B meson semileptonic decays

- Physics Motivation
- Inclusive properties:
  - Semileptonic width
  - Moments of inclusive quantities
- Exclusive decays
- What is the semileptonic width made of?
- Charmless semileptonic decays
- Conclusions

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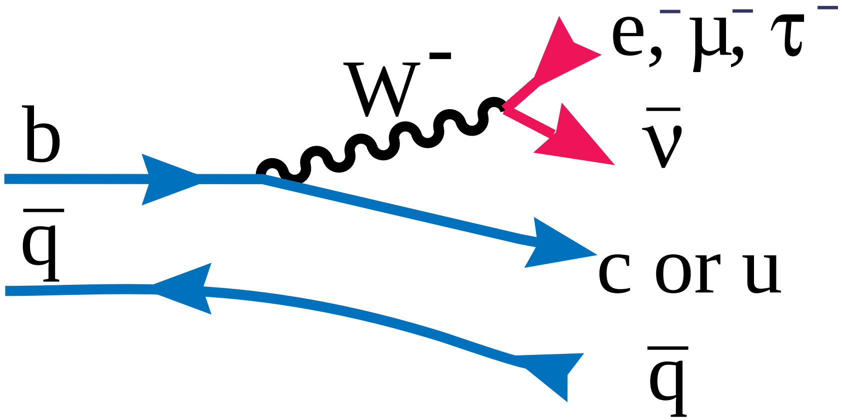
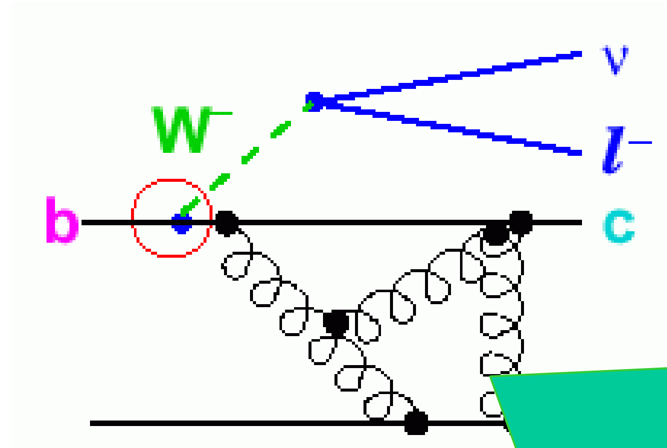
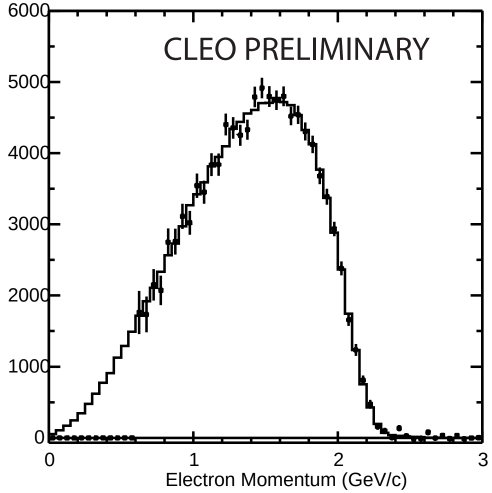
Physics Motivation

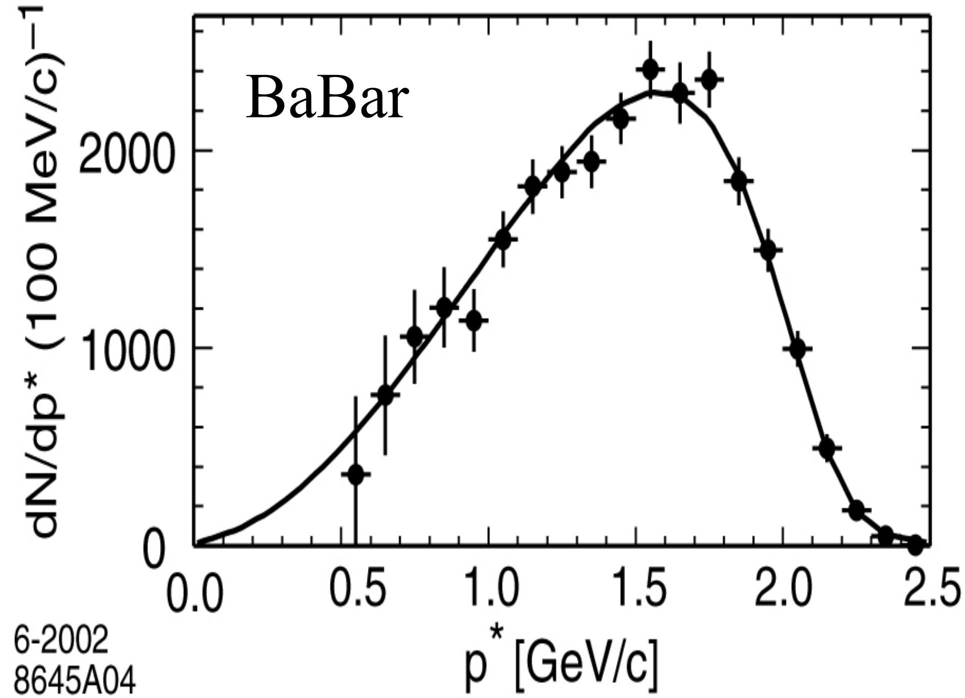




- Ultimate goal: a precise determination of V_{cb} (more details in M. Calvi talk) & Vub (more details in E. Thorndike talk) but we need to take care of the **hadronic matrix element**

Inclusive semileptonic branching fractions





High momentum lepton tag to identify $b \to (c,u)\ell\nu$

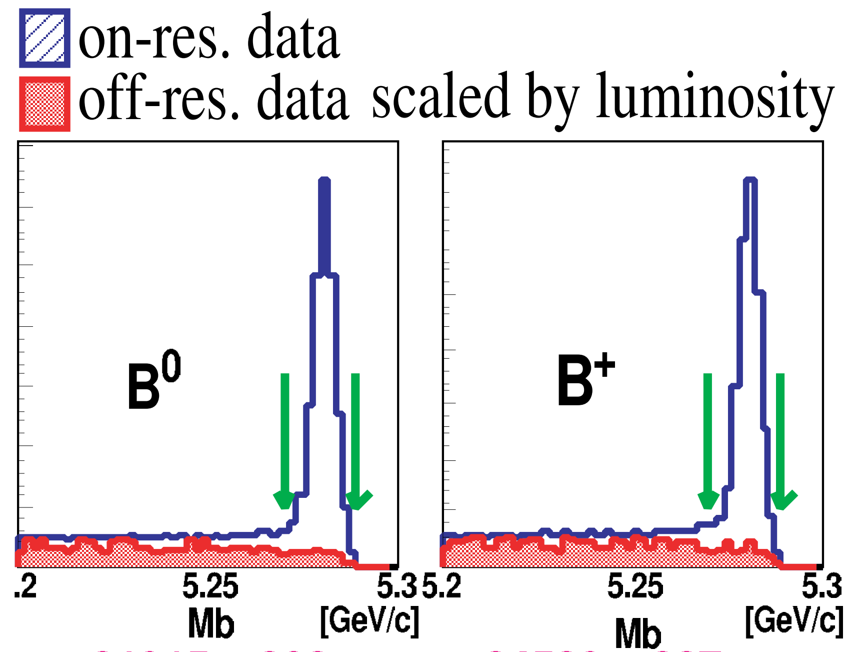
CLEO (new-prelim) [10 fb^{-1}]	10.88±0.08 ±0.33%
BaBar [5.07fb^{-1}]	10.87±0.18±0.30%
Belle[5.1fb^{-1}]	10.90±0.12±0.49%
LEP (most recent EW fit)	10.59±0.22%

Belle: inclusive semileptonic decays with fully reconstructed tags

Tagging modes considered:

$\bar{B}^o \to$
- $D^{*+}\pi^- / D^{*+}\rho^- / D^{*+} a_1$
- $D^{+}\pi^- / D^{+}\rho^- / D^{+} a_1$

$B^- \to$
- $D^{*o}\pi^- / D^{*o}\rho^- / D^{*o} a_1$
- $D^{o}\pi^- / D^{o}\rho^- / D^{o} a_1$



21915 ± 202 events purity:87.2%

24529 ± 227 events purity:85.6%

$D^o \to K^+ \pi^-$, $K^+ \pi^- \pi^o$, $K^+ \pi^- \pi^o$, $K^+ \pi^- \pi^+ \pi^-$,$K_s \pi^- \pi^+$

$D^+ \to K^+ \pi^+ \pi^-$,

Belle: inclusive charged and neutral B branching fractions

The inclusive charged and neutral B semileptonic branching fractions measured separately:

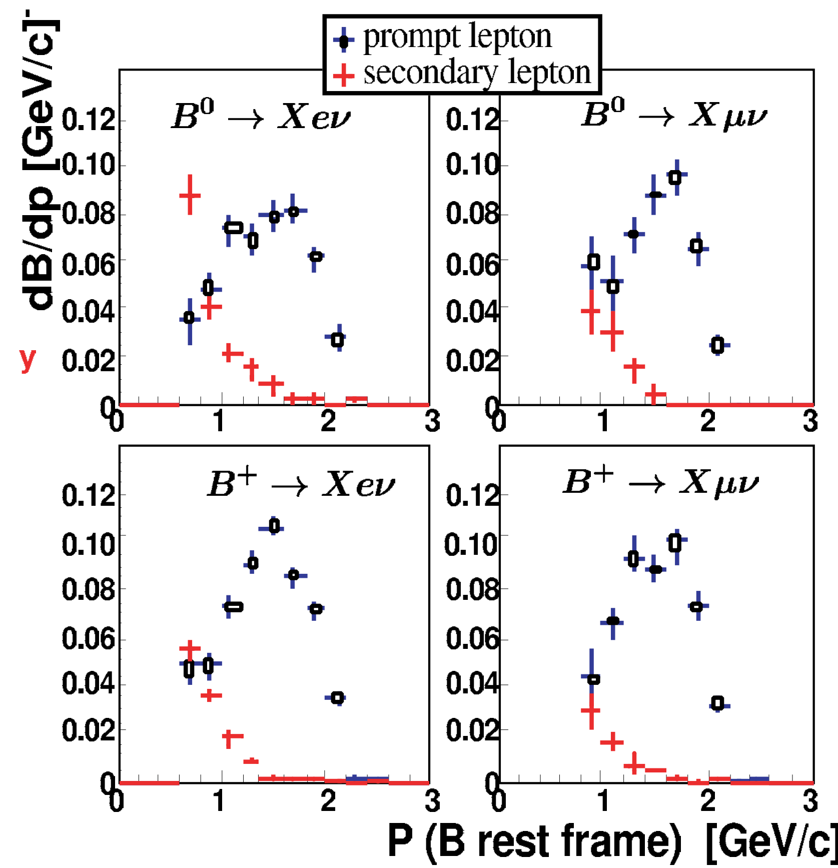
$\mathcal{B}(B^0 \to X\ell\nu) = (10.32 \pm 0.32 \pm 0.29)\%$

$\mathcal{B}(B^+ \to X\ell\nu) = (11.92 \pm 0.26 \pm 0.32)\%$

$\Rightarrow f^+/f^0 = 1.14 \pm 0.04|_{exp} \pm 0.01|_{theory}$

$\mathcal{B}(B \to X\ell\nu) = (11.19 \pm 0.20|_{exp} \pm 0.31|_{theory})\%$

preliminary



What makes up the $b \to c\ell\nu$ width?

PDG 2003 average HFAG working group

	B(%)
$B \to X\ell\nu$	10.70 ±0.28
$B \to D^{*}\ell\nu$	5.53 ±0.23
$B \to D\ell\nu$	2.14 ±0.20

About 27% of the semileptonic branching fraction is poorly known! This has important implications for our ability to understand HQET, OPE… we need to nail this component down with further experimental information!

The hadronic matrix element

- Theoretical framework: Heavy Quark Expansion (more on N. Uraltsev talk)
- Issues to be explored by experiments:
  - Underlying theoretical accuracy: are all the uncertainties quantified? In particular ansatz of quark-hadron duality.
  - Experimental determination of the Heavy quark expansion parameters, in particular:
    - m_b,m_c at the relevant mass scale
    - μ_π^2 [λ_1] kinetic energy of the b quark
    - μ_G^2 [λ_2] expectation value of chromomagnetic op.

m_b: a multifaceted fundamental parameter

Important for $V_{c(u)b}$

	m_{kin}(GeV)	$\overline{m}_b(\overline{m}_b)$ (GeV)	method
Beneke,Signer, Smirnov	-	4.26±0.12	Sum rules
Melnikov	4.56±0.06	4.20±0.1	Sum rules
Hoang	4.57±0.06	4.25±0.09	Sum rules
Jamin,Pich	-	4.19±0.06	Sum rules, no resummation
Pineda,Yndurain	-	$4.44^{-0.04}_{+0.03}$	Q(1S) mass
NRQCD	-	4.28±0.03±0.03±0.10	Lattice HQET (n_f=2)

O expansion

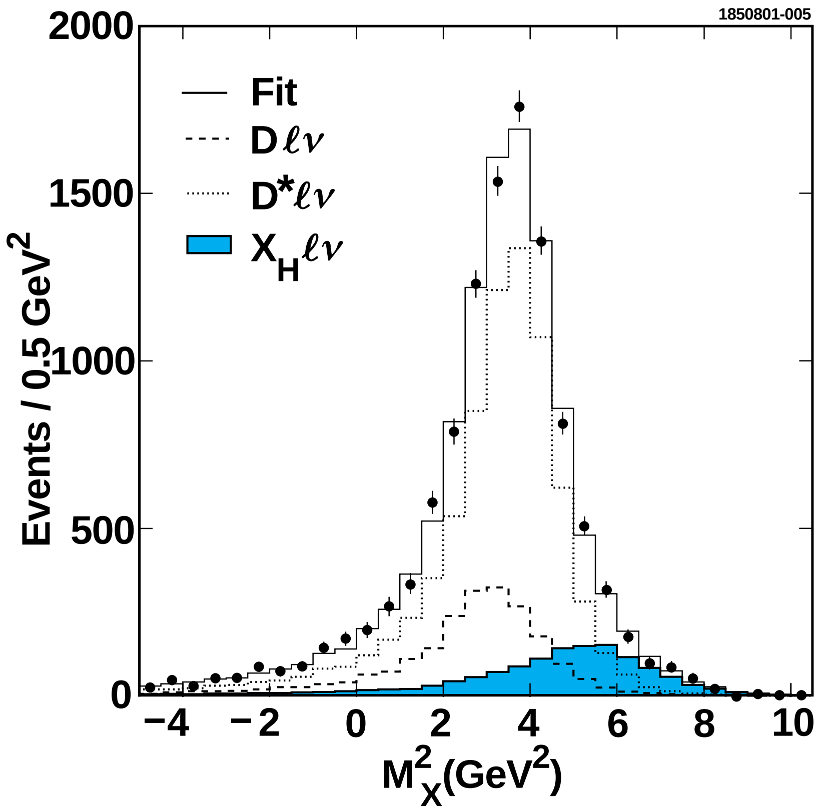
Jet observables sensitive to b mass(LEP)

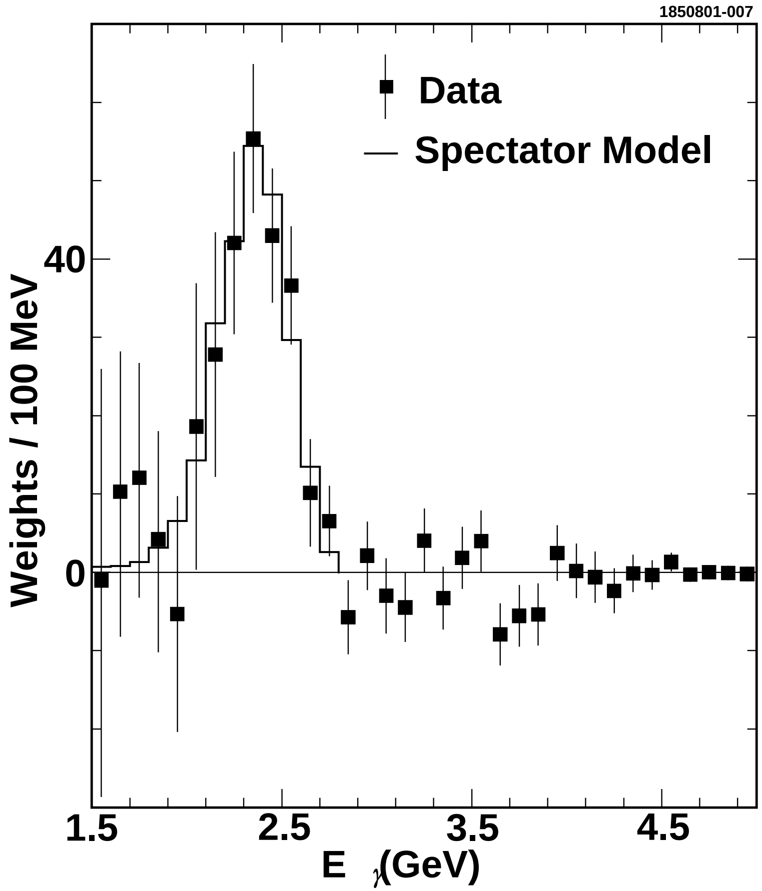
+ pole mass $m_b^{pole} \approx m_{kin} + 0.255$ GeV Bigi-Mannel hep/ph/0212021

Experimental tools: moments of the kinematic variables

- Approaches used:
  - Moments of E_ℓ
  - Moments of M_x invariant mass of the hadronic system recoling against the ℓ-ν pair
  - Multivariate analysis including q2, E_ℓ , M_x
- Data available from CLEO, BaBar, Belle

CLEO: M_X with cut p_ℓ>1.5 GeV/c and $b \rightarrow s\gamma$ (prl87[2001]251808;prl87[2001]251807)



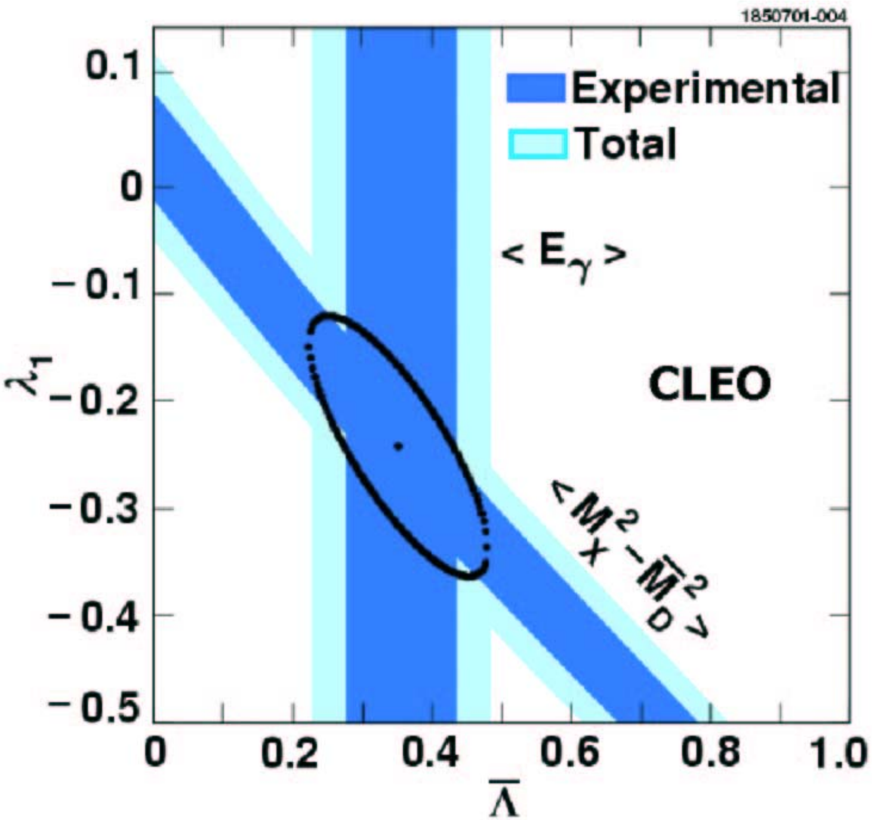


$$\left\langle M_X^2 - \bar{M}_D^2 \right\rangle = (0.251 \pm 0.023 \pm 0.062)\, GeV^2$$

$$\left\langle \left(M_X^2 - \bar{M}_D^2\right)^2 \right\rangle = (0.639 \pm 0.056 \pm 0.178)\, GeV^2$$

$$\left\langle E_\gamma \right\rangle = (2.346 \pm 0.032 \pm 0.011)\, GeV$$

The HQE parameters



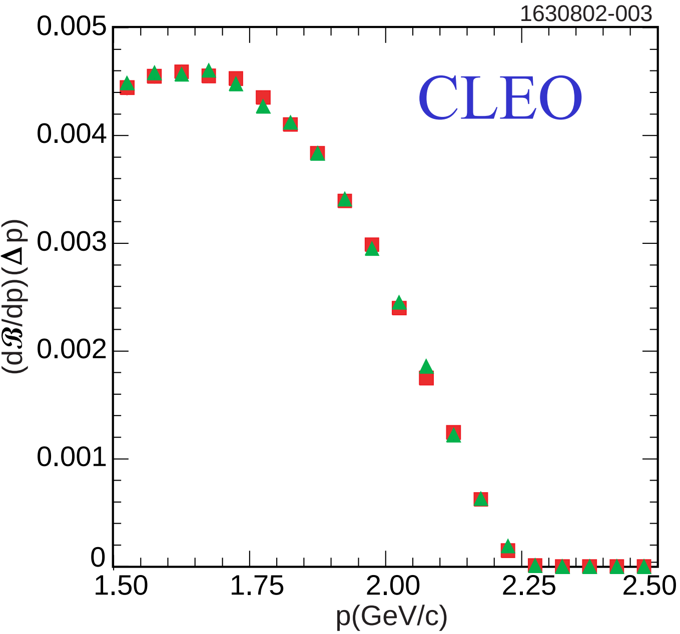
$$\bar{\Lambda} = (0.35 \pm 0.07 \pm 0.10)\,GeV$$

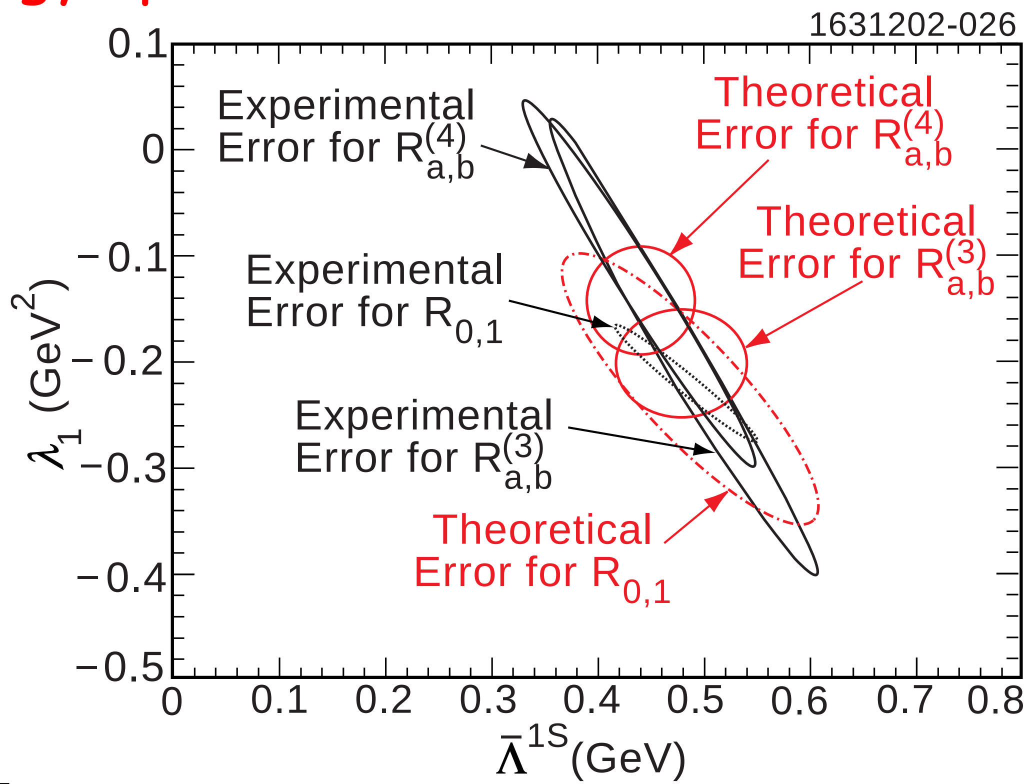
$$\lambda_1 = (-0.238 \pm 0.071 \pm 0.078)\,GeV^2$$

Scheme dependent

MS to order $1/M^3$, $\beta_0\alpha_s^2$

Truncated moments of the lepton energy spectrum





$$R_0 = \frac{\int_{1.7GeV} \left(\frac{d\Gamma}{dE_l}\right) dE_l}{\int_{1.5GeV} \left(\frac{d\Gamma}{dE_l}\right) dE_l} \qquad R_1 = \frac{\int_{1.5GeV} E_l \left(\frac{d\Gamma}{dE_l}\right) dE_l}{\int_{1.5GeV} \left(\frac{d\Gamma}{dE_l}\right) dE_l}$$

Gremm, Kapustin, Ligeti, Wise PRL77(1996)20

m_b(pole)=(4.90 ±0.08|exp ±0.13|th) GeV⇔

m_b(pole)=(4.82 ±0.06)GeV analysis of beauty production at threshold

m_b^{1S}=(4.82 ±0.07|exp ±0.11|th)GeV/c^2

λ_1=(-0.25 ±0.02 ±0.05 ±0.14) GeV^2

Summary of the CLEO measurements

method	$\bar{\Lambda}$(GeV)	λ_1(GeV^2)
$b \to s\gamma, M_x$	0.35±0.07 ±0.1	-0.238± 0.071±0.078
Truncated lepton energy mom	0.39 ±0.03 ±0.06 ±0.12	-0.25 ±0.02 ±0.05 ±0.14

Agreement even too good! $1/m_b^3$ dominant uncertainty

Consistent with m_b extracted from b production at threshold

DELPHI study of spectral moments

- Measured first 3 moments of E_ℓ and M_X, using a multiparameter fit (more details in M. Calvi's talk)

$\bar{\Lambda}$=0.40 ±0.10 ±0.02 GeV

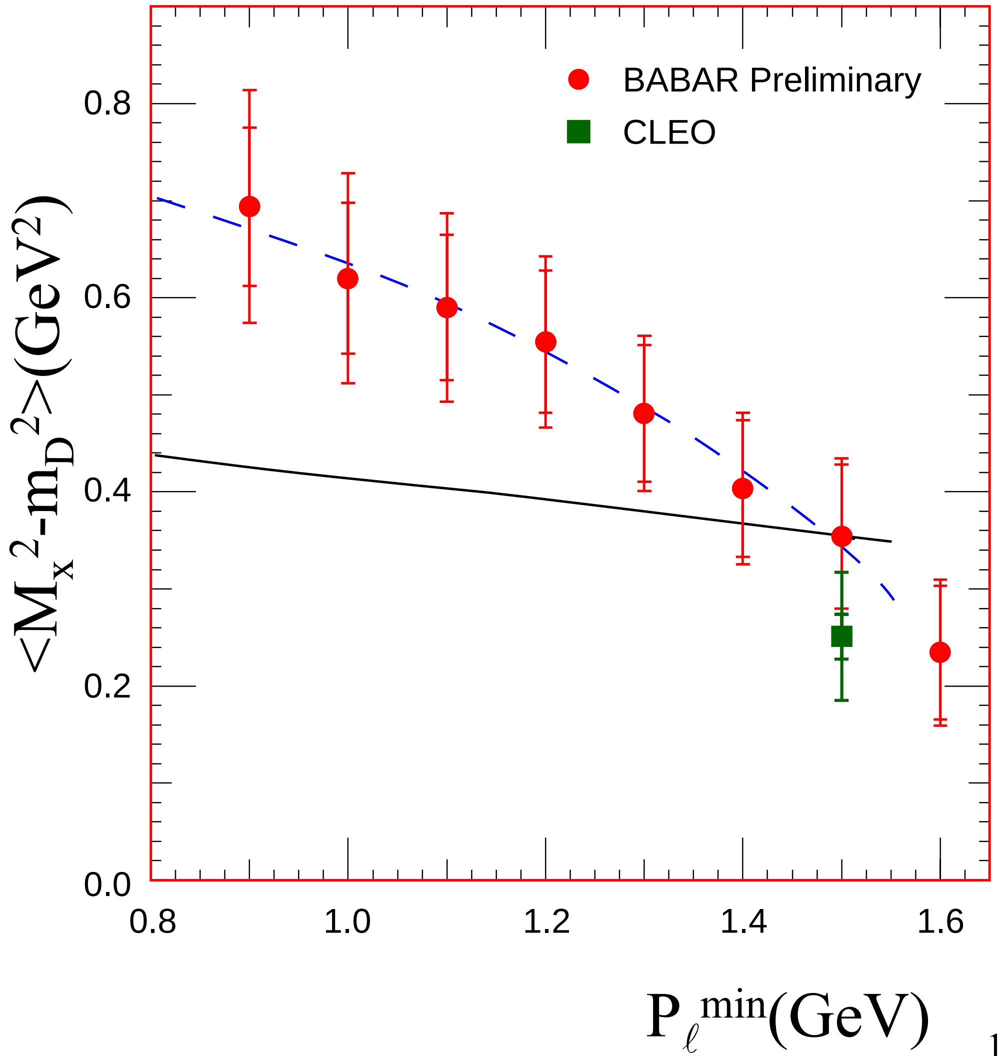
λ_1=(-0.15 ±0.07 ±0.03) GeV^2

Consistent with CLEO results

Amazingly small systematic errors

First moment of M_x from BaBar

- Data seem to show that average mass higher if momentum cut is relaxed: tail of high mass states predicted by N. Isgur [plb448(1999)111]?
- "Underlying assumptions of HQE + OPE require further scrutiny"
- Updated results from BaBar and CLEO expected at summer conferences

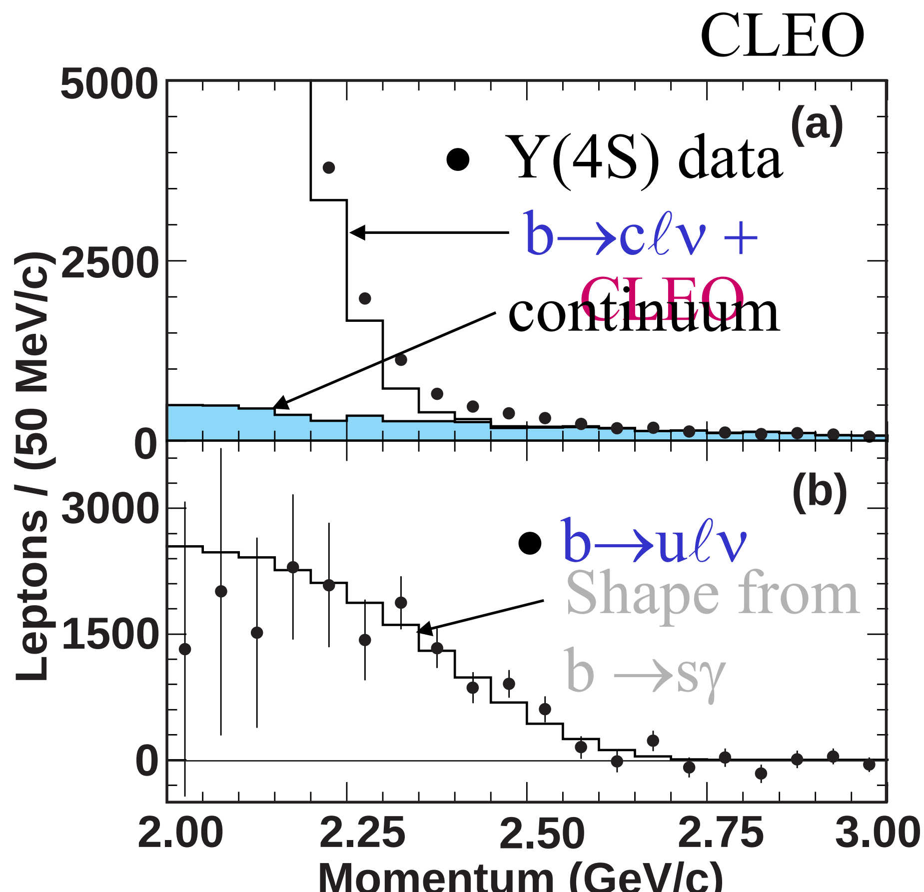


The quest for $b \to u\ell\nu$ decays: inclusive approach

- The experimental challenge: single out the tiny $b \to u\ell\nu$ component from the dominant $b \to c\ell\nu$
- Approaches taken:
  - Single out endpoint of lepton spectrum
  - M_x below M_D
  - More complex multivariate analysis, fitting explicitly for $b \to c\ell\nu$ contribution.
- All the suppression techniques introduce theoretical uncertainties that need to be addressed

b→uℓν from lepton endpoint

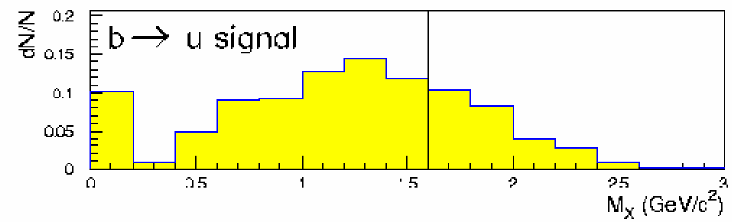
- This technique gave the first evidence for b→uℓν decays
- Momentum cut reduced predictive power of OPE, but, up to $1/m_b$ corrections, shape can be extrapolated from b→sγ →use measured b→sγ shape to reduce theoretical error

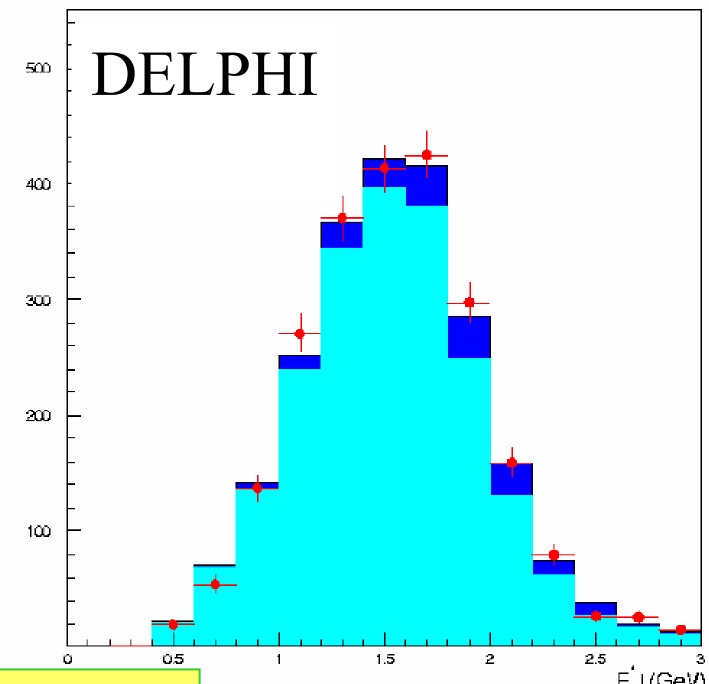


$B(b \to u \ell \nu) = (1.77 \pm 0.29 \pm 0.38) \times 10^{-3}$

$b \to u\ell\nu$ using M_x distribution

- ALEPH & DELPHI, OPAL select samples of charm-poor semileptonic decays with a large number of selection criteria
- Can they understand $b \to c\ell\nu$ feedthrough < 1% ?



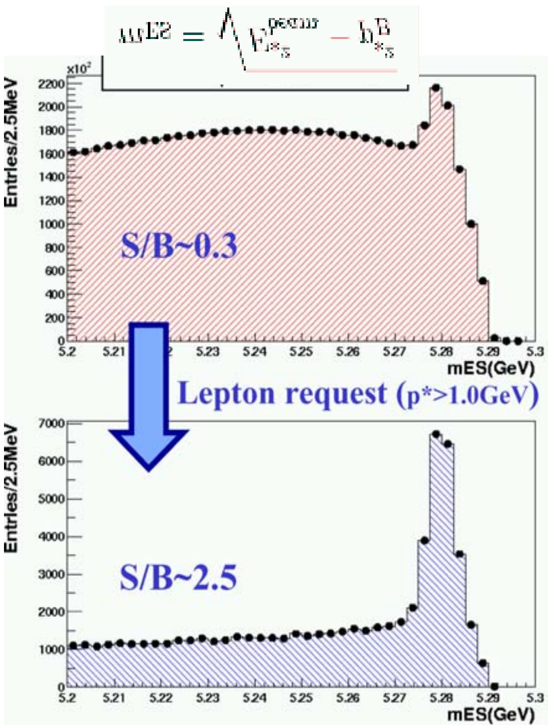


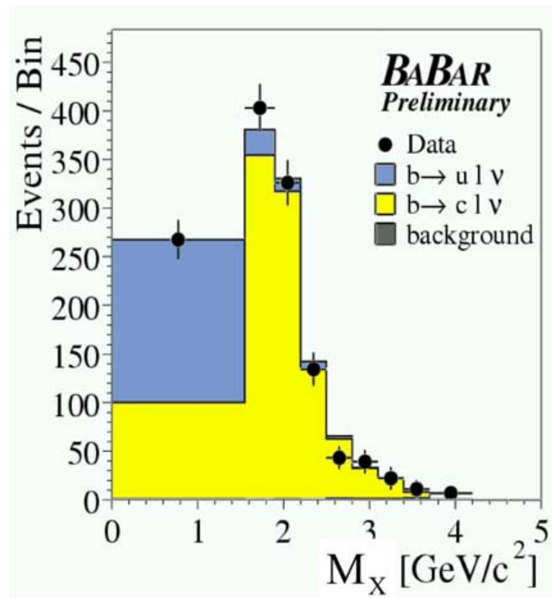
LEP combined results

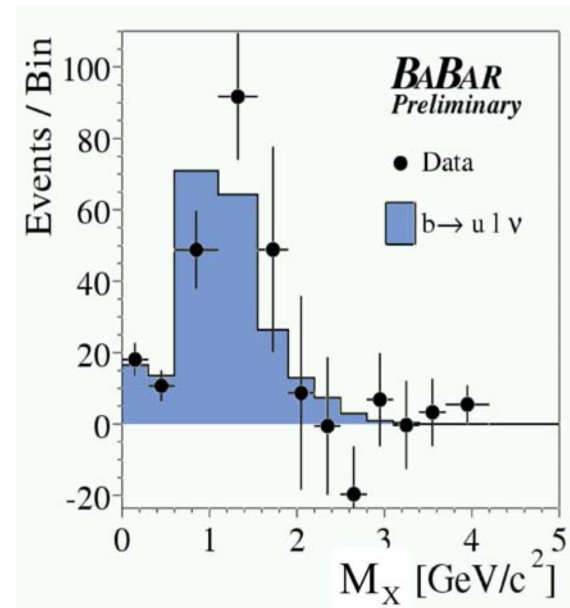
$B(b \to u\ell\nu) = (1.71 \pm 0.31|_{stat+det} \pm 0.37|_{b\to c} \pm 0.21|_{b\to u}) \times 10^{-3}$

$b \to u\ell\nu$ from BaBar: study of M_x with B tags

- Use fully reconstructed B tags



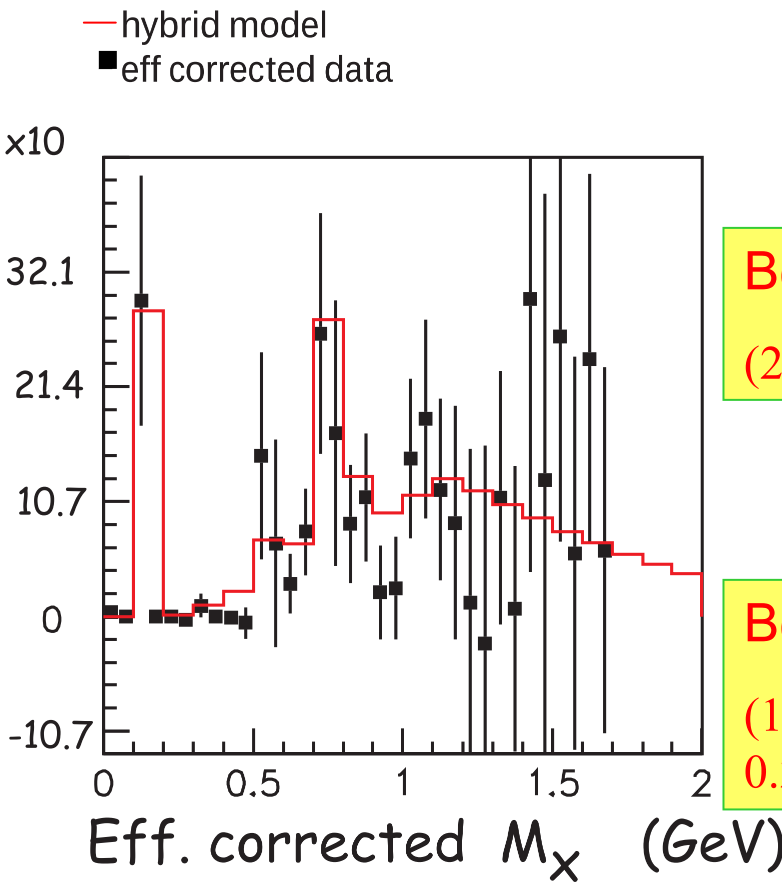




Preliminary

$$\mathcal{B}(B \to X_u \ell \bar{\nu}) = (2.14 \pm 0.29(stat) \pm 0.25(syst) \pm 0.37(theo)) \times 10^{-3}$$

Inclusive $b \to u \ell \nu$ from Belle



- Measure $B(b \to u \ell \nu)$ using:
  - Pseudo full reconstruction of the $\Upsilon(4S)$ [$D^{(*)}\ell$ tags]

$B(b \to u \ell \nu) =$

$(2.62 \pm 0.63|_{stat} \pm 0.23|_{sys} \pm 0.05|_{b \to c} \pm 0.41|_{b \to u}) \times 10^{-3}$

  - Advanced ν reconstruction

$B(b \to u \ell \nu) =$

$(1.64 \pm 0.14|_{stat} \pm 0.36|_{sys} \pm 0.28|_{b \to c} \pm 0.22|_{b \to u} \pm 0.29|_{theory}) \times 10^{-3}$

preliminary

Summary of inclusive $b \to u \ell \nu$ determinations

Experiment	Method	$BF(B \to u \ell \nu)(\times 10^3)$
CLEO	Endpoint(2.2-2.6 GeV)	$1.77 \pm 0.29|_{exp} \pm 0.38|_{fu}$
LEP(Vub WG ave)	M_x	$1.71 \pm 0.31 \pm 0.37 \pm 0.21$
BaBar	Endpoint(2.3-2.6)+f_u CLEO	$2.05 \pm 0.27|_{exp} \pm 0.46|_{fu}$
BaBar	M_X	$2.14 \pm 0.29 \pm 0.25 \pm 0.37$
BELLE	$D^{(*)}\ell$ tags	$2.62 \pm 0.63 \pm 0.23 \pm 0.05 \pm 0.41$
BELLE	Improved ν reco	$1.64 \pm 0.14 \pm 0.36 \pm 0.28 \pm 0.22$

preliminary

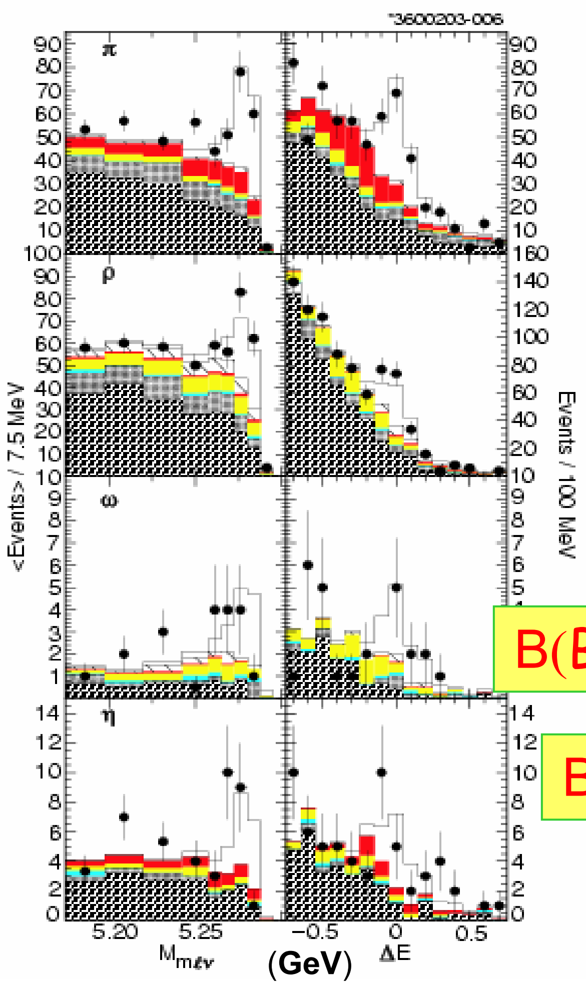
Additional theoretical uncertainties may need to be added (higher twist effects, Mx or other $b \to u$ enhancing cuts)!

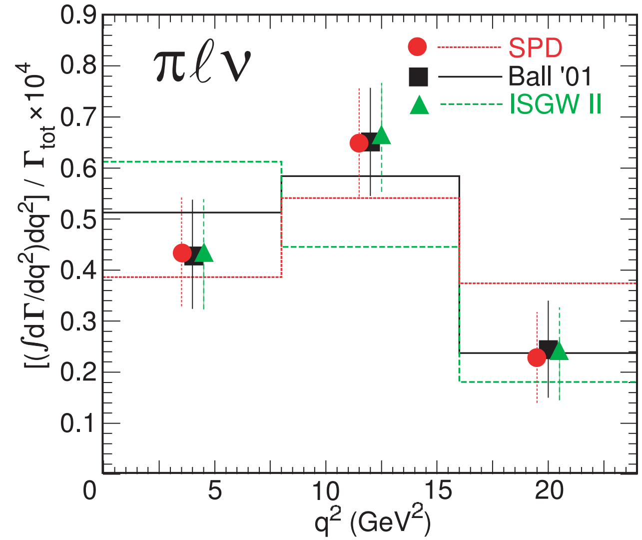
Exclusive decays: $B \to \rho \ell \nu / \pi \ell \nu$

- Important to extract V_{ub}, especially when q^2 dependence will be mapped precisely & more refined input from lattice calculations will be available [see talk by D. Becirevic,M.A.]
- No simple HQET effective theory available (light quark in the final state): evaluation of theoretical uncertainties difficult
- Study of q^2 dependence and V/P ratio are very useful checks on theory [historically they have helped in ruling out quark model calculations of $B \to \rho \ell \nu / \pi \ell \nu$.

$B \to \rho \ell \nu / \pi \ell \nu$ (CLEO)

- Use detector hermeticity to reconstruct ν
- CLEO finds rough q^2 distribution



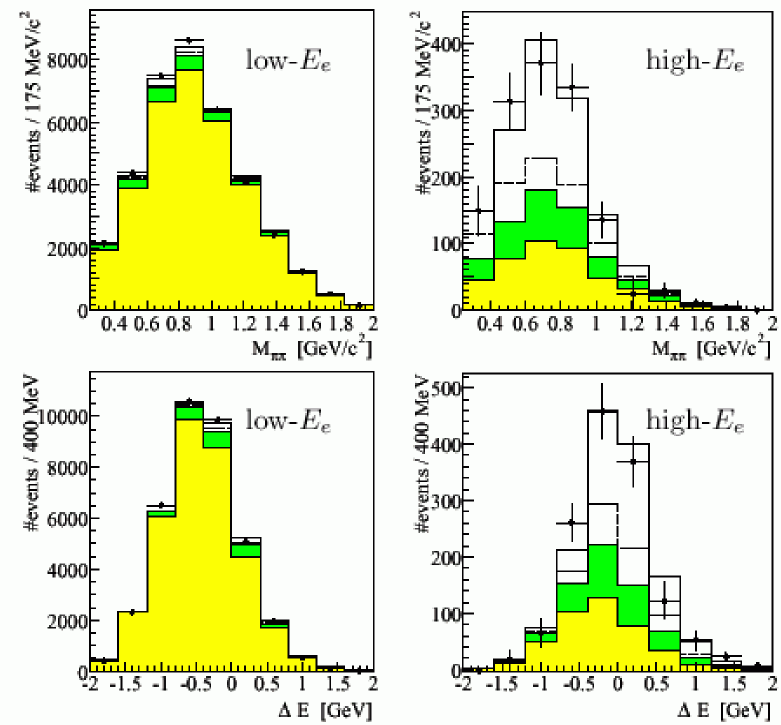


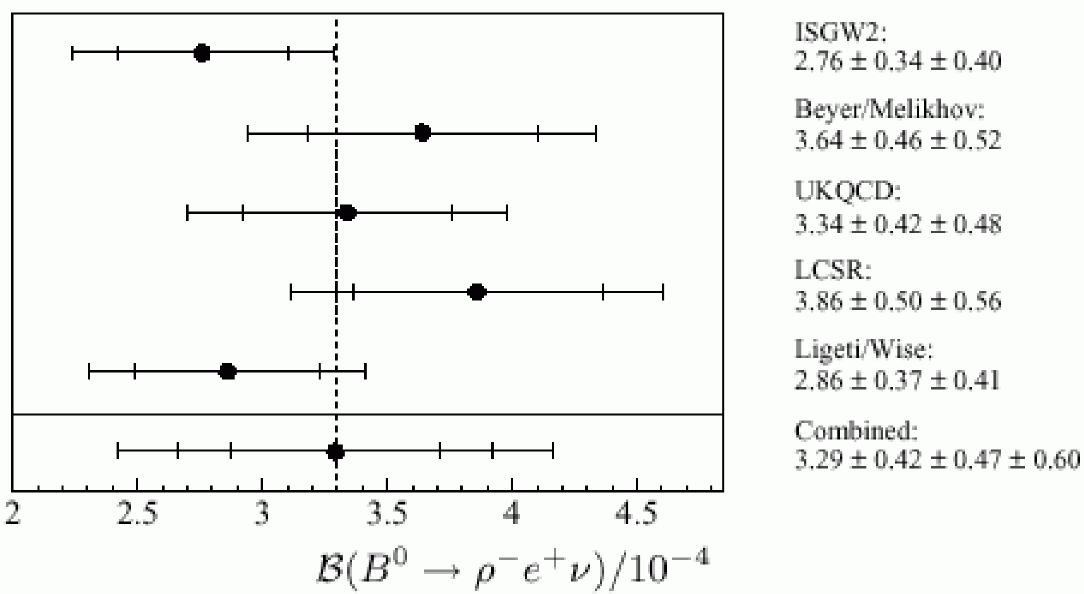
$$B(B^o \to \pi^- \ell \nu) = (1.33 \pm 0.18|_{stat} \pm 0.11|_{exp} \pm 0.01|_{ff,sig} \pm 0.07|_{ff,cf}) \times 10^{-4}$$

$$B(B^0 \to \rho^- \ell \nu) = (2.17 \pm 0.34|_{stat} {}^{+0.47}_{-0.54}|_{sys} \pm 0.41|_{ff,sig} \pm 0.01|_{ff,cf}) \times 10^{-4}$$

$B \to \rho \ell \nu$ BaBar

- Used 50.5 1/fb on-resonance and 8.7 1/fb 40 MeV below Υ(4s) resonance
- Study 5 modes $B \to H_u e\nu$ where $H_u = \rho^0, \rho^\pm, \omega, \pi^0, \pi^\pm$ in 2 lepton energy ranges:
  - LOLEP : $2.0 < E_e < 2.3$ GeV (large $b \to c\, e\, \nu$ backgrounds)
  - HILEP : $2.3 < E_e < 2.7$ GeV (large continuum backgrounds)





BABAR PRELIMINARY

Summary on $B \to \rho \ell \nu / \pi \ell \nu$

experiment	Decay mode	B.F ($\times 10^{-4}$)
CLEO	$B \to \pi \ell \nu$	$1.33 \pm 0.18 \pm 0.11 \pm 0.01 \pm 0.07$
CLEO	$B \to \rho \ell \nu$	$2.17 \pm 0.34 ^{+0.47}_{-0.54} \pm 0.41 \pm 0.01$
BaBar (prel)	$B \to \rho \ell \nu$	$3.29 \pm 0.42 \pm 0.47 \pm 0.60$

Conclusions

- Experimental studies of b $\rightarrow$(c,u) $\ell\nu$ have reached a great level of sophistication, but several key issues need still to be tackled
  - Full understanding of the composition of the semileptonic width
  - Precise determination of the theory parameters
  - Assessment of non-quantified theory errors [quark hadron duality, effects of higher twists…]
  - Reliable determination of the theoretical errors in exclusive $B\rightarrow\rho\ell\nu / \pi\ell\nu$ transitions
- Large data sample at b-factories will allow to pursue analyses that are likely to have more controlled theoretical errors
- Charm data at threshold will help in the understanding of theoretical error [more on this later…]