Recent Results on Charmonium Decays at CLEO-c

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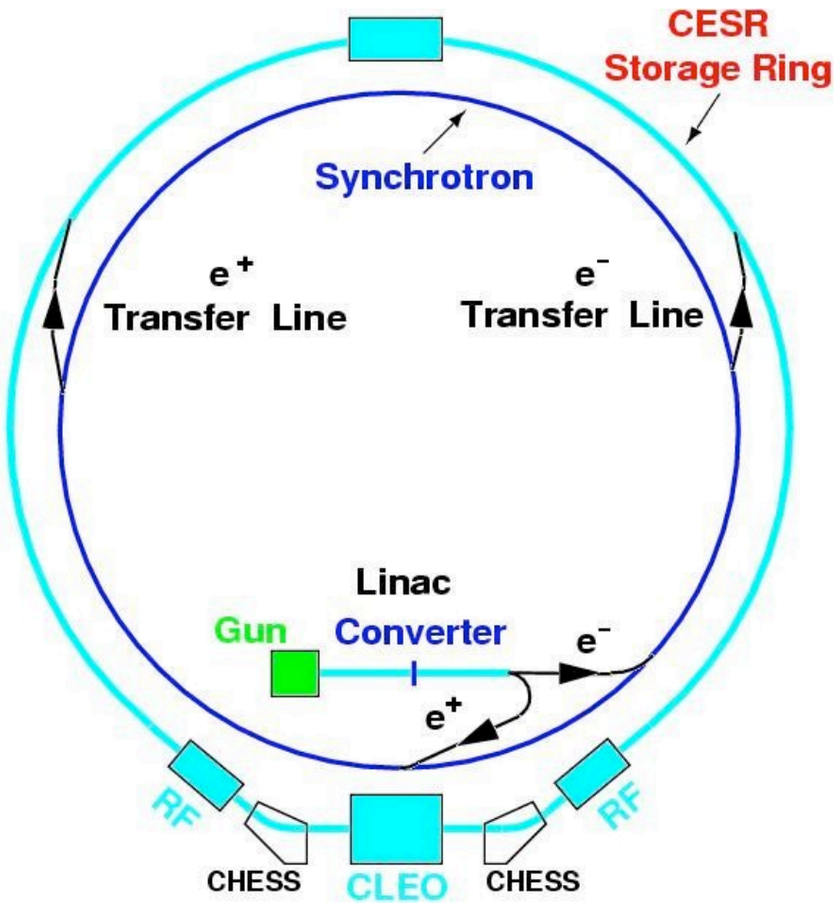
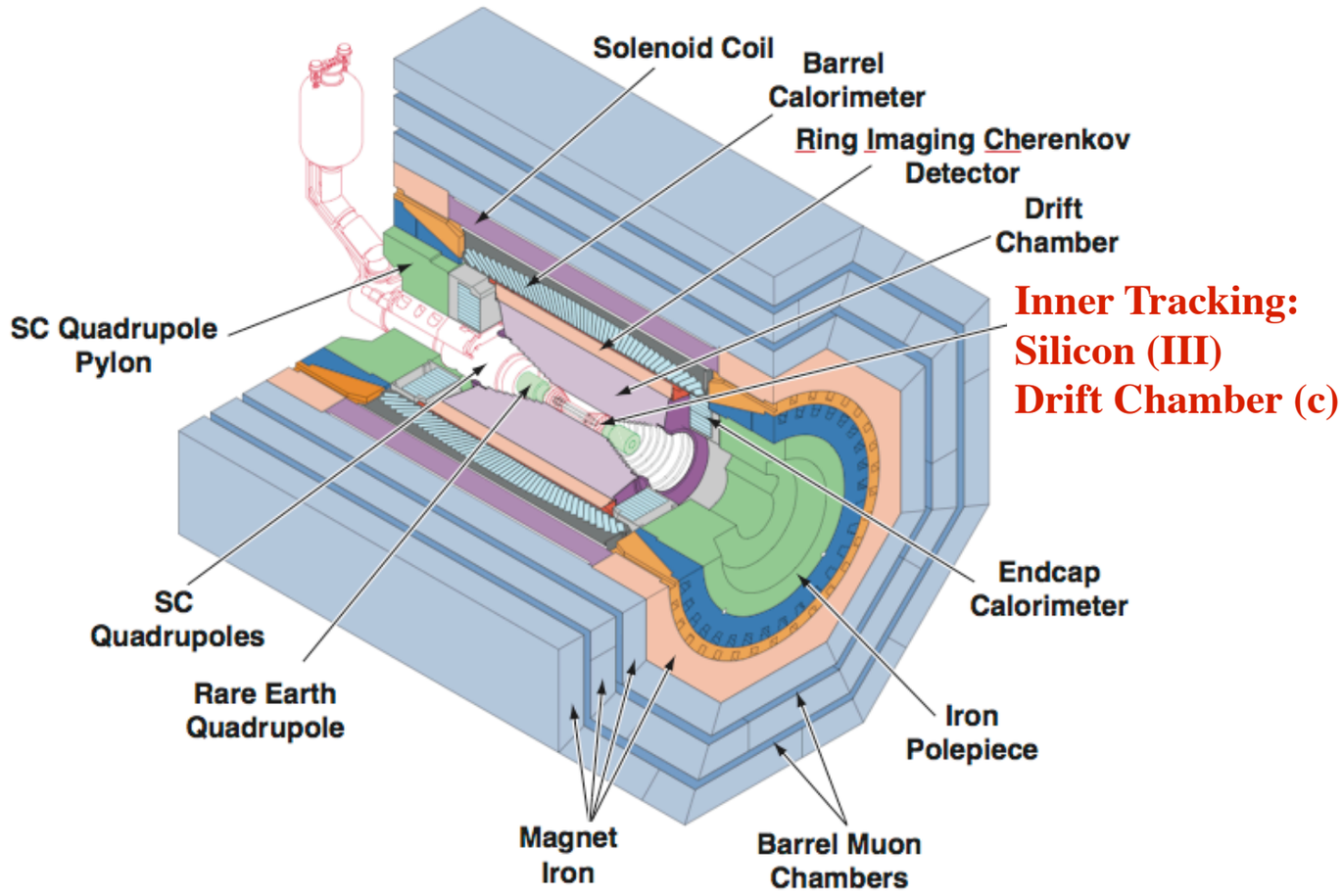
Charm 2010
Beijing, China

Overview of the CLEO Experiment

CESR at Cornell University: symmetric e^+e^- collisions at bottomonium (III) and charmonium (c) energies





CLEO III (2000 - 2003)

Select Data Samples:

$\Upsilon(4S)$	~ 15.5 fb^{-1}
$\Upsilon(3S)$	~ 6M events
$\Upsilon(2S)$	~ 9M events
$\Upsilon(1S)$	~ 22M events

CLEO-c (2003 - 2008)

Select Data Samples:

4.17 GeV	~ 586 pb^{-1}
$\psi(3770)$	~ 818 pb^{-1}
3.97 - 4.26 GeV Scan	~ 60 pb^{-1}
$\psi(2S)$	~ 26M events
	(+1.5M CLEO-III)

1980-2010:
> 500 publications
(weak, em, strong, exotic, etc. physics)

Recent Results on Charmonium Decays at CLEO-c

1. **Study of $\psi(2S)$ decays to $\gamma p\bar{p}$, $\pi^0 p\bar{p}$, and $\eta p\bar{p}$ and Search for $p\bar{p}$ Threshold Enhancements**
   (accepted by PRD, arXiv:1007.2886)
   - $\Rightarrow$ No evidence for $p\bar{p}$ threshold enhancements in $\psi(2S)$ decays
   - $\Rightarrow$ Confirmation of the BES "X(1860)" in $J/\psi \rightarrow \gamma p\bar{p}$ (with a lower mass due to parameterization)

2. **Branching fractions for $\chi_{cJ} \rightarrow p\bar{p}\pi^0$, $p\bar{p}\eta$, and $p\bar{p}\omega$**
   (PRD 82, 011103 (2010), arXiv:1005.5374)
   - $\Rightarrow$ Interesting Dalitz structure in $\chi_{cJ} \rightarrow p\bar{p}\pi^0$
   - $\Rightarrow$ Useful for predictions of $p\bar{p} \rightarrow X$ + charmonium

3. **Search for $\psi(2S) \rightarrow \gamma\eta_c(2S)$ via fully reconstructed $\eta_c(2S)$ decays**
   (PRD 81, 052002 (2010), arXiv:0910.1324)
   - $\Rightarrow$ No signals seen in 11 potential decay modes of the $\eta_c(2S)$
   - $\Rightarrow$ $B(\psi(2S) \rightarrow \gamma\eta_c(2S)) \times B(\eta_c(2S) \rightarrow X)$ upper limits are on the order of 10^{-5}

4. **Higher-order multipole amplitudes in charmonium radiative transitions**
   (PRD 80, 112003 (2009), arXiv:0910.0046)
   - $\Rightarrow$ Observation of non-zero M2 amplitudes in $\psi(2S) \rightarrow \gamma\chi_{c1,2}$; $\chi_{c1,2} \rightarrow \gamma J/\psi$
   - $\Rightarrow$ Agreement with theory when the charm quark has a mass of 1.5 GeV and no anomalous magnetic moment

Recent Results on Charmonium Decays at CLEO-c

1. Study of ψ(2S) decays to γpp̄, π⁰pp̄, and ηpp̄ and Search for pp̄ Threshold Enhancements

(accepted by PRD, arXiv:1007.2886)

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(PRD 82, 011103 (2010), arXiv:1

⇒ Interesting Dalitz structur

⇒ Useful for predictions of

3. Search for ψ(2S) → γη_c(2S) via f

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⇒ No signals seen in 11 pote

⇒ B(ψ(2S)→γη_c(2S)) × B(

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4. Higher-order multipole amplitud

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⇒ Observation of non-zero E

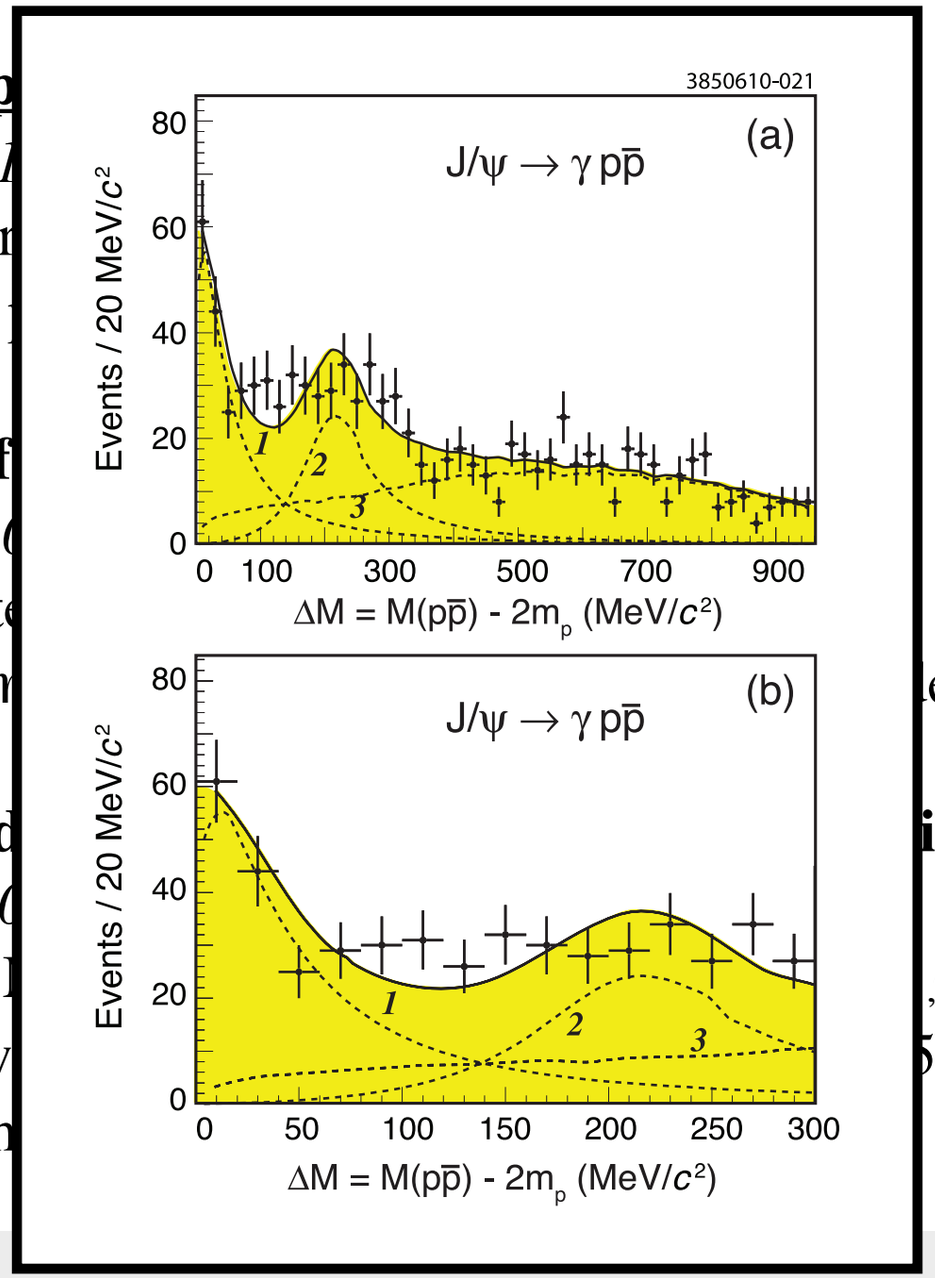
⇒ Agreement with theory w

no anomalous magnetic m

ions

,2 → γJ/ψ

5 GeV and



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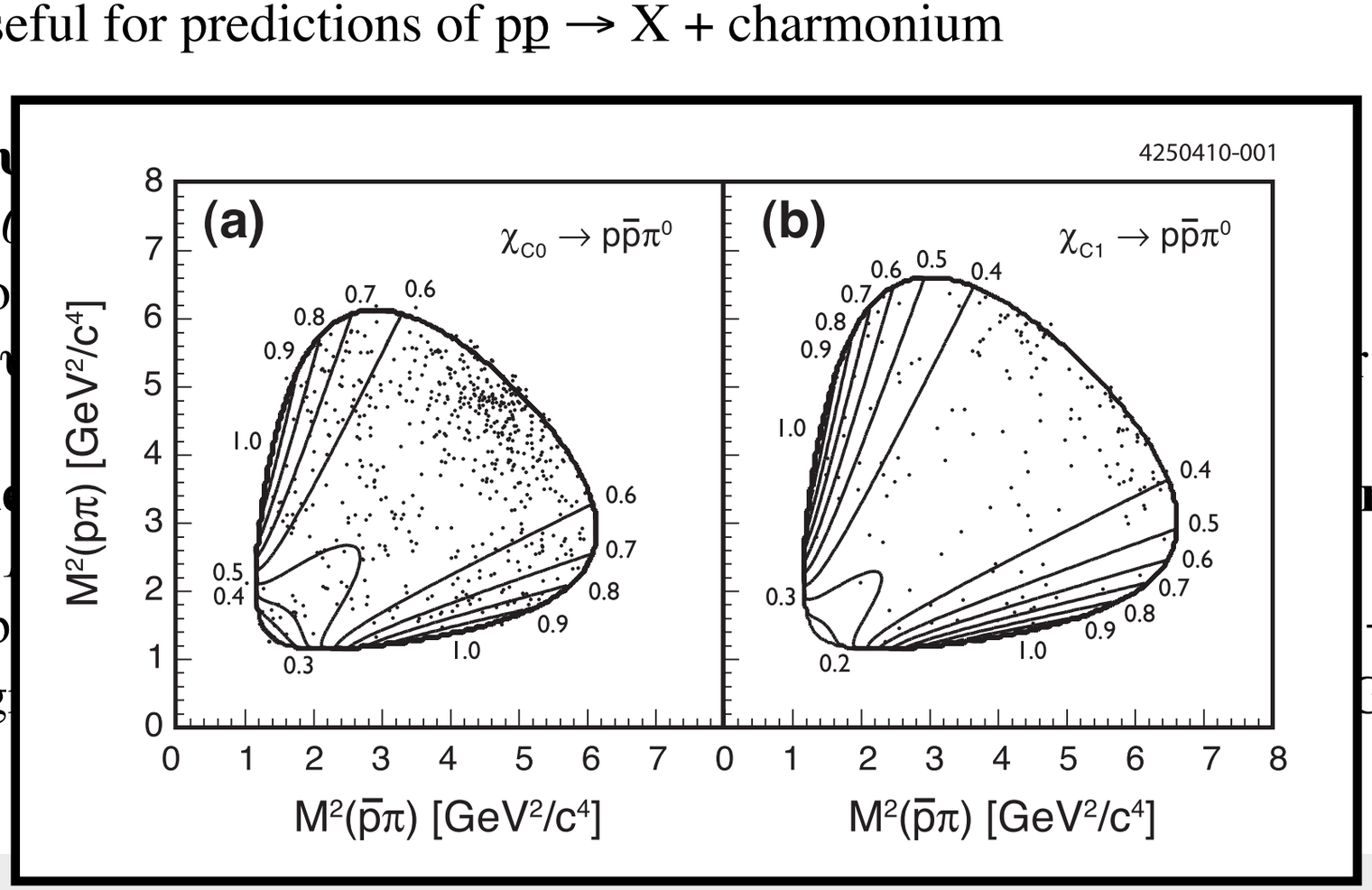

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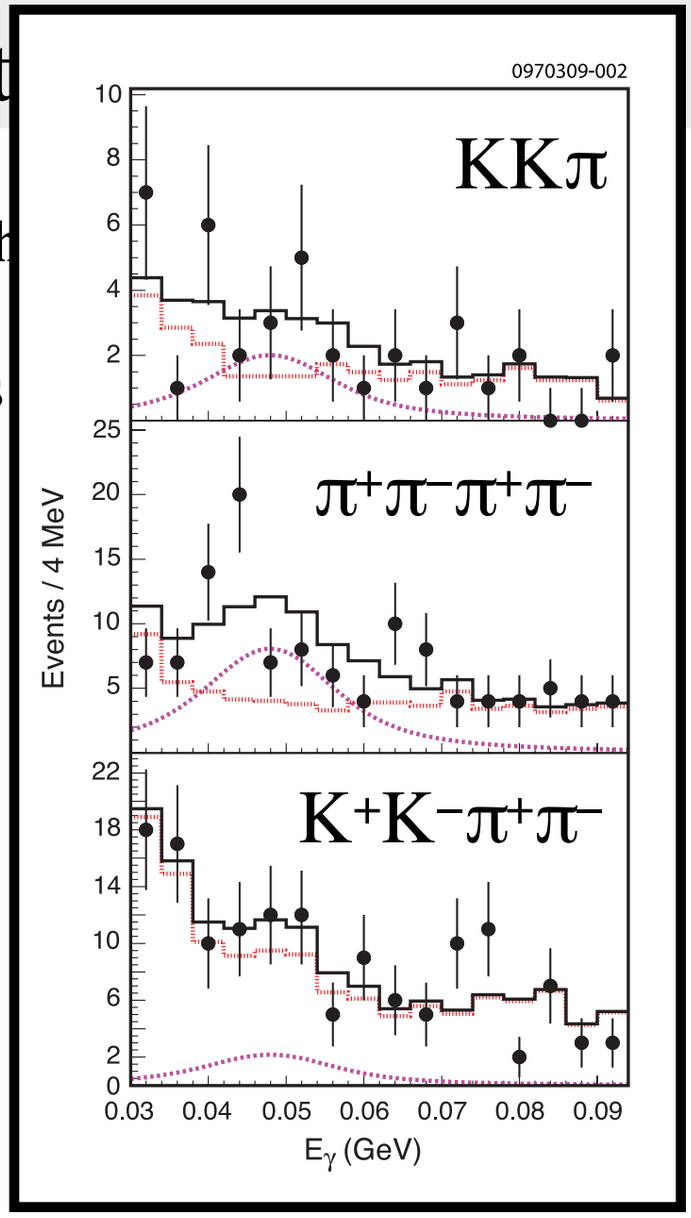

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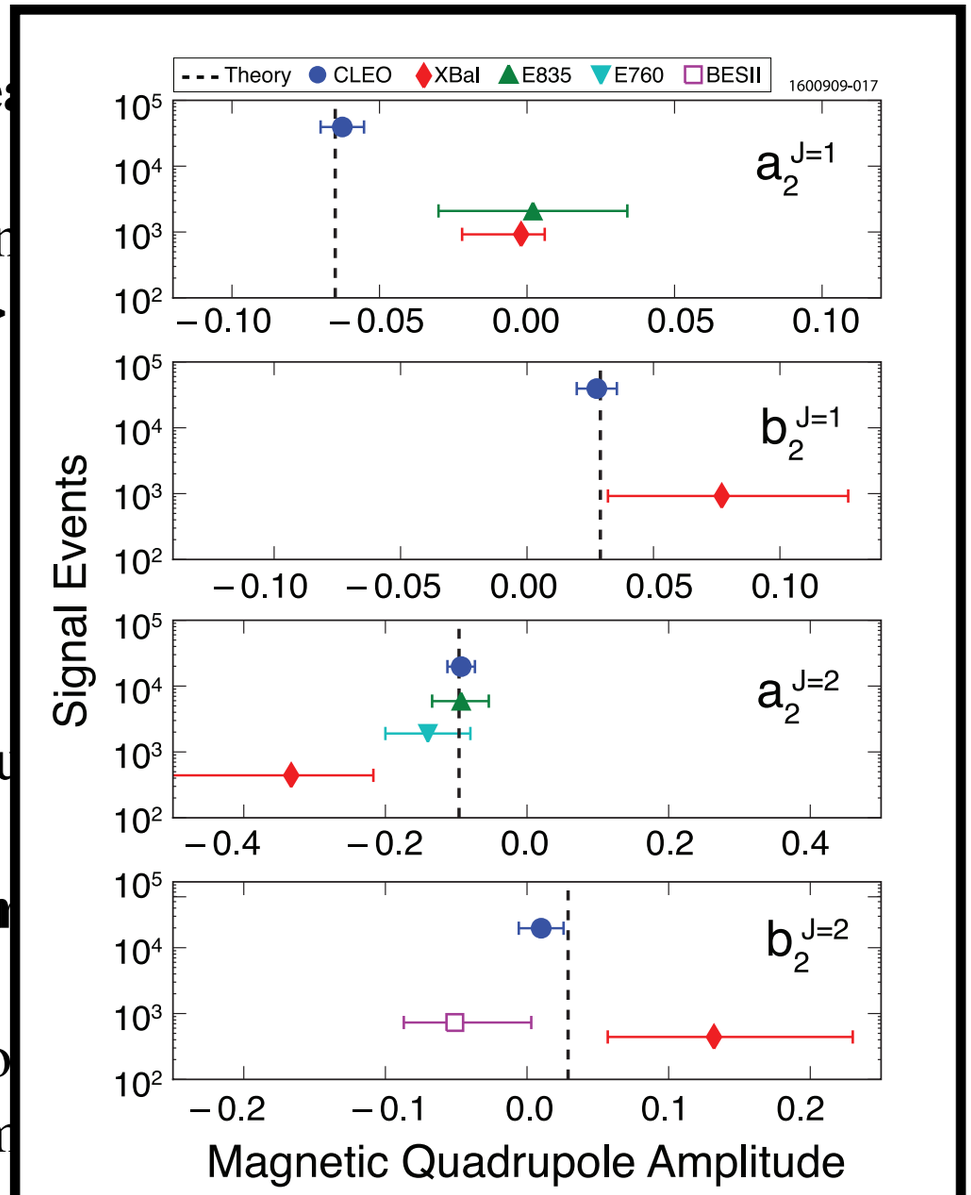

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This Talk: Transitions to the h_c Above DD Threshold

CLEO Preliminary

I. Search for $e^+e^- \to \pi^+\pi^- h_c$ at 4170 MeV

(using 586 pb^{-1} of 4170 data)

II. Search for $e^+e^- \to (\pi^0\pi^0/\pi^0/\eta)h_c$ at 4170 MeV

(using 586 pb^{-1} of 4170 data)

III. Search for $e^+e^- \to \pi^+\pi^- h_c$ at 3970 – 4260 MeV

(using 60 pb^{-1} of scan data)

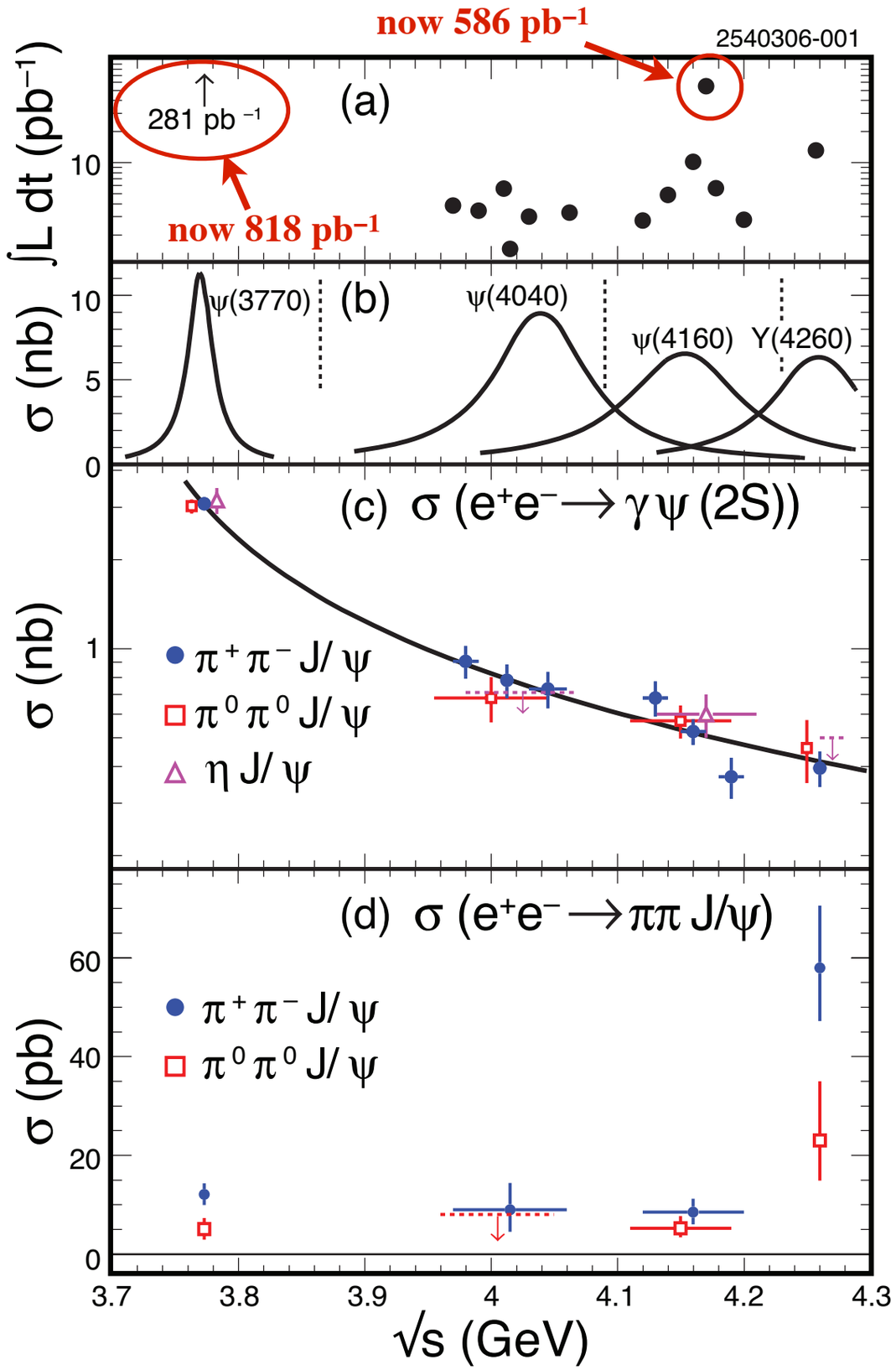
Scan Data at CLEO-c

Transitions to the J/ψ:
(PRL 96, 162003 (2006))

- observation of
  $e^+e^- \to \pi^+\pi^- J/\psi$ and $\pi^0\pi^0 J/\psi$
  attributed to the **Y(4260)**
- $\pi^0\pi^0 J/\psi$ rate consistent with isospin-0 expectation for Y(4260)
- upper limits on other transitions to J/ψ

Look for transitions to the h_c:

- don't know what to expect?
- other decays of the Y(4260)?
- useful information for h_b searches
- much more 4170 data than before



Searching for Transitions to the h_c

- Reconstruct all events exclusively using

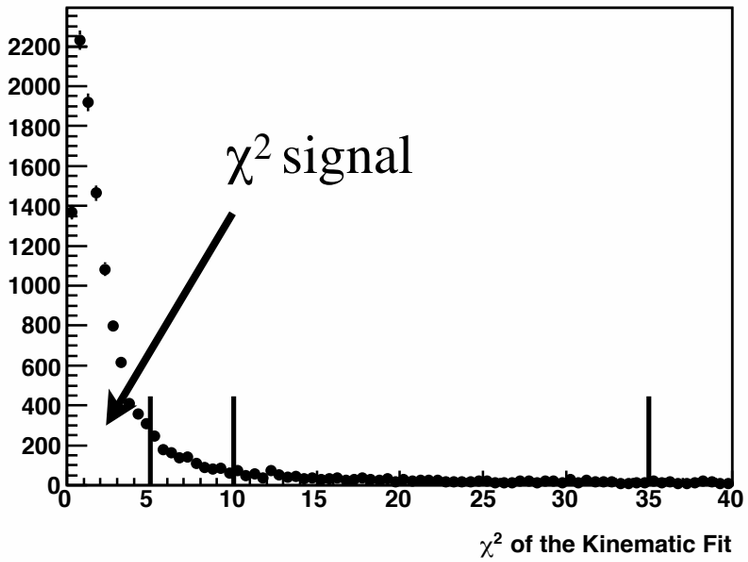
$$e^+e^- \rightarrow (\pi^+\pi^-/\pi^0\pi^0/\pi^0/\eta)\, h_c;\ \ h_c \rightarrow \gamma\eta_c;\ \ \eta_c \rightarrow X_i$$

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

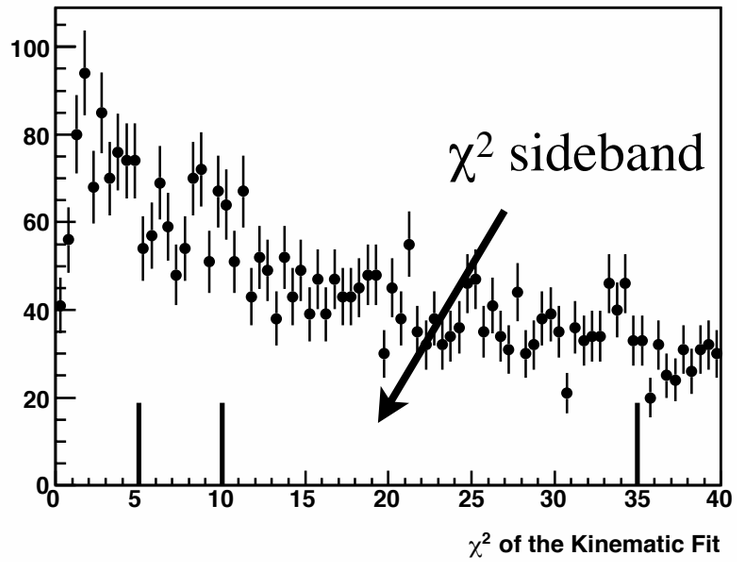
- Constrain the total 4-momentum to the e^+e^- system and use the χ^2 of the fit to filter events. Use poor χ^2 fits to study backgrounds.

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

χ^2 of the kinematic fit for **signal MC**



χ^2 of the kinematic fit for **background MC**

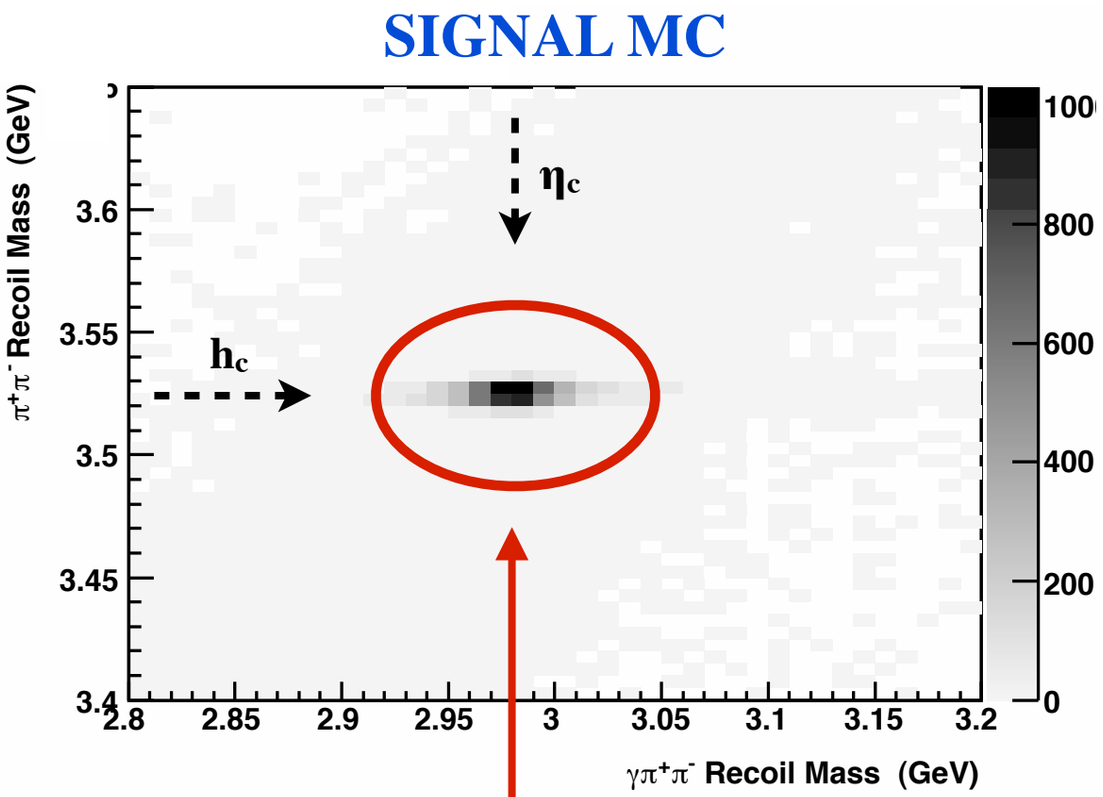


* *unmeasured (but large)* $B(\eta_c \rightarrow X_i)$

$\sum_i B(\eta_c \rightarrow X_i) \approx (12 + ?)\%$ *(PDG 2010)*

- Select the η_c using the recoil mass of the γ + $(\pi^+\pi^-/\pi^0\pi^0/\pi^0/\eta)$ system.

Properties of $e^+e^- \to \pi^+\pi^- h_c$ ($h_c \to \gamma\eta_c$ and $\eta_c \to X_i$) at 4170 MeV



Plots of $\pi^+\pi^-$ vs. $\gamma\pi^+\pi^-$ Recoil Mass

Signal MC:

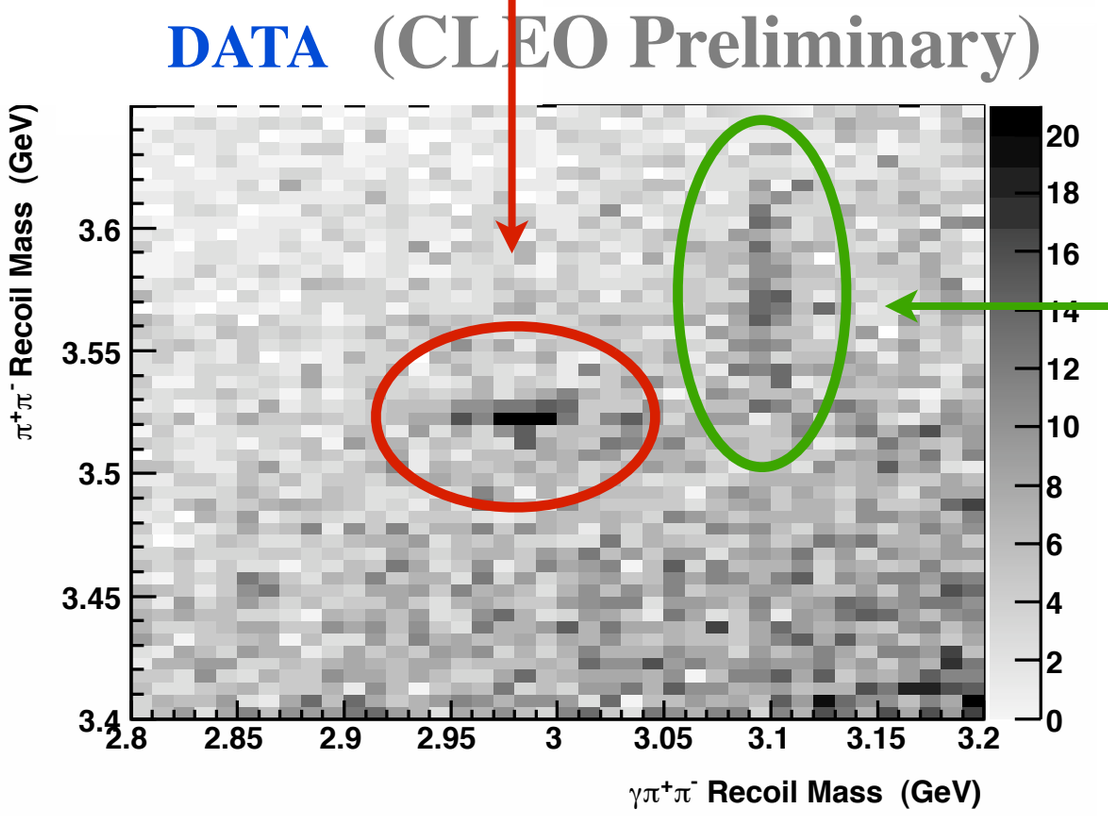
⇒ signal at intersection of h_c and η_c masses

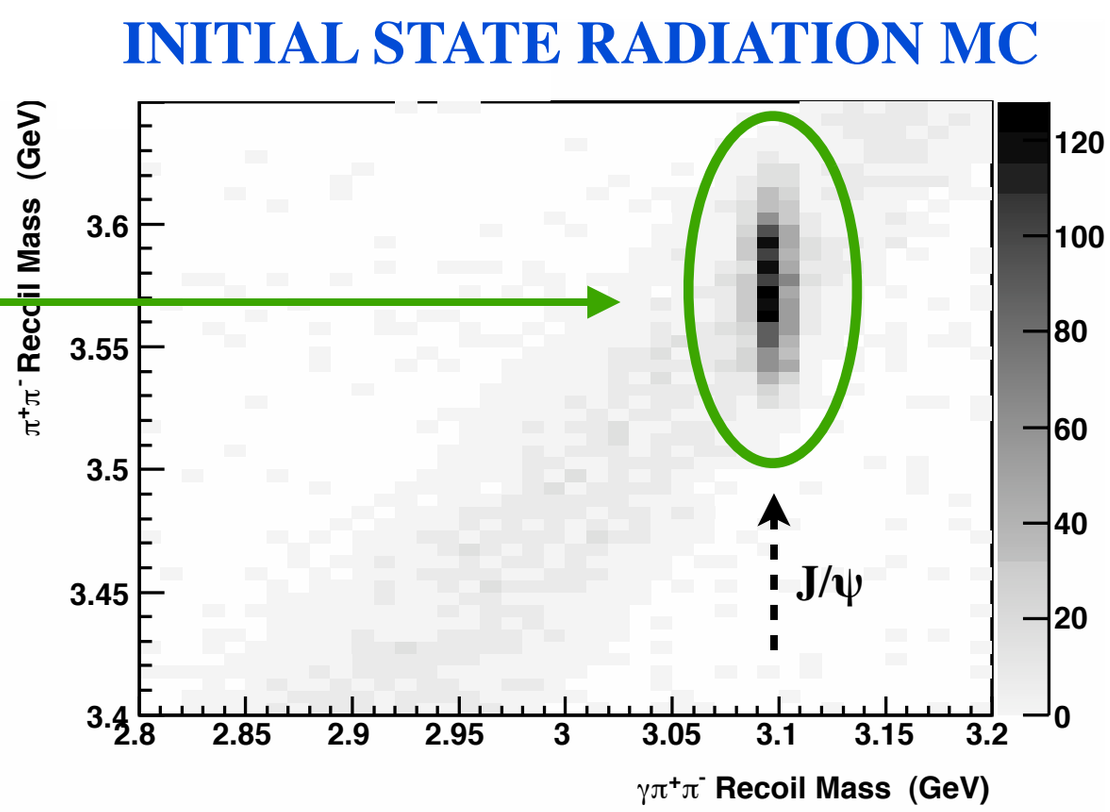
Initial State Radiation (ISR) MC:

⇒ peak in $\gamma\pi^+\pi^-$ recoil mass at J/ψ due to $e^+e^- \to \gamma_{ISR}\psi(2S) \to \gamma_{ISR}\pi^+\pi^- J/\psi$

Data:

⇒ clear signal separated from initial state radiation background!





Fits to $e^+e^- \to \pi^+\pi^- h_c$ ($h_c \to \gamma\eta_c$ and $\eta_c \to X_i$) at 4170 MeV

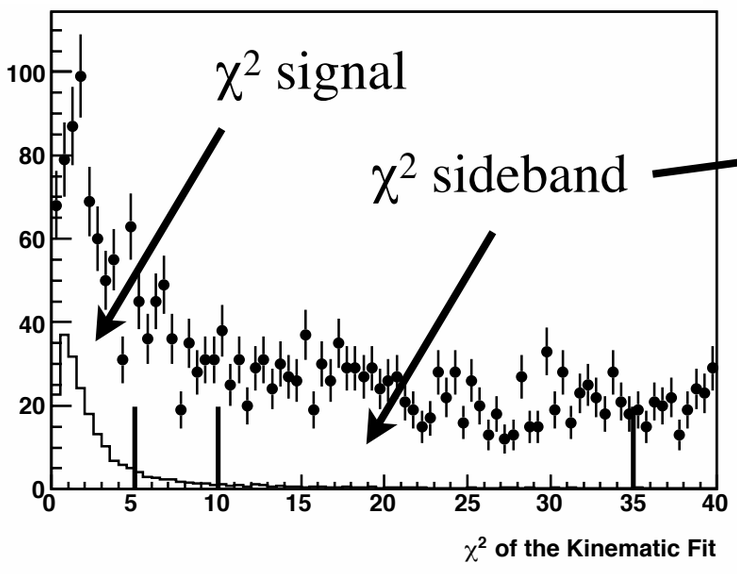
Select the η_c using the $\gamma\pi^+\pi^-$ recoil mass and plot the $\pi^+\pi^-$ recoil mass.

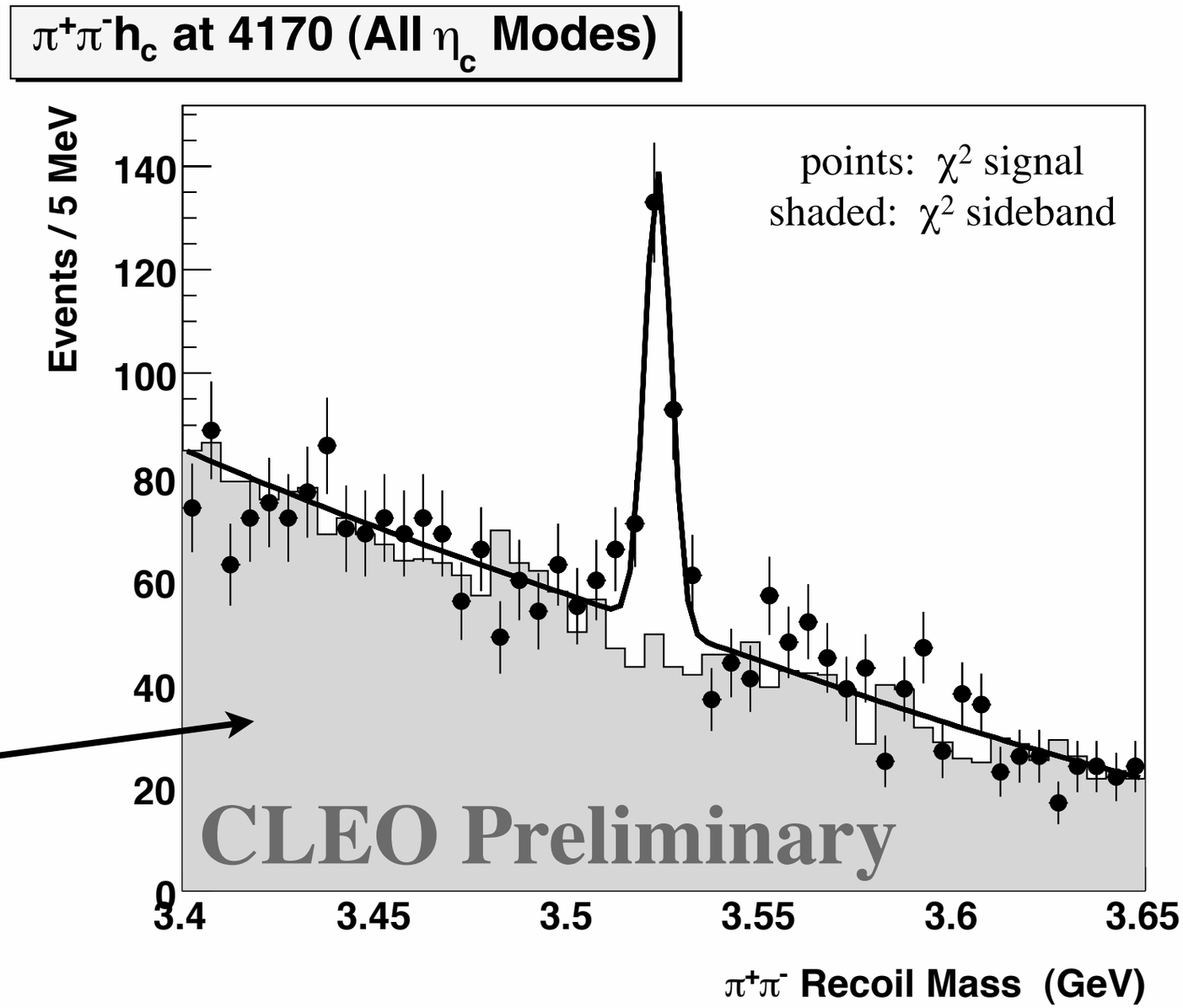
Fit Procedure:

1. Fit the χ^2 sideband with a polynomial, then scale.
   (1 parameter)

2. Fix the signal shape with signal MC, but let the mass and size float.
   (2 parameters)

χ^2 of the kinematic fit for **DATA**





150 ± 17 events with 9.4σ significance

Fits to $e^+e^- \to \pi^+\pi^- h_c$ ($h_c \to \gamma\eta_c$ and $\eta_c \to X_i$) at 4170 MeV

Select the η_c using the $\gamma\pi^+\pi^-$ recoil mass and plot the $\pi^+\pi^-$ recoil mass.

Using η_c decay modes with known branching fraction:

$\sigma_{4170}(e^+e^- \to \pi^+\pi^- h_c) \times B(h_c \to \gamma\eta_c)$
$= 6.6 \pm 1.0 \pm 1.3 \pm 1.9$ pb.

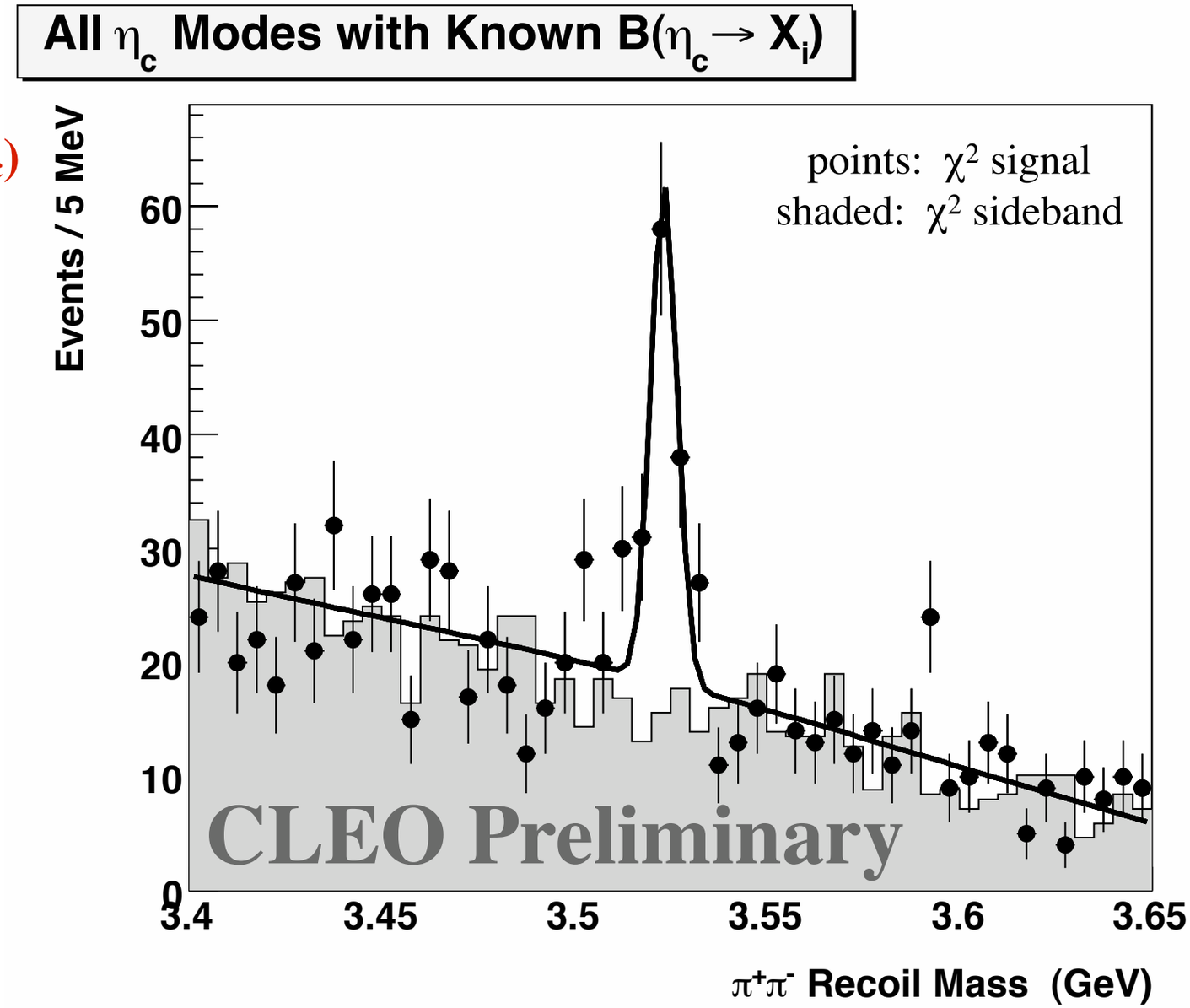
Using $B(h_c \to \gamma\eta_c)$ =
$(54.3 \pm 6.7 \pm 5.2)\%$ from BESIII
(PRL 104, 132002 (2010)):

$\sigma_{4170}(e^+e^- \to \pi^+\pi^- h_c)$
$= 12.2 \pm 1.8 \pm 2.4 \pm 4.0$ pb.

Compare to:

$\sigma_{4170}(e^+e^- \to \pi^+\pi^- J/\psi)$
$= 8 \pm 2 \pm 2$ pb.

$\Rightarrow$ $\pi^+\pi^- h_c$ is as large as $\pi^+\pi^- J/\psi$ at 4170 MeV!



74 ± 11 events with 7.7σ significance

Fits to $e^+e^- \to (\pi^0\pi^0/\pi^0/\eta)h_c$ at 4170 MeV

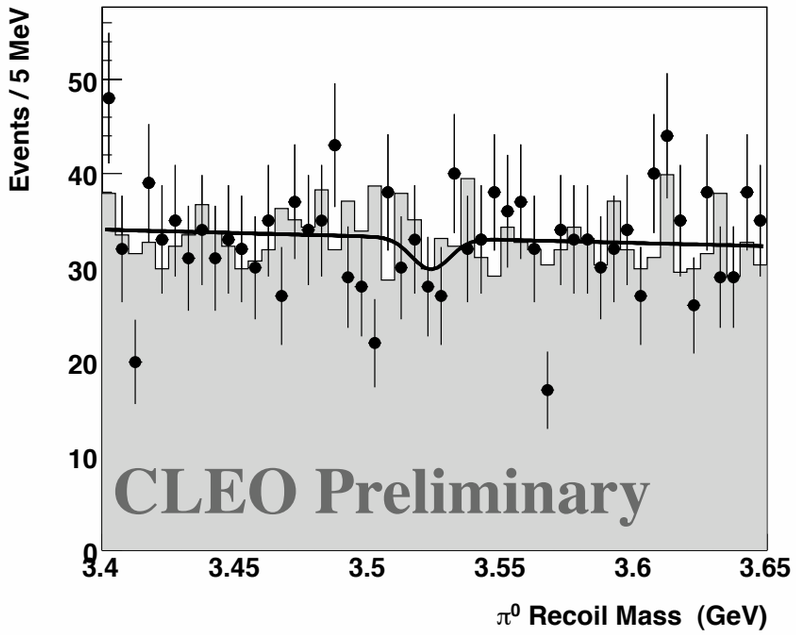
Search for $\pi^0\pi^0/\pi^0/\eta$ transitions to the h_c at 4170 MeV:

⇒ Use ratios with respect to $\pi^+\pi^- h_c$

⇒ Use all decay modes of the η_c

⇒ Mass is fixed from $\pi^+\pi^- h_c$ fits, width is from MC

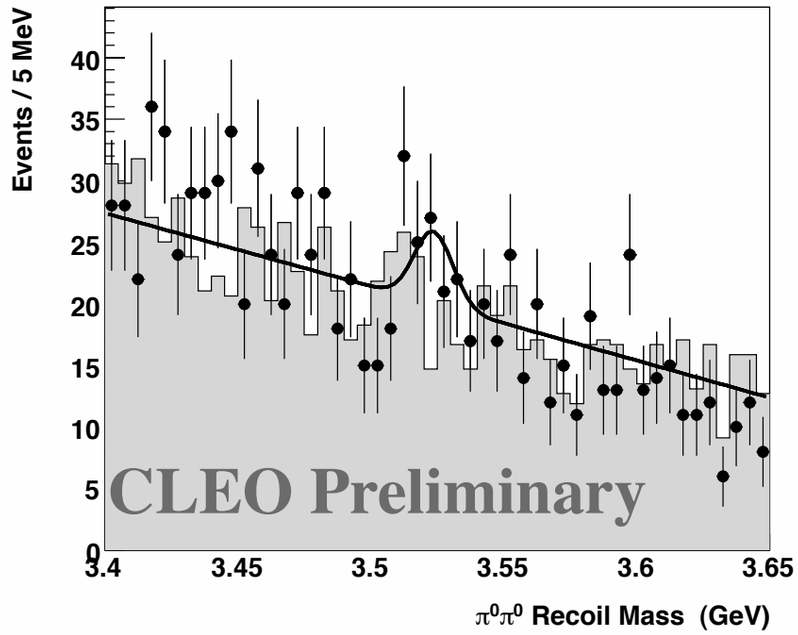
$\pi^0 h_c$ at 4170 MeV



-12 ± 13 events

$\sigma_{4170}(e^+e^- \to \pi^0 h_c)/$
$\sigma_{4170}(e^+e^- \to \pi^+\pi^- h_c)$
$= -0.10 \pm 0.11 \pm 0.03$

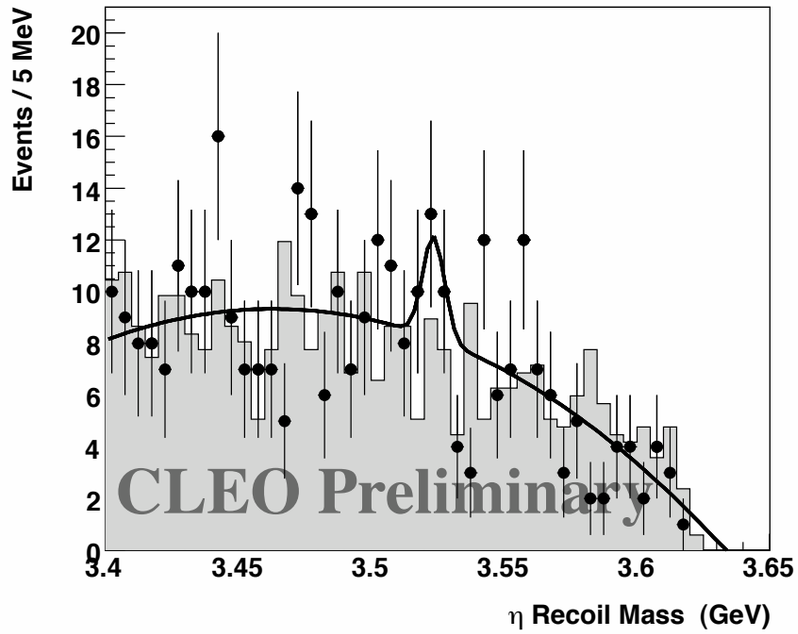
$\pi^0\pi^0 h_c$ at 4170 MeV



21 ± 12 events
2.2σ significance

$\sigma_{4170}(e^+e^- \to \pi^0\pi^0 h_c)/$
$\sigma_{4170}(e^+e^- \to \pi^+\pi^- h_c)$
$= 0.42 \pm 0.24 \pm 0.13$

ηh_c at 4170 MeV



8.1 ± 5.8 events
1.9σ significance

$\sigma_{4170}(e^+e^- \to \eta h_c)/$
$\sigma_{4170}(e^+e^- \to \pi^+\pi^- h_c)$
$= 0.17 \pm 0.12 \pm 0.04$

Fits to $e^+e^- \to \pi^+\pi^- h_c$ at 3970 – 4260 MeV

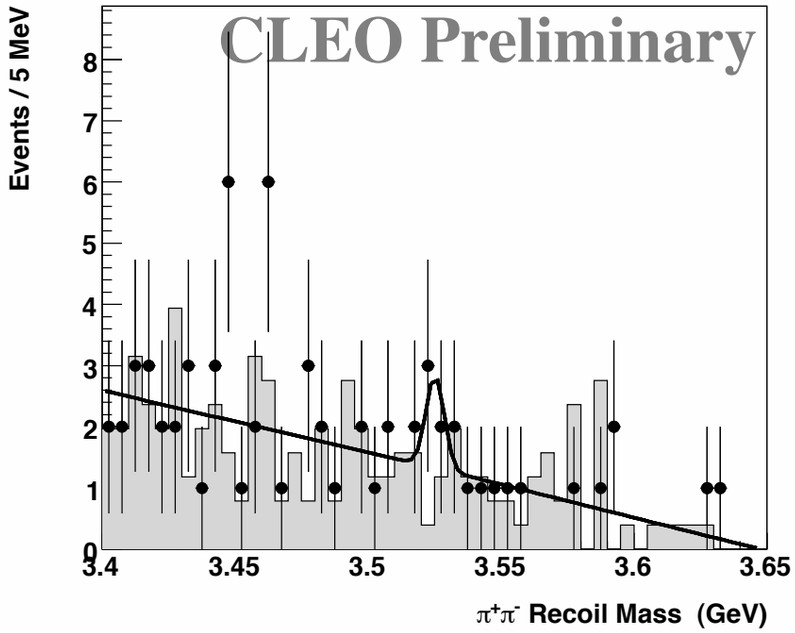
Search for $\pi^+\pi^- h_c$ at different beam energies:

⇒ Again use ratios with respect to 4170 and all decay modes of the η_c

⇒ Group data into three ranges: (1) 3970 – 4060; (2) 4120 – 4200; (3) 4260 MeV

⇒ Mass is fixed to PDG, width is from MC

3970 – 4060 MeV



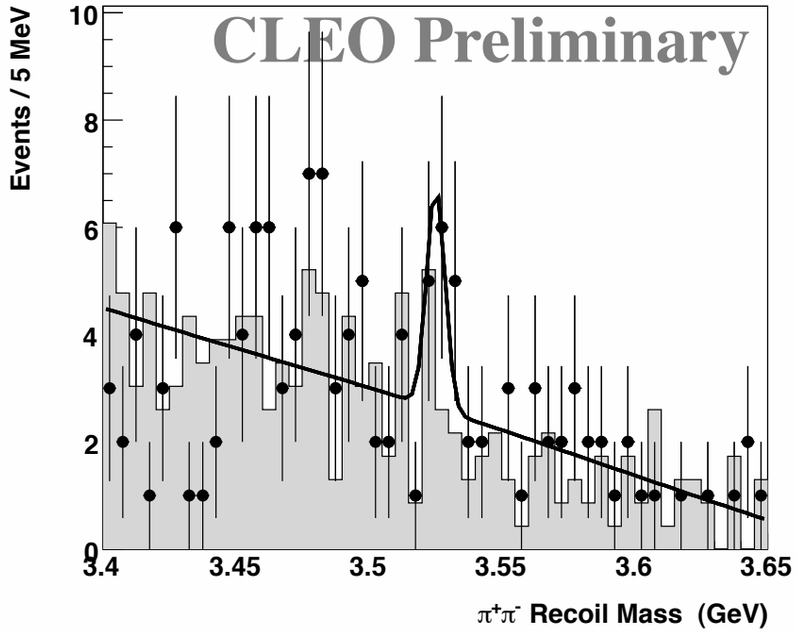
2.6 ± 2.4 events

1.2σ significance

$\sigma_{4015}(e^+e^- \to \pi^+\pi^- h_c)/$
$\sigma_{4170}(e^+e^- \to \pi^+\pi^- h_c)$
$= 0.54 \pm 0.51 \pm 0.14$

4120 – 4200 MeV

(excluding the 586pb^{-1} at 4170 MeV)

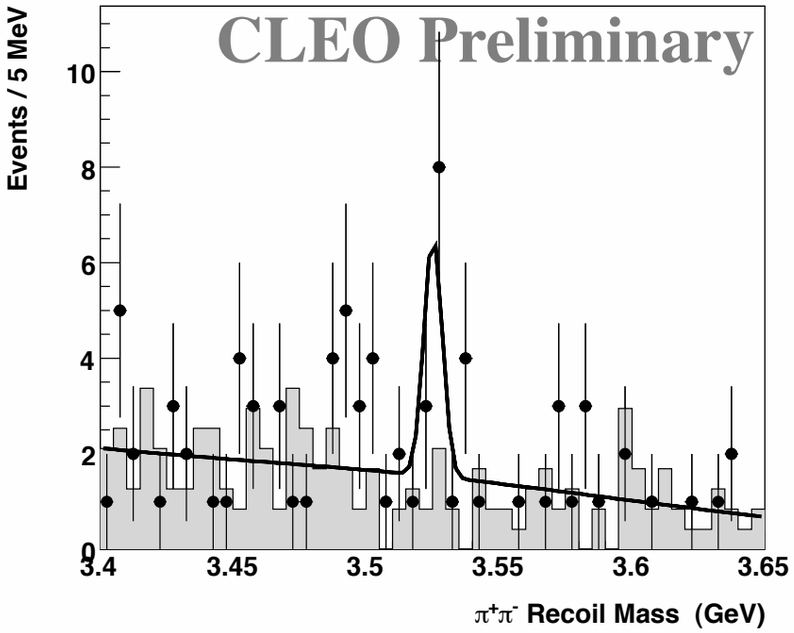


7.0 ± 3.8 events

3.1σ significance

$\sigma_{4160}(e^+e^- \to \pi^+\pi^- h_c)/$
$\sigma_{4170}(e^+e^- \to \pi^+\pi^- h_c)$
$= 1.05 \pm 0.58 \pm 0.40$

4260 MeV

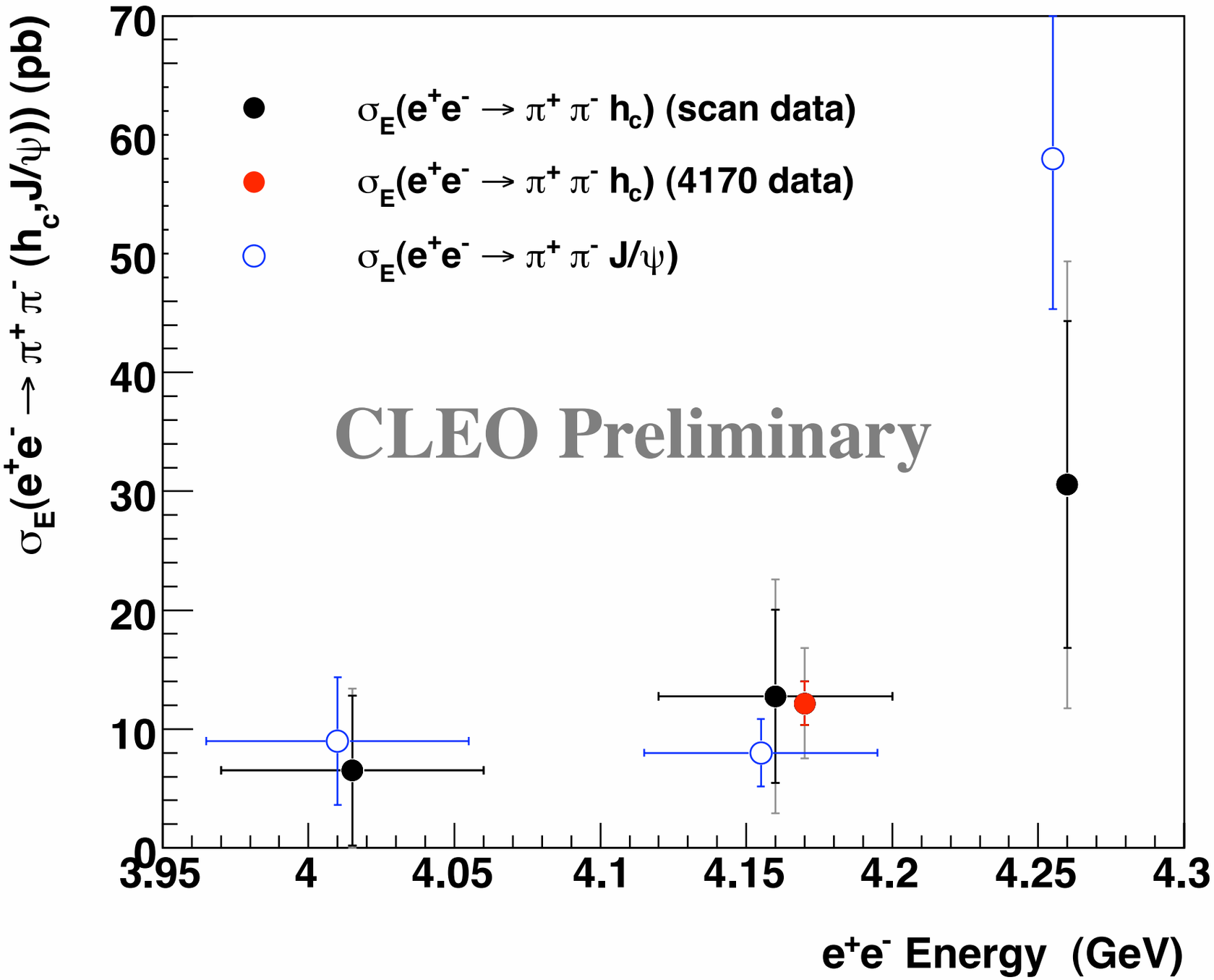


8.6 ± 3.5 events

2.0σ significance

$\sigma_{4260}(e^+e^- \to \pi^+\pi^- h_c)/$
$\sigma_{4170}(e^+e^- \to \pi^+\pi^- h_c)$
$= 2.5 \pm 1.1 \pm 0.6$

Scan of $e^+e^- \to \pi^+\pi^- h_c$ over e^+e^- Energy



Statistics are poor, but there is a suggestive rise at 4260!
(reminiscent of $\pi^+\pi^- J/\psi$??)

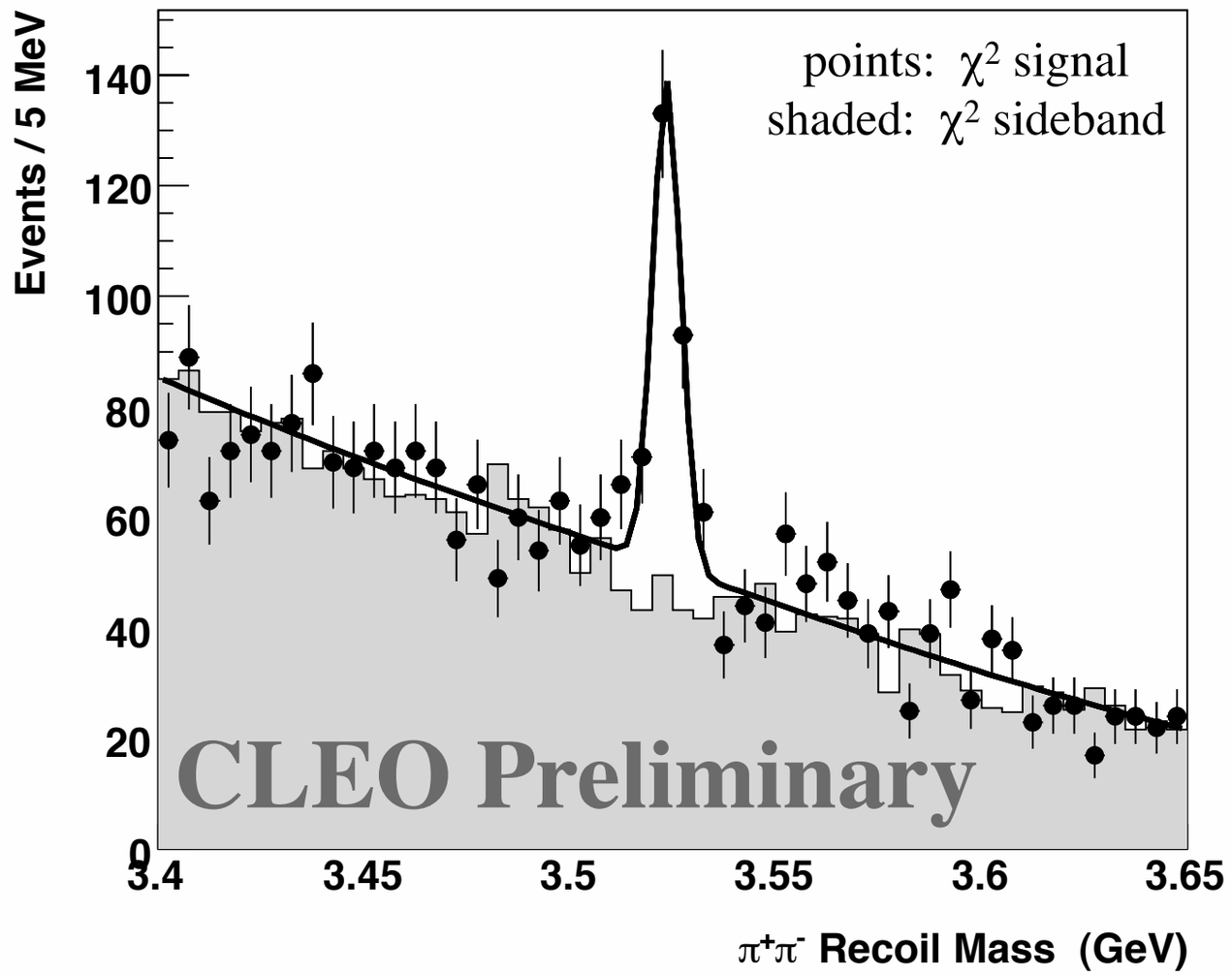
Summary

CLEO-c is still producing exciting results in charmonium:

(1) $\psi(2S)$ decays to $\gamma p\bar{p}$ and $Xp\bar{p}$;
(2) χ_{cJ} decays to $Xp\bar{p}$;
(3) search for $\psi(2S) \rightarrow \gamma\eta_c(2S)$;
(4) higher multipoles in $\psi(2S) \rightarrow \gamma\chi_{cJ}$ and $\chi_{cJ} \rightarrow \gamma J/\psi$

There are also new charmonium studies above DD threshold:

- Observation of $\pi^+\pi^- h_c$ at 4170 MeV.
- Rate is comparable to that of $\pi^+\pi^- J/\psi$.
- Suggestive rise, maybe, at 4260 MeV?
- Rate for $\pi^0\pi^0 h_c$ consistent with isospin-0.
- More data around 4260 MeV would be interesting!!
  (so would more data above the $\Upsilon(4S)$!)



Backup

Fits to $e^+e^- \to \pi^+\pi^- h_c$ at 4170 MeV

also fit all modes individually using the same method (but fixing the mass)