Prospects for $R(p\bar{p})$

Workshop on $B \to D^{*}\tau\nu$, Nagoya

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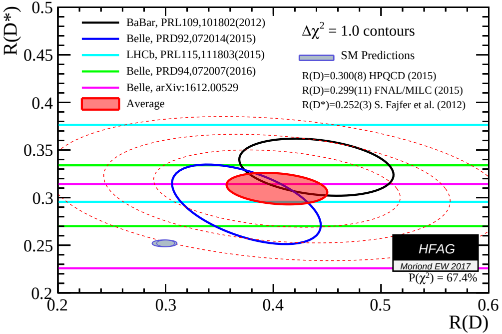
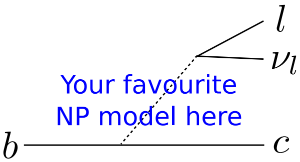
28 March 2017

Imperial College London

Tension with SM in $R(D)$ vs $R(D^*) \sim 4\,\sigma$





Assuming the discrepancy persists we want to understand the cause.

Different modes $\rightarrow$ different experimental/theoretical challenges; different physics:

- Pseudo-scalar and vector final states: $R(D^*)$ and $R(D)$.
- Mass of the spectator quarks: $R(D_s)$.
- Isospin: $R(\Lambda_c)$ and $R(\Lambda_c^*)$.
- Heavy quark transition: $D^0 \rightarrow K^- l \bar{\nu}_l$.
- Orbital angular momentum: $R(D^{**})$ (also a major feed-down for $R(D^*)$).
- $b \rightarrow u$ transition.

$b \to u$ lepton universality

$B^+ \to \tau^+ \nu_\tau$

- Simplest theoretically.

$B^0 \to \pi^+ \tau^- \overline{\nu}_\tau$

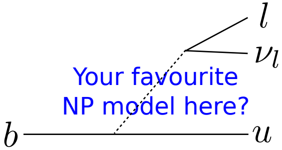
- Simplest theoretically with a final state hadron.
- Already calculated.

$\Lambda_b^0 \to p \tau^- \bar{\nu}_\tau$

- $\Lambda_b \to p$ FF already calculated.
- $\Lambda_b \to \Lambda_c$ FF already calculated.

Experimental considerations

- Need a good b decay-vertex.
- Would prefer low backgrounds.



$B^+ \to \pi^+ \pi^- \tau^+ \nu_\tau$

- Could go via a light resonance (ρ?).
- Already attempted theoretically.

$B^+ \to p \bar{p} \tau^+ \nu_\tau$

- Theoretically difficult.

$B^+ \to N^{*+} \bar{p} \tau^+ \nu_\tau$

- Theoretically difficult.

$b \to u$ lepton universality

$B^+ \to \tau^+ \nu_\tau$

- Not at LHCb

$B^0 \to \pi^+ \tau^- \overline{\nu}_\tau$

- Very difficult at LHCb

$\Lambda_b^0 \to p \tau^- \overline{\nu}_\tau$

- Maybe with hadronic τ
- Might look like the $B_s^0 \to \tau^+ \tau^-$ analysis.arXiv:1703.02508

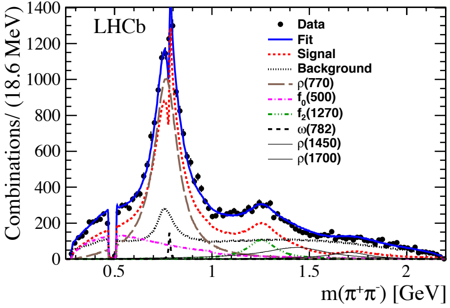
$B^+ \to p \bar{p} \tau^+ \nu_\tau$

- Experimentally preferred option

$B^+ \to \pi^+ \pi^- \tau^+ \nu_\tau$

- Lots of wide overlapping resonances.
- Expect large backgrounds.

$B^0 \to \psi \pi^+ \pi^-$: Phys.Lett. B742 (2015)



$B^+ \to N^{*+} \bar{p} \tau^+ \nu_\tau$

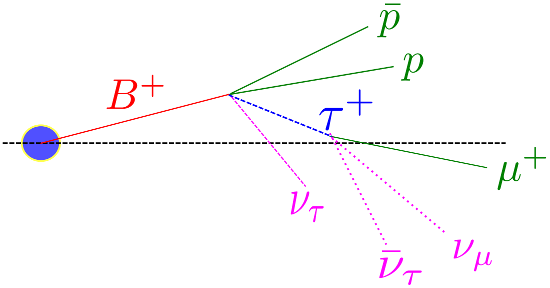
- Lots of wide overlapping resonances.

$R(p\bar{p})$

$$R(p\bar{p}) = \frac{\mathcal{B}(B^+ \to p\bar{p}\tau^+\nu_\tau)}{\mathcal{B}(B^+ \to p\bar{p}\mu^+\nu_\mu)}$$

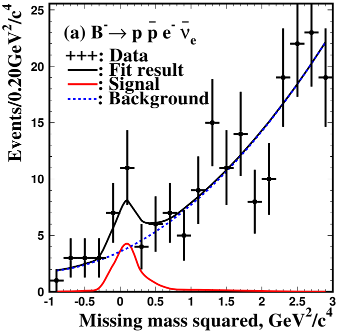
Two high momenta protons:

- Good B-decay vertex
- Low combinatorial background.
- Target flat selection efficiency.



Belle – PRD 89, 011101 (2014)

- $\mathcal{B}(B^- \to p\bar{p}e^-\overline{\nu}_e) = (8.2^{+3.7}_{-3.2} \pm 0.6) \times 10^{-6}$
- $\mathcal{B}(B^- \to p\bar{p}\mu^-\overline{\nu}_\mu) = (3.1^{+3.1}_{-2.4} \pm 0.7) \times 10^{-6}$

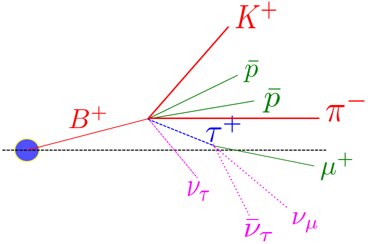


Experimental challenges

As in baryonic V_{ub}: Nature Phys. 11 (2015) 743-747

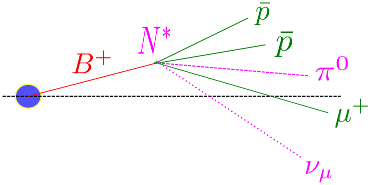
Backgrounds with extra charge tracks:

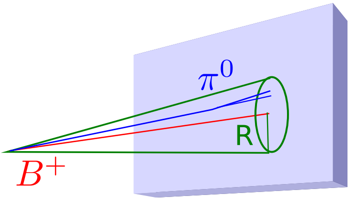
- $B^+ \to p\Lambda_c^- \mu^+ \nu_\mu$:
  - $\Lambda_c^- \to \bar{p} K^+ \pi^-$.
- $B \to N^* p \mu \nu_\mu$
  - $N^* \to p\pi$



Backgrounds with other neutral particles:

- $B^+ \to p\Lambda_c^- \mu^+ \nu_\mu$:
  - $\Lambda_c^- \to \bar{p} K^0 \pi^0$.





Theoretical challenges

We need input from theory:

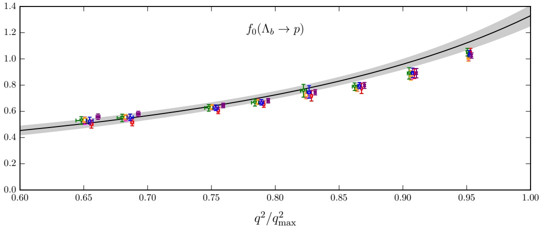
- $R(p\bar{p})$ prediction.
- Need $B \to p\bar{p}$ form-factors.
- Need $B \to \Lambda_c p$ form-factors.

Can we help?

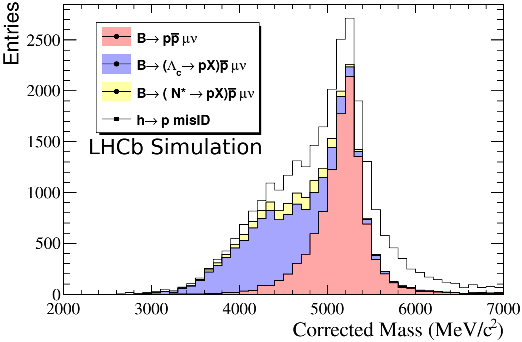
- Expect good statistics
- Should we use particular kinematic regions?
  - Is it better to have $p\bar{p}$ collinear?

Outlandish?

- $\Lambda_b \to p$ was calculated for V_{ub}. Detmold et al. Phys. Rev. D 92, 034503
- $B \to \pi^+\pi^-$ has been calculated with LCSR. Cheng et al. arXiv:1701.01633



Plan



- Initially measure the $B \to p\bar{p}\mu\nu$ branching fraction.
- Reasonably expect $\mathcal{O}(1000)$ signal events.

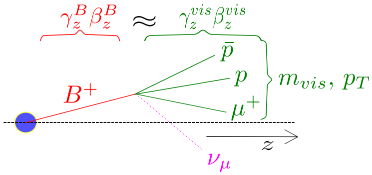
Subsequently:

- Measure differential BF in q^2.
- Attempt $B^+ \to \Lambda_c^- p\mu^+\nu$.
- Measure $R(p\bar{p})$

We should have the statistics to measure differential branching fractions → extract form-factors.

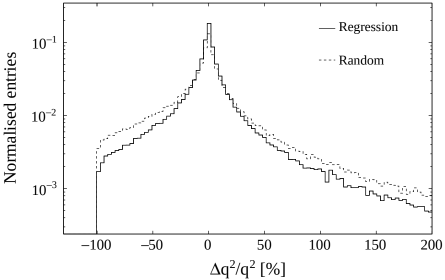
Neutrino 4-momentum not fully reconstructible:

- Can calculate q^2 with 2-fold ambiguity.
- Which solution to pick?



Help from a multivariate algorithm? Ciezarek et al. J. High Energ. Phys. (2017):21

- Flight distance and B angle are correlated to momentum.
- B momentum estimate helps to pick the correct q^2 solution.

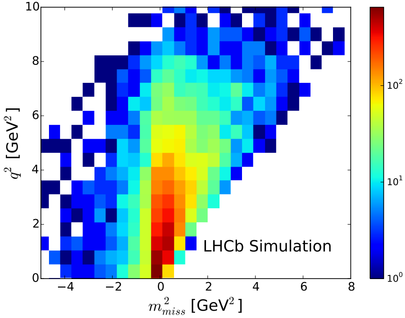


Plan

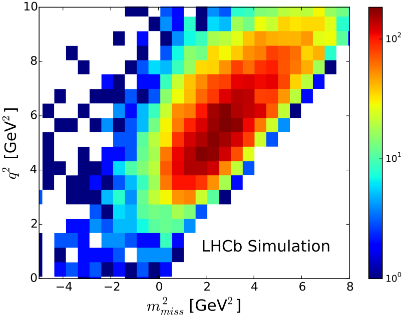
Measure $R(pp)$:

- Exploit kinematic differences between τ and μ modes.
- 3-dimensional template fit to q^2, m^2_{miss} and E^*_μ.
- Avoid warping kinematic distributions.

$B \to p\bar{p}\mu\nu$



$B \to p\bar{p}\tau\nu$



Conclusions

- A measurement of $\mathcal{B}(B \to p\bar{p}\mu\nu_\mu)$ is underway at LHCb.
- The intention is to make a measurement of $R(p\bar{p})$. Theory input would be appreciated.
- Alternative $b \to u$ lepton universality measurements are possible but are experimentally more challenging.

Thank you

Backup

BACKUP