Inclusive B Decays - Spectra, Moments and CKM Matrix Elements

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Outline

- **Motivation** for measuring moments of various spectra.
- **Moments Measurements and $|V_{cb}|$**
  - E_γ spectrum in inclusive decays $B \to X_s \gamma$
  - M_X^2 spectrum in inclusive decays $B \to X_c \ell\nu$
  - E_ℓ spectrum in inclusive decays $B \to X_c \ell\nu$
- **Moments Summary**
- **Extraction of $|V_{ub}|$**
  - More from E_γ spectrum and lepton energy endpoint ($|V_{ub}|$)
  - $|V_{ub}|$ **from** $B \to \pi \ell\nu$
  - Using more than one kinematic variable at a time ($B \to X \ell\nu$).
- **Summary**

Motivation

- **HQET+OPE** allows any inclusive observable to be written as a double expansion in powers of α_s and $1/M_B$:

$$\text{Observable}=A(\alpha_s,\beta_o\alpha_s^2)+B(\alpha_s)\bar{\Lambda}/M+C\lambda_1/M^2+D\lambda_2/M^2+E\bar{\Lambda}^2/M2+O(1/M^3)$$

$O(1/M)$: $\bar{\Lambda}$ energy of light degrees of freedom

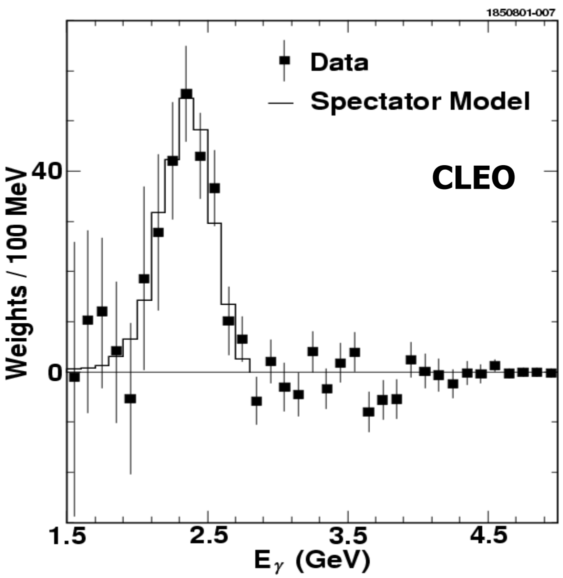
$O(1/M^2)$ λ_1 - kinetic energy squared of b quark

λ_2 hyperfine splitting (known from B/B^* and D/D^* ΔM)

$O(1/M^3)$ $\rho_1, \rho_2, \tau_1, \tau_2, \tau_3, \tau_4$ $\sim(.5\text{ GeV})^3$ from dimensional considerations

- Γ_{sl} = $|V_{cb}|^2$ $\left(A(\alpha_s,\beta_o\alpha_s^2)+B(\alpha_s)\bar{\Lambda}/M_B+C\lambda_1/M_B^2+\ldots\right)$
- Measurement of 1 observable gives a band in $\bar{\Lambda}-\lambda_1$ space. Measurement of 2 gives an intersection and $(\bar{\Lambda},\lambda_1)$
- $\bar{\Lambda}$, λ_1 combined with the Γ_{sl} measurements => better $|V_{cb}|^2$
- **ISSUES:** assumption of quark-hadron duality, scheme dependence, size of higher order terms.

Hadronic Mass and Photon Energy



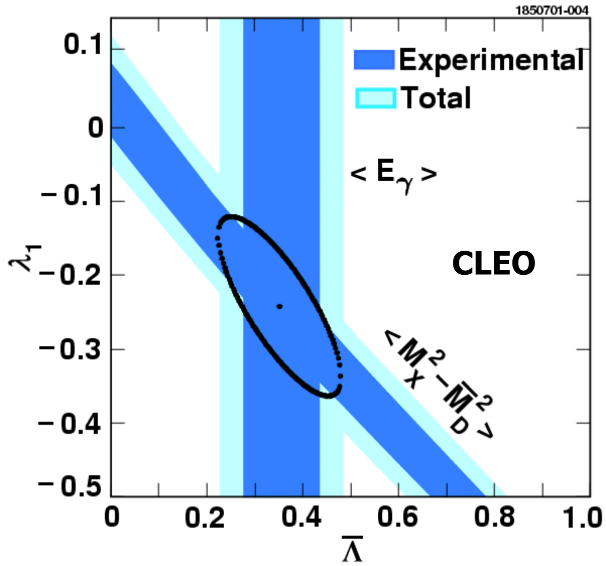
$$\langle E_\gamma \rangle = 2.346 \pm 0.032 \pm 0.011\, GeV$$

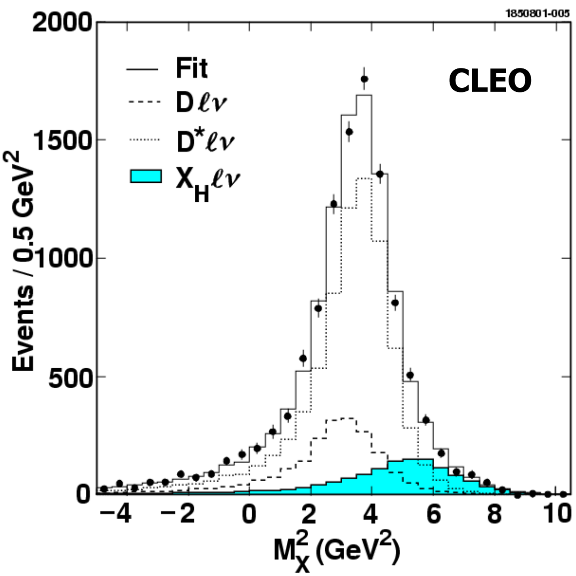
$$\langle E_\gamma^2 \rangle - \langle E_\gamma \rangle^2 = 0.0226 \pm 0.0066 \pm 0.0020\ GeV^2$$

$$\langle (M_X^2 - \overline{M}_D^2) \rangle = 0.251 \pm 0.023 \pm 0.062\, GeV^2$$

$$\langle (M_X^2 - \langle M_X^2 \rangle)^2 \rangle = 0.576 \pm 0.048 \pm 0.163\ GeV^4$$

PRL 87 251807 '01
PRL 87 251808 '01





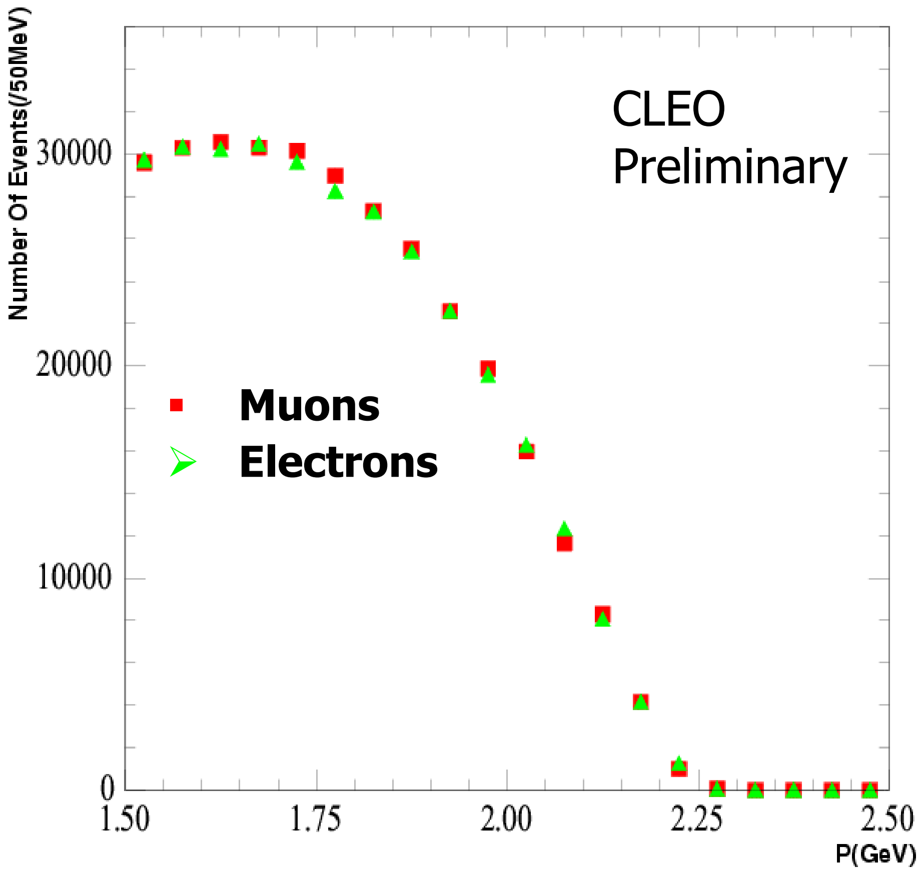
In $\overline{MS}$ scheme, at order $1/M_B^3$ and $\alpha_s^2\beta_o$

$\overline{\Lambda}$= 0.35 $\pm$ 0.07 $\pm$ 0.10 GeV
λ_1= -.236 $\pm$ 0.071 $\pm$ 0.078 GeV^2

$|V_{cb}|$=(4.04 $\pm$ 0.09 $\pm$ 0.05 $\pm$ 0.08) 10^{-2}

Γ_{sl} $\quad$ $\overline{\Lambda}$, λ_1 $\quad$ Theory

Lepton Energy Moments (CLEO Preliminary)



Unfolded Lepton Energy Spectrum

for leptons from $B \to X \ell \nu$

$$R_0 = \frac{\int_{1.7} \frac{d\Gamma_{sl}}{dE_l} dE_l}{\int_{1.5} \frac{d\Gamma_{sl}}{dE_l} dE_l}$$

$$R_1 = \frac{\int_{1.5} E_l \frac{d\Gamma_{sl}}{dE_l} dE_l}{\int_{1.5} \frac{d\Gamma_{sl}}{dE_l} dE_l}$$

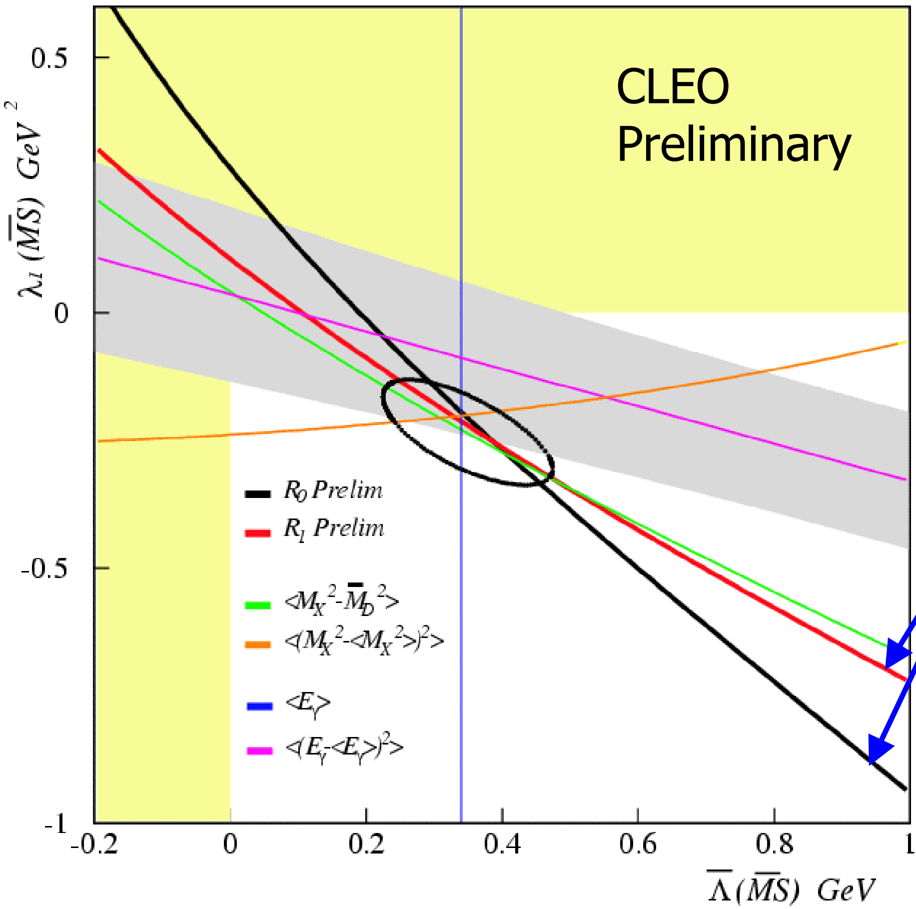
M.Gremm, A. Kapustin, Z. Ligeti M. Wise, I. Stewart

R_0 = 0.6187$\pm$0.0014 $\pm$0.0016

R_1 = 1.7810$\pm$0.0007$\pm$0.0009 GeV

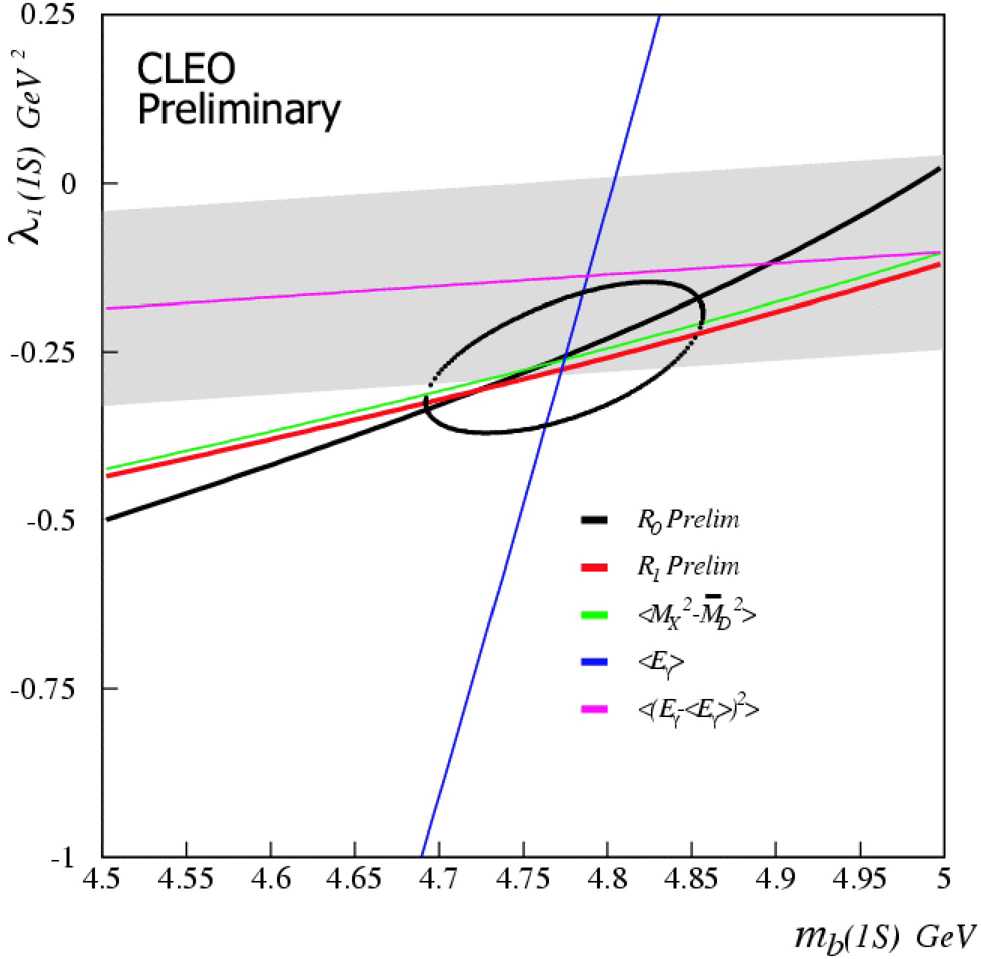
CLEO CONF 02-10
ICHEP02 ABS932

Consistency Among Observables



- Λ and λ_1 ellipse extracted from 1st moment of $B \to X_s \gamma$ photon energy spectrum and 1st moment of hadronic mass² distribution($B \to X_c \ell\nu$). We use the HQET equations in MS scheme at order $1/M_B^3$ and $\alpha_s^2\ \beta_0$.
  - **MS Expressions:** *A. Falk, M. Luke, M. Savage, Z. Ligeti, A. Manohar, M. Wise, C. Bauer*
- The red and black curves are derived from the new CLEO results for $B \to X \ell\nu$ lepton energy moments.
  - **MS Expressions:** *M.Gremm, A. Kapustin, Z. Ligeti and M. Wise, I. Stewart (moments) and I. Bigi, N.Uraltsev, A. Vainshtein(width)*
- Gray band represents total uncertainty for the 2nd moment of photon energy spectrum.

Consistency Across Schemes- 1S Mass v. $\overline{\text{MS}}$



- Λ and λ_1 ellipse extracted from 1st moment of $B \to X_s\,\gamma$ photon energy spectrum and 1st moment of hadronic mass² distribution ($B \to X_c\,\ell\nu$). We use the HQET equations in 1S scheme at order $1/M_B^3$ and $\alpha_s^2\,\beta_o$.

1S Expressions(recent): *C. Bauer, M. Trott (hep-ph/0205039) C. Bauer, A. Manohar, Z.Ligeti and M. Luke private communication*

In 1S mass scheme, at order $1/M_B^3$ and $\alpha_s^2\beta_o$

$|V_{cb}|=(4.05\pm0.09\pm0.04\pm0.10)\ 10^{-2}$

(recall $\overline{\text{MS}}$: $|V_{cb}|=(4.04\pm0.09\pm0.05\pm0.08)\ 10^{-2}$)

Moments Summary

- CLEO has measured six moments, two each from 1) the photon energy distribution in $B \to X_s \gamma$ events 2) the hadronic mass2 distribution in $B \to X_c \ell\nu$ events and 3) most recently the lepton energy spectrum in $B \to X_c \ell\nu$ events.

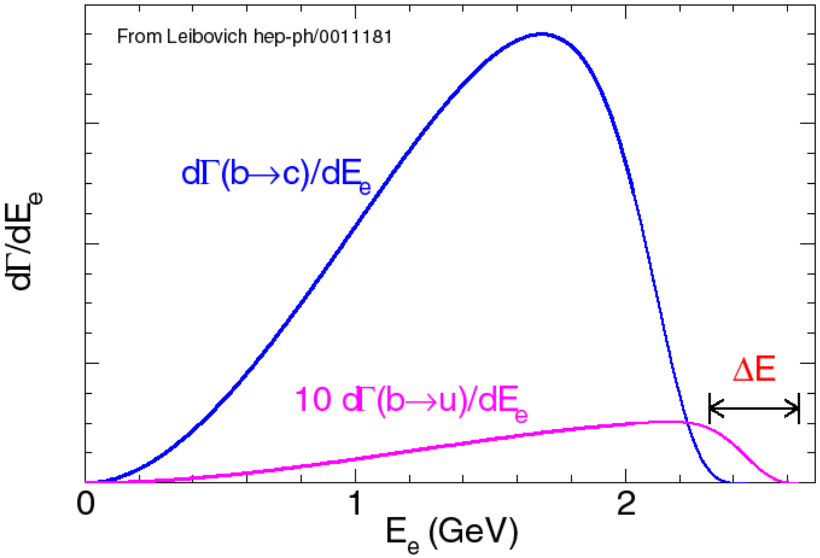
- The allowed values for HQET parameters $\bar{\Lambda}$ and λ_1 are in agreement for all measurements.

- Additionally, CLEO has used the HQET expressions from the 1S mass renormalization scheme and has extracted a value of $|V_{cb}|$ in excellent agreement with that derived from the $\overline{MS}$ scheme.

- There remains some ambiguity on the treatment of uncertainties due to the higher order HQET terms.

$|V_{ub}|$ from Lepton Endpoint (using $b \to s\gamma$)

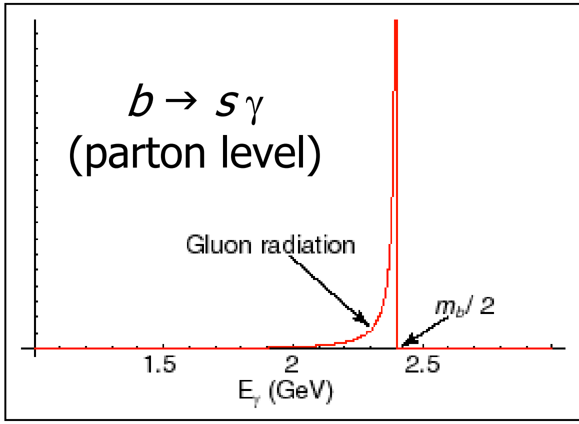
- $|V_{ub}|$ from $b \to u \ell \nu$
  - We measure the endpoint yield
  - Large extrapolation to obtain $|V_{ub}|$
  - High E cut leads to theoretical difficulties (we probe the part of spectrum most influenced by fermi momentum)

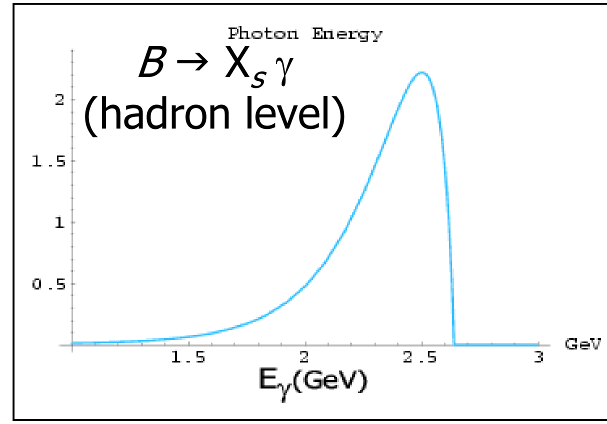


- **GOAL**: Use $b \to s\gamma$ to understand Fermi momentum and apply to $b \to u \ell \nu$ for improved measurement of $|V_{ub}|$

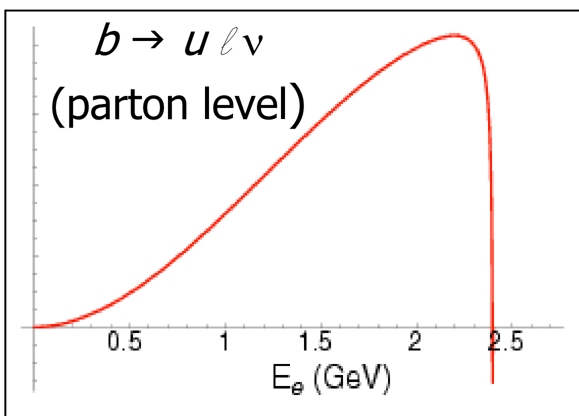
Kagan-Neubert
DeFazio-Neubert

B → lightquark shape function, SAME (to lowest order in Λ_{QCD}/m_b) for $b \to s\gamma$ ⇨ $B \to X_s\gamma$ and $b \to u\ell\nu$ ⇨ $B \to X_u\ell\nu$.



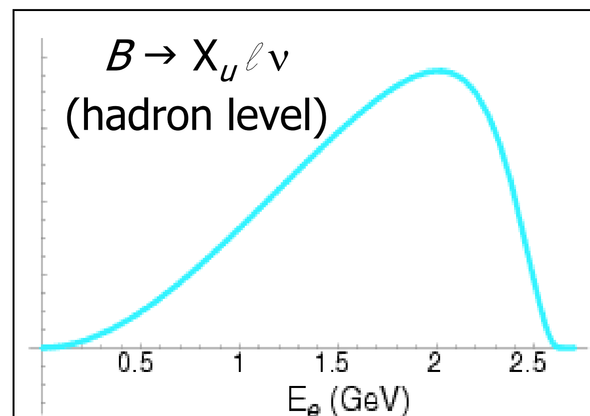


Convolute with light cone shape function.



Fraction of $b \to u\ell\nu$ spectrum above 2.2 is

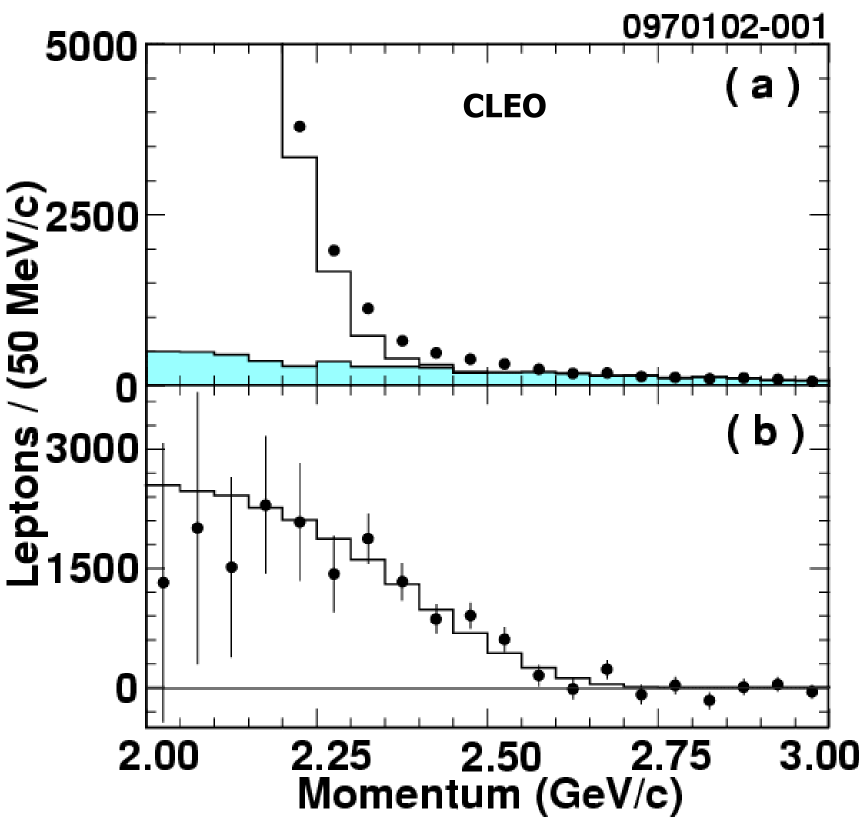
0.13 ± 0.03



$|V_{ub}|$ from Lepton Endpoint (using $b \to s\gamma$)

$|Vub| = (4.08 \pm 0.34 \pm 0.44 \pm 0.16 \pm 0.24)10\text{-}3$

The 1st two errors are from experiment and 2nd from theory

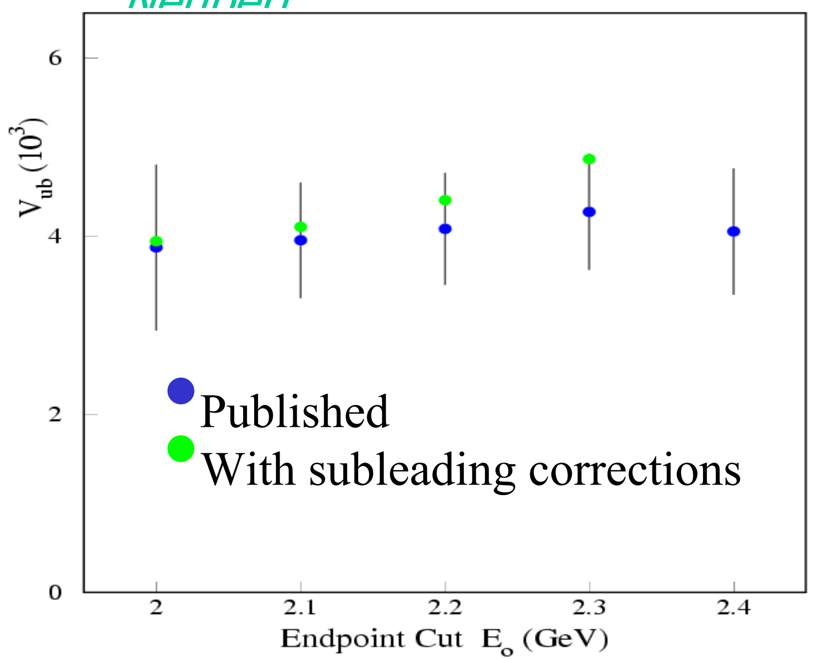


PRL 88 231803 '02

- Subleading corrections large

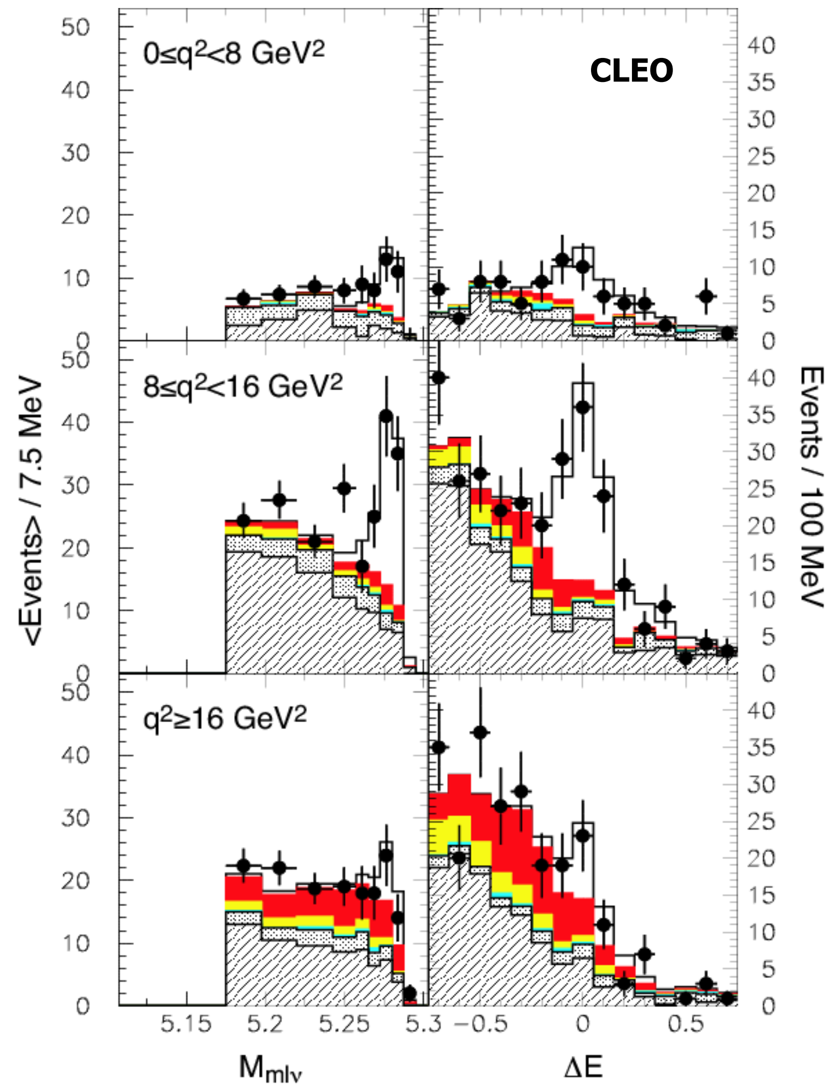
  C. Bauer, M. Luke, T. Mannel
  A. Leibovich, Z. Ligeti, M. Wise

- Method for partial inclusion of subleading corrections: *Neubert*



$|V_{ub}|$ from **B**($B \to \pi \ell \nu$) with Reduced Model Dependence

- Use missing four-momentum in full B reconstruction.
- Sample of 9.7 M BB pairs.
- Lower lepton momentum cut than in previous CLEO analysis
- $B \to (\pi^+, \pi^o, \rho^+, \rho^o, \omega\ \eta)\ \ell\ \ \nu$
- Sample size allows parsing into 3 bins of q^2 (reduces dependence on modeling of q^2 shape)



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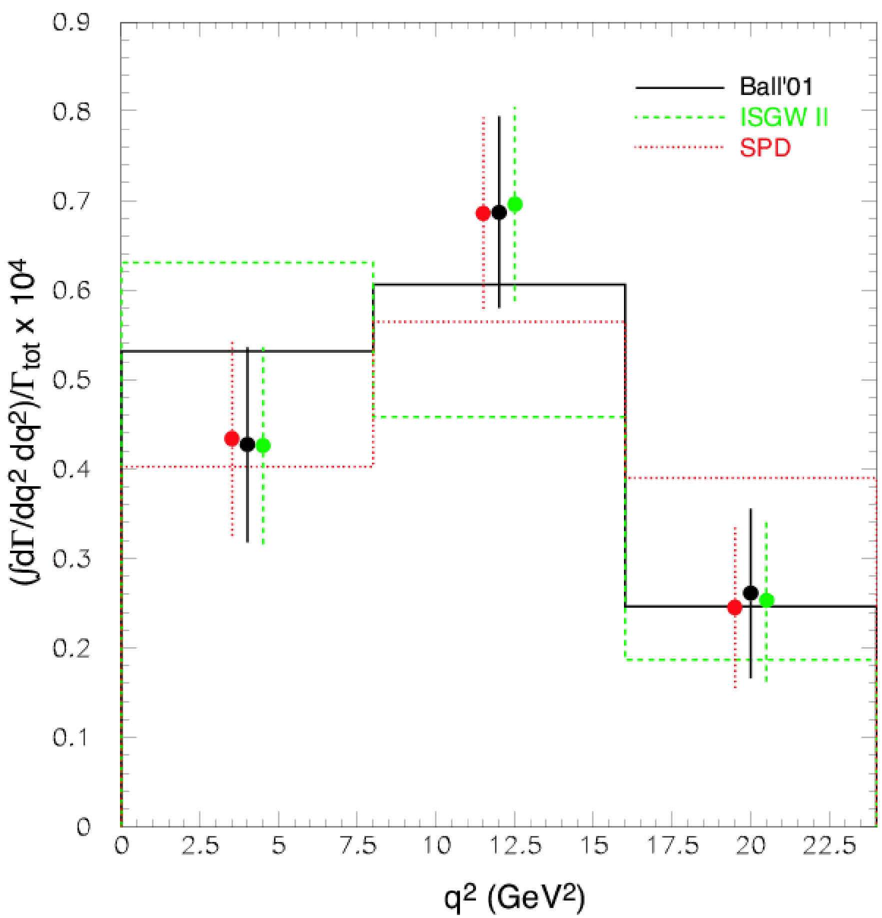
Branching fractions in restricted q^2 bins



- Three $b \to u \ell \nu$ models of q^2 distribution.
- Averaging detection efficiency over smaller q^2 range => smaller variation in fits to width.
- Shown are the best fits to $d\Gamma/dq^2$ for *SPD, Ball'01 & ISGW2*

$|V_{ub}|$ from $\mathscr{B}(B \to \pi \ell \nu)$ with Reduced Model Dependence

$$\mathscr{B}(B \to \pi \ell \nu) = (1.376 \pm 0.180 ^{+0.116}_{-0.135} \pm 0.008 \pm 0.102 \pm 0.021) 10^{-4}$$

stat *syst* *ffπ,* *ffρ* *model*

$$|V_{ub}| = (3.32 \pm 0.21 ^{+0.17}_{-0.19} {}^{+0.55}_{-0.39} \pm 0.12 \pm 0.07) 10^{-3}$$

Preliminary

$B \to X \ell \nu$ with Neutrino Reconstruction

- Neutrino four-momentum inferred from hermeticity of detector.
- Maximum likelihood fit over full three dimensional decay distribution
- Contributions from $B \to X_c \ell \nu$ (D,D*,D**and NR) and $B \to X_u \ell \nu$.

$|V_{ub}| = (4.05 \pm 0.18 \pm 0.58 \pm 0.25 \pm 0.21 \pm 0.56)\ 10^{-3}$

	stat	syst	b->c model	b->u model	theory

Preliminary

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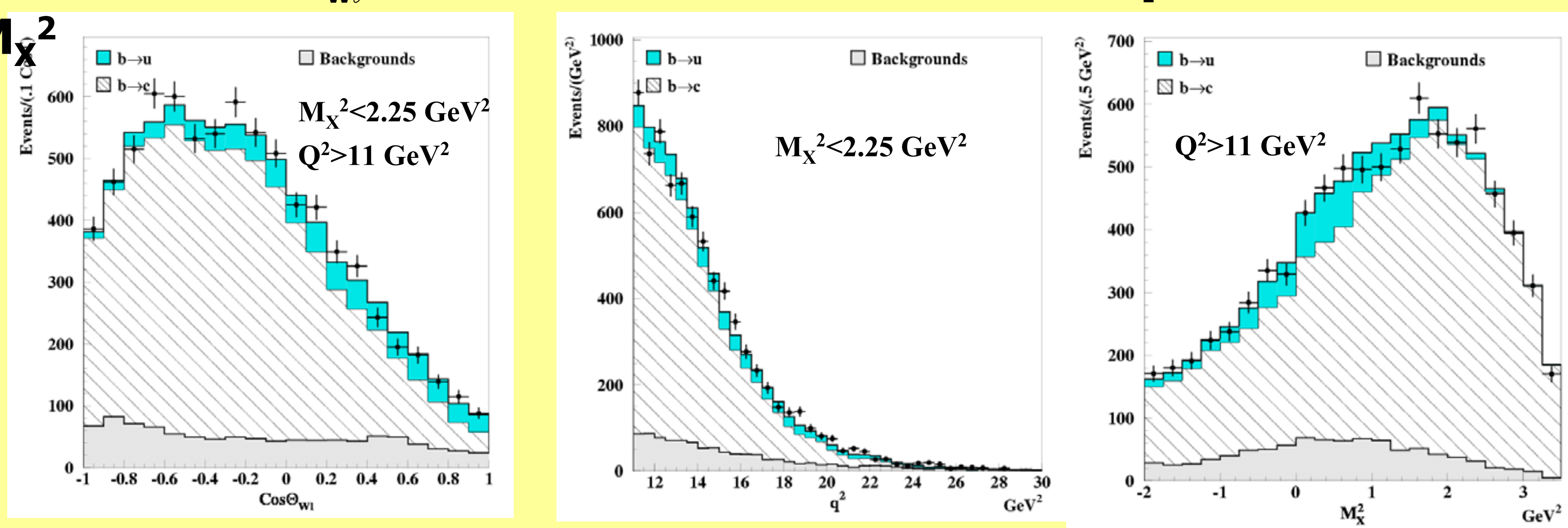
$\mathrm{Cos}\theta_{w\ell}$ q^2 M_X^2



Summary

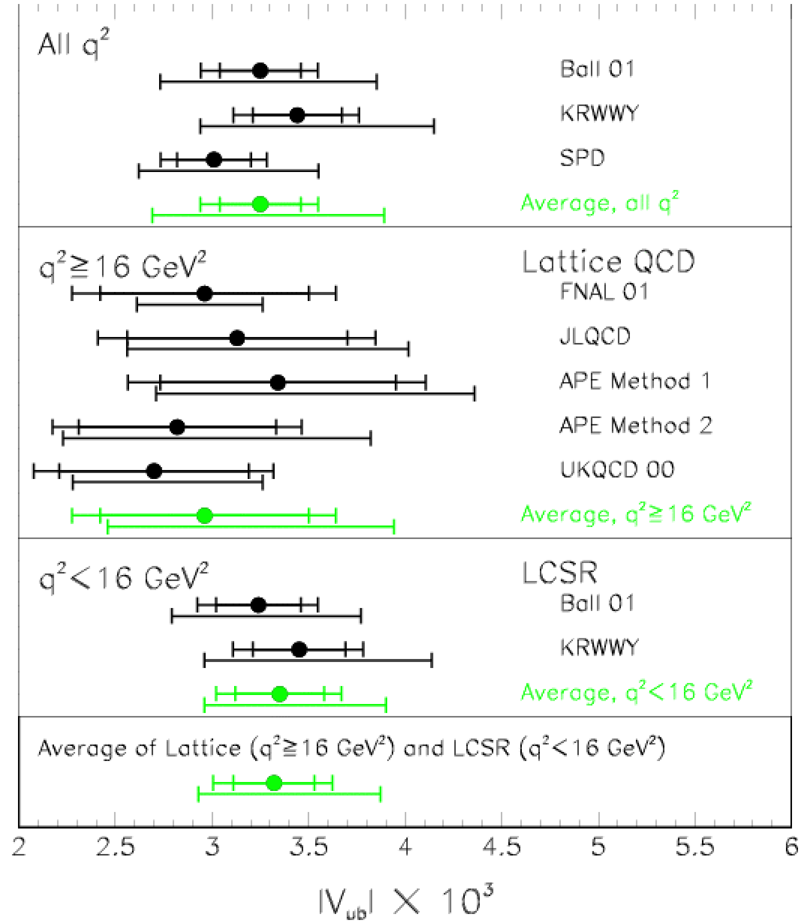
Endpoint $|V_{ub}| = (4.08 \pm 0.63)\ 10^{-3}$
$B \to \pi \ell \nu$ $|V_{ub}| = (3.32\ {+/-}\ 0.63/0.50)\ 10^{-3}$
3-D LL Fit $|V_{ub}| = (4.05 \pm 0.89)\ 10^{-3}$

- CLEO has measured the yield of $B \to X_u \ell \nu$ above the lepton energy endpoint of $B \to X_c \ell \nu$. The total rate is extrapolated by using our well measured photon energy spectrum in $b \to s\gamma$. $|V_{ub}|$ is extracted from the total rate. Additional subleading corrections to the shape function are currently being investigated.

- CLEO presented an updated $B \to \pi \ell \nu$ Branching ratio and a new (exclusive) extraction of $|V_{ub}|$.

- CLEO has also performed a log-likelihood fit to $B \to X \ell \nu$ in three independent kinematic variables. A preliminary value of $|V_{ub}|$ was presented. The weight in the fit of events near the endpoint is not fully understood – do not average the inclusive results.

Backup I



All q^2
Ball 01
KRWWY
SPD
Average, all q^2
$q^2 \geqq 16$ GeV^2
Lattice QCD
FNAL 01
JLQCD
APE Method 1
APE Method 2
UKQCD 00
Average, $q^2 \geqq 16$ GeV^2
$q^2 < 16$ GeV^2
LCSR
Ball 01
KRWWY
Average, $q^2 < 16$ GeV^2
Average of Lattice ($q^2 \geqq 16$ GeV^2) and LCSR ($q^2 < 16$ GeV^2)
2 2.5 3 3.5 4 4.5 5 5.5 6
$|V_{ub}| \times 10^3$