Exotic charmonium mesons at BaBar

Valentina Santoro
Ferrara University and INFN
Representing the BaBar Collaboration

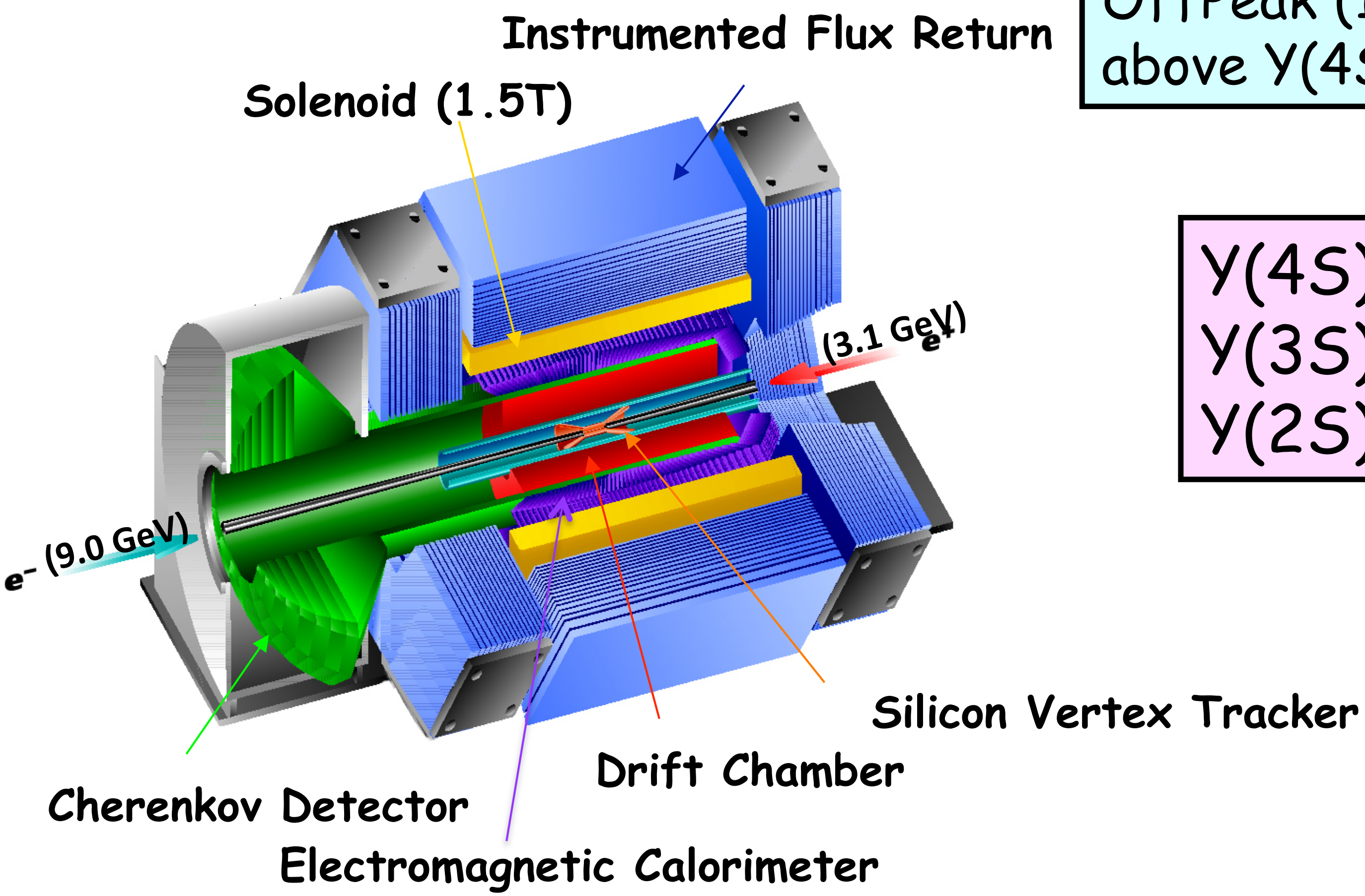
Outline

Charmonium spectrum
The X(3872)
The Y Saga
The Z(4430)

The BaBar detector and data sample

BaBar is a powerful *b* factory: 467 million of $B\bar{B}$ pairs in the total data sample

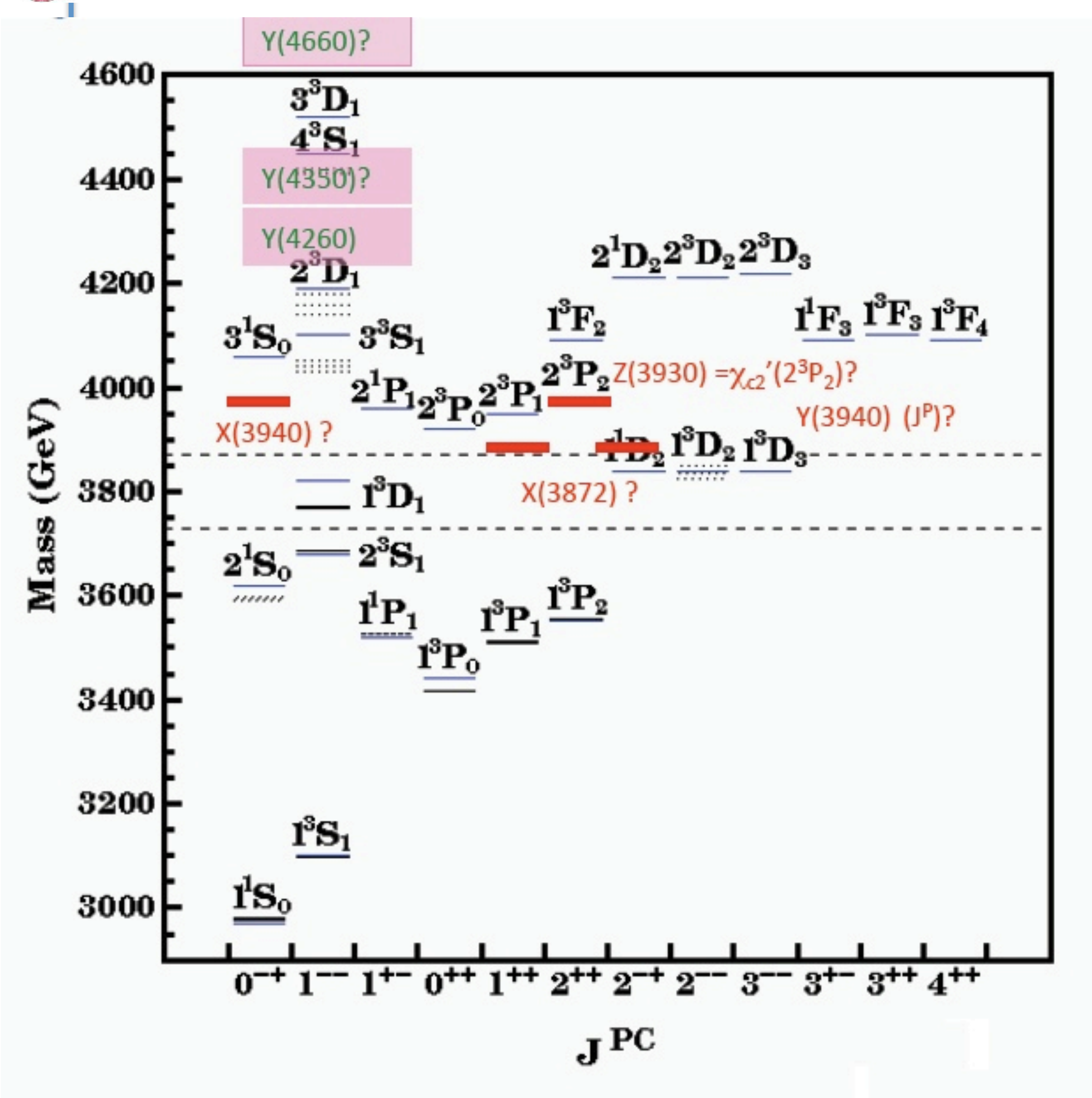
BaBar is also a *c* factory: 1.3 million Charm events per fb



OffPeak (10.54GeV) + Scan above Υ(4S): 53.9 fb^{-1}

Υ(4S): 432 fb^{-1}
Υ(3S): 30.2 fb^{-1}
Υ(2S): 14.5 fb^{-1}

Charmonium spectrum

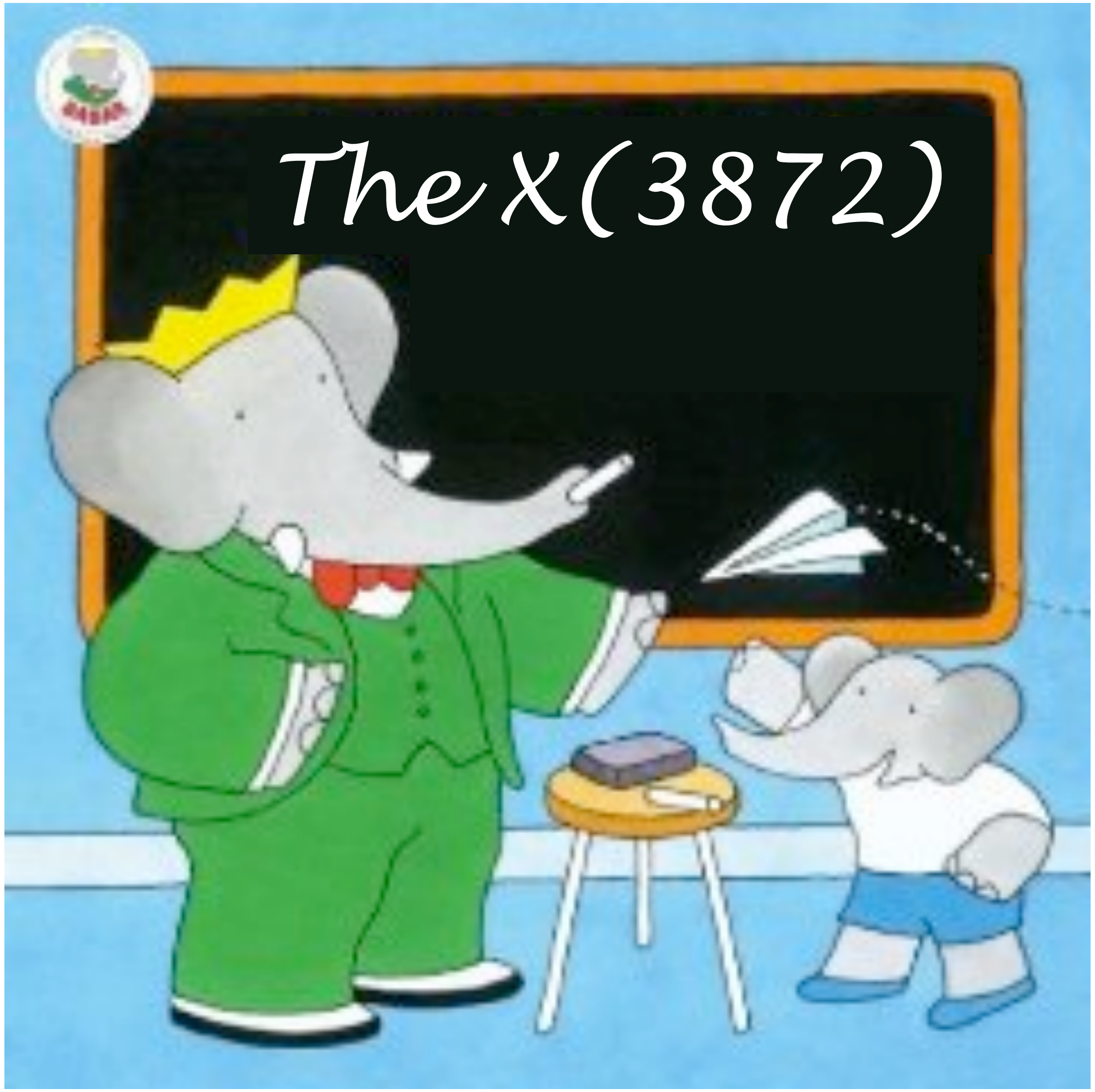


Charmonium properties are well understood up to ψ(3770) (i.e. about the $D\bar{D}$ threshold)

$c\bar{c}$ states above open charm threshold are expected to have significant width values and to decay mainly to open charm channels

But the X(3872) is narrow, and there are too many $J^{PC}=1^{--}$ states, which don't seem to decay via open charm modes;

Interpretation not clear


The X(3872)

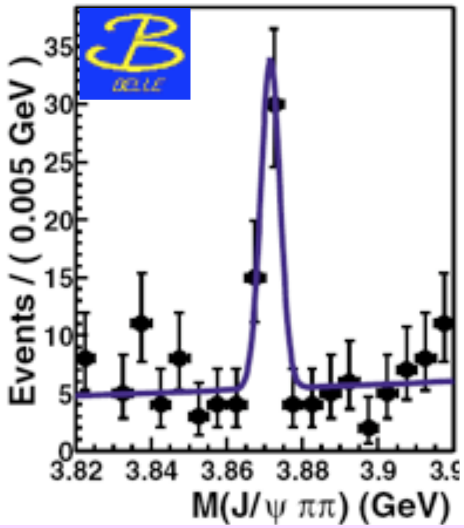
The Discovery

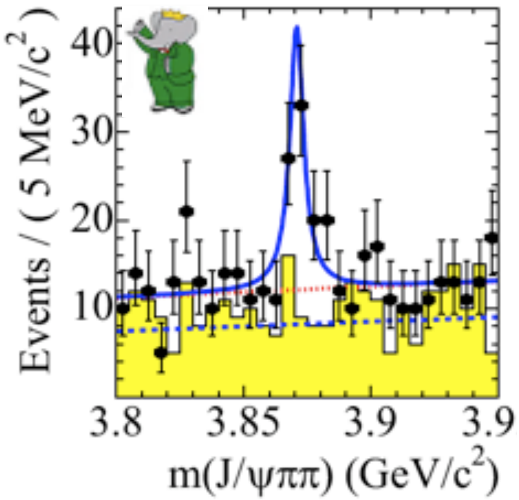
Discovered by Belle in B -> $J/\psi\pi^+\pi^-$ K; confirmed by CDF, D0 and BaBar

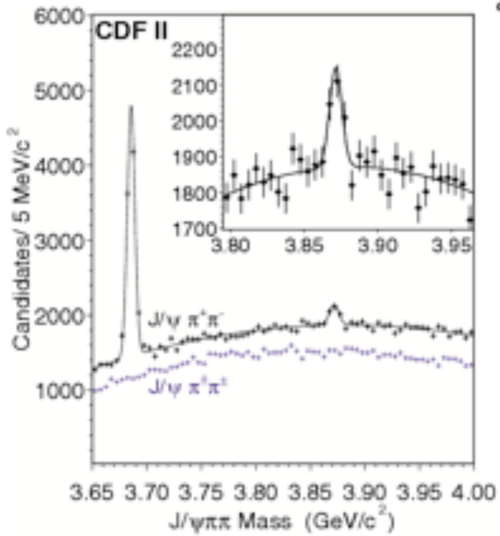
Narrow (Γ<2.3MeV) particle with mass m(X)=3871.4+/-0.6 MeV/c^2

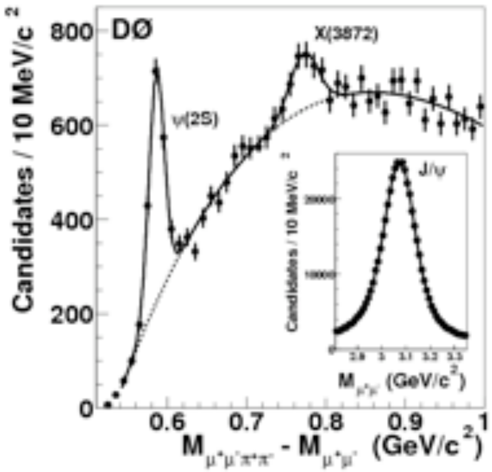
Phys. Rev. D 71, 071103 (2005)
Phys. Rev. D 73, 011101 (2006)

Phys. Rev. Lett. 93, 072001 (2004)
Phys. Rev. Lett. 93, 162002 (2004)



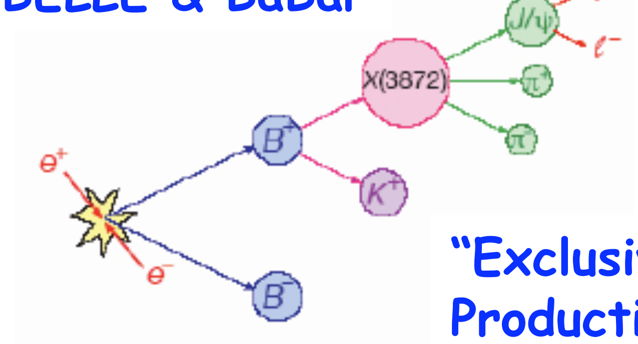






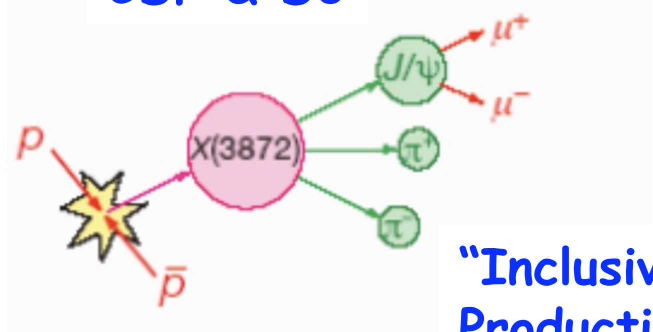
Phys. Rev. Lett. 91, 262001 (2003)

BELLE & BaBar



"Exclusive Production (B decay)"

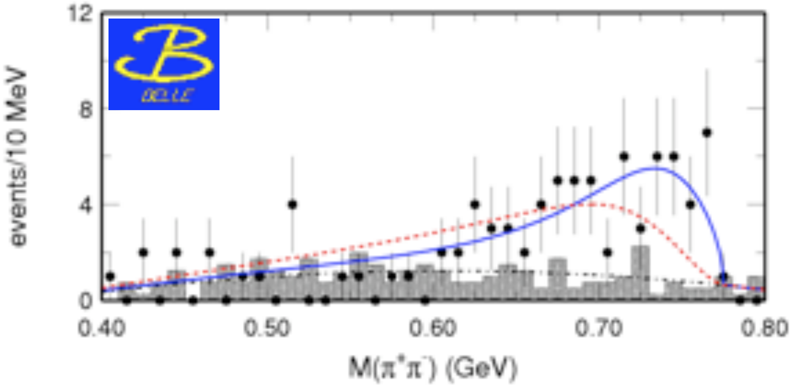
CDF & D0



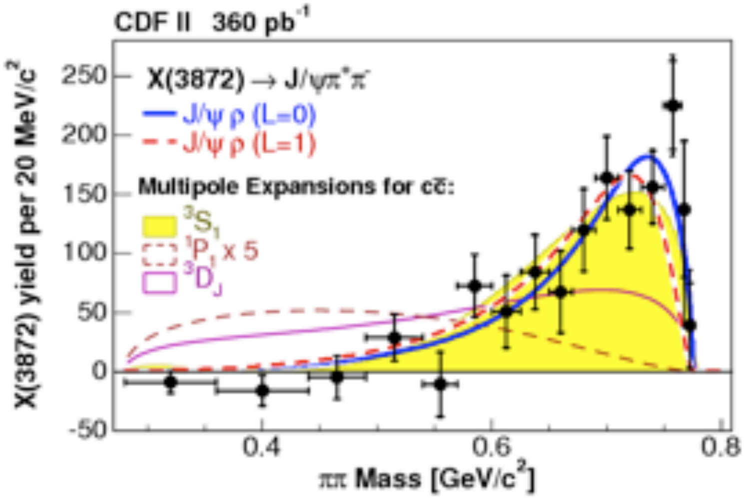
"Inclusive Production"

Feature: $\pi^+\pi^-$ mass

hep-ex/0505038

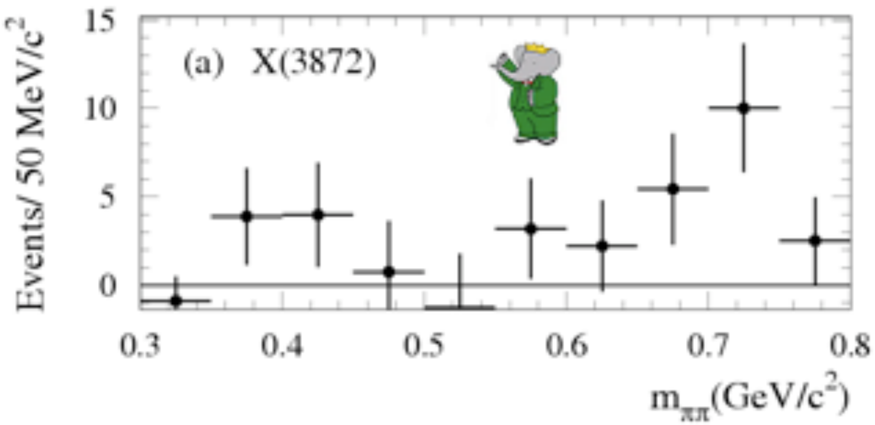


- ✓Belle and CDF analyzed the $\pi^+\pi^-$ mass distribution from X -> J/ψ $\pi^+\pi^-$.
- ✓Both seem to favor a "ρ-like" shape, with J/ψ-ρ in an S-wave
- ✓ Shape in BaBar is similar, no attempt to fit
- ✓Disfavor Charmonium interpretation; not if it is 2^{-+}



Phys. Rev. Lett. 96, 102002 (2006)

106 fb^{-1}



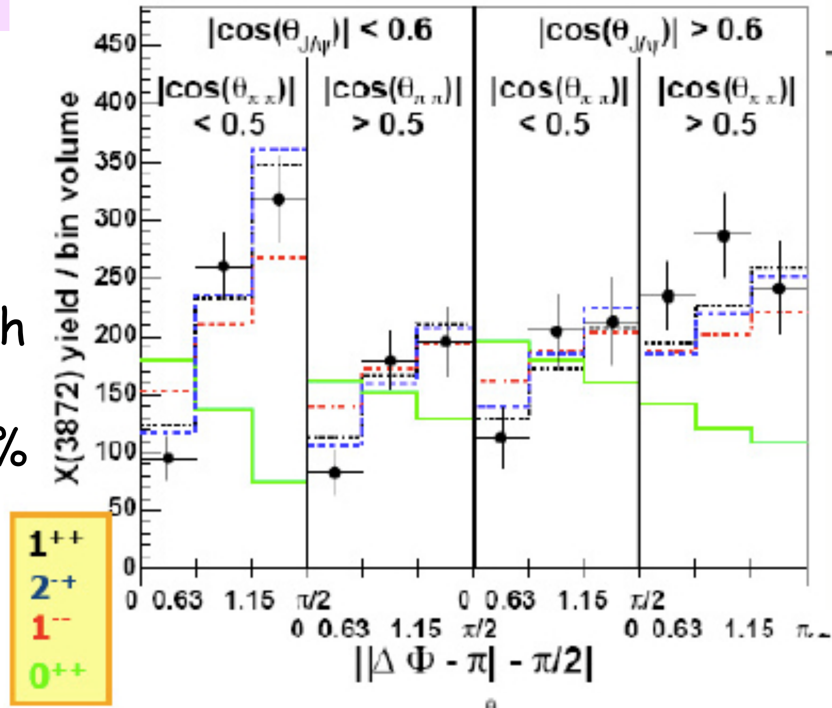
Phys. Rev. D 71, 071103 (2005)

Angular analysis, and analysis of $\pi^+\pi^-$ mass distribution

Phys. Rev. Lett. 98, 132002 (2007)

CDF analyzed angular distribution of daughters,and tested against various J^{PC} assignments
Angular analysis compatible with both 1^{++} and 2^{-+}
χ^2 prob.(1^{++})=27.8%, (2^{-+})=25.8%

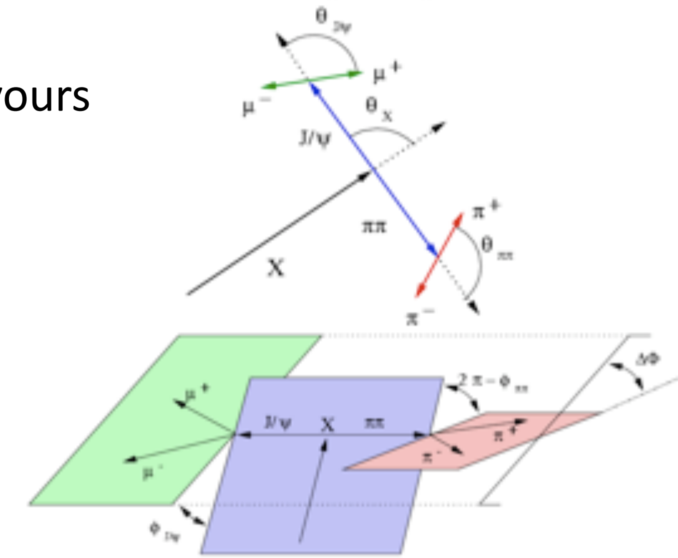
Method tested using $\psi(2S)\to J/\psi\pi\pi$ decays



J^{PC}	χ^2 prob.
1^{++}	27.8%
2^{-+}	25.8%
1^{--}	0.02%
2^{+-}	$5.5\cdot10^{-5}$
1^{+-}	$3.8\cdot10^{-5}$
2^{--}	$3.8\cdot10^{-5}$
3^{+-}	$3.8\cdot10^{-5}$
3^{--}	$2.4\cdot10^{-5}$
2^{++}	$1.1\cdot10^{-5}$
1^{-+}	$4.1\cdot10^{-6}$
0^{-+}	$3.5\cdot10^{-17}$
0^{+-}	$<1\cdot10^{-20}$
0^{++}	$<1\cdot10^{-20}$

Angular analysis from Belle favours 1^{++} disfavours 0^{++}, 0^{-+}, 1^{+-}

hep-ex/0505038



If charmonium:
η_{c2} (1^1D_2) -> 2^{-+}
χ_{c1} (2^3P_1) -> 1^{++}

$D\overline{D}^{*0}$ decays

605 fb^{-1}

Belle discovered X(3872) in B-> $D^0\overline{D}^0\pi^0K$

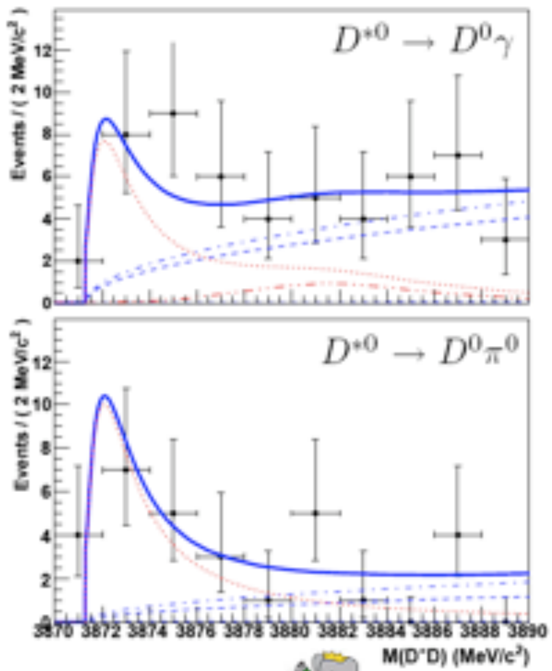
Found mass 2.0σ higher than W.A. for X(3872)

Phys. Rev. Lett. 97, 162002 (2006)

Recent update confirms $D^0\overline{D}^{0*}$ decay

(8.8σ)Compute m(X)=3872.6 ±0.5 ±0.4 MeV/c^2

arXiv:0810.0358



BaBar search:

confirms X(3872) signal (4.9σ)

D^0 and D^{*0} masses constrained to the CLEO values

$m(D^0)+m(D^{*0})$ =3871.80 ± 0.37 MeV/c^2

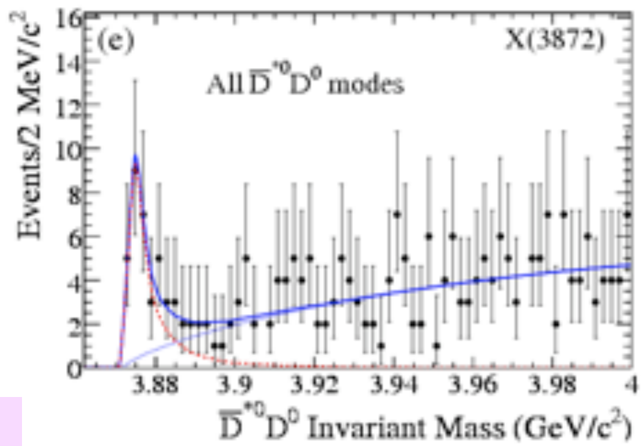
Fitted X mass: 3875.1 +0.7 -0.5 ± 0.5 MeV/c^2

Ratio of $D^0\overline{D}^0\pi^0/D^0\overline{D}^0\gamma$ matches $\overline{D}^{0*}$ expectation

Mass ~4.5σ above X(3872)

Angular study inconclusive

347 fb^{-1}



Phys. Rev. D 77, 011102 (R) (2008)

Radiative decays

Radiative decays may discriminate between η_{c2}, $\chi_{c1}(2P)$, and $D^0\overline{D}^{0*}$

Electromagnetic transitions for charmonium:

η_{c2} (1^1D_2)-> $\psi(nS)\gamma$ forbidden (M2)

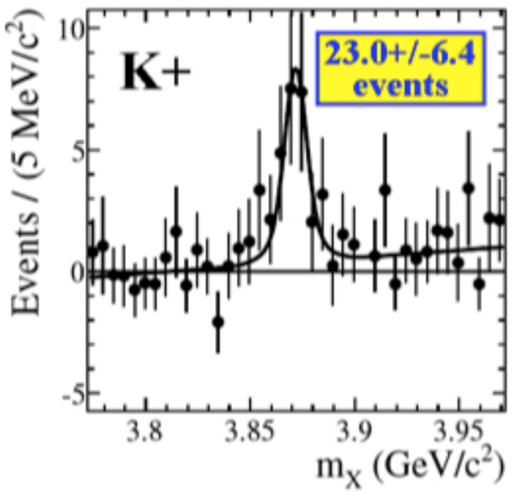
χ_{c1} (2^3P_1)-> $[J/\psi,\psi(2S)]\gamma$ allowed (E1)

Predictions for relative rate varies, but are of similar order

Radiative decays of the $D^0\overline{D}^{0*}$ molecule:

Decay to $J/\psi\gamma$ is possible in vector meson dominance scenario

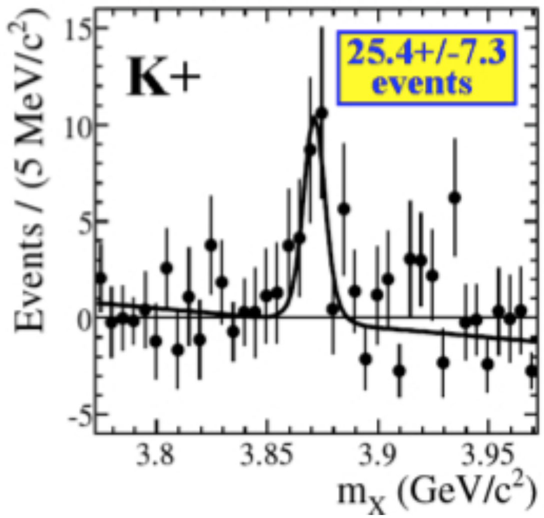
$\psi(2S)\gamma$ proceeds via annihilation, highly disfavored



X(3872) -> $J/\psi\ \gamma$ (3.6 σ)

424 fb^{-1}

PRL 102, 132001 (2009)



X(3872)-> $\psi(2S)\ \gamma$ (3.5σ)

Measure: BF(**B^+-> X(3872) K^+, X(3872)-> $J/\psi\ \gamma$**)
=(2.8+/-0.8+/-0.2) x 10^{-6}

Consistent with previous BaBar measurement:
(3.3+/-1.0+/-0.3) x 10^{-6}

Measure:
BF(**B^+-> X(3872) K^+, X(3872) -> $\psi(2S)\ \gamma$**)
=(9.5+/-2.7+/-0.9) x 10^{-6}

Ratio of BFs: (X(3872) -> $\psi(2S)\ \gamma$)/ (X(3872)-> $J/\psi\ \gamma$)= 3.4 ±1.4

Interpretations

Summary of X(3872) Properties

Narrow with mass m(X)=3871.4+/-0.6 MeV/c^2

Observed in X(3872) J/ψππ, dipion mass is "ρ-like"

Also seen in decays X(3872) -> $D^0\bar{D}^{0*}$ and X(3872) -> J/ψ γ, ψ(2S)γ

Spin-parity identified as either $J^{PC} = 1^{++}$ or 2^{-+}

Charmonium Hybrid

Lightest mass prediction m($c\bar{c}g$) > 4.2GeV/c^2

Tetraquark State:

No evidence for charged partners

Conventional Charmonium

$\chi_{c1}(2^3P_1)$ (1^{++}) or $\eta_{c2}(1^1D_2)$ (2^{-+})

X(3872) is narrow and for unnatural spin-parity cannot decay to ->$\bar{D}D$

Not expected to violate isospin, X -> J/ψ ρ;

Near $\bar{D}^{*0}D$ and J/ψω threshold, -> isospin violating decay could be significant

Mass is ok for η_{c2} but would expect -> J/ψ γ to be suppressed

Mass inconsistent with predicted χ_{c1}(2P)

$\bar{D}^0D^{0*}$ Molecular interpretation:

m(D^0) + m($\bar{D}^{0*}$) = 3871.8+/-0.4 MeV/c^2

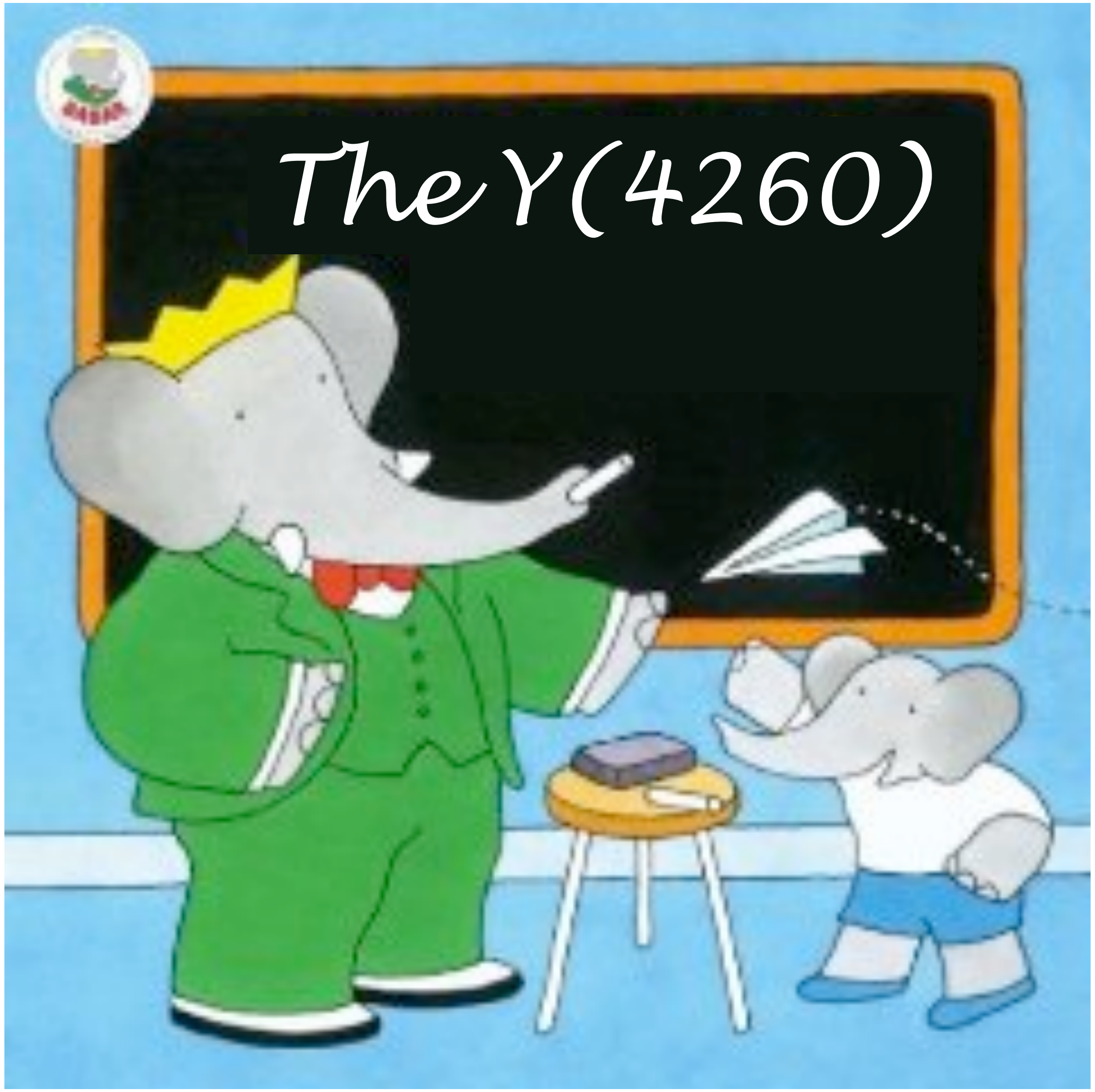
Decays to X(3872) -> J/ψ ρ, $D^0\bar{D}^{0*}$, J/ψ ω expected

Compatible with $J^{PC} = 1^{++}$ assignment;

Mass shift [which BaBar measures] not expected

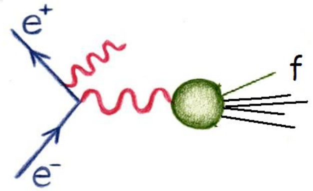
Expect X -> ψ(2S) γ to be suppressed

Successful predictions vary by model


The Y(4260)

Discovery of the Y(4260)

BaBar discovered in 2005 in $J/\psi\pi\pi$ events after ISR (233 fb^{-1})

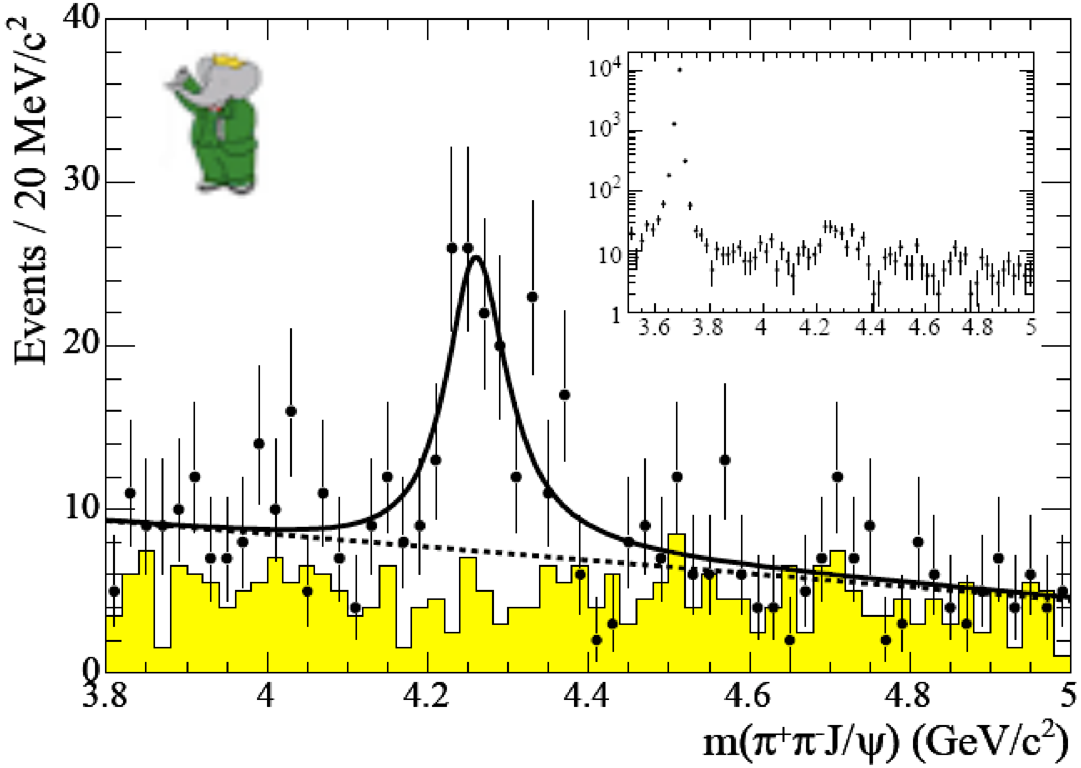


$J^{PC} = 1^{--}$

Phys. Rev. Lett. 95 (2005) 142001

Broad structure Y(4260)

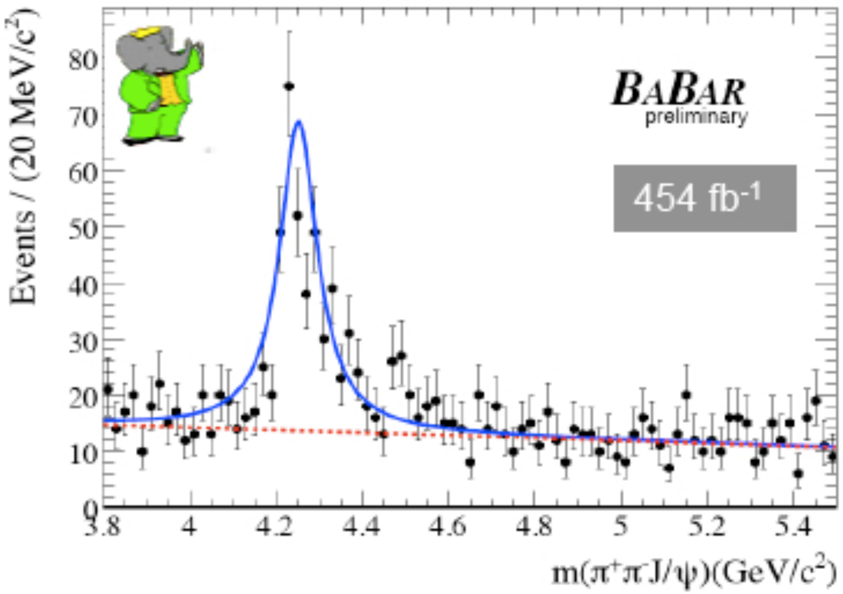
$$m_Y = (4259 \pm 8^{+2}_{-6})\ \mathrm{MeV}/c^2$$
$$\Gamma_Y = (88 \pm 23^{+6}_{-4})\ \mathrm{MeV}$$



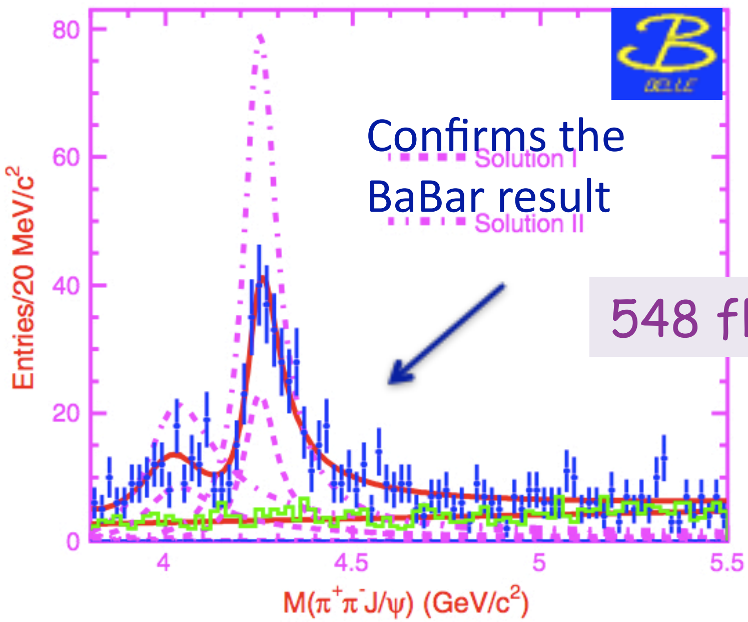
Confirmations from CLEO-c, CLEO-III and Belle with some spread in the resonance parameters.

All the 1^{--} slots in the charmonium spectrum are already filled

And confirmation…..

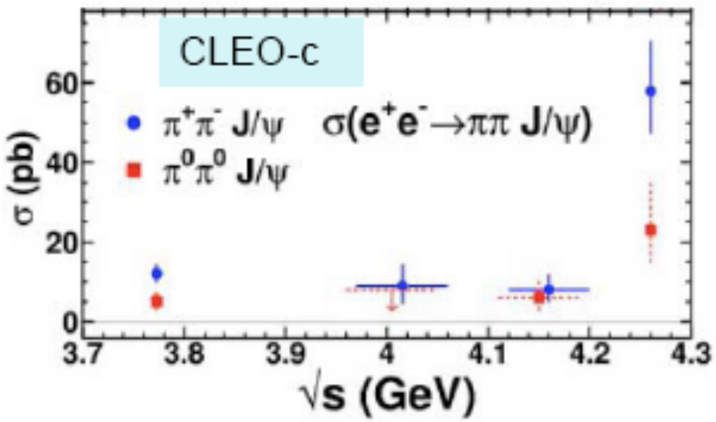


arXiv:0808.1543



Confirms the BaBar result

Phys. Rev. Lett. 99, 182004 (2007)



$J/\psi\pi^+\pi^- = 11\sigma$

$J/\psi\pi^0\pi^0 = 5.1\sigma$

$(\pi^+\pi^-)/(\pi^0\pi^0) \approx 2 \rightarrow I=0$

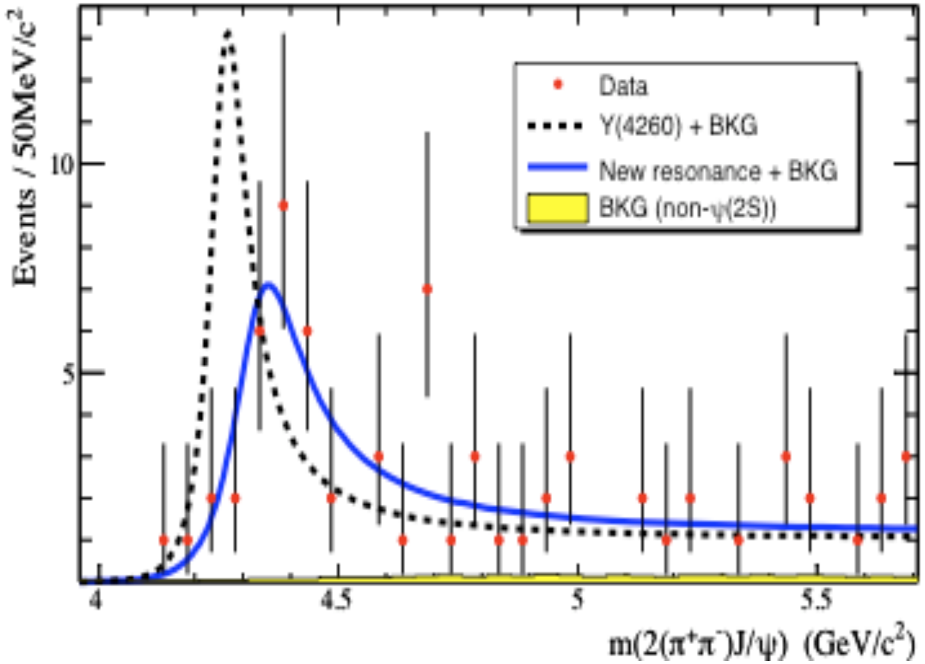
State	M, MeV/c²	Γ$_{tot}$, MeV
Y(4008)	$4008 \pm 40^{+114}_{-28}$	$226 \pm 44 \pm 87$
Y(4260)	$4259 \pm 8^{+2}_{-6}$	$88 \pm 23^{+6}_{-4}$
Y(4260)	$4252 \pm 6^{+2}_{-3}$	$105 \pm 18^{+4}_{-6}$
Y(4260)	$4284^{+17}_{-16} \pm 4$	$73^{+39}_{-25} \pm 5$
Y(4260)	$4247 \pm 12^{+17}_{-32}$	$108 \pm 19 \pm 10$

Search for the ISR Y(4260)→$\pi^+\pi^-\psi(2S)$

Y(4260) discovered in ISR $\pi^+\pi^- J/\psi$. How about $\pi^+\pi^-\psi(2S)$ in ISR?

Search for Y(4260)-> $\pi^+\pi^-\psi(2S)$

298 fb^{-1}



Single resonance fit => mass=(4324±24) MeV/c^2, Γ=(172±33) MeV

Incompatible with ψ(4415) (Prob= 2.0×10^{-9}); Poorly described by Y(4260)

Prob=4.5 $\times10^{-3}$ that the two structures are the same

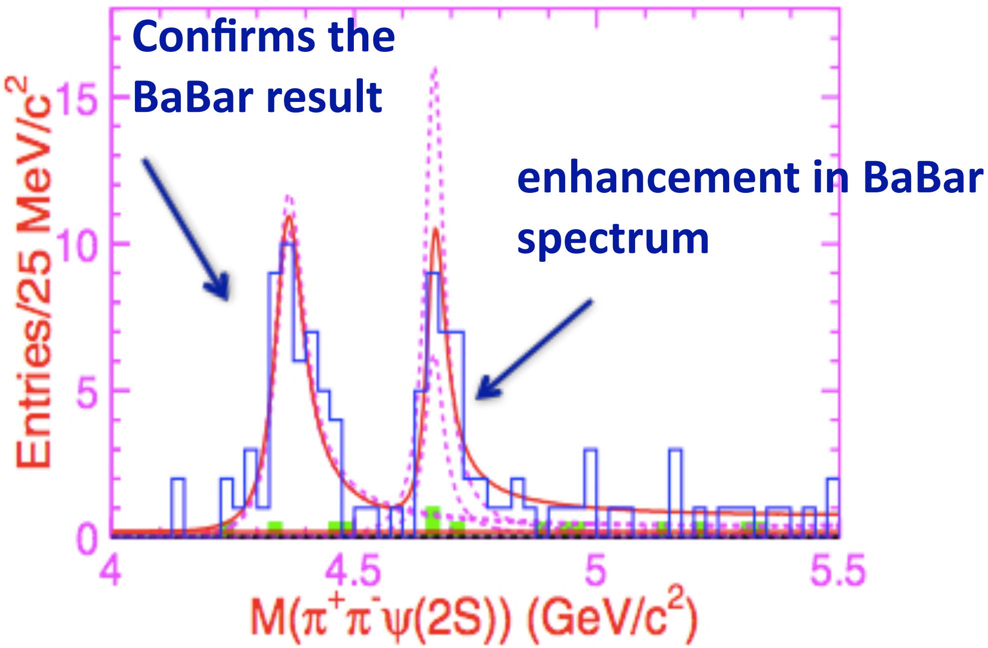
Phys. Rev. Lett. 98 (2007) 212001

Belle's result

ISR $\pi^+\pi^-\psi(2S)$

548 fb^{-1}

Belle confirmed the observation of the Y(4360). In addition BELLE reported a state around 4660 MeV.



State	M, MeV/c^2	Γ_{tot}, MeV
Y(4325)	4324 ± 24	172 ± 33
Y(4325)	$4361 \pm 9 \pm 9$	$74 \pm 15 \pm 10$
Y(4660)	$4664 \pm 11 \pm 5$	$48 \pm 15 \pm 3$

Phys. Rev. Lett. 99 (2007) 142002

Analysis ongoing at BaBar to confirm the Y(4660)

Possible interpretation of the Y(4260)

There are several theoretical interpretations that have been proposed:

- $c\bar{c}g$ hybrid state.
  - $J/\psi\pi^0\pi^0$, $J/\psi\eta\eta$, $\omega+\chi_{c0,c1,c2}$

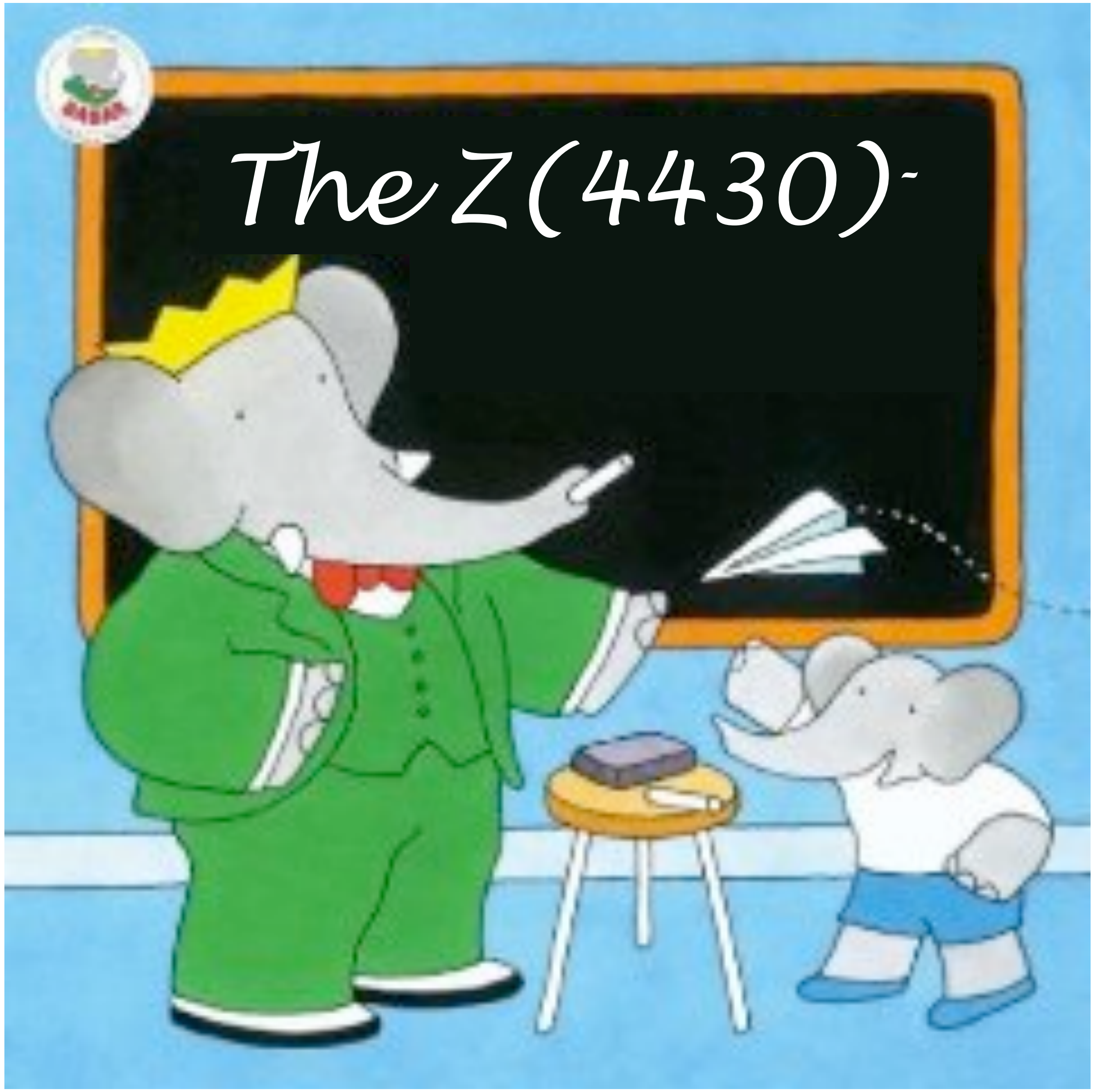
Shi-Lin Zhu, Phys. Lett. B 625 212 (2005)

- the first orbital excitation of a diquark-antidiquark state $[cs,\bar{c}\bar{s}]$
  - Dominant decay Y(4260)->$D_s\bar{D}_s$
  - Expected Y(4260)->$J/\psi f^0$

L.Maiani et al. ,Phys.Rev.D72 031502,2005.

- Baryonium state
  - Predict 2 new resonances (4330)(charged) (4560) (neutral)

C. F. Qiao , J. Phys. G 35 075008 (2008)


The Z(4430)-

The Z(4430)$^-$

PRL 100, 142001 (2008)

Belle claimed a new charged charmonium-like state in the decay:

$B \to Z^- K$, $Z^- \to \psi(2S)\pi^-$

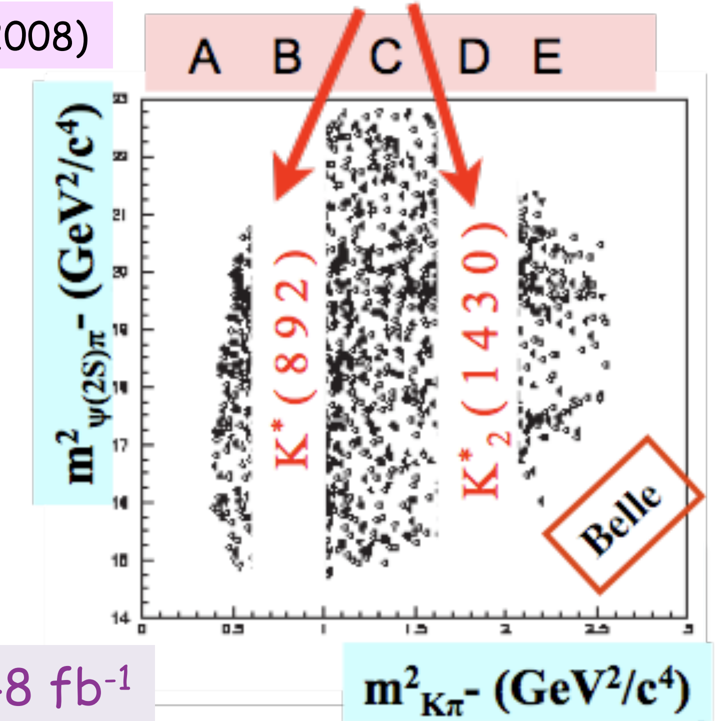
The reported mass and width are:

m=4433 ± 4(stat) ± 2(syst) MeV/c^2

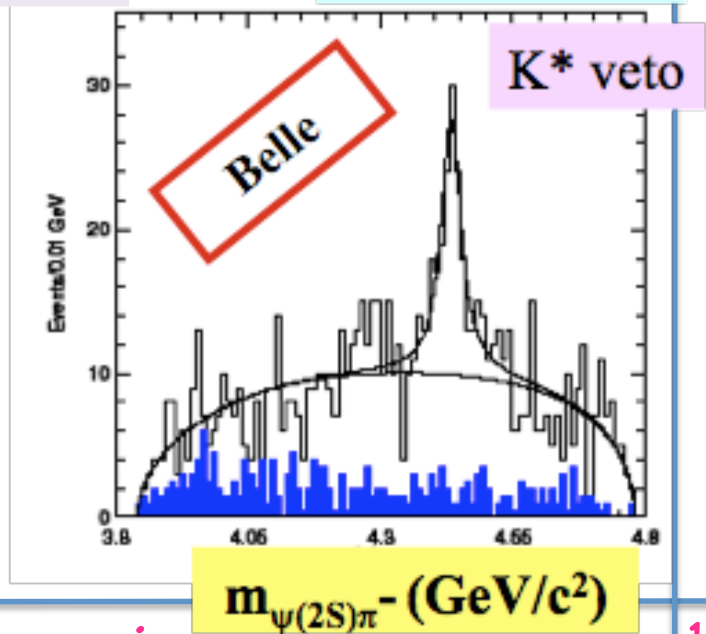
$\Gamma=45^{+18}_{-13}$(stat)$^{+30}_{-13}$(syst) MeV

121 ± 30 events; significance 6.5σ

If this result is confirmed first observation of a genuine $c\bar{c}d\bar{u}$ "tetraquark" state, since it is charged and carries hidden charm
Maiani: 0708.3997 (hep-ph) ,
Karliner & Lipkin arxiv: 0802.0649



548 fb^{-1}



BaBar search for Z

Search for the Z(4430)$^-$ with 413 fb^{-1} in the decay modes

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

- Describe the Kπ^- system in detail, since structure in the Kπ^- mass and angular distributions dominates each Dalitz plot

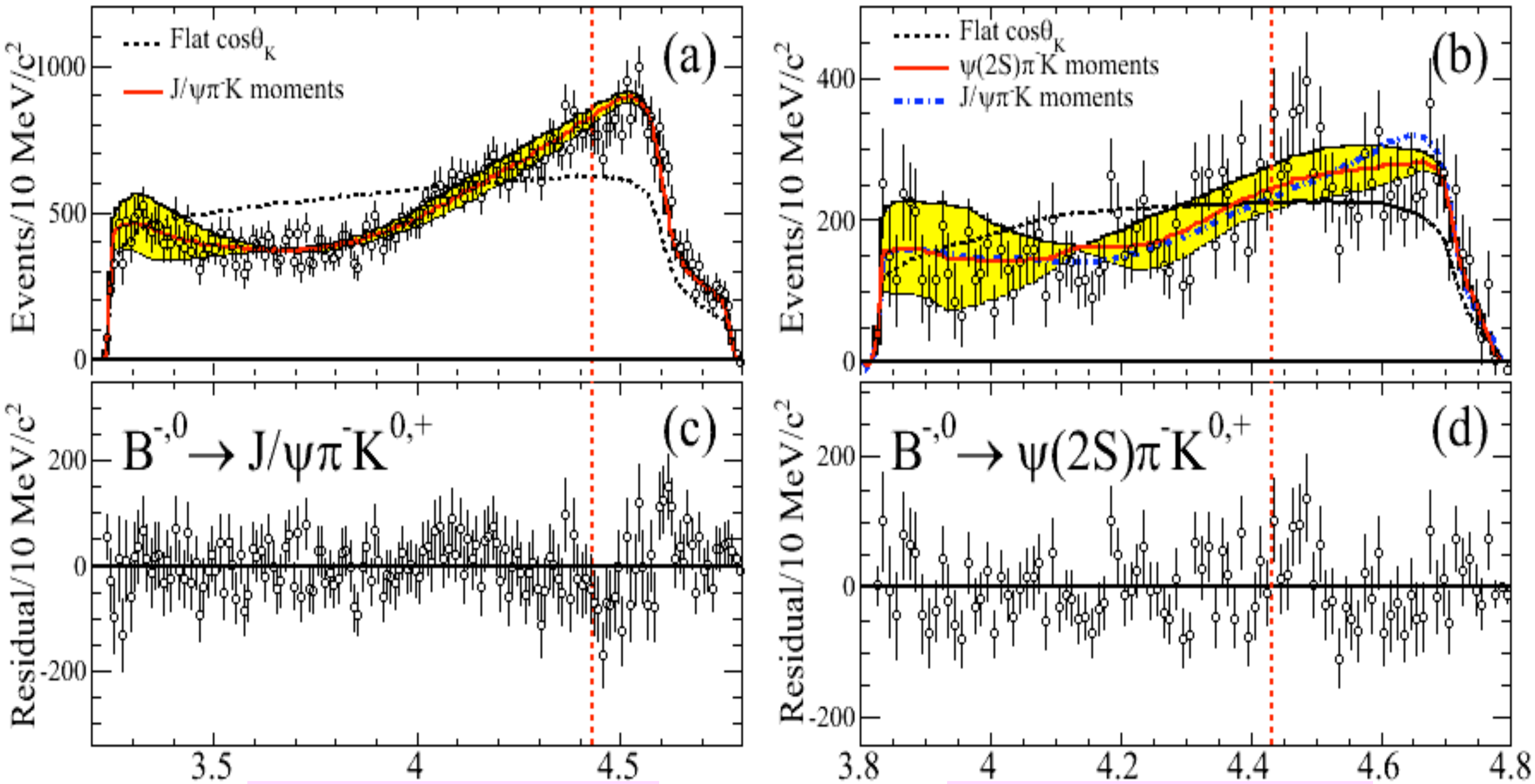
- Correct the data for efficiency event-by-event across the Dalitz plot, and describe using only Kπ^- S-, P-, and D-wave intensity contributions

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

We will use "ψ" to denote "J/ψ or ψ(2S)" unless otherwise indicated

The corrected $m_{\psi\pi}$ - distributions

All Kπ mass values



$m_{J/\psi\pi^-}$ (GeV/c^2)

$m_{\psi(2S)\pi^-}$ (GeV/c^2)

The $K\pi^-$ reflections reproduce the data; no evidence for additional structure

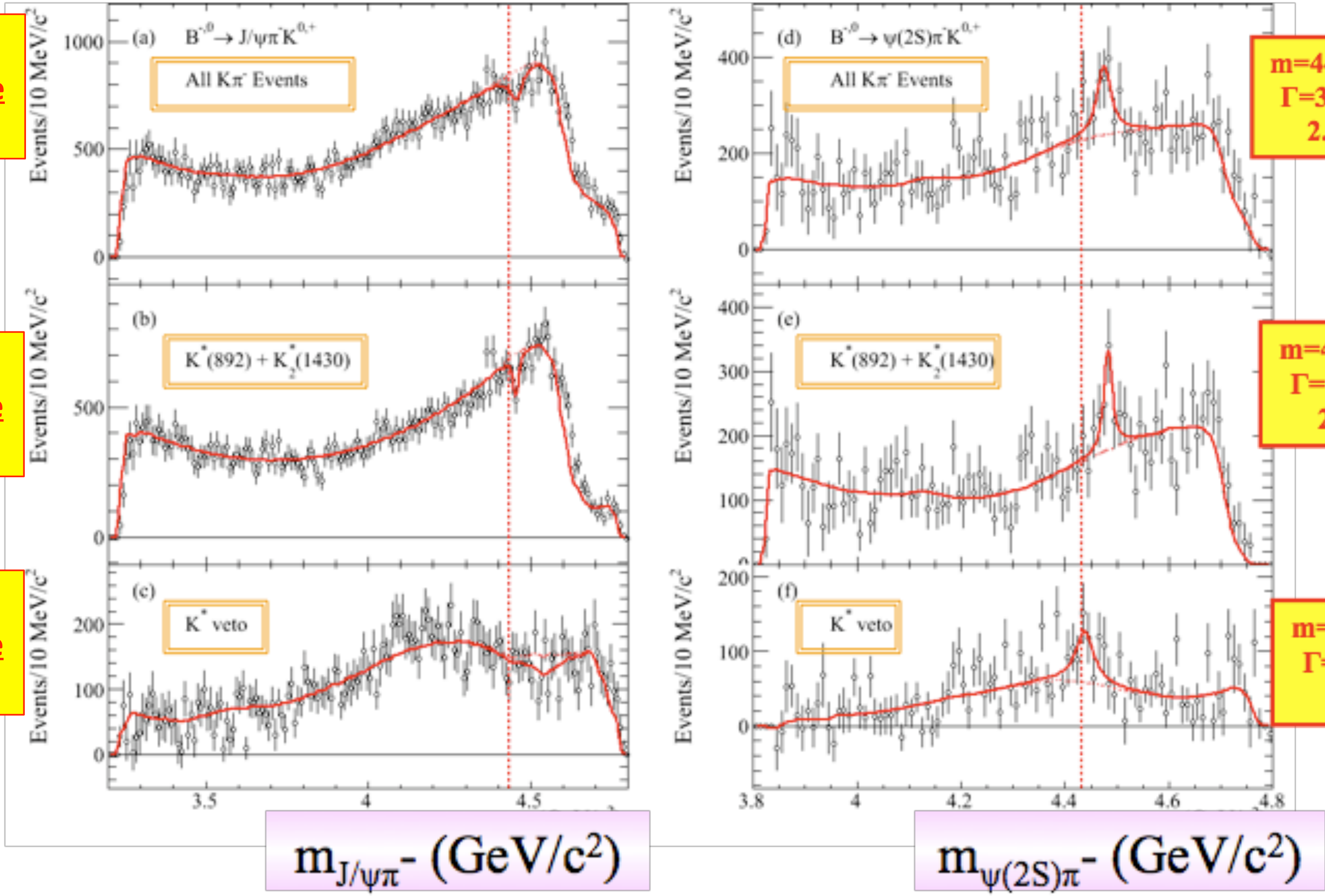
Fit to the ψπ distribution

Four free parameters; m_Z, Γ_Z, N_Z, and $N_{K\pi^-,bkg}$

No or negative signal

No or negative signal

No or negative signal



m=4476±8
Γ=32±16
2.7σ

m=4483±3
Γ=17±12
2.5σ

m=4439±8
Γ=41±33
1.9σ

We conclude that our analyses provide no significant evidence for the existence of the $Z(4430)^-$

Summary of BaBar Z results

- $B \to J/\psi\pi^- K$ (mass & width free) no BW signal is obtained
- $B \to \psi(2S)\pi^- K$ (mass and width free):
  - Shifted mass enhancement for all $K\pi^-$ mass values
  - m=4476±8 MeV/c^2; Γ=32±16 MeV; signal size: 2.7σ
  - Shifted mass enhancement in the $K^*(892)$ and $K^*_2(1430)$ regions: m=4483±3 MeV/c^2; Γ=17±12 MeV; signal size 2.5σ
  - mass enhancement with the K* veto (BELLE SELECTION)
  - m=4439±8 MeV/c^2; Γ=41±33 MeV; signal size 1.9σ

arXiv:0811.0564
Accepted by PRD

Conclusion

- ✓ Charmonium spectroscopy has been revitalized by the discovery of many new states above the open charm threshold.
- ✓ A review of some of these new states has been presented.
- ✓ Many experimental results have been shown, with just enough data to whet the appetite, but at a statistical level which does not permit a clear understanding of the observed signals
- ✓ As always, more data are required, possibly from LHCB, but more reliably from the proposed SuperB projects, should they materialize in the future


Thanks for your
attention

Back up slide