

Observation of a Narrow Meson Decaying to $D_s^+ \pi^0$ at a Mass of 2.32 GeV/c²

- BaBar publication April 28, 2003
hep-ex/0304021
- Press release: "Initial studies indicate that the particle is an **unusual configuration** of a 'charm' quark and a 'strange' anti-quark. "
- Someone plotted the invariant mass of D_s^+ and π^0 by chance...

Heavy Quark Effective Theory

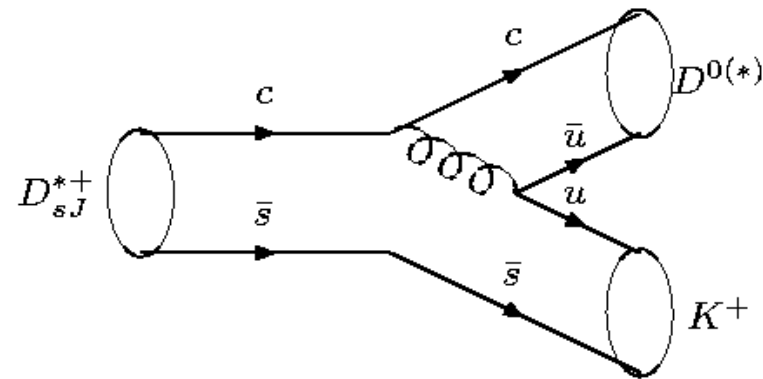
- The dynamics of mesons containing 1 heavy quark are governed by the light quark:
 - the hydrogen atoms of hadron physics!
- P-wave mesons: the light quark's spin ($s=\frac{1}{2}$) couples to the orbital momentum ($l=1$)
 - 2 degenerate $j_{\text{light quark}}=3/2$ states
 - Together with spin of heavy quark: $J^P=1^+$ and 2^+
 - 2 degenerate $j_{\text{light quark}}=1/2$ states
 - Together with spin of heavy quark: $J^P=0^+$ and 1^+

Theoretical expectation for $\bar{S}C$ mesons

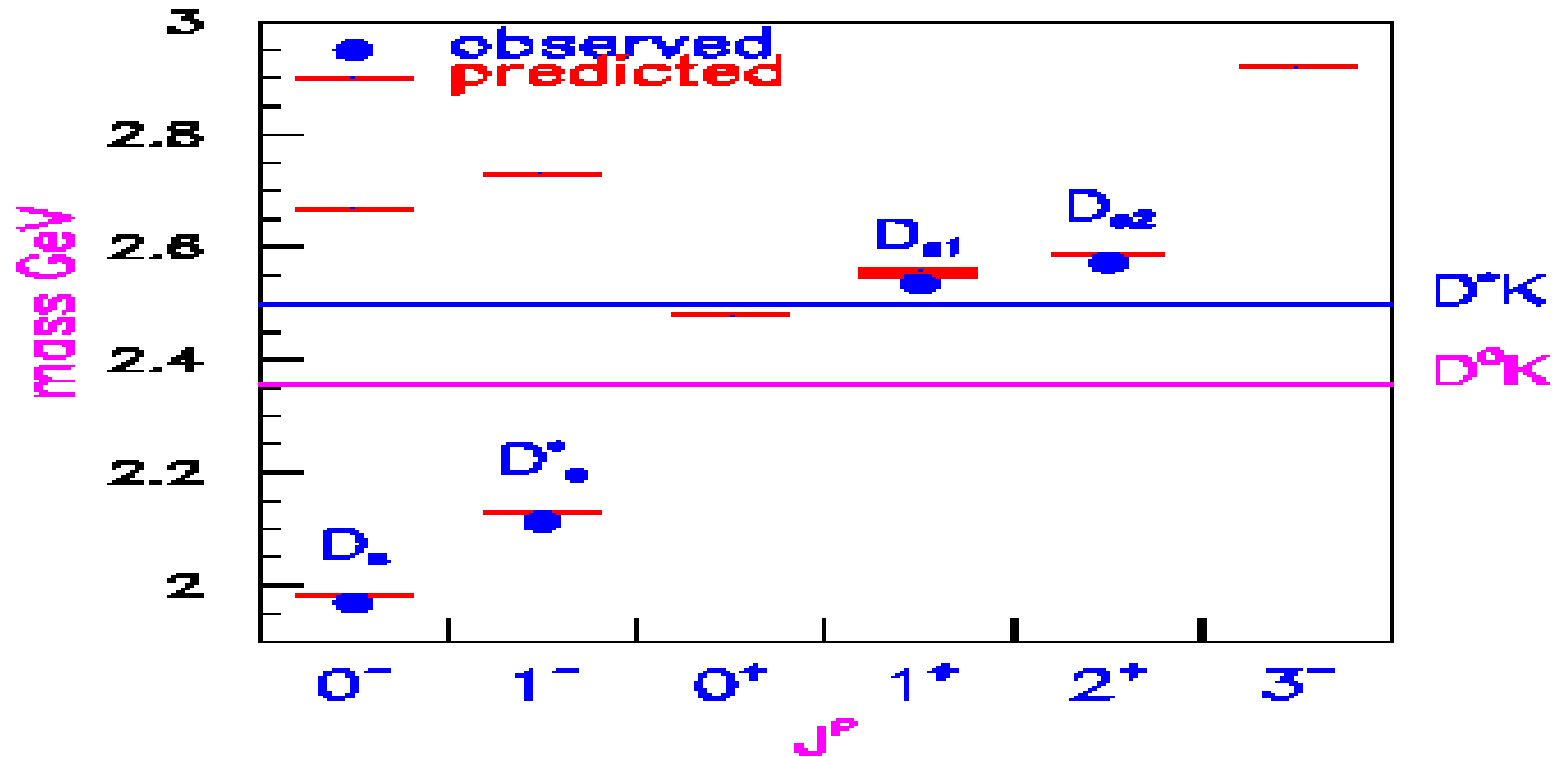
- P-wave D_s^+ mesons:

Name	$2S+1L_J$	J^P	$j_{\text{light quark}}$	Decay		Width
D_{s1}^+	$1P_1$	1^+	$3/2$	D-wave	D^*K	Small
D_{s0}^{*+}	$3P_0$	0^+	$1/2$	S-wave	DK	Large
D_{s1}^{*+}	$3P_1$	1^+	$1/2$	S-wave	D^*K	Large
D_{s2}^{*+}	$3P_2$	2^+	$3/2$	D-wave	DK and D^*K	Small

- Theory predicts the mass spectrum
 - Using various models, like the “flux-tube-model” ... Phys.Rev.D43,1679 (1991)
- S-wave transition gives large width \rightarrow hard to detect!!
 - Why??



Theory - experiment comparison



- Expect two more P - states:
 - 3P_0 ($J^{PC}=0^{++}$) and 3P_1 ($J^{PC}=1^{++}$)
 - $2.4 < m < 2.6$ GeV
 - Decay with kaons
 - Strong decay, large width \rightarrow difficult to detect

Experimental status of $\bar{S}C$ mesons

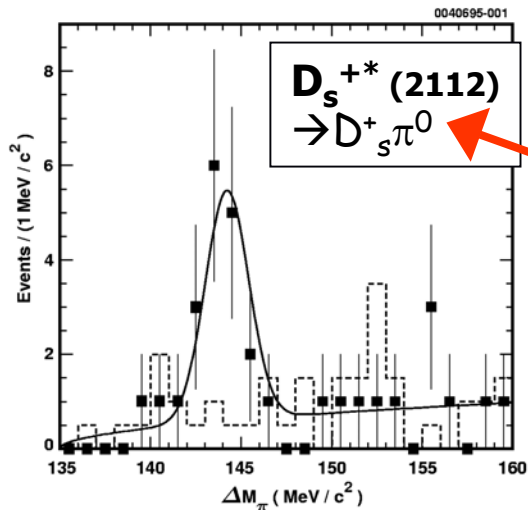
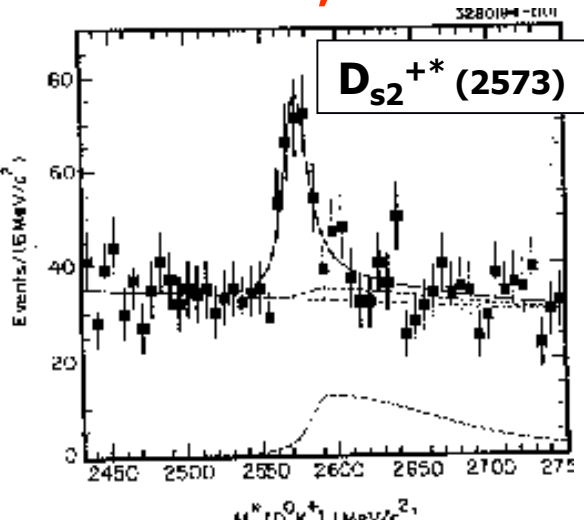
- Present situation of $(c \bar{s})$ states:
(no u,d quarks, therefore no isospin, I=0)

Name	$2S+1L_J$	Mass(MeV)	Decay	J^P	Lifetime/width
D_s^+	$1S_0$	1969	kaons	0^-	$0.5 \cdot 10^{-12} \text{s}$
D_s^{*+}	$3S_1$	2112	$D_s^+ \gamma$	1^-	$< 1.9 \text{ MeV}$
D_{s1}^+	$1P_1$	2536	$D^* K$	1^+	$< 2.3 \text{ MeV}$
D_{s0}^{*+}	$3P_0$?	?	0^+	?
D_{s1}^{*+}	$3P_1$?	?	1^+	?
D_{s2}^{*+}	$3P_2$	2573	$D^0 K^+$	2^+	15 MeV

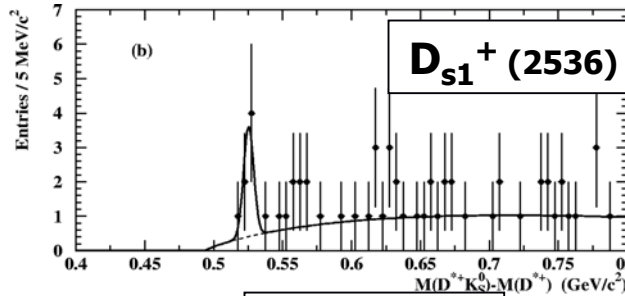
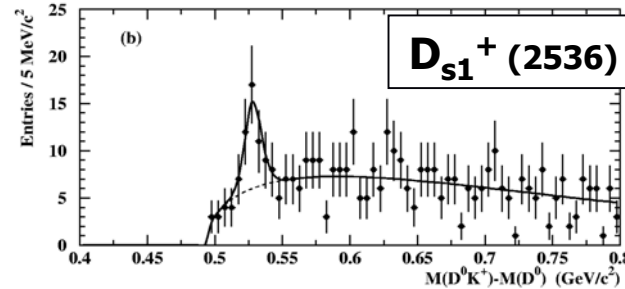
Experimental status (2)

- Some peaks from the past:

CLEO '94, '95



OPAL '97



Z.Phys.C76,425

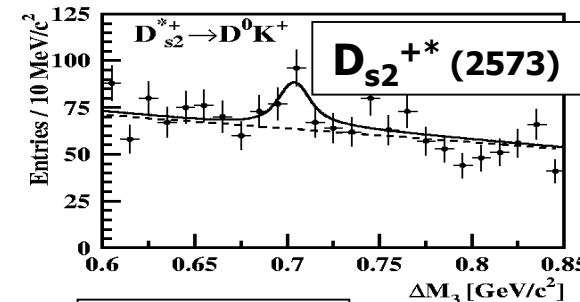
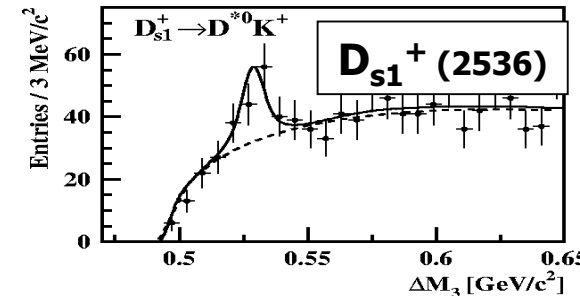
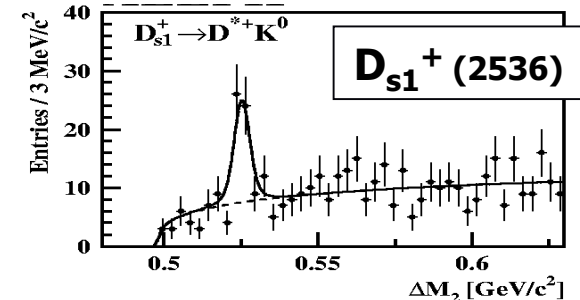
Same final state!
Peak would be at $\Delta M = 448$ MeV...

hep-ph/9403325

PRL 75, 3232

Eduardo & Niels - $D_s^+ \pi^0$

ALEPH '01



hep-ex/0112010

The mass peak!

- Found $D_s^+ \pi^0$ resonance

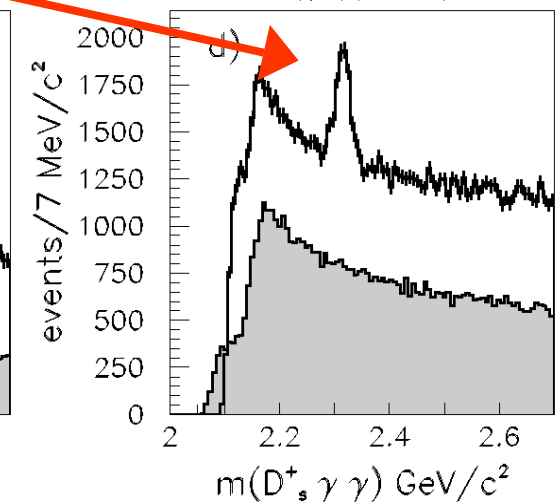
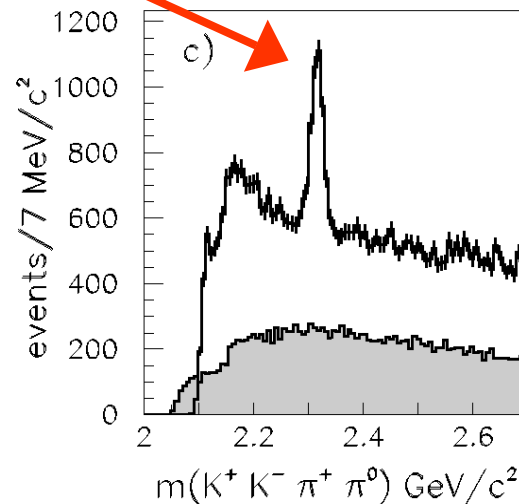
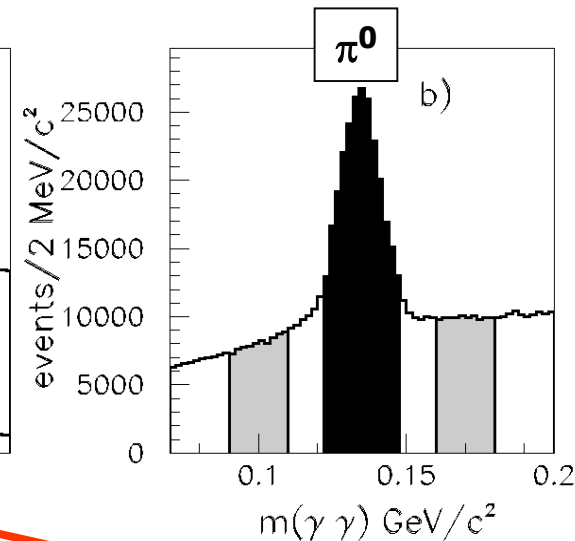
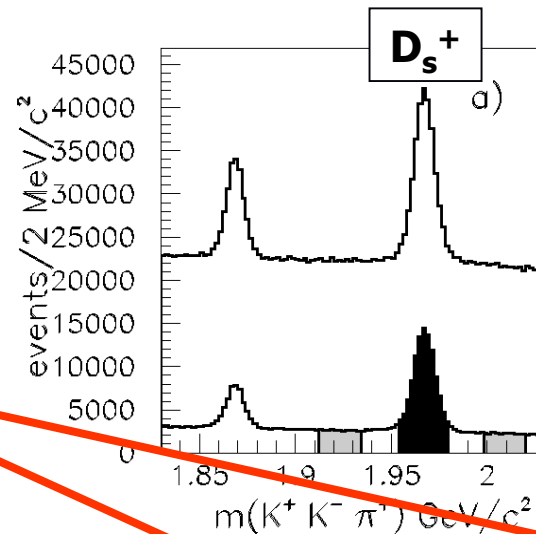
- 1267 +/- 53 events
- $M = 2317 \text{ MeV}$
- Width = exp. resolution

- 1999-2002

- 91.5 fb^{-1}

- Continuum: $e^+e^- \rightarrow c \bar{c}$

- $\sim 10 \cdot 10^6$ events after preselection of $K^+ K^- \pi^+ \pi^0$



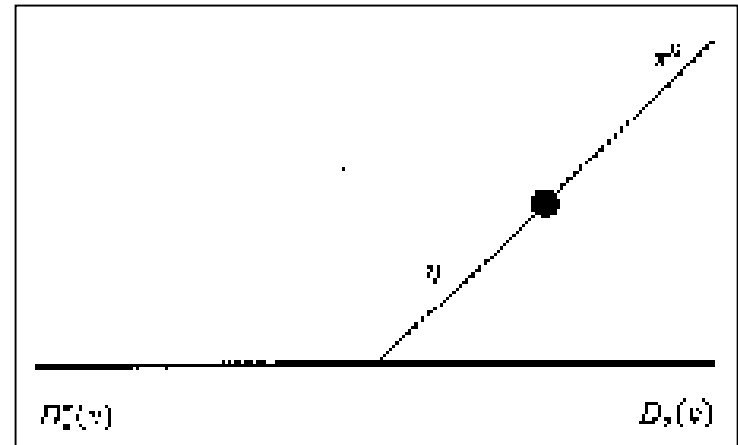
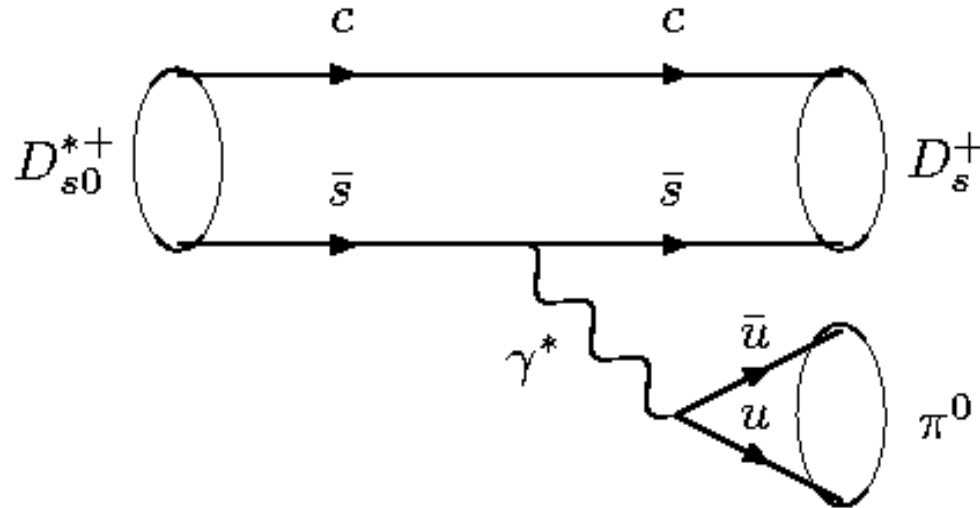
Spin and parity

- No sign of $D_{sJ}^{+*} \rightarrow D_s^+ \gamma$
- $\cos \theta$ is flat, indicating $J=0$
 - must be spin 0
 - can't be $L=0, S=0$: ground state
 - $L=1, S=1$ making 3P_0 -state
- Decay to 2 pseudoscalars. The parity of the final state is therefore:
 - $P = (-1)(-1) (-1)^J = (-1)^J$
- D_s^+ and π^0 have spin 0, therefore:
 - $J^P = 0^+, 1^-, 2^+, 3^-, \dots$ Probably $J^P = 0^+$

Isospin

- $D_{s0}^{*+} \rightarrow D_s^+ \pi^0$
- Isospin is violated:
 $|0,0\rangle \rightarrow |0,0\rangle + |1,0\rangle$
- \rightarrow Electroweak decay ?
- (" Isospin violating decay via $\eta - \pi^0$ mixing " ?)

hep-ph/9401301



Experimental checks

- Checked with $50 \cdot 10^6$ MC events

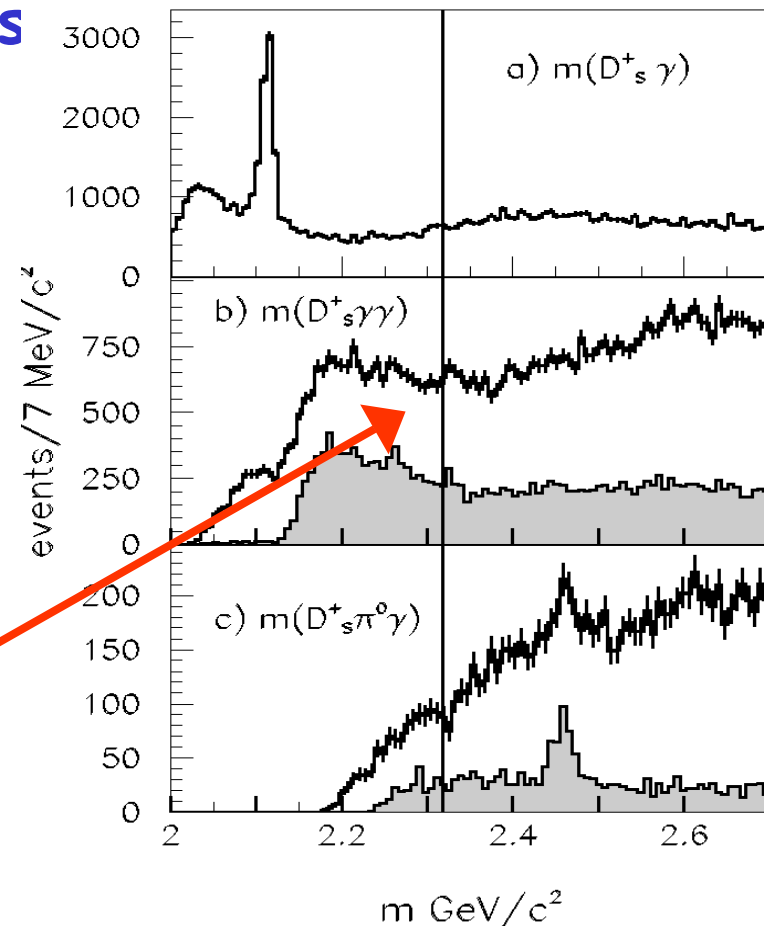
- Not a reflection of other resonances

- Other decays ?:

- ~~$D_{s0}^{+*} \rightarrow D^+ K^0$: mass!~~
- ~~$D_{s0}^{+*} \rightarrow D_s^+ \pi^0$ (strong) : isospin!~~
- ~~$D_{s0}^{+*} \rightarrow D_s^+ \gamma$: spin!~~

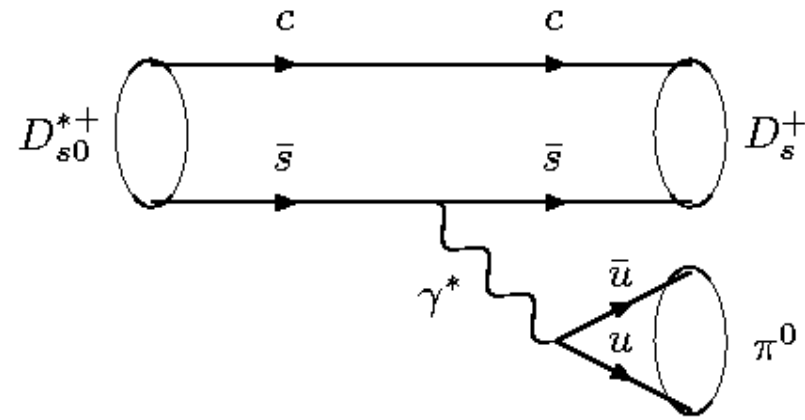
- $D_{s0}^{+*} \rightarrow D_s^+ \gamma \gamma$ } : small BR ??
- $D_{s0}^{+*} \rightarrow D_s^{+*} \gamma$ }

(phase space? 205 MeV for the photon...)



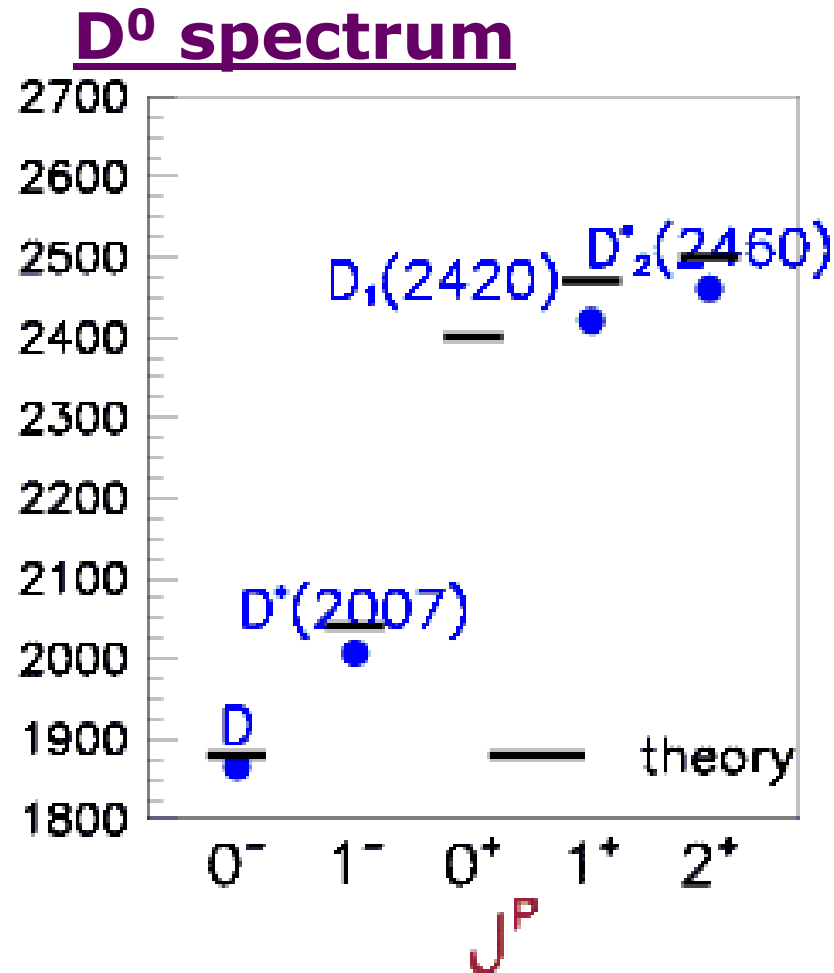
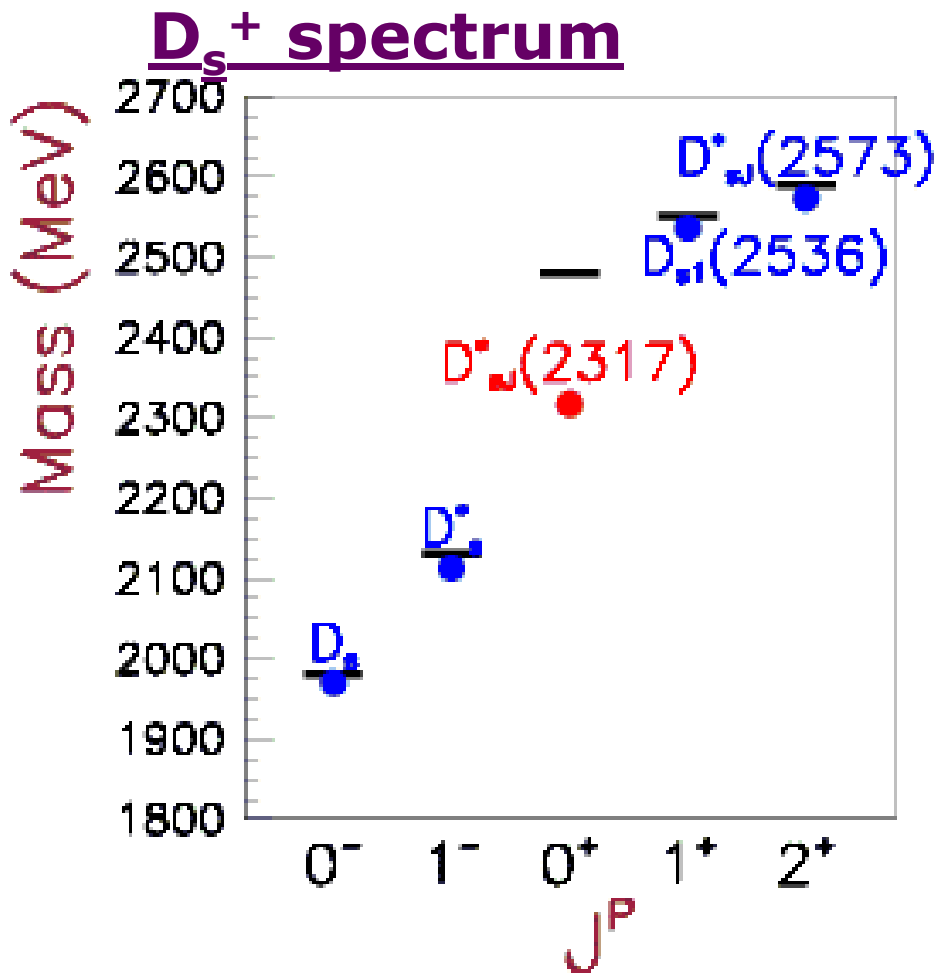
Conclusions of the paper

- Mass smaller than other P-states?
 - Only 100 MeV, or so...
- Width too small for a S-wave transition
 - But it is EM decay, not strong decay...
- Isospin is violated:
 - $|0,0\rangle \rightarrow |0,0\rangle + |1,0\rangle$
 - OK for EM decay ...



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D_{s1}^{*+}	3P_1	?	?	1^+	?
D_{s2}^{*+}	3P_2	2573	$D^0 K^+$	2^+	15 MeV

Excellent theory prediction?



Rumours

- Belle also sees it.
- Is it a 4-quark bound state ("tetraquark") ?
 - DK molecule ?
- Is it a 5-quark bound state ("pentaquark") ?
 - Bound state of $D_s \bar{p}$
 - Limits by E791 (PL B448, 303 1999), but not stringent)

