Model independent determination of $|V_{ub}|$ using exclusive B and D decays

Physics reach of rare and exclusive B decays

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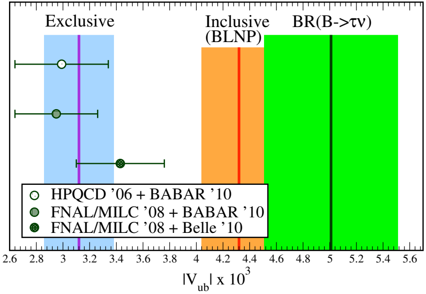
LHCb

Motivation



- Three ways to measure $|V_{ub}|$, none of them agree with each other:
  - $B^0 \to \pi^- \mu^+ \nu$ decays, rely on lattice QCD.
  - $B \to X_u \mu^+ \nu$ decays, need to extrapolate through open charm region.
  - $B^+ \to \tau^+ \nu_\tau$, difficult experimentally.
- BELLE's latest results [here] have poured cold water on the $B^+ \to \tau^+ \nu_\tau$ excitement.

Model independent $|V_{ub}|$

- Paper - [P.R.D70 114005] (and Refs. therein) outlines another method of measuring $|V_{ub}|$.
- At low recoil ($y = E_h/m_h$) can use operator product expansion to control the long distance effects.
- Theoretically cleaner than the exclusive/inclusive methods, and model independent.
- Need to measure ratio of branching fractions $B^+ \to \rho^0\mu^+\nu$ and $B^0 \to K^{*0}\mu^+\mu^-$.

$$\frac{\mathcal{B}(B^+ \to \rho^0\mu^+\nu)}{\mathcal{B}(B^0 \to K^{*0}\mu^+\mu^-)} \ \alpha \ |V_{ub}|^2 \frac{R_B(y)}{N_{eff}(y)}$$

- Measurement is contaminated by $R_B(y)$, the ratio of helicity amplitudes of the two decays.
- Dominant theoretical uncertainty on $\mathcal{B}(B^0 \to K^{*0}\mu^+\mu^-)$ of $\sim$10% comes from $N_{eff}(y)$.

Use D decays to reduce form factor uncertainties.

- Can reduce the uncertainty of $R_B(y)$ using D decays.
- $R_B(y)$ and $R_D(y)$ must be taken at the same value of y.

$$\frac{R_B(y)}{R_D(y)} = 1 + \mathcal{O}(m_s(\frac{1}{m_c} - \frac{1}{m_b}))$$

- The proposed D decays are $D^+ \to K^{*0}\mu^+\nu$ and $D^+ \to \rho^0\mu^+\nu$.
- The corrections shown above are even smaller than the dimensional estimate [P.L.B420, 359,P.R.D. 53, 4937].

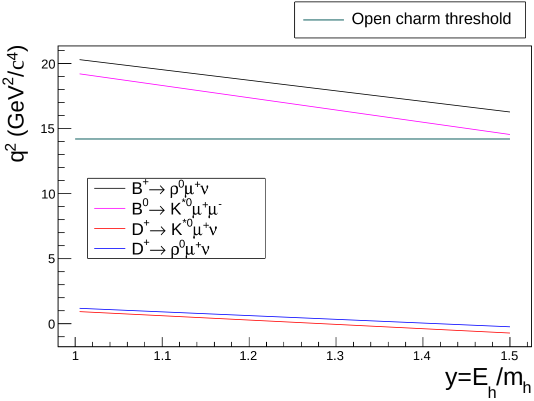
Model independent $|V_{ub}|$

- End up with a double ratio of branching fractions.
- Estimated theoretical error on $|V_{ub}|$ is 5%.

$$|V_{ub}|^2 \alpha \frac{\frac{\mathcal{B}(B^+ \to \rho^0 \mu^+ \nu)}{\mathcal{B}(B^0 \to K^{*0} \mu^+ \mu^-)}}{\frac{\mathcal{B}(D^+ \to \rho^0 \mu^+ \nu)}{\mathcal{B}(D^+ \to K^{*0} \mu^+ \nu)}}$$

- Need to measure the branching fraction of these decays at low recoil.
- Low recoil is low enough as long as q^2 is above open charm threshold ($q^2 > 14.2\,\mathrm{GeV}^2/c^4$) - translates into recoil range of $y = 1 - 1.5$ for $B^0 \to K^{*0}\mu^+\mu^-$.

Recoil vs q^2- vectors



- The maximum recoil for $D^+ \to K^{*0}\mu^+\nu$ is 1.3, but as form factor only varies by 20% across this region can extrapolate beyond kinematic limit to 1.5 [P.L.B420, 359,P.R.D. 53, 4937]

Don't need to use vectors, can use psudeoscalars?

- Can also form the same ratio with scalars:

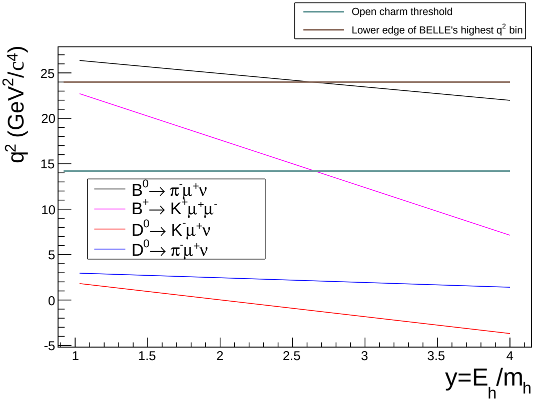
$$|V_{ub}|^2 \alpha \frac{\frac{\mathcal{B}(B^0 \to \pi^- \mu^+ \nu)}{\mathcal{B}(B^+ \to K^+ \mu^+ \mu^-)}}{\frac{\mathcal{B}(D^0 \to \pi^- \mu^+ \nu)}{\mathcal{B}(D^0 \to K^- \mu^+ \nu)}} \quad ?$$

- Experimentally much easier, does the theory work for these decays too?
- Low recoil for $B^+ \to K^+ \mu^+ \mu^-$ is $y = 1 - 2.6$.

Analysis Strategy

- Would then need to measure four decays between 1-2.6.
  - $B^0 \to \pi^- \mu^+ \nu$: $\mathcal{B} = (1.34 \pm 0.08) \times 10^{-4}$
  - $B^+ \to K^+ \mu^+ \mu^-$: $\mathcal{B} = (4.8 \pm 0.7) \times 10^{-7}$
  - $D^0 \to \pi^- \mu^+ \nu$: $\mathcal{B} = (0.24 \pm 0.02)\%$
  - $D^0 \to K^- \mu^+ \nu$: $\mathcal{B} = (3.31 \pm 0.13)\%$
- $D^0 \to K^- \mu^+ \nu$ has a huge rate and $B^+ \to K^+ \mu^+ \mu^-$ has a very distinctive signature.
- $D^0 \to \pi^- \mu^+ \nu$ has an order of magnitude less BF than $D^0 \to K^- \mu^+ \nu$ and more background.
- $B^0 \to \pi^- \mu^+ \nu$ is difficult - at LHCb we probably can't do better than b-factories. For now the plan is to get it from the literature.

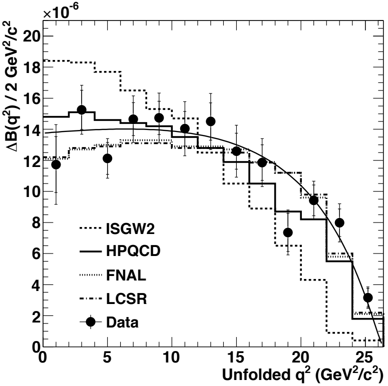
Recoil vs q^2- psuedoscalar modes



- Low recoil ($y = 1 - 2.6$) corresponds to very high q^2 values for the π modes due to the low π mass.
- Will have to extrapolate $D^0 \to K^- \mu^+ \nu$ from 2.0 to 2.6.

$B^0 \to \pi^- \mu^+ \nu$

- We will get $B^0 \to \pi^- \mu^+ \nu$ from the literature, below is from BELLE.



- Only the last bin corresponds to $y = 1 - 2.6$, with a stat error of $22\% \to 11\%$ on $|V_{ub}|$.
- This will be the limiting factor for $|V_{ub}|$ unless we can use the other bins somehow.

$B^+ \to K^+\mu^+\mu^-$

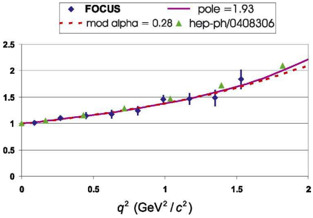
- Assuming systematic of 5%, rough estimate of yields gives estimated error on $|V_{ub}|$.

Recoil range	q^2 range	$N_{B^+\to K^+\mu^+\mu^-}$	$\sigma(d\mathcal{B}/dy)$	$\sigma(\|V_{ub}\|)$
$1-1.8$	$18-22$	500	6.7%	3.3%
$1-2.2$	$16-22$	1000	5.9%	2.9%
$1-2.6$	$14-22$	1500	5.6%	2.8%

- With $3\,\text{fb}^{-1}$, $B^+ \to K^+\mu^+\mu^-$ will not be the limiting factor for this analysis.

$D^0 \to \pi^- \mu^+ \nu$ and $D^0 \to K^- \mu^+ \nu$

- Expect $\mathcal{O}(1M)$ $D^0 \to K^- \mu^+ \nu$ candidates, $\mathcal{O}(100K)$ $D^0 \to \pi^- \mu^+ \nu$ candidates.
- $\sim$3% of $D^0 \to \pi^- \mu^+ \nu$ lie in the low $(1 - 2.6)$ recoil region.



$f^+(q^2)$ for $D^0 \to K^- \mu^+ \nu$.

- Unlike $D^+ \to K^{*0} \mu^+ \nu$, the form factor for $D^0 \to K^- \mu^+ \nu$ varies by 100%, still OK to extrapolate?

Summary

- $|V_{ub}|$ is an interesting parameter and worth measuring (if $< 20\%$ precision).
- With the relatively large samples of FCNC available at high q^2 at LHCb, a model independent measurement becomes possible.
- $D^+ \to \rho^0 \mu^+ \nu$ is very difficult to measure at LHCb.
- Measurement with pseudo-scalars is much easier experimentally.
- The pion is very light, causes issues when requiring a common recoil range between all modes.
- If no-one comes up with a show-stopper, we will go ahead and measure this.