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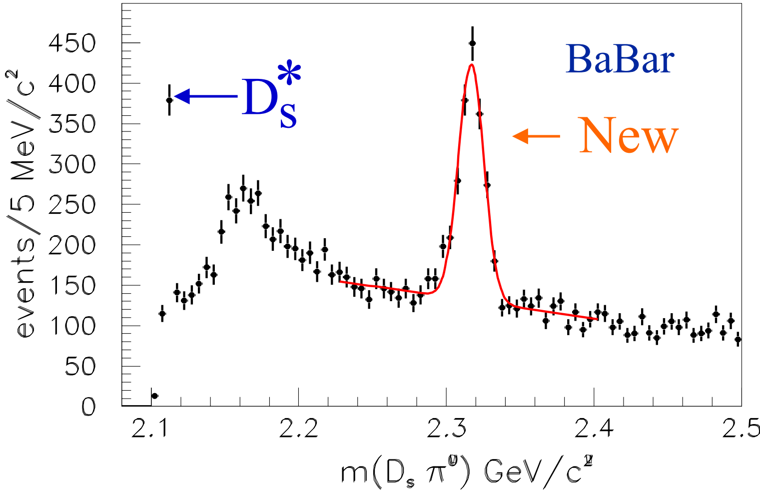
New Narrow $c\bar{s}$ States from CLEO:

Observation of the $D_{sJ}(2463)\rightarrow D_s^*\pi^o$ & Confirmation of the $D_{sJ}^*(2317)\rightarrow D_s\pi^o$

The D_s** States

- Formed of $c\bar{s}$ quarks, just like atom consider quark spin and angular momentum
  - Ground state $J^P=0^-$, called D_s^+
  - 1^- state, $D_s^* \to \gamma D_s$ (94%) M1, $\to \pi^o D_s$ (6%), isospin violating strong decay
  - Also seen relatively narrow 1^+ and 2^+ decays into $D^{(*)}K$
  - Expectation was remaining 0^+ & 1^+ states would also decay into $D^{(*)}K$

The $D_s^+\pi^o$ state



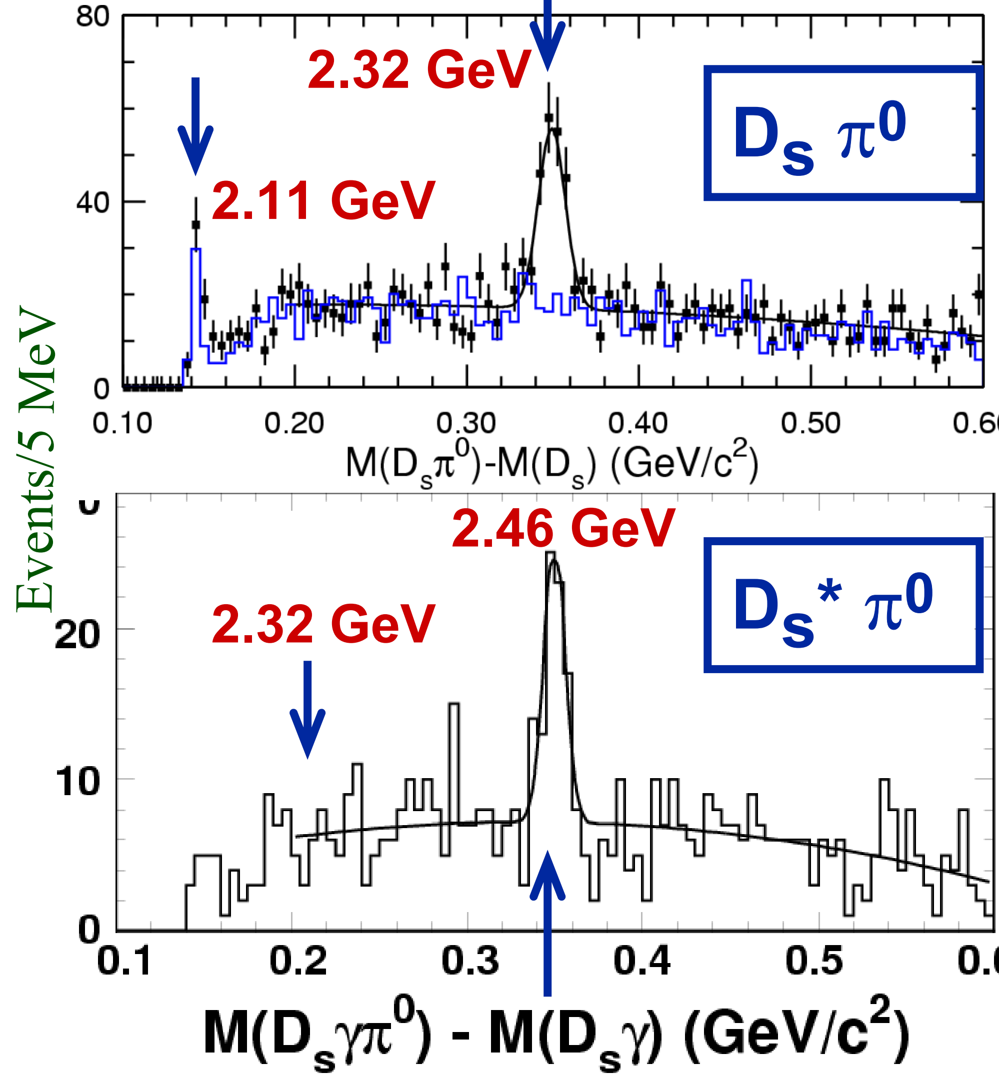
- New state, mass 2316.8±0.4±3.0 MeV, width consistent with mass resolution ~9 MeV found by BaBar
- Lighter than most potential models
- What can this be?
  - Four quark states: "Baryonia" or DK molecule Barnes, Close & Lipkin hep-ph/0305025
  - Van Beveren & Rupp: Quasi bound state scalar due to coupling to DK threshold using unitarized meson model hep-ph/0305035
  - Cahn & Jackson: Poor explanation using non-relatavistic vector & scalar exchange forces hep-ph/0305012
  - Etc…..

HQET + Chiral Symmetry

- "Ordinary" excited $c\bar{s}$ state: D_s**, narrow because it is below DK threshold, in $D_s\pi$ decay isospin is violated.
- Use HQET + chiral symmetry to explain, Bardeen, Eichten & Hill hep-ph/0305049
  - Parity Doubling: Two orthogonal linear combinations of meson fields $D(0^-,1^-)+D(0^+,1^+)$ & $D(0^-,1^-)-D(0^+,1^+)$ transform as $SU(3)_L x SU(3)_R$ and split into $(0^-,1^-)$ & $(0^+,1^+)$ doublets
  - Must decay as $(0^+,1^+) \rightarrow (0^-,1^-)$ + pseudoscalar; for ex: $D_s{**} \rightarrow D_s\eta$, which becomes $D_s\,\pi$ via $\eta-\pi$ mixing

CLEO Sees Two States

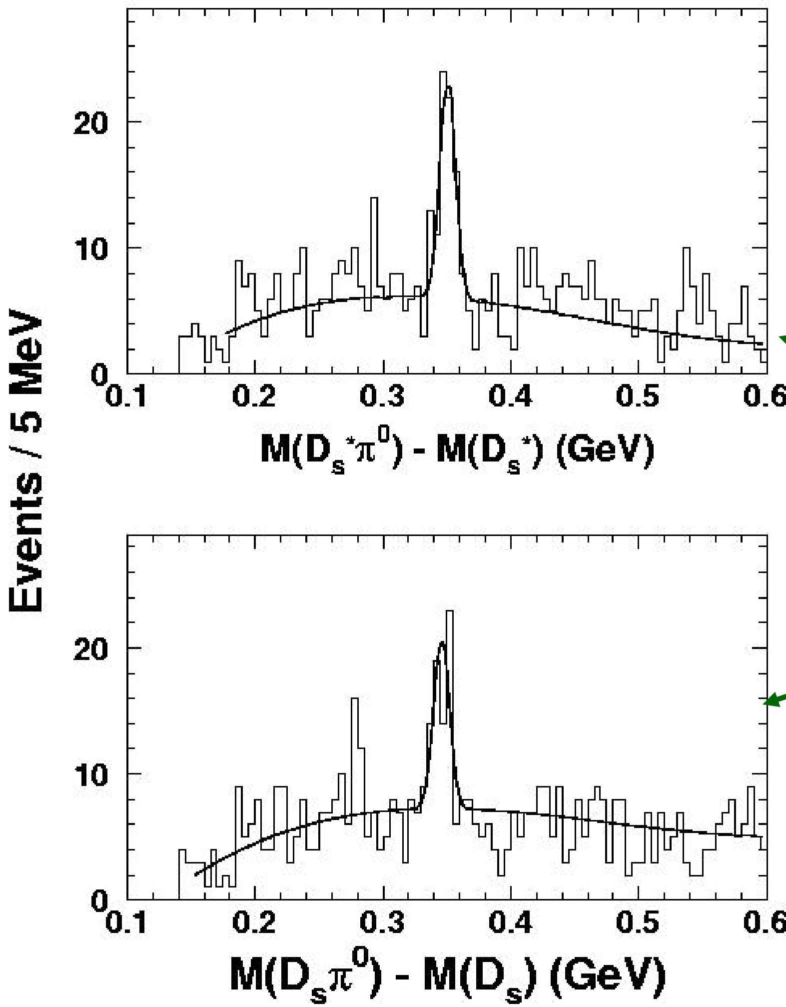
- Confirms the BaBar observation of $D_s(2317)$
  - $\sigma = 8.0^{+1.3}_{-1.2}$ MeV
  - Detector res: 6.0±0.3 MeV
  - 165±20 events in peak
- See 2nd state decaying into $D_s^*\pi^o$, at 2463 MeV
  - $\sigma = 6.1 \pm 1.0$ MeV
  - Detector res: 6.6±0.5 MeV
  - 55±10 events in peak



Can these states be reflections of other states? each other?

- No known source has been thought of to create these peaks
- However, since the mass differences are both ~350 MeV, they can reflect into each other!
- Which is feeding which and how much?

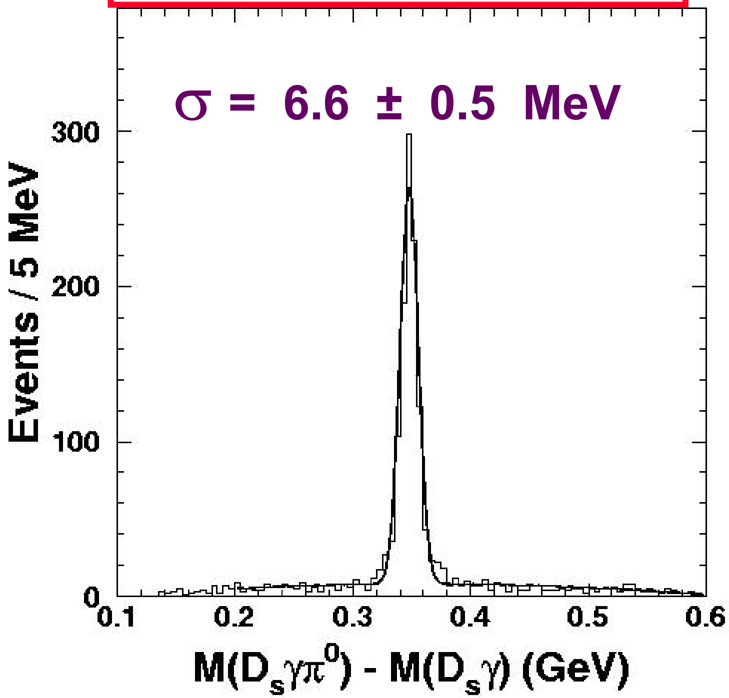
Feed Down: $D_s(2460)$ Signal, Reconstructed as $D_s(2317)$



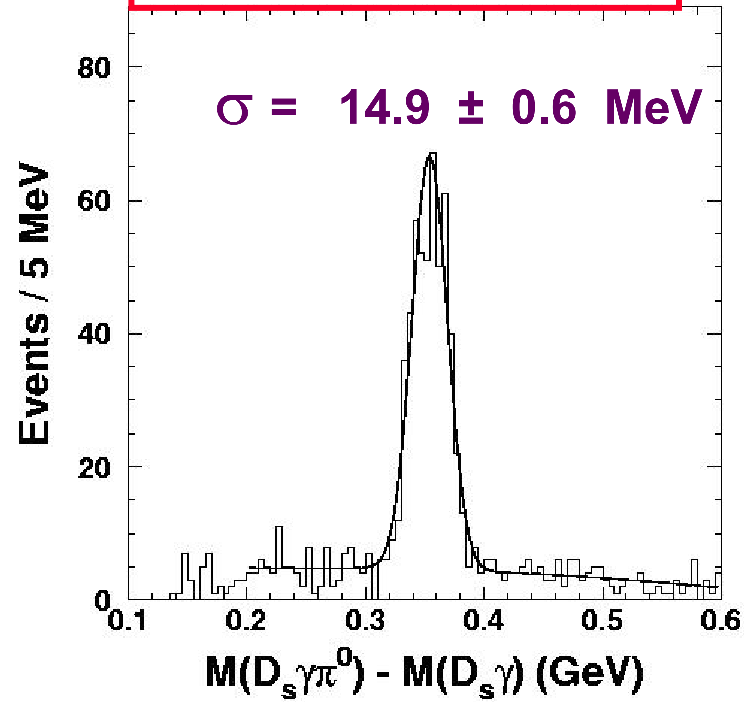
All events in the $D_s^*\pi^0$ mass spectrum are used to show the $D_s(2460)$ signal "feed down" to the $D_s(2317)$ spectrum.

Feed up: $D_s{}^*\pi^0$ Monte Carlo Simulations

$D_s(2463)\rightarrow D_s{}^*\pi^0$ Signal



$D_s(2317)\rightarrow D_s\pi^0$ Signal + Random γ



Thus $D_s(2317)$ does "feed up" to the $D_s(2463)$ by attaching to a random γ. However, the probability is low, only 9%, and the width is 14.9 MeV rather than 6.6 MeV

Basic Idea

- We are dealing with two narrow resonances which can reflect (or feed) into one another
- From the data and the MC we can calculate the amount of cross feed and thus extract the "true" signals in the data.

Calculation of Rates

R0 ≡ reconstructed $D_{sJ}^*(2317) \to D_s\pi^0$ excluding feed-down.

R1 ≡ reconstructed $D_{sJ}(2463) \to D_s^*\pi^0$ excluding feed-up.

N0 ≡ number of events extracted from fit to $D_s\pi^0$ mass spectrum. (190±19)

N1 ≡ number of events extracted from fit to $D_s^*\pi^0$ mass spectrum (55±10)

$$N0 = R0 + \text{feed-down} = R0 + R1 \times f_1$$

$$N1 = R1 + \text{feed-up} = R1 + R0 \times f_o$$

f_o ≡ the probability that the photon from a D_s^* is reconstructed & reflects on $D_s^*\pi^o$ peak (9.1±0.7±1.5)%

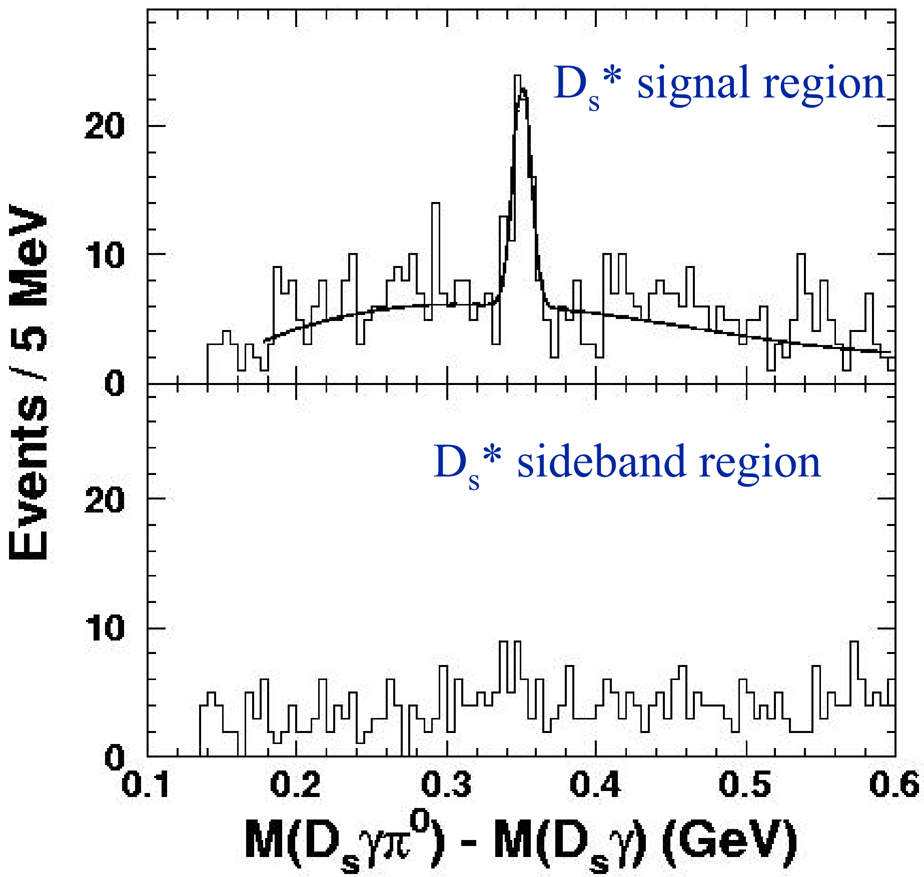
f_1 ≡ the probability that a D_s pickup a random γ to form D_s^*. (84±4±10)%

$$R0 = 155 \pm 23$$

$$R1 = 41 \pm 12$$

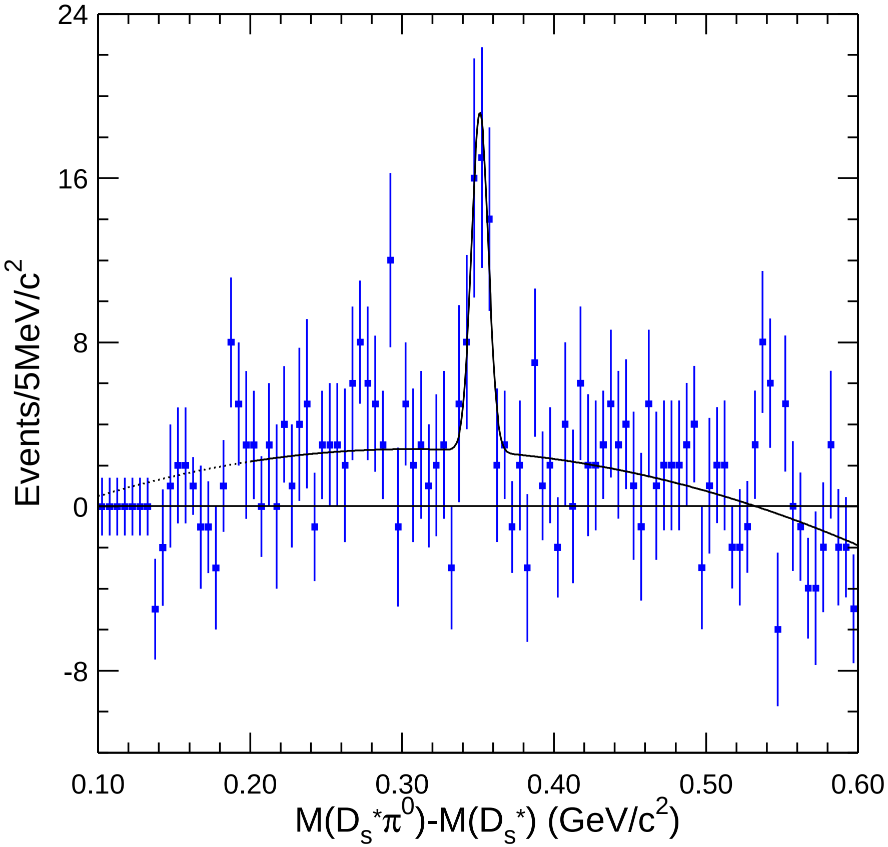
Probability that background + $D_s\pi^o$ feed-up explains signal is ruled out at >5σ level

Alternative Way to Estimate $D_s^*\pi^o$ Signal - idea



- The D_s* side band spectrum should contain as much feed-up as in D_s* "signal". We can do a sideband subtraction and fit the spectrum.

Alternative Way to Estimate $D_s^*\pi^o$ Signal: Sideband subtraction



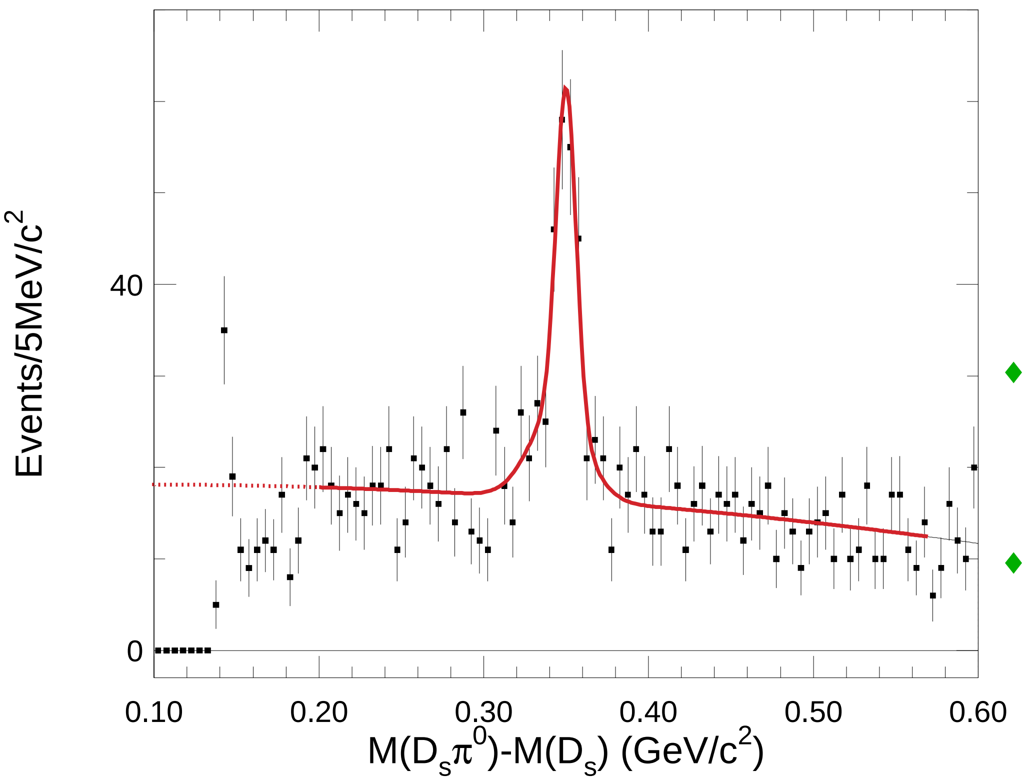
	Sideband subtraction	Conventional method
# of events	45.7 ± 11.6	41 ± 12
$M(D_s^*\pi^0) - M(D_s^*)$ MeV	351.2 ± 1.7	350.6 ± 1.2
Signal width (σ) MeV	5.5 ± 1.1	6.6 ± 0.5 Monte Carlo

This sideband subtracted signal is significant at the 5.7 σ level

Alternative Way to Estimate $D_s\pi^o$ Signal: fit to two Gaussians

χ^2= 66.6 for 80 - 10 d.o.f., C.L.= 59.4%

Errors		Parabolic	Minos	
Function 1: Gaussian (sigma)				
AREA	106.94	± 35.38	- 39.41	+ 0.0000E+00
MEAN	0.35003	± 1.2474E-03	- 1.2027E-03	+ 1.3577E-03
SIGMA	5.97283E-03	± 1.1838E-03	- 1.1336E-03	+ 1.3571E-03
Function 2: Gaussian (sigma)				
AREA	81.261	± 39.28	- 0.0000E+00	+ 39.82
MEAN	0.34490	± 6.0795E-03	- 0.0000E+00	+ 0.0000E+00
SIGMA	1.65240E-02	± 6.3016E-03	- 0.0000E+00	+ 0.0000E+00
Function 3: Polynomial of Order 2				



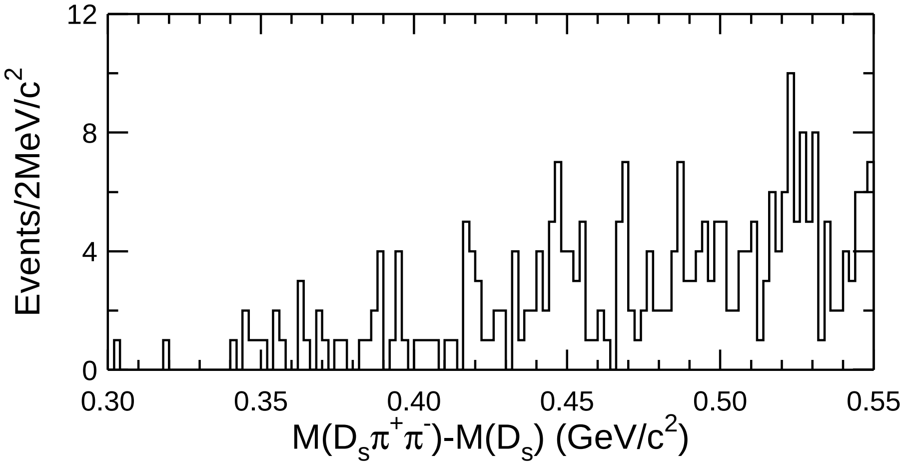
- We can fit the spectrum using two Gaussian functions whose means and widths are allowed to float.
- The fit is consistent with the existence of a narrow signal and a broader feed-down contribution.

	Narrow Width	Broad width	Single Gaussian
Data	5.9±1.2	16.5±6.3	8.3±1.2
MC	6.4±0.4	14.9±0.6	

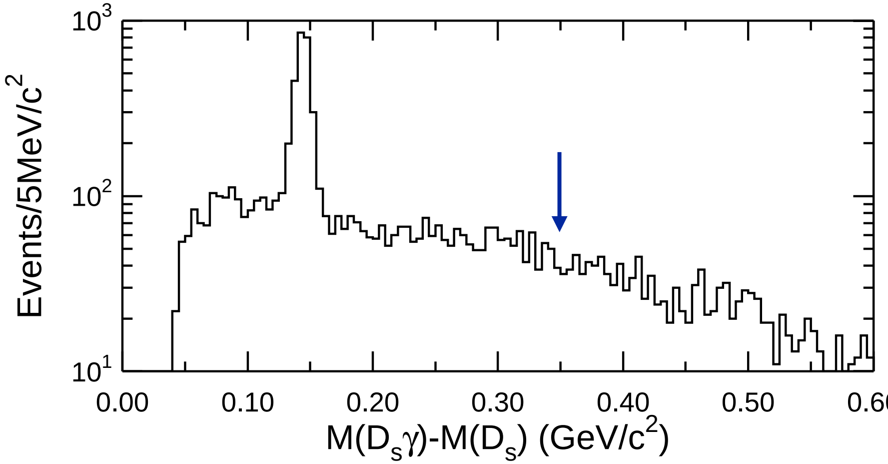
- The amount of feed-down is consistent within error with the previous calculation.
- The feed-down not only broadens the peak, but also shifts the center position. Using this fit we extract a more precise mass difference.

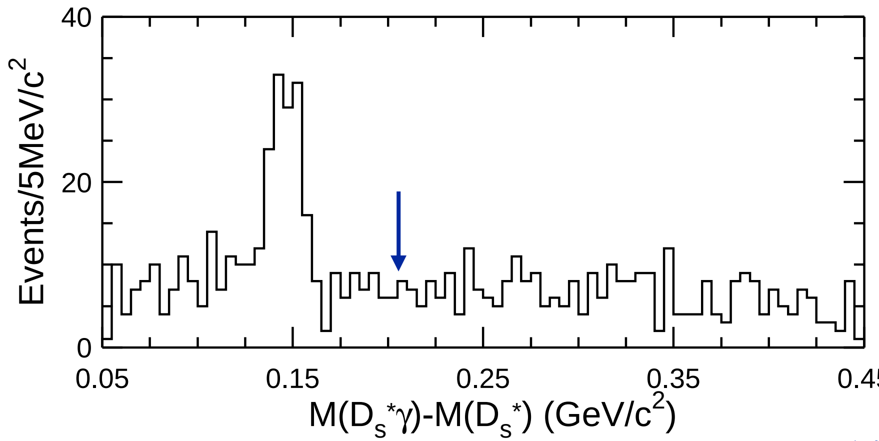
Search for other decay modes of $D_s(2317)$

$D_s \pi^+ \pi^-$



Electromagnetic Decay





These distributions were fit to Gaussians at the expected masses using MC widths to get upper limits

Upper Limits on other $D_s(2317)$ modes

Mode	Yield	Efficiency(%)	90% cl	Theory
$D_s\pi^o$	150±49	13.1±0.7	-	1
$D_s^*\pi^o$	-1.7±3.9	3.6±0.3	<0.11	0
$D_s\gamma$	-22±13	18.4±0.9	<0.052	0
$D_s^*\gamma$	-2.0±4.1	5.3±0.4	<0.059	0.08
$D_s\pi^+\pi^-$	1.6±2.6	19.6±0.7	<0.019	0

- Corrected for feed across
- Theory: Bardeen, Eichten and Hill

Upper Limits on other $D_s(2463)$ modes

Mode	Yield	Efficiency(%)	90% cl	Theory
$D_s^{*}\pi^{o}$	41±11	6.0±0.2	-	1
$D_s\gamma$	40±17	19.8±0.4	<0.49	0.24
$D_s^{*}\gamma$	-5.1±7.7	9.1±0.3	<0.16	0.22
$D_s\pi^+\pi^-$	2.5±5.4	19.5±1.5	<0.08	0.20
$D_{s(2317)}\gamma$	3.6±3.0	2.0±0.1	<0.58	0.13

- Corrected for feed across
- Theory: Bardeen, Eichten and Hill

$D_s(2463) \rightarrow D_s \pi^+ \pi^-$?

- Above threshold for $D_s \pi^+ \pi^-$, If this rate is large, this particle would be wide. Not isospin but OZI violating
- However no observed signal, B relative to $D_s^* \pi^o$ is <8% @ 90% c.l.
- BEH prediction is 19%, thus decay rate is not large but u.l is lower than prediction. Does this kill the model?
  - Must calculate relative decay rates for $D_s(2463) \rightarrow \eta + D_s^* \rightarrow \pi^o + D_s^*$ versus $D_s(2463) \rightarrow \sigma + D_s^* \rightarrow \pi^+ \pi^- + D_s^*$
  - This is a difficult calculation, but it would nice at some point to see this decay mode

Conclusions I

- CLEO confirms the BABAR discovered $c\bar{s}$ state near 2317 MeV. $mD_s(2317)-mD_s = 350.0 \pm 1.2 \pm 1.0$ MeV
- Likely to be 0^+ because of lack of decays into $D_s^*\pi^o$
- We have observed a new state near 2463 MeV,

  $mD_s(2463)-mD_s^* = 351.2 \pm 1.7 \pm 1.0$ MeV, likely to be 1+ because of lack of decay into $D_s\pi^o$ and DK
- The mass splittings are consistent with being equal as predicted by BEH if these are the 0^+ & 1^+ states (difference is 1.2 ± 2.1 MeV)
- The widths are narrow, consistent with our mass resolution (after deconvolution), both have $\Gamma < 7$ MeV

Conclusions II

- Theories of QCD and Lattice QCD are necessary to extract information on fundamental parameters in the quark sector.
- The BEH model couples HQET with Chiral Symmetry and makes predictions about masses, widths and decay modes. This theory has previously not been considered as favored
- These results provide powerful evidence for this model
- However, it would be nice to see other decays