Inclusive $b \to u\ell\nu$ and $b \to s\gamma$ spectrum

Masahiro Morii

Harvard University

BABAR Collaboration

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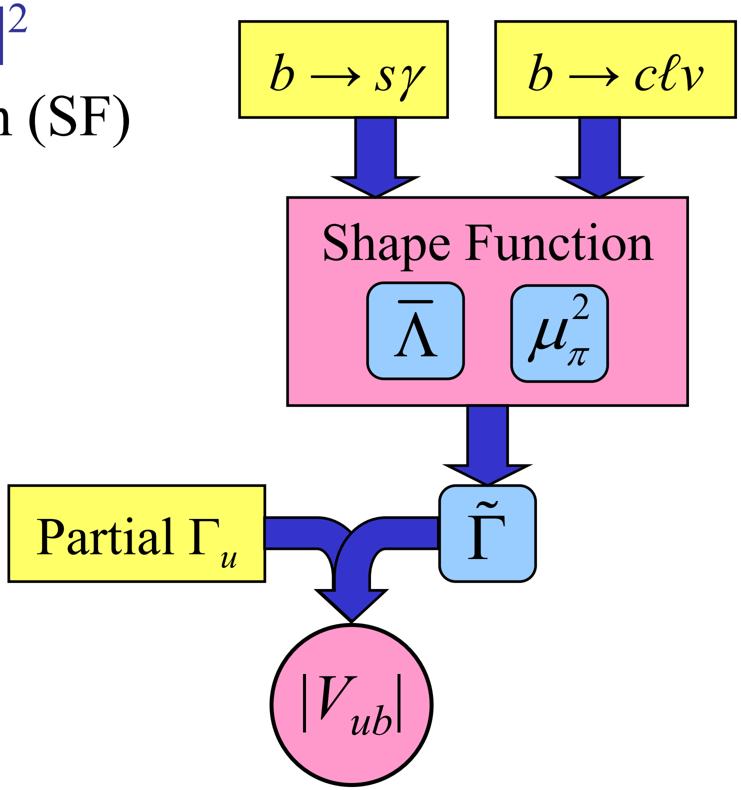
Experimental Program

Inclusive rate $\Gamma_u = \Gamma(B \to X_u \ell \nu) \propto |V_{ub}|^2$

- Total rate not measurable due to $b \to c$ background
- Measure partial rate in the "charm-free" regions of phase space

Expect theory to calculate $\tilde{\Gamma} = \Gamma_u / |V_{ub}|^2$

- Inputs required for the shape function (SF)
  - E_γ spectrum in $b \to s\gamma$
  - E_ℓ and m_X spectra in $b \to c\ell\nu$
- SF errors considered "experimental"
- Theoretical errors include:
  - Perturbative
  - Sub-leading SF
  - Weak annihilation (WA)



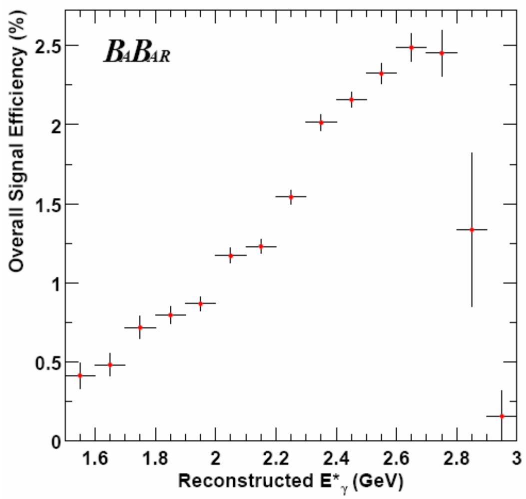
Measurements of $b \to s\gamma$

E_γ spectrum depends on the shape function

- Measure E_γ moments (1st, 2nd, 3rd) → fit with theory, or
- Fit the spectrum itself with theory
  - Is there a preference?

Two types of measurements:

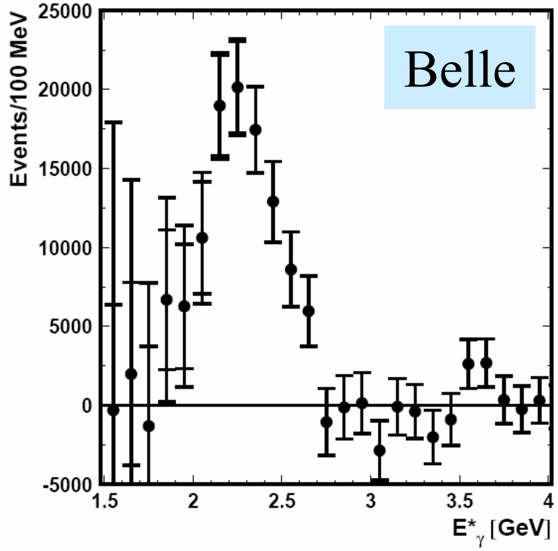
- Inclusive measurement detects only the photon
  - Poor S/B ratio forces tight selection cuts
  - Efficiency depends strongly on E_γ



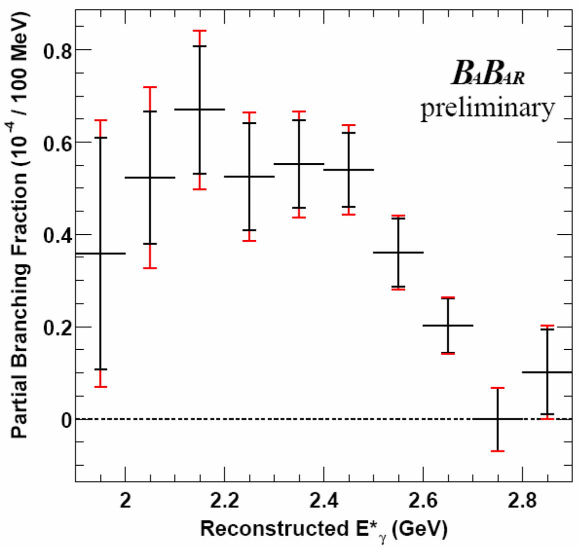
- Sum-of-exclusive measurement reconstructs a large number of exclusive decay channels and add them up
  - Better S/B ratio
  - Efficiency depends on the s-quark fragmentation model

Inclusive $b \to s\gamma$

Inclusive E_γ spectrum can be measured above ~1.9 GeV



Belle, efficiency-corrected

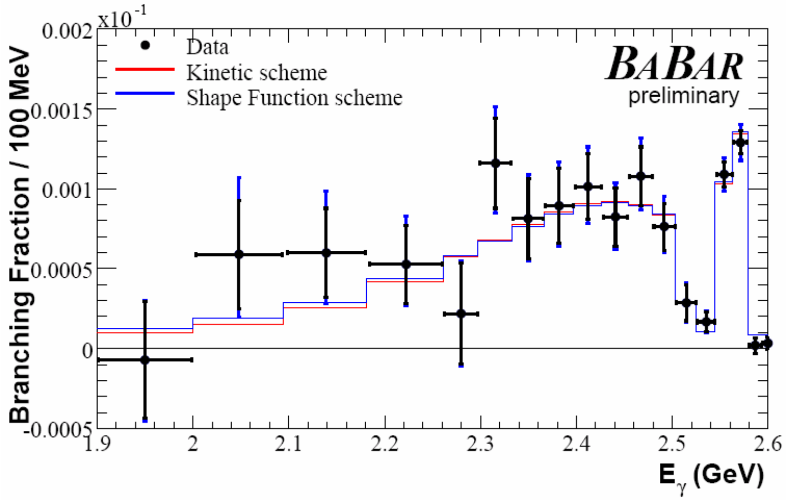


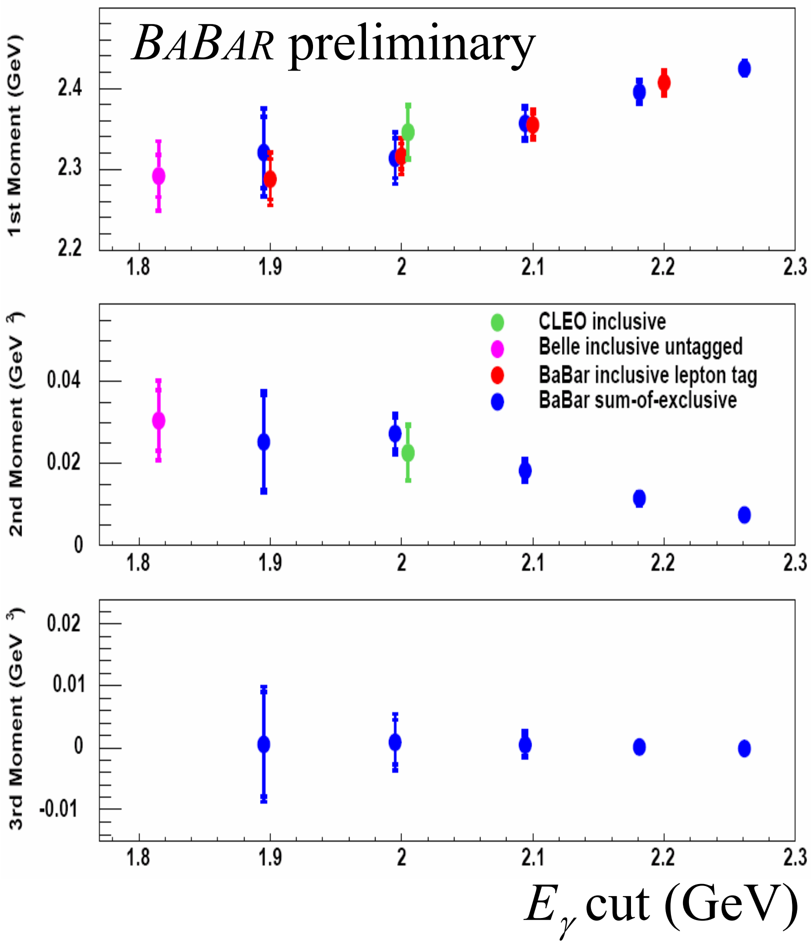
BABAR, partial BF

	Data	E_γ cut	$<E_\gamma>$	$<E_\gamma^2> - <E_\gamma>^2$	Ref.
BABAR	80 fb^{-1}	1.9 GeV	2.288 ± 0.033	not yet	Mommsen, Moriond talk
Belle	140 fb^{-1}	1.8 GeV	2.292 ± 0.043	0.0305 ± 0.0097	PRL 93:061803,2004

Sum of Exclusive $B \to X_s\gamma$

BABAR uses 38 channels: ($K^\pm$ or K_S) plus ≤4 pions, etc.





- Data sample is 80 fb^{-1}
- Measure E_γ spectrum and the first three truncated moments
  - Table of values in R. Mommsen's talk at Moriond Electroweak

Shape Function Parameters

Fit the E_γ spectrum from the *BABAR* Σ(excl.) measurement with

- Kinetic scheme by Benson, Bigi, Uraltsev (Nucl.Phys.B710:371,2005)
- Shape-function scheme by Neubert (Eur.Phys.J.C40:165,2004)

	Kinetic		Shape-function	
	$\bar{\Lambda}$ (GeV)	μ_π^2 (GeV^2)	$\bar{\Lambda}$ (GeV)	μ_π^2 (GeV^2)
$b \to s\gamma$	$0.59^{+0.06}_{-0.04}$	$0.30^{+0.07}_{-0.05}$	0.63 ± 0.04	$0.19^{+0.06}_{-0.05}$
$b \to c\ell\nu$	0.67 ± 0.07	0.45 ± 0.06	0.65 ± 0.08	0.15 ± 0.07

Preliminary

BABAR PRL 93:011803,2004

Neubert PLB612:13,2005

- $b \to s\gamma$ and $b \to c\ell\nu$ agree, and have comparable precision
- Final results based on the moments in the works

$|V_{ub}|$ results in this talk use the SF parameters from $b \to c\ell\nu$

- Caveat: Error on $\bar{\Lambda}$ is 80 MeV (*BABAR*) vs. 70 MeV (Belle)

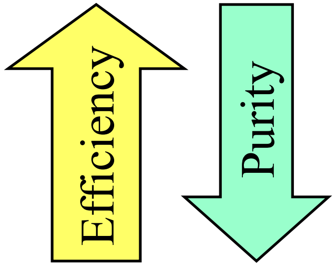
Measurements of $b \to u\ell\nu$

Three degrees of freedom in $B \to X_u \ell \nu$

- Lepton energy E_ℓ : Easy to measure
- Hadronic system mass m_X : Efficient for $b \to c$ rejection
- Lepton-neutrino mass squared q^2 : Mild dependence on the SF

Sample selection technique determines the available variable(s)

- Inclusive lepton sample ➔ E_ℓ
- Lepton + missing momentum ➔ E_ℓ and q^2
- Recoil of reconstructed B ➔ E_ℓ, m_X and q^2



Experiments measure partial branching fraction $\Delta\mathcal{B}$

- Translation to $|V_{ub}|$ requires τ_B and $\tilde{\Gamma} = \Gamma_u/|V_{ub}|^2$
- *BABAR*/Belle use Bosch, Lange, Neubert, Paz (NPB699:335,2004) for the latter

Lepton Endpoint

Experiments push the E_ℓ cut as low as possible

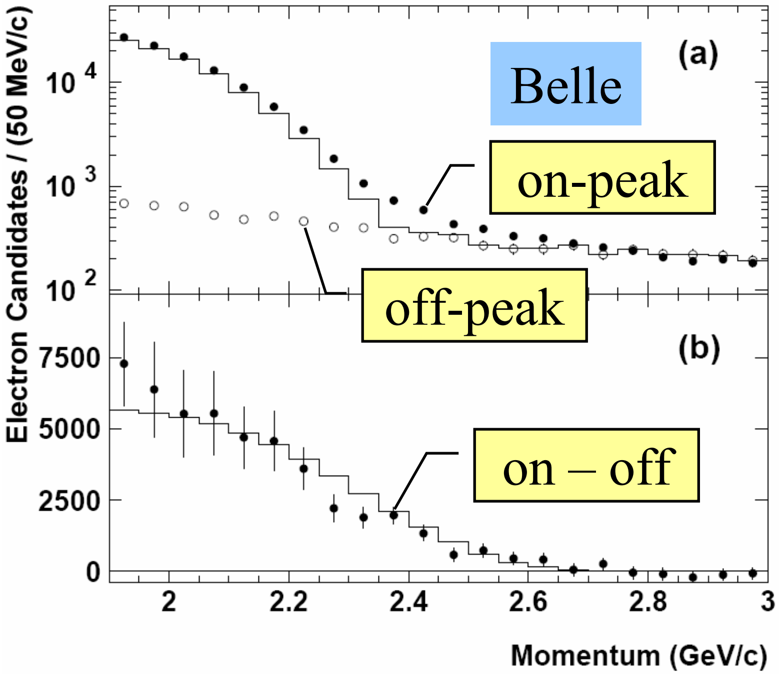
	Data	E_ℓ (GeV)	$\lvert V_{ub}\rvert \times 10^3$	Ref.
BABAR	80 fb^{-1}	2.0-2.6	$3.93 \pm 0.34_{exp} \pm 0.38_{SF} \pm 0.18_{theo}$	hep-ex/0408075
Belle	27 fb^{-1}	1.9-2.6	$4.49 \pm 0.42_{exp} \pm 0.32_{SF} \pm 0.20_{theo}$	hep-ex/0504046

- Better efficiency
- Weaker SF dependence
- Smaller WA error

- $S/B < 1/10$ ➔ Background modeling!

Pushing below 1.9 GeV difficult

- Hit poorly-understood $B \to D^{**}\ell\nu$



Lepton + Neutrino

Find lepton with $E_\ell > 1.9$ GeV and assume $\mathbf{p}_\nu = \mathbf{p}_{\text{miss}}$ of the event

- Now we have E_ℓ and q^2

Define charm-free space by calculating

Maximum hadronic mass squared →

$$s_h^{\max} = m_B^2 + q^2 - 2m_B\left(E_\ell + \frac{q^2}{4E_\ell}\right) + \text{correction for } B \text{ motion in the c.m.s.}$$

- $s_h^{\max} < m_D^2$ rejects the charm background
  - Actual cut is $s_h^{\max} < 3.5\ \text{GeV}^2$
- Signal/background = 1/2

	Data	$\lvert V_{ub}\rvert \times 10^3$	Ref.
BABAR	80 fb^{-1}	$3.89 \pm 0.40_{\text{exp}} \pm 0.45_{\text{SF}} \pm 0.21_{\text{theo}}$	hep-ex/0408045

- Final result will have smaller experimental errors

Recoil B Analysis

Reconstruct one B completely in $B \to D^{(*)} + \text{hadrons}$

- Efficiency ~0.2%/B

Recoil gives a clean and unbiased sample of B

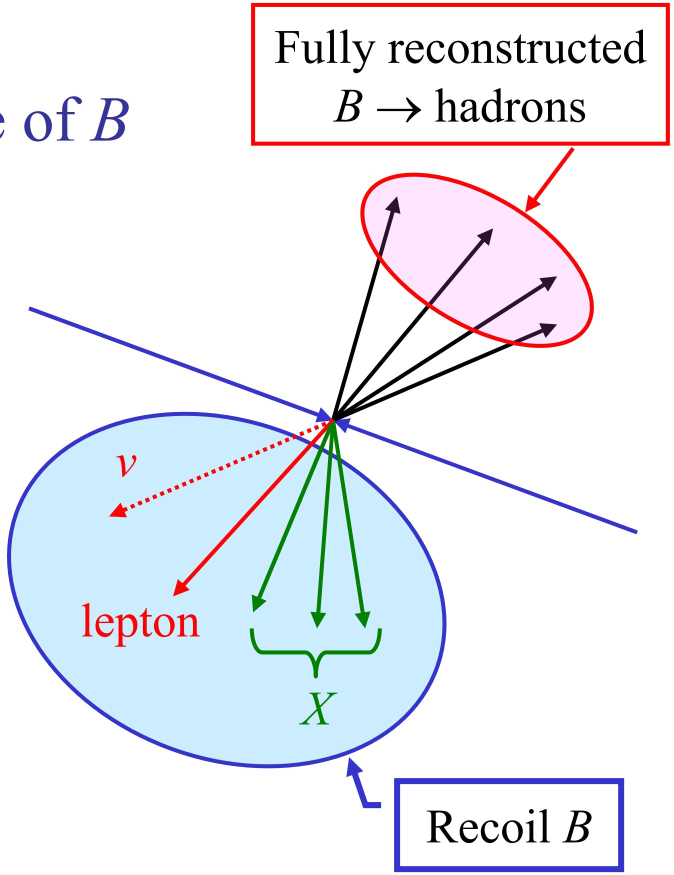
- Charge and 4-momentum known

Find a lepton in the recoil B and require

- Charge conservation
- Missing mass = 0
- Veto against K (likely from D)

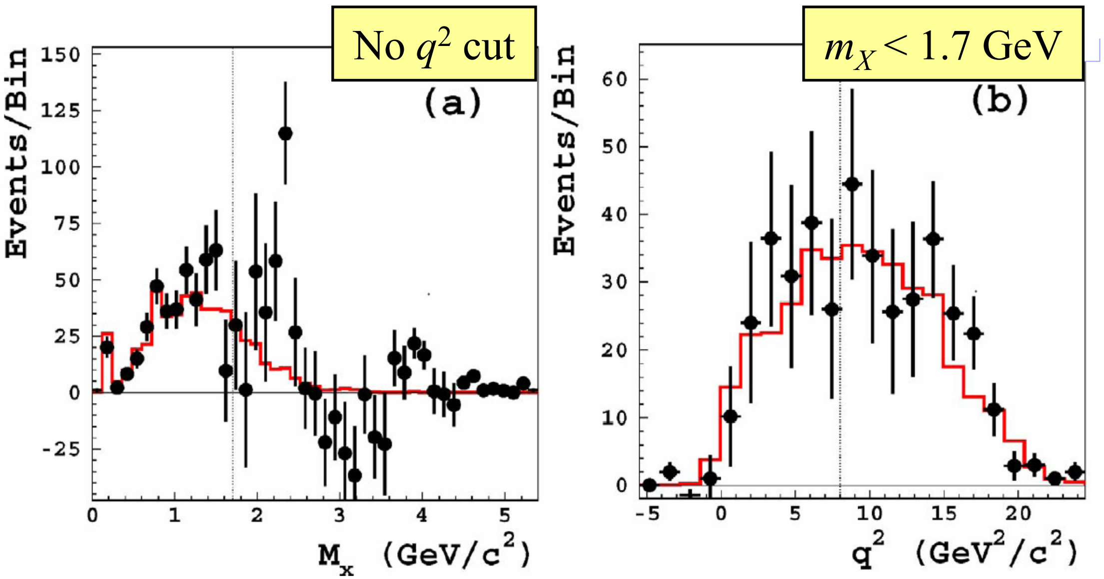
We get complete event kinematics

- Leave E_ℓ cut loose (>1 GeV)
- Use m_X and/or q^2 to select signal

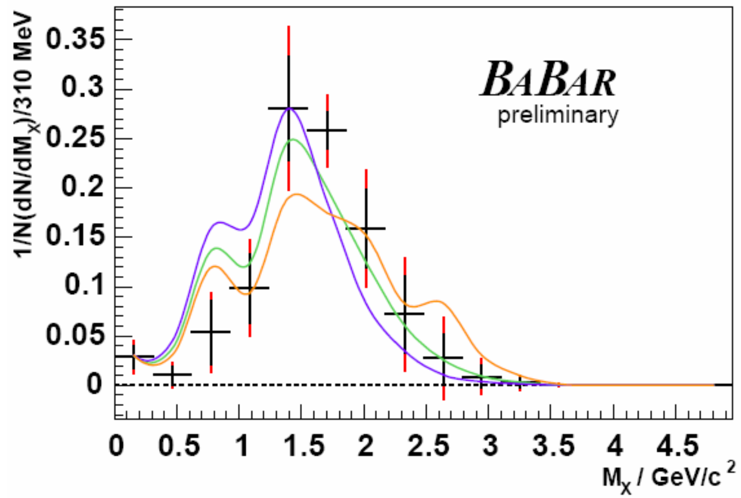


m_X and q^2 Spectra

Experiments plan to measure the m_X and q^2 spectra in $b \to u\ell\nu$



Belle, background-subtracted distributions



BABAR, corrected for efficiency and resolution

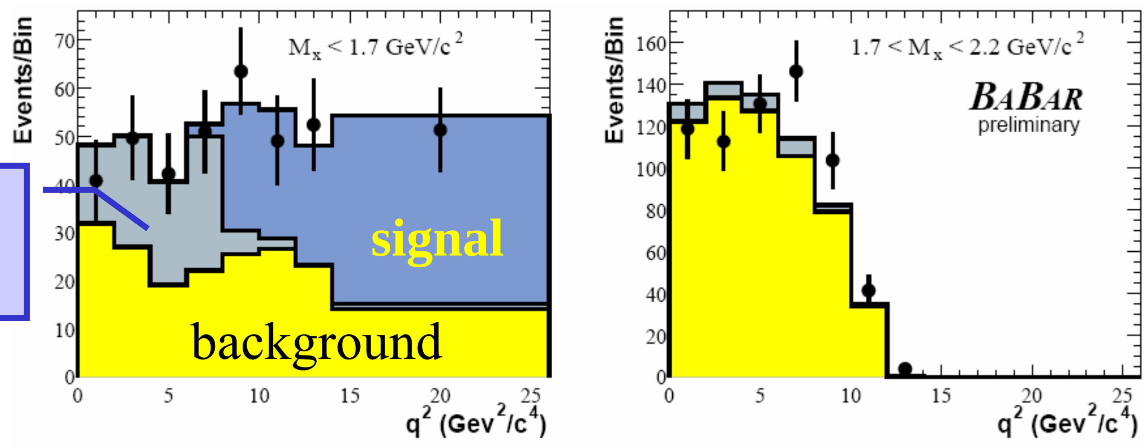
- Potential goal: determine the SF parameters with $b \to u\ell\nu$
- What else can we learn?

m_X vs. q^2

Select $m_X < 1.7$ GeV and $q^2 > 8$ GeV^2

- Proposed by Bauer, Ligeti, Luke (PRD64:113004, 2001)

$b \to u\ell\nu$ outside the signal region



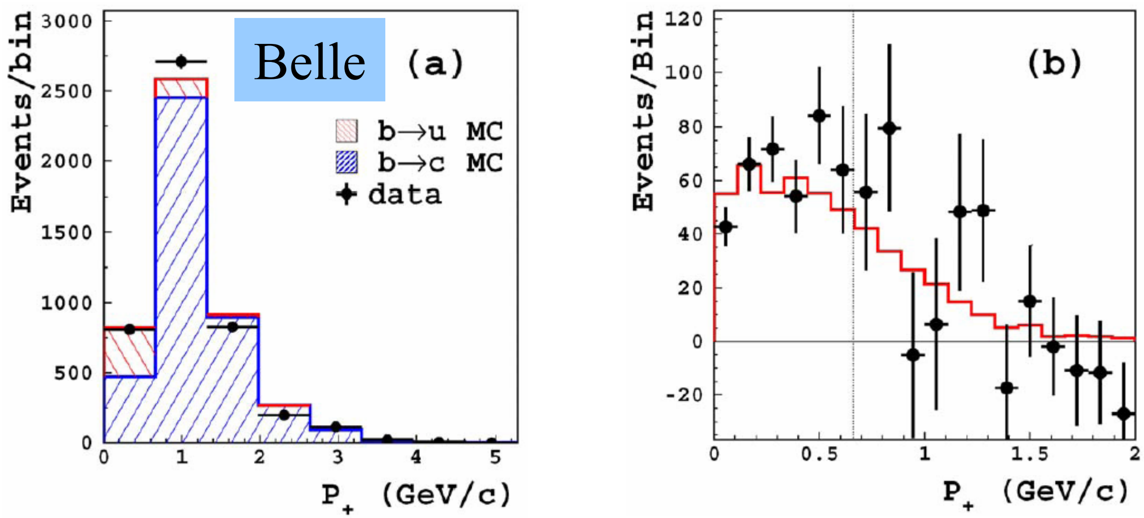
	Data	$\|V_{ub}\| \times 10^3$	Ref.
BABAR	80 fb^{-1}	$4.45 \pm 0.49_{exp} \pm 0.40_{SF} \pm 0.22_{theo}$	hep-ex/0408068
Belle	253 fb^{-1}	$4.34 \pm 0.34_{exp} \pm 0.33_{SF} \pm 0.22_{theo}$	Bizjak, CKM05 talk

- Reminder: SF errors differ because the error on $\bar{\Lambda}$ is different

P_+ Variable

Define $P_+ = E_X - P_X$ and cut at $P_+ < 0.66$ GeV

- Proposed by Bosch, Lange, Neubert, Paz (PRL93:221801,2004)



	Data	$\|V_{ub}\| \times 10^3$	Ref.
Belle	253 fb^{-1}	$3.87 \pm 0.33_{exp} \pm 0.35_{SF} \pm 0.13_{theo}$	Bizjak, CKM05 talk

Note small theoretical error

Inclusive $|V_{ub}|$ in May 2005

	Data	Cuts	$\|V_{ub}\| \times 10^3$
BABAR	80 fb^{-1}	$E_\ell > 2.0$ GeV	$3.93 \pm 0.34_{exp} \pm 0.38_{SF} \pm 0.18_{theo}$
Belle	27 fb^{-1}	$E_\ell > 1.9$ GeV	$4.49 \pm 0.42_{exp} \pm 0.32_{SF} \pm 0.20_{theo}$
BABAR	80 fb^{-1}	$E_\ell > 1.9$ GeV, $s_h^{max} < 3.5$ GeV^2	$3.89 \pm 0.40_{exp} \pm 0.45_{SF} \pm 0.21_{theo}$
BABAR	80 fb^{-1}	$m_X < 1.7$ GeV, $q^2 > 8$ GeV^2	$4.45 \pm 0.49_{exp} \pm 0.40_{SF} \pm 0.22_{theo}$
Belle	253 fb^{-1}	$m_X < 1.7$ GeV, $q^2 > 8$ GeV^2	$4.34 \pm 0.34_{exp} \pm 0.33_{SF} \pm 0.22_{theo}$
Belle	253 fb^{-1}	$P_+ < 0.66$ GeV	$3.87 \pm 0.33_{exp} \pm 0.35_{SF} \pm 0.13_{theo}$

- Experimental errors 8–11% → 5% if combined
- Shape-function errors 7–12% → 8% on average
- Theoretical errors 3–5% → 4% on average

We have determined $|V_{ub}|$ to $5\%_{exp} \oplus 8\%_{SF} \oplus 4\%_{theo} \approx 10\%$

- We said this last summer – Do we believe it now?

Inclusive $|V_{ub}|$ at Moriond 2007

- Experimental error (5%) in $|V_{ub}|$ will shrink with the statistics
  - Even syst. errors improve with larger control samples
  - 500 fb^{-1}/expt. by summer 2006 ➔ 2.5%?
- Largest uncertainty (8%) comes from the shape function
  - Will improve as soon as we start using the new $b \to s\gamma$ results
  - *BABAR* Σ(excl.) result alone can reduce the error on $\overline{\Lambda}$ by a factor 2
  - 2 expts. × 2 methods × more data ➔ 3%?
- Theory error (4%) will be the largest error (again)
  - We'd better be darn sure about them
  - We'd better have a strategy to shrink them

Questions + Remarks

How robust are the current theory errors?

- *BABAR*/Belle rely on calculation by one group
  - Error estimates come from Lange, Neubert, Paz, hep-ph/0504071
  - We'd love to have an independent calculation or two
- Sub-leading SF error small (0.5% for m_X-q^2) ➔ Do we all agree?
- P_+ cut has small theo. error (3%) ➔ Will another group confirm?

What can we do to shrink the theory errors?

- Leading error is perturbative ➔ Any hope for improvement?
- We will pursue B^+-B^0 difference → Precision unknown yet
- Experimental handles on sub-leading SFs?

> $|V_{ub}|$ will be determined to a 5% precision in 2 years
> if the theory error becomes 3%, *and we believe it*