New Charmonium(-like) States
Results from Belle and BaBar

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Outline

- Static Charmonium Potential
  - some trivial things
  - some not so trivial things

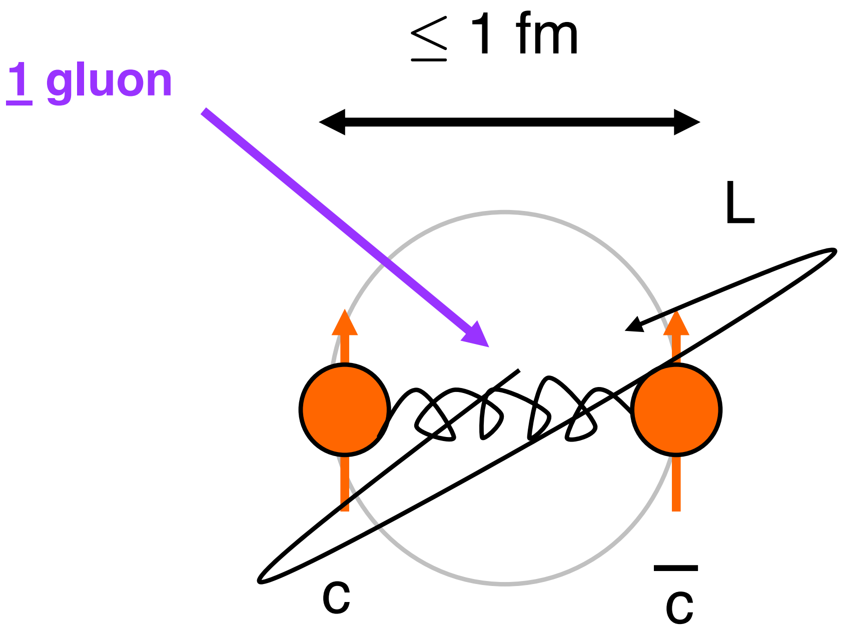
- X(3872)
  - radiative decays
  - strong decays
- Y(3940)
- Y(4260)
- Z(4430)+

- Belle-II

}

1. Comparison
   Belle Experiment
   BaBar Experiment
2. Implications of
   Potential Model

Charmonium



Static Quark-Antiquark Potential for Charmonium

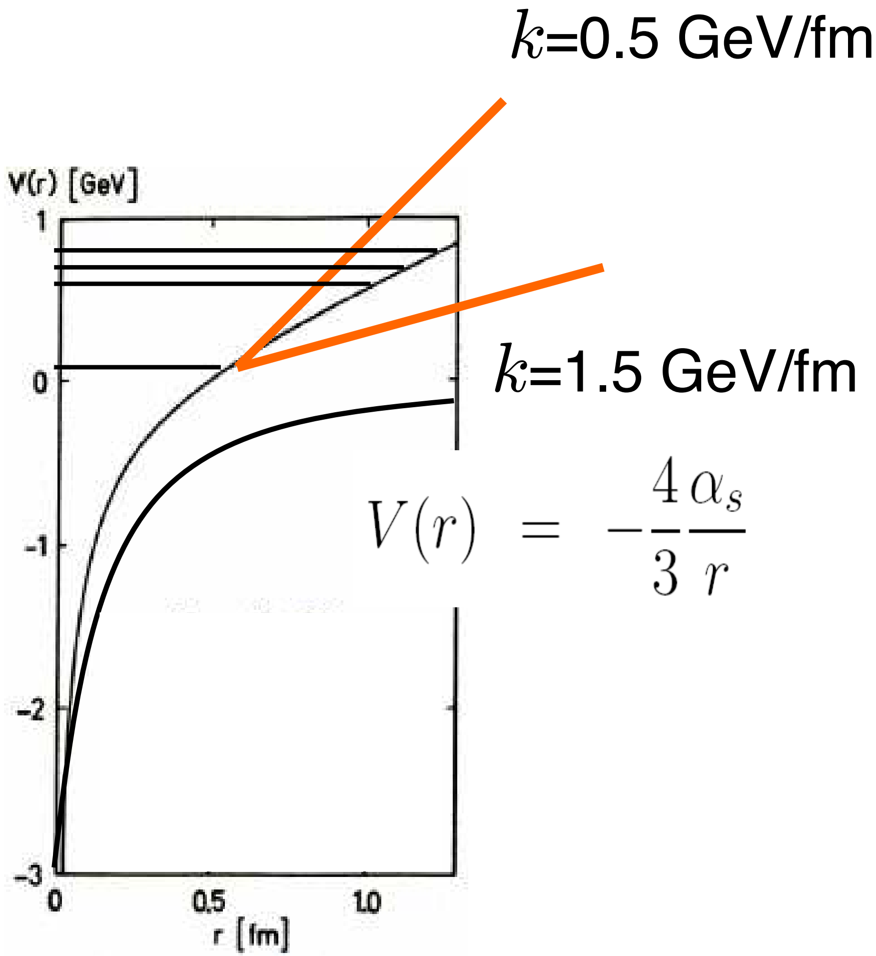
- Coulomb-Potential
  + Confinement-Term

$$V(r) = -\frac{4}{3}\frac{\alpha_s}{r} + \boxed{kr}$$

spin-spin $$+\frac{32\pi\alpha_s}{9m_c^2}\delta_r \vec{S}_c\vec{S}_{\bar{c}}$$

spin-orbit $$+\frac{1}{m_c^2}\left(\frac{2\alpha_s}{r^3} - \frac{k}{2r}\right)\vec{L}\vec{S}$$

tensor $$+\frac{1}{m_c^2}\frac{4\alpha_s}{r^3}\left(\frac{3\vec{S}_c\vec{r}\cdot\vec{S}_{\bar{c}}\vec{r}}{r^2} - \vec{S}_c\vec{S}_{\bar{c}}\right)$$



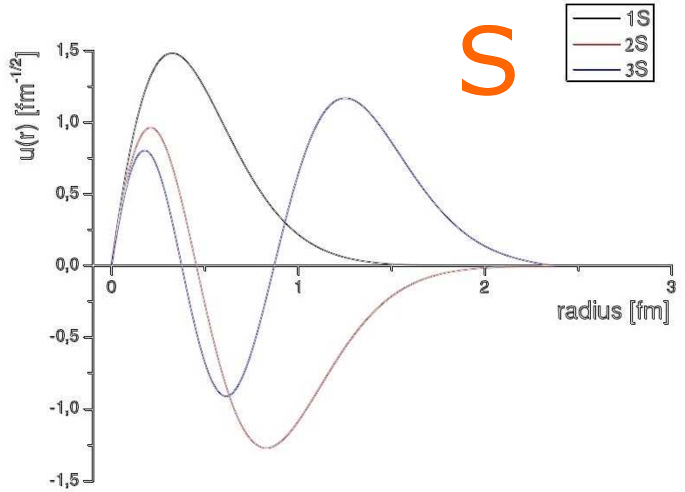
- solve Schrödinger equation
  (m_c heavy → non-relativistic)
  → states

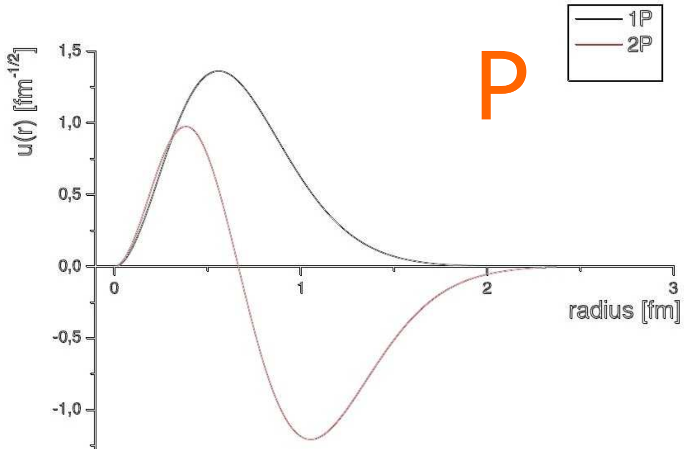
$$\Psi(r,\theta,\phi) = R_{nl}(r)Y_{lm}(\theta,\phi)$$

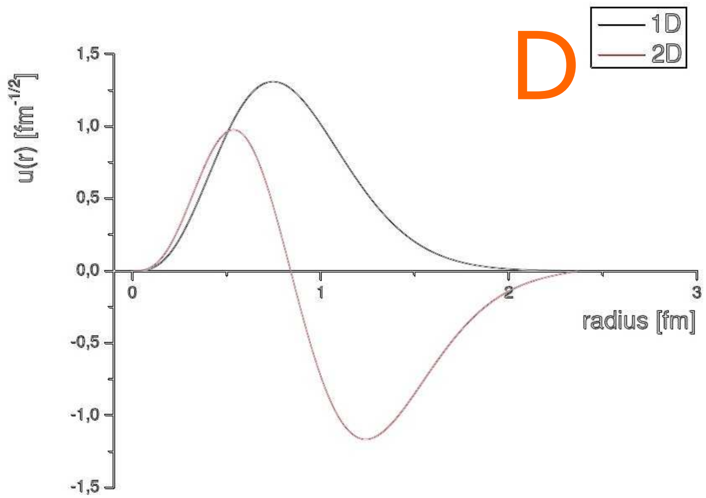
$$\left[-\frac{1}{m_q}\left(\frac{\partial^2}{\partial r^2} + \frac{2}{r}\frac{\partial}{\partial r} + \frac{l(l+1)}{m_q r^2} + V(r)\right)\right]R_{nl}(r) = E_{nl}R_{nl}(r)$$

Charmonium States

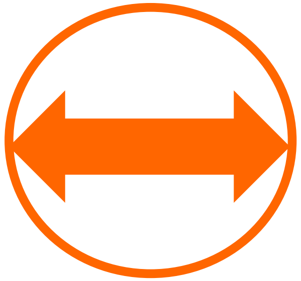
radial wavefunction



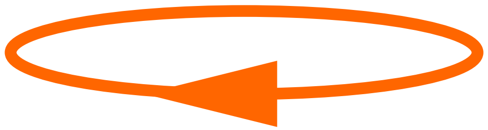




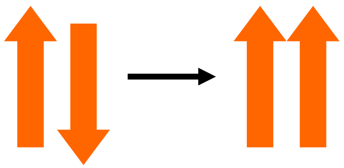
radial
n



orbital
L



spin
S



spectroscopic notations

$n^{2S+1} L_J$

J^{PC}

Master thesis
M. Ullrich, Gießen, 2010
Master thesis
M. Werner, Gießen, 2010

$$\vec{J} = \vec{L} + \vec{S}$$

$$P = (-1)^{L+1}$$ parity

$$C = (-1)^{L+S}$$ charge conjugation

Mass of a Charmonium State

(Potential Model)

n dependant term

$$M(n^{2S+1}l_j) = E_{nl} + 2m_q + \frac{2\alpha_s}{3m_q^2}\int d^3r\Psi^*(\vec{r})\left(\frac{1}{r}\vec{\nabla}^2 + \frac{1}{r}\frac{\partial^2}{\partial r^2}\right)\Psi(\vec{r})$$

$$+ \frac{4\pi\alpha_s}{3m_q^2}|\Psi(0)|^2 + \frac{32\pi\alpha_s}{9m_q^2}\left(\frac{1}{2}S(S+1) - \frac{3}{4}\right)|\Psi(0)|^2$$

spin-spin

$$+ \alpha_s\frac{j(j+1) - l(l+1) - S(S+1)}{m_q^2}\left\langle\frac{1}{r^3}\right\rangle + \alpha_s\frac{S_{12}}{3m_q^2}\left\langle\frac{1}{r^3}\right\rangle$$

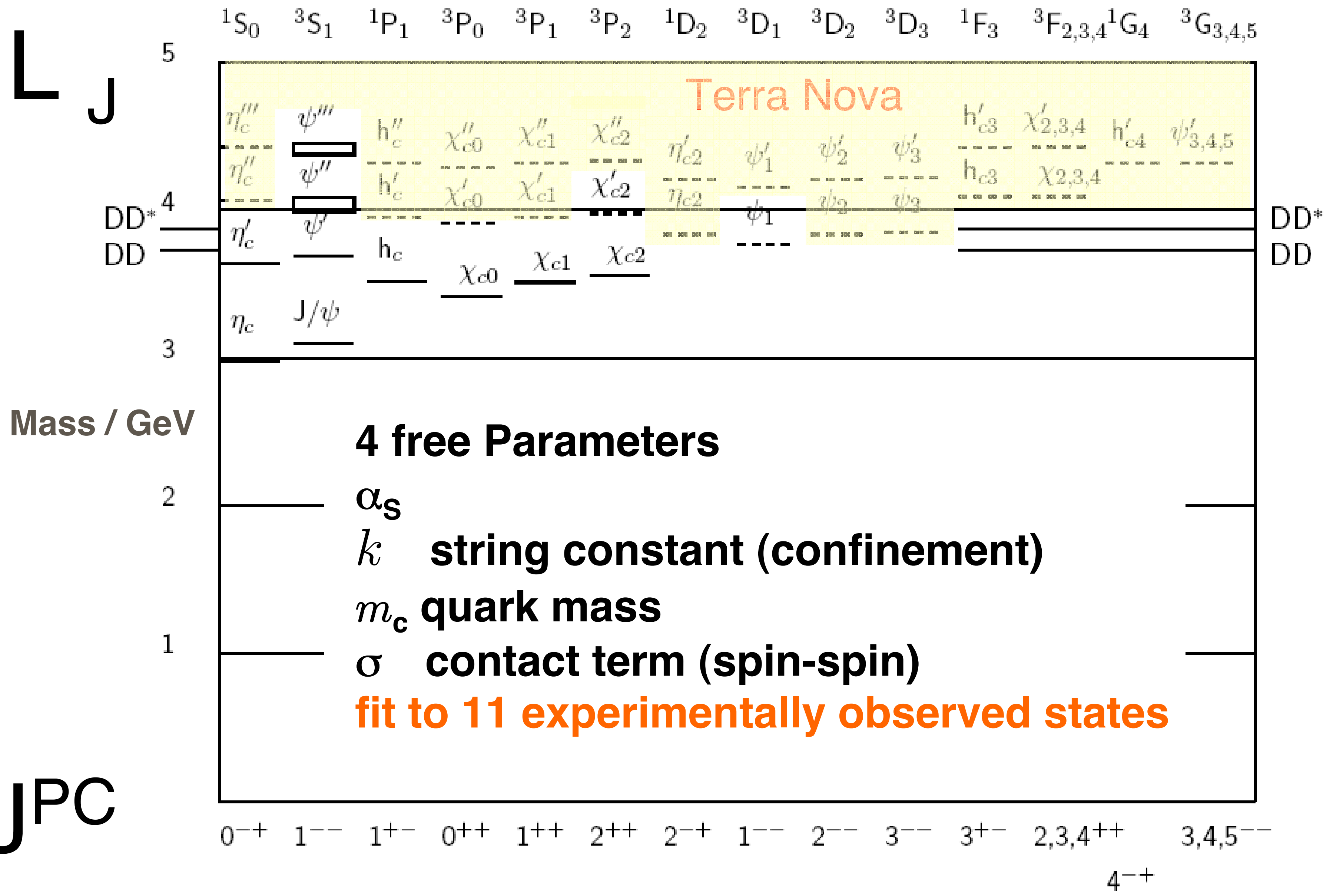
spin-orbit

tensor

Master thesis
M. Ullrich, Gießen, 2010
Master thesis
M. Werner, Gießen, 2010

Charmonium Excited States $n \leq 3, L \leq 4$

$n^{2S+1} L_J$



4 free Parameters

α_s

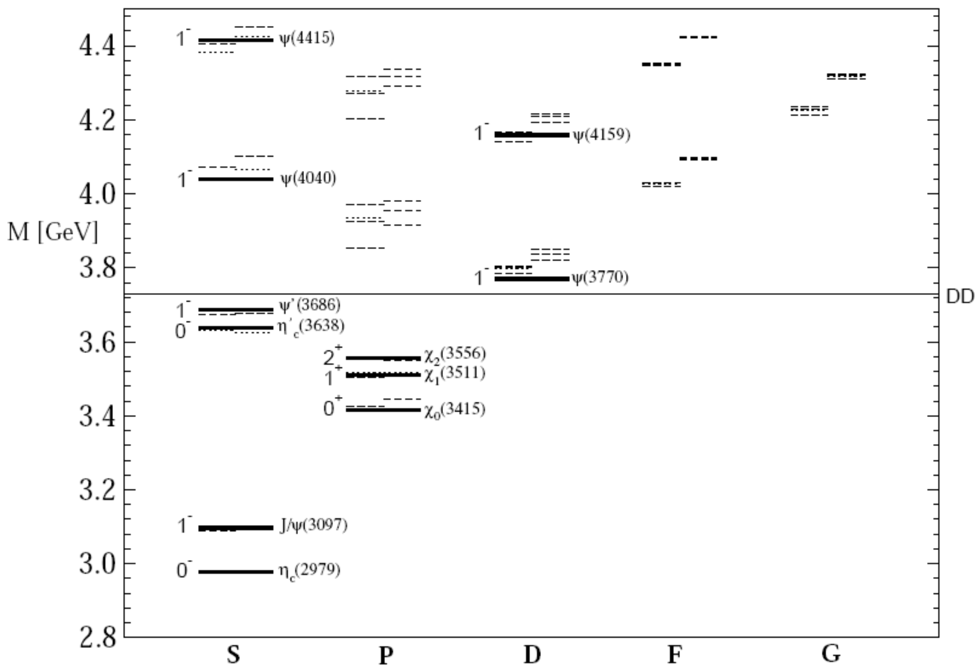
k **string constant (confinement)**

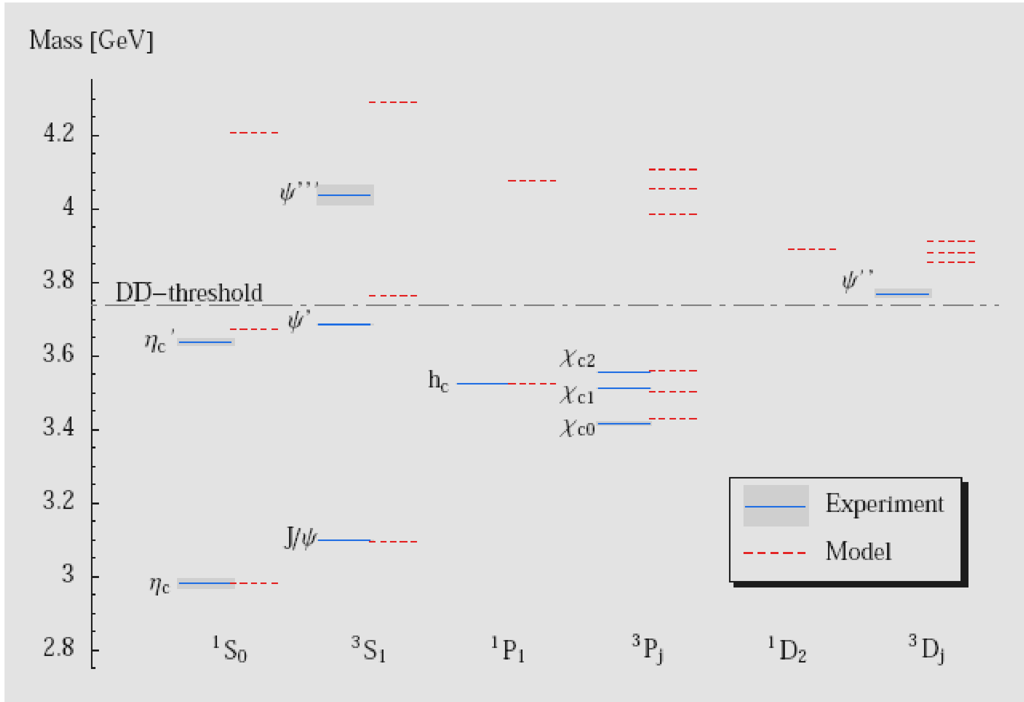
m_c **quark mass**

σ **contact term (spin-spin)**

fit to 11 experimentally observed states

J^{PC}





Barnes, Godfrey, Swanson
Phys. Rev. D72(2005)054026

α_S = 0.55
k = 0.723 GeV/fm
m_c = 1.4794 GeV

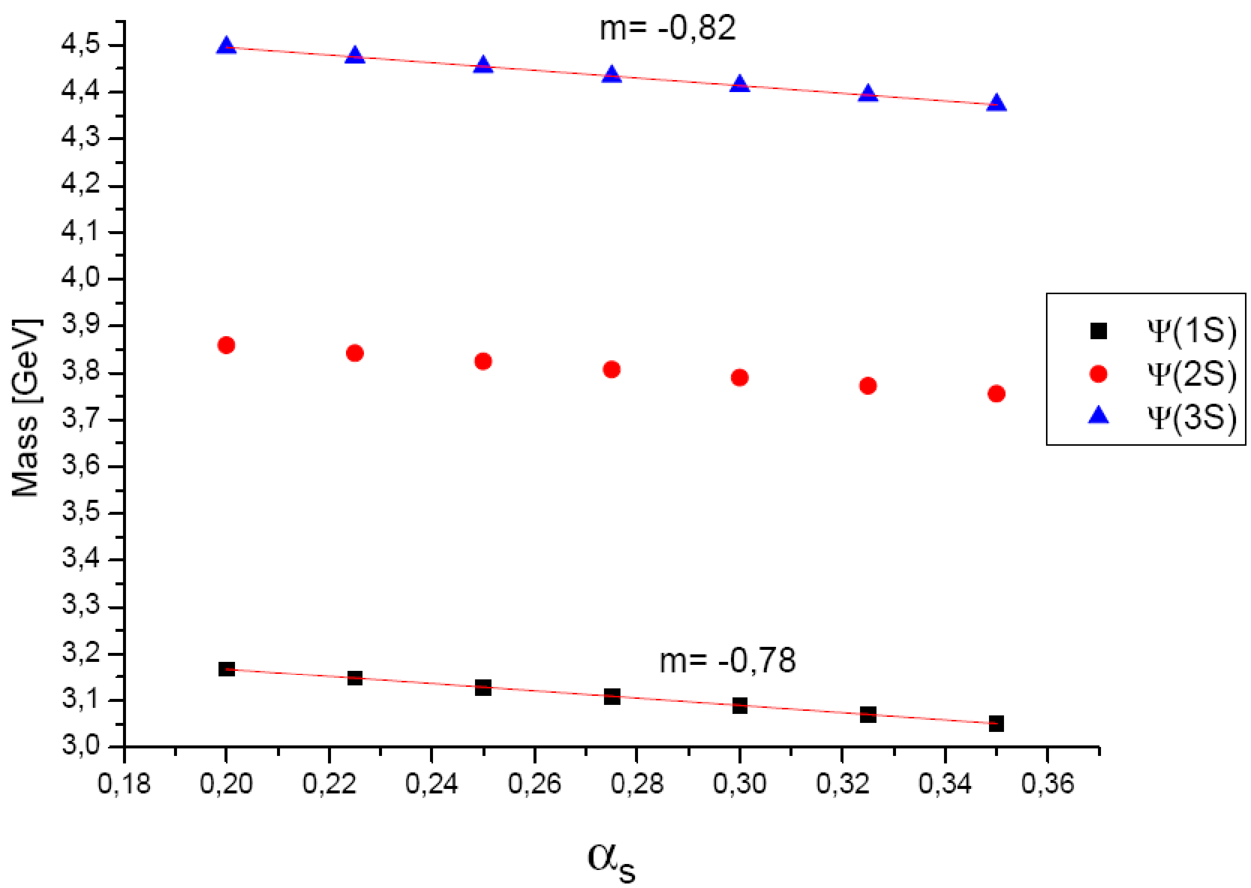
Eiglsperger
arXiv:0707.1269[hep-ph]
Weise, HIRSCHEGG 2007

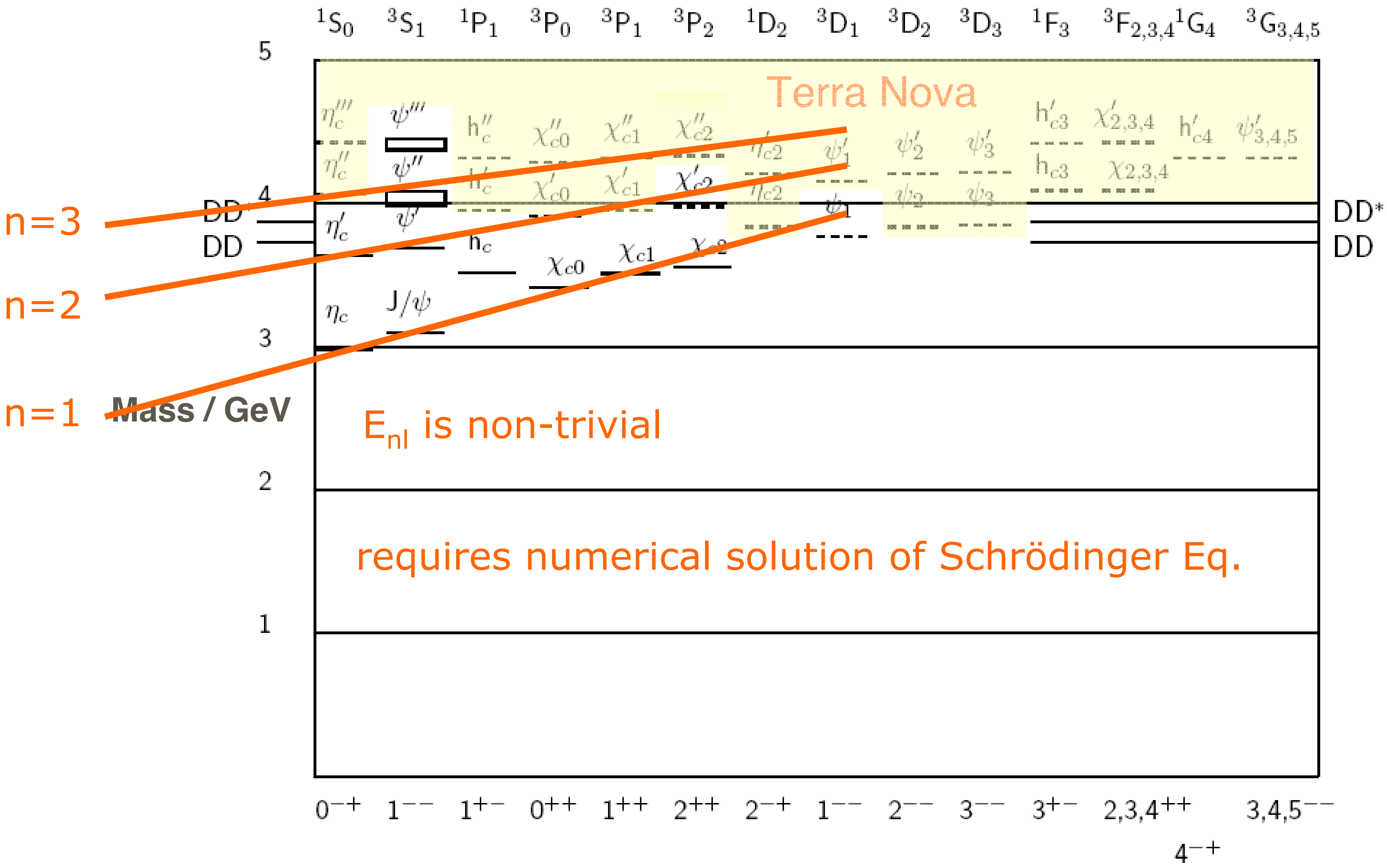
α_S = 0.29
k = 1.306 GeV/fm
m_c = 1.2185 GeV

Note: string tension from Lattice QCD k$\simeq$1 GeV/fm

α_s

- Strong coupling is assumed constant for $0 \leq r \leq \infty$
- Mass solutions depend on α_s with $\Delta m \leq 100$ MeV for $\Delta\alpha_s \leq 0.1$



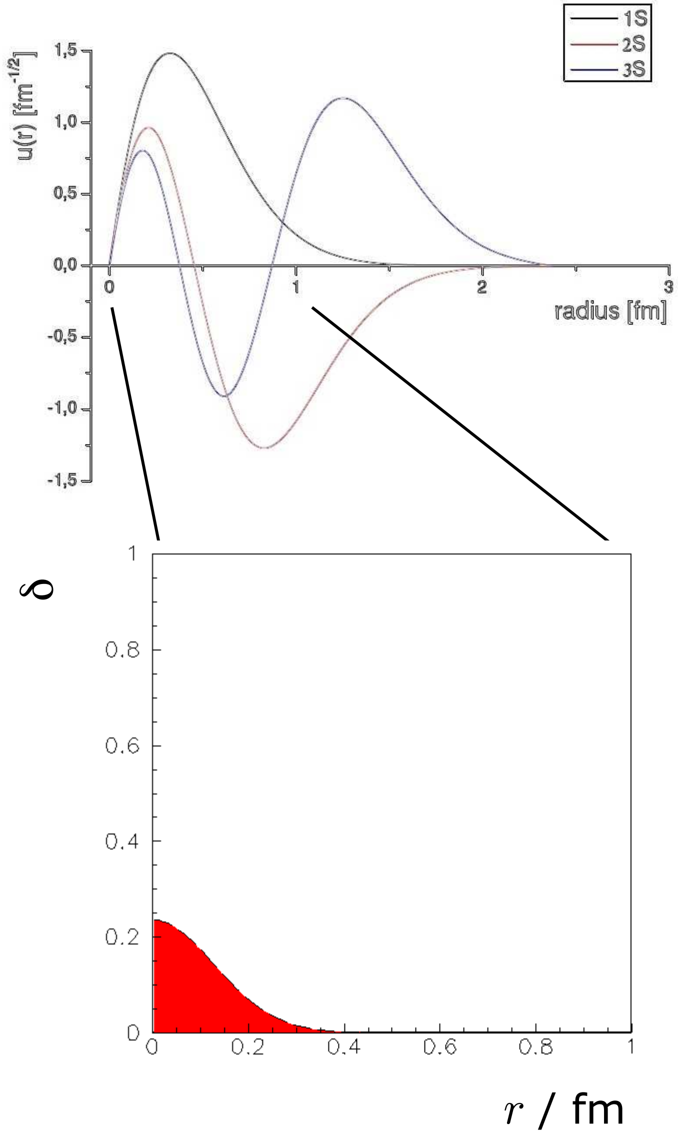


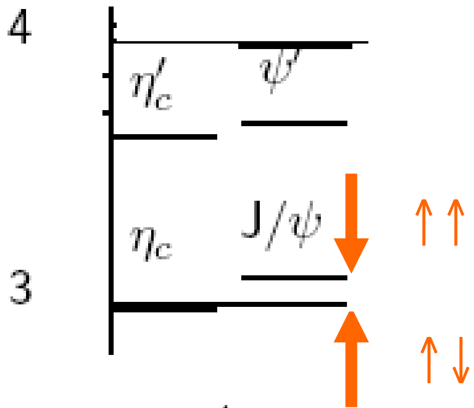
E_{nl} is non-trivial

requires numerical solution of Schrödinger Eq.

Short-range Forces: Spin-Spin Term

- consequence of one-gluon exchange
- spin-spin term is put into the potential, i.e. not treated as a mass shift
- radial only
- „contact term“, Gaussian
- fit to experimental data gives $\sigma \simeq 1$ GeV





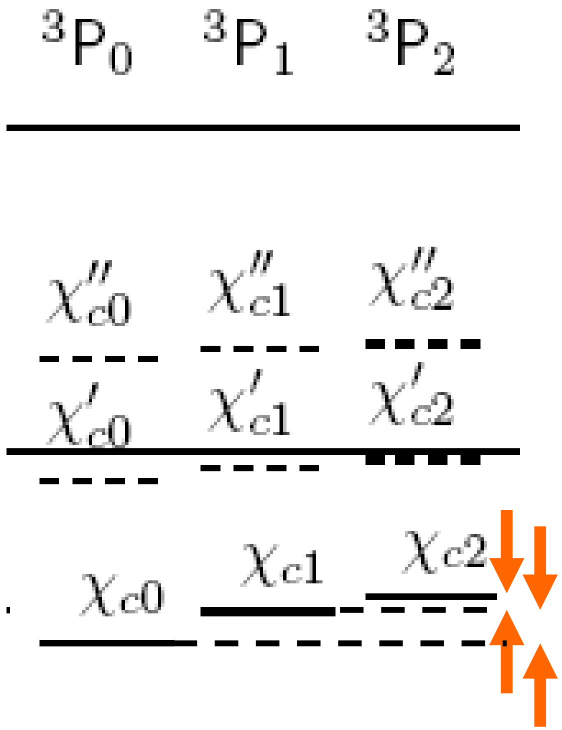
$$V(r) = -\frac{4}{3}\frac{\alpha_s}{r} + br + \frac{32\pi\alpha_s}{9m_c^2}\,\tilde{\delta}_\sigma(r)\,\vec{S}_c \cdot \vec{S}_{\bar{c}}$$

$$\tilde{\delta}_\sigma(r) = (\sigma/\sqrt{\pi})^3\, e^{-\sigma^2 r^2}$$

Long-range forces: Testing Confinement

- Testing e.g. mass splitting of P-wave states <r>$\simeq$0.7 fm
  - Coulomb term transforms as Lorentz vector (photon = vector)
  - Linear term transforms as Lorentz scalar
  - Scalar implies: >=2 gluons needed

$$V(r) = -\frac{4}{3}\frac{\alpha_s}{r} + \boxed{kr}$$



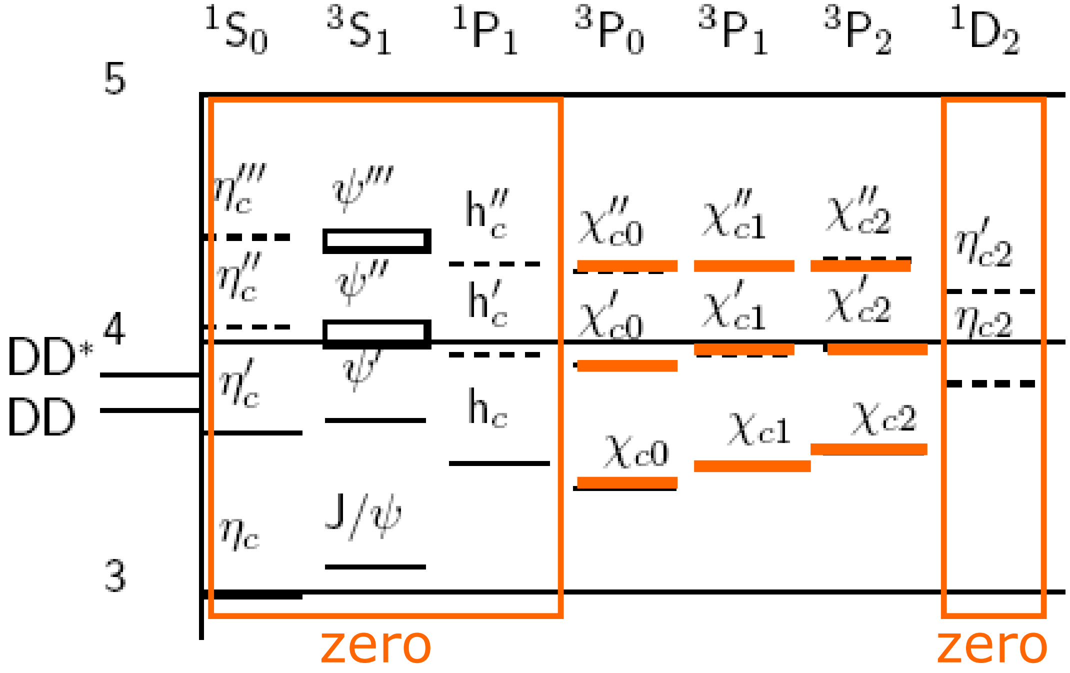
$$R = \frac{m(^3P_2) - m(^3P_1)}{m(^3P_1) - m(^3P_0)}$$

R_{exp}=0.48 $\pm$ 0.01

$R_{vector} \geq$ 0.8

$\rightarrow$ Confinement term is needed.
$\rightarrow$ Confinement is scalar.

Tensor Term



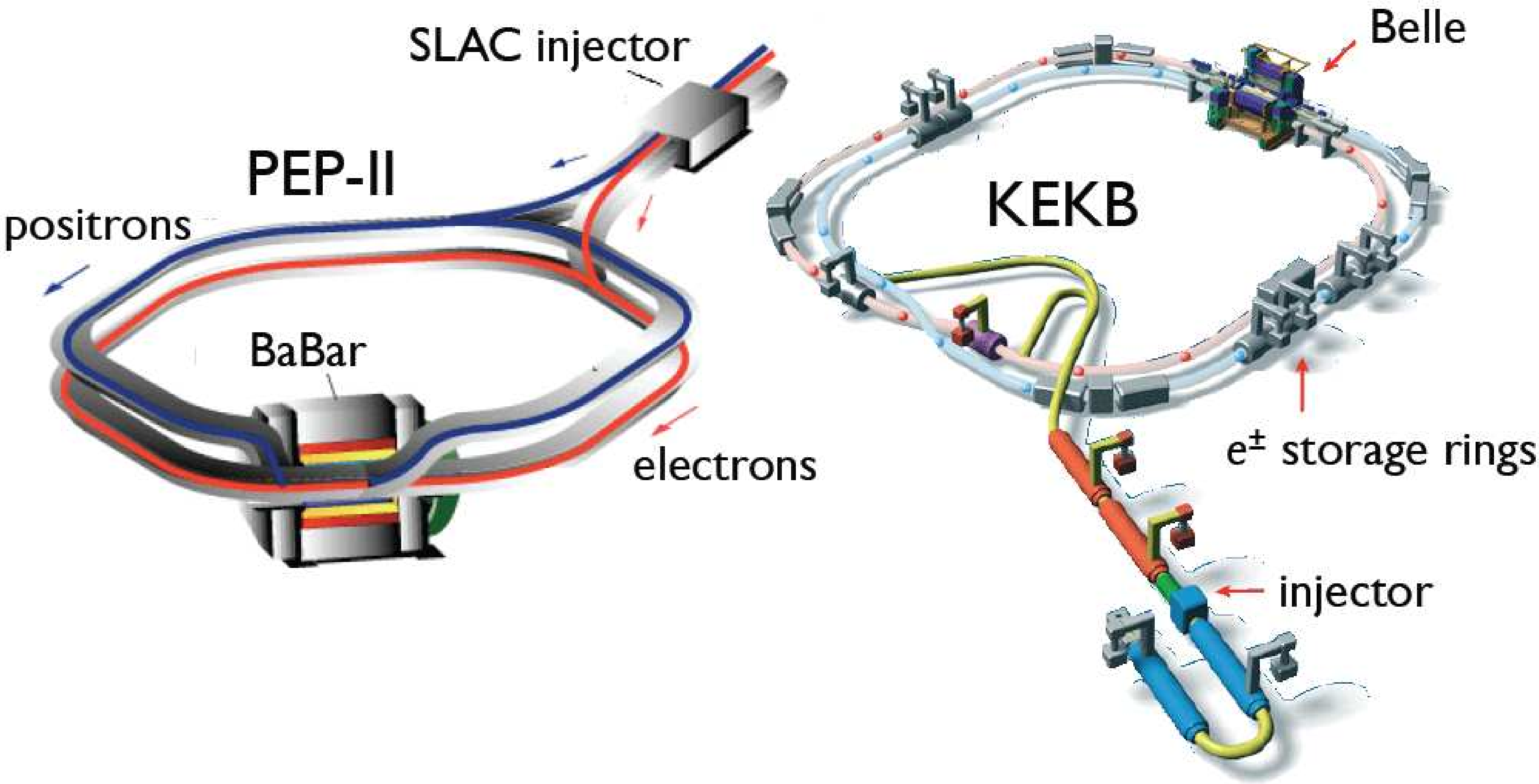
- treated as perturbation
- has diagonal and non-diagonal elements
- vanishes for S=0
- vanishes for L=0
- same order of magnitude and same range as LS term

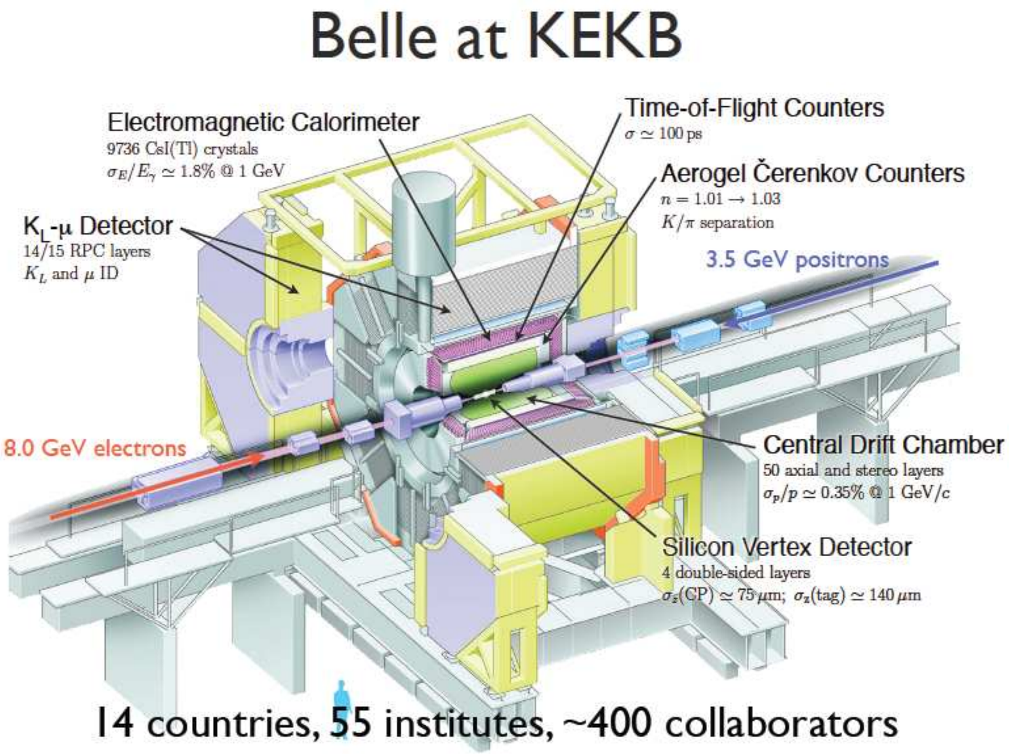
$$+\alpha_s \frac{j(j+1)-l(l+1)-S(S+1)}{m_q^2}\left\langle\frac{1}{r^3}\right\rangle + \alpha_s \frac{S_{12}}{3m_q^2}\left\langle\frac{1}{r^3}\right\rangle$$

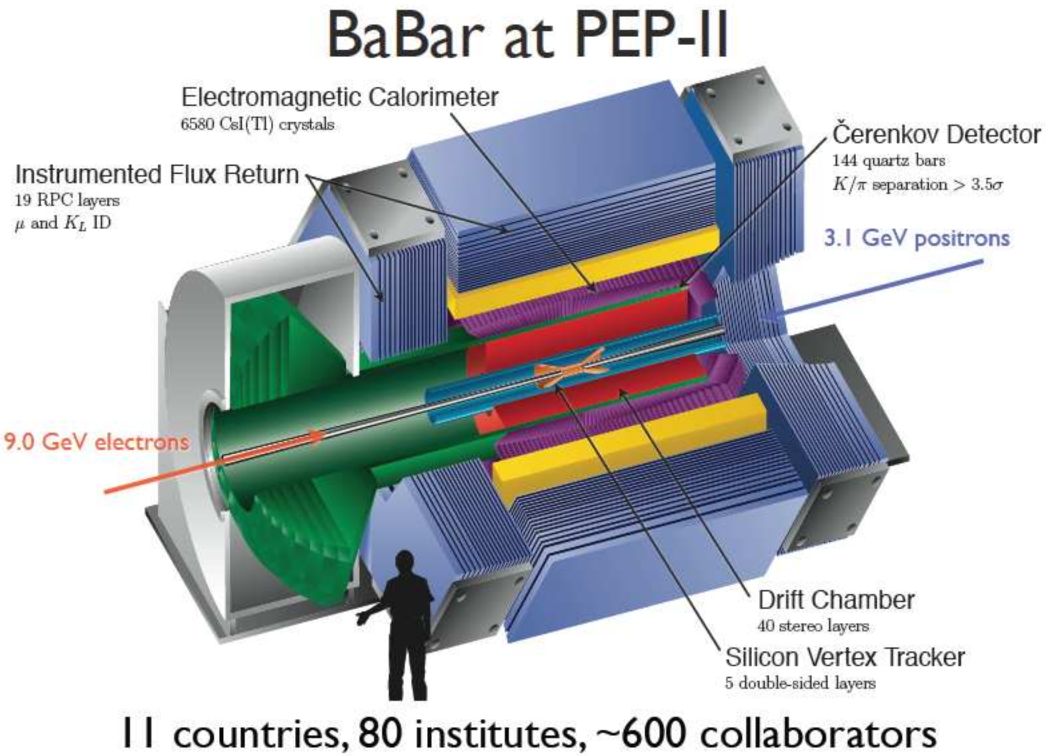
Among all the states used as input for potential model fit, only χ_{cJ} are shifted by tensor term.

j	l-1	l	l+1
S_{12}	$-\frac{2l+2}{2l-1}$	2	$-\frac{2l}{2l+3}$

B Factories


SLAC injector
PEP-II
positrons
BaBar
electrons
Belle
KEKB
e± storage rings
injector



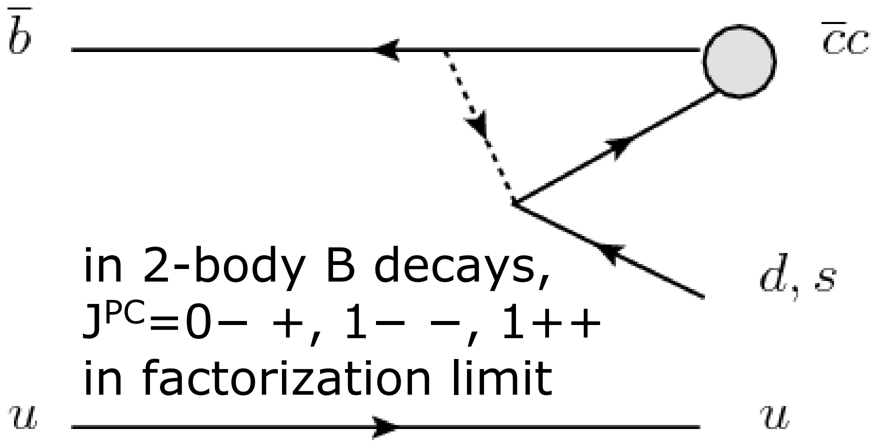


$\geq$ **1000 /fb**
On-resonance samples:
Y(4S): 711 /fb
Y(5S): 121 /fb
Y(3S): 3.0 /fb
Y(2S): 24 /fb
Y(1S): 5.7 /fb
Off-resonance: 87 /fb

~553 /fb
On-resonance samples:
Y(4S): 433 /fb
Y(3S): 30 /fb
Y(2S): 14 /fb
Off-resonance: 54 /fb

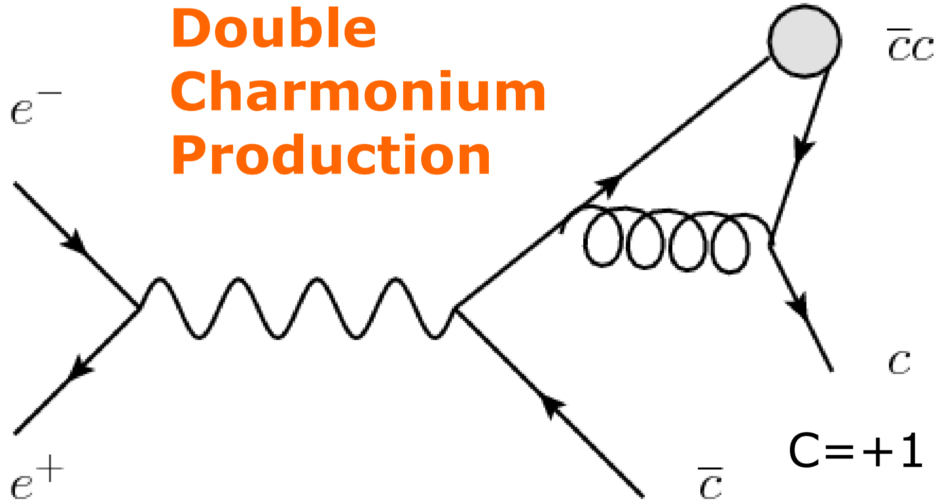
Production of Charmonium

B Decays



in 2-body B decays,
J^{PC}=0− +, 1− −, 1++
in factorization limit

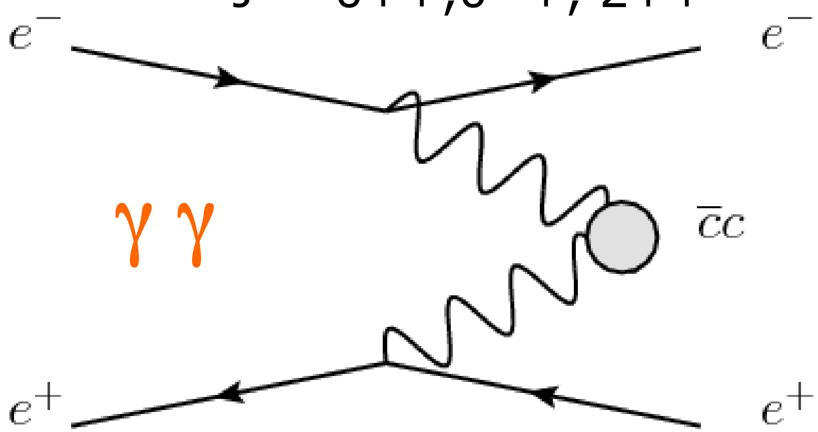
Double Charmonium Production



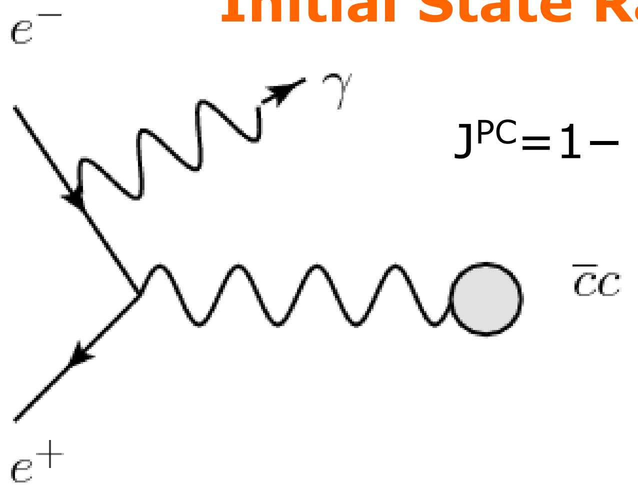
C=+1

γ γ

J^{PC}=0++,0−+, 2++

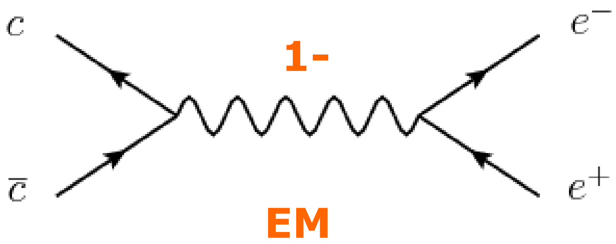


Initial State Radiation



J^{PC}=1− −

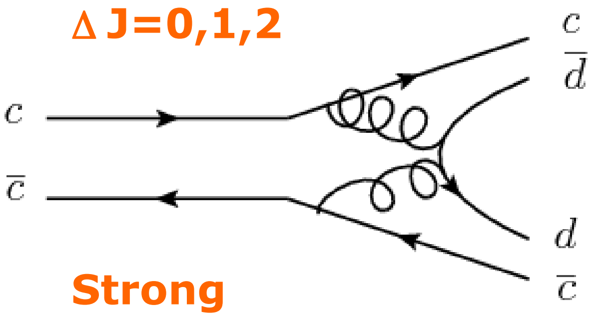
Decays of Charmonium States



Annihilation

e.g. $J/\psi \to \pi^+ \pi^- \pi^0$
OZI suppressed

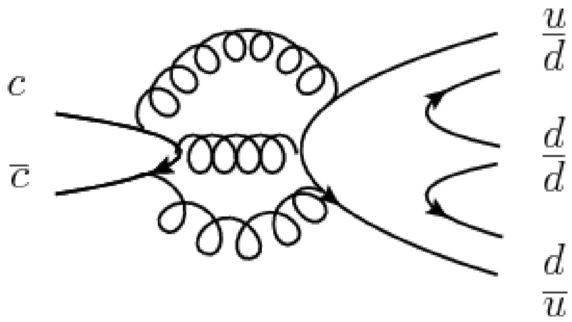
Δ J=0,1,2



Strong

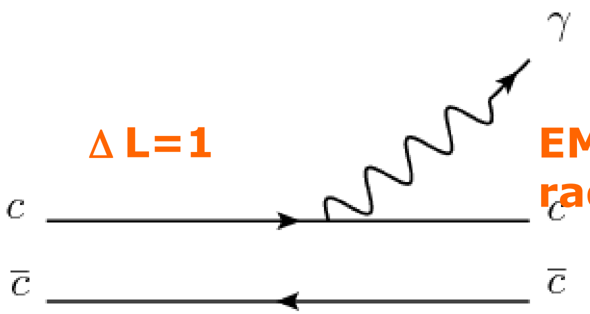
$D^{o(*)}$

$\bar{D}^{o(*)}$



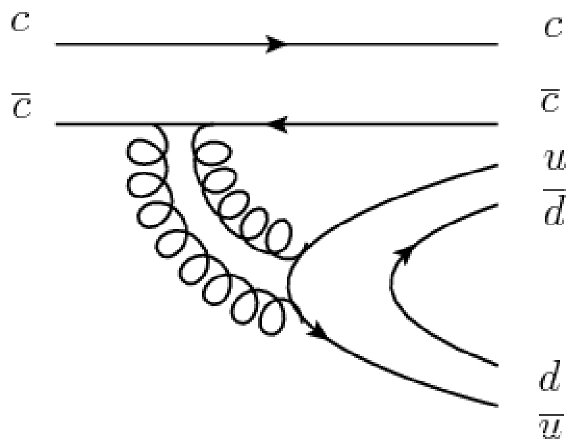
Strong
$\sim 1/\alpha_s^2$

Δ L=1



EM
radiative

e.g. $\psi' \to \chi_{cJ}\ \gamma$



Strong
spectator
isospin
transition ?
(if $(\pi\pi)=\rho$)
$\sim 1/\alpha_s^2$
e.g. $\psi' \to J/\psi\ \pi^+ \pi^-$

X(3872)

A molecular state?

X(3872)

Belle, Phys. Rev. Lett.91(2003)262001
CDF-II, Phys. Rev. Lett.93(2004)072001
D0, Phys. Rev. Lett.93(2004)162002
BaBar, Phys. Rev. D71(2005)071103

- observed
  in more than one
  decay channel

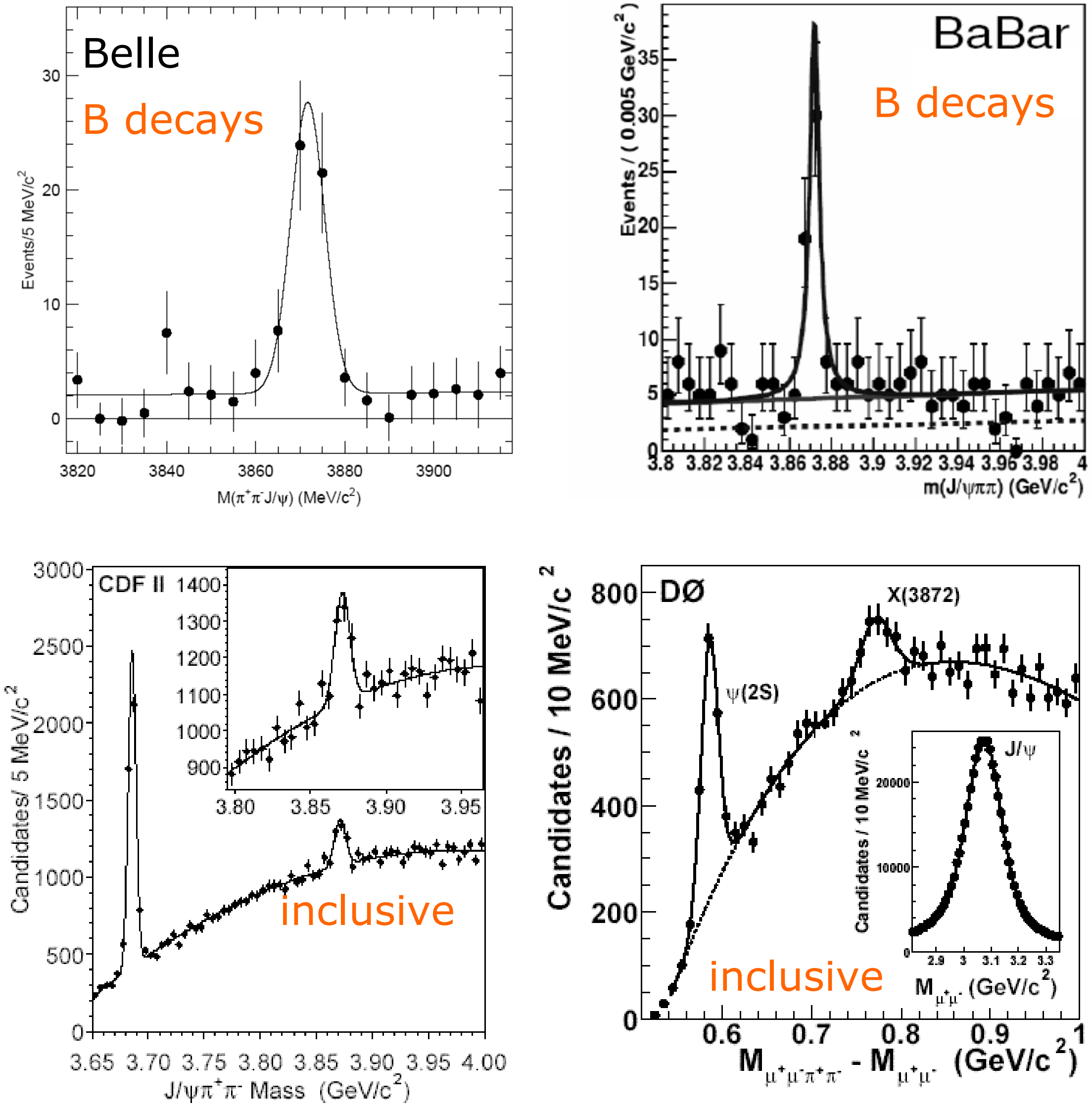
$$X(3872) \rightarrow J/\psi\pi^+\pi^-$$
$$X(3872) \rightarrow J/\psi\gamma$$
$$X(3872) \rightarrow J/\psi\pi^+\pi^-\pi^0$$
$$X(3872) \rightarrow D^0\overline{D}^0\pi^0$$
$$X(3872) \rightarrow D^0\overline{D}^0\gamma$$
$$X(3872) \rightarrow \psi'\gamma$$

- narrow width
  Γ<2.3 MeV (90% CL)

- Mass 3871.46$\pm$0.19 MeV
  very close to threshold

$$M_X - (m_{D^*} + m_{\bar{D}^0}) =$$
-0.32 ± 0.35 MeV

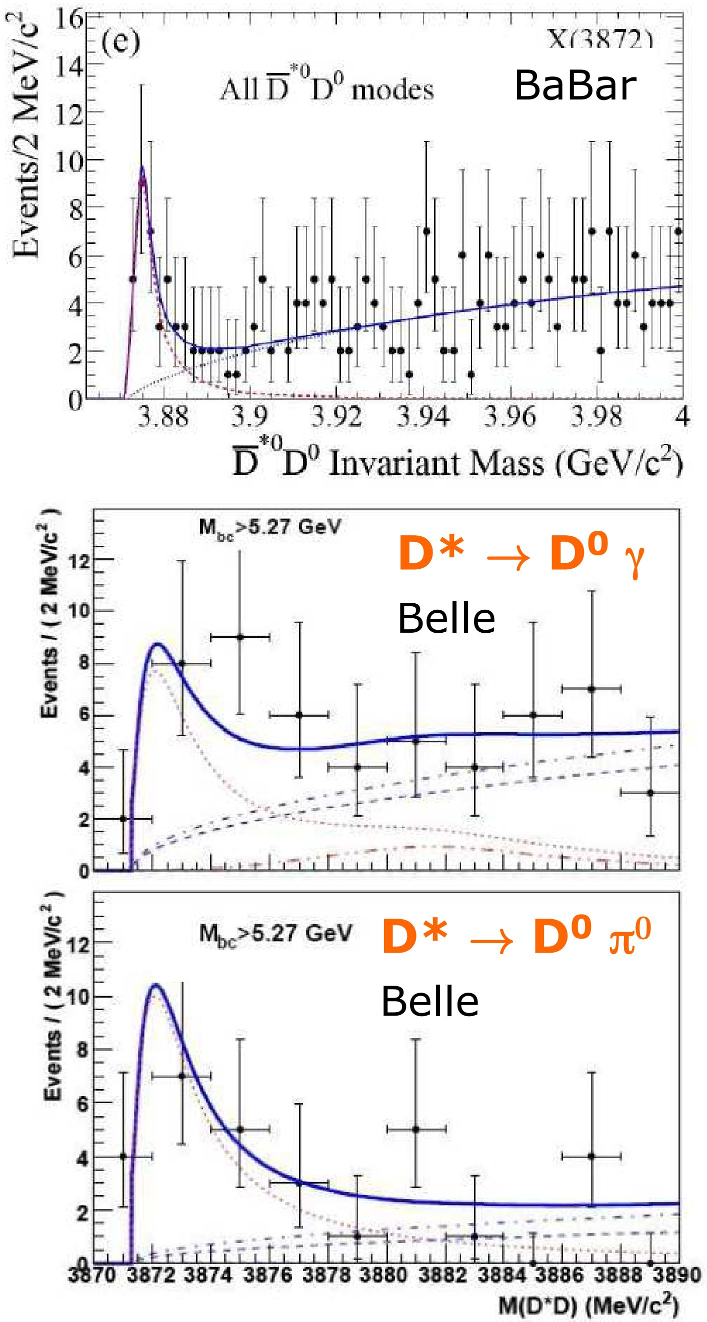
S-wave molecular state?



$\bar{p}p$, $\sqrt{s}$=1.8 TeV

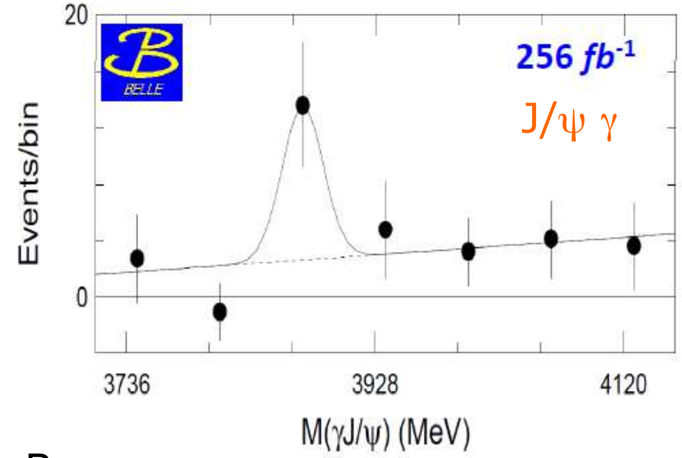
Strong Decay X(3872) $\rightarrow \bar{D}D^*$

- Decay into $\bar{D}D^*$ is dominant
  BR is factor $9.4^{+3.6}_{-4.3}$
  higher than for $J/\psi\ \pi^+\ \pi^-$
- BaBar, Phys. Rev. D77(2008)011102(R)
  m=$3875.1^{+0.7}_{-0.5} \pm 0.5$ MeV
  - binned maximum likelihood fit
  - 1-dim fit, M(D*D)
  - signal pdf from MC
  - exponential function background
- Belle, Phys. Rev. D81(2010)031103
  m=$3872.9^{+0.6}_{-0.4}{}^{+0.4}_{-0.5}$ MeV
  - unbinned maximum likelihood fit
  - 2-dim fit
    - beam constraint mass
      Gaussian signal
      Argus function for background
    - M(D*D)
      Breit-Wigner signal
      square root for background

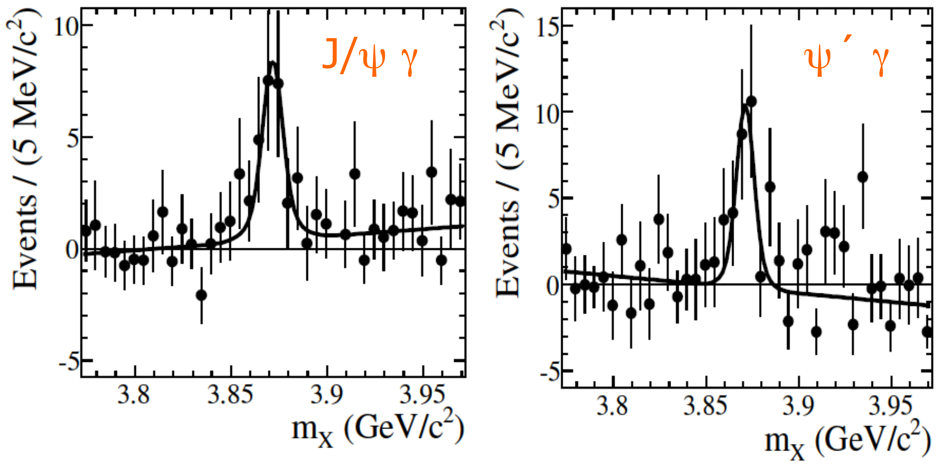


Radiative Decay X(3872) → J/ψ γ, ψ´γ

- Rare Decay
  BR is factor ~6
  smaller than BR(X→ J/ψ $\pi^+ \pi^-$)
  Combined branching fraction
  BR(B decay) × BR(X decay) ≃ 10^{-6}
- Evidence for X(3872)→ J/ψ γ by Belle
  256/fb
  13.6±4.4 events
  arXiv:hep-ex/0505037
- Confirmed by BaBar
  424/fb
  23.0±6.4 events
  Phys. Rev. D 74(2006)071101
- Proof for positive C parity J^{P+}
- BaBar found evidence
  for X(3872)→ψ´γ
  424/fb
  25.4±7.4 events
  Phys. Rev. Lett. 102(2009)132001



BaBar

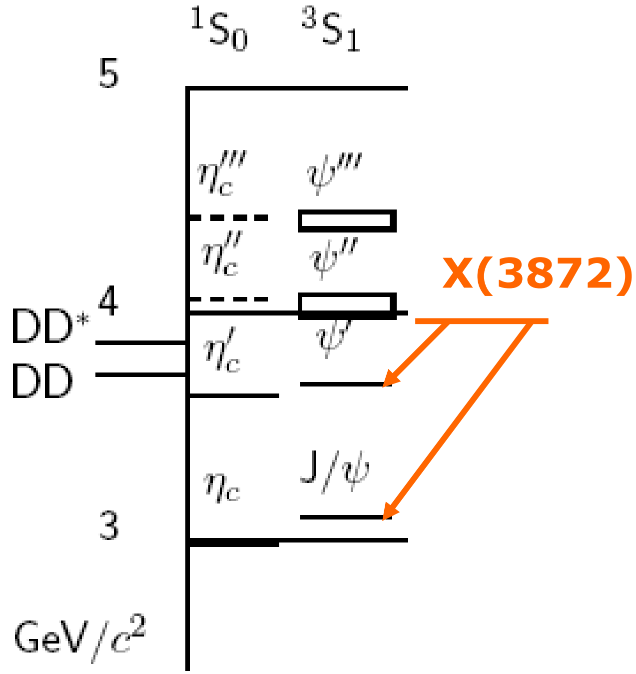


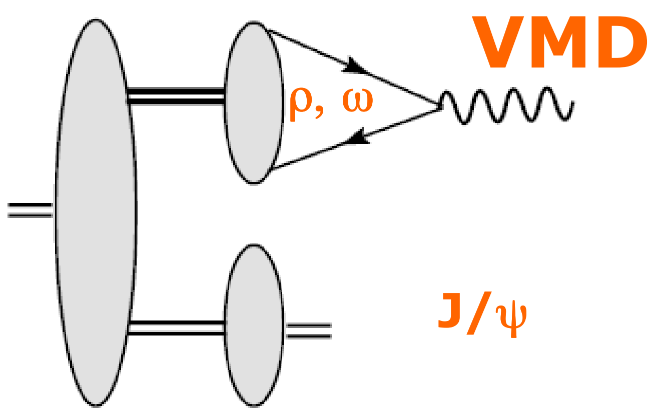
$$\frac{\mathcal{B}(X(3872) \to \psi'\gamma)}{\mathcal{B}(X(3872) \to J/\psi\gamma)} = 3.4 \pm 1.4$$

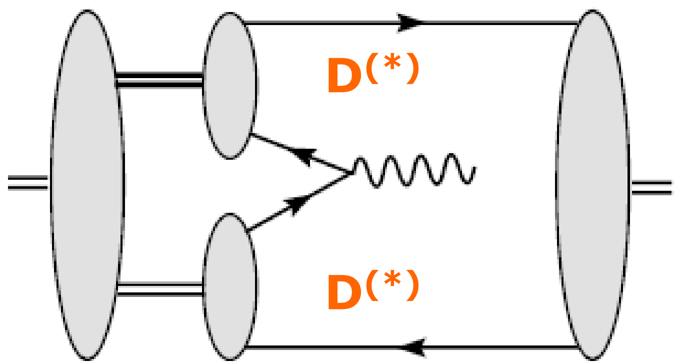
(large)

Radiative Decay X(3872) $\to$ J/ψ γ, ψ´γ

- X(3872) $\to$ J/ψ γ, E_γ=775 MeV
  VMD contributes (ρ, ω)
- X(3872) $\to$ ψ´γ, E_γ=186 MeV
  can only proceed through
  light quark annihilation
  $\to$ expected small
  $\to$ BaBar measurement surprising
- New measurement by Belle
  Preliminary, QWG10, 711/fb





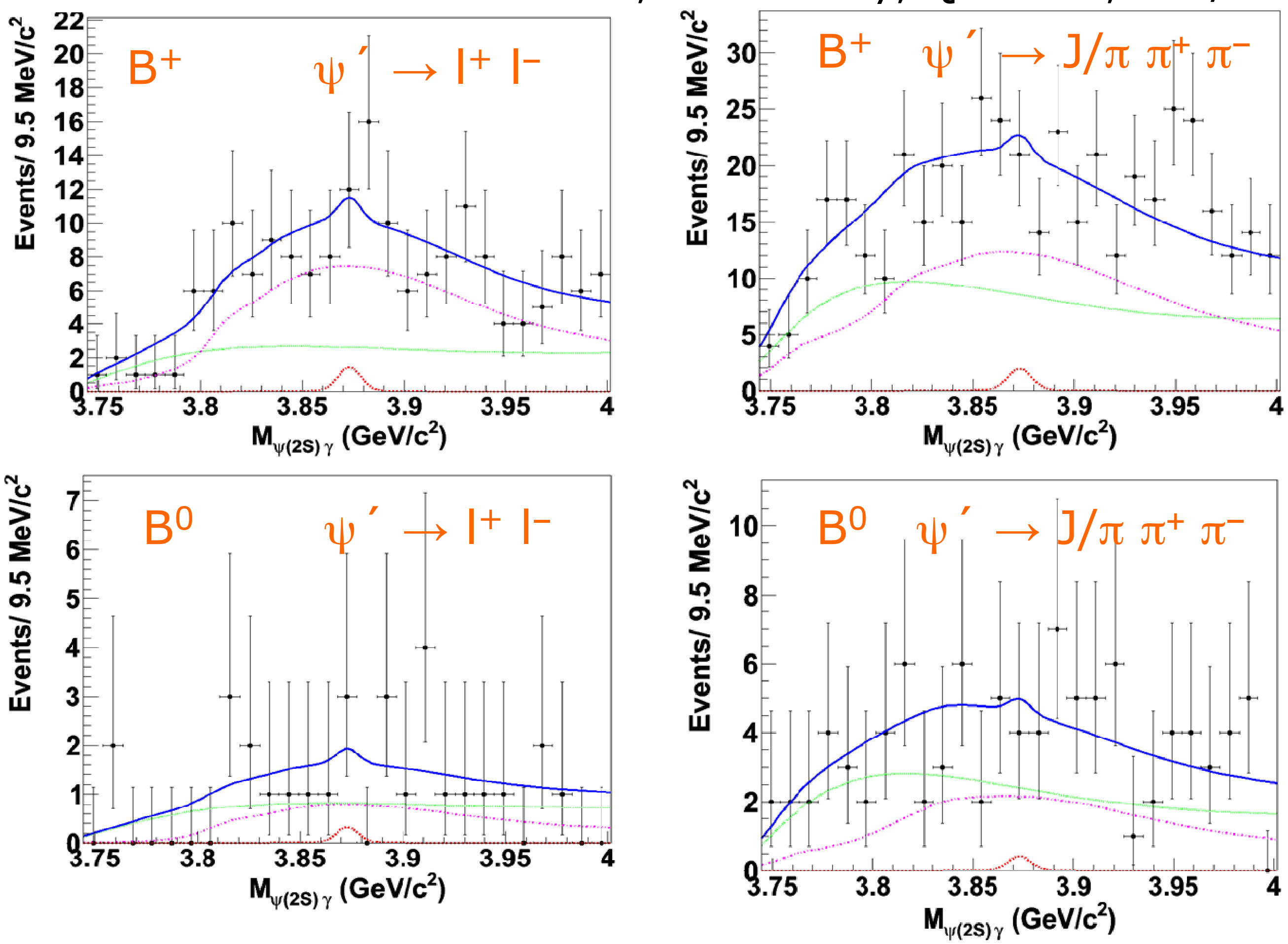


Swanson, Phys. Rept. 429(2006)243

New Measurement of X(3872) Radiative Decays
X(3872)→ψ´γ

ψ´K and ψ´K* background is different for ll and J/ψ ππ
→ simultaneous fit, 2nd order Chebyshev polynom
Combinatorial Background

Belle, Preliminary, QWG´10, 711/fb



$B^+ \rightarrow K^+$ X(3872)
$5.0^{+11.9}_{-11.0}$ events
(0.4σ)
BR<3.4 x 10^{-6} (90% CL)

$B^0 \rightarrow K^0$ X(3872)
$1.5^{+4.8}_{-3.9}$
(0.2σ)
BR<6.6 x 10^{-6} (90% CL)

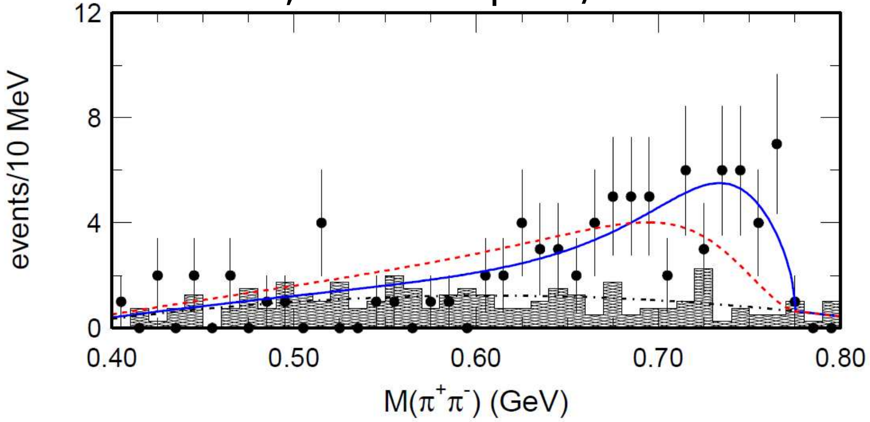
No signal observed

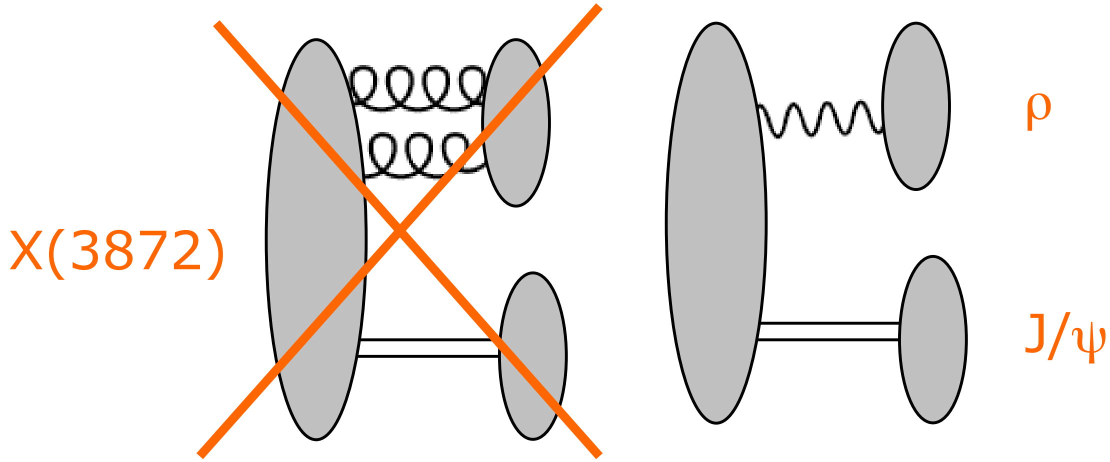
No indication, that X→(n=2) charmonium is stronger than X→(n=1) charmonium

Isospin Violation

- $X(3872) \to J/\psi\ \pi^+\ \pi^-$
  observation: $\pi^+\pi^-$ invariant mass peaks at ρ^0
- $X(3872) \to J/\psi\rho$*(I=1)* violates isospin
- Reason?
  - u-d mass difference (in strong interactions)
  - u-d charge difference (in EM interactions)
- X(3872) can only decay into $\bar{D}^0{}^*D^0$, [cu]
  not in $D^{+*}D^-$, [cd]
  (threshold is 8 MeV higher)
- $\to$ this decay is EM, not strong

Belle, arXiv:hep-ex/0505038





Isospin violating Charmonium Transistions

Only one decay for charmonium measured in PDG.

ψ'

Decays into $J/\psi(1S)$ and anything

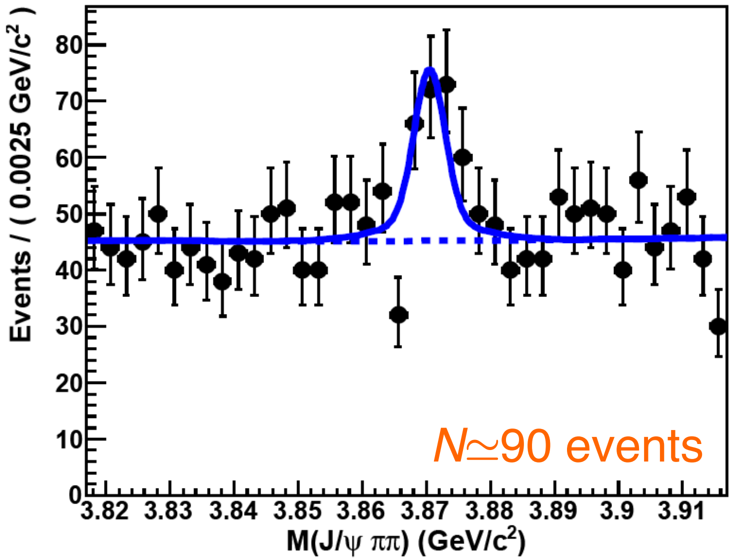
$J/\psi(1S)$ anything	(59.5 ± 0.8) %		–
$J/\psi(1S)$ neutrals	(24.5 ± 0.4) %		–
$J/\psi(1S)\pi^+\pi^-$	(33.6 ± 0.4) %		477
$J/\psi(1S)\pi^0\pi^0$	(17.73 ± 0.34) %		481
$J/\psi(1S)\eta$	(3.28 ± 0.07) %		199
$J/\psi(1S)\pi^0$	$(1.30 \pm 0.10) \times 10^{-3}$	S=1.4	528

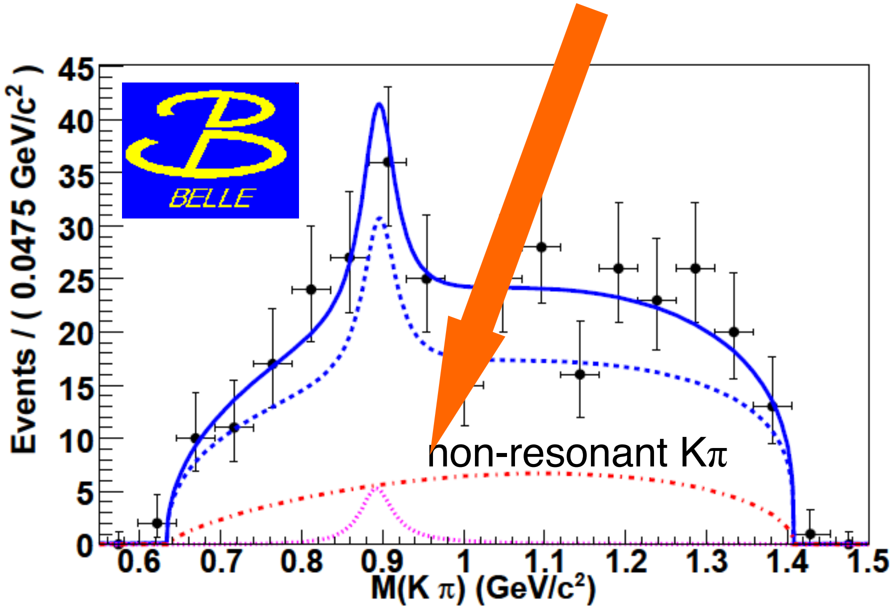
Another one
$\psi' \rightarrow h_c \pi^0$
see Bes3 results, talk by R. Mitchell

B → X(3872) K π

small K*(892) signal

Belle, arXiv:0809.1224, 605/fb





$$BR(B^0 \to X[K^+\pi^-]_{non-res} \times BR(X \to J/\psi\pi^+\pi^-) = (8.1 \pm 2.0^{+1.1}_{-1.4}) \times 10^{-6}$$

$$BR(B^0 \to XK^{*0} \times BR(X \to J/\psi\pi^+\pi^-) < 3.4 \times 10^{-6} \quad \text{at } 90\% \text{ C.L.}$$

$$BR(B^+ \to XK+) \times BR(X \to J/\psi\pi^+\pi^-) = (8.10 \pm 0.92 \pm 0.66) \times 10^{-6}$$

Belle, arXiv:0809.1224

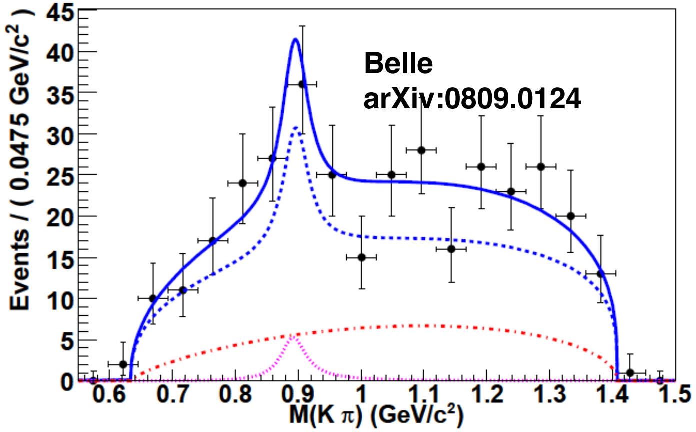
$(8.4 \pm 1.5 \pm 0.7) \times 10^{-6}$

BaBar, Phys. Rev. D77(2008)111101

BR(B→ K X) ≃ BR(B → K π X)
non-resonant Kπ as strong as resonant K
(although phasespace smaller)

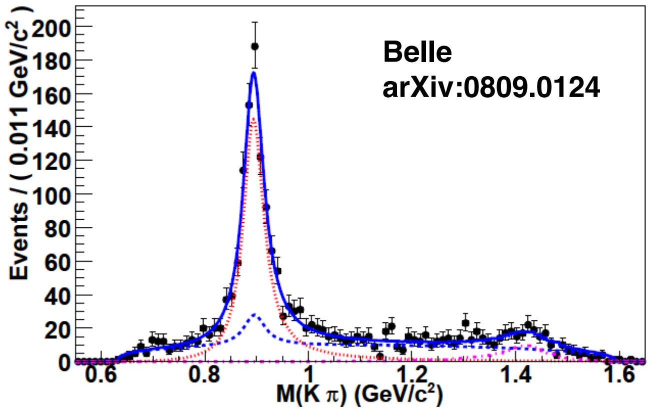
B→KπX(3872) is very different from other B→KπCharmonium

KπX(3872)



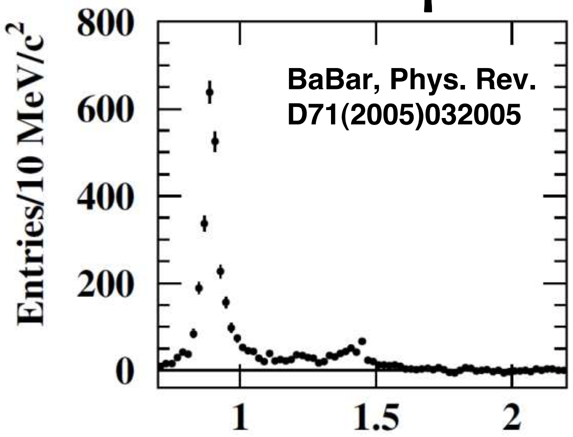
M(Kπ) / GeV

Kπψ′



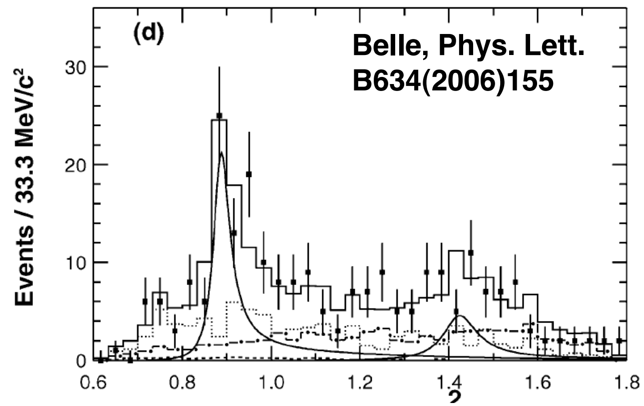
M(Kπ) / GeV

KπJ/ψ



M(Kπ) / GeV

Kπχ_{c1}

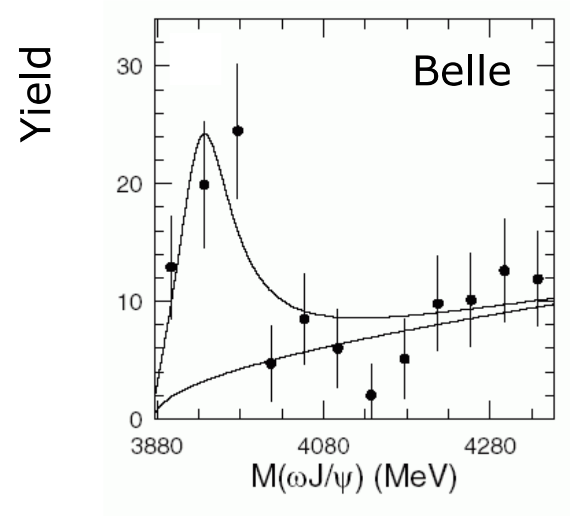


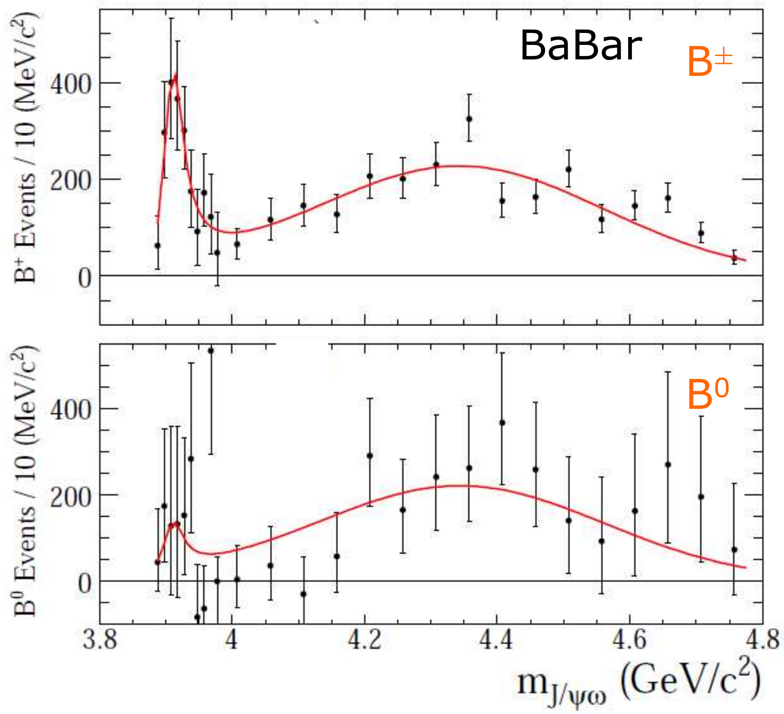
M(Kπ) / GeV

Y(3940)

Y(3940)

- only decay seen so far: $J/\psi\omega$
- quite narrow
  radially excited P wave state?
  $n \geq 2$ has nodes in wave function
  $\rightarrow$ width narrower
- Belle, Phys. Rev. Lett. 94(2005)182002
  275×10^6 B meson pairs
  mass 3943±11(stat.)±13(syst.) MeV
  width 87±22(stat.)±26(syst.) MeV
  - BG ~ q*(m)
    momentum of particles in $J/\psi\omega$ restframe
  - mass resolution fixed $\Delta m(J/\psi\omega) \simeq 6$ MeV
    factor >10 narrower than Breit-Wigner
- BaBar, Phys. Rev. D82(2010)011101
  467×10^6 B meson pairs
  mass $3919.1^{+3.8}_{-3.4}$ (stat.)±2.0 (syst.) MeV
  width 31^{+10}_{-8}(stat.)±5(syst.) MeV
  - BG Gaussian
  - mass dependant resolution



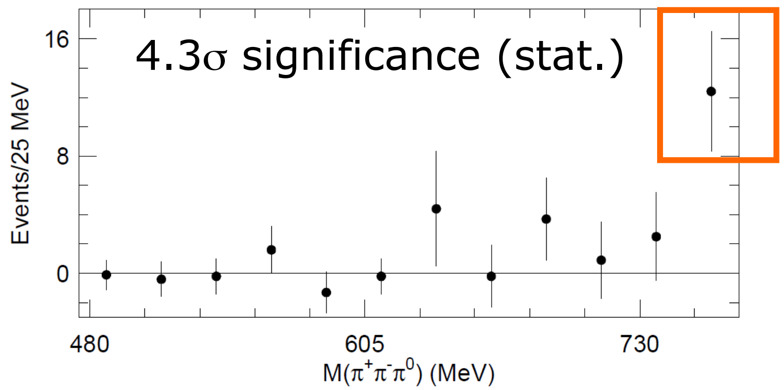


X(3872)$\to$3π and Y(3940)$\to$3π

Isospin violating decays.

Observation of X(3872) → J/ψ ω(→ $\pi^+ \pi^- \pi^0$)

- Belle, arXiv:hep-ex/0505037
  256/fb



- Isospin violation
  (additional π^0)
  seems large

$$\frac{\mathcal{B}(X \to \pi^+\pi^-\pi^0 J/\psi)}{\mathcal{B}(X \to \pi^+\pi^- J/\psi)} = 1.0 \pm 0.4(\mathrm{stat}) \pm 0.3(\mathrm{syst})$$

Belle
MC efficiency corrected

- → BaBar
  re-analysis of Phys. Rev. Lett.101(2008)082001
  with new ω mass cut
  BaBar, Phys. Rev. D82(2010)011101, 433/fb

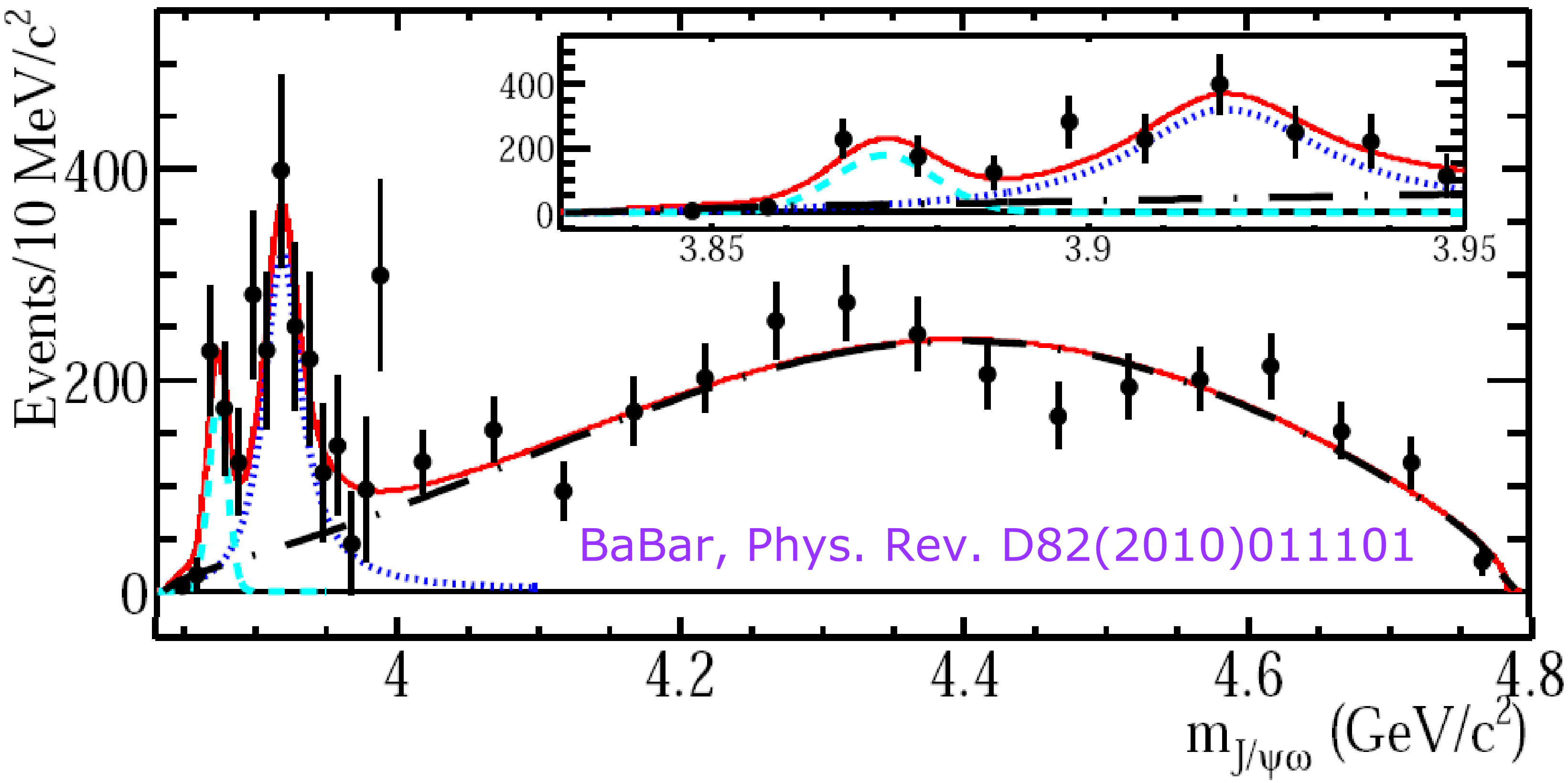
BaBar, Phys. Rev. D82(2010)011101, 433/fb

	Belle hep-ex/0505037	BaBar Phys. Rev. Lett.101(2008)082001	BaBar QWG10
Cut on $\Delta E = \sqrt{(E_B^{cms})^2 - (p_B^{cms})^2}$	±35 MeV (charged only)	±20 MeV (B^+) ±15 MeV (B^0)	±20 MeV (B^+) ±15 MeV (B^0)
Cut on $m(3\pi)$	≥0.7500 GeV (charged only)	0.7695-0.7965 GeV (B^+) 0.7605-0.8055 GeV (B^0)	0.7400-0.7965 GeV (B^+) 0.7400-0.8055 GeV (B^0)

PDG2008 $m(\omega)$=0.78265±0.00012 MeV

$B^+ \to K^+ X(3872)(\to J/\psi\ \omega(\to \pi^+ \pi^- \pi^0))$

X(3872) Y(3940)



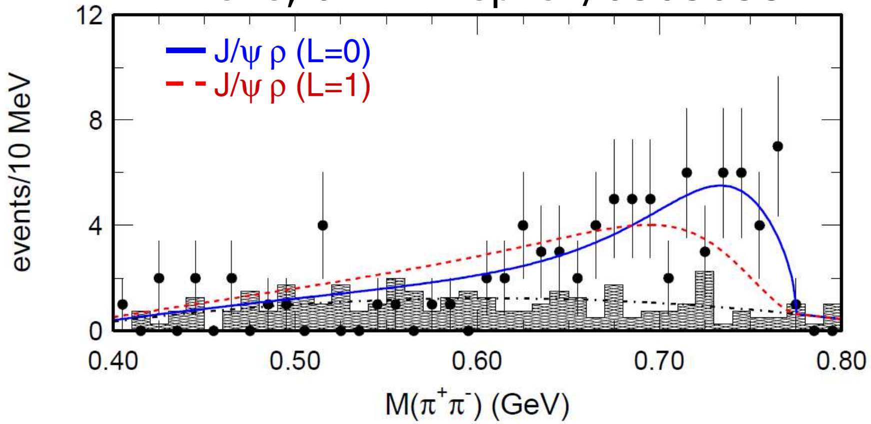
$$\frac{\mathcal{B}(X(3872) \to J/\psi\omega)}{\mathcal{B}(X(3872) \to J/\psi\pi\pi)} = 0.7 \pm 0.3$$

Large isospin violation confirmed

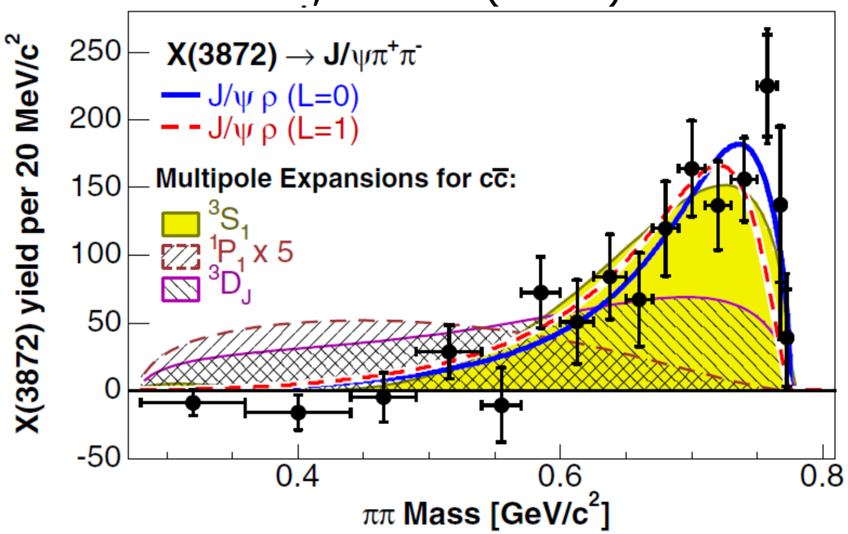
Testing the Quantum Numbers of the X(3872)

$X(3872) \rightarrow J/\psi\ 2\pi$
S-wave preferred

Belle, arXiv:hep-ex/0505038

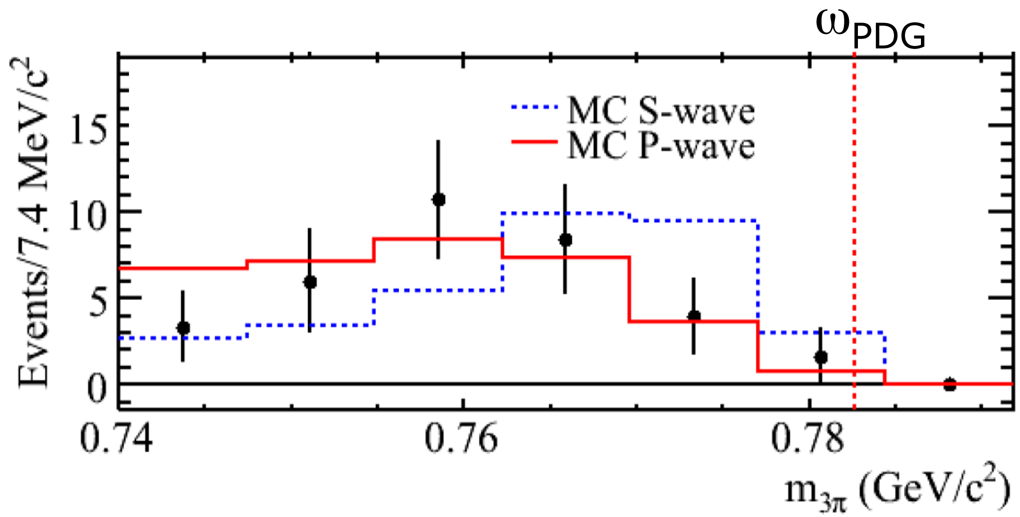


CDF-II, PRL 96(2006)102002



$X(3872) \rightarrow J/\psi\ 3\pi$
P-wave preferred

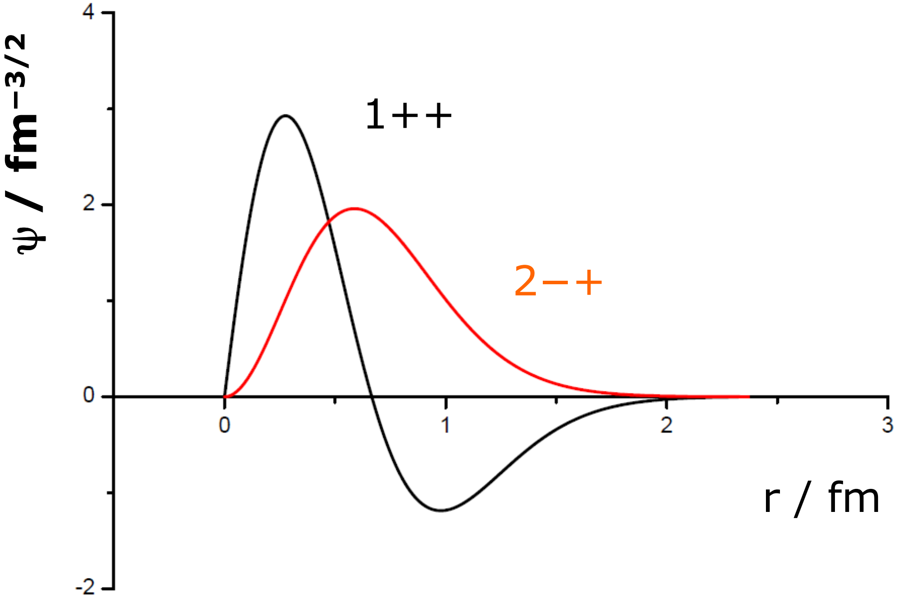
BaBar, arXiv:1005.5190, 433/fb

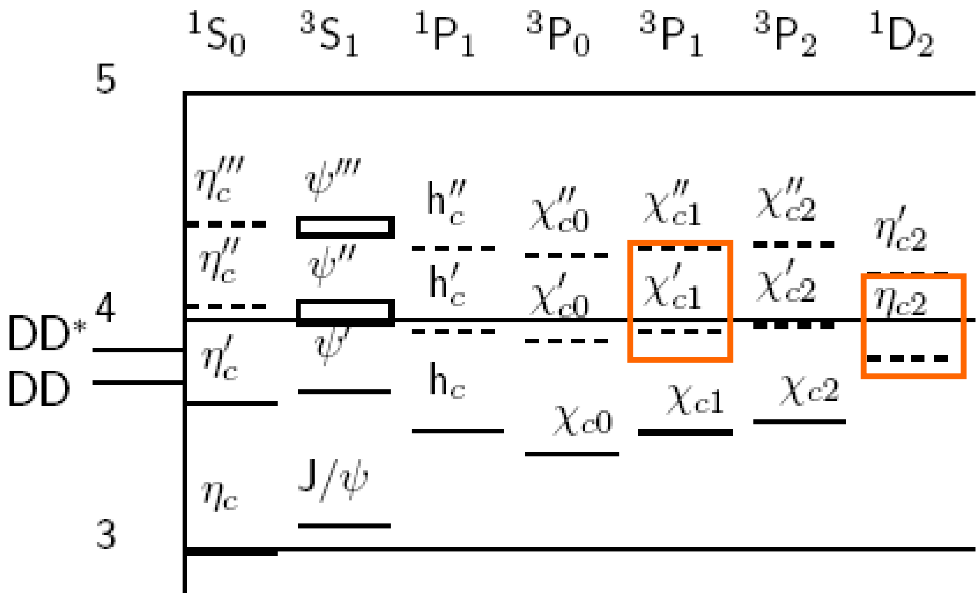


Implication for X(3872) possible Charmonium Assignment

- Case $2\pi \rightarrow P=+$
  1++
  $\chi_{c1}{}'$ $^3P_1$
  predicted mass 3953 MeV
  n=2

- Case $3\pi \rightarrow P=-$
  2−+
  η_{c2} $^1D_2$
  $\lesssim$ 100 MeV lower than $\chi_{c1}{}'$
  predicted mass 3837 MeV
  n=1
  (would be a L=2 meson)





Mass predictions by
Barnes, Godfrey, Swanson
Phys. Rev. D72(2005)054026

A student exercise:

$$B \rightarrow K\ X(3872)$$
$$0- \rightarrow 0-\ 1+$$
$$\text{parity } (-1) \rightarrow \text{parity } (-1) \times (+1) \times (-1)^{L}$$

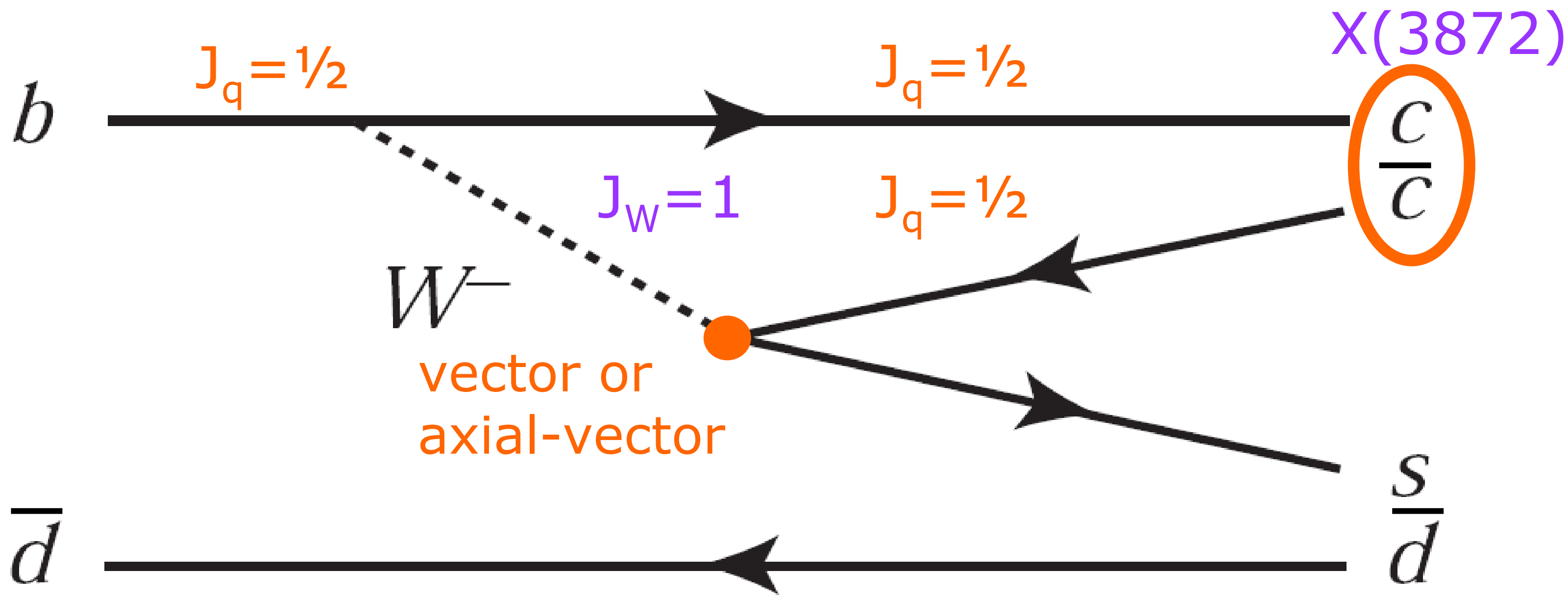
A student exercise:

$B \to K\ X(3872)$

$0- \to 0-\ 1+$

$\text{parity } (-1) \to \text{parity } (-1) \times (+1) \times (-1)^L$

We need L=1 to create J=1,
but this violates parity.

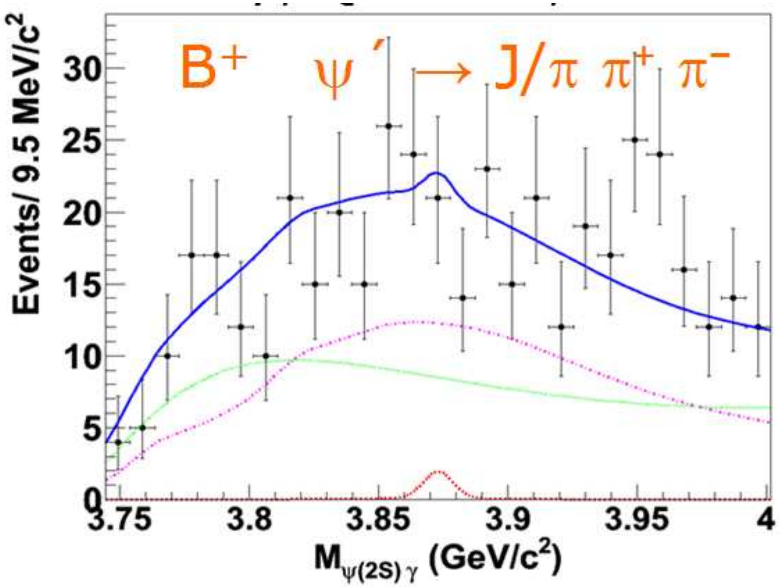


J=0 or J=1 preferred
Parity + or parity − allowed
$J^P=1^+$ no problem (e.g. $B^+ \rightarrow K^+ \chi_{c1}$ seen with BR $4.6 \pm 0.4 \times 10^{-4}$)

but J=2 very hard to be generated

X(3872): Notes

- If X(3872) is $^1D_2$
  then it is S=0
  transition to J/ψ = spin-flip!
  M1 transition. Must be suppressed.
  Example:
  E1 $\psi' \rightarrow \gamma\, \chi_{c1}$ BR=9.2±0.4 %
  M1 $\psi' \rightarrow \gamma\, \eta_c$ BR=0.34±0.05 %
  (although phasespace larger)



-

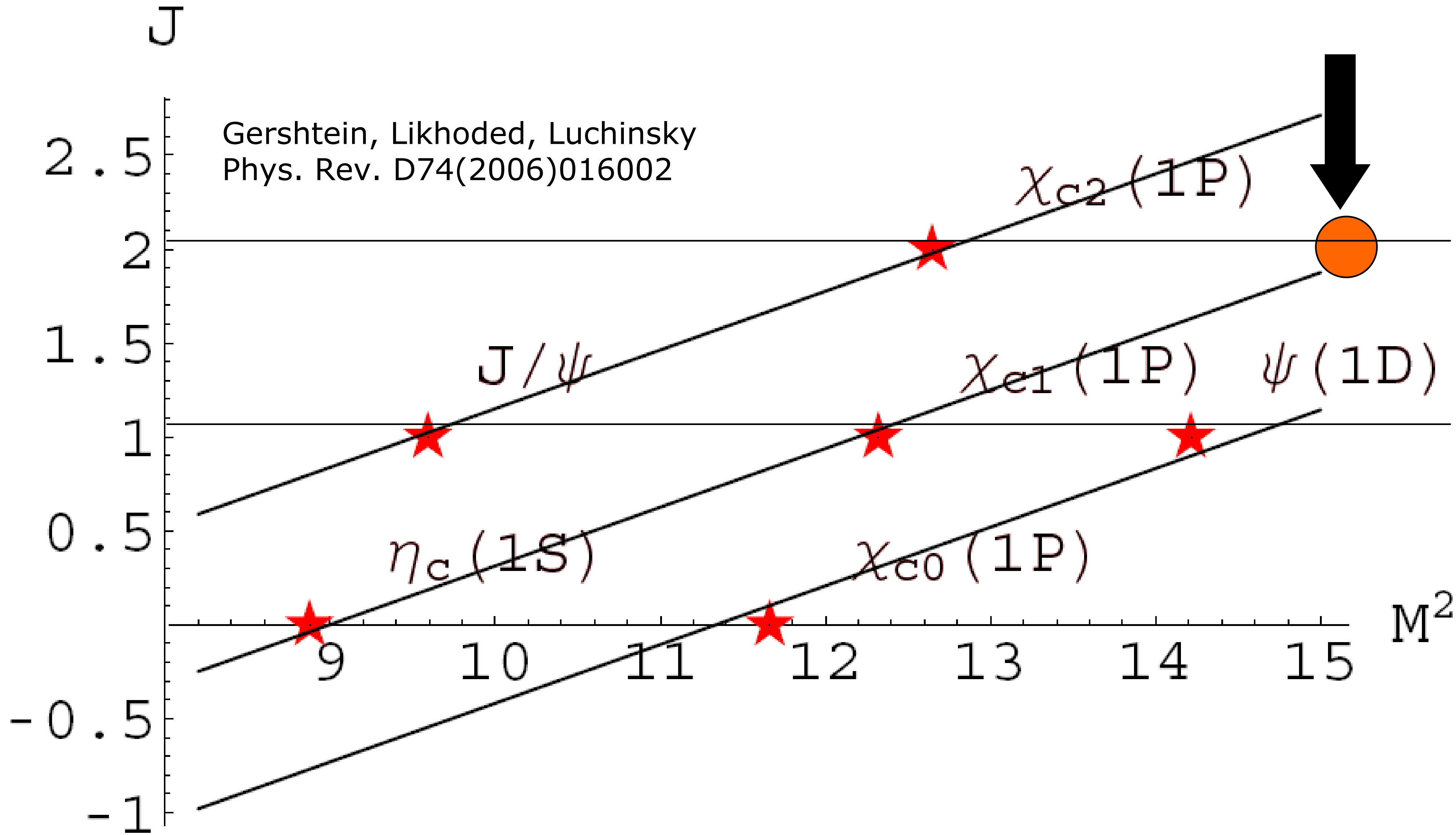
	$^3P_1$	$^1D_2$
LS term	−2	zero
Tensor term	+2/3	+2/3

$$+\alpha_s \frac{j(j+1)-l(l+1)-S(S+1)}{m_q^2}\left\langle\frac{1}{r^3}\right\rangle+\alpha_s\frac{S_{12}}{3m_q^2}\left\langle\frac{1}{r^3}\right\rangle$$

$^1D_2$ mass prediction ~50 MeV too low
Barnes, Godfrey, Swanson, Phys. Rev. D72(2005)054026

Regge Trajectories

if X(3872) is J=2

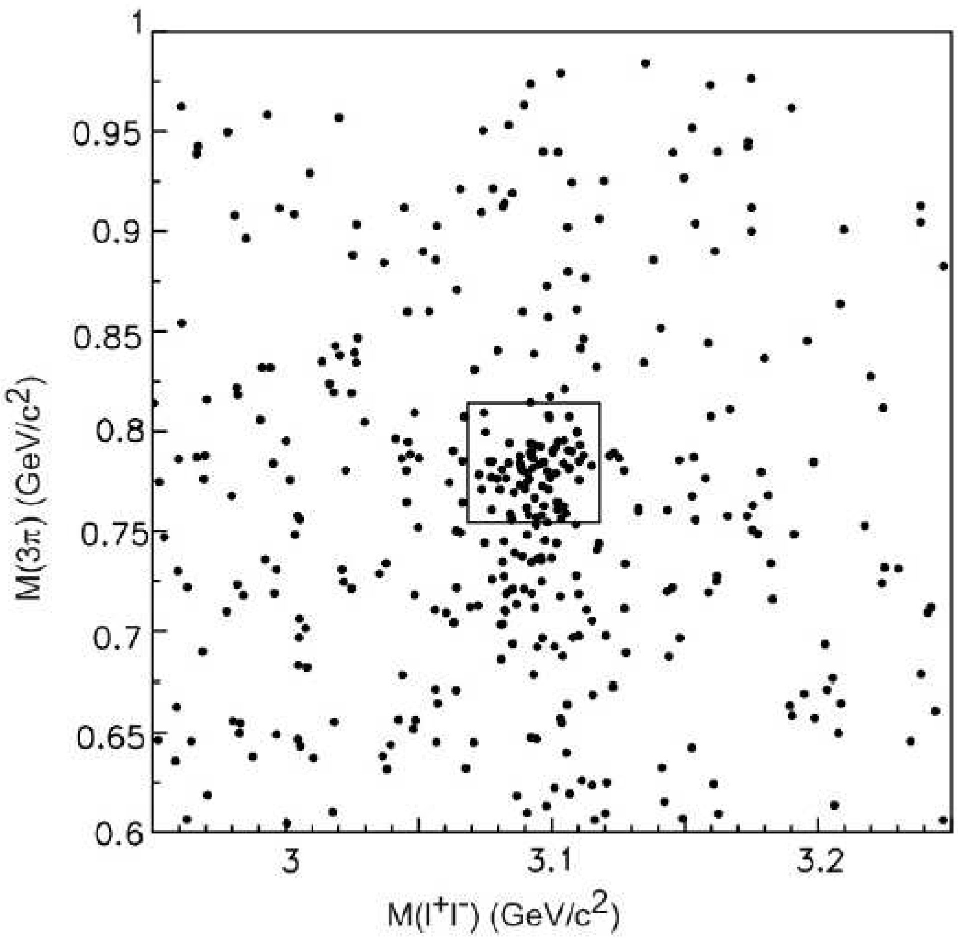


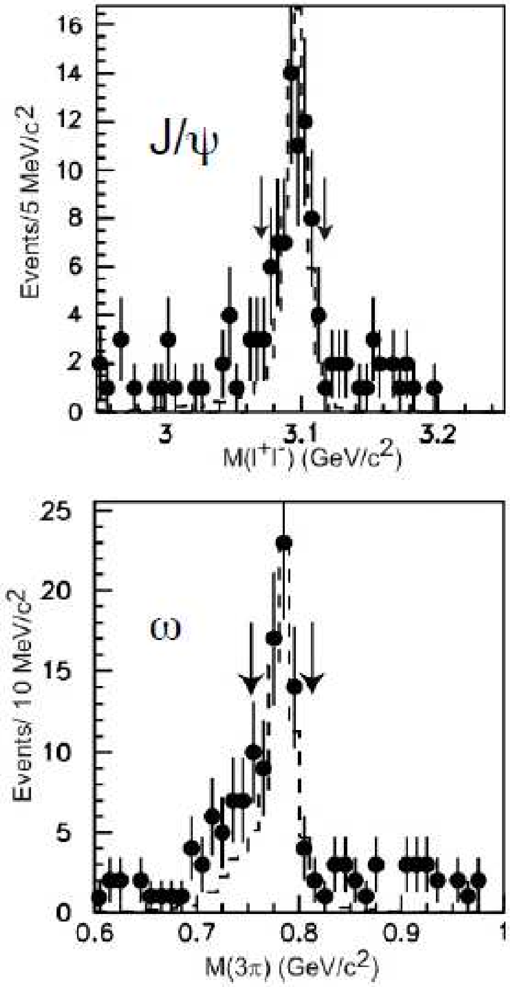
$J/\psi\omega$ in $\gamma\gamma$ collisions

$\gamma\gamma \to J/\psi\ \omega$

694/fb
includes Υ(3S) and Υ(5S) data

- Belle, Phys. Rev. Lett. 104(2010)092001
- Final state 2 vector mesons with I=0



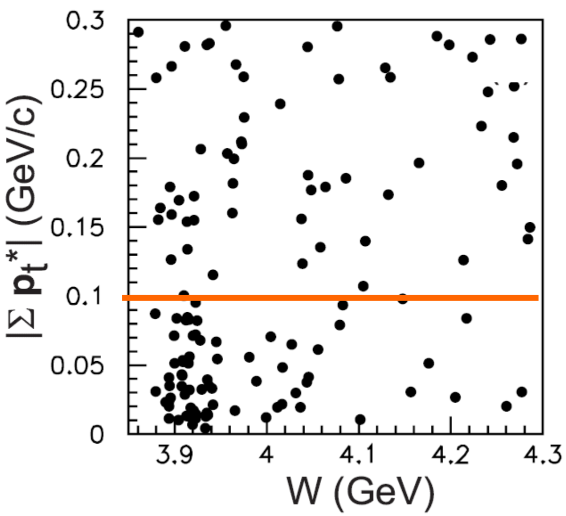


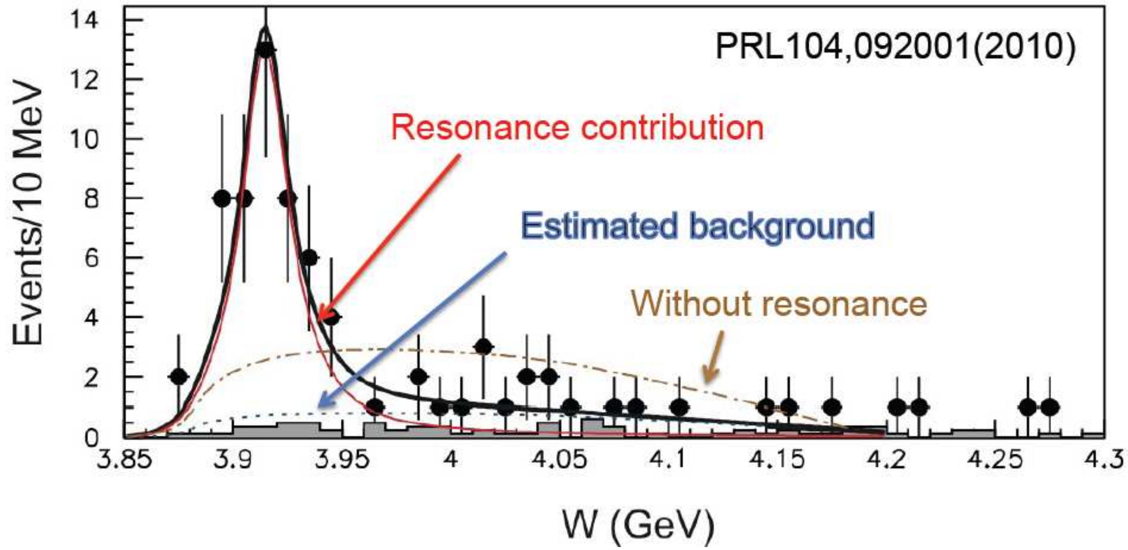
Event selection:
4 tracks
Net charge=0
π^0 candidate
Lepton ID
K rejection
P_T balance

$\gamma\gamma \rightarrow J/\psi\ \omega$

- $\gamma\gamma$ collision signal region ($P_T < 0.1$ GeV)
- Clear enhancement seen just above $J/\psi\ \omega$ threshold
- 7.7σ (stat.)
  49±14(stat.)±4(syst.) events
- M=3915±3(stat.)±2(syst.) MeV
- Γ=17±10(stat.)±3(syst.) MeV
- C=even, but J^P not yet determined (need much more statistics)
- Is this the Y(3940)? (in a 2nd production mode)

Belle





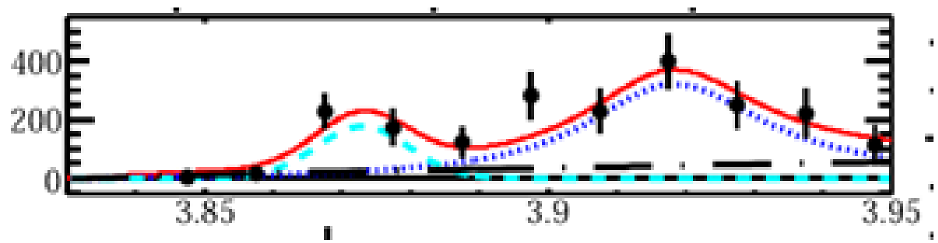
If this state is the Y(3940), it implies:

in $\gamma\gamma$ collisions $J^{PC}=1^{++}$ or 2^{-+} can not be produced

(only 0^{++}, 0^{-+}, 2^{++})

X(3872) and Y(3940) would have different J^{PC}

$\rightarrow$ mixing forbidden (in B decays)



M($J/\psi\omega$) / GeV

(see p. 29)

Y(4260)

$J^P = 1^{--}$, but coupling to e^+e^- small.

(a hybrid state?)

Note: recent notation
by PDG as X(4260)

Y(4260): Reminder

- initial state radiation events
  $e^+e^- \rightarrow \gamma\ J/\psi\pi^+\pi^-$
  (undetected γ parallel to beam axis)

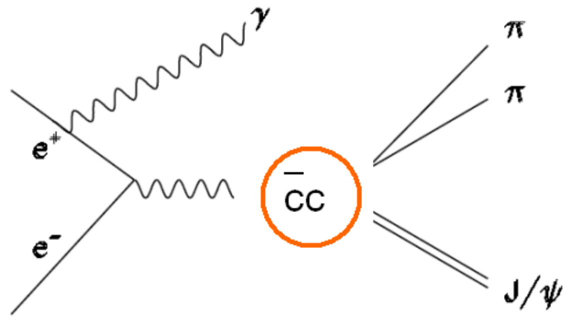
- mass >4 GeV
  (far above DD(*) threshold)

- width < 100 MeV
  (quite narrow)

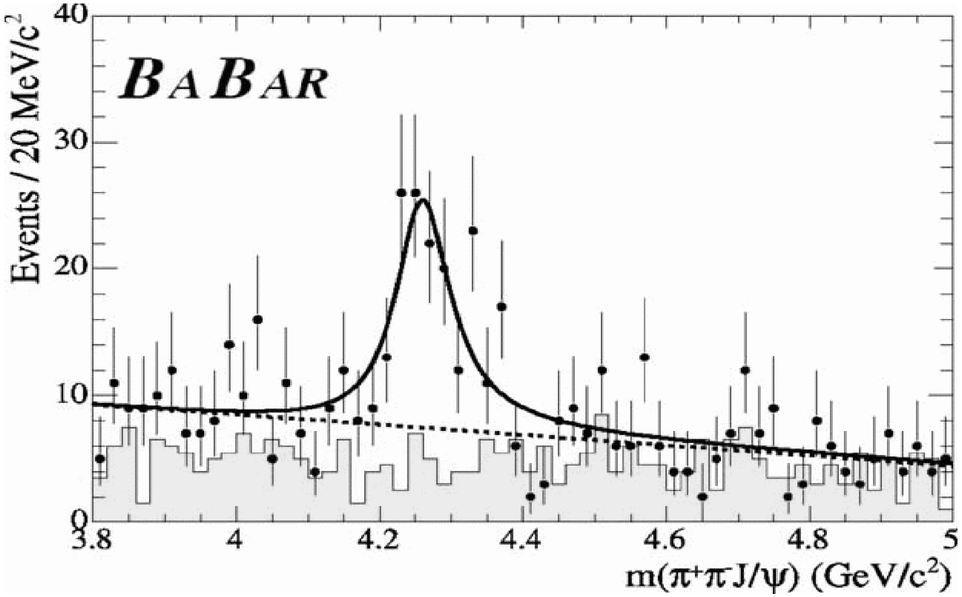
- significance $>10\sigma$

- quantum numbers must be
  (based upon production
  mechanism)
  $J^{PC}=1^{--}$

initial state radiation



Phys. Rev. Lett. 95(2005)142001



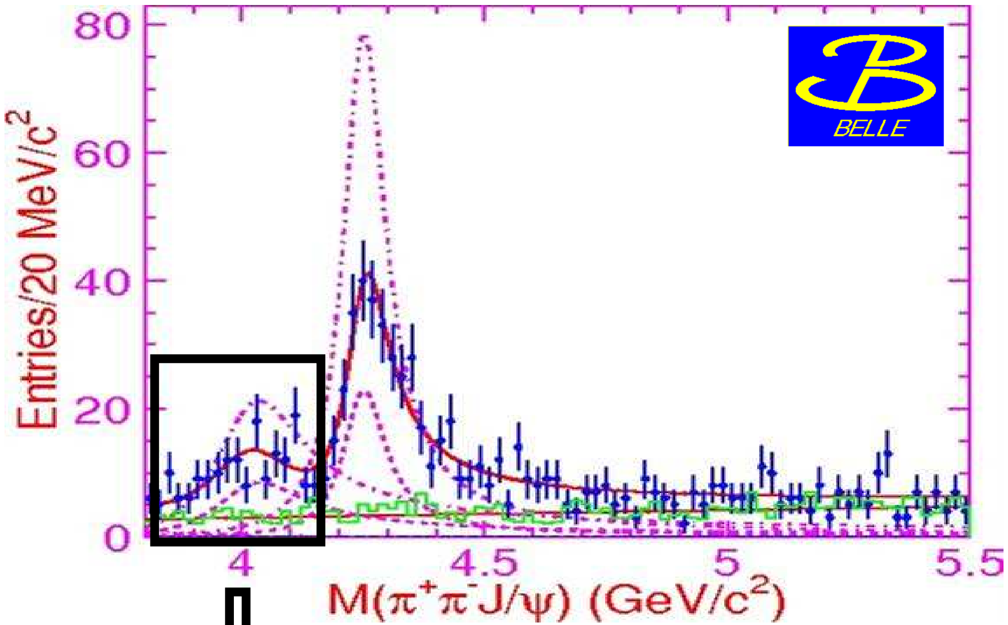
Y(4260) Parameters

	BaBar [1]	CLEO-III [2]	Belle [3]	Belle [4]	BaBar [5]
	211 fb^{-1}	13.3 fb^{-1}	553 fb^{-1}	548 fb^{-1}	454 fb^{-1}
N	125±23	$14.1^{+5.2}_{-4.2}$	165±24	324±21	344±39
Significance	$\simeq 8\sigma$	$\simeq 4.9\sigma$	$\geq 7\sigma$	$\geq 15\sigma$	–
m / MeV	$4259 \pm 8^{+2}_{-6}$	$4283^{+17}_{-16} \pm 4$	$4295 \pm 10^{+10}_{-3}$	$4247 \pm 12^{+17}_{-32}$	$4252 \pm 6^{+2}_{-3}$
Γ / MeV	$88 \pm 23^{+6}_{-4}$	70^{+40}_{-25}	$133 \pm 26^{+13}_{-6}$	108±19±10	$105 \pm 18^{+4}_{-6}$

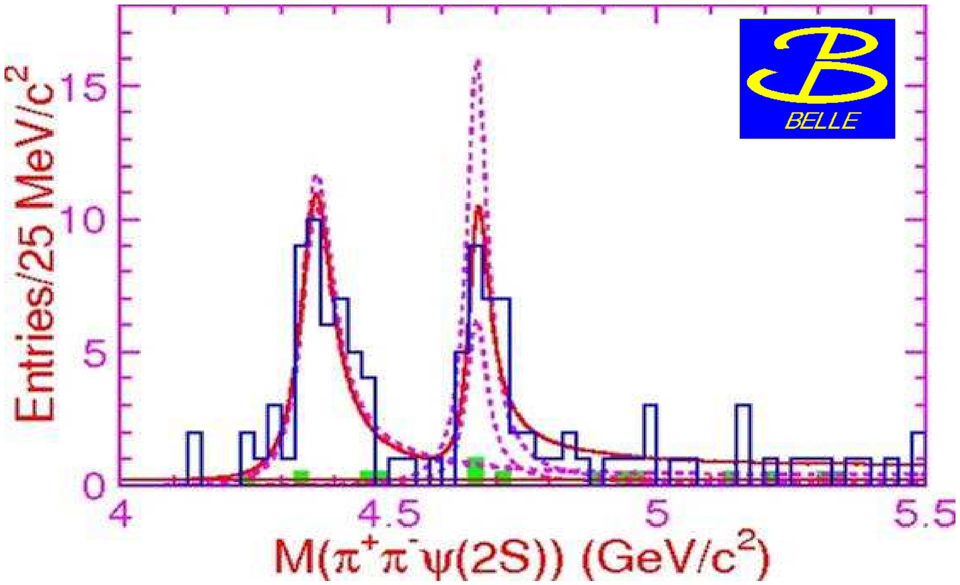
[1] Phys. Rev. Lett. 95(2005)142001
[2] Phys. Rev. Lett. 96(2006)162003
[3] arXiv:hep-ex/0612006
[4] Phys. Rev. Lett. 99(2007)182004
[5] arXiv:0808.1543[hep-ex]

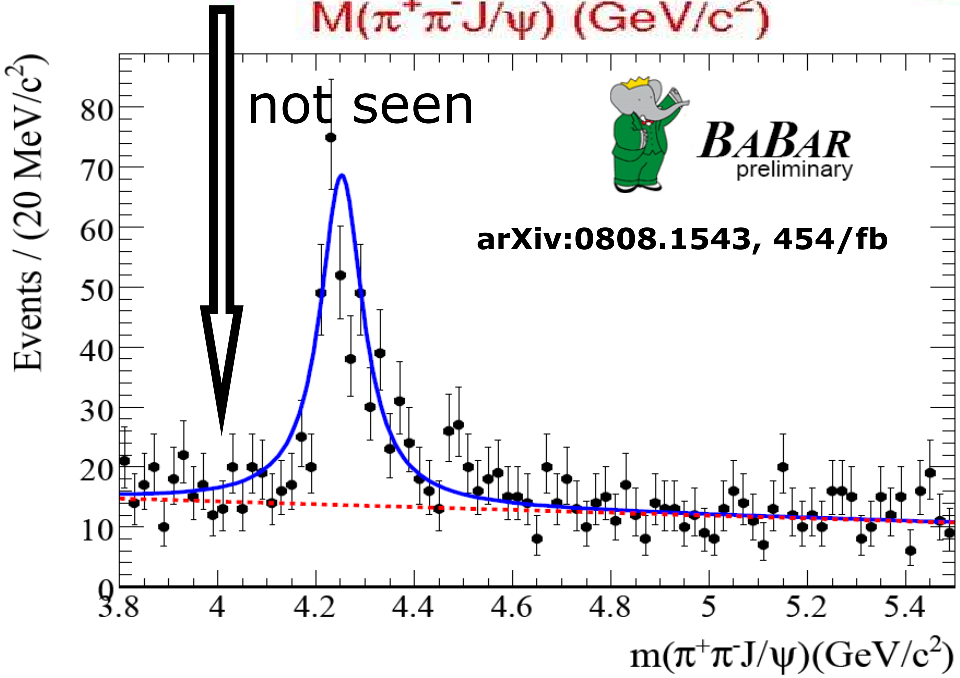
$e^+e^- \rightarrow \gamma_{ISR}\ J/\psi\ (\psi')\ \pi^+\pi^-$: Y(4008,4260,4350,4660)

Phys. Rev. Lett. 99(2007)182004, 550/fb

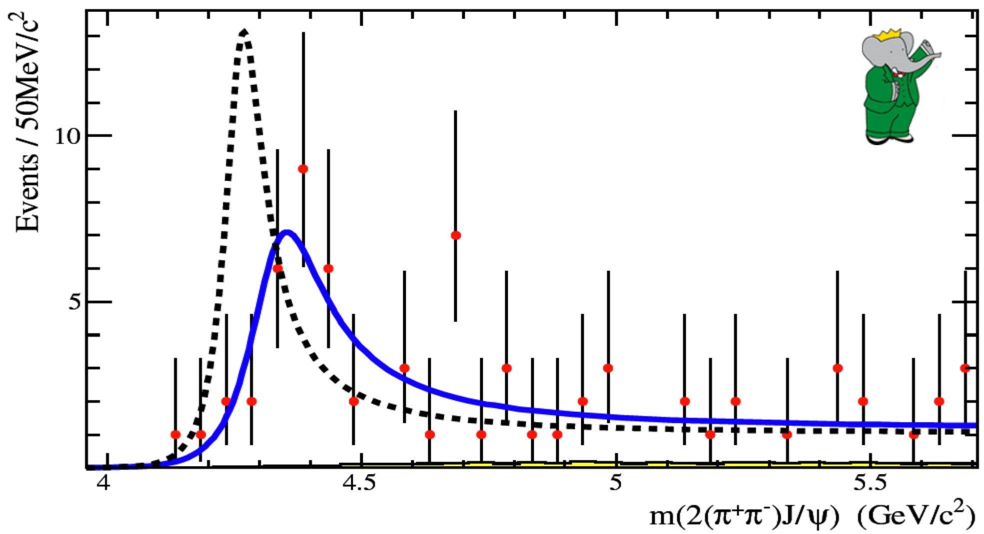


Phys. Rev. Lett. 99(2007)142002, 670/fb





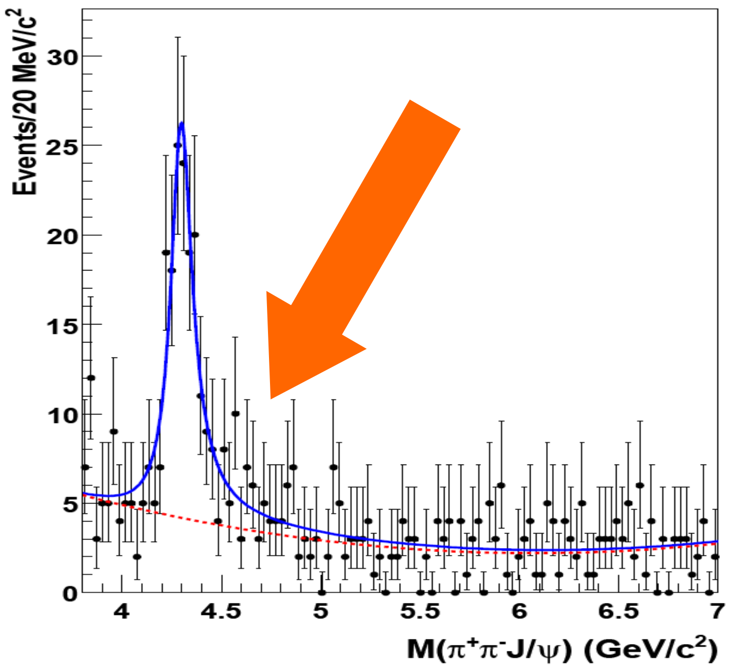
Phys. Rev. Lett. 98(2007)212001, 298/fb

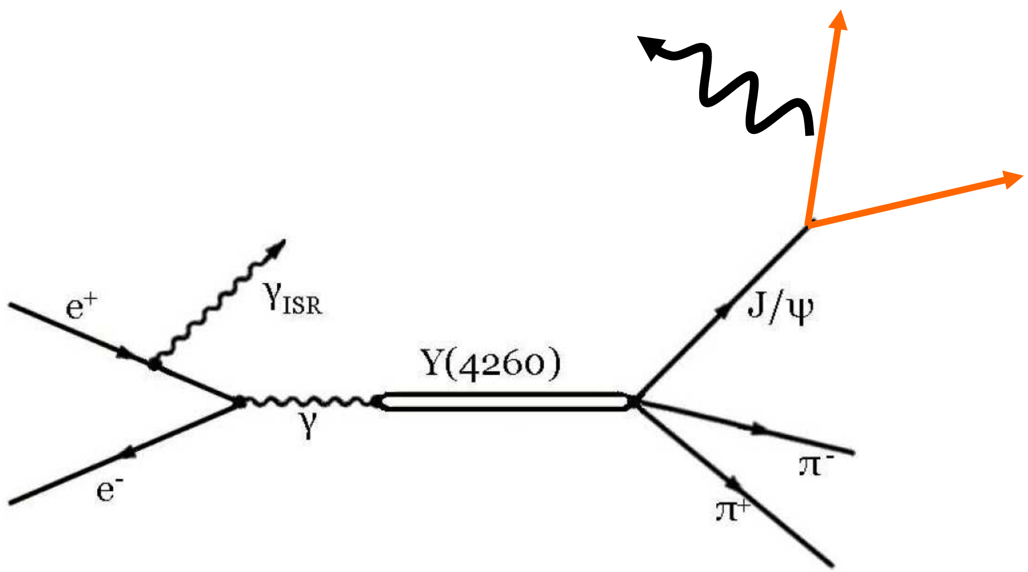


What is the tail $\leq$4.7 GeV?

- Threshold m(D)+m(D**) = 4326 MeV
  Lineshape distorted? No.
- Non-corrected radiative effects? No.
  Radiative lower mass tail in $J/\psi \to e^+ e^-$
  might generate higher mass tail in m(J/ψ-with-wrong-mass $\pi^+\pi^-$).
- Fit funtion: Breit Wigner x Phasespace x Efficiency
  Efficiency $a(m-m_0)+b$ with $a=7.4\pm 1.3$ GeV^{-1}, $b=9.31 \pm 0.07$ (Belle)
  changes factor ~2 over peak

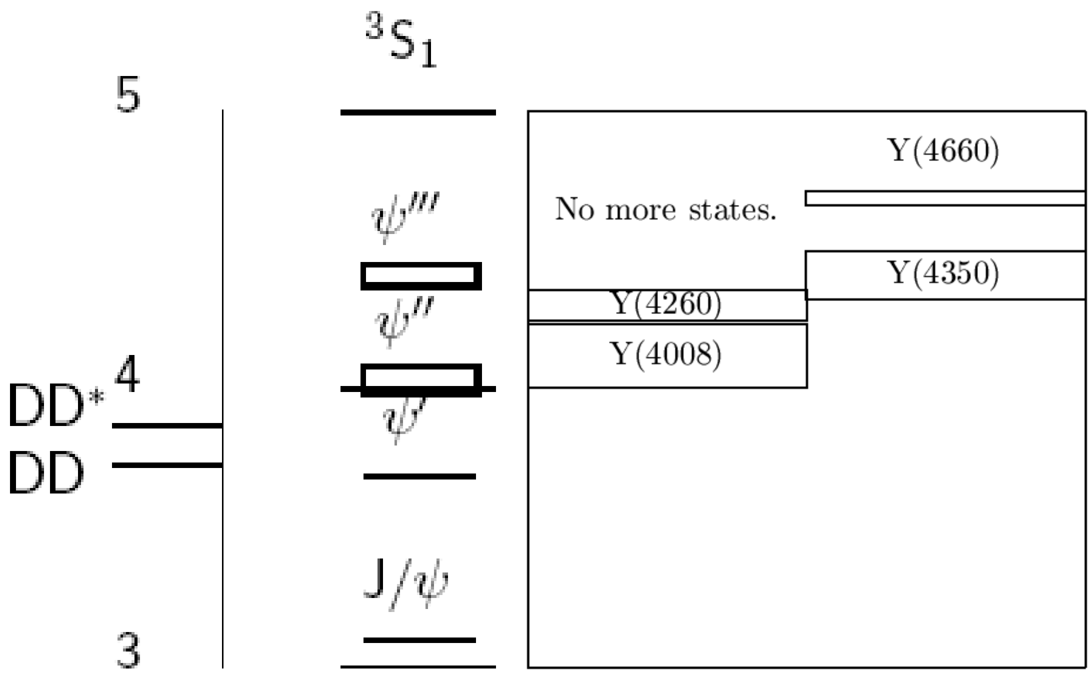
Belle, hep-ex/0612006

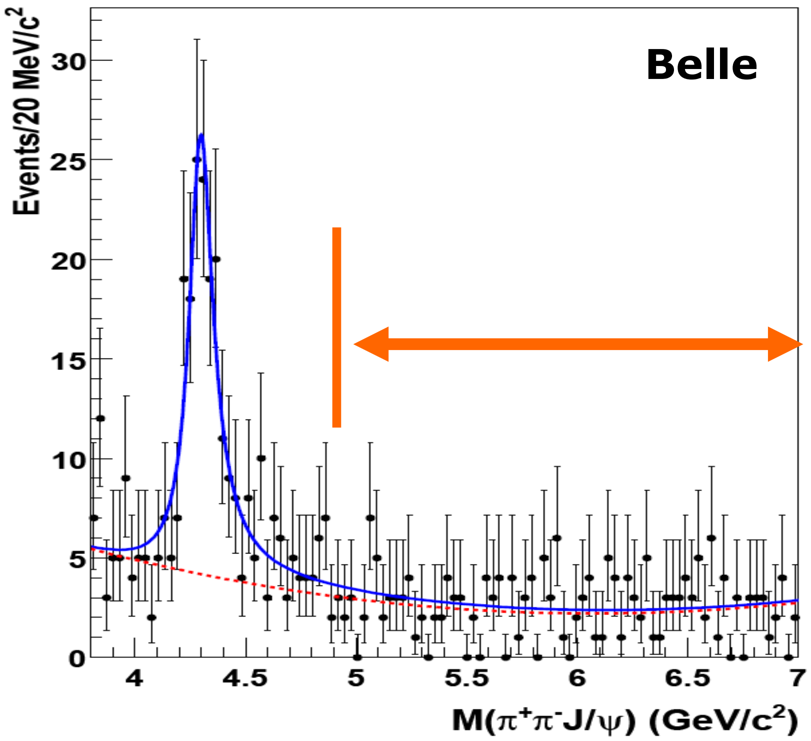




Y States

1 − −





No more [J/ψ π^+ π^-] state up to 7 GeV

All same quantum number
1 − −
but apparently

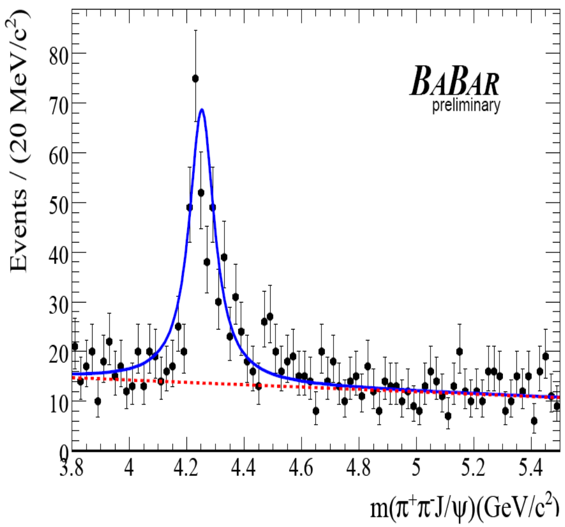
- no mixing with other ψ states
- no mixing among them
  Y(4260) seems not decay to ψ´ π^+ π^-
  Y(4350) seems not decay to J/ψ π^+ π^-

Note: radiative transistions between the states forbidden by parity

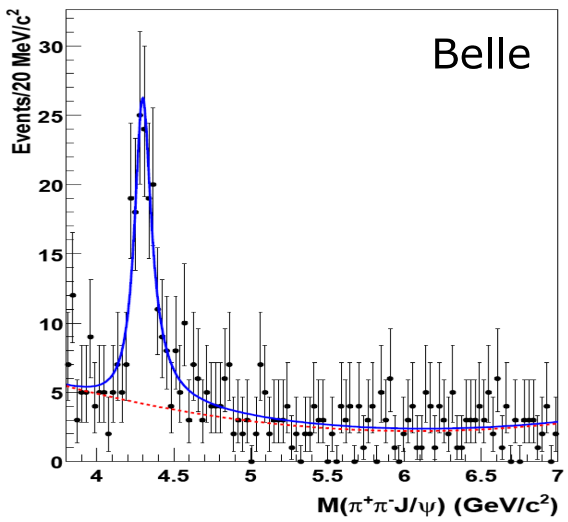
Y(4260): Comparison Belle and BaBar

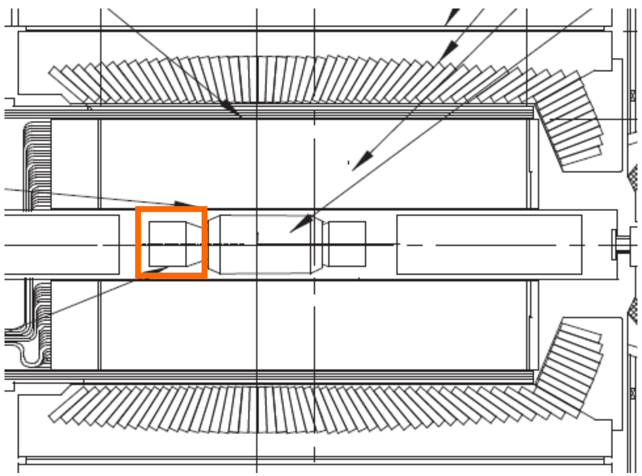
- BaBar collisions head-on, dipole magnet close to IR
- Belle: steering angle
- slightly higher background at BaBar (also seen as MRad SVD radiation dose)
- backward acceptance for $\theta \simeq 180^o$ limited

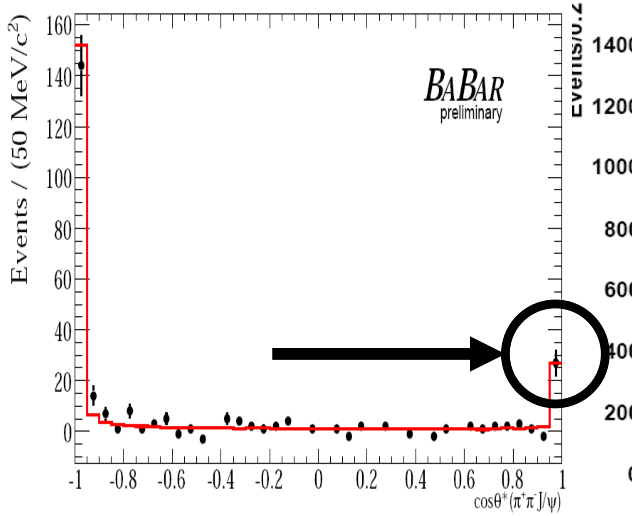
arXiv:0808.1543, 454/fb

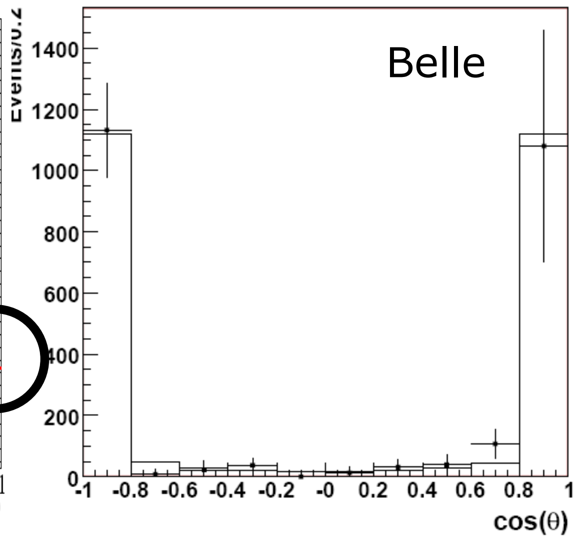


hep-ex/0612006, 553/fb









CMS polar angle of Y(4260) to e− beam

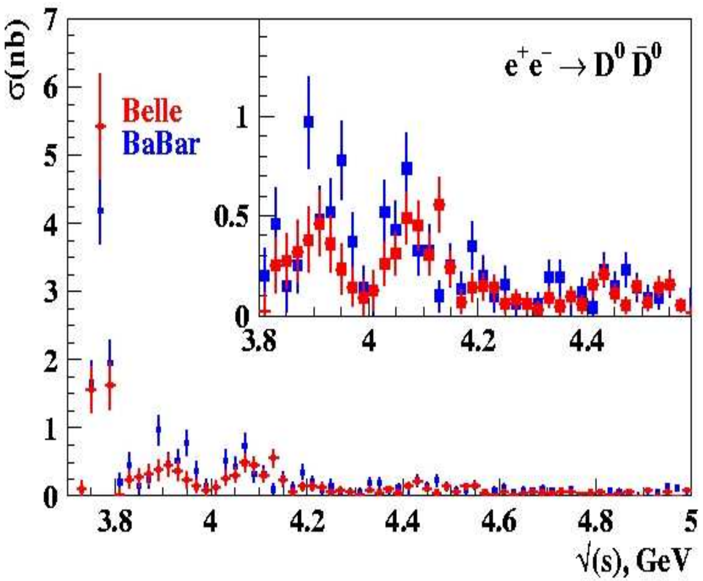
Y(4260): Notes

- Decay to $\bar{D}D$, $\bar{D}D^*$, $\bar{D}^*D^*$ not seen
  see Talk G. Pakhlova, PsiPhi09
  but e.g. BR($\psi''\rightarrow \bar{D}D$) > 90%

- Small coupling to $e^+ e^-$
  (although $J^P=1^-$)
  BR($J/\psi\ \pi^+\pi^-$) x $\Gamma(e^+e^-)$ =
  $(7.5\pm0.9\pm0.8)$ eV
  BaBar, arXiv:0808.1543

- Small coupling to $\bar{p}p$
  BR($Y(4260)\rightarrow \bar{p}p$)/
  BR($Y(4260)\rightarrow J/\psi\ \pi^+\pi^-$)<0.13
  BaBar, Phys. Rev. D73(2006)091103
  > implications for Panda

What is blocking these decays?



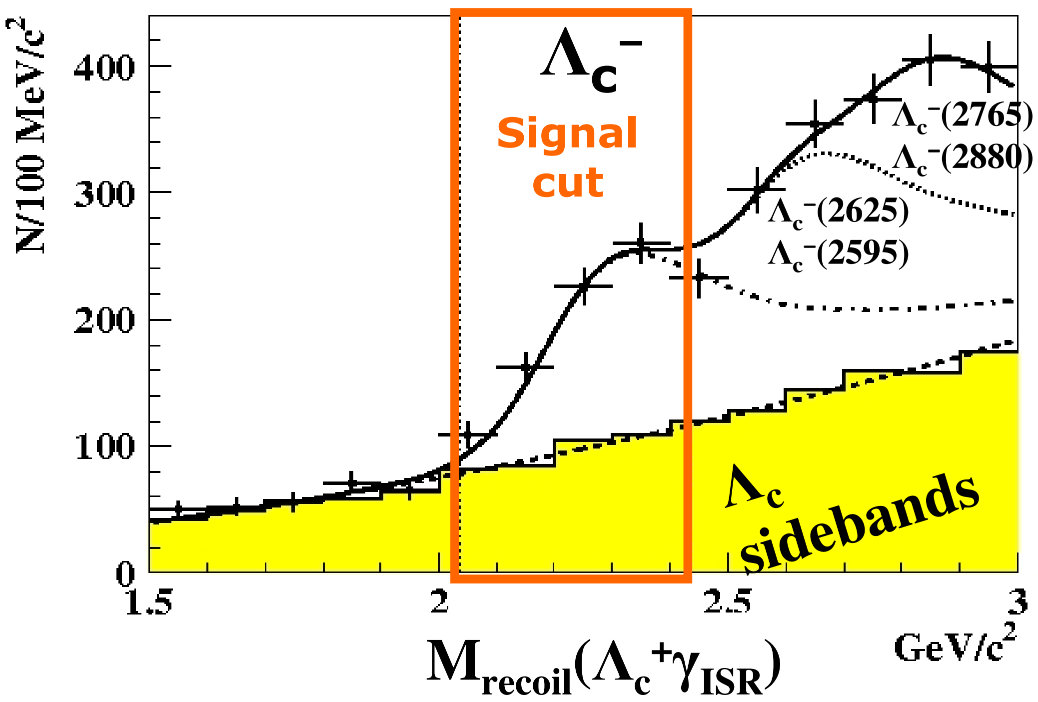
X(4630) highest charmonium(-like) state observed so far only new state with decay to baryons seen

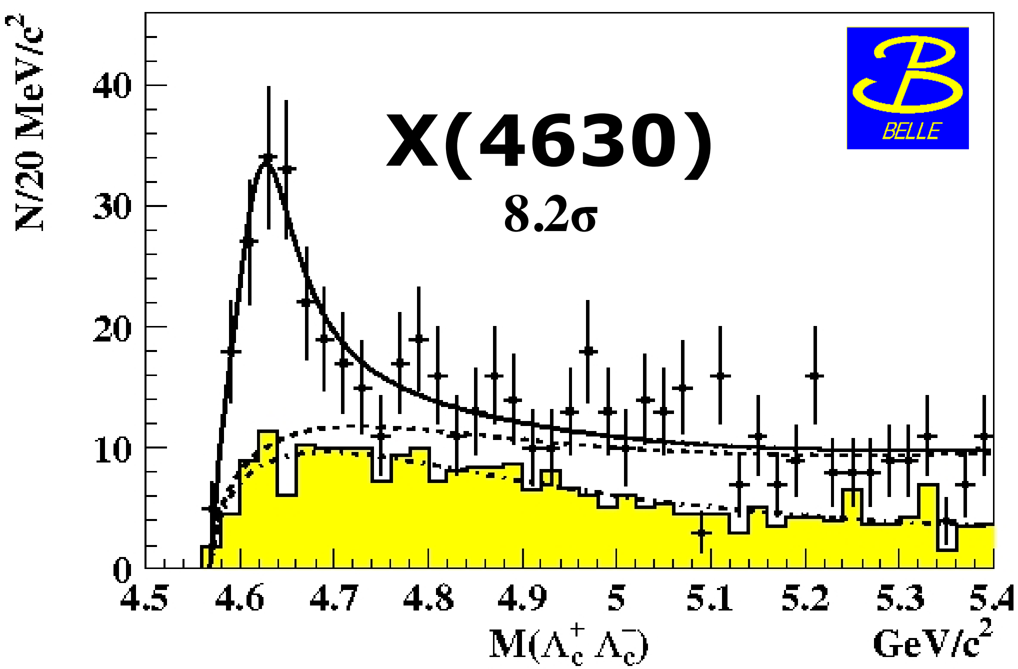
$e^+e^- \to \Lambda_c^+ \Lambda_c^- \gamma_{ISR}$

$\Lambda_c \to pK_s^0$, $pK^-\pi^+$, $\Lambda\pi^+$
Λ_c^- is tagged by anti-proton, (partial reconstruction, recoil mass)

- 5^3S_1 or 4^3D_1 ?
  Segovia, Yasser, Entem, Fernandez
- 6^3S_1 ?
  Li, Chao
- 2-baryon threshold effect?
  as seen in B decays, J/ψ decays

Phys. Rev. Lett. 101(2008)172001, 670/fb

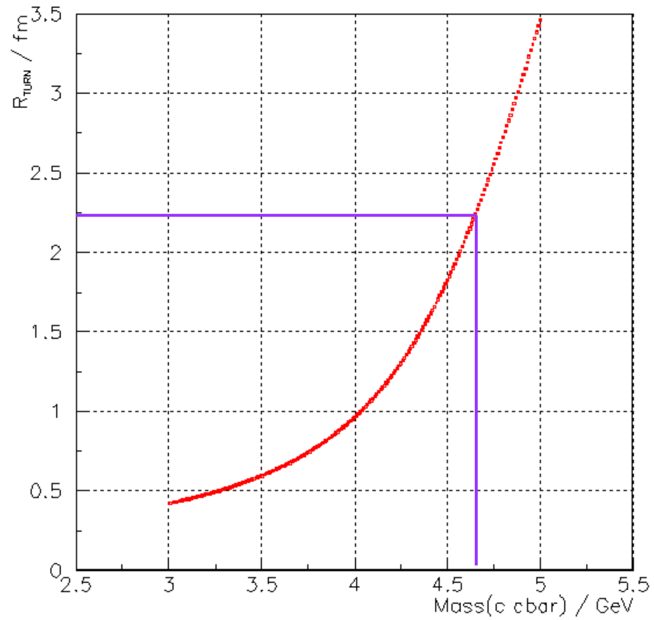


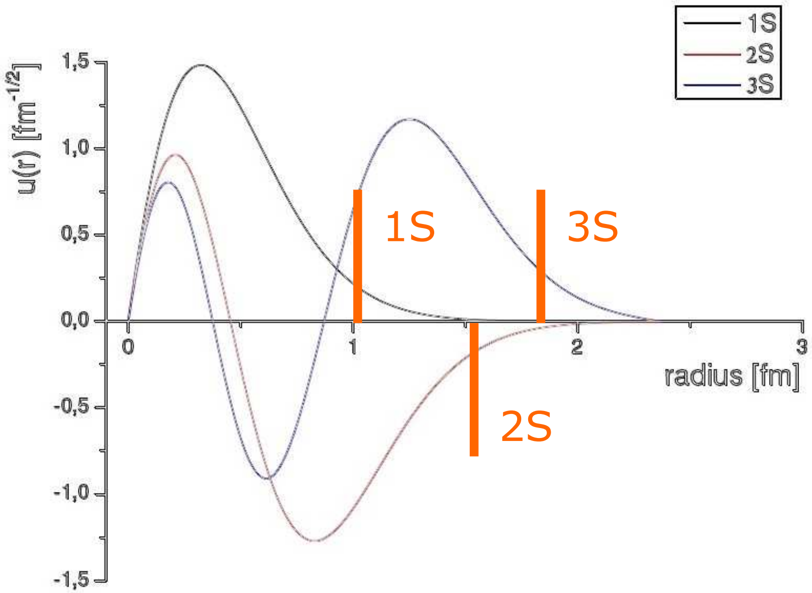


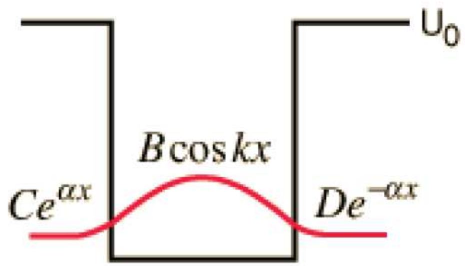
Potential Model:
Wronski-Determinant must be =0 at turning point

$$r_{\text{turning point}} = \frac{E-2m}{2\sigma} + \sqrt{\frac{4m^2-4mE+E^2}{4\sigma^2} + \frac{4\alpha_s}{3\sigma}}$$

- at m=4.660 GeV, the turning point of the wave function is at r>2 fm!
- large fraction of wave function is in string breaking regime r>1.35 fm



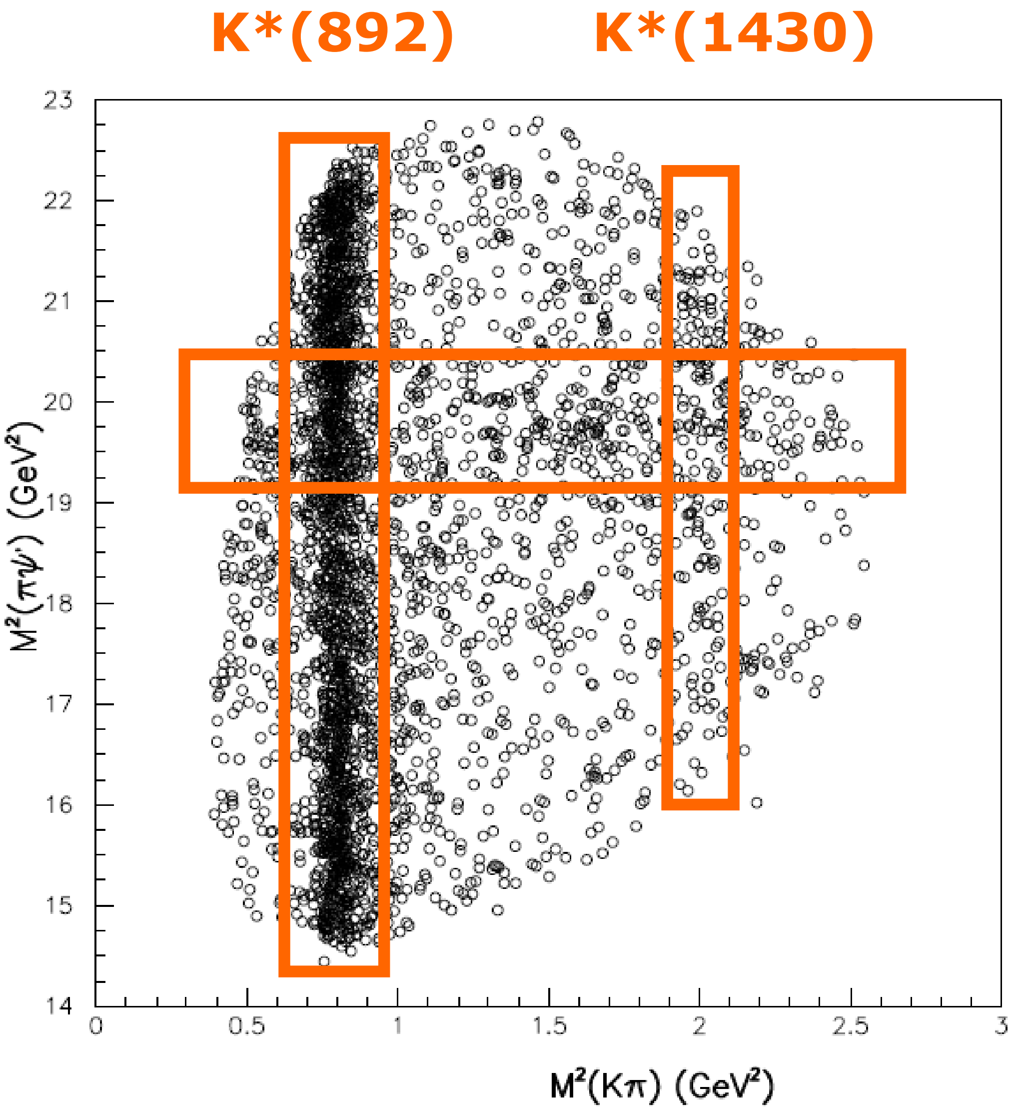




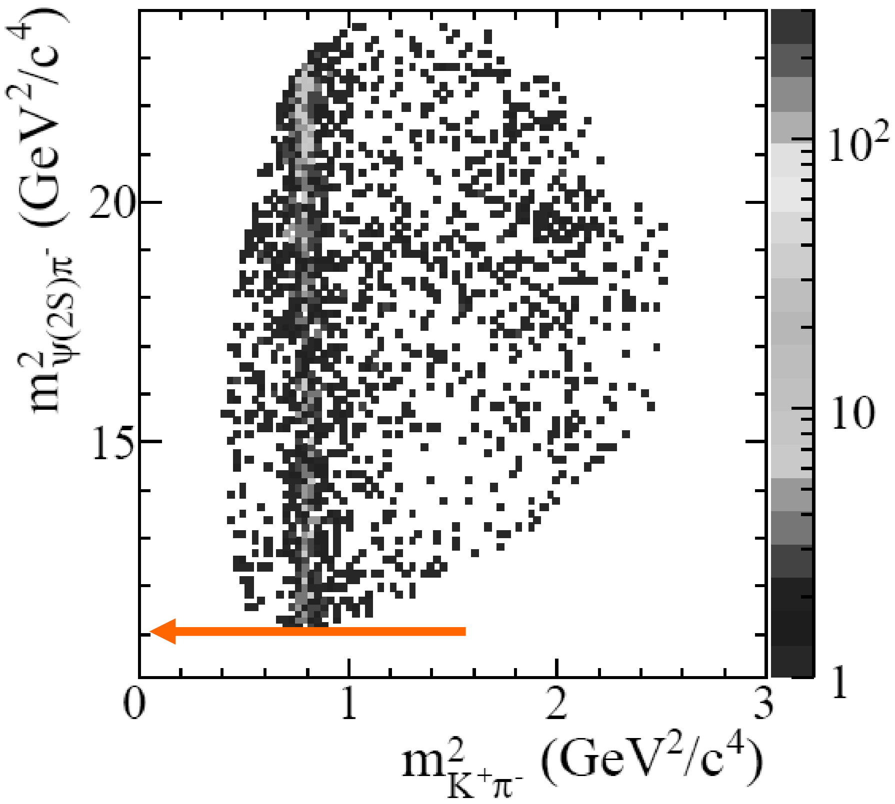
$Z(4430)^+$

A charged charmonium(-like) state.

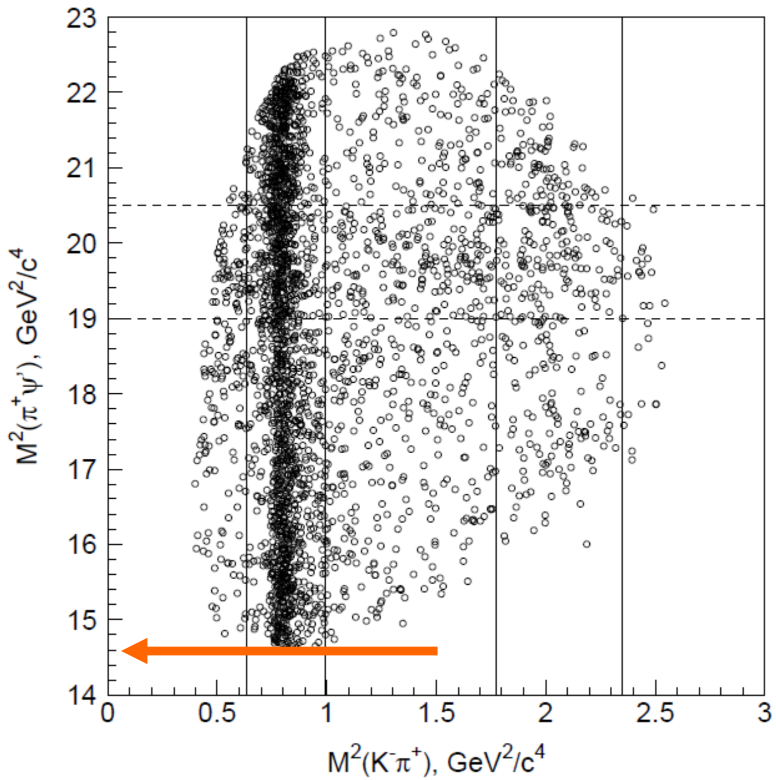
$B^0 \rightarrow K^+ \psi' \pi^-$



Z(4430)$^+$



BaBar
Phys. Rev. D79(2008)112001
413/fb

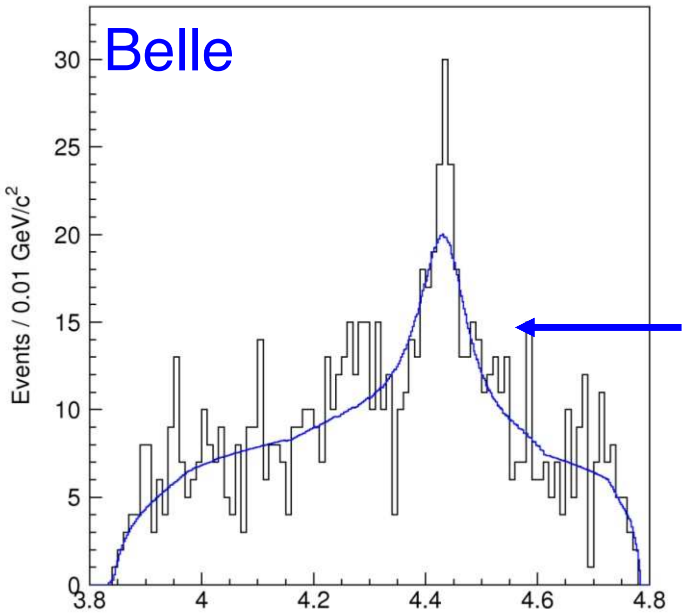


Belle
Phys. Rev. D80(2009)031104
605/fb

Dalitz plot shows same features, although different range.

Belle and BaBar data look similar.

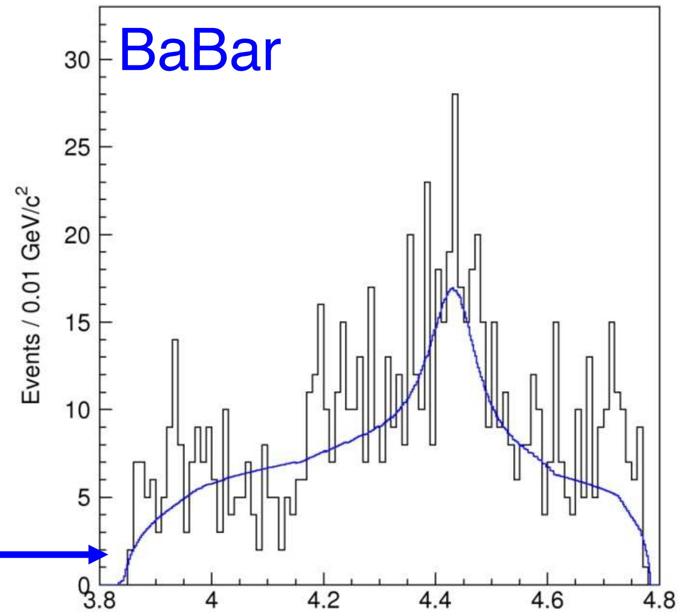
with K* veto



M (π ψ′) GeV

Result of Belle Dalitz fit analysis.

The same curve divided by 1.18 (scaled with Integrated luminosity)



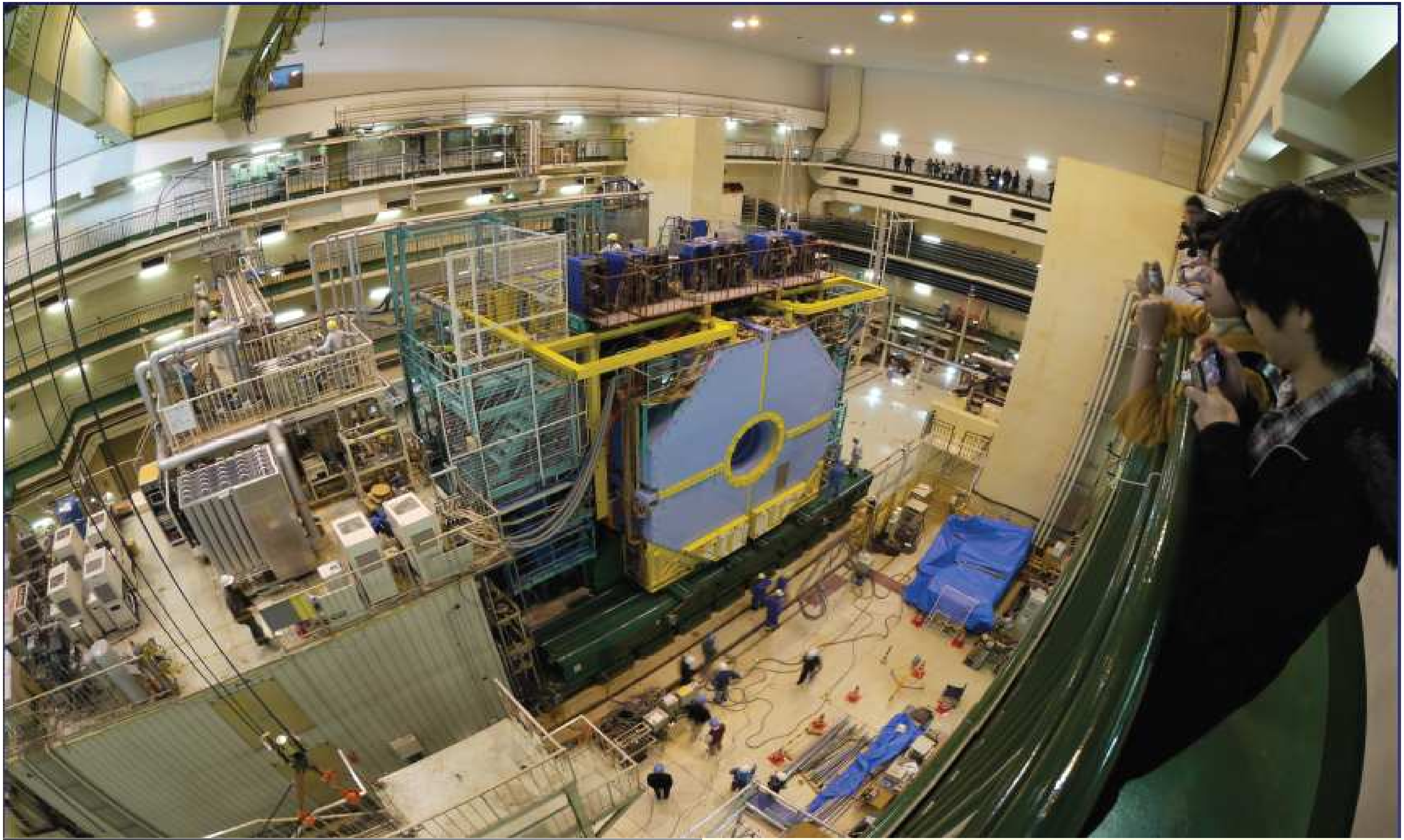
M (π ψ′) GeV

Enhancement in **Mass(πψ′)** is seen in both data samples, only interpretation is different.

Belle-II

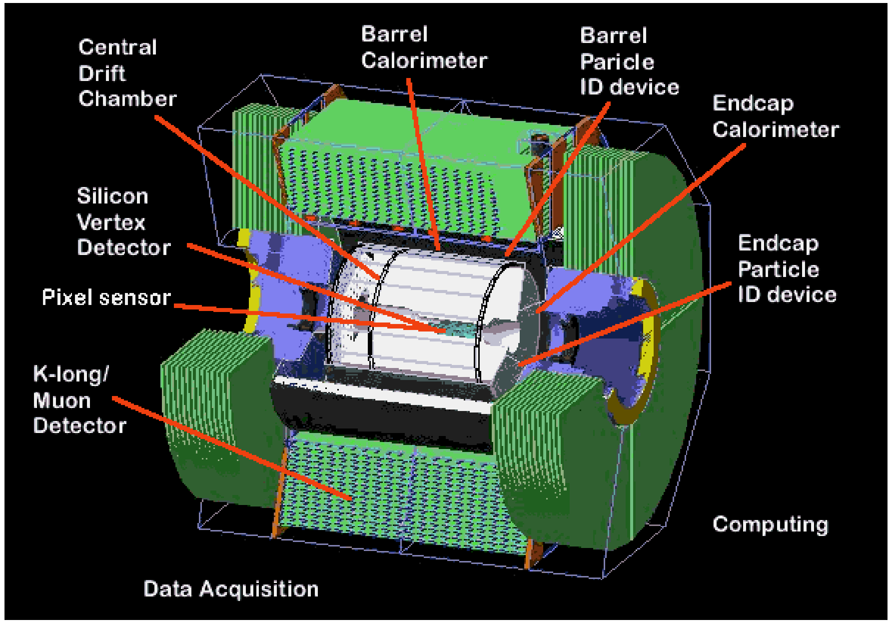
Belle Rollout, 09.12.2010

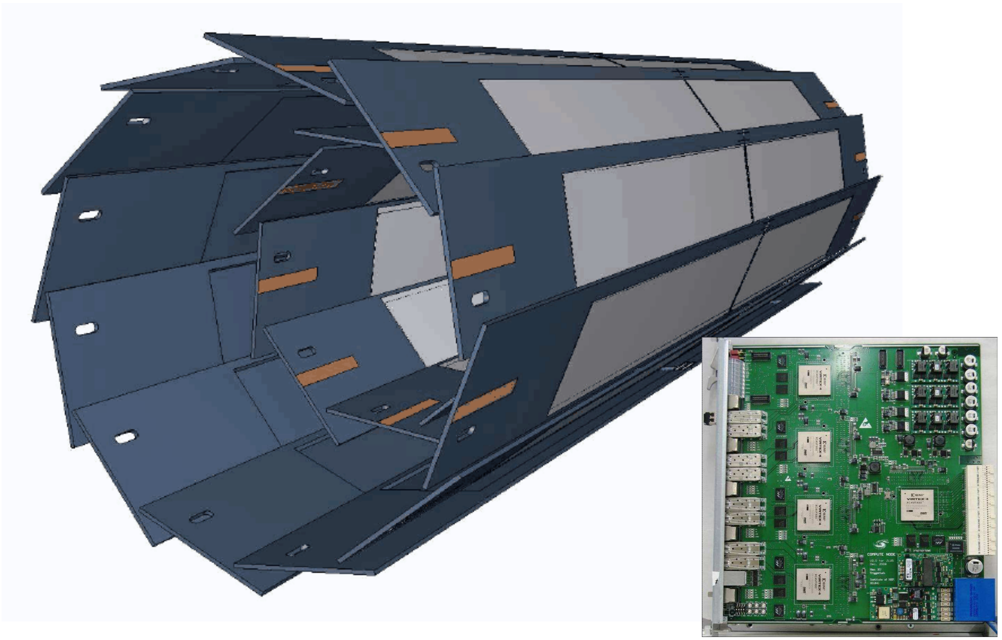
Belle Rollout, 09.12.2010



Belle-II and Super-KEKB

- Luminosity x 40 (8×10^{35} cm^{-2} s^{-1})
  plan 50 ab^{-1} by $\leq$2021
- Groundbreaking Ceremony: 8.04.2011
- Technical Design Report, see arXiv:1011.0352
- Several new detectors, e.g. DEPFET Pixel Detector
  - vertex resolution $\Delta z \geq 20$ μm for p>1 GeV/c
  - improved low momentum tracking, e.g. for $D^{*+} (\rightarrow D^0 \pi^+)$
  - schedule: detectors installed by 01.10.2014





Summary

- Although BaBar and Belle finished data taking, results from spectroscopy analyses are flourishing.
- Even >5 years after discovery of X(3872), Y(4260), … their nature is not understood.
- The next steps ahead: Bes-III, LHCb, Belle-II, $\overline{\text{P}}$ANDA, ……, SuperB …

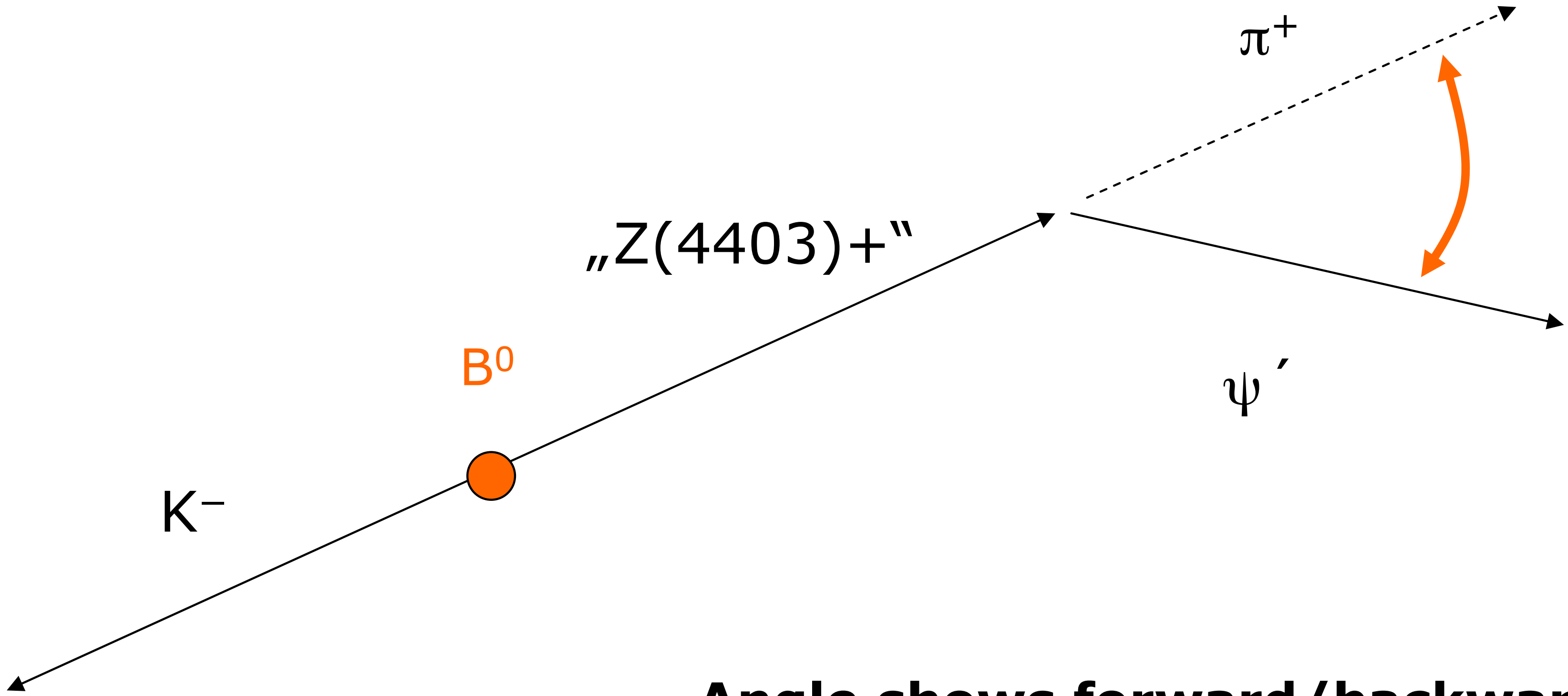
Backup Slides

Luminosity prospect

64

K* is peaking with respect to this angle

in B meson rest frame

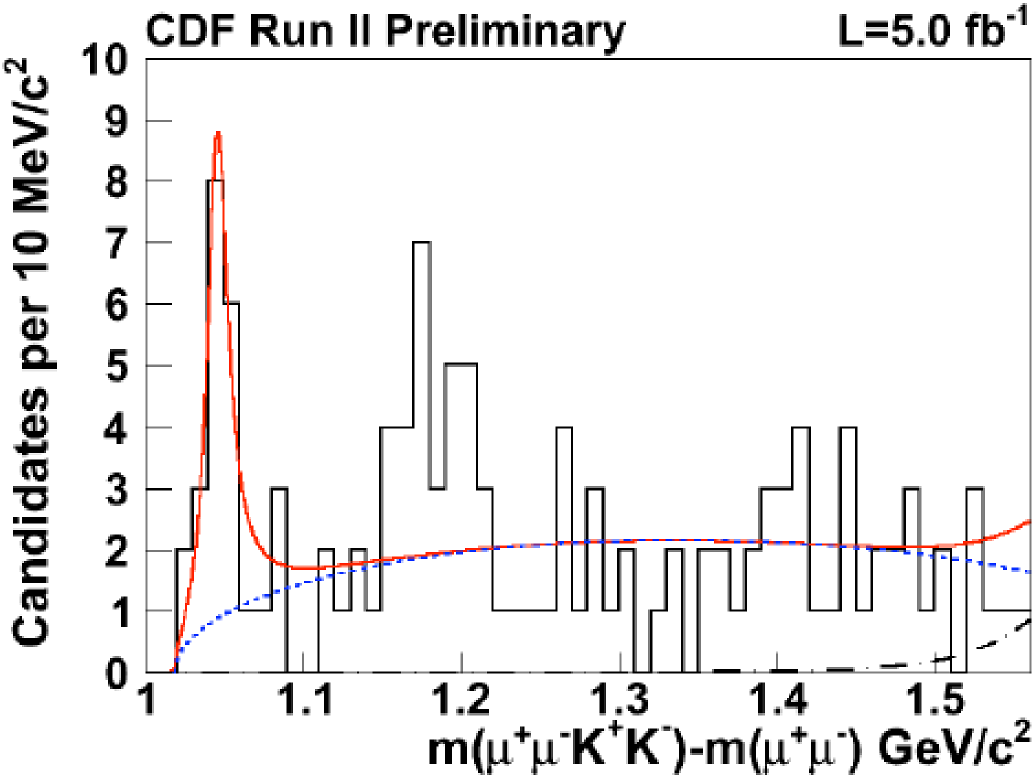


Angle shows forward/backward asymmetry for K*
(because of P-wave ?)

Y(4140)

A state with strange quarks?

$B^+ \to K^+ Y(4140) (\to J/\psi\phi)$



Signal PDF: S-wave BW convoluted with resolution (1.7 MeV)

Background PDF: 3-body phase space (blue dot)

Fixed component for Bs component (black dot dash)

Δm, Γ consistent with previous result, yield is increased

Result w/ 5.0 fb^{-1}:

Yield = 19±6
Δm = $1046.7^{+2.9}_{-3.0}$ MeV/c^2
Γ = $15.3^{+10.4}_{-6.1}$ (stat) MeV/c^2
$\sqrt{(-2\log(L_{max})/L_0)}$ = 5.91

Result w/ 2.7 fb^{-1}:

Yield = 14±5
Δm = 1046.3± 2.9 (stat) MeV/c^2
Γ = $11.7^{+8.3}_{-5.0}$ (stat) MeV
8

Kai Yi et al., ICHEP 2010

Analysis with 2.7/fb in Phys. Rev. Lett. 102(2009)242002

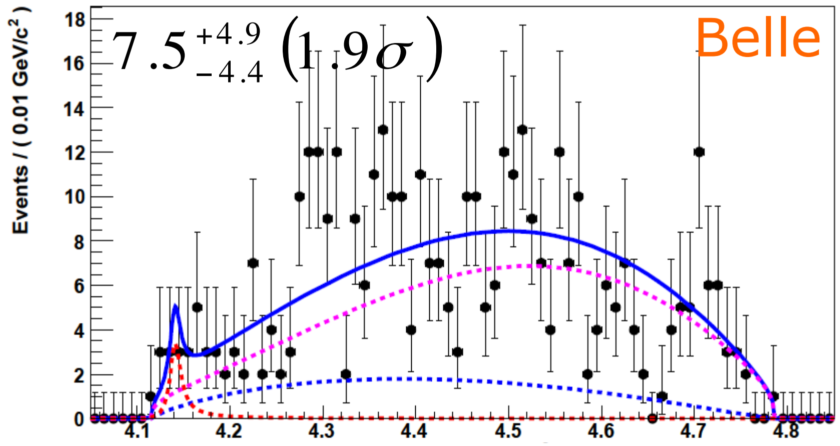
$B^+ \to K^+ Y(4140)(\to J/\psi\phi)$

- D_s^{0*} D_s molecule?
  - Beware: there is no neutral $D_s^{(*)}$ meson.
  - $m(D_s^+)+m(D_s^+)$= 3937 MeV $\to$ too low.
  - $m(D_s^{+*})+m(D_s^+)$= 4286 MeV $\to$ too high
- J/ψ ϕ molecule?
  - both neutral and heavy
  - $m(J/\psi)+m(\phi)$= 4116 MeV
  - close, but positive „binding energy" (would be a virtual state)

$Br(B^+ \to Y(4140)K^+)$ x $Br(Y \to J/\psi\phi)$

CDF $(9.0 \pm 3.4 \pm 2.9)\times 10^{-6}$

Belle $<6 \times 10^{-6}$ at 90% CL

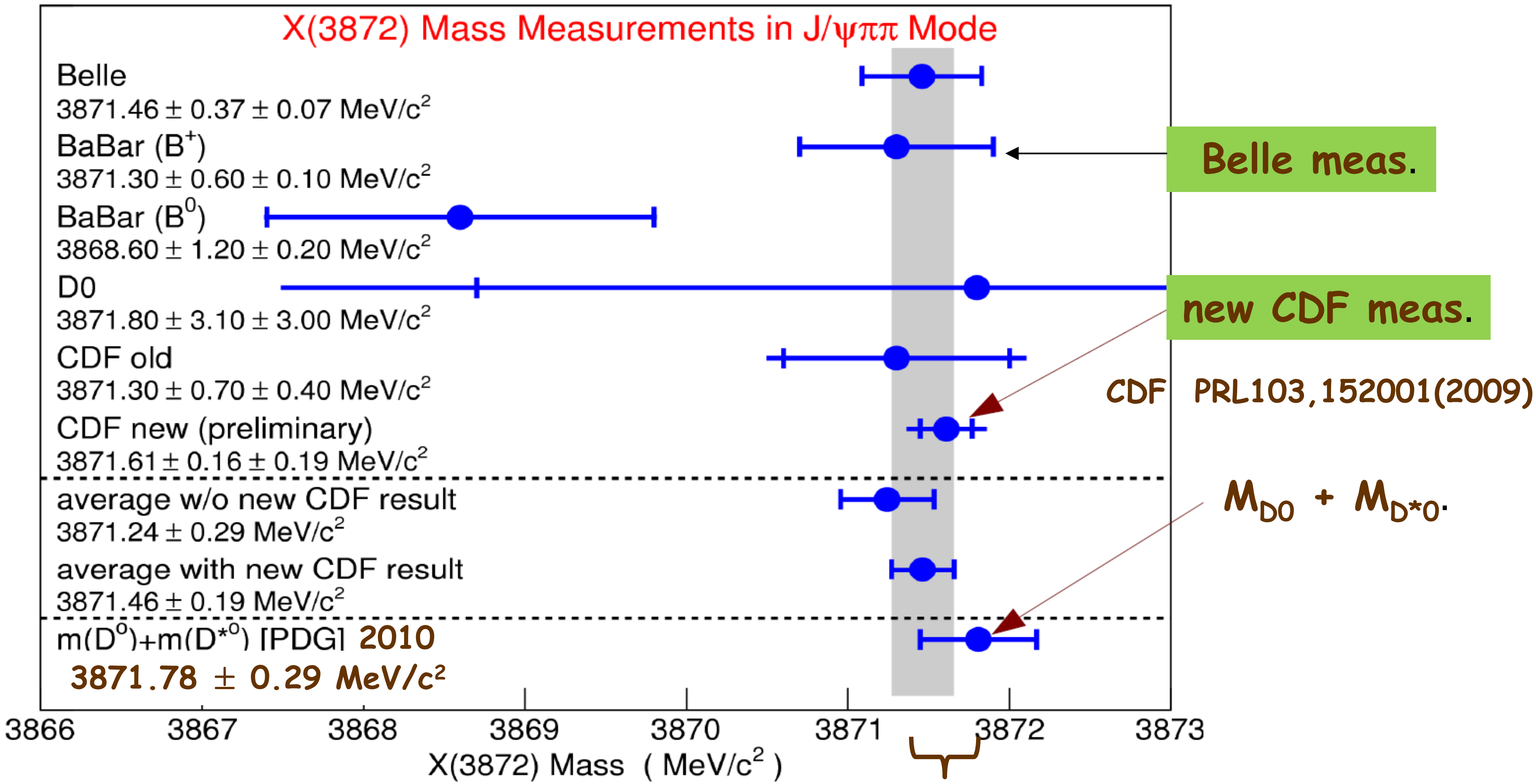


M(J/ψφ) / GeV

Belle, Lepton-Photon-09
771/fb

X(3872) mass in $\pi^+\pi^- J/\psi$ channel only

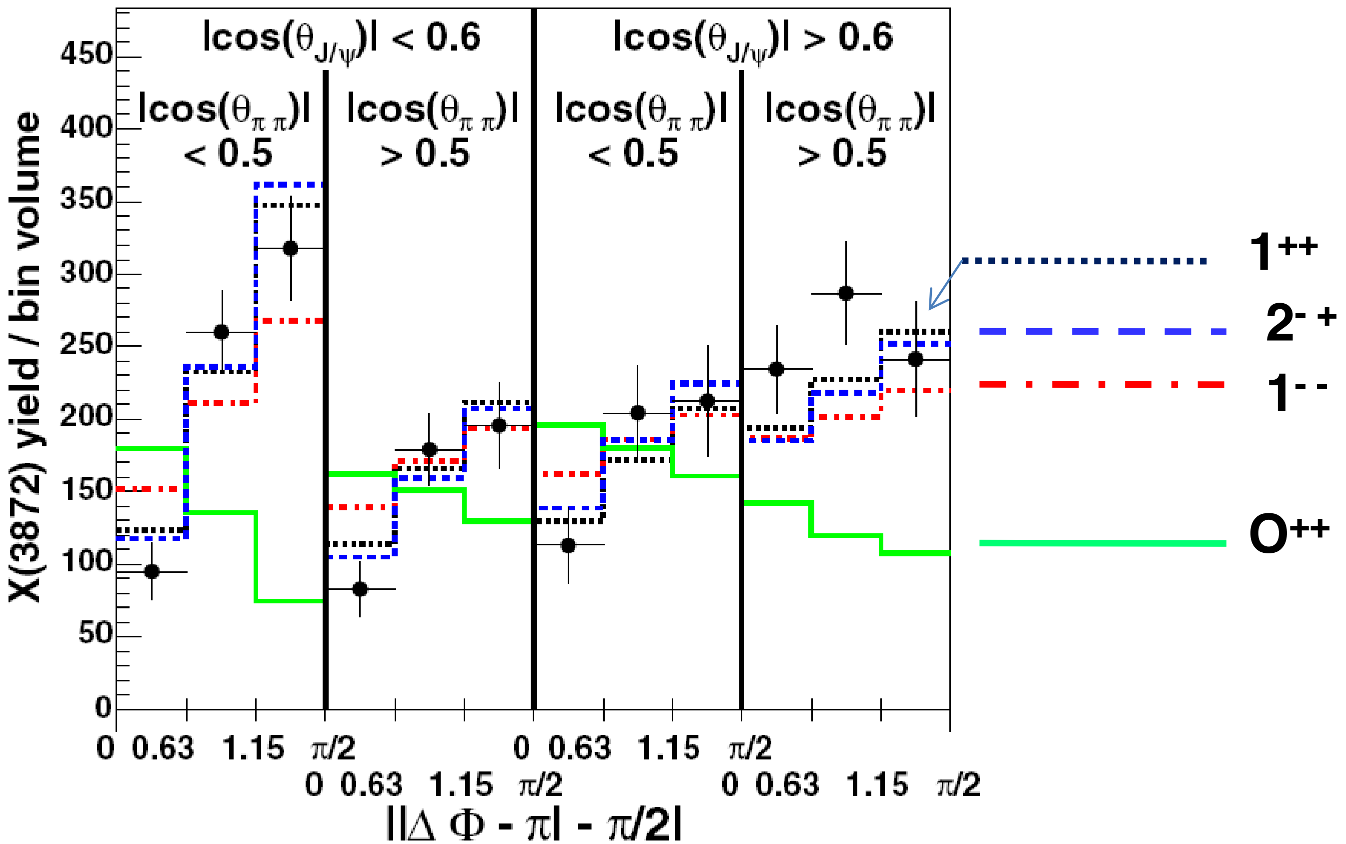
$\langle M_X \rangle = 3871.46 \pm 0.19$ MeV



$\Delta m = -0.32 \pm 0.35$ MeV

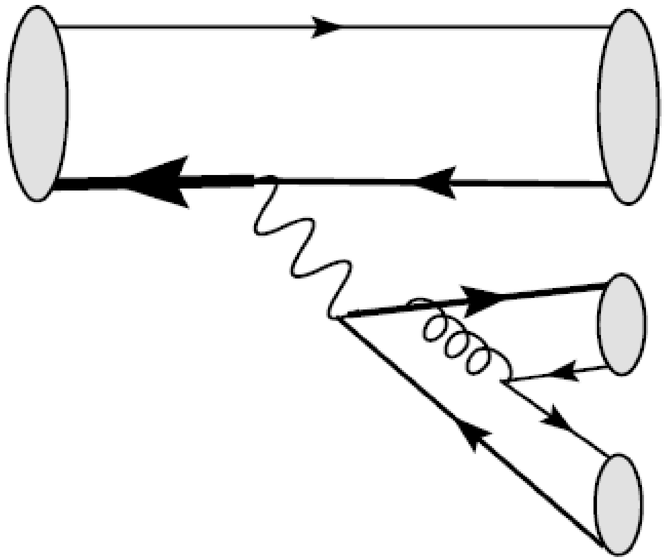
All J^{PC} values other than 1^{++} or 2^{-+} are ruled out with high confidence

CDF: PRL 98 132002



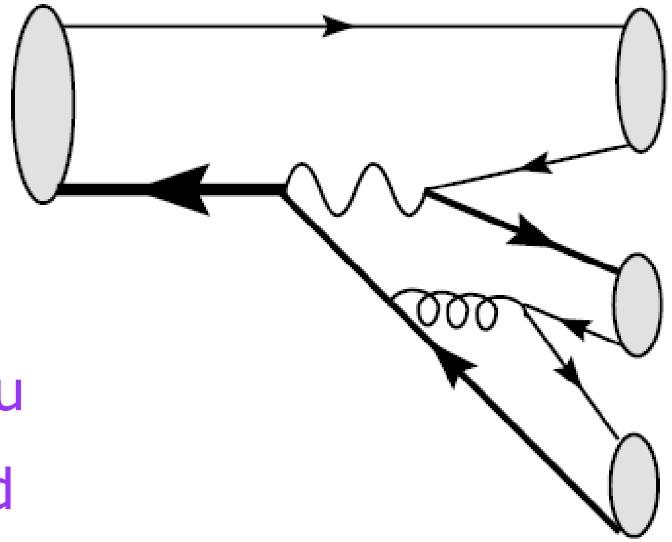
B^+ and B^0 decays are quite different.

Swanson, Phys. Rept. 429(2006)243



$B^+ = B_u$

$B^0 = B_d$



$B^0 \rightarrow K^+$
$B^0 \rightarrow K^0$
$B^+ \rightarrow K^+$
$B^+ \rightarrow K^0$
any combination possible

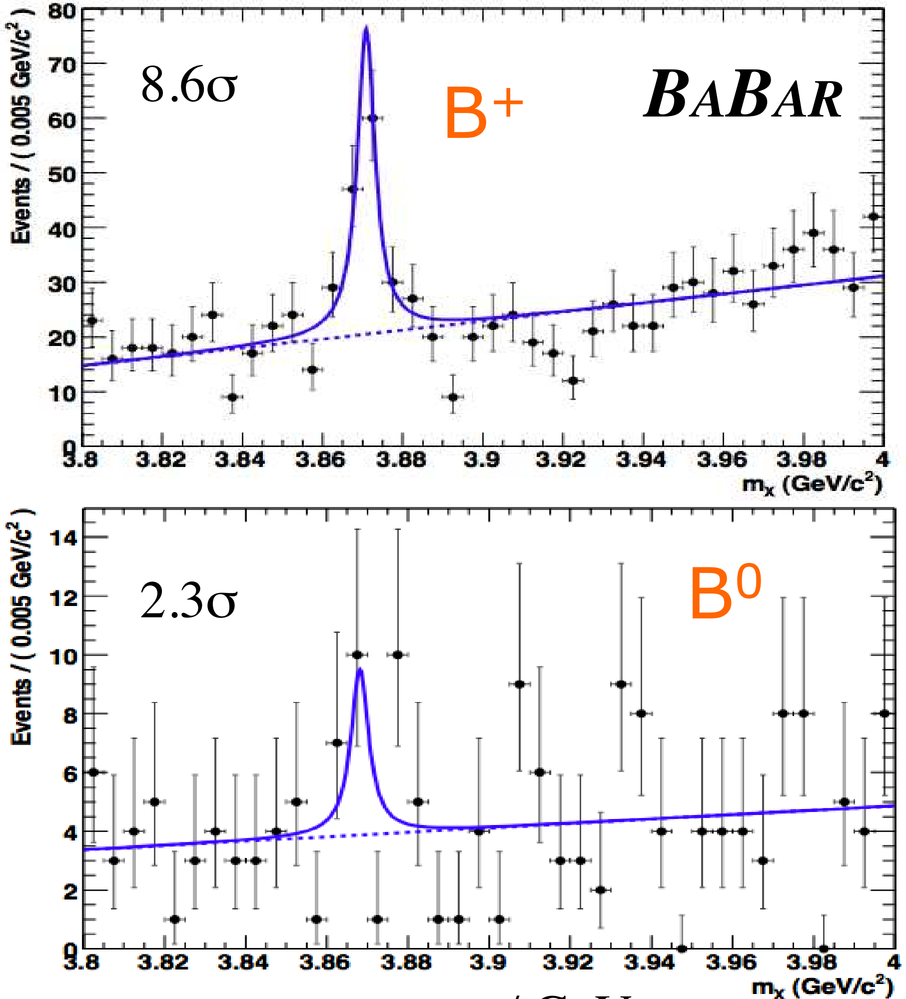
color enhanced

$B^+ \rightarrow K^+$
$B^0 \rightarrow K^0$
(charge sign changes by $W^\pm$,
and changes back,
$\rightarrow$ same charge for B and K)

color suppressed
(color is locked by spectator quark)

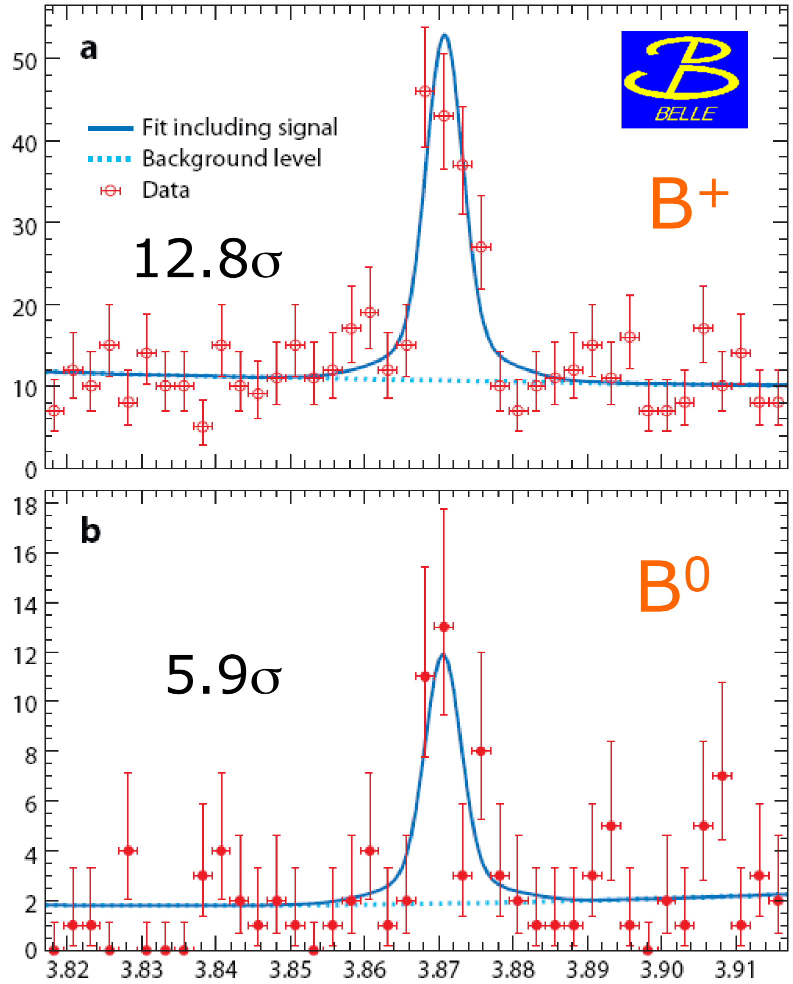
X(3872)→J/ψπ⁺π⁻ in B⁺ and B⁰

Phys. Rev. D 77(2008)111101, 413/fb



$m_{J/\psi\pi+\pi-}$ / GeV

arXiv:0809.1224, 605/fb

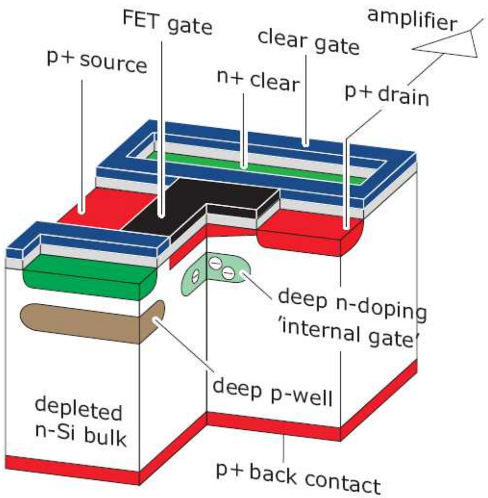


$m_{J/\psi\pi+\pi-}$ / GeV

Ratio B^0/B^* = 0.82±0.22±0.05 (Belle)   0.41±0.24±0.05 (BaBar)

Predictions for molecule
e.g. Braaten, Lu,
Phys. Rev. D 77(2008)014029

A cross section through the device is shown in Fig. 4.3. A p-channel MOSFET or JFET (junction field effect transistor) is integrated onto a silicon detector substrate, which becomes fully depleted by a sufficiently high negative voltage to a p^+ contact on the back side. A potential minimum is formed by sideward depletion [4], which is shifted directly underneath the transistor channel at a depth of about $1\,\mu$m by an additional phosphorus implantation underneath the external gate. Incident particles generate electron-hole pairs within the fully depleted bulk. While the holes drift to the back contact, electrons are accumulated in the potential minimum, called the "Internal Gate". When the transistor is switched on, the electrons modulate the channel current. The readout is non-destructive and can be repeated many times.

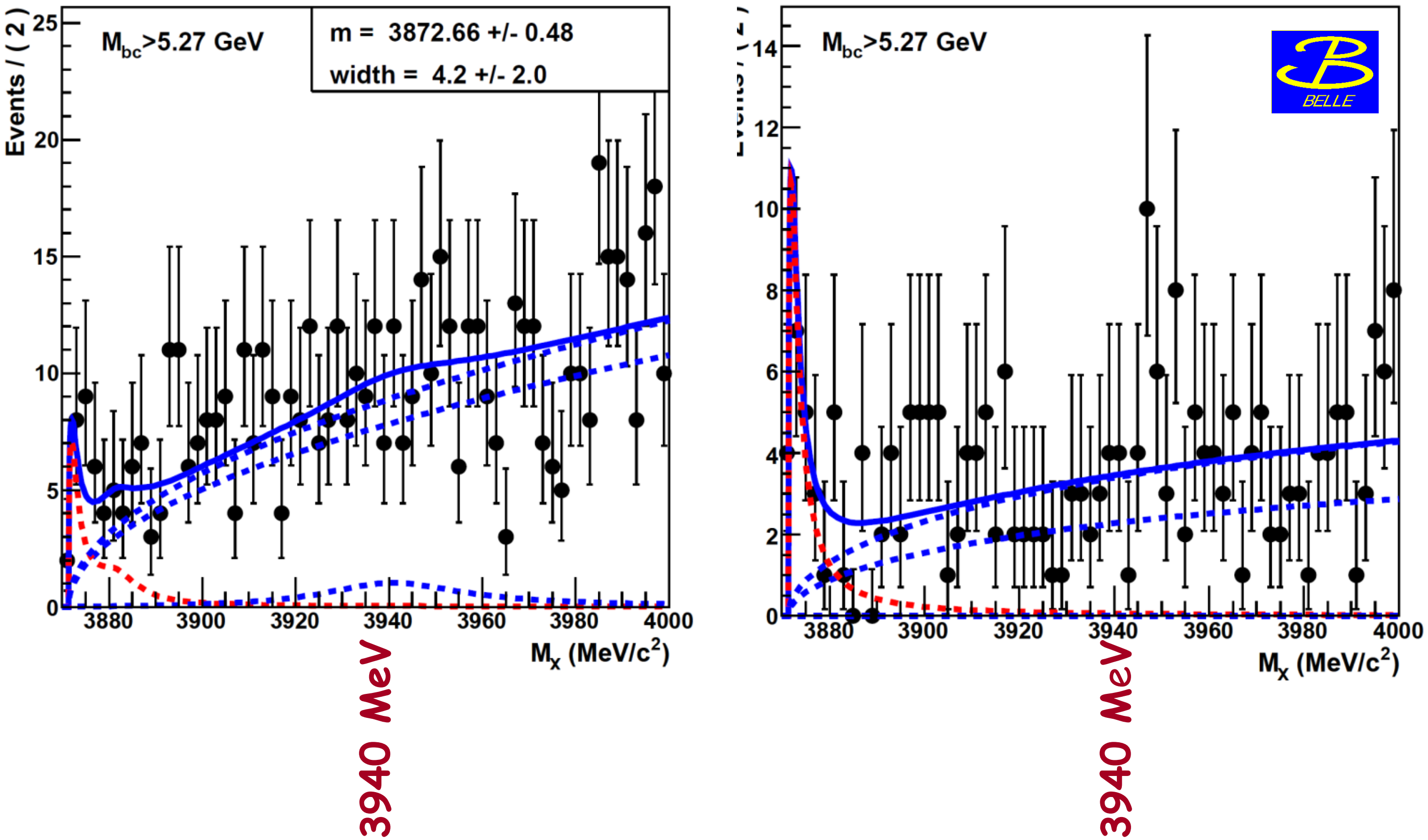


The removal of the signal charge and thermally generated electrons from the internal gate is called "Clear". A neighboring n^+ contact is pulsed at a positive voltage providing a punch-through into the internal gate. Any reset noise is avoided if the entire charge is removed. An advantage of the DEPFET device is the amplification of the signal charge just above the position of its generation, thus avoiding any lateral charge transfer where losses could occur. The most important feature of the DEPFET is the very small capacitance of the internal gate, resulting in a very low noise performance even at room temperature.

Y(3940) → DD* ?

B→KDD*

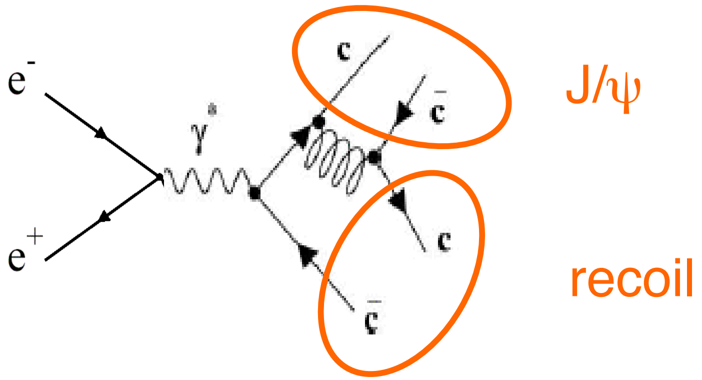
ArXiv:0810.0358



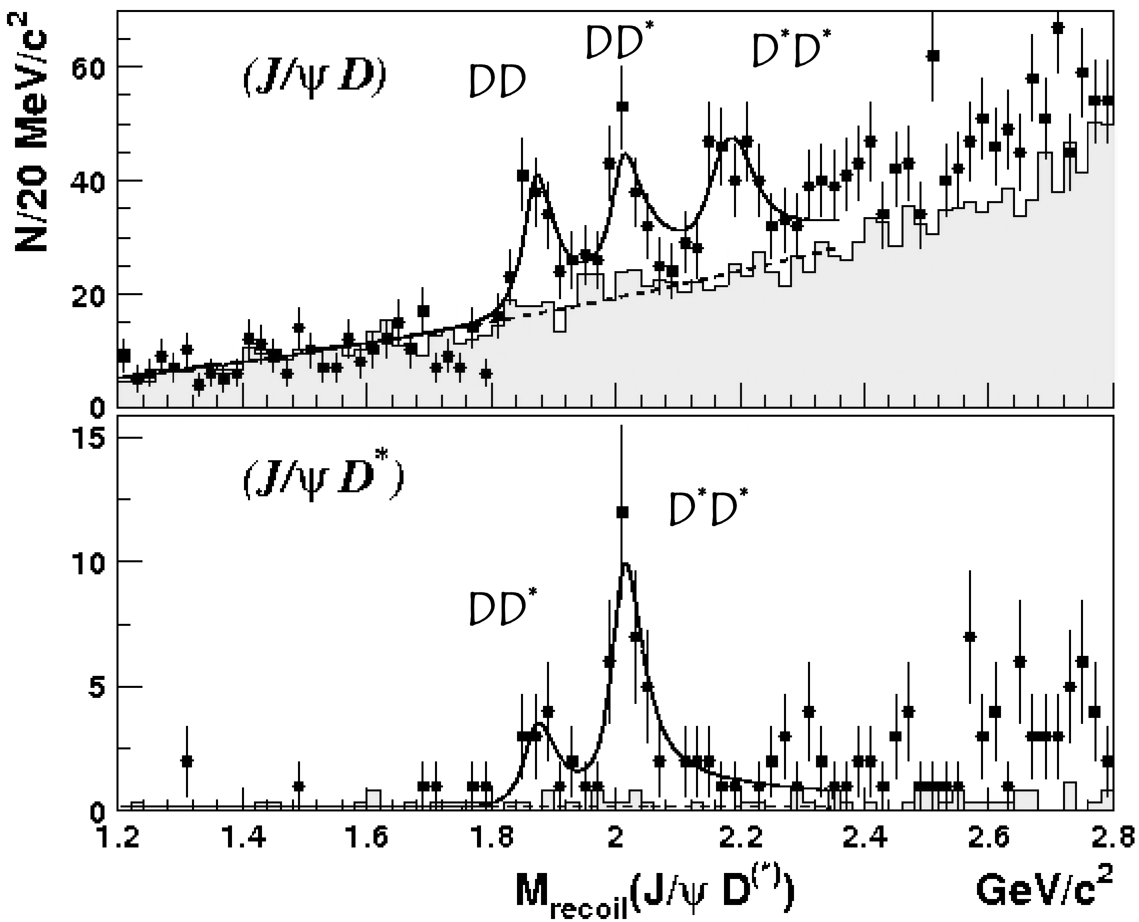
$$\frac{\mathcal{B}(Y(3940) \to \omega J/\psi)}{\mathcal{B}(Y(3940) \to D^{*0}\bar{D}^0)} > 0.75$$

C=+ States

Double charmonium production
Recoil mass
(direct production in continuum)



Belle, 693/fb, arXiv:0708.3812

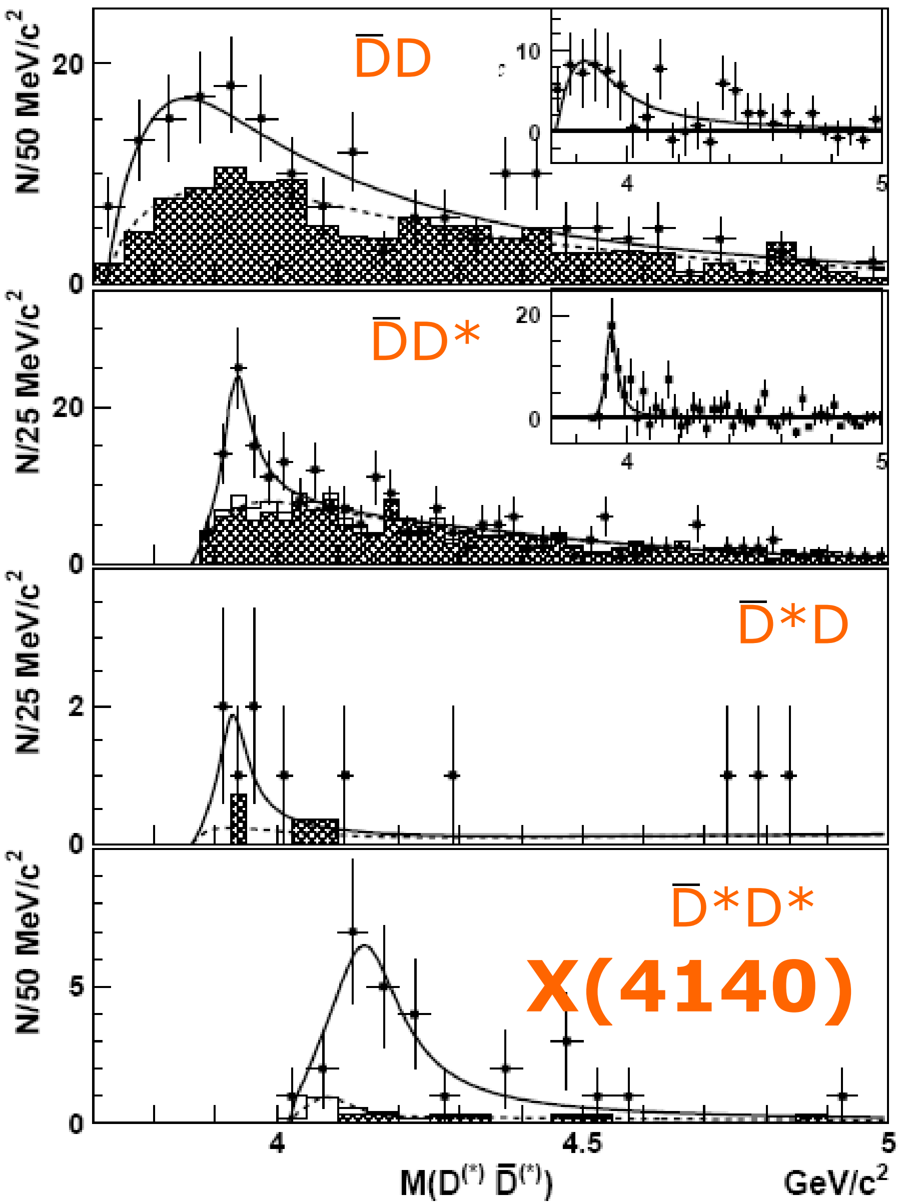


recoil = $D^{(*)}D^{(*)}$

C=+ preferred

High branching fraction
for this process unexplained
(probably non-pertubative QCD)

Any of the $D^{(*)}D^{(*)}$ seems to indicate S-wave enhancement



Too high
for molecular
Hypothesis.

Constituents	J^{PC}	Mass [MeV]
$D\bar{D}^*$	0^{-+}	≈ 3870
$D\bar{D}^*$	1^{++}	≈ 3870
$D^*\bar{D}^*$	0^{++}	≈ 4015
$D^*\bar{D}^*$	0^{-+}	≈ 4015
$D^*\bar{D}^*$	1^{+-}	≈ 4015
$D^*\bar{D}^*$	2^{++}	≈ 4015

Predictions of molecular states
one-pion exchange model
Törnqvist
Phys. Lett. B590(2004)209
Phys. Rev. Lett. 67(1991)556

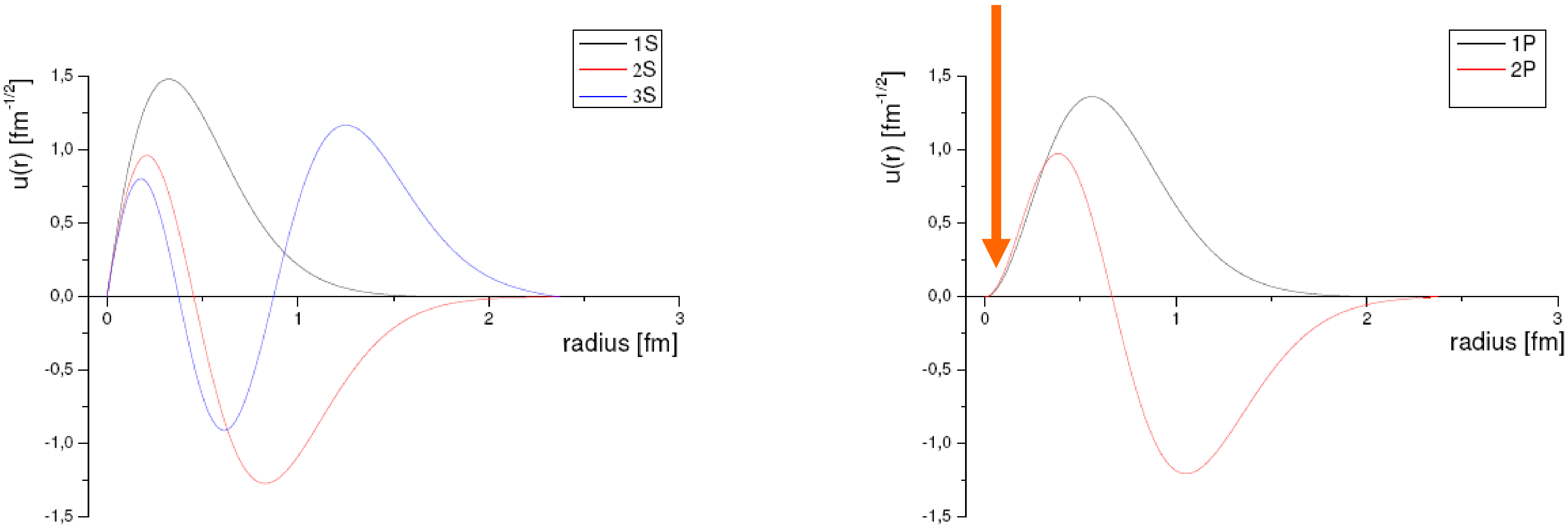
C=+ states

- Cannot annihilate to γ ($e^+ e^-$)
- only decay to $\gamma\gamma$ or gluon gluon

$$\Gamma(^3S_1 \to \gamma) = \frac{65\pi}{9} \frac{\alpha_{em}}{m_c^2} |\psi(r=0)|^2$$

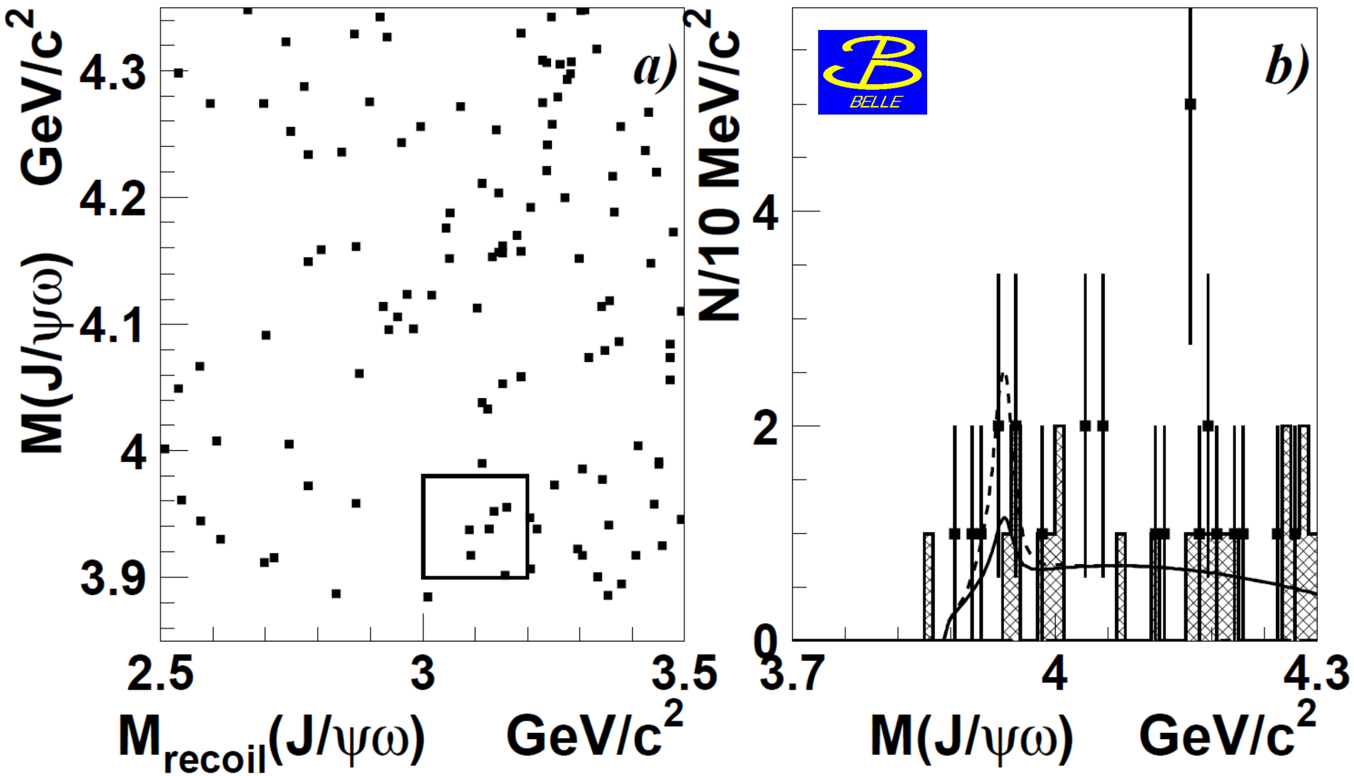
$$\Gamma(^3P_0 \to \gamma\gamma) = \frac{256}{3} \frac{\alpha_{em}^2}{m_c^4} |\frac{\partial\psi}{\partial r}(r=0)|^2$$

sensitive to derivative of wavefunction



$[\omega J/\psi]$ in double charmonium production?

$e^+e^- \to J/\psi + (\omega\ J/\psi)$



Phys. Rev. Lett. 98(2007)082001

$$\frac{\mathcal{B}(X(3940) \to \omega\, J/\psi)}{\mathcal{B}(X(3940) \to D^{*0}\bar{D}^0)} < 0.6$$