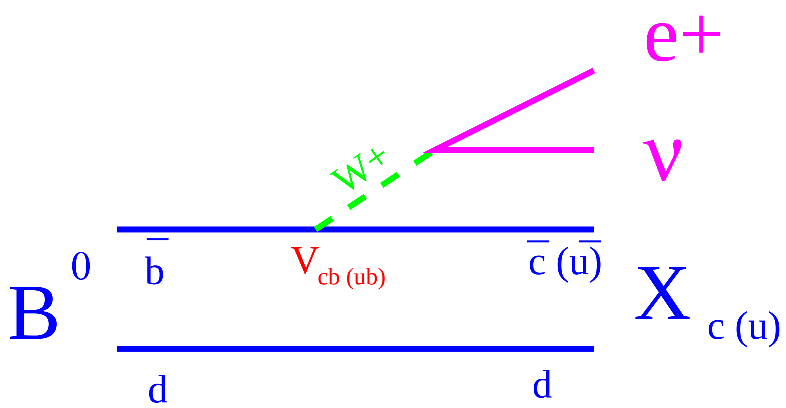
Semileptonic B decays – $|V_{ub}|$ and $|V_{cb}|$



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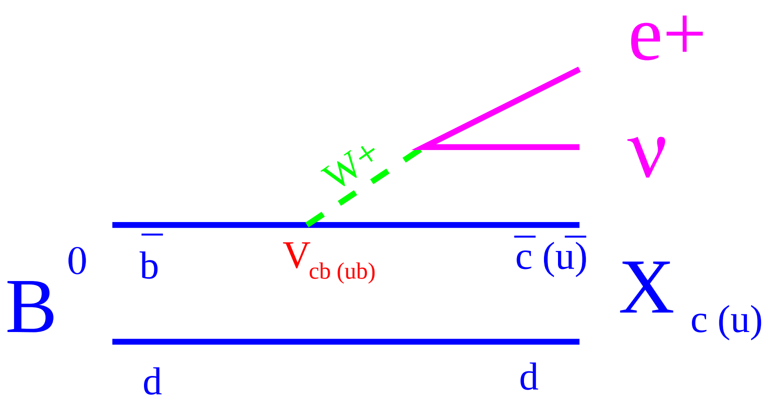
May 18, 2002

Outline

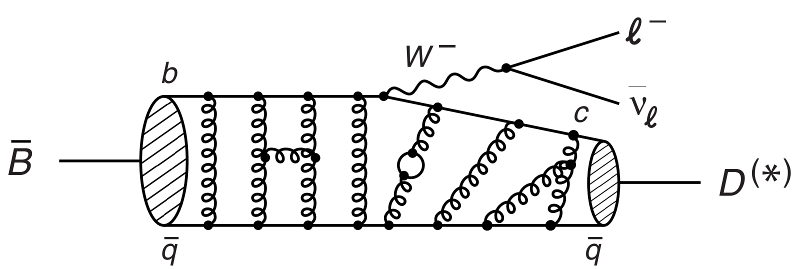
- Introduction: CKM from semileptonic B decays
- $|V_{cb}|$
  - Exclusive decays: $B \to D^{(*)}\ell\nu$
  - Inclusive decays: $B \to X_c\ell\nu$
- $|V_{ub}|$
  - Exclusive decays: $B \to \pi\ell\nu, \rho\ell\nu$
  - Inclusive decays: $B \to X_u\ell\nu$
- Summary and Outlook

CKM Measurements in Semileptonic B Decays



$$\Gamma(b \to x\ell\nu) = \frac{G_F^2 m_b^5}{192\pi^3}|V_{xb}|^2$$

Rates give CKM^2



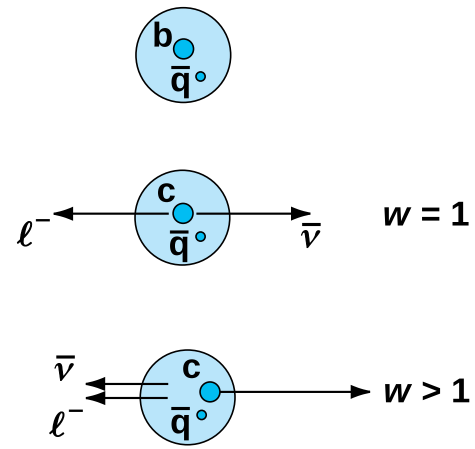
Complication!

QCD Corrections needed to extract weak decay physics

perturbative corrections and non-perturbative QCD Corrections: from HQET, Lattice QCD

Use many techniques and compare results to gain confidence in QCD corr.

$|V_{cb}|$ from $\bar{B} \to D^{(*)}\ell\bar{\nu}$



Extracting $|V_{cb}|$ from exclusive decays:

The decay rate is given by

$$\frac{d\Gamma}{dw} = \frac{G_F^2}{48\pi^3}|V_{cb}|^2[\mathcal{F}(w)]^2\mathcal{K}(w)$$

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

- $\mathcal{K}(w)$ contains kinematic factors and is *known*
- $\mathcal{F}(w)$ is the form factor describing $B \to D^{(*)}$ transition
- HQET relations simplify the form factor
- HQS normalizes at zero recoil ($w = 1$): As $M_Q \to \infty$, $\mathcal{F}(1) \to 1$

Plan: Measure $d\Gamma/dw$ and Extrapolate to $w = 1$ to extract $\mathcal{F}(1)|V_{cb}|$.

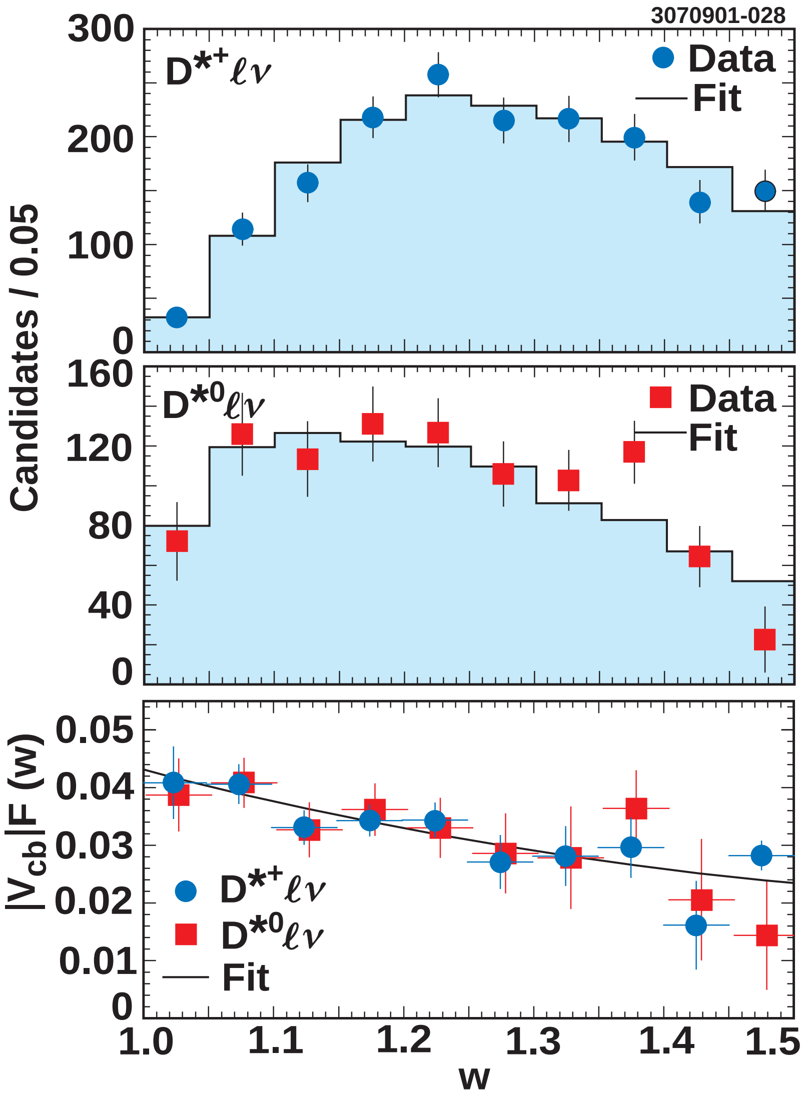
$B \to D^{(*)}$ Form Factor - QCD complications

- Must know form factor shape to extrapolate
- Must know $\mathcal{F}(1)$ to extract $|V_{cb}|$

The most general Lorentz-invariant form factor is simplified by

- Massless leptons
  - For $B \to D\ell\nu$ only vector current one FF: F_1
  - For $B \to D^*\ell\nu$ three FFs: A_1, A_2, V but ...
- Heavy Quark Symmetry
  - $M_Q \to \infty$: one form factor, the famous Isgur-Wise Function
  - Form Factor Ratios R_1 and R_2 approximately constant in w
- QCD dispersion relations constrain the shape (Boyd *et al.*)
  - Parameterization of FF: Caprini *et al.* NPB530 (1998) 153
  - Includes curvature but one shape parameter: ρ^2, slope at $w = 1$

CLEO $\bar{B} \to D^* \ell \bar{\nu}$ hep-ex/0203032



($3.1\ \mathrm{fb}^{-1}$ 3.3 M $B\bar{B}$)

Reconstruct $D^{*+}\ell\nu$ and $D^{*0}\ell\nu$

Given yields in 10 w bins

Fit using Caprini form factor

Parameters:

- $\mathcal{F}(1)|V_{cb}|$ (intercept)
- ρ^2 (slope)

$\mathcal{F}(1)|V_{cb}| = (43.1 \pm 1.3 \pm 1.8) \times 10^{-3}$

$\rho^2 = 1.61 \pm 0.09 \pm 0.21$

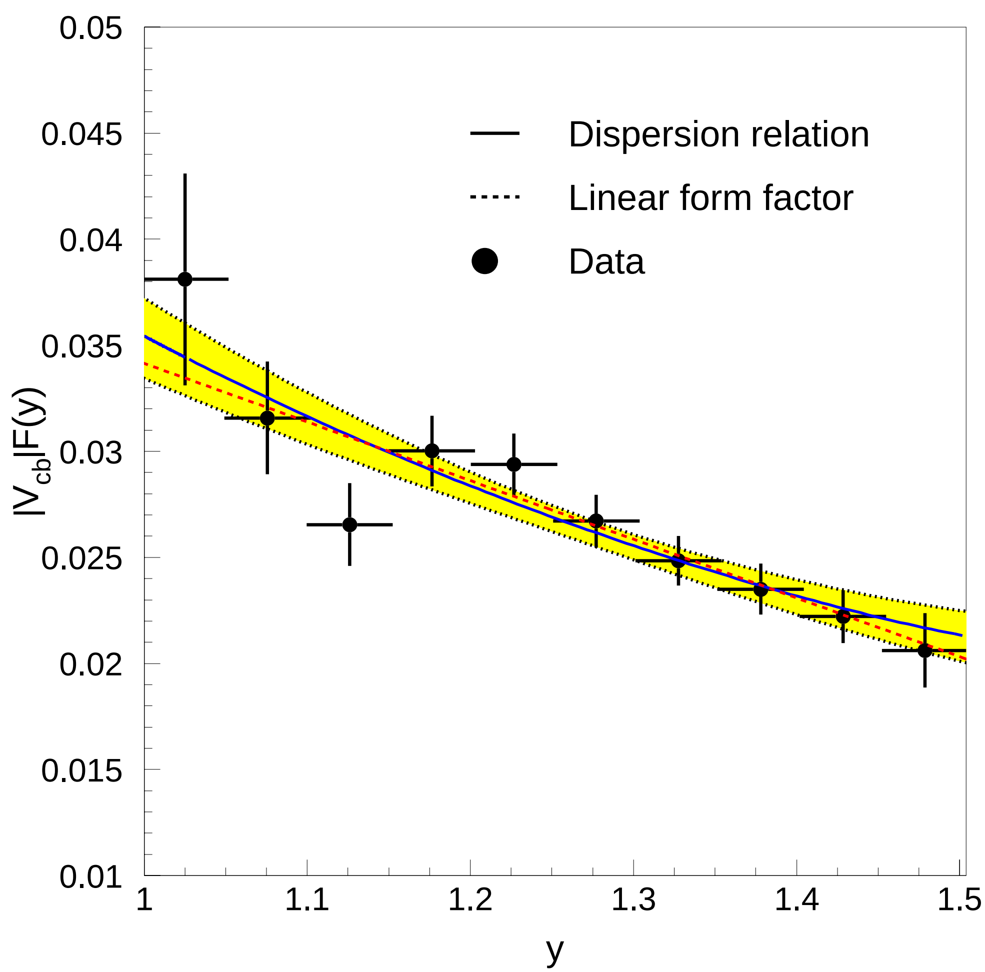
Theory: $\mathcal{F}(1) = 0.91 \pm 0.04$

$|V_{cb}| = (47.4 \pm 1.4 \pm 2.0 \pm 2.1) \times 10^{-3}$

7% precision

Systematics! efficiency, bkgds, BFs

BELLE $\bar{B} \to D^{*+} e^- \bar{\nu}$ PLB 526 (2002) 258



(10 fb^{-1} 11 M $B\bar{B}$)

Similar to CLEO and LEP analyses

Uses only electrons

Extrapolation procedure gives correlation for ρ^2 and $\mathcal{F}(1)|V_{cb}|$

Average for $B \to D^*\ell\nu$

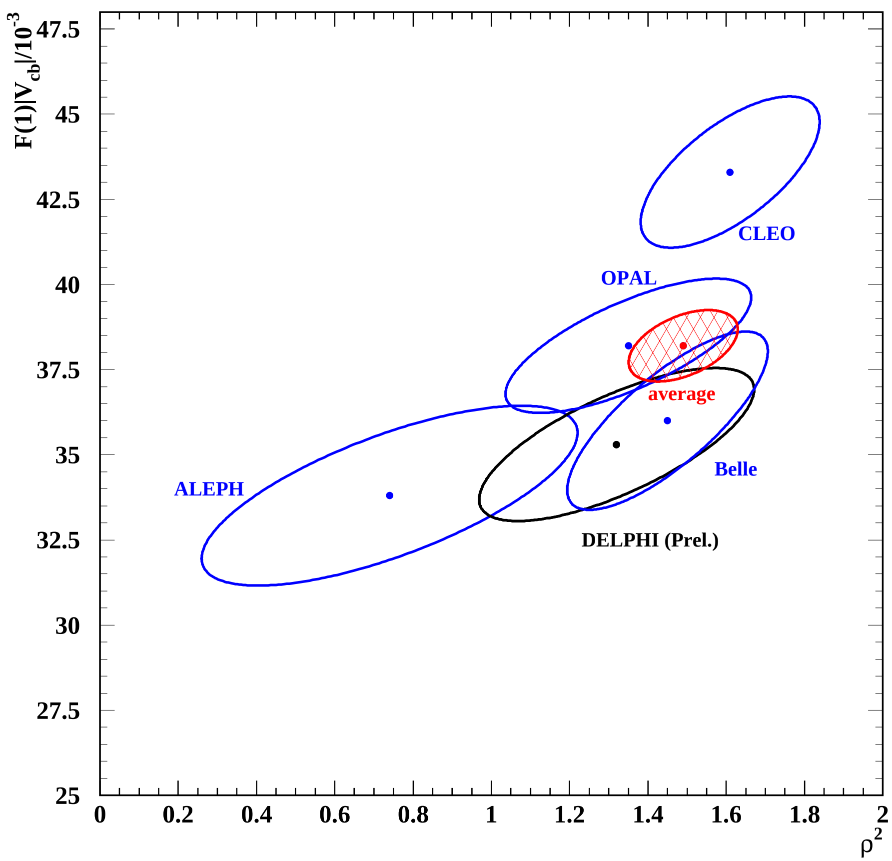
From LEP $|V_{cb}|$ working group updated for PDG02

Adjusted to common set of input parameters

- D branching fractions and B lifetimes
- Form-factor ratios R_1 and R_2
- $B \to D^* X\ell\nu$ background parameters

Fits for $\mathcal{F}(1)|V_{cb}|$ and ρ^2 accounting for correlations between experimental inputs, systematics and statistical correlation between $\mathcal{F}(1)|V_{cb}|$ ρ^2

Results of Average I



Note correlations in $\mathcal{F}(1)|V_{cb}|$ and ρ^2

5% C.L. from combined fit

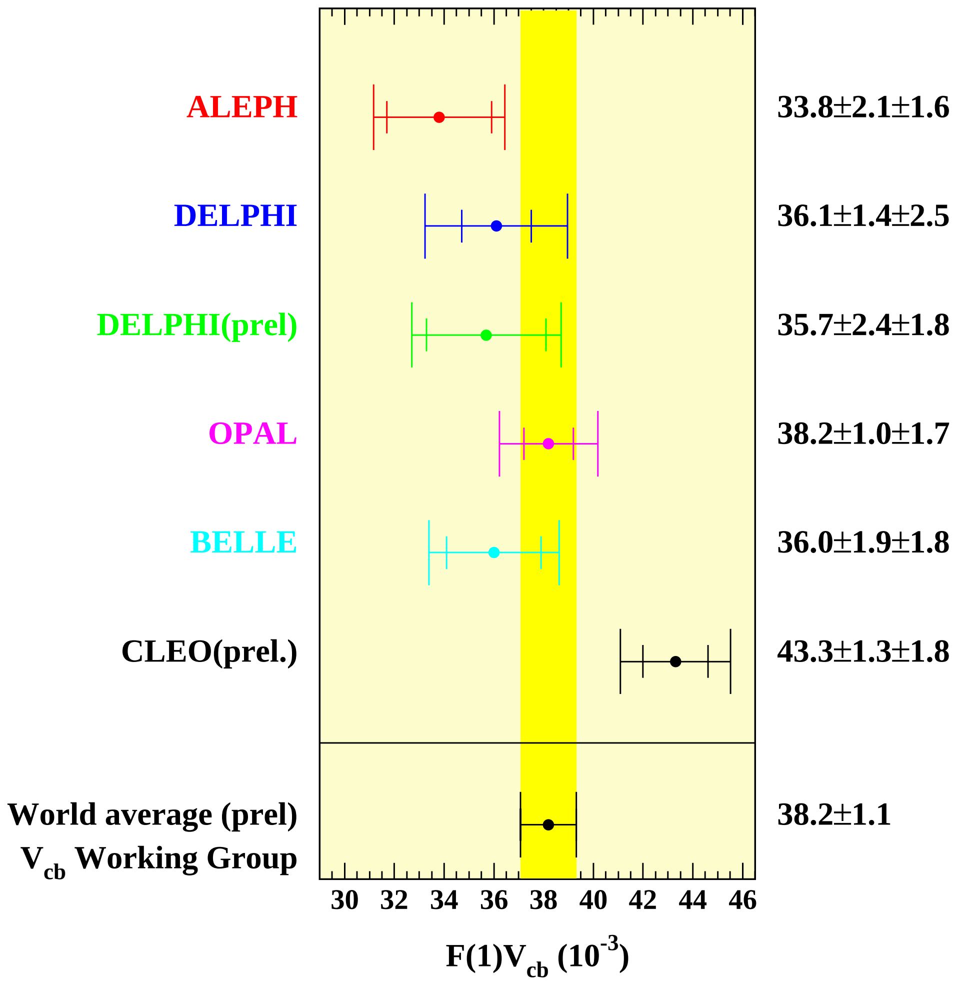
N.B. CLEO

- Includes D^{*0}
- Fits data simultaneously for $D^* X \ell \nu$ background

Others share $D^* X \ell \nu$ estimate & model

Ellipses are $\Delta\chi^2 = 1$ for each measurement (stat+syst)

Results of Average II



$$\mathcal{F}(1)|V_{cb}| = (38.2 \pm 1.1) \times 10^{-3}$$

With $\mathcal{F}(1) = 0.91 \pm 0.04$ $|V_{cb}| = (42.2 \pm 1.1_{\rm exp} \pm 1.9_{\rm thr}) \times 10^{-3}$

Comments about Average

- Need common treatment of input parameters and systematic errors
- Essential to use same form factor parameterization
- $C(\mathcal{F}(1)|V_{cb}|, \rho^2)$ on systematic errors needed

Important Issues For Future

- Background from $B \to D^* X \ell \nu$ - input from new data
- Form Factor Ratios R_1 and R_2 poorly known - can be measured
- Effect of EW radiative corrections on extrapolation and efficiency
- $\mathcal{F}(1)$ theory uncertainty currently $\sim 5\%$
  should be reduced with unquenched Lattice results

Choosing Exclusive Final States

- $D^*\ell\nu$ has larger rate than $D\ell\nu$
- larger background in $D\ell\nu$ (from $D^*\ell\nu$!)
- $V-A$ kinematics favors D^* in extrapolation to low w
  - $\mathcal{K}_D(w) = (M_B + M_D)^2 M_D^3 (\sqrt{w^2-1})^3$
  - $\mathcal{K}_{D^*}(w) \propto \sqrt{w^2-1}$
- Luke's Theorem: For $\mathcal{F}(1)$, HQS-breaking corrections $\mathcal{O}(1/M_Q^2)$ for $D^*\ell\nu$ and at $\mathcal{O}(1/M_Q)$ for $D\ell\nu$

Bottom line: Most information from $B \to D^*\ell\nu$, but $B \to D\ell\nu$ can help in the end with FF parameter determinations.

ALEPH, BELLE and CLEO have $B \to D\ell\nu$ measurements:

- Less precise than $B \to D^*\ell\nu$
- Consistent determination of $|V_{cb}| = (41.3 \pm 4.0_{\text{exp}} \pm 2.9_{\text{thr}}) \times 10^{-3}$

Inclusive $b \to c\ell\nu$

Rather than focussing on one hadronic final state where corrections may be calculated reliably,

Sum over all states and compare to quark-level calculation

$$\sum_i \Gamma(B \to X_c^{(i)}\ell\nu) = \Gamma(b \to c\ell\nu)$$

Relies on assumption of quark-hadron duality

Hard to quantify; must be tested!

Theoretical Tools for Inclusive $b \to c\ell\nu$

Heavy Quark Expansion in powers of $1/M_B$ and α_s

Operator Product Expansion - introduce parameters as matrix elements of nonperturbative operators:

At order $1/M$:

$\bar{\Lambda}$ - $\approx M_B - m_b$ energy of light degrees of freedom

At order $1/M^2$:

λ_1 - kinetic energy of b quark in B meson

λ_2 - hyperfine interaction of b spin with light d.o.f.

At order $1/M^3$:

$\rho, \mathcal{T}$ - six more parameters with less-intuitive interpretations

and so on . . .

Use HQE/OPE tools to predict rate

$$\Gamma = \frac{G_F^2|V_{cb}|^2 M_B^5}{192\pi^3}\left[\mathcal{G}_0 + \frac{1}{M_B}\mathcal{G}_1(\bar\Lambda) + \frac{1}{M_B^2}\mathcal{G}_2(\bar\Lambda,\lambda_1,\lambda_2) + \frac{1}{M_B^3}\mathcal{G}_3(\bar\Lambda,\lambda_1,\lambda_2|\rho_1,\rho_2,\mathcal{T}_1,\mathcal{T}_2,\mathcal{T}_3,\mathcal{T}_4) + \mathcal{O}\left(\frac{1}{M_B^4}\right)\right]$$

and moments of decay spectra in $B \to X_c \ell\nu$:

$\langle E_\ell\rangle$,$\langle E_\ell^2\rangle$,$\langle M_X^2\rangle$ [Falk,Luke,Savage,Gremm,Kapustin]

and $B \to X_s\gamma$: $\langle E_\gamma\rangle$,$\left\langle E_\gamma^2\right\rangle$ [Bauer, Z.Ligeti *et al.*]

Example:

$$\langle E_\gamma\rangle = \frac{M_B}{2}[1 - .385\frac{\alpha_s}{\pi} - .620\beta_0(\frac{\alpha_s}{\pi})^2 - \frac{\bar\Lambda}{M_B}(1 - .954\frac{\alpha_s}{\pi} - 1.175\beta_0(\frac{\alpha_s}{\pi})^2) - \frac{13\rho_1 - 33\rho_2}{12M_B^3} - \frac{\mathcal{T}_1 + 3\mathcal{T}_2 + \mathcal{T}_3 + 3\mathcal{T}_4}{4M_B^3} - \frac{\rho_2 C_2}{9M_B M_D^2 C_7} + \mathcal{O}(1/M_B^4)]$$

Roadmap for Inclusive $|V_{cb}|$

Milestones:

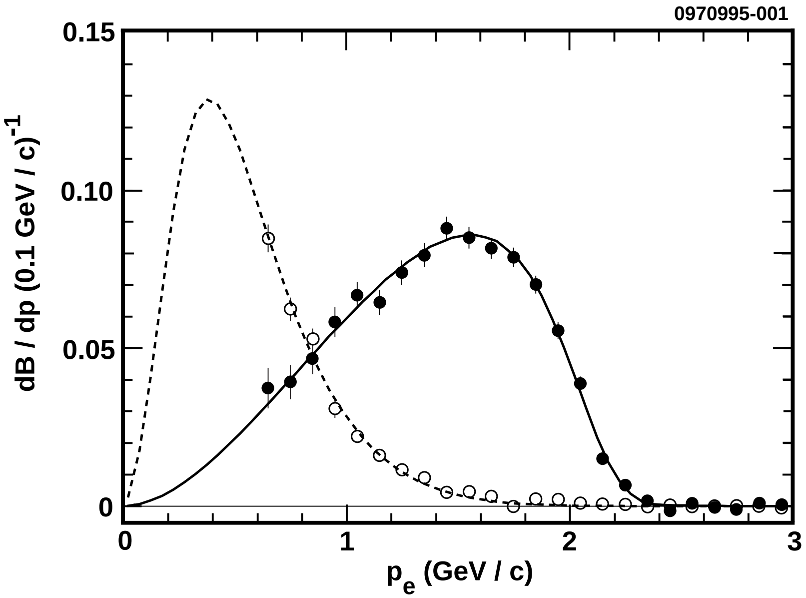
- Theory
  - Expressions for Γ and moments
- Experiment
  - Inclusive branching fraction $\mathcal{B}(B \to X\ell\nu)$
  - Lifetimes
  - Moments: $\langle E_\gamma \rangle$ in $b \to s\gamma$, $\langle M_X^2 \rangle$ in $B \to X_c\ell\nu$

Recent improvements on $|V_{cb}|$ use experimental measurements of theory parameters to bound HQET parameters.

Other improvements come from new branching fraction and lifetime measurements.

Inclusive Semileptonic Branching Fraction

Analyses by CLEO, BABAR, BELLE (ARGUS)



Use high p lepton to tag B

Measure second lepton

Separate primary and secondary using charge and angular correlations

CLEO PRL76 (1996)1570 (2 fb^{-1}) $\mathcal{B}(B \to Xe\nu) = (10.49 \pm 0.17 \pm 0.43)\%$

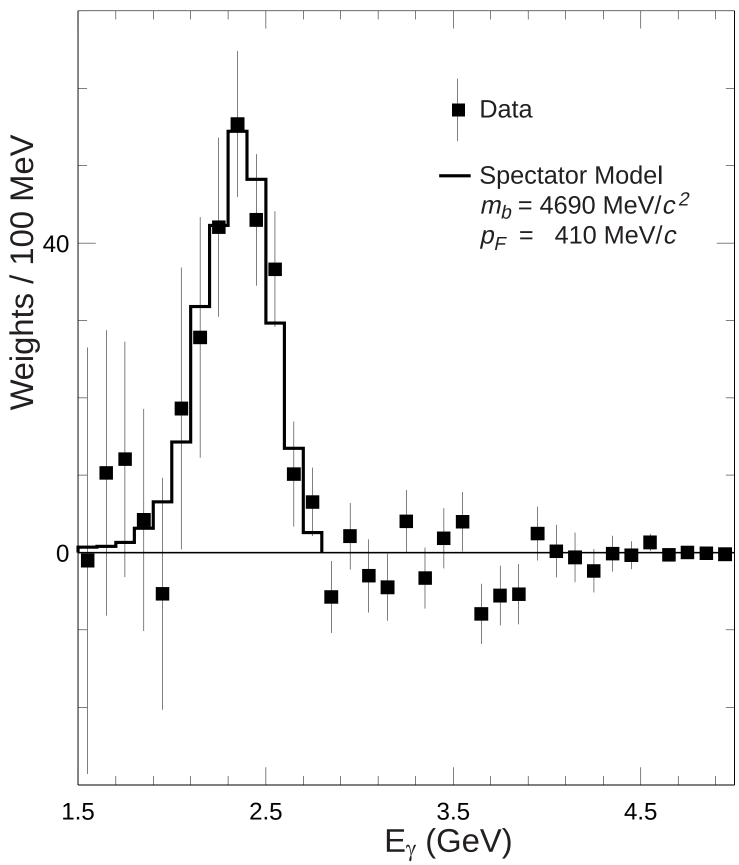
BELLE CONF-0123 (5 fb^{-1}) $\mathcal{B}(B \to Xe\nu) = (10.86 \pm 0.14 \pm 0.47)\%$

BABAR PRELIMINARY (5 fb^{-1}) $\mathcal{B}(B \to Xe\nu) = (10.82 \pm 0.21 \pm 0.38)\%$

Compare to

LEP Avg Working Group $\mathcal{B}(b \to X\ell\nu) = (10.59 \pm 0.09 \pm 0.15 \pm 0.26)\%$

$B \to X_s\gamma$: E_γ Moments



CLEO $b \to s\gamma$ spectrum

PRL **87**, 251807 (2001) $\langle E_\gamma \rangle \approx m_b/2$

Broadened by

- Fermi motion
- gluon bremsstrahlung
- B boost in lab

Use first moment to determine $\bar{\Lambda}$

$$\bar{\Lambda} = 0.35 \pm 0.08 \pm 0.10 \text{ GeV}$$

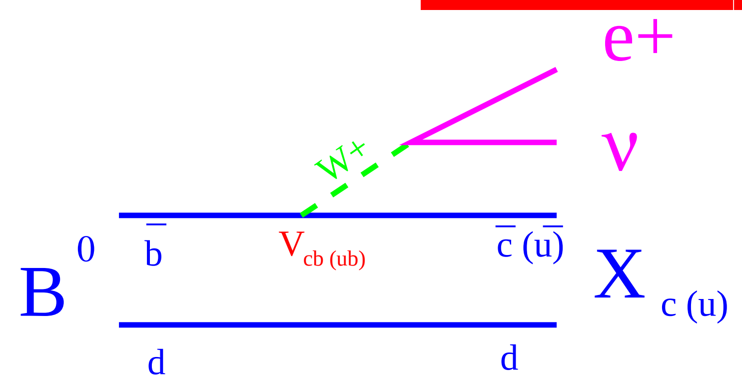
Theory: Bauer PRD57, 5611 (1998)

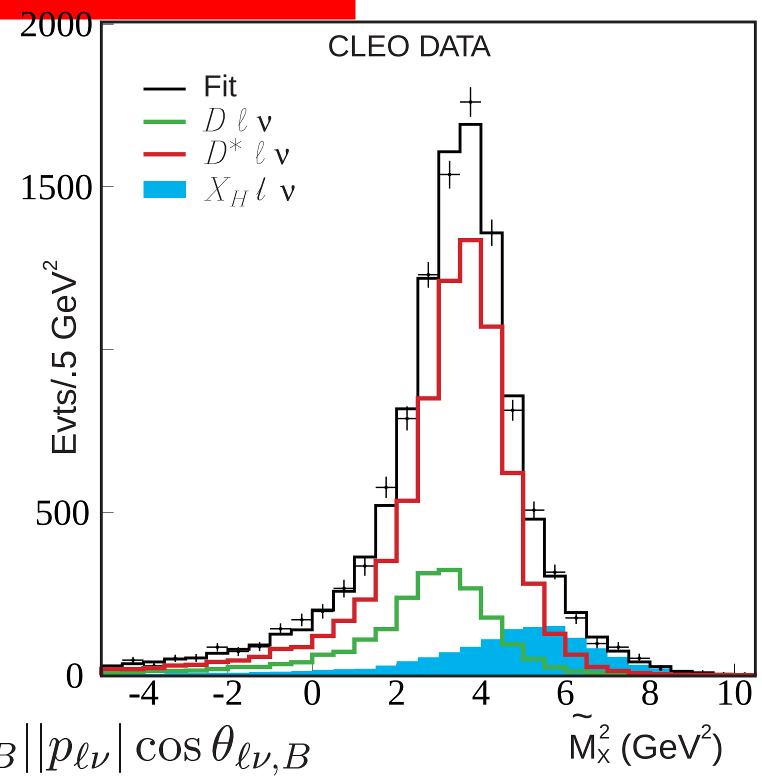
Ligeti *et al.*, PRD60, 034019 (1999)

$$\langle E_\gamma \rangle = 2.346 \pm 0.032 \pm 0.011 \text{ GeV}$$

$$\langle (E_\gamma - \langle E_\gamma \rangle)^2 \rangle = 0.0231 \pm 0.0066 \pm 0.0022 \text{ GeV}^2$$

$B \to X_c \ell \nu$: M_X^2 Moments





CLEO PRL 88, 251808 (2001)

Require $E_\ell > 1.5$ GeV

(P_ν, E_ν) from hermetic detector

$$M_X^2 = M_B^2 + M_{\ell\nu}^2 - 2E_B E_{\ell\nu} + 2|p_B||p_{\ell\nu}|\cos\theta_{\ell\nu,B}$$

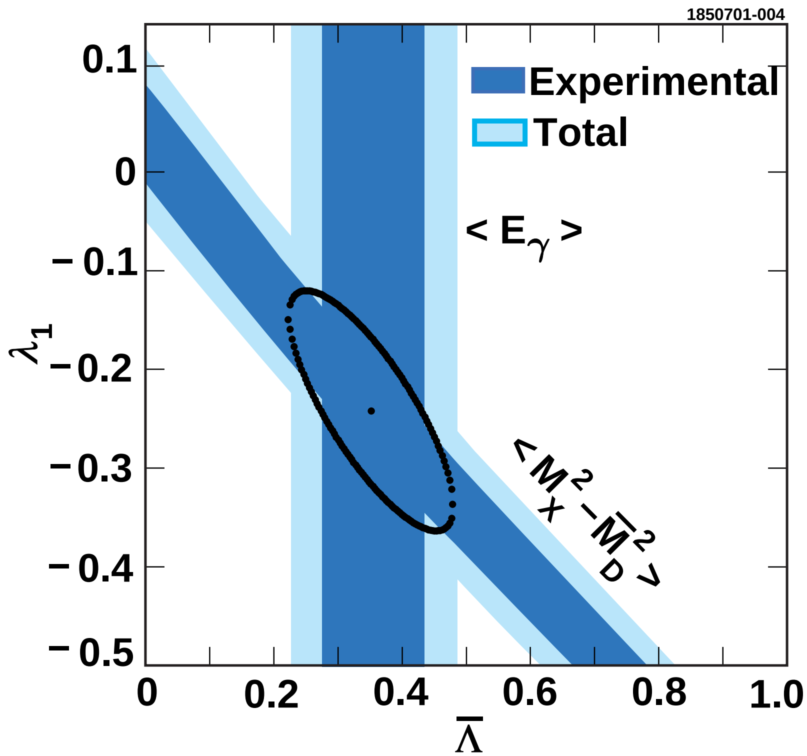
$$\approx \widetilde{M_X^2} = M_B^2 + M_{\ell\nu}^2 - 2E_B E_{\ell\nu}$$

$$\langle M_X^2 - \overline{M_D}^2 \rangle = 0.251 \pm 0.023 \pm 0.062 \text{ GeV}^2$$

$$\langle (M_X^2 - \overline{M_D}^2)^2 \rangle = 0.639 \pm 0.056 \pm 0.178 \text{ GeV}^4$$

Spin-average D mass:
$\overline{M_D} = (M_D + 3M_{D^*})/4$

Determination of $\bar{\Lambda}$ and λ_1



$\bar{\Lambda} \; = \; 0.35 \; \pm 0.07 \; \pm 0.10$ GeV

$\lambda_1 = -0.238 \pm 0.071 \pm 0.078$ GeV^2

Warning: scheme dependence

$\overline{MS}$ to order $1/M^3$, $\beta_0 \alpha_s^2$

Using

$\mathcal{B}(B \to X_c \ell \nu) = (10.39 \pm 0.46)\%$

(CLEO $B \to X_u \ell \nu$ removed)

τ_B (PDG2000)

gives

$|V_{cb}| = (40.4 \pm 0.5 \pm 0.9 \pm 0.8) \times 10^{-3}$

(M) (Γ) (T)

3.2% determination of V_{cb}

implicit q-H duality assumption

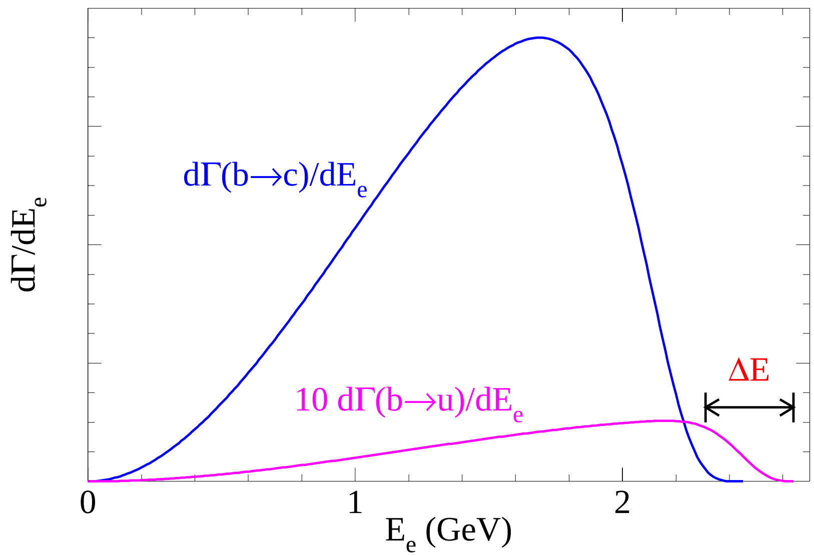
Work in progress on E_ℓ moments

Consistency?

Stay tuned Summer results expected from many experiments

Experimental Challenges in $b \to u\ell\nu$

From Leibovich hep-ph/0011181



Large $b \to c\ell\nu$ backgrounds

- Signal is 1% of background!
- Suppress using kinematics

Approaches:

- Exclusive
  + Constraints from full recon
- Inclusive
  + Kinematic cuts
  – $E_\ell >\sim 2.4$ GeV
  – $M_X < M_D$
  – $q^2 >\sim 12$ GeV^2

Both approaches currently suffer from large uncertainties

- Exc. Unknown form factors
- Inc. Effect of kinematic cuts

Exclusive $B \to \pi\ell\nu$ and $B \to \rho\ell\nu$

Powerful kinematic constraints for full reconstruction $(\Delta E, M_B)$

ν reconstruction using hermticity of detector:

- $E_{\mathrm{miss}} = 2E_{\mathrm{beam}} - \sum_i E_i$
- $\vec{p}_{\mathrm{miss}} = -\sum_i \vec{p}_i$

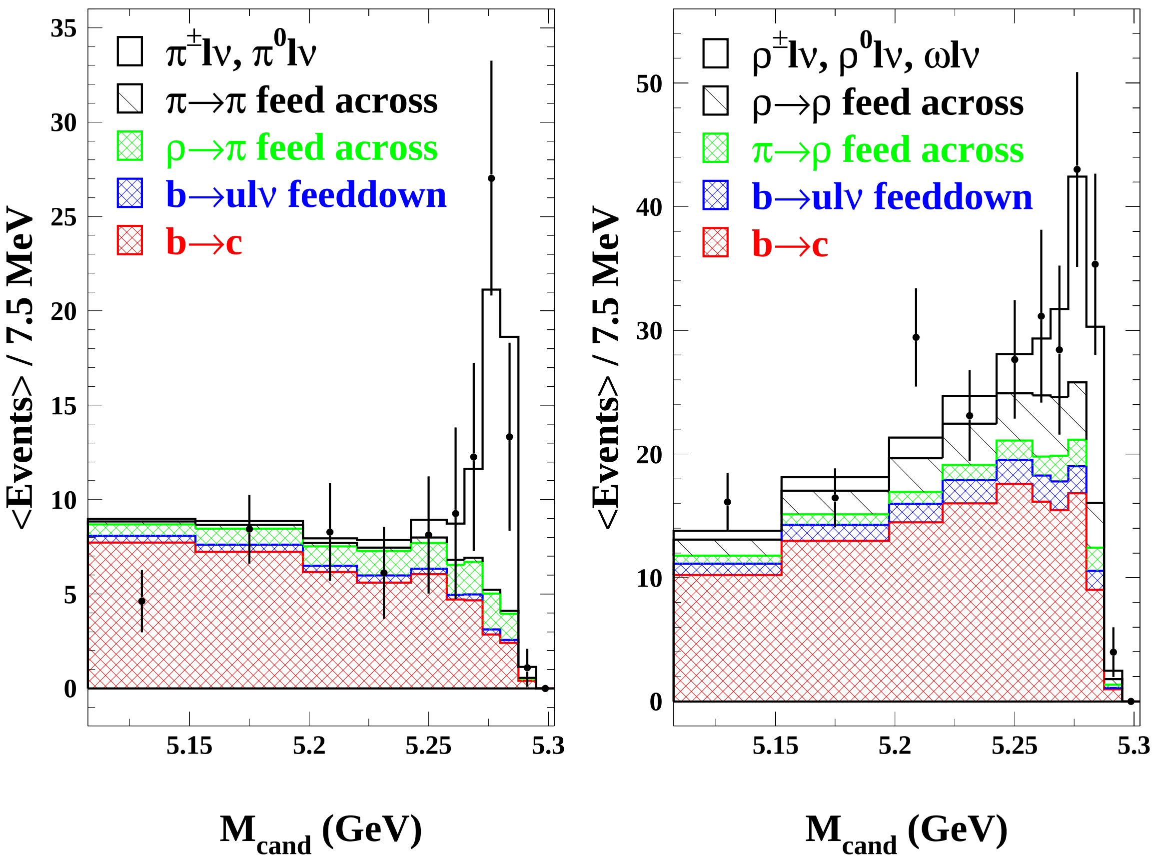
Evaluate $\mathcal{B}$ using form factors and extract $|V_{ub}|$ from

$$\Gamma = \frac{\mathcal{B}}{\tau_{\mathcal{B}}} = \gamma_u |V_{ub}|^2$$

Form factors (and γ) from

- Lattice - *e.g.* UKQCD
- Quark Models - *e.g.* ISGW2, WSB
- Light Cone Sum Rules - *e.g.* Ball and Braun
- HQS - *e.g.* Ligeti and Wise from $D \to K^*\ell\nu$

CLEO PRL77, 5000(1996) First Observation $\bar{B} \to \pi \ell \bar{\nu}$ and $\bar{B} \to \rho \ell \bar{\nu}$



($2.66\ \mathrm{fb}^{-1}$)

$E_\ell > 1.5$ GeV

$S/N \approx 2$

Isospin constraint

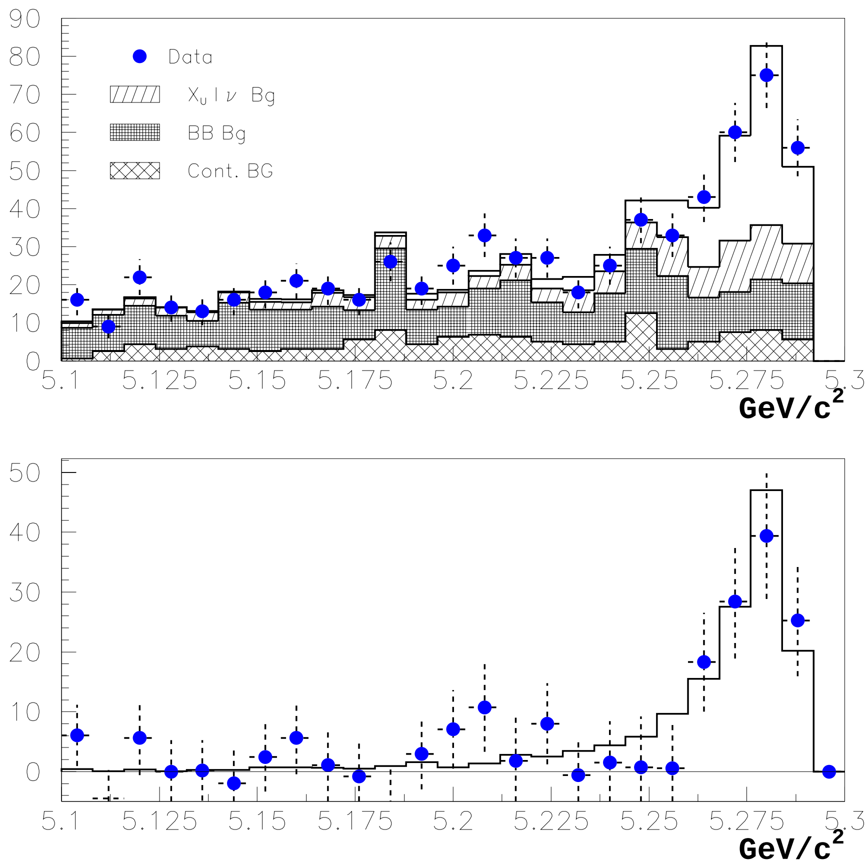
- $\Gamma_{\pi^-} = 2\Gamma_{\pi^0}$
- $\Gamma_{\rho^-} = 2\Gamma_{\rho^0}$

$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu) = (1.8 \pm 0.4 \pm 0.3 \pm 0.2) \times 10^{-4}$$

$$\mathcal{B}(B^0 \to \rho^- \ell^+ \nu) = (2.5 \pm 0.4^{+0.5}_{-0.7} \pm 0.5) \times 10^{-4}$$

Evaluate $|V_{ub}|$ using five form factors

BELLE-CONF-0124 (2001) $\bar{B} \to \pi \ell \bar{\nu}$



(21.3 fb^{-1})

Belle ν reconstruction

$E_{\text{miss}} = 2E_{\text{beam}} - \sum_i E_i$

$\vec{p}_{\text{miss}} = -\sum_i \vec{p}_i$

$E_\nu = |\vec{P}_{\text{miss}}|$ and $\vec{p}_\nu = \vec{p}_{\text{miss}}$

Cut $|\Delta E| < 0.3$ GeV

Fit M_{bc}

Preliminary

$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu) = (1.28 \pm 0.20 \pm 0.26) \times 10^{-4}$ ISGW2 + WSB

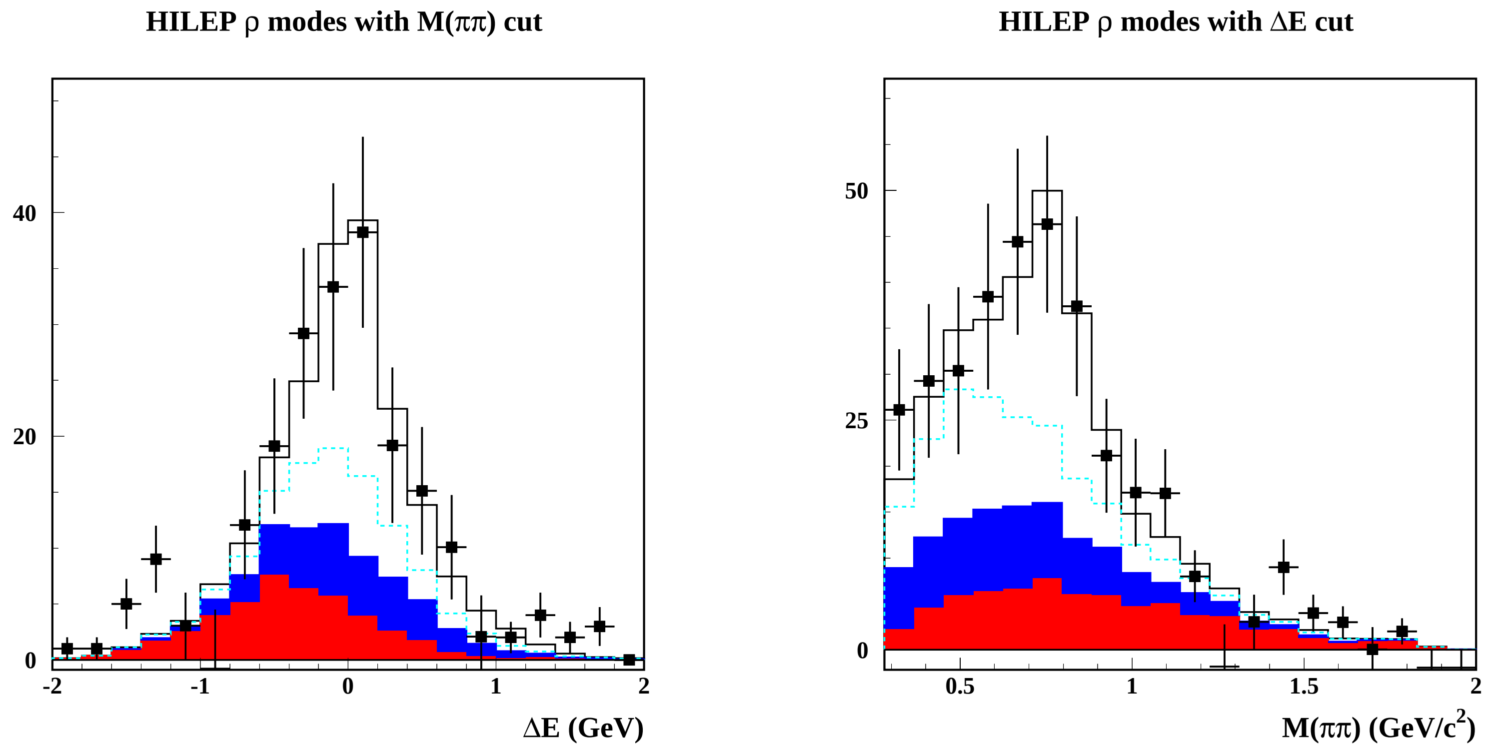
Updated at Moriond02 (H. Ishino): 29.2 fb^{-1}

2d-fit to ΔE and p_ℓ

Uses more recent models for form factors

$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu) = (1.89 \pm 0.15 \pm 0.30) \times 10^{-4} \qquad \text{LCSR}$$
$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu) = (1.92 \pm 0.16 \pm 0.30) \times 10^{-4} \qquad \text{UKQCD}$$

CLEO PRD61, 052001 (2000) $\bar{B} \to \rho \ell \bar{\nu}$



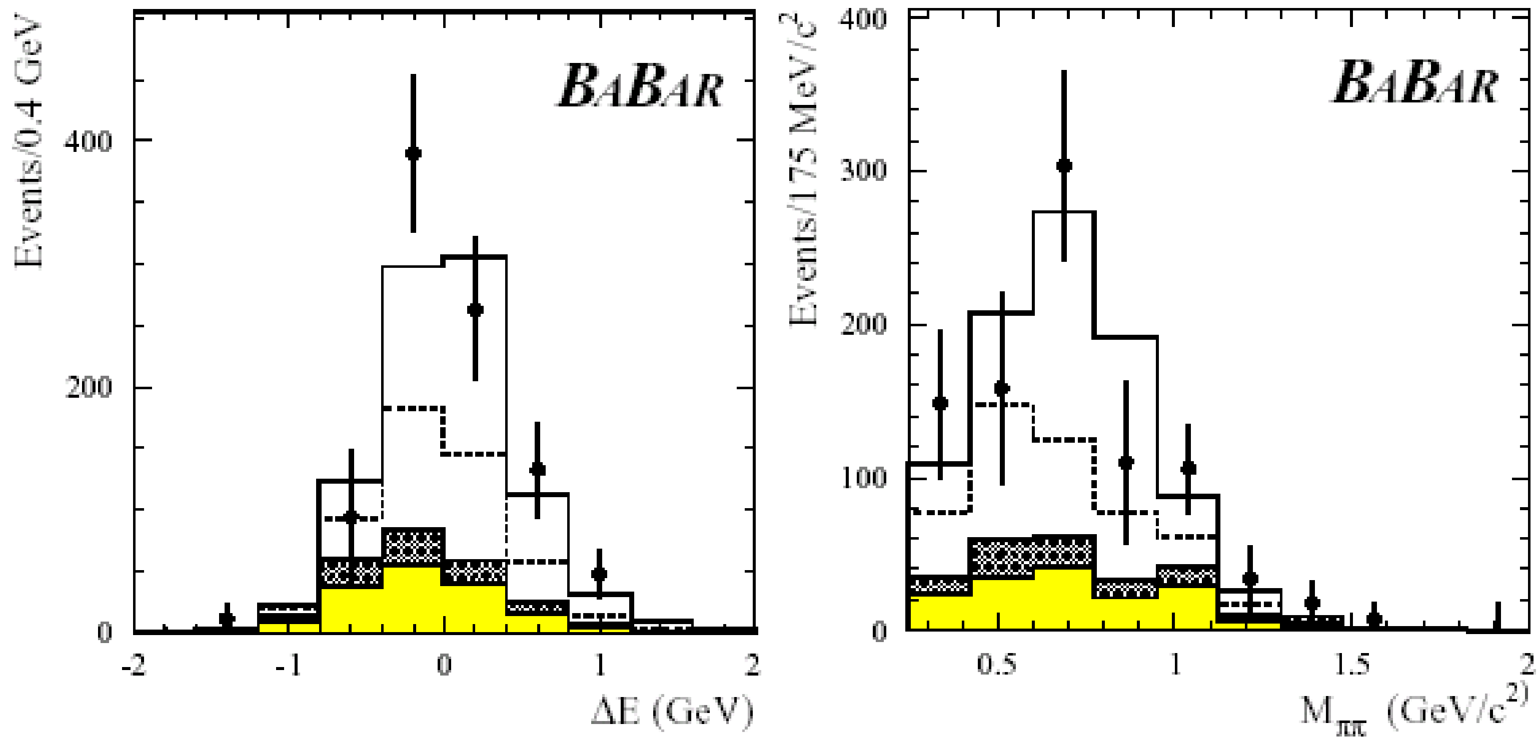
Looser cuts than 1996; 3.1 fb^{-1}

$E_\ell > 1.7$ GeV; Most sensitivity for $E_\ell > 2.3$ GeV

$$\mathcal{B}(B^0 \to \rho^- \ell^+ \nu) = (2.69 \pm 0.41^{+0.35}_{-0.40} \pm 0.50) \times 10^{-4}$$

Statistically independent of 1996 analysis

BABAR PRELIMINARY $\bar{B} \to \rho e \bar{\nu}$ - B. Serfas at CERN CKM Workshop



Uses 20.2 fb^{-1}; Very similar to CLEO's $\bar{B} \to \rho \ell \bar{\nu}$

$$\mathcal{B}(B^0 \to \rho^- e^+ \nu) = (3.26 \pm 0.65^{+0.63}_{-0.65} \pm 0.44) \times 10^{-4}$$

Exclusive $|V_{ub}|$ Summary

	$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu) \times 10^{-4}$	$\mathcal{B}(B^0 \to \rho^- \ell^+ \nu) \times 10^{-4}$
CLEO	$1.8 \pm 0.4 \pm 0.3 \pm 0.2$	$2.5 \pm 0.4^{+0.5}_{-0.7} \pm 0.5$
		$2.69 \pm 0.41^{+0.35}_{-0.40} \pm 0.5$
Belle	$1.28 \pm 0.20 \pm 0.26 \pm ?.??$	
BaBar		$3.26 \pm 0.65^{+0.63}_{-0.65} \pm 0.44$

CLEO Combined:

$$|V_{ub}| = (3.25 \pm 0.14^{+0.21}_{-0.29} \pm 0.55) \times 10^{-3}$$

- Limited by knowledge of form factors
- Lattice calculations can help
- Updates coming from all experiments

Inclusive $\bar{B} \to X_u \ell \bar{\nu}$

Extract $|V_{ub}|$ from measured branching fraction using OPE

$$|V_{ub}| = 0.00445 \left[\frac{\mathcal{B}(B \to X_u \ell \nu)}{0.002} \frac{1.55\ \text{ps}}{\tau_B} \right]^{\frac{1}{2}} (1.0 \pm 0.020 \pm 0.052)$$

Uncertainties from OPE and b quark mass (± 90 MeV)

Hoang *et al.* (1999) and Uraltsev *et al.* (1998)

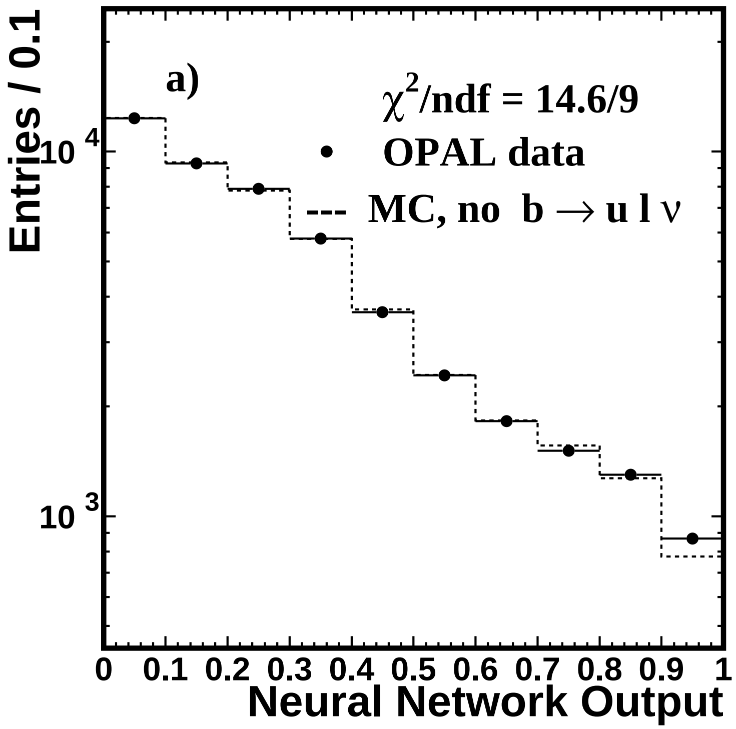
Different strategies for beating down the background

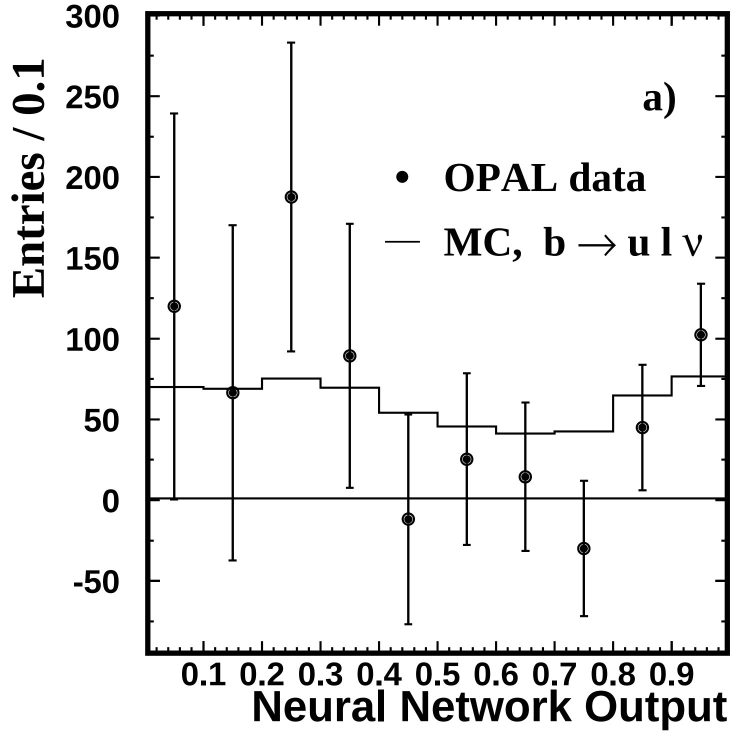
Choice of Kinematic Cuts

- $E_\ell >\sim 2.4$ GeV (keeps about 5–10% of $b \to u \ell \nu$)
- $q^2 >\sim 12\ \text{GeV}^2$ (keeps about 20%)
- $M_X < M_D$ (keeps about 70%)

But these cuts introduce additional uncertainties

OPAL EPJ C21 (2001) 399

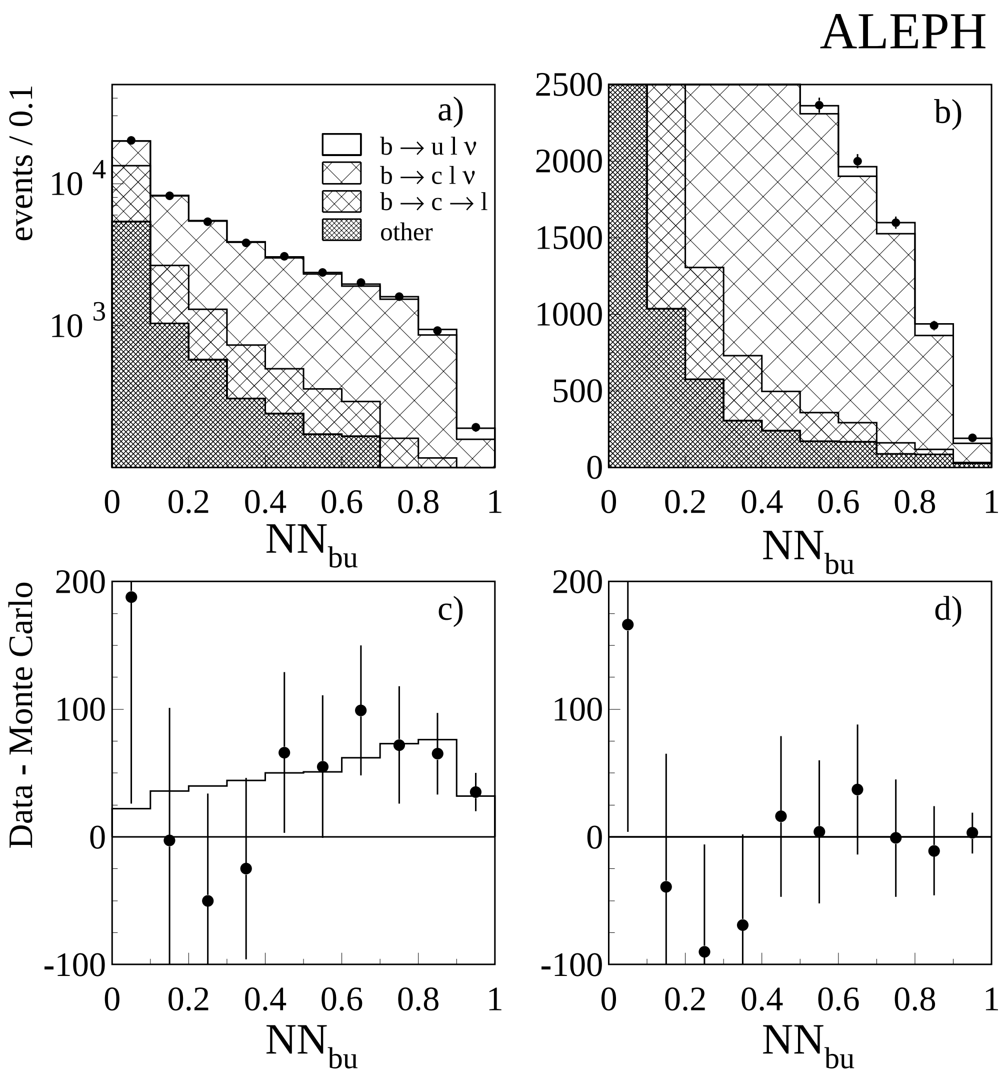




Huge background suppressed with 7 variable Neural Net

Small signal extraction depends on $b \to c\ell\nu$ model! $S/B = 0.05$

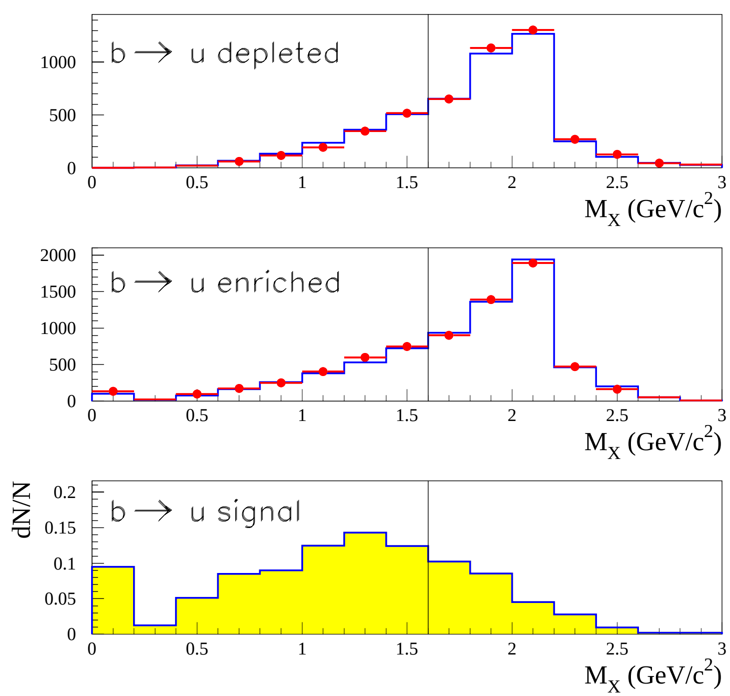
ALEPH EPJ C6 (1999) 555

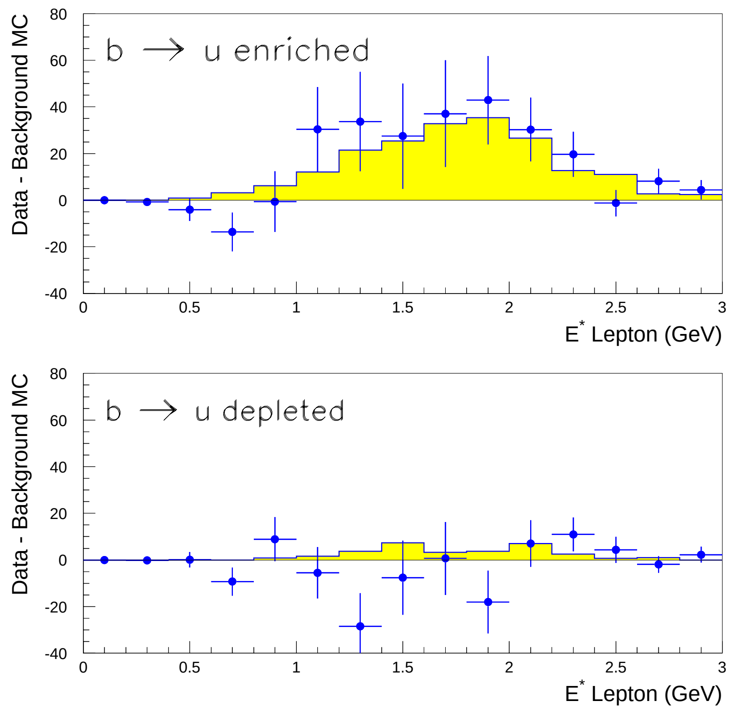


20 vararaible NN

$S/B = 0.07$

DELPHI PLB 478 (2000) 14



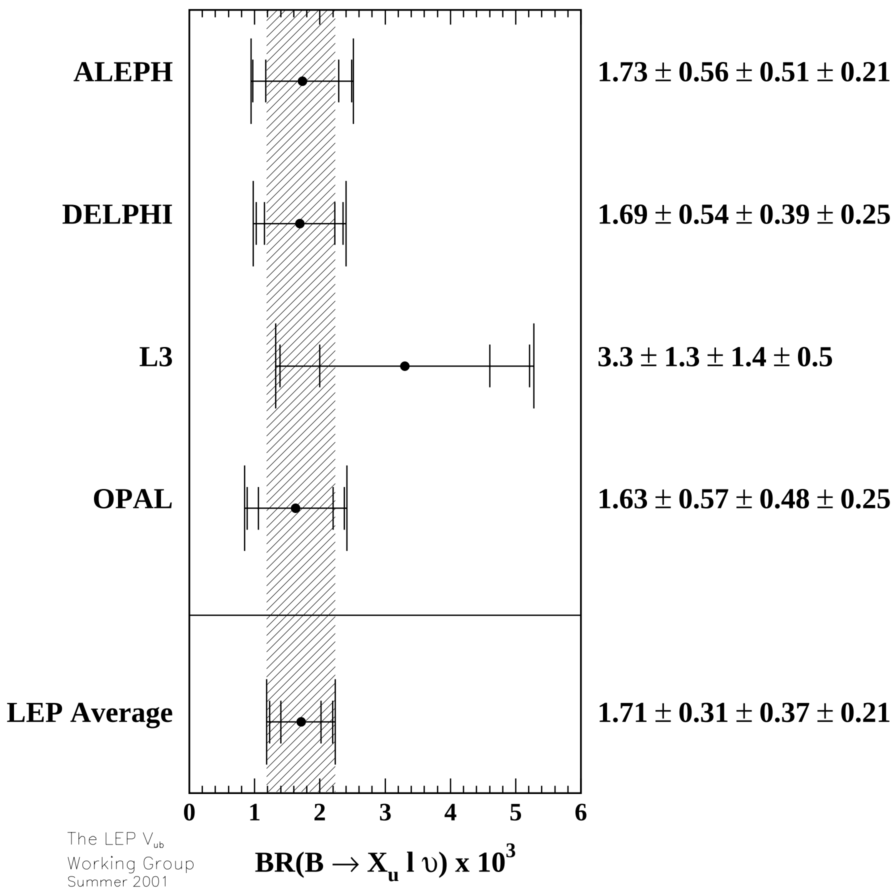


Use charm vertex to suppress bkgd

$M_X < 1.6$ signal region

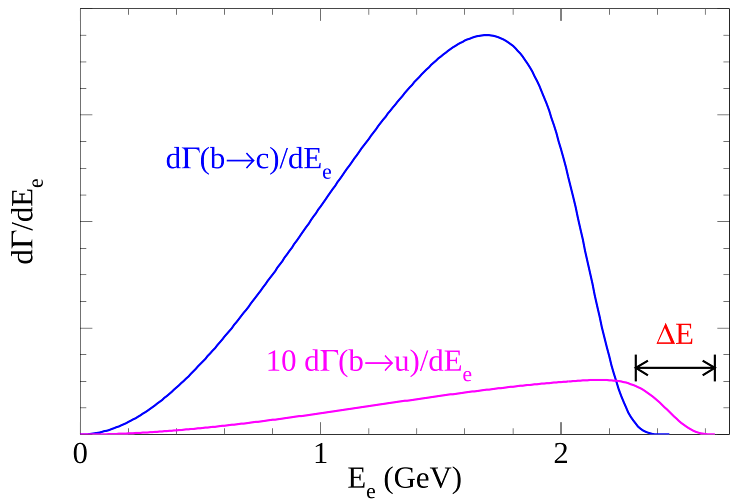
$S/B = 0.10$

Inclusive $|V_{ub}|$ - LEP Summary



LEP $|V_{ub}|$ Working Group

$|V_{ub}|$ from lepton spectrum and $b \to s\gamma$



To measure $b \to u\ell\nu$

Must suppress $b \to c\ell\nu$

Cutting on E_ℓ introduces problems:

- Large model dependence
  (What fraction above cut?)
- At edge of spectrum
  sensitive to b quark motion

Idea:[1] Reduce problems by using $b \to s\gamma$ photon spectrum

Common shape function for $b \to$ light transitions (to leading order)

Tells how to smear from $b \to s\gamma$ to $B \to X_s\gamma$ *and* $b \to u\ell\nu$ to $B \to X_u\ell\nu$

[1](Neubert, Kagan, De Fazio ; Leibovich, Low, Rothstein)

$|V_{ub}|$ from lepton spectrum and $b \to s\gamma$

Measure $B \to X_u \ell\nu$ in a lepton momentum interval (p) at the $\bar{B} \to X\ell\bar{\nu}$ endpoint

- $\Delta\mathcal{B}_{ub}(p)$ is the branching fraction for $B \to X_u \ell\nu$ in (p),
- $f_u(p)$ is the fraction of the $B \to X_u \ell\nu$ spectrum in (p), and
- $\mathcal{B}_{ub} \equiv \mathcal{B}(B \to X_u \ell\nu)$ is the $B \to X_c \ell\nu$ branching fraction.

New measurement of $f_u(p)$

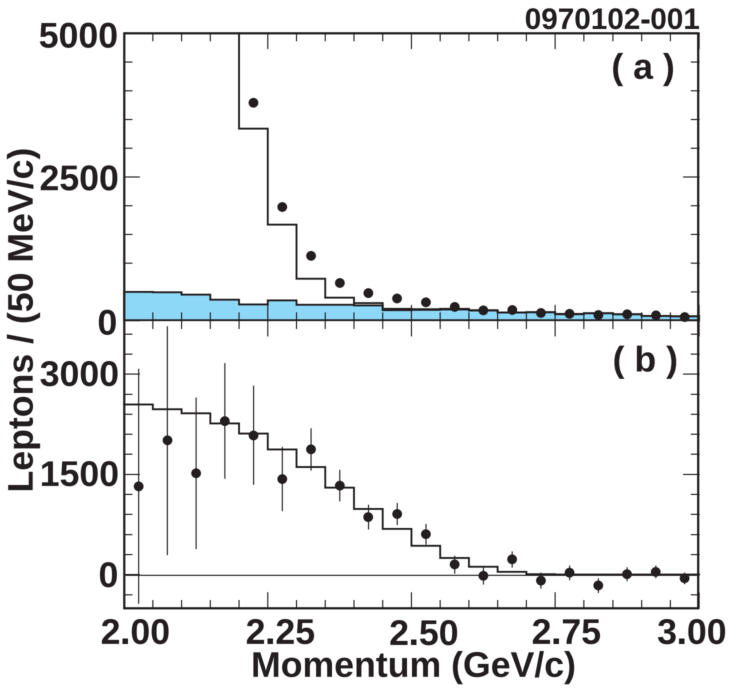
- fit $b \to s\gamma$ data to a shape function (Kagan-Neubert)
- use shape parameters to determine $f_u(p)$ (De Fazio-Neubert)

Then get $\mathcal{B}_{ub}$ from $\Delta\mathcal{B}_{ub}(p) = f_u(p)\,\mathcal{B}_{ub}$ and obtain $|V_{ub}|$ from

$$|V_{ub}| = \left[(3.07 \pm 0.12) \times 10^{-3}\right] \times \left[\frac{\mathcal{B}_{ub}}{0.001}\frac{1.6\ \mathrm{ps}}{\tau_B}\right]^{\frac{1}{2}}$$

(Hoang-Ligeti-Manohar) (Bigi-Uraltsev-Shifman-Vainshtein)

$|V_{ub}|$ from lepton spectrum and $b \to s\gamma$



In $(2.2 < p_\ell < 2.6)$ GeV/c

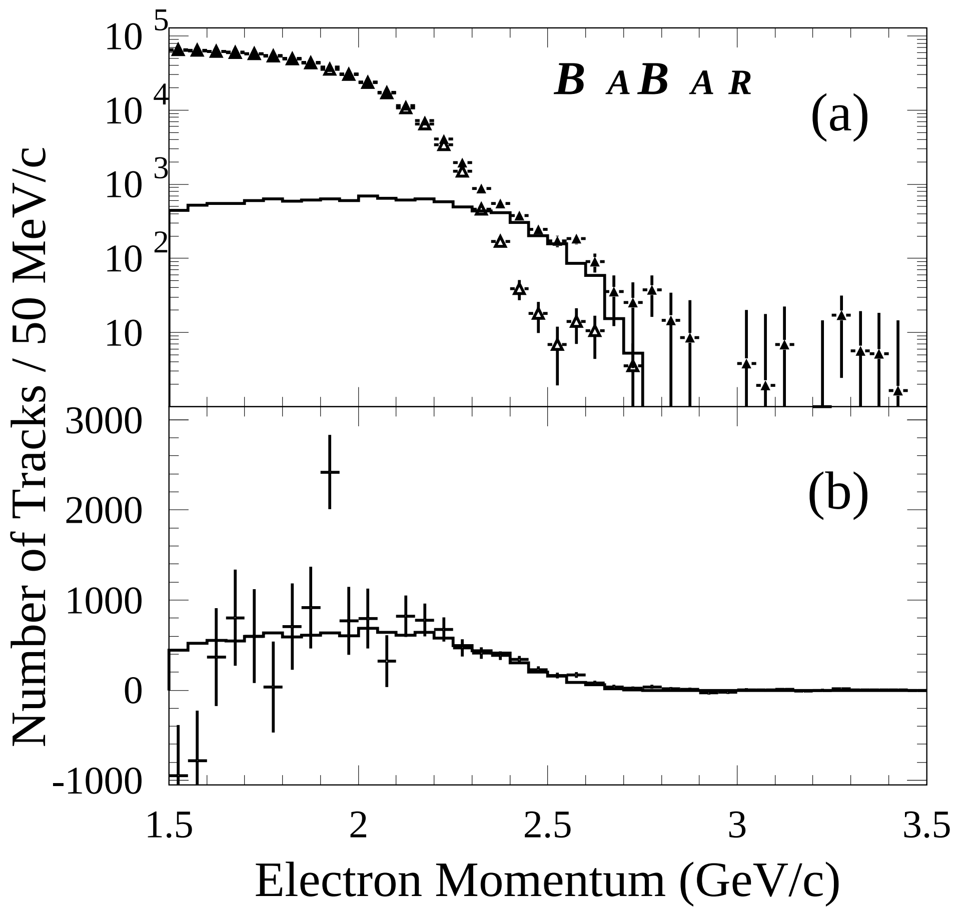
- suppress and subtract $q\bar{q}$
- subtract $B \to X_c \ell \nu$ yield
- $N_{ub} = 1901 \pm 122 \pm 256$ $B \to X_u \ell \nu$ events
- $\Delta \mathcal{B}_{ub} = (2.35 \pm 0.15 \pm 0.35) \times 10^{-4}$
- From the $b \to s\gamma$ spectrum $f_u = 0.130 \pm 0.024 \pm 0.015$

Improvement on f_u from use of $b \to s\gamma$ spectrum – knowledge of non-perturbative QCD in B to light decays

$|V_{ub}| = (4.08 \pm 0.34_{\text{exp}} \pm 0.44_{f_u} \pm 0.16_\Gamma \pm 0.24_{\Lambda/M_B}) \times 10^{-3}$

Improved 15% uncertainty CLEO hep-ex/0202019 (to appear in PRL)

BABAR lepton endpoint PRELIMINARY



(20.6 fb^{-1})

Similar to CLEO (9.1 fb^{-1})

Less Off-$\Upsilon(4S)$ data

(2.6 fb^{-1} vs 4.35 fb^{-1})

Fit $q\bar{q}$ to subtract

solid=data open=$B\bar{B}$ bkgd

hist=$b \to u\ell\nu$ ISGW2

$\Delta B_{ub}(2.3\text{–}2.6\ \mathrm{GeV}/c) = (0.152 \pm 0.014 \pm 0.014) \times 10^{-3}$

Good agreement with CLEO $\Delta B_{ub} = (0.143 \pm 0.010 \pm 0.014) \times 10^{-3}$

Summary and Outlook

$|V_{cb}|$

- agreement(?) inclusive and exclusive techniques sub 5%
- data in hand at B factories to put our understanding to the test
- Exclusive Future
  - unquenched lattice for $\mathcal{F}(1)$
  - data on form factor R_1, R_2, shape
- Inclusive Future
  - new $\mathcal{B}$, τ from Belle and Babar
  - looks promising but need confirmation with more moments
  - E-moments in the summer

$|V_{ub}|$

- again good agreement on inclusive and exclusive 15–20%
- Exclusive Future
  - More statistics from Belle, Babar, CLEO
  - Lattice form factor for $\pi\ell\nu$
- Inclusive Future
  - better shape function from $b \to s\gamma$ statistics
  - use of M_X and q^2 cuts - is there argreement?
  - better control of theory uncertainties?
  - higher twist corrections to shape function?
  - better $b \to c\ell\nu$ improves $b \to u\ell\nu$

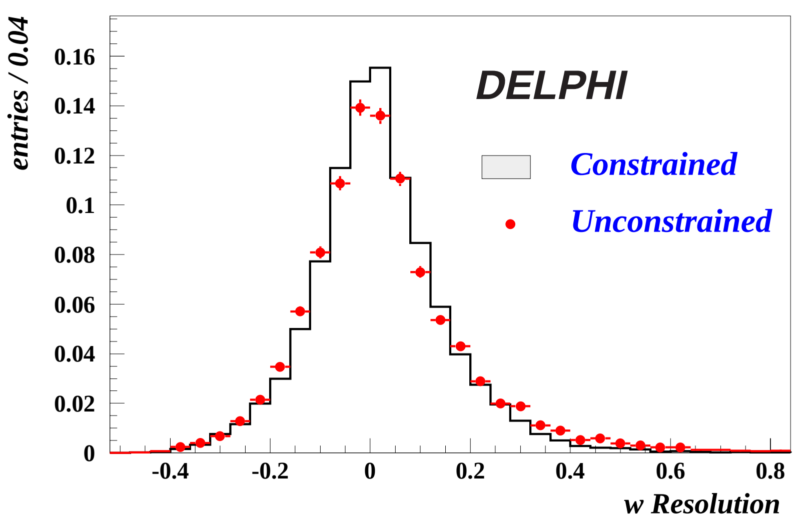
Many improvements in understanding to come with B factory data.

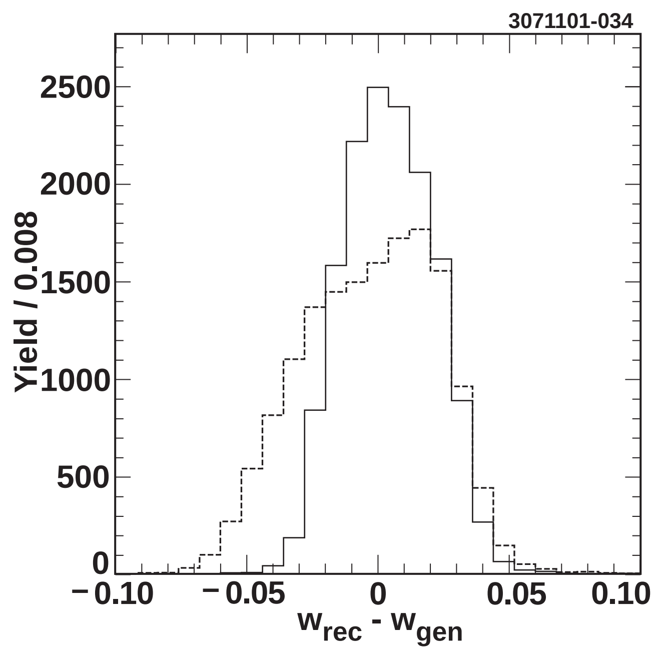
Backup Slides

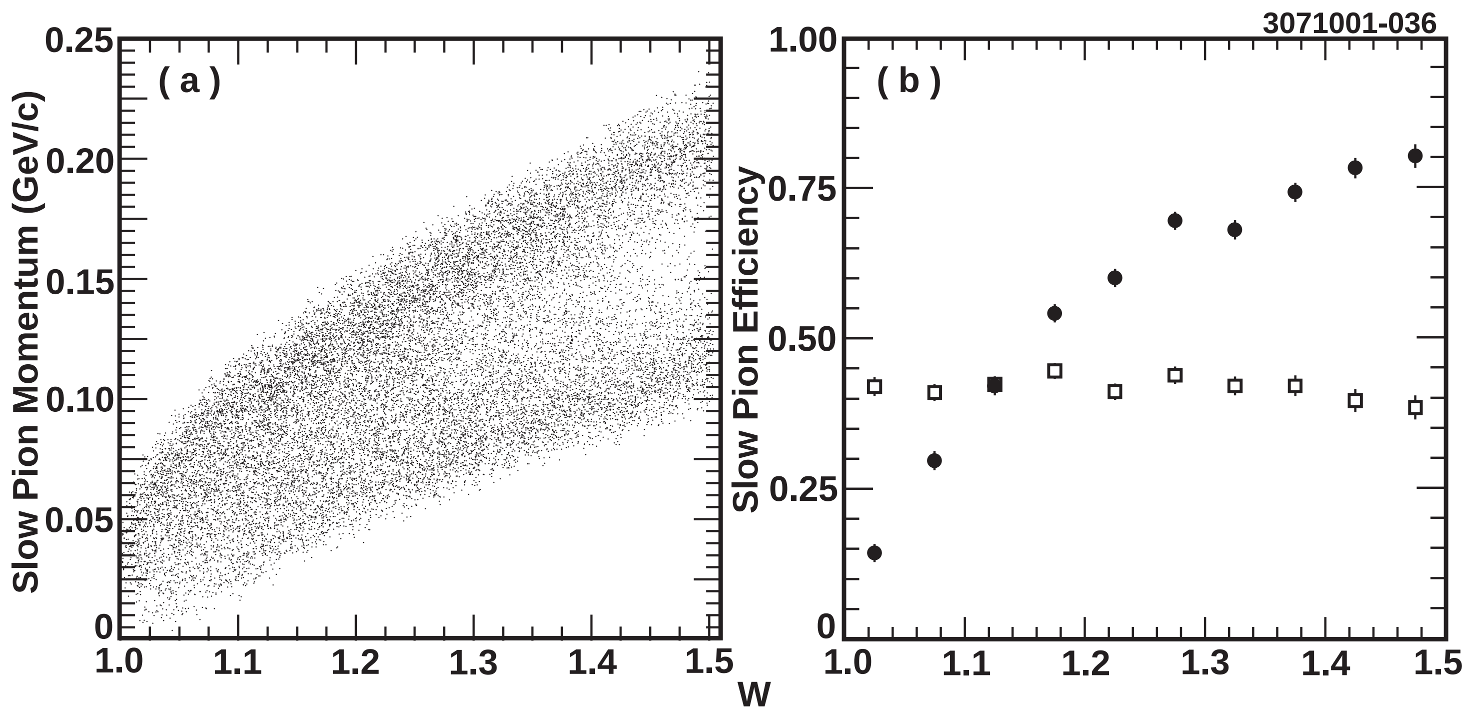
$D^*\ell\nu$ at $\Upsilon(4S)$ and Z Experiments

Main differences arise from B momentum in lab frame:
At LEP $p_B \sim 30$ GeV/c; At $B\bar{B}$ threshold $p_B \sim 0.3$ GeV/c

- w is boost of D^* in B rest frame
- LEP resolution on σ_w ~0.07–0.14 compared to $\sigma_w \sim 0.03$ at 4S







- 4S experiments suffer from π efficiency turn on

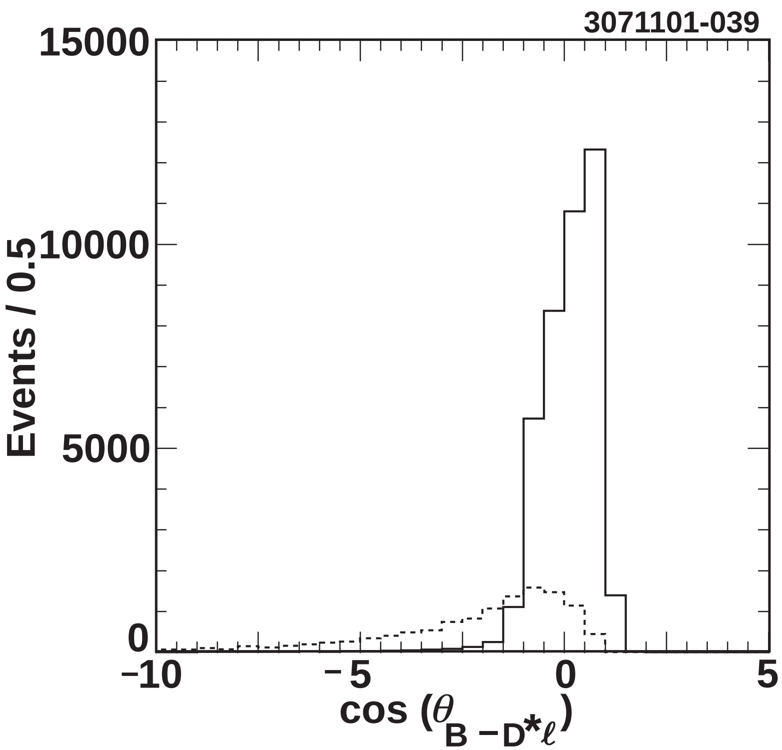
  At LEP Efficiency is flat

  – In $D^{*+} \to D^0\pi^+$ the π momentum comes from the boost of the D^*

  – Low efficiency below 0.05 MeV - precisely most interesting events for extrapolation to w=1.

  – Does not apply to $D^{*0} \to D^0\pi^0$; π^0 efficiency is flat.

- LEP expts. have more exposure to $B \to D^* X \ell \nu$
  - poorer missing mass resolution – 4S can separate sig/bkgd
  - larger systematic from poorly known $B \to D^{**} \ell \nu$ and non-resonant $B \to D^* \pi \ell \nu$ modes



CLEO fits $D^* X \ell \nu$ systematic=0.3%

BELLE cuts systematic=1.2%

LEP systematic=1.2–5%