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FCP 01 Vanderbilt, Heavy Flavors II

Results on Semileptonic and Rare *b* Decays From DELPHI

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1. Extraction of V_{cb} from $\bar{B}^0 \rightarrow D^{*+} l^- \bar{\nu}$
2. Semileptonic b branching fraction
3. Charm counting

Extracting of V_{cb}

Analysis Summary

[CERN-EP/2001-002]

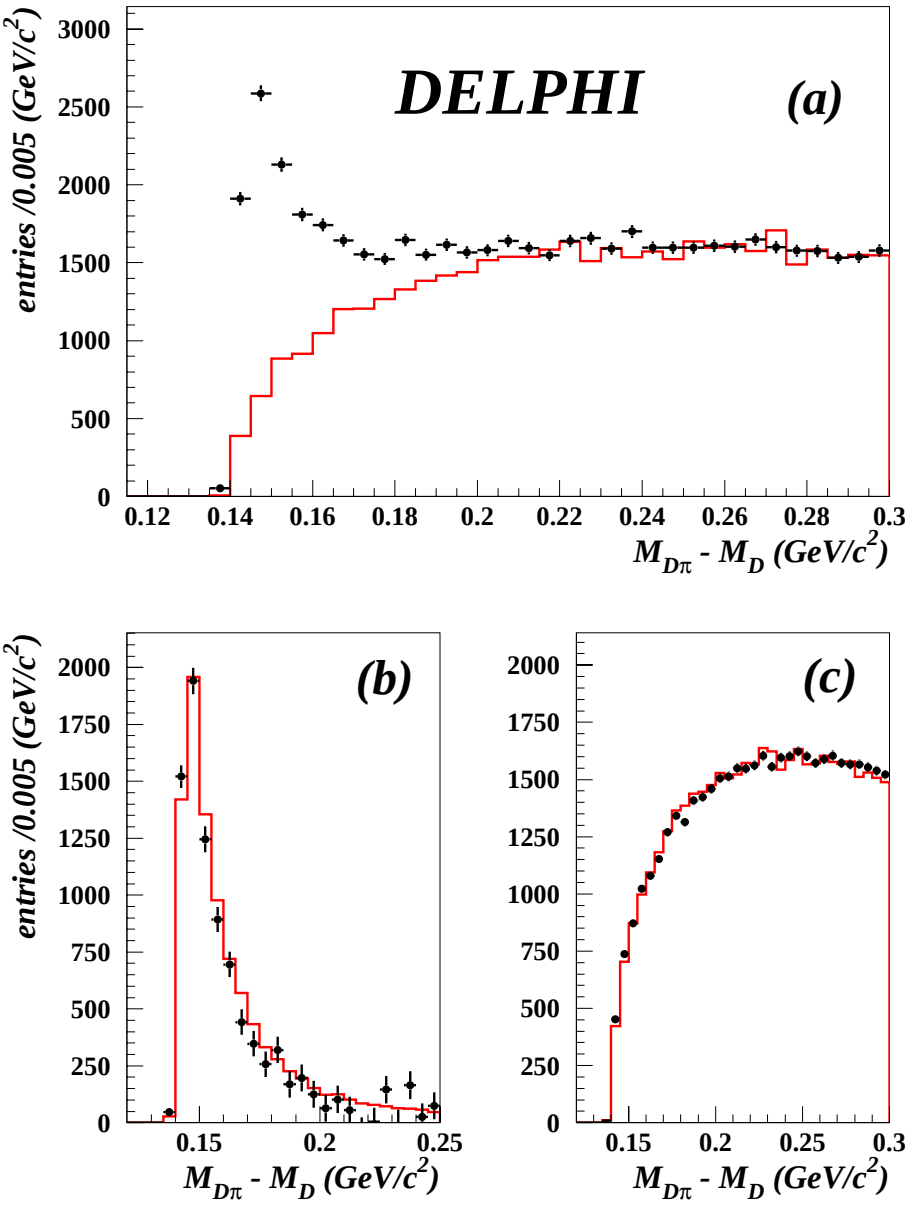
- DELPHI 1992 to 1995 data
- Select hadronic events with one identified e/μ ($p_t > 1$ GeV/c)
- Inclusive reconstruction of D^0 based on decay length significance and rapidity
- Search for soft pion π^* and identification of D^{*+} according to $\Delta m = m(D^0\pi^*) - m(D^0)$
- Reconstruction of event kinematics, b direction from 3-momentum conservation and vector joining vertices
- Determine recoil variable w

$$w = v_{\bar{B}^0_d} \cdot v_{D^{*+}} = (m^2_{\bar{B}^0_d} + m^2_{D^{*+}} - q^2)/(2m_{\bar{B}^0_d} m_{D^{*+}})$$

  Utilize squared mass $\mu^2 = m^2_\nu$ recoiling against $D^{*+}l$ system to reject D^{**} ($\mu^2 < 2$ GeV$^2/c^4$) and improve w resolution ($\mu^2 = 0$)

- Extrapolate $\mathrm{d}N/\mathrm{d}w$ at zero recoil

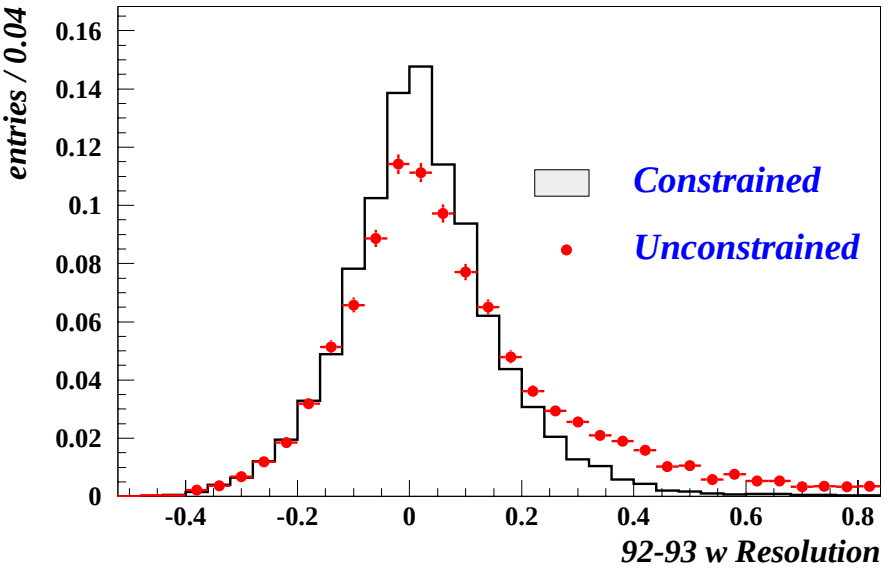
Inclusive D^{*+}

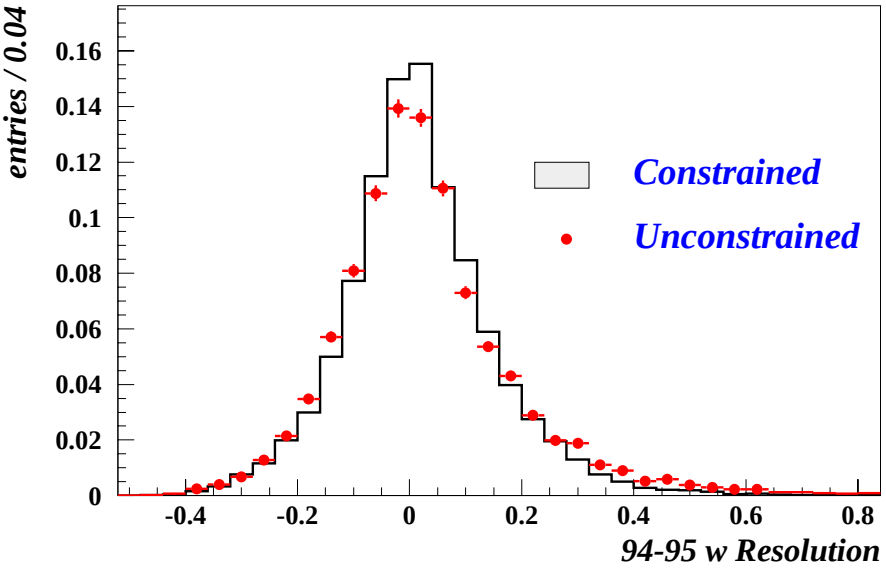


10,232 D^{*+} candidates within $\Delta m < 0.165$

(Signal 4666±130, Comb. bkgrd. 3737±70, D^{**} 1469±10)

w Resolution





$$\sigma(w) = 0.125$$

Determination of $|V_{cb}|$ (1)

- Extrapolation $\mathrm{d}N/\mathrm{d}w$ to zero recoil ($w = 1$)

$$\frac{d\Gamma(\bar{B} \to D^{*+} l^- \nu)}{dw} = \frac{G_F^2}{48\pi^3}(m_B - m_{D^*})^2 m_{D^*}^3 \sqrt{w^2-1}(w+1)^2 \times \left(1 + \frac{4w}{w+1}\frac{m_B^2 - 2w m_B m_{D^*} + m_{D^*}^2}{(m_B - m_{D^*})^2}\right)|V_{cb}|^2 \mathcal{F}^2(w)\,.$$

$$\mathcal{A}_1(w) = \mathcal{A}_1(1)[1 - 8\rho^2_{\mathcal{A}_1} z(w) + + (53\rho^2_{\mathcal{A}_1} - 15)z(w)^2 - (231\rho^2_{\mathcal{A}_1} - 91)z(w)^3]$$

[I. Caprini et al., NPB 530 (1998) 153]

- Minimum χ^2 fit

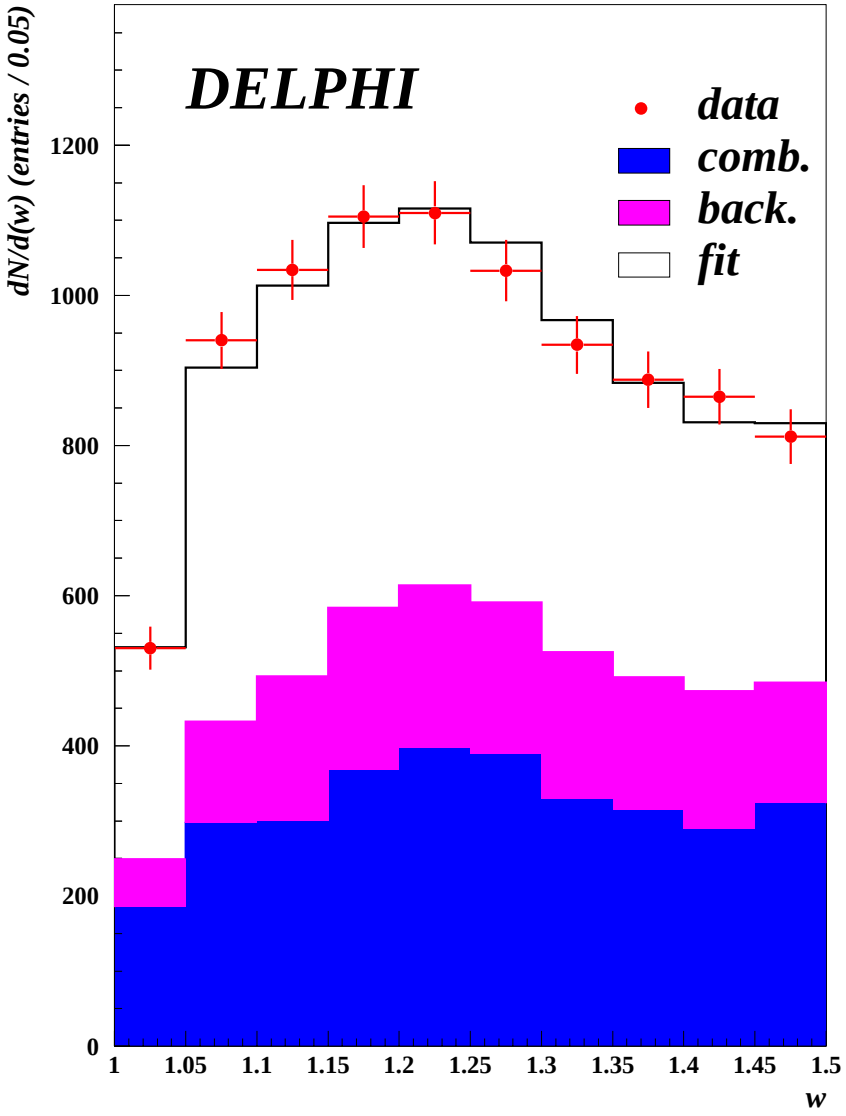
$$\begin{aligned} \mathcal{A}_1(1)|V_{cb}| &= (35.5 \pm 1.4) \times 10^{-3} \\ \rho^2_{\mathcal{A}_1} &= 1.34 \pm 0.14 \\ \mathcal{B}(\bar{B}^0 \to D^{*+} l^- \bar{\nu}_l) &= (4.70 \pm 0.12)\% \end{aligned}$$

- $\mathcal{A}_1(1) \approx \mathcal{F}(1) = 0.91 \pm 0.03$

$$|V_{cb}| = (39.0 \pm 1.5(stat)^{+2.5}_{-2.6}(syst.\,exp.) \pm 1.3(syst.\,th.)) \times 10^{-3}$$

Results agree with world average

Determination of $|V_{cb}|$ (2)



Semileptonic b branching fraction

Analysis Summary

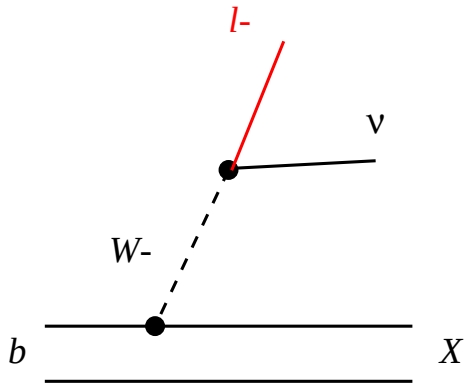
[DELPHI Paper #259]

- 1994 and 1995 data used, corresponding to 1,030,000 and 515,000 hadronic Z decays (Analysis III also uses 1992 and 1993 data)
- $Z \rightarrow b\bar{b}$ decays tagged by using the impact parameter information
- $\mathcal{B}(b \rightarrow l^{-}\bar{\nu}X)$ extracted by four different analyses
  - I: Single lepton + di-lepton fit
  - II: Single lepton + charge correlation fit
  - III: Muon multitag fit
  - IV: Inclusive reconstructed b + charge correlation
- Combination of results

Primary and cascade decays

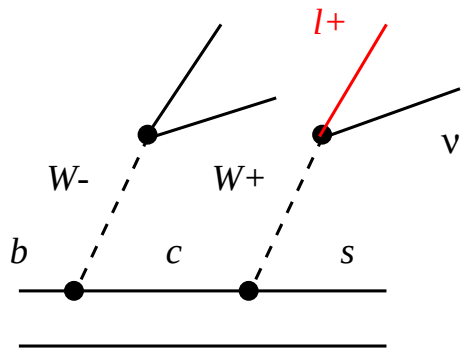
Primary Decay

$b \to l^- \bar{\nu} X$



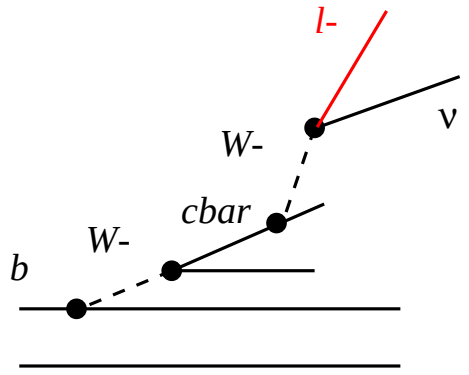
Cascade Decay

$b \to c \to l^+ \nu X$



Cascade Decay

$b \to c \to l^- \bar{\nu} X$



Lepton spectra obtained from ACCMM model

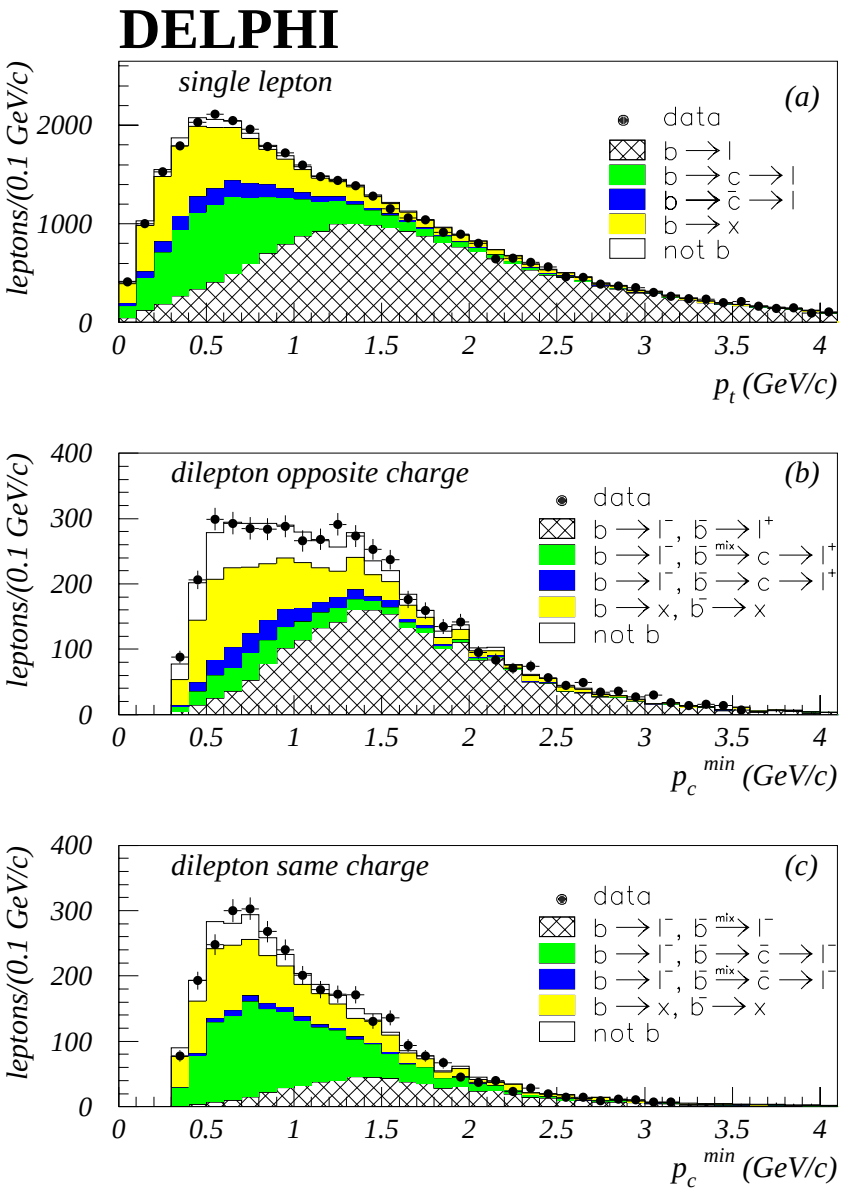
Model systematics by comparing with ISGW and ISGW** model

[Altarelli et al. NPB 208 (1982) 365, Isgur et al. PRD 39 (1989) 799]

Analysis I: Single lepton + di-lepton fit (1)

- Single lepton sample
  - Event divided into two hemisphere $\perp$ thrust axis
  - One hemisphere b tagged (purity = 95.1%), identified lepton (muon, electron) with $p > 3$ GeV in opposite hemisphere
  - Secondary vertex search in lepton hemisphere $\Rightarrow p_t$ relative to PV-SV direction
- Di-lepton sample
  - One identified lepton in each hemisphere
  - No b tag, $p_t > 1.2$ GeV/c for one lepton
  - Events classified into “like sign” and “unlike sign”
- $\mathcal{B}(b \rightarrow l^-)$, $\mathcal{B}(b \rightarrow c \rightarrow l^+)$, $\mathcal{B}(b \rightarrow \bar{c} \rightarrow l^+)$ and $\bar{\chi}$ extracted by a simultaneous fit exploiting kinematics (p, p_t, p_c) and charge correlation

Analysis I: Single lepton + di-lepton fit (2)



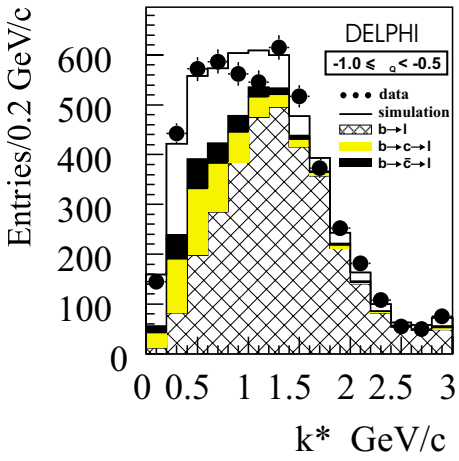
$$p_c = \sqrt{p_t^2 + p^2/100}$$

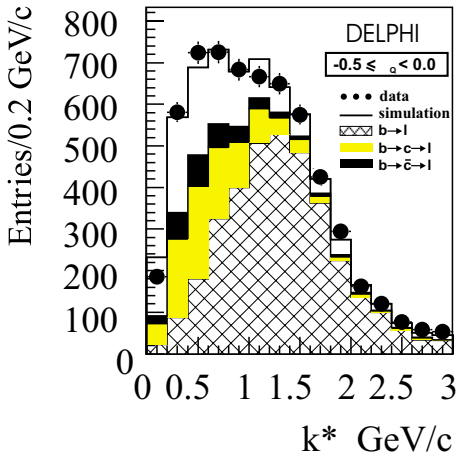
Analysis II: Single lepton + charge correlation (1)

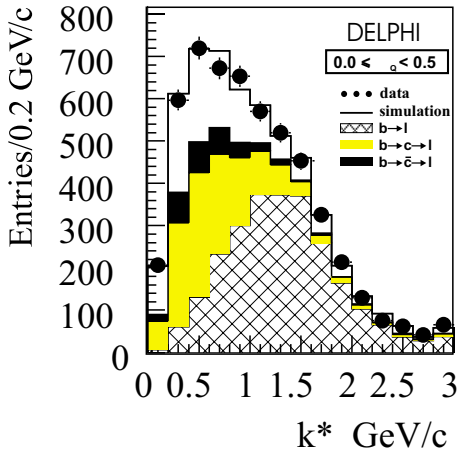
- Identified lepton with $p > 3$ GeV
- b tag in opposite hemisphere (purity = 84.0%)
- Inclusive b vertex reconstructed, b energy determined from particles in b jet in lepton hemisphere $\Rightarrow$ inclusive b four-vector, lepton momentum b rest frame k^* ($\sigma(k^*) \approx 200$ MeV/c)
- b quark charge Q_b determined from inclusive variables (jet charge, vertex charge, charge of kaon or lepton from b decay, charge of leading fragmentation particle) in opposite hemisphere
- Charge correlation $\lambda_Q = Q_l \cdot Q_b$

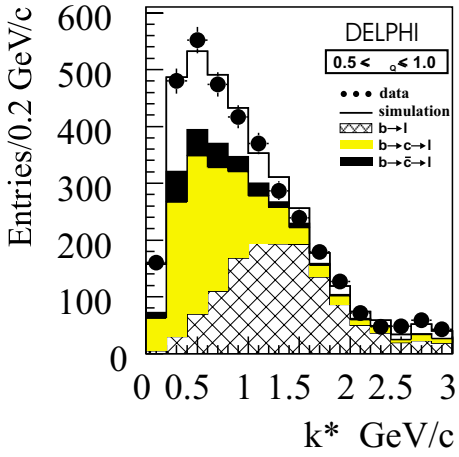
  $\lambda_Q < 0$ ($\lambda_Q > 0$) for direct (cascade) decays
- $\mathcal{B}(b \to l^-)$, $\mathcal{B}(b \to c \to l^+)$ and $\mathcal{B}(b \to \bar{c} \to l^+)$ extracted by a two-dimensional fit to k^* and λ_Q

Analysis II: Single lepton + charge correlation (2)









Analysis III: Muon multitag fit (1)

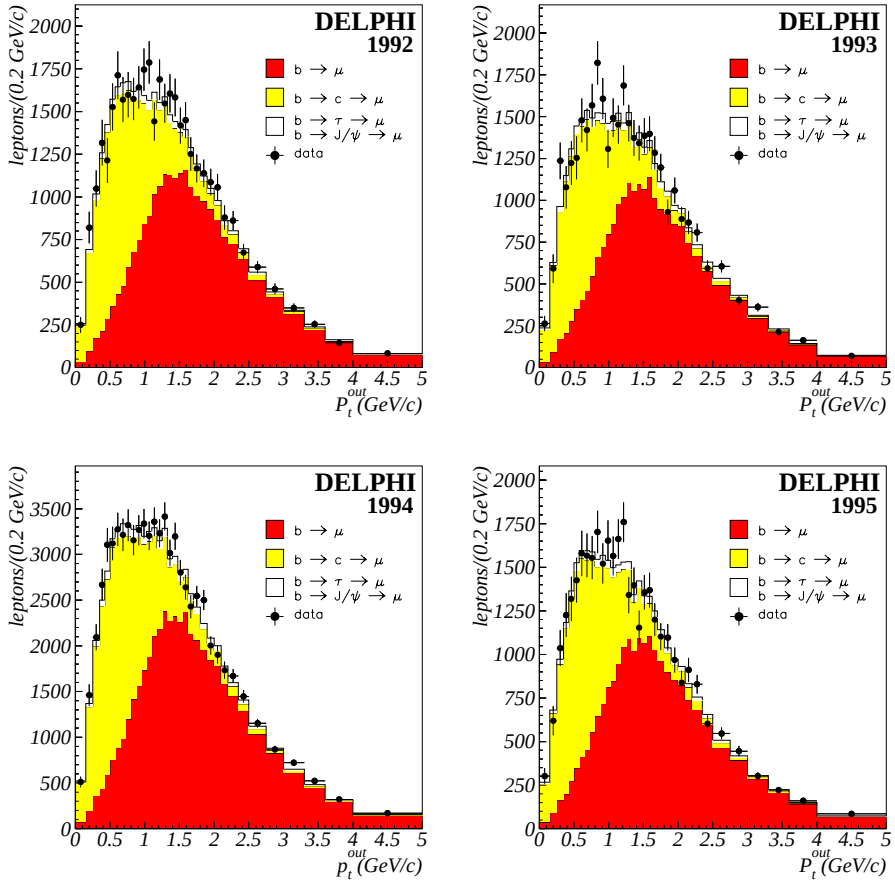
- Identified muons with $p > 3$ GeV/c
- Flavor tagging

  Discriminators (lifetime information, event shape) used to class events into 6 categories: uds loose, uds tight, charm, b loose, b standard and b tight
- Flavor deconvolution

  Muon spectra $D_j^{\mu}(z)$, $j = b, c, uds$ and $z = p, p_t^{in}, p_t^{out}$ extracted from muon spectra in each tagging class $n_I^{\mu}(z)$
- Background extraction

  Similar deconvolution for charged particles, fake muon background extracted from data
- $\mathcal{B}(b \to \mu)$, $\mathcal{B}(b \to c(c) \to \mu)$ extracted by fit to genuine muon distribution $n_b^{g\mu}(z)$

Analysis III: Muon multitag fit (2)



Analysis IV: Inclusive b and charge correlation

- Identified lepton with $p > 3$ GeV/c
- b tagging in opposite hemisphere (purity = 92.6%)
- Estimation of b quark charge in lepton hemisphere
  - Reconstruction of b hadron vertex
  - Identification of tracks coming from b decay vertex based on rapidity, momentum, PV/SV probability
  - b quark charge determined from jet charge, vertex charge, charge of leading fragmentation particle, charge of identified kaon from b decay using a neural network
- Lepton momentum in b rest frame k^*
- $\mathcal{B}(b \to l^-)$, $\mathcal{B}(b \to c \to l^+)$ and $\mathcal{B}(b \to \bar{c} \to l^+)$ extracted by fit to k^* spectra of “like sign” and “unlike sign”

Results

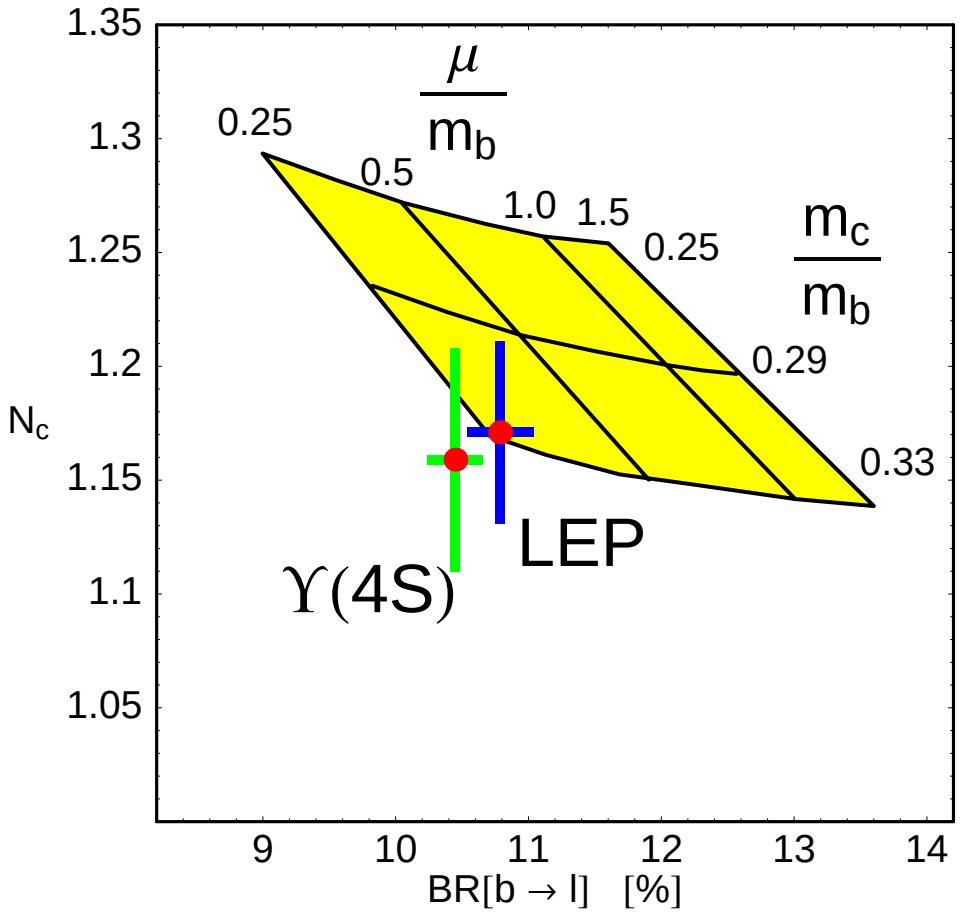
	$\mathcal{B}(b \to l^-)$
Analysis I	$10.75 \pm 0.11 \pm 0.26^{-0.25}_{+0.42}$
Analysis II	$10.78 \pm 0.14 \pm 0.29^{-0.34}_{+0.53}$
Analysis III	$10.69 \pm 0.11 \pm 0.28^{-0.37}_{+0.44}$
Analysis IV	$10.75 \pm 0.15 \pm 0.28^{-0.24}_{+0.43}$

$$\begin{aligned}
\mathcal{B}(b \to l^-) &= (10.73 \pm 0.08(stat) \pm 0.22(syst)^{-0.30}_{+0.44}(model))\% \\
\mathcal{B}(b \to c \to l^+) &= (7.91 \pm 0.20(stat) \pm 0.29(syst)^{+0.14}_{-0.20}(model))\% \\
\mathcal{B}(b \to \bar{c} \to l^+) &= (1.69 \pm 0.18(stat) \pm 0.26(syst)^{+0.30}_{-0.44}(model))\% \\
\bar{\chi} &= 0.127 \pm 0.013(stat) \pm 0.006(syst) \pm 0.004(model)
\end{aligned}$$

- Compatible with the recent results of the semileptonic branching fraction obtained at LEP and with theoretical calculations
- Systematics dominated by model uncertainty

$\mathcal{B}(b \to l^-)$ **vs** n_c

[Neubert and Sachrajda, NPB 483 (1997) 339]



Data points: Summer 2000 combination

Charm counting

Measurement of n_c

- Charm counting

  "the classical analysis", measure the inclusive rates of charmed particles (D^0, D^+, D_s^+, ...) in b decays and add them up

- Inclusive no, single and double charm rate

  e.g. by fitting the impact parameter information (DELPHI)

- Double charm rate (wrong sign charm rate)

$$n_c = 1 + \mathcal{B}(b \to c\bar{c}s) - \mathcal{B}(b \to \text{no charm})$$

Wrong sign D

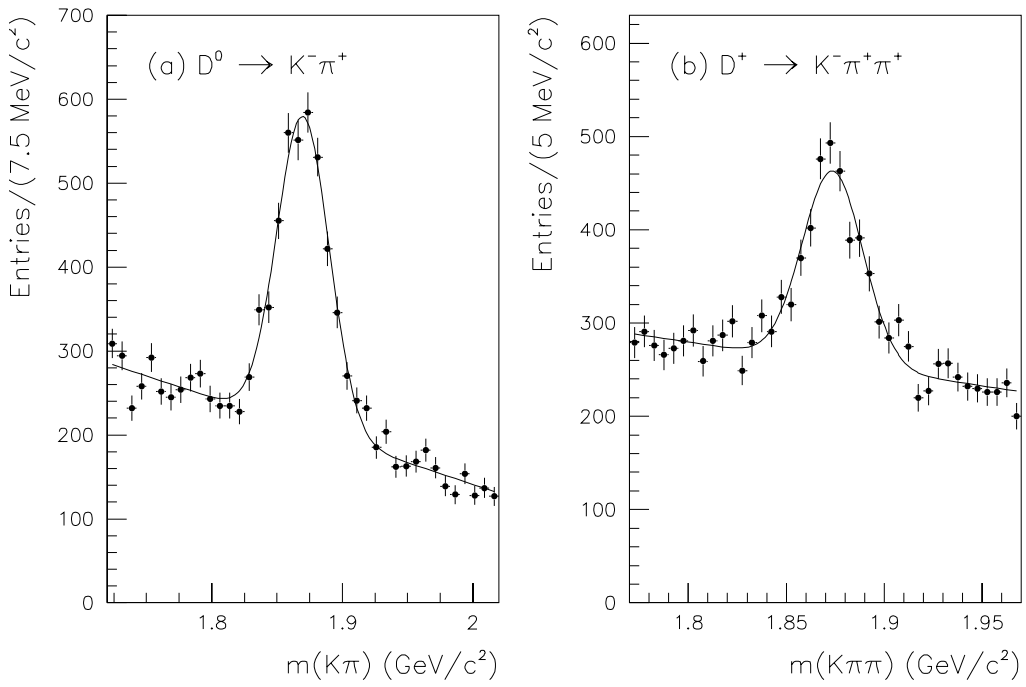
Analysis Summary

- b tagged hadronic Z events (purity = 96%)
- Exclusive D reconstruction
  - D mesons searched for in $D^0 \to K^-\pi^+$ and $D^+ \to K^-\pi^+\pi^+$ by trying all track combinations in a hemisphere
  - D vertex fit
  - D candidates selected by using four discriminant variables (kaon RICH information, $\Delta l/l$, x_E, $\cos\theta_D$)

$$y_D = \frac{k}{1+k}\,, \quad k = \prod_i \frac{s_i(x_i)}{b_i(x_i)}\,.$$

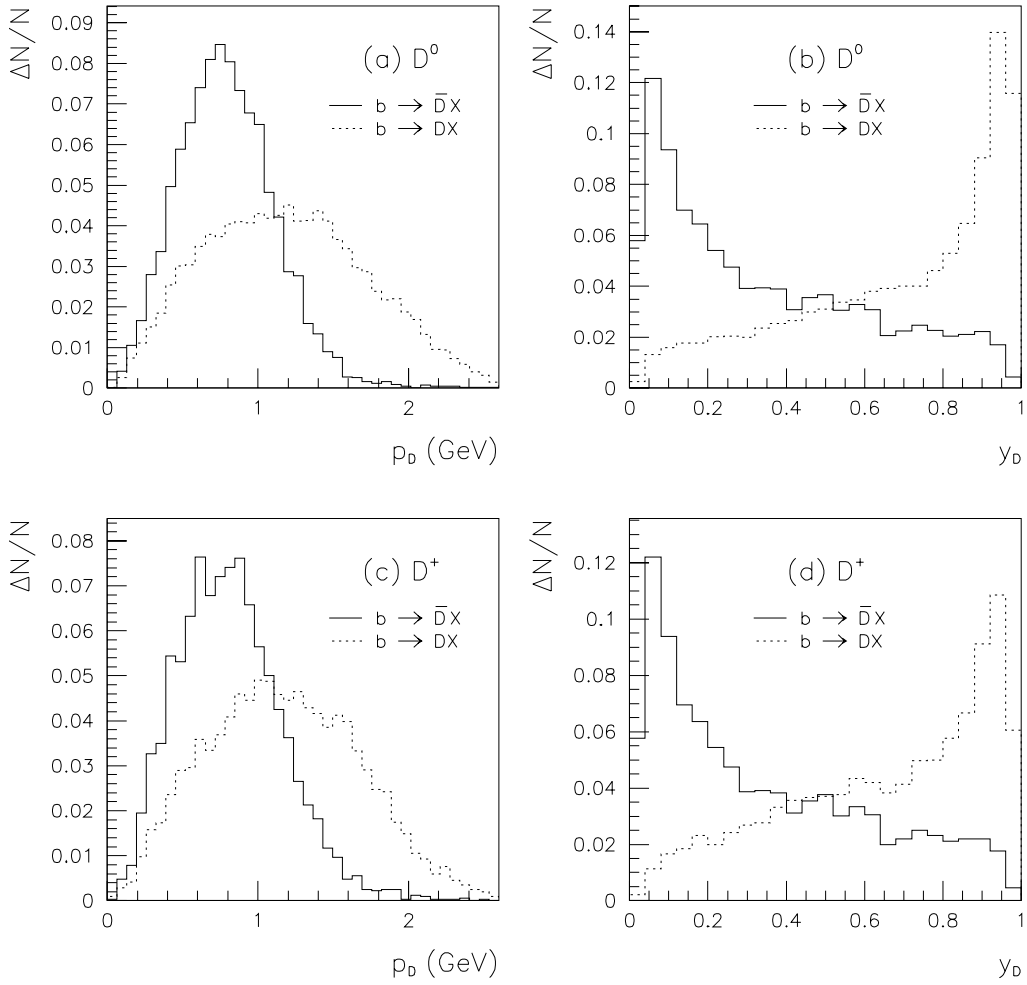
- Two discriminant variables
  - D momentum in b rest frame p_D with inclusively reconstructed b four-vector ($\sigma(p_D) \approx 300$ MeV/c)
  - Neural network tag $y_{\rm ws}$, b decay flavor estimated from charge of identified particles (kaons, protons, electrons and muons)
- $\mathcal{B}(b \to \bar{D}X)$ extracted by two-dimensional binned likelihood fit to p_D and $y_{\rm ws}$

Exclusive D

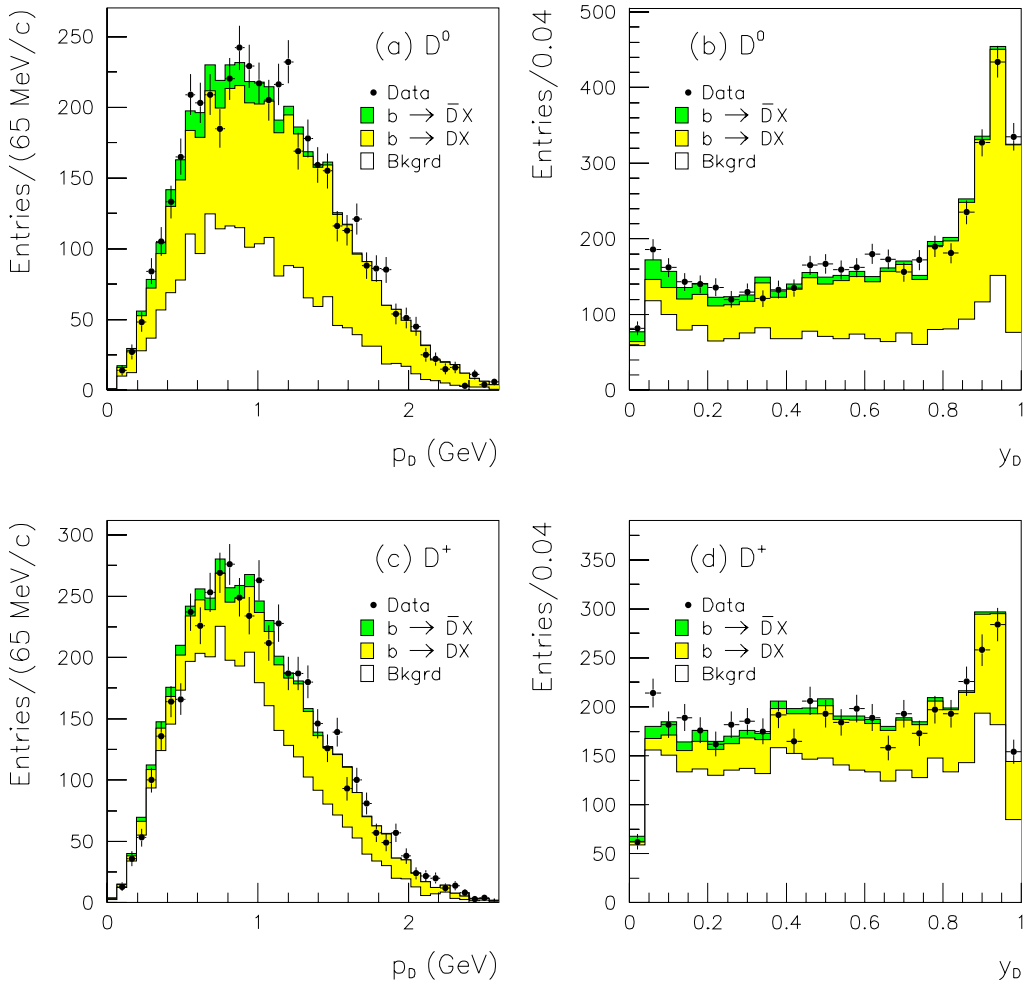


$$y_{D^0} > 0.8, y_{D^+} > 0.6$$

Discriminant variables



Wrong sign fit



$$\mathcal{B}(b \to \bar{D}^0 X) = (6.9 \pm 1.3(stat) \pm 1.1(syst))\%$$
$$\mathcal{B}(b \to D^- X) = (2.6 \pm 1.3(stat) \pm 1.1(syst))\%$$
$$\mathcal{B}(B \to DX) = (9.4 \pm 1.8(stat) \pm 1.5(syst))\%$$

(preliminary result)

Conclusion

- Extracting of V_{cb}

$$|V_{cb}| = (39.0 \pm 1.5(stat)^{+2.5}_{-2.6}(syst.\ exp.) \pm 1.3(syst.\ th.)) \times 10^{-3}$$

- Semileptonic b branching fraction

$$\begin{aligned}
\mathcal{B}(b \to l^-) &= (10.73 \pm 0.08(stat) \pm 0.22(syst)^{-0.30}_{+0.44}(model))\% \\
\mathcal{B}(b \to c \to l^+) &= (7.91 \pm 0.20(stat) \pm 0.29(syst)^{+0.14}_{-0.20}(model))\% \\
\mathcal{B}(b \to \bar{c} \to l^+) &= (1.69 \pm 0.18(stat) \pm 0.26(syst)^{+0.30}_{-0.44}(model))\% \\
\bar{\chi} &= 0.127 \pm 0.013(stat) \pm 0.006(syst) \pm 0.004(model)
\end{aligned}$$