Univerza v Ljubljani

THE UNIVERSITY OF TOKYO

Flavour Physics at B-factories and Hadron Colliders

Part 9: measurements of V_{ub}

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Contents

Importance of V_{ub}

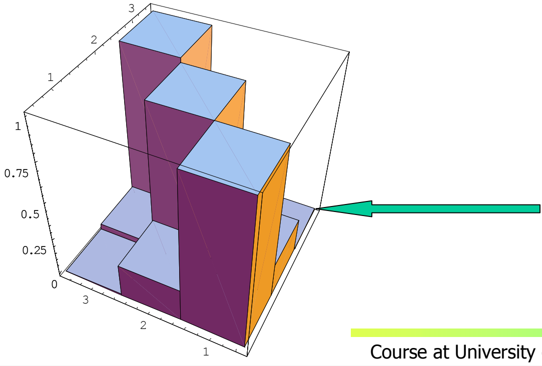
Measurements of $|V_{ub}|$

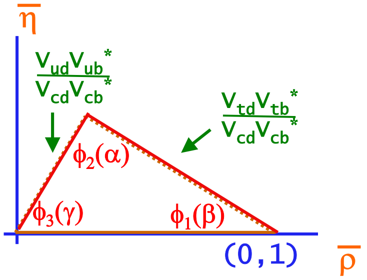
Measurements of the B meson decay constant f_B

Unitary triangle: V_{ub}

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

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



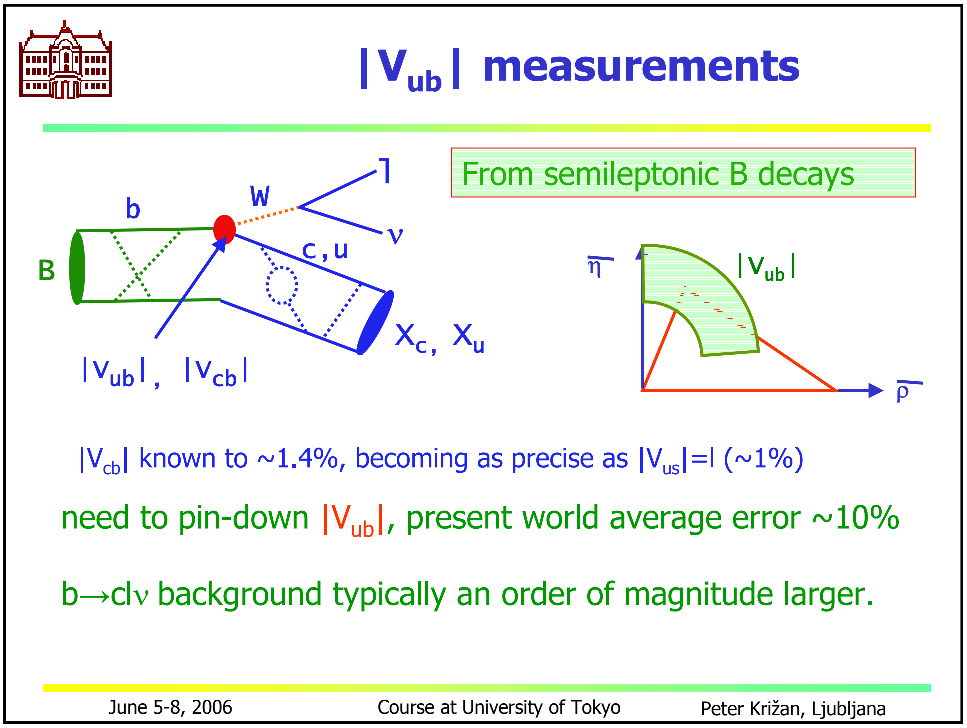


CKM matrix measurements

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



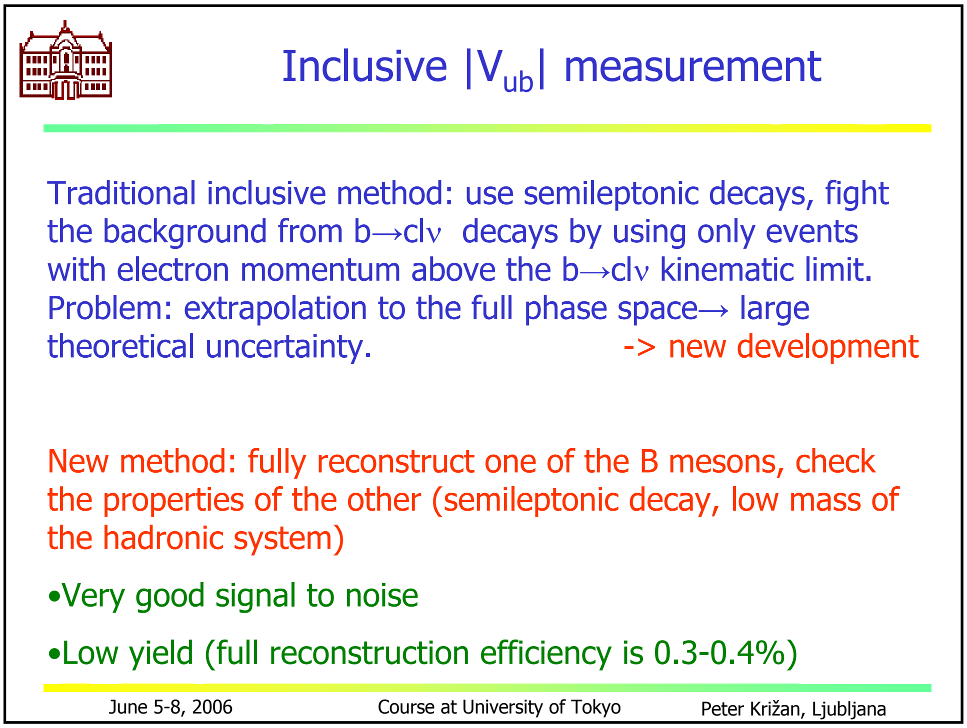
$|V_{ub}|$ measurements

From semileptonic B decays

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

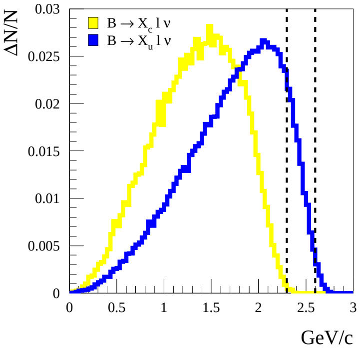
$b \to c l \nu$ (yellow) an order of magnitude larger than $b \to u l \nu$ (blue)

Measurement region - traditionally: between the $b \to c l \nu$ endpoint and the $b \to u l \nu$ endpoint

2.3 GeV/c $< p_e^* < 2.6$ GeV/c (CMS)

-> Huge extrapolation, model dependent...

New: reduce the background and model the remaining background better



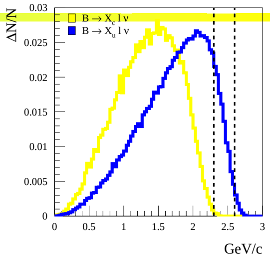
Electron spectrum endpoint: the method

Measurement region:

1.9 GeV/c $< p_e^* < 2.6$ GeV/c (CMS)

Background estimation region:

1.5 GeV/c $< p_e^* < 1.9$ GeV/c (CMS)



Deal with large backgrounds:

BB backgrounds

- $B \to X_c l \nu$
- Leptons from other decays
  (J/ψ, ψ (2S), γ conv.)
- Fake electrons

MC simulation:
$D^{**} e \nu$ (ISGW2)
$D^* e \nu$ (HQET)
$D e \nu$ (ISGW2)

QED radiative corrections included

Fit $(D^{*}+D) l \nu / D^{**} l \nu$ relative contributions

Veto on invariant mass

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

How to deal with large non-BB background

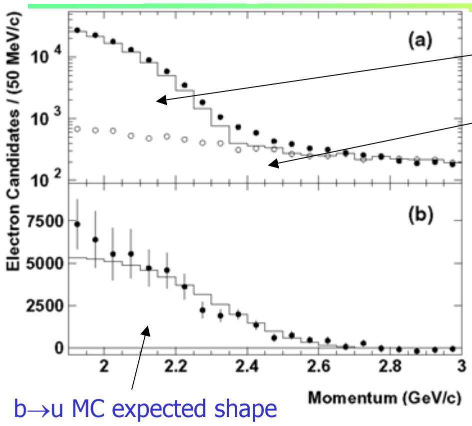
Non BB backgrounds

- 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
(8.8fb^{-1} of offresonance data)

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



BB 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%

$|V_{ub}|$ extraction

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

Partial BR -> determine from the data

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

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

$\underline{1.9\ \mathrm{GeV}/c < p_e < 2.6\ \mathrm{GeV}/c}$:

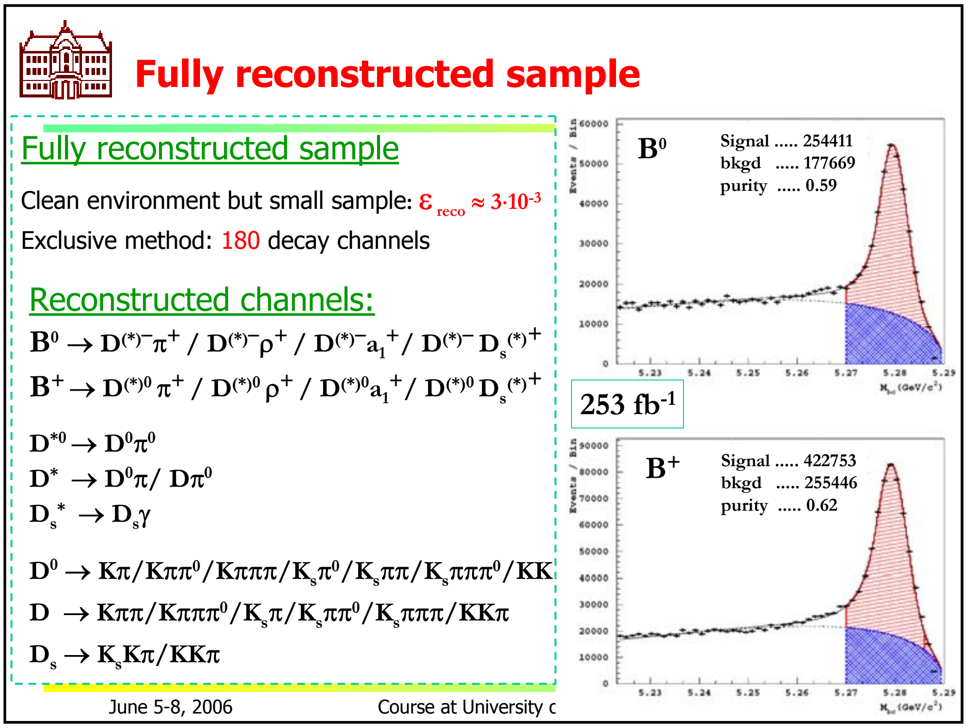
$$\boxed{|V_{ub}| = (4.50 \underbrace{\pm 0.42}_{\text{exp}} \underbrace{\pm 0.32}_{\text{SF}} \underbrace{\pm 0.21}_{\text{theo}}) \times 10^{-3}}$$

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: $\varepsilon_{reco} \approx 3\cdot10^{-3}$

Exclusive method: 180 decay channels

Reconstructed channels:

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

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

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

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

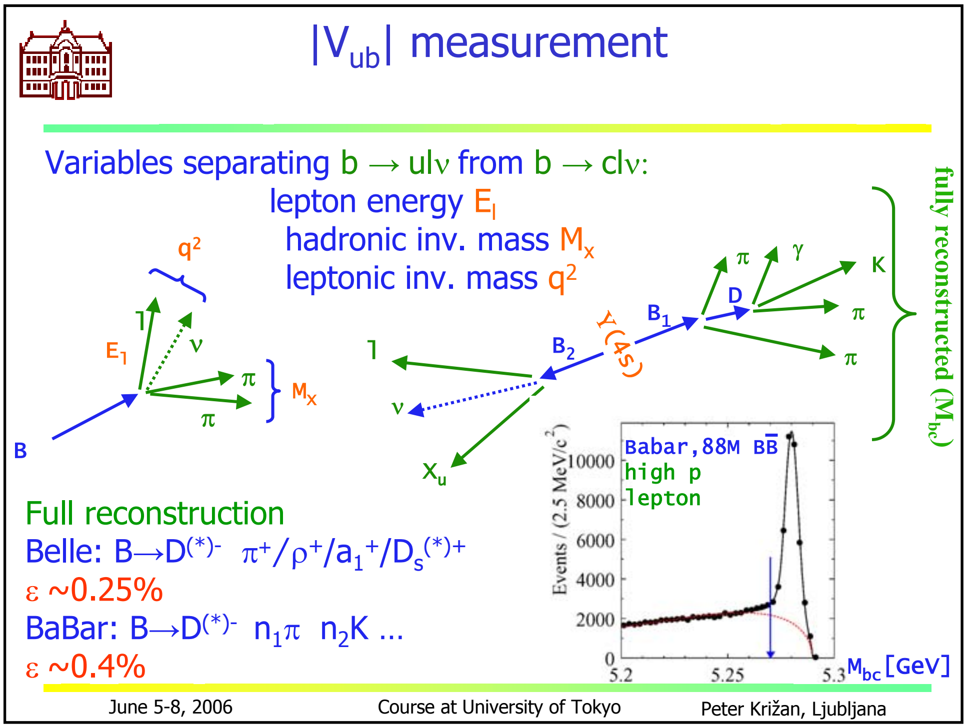
$D_s^* \to D_s\gamma$

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

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

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

253 fb^{-1}



$|V_{ub}|$ measurement

Variables separating $b \to ul\nu$ from $b \to cl\nu$:

lepton energy E_l

hadronic inv. mass M_x

leptonic inv. mass q^2

Full reconstruction

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

ε ~0.25%

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

ε ~0.4%

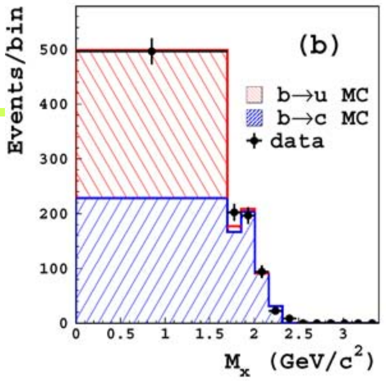
M_x analysis

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^2

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

M_x / q^2

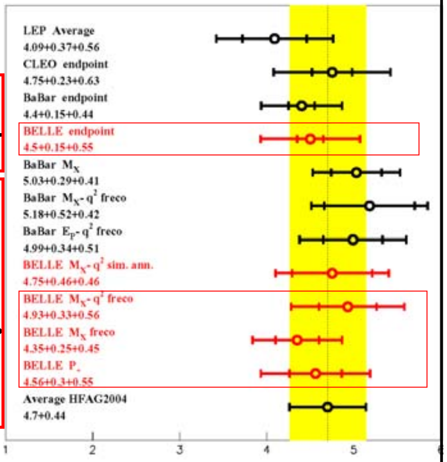
$|V_{ub}| = (4.93 \pm 0.33 \pm 0.56) \times 10^{-3}$ 13%

M_x

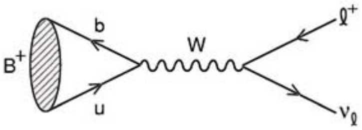
$|V_{ub}| = (4.35 \pm 0.25 \pm 0.45) \times 10^{-3}$ 12%

P_+

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



Purely leptonic decay: $B^- \rightarrow \tau^- \nu_\tau$



$B^- \to \ell^- \bar{\nu}$ decay occurs by W boson annihilation in the Standard Model

$$\mathcal{B}(B^- \to \ell^- \bar{\nu}) = \frac{G_F^2 m_B m_\ell^2}{8\pi} \left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

Provide a direct measurement of B meson decay constant f_B and constraint on CKM matrix elements $|V_{ub}|/|V_{td}|$

$\Rightarrow$ $\tau\nu$ mode is favored over $e\nu$ and $\mu\nu$ final states due to helicity suppression

CKMfitter predictions

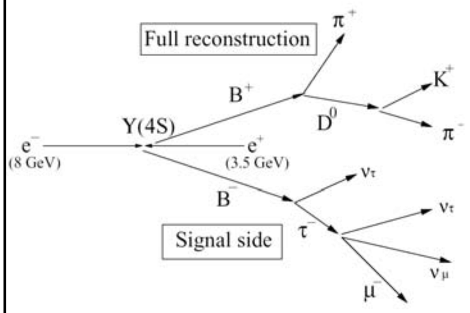
$\mathcal{B}(B^- \to \mu^- \bar{\nu}) = (4.2^{+1.4}_{-1.1}) \times 10^{-7}$ and $\mathcal{B}(B^- \to \tau^- \bar{\nu}) = (9.3^{+3.4}_{-2.3}) \times 10^{-5}$

Sensitive to new physics

Charged Higgs bosons $H^\pm$ instead of W boson

$B^- \rightarrow \tau^- \nu_\tau$ – event selection

Fully reconstruct one B meson in the event (tag B) and compare the remaining particles with the signature expected for the signal decay

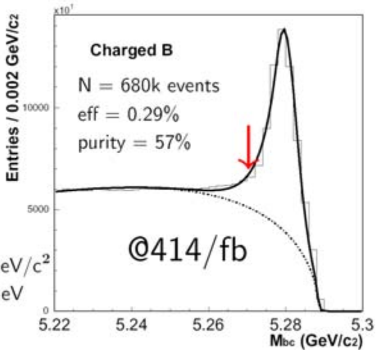


Tag B reconstructed in a set of hadronic final states

$$B^\pm \rightarrow \overline{D}^{(*)0} + \pi^\pm /\ \rho^\pm /\ a_1^\pm /\ D_S^{(*)\pm}$$

$$\rightarrow \overline{D}^0\pi^0/\overline{D}^0\gamma \qquad \rightarrow \overline{D}_S^+\gamma$$

$\overline{D}^0 \rightarrow$ 7 modes, $\overline{D}^- \rightarrow$ 6 modes, $\overline{D}_S^+ \rightarrow$ 2 modes



Signal region:

Beam constrained mass: $M_{bc} = \sqrt{E_{\rm beam}^2 - p_B^2} > 5.27$ GeV/c^2

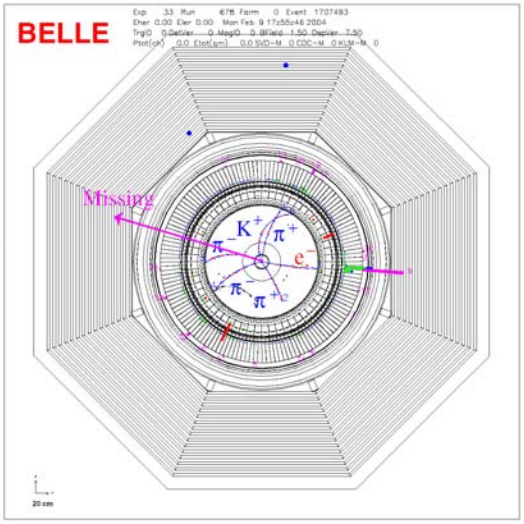
Energy difference: -0.08 $< \Delta E = E_B - E_{\rm beam} <$ 0.06 GeV

Event candidate $B^- \rightarrow \tau^- \nu_\tau$

$$B^+ \rightarrow D^0\pi^+$$

$$(\rightarrow K\pi^-\pi^+\pi^-)$$

$$B^- \rightarrow \tau(\rightarrow e\nu\bar{\nu})\nu$$



$B^- \rightarrow \tau^- \nu_\tau$ - results

Branching fractions

$$\mathcal{B}(B^- \to \tau^- \bar{\nu}) = \frac{N_S}{2\varepsilon_{\rm sel}\varepsilon_{\rm tag}N_{B\bar{B}}}$$
$$= 1.06^{+0.34}_{-0.28}(\text{stat})^{+0.22}_{-0.25}(\text{sys}) \times 10^{-4}$$

First evidence of purely leptonic B decay

(SM exportation : $\mathcal{B} = (1.59 \pm 0.40) \times 10^{-4}$)

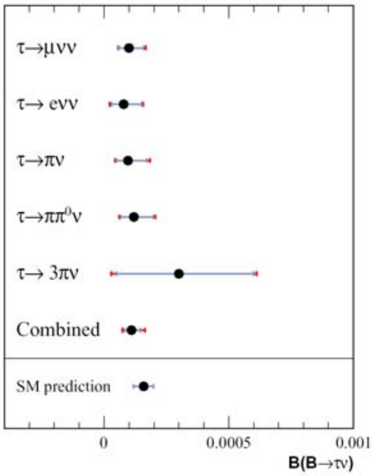
⇒ Result is consistent with SM expectation.

Using V_{ub} from HFAG average

$V_{ub} = (4.39 \pm 0.33) \times 10^{-3}$

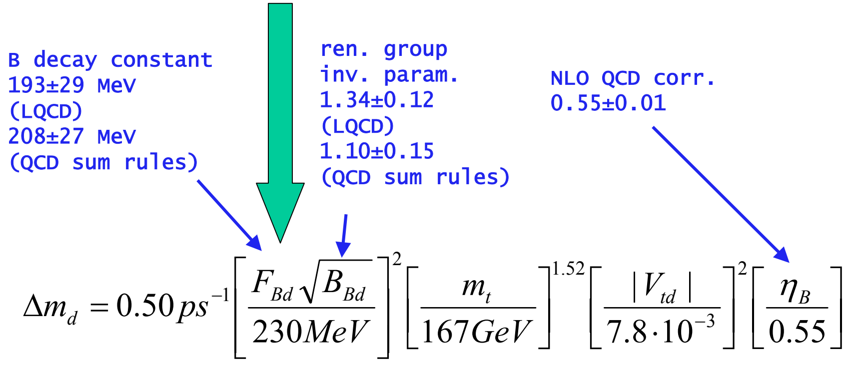
⇒ $f_B = 176^{+28+20}_{-23-19}$ MeV

First direct measurement of the B meson decay constant



Impact of the f_B measurement

When interpreting the B_d oscillations measurement, can replace theoretical predictions of $\mathbf{f_B}$ with experimental data



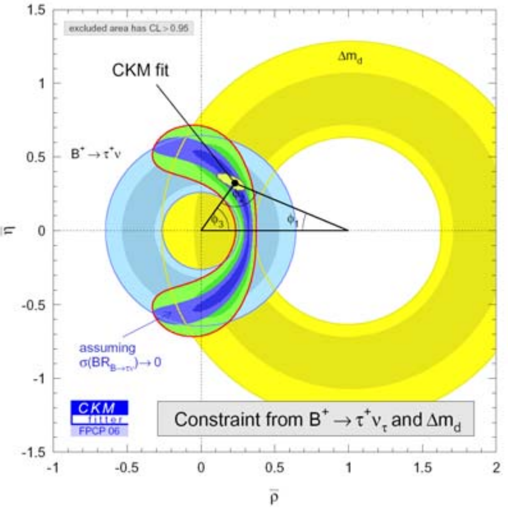
B decay constant
193±29 MeV
(LQCD)
208±27 MeV
(QCD sum rules)

ren. group
inv. param.
1.34±0.12
(LQCD)
1.10±0.15
(QCD sum rules)

NLO QCD corr.
0.55±0.01

$$\Delta m_d = 0.50\,ps^{-1}\left[\frac{F_{Bd}\sqrt{B_{Bd}}}{230MeV}\right]^2\left[\frac{m_t}{167GeV}\right]^{1.52}\left[\frac{|V_{td}|}{7.8\cdot 10^{-3}}\right]^2\left[\frac{\eta_B}{0.55}\right]$$

Impact of B$^-$ → $\tau^- \nu_\tau$



Constraint in the (ρ, η) plane from $\mathcal{B}(B^- \to \tau\bar\nu)$ and Δm_d

$$\frac{\mathcal{B}(\mathcal{B} \to \tau\nu)}{\Delta m_d} = \frac{|V_{ub}|^2}{|V_{td}|^2} = \frac{1}{[1-(\lambda^2/2)^2]} \frac{\bar\rho^2 + \bar\eta^2}{(1-\bar\rho)^2 + \bar\eta^2}$$

Charge Higgs limits from B$^-$ → $\tau^- \nu_\tau$

If the theoretical prediction is taken for **f$_\mathbf{B}$** → limit on charged Higgs mass vs. tanβ

$$\mathcal{B}(B \to \tau\nu) = \mathcal{B}(B \to \tau\nu)_{\rm SM} \times r_H$$

$$r_H = 1 - \frac{m_B^2}{m_H^2} \tan\beta$$

$$\Rightarrow r_H = 0.67^{+0.29}_{-0.26}$$