Update on search for $\Lambda_b \to p\mu\nu$

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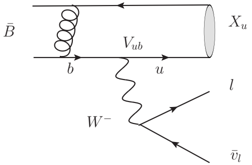
Current Status of $|V_{ub}|$

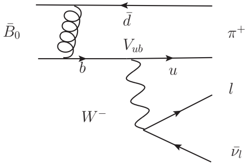
- Semi-Leptonic B Decays:

Inclusive ($\bar{B} \to X_u l \bar{\nu}_l$)



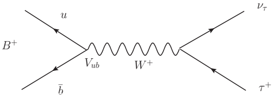
$$|V_{ub}| = (4.41 \pm 0.15^{+0.15}_{-0.17}) \times 10^{-3}$$

Exclusive ($\bar{B}_0 \to \pi^+ l \bar{\nu}_l$)

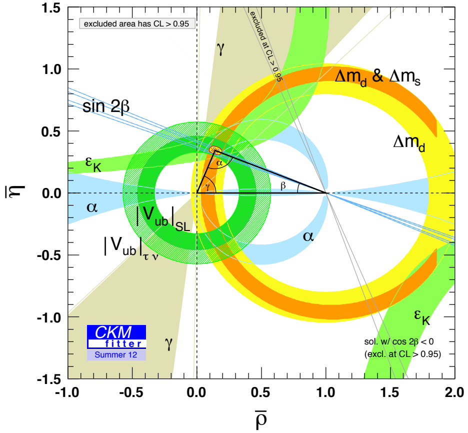


$$|V_{ub}| = (3.23 \pm 0.31) \times 10^{-3}$$

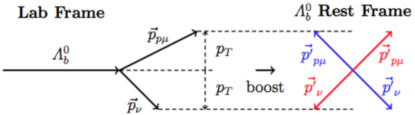
- Leptonic B decays ($B^+ \to \tau^+ \nu_\tau$):

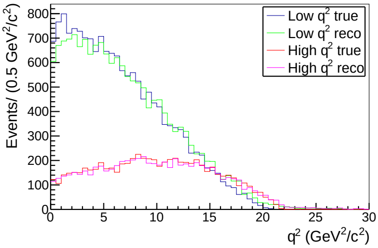


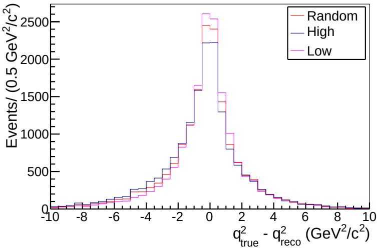
$|V_{ub}|$ Constraints on the Unitarity Triangle



Neutrino Reconstruction

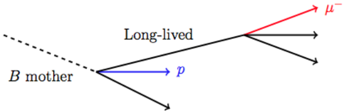






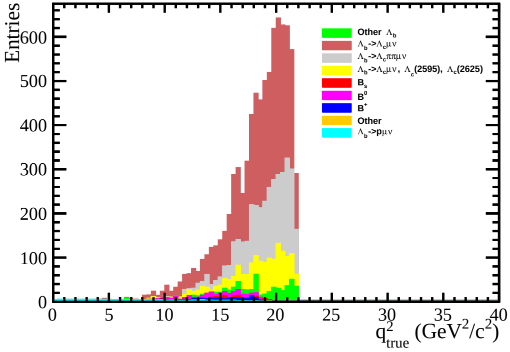
Generator Level Studies

- Generator Level (GL) Sample of 3 million inclusive $b\bar{b}$ events.
- Generator Level Cuts:
  - Within LHCb acceptance
  - At least one lepton with $p_{\mathrm{T}} > 1.5$ GeV/c
- Expect this number of events in $\sim$0.01pb^{-1} at $\sqrt{s} = 7$ TeV.
- Search events for protons and muons produced from the decay of the same B hadron. Ignore protons and muons produced by long-lived intermediaries.

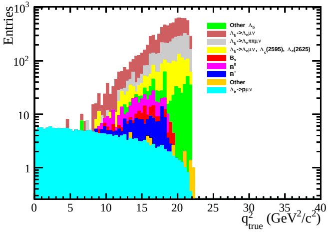


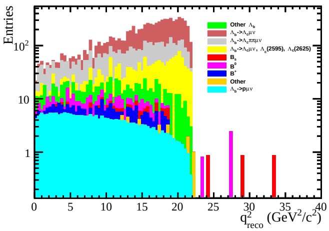
Opposite Sign q^2 Distribution

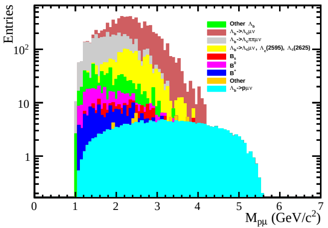
- Plot opposite sign and same sign $p\mu$ combinations.
- Always choose p, $\overline{p}$, μ^+, μ^- with highest momentum.
- Include normalised sample $\Lambda_b \to p\mu\nu$ phase space GL MC.

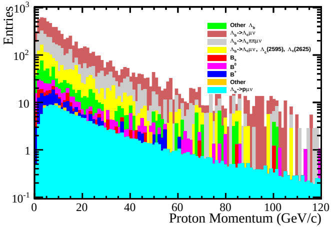


Opposite Sign $p\mu$ Combinatons









Opposite Sign and Same Sign Statistics

- Find 3391 opposite sign and 716 same sign combinations.

For Opposite Sign:

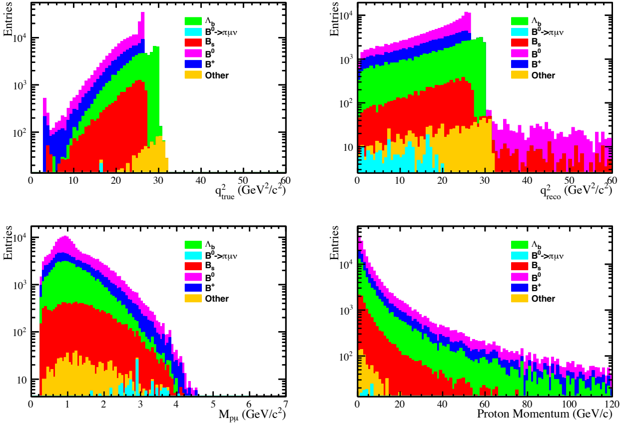
Category	Fraction	Weighted Fraction
B^0	0.055	0.018
B^+	0.031	0.010
B_s^0	0.017	0.006
$\Lambda_b^0 \to \Lambda_c^+ \mu^- \overline{\nu}_\mu$	0.494	0.532
$\Lambda_b^0 \to \Lambda_c^+ \pi^+ \pi^- \mu^- \overline{\nu}_\mu$	0.244	0.262
$\Lambda_b^0 \to \Lambda_c^+(2595) \mu^- \overline{\nu}_\mu$, $\Lambda_b^0 \to \Lambda_c^+(2625) \mu^- \overline{\nu}_\mu$	0.115	0.124
Λ_b^0 other	0.042	0.045
B other	0.002	0.002

For Same Sign:

Category	Fraction	Weighted Fraction
B^0	0.124	0.045
B^+	0.080	0.029
B_s^0	0.018	0.007
Λ_b^0	0.751	0.887
B other	0.027	0.031

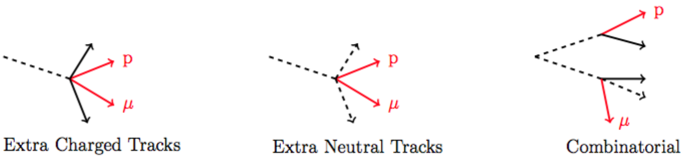
Opposite Sign $\pi\mu$ Combinations

- Can also look for $\pi\mu$ or $K\mu$.



Main backgrounds

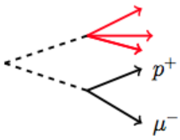
- From generator level studies it is clear that $\Lambda_b^0 \to \Lambda_c^+ \mu^- \overline{\nu}_\mu$ is a major background.
- This makes sense as branching fraction for Λ_c^+ to a proton together with anything else is $50 \pm 16\%$ and $|V_{cb}|^2/|V_{ub}|^2{\sim}100$.



Isolation

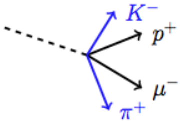
- Train a boosted decision tree to discriminate between charged tracks.
- Use following variables: Track p_{T}, Opening angle, min χ^2_{IP}, Ghost Probability, χ^2_{IP}, Track χ^2 and χ^2_{FD}.

BDT Signal Tracks



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

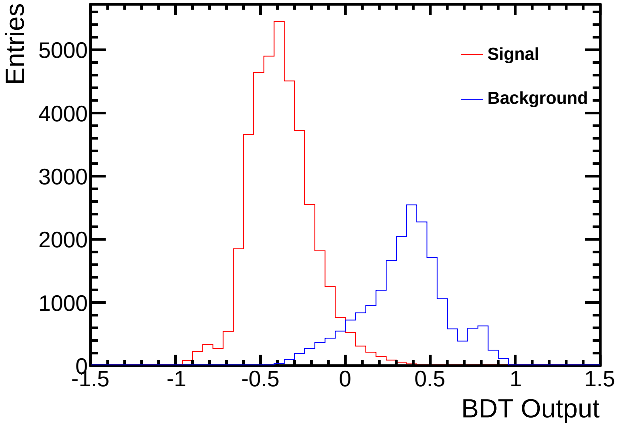
BDT Background Tracks



$\Lambda_b^0 \to \Lambda_c^+(\to pK^-\pi^+)\mu^-\overline{\nu}_\mu$

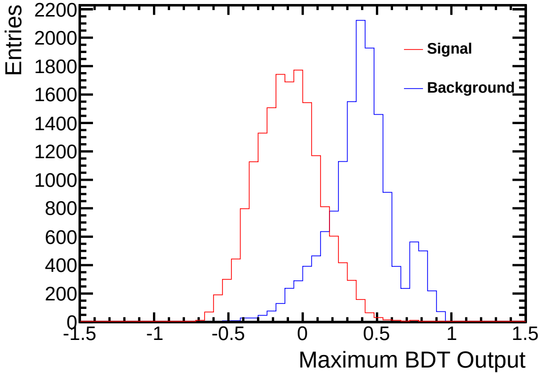
Training Stage

- Train BDT offline on samples.



Running Stage

- Run BDT online on all tracks in event. Store maximum BDT output. for each event

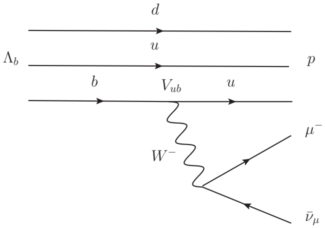


$\Lambda_b \to p\mu\nu$ Form Factors

The tree-level matrix element for this decay may be written as:

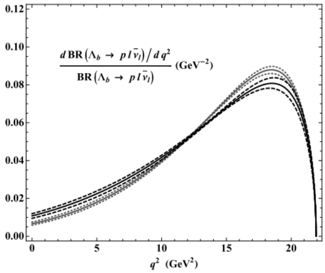
$$\mathcal{M} = -i\frac{G_F}{\sqrt{2}} V_{ub} H_\nu \overline{u}_\mu \gamma^\nu (1-\gamma_5) v_{\nu_\mu}$$

where $H_\nu = < N^+(p',s')|\overline{u}\gamma_\nu(1-\gamma_5)b|\Lambda_b^0(p,s) >$

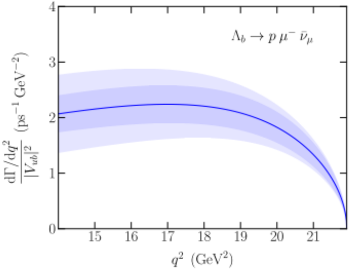


- In general: $H_\nu = \overline{u}_N(p')[F_1^V\gamma_\nu + F_2^V v_\nu + F_3^V v'_\nu + (F_1^A\gamma_\nu + F_2^A v_\nu + F_3^A v'_\nu)\gamma_5]u_{\Lambda_b}(p)$
- Light Cone Sum Rules (LCSR) and Lattice QCD can be used to theoretically predict the 6 form factors.

LCSR, arXiv:1108.2971
A. Khodjamirian et al.

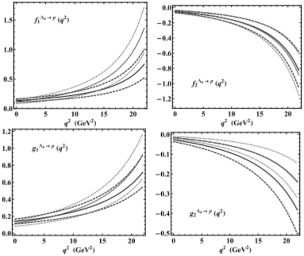


LQCD, arXiv:1306.0446
W. Detmold et al.

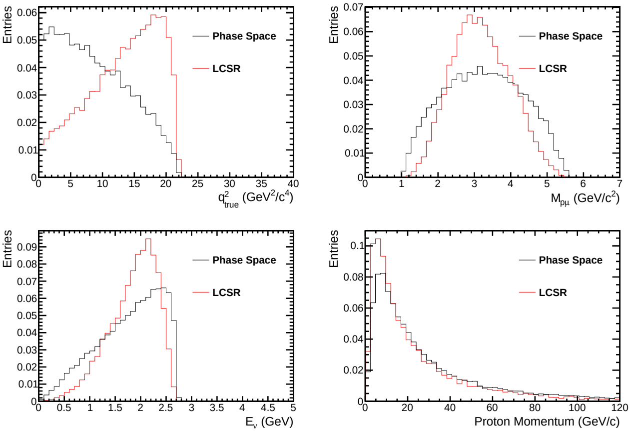


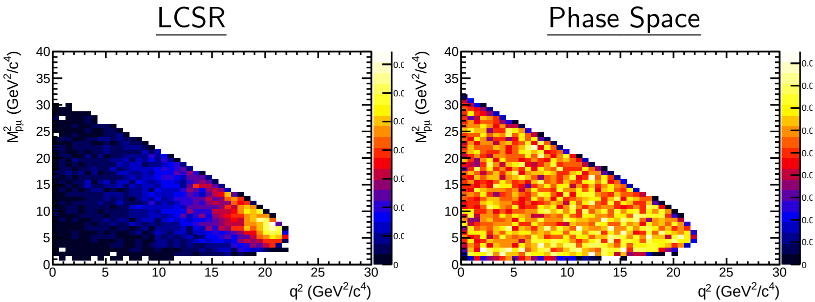
- Theoretical predictions give a very different prediction for the q^2 dependence of the differential rate, $\frac{d\Gamma}{dq^2}$ to the prediction purely based on phase space.
- Create a class in EvtGen to compute the form factors for a given value of q^2.
- Use LCSR predictions provided by arXiv:1108.2971:
- Strong rise at high q^2 compared to $B \to \pi\mu\nu$ as for $\Lambda_b \to p\mu\nu$ width contains only a S-wave phase-space factor (arXiv:1108.2971).

$$
\begin{aligned}
f_i(q^2) &= \frac{f_i(0)}{1 - q^2/m^2_{B^*(1^-)}} \left\{ 1 + b_i \left(z(q^2, t_0) - z(0, t_0) \right) \right\}, \\
g_i(q^2) &= \frac{g_i(0)}{1 - q^2/m^2_{B^*(1^+)}} \left\{ 1 + \tilde{b}_i \left(z(q^2, t_0) - z(0, t_0) \right) \right\}.
\end{aligned}
$$



LCSR and Phase-space generator level MC




LCSR
Phase Space
$M^2_{p\mu}$ (GeV^2/c^4)
q^2 (GeV^2/c^4)

Conclusion

- Generator level studies indicate that the decay $\Lambda_b^0 \to \Lambda_c^+ \mu^- \overline{\nu}_\mu$ and related decay modes will form a major background to this decay.
- Isolation can help reduce backgrounds involving additional charged tracks. Still need to optimise this.
- New MC required which makes use of form factor predictions for $\Lambda_b \to p\mu\nu$.
- Methods for estimating or rejecting the combinatorial background required.