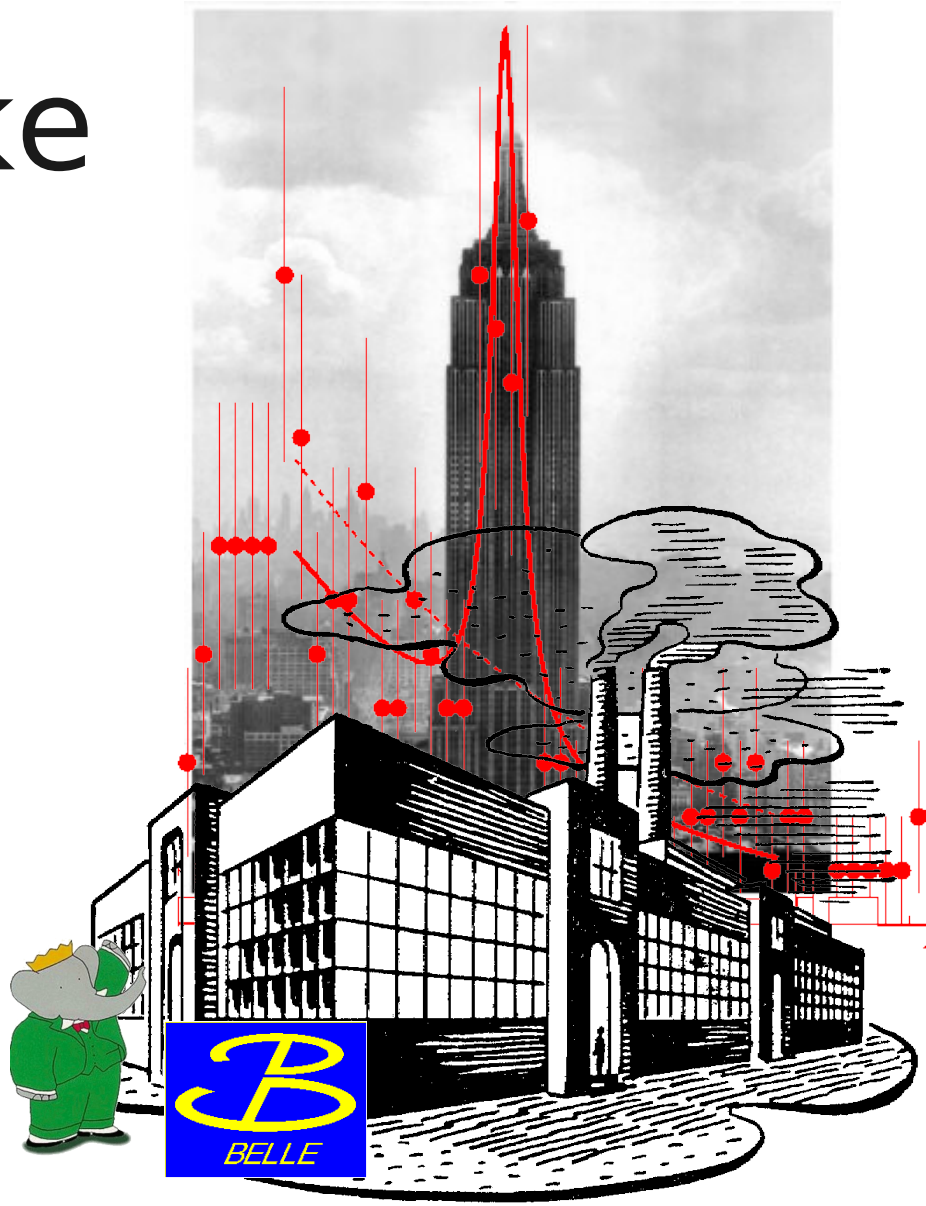
New Charmonium-like States at B-Factories

Thomas Kuhr

for the BaBar and Belle collaborations

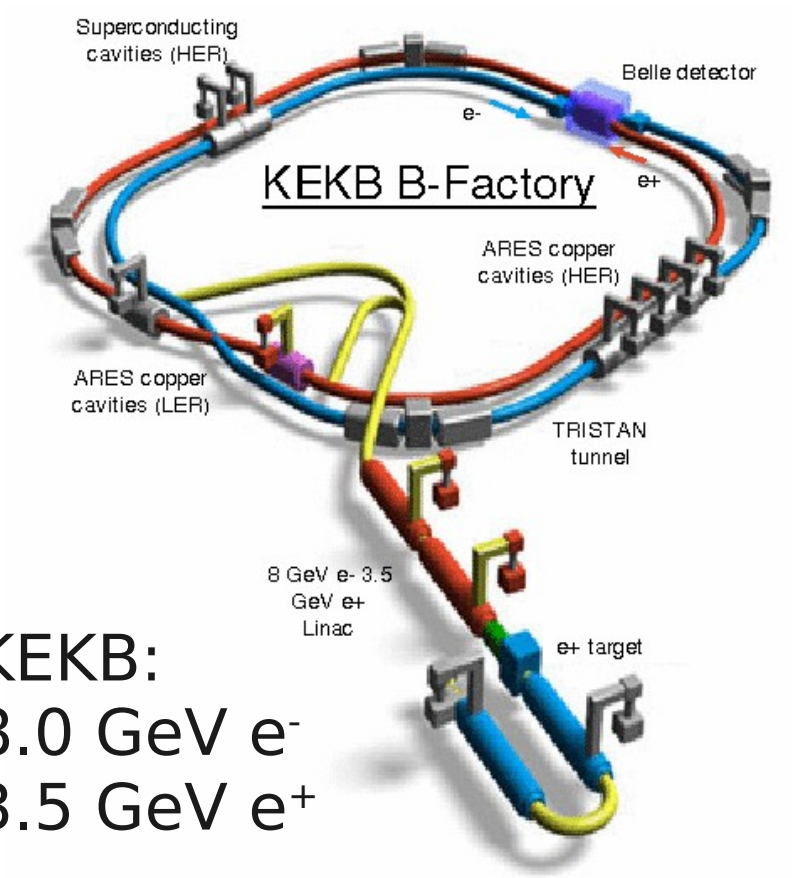
DIS 2009

27.04.2009

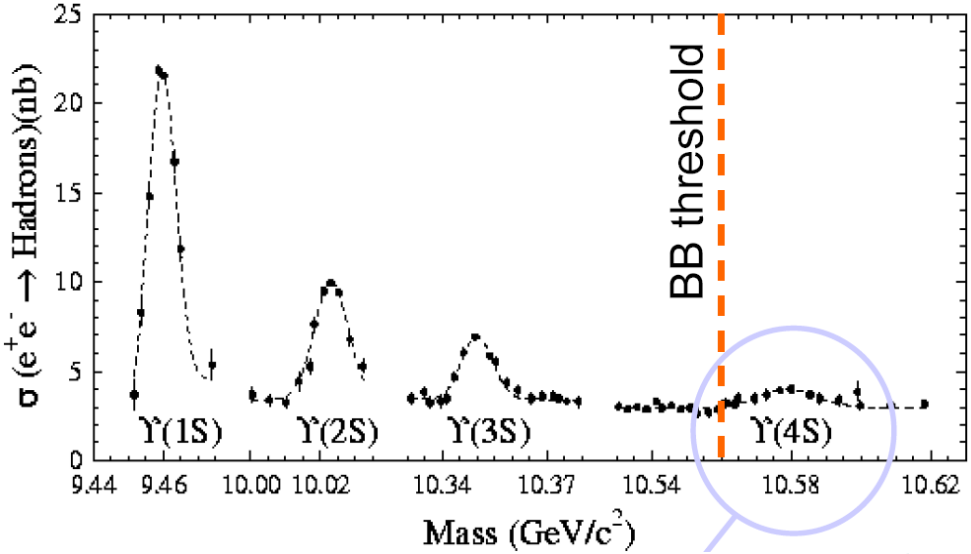


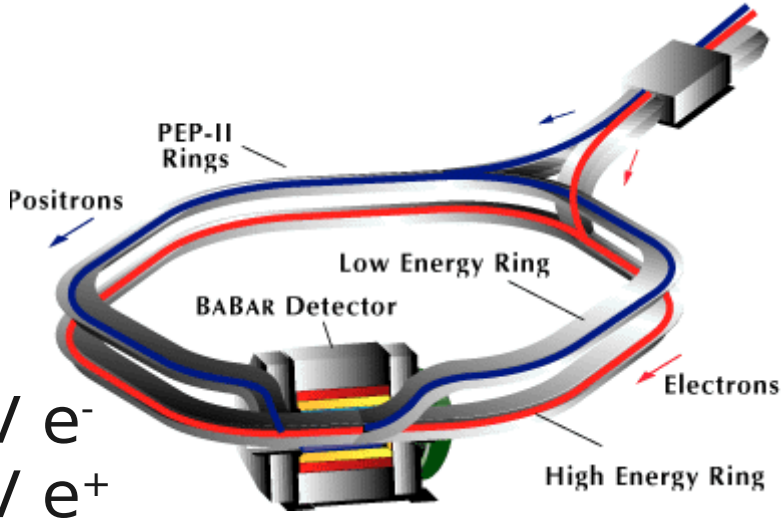
B-Factories

- $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$
- B mesons at rest in CMS



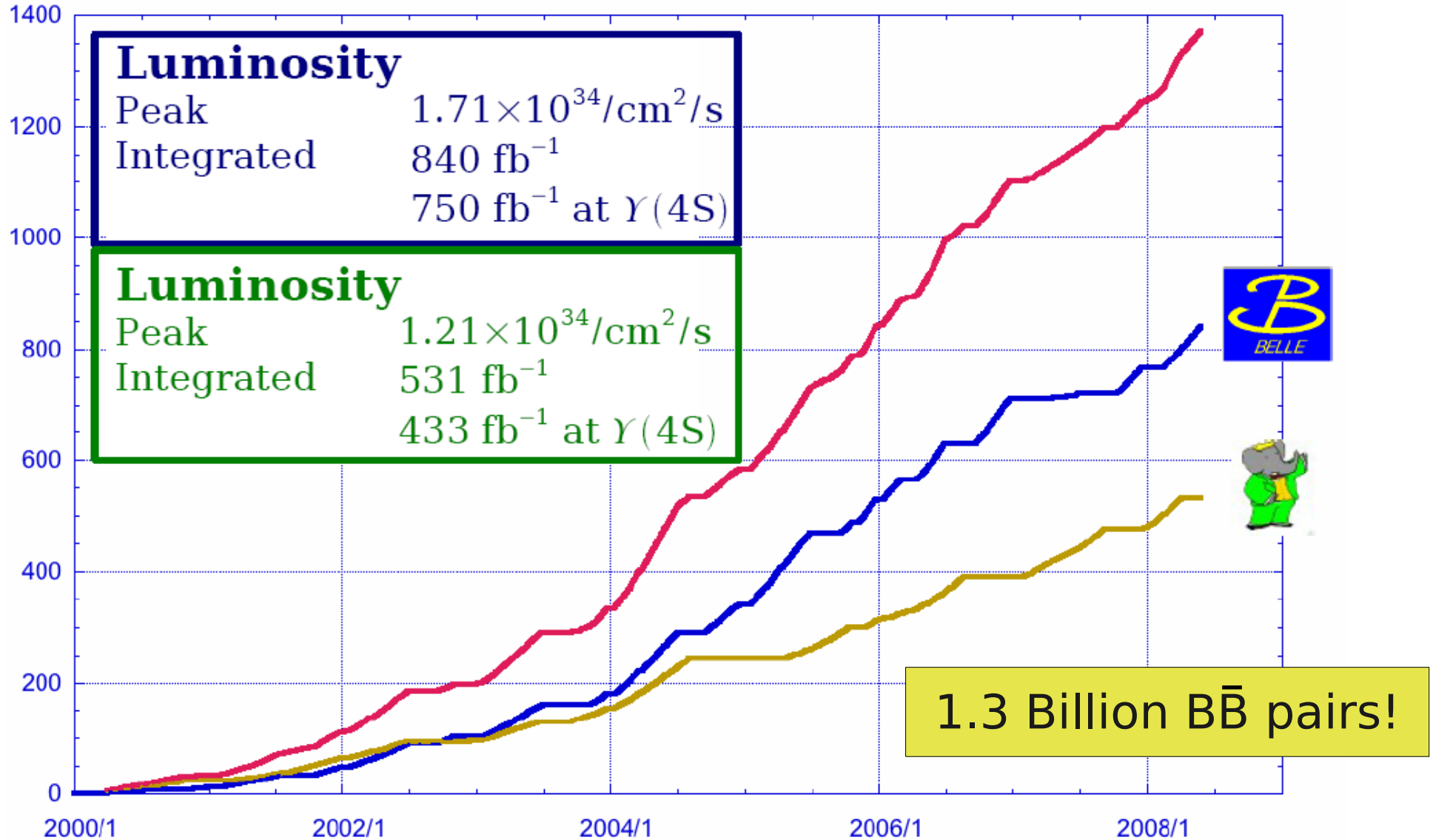
KEKB:
8.0 GeV e^-
3.5 GeV e^+



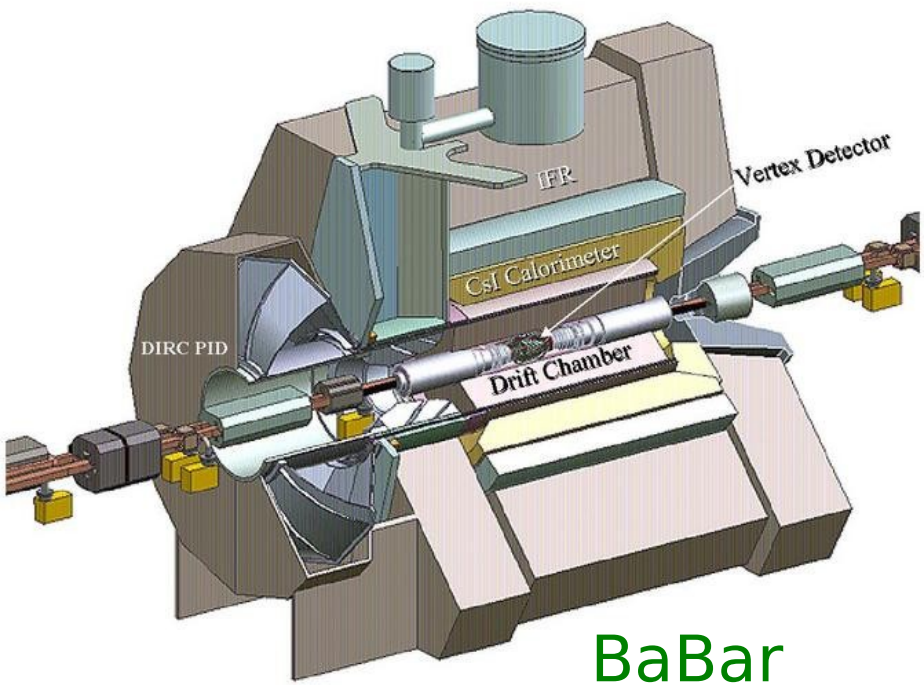


PEP-II:
9.0 GeV e^-
3.1 GeV e^+

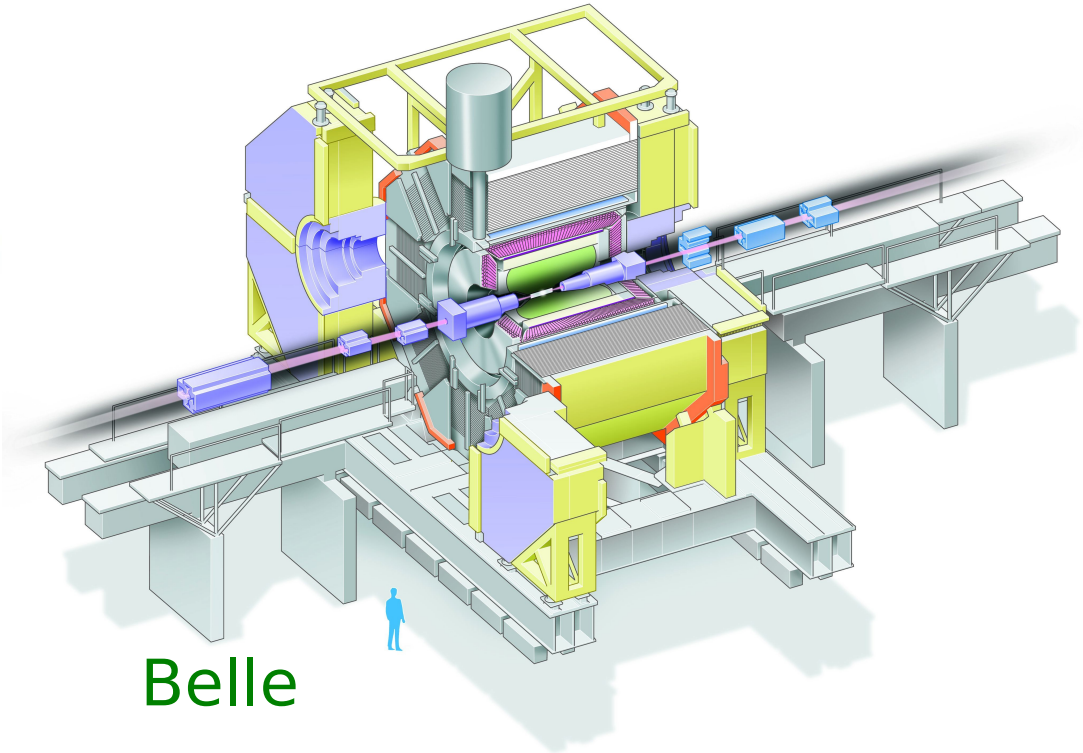
B-Factories Performance



BaBar and Belle Detectors



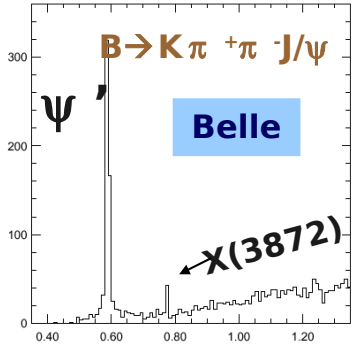
BaBar



Belle

- Silicon tracker + drift chamber → charged particles
- EM calorimeter → photons
- Instrumented flux return yoke → muons, K_L
- dE/dx, ToF, Cherekov → particle identification

New States

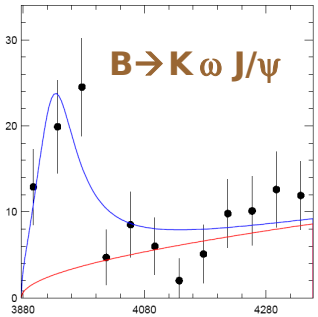


X(3872)

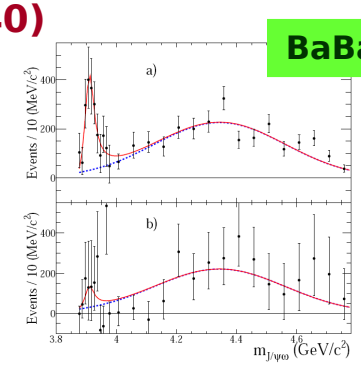
M(π +π -J/ψ) – M(J/ψ)

Belle

Y(3940)

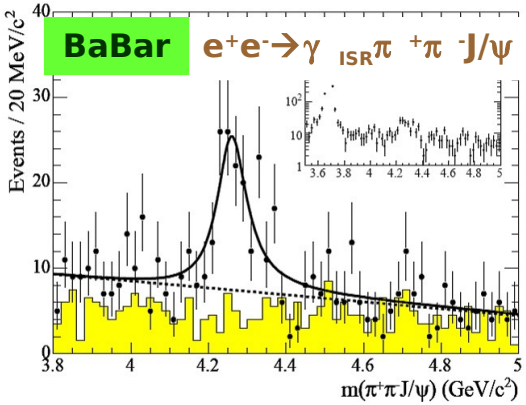


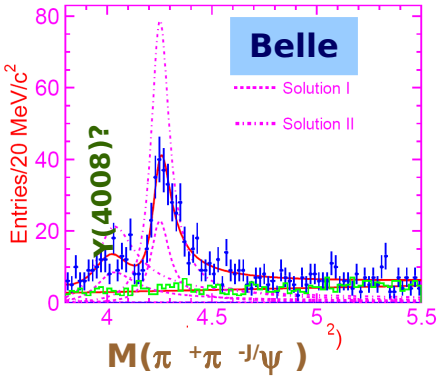
M(ω J/ψ)



M(ω J/ψ)

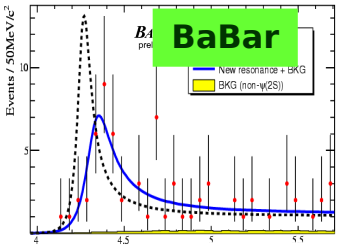
Y(4260)



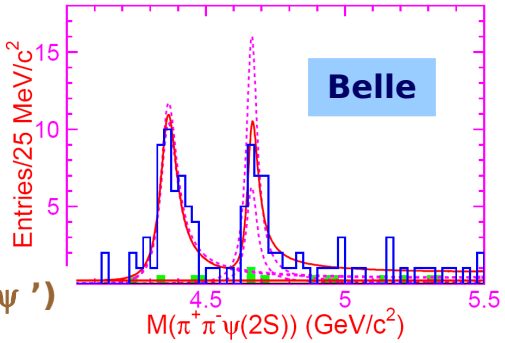


M(π +π -J/ψ)

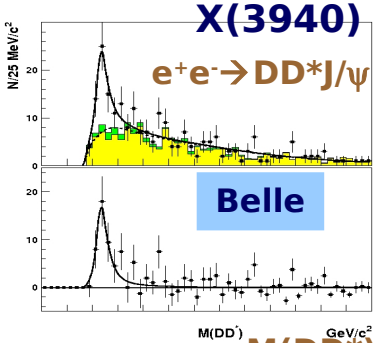
e+e-→γ ISRπ +π -ψ ' Y(4350) & Y(4660)



M(π +π -ψ ')

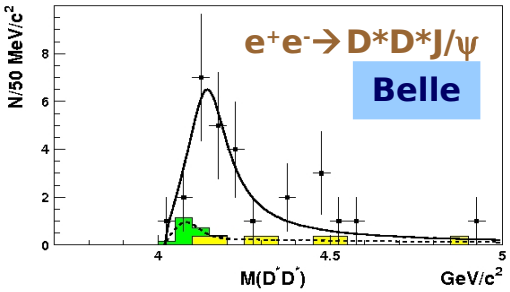


X(3940)

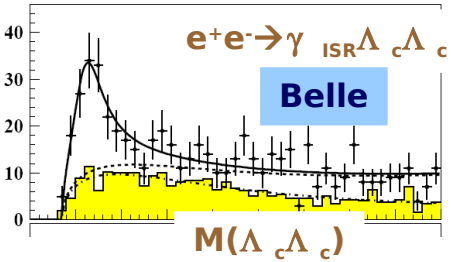


M(DD*)

X(4160)



M(D*D*)

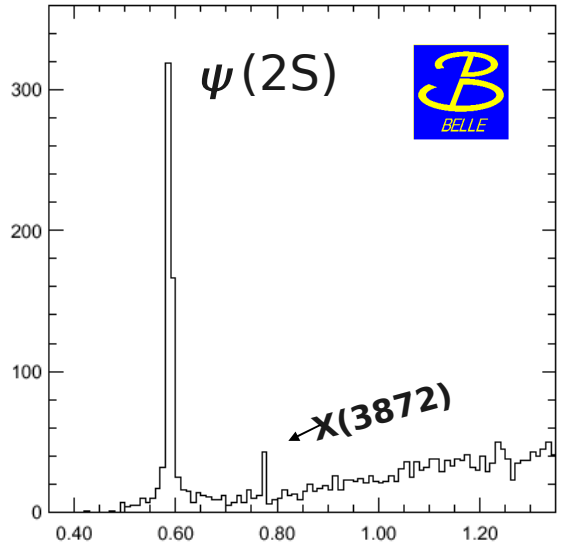


M(Λ cΛ c)

X(3872)

- Discovered 2003 by Belle in $X \to J/\psi\pi^+\pi^-$
- Confirmed by CDF, D0 and BaBar
  - ✓ Narrow resonance (Γ < 2.3 MeV @ 90% CL)
  - ✓ $J^{PC} = 1^{++}$ or 2^{-+}
  - ✓ Observed in B decays and prompt production in $p\bar{p}$

PRL 91, 262001 (2003)



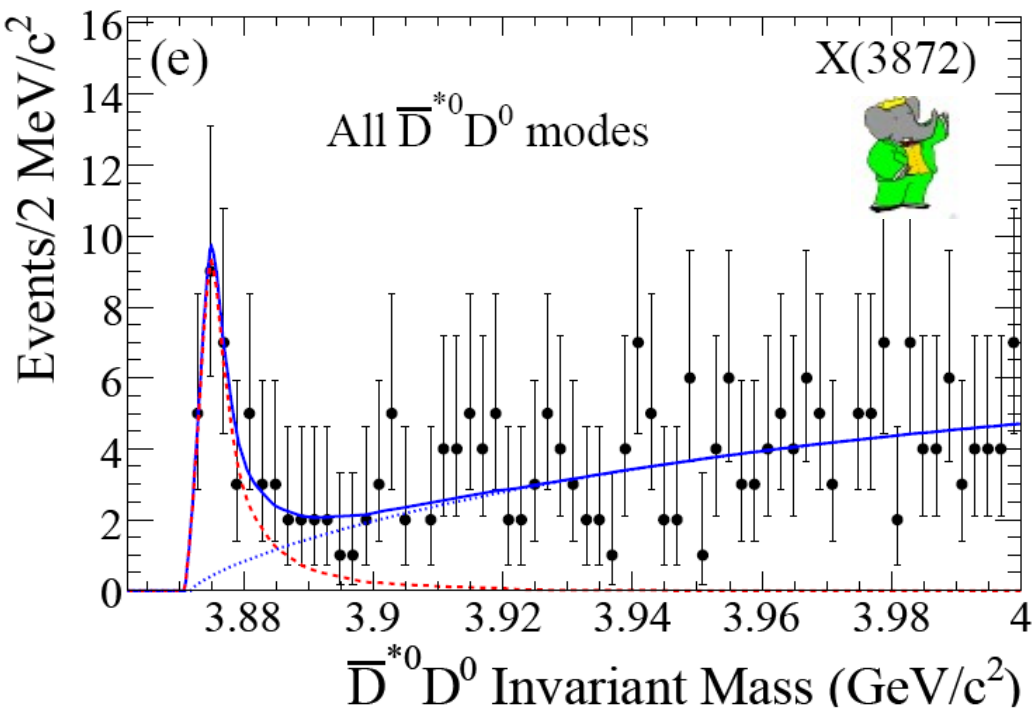
- What is the X(3872)?
  - Charmonium
    - Properties don't fit
  - $D^0\bar{D}^{*0}$ molecule
    - $m(X) \approx m(D^0) + m(D^{*0})$
  - Diquark-antidiquark state
  - $c\bar{c}$-gluon hybrid

$X(3872) \to D^0\bar{D}^{*0}$

- First observation (6.4 σ) by Belle in $B^{+/0} \to D^0\bar{D}^0\pi^0K$

PRL 97, 162002 (2006)

PRD 77, 011102 (2008)

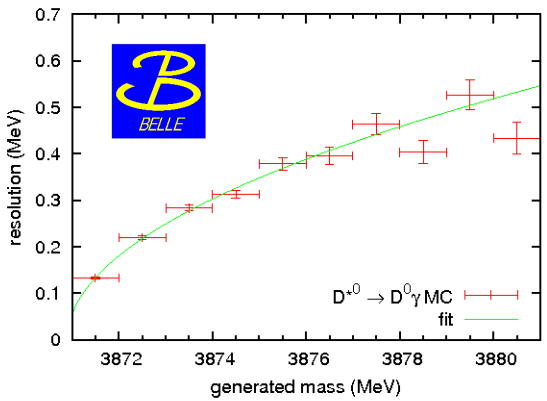


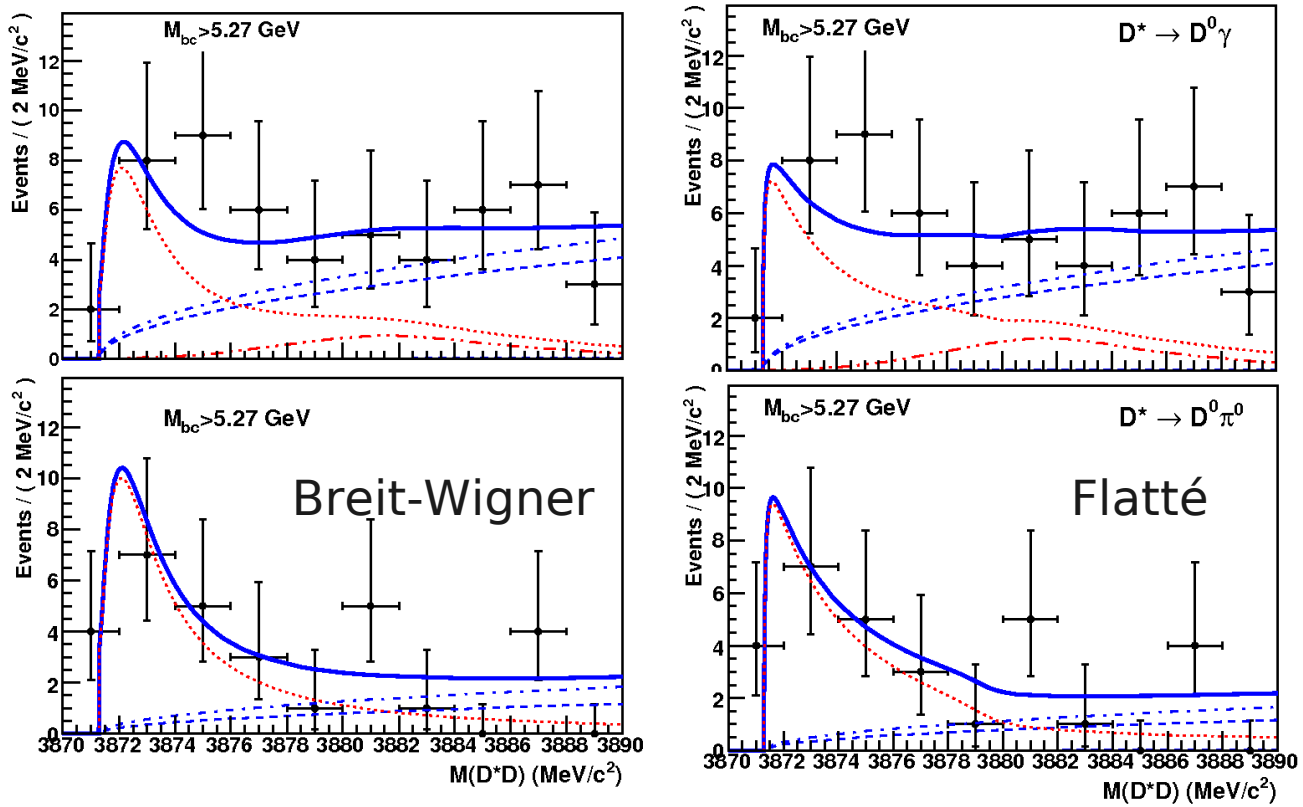
- $B^{+/0} \to D^0\bar{D}^{*0}K$,
  $D^{*0} \to D^0\pi^0/D^0\gamma$
- Significance: 4.9 σ
- Template fit:
  $M = 3875.1\ ^{+0.7}_{-0.5} \pm 0.5$ MeV
  $\Gamma = 3.0\ ^{+1.9}_{-1.4} \pm 0.9$ MeV

$M(X \to J/\psi\pi\pi) =$
3871.46 ± 0.19 MeV
[my average]

$X(3872) \to D^0\bar{D}^{*0}$

hep-ex 0810.0358

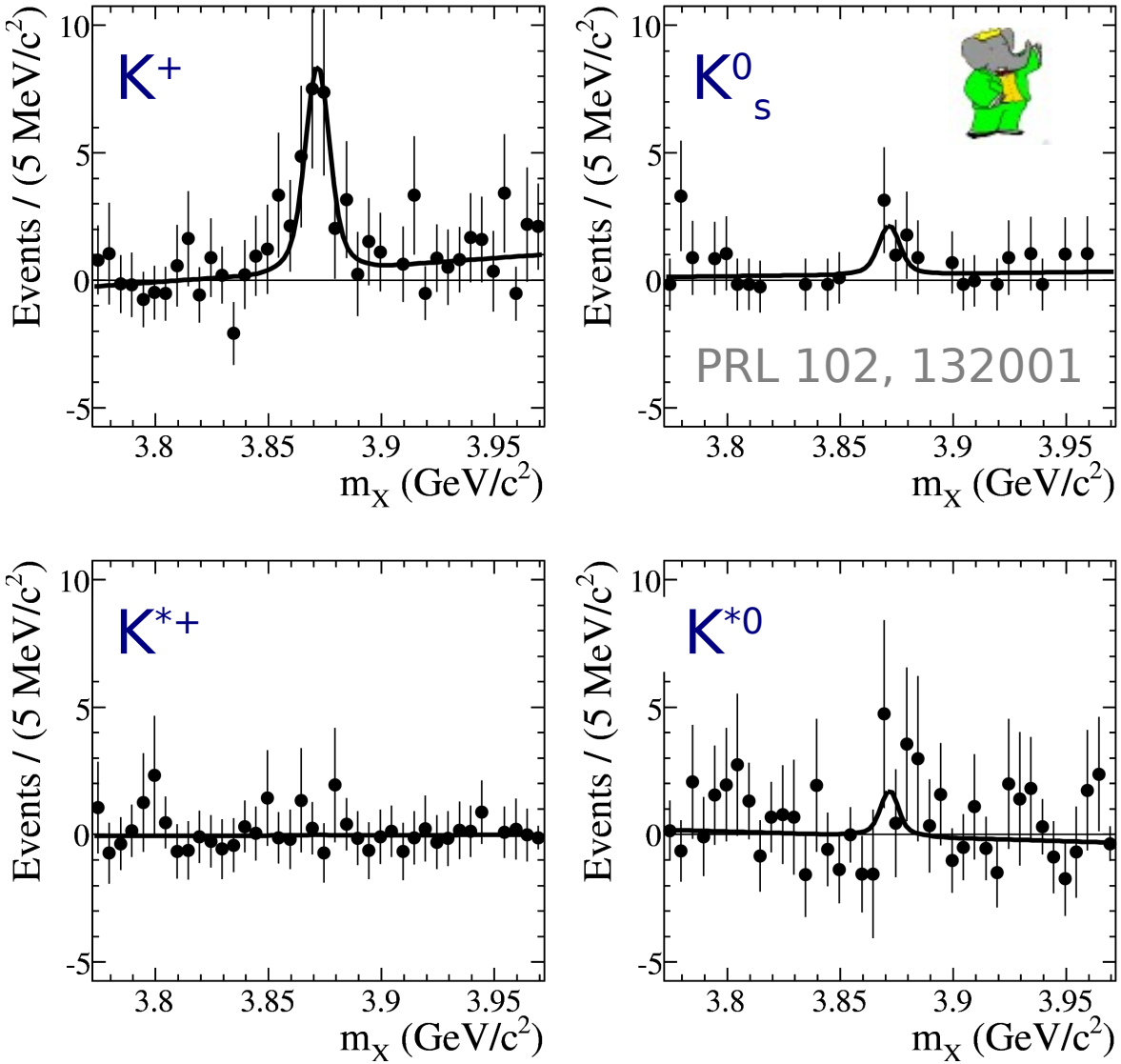




- $B^{+/0} \to D^0\bar{D}^{*0}K$
  $D^{*0} \to D^0\pi^0/D^0\gamma$
- Sig.: 8.8 σ
- Relativistic Breit-Wigner with mass dependent resolution:
  $M = 3872.6\ ^{+0.5}_{-0.4} \pm 0.4$ MeV, $M(X \to J/\psi\pi\pi) = 3871.46 \pm 0.19$ MeV
  $\Gamma = 3.9\ ^{+2.5}_{-1.3}\ ^{+0.8}_{-0.3}$ MeV, $BR(B \to X(D^0D^{*0})K) = (0.73 \pm 0.17 \pm 0.08) \times 10^{-4}$
- Alternative fit with Flatté distribution [PRD 76, 034007]

X(3872) → J/$\psi\gamma$

- Belle: 4.0 σ
  hep-ex 0505037 (2005)
- BaBar: 3.4 σ
  PRD 74, 071101 (2006)
- $B^{+/0} \to J/\psi\gamma K$
- $K = K^+/K^0_s/K^{*+}/K^{*0}$
- Significance: 3.6 σ
- BR($B \to X(J/\psi\gamma)K$) [10^{-6}]:
  - $B^+ \to X(J/\psi\gamma)K^+$:
    2.8 ± 0.8 ± 0.1
  - $B^0 \to X(J/\psi\gamma)K^0$:
    < 4.9 @ 90% CL
  - $B^{+/0} \to X(J/\psi\gamma)K^{*+/0}$:
    < 4.8/2.8 @ 90% CL



$X(3872) \to \psi(2S)\gamma$

PRL 102, 132001 (2009)

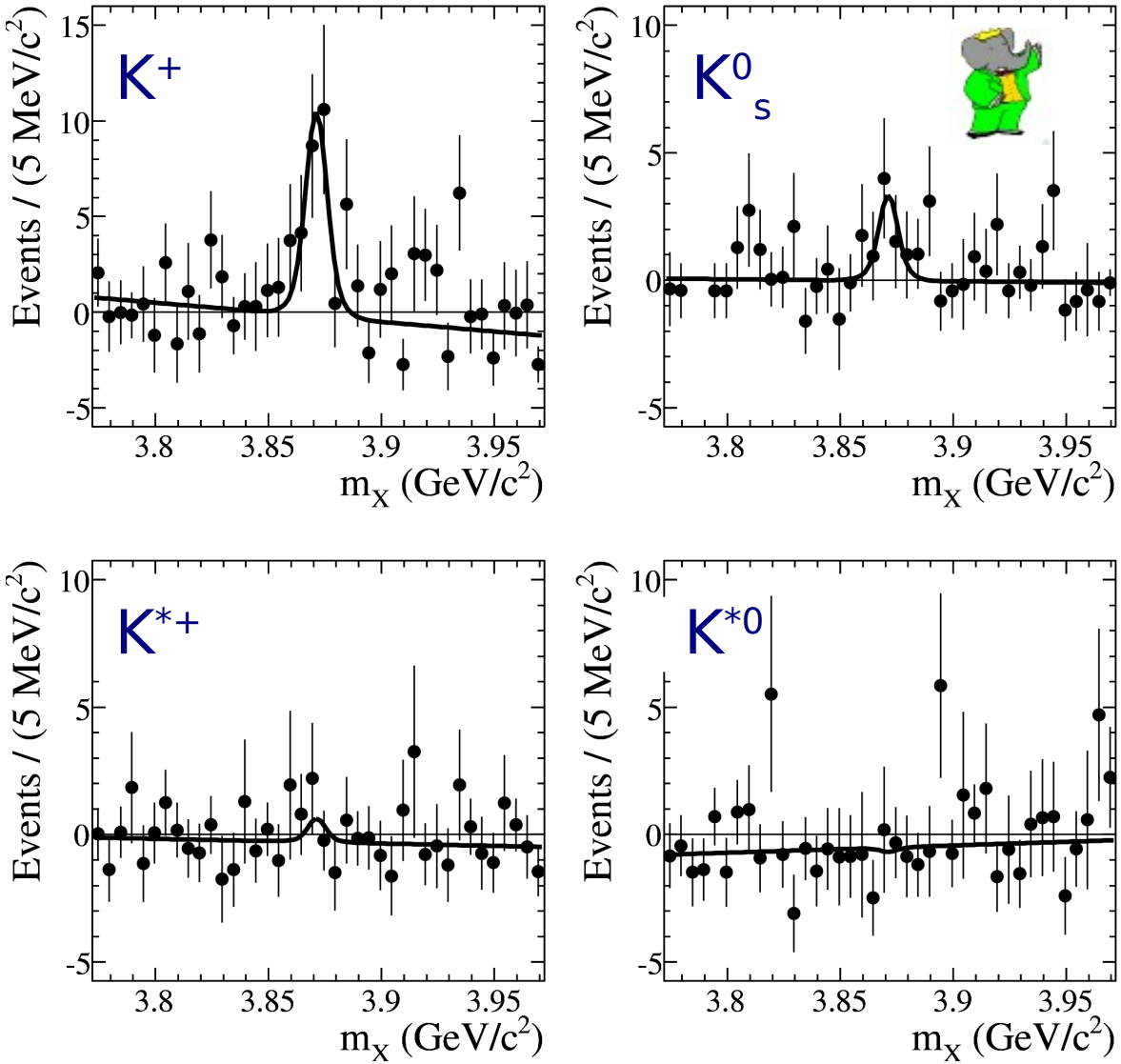
- $B^{+/0} \to \psi(2S)\gamma K$
- $K = K^+/K^0_s/K^{*+}/K^{*0}$

➢ Significance: 3.5 σ

➢ $BR(B^+ \to X(\psi(2S)\gamma)K^+) = (9.5 \pm 2.7 \pm 0.6) \times 10^{-6}$

➔ $BR(X \to \psi(2S)\gamma) / BR(X \to J/\psi\gamma) = 3.4 \pm 1.4$

➔ Molecule model expects < 0.01
[PLB 598:197-202]

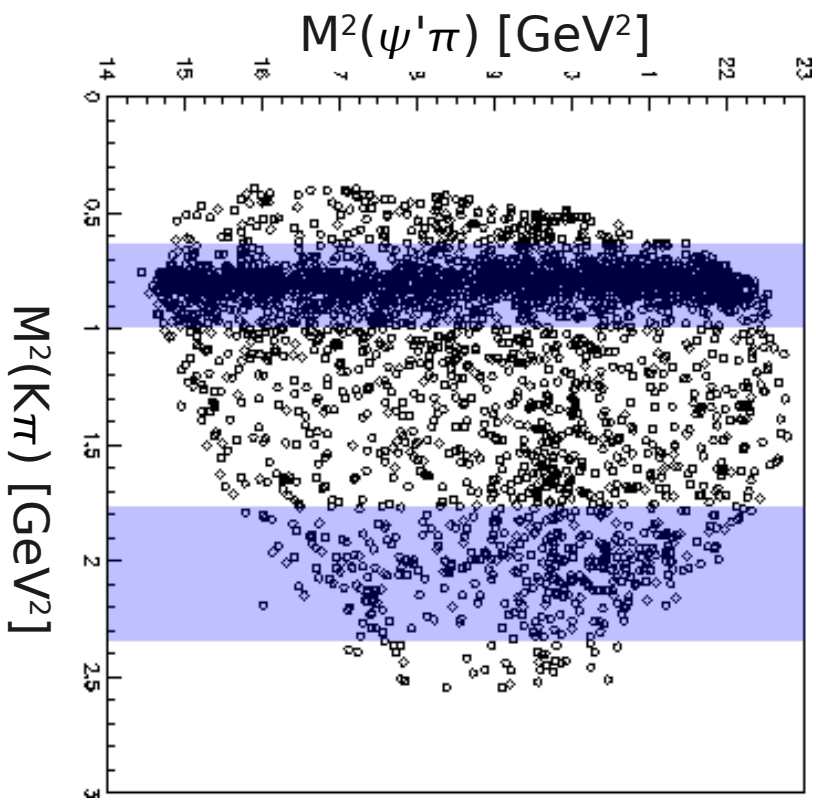


First Observation of Z^+

Definitely not a charmonium!

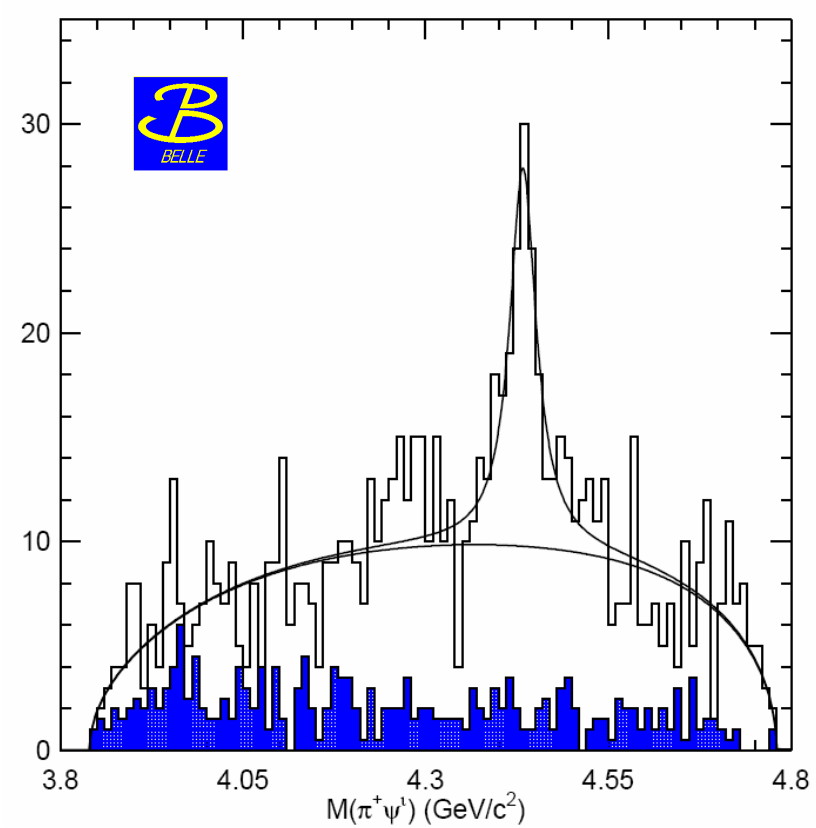
- $B^{+/0} \to \psi(2S)\pi^{\pm}K$, $K = K^+/K^0_s$

PRL 100, 142001 (2008)



K*(890) veto

K*(1430) veto

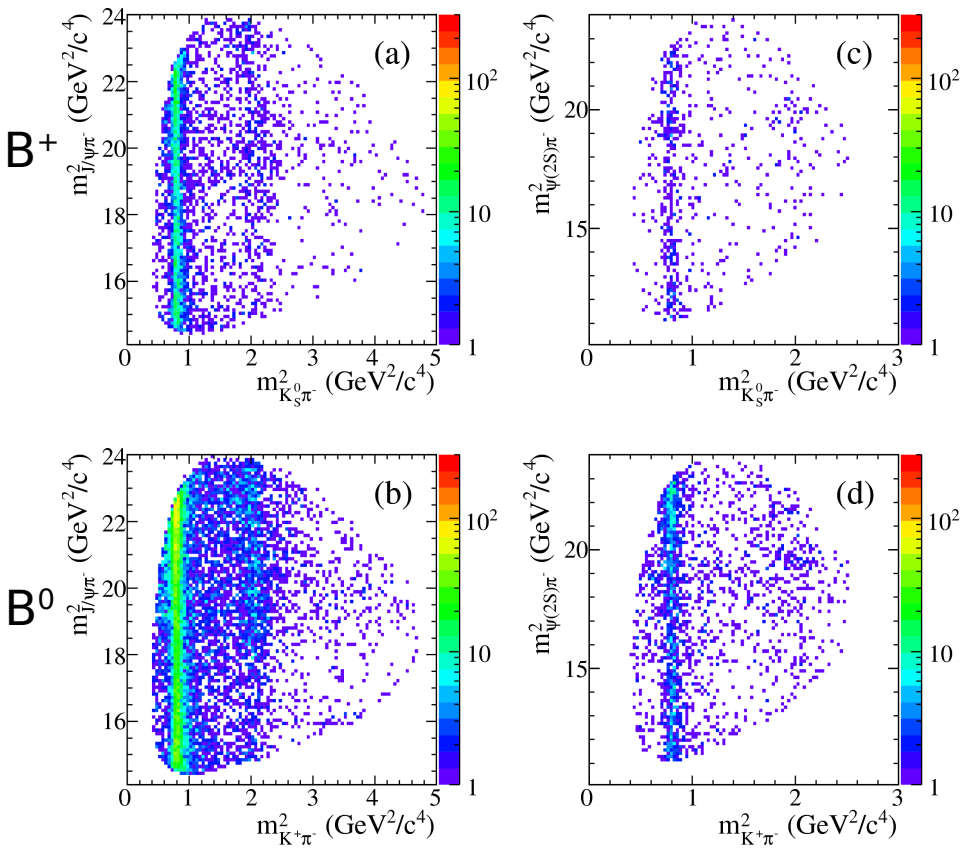


- Significance: 6.5 σ, $BR(B^0 \to Z^+(\psi(2S)\pi)K^-) = (4.1 \pm 1.0 \pm 1.4) \times 10^{-5}$
- $M = 4433 \pm 4 \pm 2$ MeV, $\Gamma = 45^{+18}_{-13}{}^{+30}_{-13}$ MeV

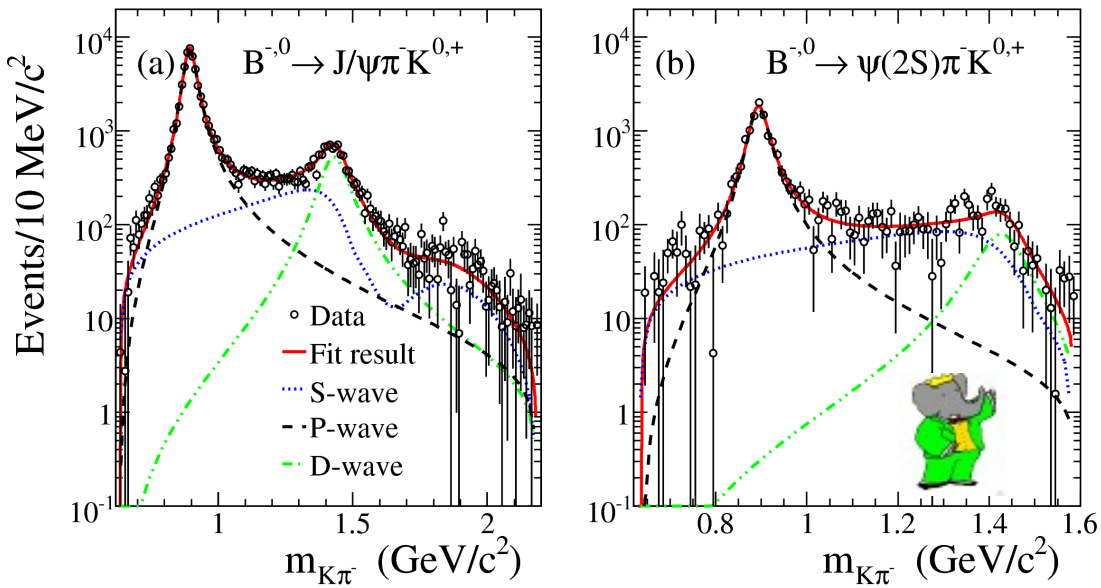
Search for Z^+ at BaBar

- Detailed analysis of $B \to J/\psi\pi^{\pm}K$ and $\psi(2S)\pi^{\pm}K$

hep-ex 0811.0564

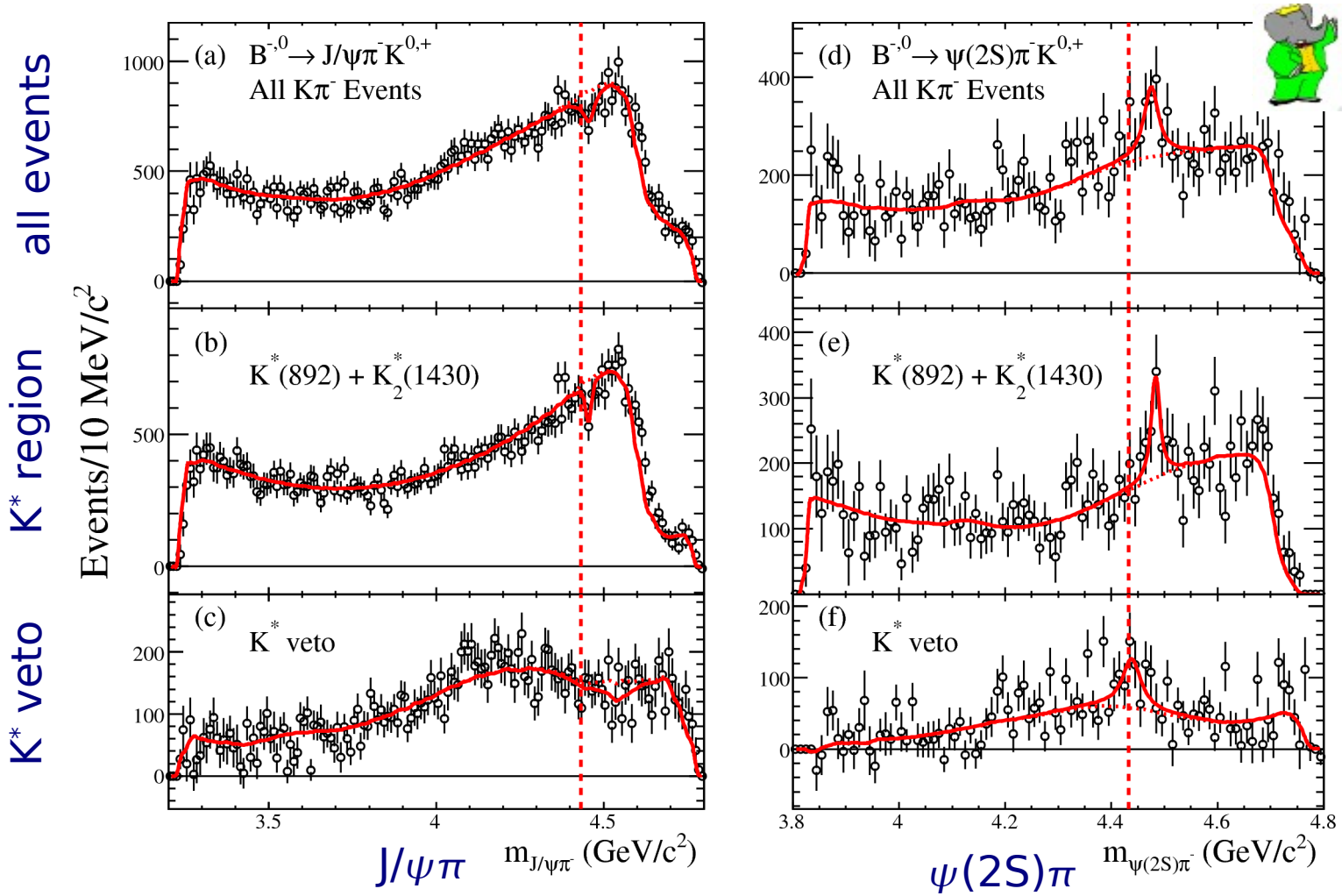


- ✔ $K\pi$ spectrum well described by S, P and D waves



- ➔ $K\pi$ composition and angular distr. affect $\psi\pi$ spectrum, but can't create narrow peaks

Search for Z^+ at BaBar



Sig.: 2.7 σ

M = 4476 ± 8 MeV

Γ = 32 ± 16 MeV

Sig.: 2.5 σ

M = 4483 ± 3 MeV

Γ = 17 ± 12 MeV

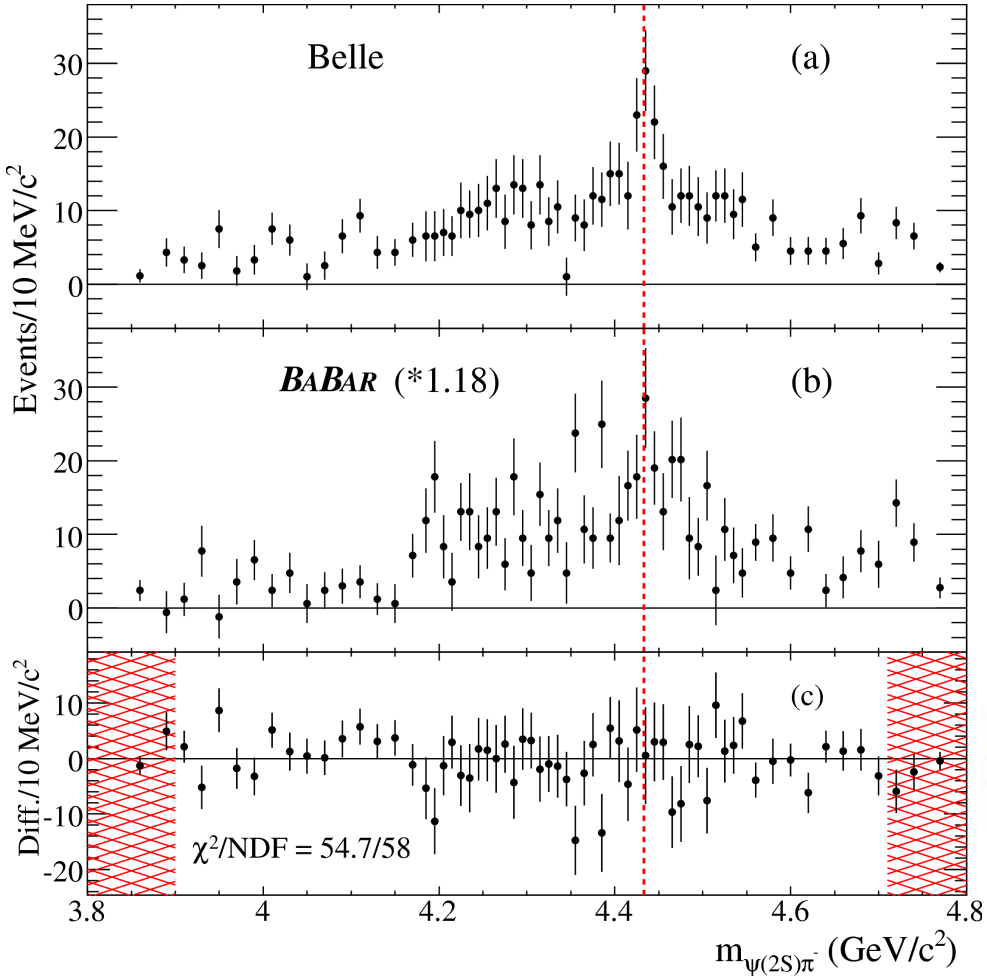
Sig.: 1.9 σ

M = 4439 ± 8 MeV

Γ = 41 ± 33 MeV

No or negative signal No significant signal

Comparison BaBar/Belle

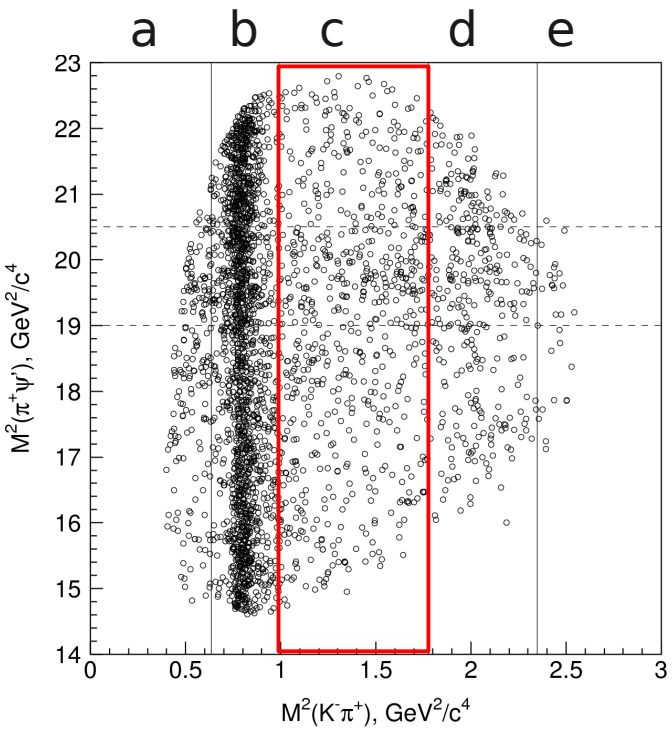


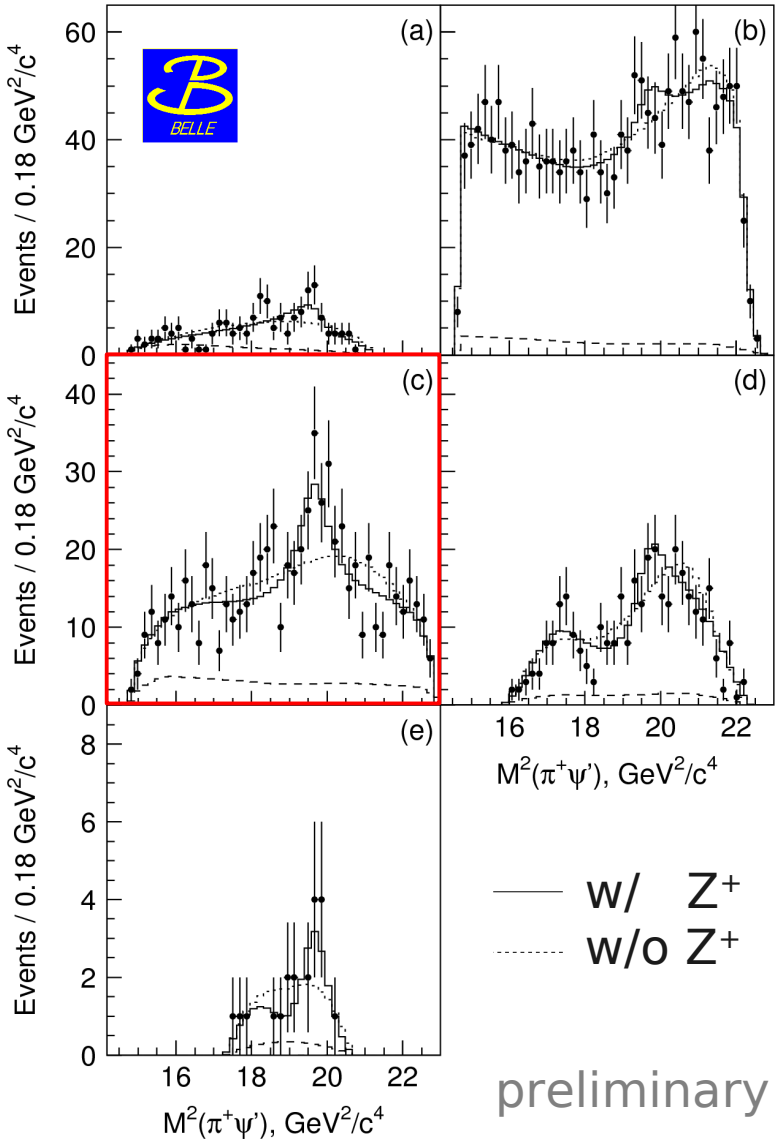
- Comparison of background subtracted distributions with K* veto
- ✔ Statistically consistent: $\chi^2/ndf = 54.7/58$
- Data sample size:
  - BaBar: 413 fb^{-1}
  - Belle : 605 fb^{-1}

- $BR(B^0 \to Z^+(\psi(2S)\pi^+)K^-)$ [10^{-5}]: BaBar : < 3.1 @ 95% CL
  Belle : 4.1 ± 1.0 ± 1.4 (K^* veto)

Z^+ Dalitz Analysis at Belle

- Dalitz plot analysis with
  κ,
  $K^*(892)$,
  $K^*(1410)$,
  $K^*_0(1430)$,
  $K^*_2(1430)$,
  $K^*(1680)$,
  Z^+





➔ Significance: 6.4 σ
5.4 σ with model variations
4.7 σ with 6.8% $K^*_3(1780)$

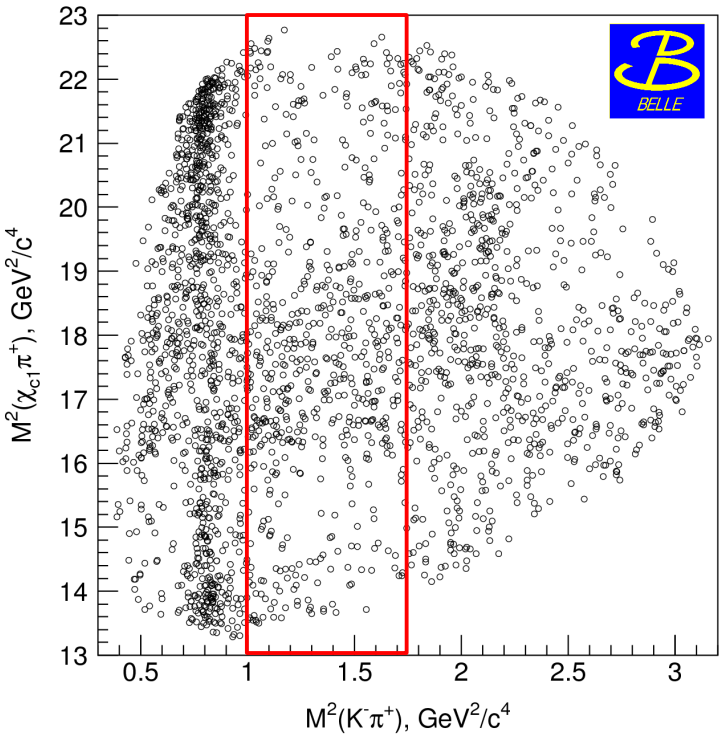
Z^+ Result

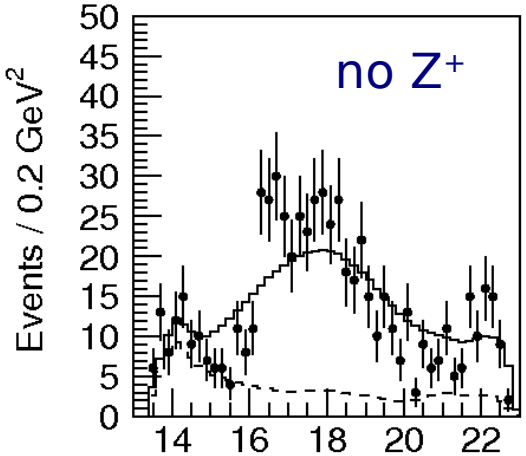
	Sig [σ]	Mass [MeV]	Γ [MeV]	BR [10^{-5}]
K^* veto				
Belle	6.5	$4433 \pm 4 \pm 2$	45^{+18+30}_{-13-13}	$4.1 \pm 1.0 \pm 1.4$
BaBar	1.9	4439 ± 8	41 ± 33	-
No K^* veto				
Belle	6.4	4443^{+15+19}_{-12-13}	107^{+86+74}_{-43-56}	$3.2^{+1.8+5.3}_{-0.9-1.6}$
BaBar	2.7	4476 ± 8	32 ± 16	< 3.1 @ 95% CL

- First Z^+ observation confirmed in Dalitz analysis by Belle
- No confirmation from other experiments so far

More Z^+

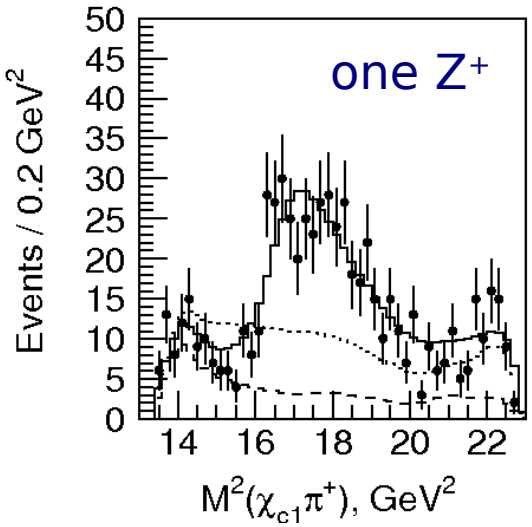
- $\bar{B}^0 \to \chi_{c1}\pi^+K^-$

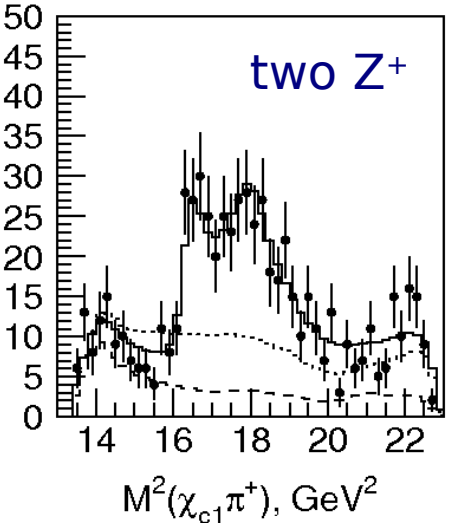




PRD 78, 072004 (2008)

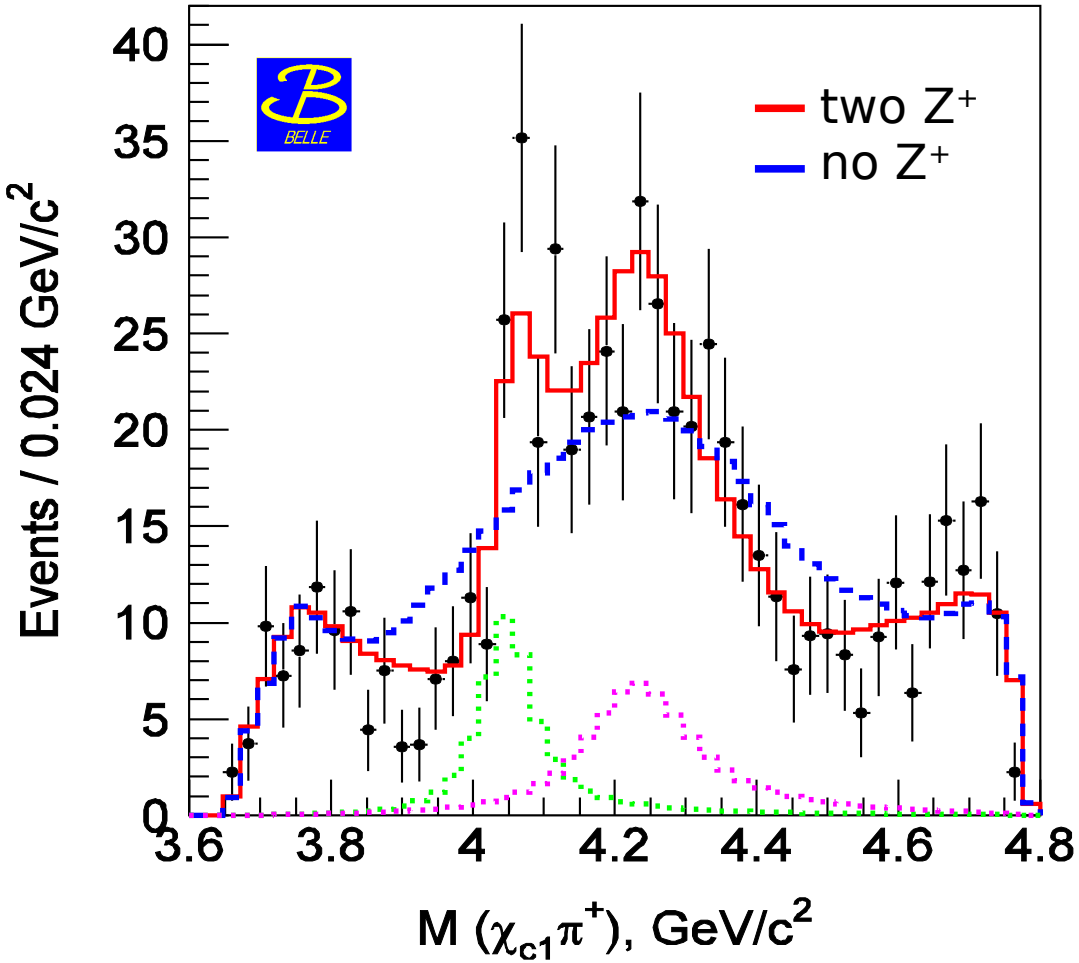
$M^2(K\pi) \in$ [1, 1.75] GeV^2





- Dalitz plot analysis with known $K\pi$ resonances

$Z^+_{1,2}$ Results



- Significance (w/ syst.):
  two Z^+ : 13.2 σ (8.1 σ)
  vs. one Z^+ : 5.7 σ (5.0 σ)
- Mass [MeV]
  Z_1: $4051 \pm 14 \,^{+20}_{-41}$
  Z_2: $4248 \,^{+44}_{-29} \,^{+180}_{-35}$
- Γ [MeV]
  Z_1: $82 \,^{+21}_{-18} \,^{+47}_{-22}$
  Z_2: $177 \,^{+54}_{-39} \,^{+316}_{-61}$
- $BR(B^0 \to Z^+(\chi_{c1}\pi^+)K^-)$ [10^{-5}]
  Z_1: $3.0 \,^{+1.5}_{-0.8} \,^{+3.7}_{-1.6}$
  Z_2: $4.0 \,^{+2.3}_{-0.9} \,^{+19.7}_{-0.5}$

Summary

X(3872)

- Latest Belle measurement of X(3872) mass in DD^* mode agrees with mass in $J/\psi\pi^+\pi^-$ mode
- First evidence for $X(3872) \to \psi(2S)\gamma$ by BaBar

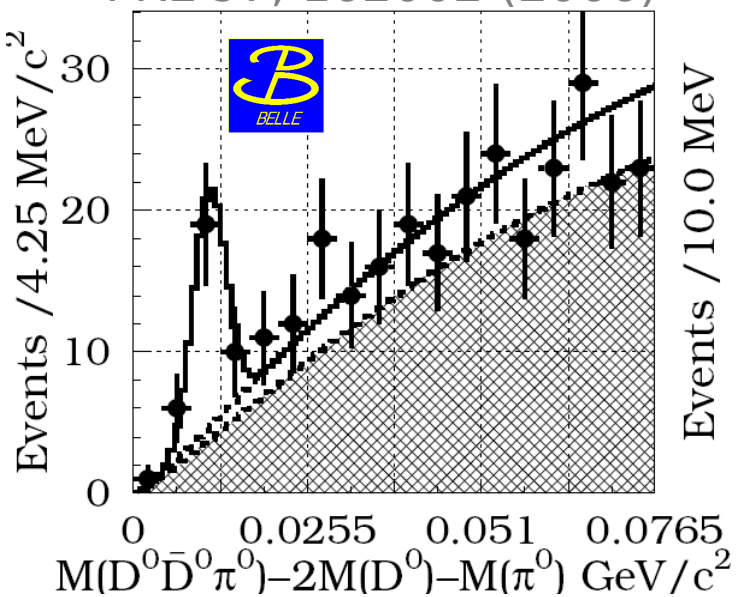
Z^+

- Observation of $Z(4430)^+ \to \psi(2S)\pi^+$ confirmed in Dalitz plot analysis by Belle
- No confirmation by BaBar, no signal in $J/\psi\pi^+$
- Two further charged states $Z(4050/4250)^+ \to \chi_{c1}\pi^+$ observed by Belle

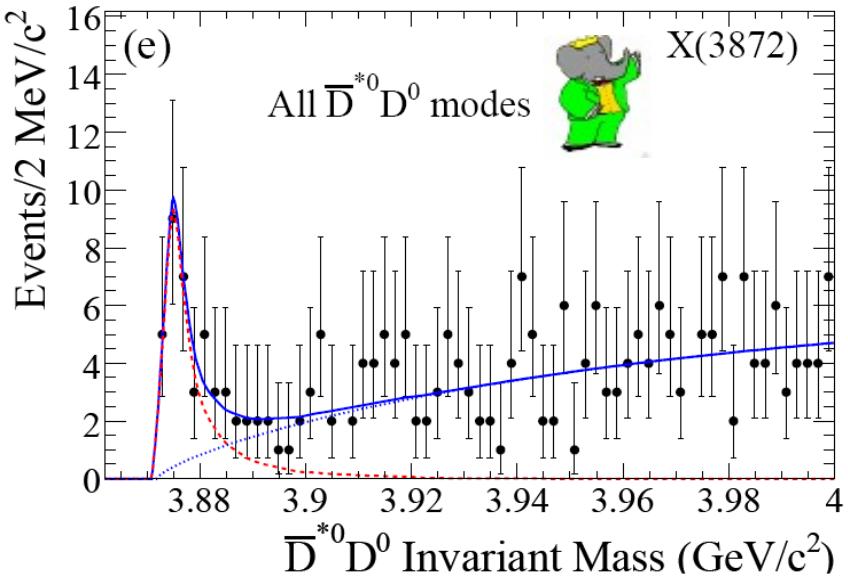
Backup

$X(3872) \to D^0\bar{D}^{*0}$

PRL 97, 162002 (2006)



PRD 77, 011002 (2008)



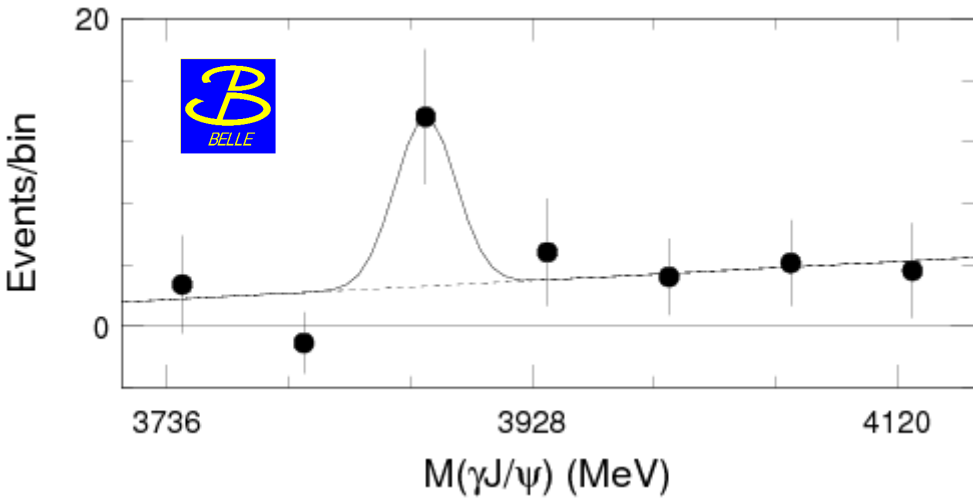
- $B^{+/0} \to D^0\bar{D}^0\pi^0 K$, $K = K^+/K^0_s$
  - Significance: $6.4\ \sigma$
  - Gaussian signal:
    $M = 3875.2 \pm 0.7\ ^{+0.9}_{-1.8}$ MeV

    $M(X \to J/\psi\pi\pi) = 3871.46 \pm 0.19$ MeV

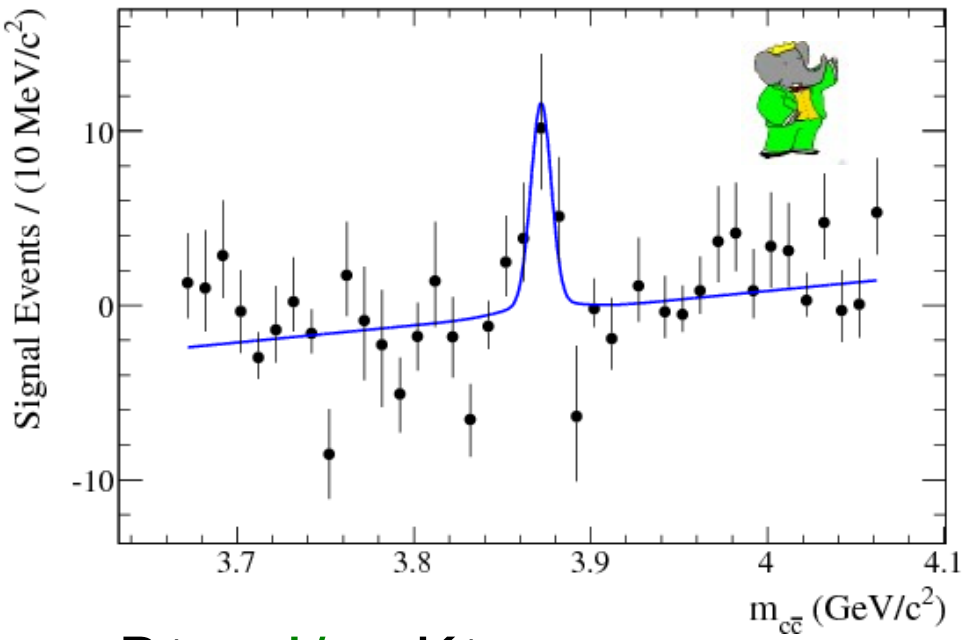
- $B^{+/0} \to D^0\bar{D}^{*0} K$, $D^{*0} \to D^0\pi^0/D^0\gamma$
  - Significance: $4.9\ \sigma$
  - Template fit:
    $M = 3875.1\ ^{+0.7}_{-0.5} \pm 0.5$ MeV
    $\Gamma = 3.0\ ^{+1.9}_{-0.5} \pm 0.5$ MeV

X(3872) → J/ψγ

hep-ex 0505037 (2005)



PRD 74, 071101 (2006)



- $B^{+/0} \to J/\psi\gamma K$, $K = K^+/K^0_s$
  - Significance: 4.0 σ
  - BR(B→X(J/ψγ)K) = $(1.8 \pm 0.6 \pm 0.1) \times 10^{-6}$

- $B^+ \to J/\psi\gamma K^+$
  - Significance: 3.4 σ
  - BR(B^+→X(J/ψγ)K^+) = $(3.3 \pm 1.0 \pm 0.3) \times 10^{-6}$

➔ charge parity C = +1