CP violation and related issues

Part 9: measurements of V_{ub}

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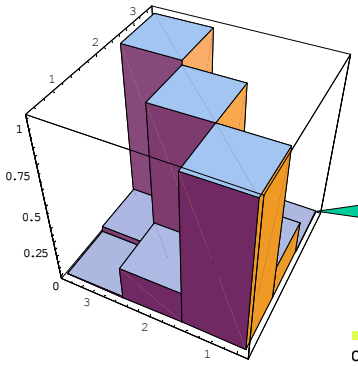
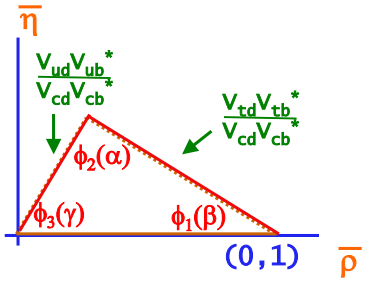
Contents

Unitary triangle: V_{ub}

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$V = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$





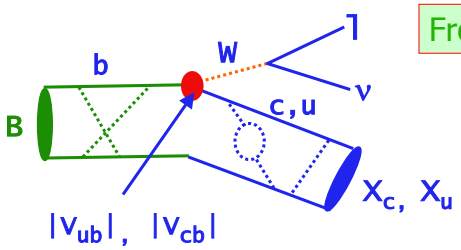
CKM matrix measurements

CKM matrix is unitary

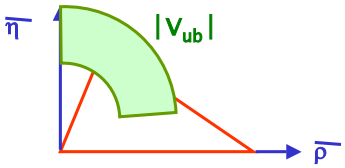
-> angles should add up to 180^0
-> sides should fit the same triangle

Deviations of individual measurements could signal processes not included in SM

$|V_{ub}|$ measurements



From semileptonic B decays



$|V_{cb}|$ known to ~1.4%, becoming as precise as $|V_{us}|=|$ (~1%)

need to pin-down $|V_{ub}|$, present world average error ~10%

b→clν background typically an order of magnitude larger.

Inclusive $|V_{ub}|$ measurement

Traditional inclusive method: use semileptonic decays, fight the background from b→clν decays by using only events with electron momentum above the b→clν kinematic limit. Problem: extrapolation to the full phase space→ large theoretical uncertainty. -> new development

New method: fully reconstruct one of the B mesons, check the properties of the other (semileptonic decay, low mass of the hadronic system)

- Very good signal to noise
- Low yield (full reconstruction efficiency is 0.3-0.4%)

Electron spectrum endpoint

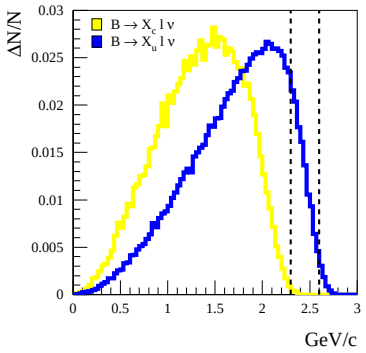
b→clν (yellow) an order of magnitude larger than b→ulν (blue)

Measurement region - traditionally: between the b→clν endpoint and the b→ulν endpoint

$2.3\ \mathrm{GeV/c} < p_e^* < 2.6\ \mathrm{GeV/c}$ (CMS)

-> Huge extrapolation, model dependent...

New: reduce the background and model the remaining background better



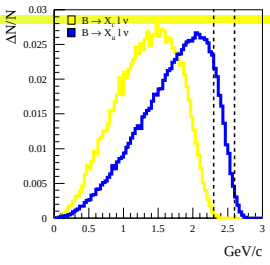
Electron spectrum endpoint: the method

Measurement region:

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

Background estimation region:

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



Deal with large backgrounds:

BB backgrounds

- B→X$_c$ln ← MC simulation: D**eν (ISGW2), D*eν (HQET), Deν (ISGW2) ← QED radiative corrections included
- Leptons from other decays (J/ψ, ψ (2S), γ conv.) ← Veto on invariant mass
- Fake electrons ← Estimated using $K_s \to \pi^+\pi^-$

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

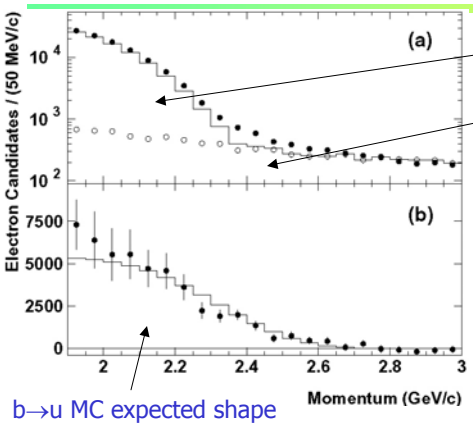
How to deal with large non-BB background

Non BB 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)

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



BB background (b→c MC expectation)

continuum background

Systematic uncertainty:
Model dependent signal eff.1.7% - 3.4%
$B \to X_c l \nu$ background estimation 17%

$|V_{ub}|$ extraction

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

Partial BR -> determine from the data

Bosch, Lange, Neubert, Paz, Nucl.Phys. B699 (2004)

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

1.9 GeV/c $< p_e <$ 2.6 GeV/c :

$$|V_{ub}| = (4.50 \pm 0.42 \pm 0.32 \pm 0.21) \times 10^{-3}$$

exp SF theo

Total error on $|V_{ub}|$ 13%

New inclusive $|V_{ub}|$ measurement

New method: fully reconstruct one of the B mesons, check the properties of the other (semileptonic decay, low mass of the hadronic system)

- Very good signal to noise
- Low yield (full reconstruction efficiency is 0.3-0.4%)

Fully reconstructed sample

Fully reconstructed sample

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

Exclusive method: 180 decay channels

Reconstructed channels:

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

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

$D^{*0} \to D^0\pi^0$

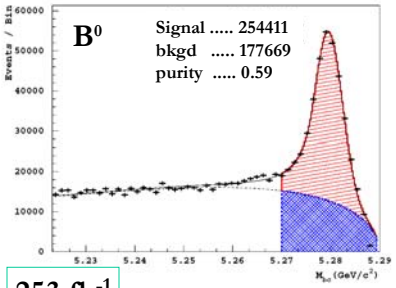
$D^* \to D^0\pi / D\pi^0$

$D_s^* \to D_s\gamma$

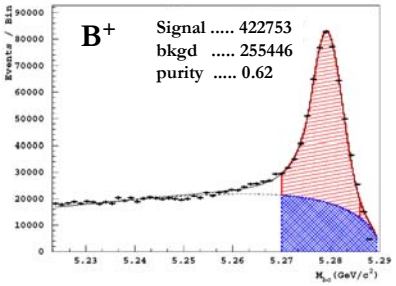
$D^0 \to K\pi / K\pi\pi^0 / K\pi\pi\pi / K_s\pi^0 / K_s\pi\pi / K_s\pi\pi\pi^0 / KK$

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

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



253 fb^{-1}



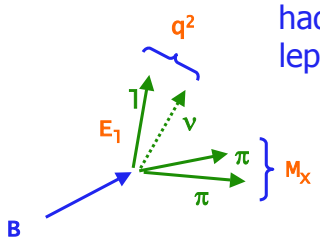
$|V_{ub}|$ measurement

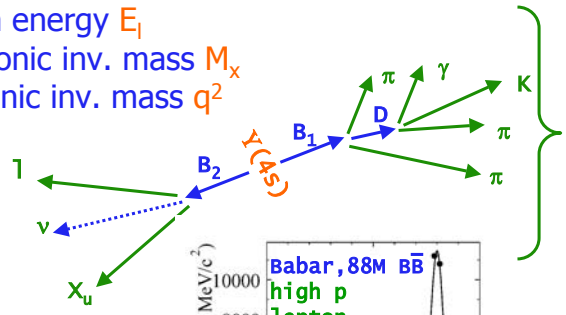
Variables separating $b \to u l \nu$ from $b \to c l \nu$:

lepton energy E_l

hadronic inv. mass M_X

leptonic inv. mass q^2





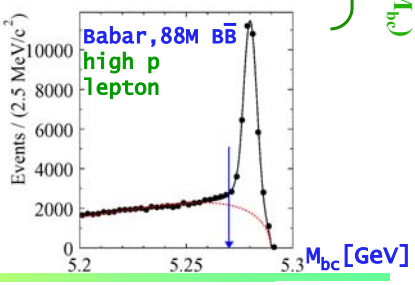
Full reconstruction

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

$\varepsilon \sim 0.25\%$

BaBar: $B \to D^{(*)-}\ n_1\pi\ n_2K$ ...

$\varepsilon \sim 0.4\%$



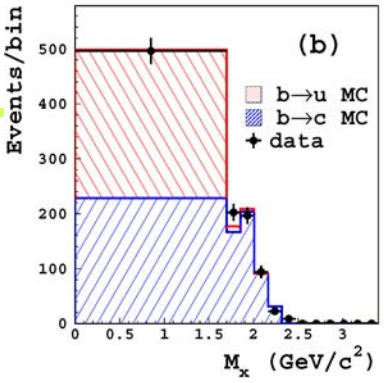
M_x analysis

Use the mass of the hadronic system M_x as the discriminating variable against $b \to c l \nu$

M_x = mass of all hadrons from the B decay. Expect

- M_x for $b \to c l \nu$ to be above 1.8 GeV ($b \to c l \nu$ results in a D meson with >1.8 GeV)
- M_x for $b \to u l \nu$ to mainly below 1.8 GeV ($B \to \pi l \nu, \rho l \nu, \omega l \nu$ ...)

M_x analysis



M_x<1.7 GeV/c^2 / q^2>8 GeV^2/c^4

Total error on $|V_{ub}|$ 12%

253 fb^{-1}

$$|V_{ub}| = (4.93 \pm 0.25 \pm 0.22 \pm 0.15 \pm 0.13 \pm 0.46\,^{+0.20}_{-0.22}) \times 10^{-3}$$

stat syst b→u b→c SF theo

model dep.

M_x<1.7 GeV/c^2 / no q^2 cut : total error on $|V_{ub}|$ 11%

253 fb^{-1}

$$|V_{ub}| = (4.35 \pm 0.20 \pm 0.15 \pm 0.13 \pm 0.05 \pm 0.40\,^{+0.13}_{-0.14}) \times 10^{-3}$$

stat syst b→u b→c SF theo

model dep.

$|V_{ub}|$ Results

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

$|V_{ub}| = (4.50 \pm 0.15 \pm 0.55) \times 10^{-3}$ 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%