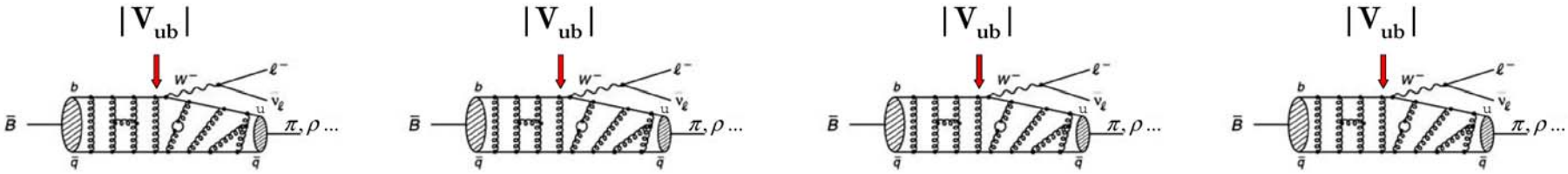
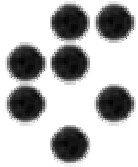


Measurement of $|V_{ub}|$ at

BELLE

Ilija Bizjak,

Jozef Stefan Institute



2005-10-27

PANIC 2005

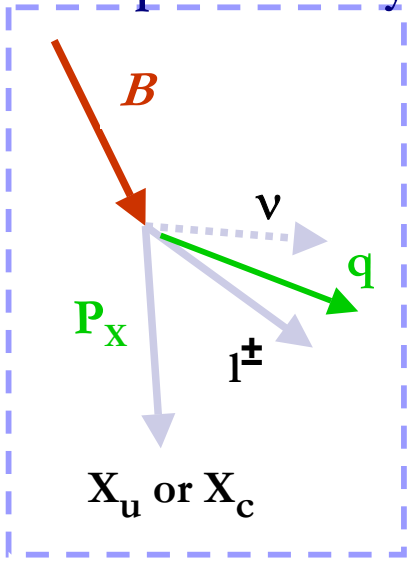
$|V_{ub}|$ determination at Belle

INCLUSIVE

✓ Using endpoint of momentum spectrum for $e^{\pm}$ with 27 fb^{-1}

Endpoint of momentum spectrum region above 1.9 GeV/c } Measure partial branching fraction + obtain $|V_{ub}|$

semileptonic decay



✓ Full reconstruction tagging with 253 fb^{-1}

3 kinematical sel. where $b \to c$ decays are suppressed:

1) $M_X < 1.7$ GeV/c^2 / $q^2 > 8$ GeV^2/c^2
2) $M_X < 1.7$ GeV/c^2 / no q^2 cut
3) $P_+ \equiv E_X - p_X$ analysis : $P_+ < 0.66$

} Measure partial rate + obtain $|V_{ub}|$

EXCLUSIVE

✓ Using $D^{(*)}l\nu$ tagging with 253 fb^{-1}

Exclusive reconstruction of $\pi l\nu$ } Measure branching fraction for $\pi/\rho l\nu$ + obtain $|V_{ub}|$

endpoint : Phys. Lett. B 621, 28 (2005)

full recon: submitted to PRL, hep-ex/0508018

Inclusive $|V_{ub}|$ determination

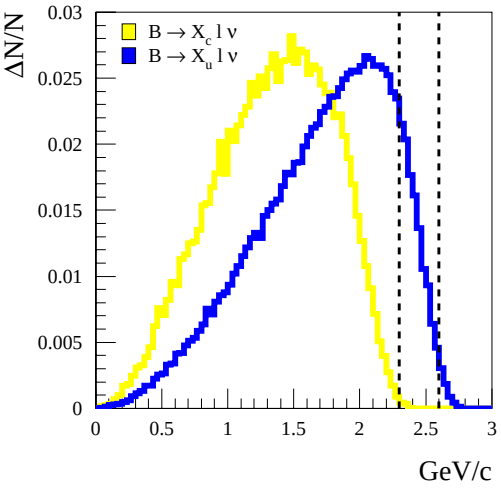
Electron momentum endpoint

Measurement region:

$$1.9\ \text{GeV/c} < p_e^* < 2.6\ \text{GeV/c (CMS)}$$

Background estimation region:

$$1.5\ \text{GeV/c} < p_e^* < 1.9\ \text{GeV/c (CMS)}$$



Deal with LARGE backgrounds: electrons from

- $B\bar{B}$ processes
- non $B\bar{B}$ processes

$B\bar{B}$ backgrounds

- $B \to X_c l\nu$
- Leptons from other decays

  (J/ψ, ψ (2S), γ conv.)
- Fake electrons

MC simulation:
- D**eν (ISGW2)
- D*eν (HQET)
- Deν (ISGW2)

QED radiative corrections included

Fit (D*+ D)lν/ D** lν relative contributions

Veto on invariant mass

Estimated using $K_s \to \pi^+\pi^-$

How to deal with large non-$B\bar{B}$ background

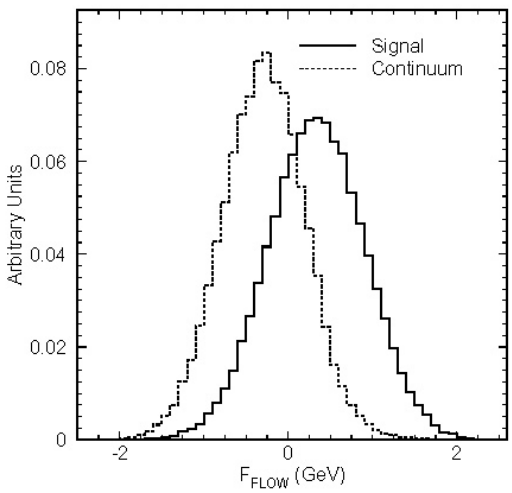
Non $B\bar{B}$ backgrounds

- Continuum ($e^+e^- \to qq$)
- QED processes

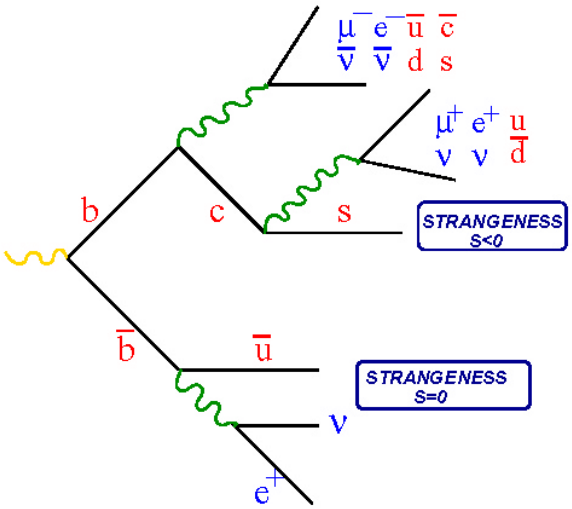
Visible energy
Charged multiplicity
Fox-Wolfram moments
Fisher discriminant:
Energy flow variables
Thrust axis
Rare B decay tag

+ Subtraction of continuum ($8.8 fb^{-1}$ of offresonance data)

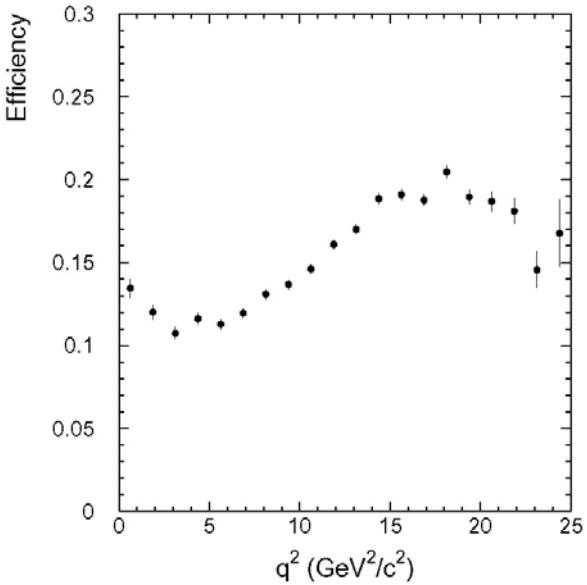
Energy flow variable



Rare B decay tag

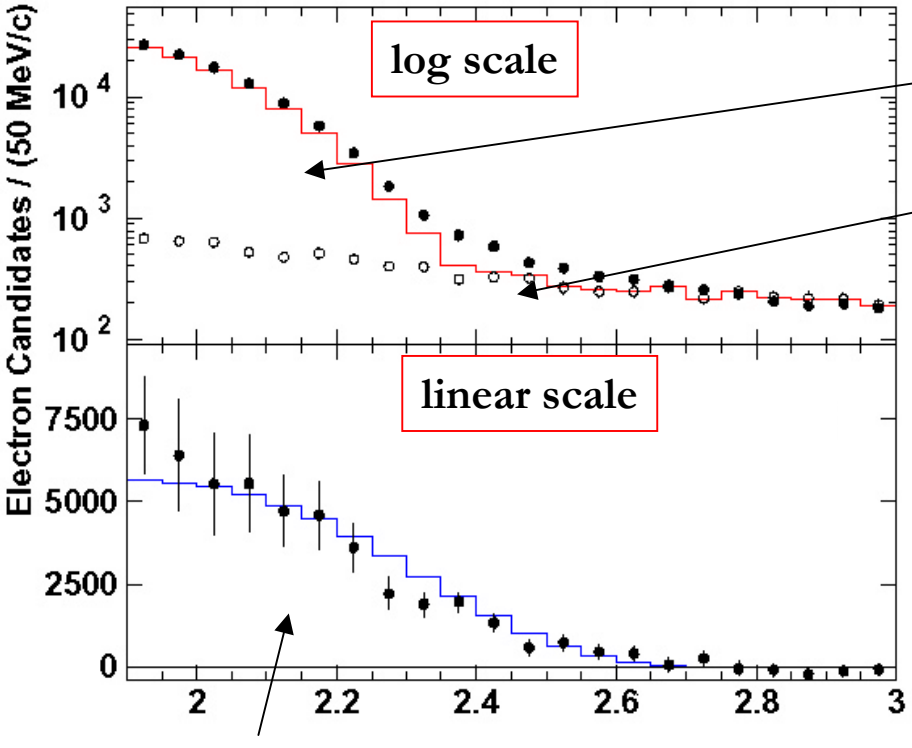


Acceptance of selection requirements as a funct. of q^2



I. Bizjak, PANIC 2005

Electron spectrum endpoint: the result (27 fb^{-1})



$B\bar{B}$ background (b→c MC expectation)

continuum background

b→u MC expected shape

Systematic uncertainty:

Model dependent signal eff. ... 1.7% - 3.4%

$B \to X_c l\nu$ background estimation ... 17%

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

$$|V_{ub}| = \sqrt{\frac{(1+\delta_{rad})\times \Delta Br\left(X_u l\nu\right)}{\tau_B}\frac{1}{R}}$$

total error on $|V_{ub}|$ 11%

$$|V_{ub}| = (4.82 \pm 0.47 \pm 0.31) \times 10^{-3}$$

stat + syst

Shape function parameter determination

$m_b(SF) = 4.60 \pm 0.040,\ \mu_\pi^2(SF) = 0.20 \pm 0.040$

(hep-ph/0507253)

+ theoretical error

Fully reconstructed sample

Fully reconstructed sample

Clean environment but small sample: $\varepsilon_{reco} \approx 3 \cdot 10^{-3}$

Exclusive method: 180 decay channels

Test of quality of reconstruction: $M_{BC} = \sqrt{E_{beam}^2/c^4 - p_B^2/c^2}$

Reconstructed channels:

$B^0 \to D^{(*)-}\pi^+ / D^{(*)-}\rho^+ / D^{(*)-}a_1^+ / D^{(*)-} D_s^{(*)+}$

$B^+ \to D^{(*)0}\pi^+ / D^{(*)0}\rho^+ / D^{(*)0}a_1^+ / D^{(*)0} D_s^{(*)+}$

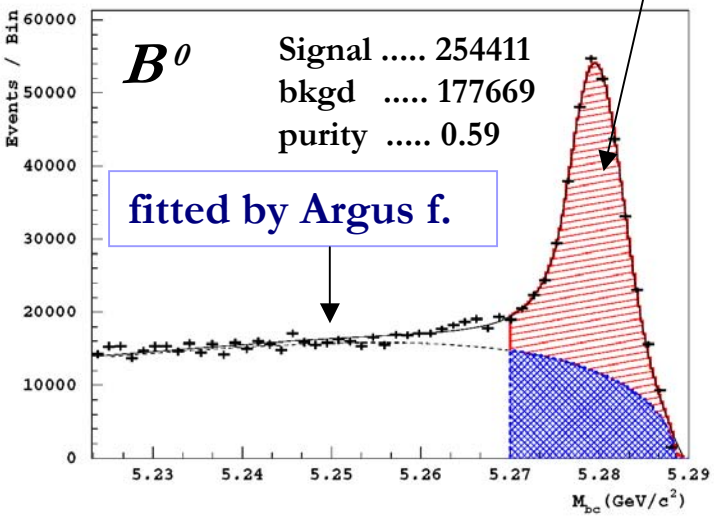
$D^{*0} \to D^0\pi^0 \quad D^* \to D^0\pi / D\pi^0 \quad D_s^* \to D_s\gamma$

$D^0 \to K\pi / K\pi\pi^0 / K\pi\pi\pi / K_s\pi^0 / K_s\pi\pi / K_s\pi\pi\pi^0 / KK$

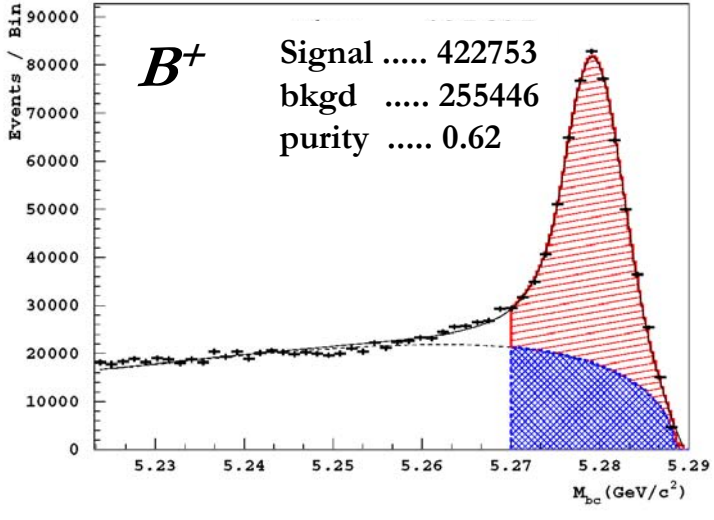
$D \to K\pi\pi / K\pi\pi\pi^0 / K_s\pi / K_s\pi\pi^0 / K_s\pi\pi\pi / KK\pi$

$D_s \to K_sK\pi / KK\pi$

fitted by Crystal Ball f.



out of 275 milion $B\bar{B}$



Selection of $B \to X_u l \nu$ events

① From reconstructed events select events with **high momentum leptons**

$p^* > 1 GeV/c$

Charged B tag:
require charge consistency
→ sample of semileptonic decays

+

② **Additional selection criteria:**

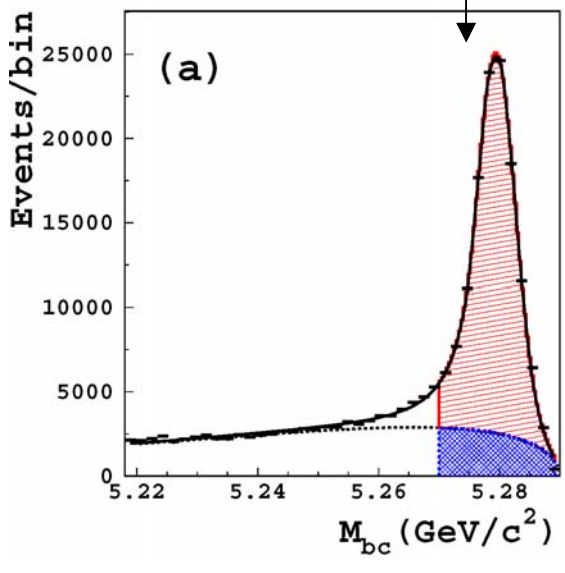
Require only one lepton

Total charge: $\Sigma Q=0$

$-1 < |m_{miss}^2| < 0.5 GeV^2/c^4$

$No(K^+)=0$, $No(K^0_S)=0$

$\cos\vartheta_{miss} < 0.95$



③ Construct kinematical variable distributions

M_x , q^2 , $P_+ \equiv E_X - p_X$

④ Estimate excess events over the $b \to c$ contribution (MC simulation)

⑤ Calculate $|V_{ub}|$

I. Bizjak, PANIC 2005

Partial rate calculation

Number of excess events

Unfolding factor F

$$W(\Delta\Phi) = \frac{\Delta\Gamma_{ul\nu}(\Delta\Phi)}{\Gamma(Xl\nu)} = \frac{N_{b\to u}}{N_{sl}} \cdot \frac{F}{\varepsilon_{sel}} \cdot \frac{\varepsilon^{sl}_{frec}}{\varepsilon^{b\to u}_{frec}} \frac{\varepsilon^{sl}_{\ell}}{\varepsilon^{b\to u}_{\ell}}$$

Number of semileptonic events

Ratio of efficiencies for *b→u* and *sl*

selection efficiency

$$\Delta\Gamma_{ul\nu}(\Delta\Phi) = W(\Delta\Phi) \times \Gamma(Xl\nu)$$

from the world average

$$|V_{ub}| = \sqrt{\frac{\Delta\Gamma_{ul\nu}(\Delta\Phi)}{R(\Delta\Phi)}}$$

Non-perturbative part of R(ΔΦ) calculation packed in the "shape function"

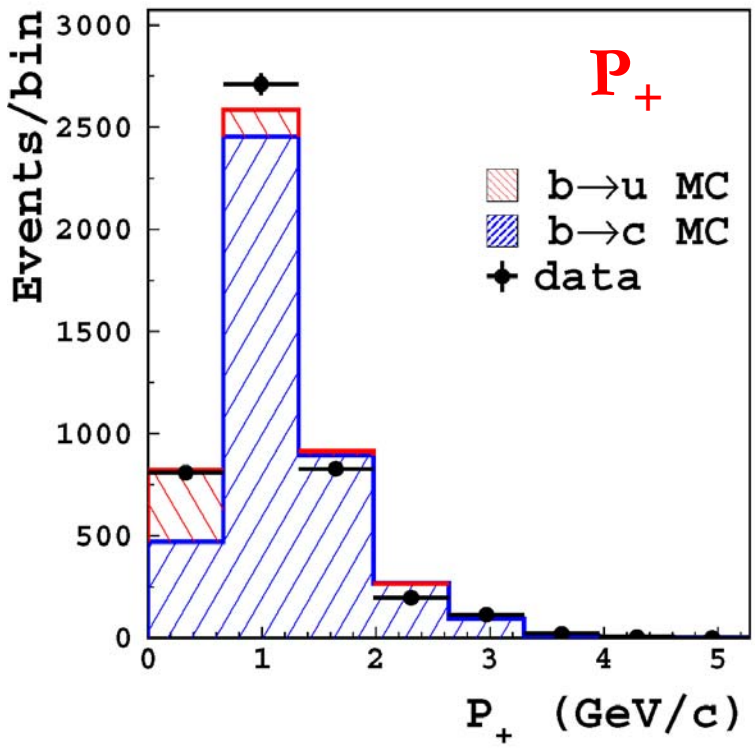
$$m_b(SF) = 4.60 \pm 0.040,\ \mu_\pi^2(SF) = 0.20 \pm 0.040$$

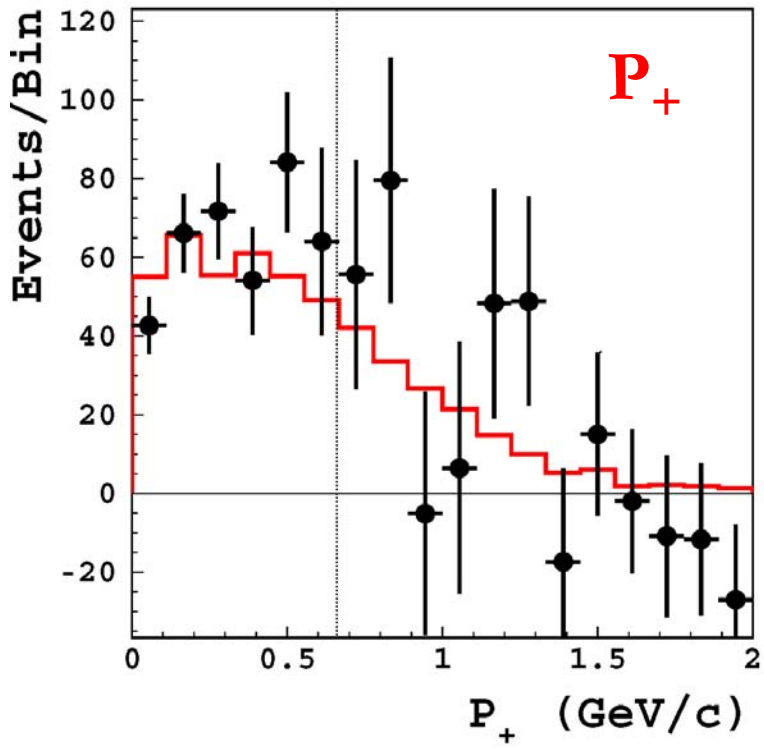
hep-ph/0507253

P_+ analysis

$P_+ < 0.66$ GeV/c

$P_+ = E_x/c - p_x$
$P_- = E_x/c + p_x$





Total error on $|V_{ub}|$ 11%

$$|V_{ub}| = (4.19 \pm 0.20 \pm 0.19 \pm 0.13 \pm 0.18 \pm 0.24\ ^{+0.14}_{-0.15}) \times 10^{-3}$$

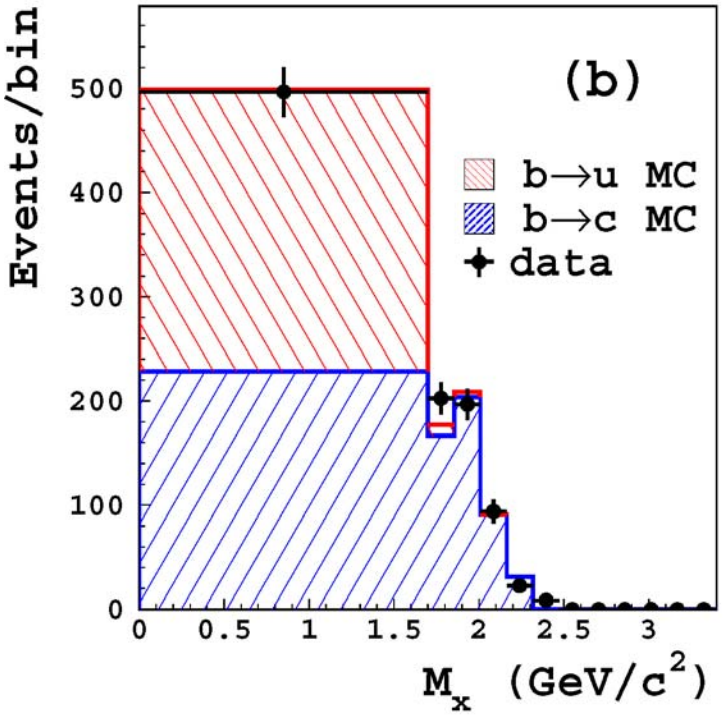
stat syst b→c b→u SF theo

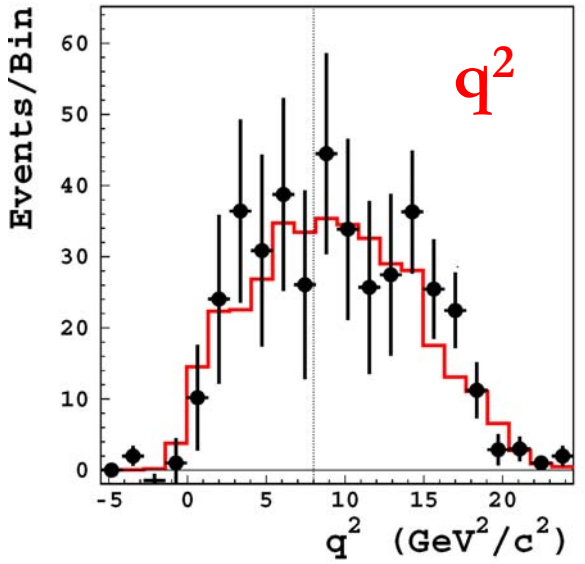
model dep.

I. Bizjak, PANIC 2005

M_x/q^2 analysis

M_x<1.7 GeV/c² / q^2>8 GeV²/c²





Total error on $|V_{ub}|$ 10%

$$|V_{ub}| = (4.70 \pm 0.24 \pm 0.21 \pm 0.15 \pm 0.12 \pm 0.20\,^{+0.22}_{-0.25}) \times 10^{-3}$$

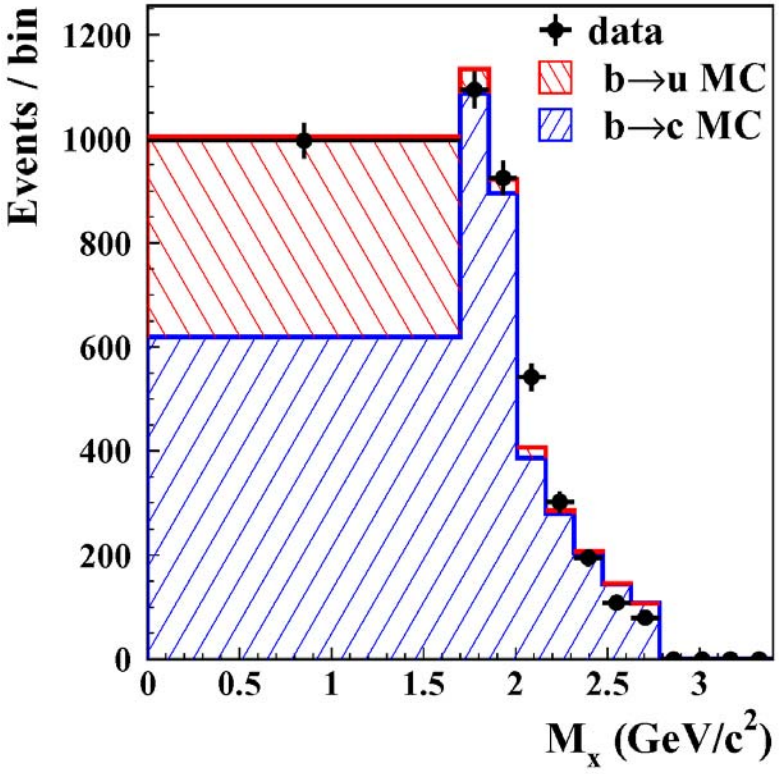
stat syst b→u b→c SF theo

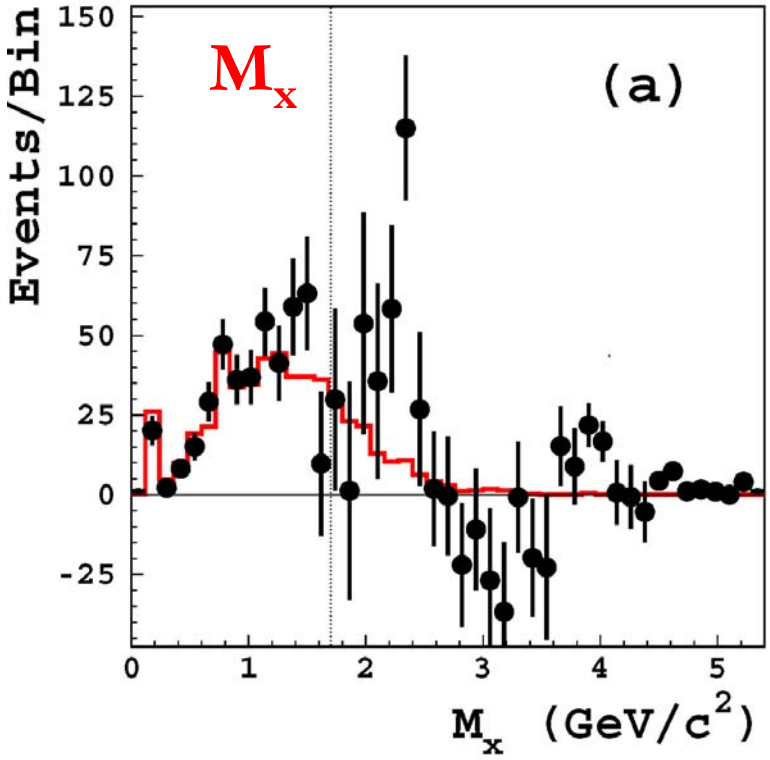
model dep.

I. Bizjak, PANIC 2005

M_x analysis

M_x<1.7 GeV/c² / no q^2 selection





total error on $|V_{ub}|$ 9%

$$|V_{ub}| = (4.09 \pm 0.19 \pm 0.14 \pm 0.12 \pm 0.05 \pm 0.18\ ^{+0.14}_{-0.15}) \times 10^{-3}$$

stat syst b→u b→c SF theo

model dep.

I. Bizjak, PANIC 2005

Inclusive $|V_{ub}|$ Results (comparison by HFAG)

Results recalculated using s.f. parameters

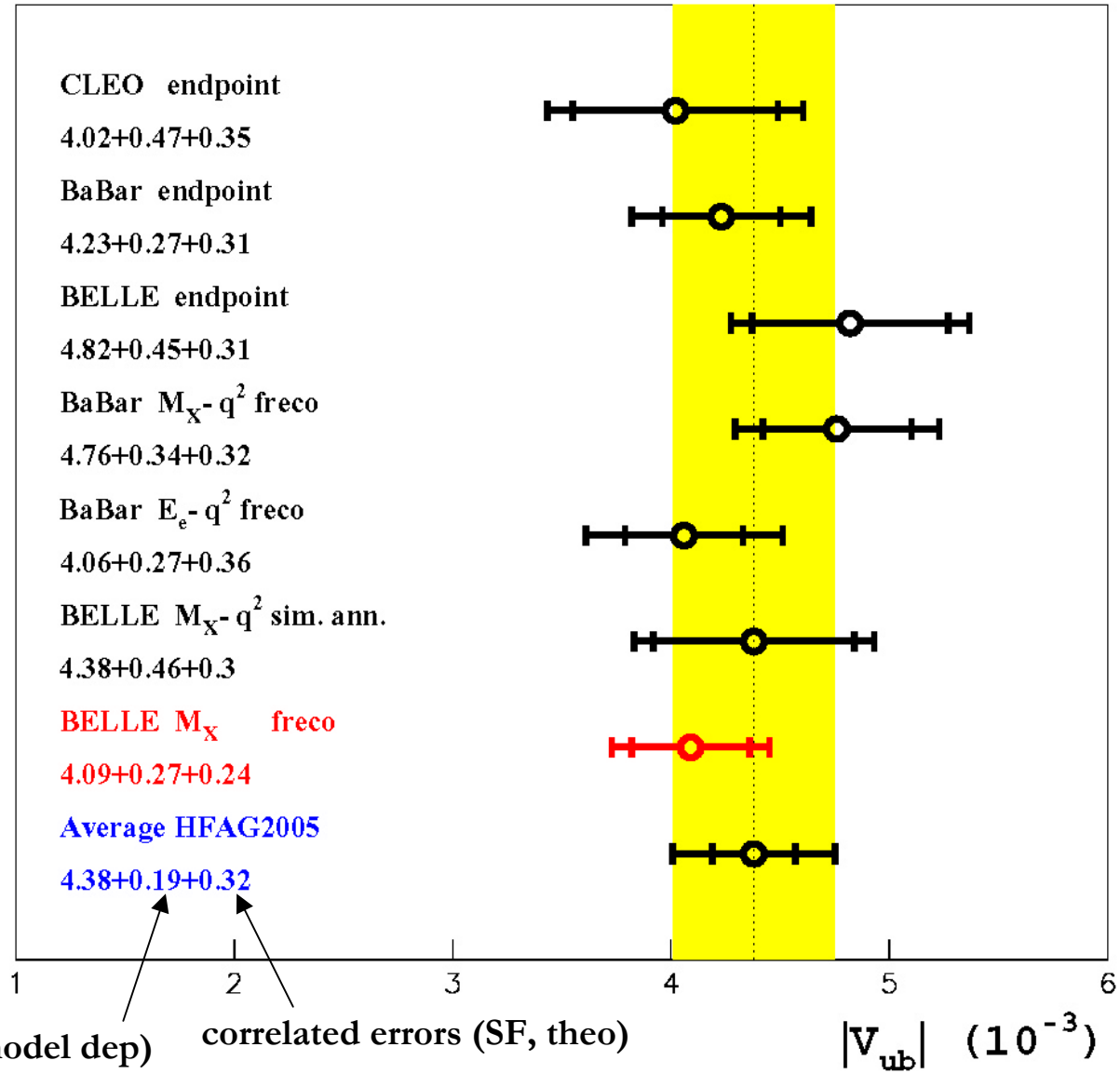
$m_b(SF) = 4.60 \pm 0.040, \mu_\pi^2(SF) = 0.20 \pm 0.040$

Belle Endpoint result

Phys. Lett. B 621, 28 (2005)

Belle final full recon result

submitted to PRL, hep-ex/0508018

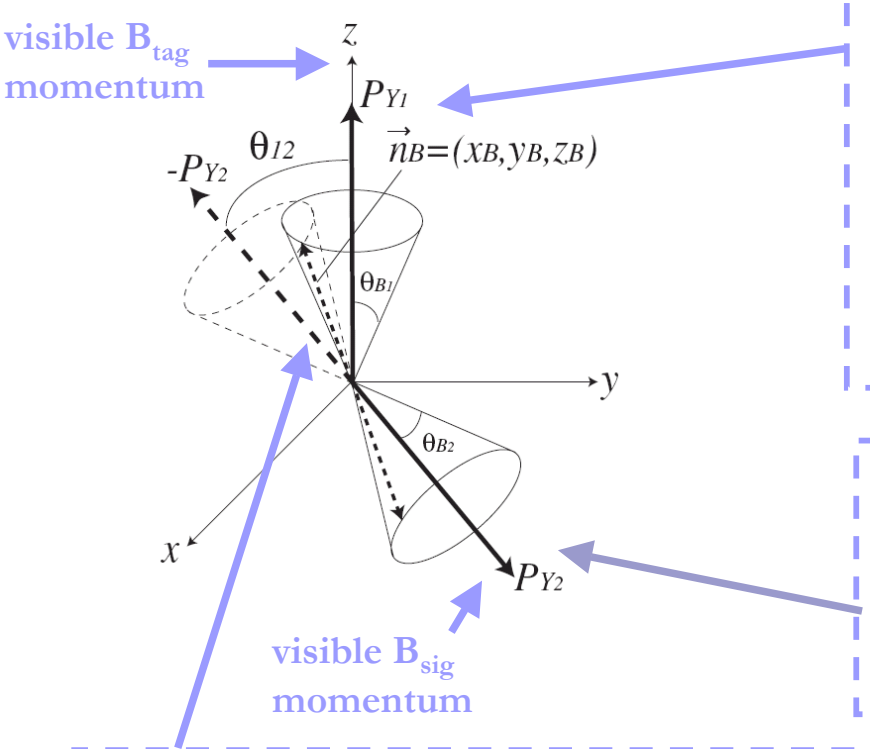


uncorrelated errors (stat, syst, model dep)

correlated errors (SF, theo)

Exclusive $|V_{ub}|$ determination

$D^{(*)}l\nu$ tagging



Tag side reconstruction

$\bar{B}^0_{tag} \to D^{*+} l^- \bar{\nu}$ / $D^+ l^- \bar{\nu}$

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

$\hookrightarrow$ 6 decay modes

$\hookrightarrow$ 10 decay modes

$B^-_{tag} \to D^{*0} l^- \bar{\nu} / D^0 l^- \bar{\nu}$

$\hookrightarrow D^0\pi^0$

Signal side reconstruction

$B^0_{sig} \to \pi^- l^+ \nu$ / $\pi^-\pi^0 l^+\nu$ $\to \rho^-$

$B^+_{sig} \to \pi^0 l^+ \nu$ / $\pi^+\pi^- l^+\nu$ $\to \rho^0$

Double semileptonic decay: Back-to-back correlation of the two *B* mesons constrains their direction to the intersection of the 2 cones.

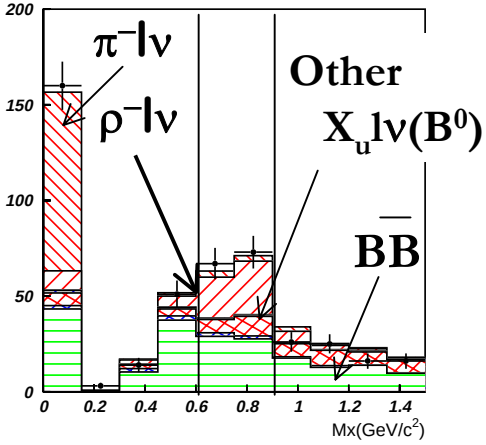
$$x_B = \pm\sqrt{1 - \frac{1}{\sin\theta_{12}}(\cos^2\theta_{B_1} + \cos^2\theta_{B_2} - 2\cos\theta_{B_1}\cos\theta_{B_2}\cos\theta_{12})},$$

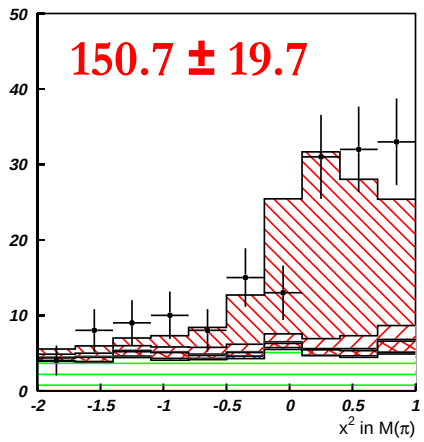
$0 \le x_B^2 \le 1$ for signal

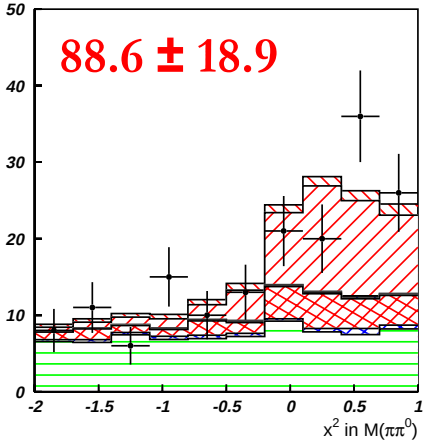
Signal extraction

Extract $\pi^- l^+ \nu$, $\rho^- l^+ \nu$, $\pi^0 l^+ \nu$, $\rho^0 l^+ \nu$ by 2D fitting in (Mx, x_B^2)

$\pi^-/\rho^- l\nu$

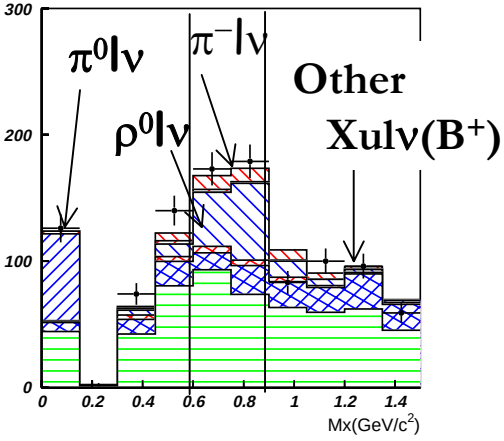


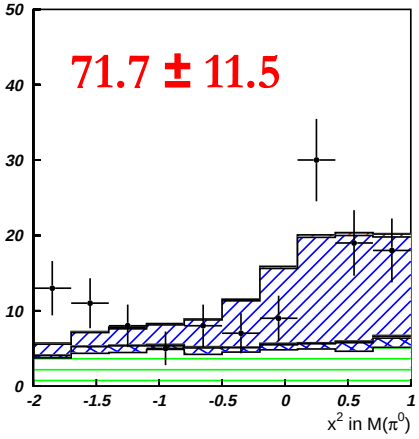


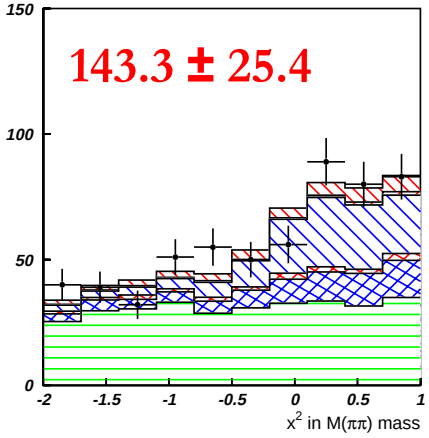


M_X dist. $\quad$ x_B^2 dist. in π mass $\quad$ x_B^2 dist. in ρ mass

$\pi^0/\rho^0 l\nu$







I. Bizjak, PANIC 2005

Branching fractions & $|V_{ub}|$

q^2	$\pi^- l \nu$	$\pi^0 l \nu$
Total	1.48±0.20±0.16±0.04	0.76±0.13±0.08±0.04
<16	1.08±0.16±0.11±0.04	0.54±0.11±0.06±0.03
>16	0.40±0.12±0.04±0.02	0.22±0.08±0.02±0.01

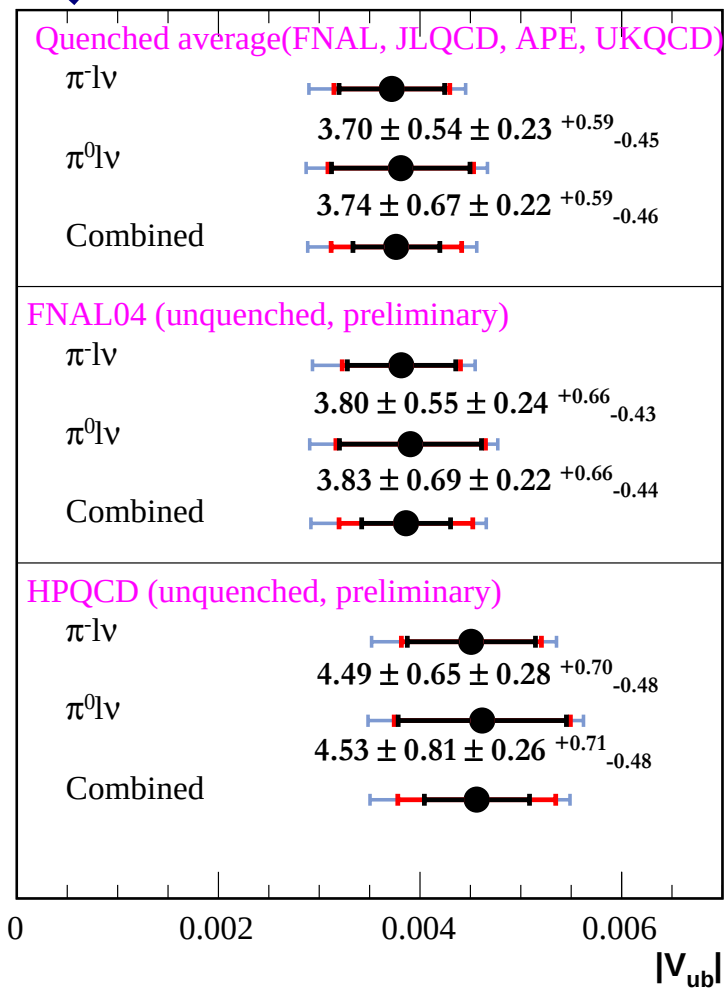
Err. : stat. ± sys ± F.F.

q^2	$\rho^- l \nu$	$\rho^0 l \nu$
Total	2.07±0.47±0.25±0.14	1.39±0.23±0.17±0.02

$\times 10^{-4}$

Preliminary

EPS05-542
hep-ex/0508018



$|V_{ub}|$ from Br ($B \to \pi l \nu$, q^2>16)

$$|V_{ub}| = \sqrt{\frac{\Delta B(B \to \pi l \nu)}{\Gamma_{thy} \cdot \tau_B}}$$

<u>unquenched lattice QCD results:</u>

FNAL'04 : $(3.81 \pm 0.44 \pm 0.23\ ^{+0.66}_{-0.43}) \times 10^{-3}$

HPQCD : $(4.50 \pm 0.52 \pm 0.27\ ^{+0.70}_{-0.48}) \times 10^{-3}$

stat syst theo

Conclusions

Lepton endpoint measurement

- with lowest cut ($p^* > 1.9$ GeV/c)
- $|V_{ub}|$ error 11%, a competitive result

Full reconstruction

- The M_X result is the most accurate $|V_{ub}|$ measurement to date (total error 9%)
- P_+ usable (but with largest total error)
  - smallest theoretical error
  - largest sensitivity to b→c background
  - largest sensitivity to SF parameter determination

INCLUSIVE

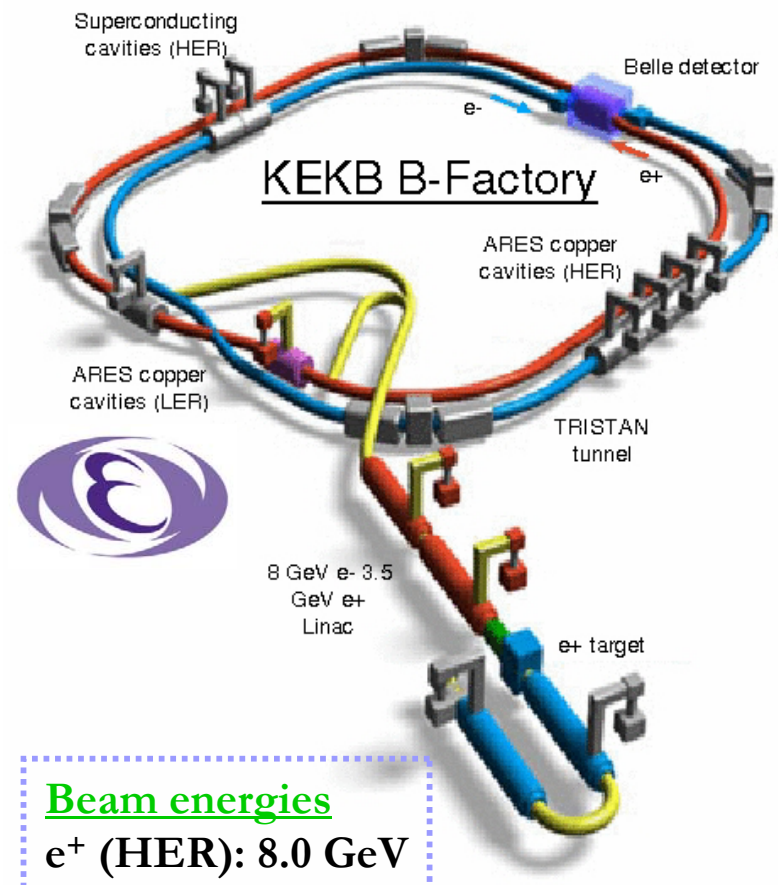
EXCLUSIVE

$D^{(*)}l\nu$ tagging

- Experimental error ~ 13 %
  (statistical uncertainty is dominant ~ 11%)
- Theoretical error ~ 16 %

backup slides

Belle detector @ KEKB



Beam energies

e^+ (HER): 8.0 GeV

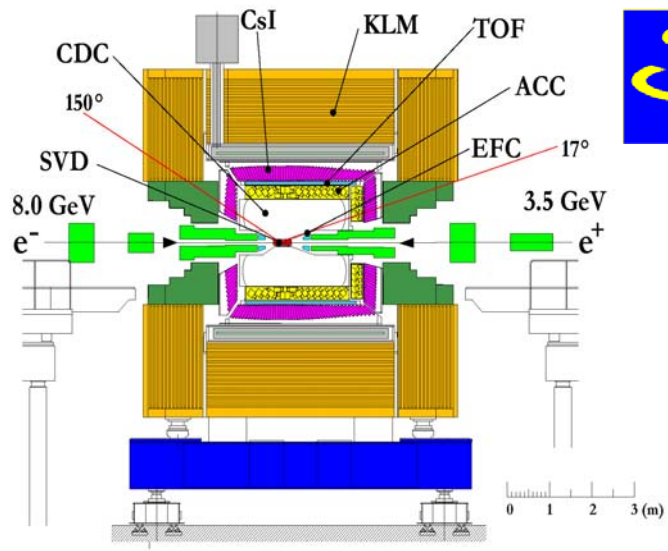
e^- (LER): 3.5 GeV

E_{CM}=10.58 GeV

5 years of data taking:

$L_{max}=15.6 \cdot 10^{33}\ cm^{-2}s^{-1}$

$L_{int}= 468.9\ fb^{-1}$ ... 426 million B meson events



SVD: Silicon Vertex Detector
CDC: Central Drift Chamber
CsI: CsI Calorimeter
KLM: K_L and muon detector
TOF: Time of Flight Counter
ACC: Aerogel Cherenkov Counter
EFC: E-M Forward Calorimeter

{ Belle Detector covers large part of solid angle }

I. Bizjak, PANIC 2005

Uncertainty breakdown – full. recon.

The break-down of relative uncertainty contributions of the partial rate measurement

SOURCE	M_X/q^2	M_X	P_+
statistics	10.0	9.1	9.4
systematics:			
binning	2.0	2.0	2.0
$r^{sl}_{b\to u}$	2.4	1.9	2.0
$\mathcal{B}(X\ell\nu)/\tau_B$	3.0	3.0	3.0
$b \to c$ MC statistics	5.8	4.0	4.8
$b \to u$ MC statistics	2.9	2.0	2.5
Detector simulation	4.1	2.5	5.6
K_L simulation	1.5	2.8	2.8
total systematics	8.9	7.1	9.2
$b \to u$ modeling:			
SF related	6.0	5.9	6.2
$g \to s\bar{s}$	1.5	1.5	1.5
total $b \to u$ modeling	6.2	6.1	6.4
$b \to c$ modeling:			
D/D^* form factor modeling	5.2	1.0	8.0
$\mathcal{B}(B \to D^*\ell\nu)$	1.0	1.0	2.0
$\mathcal{B}(B \to D^{**}\ell\nu)$	0.1	1.7	2.8
total $b \to c$ modeling	5.3	2.2	8.7

given in %

The break-down of relative uncertainty contrib. for $|V_{ub}|$

$\Delta\Phi$	$\lvert V_{ub}\rvert \times 10^3$	stat	syst	$b \to u$	$b \to c$	SF	th.
M_X/q^2	4.70	5.0	4.4	3.1	2.7	4.2	$^{+4.8}_{-5.2}$
M_X	4.09	4.6	3.5	3.1	1.1	4.5	$^{+3.5}_{-3.8}$
P_+	4.19	4.7	4.6	3.2	4.4	5.8	$^{+3.4}_{-3.5}$

Partial branching fractions

(What is actually being measured)

Electron endpoint

"statistical" "systematic"

$$\Delta Br\ (\ 1.9 < P_l < 2.6\ ) = (8.47 \pm 0.37 \pm 1.53)\times 10^{-4}$$

Full reconstruction tagging

"statistical" "systematic"

$$\Delta Br\ (M_x < 1.7,\ q^2 > 8,\ p^* > 1) = (8.41 \pm 1.14 \pm 0.69)\times 10^{-4}$$

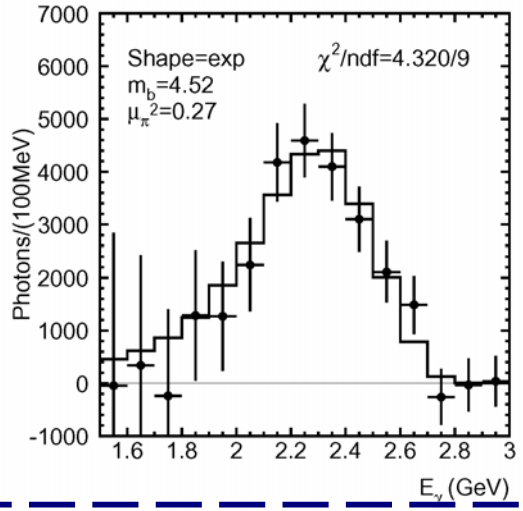
$$\Delta Br\ (M_x < 1.7,\ p^* > 1) = (1.24 \pm 0.15 \pm 0.08)\times 10^{-3}$$

$$\Delta Br\ (P_+ < 0.66,\ p^* > 1) = (1.10 \pm 0.15 \pm 0.12)\times 10^{-3}$$

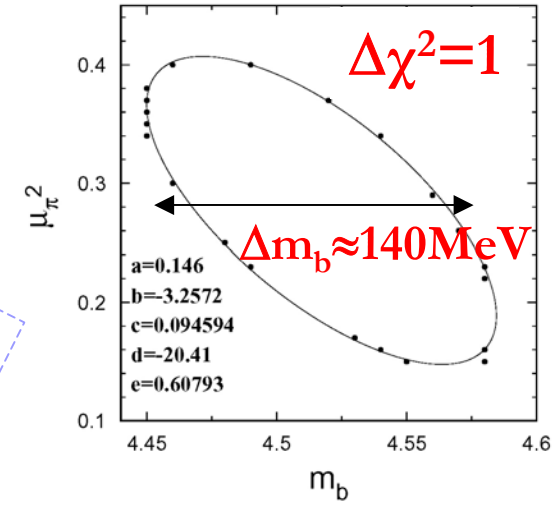
Shape function parameters

Shape function parameters from fit to shape of b→ sγ

$$m_b(\mathrm{SF}) = 4.52 \pm 0.070,\ \mu_\pi^2(\mathrm{SF}) = 0.27 \pm 0.130$$



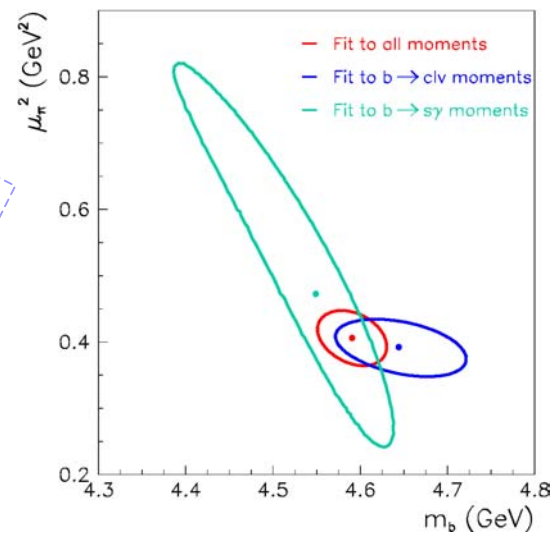
hep-ex/0506057



Shape function parameters from a combined fit to moments of b→ sγ and b→ clν distributions from several experiments

hep-ph/0507253

$$m_b(\mathrm{SF}) = 4.60 \pm 0.040,\ \mu_\pi^2(\mathrm{SF}) = 0.20 \pm 0.040$$



$|V_{ub}|$ Results using $m_b(SF) = 4.52 \pm 0.070, \mu_\pi^2(SF) = 0.27 \pm 0.130$

Electron endpoint ($p^* > 1.9$ GeV/c)

$|V_{ub}| = (5.08 \pm 0.47 \pm 0.49) \times 10^{-3}$ 13%

Full reconstruction tagging

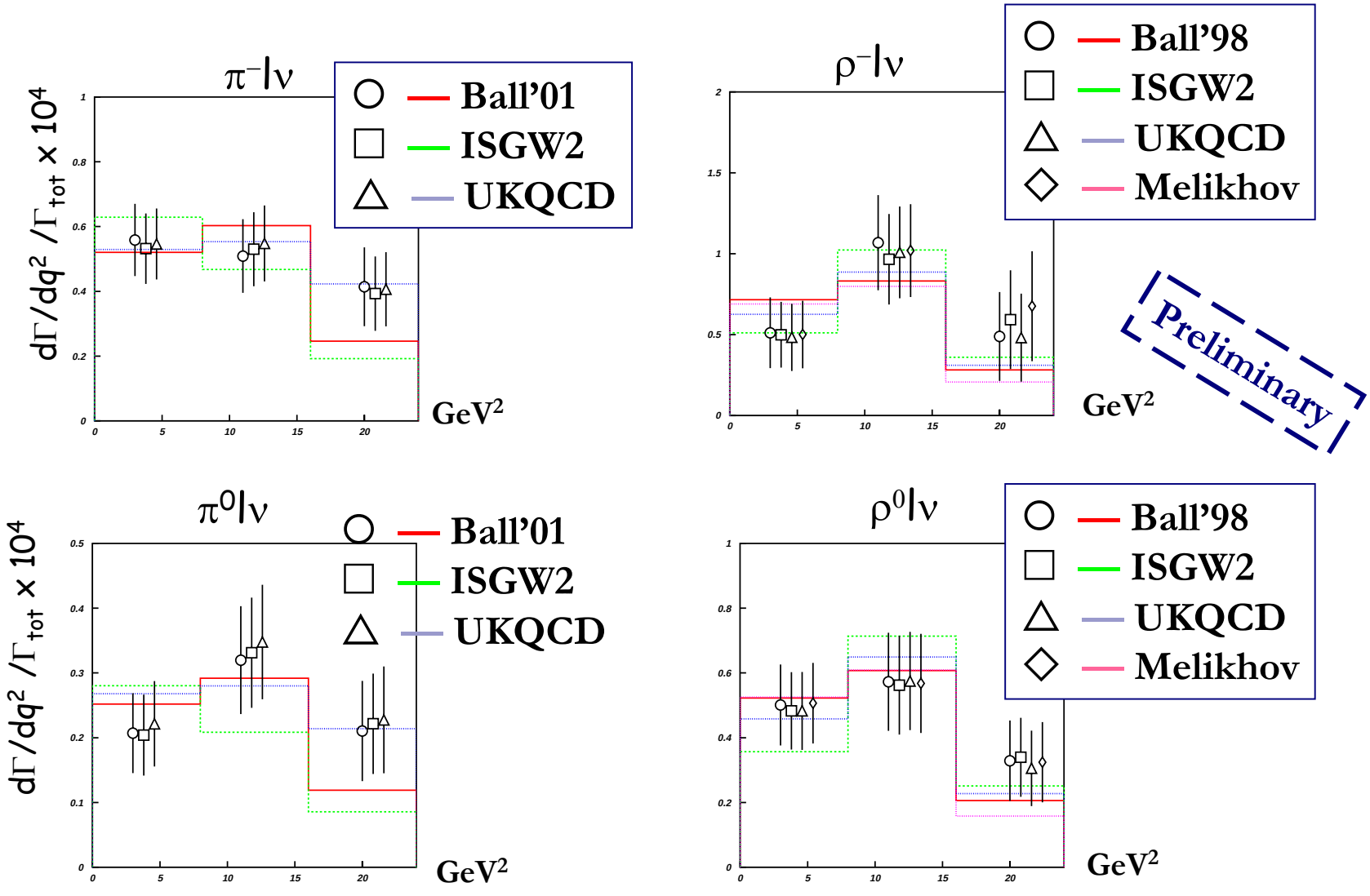
$|V_{ub}| = (4.93 \pm 0.33 \pm 0.56) \times 10^{-3}$ M_x / q^2 13%

$|V_{ub}| = (4.35 \pm 0.25 \pm 0.45) \times 10^{-3}$ M_x 12%

$|V_{ub}| = (4.56 \pm 0.30 \pm 0.55) \times 10^{-3}$ P_+ 14%

correlated errors (SF, theo)

uncorrelated errors (stat, syst, model dep)

Extraction of q^2 distribution

Experimental determination of the q^2 distribution for exlcusive $\pi l \nu$ and $\rho l \nu$ modes to minimize F.F. dependence