Recent results for exotic states from Belle

Tagir AUSHEV
For the Belle Collaboration
(EPFL, Lausanne)

Introduction
Belle & KEKB
X(3872)
X(3940), Y(3940), Z(3930)
Y(4140)
Y_b(10580)
Summary

New XYZ states

- Many new states are recently observed/studied by Belle:

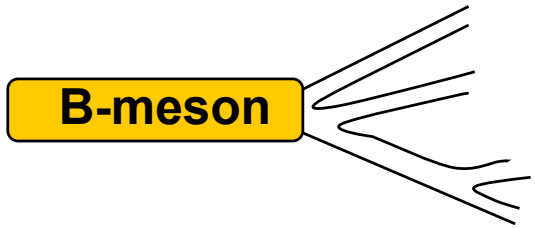
  X(3872), X(3940), Y(3940), X(4160),

  Y(4008), Y(4260), Y(4350), Y(4660),

  Yb(10580), …
- Only few of them will be presented today due to the limited time

XYZ production processes at B-factory Experiments

Hadronic decays of B meson

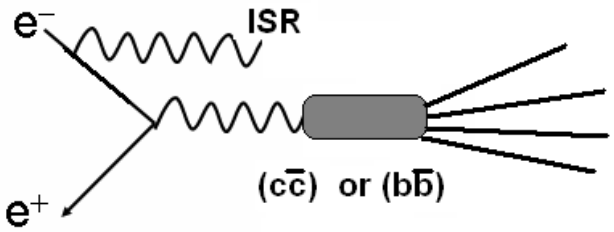


e^+e^- annihilation processes

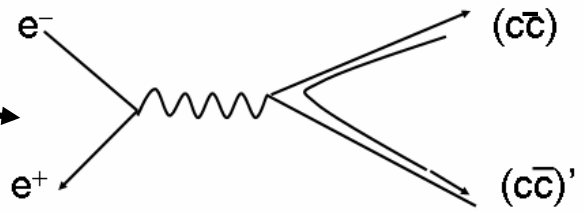
ISR processes

double charmonium production

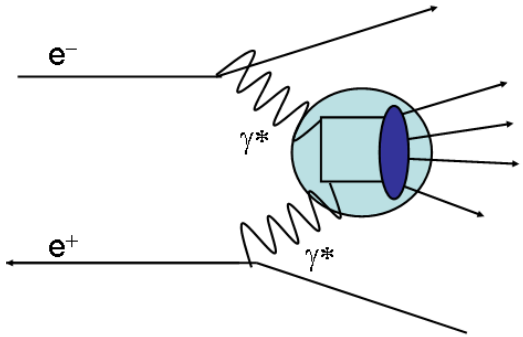
Y(nS) decays



C-odd

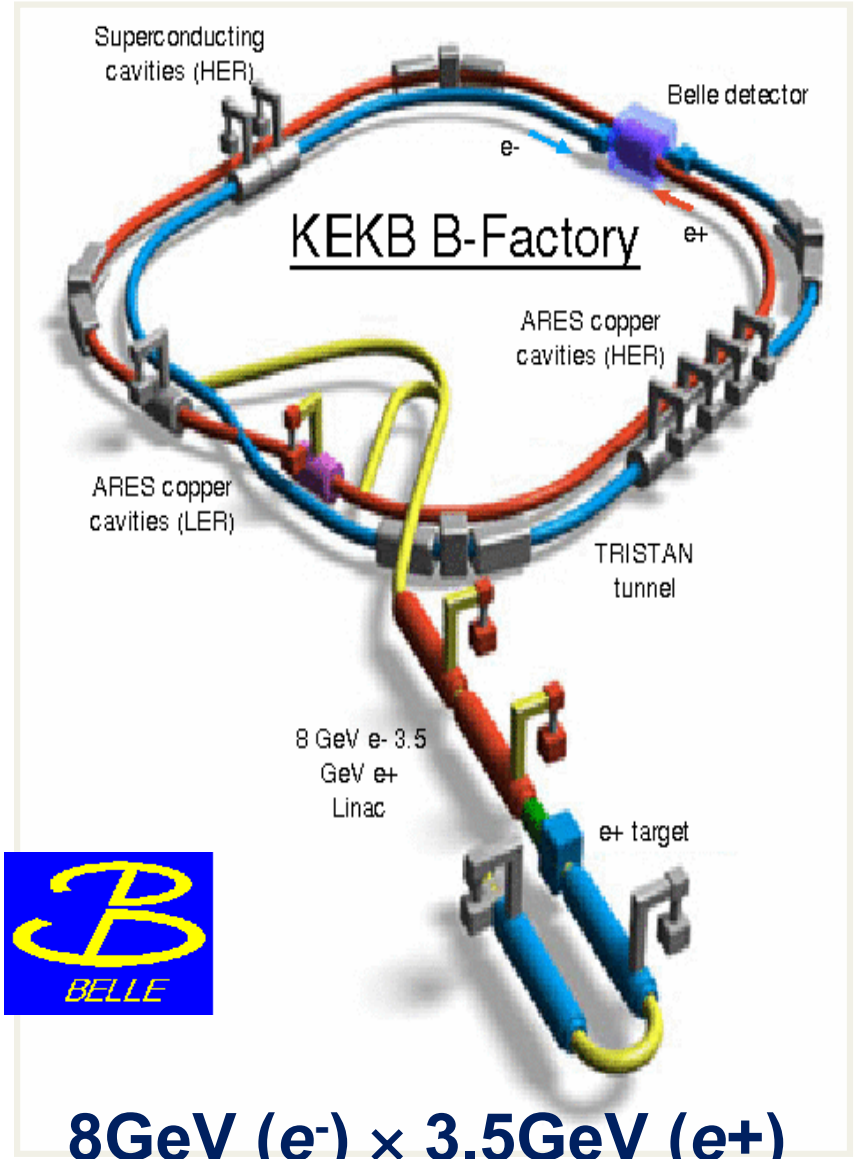


Two-photon collisions

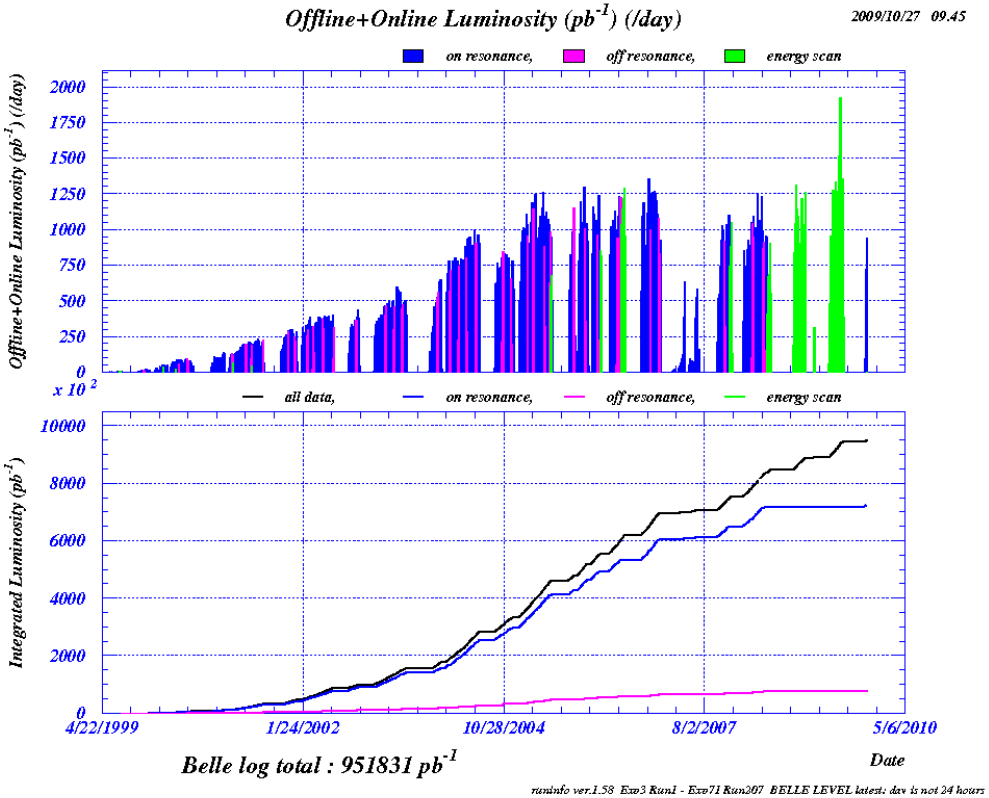


C-even

KEKB B-factory



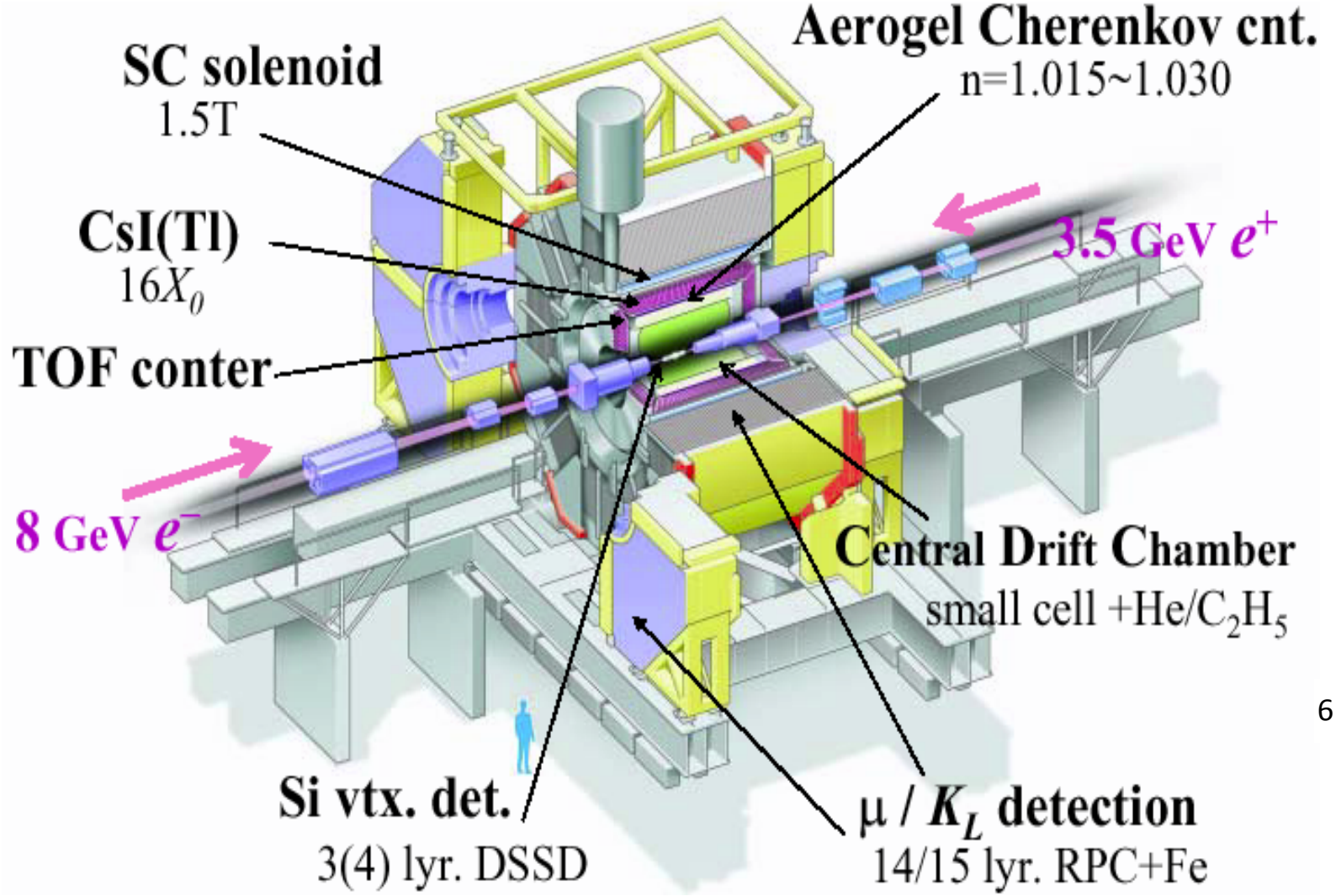
8GeV (e^-) × 3.5GeV (e+)



$$L_{peak} = 2.11 \times 10^{34}\, cm^{-2} s^{-1}$$

$$\int Ldt = (710(4S) + \approx 200)\, fb^{-1}$$

Belle detector



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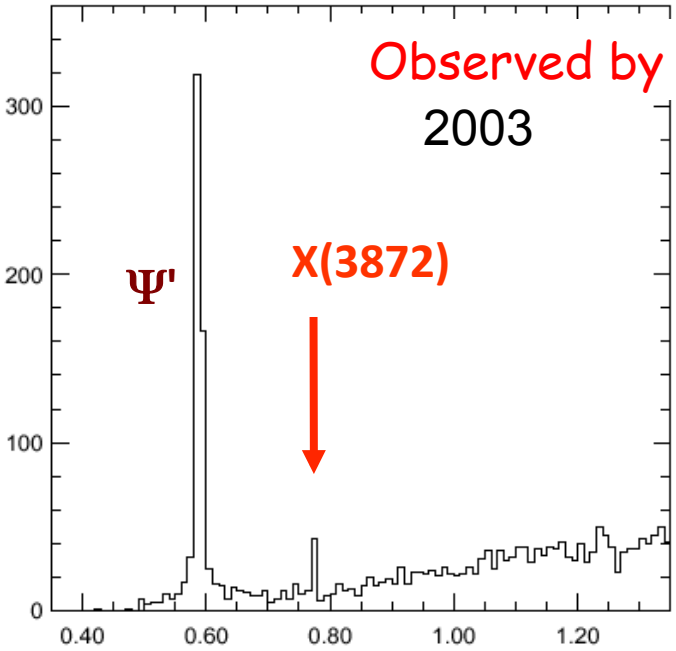
Observation of X(3872)



Confirmed by CDF, D0, BaBar

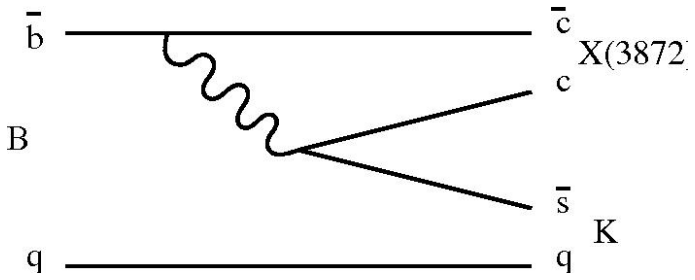
	M(X(3872)), MeV/c²
B→XK	3871.46±0.37±0.07
B→XK	3871.4±0.6±0.1
X→J/ψπ+π-	3871.61±0.16±0.19
Our average	3871.50±0.19
M(D⁰)+M(D*⁰)	3871.81±0.36

Mass of X(3872) is close to *DD** threshold

Not fittable to any known cc-bar states

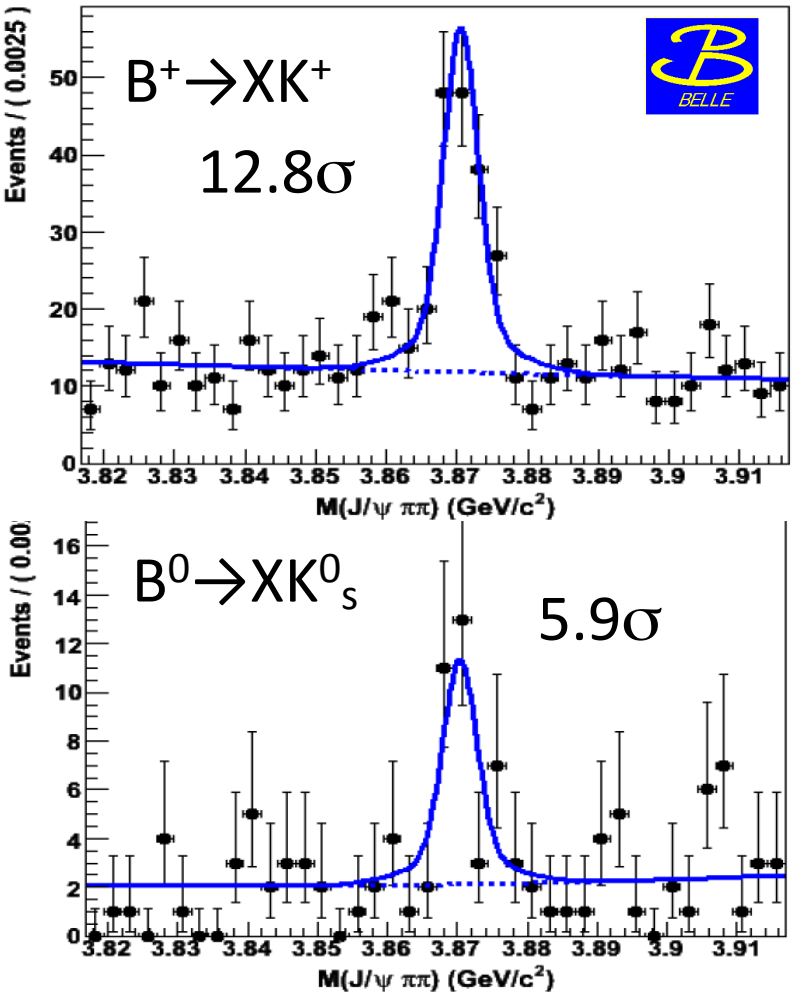
What is it:

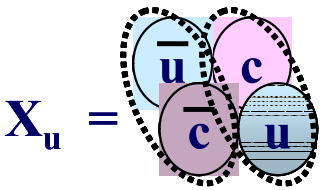
charmonium, *DD**-molecule, tetraquark...?

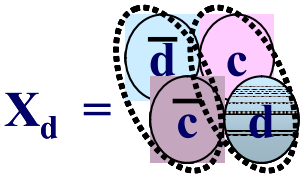


Charged and neutral partners of X(3872)

$X(3872)\to J/\psi\pi^+\pi^-$







diquark-antidiquark models

Xu and Xd from B^0 and B^+ decays

$\Delta M_X = 8\pm3$ MeV

Maiani et al PRD71, 014028

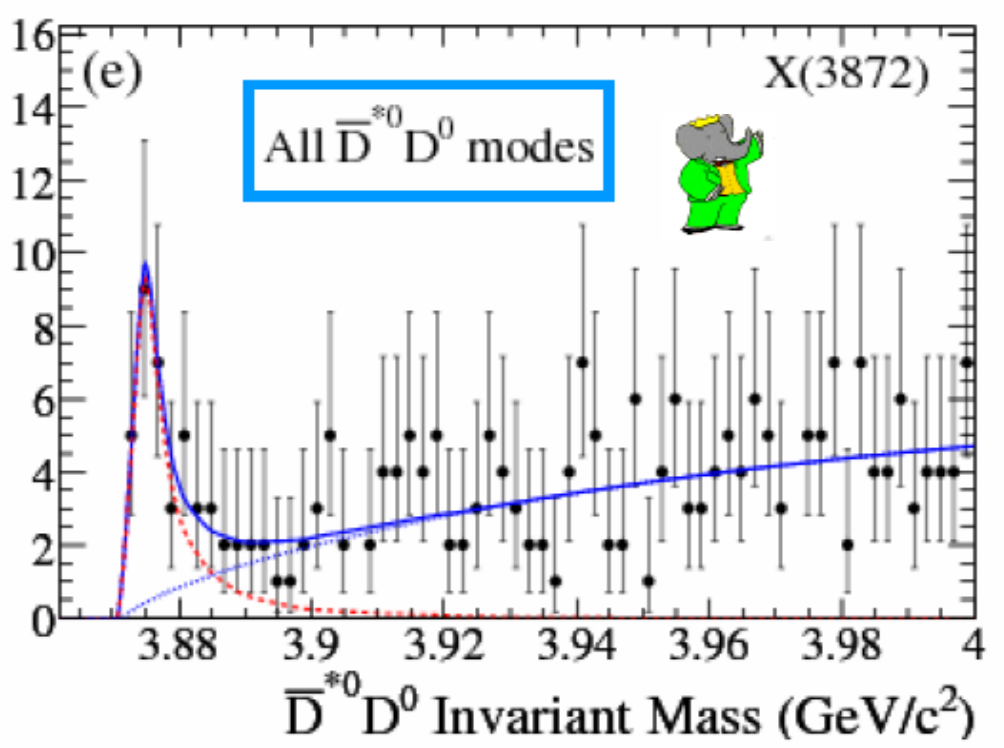
$\Delta M_X = (+0.18\pm0.89\pm0.26)$ MeV/c^2

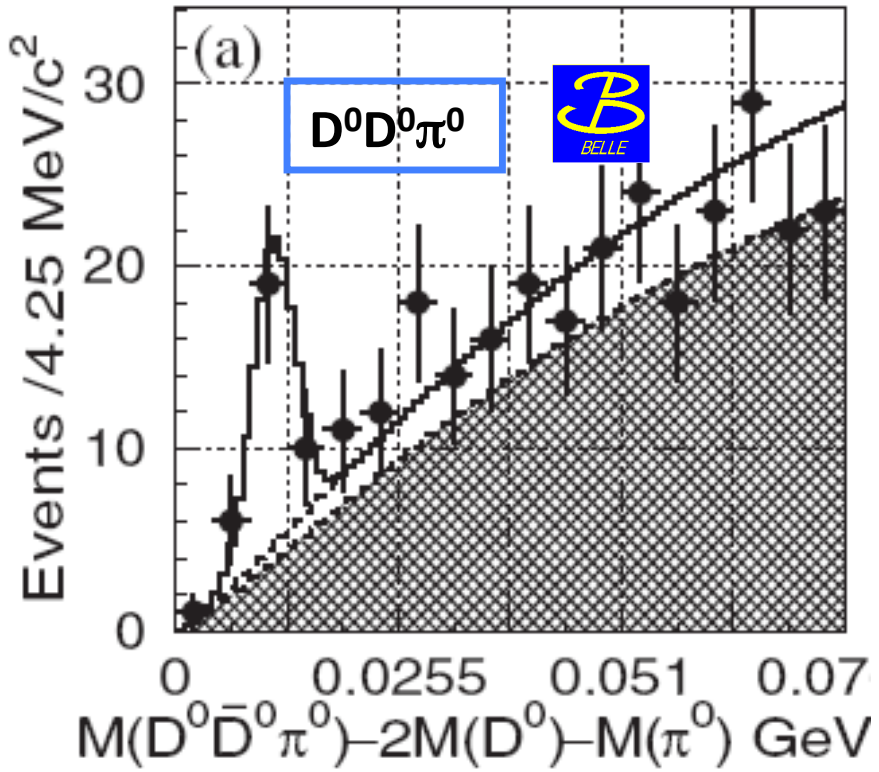
$Br(B^0\to XK^0) / Br(B^+\to XK^+) = 0.82 \pm 0.22 \pm 0.05$

$Br(B^0\to XK^0)\, Br(J/\psi\pi^-\pi^+) = (6.65 \pm 1.63 \pm 1.00)\times10^{-6}$

$Br(B^+\to XK^+)\, Br(J/\psi\pi^-\pi^+) = (8.10 \pm 0.92 \pm 0.66)\times10^{-6}$

BaBar & Belle see a DD* threshold enhancement in B→KDD*



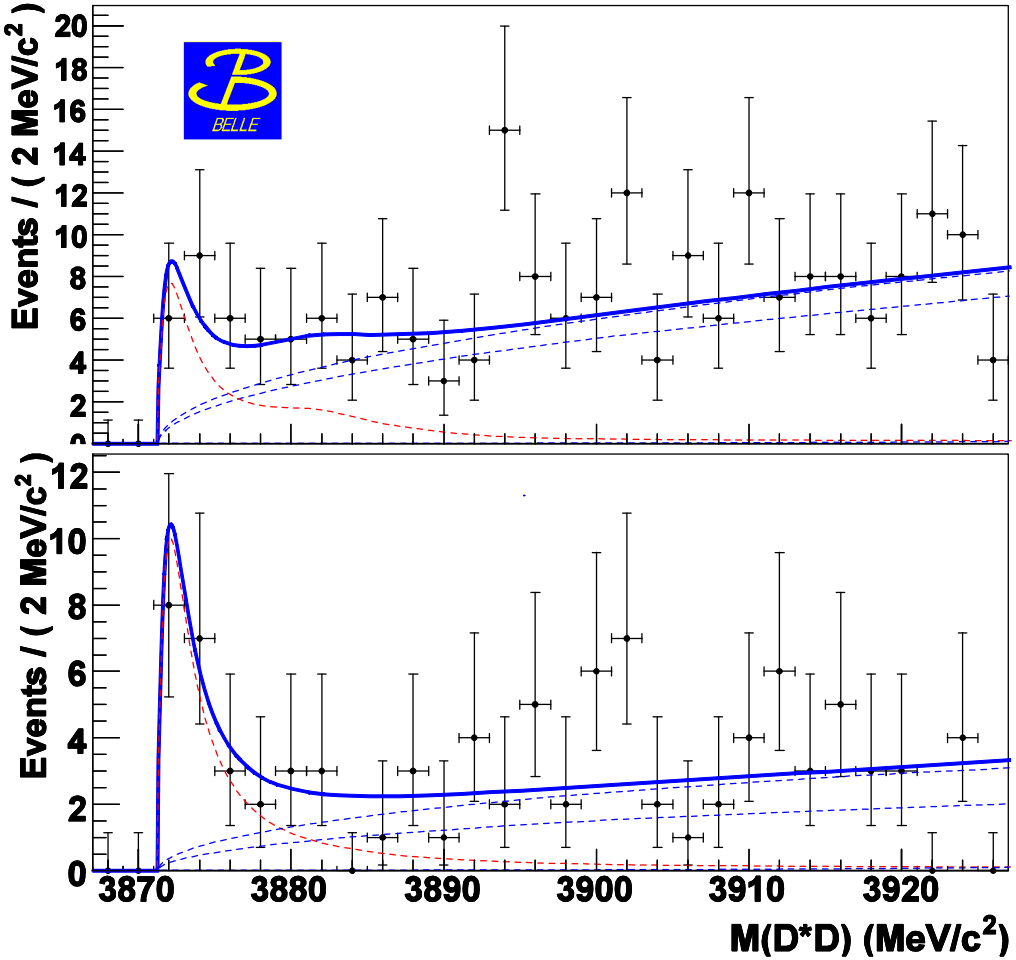


B. Aubert et al. (BaBar) Phys. Rev. D77, 011102 (2008)

Both saw higher mass & BR(DD*) ≈ 10x BR($\pi^+\pi^-J/\psi$)

	Mass, MeV	Width, MeV	B^+ BR x 10^4
Belle	$3875.4\pm0.7^{+1.2}_{-2.0}$		$1.25\pm0.31\pm0.30$
BaBar	$3875.1^{+0.7}_{-0.5}\pm0.5$	$3.0^{+1.9}_{-1.4}\pm0.9$	$1.67\pm0.36\pm0.47$

$B \to X(3872)\, K;\ X(3872) \to \underline{D}^{*0} D^0;\ \underline{D}^{*0} \to D^0 (\gamma, \pi^0)$



$M_{D^*D} = (3872.6^{+0.5}_{-0.4} \pm 0.4)$ MeV

BaBar: $(3875.1^{+0.7}_{-0.5} \pm 0.5)$ MeV

$\sigma(\mathrm{RBW}) = (3.9^{+2.5}_{-1.3}{}^{+0.5}_{-0.3})$ MeV

Nsig = 48±11

Significance = 8.8 σ (stat)

X(3872) mass shape is also well fittable by Flatte function

$BR(B \to X(3872)(D^{*0}D^0)K) = (0.73 \pm 0.17 \pm 0.13) \times 10^{-4}$

$BR(B \to Y(3940)(D^{*0}D^0)K) < 0.67 \times 10^{-4}$ @ 90% C.L.

The X,Y,Z near 3940 MeV

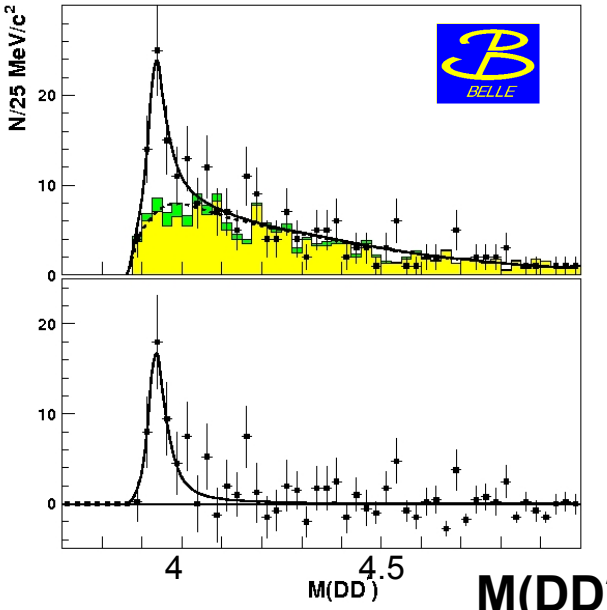
not seen in ωJ/ψ → **X(3940)**

probably different

not seen in DD* → **Y(3940)**

Probably the χ_{c2}' → **Z(3930)**

$e^+e^- \to J/\psi\, DD^*$



M(DD*)

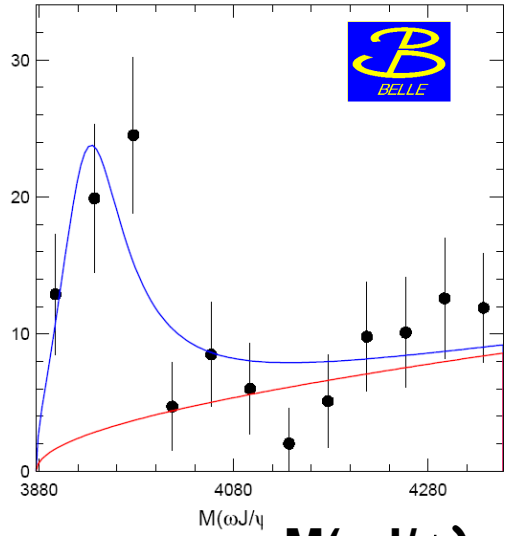
$M = 3942\ ^{+7}_{-6} \pm 6$ MeV

$\Gamma_{tot} = 37\ ^{+26}_{-15} \pm 12$ MeV

$N_{sig} = 52\ ^{+24}_{-16} \pm 11$

PRL 100, 202001 (2008)

$B \to K\, \omega J/\psi$

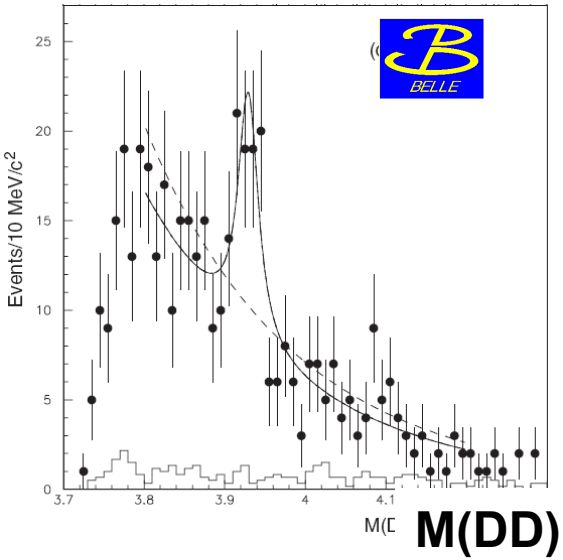


M(ωJ/ψ)

M≈3940 ± 11 MeV
Γ≈ 92 ± 24 MeV

PRL94, 182002 (2005)

$\gamma\gamma \to DD$



M(DD)

M = 3929±5±2 MeV

Γ_{tot} **= 29±10±2 MeV**

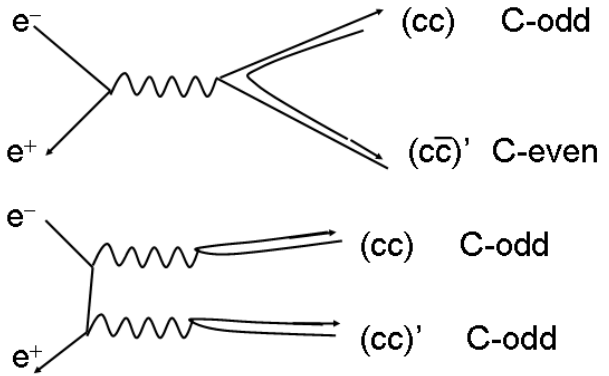
Nsig =64 ± 18evts

PRL 96, 082003 (2006)

X(3940) in Double charmonium production

Tagging a J/ψ at one side

First Analysis: Belle PRD 70, 071102 (2004)
Belle, PRL 98, 082001 (2007)



J/ψ

η_c, χ_c, X?

J/ψ

X? (suppressed)

Recoil masses

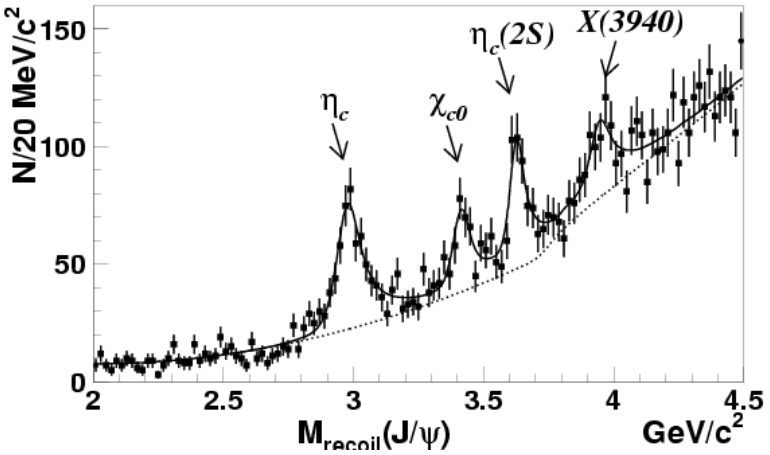
X(3940)

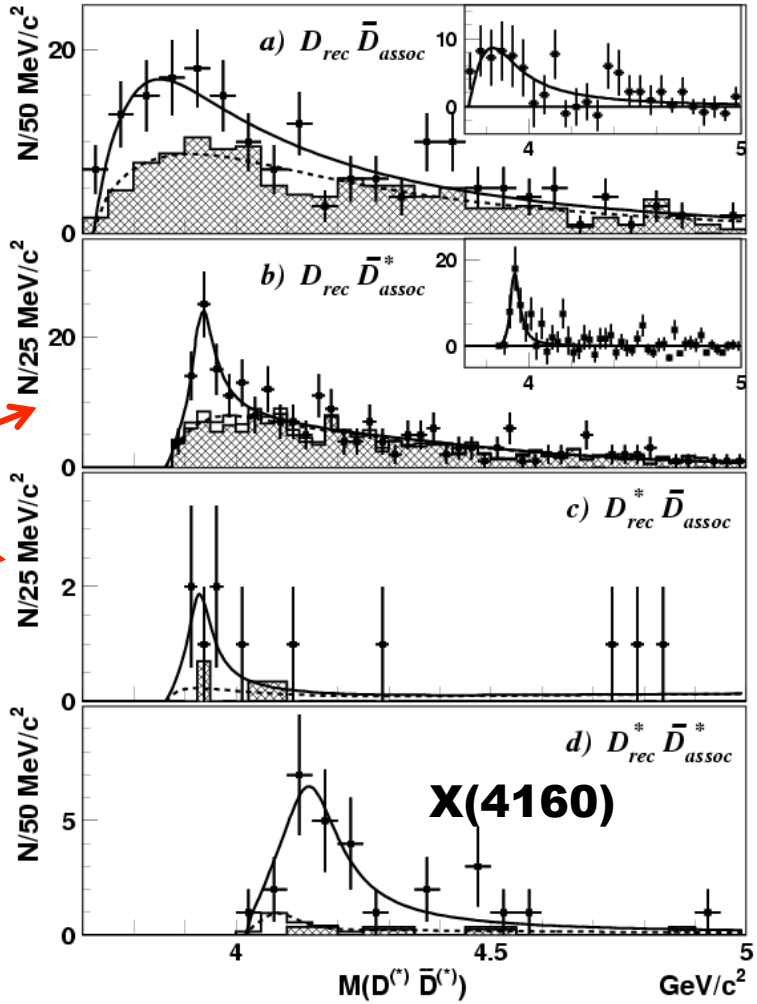
Others are…

J=0, P=+ or −,

C=+ (even)

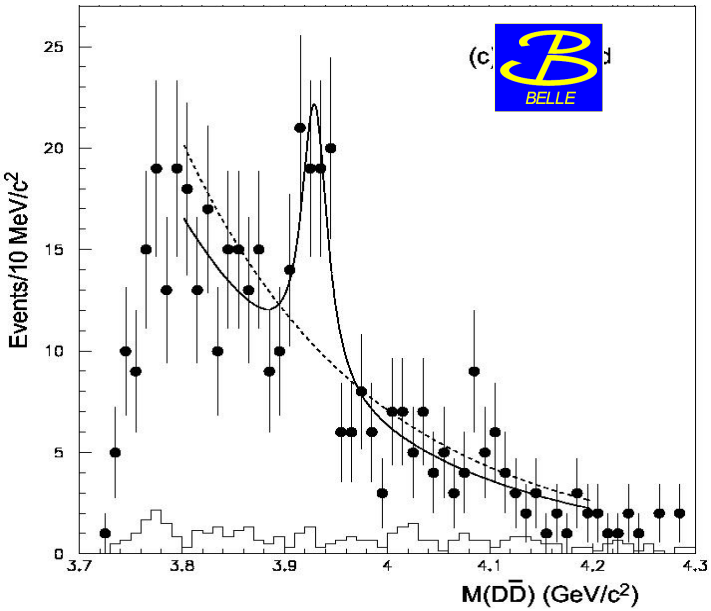
Here is
X(3940) → DD*



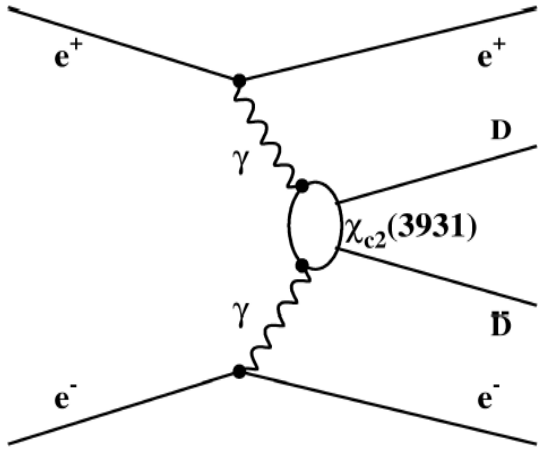


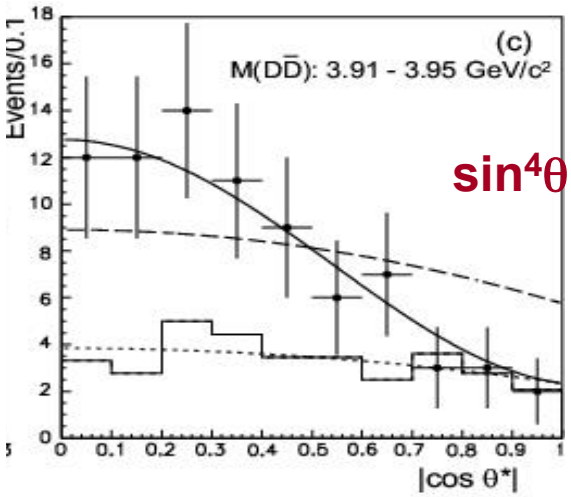
$\gamma\gamma \rightarrow Z(3930) \rightarrow D\bar{D}$

Belle PRL 96, 082003 (2006)



395 fb^{-1}



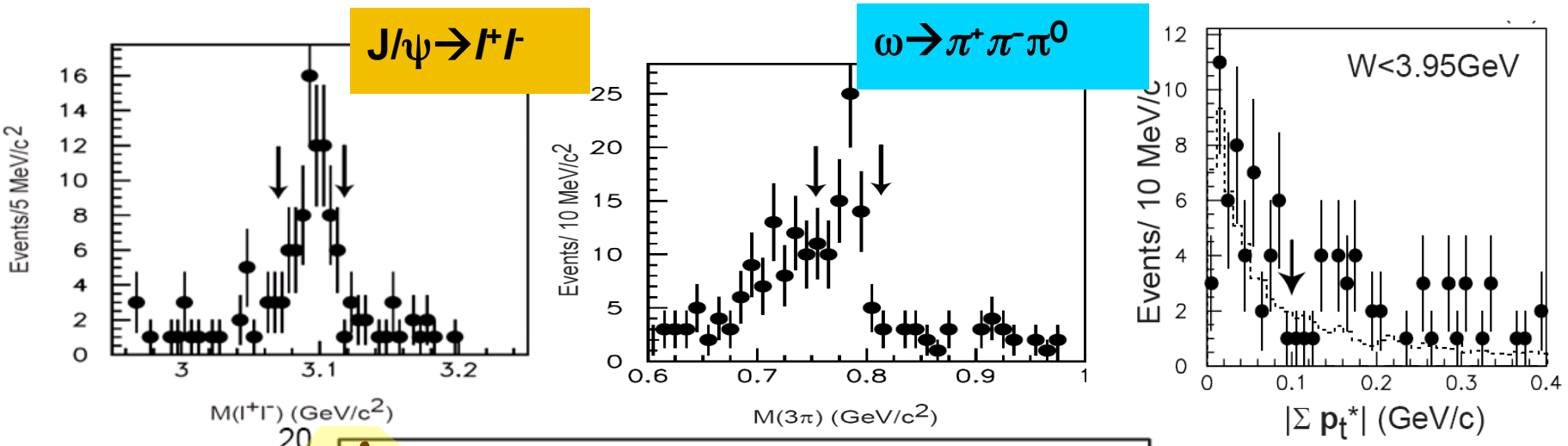


sin$^4\theta$ (J=2)

BELLE
m(3930)=3929±5±2 MeV/c²
Γ(3930)=29±10±2 MeV
$\Gamma_{\gamma\gamma}$·BF(Z(3930→DD̄))=0.18 ±0.05±0.03 keV

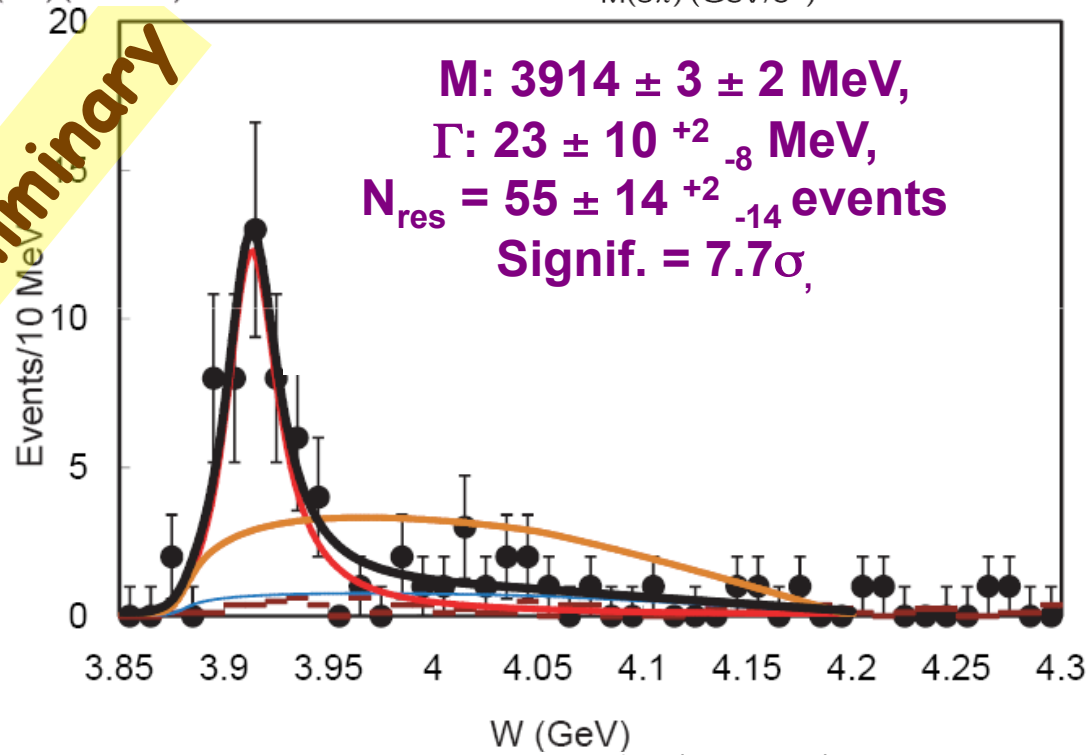
Matches well χ_{c2}' expectations

New peak in γγ→ωJ/ψ from Belle



694 fb^{-1}

preliminary



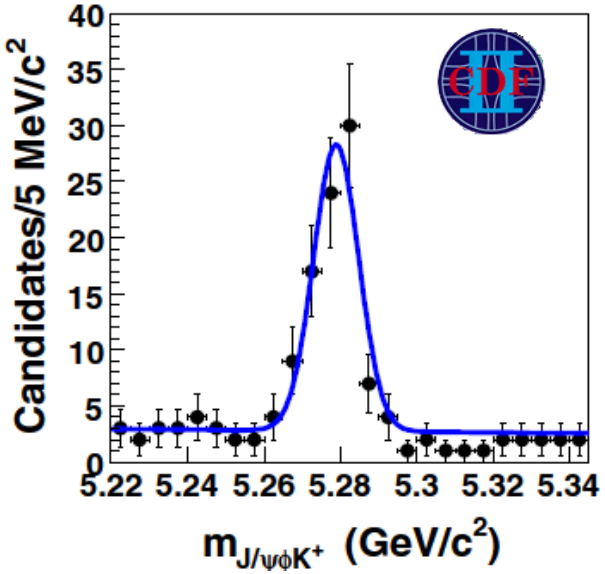
Two-photon production of Y(3940)?

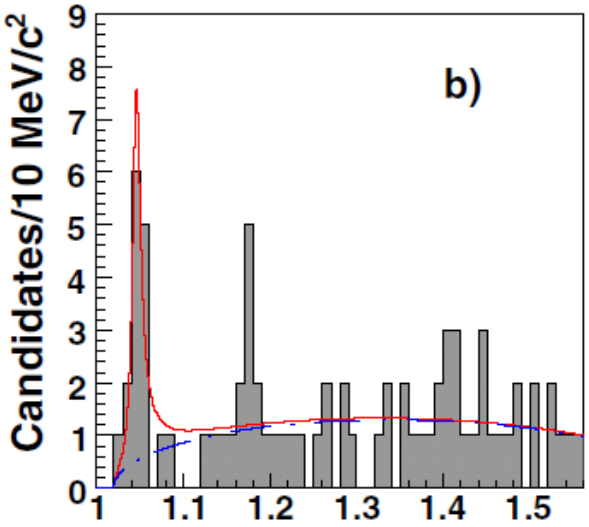
or New decay mode of Z(3930)?

Y(4140)→J/ψ φ

CDF, PRL 102, 242002 (2009)

CDF observed new charmonium-like particle

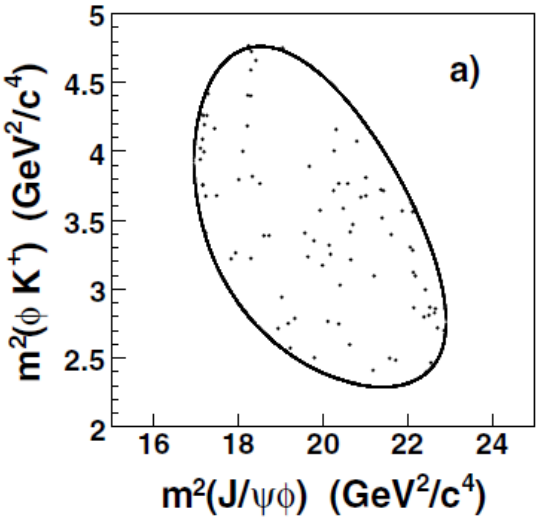




$B^+ \to J/\psi\ \phi\ K^+$

14 ± 5 events (3.8σ)

from 2.7 fb^{-1}



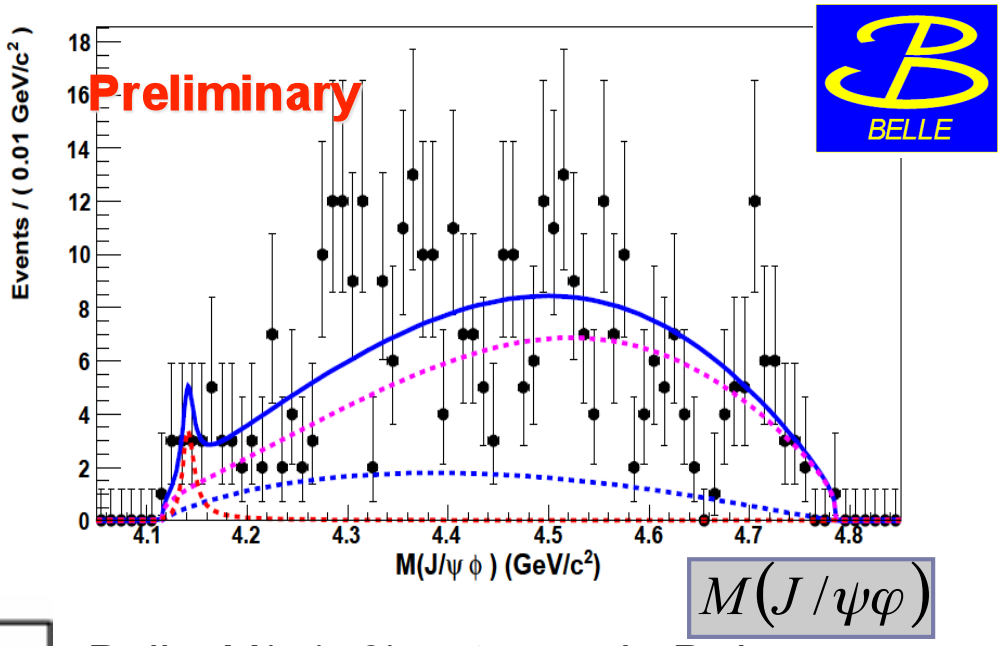
M = 4143.0 ±2.9 ±1.2 MeV/c^2

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

Ds* $\overline{\text{Ds*}}$ molecule or tetraquark ?

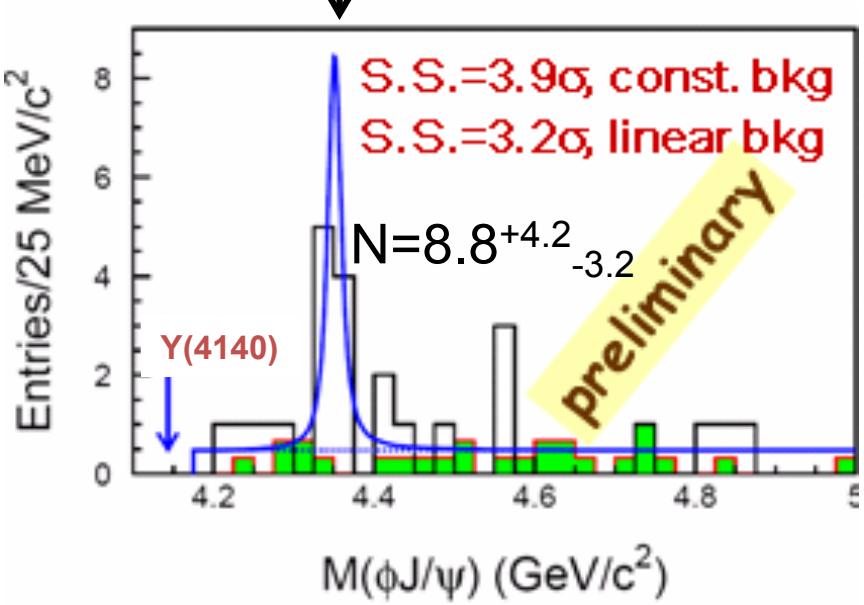
Searches at Belle

$B^+ \to J/\psi\, \phi\, K^+$



$BF(B \to YK)\,BF(Y \to J/\psi\phi) < 6 \times 10^{-6}$ (@90%CL)

$\gamma\gamma \to J/\psi\, \phi$



Belle: Y(4140) not seen in B decays or in two-photon

Instead, a new peak is seen at around 4.35 GeV in $\gamma\gamma \to J/\psi\phi$

$M = 4350.6\ ^{+4.6}_{-5.1} \pm 0.7$ MeV/c²

$\Gamma = 13.3\ ^{+17.9}_{-9.1} \pm 4.1$ MeV

Observation of $\Upsilon(5S) \rightarrow \Upsilon(1S)\,\pi^+\pi^-,\ \Upsilon(2S)\pi^+\pi^-$

K.-F. Chen et al. (Belle coll),
PRL 100, 112001 (2008)

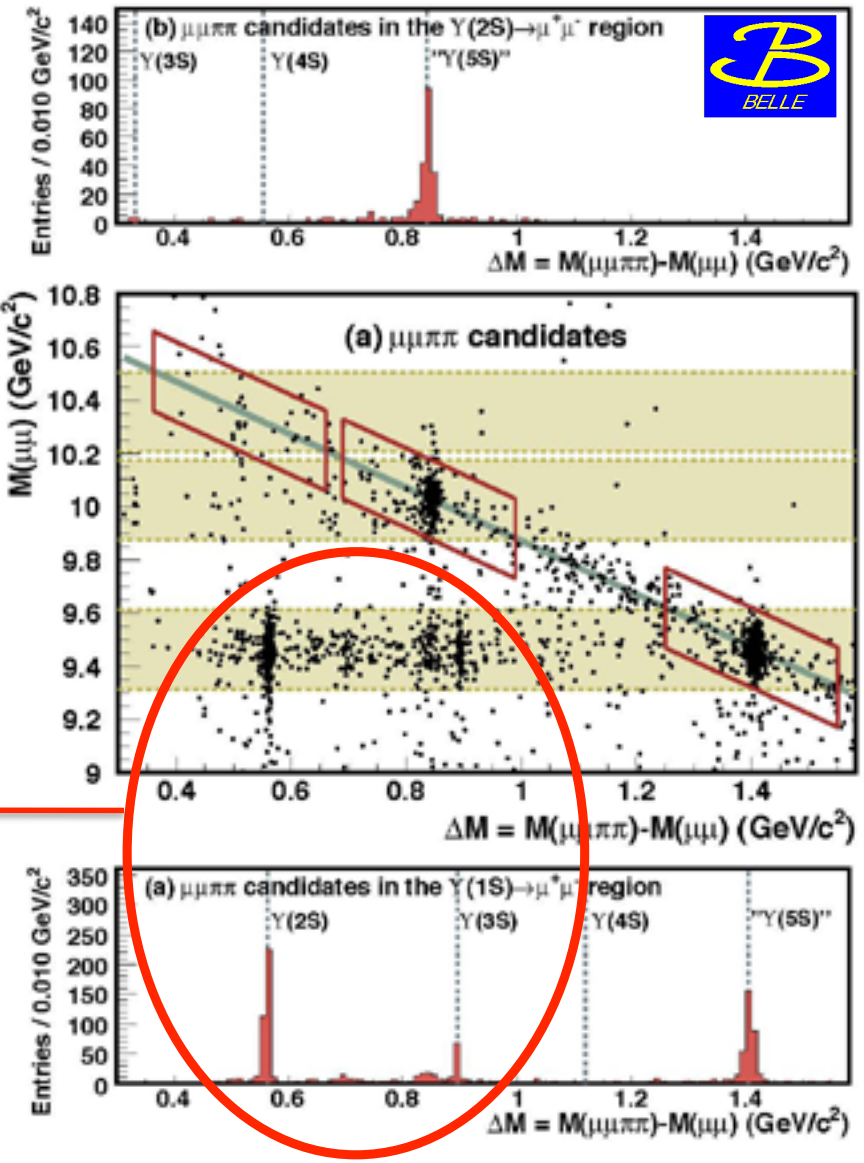
$L = 21.7\ fb^{-1}$

-> look for: $\mu^+\mu^- h^+ h^-$

$e^+e^- \rightarrow \Upsilon(1S)\,\pi^+\pi^- X$

$e^+e^- \rightarrow \Upsilon(2S)\,\pi^+\pi^- X$

Radiative return/ISR
Ex: $\Upsilon(5S) \rightarrow \Upsilon(2S)\gamma$
$\searrow \Upsilon(1S)\pi\pi$



Is the $\Upsilon(10860)$ purely $\Upsilon(5S)$?

4 modes seen : $\Upsilon(5S) \to \Upsilon(nS)\, h^+h^-$

Process	σ(pb)	$\mathcal{B}(\%)$	Γ(MeV)
$\Upsilon(1S)\pi^+\pi^-$	$1.61 \pm 0.10 \pm 0.12$	$0.53 \pm 0.03 \pm 0.05$	$0.59 \pm 0.04 \pm 0.09$
$\Upsilon(2S)\pi^+\pi^-$	$2.35 \pm 0.19 \pm 0.32$	$0.78 \pm 0.06 \pm 0.11$	$0.85 \pm 0.07 \pm 0.16$
$\Upsilon(3S)\pi^+\pi^-$	$1.44^{+0.55}_{-0.45} \pm 0.19$	$0.48^{+0.18}_{-0.15} \pm 0.07$	$0.52^{+0.20}_{-0.17} \pm 0.10$
$\Upsilon(1S)K^+K^-$	$0.185^{+0.048}_{-0.041} \pm 0.028$	$0.061^{+0.016}_{-0.014} \pm 0.010$	$0.067^{+0.017}_{-0.015} \pm 0.013$

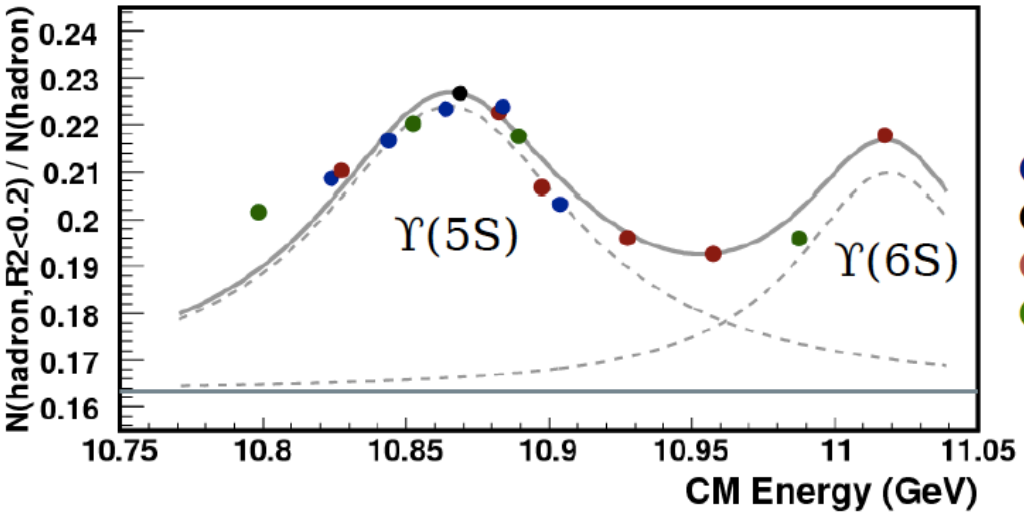
Expectation: $\Upsilon(5S)$ width comparable to $\Upsilon(2S/3S/4S)$

Process	$\Gamma_{\rm total}$	$\Gamma_{e^+e^-}$	$\Gamma_{\Upsilon(1S)\pi^+\pi^-}$
$\Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^-$	0.032 MeV	0.612 keV	0.0060 MeV
$\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$	0.020 MeV	0.443 keV	0.0009 MeV
$\Upsilon(4S) \to \Upsilon(1S)\pi^+\pi^-$	20.5 MeV	0.272 keV	0.0019 MeV
$\Upsilon(10860) \to \Upsilon(1S)\pi^+\pi^-$	110 MeV	0.31 keV	0.59 MeV

larger by $> 10^2$

Is it not pure $\Upsilon(5S)$?

Hadronic cross-section

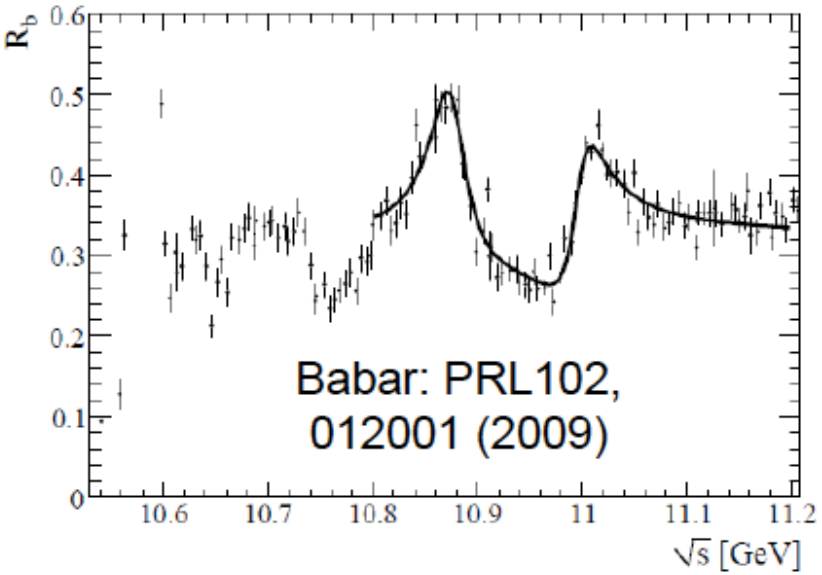


- 2005 scan
- 2006 Υ(5S) data
- 2007 scan
- 2007 30pb^{-1}

Fit with fixed PDG Breit-Wigners values for Υ(5S) and Υ(6S): good agreements. Floating the Υ(5S) parameters return consistent result:

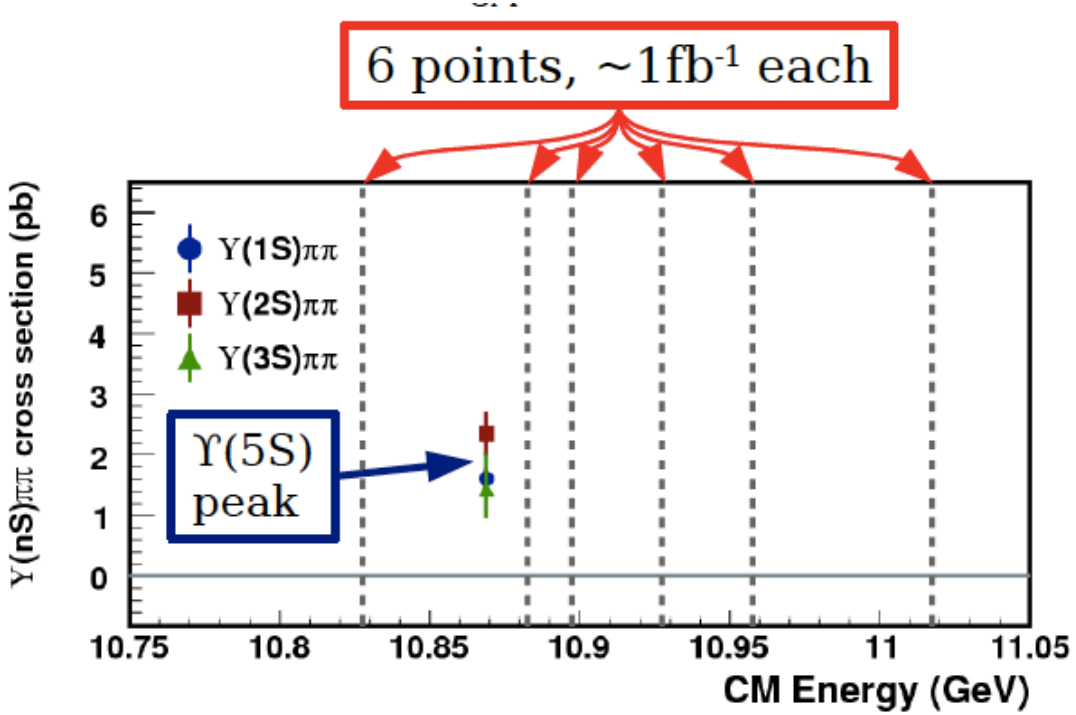
(μ, Γ)~(10861,107) MeV

BaBar made a small step scan and perfectly confirmed the shape and Υ(5S) and Υ(6S) parameters



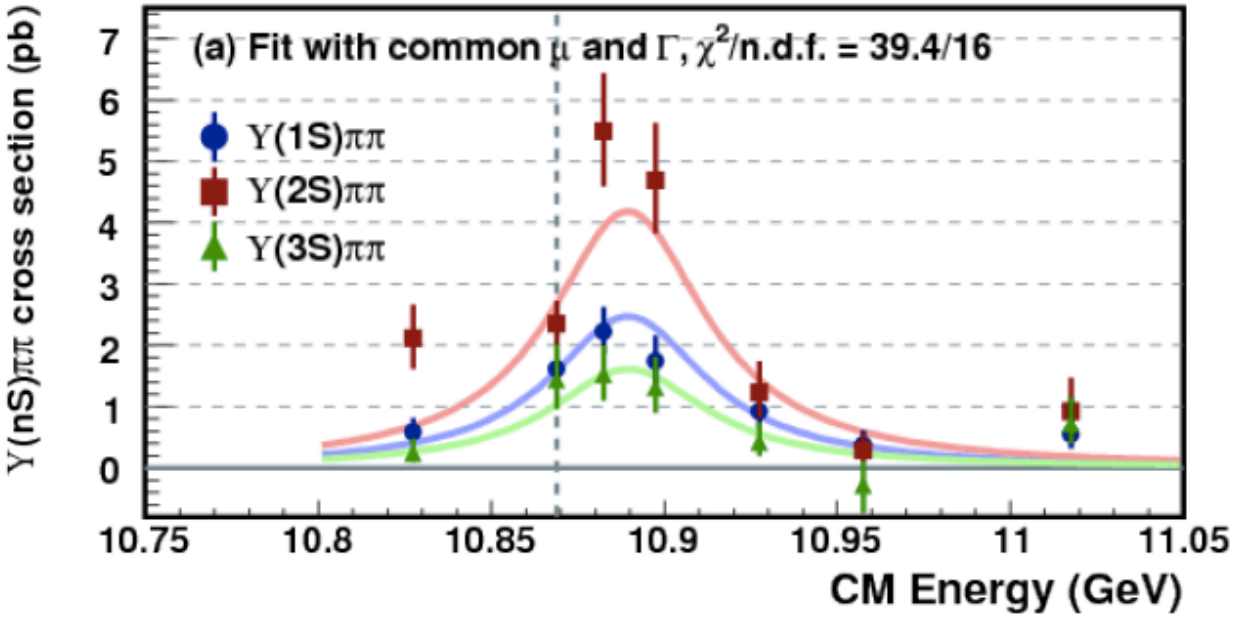
Energy scan at KEKB

- December 2007: 7/fb collected between Υ(5S) and Υ(6S):
  do the same work as a function of E_{CM}



The next energy point was chosen based on the fly decision by real time monitoring. Analysis was installed at the farm and histograms such as "$M_{\mu\mu\pi\pi}$-$M_{\mu\mu}$" could be monitoring **on the fly**.

Υ(nS)ππ production

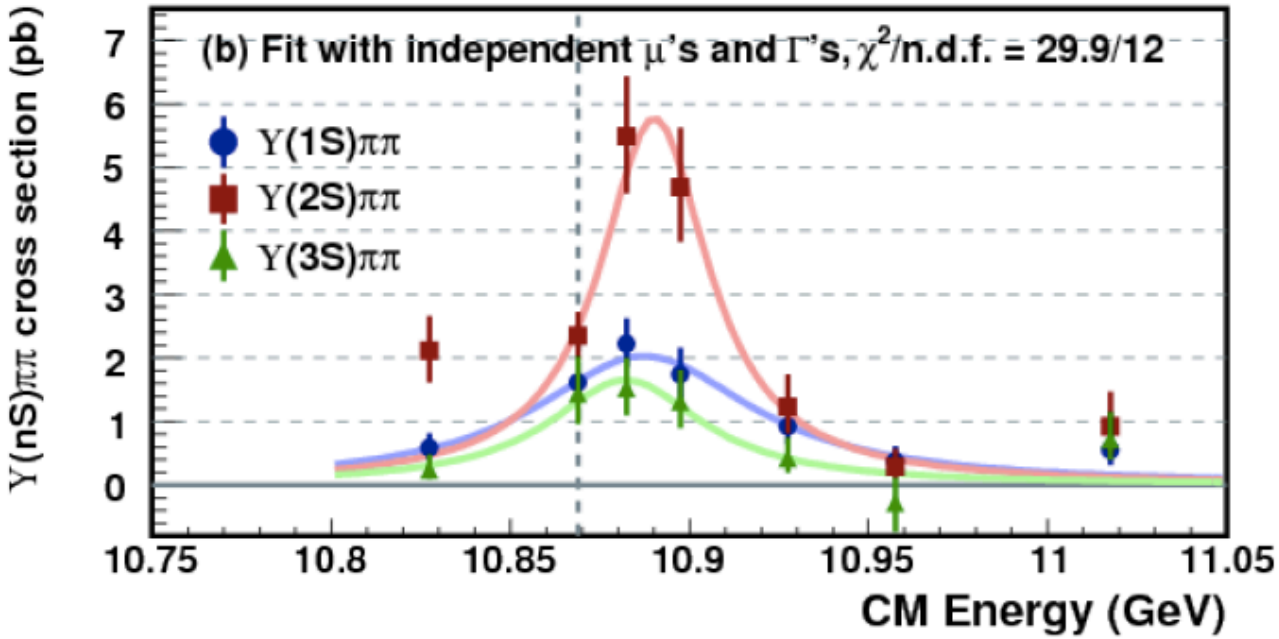


Assume one new particle produce all final states ⇨
fit the three cross-sections with the same Breit-Wigner function:

	$\Upsilon(1S)\pi\pi$	$\Upsilon(2S)\pi\pi$	$\Upsilon(3S)\pi\pi$
Peak (pb)	$2.46^{+0.27}_{-0.25} \pm 0.18$	$4.18^{+0.49}_{-0.46} \pm 0.55$	$1.61^{+0.31}_{-0.28} \pm 0.21$
Mean (MeV)		$10889.6 \pm 1.8 \pm 1.5$	
Width (MeV)		$54.7^{+8.5}_{-7.2} \pm 2.5$	

20 MeV higher than the Υ(5S) and half the width!

Υ(nS)ππ production



Assume three new particles ⇨ fit with three Breit-Wigner function:

	$\Upsilon(1S)\pi\pi$	$\Upsilon(2S)\pi\pi$	$\Upsilon(3S)\pi\pi$
Peak (pb)	$2.03^{+0.27}_{-0.22} \pm 0.15$	$5.77^{+0.90}_{-0.80} \pm 0.68$	$1.65^{+0.36}_{-0.32} \pm 0.21$
Mean (MeV)	$10887.4^{+4.1}_{-4.5} \pm 1.6$	$10890.3^{+2.3}_{-1.9} \pm 1.4$	$10882.3^{+7.2}_{-7.3} \pm 1.5$
Width (MeV)	$74^{+19}_{-14} \pm 3$	$37.0^{+7.9}_{-6.2} \pm 3.1$	$52^{+20}_{-14} \pm 1$

Means are similar and widths consistent within ~2σ

Summary

- More and more new states since 2003 from Belle, BaBar, and CLEO, CDF, …

- **Recent updates** on XYZ resonances

  X(3872) : Mass splitting is not found in decays from B mesons

  Updated analysis for $X(3872) \rightarrow D^{*0}D^{0}$ to be submitted to arXiv soon

- **Very New Topics**:

  CDF's new particle $Y(4140) \rightarrow J/\psi\omega$, not seen at Belle

  New structures seen in two-photon processes:

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

- Hint for $Y_b(10580)$ from Y(5S) data