Imperial College London

Semileptonic Decays at LHCb Beauty 2019

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on behalf of the LHCb collaboration

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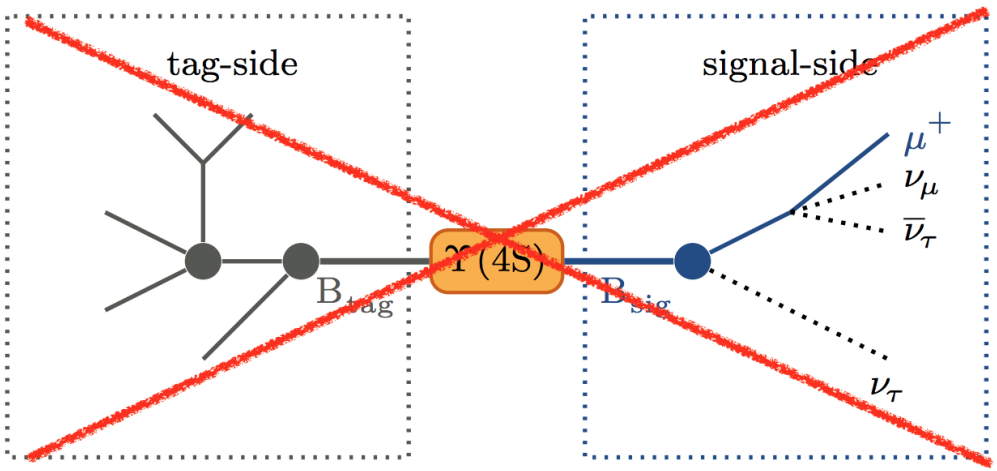
Introduction

- Tools and techniques for semileptonic decays at LHCb
- The limit for the rare decay $B^- \to \mu^- \mu^+ \mu^- \nu$
- The measurement of the semitauonic ratio $R(J/\psi)$
- The preliminary measurement of $B^- \to p\bar{p}\mu^-\overline{\nu}$
- Other talks on analyses using semileptonic decays at LHCb:
  - Michel de Cian: Lifetime measurements
  - Marcello Rotondo: Heavy flavour production

Semileptonics at a Hadron Collider

- At B-factories, strong kinematic constraints are provided by the other B in the decay
- Con: No equivalent tagging technique at LHCb can be used
- Pro: Large B production
- At LHCb, rely on the visible products and the strongly boosted B particles

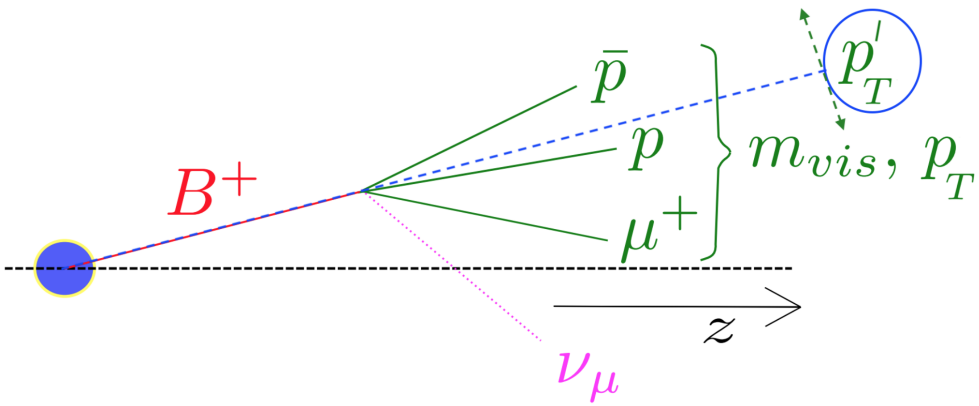


arXiv:1807.08680

Diverse physics program for semileptonic decays (measuring CKM matrix elements, form factors, LFU, production properties, CPV)

Corrected Mass

- Apply a correction to the B mass to try an get a sharp peak for use in fitting
- Use a correction to the visible mass which contains information from the momentum carried away by the neutrino
- Strongly boosted B helps with the vertex reconstruction
- The p'_T is the momentum transverse to the B flight direction



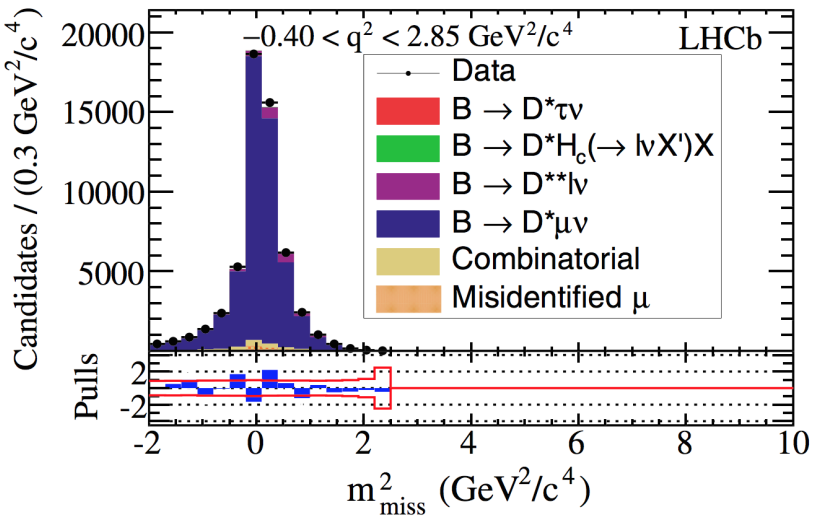
$$m_{CORR} = \sqrt{m_{vis}^2 + |p'_T|^2} + |p'_T|$$

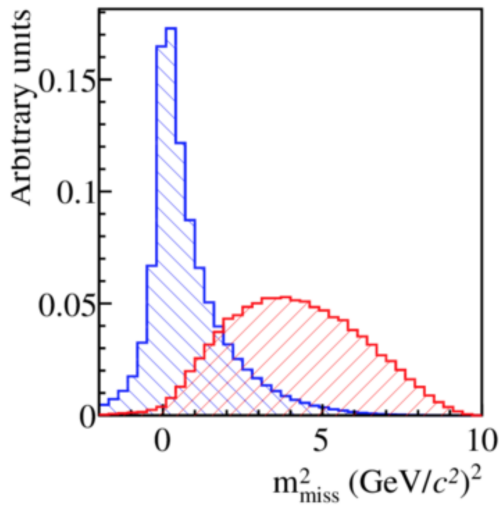
Approximate B Momentum

- An alternative method is to make an approximation of the B momentum

$$p_z(B) \approx (m_b/m_{vis})p_z(vis)$$

- Allows reconstruction of variables like missing mass, lepton energy in the B-frame and q^2

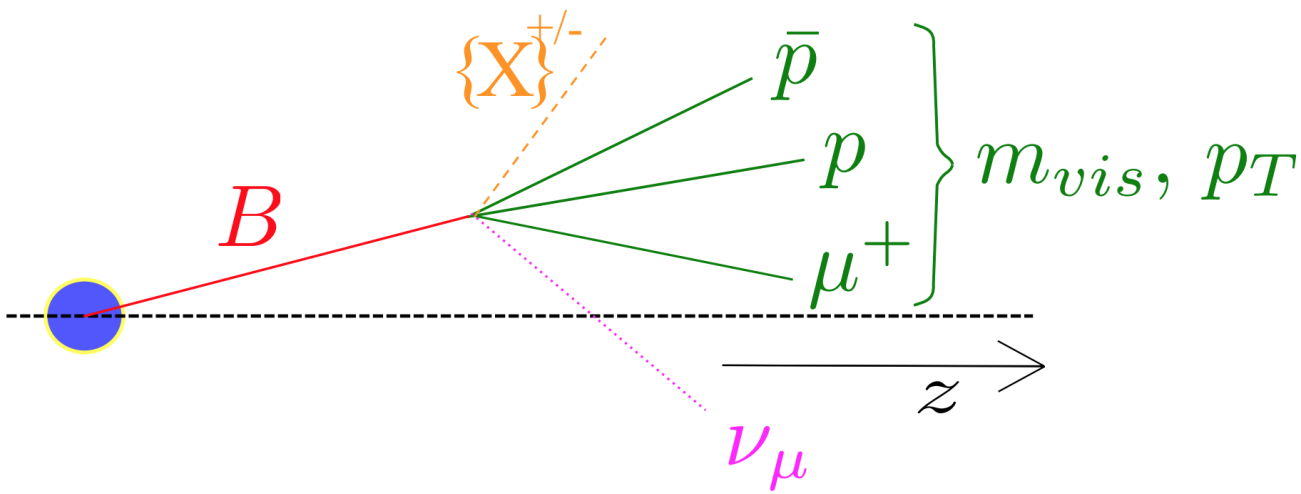




arxiv.org/abs/1506.08614

Charged Track Isolation

- Backgrounds with additional charged tracks become a large source of background when you do not reconstruct the full signal decay.
- An MVA applied to tracks around the event has been developed to help with this



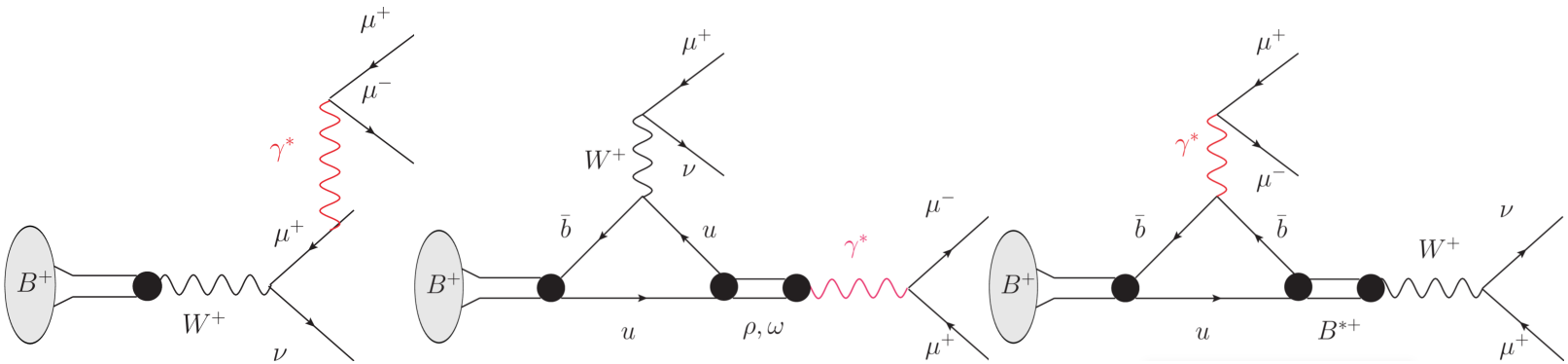
- Score the additional tracks on how likely it is that they are associated with the B decay vertex

Motivation for $B^- \to \mu^-\mu^+\mu^-\nu$

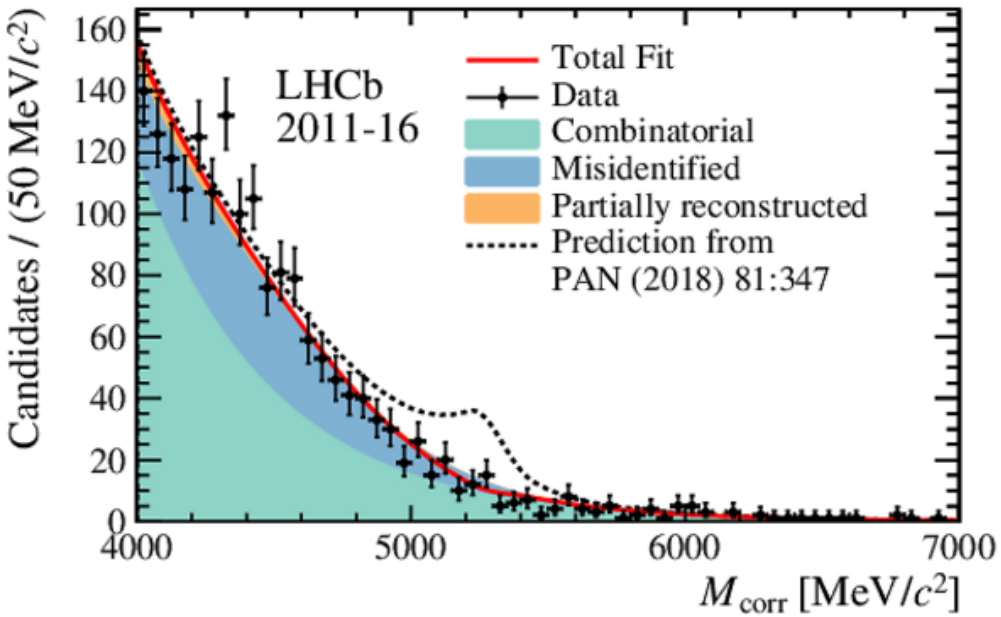
- Very rare $|V_{ub}|$ mediated decay
- Test of a prediction from Danilina and Nikitin
  $\mathcal{B}(B^- \to \mu^-\mu^+\mu^-\nu) \approx 1.3 \times 10^{-7}$

DOI: 10.1134/S1063778818030092

- Decays $B^- \to \mu^-\nu$ and $B^- \to \mu^-\nu\gamma$ are very difficult at LHCb
- The decay $B^- \to \mu^-\mu^+\mu^-\nu$ receives a contribution of the radiative decay with a virtual photon



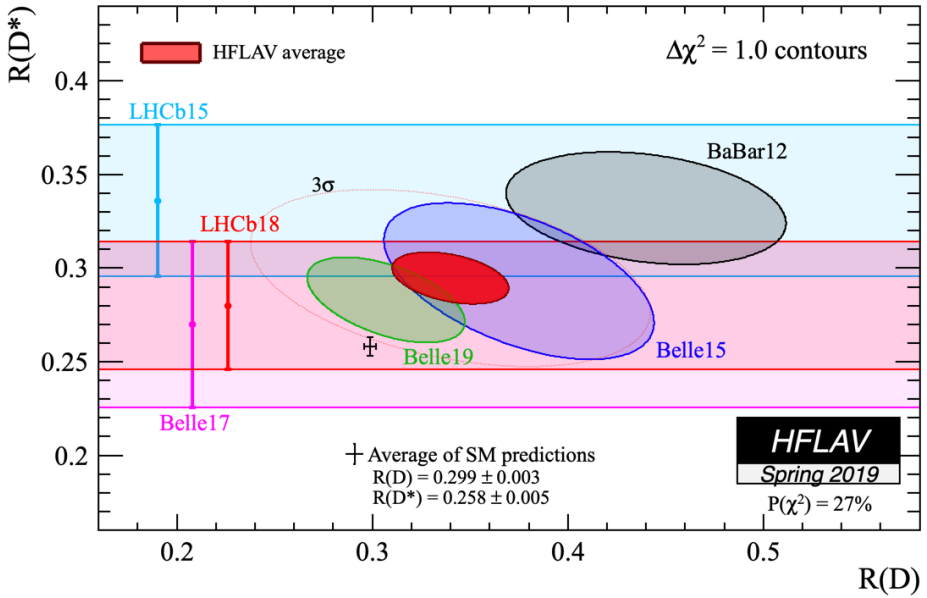
Result for $B^- \to \mu^-\mu^+\mu^-\nu$



- arxiv.org/abs/1812.06004
- Fit in corrected mass
- Lower than the prediction from Danilina and Nikitin
- Limit set at

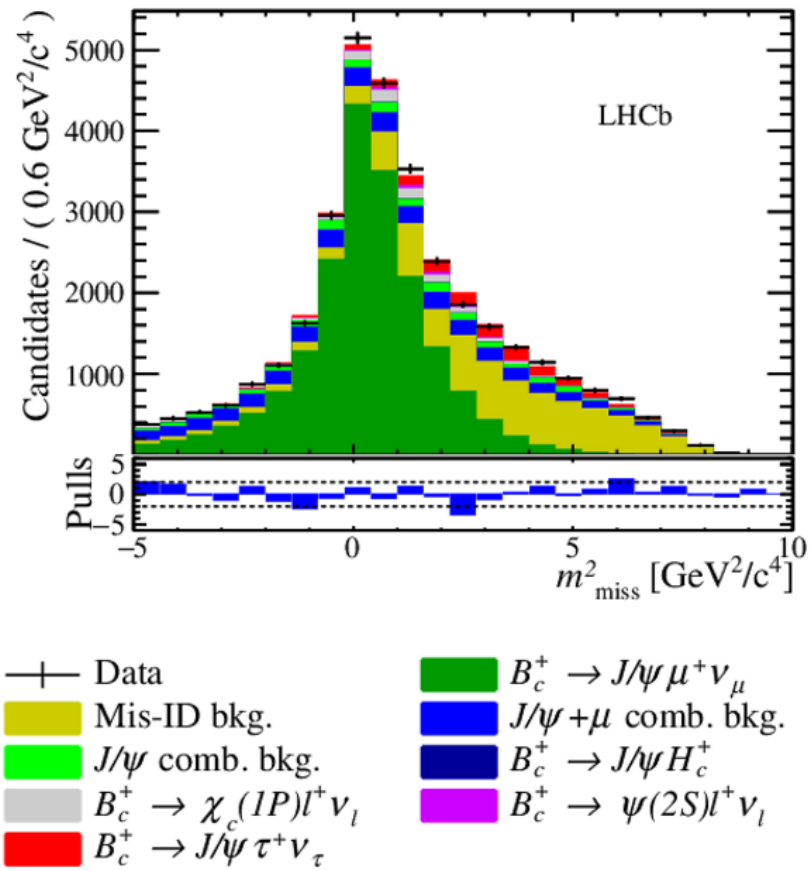
$$\mathcal{B}(B^- \to \mu^-\mu^+\mu^-\nu) < 1.6 \times 10^{-8}, \text{ 95\% confidence level}$$

Motivation for $R(J/\psi)$



- Looking for more LFU measurements with $b \to c\tau\nu$ results to contribute
- The ratio $R(J/\psi)$ is a B_c probe on LFU
- Test of predictions ranging from ≈ 0.25 to ≈ 0.3 for $R(J/\psi)$, depending on the modeling of the form factors
  - See Judd Harrison's slides for a new lattice QCD prediction 0.3050(74)(Preliminary).

Result of $R(J/\psi)$



- Fit in three dimensions, missing mass, decay time and a function Z of q^2 and lepton energy in the B-frame
- The ratio of $R(J/\psi)$ is measured
- Largest systematics are from the lack of knowledge of the form factors and MC statistics
- Less than 2σ above the range of predictions
- arxiv.org/abs/1711.05623

$$R(J/\psi) = 0.71 \pm 0.17(\text{stat}) \pm 0.18(\text{syst})$$

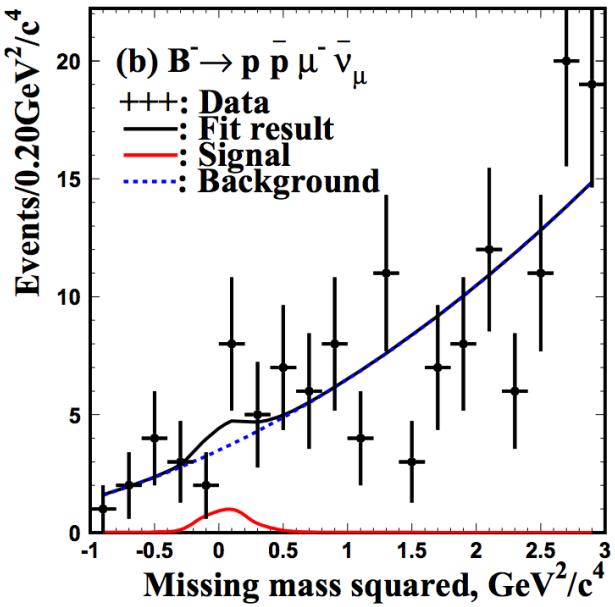
Motivation for $B^- \to p\bar{p}\mu^-\bar{\nu}$

- It is the first observation of a semileptonic decay of a meson to baryons.
- In hadronic decays with a $p\bar{p}$ in the final state a strong threshold enhancement effect is observed. This is a clean environment to study this.
- The first step in the study of the semitauonic ratio measurement $R(p\bar{p})$ is the discovery of the muon mode.
- Evidence provided from the Belle experiment with (3.0σ) for $B^- \to p\bar{p}e^-\bar{\nu}$ and (1.3σ) for $B^- \to p\bar{p}\mu^-\bar{\nu}$.

The branching fraction measurement from the Belle experiment is

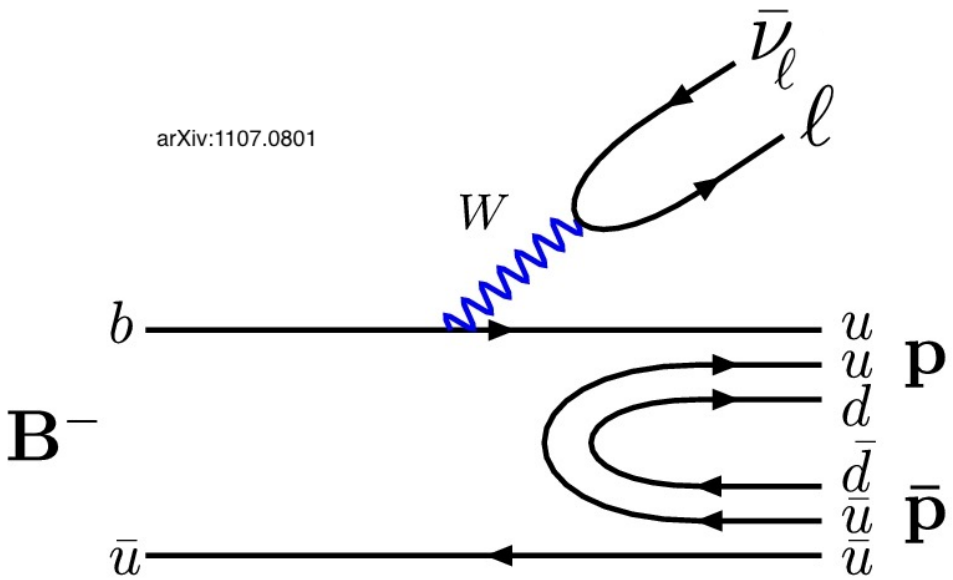
$$\mathcal{B}(B^- \to p\bar{p}\ell^-\bar{\nu}) = (5.8^{+2.4}_{-2.1} \pm 0.9) \times 10^{-6}$$

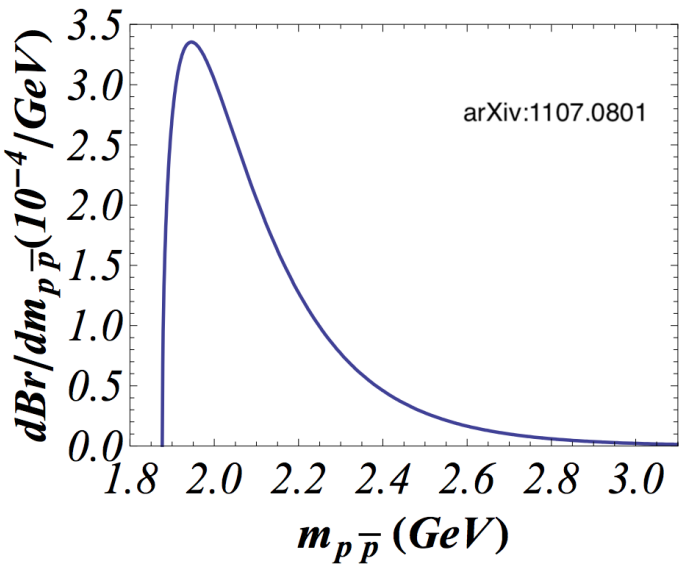
arxiv.org/abs/1306.3353



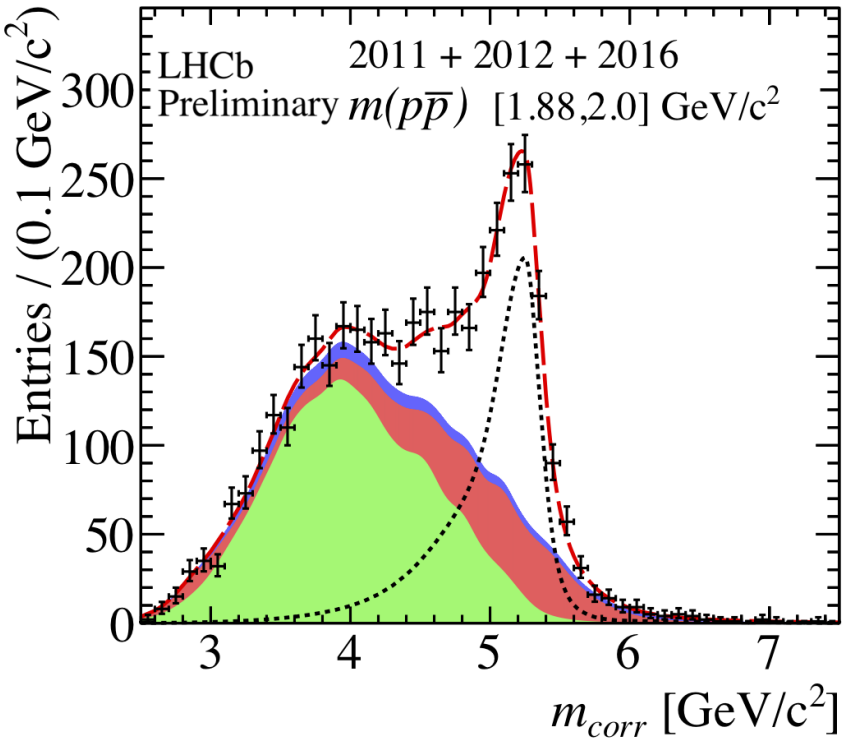
Motivation for $B^- \to p\bar{p}\mu^-\bar{\nu}$

- Prediction using pQCD from Geng and Hsiao arXiv:1107.0801
- Over-prediction of the branching fraction,
  $\mathcal{B}(B^- \to p\bar{p}\ell^-\bar{\nu}) = (1.04 \pm 0.24 \pm 0.12) \times 10^{-4}$
- Contains a prediction for the differential branching fraction as a function of $p\bar{p}$ mass





Preliminary result for $B^- \to p\bar{p}\mu^-\bar{\nu}$



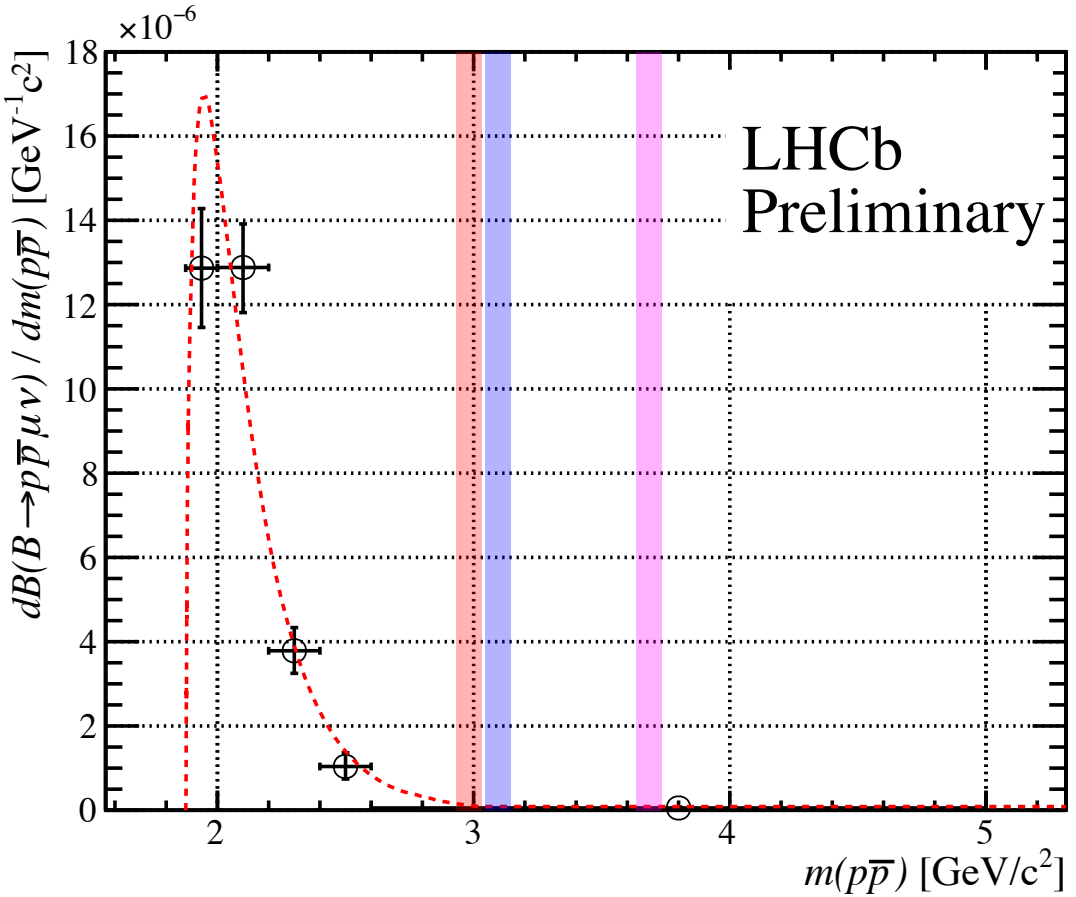
- Fit performed in corrected mass for bins of $m(p\bar{p})$
- Normalised to $B^- \to (J/\psi \to \mu^+\mu^-)K^-$

Preliminary measurement of the branching fraction from LHCb is:

$$\mathcal{B}(B^- \to p\bar{p}\mu^-\bar{\nu}) = (5.27^{+0.23}_{-0.24} \pm 0.21 \pm 0.15) \times 10^{-6}$$

(stat., syst., norm. BF)

Preliminary result for $B^- \to p\bar{p}\mu^-\bar{\nu}$



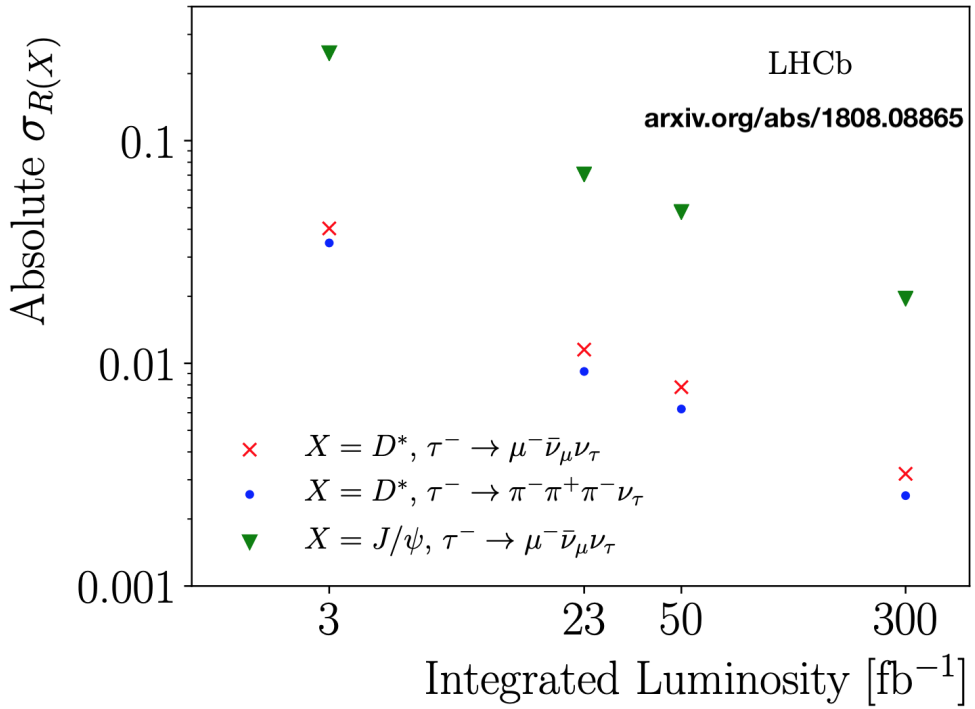
- Differential branching fraction in bins of $m(p\bar{p})$
- Threshold enhancement effect is clearly visible
- Model overlaid is normalised to the observed branching fraction. The shape is compatible with the result

Conclusions

- Limit on the rare decay $B^- \to \mu^- \mu^+ \mu^- \nu$
- Measurement of the B_c semitauonic ratio $R(J/\psi)$
- First observation of $B^- \to p\bar{p}\mu^- \bar{\nu}$ and measurement of its differential branching fraction

But what comes next?

The Future of Semileptonics at LHCb



- More measurements of decays with a $b \to c\tau\nu$ quark transition
- High B production means LHCb can probe rarer and rarer semileptonic decays
- Potential for a $b \to u\tau\nu$ measurement at LHCb with $R(p\bar{p})$

Many more exciting things to come from LHCb semileptonics!