Charm Counting in b-Hadron Decays

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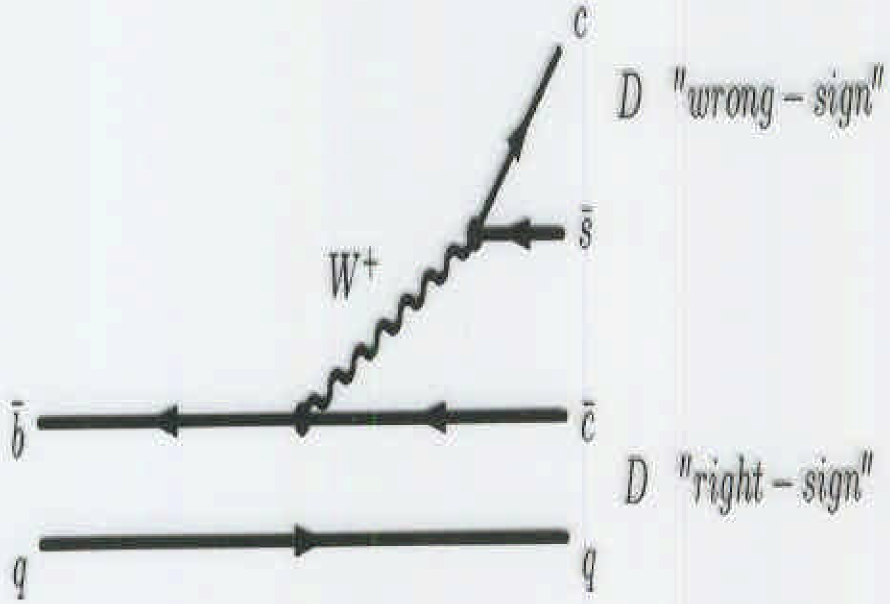
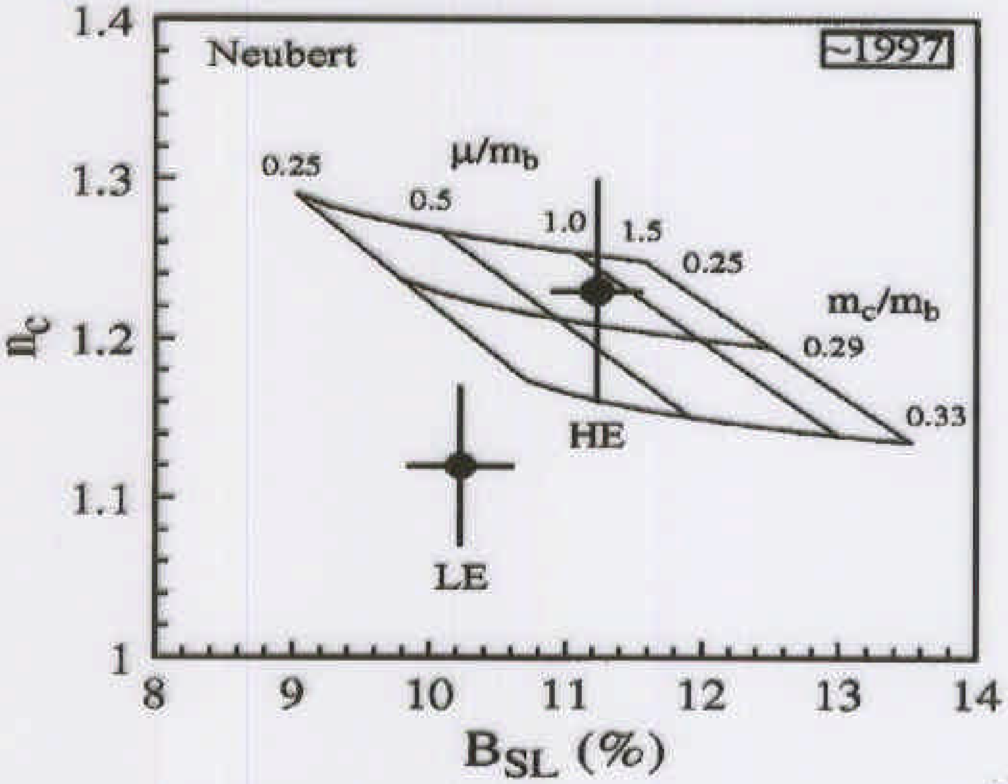


Motivation

$n_c (= n_c + n_{\bar{c}})$ is the average number of charm quarks per b-quark decay



- Circa 1997 there were two main puzzles:
  - Why were low energy BR_{SL} measurements so much lower than high energy? (subsequent LEP analyses are compatible)
  - Why were low energy BR_{SL} measurements so much lower than theory?
- Increased non-leptonic B-decay rate could account for low BR_{SL}:
  - no evidence for large BR(B→ no charm),
  - increasing BR($b \rightarrow c\bar{c}s$) also increases n_c.

⇒ **constrain the theory by measuring both BR_{SL} and n_c**

Measurements of n_c

(1) Charm counting:

the classic analysis, measure the inclusive production rates of exclusively reconstructed $D^0, D^+, D_s^+, \Lambda_c^+, \Xi_c^{0,+}$ and their anti-particles in b-decays (CLEO, ALEPH, DELPHI and OPAL).

(2) Inclusive no, single and double-open charm rate:

fitting the contributions to the impact parameter hemisphere probability (DELPHI) or
(New!) secondary vertex decay length and number distributions (SLD - almost ready)

(3) Exclusive wrong-sign and double-open charm rate:

from CLEO, ALEPH and (New!)DELPHI- this talk.

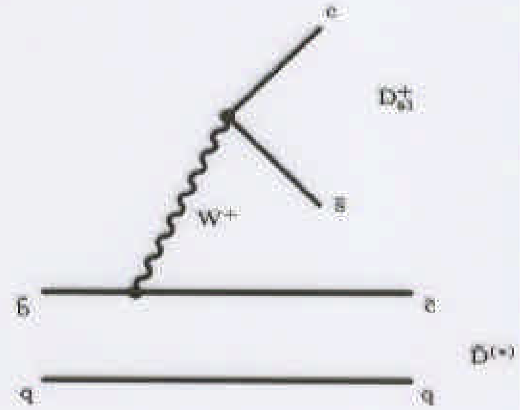
New DELPHI measurement of BR(B→ D X) ,D=wrong-sign D^0 or D^+

Analysis Overview

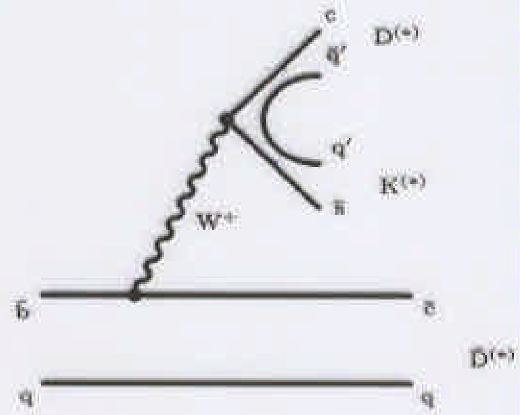
- **Data**
2.1 million $Z^0 \rightarrow q\bar{q}$ DELPHI events taken in 1994-95

- **$B \rightarrow DX$ wrong-sign M.C.**
$B \rightarrow D^{(*)}K^{(*)}\bar{D}^{(*)}$ and
$B \rightarrow D^+_{s1}\bar{D}^{(*)}$
$\hookrightarrow D^*K.$

(a)



(b)



- apply DELPHI $Z^0 \rightarrow b\bar{b}$ **tag** for purity of 96%,
- Exclusively reconstruct, $D^0 \rightarrow K^-\pi^+$ and $D^+ \rightarrow K^-\pi^+\pi^+$
- Increase the sample purity in wrong-sign D^0,D^+ via a neural network **B-decay flavour tag**.
- Extract the wrong-sign purity from the data by **fitting the D-momentum spectrum** in the B-rest frame.

D-reconstruction

- Form all combinations of $K^-\pi^+$ and $K^-\pi^+\pi^+$:
- Base final selection on five discriminant variables, x_i:
  - kaon tag probability of kaon candidate
  - $P(\chi^2)$
  - L/σ_L
  - $x_E(D)$
  - $\cos(\theta_D)$

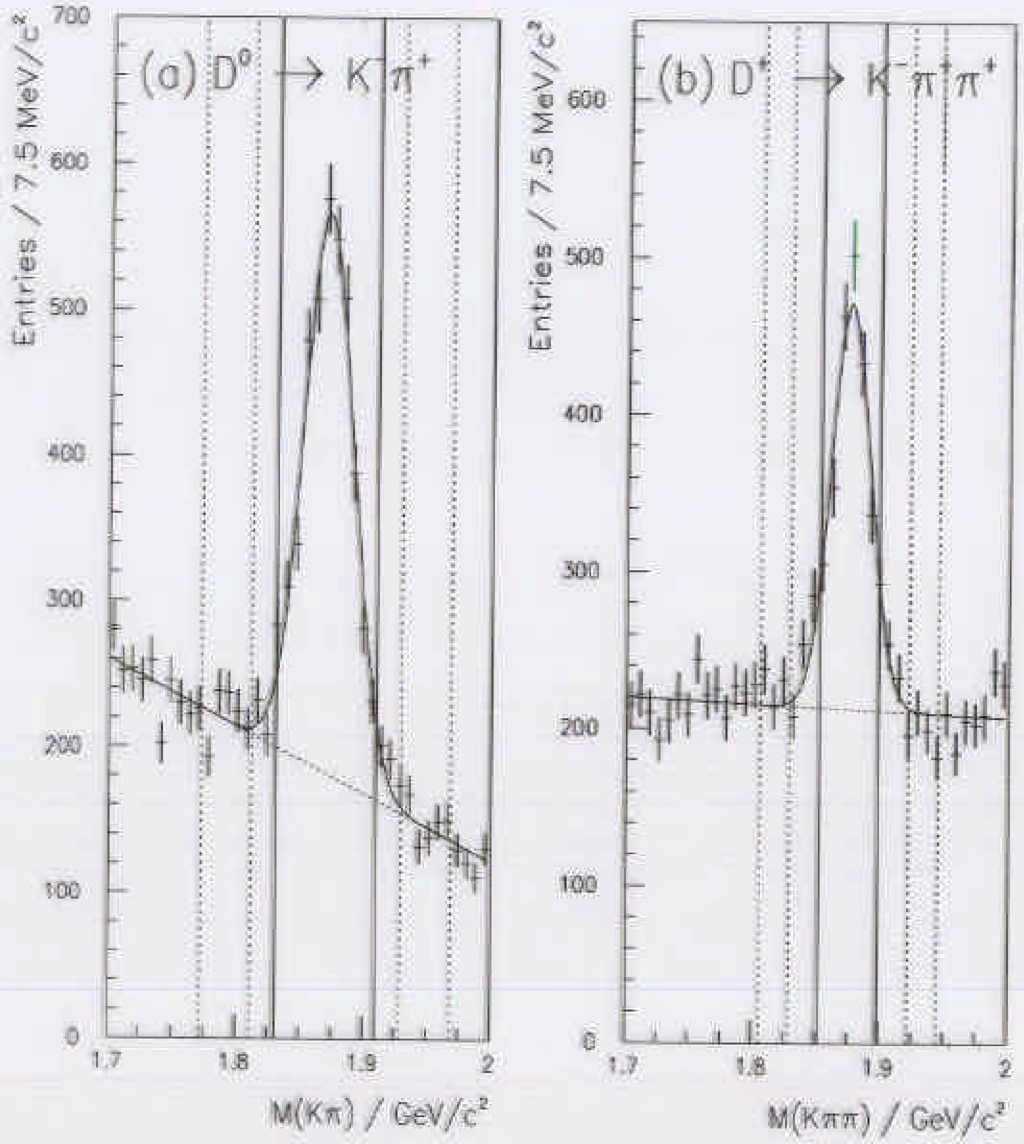
$$x(D) = \frac{R(D)}{1+R(D)}, \quad R(D) = \prod_i \frac{f_s(x_i;D)}{f_b(x_i;D)}$$

- peaks at 1(0) for signal(combin. background)
- take p.d.f.'s from simulation

- Require $x(D^0) > 0.8, x(D^+) > 0.875$

Signal band: 4,295(2,436), $D^0 + \bar{D}^0(D^+ + D^-)$

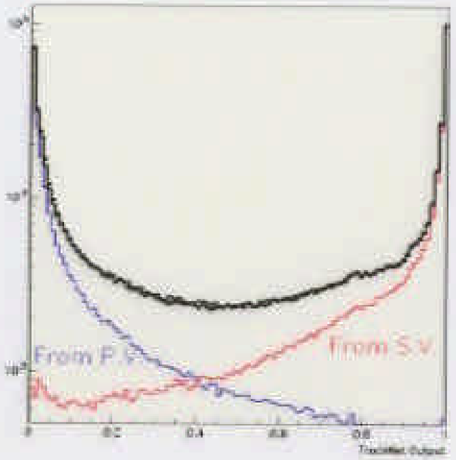
Side bands : 1,935(1,323), $D^0 + \bar{D}^0(D^+ + D^-)$



The DELPHI B-decay flavour tag

• TrackNet

separates fragmentation tracks from secondary decay tracks



• At the *hemisphere level* combine tracks in likelihood ratio:

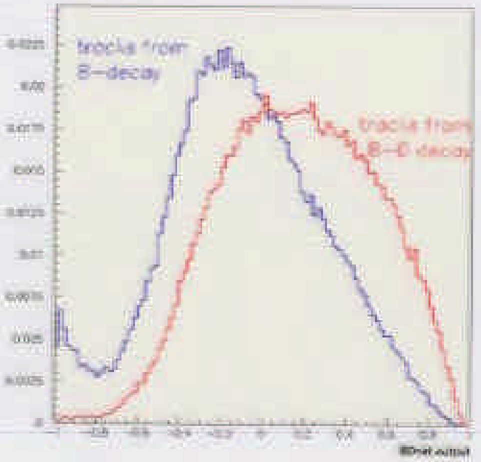
$$H(\mathrm{B}; frag., decay) = \sum_{tracks} \ln\left(\frac{1+T(Q|B)}{1-T(Q|B)}\right) \cdot Q_i$$

(sum over frag. or decay tracks via TrackNet)

• Finally, combine the flavour tags;

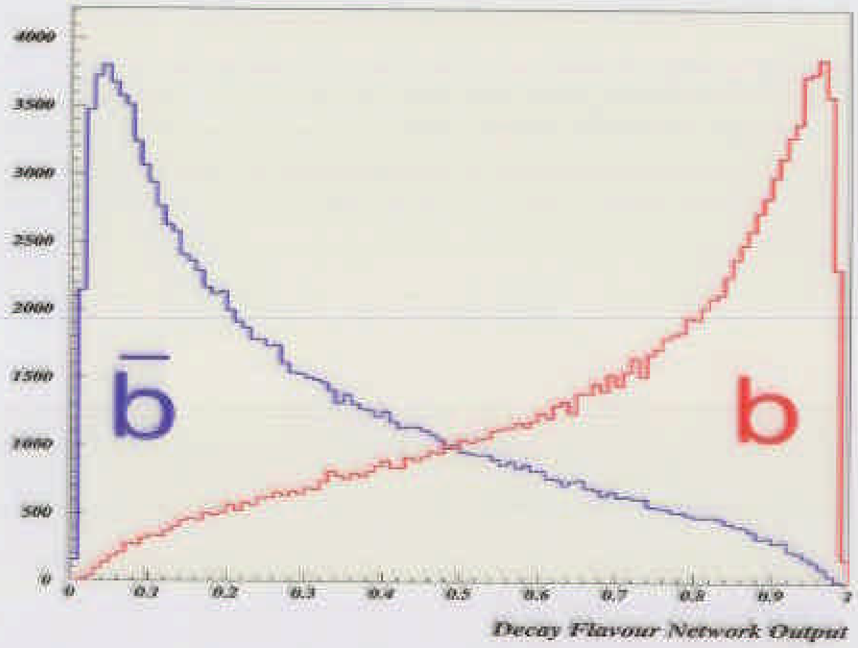
$H(B, decay), H(B, frag.), H(B, prod.)^{opp.hem.}$

with DELPHI inclusive B-species probabilities as inputs to a DELPHI *B-decay flavour network*.



• BDNet

separates B-decay tracks from cascade B-D tracks

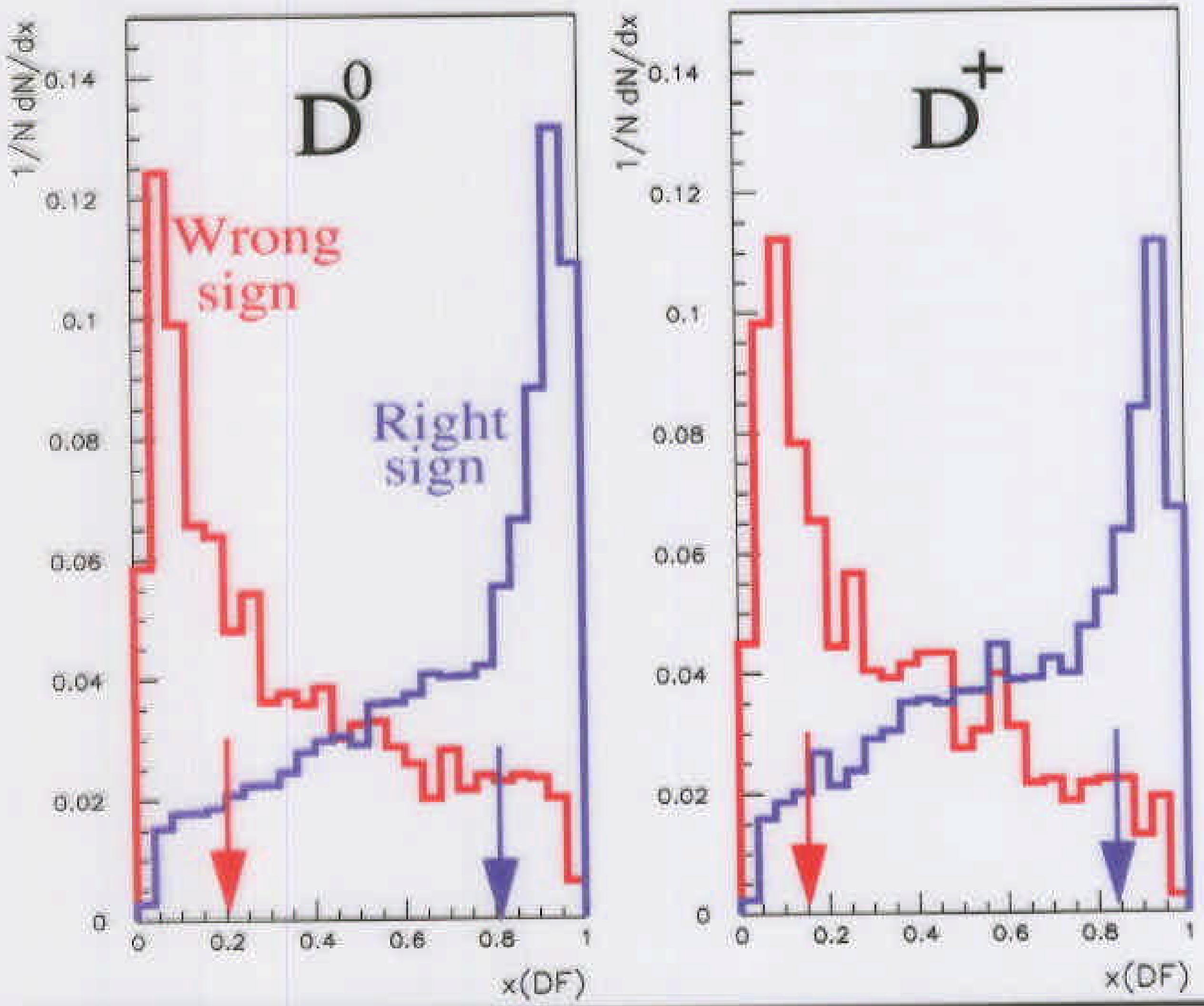


• Based on particle ID and BDNet, construct a network to give $T(Q|\mathrm{B}^+, \mathrm{B}^0, \mathrm{B}_s, \mathrm{Baryon})$ .Train separately on fragmentation and decay tracks.

Wrong-sign tagged sample

Use the B-decay flavour network, $x(DF)$, to separate wrong-sign from right-sign D-mesons:

- form $x(DF)$ for all tracks in hemisphere *except* the exclusive D-candidate tracks,
- separate D from $\bar{\mathrm{D}}$ using the kaon charge.



$x(DF) < 0.2(0.15)$ **giving** $\sim 66\%$ **wrong-sign D purity**
$x(DF) > 0.8(0.85)$ **giving** $\sim 1\%$ **wrong-sign D purity**

$$\frac{BR(\mathrm{B} \to \mathrm{D}^0\mathrm{X})}{BR(\mathrm{B} \to \bar{\mathrm{D}}^0\mathrm{X})} = \Delta(\mathrm{D}^0)\frac{N_{W.S.}(\mathrm{D}^0)}{N_{R.S.}(\mathrm{D}^0)}, \quad \frac{BR(\mathrm{B} \to \mathrm{D}^+\mathrm{X})}{BR(\mathrm{B} \to \mathrm{D}^-\mathrm{X})} = \Delta(\mathrm{D}^+)\frac{N_{W.S.}(\mathrm{D}^+)}{N_{R.S.}(\mathrm{D}^+)}$$

- $\Delta(\mathrm{D}^0) = 0.71 \pm 0.04$, $\Delta(\mathrm{D}^+) = 0.64 \pm 0.06$ from simulation
- $N_{W.S.}$ and $N_{R.S.}$ from tagged samples

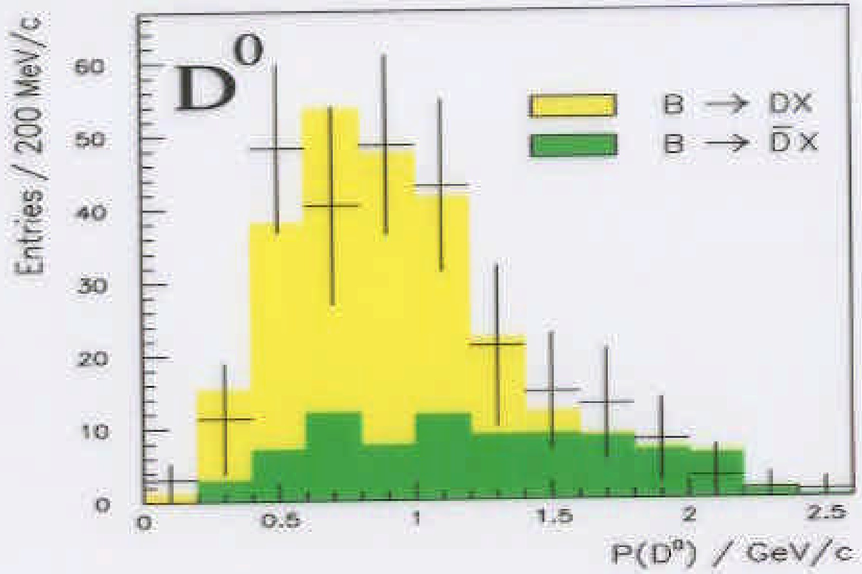
Extracting $N_{W.S.}$, $N_{R.S.}$ from data

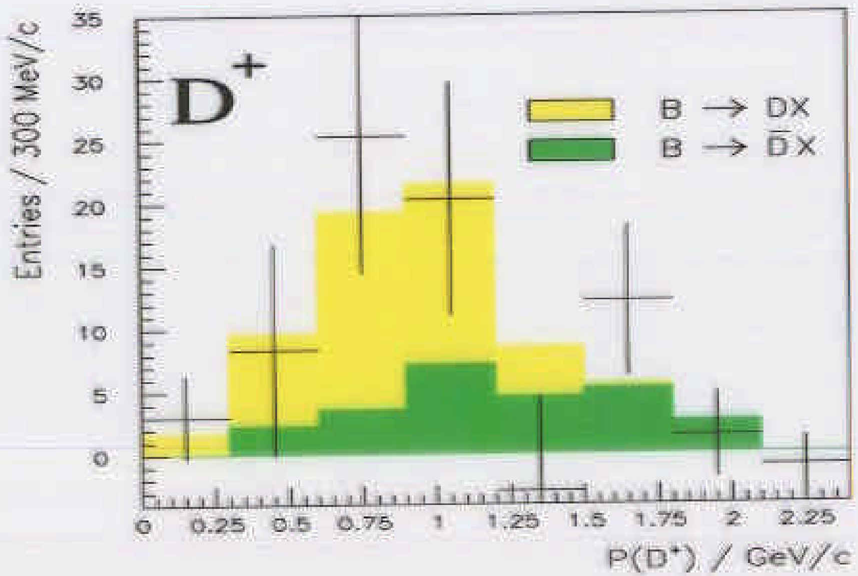
$N_{W.S.}$ component of the W.S.-tagged sample:

- Signal band: 626(235), $D^0 + \bar{D}^0 (D^+ + D^-)$
  Side bands : 337(153), $D^0 + \bar{D}^0 (D^+ + D^-)$
- Use fact that the D-momentum spectrum in the B-rest frame is softer for W.S. D's than for R.S.
- Fit for $N_{W.S.}$

$N_{R.S.}$ component of the R.S.-tagged sample:

- number of candidates in the R.S.-tagged sample (wrong sign background negligible $\sim 1\%$).





PRELIMINARY Results

Fit result

$$\frac{BR(\mathrm{B} \to \mathrm{D^0X})}{BR(\mathrm{B} \to \mathrm{\bar{D}^0X})} = 12.9 \pm 2.8\%$$

$$\frac{BR(\mathrm{B} \to \mathrm{D^+X})}{BR(\mathrm{B} \to \mathrm{D^-X})} = 12.3 \pm 6.7\%$$

Extract the wrong-sign only fractions using inclusive rates (PDG98):

$\mathrm{BR}(\mathrm{B} \to \mathrm{D^0}, \mathrm{\bar{D}^0X}) = 60.1 \pm 3.2\%$

$\mathrm{BR}(\mathrm{B} \to \mathrm{D^+}, \mathrm{\bar{D}^-X}) = 23.7 \pm 2.3\%$

$$BR(\mathrm{B} \to \mathrm{D^0X}) = 6.9 \pm 1.3(stat.) \pm 1.0(syst.) \pm 0.4(BR)\%$$
$$BR(\mathrm{B} \to \mathrm{D^+X}) = 2.6 \pm 1.3(stat.) \pm 1.1(syst.) \pm 0.3(BR)\%$$

Sources of systematic error:

- D-momentum shapes
- Model dependence
- Background corrections
- Efficiency correction factor, $\Delta(D)$

Preliminary world averaging- common inputs

(No official averaging of η_c exists. Latest average prepared by P. Roudeau.)

- **BR(b → no charm X)** = (sum of $b \to u\bar{u}d$, $b \to sg$ and $b \to (c\bar{c})X$) from DELPHI inclusive double-open charm analysis: $3.3 \pm 2.1\%$

- *New evaluation* of the charmonium contribution **BR**($b \to (c\bar{c})X$):

Decay Channel	Prompt rate	Source
$BR(b \to J/\Psi X)$	$0.812 \pm 0.064\%$	CLEO/LEP average
$BR(b \to \Psi' X)$	$0.355 \pm 0.049\%$	CLEO/LEP average
$BR(b \to \chi_c^1 X)$	$0.39 \pm 0.07\%$	CLEO
$BR(b \to \chi_c^2 X)$	$0.22 \pm 0.10\%$	CLEO

- measured rate corrected for cascade decays $\Psi' \to J/\Psi X$, $\Psi' \to \chi_c\gamma, \chi_c \to J/\Psi\gamma$
- rates of unmeasured resonances η_c, χ_c^0, h_c from model of *Beneke, Maltoni and Rothstein*
- **BR**($b \to (c\bar{c})X$)$= 2.4 \pm 0.3\%$

Prelim. world averaging- double open charm

- $n_c = 1 -$ BR(b $\rightarrow$ no c X)+ BR(b $\rightarrow$ double c X)+ 2.BR(b $\rightarrow$ $(c\bar{c})$ X)
- Inclusive double-open charm analysis (DELPHI):

BR(b $\rightarrow$ double charm X)=$13.6 \pm 4.2\%$

$$\Rightarrow n_c = 1.151 \pm 0.048$$

- Exclusive double-open charm measurements:

Correct for current PDG and *new treatment* of correlated systematics to give:

	$\mathrm{BR(b \rightarrow D^0, D^+ \bar{D} X)}$	$\mathrm{BR(b \rightarrow D_s^+ \bar{D} X)}$	$\mathrm{BR(b \rightarrow \Lambda_c^+ \bar{D} X)}$
CLEO	$0.072 \pm 0.020 \pm 0.002$	$0.078 \pm 0.031 \pm 0.029$	0.009 ± 0.006
ALEPH	$0.110 \pm 0.038 \pm 0.007$	$0.168 \pm 0.044 \pm 0.051$	-
(NEW) DELPHI	$0.092 \pm 0.022 \pm 0.002$	-	-
Average	0.085 ± 0.014	0.087 ± 0.043	0.009 ± 0.006

BR(b $\rightarrow$ double charm X) =BR$(\mathrm{b \rightarrow D^0, D^+ + D_s^+ + \Lambda_c^+ \bar{D} X})$

$$\Rightarrow n_c = 1.196 \pm 0.050$$

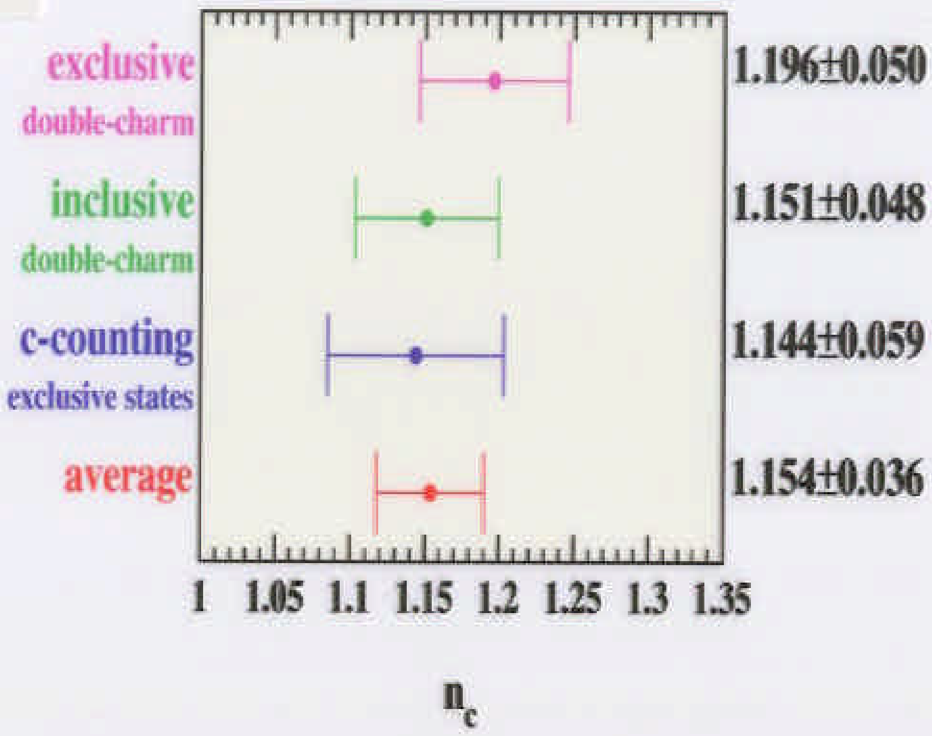
Prelim. world averaging- charm counting

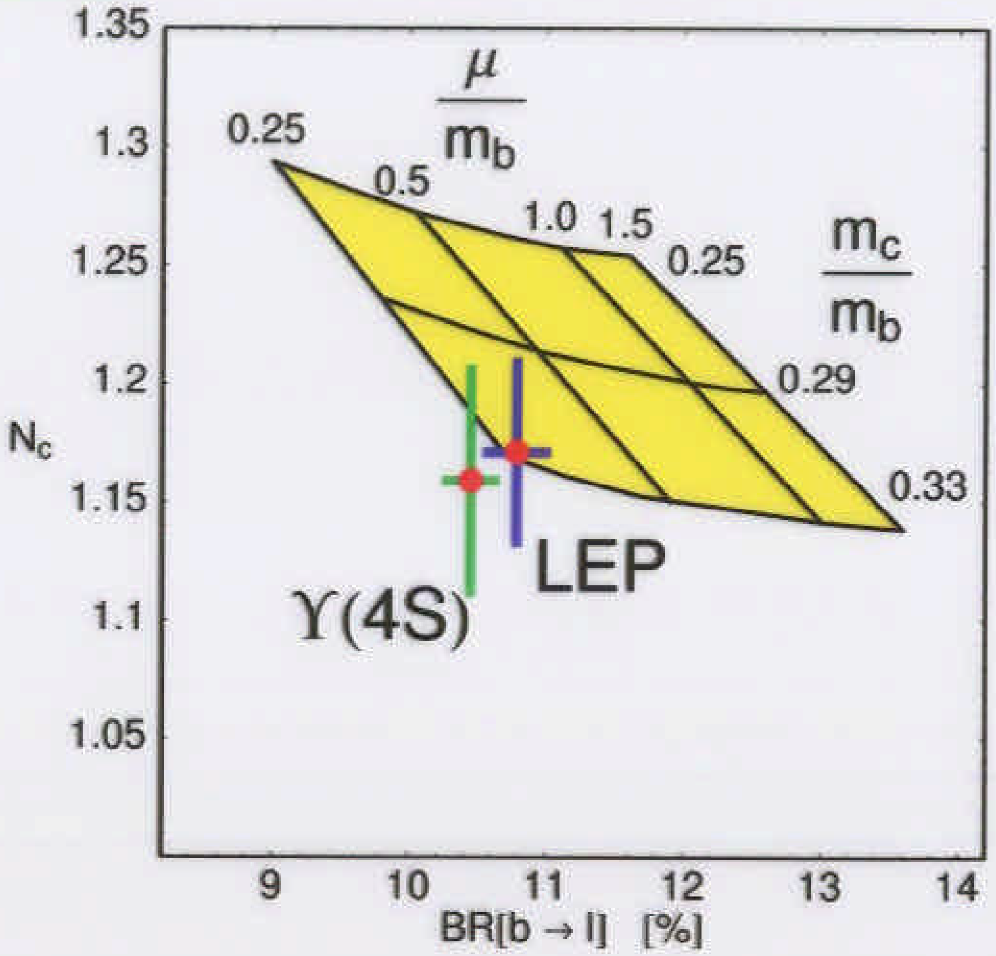
- $n_c = \mathrm{BR}(b \to D^0, D^+, D_s^+, \Lambda_c^+ X)) + 2.\mathrm{BR}(b \to (c\bar{c})\, X)$
- Experiments measure in general,
  $\mathrm{BR}(b \to D^0, D^+, D_s^+, \Lambda_c^+ X) \times \mathrm{BR}(D \to X)$ so results dominated by errors on final state branching fractions:

Decay channel	LEP	CLEO
$\mathrm{BR}(b \to D^0, \bar{D}^0 X)$	$59.3 \pm 2.3 \pm 1.4\%$	$64.9 \pm 2.4 \pm 1.5\%$
$\mathrm{BR}(b \to D^+, D^- X)$	$22.5 \pm 1.0 \pm 1.5\%$	$24.0 \pm 1.3 \pm 1.6\%$
$\mathrm{BR}(b \to D_s^+, D_s^- X)$	$17.3 \pm 1.1 \pm 4.3\%$	$11.8 \pm 0.9 \pm 2.9\%$
$\mathrm{BR}(b \to \Lambda_c^+, \Lambda_c^- X)$	$10.2 \pm 1.0 \pm 2.7\%$	$5.5 \pm 1.3 \pm 1.4\%$

- Need to correct for unmeasured states - *new evaluation* of charm-strange baryon contribution:
  $\mathrm{BR}(B \to \bar{\Xi}_c^{0,+}, \Xi_c^{0,-} X) = (0.4 \pm 0.3)\mathrm{BR}(B \to \bar{\Lambda}_c^-, \Lambda_c^+ X)$
- correlated average: $\boxed{n_c = 1.144 \pm 0.059}$

Conclusions





- $BR_{SL}(\Upsilon(4S)) = 10.45 \pm 0.21\%$(PDG98)
- $BR_{SL}(LEP) = 10.56 \pm 0.21\%$ (see S.Blyth PA-07f)

$$BR_{SL} = \frac{\langle\tau(B_d^0)\rangle + \langle\tau(B^+)\rangle}{2\cdot\langle\tau(b)\rangle} \cdot BR_{SL}(LEP)$$
$$= 10.79 \pm 0.25\%$$

(using latest lifetimes- see A.Stocchi PA-07a)

- Compare to theory prediction of Neubert, Sachrajda.

- **Experimentally we have a a consistent picture**