OPAL Results on Excited Charm Meson Production in Hadronic Z^0 Decays

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OUTLINE

- **Production of D_1^0 and D_2^{*0}**
- **Production of $D_{s1}^{\pm}(2536)$**

} Z. Phys. **C76** (1997) 425.

- **Search for $D^{*\prime\pm}(2629)$** } Preliminary
- **Summary**

Orbitally-Excited (L=1) Charm Mesons

In HQ limit get two degenerate doublets:

heavy-quark limit

$$\mathbf{S = (0,1) + L = 1 \Rightarrow {}^1P_1 + \left\{ \begin{array}{c} {}^3P_0 \\ {}^3P_1 \\ {}^3P_2 \end{array} \right\}} \quad \left\{ \begin{array}{c} 2^+ \\ 1^+ \end{array} \right\}_D \text{ narrow} \qquad \left\{ \begin{array}{c} 1^+ \\ 0^+ \end{array} \right\}_S \text{ broad}$$

$c\bar{q}$	$\bar{u}$	$D_J^{(*)0}$	$D_1^0\,(2420)$	$D_2^{*0}\,(2460)$
	$\bar{d}$	$D_J^{(*)+}$	$D_1^+\,(2420)$	$D_2^{*+}\,(2460)$
	$\bar{s}$	$D_{sJ}^{(*)+}$	$D_{s1}^+\,(2536)$	$D_{s2}^{*+}\,(2573)$

- **All 6 narrow states have been observed:**

  ARGUS,CLEO,fixed-target,LEP

- $\Gamma \sim$ **20 MeV except for** $\Gamma_{D_{s1}^+(2536)} < 2.3$ **MeV @ 90% C.L.**
- **Assume** $D_J^{(*)}$ $(D_{sJ}^{(*)})$ **final states saturated by** $D^{(*)}\pi$ $(D^{(*)}K)$**:**
- **Spin parity conservation constrains the final states** $(X = \pi, K)$ **:**

J^P	D^*X	DX
0^+	NO	L=0
1^+	L=0,2	NO
2^+	L=2	L=2

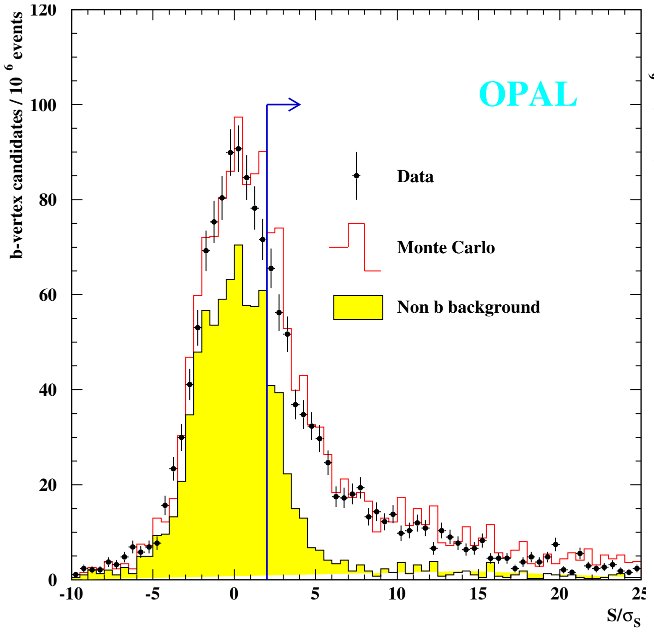
Production of Orbitally-Excited Charm Mesons

Reconstruct the decay sequence

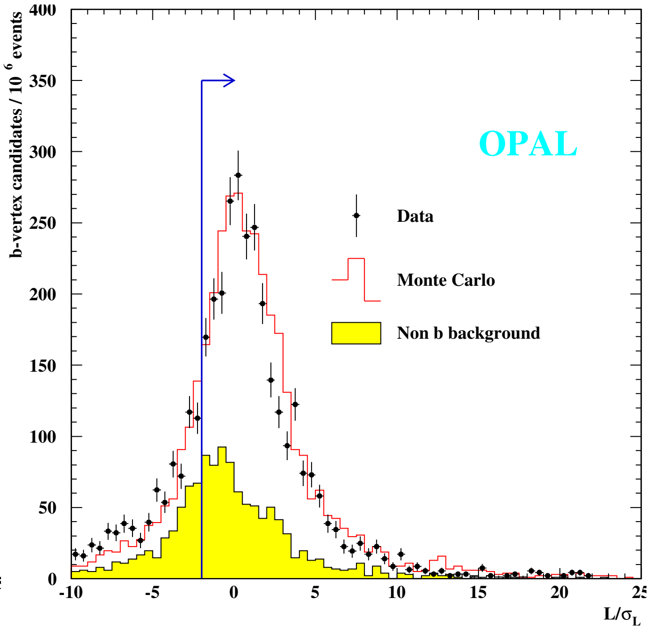
$$\mathrm{D_J^{(*)0}} \rightarrow \mathrm{D^{*+}}\pi^-$$
$$\hookrightarrow \mathrm{D^0}\pi^+$$
$$\hookrightarrow \mathrm{K^-}\pi^+$$

- $\mathrm{c\bar{c}}$ enrichment $\mathrm{x(D^{**0})} > 0.5$ and $\mathrm{c}\tau(\mathrm{D^0}) < 0.03\,$cm
- $\mathrm{b\bar{b}}$ enrichment using B and $\mathrm{D^0}$ vertexing

Decay length significance distributions

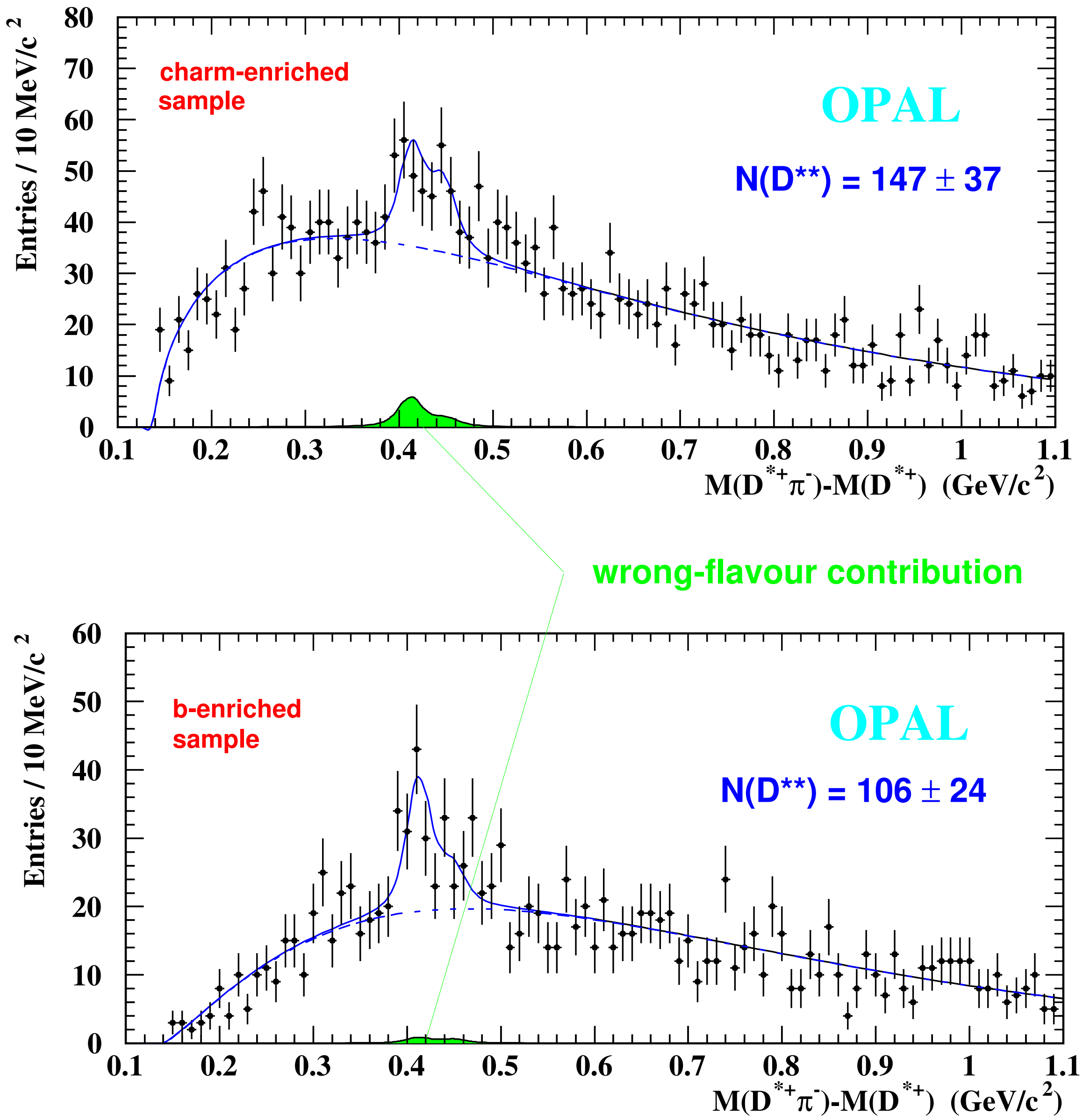


B vertex wrt primary



$\mathrm{D^0}$ vertex wrt B vertex

Production of Orbitally-Excited Charm Mesons



Simultaneous fit to the two ΔM distributions for:

- $\mathrm{c} \rightarrow \mathrm{D}^{**0}$ contribution
- $\mathrm{b} \rightarrow \mathrm{D}^{**0}$ contribution
- f_1, the fraction of the signal attributed to the 1^+ state

Production of Orbitally-Excited Charm Mesons

Results from fit to $\mathrm{c\overline{c}}$ and $\mathrm{b\overline{b}}$-enriched distributions:

$$\overline{n}_{\mathrm{Z^0\to c\overline{c}\to D^{**0}}(x_E>0.5)} \cdot \mathrm{Br}^{**} = \left(\ 5.4\ ^{+1.4}_{-1.3}\ ^{+0.6}_{-0.8}\right)\ 10^{-3}$$

$$\overline{n}_{\mathrm{Z^0\to b\overline{b}\to D^{**0}}(x_E>0.2)} \cdot \mathrm{Br}^{**} = \left(16.1\ ^{+3.7}_{-3.6}\ ^{+2.0}_{-1.8}\right)\ 10^{-3}$$

$$f_1^{\mathrm{c\overline{c}}} = 0.56 \pm 0.15\ ^{+0.03}_{-0.04}$$

$$f_1^{\mathrm{b\overline{b}}} = 0.77\ ^{+0.16}_{-0.14} \pm 0.04$$

Extrapolation to full range of $\mathrm{x_E}(\mathrm{D^{**}})$ performed with MC

Fraction (%)	OPAL	Pei	Becattini
$\mathrm{b \to D_1^0}$	$5.0 \pm 1.4 \pm 0.6$	-	-
$\mathrm{b \to D_2^{*0}}$	$4.7 \pm 2.4 \pm 1.3$	-	-
$\mathrm{c \to D_1^0}$	$2.1 \pm 0.7 \pm 0.3$	3.5	1.8
$\mathrm{c \to D_2^{*0}}$	$5.2 \pm 2.2 \pm 1.3$	5.0	2.4

$$\mathrm{Br}^{**} \equiv \mathrm{Br}(\mathrm{D^{**0} \to D^{*+}}\pi^-)$$

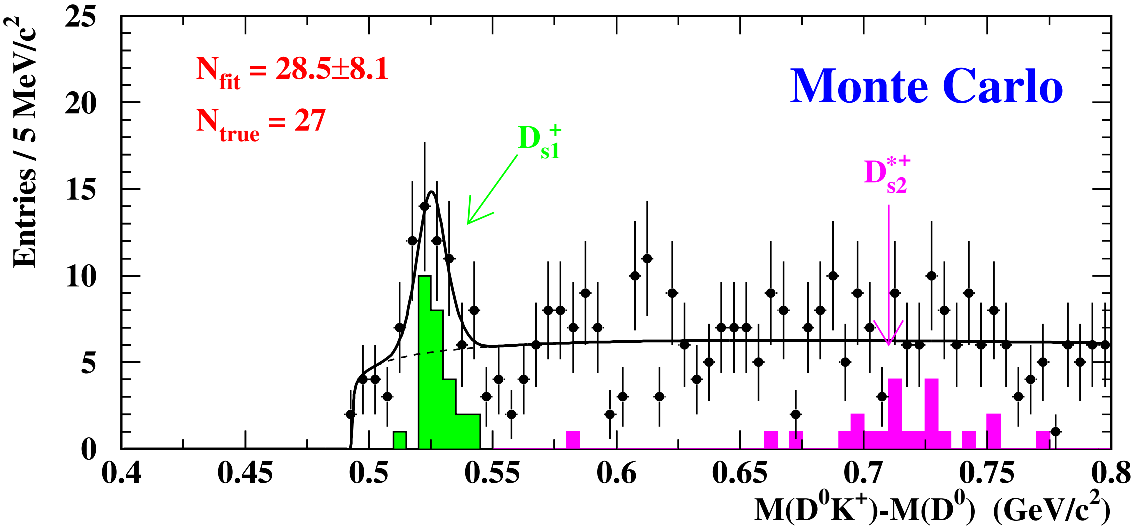
$$\mathrm{Br}(\mathrm{D_1^0 \to D^{*+}}\pi^-) = 0.65$$

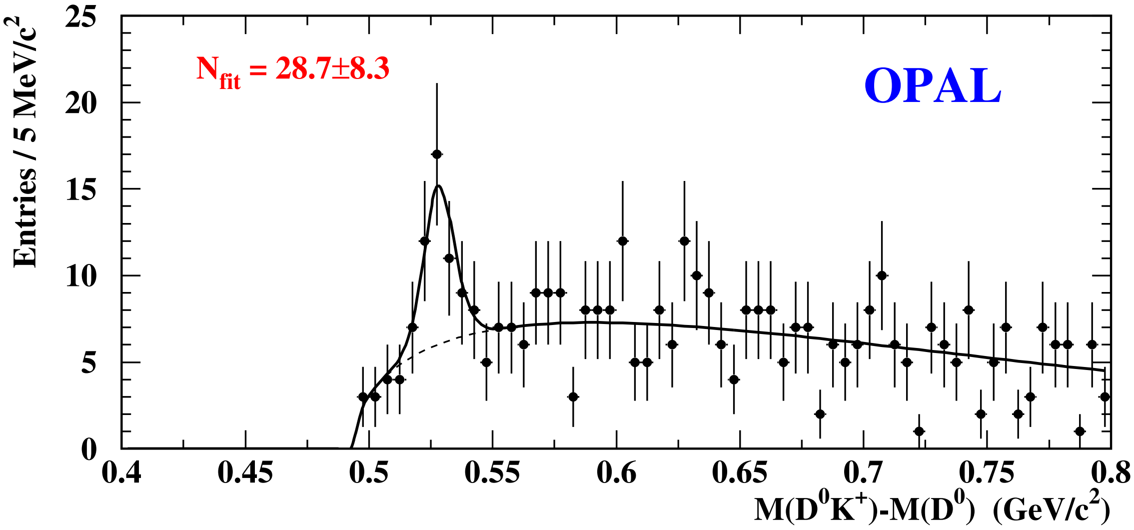
$$\mathrm{Br}(\mathrm{D_2^{*0} \to D^{*+}}\pi^-) = 0.21 \pm 0.04$$

Production of the $D_{s1}^+(2536)$

$$D_{s1}^+(2536) \quad \rightarrow \quad D^{*0}\,\boxed{K^+} \qquad \text{partial reconstruction}$$
$$\hookrightarrow \boxed{D^0}\,(\pi^0, \gamma)$$
$$\hookrightarrow K^-\pi^+$$

$x(D_{s1}^+) > 0.6$





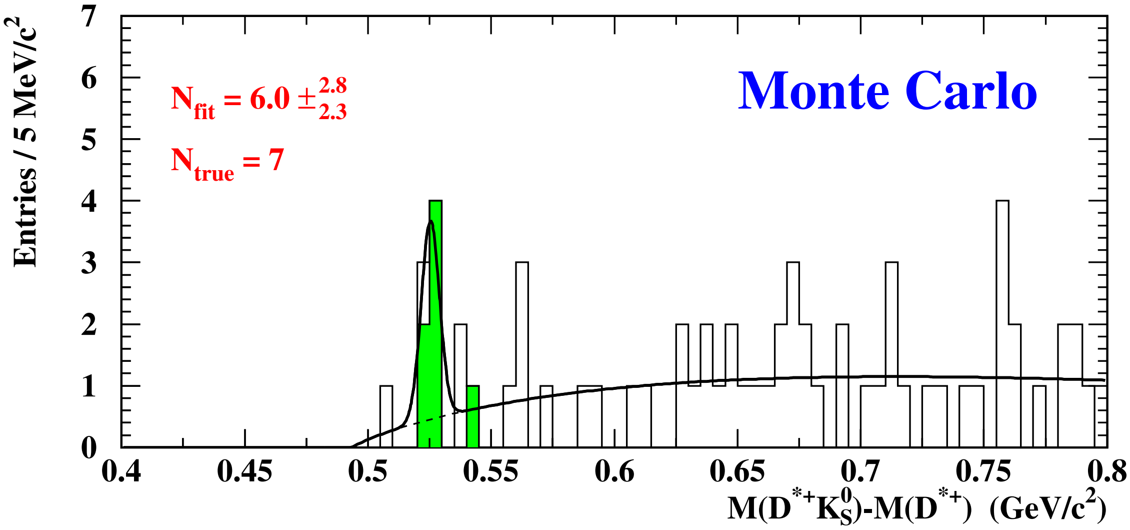
$$\overline{n}_{Z^0 \rightarrow D_{s1}^+ (x_E > 0.6)} \cdot \mathrm{Br}(D_{s1}^+ \rightarrow D^{*0}K^+) = (1.9 \pm 0.5 \pm 0.2)\, 10^{-3}$$

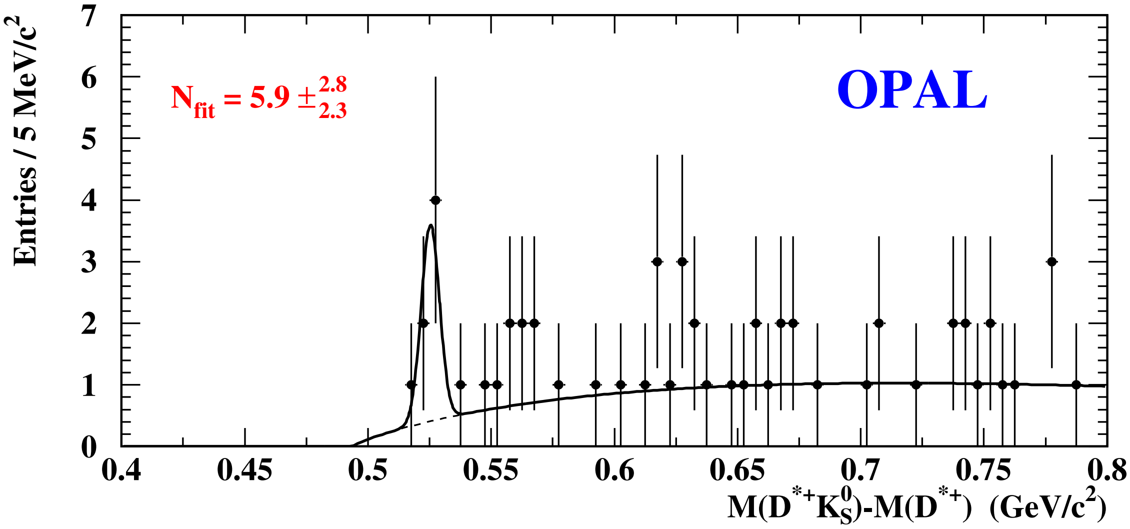
Production of the $D_{s1}^+(2536)$

$$D_{s1}^+(2536) \rightarrow D^{*+}K_s^0$$
$$\hookrightarrow D^0\pi^+$$
$$\hookrightarrow K^-\pi^+$$

$x(D_{s1}^+) > 0.6$

good sig/bkgd for
D^{*+} (kinematics)
K_s^0 (vertexing)





$$\overline{n}_{Z^0 \rightarrow D_{s1}^+(x_E>0.6)} \cdot \mathrm{Br}(D_{s1}^+ \rightarrow D^{*+}K^0) = \left(1.0^{+0.05}_{-0.04} \pm 0.1\right) 10^{-3}$$

Calculation of $f(c \to D_{s1}^{+}(2536))$

- Assume $D^{*0}K^{+}$, $D^{*+}K^{0}$ saturate final states.

$$\bar{n}_{Z^0 \to D_{s1}^{+}(x_E > 0.6)} = 0.0029^{+0.0007}_{-0.0006} \pm 0.0002$$

Correct for

— small residual contribution from $b\bar{b}$ events

— extrapolation of charm fragmentation function

$$2 \cdot \frac{\Gamma_{c\bar{c}}}{\Gamma_{\mathrm{had}}} \cdot f(c \to D_{s1}^{+}(2536)) = (5.6^{+1.5}_{-1.3} \pm 0.6 \pm 0.8)10^{-3}$$

or (using $\Gamma_{c\bar{c}}/\Gamma_{\mathrm{had}} = 0.172$)

$$f(c \to D_{s1}^{+}(2536)) = 0.016 \pm 0.04 \pm 0.003$$

Predictions: Pei .011

Becattini .0054

Summary: LEP P-Wave Charm Meson Production

Fraction (%)	OPAL	DELPHI*	ALEPH†	Pei	Becattini
$b \to D_1^0$	$5.0 \pm 1.4 \pm 0.6$	2.0 ± 0.6	2.3 ± 0.7	–	–
$b \to D_2^{*0}$	$4.7 \pm 2.4 \pm 1.3$	4.8 ± 2.0	< 2.0 (95% CL)	–	–
$c \to D_1^0$	$2.1 \pm 0.7 \pm 0.3$	1.9 ± 0.4	1.6 ± 0.5	3.5	1.7
$c \to D_2^{*0}$	$5.2 \pm 2.2 \pm 1.3$	4.7 ± 1.3	4.7 ± 1.0	5.0	2.4
$f_1^{b\bar{b}}$	0.77 ± 0.16	0.58 ± 0.12	> 0.8 (95% CL)	–	–
$f_1^{c\bar{c}}$	0.56 ± 0.15	0.58 ± 0.08	0.47 ± 0.09	–	–
$c \to D_{s1}^+$	$1.6 \pm 0.4 \pm 0.3$	–	$0.77 \pm 0.20 \pm 0.08$	1.1	0.54
$c \to D_{s2}^{*+}$	–	–	$1.3 \pm 0.5 \pm 0.2$	1.7	–
$b \to D_{s1}^+$	–	–	$1.1 \pm 0.3 \pm 0.2$	–	–
$b \to D_{s2}^{*+}$	–	–	$2.2 \pm 0.8 \pm 0.5$	–	–

* Preliminary (DELPHI 98-128/CONF 189)- statistical errors only. f_1 errors from numbers in Table 2

† Preliminary (ALEPH 98-047/CONF 98-021, 98-22/CONF 98-12)

Search for a Radial-Excitation of the D^{*+}

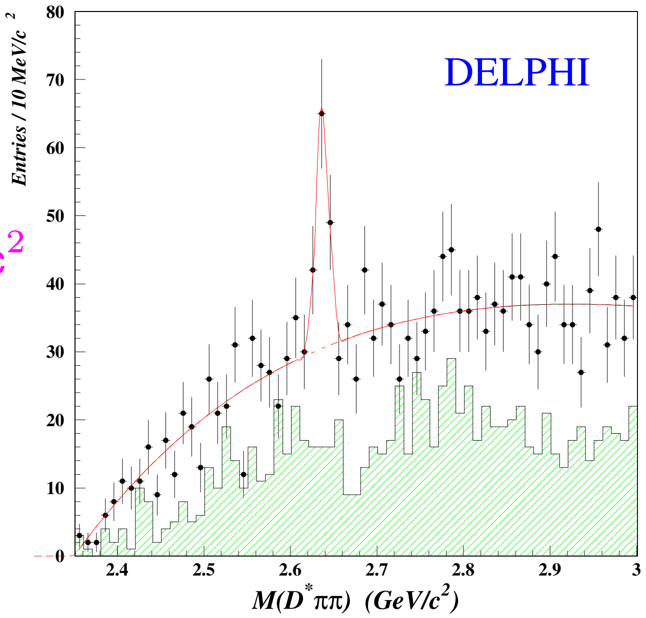
DELPHI observation:

Narrow resonance in $\mathrm{D}^{*+}\pi^+\pi^-$ final state

$\mathrm{N_{obs}} = 66 \pm 14$

$\mathrm{M} = 2637 \pm 2 \pm 6$ MeV/c^2

$\Gamma <$ 15 MeV/c^2 (95% CL)



Interpreted as $\mathrm{D}^{*\prime\pm}$ - a radial excitation of the $\mathrm{D}^{*\pm}$ $(2^3\mathrm{S}_1)$

Predicted mass is 2629 ± 20 MeV/c^2

Systematic checks of reconstruction using $\mathrm{D}^{**0} \rightarrow \mathrm{D}^{*+}\pi^-$

$$R' \equiv$$

$$\frac{\bar{\mathrm{n}}_{\mathrm{Z}^0 \rightarrow \mathrm{D}^{*\prime\pm}} \cdot \mathrm{Br}(\mathrm{D}^{*\prime+} \rightarrow \mathrm{D}^{*+}\pi^+\pi^-)}{\sum_{\mathrm{J}=1,2} \bar{\mathrm{n}}_{\mathrm{Z}^0 \rightarrow \mathrm{D}_\mathrm{J}^{(*)0}} \cdot \mathrm{Br}(\mathrm{D}_\mathrm{J}^{(*)0} \rightarrow \mathrm{D}^{*+}\pi^-)} = 0.49 \pm 0.18 \pm 0.10$$

Search for a Radial-Excitation of the D^{*+}

OPAL analysis (4.23×10^6 multihadrons):

Reconstruct the decay sequence

$$
\begin{aligned}
\mathrm{D}^{*\prime +} \quad \rightarrow \quad & \mathrm{D}^{*+}\pi^+\pi^- \\
& \hookrightarrow \mathrm{D}^0\pi^+ \\
& \qquad \hookrightarrow \mathrm{K}^-\pi^+
\end{aligned}
$$

D^{*+} selection well established and previously published.

Look in b and c-enriched samples of hadronic Z^0 decays

- Charm enrichment: $x_{\mathrm{D}^{*+}} > 0.4$, $p_{\pi^+\pi^-} > 3.6$ GeV/c
- Bottom enrichment: vertexing for D^0 and $\pi^+\pi^-$

OPAL reconstruction efficiency:

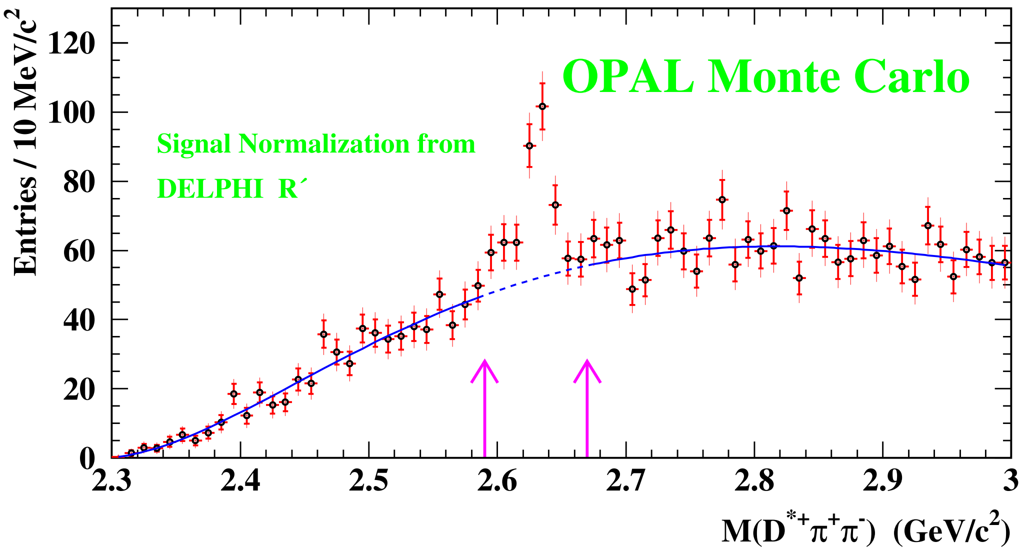
– b-events 6.9 ± 0.6%

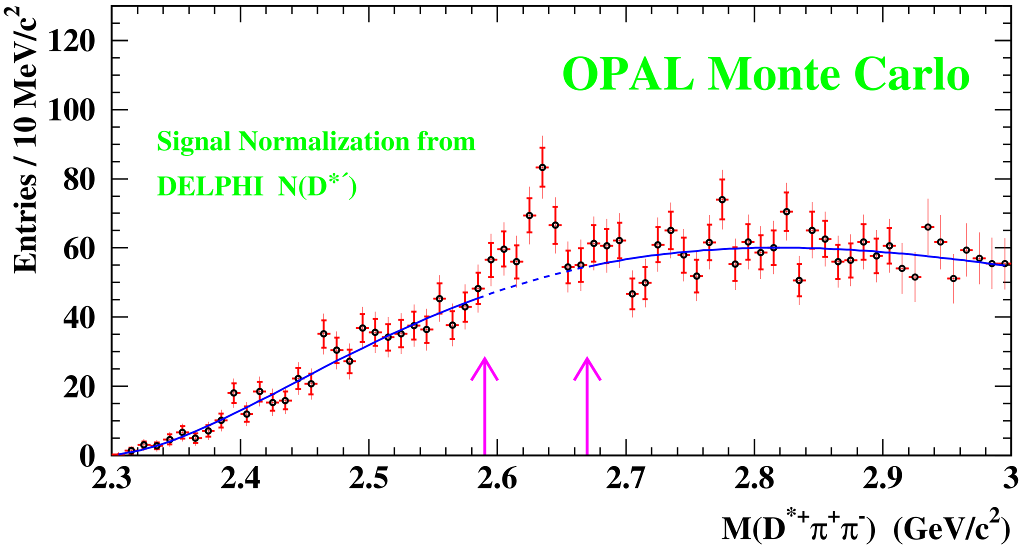
– c-events 7.1 ± 0.6%

$$\frac{\epsilon \cdot \mathrm{Br} \cdot \mathrm{N_{MH}}\ (\mathrm{OPAL})}{\sum_{\mathrm{i}=1,2} \epsilon_{\mathrm{i}} \cdot \mathrm{Br_i} \cdot \mathrm{N_{MH}}\ (\mathrm{DELPHI})} \cong 1.1 \pm 0.1$$

Search for a Radial-Excitation of the D^{*+}

Search results from combined heavy-flavour enriched sample (Monte Carlo)



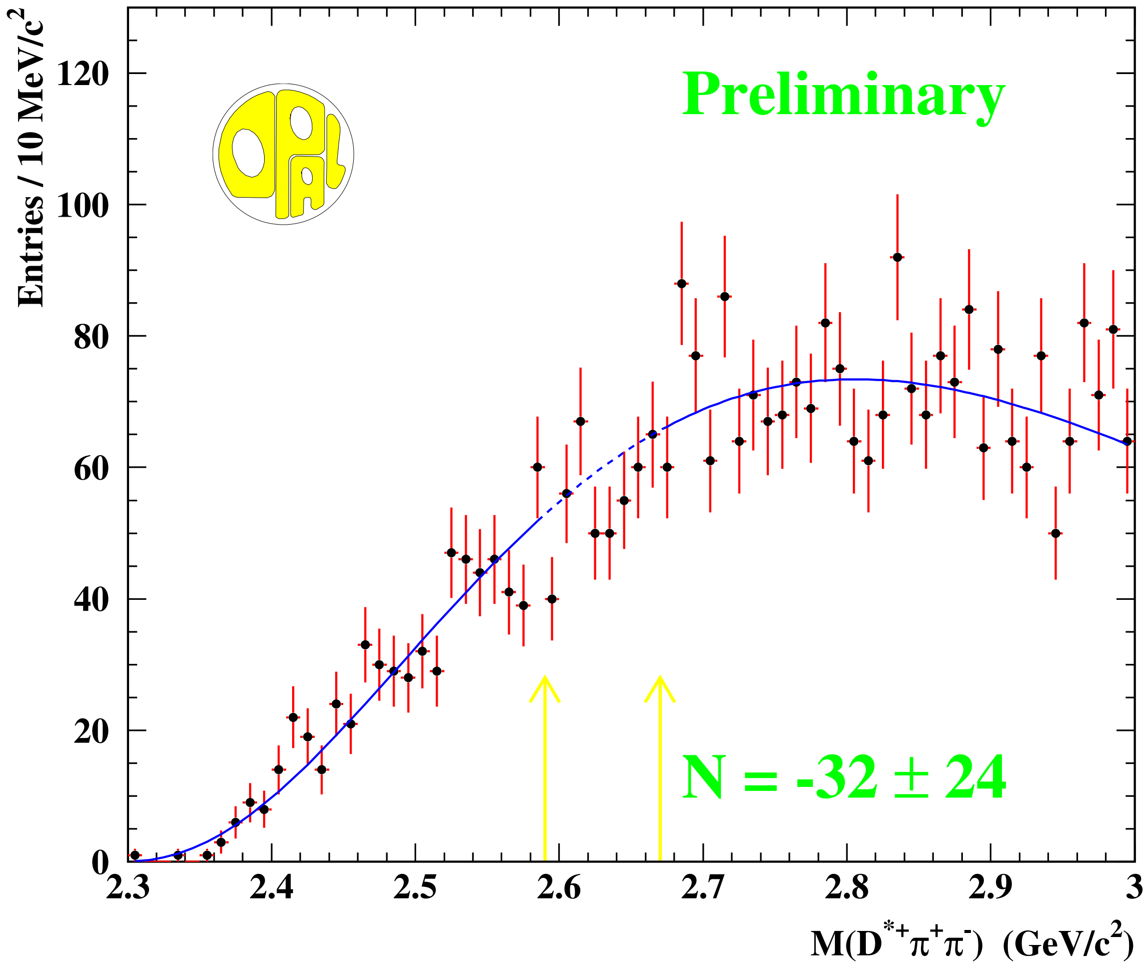


- Two signal normalizations used for MC
- Signal region (arrows) 2.59 - 2.67 GeV

Search for a Radial-Excitation of the D^{*+}

Search results from combined heavy-flavour enriched sample

(OPAL Data)



$N(D^{*\prime\pm}) < 32.8$

$f(Z \to D^{*\prime\pm}(2629)) \cdot Br(D^{*\prime+} \to D^{*+}\pi^+\pi^-) < 2.1 \times 10^{-3}$

$$R' \equiv \frac{\bar{n}_{Z^0 \to D^{*\prime\pm}} \cdot Br(D^{*\prime+} \to D^{*+}\pi^+\pi^-)}{\sum_{J=1,2} \bar{n}_{Z^0 \to D_J^{(*)0}} \cdot Br(D_J^{(*)0} \to D^{*+}\pi^-)} < 0.21$$

(All limits are at the 95% CL)

$D^{*\prime\pm}$ Search: Systematic Checks

- Use similar selection for reconstruction of $D^{**0} \to D^{*+}\pi^-$
- Allowance for finite width (up to 15 MeV/c^2)
- Variation of width of signal region
- Variation of relative rates from c and b events
- Differences between reconstruction efficiencies for

$$D^{*\prime +} \to D_1^{0\prime}\pi^+ \to D^{*+}\pi^+\pi^-$$

$$D^{*\prime +} \to D^{*+}\pi^+\pi^-$$

error source	relative contribution		
	$\mathbf{c}$	$\mathbf{b}$	$\mathbf{c+b}$
relative errors on Monte Carlo efficiency			
Monte Carlo statistics	9.3%	9.1%	6.2%
detector resolution	8.9%	0.7%	5.1%
kaon dE/dx	0.5%	0.9%	0.7%
pion dE/dx	0.8%	0.8%	0.8%
$D^{*\prime +}$ width	1.2%	16.7%	3.6%
fragmentation modelling	2.7%	2.8%	1.9%
production rates in b/c	none	none	0.3%
total	13.2%	19.3%	9.1%
relative errors on external branching ratios			
D^{*+}, D^0 branching ratios	3.1%	3.1%	3.1%
error on $\Gamma_{q\bar{q}}/\Gamma_{had}$	4.5%	0.6%	none
total	5.5%	3.1%	3.1%

Summary: $D^{*\prime\pm}$ Search

OPAL cannot confirm the DELPHI evidence for the existence of a narrow $D^{*\prime\pm}(2629)$

Limits are set for production in hadronic Z^0 decays,

$$f(Z \to D^{*\prime\pm}(2629)) \cdot Br(D^{*\prime+} \to D^{*+}\pi^+\pi^-) < 2.1 \times 10^{-3}$$

for production in $Z^0 \to c\bar{c}$ events,

$$f(c \to D^{*\prime\pm}(2629)) \cdot Br(D^{*\prime+} \to D^{*+}\pi^+\pi^-) < 1.2 \times 10^{-2}$$

and production in $Z^0 \to b\bar{b}$ events

$$f(b \to D^{*\prime\pm}(2629)) \cdot Br(D^{*\prime+} \to D^{*+}\pi^+\pi^-) < 1.0 \times 10^{-2}$$