Production of Excited P-wave Charm Mesons at HERA

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- D_1^0 and D_2^{*0} Production
- Search for Radially Excited $D^{*'\pm}$
- Production of the Charm-strange Meson D_{s1}
- Summary

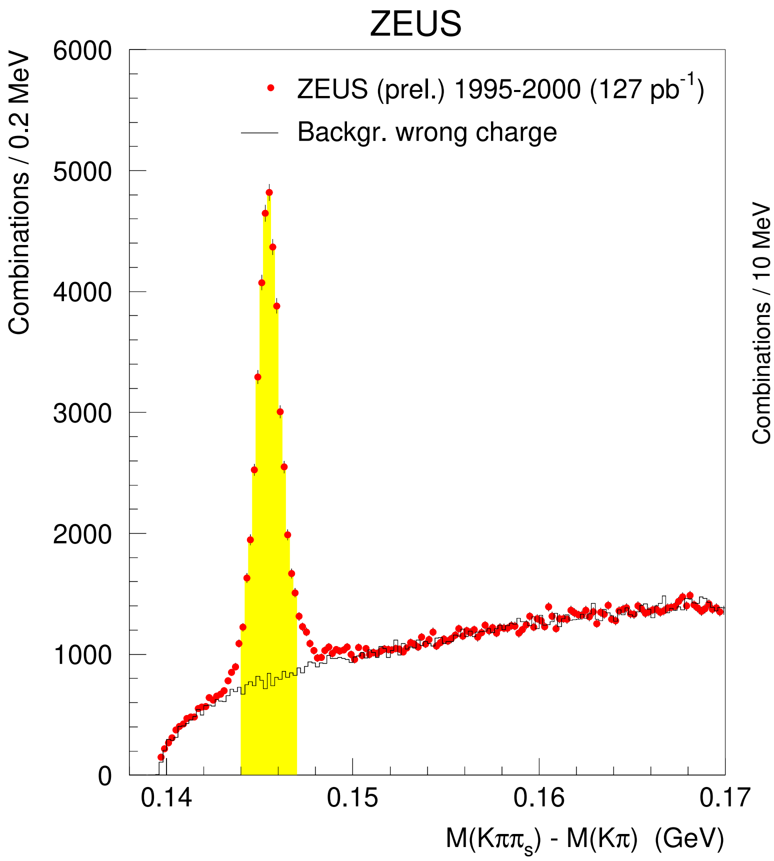
Ground State Charm Mesons

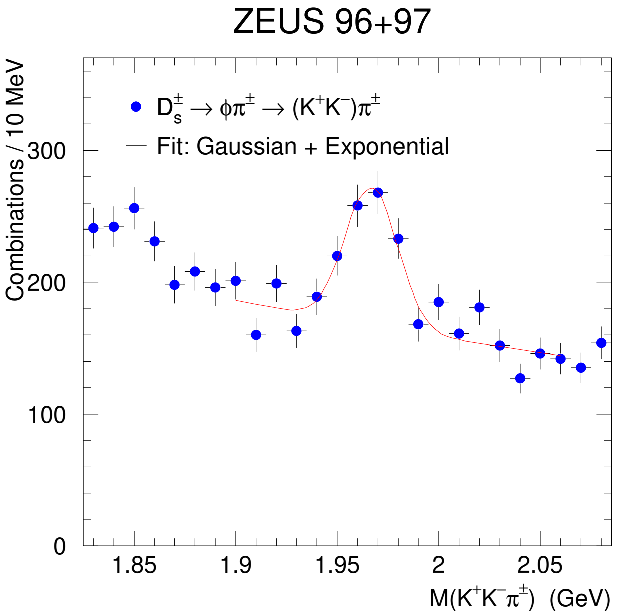
$D^{*+} \to D^0\pi_s^+ \to (K^-\pi^+)\pi_s^+$ **(+ c.c.)**

$f(c \to D^{*+}) \approx 24\%$, $BR = 2.6\%$

$\Delta M = M(D^{*+}) - M(D^0) = 0.14542$ **GeV** $\sim m_\pi$

$P_\perp^{D^*} > 2$ **GeV and** $-1.5 < \eta^{D^*} < 1.5$





In the yellow band after background subtraction:

$\boxed{N(D^{*\pm}) = 31350 \pm 240}$ **from L = 127 pb^{-1}**

better than 1% stat. precision

Other charm signals: $D^* \to D^0\pi_s \to (K^-\pi^+\pi^+\pi^-)\pi_s$

$D_s \to \phi\pi \to (K^-K^+)\pi$

$D^0 \to K^-\pi^+$

s-l electrons or muons

Charm Fragmentation Universality from γ_s

D_s and D^* Cross Section Comparison

Ratio $\sigma(ep \to D_s X)/\sigma(ep \to D^* X)$:

$$\frac{\sigma(ep \to D_s X)}{\sigma(ep \to D^* X)} = 0.41 \pm 0.07^{+0.03}_{-0.05} \pm 0.10(BR)$$

Compare with e^+e^-:

$$\frac{f(c \to D_s)}{f(c \to D^*)} = 0.43 \pm 0.04 \pm 0.11(BR)$$

Strangeness suppression factor (ep):

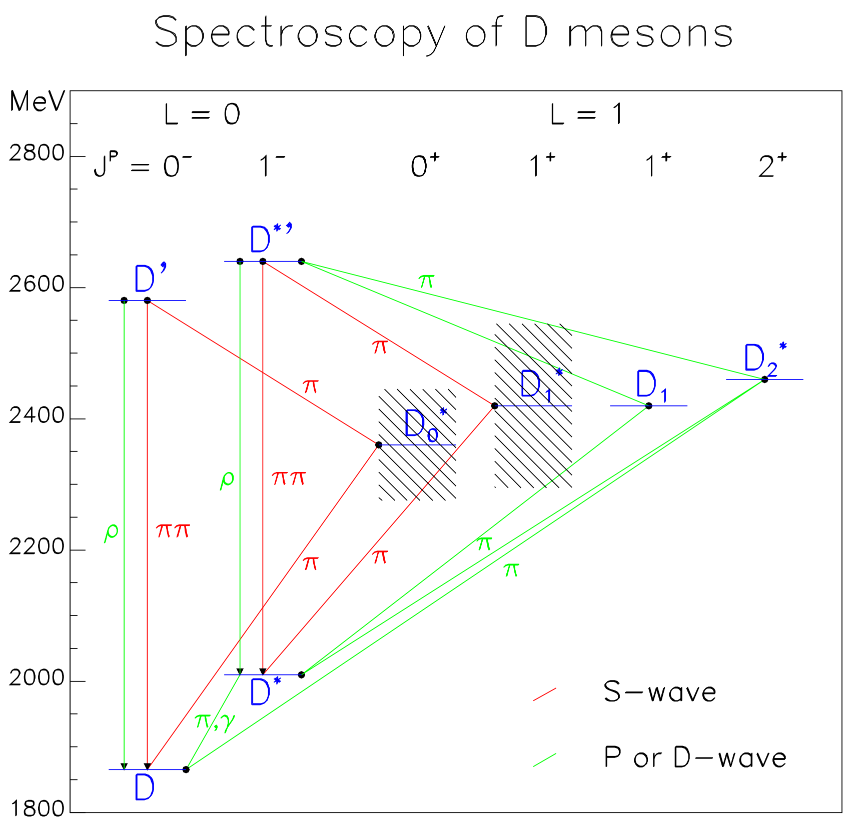
$$\gamma_s = P_s/P_{u,d} = 0.27 \pm 0.05$$

Compare with e^+e^-:

$$\gamma_s = P_s/P_{u,d} = 0.26 \pm 0.03$$

Consistent picture:
Tends to support
charm fragmentation universality

Excited Charm Mesons



In HQET: two doublets of P-wave D mesons

Wide: D_0^* $(J^P = 0^+)$, D_1^* $(J^P = 1^+)$

Narrow: D_1 (1^+), D_2^* (2^+)

Non-strange P-wave mesons: $D_1^0(2420)$,$D_2^{*0}(2460)$

Both are narrow ($\approx$ 20 MeV) and decay to D^* π

A broad state $D_1^{*0}(2461)$ reported by CLEO

Charm-strange P-wave mesons: $D_{s1}^{\pm}(2536)$,$J^P = 1^+(?)$
$D_{sJ}^{\pm}(2573)$,$J^P = 2^+(??)$

ZEUS 1995-2000 PHP+DIS

$$D^{*+} \rightarrow D^0\pi_s^+ \rightarrow (K^-\pi^+)\pi_s^+ \ \textbf{(+c.c.)}$$

$$p_\perp^{D^*} > 2 \ \textbf{GeV} \ , \ |\ \eta^{D^*}| < \textbf{1.5}$$

D_1^0 and D_2^{*0} Production

Add extra track(π_4) to D^* candidate such that total charge is 0

Plot: $M(K,\pi,\pi_s,\pi_4) - M(K,\pi,\pi_s) + M(D^*(2.010))$

Fit D_1^0 and D_2^{*0} to Breit-Wigner shapes convoluted with a Gaussian

Breit-Wigner masses,widths fixed to PDG

Resolution: 5 MeV from MC simulation

Fit done by unbinned likelihood method

Background is described with:

$x^\alpha \cdot exp(-\beta \cdot x + \gamma \cdot x^2)$

$x = M(K,\pi,\pi_s,\pi_4) - M(K,\pi,\pi_s) - m_\pi$

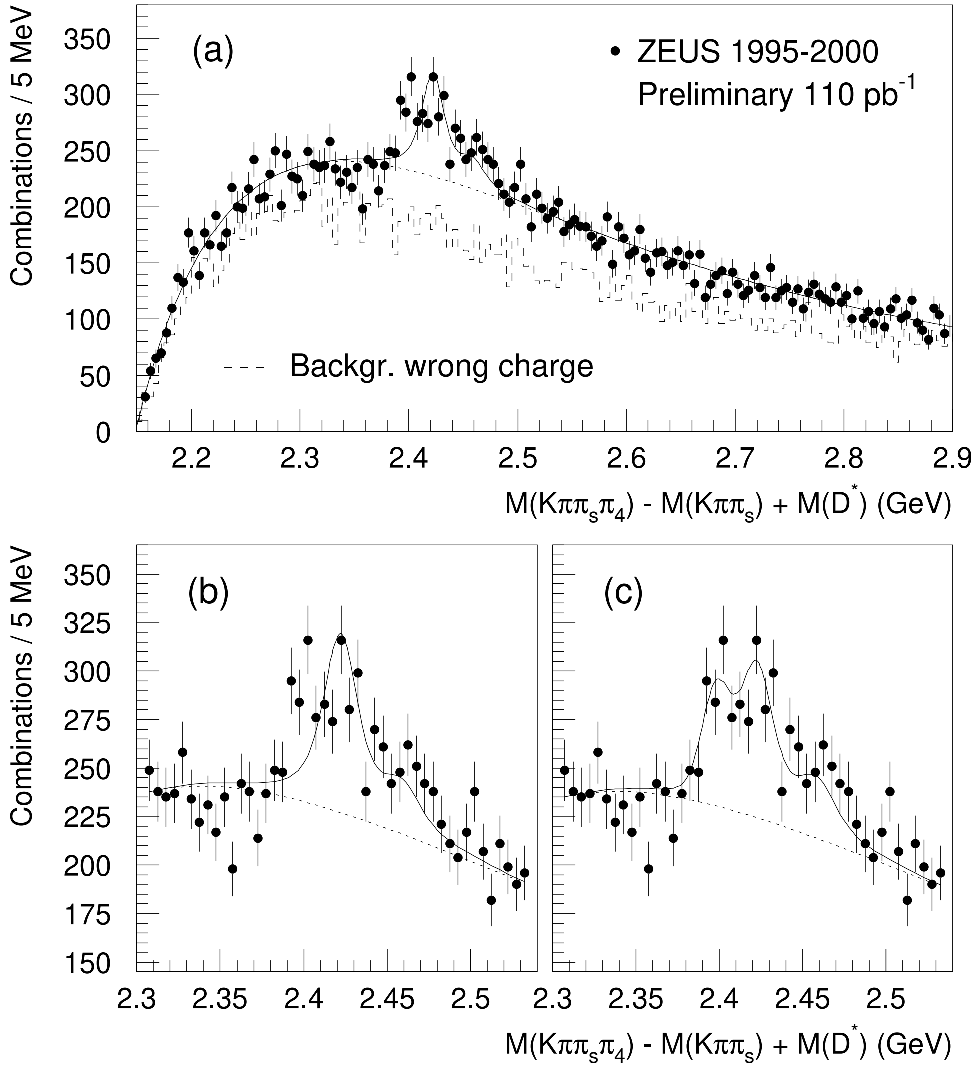
Fold in helicity spectrum for D_1^0 and D_2^{*0}

$\frac{dN}{d\cos\alpha} \propto 1 + 3\cos^2\alpha$ $\quad (1^+ \text{ state } \; \mathrm{j} = 3/2 \text{ doublet})$

$\frac{dN}{d\cos\alpha} \propto 1 - \cos^2\alpha$ $\quad (2^+ \text{ state } \; \mathrm{j} = 3/2 \text{ doublet})$

α**: angle between π_4 and π_s in D^* rest frame**

D_1^0 and D_2^{*0} Production



See enhancement in $D^{*\pm}\pi^{\mp}$; not in $D^{*\pm}\pi^{\pm}$

$N(D_1^0) = 526 \pm 65, N(D_2^{*0}) = 203 \pm 60$

Excess of events near M = 2.4 GeV

Including an extra resonance (Gaussian)(c)

- 211 ± 49 **entries**
- **Mass:** $2398.1 \pm 2.1(\mathrm{stat.})^{+1.6}_{-0.8}(\mathrm{syst.})\mathrm{MeV}$
- **Width consistent with resolution**

So-far unobserved excited charm meson, or due to interference effect(?)

D_1^0 and D_2^{*0} Production

Fraction of D^* from D_1^0 and D_2^{*0}

Acceptance Corrected using Pythia

$$R_{D_1^0 \to D^{*\pm}\pi^{\mp}/D^{*\pm}} = 3.40 \pm 0.42(stat.)^{+0.78}_{-0.63}(syst.)\%$$

$$R_{D_2^{*0} \to D^{*\pm}\pi^{\mp}/D^{*\pm}} = 1.37 \pm 0.40(stat.)^{+0.96}_{-0.33}(syst.)\%$$

Extrapolate to full kinematic region,using

- $f(c \to D^{*+}) = 0.235 \pm 0.007 \pm 0.007$
- $\Gamma(D_2^{*0} \to D^+\pi^-)/\Gamma(D_2^{*0} \to D^{*+}\pi^-) = 2.3 \pm 0.6$
- **Isospin Conservation**

	$f(c \to D_1^0)$ [%]	$f(c \to D_2^{*0})$ [%]
ZEUS Prelim.	$1.46 \pm 0.18^{+0.33}_{-0.27} \pm 0.06$	$2.00 \pm 0.58^{+1.40}_{-0.48} \pm 0.41$
CLEO	1.8 ± 0.3	1.9 ± 0.3
OPAL	2.1 ± 0.8	5.2 ± 2.6
ALEPH Prelim.	1.6 ± 0.5	4.7 ± 1.0
DELPHI Prelim.	1.9 ± 0.4	4.7 ± 1.3

Fractions consistent with e^+e^- results

Search For Radially Excited $D^{*'\pm}$

Radial excitations predicted above $2500\,\mathrm{MeV}$

DELPHI see a peak in $D^{*+}\pi^{+}\pi^{-}$ **at** $M = 2637\,\mathrm{MeV}, \Gamma < 15\,\mathrm{MeV}$
[PLB 426 (1998) 231]

OPAL and CLEO do not see this.
[OPAL PN 352,CLEO hep-ex 9901008]

What about HERA?

Add $\pi^{+}\pi^{-}$ **pair** (π_4, π_5) **to** D^* **candidate**

$p_{\perp}(\pi) > 0.125\,\mathrm{GeV}$ **for extra pions**

Plot: $M(K,\pi,\pi_s,\pi_4,\pi_5) - M(K,\pi,\pi_s) + M(D^*)$

Background is described with:

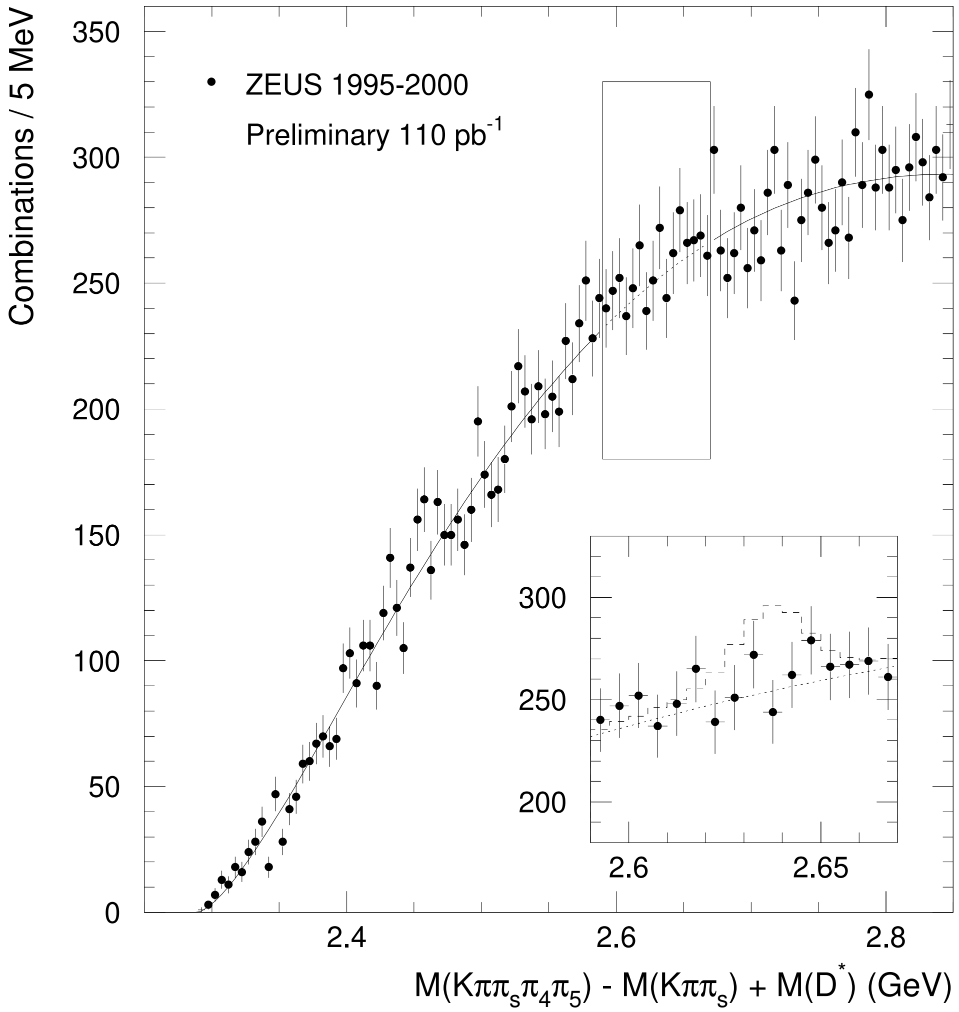
$x^{\alpha} \cdot e^{(-\beta \cdot x)}$

$x = M(K,\pi,\pi_s,\pi_4,\pi_5) - M(K,\pi,\pi_s) - 2 * m_{\pi}$

Look in mass window $2590 < M < 2670\,\mathrm{MeV}$

Fit background outside window,and interpolate

Search For Radially Excited $D^{*\prime\pm}$



Signal: 91 ± 75 **entries**

$$R_{D^{*\prime +} \to D^{*+}\pi^+\pi^- / D^{*+}} < 2.3\% \quad (95\% \quad C.L.)$$

Extrapolate to full kinematic range

Using the known value for $f(c \to D^*)$**:**

$$f(c \to D^{*\prime +}) \cdot B_{D^{*\prime +} \to D^{*+}\pi^+\pi^-} < 0.7\% \; (95\% \; C.L.)$$

OPAL limits (hep-ex/0101045):

$$f(c \to D^{*\prime +}) \cdot B_{D^{*\prime +} \to D^{*+}\pi^+\pi^-} < 0.9\% \; (95\% \; C.L.)$$

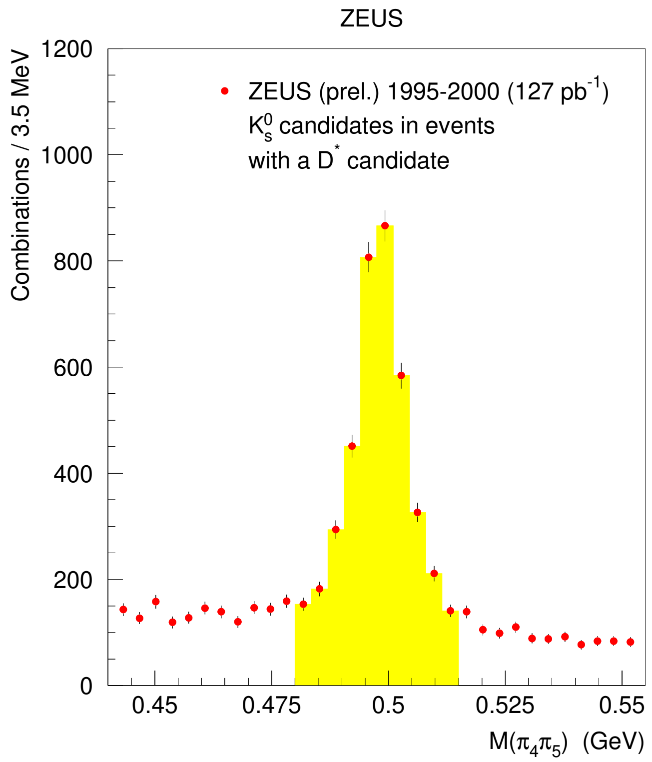
$$f(b \to D^{*\prime +}) \cdot B_{D^{*\prime +} \to D^{*+}\pi^+\pi^-} < 2.4\% \; (95\% \; C.L.)$$

D_{s1} Production

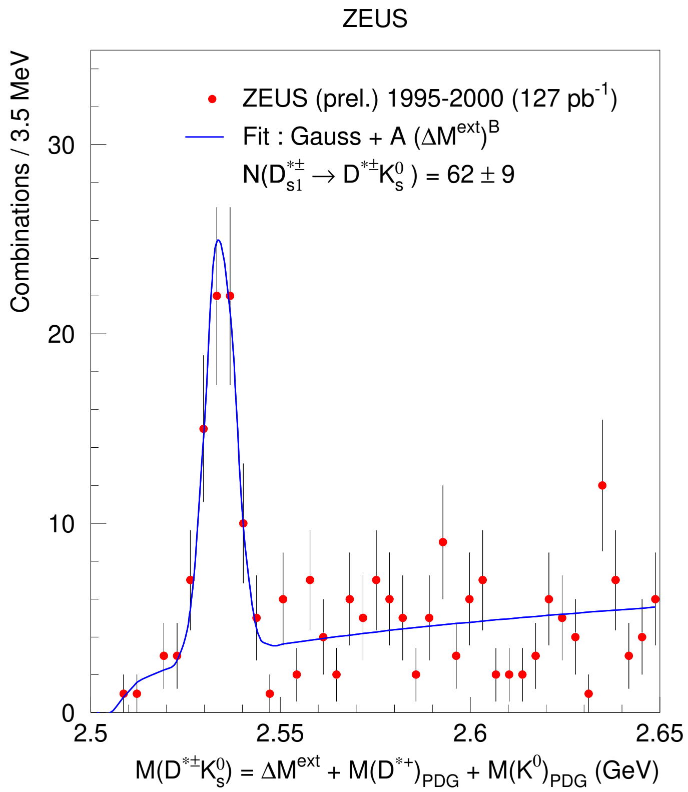
Reconstruct D_{s1} in the decay mode

$D_{s1}^{\pm}(2536) \to D^{*\pm} K_S^0$, $\quad K_S^0 \to \pi^+\pi^-$

K_S^0 signal extracted from a V0-finding package



Signal region:
$0.480 < M(\pi^+\pi^-) < 0.515$ **GeV**



Large clean signal in
$D_{s1}^{\pm}(2536) \to D^{*\pm} K_S^0$

Unbinned fit:

$\boxed{N(D_{s1}^{\pm}) = 62.3 \pm 9.3}$

(ZEUS prel.)

$M(D_{s1}^{+}) = 2534.2 \pm 0.6(\pm 0.5)$ **MeV**

PDG: $2535.35 \pm 0.34(\pm 0.5)$ **MeV**

D_{s1} Production

Helicity Parameter $\left(\frac{dN}{d\cos\alpha} \propto 1 + R \cdot \cos^2\alpha\right)$ **:**

CLEO $(D_{s1}^+ \to D^{*0}K^+)$ **:** $R = -0.23^{+0.40}_{-0.32}$ $\Longrightarrow J^P = 1^+ (R=0)$

$\boxed{R = -0.53 \pm 0.32(\text{stat.})^{+0.05}_{-0.14}(\text{syst.})}$ **(ZEUS prel.)**

Consistent with $J^P = 1^+$ of CLEO

Fraction of c quark hadronizing into D_{s1}^+:

$\boxed{f(c \to D_{s1}^+) = 1.24 \pm 0.18(\text{stat.})^{+0.08}_{-0.06}(\text{syst.}) \pm 0.14(\text{br.})\%}$

OPAL : $f(c \to D_{s1}^+) = 1.6 \pm 0.4 \pm 0.3\%$

Fractions of excited D mesons similar in e^+e^-, ep
$\Longrightarrow$ **Charm fragmentation universality**

With $f(c \to D_1^0) \approx 2\%$ **and** $\gamma_s \approx 0.3$**,**
expect $f(c \to D_{s1}^+) \approx 0.6\%$

Experimental value twice as large !

Summary and Outlook

- **Large samples of charm events have been analysed**
- **First observation of P-wave charm mesons** $D_1^0(2420)$, $D_2^{*0}(2460)$, $D_{s1}^{\pm}(2536)$ **at HERA**
- **Production rates** $f(c \to D_1^0, D_2^{*0}, D_{s1}^+)$ **have been measured and compared to** e^+e^-
- $f(c \to D_{s1}^+) \approx 1.2\%$ **consistent with OPAL; twice as expected from** $f(c \to D_1^0) \approx 2\%$ **and** $\gamma_s \approx 0.3$
- **No evidence for the radially excited state** $D^{*'\pm}(2637) \to D^{*\pm}\pi^+\pi^-$ **seen by DELPHI**
- **Evidence for charm fragmentation universality in** e^+e^- **and** ep **from** γ_s **and P-wave** D **meson production rates**