

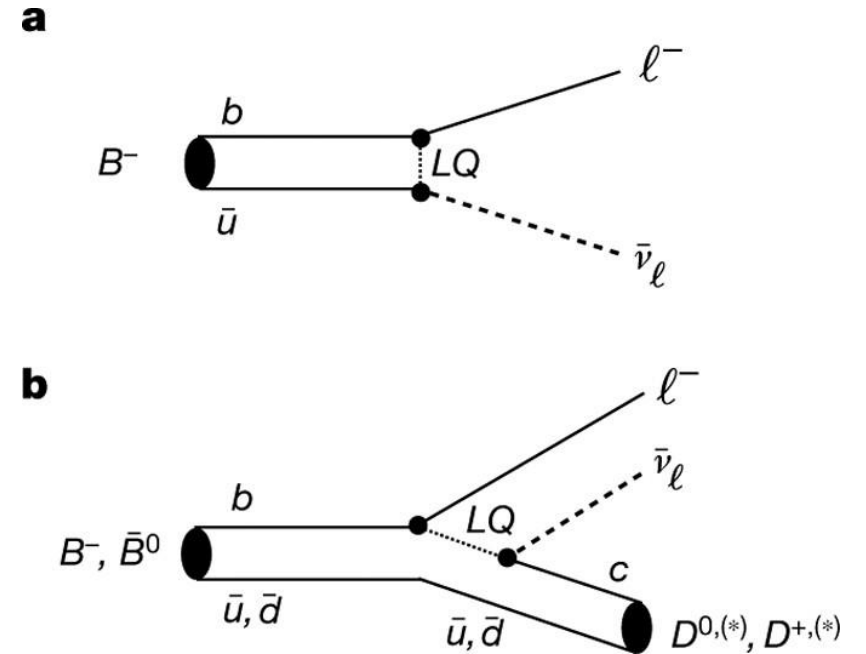
Analysis Sensitivity Test for Novel Asymmetric Leptoquark Pair Production Mechanism

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Introduction

- Leptoquarks (LQ's) are hypothesized BSM particles that have both baryon and lepton number, so they can couple to both quarks and leptons
- The search for LQ's have revived in recent years due to higher energy events at the LHC
- Can help to explain strange behaviors with B-meson decays; main player being lepton flavour universality (LFU)
 - We don't expect it to be violated in these processes, but it seems the case due to discrepancies between theory and experiment



Scalar Leptoquarks

- There are both scalar and vector leptoquarks proposed, but we focus on the scalar leptoquarks, specifically the R2 and S1 LQ's

$$F = 3B + L$$

| $SU(3)_c \times SU(2)_L \times U(1)_Y$ | Symbol | Q-L Chirality | F |
|----------------------------------------|--------|---------------|----|
| $(\mathbf{3}, \mathbf{2}, 7/6)$ | R_2 | RL, LR | 0 |
| $(\mathbf{3}, \mathbf{1}, 1/3)$ | S_1 | LL, RR | -2 |

$$\mathcal{L}_{S_1, \text{int}} = Y_{1,ij}^{RR} \bar{u}_i^c \ell_j S_1^\dagger + Y_{1,ij}^{LL} (\bar{Q}_i^{cT} i\sigma_2 L_j) S_1^\dagger + \text{h.c.}$$

$$\mathcal{L}_{R_2, \text{int}} = Y_{2,ij}^{LR} (\bar{Q}_i^T \ell_j R_2) + Y_{2,ij}^{RL} (R_2^T \bar{u}_i i\sigma_2 L_j) + \text{h.c.}$$



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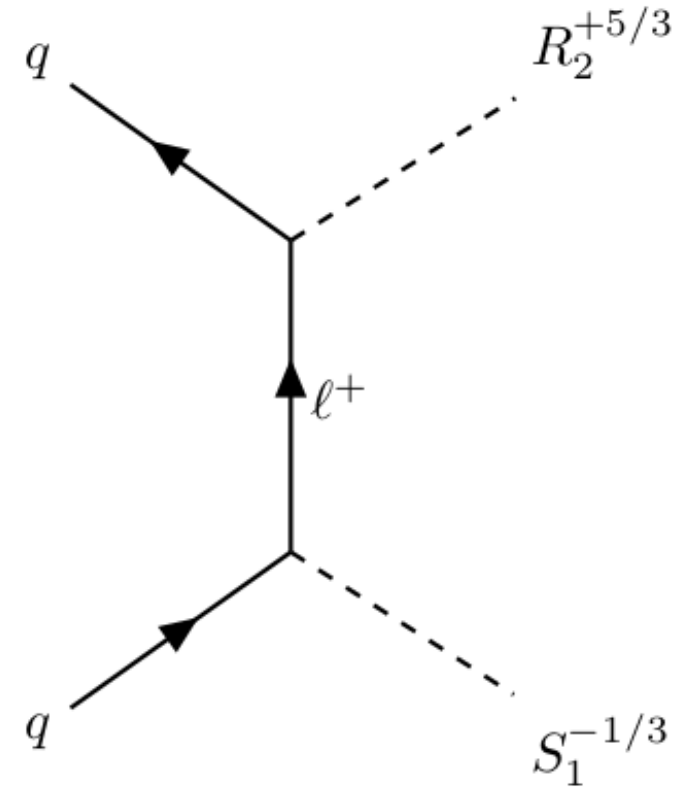
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Novel Asymmetric Production Method

- We will look at a new method that pair produces two different LQ's, as opposed to ordinary charge-conjugate pair
- Desirable qq initial state for LHC
- Requires LQ's to couple to lepton of same chirality and flavor
- Yukawa couplings will determine what these quarks and leptons can/should be

| Symbol | Q-L Chirality |
|--------|---------------|
| R_2 | RL, LR |
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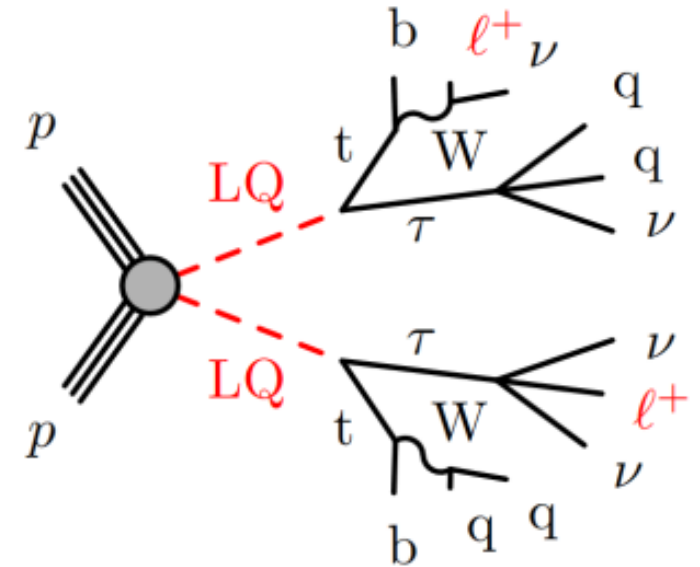


Analysis Channel

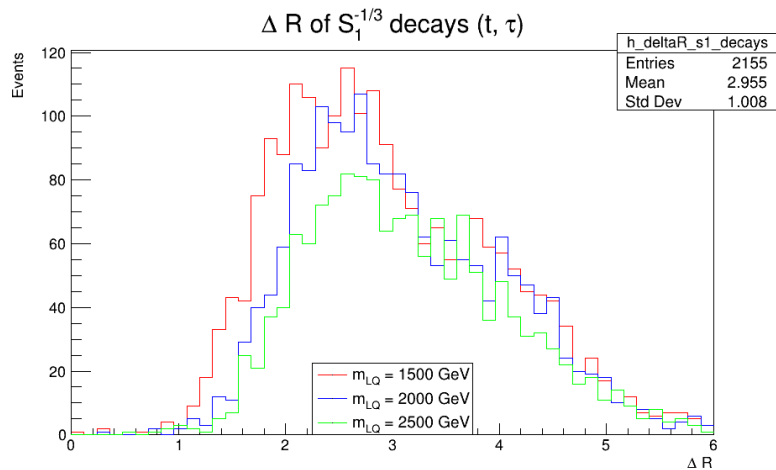
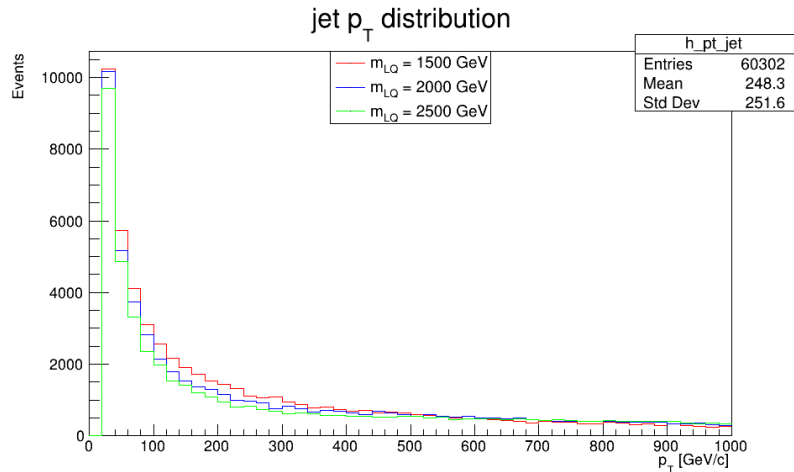
- Our group focuses on the 2ISS+1tau channel/signature; we are in the Tau+X subgroup -> looking at heavy decay products
- To achieve this, we must specify Yukawa couplings such that we have $\beta(LQ \rightarrow t\tau)$ be a sufficient value:

$$Y_{1,i3}^{RR} \neq 0, Y_{2,i3}^{LR} \neq 0$$

- Coupling to only right-chiral 3rd gen leptons -> only the tau
- All quarks to avoid PDF suppression of heavy quark initial states



Test Event Generation and Official MC Request



- **Test our model by generating a small number of samples**
 - Provide it all the necessary parameters, Yukawa couplings, mass points, kinematic cuts, etc.
- **Hard-scattering simulation with MG5_aMC@NLO, showering with Pythia8**
- **Convert final state raw events into readable data**
- **Can then make “validation” plots for the kinematics to ensure model works**
- **Send off an official MC sample request**
 - <https://its.cern.ch/jira/browse/ATLMCPROD-11359>
 - <https://indico.cern.ch/event/1439002/#31-taux-pp-lq-mc-request-1010>



2ISS+1tau Analysis with ttH as Signal



2ISS+1tau Analysis for Rel.22 with ttH as Signal

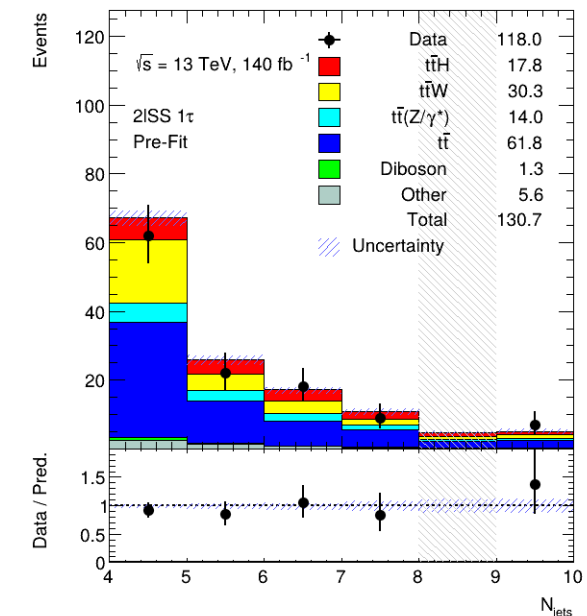
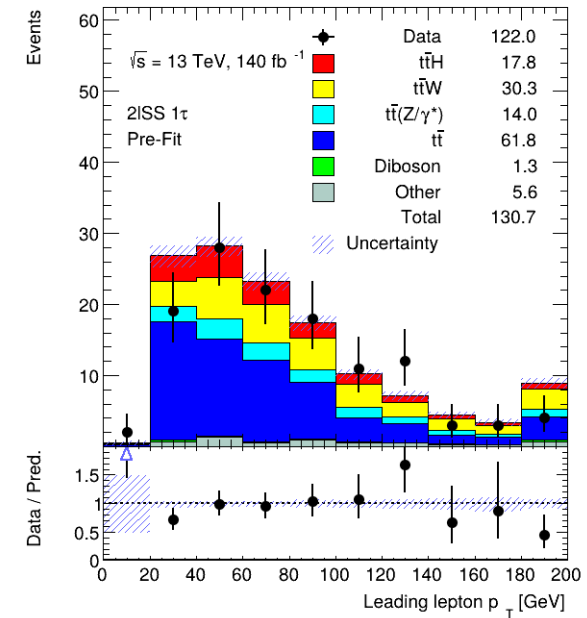
- The full/official LQ samples that we requested were not produced in time
- We still needed to port the previous 2ISS+1tau analysis from Rel.21 to Rel.22
 - Very involved! Many variables changed or were removed entirely; little documentation
- Once we show it works and we get the LQ samples, we just move ttH to background and LQ to new signal

| | | | |
|----|------------------------------------------------------------------|----------------------------------------|-------------------------|
| 0 | + 545824/mc.MGPy8EG_A14N23LO_LQpair_tttautau_m1500_y10_lepfil.py | (FullSim)Mass = 1500 GeV; yukawa=0.5 | events: 100000 |
| | | submitted edit (saved) | |
| T: | running register | register register | Produced events: None |
| 1 | + 545825/mc.MGPy8EG_A14N23LO_LQpair_tttautau_m2000_y10_lepfil.py | (FullSim)Mass = 1600 GeV; yukawa=0.5 | events: 100000 |
| | | submitted edit (saved) | |
| T: | done running | register register | Produced events: 100000 |
| 2 | + 545826/mc.MGPy8EG_A14N23LO_LQpair_tttautau_m2500_y10_lepfil.py | (FullSim)Mass = 1700 GeV; yukawa=0.5 | events: 100000 |
| | | submitted edit (saved) | |
| T: | running register | register register | Produced events: 90000 |

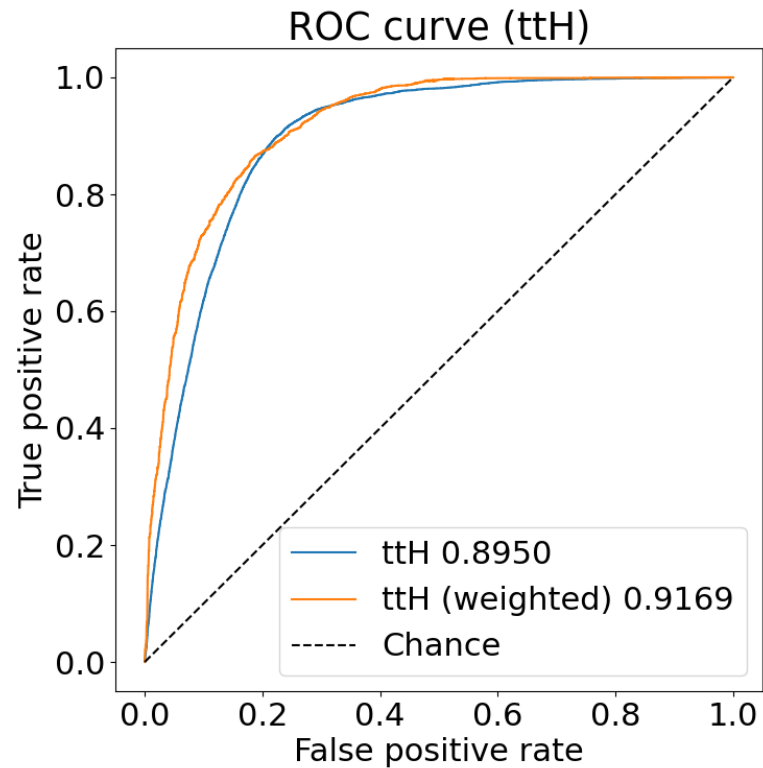


Pre-Fit Plots/Tables

- There are a ton of other processes that can contribute to the 2ISS+1tau channel, such as various Higgs productions, boson production, top quark production, etc.
- We apply weights to have the simulated processes more closely resemble the actual yields in experiment; selections for more kinematic cuts and other things
- More “validation plots”

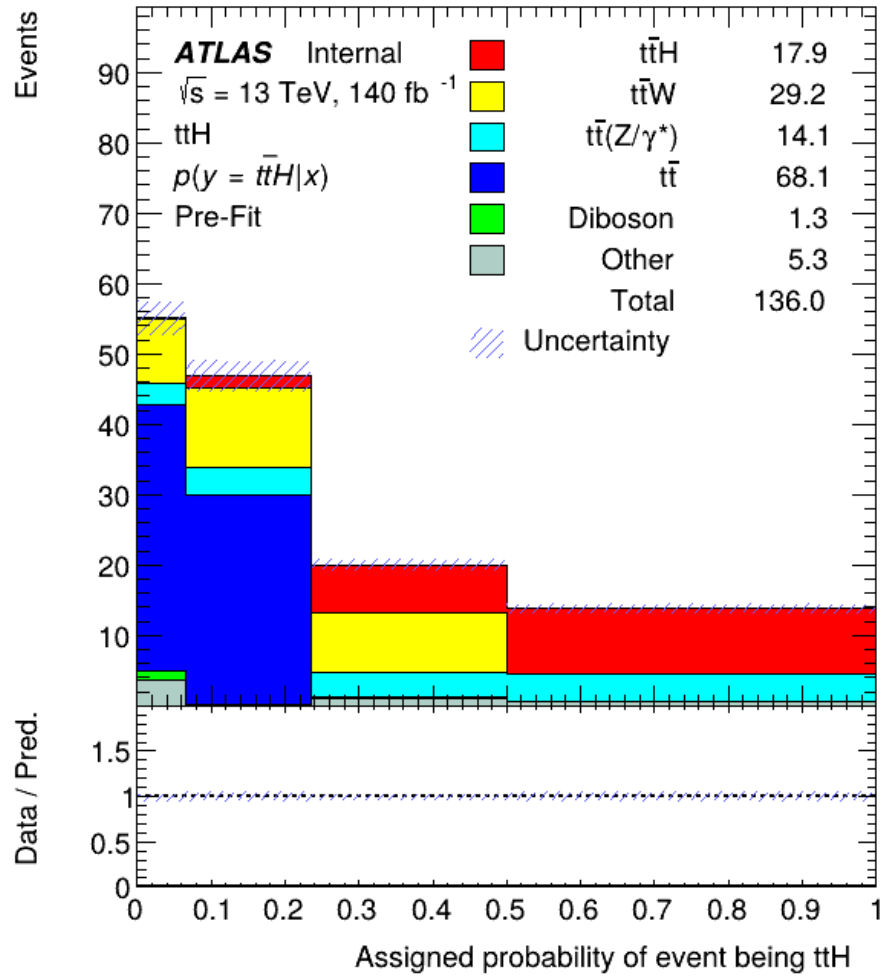


Machine Learning

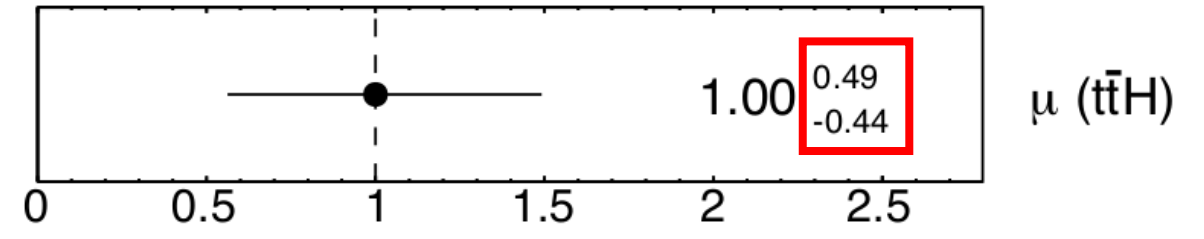


- **Due to the huge number of features in the ntuples, and attractive model for separating signal from background is machine learning**
- **Used a simple ResNet-6 for the training; a more complicated model could be trained for a future analysis**
- **Produces probabilities for events being classified as signal**

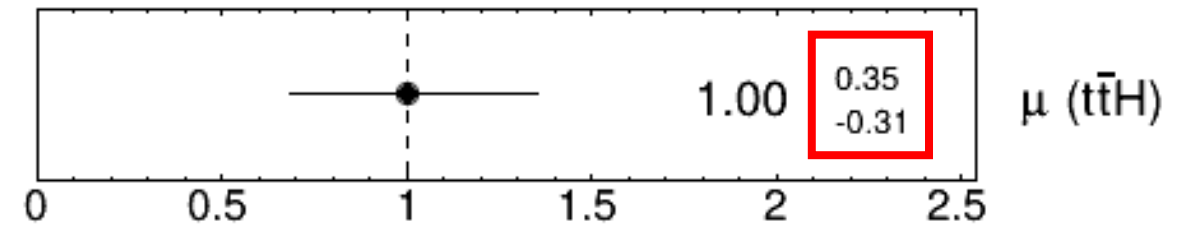




Previous Rel.21



New Rel.22



Conclusions/Next Steps

- **Look further into PLV and prompt variables to aid in classifying fakes; will help to reduce $t\bar{t}$ background, for instance, among many other things**
 - **Fine tune model parameters, perhaps train a better model like a transformer**
 - **Plug in the LQ samples as signal once they are done being produced**
 - **Look into non mass-degenerate LQ's, as well as Yukawa coupling matrix elements that are not equal; we could prioritize the prevalent ones**
-
- **Huge thanks to everyone at UMICH for doing this program, and thanks to all the summer students too for being cool and making the summer super fun!**



References

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