The New Narrow "D_s" States – A minireview

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(From the BaBar Collaboration)

Results from:

BaBar (abstract 395, PRL 90 (2003) 242001, A. Palano PIC)

Belle (abstract 570, R. Chistov & K. Trabelsi FPCP 2003)

CLEO (abstract 813, hep-ex/0305100, submitted to PRD, J. Urheim CIPANP)

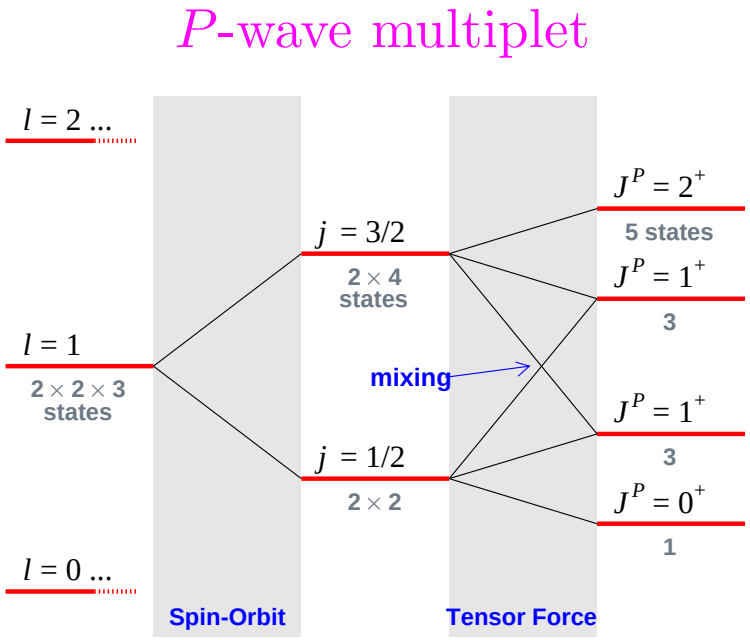
CDF (M. Shapiro FPCP 2003)

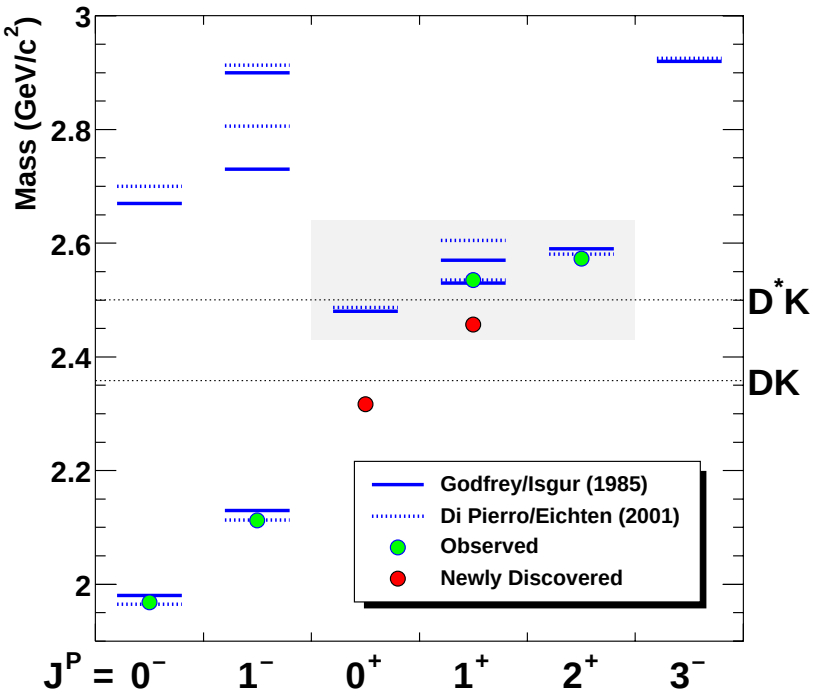
Two new narrow states (names from presumed quantum numbers, $q\bar{q}$ model):

$$D^*_{sJ}(2317)^\pm$$
$$D_{sJ}(2460)^\pm$$

The D_s Level Scheme

Light quark angular momentum (j), combined with heavy quark spin.





Figures: Courtesy of David Williams

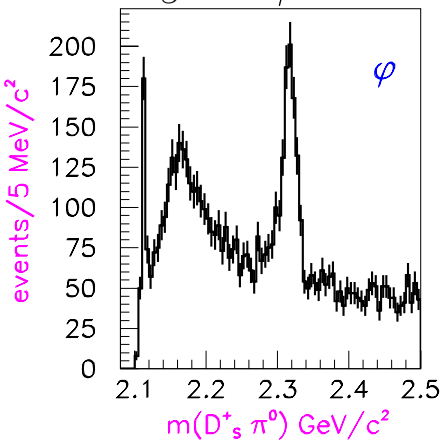
Conventional wisdom: P-wave $j = 1/2$ states heavy enough for isospin-allowed strong decays to produce large widths. E.g., $D_{s0}^{*\pm} \to D^0 K^\pm$.

The New Narrow State at 2317 MeV in $M(D_s\pi^0)$

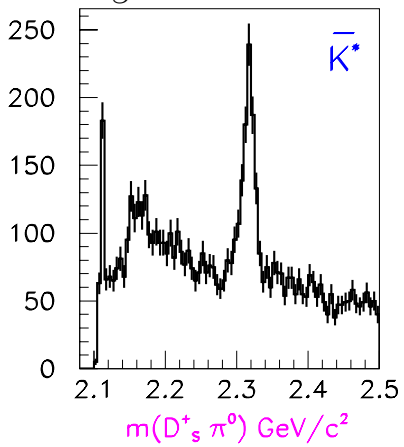
Mass peak consistent with experimental resolution. Hence $\Gamma <$ several MeV.

BaBar

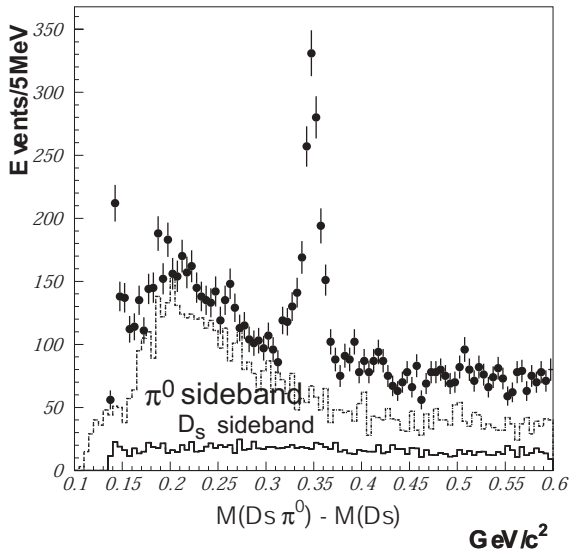
$D_s \to \phi\pi$



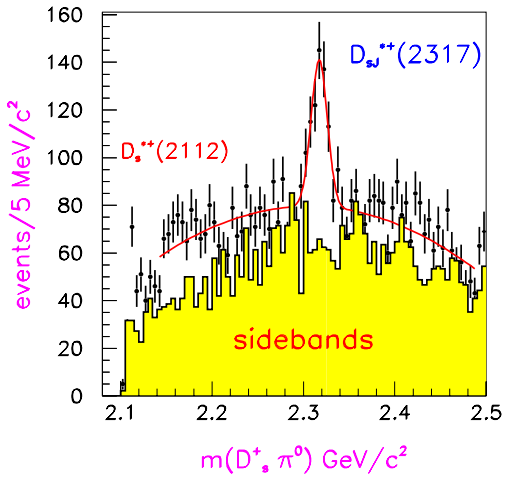
$D_s \to K^*K\pi$

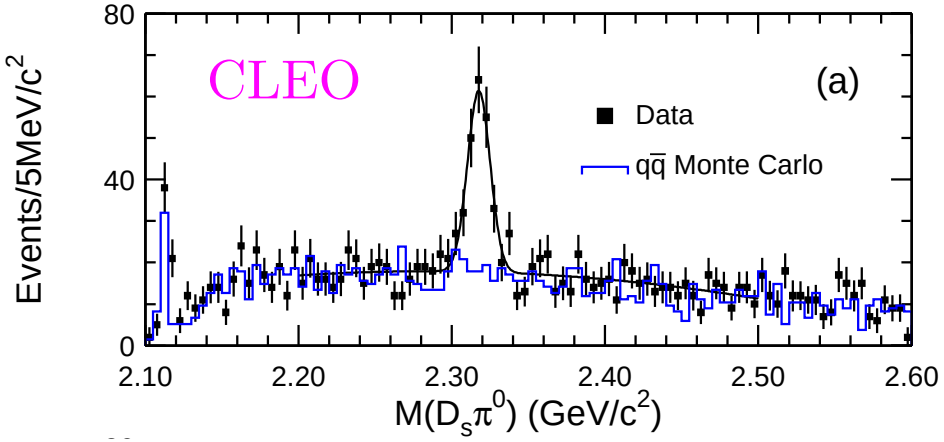


Belle preliminary



$D_s \to KK\pi\pi^0$



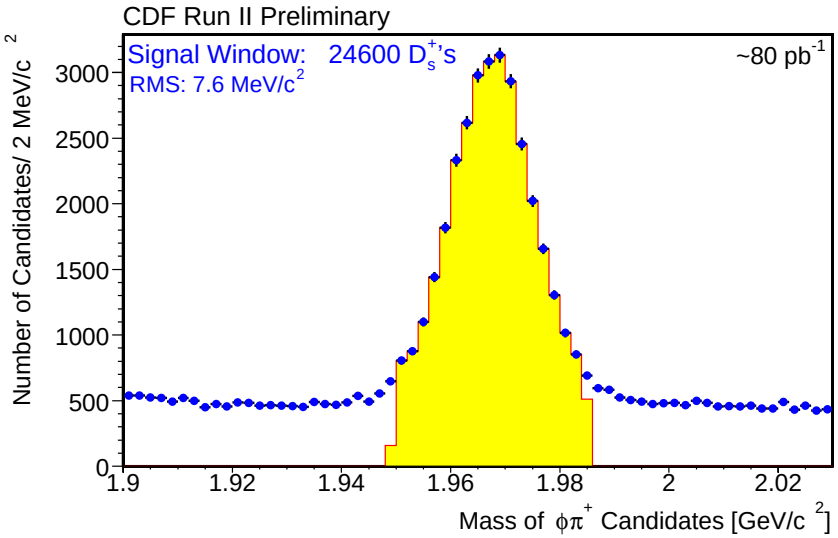


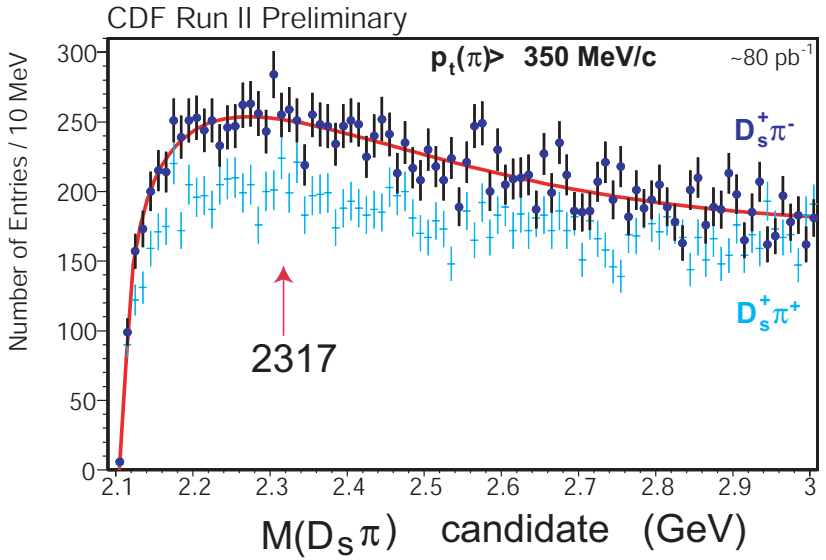
Isospin of State at $M = 2317$ MeV

Narrow decay width suggests isospin violating decay, $I \neq 1$.

Not seen in $D_s^{\pm}\pi^{\mp}$, $D_s^{\pm}\pi^{\pm}$, hence $I = 0$.

CDF preliminary





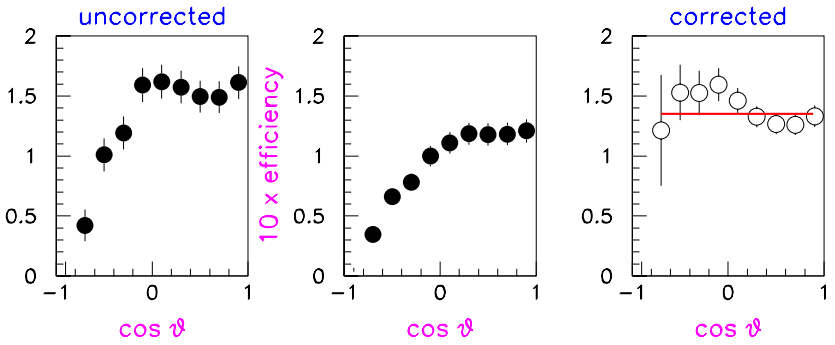
Sensitivity estimated with $D_2^* \to D\pi$ modes, relative D_s:D rates.

Working to further quantify using $D_{sJ}(2573) \to DK$ for normalization.

$D^*_{sJ}(2317)^\pm$ Spin-Parity

$D^*_{sJ}(2317) \to D_s\pi^0$. If parity conserved, then natural J^P (hence $*$).

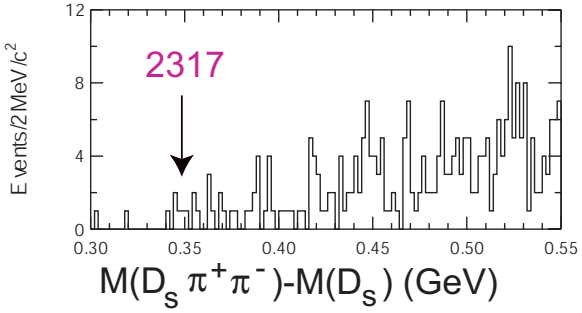
BaBar



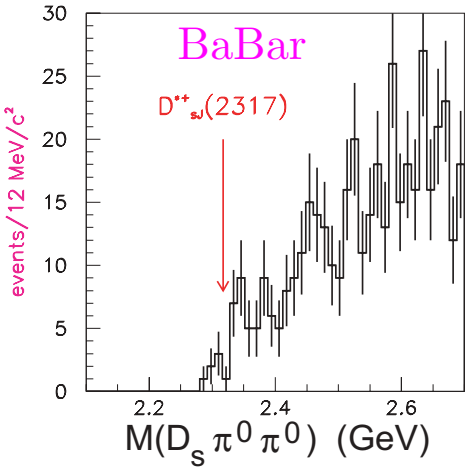
$D^*_{sJ}(2317) \to D_s\pi^0$ helicity angle distribution consistent with uniform; consistent with 0^+, or with isotropic polarization.

Not seen in $D_s\pi^+\pi^-$ or $D_s\pi^0\pi^0$, which are forbidden for 0^+:

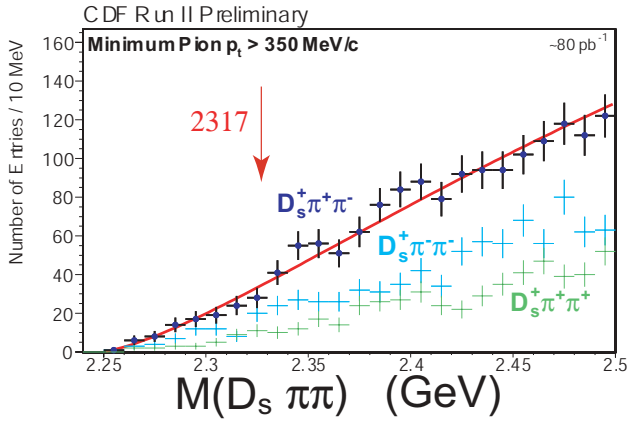
CLEO



BaBar



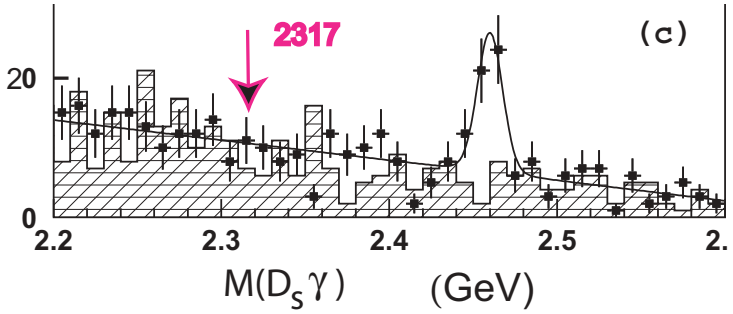
CDF preliminary



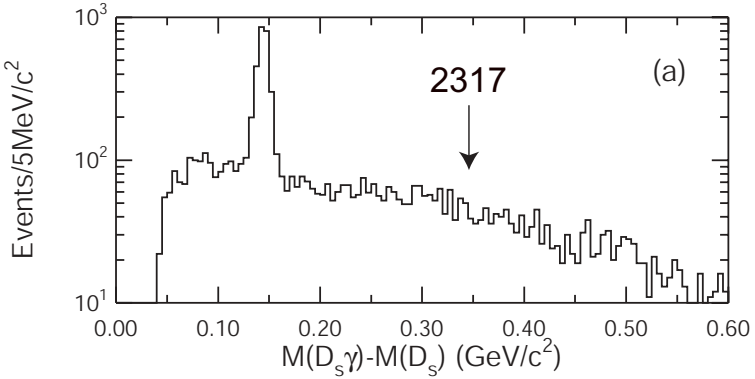
$D^*_{sJ}(2317)^{\pm}$ Spin-Parity (continued)

If $D^*_{sJ}(2317)$ is spin zero, then decay to $D_s\gamma$ is forbidden. Not seen.

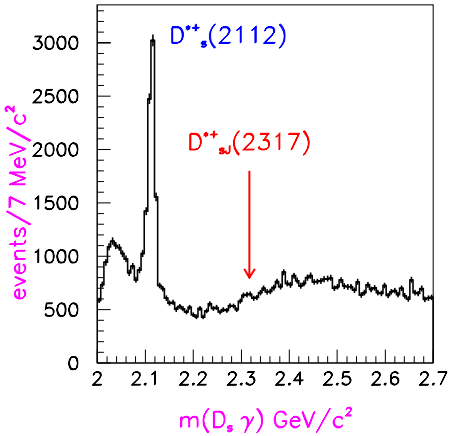
Belle preliminary $B \to DD_s\gamma$



CLEO



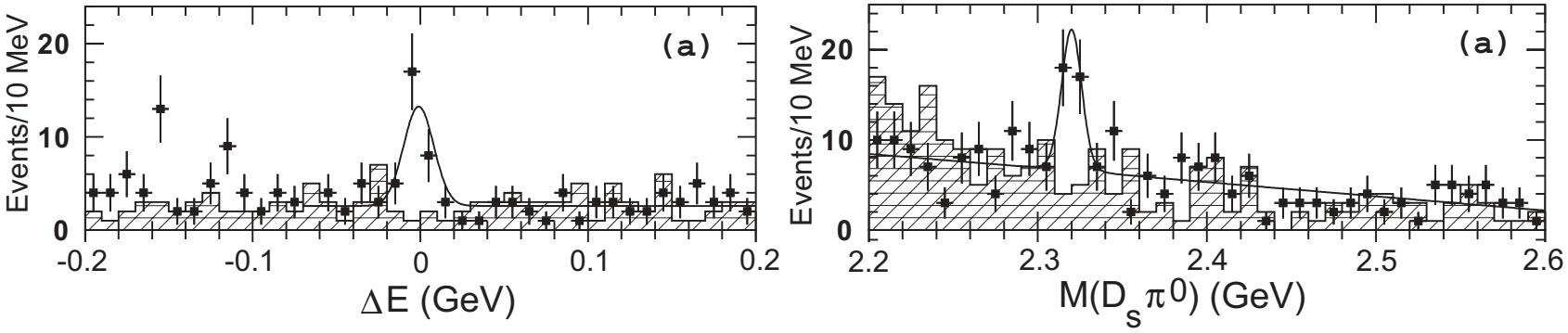
BaBar



Look forward to angular analysis in $B \to DD^*_{sJ}(2317)$ decays.

Observation of $D^*_{sJ}(2317)$ in Exclusive $B \to D D_s \pi^0$ Decays

(Belle preliminary, $124 \times 10^6 B\bar{B}$, $D_s^+ \to \phi\pi^+, \bar{K}^{*0}K^+, K_S^0 K^+$)



B Decay channel	Yield (ΔE)	$\mathcal{B}(10^{-4})$
$\bar{D}^0 D^*_{sJ}(2317)$, $D^*_{sJ}(2317) \to D_s\pi^0$	$13.7^{+5.1}_{-4.5}$	$8.1^{+3.0}_{-2.7} \pm 2.4$
$\bar{D}^- D^*_{sJ}(2317)$, $D^*_{sJ}(2317) \to D_s\pi^0$	$10.3^{+3.9}_{-3.1}$	$8.6^{+3.3}_{-2.6} \pm 2.6$
$\bar{D}^0 D^*_{sJ}(2317)$, $D^*_{sJ}(2317) \to D_s\gamma$	$3.4^{+2.8}_{-2.2}$	$2.4^{+2.0}_{-1.5} (< 5.7)$
$\bar{D}^- D^*_{sJ}(2317)$, $D^*_{sJ}(2317) \to D_s\gamma$	$2.3^{+2.5}_{-1.9}$	$2.6^{+2.8}_{-2.2} (< 7.1)$

cf (RPP 2002): $B^+ \to \bar{D}^0 D_s^+ = (1.3 \pm 0.4)\%$, $B^0 \to D^- D_s^+ = (0.8 \pm 0.3)\%$;

$B^+ \to \bar{D}^0 D_s^{*+} = (0.9 \pm 0.4)\%$, $B^0 \to D^- D_s^{*+} = (1.0 \pm 0.5)\%$.

$D^*_{sJ}(2317)^\pm$ Summary

Quantity	BaBar	Belle	CLEO
Dataset (fb^{-1})	91	87	13.5
D_s Modes	$\phi\pi$, K^*K	$\phi\pi$	$\phi\pi$
Mass (MeV)	$2316.8 \pm 0.4 \pm 3$	$2317.2 \pm 0.5 \pm 0.9$	$2318.5 \pm 1.2 \pm 1.1$
$M(2317) - M(D_s)$ (MeV)	$348.4 \pm 0.4 \pm 3$	$348.7 \pm 0.5 \pm 0.7$	$350.0 \pm 1.2 \pm 1.0$
Width (MeV, 90% C.L.)	< 10	†	< 7
$\mathcal{B}(D_s\pi^+\pi^-)/\mathcal{B}(D_s\pi^0)$ (90% C.L.)			< 0.019
$\mathcal{B}(D_s\gamma)/\mathcal{B}(D_s\pi^0)$ (90% C.L.)		< 0.05	< 0.052
$\mathcal{B}(D^*_s\pi^0)/\mathcal{B}(D_s\pi^0)$ (90% C.L.)			< 0.11
$\mathcal{B}(D^*_s\gamma)/\mathcal{B}(D_s\pi^0)$ (90% C.L.)			< 0.059
$\frac{\sigma\cdot\mathcal{B}(D^*_{sJ}\to D_s\pi^0)}{\sigma(D_s)}$ ($p > 3.5$ GeV)			$(7.9 \pm 1.2 \pm 0.4) \times 10^{-2}$

† $\sigma = 7.6 \pm 0.5$ MeV consistent with resolution.

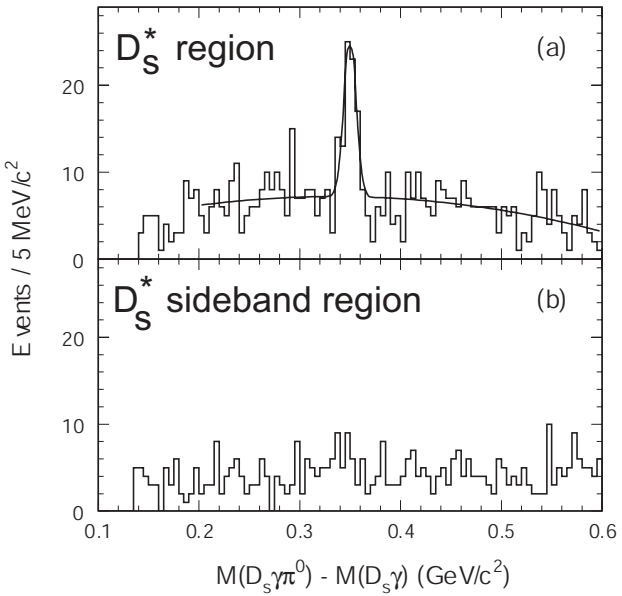
$I = 0$ favored (Narrow width to $D_s\pi^0$, CDF search in $D_s\pi^\pm$)

J^P natural, consistent with 0^+

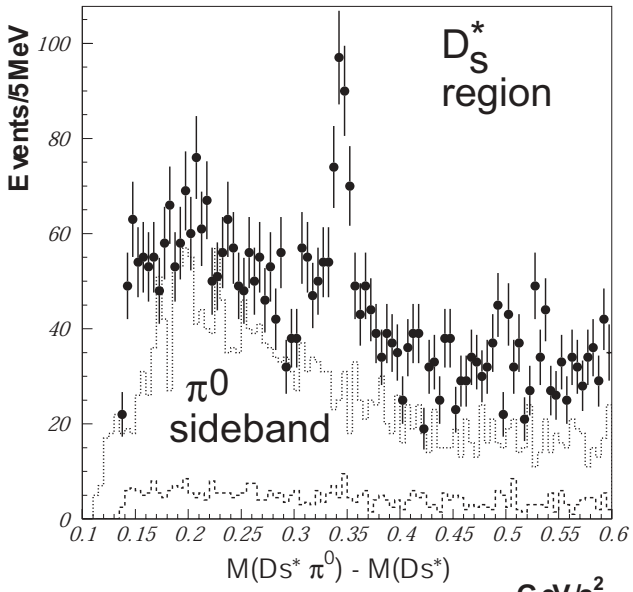
The New Narrow State at 2460 MeV in $D_s\pi^0\gamma$

Mass peak consistent with experimental resolution. Hence $\Gamma <$ several MeV.

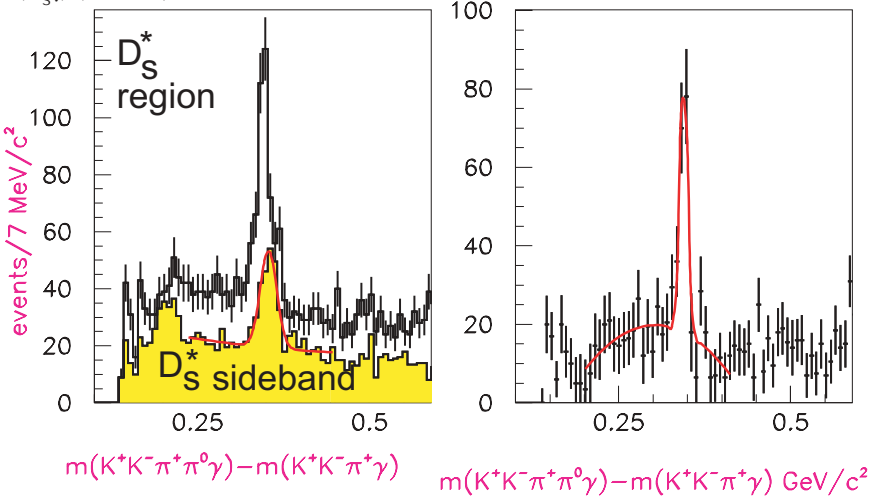
CLEO



Belle preliminary



BaBar preliminary



Reflection (Cross-feed) Ambiguity

$$\Delta M(D_{sJ}(2460) - D_s^*(2112)) \sim \Delta M(D_{sJ}^*(2317) - D_s) \sim 350 \text{ MeV}$$

$\rightarrow$ Feed-up of $D_{sJ}^*(2317)$ to $D_{sJ}(2460)$ peak possible by adding a random photon consistent with $D_s^*(2112) \rightarrow D_s\gamma$.

$\rightarrow$ Feed-down of $D_{sJ}(2460)$ to $D_{sJ}^*(2317)$ peak possible by neglecting the photon in the $D_s^*(2112) \rightarrow D_s\gamma$ transition.

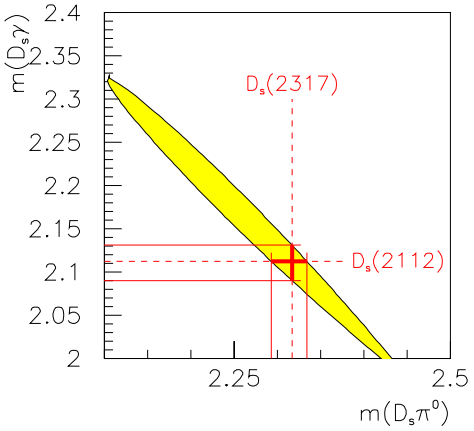
$\Rightarrow$ Ambiguity in $D_{sJ}(2460)$ decays: Is it $D_{sJ}(2460) \rightarrow D_s^*(2112)\pi^0$ or $D_{sJ}(2460) \rightarrow D_{sJ}^*(2317)\gamma$?

BaBar/Belle/CLEO all correct for cross-feeds under the $D_{sJ}(2460) \rightarrow D_s^*(2112)\pi^0$ hypothesis.

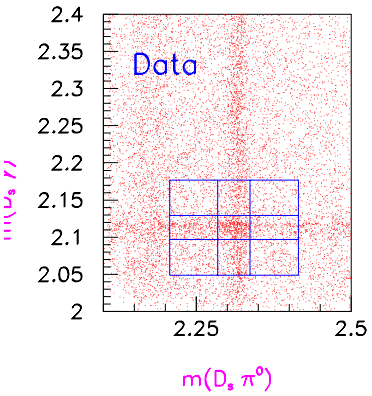
Study of Cross-feed Ambiguity (BaBar preliminary)

$D_s\pi^0\gamma$: The $M(D_s\gamma)$ vs $M(D_s\pi^0)$ scatter plot.

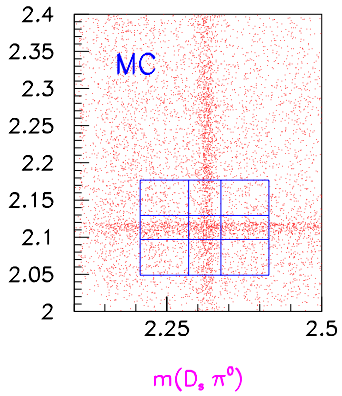
2460 boundary



Data

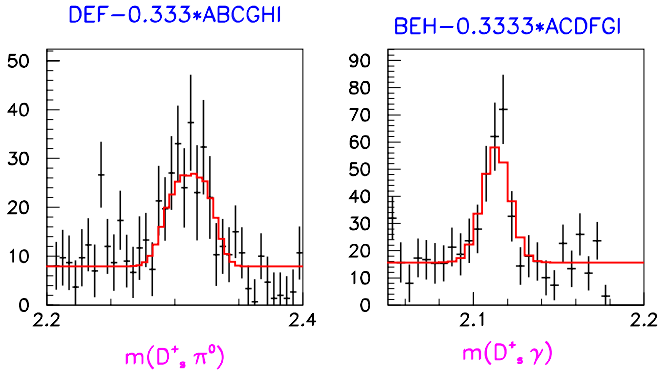


Monte Carlo

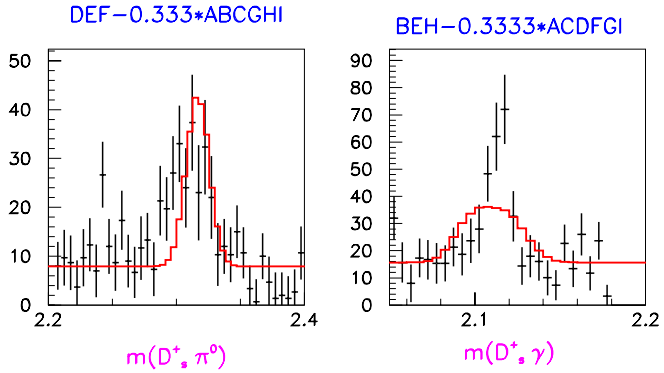


Projections with linear background subtraction:

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



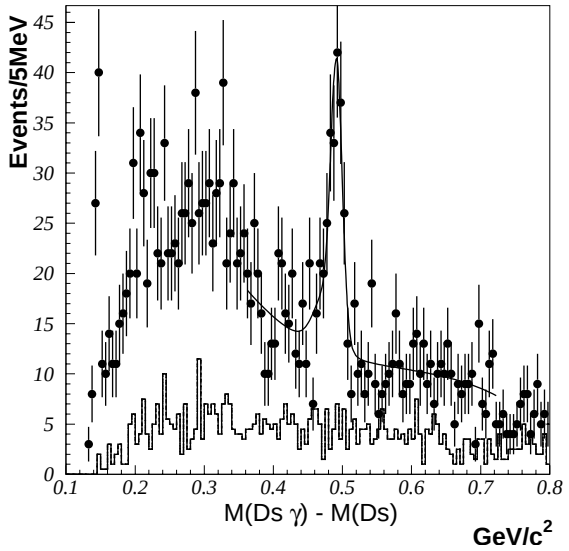
Is it $D_{sJ}(2460) \to D_{sJ}^*(2317)\gamma$?



Conclusion: Much better fit to $D_{sJ}(2460) \to D_s^*(2112)\pi^0$

$D_{sJ}(2460)$ Spin-Parity

Observed in $D_{sJ}(2460) \to D_s\gamma$, hence $J \neq 0$.



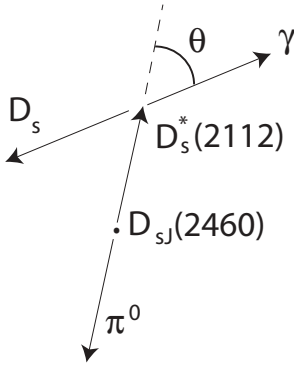
Belle preliminary; Continuum

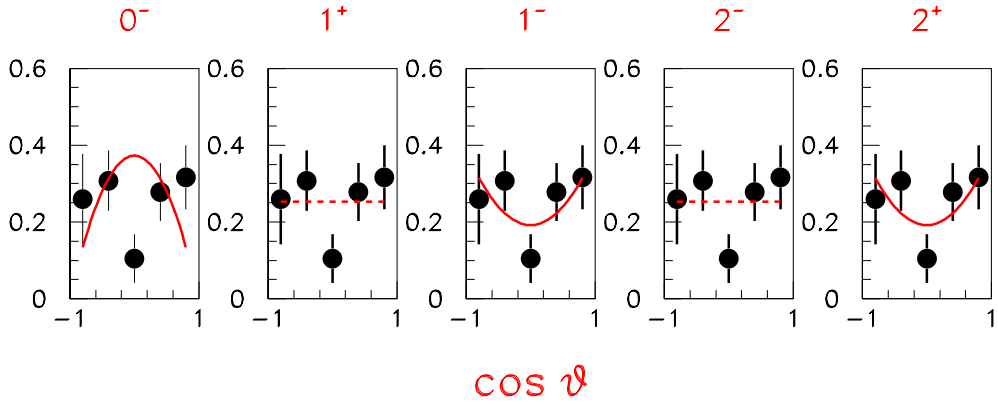
No $D_{sJ}(2317)$ seen (forbidden for spin 0)

$N(D_{sJ}(2460) \to D_s\gamma) = 152 \pm 18 \pm 11$

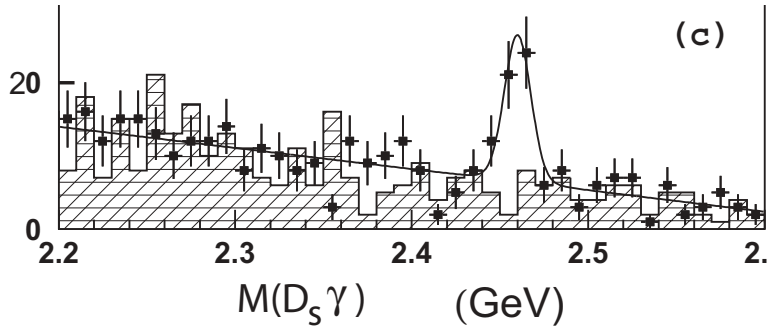
Rules out $J = 0$

Helicity angle in $D_{sJ}(2460) \to D_s^*(2112)\pi^0$, $D_s^*(2112)\pi^0 \to D_s\gamma$ (BaBar preliminary)
Inconsistent with $J^P = 0^-$. [nb: no prediction for 1^+, 2^-.]





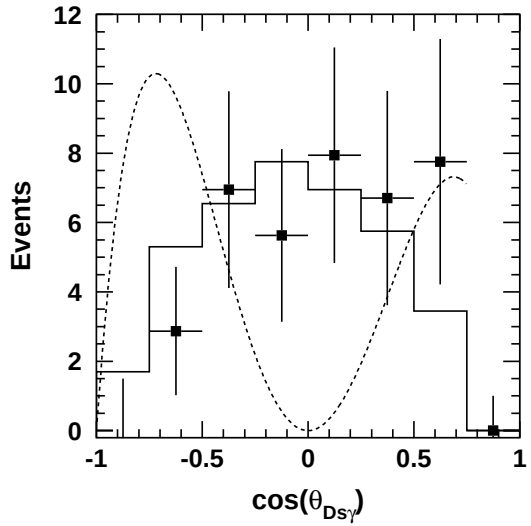
Angular analysis in $B \to DD_{sJ}(2460) \to DD_s\gamma$ (Belle preliminary)



$B \to DD_s\gamma$

$\mathcal{B}(B \to DD_{sJ}(2460) \to DD_s\gamma)$
$= \left(6.7^{+1.3}_{-1.2} \pm 2.0\right) \times 10^{-4}$

$$\frac{\mathcal{B}(D_{sJ}(2460) \to D_s\gamma)}{\mathcal{B}(D_{sJ}(2460) \to D_s^*\pi^0)} = 0.38 \pm 0.11 \pm 0.04$$



$B \to DD_{sJ}(2460) \to DD_s\gamma$

Data = points with errors

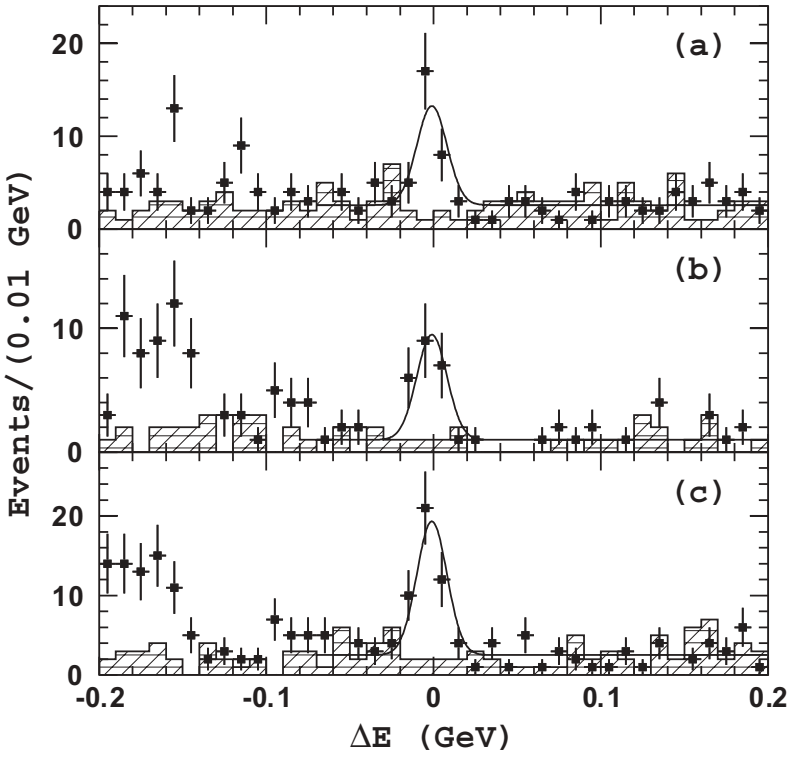
Spin 1 = histogram; Spin 2 = dashed line.

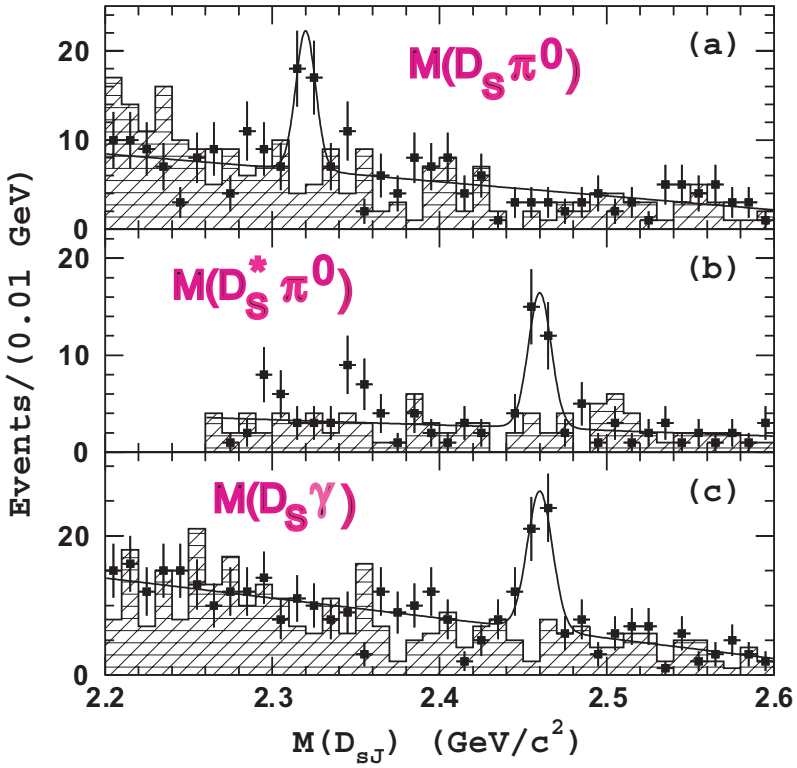
Consistent with $\sin^2\theta$, as expected for 1^+

Observation in Exclusive B Decays (Belle preliminary)

$124 \times 10^6 B\bar{B}$

$B \to D D_{sJ}^{(*)}$, $D \to K\pi, K\pi\pi, K\pi\pi\pi$, $D_s \to \phi\pi, \bar{K}^{*0}K^+, K_S^0 K^+$





Exclusive B Decays (Belle preliminary)

B Decay channel	Yield (ΔE)	$\mathcal{B}(10^{-4})$
$\bar{D}^0 D_{sJ}(2460)$, $D_{sJ}(2460) \to D_s^* \pi^0$	$7.2^{+3.7}_{-3.0}$	$11.9^{+6.1}_{-4.9} \pm 3.6$
$D^- D_{sJ}(2460)$, $D_{sJ}(2460) \to D_s^* \pi^0$	$11.8^{+3.8}_{-3.2}$	$22.7^{+7.3}_{-6.2} \pm 6.8$
$\bar{D}^0 D_{sJ}(2460)$, $D_{sJ}(2460) \to D_s \gamma$	$19.1^{+5.6}_{-5.0}$	$5.6^{+1.6}_{-1.5} \pm 1.7$
$D^- D_{sJ}(2460)$, $D_{sJ}(2460) \to D_s \gamma$	$18.5^{+5.0}_{-4.3}$	$8.4^{+2.4}_{-2.2} \pm 2.5$
$\bar{D}^0 D_{sJ}(2460)$, $D_{sJ}(2460) \to D_s^* \gamma$	$4.4^{+3.8}_{-3.3}$	$3.1^{+2.7}_{-2.3} (< 7.5)$
$D^- D_{sJ}(2460)$, $D_{sJ}(2460) \to D_s^* \gamma$	$1.1^{+1.8}_{-1.2}$	$1.3^{+2.0}_{-1.4} (< 4.6)$
$\bar{D}^0 D_{sJ}(2460)$, $D_{sJ}(2460) \to D_s \pi^0$	< 2.4	< 2.2
$D^- D_{sJ}(2460)$, $D_{sJ}(2460) \to D_s \pi^0$	< 2.4	< 2.8
$\bar{D}^0 D_{sJ}(2460)$, $D_{sJ}(2460) \to D_s \pi^+ \pi^-$	< 4.0	< 2.4
$D^- D_{sJ}(2460)$, $D_{sJ}(2460) \to D_s \pi^+ \pi^-$	< 2.5	< 2.0

$D_{sJ}(2460)$ Summary

Quantity	BaBar	Belle	CLEO
Dataset (fb^{-1})	91	87	13.5
$N(D_s^*\pi^0, D_s^* \to D_s\gamma)$	127 ± 22	$126 \pm 25 \pm 24$	41 ± 12
Mass (MeV)	$2457.0 \pm 1.4 \pm 3$	$2456.5 \pm 1.3 \pm 1.1$	$2463.6 \pm 1.7 \pm 1.2$
$M(2460) - M(D_s^*)$ (MeV)	$344.6 \pm 1.2 \pm 3$	$344.1 \pm 1.3 \pm 0.9$	$351.2 \pm 1.7 \pm 1.0$
Width (MeV, 90% C.L.)	†	†	< 7
$\frac{\mathcal{B}(D_s\pi^+\pi^-)}{\mathcal{B}(D_s^*\pi^0)}$ (90% C.L.)			< 0.08
$\frac{\mathcal{B}(D_s\gamma)}{\mathcal{B}(D_s^*\pi^0)}$ (90% C.L.)		$0.63 \pm 0.15 \pm 0.15$	< 0.49
$\frac{\mathcal{B}(D_s^*\gamma)}{\mathcal{B}(D_s^*\pi^0)}$ (90% C.L.)			< 0.16
$\frac{\mathcal{B}(D_{sJ}(2317)^*\gamma)}{\mathcal{B}(D_s^*\pi^0)}$ (90% C.L.)			< 0.58

† Width of mass peak is consistent with resolution.

$J^P \neq 0^\pm$, consistent with 1^+.

Not seen in $D_s\pi^\pm$, $D_s\pi^+\pi^-$ modes in CDF. Not seen in $D_s\pi^+\pi^-$ in B decays in Belle.

Production Rates ($p_{\rm CM} > 3.5$ GeV)

CLEO

$$\frac{\sigma\cdot\mathcal{B}(D_{sJ}^{*+}\to D_s^+\gamma)}{\sigma(D_s^+)} = 0.59 \pm 0.03 \pm 0.01$$

$$\frac{\sigma\cdot\mathcal{B}(D_{sJ}^{*}(2317)^+\to D_s^+\pi^0)}{\sigma(D_s^+)} = (7.9 \pm 1.2 \pm 0.4) \times 10^{-2}$$

$$\frac{\sigma\cdot\mathcal{B}(D_{sJ}(2460)^+\to D_s^{*+}\pi^0)}{\sigma(D_s^+)} = (3.5 \pm 0.9 \pm 0.2) \times 10^{-2}$$

Belle Preliminary

$$\frac{\sigma\cdot\mathcal{B}(D_{sJ}(2460)^+\to D_s^{*+}\pi^0)}{\sigma\cdot\mathcal{B}(D_{sJ}^{*}(2317)^+\to D_s^+\pi^0)} = 0.26 \pm 0.05 \pm 0.06$$

$$\frac{\sigma\cdot\mathcal{B}(D_{sJ}(2460)^+\to D_s^{+}\pi^0)}{\sigma\cdot\mathcal{B}(D_{sJ}^{*}(2317)^+\to D_s^+\pi^0)} < 0.06 \ (90\%\ \text{C.L.})$$

Summary

Two new narrow states have been observed with $c\bar{s}$ content:

$D^*_{sJ}(2317)$ and $D_{sJ}(2460)$.

They are consistent with being 0^+ and 1^+ states, respectively.

Their masses are lower than consensus expectation in $c\bar{s}$ spectroscopy.

Mass of $D_{sJ}(2460)$ on margin of inconsistency among experiments:

BaBar	$2457.0 \pm 1.4 \pm 3$
Belle	$2456.5 \pm 1.3 \pm 1.1$
CLEO	$2463.1 \pm 1.7 \pm 1.2$
Weighted Average*	2459.2 ± 1.2

* Adding systematic and statistical uncertainties in quadrature; neglecting possible correlations (eg, from D^*_s mass uncertainty of 0.7 MeV).

χ^2 probability for consistency is 3%.

For mass difference, weighted average is 346.6 ± 1.2, with 2% consistency.
(Removes correlated D^*_s mass uncertainty).

More results expected soon!