Confirmation of the Y(4260) and the D_s Scan

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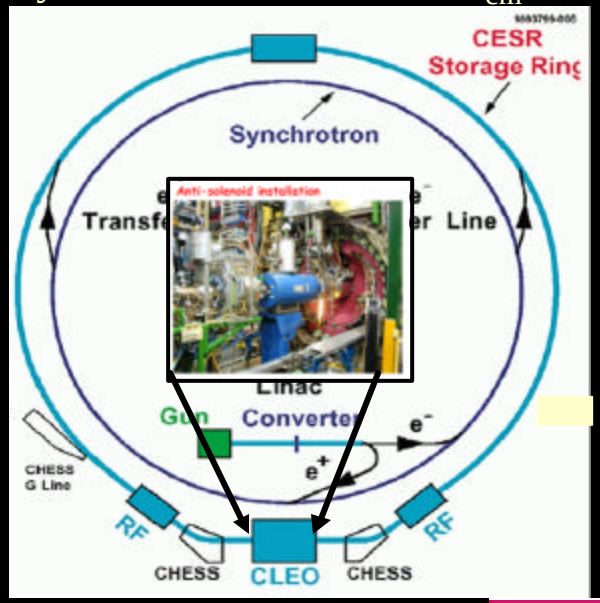
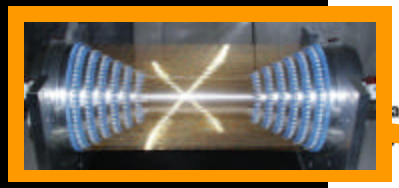
- Introduction
- The D_s Scan
- Confirmation of the Y(4260)
- Summary

CESR-c and CLEO-c

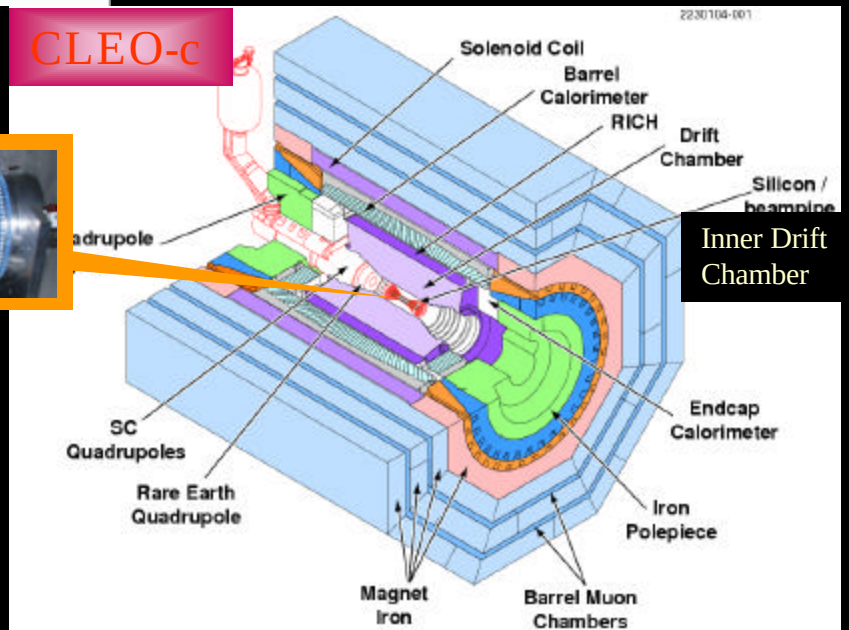
Symmetric e^+e^- collisions E_{cm}~4 GeV



- L ~ 4.2 pb^{-1}/day, up by ~20%
- Data in hand…
  - 281 pb^{-1} at $\psi(3770)$ ➔ ~ 1.8M $\bar{D}D$ pairs
  - ~200 pb^{-1} at $\psi(4170)$ ➔ 400K $\bar{D}_s D_s^*$ pairs
  - ψ' ~ 3M
- Looking ahead to 2008
  - ~1 fb^{-1} at both $\psi(3770)$ and $\psi(4170)$



CLEO-c



CLEO-*c* detector largely same as CLEO-III

- B field reduced from 1.5T→1.0T
- Silicon replaced with inner drift chamber

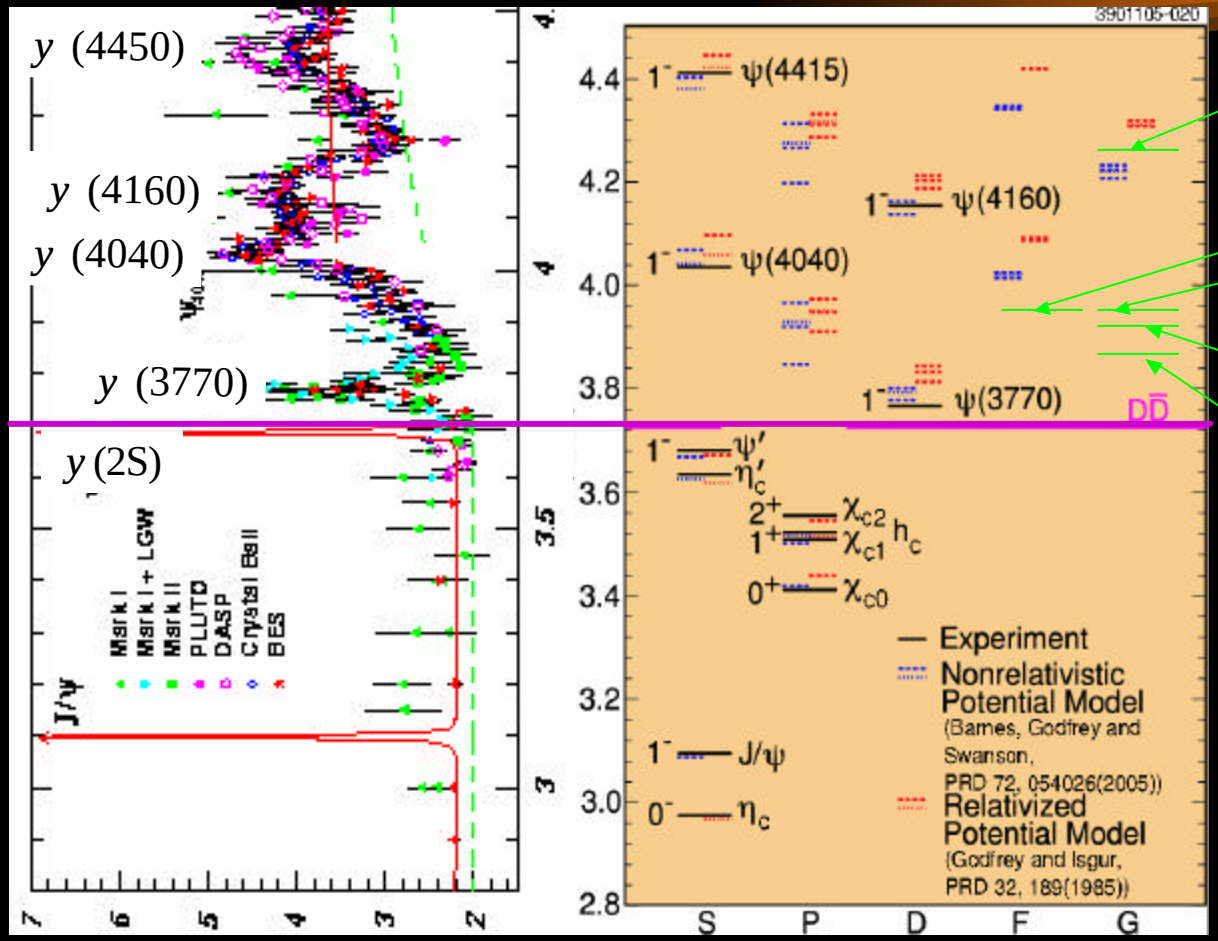
- **Tracking (93% of 4**π**)**:
  - σ_p/p ~ 0.6 %
- **CsI (93% of 4**π**)**:
  - σ_E/E ~ 5% at 100 MeV
    ~2.2% at 1 GeV
- **Particle ID**
  - RICH (80% of 4π)+dE/dx
  - ε_K>90% for π *fake*<5%

The $c\bar{c}$ Landscape

- Rich spectroscopy of states above DD threshold.
- 1^{--} states directly accessible in e^+e^- annihilation, ISR.
- Other states accessible through radiative and hadronic transitions
- $\psi(3770) \rightarrow DD$ dominant
  - No extra particles
  - Low multiplicity.
  - Coherent 1^- state.
  - Precision CKM physics

  using D mesons based on 281 pb^{-1}

  ➔ see talks by R. Briere (plenary), D. Cronin-Hennessy



Y(4260)

Y(3940)

X(3940)

Z(3930)

X(3872)

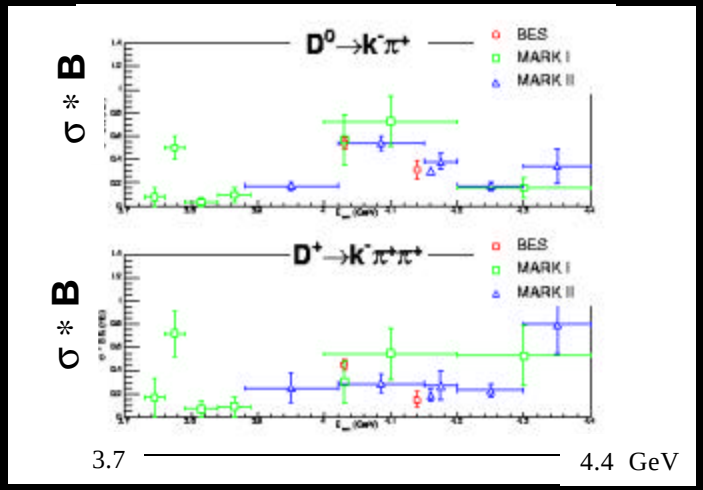
???

- Lots of great results on charmonium as well (See talk by A. Tomaradze)

The D_s Scan

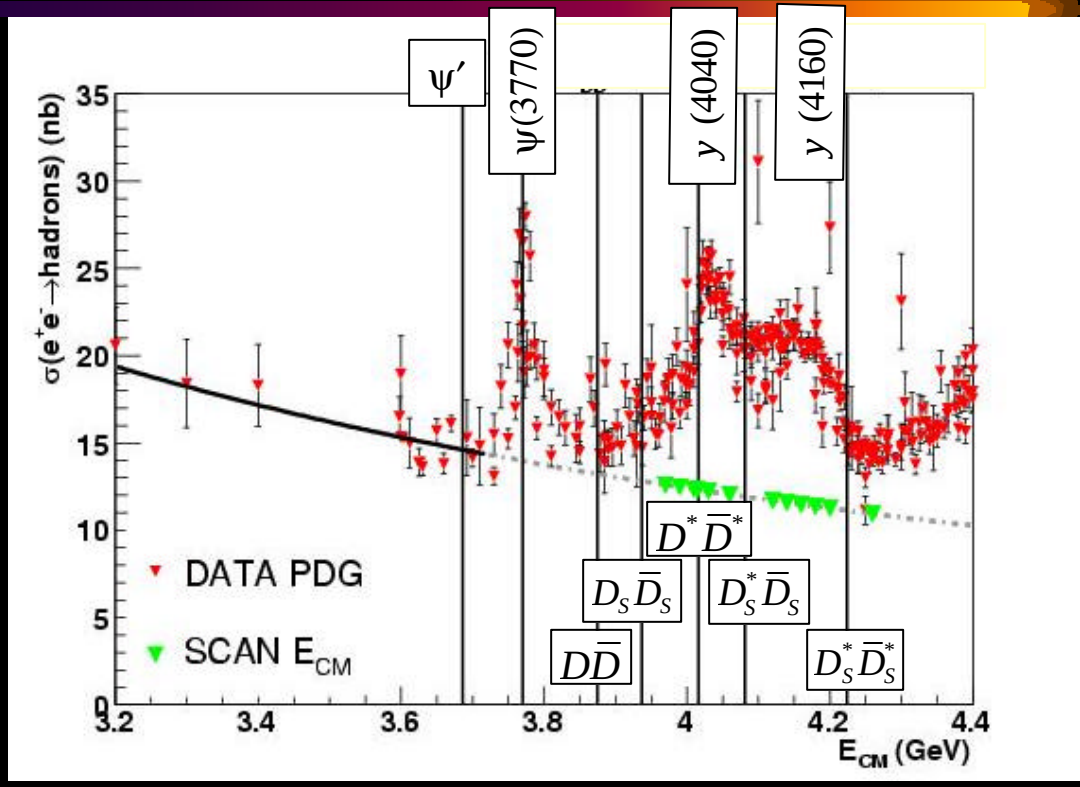
Scanning the Region: E_{CM} = 3970-4260 MeV

- **Primary Objectives**
  - Determine optimal energy for D_s studies.
  - Assess capabilities for D physics above $y(3770)$.



$s \cdot B(D_s \to fp) \sim 11$ pb (BES, at 4040 MeV)

$s \cdot B(D_s \to fp) \sim 26$ pb (Mark III, at 4140 MeV)

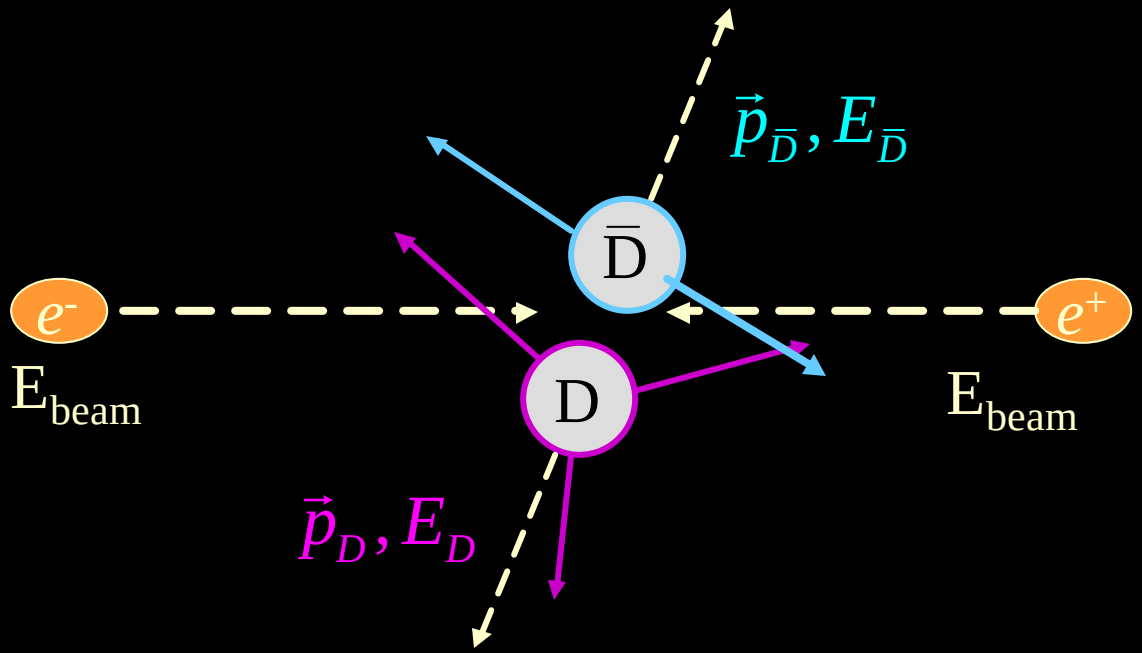


- **Additional Objectives:**
  - Detailed study of the hadronic cross section in the region above open-charm threshold.
  - $Y(4260)$: confirmation

- **Scan Data Sample:**
  - 12 energies, 60 pb^{-1}
  - As we increase energy, we cross various production thresholds

$D_{(s)}$ Reconstruction

- Play same game as at Y(4S) and ψ(3770).



For a given candidate, compute:

$$M_{bc} = \sqrt{E_{beam}^2 - p_D^2}$$

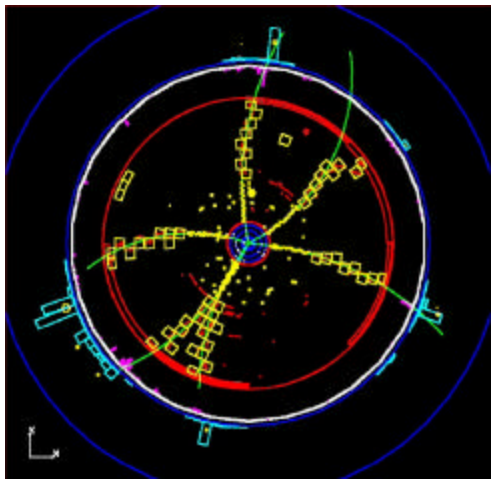
$$\Delta E = E_D - E_{beam}$$

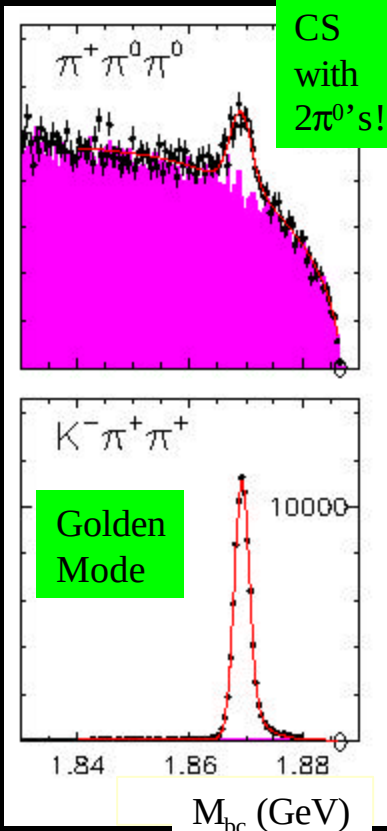
→ Essentially p_D, but less sensitive to changes in E_{beam}

Due to proximity to threshold, significant difference in (M_{bc},ΔE) space for

$D\bar{D}, D^*\bar{D}, D^*\overline{D^*}$ and $D_S\bar{D}_S, D_S^*\bar{D}, D_S^*\overline{D_S^*}$

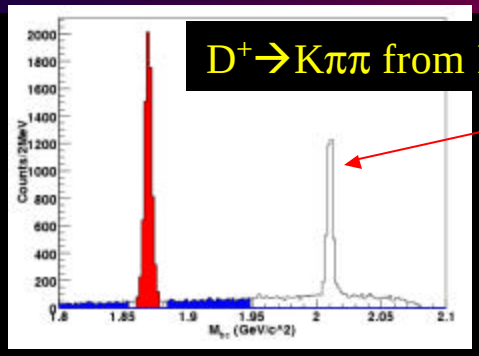
$D^+ \to K^-\pi^+\pi^+$ $D^- \to K^+\pi^-\pi^-$



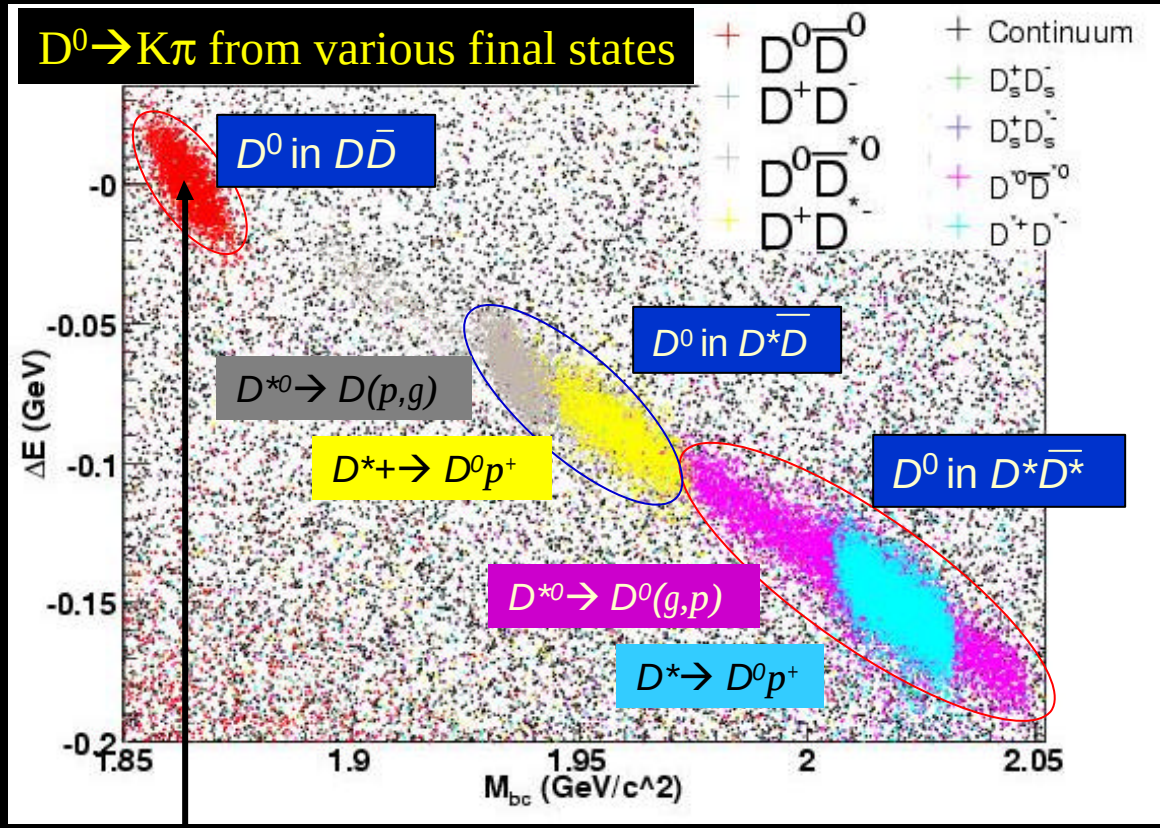


Simulations of Final States

- Reconstruct
  - D^0 in 3 modes
  - D^+ in 5 modes
  - D_s in 8 modes
- No need to reconstruct D^*, as M_{bc} differentiates event types.
- For $D\bar{D}$ and $D_s\bar{D}_s$ cut on ΔE and use M_{bc} to extract yields.
- For other event types cut on M_{bc} and use invariant mass to extract yield.
- Cut values determined by kinematics – no double counting allowed, cross-feed small and calculable.



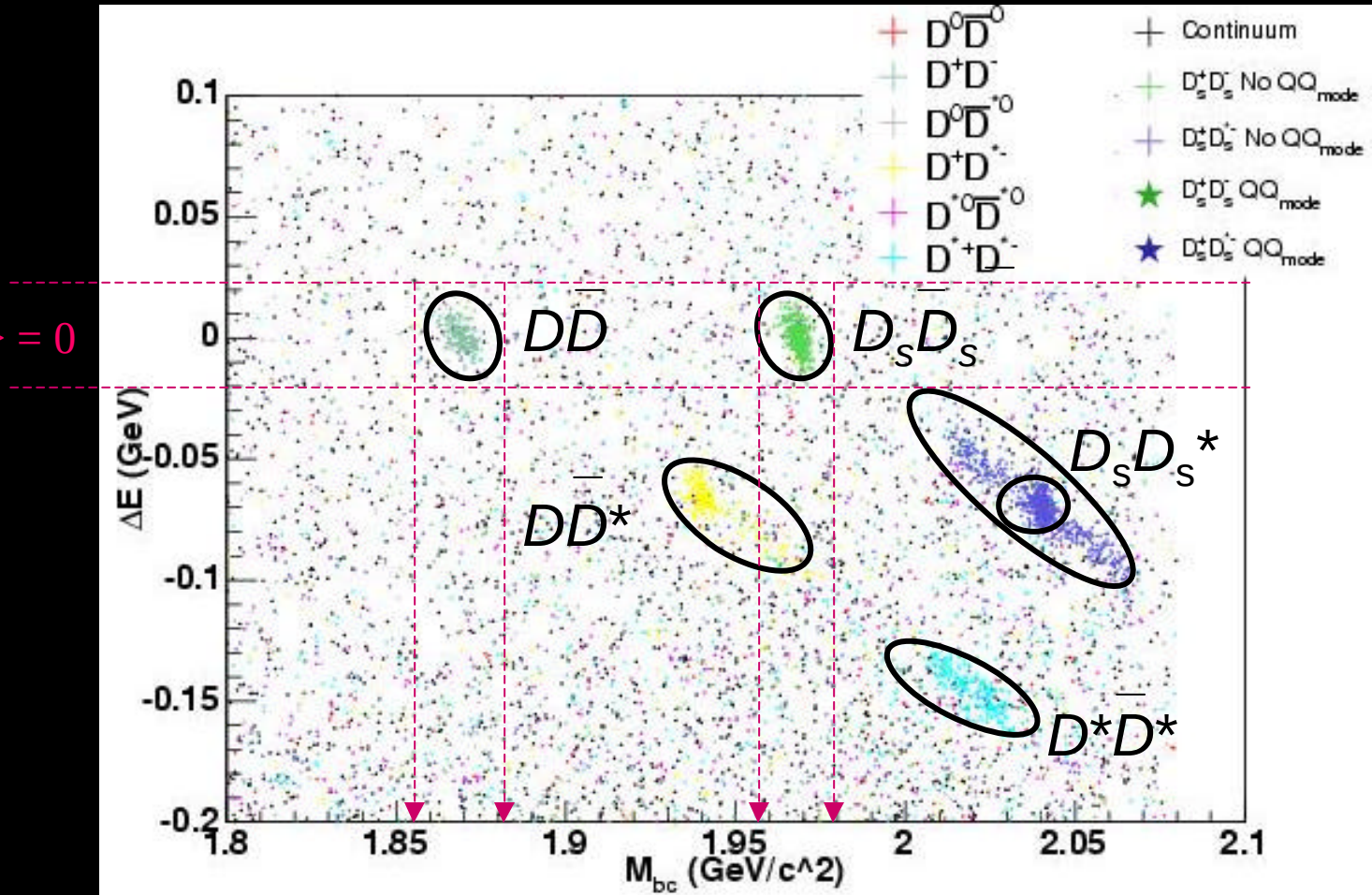
E_{cm} = 4160 MeV



$\langle M_{bc} \rangle = M_D$ and $\langle \Delta E \rangle = 0$ for $D\bar{D}$

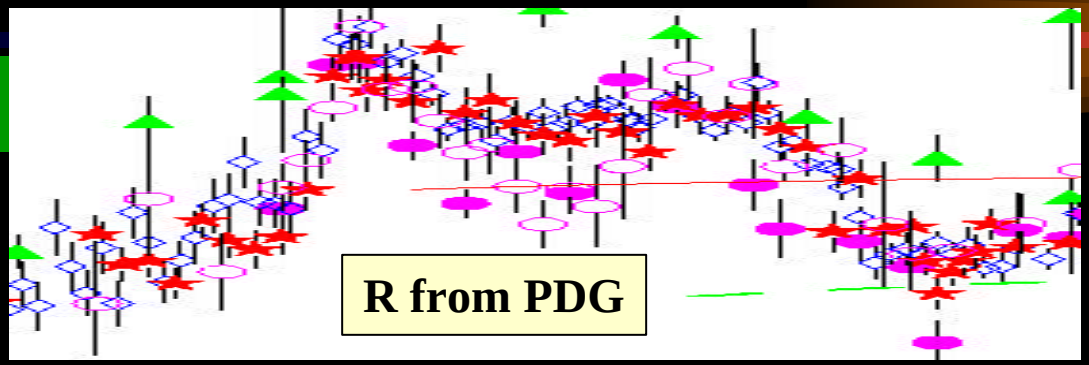
$D_s \rightarrow fp$ Reconstruction at 4160 (MC)

- Note CS $D^+ \rightarrow \phi\pi^+$
- **B**$(D^{*+} \rightarrow D^+\gamma)$=1.6% (broader component, as in D^0, very small)
- Broadening in $D_s D_s^*$ as expected due to photon



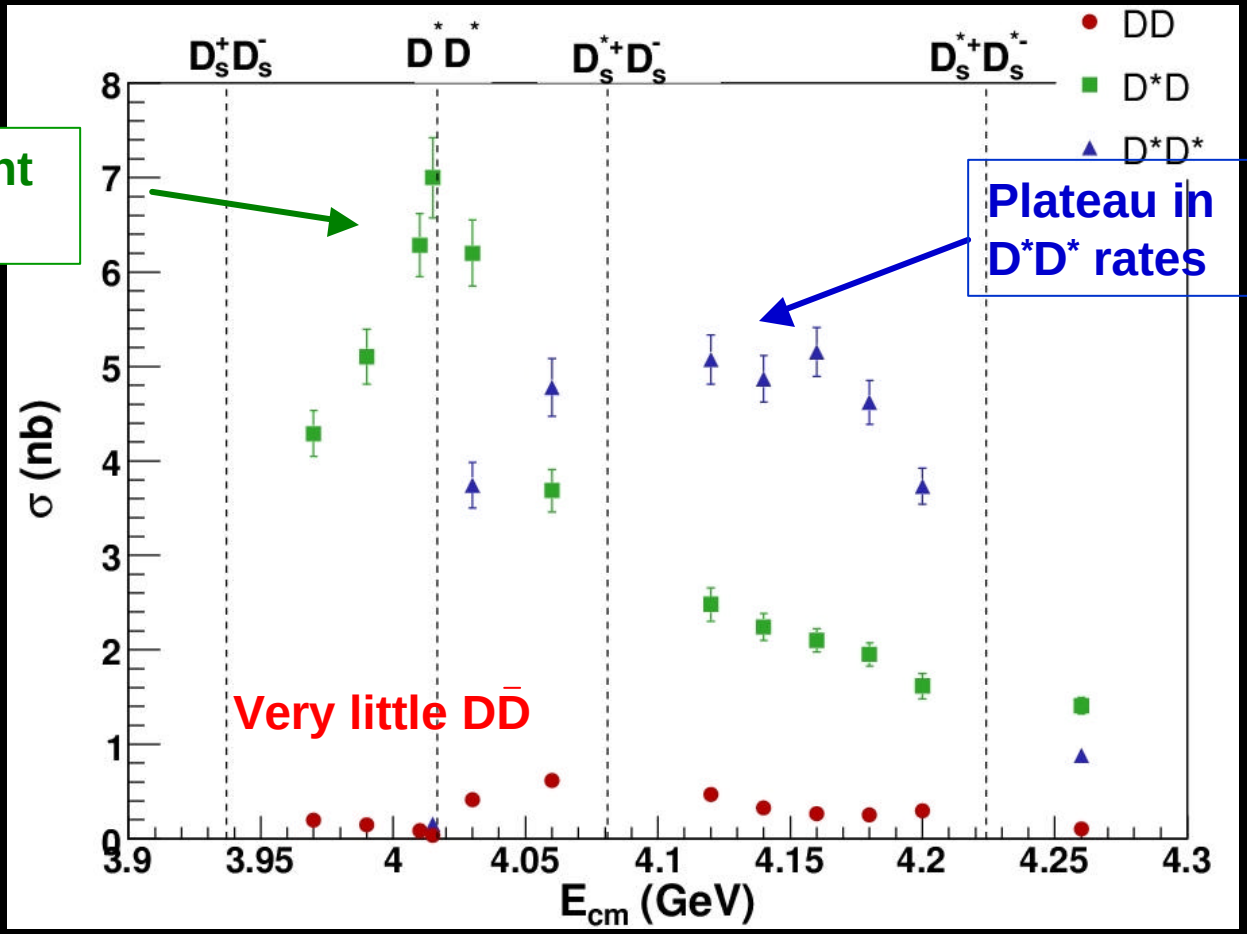
D Cross Section Measurement

PRELIMINARY



D*D Enhancement at D*D* threshold

Note:
$\sigma(D\bar{D})$~6.2 nb at $y(3770)$

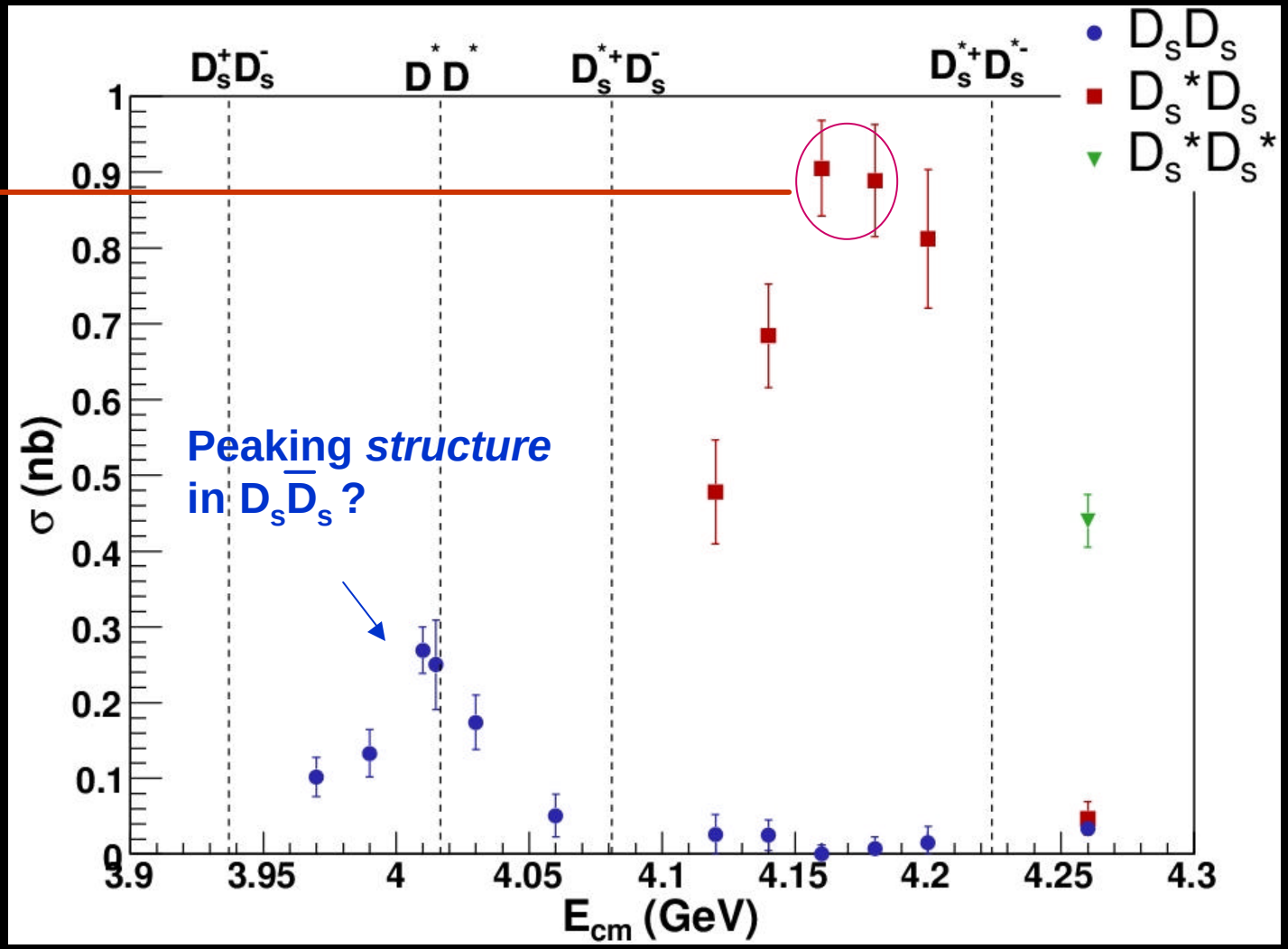


D_s Cross-Section Results

PRELIMINARY

Maximum D_s^+ yield, in $D_s^* D_s$

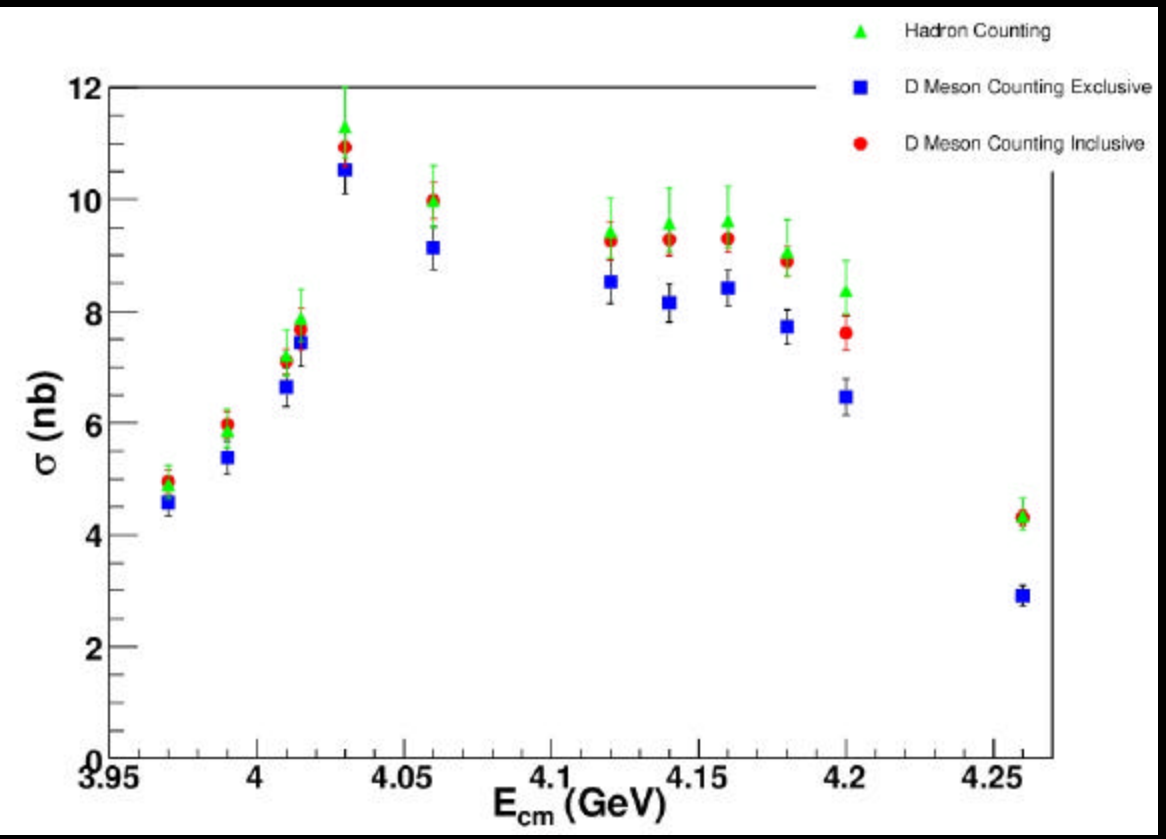
- Selected 4170 MeV as location for future D_s physics.
- 200 pb^{-1} in the can at 4170 MeV
- Goal: ~ 0.75 fb^{-1} by mid-2008



Inclusive vs. Exclusive

PRELIMINARY

Total $c\bar{c}$ cross section measured 3 ways



Inclusive hadron:
Count all hadronic events

D Meson Exclusive: sum up 3 DD and 3 D_sD_s exclusive cross-sections

D Meson Inclusive: Reconstruct all $D_{(s)}$ mesons, no requirement on ΔE, M_{bc} ➔ fit invariant mass.

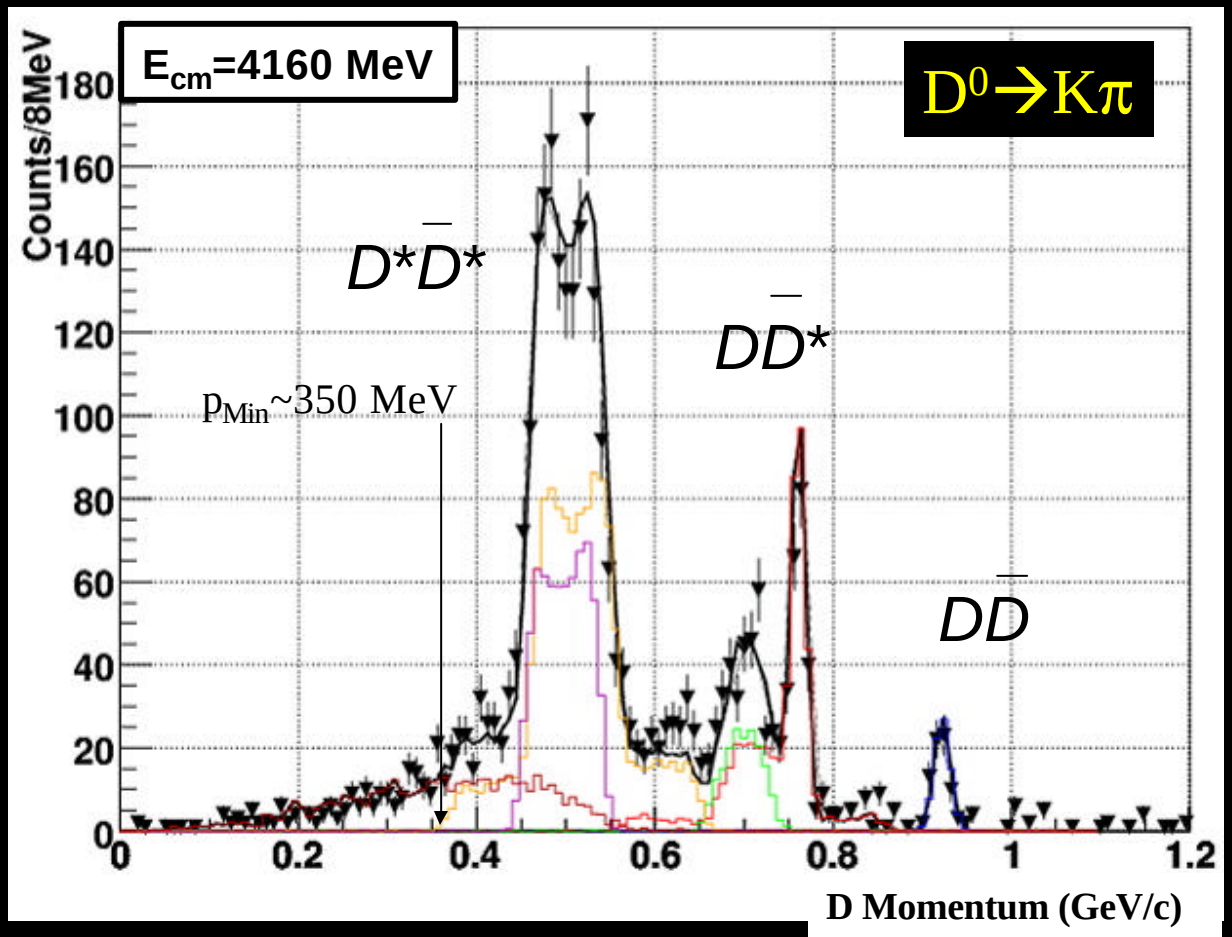
σ(Exclusive D) < σ(D inclusive) $\approx$ σ(hadrons)

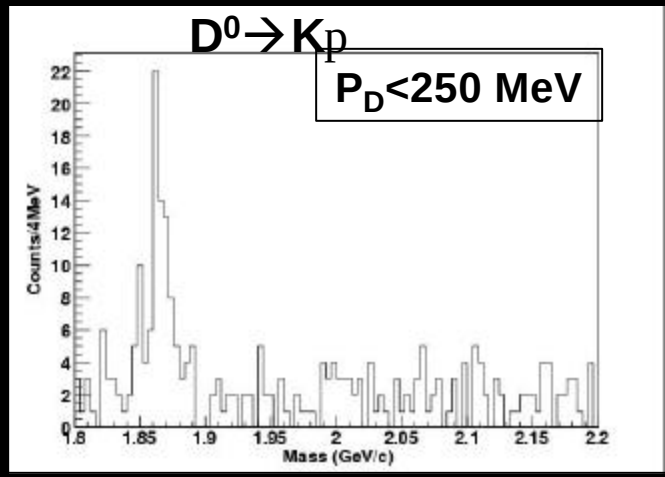
Are we missing something?

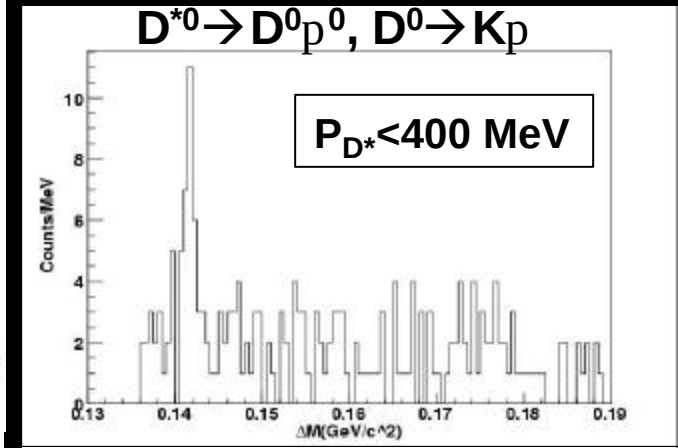
Are there multi-body events?

- **Look at momentum spectrum of $D^0 \to K\pi$**
- **Slowest D^0 from $D^*\bar{D}^*$ requires $p(D^0) > 350$ MeV/*c***

Work in progress to better understand these multi-body decays







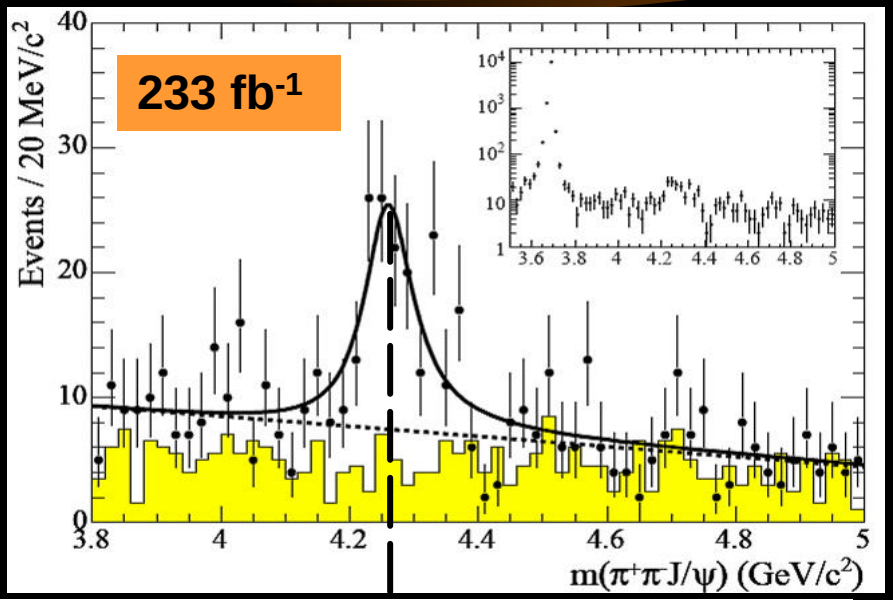
Confirmation of the Y(4260) via direct production in e^+e^- Annihilation and Observation of Y(4260) in ISR

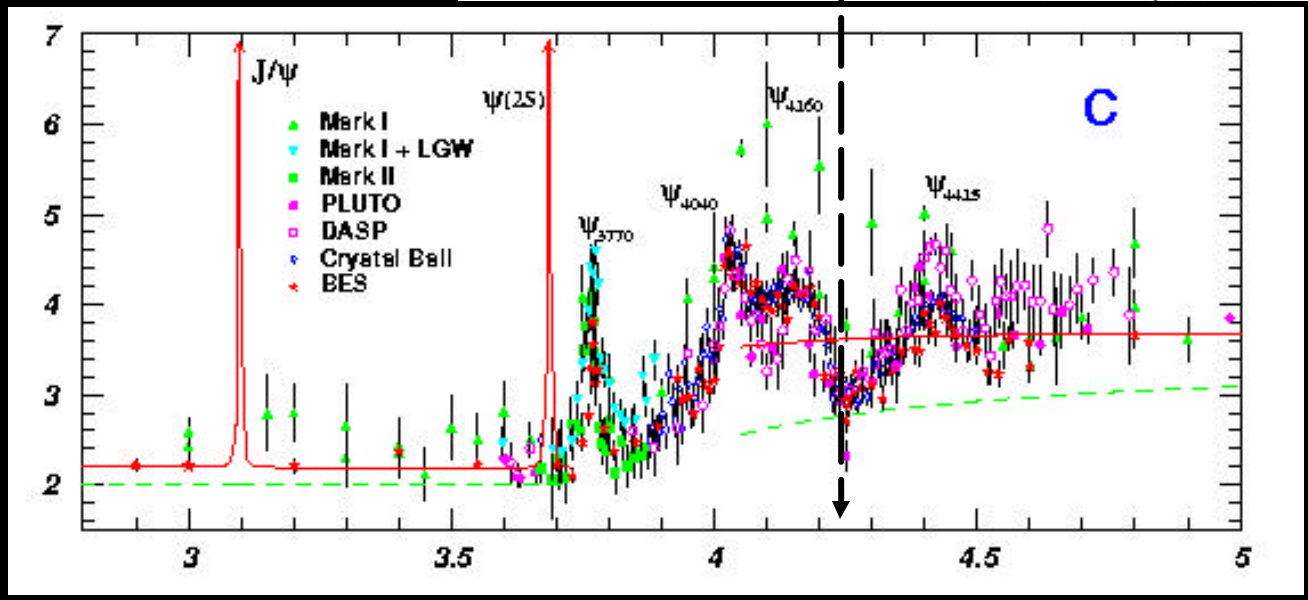
Also, see talks by J. Rosner (plenary), Eric Swanson, U. Mallik, Luc Hinz

Y(4260) Discovery

BaBar PRL **95**, 142001 (2005)

- e^+e^-? γ_{ISR}Y(4260), Y(4260)→$\pi^+\pi^- J/\psi$ ➔ $J^{PC}=1^{--}$
- At a minimum in $\sigma(e^+e^-$? hadrons)
- Why hasn't this been seen before?
  $\sigma(e^+e^- \rightarrow J/\psi\pi\pi) \approx 50$ pb^{-1} at 4.26 GeV
  (based on ISR rate at BaBar)
  Corresponds to **R~0.05**<<Error on $\sigma(e^+e \rightarrow$hadrons)
- Conventional ($c\bar{c}$) *ie.*, 4S or 2D state difficult to reconcile with expectations. ($B_{\psi\pi\pi}(4260) >> B_{\psi\pi\pi}(3770)$)
- What is it?
  Hybrid? $\chi_c\rho$ molecule?
  Conventional (cc)?
  Tetraquark ?
  Baryonium ? …

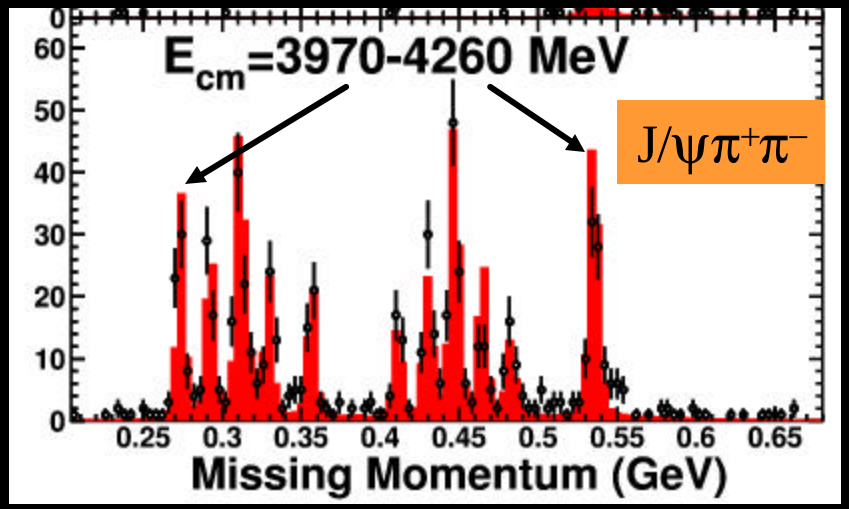


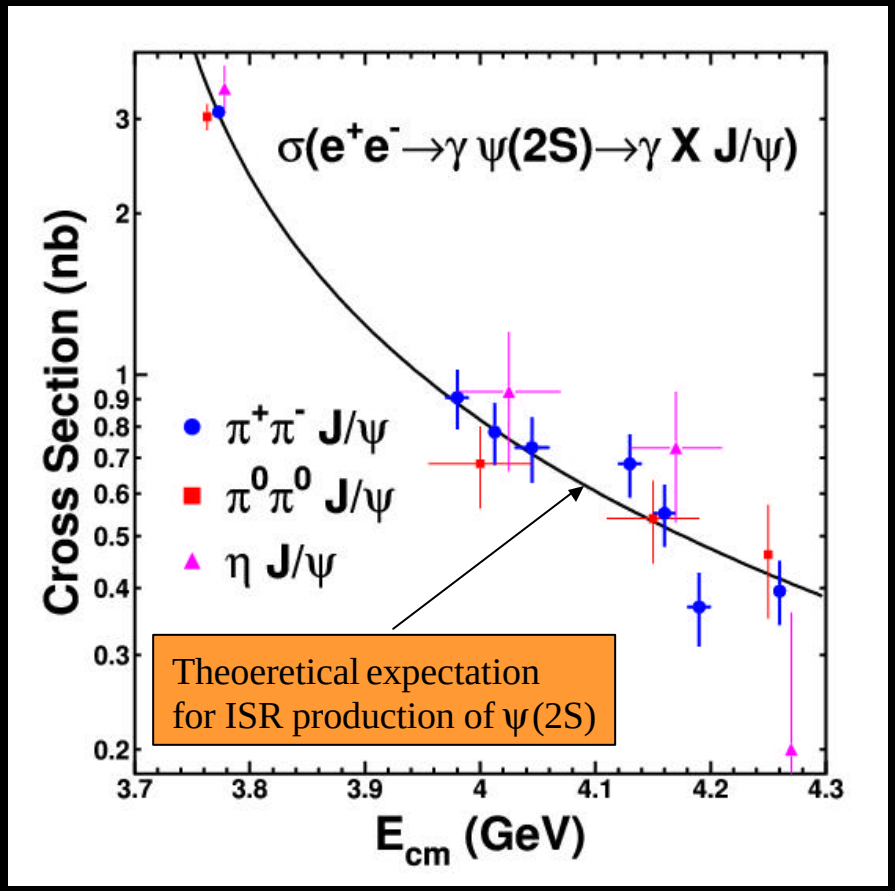


Direct Production in CLEO

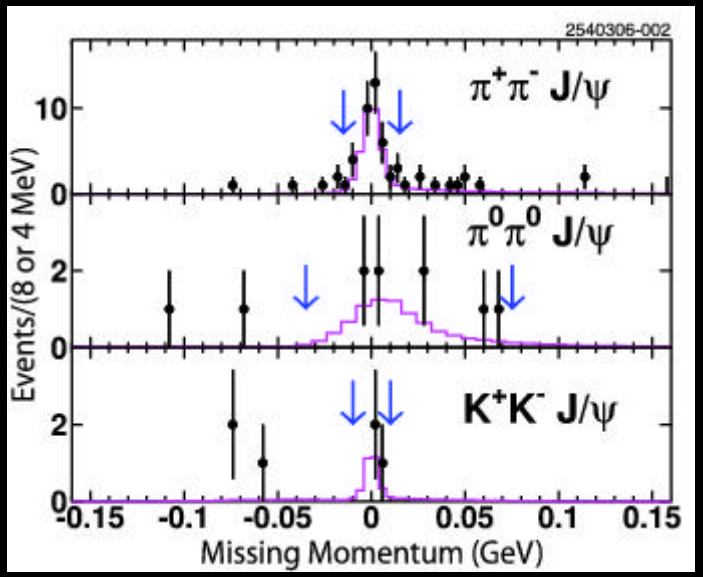
- *Key Variable:* *Missing momentum*
- *RR* $e^+e^-\rightarrow\gamma y(2S)\rightarrow(\pi^+\pi^- J/y\,,\ \pi^0\pi^0 J/y\,,\ \eta J/y\,)$ a good calibration, well understood
- Peaks at E_γ for $y(2S)$ RR, at 0 for $e^+e^-\rightarrow Y(4260)\rightarrow XJ/y$

Search for 16 final states:
$\pi^+\pi^- J/\psi$, $\pi^0\pi^0 J/\psi$, $K^+K^- J/\psi$,
$\pi^0 J/\psi$, $\eta J/\psi$, $\eta' J/\psi$, $\pi^+\pi^-\pi^0 J/\psi$, $\eta\eta J/\psi$,
$\pi^+\pi^-\psi(2S)$, $\eta\psi(2S)$,
$\omega\chi_{c0}$, $\gamma\chi_{c1}$, $\gamma\chi_{c2}$, $\pi^+\pi^-\pi^0\chi_{c1}$, $\pi^+\pi^-\pi^0\chi_{c2}$,
$\pi^+\pi^-\phi$

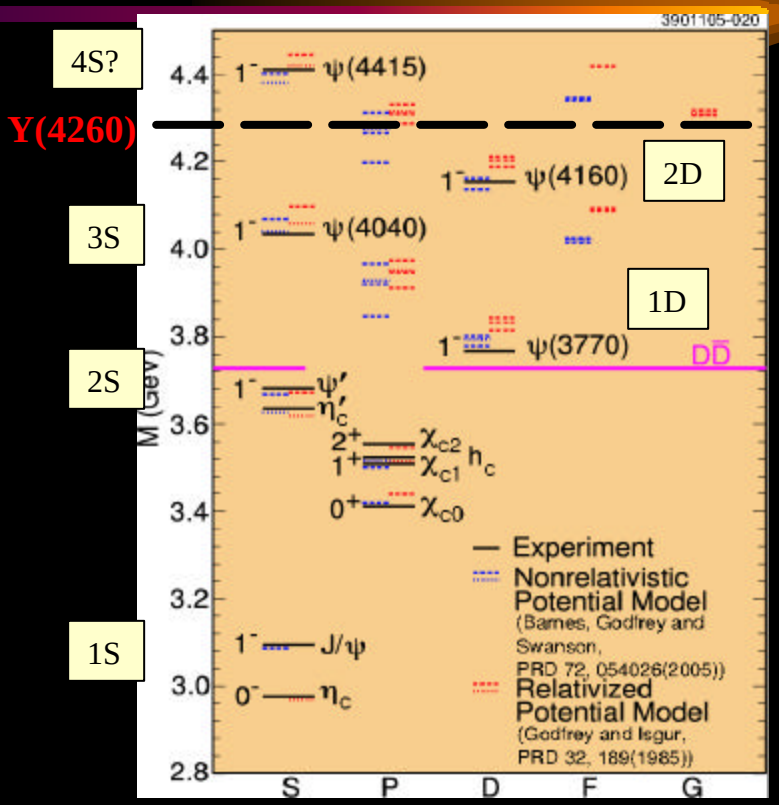




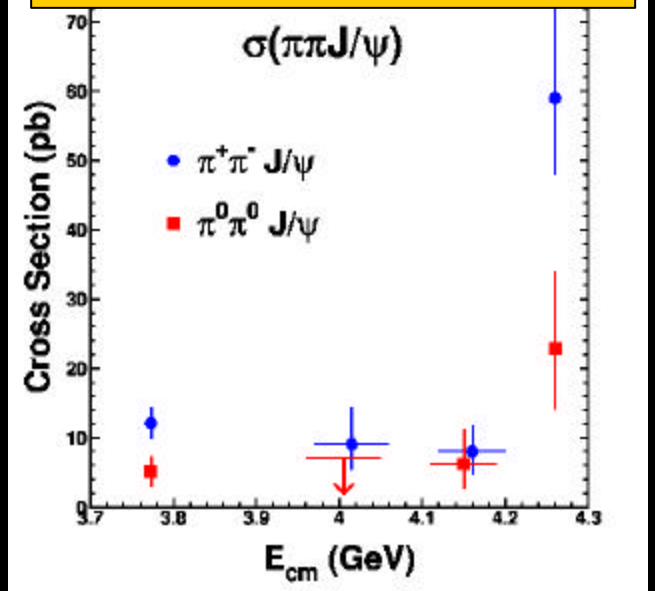
Results for the Y(4260)



N_{obs}	N_b	#s
37	2.4	11
8	0.3	5.1
3	0.07	3.7



$\sigma(e^+e^- \rightarrow Y(4260)) * \mathbf{B}(Y \rightarrow J/\psi\pi\pi)$



- $\chi_c\rho^0$ molecular model disfavored (Liu et al hep-ph/0507177)_
- Proposal that Y(4260) == ψ(4S), displacing ψ(4415) ➔ ψ(5S) also disfavored. ψ(4415)→J/ψππ small F. Estrada(hep-ph/0507035)
- Compatible with hybrid charmonium and tetraquark interpretations
  - ➔ need more studies with open charm final states

$\sigma(e^+e^- \rightarrow Y(4260)) * \mathbf{B}(Y \rightarrow J/\psi KK) = 9^{+9}_{-5} \pm 1$ pb

Y(4260) in ISR

PRELIMINARY

- Similar analysis as BaBar.
  Use ~13 fb^{-1} from Y(1S) – Y(4S)
- Select events consistent with
  $e^+e^- \rightarrow \gamma X$, $X \rightarrow J/\psi \pi^+\pi^-$, $J/\psi \rightarrow e^+e^-, \mu^+\mu^-$
- Cross-check analysis on X=ψ(2S) √
- Find:

$N_{ev} = 14.1^{+5.2}_{-4.2}$ $(4.9\,s)$

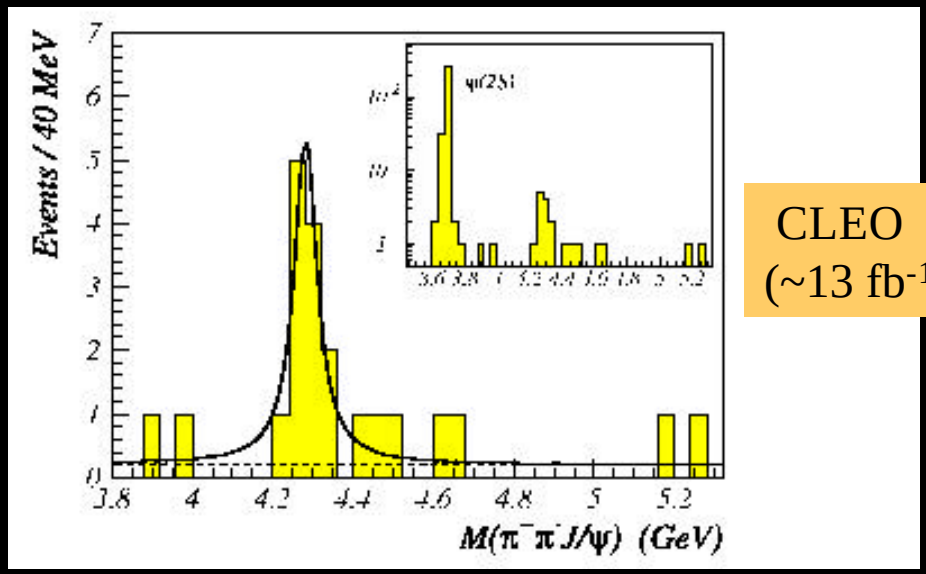
Mass = $4283^{+17}_{-16} \pm 4$ MeV

Width = $70^{+40}_{-25} \pm 5$ MeV

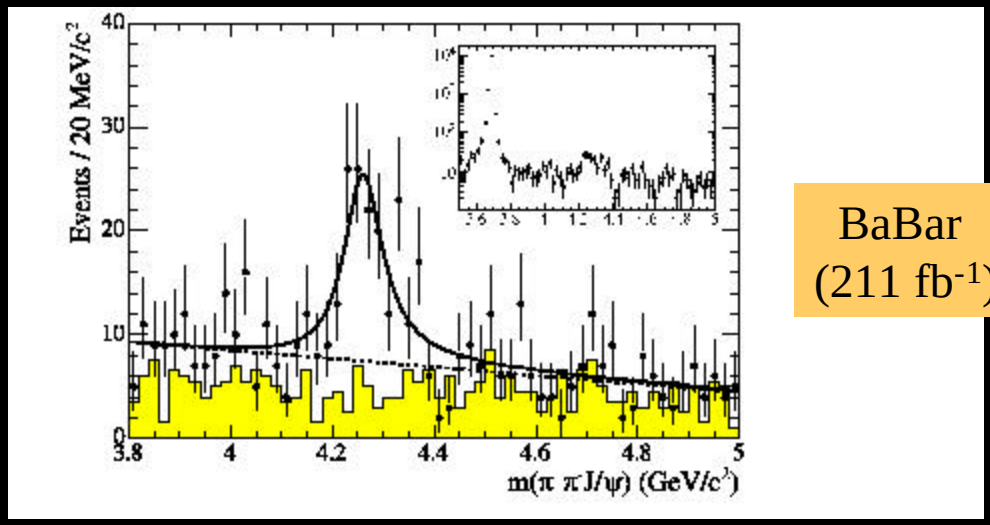
Consistent with BaBar

Mass = $4259 \pm 8^{+2}_{-6}$ MeV

Width = $88 \pm 23^{+6}_{-4}$ MeV



CLEO
(~13 fb^{-1})



BaBar
(211 fb^{-1})

Summary

- D_s scan data 3970-4260 MeV used to determine optimal energy for Ds program in CLEO-c.
  - E_{cm} = 4170 MeV best for D_s studies

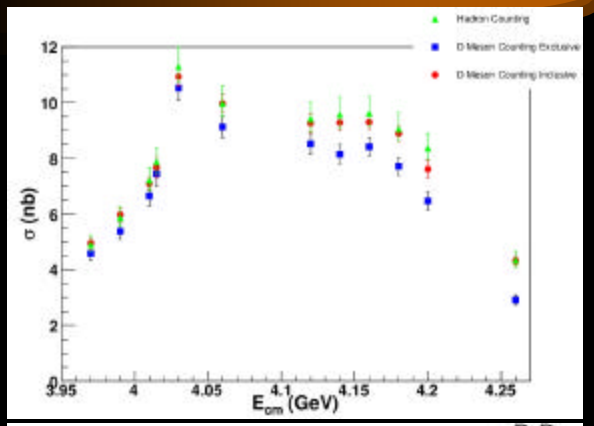
- 200 pb^{-1} at 4170 MeV now in hand.. Stay tuned…

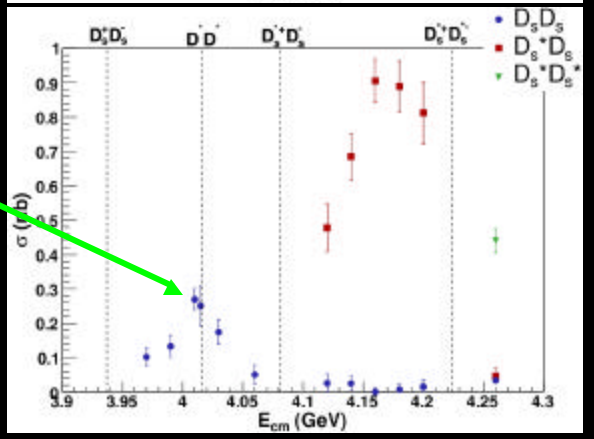
- Preliminary measurements of the $D_{(s)}^{(*)}D_{(s)}^{(*)}$ cross-sections, interesting features

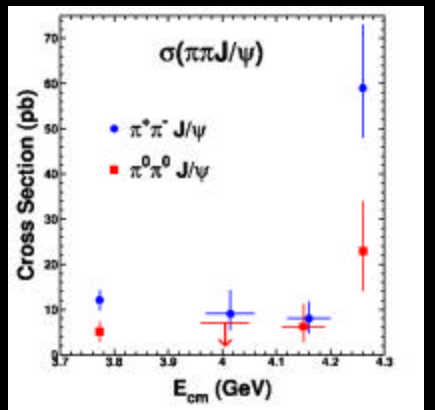
- Confirmation of the Y(4260) through direct production in e^+e^- annihilation.
  - Establish Y(4260)→$\pi^0\pi^0$J/ψ ~0.5(Y(4260)→$\pi^+\pi^-$J/ψ)
  - Evidence for Y(4260)→K^+K^-J/ψ
  - Upper limits on many other modes, also at 4040 and 4160

- Y(4260) also observed in ISR production

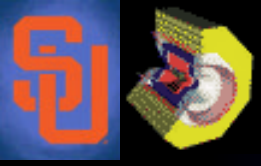
- Luminosity goals: ~0.75 - 1 fb^{-1} at ψ(3770), ψ(4170) each by mid '08. Near term: Another 100 pb^{-1} at 4170 MeV + ~30 M ψ' (July-Sep)







Stay Tuned !

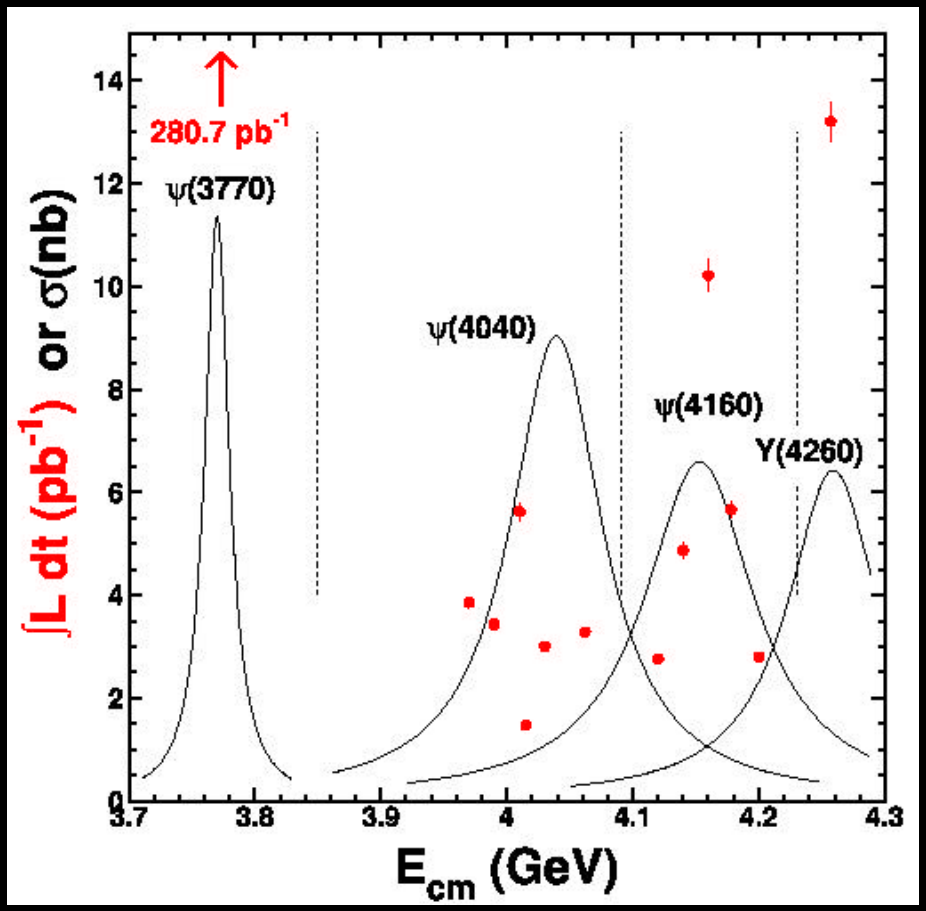


Backups

CLEO's Confirmation of Y(4260)

Phys. Rev. Lett.96:162003, 2006

- If it's a 1^{--} state, it should be directly accessible in e^+e^- annihilation.
- E_{cm}=4260 MeV was one of the scan points
- Search for 16 final states:
  $\pi^+\pi^- J/\psi$, $\pi^0\pi^0 J/\psi$, $K^+K^- J/\psi$,
  $\pi^0 J/\psi$, $\eta J/\psi$, $\eta' J/\psi$, $\pi^+\pi^-\pi^0 J/\psi$, $\eta\eta J/\psi$,
  $\pi^+\pi^-\psi(2S)$, $\eta\psi(2S)$,
  $\omega\chi_{c0}$, $\gamma\chi_{c1}$, $\gamma\chi_{c2}$, $\pi^+\pi^-\pi^0\chi_{c1}$, $\pi^+\pi^-\pi^0\chi_{c2}$,
  $\pi^+\pi^-\phi$



New states

In the last couple of years, several new states have appeared on the scene.

State	Mass (MeV)	Width (MeV)	Mode / decay	Comments	
X(3872)	$3872\pm0.5\pm0.6$	< 2.3 (narrow!)	$B\rightarrow X(3872)K^+$, $X(3872)\rightarrow J/\psi\pi^+\pi^-$	1^{++} favored	Belle03, (BaBar, CDF)
X(3940)	$3943\pm6\pm6$	< 52	$e^+e^- \rightarrow J/\psi+X(3940)$ $X(3940)\rightarrow DD^*$	η_c'' ??	Belle05
Y(3940)	$3943\pm22\pm26$	**87**$\pm11\pm13$	$B\rightarrow Y(3940)K^+$, $Y(3940)\rightarrow J/\psi\omega(\pi\pi\pi^0)$	If (cc) then $Y(3940)\rightarrow\psi\omega$ ~ 10% unusual	Belle05
Z(3930)	$3931\pm4\pm2$	**20**$\pm8\pm3$	$\gamma\gamma$-->DD	Consistent with J=2, but …	Belle05
Y(4260)	**$4259\pm6^{+2}_{-6}$**	**$88\pm23^{+6}_{-4}$**	**$e^+e^- \rightarrow g_{isr}$ Y(4260)** **Y(4260)$\rightarrow$ J/**y p^+p^-		**BaBar05, (CLEO06)**

All in the general region of the charmonium resonances,
Conventional charmonium hypothesis for all theses states difficult to explain

Tetraquarks? DD* molecules ??, hybrids??, Baryonium?? …… See review talk by Eric Swanson

Goals and Impact of CLEO-c

- Significant input for worldwide CKM program, both direct and indirect.
- Precision charm measurements + theory ➔ reduced uncertainties in *B* measurements
- Direct tests of lattice QCD and (potentially) other strongly-coupled theories to predict various hadronic parameters
- Crucial “engineering” input for others: branching fractions for normalization modes, etc.