B (&C) PHYSICS AT LEP

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ON BEHALF OF ALEPH,DELPHI,L3,OPAL COLLABORATIONS

Les Rencontres de Physique
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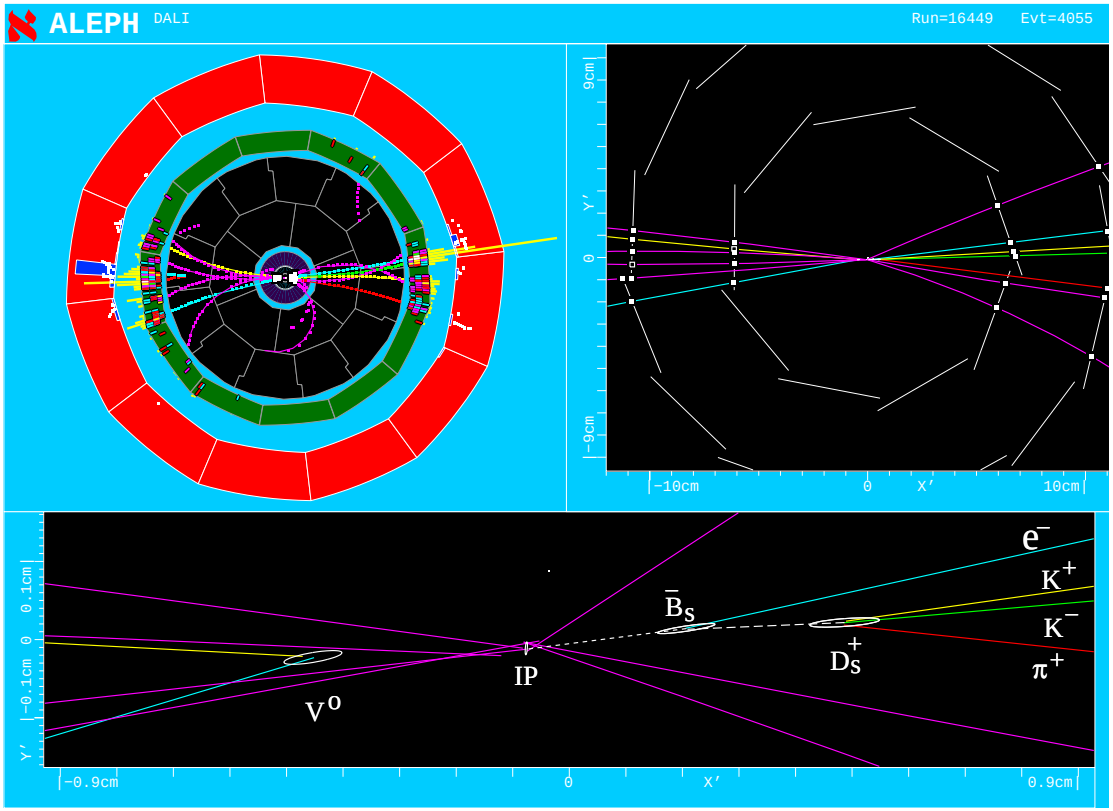
b Physics at LEP:

- LEP1: $\sqrt{s} \sim M_Z \Rightarrow \sim 0.8 \times 10^6$ $b\bar{b}$ events/experiment with B^+, B^0, B_s and b-baryons
- $b\bar{b}$ is back-to-back topology $\Rightarrow$ decay products of b and $\bar{b}$ well separated in space
- b is boosted: $E_B \sim 30$ GeV $\Rightarrow$ B flight ~2 mm: primary-secondary vertex separation
  soft decay particles boosted in the laboratory frame



OUTLINE

- b & EW Physics:
  A^{bb}_{FB}, A^{cc}_{FB}
- b & CKM matrix:
  V_{cb}
- b & Hadronic Physics:
  lifetimes, n_c, f_{Ds}

(Apologies for the many other measurements not presented)

$Z \to b\bar{b}$ (& $c\bar{c}$) Forward Backward Asymmetry

Asymmetry from interference between Vector and Axial-vector coupling of Z boson to quarks
$\Rightarrow$ precision measurement of $\sin^2\theta_{eff}$ and test of SM

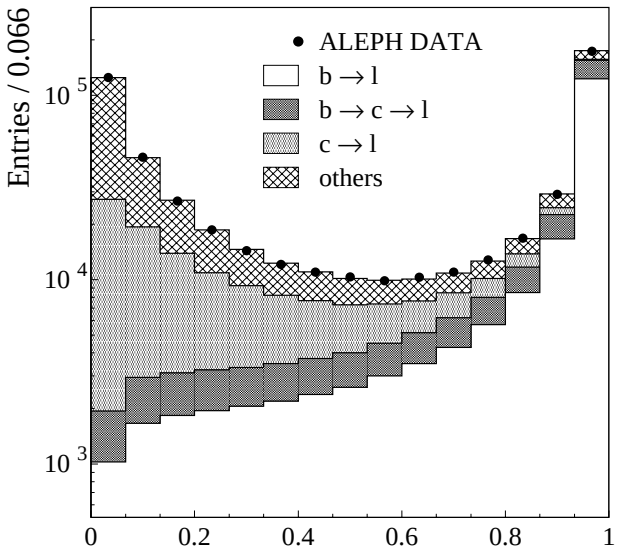
$$A_{FB}^{0,b} = \frac{3}{4} A_e A_b$$

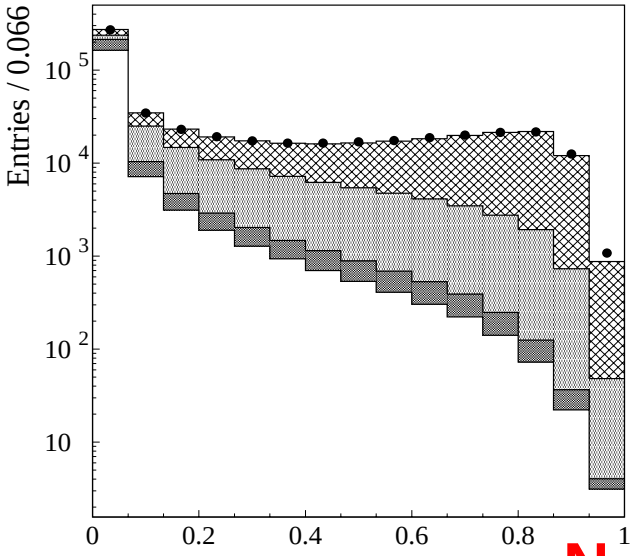
$$A_f = 2\frac{g_{V_f}/g_{A_f}}{1+(g_{V_f}/g_{A_f})^2}$$

A^{bb}_{FB} and A^{cc}_{FB} using leptons finalized by ALEPH *(1991-95 statistics)*

- Flavour tag:

b and uds separation using Neural Net

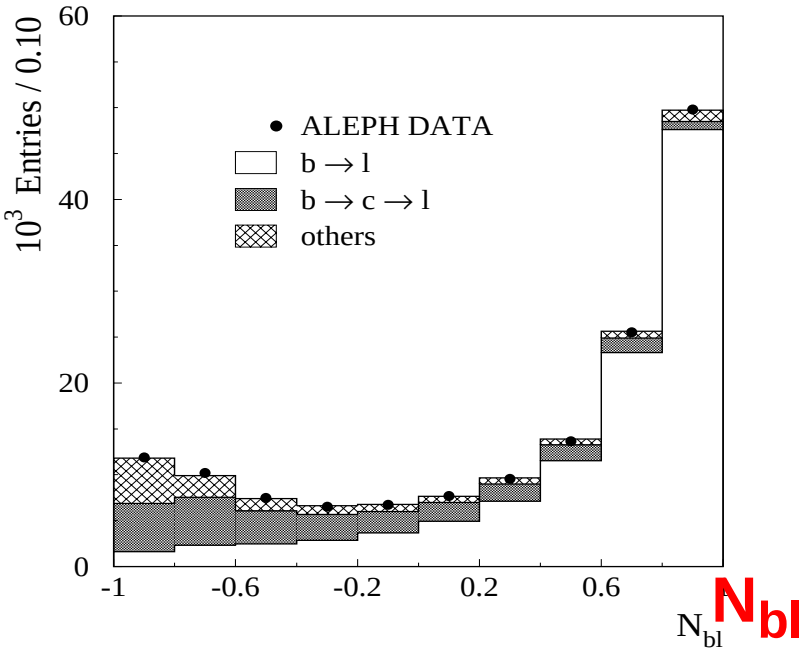




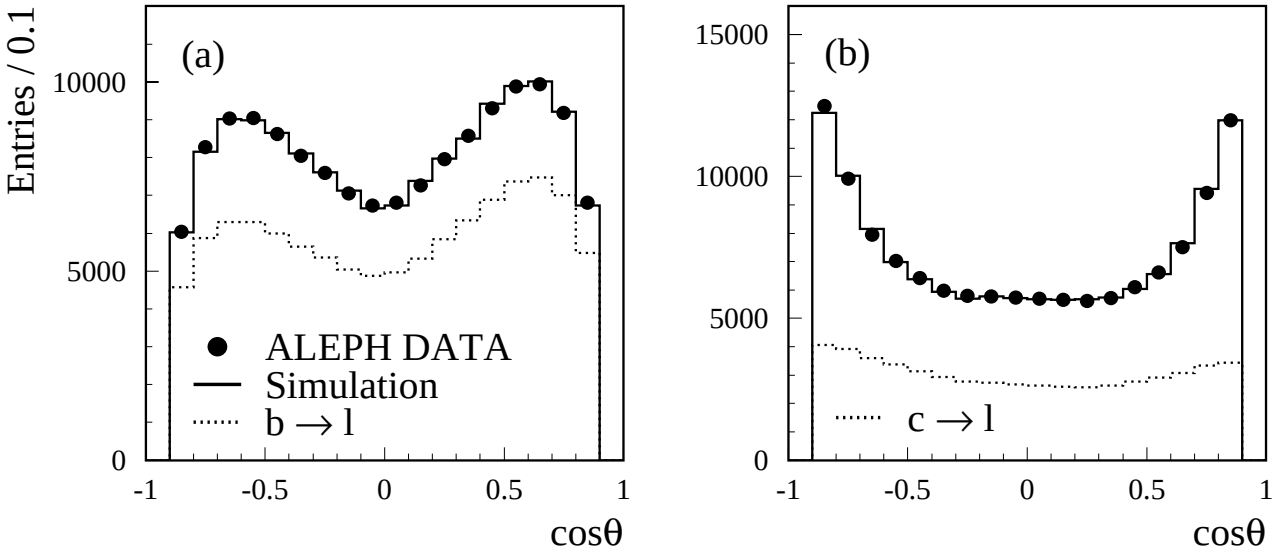
- Observed asymmetry is diluted by presence of cascade leptons

Separation of $b \to l^-$ from $b \to c \to l^+$ processes using kinematical and topological variables:

- lepton p, $p_\perp$; event missing E
- lepton jet properties ($\sum E$, $\sum p_{||}$, ...)



N_{bl}



Angular distribution in b and c enhanced regions

cos θ

- Extract: A^{bb}_{FB} , A^{cc}_{FB} and $\overline{\chi}$ (average $B^0\overline{B}^0$ mixing parameter) with maximum likelihood fit to: N_b, N_{uds}, N_{bl} and $Q_l \cos\theta_{thrust}$

❒ Combining all energies and deriving pole asymmetries (including QCD and QED corrections):

$$A^{0,b}_{FB} = 0.0998 \pm 0.0040(\text{stat.}) \pm 0.0017(\text{syst.})$$
$$A^{0,c}_{FB} = 0.0732 \pm 0.0053(\text{stat.}) \pm 0.0037(\text{syst.})$$

❒ Combining with previous ALEPH measurements of A^{bb}_{FB} using inclusive *b*-hadron decays and A^{cc}_{FB} using reconstructed D mesons:

$$\sin^2\theta_{eff} = 0.23188 \pm 0.00046$$

To be compared with the word average result from all asymmetry measurements:

$$\sin^2\theta_{eff} = 0.23149 \pm 0.00017$$

$|V_{cb}|$ from exclusive decays $\bar{B}^0 \to D^{*+} l^- \bar{\nu}$

- Study partial width dependence on w :

$$w = (v_B \cdot v_{D^*}) = \frac{m_B^2 + m_{D^*}^2 - q^2}{2 m_B m_{D^*}}$$

ν_B, ν_D : B^0 and D^{*+} 4-velocities

q^2: momentum transfer from B^0 to $l\nu$ system

- Using HQET: $\dfrac{d\Gamma}{dw} = K(w)\, F_{D^*}^2(w) \left|V_{cb}\right|^2$

$K(w)$: known kinematic factor

$F_{D^*}(w)$: hadronic form factor

In the heavy quark limit ($m_b \to \infty$) at zero recoil: $F_{D^*}(1) \to 1$

- Corrections for finite m_q and QCD give: $F_{D^*}(1) = 0.91 \pm 0.04$

- Measurements:

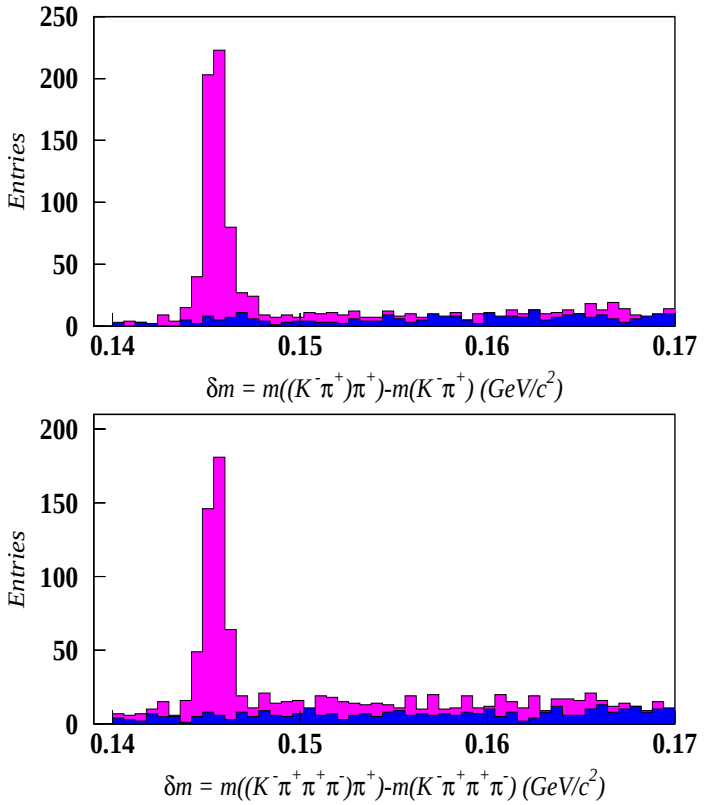
  Use an expansion of $F_{D^*}(w)$ around $w=1$

  Fit $d\Gamma/dw$ in $1. < w < 1.5$ to extract $F_{D^*}(1)|V_{cb}|$ and slope

  $\Rightarrow$ need fairly constant reconstruction efficiency about w =1

DELPHI measurement of $|V_{cb}|$ using $\bar{B}^0 \to D^{*+} l^- \bar{\nu}$

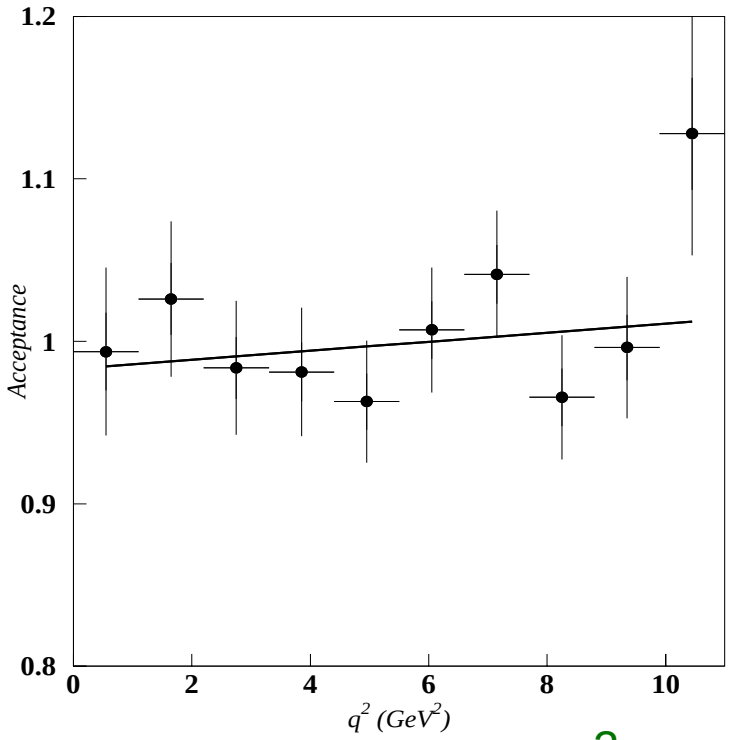
- Exclusive reconstruction of $D^{*+} \to D^0 \pi^+$



$D^0 \to K^- \pi^+$
521 ± 22
candidates

$D^0 \to K^- \pi^+ \pi^+ \pi^-$
387 ± 22
candidates

- Efficiency for $q^2 = (p_B - p_{D^*})^2$ reconstruction:



$q^2(GeV^2)$

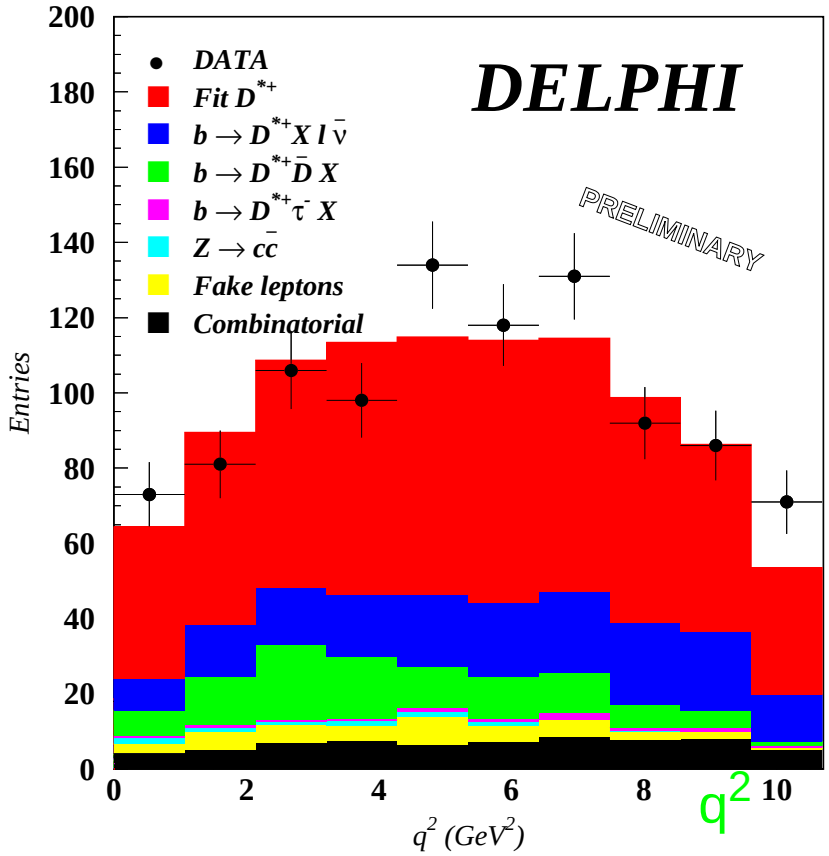
$F_{D^*}(w)$ expressed as a function of:

$R_1(w)$, $R_2(w)$ ratios of HQET form factors measured by CLEO

$h_{A1}(w) = h_{A1}(1)\,[1-8\rho^2_{A1}\,z+(53\,\rho^2_{A1}-15)\,z^2-(231\rho^2_{A1}-91)\,z^3]$ axial form factor

where ρ^2_{A1} is the slope parameter at zero recoil and $z = (\sqrt{w+1}-\sqrt{2})/(\sqrt{w+1}+\sqrt{2})$

(Caprini, Lellouch, Neubert, Nucl. Phys. B530(1998) 153.)



DELPHI result (preliminary):

$F_{D^*}(1)\ |Vcb| = 0.0357 \pm 0.0024 \pm 0.0019$

$\rho^2_{A1} = 1.23 \pm 0.21 \pm 0.32$

$BR(\bar{B}^0 \to D^{*+} l^- \nu) = (5.15 \pm 0.28 \pm 0.27)\ \%$

Systematics uncertainties:

Source		$F(1)\,\lvert V_{cb}\rvert$ (%)	ρ^2_A(%)	BR (%)
External parameters	rates, BR, b fragmentation	2.4	0.5	4.6
Detector performance	q^2 resolution	2.8	9.0	0.2
	q^2 acceptance	1.7	5.7	0.4
	track, lepton id, etc.	1.2	0.5	2.3
Signal modelling	$R_1(w)$, $R_2(w)$	0.9	22.8	-
Background modelling	D** states	2.8	7.3	0.6
	$\bar{B}_d \to D^* X \tau \bar{\nu}$, $P(c \to D^* X \tau)$	0.5	3.3	1.2
TOTAL systematic		5.2	26.	5.3
Statistical		6.7	17.	5.4

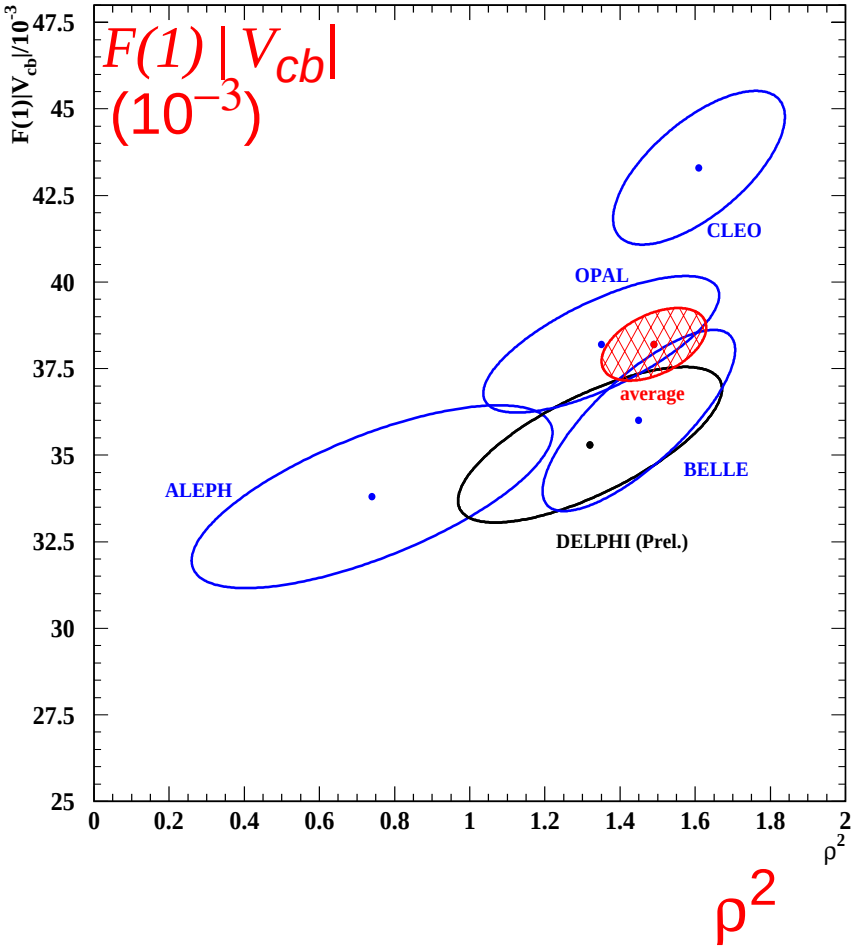
- Background rejection from presence of other particles at the b-vertex in addition to D^0,π^+, l^- :

  Residual background from $b \to D^{*+} X\, l\, \nu$:

  - total rate fitted on data: $BR(b \to D^{*+} X\, l\nu) = (0.64 \pm 0.10)\%$ compatible with expectations
  - relative fractions of different states using model of *A.K.Leibovich, Z.Ligeti et al.*

LEP Average $|V_{cb}|$ from $\overline{B}^0 \to D^{*+} l^- \overline{\nu}$

Experimental results corrected by LEP V_{cb} WG to common inputs and same form factor parametrization



$$F(1)\,|V_{cb}| = (38.2 \pm 0.5_{stat.} \pm 0.9_{syst.}) \times 10^{-3}$$

$$\rho^2_{A1} = 1.49 \pm 0.05_{stat.} \pm 0.13_{syst.}$$

Using $F(1) = 0.91 \pm 0.04$

$$|V_{cb}|^{excl} = (42.0 \pm 1.1_{exp.} \pm 1.8_{theo}) \times 10^{-3}$$

Inclusive Vcb at LEP

$$\Gamma_{sl}(b \to c\, l^- \bar{\nu}) = |V_{cb}|^2 \times f(param.) = BR_{sl} / \tau_b$$

- Semileptonic BR, LEP averages:

$$BR(b \to X\, l^- \bar{\nu}) = (10.65 \pm 0.23) \times 10^{-2}$$
$$BR(b \to u\, l^- \bar{\nu}) = (0.17 \pm 0.05) \times 10^{-2}$$

- Average b lifetime: $\tau_b = 1.564 \pm 0.014$ ps

$$\Gamma_{sl}^{LEP}(b \to c l^- \nu) = (0.441 \pm 0.010) \times 10^{-10} \text{ MeV}$$

$$|V_{cb}|^{incl} = (41.8 \pm 0.5\ (\textit{exp.: BR, }\tau) \pm 0.5\ (\textit{exp. determ. of HQET param. } \Lambda, \lambda_1 \textit{ by CLEO}) \pm 0.8\ (\textit{theory: } \alpha_s, 1/m_b^3))\ \times 10^{-3}\ *$$

To be compared with:

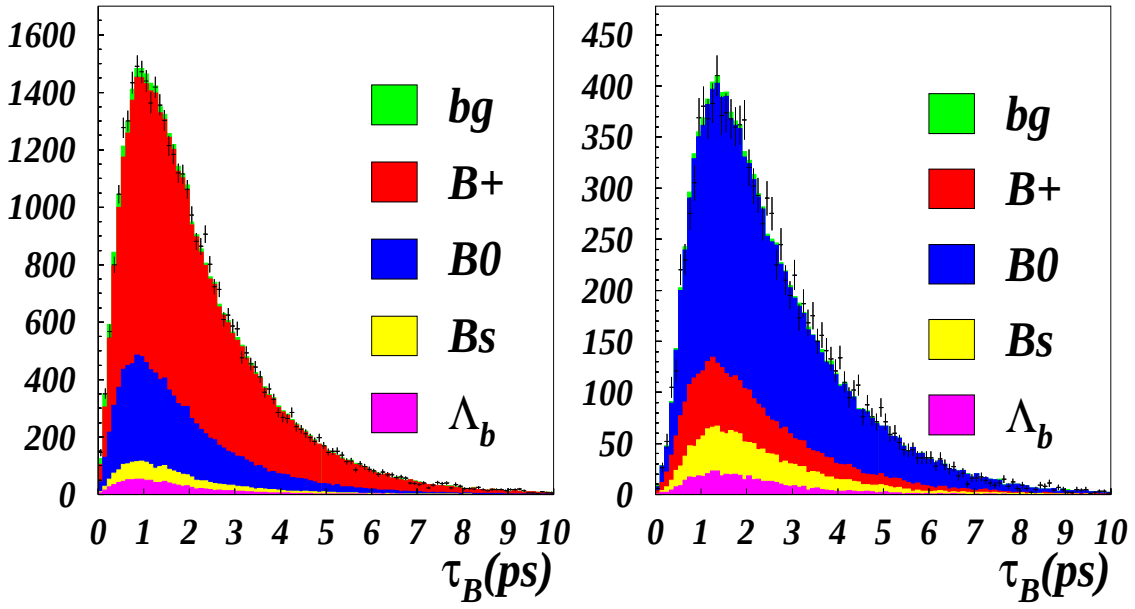
$$\Gamma_{sl}^{CLEO}(b \to c l^- \bar{\nu}) = (0.427 \pm 0.020) \times 10^{-10} \text{ MeV}$$

(*) Using: $|V_{cb}| = 41.35 \times [(BR_{sl}/0.105) \times (1.6\ ps/\tau_b)]^{1/2} \times 10^{-3}$ (→CKM workshop CERN)

b Hadron Lifetime Measurements

Different techniques used at LEP for B^0,B^+,B_s and b-baryons lifetime measurements

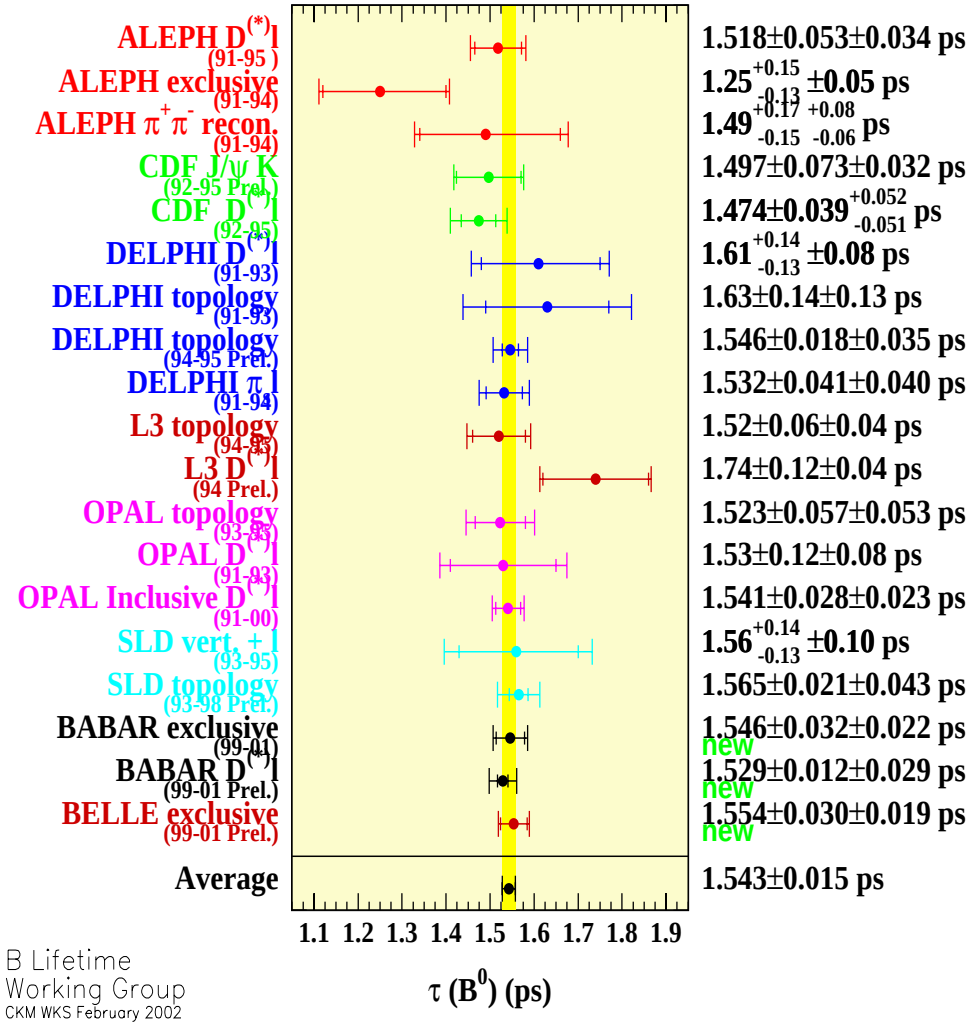
DELPHI measurement of B^+ and B^0 lifetimes

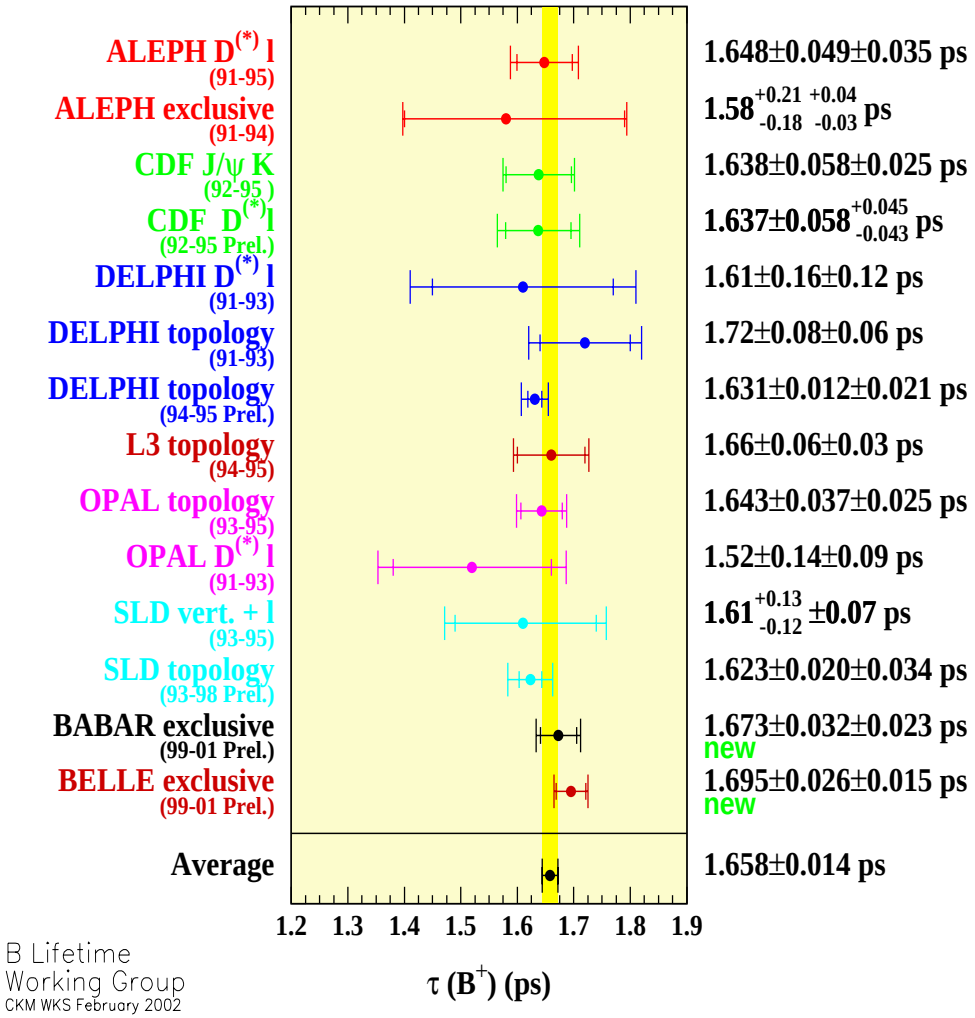


- Inclusive secondary vertices using different methods
- Resolution on B energy reconstruction ~ 2.3 GeV
- B^+/B^0 separation using Neural Net

$$\tau_{B^+} = 1.631 \pm 0.012(stat.) \pm 0.021(syst.)\ \text{ps}$$
$$\tau_{B^0} = 1.546 \pm 0.018(stat.) \pm 0.035(syst.)\ \text{ps}$$
$$\tau_{B^+}/\tau_{B^0} = 1.054 \pm 0.017(stat.) \pm 0.027(syst.)$$

Averages of b hadron lifetimes (B lifetime WG)

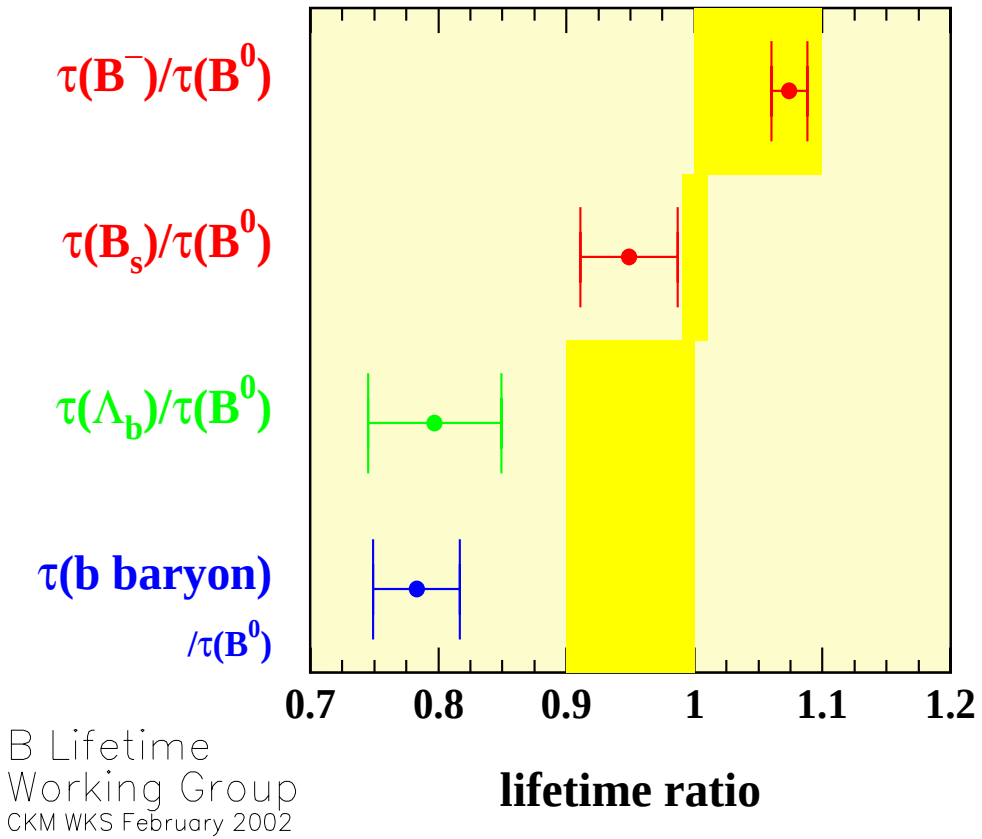




$\tau(B^0) = 1.543 \pm 0.015$ ps

$\tau(B^+) = 1.658 \pm 0.014$ ps

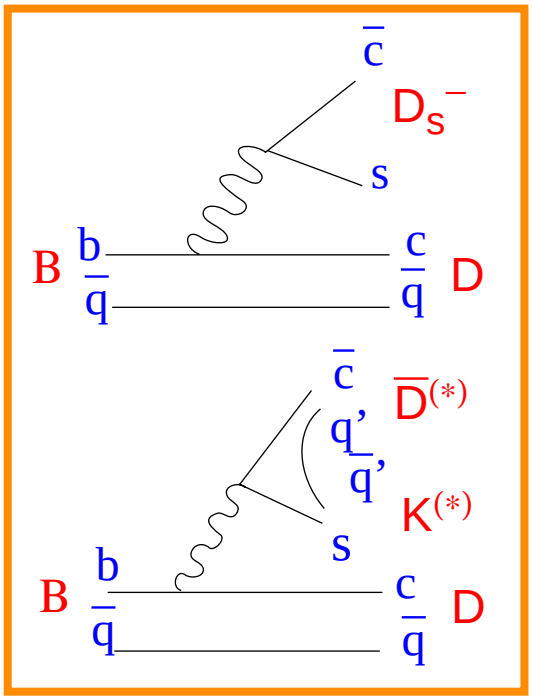
Lifetime Ratios



$\tau(B^-)/\tau(B^0)$	1.074±0.014	1.0 - 1.1	$\tau(B^+) > \tau(B^0)$ 5.3 σ
$\tau(B_s)/\tau(B^0)$	0.949±0.038	0.99 - 1.01	$\tau(B_s) \sim \tau(B^0)$ 1.3 σ
$\tau(\Lambda_b)/\tau(B^0)$	0.797±0.052	0.9 - 1.0	$\tau(\Lambda_b) < \tau(B^0)$ 3.9 σ
τ(b baryon) /τ(B⁰)	0.783±0.034	0.9 - 1.0	

In agreement with theory expectations, except for b-baryons

Inclusive b Decays to Wrong Sign Charmed Mesons



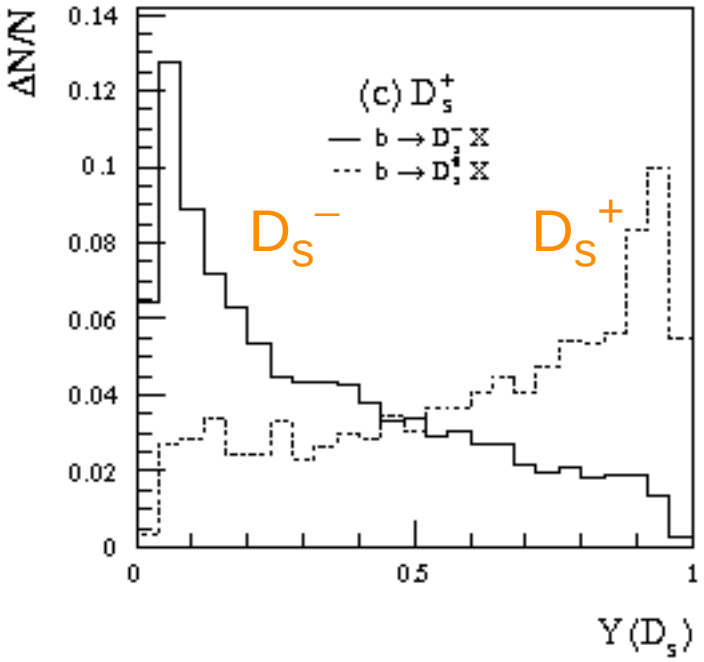
$B \to D \bar{D} X$ gives a measurement of number of charms in b decays: $n_c \approx 1 + B(b \to c \bar{c} s)$

DELPHI measurement of wrong sign charm

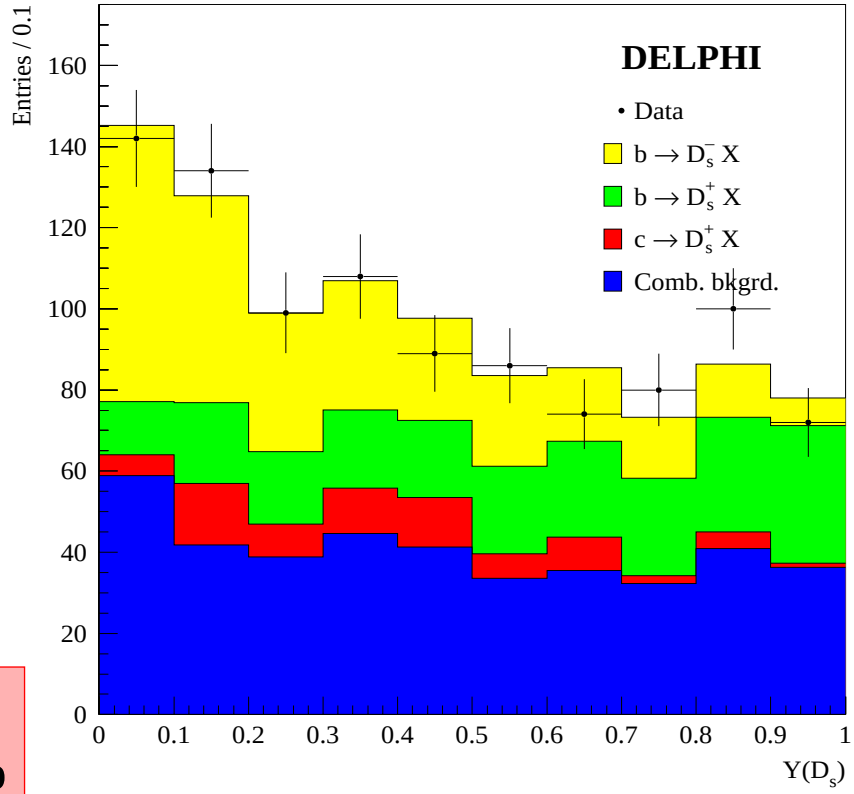
- Uses correlation between:

c charge → Decay products from exclusive reconstruction: $D^0 \to K^- \pi^+$, $D^+ \to K^- \pi^+ \pi^+$, $D^+ \to \phi \pi^+$

b charge → Neural net with B decay products



Sample	N. wrong sign	N. right sign
$D^0 \to K^- \pi^+$	383±81	3396±110
$D^+ \to K^- \pi^+ \pi^+, \pi^+$	186±86	1811±101
$D_s^+ \to \phi \pi$	286±42	221±39



- From wrong sign to right sign ratios:

$B(b \to \overline{D}\, X) = 9.3 \pm 1.7(stat.) \pm 1.3(syst.) \pm 0.4(B)$ %

$B(b \to D_s^- X) = 10.1 \pm 1.0(stat.) \pm 0.6(syst.) \pm 2.8(B)$ %

error from $B(b \to D_s^{\pm} X)$

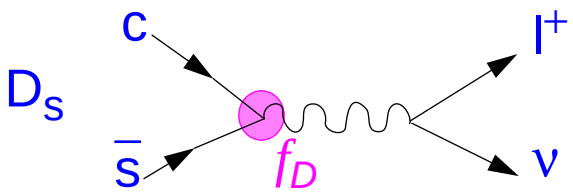
Previous results:

ALEPH: $B(b \to D^0\overline{D}^0, D^0D^-, D^+\overline{D}^0 (X)) = 7.8 \pm 1.9(stat.) \pm 1.6(syst.) \pm 0.4(B)$ %

$B(b \to D^0 D_s^-, D^+ D_s^- (X)) = 13.1 \pm 2.4(stat.) \pm 1.7(syst.) \pm 3.6(B)$ %

and in agreement with total D_s production at $\Upsilon(4S)$

D_s decay constant measurement



In the SM:

$$B(D_s \to l\upsilon) = \frac{G_F^2}{8\pi}\tau_{D_s} f_{D_s}^2 \left|V_{cs}\right|^2 M_{D_s} m_l^2 (1 - m_l^2/m_{D_s}^2)$$

- Test of f_{D_s} Lattice QCD calculations
- Measuremets are also a way to obtain the B decay constant f_B

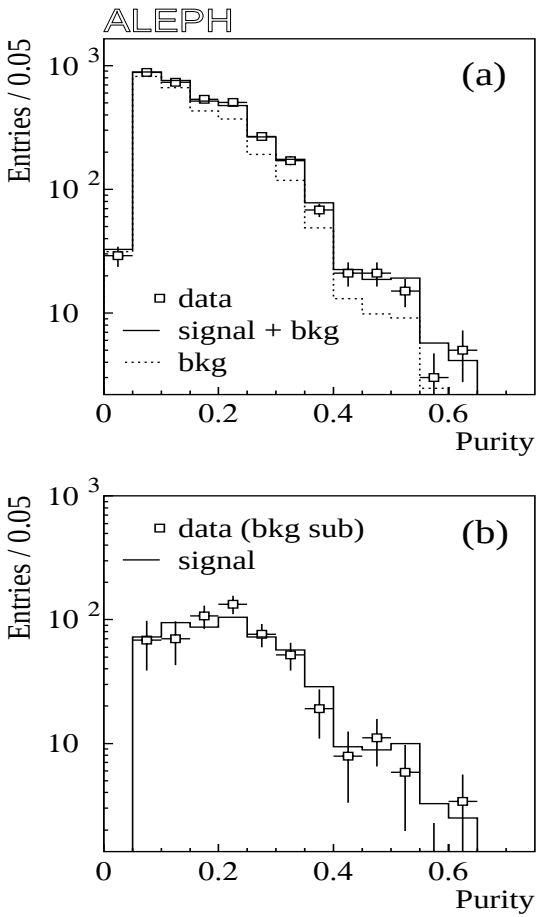
ALEPH measurement of the Branching fraction of $D_s \to \tau\,\nu$ ($\tau \to e\nu, \tau \to \mu\nu$) and $D_s \to \mu\nu$.

- Reconstruct D_s candidates in $c\bar{c}$ events: identified lepton, large missing energy and kinematic fit to reconstruct the D_s momentum
- Two discriminant variables used to separate signal against semileptonic b and c decays background (p^{Ds}, p_t^{lepton}, D_s-lepton angle etc)

◆ From branching ratios in both $D_s \to \tau\nu$ and $D_s \to \mu\nu$ channels extract:

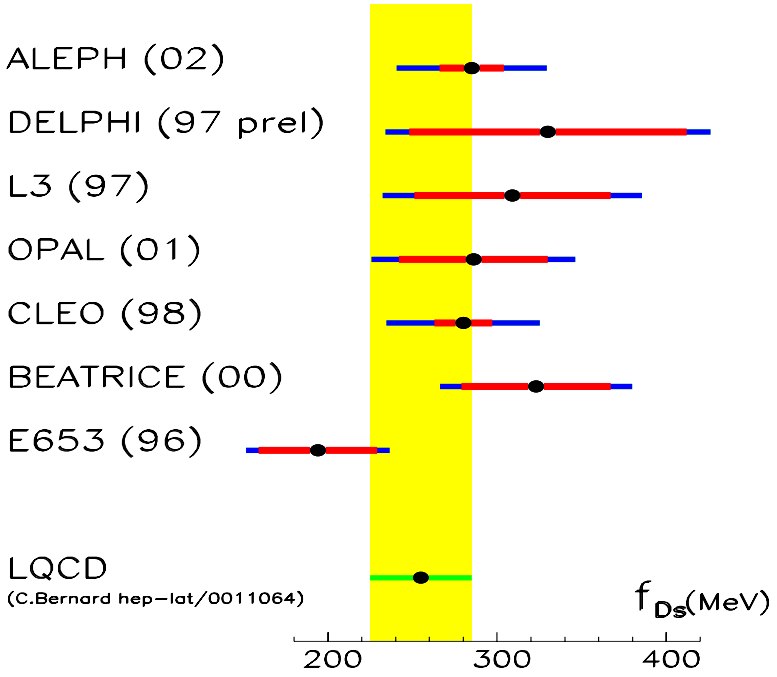
$$f_{D_s} = 285 \pm 19 \pm 40 \text{ MeV}$$

Purity in $D_s \to \mu\nu$ channel



Main systematics:

- ◆ charm hadrons production and BR
- ◆ b and c fragmentation
- ◆ detector resolution



CONCLUSIONS

~800.000 $b\bar{b}$ and ~ 700.000 $c\bar{c}$ pairs /experiment collected at LEP 1

Recent results presented on:

- A^{bb}_{FB}, A^{cc}_{FB}
- CKM parameter V_{cb}
- Lifetimes of b hadrons
- Charm production in b decays
- D_s decay contant

Other analysis are ongoing and more results are still coming