# Recent CLEO Results

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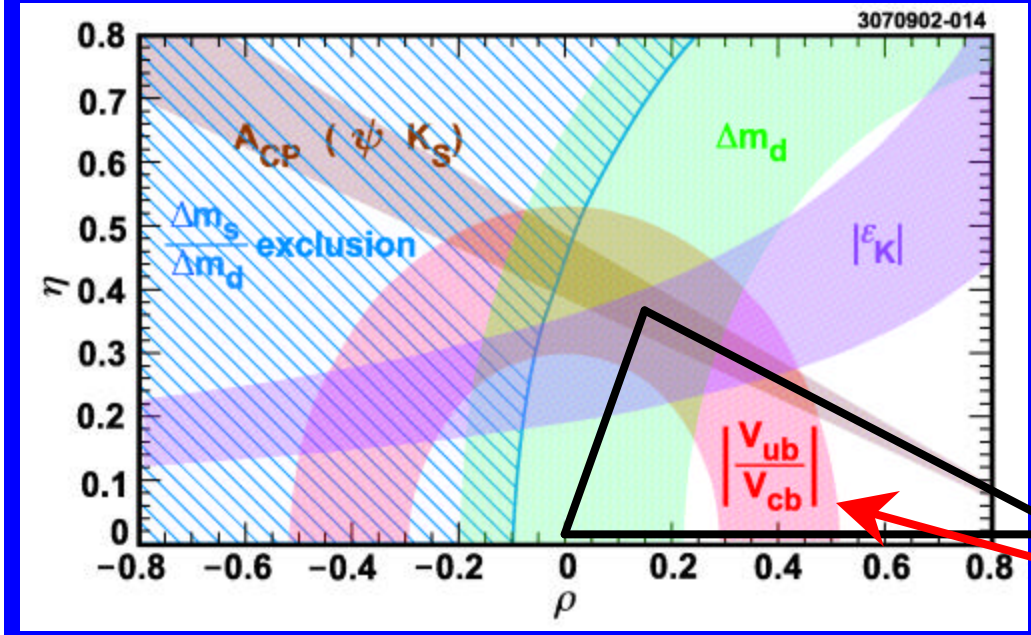
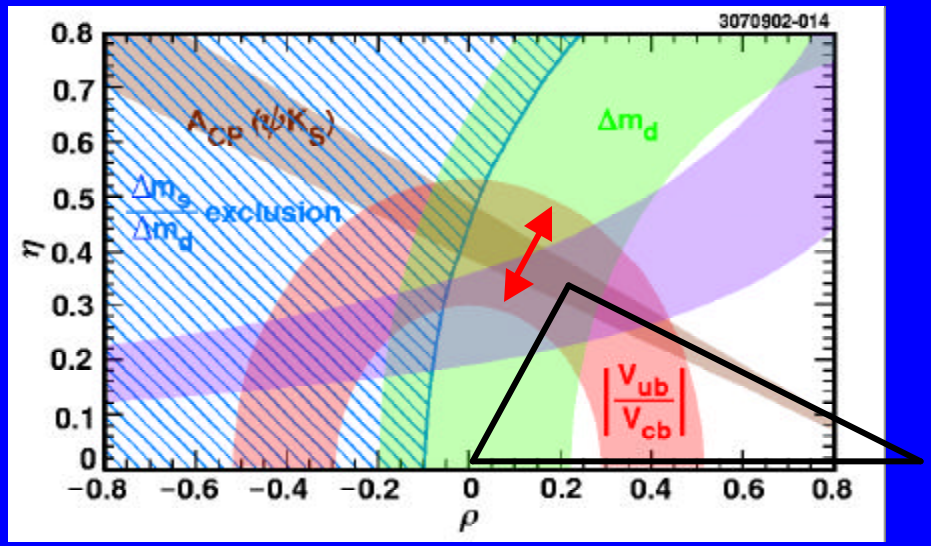
# CLEO CKM Results




Unitarity Triangle

- Motivation
  - Physics of flavor
  - CPV from CKM?
  - Look for new physics
- CLEO's contribution: $|V_{ub}|$, $|V_{cb}|$ from semileptonic B decays
  - Pioneering measurements
  - *Still among the best!*

# UT Constraint from $|V_{ub}|$




$|V_{ub}|$ from $B\to\pi l\nu$:

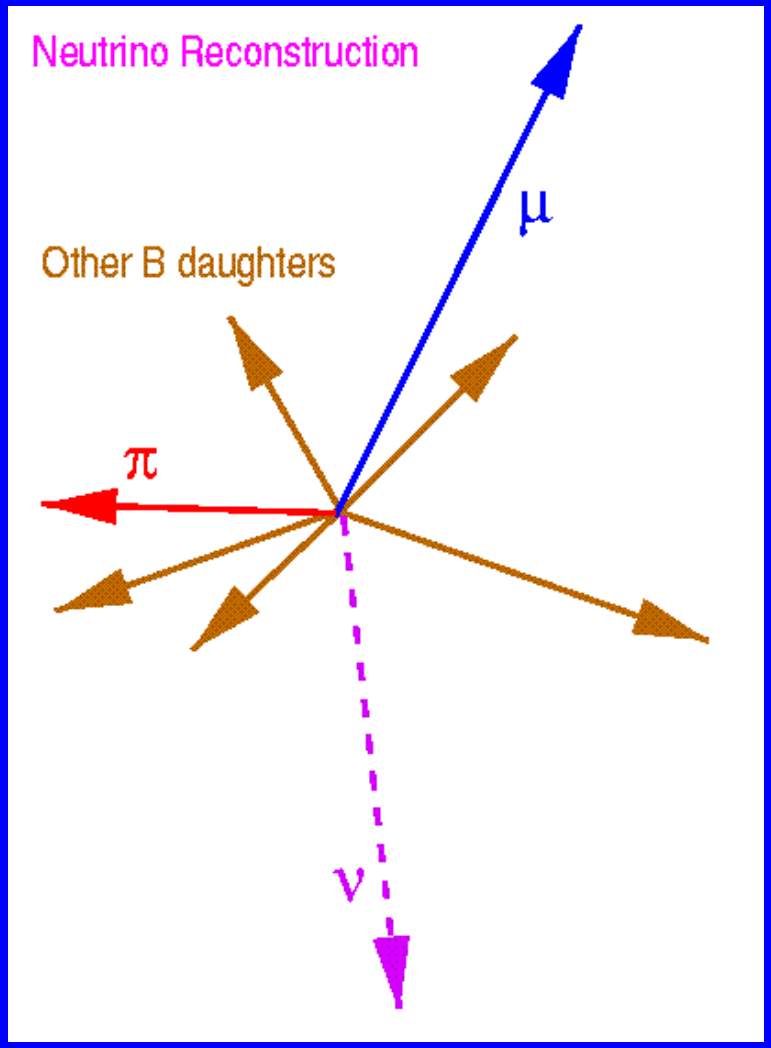
$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24p^3}|V_{ub}|^2 p_p^3 |f_+(q^2)|^2$$

Form factor $f(q^2)$:

- Encodes hadronic physics
- Not well known
- Limits $|V_{ub}|$ precision

- CLEO has measured $B\to\pi l\nu$, $\rho l\nu$ before
- New measurement that is binned in $q^2$, therefore sensitive to shape of $f(q^2)$
- FF computed in quark models, LQCD and LCSR

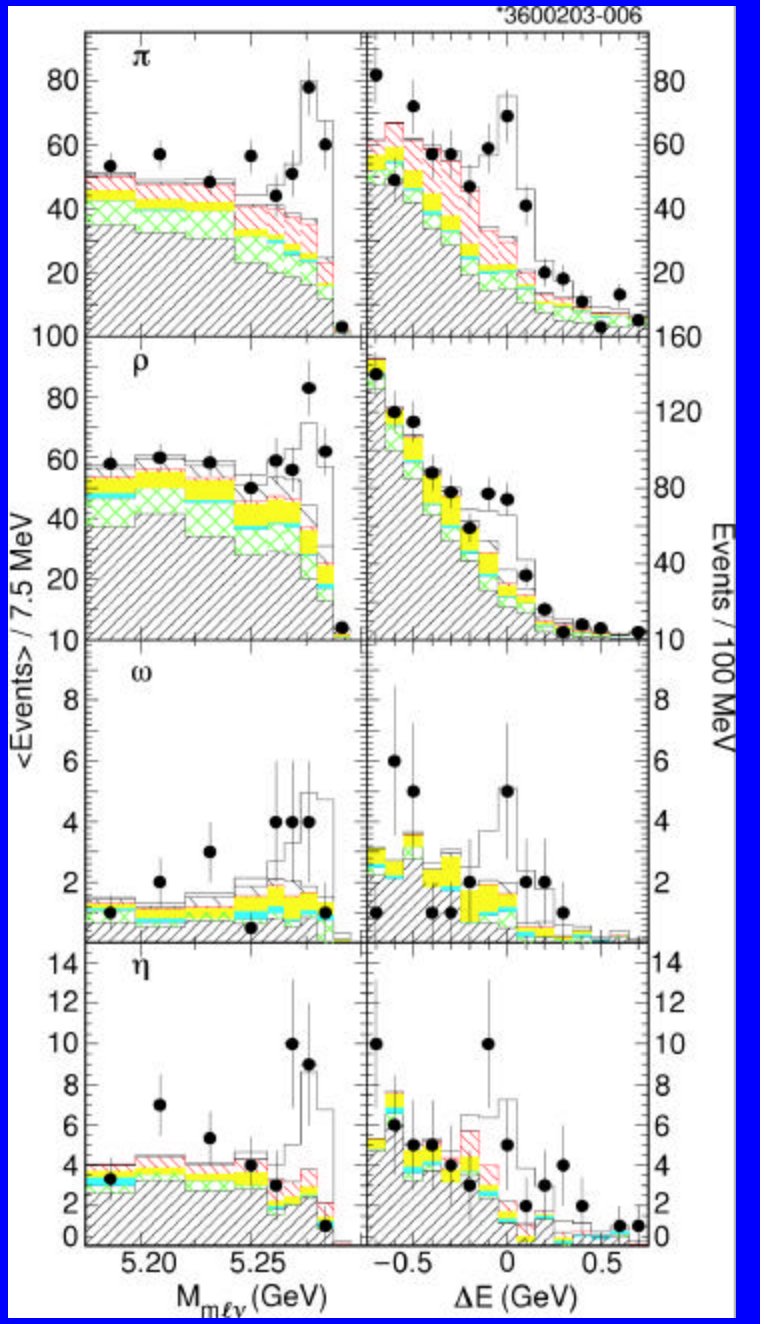
# Exclusive B→$\pi l \nu$




- Suppress b→c bkgd by reconstructing ν
- Use hermeticity of detector to infer $p_\nu$
- Clean events required
  - Remove spurious tracks
  - and hadronic showers
- (E,p) conservation → peaks in $M_B$ & $\Delta E$
- Rate and form factor give $|V_{ub}|$

# Exclusive $|V_{ub}|$

- 7 $B \to X_u l \nu$ submodes considered ($\pi, \rho, \omega, \eta$)
- 3 $q^2$ bins for $\pi, \rho$
- Simultaneous ML Fit
  - Accounts for cross feed
  - Fit projections shown on right
- Isospin constraints
  - $\frac{1}{2}\Gamma(\pi^- l \nu) = \Gamma(\pi^0 l \nu)$
  - $\frac{1}{2}\Gamma(\rho^- l \nu) = \Gamma(\rho^0 l \nu) \approx \Gamma(\omega l \nu)$



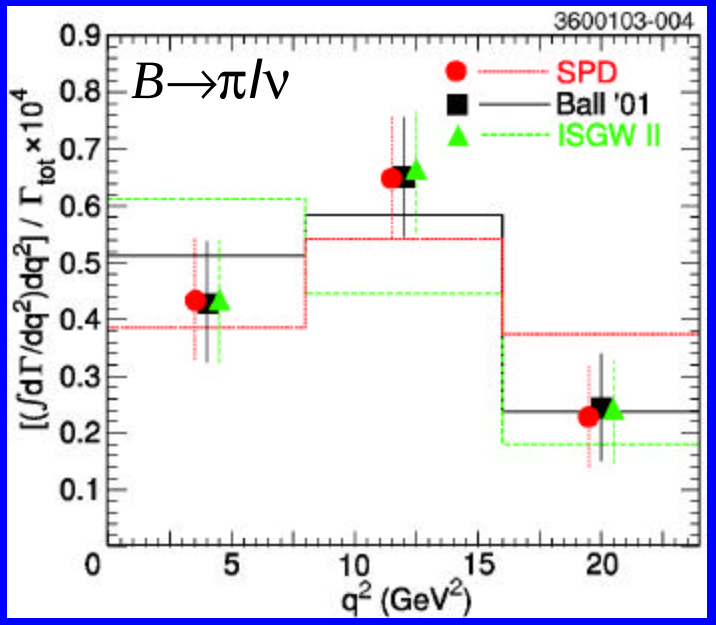

$BF(B^0 \to \pi^- l \nu) = (1.33 \pm 0.18 \pm 0.11 \pm 0.01 \pm 0.07) \times 10^{-4}$

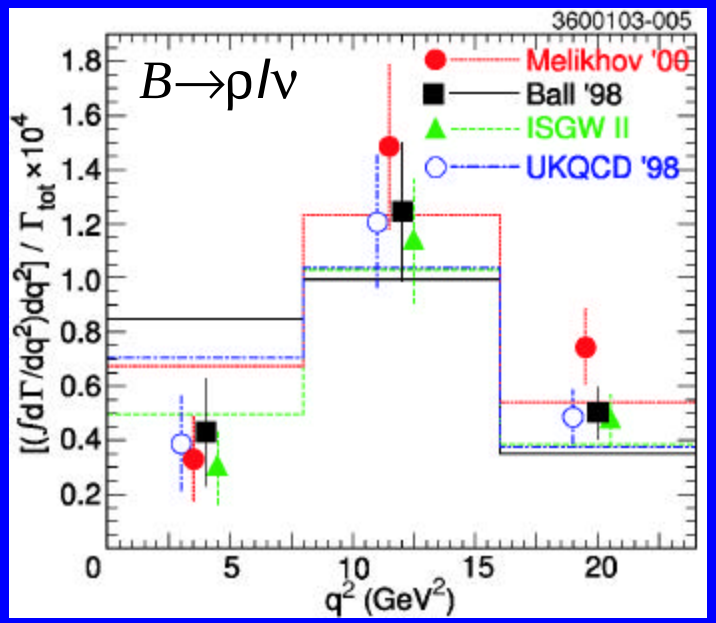
$BF(B^0 \to \rho^- l \nu) = (2.17 \pm 0.34^{+0.47}_{-0.54} \pm 0.01 \pm 0.41) \times 10^{-4}$

# Extracting $|V_{ub}|$

$$\frac{d\Gamma(B^0 \to P^-\ell^+\nu)}{dy\, d\cos\theta_{W\ell}} = |V_{ub}|^2 \frac{G_F^2 k_P^3 M_B^2}{32\pi^3} \sin^2\theta_{W\ell} |f_1(q^2)|^2$$

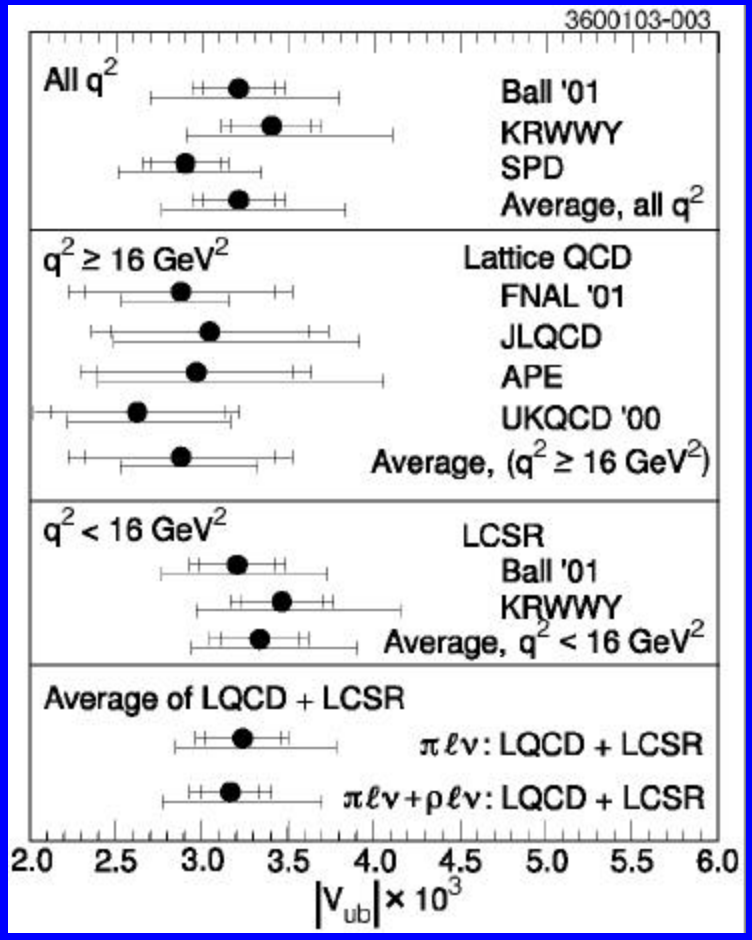
- Fit $d\Gamma/dq^2$
  - Discriminates among FFs
- $B \to \pi l \nu$
  - FF dependence is small
  - Disfavors ISGW2
- $B \to \rho l \nu$
  - Larger FF dependence⇒greater model uncertainty in $|V_{ub}|$



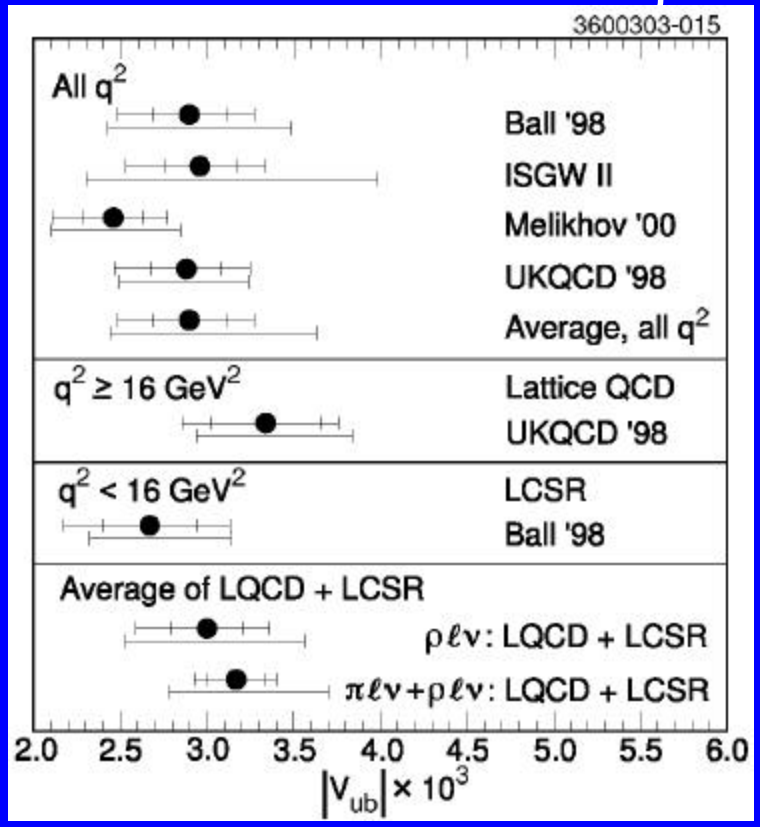



# Results

B→πlν



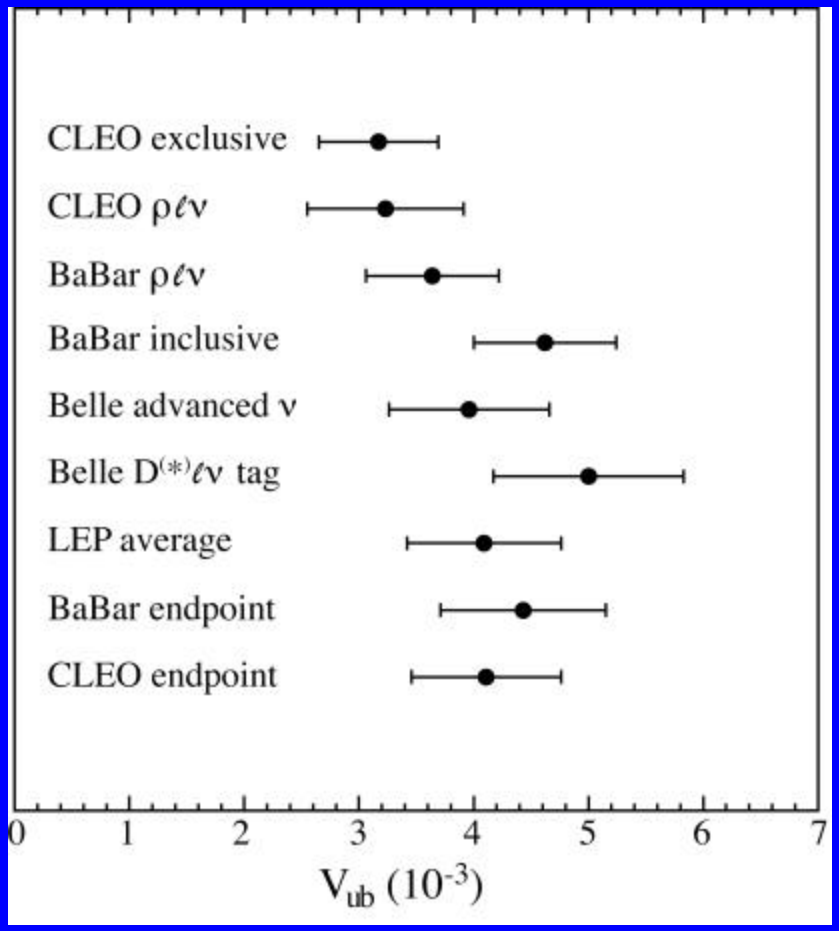

B→ρlν




PRD 68, 072003 (2003)

$$|V_{ub}| = (3.17 \pm 0.17 \pm 0.17\ ^{+0.53}_{-0.39} \pm 0.03) \times 10^{-3}$$

# World $|V_{ub}|$ Results

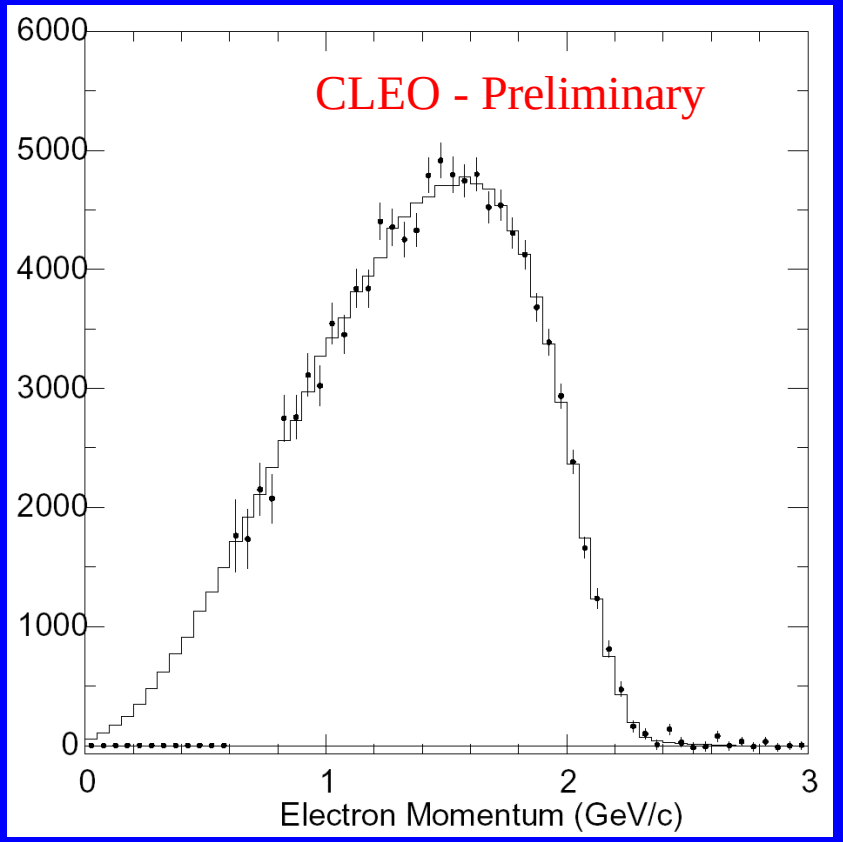



Ed Thorndike's Compilation @ FPCP `03

- All measurements are systematics limited
- CLEO pioneering new techniques and
- Using a very well-understood detector
- CLEO results still very competitive in B factory era

# *B* Semileptonic Branching Fraction

- CLEO II: 10 fb$^{-1}$ at $\Upsilon(4S)$
  - Mature, well-understood detector, data, Monte Carlo, generators, etc.
- Lepton-Tagged Analysis
  - $p_{tag}$>1.4 GeV/$c$ plus accompanying electron with $p_e$>0.6 GeV/$c$.
  - Charge, angular correlations to separate primary ($B\to Xe\nu$) from secondary ($B\to D\to Ye\nu$).
- Refined electron ID, background and efficiency determinations.
  - Maximize understanding and minimize momentum dependence.

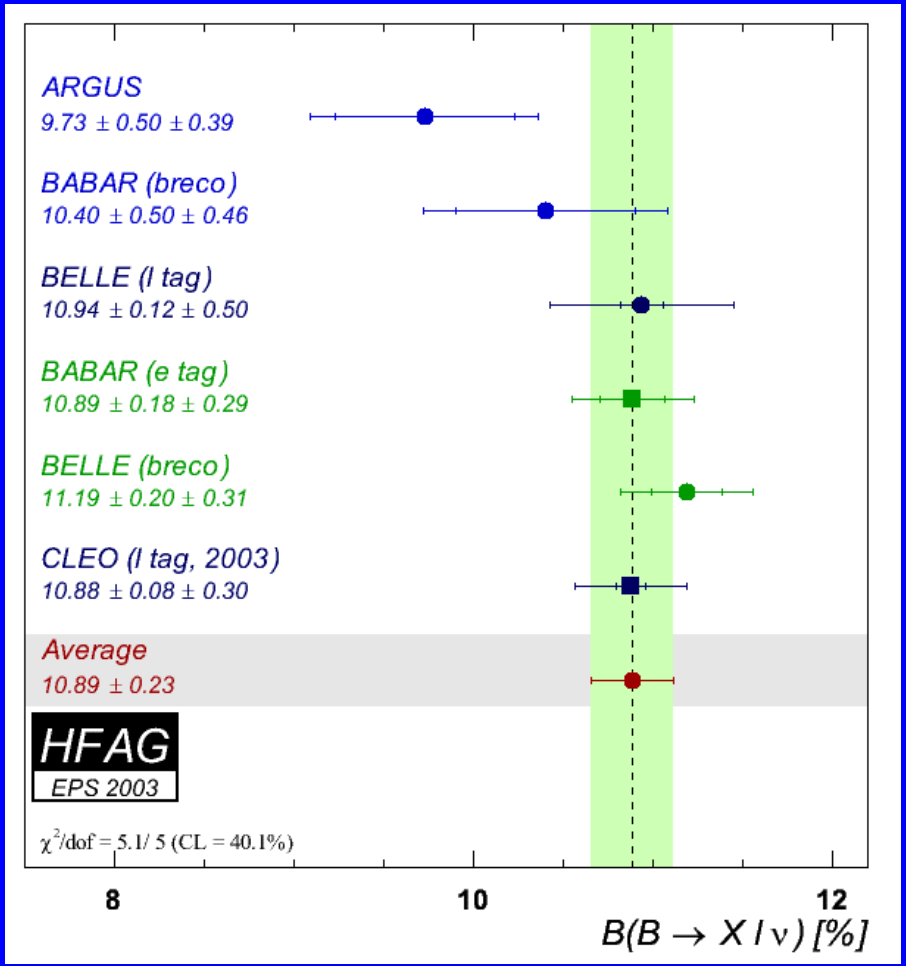



stat ± syst

$$B(B\to Xe\nu)=(10.88\pm 0.08\pm 0.33)\%$$

# $B_{SL}$ – Status

- Good agreement among different techniques, experiments.
- Measurements at $\Upsilon(4S)$ have come up and LEP $Z^0$ average has come down.
  - Most recent LEP fit result is (10.59±0.22)%



# Inclusive $|V_{cb}|$

Heavy Quark Expansion: double series in 1/M, $\alpha_s$

$$\Gamma_{sl} = \frac{G_F^2 |V_{cb}|^2 M_B^5}{192\pi^3} 0.3689 [1 - 1.54\frac{\alpha_s}{\pi} - 1.43\beta_0\frac{\alpha_s^2}{\pi^2} - 1.648\frac{\bar{\Lambda}}{M_B}(1 - 0.87\frac{\alpha_s}{\pi}) - 0.946\frac{\bar{\Lambda}^2}{M_B^2} - 3.185\frac{\lambda_1}{M_B^2}$$
$$+ 0.02\frac{\lambda_2}{M_B^2} - 0.298\frac{\bar{\Lambda}^3}{M_B^3} - 3.28\frac{\bar{\Lambda}\lambda_1}{M_B^3} + 10.47\frac{\bar{\Lambda}\lambda_2}{M_B^3} - 6.153\frac{\rho_1}{M_B^3} + 7.482\frac{\rho_2}{M_B^3}$$
$$- 7.4\frac{\mathcal{T}_1}{M_B^3} + 1.491\frac{\mathcal{T}_2}{M_B^3} - 10.41\frac{\mathcal{T}_3}{M_B^3} - 7.482\frac{\mathcal{T}_4}{M_B^3} + \mathcal{O}(1/M_B^4)] \ .$$

- Ingredients:
  - $B(B \to X_c l\nu) = (10.8 \pm 0.3)\%$ (CLEO)
  - $\tau_{B^0}$ and $\tau_{B^\pm}$ (PDG), $f_{+-}/f_{00}$ (CLEO)
  - HQE parameters $\Lambda$, $\lambda_1$, from moments $\langle E_\gamma \rangle$: $B \to X_s\gamma$, $\langle M_X^2 \rangle$: $B \to X l\nu$ (CLEO)
  - HQE parameter $\lambda_2 = 0.128 \pm 0.010$ from B*-B mass difference

  $\Rightarrow \Gamma_{SL} = (0.44 \pm 0.02) \times 10^{-10}$ MeV
- Result:

$|V_{cb}| = 0.0411 \pm 0.0005_{\text{exp } \Lambda,\lambda 1} \pm 0.0007_{\text{exp } \Gamma} \pm 0.0009_{\text{theory}}$

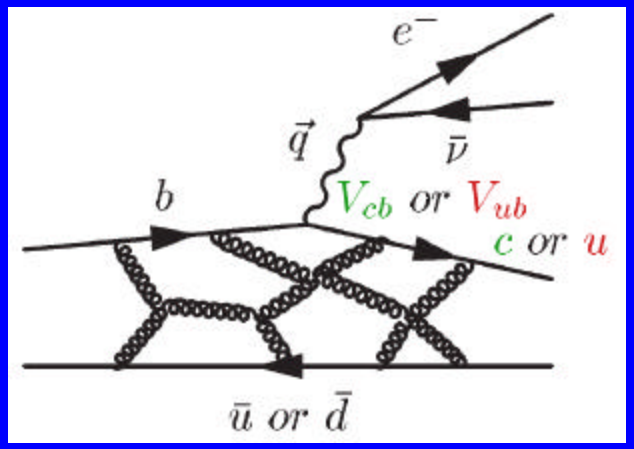
Overall precision: ~3% + quark-hadron duality.

# New and Improved Measurement of the Hadronic Mass Moments in $B \to X_c l \nu$

hep-ex/0307081 contributed to Lepton-Photon 2003

Preliminary

- Compute recoiling hadronic mass from charged lepton and neutrino kinematics - neutrino "reconstruction"
- Near hermeticity of CLEO II $\Rightarrow$ Neutrino="What's missing"

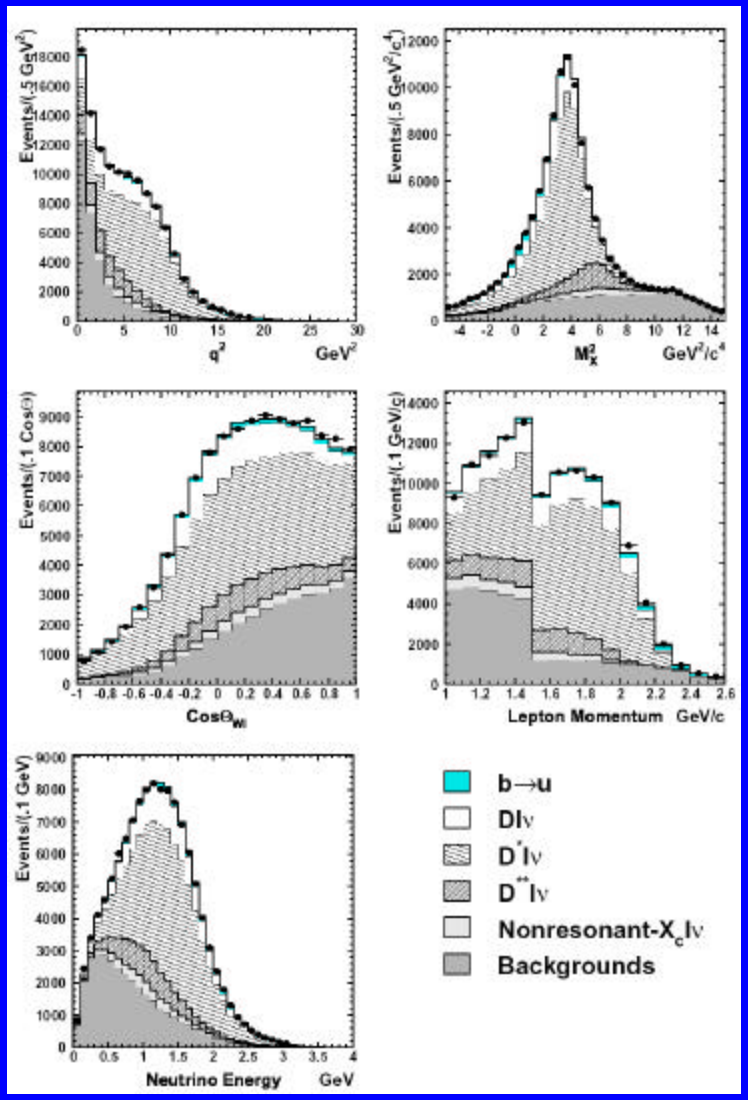



Fit 3-dimensional differential decay rate, extract hadronic mass squared as a function of lepton-energy cut ($p_l > 1$ GeV/$c$).

$$M_X^2 = M_B^2 + q^2 - 2E_{beam}(E_l + E_n) + 2\underbrace{|\vec{p}_B||\vec{q}|\cos\theta_{Bq}}_{\text{ignored}}$$

# Fit Projections

- Selection criteria:
  - Cuts to enhance $\nu$ reconstruction
  - Continuum suppression
  - Efficiency ~2% for $B \to X_c l \nu$
- Sample to fit: 122K events
- Components of fit:
  - $B \to D l \nu$ } HQET+measured FFs
  - $B \to D^* l \nu$ } HQET+measured FFs
  - $B \to D^{**} l \nu$ ISGW2
  - $B \to (X_c)_{NR} l \nu$ Goity/Roberts
  - $B \to X_u l \nu$ ISGW2+NR
  - Secondaries CLEO MC
  - Fake Leptons, Continuum fixed with data



# Results

hep-ex/0307081

Fits $\rightarrow$Mode-by-Mode BFs

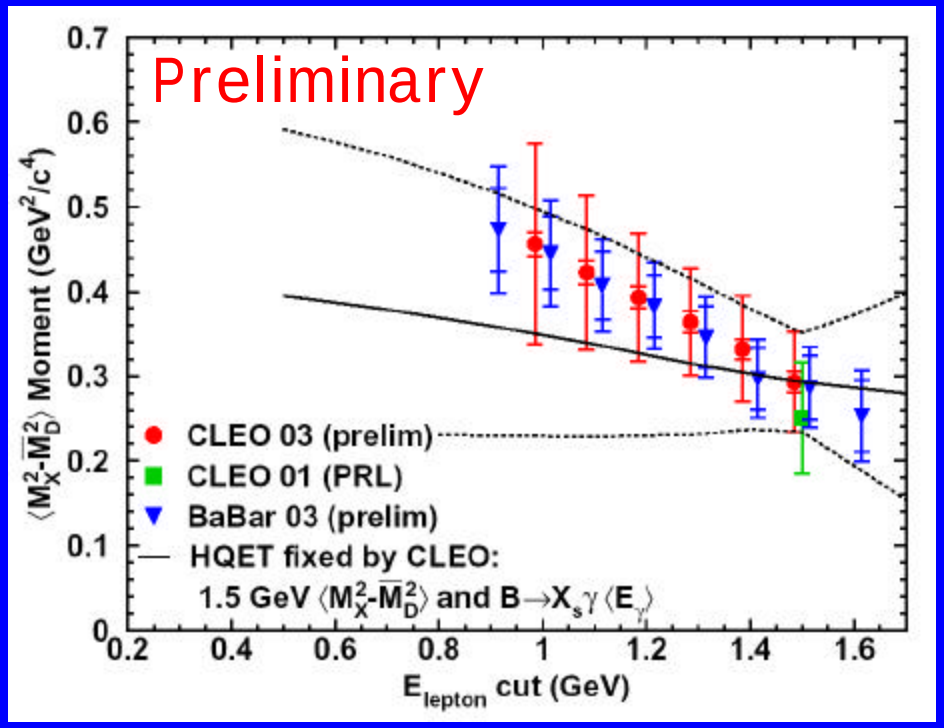
+

Generator-Level Info

(Fraction above $p_l$ cut, moment value for that cut.)

$\Downarrow$

Moment Value for $B \rightarrow X_c l\nu$




| Cut (GeV) | $\langle M_X^2 - \overline{M}_D^2 \rangle$ (GeV$^2/c^4$) |
|---|---|
| $E_\ell > 1.0$ | $0.456 \pm 0.014 \pm 0.045 \pm 0.109$ |
| $E_\ell > 1.1$ | $0.422 \pm 0.014 \pm 0.031 \pm 0.084$ |
| $E_\ell > 1.2$ | $0.393 \pm 0.013 \pm 0.027 \pm 0.069$ |
| $E_\ell > 1.3$ | $0.364 \pm 0.013 \pm 0.030 \pm 0.054$ |
| $E_\ell > 1.4$ | $0.332 \pm 0.012 \pm 0.027 \pm 0.055$ |
| $E_\ell > 1.5$ | $0.293 \pm 0.012 \pm 0.033 \pm 0.048$ |

stat $\pm$ syst $\pm$ model

- Consistent with previous CLEO measurements, BaBar summer '03, DELPHI
- Interpretation is ongoing

# More CLEO Physics Results

- Rare B decays
  - $A_{CP}$ in $B \rightarrow K^{*+}\pi^-$
  - $B \rightarrow \eta' X_s$ BF
  - Upper Limit on Baryons in $B \rightarrow X_s\gamma$
- Hadronic B Decays
  - $B \rightarrow D^{(*)}\rho$ helicity analysis (Final State Interactions)
- Upsilon Decays
  - $\Upsilon(3S) \rightarrow \omega\Upsilon(1S)$
  - Two-body $\Upsilon(nS)$ decays
  - Searches for cc states
- Charmed Baryons
  - CPV in $\Lambda_c \rightarrow \Lambda$ e $\nu$
- Charm Decays
  - Branching fractions
  - Mixing and DCSD
  - Dalitz plot analyses
    - Hadronic structure
    - CPV via interference in Dalitz Plot $D^0 \rightarrow \pi^+\pi^-\pi^0$
- $D_s$ spectroscopy
  - See talk by JC Wang

# Summary

- CLEO is still contributing to $|V_{ub}|$ and $|V_{cb}|$ measurements
  - $|V_{cb}|$ from inclusive $B \rightarrow X_c\, l\, \nu$
  - $|V_{ub}|$ from exclusive $B \rightarrow \pi/\rho/\omega/\eta\, l\, \nu$
- See other CLEO talks by
  - David Asner on CLEO-c Prospects
  - J.C. Wang on the new $D_{sJ}$ states