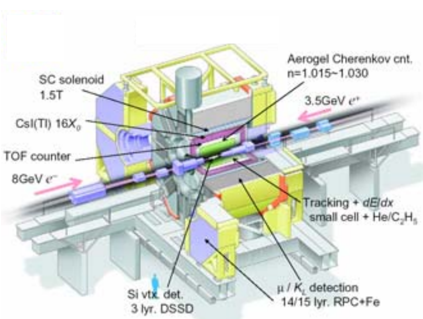
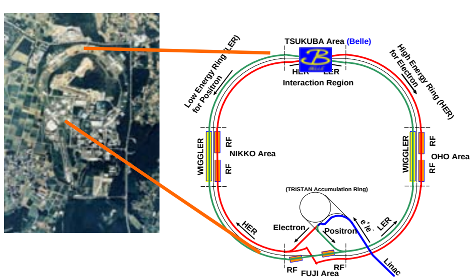
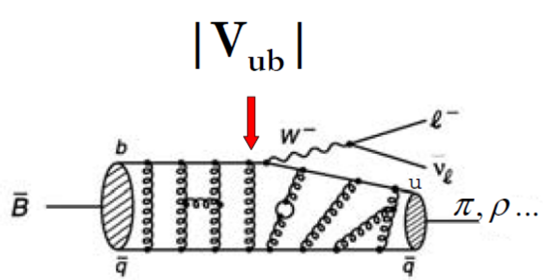
Semileptonic Decays from Belle

Youngjoon Kwon
Yonsei Univ. / Belle







Contents

- Introduction

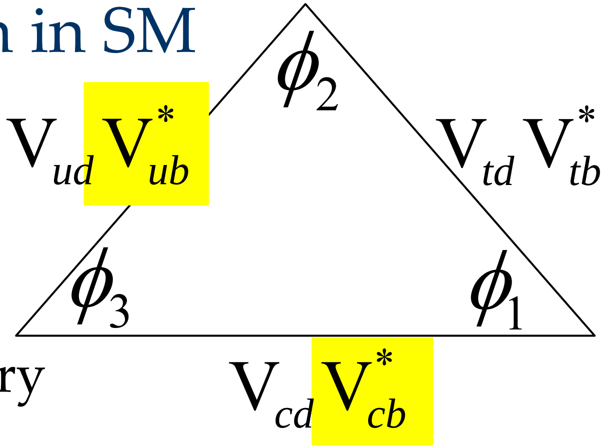
- Analyses for V_{ub}
  - Inclusive $B \to X_u l \nu$ with full-recon. **PRL submitted, hep-ex/0505088**
  - Inclusive $B \to X_u l \nu$ with end-point **PLB accepted, hep-ex/0504046**
  - Exclusive $B \to X_u l \nu$ with semileptonic tag. *(prelim.)*

- Analyses towards precise V_{cb}
  - Inclusive $B \to X e \nu$ with full-recon. **PLB 614, 27 (2005)**
  - $B \to X l \nu$ hadronic mass moments *(prelim.)*
  - $B \to X l \nu$ lepton energy moments *(prelim.)*

Motivation

- Fundamental free parameters
  - Majority of free parameters in the SM are related to quark (and lepton) flavors : masses and mixings
  - Quark flavor mixing through **CKM** matrix

- Unitarity triangle
  - Direct test of CP violation mechanism in SM
  - V_{ub}: still a weak link in CKM test
  - V_{cb} : as fundamental as V_{ub}
    - Super-high precision, experimentally
    - A good testing ground of strong int. theory



Issues in V_{ub} measurement

- Use $B \to X_u \, l \, \nu$ (semileptonic)
  - Cleaner, better understood than B → hadronic
  - More accessible than B → leptonic
  - Inclusive and Exclusive
- Experimentally challenging

$$|V_{cb}| \gg |V_{ub}|$$

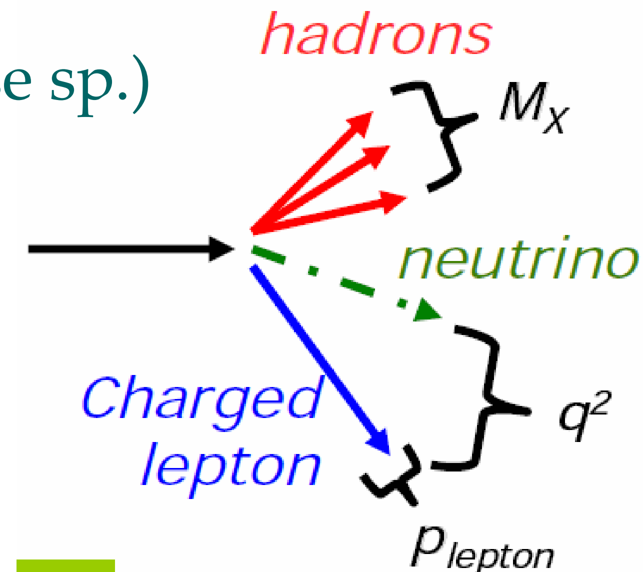
- Tight selection criteria results in

  Limited phase space

  → Extra theoretical uncertainties (from extrapolation)

Variables to suppress $b \rightarrow c\, l\, \nu$

- $p_l > \frac{\left(M_B^2 - M_D^2\right)}{2M_B} \approx 2.3\ \mathrm{GeV}/c$ (10% phase sp.)
- $q^2 > \left(M_B - M_D\right)^2 \approx 11\ \left(\mathrm{GeV}/c\right)^2$ (~80%)
- $M_X < M_D \approx 1.8\ \mathrm{GeV}/c^2$ (~30%)



* $P_+ < M_D^2 / M_B \approx 0.66\ \mathrm{GeV}$

$\left(P_+ \equiv E_X - \left|\vec{p}_X\right|\right)$

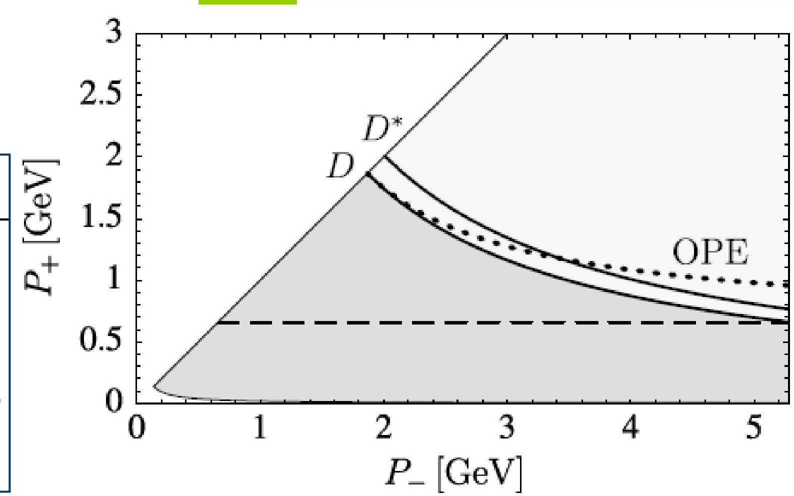
PHYSICAL REVIEW LETTERS

Proposal for a Precision Measurement of $|V_{ub}|$

Stefan W. Bosch, Björn O. Lange, Matthias Neubert, and Gil Paz

igh-Energy Phenomenology, Laboratory for Elementary-Particle Physics, Cornell
Ithaca, New York 14853, USA

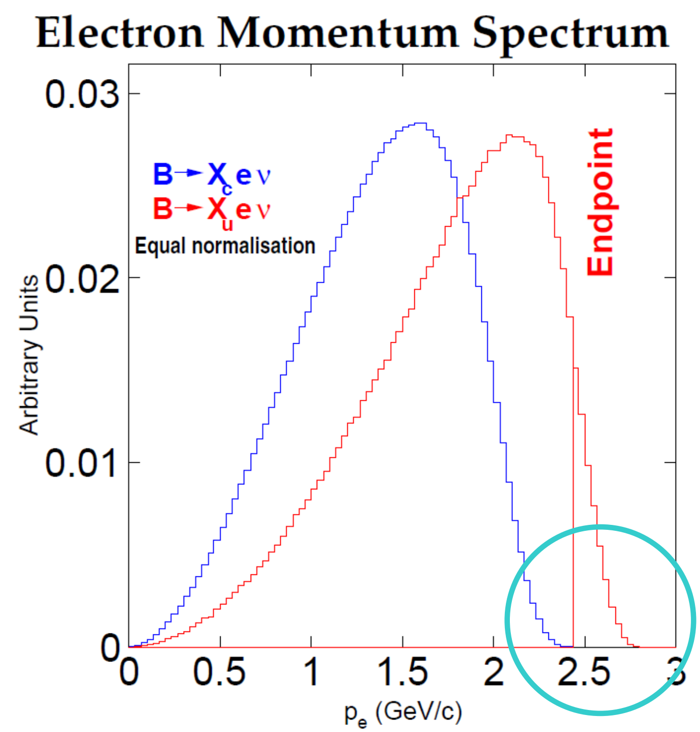
(Received 22 March 2004; published 22 November 2004)



Inclusive $B \rightarrow X_u l \nu$ with End-point

Main features

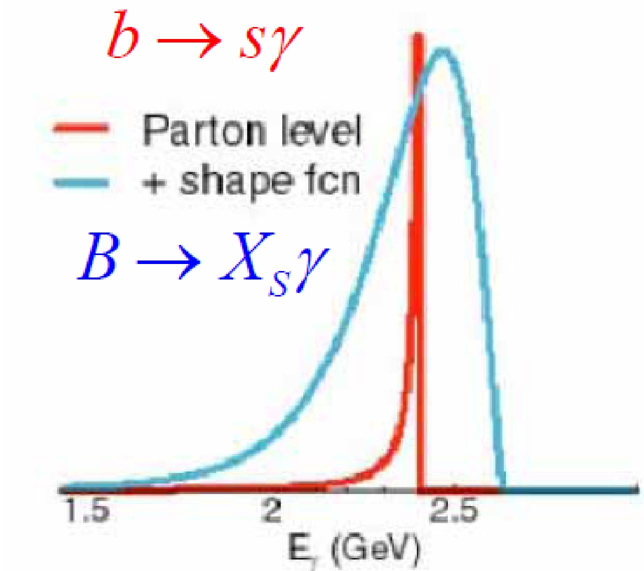
- Measure $\Delta\mathcal{B}(B \to X_u\, e\, \nu,\ p_e > p_{cut})$
- Kinematic selection
  - $p_e > p_{cut}$
  - p_{cut} = 1.9, 2.0, 2.1, 2.2, 2.3 and 2.4 GeV/c
- No requirement other than on the signal electron
  - high statistics
- Large background from $B \to X_c\, e\, \nu$
  - bkg. sys. uncertainty

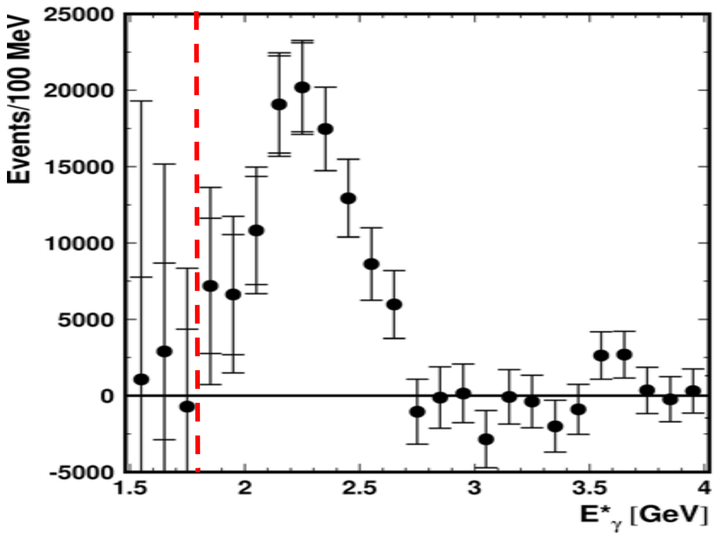


OPE breaks down
→ need shape ftn.!

b-quark Shape Function

- What is it?
  - b-quark Fermi motion inside the B-meson
- How to get it?
  - Universal at leading order for all $b \rightarrow$ light quark transitions
  - Use E(γ) in B → X_s γ





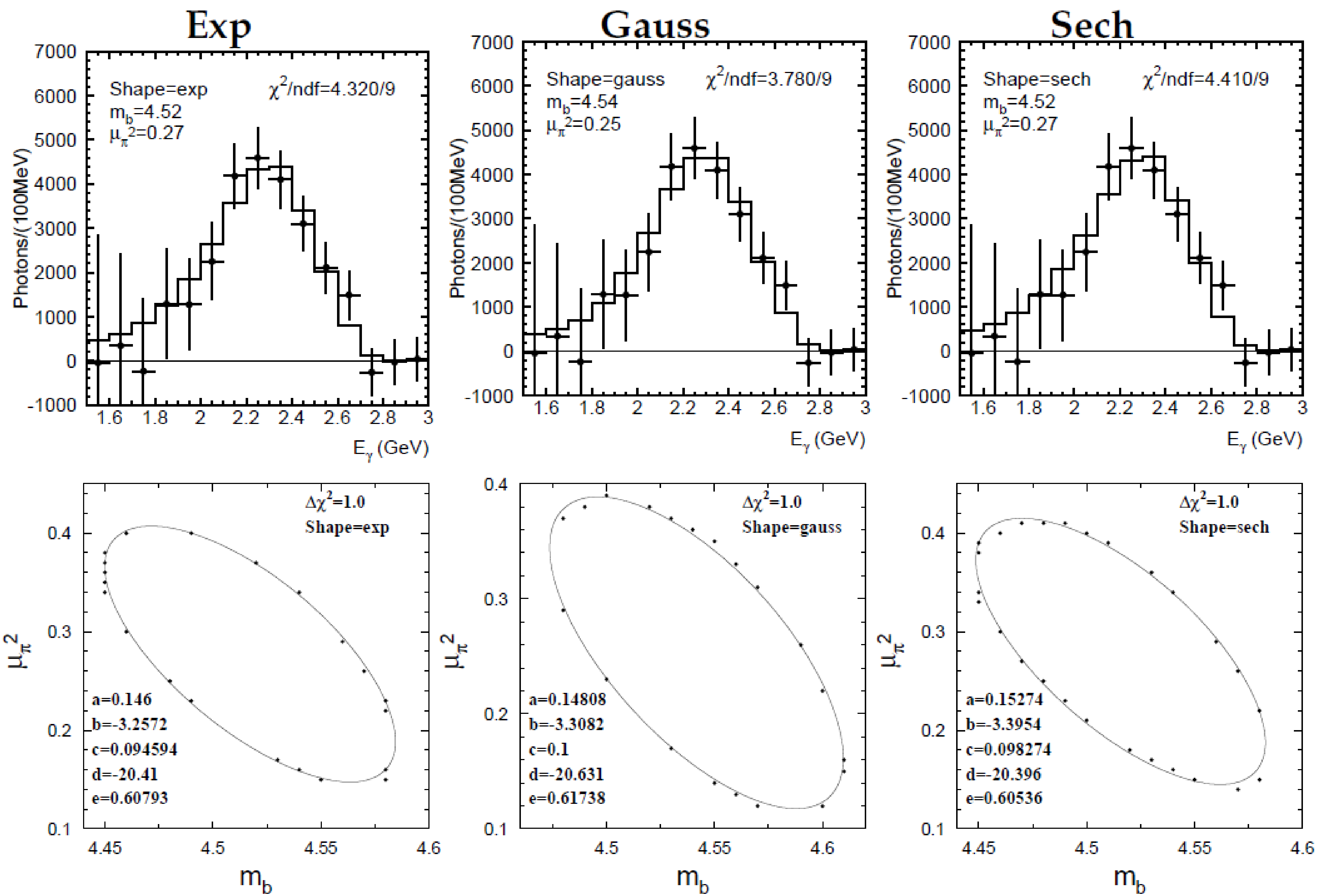
Three models for SF

$$F^{(\mathrm{exp})}(\hat{\omega};\Lambda,b) = \frac{N^{(\mathrm{exp})}}{\Lambda}\left(\frac{\hat{\omega}}{\Lambda}\right)^{b-1}\exp\left(-d_{(\mathrm{exp})}\frac{\hat{\omega}}{\Lambda}\right),$$

$$F^{(\mathrm{gauss})}(\hat{\omega};\Lambda,b) = \frac{N^{(\mathrm{gauss})}}{\Lambda}\left(\frac{\hat{\omega}}{\Lambda}\right)^{b-1}\exp\left(-d_{(\mathrm{gauss})}\frac{\hat{\omega}^2}{\Lambda^2}\right),$$

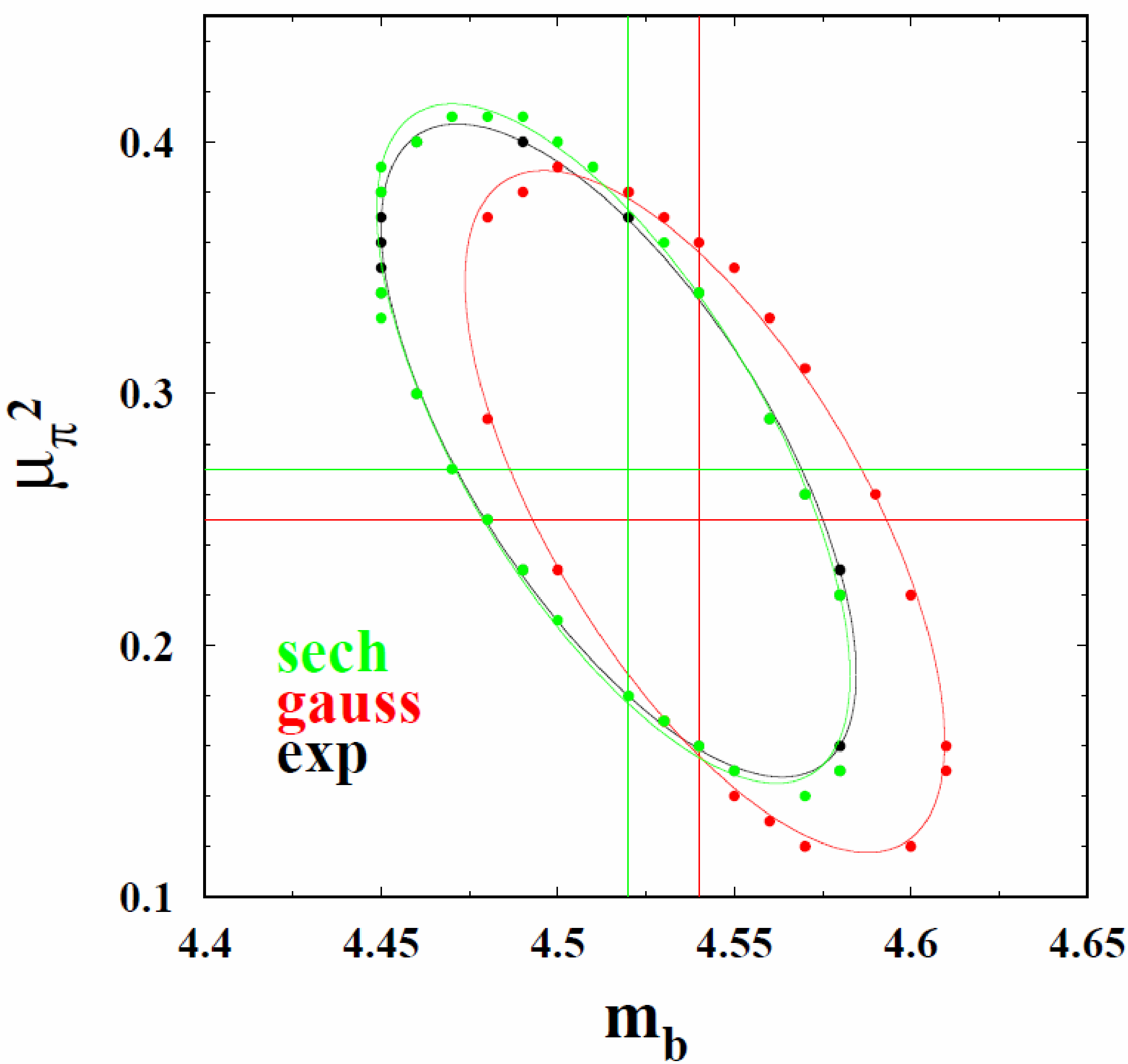
$$F^{(\mathrm{hyp})}(\hat{\omega};\Lambda,b) = \frac{N^{(\mathrm{hyp})}}{\Lambda}\left(\frac{\hat{\omega}}{\Lambda}\right)^{b-1}\cosh^{-1}\left(d_{(\mathrm{hyp})}\frac{\hat{\omega}}{\Lambda}\right).$$

Neubert & Paz, hep-ph/0504071



$m_b = 4.52, \mu_\pi^2 = 0.27$ $m_b = 4.54, \mu_\pi^2 = 0.25$ $m_b = 4.52, \mu_\pi^2 = 0.27$

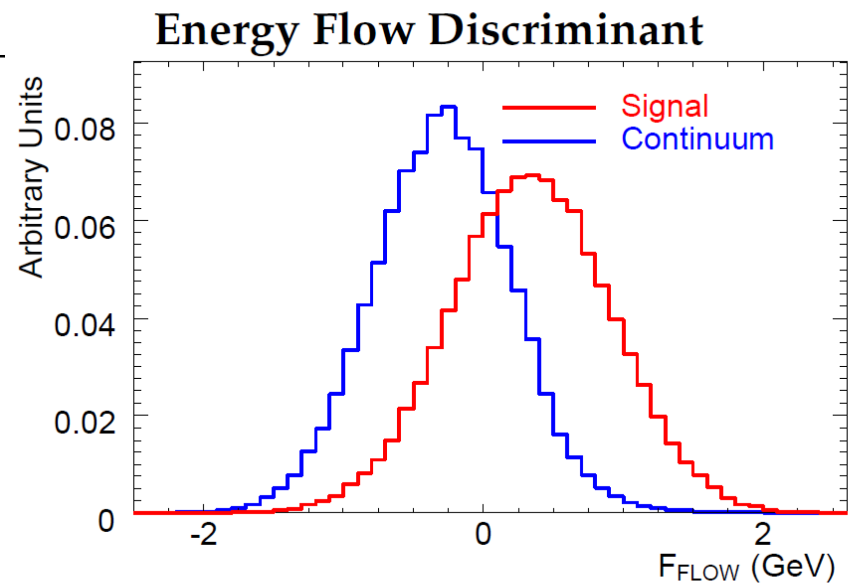
1σ Contour

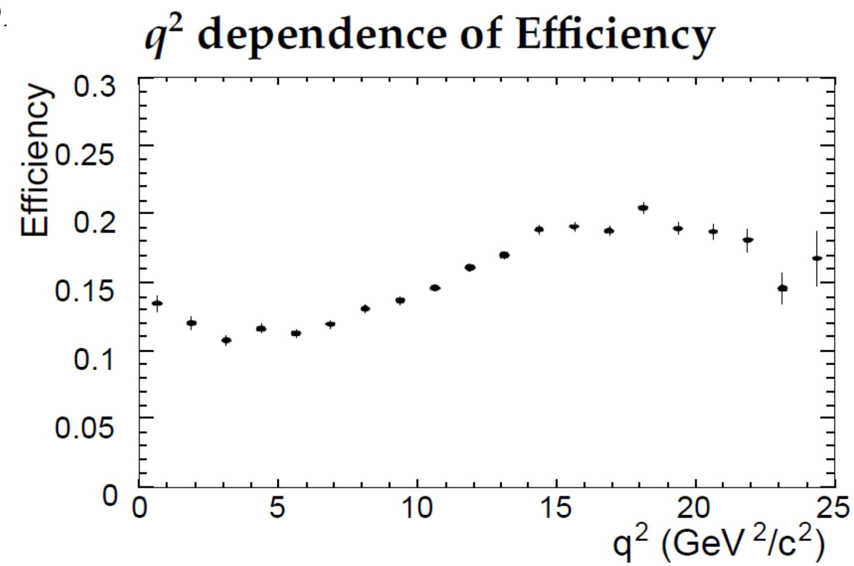


$$m_b = 4.52 \pm 0.07\ \text{GeV},\ \ \mu_\pi^2 = 0.27 \pm 0.13\ \text{GeV}^2$$

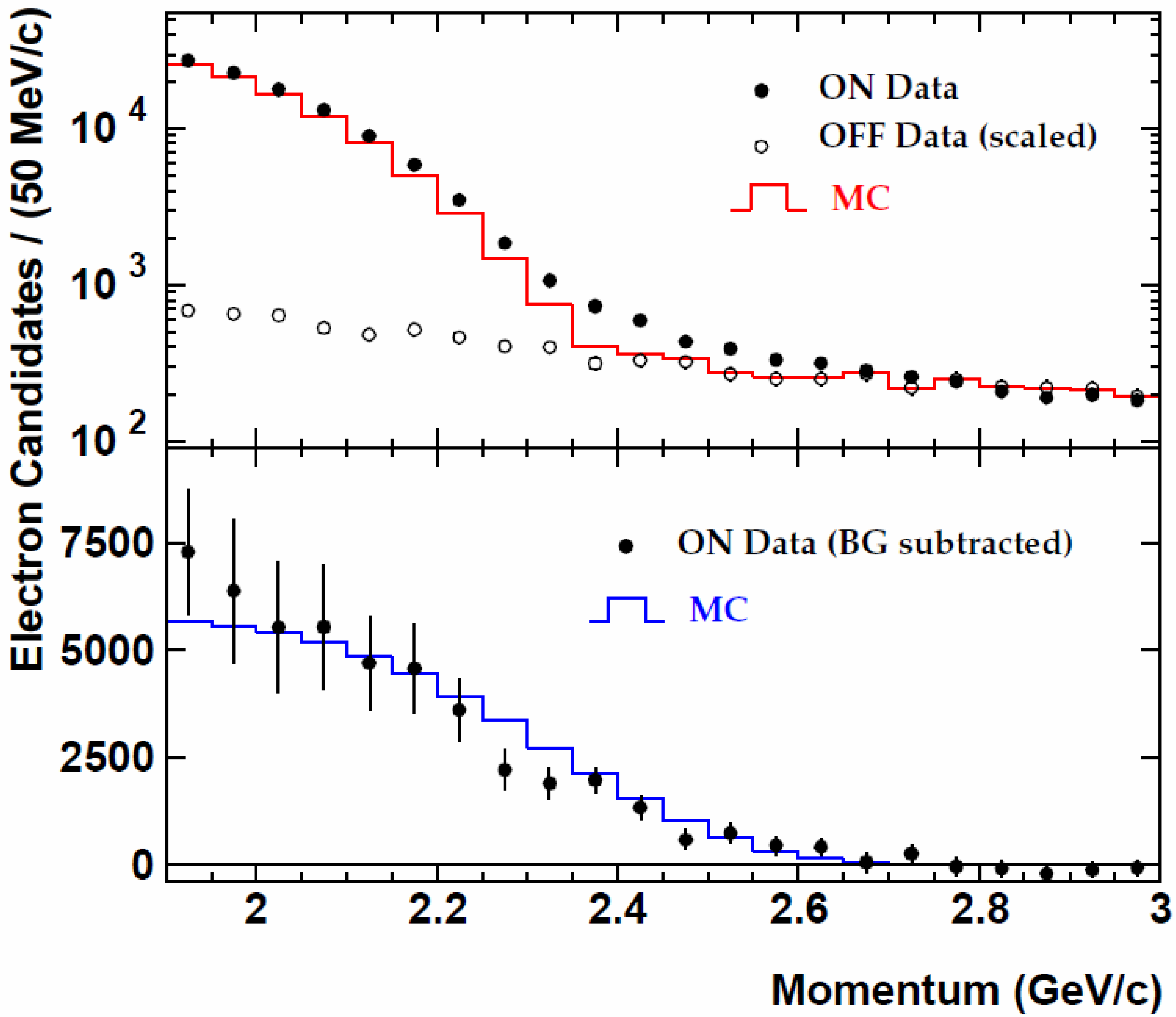
Event Selection

- Hadronic events
- Electrons in the barrel region
  - eff. ~ 94%; fake rate ~ 0.13%
  - J/ψ, $\psi(2S)$, γ, π^0 veto
- Continuum suppression
  - Fox-Wolfram moment
  - Fisher disc. for energy-flow variab
  - $|\cos\theta_{th}| < 0.75$
  - as q^2 independent as possible
- Background estimated by
  - $b \rightarrow c$ MC and Off-resonance Data
  - low-p region for check $1.5 < p_e < p_{cut}$ (GeV/c)





E(e) spectrum for $B \rightarrow X_u e \nu$



$\Delta\mathcal{B}$ – partial BF

$$\Delta B_u = \frac{N(X_u l \nu)}{2N_{BB} \cdot \varepsilon_{MC}}$$

p_{CM}	ε_{MC}	$\Delta B_u(p)$ (in 10^{-4})
$1.9-2.6$	18.0 ± 0.9	$8.47 \pm 0.37 \pm 1.53$
$2.0-2.6$	17.6 ± 0.9	$5.74 \pm 0.28 \pm 0.98$
$2.1-2.6$	17.2 ± 0.9	$3.78 \pm 0.20 \pm 0.48$
$2.2-2.6$	16.6 ± 0.9	$2.17 \pm 0.14 \pm 0.20$
$2.3-2.6$	16.5 ± 0.9	$1.18 \pm 0.10 \pm 0.07$
$2.4-2.6$	16.2 ± 1.0	$0.53 \pm 0.07 \pm 0.03$

- Two methods for $\Delta\mathcal{B}$ → V_{ub}
  - **Standard method** (DFN, JHEP 9906, 017)

$$|V_{ub}| = 0.00424\sqrt{\frac{\mathcal{B}(B \to X_u e\nu_e)}{0.002}\frac{1.604\ \mathrm{ps}}{\tau_B}} \times (1.0 \pm 0.028_{\lambda_{1,2}} \pm 0.039_{m_b})$$

  - **New method** (BLNP, NP B699 (2004))

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(1+\delta_{\mathrm{RAD}})}{\tau_B}\frac{1}{R}}$$

V_{ub} from $\Delta\mathcal{B}$

DFN

p_{CM} (GeV/c)	δ_{RAD}	$\mathcal{B}(B \to X_u e \nu_e)(10^{-3})$	$\lvert V_{ub}\rvert(10^{-3})$(DFN)
$1.9 - 2.6$	0.06 ± 0.02	$2.80 \pm 0.52 \pm 0.41$	$5.01 \pm 0.47 \pm 0.17 \pm 0.32 \pm 0.24$
$2.0 - 2.6$	0.07 ± 0.02	$2.49 \pm 0.45 \pm 0.47$	$4.73 \pm 0.42 \pm 0.19 \pm 0.40 \pm 0.23$
$2.1 - 2.6$	0.07 ± 0.02	$2.34 \pm 0.33 \pm 0.59$	$4.59 \pm 0.32 \pm 0.22 \pm 0.53 \pm 0.22$
$2.2 - 2.6$	0.09 ± 0.03	$2.16 \pm 0.25 \pm 0.73$	$4.41 \pm 0.25 \pm 0.27 \pm 0.69 \pm 0.21$
$2.3 - 2.6$	0.10 ± 0.03	$2.22 \pm 0.24 \pm 1.02$	$4.47 \pm 0.24 \pm 0.36 \pm 0.96 \pm 0.22$
$2.4 - 2.6$	0.11 ± 0.04	$2.39 \pm 0.38 \pm 1.46$	$4.63 \pm 0.37 \pm 0.53 \pm 1.32 \pm 0.22$

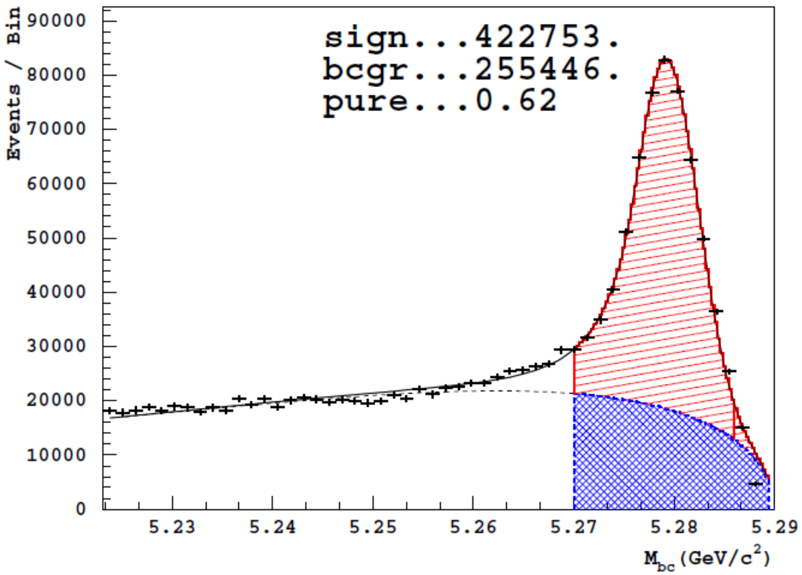
BLNP

p_{CM} (GeV/c)	R ($\lvert V_{ub}\rvert^2$ps^{-1})	$\lvert V_{ub}\rvert$ (10^{-3})(BLNP)
$1.9 - 2.6$	$21.69 \pm 3.62 ^{+2.18}_{-1.98}$	$5.08 \pm 0.47 \pm 0.42 ^{+0.26}_{-0.23}$
$2.0 - 2.6$	$16.05 \pm 3.05 ^{+1.83}_{-1.72}$	$4.87 \pm 0.43 \pm 0.46 ^{+0.28}_{-0.26}$
$2.1 - 2.6$	$10.86 \pm 2.51 ^{+1.61}_{-1.57}$	$4.83 \pm 0.33 \pm 0.56 ^{+0.36}_{-0.35}$
$2.2 - 2.6$	$6.46 \pm 1.54 ^{+1.54}_{-1.53}$	$4.77 \pm 0.26 \pm 0.57 ^{+0.57}_{-0.56}$
$2.3 - 2.6$	$3.15 \pm 0.88 ^{+1.55}_{-1.54}$	$5.07 \pm 0.71 \pm 0.52 ^{+1.25}_{-1.24}$
$2.4 - 2.6$	$1.12 \pm 0.39 ^{+1.48}_{-1.48}$	$5.70 \pm 1.00 \pm 0.67 ^{+3.77}_{-3.76}$

Inclusive B → X_u l ν with Full-Recon.

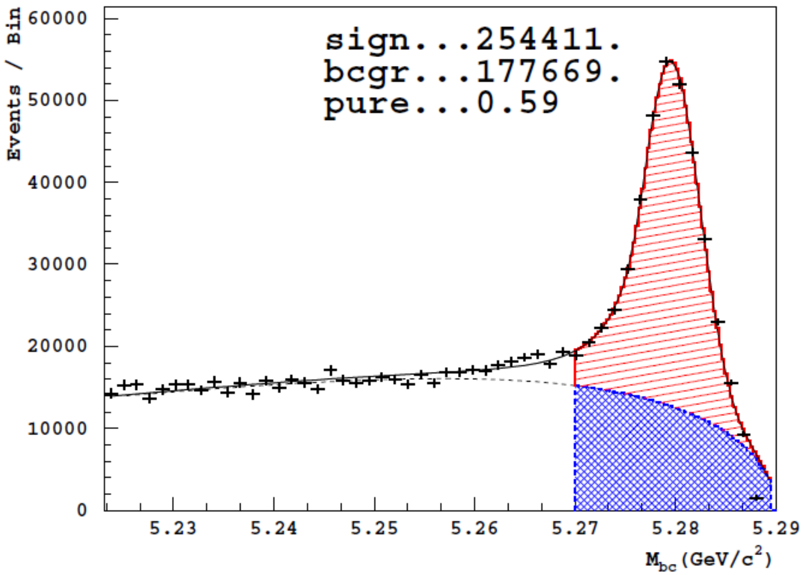
Full Reconstruction

M_{bc} for Reconstructed $B^{\pm}$



4.2×10^5 evts./253 fb^{-1}
effic. = 0.33%
purity = 62%

M_{bc} for Reconstructed B^0



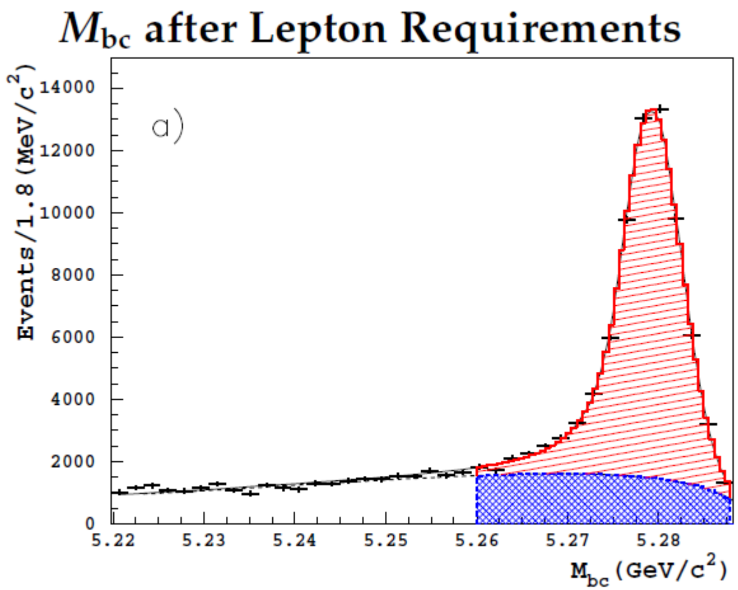
2.5×10^5 evts./253 fb^{-1}
effic. = 0.21%
purity = 59%

Signal selection

Lepton Selection

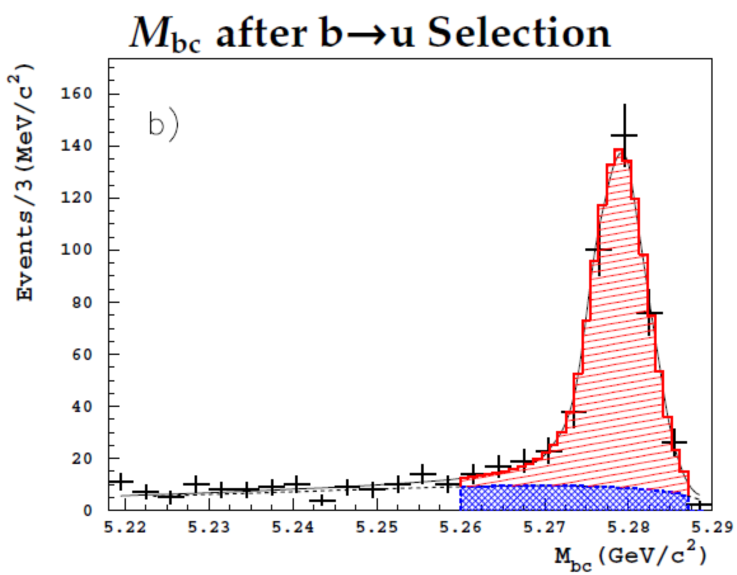
- $p > 1$ GeV/c
- leptons in the barrel region
  - J/ψ, γ, π^0 veto
- Correct charge for B+ candidate
- No other lepton

$N_{sl} = (9.15 \pm 0.05) \times 10^4$



For $b \rightarrow u$

- Total charge = 0
- $-1.0 < m^2_{\rm miss} < 0.5\,{\rm GeV}^2$
- $|\cos\theta_{\rm miss}| < 0.95$
- No reconstructed K_S or $K^\pm$

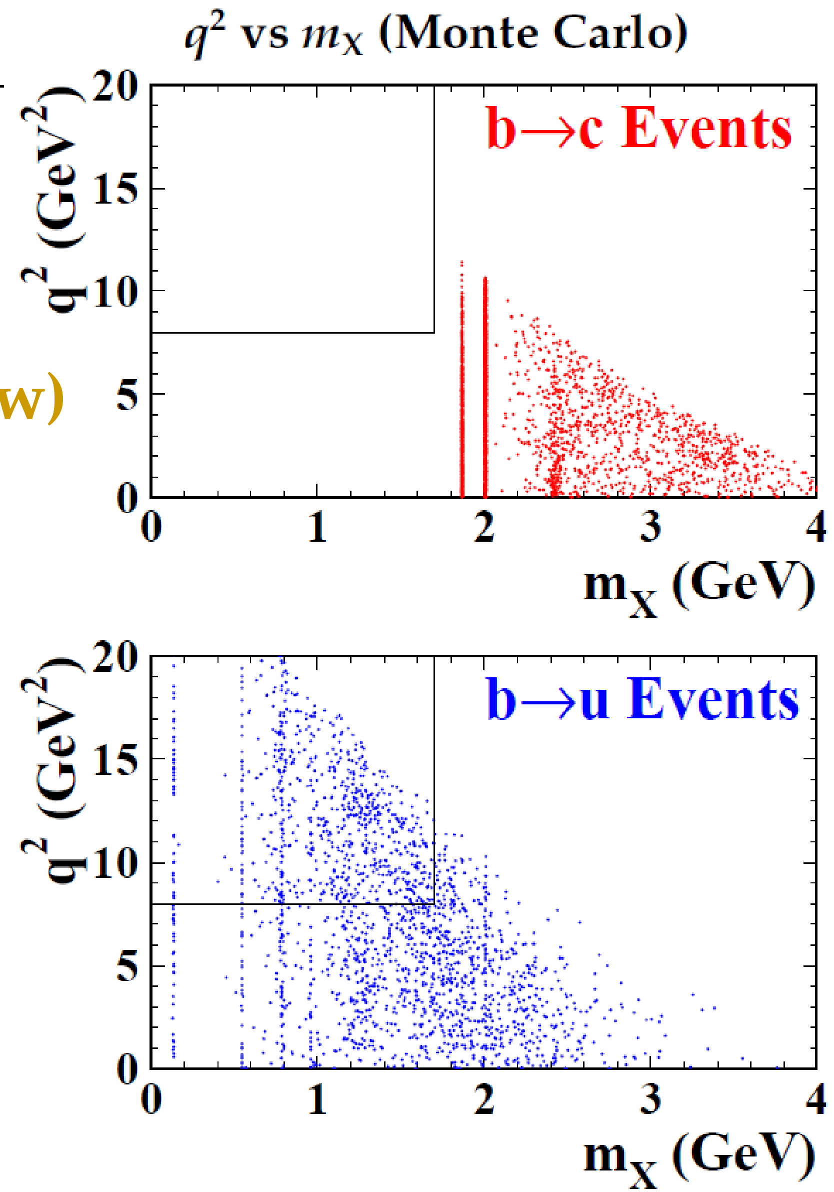


Kinematic selections

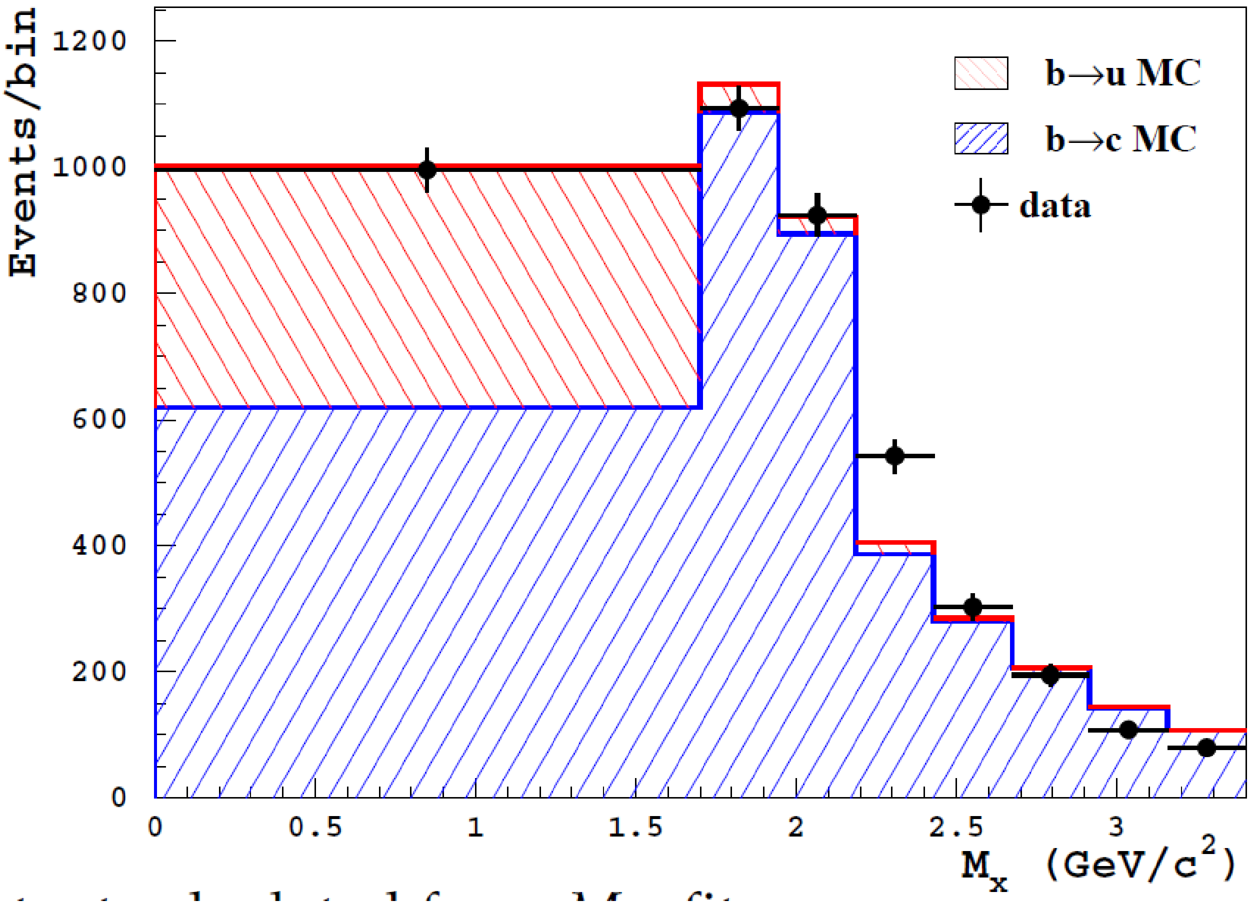
(1) $M_X < 1.7\,\text{GeV}$

(2) $M_X < 1.7\,\text{GeV}, \quad q^2 > 8\,\text{GeV}^2$

(3) $P_+ \equiv E_X - |\vec{p}_X| < 0.66\,\text{GeV}$ **(New)**

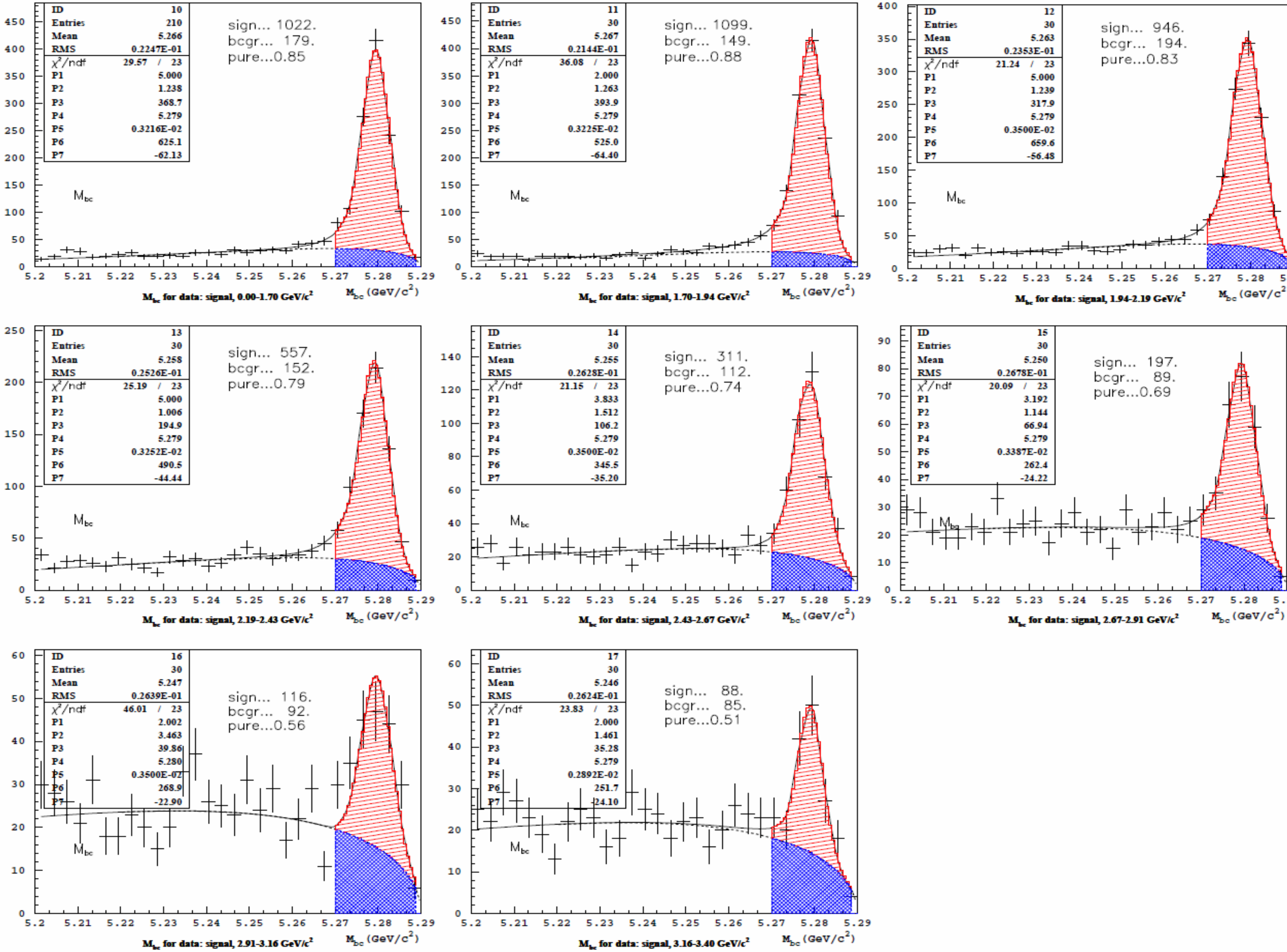


(1) $M_X < 1.7$ GeV

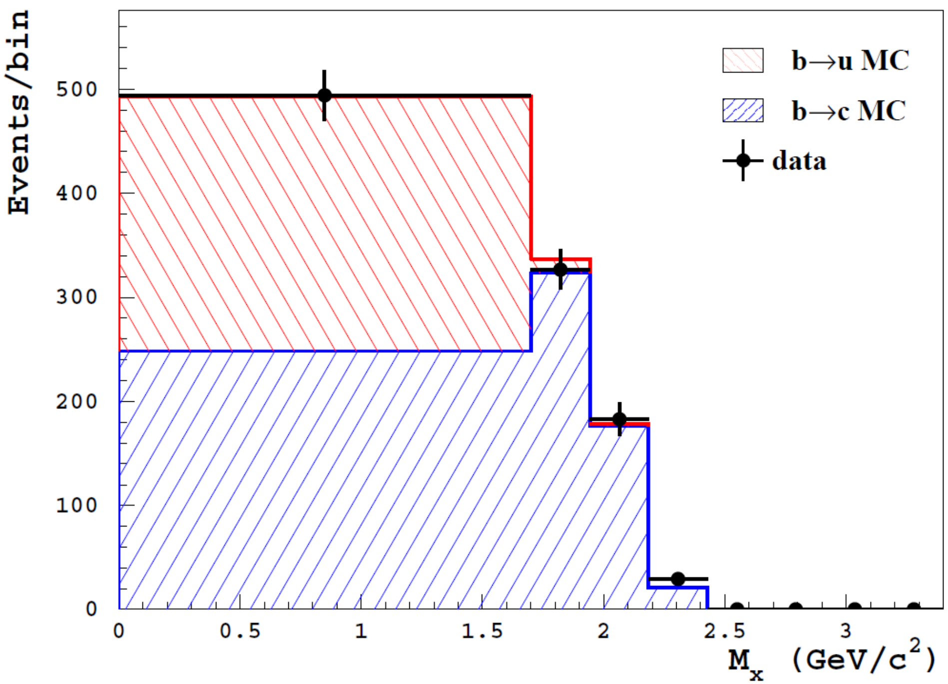


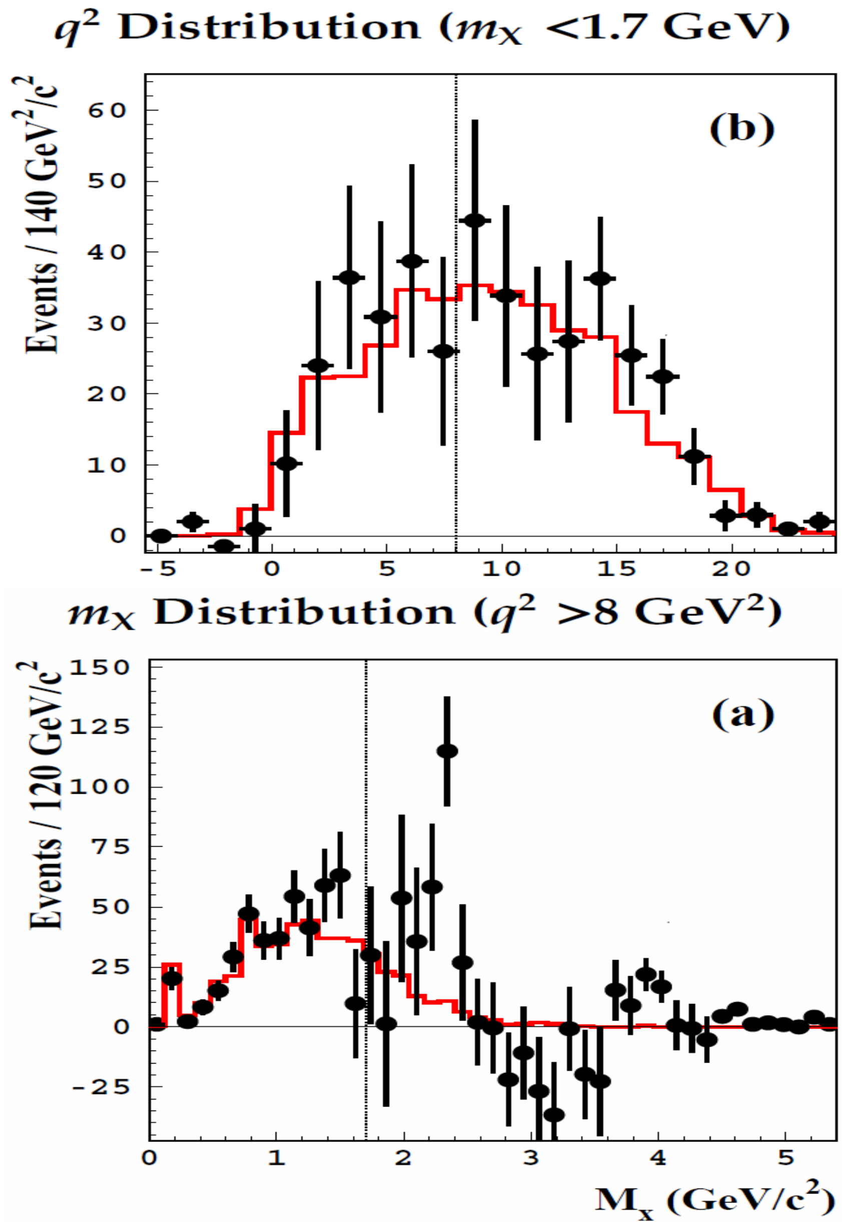
- Each bin content is calculated from Mbc fit
- 2-component fit to extract N(b→u)

Each Bin Content

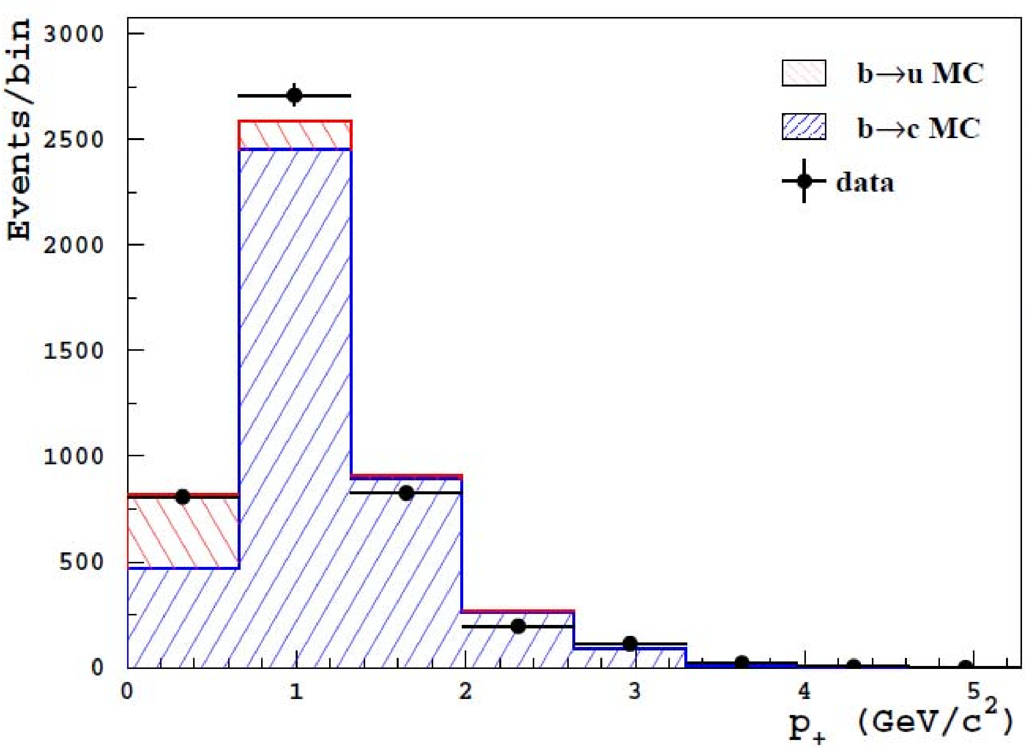


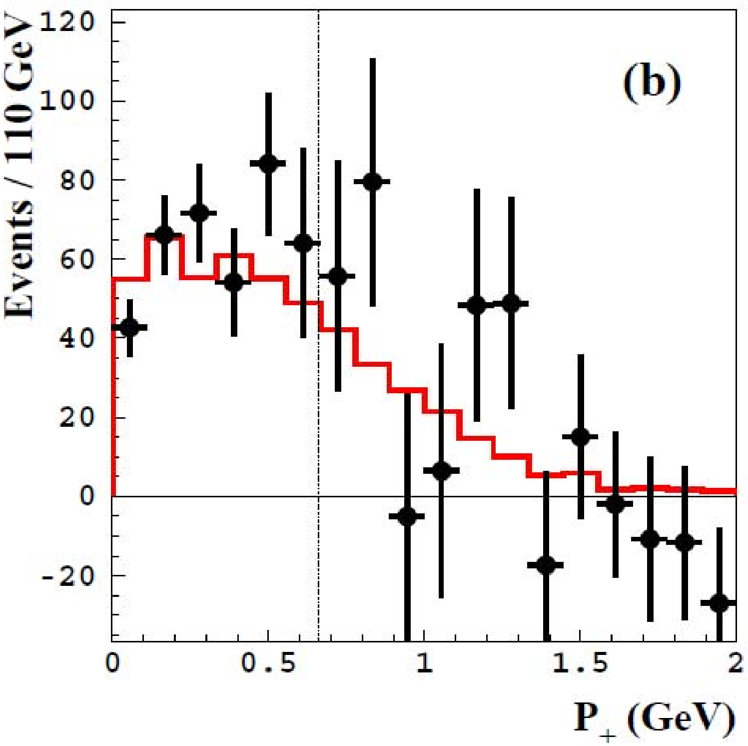
(2) $M_X < 1.7$ GeV & $q^2 > 8$ GeV^2





(3) $P_+ < 0.66$ GeV





– First measurement using P_+

Signal Yield & $\Delta\mathcal{B}$

TABLE I: $N^{\rm raw}_{b\to u}$, $\varepsilon^{b\to u}_{\rm sel}$, F and $r^{\rm sl}_{b\to u}$ for the three kinematic signal regions.

	$N^{\rm raw}_{b\to u}$	$\varepsilon^{b\to u}_{\rm sel}$	F	$r^{\rm sl}_{b\to u}$
M_X/q^2	268 ± 27	26.5%	1.03	0.687 ± 0.014
M_X	404 ± 37	28.7%	1.07	0.700 ± 0.011
P_+	340 ± 32	25.5%	1.01	0.700 ± 0.012

$$\frac{\Delta\mathcal{B}(B\to X_u\ell\nu)}{\mathcal{B}(B\to X\ell\nu)} = \frac{N^{\rm raw}_{b\to u}}{N_{\rm sl}} \times \frac{F}{\varepsilon^{b\to u}_{\rm sel}} \times \frac{\varepsilon^{\rm sl}_{\rm frec}}{\varepsilon^{b\to u}_{\rm frec}} \times \frac{\varepsilon^{\rm sl}_{\ell}}{\varepsilon^{b\to u}_{\ell}}$$

$\mathcal{B}(B\to X\ell\nu) = (10.73 \pm 0.28)\%$

$\frac{\varepsilon^{\rm sl}_{\rm frec}}{\varepsilon^{b\to u}_{\rm frec}} \times \frac{\varepsilon^{\rm sl}_{\ell}}{\varepsilon^{b\to u}_{\ell}} \equiv r^{\rm sl}_{b\to u}$

V_{ub} from $\Delta\mathcal{B}$

- New method
  - V_{ub} directly from $\Delta\mathcal{B}$

    R by Bosch, Lange, Neubert, Paz, NPB699 (2004)

    with an improved treatment of shape-function effects

    + weak annihilation effects estimated

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(B \to X_u \ell \nu)}{\mathcal{R} \cdot \tau_B}}$$

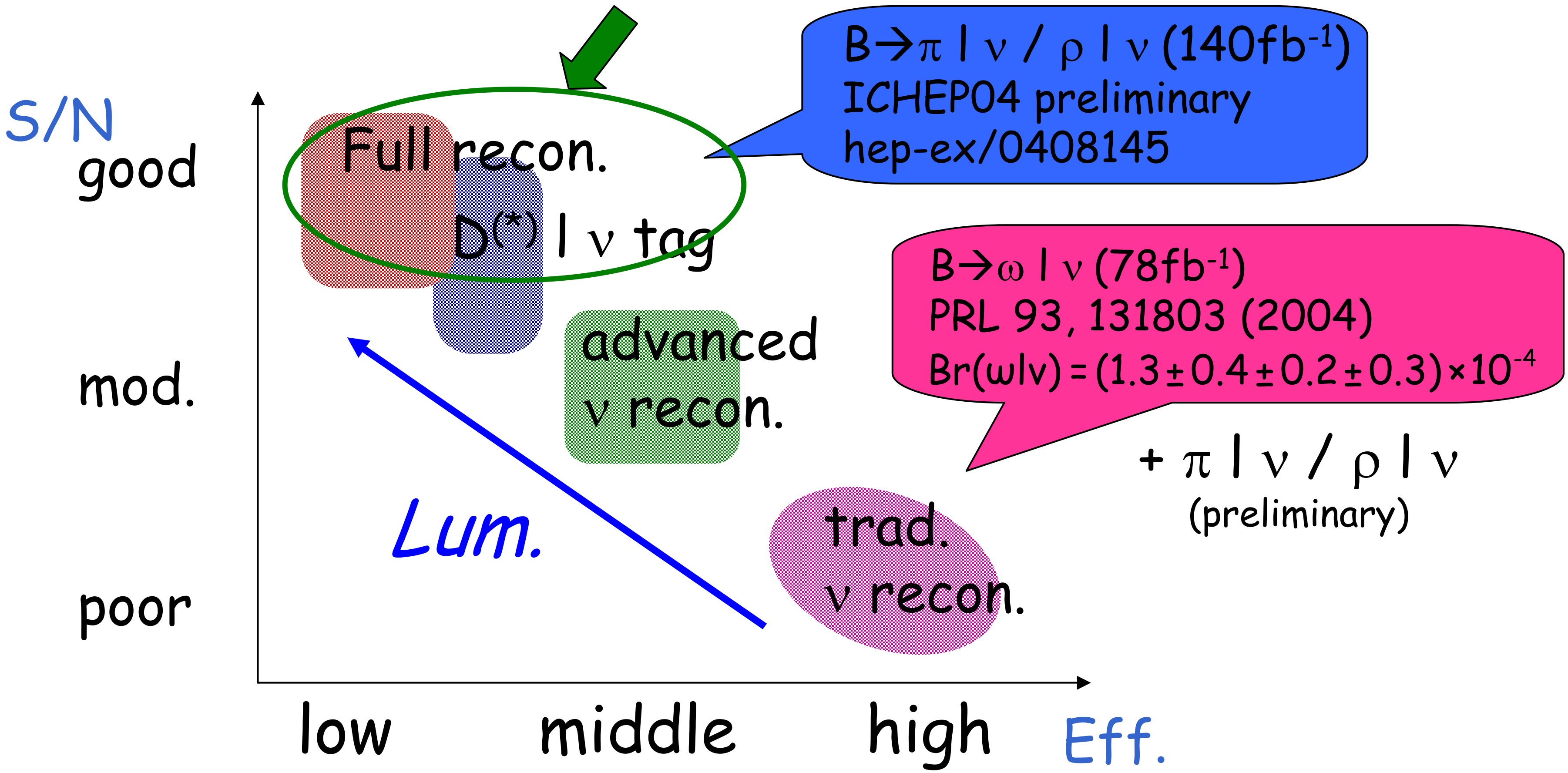
$$R(\text{ps}^{-1}) = \begin{cases} 21.6 \pm 4.0(SF)^{+2.4}_{-2.3}(thy.) & M_X / q^2 \\ 40.9 \pm 7.5(SF)^{+3.2}_{-2.9}(thy.) & M_X \\ 33.2 \pm 6.8(SF)^{+2.3}_{-2.3}(thy.) & P_+ \end{cases}$$

	$\lvert V_{ub}\rvert$	stat	syst	$b\to u$	$b\to c$	SF	theo.
m_X-q^2	4.93×10^{-3}	5.0	4.4	3.1	2.7	9.3	$^{+5.0}_{-5.5}$
m_X	4.35×10^{-3}	4.6	3.5	3.1	1.1	9.2	$^{+3.6}_{-3.9}$
P_+	4.56×10^{-3}	4.7	4.6	3.2	4.4	10.2	$^{+3.4}_{-3.5}$

Exclusive B → X_u l ν with S.L. tag

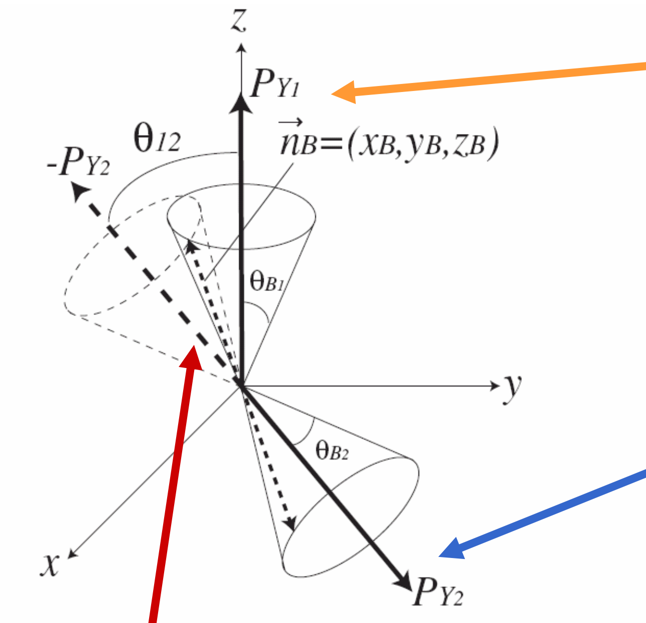
Experimental Strategy

Unique opportunity at e+e- B-factory!



How well can we measure the q^2 dist. (for π l ν) ?

Analysis Method



Tag side reconstruction

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

↳ $D^0\pi^+\,/\,D^+\pi^0$

↳ 4 decay modes

↳ 7 decay modes

Signal side reconstruction

$B_{sig} \to X_u\,\ell^+\,\nu \qquad P_\ell > 0.8\,GeV/c$

↳ π^- or $\pi^-\pi^0$

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

Kinematics of double semileptonic decay

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

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

To have intersection, need $0 \le {x_B}^2 \le 1$

2-fold ambiguity → q^2 calculated neglecting the B motion in $\Upsilon(4S)$

q^2 resolution = 0.75 GeV^2

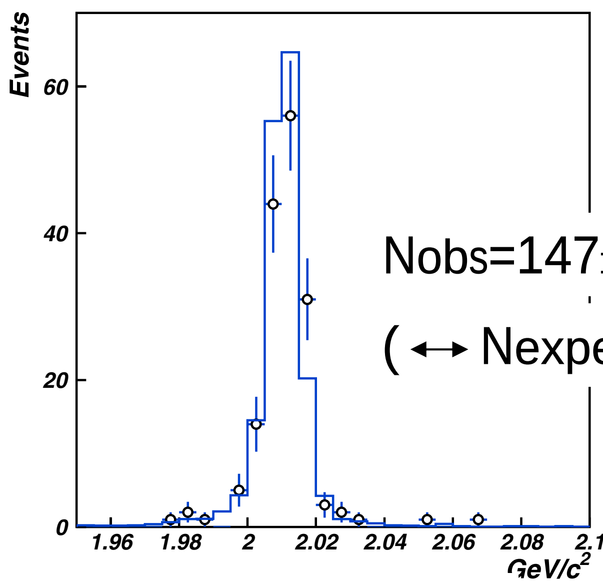
Calibration with $B_{sig} \rightarrow D^* l \nu$ Decays

- Validity of the method for double semileptonic decay detection has been tested with $B_{sig} \rightarrow D^{*-} l^+ \overline{\nu}$

$\quad \hookrightarrow \overline{D}^0 \pi^-$

$\quad\quad \hookrightarrow K^+ \pi^-$

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

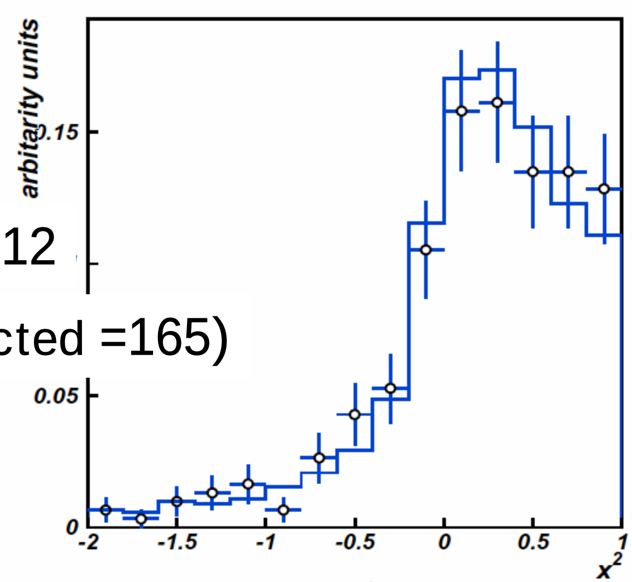


$M(K\pi\pi)$ GeV/c^2

Nobs=147±12

(↔ Nexpected =165)

x_B^2 distribution



x_B^2

Dots: Data

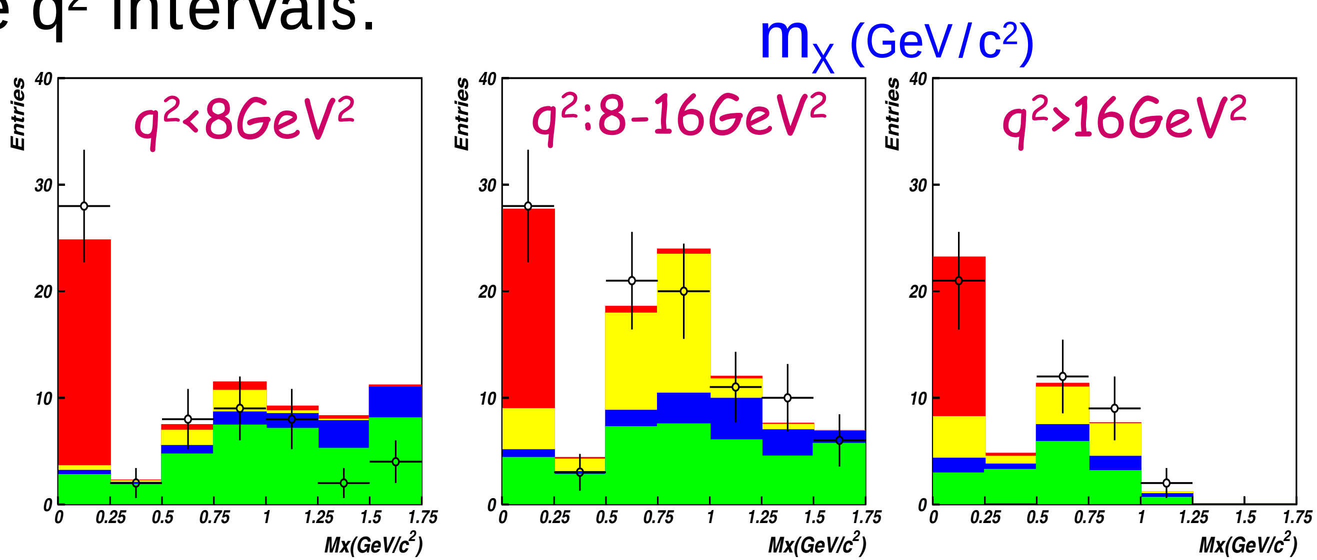
Histo: MC

- 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

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

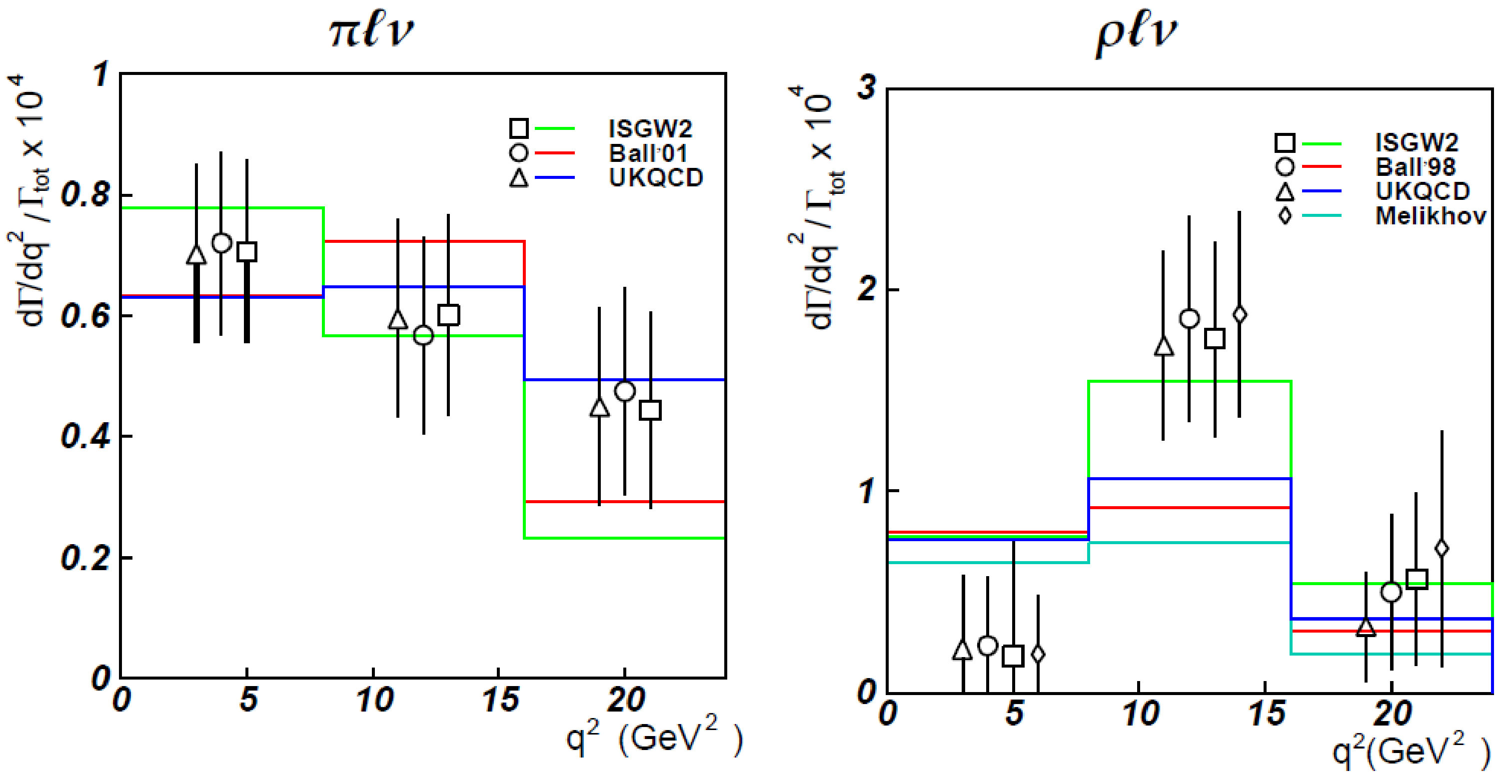


- Fitting components: $\pi l \nu$, $\rho l \nu$, other $Xu\ l \nu$, and BB
- PDF's are based on MC.
- Constraint for extracted Br:

$$Br(\pi l \nu) + Br(\rho l \nu) + Br(\text{other } X_u l \nu) = Br(X_u l \nu)$$

82±13 65±20

Results



- average Form-Factor Models
- variation as theory error

$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu) = (1.76 \pm 0.28(\text{stat.}) \pm 0.20(\text{sys.}) \pm 0.03(\text{FF})) \times 10^{-4}$$
$$\mathcal{B}(B^0 \to \rho^- \ell^+ \nu) = (2.54 \pm 0.78(\text{stat.}) \pm 0.85(\text{sys.}) \pm 0.30(\text{FF})) \times 10^{-4}$$

V_{ub} from exclusive $B \to X_u l \nu$

- V_{ub} determined with relation

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(B^0 \to \pi^- \ell^+ \nu)}{\Gamma_{th} \cdot \tau_B}}$$

- only $\pi^- \ell^+ \nu$ with $q^2 > 16\text{GeV}^2$ is used
- with Γ_{th} from Quenched LQCD

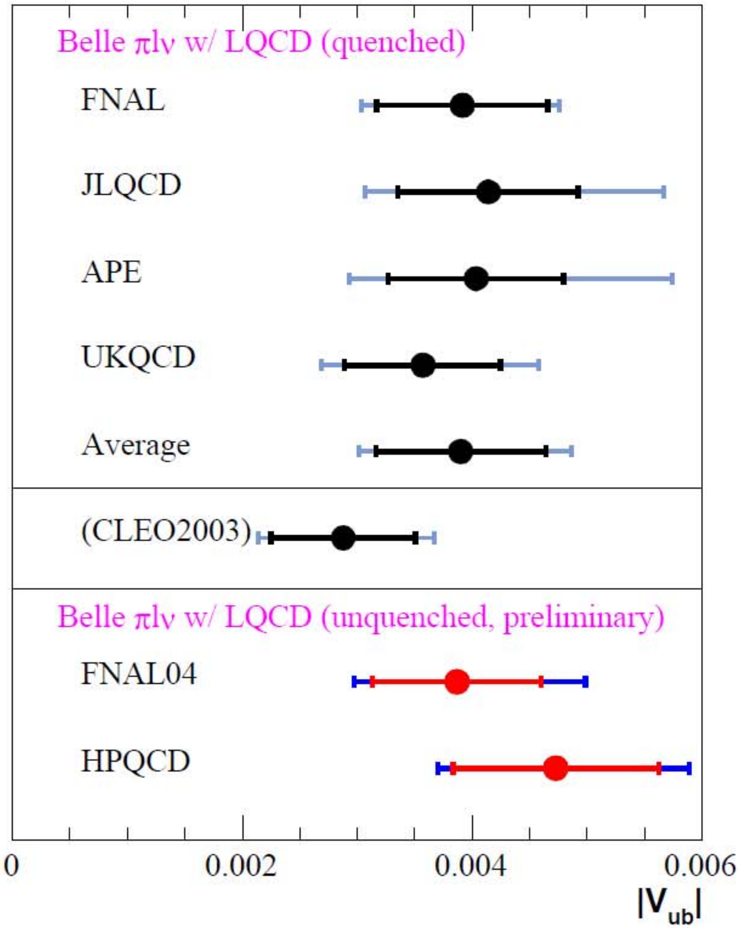
$$|V_{ub}| = (3.90 \pm 0.71 \pm 0.23^{+0.62}_{-0.48}) \times 10^{-3}$$

- with Γ_{th} from Unquenched LQCD

$$|V_{ub}| = (3.87 \pm 0.70 \pm 0.22^{+0.85}_{-0.51}) \times 10^{-3} \quad \text{(FNAL04)}$$

$$|V_{ub}| = (4.73 \pm 0.85 \pm 0.27^{+0.74}_{-0.50}) \times 10^{-3} \quad \text{(HPQCD)}$$

Belle Preliminary 140 fb^{-1}



Analyses towards precise V_{cb}

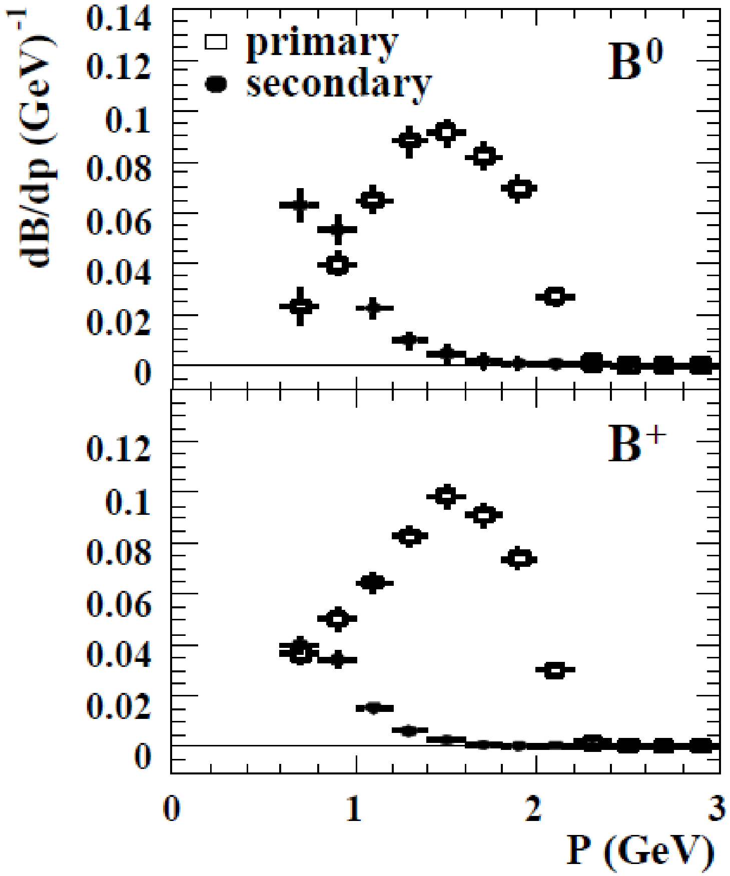
- Inclusive **B → X e ν** (0^{th} moment) PLB 614, 27 (2005)
- **B → X l ν** hadronic mass moments (*prelim.*)
- **B → X l ν** lepton energy moments (*prelim.*)

$\mathcal{B}(B \to X e \nu)$

PLB 614, 27 (2005)

- A.K.A. 0-th Moment
- Analysis with 140 fb^{-1}
- Full reconstruction in the Tag side
- Measure B^0 and $B^{\pm}$ seperately

Electron Momentum



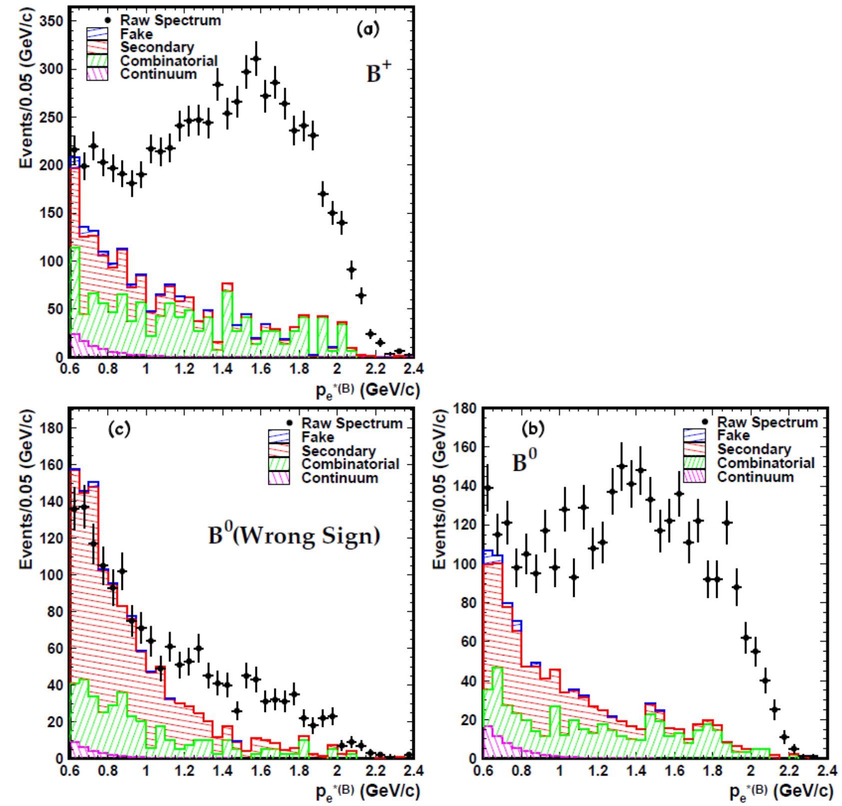
$$\mathcal{B}(B^0 \to X e \nu,\ p^* > 0.6\ \text{GeV}) = (\,9.83 \pm 0.34 \pm 0.33)\%$$

$$\mathcal{B}(B^{\pm} \to X e \nu,\ p^* > 0.6\ \text{GeV}) = (10.62 \pm 0.25 \pm 0.35)\%$$

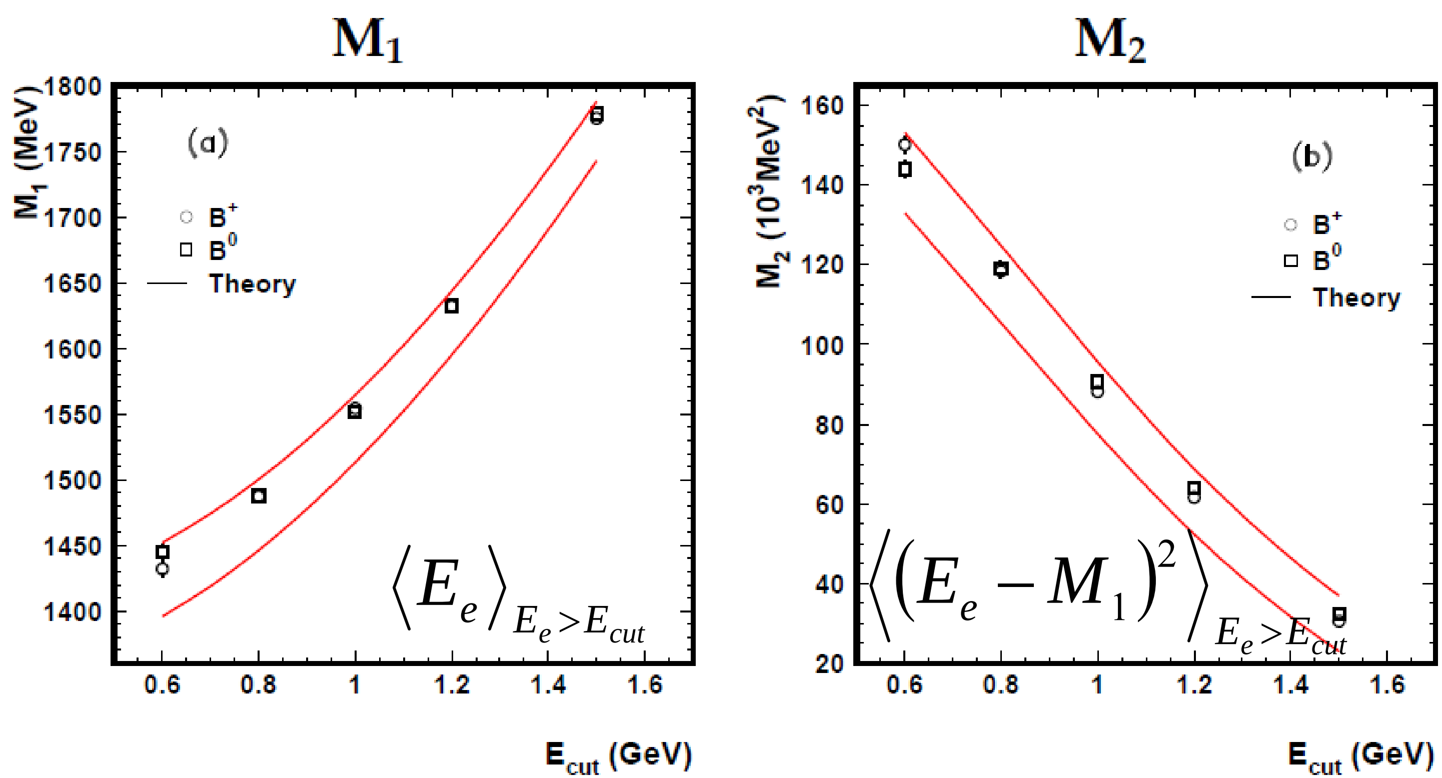
$$\frac{\mathcal{B}(B^{\pm} \to X e \nu,\ p^* > 0.6\ \text{GeV})}{\mathcal{B}(B^0 \to X e \nu,\ p^* > 0.6\ \text{GeV})} = 1.08 \pm 0.05 \pm 0.02$$

B → X l ν moments

- Leptonic and hadronic moments
  - Needed for global fit for precise V_{cb}
- Common features
  - *Preliminary* with **140 fb^{-1}**
  - Full-recon. in the tag side
  - Boost from B_{tag}
  - QED correction by PHOTOS
  - Mixing correction
  - Unfolded by SVD method



Leptonic moments

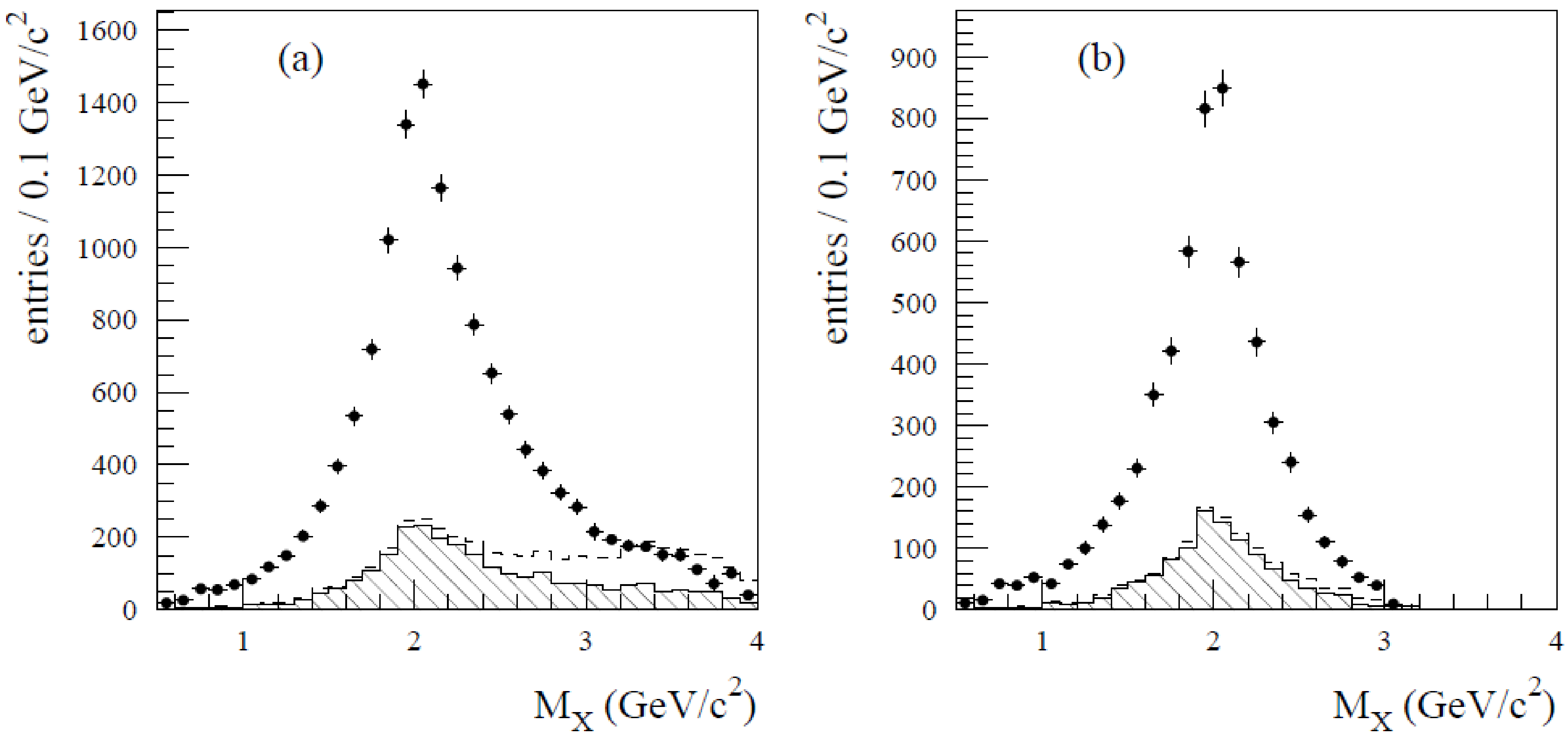


E^*_{cut} (GeV)	M_1 (MeV)		M_2 (10^3 MeV^2)	
	$B^\pm$	B^0	$B^\pm$	B^0
0.6	1432.1 ± 4.3 ± 3.6	1444.9 ± 5.5 ± 2.8	150.1 ± 1.8 ± 1.2	144.0 ± 2.1 ± 1.0
0.8	1487.1 ± 3.9 ± 2.2	1488.0 ± 5.1 ± 1.8	118.4 ± 1.4 ± 0.7	119.0 ± 1.8 ± 0.6
1.0	1554.1 ± 3.6 ± 1.1	1551.5 ± 4.7 ± 1.0	88.1 ± 1.1 ± 0.3	90.7 ± 1.4 ± 0.3
1.2	1631.7 ± 3.3 ± 0.7	1632.6 ± 4.3 ± 0.8	61.7 ± 0.8 ± 0.1	64.1 ± 1.1 ± 0.2
1.5	1774.8 ± 2.8 ± 0.7	1778.2 ± 3.8 ± 0.7	30.6 ± 0.5 ± 0.1	32.3 ± 0.7 ± 0.1

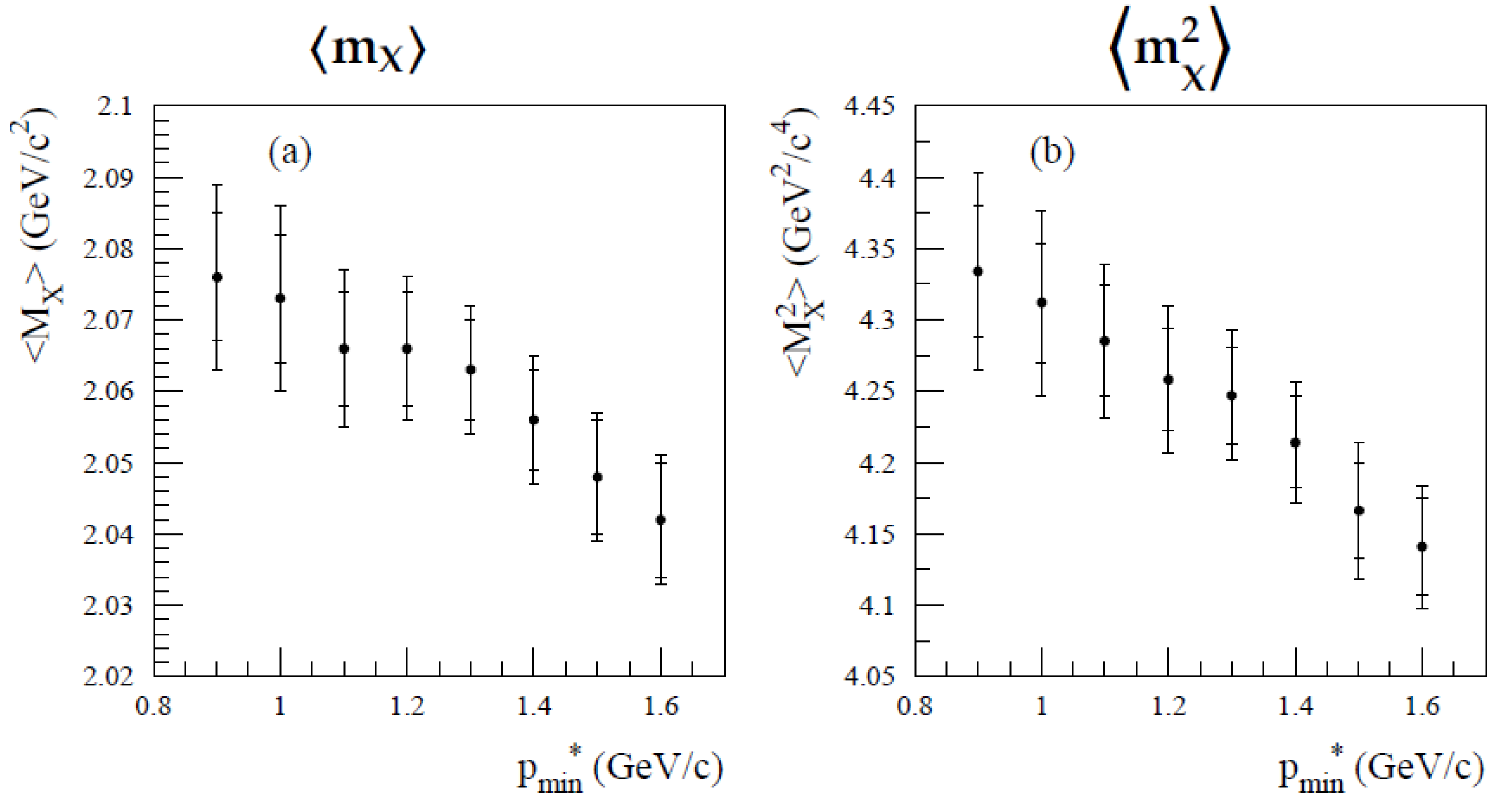
Hadronic moments

- $p_X = p_{\Upsilon_{4S}} - p_{B_{tag}} - p_\ell - p_\nu$
- M_X distribution

$p_\ell^* > 0.9$ GeV $\qquad$ $p_\ell^* > 1.6$ GeV



Hadronic moments



p^*_{cut} (GeV)	$\langle m_X \rangle$ (GeV)	$\langle m_X^2 \rangle$ (GeV^2)
0.9	$2.076 \pm 0.009 \pm 0.010$	$4.334 \pm 0.046 \pm 0.051$
1.0	$2.073 \pm 0.009 \pm 0.010$	$4.312 \pm 0.042 \pm 0.049$
1.2	$2.066 \pm 0.008 \pm 0.006$	$4.258 \pm 0.036 \pm 0.036$
1.4	$2.056 \pm 0.007 \pm 0.006$	$4.214 \pm 0.032 \pm 0.028$
1.6	$2.042 \pm 0.008 \pm 0.004$	$4.141 \pm 0.034 \pm 0.027$

Belle V_{ub} Summary