Observation of $e^+e^- \rightarrow \pi^+\pi^- h_c(1P)$

(and Other Highlights from CLEO)

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QWG 2011 (GSI)
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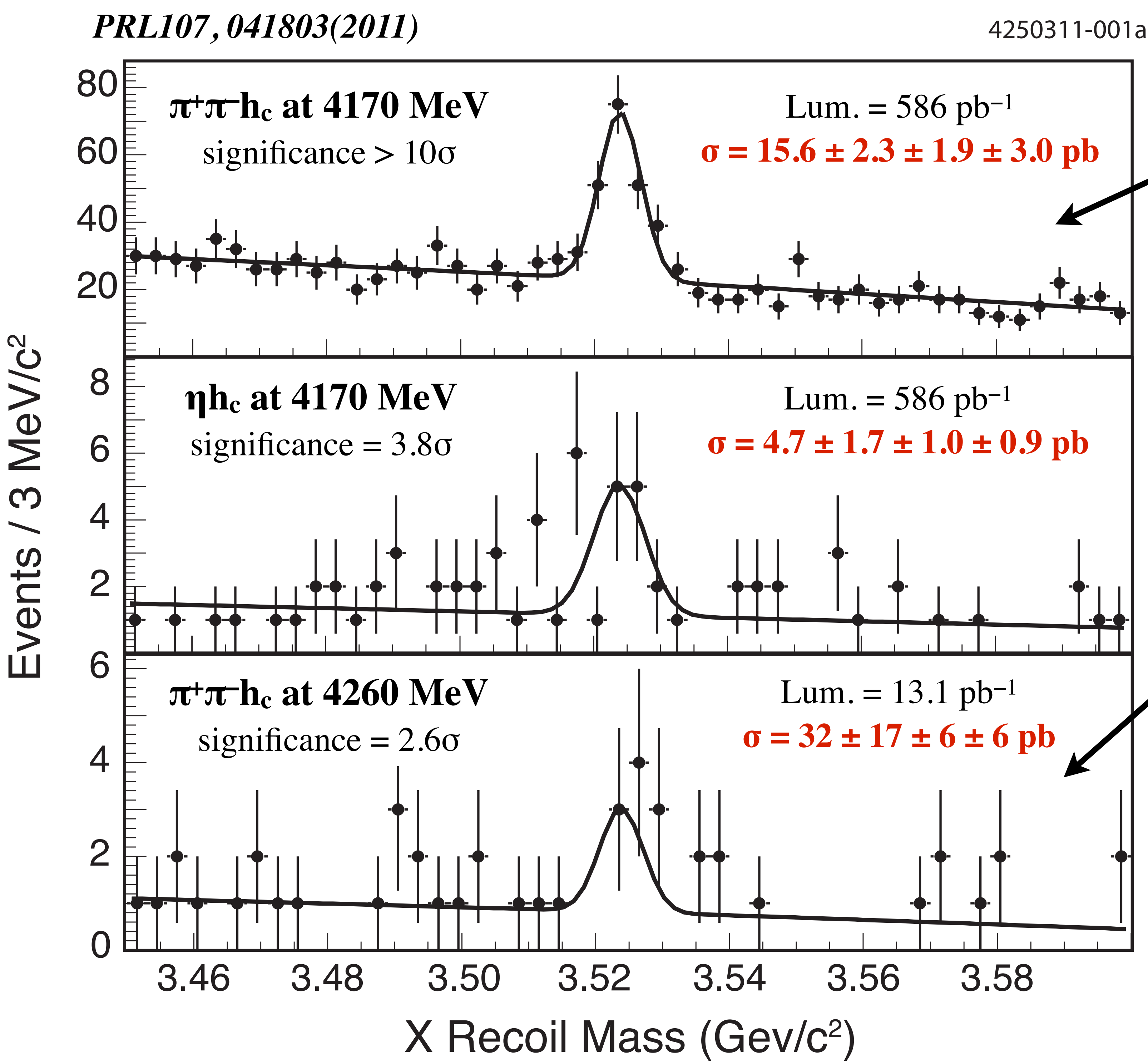
Observation of $e^+e^- \to \pi^+\pi^- h_c(1P)$ at 4170 MeV



Two Points of Interest:

(1) large production rate of the h_c above DD threshold:

* $\sigma_{4170}(\pi^+\pi^- h_c) \sim \sigma_{4170}(\pi^+\pi^- J/\psi)$
* analogous process in bottomonium led to the discovery of $h_b(1P,2P)$

(2) larger production rate of the h_c at 4260 MeV?

* suggestive of the Y(4260)?
* note that we naively expect

$$B(\pi^+\pi^- h_c) \gtrsim B(\pi^+\pi^- J/\psi)$$

if the Y(4260) is a spin-singlet hybrid

Analysis Method

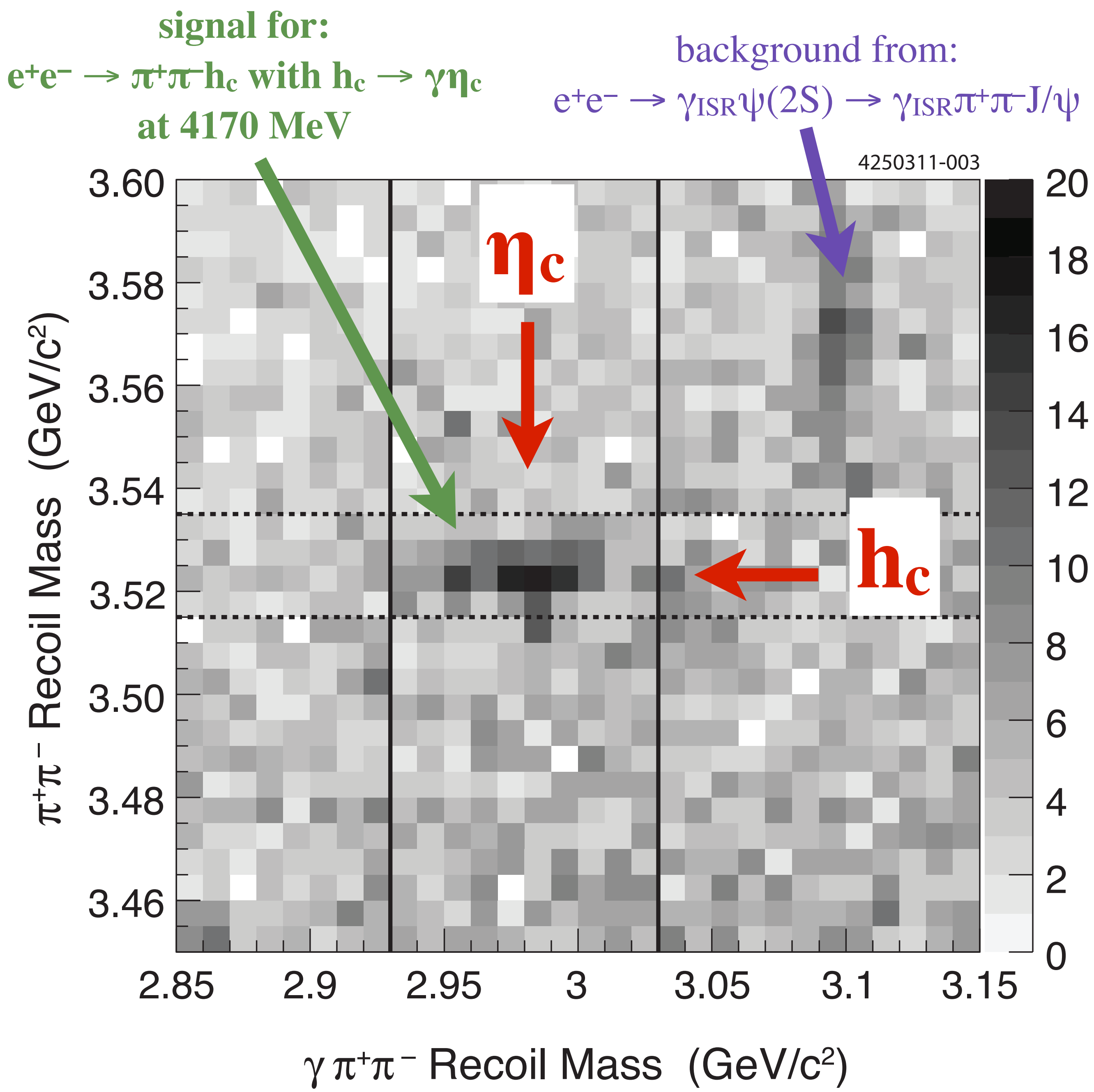
- Reconstruct all events exclusively using

$$e^+e^- \to (\pi^+\pi^-/\pi^0\pi^0/\pi^0/\eta)\ h_c;\ \ h_c \to \gamma\eta_c;\ \ \eta_c \to X_i$$

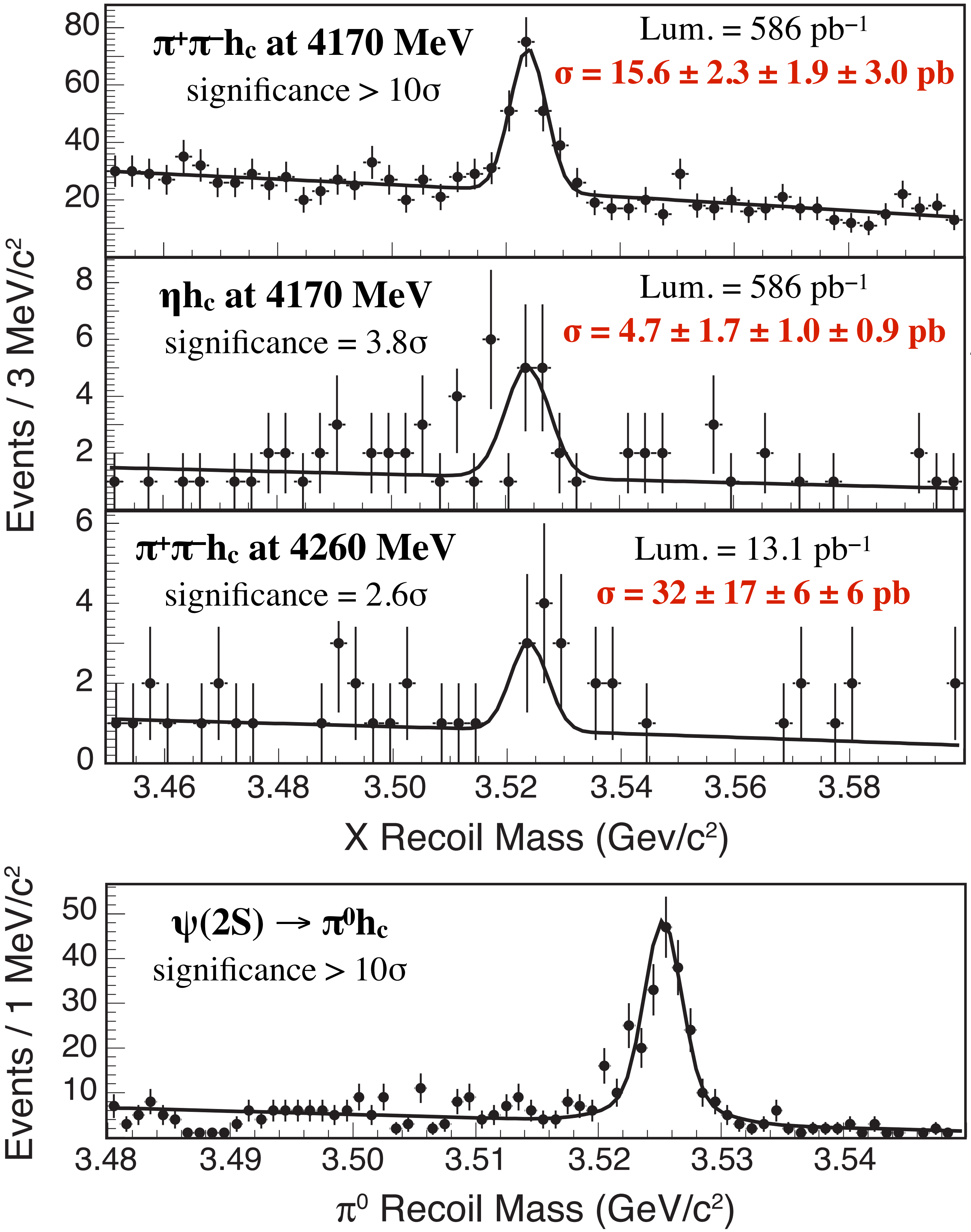
where X_i are the same 12 modes used for the CLEO-c $B(\psi(1S,2S) \to \gamma\eta_c)$ measurements *(PRL 102, 011801 (2009))*:

$\pi^+\pi^+\pi^-\pi^-$	$K^+K^-\pi^+\pi^-$
$\pi^+\pi^+\pi^-\pi^-\pi^0\pi^0$	$K^+K^-\pi^+\pi^-\pi^0$
$\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-$	$K^+K^-\pi^+\pi^+\pi^-\pi^-$
$K^\pm K_S\pi^\mp$	$K^+K^+K^-K^-$
$K^\pm K_S\pi^\mp\pi^+\pi^-$	$\eta\pi^+\pi^-$
$K^+K^-\pi^0$	$\eta\pi^+\pi^+\pi^-\pi^-$

- Constrain the total 4-momentum to the e^+e^- system and use the χ^2 of the fit to filter events.
- Select the η_c using the recoil mass of the $\gamma + (\pi^+\pi^-/\pi^0\pi^0/\pi^0/\eta)$ system.
- Look for the h_c using the recoil mass of the $(\pi^+\pi^-/\pi^0\pi^0/\pi^0/\eta)$ system.



Measuring $\sigma_E(e^+e^- \to (\pi^+\pi^-/\pi^0\pi^0/\pi^0/\eta)h_c)$



- signal sizes are proportional to
  $\sigma_E(e^+e^- \to Xh_c)$
  $\times\, B(h_c \to \gamma\eta_c)$
  $\times\, \sum_i B(\eta_c \to X_i)$
- use
  $\psi(2S) \to \pi^0 h_c$;
  $h_c \to \gamma\eta_c$;
  $\eta_c \to X_i$
  as normalization to find
  $\sigma_E(e^+e^- \to Xh_c)/$
  $B(\psi(2S) \to \pi^0 h_c)$
- multiply by
  $B(\psi(2S) \to \pi^0 h_c)$
  $= (8.4 \pm 1.3 \pm 1.0) \times 10^{-4}$
  (BESIII, PRL 104, 132002 (2010))
  to obtain:
  $\sigma_E(e^+e^- \to Xh_c)$

Results for $\sigma_E(e^+e^- \to (\pi^+\pi^-/\pi^0\pi^0/\pi^0/\eta)h_c)$

	X	$E_{c.m.}$ (MeV)	N_E^X (Events)	Sig. (σ)	$\sigma_E^X/\mathcal{B}_{\psi}^{\pi^0}$ (nb)	σ_E^X (pb)
24.5×10^6 $\psi(2S)$ decays	π^0	3686 [$\psi(2S)$]	202 ± 16	>10	$\cdots$	$\cdots$
$586 pb^{-1}$	$\pi^+\pi^-$	4170	131 ± 15	>10	$18.5 \pm 2.7 \pm 2.2$	$15.6 \pm 2.3 \pm 1.9 \pm 3.0$
$586 pb^{-1}$	$\pi^0\pi^0$	4170	7.4 ± 8.0	1.0	$3.6 \pm 3.9 \pm 1.4$	$3.0 \pm 3.3 \pm 1.1 \pm 0.6$
$586 pb^{-1}$	π^0	4170	-5 ± 11	$\cdots$	$-0.9 \pm 2.1 \pm 0.8$	$-0.7 \pm 1.8 \pm 0.7 \pm 0.1$
$586 pb^{-1}$	η	4170	12.6 ± 4.5	3.8	$5.6 \pm 2.1 \pm 1.1$	$4.7 \pm 1.7 \pm 1.0 \pm 0.9$
$20.6 pb^{-1}$	$\pi^+\pi^-$	3970–4060	0.3 ± 2.1	0.1	$1.2 \pm 9.5 \pm 6.4$	$1.0 \pm 8.0 \pm 5.4 \pm 0.2$
$26.3 pb^{-1}$	$\pi^+\pi^-$	4120–4200	4.4 ± 3.1	1.7	$13.9 \pm 9.9 \pm 8.2$	$11.7 \pm 8.3 \pm 6.9 \pm 2.3$
$13.1 pb^{-1}$	$\pi^+\pi^-$	4260	6.0 ± 3.1	2.6	$38 \pm 20 \pm 8$	$32 \pm 17 \pm 6 \pm 6$

Notes:

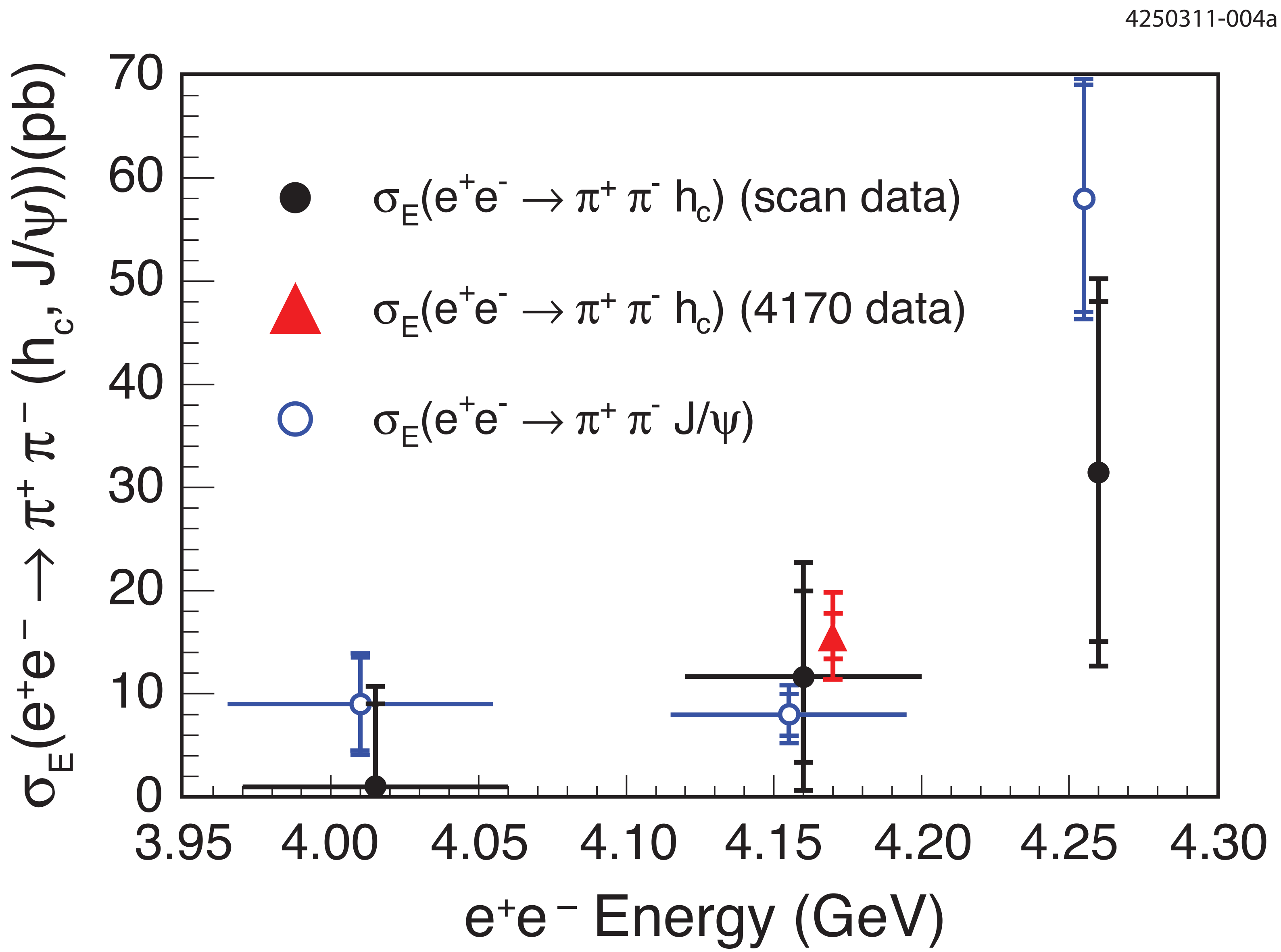
1. First errors are statistical, second systematic, and third due to $B(\psi(2S) \to \pi^0 hc)$.

2. Systematic errors cover the fitting method, the signal shape, the efficiency ratios ($e^+e^- \to Xh_c$ / $\psi(2S) \to \pi^0 h_c$), tracking efficiency, photon efficiency, number of $\psi(2S)$, and luminosities.

Important Points:

1. The cross section **$\sigma_{4170}(e^+e^- \to \pi^+\pi^- h_c) = 15.6 \pm 2.3 \pm 1.9 \pm 3.0$ pb** is comparable to **$\sigma_{4170}(e^+e^- \to \pi^+\pi^- J/\psi) = 8 \pm 2 \pm 2$ pb**.
2. There is some indication that **$\sigma_{4260}(e^+e^- \to \pi^+\pi^- h_c) = 32 \pm 17 \pm 6 \pm 6$ pb** may be even larger? *(But statistics are low.)*

$\sigma(e^+e^- \to \pi^+\pi^- h_c)$ as a Function of e^+e^- Energy



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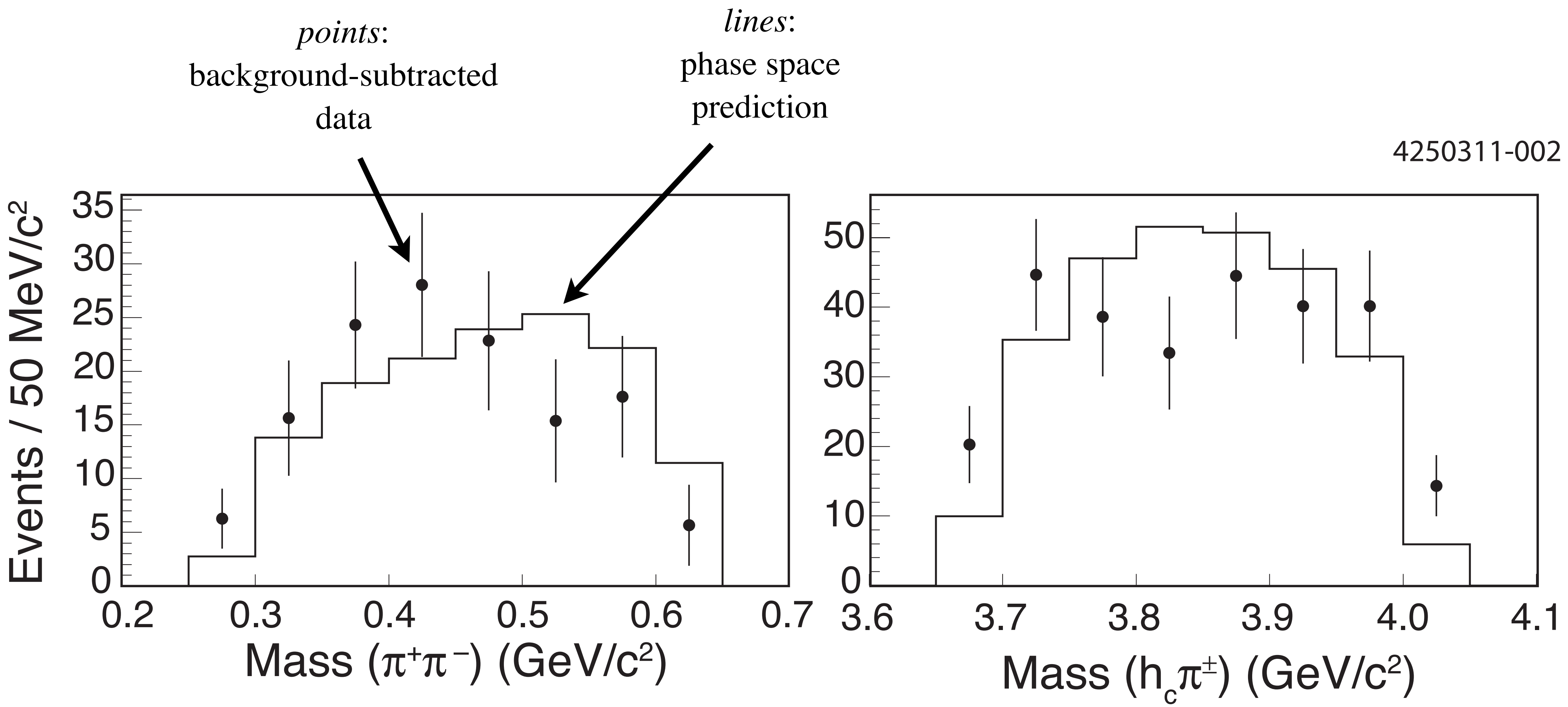
Substructure in $\pi^+\pi^-h_c$?

Look at $M(\pi^+\pi^-)$ and $M(h_c\pi^\pm)$ from $e^+e^- \rightarrow \pi^+\pi^-h_c$ at 4170 MeV:



⇒ ***The agreement between phase space and data is not great.***

⇒ ***But there is no clear evidence for anything exotic, like a Z_c.***

Summary and Prospects for $e^+e^- \to \pi^+\pi^- h_c(1P)$

Summary from CLEO:

- clear observation of $e^+e^- \to \pi^+\pi^- h_c$ at 4170 MeV

(the analogous process in bottomonium led to the discovery of the h_b(1P,2P))

- no obvious analogue of the Z_b in charmonium

- signs of the Y(4260)?

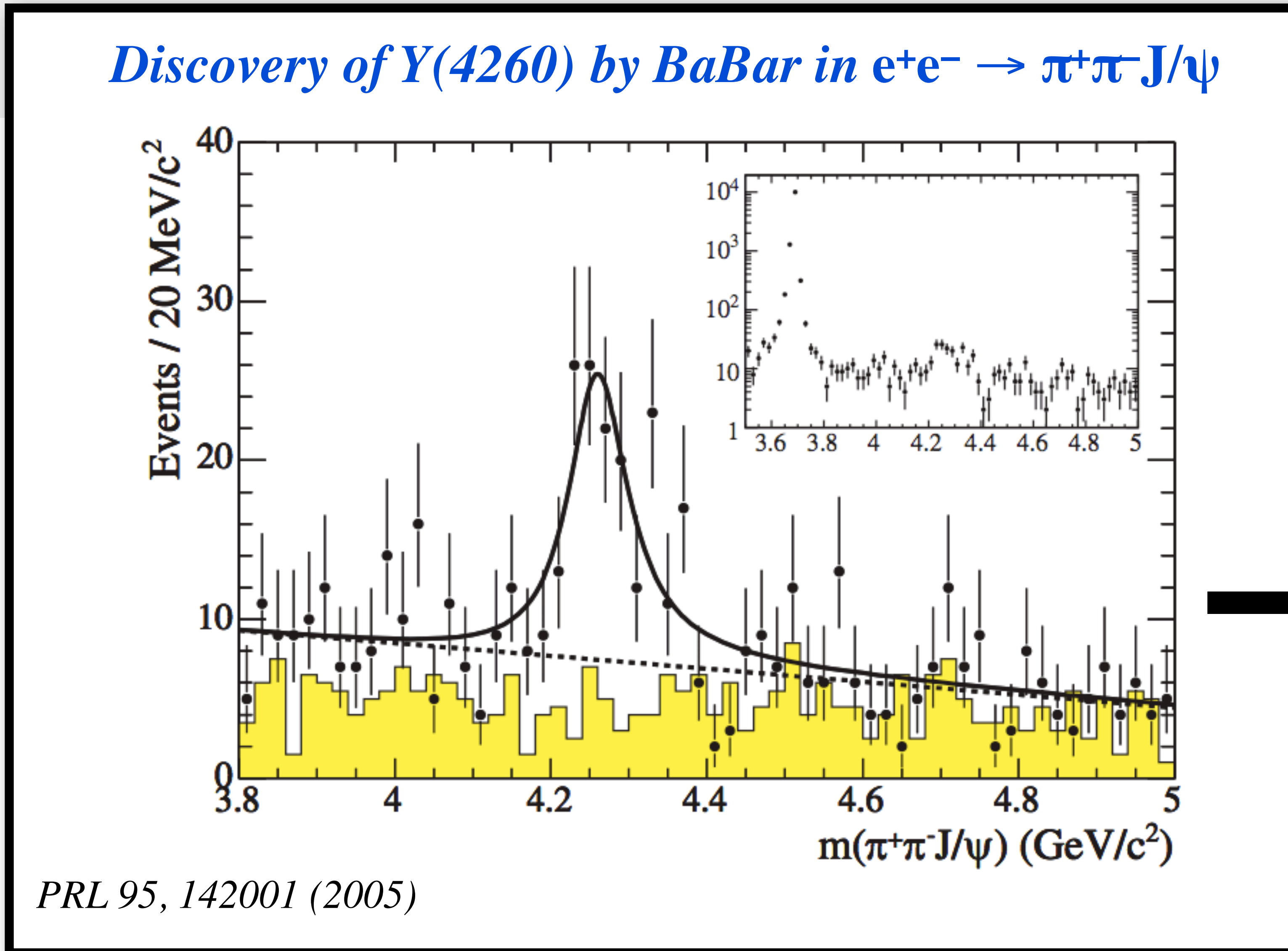
Exciting Prospects for BES??

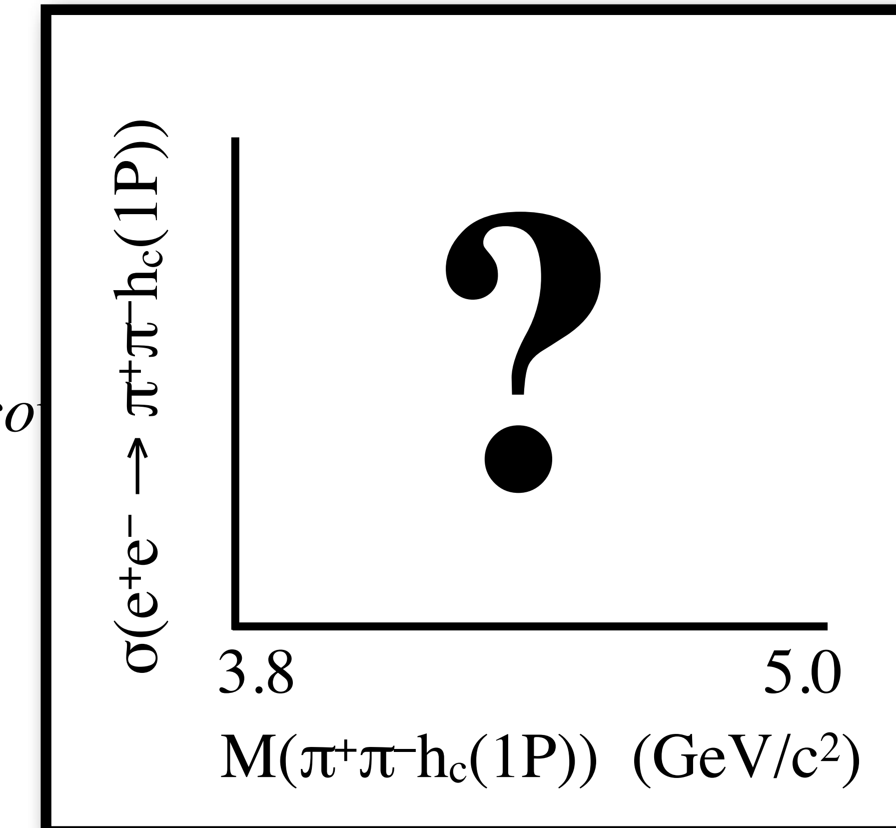
- if you scan $\pi^+\pi^- h_c(1P)$, would you map out the Y(4260)??

- at higher energies, would you find the $h_c(2P)$??

- if you scanned $\pi^+\pi^- h_c(2P)$ would you map out the Y(4360)??

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





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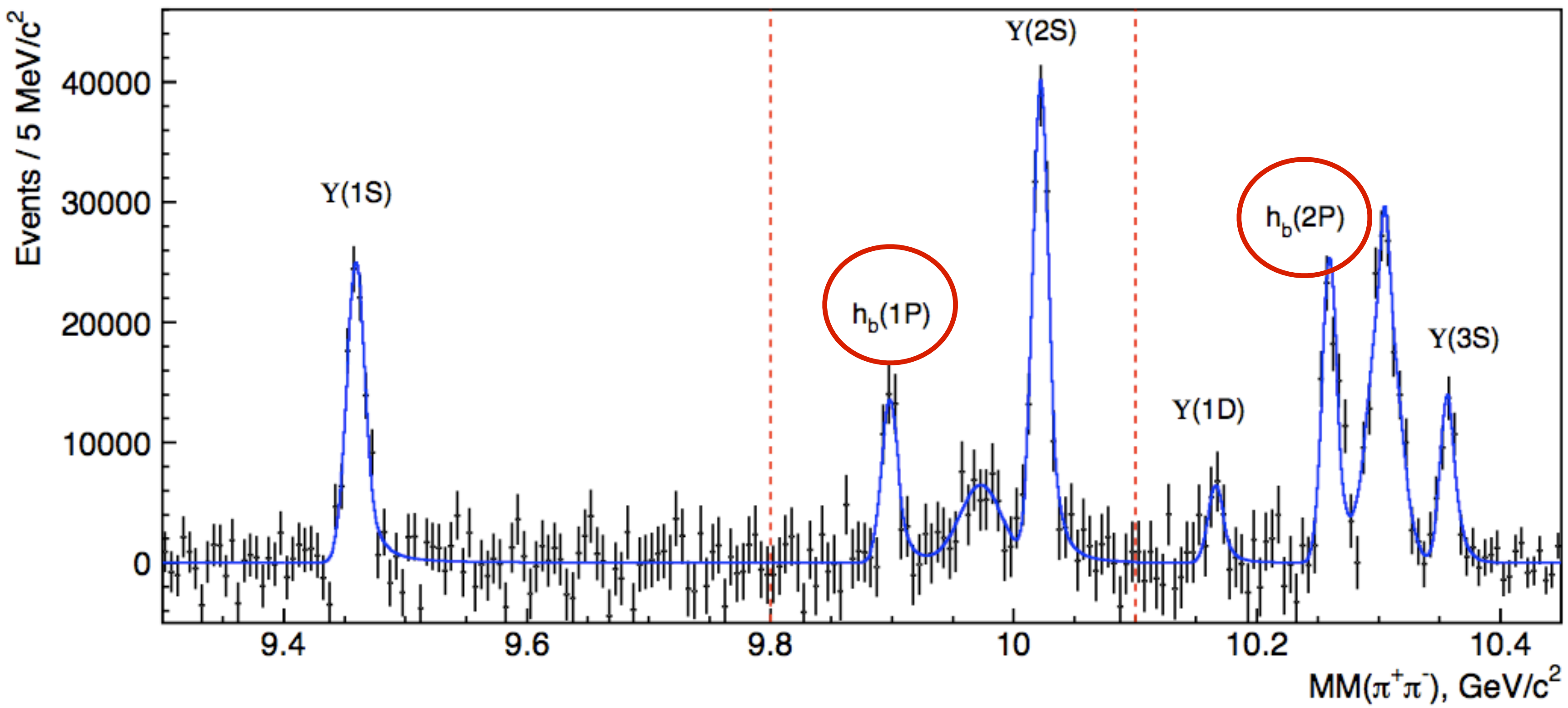
Summary and Prospects for $e^+e^- \to \pi^+\pi^- h_c(1P)$

Discovery of the $h_b(1P)$ and $h_b(2P)$ by Belle using "$\Upsilon(5S)$" Decays

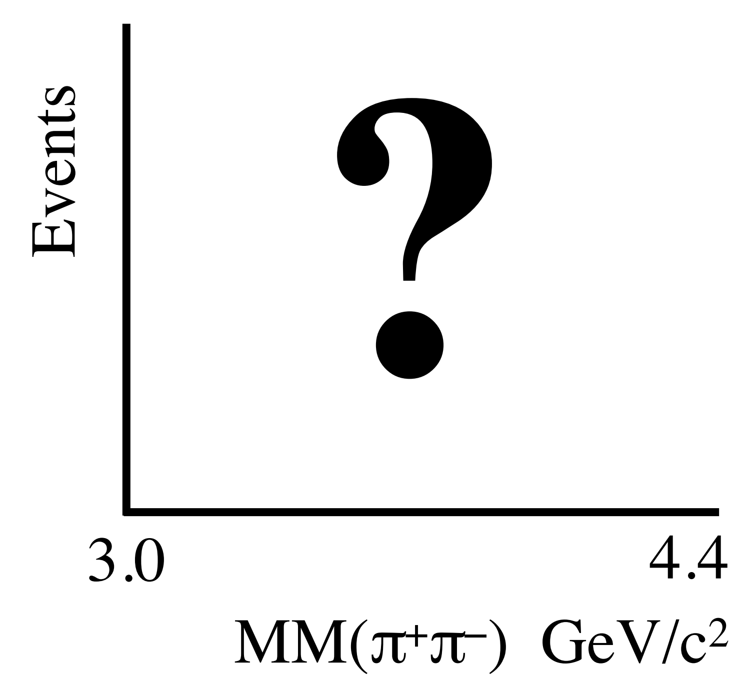


arXiv:1103.3419 [hep-ex]

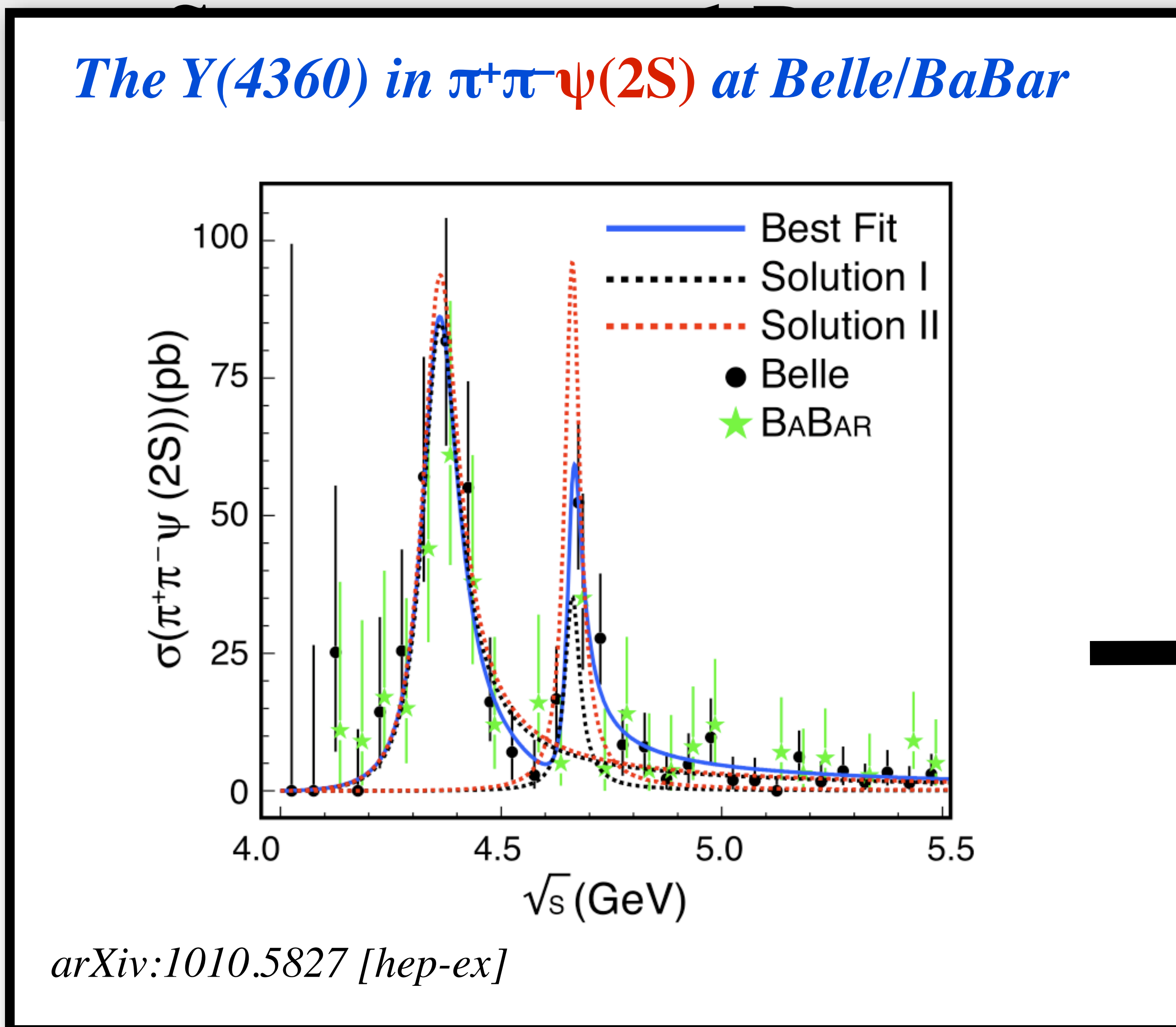
the $h_b(1P,2P)$)

Exciting Prospects for BES??

- if you scan $\pi^+\pi^- h_c(1P)$, would you map out the Y(426
- **at higher energies, would you find the $h_c(2P)$??**
- if you scanned $\pi^+\pi^- h_c(2P)$ would you map out the Y(4



for $e^+e^- \to \pi^+\pi^- h_c(1P)$



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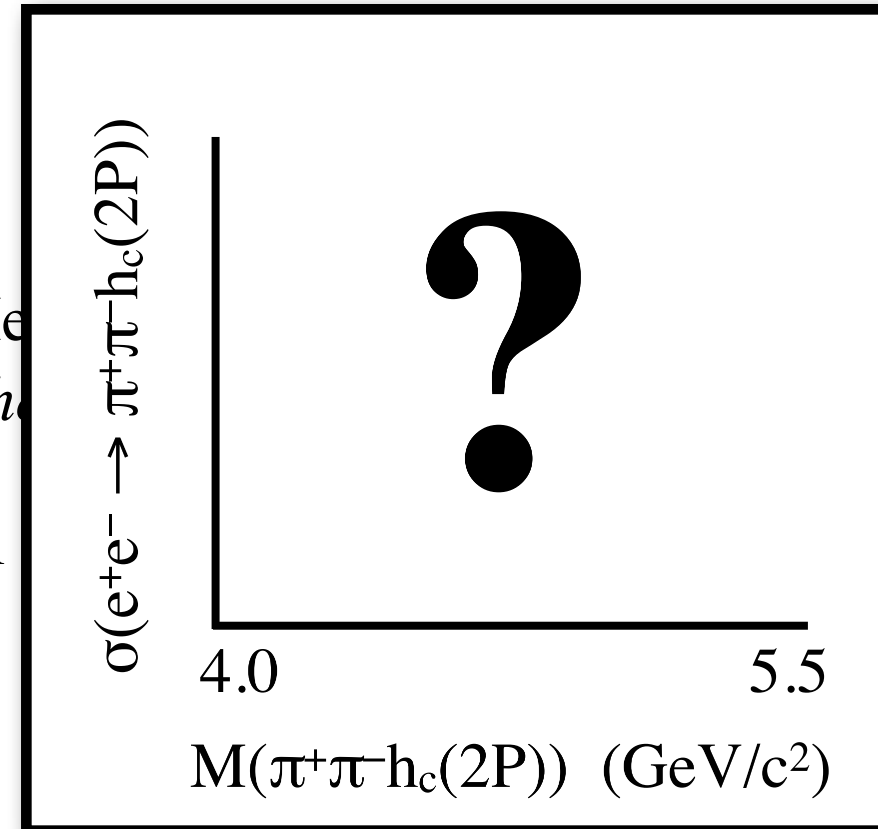
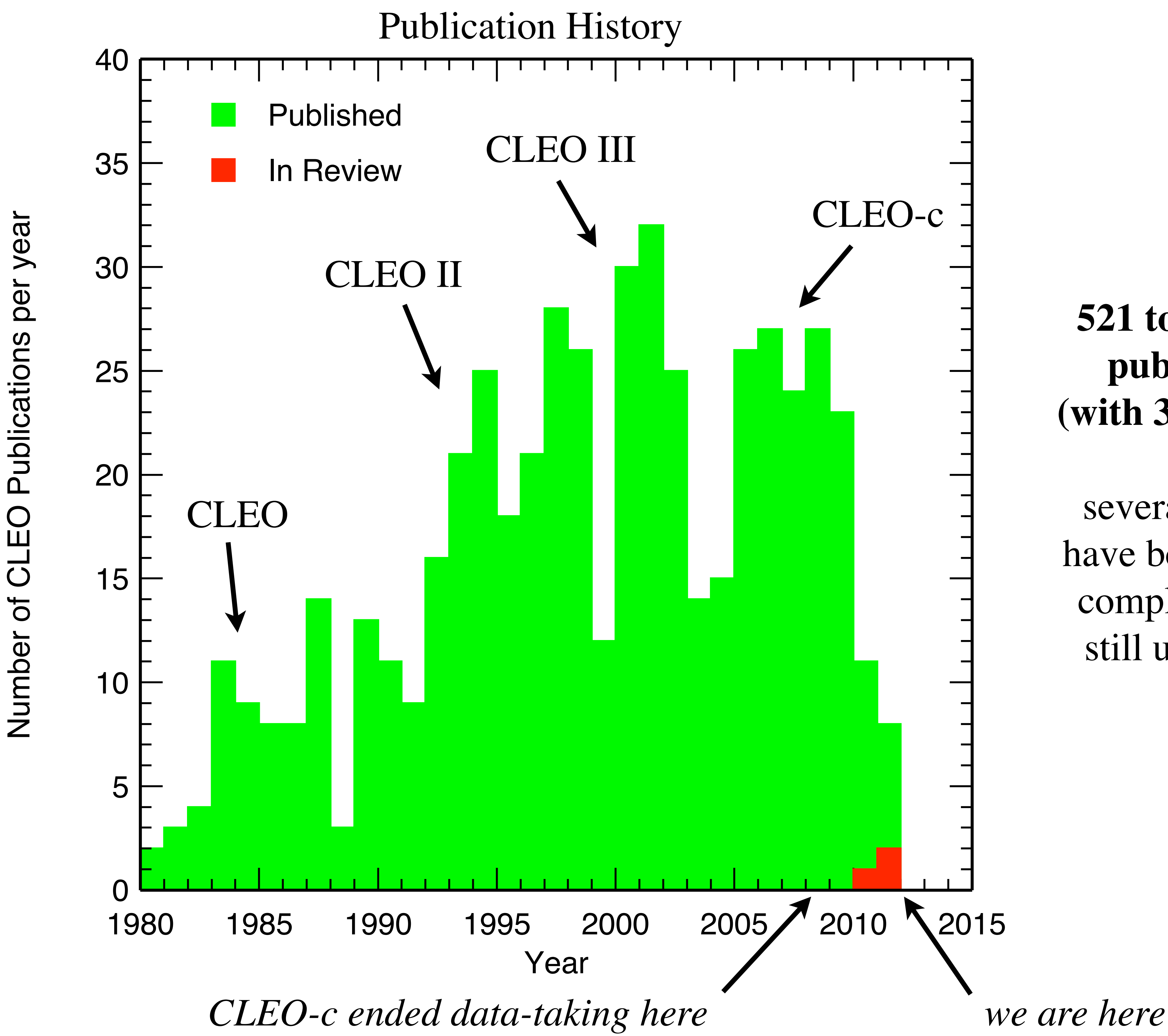


Exciting Prospects for BES??

- if you scan $\pi^+\pi^- h_c(1P)$, would you map out the Y(4260)??
- at higher energies, would you find the $h_c(2P)$??
- **if you scanned $\pi^+\pi^- h_c(2P)$ would you map out the Y(4360)??**

Part II: Other Highlights from CLEO



521 total CLEO publications (with 3 in review)!

several analyses have been recently completed or are still underway...

Other Highlights from CLEO

(1) Branching fractions for $\Upsilon(3S) \to \pi^0 h_b$ and $\psi(2S) \to \pi^0 h_c$

(PRD 84, 032008 (2011))

(2) Measurements of branching fractions for electromagnetic transitions involving the $\chi_{bJ}(1P)$ states

(PRD 83, 054003 (2011))

(3) Amplitude analyses of the decays $\chi_{c1} \to \eta\pi^+\pi^-$ and $\chi_{c1} \to \eta'\pi^+\pi^-$

(arXiv:1109.5834 [hep-ex])

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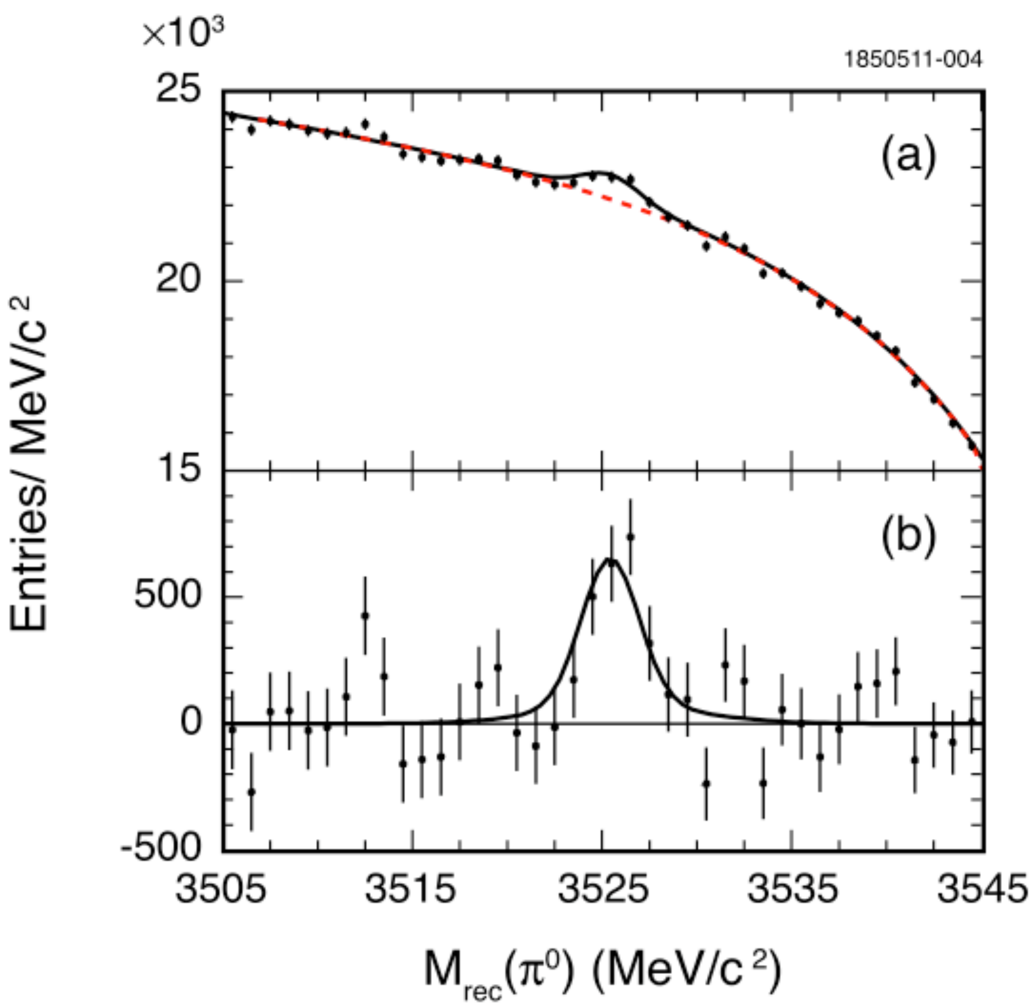

- **study of $\psi(2S) \to \pi^0 h_c$**
- 25.9×10^6 $\psi(2S)$ decays
- inclusive π^0's
- suppress $\psi(2S) \to \gamma\chi_{cJ}$
- **$B(\psi(2S) \to \pi^0 h_c) = (9.0 \pm 1.5 \pm 1.3) \times 10^{-4}$**

(consistent with BESIII)

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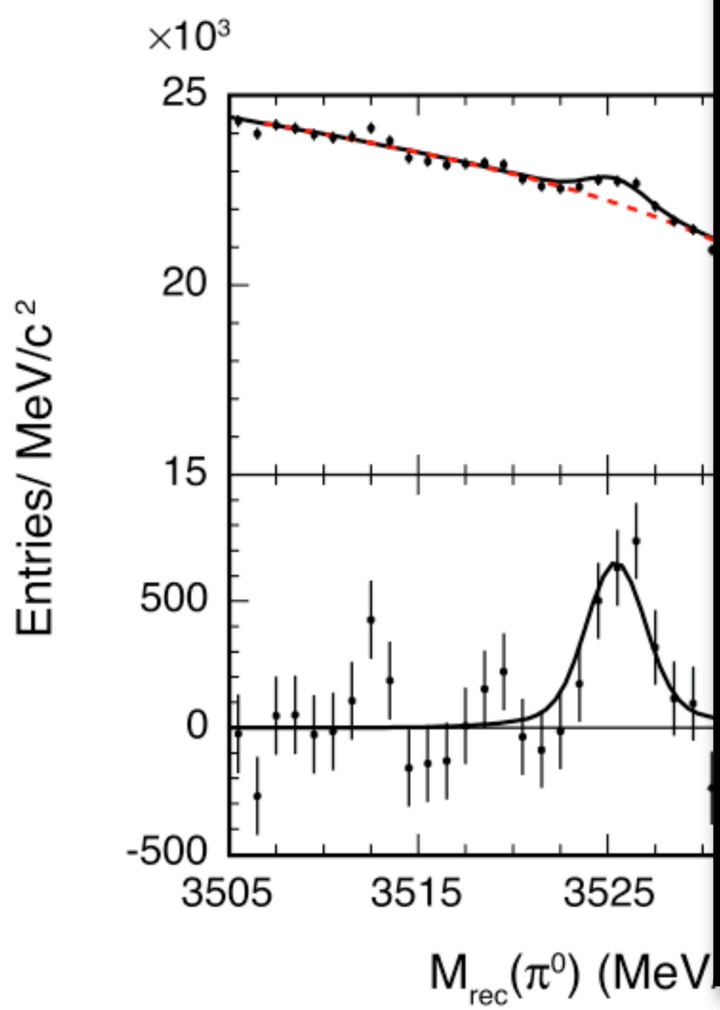

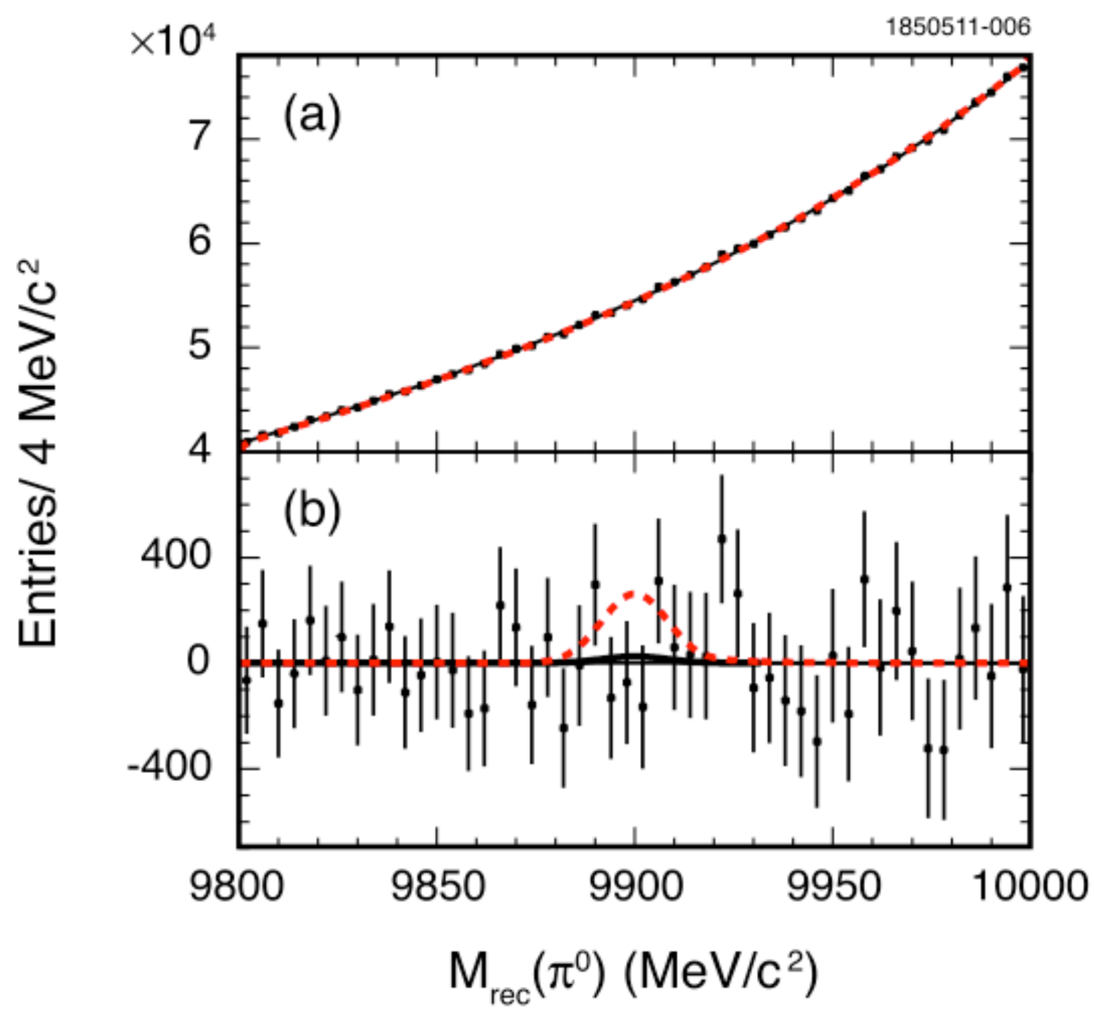

- **study of $\Upsilon(3S) \rightarrow \pi^0 h_b$**
- 5.88×10^6 $\Upsilon(3S)$ decays
- inclusive π^0's
- suppress $\Upsilon(3S) \rightarrow \gamma\chi_{bJ}$
- **$B(\Upsilon(3S) \rightarrow \pi^0 h_b) <$ 1.2×10^{-3} at 90% C.L.**

(consistent with BaBar)

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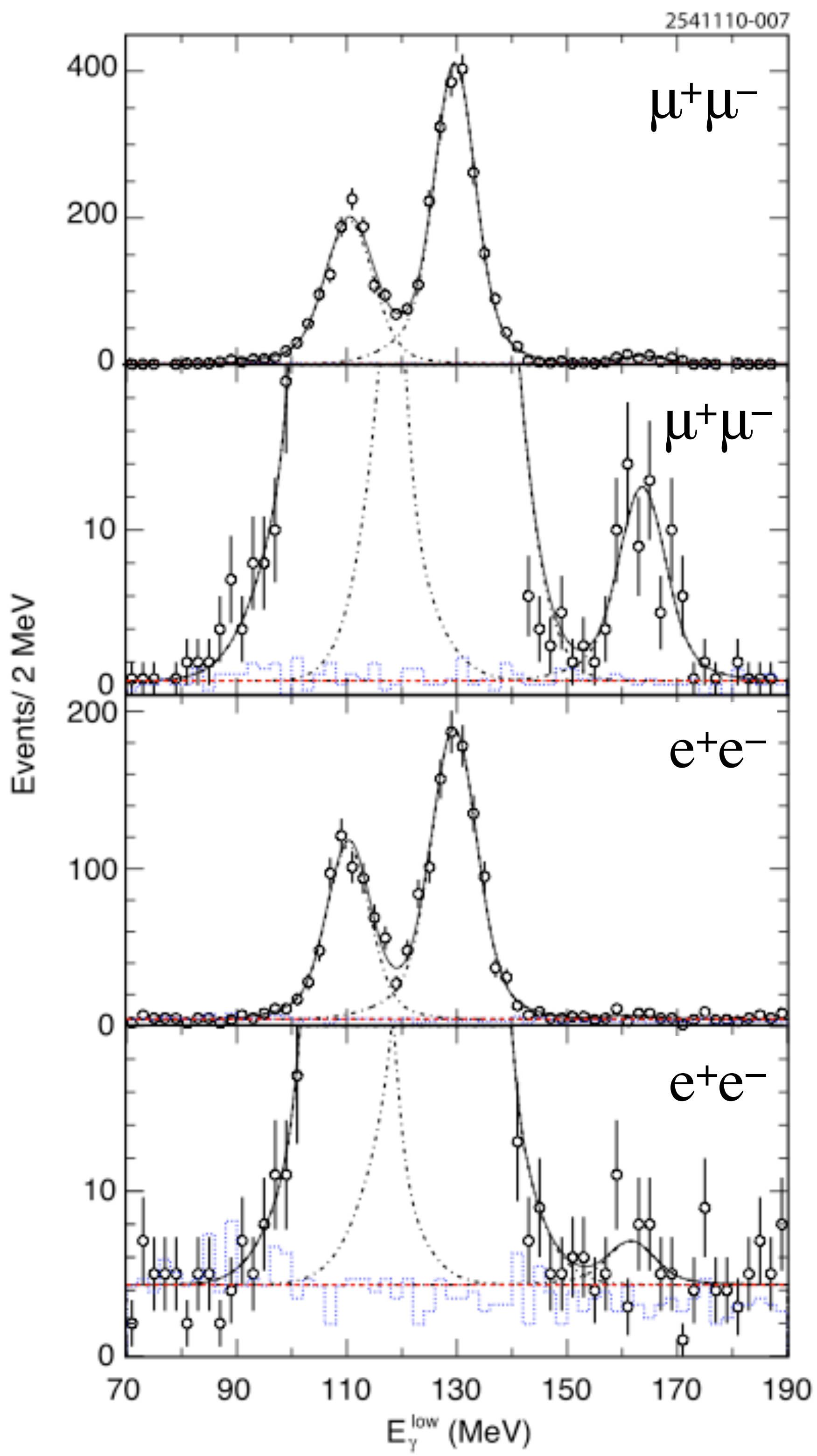

- **study of $\Upsilon(2S) \to \gamma\chi_{bJ}(1P)$;**
  $\chi_{bJ}(1P) \to \gamma\Upsilon(1S)$;
  $\Upsilon(1S) \to l^+l^-$
- 9.32×10^6 $\Upsilon(2S)$ decays
- using known
  $B(\Upsilon(1S) \to l^+l^-)$,
  obtain measurements of
  $B(\Upsilon(2S) \to \gamma\chi_{bJ}(1P)) \times$
  $B(\chi_{bJ}(1P) \to \gamma\Upsilon(1S))$
  for all J
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$\psi(2S) \to \pi^0 h_c$

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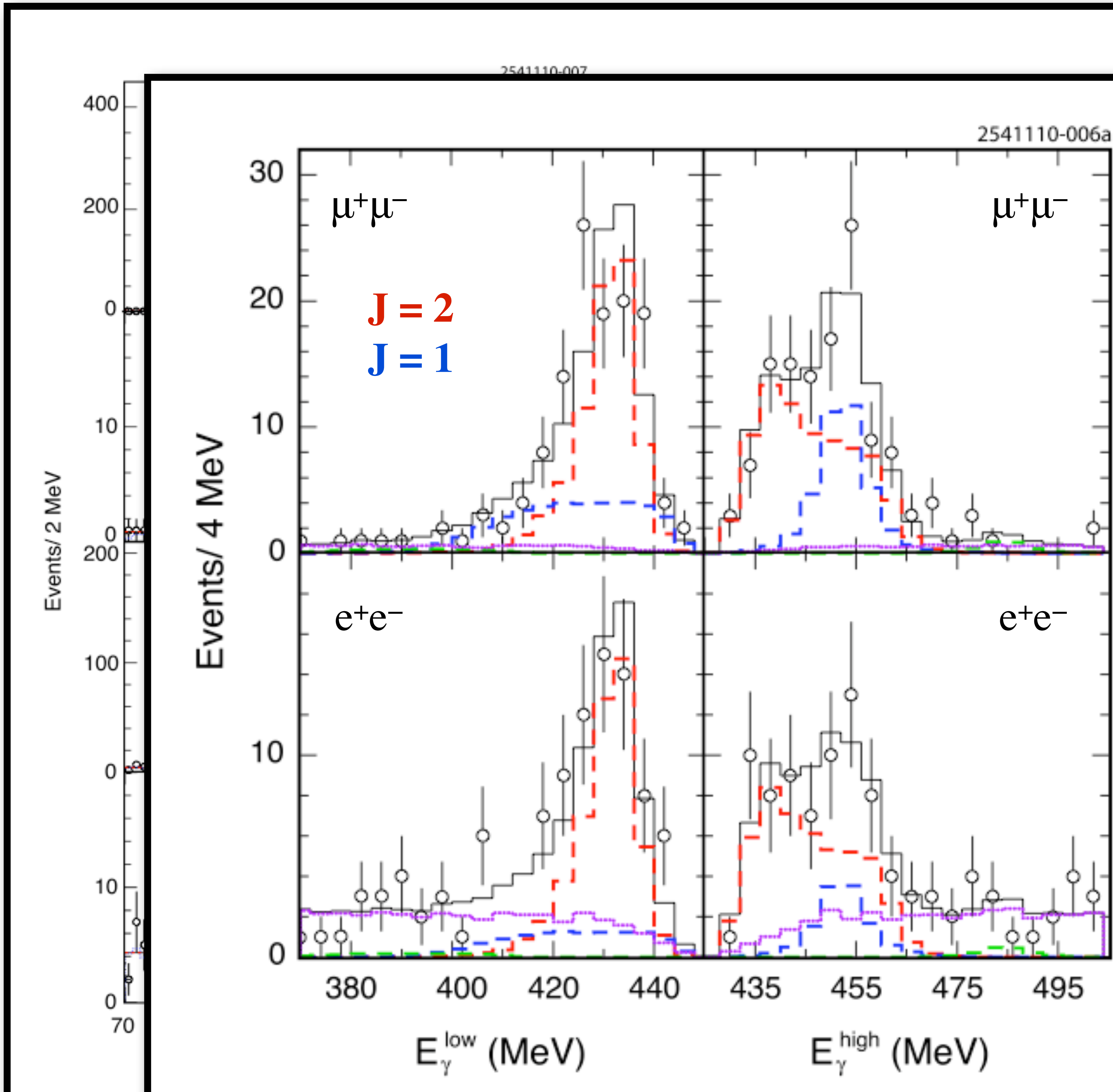
and $\chi_{c1} \to \eta'\pi^+\pi^-$

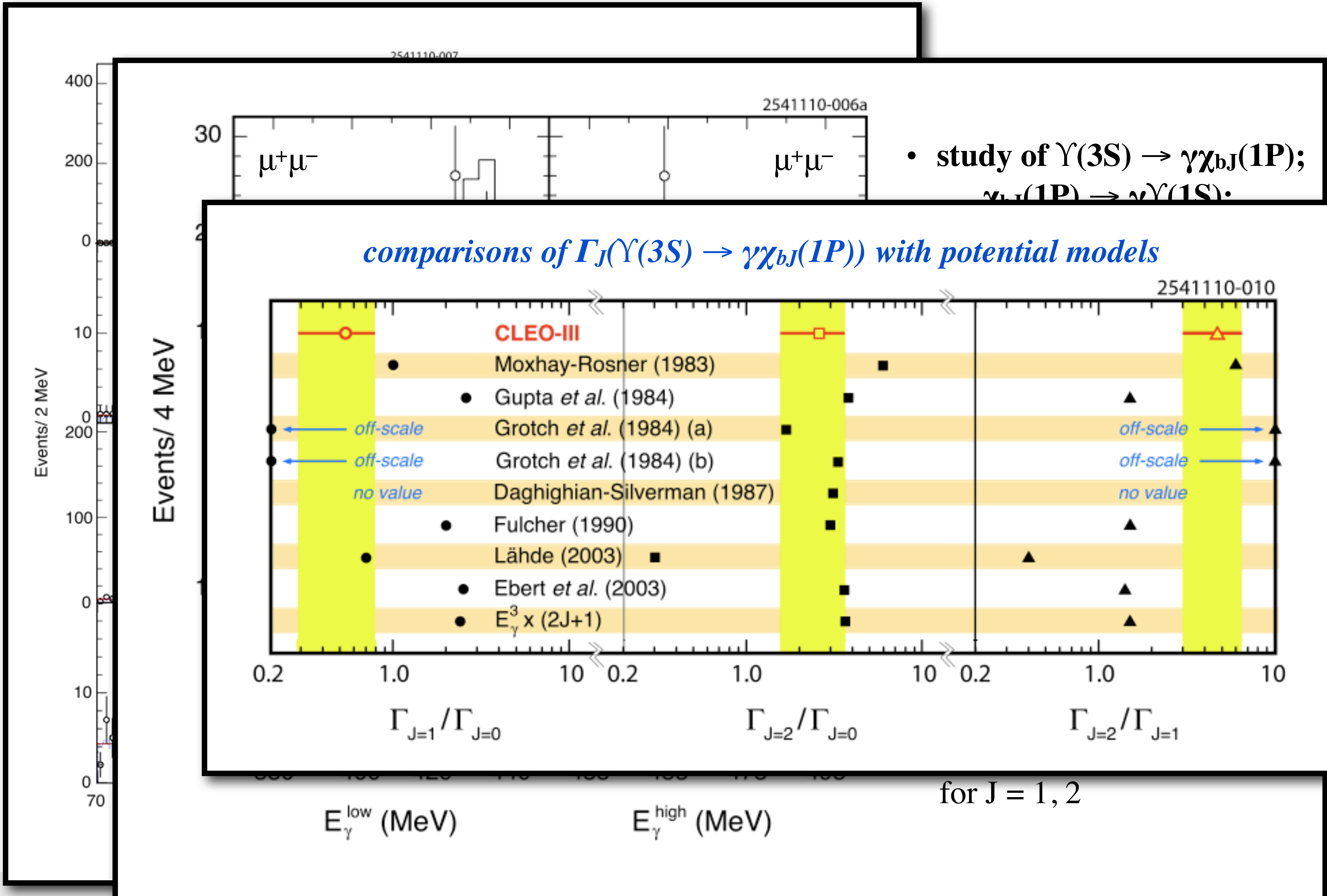
Other Highlights from CLEO



(2d fit in backup slides)

- **study of $\Upsilon(3S) \to \gamma\chi_{bJ}(1P)$; $\chi_{bJ}(1P) \to \gamma\Upsilon(1S)$;** $\Upsilon(1S) \to l^+l^-$
- 5.88×10^6 $\Upsilon(3S)$ decays
- using known $B(\Upsilon(1S) \to l^+l^-)$, obtain measurements of **$B(\Upsilon(3S) \to \gamma\chi_{bJ}(1P)) \times B(\chi_{bJ}(1P) \to \gamma\Upsilon(1S))$** for J = 1, 2
- using previous $B(\chi_{bJ}(1P) \to \gamma\Upsilon(1S))$ obtain measurements of **$B(\Upsilon(3S) \to \gamma\chi_{bJ}(1P))$** for J = 1, 2

Other Highlights from CLEO



- study of $\Upsilon(3S) \to \gamma\chi_{bJ}(1P)$; $\chi_{bJ}(1P) \to \gamma\Upsilon(1S)$;

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Other Highlights from CLEO

(1) Branching fractions for $\Upsilon(3S) \to \pi^0 h_b$ and $\psi(2S) \to \pi^0 h_c$

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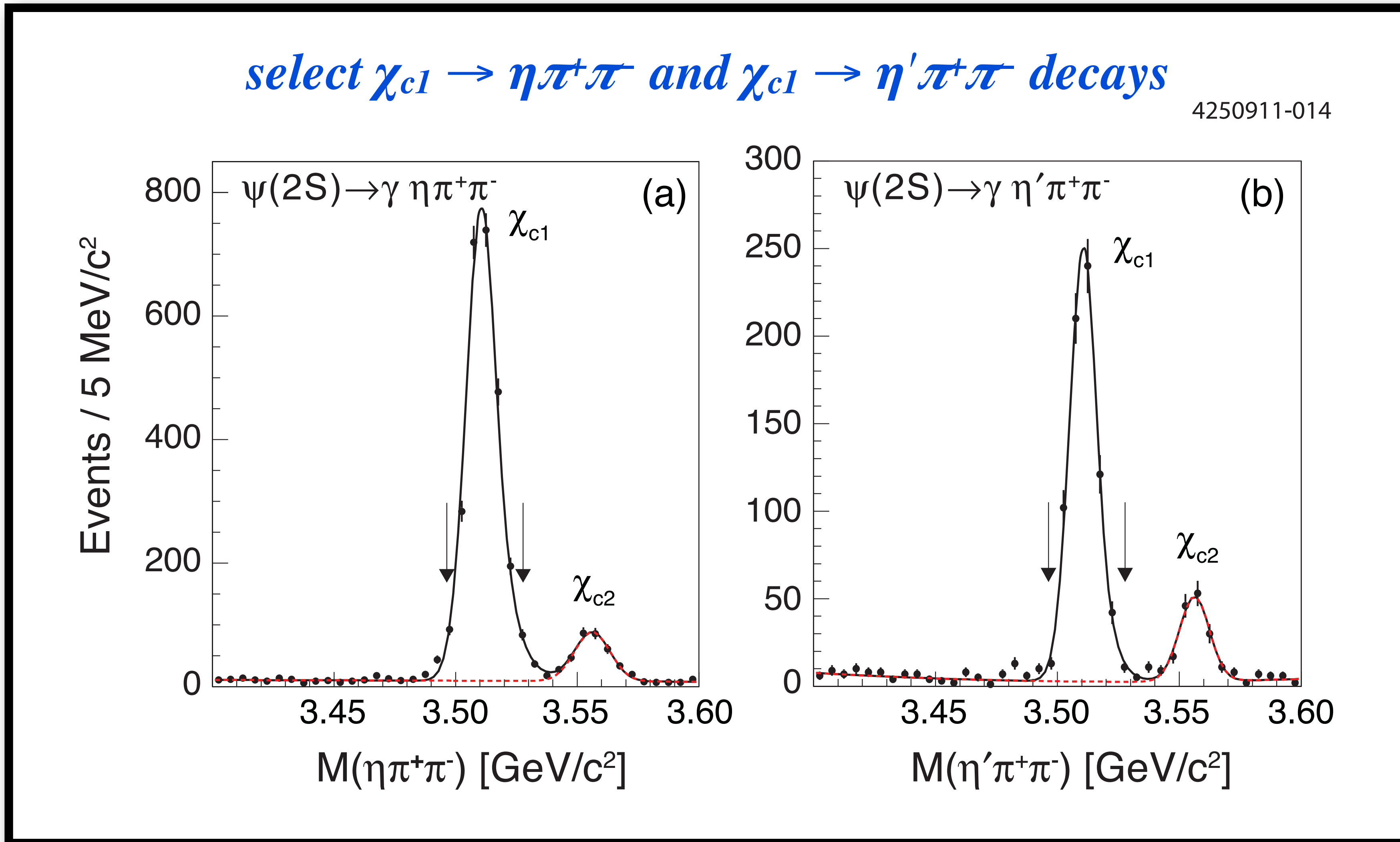

...d $\psi(2S) \to \pi^0 h_c$

... electromagnetic
...tates

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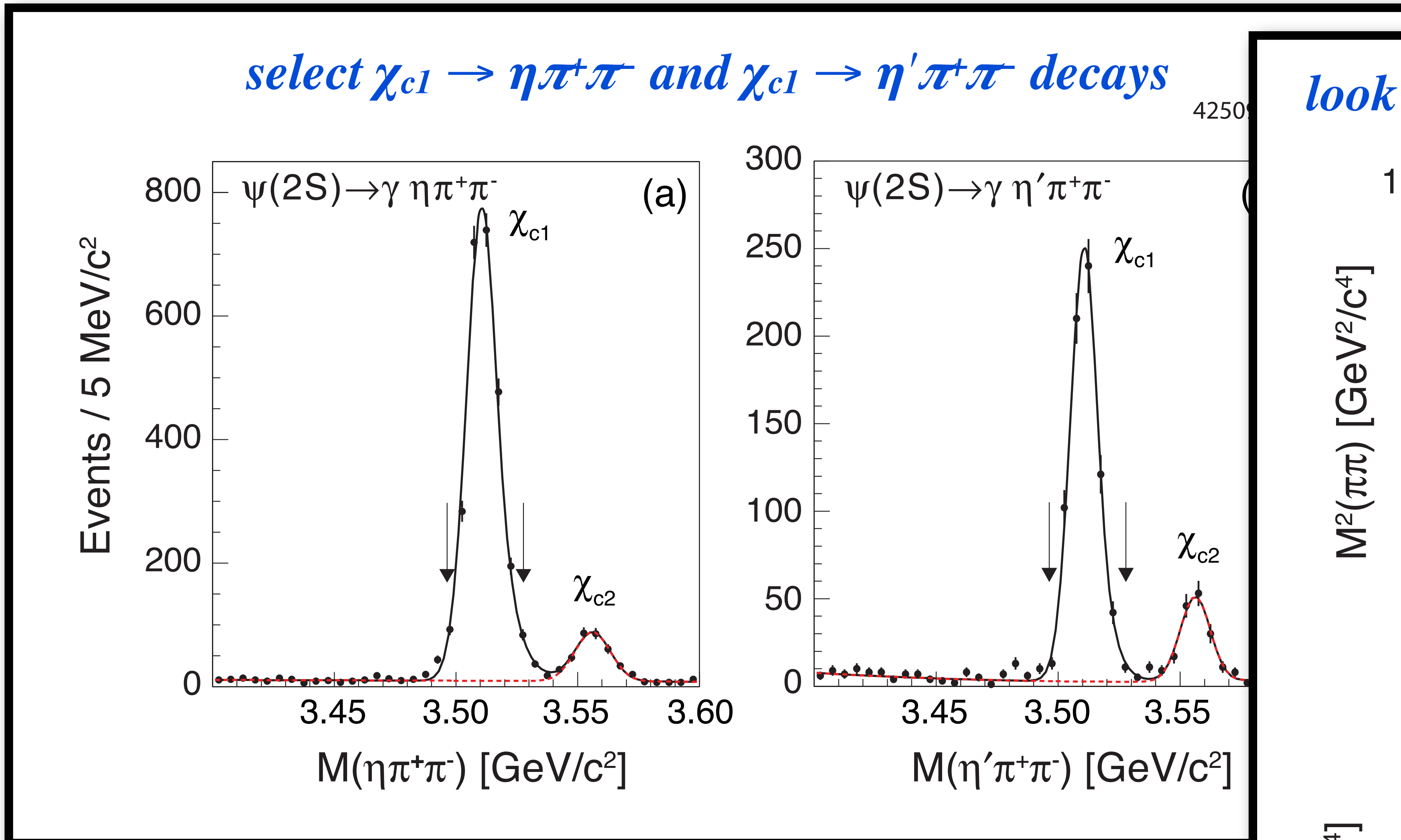
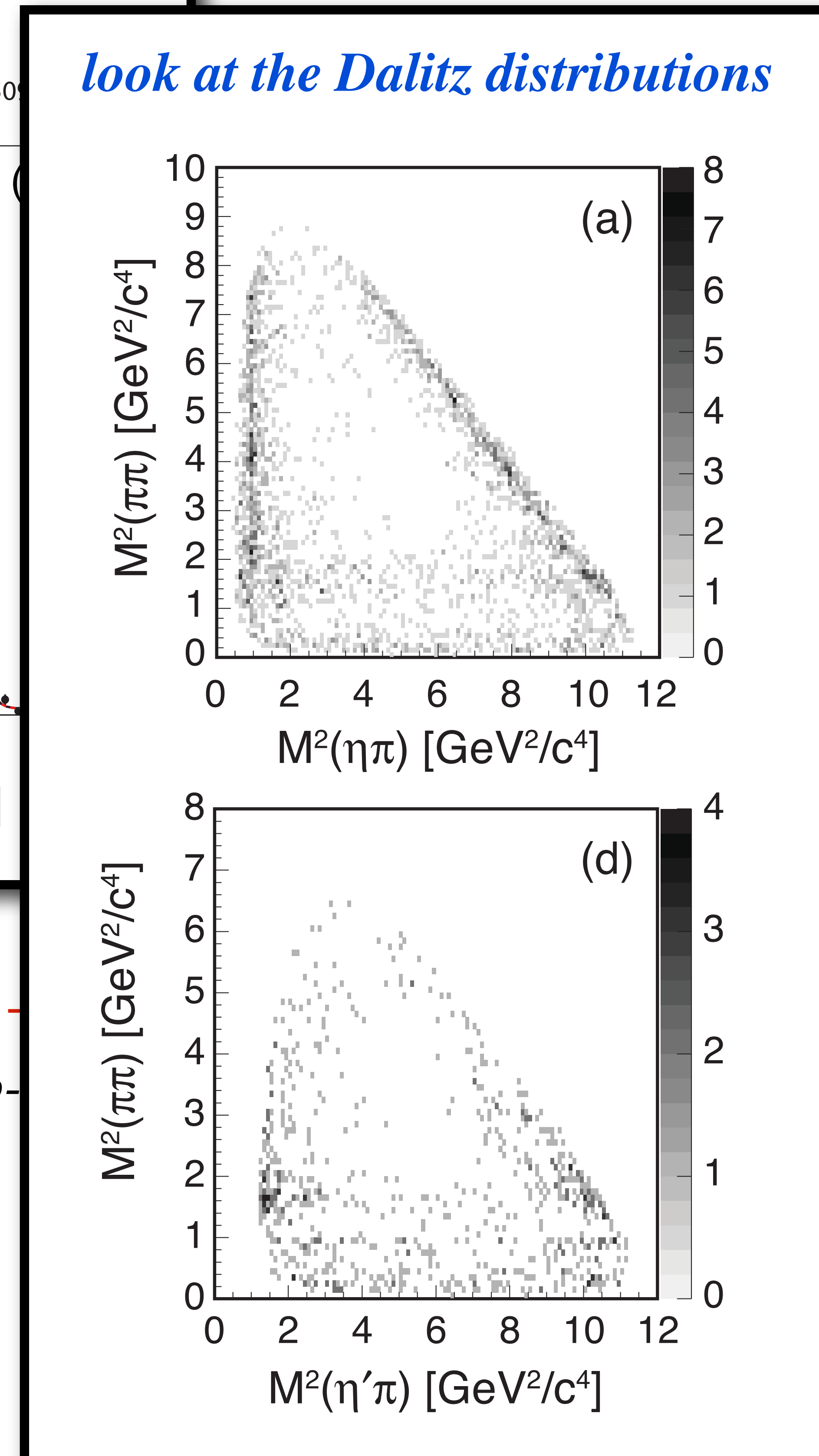




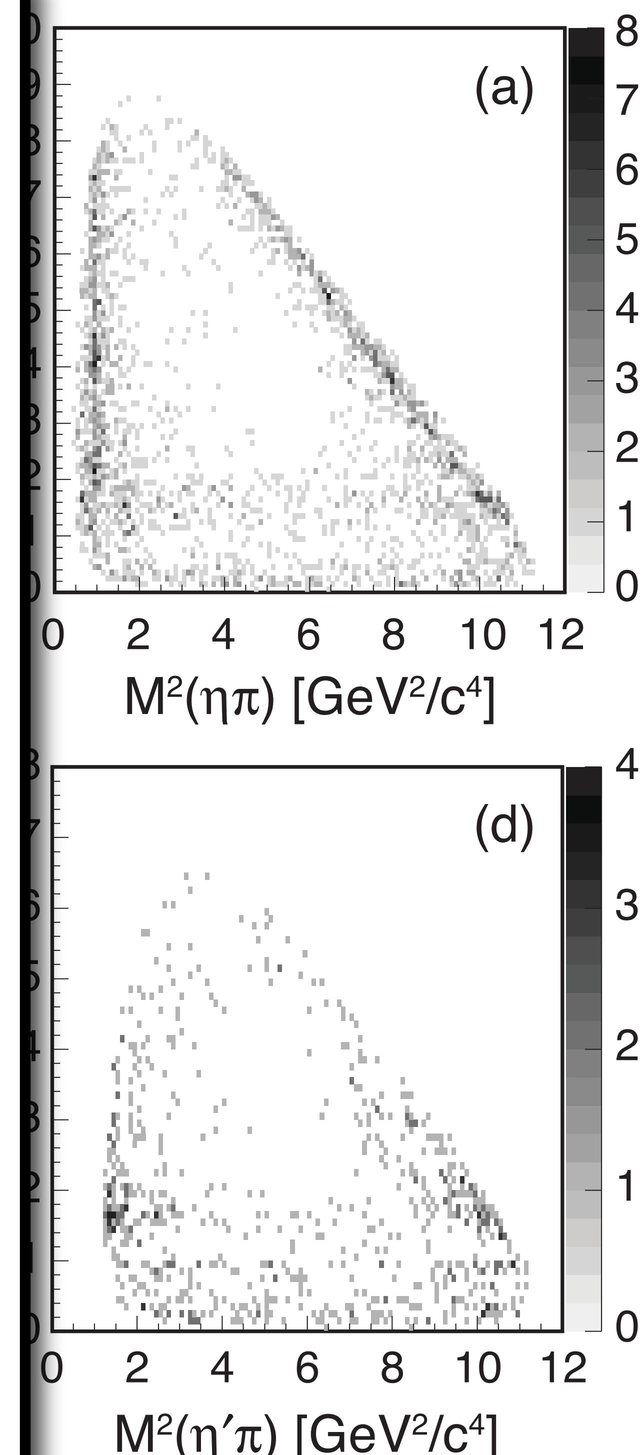
(3) Amplitude analyses of the decays χ_{c1} →

(arXiv:1109.5834 [hep-

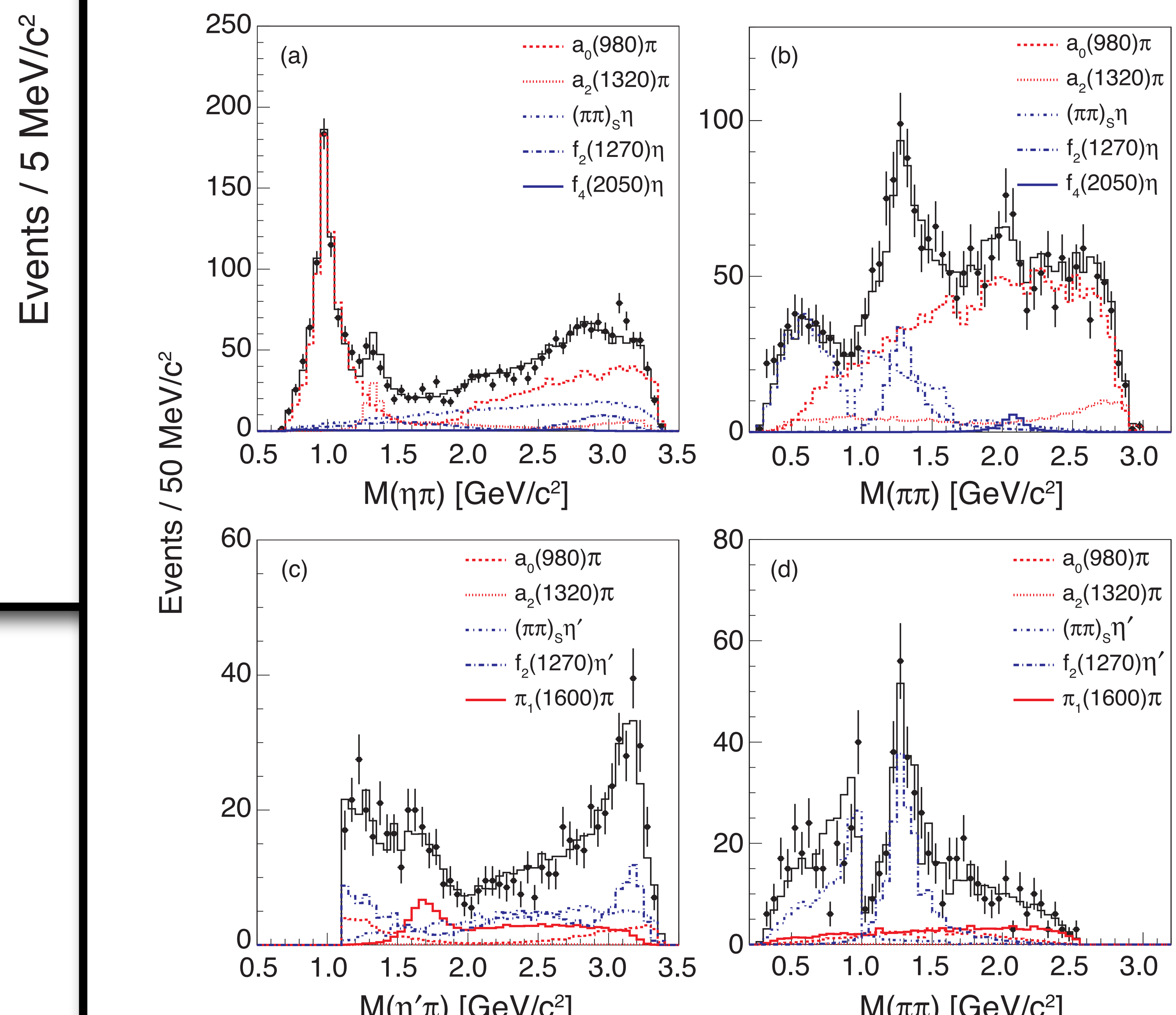
Other Highlights from CLEO

select $\chi_{c1} \to \eta\pi^+\pi^-$ and $\chi_{c1} \to \eta'\pi^+\pi^-$ decays

look at the Dalitz distributions



perform an amplitude analysis of the substructure



⇒ evidence for an exotic $\eta'\pi$ P-wave consistent with the $\pi_1(1600)$

Summary and Conclusions

⇒ **the observation of $e^+e^- \to \pi^+\pi^- h_c(1P)$ at CLEO-c raises a number of natural questions:**

- could the decay $Y(4260) \to \pi^+\pi^- h_c(1P)$ be measured?
- could $e^+e^- \to \pi^+\pi^- h_c(2P)$ be found?
- what would a scan of $\pi^+\pi^- h_c(2P)$ look like?

Could these be addressed by BESIII?

⇒ **CLEO-c data-taking ended in March 2008 and publications per year are decreasing.**

⇒ **A few recently completed analyses include:**

- π^0 transitions to the h_c and h_b
- bottomonium radiative transitions
- amplitude analyses of χ_{c1} decays

2d Fit for $B(\Upsilon(3S) \to \gamma\chi_{bJ}(1P)) \times B(\chi_{bJ}(1P) \to \gamma\Upsilon(1S))$