SuperB Physics Workshop

Spectroscopy: SuperB potentialities in view of recent B-Factory experience

an “interested ousider” view...

- which puzzles could be addressed with O(50 ab^{-1})

! highly subjective!

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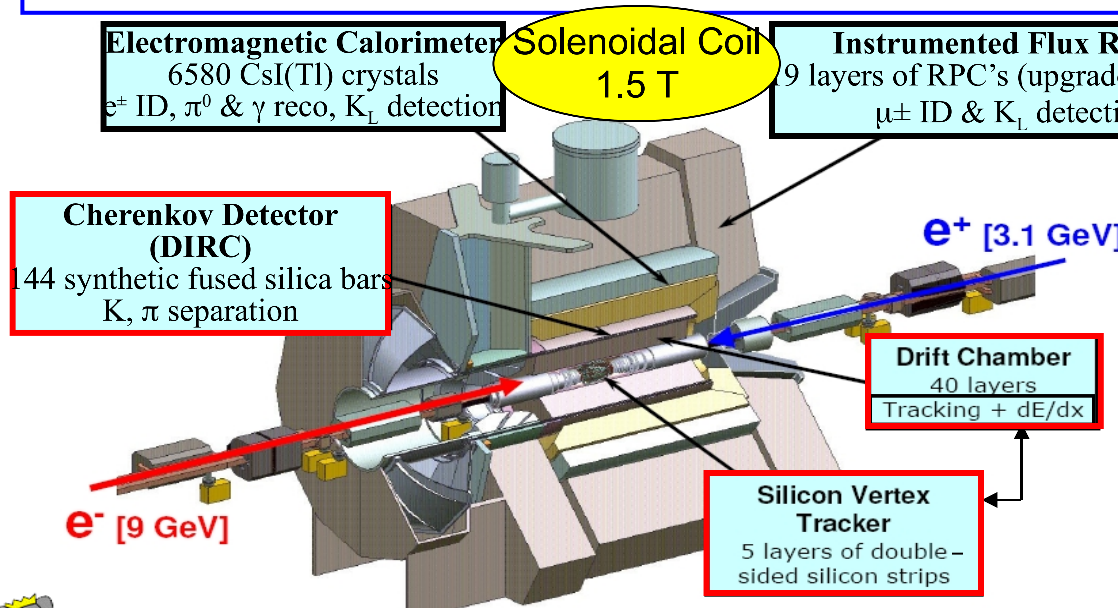
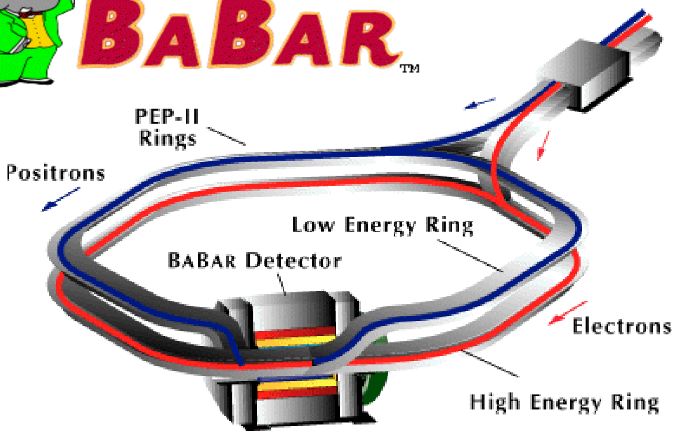
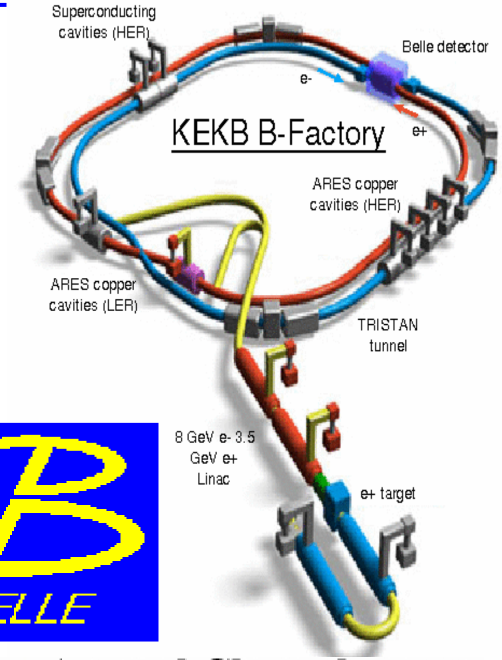
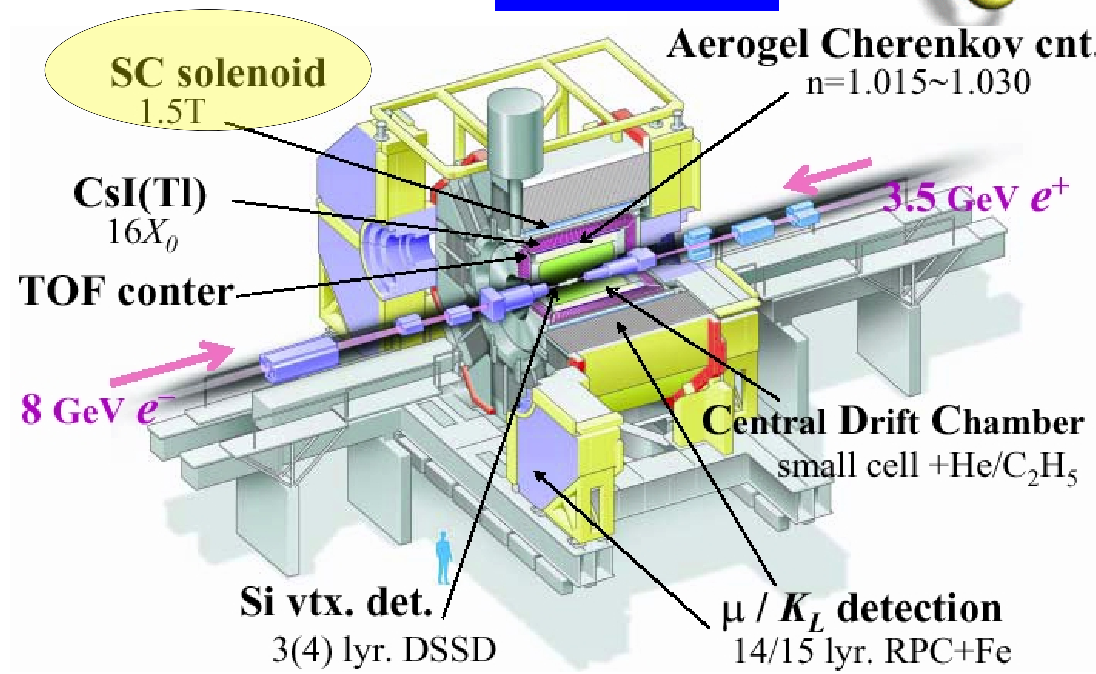
BaBar and Belle



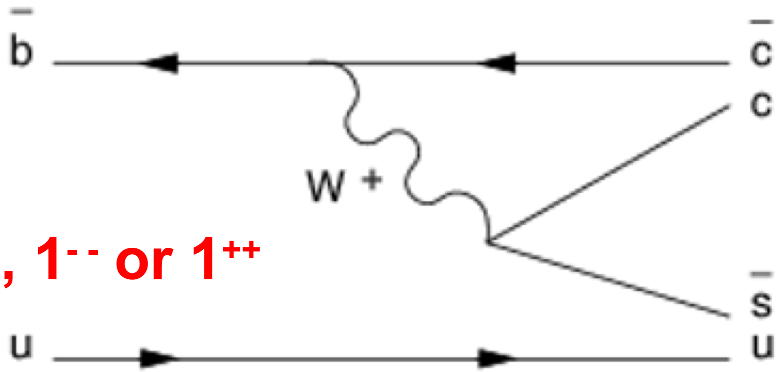






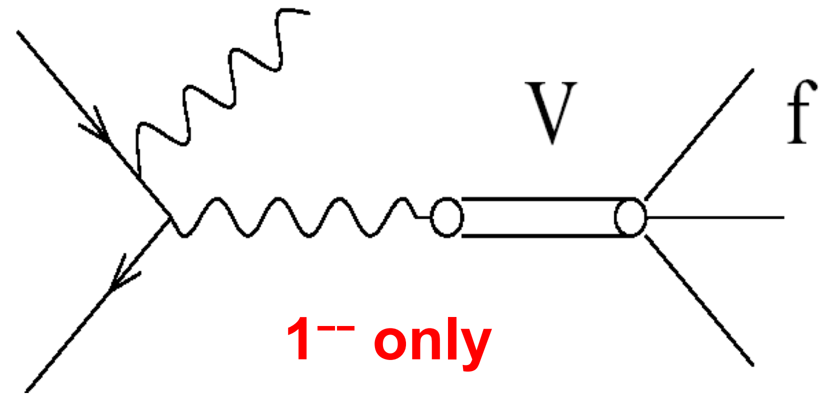
Charmonium at B-factories

B→$c\bar{c}$ $K^{(*)}$



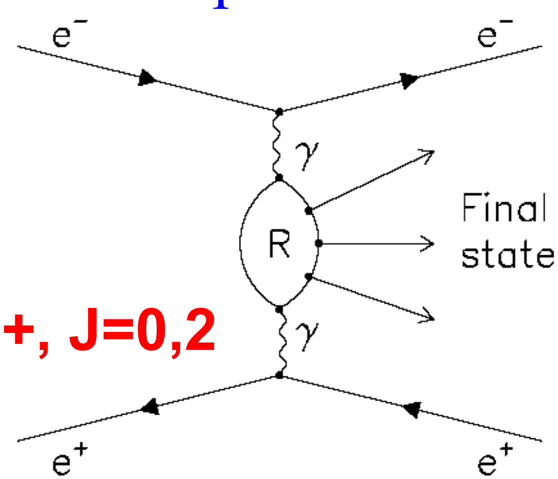
0^{-+}, 1^{--} or 1^{++}

ISR production



1^{--} only

two-photon fusion

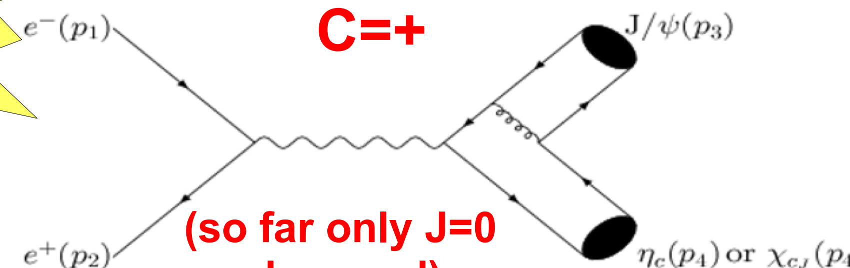


C=+, J=0,2

first observed at B-factories

double $c\bar{c}$

C=+



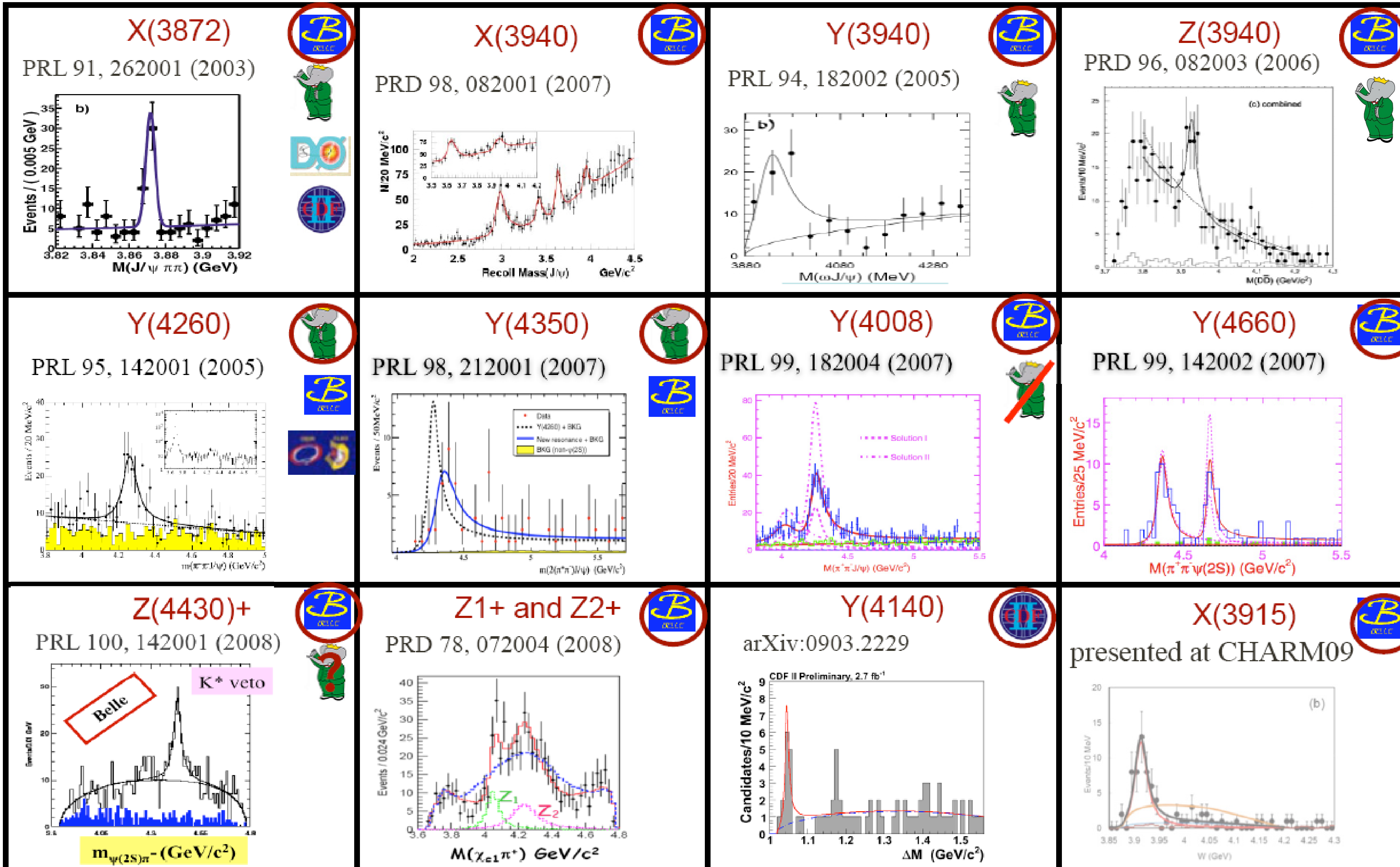
(so far only J=0 observed)

Experimentally clean environment
+
large cross section

New states since 2002

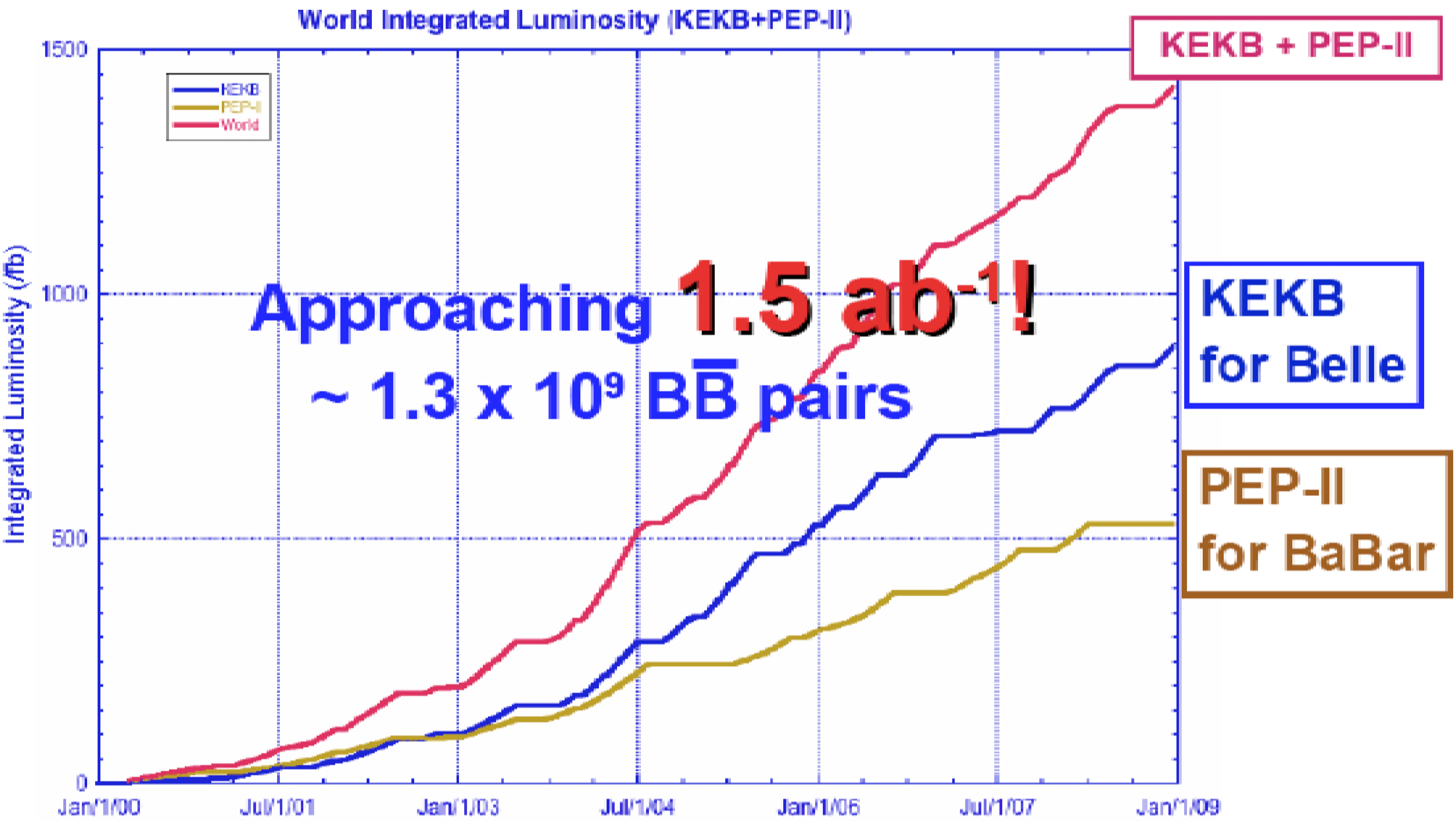
year	State	Mass MeV	Width MeV	J^{PC}	Process	Experiment	established?
2002	$\eta_c(2S)$	3637±4	14±7	0^{-+}	$B \to \eta_c(2S)K$ $\gamma\gamma \to \eta_c(2S) \to K\bar{K}\pi$ double $c\bar{c}$	Belle, BaBar BaBar,CLEO Belle,BaBar	YES
2003	$X(3972)$	3871.9±0.7	$3.0^{+1.9}_{-1.4} \pm 0.9$	$1^{++}/2^{-+}$	$B \to KX(3972)\ X \to \pi^+\pi^- J/\psi$ $p\bar{p}$ inclusive, $X \to \pi^+\pi^- J/\psi$ $B \to KX,\ X \to \pi^+\pi^-\pi^0 J/\psi$ $B \to KX,\ X \to D^*\bar{D}$ $B \to KX,\ X \to \gamma J/\psi$ $B \to KX,\ X \to \gamma\psi(2S)$	Belle, BaBar CDF, D0 Belle (unpublished) Belle, BaBar Belle, BaBar BaBar	YES
2004	$h_c(1P)$	3525.67	< 1	1^{+-}	$\psi(2S) \to \pi^0 h_c,\ h_c \to \gamma\eta_c$ $p\bar{p} \to h_c \to \gamma\eta_c$	CLEO FNAL E835	YES
2004	X(3940)	$3945^{+7}_{-6} \pm 6$	$37^{+26}_{-15} \pm 8$	$0^{?+}$	$e^+e^- \to J/\psi X,\ X \to D\bar{D}^*$	Belle	not yet
2004	Y(3940)	3916 ± 6	40^{+18}_{-13}	$?^{?+}$	$B \to KY\ Y \to J/\psi\omega$	Belle, Babar	YES
2005	$\chi_{c2}(2P)$	$3929 \pm 5 \pm 2$	$29 \pm 10 \pm 2$	2^{++}	$\gamma\gamma \to D\bar{D}$	Belle	not yet
2006	$Y(4260)$	4263 ± 9	94 ± 14	1^{--}	$e^+e^- \to \gamma_{ISR}\pi^+\pi^- J/\psi$ $e^+e^- \to Y(4260),\ Y \to J/\psi X$	Babar, CLEO,Belle CLEO	YES
2007	$Y(4350)$	$4361 \pm 9 \pm 9$	$74 \pm 15 \pm 10$	1^{--}	$e^+e^- \to \gamma_{ISR}\pi^+\pi^-\psi(2S)$	Babar, Belle	YES
2007	$Y(4660)$	4263 ± 9	94 ± 14	1^{--}	$e^+e^- \to \gamma_{ISR}\pi^+\pi^-\psi(2S)$	Belle	not yet
2007	$Y(4008)$	$4008 \pm 40^{+114}_{-28}$	$226 \pm 44 \pm 87$	1^{--}	$e^+e^- \to \gamma_{ISR}\pi^+\pi^- J/\psi$	Belle	no evidence in Babar
2007	$Z^+(4430)$	$4433 \pm 4 \pm 2$	45^{+18+30}_{-13-13}	?	$B \to KZ^+,\ Z^+ \to \psi(2S)\pi^+$	Belle	??
2008	$Z_1^+(4050)$	$4041 \pm 14 \pm 20$	45^{+18+30}_{-13-13}	?	$B \to KZ_1^+,\ Z^+ \to \chi_{c1}(1P)\pi^+$	Belle	not yet
2008	$Z_2^+(4250)$	$4248^{+44+180}_{-29-35}$	$177^{+54+316}_{-39-61}$	?	$B \to KZ_2^+,\ Z^+ \to \chi_{c1}(1P)\pi^+$	Belle	not yet
2008	$\eta_b(1S)$	9390.4 ± 3.1	-	0^{-+}	$\Upsilon(3,2S) \to \gamma X$	Babar	seen in $\Upsilon(3S)$ and $\Upsilon(2S)$
2009	Y(4140)	$4143.0 \pm 2.9 \pm 1.2$	$11.7^{+8.3}_{-5.0} \pm 3.7$	C=+	$B \to J/\psi\phi K$	CDF	not yet

... the XYZ(s): what are they?



New

B factories integrated luminosity



Super Flavour Factories

Two projects for high-luminosity asymmetric Super-B-factories

$\int \mathcal{L}\, dt \approx O(50\ ab^{-1})$

$O(5\text{x}10^{10})\ B\bar{B}$ pairs

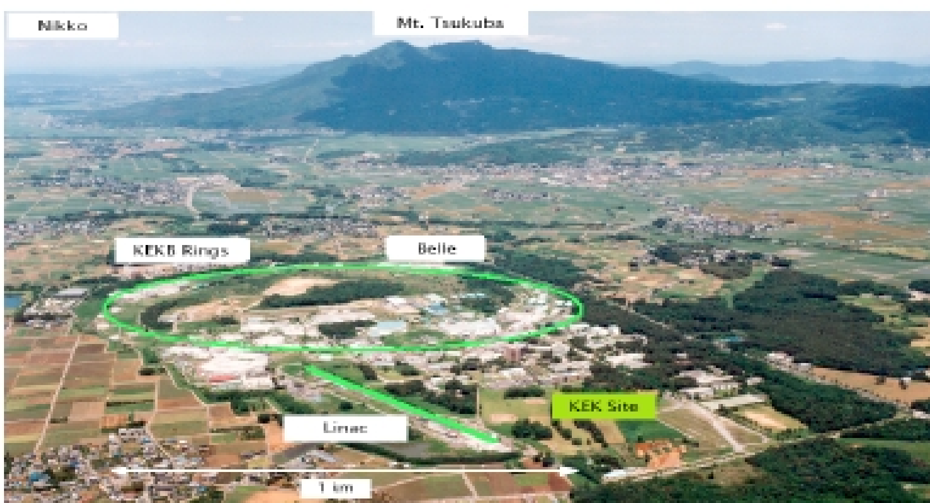
Super KEKB
Quest for BSM

SuperB

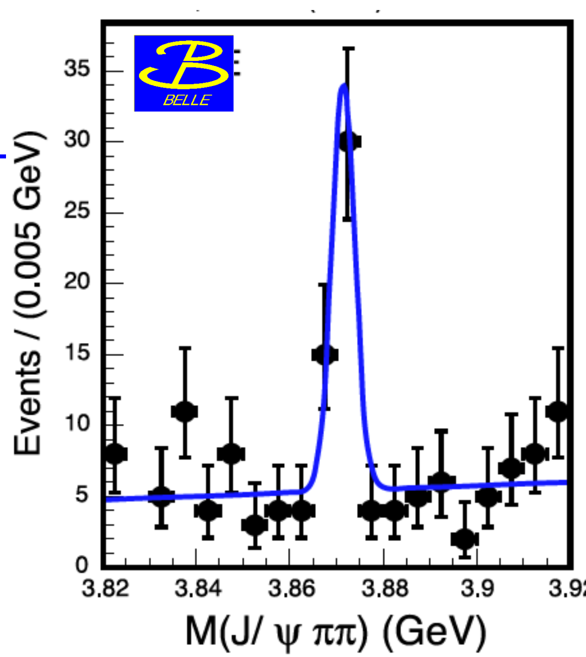
- **KEK/Japan**
- **more convential design**
  - high beam current
  - high RF
- **Crab crossing concept**
- $\mathcal{L} = 8\text{x}10^{35}\ cm^{-2}s^{-1}$

- **Rome/Italy**
- **Challenging design (ILC-like)**
  - Crab waist
  - vertical beam size nanometer range
- **Use of PEP-II magnets**
- $\mathcal{L} > 1\text{x}10^{36}\ cm^{-2}s^{-1}$

From A. Denig's talk at Charm '09



X(3872)



$\mathrm{M} = 3871.9 \pm 0.7\,\mathrm{MeV/c^2}$

$\Gamma = 3.0^{+1.9}_{-1.4} \pm 0.9$ MeV

- Observed by Belle as a narrow peak in $J/\psi\, \pi^+\pi^-$ invariant mass
  $B \to K\ J/\psi\, \pi^+\pi^-$ decays if $c\bar{c}$ suggest J=0,1

  PRL 91 (2003) 262001

  soon confirmed by CDF/D0 in inclusive $p\bar{p}$
  and by Babar in B decays

$\mathcal{B}(B^+ \to K^+X) \cdot \mathcal{B}(X \to J/\psi\pi^+\pi^-) = (9.5 \pm 1.9) \cdot 10^{-6}$

$\mathcal{B}(B^+ \to K^+X) < 3.2 \cdot 10^{-4}$ at 90%CL $\longrightarrow$ $\mathcal{B}(X \to J/\psi\pi^+\pi^-) > 3\%$

PRL 96 (2006) 052002

- $\pi\pi$ mass clusters at high end of PhSp: ρ^0?
  $J/\psi\pi^0\pi^0$ almost impossible at Tevatron or B-factories
  very easily reconstructed at Panda, as any exclusive final state with J/ψ

- if confirmed, decay to $J/\psi\, \pi^+\pi^-\pi^0$ (possibly sub-threshold ω)
  I=1 vs I=0

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

hep-ex/0505037

- Mass close to $D^0\bar{D}^{*0}$ threshold: $m(D^0\overline{D^{*0}}) = 3871.81 \pm 0.36\ \mathrm{MeV}/c^2$

- Angular distribution studied by Belle (1^{++}) and CDF (1^{++} or 2^{-+})

hep-ex/0508038

PRL 98 (2007) 132002

Radiative decays of the X(3872)

- radiative decay to $\gamma J/\psi$ (Belle/Babar) and $\gamma\psi(2S)$ (Babar)

C=+

$$\frac{\mathcal{B}(X\to\gamma J\psi)}{\mathcal{B}(X\to\pi^+\pi^- J/\psi)} = 3.4 \pm 1.2$$

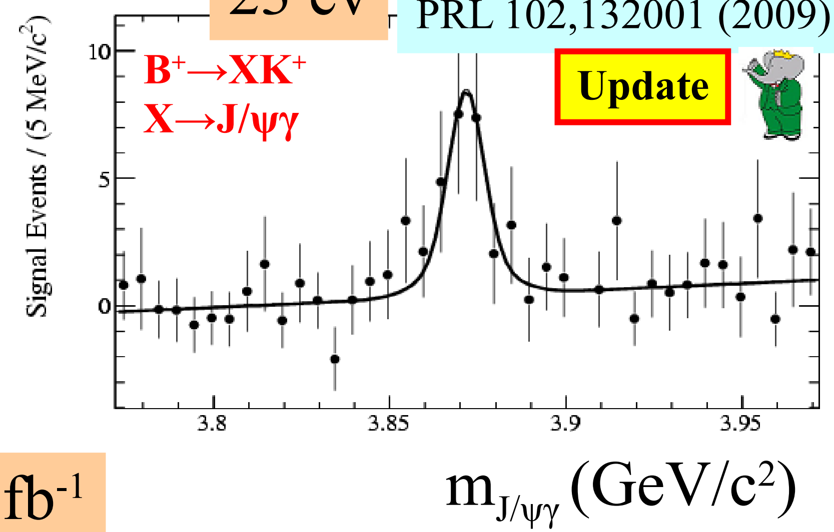
too large for $\chi_{c1}(2P)$?

$$\frac{\mathcal{B}(X\to\gamma\psi(2S))}{\mathcal{B}(X\to\gamma J/\psi)} = 3.4 \pm 1.4$$

too large for $D^0\overline{D}^{0*}$ molecule?

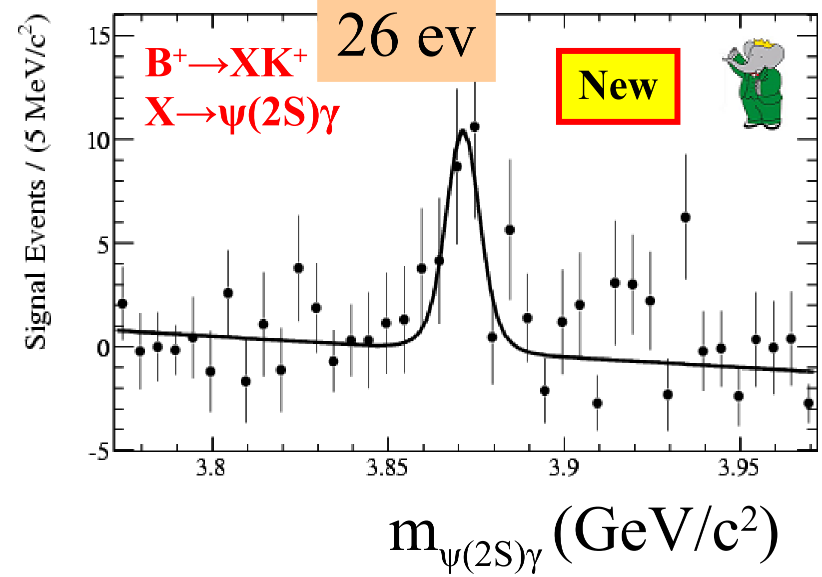
23 ev

PRL 102,132001 (2009)



424 fb^{-1}

26 ev

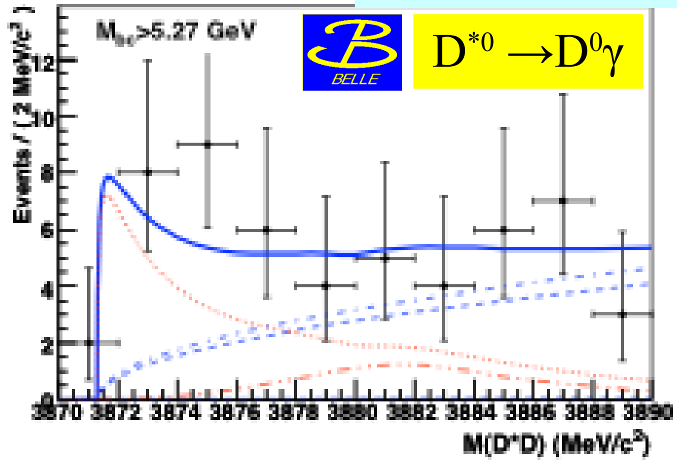


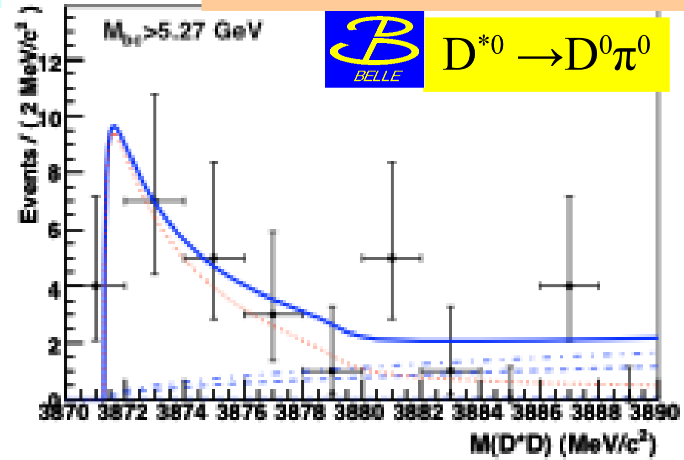
X(3872) →$D\bar{D}^{(*)}$

arXiv:0810.0358

605 fb^{-1} 48±11 ev

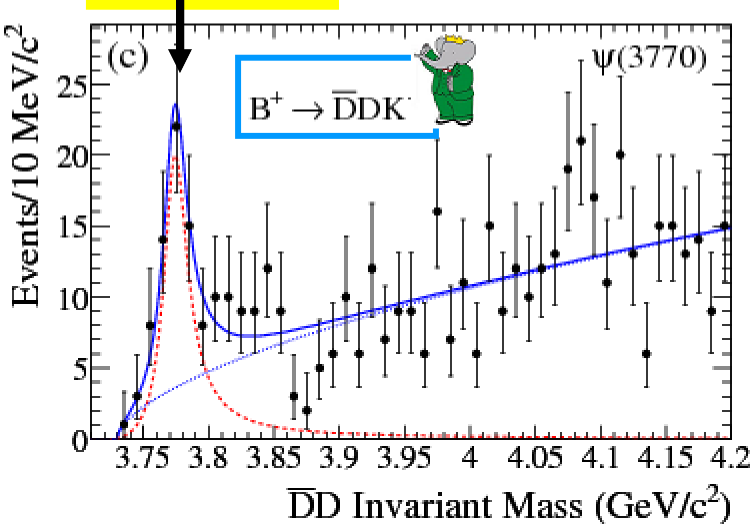
- Belle updated it's first measurement and find mass compatible to J/ψππ

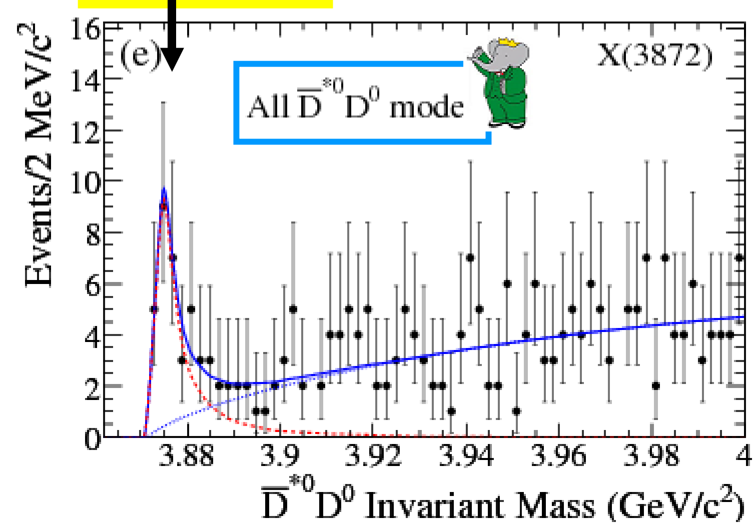




- Babar studies also $D\bar{D}$ (finds no signal) and finds a mass ~3MeV higher

ψ(3770) PRD 77, 011102 (2008) **X(3872)**





- resolution
- background modeling
- lineshape at threshold

lineshape in $p\bar{p}$ formation?

No X→D^0D^0

347 fb^{-1} 33±7 ev

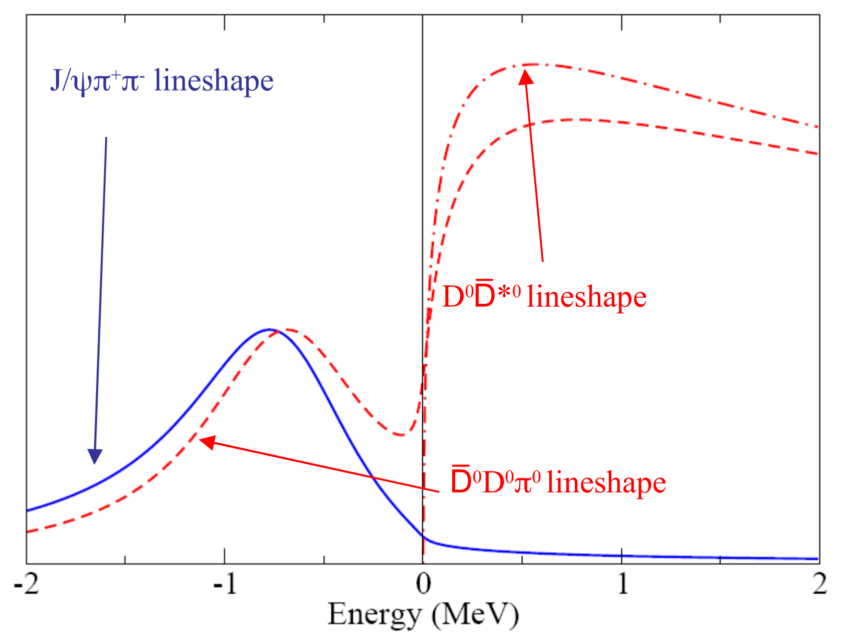
X(3872) lineshape

Year	Collaboration	Channel	Mass measurement
2003-2009	Belle/BaBar/CDF/D0	$J/\psi\ \pi^+\ \pi^-$	$M = (3871.4 \pm 0.6)$ MeV/c²
2006	Belle	$\bar{D}^0 D^0 \pi^0$	$M = (3875.2 \pm 0.7^{+1.2}_{-2.0})$ MeV/c²
2008	BaBar	$D^0 \bar{D}^{*0}$	$M = (3875.1^{+0.7}_{-0.5} \pm 0.5)$ MeV/c²
2008	Belle	$D^0 \bar{D}^{*0}$	$M = (3872.6\ ^{+0.5}_{-0.4} \pm 0.4)$ MeV/c²

- Proximity to $D\bar{D}^*$ threshold affects lineshape differently in different final states if
  - cusp (no resonance)
  - molecule
  - hadrocharmonium
  - di-quark/anti-diquark

- Narrow ⇒ peak position shift for J=2

Need to deconvolute (energy-dependent) resolution



large statistics

arXiv:0907.3167 (2009)
PRL 100, 062006 (2008)

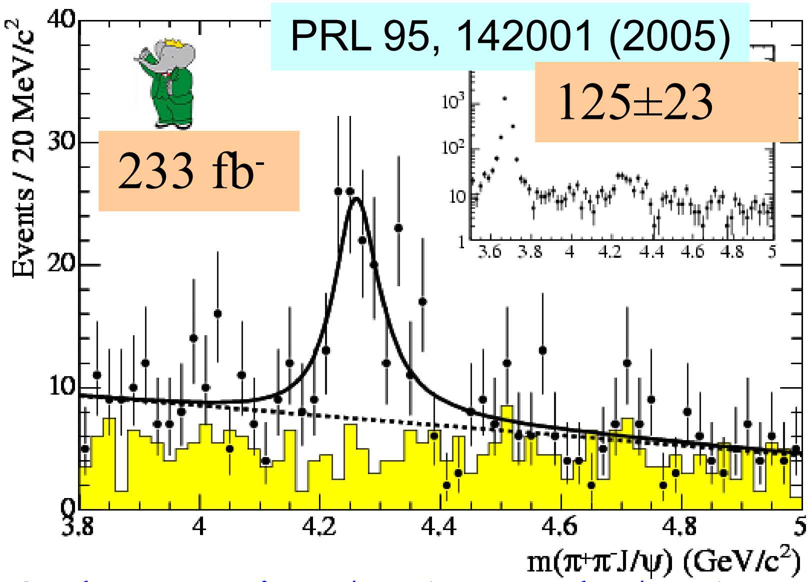
Naive estimate of yields at super B factories

$B^+ \to K^+ X(3872)$ with

$X(3872) \to$	events	$\int$ L (fb^{-1})	yield with 50 ab^{-1}
$\pi^+\pi^- J/\psi$	93 ± 17	413	≈ 11 k
$\gamma J/\psi$	23.0 ± 6.4	424	≈ 2.7 k
$\gamma\psi(2S)$	25.4 ± 7.3	424	≈ 3 k
$D\bar{D}^*$	33 ± 7	347	≈ 4.5 k
	48 ± 11	605	

- detailed line-shape determination
- angular distributions in $\pi\pi$ J/ψ, γ J/ψ and γ $\psi(2S)$

Y(4260): the 1^{--} family with $J/\psi\pi\pi$ decays



- Observed by Babar in ISR production
- soon confirmed by CLEO (ISR and on-peak running)
- confirmed by Belle

$$M = 4263^{+8}_{-9}\ \mathrm{MeV}/c^2$$

$$\Gamma = 95 \pm 14\ \mathrm{MeV}$$

$$\Gamma_{ee}\mathcal{B}(J/\psi\pi^+\pi^-) = 5.9^{+1.2}_{-0.9}\ \mathrm{eV}$$

$c\bar{c}g$ hybrid?

all seem consistent

Only seen in $J/\psi\pi^+\pi^-$ and $J/\psi\pi^+\pi^-$ $\pi^0\pi^0/\pi^+\pi^- \sim 0.5$ (I=0)

PRL 96, 162003 (2006)

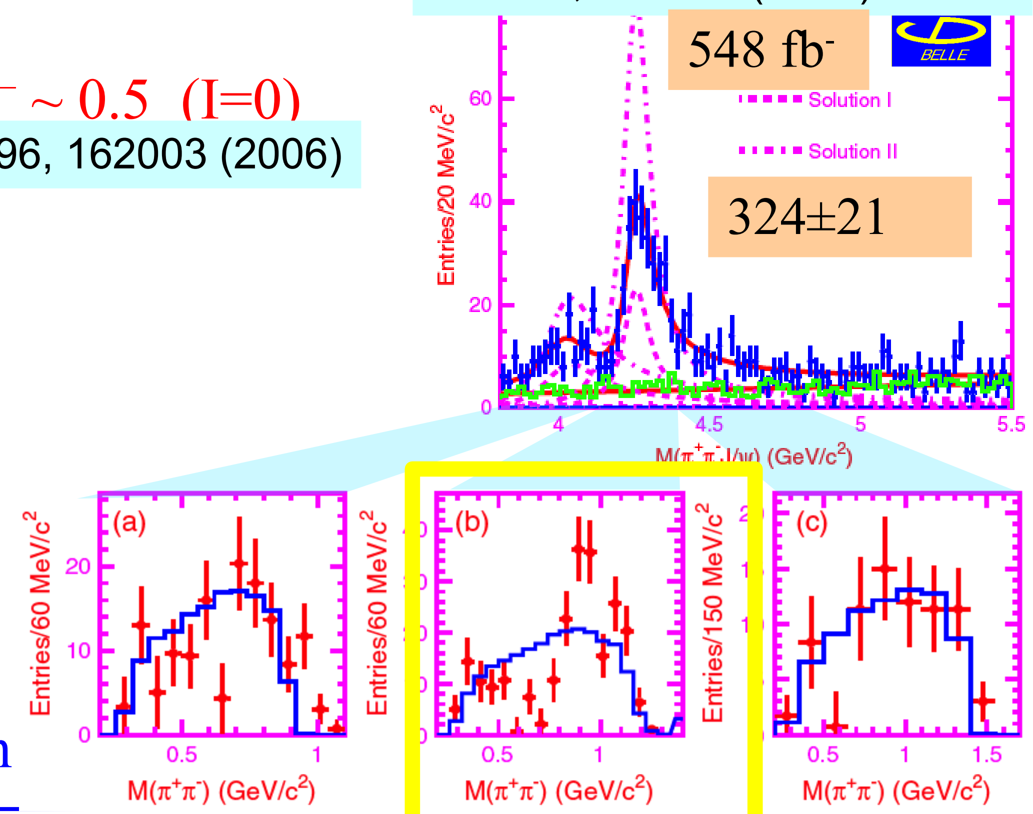
NOT seen in $D\bar{D}$ $D\bar{D}/J\psi\pi^+\pi^- < 1.0$

(nor in many other exclusive final states)

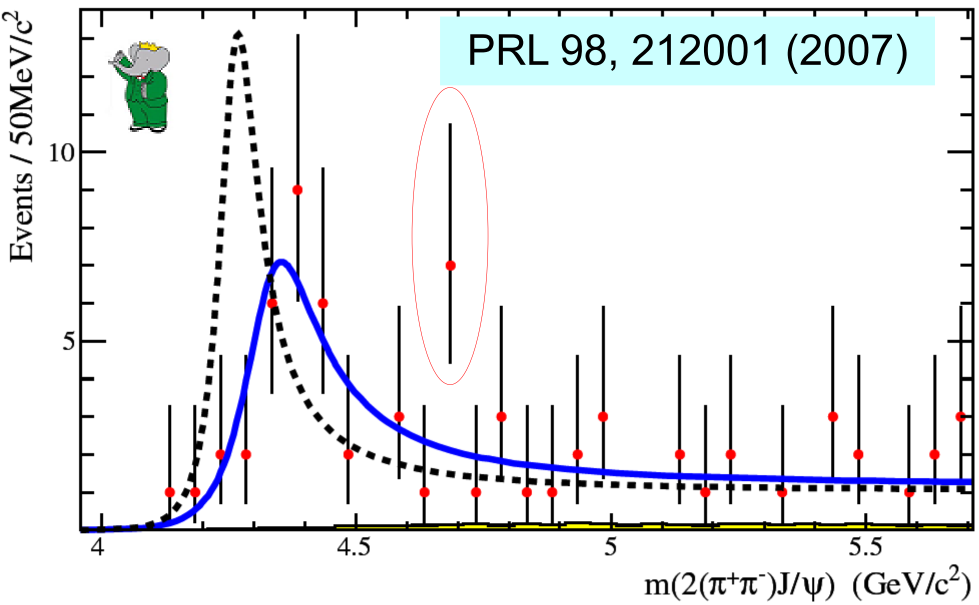
$\sigma(e+e- \to \mathrm{hadron})$ has a dip at ~4260 MeV

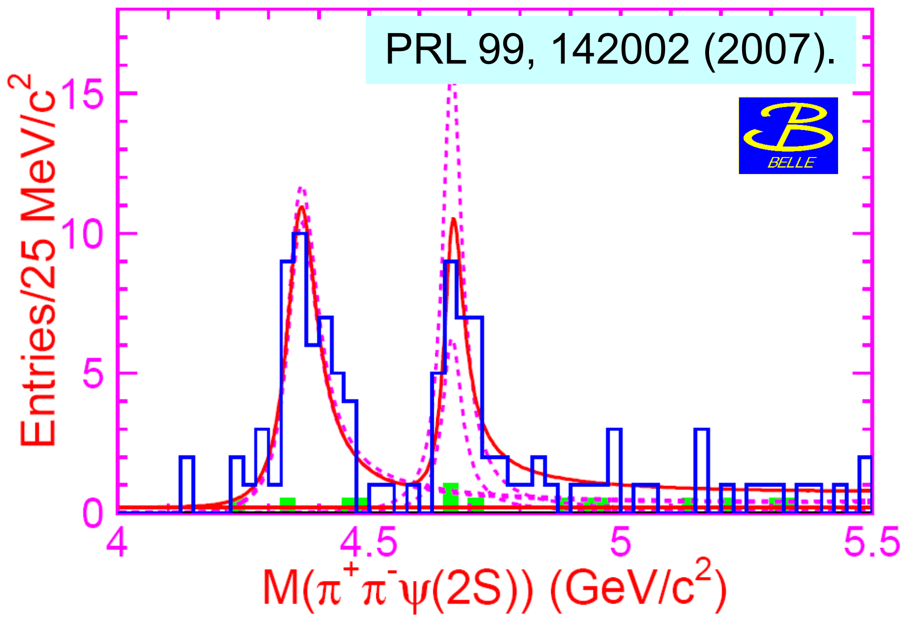
From the total cross section we can set a limit on $B(Y(4260) \to J/\psi\pi^+\pi^-) > 8\%$ that means $\Gamma(Y(4260) \to J/\psi\pi^+\pi^-) > 8$ MeV!

$\pi^+\pi^-$ invariant mass shows peculiar pattern



Y(4350) and Y(4660): 1^{--} with $\psi(2S)\pi^+\pi^-$ decays





- observed by BaBar in ISR $\psi(2S)\pi^+\pi^-$
- confirmed by Belle, which finds a significant excess also at 4660 MeV
- no evidence for Y(4260)...
- why are there states decaying to 2^3S_1 and not to 1^3S_1

Y from ISR at super-B factories

$e^+e^- \to \gamma_{ISR} Y$	events	$\int$ L (fb^{-1})	yield with 50 ab^{-1}
$Y(4260) \to \pi^+\pi^- J/\psi$	125 ± 23	233	
	324 ± 21	548	$\approx$ 30 k
$Y(4350) \to \pi^+\pi^- \psi(2S)$	≈ 25	298	
	≈ 50	673	$\approx$ 3.5 k
$Y(4660) \to \pi^+\pi^- \psi(2S)$	$\approx$40	673	$\approx$ 3 k

Very naive estimate: ISR detection efficiency depends on boost/crossing etc...

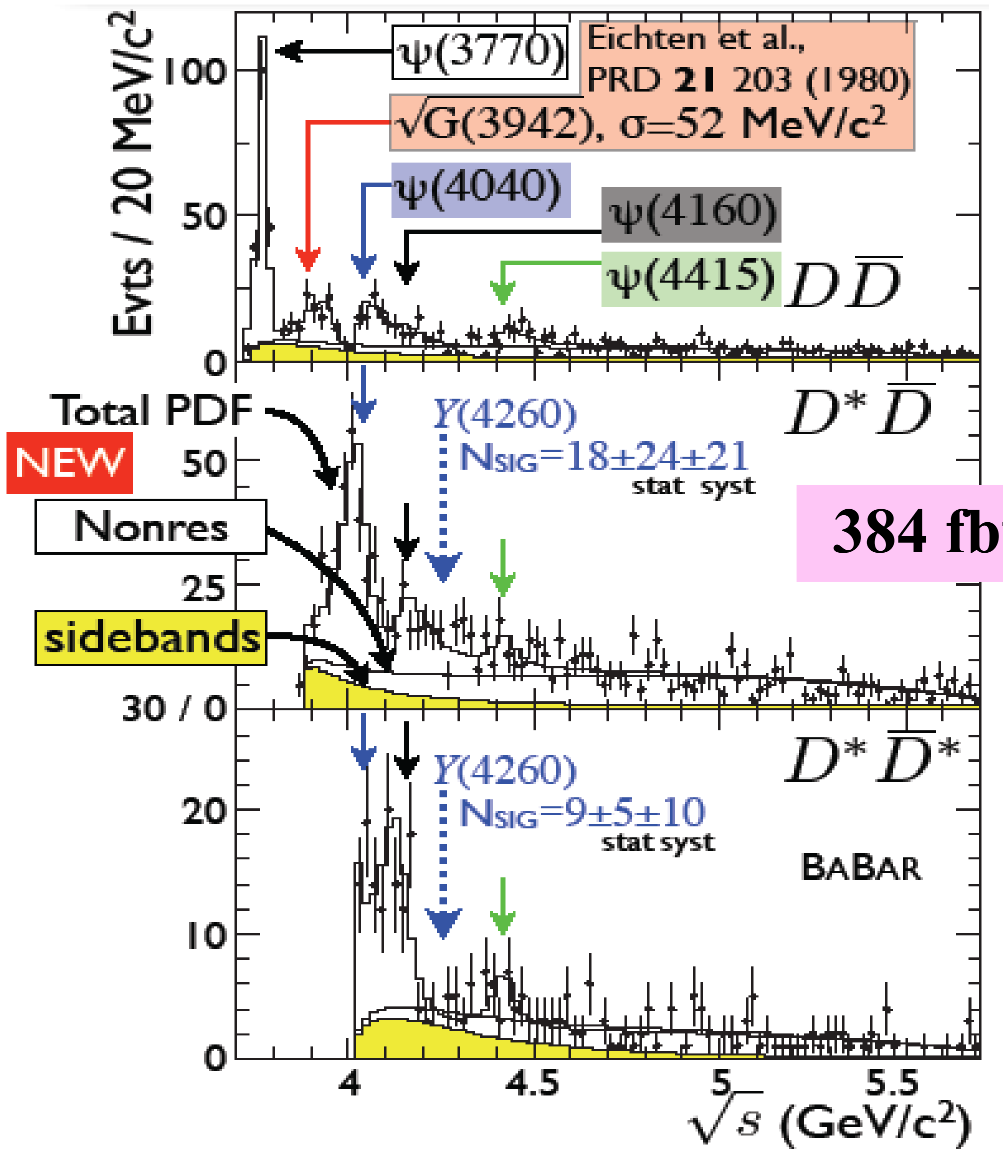
- line-shape:
  - determine Y(4260)→ψ(2S)ππ and Y(4260)→J/ψππ

- decay dinamics: ππ invariant mass and angular distributions

Also: search for other exclusive charmonium final states: ηψ, γχ, χππ...

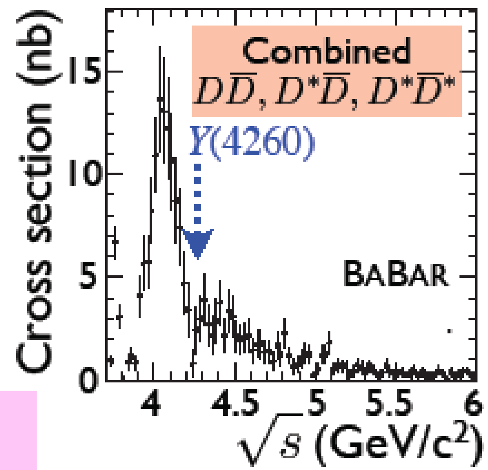
Open charm cross sections from ISR: BaBar

PRD 79,092001 (2009)



384 fb^{-1}

Limits on $Y(4260)$



$$\frac{\mathcal{B}(D\bar{D})}{\mathcal{B}(J/\psi\pi\pi)} < 1.0$$

$$\frac{\mathcal{B}(D^*\bar{D})}{\mathcal{B}(J/\psi\,\pi\pi)} < 34$$

NEW

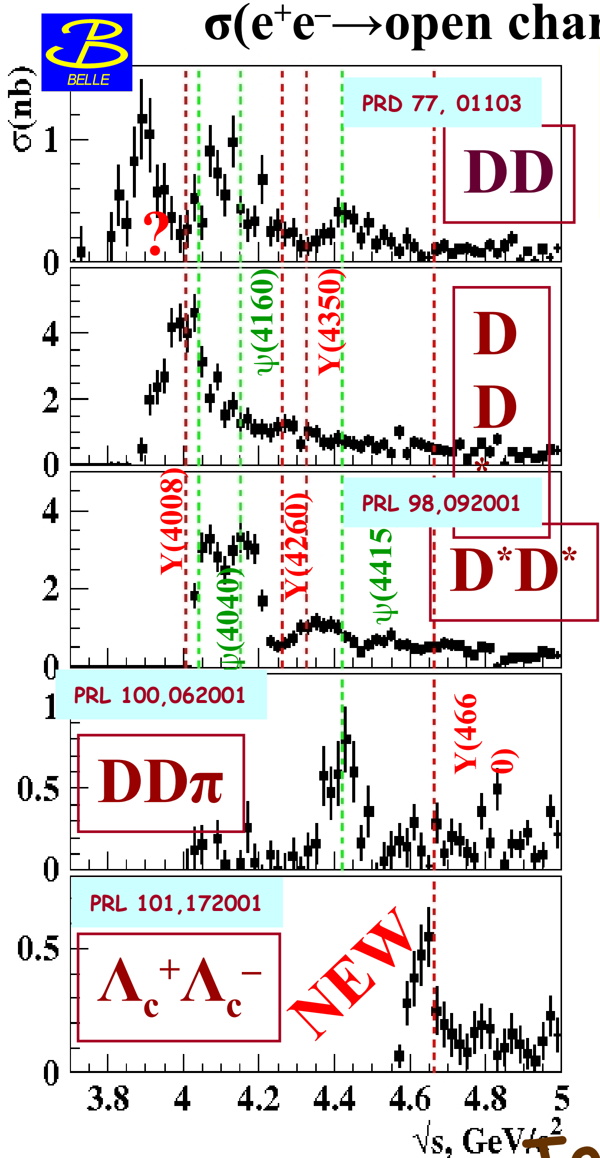
$$\frac{\mathcal{B}(D^*\bar{D}^*)}{\mathcal{B}(J/\psi\,\pi\pi)} < 40$$

at 90% C.L.

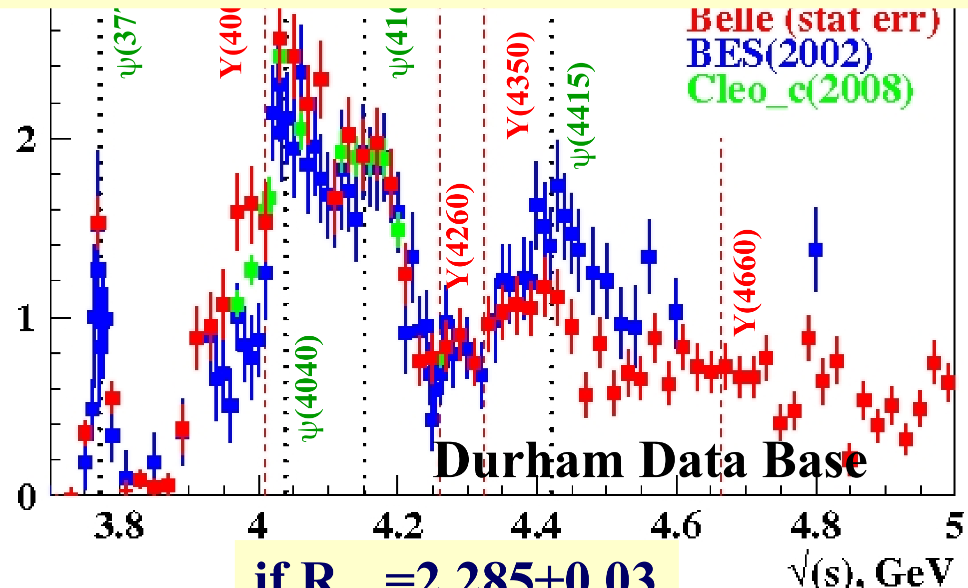
Branching fraction ratios

ψ	BF Ratios (± stat ± syst) NEW
4040	$\mathcal{B}(D\bar{D})/\mathcal{B}(D^*\bar{D})$ = 24 ± 5 ±12
"	$\mathcal{B}(D^*\bar{D}^*)/\mathcal{B}(D^*\bar{D})$ = 18 ± 14 ± 3
4160	$\mathcal{B}(D\bar{D})/\mathcal{B}(D^*\bar{D}^*)$ = 2 ± 3 ± 2
"	$\mathcal{B}(D^*\bar{D})/\mathcal{B}(D^*\bar{D}^*)$ = 34 ± 14 ± 5
4415	$\mathcal{B}(D\bar{D})/\mathcal{B}(D^*\bar{D}^*)$ = 14 ± 25 ± 3
"	$\mathcal{B}(D^*\bar{D})/\mathcal{B}(D^*\bar{D}^*)$ = 17 ± 25 ± 3

Open charm cross sections from ISR: Belle



Belle: Sum of all measured exclusive contributions



if R_{uds}=2.285±0.03

This means that the ISR Y states have Γ(ππJ/ψ(ψ')) > 1 MeV

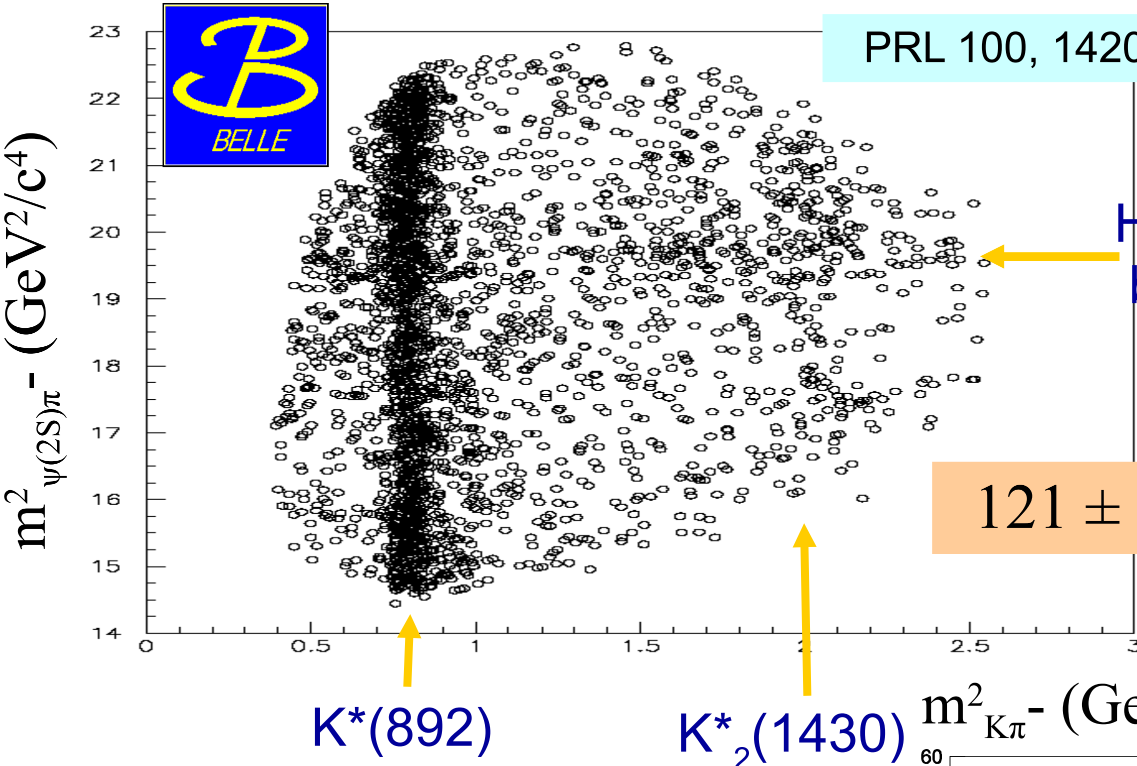
Too large for charmonium

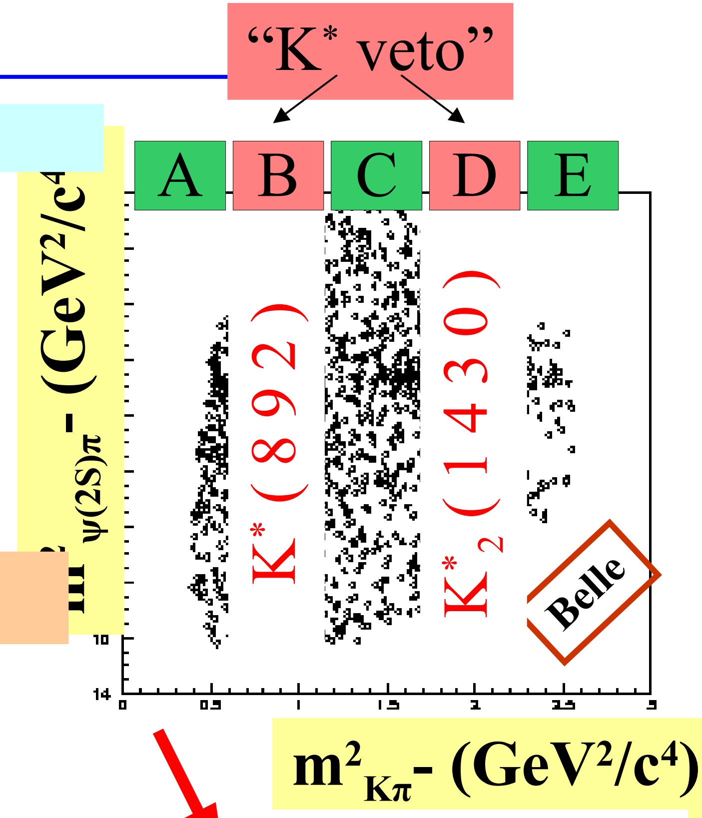
Perspectives at super B factories (and BES-III)

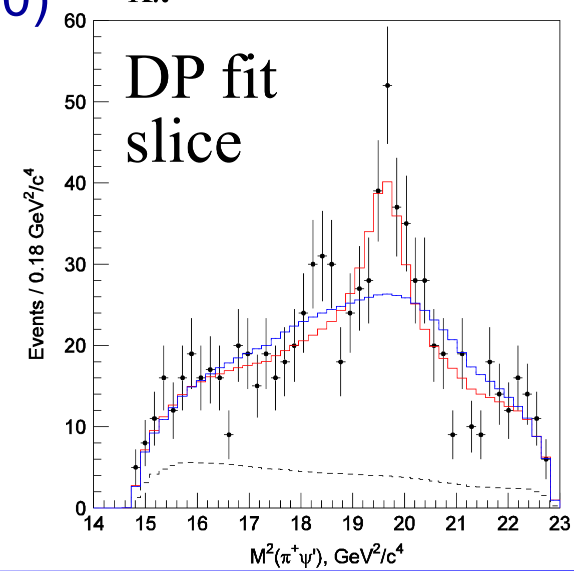
- super B factories will have >50 times larger samples as by-product while running at $\Upsilon(4S)$ or $\Upsilon(5S)$
  - measure precisely the cross section for fully reconstructed exclusive final states

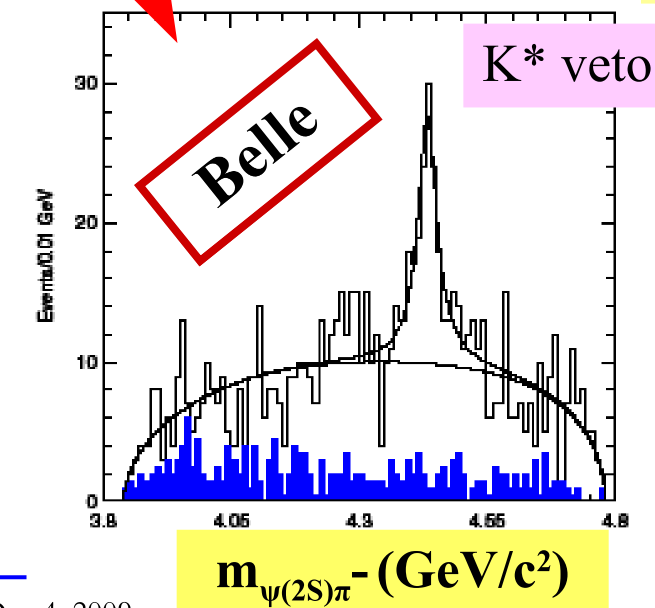
- a scan of the 4 GeV region by SuperB or BES-III would have comparable or larger samples with much less integrated luminosity
  - measure precisely also inclusive (or semi-inclusive) cross sections

$Z(4430)^-$









$$M = (4443^{+15+17}_{-12-13})\,\text{MeV}/c^2,$$

$$\Gamma = (109^{+86+57}_{-43-52})\,\text{MeV},$$

$$\mathcal{B}(B^0 \to Z^+ K^+) \times \mathcal{B}(Z^+ \to \psi(2S)\pi^+) = (3.2^{+1.8\,+5.3}_{-0.9\,-1.6})10^{-5}$$

Search for $Z(4430)^-$ at BaBar

Search in four B decay modes:

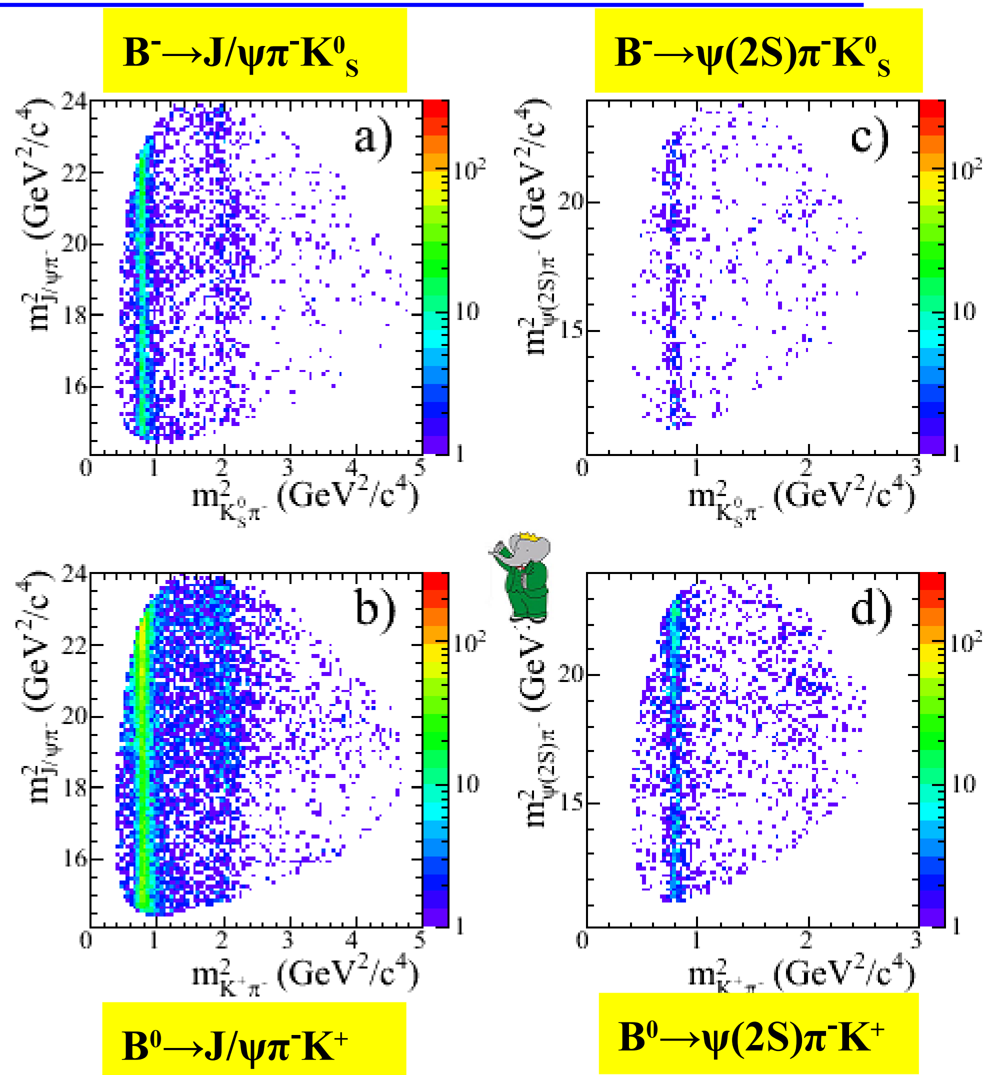
$B^{-/0} \to J/\psi \;\; \pi^- K^{0/+}$

$B^{-/0} \to \psi(2S) \; \pi^- K^{0/+}$

[in the following ψ denotes J/ψ and $\psi(2S)$]

- subtract background (sidebands)
- correct for efficiency event by event
- describe in detail the $K\pi^-$ system
  - ➔ structures in the $K\pi^-$ mass and angular distributions dominate each Dalitz plot

Project each $K\pi^-$ description onto the relevant $\psi\pi^-$ mass distribution to investigate the need for $Z(4430)^-$ signal above this "$K\pi^-$ background"



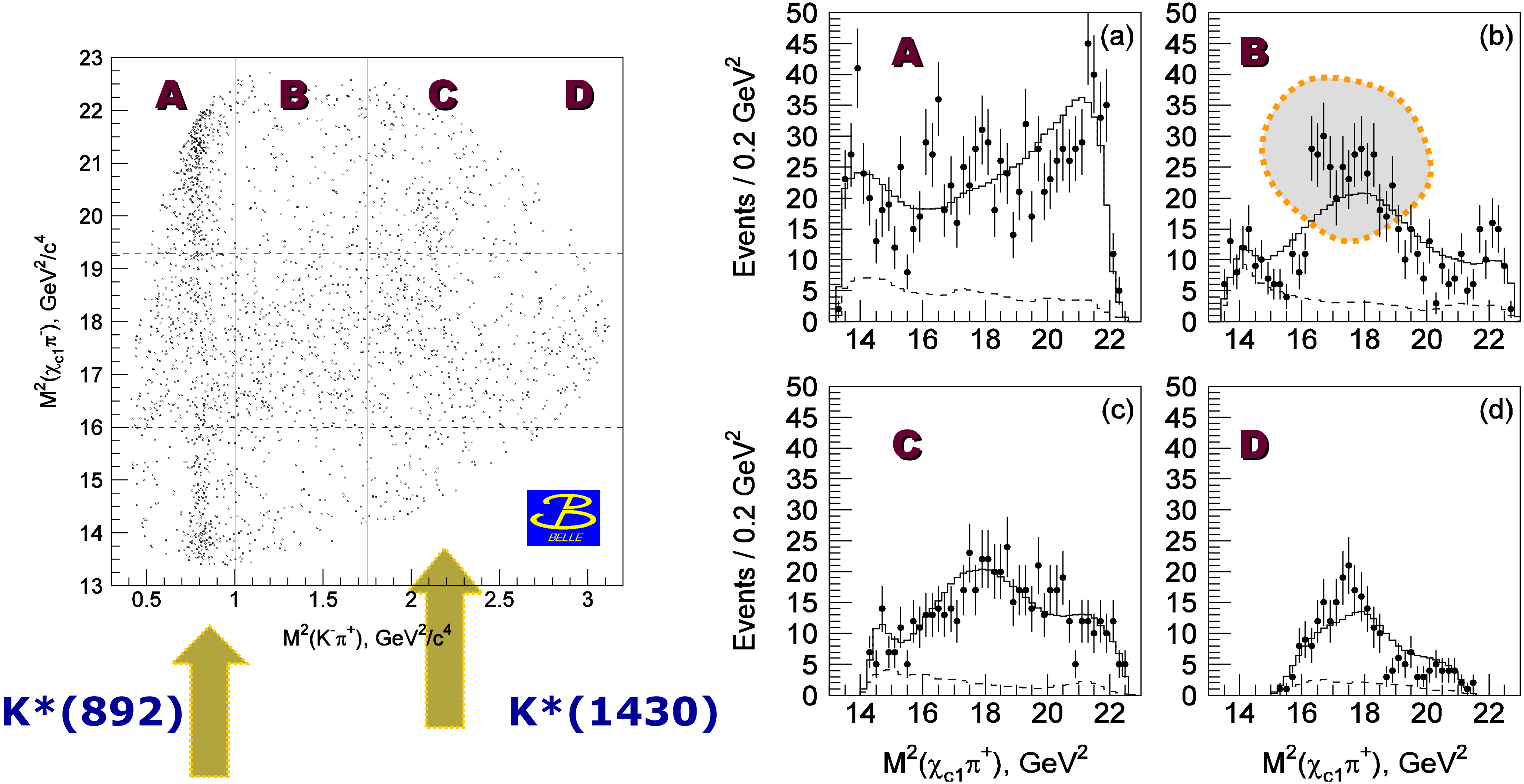
PRD 79, 112001 (2008)

$K\pi^-$ reflections reproduce data

No evidence for $Z(4430)^-$

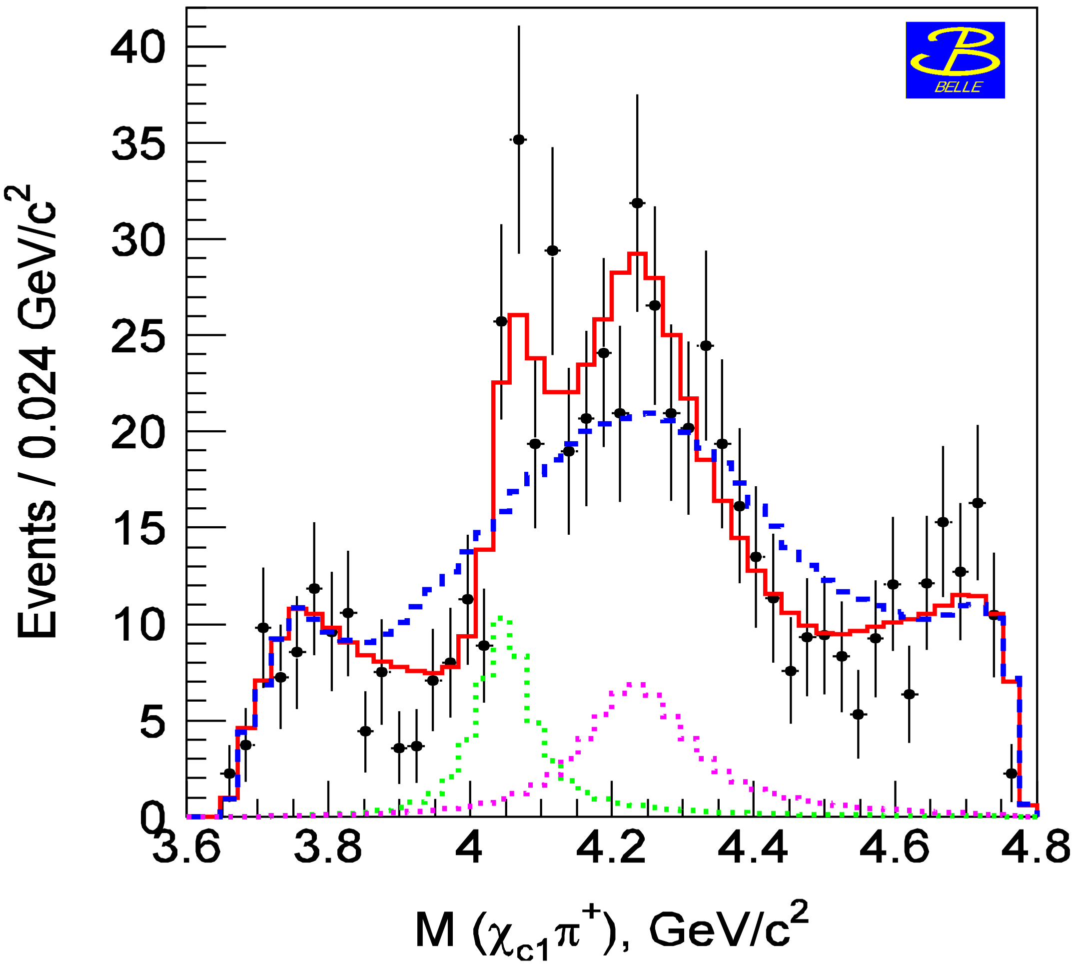
More charged states in $B^0 \to \chi_{c1}(1P)\pi^+ K^-$?

Dalitz plot fit including all known K*:
κ, K*(892), K*(1410), $K^*_0(1430)$, $K^*_2(1430)$, K*(1680), $K^*_3(1780)$



CL of the fit ~10^{-10}

Parameters of $Z_1^+(4050)$ and $Z_2^+(4430)$



$$M_1 = (4051 \pm 14^{+20}_{-41})\ \mathrm{MeV}/c^2,$$

$$\Gamma_1 = (82^{+21+47}_{-17-22})\ \mathrm{MeV},$$

$$M_2 = (4248^{+44+180}_{-29-35})\ \mathrm{MeV}/c^2,$$

$$\Gamma_2 = (177^{+54+316}_{-39-61})\ \mathrm{MeV},$$

with the product branching fractions of

$$\mathcal{B}(\bar{B}^0 \to K^- Z_1^+) \times \mathcal{B}(Z_1^+ \to \pi^+ \chi_{c1}) = (3.0^{+1.5+3.7}_{-0.8-1.6}) \times 10^{-5},$$

$$\mathcal{B}(\bar{B}^0 \to K^- Z_2^+) \times \mathcal{B}(Z_2^+ \to \pi^+ \chi_{c1}) = (4.0^{+2.3+19.7}_{-0.9-0.5}) \times 10^{-5}.$$

PRD 78, 072004 (2008)

Naive estimate of yields for the Z^+'s

- Very large samples (~100k to 1.5 M) for

  $B^{-/0} \to J/\psi\ \pi^- K^{0/+}$

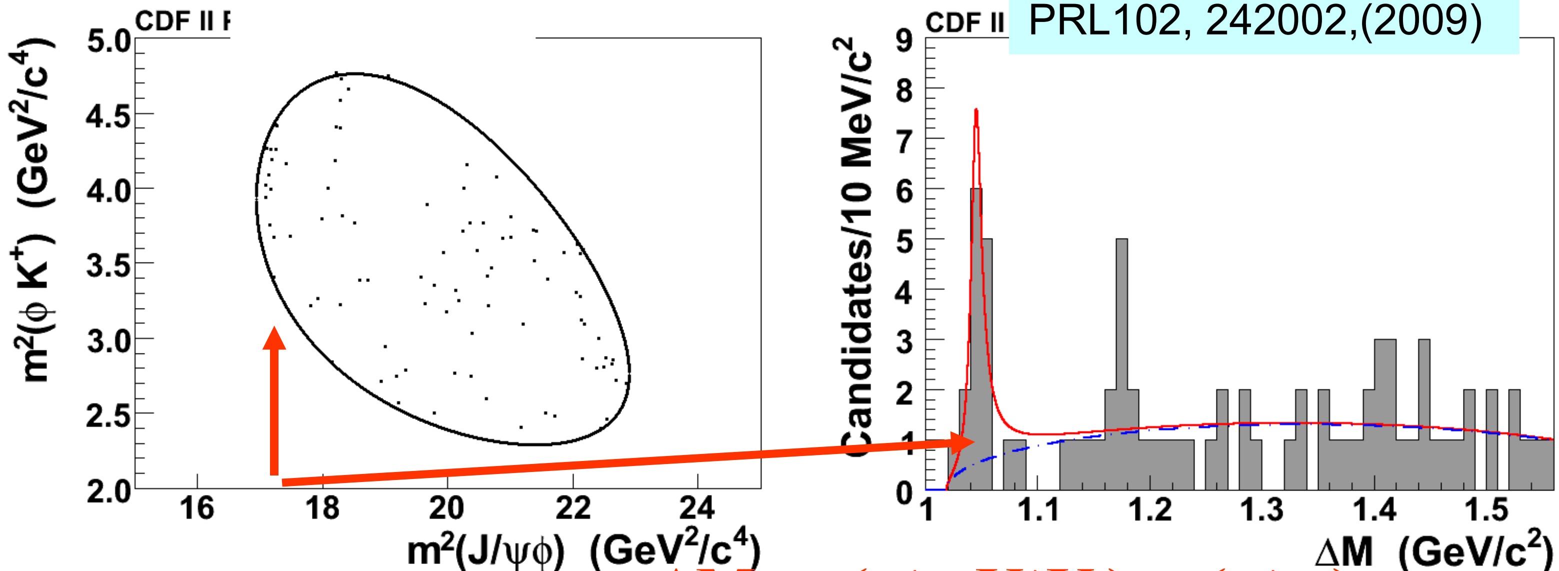
  $B^{-/0} \to \psi(2S)\ \pi^- K^{0/+}$

  $B^{-/0} \to \chi_{c1}(1P)\ \pi^- K^{0/+}$

  will allow a full angular analysis of the decay (including ψ polarization)

- just scaling the yields by luminosity: expect to observe ~ few k signal events for each Z^+

from CDF... Y(4140) decaying to J/ψφ



$\Delta M = m(\mu^+\mu^-K^+K^-) - m(\mu^+\mu^-)$

- Including systematics:

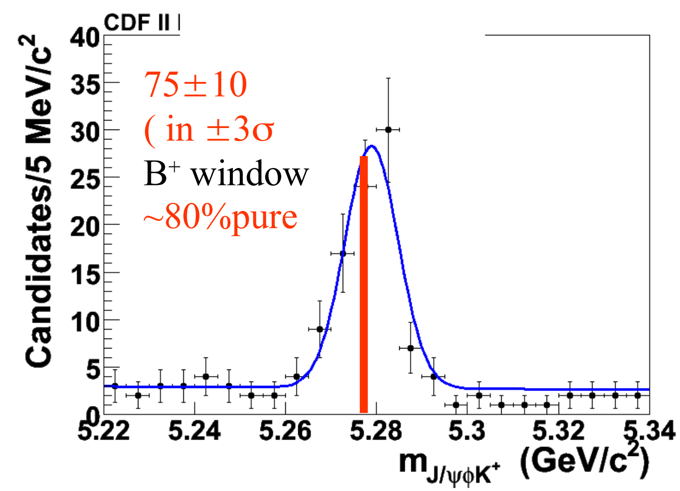
  Yield $= 14 \pm 5$

  $\Delta m = 1046.3 \pm 2.9 \pm 1.2$ MeV/c²

  Mass $= 4143.0 \pm 2.9 \pm 1.2$ MeV/c²

  Width $= 11.7\ ^{+8.3}_{-5.0} \pm 3.7$ MeV

  Significance: 3.8σ



$Br(B \to J/\psi\varphi K) \approx 10^{-4}$ expect O(10k) events search for substructures

Conclusions

- B-factories discovered numberless new states: D_{sJ}, charmed baryons, missing charmonium and bottomonium states
  - Not just a new zoo: multi-quark bound states ⇔ low energy regime
    - many new states with peculiar features – not easily accomodated within the standard mesons
    - most states observed in only one decay mode, limited statistics
  - in depth study need larger statistics ⇒ super B factories

discovery

O(1 ab^{-1})

study

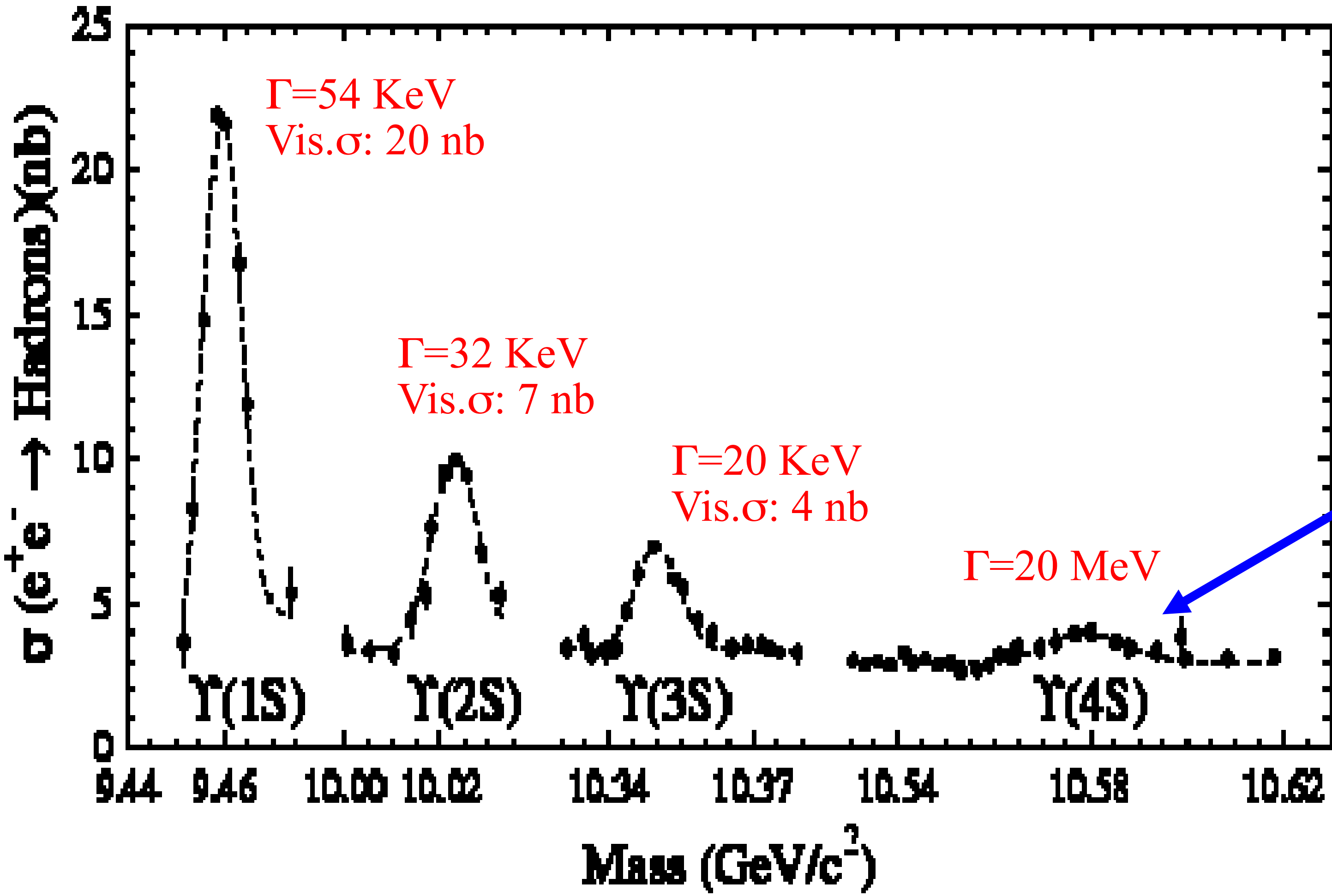
O(50 ab^{-1})

(question to theorists: how relevant is to fully understand them?)

Additional slides

Bottomonium at B-Factories

Copious production of 1^{--} in e^+e^- annihilations when $\sqrt{s} = M(\Upsilon)$



Initial State Radiation (ISR) yields large samples also when running at the $\Upsilon(4S)$

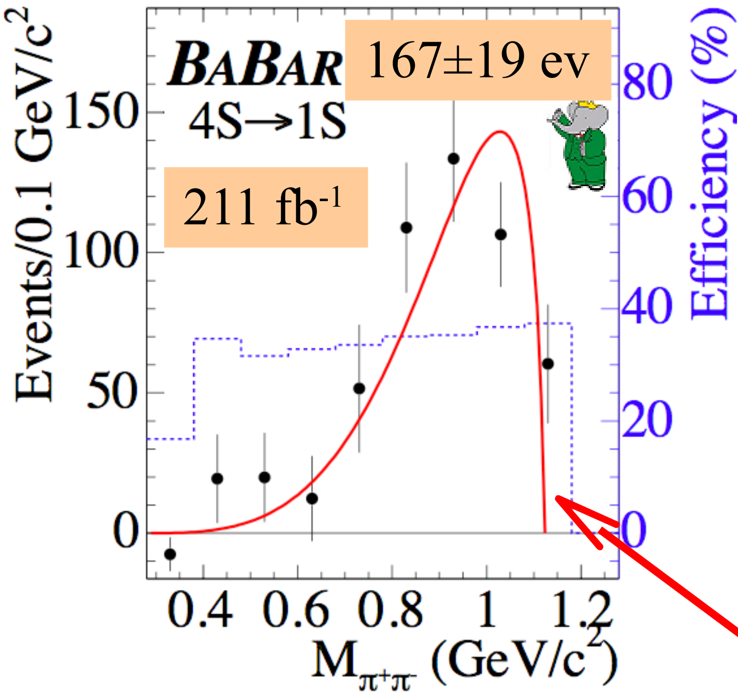
$\sigma(e^+e^- \rightarrow \Upsilon(3S)\gamma_{ISR}) \sim 29$ pb
$\sigma(e^+e^- \rightarrow \Upsilon(2S)\gamma_{ISR}) \sim 17$ pb
$\sigma(e^+e^- \rightarrow \Upsilon(1S)\ \gamma_{ISR}) \sim 19$ p

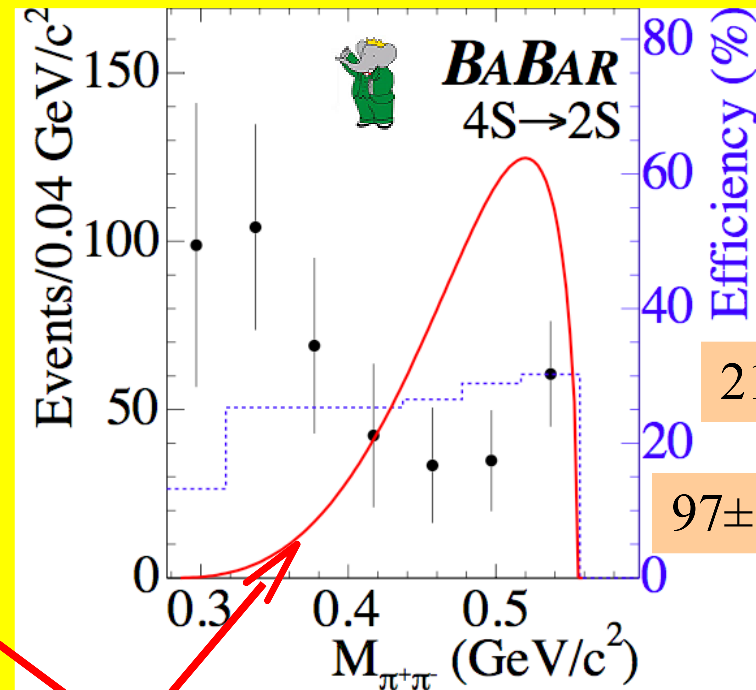
few M events for "free" while running at the $\Upsilon(4S)$

can be used to study $\Upsilon(nS)$ in fully reconstructed final states

inclusive searches or final states with missing particles require on-peak running

$M(\pi^+\pi^-)$ in $\Upsilon(4S)\to\pi^+\pi^-\Upsilon(1S,2S)$

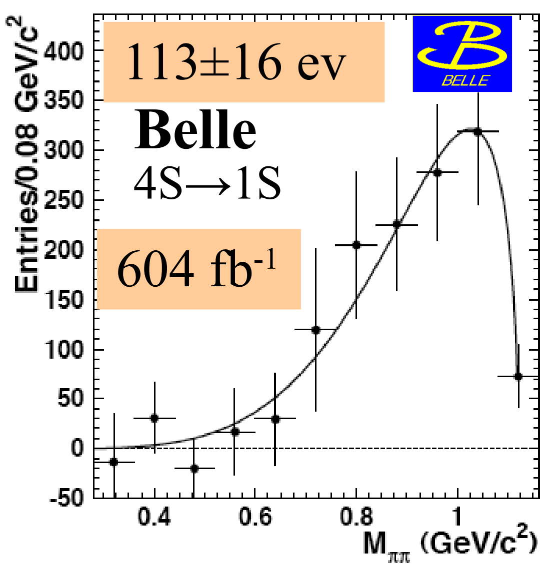




PRL 96, 232001(2006)

211 fb^{-1}

97±15 ev

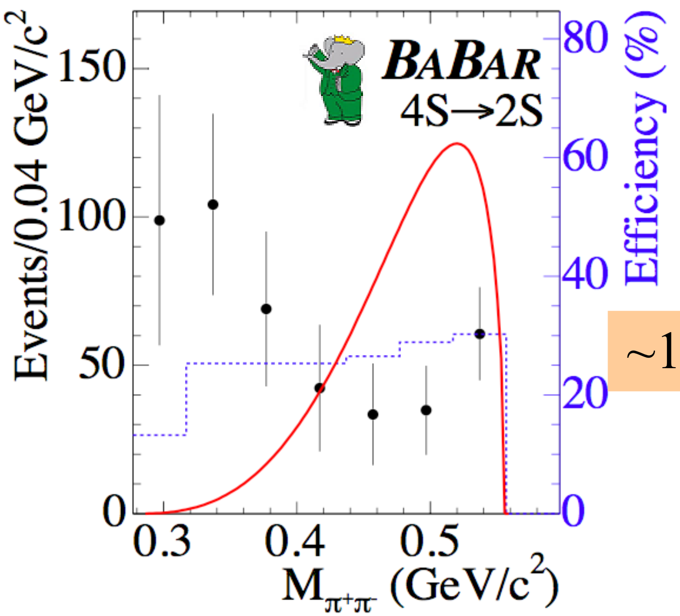


QCD multipole expansion

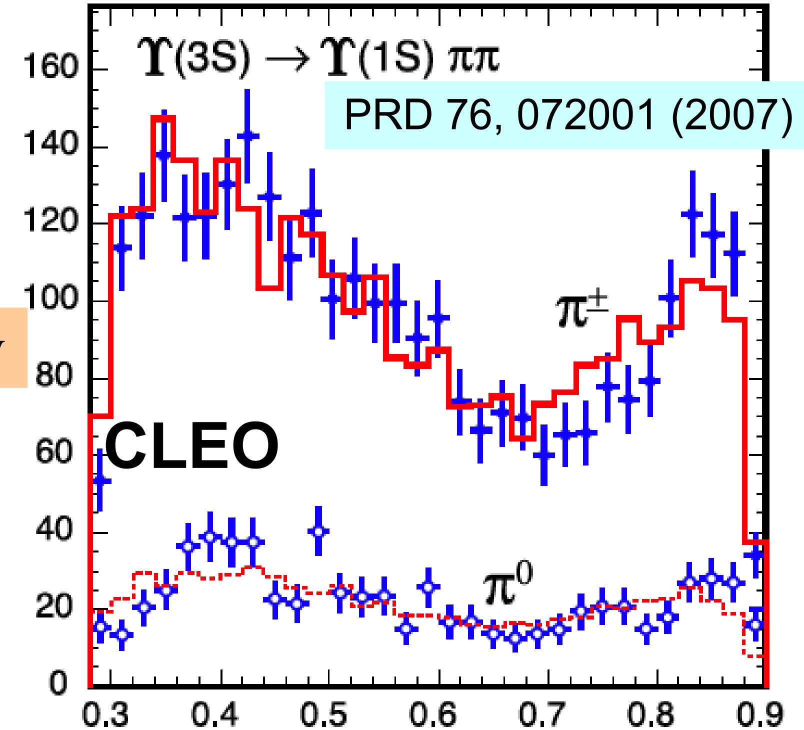
PRD 79, 011103 (2009).

"Double bump" structure in $\Upsilon(4S)\to\pi^+\pi^-\Upsilon(2S)$?

Similar to $\Upsilon(3S)\rightarrow\pi^+\pi^-\Upsilon(1S)$?



~100 ev ⟷ ~3000 ev



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long standing puzzle

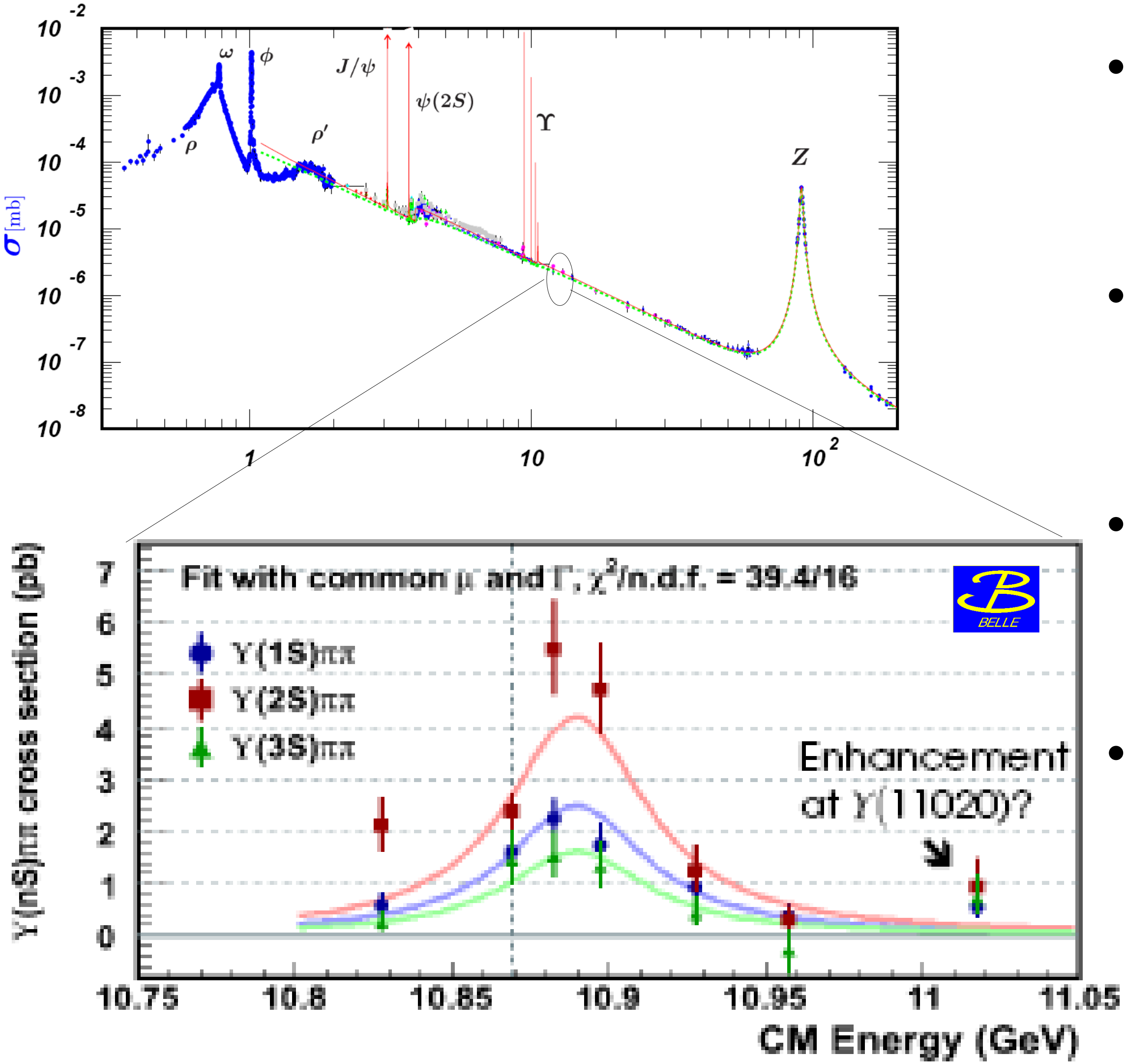
with 50 ab^{-1}

~25 k
$\Upsilon(4S)\rightarrow\pi^+\pi^-\Upsilon(2S)$

~40 k
$\Upsilon(4S)\rightarrow\pi^+\pi^-\Upsilon(1S)$

decay dinamics

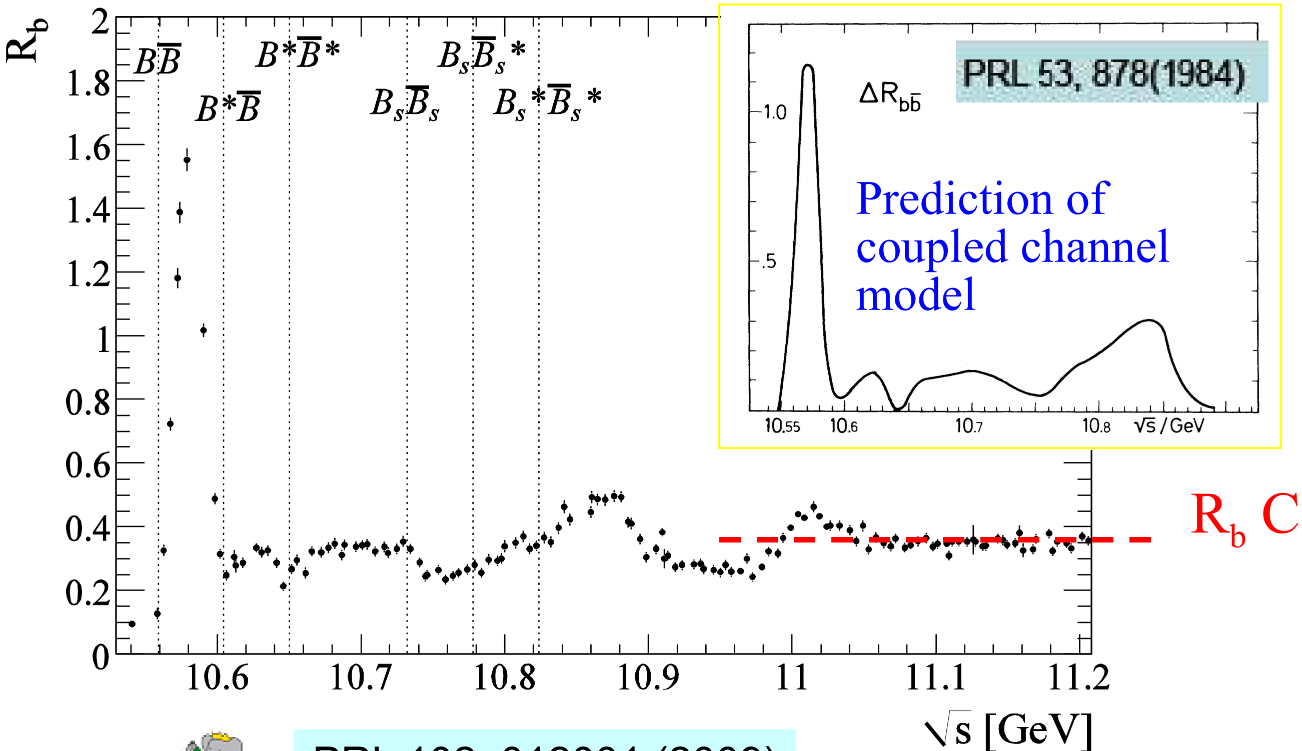
b-quark counterparts of the Υ(4260)?



- Search for states decaying to $\Upsilon(nS)\pi\pi$ above open-b threshold
- scan and measure exclusive cross section at each point
- mass and width not in agreement with Υ(5S) from PDG
- partial widths $\Gamma(\Upsilon(nS)\pi\pi)$ way too large ~ MeV range!!!

arXiv:0808.2445

BaBar measurement of R_b



R_b Cont.

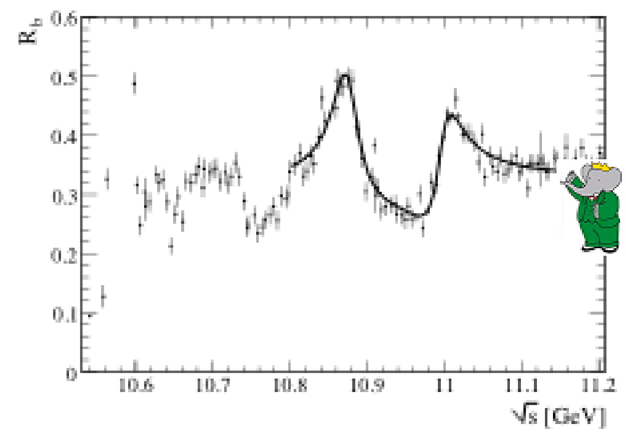
PRL 102, 012001 (2009)

~ 4 fb^{-1}

inclusive cross section

$\Upsilon(5S)$ and $\Upsilon(6S)$ parameters also different from PDG average

consistent with Belle's $\Upsilon\pi\pi$?



>10 luninosity scan possible at super B-factories

Exclusive modes ⇔ coupled channel

- Interpretation of structure at ~10.62 & ~10.7 GeV dependent on threshold openings
- Distribution shows significant features above $\Upsilon(4S)$