Charmless Semileptonic B Decays at e^+e^- Colliders

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On behalf of the Belle Collaboration.

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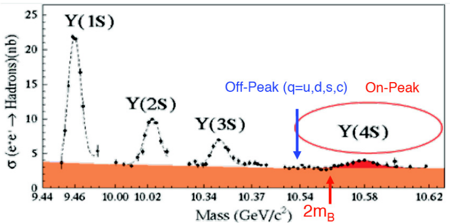
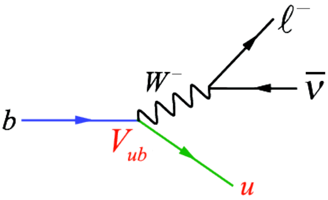
Introduction and Motivation

- Beam energies at B-Factories tuned to produced B pairs through $e^+e^- \to \Upsilon(4S) \to B\bar{B}$.
- $\mathcal{B}(\Upsilon(4S) \to B\bar{B}) \approx 96\%$.
- B decays are used to extract CKM matrix elements $|V_{cb}|$, $|V_{ub}|$





- Semileptonic decays ideal to study $|V_{ub}|$.
- Two approaches:
  - inclusive*:

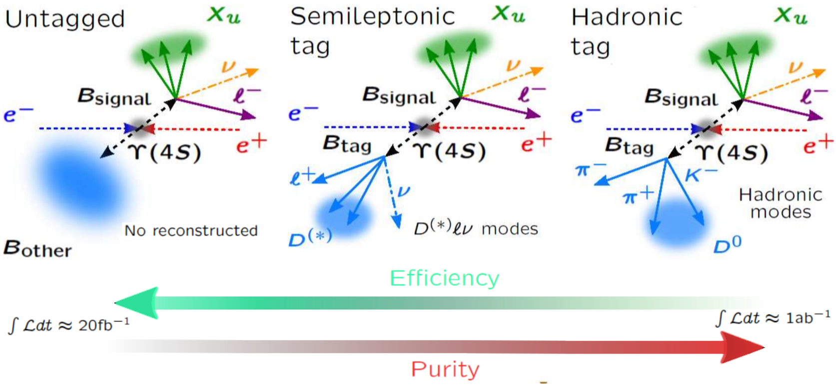
    $|V_{ub}| = (4.39 \pm 0.15^{+0.12}_{-0.14}) \times 10^{-3}$
  - exclusive**:

    $|V_{ub}| = (3.23 \pm 0.30) \times 10^{-3}$

Disagreement $(2 \to 3)\sigma$

*HFAG End 2011 (GGOU)
** Simulataneous fit using BCL parametrization, HFAG End 2011

Reconstruction of B mesons

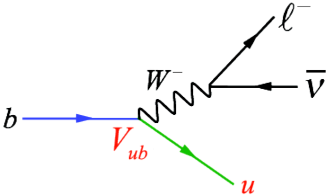


How to reconstruct Semileptonic decays?

- Charged lepton: $e^{\pm}, \mu^{\pm}$
- Hadron: X_u, π, ρ, ω, etc.
- Neutrino inferred from P_{miss}

$$(E_{\text{miss}}, \vec{p}_{\text{miss}}) = (E_{\text{beams}} - \sum_i E_i, \vec{p}_{\text{beams}} - \sum_i \vec{p}_i)$$

Inclusive $B \to X_u \ell \nu$



- Sum over all possible final state hadrons.
- Decay rates based on Operator Product Expansion (OPE) and Heavy Quark Effective Theory (HQET)
- $\Gamma(B \to X_u \ell \nu) = \frac{G_F^2 m_b^5}{192\pi^3} |V_{ub}|^2$
  free quark decay

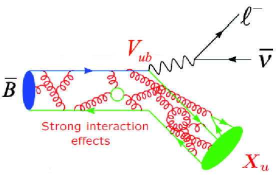
Non-perturbative corrections include parameters that need to be precisely measured to extract $|V_{ub}|$, e.g.

- Kinetic energy of b quarks, μ_π^2
- Chromomagnetic moment, μ_G^2
- Higher order terms: ρ_{LS}^3, ρ_D^3

Experimental Aspects

- $|V_{cb}| \approx 50|V_{ub}|$
- Full reco of one B
- Cut on phase space

Inclusive $B \to X_u \ell \nu$



- Sum over all possible final state hadrons.
- Decay rates based on Operator Product Expansion (OPE) and Heavy Quark Effective Theory (HQET)
- $\Gamma(B \to X_u \ell \nu) =$
  $\frac{G_F^2 m_b^5}{192\pi^3} |V_{ub}|^2 (1 - A_{\text{EW}}) A_{\text{QCD pert}} A_{\text{QCD non-pert}}$
  free quark decay

Non-perturbative corrections include parameters that need to be precisely measured to extract $|V_{ub}|$, e.g.

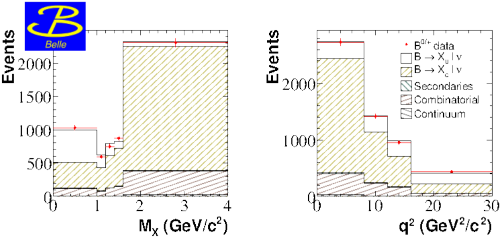
- Kinetic energy of b quarks, μ_π^2
- Chromomagnetic moment, μ_G^2
- Higher order terms: ρ_{LS}^3, ρ_D^3

Experimental Aspects

- $|V_{cb}| \approx 50|V_{ub}|$
- Full reco of one B
- Cut on phase space

- 657×10^6 $B\bar{B}$ pairs
- Multivariate methods (BDT)
- Access $\approx$ 90% phase space
- 2D fit to (M_X, q^2) for $p_\ell^* > 1$ GeV
- $N_{sig} = 1032 \pm 91$
- Leading Uncertainties: signal SF and bkg modeling.

PRL:104:021801 (2010)



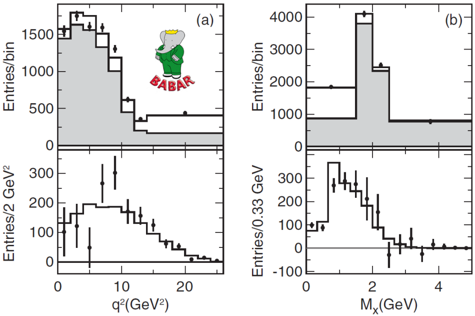
Fit projections

$$\Delta\mathcal{B}(B \to X_u \ell \nu) = (1.96 \pm 0.17_{\text{stat}} \pm 0.16_{\text{syst}}) \times 10^{-3}$$

Babar Inclusive $B \to X_u \ell \nu$

- 467×10^6 $B\bar{B}$ pairs
- Cut based method for Bkg suppression
- Measurement of $\Delta\mathcal{B}$ in several regions of phase space.
- 2D fit to (M_X, q^2) for $p_\ell^* > 1$ GeV
- $N_{sig} = 1470 \pm 130$ ($p_\ell^* > 1$ GeV^2)
- Leading Uncertainties: signal SF and bkg modeling.

PRD:86:032004 (2012)



Fit projections

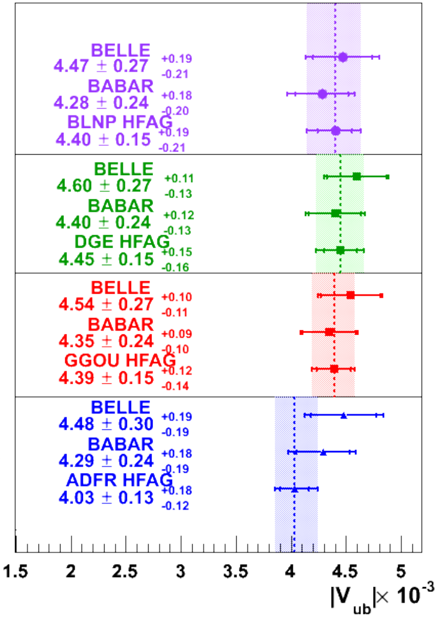
$\Delta\mathcal{B}(B \to X_u \ell \nu) = (1.80 \pm 0.13_{stat} \pm 0.15_{syst}) \times 10^{-3}$

Inclusive $|V_{ub}|$ ($p_\ell^* > 1.0$ GeV)

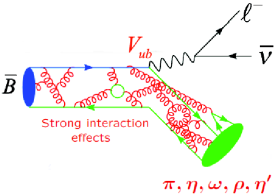
QCD calculations used to extract $|V_{ub}|$:

- BLNP
  NP B699, 335 (2004)
- DGE
  JHEP 0601, 096 (2006)
- GGOU
  JHEP 0710, 058 (2007)
- ADFR
  Eur. Phys. J. C59, 831 (2009)

Main theoretical uncertainties due to m_b, α_s, μ_π^2. May be different for the different calculations.



Exclusive $B \to X_u \ell \nu$



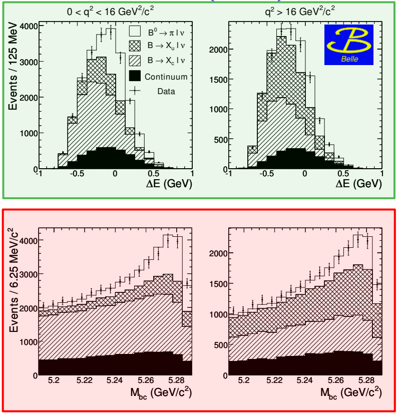
- Reconstruct a particular final state.
- Decay rates depend whether the B meson (pseudoscalar) decays into a vector or pseudoscalar light meson.

- $\frac{d\Gamma(B \to P\ell\nu)}{dq^2} = \frac{G_F^2 p_P^3}{24\pi^3} |V_{ub}|^2 |f_+(q^2)|^2$ (e.g. π, η), $|f_+(q^2)|^2$ is a form factor.
- $\frac{d\Gamma(B \to V\ell\nu)}{dq^2} = \frac{G_F^2 p_V q^2}{96\pi^3 m_B C_V^2} |V_{ub}|^2 (|H_0|^2 + |H_+|^2 + |H_-|^2)$ (e.g. ρ, ω)
- H_0, H_+, H_-, helicity functions that can be written in terms of 3 form factors
- $q^2 = (P_B - P_m)^2 = (P_\ell + P_\nu)^2$
- F.F. calculations using different methods (LQCD, LCSR, quark models)

Untagged $B \to \pi \ell \nu$

Belle Untagged

PRD83:071101 (2011)



$M_{bc} > 5.27\text{GeV}^2$

$|\Delta E| < 0.125\text{GeV}$

Fit projections

Untagged Method

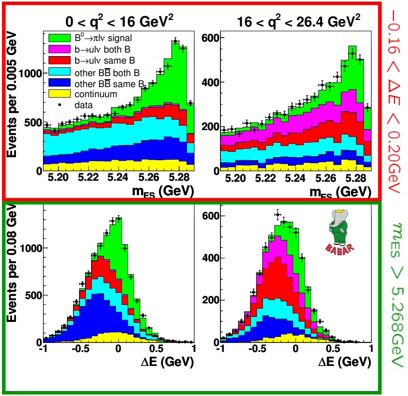
- $p_\ell^* > 1 \to 2\text{GeV}$
- High statistics but also high backgrounds
- Signal yields from fit to $(M_{bc}, \Delta E)$
  $\Delta E = E_B^* - \sqrt{S}/2$
  $M_{bc} = \sqrt{S/4 - |p_B^*|^2}$
- Leading syst : detector effect

- $\int \mathcal{L} dt = 605\text{fb}^{-1}$
- Tight neutrino selection
- Cut based technique
- 2D binned maximum likelihood fit to $(\text{M}_{\text{bc}}, \Delta\text{E})$ in 13 bins of q^2
- $\text{N}_{\text{sig}} \approx 21486$

$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu) = (1.49 \pm 0.04_{\text{stat}} \pm 0.07_{\text{syst}}) \times 10^{-4}$$

Babar Untagged $B \to \pi\ell\nu$

PRD:86:092004 (2012)

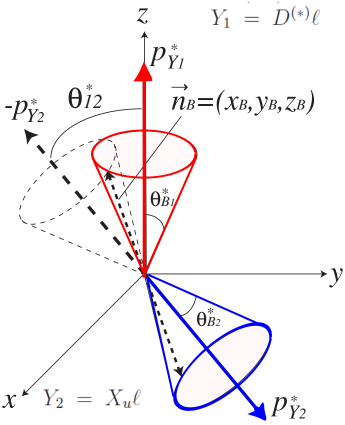


Fit projections on ΔE and m_{ES} in regions of q^2

PRD:86:092004 (2012) Loose Untagged

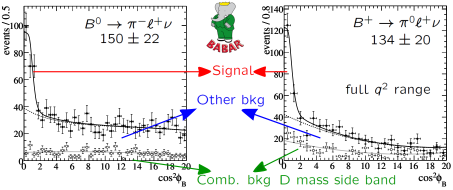
- $\int \mathcal{L}dt = 416.1\text{fb}^{-1}$
- Loose neutrino selection
- 2D binned maximum likelihood fit to $(m_{\text{ES}}, \Delta E)$ in 12 q^2 bins
- $N_{\text{sig}} = 12448 \pm 361$ (Combined π^+ and π^0)
- $\mathcal{B}(B \to \pi\ell^+\nu) =$ $(1.45 \pm 0.04_{\text{stat}} \pm 0.06_{\text{syst}}) \times 10^{-4}$ (Averaged using isospin)

Semileptonic Tag Method



- $B_{\mathrm{tag}} \to D^{(*)}\ell\nu$ with $D^{(*)}$ reconstructed in hadronic modes
- Identify two leptons $\ell^+\ell^-$
- Kinematic constraint $P_\nu^{*2} = 0 = (P_B^* - P_Y^*)^2$
- $\cos\theta_{BY} = \frac{2E_B E_Y - m_B^2 - m_Y^2}{2|p_B||p_Y|}$
- Discriminating variable: x_B^2 ($\cos^2\phi_B$)
- $x_B^2 = 1 - \frac{1}{\sin^2\theta^*_{12}}(\cos^2\theta^*_{B1} + \cos^2\theta^*_{B2} - 2\cos\theta^*_{B1}\cos\theta^*_{B2}\cos\theta^*_{12})$
- For signal $0 \leq x_B^2 \leq 1$
- Leading systematic: B_{tag} efficiency

SL Tag $B \to \pi \ell \nu$

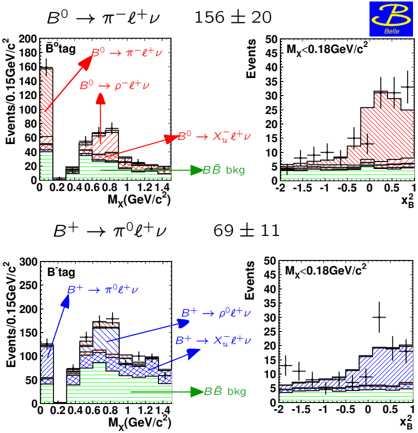


PRL101:081801 (2008) Babar

- $\int \mathcal{L}dt = 348\text{fb}^{-1}$
- Yields extracted from a fit to $\cos^2\phi_B$
- $\mathcal{B}(B^0 \to \pi^- \ell^+ \nu) = (1.38 \pm 0.21 \pm 0.07) \times 10^{-4}$
- $\mathcal{B}(B^+ \to \pi^0 \ell^+ \nu) = (0.96 \pm 0.15 \pm 0.07) \times 10^{-4}$

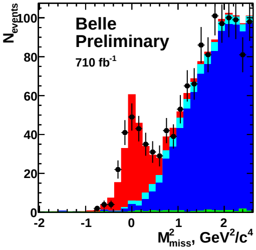
PLB648:139 (2007) Belle

- $\int \mathcal{L}dt = 253\text{fb}^{-1}$
- Yields extracted from a fit to (x_B^2, M_X)
- $\mathcal{B}(B^0 \to \pi^- \ell^+ \nu) = (1.38 \pm 0.19 \pm 0.14) \times 10^{-4}$
- $\mathcal{B}(B^+ \to \pi^0 \ell^+ \nu) = (0.77 \pm 0.14 \pm 0.08) \times 10^{-4}$

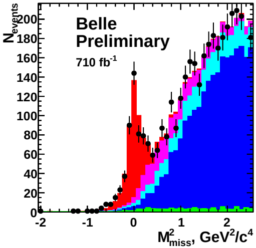


Hadronic Tag $B \to \pi\ell\nu$

$B^+ \to \pi^0\ell\nu$



$B^0 \to \pi^+\ell\nu$



Hadronic Tag Method

- Loose selection on P_ℓ
- Know kinematic and flavor of signal B
- Discriminating variable : M^2_{miss}
- Leading syst : B_{tag} eff. and shapes of bkg
- Belle uses B tagging method based on NeuroBayes [NIM A654 (2011)]

Components:

- Signal
- $B \to \rho\ell\nu$
- other $B \to X_u\ell\nu$
- $B \to X_c\ell\nu$
- $e^+e^- \to q\bar{q}$

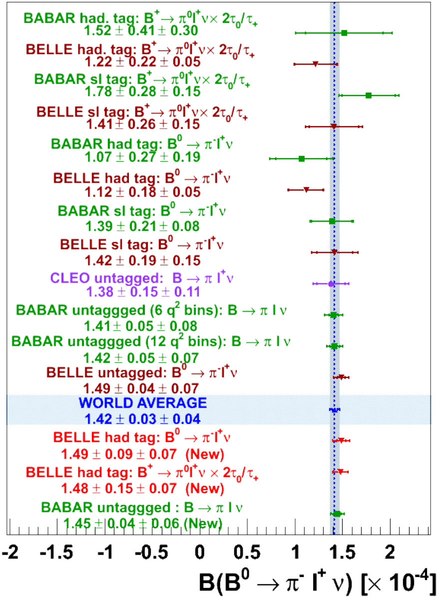
- $\int \mathcal{L}dt = 710\text{fb}^{-1}$
- E.B.M.L fit to M^2_{miss}

Signal Yields & branching ratios at Belle (old, new)

Channel	Yield*	Yield	$\mathcal{B}[10^{-4}]$
$B^+ \to \pi^0\ell\nu$	49±9	232±23	$0.80 \pm 0.08 \pm 0.04$
$B^0 \to \pi^+\ell\nu$	59±10	463±28	$1.49 \pm 0.09 \pm 0.07$

*arXiv:0812.1414v1[hep-ex], Dataset:605[fb^{-1}]

Branching Fraction Comparison $B \to \pi \ell \nu$



Isospin relation

$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu) = 2\frac{\tau_{B^0}}{\tau_{B^+}}\mathcal{B}(B^+ \to \pi^0 \ell^+ \nu)$$

World Average $\mathcal{B}(B^0 \to \pi^- \ell^+ \nu)$
$(1.42 \pm 0.03 \pm 0.04) \times 10^{-4}$

Note

- Most precise measurements to date: untagged. $\mathcal{B}(B^0 \to \pi^- \ell^+ \nu) = (1.49 \pm 0.04 \pm 0.07) \times 10^{-4}$ (Belle untagged)
- Preliminary results from Belle Had. tag are competitive with untagged results $\mathcal{B}(B^0 \to \pi^- \ell^+ \nu) = (1.49 \pm 0.09 \pm 0.07) \times 10^{-4}$ (Belle Had. tag)

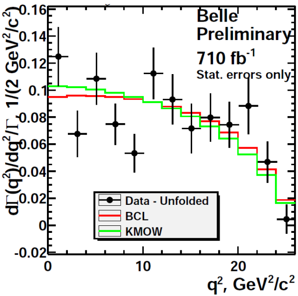
Extraction of $|V_{ub}|$ from $B \to \pi \ell \nu$

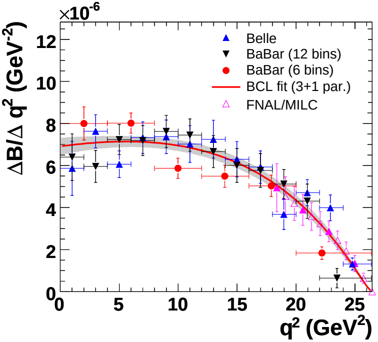
Depending on the form factor model $|V_{ub}|$ can be extracted via:

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(q^2)}{\tau_B \zeta}}$$

where $\tau_{B^0} = 1.519 \pm 0.007$ ps, $\tau_{B^+} = 1.649 \pm 0.008$ ps and ζ is given by the theoretical calculation:

$B^0 \to \pi^+ \ell \nu$





$|V_{ub}|$ can also be extracted from a simultaneous fit of the BCL [PRD79:013008 (2009)] to data and LQCD calculations. Using untagged measurements (2011) this leads to

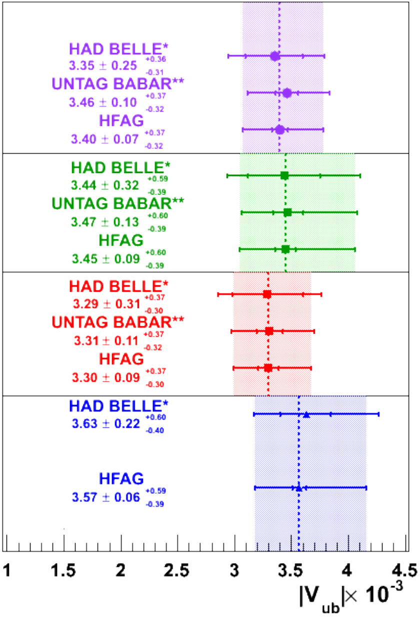
$|V_{ub}| = (3.23 \pm 0.30) \times 10^{-3}$.

$\chi^2/DOF = 58.9/31$

Exclusive $|V_{ub}|$ from $B^0 \to \pi^- \ell^+ \nu$

QCD calculations to extract $|V_{ub}|$:

- KMOW (LCSR, $q^2 < 12$ GeV^2) PRD 83 (2011) 094031
- HPQCD (Unquenched LQCD, $q^2 > 16$ GeV^2) PRD 73 (2005) 074502
- FNAL (Quenched LQCD, $q^2 > 16$ GeV^2) NPPS 140 (2005) 461
- Ball/Zwicky (LCSR, $q^2 < 16$ GeV^2) PRD 71 (2005) 014015



Error dominated by theoretical uncertainties.

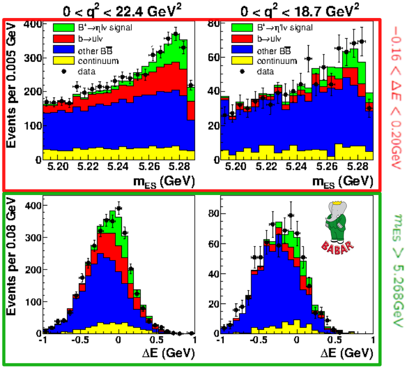
* To be submitted to PRD

** PRD:86:092004 (2012)

Inner bars are syst. err. and outer bars are theo. err.

Other Exclusive channels ($B \to \eta^{(\prime)}\ell\nu$)

PRD:86:092004 (2012)

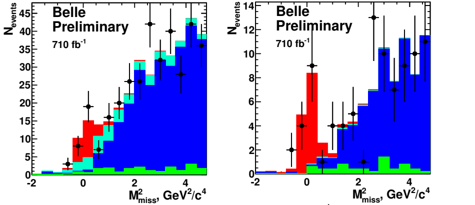


Babar Loose Untagged

$B \to \eta\ell\nu$
$N_S = 867 \pm 101$
$\mathcal{B}(B \to \eta\ell\nu)[10^4] = 0.38 \pm 0.05 \pm 0.04$

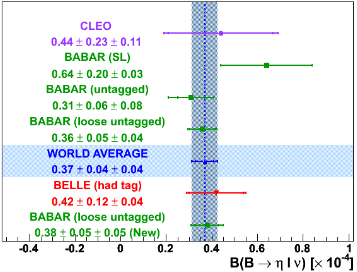
$B \to \eta'\ell\nu$
$N_S = 141 \pm 49$
$\mathcal{B}(B \to \eta'\ell\nu)[10^4] = 0.24 \pm 0.08 \pm 0.03$

Belle Hadronic Tag



$B \to \eta\ell\nu$
$N_S = 39 \pm 11$
$\mathcal{B}(B \to \eta\ell\nu)[10^4] = 0.42 \pm 0.12 \pm 0.05$

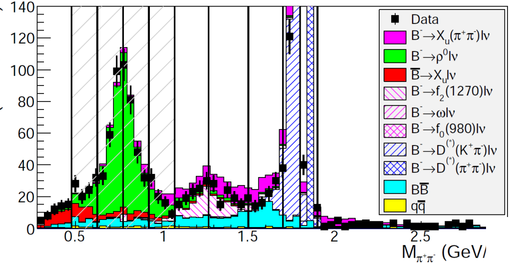
$B \to \eta'\ell\nu$
$N_S = 6.1 \pm 4.7$
$\mathcal{B}(B \to \eta'\ell\nu) < 0.57 \times 10^{-4}$ at 90% CL

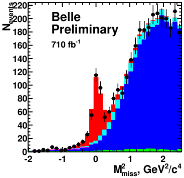


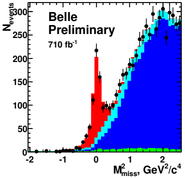
$B^+ \to \rho^0 \ell^+ \nu$ and $B^+ \to \rho^- \ell^+ \nu$

Belle Hadronic Tag

Invariant mass $M_{\pi^+\pi^-}$



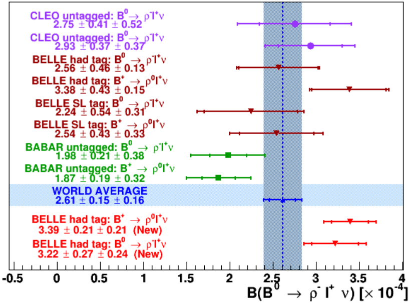




$B^0 \to \rho^- \ell^+ \nu$
$N_S = 343 \pm 28$
$\mathcal{B}(B^0 \to \rho^- \ell^+ \nu)[10^4] =$
$3.22 \pm 0.27 \pm 0.24$

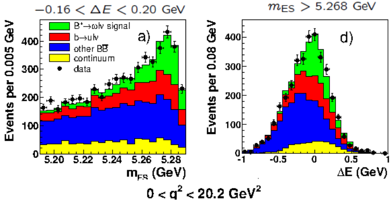
$B^+ \to \rho^0 \ell^+ \nu$
$N_S = 622 \pm 35$
$\mathcal{B}(B^+ \to \rho^0 \ell^+ \nu)[10^4] =$
$1.83 \pm 0.10 \pm 0.10$

- Smallest systematics in Had. Tag
- ρ is a wide resonance.
- Untagged measurements require harsh kinematic cuts to suppress large bkg.
- $B \to X_u \ell \nu$ bkg similar to signal, increase syst. error



$B^+ \to \omega\ell^+\nu$

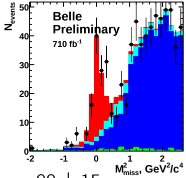
PRD:86:092004 (2012)



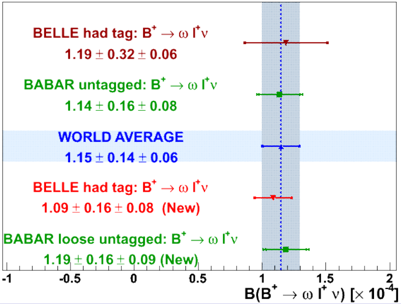
Babar Loose Untagged

N_{sig}	1861 ± 233
$\mathcal{B}(B^0 \to \omega\ell^+\nu)[10^4] =$	$1.19 \pm 0.16 \pm 0.09$

Belle Hadronic Tag



$N_{\mathrm{sig}} = 99 \pm 15$
$\mathcal{B}(B^0 \to \omega\ell^+\nu)[10^4] =$
$1.09 \pm 0.16 \pm 0.08$



The sum of all measured exclusive modes only represents ≈ 26% of the inclusive measurement, $\mathcal{B}(B \to X_u\ell\nu) = (2.33 \pm 0.22) \times 10^{-3}$ [PDG].

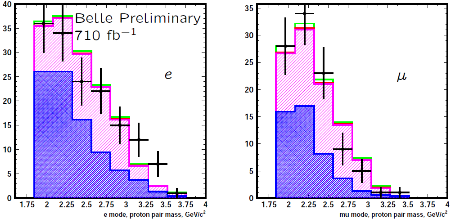
Necessary: measure higher mass

resonances to fully understand the

charmless semileptonic decay spectrum.

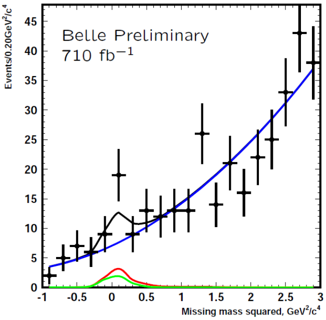
Search for $B^- \to p\bar{p}\ell^-\nu$

- Phenomenological calculation $\mathcal{B}(B^- \to p\bar{p}\ell^-\nu) = (1.04 \pm 0.38) \times 10^{-4}$ [PLB 704, 495 (2011)]
- First evidence (3.19σ) of baryon-antibaryon system in SL decays at Belle
- Hadronics Tag (NeuroBayes)



Invariant mass of $p\bar{p}$

Unbinned Maximum Likelihood Fit to $M^2_{\rm miss}$



Signal (e), Signal (μ), bkg

Yield	$\mathcal{B} \times 10^{-6}$	Upper limit $\mathcal{B}$
$18.1^{+10.5}_{-8.6}$	$5.78^{+2.42}_{-2.13} \pm 0.86$	9.6×10^{-6}, 90% CL

Total Syst. Unc. : 14.9%
Leading syst. : Signal Decay Model

Summary and Prospects

- Disagreement between inclusive and exclusive V_{ub} still present.
- Error in exclusive V_{ub} from $B \to \pi \ell \nu$ dominated by theoretical Uncertainties.
- Hadronic tag measurements are dominated by statiscal uncertainties.
- Need updated models for (ρ, ω, η) to make possible a $|V_{ub}|$ measurement.
- First evidence of baryon-antibaryon system in SL decays.
- Study higher charmless resonances with $m_{X_u} > 1$ GeV.

Back Up Slides

Systematic Uncertainties Inclusive $|V_{ub}|$ Belle

TABLE I. Uncertainties in the partial charmless semileptonic branching fraction (in percent).

$p_\ell^{*B} > 1.0$ GeV	$\Delta\mathcal{B}/\mathcal{B}$ (%)
$\mathcal{B}(D^{(*)}\ell\nu)$	1.2
$(D^{(*)}\ell\nu)$ form factors	1.2
$\mathcal{B}(D^{**}e\nu)$ & form factors	0.2
$B \to X_u\ell\nu$ (SF)	3.6
$B \to X_u\ell\nu$ ($g \to s\bar{s}$)	1.5
$\mathcal{B}(B \to \pi/\rho/\omega\ell\nu)$	2.3
$\mathcal{B}(B \to \eta, \eta'\ell\nu)$	3.2
$\mathcal{B}(B \to X_u\ell\nu)$ unmeasured	2.9
Cont./Comb.	1.8
Sec./Fakes/Fit.	1.0
PID/Reconstruction	3.1
BDT	3.1
Systematics	8.1
Statistics	8.8

PRL:104:021801 (2010)

Systematic Uncertainties Inclusive $|V_{ub}|$ Babar

Phase space restriction	$M_X < 1.55$ GeV	$M_X < 1.70$ GeV	$P_+ < 0.66$ GeV	$M_X < 1.70$ GeV, $q^2 > 8$ GeV^2	$M_X - q^2$	$p^*_\ell > 1.0$ GeV	$p^*_\ell > 1.3$ GeV
Data statistical uncertainty	7.1	8.9	8.9	8.0	7.1	9.4	8.8
MC statistical uncertainty	1.3	1.3	1.3	1.6	1.1	1.1	1.2
Detector effects							
Track efficiency	0.4	1.0	1.1	1.7	0.7	1.2	1.0
Photon efficiency	1.3	2.1	4.0	0.7	1.0	0.9	0.9
π^0 efficiency	1.2	0.9	1.1	0.9	0.9	2.9	1.1
Particle identification	1.9	2.4	3.3	2.9	2.3	2.9	2.2
K_L production/detection	0.9	1.3	1.1	2.1	1.6	1.3	0.6
K_S production/detection	0.8	1.4	1.7	2.1	1.2	1.3	0.3
Signal simulation							
Shape function parameters	2.0	1.3	1.2	0.7	5.4	6.4	6.6
Shape function form	1.2	1.6	2.6	1.2	1.5	1.1	1.1
Exclusive $\bar{B} \to X_u \ell \bar{\nu}$	0.6	1.3	1.6	0.7	1.9	5.3	3.4
$s\bar{s}$ production	1.2	1.6	1.1	1.0	2.7	3.1	2.4
Background simulation							
B semileptonic branching ratio	0.9	1.4	1.5	1.4	1.0	0.8	0.7
D decays	1.1	0.6	1.1	0.6	1.1	1.6	1.5
$B \to D\ell\nu$ form factor	0.5	0.5	1.3	0.4	0.4	0.1	0.2
$B \to D^*\ell\nu$ form factor	0.7	0.7	0.9	0.7	0.7	0.7	0.7
$B \to D^{**}\ell\nu$ form factor	0.8	0.9	1.3	0.4	0.9	1.0	0.3
$B \to D^{**}$ reweighting	0.5	1.4	1.5	1.0	1.9	0.4	1.5
m_{ES} background subtraction							
m_{ES} background subtraction	2.0	2.7	1.9	2.6	1.9	2.0	2.5
Combinatorial backg.	1.8	1.8	2.6	1.8	1.0	2.1	0.5
Normalization							
Total semileptonic BF	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Total systematic uncertainty	5.5	6.7	8.3	6.6	8.4	11.0	9.3
Total experimental uncertainty	9.0	11.1	12.2	10.4	11.0	14.4	12.8

PRD:86:032004 (2012)

Inclusive $|V_{ub}|$ in kinematic regions Babar

QCD calculation	Phase space region	$\Delta\Gamma_{\text{theory}}(\text{ps}^{-1})$	$\lvert V_{ub}\rvert(10^{-3})$
BLNP	$M_X \leq 1.55$ GeV	$39.3^{+4.7}_{-4.3}$	$4.17 \pm 0.15 \pm 0.12^{+0.2}_{-0.2}$
	$M_X \leq 1.70$ GeV	$46.1^{+5.0}_{-4.4}$	$3.97 \pm 0.17 \pm 0.14^{+0.2}_{-0.2}$
	$P_+ \leq 0.66$ GeV	$38.3^{+4.7}_{-4.3}$	$4.02 \pm 0.18 \pm 0.16^{+0.2}_{-0.2}$
	$M_X \leq 1.70$ GeV, $q^2 \geq 8$ GeV^2	$23.8^{+3.0}_{-2.4}$	$4.25 \pm 0.19 \pm 0.13^{+0.2}_{-0.2}$
	$M_X - q^2$, $p^*_\ell > 1.0$ GeV	$62.0^{+6.2}_{-5.0}$	$4.28 \pm 0.15 \pm 0.18^{+0.1}_{-0.2}$
	$p^*_\ell > 1.0$ GeV	$62.0^{+6.2}_{-5.0}$	$4.30 \pm 0.18 \pm 0.21^{+0.1}_{-0.2}$
	$p^*_\ell > 1.3$ GeV	$52.8^{+5.3}_{-4.3}$	$4.29 \pm 0.18 \pm 0.20^{+0.1}_{-0.2}$
DGE	$M_X \leq 1.55$ GeV	$35.3^{+3.3}_{-3.5}$	$4.40 \pm 0.16 \pm 0.12^{+0.2}_{-0.1}$
	$M_X \leq 1.70$ GeV	$42.0^{+4.8}_{-4.8}$	$4.16 \pm 0.18 \pm 0.14^{+0.2}_{-0.2}$
	$P_+ \leq 0.66$ GeV	$36.9^{+5.5}_{-5.8}$	$4.10 \pm 0.19 \pm 0.17^{+0.3}_{-0.2}$
	$M_X \leq 1.70$ GeV, $q^2 \geq 8$ GeV^2	$24.4^{+2.4}_{-2.0}$	$4.19 \pm 0.19 \pm 0.12^{+0.1}_{-0.1}$
	$M_X - q^2$, $p^*_\ell > 1.0$ GeV	$58.7^{+3.5}_{-3.2}$	$4.40 \pm 0.16 \pm 0.18^{+0.1}_{-0.1}$
	$p^*_\ell > 1.0$ GeV	$58.7^{+3.5}_{-3.2}$	$4.42 \pm 0.19 \pm 0.23^{+0.1}_{-0.1}$
	$p^*_\ell > 1.3$ GeV	$50.4^{+3.3}_{-3.0}$	$4.39 \pm 0.19 \pm 0.20^{+0.1}_{-0.1}$
GGOU	$M_X \leq 1.55$ GeV	$41.0^{+4.6}_{-3.8}$	$4.08 \pm 0.15 \pm 0.11^{+0.2}_{-0.2}$
	$M_X \leq 1.70$ GeV	$46.8^{+4.2}_{-3.6}$	$3.94 \pm 0.17 \pm 0.14^{+0.1}_{-0.1}$
	$P_+ \leq 0.66$ GeV	$44.0^{+8.6}_{-6.3}$	$3.75 \pm 0.17 \pm 0.15^{+0.3}_{-0.3}$
	$M_X \leq 1.70$ GeV, $q^2 \geq 8$ GeV^2	$24.7^{+3.2}_{-2.4}$	$4.17 \pm 0.18 \pm 0.12^{+0.2}_{-0.2}$
	$M_X - q^2$, $p^*_\ell > 1.0$ GeV	$60.2^{+3.0}_{-2.5}$	$4.35 \pm 0.16 \pm 0.18^{+0.0}_{-0.1}$
	$p^*_\ell > 1.0$ GeV	$60.2^{+3.0}_{-2.5}$	$4.36 \pm 0.19 \pm 0.23^{+0.0}_{-0.1}$
	$p^*_\ell > 1.3$ GeV	$51.8^{+2.8}_{-2.3}$	$4.33 \pm 0.18 \pm 0.20^{+0.1}_{-0.1}$
ADFR	$M_X \leq 1.55$ GeV	$47.1^{+5.2}_{-4.3}$	$3.81 \pm 0.14 \pm 0.11^{+0.1}_{-0.2}$
	$M_X \leq 1.70$ GeV	$52.3^{+5.4}_{-4.5}$	$3.73 \pm 0.16 \pm 0.13^{+0.1}_{-0.1}$
	$P_+ \leq 0.66$ GeV	$48.9^{+5.6}_{-4.6}$	$3.56 \pm 0.16 \pm 0.15^{+0.1}_{-0.1}$
	$M_X \leq 1.70$ GeV, $q^2 \geq 8$ GeV^2	$30.9^{+3.0}_{-2.5}$	$3.74 \pm 0.16 \pm 0.11^{+0.1}_{-0.1}$
	$M_X - q^2$, $p^*_\ell > 1.0$ GeV	$62.0^{+5.7}_{-5.0}$	$4.29 \pm 0.15 \pm 0.18^{+0.1}_{-0.1}$
	$p^*_\ell > 1.0$ GeV	$62.0^{+5.7}_{-5.0}$	$4.30 \pm 0.19 \pm 0.23^{+0.1}_{-0.1}$
	$p^*_\ell > 1.3$ GeV	$53.3^{+5.1}_{-4.4}$	$4.27 \pm 0.18 \pm 0.19^{+0.1}_{-0.1}$

Systematic Uncertainties Semileptonic Tag Belle

Table: Summary of systematic errors (%) for $\mathcal{B}(B^0 \to \pi^-/\rho^-\ell^+\nu)$.

Source	$B^0 \to \pi^-\ell^+\nu$ q^2 interval (GeV$^2/c^2$) $q^2 < 8$	$8-16$	≥ 16	< 16	all	$B^0 \to \rho^-\ell^+\nu$ q^2 interval (GeV$^2/c^2$) $q^2 < 8$	$8-16$	≥ 16	< 16	all
Tracking efficiency	1	1	1	1	1	1	1	1	1	1
π^0 reconstruction	–	–	–	–	–	2	2	2	2	2
Lepton identification	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
Kaon identification	2	2	2	2	2	2	2	2	2	2
$D^*\ell\nu$ calibration	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3
$Br(X_u\ell\nu)$ in the fitting	0.8	2.4	1.8	1.6	1.4	4.8	3.9	23.8	1.9	7.1
$B\bar{B}$ background shape	1.1	2.2	2.8	1.2	1.3	3.8	2.9	17.0	3.0	6.1
$Br(D^{**}\ell\nu)$	1.0	1.5	0.2	1.2	0.9	0.5	0.3	2.5	0.3	0.8
K_L^0 production rate	0.1	0.3	0.4	0.2	0.3	1.0	0.7	2.9	0.8	1.3
$N_{B\overline{B}}$	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
f_+/f_0	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
χ_d	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
exp. total	10.4	10.9	10.8	10.5	10.5	12.1	11.5	31.3	11.1	14.1
FF for signal	0.7	3.8	0.9	2.2	1.8	6.1	3.5	6.8	4.3	3.6
FF for cross-feed	1.8	2.1	1.5	1.9	1.4	0.5	0.7	2.4	0.6	1.0
FF total	1.9	4.3	1.7	2.9	2.3	6.1	3.6	7.2	4.3	3.7

Systematic Uncertainties Semileptonic Tag Babar

Table: Summary of systematic errors (%) for $\mathcal{B}(B^+ \to \pi^0/\rho^0\ell^+\nu)$.

Source	$B^+ \to \pi^0\ell^+\nu$ q^2 interval (GeV$^2/c^2$)					$B^+ \to \rho^0\ell^+\nu$ q^2 interval (GeV$^2/c^2$)				
	$q^2 < 8$	$8-16$	≥ 16	< 16	all	$q^2 < 8$	$8-16$	≥ 16	< 16	all
Tracking efficiency	–	–	–	–	–	2	2	2	2	2
π^0 reconstruction	2	2	2	2	2	–	–	–	–	–
Lepton identification	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
Kaon identification	–	–	–	–	–	4	4	4	4	4
$D^*\ell\nu$ calibration	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
$Br(X_u\ell\nu)$ in the fitting	0.2	3.1	3.0	2.1	1.2	2.0	3.7	20.0	3.0	6.6
$B\bar{B}$ background shape	1.9	5.5	2.7	4.3	3.7	5.3	4.3	16.3	1.5	2.8
$Br(D^{**}\ell\nu)$	1.3	0.8	0.8	0.9	0.9	0.2	1.6	3.0	0.9	1.4
K_L^0 production rate	0.3	1.1	0.6	0.8	0.8	0.3	0.2	1.9	0.1	0.4
$N_{B\overline{B}}$	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
f_+/f_0	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
exp. total	10.1	11.8	10.7	11.0	10.7	12.1	12.2	28.1	11.2	12.9
FF for signal	1.2	0.5	1.3	0.3	0.2	2.1	7.1	3.9	3.7	3.5
FF for cross-feed	0.7	0.8	0.6	0.8	0.6	3.3	1.1	1.0	1.5	1.2
FF total	1.4	0.9	1.4	0.8	0.6	3.9	7.2	4.0	4.0	3.7

Systematic Uncertainties Semileptonic Tag Babar

Table: Summary of systematic errors (%) for $\mathcal{B}(B^+ \to \pi^0 \ell^+ \nu)$ & $\mathcal{B}(B^0 \to \pi^- \ell^+ \nu)$.

	$\mathcal{B}(B^+ \to \pi^0 \ell^+ \nu)$	$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu)$
π^0 reconstruction	3%	–
ℓ identification	3%	3%
Tag efficiency	1.7%	0.5%
Track Efficiency	0.36%	0.72%
$B\bar{B}$ pair counting	1.1%	1.1%
Final State radiation	1.2%	1.2%
$\Upsilon(4S) \to B\bar{B}$ fraction	1.4%	1.4%
FF and BF	4%	3.8%
Total	6.5%	5.4%

Exclusive Untagged Babar

TABLE III. Values of signal yields, $\Delta\mathcal{B}(q^2)$ and their relative uncertainties (%) for $B^0 \to \pi^- \ell^+ \nu$ and $B^+ \to \pi^0 \ell^+ \nu$ decays.

Decay mode	$\pi^- \ell^+ \nu$				$\pi^0 \ell^+ \nu$			
q^2 range (GeV^2)	$q^2 < 12$	$q^2 < 16$	$q^2 > 16$	$0 < q^2 < 26.4$	$q^2 < 12$	$q^2 < 16$	$q^2 > 16$	$0 < q^2 < 26.4$
Unfolded yield	5604.1	6982.4	2314.2	9296.5	2231.7	2666.7	537.3	3204.1
$\Delta\mathcal{B}(q^2)$ (10^{-4})	0.83	1.07	0.40	1.47	0.46	0.61	0.16	0.77
Statistical error	4.3	3.8	6.7	3.5	6.6	5.3	17.8	5.7
Detector effects	3.4	3.5	3.2	2.8	2.9	2.8	3.0	2.6
Continuum bkg	0.4	0.4	1.4	0.4	1.2	0.8	7.1	1.1
$b \to u\ell\nu$ bkg	1.6	1.4	2.1	1.3	1.7	1.5	5.9	1.9
$b \to c\ell\nu$ bkg	0.6	0.5	0.6	0.5	0.6	0.4	1.0	0.4
Other effects	2.2	2.1	2.1	2.1	2.1	2.1	2.5	2.0
Total uncertainty	6.2	5.8	8.1	5.1	7.9	6.5	20.4	6.9

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Exclusive Untagged Babar

TABLE IV. Values of signal yields, $\Delta\mathcal{B}(q^2)$ and their relative uncertainties (%) for combined $B \to \pi\ell^+\nu$, $B^+ \to \omega\ell^+\nu$, combined $B^+ \to \eta\ell^+\nu$ ($\gamma\gamma$ and 3π decay channels) and $B^+ \to \eta'\ell^+\nu$ decays.

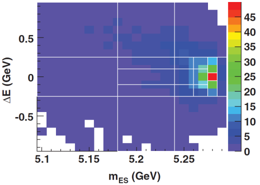
Decay mode	Combined $\pi\ell^+\nu$				$\omega\ell^+\nu$	$\eta\ell^+\nu$	$\eta'\ell^+\nu$
q^2 range (GeV^2)	$q^2 < 12$	$q^2 < 16$	$q^2 > 16$	$0 < q^2 < 26.4$	$0 < q^2 < 20.2$	$0 < q^2 < 22.4$	$0 < q^2 < 18.7$
Unfolded yield	7805.4	9618.9	2829.0	12447.9	1860.8	867.3	141.1
$\Delta\mathcal{B}(q^2)$ (10^{-4})	0.83	1.08	0.37	1.45	1.19	0.38	0.24
Statistical error	3.6	3.2	5.8	3.0	13.0	13.7	34.9
Detector effects	3.7	3.8	3.5	3.1	3.9	9.8	7.7
Continuum bkg	0.4	0.6	3.3	0.6	3.2	...	5.8
$b \to u\ell\nu$ bkg	1.6	1.4	4.0	1.4	5.1	8.4	4.9
$b \to c\ell\nu$ bkg	0.4	0.4	0.4	0.3	1.0	2.1	3.3
Other effects	1.8	1.7	1.5	1.6	1.8	1.8	2.4
Total uncertainty	5.8	5.5	8.7	4.9	15.0	19.0	36.7

PRD:86:092004 (2012)

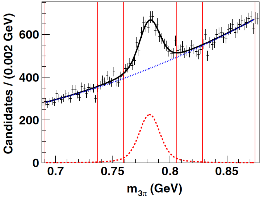
Untagged $B \to \omega \ell \nu$ Babar (PRD:87:032004(2013))

Distribution of $(\Delta E, m_{ES})$

for true ω signal



ω invariant mass in data



Untagged Babar

- 467 million $B\bar{B}$
- Combinatoric bkg is subtracted using a fit to the mass side band data.
- Neural network signal selection.
- Fit to $m_{ES}, \Delta E$ in 5 bins of q^2 of different size.
- Leading syst: signal form factors.
- $m_{3\pi}$ introduces a systematic of 1.5%

Signal Yields & branching ratios

Channel	Yield	$\mathcal{B}[10^{-4}]$
$B^+ \to \omega \ell \nu$	1125±131	$1.21 \pm 0.14 \pm 0.08$

Exclusive Had Tag Belle (To be submitted to PRD)

Source of uncertainty	Assigned systematic uncertainty for $\bar{B} \to X_u \ell^- \bar{\nu}_\ell$ decays				
X_u	π^+	π^0	ρ^+	ρ^0	$\omega(3\pi)$
Detector Simulation:					
Track reconstruction	0.34	-	0.34	0.68	0.68
π^0 reconstruction	-	2.0	2.0	-	2.0
Lepton identification	1.0	1.0	1.0	1.0	1.0
Kaon veto	0.9	-	1.0	2.0	2.0
Continuum description	1.0	0.5	0.5	0.7	0.0
X_u cross feed	0.9	-	5.0	2.4	-
Tag calibration	4.5	4.2	4.5	4.2	4.2
Combined	4.9	4.8	7.2	5.4	5.2
Form Factor Shapes:	1.1	1.9	1.7	1.3	3.8
Total systematic error	5.0	5.1	7.4	5.6	6.4