Studies of the CKM matrix with semileptonic b-hadron decays at LHCb

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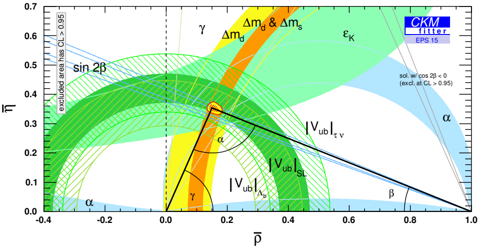
Outline

- Status of CKM matrix
- B_s^0 and Λ_b^0 decays
  - Production at LHCb
  - Form factor measurements
- $\frac{|V_{ub}|}{|V_{cb}|}$ with $\Lambda_b^0 \to p\mu^-\overline{\nu}$ at LHCb
- Future prospects at LHCb
  - $B_s^0 \to K^-\mu^+\nu$
  - Fully leptonic $B^+ \to \mu^+\mu^-\mu^+\nu$

Status of CKM matrix

Precision measurements of CKM elements $|V_{ub}|$ and $|V_{cb}|$:

- improve precision: $|V_{ub}|$ ($\simeq$ 12% rel. error), $|V_{cb}|$ ($\simeq$ 3%) (PDG 2014)
- resolve tension between inclusive and exclusive measurements
- test the unitarity of the CKM matrix complementary to measurement of $\sin(2\beta)$

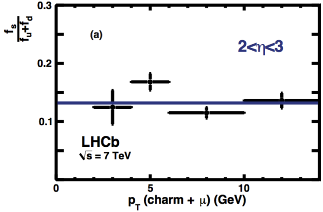


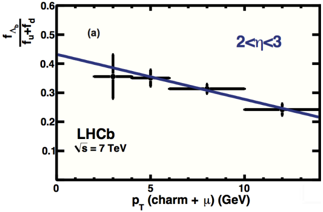
Eur. Phys. J. C41, 1-131 (2005)
Updated results and plots (2015)

- $|V_{ub}|_{SL}$: standard modes for exclusive semileptonic decays
  $\overline{B} \to \pi l \bar{\nu}_l \propto |V_{ub}|$ and
  $\overline{B} \to D^{(*)} l \bar{\nu} \propto |V_{cb}|$
- $|V_{ub}|_{\Lambda_b}$: $|V_{ub}|/|V_{cb}|$ from Λ_b decay - latest LHCb result

LHCb's unique Λ_b and B_s production

- Standard modes are hard to reconstruct at LHCb!
- Alternative: decays of Λ_b and B_s
- At $s = \sqrt{7}$ TeV $\cong$ 100,000 $b\bar{b}$ produced per second



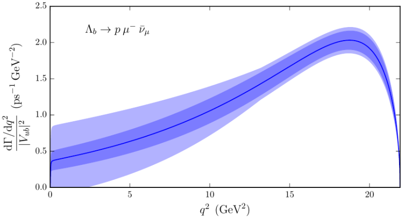


Phys. Rev. D 85, 032008 (2012)

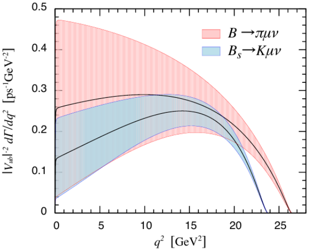
- Production fraction of B_s mesons $\approx$ 14%
- Production fraction of Λ_b dependent on charmed hadron-muon pair's transverse momentum and b-hadron pseudorapidity, η, $\approx$ 20%

Lattice QCD calculations for Λ_b and B_s

To be able to extract $|V_{ub}|$ or $|V_{cb}|$ from exclusive decays, measurement of form factors (FF) is necessary!



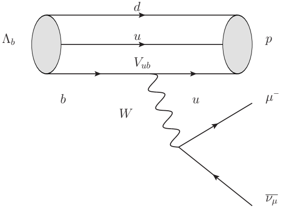
Phys. Rev. D 92, 034503 (2015)

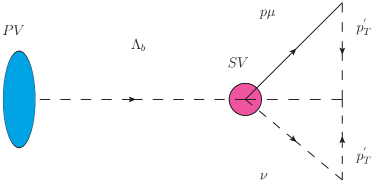


Phys. Rev. D 91, 07451 (2015)

- Differential decay rate $\frac{d\Gamma[B_s \to Pl\nu]}{dq^2} \propto |V_{ub}|^2 \times (A(q^2)|f_+(q^2)|^2 + B(q^2)|f_0(q^2)|^2)$
- Calculated non-pertubatively with lattice QCD
- $f_+(q^2)$ and $f_0(q^2)$ parametrize the hadronic contributions
- Recent calculation of $B_s \to K\mu\nu$ FF improved compared to the standard mode by factor of 2

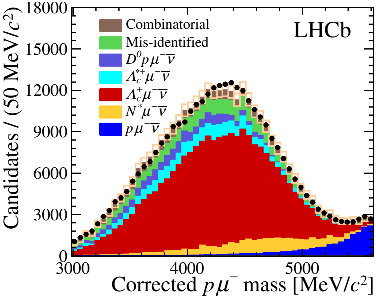
Why $\Lambda_b^0 \rightarrow p\mu^-\overline{\nu}$ at LHCb?

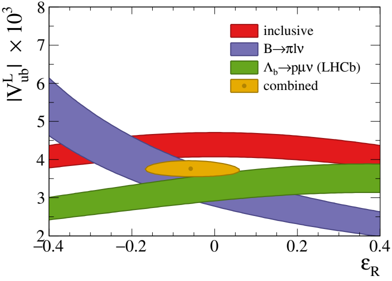




- Baryonic version of standard mode but with proton and muon $\rightarrow$ higher identification rates at LHCb
- Displaced vertex (Λ_b^0 flies on average 1 cm before decaying) $\rightarrow$ LHCb's excellent vertexing and tracking ability.
- Challenges: big backgrounds from $\Lambda_b^0 \rightarrow \Lambda_c^+(\rightarrow pX)\mu^-\overline{\nu}$ decays, missing neutrino in a final state, high precision
- Method: fit to corrected mass, $M_{(\Lambda_b^0)_{corr}} = \sqrt{M_{p\mu^-}^2 + |p_T^{'2}|} + |p_T^{'}|$
  $M_{p\mu^-}$: invariant visible mass
  $p_T^{'}$: missing momentum transverse to the direction of flight of Λ_b^0

$\Lambda_b^0 \to p\mu^-\overline{\nu}$ - Results



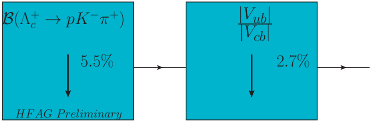


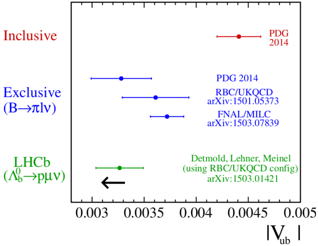
Nature Physics 11, 743–747 (2015)

- Measurement of ratio $\frac{\mathcal{B}(\Lambda_b^0 \to p\mu^-\overline{\nu})_{q^2>15GeV/c^2}}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\mu^-\overline{\nu})_{q^2>7GeV/c^2}} \times R_{FF} = \frac{|V_{ub}|^2}{|V_{cb}|^2} \to$ $|\mathbf{V_{ub}}| = (\mathbf{3.27} \pm \mathbf{0.15}(\mathbf{exp}) \pm \mathbf{0.16}(\mathbf{LQCD}) \pm \mathbf{0.06}(|\mathbf{V_{cb}}|)) \times \mathbf{10^{-3}}$
- 17687 ± 733 events were observed in Run 1 with 2fb^{-1}
- Consistent with other exclusive $|V_{ub}|$ measurements
- Right-handed coupling not supported by this measurement

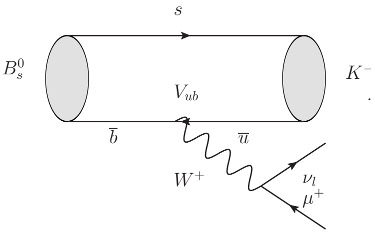
New HFAG world average for $\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$

- In measurement of $\Lambda_b^0 \to p\mu^-\overline{\nu}$, $\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$ used published by Belle, with $6.84 \pm 0.24\,^{+0.21}_{-0.27}\,\%$
- Another measurement was published later using BESIII data
- HFAG performed global fit to all branching fractions of the Cabibbo-favoured Λ_c^+ decays yielding $6.46 \pm 0.24\%$





Future prospects at LHCb



- $B_s^0 \to K^-\mu^+\nu \to$ natural candidate for the next measurement!
- Most dangerous background $B_s^0 \to K^{*-}(\to K^-\pi^0)\mu^+\nu$

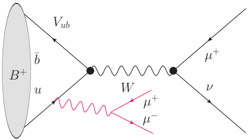
Decay	$\Lambda_b^0 \to p\mu^-\overline{\nu}$	$B_s^0 \to K^-\mu^+\nu$
Production fraction	20%	14%
Branching fraction	4×10^{-4}	1×10^{-4}
Source of backgrounds	Λ_c^+	Λ_c^+, D^0, D^+, D_s
$\mathcal{B}(X_c)$ error (PDG 2014)	$^{+5.3\%}_{-4.7\%}$ (biggest systematic!)*	$\pm 3.9\%$
Theory error FF (slide 5)	5%	$< 5\%$
Normalization channel	$\Lambda_b^0 \to \Lambda_c^+\mu^-\nu$	$B_s^0 \to D_s^-\mu^+\nu$

* will be soon improved (slide 8)

Other future prospects at LHCb

Semileptonic decays

- E.g $B \to \rho\mu\nu$, $B \to p\bar{p}\mu\nu$, but additional final states $\to$ more complicated for FF calculation



Fully leptonic decays

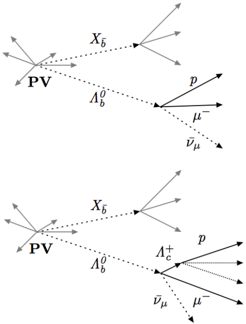
- Measurement of $B^+ \to \tau^+\nu$ at LHCb not feasible $\to$ $B^+ \to \mu^+\nu$ $\to$ helicity suppressed ($\sim 1/250$)
- Addition of virtual photon decaying into a pair of muons lifts the helicity suppression
- Final state with 3 muons $\to$ good experimental signature
- Decay not observed yet $\to$ rare $\approx 10^{-8}$
- Need computation of FF, arXiv:1606.03080v1

Conclusion

- Probing CKM structure with exclusive semileptonic decays is becoming more precise $\rightarrow$ both theoretically and experimentally
- LHCb's production of Λ_b^0 and B_s^0 provide interesting alternative to standard modes $\rightarrow$ already published $\Lambda_b^0 \rightarrow p\mu^-\overline{\nu}$ analysis
- Tension between inclusive and exclusive measurements persists
- New ideas with semileptonic or fully leptonic B-decays are under way

Backup

Facing challenges of search for $\Lambda_b^0 \to p\mu^-\overline{\nu}$



Nature Physics 11, 743–747 (2015)

To reduce V_{cb} backgrounds:

- charm has a big lifetime $\to$ vertex quality cut
- charm backgrounds have presence of additional tracks $\to$ train MVA technique to distinguish them
- reject candidates if: $\sigma_{Mcorr} >$ 100 MeV/c^2