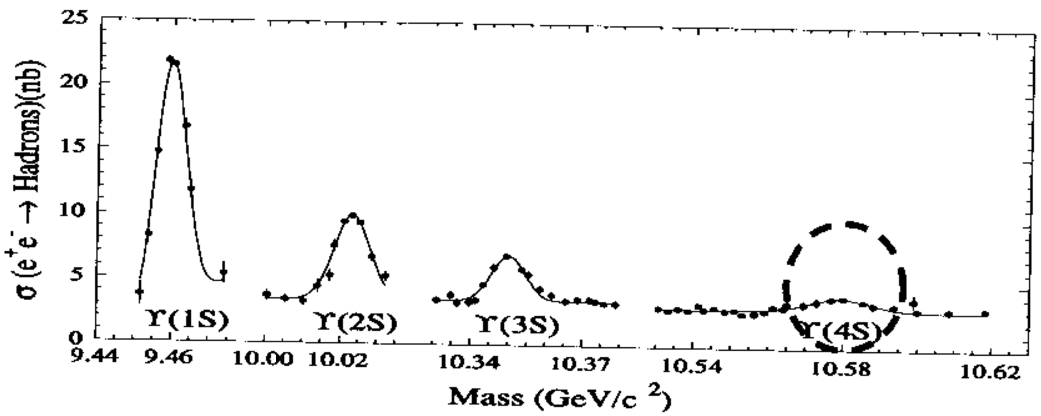
Recent Results on
Charm and B Hadronic Decays
From CLEO

Jorge L. Rodriguez
University of Hawaii
October 11, 1998

- First Observation of $B^0 \to D^{*+}D^{*-}$
- Polarization in $B^0 \to D^{*-}\rho^+$ and $B^- \to D^{*0}\rho^-$
- Measurements in $B^- \to D_J^0\pi^-$
- Measurement of $D^0 \to K^+\pi^-$
- Search for Radially Excited Charmed Mesons

CLEO Detector and Data Sets



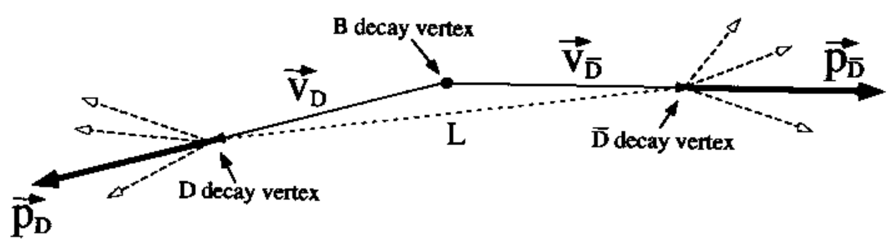
- CLEOII
  - 3 concentric drift chambers
  - ToF and dE/dx for PID
  - CSI calorimeter
- CLEOII Data set
  - 3.1 fb^{-1} on the Y(4s)
  - 1.6 fb^{-1} below resonance
- CLEOII/SVX
  - Silicon vertex detector SVX
  - r-ϕ (z) resolution ~15 (20) μm
  - Gas change in DR (He/Propane)
- CLEOII/SVX data set
  - 2.5 fb^{-1} on the Y(4s)
  - 1.3 fb^{-1} below resonance

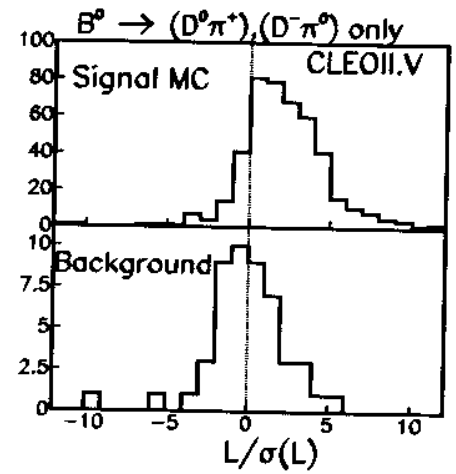
Analysis Procedure

Combine both CLEOII and CLEOII/SVX data (5.8 Million BB pairs)

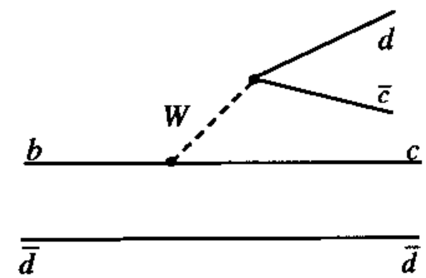
- Full reconstruction of the decay into $B_d \to (D^0\pi^+)(\overline{D}^0\pi^-)$ or $(D^0\pi^+)(D^-\pi^0)$ (background considerations)
  - Five D^0 and six D^+ decay modes, only the $D^0\pi^+$ or $D^+\pi^0$, D^* decays
    - 3D vertex constrained fit on D, mass constrained fit on D* candidates
  - B candidates have lowest χ^2 formed from m_D mass and D^*,D Δm
  - In CLEOII/SVX data cut on L/σ (long life of the D^+ and the SVX)

$$L \equiv \left(V_D - V_{\overline{D}}\right)\cdot\frac{\left(\vec{P}_D - \vec{P}_{\overline{D}}\right)}{\left|\vec{P}_D - \vec{P}_{\overline{D}}\right|}$$





First Observation of $B^0 \to D^{*+}D^{*-}$



External W Emission

- Potentially interesting CPVD
  - probe sin 2β via time–dependent asymmetries due to B–B mixing
  - Partial wave analysis leads to CP even/odd states

- Expected rate from measurement of the $Br(B^0 \to D_s^{*+} D^{*-})$

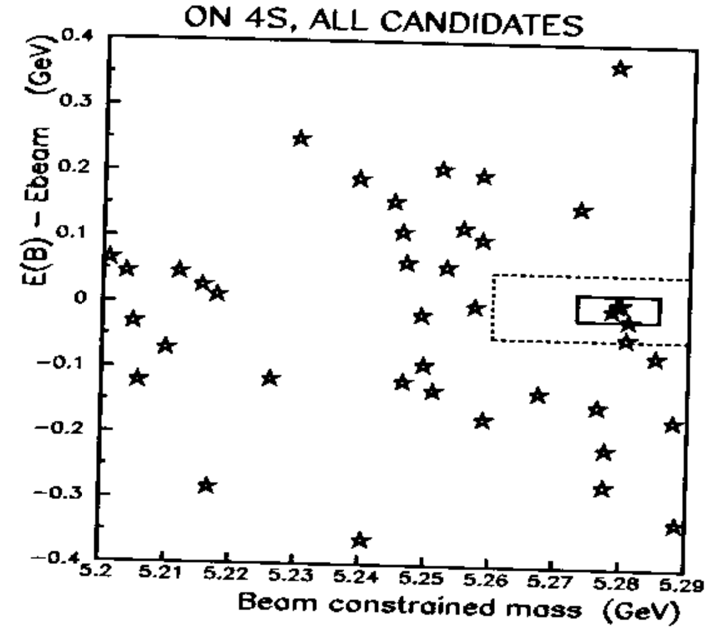
$$Br(B \to D^{*+}D^{*-}) = Br(B \to D_s^{*+}D^{*-}) \cdot \left(\frac{f_{D^*}}{f_{D_s^*}}\right)^2 \tan^2\theta_c \approx 1\times 10^{-3}$$

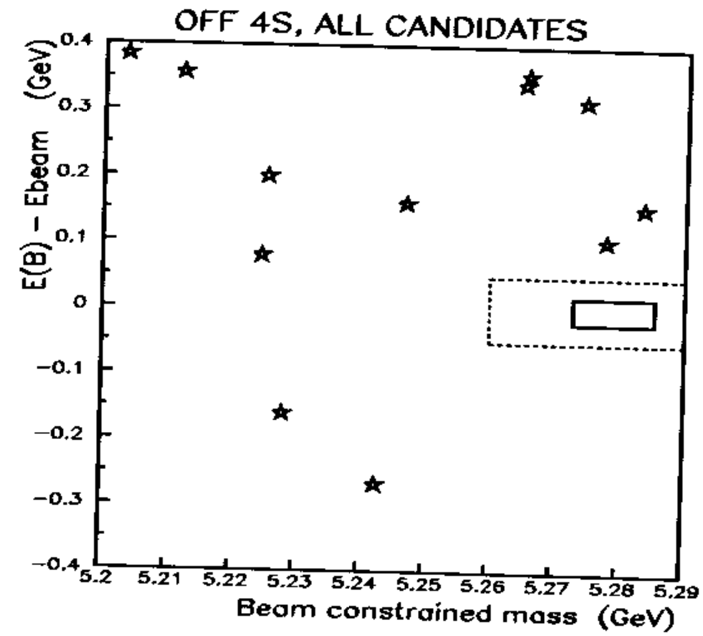
Results

- Observable ΔE and M_{BC}
  - $\Delta E = E_{recon} - E_{beam}$
  - $M_{BC} = (E^2_{beam} - \Sigma p^2)^{1/2}$

- Background estimation
  - Grand sideband = 0.26 events
  - From Combinatorial, continuum
    $B\overline{B} \to D^{*+} X D^{*-} X, D^{*-} D^{*+} X$

    Total = 0.37





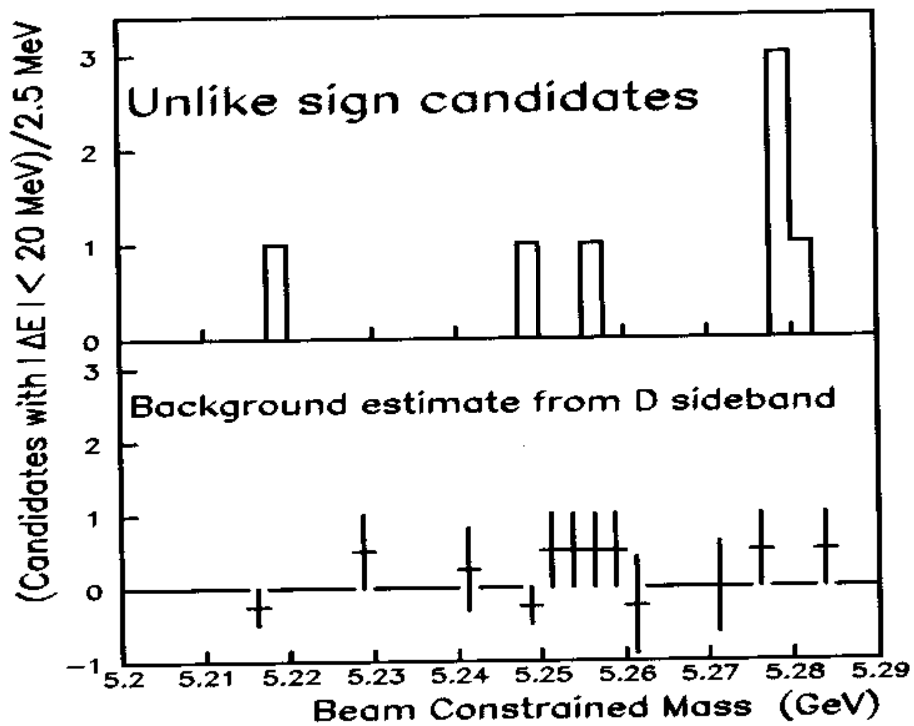
Results continued

Preliminary

$$Br(B \to D^{*+} D^{*-}) = (7.8^{+5.4}_{-3.8} \pm 1.5) \times 10^{-4}$$

- Four candidates observed
- Probability of signal given 0.37 background events is less than 8.7×10^{-5}

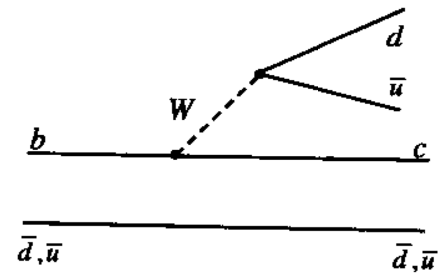
CLEOII & CLEOII/SVX (5.6 fb^{-1})



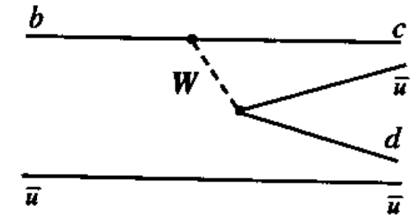
Polarization in $B \rightarrow D^{*}\rho^{+}$

Partial Wave Analysis of Angular Distribution

- $\bar{B}^{0} \rightarrow D^{*+}\rho^{-}$: $A \propto V_{cb}V^{*}_{ud}\, a_1 A_{ext}$
- $B^{-} \rightarrow D^{*0}\rho^{-}$: $A \propto V_{cb}V^{*}_{ud}\, (a_1 A_{ext} + x a_2 A_{int})$
- Look for FSI by extracting the phases
  - No CKM phase → strong phase only
- Tests of Factorization
  - Polarization in $B \rightarrow D^{*-}\rho^{+}$ vs. $B \rightarrow D^{*-} l^{+}\nu$



External W Emission

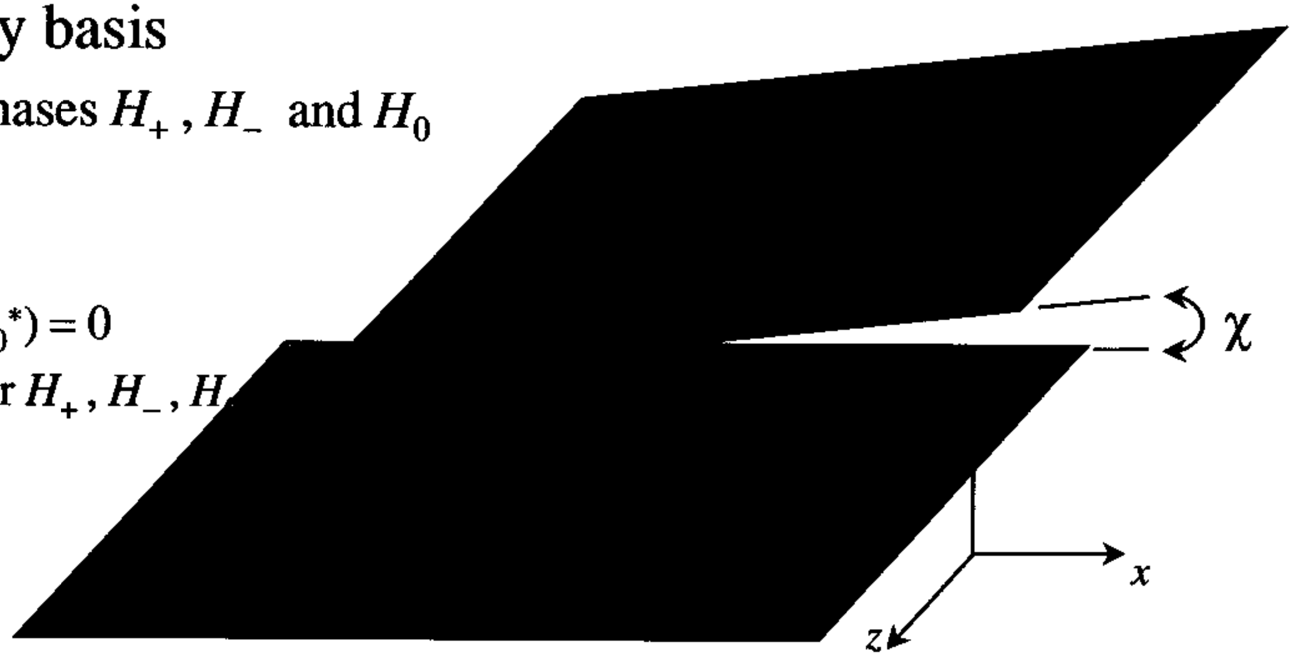


Internal W Emission

Angular Distribution in $B \to D^{*}\rho^{-}$

Expand in the Helicity basis

- Amplitudes and phases H_+, H_- and H_0
- No FSI if
  - $\mathrm{Im}(H_0 H_-^*) = 0$
  - $\mathrm{Im}(H_+ H_0^* - H_+ H_0^*) = 0$
  - Trivial phases for H_+, H_-, H



$$\frac{d\Gamma}{d\cos\theta_{D^*}\, d\cos\theta_{D^*} d\chi} \propto$$

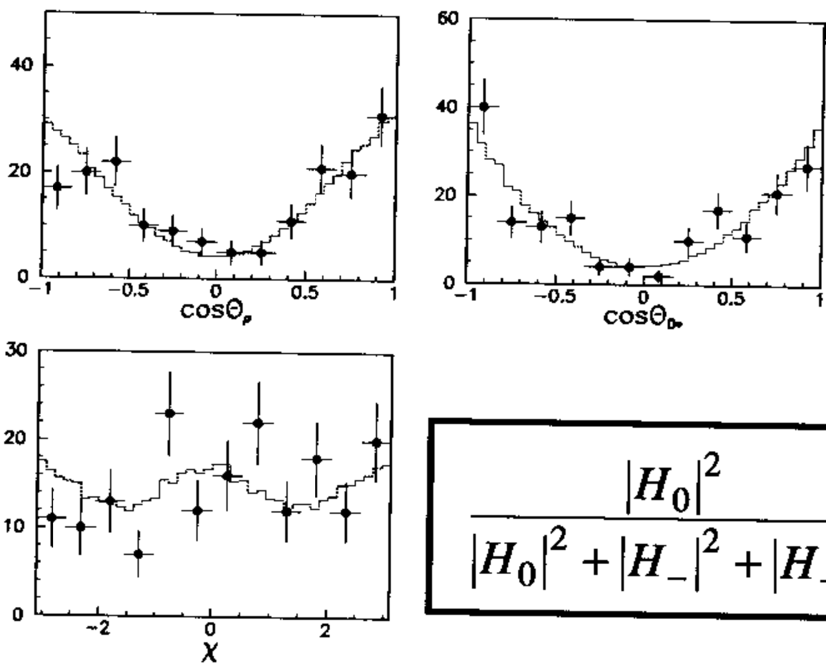
$$4|H_0|^2 \cos^2\theta_{D^*} \cos^2\theta_\rho + \left(|H_-|^2 + |H_+|^2\right)\sin^2\theta_{D^*} \sin^2\theta_\rho$$
$$+ 2\left[\mathrm{Re}\left(H_+ H_-^*\right)\cos 2\chi - \mathrm{Im}\left(H_+ H_-^*\right)\sin 2\chi\right]\sin^2\theta_{D^*} \sin^2\theta_\rho$$
$$+ \left[\mathrm{Re}\left(H_+ H_0^* + H_- H_0^*\right)\cos\chi - \mathrm{Im}\left(H_+ H_0^* - H_- H_0^*\right)\sin\chi\right]\sin 2\theta_{D^*} \sin 2\theta_\rho$$

Extraction of Helicity Amplitudes

- 3D Unbinned Likelihood analysis
  - Independent variables $\cos(\theta_{D^*})$, $\cos(\theta_\rho)$ and χ
  - Parameters of the fit:
    - Magnitude and phases for the complex helicity amplitudes H_+, H_-, with $H_0 = 1$ $\alpha_0 = 0$ fixed
    - 24 parameters describing the shape of the M_{BC} for each D^0 submode These are fixed to values obtained in fit without the angular distribution
- Moments Analysis
  - Direct determination of coefficients in the differential decay rate
  - Less statistically powerful than 3D L.L fit

Results of the $B^{-} \rightarrow D^{*0}\rho^{-}$ L.L. Fit

Based on CLEOII (3.1 fb^{-1})



Coefficient	From LL Fit	From Moments
H_0^2	-	0.626 ± 0.074
$H_+^2 + H_-^2$	0.143 ± 0.060	0.168 ± 0.036
$\mathrm{Im}(H_- H_0^* - H_+ H_0^*)$	-0.071 ± 0.109	-0.145 ± 0.101
$\mathrm{Re}(H_- H_0^* + H_+ H_0^*)$	0.250 ± 0.105	0.193 ± 0.109
$\mathrm{Im}(H_+ H_-^*)$	-0.011 ± 0.032	0.002 ± 0.027
$\mathrm{Re}(H_+ H_-^*)$	0.068 ± 0.029	0.043 ± 0.025

$$\frac{|H_0|^2}{|H_0|^2 + |H_-|^2 + |H_+|^2} = 85.7 \pm 4.7 \pm 4.0\ \%$$

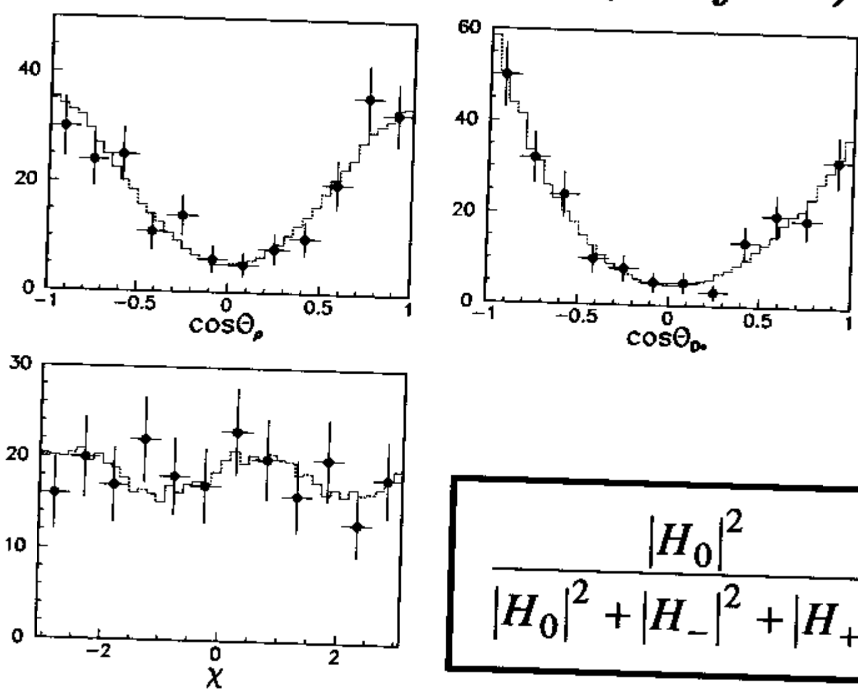
Preliminary

$$|H_-| = 0.283 \pm 0.068 \pm 0.039$$
$$|H_+| = 0.228 \pm 0.069 \pm 0.036$$

$$\delta_+ = 1.13 \pm 0.27 \pm 0.17$$
$$\delta_- = 0.95 \pm 0.31 \pm 0.19$$

Results of the $B^0 \to D^{*-}\rho^+$ L.L. Fit

Based on CLEOII (3.1 fb^{-1})



Coefficient	From LL Fit	From Moments
H_0^2	-	0.751 ± 0.073
$H_+^2 + H_-^2$	0.140 ± 0.040	0.159 ± 0.034
$\mathrm{Im}\left(H_- H_0^* - H_+ H_0^*\right)$	0.110 ± 0.074	0.042 ± 0.103
$\mathrm{Re}\left(H_- H_0^* + H_+ H_0^*\right)$	0.341 ± 0.088	0.352 ± 0.104
$\mathrm{Im}\left(H_+ H_-^*\right)$	0.053 ± 0.021	0.057 ± 0.024
$\mathrm{Re}\left(H_+ H_-^*\right)$	0.023 ± 0.024	0.018 ± 0.023

$$\frac{|H_0|^2}{|H_0|^2 + |H_-|^2 + |H_+|^2} = 87.8 \pm 3.4 \pm 3.0\ \%$$

Preliminary

$$|H_-| = 0.317 \pm 0.052 \pm 0.013$$
$$|H_+| = 0.152 \pm 0.058 \pm 0.037$$

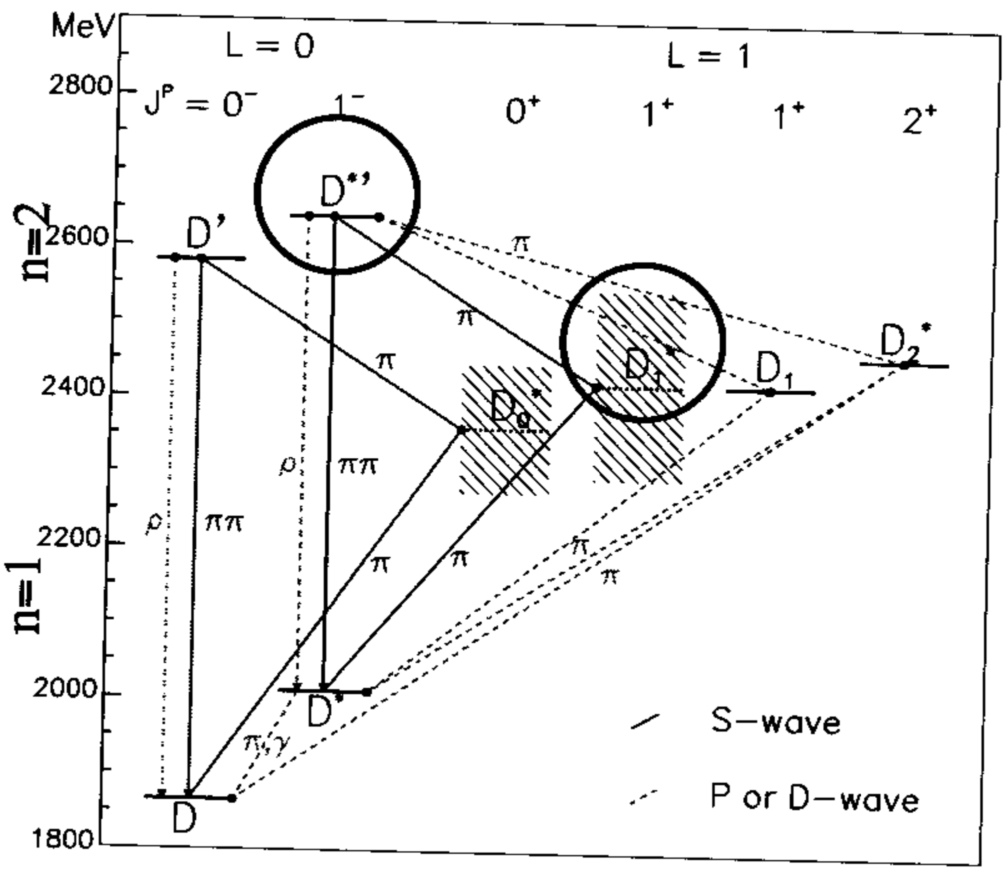
$$\delta_+ = 0.19 \pm 0.23 \pm 0.14$$
$$\delta_- = 1.47 \pm 0.37 \pm 0.32$$

Discussion

- Factorization: Compare with semi–leptonic decay
  - At $q^2 = m^2_\rho$ expect ~ 90% longitudinal polarization
  - From $B^0 \rightarrow D^{*-}\rho^+$ fit we find 87.8 ± 4.5 % logitudinal polarization
- Non–trivial phases suggest FSI
  - First observation in B decays
  - Need more statistics to confirm (CLEOII/SVX data to be added)

Spectroscopy of Charmed Mesons

Spectroscopy of D mesons



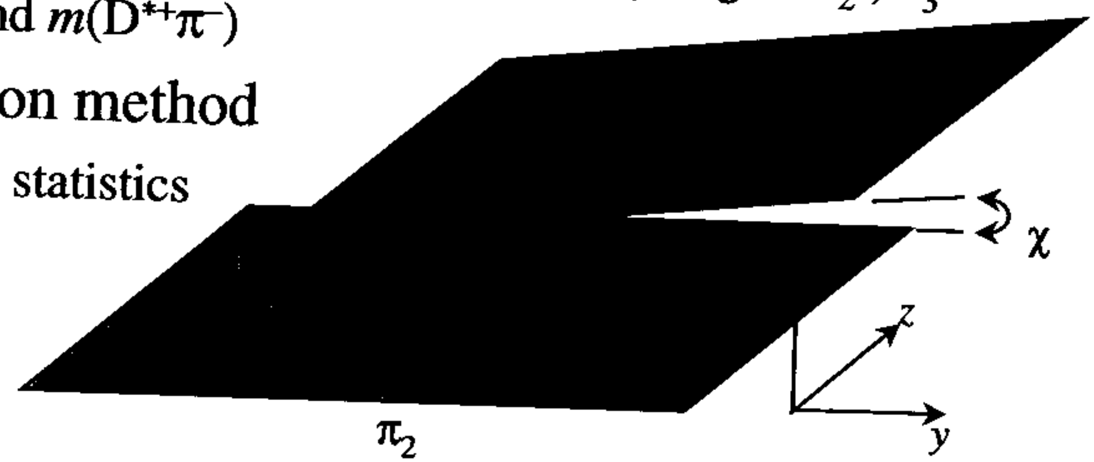
- Observed D** resonance
  - $D_1(2420) \Rightarrow J^P = 1^+$, $j = 3/2$
  - $D_2^*(2460) \Rightarrow J^P = 2^+$, $j = 3/2$
  - Continuum production
  - Spin–Parity assignments from
    - Angular distribution of decay
    - Ratios of $D\pi/D^*\pi$ decays

New CLEO Results

- First observation of the $D_1(j=1/2)$
- Search for the 1st radial excitation of charmed state $D^{*\prime}$

Measurements in $B \to D_J^0 \pi^-$

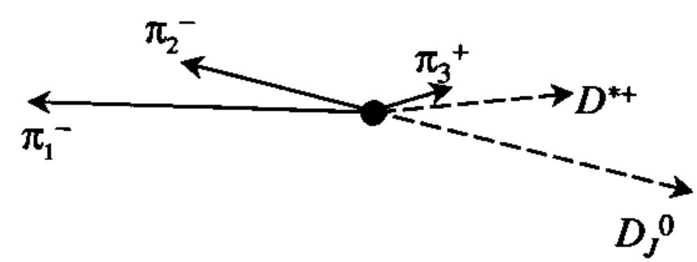
- Exploit the polarization (0-helicity) of the D_J in $B \to D_J^0\pi^-$
  - Full Partial wave analysis of entire decay chain
    $B \to D_J^0 \pi^-$, $D_J^0 \to D^{*+} \pi^-$, $D^{*+} \to D^0\pi^+$
    - $D_1^0(j=1/2)$ unobserved but is expected to be mostly *S* wave
    - $D_1(2420)^0$ observed and found to be mostly D wave
    - $D_2^*(2460)^0$ observed, pure D wave
  - Use additional information provided by the two helicity angles θ_2 , θ_3 the azimuthal angle χ and $m(D^{*+}\pi^-)$
- Use partial reconstruction method
  ☺ Large increase ~ 10 × in statistics
  ☹ Background systematics



Analysis Procedure

- Partial reconstruction of $B^- \to D_J^0 \pi_1^-$ $D_J^0 \to D^{*+} \pi_2^-$ $D^{*+} \to D^0 \pi_3^+$
  - Reconstruct entire decay, up to a quadratic ambiguity, by measuring only the 4-momenta of the $\pi_1\, \pi_2\, \pi_3$ and by imposing energy-momentum conservation at each decay vertex
- Goals are to measure
  - The branching fractions
    - $B \to D_1(2420)^0 \pi^-$
    - $B \to D_1^0(j=1/2)\, \pi^-$
    - $B \to D_2^*(2460)^0 \pi^-$
    - $B \to D^{*+} \pi^- \pi^-$ (non–resonant)
  - Properties of the broad $D_1(j=1/2)^0$ resonance
    - Mass
    - Width

G. Brandenburg *et. al.*, PRL 80 (1998)



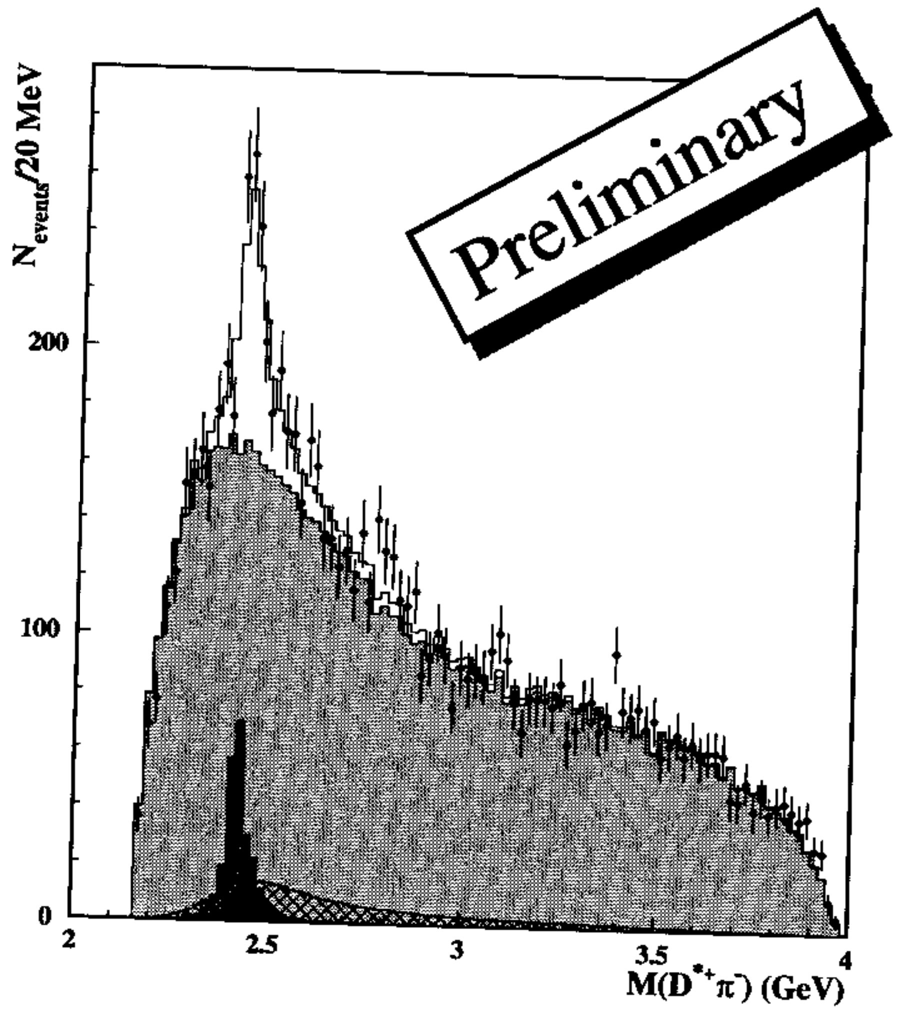
Analysis Procedure cont.

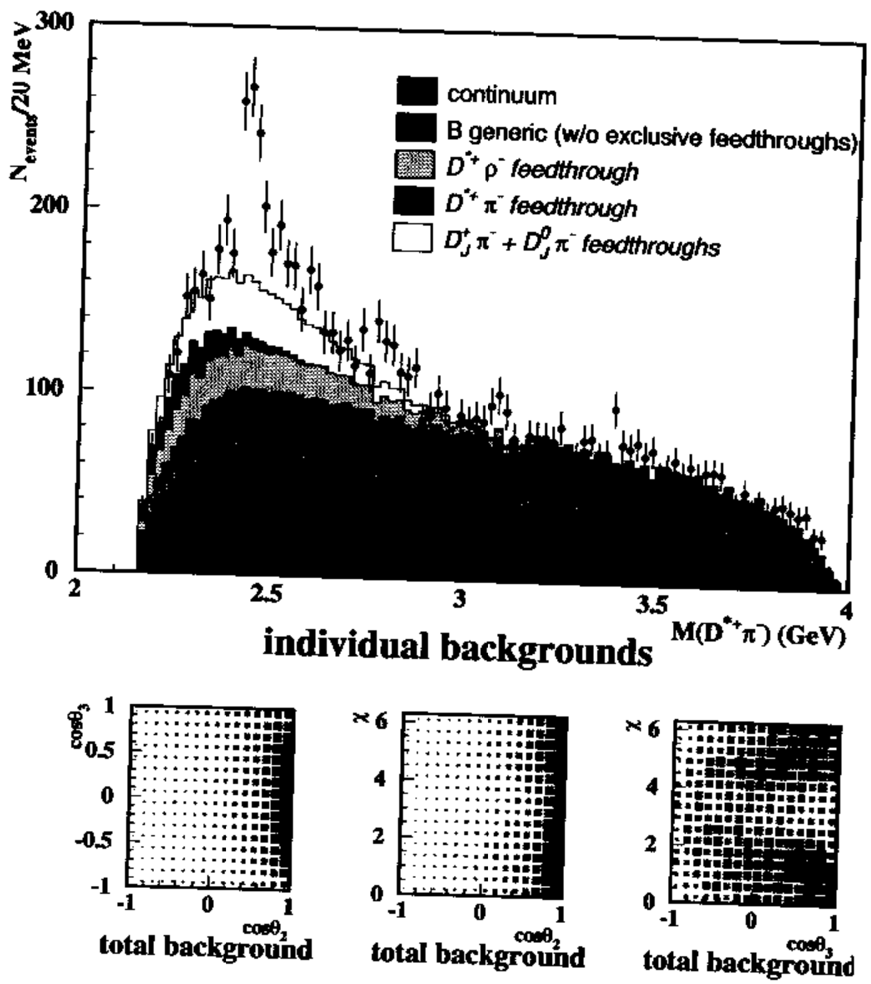
- Signal extraction via 4D unbinned M.L.L.
  - Independent variables in fit
    - $\cos(\theta_2)$, $\cos(\theta_3)$, χ and $m(D^{*+}\pi^-)$
  - Parameters of the fit
    - Yields (3 resonant and one non-resonant $B \to D^{*+}\pi^- \pi^-$ decays)
    - Line shape (Mass and Width) of the broad D_1(j=1/2) resonance
    - strong phases (δ_1, δ_2) relative to the 1^+ narrow state
    - Mixing and interference between resonances (ϕ, β)
  - Strong phase shifts and mixing among the resonances

$$\begin{aligned} A_{B\to D^{*+}\pi^-\pi^-} &= \alpha_{1n}A_{1n}\left(a_{1d}\cos\beta + a_{1s}\cos\beta\, e^{i\phi}\right) \\ &+ \alpha_{1b}A_{1b}\left(a_{1s}\cos\beta - a_{1d}\cos\beta\, e^{i\phi}\right)e^{i\delta_1} \\ &+ \alpha_2 A_2 a_2\, e^{i\delta_2} \\ &+ \alpha_{non-res}\, e^{i\delta_{non-res}} \end{aligned}$$

A_i are the Breit Wigner amplitudes
α_i are the resonance normalization
a_i are the angular amplitudes ($D^j_{m'm}$)
β, ϕ are the mixing parameters
δ_i are the strong phases

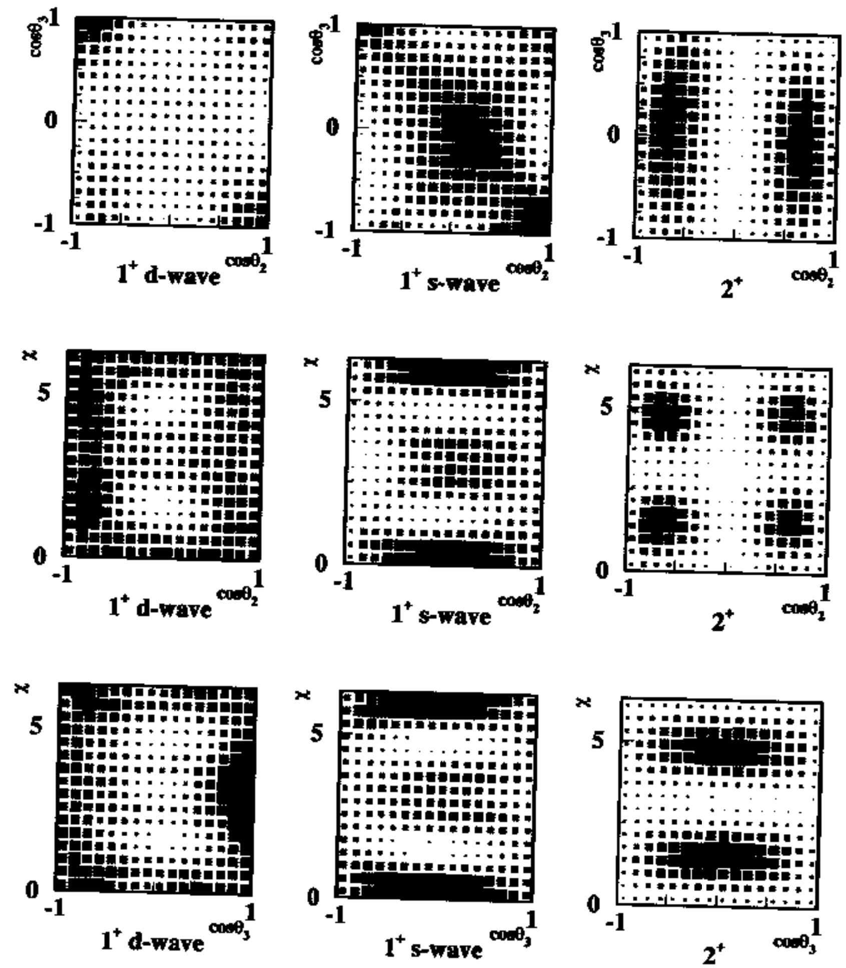
Projection of 4D L.L. Fit on to $m_{D^{*+}\pi^-}$





Angular Distributions

- Projections of the reconstructed angular distributions in signal Monte Carlo
- The smearing and acceptances of the reconstruction procedure are included



The D_J Resonances

From the likelihood fit

C.L. = 86%

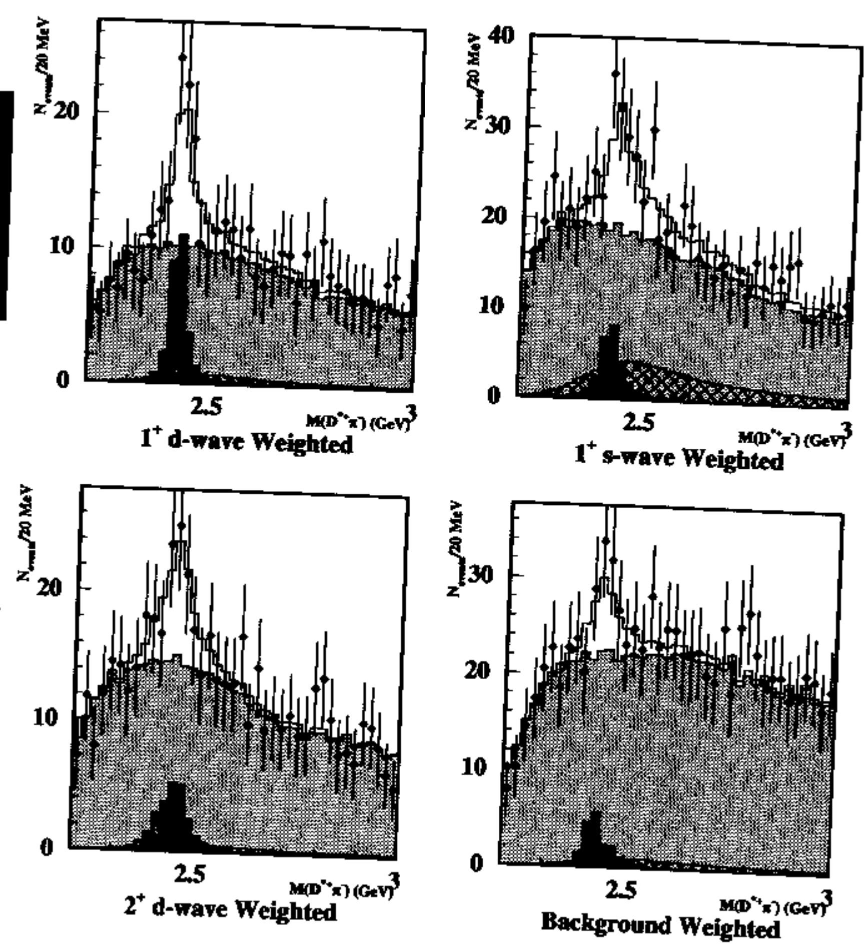
- Properties of the D_1^0

$$M_{D_1^0(j=\frac{1}{2})} = 2.461^{+0.041}_{-0.034} \pm 0.010 \pm 0.032 \text{ GeV}$$

$$\Gamma_{D_1^0(j=\frac{1}{2})} = 290^{+101}_{-79} \pm 26 \pm 36 \text{ MeV}$$

  - Second systematic error due to uncertainty in modeling of strong phases

- Spin–Parity assigned to 1^+
  - Tests of the J^P assignment favor the 1^+ assignment by 2σ relative to the next nearest 0^- (tried 0^-, 1^-, 1^+, 2^+, 2^-)



Preliminary

$Br(B \rightarrow D_J{}^0\pi^-)$ Results

Based on CLEOII (3.1 fb^{-1})

From the 4D Unbinned L.L. Fit: C.L. = 86%

Preliminary ★new

$$Br\left(B^- \rightarrow D^{*+}\pi^-\pi^- \text{ total}\right) = (29.2 \pm 4.5 \pm 3.7 \pm 3.1)\times 10^{-4}$$

$$Br\left(B^- \rightarrow D^{*+}\pi^-\pi^- \text{ non-res}\right) = (9.7 \pm 3.6 \pm 1.5 \pm 1.9)\times 10^{-4}$$

$$Br\left(B^- \rightarrow D_1(2420)^0\pi^-\right)\cdot Br\left(D_1(2420)^0 \rightarrow D^{*+}\pi^-\right) = \left(6.9^{+1.8}_{-1.4} \pm 1.1 \pm 0.4\right)\times 10^{-4}$$

$$Br\left(B^- \rightarrow D_1^0(j=\tfrac{1}{2})\pi^-\right)\cdot Br\left(D_1^0(j=\tfrac{1}{2}) \rightarrow D^{*+}\pi^-\right) = (10.6 \pm 1.9 \pm 1.7 \pm 2.3)\times 10^{-4}$$

$$Br\left(B^- \rightarrow D_2^*(2460)^0\pi^-\right)\cdot Br\left(D_2^*(2460)^0 \rightarrow D^{*+}\pi^-\right) = (3.1 \pm 0.84 \pm 0.45 \pm 0.28)\times 10^{-4}$$

- 2^{nd} systematic error is dominated by the uncertainty in modeling of the strong phases
- Destructive interference between resonance

Discussion

- Using the D_J branching fractions D_1=2/3, D_2=0.20

  $Br\left(B^- \to D_1(2420)^0\pi^-\right) = \left(1.04^{+0.27}_{-0.21} \pm 0.17 \pm 0.07\right)\times 10^{-3}$

  $Br\left(B^- \to D_1^0(j=\frac{1}{2})\pi^-\right) = (1.59 \pm 0.29 \pm 0.26 \pm 0.35)\times 10^{-3}$ ★first

  $Br\left(B^- \to D_2^*(2460)^0\pi^-\right) = (1.55 \pm 0.42 \pm 0.23 \pm 0.14)\times 10^{-3}$ ★first

Preliminary

- Larger than expected Branching fractions
  - Theoretical estimates (Neubert CERN–TH/97-240)
  - Need better measurement of the D_J branching fractions
- Quark model predictions

	$M_{D_1^0(j=\frac{1}{2})} - M_{D_1(2420)^0}$	$\Gamma_{D_1^0(j=\frac{1}{2})}$
Measured	39.2^{+42}_{-35} MeV	290^{+104}_{-83} MeV
Godfrey & Kokoski	+10 MeV	250-1000 MeV

★first

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

- Proceed either through $D^0 \overline{D^0}$ mixing or through $D^0 \to K^+\pi^-$
  - Highly suppressed in Standard. Model
  - Look for new physics
- Measure the Ratio $$R = \frac{\Gamma(D^0 \to K^+\pi^-)}{\Gamma(D^0 \to K^-\pi^+)}$$
- In Standard Model contributions to R
  - Mixing 10^{-3} to 10^{-10}
  - DCSD is of order $\tan^4\theta_C \sim 3\times10^{-3}$
- CLEO can now do a time dependent measurement
  - $N_{DCSD} \propto e^{-\Gamma t}$
  - $N_{Mixing} \propto t^2 e^{-\Gamma t}$

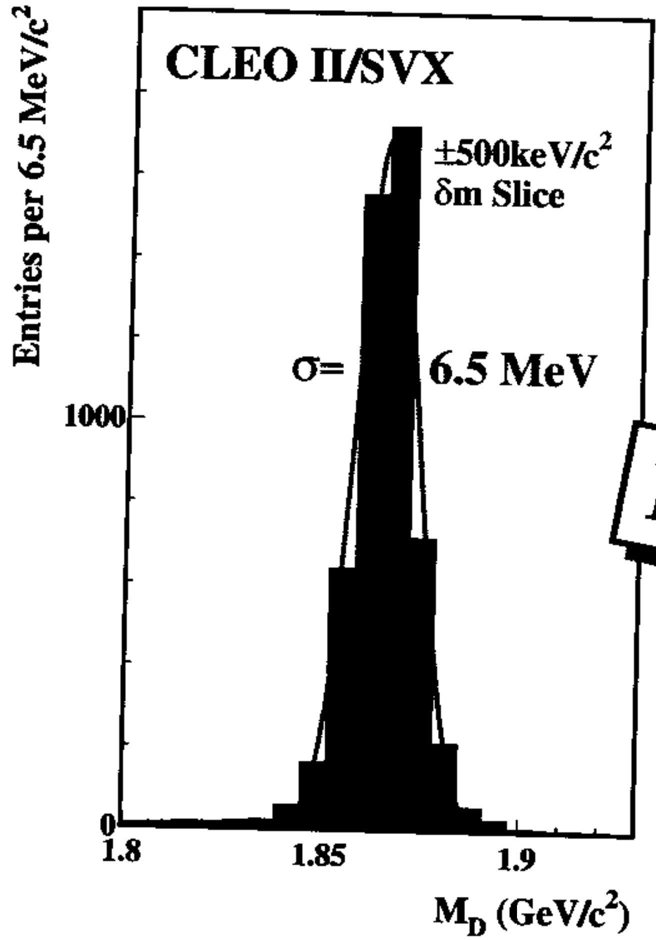
Analysis Procedure

sign of π_s tags the flavor of the D^0

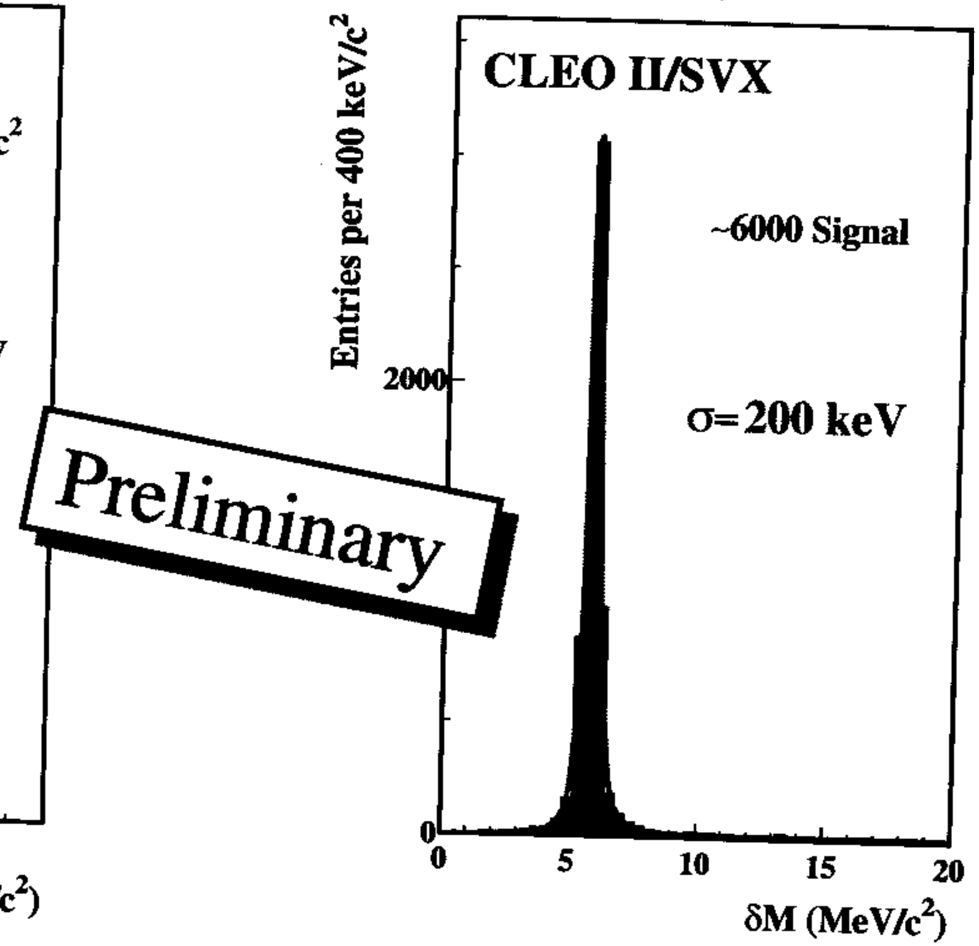
- Begin with $D^{*+} \rightarrow D^0 \pi_s^+$, $D^0 \rightarrow K^+ \pi^-$ (W.S.)
  - Selecting high momentum D^{*+} (x_p cut)
  - Particle ID from dE/dx
  - Signal extracted from
    - Invariant mass of D^0
    - D^{*+}, D^0 mass difference (δm)
- Background considerations for W.S.
  - Real $\overline{D^0} \rightarrow K^+ \pi^-$ with random π_s^+
    - Peaks in the D^0 mass but not in δm
  - Mis–identification of K/π
    - Broad peak in δm but not in D^0 mass
    - Most serious is double misID (form M_{flip} and veto if w/in 4σ)
  - Use Monte Carlo to model the backgrounds in the fit

Right Sign Distributions

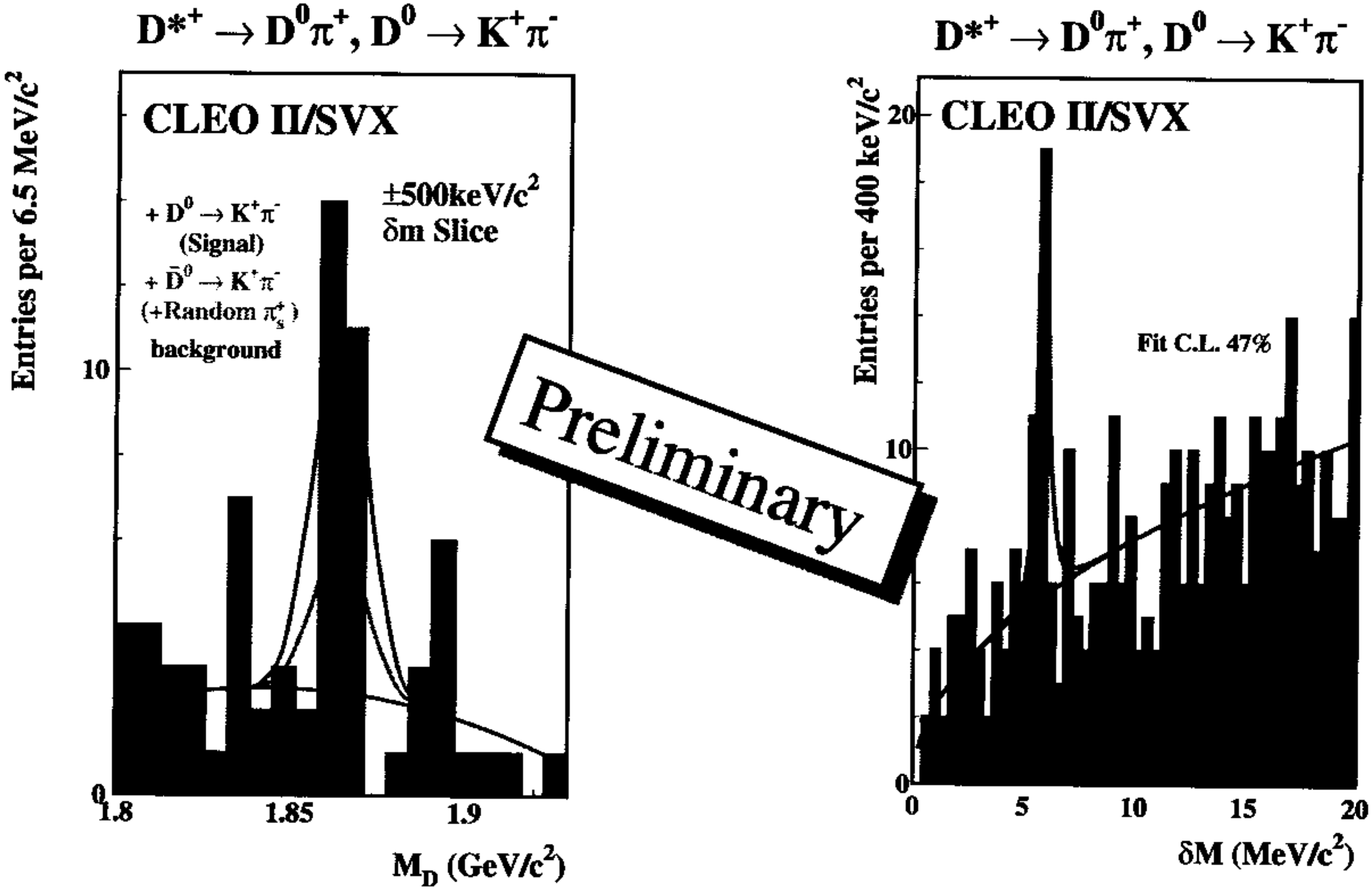
$D^{*+} \to D^0\pi^+, D^0 \to K^-\pi^+$



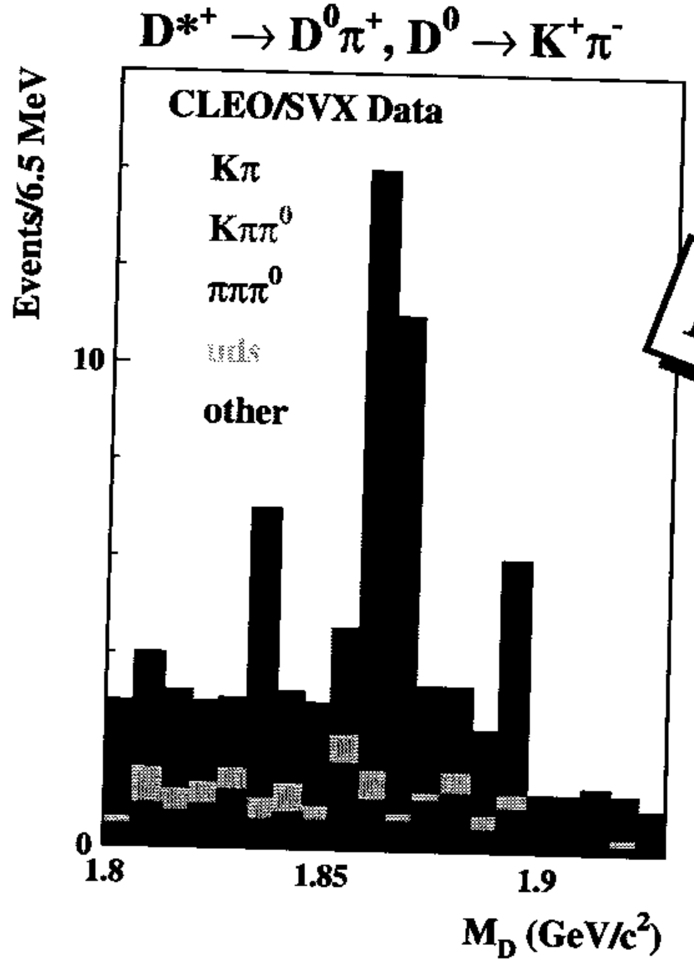
$D^{*+} \to D^0\pi^+, D^0 \to K^-\pi^+$

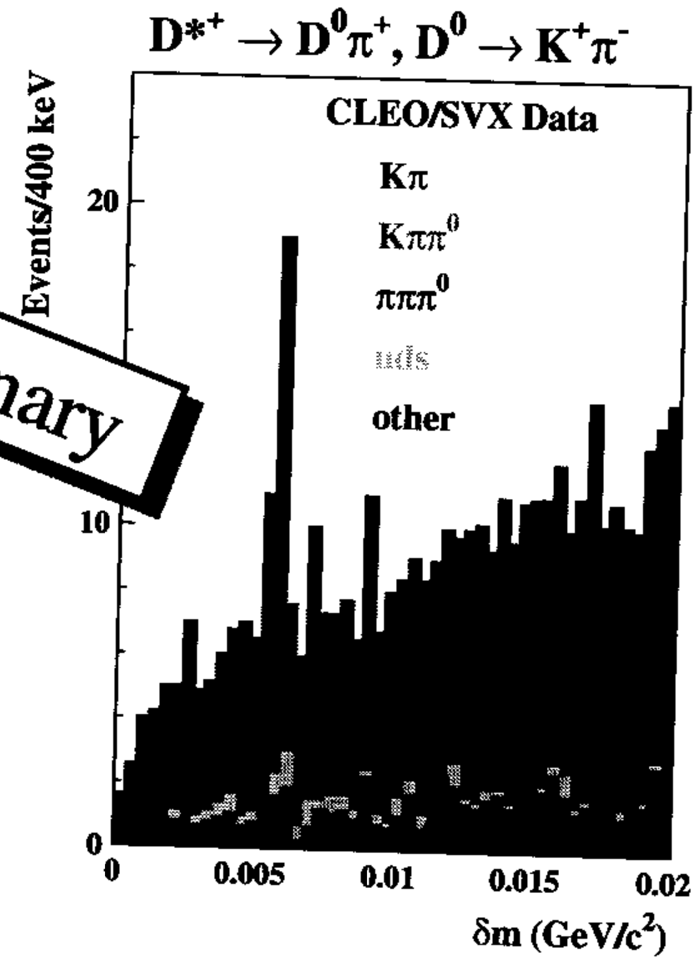


Wrong Sign Distributions



Backgrounds in Wrong Sign





Preliminary

Results for the $D^0 \to K^+\pi^-$

Based on CLEOII/SVX ($3.8\ fb^{-1}$)

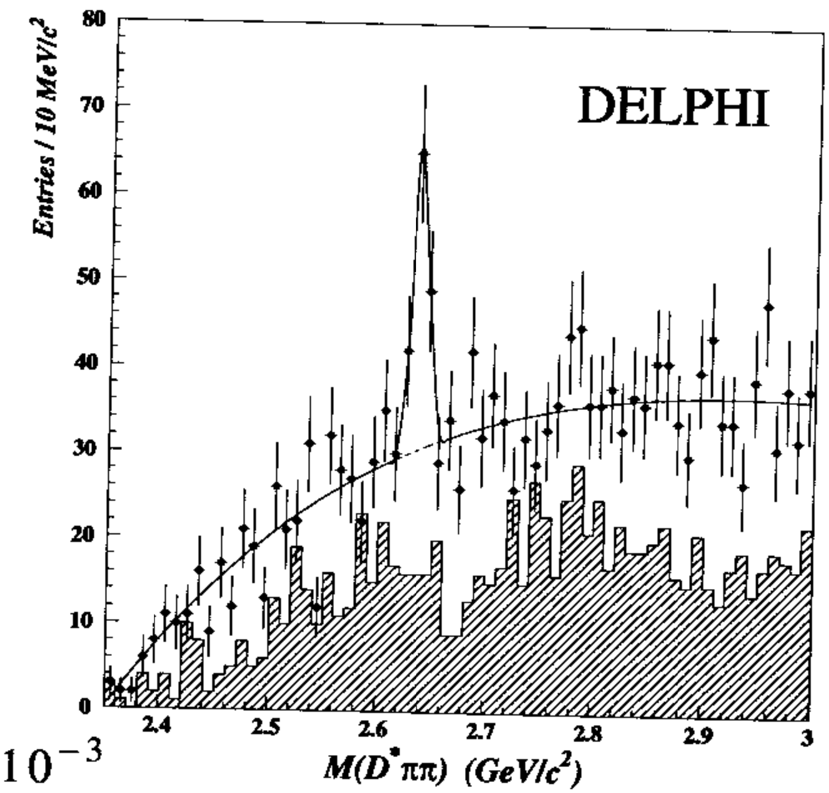
Preliminary

Experiment	$\frac{\Gamma(D^0 \to K^+\pi^-)}{\Gamma(D^0 \to K^-\pi^+)}$
CLEOII/SVX	$0.0032 \pm 0.0012 \pm 0.0015$
CLEOII	$0.0077 \pm 0.0025 \pm 0.0025$
E791	$0.0068 \pm 0.0034 \pm 0.0007$
ALEPH	$0.0177 \pm 0.0058 \pm 0.0031$
PDG	0.0072 ± 0.0025

- Significant reduction in statistical error over previous measurements
  - This measurement with CLEOII/SVX only ~ 2 × more statistics
  - Plan to add the rest of the CLEOII data as well ~ 5 × more statistics
- Time dependent R analysis planned with CLEO/SVX data

Charm Radial Excitation the $D^{*\prime}$

- DELPHI, claimed first observation of $D^{*\prime}$
  - Found 66 ± 14 events
  - mass $2637 \pm 2 \pm 6$ MeV
  - $\Gamma < 15$ MeV (@ 95% C.L.)
  - Q.N. assignment based on measured mass



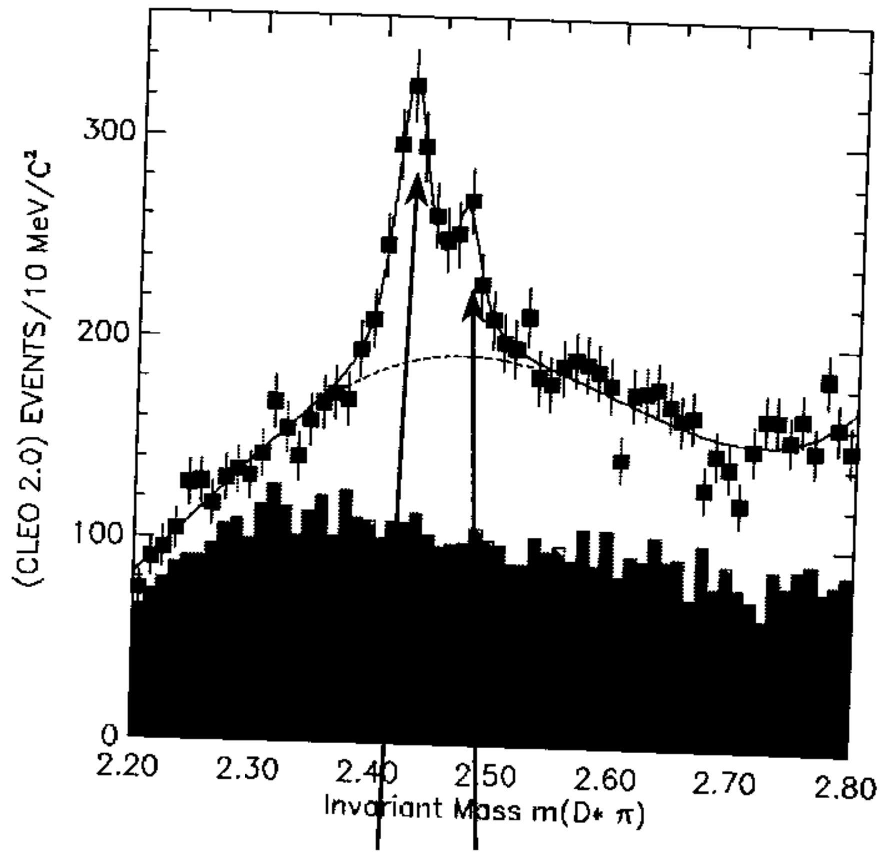
- Not confirmed by OPAL (ICHEP98)
  - Analysis similar to DELPHI's
  - No events seen limit @ 95% C.L.

$$f_{Z^0 \to D^{*\prime +}} Br\left(D^{*\prime +} \to D^{*+}\pi^+\pi^-\right) < 2.1 \times 10^{-3}$$

Analysis Procedı

Similar to DELPHI and OPAL

- Full reconstruction of decay
  - $D^{*\prime} \to D^{*+}\pi^-\pi^+$
- Start with continuum D^{*+}
  - x_p cut, I.P. cuts, dE/dx and ToF
  - Mass cuts on D^0 and D^*, $D^0\,\delta m$
  - Use $D^0 \to K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-3\pi$
- Test by looking for $L = 1$ states
  - fit to two B.W.s convoluted with Gaussian and a background shape



D_1 D_2^* mass peaks

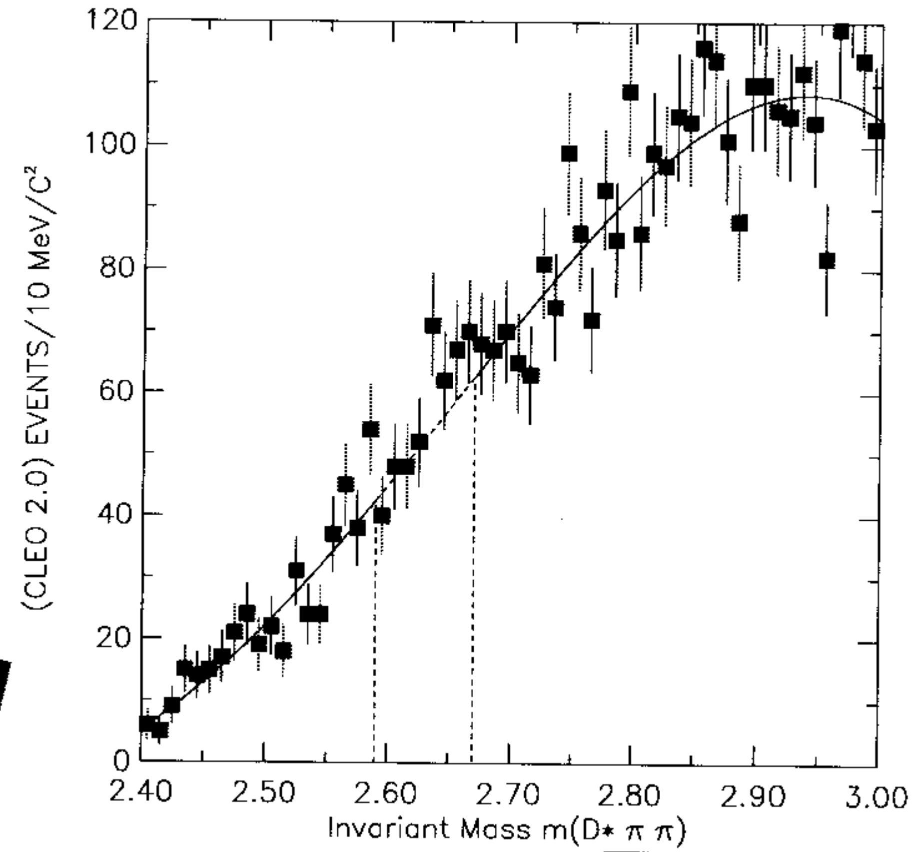
CLEO's Search for the $D^{*\prime}$

Based on CLEOII (4.9 fb^{-1})

- Add another π
- Look for excess at ~ 2.637 GeV

- No excess observed

Preliminary



$$R = \frac{N_{D^{*\prime +}} Br\left(D^{*\prime +} \to D^{*+}\pi^+\pi^-\right)}{N_{D_2^{*0}} Br\left(D_2^{*0} \to D^{*+}\pi^-\right) + N_{D_1^0} Br\left(D_1^0 \to D^{*+}\pi^-\right)} < 0.16$$

$= 0.49 \pm 0.18 \pm 0.10$ (DELPHI)

includes both bb and cc production

Discussion

- Conclude: $D^{*\prime}$ continuum production, at 10 GeV, of $D^{*\prime} \rightarrow D^{*+}\pi^{-}\pi^{+}$ is not observed

- While production of $D^{*\prime}$ of could be via $Z^0 \rightarrow b \rightarrow D^{*\prime}$
  - OPAL also sees no $D^{*\prime}$ production in a similar analysis
  - DELPHI's signal is 57% in cc sample

- Also small width inconsistent with theoretical expectation
  - Melikov, Pene
  - Page, HQ symmetry hep–ph/9809575
  - Favor $J^P = 2^-, 3^-$ assignment to observed DELPHI signal

Summary and Conclusions

- Result in B Hadronic Decays
  - First observation of the decay $B^0 \to D^{*+}D^{*-}$
  - Full partial wave analysis $B \to D^*\rho^+$
    - First evidence for FSI in B decays
  - Full partial wave analysis of $B \to D^{**}\pi^-$
    - First observation of $B^- \to D_1(j{=}1/2)^0\pi^-$ and $B^- \to D_2^*(2460)^0\pi^-$
- Result in Charm Hadronic Decays
  - First observation of the $D_1(j{=}1/2)^0$

    $M_{D_1^0(j=\frac{1}{2})} = 2.461^{+0.041}_{-0.034} \pm 0.010 \pm 0.032$ GeV, $\Gamma_{D_1^0(j=\frac{1}{2})} = 290^{+101}_{-79} \pm 26 \pm 36$ MeV
  - New measurement of the $\Gamma(D^0 \to K^+\pi^-)/\Gamma(D^0 \to K^-\pi^+)$ underway
    - Large increase in statistics over previous measurements
    - Time dependent measurement with CLEOII/SVX
  - DELPHI's 1st radial excitation of the charmed meson not confirmed