New Narrow State Decaying to $D_s\pi^0$

Work of Antimo Palano

R. Cahn

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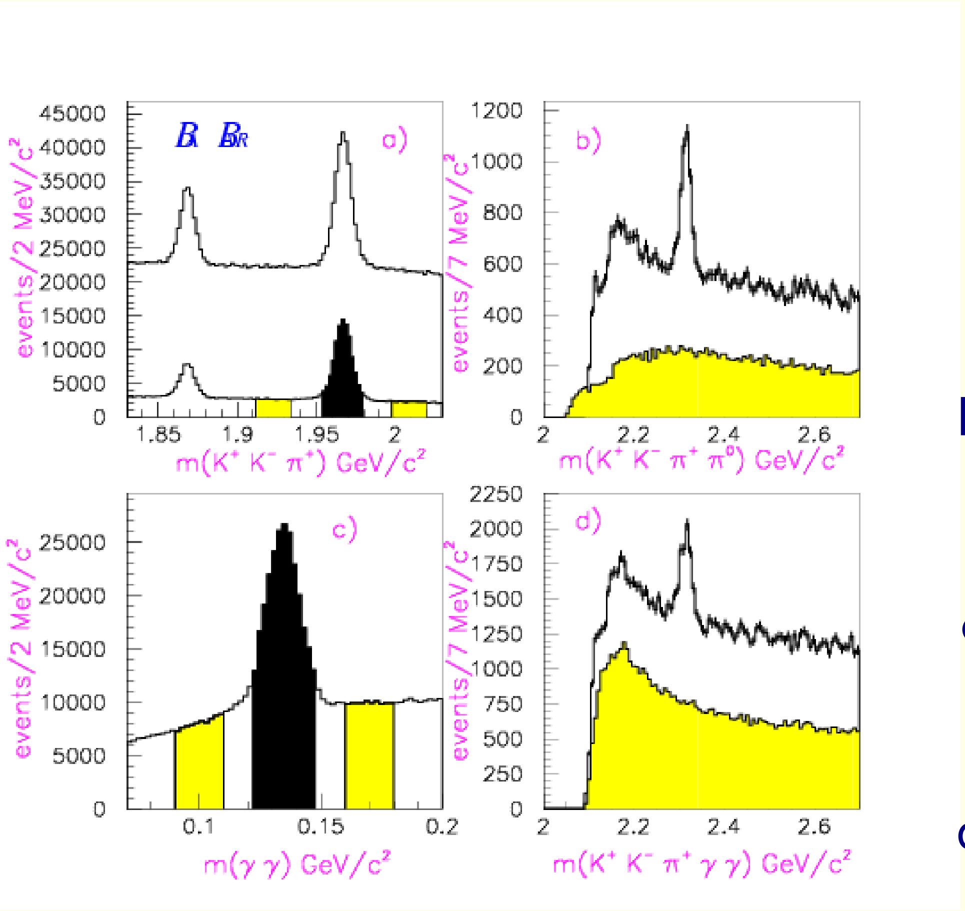


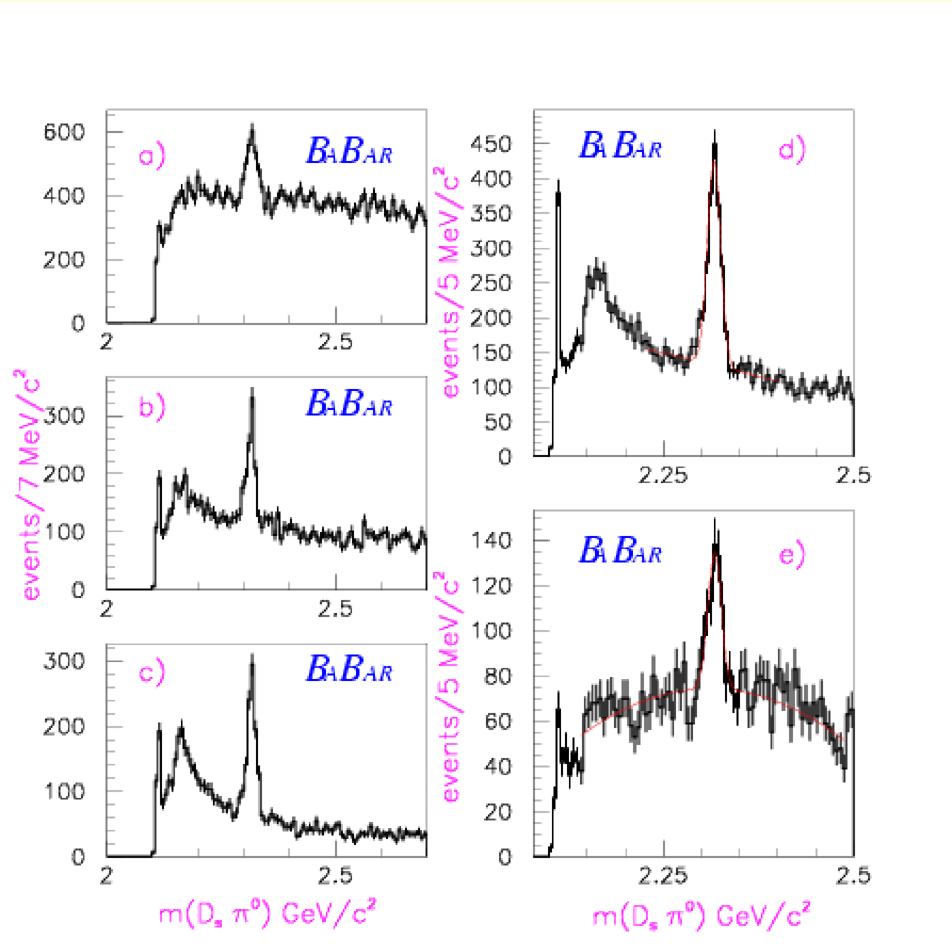
a. π^0 candidates have two photons $E_\gamma > 100$ MeV. Keep only candidates whose photons don't make other candidate π^0. Reduce bkgd by requiring ϕ or K^*, $|\cos\theta_h| > 0.5$

b. Upper: good D_s with good π^0 Lower: D_s sidebands with good π^0

c. $\gamma\gamma$ invariant mass with π^0 and sideband regions marked.

d. Includes all $\gamma\gamma$ with invariant mass in signal region. Shaded is signal D_s with $\gamma\gamma$ sidebands.

$D_s\pi^0$ Invariant Mass Spectrum



a. $2.5 < p^* < 3.5$ GeV

b. $3.5 < p^* < 4.5$ GeV

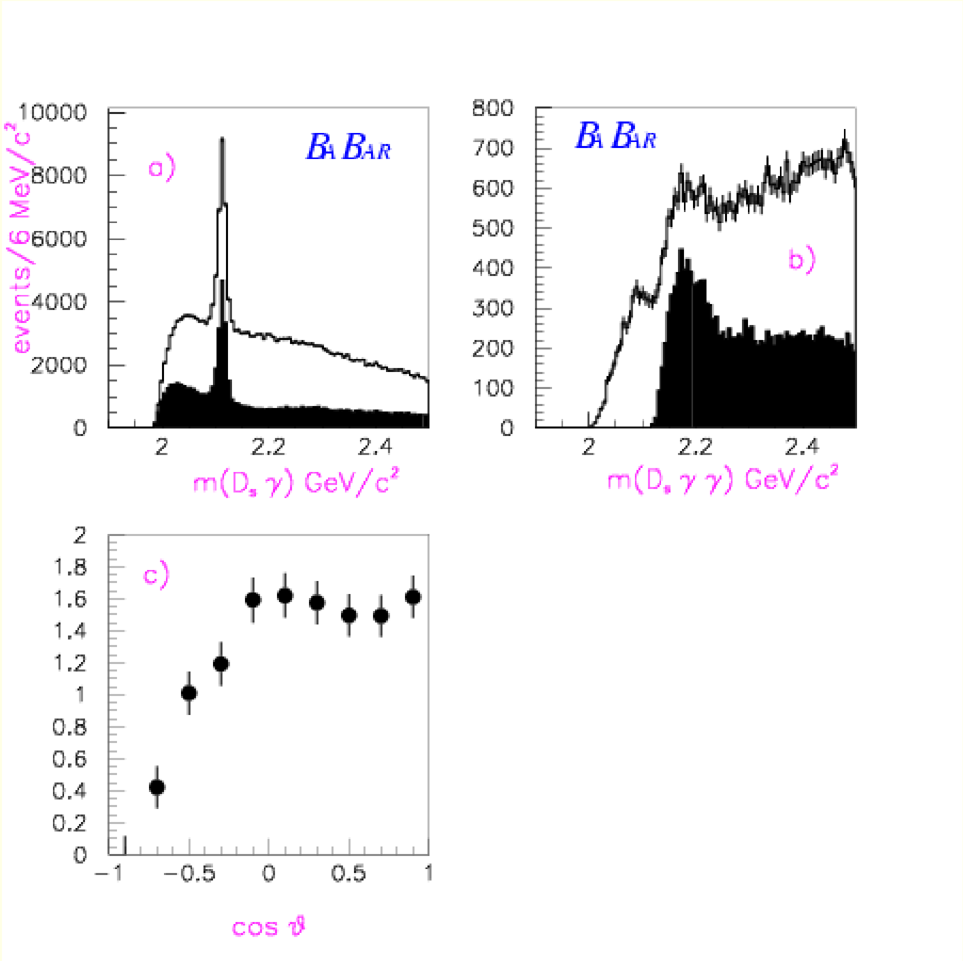
c. $4.5 \text{ GeV} < p^*$

d. $3.5 \text{ GeV} < p^*$

e. $3.5 \text{ GeV} < p^*$

$[D_s \to K^+K^-\pi^+\pi^0]$

Look for Signs of Radiative Cascade



a. See D_s^* but no $D_s(2317)$. Shaded region is $p^* > 3.5$ GeV

b. No $D_s(2317)$ here, either. Shaded region as a $D_s^*(2112)$.

c. Angular distribution of π^0 relative to line of flight. Large acceptance correction makes this obscure.

Spectroscopy of D and D_s Systems

- D_s and D systems are remarkably similar.

- Lowest lying s-wave (0^-, 1^-) states are well known, with splittings of just over a pion mass.

- Narrow $J^P = 1^+$ and 2^+ states are observed.

- Reports of broad states in ordinary D system:

  – CLEO: $m = 2461^{+41}_{-34} \pm 10 \pm 32$ MeV, $\Gamma = 290^{+101}_{-79} \pm 26 \pm 36$ MeV $J = 1$
  – Belle: $m = 2290 \pm 22 \pm 20$ MeV, $\Gamma = 305 \pm 30 \pm 25$ MeV $J = 0$

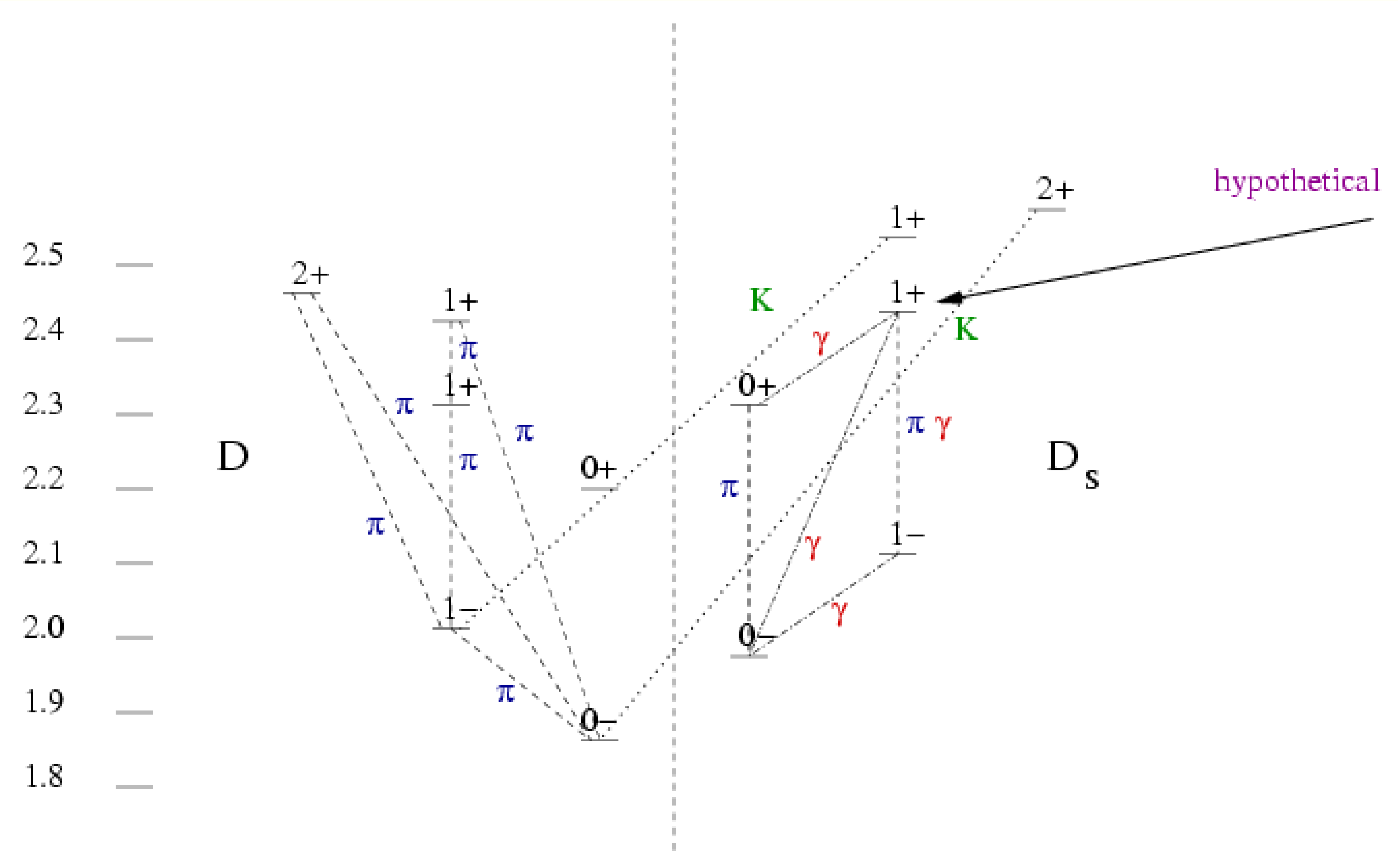
		D				D_s	
J^P	$m(GeV)$	$\Gamma(MeV)$	Decays to	J^P	$m(GeV)$	$\Gamma(MeV)$	Decays to
0^-	1.864	0	–	0^-	1.969	0	–
1^-	2.007	0	$D\pi$	1^-	2.112	0	$D_s\gamma$
1^+	2.422	19	$D^*\pi$	1^+	2.535	< 2.3	D^*K
2^+	2.459	23	$D\pi, D^*\pi$	2^+	2.573	18	DK

Table 1: Comparison of the spectra of D and D_s states.

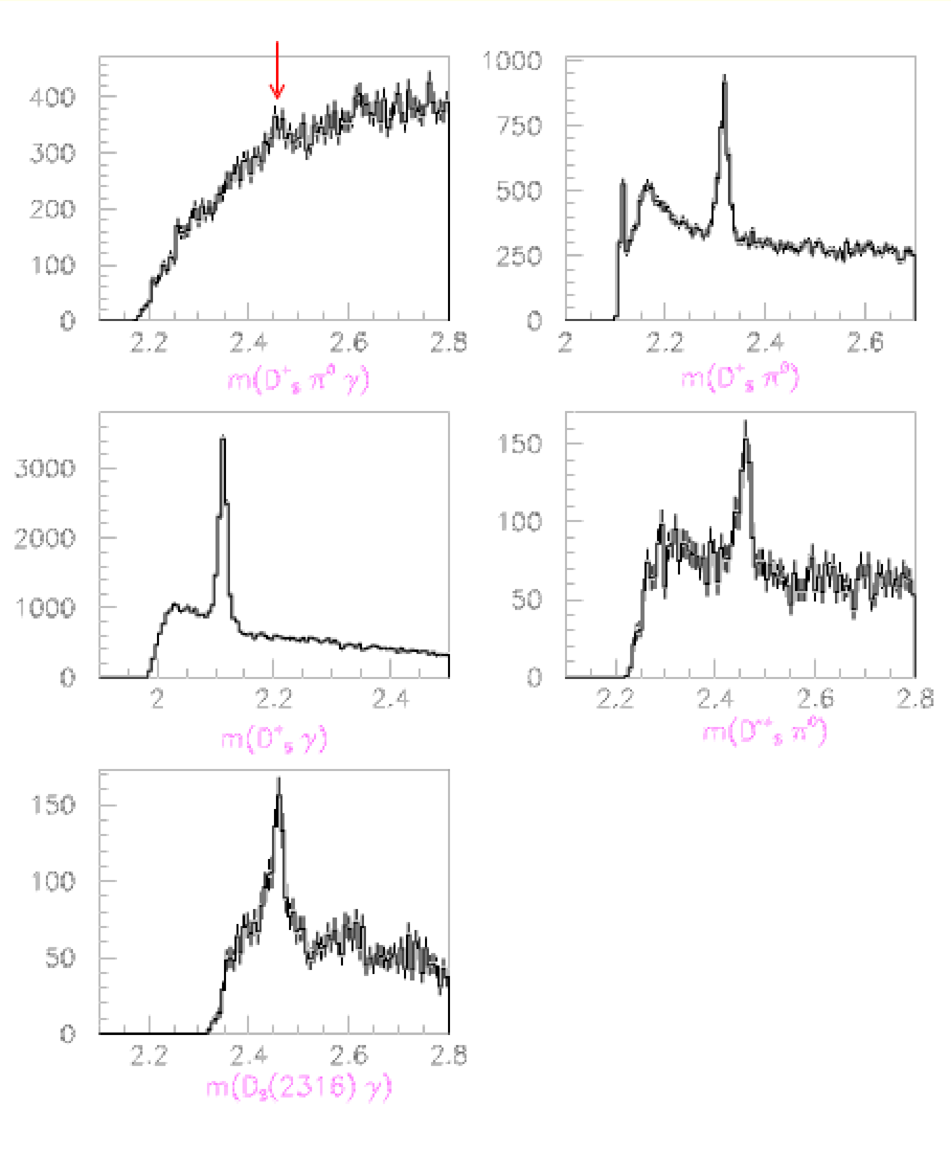
Spectroscopy of Heavy-Light Mesons

- This is "atomic physics." Ignore nucleus (heavy quark).
- Light-quark angular momentum almost conserved $\vec{j} = \vec{L} + \vec{s}$
- The p-wave mesons consist then of two doublets, one with $j = 3/2$ and one with $j = 1/2$.
- The state with total $J = 2$ is entirely in the $j = 3/2$ multiplet, while the state with total $J = 0$ is entirely in the $s_l = 1/2$ multiplet.
- The mass eigenstates with $J = 1$ are mixtures of $s_l = 3/2$ and $s_l = 1/2$.
- The mixing is due to interactions between the light and heavy degrees of freedom and are suppressed by $1/m_c$.
- Without this mixing, the states with $s_l = 3/2$ cannot decay to the s-wave states D and D^* by s-wave pion emission, but require d wave.

- This keeps the $D_1(2420)$ narrow.
- Conversely, the $s_l = 1/2$ p-wave D states should be broad,


hypothetical
2+
1+
1+
K
2.5
2+
1+
K
2.4
γ
π
1+
0+
2.3
π
π
π γ
D
D s
2.2
π
0+
π
π
γ
2.1
1−
1−
γ
2.0
0−
π
1.9
0−
1.8

Is there a New State at 2460?



- $m(D_s\pi^0\gamma)$, $p^*(D_s\pi^0\gamma) > 3.5$ GeV
- $m(D_s\pi^0)$, $p^*(D_s\pi^0\gamma) > 3.5$ GeV
- $m(D_s\gamma)$, $p^*(D_s\pi^0\gamma) > 3.5$ GeV
- $m(D_s^*\pi^0)$, $p^*(D_s\pi^0\gamma) > 3.5$ GeV
- $m(D_s(2371)\gamma)$, $p^*(D_s\pi^0\gamma) > 3.5$ GeV

Is the 2317 a Reflection of 2460?

- Perhaps $D_s(2460) \to D_s(2112)\pi^0, D_s(2112) \to D_s(1969)\gamma$

- Then look at $D_s(1969)\pi^0$ invariant mass

- If decay of $D_s^* \to D_s\gamma$ gives D_s at θ relative to line of flight, $m_{D_s\pi^0} = 2.316(1 + 0.009\cos\theta)$ GeV

- Total width $=$ 41 MeV, $\sigma = 12$ MeV, perfect resolution

- Too narrow, too few events

Is the 2460 a Reflection of 2317?

- Start with $D(2317)$, add random photon to make $D_s(2112)$
- What is invariant mass of $D_s(1969) + \pi^0 + \gamma$?

$m_{D_s\,\gamma}$ (GeV)	$m_{peak}(GeV)$	σ (GeV)
2.062	2.408	0.008
2.112	2.459	0.012
2.162	2.510	0.016
2.212	2.561	0.020

Table 2: Induced peaks in the invariant $D_s + \pi^0 + \gamma$ spectrum as a function of the pseudo D_s^* mass, $m_{D_s\,\gamma}$, and their apparent widths.

Predicting the Mass of the Fourth P-wave State

- Calculations by Dave Jackson (sworn to secrecy)
- Start from eigenstates of j^2: $j = 1/2, 3/2$
- Two quark spins, $\vec{\sigma_1}/2 = \vec{s}$, $\vec{\sigma_2}$
- Add spin-orbit $\vec{L}\cdot\vec{s}$ and tensor $S_{12} = 3\vec{\sigma_1}\cdot\hat{r}\vec{\sigma_2}\cdot\hat{r} - \vec{\sigma_1}\cdot\vec{\sigma_2}$ forces
- $2\vec{L}\cdot\vec{s} = j(j+1) - \ell(\ell+1) - 3/4$
- Tensor force is $\Delta L = 2$, $\Delta s_1 = 1$, $\Delta j = 1$ operator, mixes $j = 1/2$ and $j = 3/2$ with $J = 1$
- $M_{op} = A + B\vec{L}\cdot\vec{s} + CS_{12}$
- Input $m_{J=2} = 2.572$ GeV, $m_{J=1} = 2.536$ GeV, $m_{J=0} = 2.316$ GeV
- Output $m_{J=1} = 2.641$ GeV or 2.118 GeV