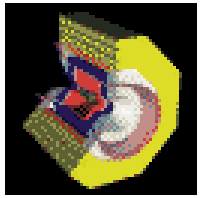
Branching Ratios and Angular Distribution of $B \to D^* \rho$ Decays

István Dankó

Rensselaer Polytechnic Institute

(CLEO Collaboration)

CESR



CLEO

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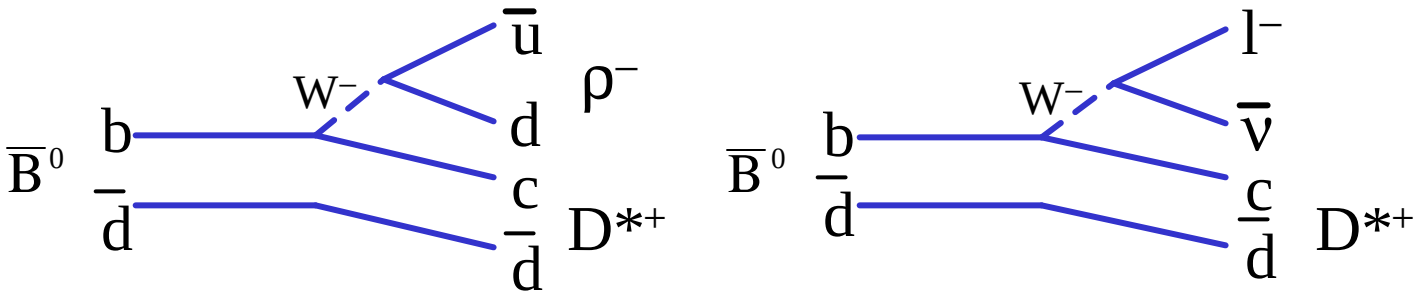
Outline

- Motivation
- CLEO detector and data
- Event Selection
- Maximum Likelihood Fit
- Results:
  - Branching Fractions
  - Helicity Amplitudes
- Conclusion

EPS Abstract: 119
CLEO Collaboration, S. E. Csorna *et al*., Phys. Rev. D. **67**, 112002 (2003)

Motivation

- Hadronic decays are complicated by final-state interactions.
- Factorization hypothesis (FH): the products of two-body B meson decays hadronize independently.
- The validity of the FH has to be tested experimentally.
- If FH is valid then certain 2-body hadronic decays are analogous to similar semileptonic decays:



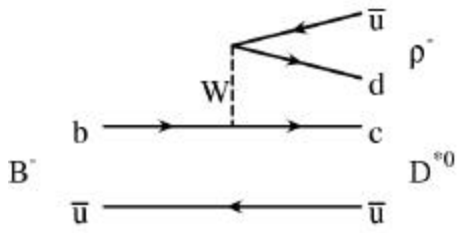
- Experimental tests:
  - Comparing decay rates,
  - Comparing the polarization of the $B^0 \to D^{*+}\rho^-$ decay to that of the $B^0 \to D^{*+}l^-\nu$ decay at the same momentum transfer ($q^2=M_\rho{}^2=M_{l\nu}{}^2$).

J. Körner and G. Goldstein, Phys. Lett **89B**, 105 (1979)

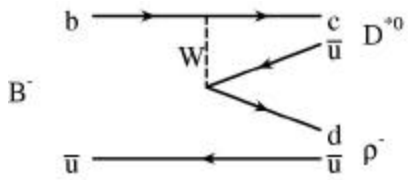
$B \to D^{*}\rho$ Decay

$$B^{-} \to D^{*0} r^{-}$$

- Color-enhanced diagram (a_1)
- Color-suppressed diagram (a_2)



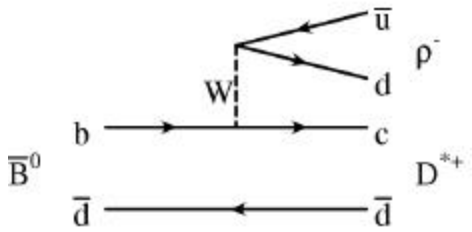
Color-allowed



Color-suppressed

$$\overline{B}^{0} \to D^{*+} r^{-}$$

- Color-enhanced diagram (a_1)



Color-allowed

Relative effective coupling strength in BSW model:

$$\frac{Br(B^{-} \to D^{*0} r^{-})}{Br(\overline{B}^{0} \to D^{*+} r^{-})} \approx (1 + 0.75 a_2 / a_1)^2$$

M. Bauer, B. Stech, and M. Wirbel, Z. Phys. C **34**, 103 (1987)

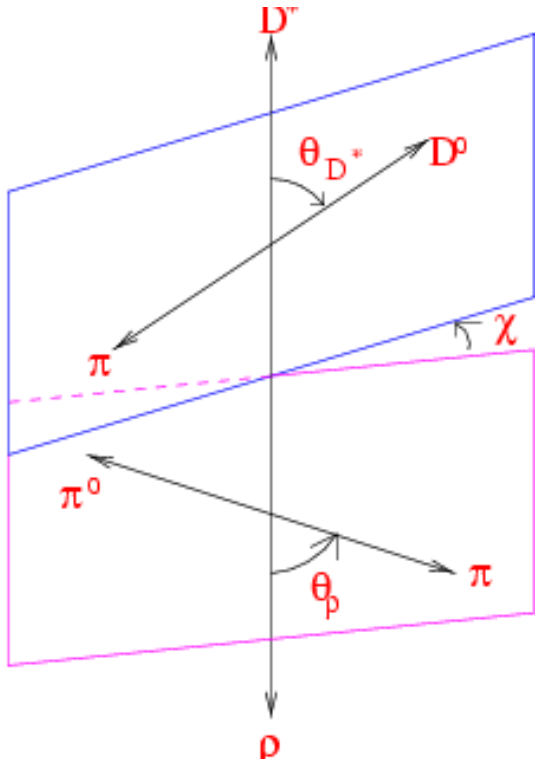
B → D*ρ : Angular Distribution

- Three possible helicity final states (P → VV decay):

$$|0,0\rangle \sim \frac{3}{2\sqrt{2p}}\cos q_{D^*}\cos q_r$$

$$|1,1\rangle \sim \frac{3}{4\sqrt{2p}}\sin q_{D^*}\sin q_r e^{ic}$$

$$|-1,-1\rangle \sim \frac{3}{4\sqrt{2p}}\sin q_{D^*}\sin q_r e^{-ic}$$



- Angular distribution is described by the coherent sum of the three helicity states:

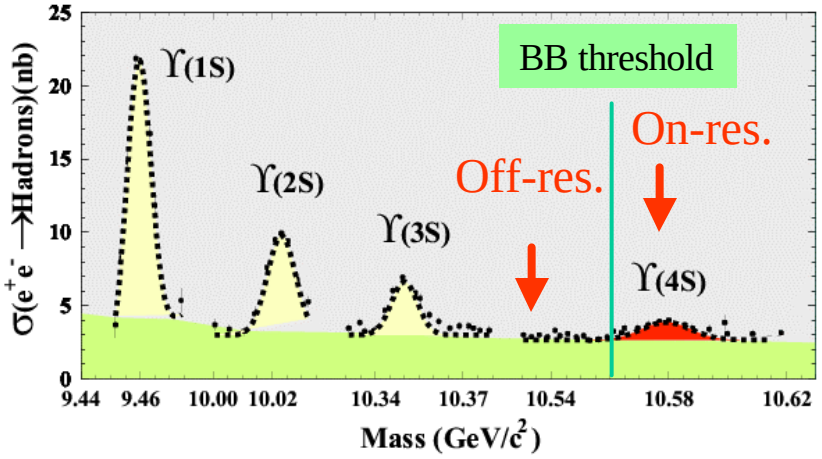
$$\frac{d^3\Gamma}{d\cos q_{D^*} d\cos q_r dc} = \left|H_0|0,0\rangle + H_+|1,1\rangle + H_-|-1,-1\rangle\right|^2 = A(q_{D^*}, q_r, c)$$

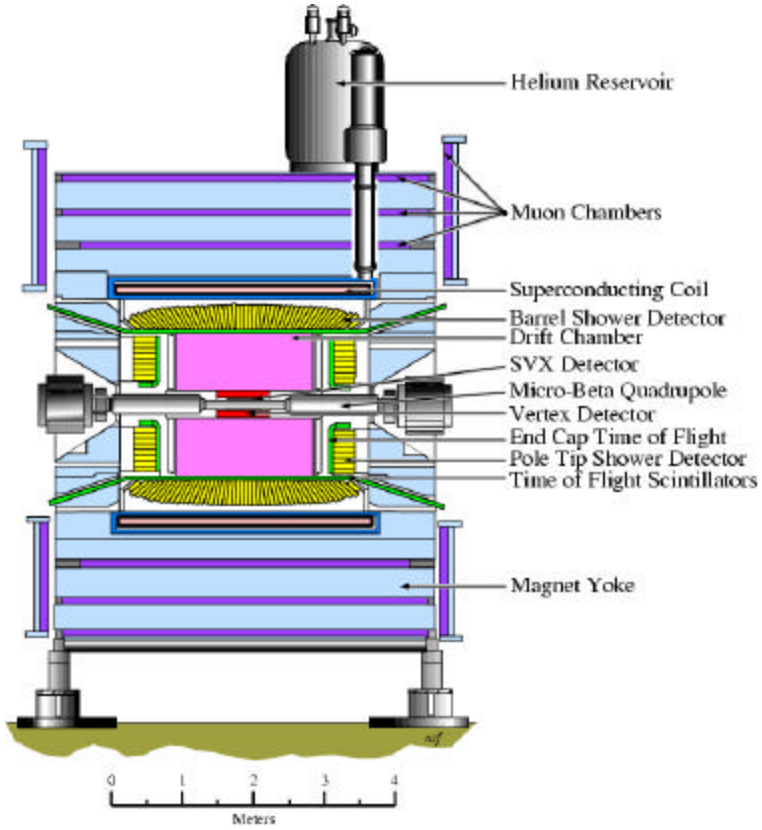
H_0, H_+, H_- : complex helicity amplitudes ($H=|H|e^{i\alpha}$)

- Previous CLEO measurements:
  - Phys. Rev. D **50**, 43 (1994): 0.89 fb^{-1} data, ($\cos\theta_{D^*}$,$\cos\theta_\rho$)
  - CLEO CONF 98: 3.1 fb^{-1} data, ($\cos\theta_{D^*}$,$\cos\theta_\rho$, χ)

CLEO detector and data sample

- The data were collected by the CLEO II/II.V detector at the Cornell Electron Storage Ring (CESR).
- CLEO II:
  - Tracking Chambers (1.5T B, 95% 4π),
  - TOF,
  - CsI EM Calorimeter (98% 4π),
  - Muon detectors (85% 4π)
- CLEO II.V:
  - Si Vertex Detector,
  - He-Propane DR gas.





9.1 fb^{-1} $e^+e^- \to \Upsilon(4S) \to B\overline{B}$

(9.7 million BB pairs)

4.6 fb^{-1} $e^+e^- \to q\overline{q}$ $(q = u, d, c, s)$

to study background

Event reconstruction and selection criteria

$$B^- \to D^{*0} r^- \quad (D^{*0} \to D^0 p^0 (62\%)) \qquad \bar{B}^0 \to D^{*+} r^- \quad (D^{*+} \to D^0 p^+ (68\%))$$

$$D^0 \to \begin{cases} K^- p^+ & (3.8\%) \\ K^- p^+ p^0 & (13\%) \\ K^- p^+ p^- p^+ & (7.5\%) \end{cases} \qquad r^- \to p^- p^0 \qquad p^0 \to gg$$

- Charge track selection:
  - If p > 250 MeV:
    - Originate from interaction point and well measured
    - dE/dx consistent with K or π hypothesis within 2.5σ
    - No lepton
  - If p < 250 MeV (from D* and D^0)
    - Only loose requirement of consistency with originating from interaction point
- π^0 selection:
  - Photon pair in barrel calorimeter
  - E_γ > 30-65 MeV (mode dependent)
  - $| M_{\gamma\gamma} - M_{\pi 0} | < 2.5\sigma$
- D^0 selection:
  - $| M_{K(n\pi)} - M_{D0} | < 2.5\sigma$
  - $D^0 \to K^-\pi^+\pi^0$: densely populated region of the Dalitz plot
- D^{*0} and D^{*+} selection:
  - $| \Delta M - \Delta M_{PDG} | < 2.5\sigma$
    ($\Delta M = M_{D^*} - M_{D0}$)
- ρ^- selection:
  - $| M_{\pi\pi} - M_\rho | < 150$ MeV/c^2
- B selection:
  - $\left| \sum E_i - E_{beam} \right| < 2.5 s_{\Delta E}$
- Background suppression:
  - Fox-Wolfram moment $R_2 < 0.5$
  - $| \cos \theta_S | < 0.7\text{-}0.9$
  - $| \cos \theta_B | < 0.95$

Maximum Likelihood Fit

$$\prod_{j=1}^{3}\frac{e^{-n_j}n_j^{n_j}}{n_j!}\prod_{i=1}^{n_j}\frac{n_j^S P_{ji}^S\left(M,m,\cos\theta_{D^*},\cos\theta_r,c\right)+n_j^B P_{ji}^B\left(M,m,\cos\theta_{D^*},\cos\theta_r,c\right)}{n_j^S+n_j^B}$$

- Unbinned maximum likelihood fit:
  - $\nu_j = n_j^S + n_j^B$ number of signal and background events in the j^{th} D^0 decay mode,
  - Probability density function (pdf):

$$P(M,m,\cos\theta_{D^*},\cos\theta_r,c) = M_B(M)M_r(m)A(\cos\theta_{D^*},\cos\theta_r,c)$$

Signal pdf:
M_B: Gaussian distribution for $M=\sqrt{E_{beam}^2-p_B^2}$
M_ρ: Breit-Wigner with Blatt-Weiskopf form-factor
A: angular distribution corrected by detector acceptance

Background pdf:
M_B: ARGUS-type function
M_ρ: flat distribution
A : 2nd order polynomials in $\cos\theta_{D^*}$ and $\cos\theta_\rho$, 1st order polynomial of $\cos(\chi+\chi_0)$)

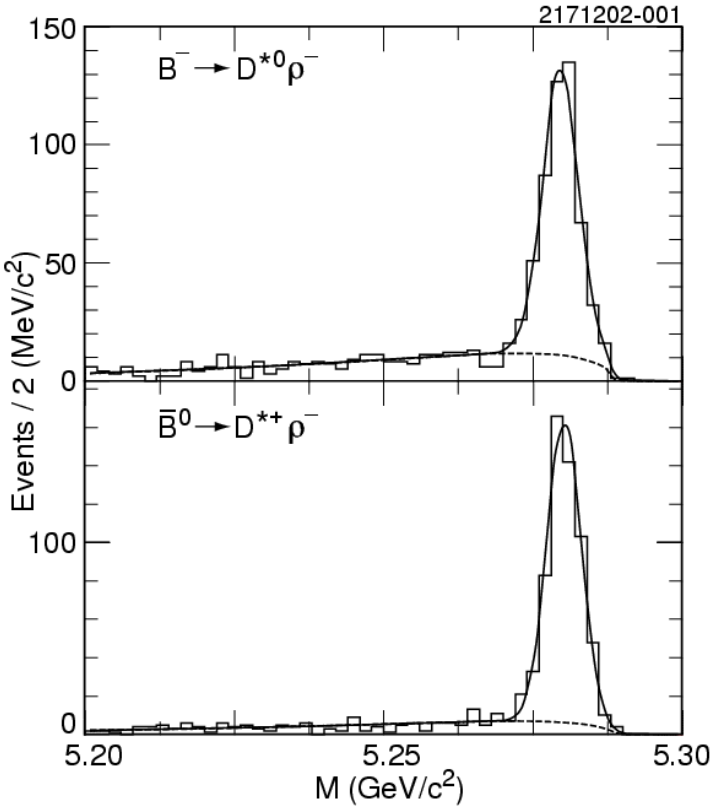
- Two-step fit:
  - For signal and background and mass distribution parameters (no angular part);
  - For helicity amplitudes (signal, background and mass parameters are fixed).

Branching Ratio

- To extract number of signal and background events: maximum likelihood fit to all events with $5.2 < M_B < 5.3$ GeV/c^2 (angular distribution ignored)

$$Br(B^- \to D^{*0}\, r^-) = (0.98 \pm 0.06 \pm 0.16 \pm 0.05)\%$$

$$Br(\overline{B}^0 \to D^{*+}\, r^-) = (0.68 \pm 0.03 \pm 0.09 \pm 0.02)\%$$



1st Syst. Error

2nd Syst. Error

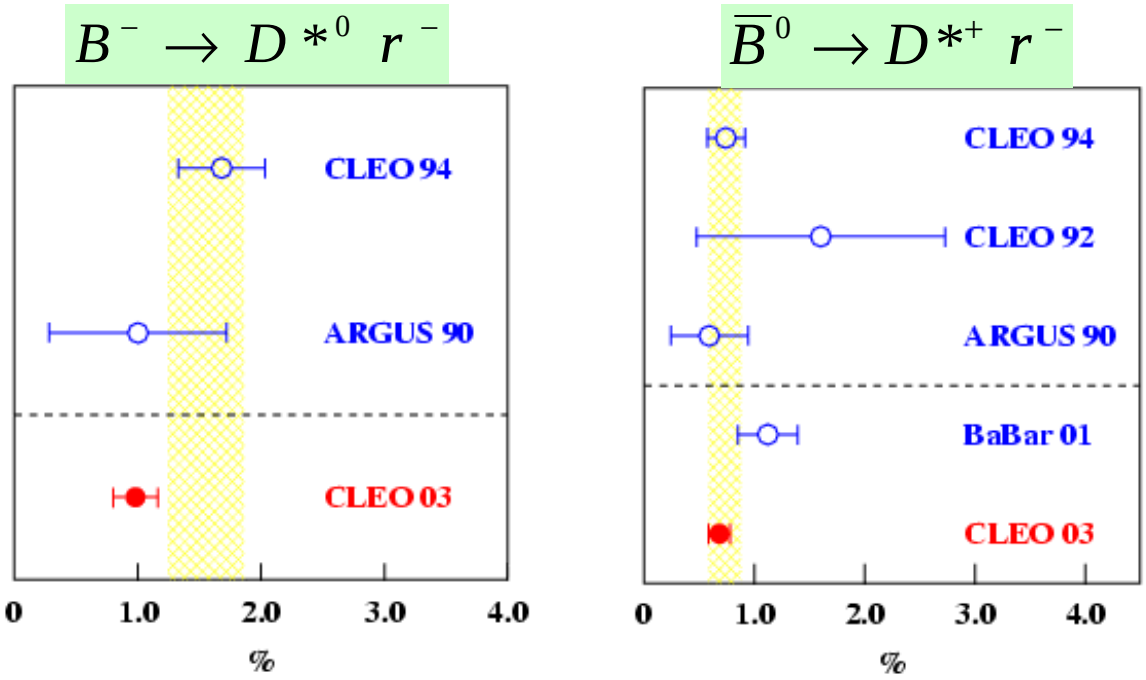
- δN_{BB} ~ 2%
- background shape ~ 3%
- efficiency ~ 10 – 18%

- D* and D^0 Br ratio error

	D^0 decay mode, j	n_j^S	ε (%)
B^-	$K^-\pi^+$	148.9±13.8	6.56±0.04
	$K^-\pi^+\pi^0$	177.4±16.6	2.20±0.02
	$K^-\pi^+\pi^-\pi^+$	136.0±15.2	3.04±0.03
B^0	$K^-\pi^+$	196.3±14.6	10.88±0.05
	$K^-\pi^+\pi^0$	196.1±16.4	3.67±0.03
	$K^-\pi^+\pi^-\pi^+$	170.6±13.9	4.46±0.03

Branching Ratio

- Comparison with previous results:



- BSW effective couplings:

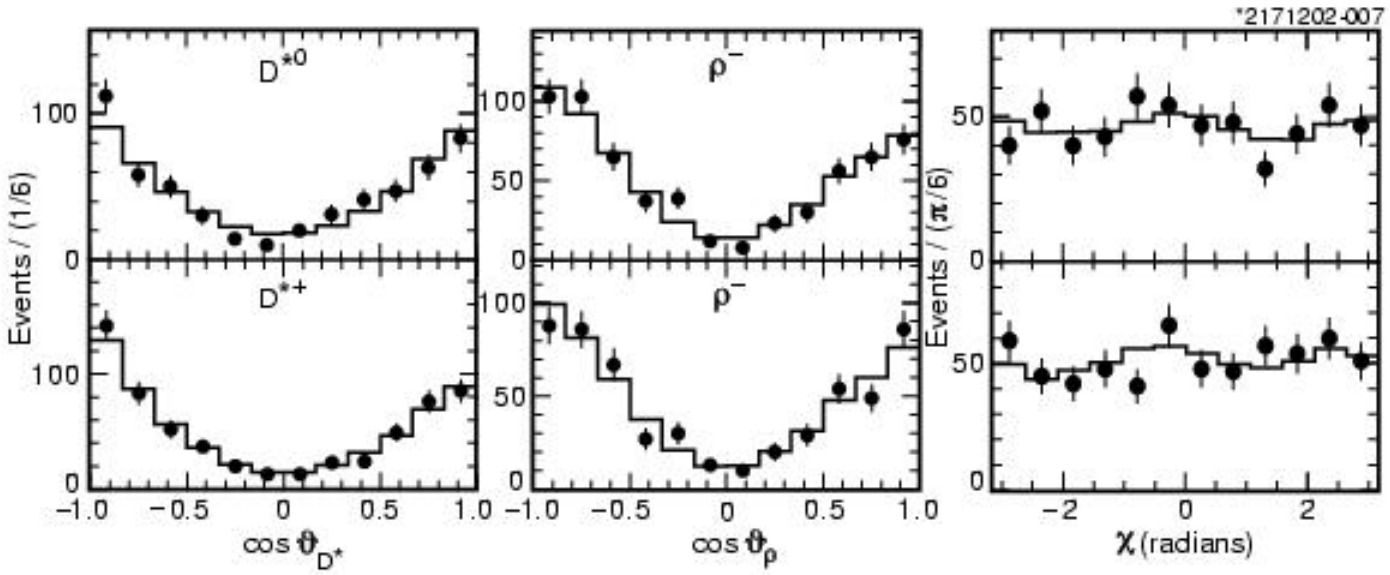
$$\frac{Br(B^- \to D^{*0} r^-)}{Br(\bar{B}^0 \to D^{*+} r^-)} \approx (1 + 0.75 a_2 / a_1)^2$$

$$a_2 / a_1 = 0.21 \pm 0.03 \pm 0.05 \pm 0.04 \pm 0.04$$

3rd syst. error is from f_{+-}/f_{00}=1.072±0.045±0.027±0.024 (PDG 02)

Helicity Amplitudes

- Maximum likelihood fit including events with $5.27 < M < 5.30$ GeV/c^2 only:
  - n_j^S , n_j^B (scaled) and mass distribution parameters are fixed,
  - helicity parameters ($|H_+|$, $|H_-|$, α_+-α_0, α_--α_0) are allowed to float in the fit ($|H_0|^2+|H_+|^2+|H_-|^2=1$, and $\alpha_0=0$),
- Detector acceptance depends on the polarization (angular distribution) due to detector smearing $\Rightarrow$ needs iteration until helicity amplitudes converge.



Helicity Amplitudes

- Helicity amplitudes ($H=|H|e^{i\alpha}$) $\quad |H_0|^2+|H_+|^2+|H_-|^2=1$

	$B^- \to D^{*0}\rho^-$	$B^0 \to D^{*+}\rho^-$
$\lvert H_0\rvert$	0.944±0.009±0.009	0.941±0.009±0.006
$\lvert H_+\rvert$	0.122±0.040±0.010	0.107±0.031±0.011
α_+	1.02±0.28±0.11	1.42±0.27±0.04
$\lvert H_-\rvert$	0.306±0.030±0.025	0.322±0.025±0.016
α_-	0.65±0.16±0.06	0.31±0.12±0.04

- Systematic uncertainties:
  - Acceptance parametrization
  - Detector smearing
  - Background level/shape (dominant)
  - Non-resonant $\pi^-\pi^0$ contribution
  - Polarization dependence on $m_{\pi\pi}$

- Non-trivial helicity amplitude phases (α_+ , α_-)

  Significance:

$$B^- \to D^{*0}\, r^- : 3.19\,s$$
$$\overline{B}^0 \to D^{*+}\, r^- : 2.75\,s$$

  - Indication of FSI
  - Important for direct CPV in B decay

Longitudinal Polarization

- Longitudinal polarization:

$$\frac{\Gamma_L}{\Gamma} = \frac{|H_0|^2}{|H_0|^2 + |H_+|^2 + |H_-|^2}$$

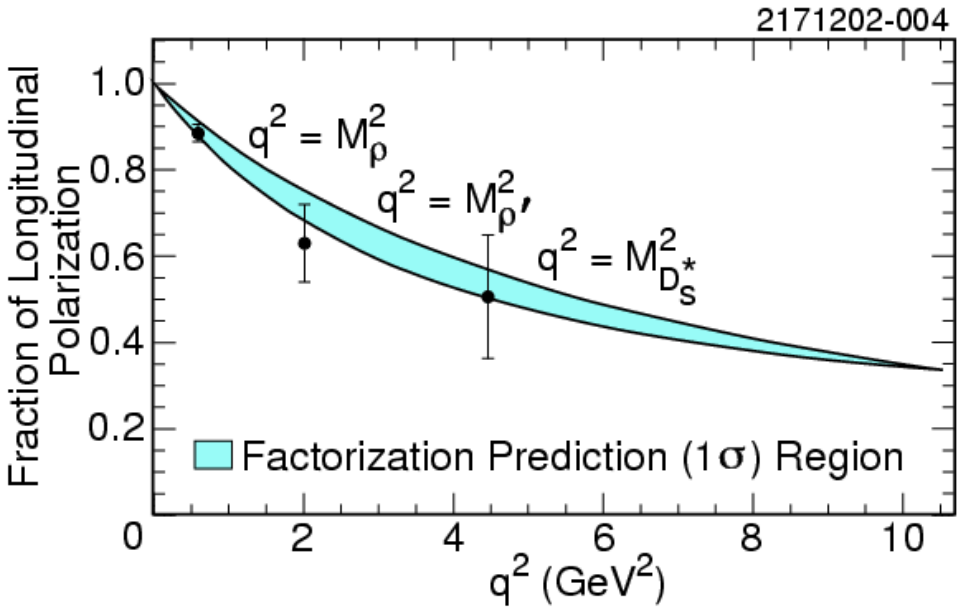
$$\frac{\Gamma_L}{\Gamma}\left(\overline{B}^0 \to D^{*+} r^-\right) = 0.885 \pm 0.016 \pm 0.012$$

$$\frac{\Gamma_L}{\Gamma}\left(B^- \to D^{*0} r^-\right) = 0.892 \pm 0.018 \pm 0.016$$

- Previous CLEO measurements of long. polarization in $B^0 \to D^{*+}\rho^-$:

$$\frac{\Gamma_L}{\Gamma} = 0.93 \pm 0.05 \pm 0.05 \qquad (1994)$$

$$\frac{\Gamma_L}{\Gamma} = 0.878 \pm 0.034 \pm 0.030 \qquad (1998)$$



- HQET with factorization:

$$\frac{\Gamma_L}{\Gamma}\left(\overline{B}^0 \to D^{*+} r^-\right) = 0.895 \pm 0.019$$

Consistent with measurement!

$B^0 \to D^{*+}\rho'^-$: CLEO Coll., PRD 64, 092001 (2001); $B^0 \to D^{*+}D_S^{*-}$: CLEO Coll., PRD 62, 112003 (2000)

Conclusion

- CLEO has measured the branching ratio and helicity amplitudes of the decays $B^- \to D^{*0}\rho^-$ and $B^0 \to D^{*+}\rho^-$.
- Calculated the the ratio of effective coupling constants a_2/a_1 and the degree of longitudinal polarization.
- The fraction of longitudinal polarization for $B^0 \to D^{*+}\rho^-$ decay confirms the validity of the factorization hypothesis at relatively low q^2:

$$\frac{\Gamma_L}{\Gamma}(\overline{B}^0 \to D^{*+}\, r^-) = \frac{\Gamma_L}{\Gamma}(\overline{B}^0 \to D^{*+}\, \ell^- \overline{n}^-)\Big|_{q^2 = M_r^2}$$

- Measurement of the helicity amplitudes indicates a strong possibility of non-trivial helicity amplitude phases which would arise from final-state interactions (indication of FSI has been reported in $B \to J/\psi K^*$ by CDF (PRL 85, 4668 (2000) and $B \to D\pi$ by CLEO (PRL 88, 062001 (2002))

- CLEO Collaboration, Phys. Rev. D **67**, 112002 (2003)