Recent results on semileptonic decay from CLEO

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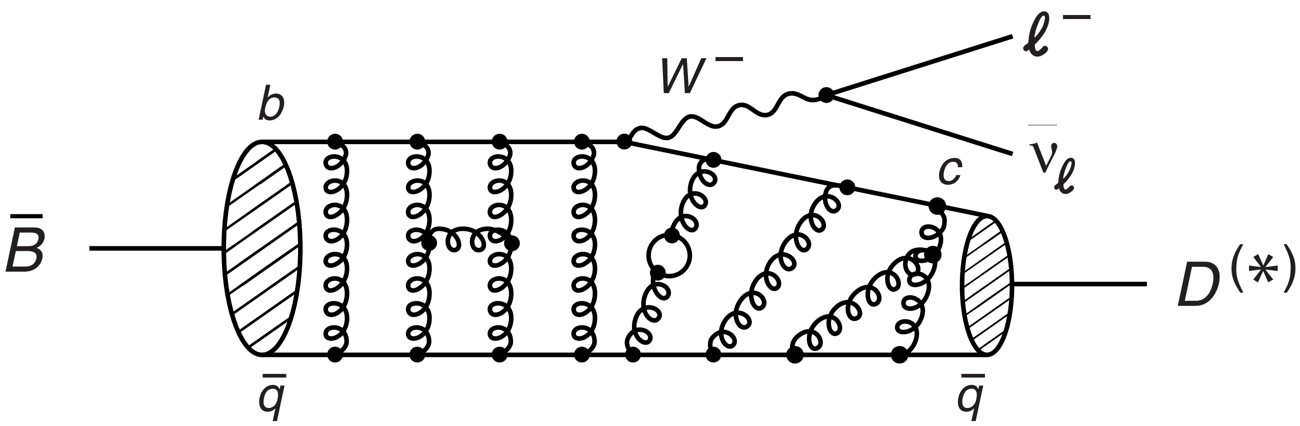
Outline

- Semileptonic decay dynamics
- $B \to \rho\ell\nu$: new branching fraction and $|V_{ub}|$
- Conclusions

CLEO Collaboration

Albany, CalTech, UCSD, UCSB, Carleton, CMU, Colorado, Cornell, Florida, Harvard, Hawaii, UIUC, Ithaca, Kansas, McGill, Minnesota, OSU, Oklahoma, Purdue, Rochester, SLAC, SMU, Syracuse, VPI, Wayne State

Why use SL decays to measure $|V_{\mathrm{CKM}}|$?



SL decays are relatively simple to measure and interpret.

- Strong interactions affect the hadronic current only $\Rightarrow$ can rigorously parametrize their effect in terms of form factors.

- Relative simplicity of SL decays permits theoretical predictions for the FFs and thus for the rate with much smaller uncertainties than for hadronic decays.

$$\mathcal{B}(B \to \rho\ell\nu) = |V_{ub}|^2\tilde{\Gamma}_{\text{theory}}/\tau_B$$

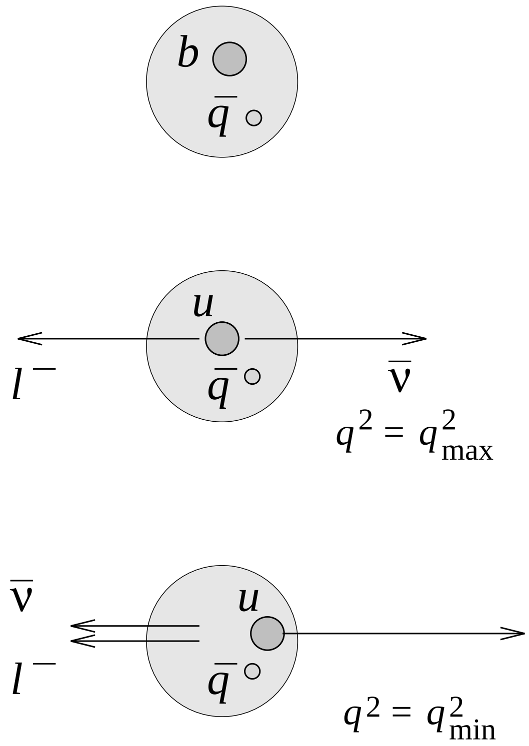
- Branching fractions:

  $\approx 5\%$ for $B \to D^*\ell\nu$

  $\approx 2 \times 10^{-4}$ for $B \to \rho\ell\nu$.

Definition of q^2

$$q^2 \equiv M_W^2 = (p_\ell + p_\nu)^2 = (p_B - p_\rho)^2$$



- In $B \to D^*\ell\nu$ decay, $p_{D^*} \approx p_{c\ \mathrm{quark}} \Rightarrow q^2 = q^2_{\mathrm{max}}$ is a reliable point to normalize theoretical predictions.
- Not so for $b \to u\ell\nu$ decays $\Rightarrow$ theoretical predictions much more difficult.
- Larger kinematic range in $b \to u\ell\nu$ decays is another difficulty.

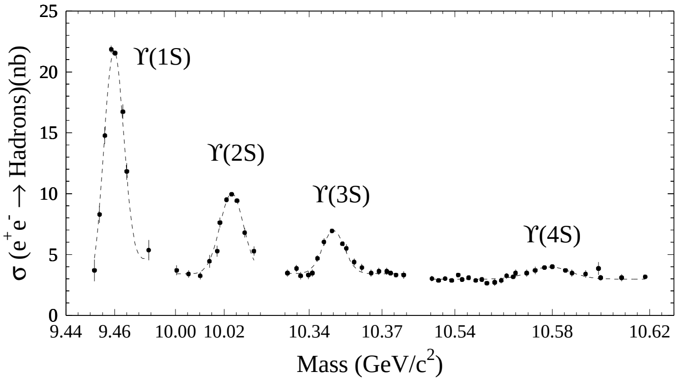
- Measure q^2 using ρ momentum. q^2 related to $w = E_\rho/M_\rho = (M_B^2 + m_\rho^2 - q^2)/2M_BM_\rho$

Decay	q^2 range (GeV$^2/c^4$)	w range
$B \to D^*\ell\nu$	$m_\ell^2 \to 10.7$	$1 \to 1.50$
$B \to D\ell\nu$	$m_\ell^2 \to 11.7$	$1 \to 1.59$
$B \to \rho\ell\nu$	$m_\ell^2 \to 20.3$	$1 \to 3.51$
$B \to \pi\ell\nu$	$m_\ell^2 \to 26.4$	$1 \to 18.9$

CLEO and CESR

- Cornell Electron Storage Ring (CESR)

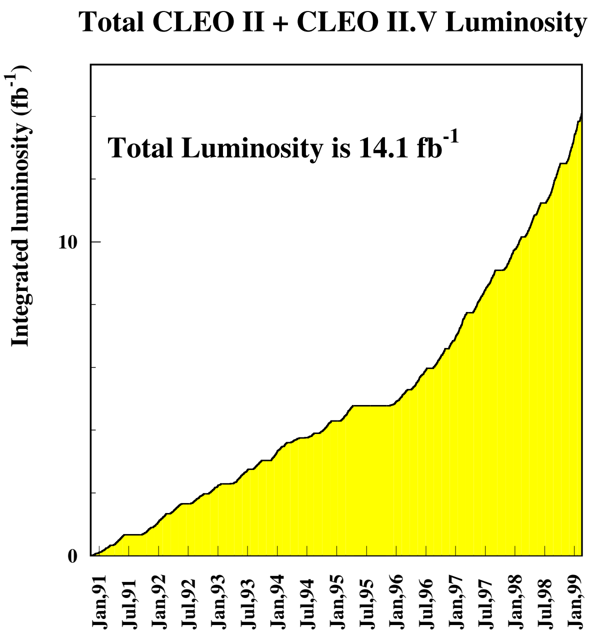
  $E_{\rm com} \approx M(\Upsilon(4S)) \qquad \mathcal{L}_{\rm max} \approx 0.8 \times 10^{33}\ {\rm cm}^{-2}{\rm sec}^{-1}$



- $\sigma(B\bar{B}) \approx 1$ nb, $\sigma(q\bar{q}$ continuum$) \approx 3$ nb
- 1/3 of $\mathcal{L}$ taken below $B\bar{B}$ thresh. to study continuum.
- B-mesons $\approx$ at rest $\Rightarrow$ use event shape variables to distinguish from jet-like continuum events.

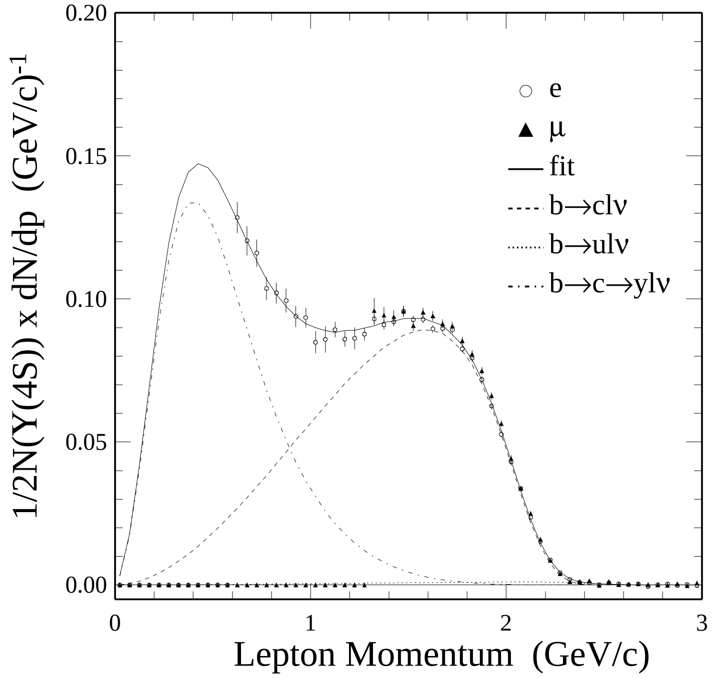
<u>CLEO</u>

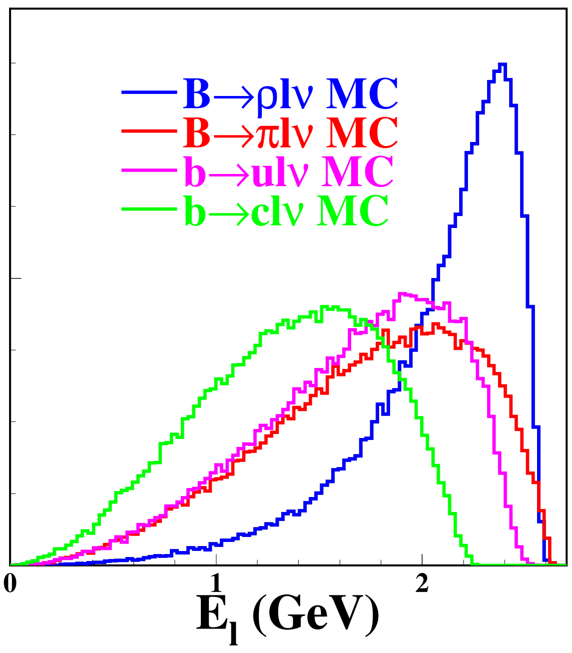
- 95(98)% solid angle coverage for tracks (calorim.)
- $\sigma_{\pi^0} \approx 6$ MeV/c^2
- Results presented today based on $\approx 3 \times 10^6$ $B\bar{B}$ pairs



Extracting a $B \to \rho \ell \nu$ signal

- $\Gamma(B \to X_u \ell \nu)/\Gamma(B \to X_c \ell \nu) \approx 2.0|V_{ub}/V_{cb}|^2$

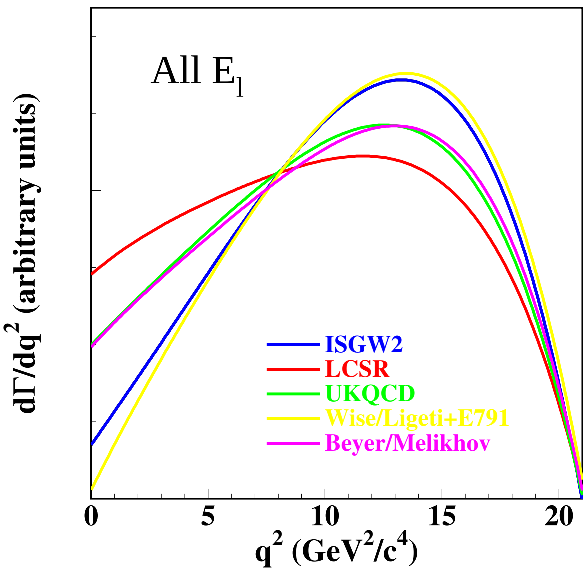


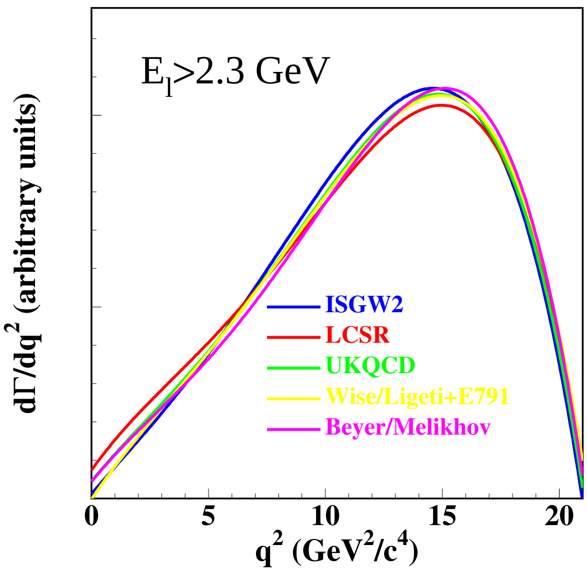


- $b \to c \ell \nu$ E_ℓ endpoint at CLEO ≈ 2.4 GeV $\Rightarrow$ require $E_\ell > 2.0$ GeV or $E_\ell > 2.3$ GeV.
- Large fraction of $B \to \rho \ell \nu$ events at large E_ℓ ($24\% - 35\%$ have $E_\ell > 2.3$ GeV).
- Allow data to determine normalization of $b \to c \ell \nu$ background.

Describing signal kinematics

- Rely on FF model to determine signal distributions.
- Compute results with 5 models in order to determine "model dependence" systematic error:
  - Quark models: ISGW2 (PRD **52** 2783).
  - Beyer/Melikhov (PLB **436** 344).
  - Lattice QCD (UKQCD) (PLB **416** 392).
  - Light-cone sum rules (Ball *et al.*) (PRD **58** 094016).
  - Ligeti/Wise+E791 $D \to K^* \ell \nu$ FFs (PRD **53** 4937).





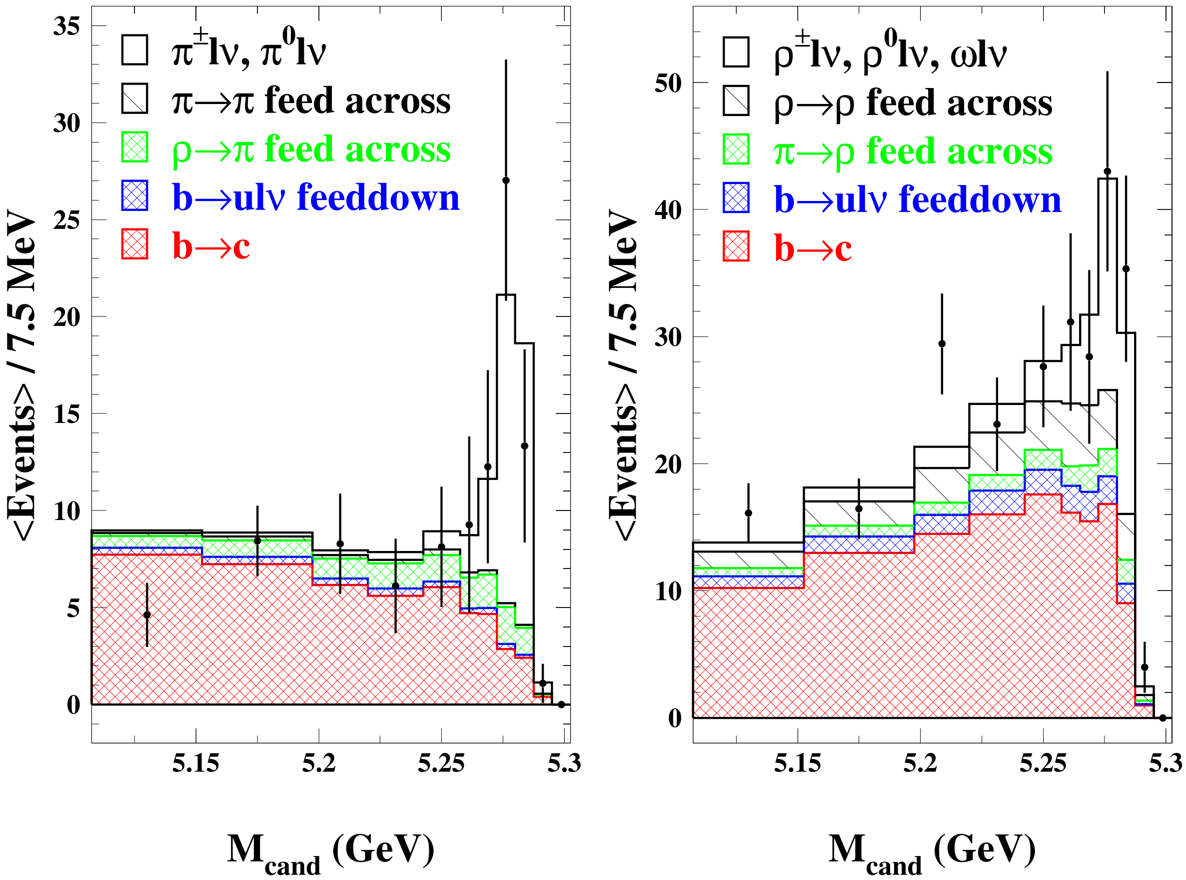
- Model dep. determined by ε of E_ℓ requirement:
  - $24 - 35\%$ have $E_\ell > 2.3$ GeV.
  - $52 - 68\%$ have $E_\ell > 2.0$ GeV.

Method #1: ν reconstruction

- PRL **77** 5000
- Reconstruct ℓ and ($\rho^{\pm}$, ρ^{0}, ω, $\pi^{\pm}$, or π^{0}).
- Estimate $\mathbf{p}_{\nu}$ and E_{ν} using missing $\mathbf{p}$ and E of event.
- To improve resolution on $\mathbf{p}_{\nu}$ and E_{ν}, require
  - Exactly 1 lepton. Total charge in event$=0$.
  - Require $M_{\nu} = \sqrt{E_{\nu}^{2} - |\mathbf{p}_{\nu}|^{2}}$ consistent with 0.
- For $B^{0} \to \rho^{-}\ell^{+}\nu$, $\varepsilon \approx 1.5\%$ for ISGW2 FFs and $E_{\ell} > 2.0$ GeV.
- $\sigma(|\mathbf{p}_{\nu}|) \approx 110$ MeV$/c$, $\sigma(E_{\nu}) \approx 260$ MeV.
- Low $b \to c\ell\nu$ backgrounds. Sensitivity to $B \to \rho(\pi)\ell\nu$ down to 2.0 (1.5) GeV.
- Extract signal yields with fit to M_{cand}, ΔE, and $M(\pi\pi)$

$$M_{\text{cand}} = \sqrt{E_{\text{beam}}^{2} - |\mathbf{p}_{\rho} + \mathbf{p}_{\ell} + \mathbf{p}_{\nu}|^{2}}$$
$$\Delta E = E_{\rho} + E_{\ell} + |\mathbf{p}_{\nu}| - E_{\text{beam}}$$

ν reconstruction results



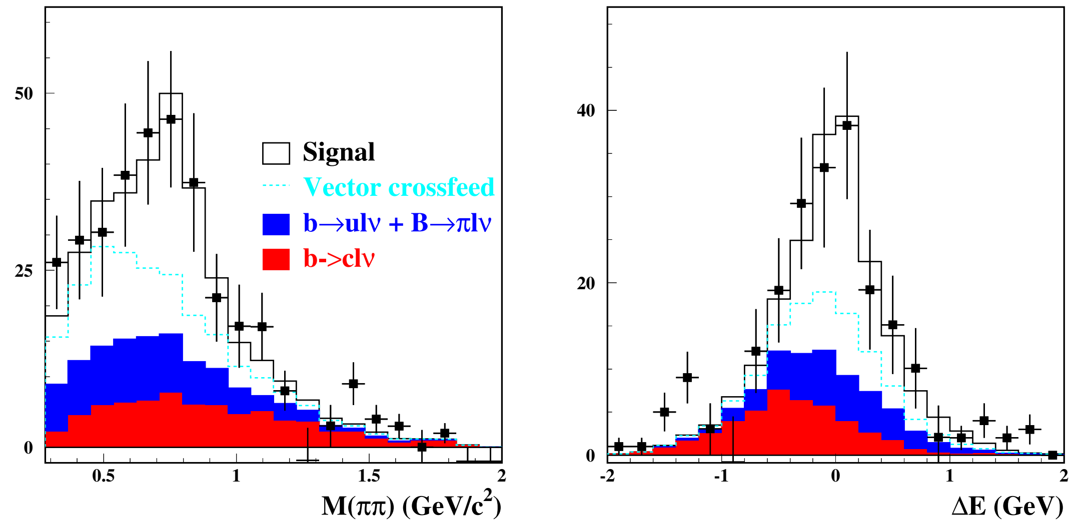
$$
\begin{aligned}
\mathcal{B}(B^0 \to \rho^- \ell^+ \nu) &= (2.5 \pm 0.4^{+0.5}_{-0.7} \pm 0.5) \times 10^{-4} \\
\mathcal{B}(B^0 \to \pi^- \ell^+ \nu) &= (1.8 \pm 0.4 \pm 0.3 \pm 0.2) \times 10^{-4} \\
|V_{ub}| &= (3.3 \pm 0.2^{+0.3}_{-0.4} \pm 0.7) \times 10^{-3}
\end{aligned}
$$

Errors are statistical, systematic, and theoretical.

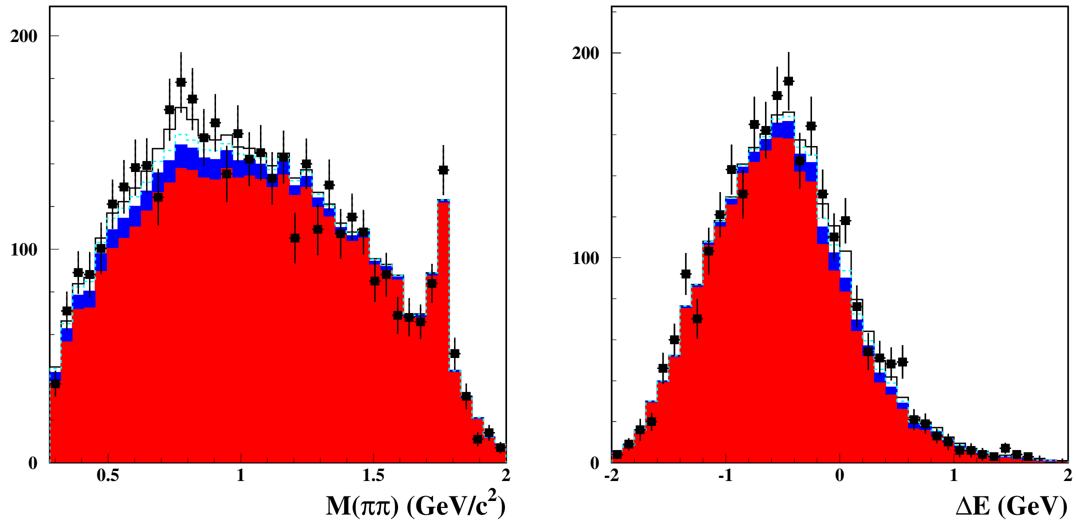
Method #2: $B \to \rho \ell \nu$ $M(\pi\pi)$ vs. ΔE analysis

- Submitted to PRD, hep-ex/9905056.

$E_\ell > 2.3$ GeV

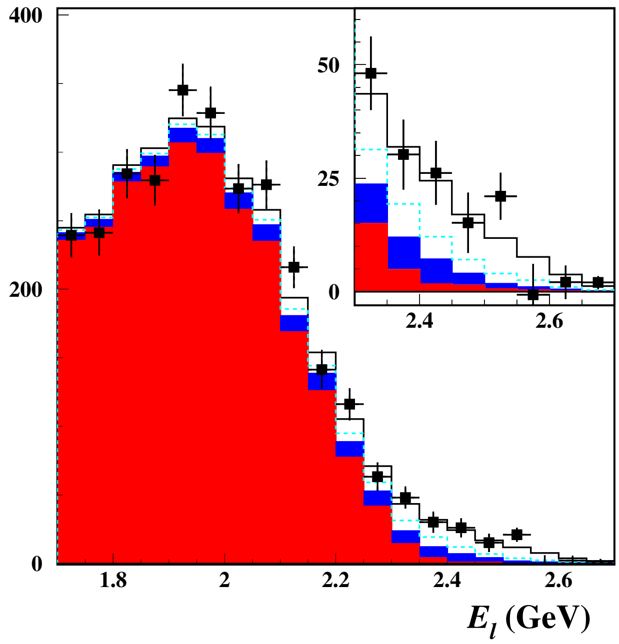


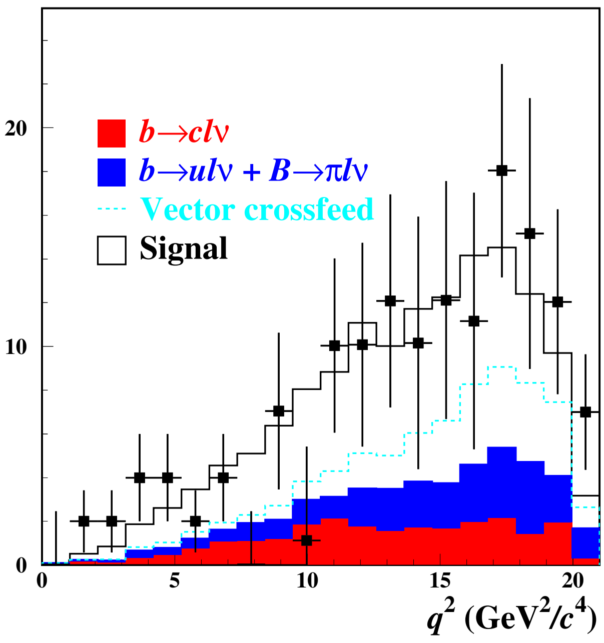
$2.0 < E_\ell < 2.3$ GeV



- Continuum is subtracted.
- For $E_\ell > 2.3$ GeV, ≈ 220 of 819 $\pi\pi$ events are signal before any $M(\pi\pi)$ or ΔE cut.

E_ℓ (GeV) $\qquad$ q^2 (GeV$^2/c^4$)



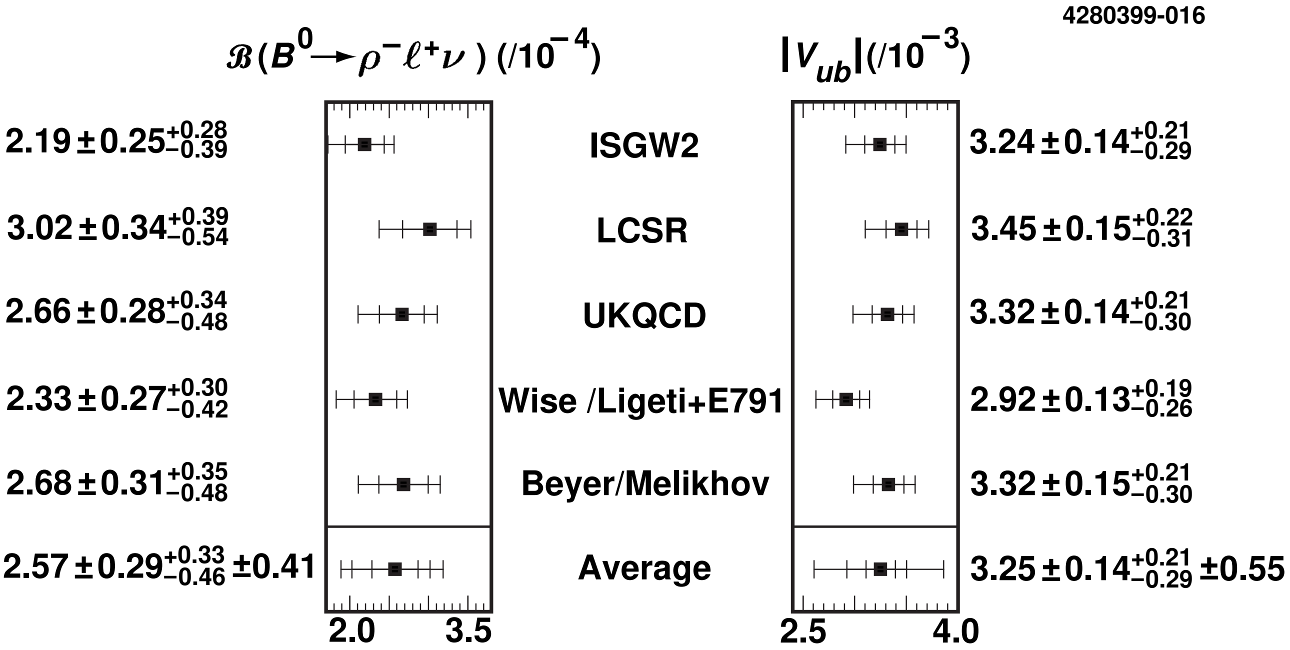


- Higher efficiency - but backgrounds limit sensitivity for $B \to \rho\ell\nu$ to $E_\ell > 2.3$ GeV where the $b \to c\ell\nu$ contribution is small and continuum is biggest background. Separate events into 3 lepton energy bins (2.3–2.7 GeV, 2.0–2.3 GeV, 1.7–2.0 GeV).
- For $B^0 \to \rho^-\ell^+\nu$, $\varepsilon \approx 4\%$ for ISGW2 FFs and $E_\ell > 2.3$ GeV.
- Data determine overall normalization and E_ℓ spectrum of each background contribution.

$$\begin{aligned}\mathcal{B}(B^0 \to \rho^-\ell^+\nu) &= (2.69 \pm 0.41^{+0.35}_{-0.40} \pm 0.50) \times 10^{-4}\\ |V_{ub}| &= (3.23 \pm 0.24^{+0.23}_{-0.26} \pm 0.58) \times 10^{-3}\end{aligned}$$

Results for $\mathcal{B}(B \to \rho\ell\nu)$ and $|V_{ub}|$

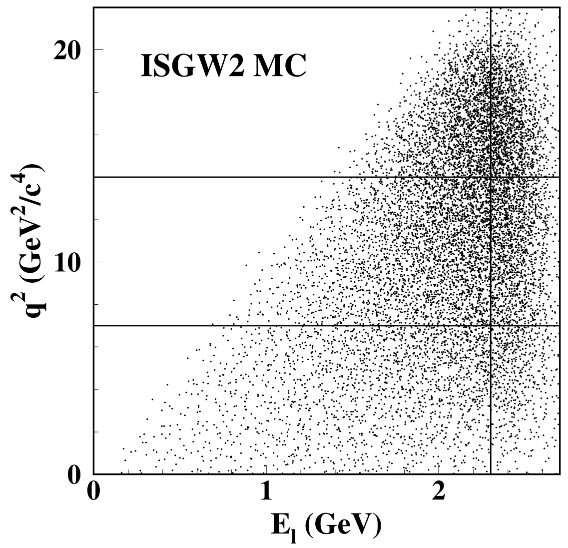
- CLEO has averaged two $B \to \rho\ell\nu$ results accounting for correlations in sys. error including theoretical
- Statistical overlap negligible.

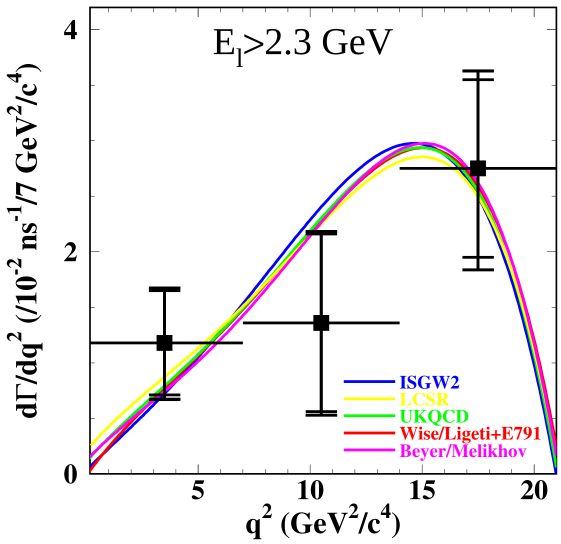


- $\delta\mathcal{B}$ is ($\pm\frac{1}{2}$ full range) of models.
- $\delta|V_{ub}|$ is ($\pm\frac{1}{2}$ full range) $\bigoplus$ 15% for FF model uncertainty in $\Gamma/|V_{ub}|^2$.
- On $|V_{ub}|$: Errors are statistical (4%), systematic ($^{+7}_{-9}\%$), theoretical due to kinematics (8%), and theoretical due to $\Gamma/|V_{ub}|^2$ (15%).

The q^2 distribution in $B \to \rho\ell\nu$ decay

- Measure $\Delta\Gamma(B \to \rho\ell\nu)$ in bins of q^2 using $E_\ell > 2.3$ GeV data.
- Measure q^2 using ρ momentum and $E_{\text{beam}} = E_B$. Uncertain due to unknown $\mathbf{p}_B$.





Results: $\Delta\Gamma(B \to \rho^+\ell\nu) =$

$$(7.6 \pm 3.0^{+0.9}_{-1.2} \pm 3.0) \times 10^{-2}\ \text{ns}^{-1}(0 < q^2 < 7\ \text{GeV}^2/c^4)$$

$$(4.8 \pm 2.9^{+0.7}_{-0.8} \pm 0.7) \times 10^{-2}\ \text{ns}^{-1}(7 < q^2 < 14\ \text{GeV}^2/c^4)$$

$$(7.1 \pm 2.1^{+0.9}_{-1.1} \pm 0.6) \times 10^{-2}\ \text{ns}^{-1}(14 < q^2 < 21\ \text{GeV}^2/c^4)$$

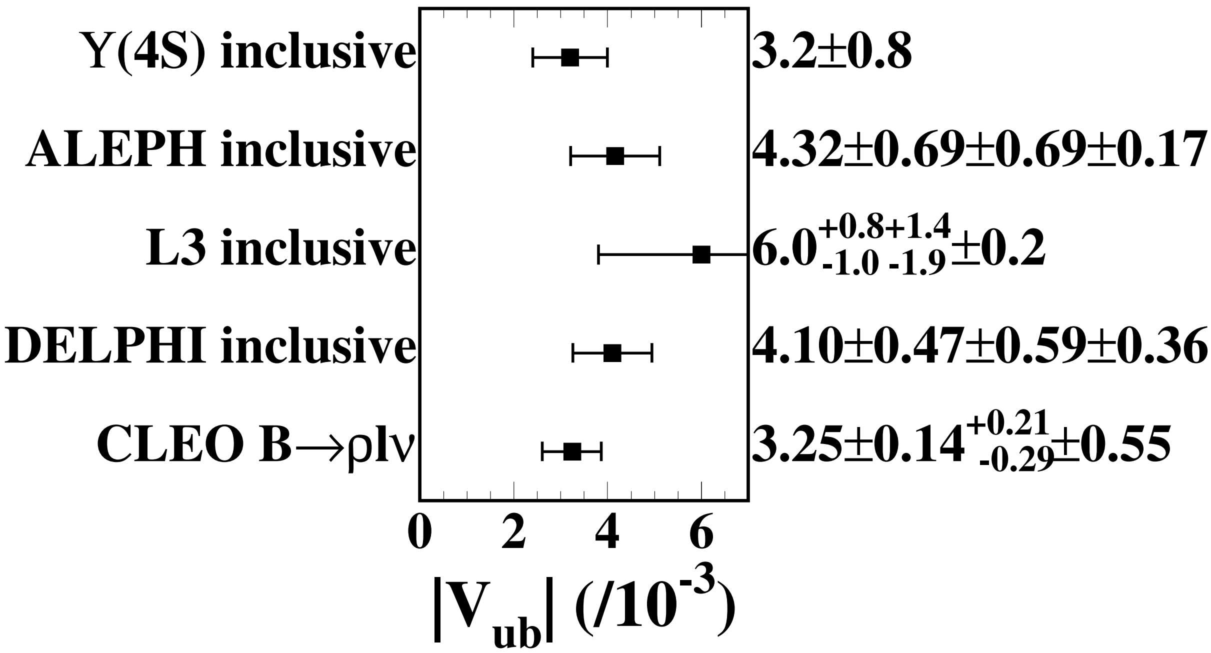
- Theory error in highest q^2 region is 60% that on full $\mathcal{B}$ $\Rightarrow$ measure $|V_{ub}|$ using high q^2 region only?
- $E_\ell < 2.0$ GeV data needed to distinguish models.

Conclusions

- 2 statistically independent measurements of $\mathcal{B}(B \to \rho\ell\nu)$ and $|V_{ub}|$ at CLEO:

$$\mathcal{B}(B \to \rho^+\ell\nu) = (2.57 \pm 0.29^{+0.33}_{-0.46} \pm 0.41) \times 10^{-4}$$
$$|V_{ub}| = (3.25 \pm 0.14^{+0.21}_{-0.29} \pm 0.55) \times 10^{-3}$$

- On $|V_{ub}|$: Errors are statistical (4%), systematic ($^{+7}_{-9}\%$), theoretical due to kinematics (8%), and theoretical due to $\tilde{\Gamma}_{\mathrm{theory}} \equiv \Gamma/|V_{ub}|^2$ (15%).



- We have made the most precise measurement of $|V_{ub}|$.
- First measurement of q^2 distribution using $E_\ell > 2.3$ GeV events.