New Spectroscopy with Charm quarks at B factories.

Charm 2006, Beijing

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*for The **BaBar** Collaboration*

Outline

- *Charm Spectroscopy:*
  - New results on Charmed-strange Mesons.
  - *Observation of a new Ds Meson at a mass of 2.86 GeV.*
- *Charmonium spectroscopy:*
  - *Study of ISR production of the $D\bar{D}$ system.*

Charge conjugation is implied through all this presentation

Update on Charmed-strange Mesons $D_{sJ}^{*}(2317)^{+}$ and $D_{sJ}(2460)^{+}$

BABAR: 232 fb^{-1}
Submitted to PRD

- Comprehensive study of decays to D_s^+ plus one or two $\pi^{\pm}$, π^0, or γ's
  - Decay pattern if $J^P=0^+$ and $J^P=1^+$, respectively

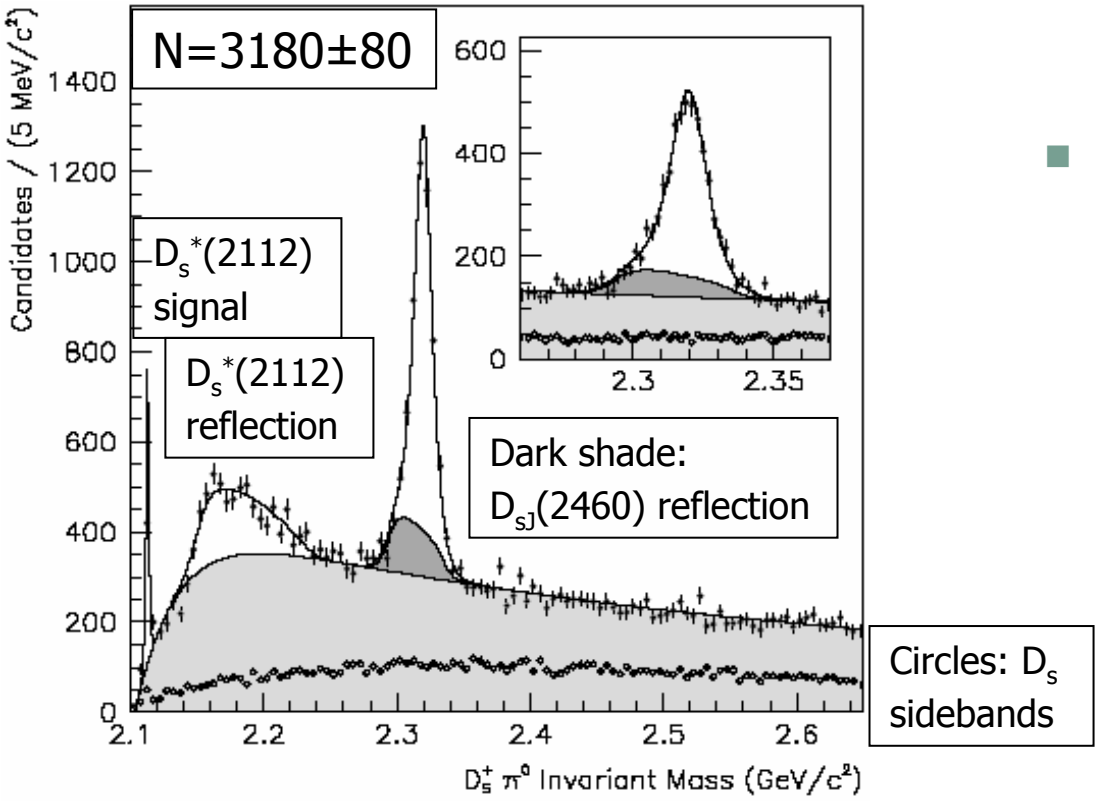
$D_s^+\pi^0$ only decay mode observed for $D_{sJ}^{*}(2317)^{+}$

Decay Channel	$D_{sJ}^{*}(2317)^{+}$	$D_{sJ}(2460)^{+}$
$D_s^+\pi^0$	Seen	Forbidden
$D_s^+\gamma$	Forbidden	Seen
$D_s^+\pi^0\gamma$ (a)	Allowed	Allowed
$D_s^*(2112)^+\pi^0$	Forbidden	Seen
$D_{sJ}^*(2317)^+\gamma$	—	Allowed
$D_s^+\pi^0\pi^0$	Forbidden	Allowed
$D_s^+\gamma\gamma$ (a)	Allowed	Allowed
$D_s^*(2112)^+\gamma$	Allowed	Allowed
$D_s^+\pi^+\pi^-$	Forbidden	Seen

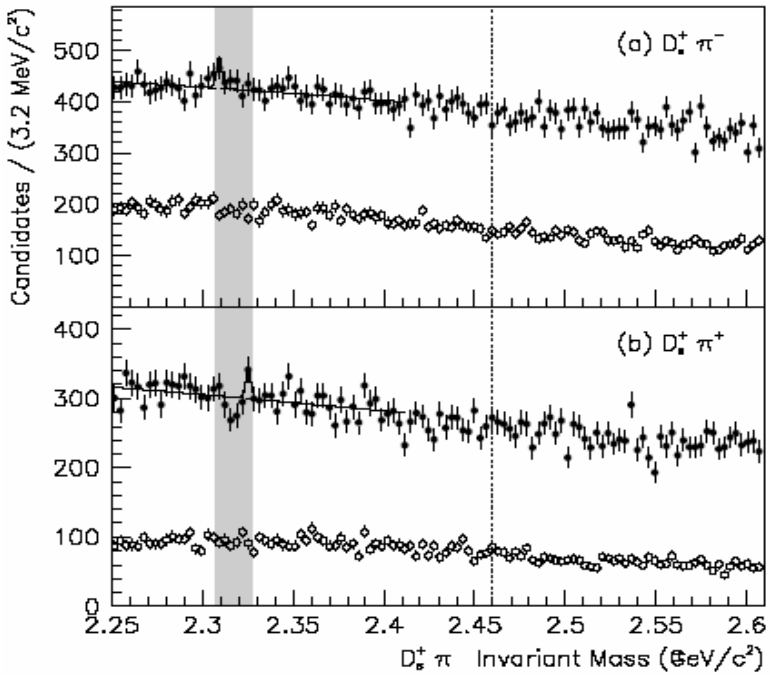
(a) Non-resonant only

$D_{sJ}^{*}(2317)^{+} \rightarrow D_s^{+}\pi^0$

BABAR: 232 fb^{-1}



- *No indication of neutral or doubly-charged partner near 2317 MeV ➔ I=0*



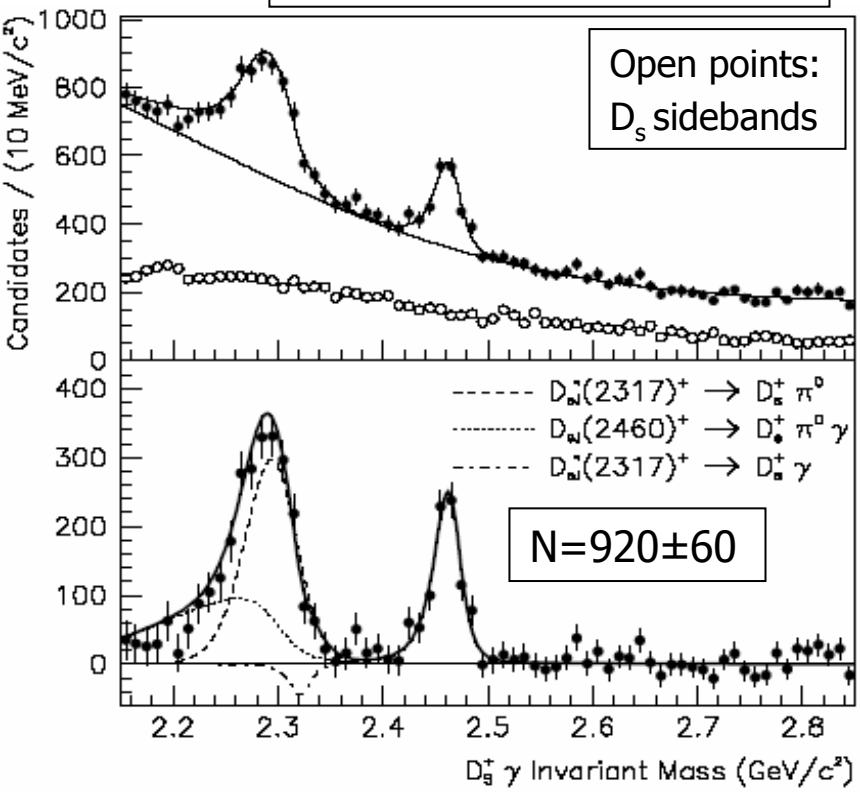
$$m = (2319.6 \pm 0.2 \pm 1.4)\ \mathrm{MeV/c^2}$$

$$\Gamma < 3.8\ \mathrm{MeV}\ @\ 95\%\ \mathrm{CL}$$

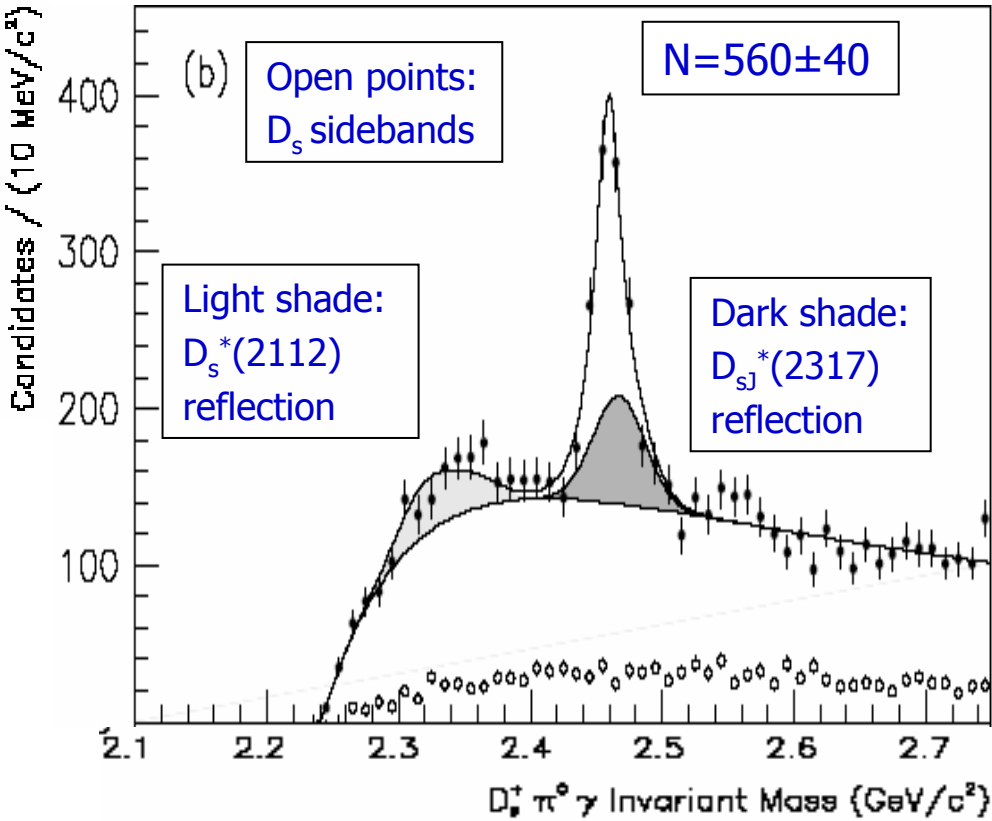
$D_{sJ}(2460)^+ \to D_s^+ \gamma$ / $D_s^*(2112)^+ \pi^0$

BABAR: 232 fb^{-1}

$D_{sJ}(2460)^+ \to D_s^+ \gamma$



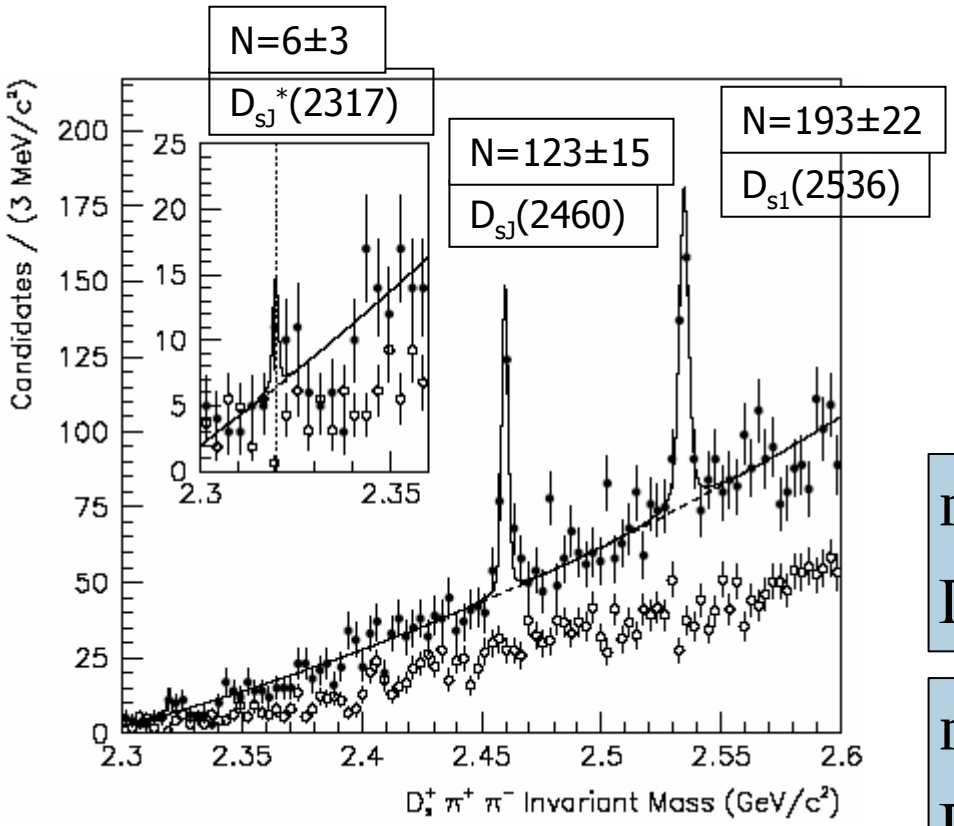
$D_{sJ}(2460)^+ \to D_s^*(2112)^+ \pi^0$



$$\frac{\mathrm{B}(D_{sJ}(2460)^+ \to D_s^+ \gamma)}{\mathrm{B}(D_{sJ}(2460)^+ \to D_s^+ \pi^0 \gamma)} = 0.337 \pm 0.036 \pm 0.038$$

$D_{sJ}(2460)^+ \to D_s^+\pi^+\pi^-$

BABAR: 232 fb^{-1}



- No indication of $D_{sJ}^*(2317)^+$
- Also observe $D_{s1}(2536)^+$

$$m = (2460.2 \pm 0.2 \pm 0.8)\ \mathrm{MeV}/c^2$$
$$\Gamma < 3.5\ \mathrm{MeV}\ @\ 95\%\ \mathrm{CL}$$

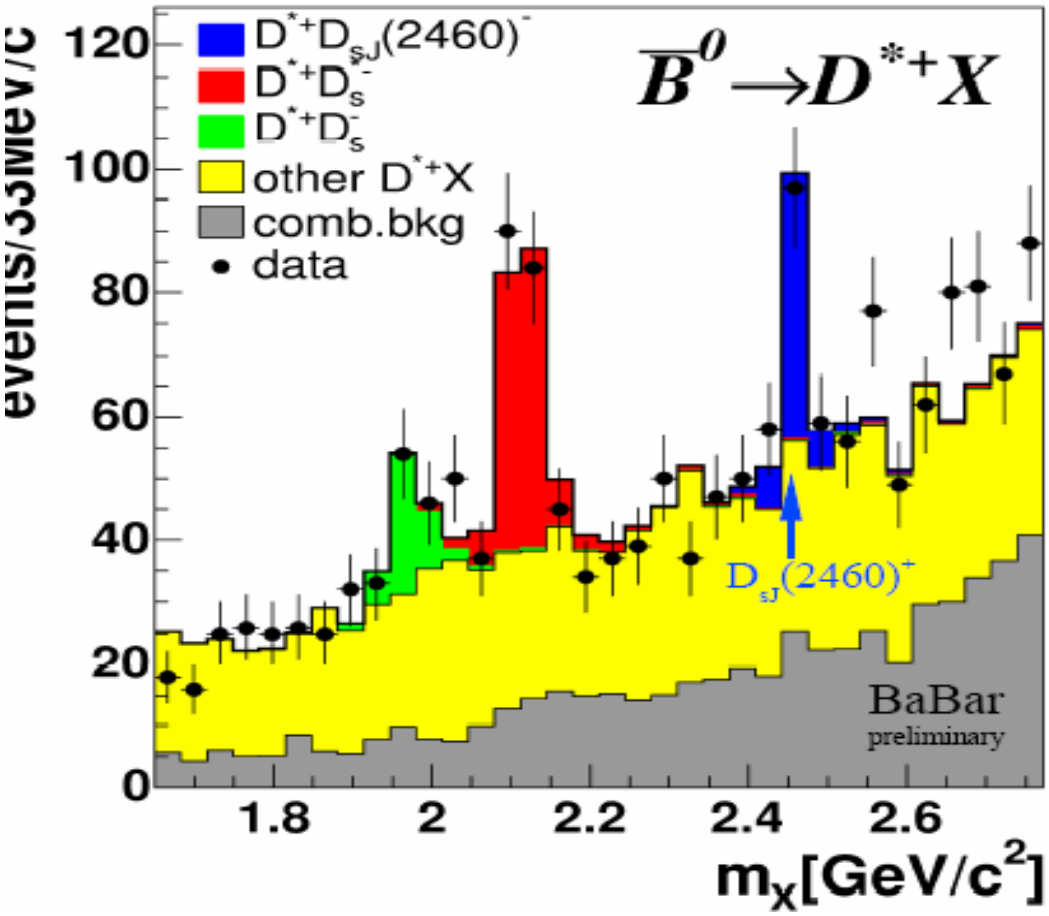
$$m = (2534.6 \pm 0.3 \pm 0.7)\ \mathrm{MeV}/c^2$$
$$\Gamma < 2.5\ \mathrm{MeV}\ @\ 95\%\ \mathrm{CL}$$

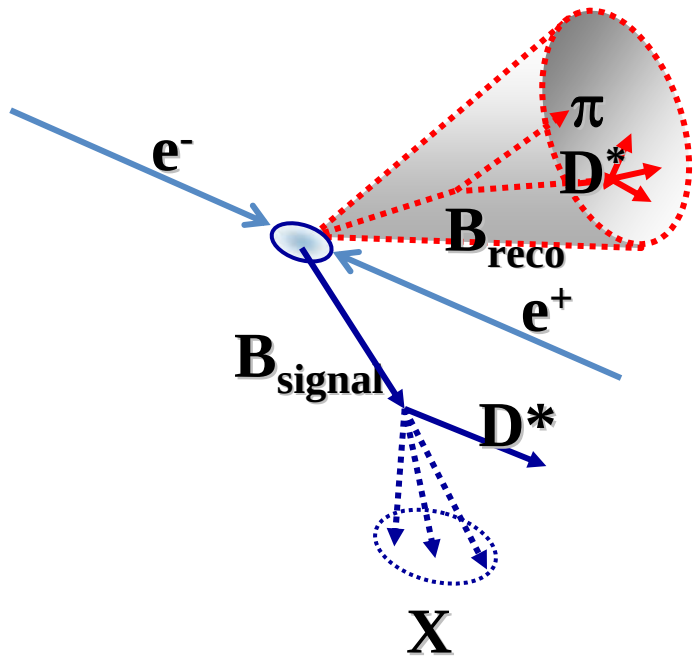
$$\frac{\mathrm{B}(D_{sJ}(2460)^+ \to D_s^+\pi^+\pi^-)}{\mathrm{B}(D_{sJ}(2460)^+ \to D_s^+\pi^0\gamma)} = 0.077 \pm 0.013 \pm 0.008$$

$D_{sJ}(2460)^+$ Absolute Branching Fractions.

- $B\bar{B}$ sample with one B fully reconstructed → study decays of other $B \to D^{(*)+,0} X$
  - Observe $D_{sJ}(2460)$ signals in the recoil mass, m_X

BABAR: 230M $B\bar{B}$





$D_{sJ}(2460)^+$ Absolute BFs, cont.

BABAR: 122M $B\bar{B}$
PRL 93, 181801 (2004)

- Combine with previously measured, exclusive product BFs $B \to \bar{D}^{(*)} D_{sJ}(2460)^+$, $D_{sJ}(2460)^+ \to D_s^+\gamma$ / $D_s^*(2112)^+\pi^0$ to obtain absolute BFs:

Preliminary

$$B(D_{sJ}(2460)^+ \to D^*_s(2112)^+\pi^0) = 0.56 \pm 0.13 \pm 0.09 \; (D_s^{*+} \to D_{s+}{}^+\gamma)$$
$$B(D_{sJ}(2460)^+ \to D_s^+\gamma) = 0.16 \pm 0.04 \pm 0.03$$

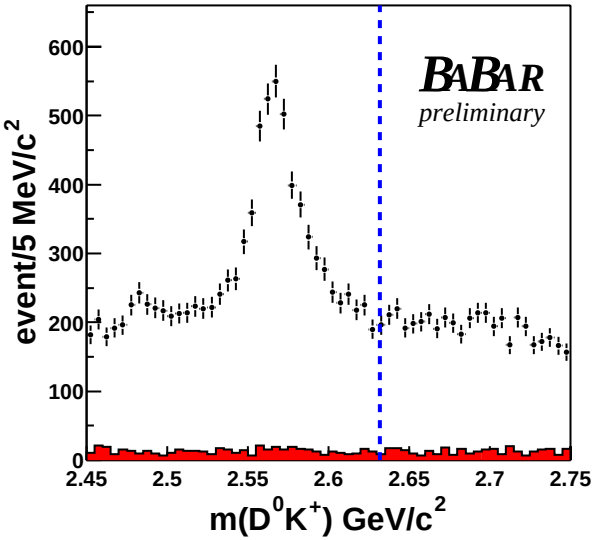
Sum of BFs for $D_{sJ}(2460)^+$ decaying to $\pi^0/\gamma = 72 \pm 19\%$

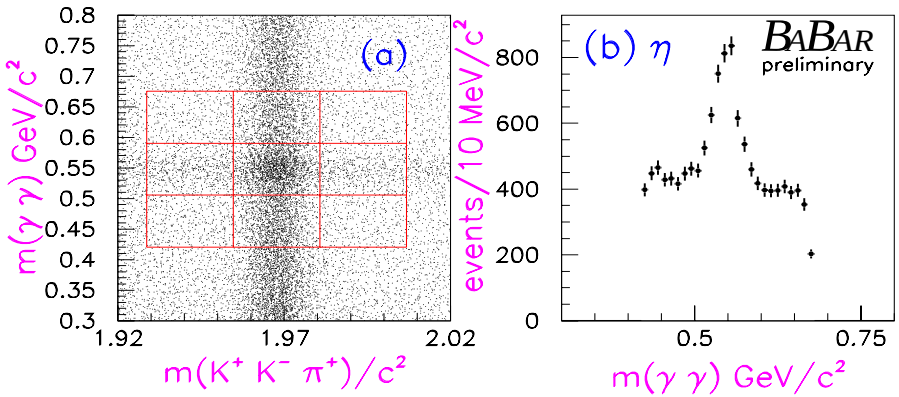
$B(D^+_s \to f\,p^+) = (4.62 \pm 0.36 \pm 0.51)\%$
as determined in this analysis

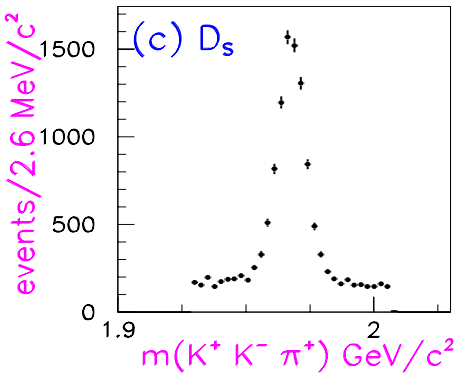
No evidence for $D_s(2636)^+$ claimed by SELEX experiment

BABAR: 92 fb^{-1}

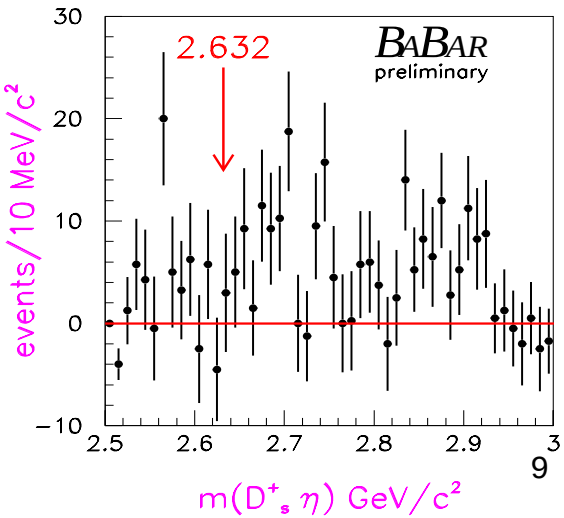
- Study of inclusive $e^+e^- \rightarrow D^0K^+ X$
- Study of inclusive $e^+e^- \rightarrow D_s^+\eta X$







No evidence for:
$D_s(2636)^+ \rightarrow D^0K^+$
$D_s(2636)^+ \rightarrow D_s^+\eta$



Observation of a new Ds meson at a mass of 2.86 GeV.

BABAR: 240 fb^{-1}

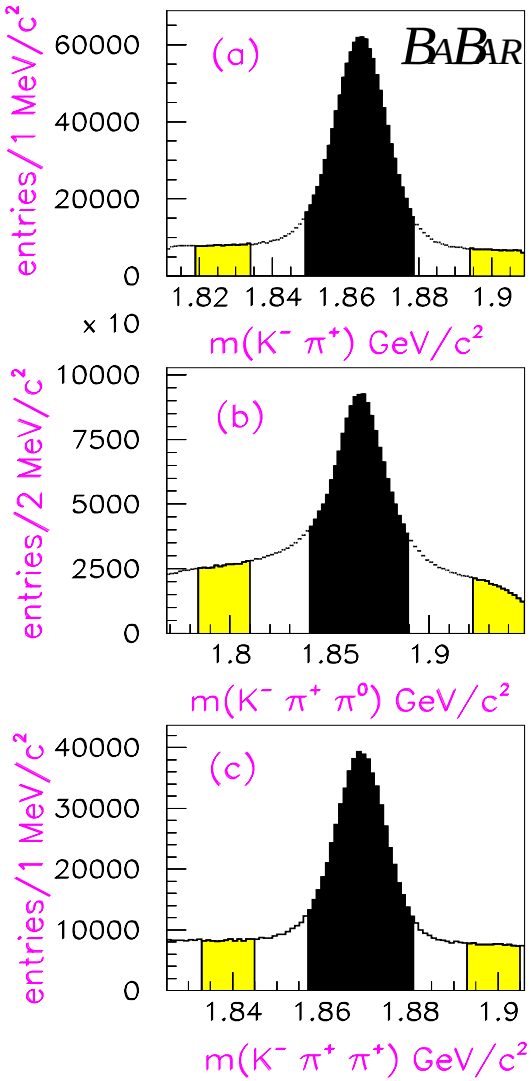
- Study of the inclusive production of:
- $e^+e^- \rightarrow K^+D^0 X$

  $\rightarrow K^- \pi^+$

  $\rightarrow K^- \pi^+\pi^0$
- $e^+e^- \rightarrow K^0_S D^+ X$

  $\rightarrow K^- \pi^+ \pi^+$

Require from now on the center of mass momentum p(DK)>3.5 GeV/c*



Study of the D^0K^+ system, $D^0 \rightarrow K^- \pi^+$

Presence of:

- **Reflection from $D_{s1}(2536)^+$**

$D_{s1}(2536)^+ \rightarrow K^+D^{*0}$

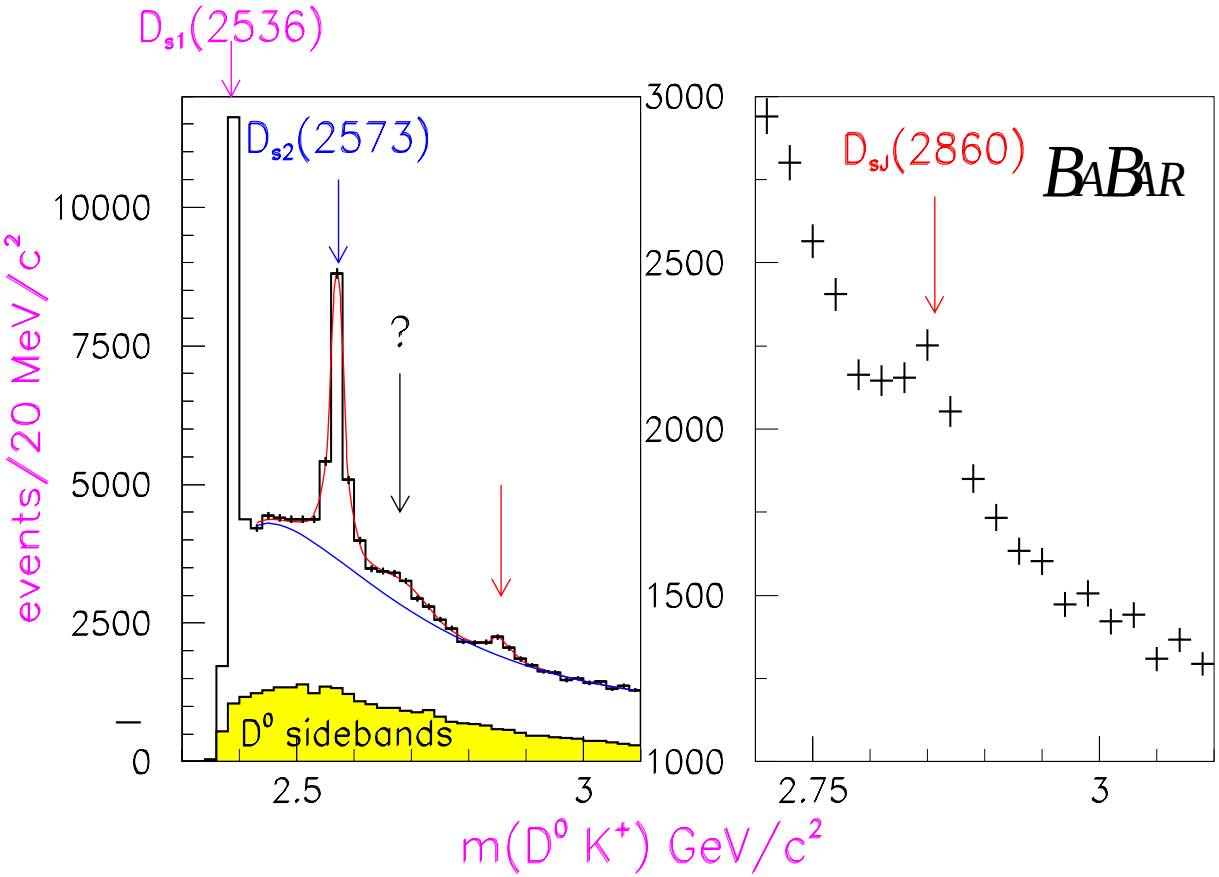
$\rightarrow D^0 \pi^0/\gamma$

produces a narrow structure at threshold.

- **Signal of $D_{s2}(2573)^+$.**

- **Broad structure around 2.7 GeV**

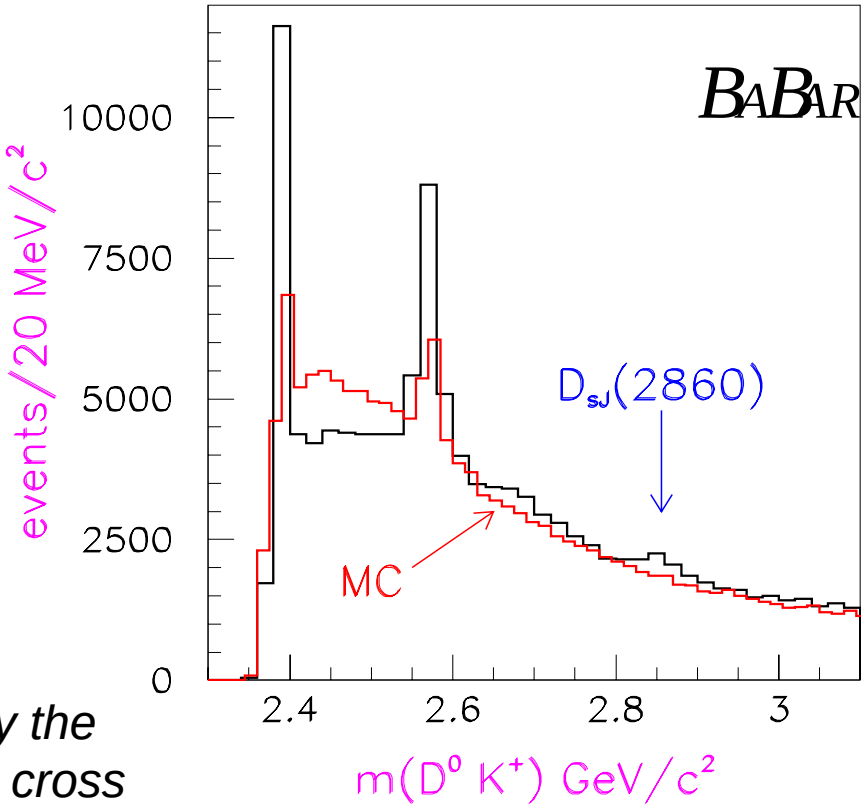
- ***New structure at 2.86 GeV***



Study of the D K system

This new structureat 2.86 GeV is:

Not observed in the D^0 sidebands.
Not observed in the $e^+e^- \rightarrow ccX$ Monte Carlo
Not due to D* reflections.

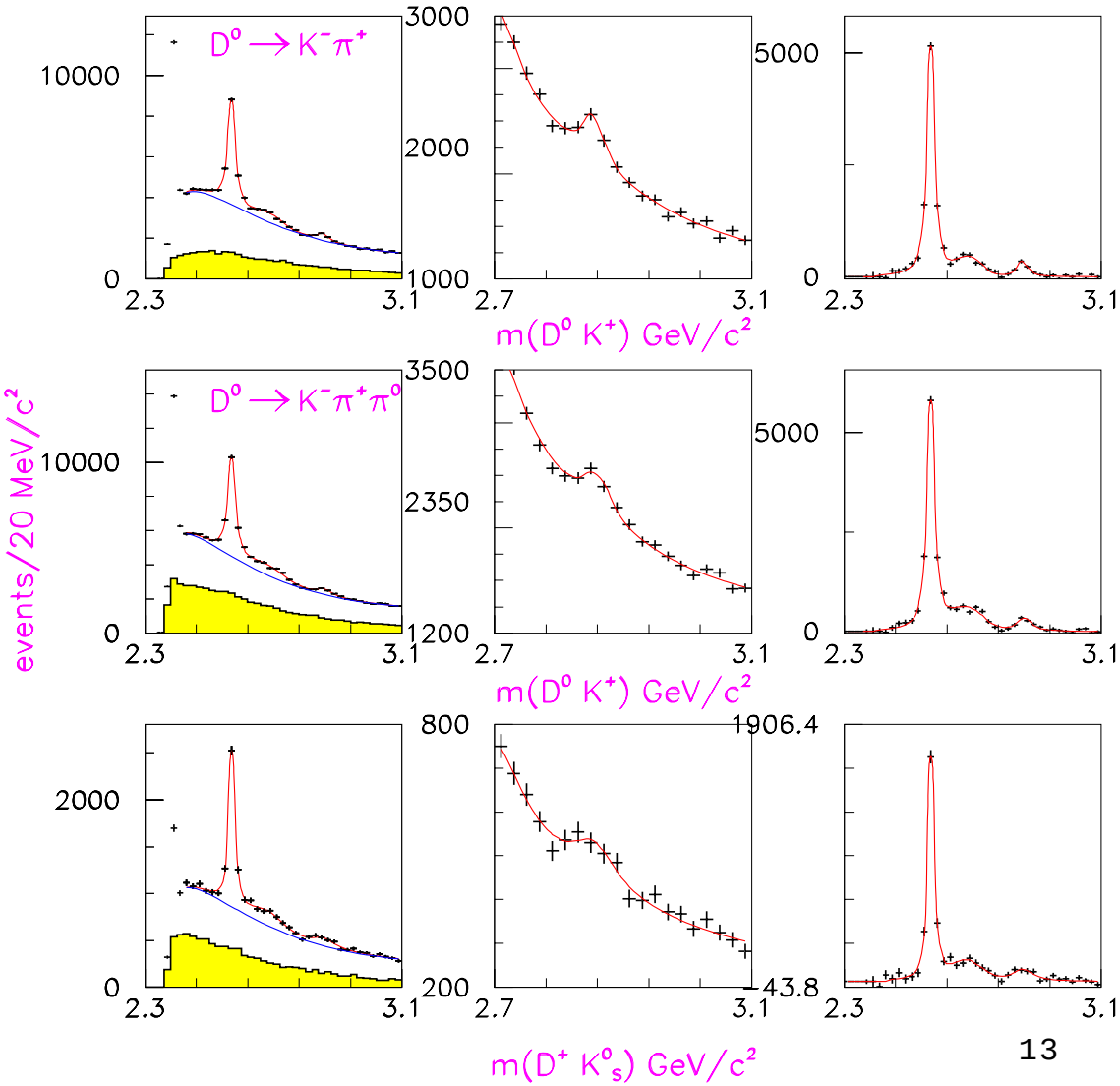


The Monte Carlo does not describe correctly the resonance yields: poor knowledge of charm cross Sections.

Other observations of $D_{sJ}(2860)^+$.

Yellow: D sidebands

- D^0K^+, $D^0 \rightarrow K^- \pi^+$: 872±139 events (6.3 σ)
- D^0K^+, $D^0 \rightarrow K^- \pi^+\pi^0$: 1099±214 events (5.1 σ)
- $D^+K^0_S$: 585±212 events (2.8 σ)



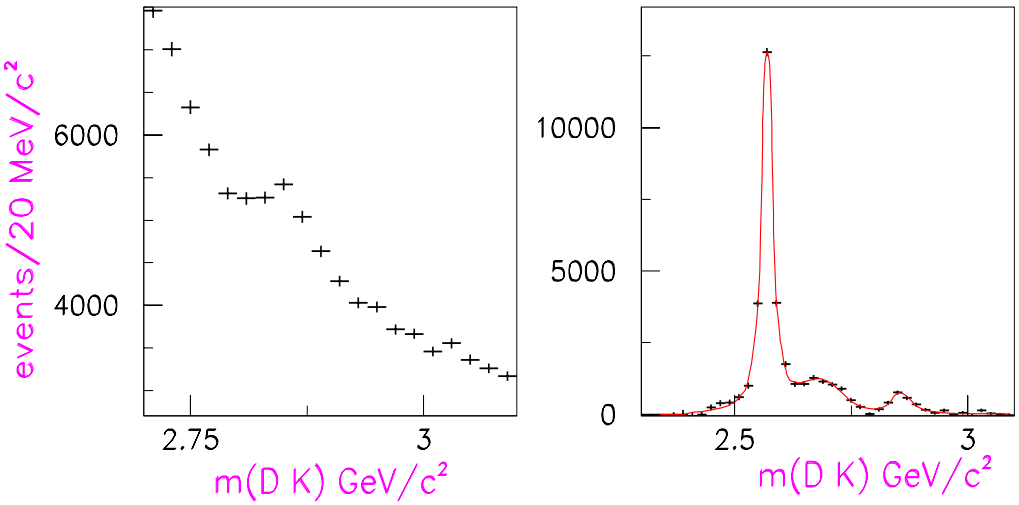
Removing the $D_{sJ}(2860)^+$ from the fit:

$\Delta\chi^2=108$ for $\Delta NDF=5$

Study of the DK system

$D_{s2}(2572)^+$ parameters:
m=2572.2±0.3±1.0 MeV/c^2
Γ=27.1±0.6±5.6 MeV/c^2

Sum of the three mass spectra



$D_{s2}(2860)^+$ parameters:
m=2856.6±1.5±5.0 MeV/c^2
Γ=48±7±10 MeV/c^2

Need extra structure around 2.7 GeV (better described by a Gaussian).
*Activity in this region seen in the D^0 sidebands of channel N2 for very low p**

$X(2680)^+$ parameters (if fitted using a Breit Wigner):
m=2688±4±2 MeV/c^2
Γ=112±7±36 MeV/c^2

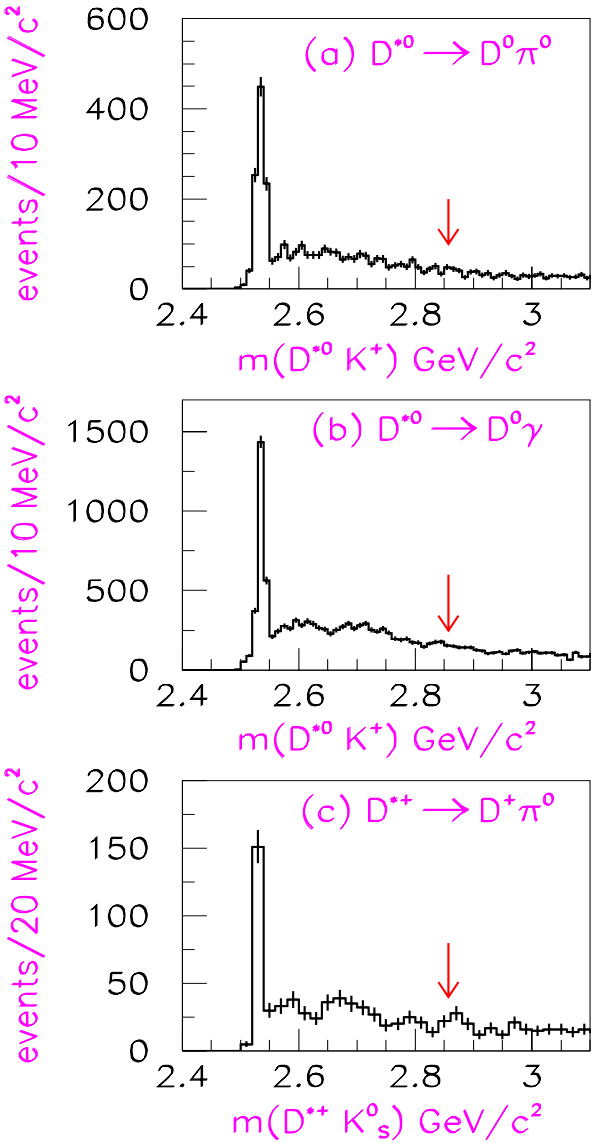
Search for D*K decays

No evidence for $D_{sJ}(2860)$ decay to:

$D^{*0} K^+$, $D^{*0} \rightarrow D^0 \pi^0$
$D^{*0} K^+$, $D^{*0} \rightarrow D^0 \gamma$
$D^{*+} K^0_S$, $D^{*+} \rightarrow D^+ \pi^0$

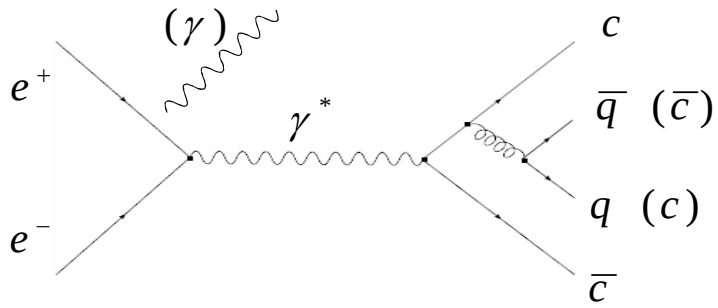
Since $D_{sJ}(2860)$ decays to two pseudoscalars:

$J^P = 0^+, 1^-, 2^+, \boxed{3^-?}$

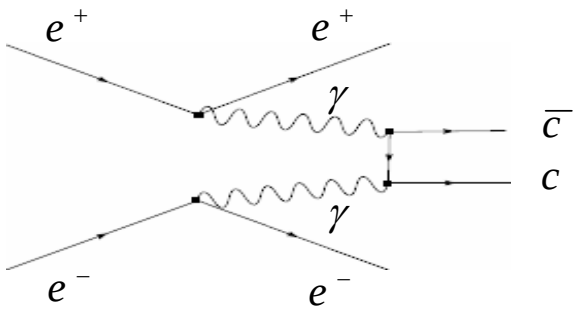


Charmonium Production at BABAR, Belle, and CLEO

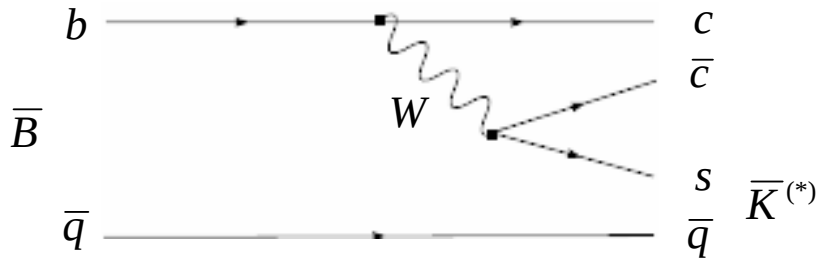
- Continuum production: $\sqrt{s} \leq 10.58$ GeV
  - $e^+e^- \rightarrow c\bar{c}$ (Initial State Radiation, double charmonium)



- Two photon



- Production in B decay: $\sqrt{s} \approx 5.28$ GeV
  - $b \rightarrow c$ transition $B \rightarrow (c\bar{c})K^{(*)}$



Tetraquarks, $D^*\bar{D}$ molecules, $c\bar{c}g$ hybrids, etc.

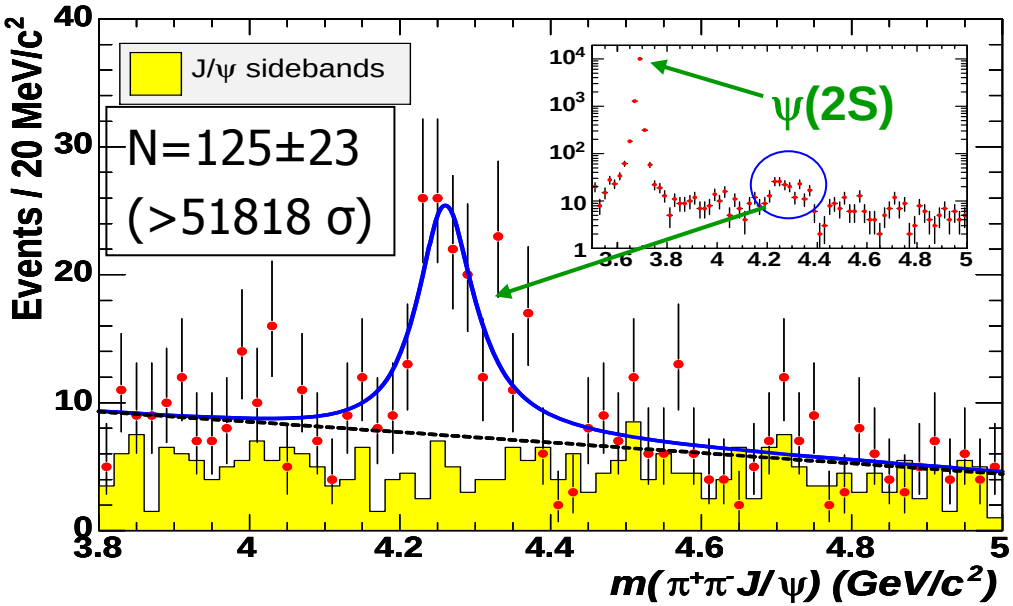
Charmonium-candidate States

State	Mass (MeV)	Width (MeV)	Decay mode(s)	J^{PC}
X(3872)	3871.2 ± 0.6	<2.3 @ 90% CL	$\pi^+\pi^- J/\psi$ $\gamma J/\psi$ $\bar{D}^0 D^0 \pi^0$	1^{++} I=0
X(3940)	3943 ± 9	<52 @ 90% CL	$D^*\bar{D}$ Not $D\bar{D}$ or $\omega J/\psi$	0^{-+} ?
Y(3940)	3943 ± 17	87 ± 34	$\omega J/\psi$	C=+1 I=0
Z(3930)	3929 ± 6	29 ± 10	$D\bar{D}$	2^{++}
Y(4260)	$4259\ ^{+8}_{-10}$	$88\ ^{+24}_{-23}$	$\pi^+\pi^- J/\psi$, $\pi^0\pi^0 J/\psi$ Not $\pi^+\pi^-\phi$, $D\bar{D}$, $p\bar{p}$	1^{--} I=0

BABAR: 233 fb^{-1}

Y(4260)→$\pi^+\pi^-$J/ψ

- Observed in ISR events ➔ $J^{PC} = 1^{--}$
  - $\Gamma_{ee}^{Y} \times \mathrm{B}(Y(4260) \to \pi^+\pi^-\,\mathrm{J}/\psi) = (5.5 \pm 1.0^{+0.8}_{-0.7})\ \mathrm{eV}$



Assuming single resonance

Peak cross section:
$\sigma(e^+e^- \to Y) = (51 \pm 12)$ pb

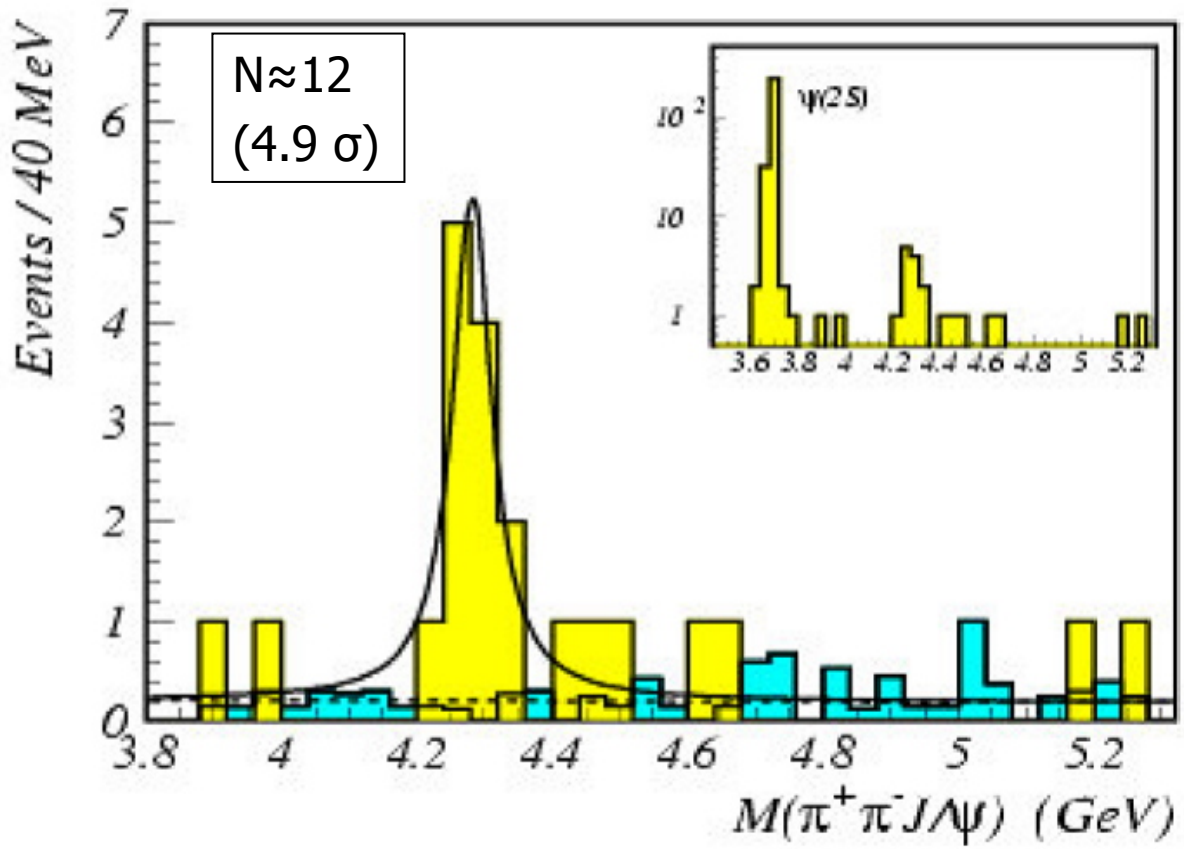
$$m_Y = (4259 \pm 8^{+2}_{-6})\ \mathrm{MeV/c^2}$$
$$\Gamma_Y = (88 \pm 23^{+6}_{-4})\ \mathrm{MeV}$$

- Indication in B-decay ⇐ needs confirmation

BABAR: 232M BB

Confirmation of Y(4260) from CLEO-III

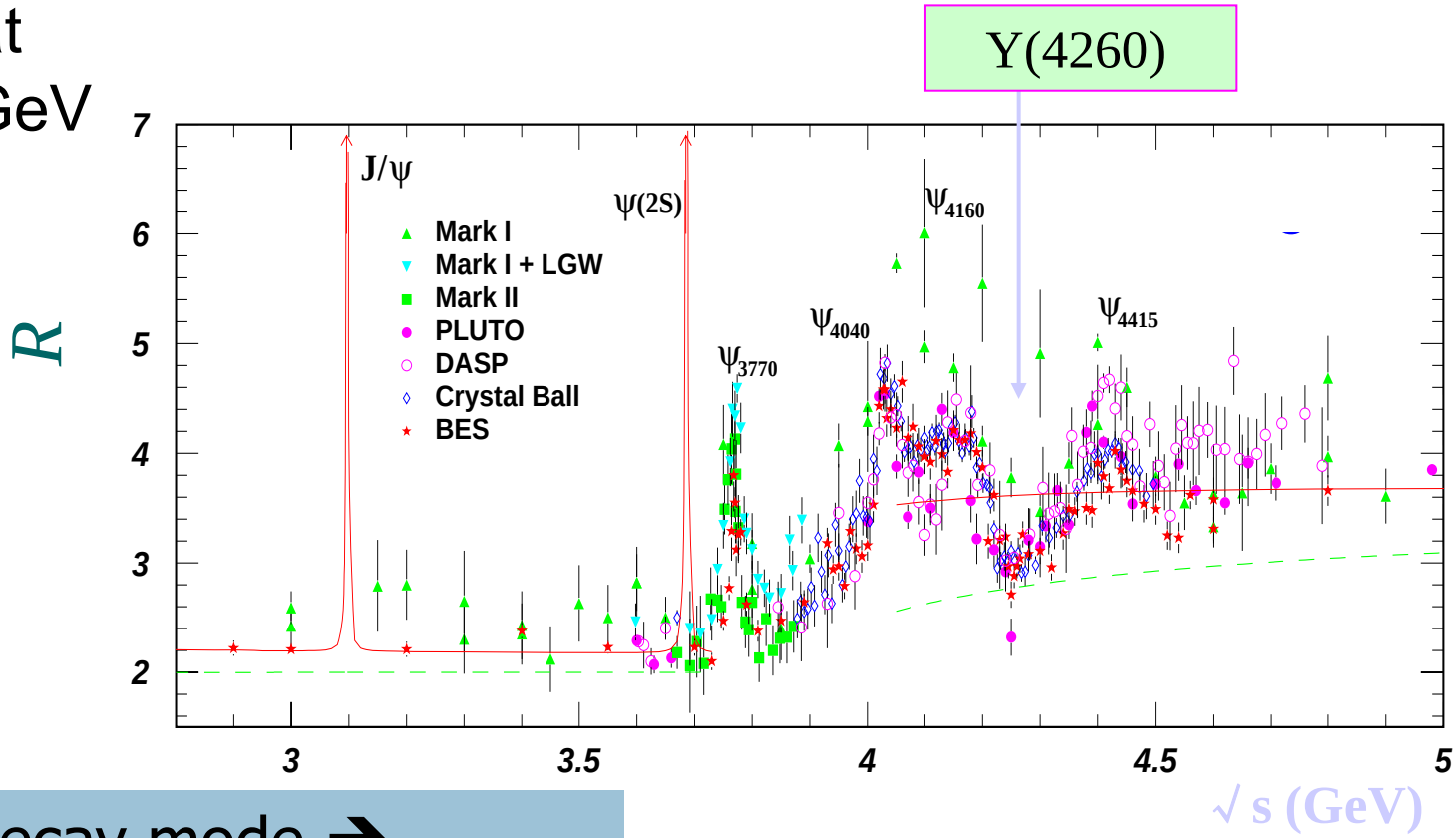
- ISR production of $\pi^+\pi^- J/\psi$ events in CLEO-III data near $\sqrt{s}$=10.58 GeV



CLEO-III: 13.3 fb^{-1}
Preliminary

No evidence for Y(4260) in R-scan

- Dip in R at √s=4.26GeV



Y(4260) decay mode ➔ conventional charmonium interpretation does not fit well

Y(4260): charmonium state?

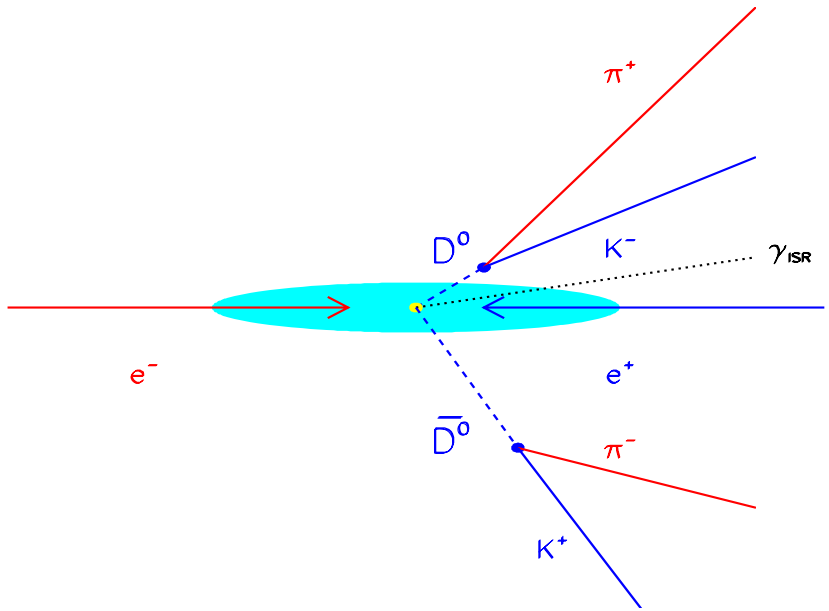
- Not easy to classify Y(4260) as a standard $J^{PC}=1^{--}$ charmonium state. Other possibilities involve:
- Mesonic or baryonic molecule;
- Hybrid meson;
- A coupled channel signal.

Need to study other decay modes.

Study of exclusive production of $D\bar{D}$ states in ISR

BABAR: 289 fb^{-1}

- Efficiency for detecting the ISR photon small, therefore reconstruct the γ_{ISR} as a missing particle.

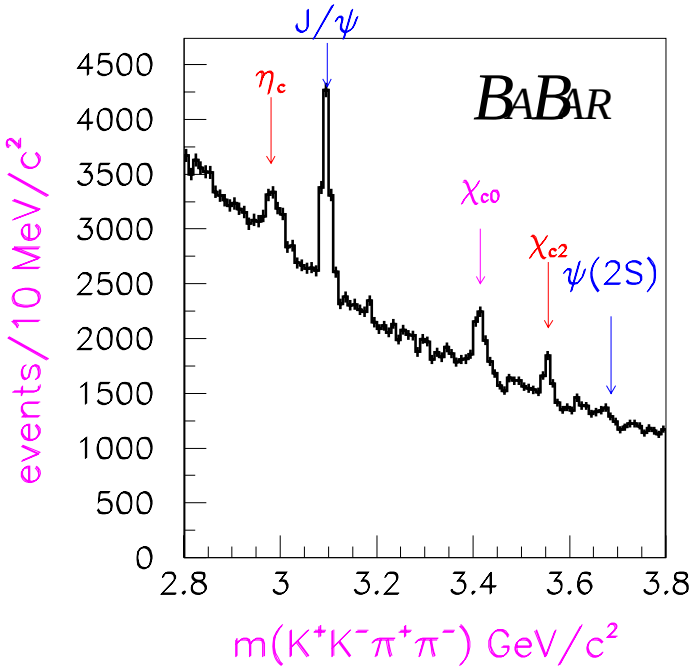


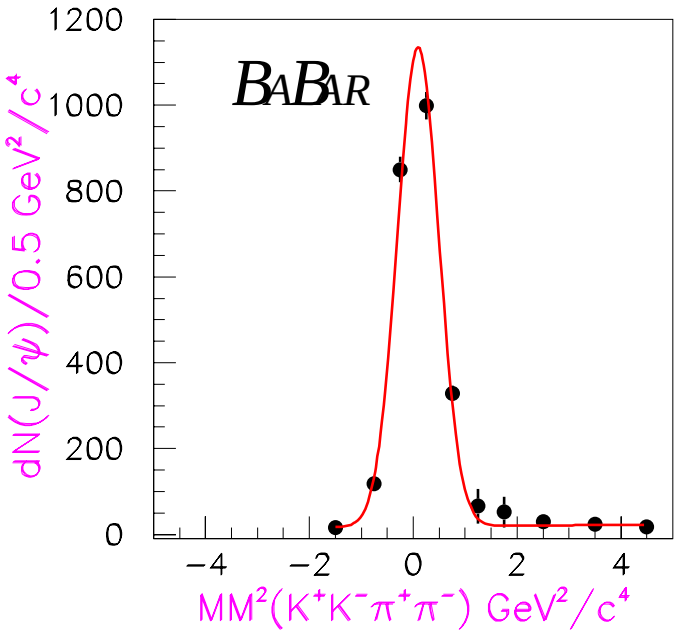
Calibration performed using the $K^+K^-\pi^+\pi^-$ control sample

- *$K^+K^-\pi^+\pi$ effective mass: contributions from two photon and ISR events*
- Plot of the number of J/ψ as a function of the missing mass squared:

$$MM^2 = |\mathbf{p}_{e+} + \mathbf{p}_{e-} - \mathbf{p}_{K+} - \mathbf{p}_{K-} - p_{\pi+} - p_{\pi-}|^2$$

$$\sigma(MM^2) = 0.400\ \text{GeV}^2$$

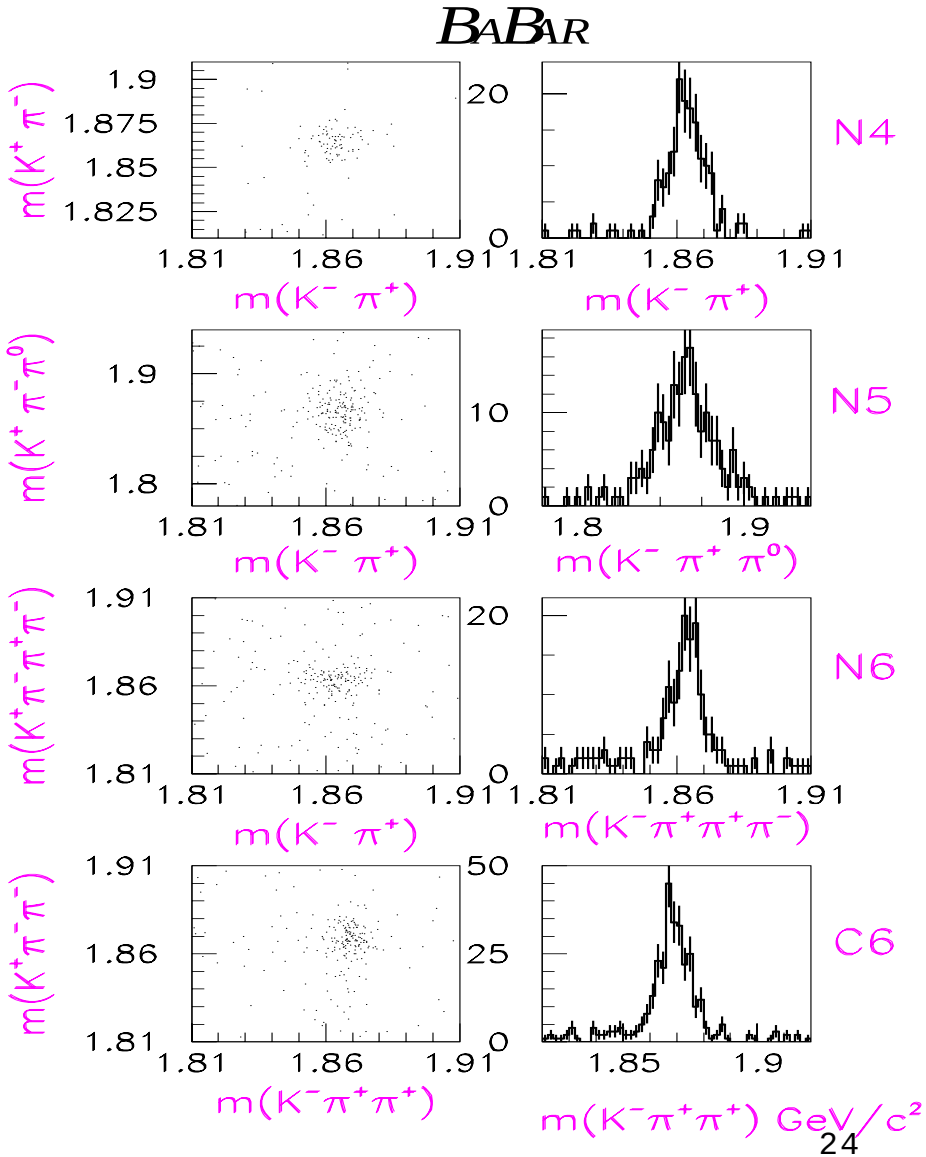




Reconstructed 4 $D\bar{D}$ channels.

- N4: $D^0 \to K^-\pi^+, D^0 \to K^+\pi^-$
- N5: $D^0 \to K^-\pi^+, D^0 \to K^+\pi^-\pi^0$
- N6: $D^0 \to K^-\pi^+,, D^0 \to K^+\pi^-\pi^+\pi^-$
- C6: $D^+ \to K^-\pi^+\pi^+, D^- \to K^+\pi^-\pi^-$

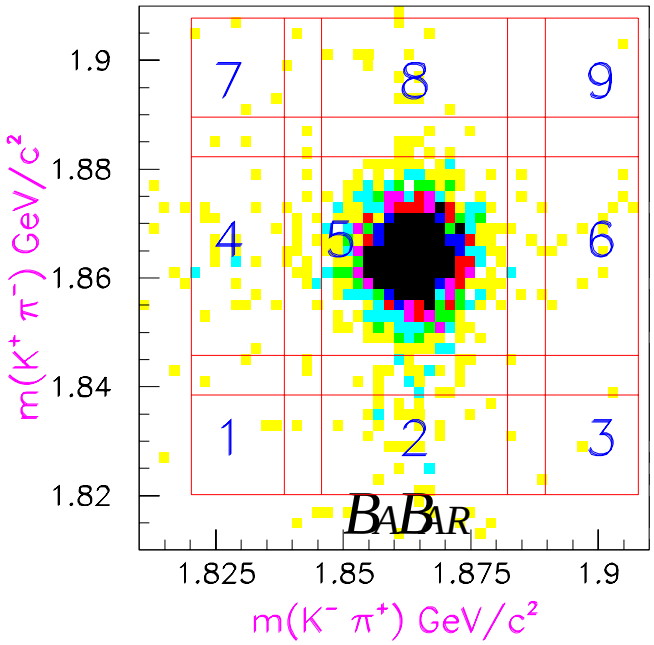
Labels:
Charged or Neutral
Number of particles in the final state

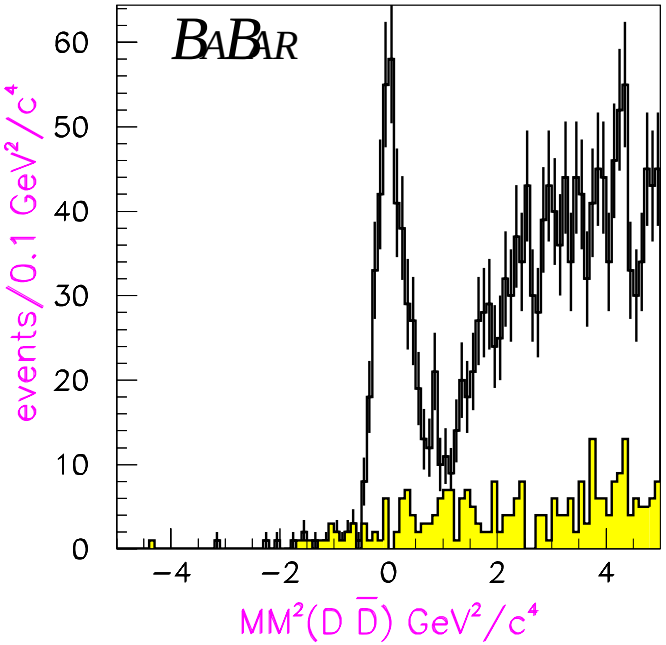


Channels reconstruction

- *Background estimated using the 9-tiles method.*
- Signal: tile 5.
- Background: 2+4+6+8-(1+3+7+9)

Yellow: sidebands background

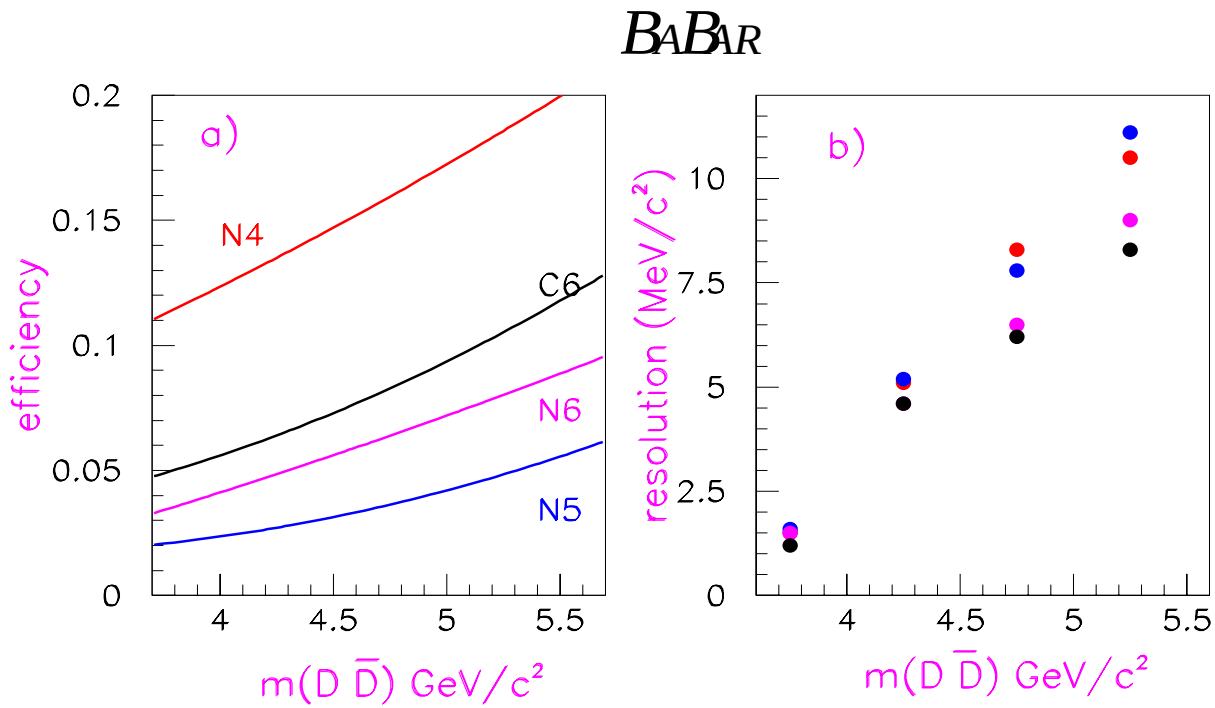




ISR events defined by the cut: $|MM^2|<1\ GeV^2$

Efficiency and resolution

- Efficiency x B.F. = 0.59 x 10^{-3}
- Mass resolution: 5 MeV at the Y(4260)

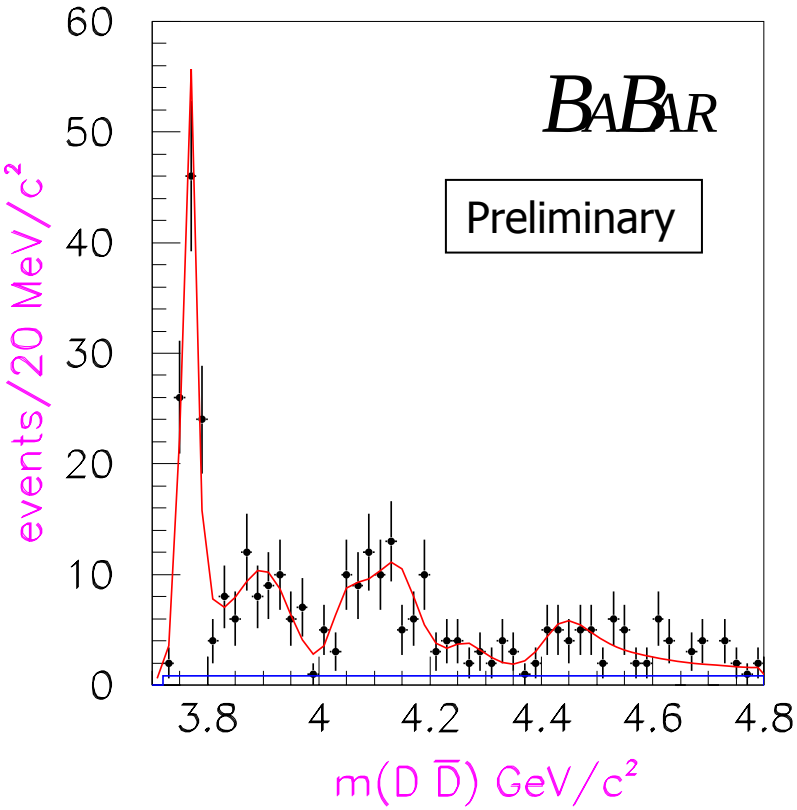


$D\bar{D}$ mass spectrum

$$\frac{\mathrm{B}(Y(4260) \to D\bar{D})}{\mathrm{B}(Y(4260) \to \pi^+\pi^- \mathrm{J}/\psi)} < 7.6 \text{ @ } 95\% \text{ CL}$$

- Mass spectrum fitted with interfering:
  - $\psi(3770)$
  - $\psi(4040)$
  - $\psi(4160)$
  - $\psi(4415)$
  - $\psi(4260)$
- Presence of structure at 3.9 GeV

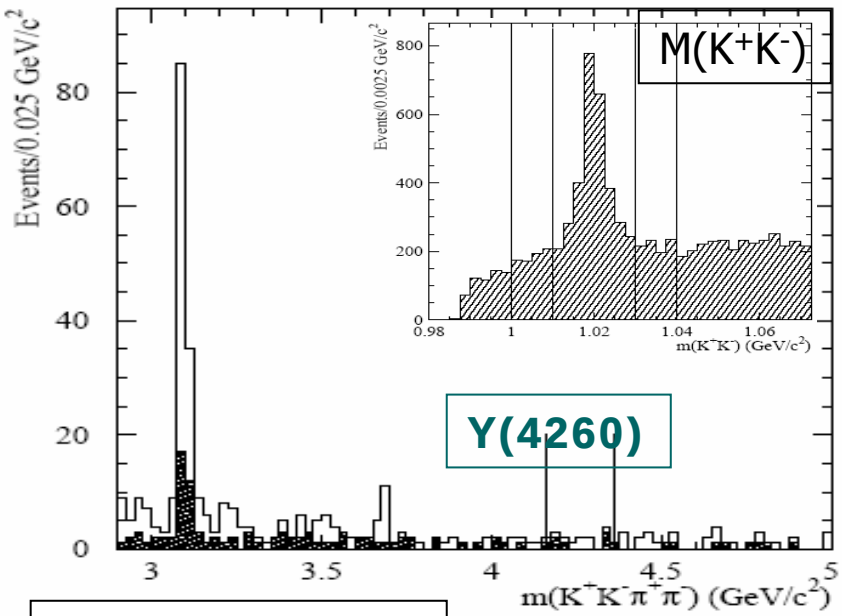
(Not due to a new charmonium state but to a threshold effect predicted by E. Eichten et al.,Phys.Rev. D21 (1980) 203.)



No Indication for Y(4260) in Other ISR-produced Final States

BABAR: 232 fb^{-1}

Preliminary



Shaded: ϕ sidebands

$$\Gamma_{ee}^{Y} \times \mathrm{B}(Y(4260) \to \pi^+\pi^-\phi) < 0.4\ \mathrm{eV}\ @\ 90\%\ \mathrm{CL}$$

Events having a reconstructed γ_{ISR} photon.

$$\frac{B(Y(4260) \to p\bar{p})}{B(Y(4260) \to \pi^+\pi^- \mathrm{J}/\psi)} < 0.13\ @\ 90\%\ \mathrm{CL}$$

BABAR: 232 fb^{-1}

Conclusions

- New measurements of the D_{sJ} parameters.
- Observation of a new D_s meson at a mass of 2.86 GeV/c^2
- No evidence for Y(4260) $\rightarrow D \bar{D}$