



Measurement of $|V_{ub}|$ at Belle

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for

Belle Collaboration



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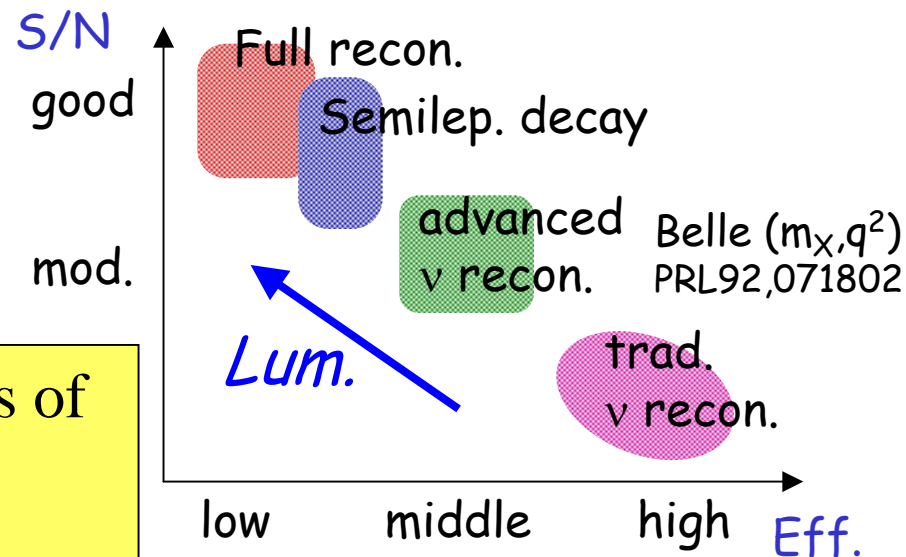
Introduction

■ $|V_{ub}|$ measurement

- ▶ Crucial to test the standard model of the CP violation.
- ▶ Both inclusive/exclusive $B \rightarrow X_u l \nu$ decays are useful.

■ Belle explores B tagging technique to extract $B \rightarrow X_u l \nu$ in good quality.

- ▶ Good signal-to-noise
- ▶ Sufficient statistics



In this talk, we report measurements of

■ **Inclusive $B \rightarrow X_u l \nu$**

with fully reconstructed tag.

■ **Exclusive $B \rightarrow X_u l \nu$**

with semileptonic decay tag.

with 140fb^{-1} (152M $B\bar{B}$)
Results are preliminary

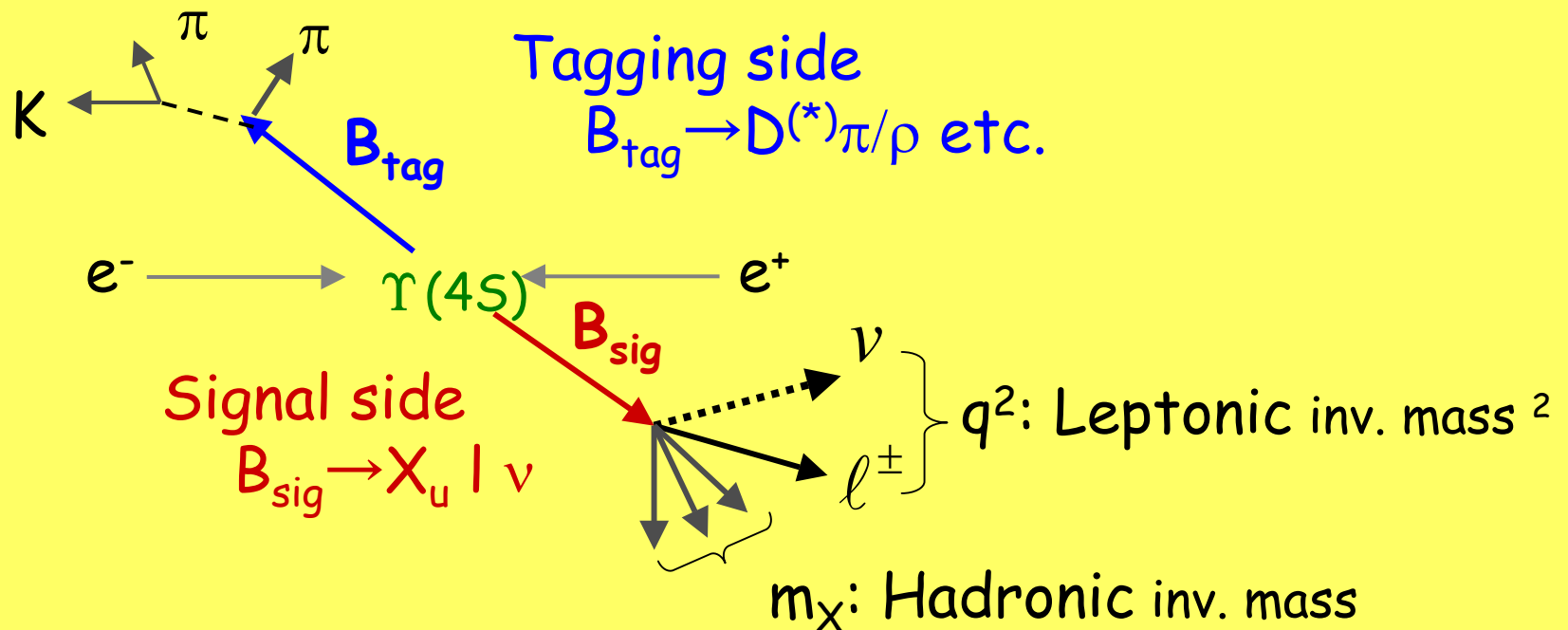
Inclusive $B \rightarrow X_u l \nu$ w/ Fully Reconstructed Tag

■ Tagging side:

- ▶ Full reconstruction of B_{tag} using hadronic decay modes.

■ Signal side:

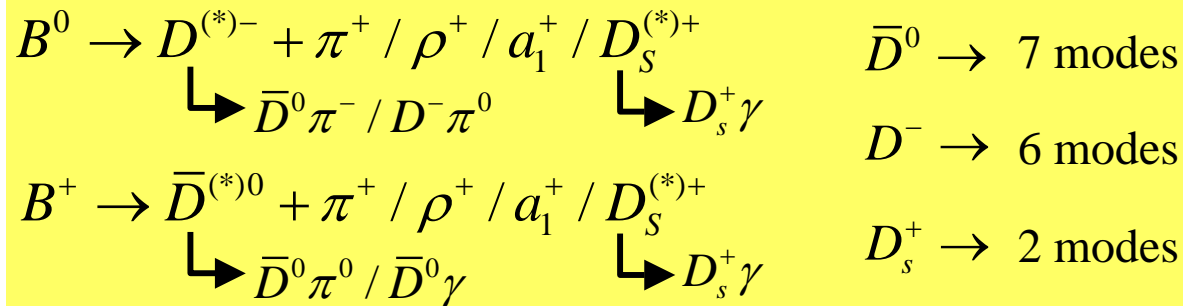
- ▶ Lepton Detection
- ▶ Neutrino reconstruction using $P_{\text{miss}}, E_{\text{miss}}$.
- ▶ Reconstruction of (m_X, q^2)



Full Reconstruction of B_{tag}

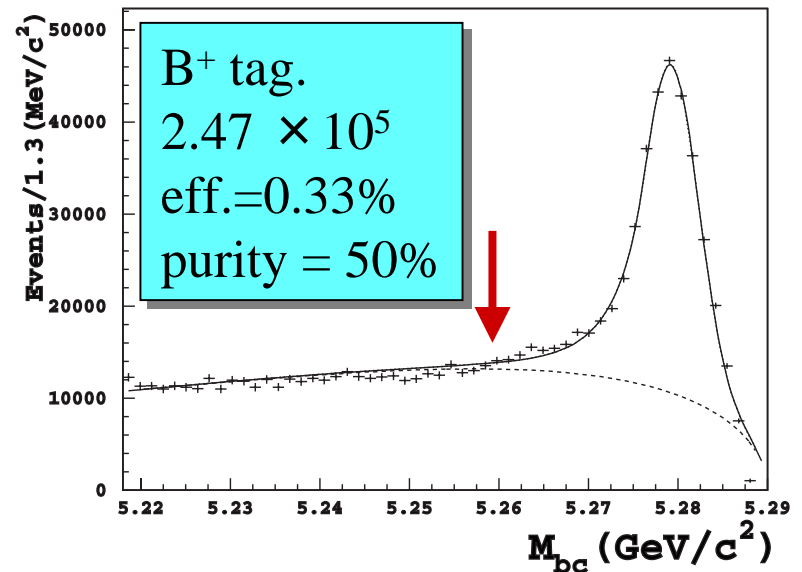
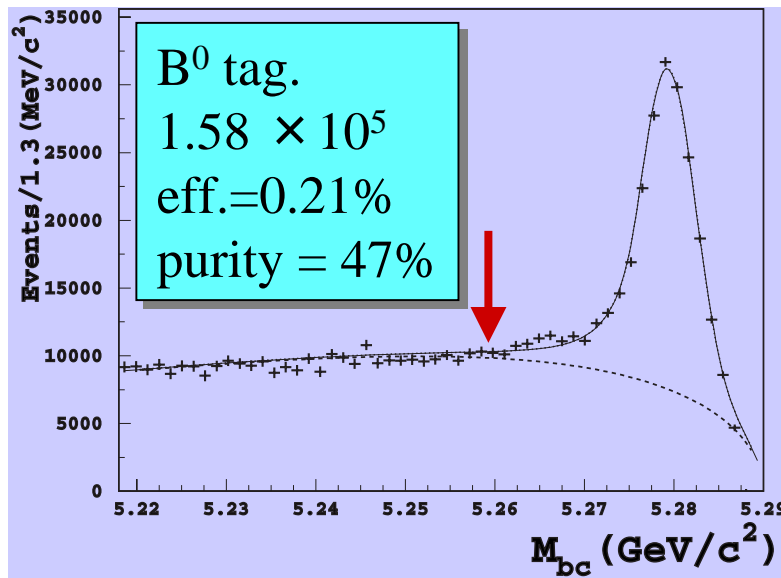
Inclusive $B \rightarrow X_u l \nu$

Reconstructed modes (180 in total)



M_{bc} (beam constrained mass) distribution

140fb⁻¹ data



2004/8/17 Signal region: $M_{\text{bc}} > 5.26 \text{ GeV}/c^2$, $-0.2 \text{ GeV} < \Delta E < 0.05 \text{ GeV}$

Reconstruction of Signal Side

Inclusive $B \rightarrow X_u l \nu$

Semileptonic lepton selection

- Lepton momentum $P_l > 1.0 \text{ GeV}/c$
- Lab. angle $26 \sim 140 \text{ deg.}$
- + J/ ψ veto, conversion veto etc.

Reduction of $b \rightarrow c$ background

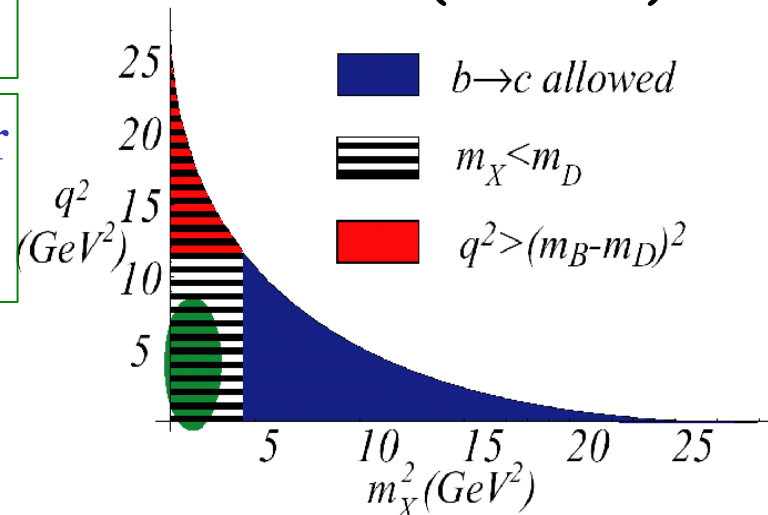
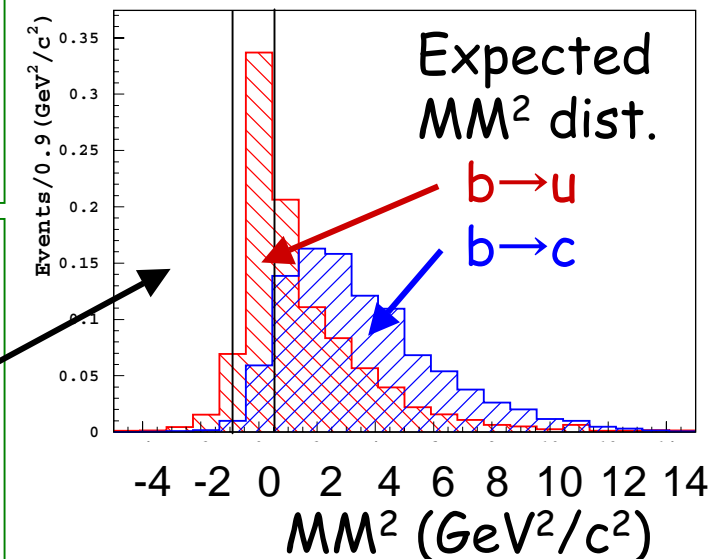
- Number of leptons $N_l = 1$
- Total net charge $\sum Q_i = 0$
- Missing mass $-1.0 < MM^2 < 0.5 \text{ GeV}^2$
- Missing mom. Direction $\cos \theta_{MM} < 0.95$
- Number of kaons $N_{K^+} = N_{K^S} = 0$

Phase space cut to minimize theory error

$$m_X < 1.7 \text{ GeV}/c^2, q^2 > 8 \text{ GeV}^2$$

✱ same as our previous (m_X, q^2) measurement with simulated annealing [PRL 92, 071802 (2004)]

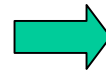
→ Normalization to $B \rightarrow X l \nu$



Signal Yield Extraction

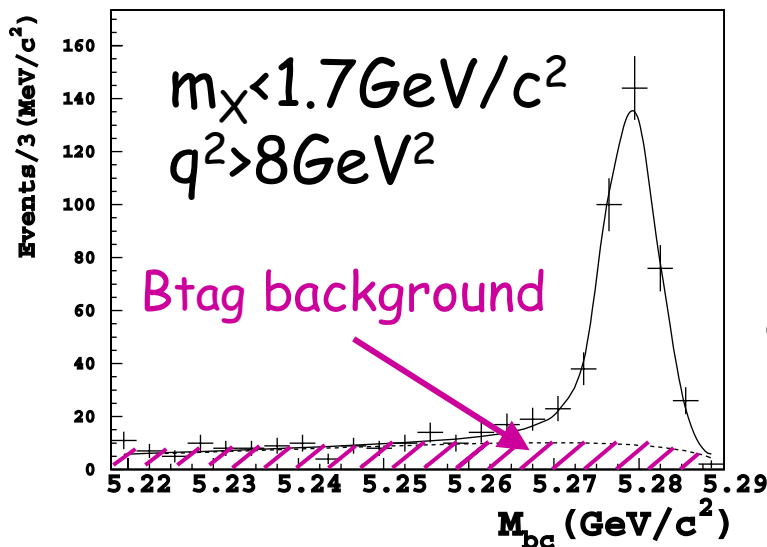
Inclusive $B \rightarrow X_u l \nu$

- Fit M_{bc} distribution in each m_X region with Gaussian+'Argus' to subtract the combinatorial background in the B_{tag} sample.
- Fit the obtained m_X distribution with expected $b \rightarrow u$ and $b \rightarrow c$ distribution.



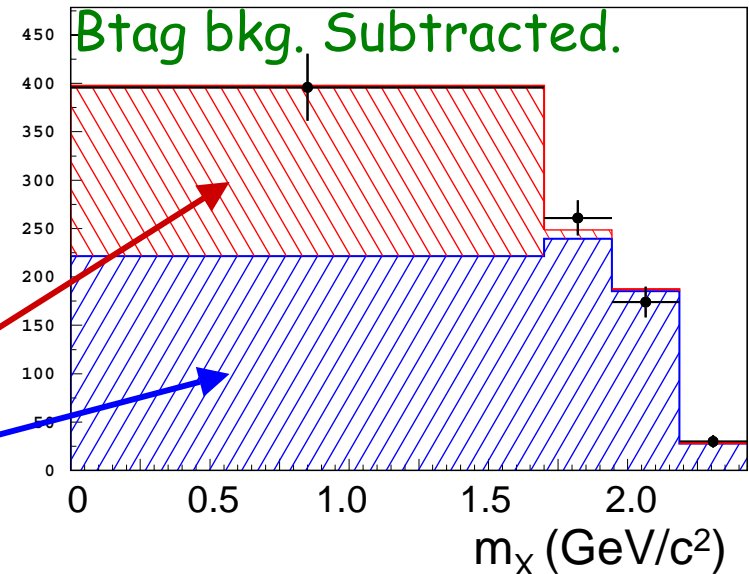
$$N_{b \rightarrow u} = 174 \pm 26$$

M_{bc} distribution for each m_X region



m_X distribution with B_{tag} bkg. Subtracted.

Expected dist. of
 $b \rightarrow u$
 $b \rightarrow c$



- The number of semileptonic leptons is extracted by similar fitting on M_{bc} before the $b \rightarrow u$ selection cut.



$$N_{sl} = (5.07 \pm 0.4) \times 10^4$$

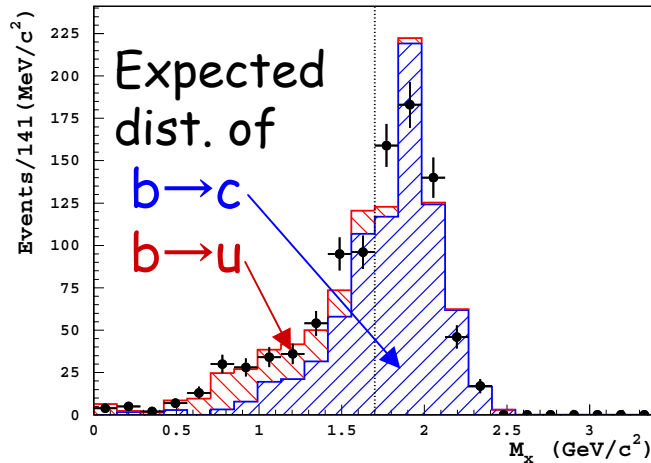
Event Distribution in m_X and q^2

Inclusive $B \rightarrow X_u l \nu$

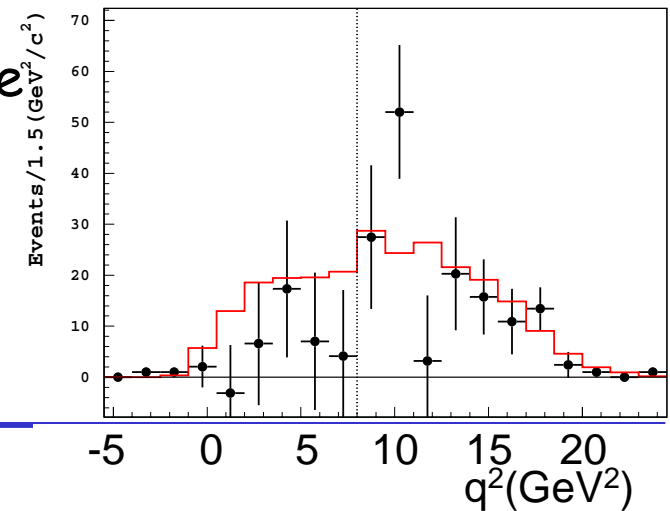
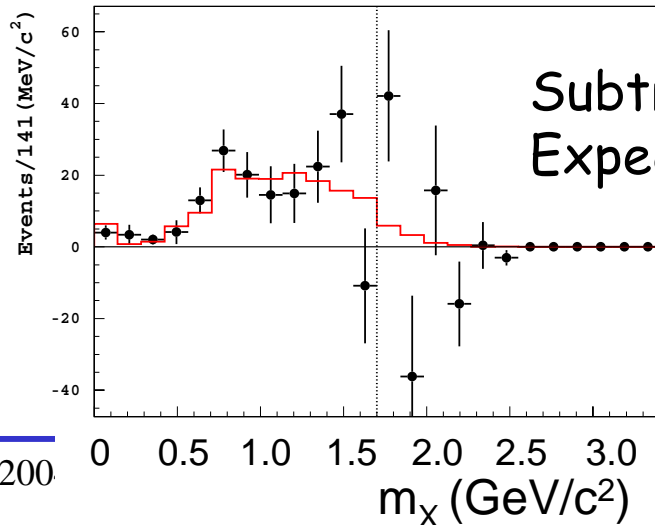
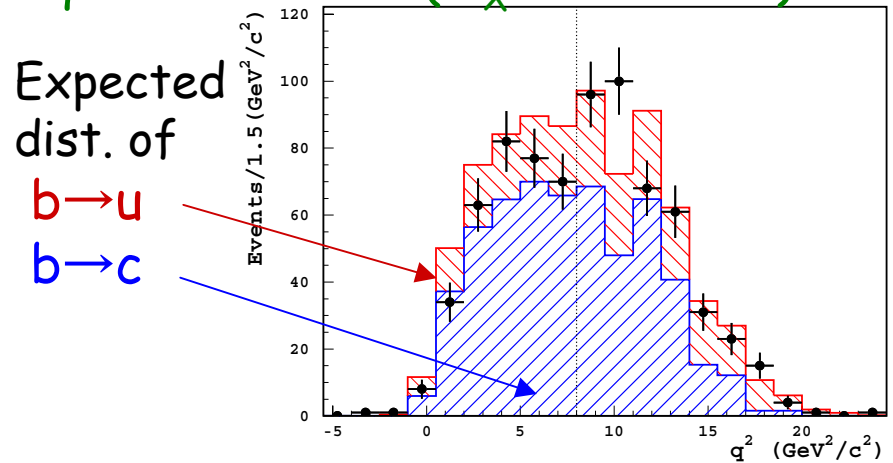
- Event distribution in m_X and q^2 with the normalization fixed to the fitting with the coarse bin.

140fb⁻¹

m_X distribution ($q^2 > 8 \text{ GeV}^2$)



q^2 distribution ($m_X > 1.7 \text{ GeV}/c^2$)



Partial Branching Fraction

Inclusive $B \rightarrow X_u l \nu$

Relative partial branching fraction

$$\frac{\Delta B(B \rightarrow X_u l \nu)}{B(B \rightarrow X l \nu)} = \frac{N_{b \rightarrow u}}{N_{sl}} \times F \times \frac{1}{\mathcal{E}_{sel}^{b \rightarrow u}} \times \frac{\mathcal{E}_{frec}^{sl}}{\mathcal{E}_{frec}^{b \rightarrow u}} \times \frac{\mathcal{E}_l^{sl}}{\mathcal{E}_l^{b \rightarrow u}}$$

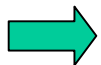
Corrections:

- Unfolding the m_X/q^2 resol. 0.984 ± 0.014
- $b \rightarrow u$ selection efficiency: 0.274
- Full recon. efficiency ratio: $\left. \begin{array}{l} \\ \end{array} \right\} 0.75 \pm 0.048$
- Fraction of semileptonic leptons with $Pl > 1.0 \text{ GeV}/c$

Partial branching fraction

$$Br(B \rightarrow X l \nu) = 0.1073 \pm 0.0028 \quad (\text{PDG2004})$$

140fb⁻¹ preliminary



$$\Delta B(B \rightarrow X_u l \nu) = [0.99 \pm 0.15 \pm 0.18 \pm 0.04 \pm 0.07] \times 10^{-3}$$

stat. syst. $b \rightarrow u$ $b \rightarrow c$

$m_X < 1.7 \text{ GeV}/c^2, q^2 > 8 \text{ GeV}^2$

$|V_{ub}|$ Determination

Inclusive $B \rightarrow X_u \ell \nu$

- Extrapolation to the total br.

$$B(B \rightarrow X_u \ell \nu) = \Delta B(B \rightarrow X_u \ell \nu) / f_u$$

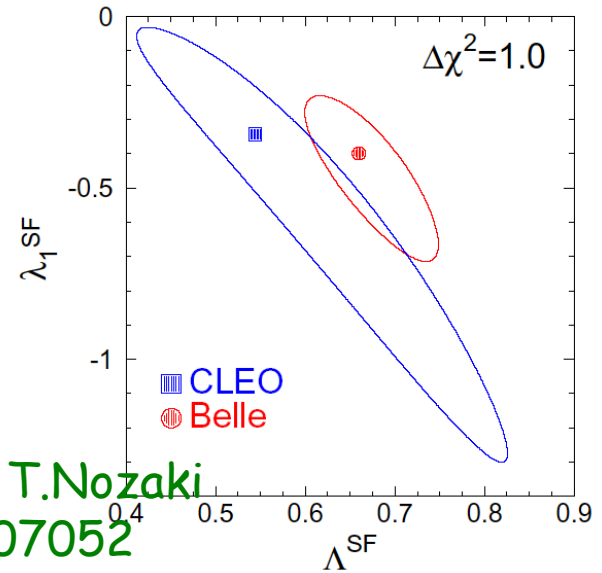
- New determination of b-quark shape function (SF) parameters from Belle's $B \rightarrow X_s \gamma$ photon spectrum.

+ Higher order correction (FN \rightarrow BLL)

+ Contribution from sub-leading SF + W.A.

$$f_u = 0.294 \pm 0.044$$

A.Limosani, T.Nozaki
Hep-ph/0407052



➔ $B(B \rightarrow X_u \ell \nu) = [3.37 \pm 0.50 \pm 0.60 \pm 0.14 \pm 0.24 \pm 0.50] \times 10^{-3}$

from f_u error

PDG formula $|V_{ub}| = 0.00424 \left[\frac{B(B \rightarrow X_u \ell \nu) 1.61 ps}{0.002 \tau_B} \right]^{1/2}$ +latest HQ parameters

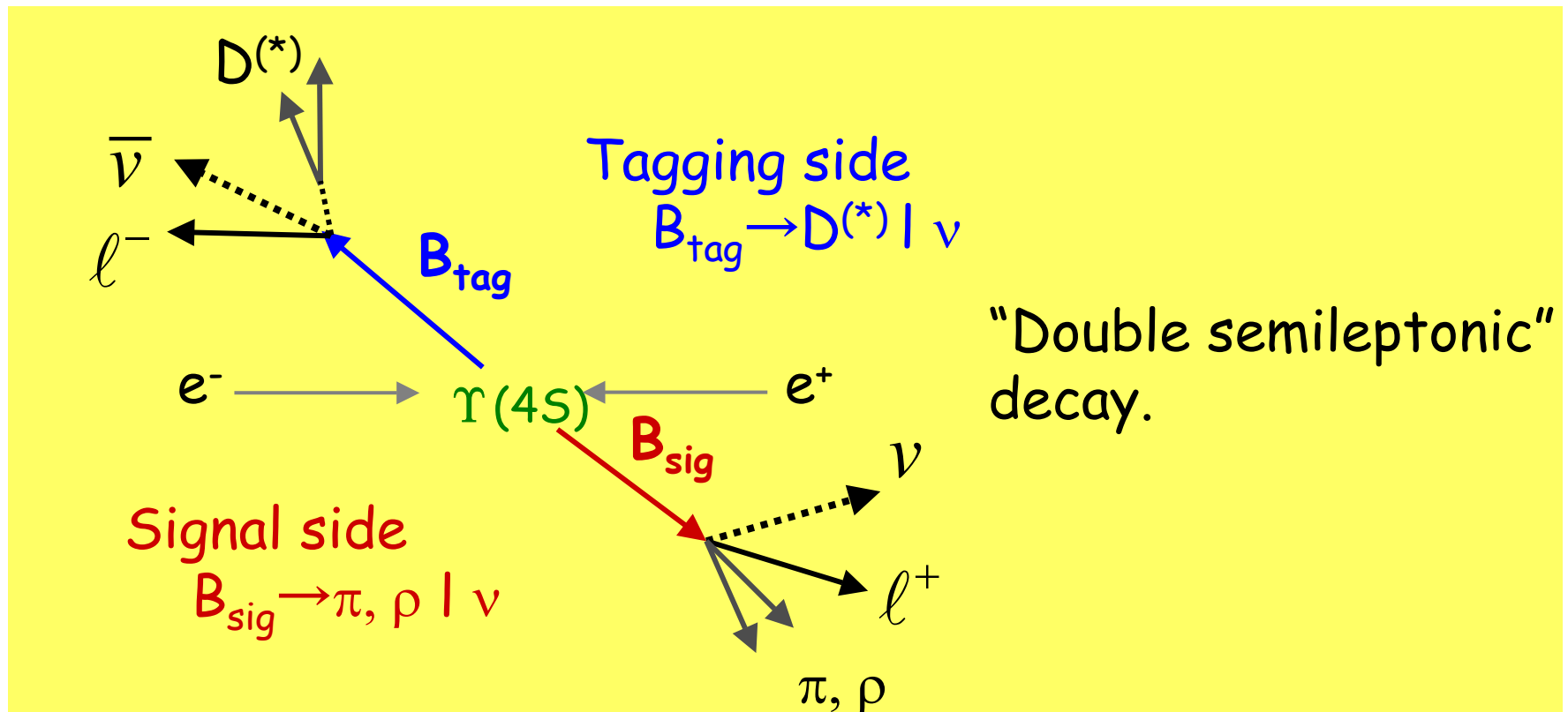
➔ $|V_{ub}| = [5.54 \pm 0.42 \pm 0.50 \pm 0.12 \pm 0.19 \pm 0.42 \pm 0.27] \times 10^{-3}$

stat. syst. b \rightarrow u. b \rightarrow c. f_u Br \rightarrow $|V_{ub}|$

140fb⁻¹ preliminary

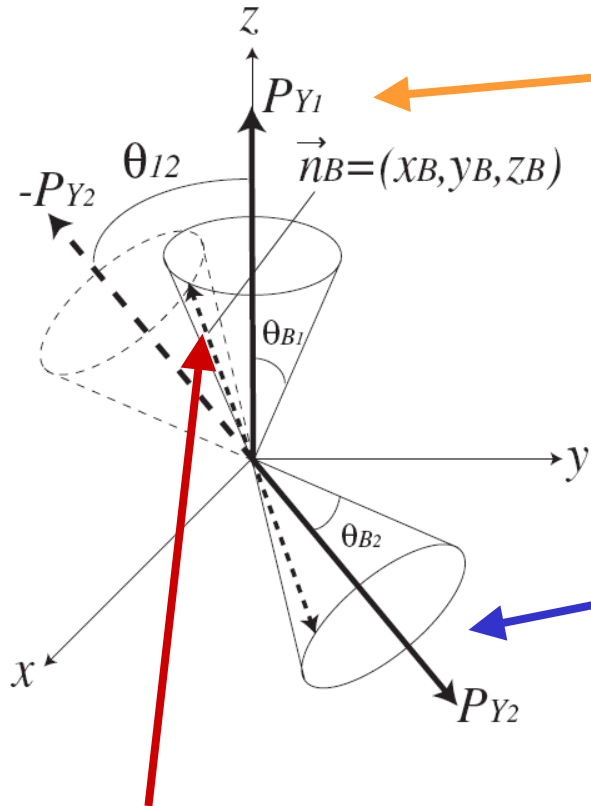
Exclusive $B \rightarrow X_u l \nu$ w/ Semileptonic Decay Tag

- New method for clean extraction of $B \rightarrow \pi l \nu, \rho l \nu$ decays.



Analysis Method

Exclusive $B \rightarrow X_u l \nu$



Tag side reconstruction

$$B_{tag} \rightarrow D^{*+} \ell^- \bar{\nu} / D^+ \ell^- \bar{\nu}$$

$$\hookrightarrow D^0 \pi^+ / D^+ \pi^0$$

4 decay modes

7 decay modes

Signal side reconstruction

$$B_{sig} \rightarrow X_u \ell^+ \nu \quad P_\ell > 0.8 \text{ GeV} / c$$

$$\hookrightarrow \pi^+ \text{ or } \pi^+ \pi^0$$

$$N(\pi^-) = 1, N(\pi^0) \leq 1$$

Kinematics of double semileptonic decay

Back-to-back correlation of the two B constrains their direction to the intersection of the 2 cones.

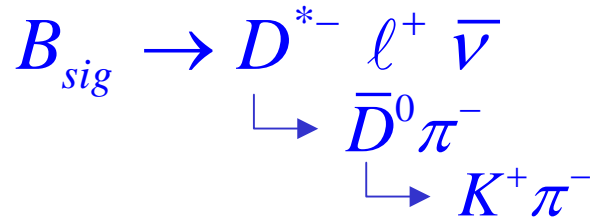
$$x_B = \pm \sqrt{1 - \frac{1}{\sin^2 \theta_{12}} (\cos^2 \theta_{B_1} + \cos^2 \theta_{B_2} - 2 \cos \theta_{B_1} \cos \theta_{B_2} \cos \theta_{12})},$$

To have intersection,
must be $0 \leq x_B^2 \leq 1$

Calibration with $B_{sig} \rightarrow D^* l \nu$ Decays

Exclusive $B \rightarrow X_u l \nu$

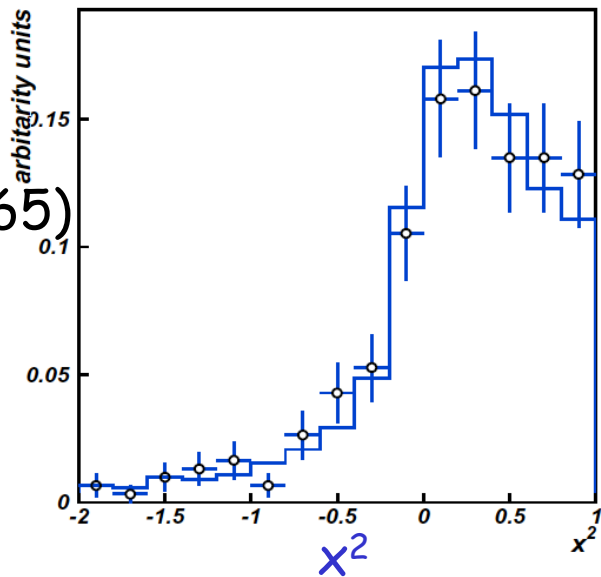
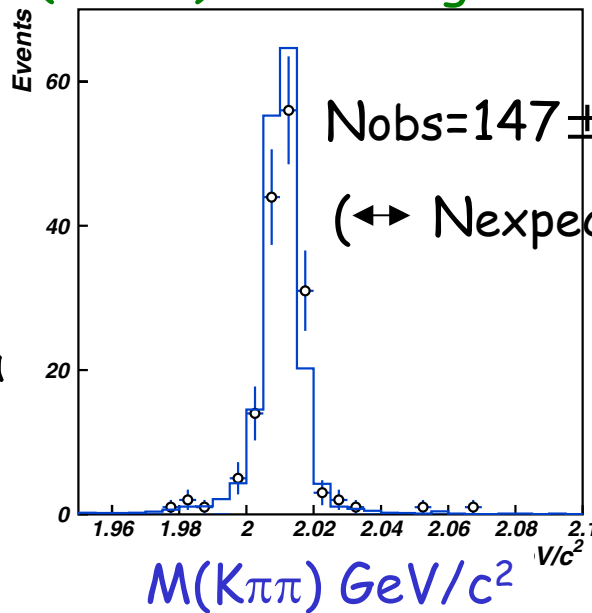
- Validity of the method for double semileptonic decay detection has been tested with



$M(K^+\pi^-\pi^-)$ on the signal side

χ^2 distribution

Dots: Data
Histo: MC



- The ratio $N_{obs}/N_{expected} = 0.89 \pm 0.08$ is used to correct the MC efficiency for $\pi l \nu$ and $\rho l \nu$ detection.

The method works !

Signal Extraction

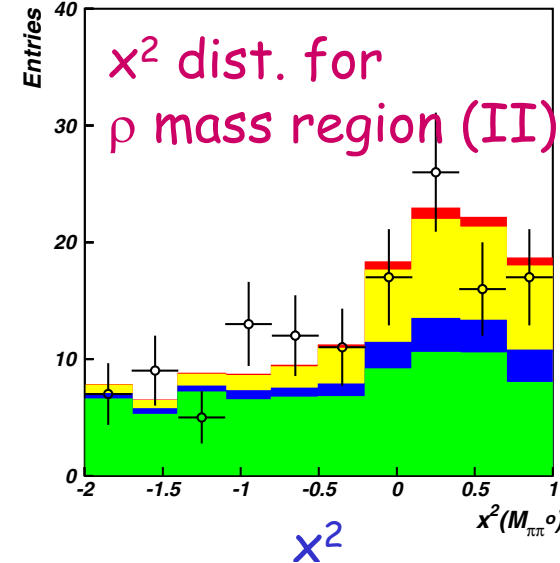
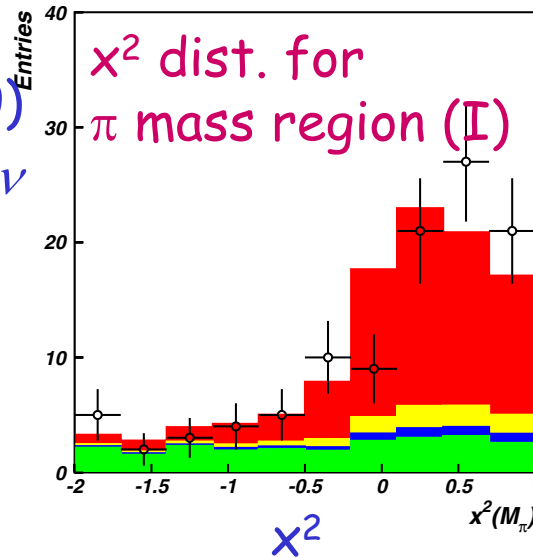
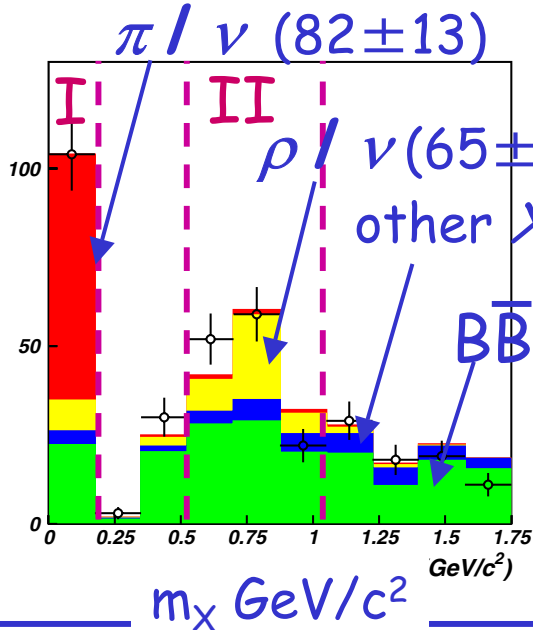
Exclusive $B \rightarrow X_u l \nu$

■ We extract $\pi l \nu / \rho l \nu$ signals simultaneously by fitting 2D (m_X, x^2) distribution.

- ▶ Fitting components: $\pi l \nu$, $\rho l \nu$, other $X_u l \nu$, $B\bar{B}$ background.
- ▶ PDF's are based on MC.
- ▶ Constraint for extracted Br: $Br(\pi l \nu) + Br(\rho l \nu) + Br(\text{other } X_u l \nu) = Br(X_u l \nu)$

Fitting results for all q^2 data.

140fb⁻¹



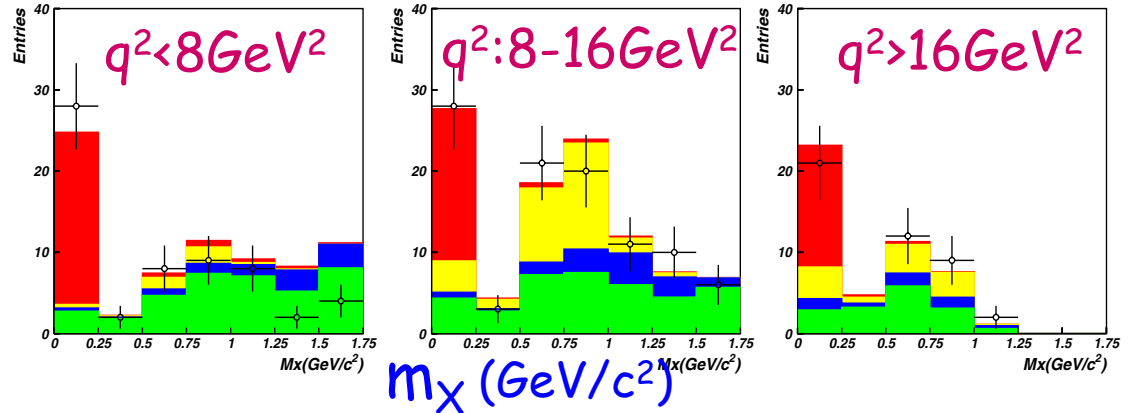
$\pi l \nu$ decays are cleanly extracted!

Extraction of q^2 Distribution

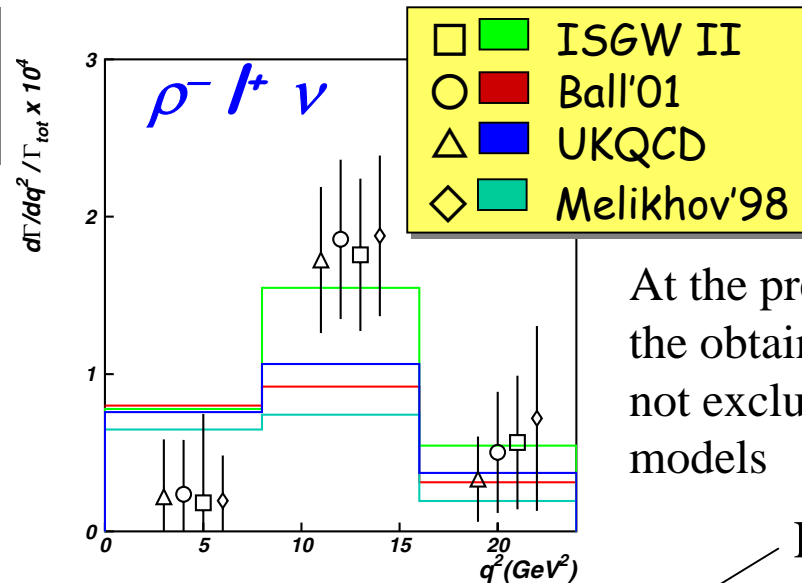
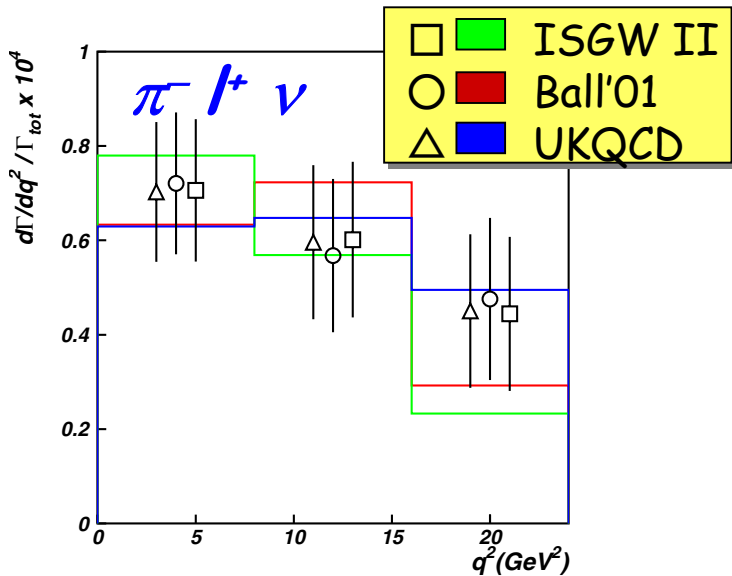
Exclusive $B \rightarrow X_u l \nu$

- q^2 distribution is extracted by fitting the (m_X, x^2) distribution for three q^2 intervals.

m_X dist. for three q^2 intervals



Extracted q^2 dist.



At the present accuracy, the obtained q^2 dist. does not exclude any tested models

FF-dep.

$$B_{total} = [1.76 \pm 0.28 \pm 0.20 \pm 0.03] \times 10^{-3}$$

$$B_{total} = [2.54 \pm 0.78 \pm 0.85 \pm 0.30] \times 10^{-3}$$

140fb⁻¹
Preliminary

$|V_{ub}|$ from $B^0 \rightarrow \pi^- l^+ \nu$

Exclusive $B \rightarrow X_u l \nu$

■ $|V_{ub}|$ determined from $B > 16 \text{ GeV}^2$ ($B^0 \rightarrow \pi^- l^+ \nu$) with lattice QCD.

■ w/ quenched LQCD [FNAL/JLQCD/APE/UKQCD] $|V_{ub}| = \sqrt{\frac{B(B \rightarrow \pi l \nu)}{\tilde{\Gamma}_{phy} \tau_B}}$

Average $\tilde{\Gamma}_{thy} = 1.92^{+0.32}_{-0.12} \pm 0.47$

➔ $(3.90 \pm 0.71 \pm 0.23^{+0.62}_{-0.48}) \times 10^{-3}$

■ w/ unquenched LQCD [FNAL/HPQCD]

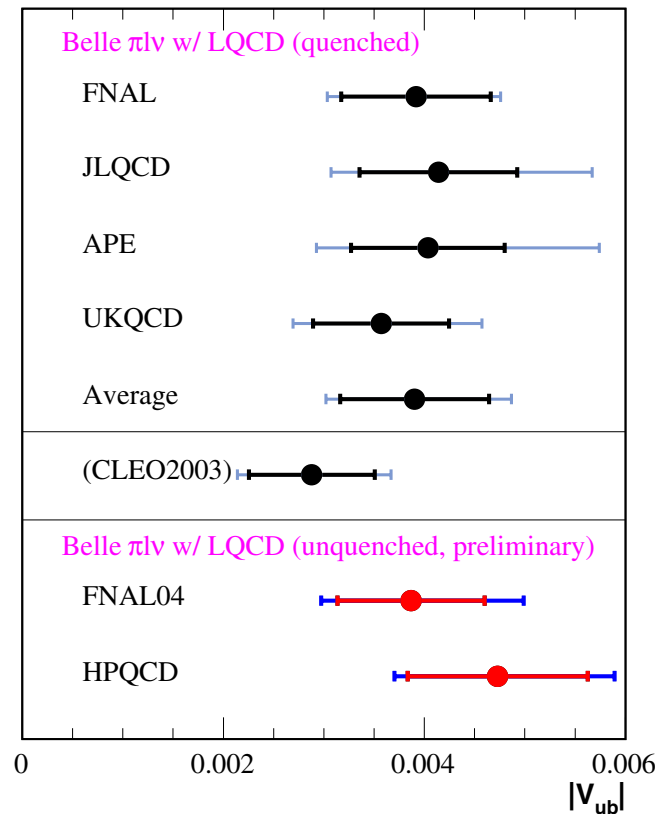
Preliminary results reported at Lattice'04.

FNAL'04 $\tilde{\Gamma}_{thy} = 1.96 \pm 0.51 \pm 0.39$

➔ $(3.87 \pm 0.70 \pm 0.22^{+0.85}_{-0.51}) \times 10^{-3}$

HPQCD $\tilde{\Gamma}_{thy} = 1.31 \pm 0.33$

➔ $(4.73 \pm 0.85 \pm 0.27^{+0.74}_{-0.50}) \times 10^{-3}$



140fb-1, preliminary

— 4th error from $\tilde{\Gamma}_{thy}$
FF-dep. in Br is small for $\pi l \nu$ data

Summary

We have obtained preliminary $|V_{ub}|$ results from

■ **Inclusive $B \rightarrow X_u l \nu$ w/ fully reconstructed tag.**

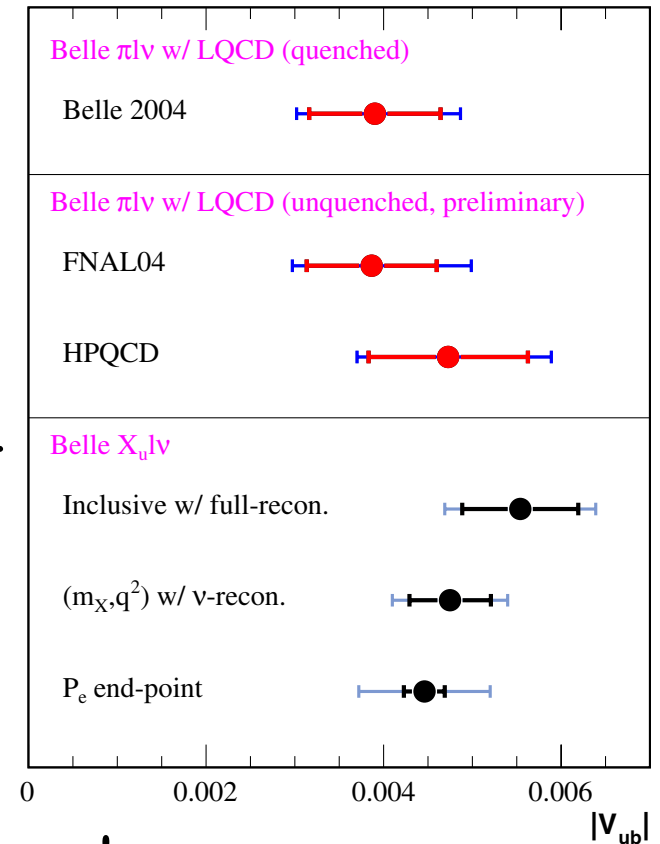
- ▶ Results are compatible and consistent with the previous exp's.

■ **Exclusive $B \rightarrow X_u l \nu$ ($B^0 \rightarrow \pi l \nu$) w/ semileptonic decay tag.**

- ▶ Results are compatible and consistent with the previous exp's and inclusive results.
- ▶ New method for clean signal extraction has been demonstrated.

■ **These measurements are promising approach at B-factories in the coming years !**

Belle $|V_{ub}|$



Backup Slides

Systematic Uncertainties

Inclusive $B \rightarrow X_u l \nu$

$b \rightarrow u$ MC

statistics = 4%

model dep. = 4.2%

Variate inclusive parameters
within errors

$b \rightarrow c$ MC

statistics = 15%

model dep. = 5%

$Dl\nu$ ($\rho_D = 1.19 \pm 0.19$) ... 5.6%

$D^*l\nu$ ($\rho_{A1} = 1.51 \pm 0.13$) ... 3.9%

$D^{**}l\nu$... 1.6%

Detector sim. for $b \rightarrow c$ & $b \rightarrow u$ MC = 6.5%

Correlated errors, added/subtracted in linear for the two MC's

Adding:

Kaon ID = 6%

tracking = 2%

Subtracting:

Lept. sel. = 1%

γ clusters = 1%

Systematic error of R_e^{freco} and R_e^{lept} ... 6.4%

Systematic Uncertainty

Exclusive $B \rightarrow X_u \ell \nu$

Major contribution

■ $D^* \ell \nu$ calibration

- ▶ Statistics of detected $D^* \ell \nu$ 8.3%
- ▶ Error of $Br(B^0 \rightarrow D^* \ell \nu)$ 4.3%

■ $B\bar{B}$ background shape

tested $\Delta B(\pi \ell \nu)$ ($\Delta B(\rho \ell \nu)$) in MC by

- ▶ removing charged track by 1%
-4.2(+23.5) %
- ▶ removing π^0 by 3% -1.1(+12.8) %
- ▶ Replacing K^\pm with π^\pm by 2%
-0.5(+16.6) %

Source	$\pi^- \ell^+ \nu$	$\rho^- \ell^+ \nu$
Tracking efficiency	1	1
π^0 reconstruction	–	3
Lepton identification	2.1	2.1
Kaon identification	2	2
$D^* \ell \nu$ calibration	9.8	9.8
$Br(X_u \ell \nu)$ in the fitting	0.2	3.4
$B\bar{B}$ background shape	4.4	31.5
$N_{B\bar{B}}$	0.5	0.5
f_+/f_0	2.4	2.4
χ_d	1.0	1.0
total	11.5	33.5

Significant change in $\Delta B(\rho \ell \nu)$, due to the broad width of ρ meson.

B → π Form-Factor from LQCD

Exclusive $B \rightarrow X_u l \nu$

- Four quenched calculations from FNAL, JLQCD, APE and UKQCD (used in CLEO2003).

▶ Average $\tilde{\Gamma}_{thy} = 1.92^{+0.32}_{-0.12} \pm 0.47$

Include 15%
quenching error

- Preliminary **unquenched** results from FNAL and HPQCD (reported at Lattice'04).

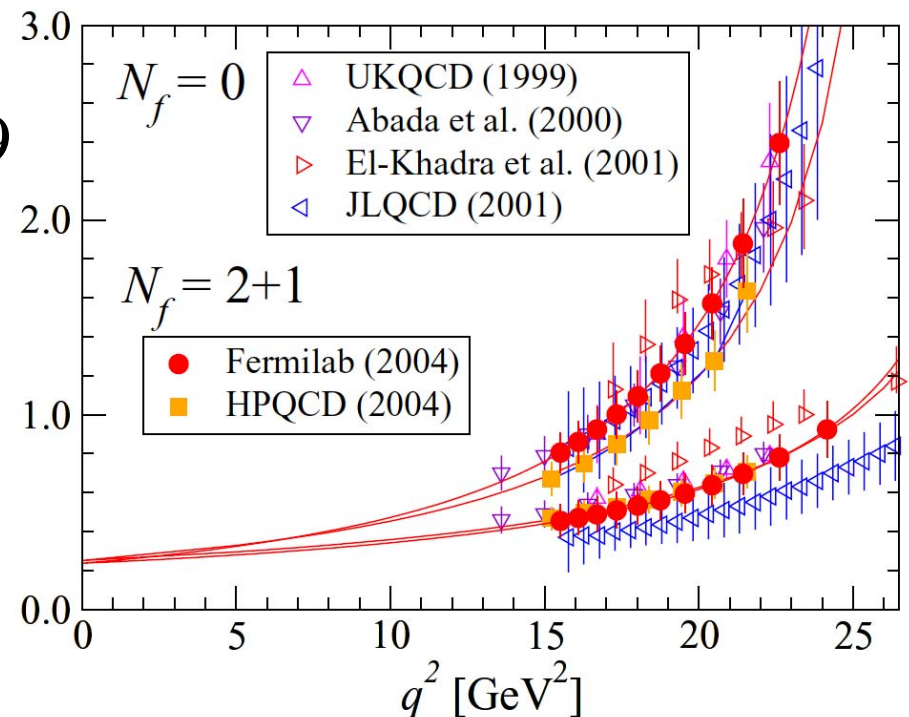
- ▶ FNAL (M.Okamoto)

$$\tilde{\Gamma}_{thy} = 1.96 \pm 0.51 \pm 0.39$$

- ▶ HPQCD(J.Shigemitsu)

$$\tilde{\Gamma}_{thy} = 1.31 \pm 0.33$$

($\tilde{\Gamma}_{thy}$ given for $q^2 > 16 \text{ GeV}^2$)



■ FNAL'04 $\tilde{\Gamma}_{phy} = 1.96 \pm 0.51(stat.) \pm 0.39(syst.)$

- | | | | |
|------------------------------|------|---|----|
| ▶ Statistical | ~10% | } | ×2 |
| ▶ Lattice-continuum matching | ~7% | | |
| ▶ Chiral extrapolation | ~6% | | |
| ▶ Discretization | ~5% | | |

■ HPQCD $\tilde{\Gamma}_{phy} = 1.31 \pm 0.33 [0.13(stat) \pm 0.30(syst)]$

- | | | | |
|----------------------------------|-----|---|----|
| ▶ Statistical | ~5% | } | ×2 |
| ▶ Higher order operator matching | ~9% | | |
| ▶ Chiral extrapolation | ~5% | | |
| ▶ Relativistic+discretization | ~5% | | |

Number given by M.Okamoto (FNAL) and J.Shigemitsu (HPQCD) in private communications.