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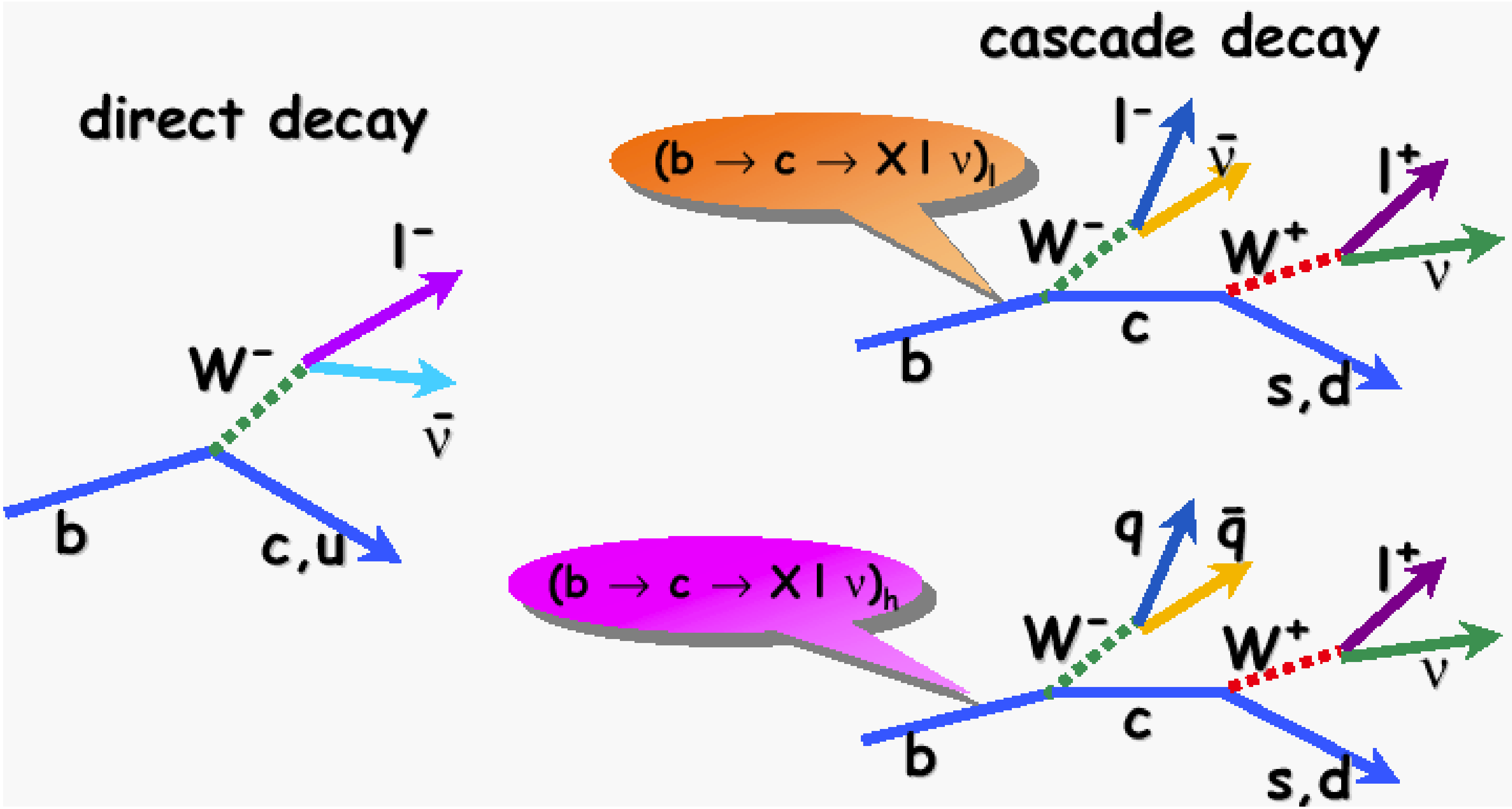
The b semileptonic branching ratio in $Z \to b\bar{b}$ decays

Alessia Tricomi
University of Catania and INFN Bari & Catania
on behalf of LEP Collaborations

Inclusive semileptonic branching fractions



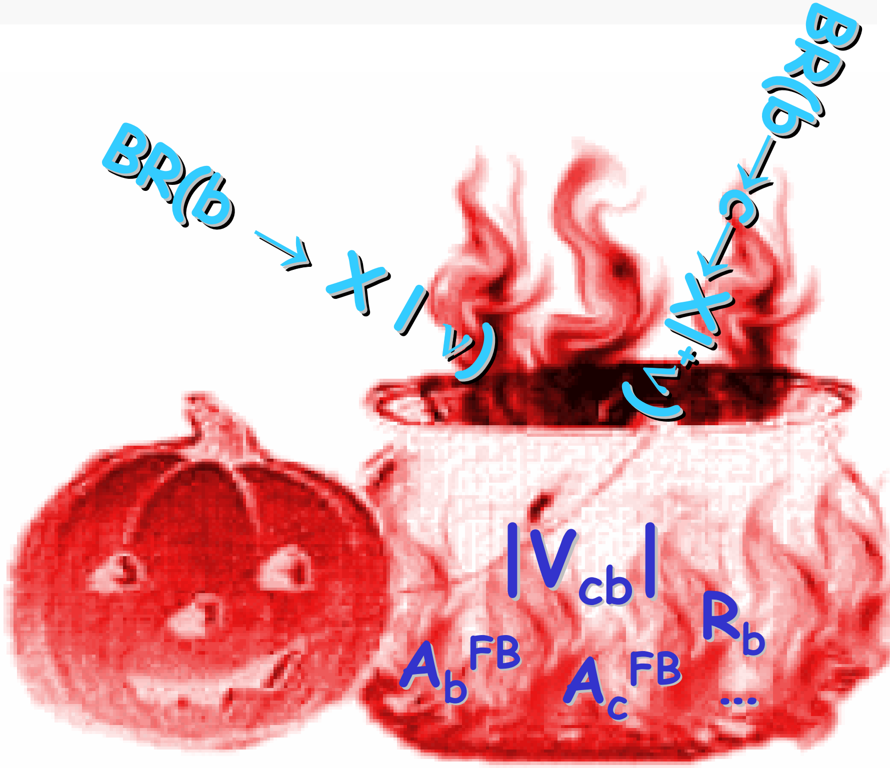
Motivations

$$BR(b \to X\,l\,\nu) = \frac{\Gamma(b \to X\,l\,\nu)}{\Gamma(b \to \text{anything})}\;\tau_b$$

with $\Gamma(b \to X\,l\,\nu) = \gamma_c|V_{cb}|^2 + \gamma_u|V_{ub}|^2$

Measuring $BR(b \to X\,l\,\nu)$

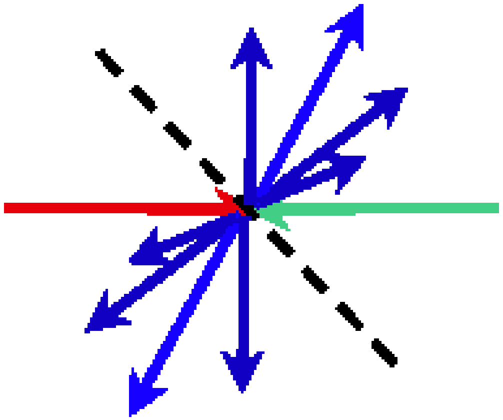
- Golden route to determine $|V_{cb}|$ (M. Battaglia talk, CP2 session)
- Test of the modelling of heavy hadron dynamics
- Input to many HF analysis
- Comparison to Y(4S) results



Measuring $BR(b \to c \to X\,l^+\,\nu)$

- main bkg for $BR(b \to X\,l\,\nu)$
- also input to many HF analyses

Analysis techniques



Several measurement techniques used

- Common to all LEP experiments:
  - Divide hadronic events in two hemispheres
  - Use lifetime info to tag b hemispheres
    high b purity samples (> 95%)
  - Look for leptons in the opposite hemispheres

Need to distinguish $b \rightarrow X\, l^- \nu$ from other lepton sources

- $b \rightarrow c \rightarrow X\, l^+ \nu$ (wrong sign cascade) → ALEPH, DELPHI, OPAL
- $b \rightarrow \bar{c} \rightarrow X\, l^- \nu$ (same sign cascade) → DELPHI
- $b \rightarrow \tau^- X \rightarrow l^-$
- $c \rightarrow X\, l^+ \nu$
- Bkg (leptons from J/ψ, gluon splitting, misidentified leptons)

The key issue

First LEP analyses:

only lepton spectrum info used to distinguish different components

Large dependence on modelling of b fragmentation and decay

Present LEP analyses:

Use additional information to reduce model dependence

(correlation of lepton charge with opposite hemisphere charge estimators)

Model depedence reduced, but ... able

New ALEPH result:

Two separate analyses (1. lep ... 2. charge correlation estimators)

No NN combination used → Good check of systematic effects

New treatment of modelling → Consistent results wrt usual treatment with completely different approach

Fragmentation from ALEPH data → No dependence on fragmentation model

ALEPH new $b \to X\, l\, \nu$: p_T analysis

TAG Hemisphere (B sample)

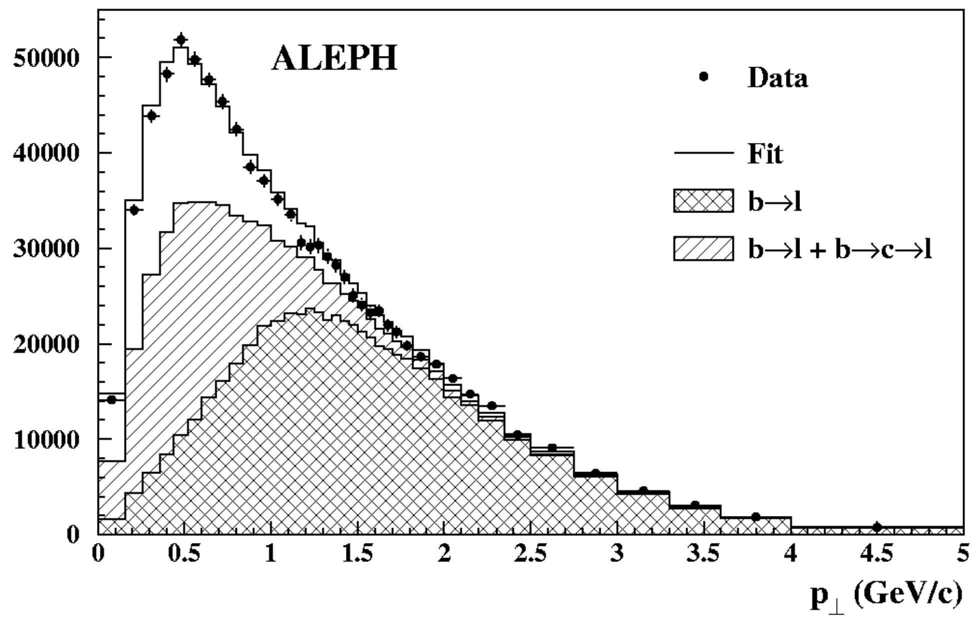
Tight cut on lifetime-mass tag

Lepton Analysis Hemisphere

Identify leptons

↓

Count them and use the p_T distribution to separate different components
Study of lepton rate wrt p_T allows $BR(b \to l)$ and $BR(b \to c \to l)$ to be fitted simultaneously



$$L = \frac{\mu_1 e^{-\mu_1}}{N_1!} \times \left[\prod_i F(P^i_t) \right]$$

counting → Weighted sum

p_T spectrum → Relative contributions

of cascade and direct BR

ALEPH new $b \to X l \nu$: charge correlation analysis

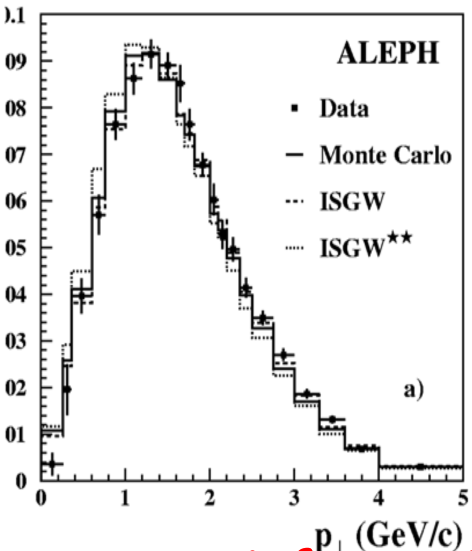
Distinguish $b \to l$ wrt $b \to c \to l$ using charge correlation wrt other b hemisphere

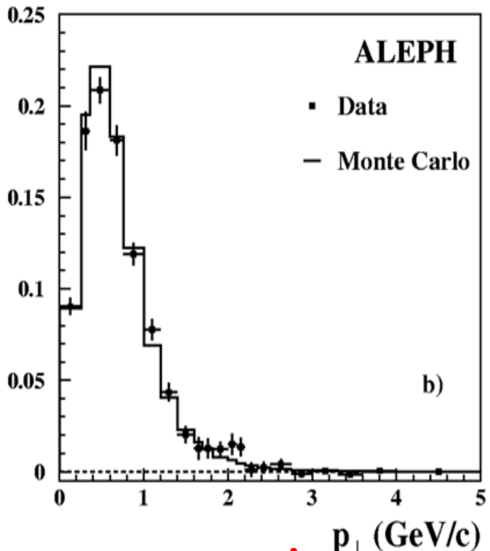
TAG Hemisphere | **Lepton Analysis Hemisphere**

P sample: high p_T lepton (1.25 GeV/c)
J sample: loose lifetime-mass tag+jet charge cut

Lepton charge
Q_{HEMI}=f(jet ch., i.p. signif.)

Measure fraction of:
Opposite sign | Same sign





p_T information not used

Extract p_T spectrum

Fit numbers of opposite (same) charge lepton candidates n_{OC} (n_{SC}) to the expected fractions

$$L = \underbrace{\frac{\mu_1 e^{-\mu_1}}{N_1!}}_{\text{counting}} \times \left[{f^P_{oc}}^{n_{oc}} (1 - f^P_{oc})^{n_{sc}} \right]_P \times \left[{f^J_{oc}}^{n_{oc}} (1 - f^J_{oc})^{n_{sc}} \right]_J$$

$f_{P,J}$ & $(1 - f_{P,J})$: sensitive to $b \to l$ wrt $b \to c \to l$ relative ratio. Can be expressed in terms of P_b= probability to correctly tag Q_b determined from data using a double tag technique

ALEPH new $b \to X l \nu$ measurement

2 methods (3 tags used)

"p_T analysis": the p_T of the leptons respect to the jet axis used to separate components

Larger statistical power

But large dependence on $b \to X l \nu$ decay modelling and hence on the shape of the p_T spectrum

"charge correlation analysis": the correlation between lepton charge and charge estimators (hemisphere charge or high p_T lepton charge) in the opposite hemisphere gives info about their relative proportions

Slightly worse statistical power

Reduced dependence on the $b \to X l \nu$ decay modelling
Mainly affected by the uncertainty in the rate of $b \to \bar{c} \to X l^- \nu$

Lepton spectrum extraction possible

ALEPH new $b \to X l \nu$: new approach for the $b \to l$ decay modelling

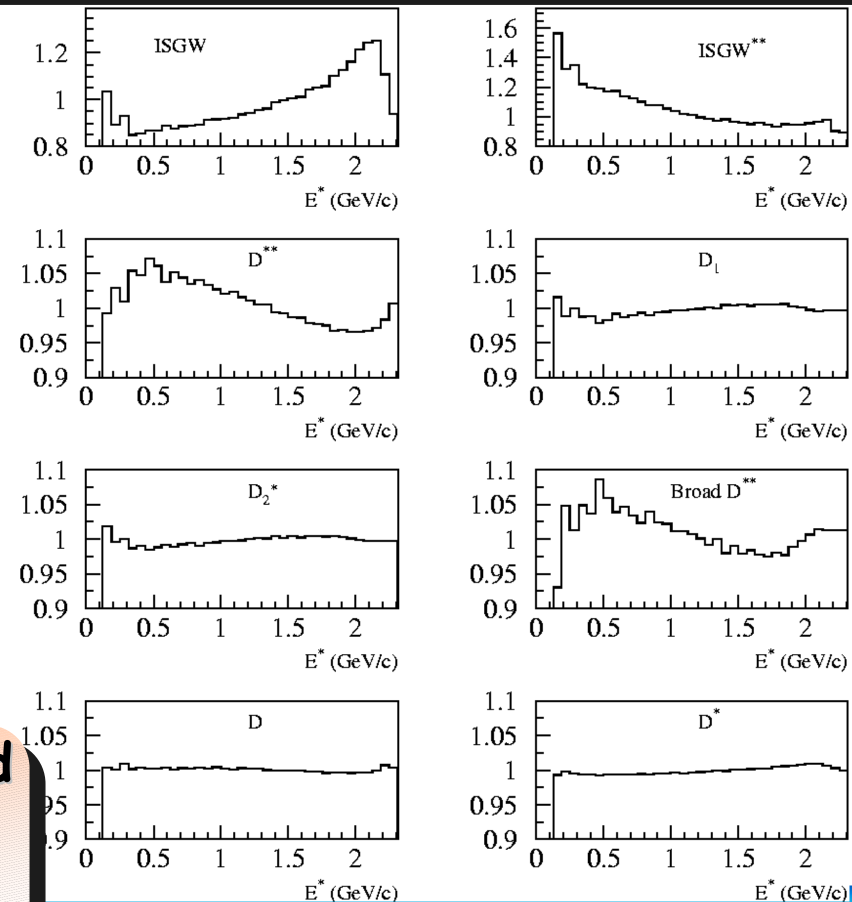
"Standard" treatment:
Fit to CLEO data with ACCMM, ISGW and ISGW**.
Use
- ACCMM Model for central value
- ISGW and ISGW** for systematics

Since

The shape of the $B^{0(+)} \to l$ spectrum depends on the following rates:

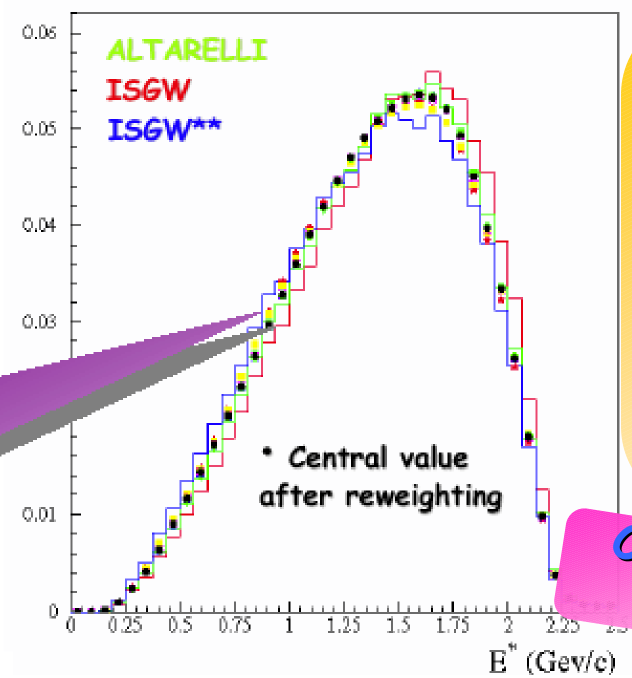
1) $BR(B \to D l \nu)$ = $(1.95 \pm 0.27)\%$
2) $BR(B \to D^* l \nu)$ = $(5.05 \pm 0.25)\%$
3) $BR(B \to D^* X\, l \nu)$ = $(2.7 \pm 0.7)\%$
   4) $BR(B \to D_1 l \nu)$ = $(0.63 \pm 0.11)\%$
   5) $BR(B \to D^*_2 l \nu)$ = $(0.23 \pm 0.09)\%$
   6) Broad D**
   7) Non resonant D**

New approach:
Reweight MC for the measured rates
Systematics: vary relative D/D*/D** fraction by their errors



B_s and b baryon production rates reweighted to latest experimental results and uncertainties in the modelling accounted by enlarging the uncertainties for B BR by 25%

ALEPH new b → X l ν : decay modelling and fragmentation

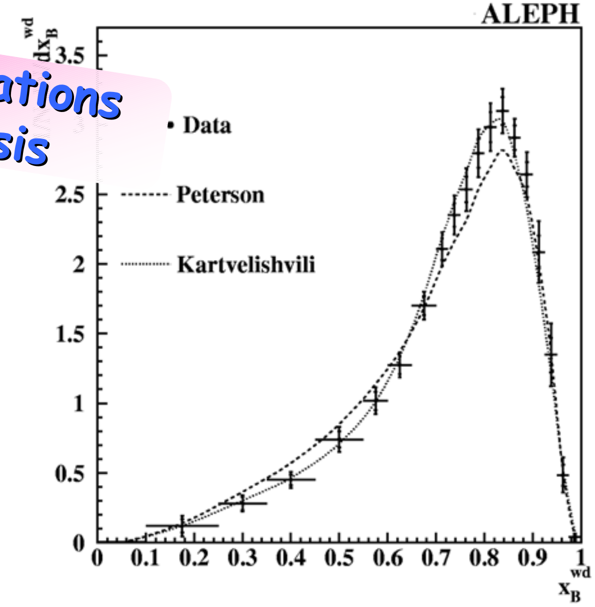


"new spectra" in agreement with ACCMM one!

Energy spectrum of weakly decaying B taken from ALEPH data
$\langle X_b \rangle = 0.716 \pm 0.006 \pm 0.006$
[PLB 512 (2001) 30]

No dependence on fragmentation model !
(K. Harder talk, HQ-1)

Correlate the variations with $\langle X_b \rangle$ analysis



Usual LEP procedure for c→l and b→c→l decay modelling

c→l

• Use the spectra given by a combined fit of ACCMM to DELCO and MARK III data (C.V. and ± σ)

b→c →l

• Use the c→l models to describe the second step in the process and vary at the same time the B→D spectrum obtained by fitting Peterson on CLEO data

ALEPH $b \to X l \nu$ & $b \to c \to X l \nu$ results

	Transverse Momentum Analysis (%)	Charge correlation analysis (%)
$BR(b \to l)$	$11.07 \pm 0.07_{stat} \pm 0.13_{sys} \pm 0.44_{mod}$	$10.57 \pm 0.11_{stat} \pm 0.29_{sys} \pm 0.20_{mod}$
$BR(b \to c \to l)$	$7.52 \pm 0.10_{stat} \pm 0.44_{sys} \pm 0.35_{mod}$	$8.30 \pm 0.16_{stat} \pm 0.21_{sys} {}^{+0.12}_{-0.16}{}_{mod}$

Two different strategies used to measure $BR(b \to l)$ & $BR(b \to c \to l)$, combined only *a posteriori*

1. p_T analysis significantly affected by $(b \to l)$ modelling
2. Charge correlation analysis less model dependent but suffers for the uncertainty on the rate of $b \to W \to \bar{c} \to l$ decay

Agreement between the two results is a crucial consistency check

Results averaged using B.L.U.E. technique

$BR(b \to l)$ $10.70 \pm 0.10_{stat} \pm 0.23_{sys} \pm 0.26_{mod}$

$W(p_T)=0.25$ $W(Qb)=0.75$

$BR(b \to c \to l)$ $8.18 \pm 0.15_{stat} \pm 0.22_{sys} {}^{+0.10}_{-0.14}{}_{mod}$

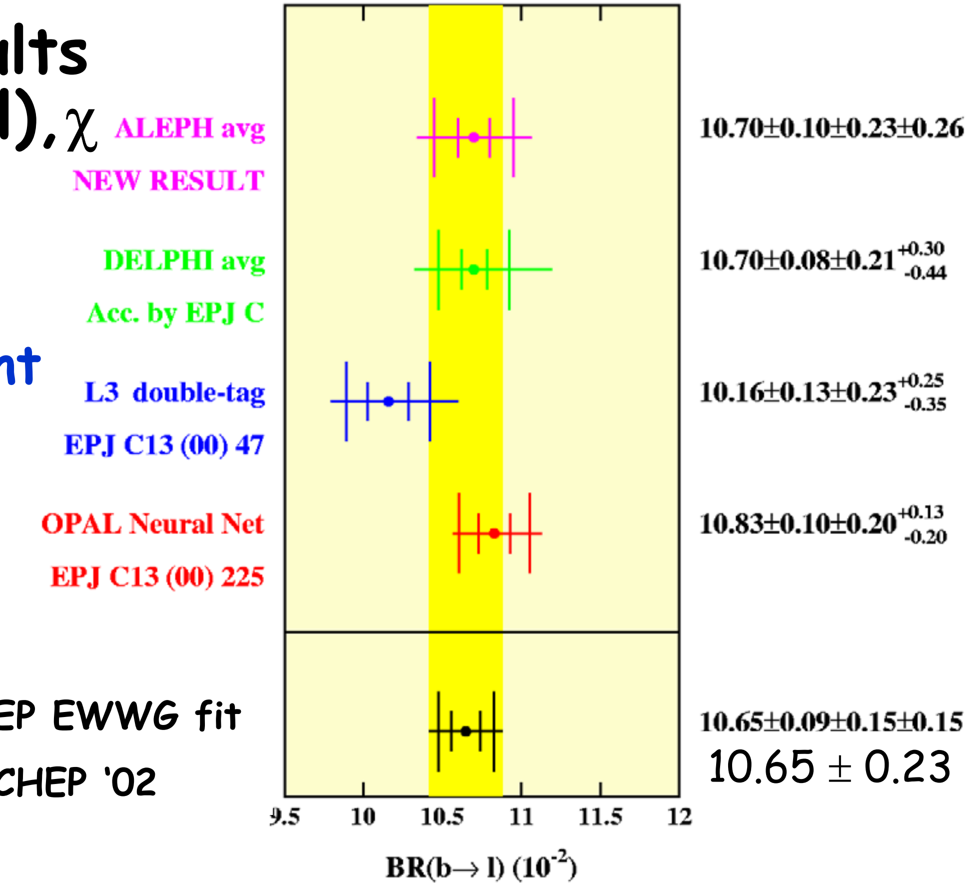
$W(p_T)=0.15$ $W(Qb)=0.85$

In both cases new treatment for the $b \to l$ modelling using measured rates of the different c hadrons in the final states

Consistent results with standard LEP approach

LEP BR($b \to X\, l\, \nu$) average

- <u>Global fit</u> to Heavy Flavours results
  R_b, BR($b \to l$), BR($b \to c \to l$), BR($c \to l$), χ
  - common input parameter values and systematic definitions used by all experiments
  - B.L.U.E. technique: take into account correlated systematics
    - sample composition
    - b and c lifetimes
    - B^+, B^0, B_s, Λ_b production fractions
    - $g \to bb$, $g \to cc$
    - b and c fragmentation
    - Λ_b polarisation
    - semileptonic decay models



uncertainty from the modelling of $b \to l$ dominates (0.15 of 0.23 total error)

$+1\sigma$	ISGW	11% D**
central	ACCMM	tuned to CLEO data
-1σ	ISGW**	33%D**

$BR(b \to X\, l\, \nu)$

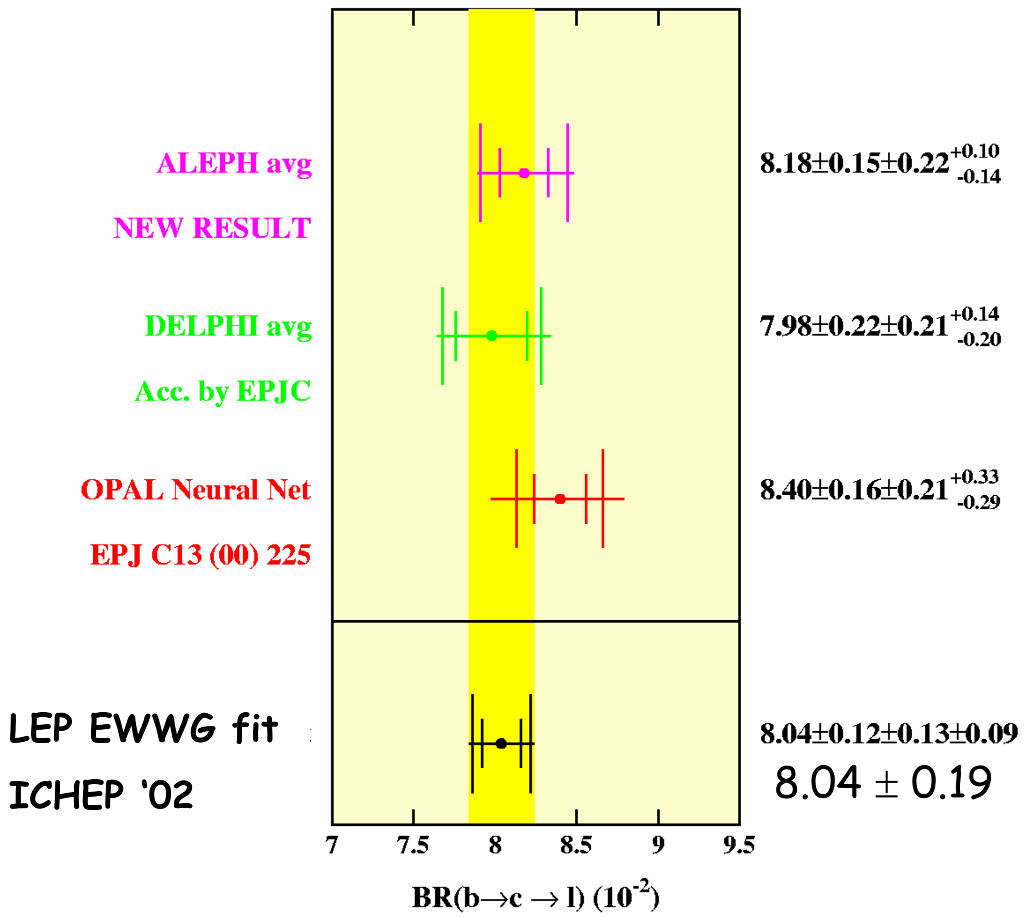
The sum of exclusive semileptonic BR agrees with the inclusive within ~1.5σ

$\bar{B} \to X\, l^- \bar{\nu}$ (CLEO+ARGUS)*	10.38 ± 0.32
$\bar{B} \to X\, l^- \bar{\nu}$ $(BABAR)_{prel}$	10.87 ± 0.35
$\bar{B} \to X\, l^- \bar{\nu}$ $(BELLE)_{prel}$	10.90 ± 0.52
$B \to X\, l^- \bar{\nu}$ (Υ(4S))	10.63 ± 0.25
$b \to X\, l^- \nu$ (LEP)	10.65 ± 0.23
$B \to D\, l^- \nu$*	2.13 ± 0.22
$B \to D^*\, l^- \nu$*	5.05 ± 0.25
$B \to D^{(*)} \pi\, l^- \nu$*	2.26 ± 0.44
$B \to D_1^0\, l^- \nu X$*	0.74 ± 0.16
$B \to X\, l^- \nu$*	< 0.65 90% CL
$B \to X_u\, l^- \nu$	0.17 ± 0.05
Total B exclusive	9.61 ± 0.55

*PDG values

LEP $b \to c \to X\, l\, \nu$ average

- Global fit to Heavy Flavour results from LEPEWWG
  - Large uncertainties from $b \to l$ modelling
  - Statistical error sizeable



Conclusions

- LEP has measured BR(b → l) and BR(b → c → l) with several techniques

  BR(b→l) $0.1065 \pm 0.0009_{stat} \pm 0.0015_{sys} \pm 0.0015_{mod}$ $(0.0026_{ALEPH\ mod})$

  BR(b→c→l) $0.804 \pm 0.0012_{stat} \pm 0.0013_{sys} \pm 0.0009_{mod}$
- Average results are consistent with Υ(4S) measurements

  $BR(B \to X\ l\ \nu)|_{LEP} = BR(B \to X\ l\ \nu) \times \tau_B/\tau_b = 0.1082 \pm 0.0023$

  $BR(B \to X\ l\ \nu)|_{\Upsilon(4S)} = 0.1063 \pm 0.0025$
- A careful investigation of systematic errors due to modelling and fragmentation model has been done
- New measurements from ALEPH which use a different approach for the (b → l) modelling and have no fragmentation model dependence give results consistent with the usual LEP treatment. This can be considered as a cross-check of the robustness of the analyses.

ALEPH new $b \to X\, l\, \nu$: systematics

Charge correlation

BR($b \to \bar{c} \to l$) = -0.223

b frag = -0.089

$b \to l$ mod = 0.202

$c \to l$ mod = -0.038 +0.021

$b \to D$ mod = negl

Lepton p_T analysis

BR($b \to \bar{c} \to l$) = 0.010

b frag = -0.074

$b \to l$ mod = 0.426

$c \to l$ mod = -0.087 +0.072

$b \to D$ mod = -0.072 +0.060

ALEPH new $b \to c \to X\, l\, \nu$: systematics

Charge correlation (in units of 10^{-2})

$BR(b \to \bar{c} \to l) = -0.039$

b frag = -0.101

$b \to l$ mod = 0.085

$c \to l$ mod = -0.117 +0.063

$b \to D$ mod = +0.058 -0.050

Lepton p_T analysis (in units of 10^{-2})

$BR(b \to \bar{c} \to l) = -0.407$

b frag = -0.120

$b \to l$ mod = 0.348

$c \to l$ mod = -0.037 +0.020

$b \to D$ mod = -0.055 +0.049

ALEPH new b → X l ν: systematics

Source	Δ[BR(b → Xℓν)] $p_\perp$	Charge	Δ[BR(b → c → Xℓν)] $p_\perp$	Charge
R_b	negl.	negl.	negl.	negl.
R_c	$\pm$ 0.005	$\mp$ 0.007	$\mp$ 0.002	$\pm$ 0.017
$N(g \to b\bar{b})$	$\mp$ 0.002	$\mp$ 0.002	$\mp$ 0.002	$\mp$ 0.001
$N(g \to c\bar{c})$	$\mp$ 0.001	$\mp$ 0.006	$\mp$ 0.014	$\mp$ 0.006
electron ID efficiency	$\mp$ 0.063	$\mp$ 0.081	$\mp$ 0.087	$\mp$ 0.056
γ conversions	$\pm$ 0.003	$\mp$ 0.006	$\mp$ 0.022	$\mp$ 0.008
electron bkg	$\pm$ 0.004	$\mp$ 0.007	$\mp$ 0.026	$\mp$ 0.009
muon ID efficiency	$\pm$ 0.065	$\pm$ 0.063	$\pm$ 0.039	$\pm$ 0.039
muon bkg	$\pm$ 0.002	$\mp$ 0.013	$\mp$ 0.037	$\mp$ 0.015
$BR(b \to c \to X\ell\nu)\vert_\ell$	$\pm$ 0.004	$\pm$ 0.022	$\pm$ 0.002	$\mp$ 0.026
$BR(b \to J/\psi\ (\psi') \to \ell\ell)$	negl.	negl.	negl.	negl.
$BR(b \to \tau \to \ell)$	$\mp$ 0.017	$\mp$ 0.043	$\mp$ 0.053	$\mp$ 0.011
$BR(b \to W \to \bar{c} \to \ell)$	$\pm$ 0.010	$\mp$ 0.223	$\mp$ 0.407	$\mp$ 0.039
$BR(c \to X\ell\nu)$	negl.	$\mp$ 0.016	$\mp$ 0.009	$\pm$ 0.016
$BR(b \to X_u\ell)$	$\mp$ 0.032	$\mp$ 0.022	$\pm$ 0.013	$\mp$ 0.004
b fragmentation	$\mp$ 0.074	$\mp$ 0.089	$\mp$ 0.120	$\mp$ 0.101
c fragmentation	$\pm$ 0.001	$\pm$ 0.005	negl.	$\mp$ 0.005
ϵ_c sample $\mathcal{B}$	$\pm$ 0.027	$\pm$ 0.015	$\mp$ 0.009	$\mp$ 0.010
ϵ_{uds} sample $\mathcal{B}$	$\pm$ 0.015	$\pm$ 0.016	$\pm$ 0.012	$\pm$ 0.011
ϵ_c sample $\mathcal{J}$	-	$\mp$ 0.018	-	$\pm$ 0.029
ϵ_{uds} sample $\mathcal{J}$	-	negl.	-	negl.
ϵ_c sample $\mathcal{P}$	-	$\mp$ 0.012	-	$\pm$ 0.019
ϵ_{uds} sample $\mathcal{P}$	-	negl.	-	negl.
c charge tag rate	-	$\pm$ 0.036	-	$\mp$ 0.057
b charge tag rate	-	$\pm$ 0.069	-	$\mp$ 0.109
Mixing in $b \to X\ell\nu$	-	$\pm$ 0.035	-	$\mp$ 0.055
Mixing in $b \to c \to X\ell\nu$	-	$\mp$ 0.055	-	$\pm$ 0.087
bkg charge correlation	-	$\pm$ 0.027	-	$\mp$ 0.043
b tag - lept correlation	$\pm$ 0.006	$\mp$ 0.007	$\mp$ 0.025	$\mp$ 0.005
Total	$\pm$0.128	$\pm$ 0.290	$\pm$ 0.443	$\pm$ 0.212

ALEPH new b → X l ν: lepID

Muons:

- p > 2.5 GeV
- |cos θ|< 0.69
- 1 VDET Hit
- |d0| < 2.5 mm
- Efficiency from Z→μμ when p>4 GeV
  from γγ→μμ when 2.5<p<4 GeV

dE/dX > -2 for both.
Reduces K bkg in the muon sample

Electrons:

- p>2 GeV
- Pad dE/dx info
- No cut on wires
  Larger efficiency
  with no dependence
  on p_t
- ECAL efficiency
  like in the past

ALEPH new $b \to X\, l\, \nu$: b purity

$$F_b = 1 - (R_c\, \varepsilon_c + R_x\, \varepsilon_x) / F_1$$

F_1= fraction of single tagged hemispheres in the data

Small: from MC

F_b= fraction of b hemi in the data

Systematics from ε_c and ε_x estimated for each sample

	b purity	efficiency
Sample 1	97%	32%
Sample 2	87%	32%
Sample 3	90%	12%

ALEPH new b → X l ν: charge tag rate

P_b = charge tag rate is measured by using double tag method

Count fraction of events with opposite charge hemispheres in data

Correct for hemisphere correlations and udsc contribution from MC

Extract P_b

ALEPH new $b \to X\, l\, \nu$: charge tag rate

Extract F_b^{oc} from data:

From MC

$$F^{oc}(\text{data}) = \frac{R_b\, \varepsilon_b^2 F_b^{oc} + R_c\, \varepsilon_c^2 F_c^{oc} + R_x\, \varepsilon_x^2 F_x^{oc}}{R_b\, \varepsilon_b^2 + R_c\, \varepsilon_c^2 + R_x\, \varepsilon_x^2}$$

Charge corr Samples 2,3

From double tagged hemisphere fraction

$$F_2 = R_b\, \varepsilon_b^2 + R_c\, \varepsilon_c^2 + R_x\, \varepsilon_x^2$$

P_b = prob. of tagging the b charge

$$F_b^{oc} = \underbrace{P_b^2(1+\rho_1)}_{\text{Right-right}} + \underbrace{(1-P_b)^2(1+\rho_2)}_{\text{Wrong-wrong}} \rightarrow P_b$$

P_b, P_c, P_x are used to build the charge spectra

P_c, P_x taken from MC

ALEPH new b → X l ν: charge tag rate

Tag rates measured from data:

- 1) jet charge - lepton correlation $P^1_b = 0.73$
- 2) lepton - lepton correlation $P^2_b = 0.81$

a) P_b has a statistical error from data (double tagged hemispheres)

This statistical error is propagated in the measurement
Then ⊕ to statistical error from the fit

b) Systematic error on P_b due to correlation ρ_1 and ρ_2 between tag probabilities
Typical MC values for ρ_1 and ρ_2 2.3- 2.6%.
Set ρ_1 and ρ_2 to zero and take half the shift