Review of The New D_{sJ} States

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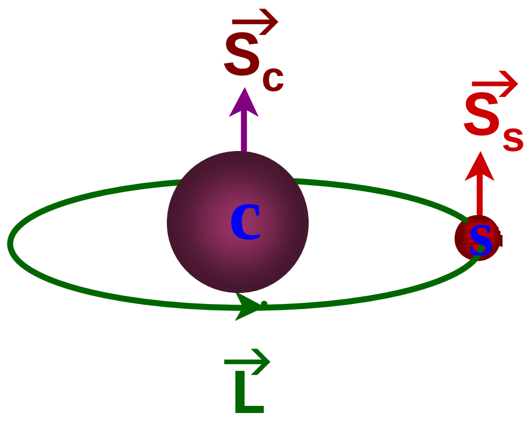
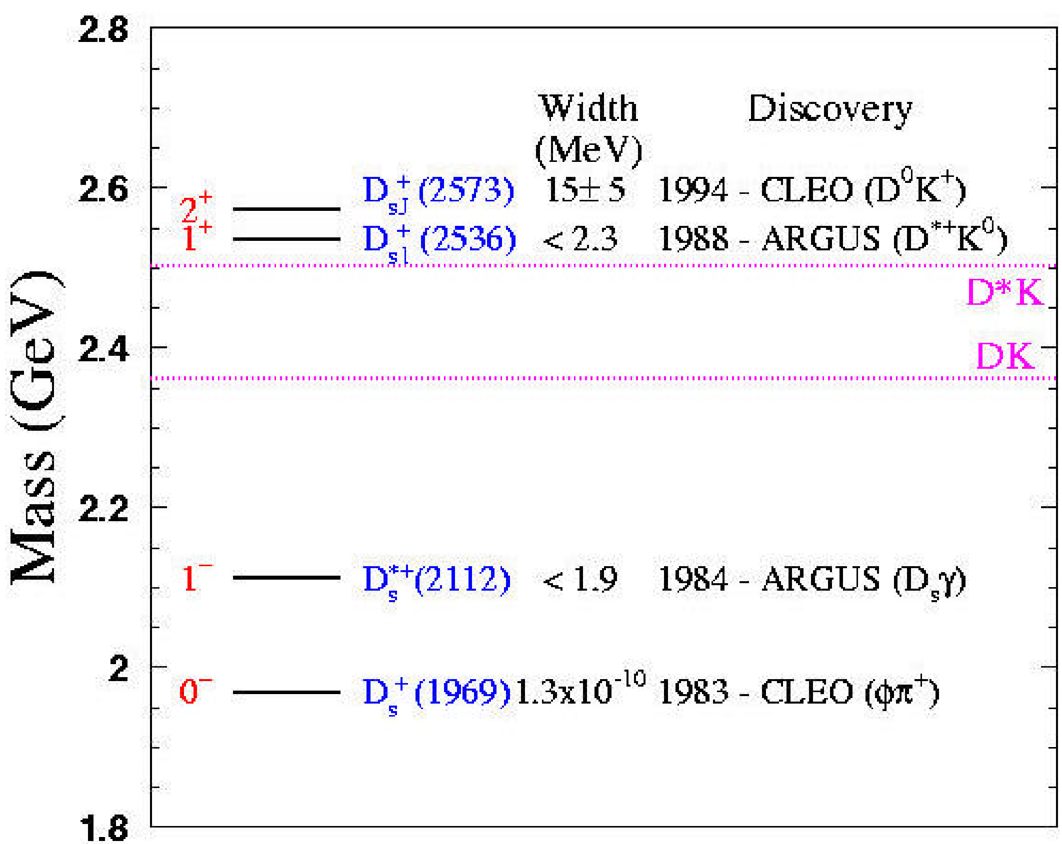
Spin Parity of D_{sJ} Mesons



$$\vec{j} = \vec{L} + \vec{S}_s$$
$$\vec{S} = \vec{S}_s + \vec{S}_c$$
$$\vec{J} = \vec{j} + \vec{S}_c$$
$$= \vec{L} + \vec{S}$$

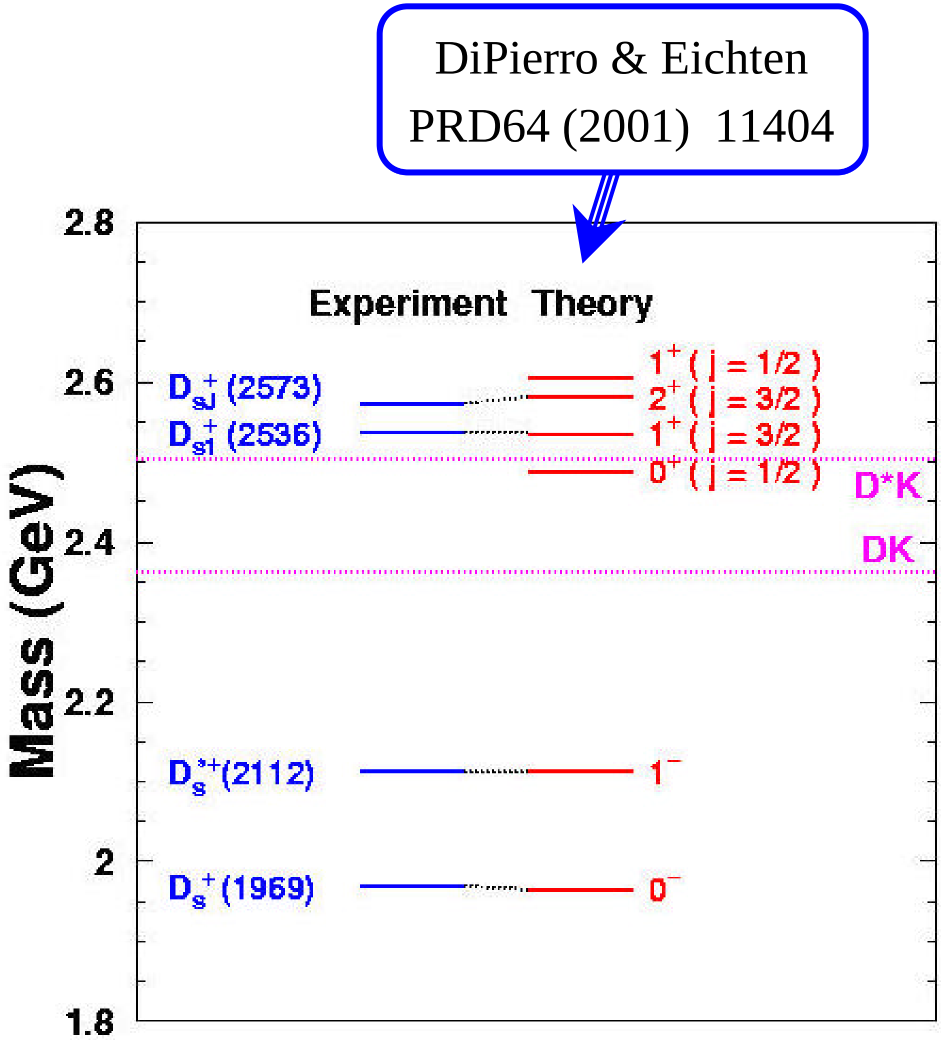
- A charmed-strange meson (D_{sJ}) composes of a ***c*** and a $\bar{s}$ quarks.
- **J** is a good quantum number. **j**, the light quark angular momentum would conserve if ***c*** quark were infinitely massive. The finite mass results in that ***c*** spin couples with **j**, causes mass splitting of doublet.
- The lightest D_{sJ} mesons are the S-wave states: $^{2S+1}L_J = {}^1S_0\ (J^P=0^-)$ & $^3S_1\ (1^-)$, with **j**=1/2.
- The P-wave D_S mesons can be considered as **j**=1/2 doublet and **j**=3/2 doublet: $^3P_0(0^+)$ & $^3P_2(2^+)$ are **j**=1/2 & **j**=3/2 respectively. $^1P_1(1^+)$ & $^3P_1(1^+)$ are mixtures of **j**=1/2 & **j**=3/2.

Brief History of D_{sJ} Discoveries Prior to 2003



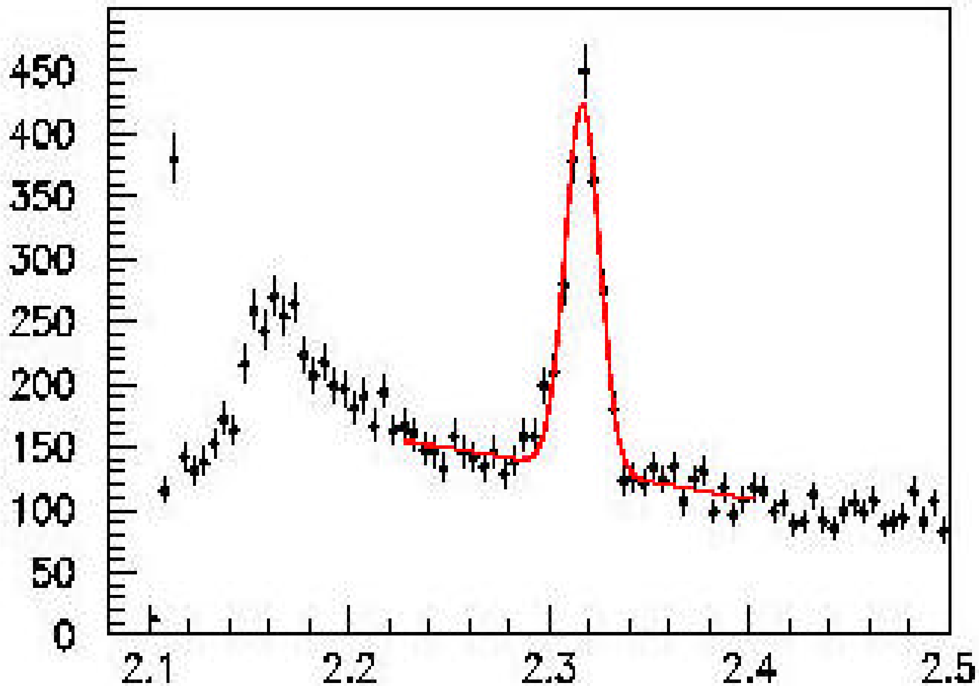
- All 4 discovered states are very narrow.
  - ✓ D_S through weak decay.
  - ✓ $D_S^* \to D_S\gamma$ & $D_S\pi^0$.
  - ✓ $D_{s1}(2536)$ is a member of **j**=3/2 doublet (may include small admixture of **j**=1/2). It decays to **j**=1/2 in D-wave.
  - ✓ $D_{sJ}(2573)$ decays also in D-wave.
- How about the other two missing states?

Theoretical Prediction



- Potential models predict the mass and width of charm mesons (e.g. DiPierro & Eichten), which worked quite well with D and D_{sJ} mesons that were already known.
- The j=1/2 doublet 0^+ & 1^+ were predicted to be massive enough to decay into DK and D*K respectively via S-wave. So the widths were expected to be broad.
- Although there were predictions of lower mass, not much attention was paid.
- Virtually "everyone" believed that $D^{(*)}K$ were the modes to look at, and they were difficult to be seen due to the width.

BaBar Discovered $D_S(2317)$



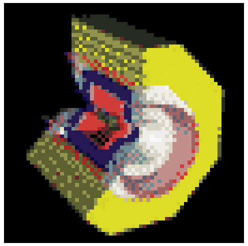
$M(D_S^+\pi^0)$ [GeV]

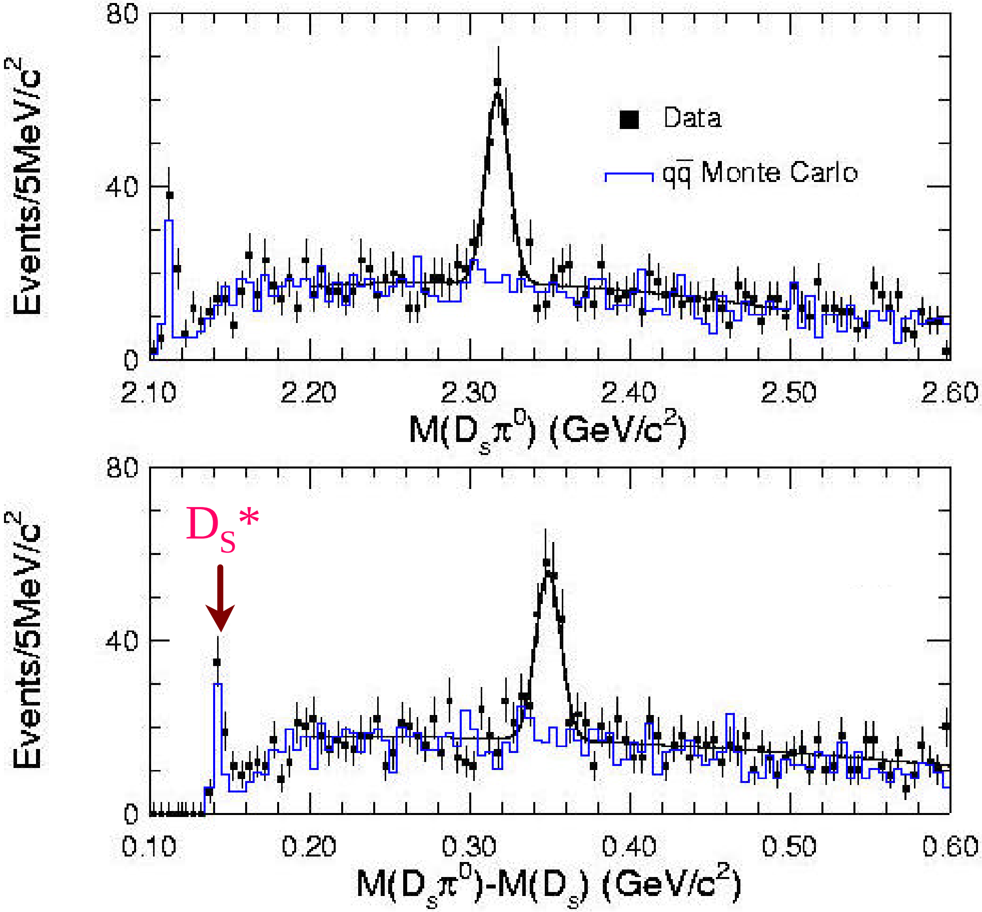
BaBar observed a $D_S\pi^0$ resonance at 2.317 GeV, with $P(D_S\pi^0) > 3.5$ GeV. Its width is consistent with the detector resolution. The spin parity is possibly $J^P=0^+$.

(hep-ex/0304021)

Could it be the missing 0^+ D_S?

CLEO Confirmed $D_S(2317)$



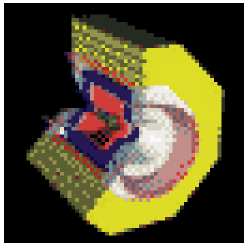


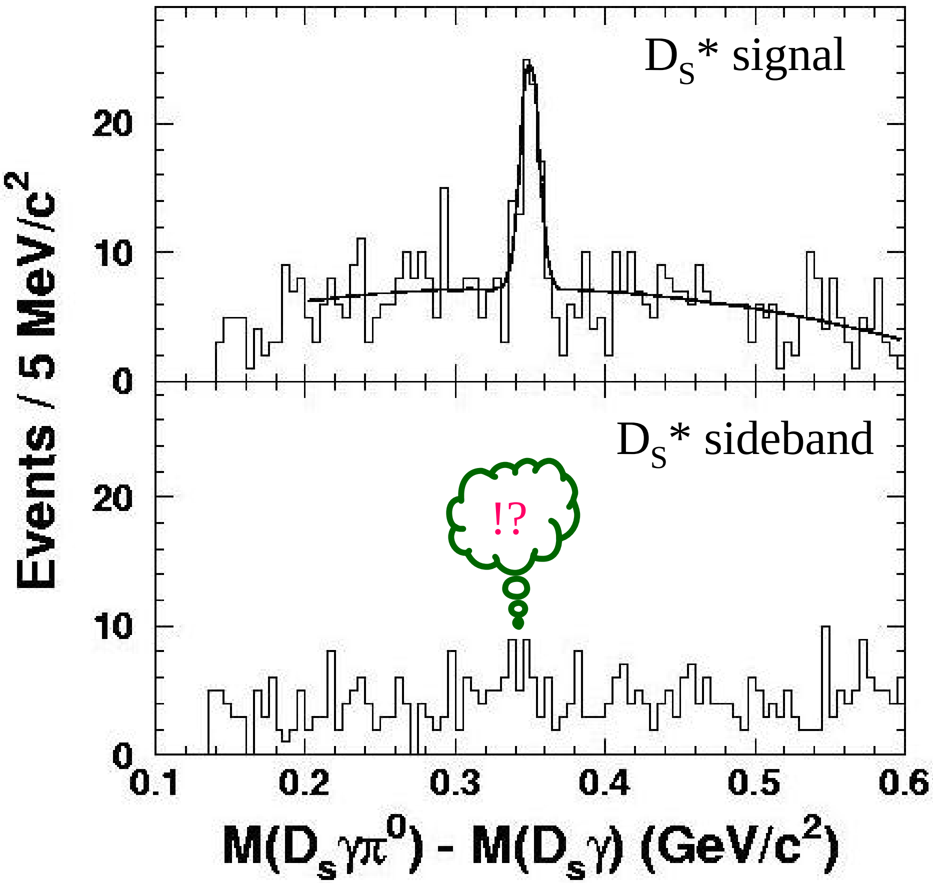
$\langle\Delta M\rangle = 349.4 \pm 1.0$ MeV
$\sigma = 8.0 \pm 1.3$ MeV
$P(D_S\pi^0) > 3.5$ GeV

CLEO quickly confirmed the narrow resonance at 2317 MeV. They noticed a slightly broader width than detector resolution (6 MeV).

(hep-ex/0305100)

CLEO Discovered $D_S(2460)$



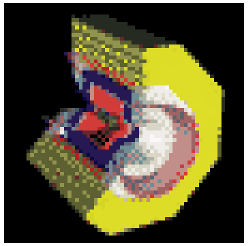


$\langle \Delta M \rangle = 349.8 \pm 1.3$ MeV
$\sigma = 6.1 \pm 1.0$ MeV
$P(D_S^*\pi^0) > 3.5$ GeV

CLEO observed a significant peak in $D_S^*\pi^0$ spectrum at ~2.46 GeV. Could it be pure reflection of $D_S(2317)$?

There is a small peak in the normalized D_S* sidebands; it accounts for only 20% of the signal.

Cross-feed of Two D_{sJ} Mesons

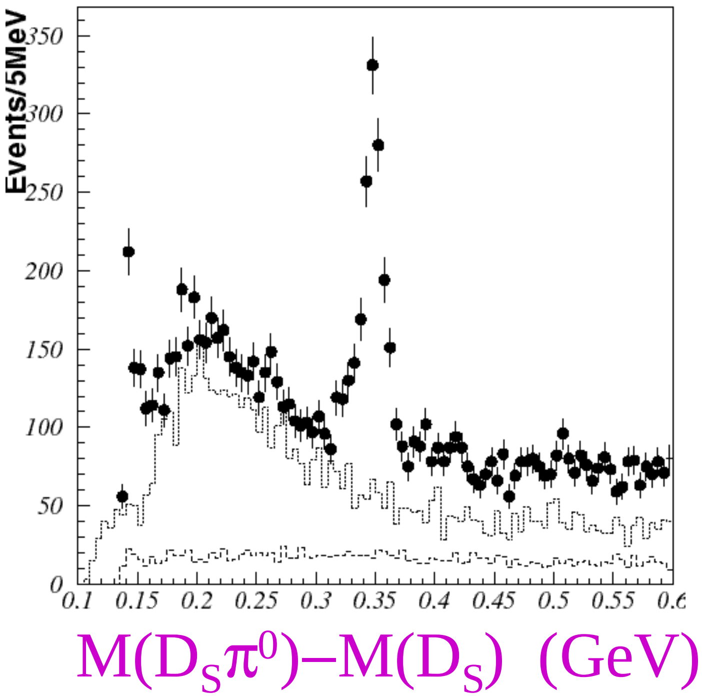


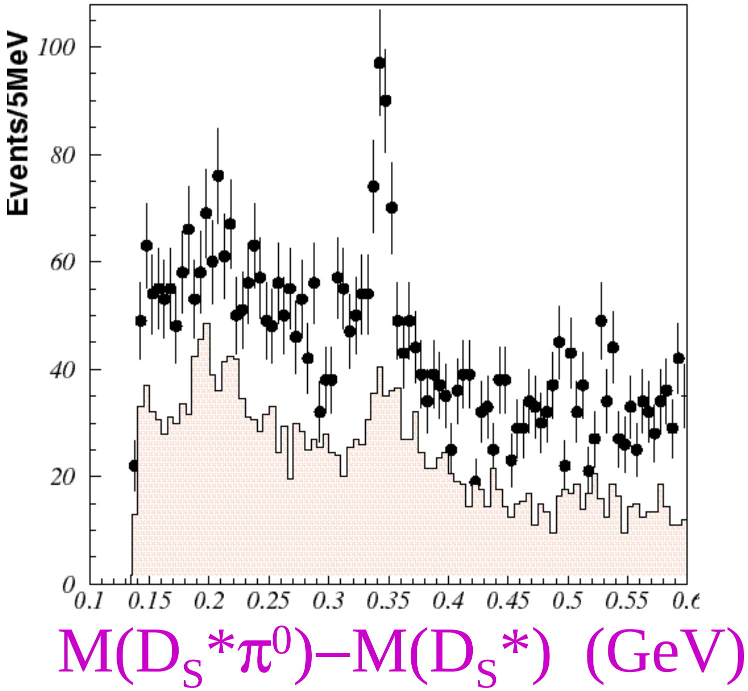
	CLEO data	MC: $D_S(2460)\to D_S^*\pi^0$	MC: $D_S(2317)\to D_S\pi^0$
Reconstruct as $D_S^*\pi^0$	σ=6.1±1.0 MeV N=55±10	σ=6.6±0.5 MeV Eff. ε_0=5.7%	Pick up a random γ σ=14.9±0.6 MeV $\varepsilon=0.09\times\varepsilon_1$ (σ=6.1)
Reconstruct as $D_S\pi^0$	σ=8.0±0.3 MeV N=190±19	Neglect the γ σ=14.9±0.4 MeV $\varepsilon=0.84\times\varepsilon_0$ (σ=8.0)	σ=6.0±0.3 MeV Eff. ε_1 = 9.7%

$D_S(2317)$ signal = 155 ± 23 (+ ~18% feed-down)
↖consistent with double Gaussians fit.

$D_S(2460)$ signal = 41 ± 12 (+ ~25% feed-up)
↖consistent with fit to sideband subtracted spectrum.

Belle Confirmed Both States

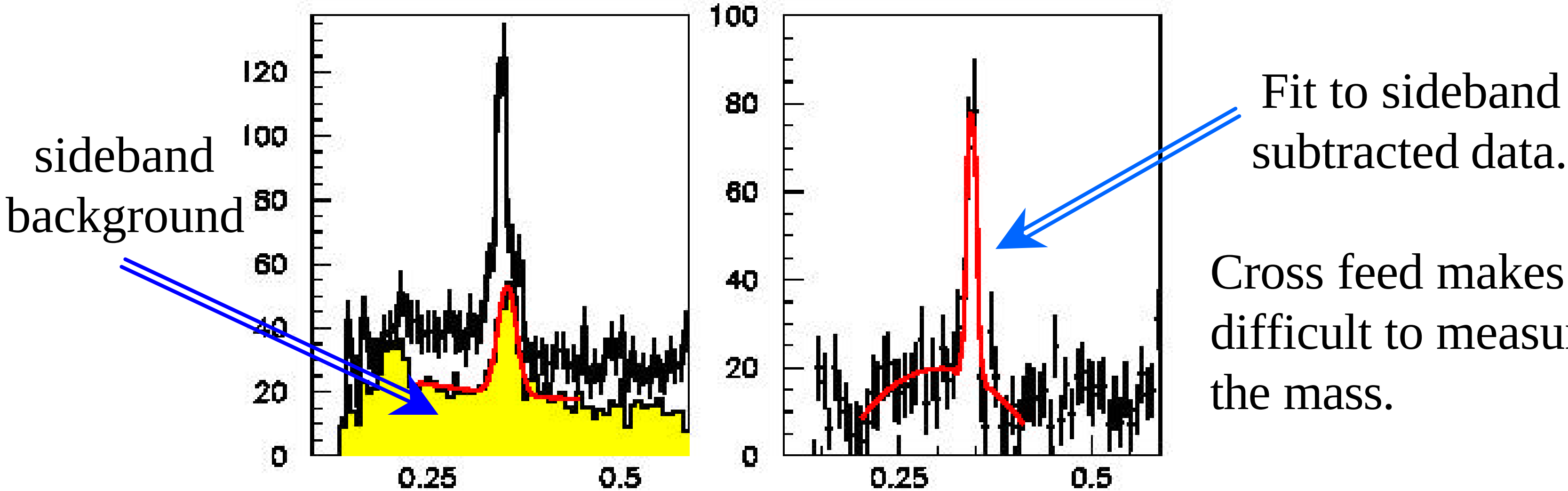




Feed-up from $D_S(2317)$ ~ 30%

BaBar Confirmed $D_S(2460)$

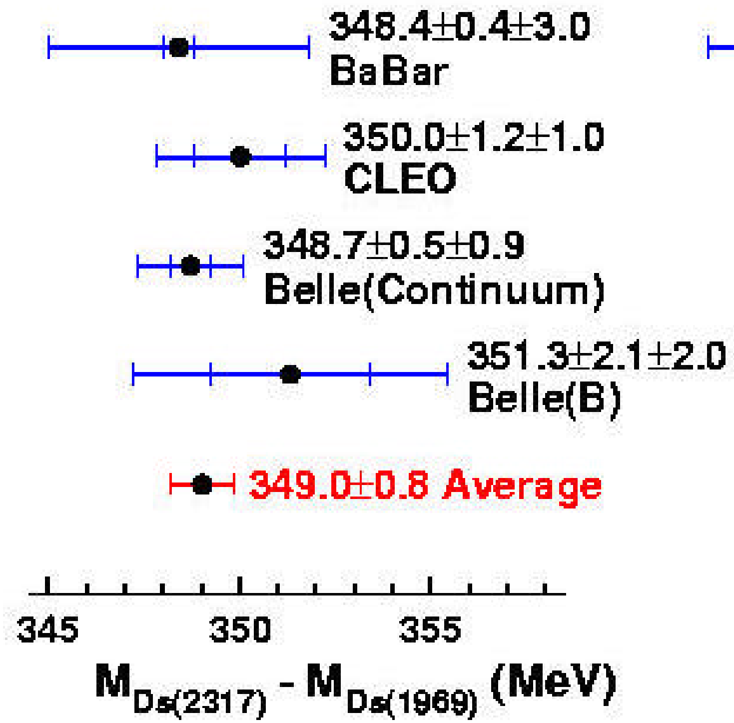
- After careful study of the cross-feed, BaBar confirmed the existence of $D_S(2460)$.
- Feedup rate at BaBar as a fraction of the 2460 signal size is ~50% compared with CLEO (~25%) & Belle (~30%).

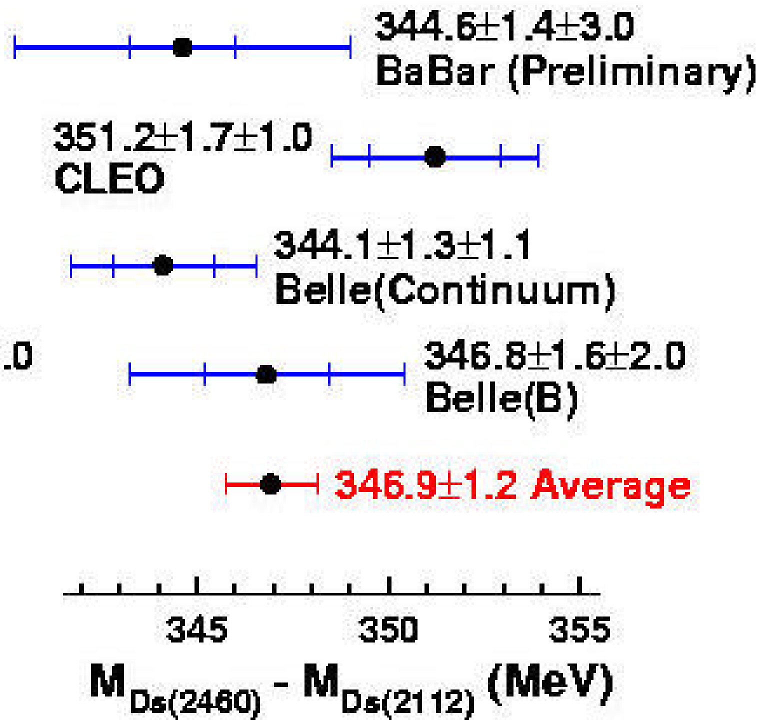


$\Delta M = M(D_S^*\pi^0) - M(D_S^*)$ (GeV)

Cross feed makes it difficult to measure the mass.

Mass and Width of The New States





$\Delta M_{2317} - \Delta M_{2460} = 2.1 \pm 1.4$ MeV

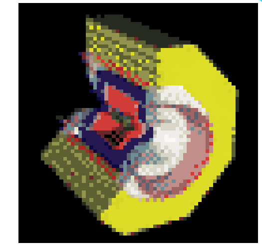
Width $\Gamma < 7$ MeV (both states) at 90% C.L. by CLEO

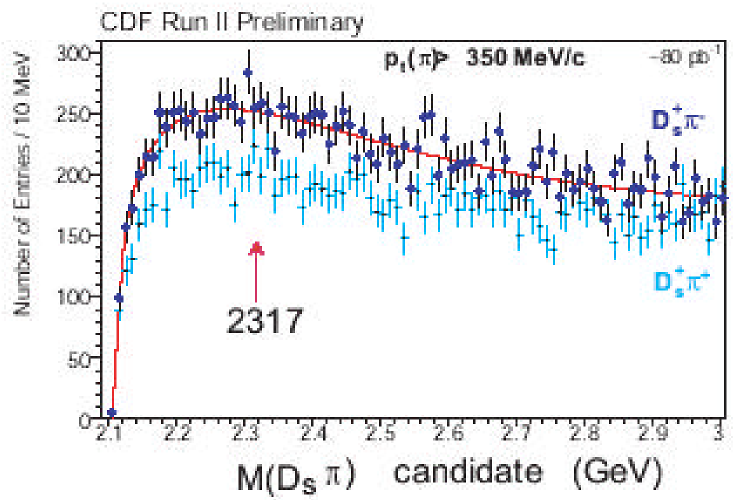
Possible Explanations

Several possible explanations appeared after the discovery, some are quite exotic.

- Barnes, Close & Lipkin: DK molecule. *(hep-ph/0305025)*
- Szczepaniak: Dπ atom. *(PLB 567 (2003),23)*
- Several authors: four quark particle. *(Cheng & Hou, PLB 566(2003)193; Terasaki, PRD68(2003) 011501; Nussinov, hep-ph/0306187)*
- Van Beveran & Rupp: use a unitarized meson model to explain the low mass as a kind of threshold effect. *(hep-ph/0305035)*
- Cahn & Jackson: use non-relativistic vector and scalar exchange force. *(hep-ph/0305012)*
- ……

Search For $D_S^{(*)+}\pi^{\pm}$

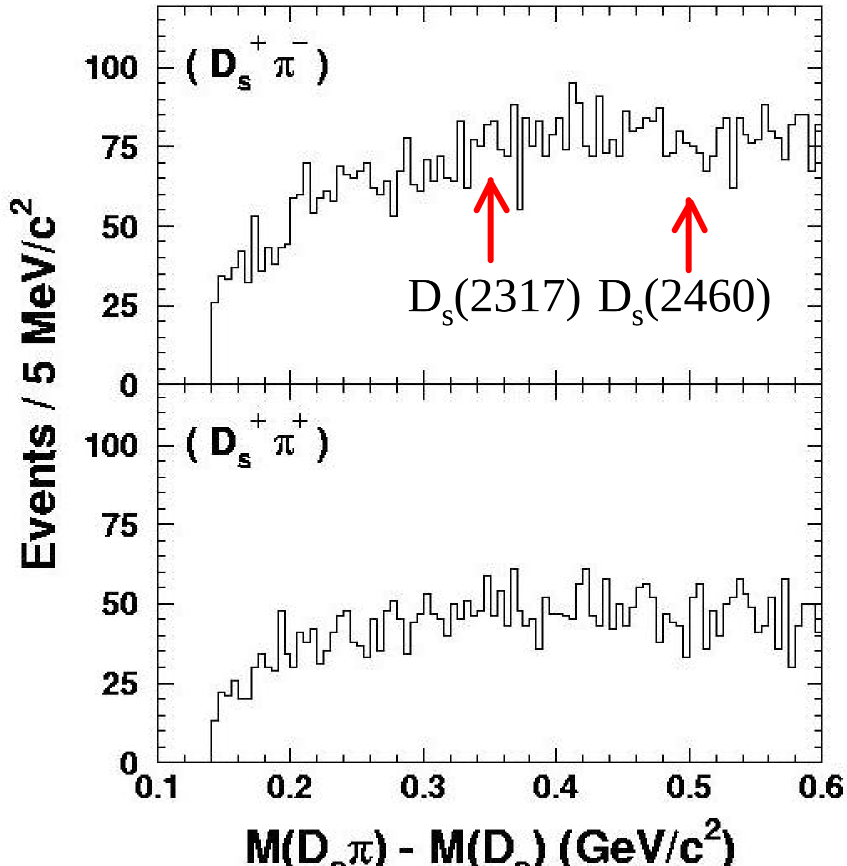




Upper limits from CLEO:

$$\frac{s\,(X \rightarrow D_S^{+} p^{-})}{s\,(D_S(2317) \rightarrow D_S^{+} p^{0})} < 0.10 \quad (90\%\ CL)$$

$$\frac{s\,(X \rightarrow D_S^{*+} p^{-})}{s\,(D_S(2460) \rightarrow D_S^{*+} p^{0})} < 0.12 \quad (90\%\ CL)$$



Atomic or molecular explanations are not ruled out.

Another Possible Explanation

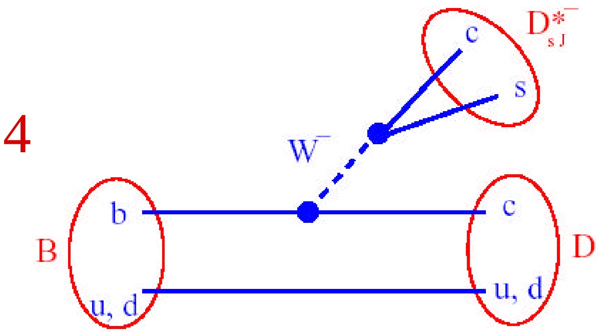
- $D_S(2317)$ and $D_S(2460)$ fit in well the quark model as ordinary 0^+ and 1^+ D_{sJ} mesons except for maybe the masses.
- Bardeen, Eichten & Hill (hep-ph/0305049) couple chiral perturbation theory with a quark model representing HQET. They infer that the $D_S(2317)$ is the 0^+ state, and predict the existence of the 1^+ partner. The mass splitting between the partners is identical to that between 0^- and 1^-: $M(1^+) - M(0^+) = M(1^-) - M(0^-)$.
- $D_S(2317)$ and $D_S(2460)$ are below DK and D*K thresholds. The strong channel to $D_S\pi^0$ and $D_S{}^*\pi^0$ are isospin suppressed. Thus the widths are very narrow.
- The measurement ($M(1^+) - M(1^-) \approx M(0^+) - M(0^-) \approx 350$ MeV) backs up the prediction.
- Interesting lattice QCD results: $M(0^+) - M(0^-) = 370(20)$ MeV, $M(1^+) - M(1^-) = 388\ (27)$ MeV. (Lepage LP2003)

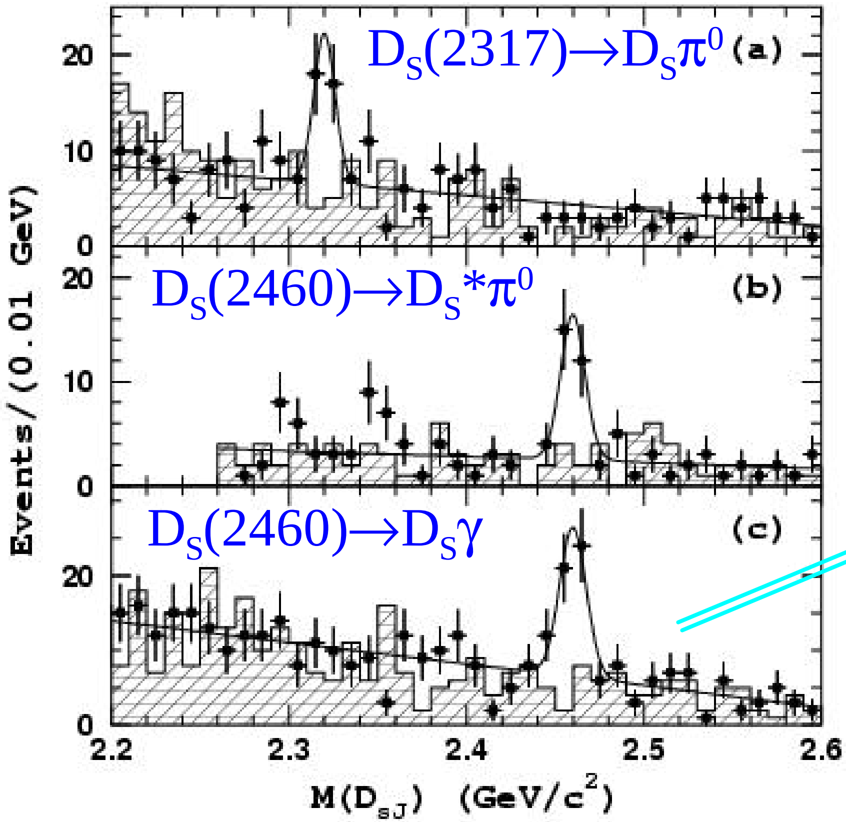
Search For Other Modes

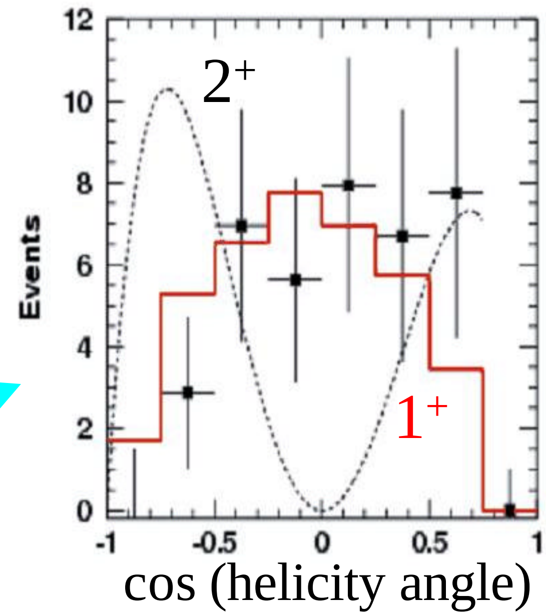
Decay Channel			Possible J^P of D_{sJ}	CLEO Ratio (90% C.L.)	Belle Ratio (90% C.L.)	BEH prediction
$D_s(2317)$	$D_s\ \pi^0$	$0^-\ 0^-$	$0^+,\ 1^-$	$\equiv 1$	$\equiv 1$	$\equiv 1$
	$D_s\ \pi^+\ \pi^-$	$0^-\ 0^-\ 0^-$	$1^-,$	< 0.019		0
	$D_s\ \gamma$	$0^-\ 1^-$	1^-	< 0.052	< 0.05 (C)	0
	$D_s^*\ \pi^0$	$1^-\ 0^-$	1^-	< 0.11		0 ⇐
	$D_s^*\ \gamma$	$1^-\ 1^-$	$0^+,\ 1^-$	< 0.059		0.08
$D_s(2460)$	$D_s^*\ \pi^0$	$1^-\ 0^-$	$1^+,\ 1^-,\ 0^-$	$\equiv 1$	$\equiv 1$	$\equiv 1$
	$D_s^*\ \gamma$	$1^-\ 1^-$	$1^+,\ 1^-,\ 0^-$	< 0.16	–	0.22
	$D_s\ \pi^0$	$0^-\ 0^-$	$0^+,\ 1^-$	Not seen	–	0
	$D_s\ \pi^+\ \pi^-$	$0^-\ 0^-\ 0^-$	$1^+,\ 1^-,\ 0^-$	< 0.08	–	0.20
	$D_s\ \gamma$	$0^-\ 1^-$	$1^+,\ 1^-,\ 0^-$	< 0.49	$0.65 \pm 0.15 \pm 0.15$(C) $0.38 \pm 0.11 \pm 0.04$ (B) $0.44 \pm 0.09 \pm 0.04$(A)	0.24 ⇐
	$D_s(2317)\ \gamma$	$(0^+)\ 1^-$	$1^+,\ 1^-$	< 0.58		0.13

Belle Found The D_{sJ} in B Decays

$$\frac{B(D_S(2460)\rightarrow D_S\gamma)}{B(D_S(2460)\rightarrow D_S^*\pi^o)} = 0.38 \pm 0.11 \pm 0.04$$







consistent with 1^+

Factorization Mystery

B mode	D_{sJ} mode	$\mathcal{B}(10^{-4})$
$D\,D_{sJ}(2317)$	$D_S\pi^o$	$8.5^{+2.6}_{-1.9} \pm 2.6$
$D\,D_S(2460)$	$D_S^*\pi^o$	$17.8^{+4.5}_{-3.9} \pm 5.3$
$D\,D_S(2460)$	$D_S\gamma$	$6.7^{+1.3}_{-1.2} \pm 2.0$

$D\,D_S$ ~1%

- Factorization implies the branching fractions be similar to $B \rightarrow DD_S$. The measurements are a factor of ~10 lower than expectations. (Predictions assume that $f_{D_{sJ}} \approx f_{D_S}$)
- Four-quark state or molecule would have $\mathcal{B}$ consistent with measurement.
  (Chen & Li hep-ph/0307075; Datta & O'donnel hep-ph/0307106; Cheng & Hou hep-ph/0305038)
- The nature of these two states are not totally settled yet. Although the normal D_S meson explanation is favored. More experimental measurements and theoretical ideas are needed to reveal their true identities.

Summary

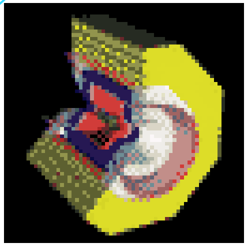
- BaBar discovered a narrow $D_S\pi^0$ resonance at ~2.32 GeV.
- CLEO discovered a narrow $D_S^*\pi^0$ resonance at ~2.46 GeV.
- Both resonances are confirmed.
- Belle observed both resonances in B decays. They also observed the radiative decay ($D_S\gamma$) of second resonance.
- Upper limits have been established in other modes.
- The two states are favored to be j=1/2 doublet 0^+ and 1^+ D_{sJ} states. Other explanations are not ruled out.

Two new states were discovered.

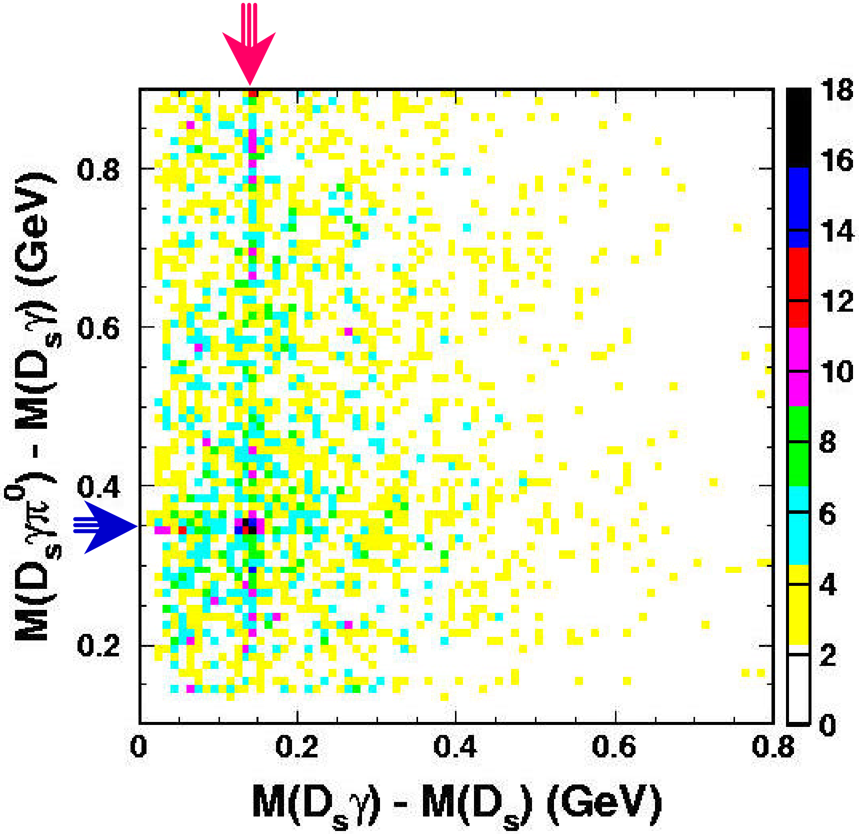
We are not completely sure if they are pure charmed-strange mesons.

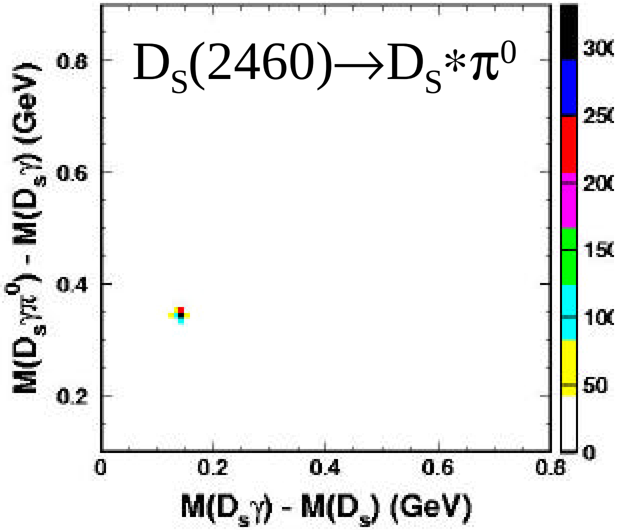
They remain Charming and **Strange**.

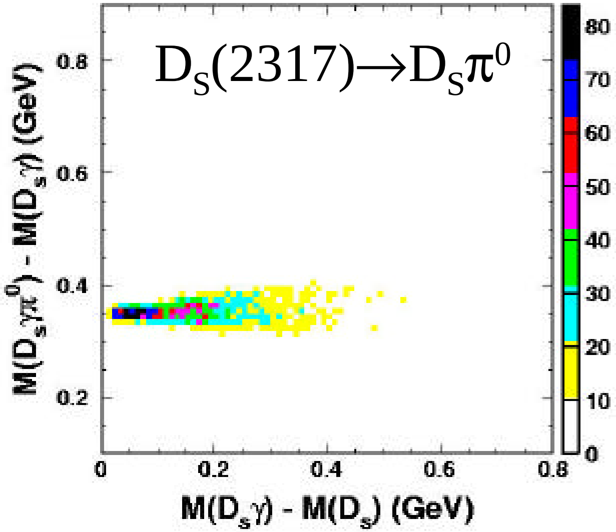
Backup slides



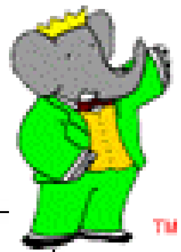
$(D_S\gamma)\pi^0$ Scatter Plot



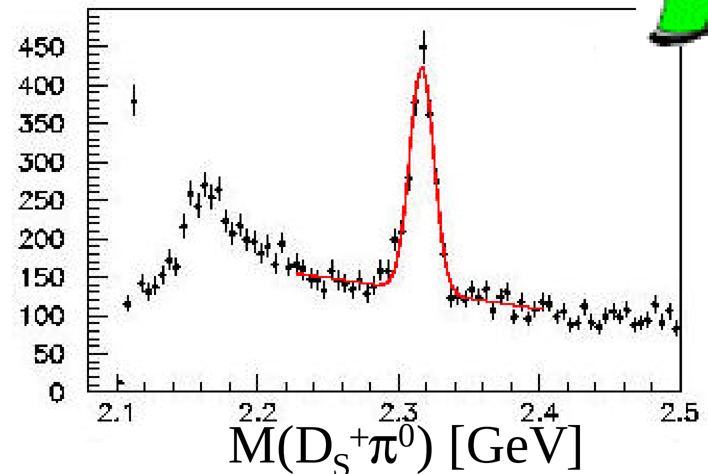




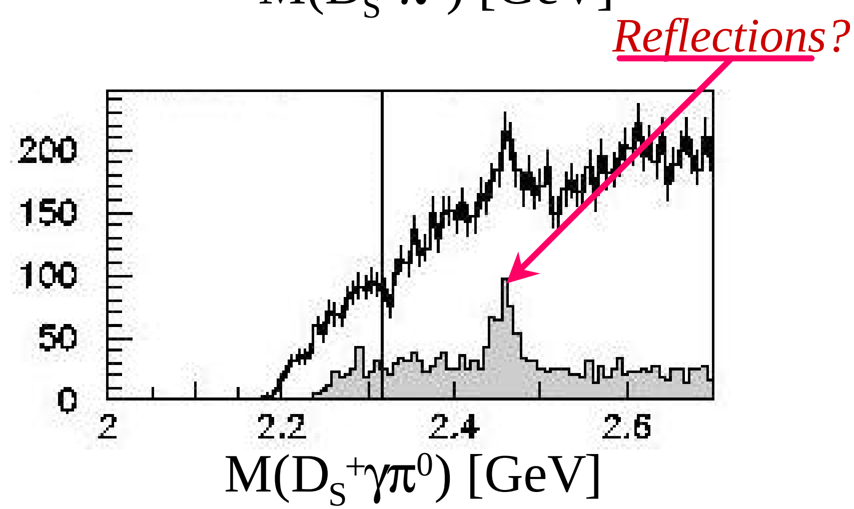
BaBar Discovered $D_S(2317)$



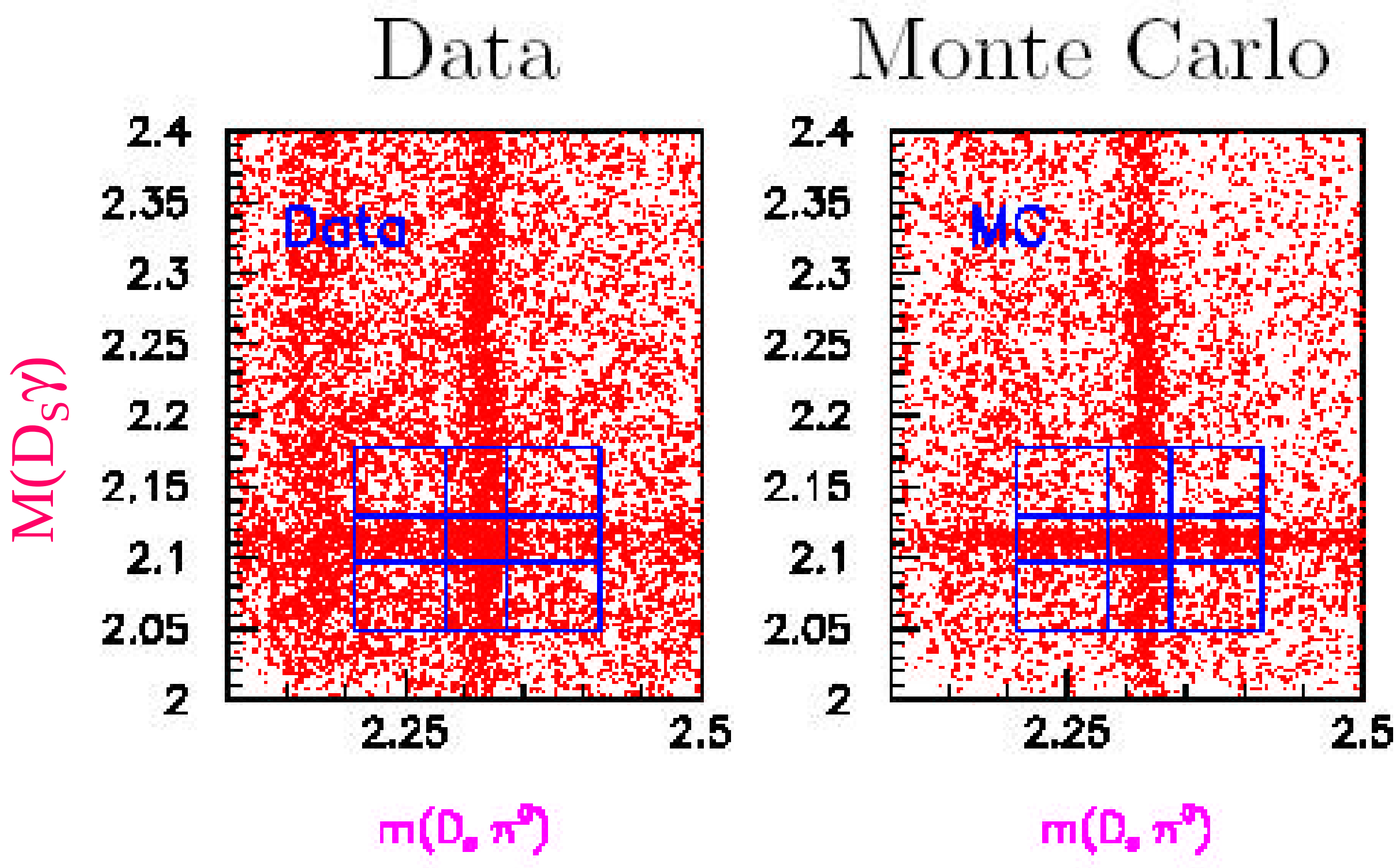
- BaBar observed a $D_S\pi^0$ resonance at 2.317 GeV, with $P(D_S\pi^0) > 3.5$ GeV. Its width is consistent with detector resolution. The spin parity possibly is $J^P=0^+$. (hep-ex/0304021).

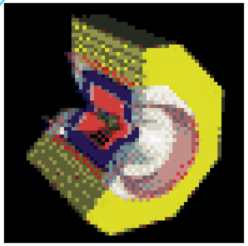


- They also noticed a peak at 2.46 GeV. "This mass corresponds to the overlap region of the $D_S^* \to D_S\gamma$ and $D_S(2317) \to D_S\pi^0$ signal bands that, because of the small width of both mesons, produces a narrow peak in the $D_S\pi^0\gamma$ mass distribution that survives a D_S^* selection."



BaBar 2D Plot





Production Rate of D_{sJ} Mesons

	Yield (P>3.5)	Efficiency (%)	Production Ratio
$D_s(2460) \to D_s^* \pi^0 \to (D_s\gamma)\, \pi^0$	41 ± 11	6.33 ± 0.21	$(3.25 \pm 0.89) \times 10^{-2}$
$D_s(2317) \to D_s \pi^0$	155 ± 23	9.76 ± 0.19	$(7.93 \pm 1.18) \times 10^{-2}$
$D_s^*(2112) \to D_s \gamma$	2591 ± 69	22.0 ± 0.6	$(5.89 \pm 0.26) \times 10^{-1}$
$D_s(1969)$	9263 ± 123	46.3 ± 0.9	1

- The final D_{sJ} candidates are required to be P>3.5 GeV.
- D_s is reconstructed in $D_s^+ \to \phi\pi^+$, $\phi \to K^+K^-$ mode. The efficiency is the value in the table times BR of the decay chain listed.