Production of charmonium(like) states in e^+e^- interactions

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for the Belle Collaboration

Belle Collaboration

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Chiba U.
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Fu-Jen Catholic U.
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Gyeongsang Nat'l U.
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Hiroshima Tech.
IHEP, Beijing
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ITEP
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Kyoto U.
Kyungpook Nat'l U.
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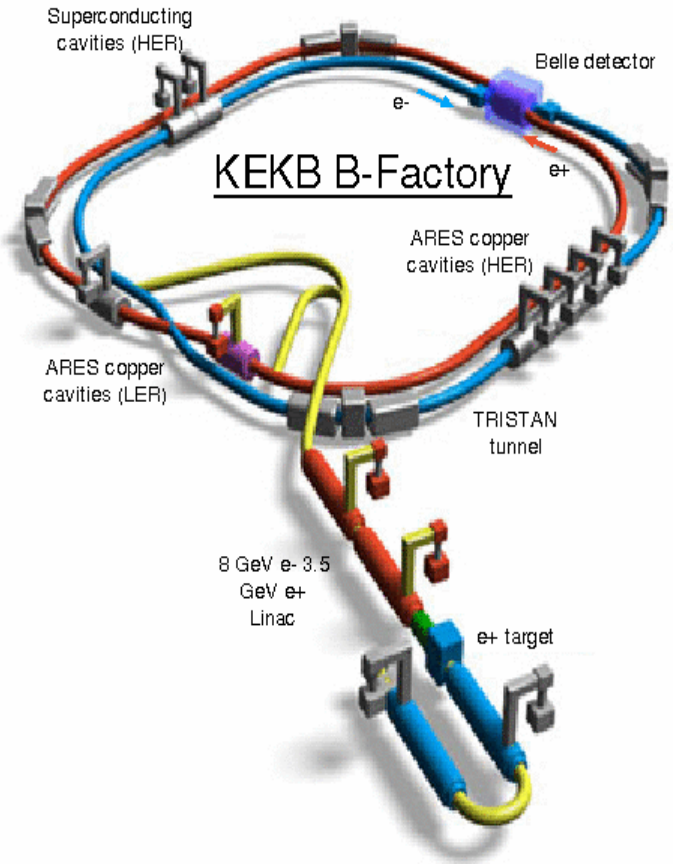
Tohuku Gakuin U.
U. of Tokyo
Tokyo Inst. of Tech.
Tokyo Metropolitan U.
Tokyo U. of Agri. and Tech.
INFN Torino
Toyama Nat'l College
VPI
Yonsei U.

13 countries +1 (this year)
55 institutes
~400 collaborators

KEKB & Belle



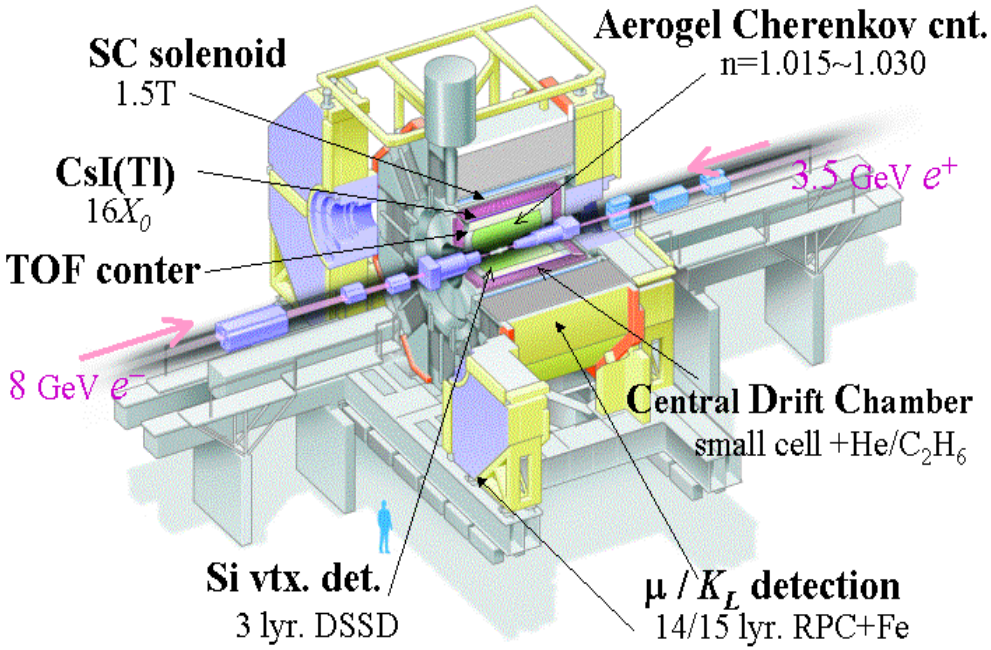
3.5GeV e^+ × 8.0GeV e^-

L_{peak} = (1.7×10^{34})/cm^2/sec

⇔ > 1.2/fb/day

L_{int} > 700/fb

Belle Detector



- Sil.VD: 3(4) layers DSSD
- CDC : small cells $He + C_2H_6$
- TOF counters.
- Aerogel CC:$n = 1.015 \sim 1.030$
- CsI(Tl) 16 X_0
- SC solenoid 1.5 T
- μK_L *detection* 14-15 layers RPC+Fe

Production mechanisms

All expected charmonium states below DD threshold are discovered:

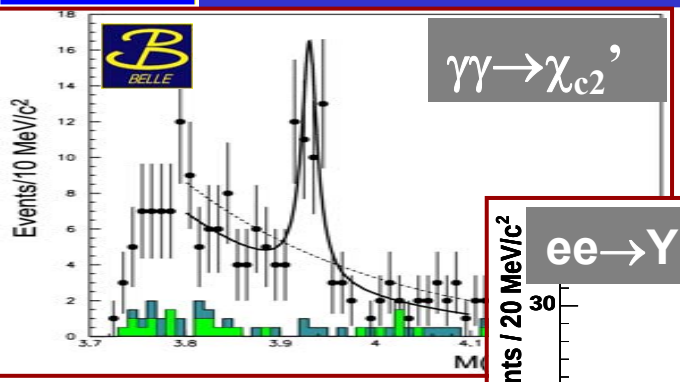
missing by 2000: $\eta_c(2S)$ Belle(2002) + h_c CLEOc(2003)

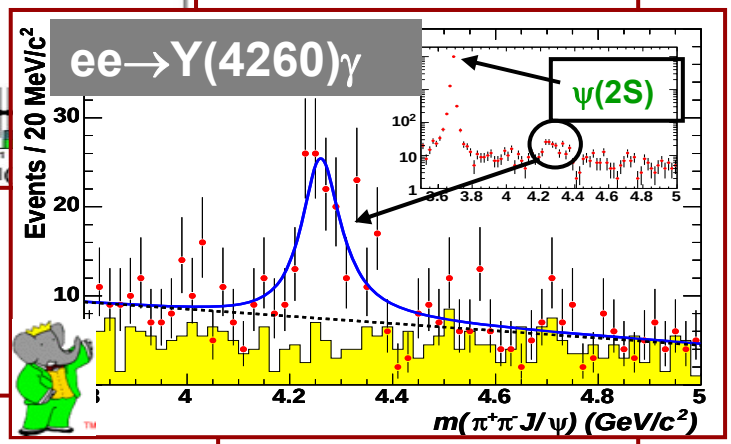
Many *new states* above ~3.7GeV are discovered by B-factories; *even more are still missing*

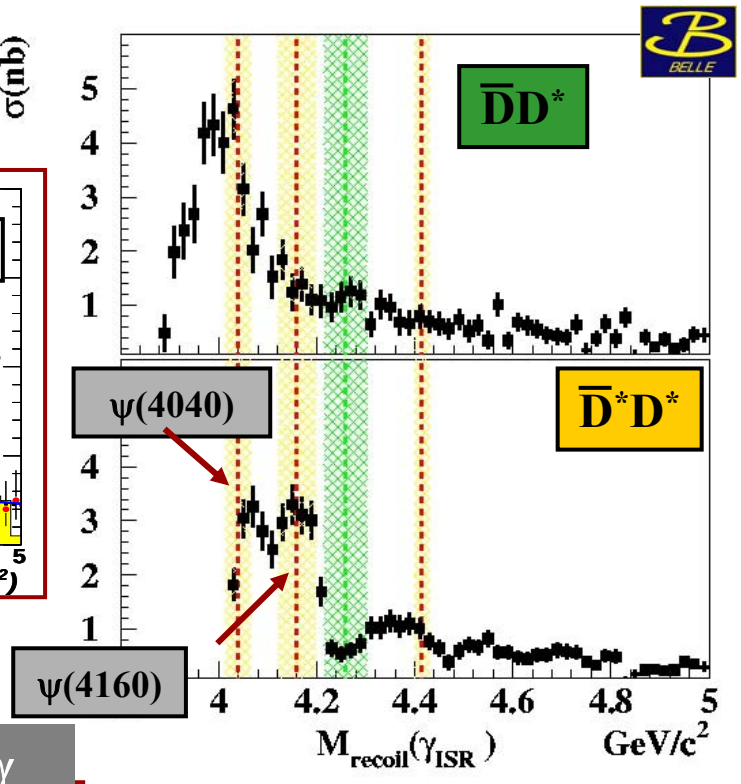
<u>Known production mechanisms and methods of search for new states (pioneered by B-factories):</u>

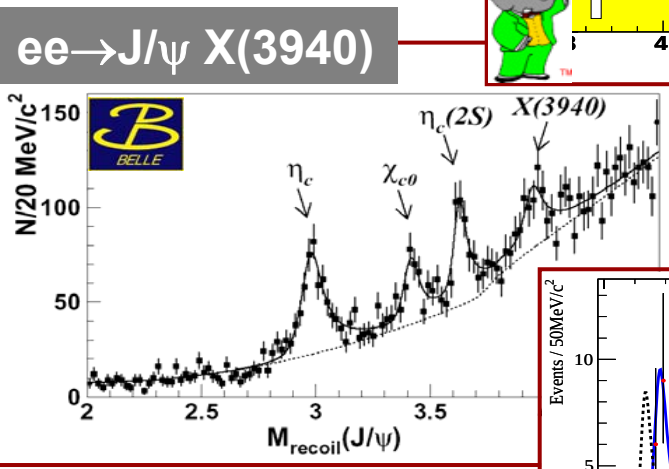
- **$ee \to X_{cc}\,\gamma_{ISR}$: access to 1^{--} states and their interference**
- **$ee \to X_{cc}\,J/\psi$: access to C=+1 (mainly J=0) states**
- **$ee \to ee\gamma\gamma \to X_{cc}$: access to $0^{+/-}$ and $2^{+/-}$ states**
- **$B \to X_{cc}\,K$: any state can be produced (beyond the scope of this talk)**

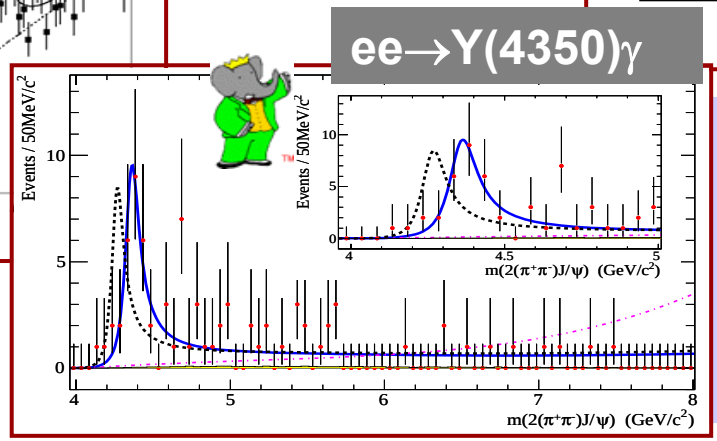
Kaleidoscope of previous results











MORE THIS YEAR?

- $ee \to \gamma\gamma \to X_{cc}$ - NO
- $ee \to X_{cc}\,\gamma$ - YES
- $ee \to X_{cc}\,J/\psi$ - YES

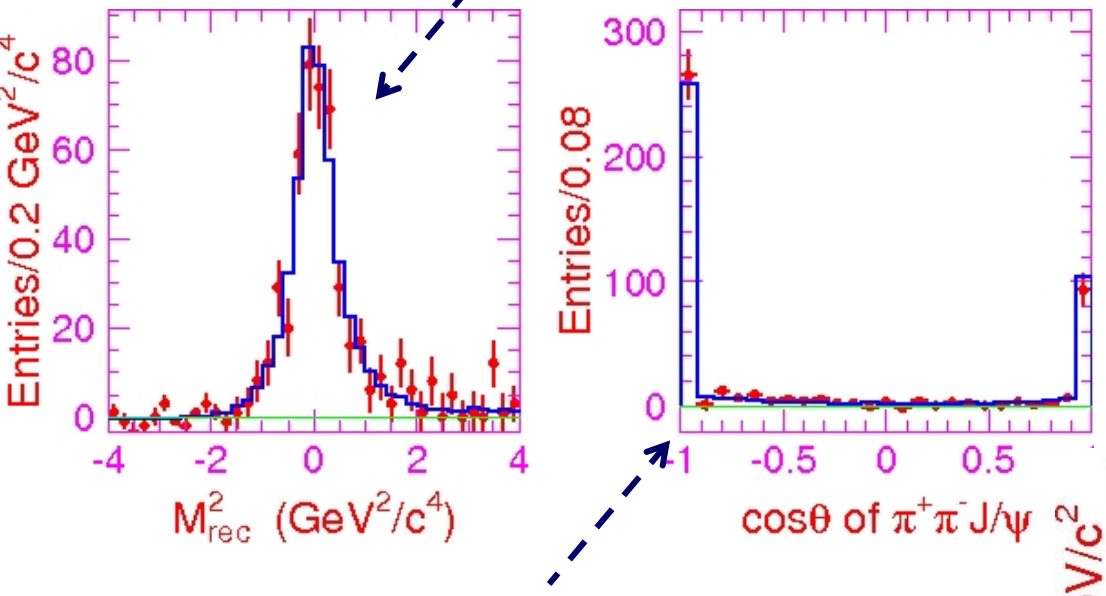
ee→J/ψππ via ISR

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

550 fb^{-1} -the same as last year (*hep-ex/0612006*) but use extra data sample ⇒ improve ISR efficiency

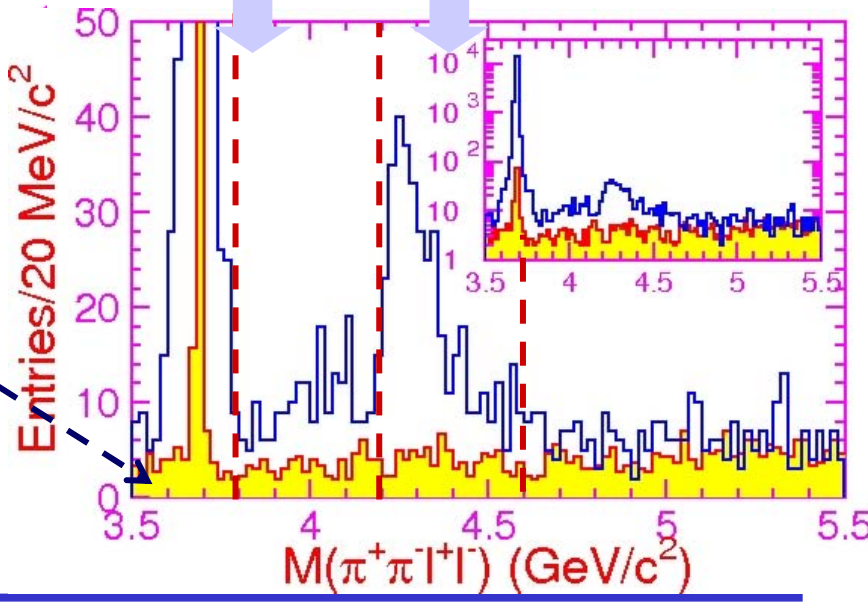
$J/\psi(\rightarrow l^+l^-)+\pi\pi$ + no extra tracks

detection of γ_{ISR} is not required

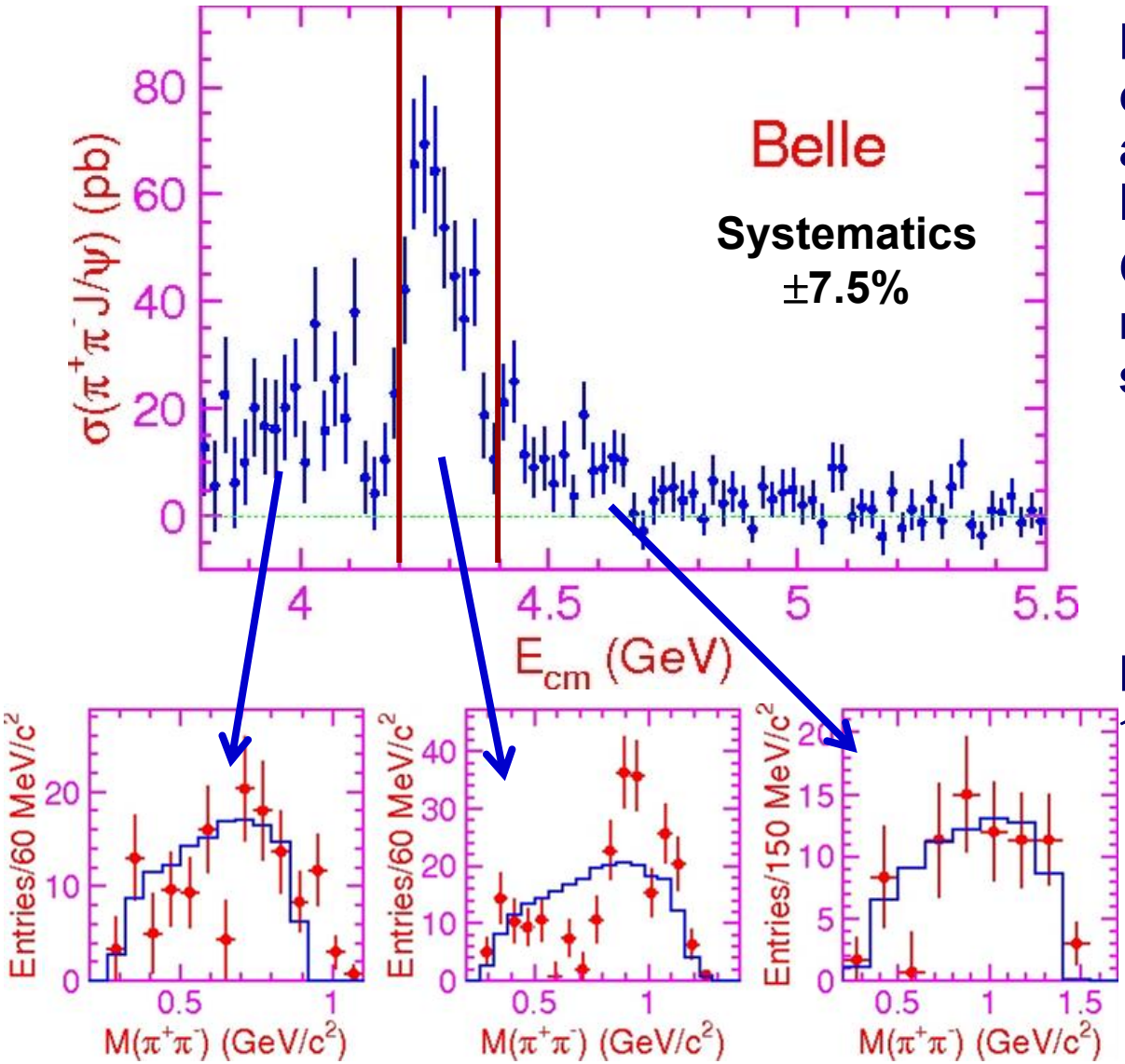


- Polar angle distribution agrees well with ISR expectation
- Combinatorial bg estimated by J/ψ sb
- Bgs from real $(J/\psi\ \pi\pi)_{\text{non ISR}}$ or $J/\psi\ X_{\text{non }\pi\pi}$ are negligibly small

120±14 ev. (8σ) 324±21 ev. (15σ)



ee→J/ψππ cross-section



Bg subtracted M(J/ψππ) corrected for efficiency and differential luminosity

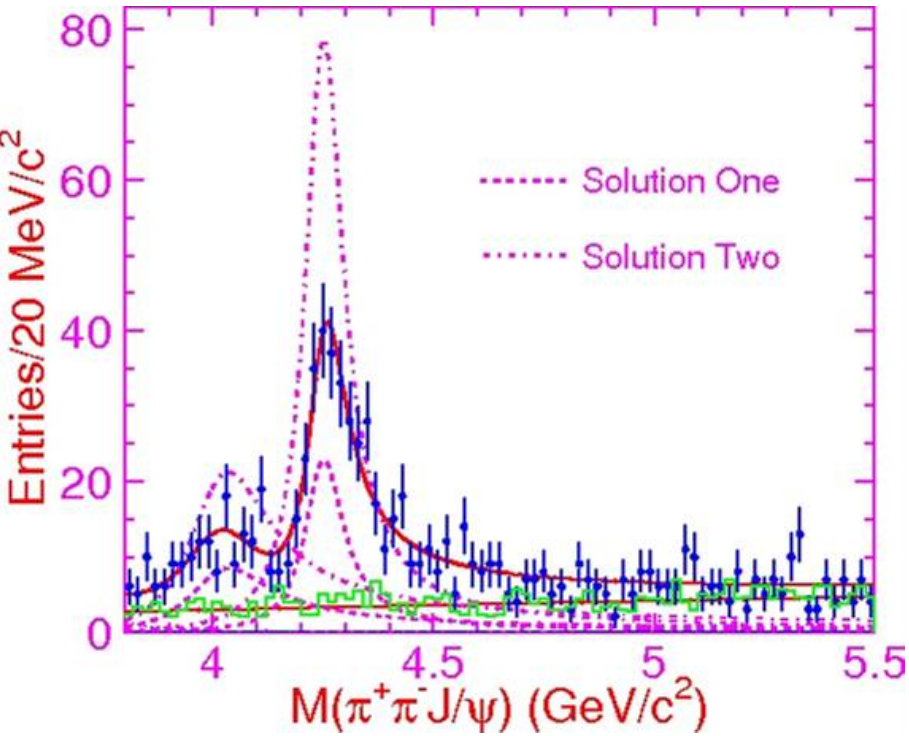
Cross-check: measurement of cross section at ψ' peak:

- $\Gamma_{ee}(\psi')=2.54\pm0.12\pm0.89$
- **PDG'06:** $\Gamma_{ee}(\psi')=2.43\pm0.05$

$M_{\pi\pi}$ 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

Interpretations



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

BW+ polynomial fit: Y(4260) parameters consistent with BaBar
Phys.Rev.Lett.95:142001,2005.

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

Parameters	Solution One	Solution Two
$M(R1)$	$4008 \pm 40^{+72}_{-28}$	
$\Gamma_{\rm tot}(R1)$	$226 \pm 44^{+87}_{-79}$	
$\mathcal{B}\cdot\Gamma_{e^+e^-}(R1)$	$5.0 \pm 1.4^{+5.6}_{-0.9}$	$12.4 \pm 2.4^{+11.9}_{-1.1}$
$M(R2)$	$4247 \pm 12^{+17}_{-26}$	
$\Gamma_{\rm tot}(R2)$	$108 \pm 19^{+8}_{-10}$	
$\mathcal{B}\cdot\Gamma_{e^+e^-}(R2)$	$6.0 \pm 1.2^{+1.7}_{-0.5}$	$20.6 \pm 2.3^{+4.9}_{-1.7}$
ϕ	$12 \pm 29^{+7}_{-66}$	$-111 \pm 7^{+28}_{-29}$

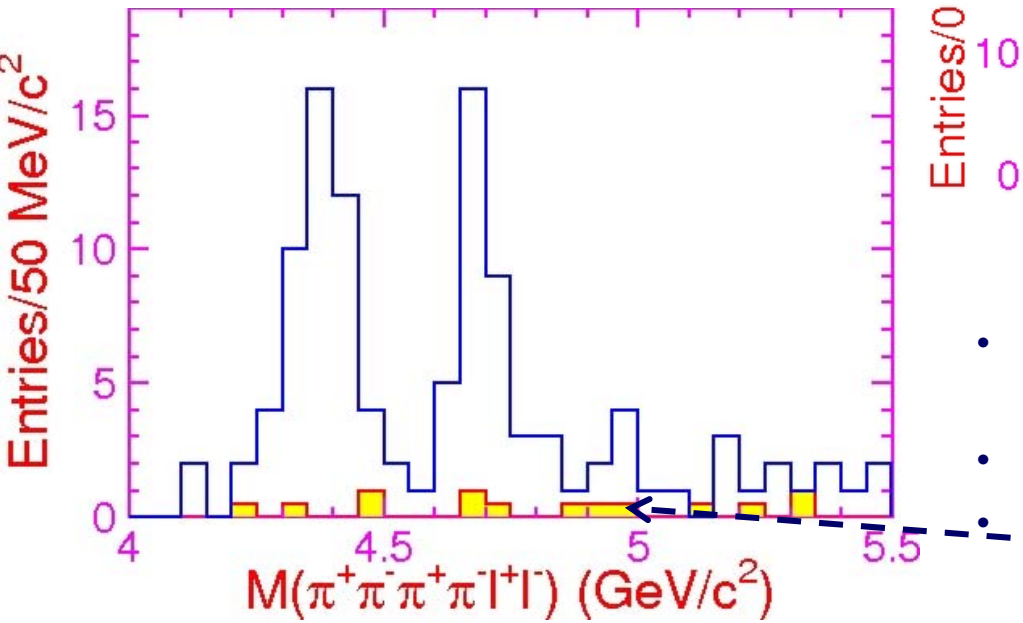
ee→ψ'ππ at √s ~4-5.5GeV via ISR

670 fb^{-1}

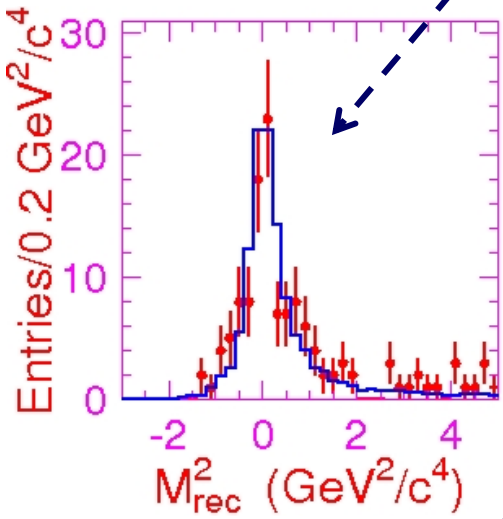
ψ(→ J/ψ ππ) + ππ + no extra tracks

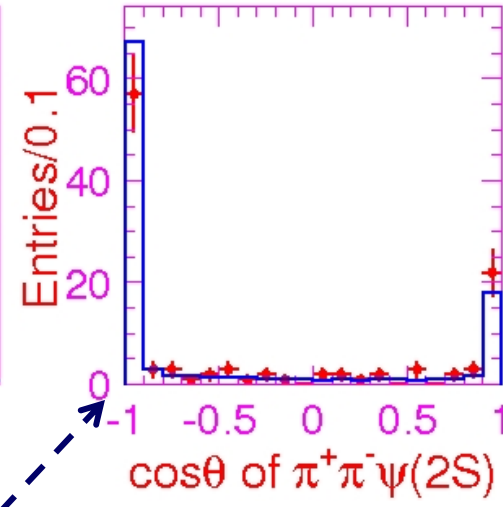
detection of γ_{ISR} is not required

Similar analysis: efficiency is smaller; bgs are almost negligible



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





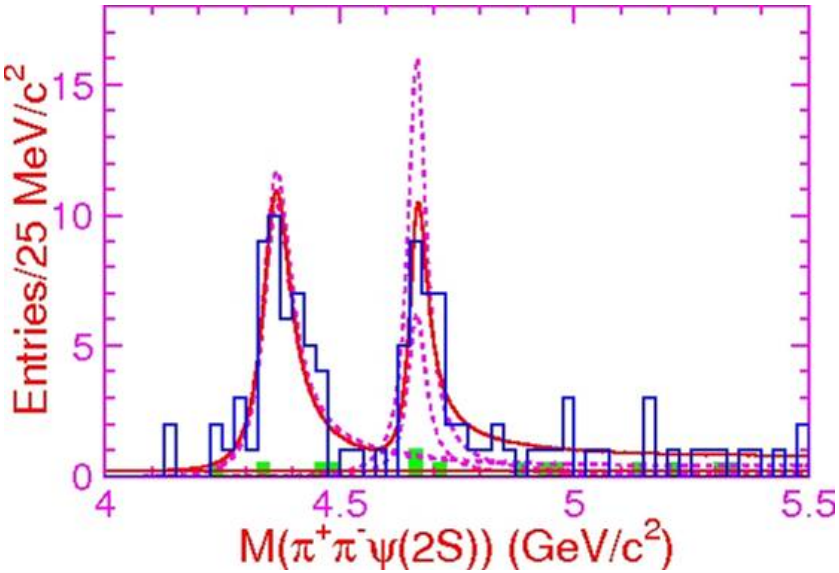
- **Polar angle distribution agrees well with ISR expectation**
- **Combinatorial bg estimated by ψ' sb**
- **Bgs real $(\psi'\pi\pi)_{non\ ISR}$ or ψ' $X_{non\ \pi\pi}$ are negligibly small**

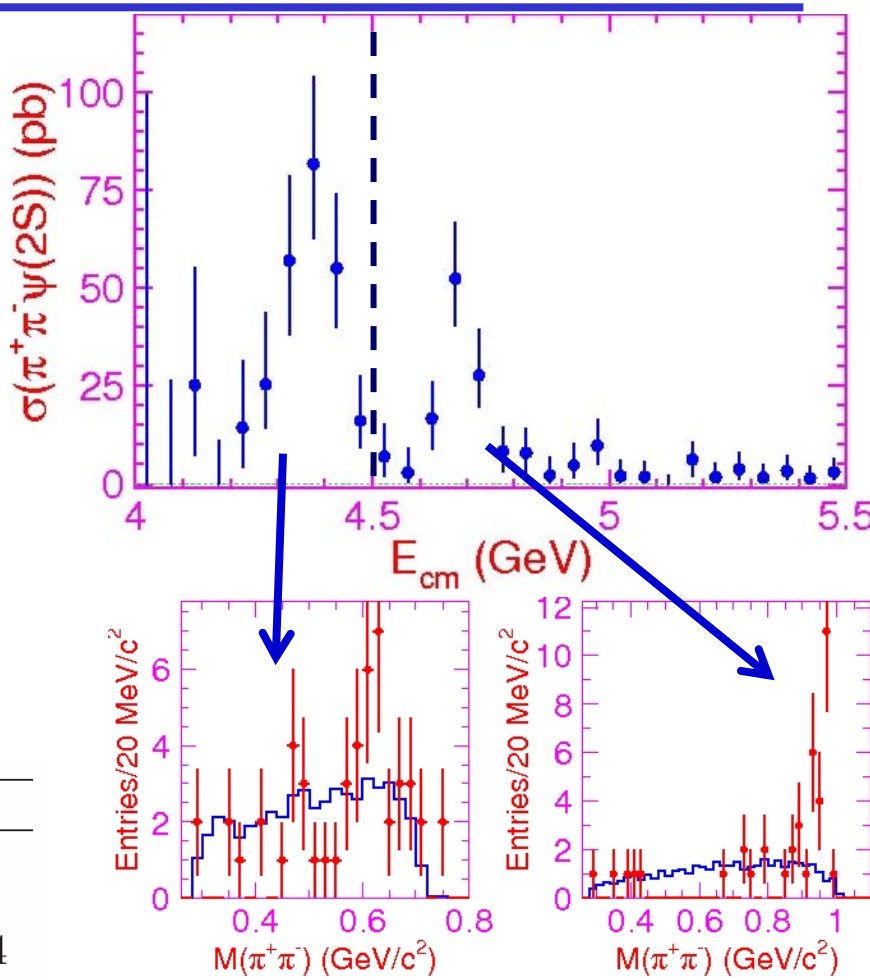
Two significant clusters: One is near BaBar reported enhancement

PRL.98:212001,2007 + NEW at M~ 4.7 GeV

Cross section and interpretation

- **Bg subtracted M(J/ψππ) corrected for efficiency and differential luminosity**

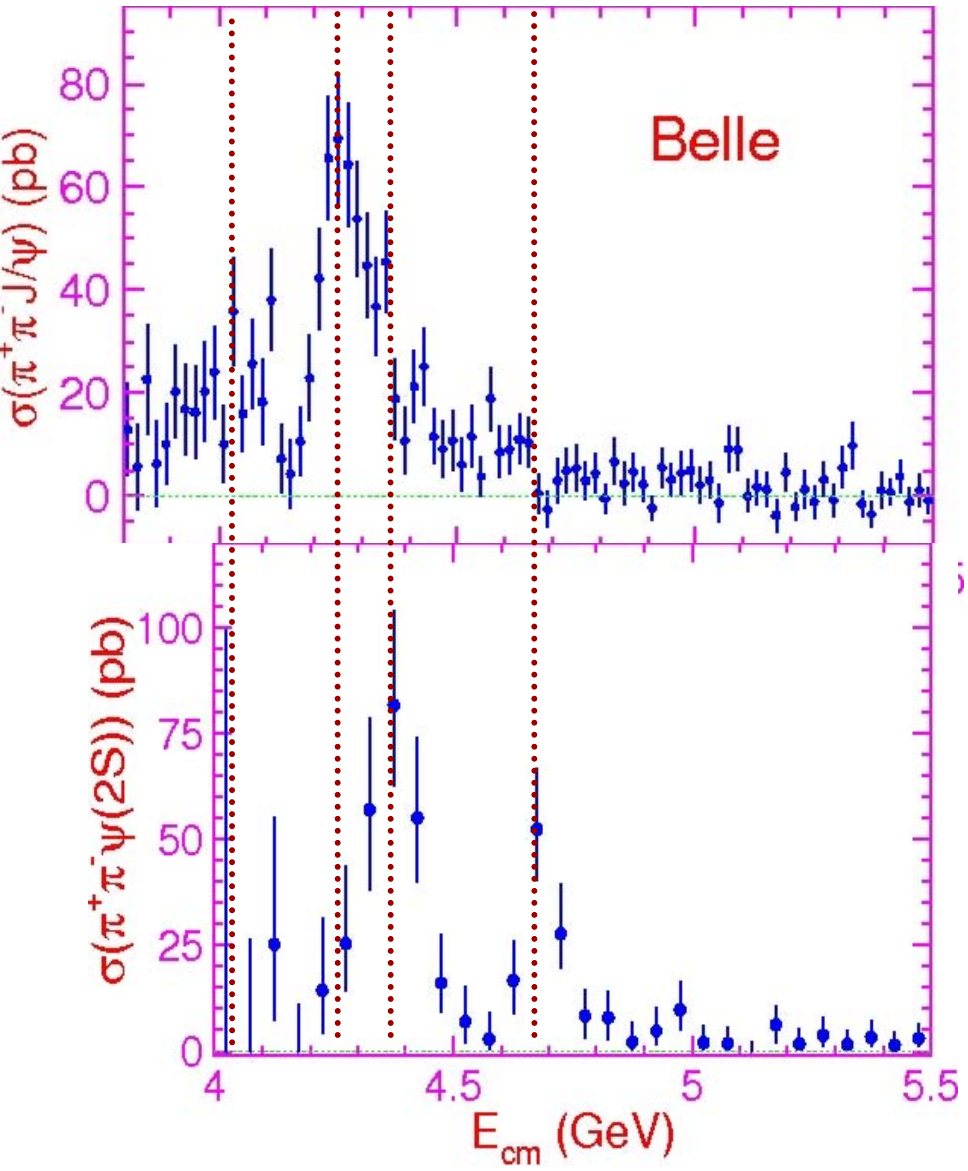




Parameters	Solution one	Solution two
$M(Y(4360))$	$4361 \pm 9 \pm 9$	
$\Gamma_{\rm tot}(Y(4360))$	$74 \pm 15 \pm 10$	
$\mathcal{B} \cdot \Gamma_{e^+e^-}(Y(4360))$	$10.4 \pm 1.7 \pm 1.5$	$11.8 \pm 1.8 \pm 1.4$
$M(Y(4660))$	$4664 \pm 11 \pm 5$	
$\Gamma_{\rm tot}(Y(4660))$	$48 \pm 15 \pm 3$	
$\mathcal{B}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

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

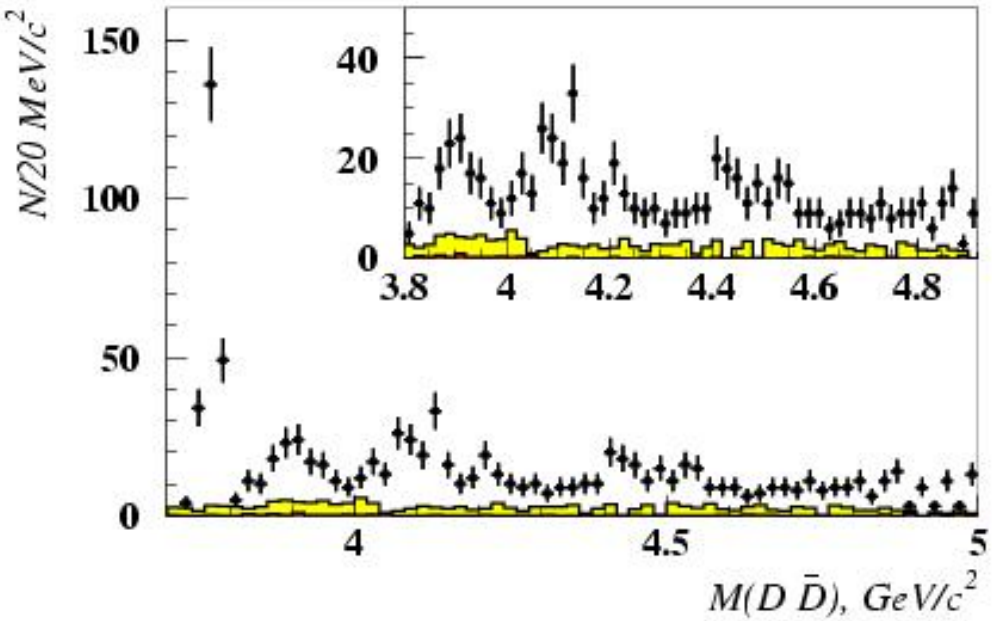
ee→J/ψππ & ee→ψ'ππ together



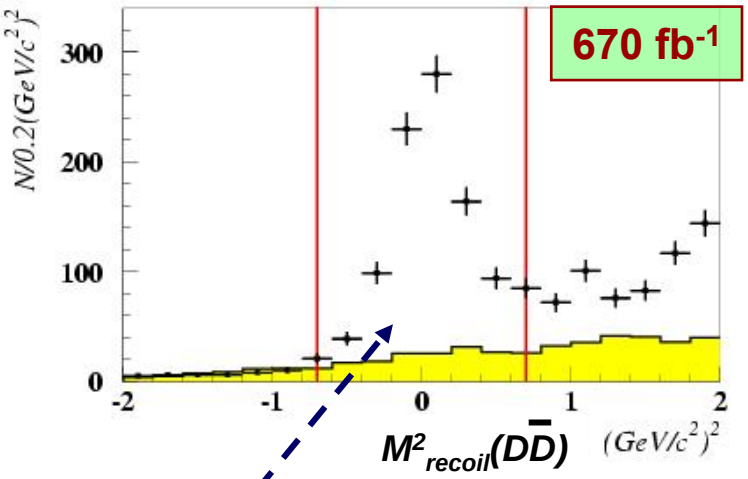
- Peak positions at M(J/ψππ) & M(ψ'ππ) are significantly different
- Can 4 states be accommodated by theory?
  - even the first one – Y(4260) is not understood yet
- These results to be submitted soon.
- Cross sections are to be send to public data base.

$e^+e^- \to DD$ at $\sqrt{s}$~3.8-5 GeV via ISR

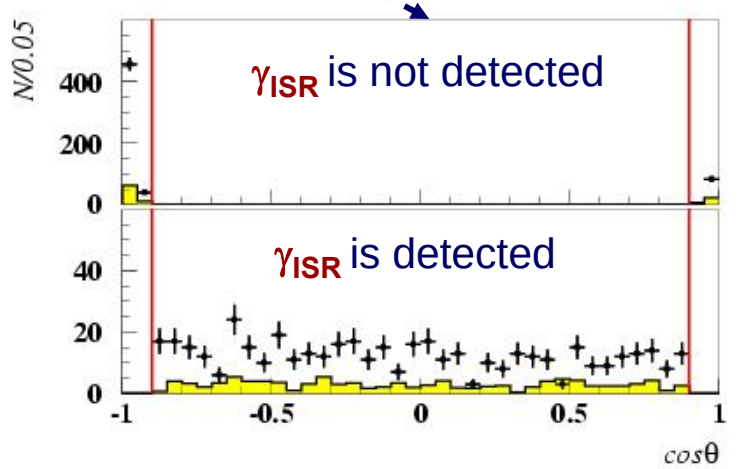
- $D^0\bar{D}^0$ or D^+D^- + *no extra tracks*
- detection of γ_{ISR} is not required
  - if γ_{ISR} is detected M(DD γ_{ISR}) is required ~ E_{cm}
- Combinatorial bgs are estimated from D sb
- Other bgs are small and taken into account



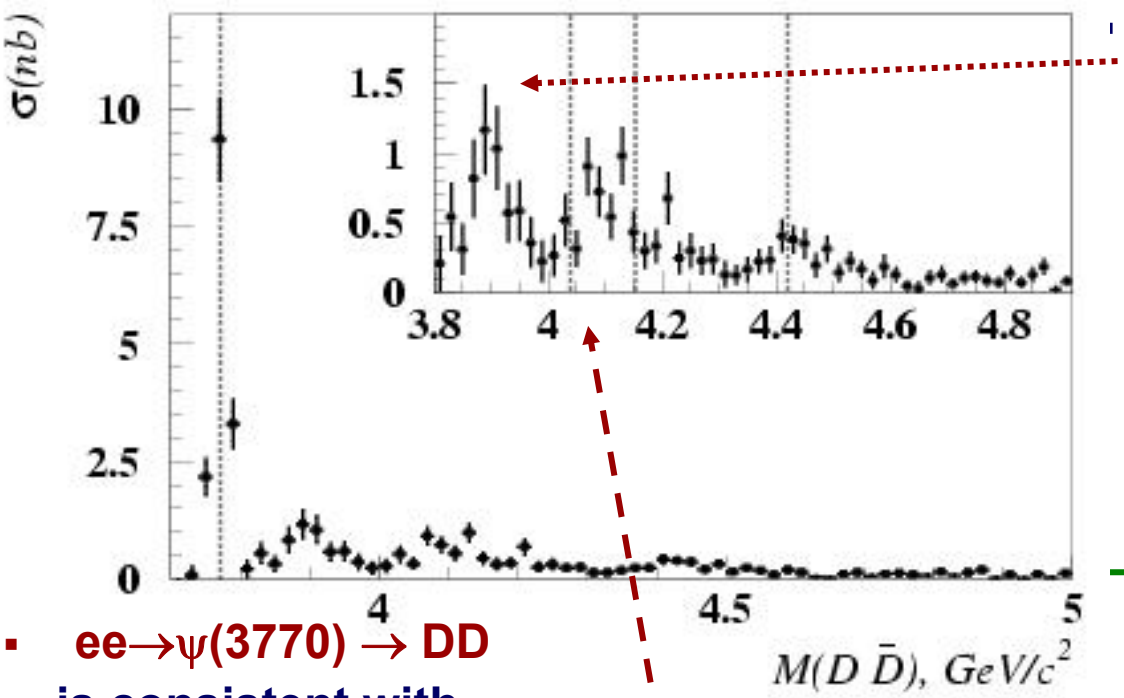
M(DD) ***is in a qualitative agreement with BaBar:*** ***hep-ex/0607083***



Consistent with ISR production



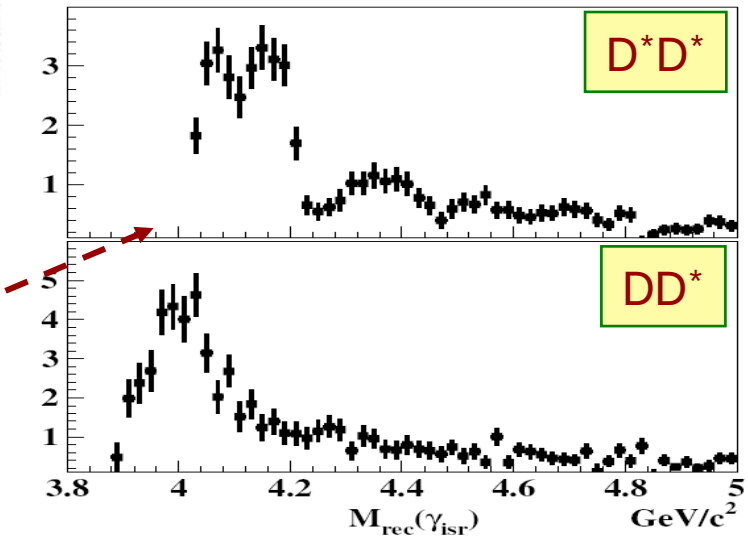
$\sigma(e^+e^- \to DD)$



Broad structure around 3.9 GeV is in *qualitative agreement* with *coupled-channel model*
Phys. Rev. D21, 203 (1980)

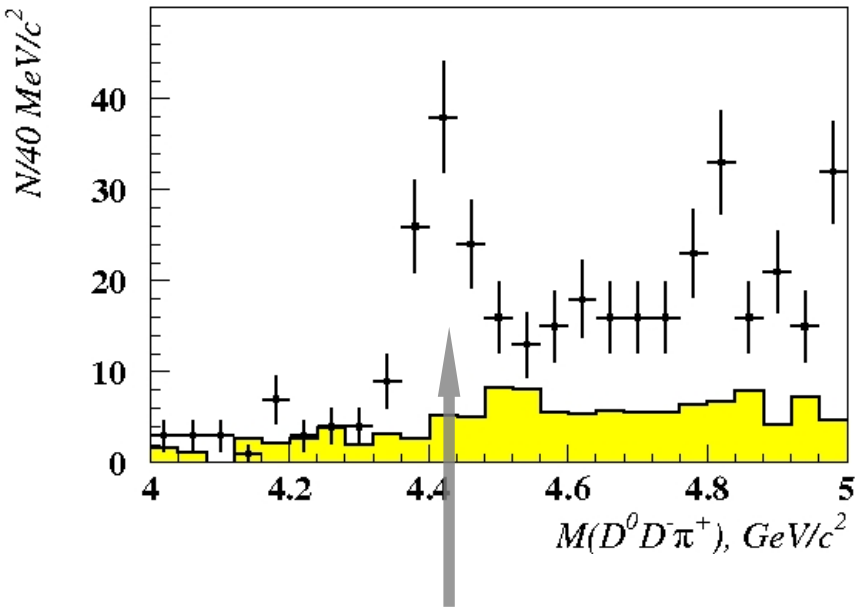
- **ee→ψ(3770) → DD is consistent with BES/CLEO measurements**
  hep-ex/0612056;
  PRL. 95, 121801 (2001)
  - **Cross section above 4 GeV has a similar shape to those measured for ee → D*D* ?**

Phys. Rev. Lett. 98, 092001 (2007)



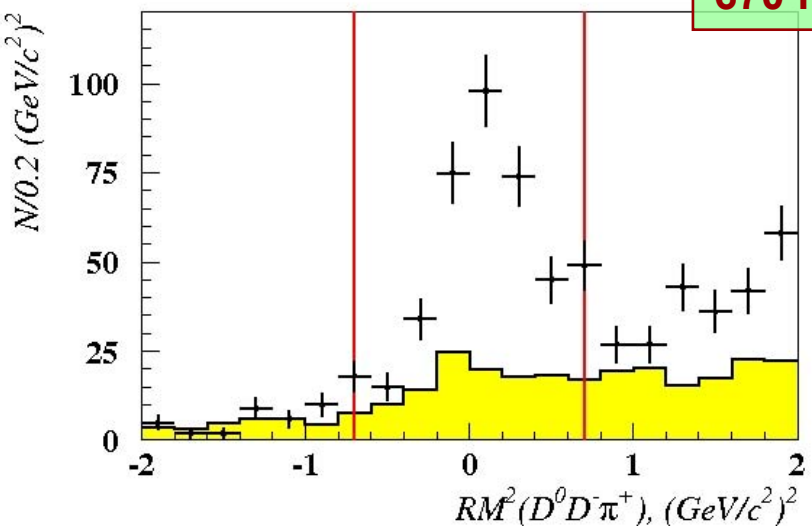
$e^+e^- \to DD\pi$ at $\sqrt{s}$ ~ 4-5 GeV via ISR

- $D^0 D^- \pi^+$ + ***no extra tracks***
- similar analysis and bgs
  - no major bgs except for ***combinatorial.***

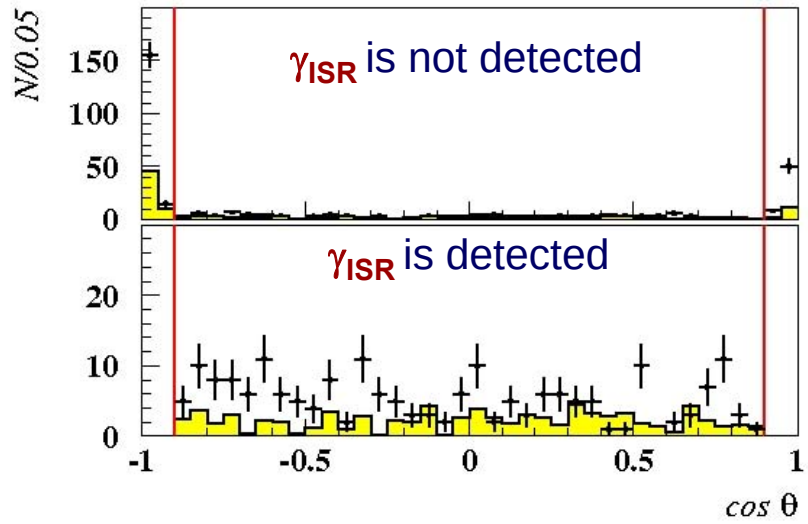


Clear $\psi(4415) \to DD\pi$ signal

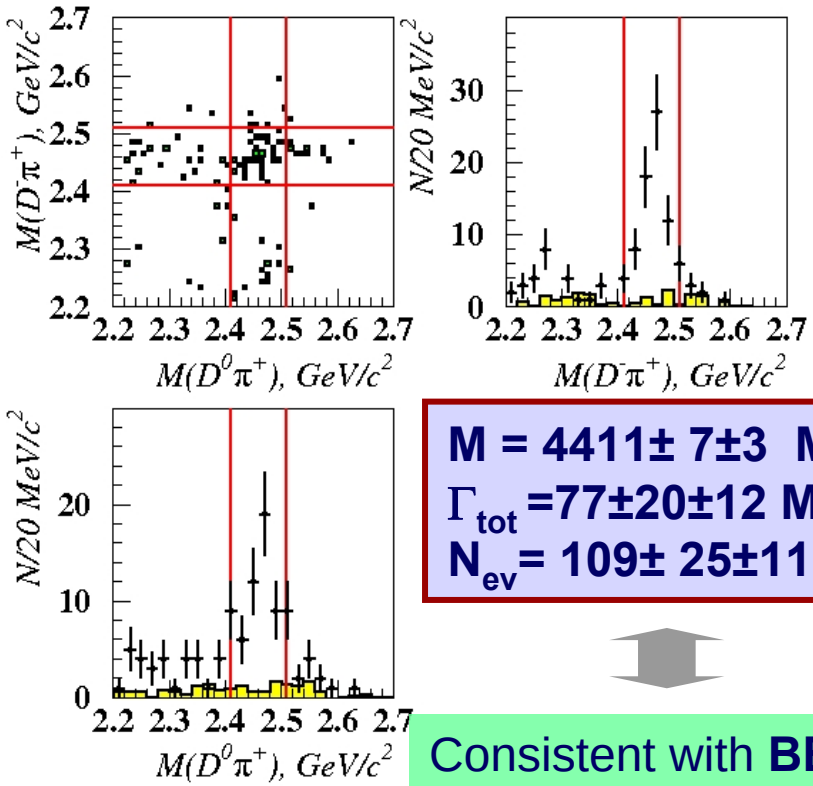
670 fb^{-1}



Consistent with ISR production



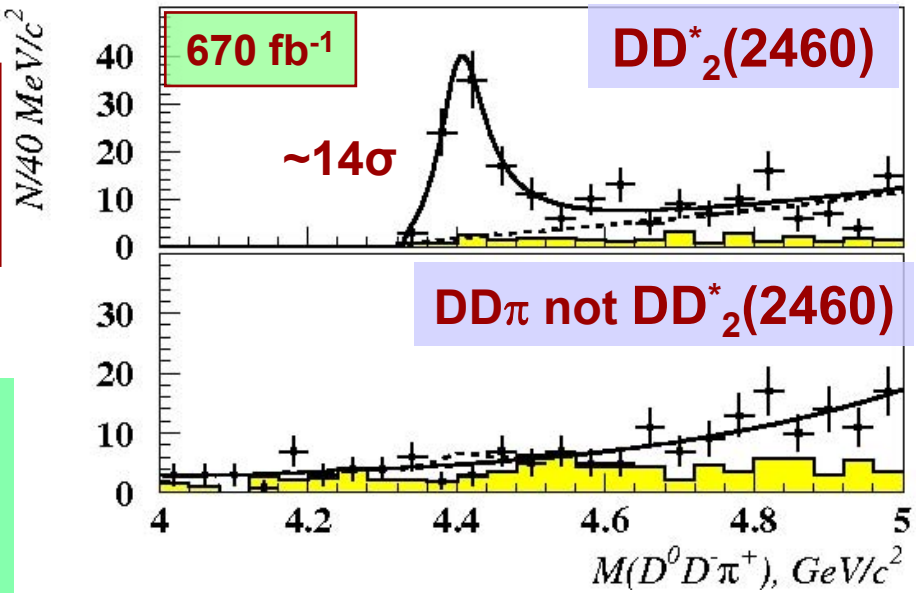
Resonant structure in $\psi(4415)\to DD\pi$



$M(D^0\pi^+)$ vs $M(D^-\pi^+)$ from **$\psi(4415)$** region

- Clear **$D^*_2(2460)$** signals
- Positive interference
- **Non $D^*_2(2460)$** contribution **is not seen**

M = 4411± 7±3 MeV
Γ_{tot} =77±20±12 MeV
N_{ev}= 109± 25±11



Consistent with **BES,**
hep-ex/0705.4500,
PDG06, Barnes at.al
Phys. Rev. D72, 054026 (2005)

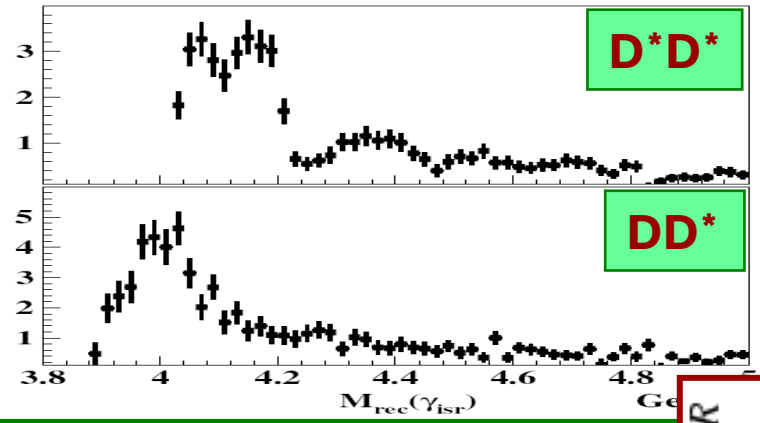
$\sigma(e^+e^-\to\psi(4415))\times Br(\psi(4415)\to DD^*_2(2460))\times Br(D^*_2(2460)\to D\pi)=(0.74\pm0.17\pm0.07)$nb

$Br(\psi(4415)\to D(D\pi)_{\text{non D2(2460)}})/Br(\psi(4415)\to DD^*_2(2460))<0.2$

Semi-inclusive cross-section via ISR

Phys. Rev. Lett. 98, 092001 (2007)

2×



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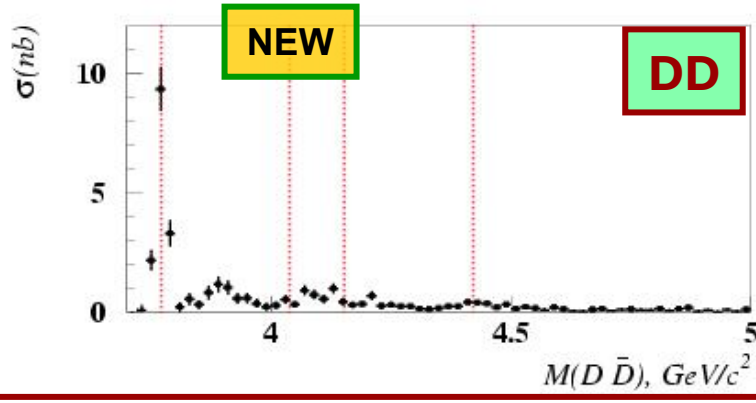

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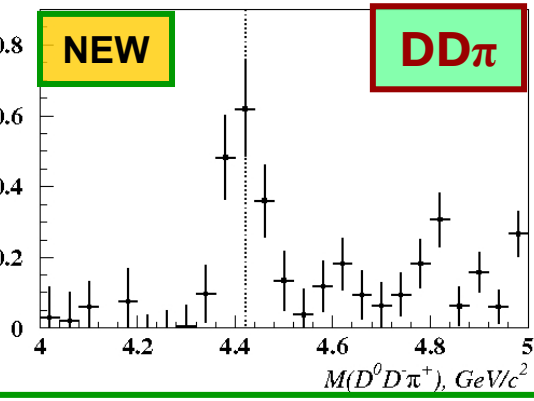

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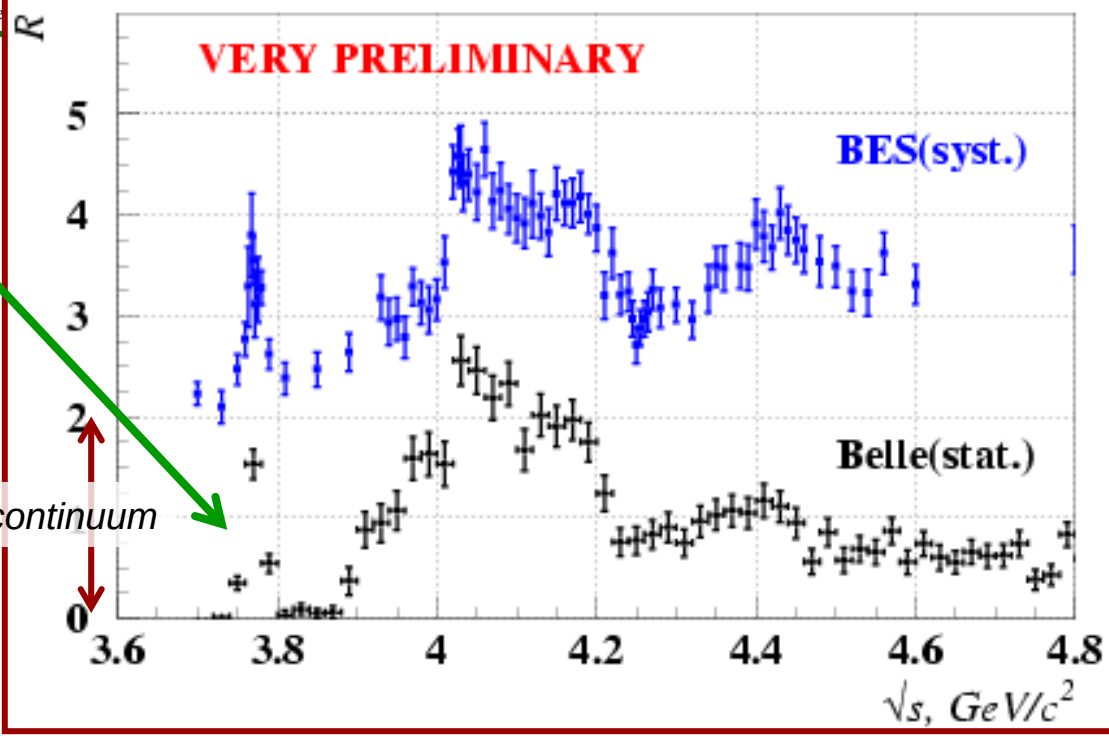
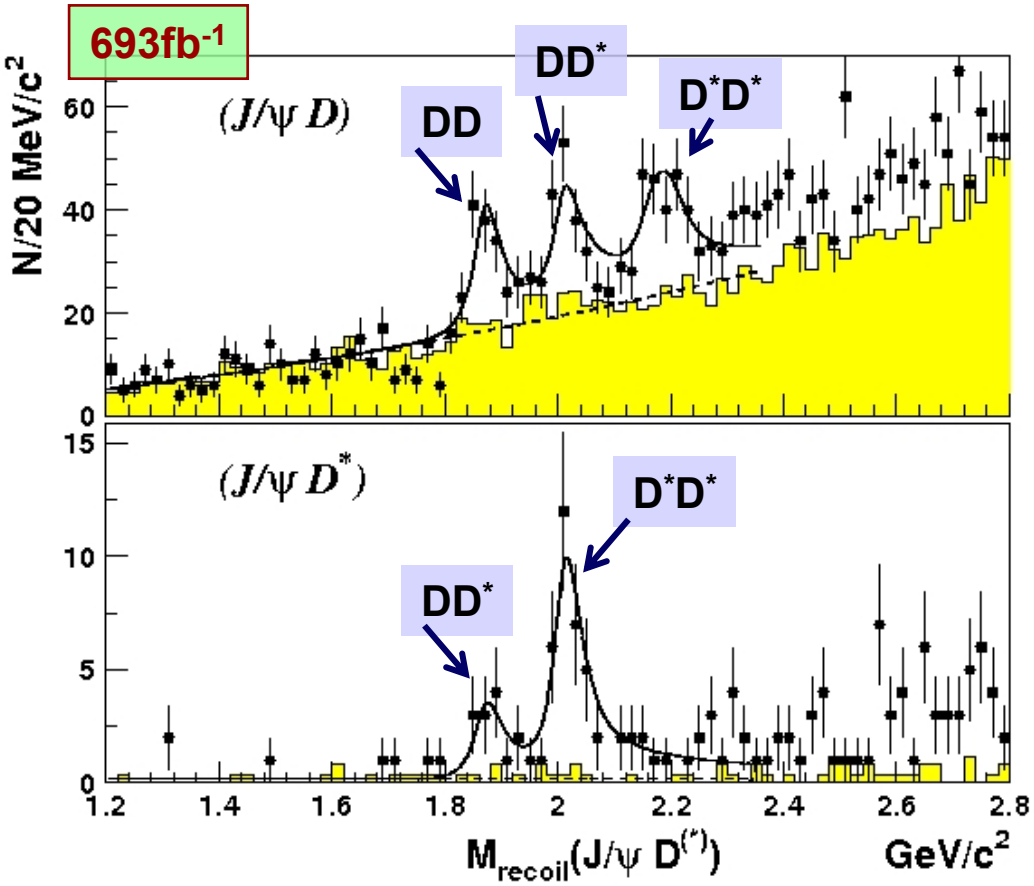


These 4 final states almost saturate inclusive cross section

ee → J/ψ D(*)D(*)



- The method is pioneered by Belle Phys. Rev. Lett. 98, 082001 (2007)
- Reconstruct J/ψ and one of two D (or D*)
- Unreconstructed D(*) is seen as a peak M_{recoil} (J/ψ D)
- D and D* recoiling against reconstructed J/ψ D are well separated (~2.5σ)
- Simultaneous fit to D-signal and D-sidebands to fix bg

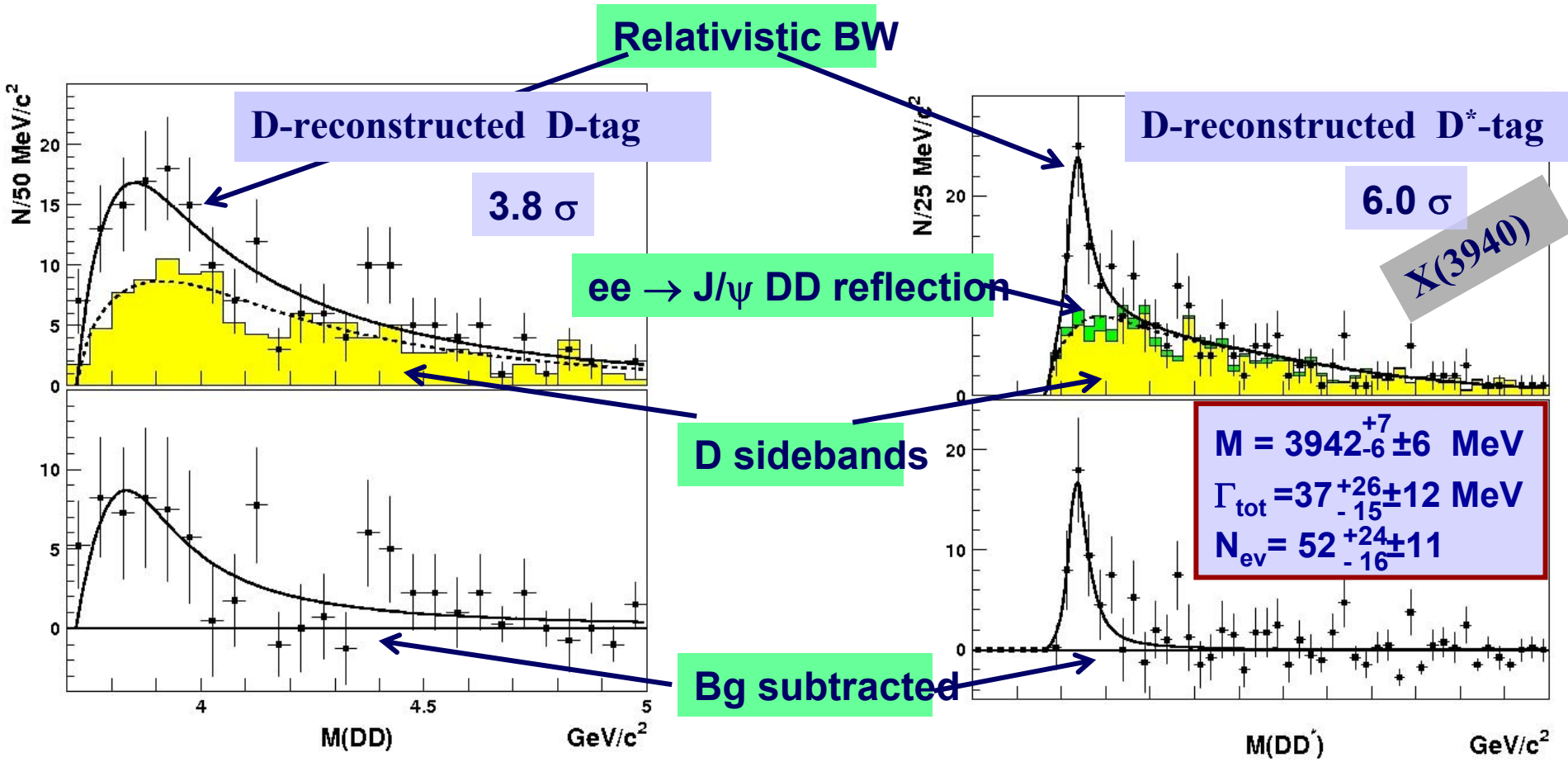
All signals are > 5σ

	$M_{\rm rec}(J/\psi D)$		$M_{\rm rec}(J/\psi D^*)$	
	N	$\mathcal{N}_\sigma$	N	$\mathcal{N}_\sigma$
$e^+e^- \to J/\psi D\overline{D}$	162 ± 25	7.6	—	—
$e^+e^- \to J/\psi D^*\overline{D}$	159 ± 28	6.5	$19.0\ ^{+6.3}_{-5.3}$	5.8
$e^+e^- \to J/\psi D^*\overline{D}^*$	173 ± 32	5.6	$47.2\ ^{+8.5}_{-7.8}$	8.4

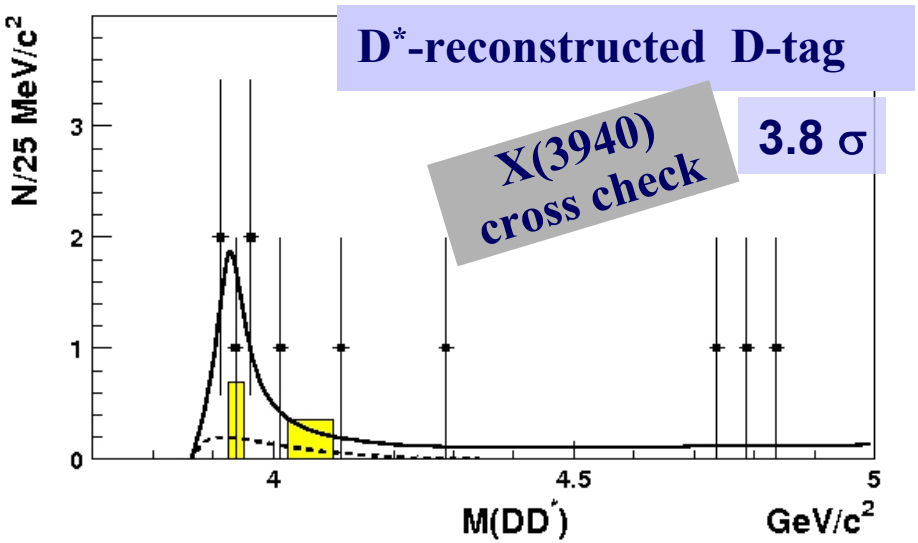
PrelImInary

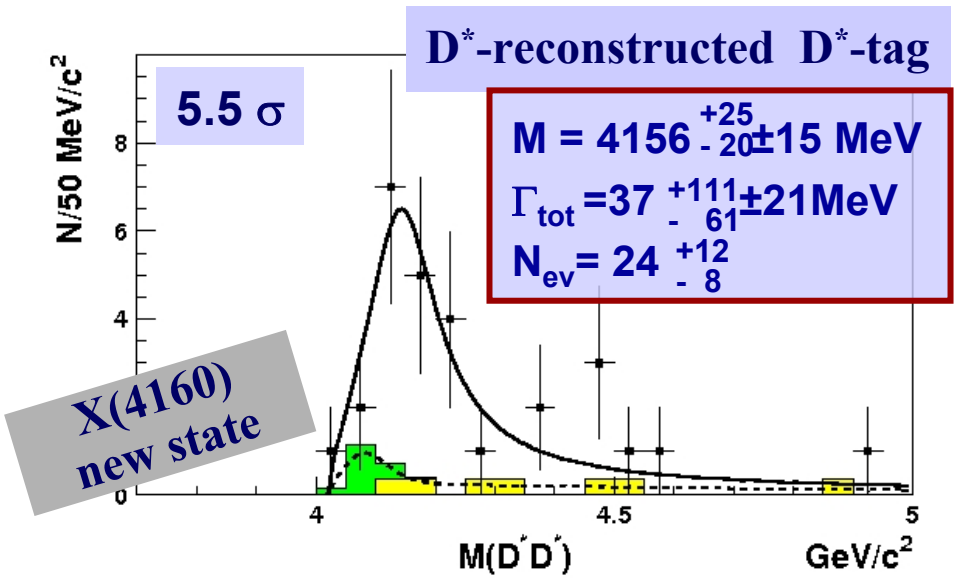
Study of ee → J/ψ DD(*)

- Tag unreconstructed $D^{(*)}$ by $|M_{recoil}(J/\psi D) - M_{D^{(*)}}| < 70$MeV
- Refit $M_{recoil}(J/\psi D) \rightarrow M_{D^{(*)}}$: improve $M_{DD^{(*)}}$ by a factor of 3-10



Study of ee → J/ψ D*D(*)





- Broad peak at M_{DD} not consistent with non resonant DD production in the process ee →J/ψ DD (3.8 σ only);

  large fitting systematic error in the parameters of this enhancement.
- X(3940)→DD* confirmed with new data (6.0 σ), M and Γ are in agreement with published results.
- New state, X(4160), is observed in D*D* decay mode.

  $M=(4156\ ^{+25}_{-20}\ \pm15)\text{MeV}/c^2$,

  $\Gamma = (139\ ^{+111}_{-61}\pm21)\text{MeV}/c^2$

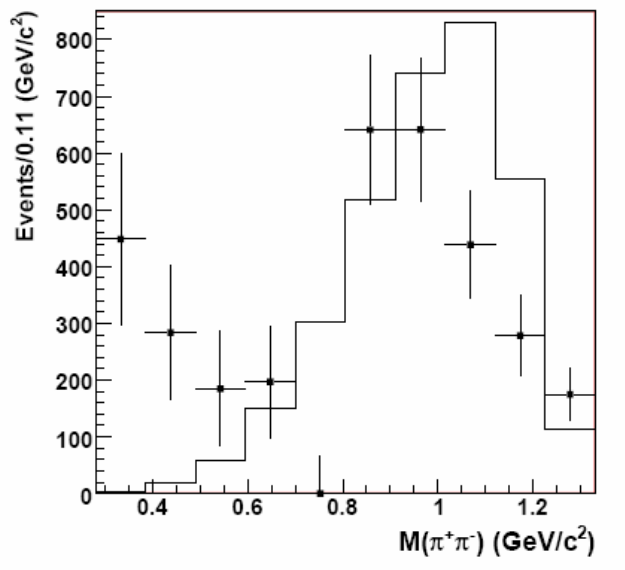
Summary

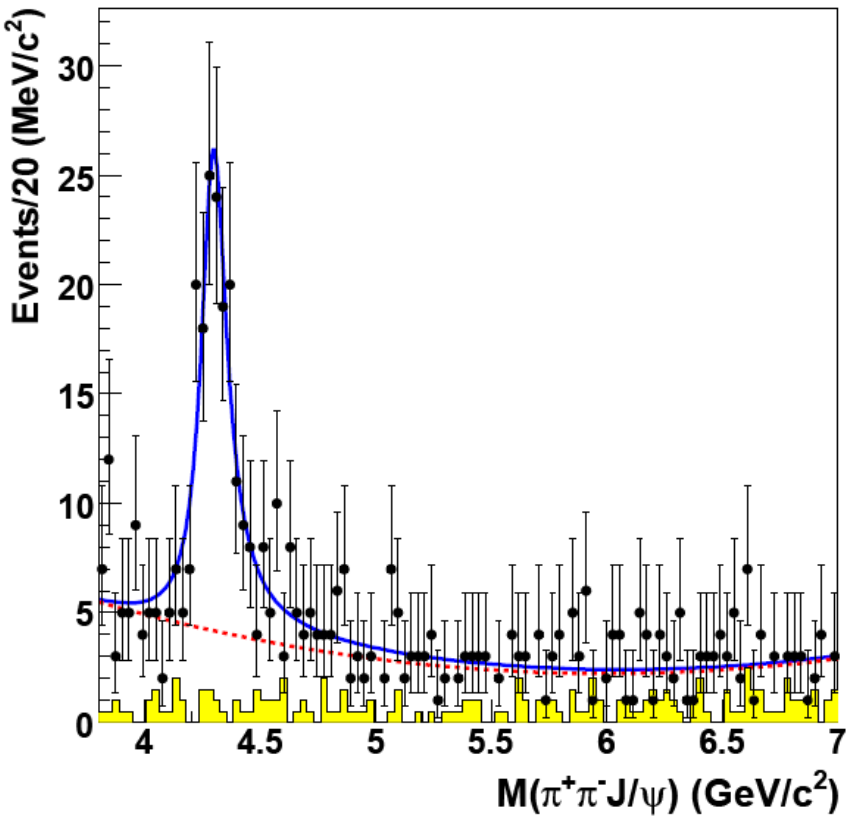
- **Exclusive multy final states ISR study at Belle:**
  - **$J/\psi\pi\pi$: Y(4260)+ NEW broad enhancement at 4.0GeV are well described by 2 coherent BW**
  - **$\psi'\pi\pi$: two well separated peaks: one is consistent with BaBar observation, another is NEW**
  - **Cross sections for $ee \to J/\psi\pi\pi$ & $ee \to \psi'\pi\pi$ are significantly different**
  - **DD cross section: complicated shape: $ee \to \psi(3770)$ consistent with BES/CLEO, broad enhancement ~ 3.9 GeV – coupled channel effect, above 4GeV has similar shape as D*D***
  - **DDπ: $\psi(4415)$ signal observed, dominated by $\psi(4415) \to DD^{**}_2$ decay**
  - **Sum of NEW DD + DDπ , together with published D^*D & D^*D^*, cross sections is close to inclusive $ee \to$ hadrons (- $ee \to$ uds continuum)**
- **Double charmonium production:**
  - **X(3940): is confirmed with a significance 6.0σ (5.7 σ including systematics);**
  - **NEW state, X(4160), observed for the first time- 5.5 σ (5.1 σ including systematics);**

BACK UP SLIDE 1 Y(4260)

hep-ex/0612006

- Previous result with hadronic sample (~50% signal events are rejected)





Present study: BW+2nd order polynomial:

M = 4295 ± 10 (+10 -3) MeV
Γ_{tot} =133 ±26 (+13 -6) MeV
B * Γ_{ee} = 8.7 ±1.1 eV

M = 4263 ± 6 MeV
Γ_{tot} =126 ±18 MeV
B * Γ_{ee} = 9.7 ±1.1 eV

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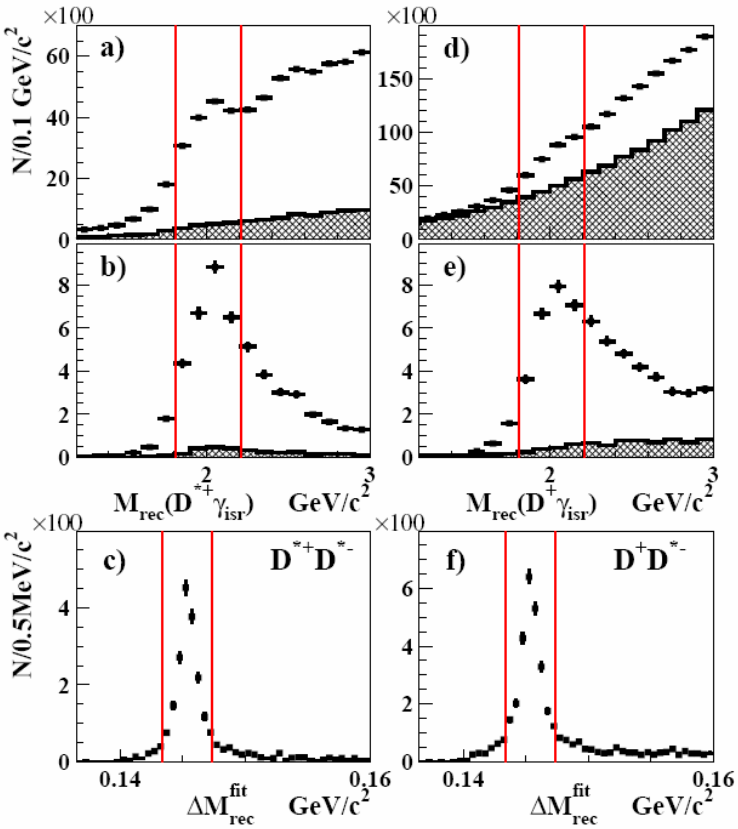
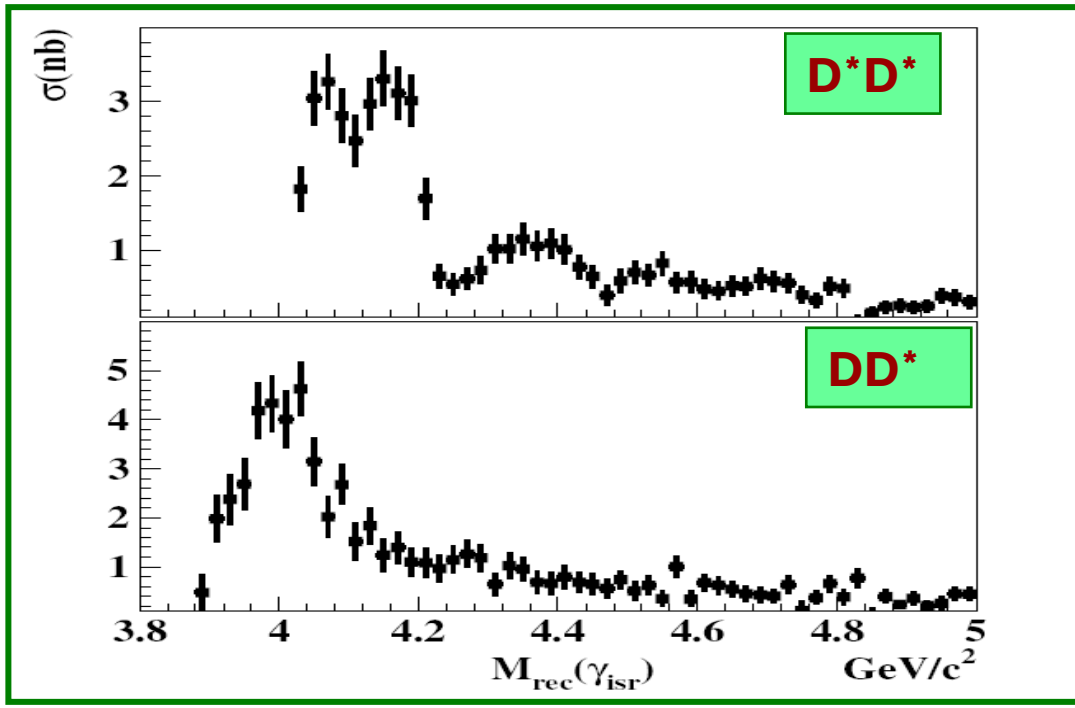


- $ee \to D^{*}D^{(*)}$ with partial reconstruction: $D^{(*)} + \gamma_{ISR} + \pi_{slow}$ (from unreconstructed D^{*})
- Use Recoil mass difference to suppress bg
- Use kinematical constrain $M_{recoil}(D^{*}\gamma_{ISR}) \to M_D$ to improve resolution



X 2 to account for neutral $D^{*}D^{(*)}$

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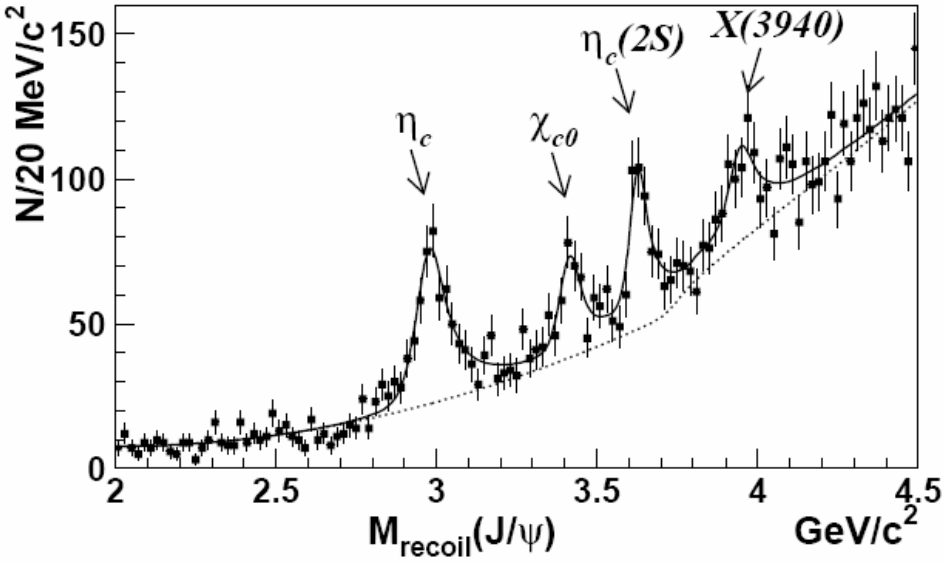
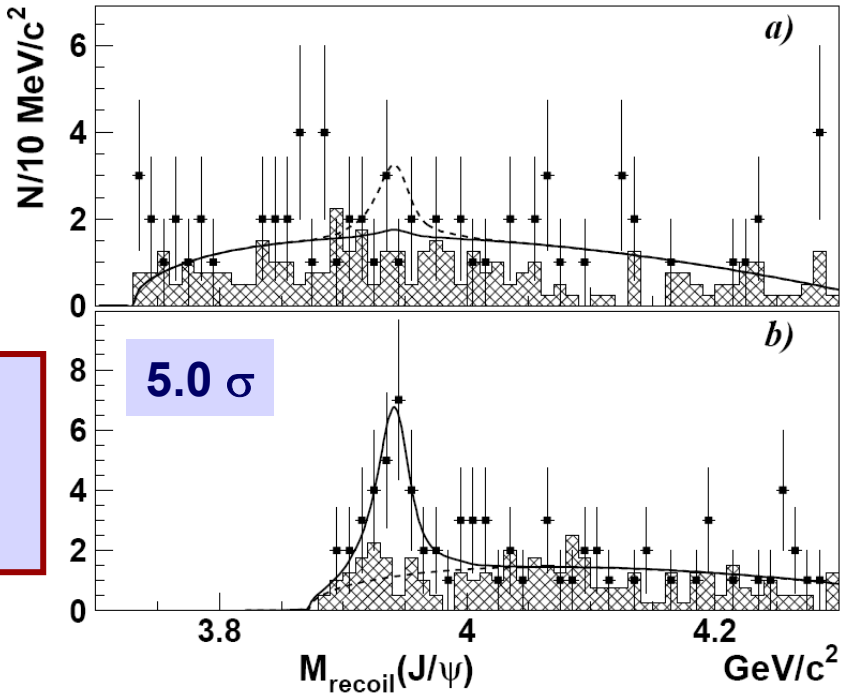
Phys. Rev. Lett. 98, 082001 (2007)



- X(3940) seen in $M_{recoil}(J/\psi)$ spectra
- Now many (overlapping) states are found to contribute to $M_{recoil}(J/\psi)$
- X(3940) parameters are obtained from X(3940) → DD* sample – consistent with the present study



$M = 3943 \pm 6 \pm 6$ MeV

$\Gamma_{tot} = 15.4 \pm 10.1$ MeV

$N_{ev} = 24.5 \pm 6.9$