Measuring Monotop Chirality at CMS

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Abstract

The heaviest quark, the top quark, will be produced with a particular property called "chirality" that can be either left-handed (LH) or right-handed (RH) in an interaction related to the dark matter (DM) in the Universe. The handedness can be reflected in several kinematic distributions of the decay products of the top quark ($t \rightarrow W+b$). We choose a ratio of the bottom-quark energy to the top-quark energy, $R=E(b)/E(t)$, to examine the chirality. A study of Monte Carlo simulations is performed to evaluate what would happen at the Large Hadron Collider if there exists a model of particle physics with a new mediating particle that decays into either a LH or RH top quark along with a dark matter particle. The simulation shows that the handedness of the top quark in such a model can be discerned to a high degree of accuracy at the Large Hadron Collider, providing a robust test of the model.

Process Diagram

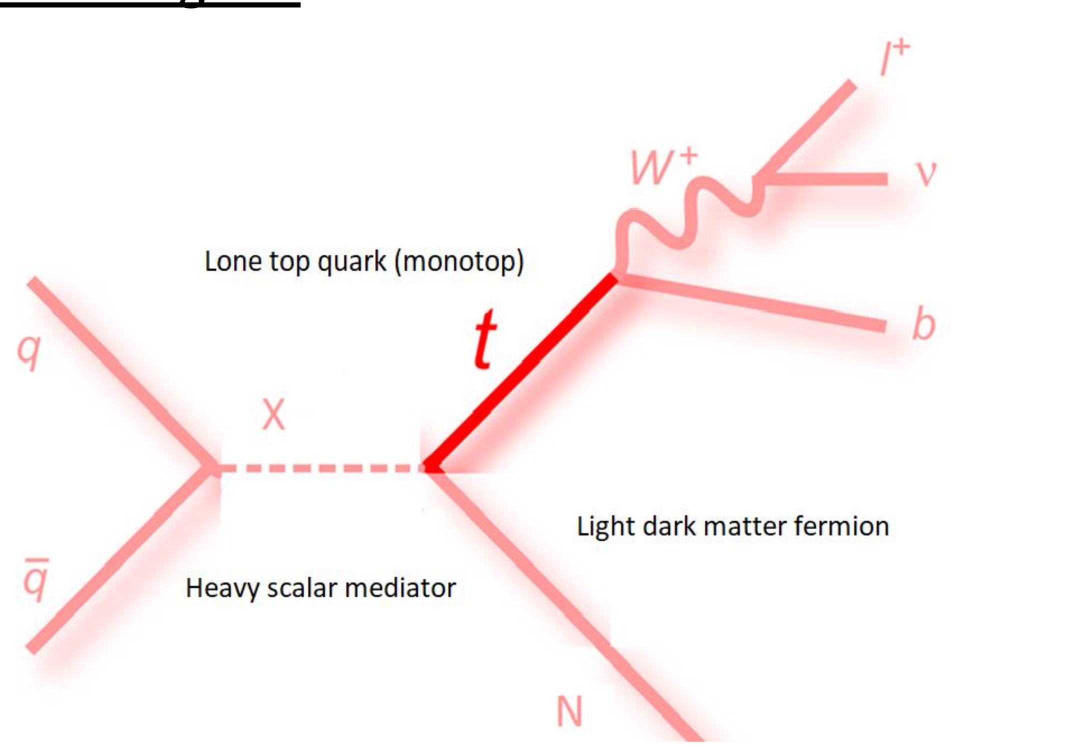
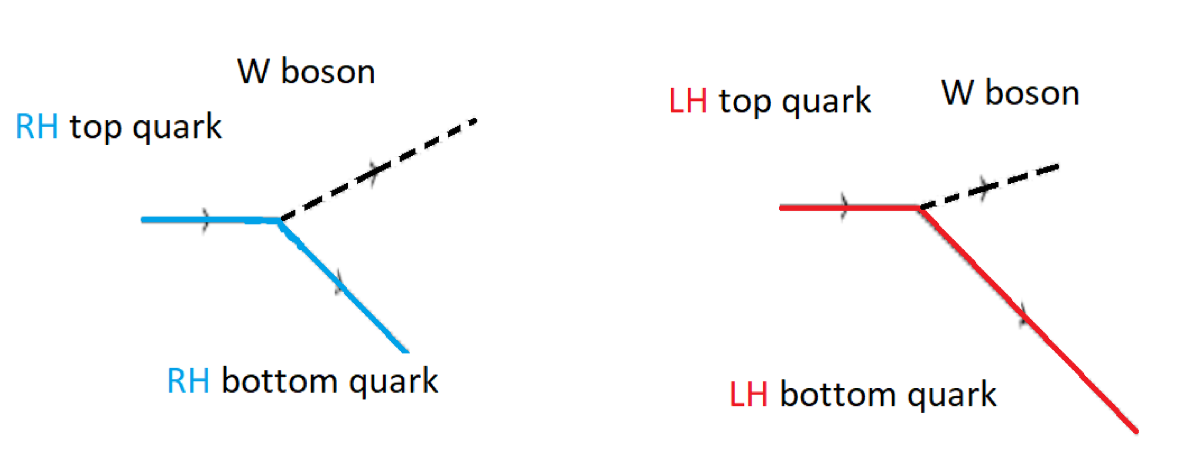


Illustration of the s-channel resonance in the singlet model.



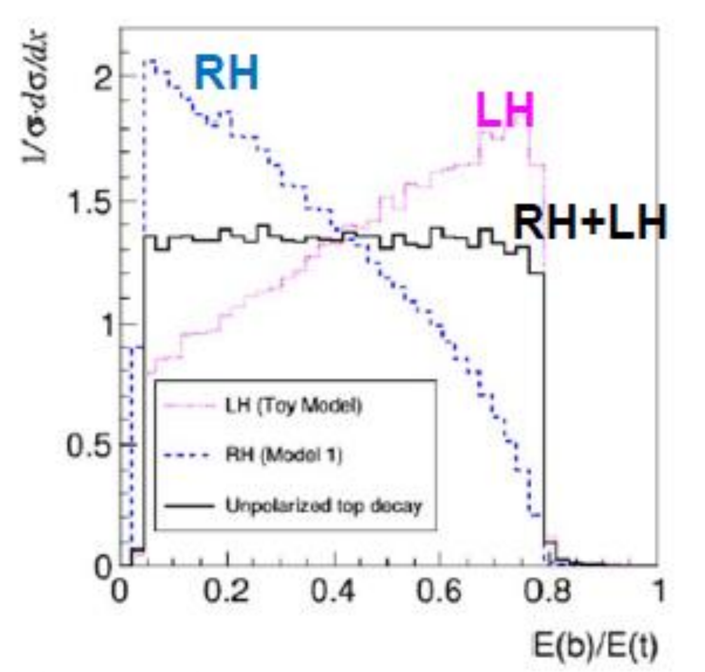
Introduction

The similarity between DM and baryon abundances may be explained by introducing a set of heavy color-tiplet scalars *X* and a light singlet Majorana fermion. *X*'s coupling to 3rd generation quarks allow a monotop final state with large missing energy (MET). *X* can couple to exclusively left handed currents, or exclusively to right handed currents. Given the predicted relative masses of *X* and *N*, during the *X* decay the top quark gets a significant Lorentz boost. The top quark has a large Yukawa coupling, so most tops decay into a longitudinal *W* and a *b* with spin aligned with the parent top's spin. But, the *W* couples only to LH current, which implies that if the top is RH then the *b* quark momentum must be anti-parallel to the spin and align opposite to the Lorentz boost . Similarly, LH tops decay into bottoms with momentum aligned along the Lorentz boost. Therefore, LH tops produce bottoms with more energy than RH tops. This suggests that *R=E(b)/E(t)* discriminates top quark chirality. (Fig. 1)

Methods

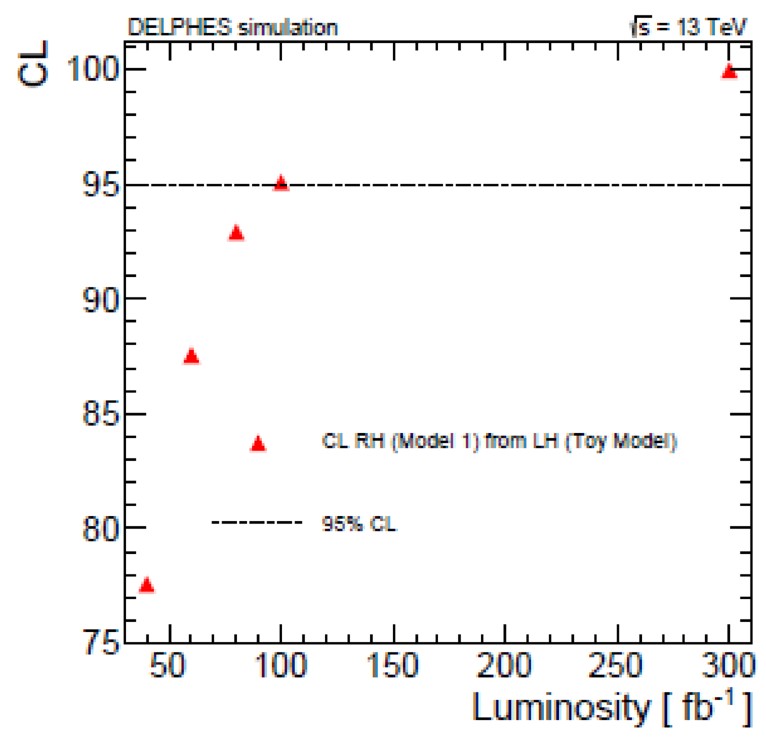
Assume couplings to 3rd generation quarks are on the order of 0.1 (so that a signal may be seen at the LHC). Further, assume that $m_N \approx 1\ GeV$, and $\sigma = 20$ fb for signal production. Simulations were prepared using MadGraph5 v1.5 for three separate mass values of *X*. The toy LH model is made to be identical to the RH model in all respects excepting the chirality. Events with energy ratio above 0.5 are chosen (as a simple way to provide a sensitivity estimation). The separation of the RH and LH distributions are then determined for different beam luminosities. (Fig. 2)

Fig. 1



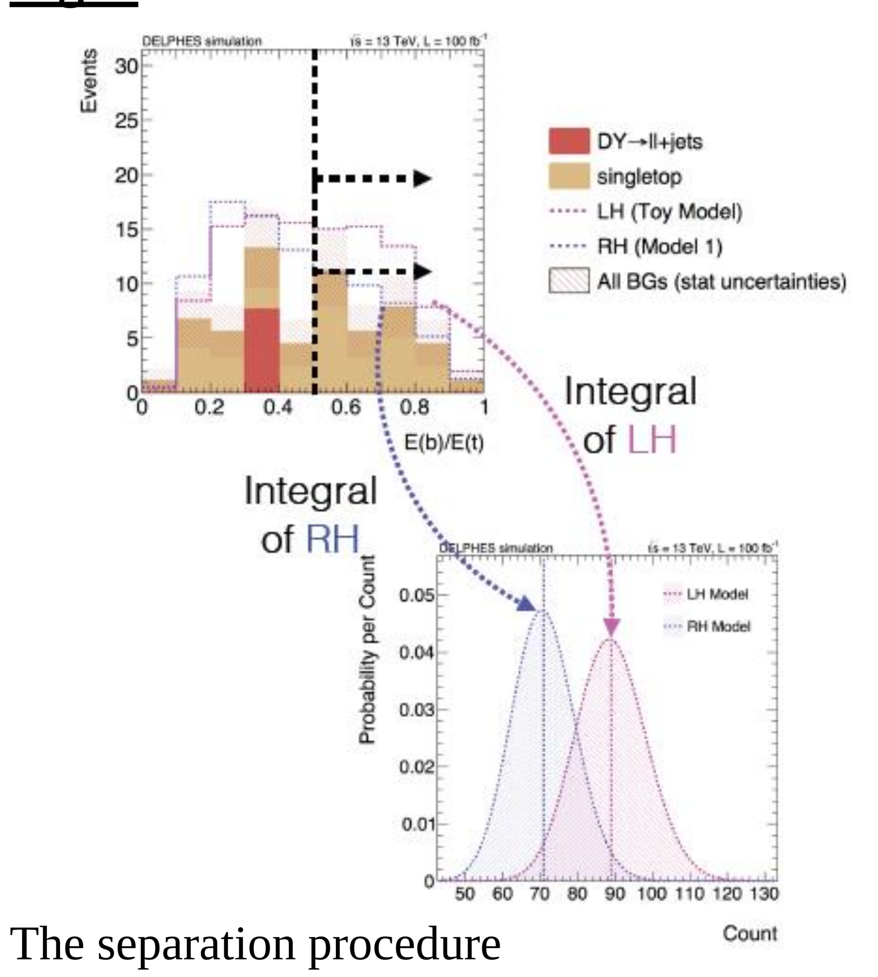
Positive η value suggests LH tops
Negative η value suggests RH tops

Fig. 2



The confidence level in the separation between the RH and LH models is plotted against the luminosity of the beam.

Fig. 3

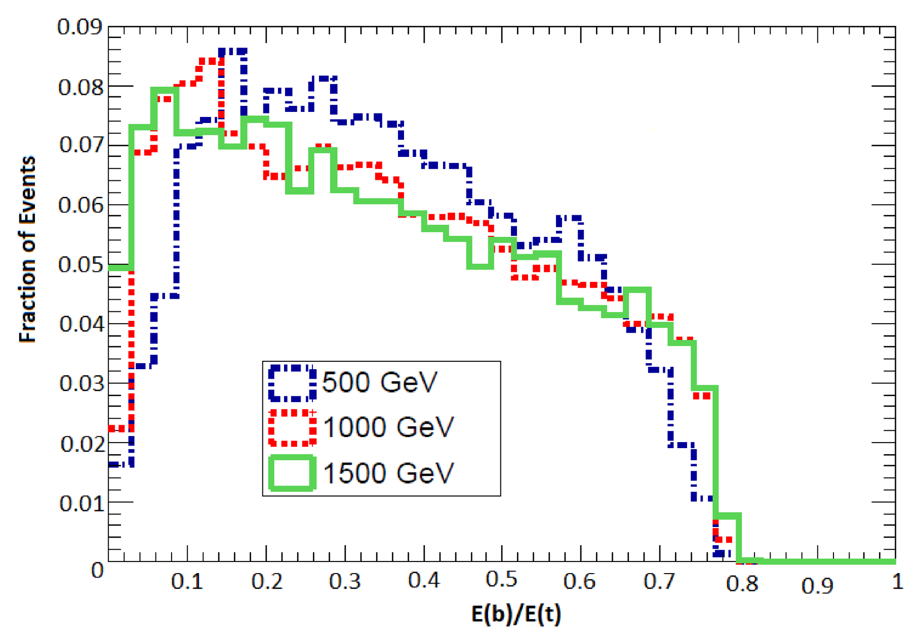


The separation procedure

Conclusion

The cut-and-count procedure is demonstrated in Fig. 3. In a standard model process there are correlations in the top/anti-top pair and their decay products, but the monotop is correlated only with the invisible DM particle. Therefore, new spin analysis methods that bypass final state particle reconstruction are desirable. The energy comparison method also remains valuable for a large range of mass values for *X* (Fig. 4). Many beyond standard model theories postulate chiral couplings between dark matter and quarks, and analyses of top quark polarization which remain uncoupled to other kinematic quantities are useful in general.

Fig. 4



Similarity of the energy distribution for different masses of *X*.

References:

"Distinguishing Standard Model Extensions using Monotop Chirality at the LHC",
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