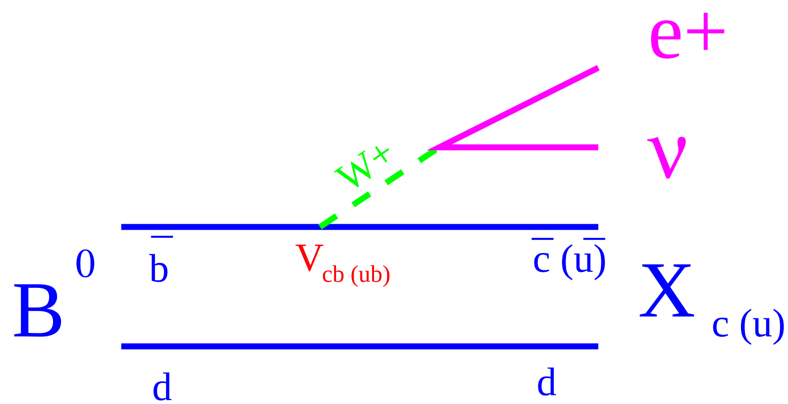
$|V_{ub}|$ from Semileptonic B decays at CLEO



Karl Ecklund, Cornell University

June 18, 2002

Outline

Introduction:

- $|V_{ub}|$ from semileptonic B decays
- Experimental Challenges

Exclusive decays: $B \to \pi\ell\nu, \rho\ell\nu$

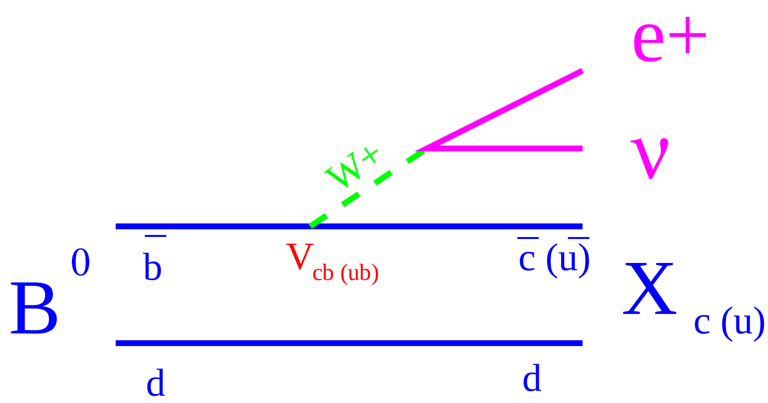
- Neutrino Reconstruction
- First Observation at CLEO
- Summary of Current Results

Inclusive Decays

- Connection to $b \to s\gamma$
- Measuring the Lepton Endpoint

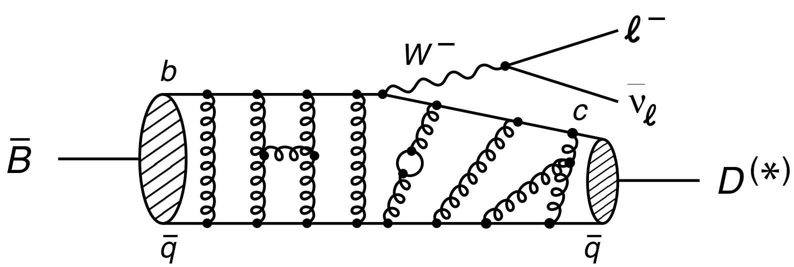
Summary and Outlook

CKM Measurements in Semileptonic B Decays



$$\Gamma(b \to u\ell\nu) \approx \frac{G_F^2 m_b^5}{192\pi^3}|V_{ub}|^2$$

Rate gives $|V_{ub}|^2$



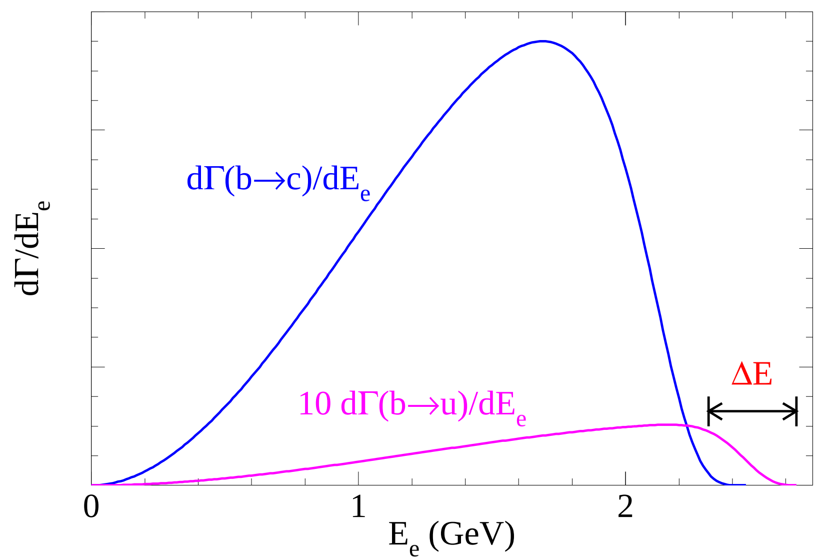
Complication!
QCD Corrections needed
to extract weak decay physics

Perturbative and non-perturbative QCD Corrections:
Directly calculate or leverage via related processes

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

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 hermeticity of detector:

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

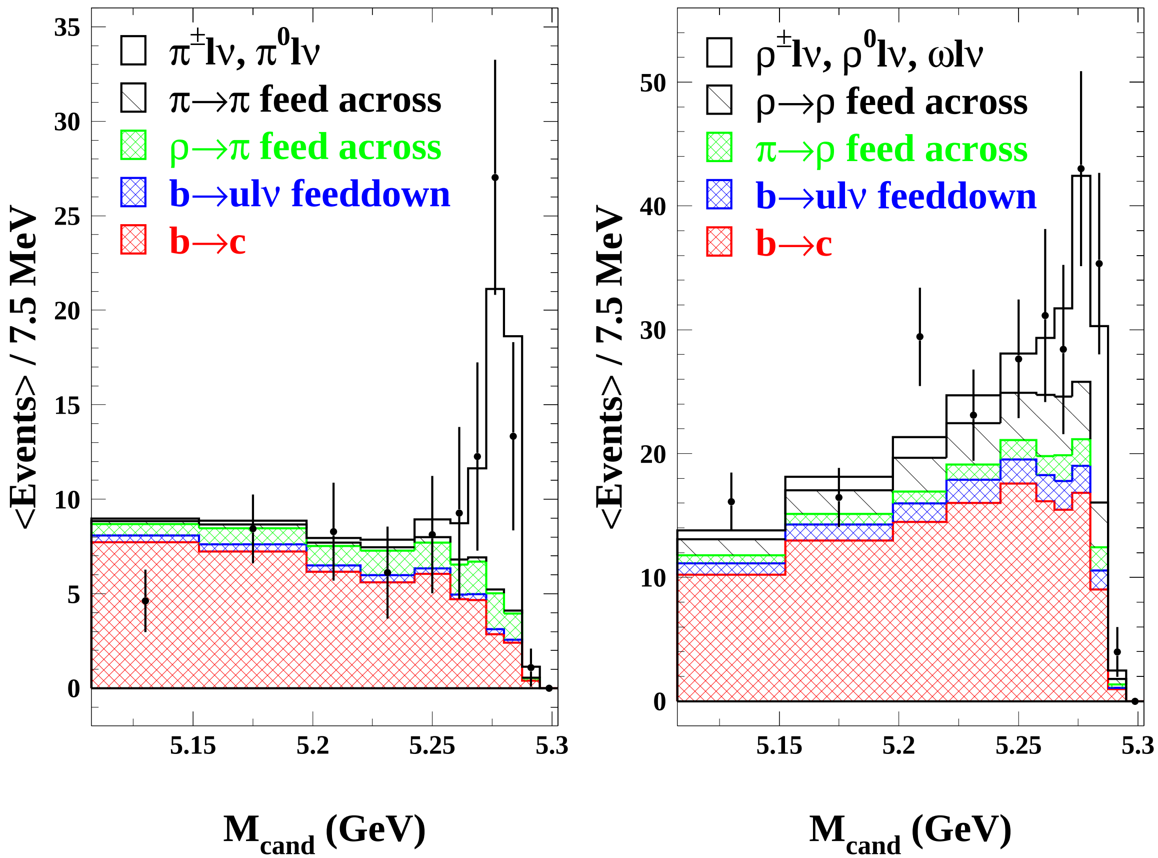
Evaluate $\mathcal{B}$ using form factors and extract $|V_{ub}|$ from

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

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

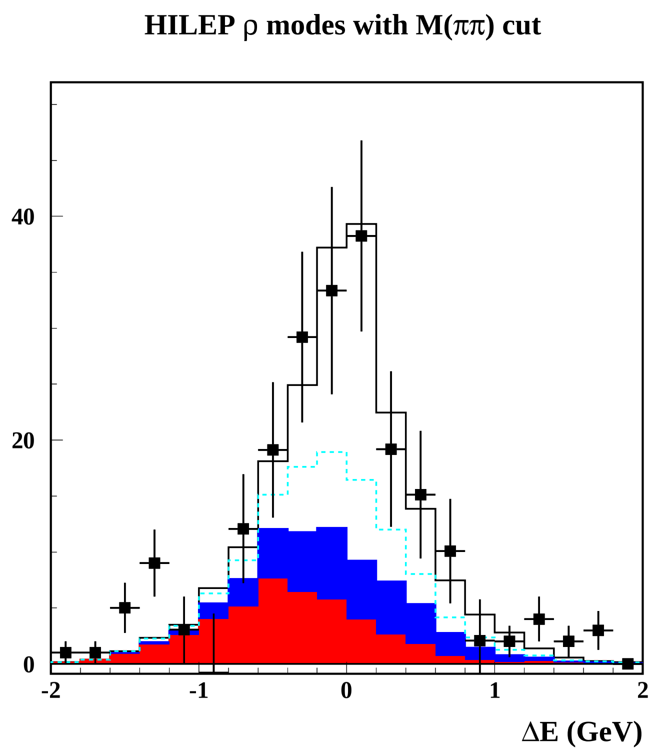
- $\Gamma_{\pi^-} = 2\Gamma_{\pi^0}$
- $\Gamma_{\rho^-} = 2\Gamma_{\rho^0}$

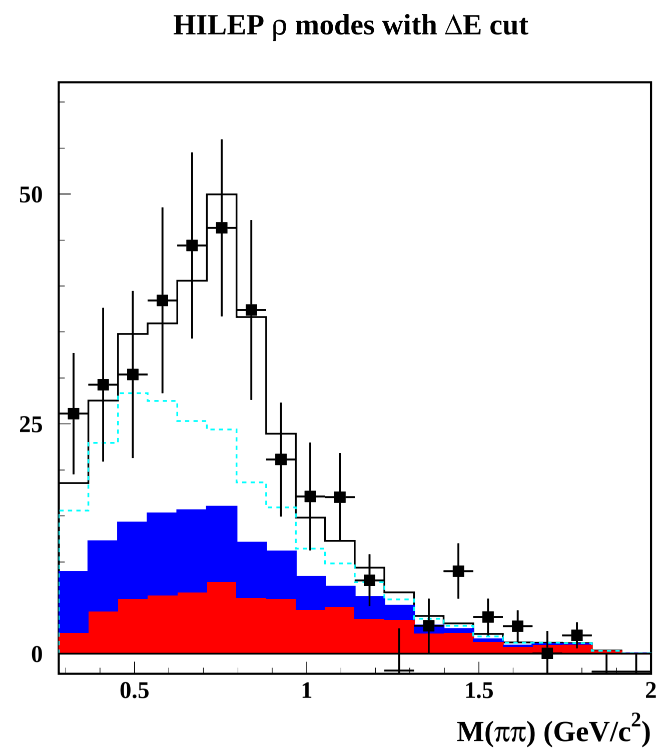
$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu) = (1.8 \pm 0.4 \pm 0.3 \pm 0.2) \times 10^{-4}$$

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

Evaluate $|V_{ub}|$ using five form factor models

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

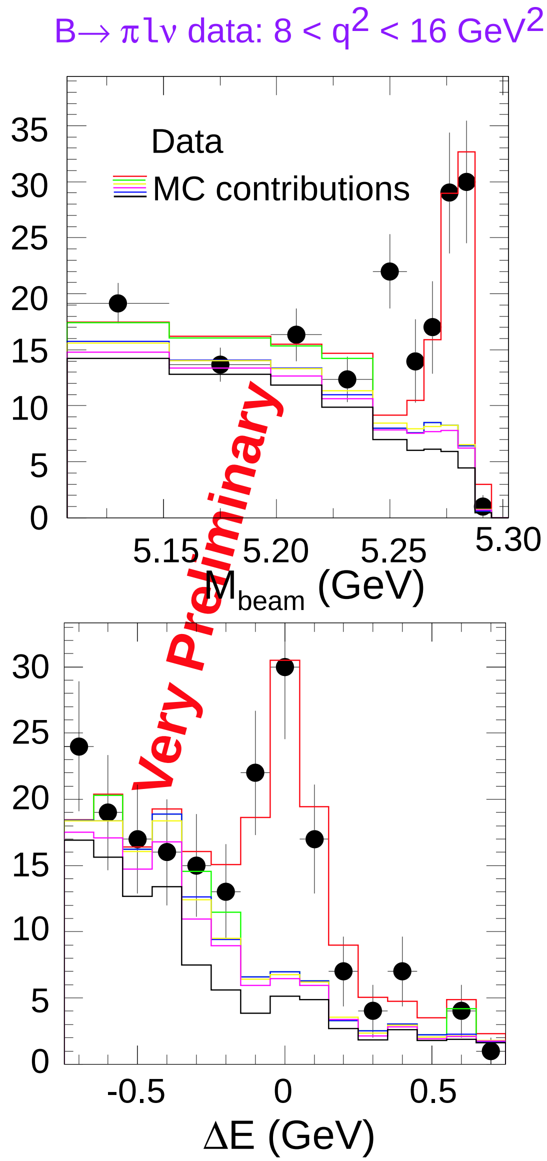
Exclusive $|V_{ub}|$ Summary

	$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu) \times 10^{-4}$	$\mathcal{B}(B^0 \to \rho^- \ell^+ \nu) \times 10^{-4}$
CLEO	$1.8 \pm 0.4 \pm 0.3 \pm 0.2$	$2.5 \pm 0.4^{+0.5}_{-0.7} \pm 0.5$
		$2.69 \pm 0.41^{+0.35}_{-0.40} \pm 0.5$

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



Preview of CLEO Update

Work in progress

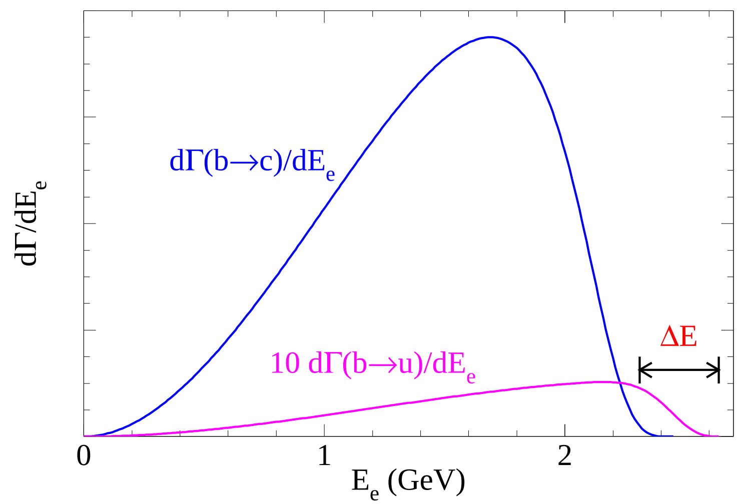
3.5× data of 1996 publication

$B \to \pi \ell \nu$ 1 of 3 q^2 bins shown

Limited q^2 shape information
help distinguish among models

Other modes (ρ, ω, η) also in progress

$|V_{ub}|$ 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

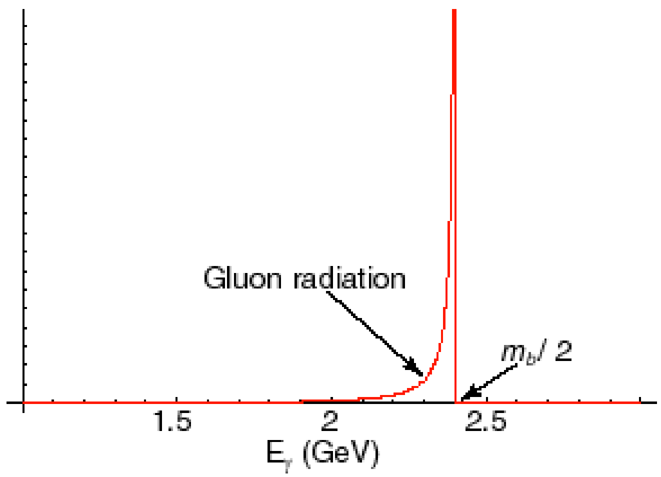
Idea: Reduce problems by using $b \to s\gamma$ photon spectrum

To first order same non-perturbative QCD effects smear the spectra

Both are heavy→light decays ($m_s, m_u, m_\ell, m_\nu \approx 0$)

Neubert; Bigi, Shifman, Uraltsev, Vainshtein; Leibovich, Low, Rothstein

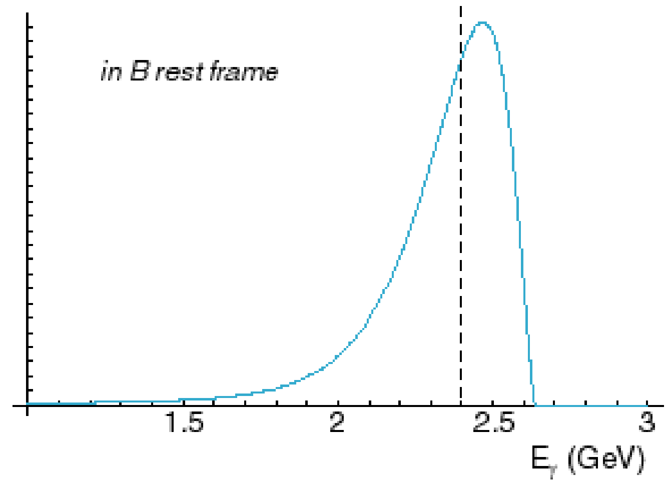
How $B \to X_s\gamma$ helps $|V_{ub}|$

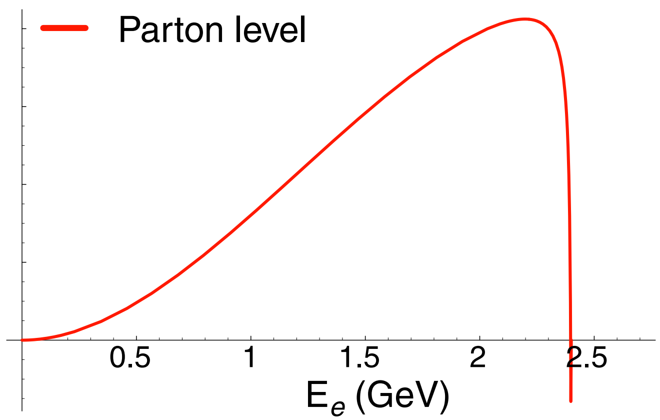


$B \to X_s\gamma$

$\Longrightarrow$

Smearing from b-quark motion in B

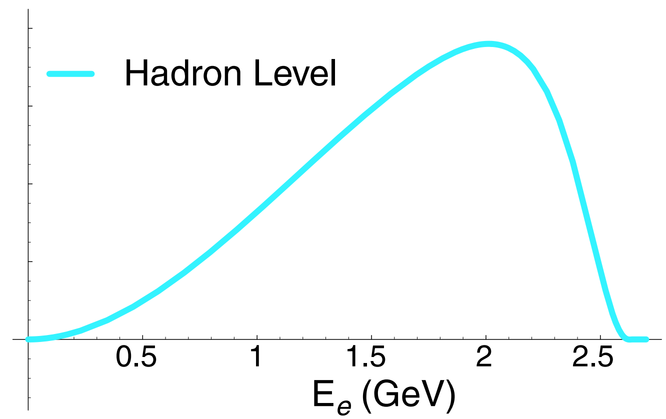




Parton Level

$\Longrightarrow$

$B \to X_u\ell\nu$



Hadron Level

$b \to s\gamma$ is sort of a Green's function for smearing

$|V_{ub}|$ from lepton spectrum

Measure $B \to X_u \ell \nu$ in a lepton momentum interval (p) at the 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 $B \to X_u \ell \nu$ branching fraction.

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)

New measurement of $f_u(p)$

Same non-perturbative shape function controls (to leading order):

- Smearing of photon energy in $B \to X_s \gamma$
- Smearing of lepton endpoint in $B \to X_u \ell \nu$

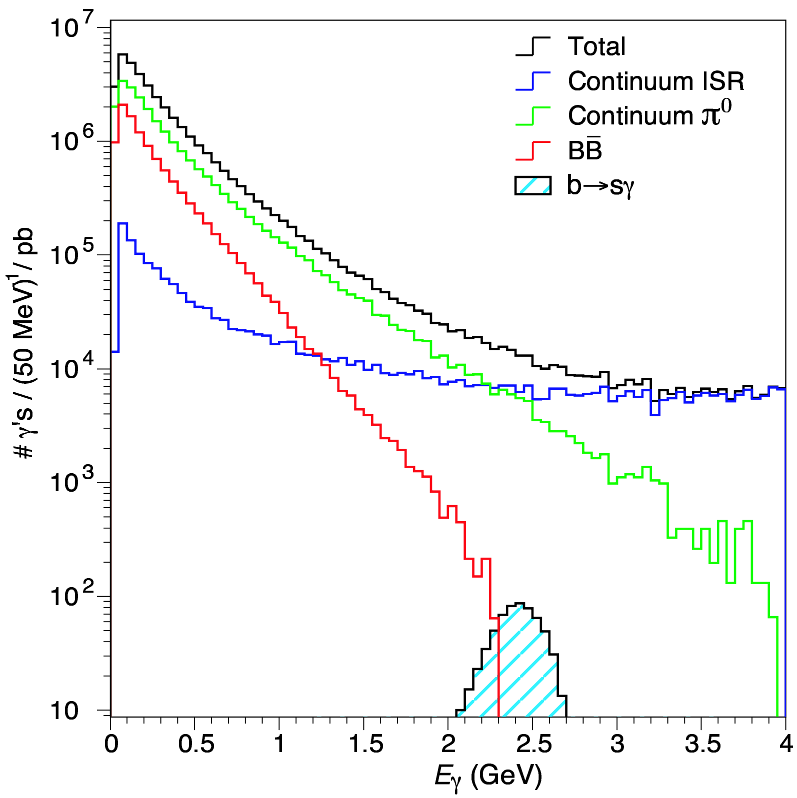
CLEO Method:

- Fit $B \to X_s \gamma$ data to a shape function (Kagan-Neubert)
- Use shape parameters to determine $f_u(p)$ (De Fazio-Neubert)

c.f. related work by Leibovich-Low-Rothstein;
emphasizes methodology *avoiding* intermediate step of using a shape function parameterization

To get $f_u(p)$, we first must study $B \to X_s \gamma$...

$B \to X_s\gamma$: E_γ Spectrum



Goal: Shape of E_γ Spectrum

Spectrum: naively a sharp line

Broadened by:

- b quark Fermi motion
- varying recoil mass (glue)

Smeared by:

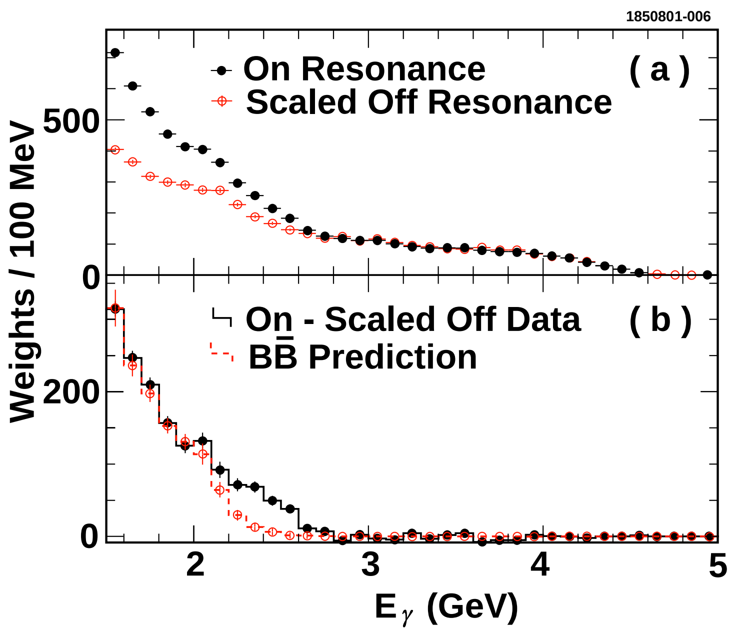
- B boost (known)
- Resolution (small)

Very large backgrounds:

- Continuum $e^+e^- \to q\bar{q}$
- Initial-state radiation $e^+e^- \to q\bar{q}\gamma$

$B \to X_s\gamma$: E_γ Spectrum

Observed Photon Spectrum



Note raised 0 in lower plot:
shows quality of cont'm subtr.
9.1 fb^{-1} On-$\Upsilon(4S)$
4.4 fb^{-1} Off-$\Upsilon(4S)$

Continuum/ISR suppression:

- Factor of $\sim$ 100 achieved
- Subtract remainder with *large cont'm dataset*

Three methods are used:

- Neural net with event shape
- Pseudo-recon. of B $(K + (1-4)\pi)$
- Lepton tag of other B

Combine into 'weights':

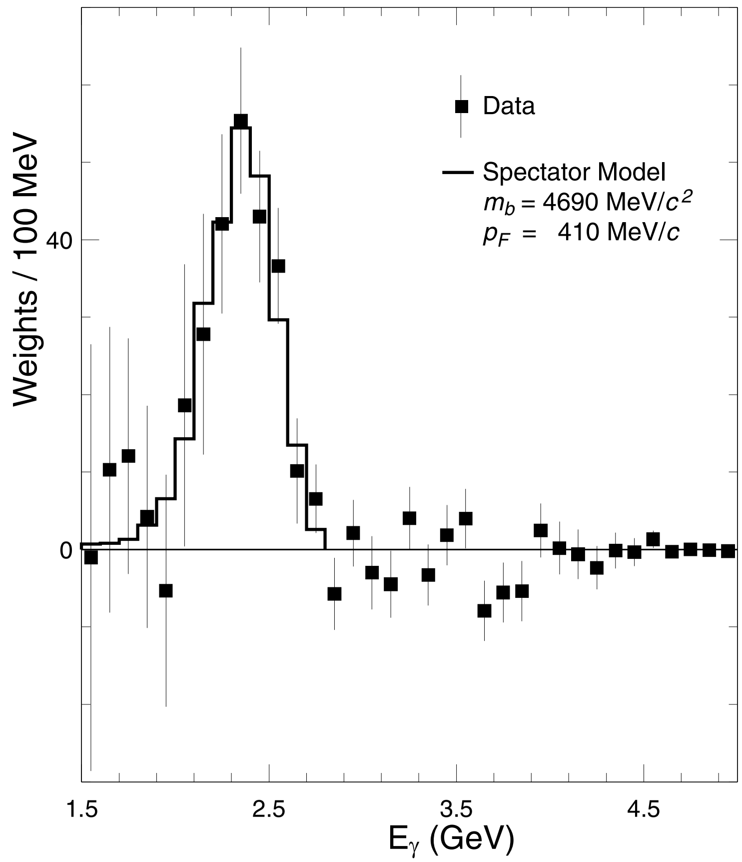
- Vary from 0 (bkg) to 1 (signal)

$B\bar{B}$ bkgnd. enters for low E_γ

- Measure almost entire spectrum
- Errors larger for softest photons

$B \to X_s\gamma$: E_γ Spectrum

CLEO E_γ spectrum

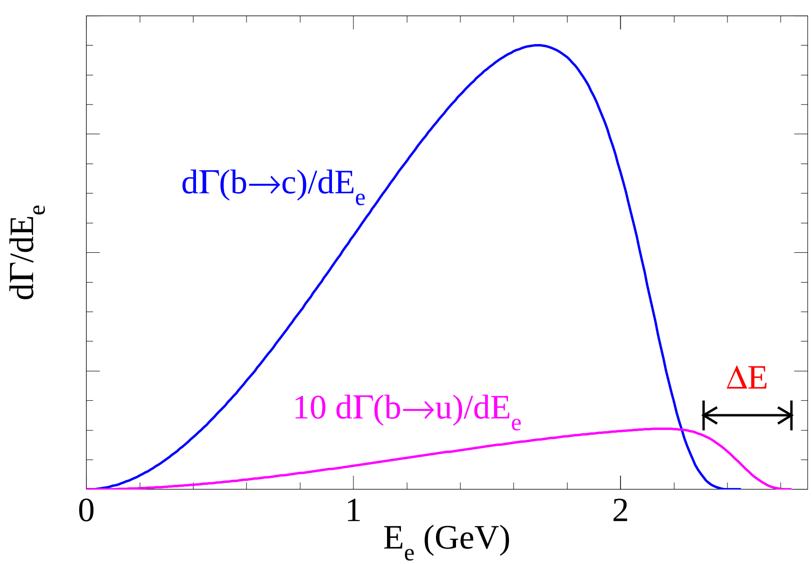


PRL **87**, 251807 (2001)

- Fit shape function to data E_γ from 1.5 – 2.8 GeV/c
- Use to determine $f_u(p)$
- Consistent with extracting 'shape' via Ali-Greub for $B \to X_s\gamma$ fed into ACCMM for $B \to X_u\ell\nu$

Measurement of Endpoint Rate

CLEO, Phys. Rev. Lett. **88**, 231803 (2002) 9.1/4.3 fb^{-1} On/Off-$\Upsilon(4S)$



Analysis Strategy:

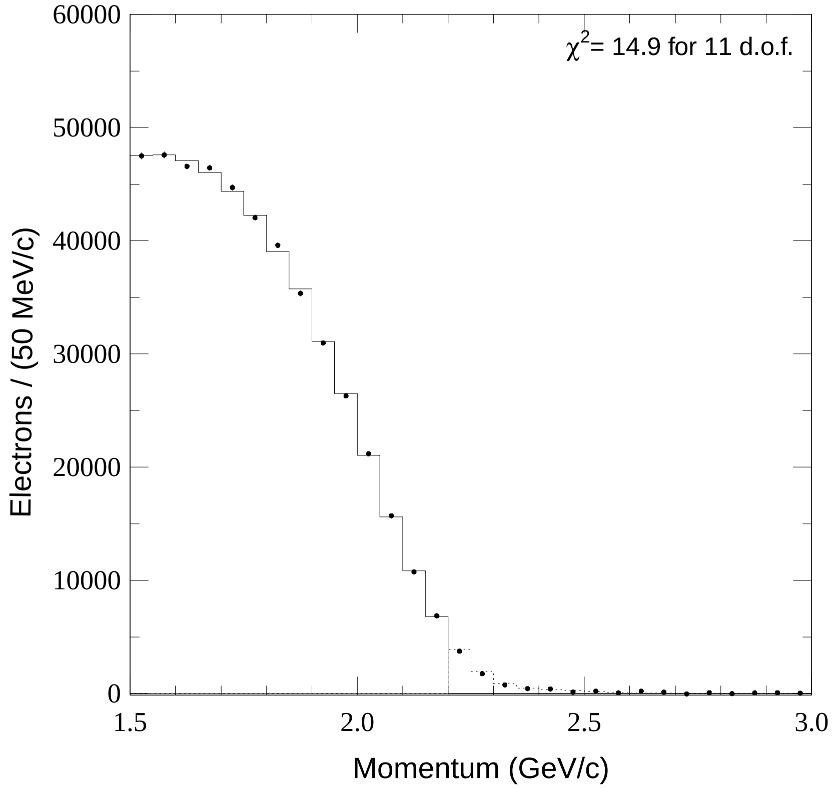
- Lepton energy cut $E > 2.2$ GeV
- Control $B \to X_c \ell \nu$ by fit below 2.2 GeV
- Remove $e^+e^- \to q\bar{q} \to \ell$
  - suppress with event shape
  - subtract with off-$\Upsilon(4S)$ data
- Remove other backgrounds

Lepton Yields:

$N_{\rm on}$	8967	$B \to X_c \ell \nu$	$4562 \pm 33 \pm 246$
$N_{\rm off}$	983	Backgrounds	$474 \pm 22 \pm 67$
$N_{B\bar{B}}$	$6938 \pm 115 \pm 20$	$B \to X_u \ell \nu$	$1901 \pm 122 \pm 256$

$B \to X_c \ell \nu$ Background Fit

Fit $1.5 < E_\ell < 2.0$ GeV



Largest background controlled to 5%

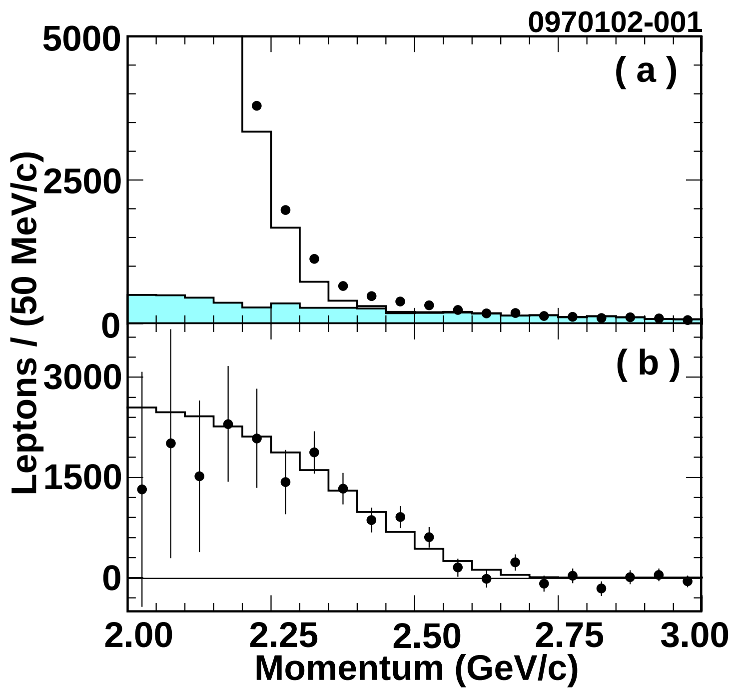
Fit Components:

- $B \to D^* \ell \nu$ and $B \to D \ell \nu$
  D^*/D ratio fixed to PDG
- $B \to D^{**} \ell \nu$ (ISGW2)
- $B \to D^{(*)} X \ell \nu$ non-resonant
- $B \to X_u \ell \nu$ (ISGW2)
  norm. to PRL**71** (1993) 4111

Systematics by varying:

- D/D^* ratio & Form Factors
- D^{**} model & non-resonant
- $X_u \ell \nu$ model

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



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

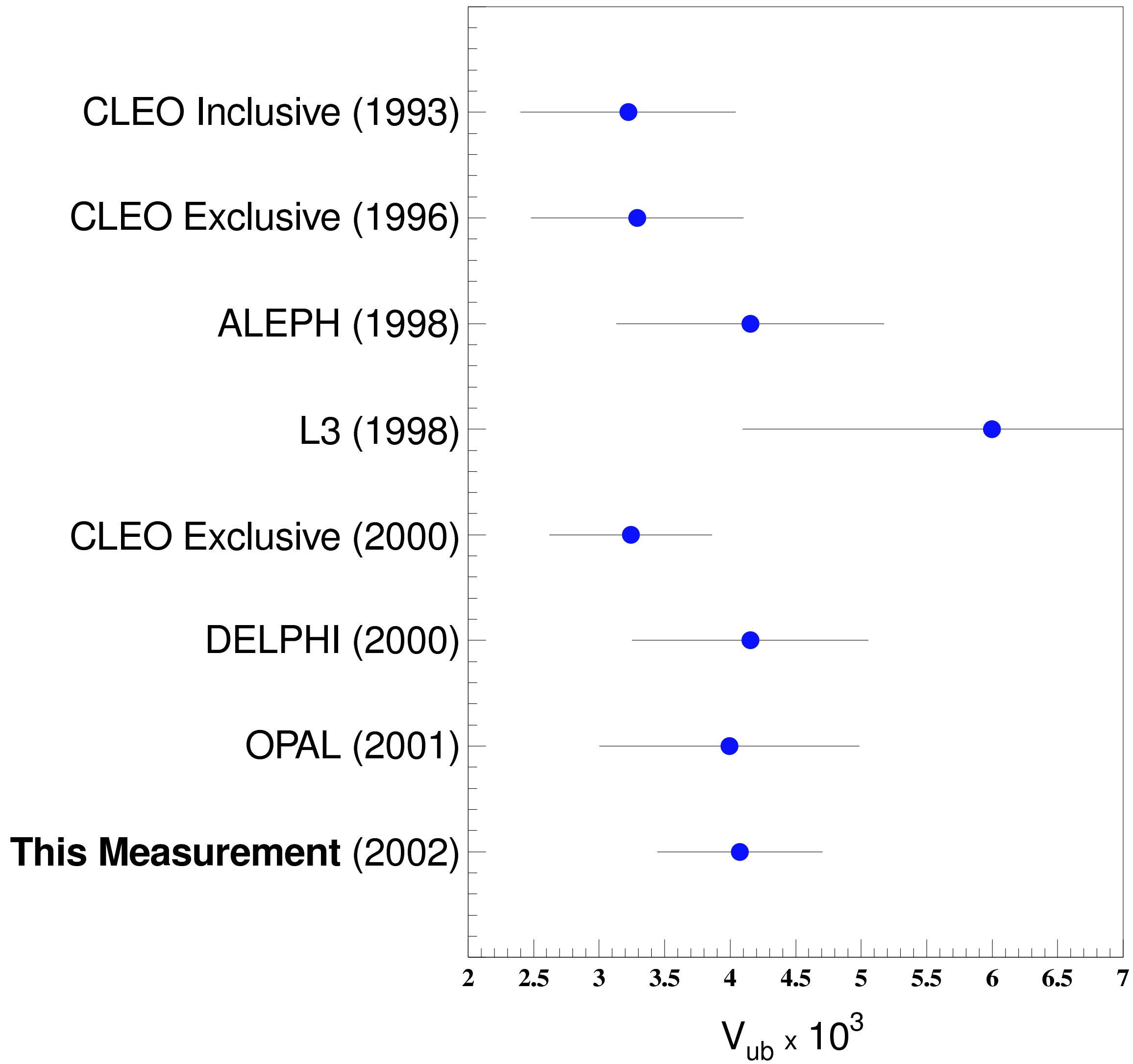
- suppress and subtract $q\bar{q}$ (cyan)
- subtract $B \to X_c \ell\nu$ yield (hist)
- $N_{ub} = 1901 \pm 122 \pm 256$ $B \to X_u \ell\nu$ events
- $\Delta \mathcal{B}_{ub} = (2.30 \pm 0.15 \pm 0.35) \times 10^{-4}$
- From the $b \to s\gamma$ spectrum $f_u = 0.130 \pm 0.024 \pm 0.015$

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, Phys. Rev. Lett. **88**, 231803 (2002)

Status of $|V_{ub}|$



Summary and Outlook

Good agreement on inclusive and exclusive 15–20%

Exclusive Future:

- More statistics from Belle, Babar, CLEO
  study shape of form factor with data!
- Lattice form factor for $\pi\ell\nu$
  only need part of q^2 to normalize

Inclusive Future:

- Better shape function from $b \to s\gamma$ statistics
- Use of M_X and q^2 cuts (try to access more of rate)
- 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.