Semileptonic b Branching Ratios and CKM elements at LEP

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on behalf of the LEP Collaborations

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Review of

#4_137, OPAL Measurement of the Branching Ratio for the Process b->$\tau\nu$ X

#4_139, OPAL Measurement of $|V_{ub}|$ using b Hadron Semileptonic Decays

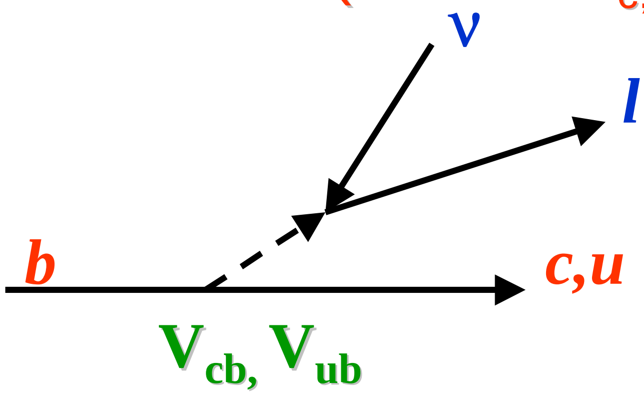
#4_215, ALEPH Inclusive semileptonic branching ratio of b hadrons produced in Z decays

#4_221, ALEPH Measurements of BR(b -> $\tau\nu$ X) and BR(b -> $\tau\nu$ D* X) and Upper Limits on BR(B ->$\tau\nu$) and BR (b -> s $\nu\nu$)

Introduction

Semileptonic b decays: golden route to determine $|V_{cb}|$ and $|V_{ub}|$ CKM matrix elements

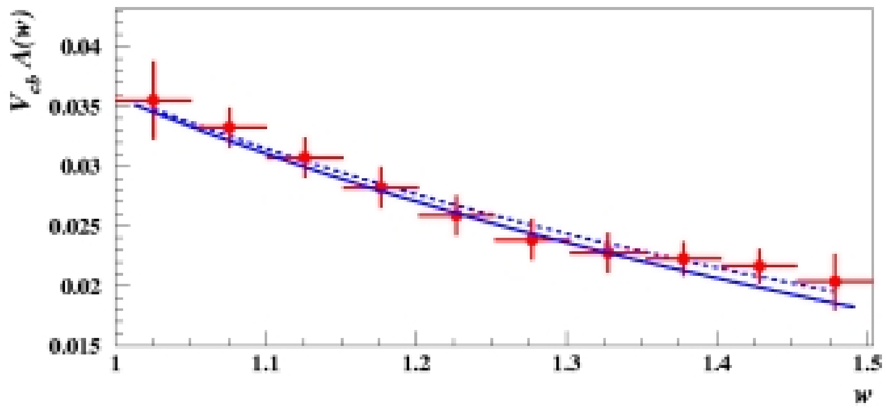
❑ Inclusive BR($b \to l^- \nu X_{c,u}$)



compare the experimental decay width with the theoretical predictions

$$\Gamma_{sl}(b \to X_{c,u} l\nu) = \frac{BR(b \to X_{c,u} l\nu)}{\tau_b} \propto |V_{cb,ub}|^2$$

❑ $B_d \to D^* l\nu$ decays



determine $|V_{cb}|$ through HQET predictions from the recoil kinematics of the D* meson

Basics of inclusive $b \rightarrow c(u) l\nu$ measurements

The "easy" part: $b \rightarrow c$

- b-tag one hemisphere and look for leptons in the other
  - High purity sample: ~ 90% purity, more than 30% efficiency
  - *main background arises from cascade $b \rightarrow c \rightarrow l$ decays*
    - lepton p, p_T, impact parameter, lepton jet topology
    - charge correlation lepton-opposite b

The "hard" part: $b \rightarrow u$

- *Access the largest phase space to limit theoretical uncertainties in extracting V_{ub}*
- *Need to suppress (and control ... !) the overwhelming $b \rightarrow c$ background*

ALEPH new b →lνX measurement (1)

Look for leptons opposite to hemispheres tagged in 3 ways

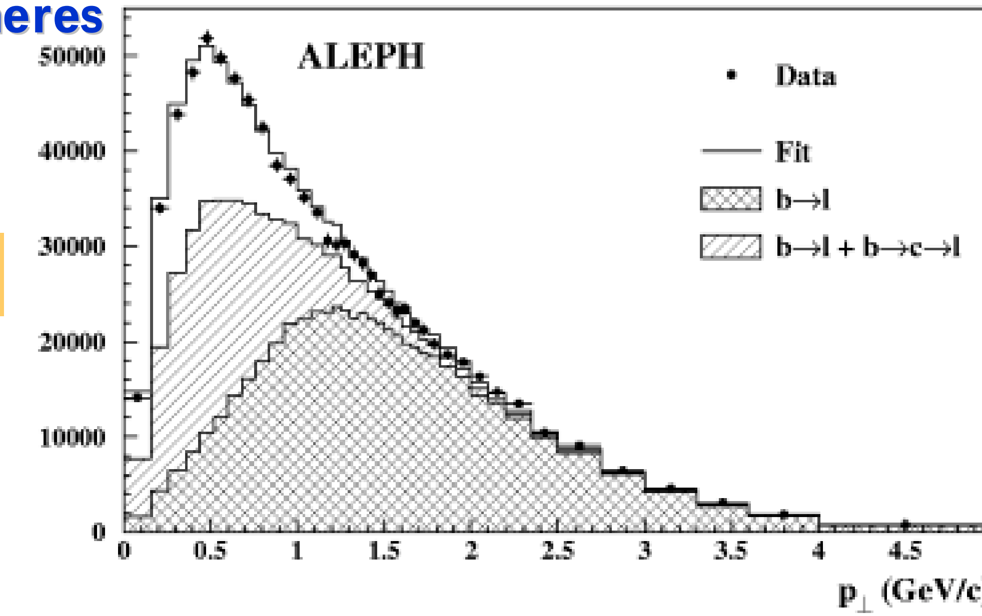
b→c→ l separated by p_T spectrum

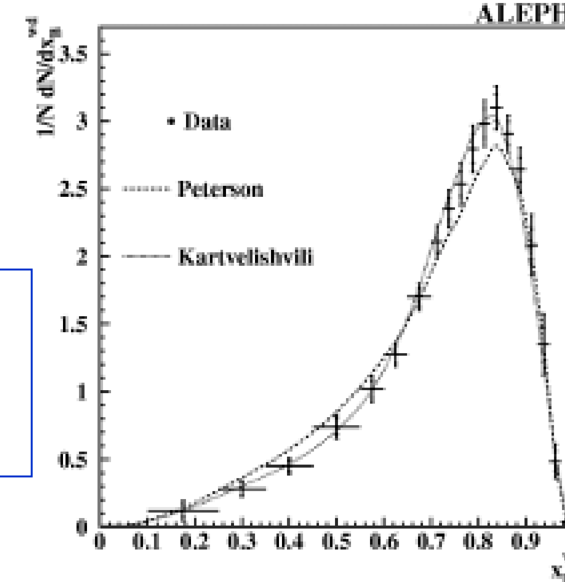
①Hard lifetime-mass tag (B sample)

$$L = \frac{e^{-\mu}\,\mu^{N}}{N!}\,\Pi_{j=1}^{N} F(p_T^{j})$$

counting — p_T spectrum

Weighted sum **Relative contributions**
of cascade and direct BR





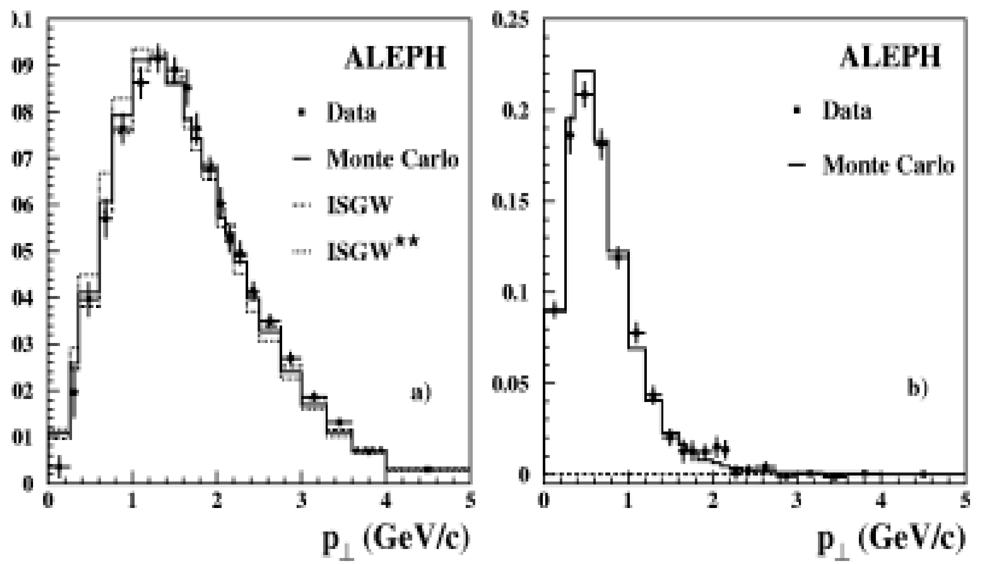
- Sensitive to the modelling of the predicted lepton spectra
- Use measured B meson momentum spectrum from ALEPH to reduce modelling systematics

ALEPH new $b \to l\nu X$ measurement (2)

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

Opposite b-tag	b charge Q_b
② lepton with $p_T > 1.25$ GeV/c (P sample)	Lepton charge
③ Loose lifetime-mass tag (J sample)	Q_{HEMI} =f(jet charge, i.p. signif.)

$$L = \underbrace{\frac{e^{-\mu}\mu^{N}}{N!}}_{\text{counting}} \times \underbrace{F_P^{N_{OP}}(1-F_P)^{N_{SP}}}_{\text{Charge (P)}} \times \underbrace{F_J^{N_{OJ}}(1-F_J)^{N_{SJ}}}_{\text{Charge (J)}}$$



Fit numbers of opposite (same) charge lepton candidates N_O (N_S) to the expected fractions $F_{P,J}$ and $(1- F_{P,J})$: 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 →lνX measurement (3)

- Two BR(b →l) compatible results

  p_T:11.07 ± 0.07$_{stat}$ ± 0.13$_{syst}$ ±0.44$_{model}$ %

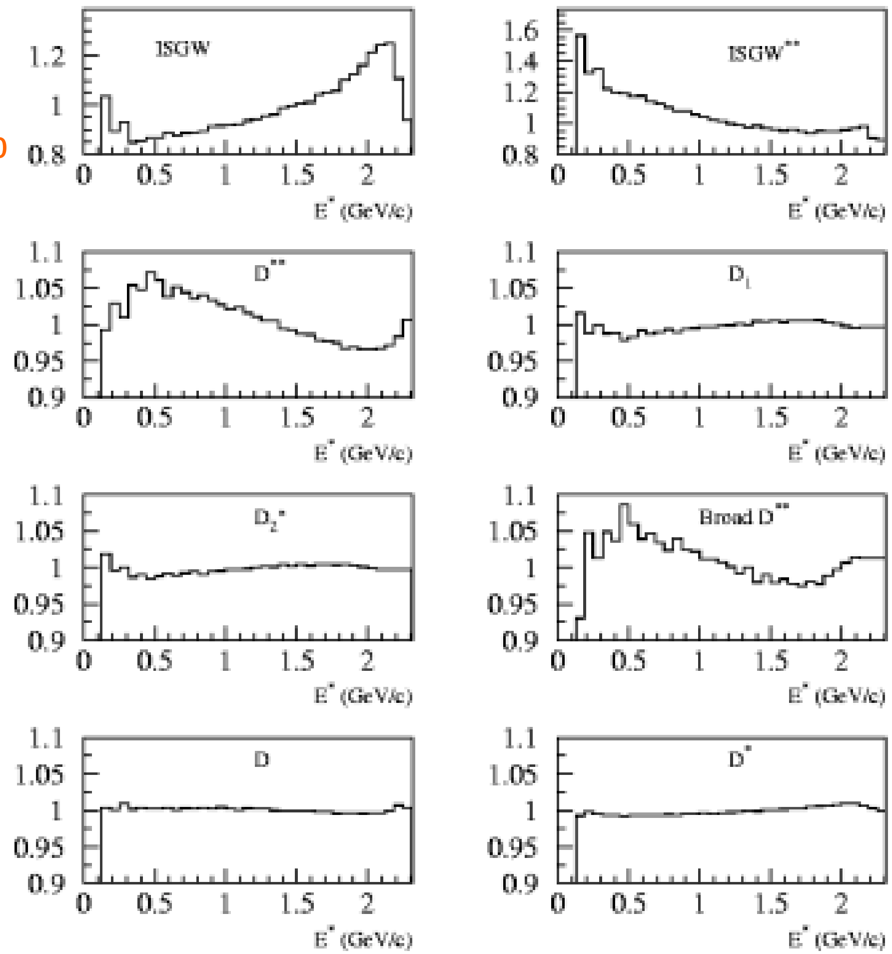
  Q_b:10.57 ± 0.11$_{stat}$ ± 0.29$_{syst}$ ±0.20$_{model}$ %

- Modelling errors:

  vary relative fractions of D/D*/D** from measured values (new approach!)

Process	BR (%)
D l ν	1.95±0.27
D *l ν	5.05±0.25
D** l ν	2.7±0.7
with D^*_1 l ν	0.63±0.11

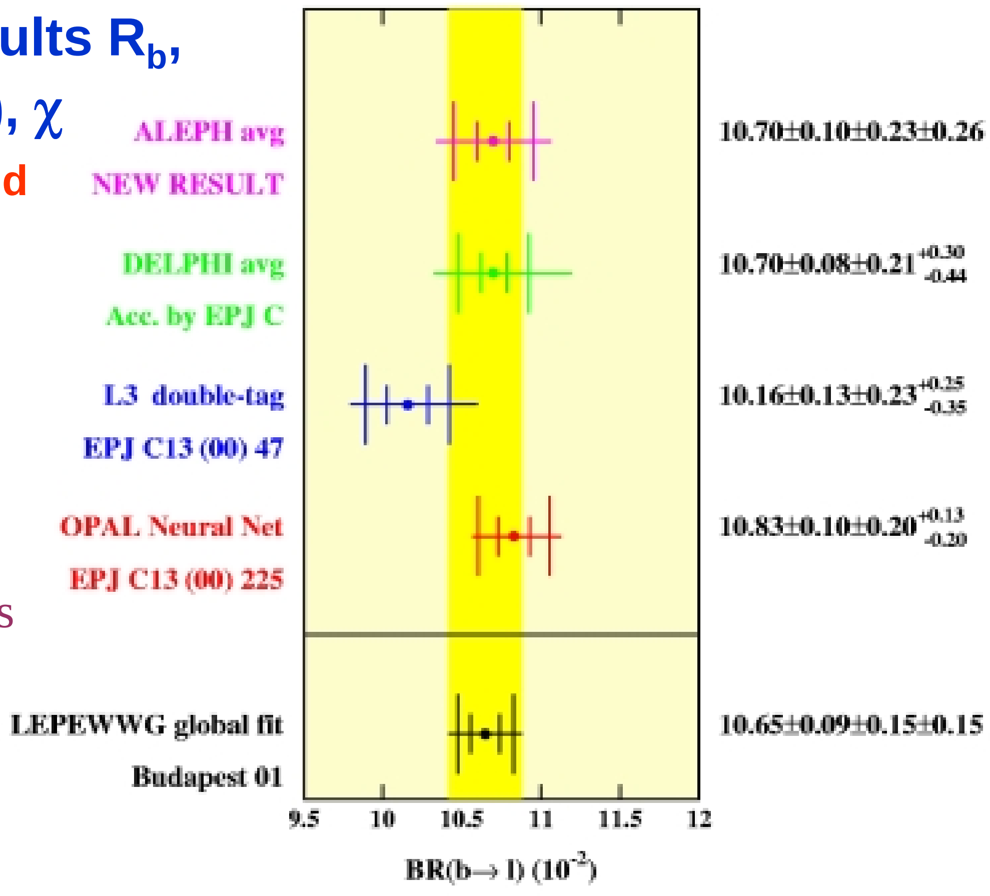
minimise the error coming from b fragmentation using ALEPH measurement



$$BR(b \to l) = (10.70 \pm 0.10_{stat} \pm 0.23_{syst} \pm 0.26_{model})\%$$

LEP BR(b→ l) average

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



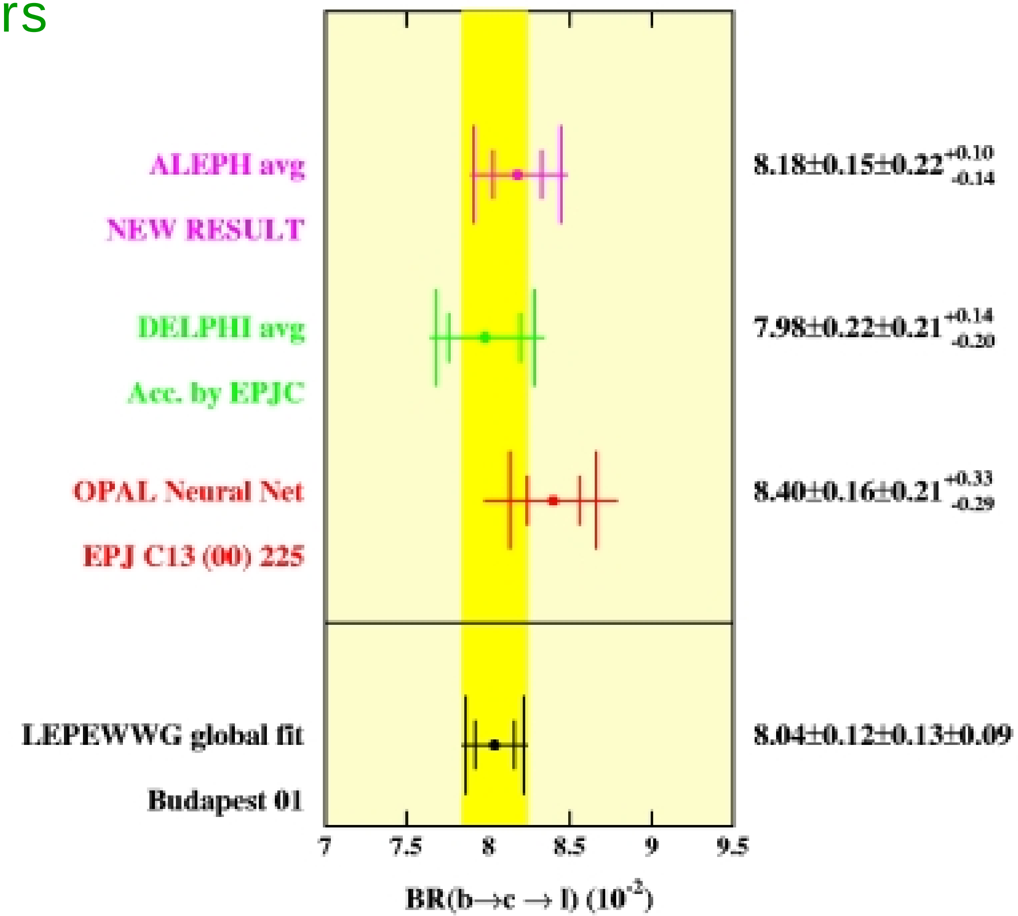
uncertainty from the modelling of b→ l dominates

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

LEP BR (b → c→ l) average

- Global fit to Heavy Flavours results from LEPEWWG

  - large uncertainty from the modelling of b→ l
  - statistical error sizeable



Toward an extraction of $|V_{cb}|$

- Semileptonic decay width predicted from Operator Product Expansion and HQET:

$$\Gamma_{sl}^{c} = \frac{G_F^2 m_b^5}{192\pi^3} |V_{cb}|^2 \left[z_0 \left(1 - \frac{\mu_\pi^2 - \mu_G^2}{2m_b^2} \right) - 2\left(1 - \frac{m_c^2}{m_b^2} \right)^4 \frac{\mu_G^2}{m_b^2} - \frac{2\alpha_S}{3} z_0^{(1)} + O(\alpha_S^2) \right]$$

Known phase space factors

- Experimentally measure

$$\Gamma_{sl}(b \to X_c l\nu) = \frac{BR(b \to X_c l\nu)}{\tau_b}$$

τ_b = average b hadron lifetime

assume the semileptonic width for all b hadrons to be equal:

$$BR(b \to X_c l\nu) = \Gamma_{sl}\left(f_{B^-}\tau_{B^-} + f_{B^0}\tau_{B^0} + f_{B_S}\tau_{B_S} + f_{\Lambda_b}\tau_{\Lambda_b} \right)$$

supported by measurements:

$BR(\Lambda_b \to Xl\nu) \stackrel{*}{=} (8.0 \pm 1.2)\%$	$BR(b \to Xl\nu) = (10.65 \pm 0.23)\%$
$\tau_{\Lambda_b} = (1.208 \pm 0.051)$ ps	$\tau_b = (1.561 \pm 0.014)$ ps

15% uncertainty in Γ_{sl} for b-baryons gives a 1.5% error on derived Γ_{sl}

*P. Gagnon talk @ EPS99 Tampere

Inclusive $|V_{cb}|$ extraction

- From OPE predictions

I.I. Bigi, M. Shifman, N. Uraltsev, *Annu. Rev. Nucl. Part. Sci.* **47** (1997) 591

$$|V_{cb}| = 0.0411\sqrt{\frac{B(b\to l\nu X_c)}{0.105}\cdot\frac{1.55\,ps}{\tau_B}}\times\left(1-0.024\left[\frac{\mu_\pi^2-0.5GeV^2}{0.2GeV^2}\right]\right)\times$$
$$(1\pm 0.015(pert)\pm 0.010(m_b)\pm 0.012(1/m_b^3))$$

Add theoretical uncertainties linearly

m_b(1 GeV) =(4.58± 0.06) GeV/c^2

average b-hadron lifetime: τ_b = 1.561±0.014 ps

$$|V_{cb}|^{incl} = (40.9 \pm 0.5_{\,exp} \pm 2.4_{\,theo})\ 10^{-3}$$

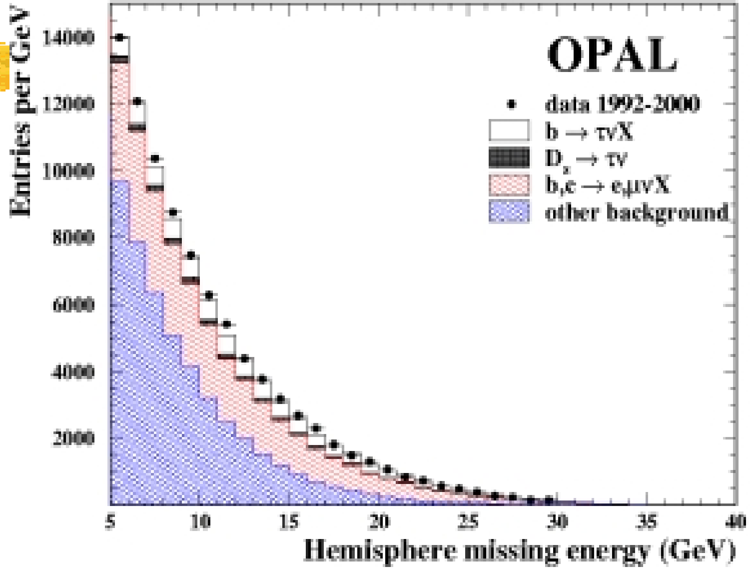
Testing HQET using b →X τ ν

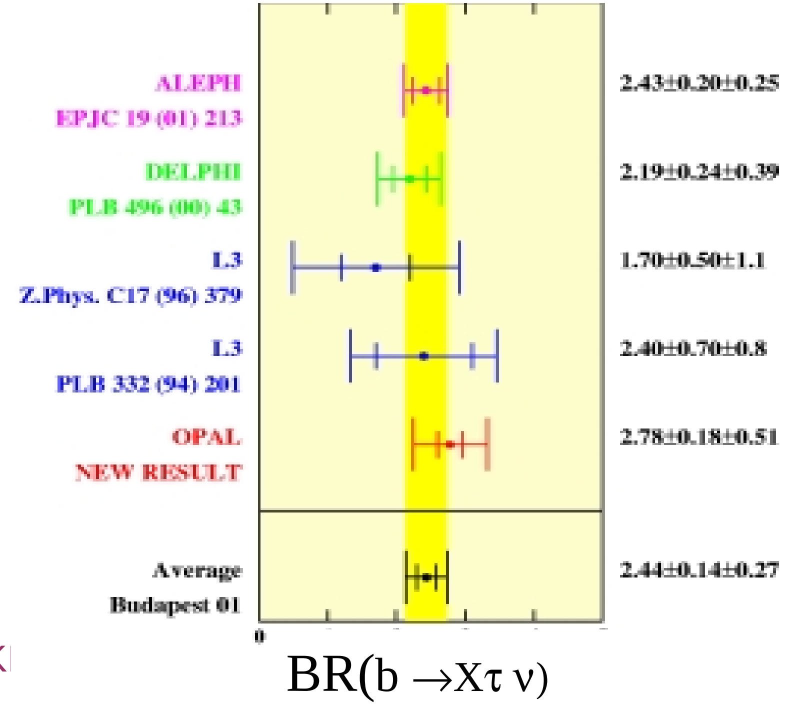
- HQET predicts the value for b →Xτ ν

  in absence of new physics the ratio

  $$R_\tau = \frac{BR(b \to X\tau\nu)}{BR(b \to cl\nu)}$$

  is controlled only by the lepton masses
- Two new measurements for this conference:
  - Look for an excess of missing energy due to the presence of two neutrinos
  - ALEPH E. Phys. J. C19 (2001) 213
  - OPAL preliminary measurement
  - Nice agreement among LEP experiments





Constraints on μ_π (λ_1) term
Constraints on tan(β)/M_{H^+}

Exclusive $|V_{cb}|$ extraction

- $B_d \rightarrow D^* l \nu$ decays

Fit the decay rate as a function of the recoil D* energy:

$$w = v(B^0)\cdot v(D^*) = \frac{m_{B_d^0}^2 + m_{D^*}^2 - q_{l\nu}^2}{2 m_{B_d^0} m_{D^*}}$$

In HQET

$$\frac{d\Gamma}{dw} = K(w) F_{D^*}^2(w) |V_{cb}|^2$$

At zero recoil (w=1)

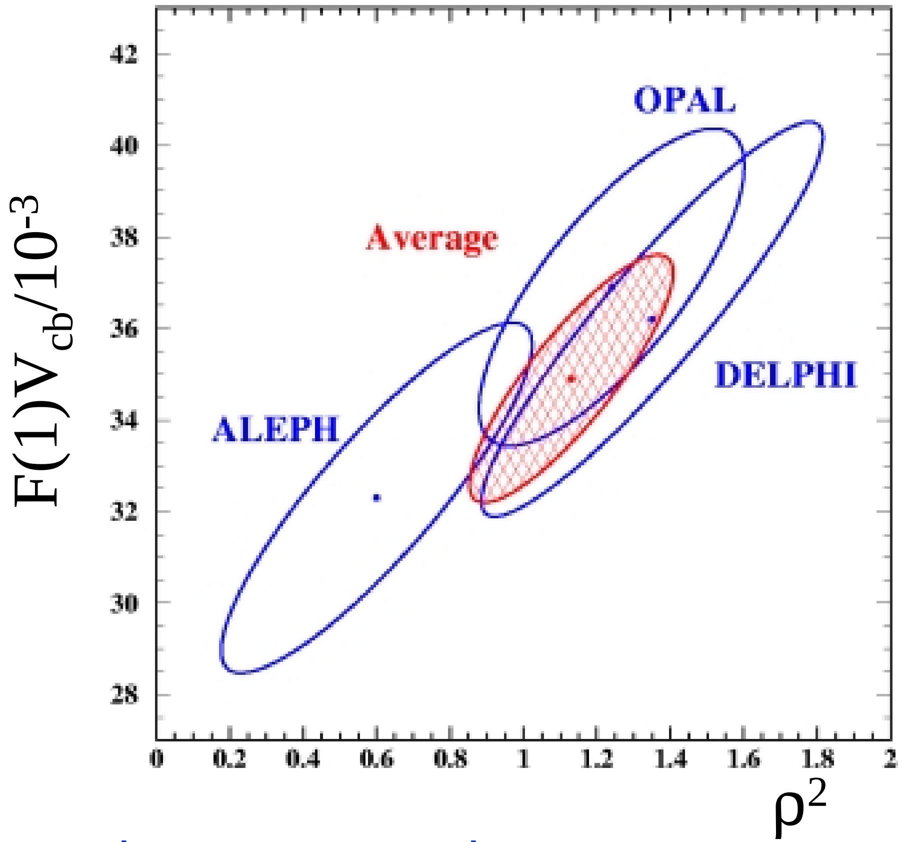
$F_{D^*}(1) = 1$ as $m_b \rightarrow \infty$

$$F_{D^*}(1) = 1 + O(\alpha_S/\pi) + \delta_{1/m_b^2} + \delta_{1/m_b^3}$$

$$= 0.88 \pm 0.05$$ **Bigi et al.**

shape around w=1 taken from Caprini, Lellouch and Neubert

- Fit simultaneously F(1) and the slope



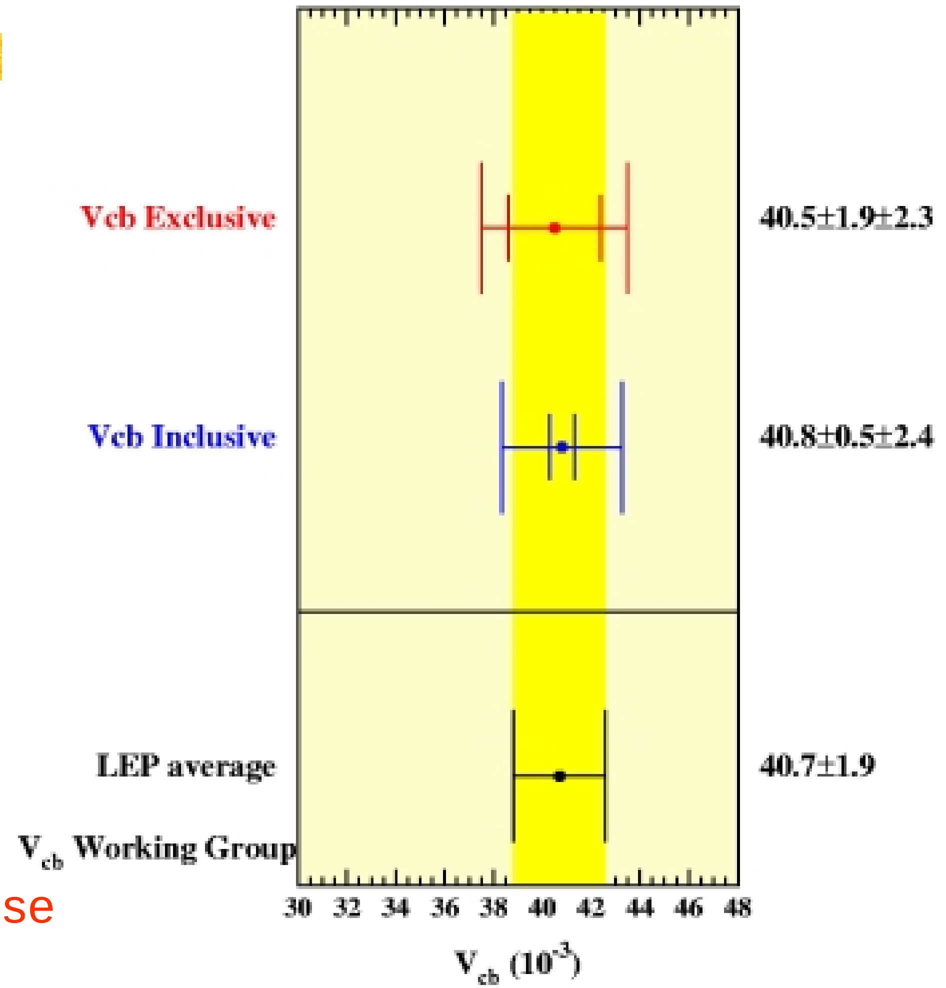
- Main exp. uncertainty: D** background subtraction
  - take 0 →100 % variation

$|V_{cb}|$ LEP average - Summary

- Inclusive: from BR($b \to l\nu X_c$)
- Exclusive: from $B \to D^* l\nu$

Average takes into account correlations

- theoretical uncertainties in μ_π
- modelling of $b \to l$
- experimental systematics



Nice agreement between the two measurements

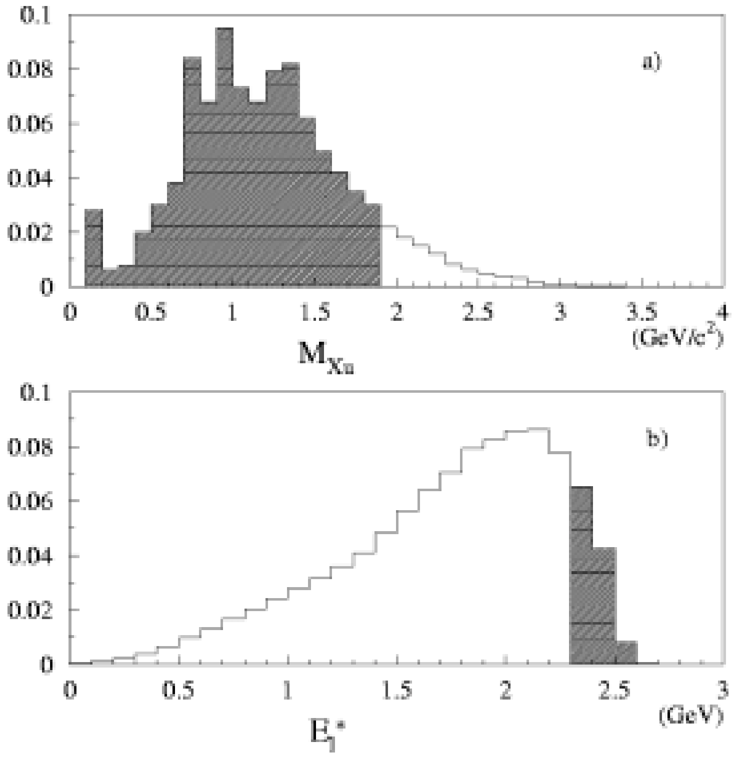
Inclusive determination is more precise

Theoretical uncertainty dominates

$$|V_{cb}| = (40.74 \pm 0.16_{exp} \pm 1.88_{theo})\ 10^{-3}$$

$b \to l\nu X_u$ measurements

- b→u/ b→c separation based upon both lepton and hadronic system characteristics (M_X < charm threshold)



Invariant mass distribution
of the hadronic system sensitive
to ~80% of the rate

Signal simulation

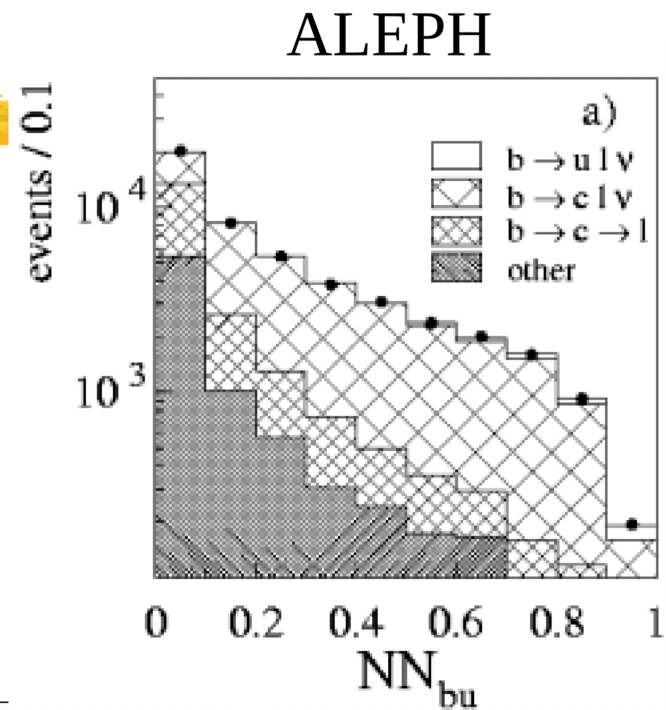
ALEPH, L3 and OPAL : hybrid model
Ramirez et al (PRD 41 (1990) 1496)

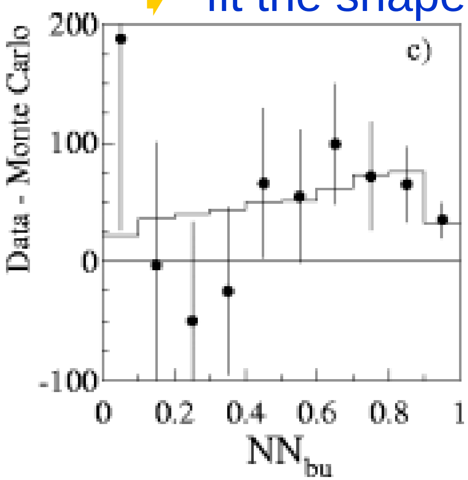
$M_X < \Lambda$ exclusive decay modes
$M_X > \Lambda$ inclusive decay modes
$\Lambda \sim 1.5$ GeV

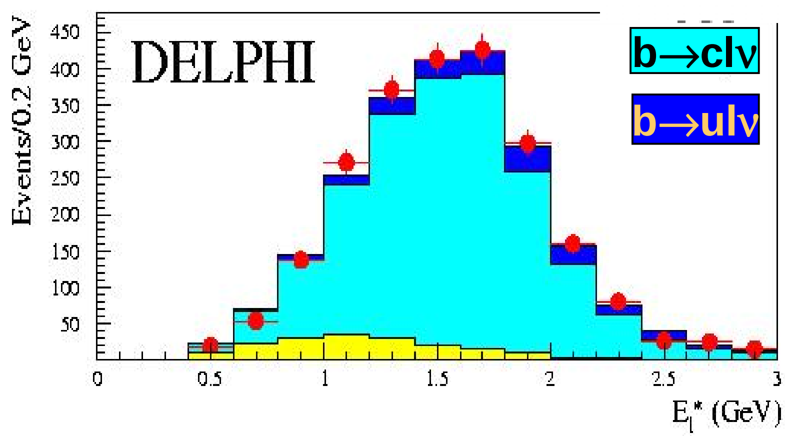
DELPHI uses an ad-hoc model similar to the hybrid one

General remarks

- Mature technique to extract the signal
  - control b→c background normalisation in signal depleted regions
    - optimisation based in minimising the b→ c shape backgrounds
    - careful understanding of the background topologies
  - fit the shape of expected signal



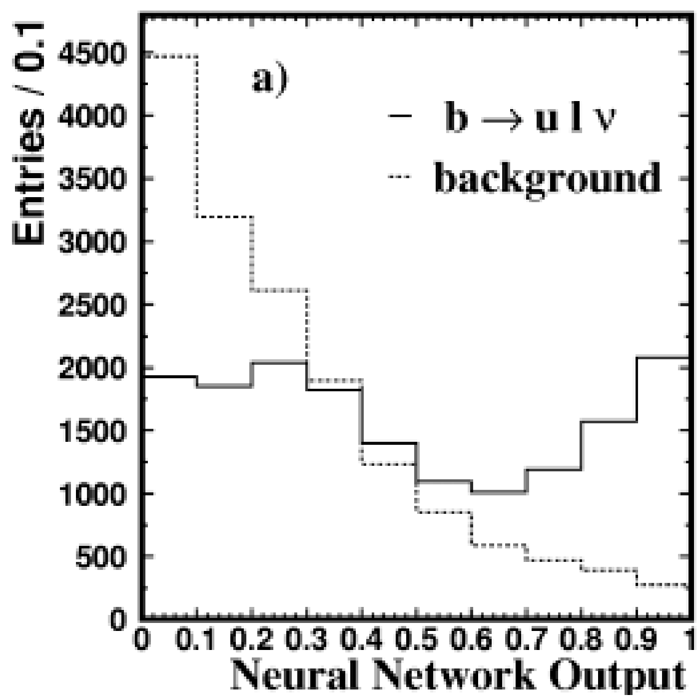


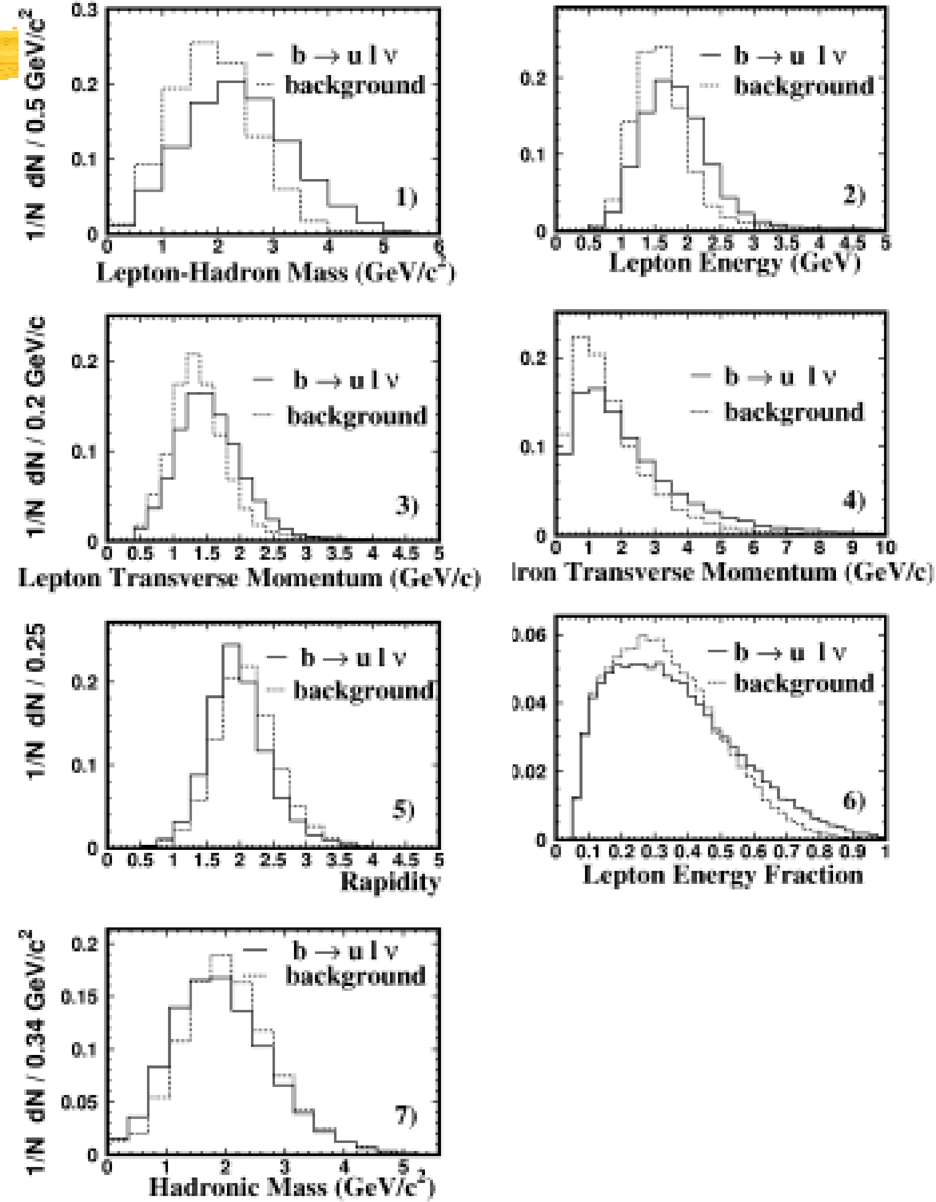


- Differences in the analysis techniques by the experiments give different sizes of systematic uncertainties for common surces

OPAL new measurement (1)

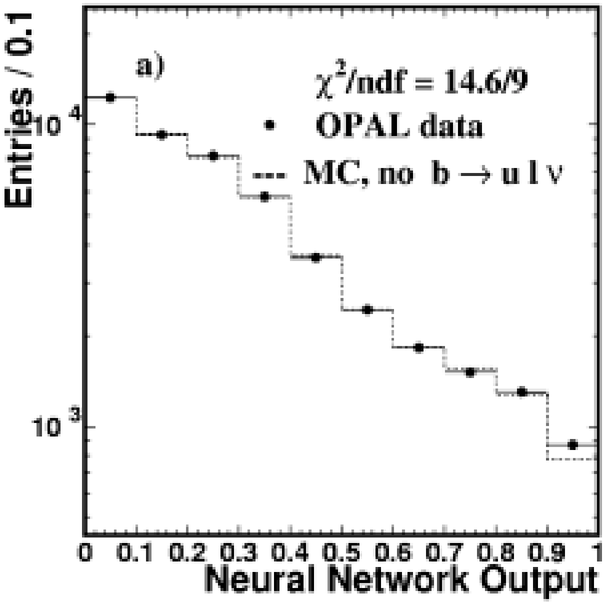
- select leptons using NN used for inclusive BR
    - remove $b \rightarrow c \rightarrow l$ decays
- separate $b \rightarrow u$ from $b \rightarrow c$ using a dedicated NN tuned to reduce total error (7 variables)

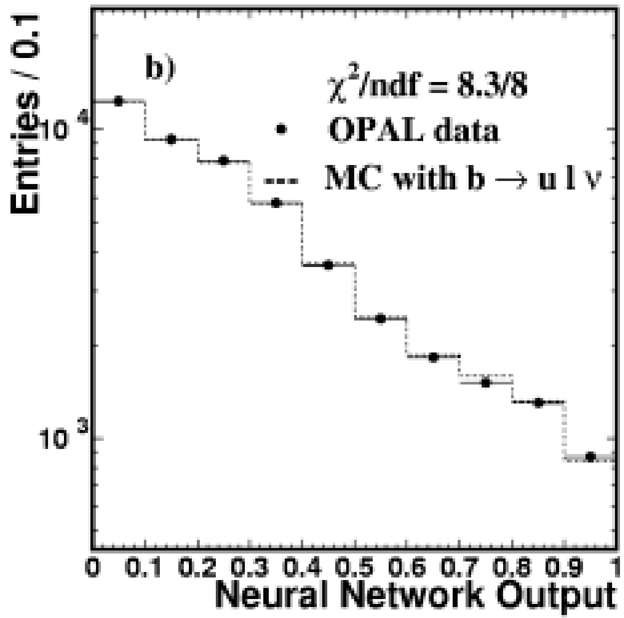




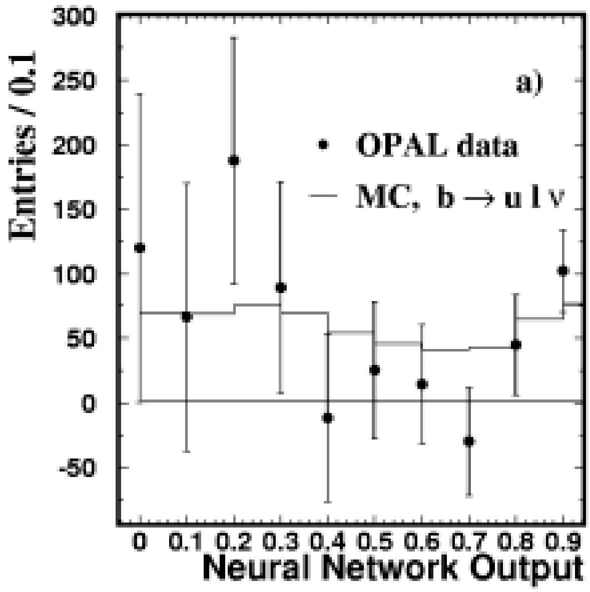
OPAL new measurement (2)

- Signal extracted from the last 3 bins





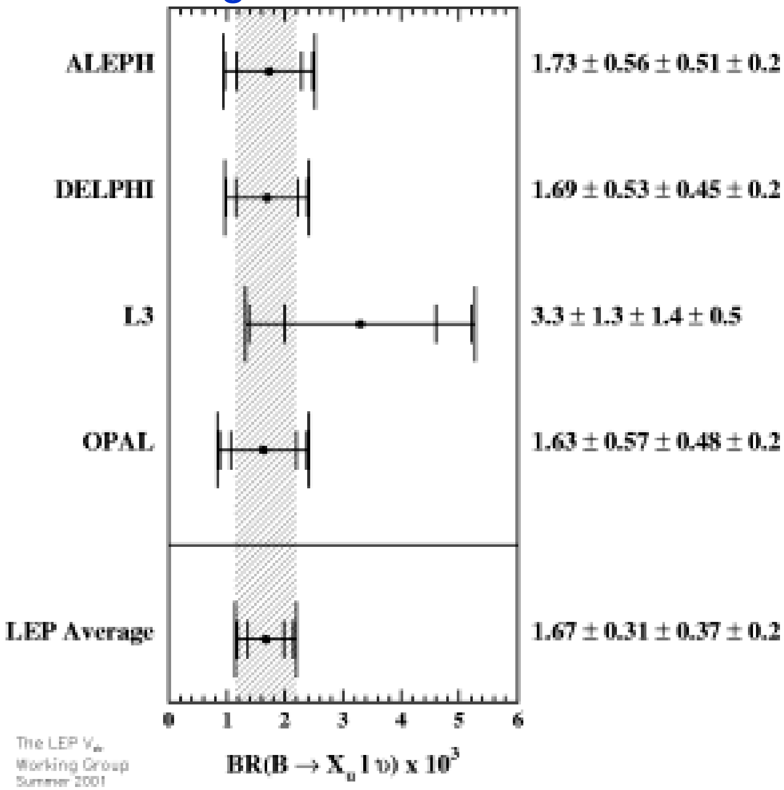
NN output after background subtraction



$$BR(b \to u l \nu) = (1.63 \pm 0.57 \pm {}^{0.55}_{0.62})\ 10^{-3}$$

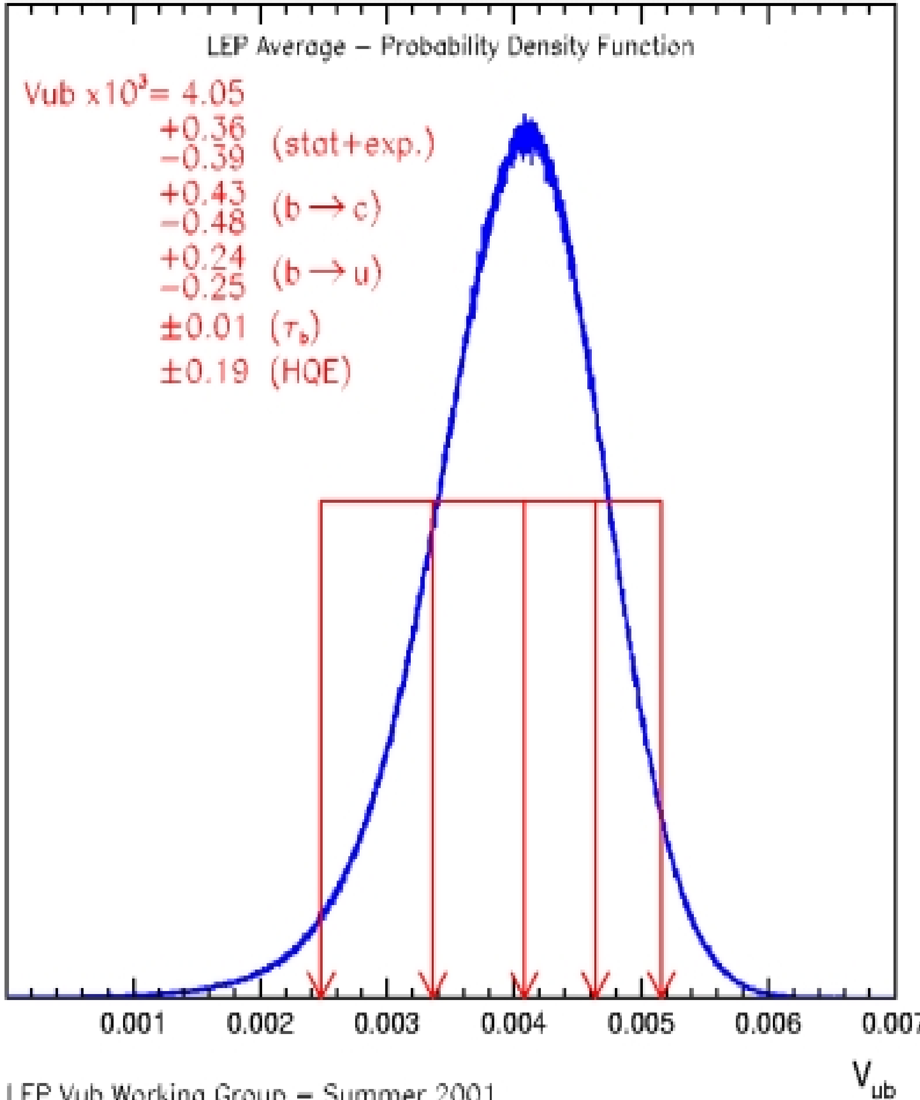
LEP average of $|V_{ub}|$

❶ Average BR measurements



❷ Use OPE predictions

$$|V_{ub}| = 0.0445\sqrt{\frac{B(b \to l\nu X_c)}{0.002}\cdot\frac{1.55\,ps}{\tau_B}}\times$$
$$(1 \pm 0.010(pert) \pm 0.035(m_b) \pm 0.030(1/m_b^3))$$



$$|V_{ub}| = (4.05 \; {}^{+\,0.64}_{-\,0.69})10^{-3}$$

Conclusions

- New and updated semileptonic B branching ratios measurements from LEP
  - $BR(b \to l) = (10.65 \pm 0.23)\%$
  - $BR(b \to c \to l) = (8.04 \pm 0.19)\%$
  - $BR(b \to \tau \nu X) = (2.44 \pm 0.30)\%$

- Updated V_{cb} and V_{ub} measurements

  $|V_{cb}| = (40.74 \pm 0.16_{exp} \pm 1.88_{theo}) 10^{-3}$

  $|V_{ub}| = (4.05 \pm 0.67_{exp} \pm 0.19_{theo}) 10^{-3}$