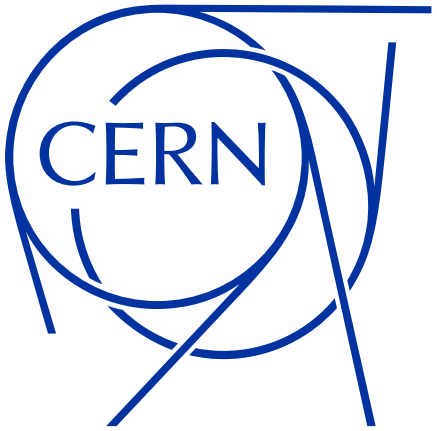


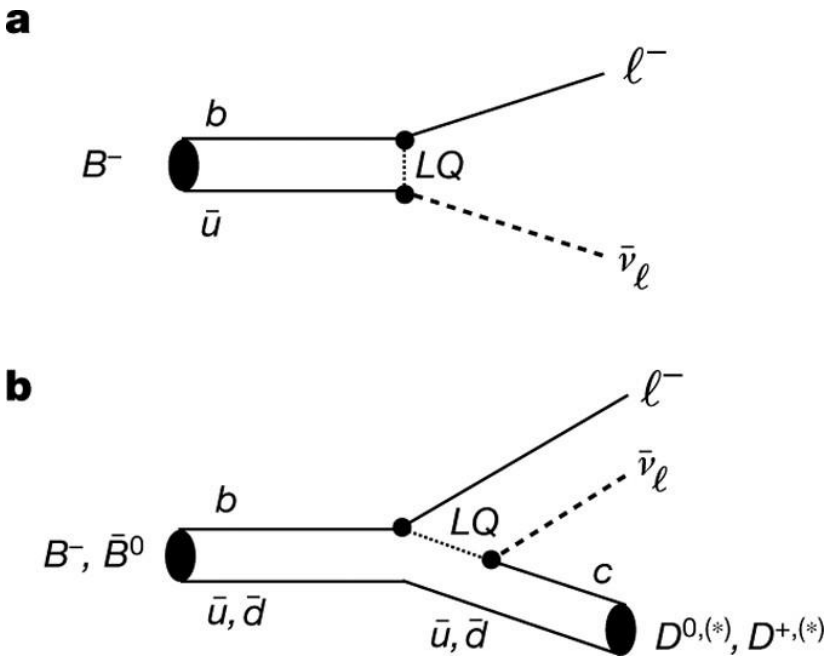
Analysis Sensitivity Test for Novel Asymmetric Leptoquark Pair Production Mechanism

Casey Hampson, André Sopczak

08.08.2024

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**

$$\mathrm{F} = 3\mathrm{B} + \mathrm{L}$$

$SU(3)_c \times SU(2)_L \times U(1)_Y$	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

$$\mathcal{L}_{S_1,\mathrm{int}} = Y^{RR}_{1,ij}\bar{u}^c_i \ell_j S^\dagger_1 + Y^{LL}_{1,ij}\left(\bar{Q}^{c\intercal}_i i\sigma_2 L_j\right) S^\dagger_1 + \mathrm{h.c.}$$

$$\mathcal{L}_{R_2,\mathrm{int}} = Y^{LR}_{2,ij}\left(\bar{Q}^T_i \ell_j R_2\right) + Y^{RL}_{2,ij}\left(R^\intercal_2 \bar{u}_i i\sigma_2 L_j\right) + \mathrm{h.c.}$$

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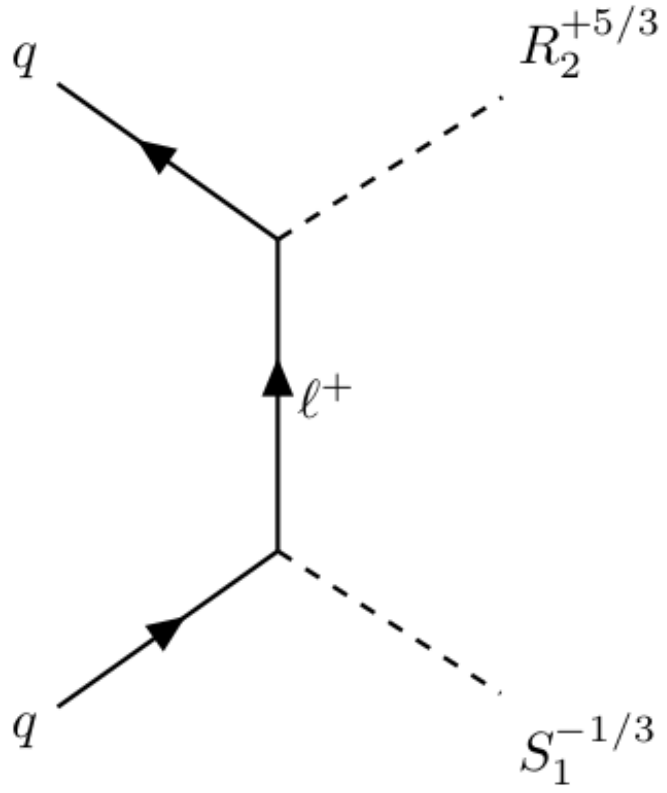
$$\mathcal{L}_{R_2,\text{int}} = Y_{2,ij}^{LR}\left(\bar{Q}_i^T \ell_j R_2\right) + Y_{2,ij}^{RL}\left(R_2^\intercal \bar{u}_i i\sigma_2 L_j\right) + \text{h.c.}$$

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	$RL,\ LR$
S_1	$LL,\ RR$

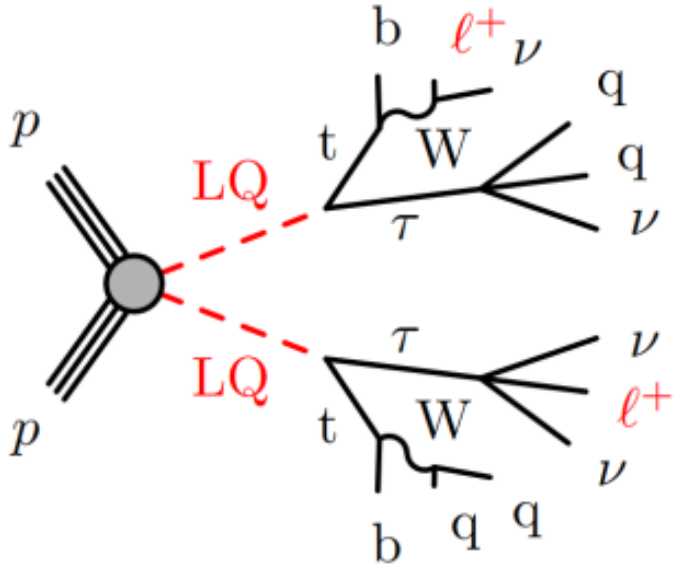


Analysis Channel

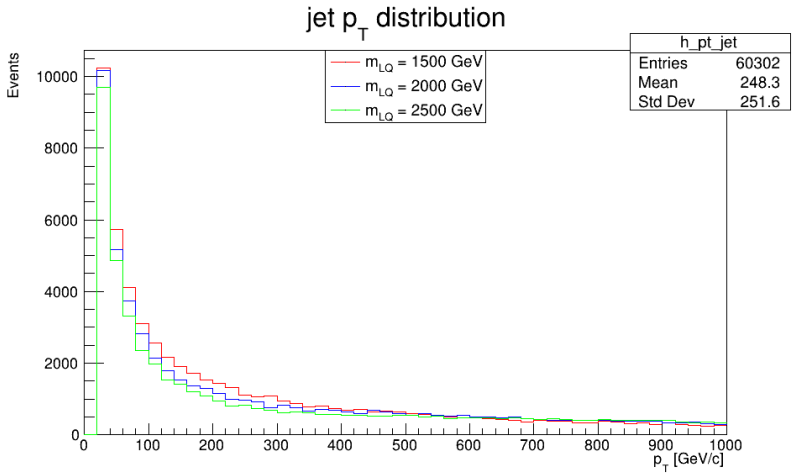
- **Our group focuses on the 2lSS+1tau channel/signature; we are in the Tau+X subgroup -> looking at heavy decay products**
- **To achieve this, we must specify Yukawa couplings such that we have $\beta(LQ \to t\tau)$ be a sufficient value:**

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

- **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

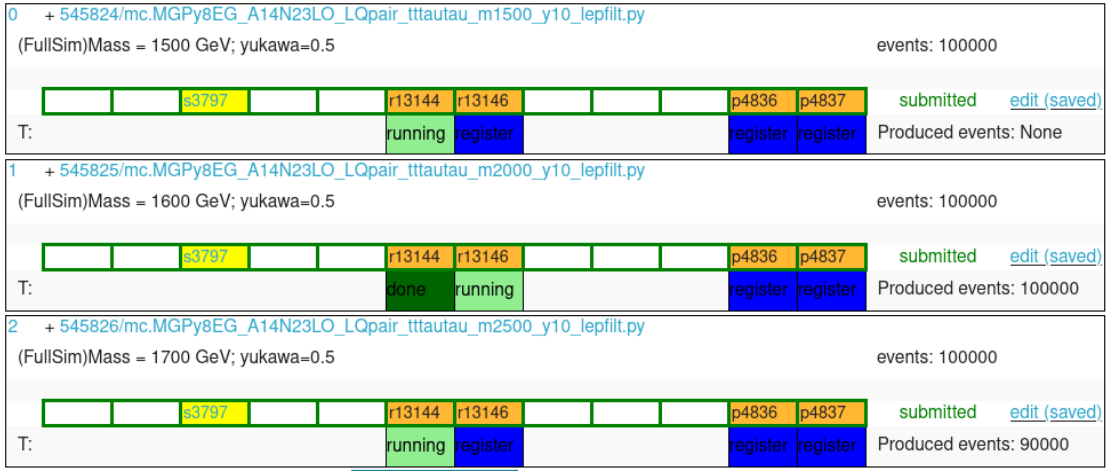


- **Test our model by generating a small number of samples**
  - Provide it all the necessary parameters, Yukawa couplings, mass points, kinematic cuts, etc.
- **Hard-scattering simulation with MG5_aMC@NLO, showering with Pythia8**
- **Convert final state raw events into readable data**
- **Can then 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

2lSS+1tau Analysis with ttH as Signal

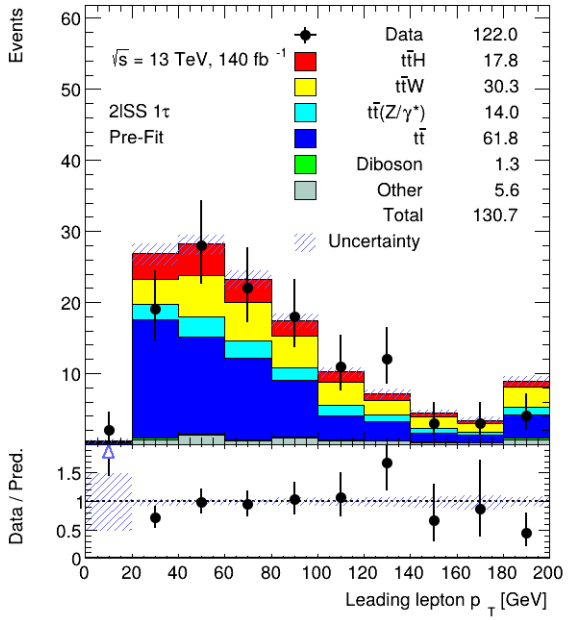
2lSS+1tau Analysis for Rel.22 with ttH as Signal

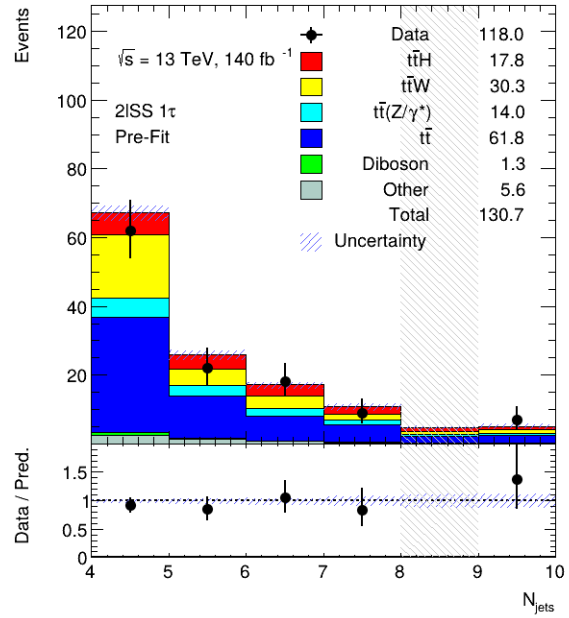
- **The full/official LQ samples that we requested were not produced in time**
- **We still needed to port the previous 2lSS+1tau analysis from Rel.21 to Rel.22**
  - Very involved! Many variables changed or were removed entirely; little documentation
- **Once we show it works and we get the LQ samples,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



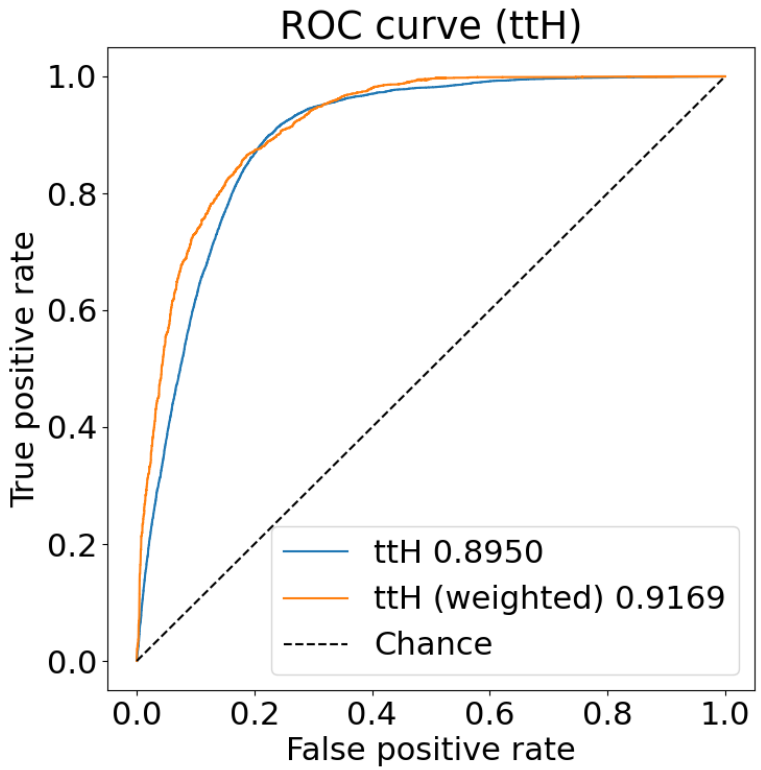
Pre-Fit Plots/Tables

- There are a ton of other processes that can contribute to the 2lSS+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”

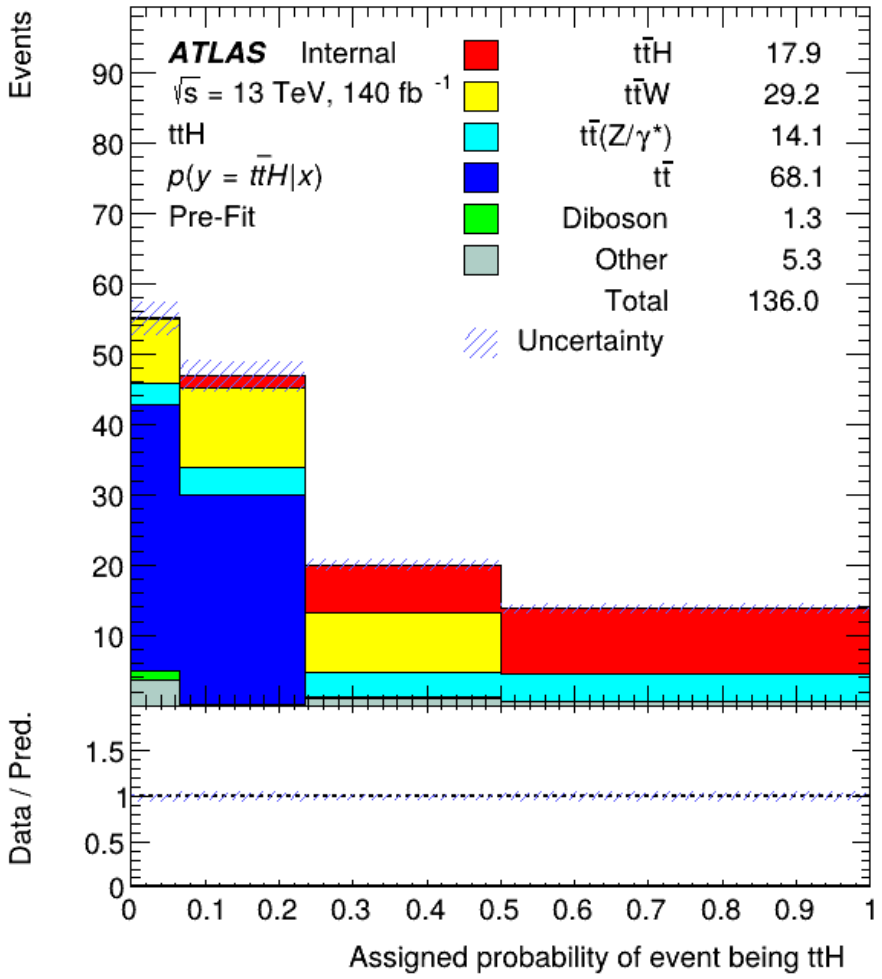




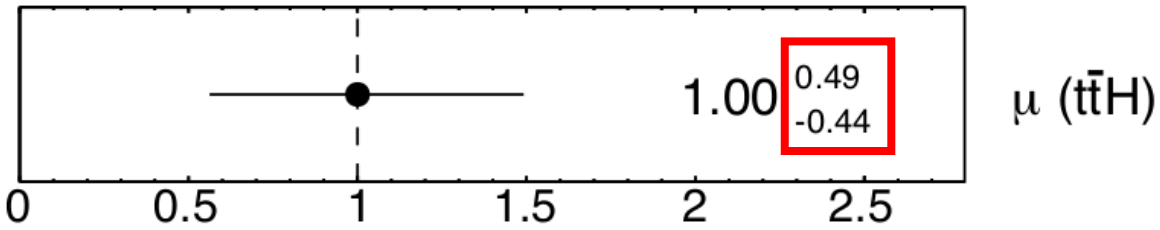
Machine Learning



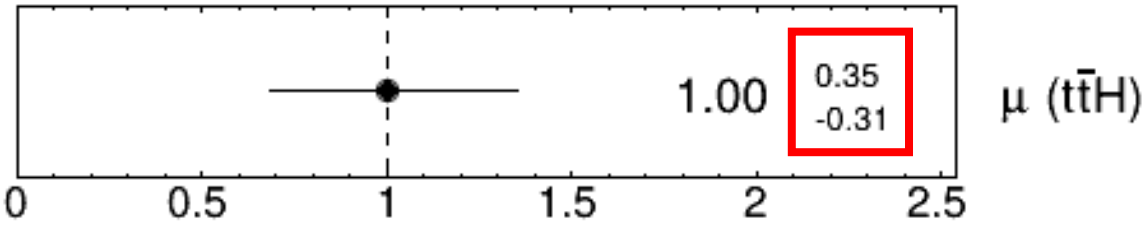
- Due to the huge number of features in the ntuples, and attractive model for separating signal from background is machine learning
- Used a simple ResNet-6 for the training; a more complicated model could be trained for a future analysis
- Produces probabilities for events being classified as signal



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 tt 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!

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