Semileptonic B Decays at Belle

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What's in This Talk

- Three Analyses for V_{ub}
  - Inclusive B→ $X_u \ell \nu$ with Full reconstruction Final
  - Inclusive B→ $X_u \ell \nu$ endpoint analysis Final
  - Exclusive B→ $X_u \ell \nu$ with semileptonic tag Preliminary

- Three Analyses for Moment with Full reconstruction
  - $\mathcal{B}$(B→Xeν) (0th Moment) Final
  - B→X$\ell \nu$ Hadronic Moment (1st, 2nd) Preliminary
  - B→X$\ell \nu$ Leptonic Moment (1st, 2nd) Preliminary

Inclusive V_{ub} with Full Reconstruction

Full Reconstruction

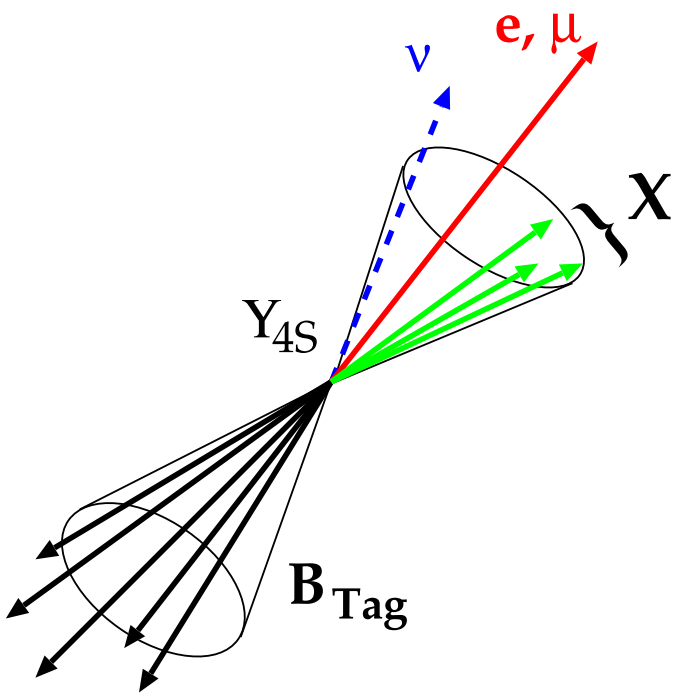
- **Fully Reconstruct one B**
  - ◇ Decay Modes

    $B \rightarrow D^{(*)} + \pi, \rho, a_1, D_s^{(*)}$

    $D^* \rightarrow D + \pi, \gamma$

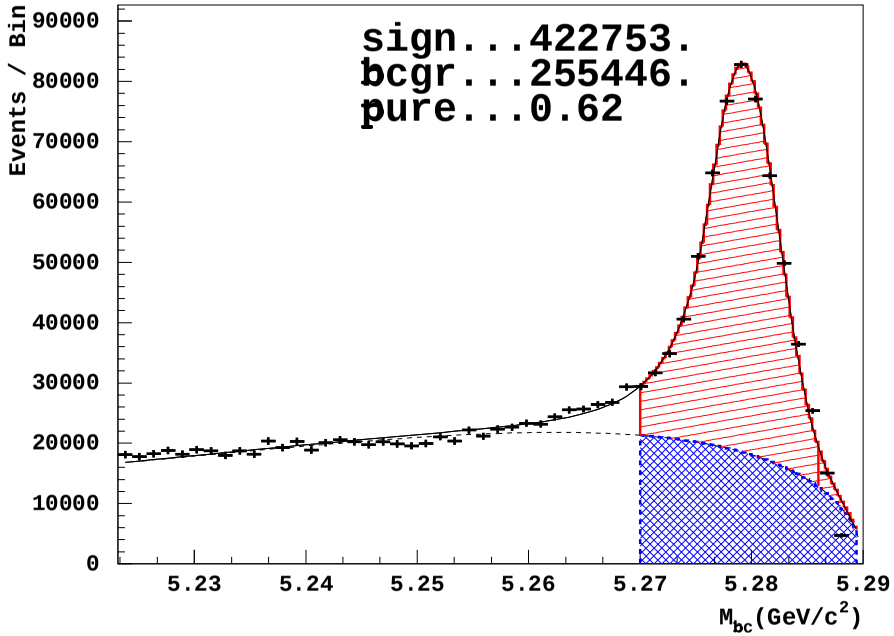
    $D \rightarrow K\pi, K\pi\pi, K\pi\pi\pi, KK...$

    .....
  - ◇ Total of ~180 modes, (~10% of B decay)
  - ◇ Modes included depend on analysis
- **Advantage**
  - ◇ good signal to noise
  - ◇ signal side can be anything
  - ◇ good kinematic reconstruction
  - ◇ can know B flavor/momentum
- **Disadvantage**
  - ◇ Low efficiency $O(10^{-3})$
  - ◇ Lot of CPU time



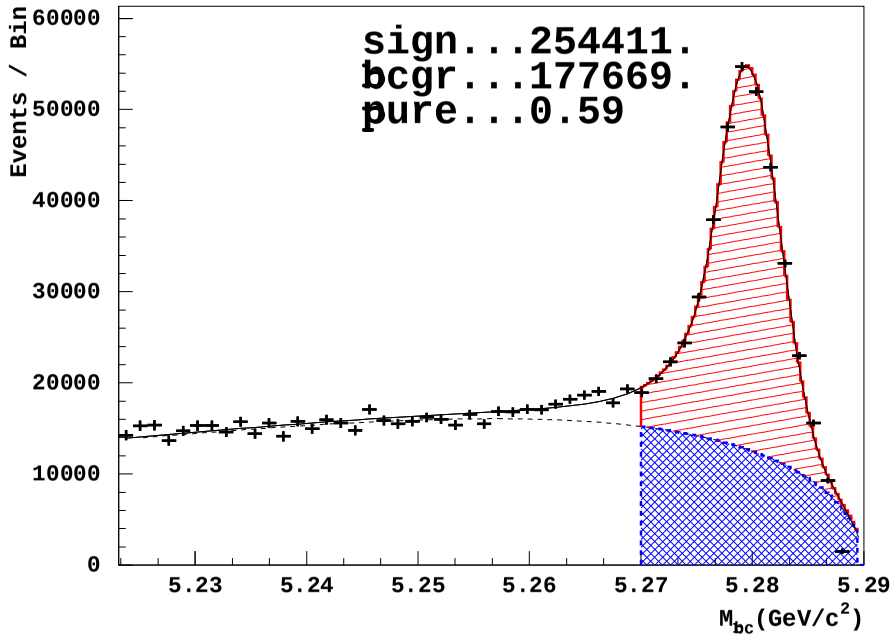
Full Reconstruction

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



4.2×10^5 Events/253 fb^{-1}
Efficiency = 0.33 %
purity = 62 %

M_{bc} for Reconstructed B^0



2.5×10^5 Events/253 fb^{-1}
Efficiency = 0.21 %
purity = 59 %

$\sim 7 \times 10^5$ unbiased/known B Mesons

Inclusive V_{ub} with Full Reconstruction

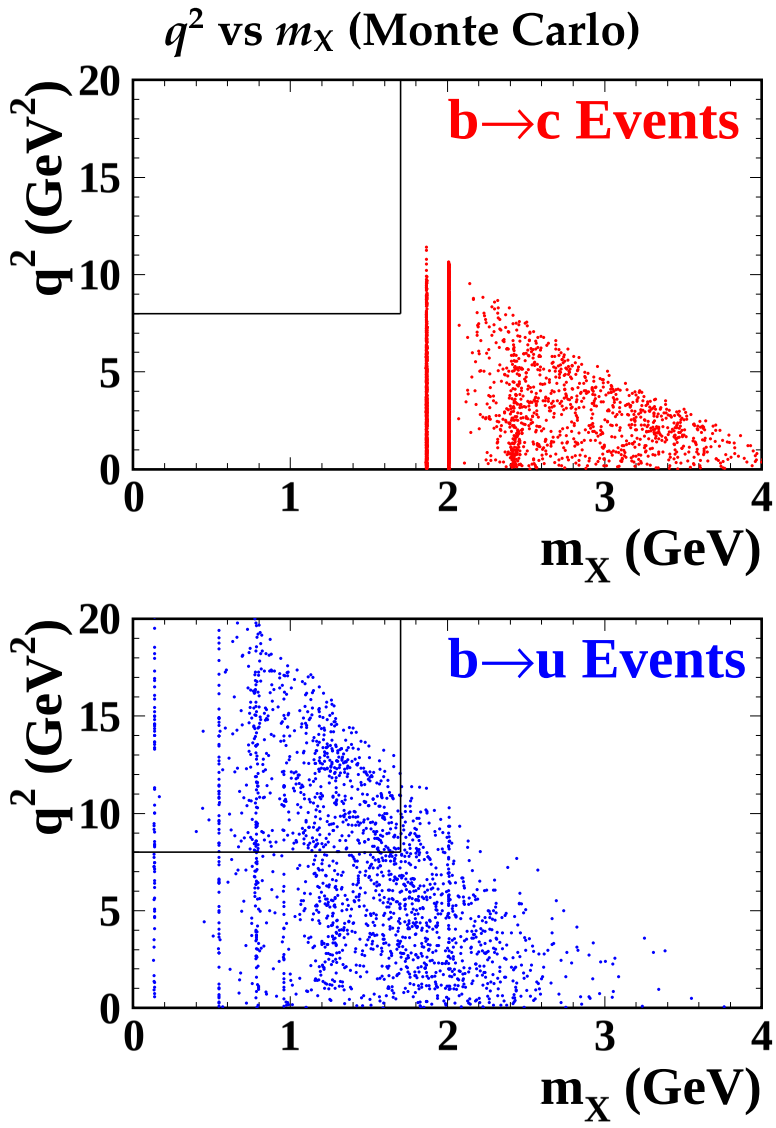
- Signal Side is $B \to X_u \ell \nu$ ($\ell = e, \mu$)
- Measure $\dfrac{\Delta\mathcal{B}(B \to X_u \ell \nu)}{\mathcal{B}(B \to X \ell \nu)} \propto |V_{ub}|^2$
- Three Kinematic Selections

  (1) $m_X < 1.7$ GeV

  (2) $m_X < 1.7$ GeV, $q^2 > 8$ GeV^2

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

- Full reconstruction Method
  - ◇ good Signal/Noise
  - ◇ good resolution

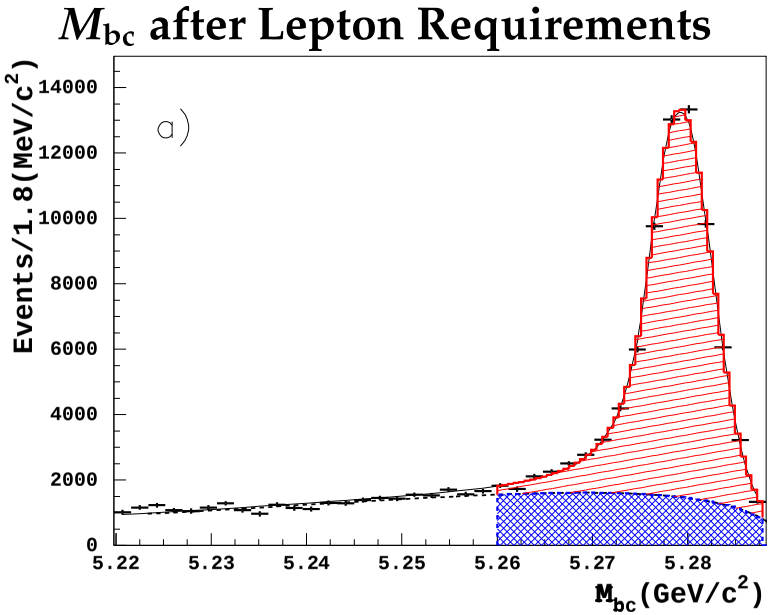


Inclusive V_{ub} with Full Reconstruction

Lepton Selection

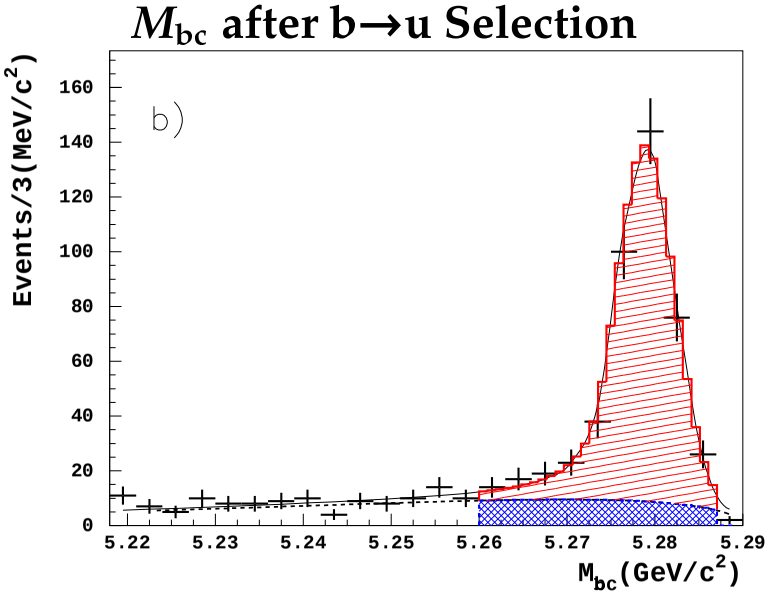
- $p^* > 1$ GeV
- J/ψ veto, conversion veto
- Correct Charge for B^+ candidate
- No other lepton

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



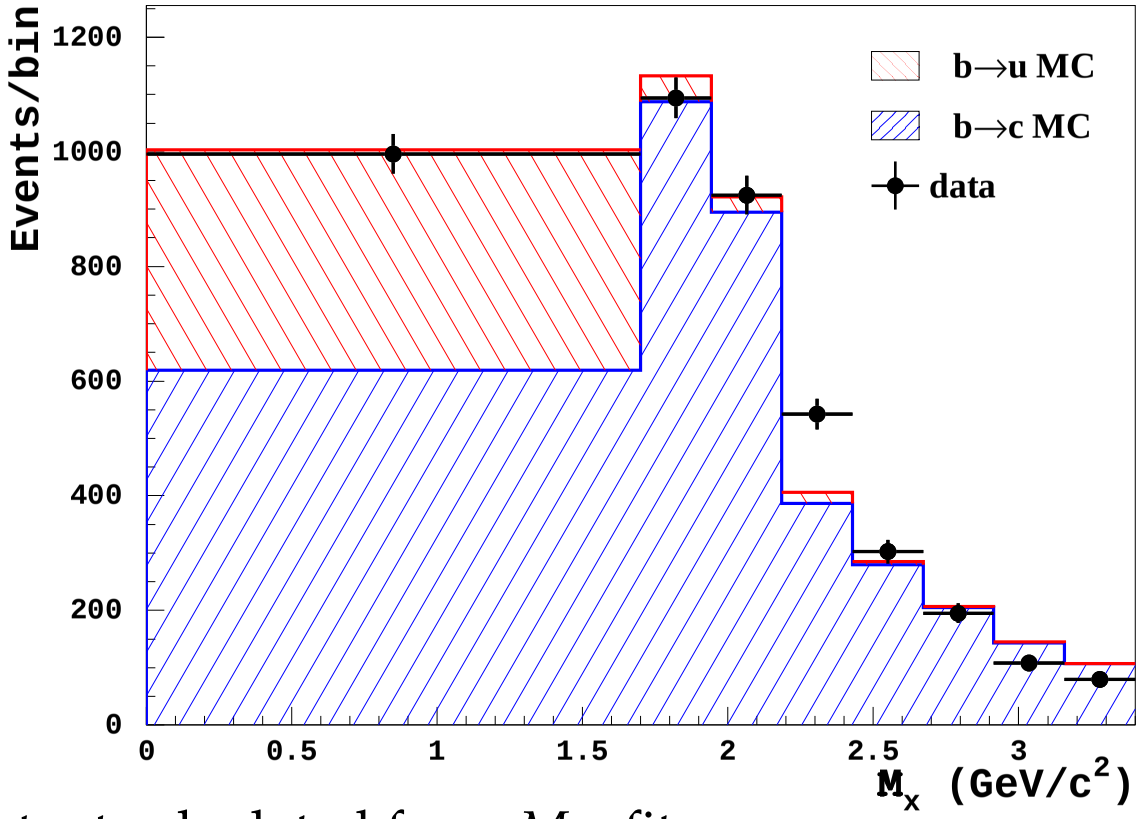
Selection for b→ u

- Total charge, $\sum Q_i = 0$
- missing mass, $-1.0 < m^2_{\rm mis} < 0.5$ GeV^2
  ($p_{\rm mis} \equiv p_{\Upsilon_{4S}} - (p_{B_{\rm tag}} + p_\ell + p_X) \approx p_\nu$)
- missing direction, $|\cos\theta_{\rm mis}| < 0.95$
- No reconstructed K^0_S or $K^\pm$
- .....



Inclusive V_{ub} with Full Reconstruction

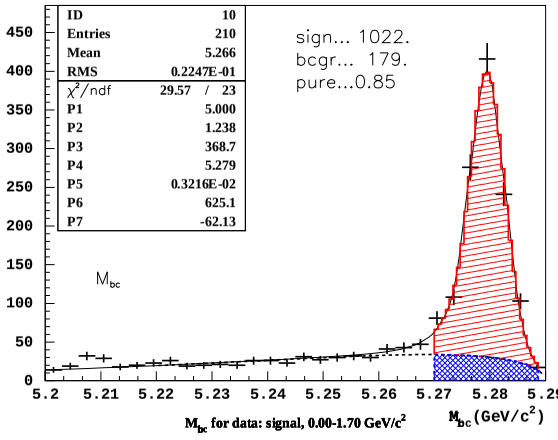
Signal Extraction with M_X distribution

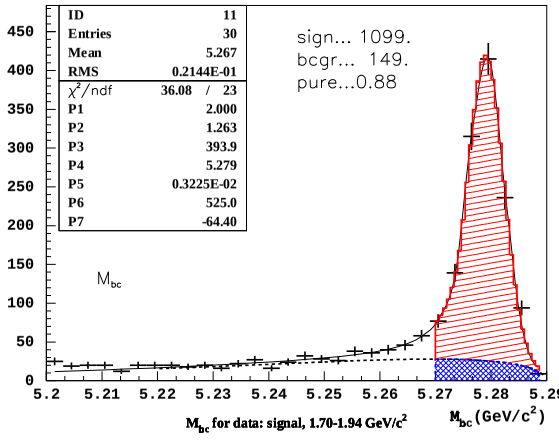


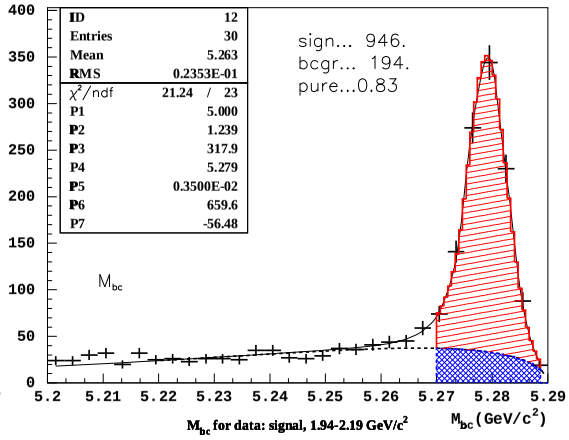
- Each bin content calculated from M_{bc} fit
- Two component fit to extract $N_{b\to u}$

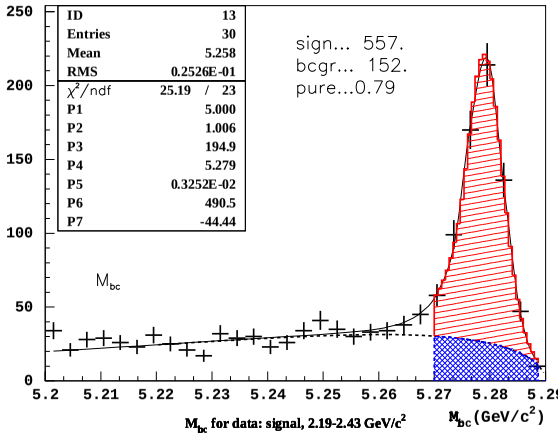
$$N_{b\to u} = 404 \pm 37$$

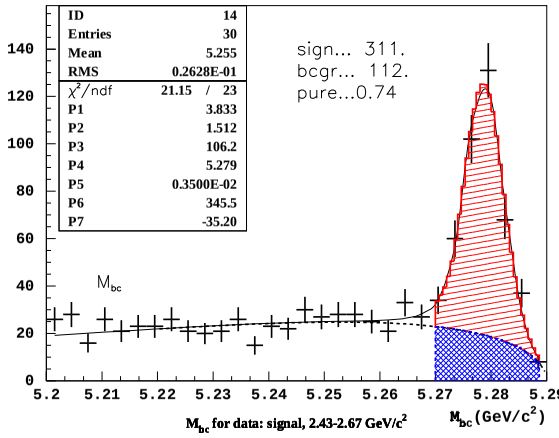
Each Bin Content

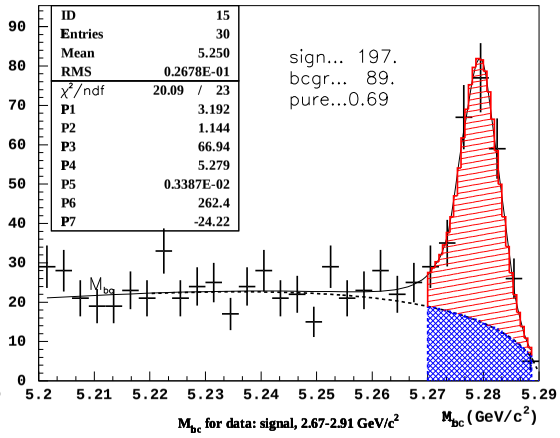


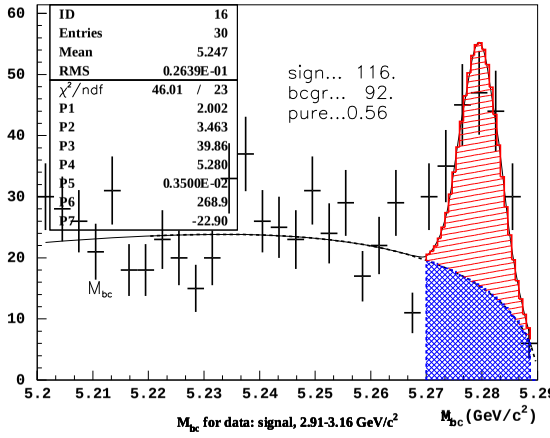


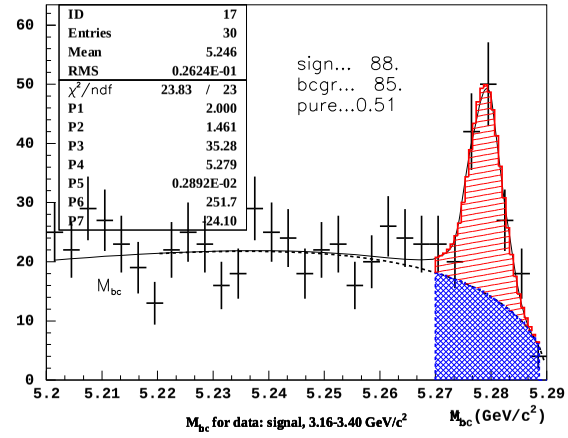






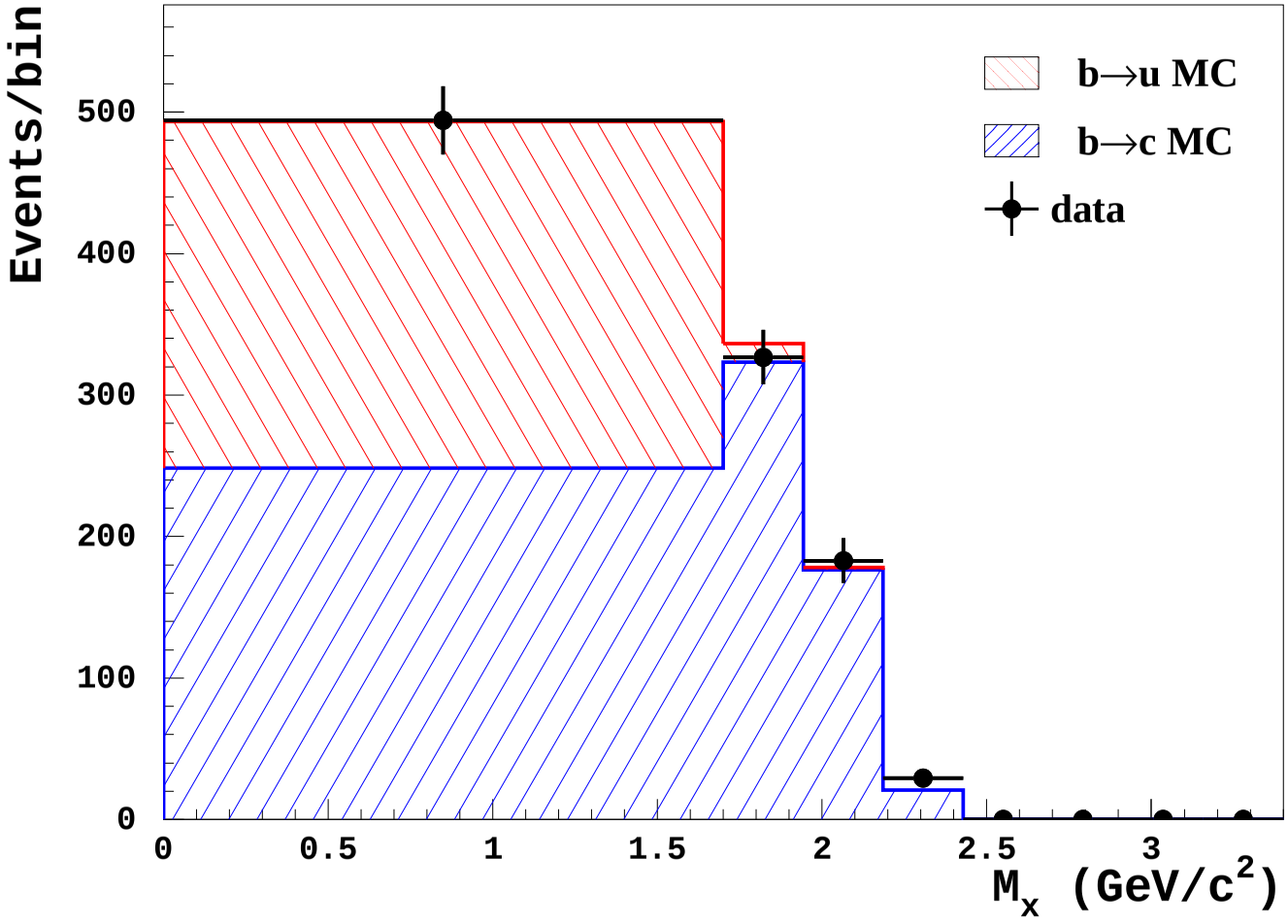






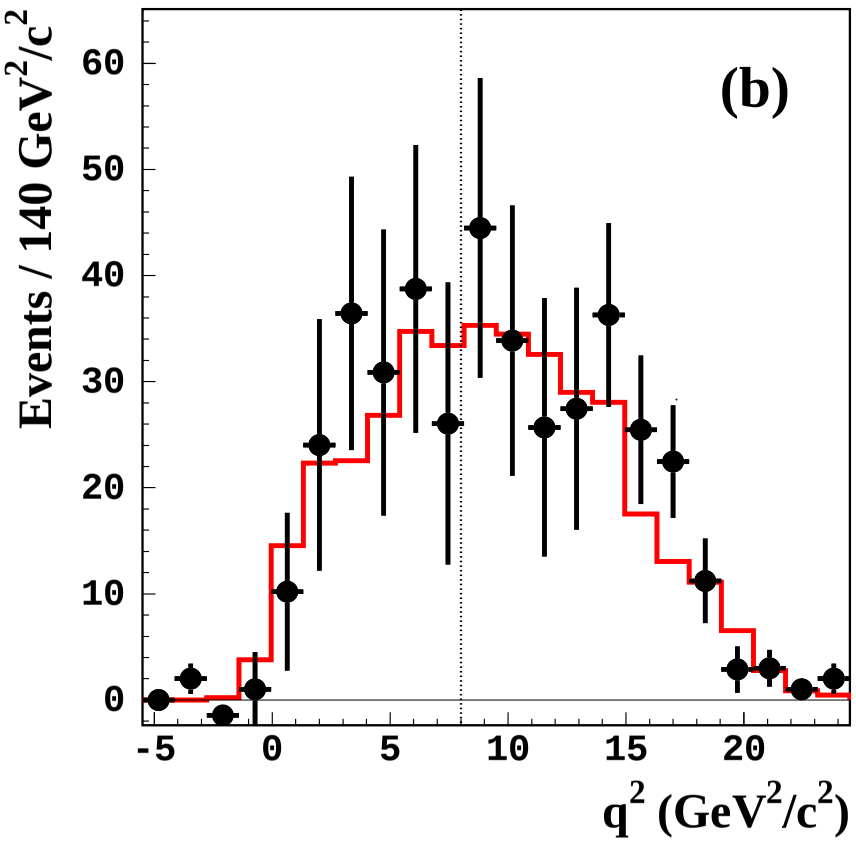
Inclusive V_{ub} with Full Reconstruction

Signal Extraction with M_X distribution with q^2 cut applied

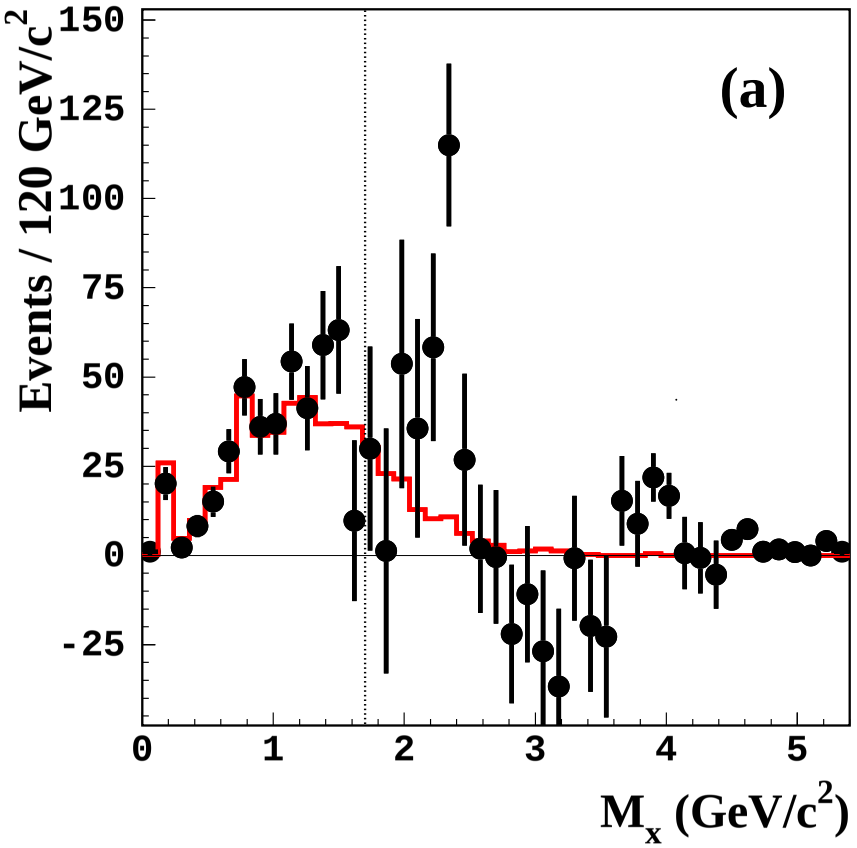


$$N_{b\to u} = 268 \pm 27$$

q^2 Distribution (m_X <1.7 GeV)



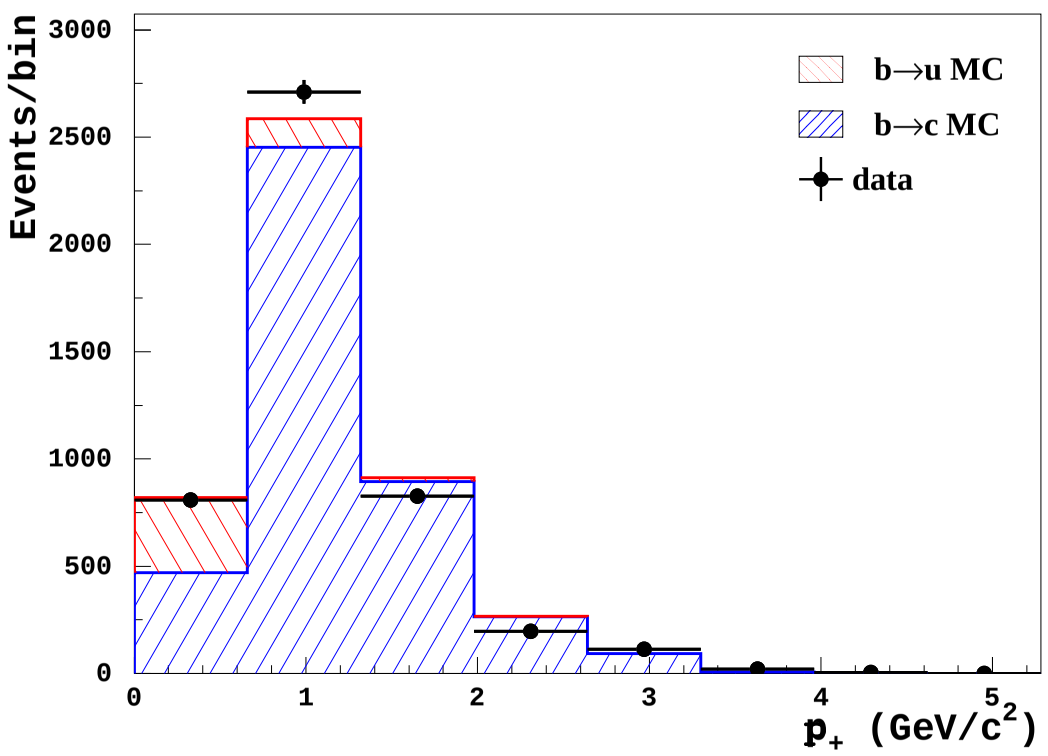
m_X Distribution (q^2 >8 GeV^2)

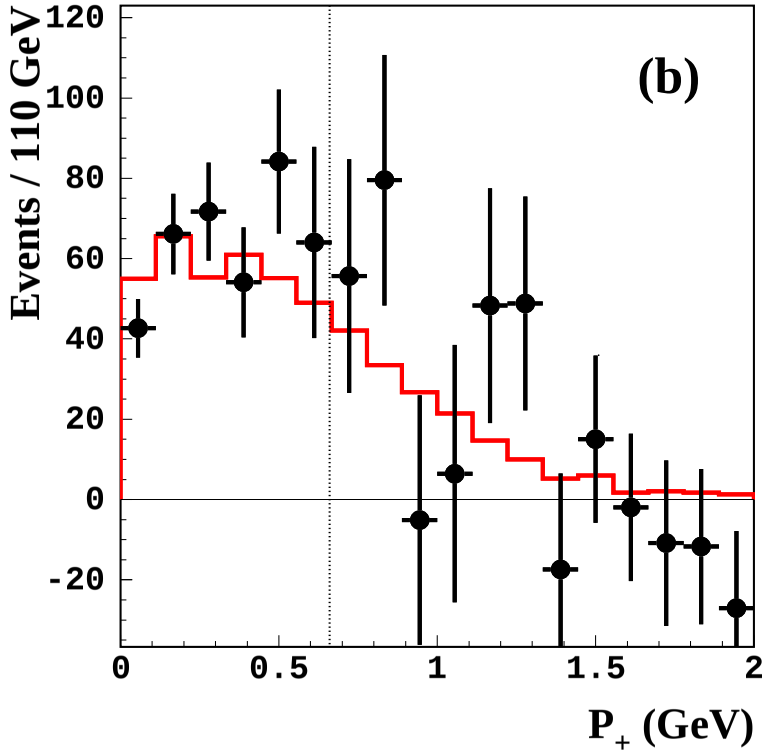


Inclusive V_{ub} with Full Reconstruction

Signal Extraction with P_+ distribution

- First Measurement using P_+





- $P_+ \equiv E^*_X - |\vec{p}^*_X|$

$$N_{b\to u} = 340 \pm 32$$

Inclusive V_{ub} with Full Reconstruction

Extraction of Partial Branching Fraction

$$\Delta\mathcal{B}(B \to X_u \ell\nu) = \frac{N_{b\to u}}{N_{sl}} \cdot \frac{\varepsilon_{b\to sl}}{\varepsilon_{b\to u}} \cdot \mathcal{B}(B \to X\ell\nu)$$

$N_{b\to u}$: Number of observed (b→u) Signal Events

N_{sl}: Number of observed B semi-leptonic Events

$\mathcal{B}(B \to X\ell\nu)$: B→semileptonic Branching fraction (0.1073 ± 0.0028)

$\varepsilon_{b\to sl}$: Selection efficiency for B→$X\ell\nu$

$\varepsilon_{b\to u}$: Selection efficiency for B→$X_u\ell\nu$

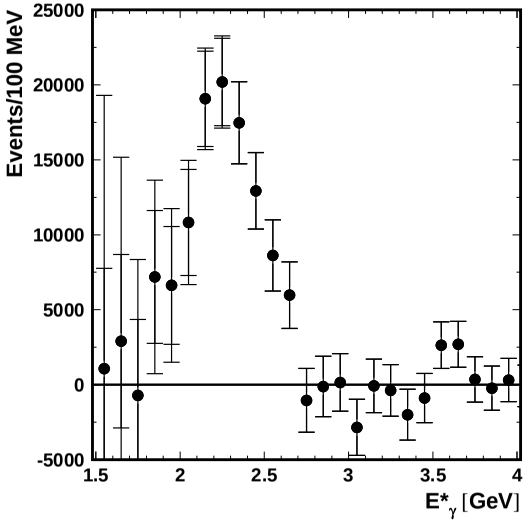
	$\Delta\mathcal{B}$	stat	syst	b→u	b→c
m_X–q^2	8.41×10^{-4}	10.0	8.9	6.2	5.3
m_X	1.24×10^{-3}	9.1	7.1	6.1	2.2
P_+	1.10×10^{-3}	9.4	9.2	6.4	8.7

Inclusive V_{ub} with Full Reconstruction

V_{ub} Extraction with the "New" V_{ub} Method

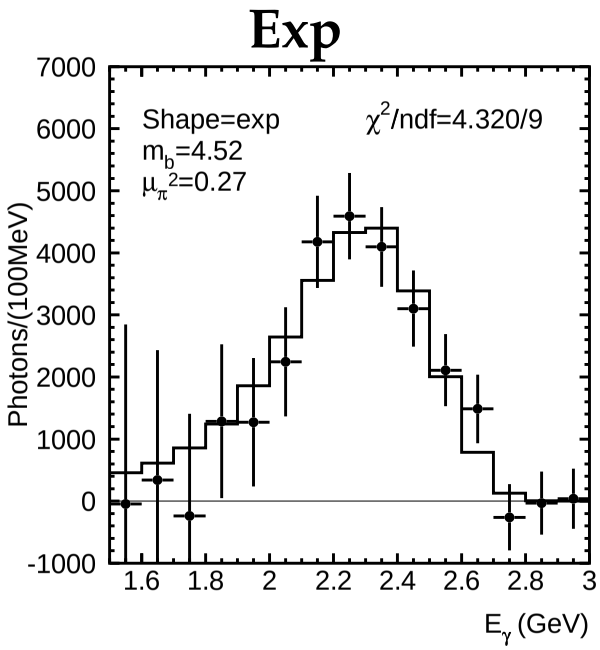
$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(B \to X_u \ell\nu)}{\mathcal{R} \cdot \tau_B}}$$

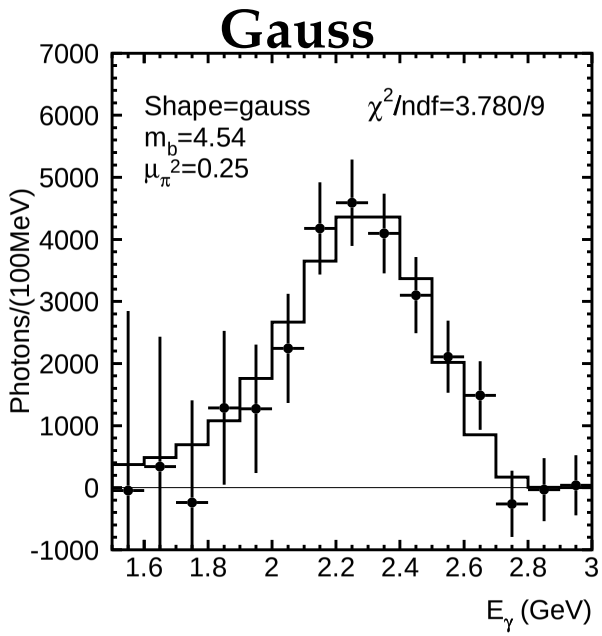
- Dirctly relate V_{ub} and $\Delta\mathcal{B}$ by $\mathcal{R}$
- Shape Function
  - ◇ similar contribution to b→ sγ events
  - ◇ fitting γ spectrum by Belle measurement
  - ◇ $m_b = (4.52 \pm 0.07)$ GeV, $\mu_\pi^2 = (0.27 \pm 0.13)$ GeV^2
- Weak annihilation effect

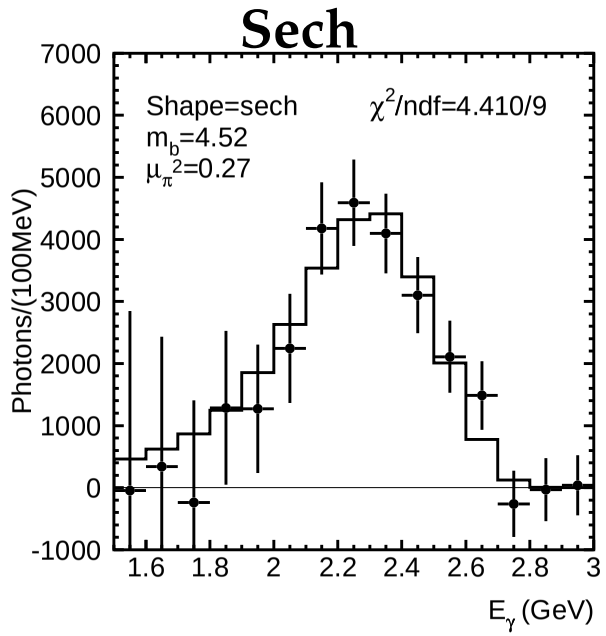


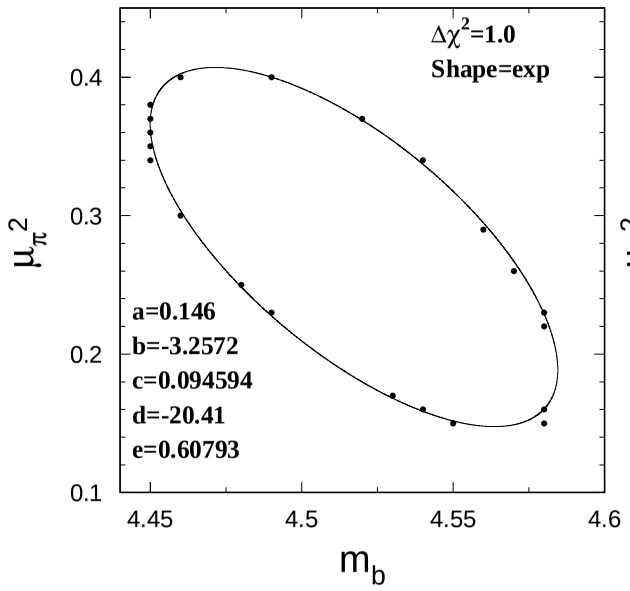
	$\|V_{ub}\|$	stat	syst	b→u	b→c	SF	theo.
m_X–q^2	4.93×10^{-3}	5.0	4.4	3.1	2.7	9.3	$^{+5.0}_{-5.5}$
m_X	4.35×10^{-3}	4.6	3.5	3.1	1.1	9.2	$^{+3.6}_{-3.9}$
P_+	4.56×10^{-3}	4.7	4.6	3.2	4.4	10.2	$^{+3.4}_{-3.5}$

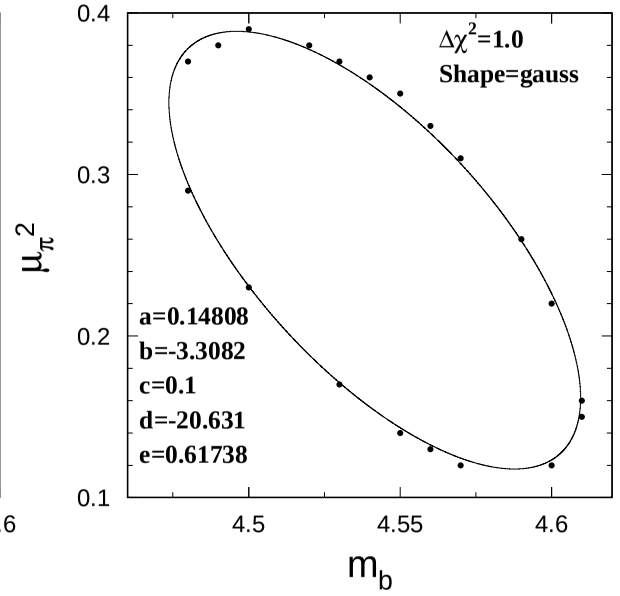
Determination SF Parameter

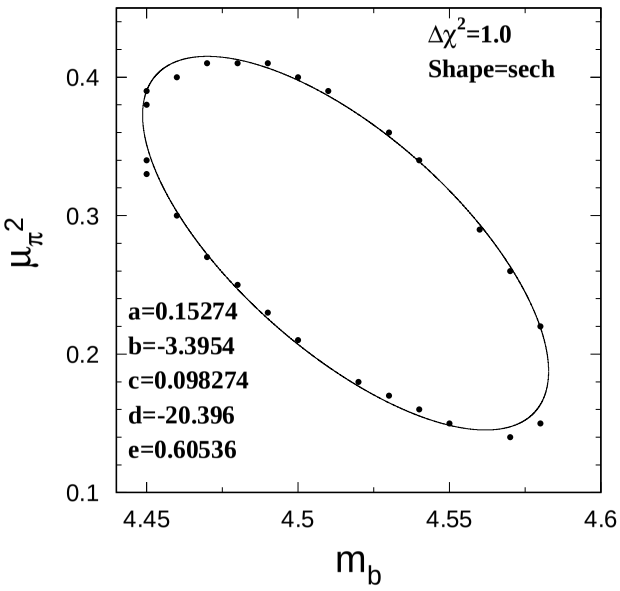






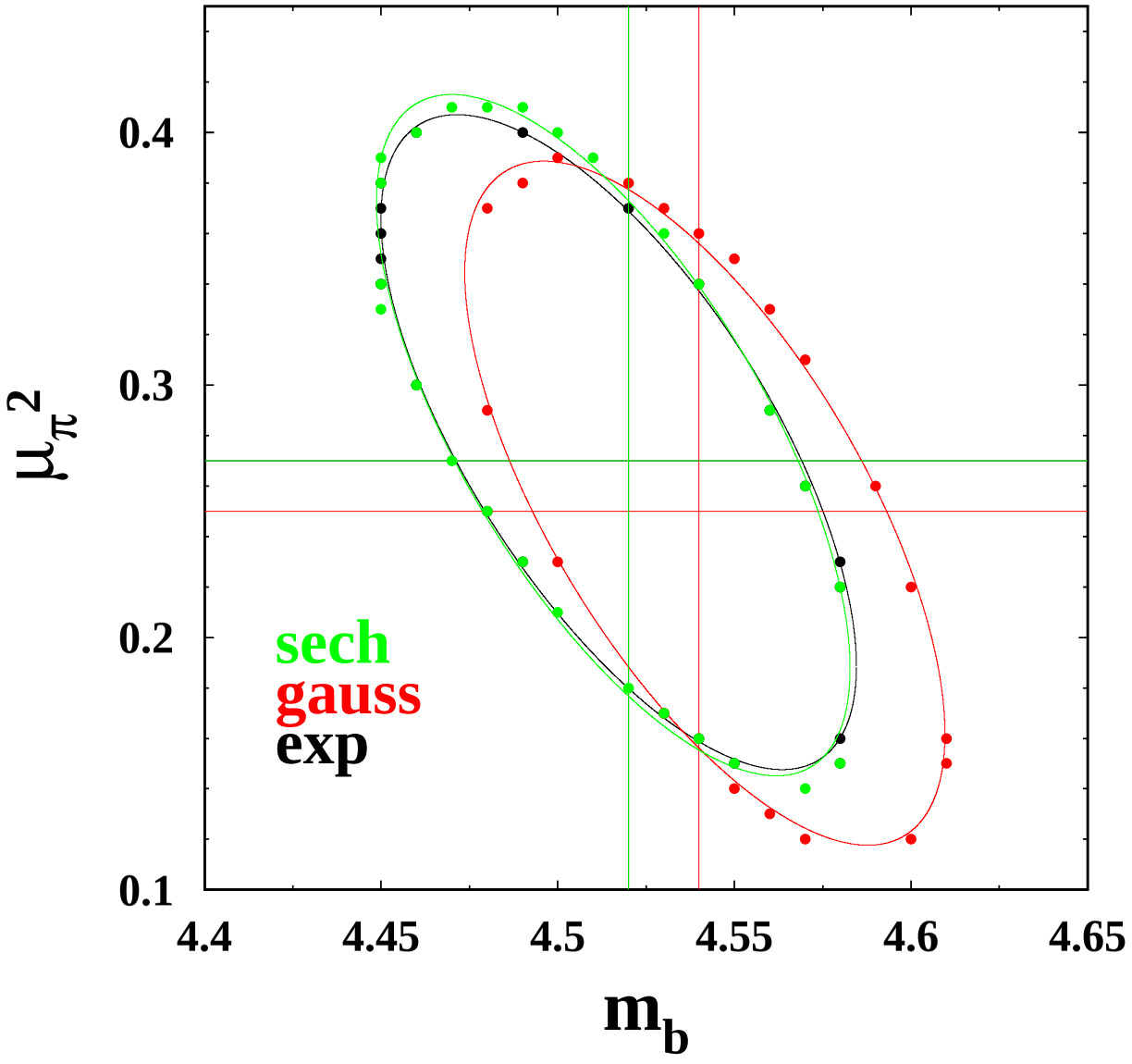






$m_b = 4.52, \mu_\pi^2 = 0.27$ $m_b = 4.54, \mu_\pi^2 = 0.25$ $m_b = 4.52, \mu_\pi^2 = 0.27$

1σ Contour

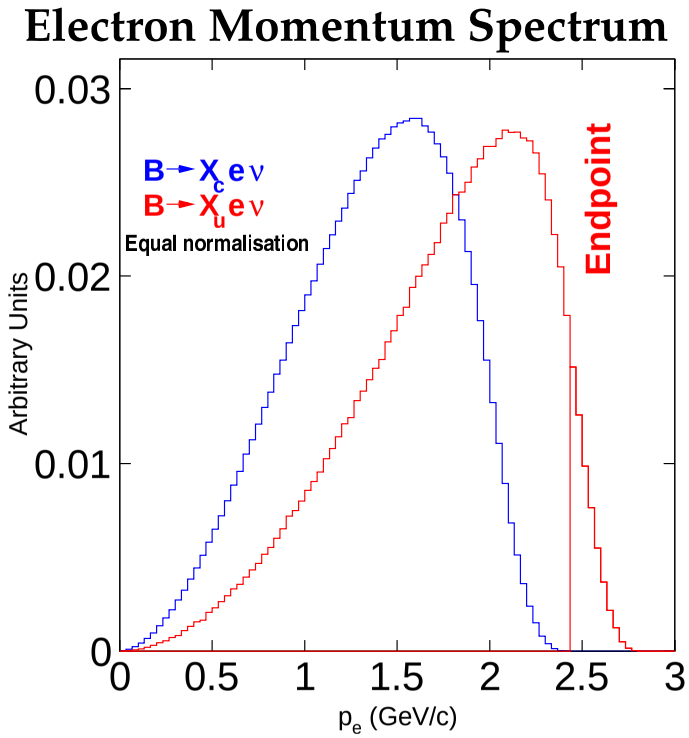


$$m_b = 4.52 \pm 0.07\ \text{GeV},\quad \mu_\pi^2 = 0.27 \pm 0.13\ \text{GeV}^2$$

Inclusive V_{ub} Electron Endpoint

Inclusive V_{ub} Electron Endpoint

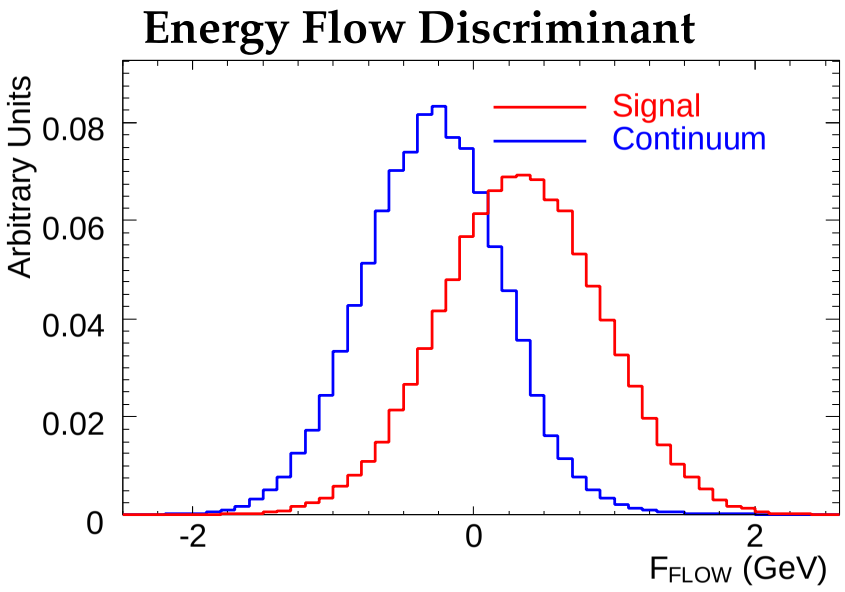
- Measure $\Delta\mathcal{B}(B \to X_u e\nu,\ p_e^* > p_{cut})$
- Another way to enhance b→u transition
- Kinematic Selection
  - $p_e^* > p_{cut}$
  - p_{cut} = 1.9, 2.0, 2.1, 2.2, 2.3 and 2.4 GeV
- No reconstruction in the other side
  - High Statistics
- Large background from $B \to X_c e\nu$
  - Error from background systematic uncertainty

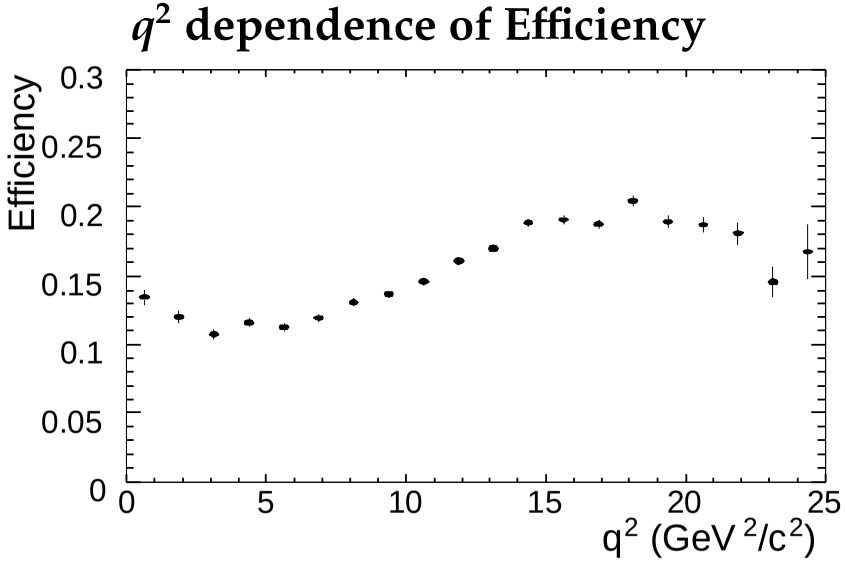


Inclusive V_{ub} Electron Endpoint

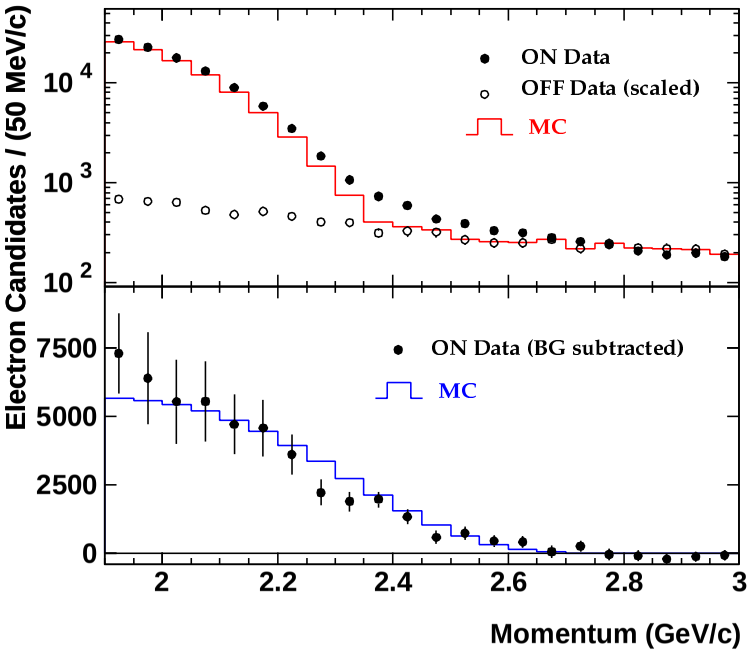
Selection

- J/ψ, ψ(2S), conversion Veto
- Fox-Wolfram moment
- Energy flow fisher discriminant
- Thrust axis direction
- ...
- As q^2 independent as possible
- Background Estimated by
  - Off-resonance Data and MC
  - $p_e^* >$ threshold to check it works





Inclusive V_{ub} Electron Endpoint



- 27.0 fb^{-1} (Already Systematic Dominant)
- $\Delta\mathcal{B} = \dfrac{N(\text{b} \to \text{u})}{N_{\text{BB}} \cdot \varepsilon_{\text{MC}}}$
- "New" V_{ub} method

$$|V_{\text{ub}}| = \sqrt{\frac{\Delta\mathcal{B} \cdot (1 + \delta_{\text{rad}})}{\mathcal{R} \cdot \tau_{\text{B}}}}$$

- Parameter from $\text{b} \to \text{s}\gamma$
- Radiative Correction by **PHOTOS**

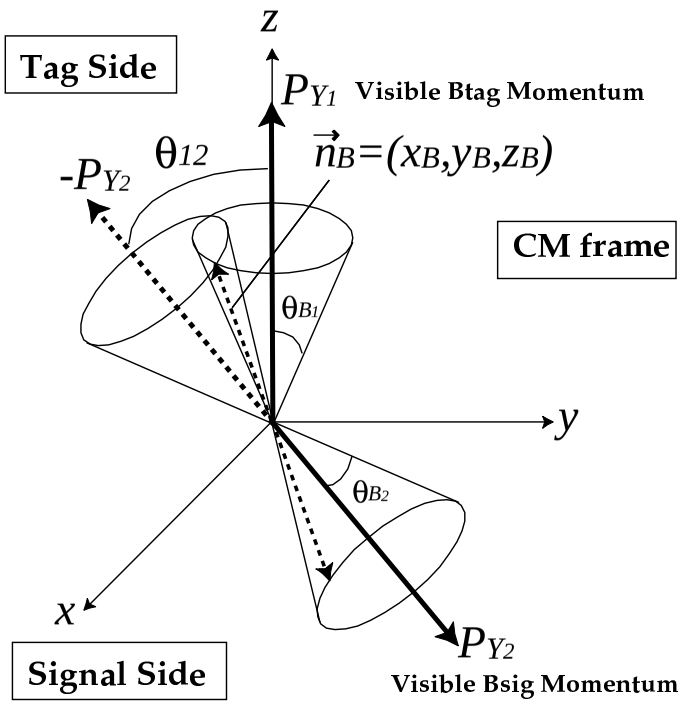
p_e^* (GeV)	$\mathcal{R}$ ($\lvert V_{ub}\rvert^2 \text{ps}^{-1}$)	$\lvert V_{ub}\rvert \times 10^{-3}$
1.9 – 2.6	$21.69 \pm 3.62^{+2.18}_{-1.98}$	$5.08 \pm 0.47 \pm 0.42^{+0.26}_{-0.23}$
2.0 – 2.6	$16.05 \pm 3.05^{+1.83}_{-1.77}$	$4.87 \pm 0.43 \pm 0.46^{+0.28}_{-0.26}$
2.1 – 2.6	$10.86 \pm 2.51^{+1.61}_{-1.57}$	$4.83 \pm 0.33 \pm 0.56^{+0.36}_{-0.35}$
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	$1.12 \pm 0.39^{+1.48}_{-1.48}$	$5.70 \pm 1.00 \pm 0.67^{+3.77}_{-3.76}$

Exclusive V_{ub} with Semileptonic Tag

Exclusive V_{ub} with Semileptonic Tag

Tag Side

- $B_{tag} \to D^{*+}\ell^-\bar{\nu}/D^+\ell^-\bar{\nu}$
  $D^{*+} \to D^0\pi^+/D^+\pi^0$
- $D^0 \to K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^+\pi^-$...(7 Modes)
- $D^+ \to K^-\pi^+\pi^+, K^-\pi^+\pi^+\pi^0$...(4 Modes)



Signal Side

- $B_{sig} \to X_u\ell^+\nu$
- Lepton with p >0.8 GeV
- $X_u = \pi^-, \pi^-\pi^0$

Kinematic Reconstruction

- B directions are constrained to the intersections of two cones

$$0 < x_B^2 \equiv 1 - \frac{1}{\sin\theta_{12}}\left(\cos^2\theta_{B_1} + \cos^2\theta_{B_2} - 2\cos\theta_{B_1}\cos\theta_{B_2}\cos\theta_{12}\right) < 1$$

- q^2 is calculated, assuming the B is stopping at CM frame,

$$q^2 = \left(E^*_{\text{beam}} - E^*_{X_u}\right)^2 - p^{*\,2}_{X_u}$$

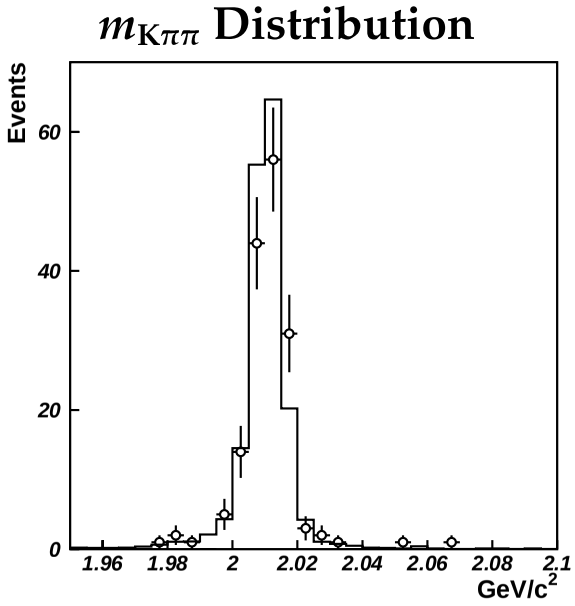
Exclusive V_{ub} with Semileptonic Tag

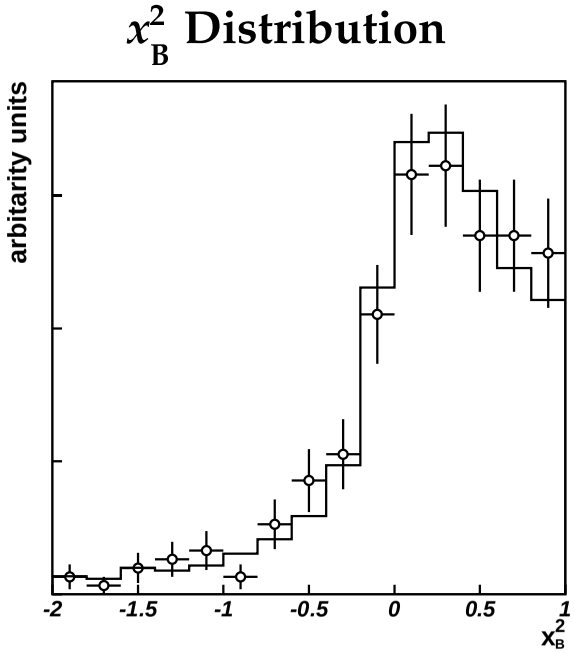
Efficiency Calibration

- Calibration Mode

  $B_{sig} \to D^{*-}\ell^+\bar{\nu}$
  $\to \bar{D}^0\pi^-$
  $\to K^+\pi^-$

- $N_{obs} = 147 \pm 12$
- $N_{exp} = 165 \pm 9$
- $\dfrac{N_{obs}}{N_{exp}} = 0.89 \pm 0.08$
  $\Rightarrow$ taken as a calibration constant
- x_B^2 distribution looks reasonable

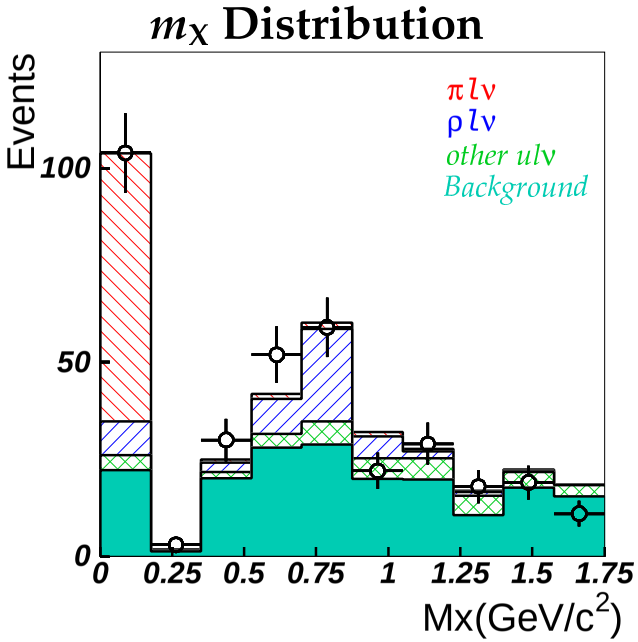


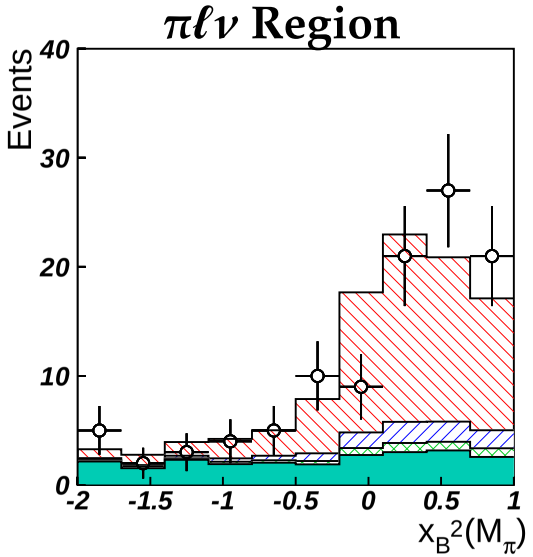


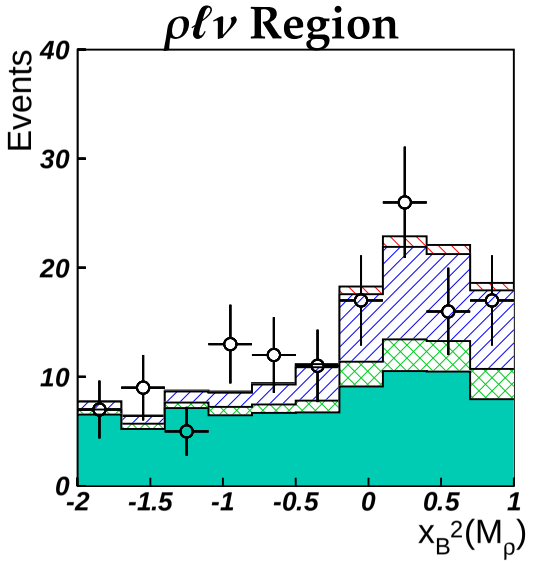
Exclusive V_{ub} with Semileptonic Tag

Signal Extraction

- fitting in 2D m_X– x_B^2 plane







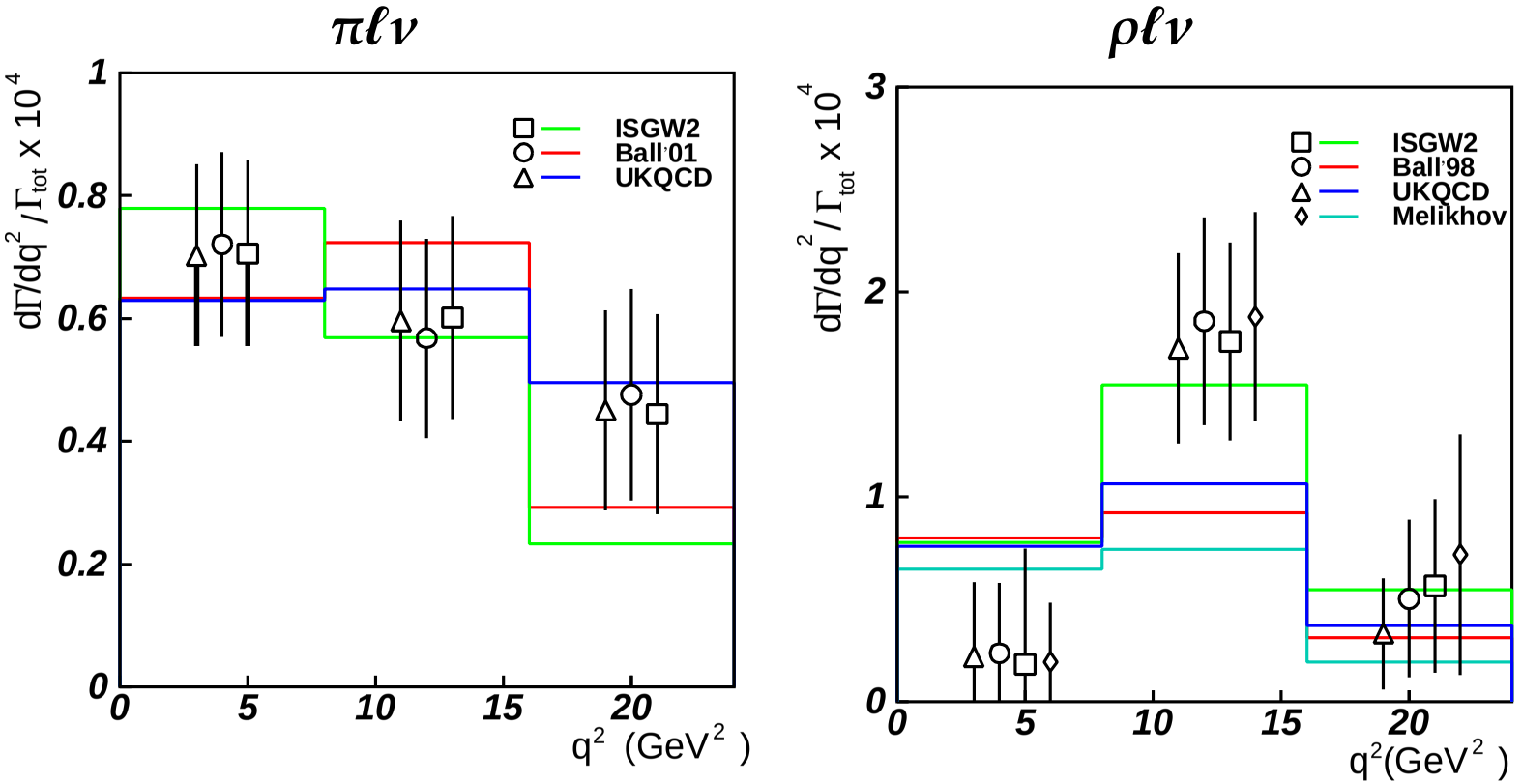
- Four component fit
  - ◇ B → $\pi\ell\nu$
  - ◇ B → $\rho\ell\nu$
  - ◇ B → $X_u\ell\nu$
  - ◇ BB background

82 ± 13 Events

65 ± 20 Events

Exclusive V_{ub} with Semileptonic Tag

Signal Yield in q^2 bin



- average Form-Factor Models
- variation as theory error

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

Exclusive V_{ub} with Semileptonic Tag

- V_{ub} determined with relation

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

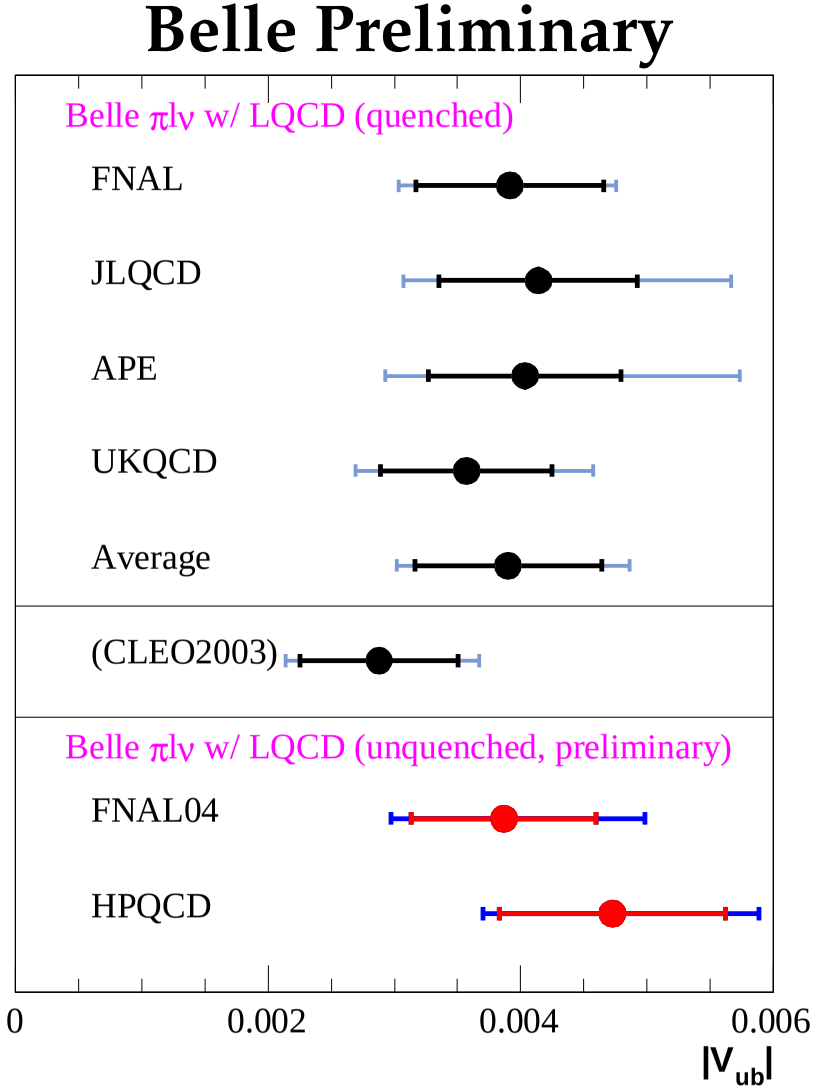
- only $\pi^- \ell^+ \nu$ with $q^2 > 16\text{GeV}^2$ is used
- with Γ_{th} from Quenched LQCD

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

- with Γ_{th} from Unquenched LQCD

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

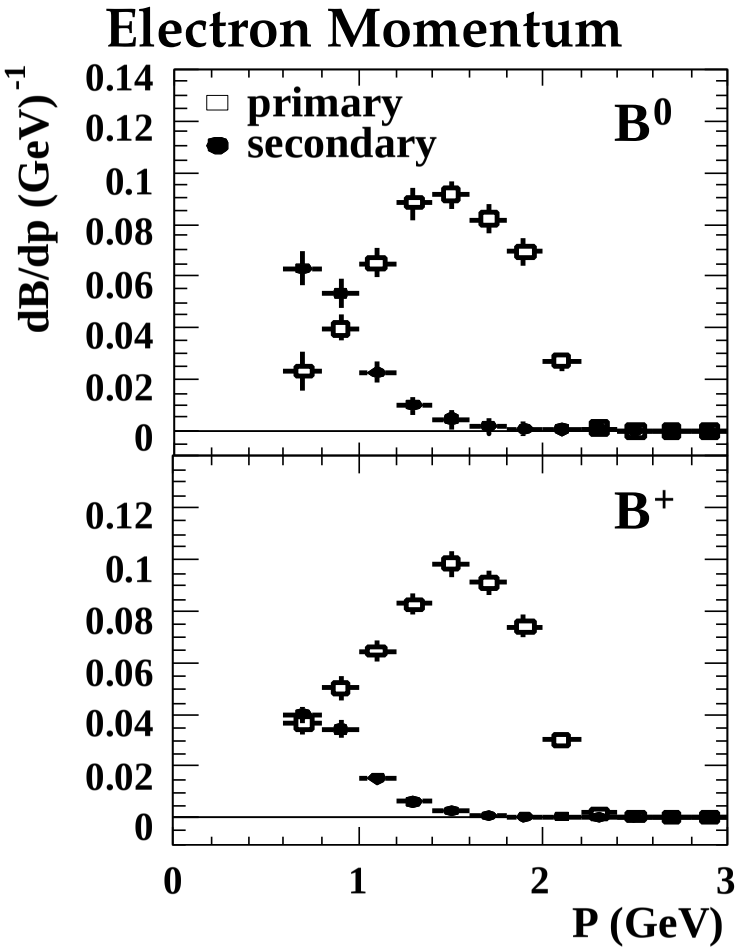
$$|V_{ub}| = (4.73 \pm 0.85 \pm 0.27^{+0.74}_{-0.50}) \times 10^{-3} \quad \text{(HPQCD)}$$



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

$\mathcal{B}(B \to Xe\nu)$

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



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

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

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

Leptonic and Hadronic Moment with Full reconstruction

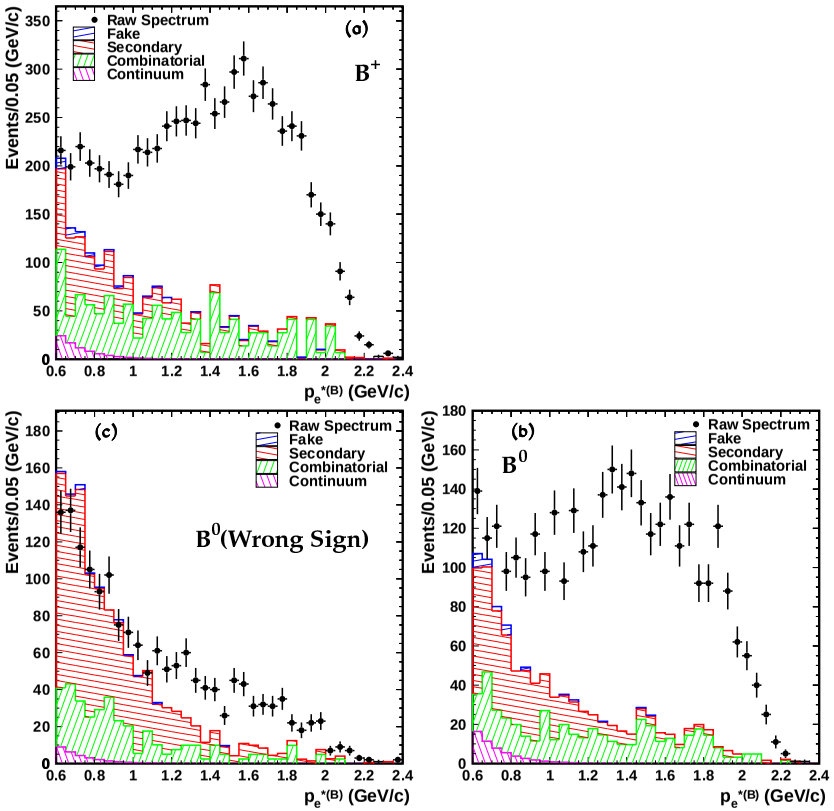
Preliminary

Leptonic/Hadronic Moment

Common for Leptonic/Hadronic

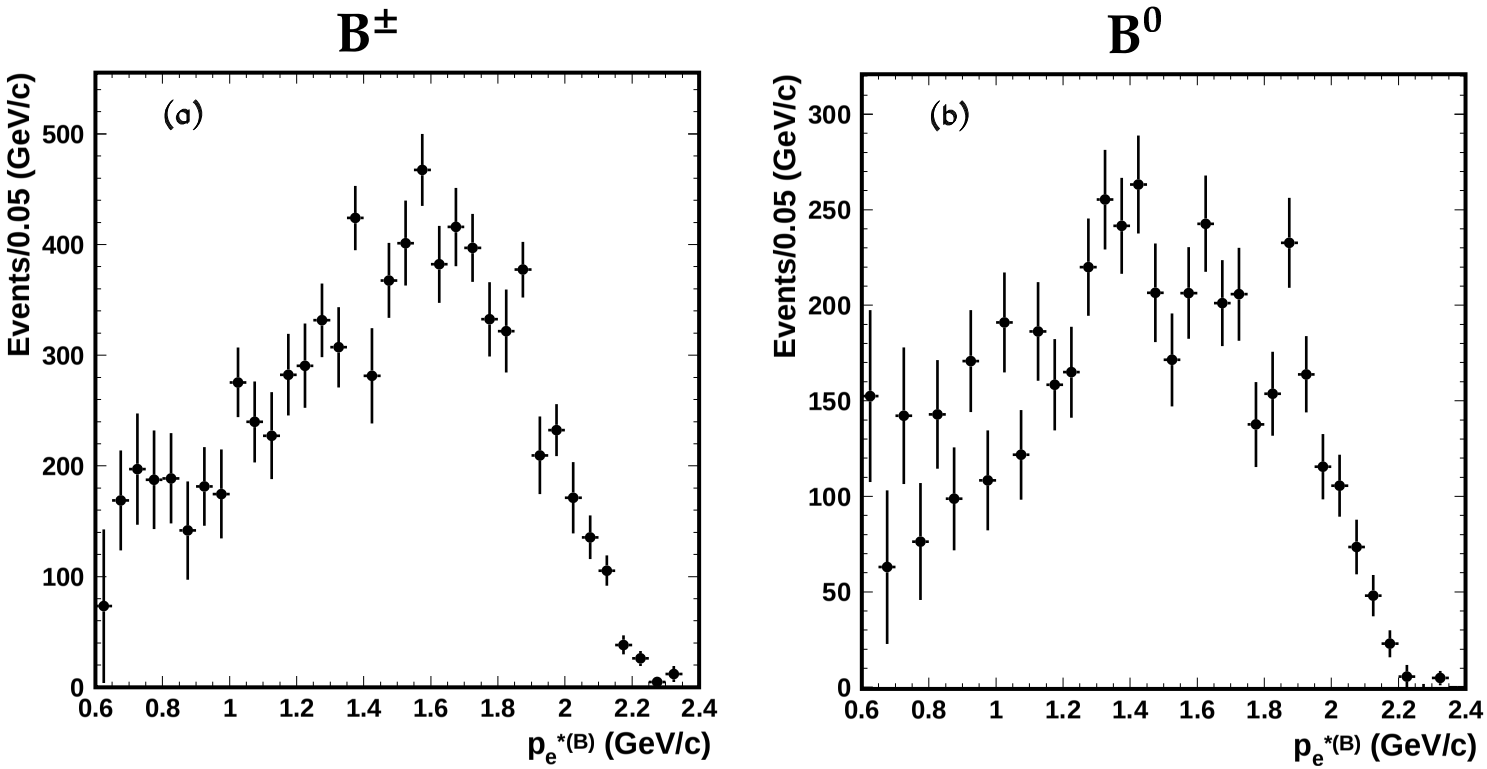
- Analysis with 140 fb^{-1}
- Full reconstruction in the Tag side
- Boost from $p_{B_{Tag}}$
- QED correction by **PHOTOS**
- Mixing Correction

Electron Momentum



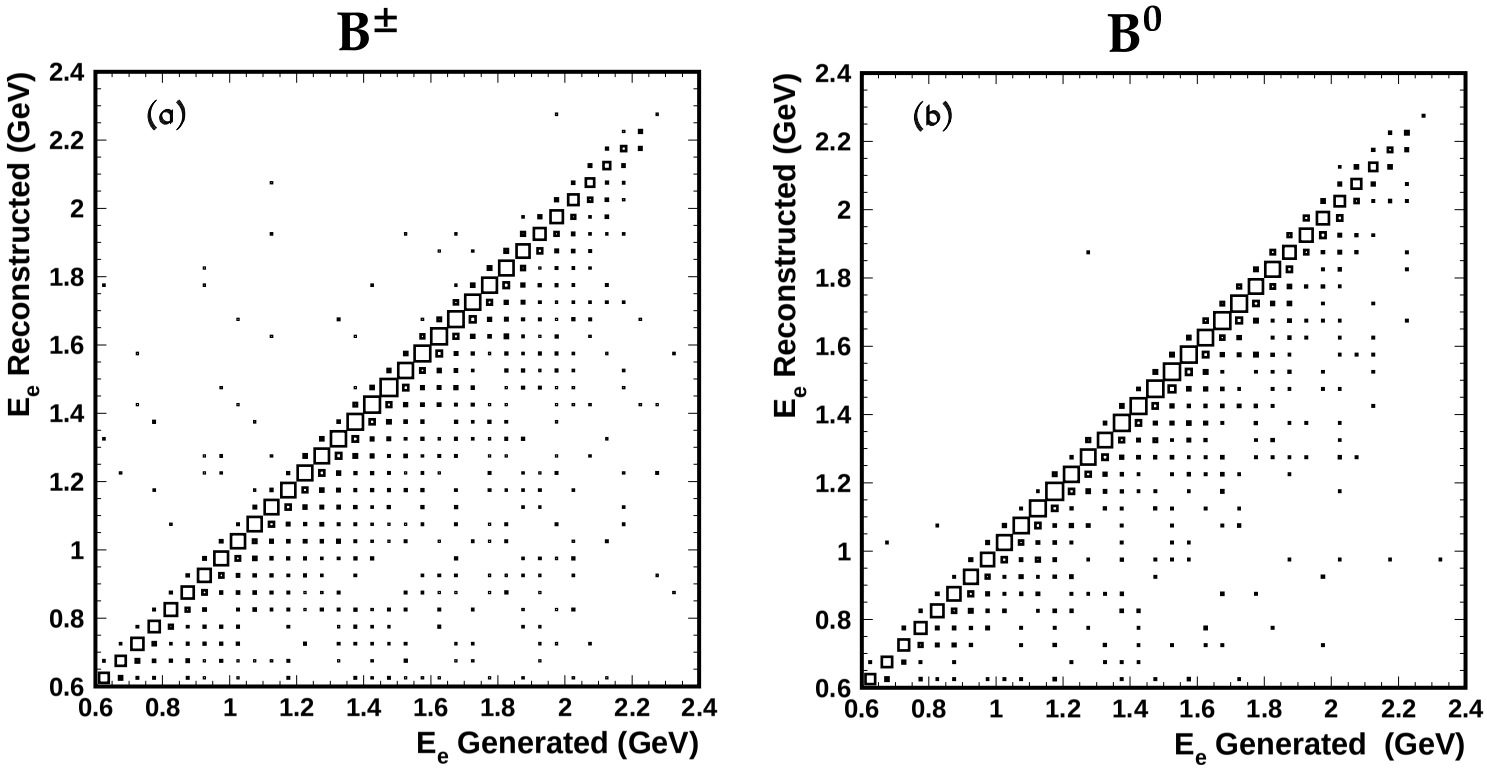
Leptonic Moment

- Background subtracted momentum distribution



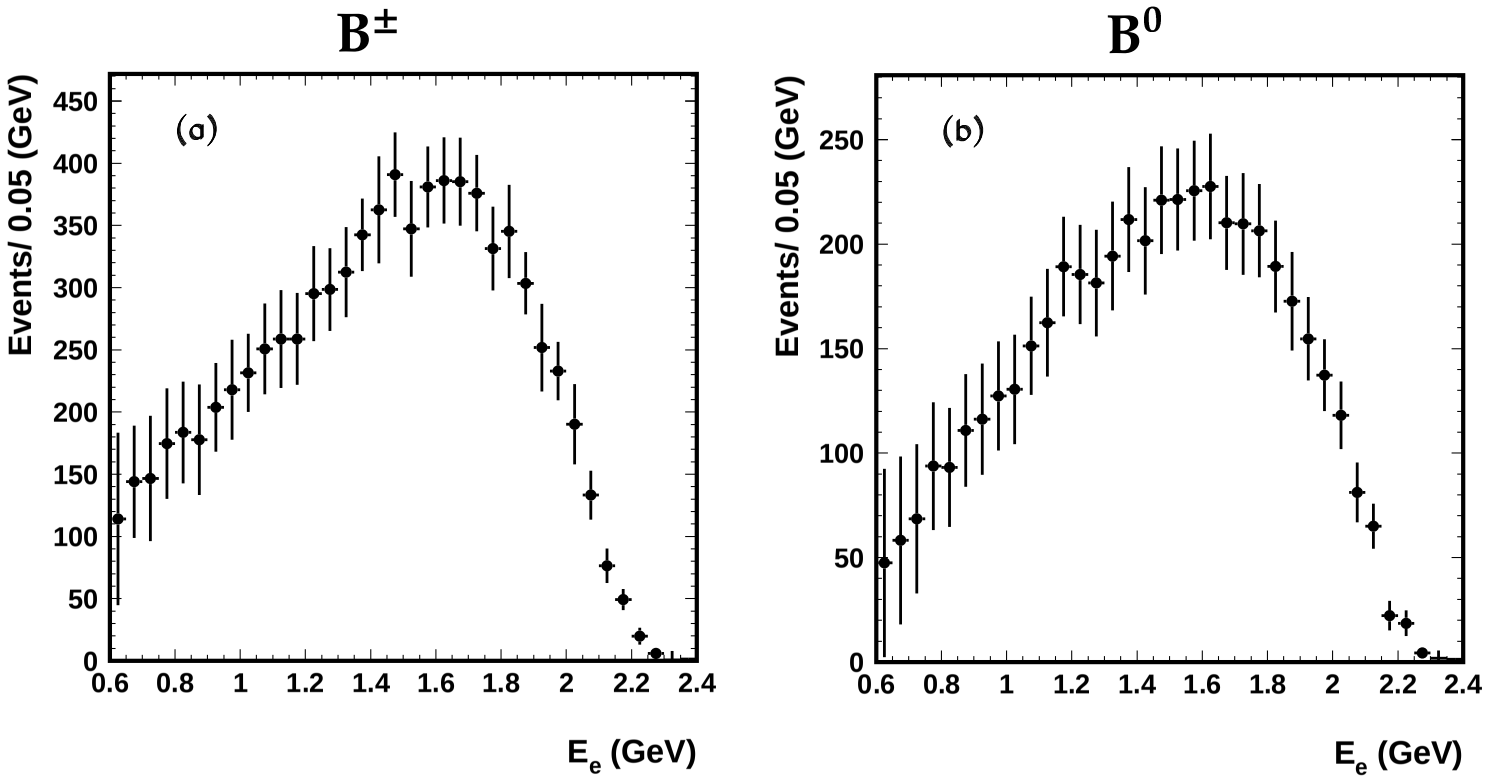
Leptonic Moment

- Unfold distribution with **SVD** (Singular Value Decomposition) Method
- Reconstructed vs True Electron Energy

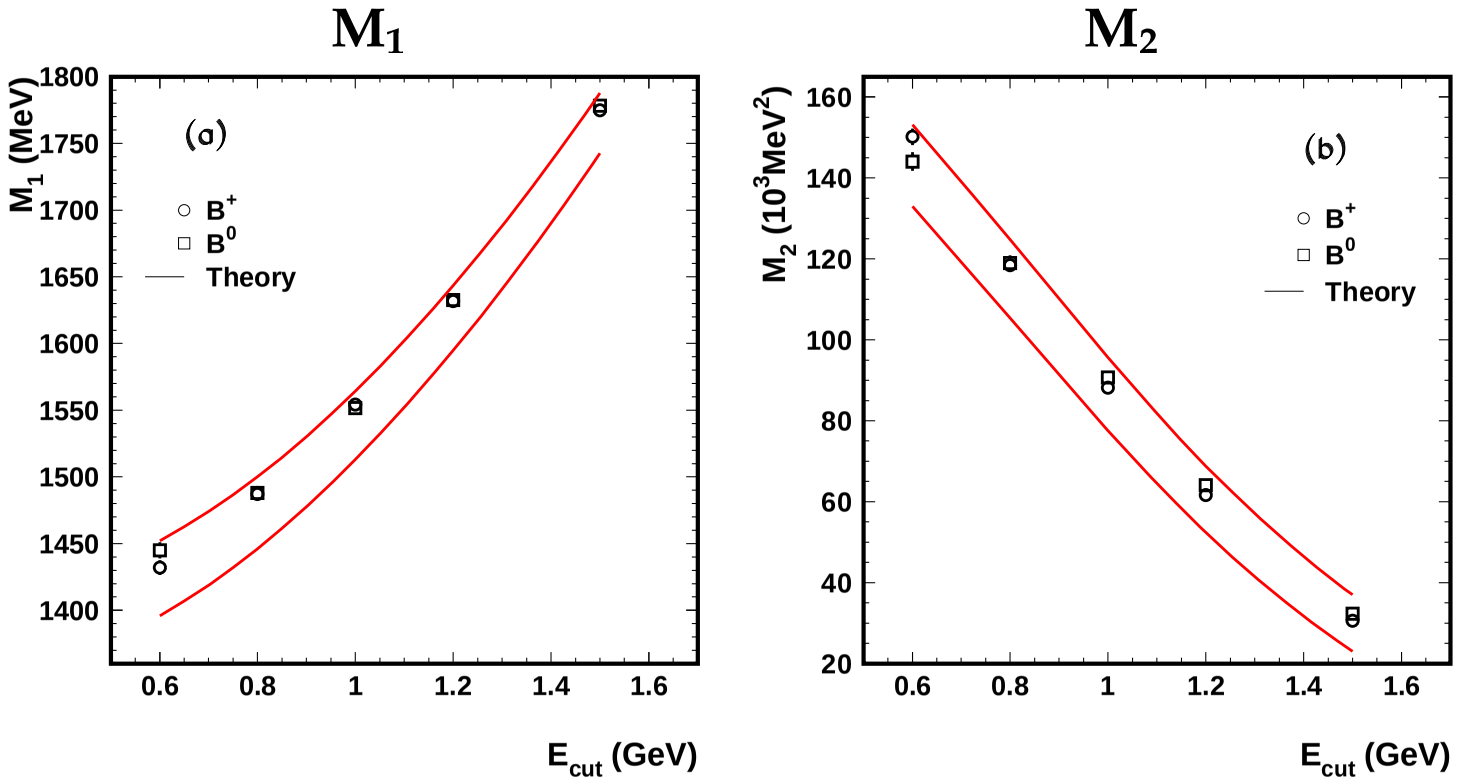


Leptonic Moment

- Unfolded energy distribution



Leptonic Moment

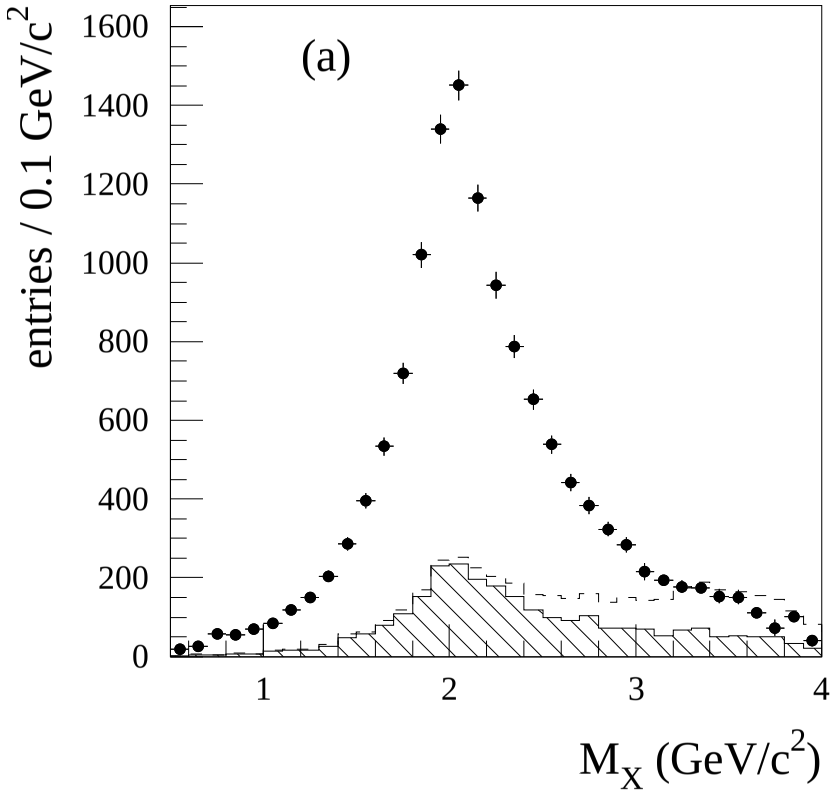


E^*_{cut} (GeV)	M_1 (MeV)		M_2 (10^3 MeV^2)	
	$B^\pm$	B^0	$B^\pm$	B^0
0.6	1432.1 ± 4.3 ± 3.6	1444.9 ± 5.5 ± 2.8	150.1 ± 1.8 ± 1.2	144.0 ± 2.1 ± 1.0
0.8	1487.1 ± 3.9 ± 2.2	1488.0 ± 5.1 ± 1.8	118.4 ± 1.4 ± 0.7	119.0 ± 1.8 ± 0.6
1.0	1554.1 ± 3.6 ± 1.1	1551.5 ± 4.7 ± 1.0	88.1 ± 1.1 ± 0.3	90.7 ± 1.4 ± 0.3
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

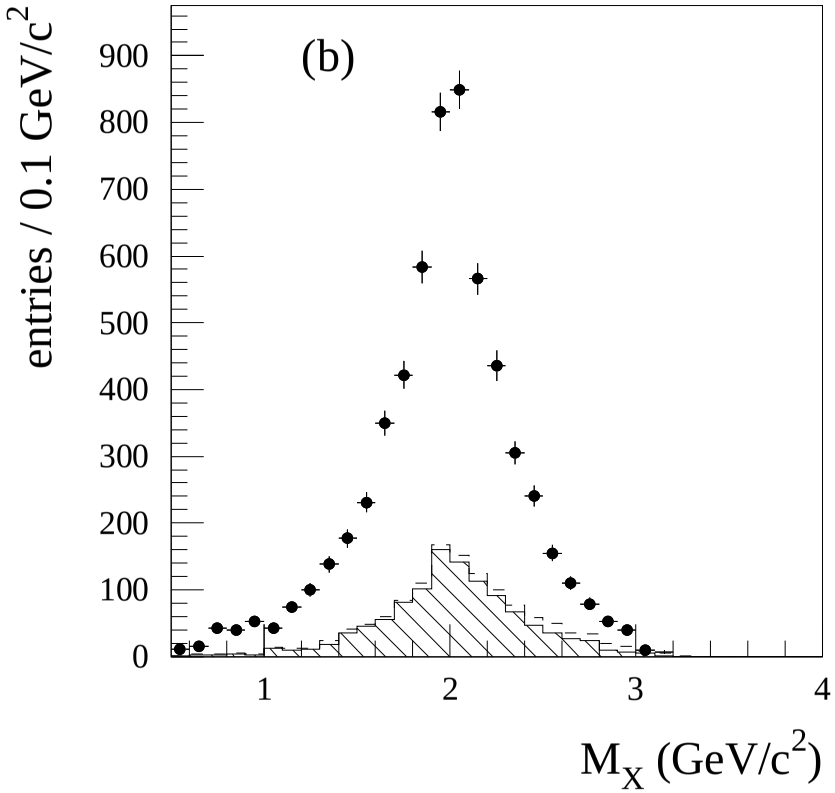
Hadronic Moment

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

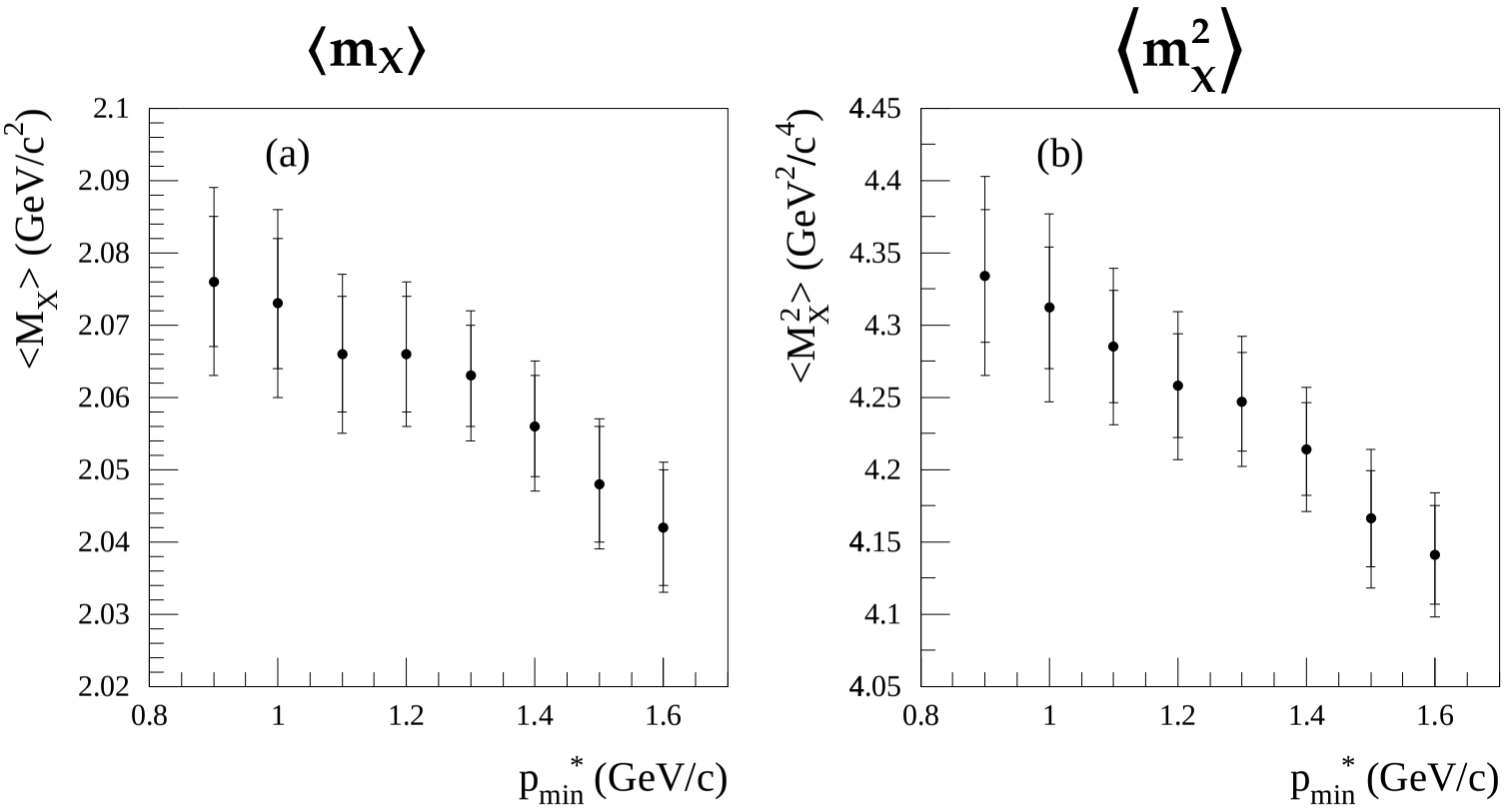
$p^*_\ell > 0.9$ GeV



$p^*_\ell > 1.6$ GeV



Hadronic Moment



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

Belle $|V_{ub}|$ Mesurement Summary