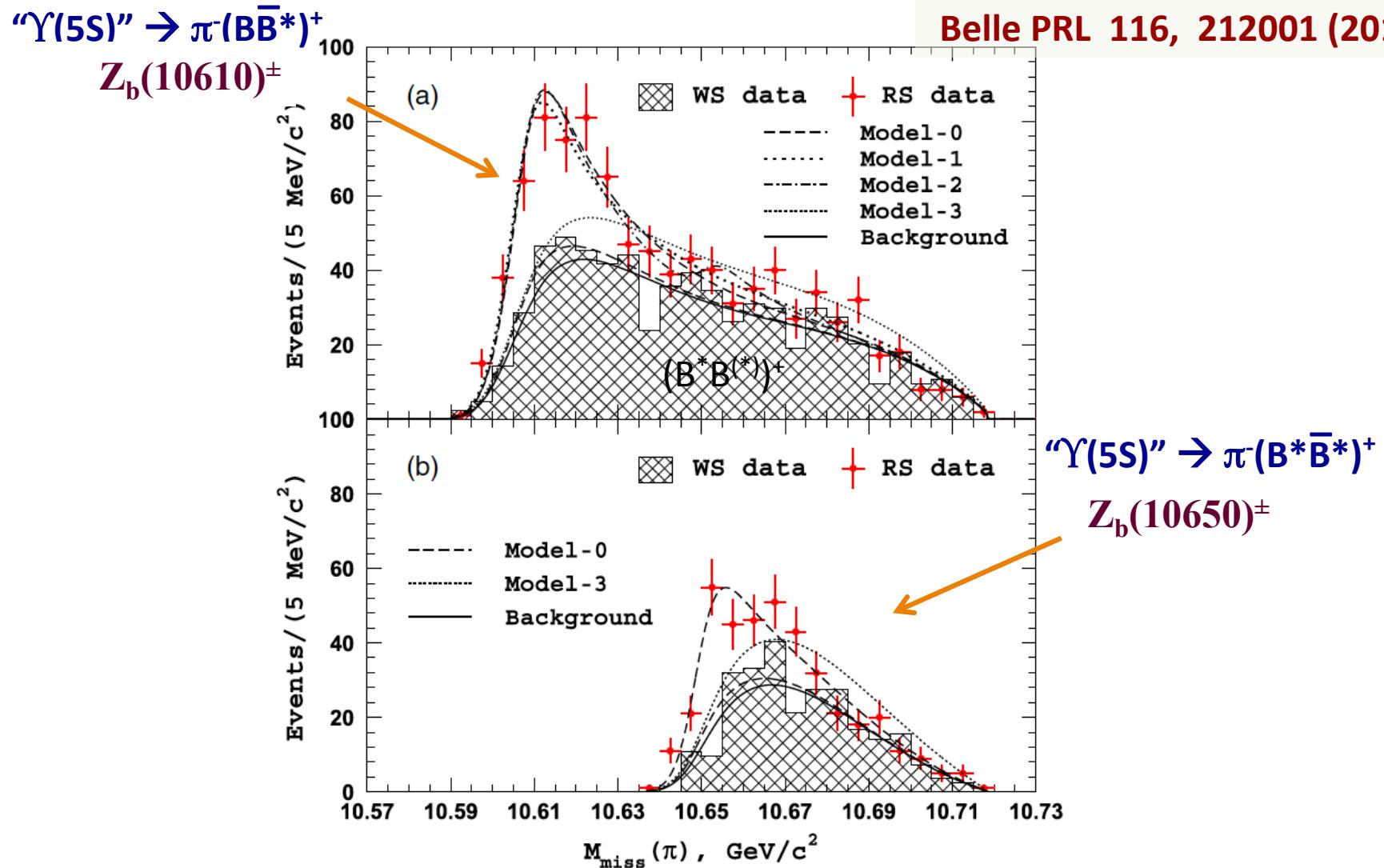
$\Upsilon(5S) \rightarrow \pi^- Z_{b1,2}^+ \rightarrow \pi^+ h_b(1P, 2P)$



$J^P = 1^+$;

Belle PRD 91, 072003 (2015)

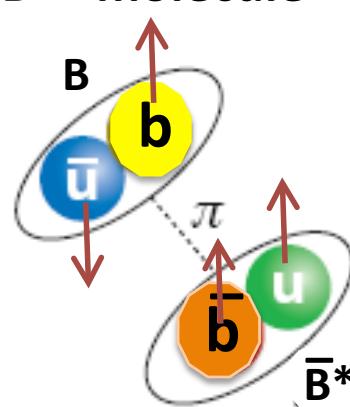
$$Z_b^+(10610) \rightarrow (B^* \bar{B})^+ \quad \& \quad Z_b^+(10650) \rightarrow (B^* \bar{B}^*)^+$$



$(B^*\bar{B}^{(*)})^+$ dominates the Z_b channels

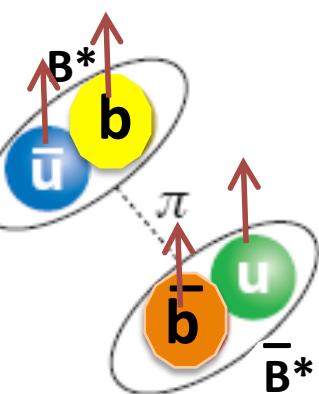
Favors molecule model: PRD87 091501(2013)etc

B-B* “molecule”



Belle PRL 116, 212001(2016)

B^*-B^* “molecule”



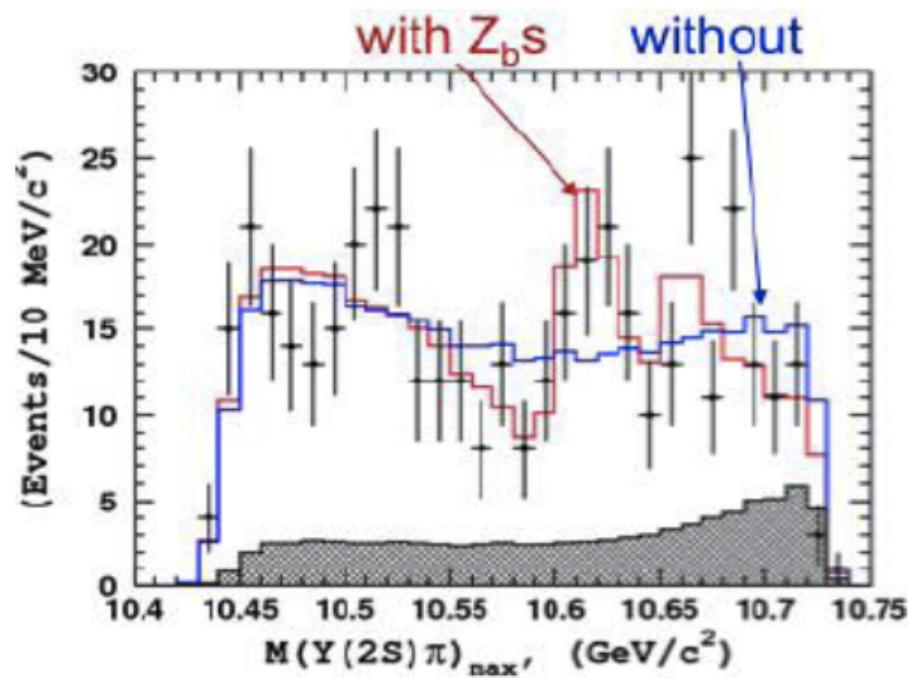
Channel	Fraction, %	
	$Z_b(10610)$	$Z_b(10650)$
$\Upsilon(1S)\pi^+$	$0.54^{+0.16+0.11}_{-0.13-0.08}$	$0.17^{+0.07+0.03}_{-0.06-0.02}$
$\Upsilon(2S)\pi^+$	$3.62^{+0.76+0.79}_{-0.59-0.53}$	$1.39^{+0.48+0.34}_{-0.38-0.23}$
$\Upsilon(3S)\pi^+$	$2.15^{+0.55+0.60}_{-0.42-0.43}$	$1.63^{+0.53+0.39}_{-0.42-0.28}$
$h_b(1P)\pi^+$	$3.45^{+0.87+0.86}_{-0.71-0.63}$	$8.41^{+2.43+1.49}_{-2.12-1.06}$
$h_b(2P)\pi^+$	$4.67^{+1.24+1.18}_{-1.00-0.89}$	$14.7^{+3.2+2.8}_{-2.8-2.3}$
$B^+\bar{B}^{*0} + \bar{B}^0B^{*+}$	$85.6^{+1.5+1.5}_{-2.0-2.1}$...
$B^{*+}\bar{B}^{*0}$...	$73.7^{+3.4+2.7}_{-4.4-3.5}$

$$M_{Z_b(10610)} - (M_B + M_{B^*}) = + 2.7 \pm 2.1 \text{ MeV}$$

$$M_{Z_b(10650)} - 2M_{B^*} = + 2.0 \pm 1.8 \text{ MeV}$$

Slightly unbound threshold resonances??

Z_b^0 search in $\Upsilon(5S) \rightarrow \pi^0\pi^0 \Upsilon(1,2,3S)$



6.5 σ stat. significance
Mass $10609 \pm 4 \pm 4$ MeV

Belle PRD 88, 052016(2013)

$Z_b^0(10610) \rightarrow \pi^0 \Upsilon(2,3S)$
First triplet candidate of Z_b .

Cross sections for $e^+e^- \rightarrow Y(nS)\pi^+\pi^-$ & $b\bar{b}$

Belle PRD 93, 011101(2016)

Data sample: $e^+e^- \rightarrow Y(nS)[\mu^+\mu^-]\pi^+\pi^-$
 • 10.6-11.02 GeV
 • 22 $\sim 1 \text{ fb}^{-1}$ scan points
 • 121 fb^{-1} on-resonance at $Y(5S)$ (3 points)

$$R_{Y\pi^+\pi^-(b\bar{b})} = \sigma_{e^+e^- \rightarrow Y\pi^+\pi^-(b\bar{b})}/\sigma_{\mu^+\mu^-}$$

Fitting Model:

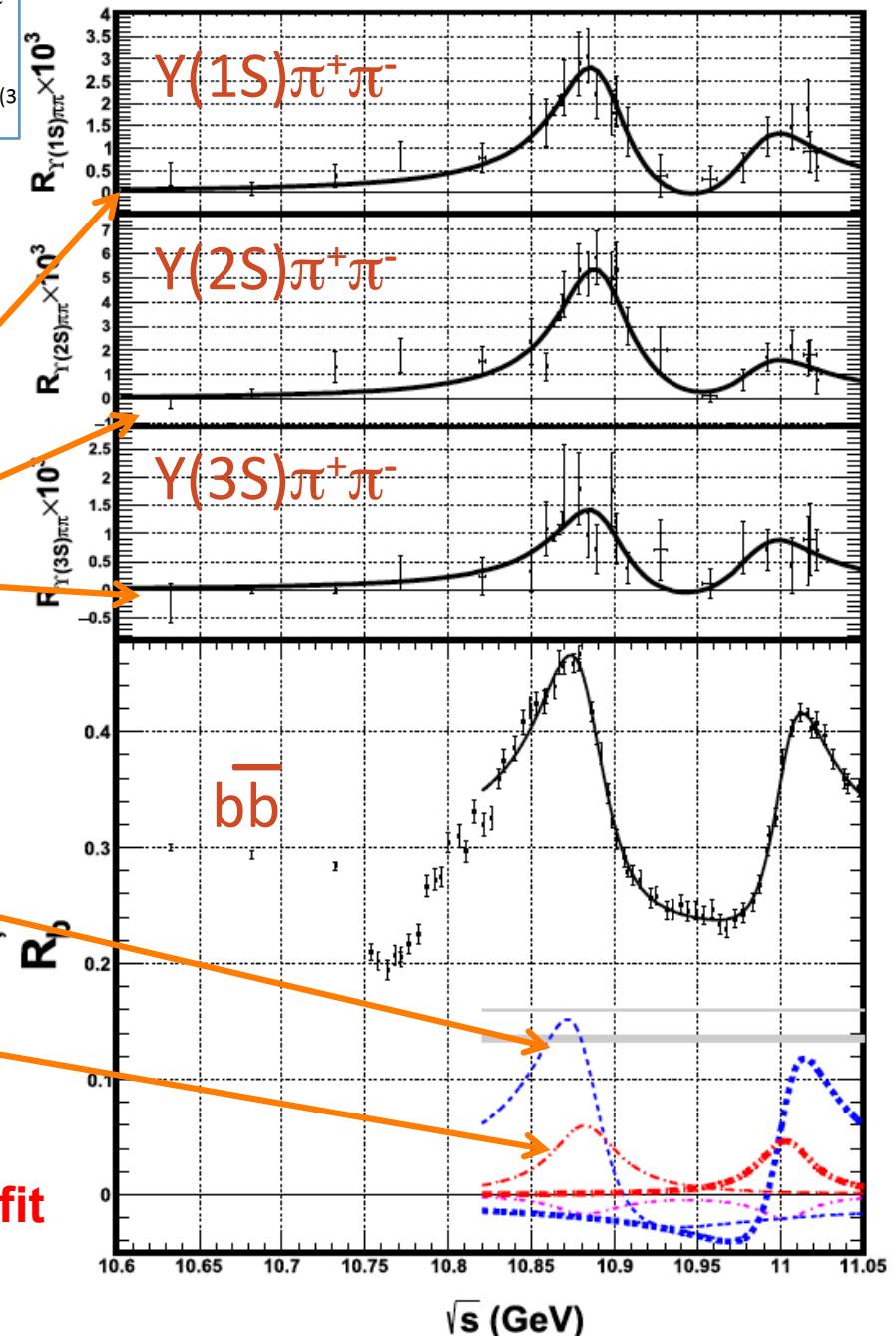
2 Breit-Wigner+ flat continuum
(coherent+incoherent)

no continuum
similar as $h_b\pi\pi$, $B^*B^{(*)}\pi$

large
continuum- $Y(5S)$ interference

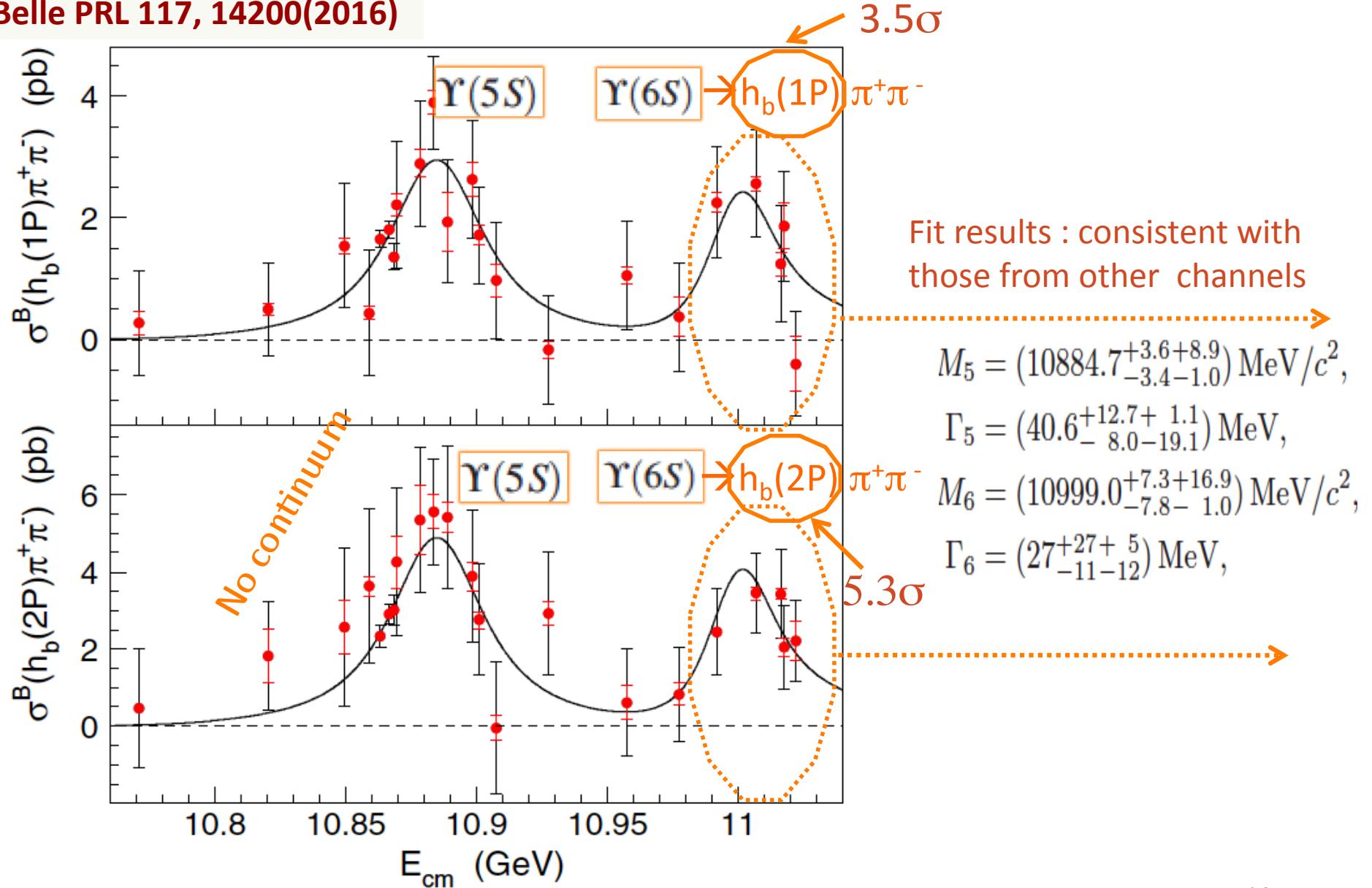
$Y(nS)\pi\pi + h_b\pi\pi + B^*B^{(*)}\pi$

Mutually incompatible, so simple
model for R should not be used to fit
 $Y(5S)$ mass, width.



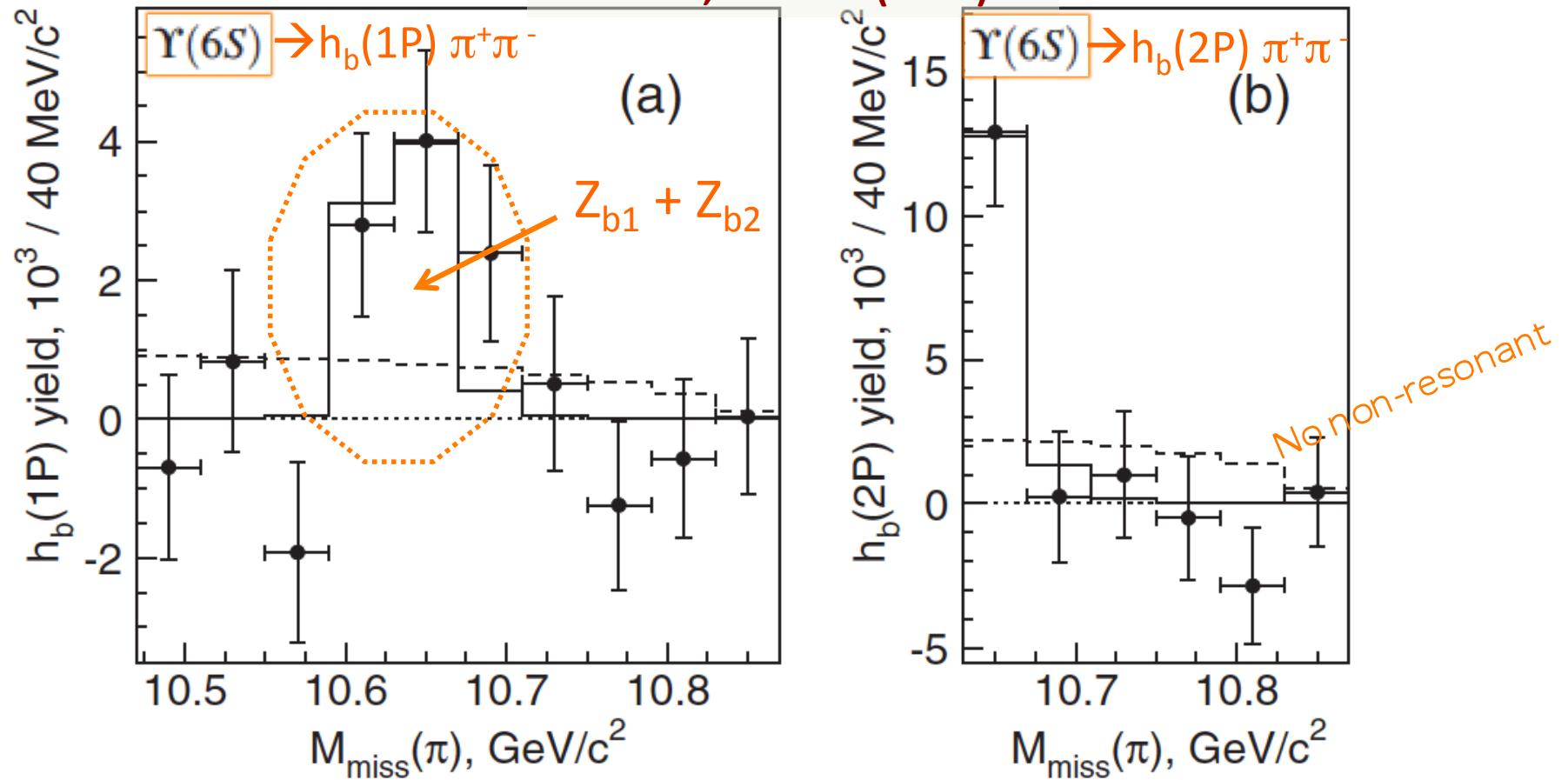
Cross sections for $e^+e^- \rightarrow h_b(nP)\pi^+\pi^-$

Belle PRL 117, 14200(2016)



Evidence of $Z_b^+(10610, 10650)$ at $\Upsilon(6S)$

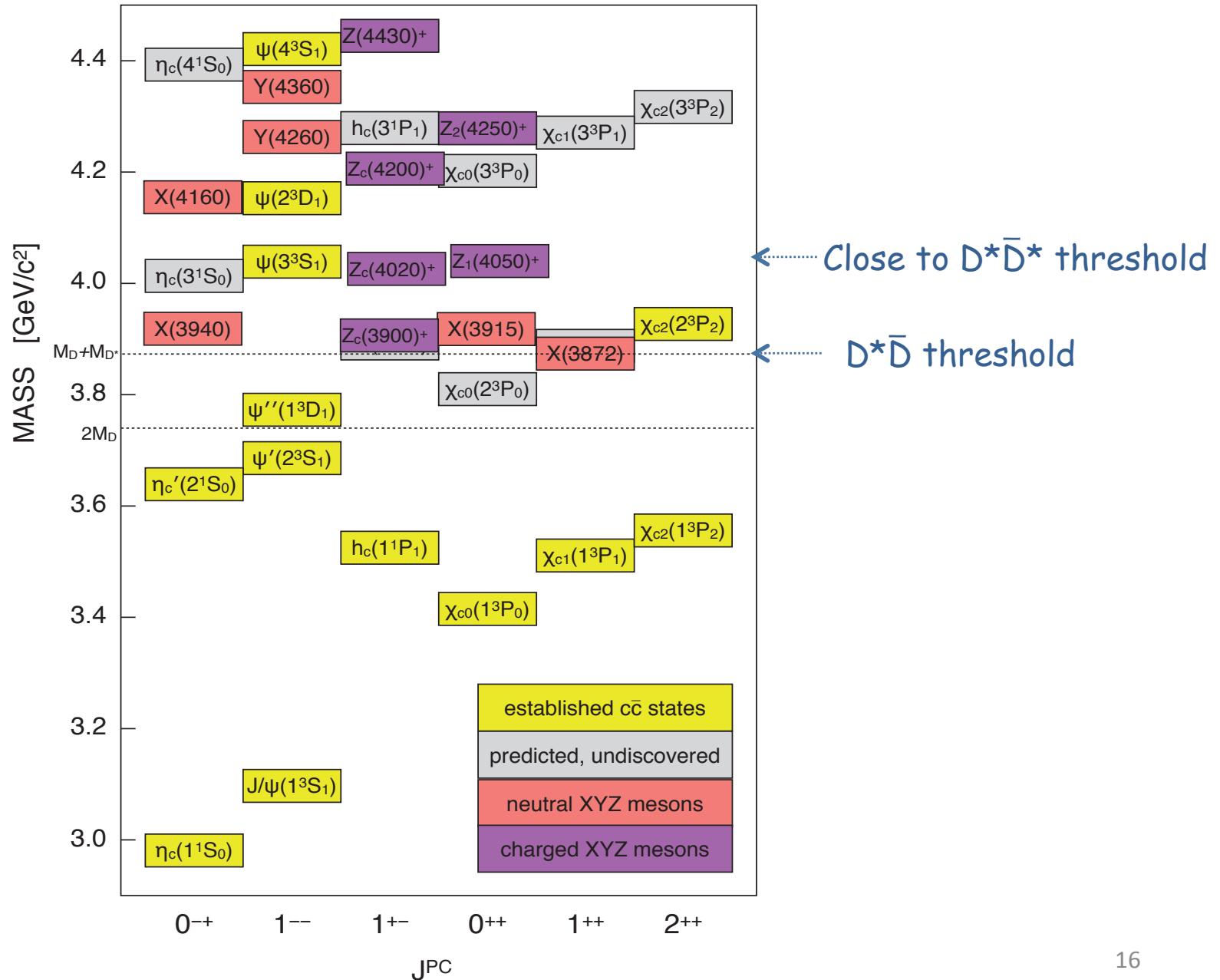
PRL 117, 142001 (2016)



Fit parameters are fixed at those of $\Upsilon(5S)$.

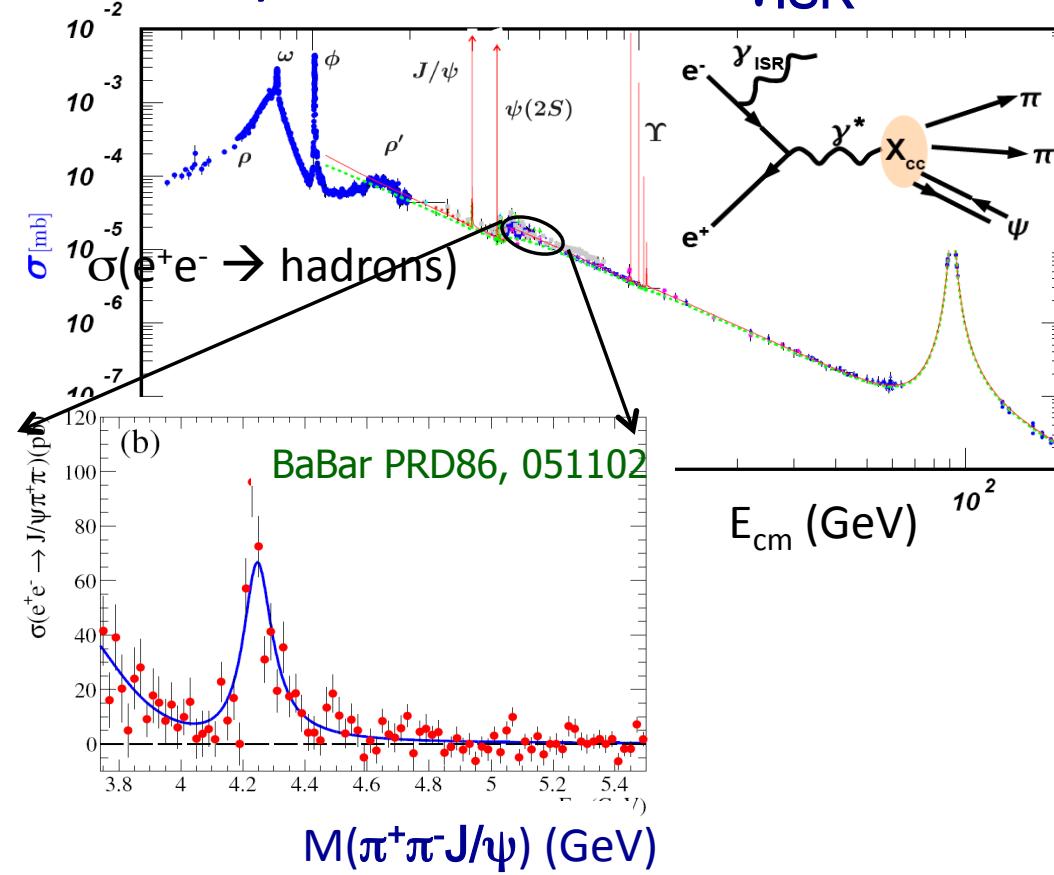
Single $Z_b(10610)$ possibility is excluded at 3.3σ in $h_b(1P)\pi\pi$, while single $Z_b(10650)$ possibility in $h_b(2P)\pi\pi$ cannot be excluded.

$c\bar{c}$ assignments for the XYZ mesons?



The $\Upsilon(4260)$

found by BaBar in $e^+e^- \rightarrow \gamma_{ISR}\pi^+\pi^-J/\psi$



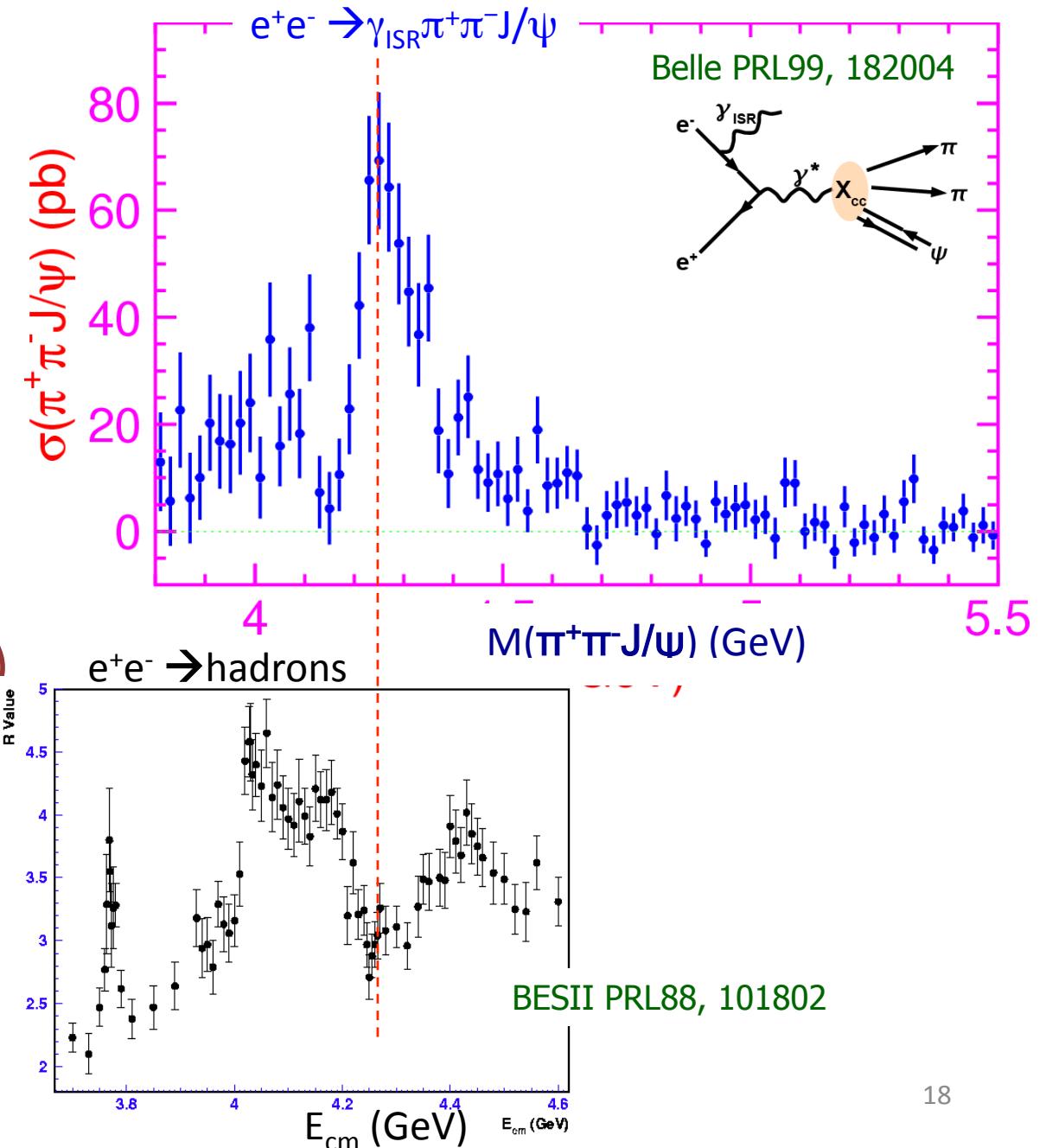
$\Upsilon(4260) \rightarrow \pi^+\pi^-J/\psi$ confirmed by Belle

No sign of $\Upsilon(4260) \rightarrow D^{(*)}\bar{D}^{(*)}$

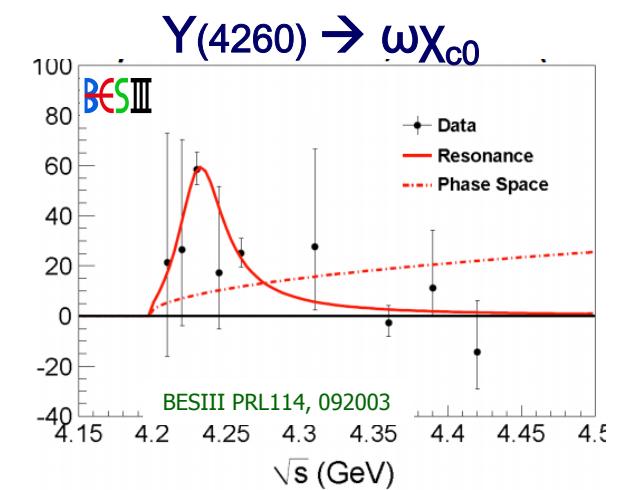
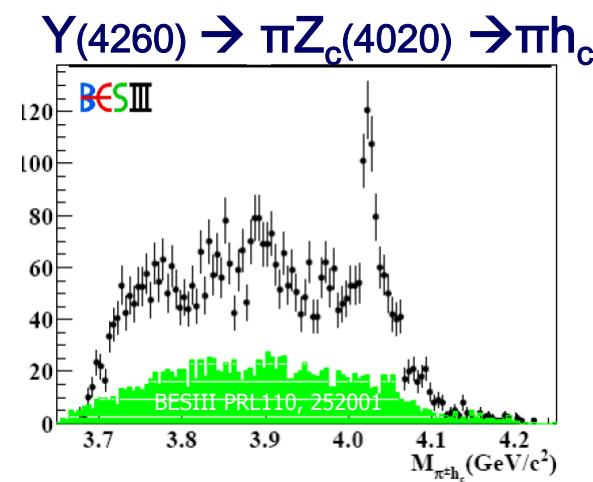
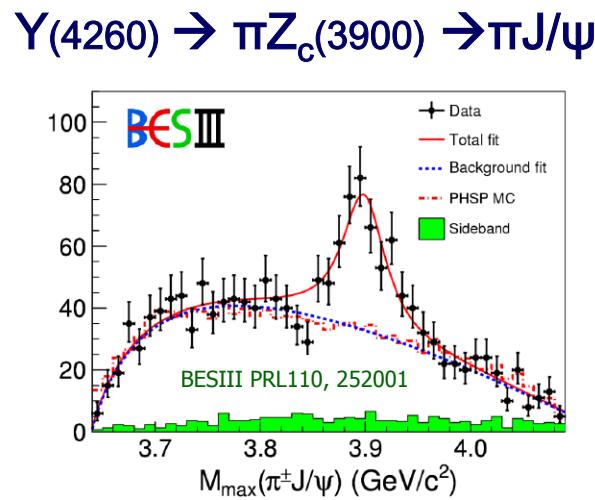
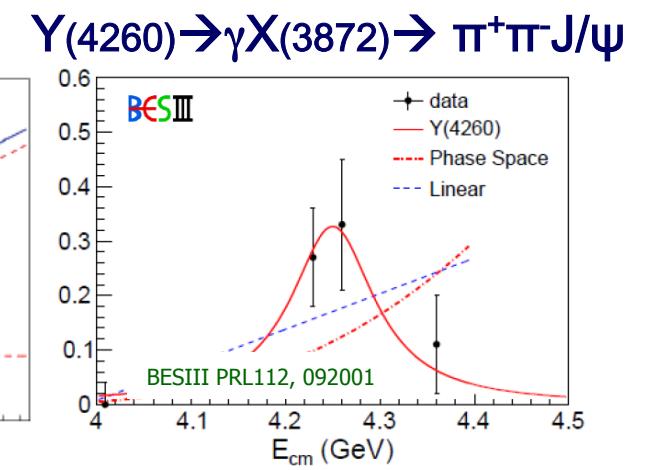
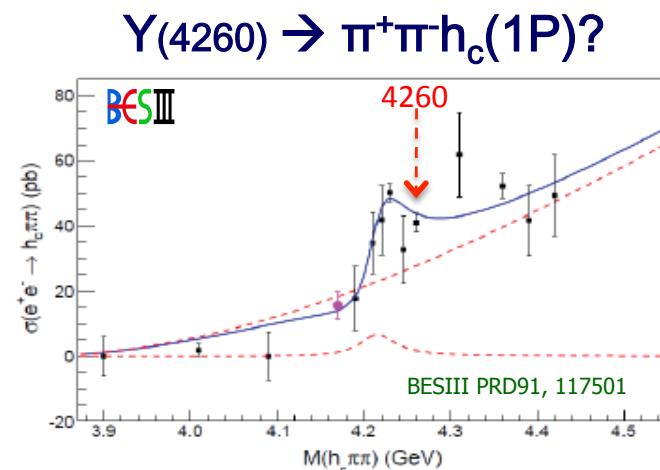
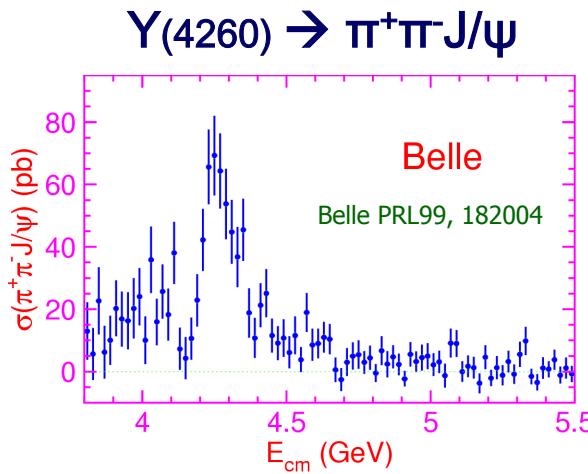
$\Upsilon(4260)$ peak in $\sigma(\pi^+\pi^-J/\psi)$
occurs at a dip in $\sigma(D^{(*)}\bar{D}^{(*)})$

$\Gamma(\pi^+\pi^-J/\psi)$ is large, but
should be OZI suppressed if $c\bar{c}$

X. H. Mo et al., PLB 640, 182



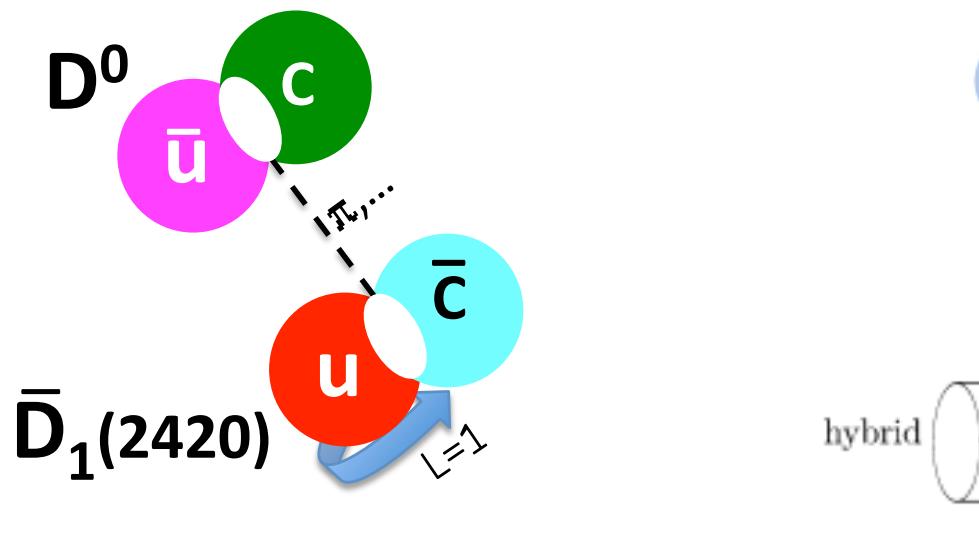
$\Upsilon(4260)$ decay modes



Models for the $\Upsilon(4260)$ I

Molecule?

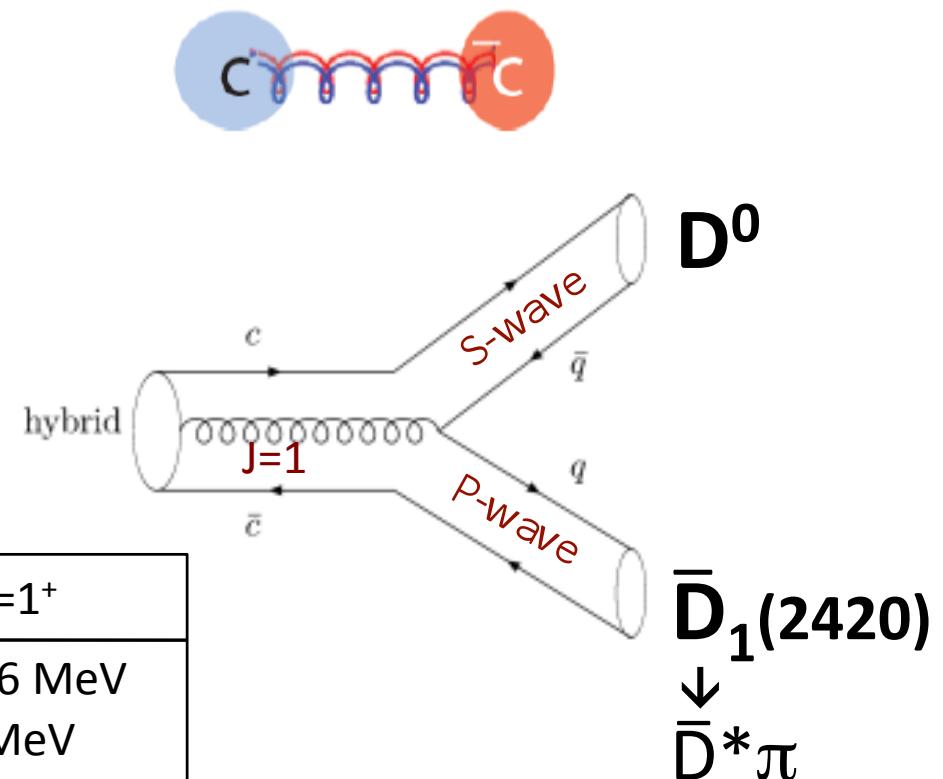
Wang, Hanhart & Zhao PRL 111, 132002 :



$D_1(2420)$ $J^P=1^+$
$M = 2421.4 \pm 0.6$ MeV
$\Gamma = 27.4 \pm 2.5$ MeV
Decay: $D_1(2420) \rightarrow D^* \pi$
"B.E." = 26 MeV

$c\bar{c}$ -gluon hybrid?

Kou & Pene PLB 631, 164:

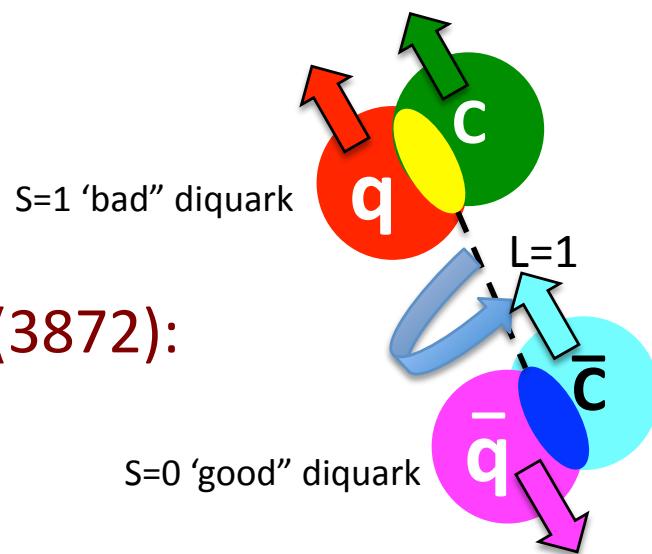


Models for the $\Upsilon(4260)$ II

QCD tetraquark?

Maiani et al. PRD 89, 114010

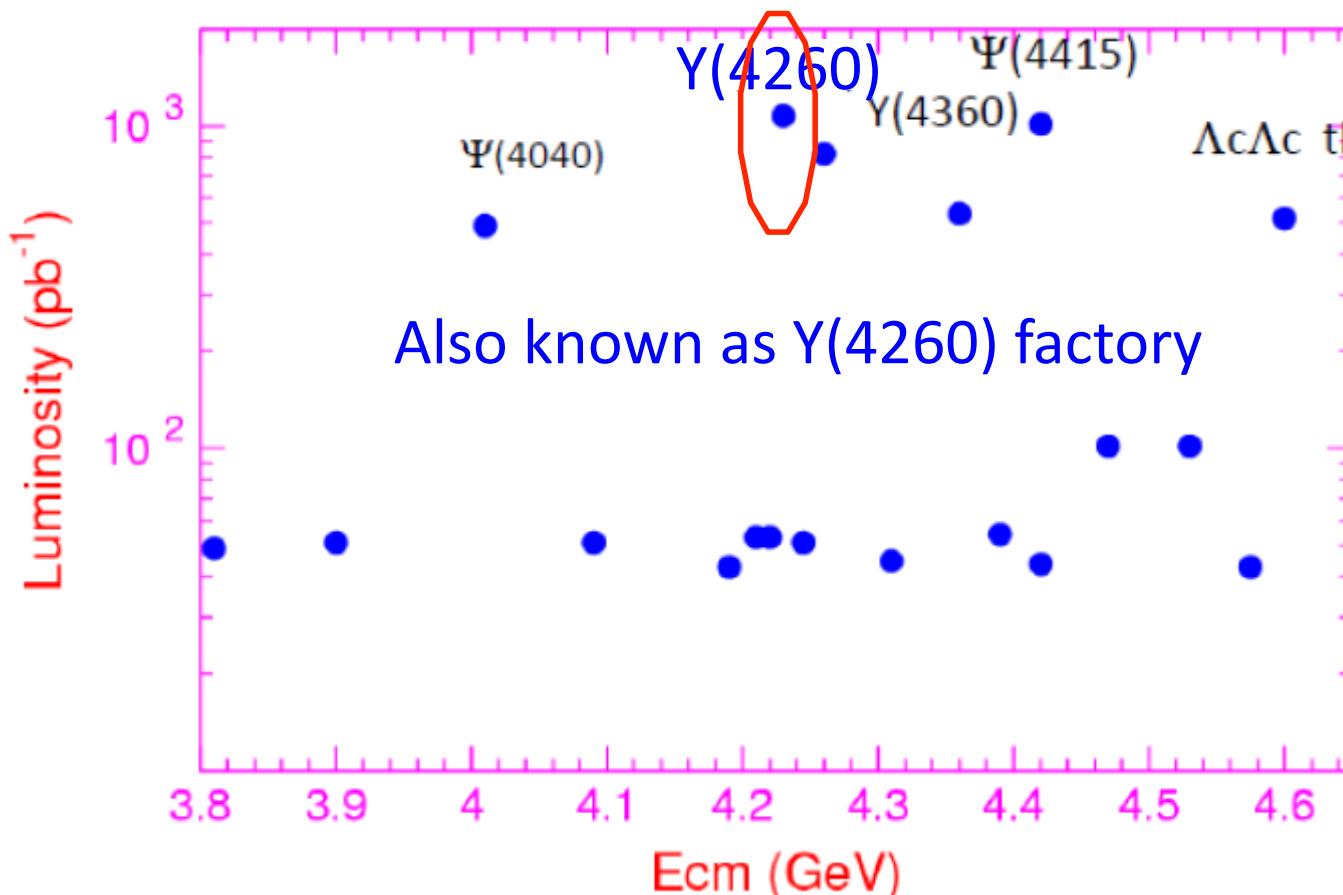
L=1 excitation of the X(3872):



Naturally accounts for
large $\Upsilon(4260) \rightarrow \gamma X(3872)$
as an allowed E1 transition

BESIII Scan Data for XYZ study

collected $\sim 5/\text{fb}$ above 4GeV



$\sim 0.6 \text{ B}$ $\psi(3686)$ events

$\sim 1.3 \text{ B}$ J/ψ events

$\sim 2.9 \text{ fb}^{-1}$ $\psi(3770)$

\sim others including scan and continuum data, etc.

$\sim 24 \times \text{CLEO-c}$

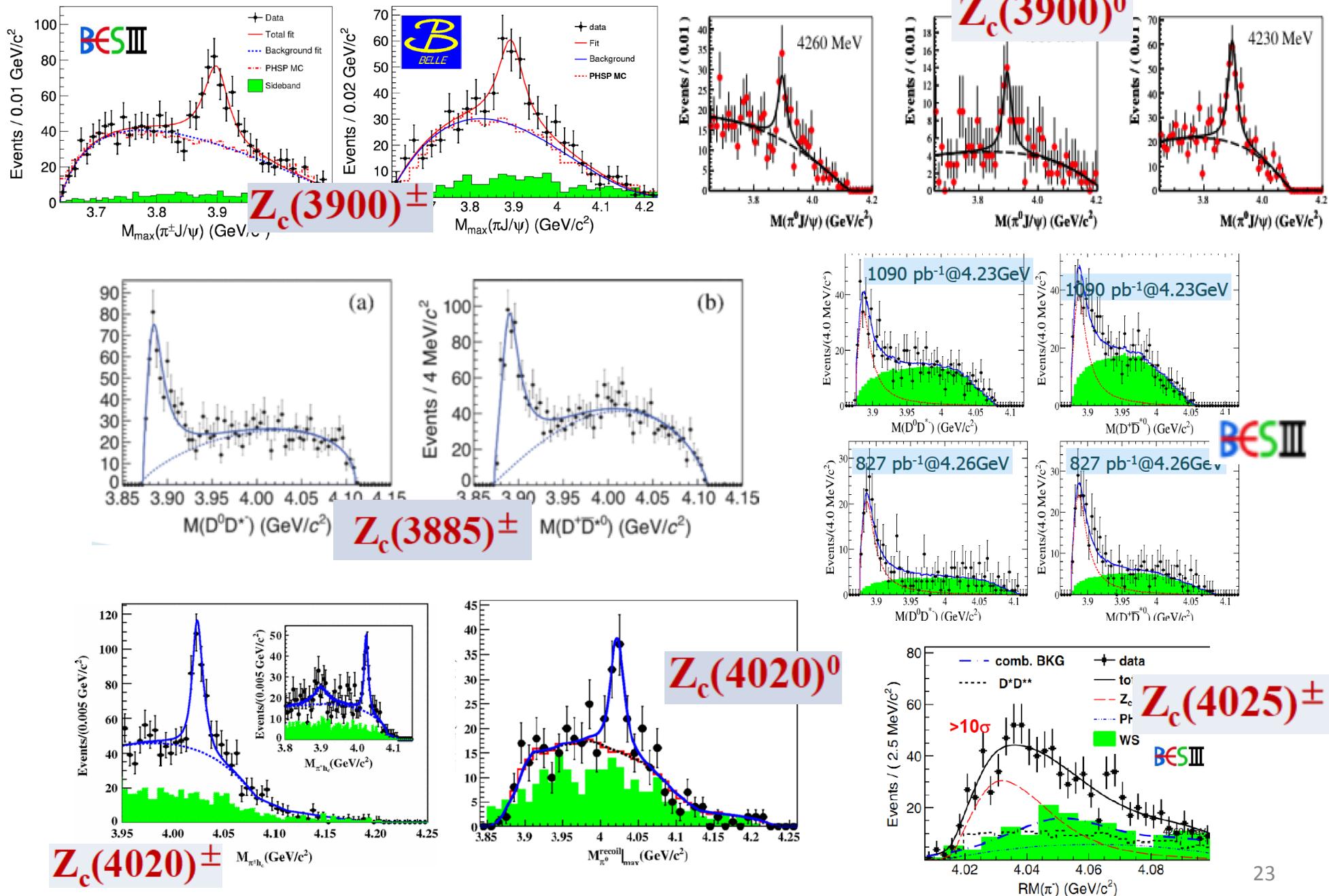
$\sim 21 \times \text{BESII}$

$\sim 11 \times \text{CLEO-c}$

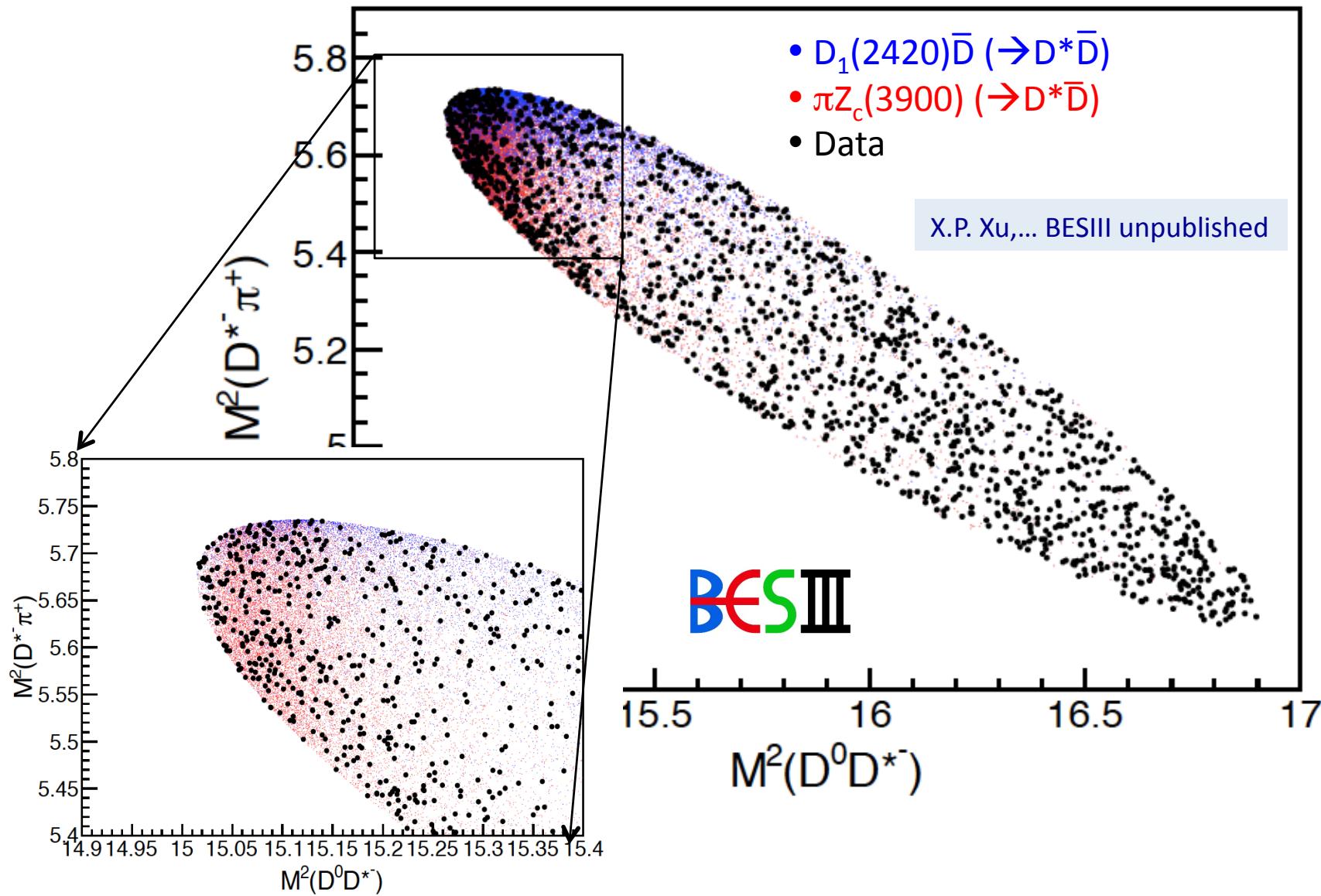
- BESIII has 50 ~ 100 times less luminosity than BelleII.
- But ~ 4000 times more efficient at producing 1^{--} states such as $\Psi(4260)$ and 1^- charged states like $Z_c(3900)$

CM energy (GeV)	$L (\text{pb}^{-1})$
3.81	50.54 ± 0.03
3.90	52.61 ± 0.03
4.009	481.96 ± 0.01
4.09	52.63 ± 0.03
4.19	43.09 ± 0.03
4.21	54.55 ± 0.03
4.22	54.13 ± 0.03
4.23 ¹	44.40 ± 0.03
4.23 ²	1047.34 ± 0.14
4.245	55.59 ± 0.04
4.26 ¹	523.74 ± 0.10
4.26 ²	301.93 ± 0.08
4.31	44.90 ± 0.03
4.36	539.84 ± 0.10
4.39	55.18 ± 0.04
4.42 ¹	44.67 ± 0.03
4.42 ²	1028.89 ± 0.13
4.47	109.94 ± 0.04
4.53	109.98 ± 0.04
4.575	47.67 ± 0.03
4.60	566.93 ± 0.11

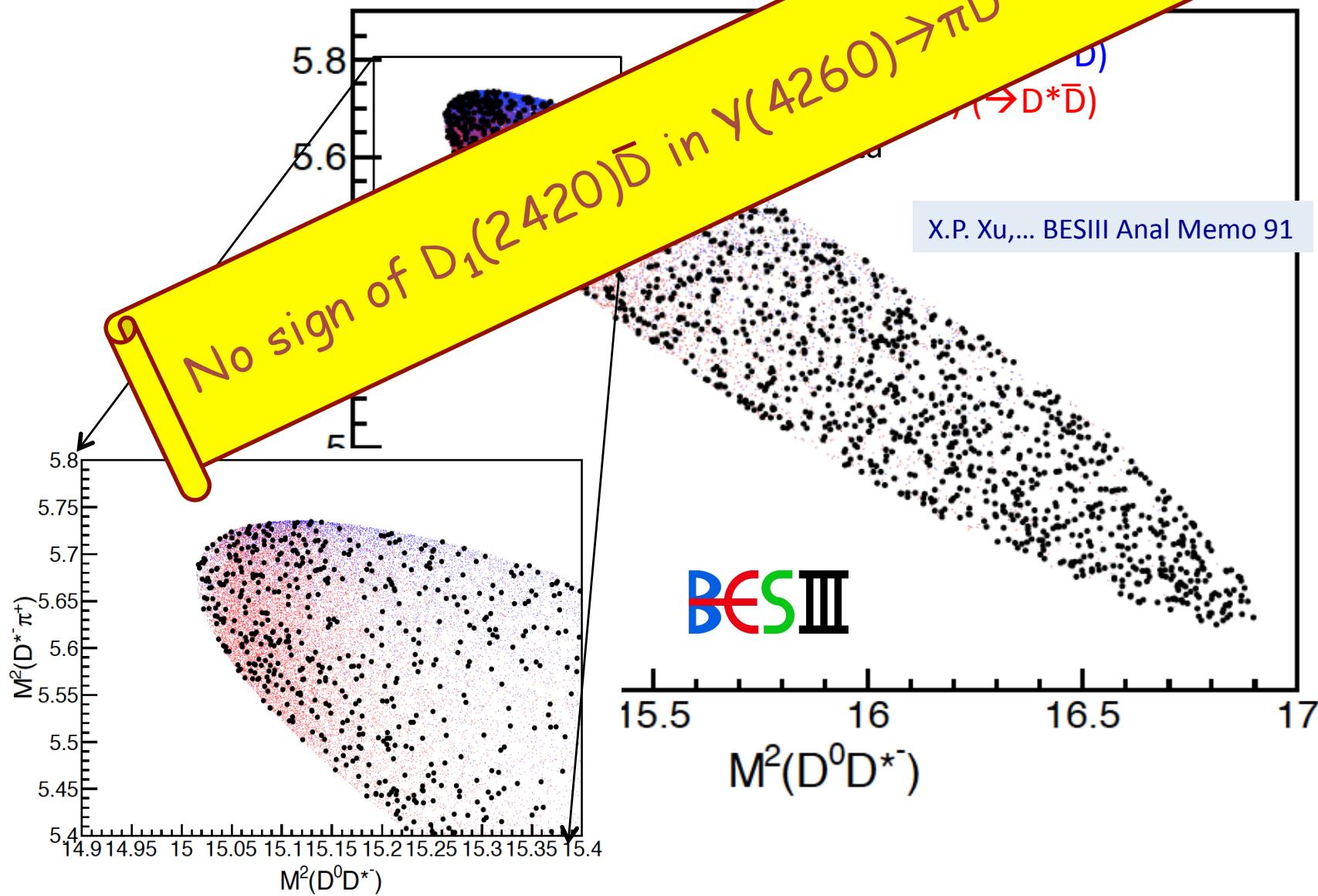
More Z_c states



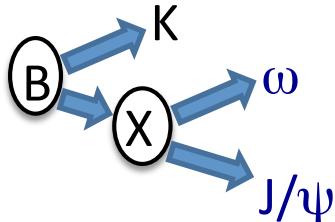
$\Upsilon(4260) \rightarrow \pi D^* \bar{D}$ Dalitz plot



$\Upsilon(4260) \rightarrow \pi D^* \bar{D}$ Dalitz plot

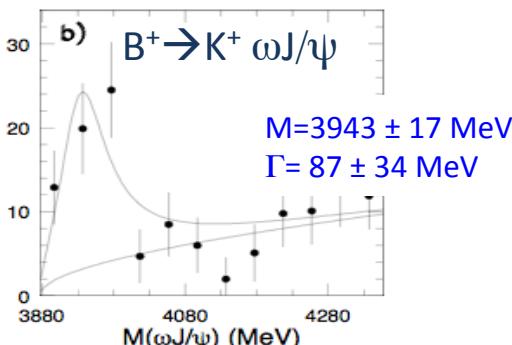


The X(3915)



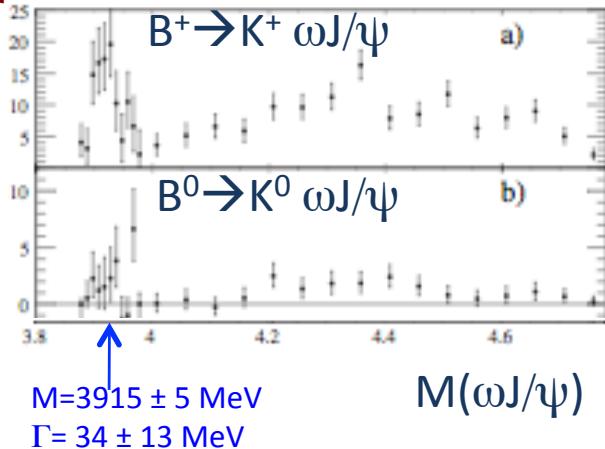
S.-K. Choi et al. (Belle) PRL 94, 182002

Belle
2005



B. Aubert et al. (BaBar) PRL101, 182001

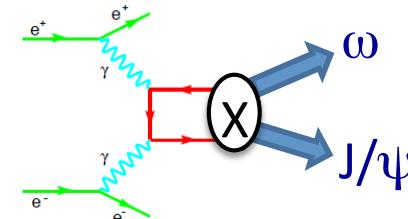
BaBar
2008



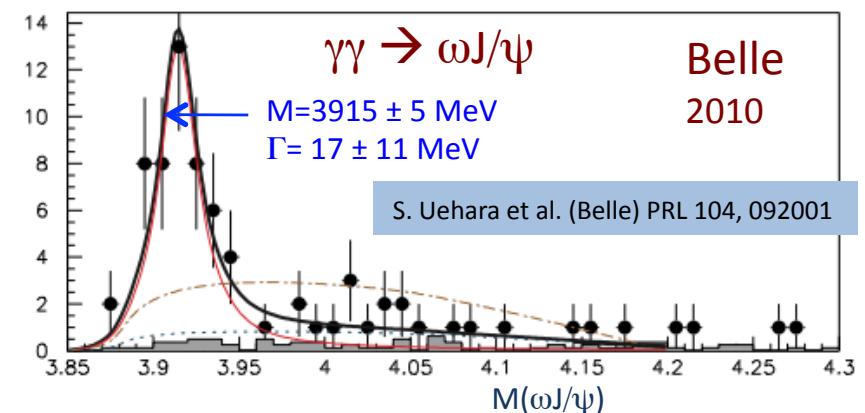
PDG: $Bf(B \rightarrow X(3915))Bf(X(3915) \rightarrow \omega J/\psi) = (3.0^{+0.9}_{-0.7}) \times 10^{-5}$

PDG Averages

$M = 3918 \pm 2 \text{ MeV}$
 $\Gamma = 20 \pm 5 \text{ MeV}$

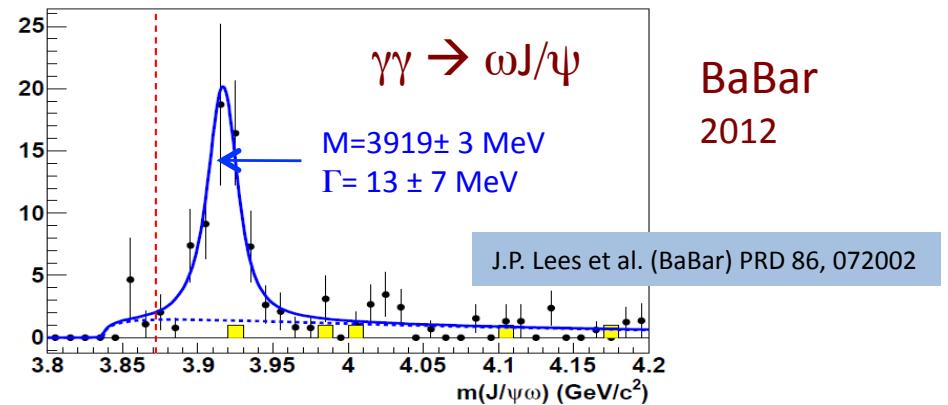


Belle
2010



S. Uehara et al. (Belle) PRL 104, 092001

BaBar
2012

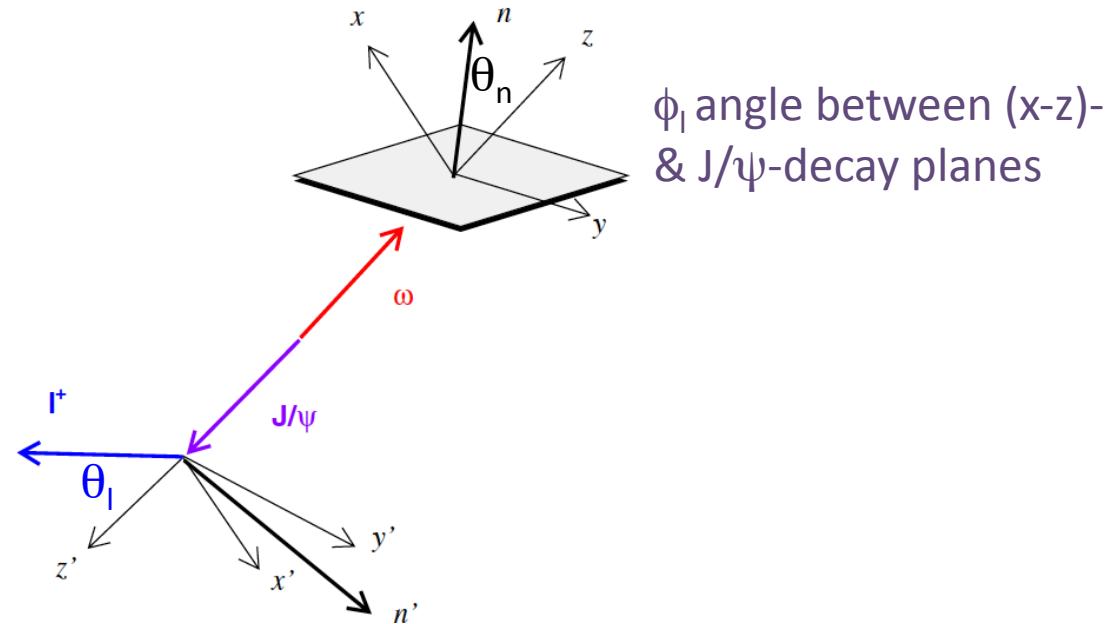


J.P. Lees et al. (BaBar) PRD 86, 072002

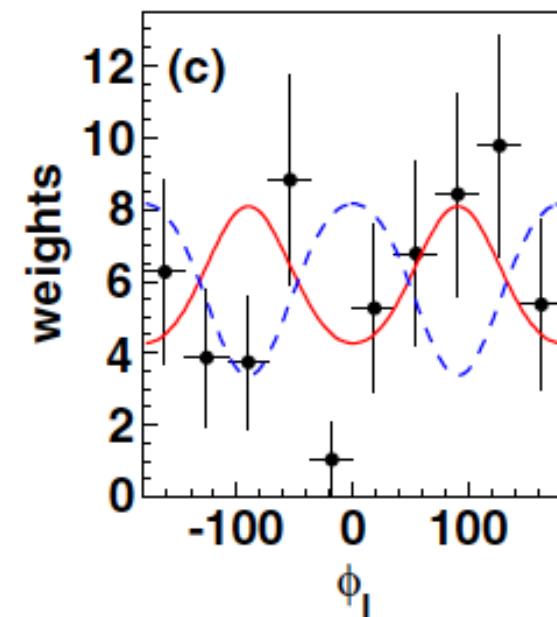
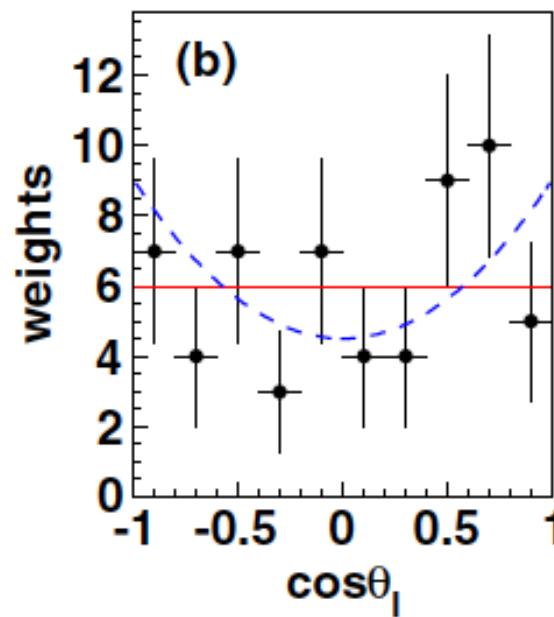
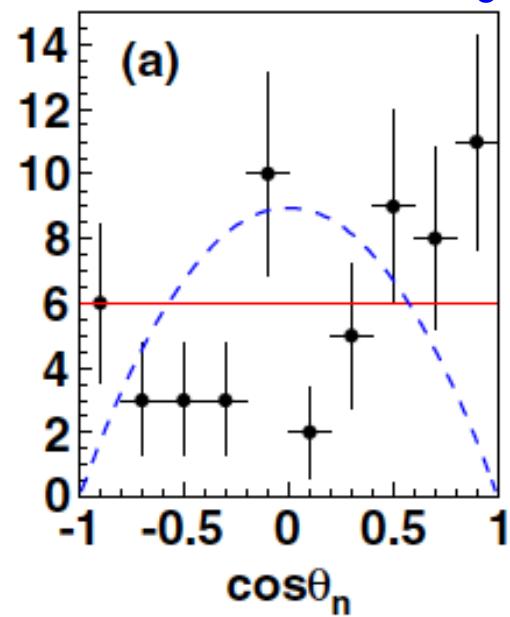
PDG: $\Gamma(X(3915) \rightarrow \gamma\gamma)Bf(X(3915) \rightarrow \omega J/\psi) = (54 \pm 9) \text{ eV}$

BaBar: $J^{PC}=0^{++}$

J.P. Lees et al. (BaBar) PRD 86, 072002

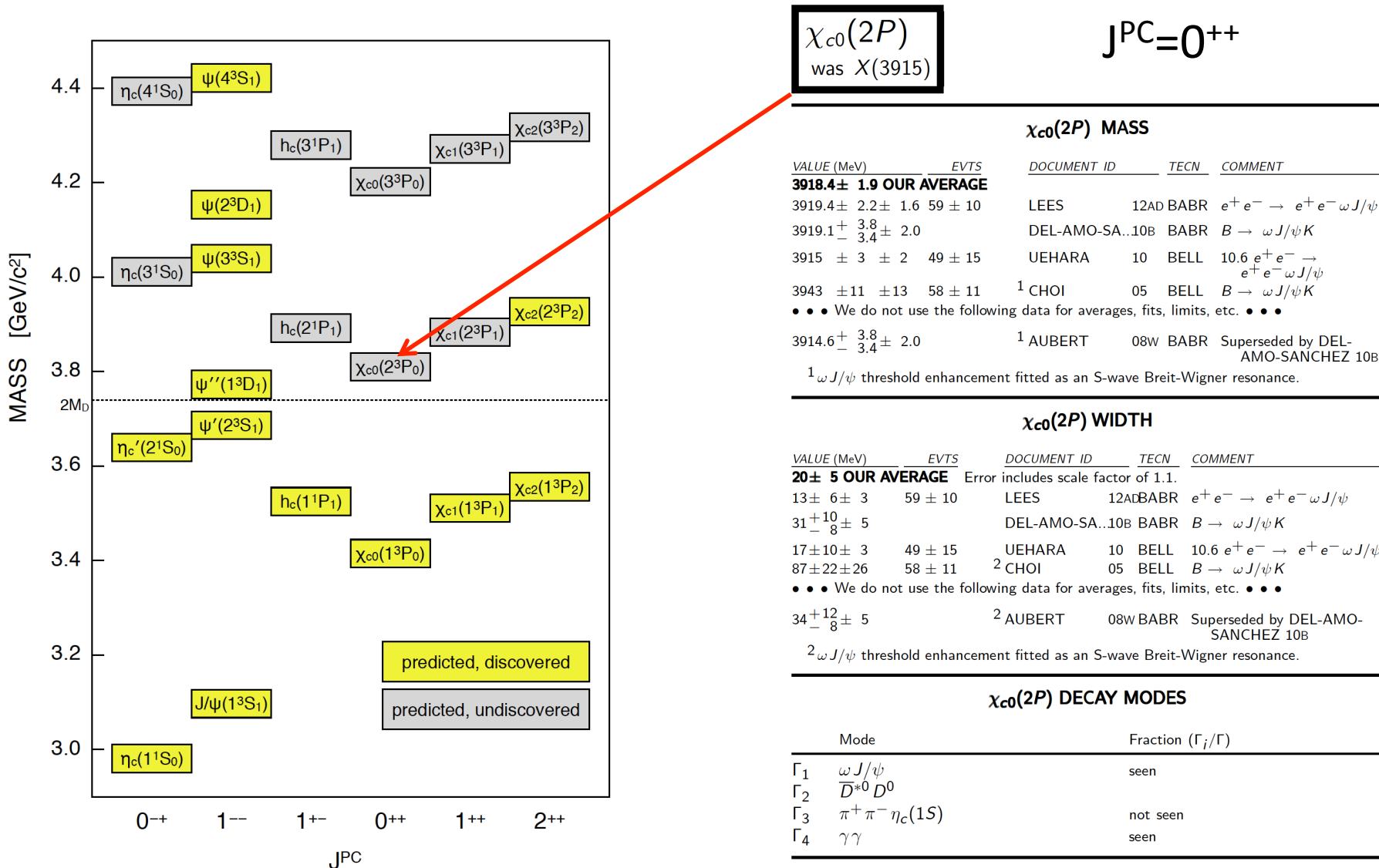


0^+ ————— 6.1%
 0^- - - - - - $10^{-11}\%$



Is it the χ_{c0}' ?

PDG 2014



The $X(3915) \neq \chi_{c0}'$

\Rightarrow Mass is too high: $R \equiv \frac{\Delta M(2P)}{\Delta M(1P)} = 0.06 \pm 0.02$ theory: $R = 0.5 \leftrightarrow 0.9$

\Rightarrow production via $\gamma\gamma$: $Bf(\chi'_{c0} \rightarrow \omega J/\psi) < 8.1\%$

contradictory!

via B decays: $Bf(\chi'_{c0} \rightarrow \omega J/\psi) > 14.6\%$

$\Rightarrow Bf(\chi'_{c0} \rightarrow D\bar{D}) < 25\%$

$Bf(\chi'_{c0} \rightarrow D^0\bar{D}^0) < 1.2 Bf(\chi'_{c0} \rightarrow \omega J/\psi)$

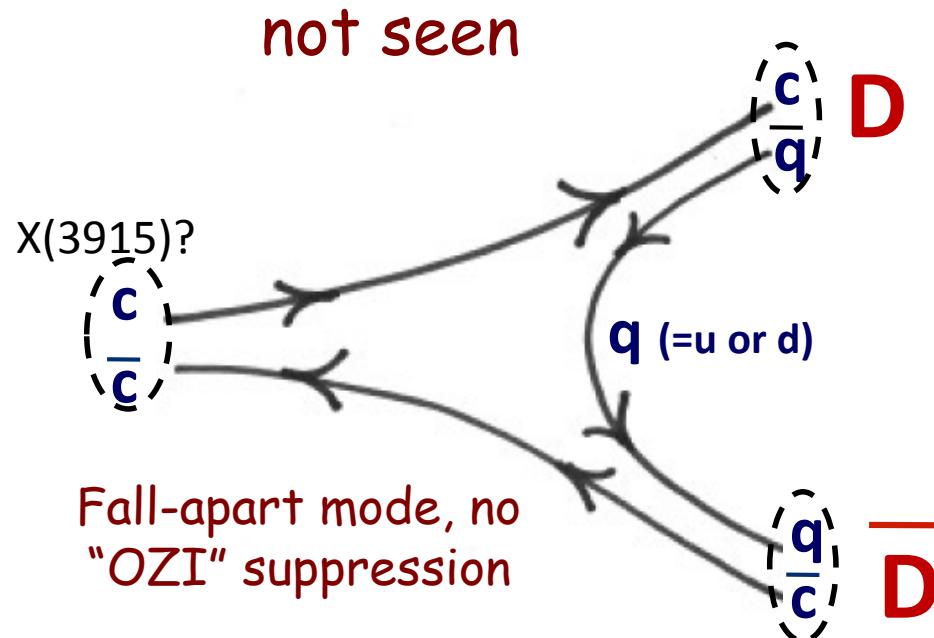
theory:

$Bf(\chi'_{c0} \rightarrow D\bar{D}) \approx 100\%$

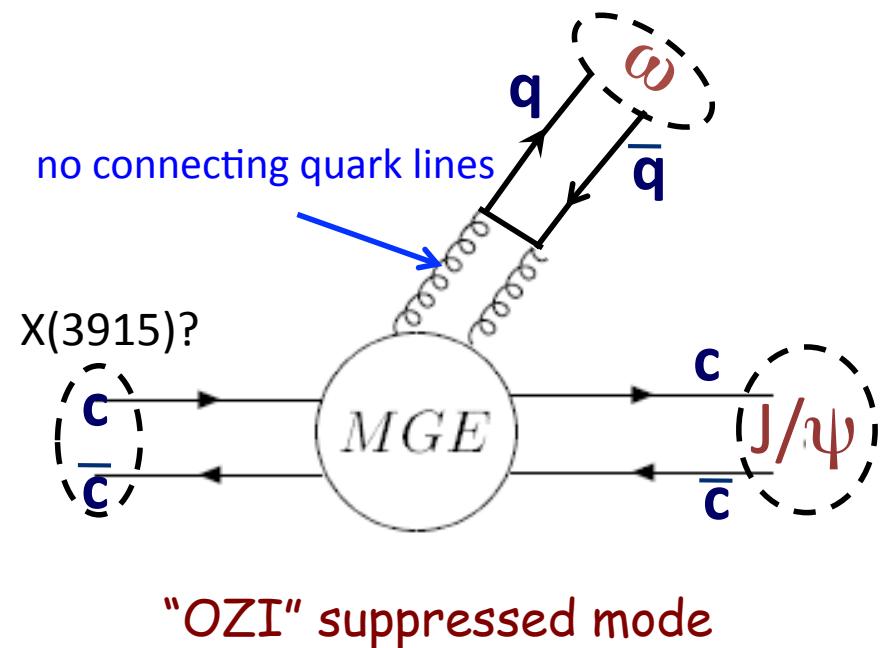
$Bf(\chi'_{c0} \rightarrow D^0\bar{D}^0) \gg Bf(\chi'_{c0} \rightarrow \omega J/\psi)$

See: Guo & Meissner PRD 86, 091501 (2012)
SLO PRD 91, 057501 (2015)
& back-up slides

If it's not the χ_{c0}' , what is it?



dominant decay mode

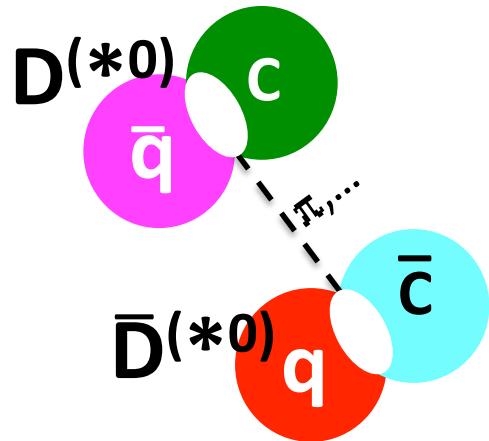


But: $Bf(X_{3915} \rightarrow D^0 \bar{D}^0) < 1.2 \times Bf(X_{3915} \rightarrow \omega J/\psi)$

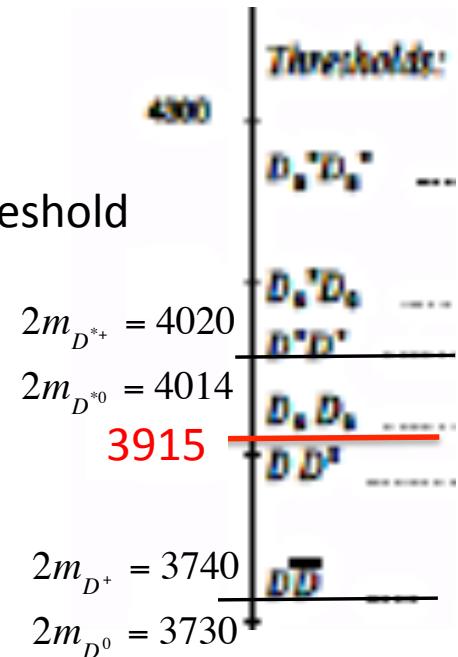
This strongly suggests that the $X(3915)$ is a 4-quark state

Model for the X(3915)?

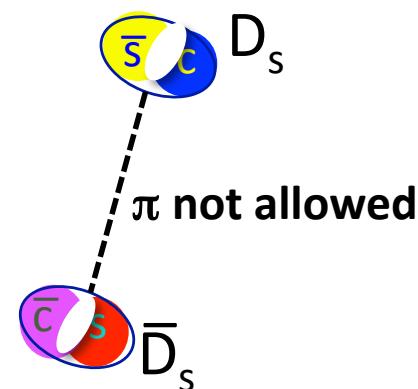
molecule?



no nearby $D^{(*)}\bar{D}^{(*)}$ threshold



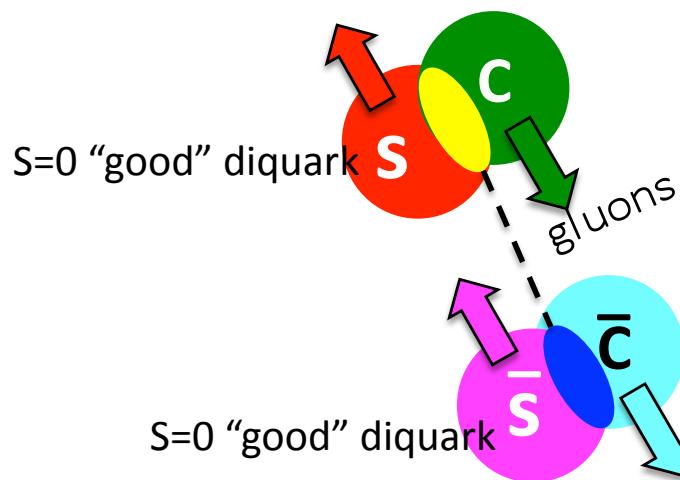
$2m_{D_s^+} = 3937$ MeV \leftarrow close, but there is no mechanism to bind $D_s^+ D_s^-$



Model for the X(3915)?

QCD diquark-diantiquark?

Maiani et al. PRD 71, 014028 (2005)

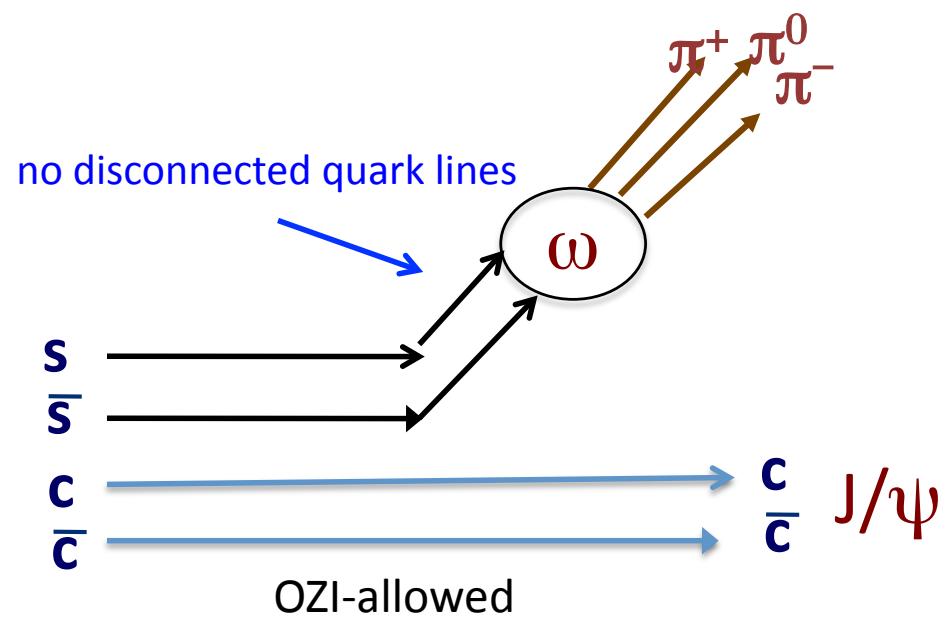


X(3872) with $u \rightarrow s$
& the $S=1$ "bad"
Diquark replaced by
an $S=0$ "good" diquark

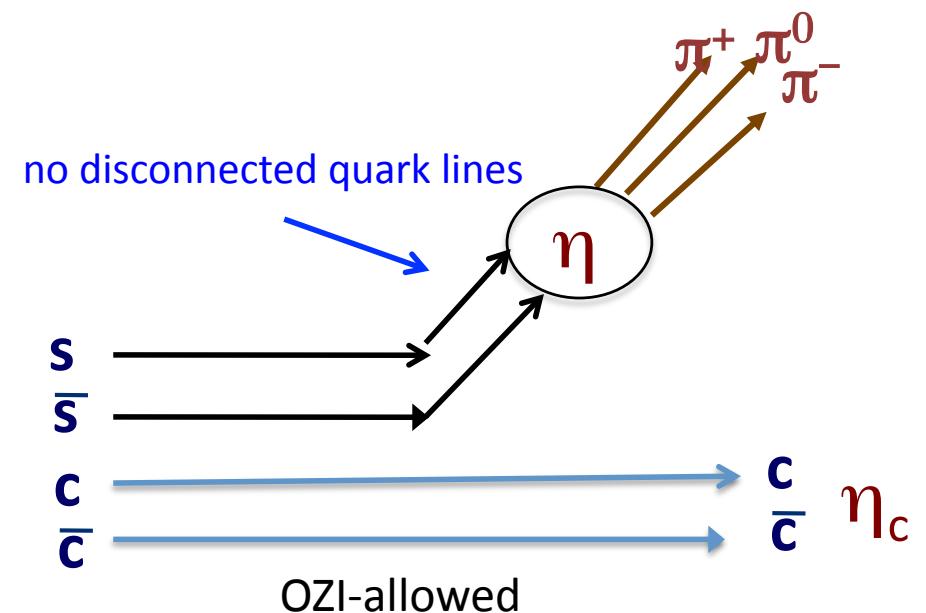
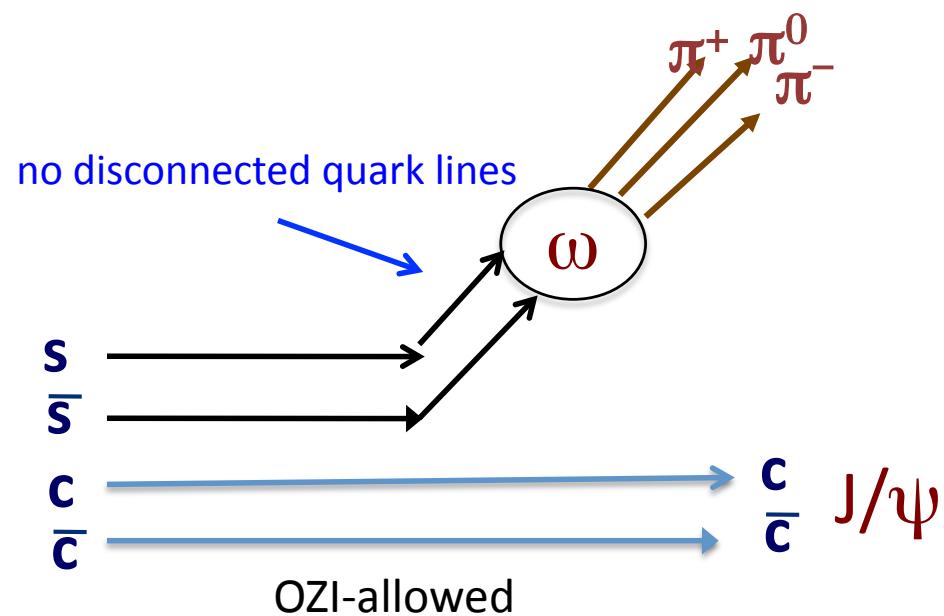
$$M_{X(3915)} \approx M_{X(3872)} + 2(m_s - m_u) - \Delta M(\text{bad} - \text{good}) \sim 3920 \text{ MeV}$$

$\sim 200 \text{ MeV}$ $\sim 160 \text{ MeV}$

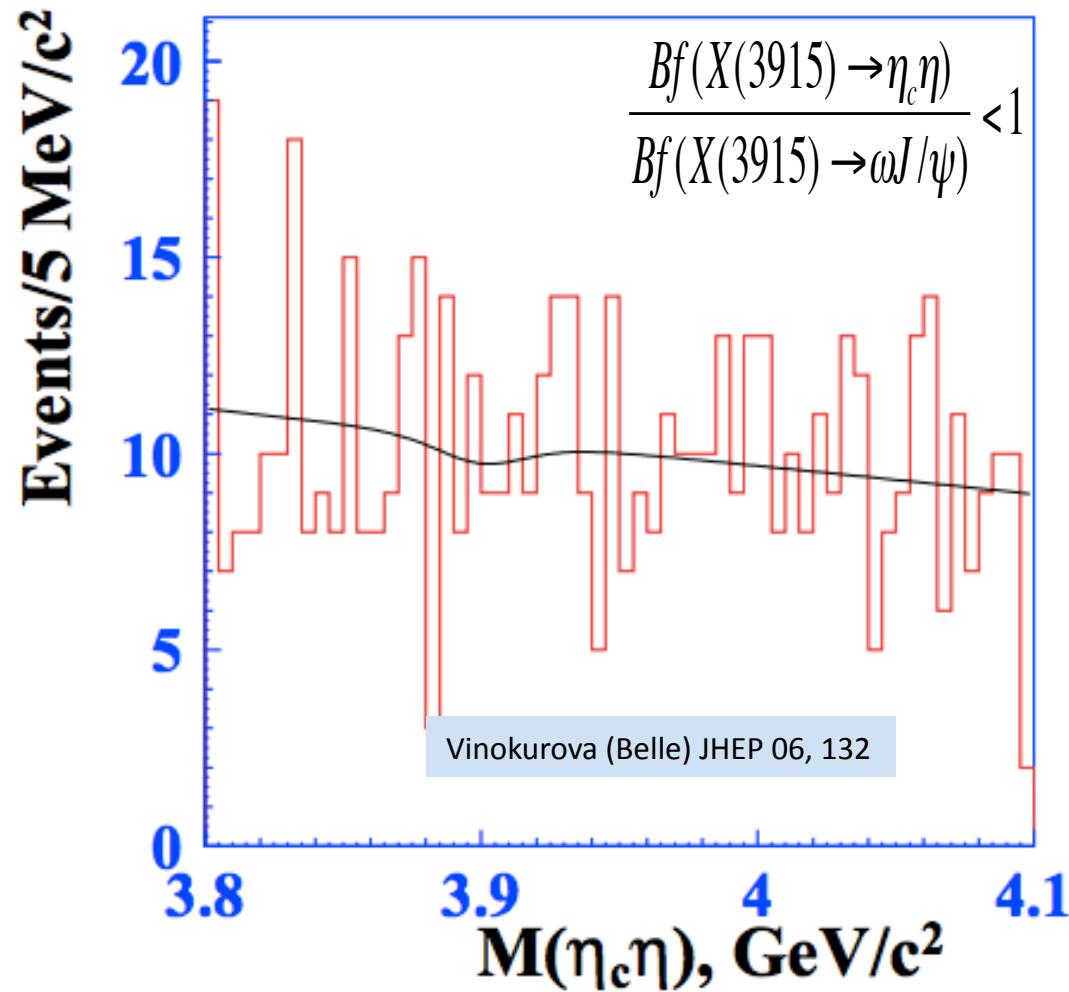
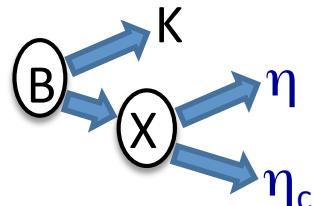
$X(3915)$ as a $c s \bar{c} \bar{s}$ tetra-quark



$X(3915)$ as a $c\bar{s}\bar{c}\bar{s}$ tetra-quark

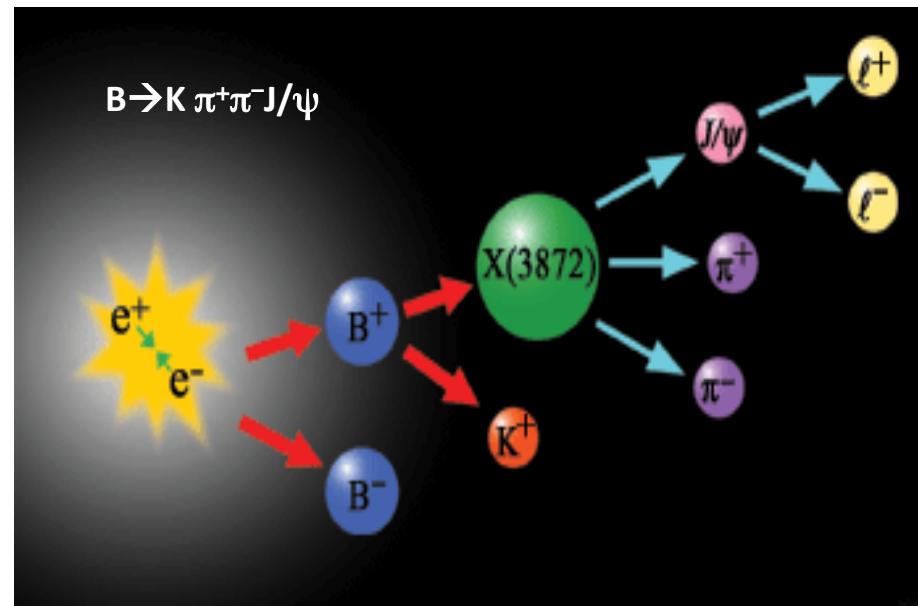


Search for $X(3915) \rightarrow \eta_c \eta$



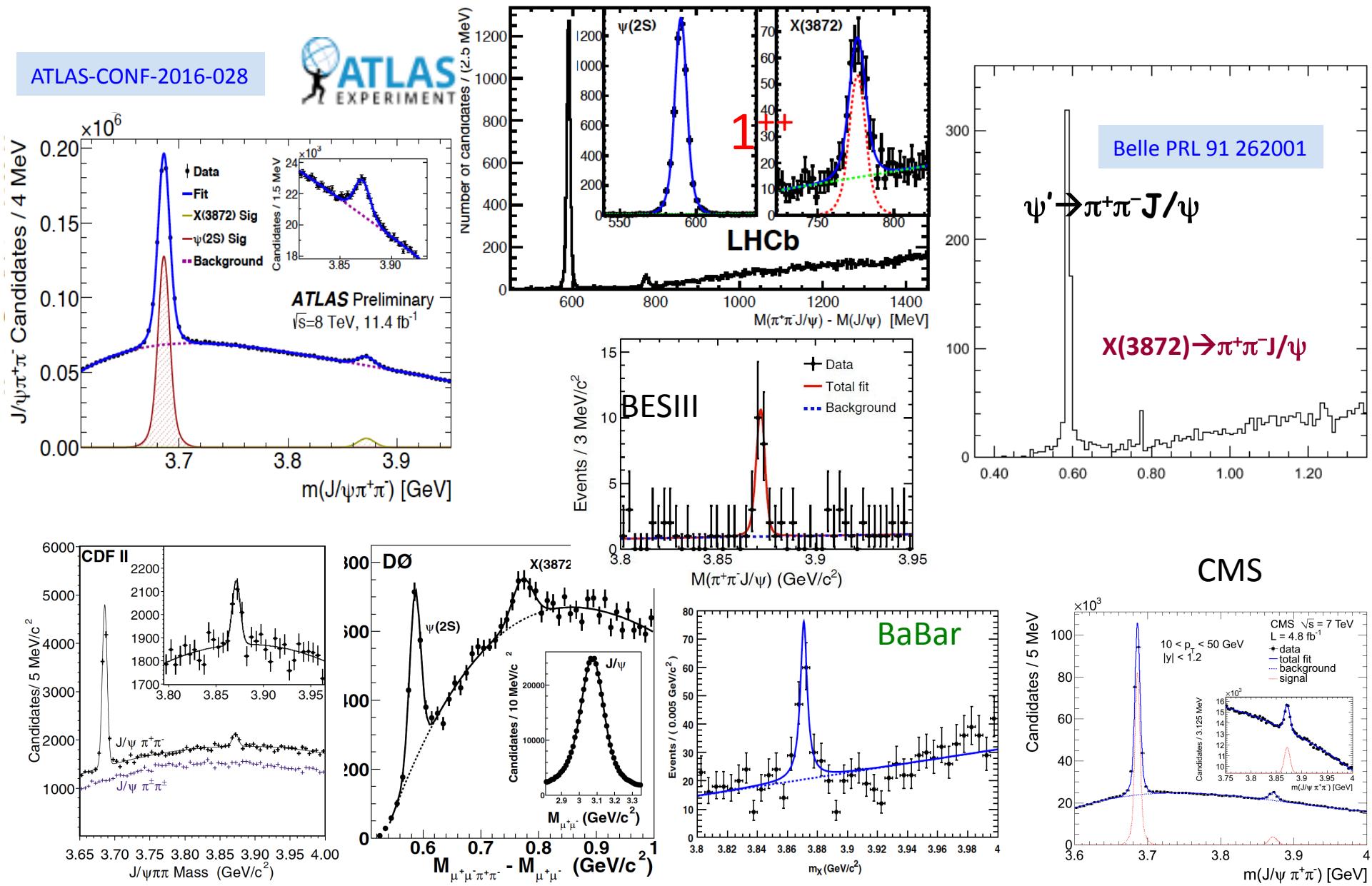
no signal, but not a very stringent limit

The X(3872)

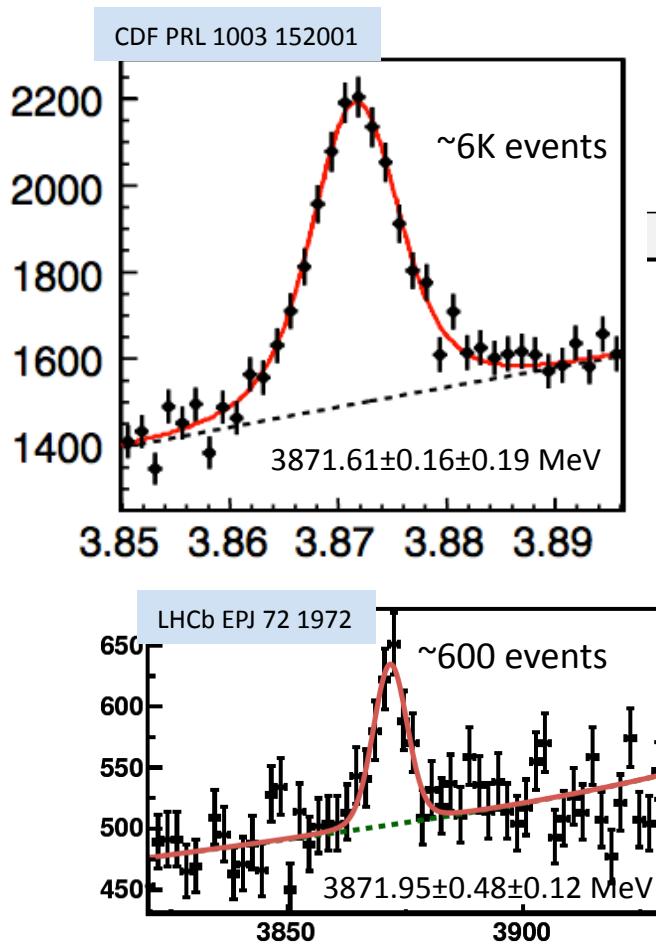


It became the most highly cited B- factory paper !

$X(3872)$: seen in B decays & $p\bar{p}$ collisions

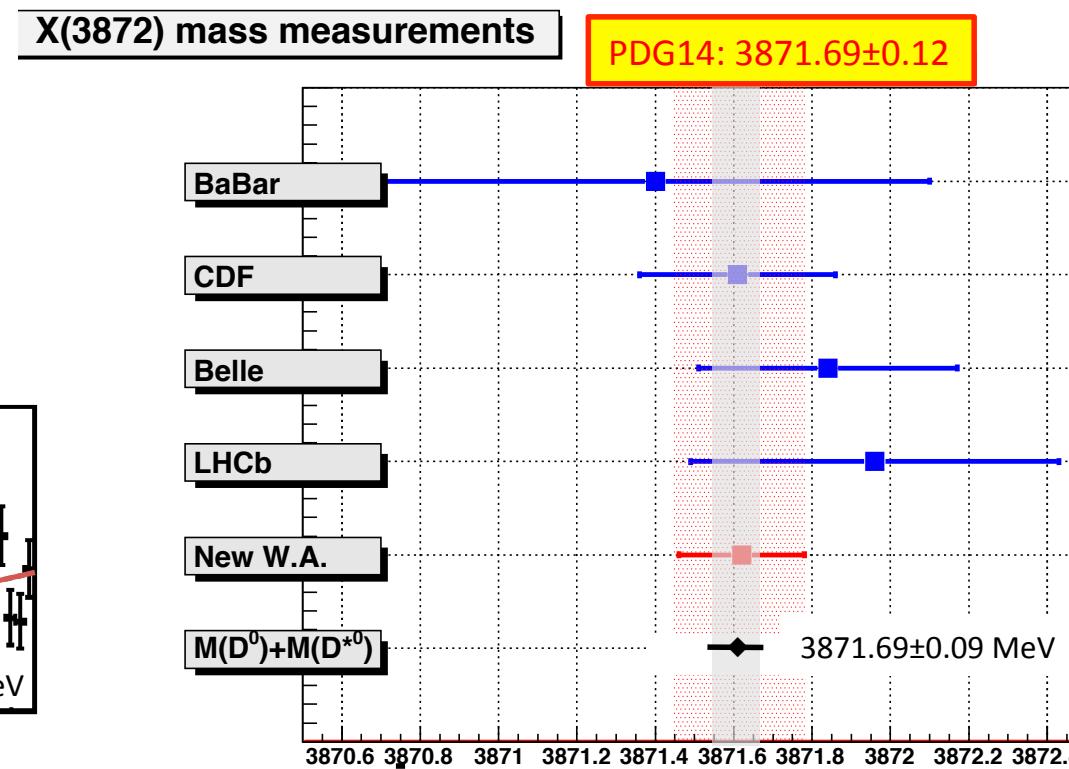


X(3872) Mass and BE



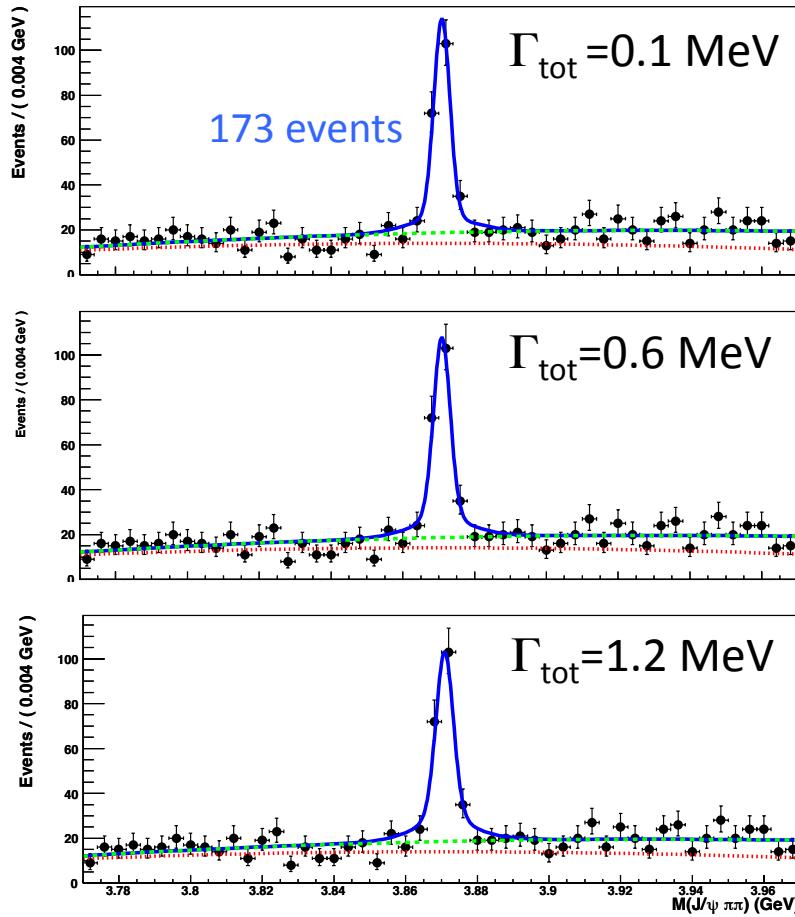
$M_{X(3872)}$ is indistinguishable from $m_{D^0} + m_{D^{*0}}$

"B.E." = 3 ± 193 keV

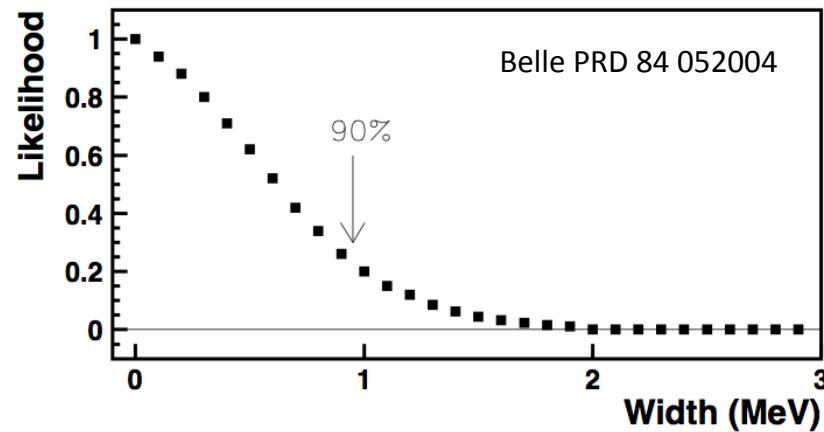


X(3872) width

Too narrow to be measured (at least so far)



$$\frac{1}{(m - m_0)^2 + (\Gamma/2)^2} \otimes \exp\left(-\frac{(m - m_0)^2}{2\sigma^2}\right)$$

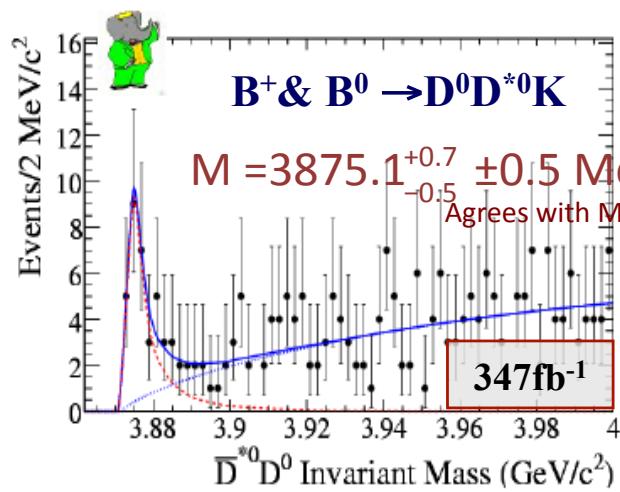


$$\Gamma_{\text{tot}} < 1.2 \text{ MeV}$$

For comparison: $\Gamma_{\chi c1} = 0.84+0.04 \text{ MeV}$

Strong coupling $X(3872) \rightarrow D\bar{D}^*$

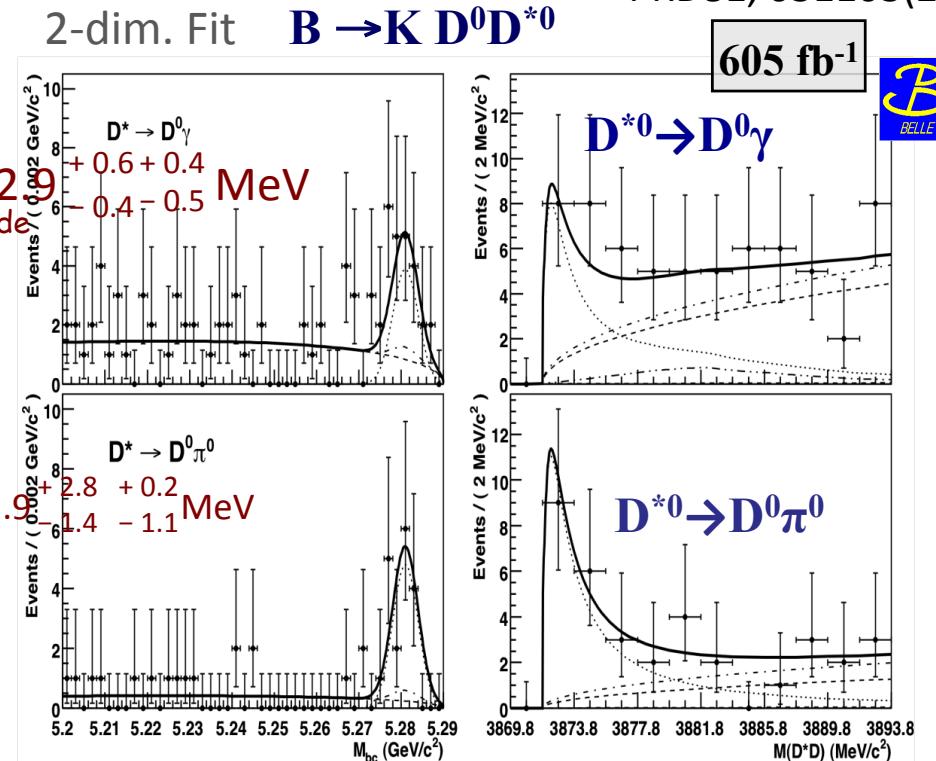
PRD81, 031103(2010)



$$B(B \rightarrow K X_{3872}) B(X_{3872} \rightarrow D^{*0} D^0) = (0.80 \pm 0.20 \pm 0.10) \times 10^{-4}$$

S-wave

$$Bf(X(3872) \rightarrow D^0 \bar{D}^{*0}) = (10 \pm 3) \times Bf(X(3872) \rightarrow \pi^+ \pi^- J/\psi)$$



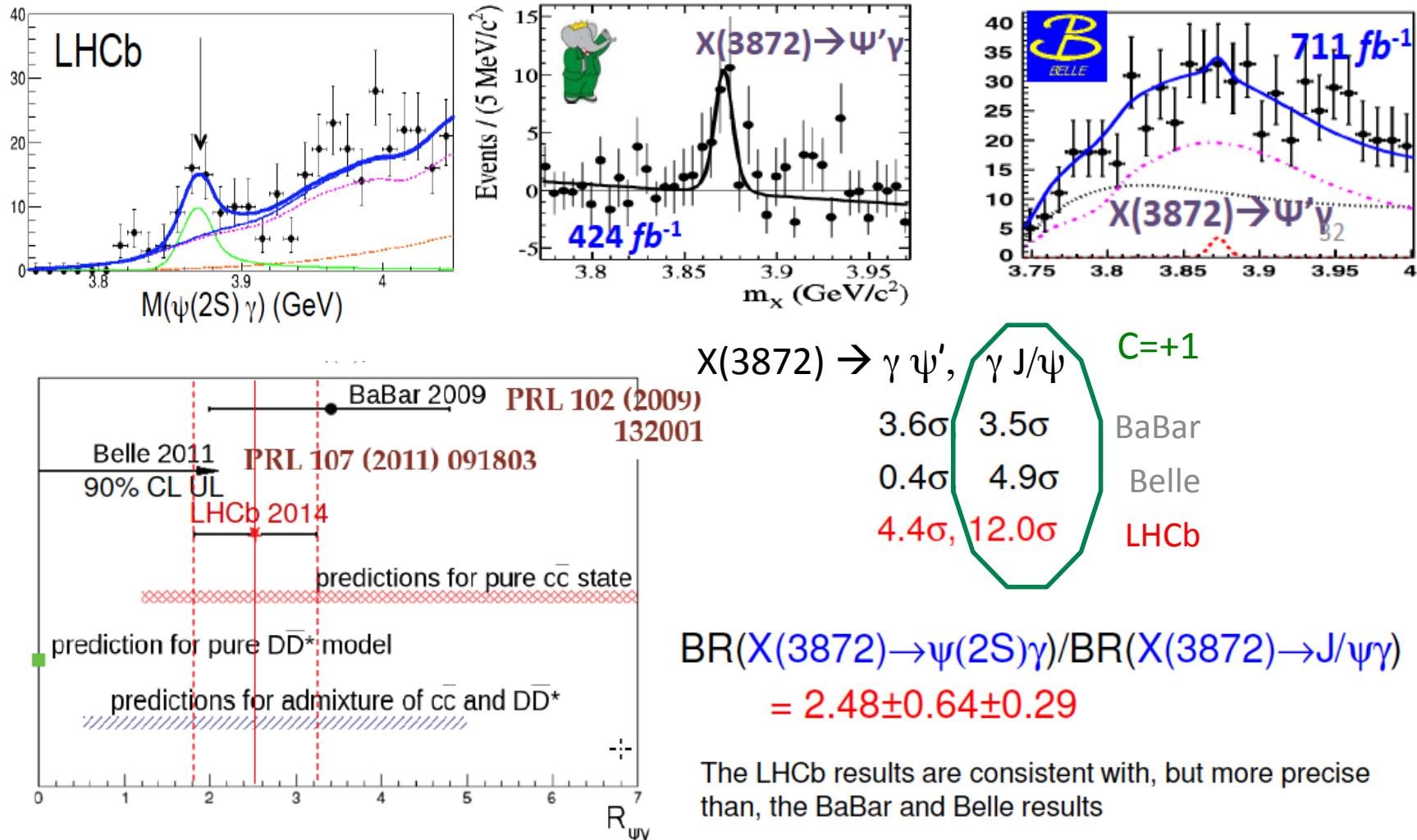
Braaten & Lu (PRD 76 094028):

Independently of the original mechanism for its existence, the strong coupling to $D\bar{D}^*$ in an S-wave & small "BE" imply unambiguously that the $X(3872)$ must be either a molecule ($BE < 0$) or a virtual ($BE > 0$) $D\bar{D}^*$ state of size $\approx 1/\sqrt{2m_D |BE|} \geq 7 \text{ fm}$

↑
"scattering length"

Radiative decays of X(3872)

$R_{\psi\gamma} = \frac{\mathcal{B}(X(3872) \rightarrow \psi(2S)\gamma)}{\mathcal{B}(X(3872) \rightarrow J/\psi\gamma)}$: a probe of the nature of X(3872)



From T. Skwarnicki (Moriond QCD 2015)

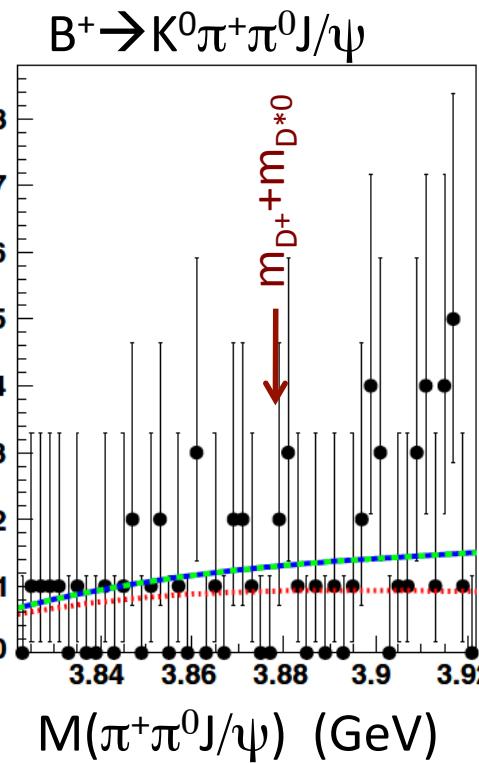
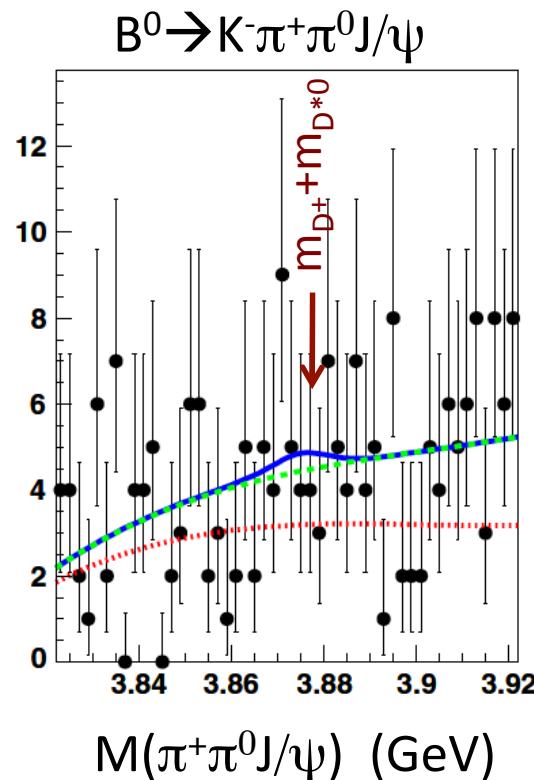
Isospin of the X(3872)

No X(3872) charged partner states in $B \rightarrow K\pi^+\pi^0 J/\psi$

(If $M(X^+) > m_{D^+} + m_{D^{*0}} \approx 3877$ MeV, $\Gamma(X^+)$ may be wide)

Belle PRD 84, 052004(R)

& BaBar PRD 71, 031501



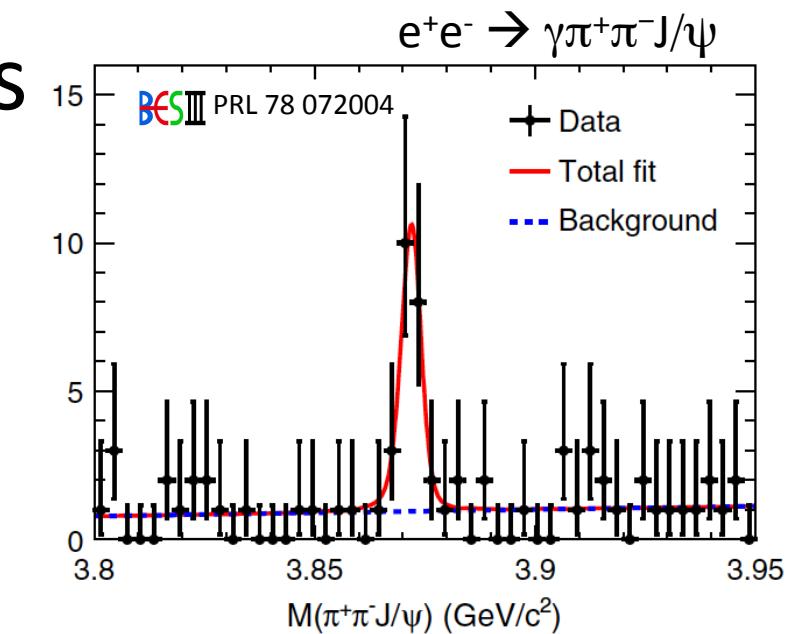
X(3872) decay modes

$X(3872) \rightarrow \gamma J/\psi$
 $\rightarrow \gamma\psi'$
 $\rightarrow \pi^+\pi^-J/\psi$
 $\rightarrow \omega J/\psi$
 $\rightarrow D^0D^{*0}$

$\Gamma_{tot} \approx 15 \text{ GeV}$ $\Gamma(X(3872) \rightarrow \pi^+\pi^-J/\psi)$
 $\Gamma_{DD^*} \approx 10 \text{ GeV}$ $\Gamma(X(3872) \rightarrow \pi^+\pi^-J/\psi)$
 $\Gamma(X(3872) \rightarrow \pi^+\pi^-J/\psi) < 80 \text{ keV}$
 $\Gamma(X(3872) \rightarrow p\bar{p}) < 0.002\Gamma(\pi^+\pi^-J/\psi) < 160 \text{ eV}$

X(3872) production modes

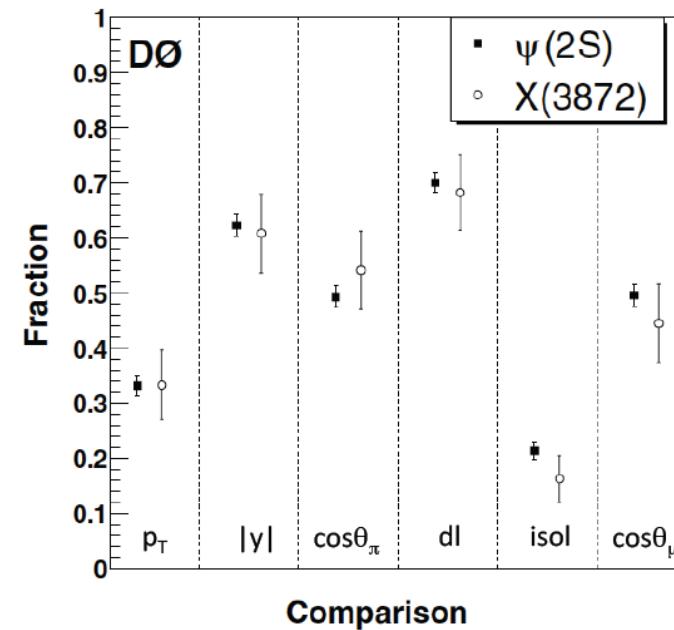
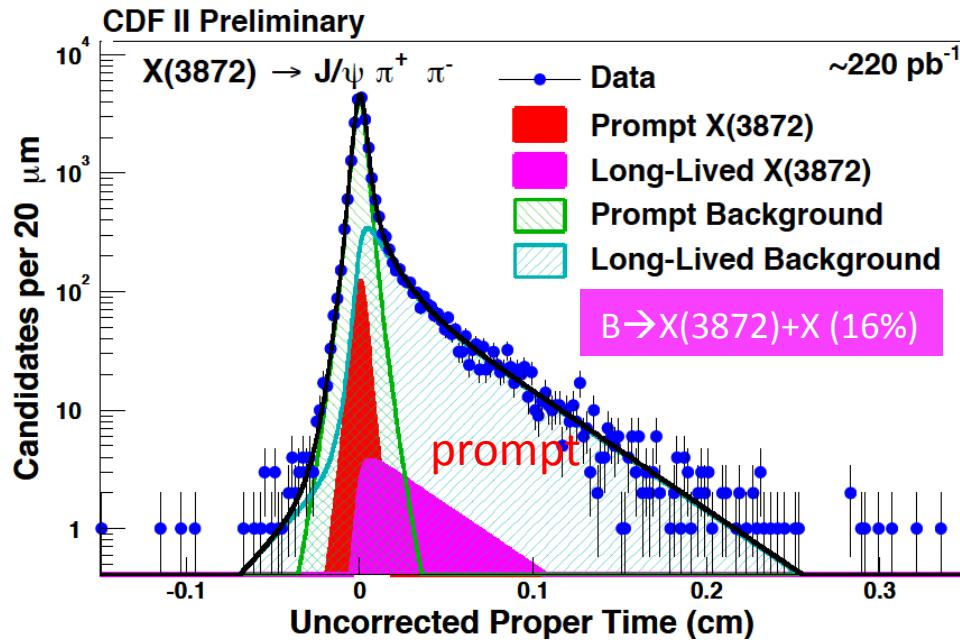
- B-meson decays
- Prompt $\bar{p}p$ (& $p\bar{p}$) collisions
- $e^+e^- \rightarrow \gamma X(3872)$
(Y(4260)?)



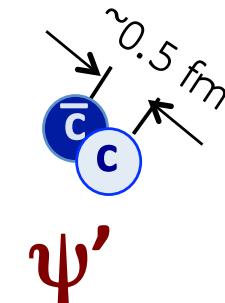
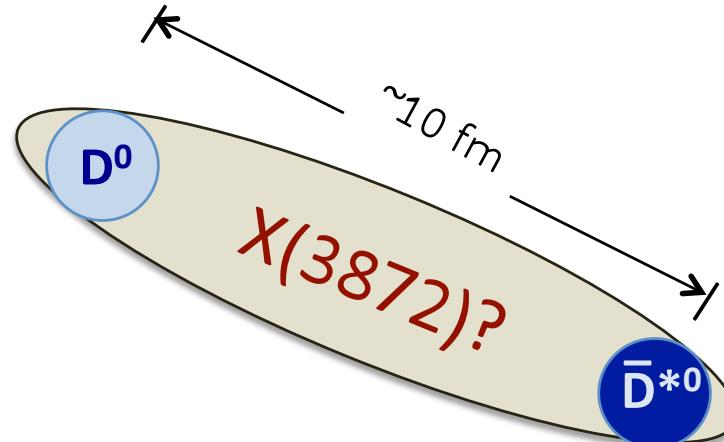
CDF: $\sim 85\%$ of $\bar{p}p \rightarrow X(3872)$ is prompt

D0: prompt $\bar{p}p \rightarrow X(3872)X \approx \bar{p}p \rightarrow \psi'X$

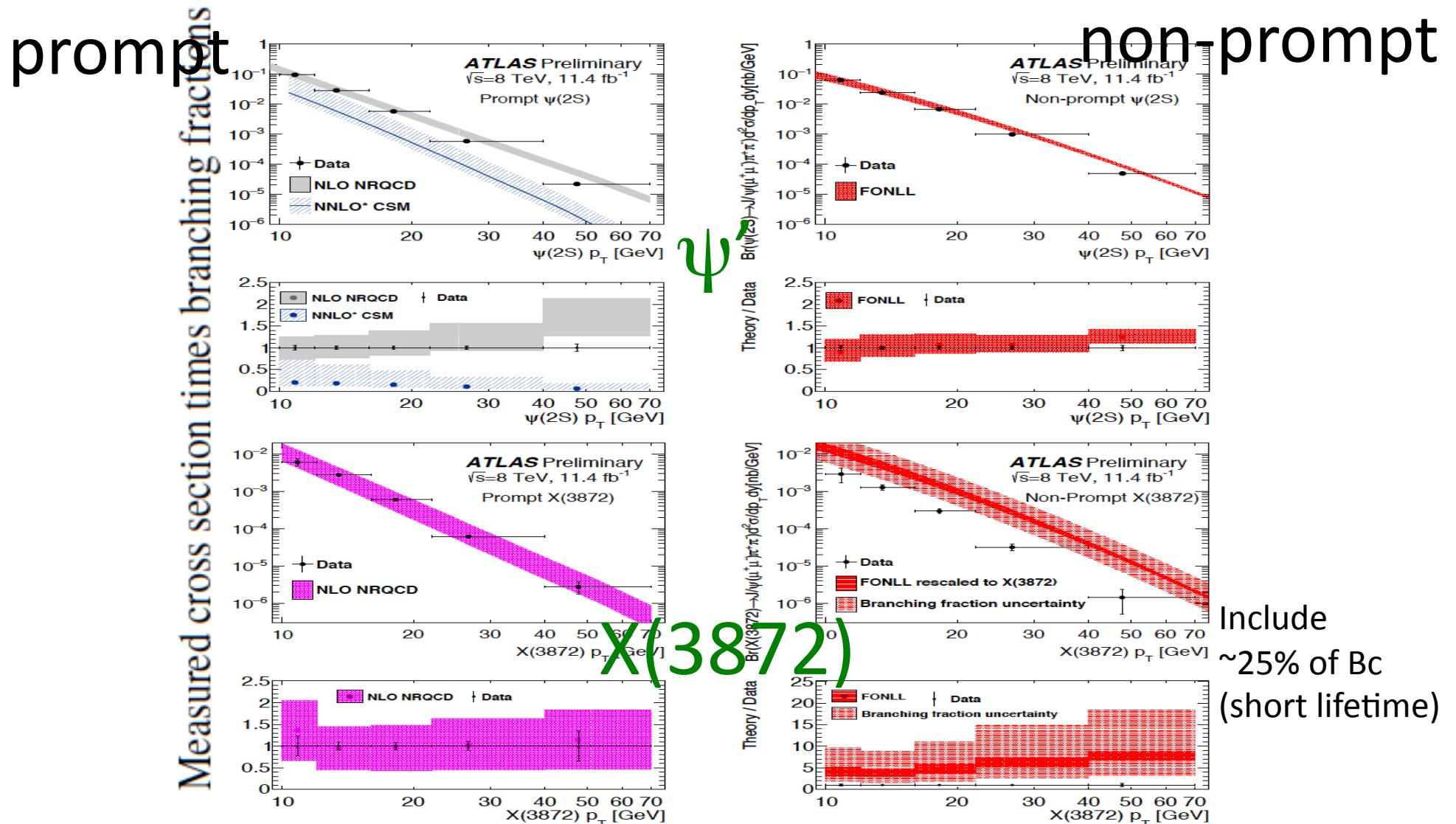
DO PRI 93, 162002



$X(3872)$ & ψ' have similar production characteristics (i.e. p_T - & $|y|$ -dependence, isolation, etc.)



ATLAS: (two lifetime model)

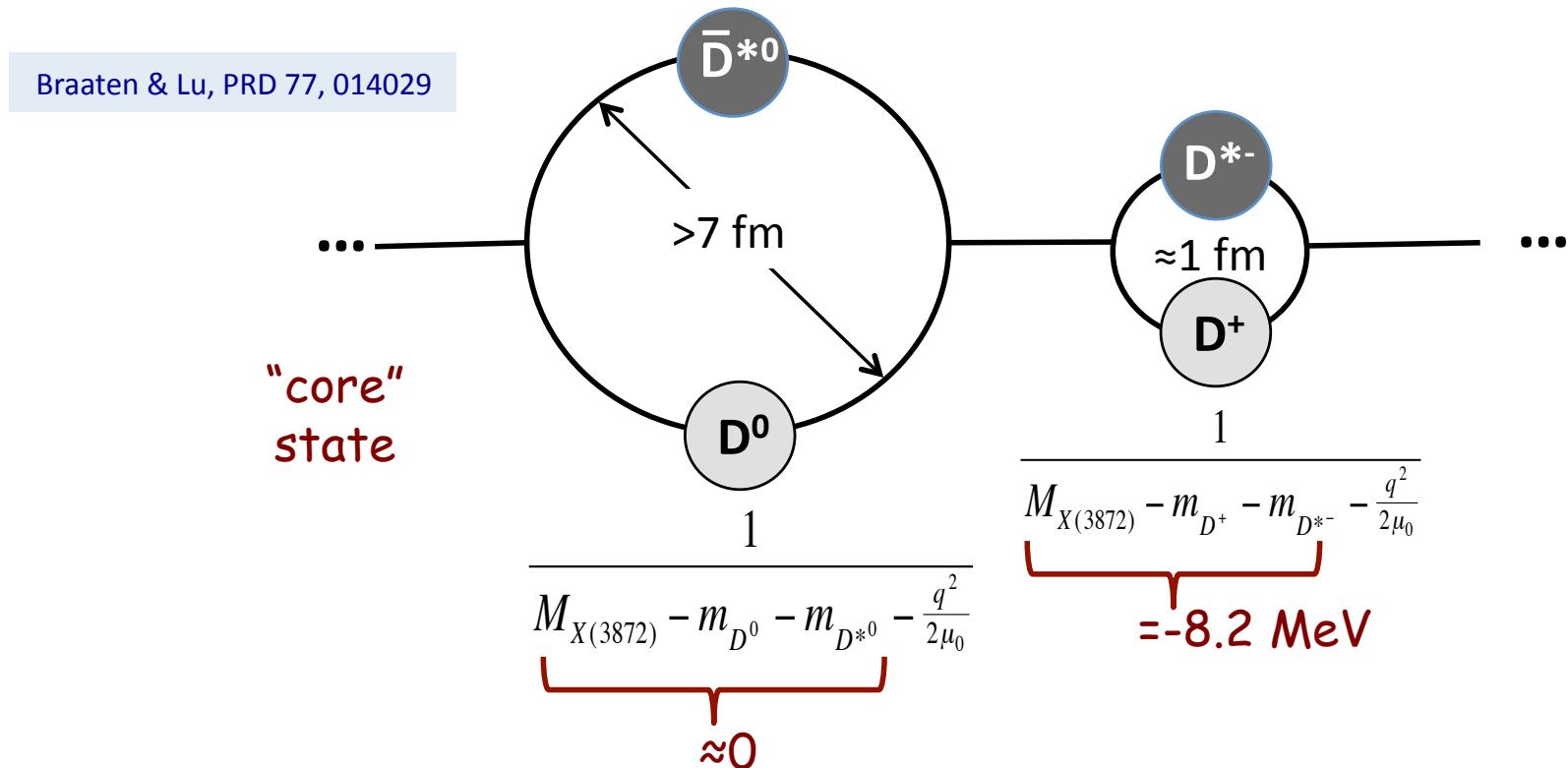


Include
~25% of B_c
(short lifetime)

$$R_B^{2L} = \frac{\mathcal{B}(B \rightarrow X(3872)) \mathcal{B}(X(3872) \rightarrow J/\psi \pi^+ \pi^-)}{\mathcal{B}(B \rightarrow \psi(2S)) \mathcal{B}(\psi(2S) \rightarrow J/\psi \pi^+ \pi^-)} = (3.57 \pm 0.33 \pm 0.11)\%$$

Isospin mixed eigenstate in the X(3872)

X(3872) $\rightarrow \rho J/\psi$
 $\rightarrow \omega J/\psi$ } Isospin violating decay modes (each other) with similar BFs

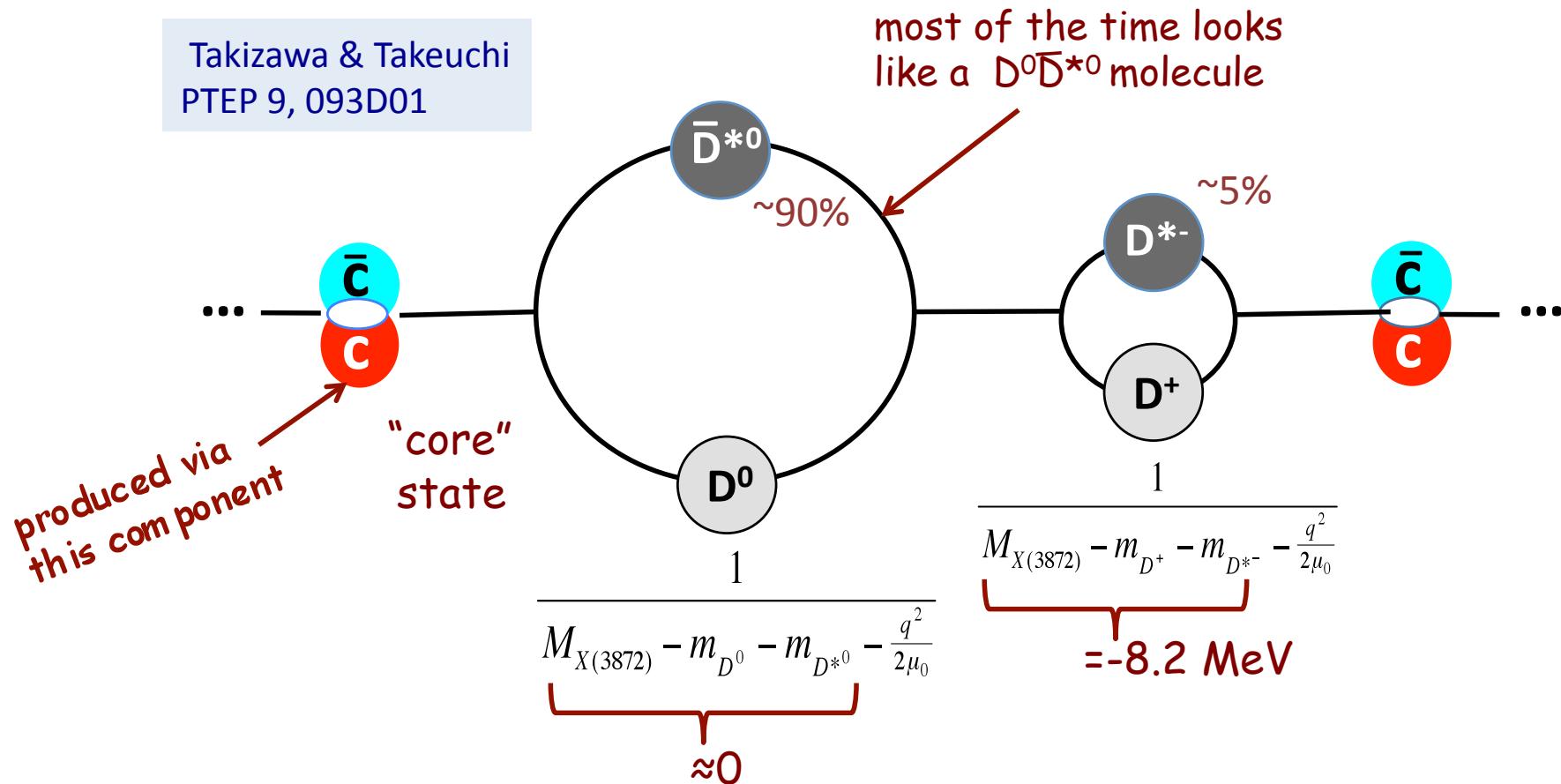


X(3872) is probably a "mostly" I=0 mixed Isospin state

is there a "mostly" I=1 mixed eigenstate near $m_{D^+} + m_{D^{*-}}$?

a mixture of $D\bar{D}^*$ & a $c\bar{c}$ “core”

Ex: “hybrid” model for the $X(3872)$

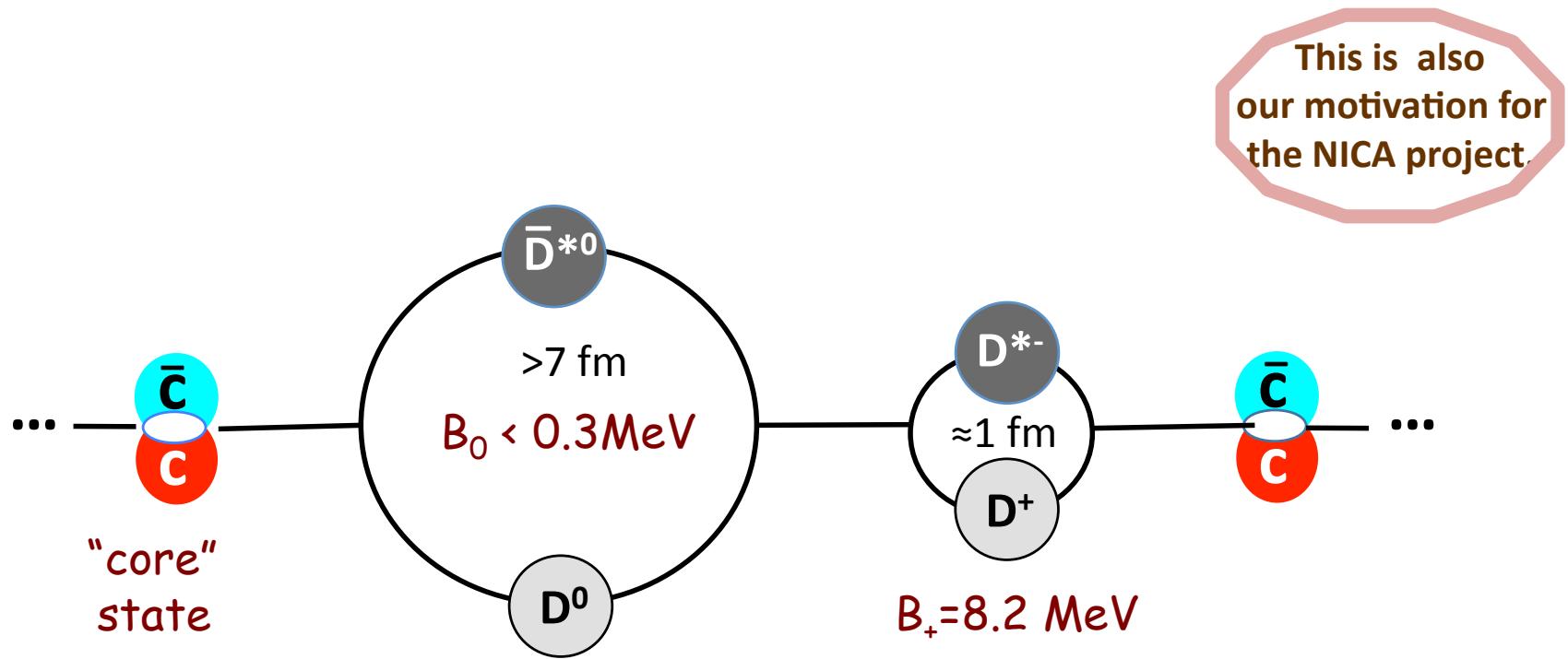


Summary

- A number of tetraquarks and pentaquarks candidates have been observed, and their properties are reviewed.
- What is the nature : molecules ? diquarkonium ? hadro-quarkonium ? or hybrid states ?
 - None of these is sufficient to account for.
 - Remains opportunities for BelleII, LHCb, BESIII and NICA.
- Production in pp & pA collisions (NICA?) potentially provides discrimination between molecule-like & diquark-like structures of XYZ states

Back-up slides

Can the X(3872) structure be probed?



Takizawa & Takeuchi, PTEP 9, 093D01

$$|X(3872)\rangle = 0.944|D^0\bar{D}^{*0}\rangle + 0.228|D^+\bar{D}^{*-}\rangle - 0.237|c\bar{c}\rangle$$

Study: $pN(pp)$ ↩ { $\psi' (\rightarrow \pi\pi J/\psi) + X$
 $X(3872) (\rightarrow \pi\pi J/\psi) + X$ at $\sqrt{s_{pN}} \approx 8 \text{ GeV}$ (near-threshold)

What's the NICA project ?

(Nuclotron-based Ion Collider fAcility)

Probing the X(3872) meson structure with near-threshold pp and pA
collisions at NICA

M.Yu. Barabanov¹, S.-K. Choi², S.L. Olsen^{3†}, A.S. Vodopyanov¹ and A.I. Zinchenko¹

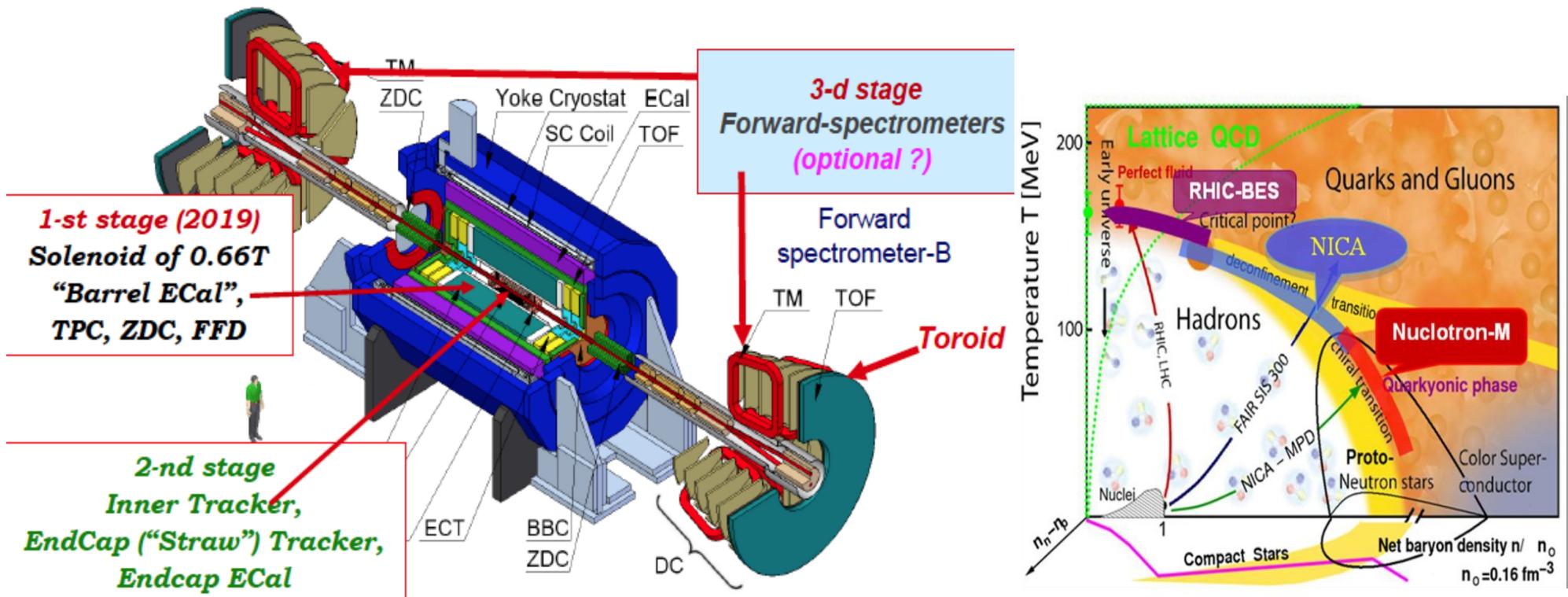
(1) *Joint Institute for Nuclear Research, Joliot-Curie 6 Dubna Moscow region Russia 141980*

(2) *Department of Physics, Gyeongsang National University, Jinju 660-701, Korea*

(3) *Center for Underground Physics, Institute for Basic Science, Daejeon 34074, Korea*

Multi-Purpose Detector (MPD)

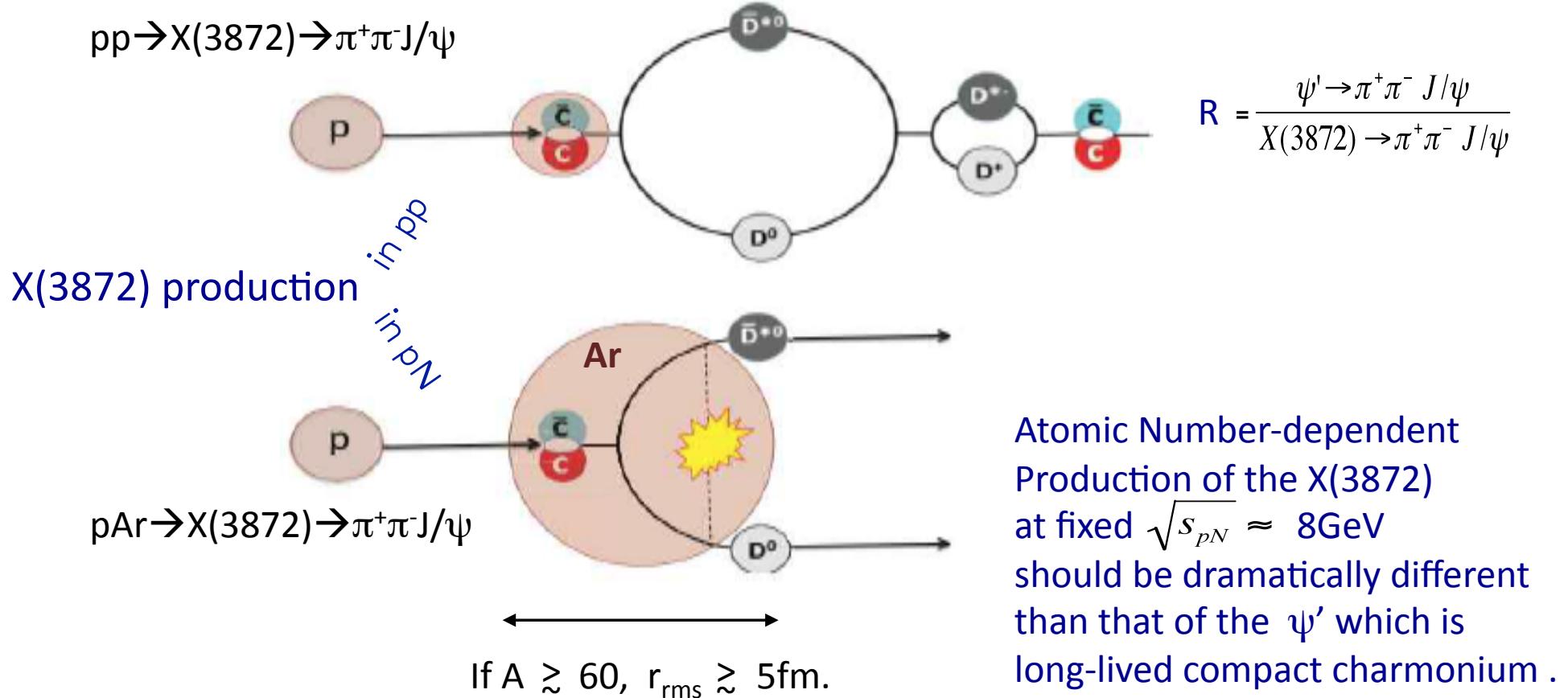
(of NICA collider at Dubna)



Design parameters has been optimized
by physics processes in nuclear collisions (heavy-ion)

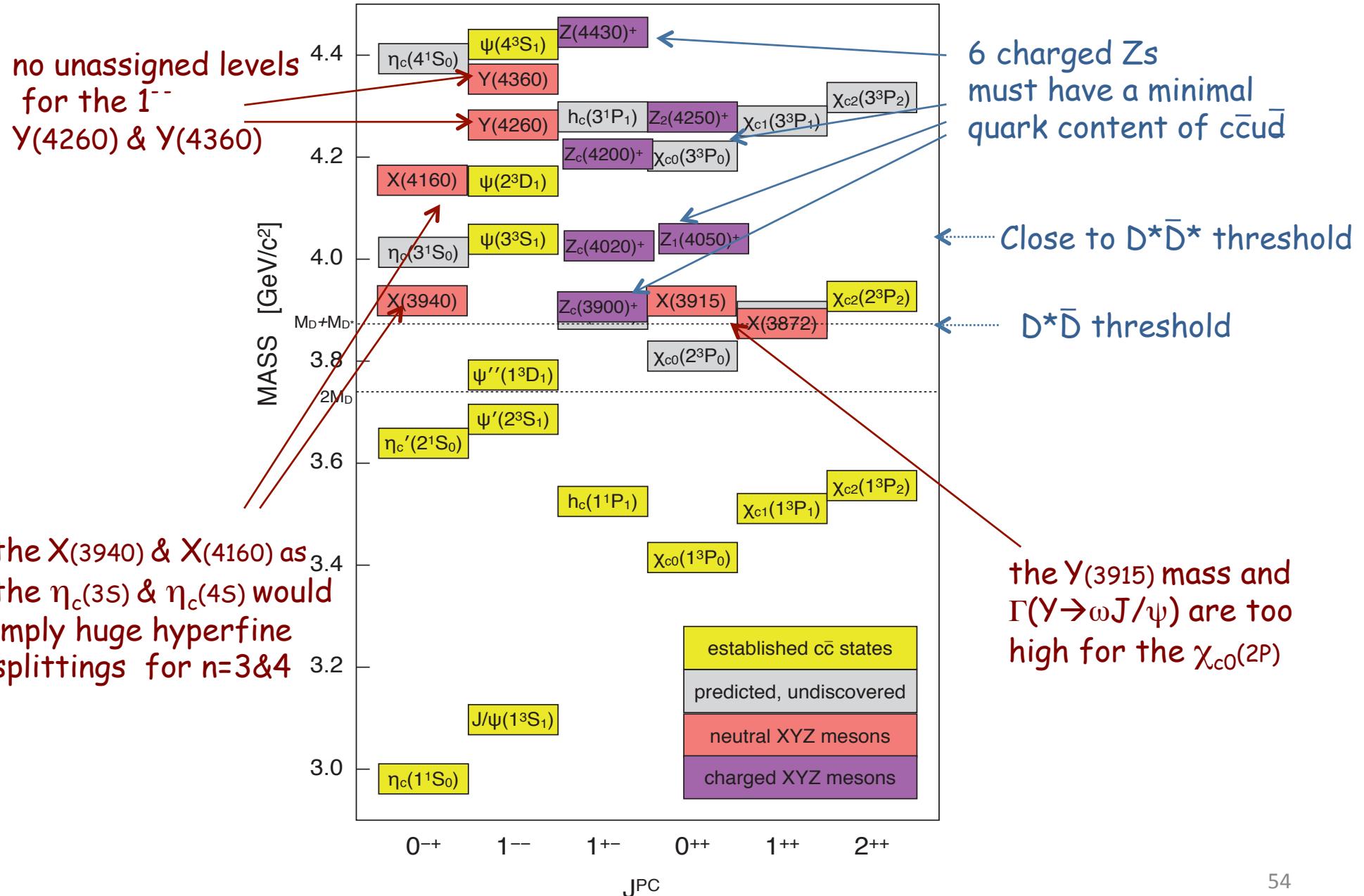
Measure Production Rate: R

To test this “hybrid” picture for the X(3872)



Survival prob of >7 fm ‘molecule’ inside nuclear matter should be small.

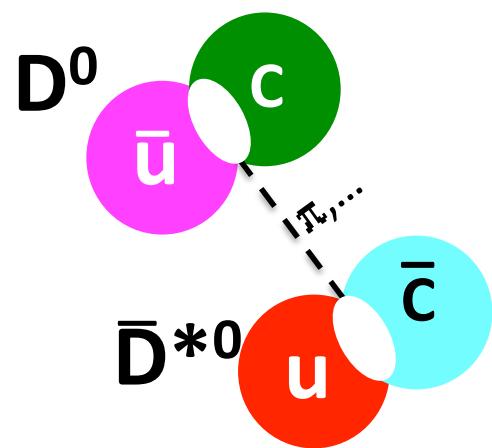
$c\bar{c}$ assignments for the XYZ mesons?



Models for the $\Upsilon(3872)$

D^0 - \bar{D}^{*0} molecule?

Lots of literature about this

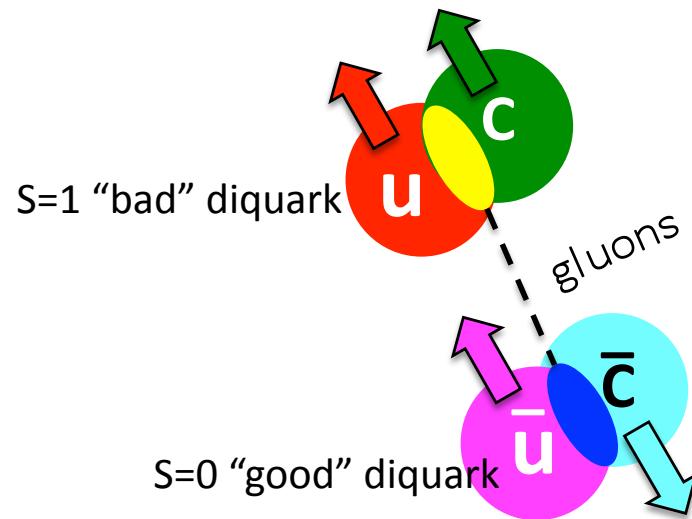


Impossible to produce such an fragile extended object in prompt high energy hadron colliders at the rates reported by CDF & CMS

QCD diquark-diantiquark?

Maiani et al.

PRD 71, 014028 (2005)



Predicts partner states (e.g., a nearby state with $u \rightarrow d$) that have yet be seen.