Measurement of $|V_{ub}|$ with simultaneous requirements on M_x and q^2

39th Rencontres de Moriond:

Electroweak Interactions and Unified Theories

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T.Nozaki (KEK)

Outline

Introduction

Reconstruction of M_x and q^2

Novel X_u reconstruction

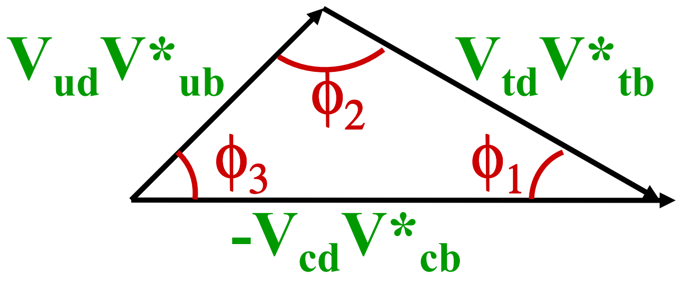
Event Selection

Results

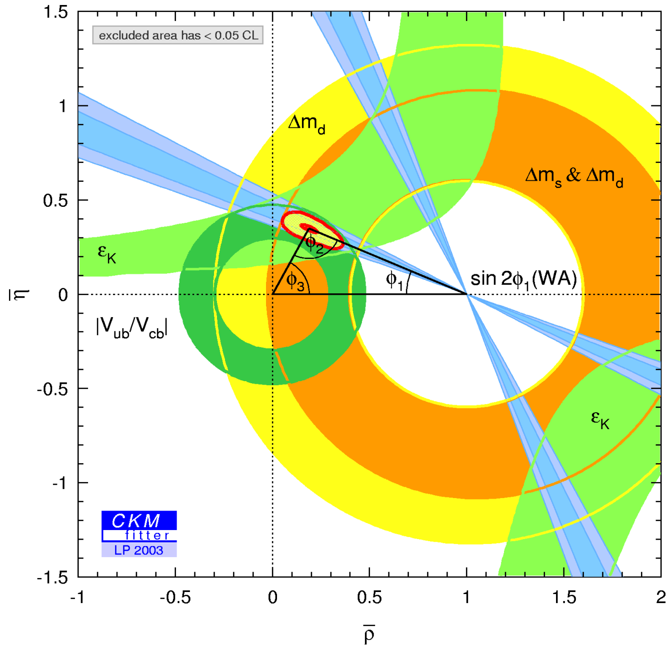
Conclusions

Introduction

- V_{ub} is one of CKM matrix elements and plays an important role in CP-violation and rare decays of the B meson.

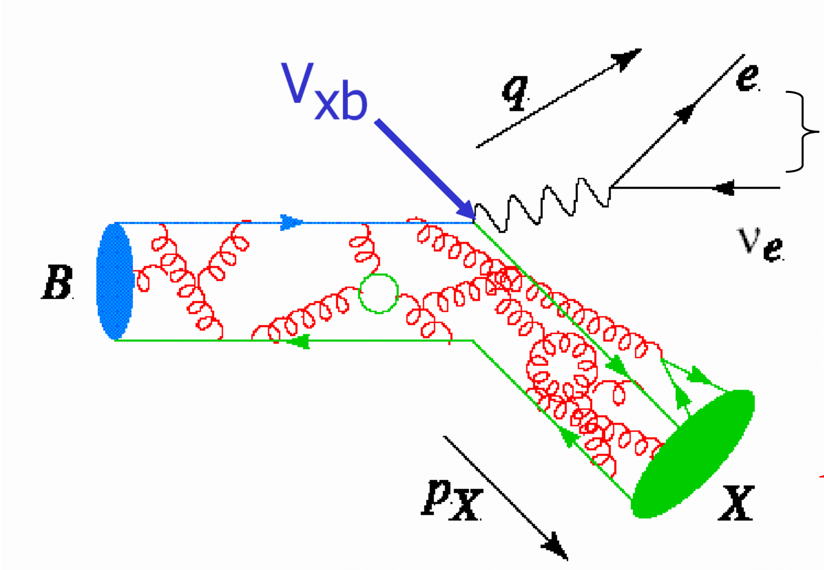


- It is an important ingredient in overconstraining the unitarity triangle by measuring its sides and angles.



Inclusive Charmless Semileptonic Decay

● Inclusive Charmless Semileptonic decay is the most promising process to determine $|V_{ub}|$



E_l

q^2

M_X

$$B(B \to X_c l \nu) \Rightarrow |V_{cb}|$$
$$B(B \to X_u l \nu) \Rightarrow |V_{ub}|$$

Total branching fraction of Inclusive charmless semileptonic decays is predicted model independently by OPE and HQET

$$|V_{ub}| = const \times \sqrt{B(B \to X_u l \nu)}(1 \pm 0.07\,(theory))$$

Inclusive Measurements

- 100 times larger b→c background must be reduced
- Cuts increase theoretical error significantly due to uncertainties in extrapolation

1) Lepton energy (End-point)

$$E_l > \frac{m_B^2 - m_D^2}{2m_B} = 2.3\,\mathrm{GeV}$$ ~10%

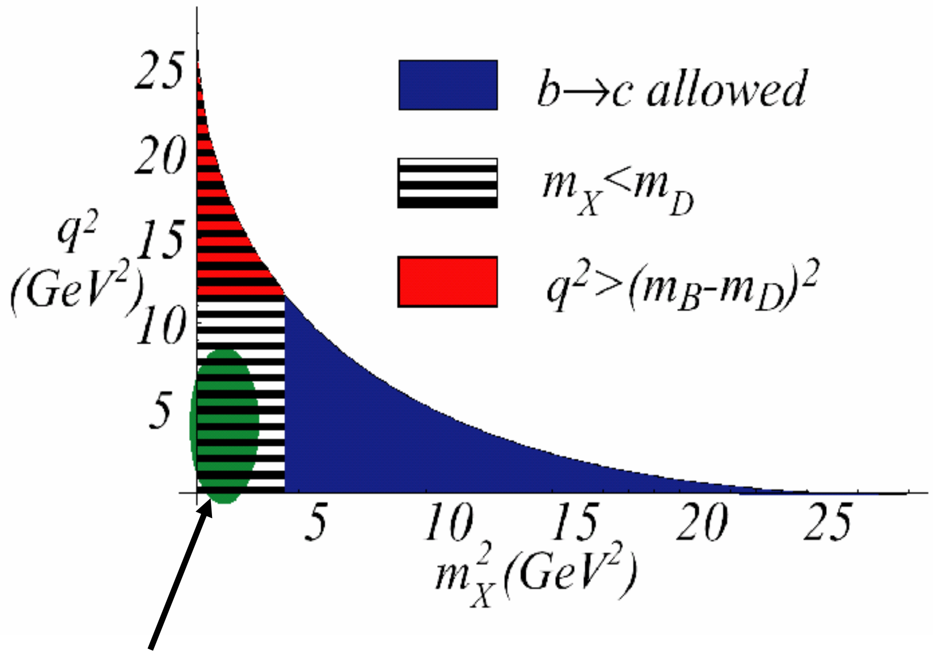
2) Leptonic invariant mass

$$q^2 > (m_B - m_D)^2 = 11.7\,\mathrm{GeV}^2$$ ~15%

3) Hadronic invariant mass

$$M_X < m_D = 1.86\,\mathrm{GeV}$$ ~80%

Acceptance for b→u l ν signals (larger the better)



Collinear region (Shape Function region): OPE fails and needs shape function

Simultaneous cuts on q^2 and Mx

To minimize the extrapolation error (= $\delta A/A$, A=acceptance)

Use Mx cut ⇨ Achieve larger A

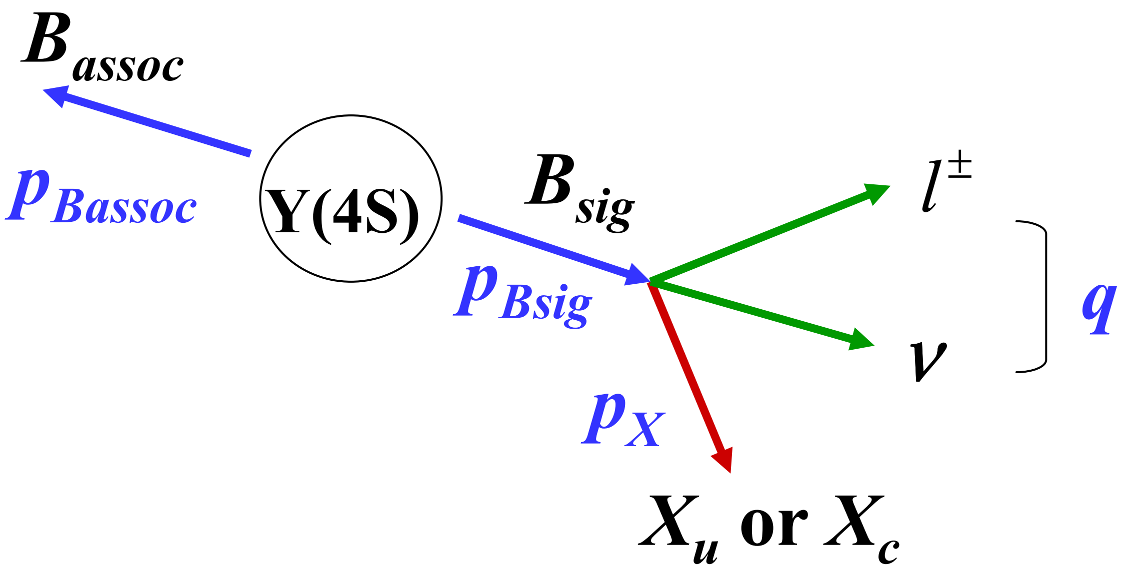
Use q^2 cut ⇨ Achieve smaller δA
by reducing the shape function contribution

Bauer, Ligeti and Luke (BLL) PR D64,113004 (2001)

Cut	Extrapolation error $\delta A/A$ ($m_b^{1S} = 4.70 \pm 0.12$ GeV)	Experiment
$E_l > 2.2$ GeV	**20%**	CLEO
Mx<1.55GeV	**18 %**	BaBar
Mx<1.7 GeV and q^2>8GeV^2	**10%**	Belle

Reconstruction of M_X and q^2 at $\Upsilon(4S)$ -1

$$\Upsilon(4S) \rightarrow B_{sig}\overline{B}_{assoc} : \quad B_{sig} \rightarrow Xl\nu, \quad \overline{B}_{assoc} \rightarrow any$$



If all particles except the neutrino are measured

$$p_{miss} = p_{\nu} \quad \rightarrow \quad MM^2 = 0$$

Reconstruction of M_X and q^2 at Υ(4S) -2

- Traditional Neutrino Reconstruction

Require $MM^2 = 0$

$p_\nu = p_{miss}$

$q^2 = (p_l + p_\nu)^2$

$M_X^2 = (p_B - p_l - p_\nu)^2$

$= M_B^2 + q^2 - 2E_{beam}(E_l + E_\nu) + 2|\vec{p}_B||\vec{p}_{l\nu}|\cos(\vartheta_{B,l\nu})$

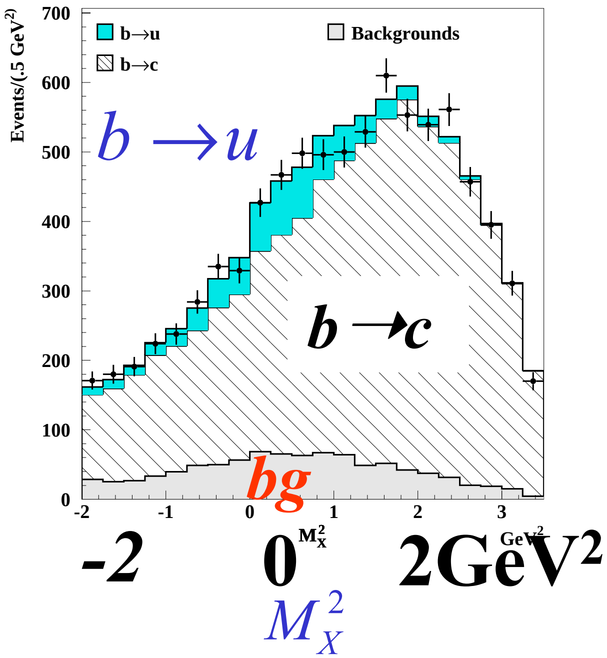
$\approx M_B^2 + q^2 - 2E_{beam}(E_l + E_\nu) \quad (|\vec{p}_B| = 0.35\text{GeV})$

Merit: good efficiency

Demerit: poor M_X resolution

poor S/N ratio

CLEO



hep-ex/0207064

Mx<1.5GeV and q^2>11GeV^2

Reconstruction of M_X and q^2 at Υ(4S) -3

- Full-reconstruction method
  - Fully reconstruct the associated B_{assoc}

=> $p_{B_{sig}} = p_{\Upsilon(4S)} - p_{B_{assoc}}$

  - Measure all momenta on the signal side

=> p_X

$$M_X = \sqrt{p_X^2}$$

$$q^2 = (p_l + p_\nu)^2 = (p_{B_{sig}} - p_X)^2$$

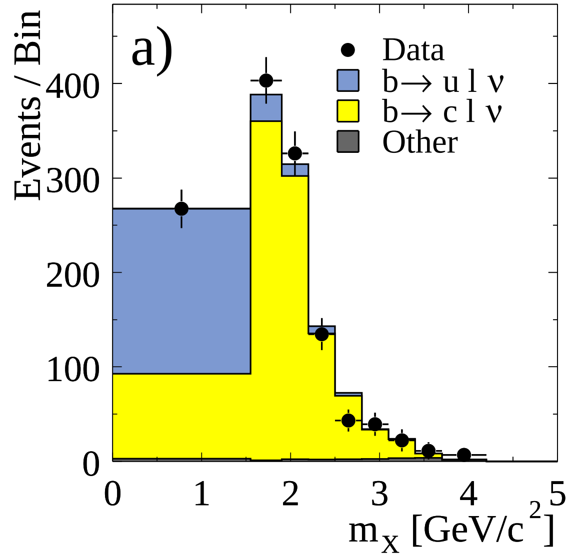
Merit: good M_X resolution

good S/N ratio ~ 2

Demerit: poor efficiency

(a few x 10^{-3})

BaBar



175 events for M_X <1.55 GeV/c^2
using 89×10^6 $B\bar{B}$ events

PRL **92**,071802(2004)

Reconstruction of M_X and q^2 at Υ(4S) -4

- Novel X_u reconstruction by Belle
  - Neutrino reconstruction
  - Separation of B and $\bar{B}$ decays using the simulated annealing method

Merit:good efficiency with reasonable M_X resolution

Demerit:Both M_X resolution and S/N ratio are worse than full-reconstruction method

Present report by Belle PRL 92, 101801(2004)

Novel X_u reconstruction by Belle -1

- Neutrino reconstruction
  - Using only good quality tracks and clusters:

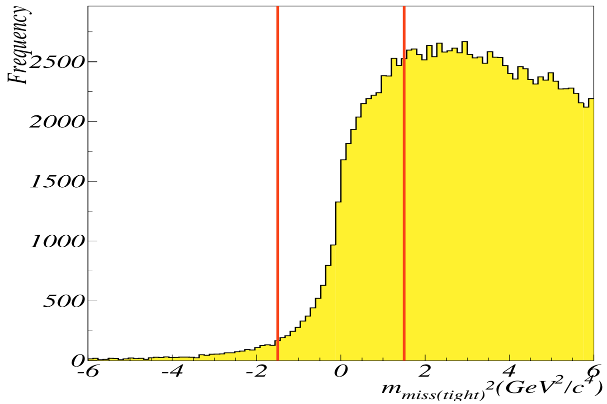
    Require $|MM^2|<1.5GeV^2$

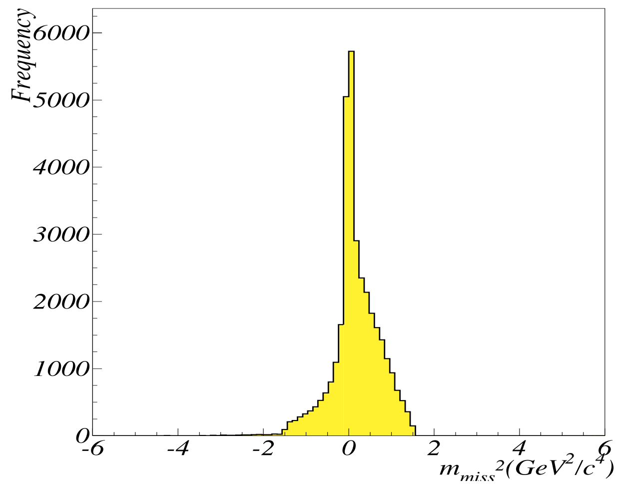
  - Add back low quality tracks/clusters iteratively ;

    select combination with smallest $|MM^2|$

    Require $|\sum_i Q_i| \leq 1$ and $32^0 < \theta_\nu < 128^0$

    and doesn't point at any K_L cluster





Novel X_u reconstruction by Belle –2
Separation of two B meson decays

Simulated Annealing Method -1

- 6 discriminants are used
  - $p^*_{B,}$ E^*_B , $\cos\theta^*_{B,}$ N_{ch} of the associated B in CMS
  - Q_B x Q_l, MM^2_{Xln}(E^*_B , M_B of associated B are fixed to known values)
- Using MC simulation, calculate PDFs for correct Xlν combinations and random Xlν combinations
- Calculate *W* with two likelihoods *L(correct)* and *L(random)*

$$W \equiv \frac{L(random)}{L(random) + L(correct)}$$

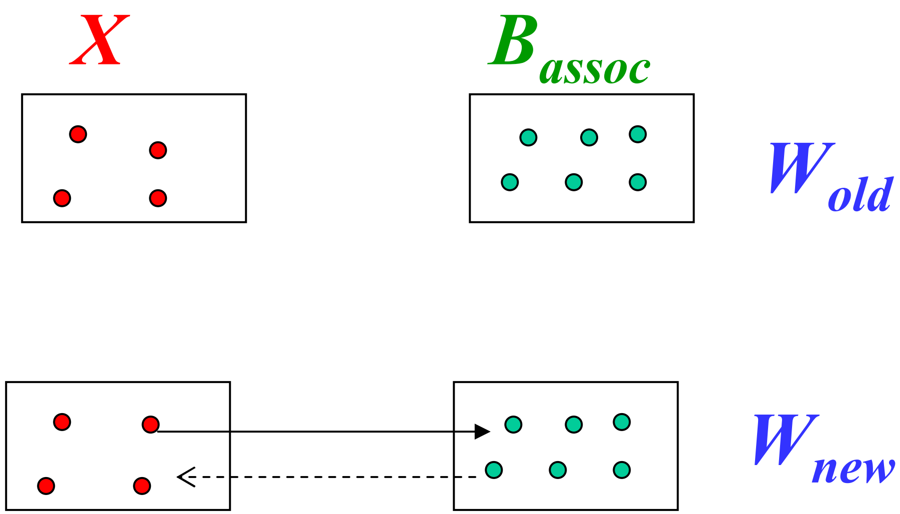
- The most likely candidate combination is found by minimizing *W* using an approximate iterative algorithm based on simulated annealing

Simulated Annealing –2

One iteration

Initial state

Random config.



Move random one particle between X and Bassoc

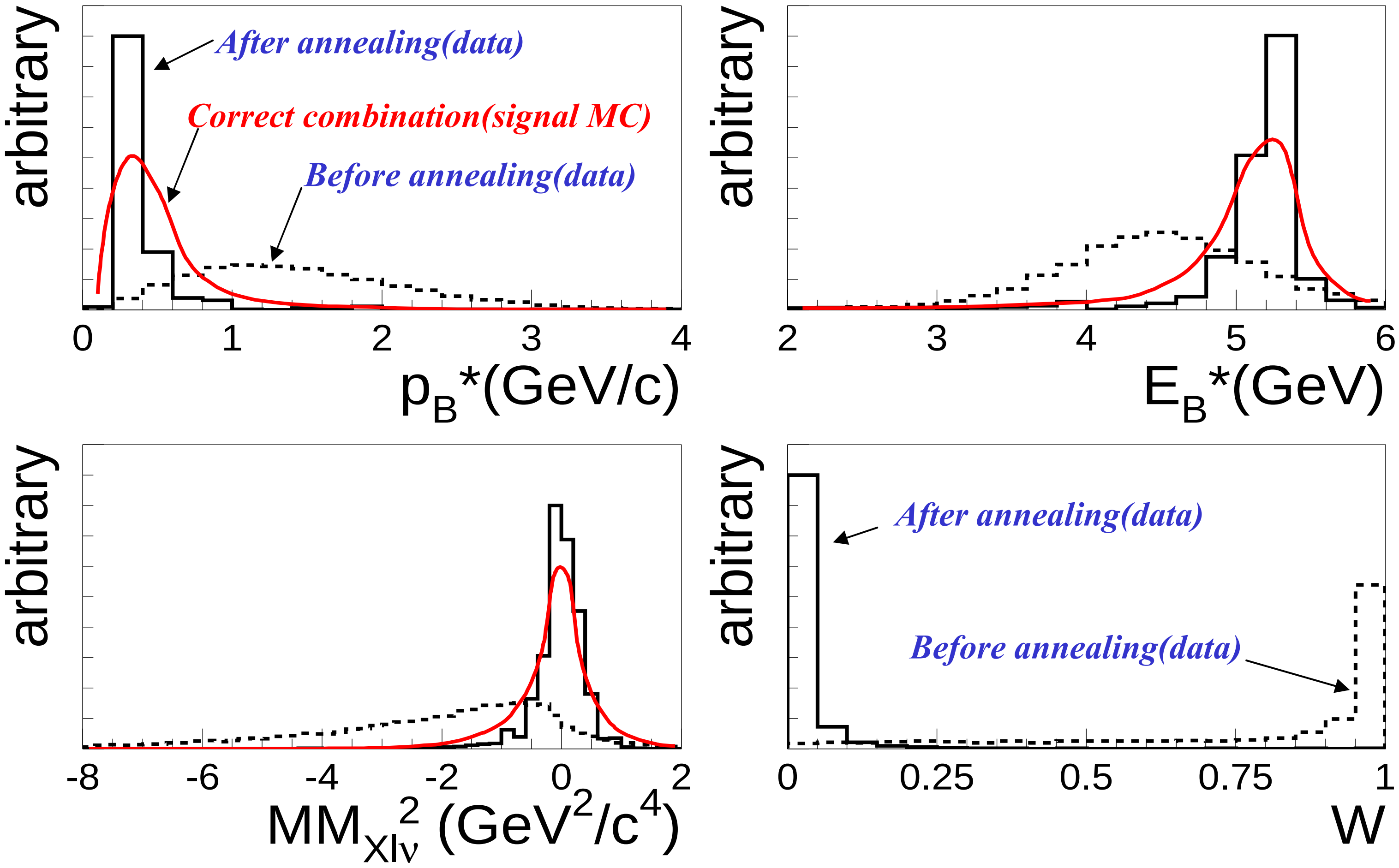
If Wnew<Wold, keep new configuration, Wnew => Wold

If Wnew>Wold, keep new configuration with probability of exp{-1000(Wnew-Wold)/Wold},otherwise keep old configuration

Repeat this process untill all particles are moved at least once and only once

In total 500 iterations are used

Simulated Annealing –3 (Results)

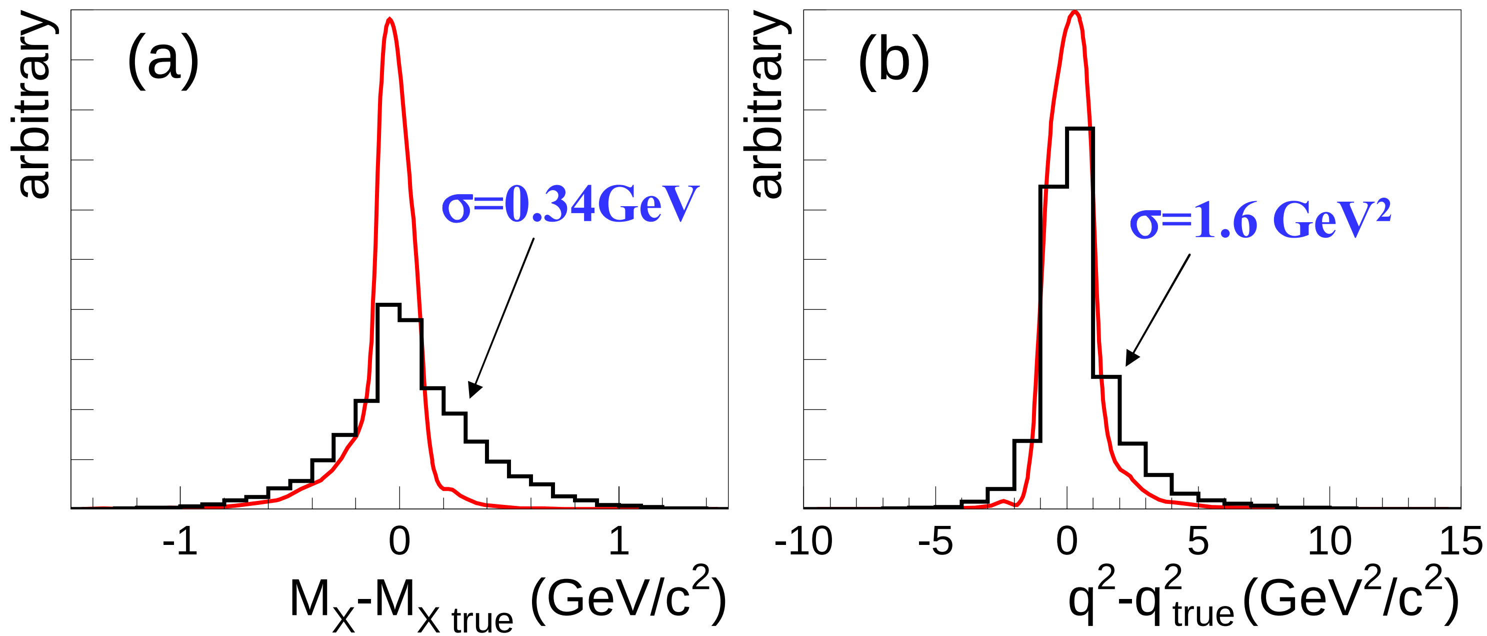


M_X and q^2 Resolutions

M_x and q^2 resolution distributions for $B \to X_u l \nu$ signal MC events

Simulated annealing results

Correct particle assignment to X_u

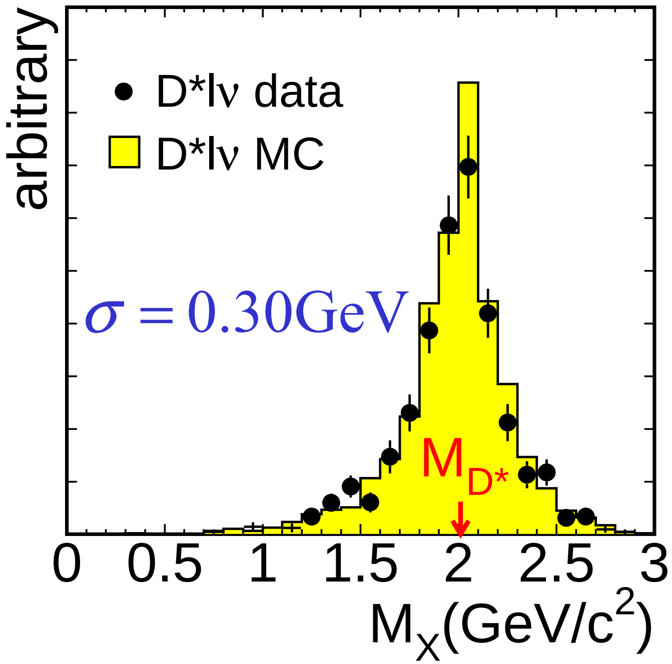


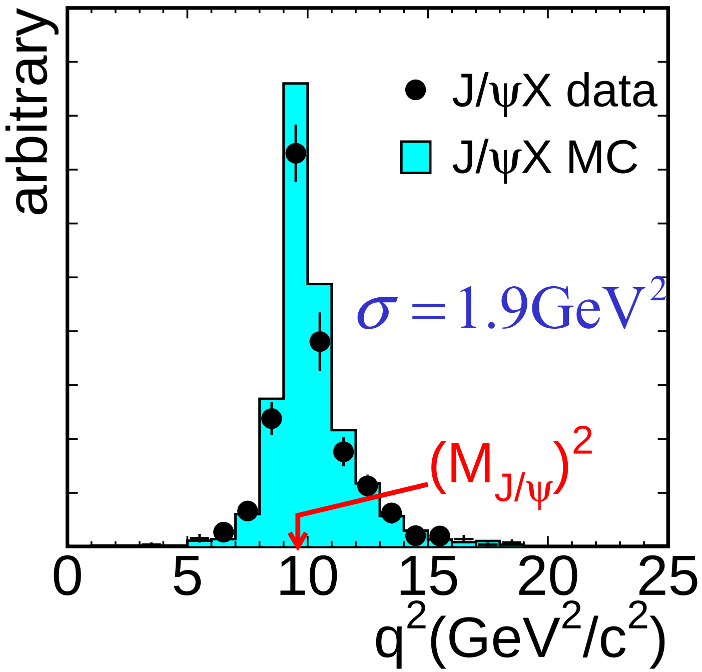
Validation Tests

38K ***D*lν***

84K ***J/ψX, J/ψ → l⁺l⁻***

l⁺**or** ***l⁻*** **treated as** ***ν***





Detection efficiency from MC is calibrated using the average efficiency ratio for these two control samples

$$r_{eff} = \varepsilon_{data} / \varepsilon_{MC} = 0.891 \pm 0.043$$

Event Selection -1

- Used data sample
  - Belle data at the energy asymmetric e^+e^- collider KEKB
  - $78.1\ fb^{-1}$ on resonance data ($85\times10^6\ B\bar{B}$) taken at the $\Upsilon(4S)$ resonance
  - $8.8\ fb^{-1}$ off resonance data (taken at 60 MeV below the resonance)
- Selection of the final candidate
  - $W<0.1$
  - $5.1<E^*_B<5.4$ GeV
  - $0.25<p^*_B<0.42$GeV
  - $-2<Q_l \cdot Q_B<1$
  - $-0.2<MM^2_{Xl\nu}<0.4\text{GeV}^2$
  - $|\cos\theta_{Bl}|<0.8$ (θ_{Bl}:angle between the thrust axis of B_{assoc} and the lepton)

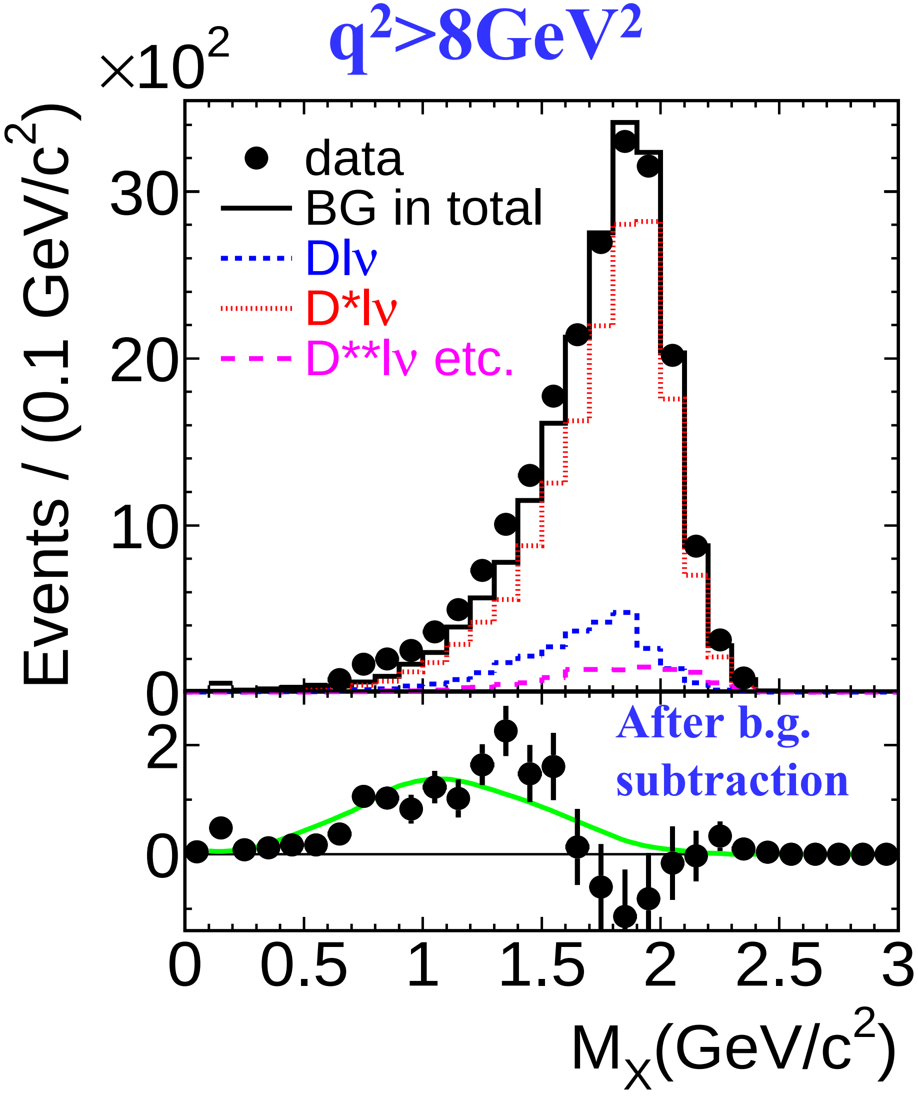
….. suppress continuum background

Event Selection -2

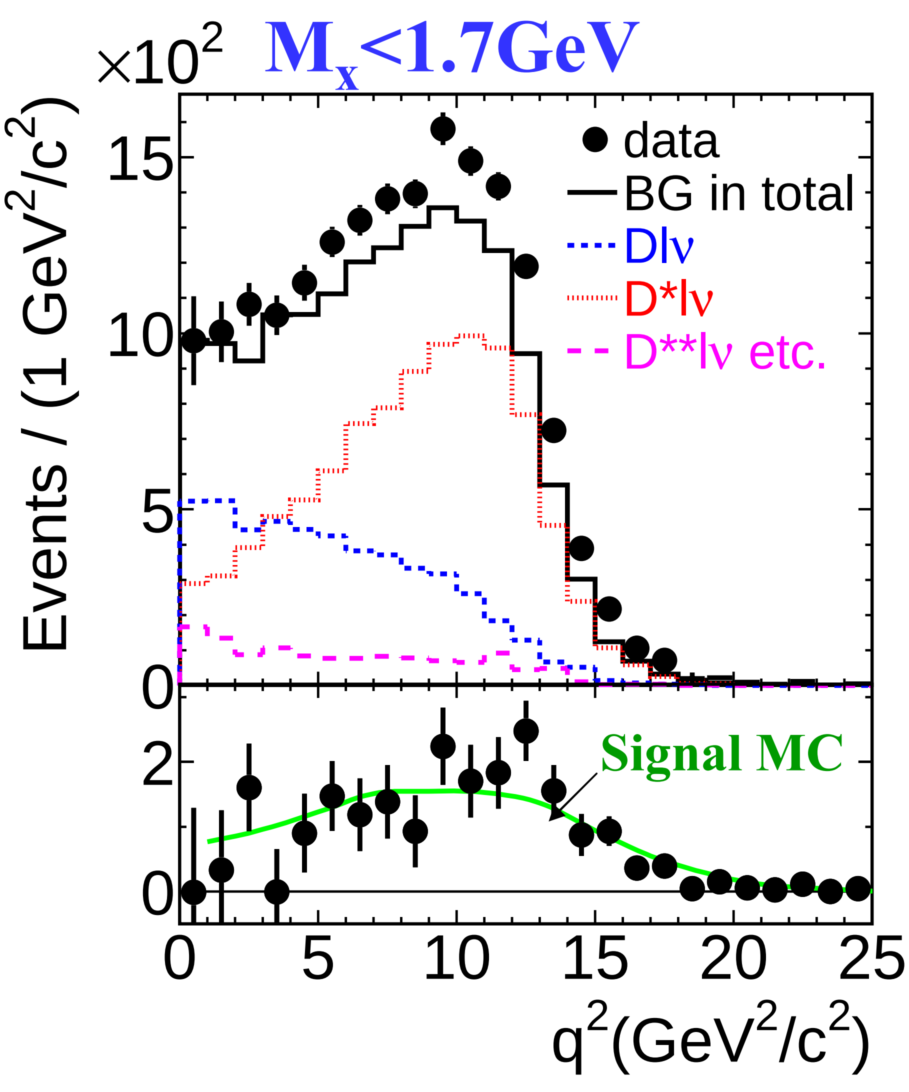
- Signal region: M_X<1.7 GeV and q^2> 8 GeV^2
  - 8910 events observed
- Background subtraction
  - Continuum b.g. = 251±48 events is estimated using off-resonance data.
  - $B \to X_c l\nu$ (dominant) and other $B\bar{B}$ backgrounds are estimated by MC.
  - MC is tuned by 2D-χ^2fitting the Mx vs q2 distributions of MC events to those of the real data in the $B \to X_c l\nu$ dominated region (Mx >1.8 GeV).
  - In the fit, fractions for $B \to D^{(*)} l\nu$, $D^{**} l\nu$, $D^{(*)}\pi l\nu$ and the total rate for other BB backgrounds are floated.
  - $B\bar{B}$ b.g. in the signal region: 7283± 130(fit)± 63(MC stat) events

    Net signal : 1376± 167(stat) events

Results



q²>8GeV²
×10²
Events / (0.1 GeV/c²)
data
BG in total
Dlν
D*lν
D**lν etc.
After b.g. subtraction
M_X(GeV/c²)
0 0.5 1 1.5 2 2.5 3
0 10 20 30
0 2

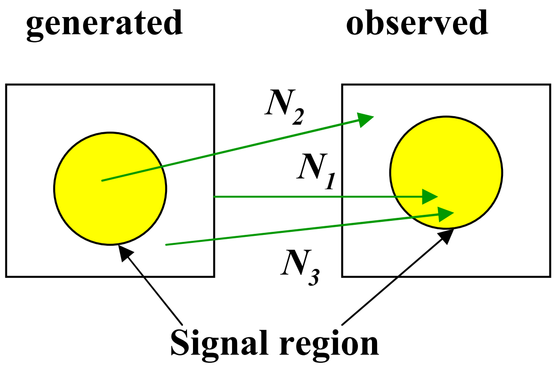


M_x<1.7GeV
×10²
Events / (1 GeV²/c²)
data
BG in total
Dlν
D*lν
D**lν etc.
Signal MC
q²(GeV²/c²)
0 5 10 15 20 25
0 5 10 15
0 2

Partial Branching Fraction ΔB for $B \to X_u l \nu$ ($M_X < 1.7$ GeV and $q^2 > 8$ GeV^2) -1

- MC simulation of $B \to X_u l\nu$ events . It is based on the inclusive model of Fazio & Neubert (hep-ph/9905351)
  - Leading order in HQE with $O(\alpha_s)$ QCD correction
  - Including the shape function effect
  - $m_b = 4.80 \pm 0.12$ GeV, $\lambda_1 = -0.30 \pm 0.11$ GeV^2

    (From CLEO data for γ energy spectrum in $b \to s\gamma$ and hadronic mass moments in $b \to cl\nu$)



- Unfolding: $N_{true} = N_{obs} \times F$ ($F \equiv 1 + N_2/N_1 - N_3/N_1$)
- Efficiency correction: $\Delta B = 0.5 \times N_{true} / (\varepsilon_{signal} \times r_{eff}) / (2N_B)$
- $N_{obs} = 1376 \pm 167$(stat) , $F = 0.938$, $\varepsilon_{signal} = 0.578\%$, $N_B = 85 \times 10^6$,
- ΔB ($M_X < 1.7$ GeV and $q^2 > 8$ GeV^2)

  $= (7.37 \pm 0.89(\text{stat}) \pm 1.12(\text{syst}) \pm 0.55(b \to c) \pm 0.24(b \to u)) \times 10^{-4}$

Partial branching fraction ΔB for $B \to X_u l \nu$ (M_X<1.7 GeV and q^2> 8 GeV^2) -3

- Systematic error (15%)
  - Dominated by distortion of M_x and q^2 distributions due to imperfect detector simulation

- Model dependence
  - $B \to X_c l\nu$ 7.4%
    - Change the form factor parameters for $Dl\nu$ and $D^*l\nu$ within the errors
    - Change fraction of $D_1l\nu$ and $D_2l\nu$ in $D^{**}l\nu$ by 25%
  - $B \to X_u l\nu$ 3.4%
    - Change the parameters of the inclusive model within the errors
    - Compare with a full exclusive implementation of the ISGW2 model

Extraction of $|V_{ub}|$

$$|V_{ub}| = 0.00444 \left(\frac{\Delta B(B \to X_u l \nu)}{0.002 \times f_u(q^2_{cut}, m_{cut})} \frac{1.55\ \text{ps}}{\tau_B} \right)^{1/2} \left[\frac{m_b^{1S}}{4.7\,\text{GeV}} \right]^{-5/2}$$

$f_u(q^2_{cut}, m_{cut})$ = fraction of events with $q^2 > q^2_{cut}$ and $M_X < m_{cut}$

$m_b^{1S} = 1/2$ of the perturb. contrib. of the mass of $\Upsilon(1S)$

$f_u(q^2_{cut}, m_{cut})$ is calculated by BLL by including shape function effect

two parameters: m_b^{1S} and λ_1

$$m_b^{1S} = 4.70 \pm 0.12\ \text{GeV}, \lambda_1 = -0.2\text{GeV}^2 \longrightarrow f_u(q^2_{cut}, m_{cut}) = 0.324 \pm 0.046$$

$$|V_{ub}| = (4.66 \pm 0.28(\text{stat}) \pm 0.35(\text{syst}) \pm 0.17(b \to c) \pm 0.08(b \to u) \pm 0.58(\text{theo})) \times 10^{-3}$$

$$= (4.66 \pm 0.76) \times 10^{-3}$$

$\delta |V_{ub}|$(theory)

Perturbative term	Weak annihilation	m_b^{1S}	Total
3%	4%	11.5%	12.5%

$\delta |V_{ub}| (m_b^{1S})$

Positive correlation

f_u	$(m_b^{1S})^{-5/2}$	Total
5%	6.5%	11.5%

Conclusions

- We have performed the first measurement of $|V_{ub}|$ with simultaneous requirements on M_X and q^2 using a novel X_u- reconstruction method.
- The result of $|V_{ub}| = (4.66 \pm 0.76) \times 10^{-3}$ is consistent with the previous measurements.
- The total error is comparable with those of previous measurements on Y(4S).