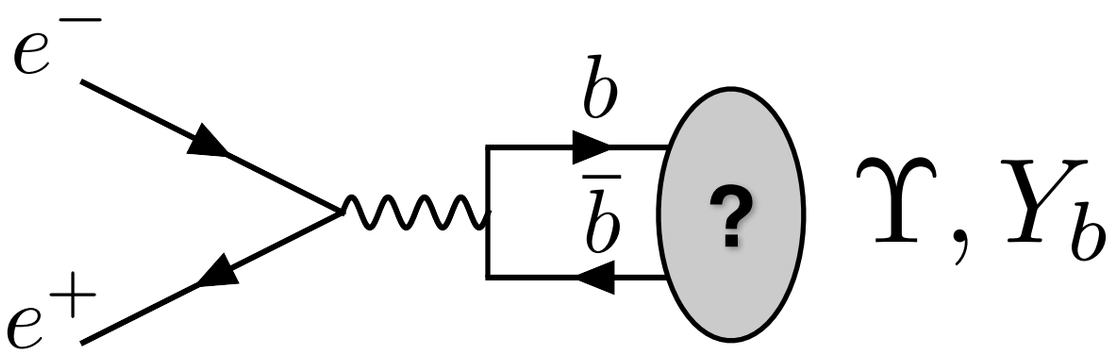
Notes on e^+e^- Cross Sections:

a brief review of where we are

Ryan Mitchell
Indiana University
Jinan XYZ Workshop
June 8, 2015

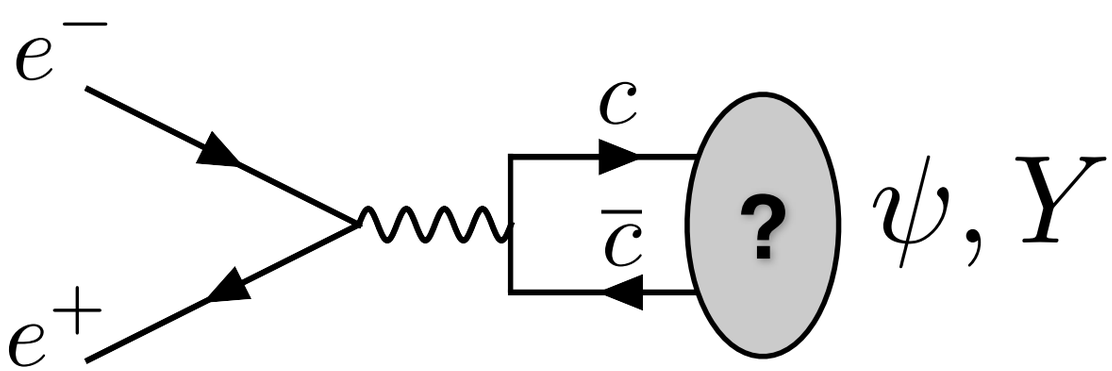
The Simplicity of the e^+e^- Process?

e^+e^- annihilation to bottomonium

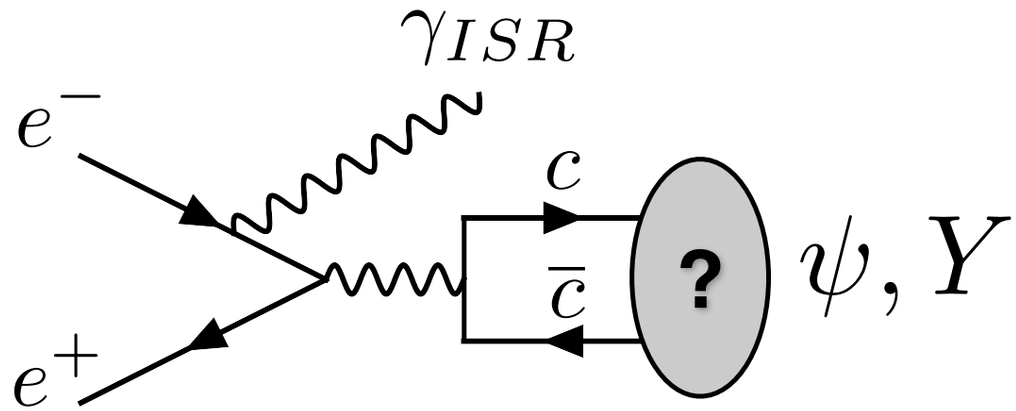


Naively, one would think this would be a simple process.

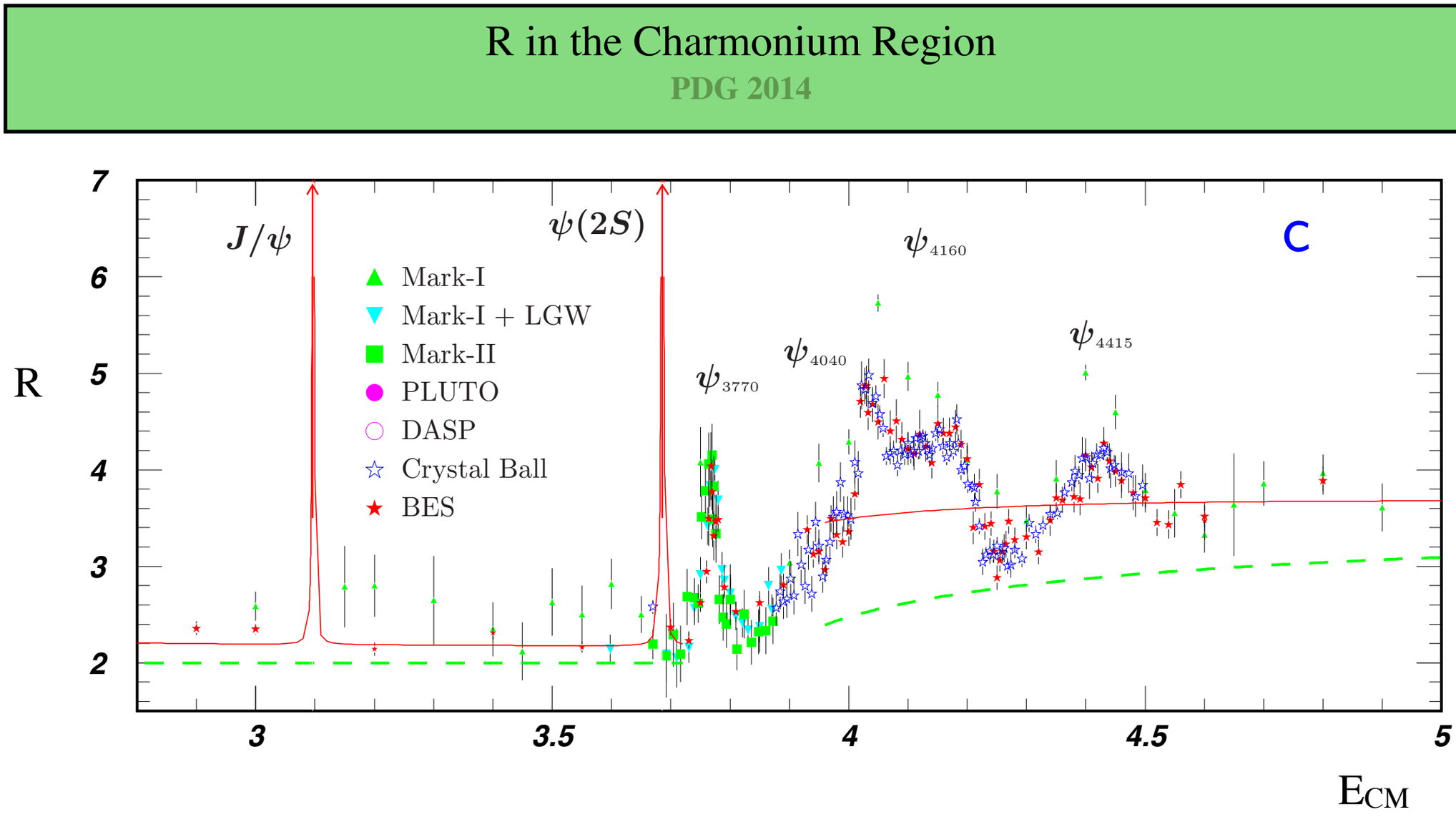
e^+e^- annihilation to charmonium



e^+e^- annihilation to charmonium (via ISR)



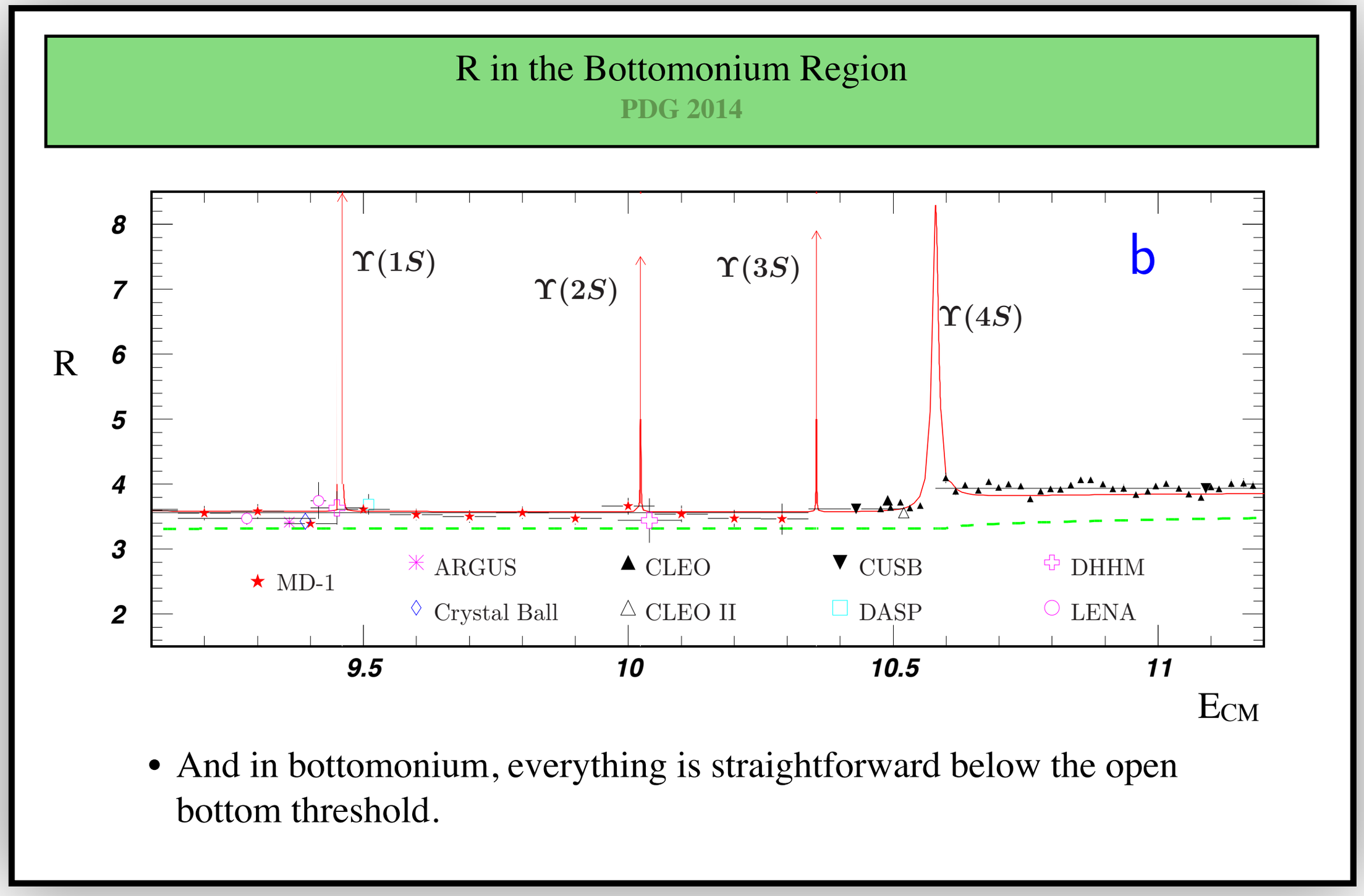
Total Cross Sections: *R in charmonium*



- R in the charmonium region suggests a tidy quark model picture:

$J/\psi = 1^3S_1$	$\psi(3770) = 1^3D_1$	$\psi(4160) = 2^3D_1$
$\psi(2S) = 2^3S_1$	$\psi(4040) = 3^3S_1$	$\psi(4415) = 4^3S_1$

Total Cross Sections: *R in bottomonium*

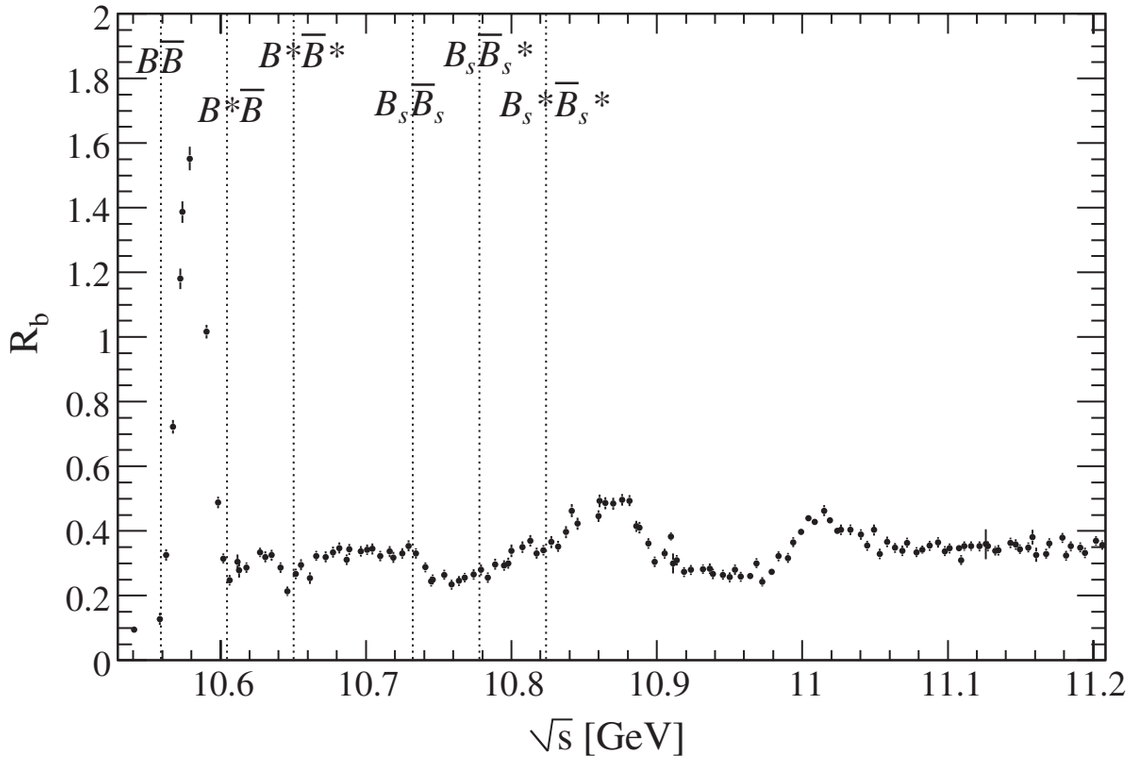


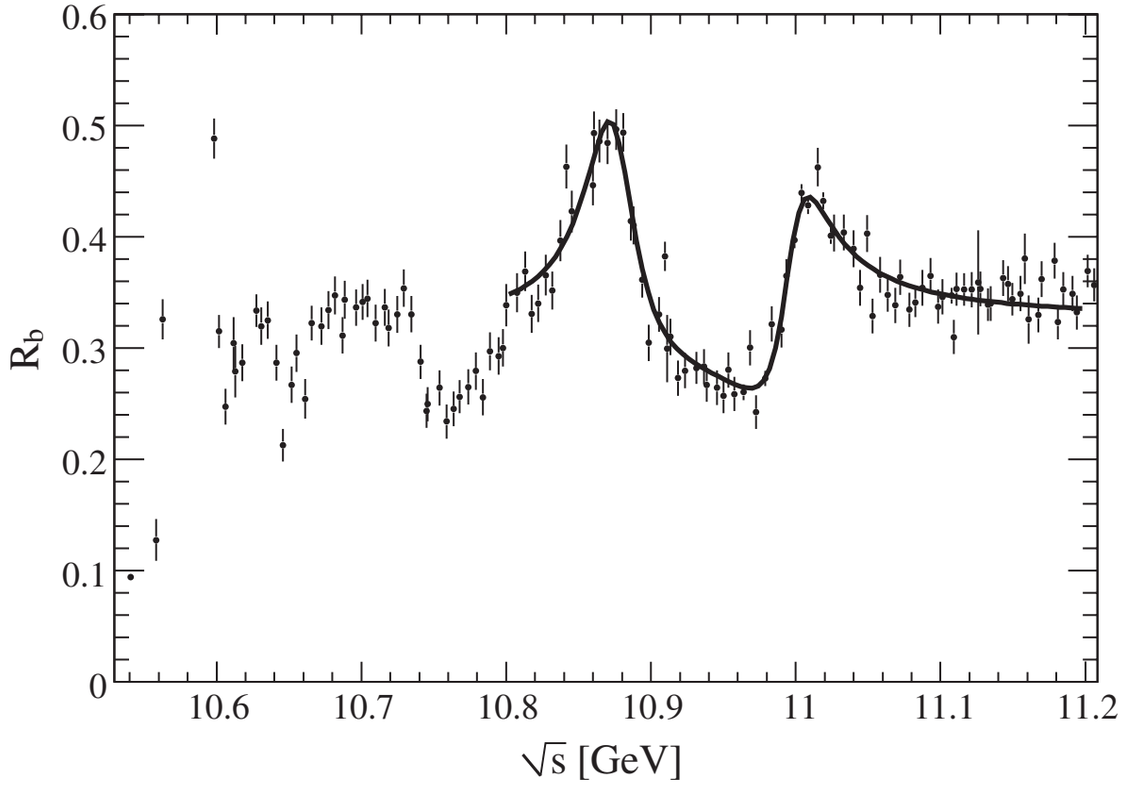
- And in bottomonium, everything is straightforward below the open bottom threshold.

Total Cross Sections: *R in bottomonium*

R_b from BaBar

PRL 102, 012001 (2009)



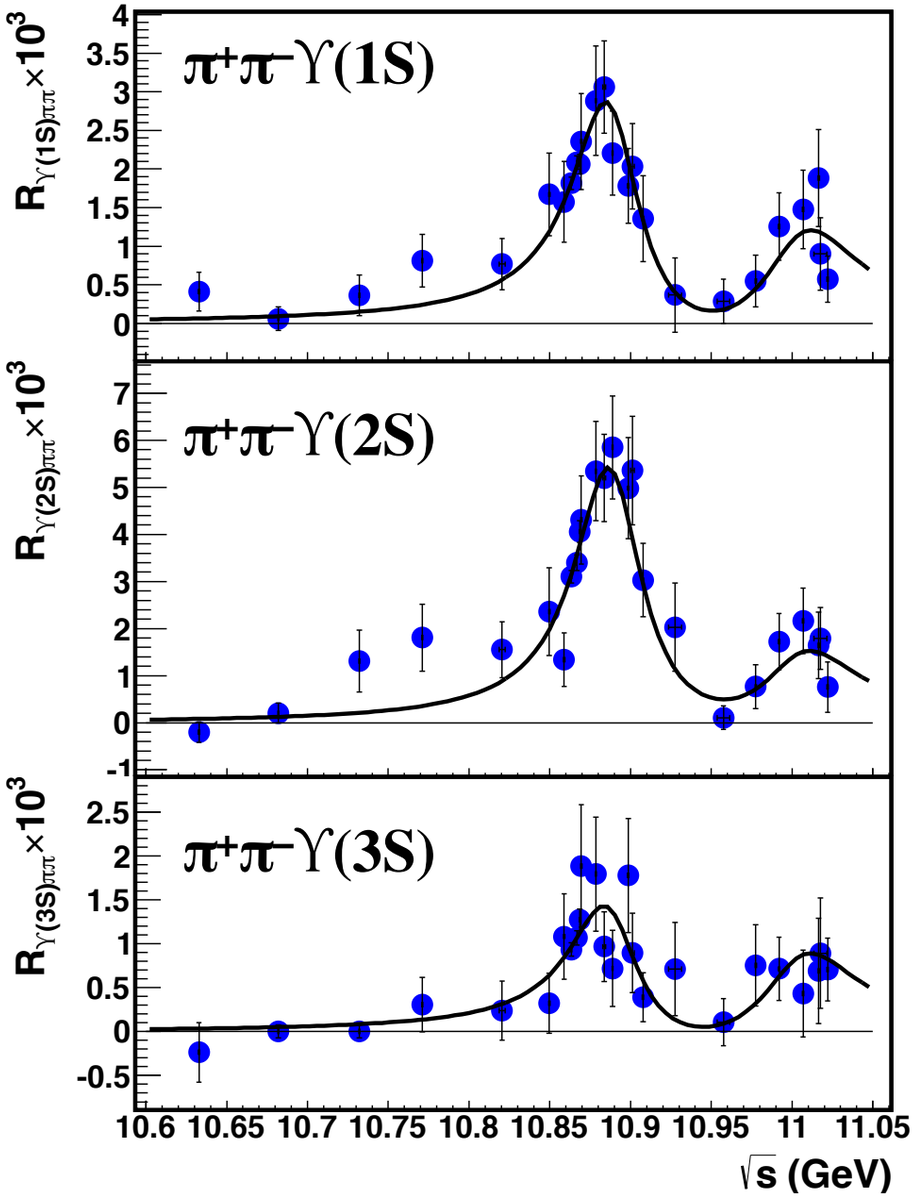


- The variety of thresholds apparently complicates matters above open bottom threshold, but an "Υ(5S)" and "Υ(6S)" seem clear.

Exclusive Cross Sections: $\pi^+\pi^-\Upsilon(1S,2S,3S)$

$e^+e^- \to \pi^+\pi^-\Upsilon(1S,2S,3S)$ at Belle

arXiv:1501.01137



- Peak positions in $\pi^+\pi^-\Upsilon(1S,2S,3S)$ are (more or less) consistent with the "$\Upsilon(5S)$" and "$\Upsilon(6S)$" from R_b.

- But from this preprint,

  B("$\Upsilon(5S)$" $\to \pi^+\pi^-\Upsilon(1S,2S,3S)$) = 0.17 ± 0.01,

  which is much larger than

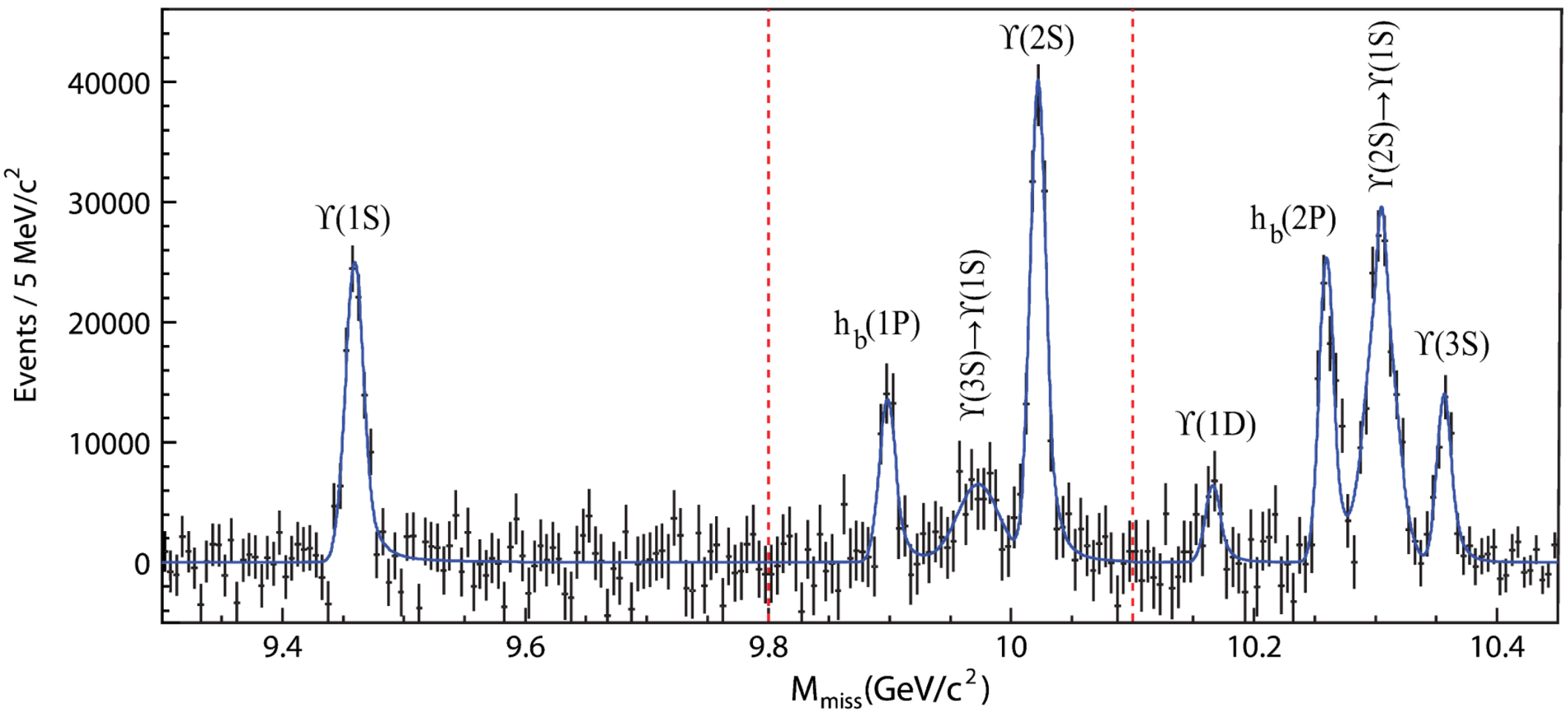
  B($\Upsilon(4S) \to \pi^+\pi^-\Upsilon(1S,2S,3S)$) ~ O($10^{-4}$).

- This suggests there is something strange happening with (or near) the "$\Upsilon(5S)$".

Exclusive Cross Sections: $\pi^+\pi^- h_b(1P,2P)$

$e^+e^- \rightarrow \pi^+\pi^-(\Upsilon(nS),h_b(nP))$ at E_{CM} ~ "$\Upsilon(5S)$" Mass at Belle

PRL 108, 032001 (2012)

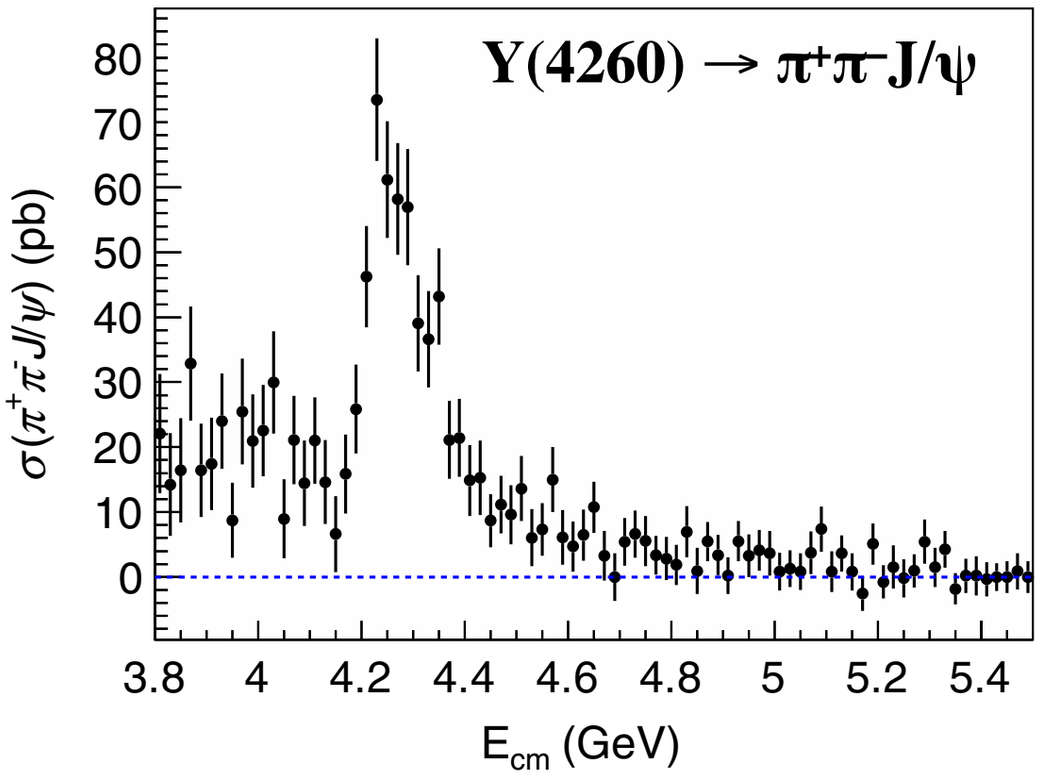


- In addition, $\sigma(e^+e^- \rightarrow \pi^+\pi^- h_b(nP))$ is comparable to $\sigma(e^+e^- \rightarrow \pi^+\pi^-\Upsilon(nS))$ around the "$\Upsilon(5S)$".

Exclusive Cross Sections: $\pi^+\pi^- J/\psi$

$e^+e^-(\gamma_{ISR}) \rightarrow \pi^+\pi^- J/\psi$ at Belle

PRL 110, 252002 (2013)

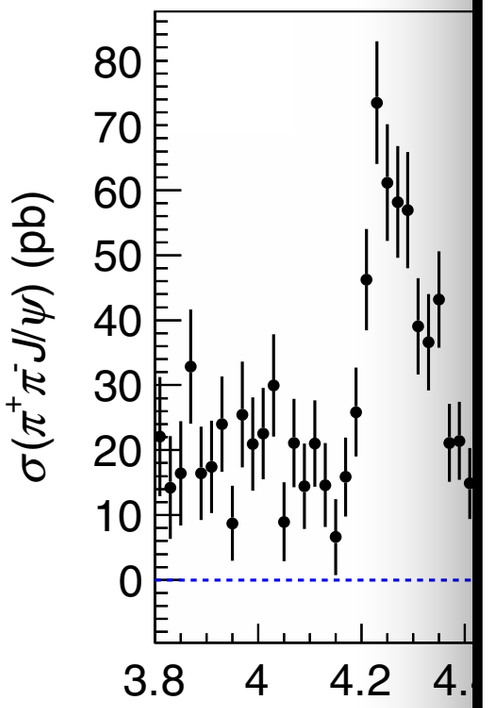


- In charmonium, the Y(4260) has no corresponding peak in R, and also has no place in the quark model.

Exclusive Cross Sections: $\pi^+\pi^- J/\psi$

$e^+e^-(\gamma_{ISR}) \rightarrow$

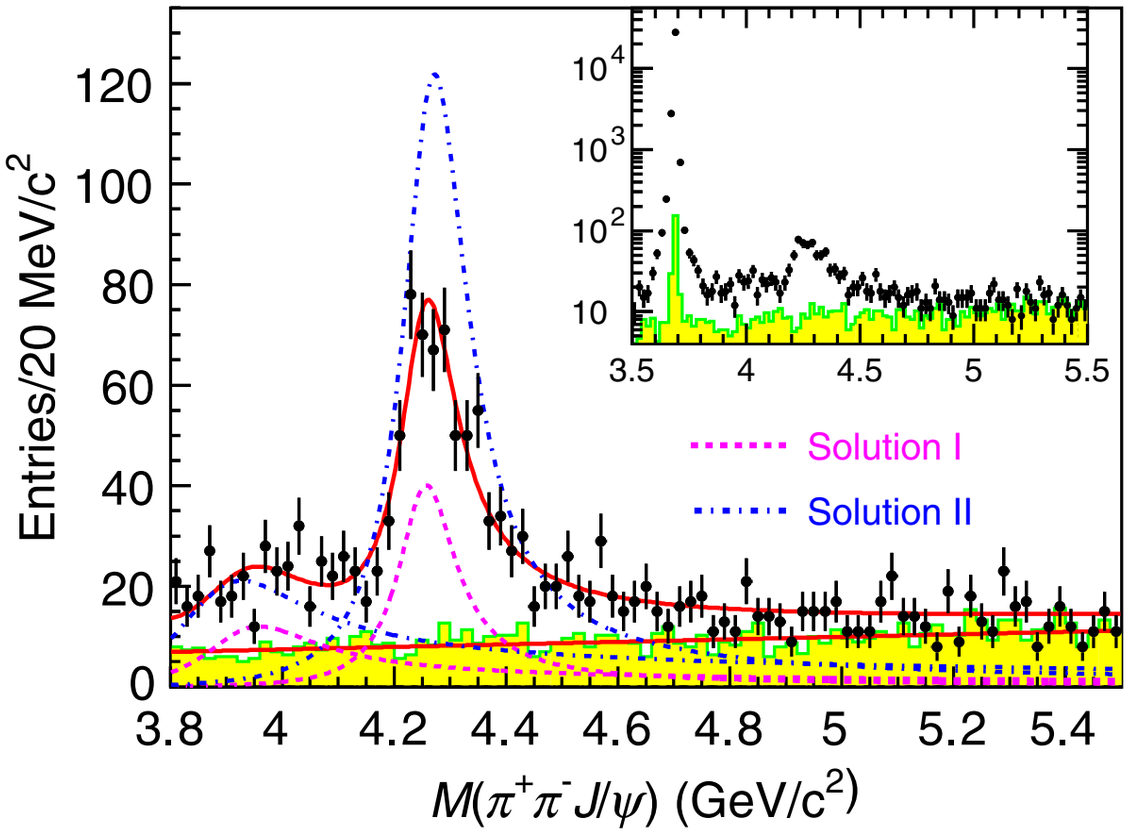
PRL 110



- In charmonium,
  corresponding p
  no place in the q

$e^+e^-(\gamma_{ISR}) \rightarrow \pi^+\pi^- J/\psi$ at Belle

PRL 110, 252002 (2013)

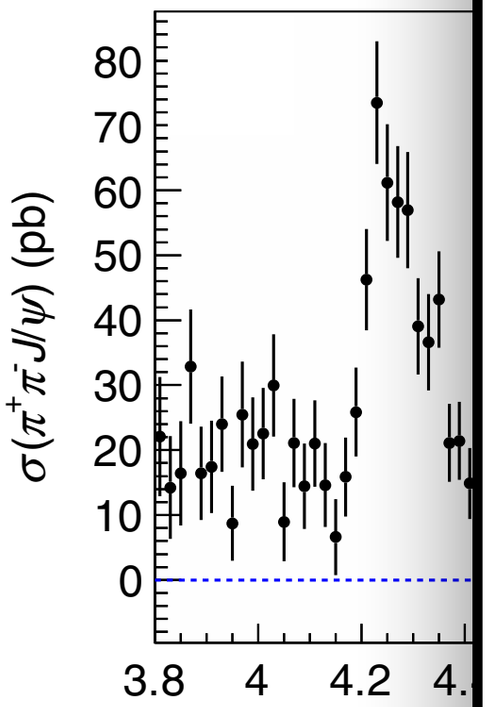


- Perhaps there are two peaks in $\pi^+\pi^- J/\psi$: Y(4008) and Y(4260)?

Exclusive Cross Sections: $\pi^+\pi^- J/\psi$

$e^+e^-(\gamma_{ISR}) \rightarrow$

PRL 110



- In charmonium,
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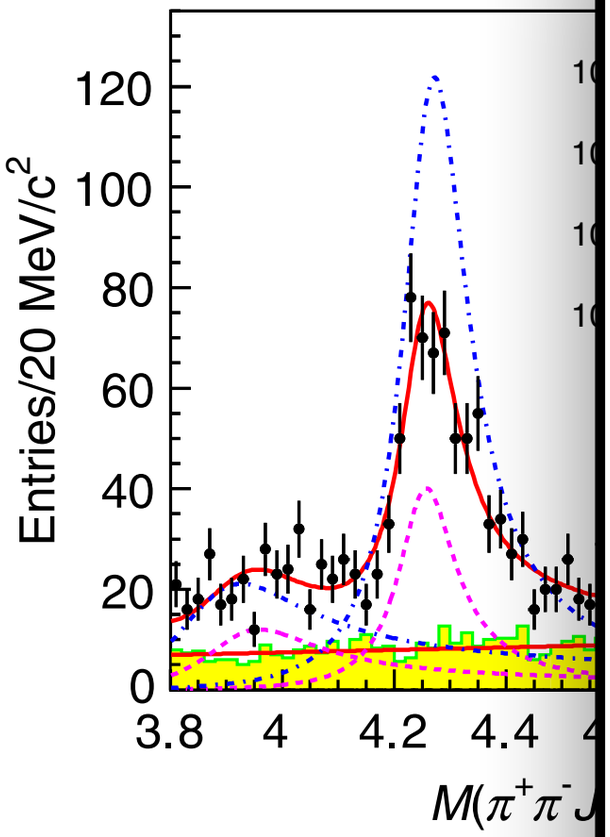
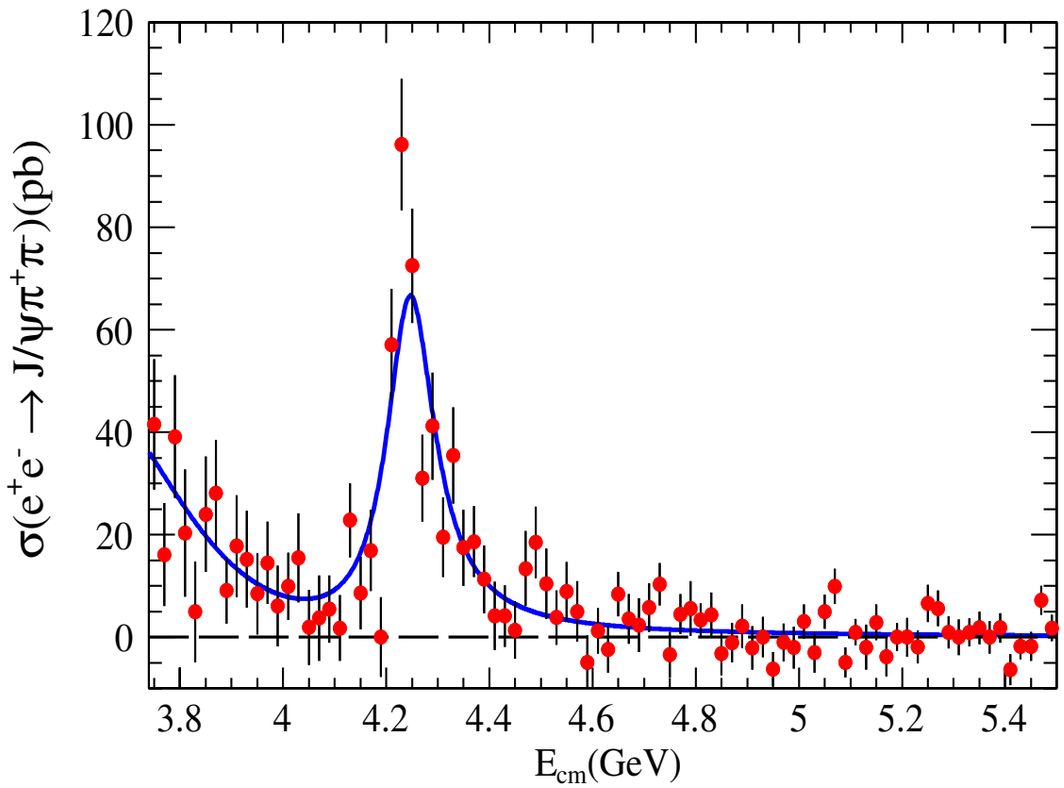
PRL 110, 252002 (2013)



- Perhaps there are tw
  Y(4008) and Y(4260

$e^+e^-(\gamma_{ISR}) \rightarrow \pi^+\pi^- J/\psi$ at BaBar

PRD 86, 051102(R) (2012)

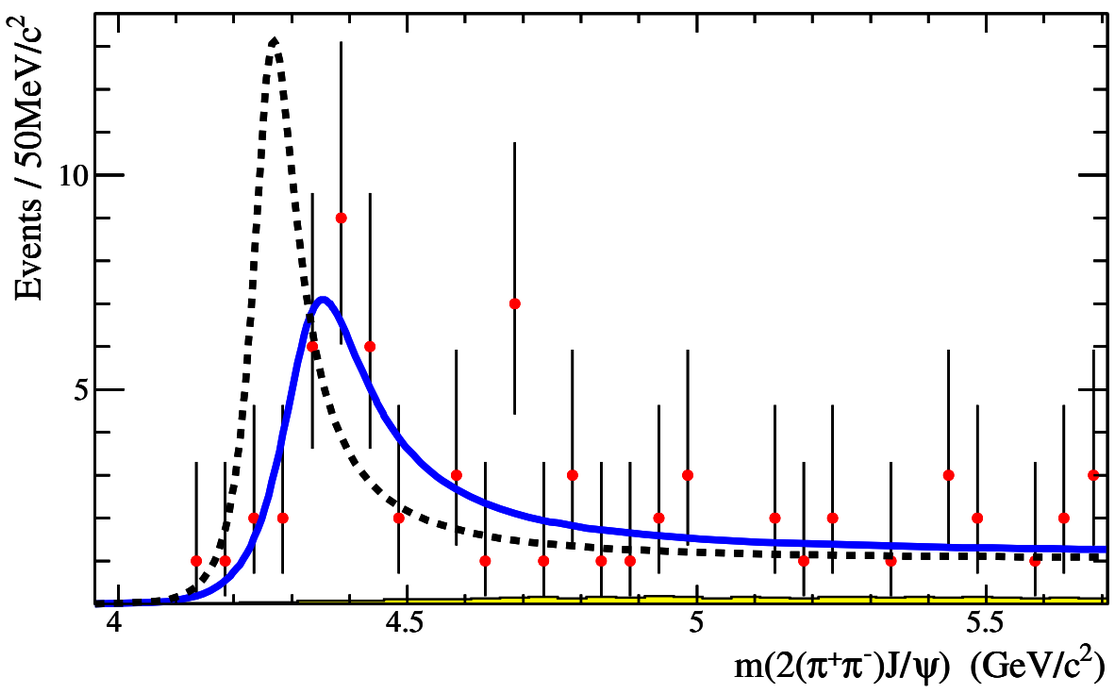


- But BaBar doesn't need another peak?

Exclusive Cross Sections: $\pi^+\pi^-\psi(2S)$

$e^+e^-(\gamma_{ISR}) \rightarrow \pi^+\pi^-\psi(2S)$ at BaBar

PRL 98, 212001 (2007)

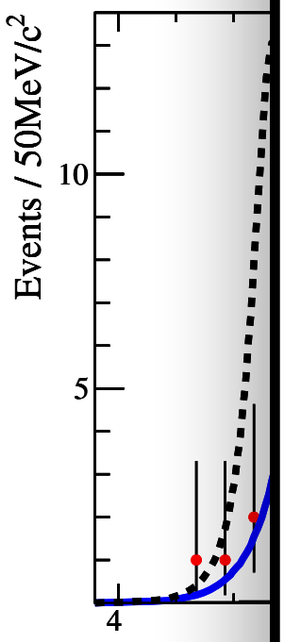


- In $\pi^+\pi^-\psi(2S)$, there is a Y(4360) instead of a Y(4260).

Exclusive Cross Sections: $\pi^+\pi^-\psi(2S)$

$e^+e^-(\gamma_{ISR}) \rightarrow \pi^+\pi^-\psi(2S)$ at BaBar

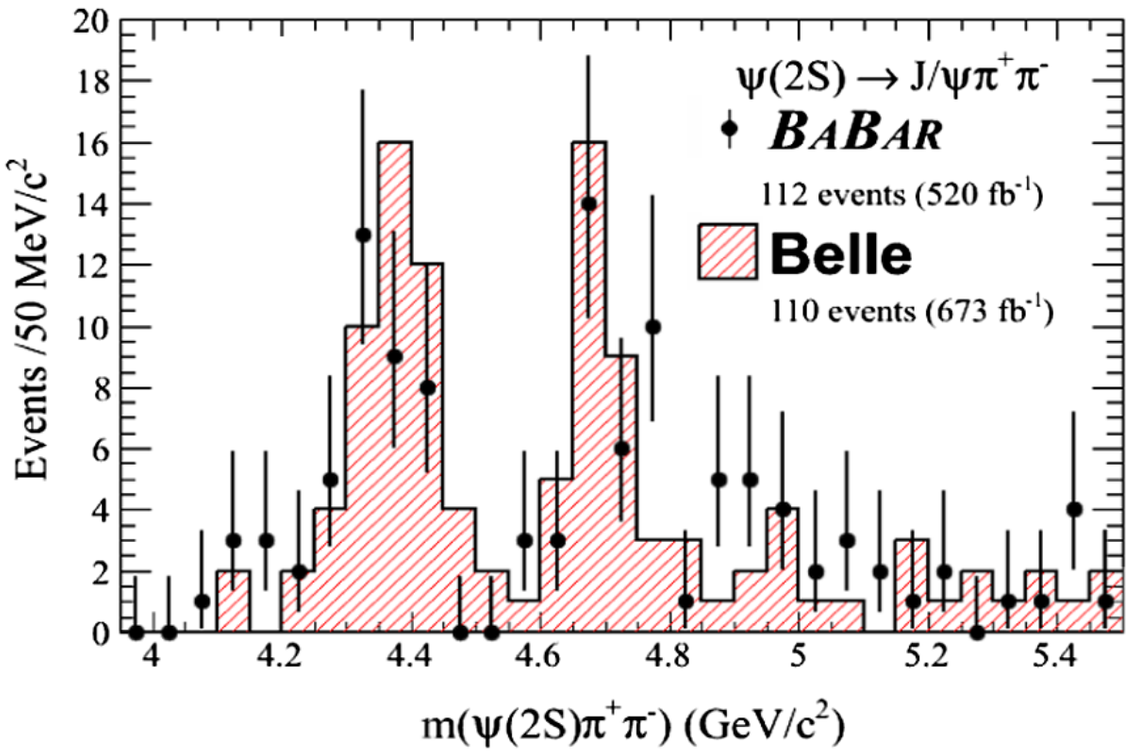
PRL 98, 212001 (2007)



- In $\pi^+\pi$
  of a Y

$e^+e^-(\gamma_{ISR}) \rightarrow \pi^+\pi^-\psi(2S)$ at BaBar (and Belle)

PRD 89, 111103(R) (2014)

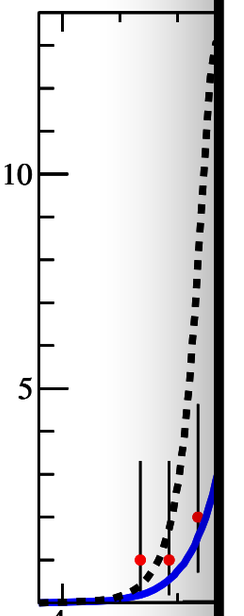


- Actually, there is a Y(4360) and a Y(4660)?

Exclusive Cross Sections: $\pi^+\pi^-\psi(2S)$

$e^+e^-(\gamma_{ISR}) \rightarrow \pi^+\pi^-\psi(2S)$ at BaB

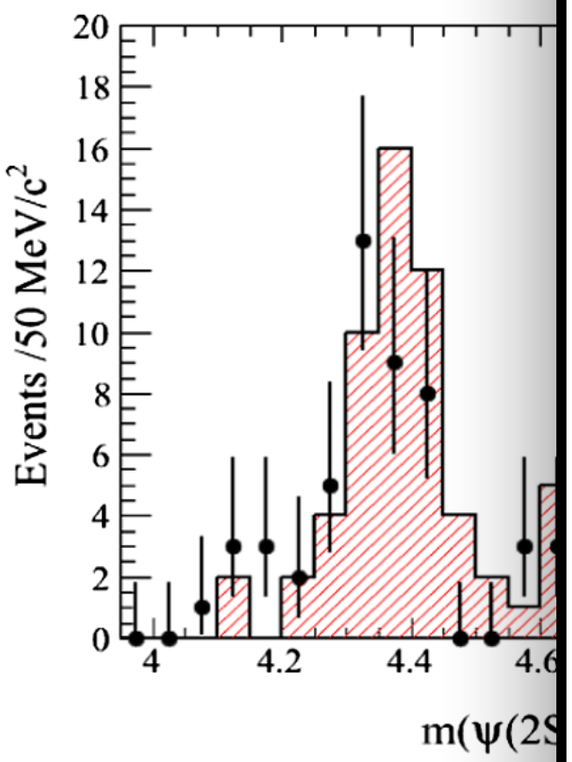
PRL 98, 212001 (2007)



- In $\pi^+\pi$
of a Y

$e^+e^-(\gamma_{ISR}) \rightarrow \pi^+\pi^-\psi(2$

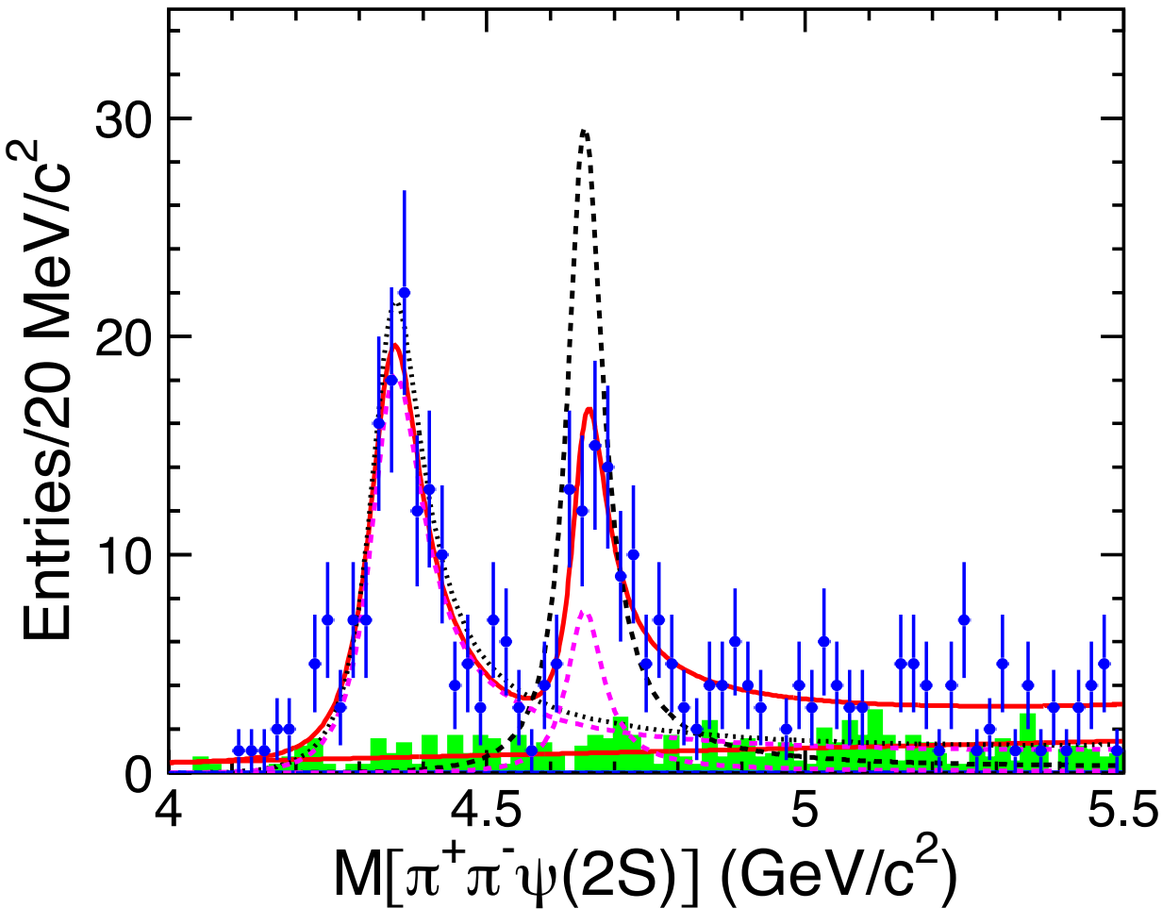
PRD 89, 111



- Actually, there is a

$e^+e^-(\gamma_{ISR}) \rightarrow \pi^+\pi^-\psi(2S)$ at Belle

arXiv:1410.7641

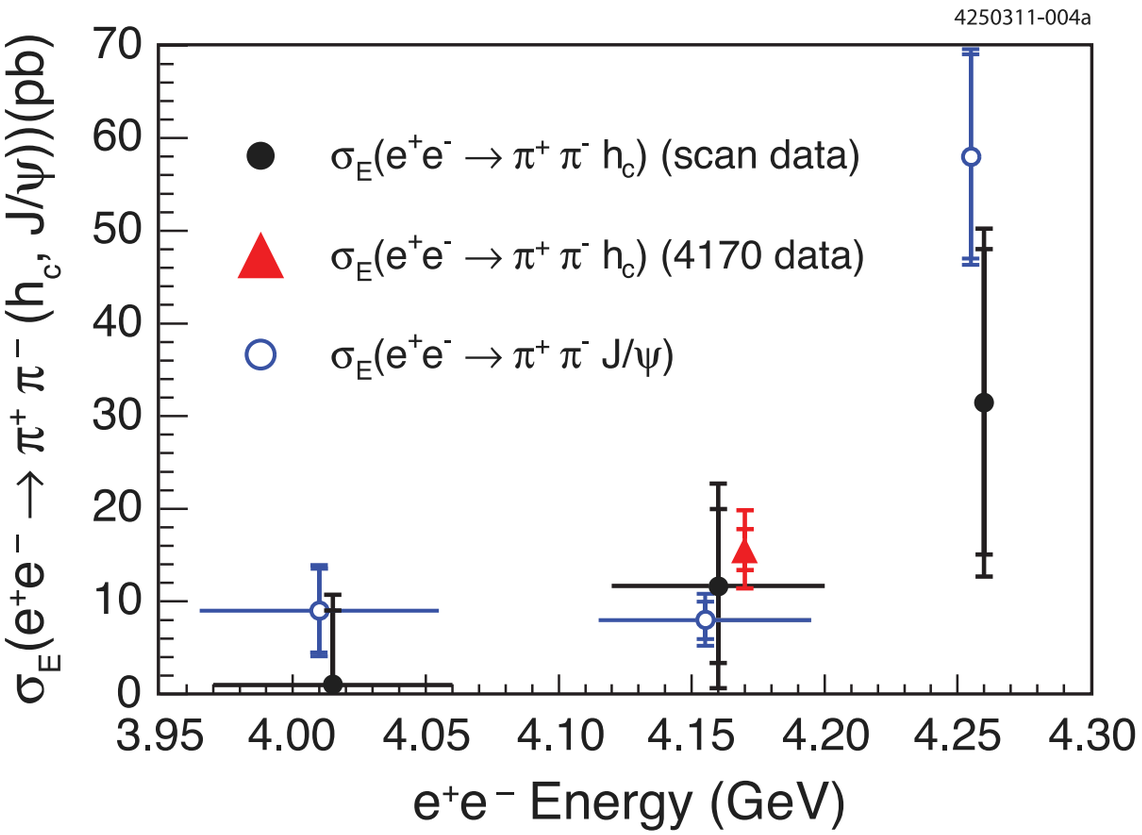


- The Y(4360) and Y(4660) are even more convincing with the full Belle statistics.

Exclusive Cross Sections: $\pi^+\pi^- h_c(1P)$

$e^+e^- \to \pi^+\pi^- h_c(1P)$ at CLEO-c

PRL 107, 041803 (2011)

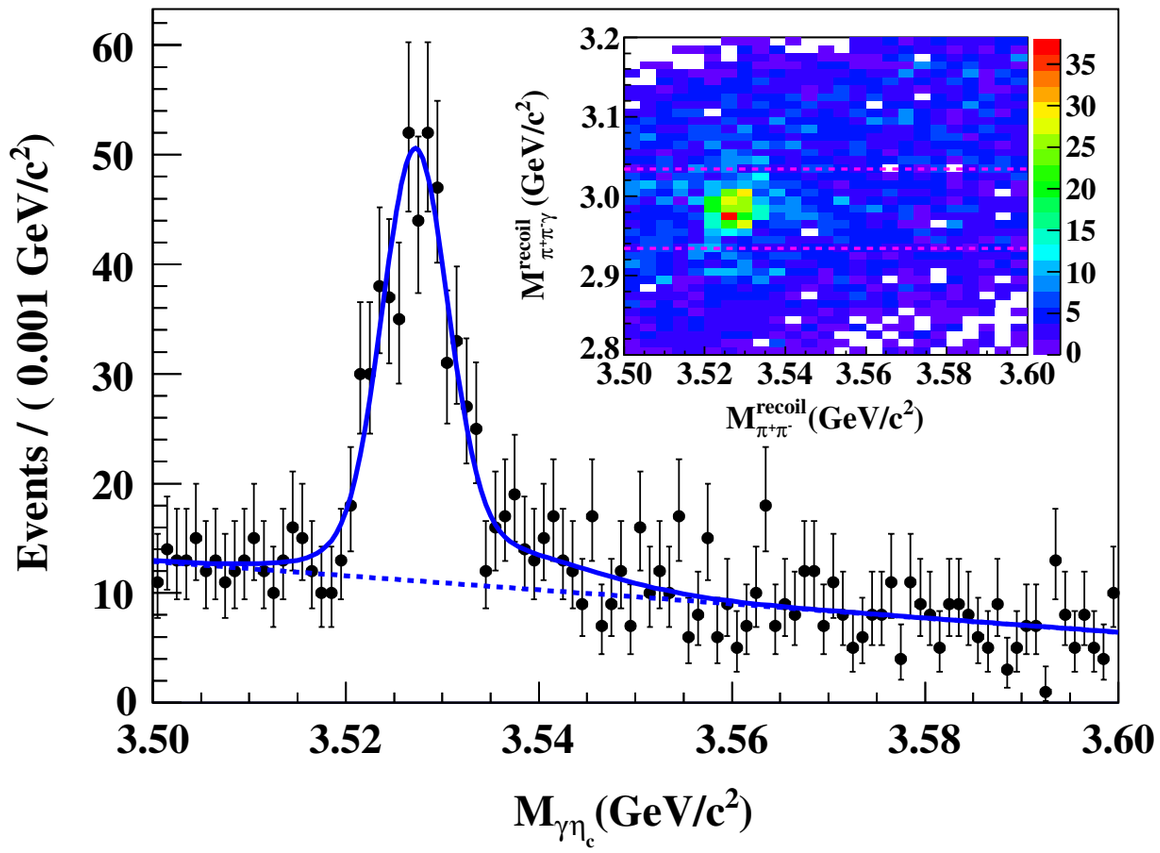


- Does $\pi^+\pi^- h_c(1P)$ show hints of the Y(4260)?

Exclusive Cross Sections: $\pi^+\pi^- h_c(1P)$

$e^+e^- \rightarrow \pi^+\pi^- h_c(1P)$ at $E_{CM} = 4.26$ GeV at BESIII

PRL 111, 242001 (2013)

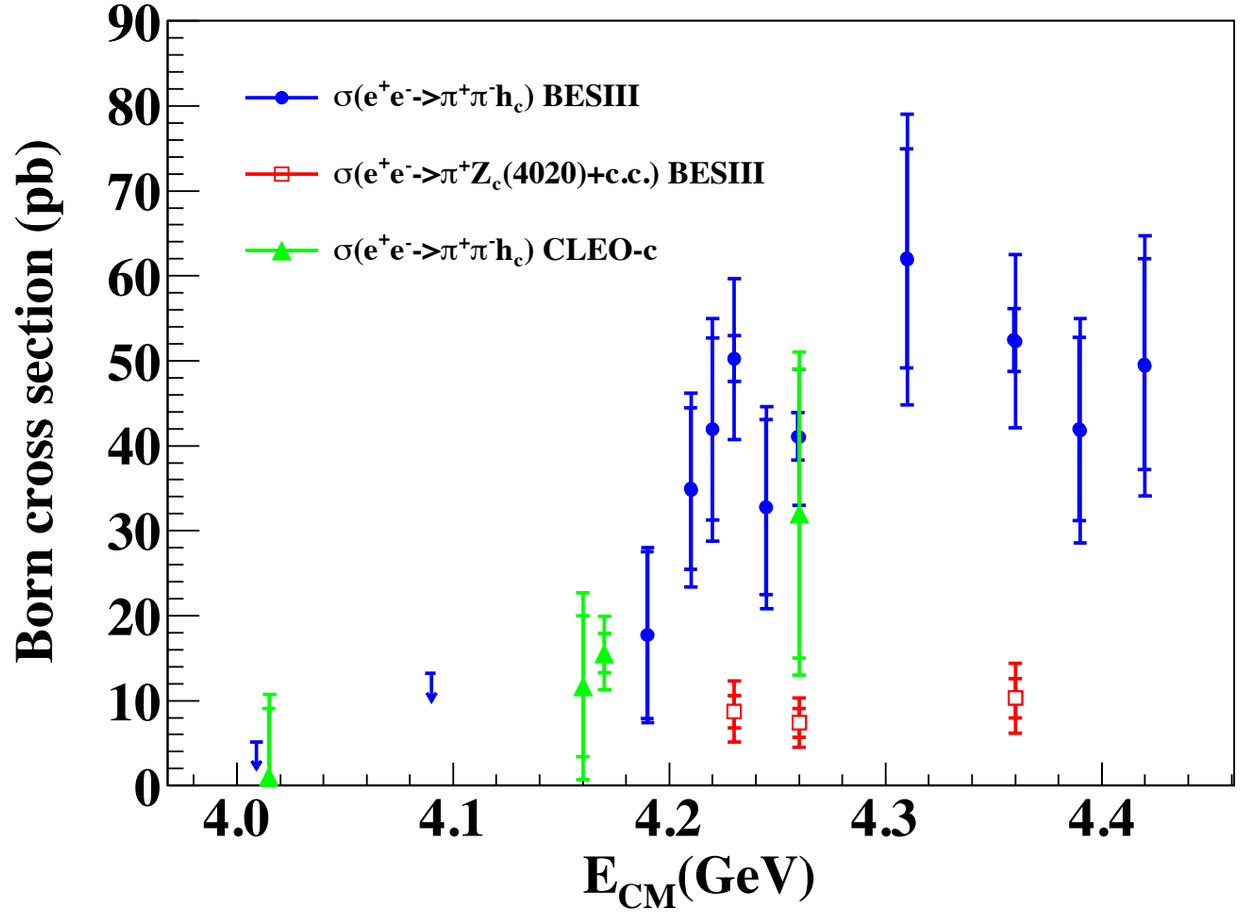


- $\sigma(e^+e^- \rightarrow \pi^+\pi^- h_c(1P))$ is comparable to $\sigma(e^+e^- \rightarrow \pi^+\pi^- J/\psi)$ around the Y(4260).

Exclusive Cross Sections: $\pi^+\pi^- h_c(1P)$

$e^+e^- \rightarrow \pi^+\pi^- h_c(1P)$ at BESIII

PRL 111, 242001 (2013)

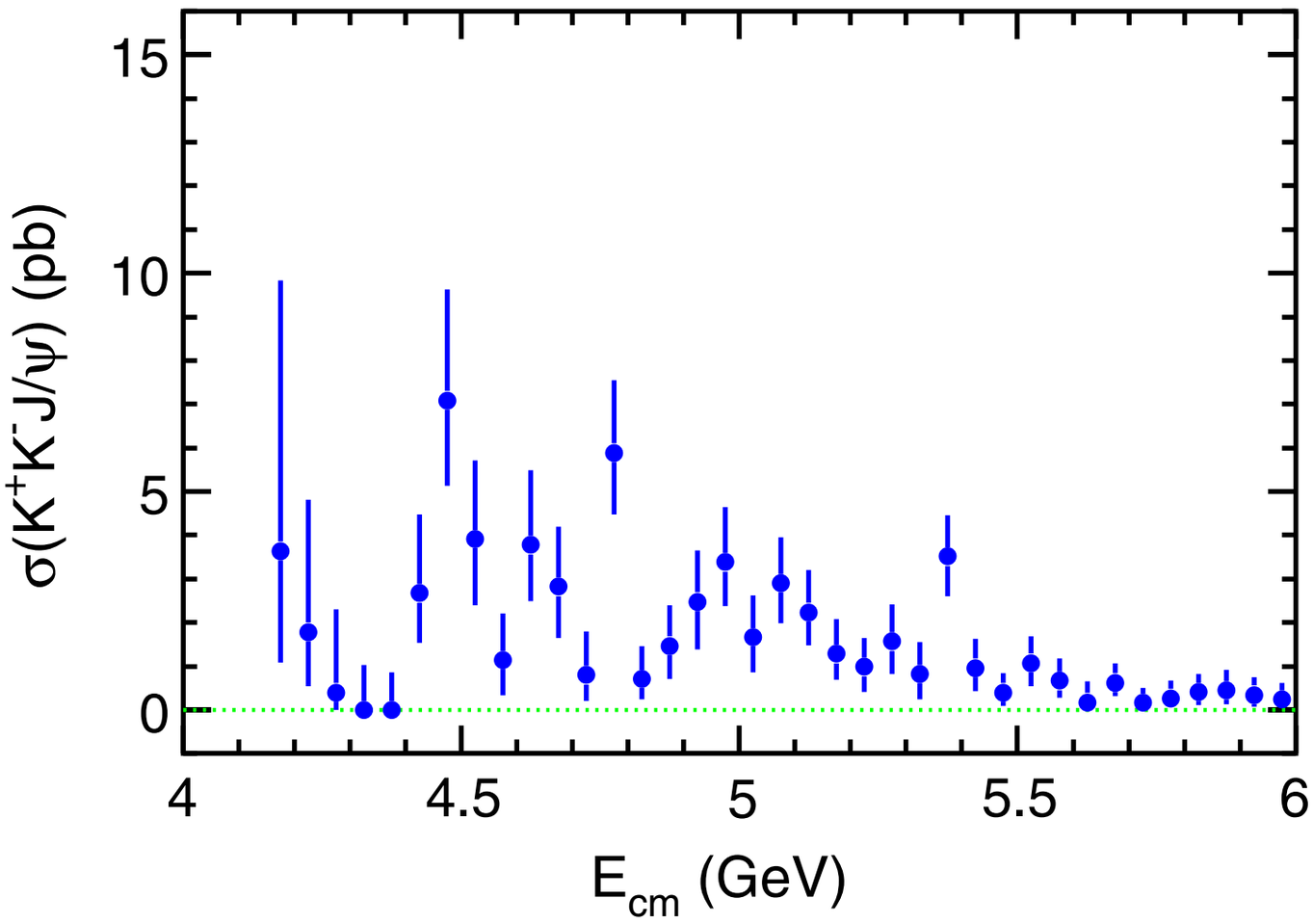


- But the energy dependence is more complicated than just Y(4260) → $\pi^+\pi^- h_c(1P)$.

Exclusive Cross Sections: K^+K^-J/ψ

$e^+e^-(\gamma_{ISR}) \rightarrow K^+K^-J/\psi$ at Belle

PRD 89, 072015 (2014)

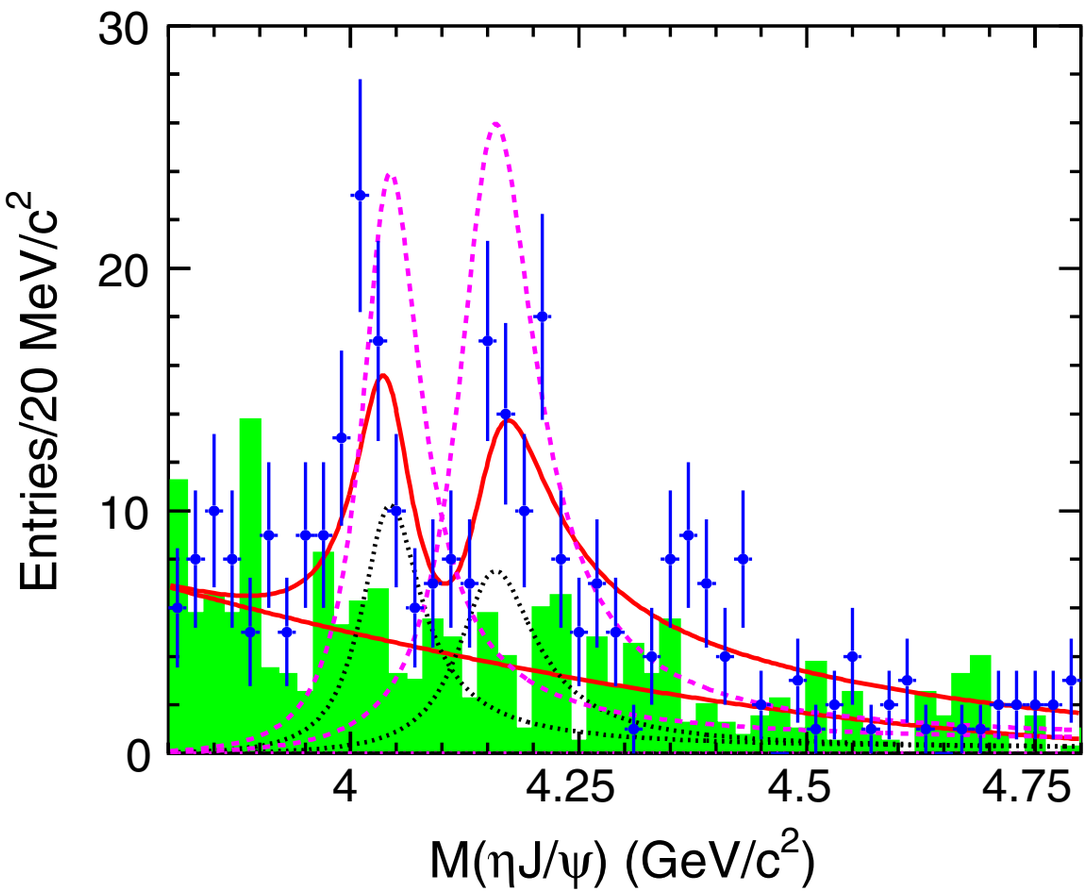


- There is surprising nontrivial structure in $e^+e^- \rightarrow K^+K^-J/\psi$.

Exclusive Cross Sections: $\eta J/\psi$

$e^+e^-(\gamma_{ISR}) \rightarrow \eta J/\psi$ at Belle

PRD 87, 051101(R) (2013)

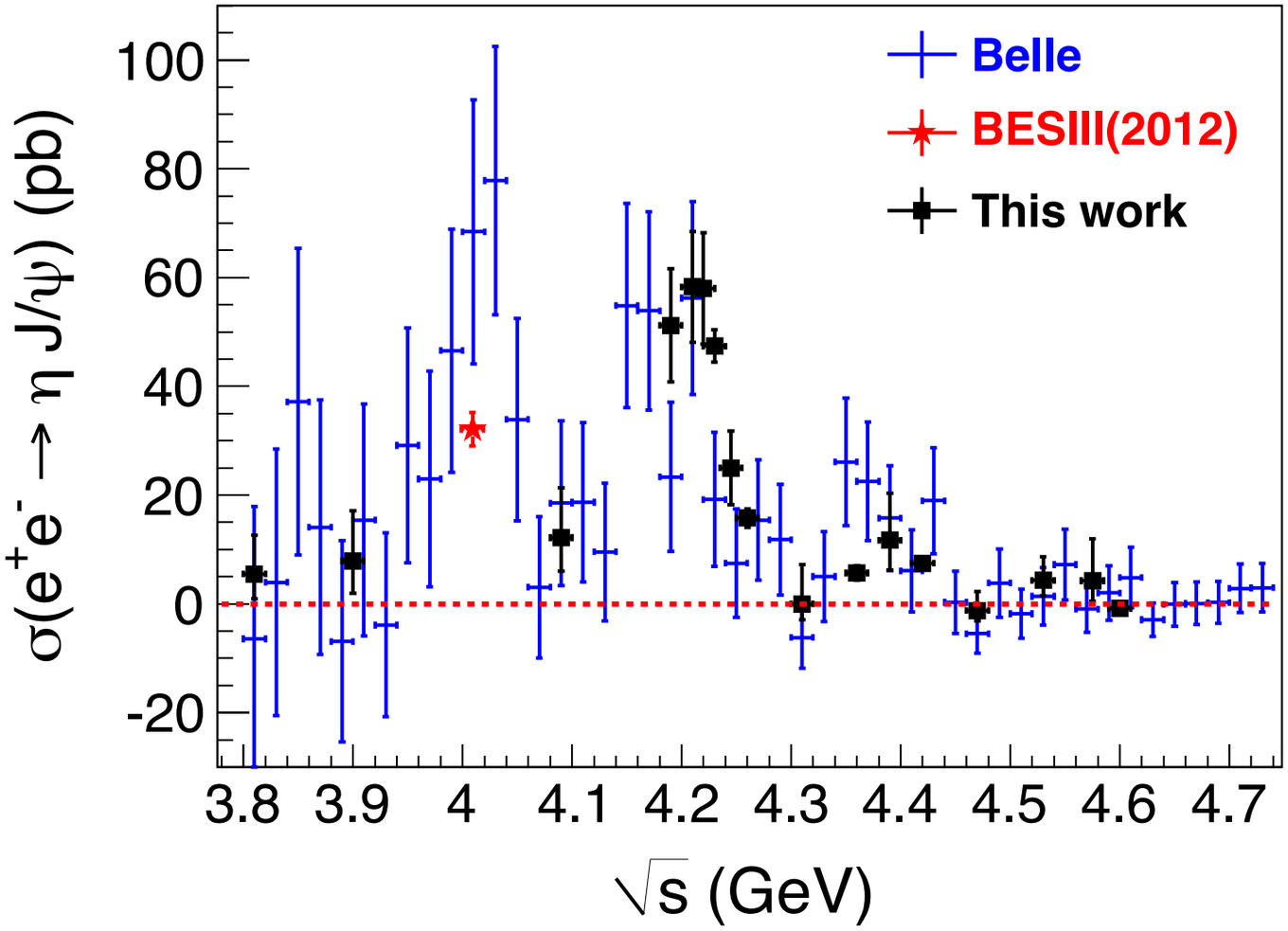


- The initial observation of $e^+e^- \rightarrow \eta J/\psi$ was fit with conventional $\psi(4040)$ and $\psi(4160)$ states.

Exclusive Cross Sections: $\eta J/\psi$

$e^+e^- \to \eta J/\psi$ at BESIII

arXiv:1503.06644

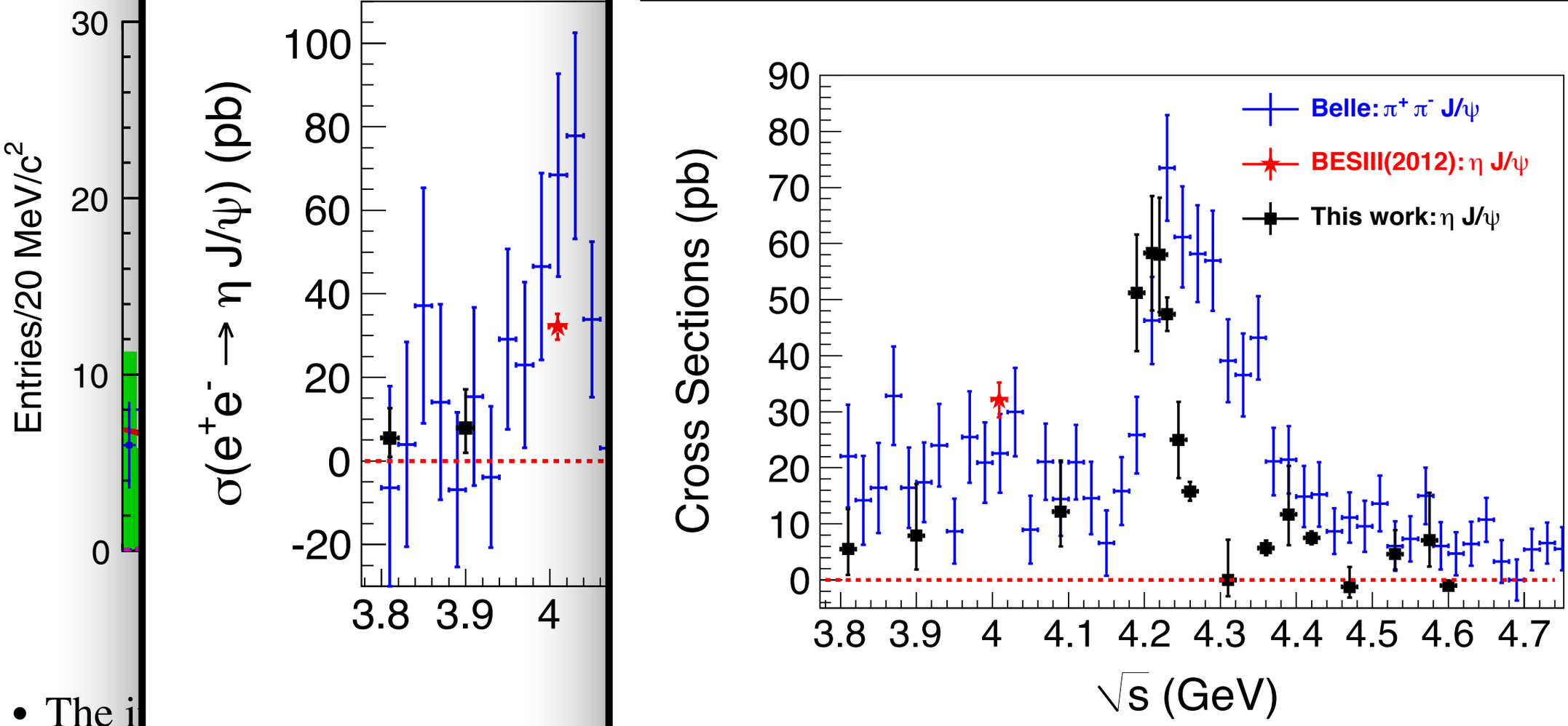


- BESIII confirms there is nontrivial structure in $\eta J/\psi$, but it's not clear if this is still consistent with the $\psi(4040)$ and $\psi(4160)$.

Exclusive Cross Sections: $\eta J/\psi$

$e^+e^- \rightarrow \eta J/\psi$ at BESIII

arXiv:1503.06644

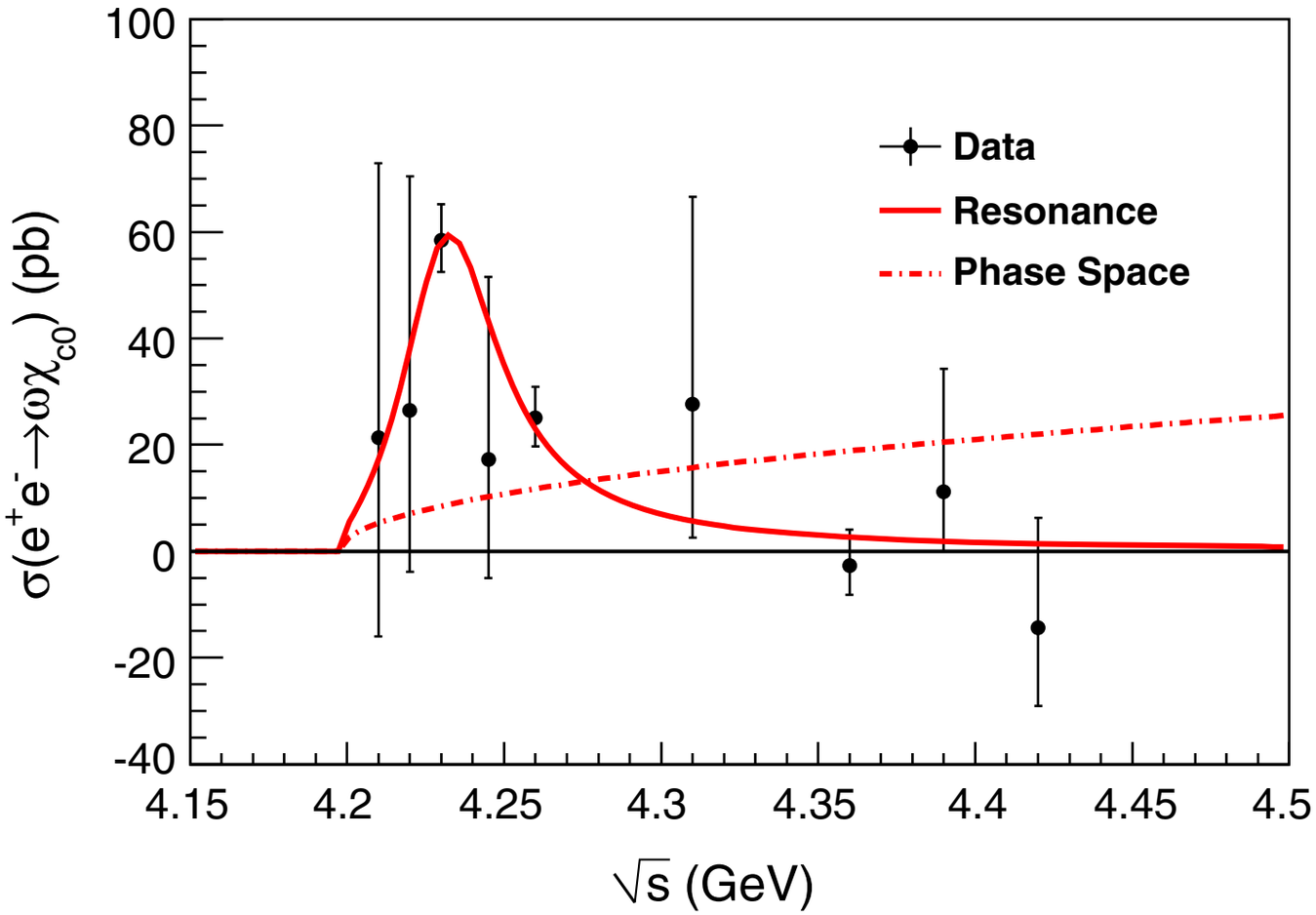


- The $\eta J/\psi$ cross section is certainly inconsistent with the $\pi^+\pi^- J/\psi$ cross section (*the Y(4260)*).

Exclusive Cross Sections: $\omega\chi_{c0}$

$e^+e^- \to \omega\chi_{c0}$ at BESIII

PRL 114, 092003 (2015)

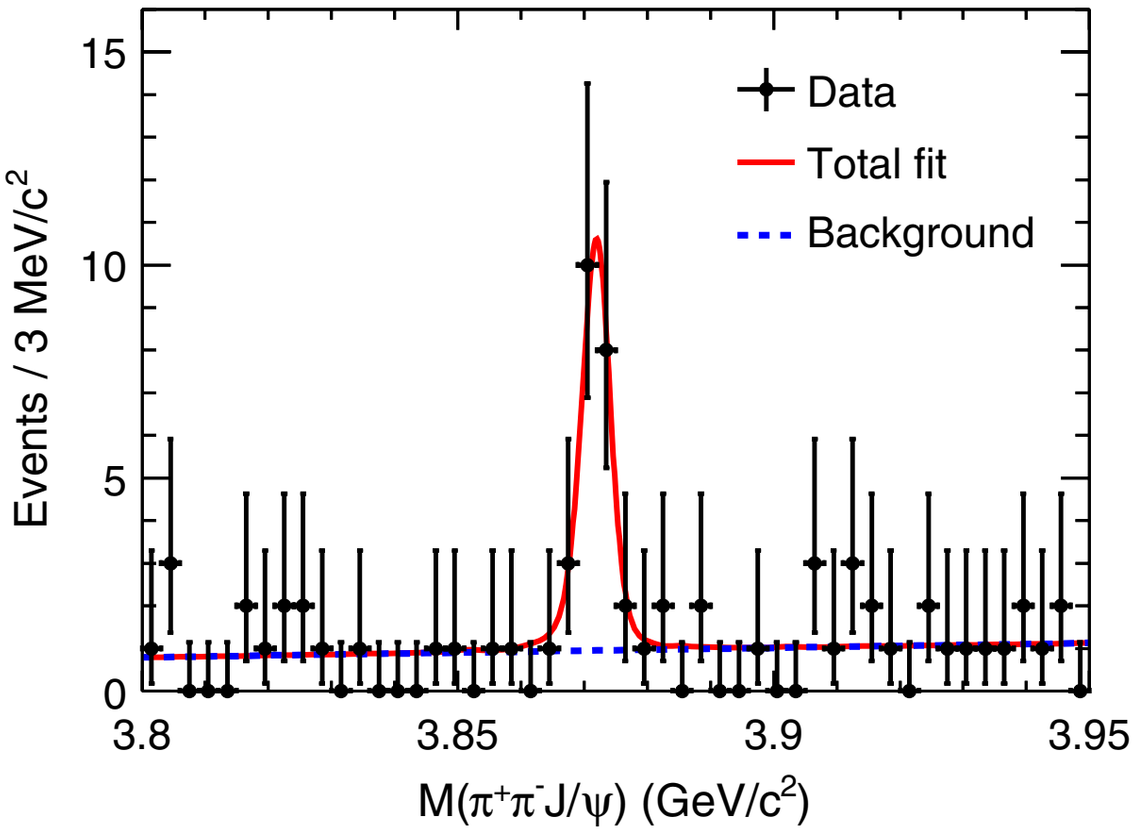


- The $\omega\chi_{c0}$ cross section is also inconsistent with the Y(4260).

Exclusive Cross Sections: $\gamma X(3872)$

$e^+e^- \rightarrow \gamma(\pi^+\pi^- J/\psi)$ at $E_{CM} \sim 4.26$ GeV at BESIII

PRL 112, 092001 (2014)

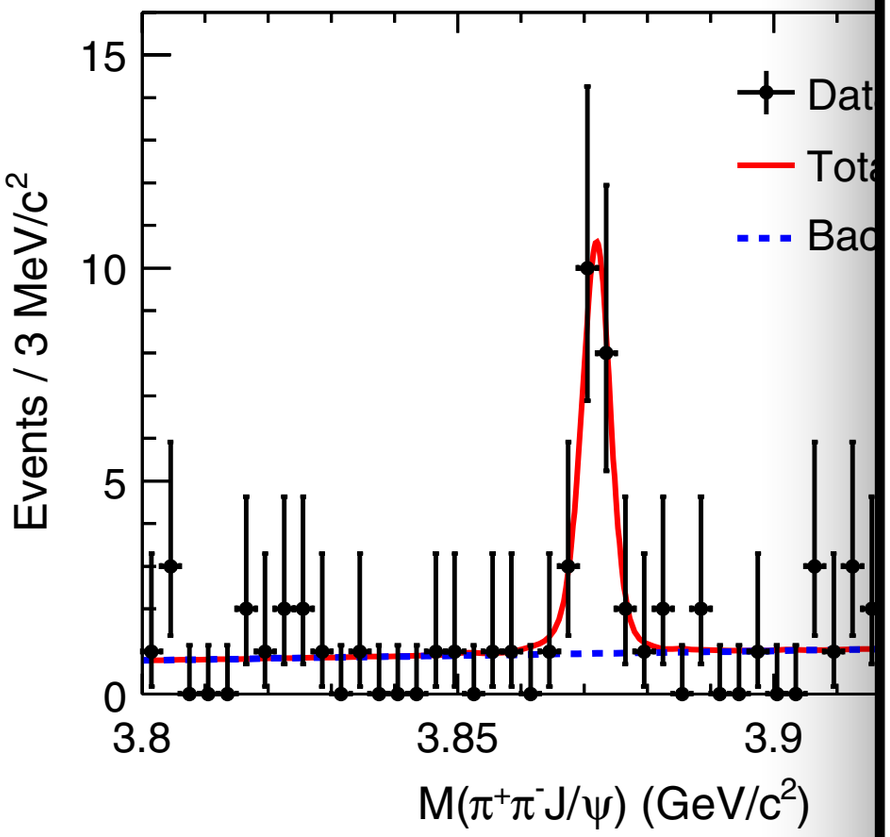


- BESIII has an observation of $e^+e^- \rightarrow \gamma X(3872)$ with $E_{CM} \sim 4.26$ GeV.

Exclusive Cross Sections: $\gamma X(3872)$

$e^+e^- \rightarrow \gamma(\pi^+\pi^- J/\psi)$ at $E_{CM} \sim 4.26$ G

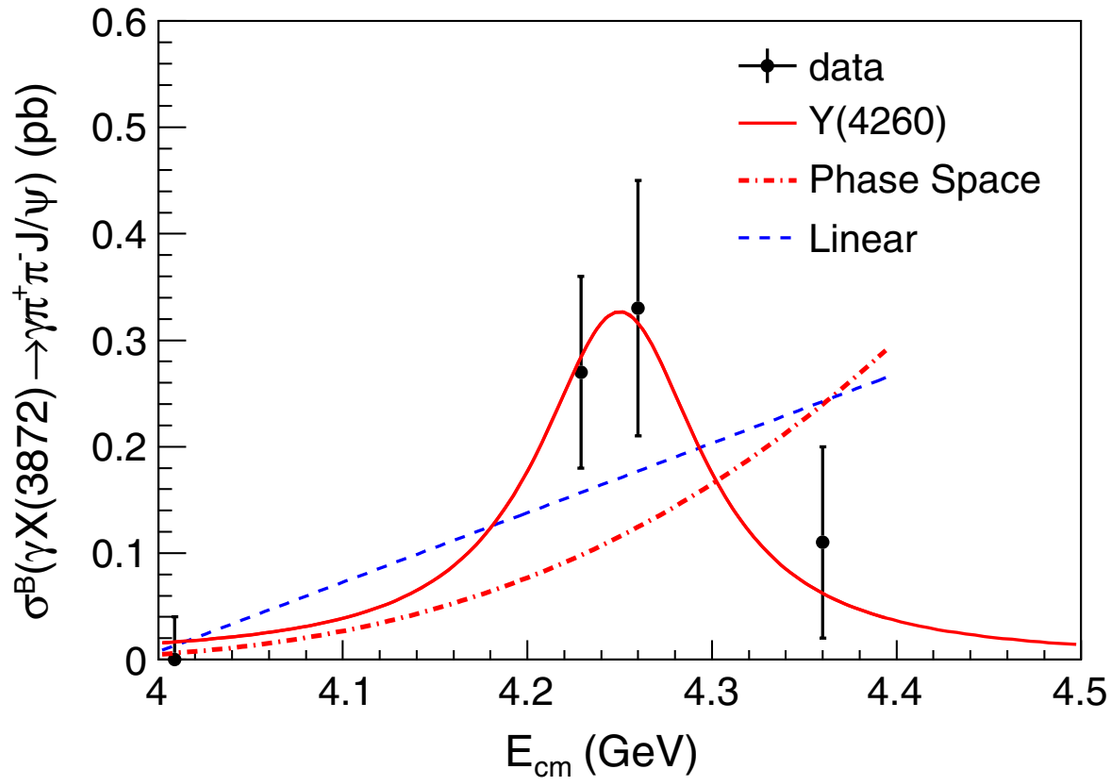
PRL 112, 092001 (2014)



- BESIII has an observation of e^+e^- –
  with $E_{CM} \sim 4.26$ GeV.

$e^+e^- \rightarrow \gamma(\pi^+\pi^- J/\psi)$ at $E_{CM} \sim 4.26$ GeV at BESIII

PRL 112, 092001 (2014)

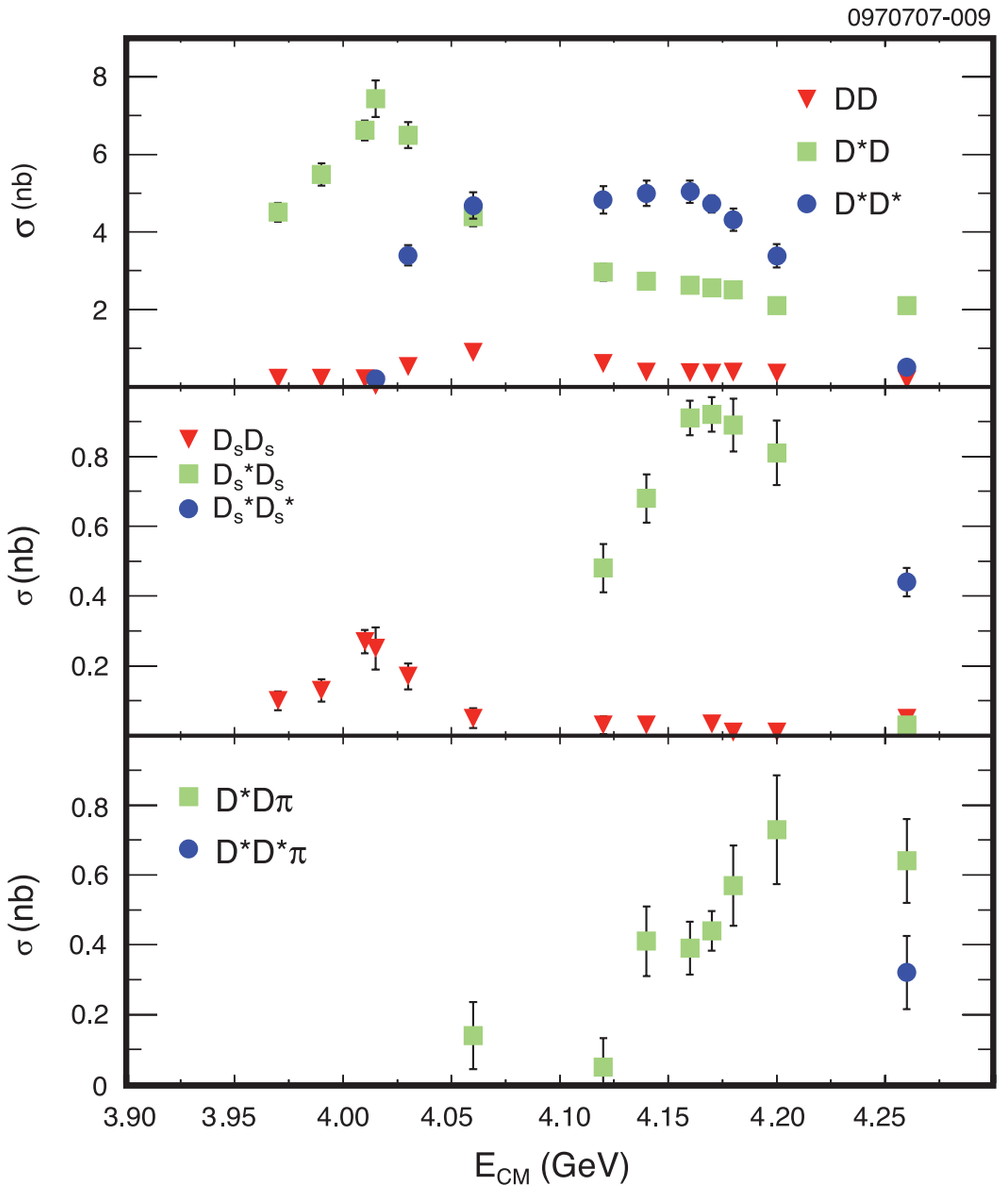


- Maybe this is $Y(4260) \rightarrow \gamma X(3872)$, but the statistics are poor.

Exclusive Cross Sections: *Open Charm*

$e^+e^- \rightarrow$ open charm at CLEO-c

PRD 80, 072001 (2009)

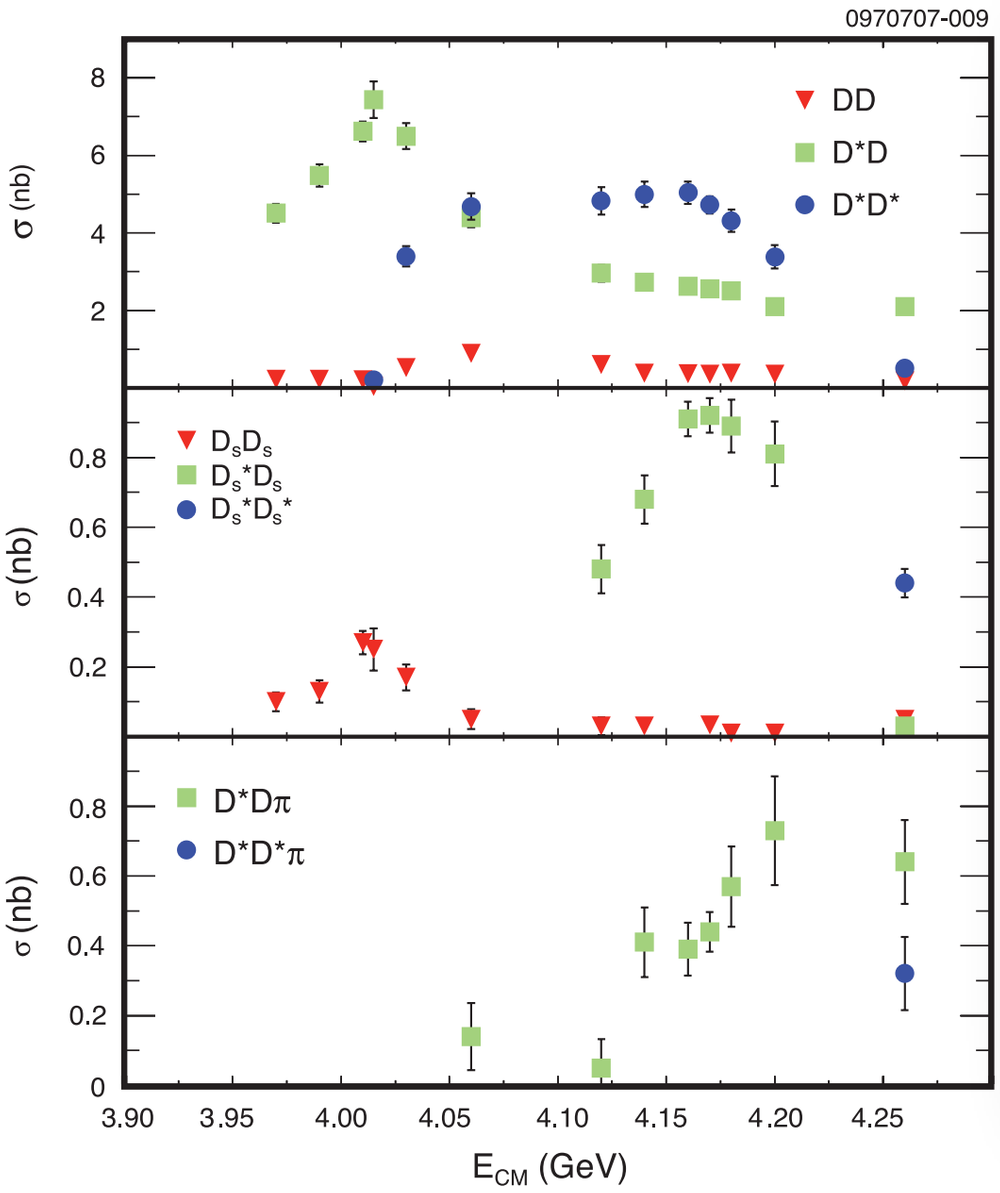


- The exclusive open charm cross sections are also difficult to interpret.

Exclusive Cross Sections: *Open Charm*

$e^+e^- \rightarrow$ open charm at CLEO-c

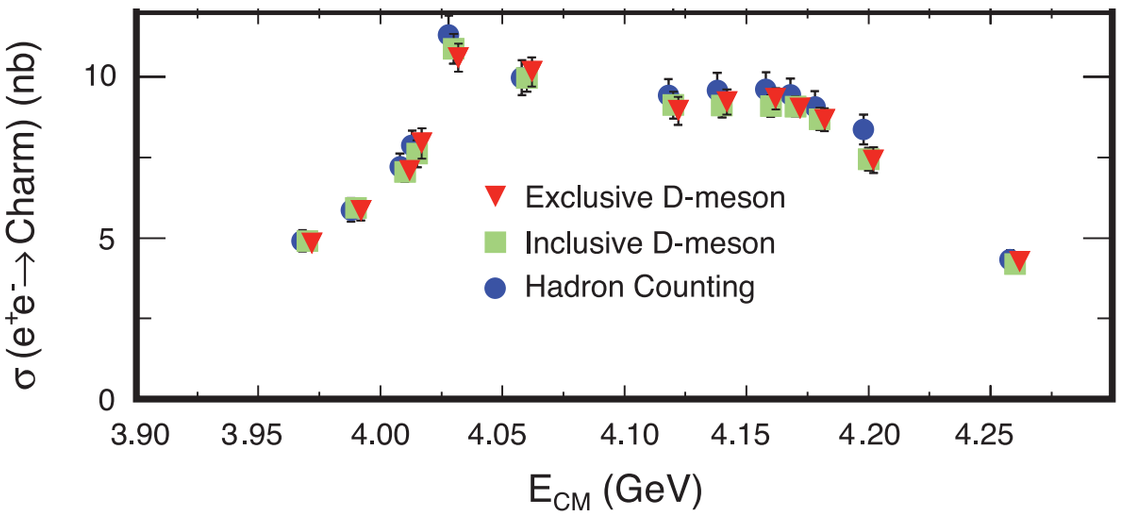
PRD 80, 072001 (2009)



- The exclusive open charm cross sections are also difficult to interpret.

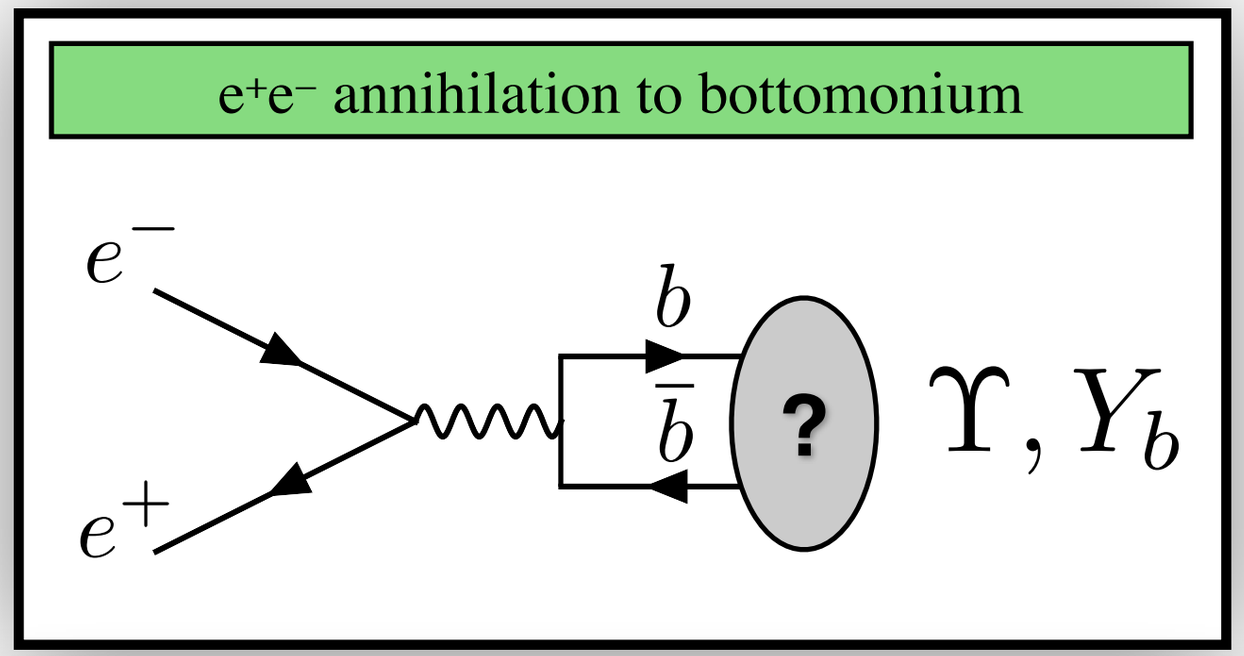
$e^+e^- \rightarrow$ open charm at CLEO-c

PRD 80, 072001 (2009)



- Although the *total* open charm cross section again seems well-behaved.

The Simplicity of the e^+e^- Process?



What seemed simple, now seems hard.

We need:

(1) more data;

(2) a global outlook.