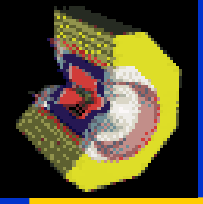
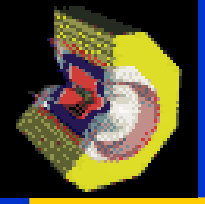


International Workshop on
Heavy Quarkonium 2006
June 27-30, 2006 • Brookhaven National Laboratory

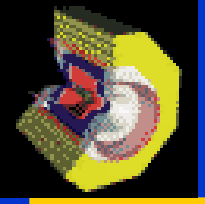
Y(4260) at CLEO

Brian Heltsley
Cornell University



Outline

- Y(4260) in ISR from $\sqrt{s}$=10 GeV
  Preliminary
- Direct $e^+e^- \rightarrow X\ J/\psi$ in charmonium region: Y(4260)
  Coan et al., PRL 96 (2006) 162003.
- Y(4260)$\rightarrow$Open Charm ?
- Conclusions

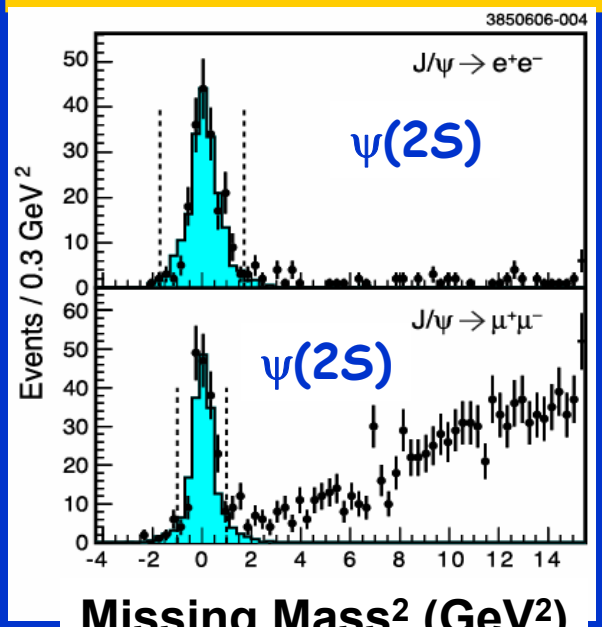


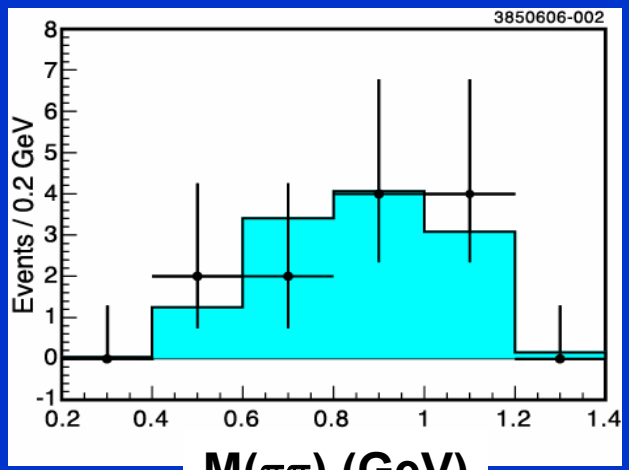
CLEO & Y(4260)

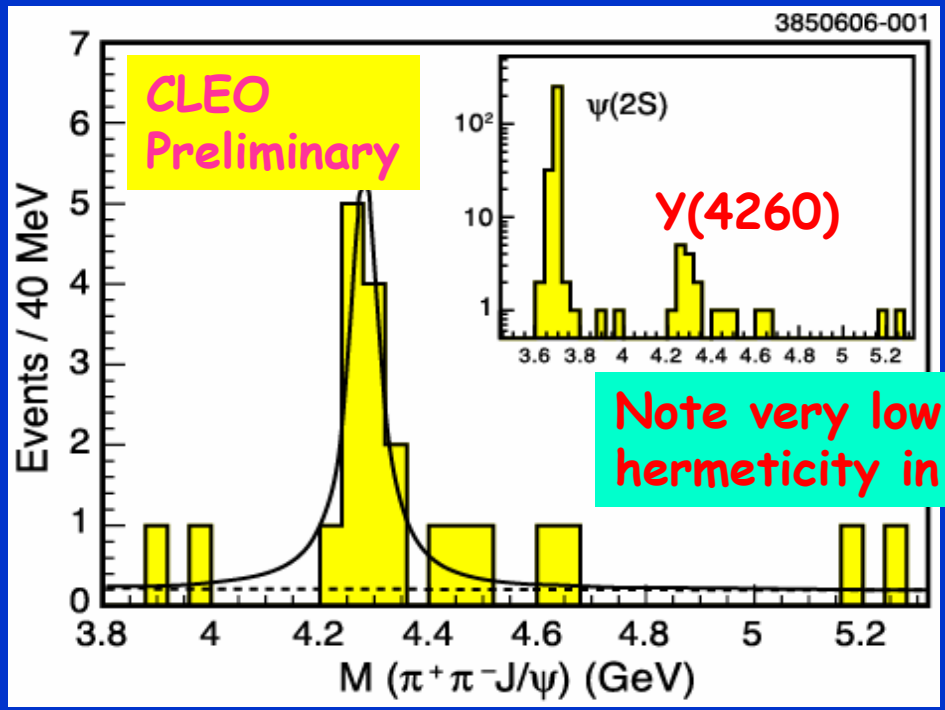
As of summer 2005 …

- BaBar observation of $e^+e^- \to \gamma$ Y(4260), Y(4260)$\to \pi^+\pi^-$ J/ψ adds another perplexing state to the charm region
  - Proposed explanations mostly unconventional
  - Y(4260) previously unconfirmed, skeptics abounded
  - Most intriguing of XYZ's, hybrid candidate?
- 1^{--} state: can be directly produced in e^+e^-
- Two-pronged approach:
  - Confirm/refute BaBar with RR's from $\sqrt{s}$=10 GeV (CLEO III)
  - Take data near/at $\sqrt{s}$=4.26 GeV
    - Performing a scan of the region anyway searching for a point of maximal D_s production, so spend a few extra days at 4.26 GeV
  - If confirmed, can we limit theory explanations by measuring what it does & does not decay into?

CLEO RR to Y(4260)

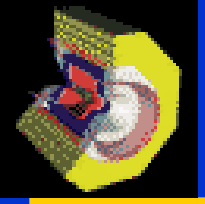




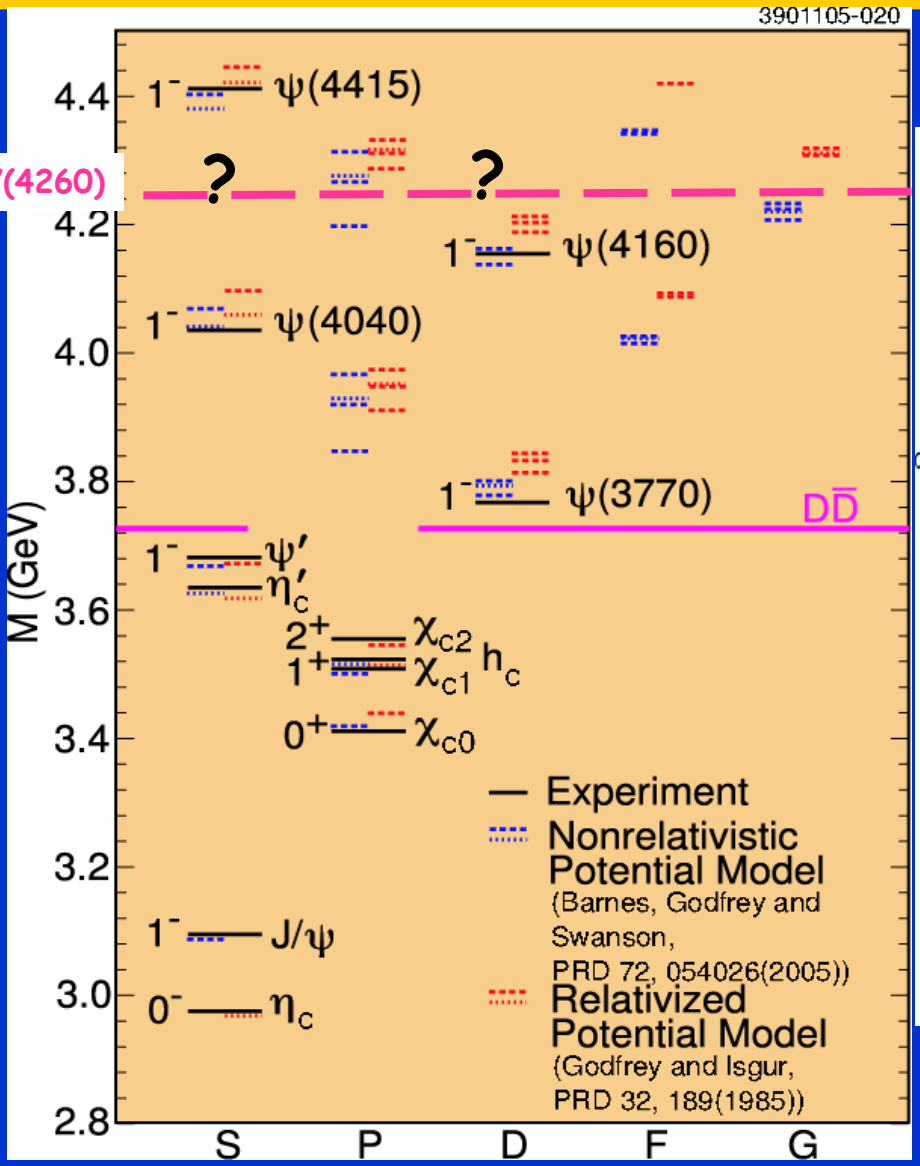


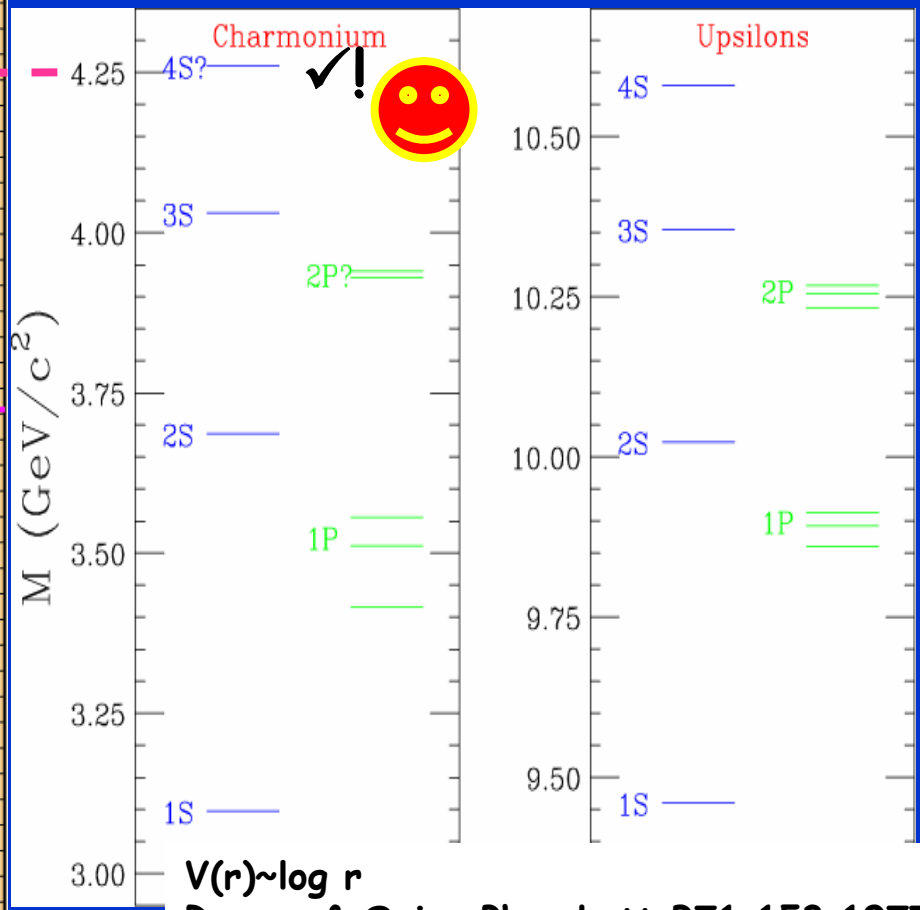
Note very low bgd: hermeticity in the c.m.

- 13.3 fb^{-1}
- N[Y(4260)] = $14.1^{+5.2}_{-4.2}$
- 4.9σ significance
- Single-resonance fit yields
  - $M = 4283^{+17}_{-16} \pm 4$ MeV
  - $\Gamma = 70^{+40}_{-25} \pm 5$ MeV
- M(ππ) consistent w/S-wave, no structure, consistent w/others

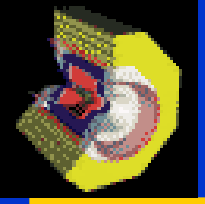


Observed & Predicted Spectra of Charmonium States





V(r)~log r
Rosner & Quigg, Phys.Lett.B71:153,1977



Theory (see Eichten talk & others to come)

- How to create enhancement & simultaneously suppress of open charm ?
  - Lengthy papers, which include review

Eichten, Lane, & Quigg, PRD 73 (2006) 014014;
Swanson, hep-ph/0601110

  - Hybrid Charmonium (ccg): Enhanced rate for D_1D; suppress $D^{(*)}D^{(*)}$, $D_s^{(*)}D_s^{(*)}$; $K^+K^-\approx\pi^+\pi^-$; π^0 J/ψ, $\pi^+\pi^-$ should exist

Zhu, PLB 625 (2005) 142001
Close & Page, PLB 628 (2005) 215
Kou & Pene, PLB 631 (2005) 164

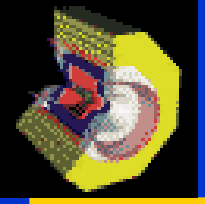
  - Tetraquark (cs)(cs): member of nonet along with X(3872) & X(3940). Must decay into D_sD_s.

Maiani, Riquer, Piccinini, & Polosa, PRD 72 (2005) 031502

    - Zhu points out could be a scalar tetraquark (uu+dd)cc but if so then should also observe isovector partner $Y'(4260)\rightarrow\pi^+\pi^-\pi^0$ J/ψ

  - χ_{cJ} ρ^0 molecule : no decay into $\pi^0\pi^0J/\psi$

Liu, Zeng, & Li, PRD 72 (2005) 054023



Theory (cont'd)

- $\chi_{cJ}\,\omega$ molecule : $\pi^0\pi^0/\pi^+\pi^- \approx 0.5$;
  $Y(4260)\to\gamma\chi_{cJ}\to\gamma\gamma\ J/\psi$, $Y(4260)\to\gamma\pi^+\pi^-\pi^0\ J/\psi$

Yuan, Wang, & Mo, PLB 634 (2006) 399

- Baryonium ($\Rightarrow$tiny KK J/ψ; visible $\pi\pi\ \psi(2S)$ & $D^*D^*\pi$; suppressed $DD\pi$)

Qiao, hep-ph/0510228v1, v2

- Conventional 4S cc
  (s-d interference suppresses open charm)

Llanes-Estrada, PRD 72 (2005) 031503

  - Oddball (3g glueball) [$\Rightarrow$ big $\phi\pi\pi$ rate]
  - 3S = $\psi(4040)$ should have a large $\pi^+\pi^- J/\psi$ partial width

- Coupled channel signal: non-exotic
  $D_s^*D_s$, D^*D^*, $D_s^*D_s^*$ P-wave channels together create Y(4260)

Beveren & Rupp, hep-ph/0605317v1

Decays Analyzed @ $\sqrt{s}$=4260

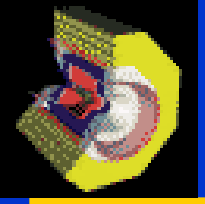
Modes:

- $\pi^+\pi^-$ J/ψ
- $\pi^0\pi^0$ J/ψ
- η J/ψ
- K^+K^- J/ψ
- π^0 J/ψ
- η' J/ψ
- $\pi^+\pi^-\pi^0$ J/ψ
- $\pi^+\pi^-$ $\psi(2S)$
- η $\psi(2S)$
- $\pi^+\pi^-$ ϕ

Using the following intermediate decays:

- $J/\psi \to \mu^+\mu^-$, e^+e^-
- $\eta \to \gamma\gamma$, $\pi^+\pi^-\pi^0$
- $\eta' \to \pi^+\pi^-\eta$, $\pi^+\pi^-\gamma$
- $\psi(2S) \to \mu+\mu-$, $e+e-$, $\pi+\pi-J/\psi$
- $\phi \to K+K-$

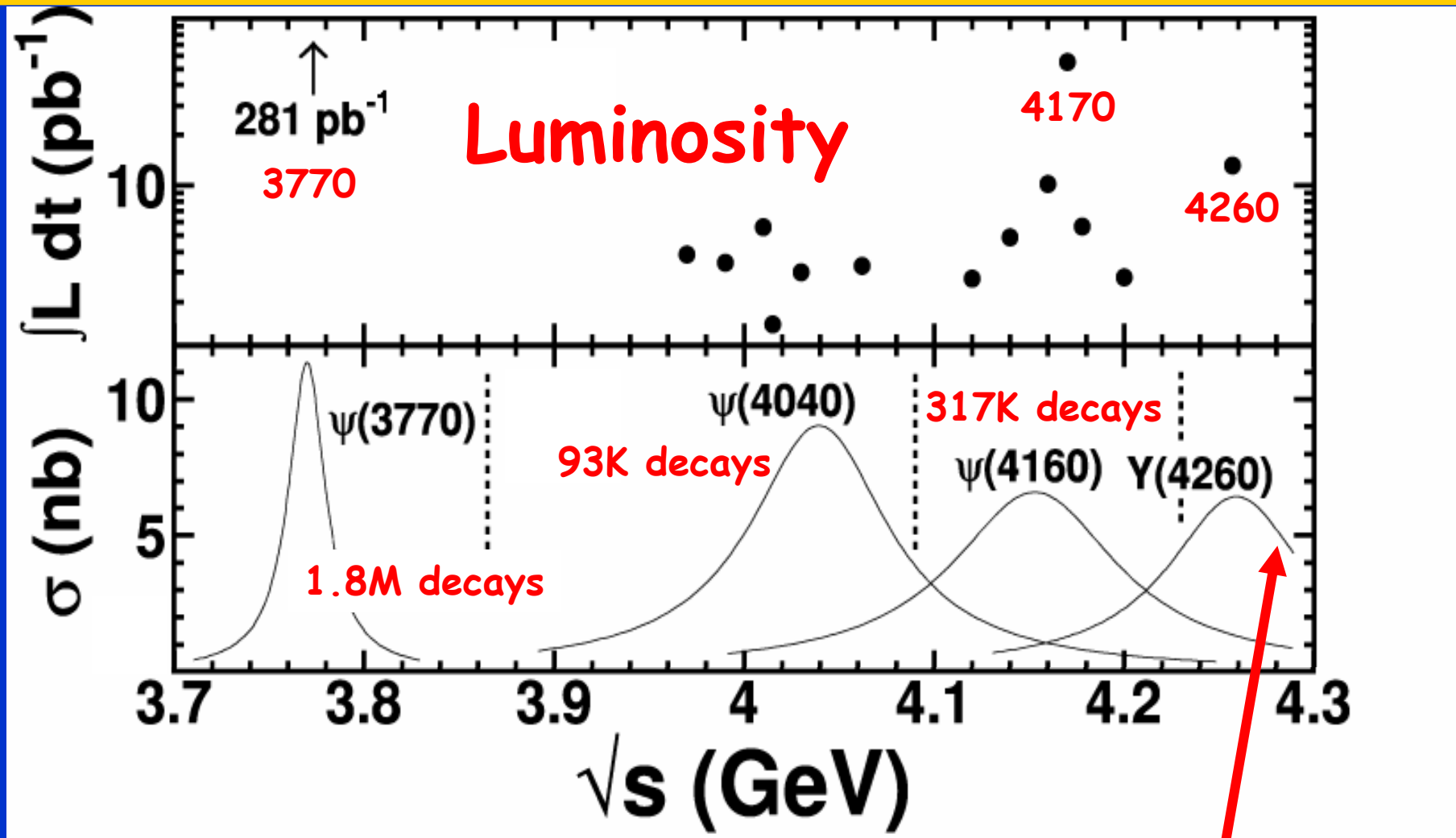
- Suite of channels motivated by the proposed scenarios.
- Open charm modes crucial to interpretation (In progress).



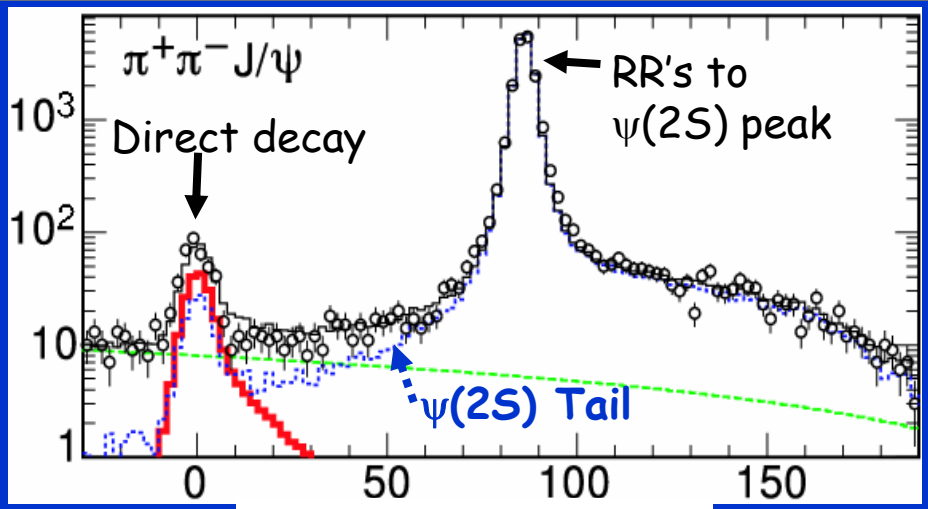
Datasets

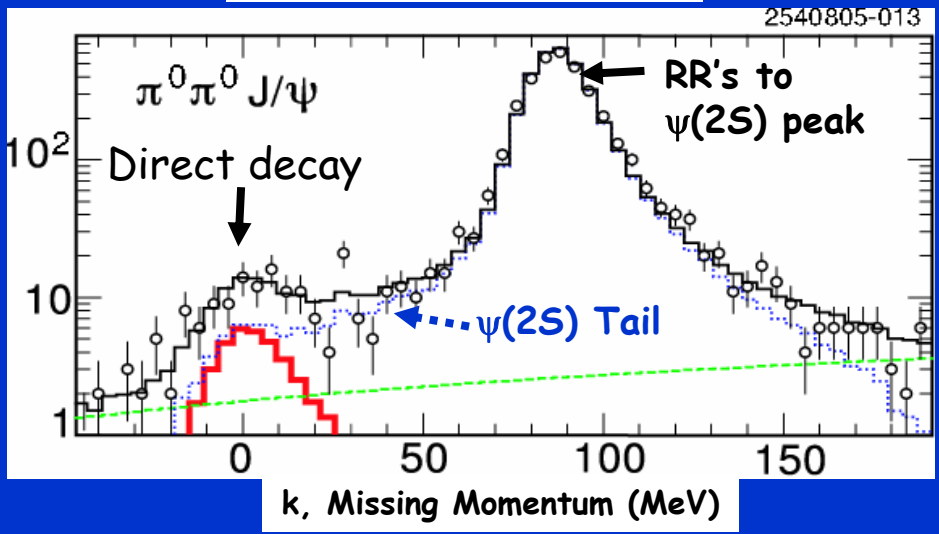
E_{CM}(MeV)	$\mathcal{L}$ (pb^{-1})	E_{CM}(MeV)	$\mathcal{L}$ (pb^{-1})
3773	281	4120	2.8
3970	3.9	4140	4.9
3990	3.4	4160	10.2
4010	5.6	4170	55
4015	1.5	4180	5.7
4030	3.0	4200	2.8
4060	3.3	4260	13.2

The CLEO Dataset



Build on previous analysis



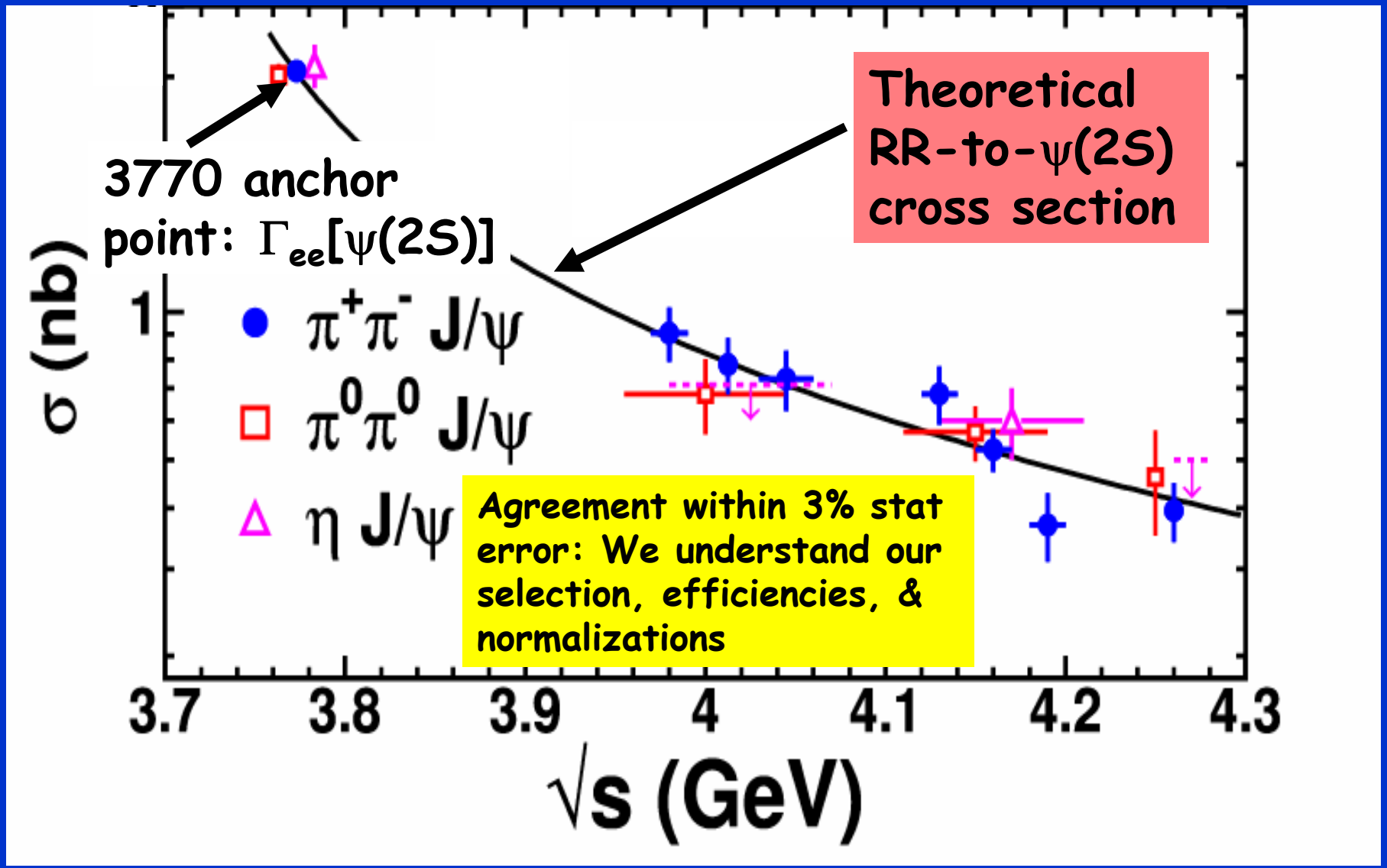


Recall $\psi(3770) \rightarrow XJ/\psi$:

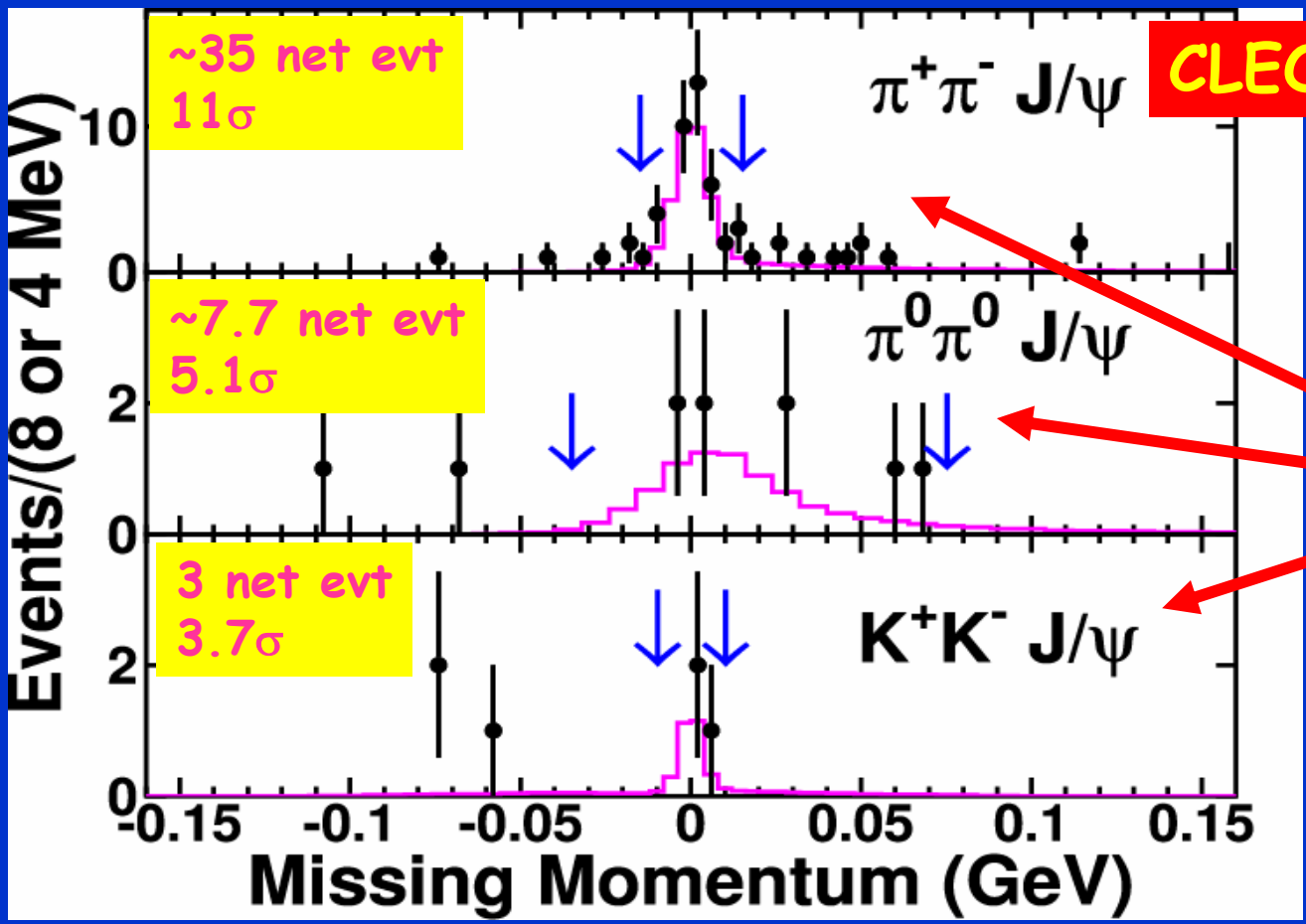
Adam et al., PRL 96 (2006) 082004

- Plot k=missing momentum (radiative photon energy)
- Small signal at k=0 [direct $\psi(3770)$ decay]
- Huge peak corresponding to $\gamma\psi(2S)$, $\gamma\psi(2S) \rightarrow XJ/\psi$ (radiative return, "RR")
- RR leaks well into the k=0 region, peaks there: 1/k
- Direct & RR's very well separated
- #RR's $\propto \Gamma_{ee}[\psi(2S)]$: predictable

Large k: $e^+e^- \to \gamma\ \psi(2S)$



Now focus on k≈0



CLEO √s=4260 data

- Almost pure signal
- BaBar was right!
- CLEO adds $\pi^0\pi^0 J/\psi$, & $K^+K^- J/\psi$

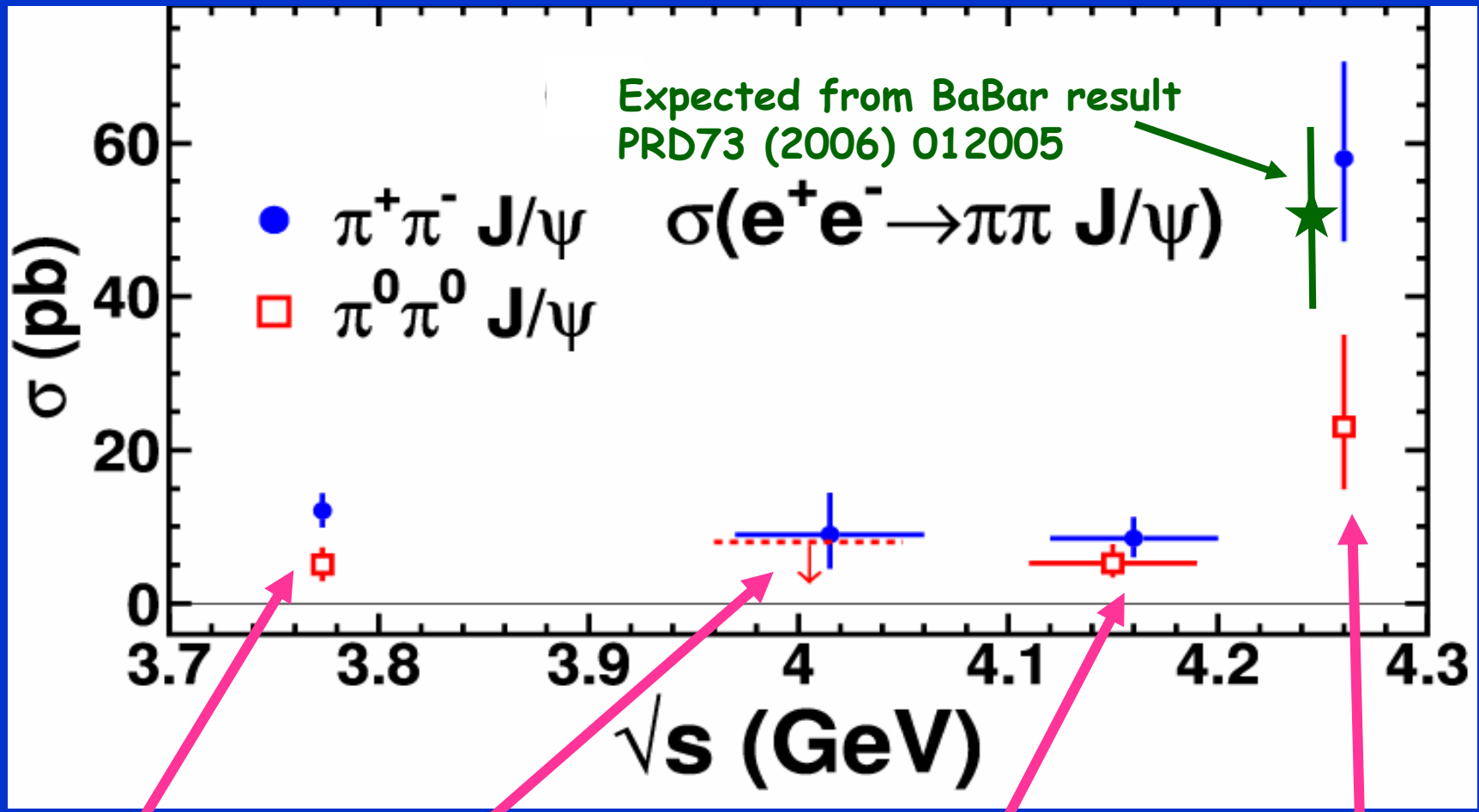
Backgrounds from J/ψ sidebands & RR's to ψ(2S) tail near k=0 are small!

Results@$\sqrt{s}$=4260 MeV

Channel	ε(%)	N_{sig}	N_{bgd}	σ(pb)	B/B($\pi^+\pi^-$ J/ψ)
$\pi^+\pi^-$ J/ψ	38	37	2.4	$58^{+12}_{-10}\pm4$	1
$\pi^0\pi^0$ J/ψ	22	8	0.3	$23^{+12}_{-8}\pm1$	$0.39^{+0.20}_{-0.15}\pm0.02$
K^+K^- J/ψ	21	3	0.07	$9^{+9}_{-5}\pm1$	$0.15^{+0.10}_{-0.08}\pm0.02$
η J/ψ	16	5	2.7	<32	<0.6
π^0 J/ψ	22	1		<12	<0.2
η' J/ψ	11	0	1.5	<19	<0.3
$\pi^+\pi^-\pi^0$ J/ψ	22	0		<7	<0.1
$\eta\eta$ J/ψ	6	1		<44	<0.8
$\pi^+\pi^-$ ψ(2S)	19	0		<20	<0.3
η ψ(2S)	15	0		<25	<0.4
$\omega\chi_{c0}$	9	11	11.5	<234	<4.0
$\gamma\chi_{c1}$	26	1	3.3	<30	<0.5
$\gamma\chi_{c2}$	27	4	3.3	<90	<1.6
$\pi^+\pi^-\pi^0$ χ_{c1}	9	0		<46	<0.8
$\pi^+\pi^-\pi^0$ χ_{c2}	9	0		<96	<1.7
$\pi^+\pi^-$ ϕ	18	7	5.5	<5	<0.1

$\pi^+\pi^-$ ϕ: <0.102 BaBar (prelim: hep-ex/0605086)

ππ J/ψ cross sections



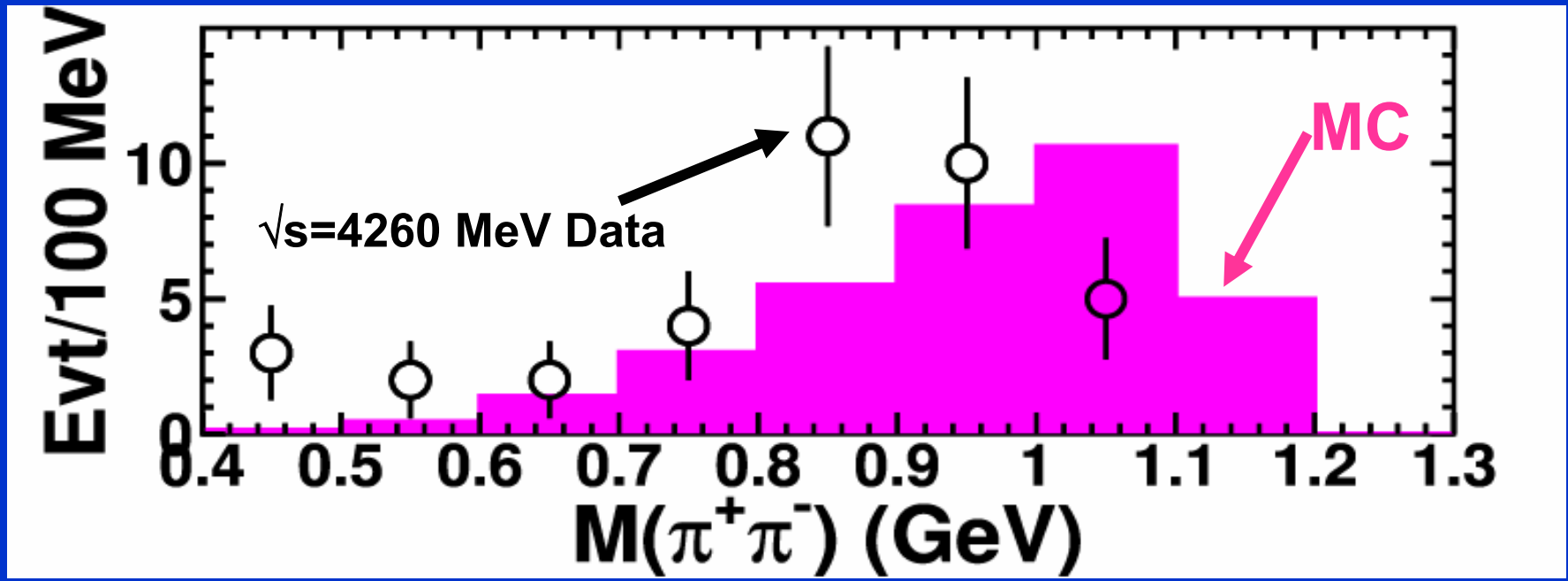
ψ(3770) signal

ψ(4040) signal?

Entire signal @4160 consistent with tail of Y(4260)

Y(4260) signals

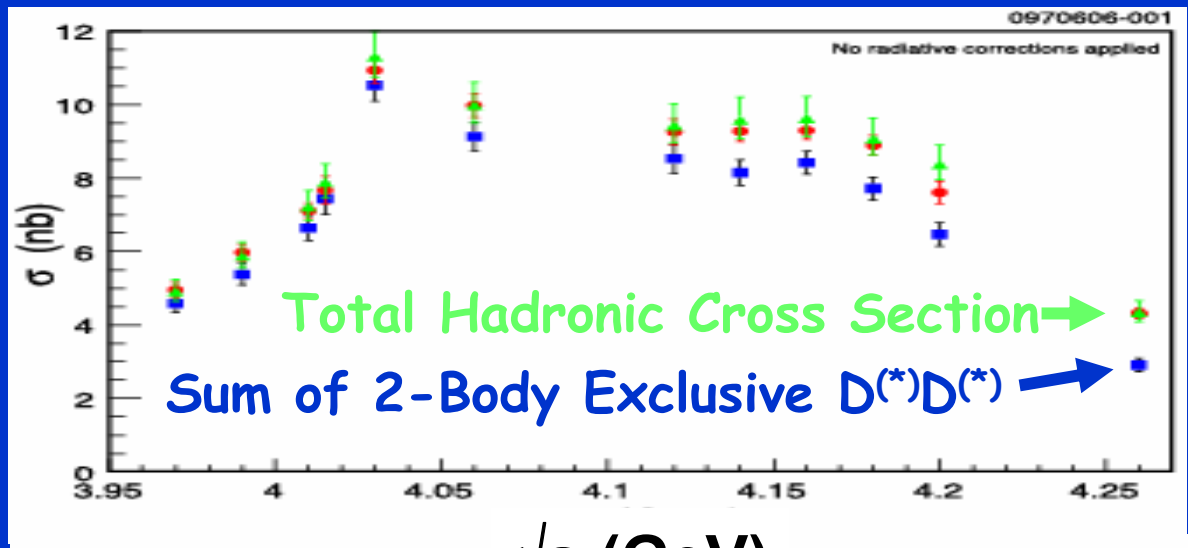
$\pi\pi$ Mass Spectrum

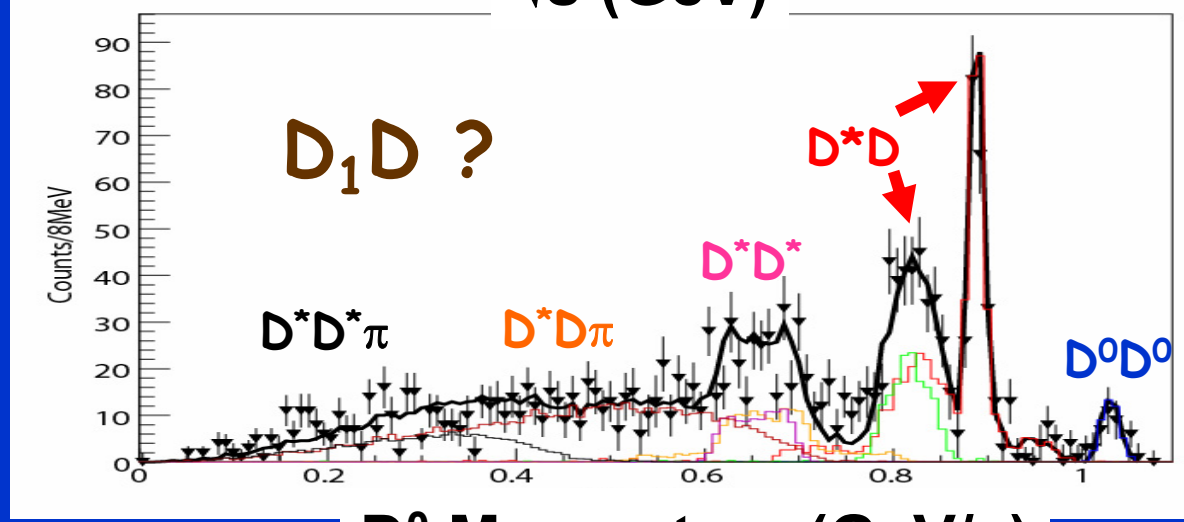


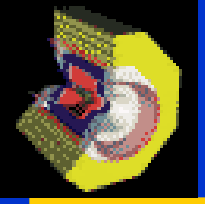
- Plot shown is <u>efficiency-corrected</u>
- No suggestion of $f_0(980)$ or $f_0(600)$ [$\equiv\sigma$] (contrary to some interpretations of BaBar spectrum, which has worse statistics)
- Slightly softer than $\psi(2S)$-like MC spectrum

Open Charm@4260

- Hybrid charmonium ⇒ $Y \to D_1 D$, $D_1' \; D \to (D^*\pi)\, D$
- 2-body open charm decomposition crucial to finding a $D_1 D$ enhancement from Y(4260)
- Difficult to distinguish from multibody production, e.g. $D^*D\pi$, $D^*D^*\pi$!
- Total charm cross section at 4260 ≈ 4 nb
- But $\pi^+\pi^- J/\psi$ is ≈ 50pb
- Need to understand open charm decomposition at ~1% level. P(D^0), angles, lower √s? HELP ?!





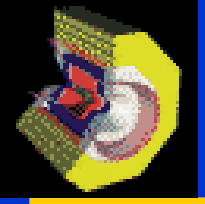


Conclusions

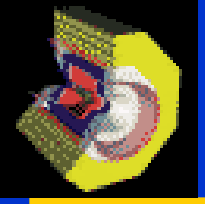
- 4.9σ evidence for Y(4260)→$\pi^+\pi^-$J/ψ in ISR from √s=10 GeV data: M, Γ consistent w/BaBar

- Direct e^+e^-→Y(4260) studies @ √s=4260 MeV
  - Signals: $\pi^+\pi^-$ J/ψ (11σ), $\pi^0\pi^0$ J/ψ (5.1σ), & K^+K^- J/ψ (3.7σ)
  - σ($\pi^+\pi^-$J/ψ) ≈ BaBar expectation
  - M(ππ) shows no structure [no $f_0(980)$ or $f_0(600)$]
  - B[ψ(4040)→ $\pi^+\pi^-$ J/ψ]<0.4% & B[ψ(4160)→ $\pi^+\pi^-$ J/ψ]<0.4%
  - Limits placed on 12 other charmonium decay modes & $\pi^+\pi^-$ φ
  - Data provides no support for Y(4260) as glueball, ψ(4S), χ_{cJ} ρ^0 molecule, or baryonium
  - Hybrid interpretation still alive & kicking

    - Y(4260)→open charm under study: Challenge in the exclusive decomposition.



Backup Slides

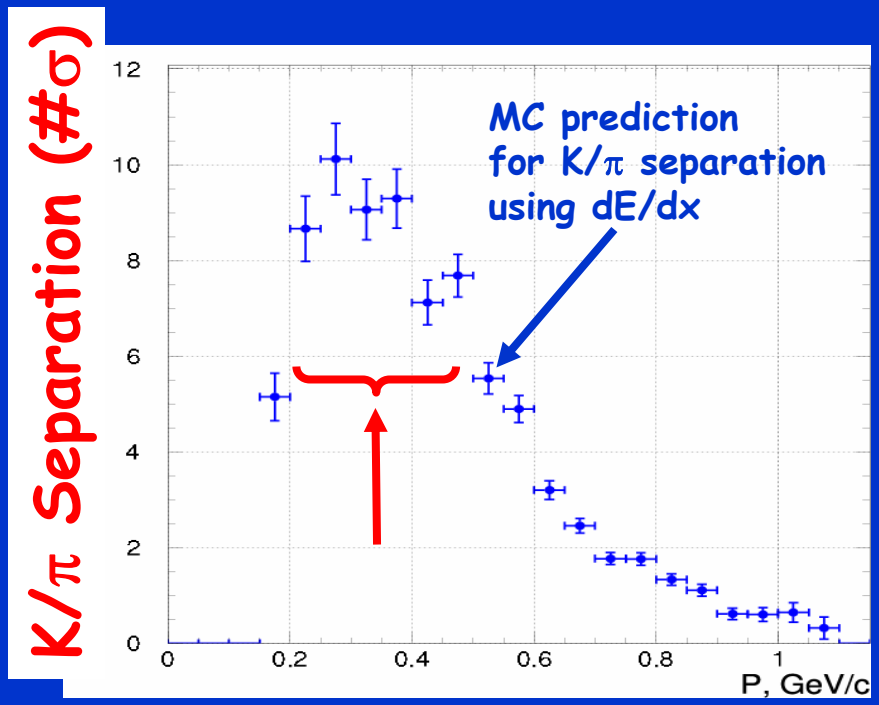


Selection & Backgrounds

- $J/\psi \to l^+l^-$: e & μ ID, bremm recovery, ~3σ dilepton mass cut
- Require event missing momentum consistent with zero within ~2.5σ
  - No missing particles!
- Background: $e^+e^- \to \gamma$ J/ψ with γ conversion
  - Require M($\pi\pi$)>400 MeV
- $e^+e^- \to \gamma$ $\psi(2S) \to \gamma$ $\pi\pi J/\psi$
  - Calibrate rate with radiative returns to peak of $\psi(2S)$ Breit-Wigner
  - Will occur at a fixed missing momentum at each E_{cm}
  - Tail of $\psi(2S)$ Breit-Wigner: $\psi(2S) \to \pi\pi J/\psi$ (no missing mom)
    - Looks just like signal, dead-reckon with theoretical calculation
- $e^+e^- \to \pi\pi\pi\pi$, $\pi\pi KK$, eeee, ee$\mu\mu$, ee$\pi\pi$
  - Will satisfy kinematics! (Corollary: Will do so for any "M(J/ψ)".)
  - Subtract statistically with WIDER "Fake M(J/ψ) Sidebands" around 2.9 & 3.3 GeV instead of 3.097 GeV
  - 20x size of $\pi^+\pi^-$ window
  - ~5x size of $\pi^0\pi^0$ window
  - 30x size of K^+K^- window
  - 12x size of η window
    - ✓ Naïve scaling by window size cross-checked by counting yields in signal and sideband windows in background MC

KK J/ψ

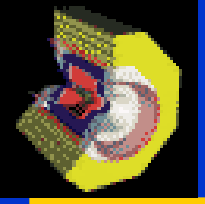
- Kinematically allowed for E_{cm}>4085
- Babar sees no signal



Our selection requires at least one of kaon candidates to have p=0.2-0.5 GeV/c & Kaon ID consistency @<3σ.

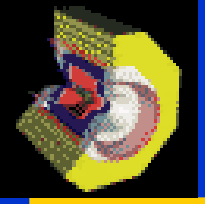
All 3 of our events have BOTH kaons id'd.

2 events in the 30x sidebands:
3 evt, 0.07 bgd:
3.7σ significance

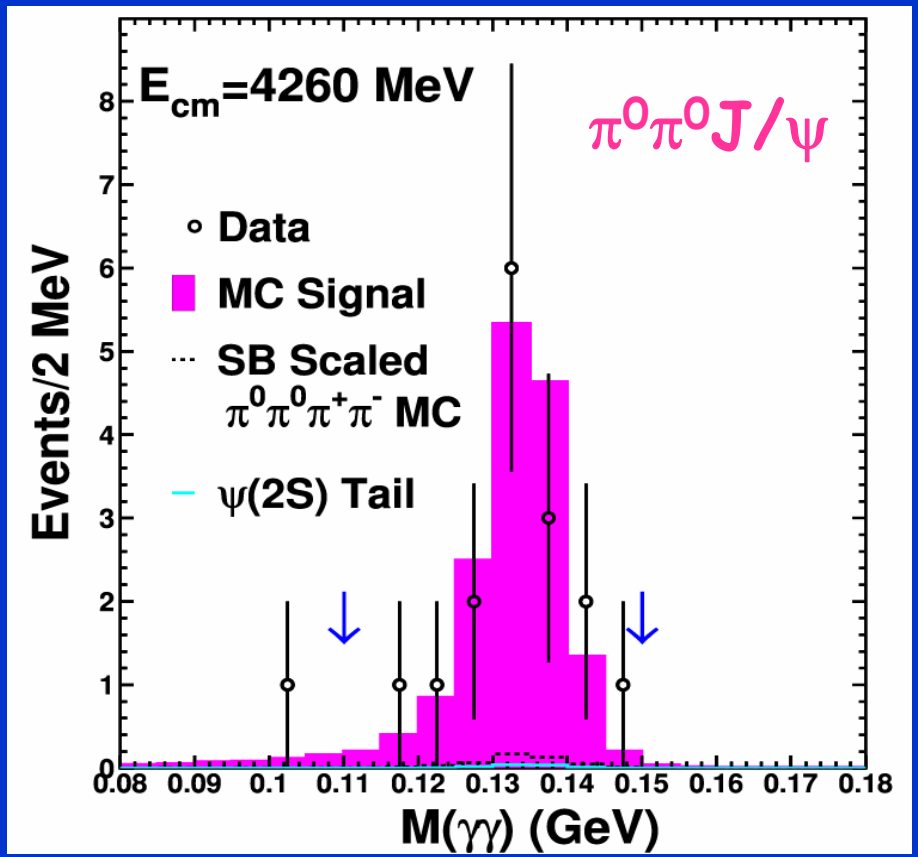


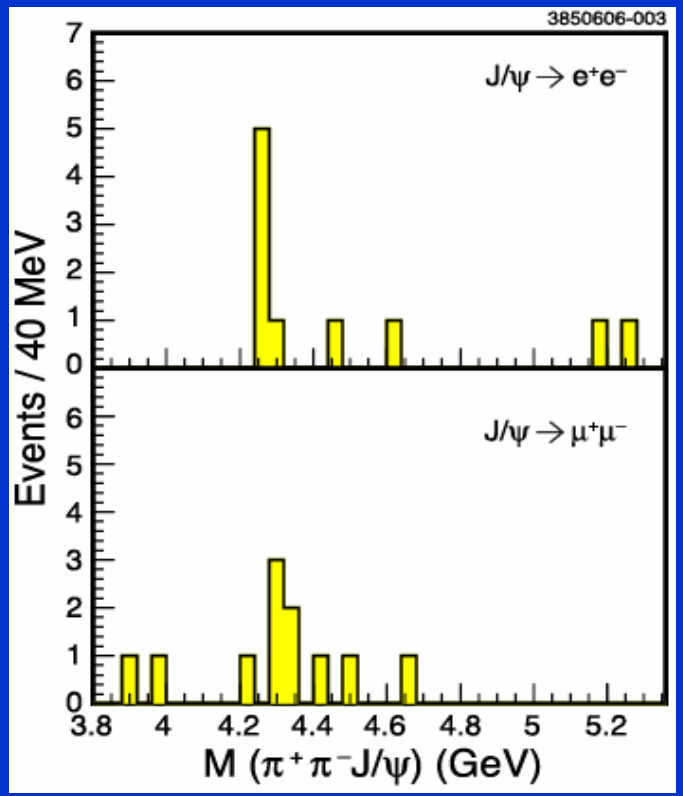
Systematics

- **Sources:**
  - tracking, lepton ID, particle ID, mass window cuts, k window cuts: conservative estimates lead to 5-10% in all modes
  - Background subtraction:
    - $\gamma\psi(2S)$ ~5%
    - Fake J/ψ subtraction (sidebands): smaller than $\gamma\psi(2S$
- **Statistical errors:** 16% ($\pi^+\pi^-$J/ψ at 4260) or larger



Other Features





What's known

- BaBar observed 8σ effect in radiative returns

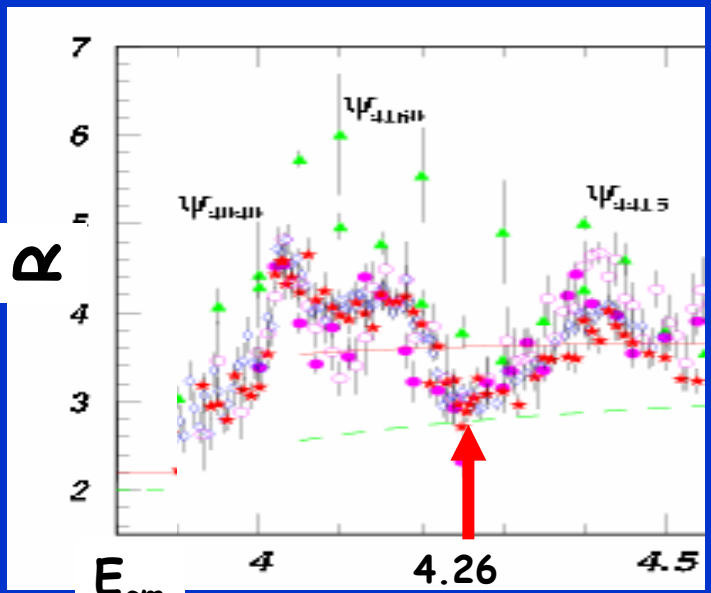
  $e^+e^- \to \gamma\ Y(4260)$

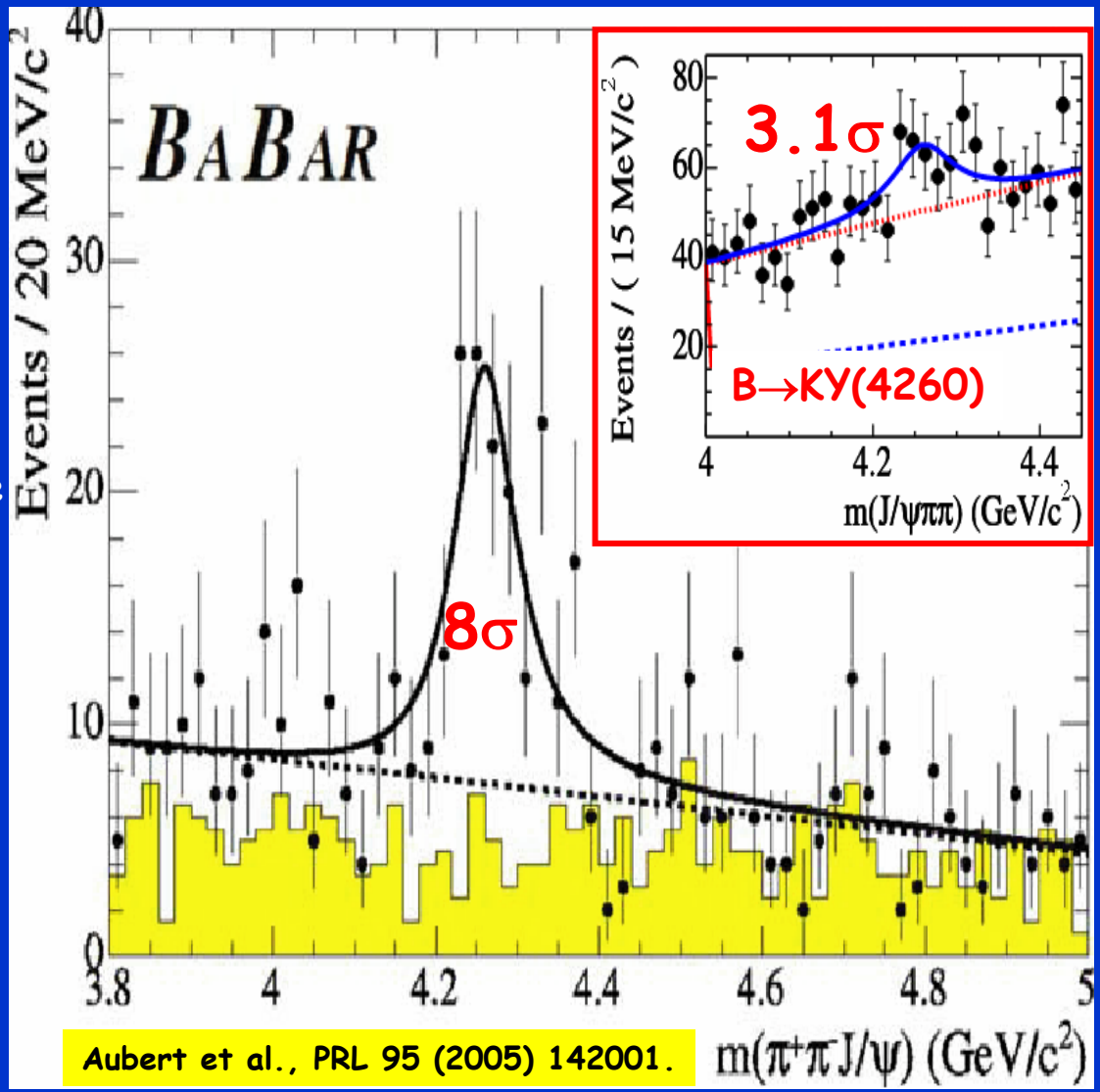
  $\to \gamma\ \pi^+\pi^-\ J/\psi$ AND

  3.1σ in $B^- \to K^-\ Y(4260)$

  $\to K^-\ \pi^+\pi^-\ J/\psi$

  - 50-90 MeV wide, 1 or several peaks
  - Predict 50 pb cross section for direct $e^+e^- \to Y(4260)$
  - No signal in two-photon production
- No official comment from Belle





CLEO & X(3872)

From summer 2004

- Limit coupling to 1γ or 2γ
- In CLEO $\sqrt{s}$=10 GeV data
- Look for 1^{--} in ISR:

  $e^+e^- \to (\gamma)$ X(3872)

  or for J=0, 2, C=+1 in untagged 2γ fusion

  $e^+e^- \to (e^+e^-)$ X(3872)
- X(3872)$\to \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$

$(2J+1)\Gamma_{\gamma\gamma}(X) \times B(X\to\pi^+\pi^- J/\psi) < 12.9$ eV

$\Gamma_{ee}(X) \times B(X\to\pi^+\pi^- J/\psi) < 8.3$ eV ,

both @90% CL

Dobbs et al. PRL 94 (2005) 032004