The Y states in ISR & observation of $e^+e^- \to \Upsilon(1S)\pi^+\pi^-$, $\Upsilon(2S)\pi^+\pi^-$ at Ecm=10.87 GeV

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(for the Belle collaboration)

IHEP, Beijing

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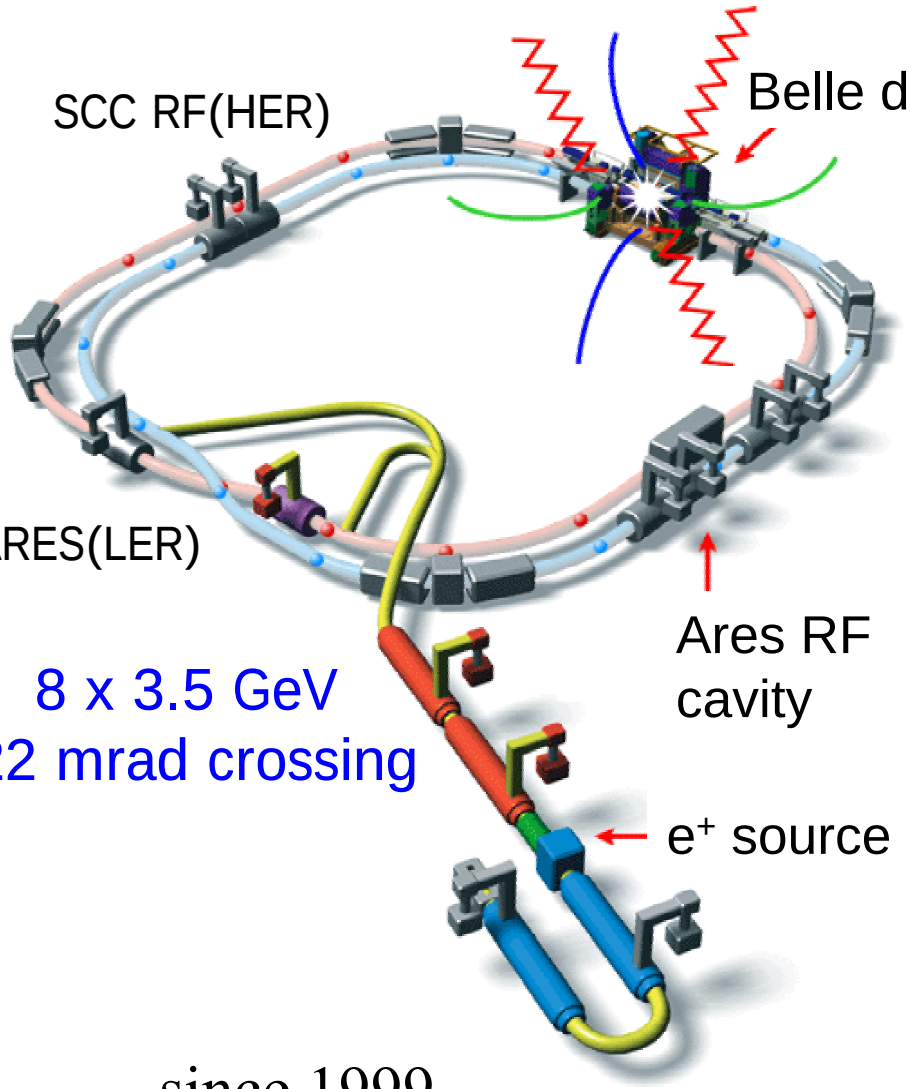
Outline

- Introduction
- Part I: the Y states
  - $e^+e^- \to \pi^+\pi^- J/\psi$
  - $e^+e^- \to \pi^+\pi^- \psi(2S)$
  - $e^+e^- \to K^+K^- J/\psi$
- Part II: the Υ_b states (c-quark → b-quark)?
  - $e^+e^- \to \pi^+\pi^- \Upsilon(1S)$
  - $e^+e^- \to \pi^+\pi^- \Upsilon(2S)$
  - $e^+e^- \to K^+K^- \Upsilon(1S)$
- Summary

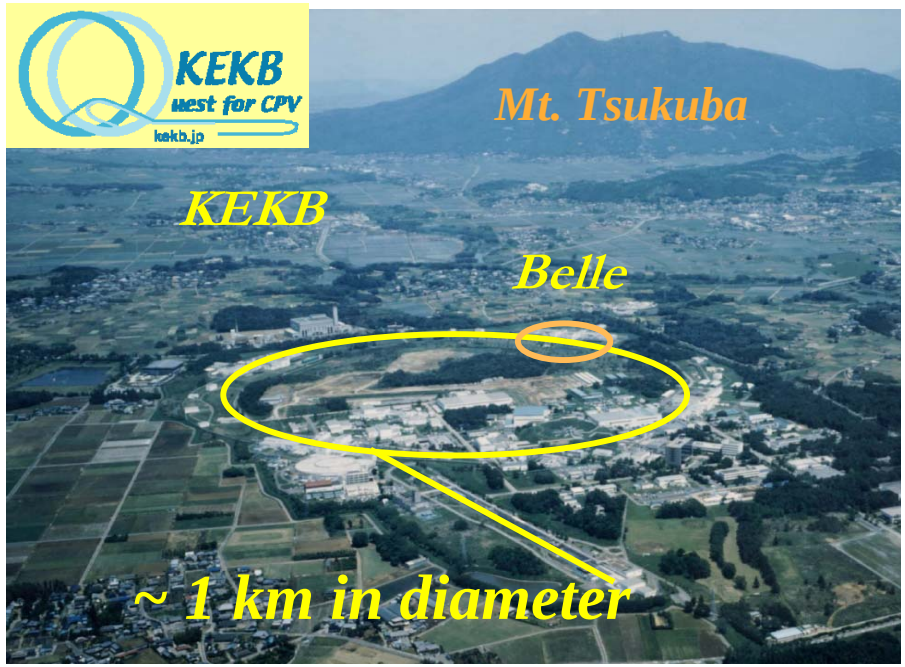
The KEKB Collider



since 1999

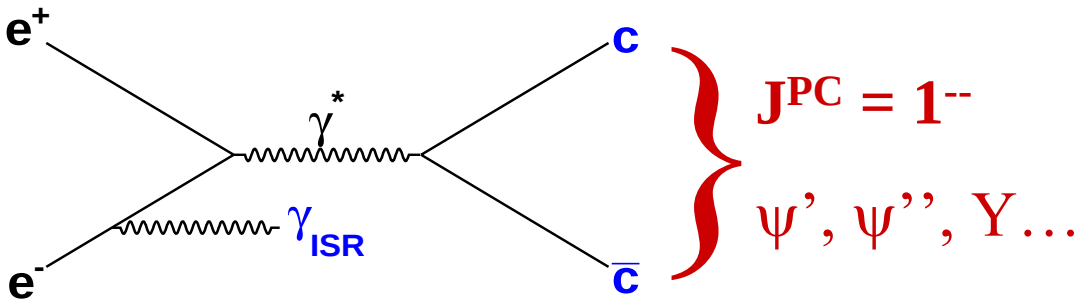
World record:

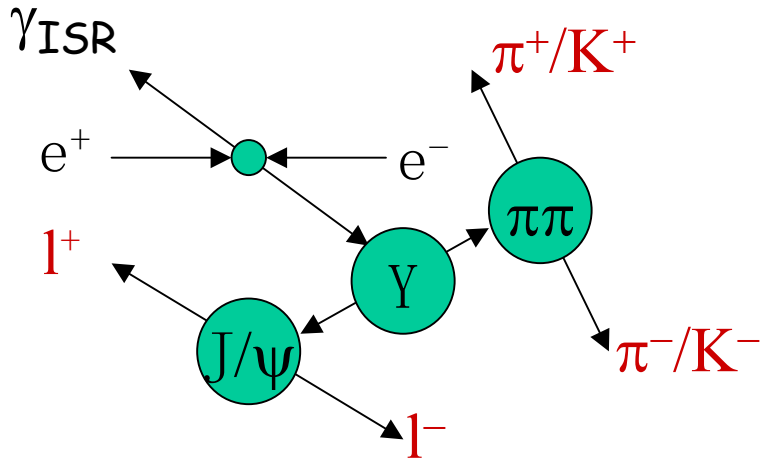
$L = 1.7 \times 10^{34}/cm^2/sec$



Part I: the Y states

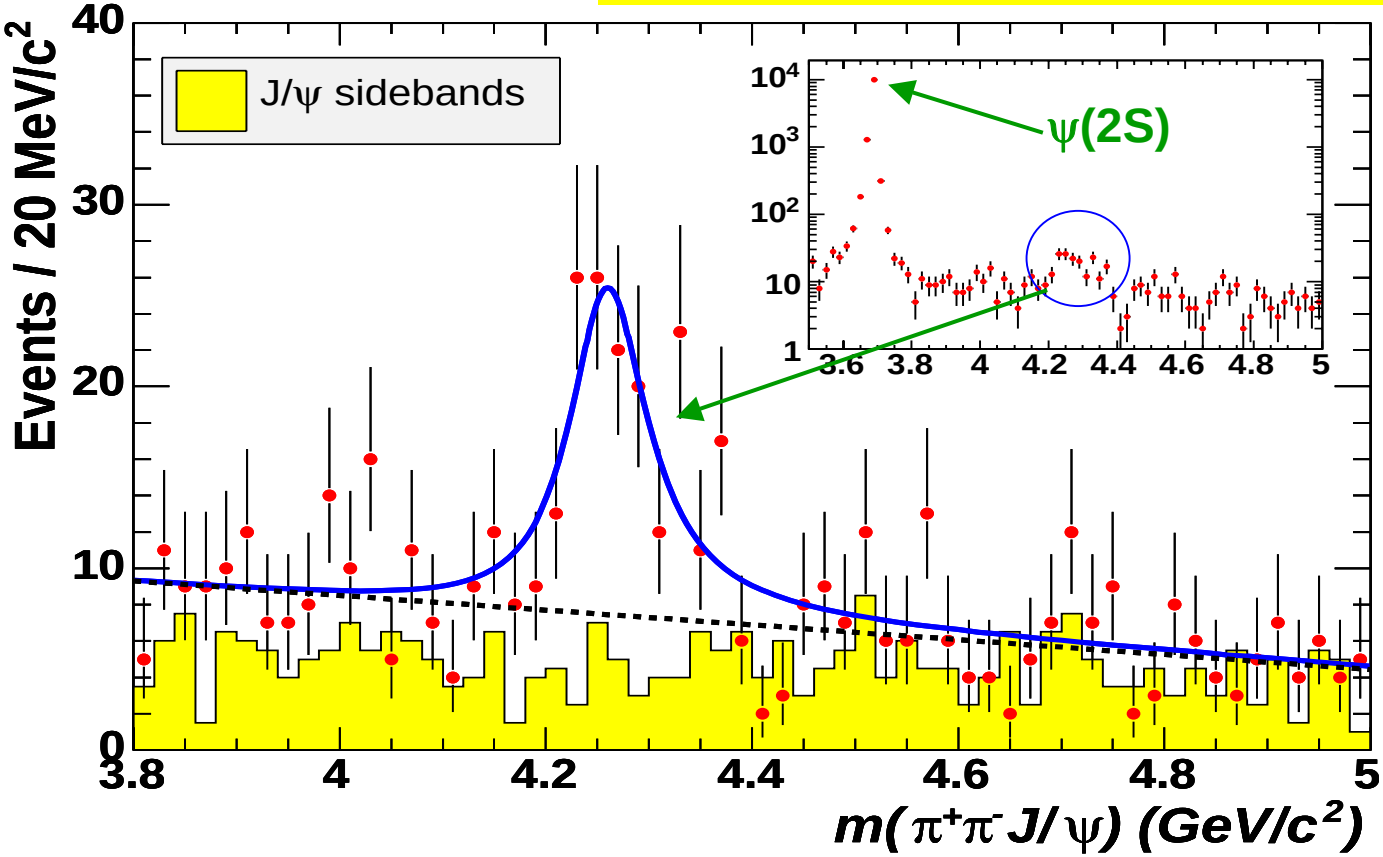
Charmonium states in ISR production





PRL95, 142001 (2005)

$\pi^+\pi^- J/\psi$ Mass



BaBar: 232 fb^{-1}

>8σ significance structure called Y(4260)

M($J/\psi\pi\pi$) of ψ(2S) with J/ψ constraint is well described by Cauchy shape funct.

- fit with Rel-BW × PhaseSpace ⊗ Reso + 2nd polynomial (BKGD)
- fit-probability (χ^2) is about 2.6%, N_{events} = 125±23

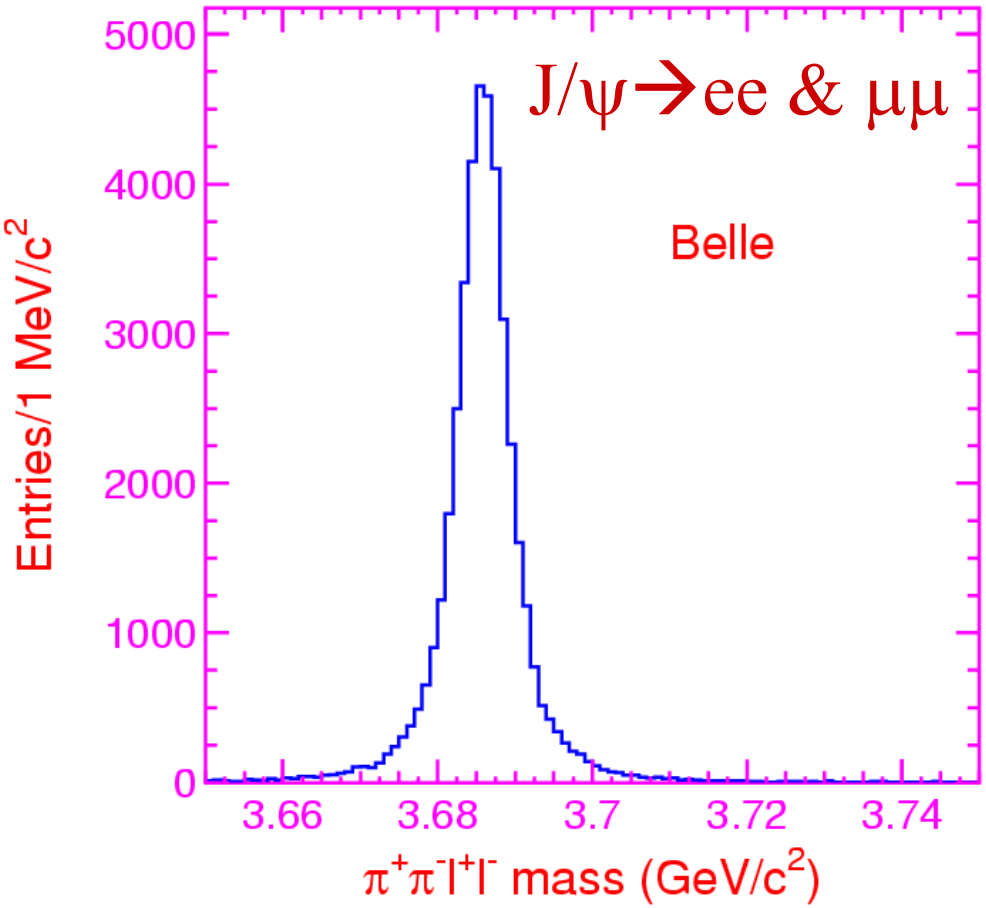
$$m = 4259 \pm 8^{+2}_{-6}\ \text{MeV}$$

$$\Gamma = 88 \pm 23^{+6}_{-4}\ \text{MeV}$$

$$\Gamma\left(Y \to e^+e^-\right)\cdot B\left(Y \to \pi^+\pi^- J/\psi\right) = 5.5 \pm 1.0^{+0.8}_{-0.7}\ \text{eV}$$

$e^+e^- \rightarrow \psi'$ as reference signal

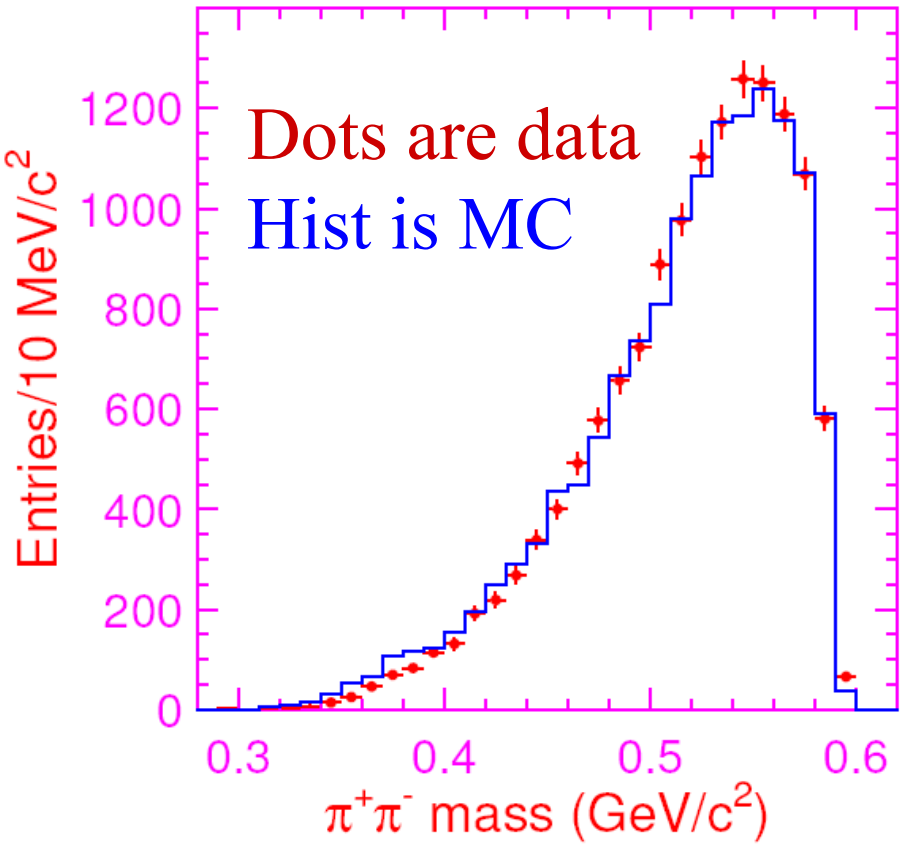
N^{obs}	Lum (/fb)	Cross section (pb)
15,444	547.8	15.42±0.12±0.89

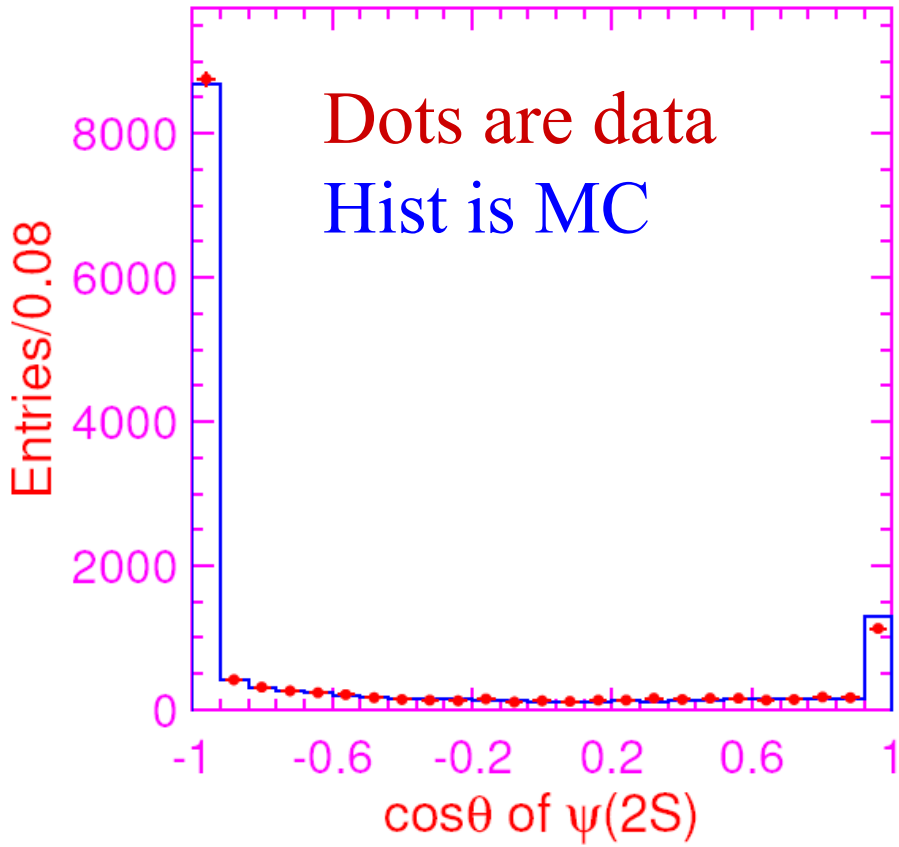


- From cross section, one gets partial width to e^+e^-.
- Γ_{ee}=2.54±0.02±0.15 keV
- PDG'06
  - Γ_{ee}=2.48 ± 0.06 keV
- Belle agrees with other experiments well.

ψ' sample: Data vs MC

We used Phokhara





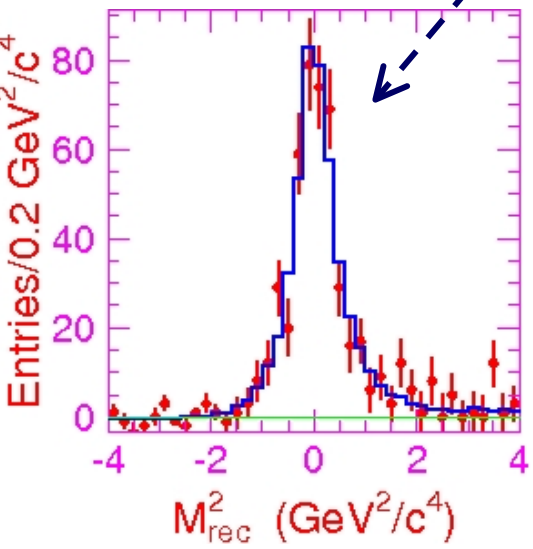
Good agreement between data and MC simulation.

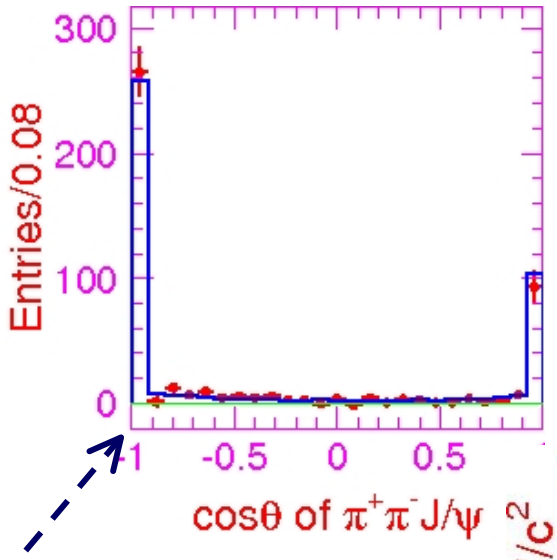
➔(ISR events & background low & MC reliable)

$e^+e^- \to \pi^+\pi^- J/\psi$ via ISR

Clear signal of missed massless particle (γ_{ISR})

Lum=548 fb^{-1}



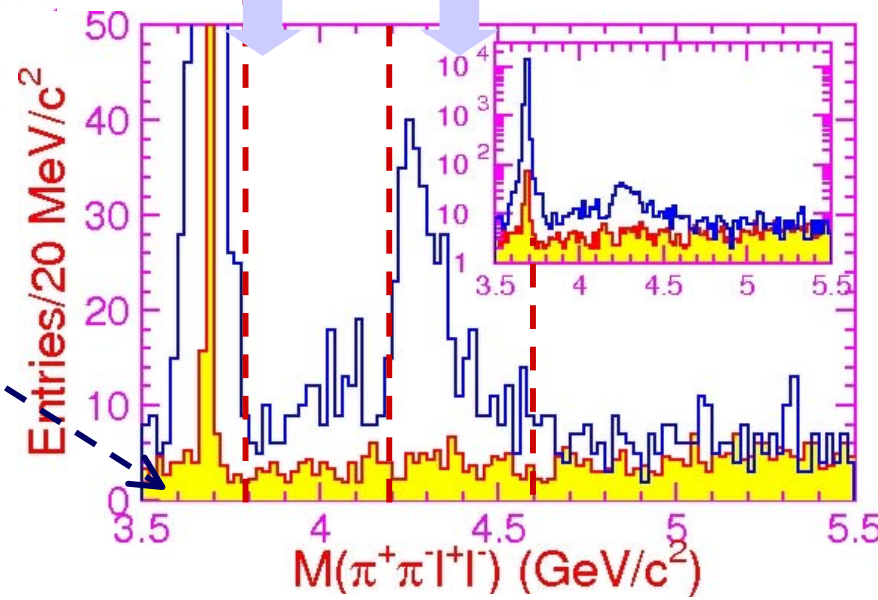


$J/\psi(\to l^+l^-)+\pi\pi$ + no extra tracks

detection of γ_{ISR} is not required

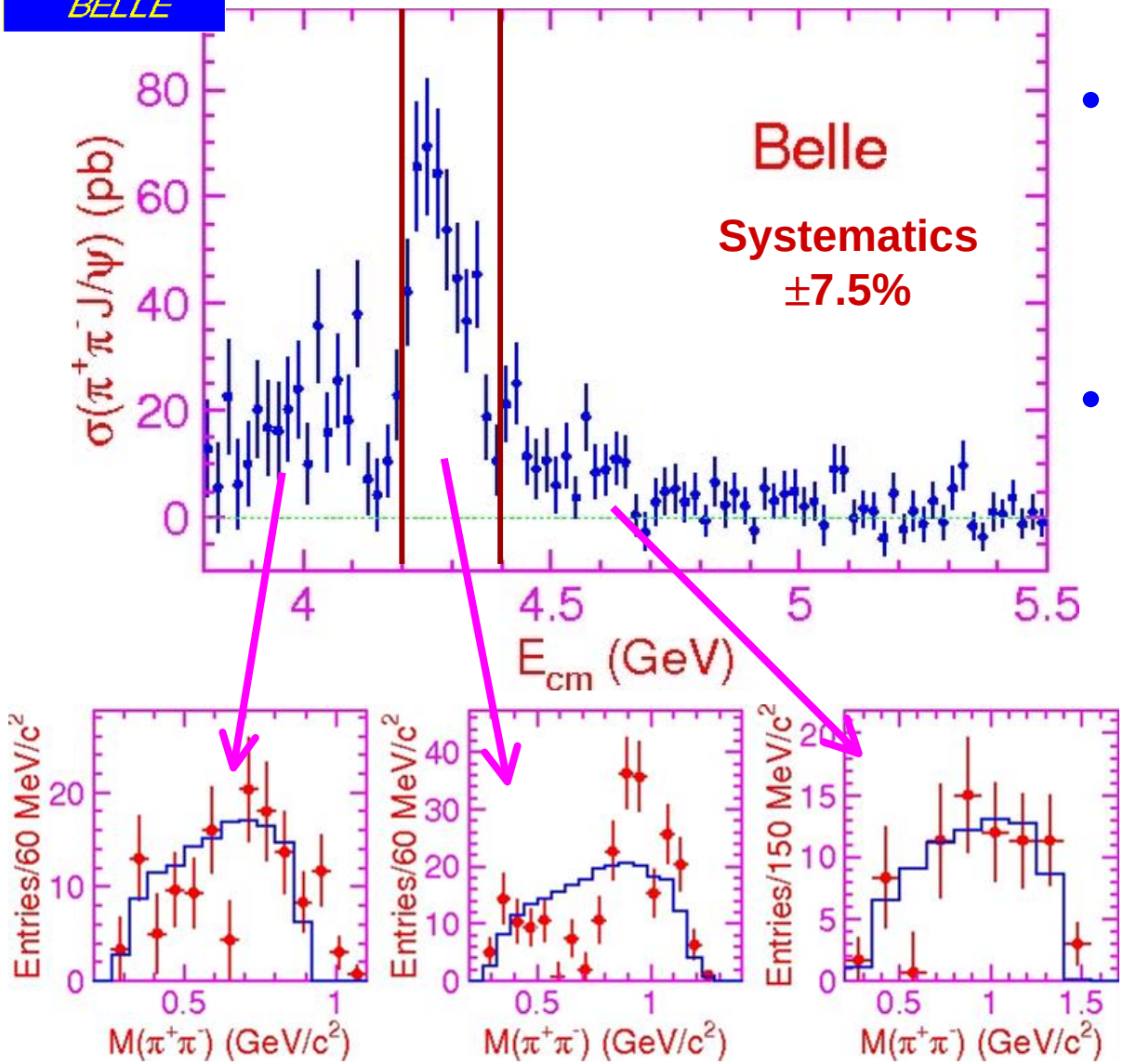
- **Polar angle distribution agrees well with ISR expectation**
- **Combinatorial background estimated by J/ψ sidebands**
- **Backgrounds from real $(J/\psi\ \pi\pi)_{non\ ISR}$ or $J/\psi\ X_{non\ \pi\pi}$ are negligibly small**

120±14 evts **324±21 evts**



Belle: C.Z.Y & C.P. Shen et al., arXiv:0707.2541, to appear in PRL

$e^+e^- \to \pi^+\pi^- J/\psi$ via ISR

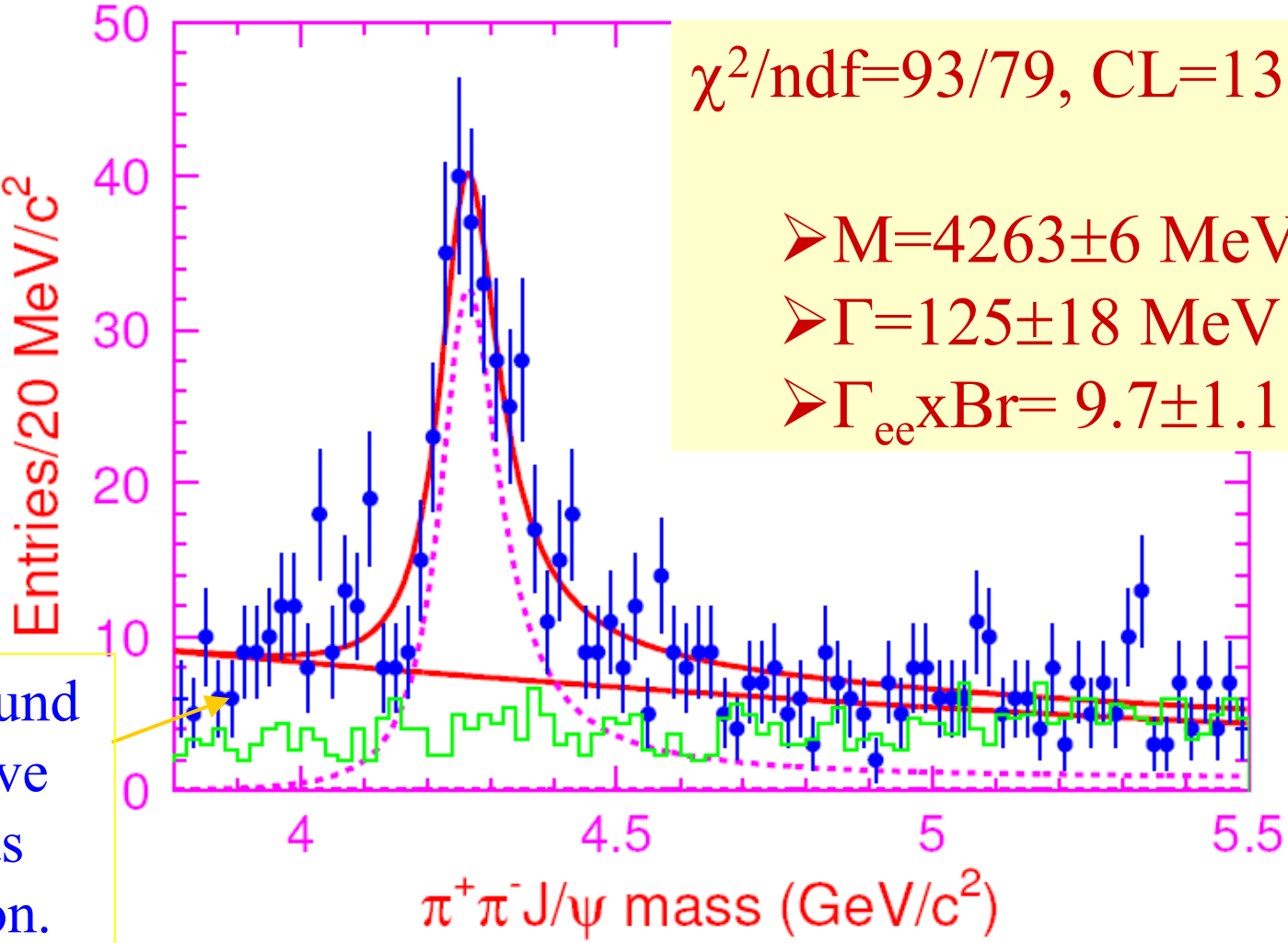


- **Background subtracted M(J/ψππ) corrected for efficiency and differential luminosity**
- **$M_{\pi\pi}$ spectra in different $\sqrt{s}$ regions:**
  - **$\sqrt{s}$ = 3.8 -4.2 & 4.4-4.6 GeV in agreement with 3-body phase space**
  - **Y(4260) region**

    $\sqrt{s}$ = 3.8 -4.15 GeV: two clusters at low and high masses (scalars?)

Belle: C.Z.Y & C.P. Shen et al., arXiv:0707.2541, to appear in PRL

$e^+e^- \to \pi^+\pi^- J/\psi$ via ISR



χ^2/ndf=93/79, CL=13%

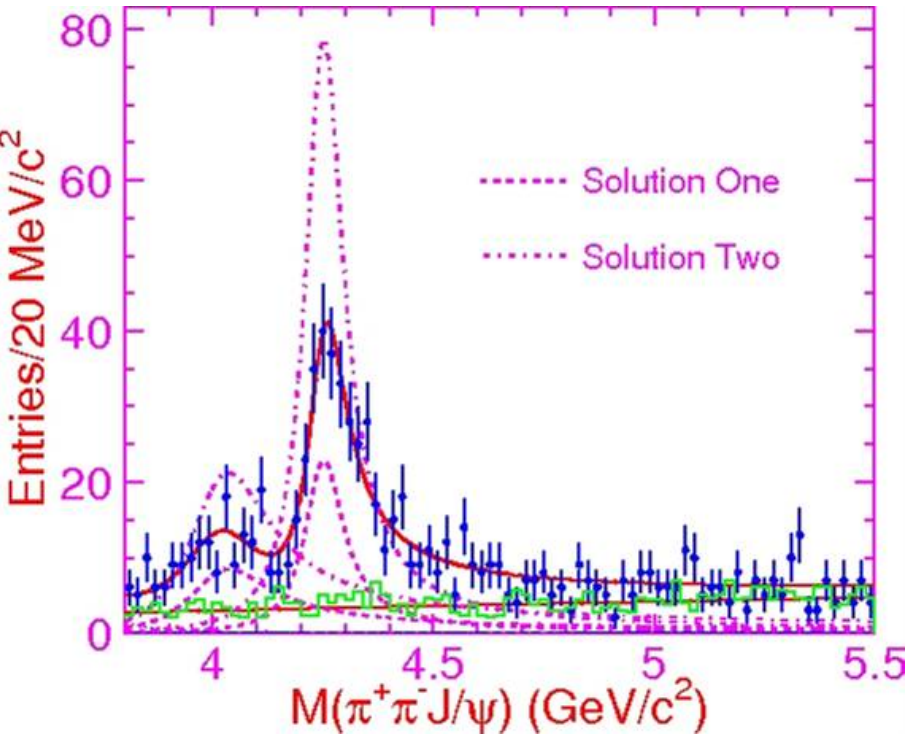
- M=4263±6 MeV
- Γ=125±18 MeV
- Γ_{ee}xBr= 9.7±1.1 eV

Background well above sidebands estimation.

Fit with function Babar used. Similar results are got.

$e^+e^- \to \pi^+\pi^- J/\psi$ via ISR

- **Non resonant $J/\psi\pi\pi$?**
- **Re-scattering ee $\to D^{(*)}D^{(*)} \to J/\psi\pi\pi$?**
- **Another broad state ?**
  - **Check the latter hypothesis and influence of interference of Y(4260) with non-Y contribution:**
  - **Fit with 2 coherent BWs**
  - **Two- fold ambiguity in amplitude (constructive-destructive interference) + model uncertainty due to ψ' tail**

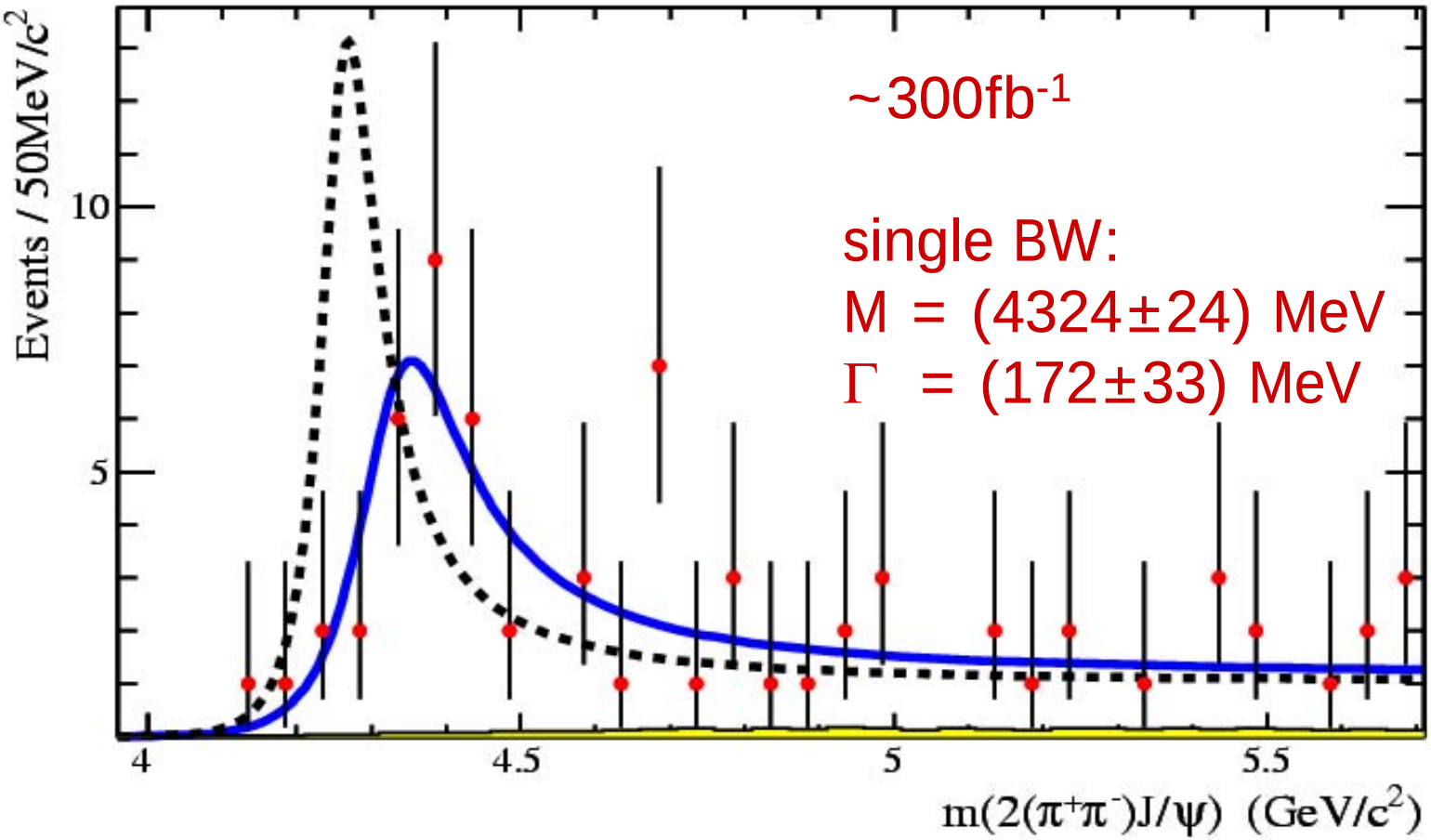


Parameters	Solution I	Solution II
$M(R1)$	$4008 \pm 40^{+114}_{-28}$	
$\Gamma_{\rm tot}(R1)$	$226 \pm 44 \pm 87$	
$\mathcal{B}\cdot\Gamma_{e^+e^-}(R1)$	$5.0 \pm 1.4^{+6.1}_{-0.9}$	$12.4 \pm 2.4^{+14.8}_{-1.1}$
$M(R2)$	$4247 \pm 12^{+17}_{-32}$	
$\Gamma_{\rm tot}(R2)$	$108 \pm 19 \pm 10$	
$\mathcal{B}\cdot\Gamma_{e^+e^-}(R2)$	$6.0 \pm 1.2^{+4.7}_{-0.5}$	$20.6 \pm 2.3^{+9.1}_{-1.7}$
ϕ	$12 \pm 29^{+7}_{-98}$	$-111 \pm 7^{+28}_{-31}$

2-BW fit with interference better describes the data: Y(4260) parameters are different (especially peak cross section – large uncertainty)

Belle: C.Z.Y & C.P. Shen et al., arXiv:0707.2541, to appear in PRL

$e^+e^- \to \pi^+\pi^-\psi(2S)$ via ISR at BaBar



BaBar: B. Aubert et al., PRL98, 212001 (2007)

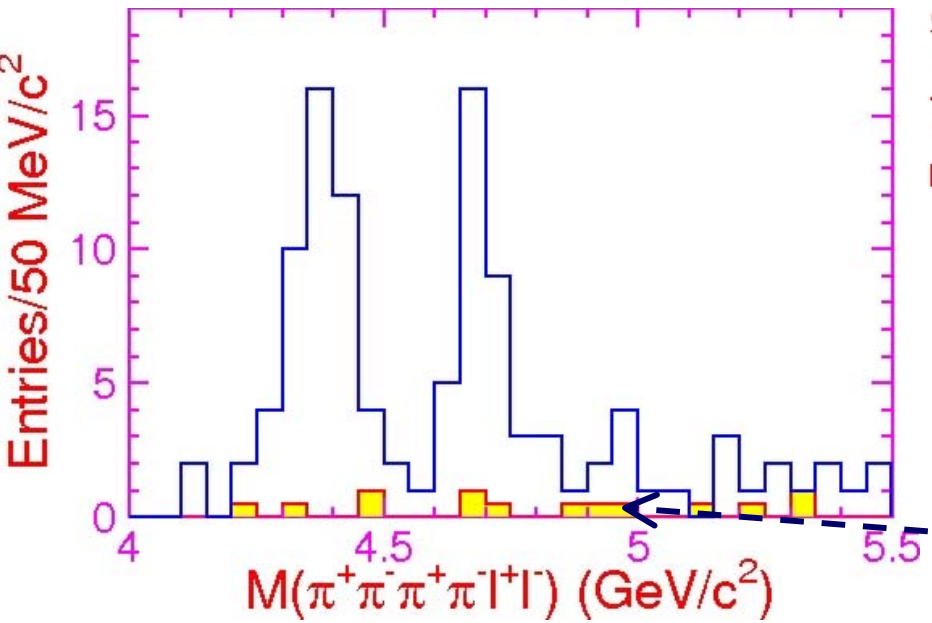
$e^+e^- \to \pi^+\pi^-\psi(2S)$ via ISR

673 fb^{-1}

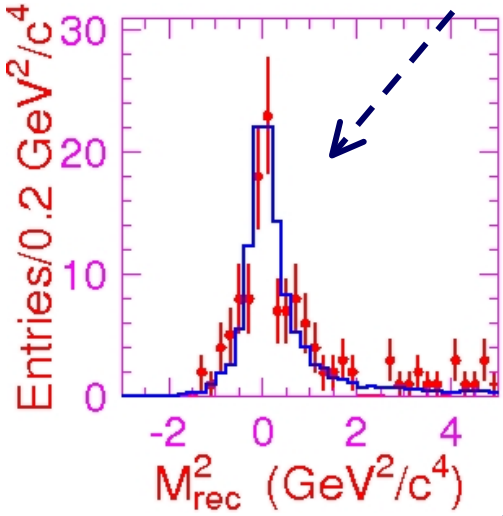
$\psi(\to J/\psi\,\pi\pi) + \pi\pi$ + no extra tracks

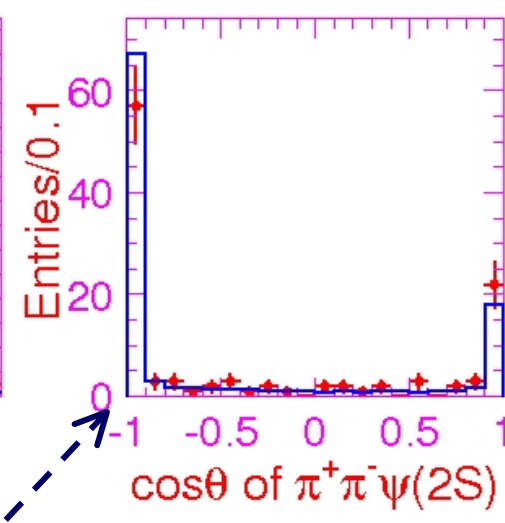
detection of γ_{ISR} is not required

Similar analysis: efficiency is smaller; bgs are almost negligible



- Clear signal of missed massless particle ($M_{rec}^2(\psi'\pi\pi)\sim 0$)



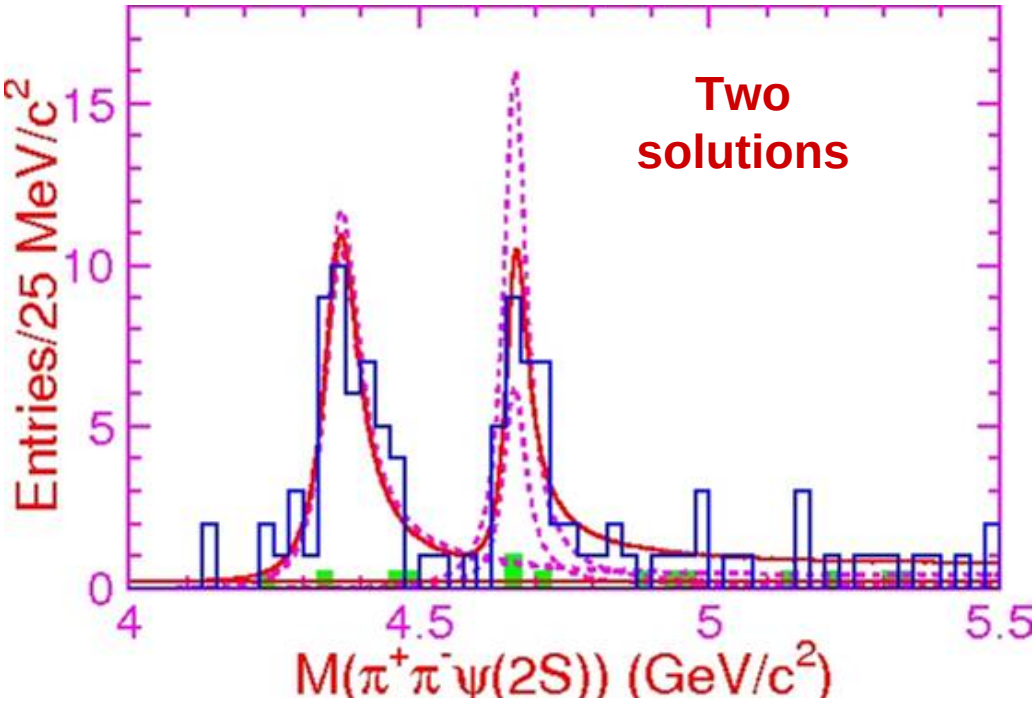


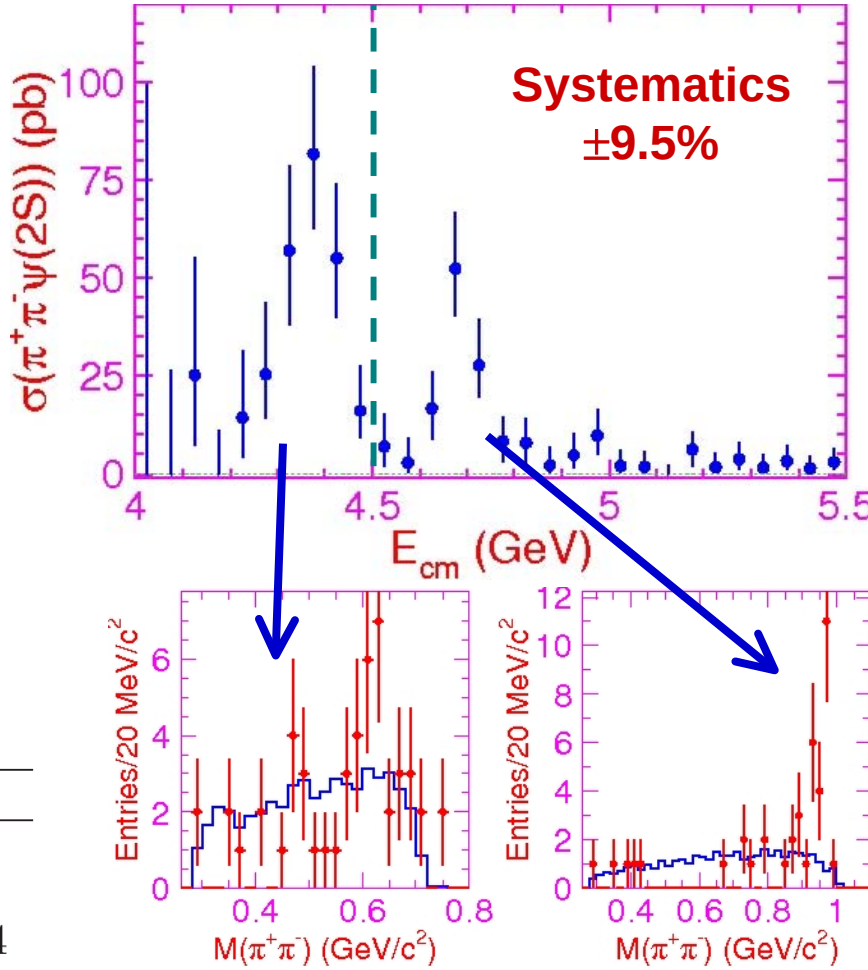
- Polar angle distribution agrees well with ISR expectation
- Combinatorial background estimated by ψ' sidebands
- Backgrounds from real $(\psi'\pi\pi)_{\text{non ISR}}$ or ψ' $X_{\text{non }\pi\pi}$ are negligibly small

Two significant clusters: One is near BaBar reported enhancement PRL98, 212001 (2007) + NEW at M~ 4.7 GeV

Belle: X.L. Wang & C.Z.Y et al., PRL99, 142002 (2007)

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





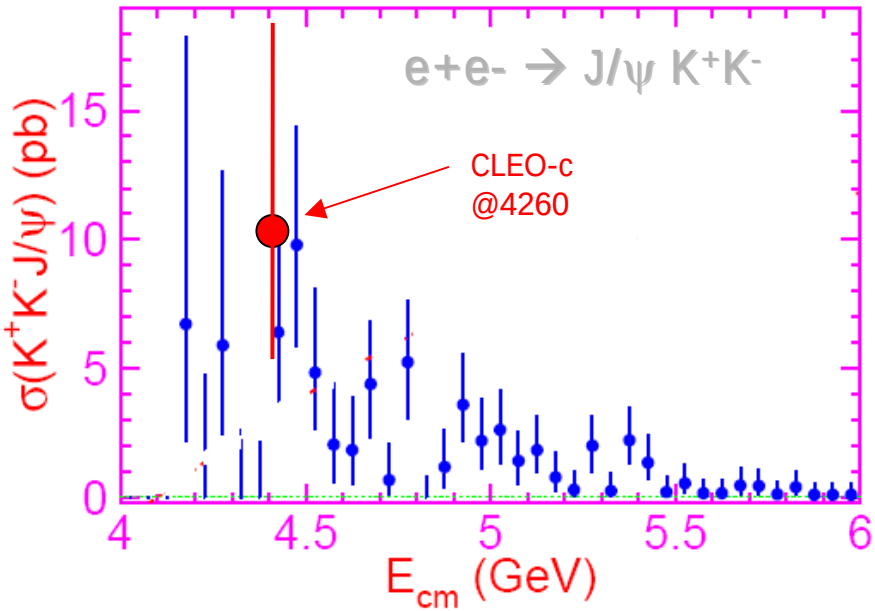
Parameters	Solution one	Solution two
$M(Y(4360))$	$4361 \pm 9 \pm 9$	
$\Gamma_{\rm tot}(Y(4360))$	$74 \pm 15 \pm 10$	
$\mathcal{B}\cdot\Gamma_{e^+e^-}(Y(4360))$	$10.4 \pm 1.7 \pm 1.5$	$11.8 \pm 1.8 \pm 1.4$
$M(Y(4660))$	$4664 \pm 11 \pm 5$	
$\Gamma_{\rm tot}(Y(4660))$	$48 \pm 15 \pm 3$	
$\mathcal{B}\cdot\Gamma_{e^+e^-}(Y(4660))$	$3.0 \pm 0.9 \pm 0.3$	$7.6 \pm 1.8 \pm 0.8$
ϕ	$39 \pm 30 \pm 22$	$-79 \pm 17 \pm 20$

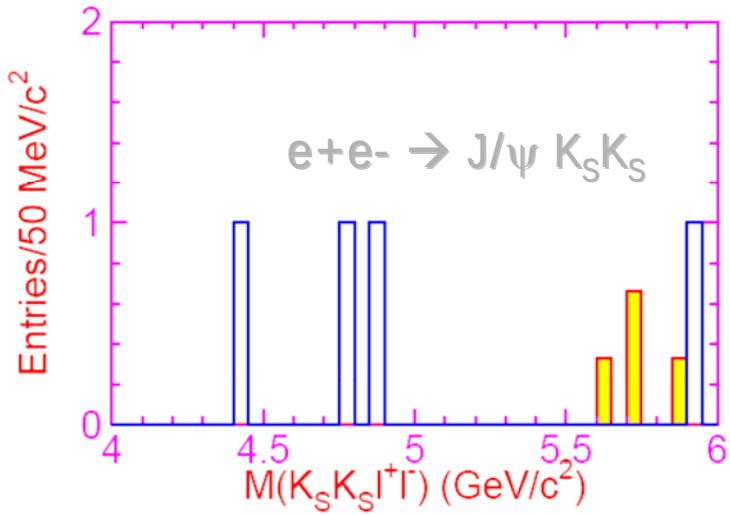
Y(4360) – consistent with BaBar
Y(4660) – NEW (5.8σ)

Belle: X.L. Wang & C.Z.Y et al., PRL99, 142002 (2007)

$e^+e^- \rightarrow K^+K^-J/\psi$ via ISR

- CLEO-c observed 3 K^+K^-J/ψ at Ecm=4.26 GeV and assumed from Y(4260)
- Belle : first observation of $e^+e^- \rightarrow J/\psi\ K^+K^-$ and evidence for $e^+e^- \rightarrow J/\psi\ K_SK_S$



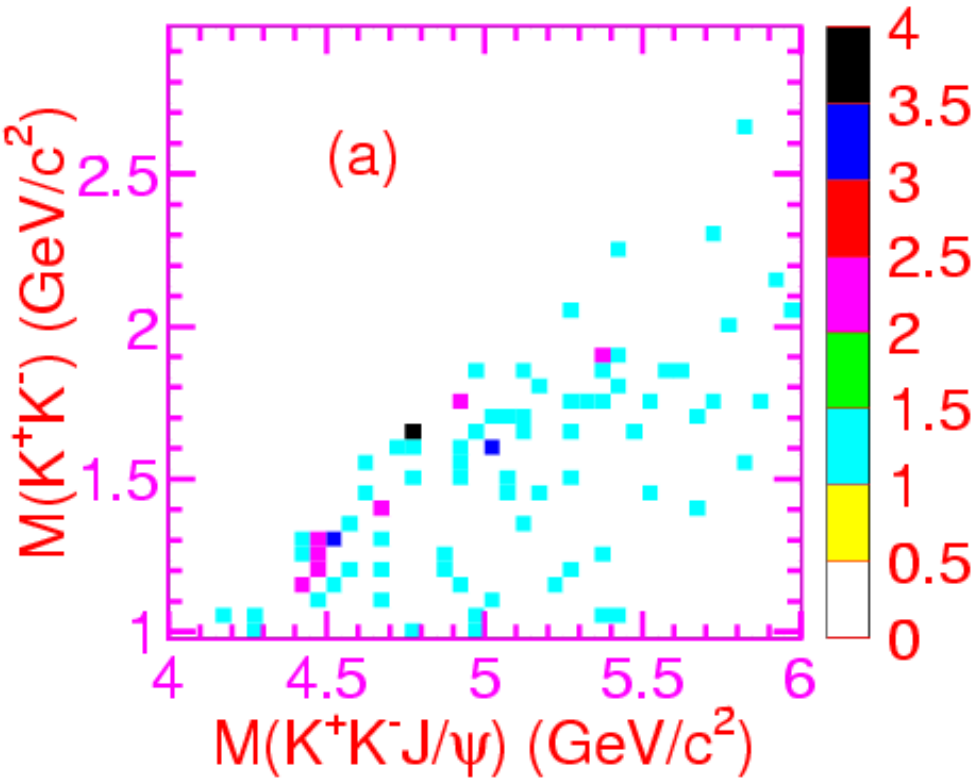


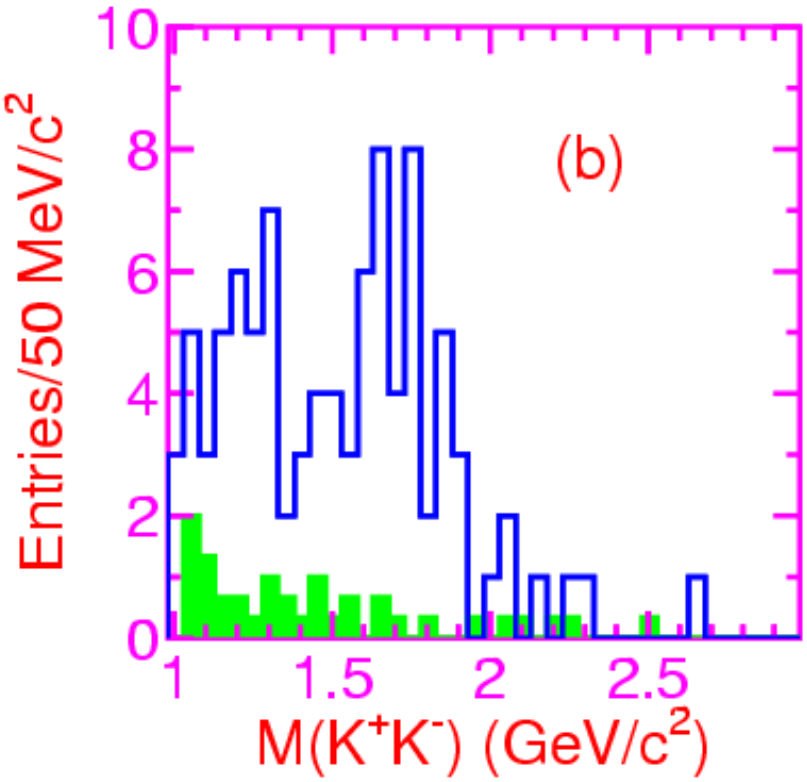
$\sigma(e^+e^- \rightarrow J/\psi K_SK_S)/\ \sigma(e^+e^- \rightarrow J/\psi K^+K-) = 0.6^{+0.5}_{-0.4}$

Consistent with isospin (0.5)

Belle: C.Z.Y & C.P. Shen et al., arXive:0709.2565

$e^+e^- \to K^+K^-J/\psi$ via ISR





KK invariant mass tends to be large!

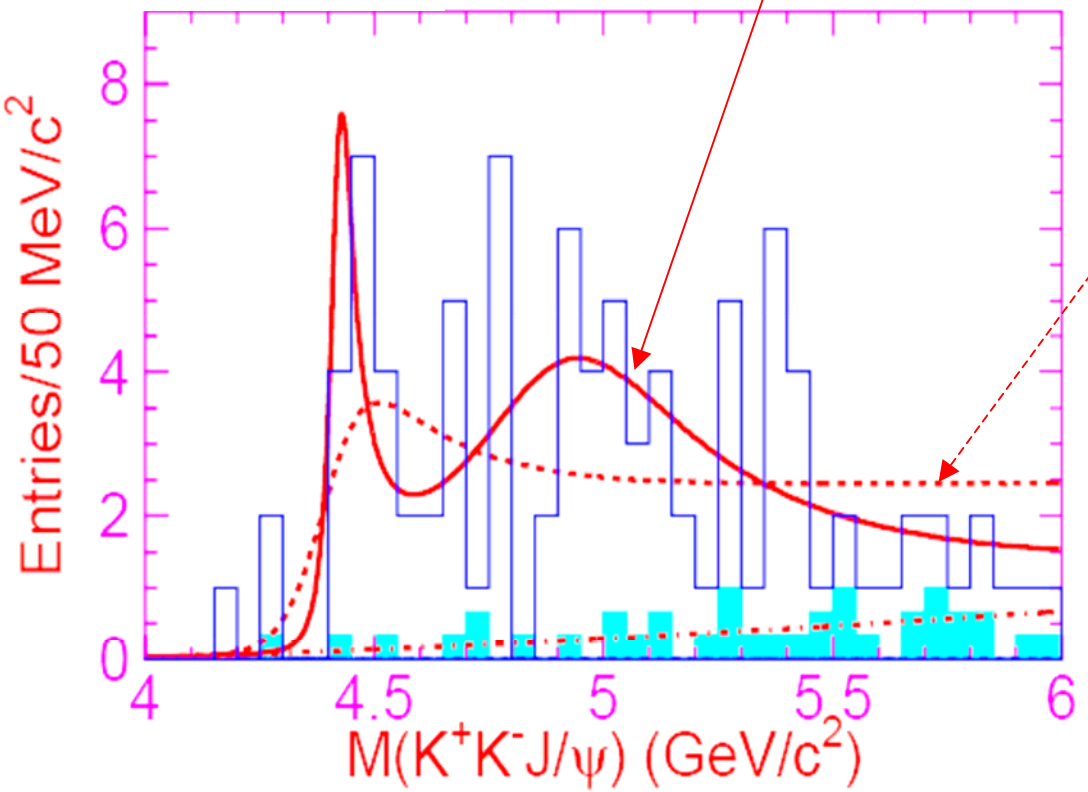
Belle: C.Z.Y & C.P. Shen et al., arXive:0709.2565

$e^+e^- \to K^+K^-J/\psi$ via ISR

New resonance or just continuum production, or other mechanism?

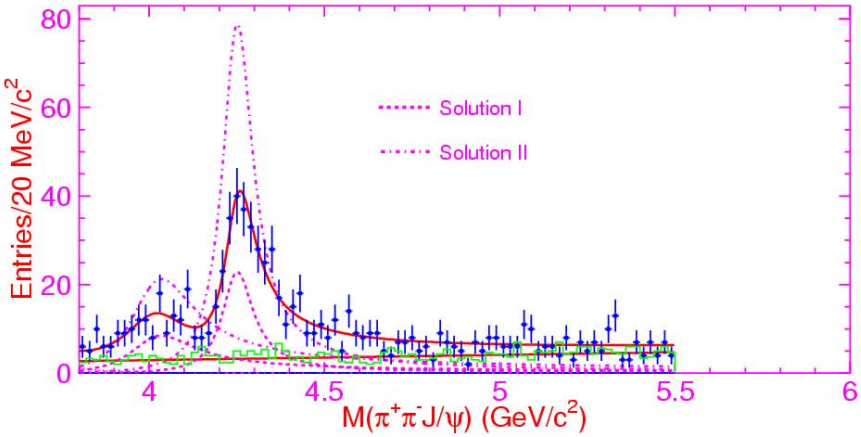
PDG $\psi(4415)$ + 1 BW:
M = (4875±132) MeV
Γ = (630±126) MeV

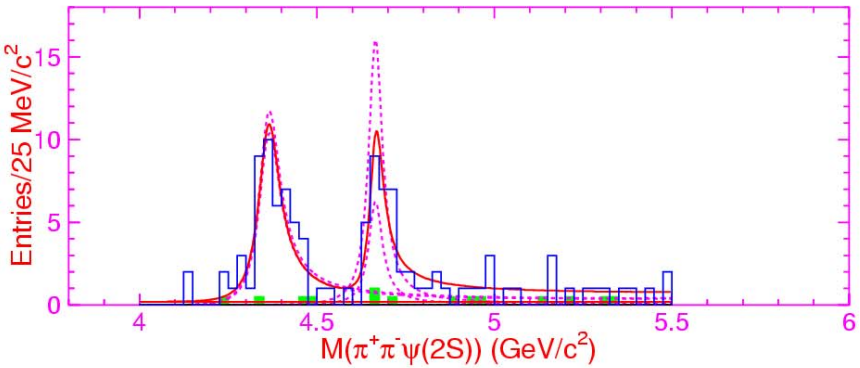
single BW:
M = (4430±38) MeV
Γ = (254±49) MeV

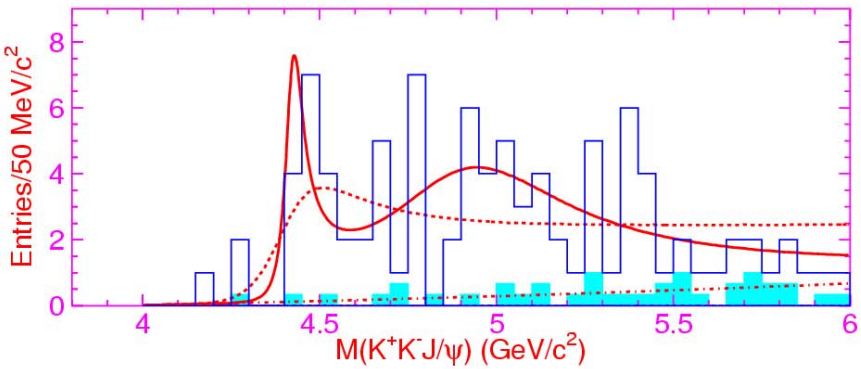


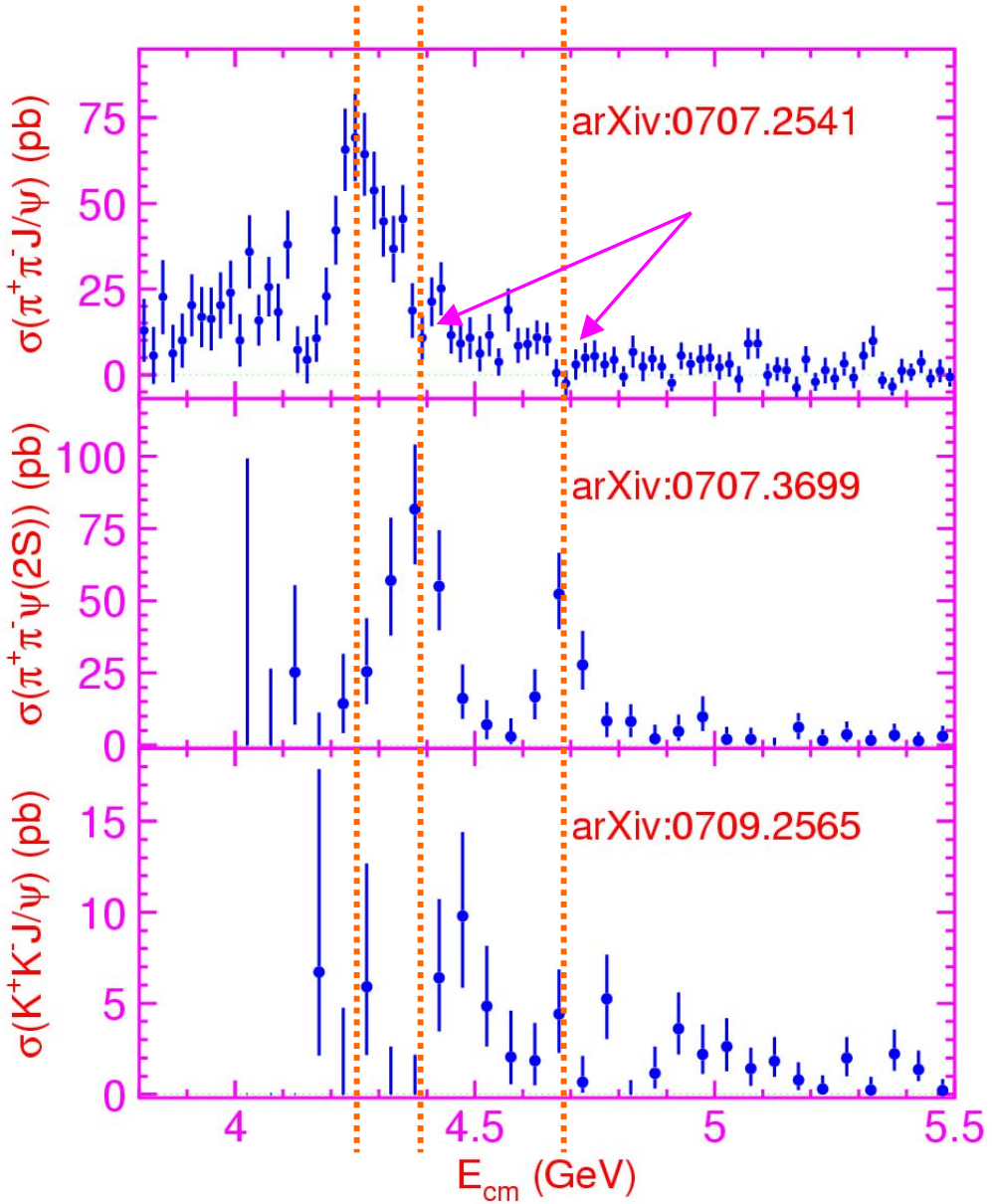
Belle: C.Z.Y & C.P. Shen et al., arXive:0709.2565

$\pi^+\pi^-J/\psi$, $\pi^+\pi^-\psi(2S)$, and K^+K^-J/ψ









Part II: the Υ_b states?

Belle: arXiv:0710.2577 [hep-ex]

Belle has ~ 22 fb^{-1} Υ(5S) data, so we can do it!

Motivations

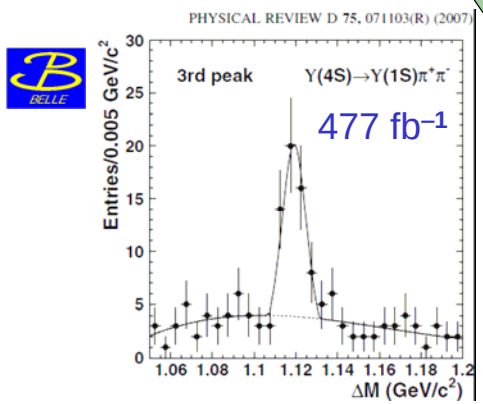
Y_b states as analogy to the Y(4260)?
G. W. S. Hou: PRD **74,** 017504 (2006).

$\Upsilon(4S)$ DECAY MODES

$\Gamma \approx$ **20.5 MeV**

$\Gamma_{ee} \approx$ **0.27 keV**

	Mode	Fraction (Γ_i/Γ)	Confidence level
Γ_1	$B\overline{B}$	> 96 %	95%
Γ_2	B^+B^-	(50.9 ±0.7) %	
Γ_3	D_s^+ anything + c.c.	(17.8 ±2.6) %	
Γ_4	$B^0\overline{B}^0$	(49.1 ±0.7) %	
Γ_5	non-$B\overline{B}$	< 4 %	95%
Γ_6	e^+e^-	(1.57±0.08) $\times 10^{-5}$	
Γ_7	$J/\psi(1S)$ anything	$< 1.9 \times 10^{-4}$	95%
Γ_8	D^{*+} anything + c.c.	< 7.4 %	90%
Γ_9	ϕ anything	(7.1 ±0.6) %	
Γ_{10}	$\phi\eta$	$< 2.5 \times 10^{-6}$	90%
Γ_{11}	$\Upsilon(1S)$ anything	$< 4 \times 10^{-3}$	90%
Γ_{12}	$\Upsilon(1S)\pi^+\pi^-$	(9.0 ±1.5) $\times 10^{-5}$	
Γ_{13}	$\Upsilon(2S)\pi^+\pi^-$	(8.8 ±1.9) $\times 10^{-5}$	
Γ_{14}	$\overline{d}$ anything	1.3 $\times 10^{-5}$	90%



$\Upsilon(10860)$ DECAY MODES

$\Gamma \approx$ **110 MeV**

$\Gamma_{ee} \approx$ **0.13 keV**

	Mode	Fraction (Γ_i/Γ)	Confidence level
Γ_1	e^+e^-	(2.8 ± 0.7) $\times 10^{-6}$	
Γ_2	$B\overline{B}X$	(59 ±14) %	
Γ_3	$B\overline{B}$	< 13.8 %	90%
Γ_4	$B\overline{B}^*$ + c.c.	(14 ± 6) %	
Γ_5	$B^*\overline{B}^*$	(44 ±11) %	
Γ_6	$B\overline{B}^{(*)}\pi$	< 19.7 %	90%
Γ_7	$B\overline{B}\pi\pi$	< 8.9 %	90%
Γ_8	$B_s^{(*)}\overline{B}_s^{(*)}(X)$	(19.5 $^{+\ 3.0}_{-\ 2.3}$) %	
Γ_9	$B_s\overline{B}_s$		
Γ_{10}	$B_s\overline{B}_s^*$ + c.c.		
Γ_{11}	$B_s^*\overline{B}_s^*$		

Inclusive Decays.

These decay modes are submodes of one or more of the decay modes above.

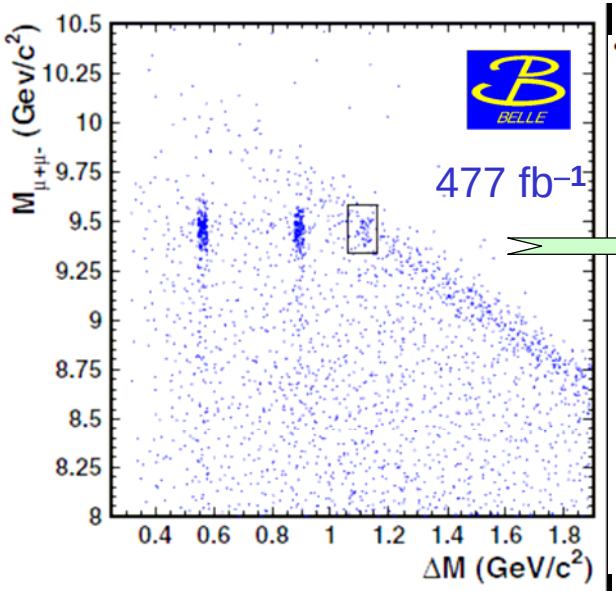
Γ_{12}	ϕ anything	(13.8 $^{+\ 2.4}_{-\ 1.7}$) %	
Γ_{13}	D^0 anything + c.c.	(108 ± 8) %	
Γ_{14}	D_s anything + c.c.	(46 ± 6) %	
Γ_{15}	J/ψ anything	(2.06± 0.21) %	

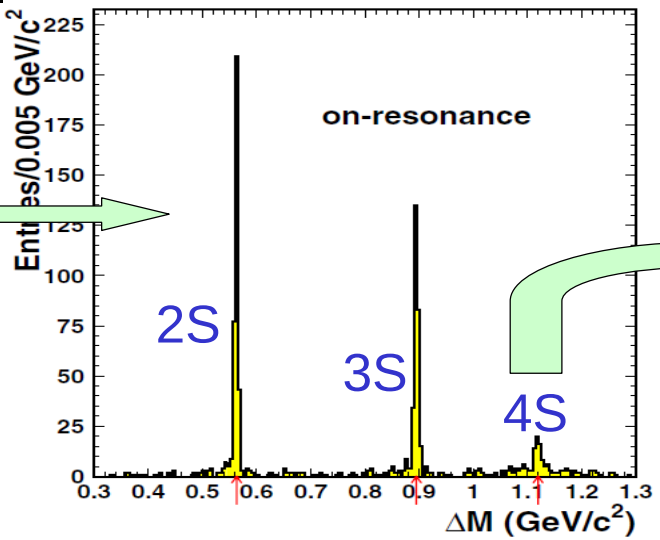
$$\frac{20.5}{110} \sim 1.7 \times 10^{-5}$$

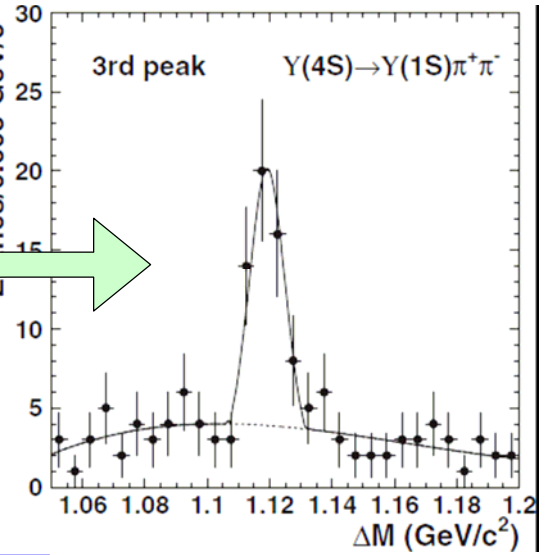
expect limits only ...

$\Upsilon(4S) \to \Upsilon(1S)\pi^+\pi^-$ Template

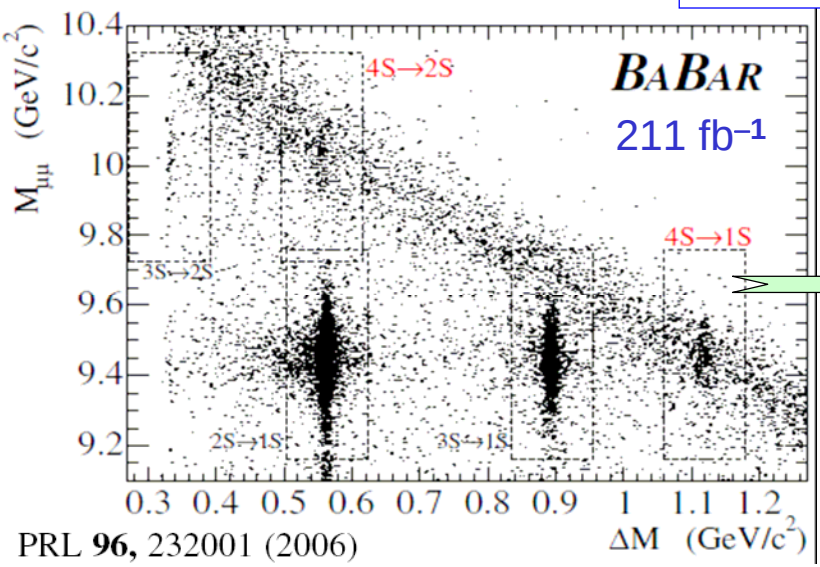
PHYSICAL REVIEW D 75, 071103(R) (2007)



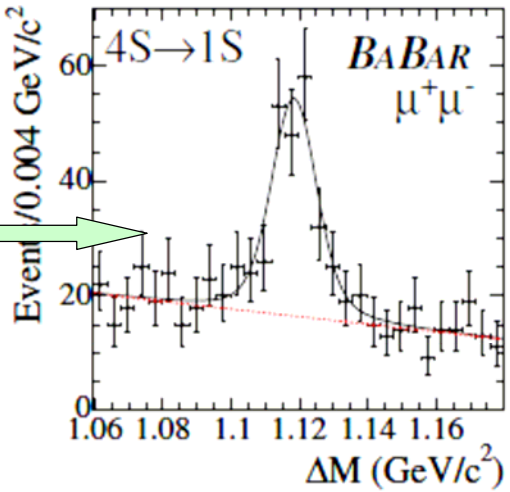


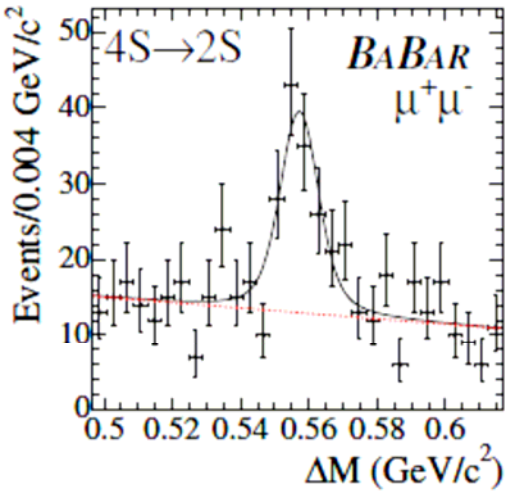


$$\Delta M = (M_{\mu^+\mu^-\pi^+\pi^-} - M_{\mu^+\mu^-})$$

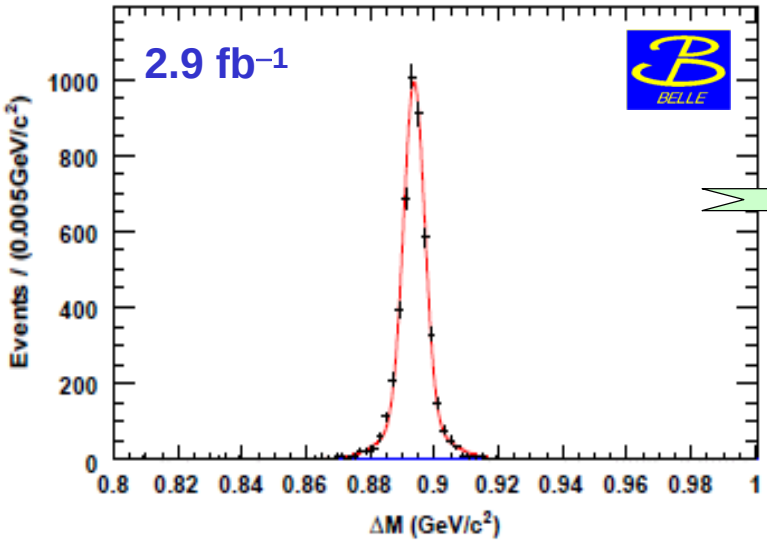


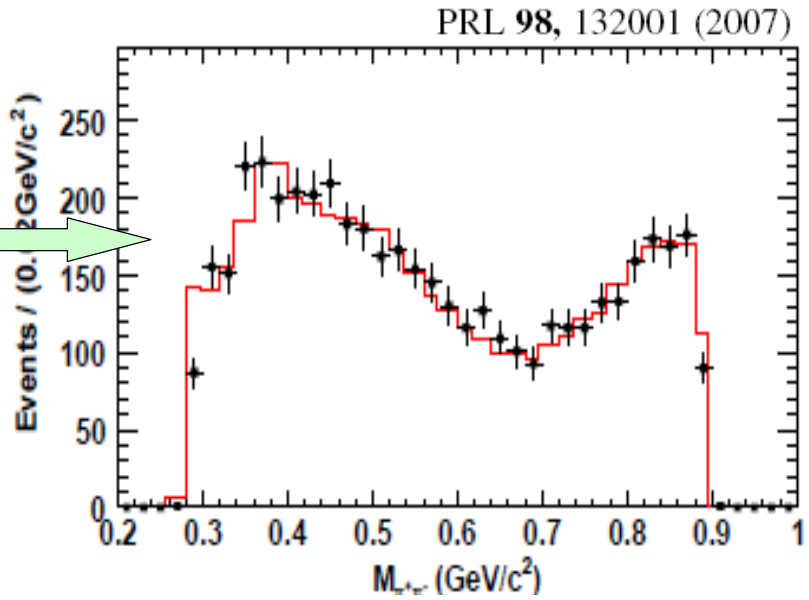
PRL 96, 232001 (2006)

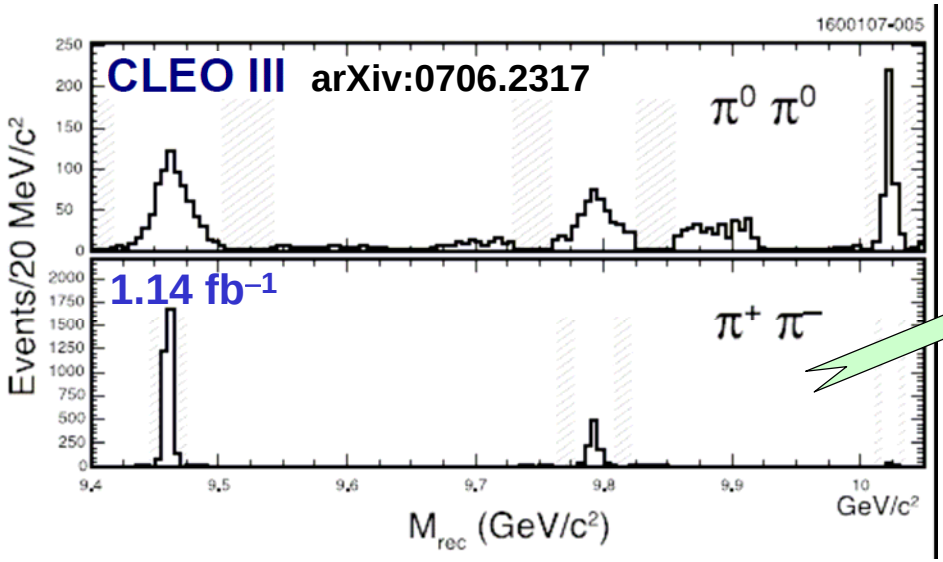


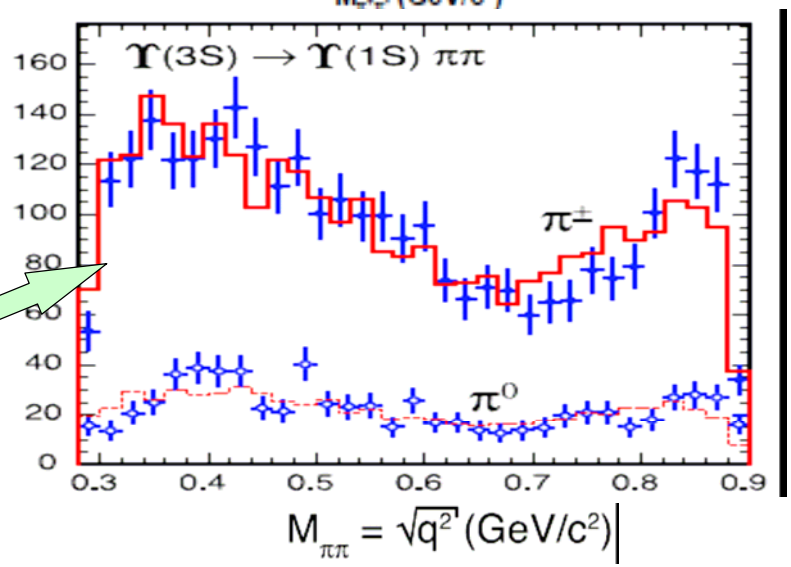


$\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$ Understanding









Event Selection for $\Upsilon(nS)h^+h^-$

- Track

  Prompt: within 5 cm of IP in z (beam direction)

  1 cm in transverse

- $\mu^+\mu^- + h^+h^-$

  Muon ID; loose h = π, K

  No other charged tracks with p_T > 100 MeV/c

- $|M(\mu^+\mu^-) - M(\Upsilon(nS))| < 150$ MeV/c^2 (3σ)

  $\Upsilon(nS)$ candidate

Main bkg : $\mu^+\mu^-\gamma \rightarrow \mu^+\mu^- e^+e^-$ that mimic $\Upsilon(1S)e^+e^-$ (conversion)

- cos $\vartheta_{\pi\pi} < 0.95$
- reject $e^\pm$ faking as $\pi^\pm$

  Electron ID
- h = K case

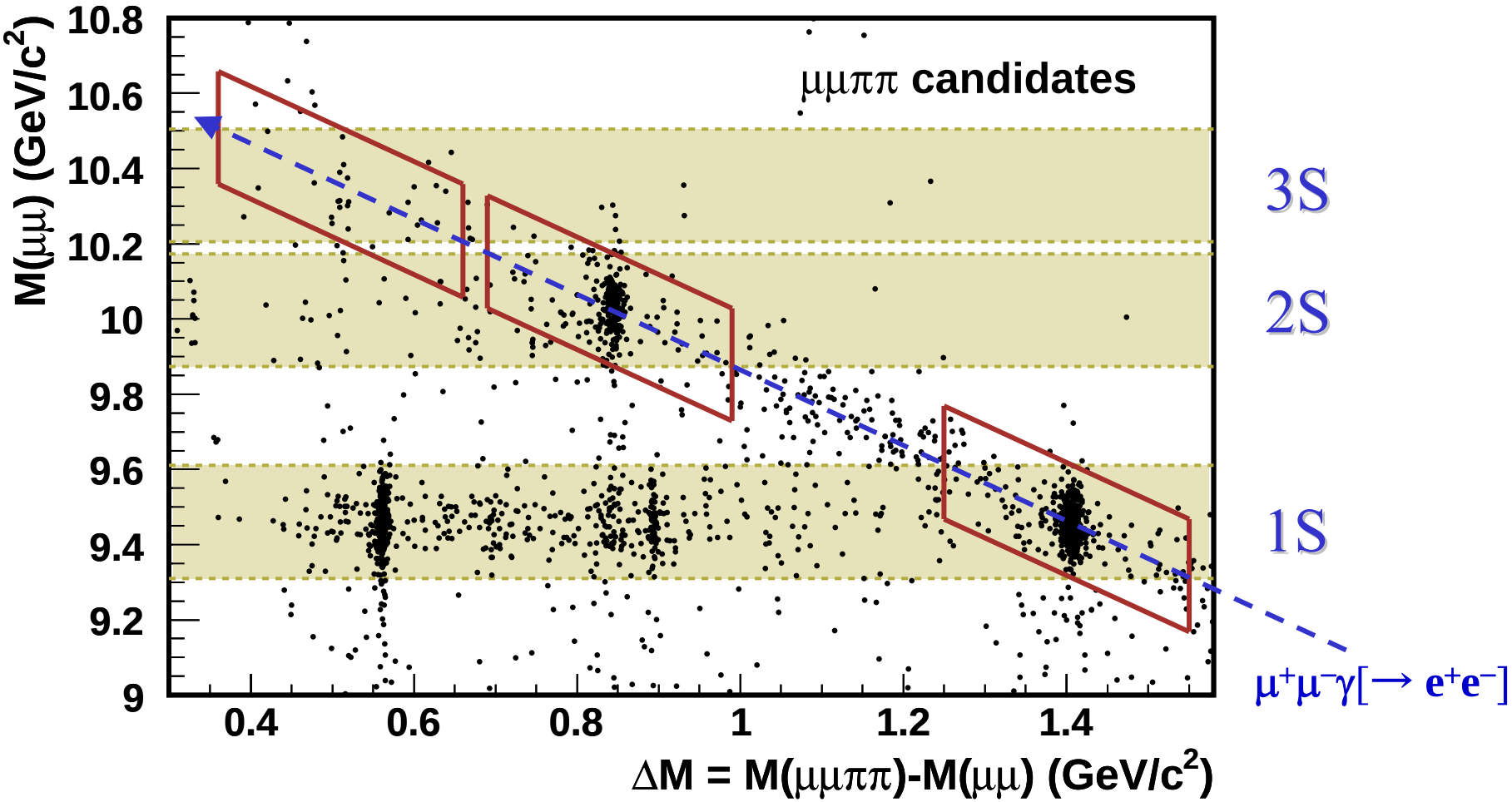
  Kaon ID

Remark: Looser than $\Upsilon(4S) \rightarrow \Upsilon(1S)\,\pi^+\pi^-$ analysis

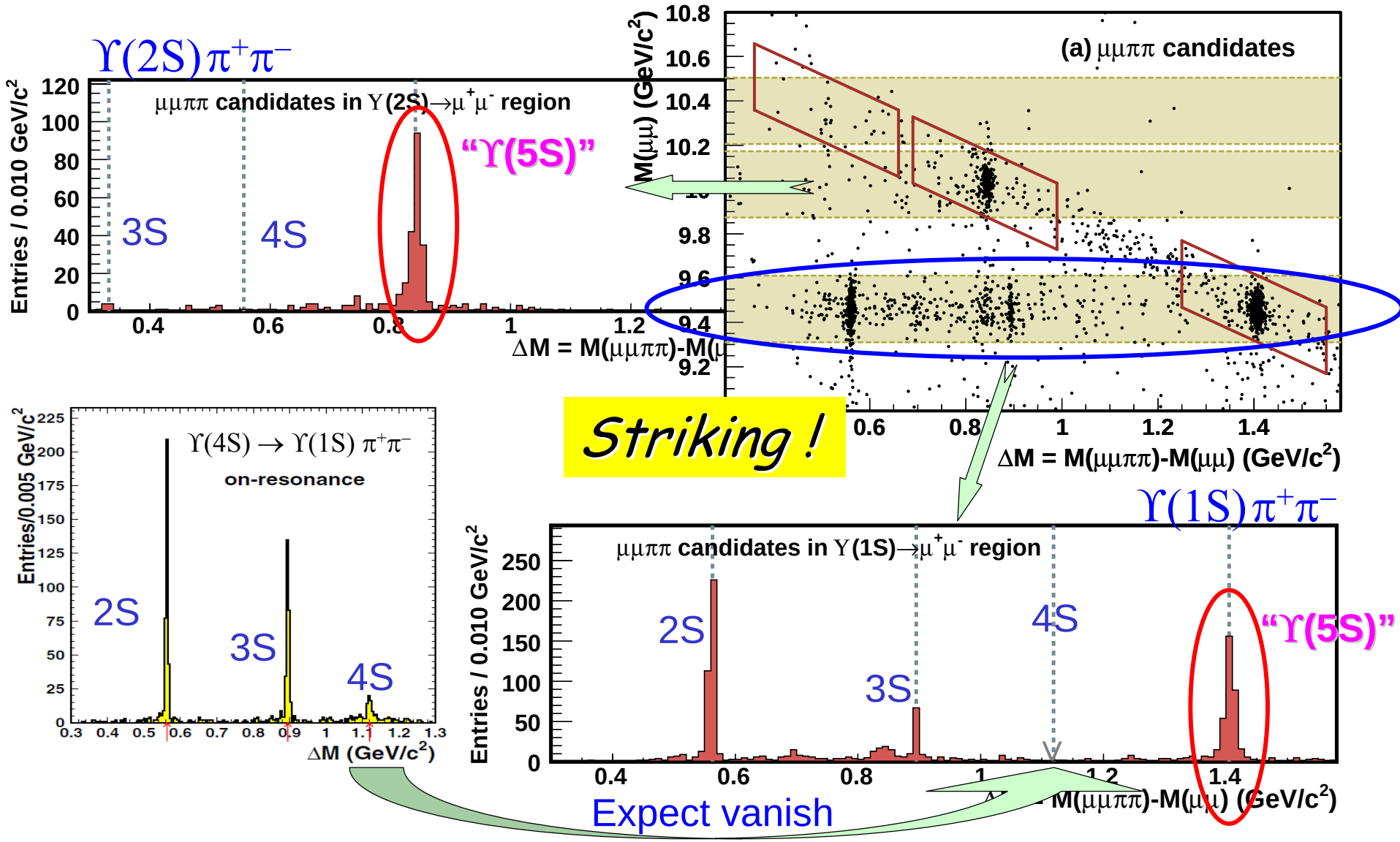
Cross checks w/ $\Upsilon(4S)$ and $\Upsilon(3S)$

$e^+e^- \to \Upsilon(nS)h^+h^-$ at 10.87 GeV

21.9 fb^{-1}

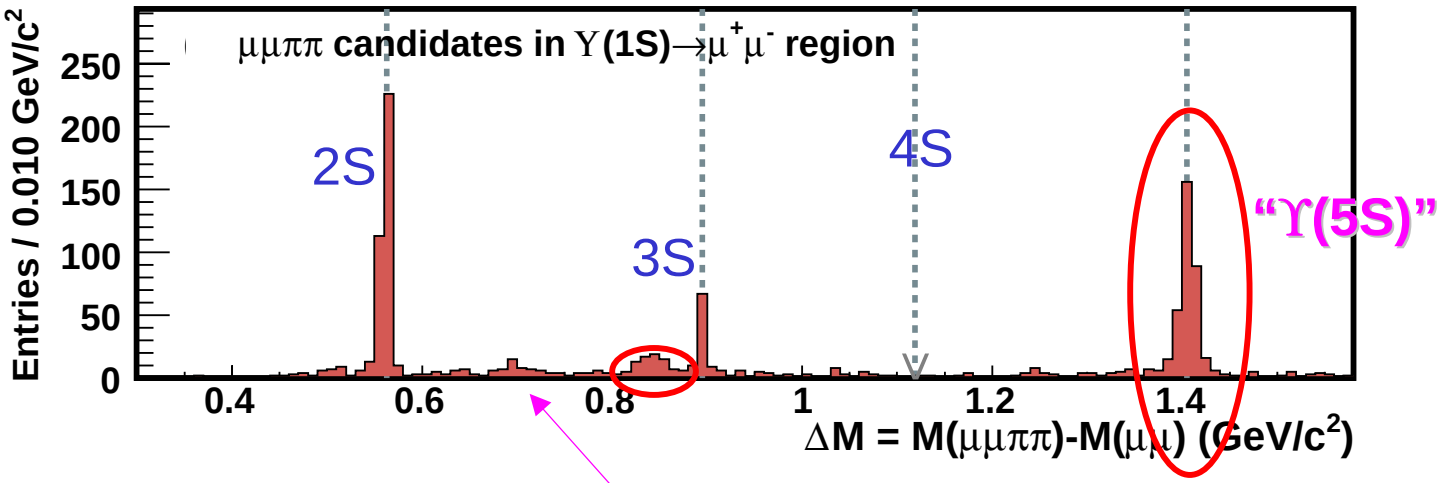


"Υ(5S)" → Υ(1S)π⁺π⁻, Υ(2S)π⁺π⁻



Remarks

$e^+e^- \to \Upsilon(1S)\pi^+\pi^-$

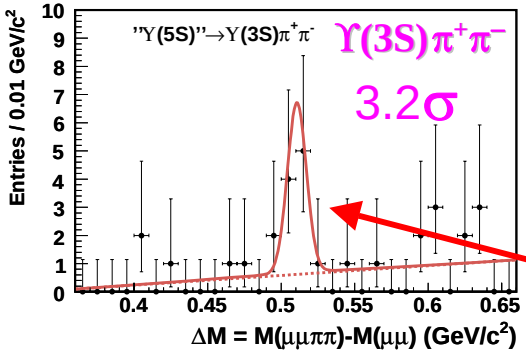


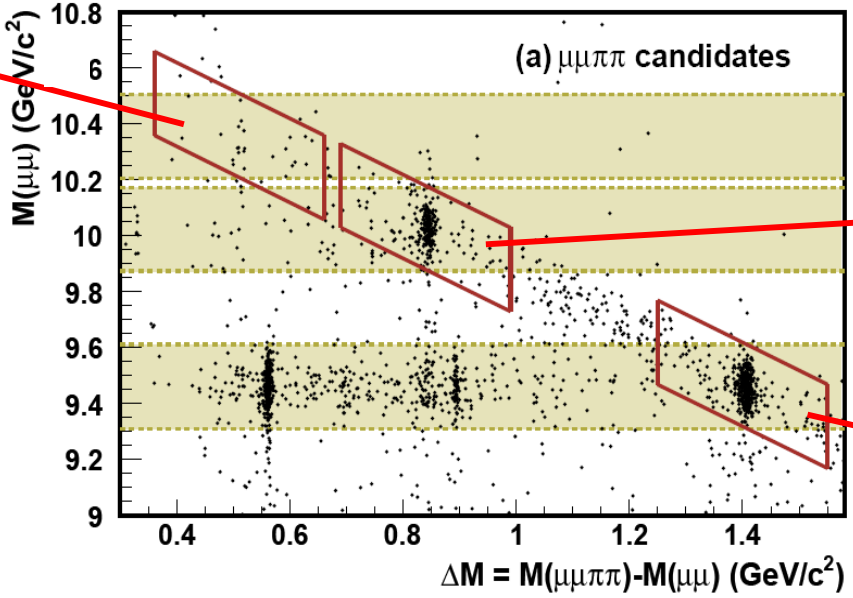
- Structure at ~ 0.84 GeV/c^2 below 3S: "$\Upsilon(5S)$" → $\Upsilon(2S)\pi^+\pi^-$
  ↳ $\Upsilon(1S)$+X

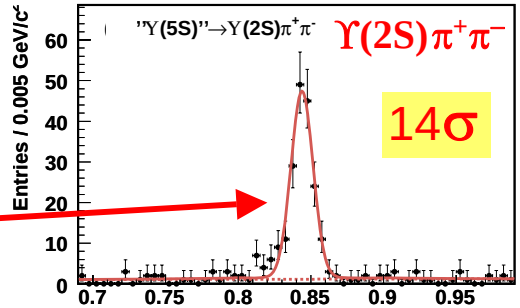
  some other reflection ?

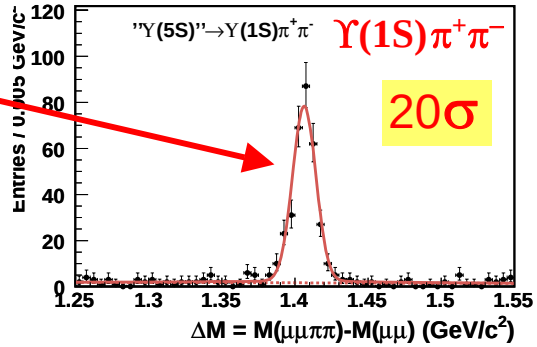
- "$\Upsilon(5S)$": single E_{CM} energy at 10.87 GeV
  No clear indication of radiative tail

“Υ(5S)” → Υ(nS)π⁺π⁻, Υ(1S)K⁺K⁻

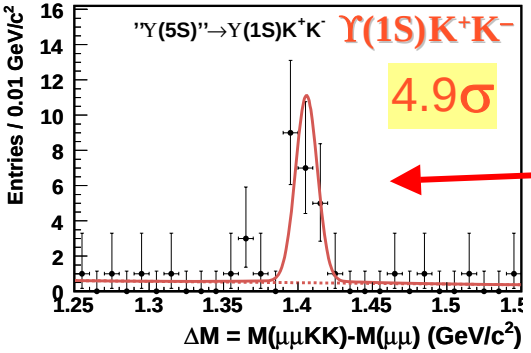


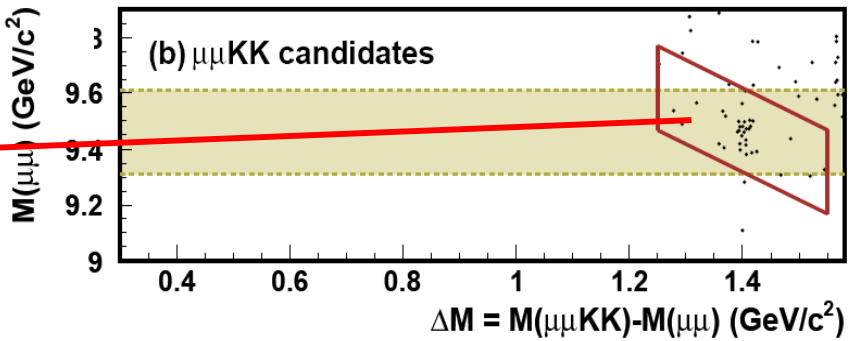






square box give ~ 3.9σ





Yield: Unbinned extended ML Fit

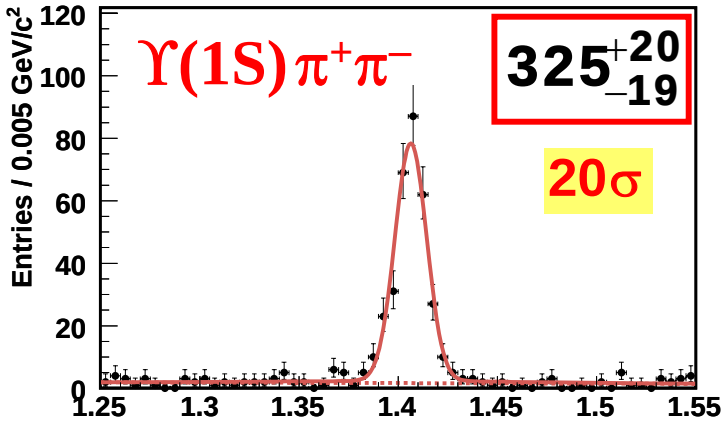
$$\mathcal{L}(N_s, N_b) = \frac{e^{-(N_s+N_b)}}{N!} \prod_{i=1}^{N} [N_s \cdot P_s(\Delta M_i) + N_b \cdot P_b(\Delta M_i)]$$

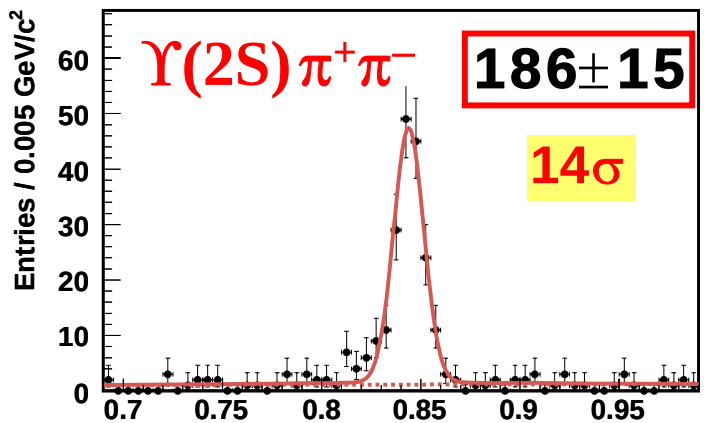
signal yield

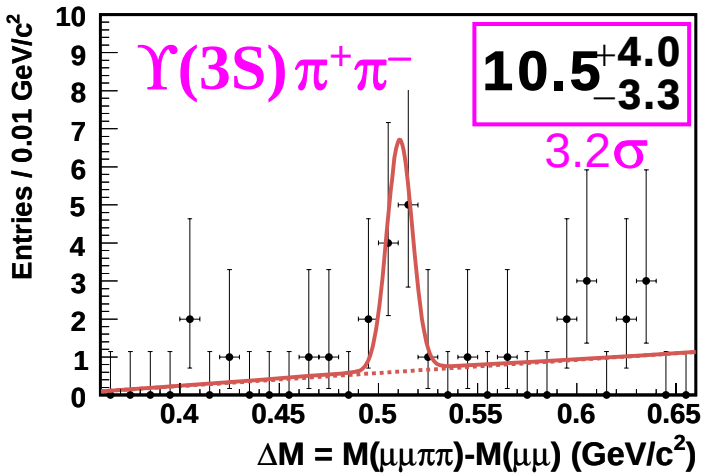
bkgrnd yield

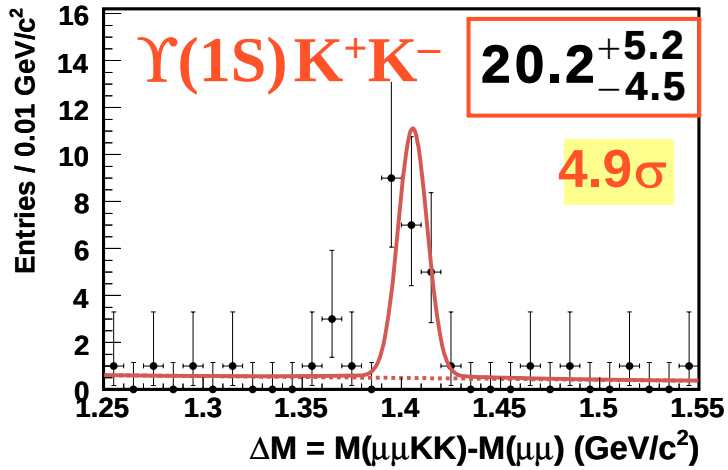
signal PDF [two Gaussians

bkgrnd PDF [linear ⇐ optimze box

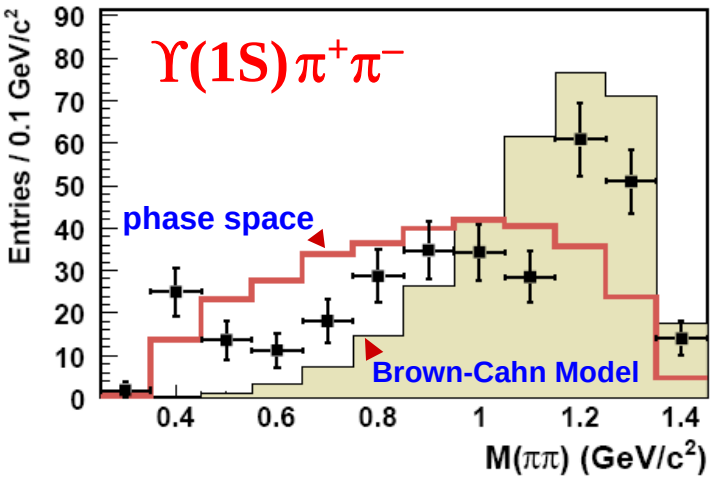


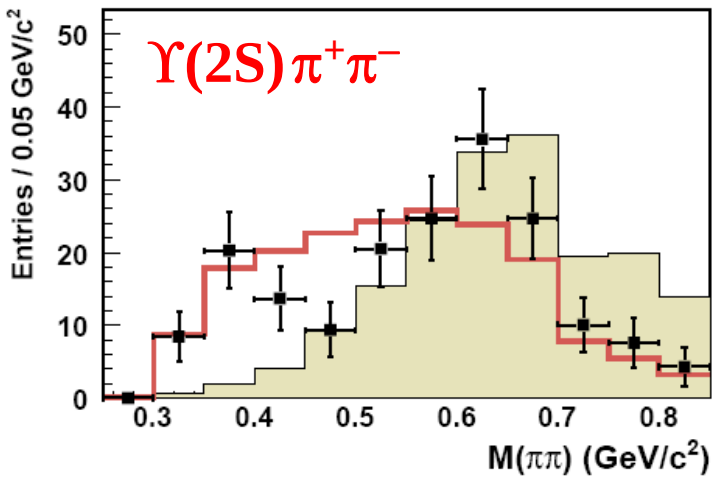


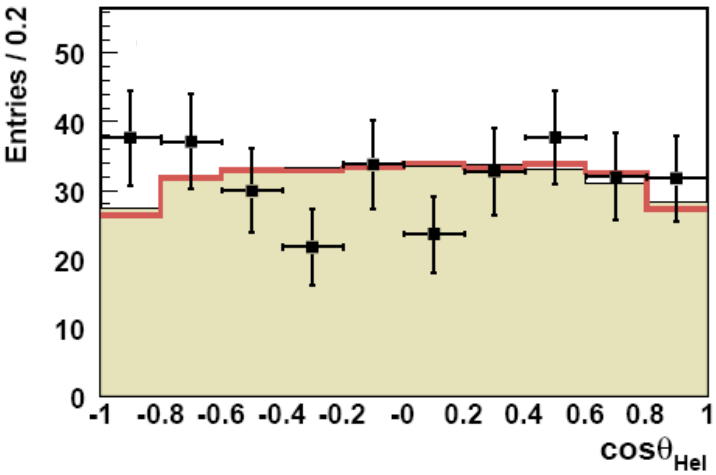


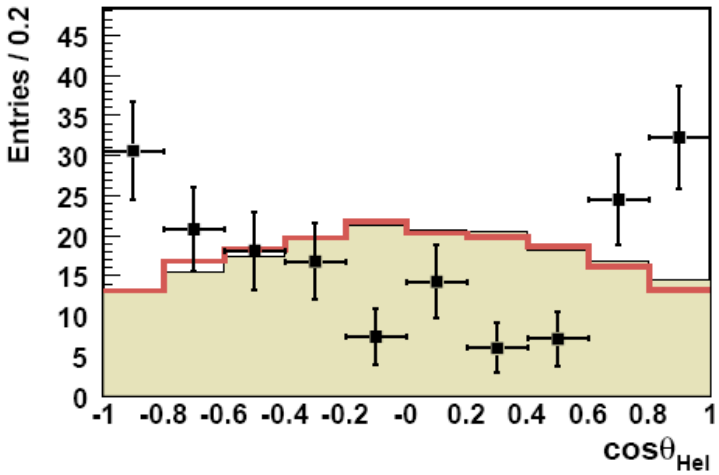


$M(\pi\pi)$ and $\cos\theta_{Hel}$ Distributions









Efficiency estimate: re-weighted MC according to data

N.B. other two modes use B-C model due to limited statistics

Summary on $\Upsilon(nS)h^+h^-$

Assume "$\Upsilon(5S)$" = $\Upsilon(5S)$

PDG values taken for $\Upsilon(nS)$ properties

Process	N_s	Σ	σ(pb)	$\mathcal{B}(\%)$	Γ(MeV)
$\Upsilon(1S)\pi^+\pi^-$	325^{+20}_{-19}	20σ	$1.61 \pm 0.10 \pm 0.12$	$0.53 \pm 0.03 \pm 0.05$	$0.59 \pm 0.04 \pm 0.09$
$\Upsilon(2S)\pi^+\pi^-$	186 ± 15	14σ	$2.35 \pm 0.19 \pm 0.32$	$0.78 \pm 0.06 \pm 0.11$	$0.85 \pm 0.07 \pm 0.16$
$\Upsilon(3S)\pi^+\pi^-$	$10.5^{+4.0}_{-3.3}$	3.2σ	$1.44^{+0.55}_{-0.45} \pm 0.19$	$0.48^{+0.18}_{-0.15} \pm 0.07$	$0.52^{+0.20}_{-0.17} \pm 0.10$
$\Upsilon(1S)K^+K^-$	$20.2^{+5.2}_{-4.5}$	4.9σ	$0.185^{+0.048}_{-0.041} \pm 0.028$	$0.061^{+0.016}_{-0.014} \pm 0.010$	$0.067^{+0.017}_{-0.015} \pm 0.013$

N.B. Resonance cross section
0.302±0.015 nb at E_{CM}=10.87 GeV

PRD **98,** 052001 (2007) [Belle]

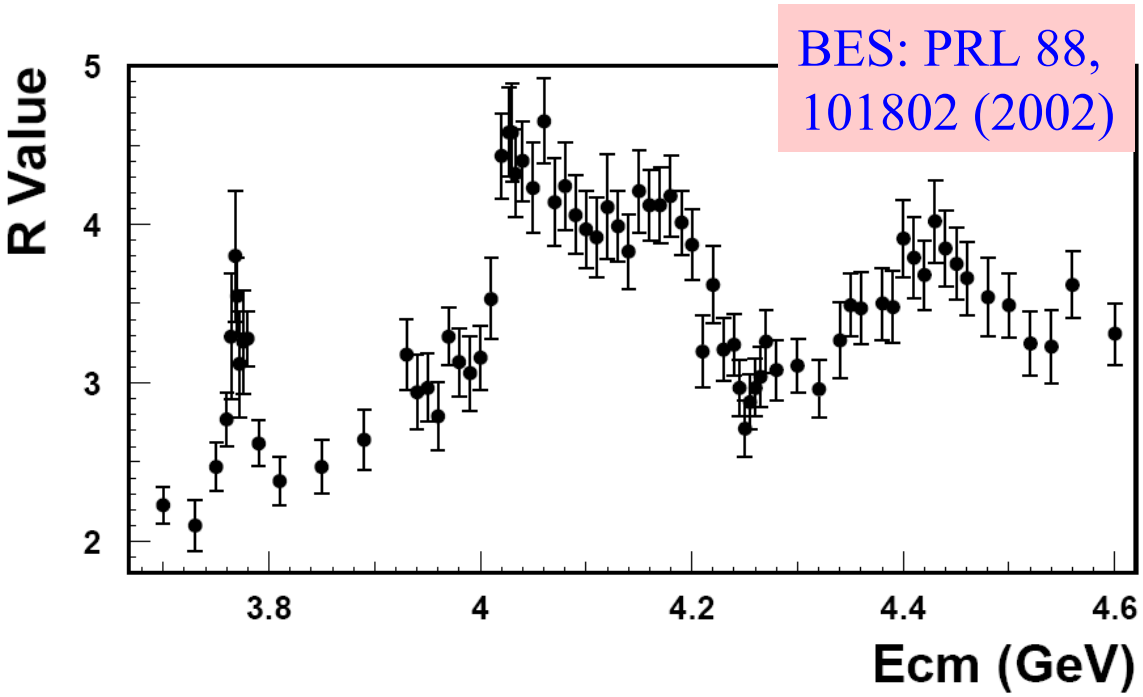
Cf
$\Upsilon(2S) \rightarrow \Upsilon(1S)\ \pi^+\pi^-$ ~ 6 keV
$\Upsilon(3S)$ 0.9 keV
$\Upsilon(4S)$ 1.8 keV

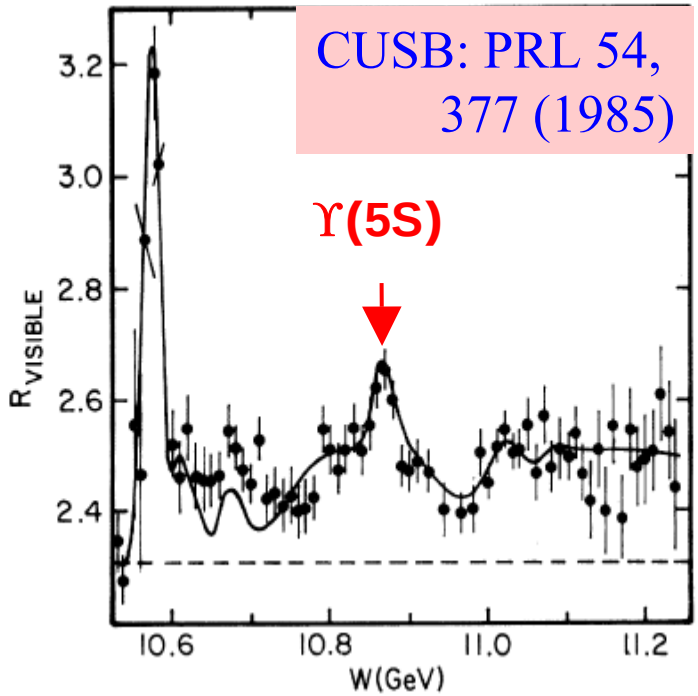
B and Γ depends strongly on $\Upsilon(5S)$ resonance parameters!

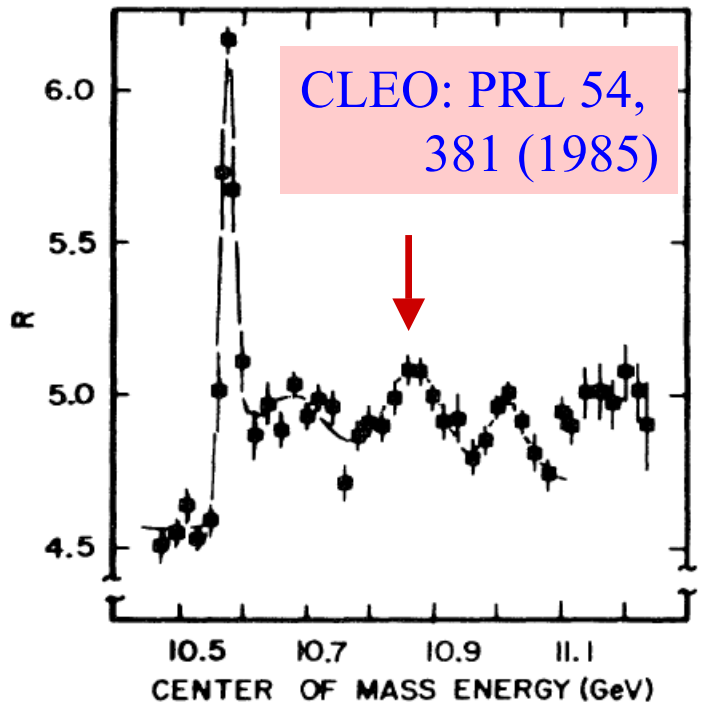
- Recall Y(4260) ⟹ Need Mechanism
- Is this $\Upsilon(5S)$, or the Y_b state?

⟹ Need Scan to tell

What is Υ(5S)?







Constructive interference between amplitudes?

We are exploring a mass regions with many open-flavor threshold!

Need more study!

Summary

- Observation of Y(4008), Y(4260), Y(4360), Y(4660) states in ISR data
- Observation of $e^+e^- \to J/\psi\, K^+K^-$
- Evidence for $e^+e^- \to J/\psi\, K_S K_S$
- Observation of $e^+e^- \to \Upsilon(1S)\,\pi^+\pi^-$, $\Upsilon(2S)\,\pi^+\pi^-$ at Ecm=10.87 GeV
- Evidence for $e^+e^- \to \Upsilon(3S)\,\pi^+\pi^-$, $\Upsilon(1S)\,K^+K^-$ at Ecm=10.87 GeV

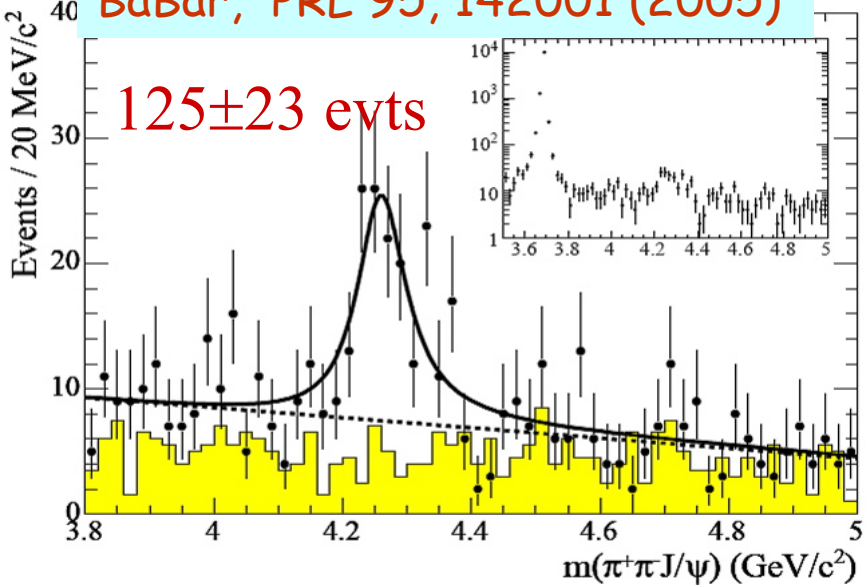
What is the nature of the Y states?

How to understand the large $\Upsilon\pi^+\pi^-$ cross section?

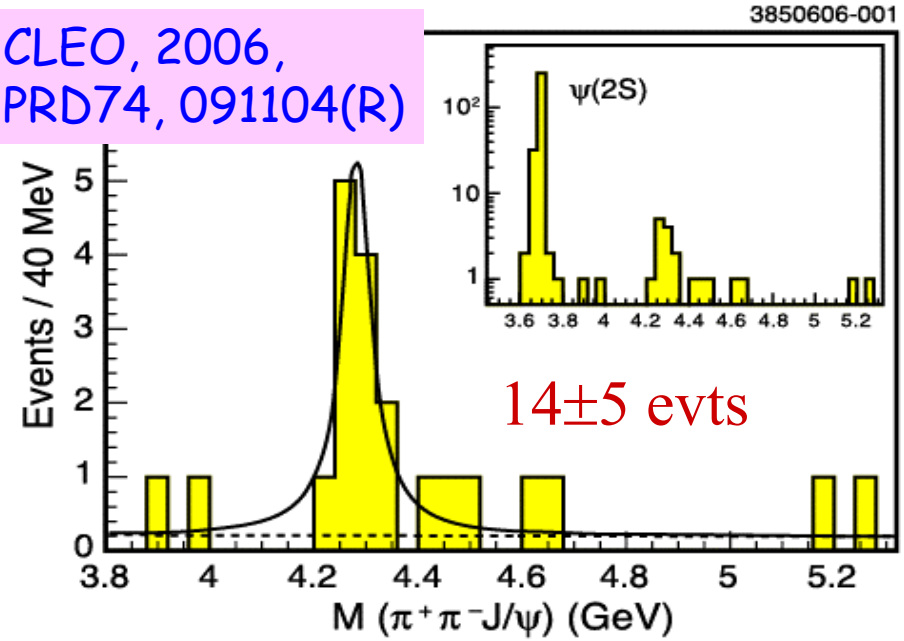
More information

Y(4260) in other experiments

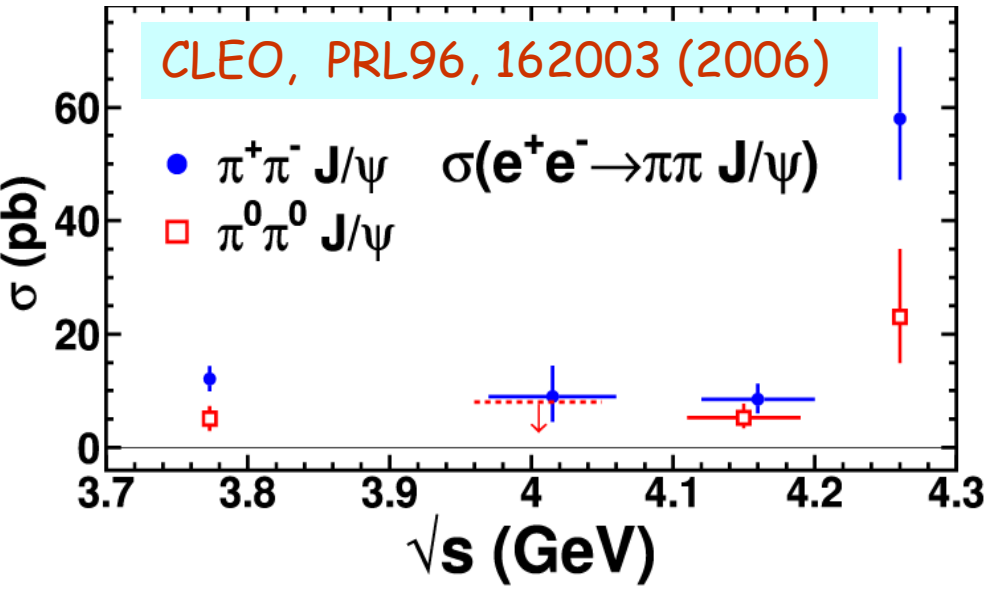
BaBar, PRL 95, 142001 (2005)

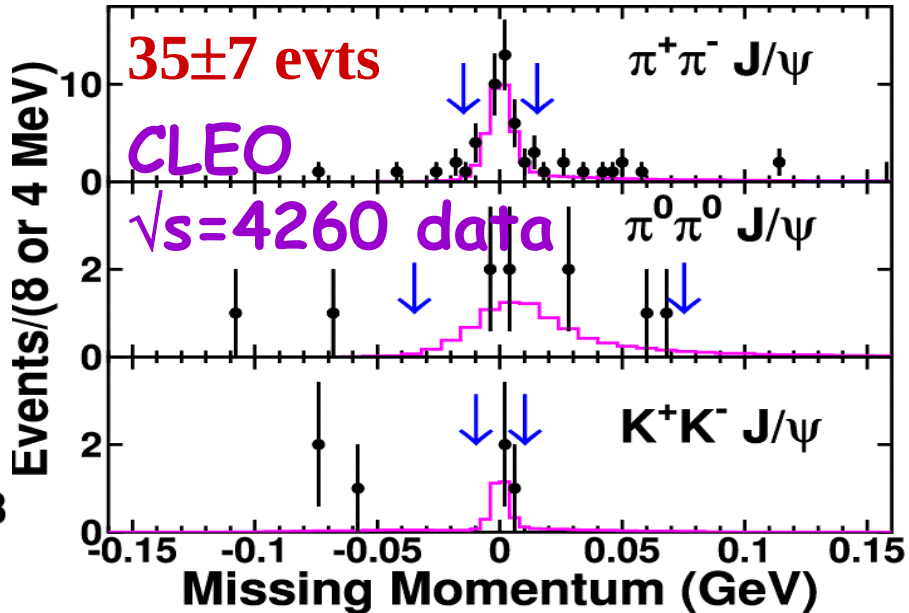


CLEO, 2006, PRD74, 091104(R)



CLEO, PRL96, 162003 (2006)





Y(4260) in other experiments

X.H. Mo et al, PLB **640**, 182 (2006)
Using R-values from BES experiment.

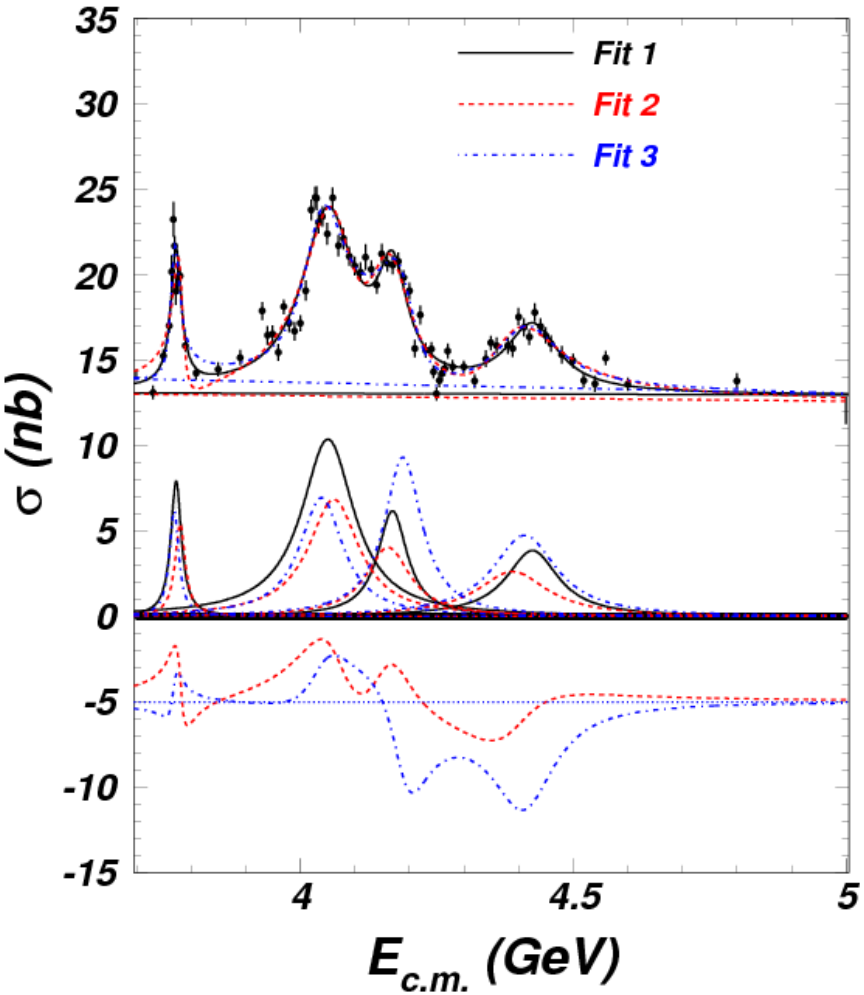
Γ_{ee}<580 eV @90% C.L.

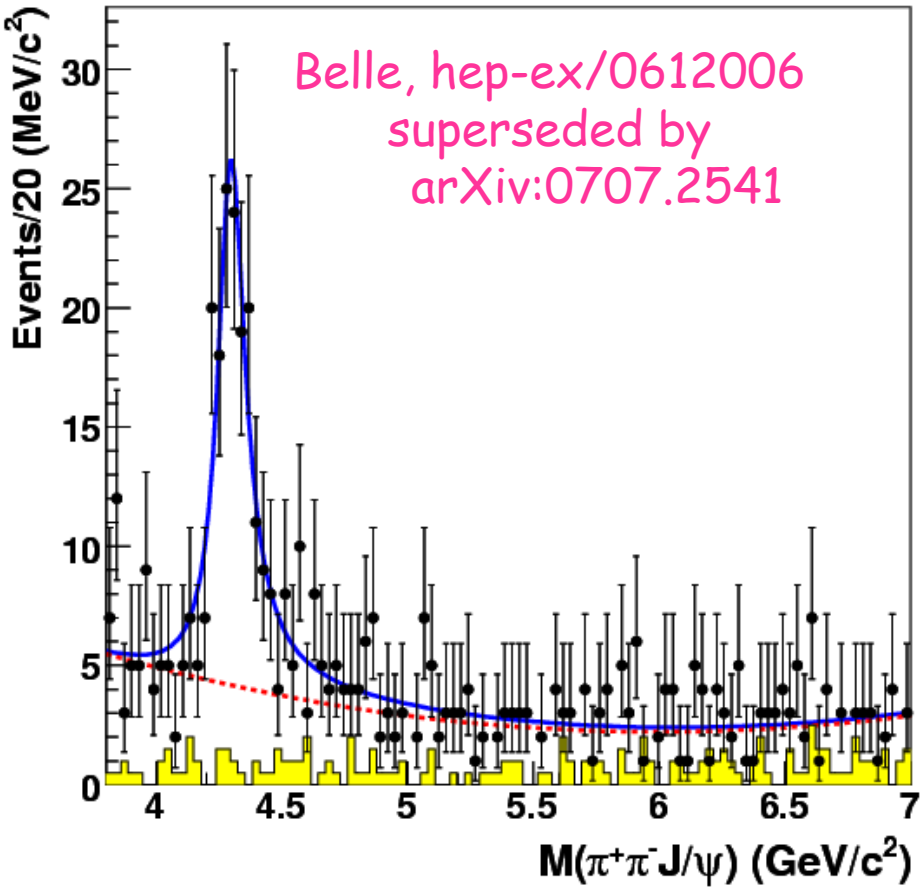
$N = 165 \pm 24$

$M = 4295 \pm 10^{+10}_{-5}$ MeV

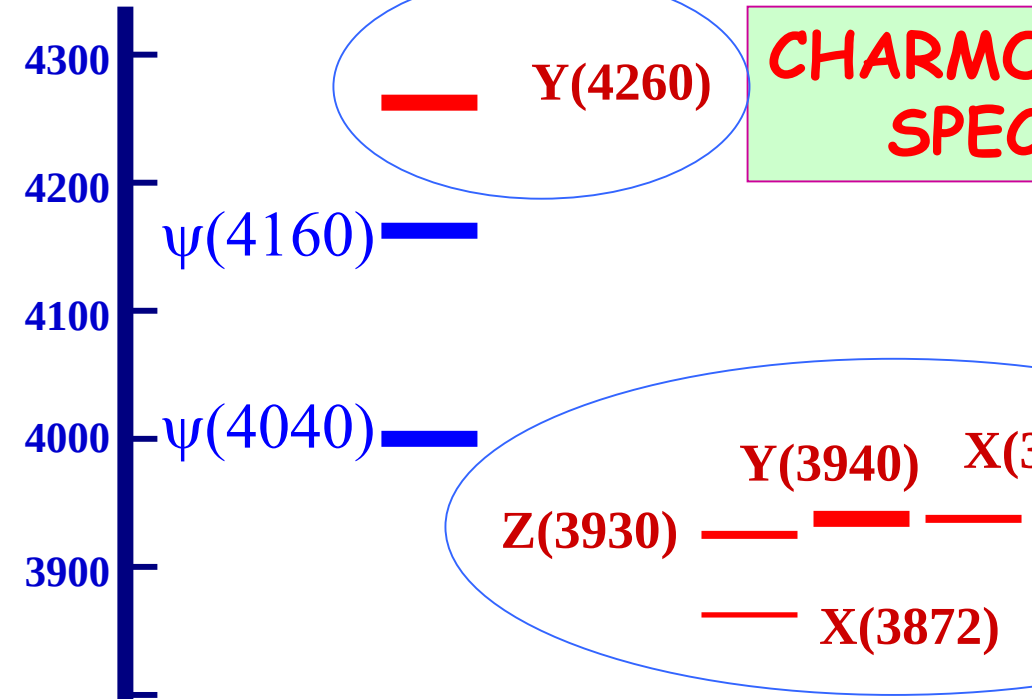
$\Gamma = 133 \pm 26^{+13}_{-6}$ MeV

$\Gamma_{ee} \cdot B(Y \to \pi^+\pi^- J/\psi) = 8.7 \pm 1.1^{+0.3}_{-0.9}$ eV





CHARMONIUM (?) SPECTRUM



Less known states:

- ψ(4040)
- ψ(4160)
- ψ(4415)

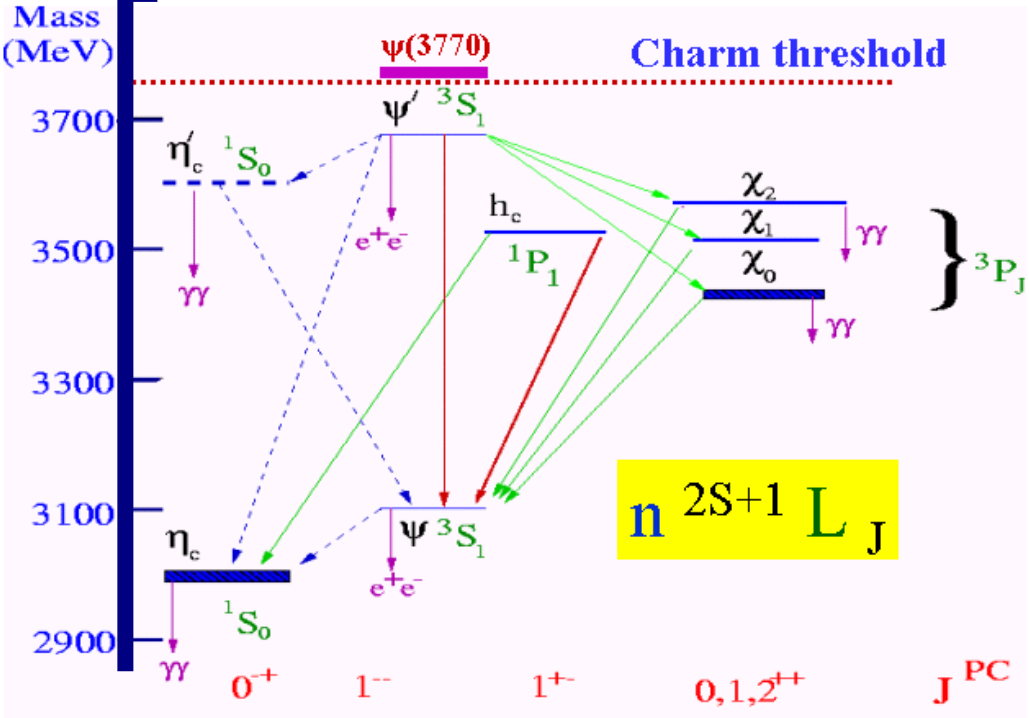
New states from B-factories:

- **X(3872)=DD* (?)**
- **X(3940)=η_c(3S) (?)**
- **Y(3940)=?**
- **Z(3930)=χ_{c2}(2P)**
- **Y(4008)= ψ(3S) (?)**
- **X(4160)=χ_{c0}(3P) (?)**
- **Y(4260)=hybrid (?)**
- **Y(4324)/Y(4360)=?**
- **Z(4430)=tetraquark(?)**
- **Y(4660)= ψ(5S) (?)**

New states every year!

What are they?

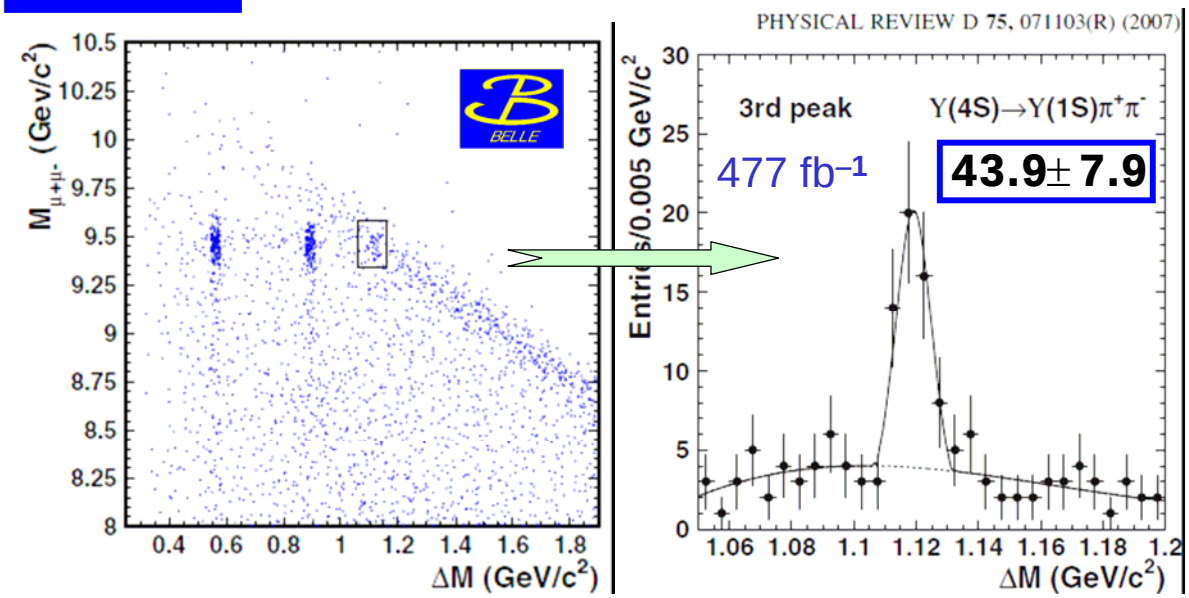
Charmonia? Exotic states?

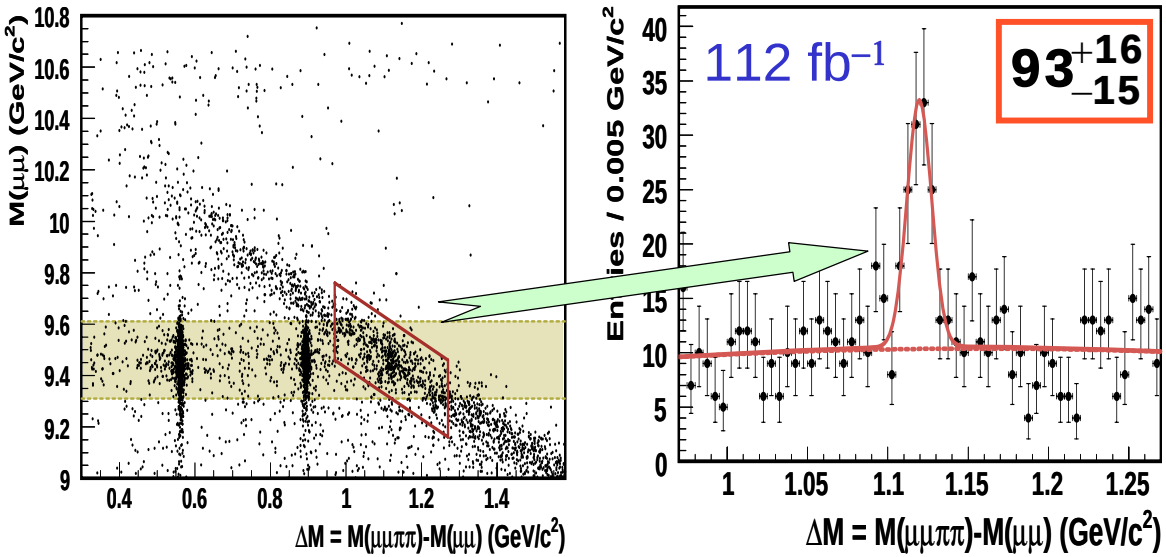


$\Upsilon(5S)$: Systematic Uncertainty

Source	$\Upsilon(1S)\pi^+\pi^-$	$\Upsilon(2S)\pi^+\pi^-$	$\Upsilon(3S)\pi^+\pi^-$	$\Upsilon(1S)K^+K^-$
Tracking	4.1%	4.6%	5.6%	4.1%
Lepton Ident.	1.0%	1.0%	1.0%	1.0%
Electron rejection	0.2%	0.2%	0.4%	3.6%
Fitting	1.5%	3.7%	1.7%	1.4%
$\pi\pi$ model	4.4%	6.8%	3.2%	13.6%
M($\mu\mu\pi\pi$) selection	2.6%	2.6%	2.6%	2.6%
Bhabha rejection	1.9%	1.9%	1.9%	1.9%
Trigger	0.9%	3.1%	4.5%	1.0%
Luminosity	1.4%	1.4%	1.4%	1.4%
Cross-section	5.0%	5.0%	5.0%	5.0%
Υ(nS) $\rightarrow \mu\mu$ bf	2.0%	8.8%	9.6%	2.0%
Total	**9.0%**	**14.4%**	**14.0%**	**16.1%**

Corrected $\Upsilon(4S) \to \Upsilon(1S)\pi^+\pi^-$





Uncover from this study
- Data and signal yield correct
- Efficiency estimate for signal normalization was wrong

New preliminary Result:

$$\mathcal{B}f = 1.06^{+0.18}_{-0.17} \pm 0.09 \times 10^{-4}$$

$$\Gamma = 2.17^{+0.37}_{-0.35} \pm 0.33 \text{ keV}$$

- Based on new data skim (112 fb^{-1}) w/ 4x efficiency
- Now consistent w/ BaBar

Revised publication coming soon

Υ(5S) data

1985: CLEO,CUSB @ CESR ~ 116 pb^{-1}

2003: CLEO III @ CESR **~ 0.42 fb^{-1}**

2005: Belle @ KEKB **~ 1.86 fb^{-1}**

engineering run

2006, June 9-31: Belle @ KEKB

≅ 21.9 fb^{-1}