New determinations of $|V_{ub}|$ and $|V_{cb}|$ using the DELPHI detector at LEP

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Hyperons, Charm and Beauty Hadrons

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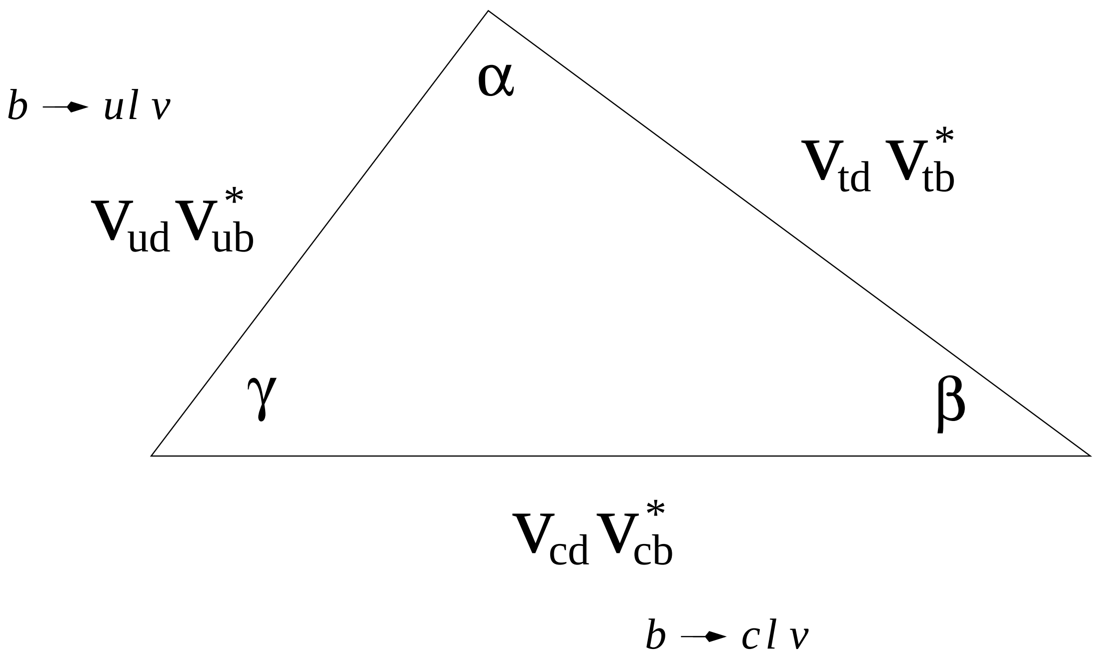


Outline of talk

- Determination of $|\mathrm{V}_{\mathrm{ub}}|$
  - The method
  - The dedicated generator
  - The analysis
  - The results
- Determination of $|\mathrm{V}_{\mathrm{cb}}|$ and a measurement of $\overline{B}^0 \to D^{*+} l\, \overline{\nu}$, $\overline{B}^0 \to D^* l\, \overline{\nu}$X
  - The method
  - Improvements in the experimental and theoretical approaches
  - The results
- Conclusions and comparison with other measurements

Determination of $|V_{ub}|$ in $b \to ul\nu$ decays

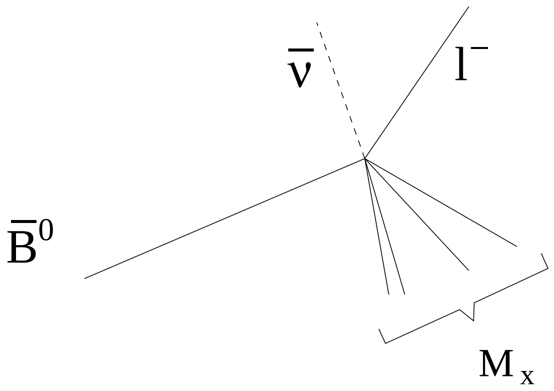
Previous Approaches:

- Endpoint of lepton spectrum in inclusive B decays
  - Theoretical uncertainties in extrapolation from small endpoint region
  - Gives PDG value of: $|V_{ub}| = (4.1 \pm 0.9) \times 10^{-3}$
  - Theoretical systematic error $\sim 20\%$

- Exclusive $B \to \pi\, l\, \nu$ and $B \to \rho\, l\, \nu$ decays
  - Model dependence in extracting $|V_{ub}|$ from form factors
  - Last published value: $|V_{ub}| = (3.3 \pm 0.2^{+0.3}_{-0.4} \pm 0.7) \times 10^{-3}$
  - Theoretical systematic errors $\sim 20\%$

New DELPHI measurement uses:

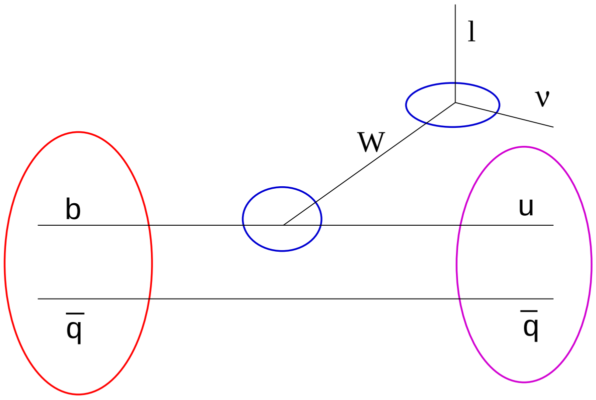
- M_x : mass of hadronic system recoiling against the lepton



- $M_x <$ charm mass for most $b \to ul\nu$ decays
- Shape can be described with a reduced model dependence

Special generator BTOOL has been developed to study application of this method.

The BTOOL generator



- kinematics of the b and spectator quarks inside the B hadron
- Q^2 distribution of W and kinematics of two body $b \to uW$ and $W \to l\nu$ decays
- hadronisation model for the $u\overline{q}$ system

Kinematics of b and spectator quarks described with three models:

Model	momentum description	Free parameters
ACCMM	b quark and light quark move back-to-back with momentum characterised by Fermi momentum p_F	Fermi momentum p_F spectator quark mass m_q
Parton	b quark carries fraction z of hadron momentum. z is described by the Peterson fragmentation function	Fragmentation parameter ϵ_b b quark mass m_b
QCD Universal Structure function	Ansatz for Fermi motion obtained directly from QCD. Light-cone momentum of heavy quark expressed as: k_+ = Effective b mass - b pole mass Function used is: $f(z) = z^a \, (1R - cz) \, e^{-cz}$ where $z = 1 - \frac{k_+}{\overline{\Lambda}}$	$\overline{\Lambda} = m_B - m_b$ kinetic energy operator $< p_b^2 >$

Kinematics of decays of b and W described by two body decays

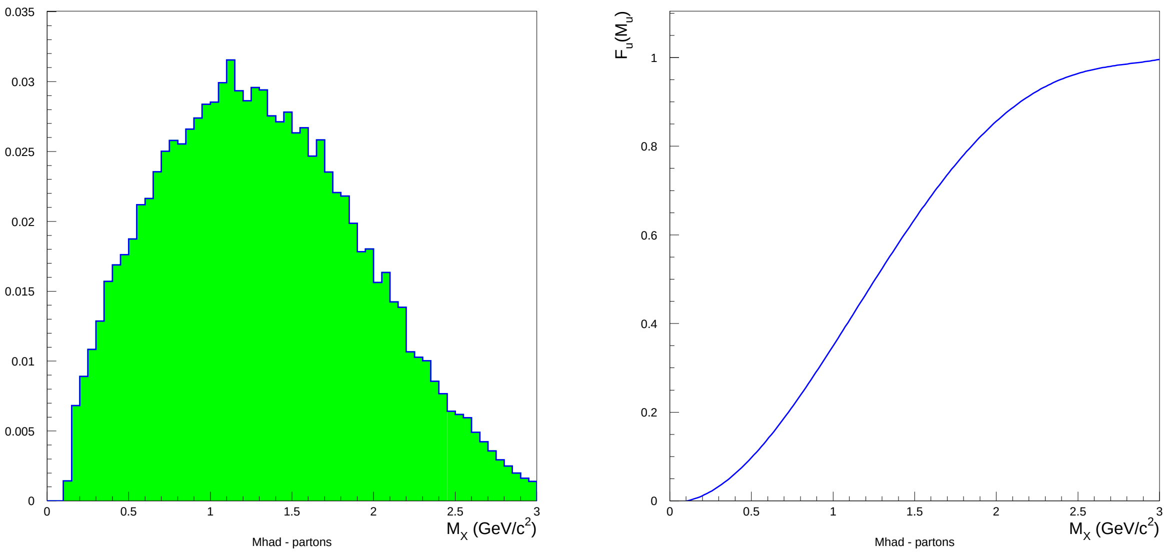
Hadronisation of $u\overline{q}$ system described with two models:

- parton shower model
- ISGW2 model taking resonant states into account

Mass of $u\bar{q}$ system before hadronisation

Define

$$F_u(M_{\rm cut}) = \#\ \text{events in b} \to \text{ul}\nu\ \ \text{distribution with } M_x < (M_{\rm cut})$$

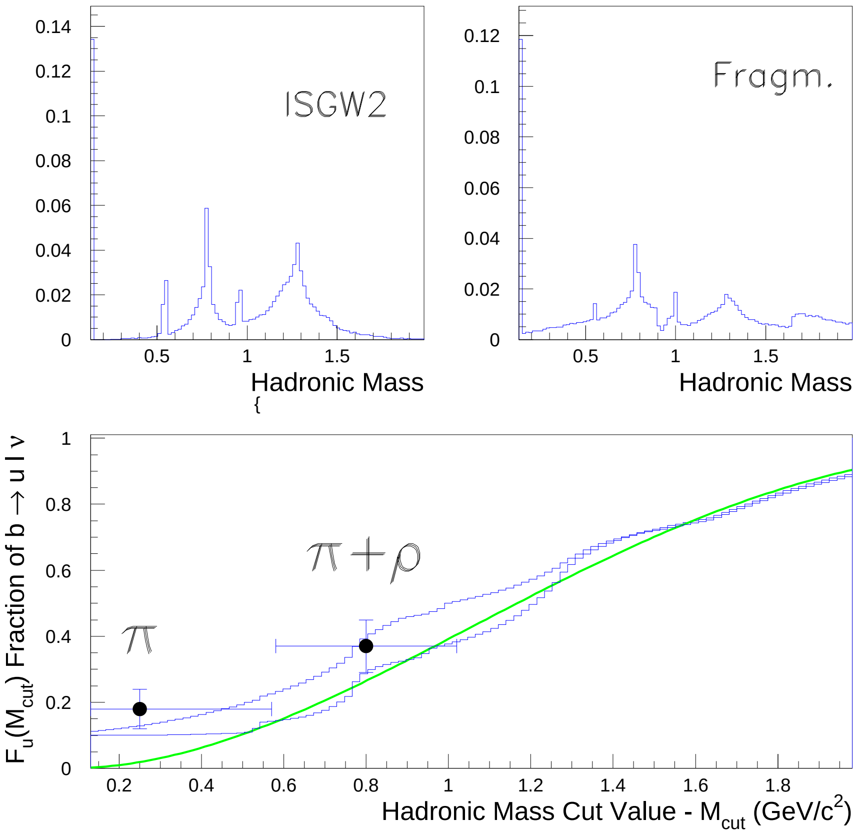


Systematic uncertainties on $F_u(M_{\rm cut})$:

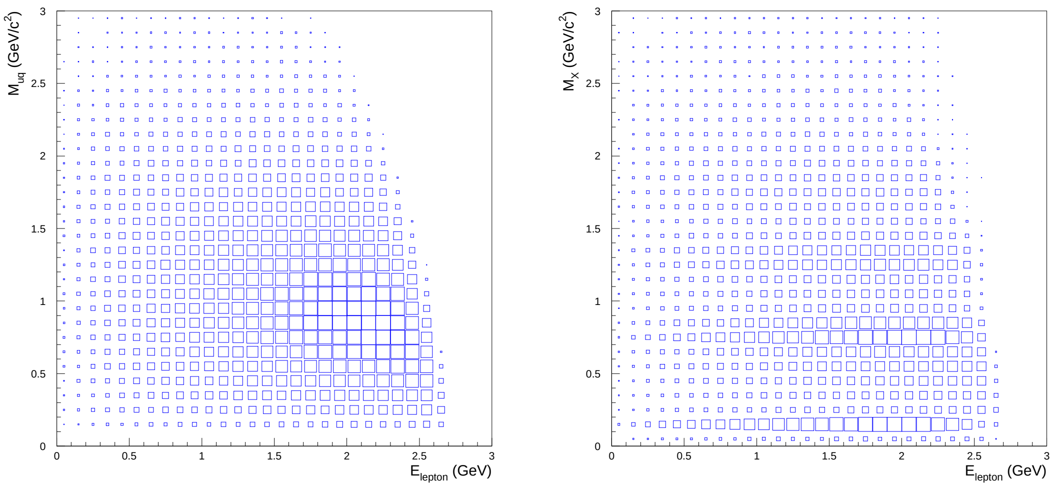
Parameter	$M_{\rm cut} = 1.25$ $F_u(M_{\rm cut}) \sim 0.48$	$M_{\rm cut} = 1.50$ $F_u(M_{\rm cut}) \sim 0.66$	$M_{\rm cut} = 1.75$ $F_u(M_{\rm cut}) \sim 0.82$
m_b	13%	8%	5%
$< p_b^2 >$	8%	5%	2%
Model	8%	3%	3%
Total Error	17%	10 %	6%

- low values of $M_{\rm cut}$ $\to$ better $b \to cl\nu$ rejection
- high values of $M_{\rm cut}$ $\to$ lower theoretical uncertainties

Choice of Hadronisation scheme $\rightarrow$ more theoretical uncertainty at low $M_{\rm cut}$ values:



Lepton Spectrum keeps memory of $u\overline{q}$ mass



Sequence of Analysis

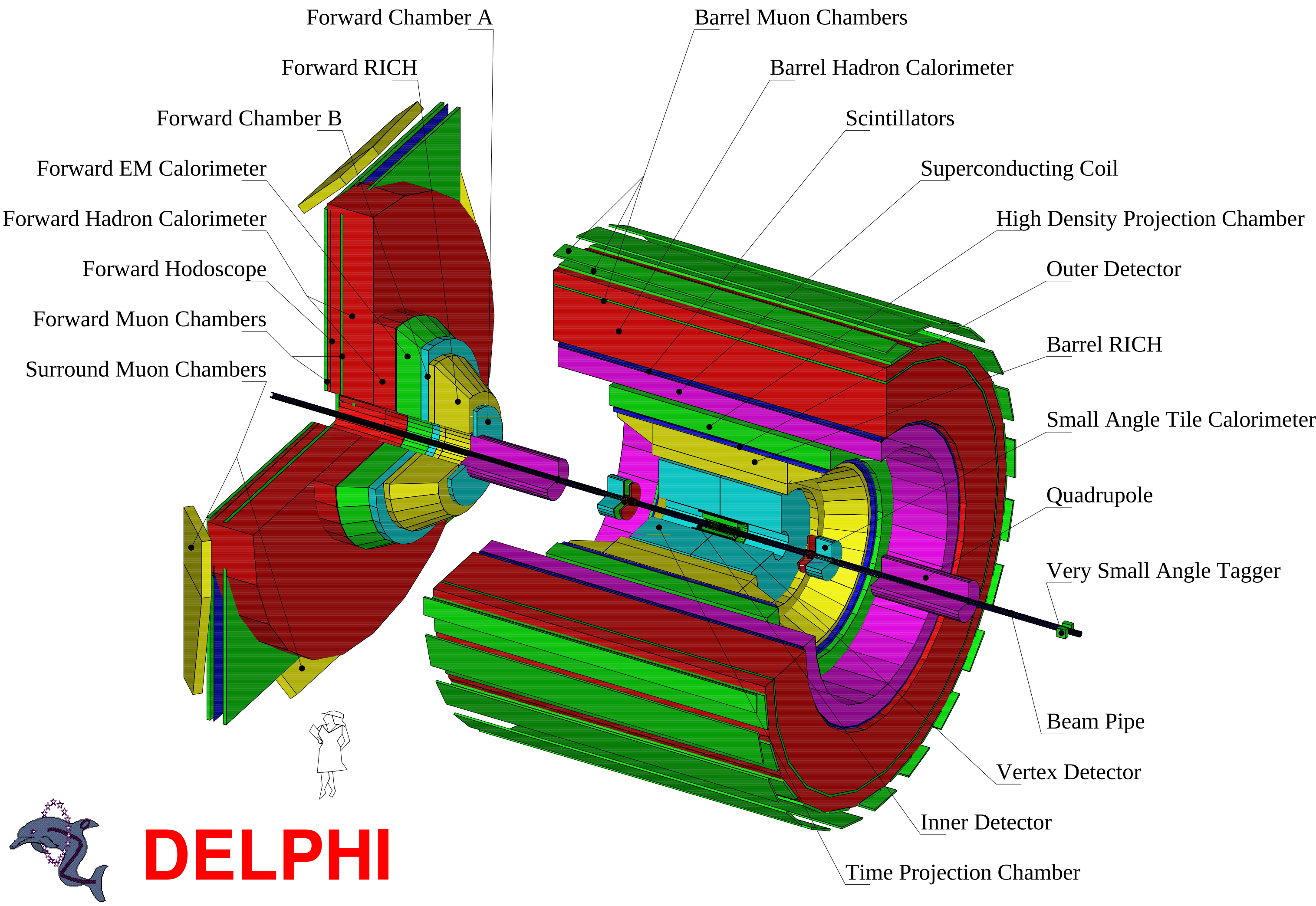
- Select semileptonic b decays

- reconstruct the mass of the hadronic system with as high an efficiency and purity as possible

- divide decays into samples enriched and depleted in $b \to ul\nu$ transitions, with a mass cut, and with independent cuts

- Fit the lepton energy distribution, interpreting data-mc excess in the $b \to ul\nu$ enriched samples as $b \to ul\nu$ signal

The DELPHI experiment



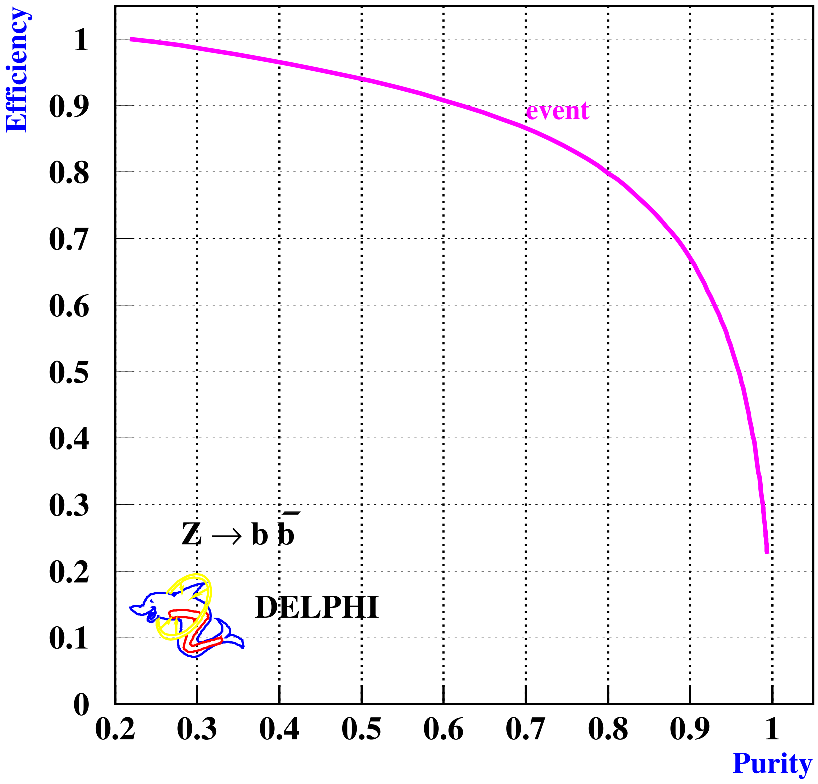
DELPHI

Analysis performed with 2.8 M Z^0hadronic decays

Five times this amount of simulated data was used

DELPHI characteristics exploited in this analysis:

- b-tagging



- μ ID
  $\epsilon = 80\%, \mathrm{misid} = 0.68\%$

- electron ID
  $\epsilon = 80\%, \mathrm{misid} = 0.68\%$

- Particle identification using RICH and TPC dE/dx:
  Charged Kaon identification, $K_s^0 \to \pi^+\pi^-$ reconstruction

- π^0 reconstruction using fine granularity of electromagnetic calorimeter

Reconstruction of Hadronic System

b tagging observables

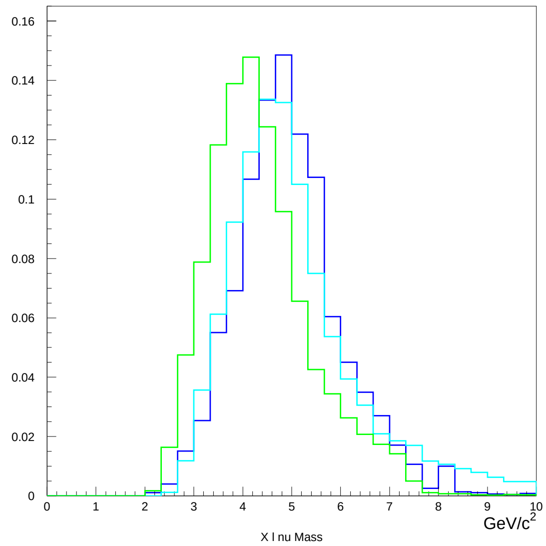
all tracks	charged tracks with VD hits
• Transverse momentum • momentum divided by Jet Energy • mass • rapidity • rank in energy • invariant mass contribution	• impact parameters w.r.t. secondary vertex in three dimensions • χ^2 contribution to secondary • impact parameter w.r.t. primary normalised to secondary decay length

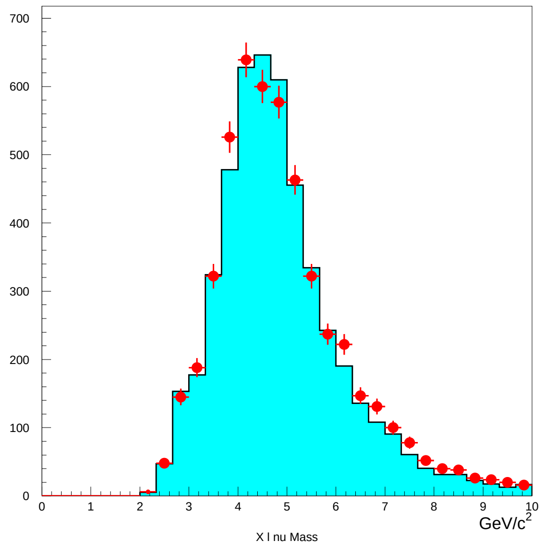
Track probability

vertex with charged tracks, K^0 and π^0 candidates

Mass of Hadronic System

Partially reconstructed vertices cause leakage into the $b \to ul\nu$ distributions:





Remove bad events where:

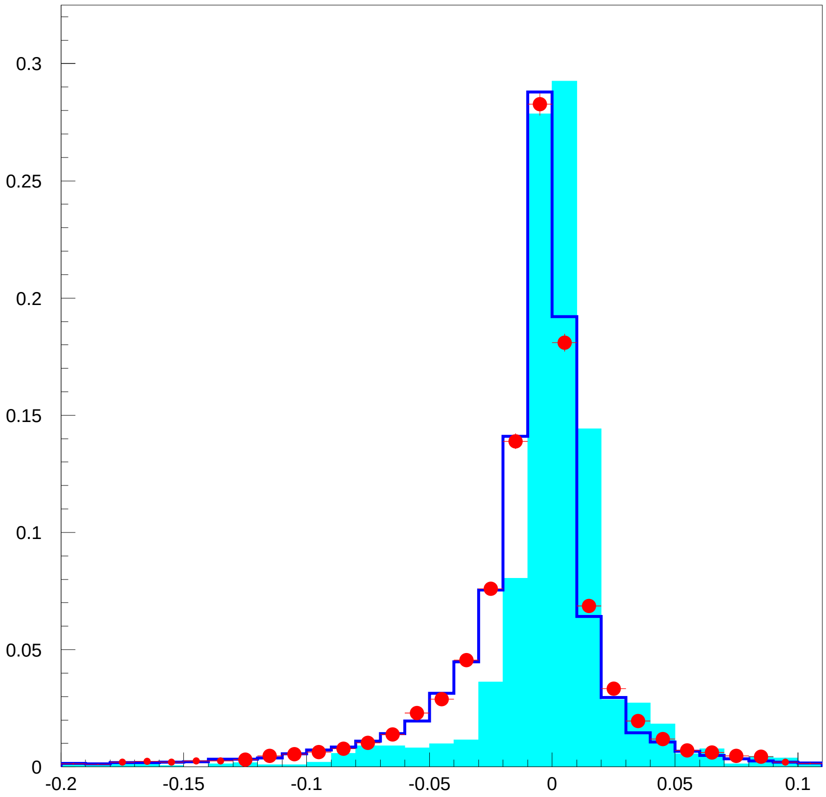
- total mass for the candidate B $< 3.0\ GeV/c^2$
- Events with hard tracks incompatible with both primary and secondary vertex
- Events with two identified leptons ($b \to c \to l$ cascade candidates)
- Events with a soft pion compatible with a $D^{*+} \to D^0\pi^+$ decay
- Events where the lepton charge is equal to that of the hadronic system
- In cases with a low total mass for the candidate B $< 4.5\ \mathrm{GeV/c^2}$ the hadronic mass is rescaled

Semileptonic B sample:

~ 12000 events
B efficiency : 16.5%
B purity : 2%

Enriching sample in $b \to ul\nu$

- **Impact parameter of lepton w.r.t. secondary vertex**



$\to$ Cut placed at 0.015 cm

- **Strange particle tagging:**

  Monte Carlo studies show that:

  $b \to cl\nu$ events : 37% with identified kaon

  $b \to ul\nu$ events : 14% with identified kaon

$\to$ Cut placed on decays with an identified $K^{\pm}$ or K^0 with $p > 2.5\mathrm{GeV/c}$

RESULTS

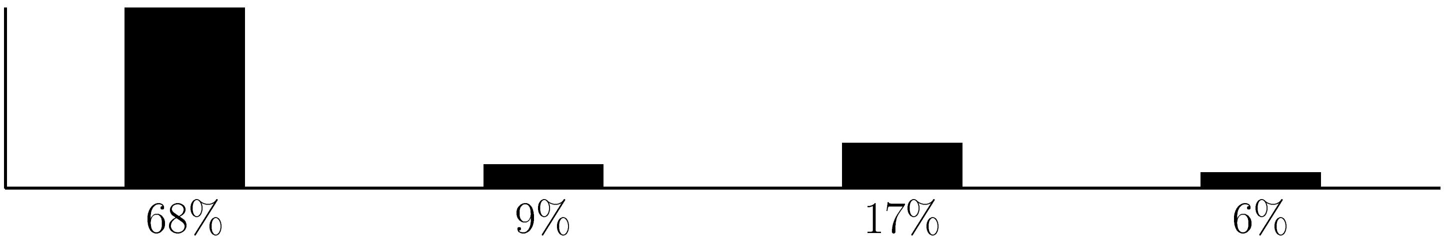
data : 12134 ± 110
mc : 11898 ± 50

	$M_x < 1.6\mathrm{GeV/c^2}$	$M_x > 1.6\mathrm{GeV/c^2}$
data :	3373 ± 58	8761 ± 94
mc :	3263 ± 27	8635 ± 42

	enriched	depleted	enriched	depleted
data :	2292 ± 48	1081 ± 33	5017 ± 71	3744 ± 61
mc :	2108 ± 22	1155 ± 15	4950 ± 32	3685 ± 27
	Sample i	Sample ii	Sample iii	Sample iv

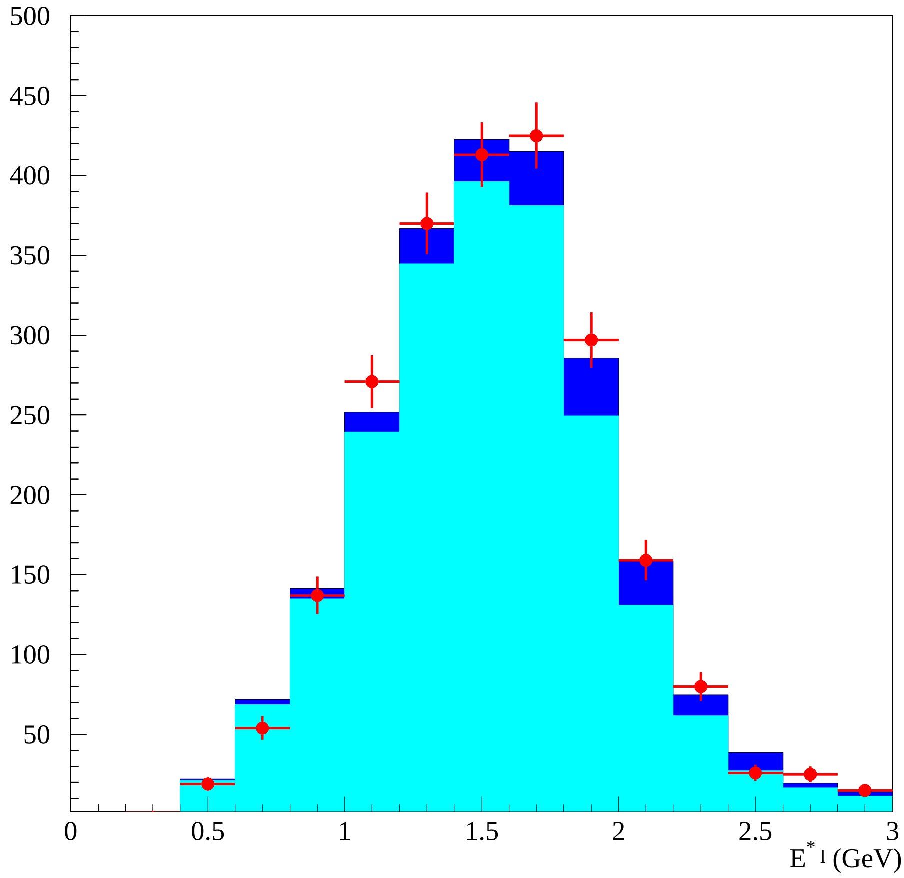
Excess$=184 \pm 53$

Signal Fraction



Extracting $|V_{ub}|$

Fit to lepton energy distribution in each class, with an overall normalisation factor.



$$\frac{|V_{ub}|}{|V_{cb}|} = 0.104 \pm 0.012(\mathrm{stat}) \pm 0.015(\mathrm{syst}) \pm 0.008(\mathrm{model}))$$

$$\mathrm{normalisation} = 0.985 \pm 0.011$$

systematic uncertainties

Charm decay systematics	Value $\pm$ Range	Syst. Error
$BR(D \to K^0 X)$	0.53 ± 0.05	0.0062
$BR(D \to 0, 1\text{prong})$	0.22 ± 0.02	0.0020
$\frac{BR(b \to l)}{BR(c \to l)}$	$\frac{0.112 \pm 0.002}{0.094 \pm 0.010}$	0.0063
Total		0.0091

B hadron production/decay	Value $\pm$ Range	Syst. Error
$f(B_u) + f(B_d)$	0.834 ± 0.026	0.0049
$< x_b >$	0.702 ± 0.008	0.0010
b lifetime	1.566 ± 0.018	0.0014
$BR(b \to c\bar{c}s)$	0.15 ± 0.03	0.0025
$BR(B \to D^* l\nu + D^{**} l\nu)$	0.069 ± 0.010	0.0048
Total		0.0075

Detector Systematics	Value $\pm$ Range	Syst. Error
Lepton ID efficiency	$\pm 2.5\%$	0.0015
e/μ ID purity	$\pm 10\% / \pm 4.5\%$	0.0020
Hadronic Multiplicity		0.0065
Neutral Energy Resolution		0.0010
l impact parameter resolution		0.0070
K ID Efficiency	$\pm 5\%$	0.0017
Total		0.0101

$b \to u l \nu$ model	Value $\pm$ Range	Syst. Error
Signal efficiency	$\pm 2.4\%$	0.0012
m_b	4.82 ± 0.10	0.0057
$< p_b^2 >$	0.4 ± 0.1	0.0012
Kinematic Model		0.0010
Hadronisation model		0.0060
Total		0.0085

Total systematic error $= 0.0177$

systematic uncertainties

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Kinematic Model		0.0010
Hadronisation model		0.0060
Total		0.0085

Total systematic error $= 0.0194$

Determination of $|\mathrm{V_{cb}}|$ from a study of the decay $\overline{B}^0 \rightarrow D^{*+} l \, \overline{\nu}$

Define ω, the product of the $\overline{B}^0$ and D^{*+} four velocities:

$$\omega = k_{\overline{B}^0} \cdot k'_{D^{*+}}$$

For heavy quarks, the decay rate as a function of ω is:

$$d\Gamma/d\omega = \frac{G_F^2}{48\pi^3 \hbar \tau_{\overline{B}^0}} M^3_{D^{*+}} (M_{\overline{B}^0} - M_{D^{*+}}) \sqrt{\omega^2 - 1} (\omega + 1)^2$$
$$\times |\mathrm{V_{cb}}|^2 \mathcal{F}^2(\omega) [1 + \frac{4\omega}{1+\omega} \frac{1 - 2\omega r + r^2}{(1-r)^2}]$$

When $\omega = 1$, $\mathcal{F}(1) \rightarrow 1$; modified by QCD, HQET

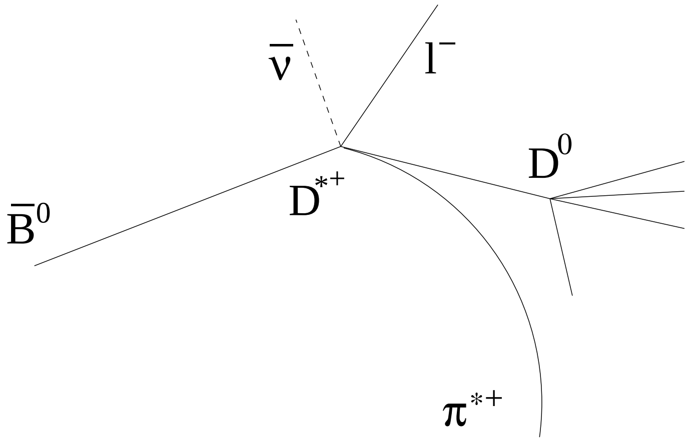
$$\mathcal{F}(1) = 0.91 \pm 0.03$$

$\mathcal{F}(1)$ determined from a fit to ω and an extrapolation to $\mathcal{F}(1)$ (where the phase space vanishes).
Extracted value depends on:

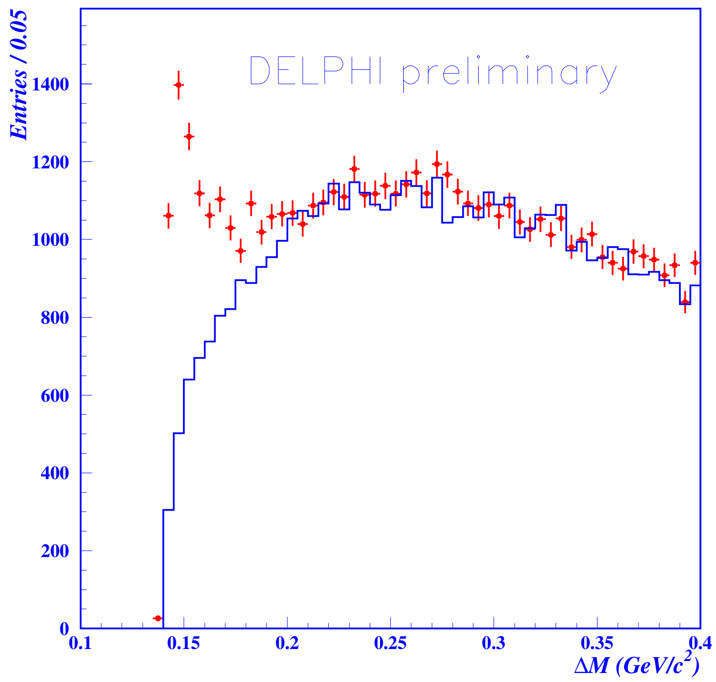
- $\mathcal{F}(1)$ curvature parametrization
- Knowledge of background
- Shape of background
- Experimental ω resolution

This measurement is the first one to use the latest parametrisations of the $\mathcal{F}(1)$ curvature (Caprini *et. al.*) and the latest predictions of the ω description of the $D**$ cascade background (Morenas *et. al.*).

- The analysis of Zeit.Phys. C71 (1996) 539 is updated
- The full data set is used
- New experimental treatments give a much reduced error



$\sim 7000\ D^{*+}$ events are selected:



Fit for $|\mathrm{V_{cb}}|$ depends crucially on kinematics of the $\overline{B}^0$ and D^*

- Direction of $\overline{B^0}$ measured in a new way, using the vector joining the primary and secondary vertices

- Combination made with the old method of momentum conservation

- Mass of system recoiling against the $D^{*+}l\nu$ constrained to be 0 $(= M_\nu^2)$

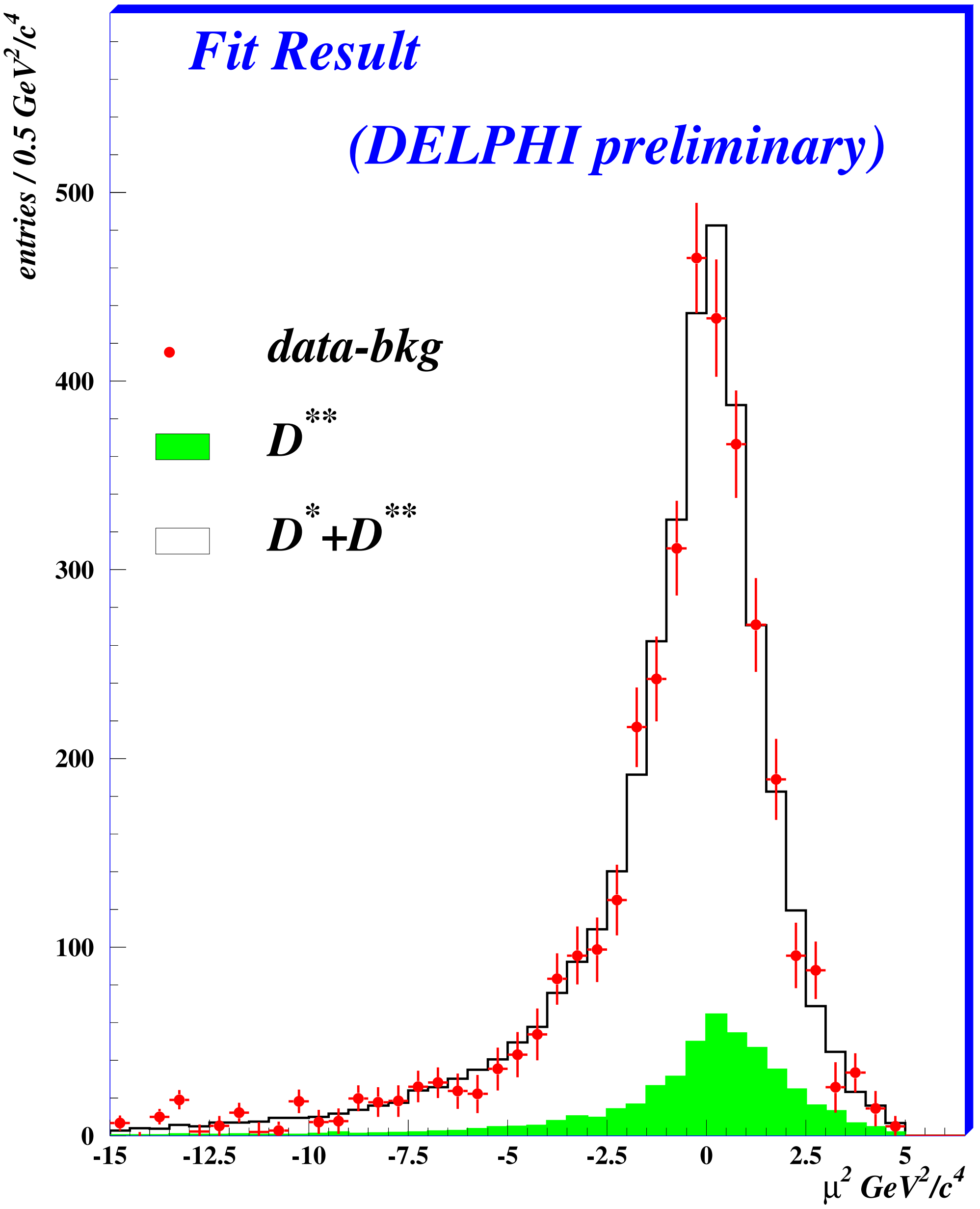
1994-1995	:	$\sigma(\phi) = \sigma(\theta) = 18 \text{ mrad}$
1992-1993	:	$\sigma(\phi) = 18 \text{ mrad};$
		$\sigma(\theta) = 35 \text{ mrad}$

D^{**} Background

Measured by plotting the invariant mass, μ^2, of the system recoiling against the $D^{*+}l\nu$

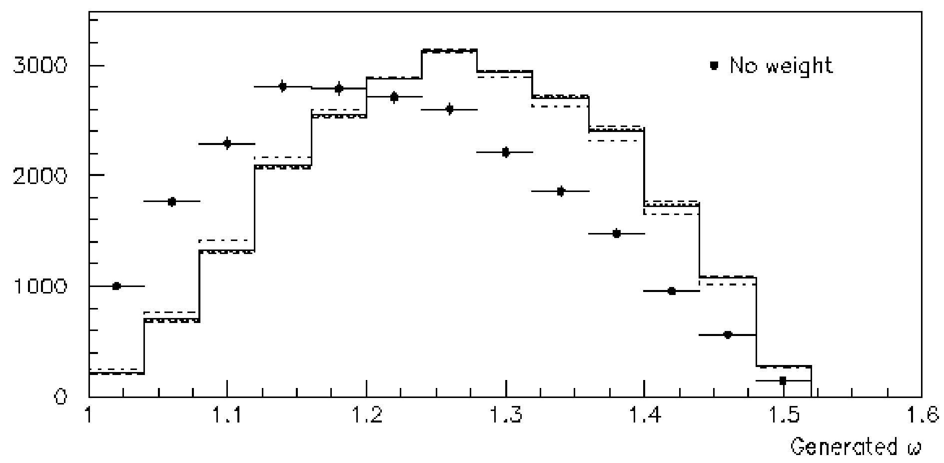
$\overline{B}^0 \rightarrow D^{*+}l\,\overline{\nu}$ events : $\mu^2 = 0$, (or M_ν^2)

$b \rightarrow D^{**}l\nu, D^{**} \rightarrow D^{*+}X$ events : $\mu^2 > 0$



$$\frac{BR(b \rightarrow D^{**}l\nu)}{BR(b \rightarrow D^{**}l\nu) + BR(b \rightarrow D^{*+}l\nu)} = (19 \pm 8)\%$$

Shape of D^{**} ω distribution

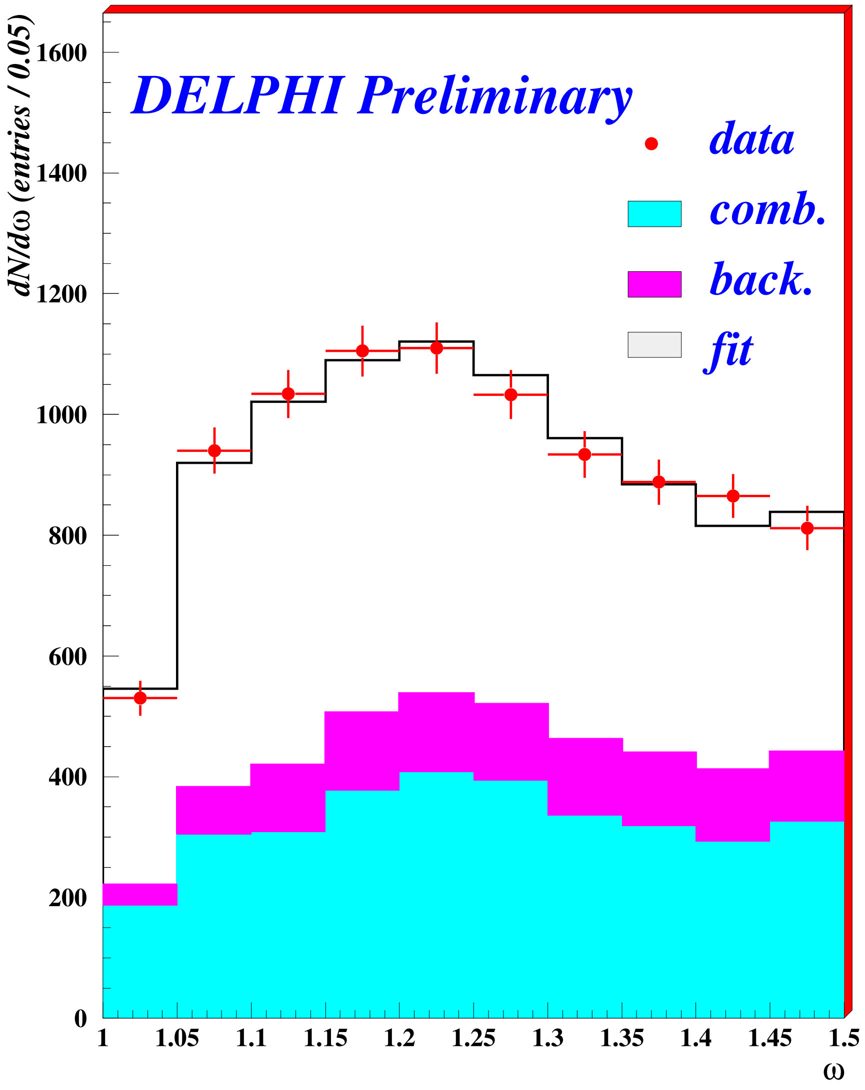


$|V_{cb}|$ fit

Following *Neubert et.al.* introduce new function:

$$\mathcal{F}(\omega) \rightarrow \mathcal{A}(\omega)$$

- Accounts for terms up to $\mathcal{O}(1-\omega)^4$
- One free parameter, $\rho^2_{\mathcal{A}_1}$



$$|V_{cb}| \cdot A_1(1) = (37.48 \pm 1.38(\text{stat}) \pm 1.61(\text{syst})) \times 10^{-3}$$
$$\rho^2_{A_1} = (1.38 \pm 0.13(\text{stat}) \pm 0.14(\text{syst})$$

Using the value $A_1(1) = 0.91 \pm 0.03$ gives a value of $|V_{cb}|$

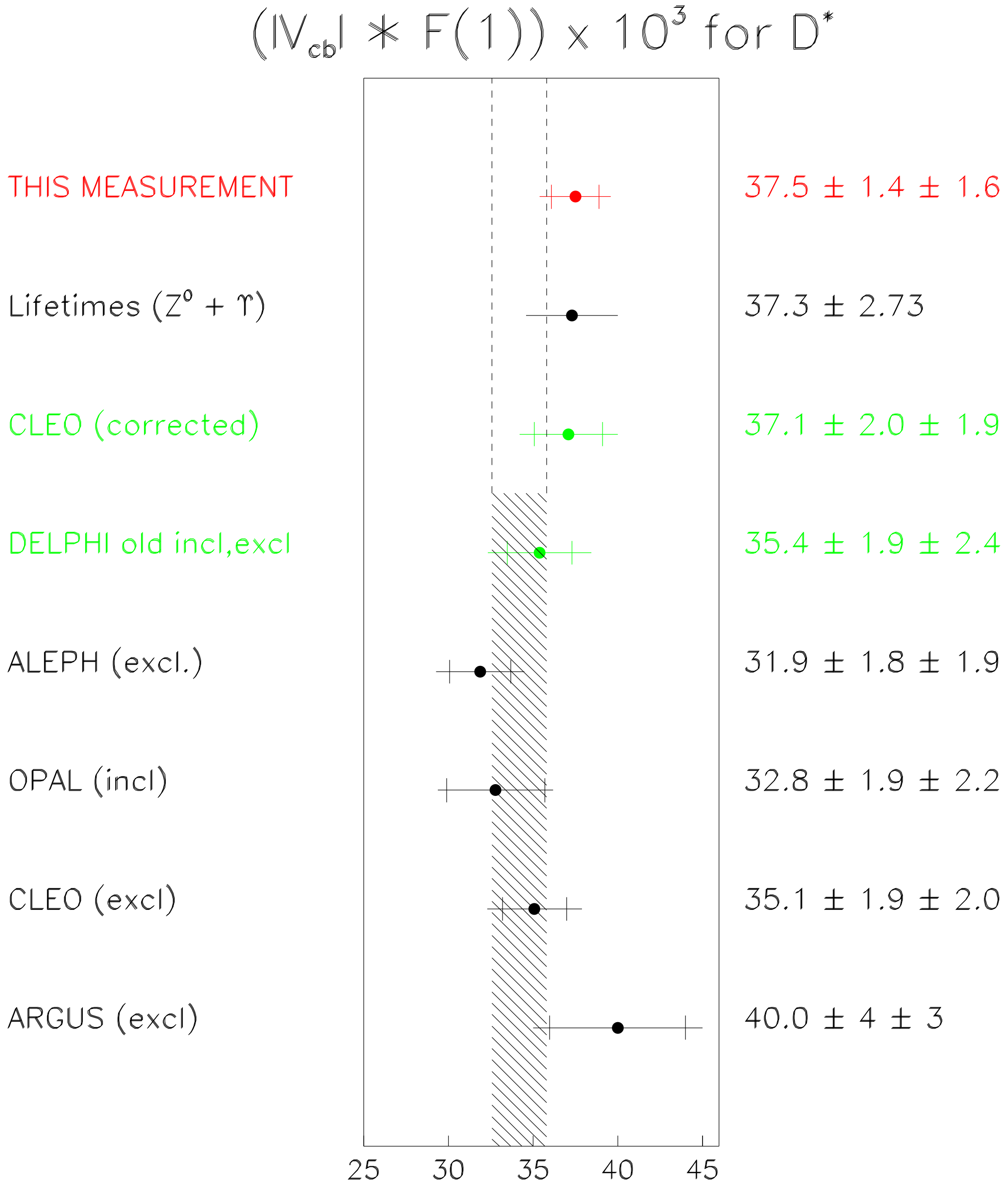
$$|V_{cb}| = (41.19 \pm 1.52(\text{stat}) \pm 1.77(\text{syst} \pm 1.36(\text{theory})) \times 10^{-3})$$

Conclusions

Using improved experimental methods and a new theoretical parametrisation DELPHI has measured the following quantities:

$$|\mathrm{V_{cb}}| \cdot A_1(1) = (37.48 \pm 1.38(\mathrm{stat}) \pm 1.61(\mathrm{syst})) \times 10^{-3}$$

$$|\mathrm{V_{cb}}| = (41.19 \pm 1.52(\mathrm{stat}) \pm 1.77(\mathrm{syst} \pm 1.36(\mathrm{theory})) \times 10^{-3})$$

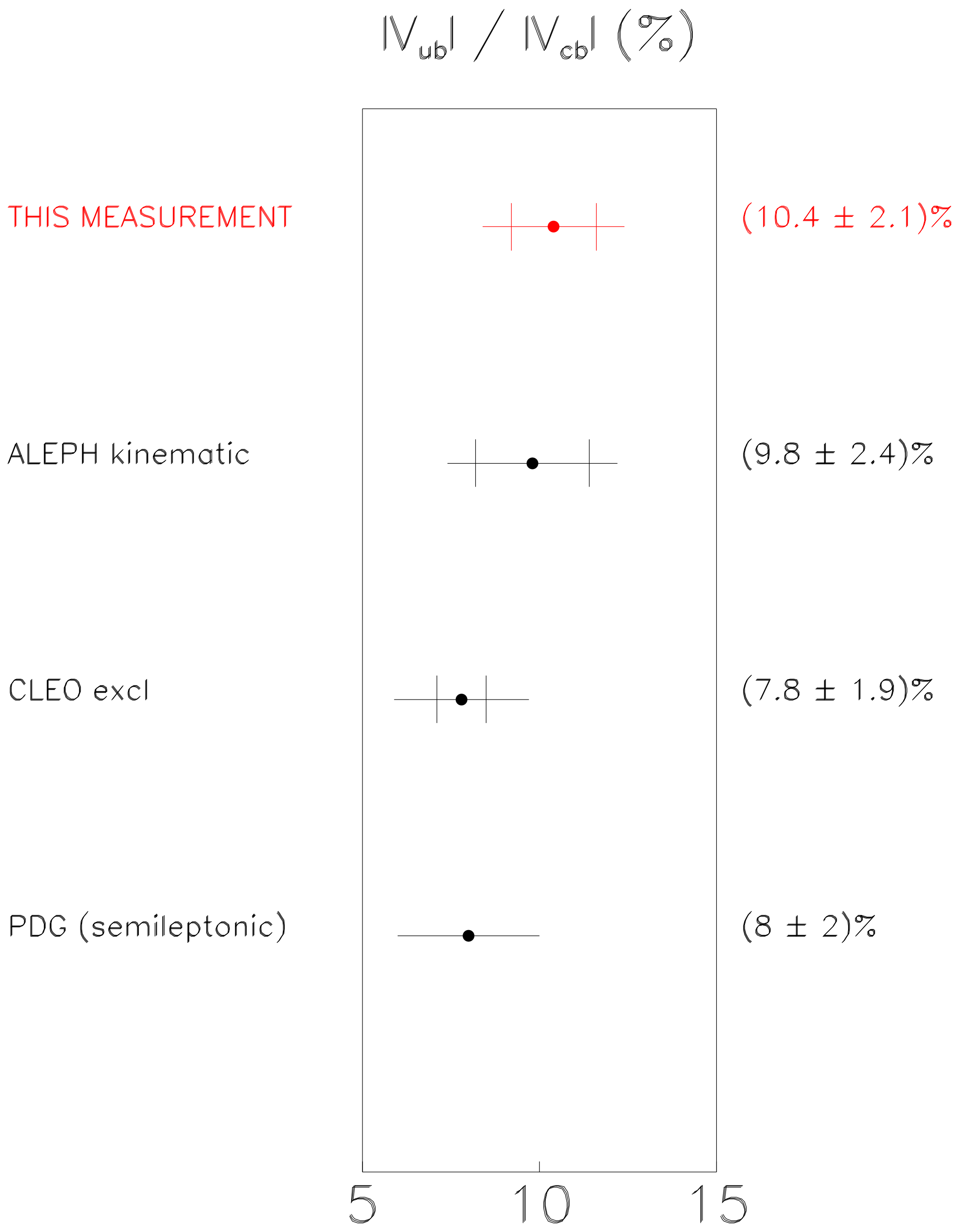


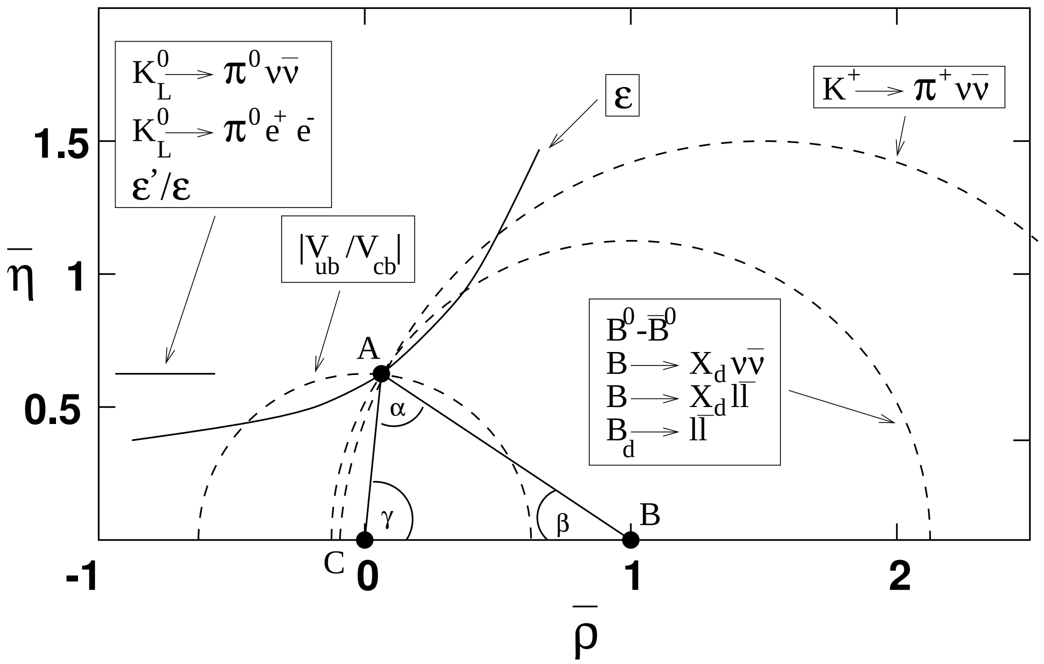
DELPHI has measured the ratio $\frac{|V_{ub}|}{|V_{cb}|}$ with a reduced theoretical error:

$$\frac{|V_{ub}|}{|V_{cb}|} = 0.104 \pm 0.012 \text{ stat} \pm 0.015 \text{ syst} \pm 0.008 \text{ model}$$

Combined with the DELPHI $|V_{cb}|$ measurement this gives:

$$|V_{ub}| = (4.3 \pm 0.8) \times 10^{-3}$$





$K_L^0 \rightarrow \pi^0 \nu\bar{\nu}$
$K_L^0 \rightarrow \pi^0 e^+ e^-$
ε'/ε
ε
$K^+ \rightarrow \pi^+ \nu\bar{\nu}$
$|V_{ub}/V_{cb}|$
B^0-$\bar{B}^0$
$B \rightarrow X_d \nu\bar{\nu}$
$B \rightarrow X_d l\bar{l}$
$B_d \rightarrow l\bar{l}$
A
B
C
α
β
γ
1.5
1
0.5
-1
0
1
2
$\bar{\eta}$
$\bar{\rho}$