Oct 25th, 3:00 PM - 5:00 PM

Search for pair production of vector-like quarks in CMS Run 2 data

Julie Hogan
j-hogan@bethel.edu

Search for VLQ pair production in single lepton events from CMS Run 2

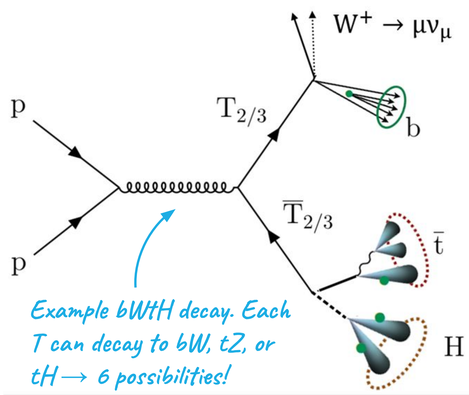
Dr. Julie Hogan, B. Burgstahler, C. Holz, S. Johnson, G. Knefelkamp, B. Luetke, E. Scharnick
Bethel University

Vector-Like Quarks

The **Compact Muon Solenoid experiment** (CMS) at the CERN Large Hadron Collider records proton-proton collision data in order to study the particles and forces that exist in very high energy conditions. The discovery of the Higgs boson in 2012 was a triumph for the field of particle physics, but pointed toward the **probable existence of unknown high-mass particles.**

Vector-like quarks (VLQs) are heavy fermions that are predicted in several "new physics" models. Their decays to lighter particles like bottom or top quarks and W, Z, or Higgs bosons create exciting detector signatures that we can search for in CMS.

The VLQs "T" & "B" would be similar to standard model t & b quarks → but much much heavier!



Event Selection

We select events with 1 electron or muon, missing energy, and several large-radius jets. A jet's parent particle is identified by a Deep Neural Network called "DeepAK8"[1].

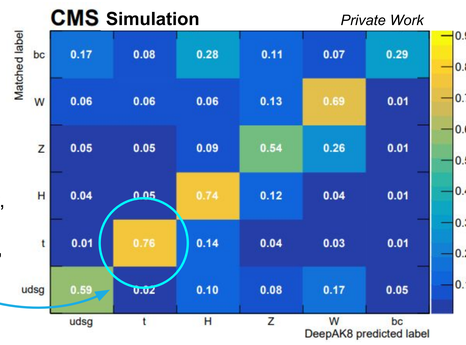
Leptons:

- One tight electron/muon
- No extra loose leptons
- "Missing" pT >= 50 GeV
  - Imbalance of momentum in the event
  - Represents undetected particles like neutrinos

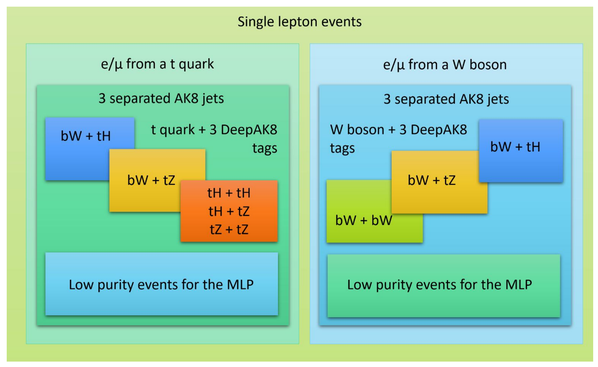
Jets (quark showers):

- Total jet p_T >= 510 GeV
- 3+ large jets required
- DeepAK8 particle labels
  - W boson, Z boson, Higgs boson, top quark, bottom quark, or "other"
  - Very good at separating t, W, Z, and H from each other!

In simulation, DeepAK8 labels 75% of top quark jets correctly!



Event Categorization



Information from the lepton and DeepAK8 jet labels can be combined to identify which b, t, W, Z, and H particles were found.

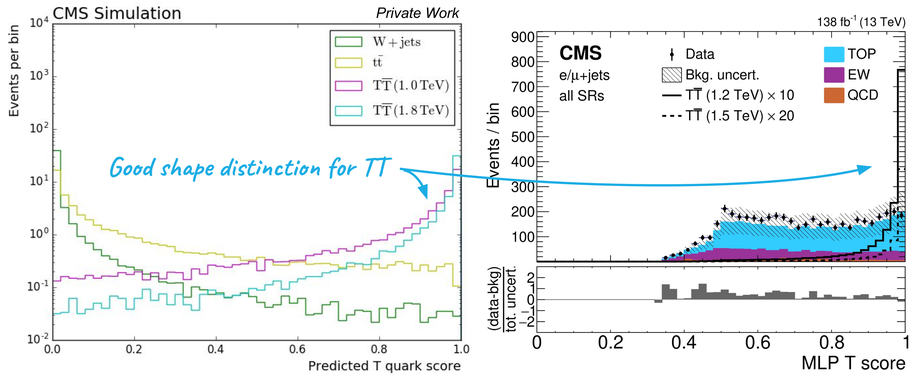
High purity: events with 2 bW, tZ, tH pairs
Low purity: all others. Train a neural net!

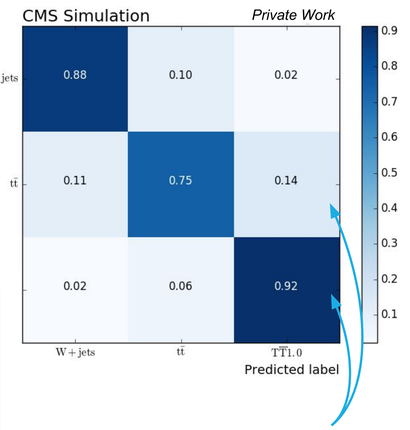
Dividing events into categories gives more statistical power when fitting the data.

Deep Neural Network Training and Optimization

To separate signal from background in low purity categories, we trained a **MultiLayer Perceptron (MLP) Network** using scikit-learn [2].

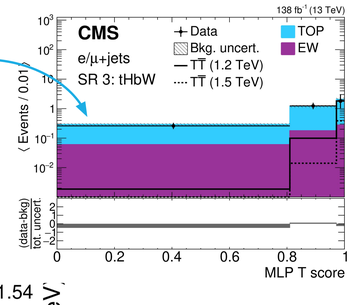
- Fully-connected deep neural network that can handle multiple labels
- **Trained to separate T or B signal from top pair and W boson backgrounds**
- Architecture has 3 hidden layers with 10 nodes, given 16 training observables
- Optimized for high accuracy and high "F1" score to help reduce false positives

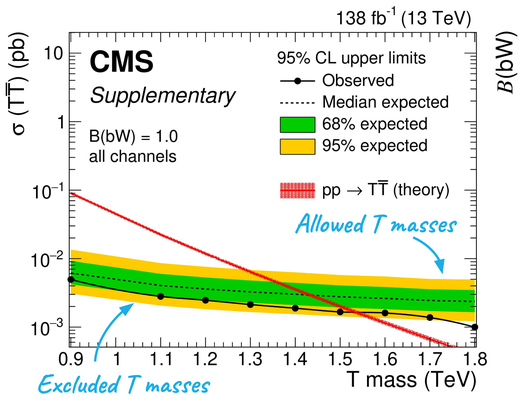


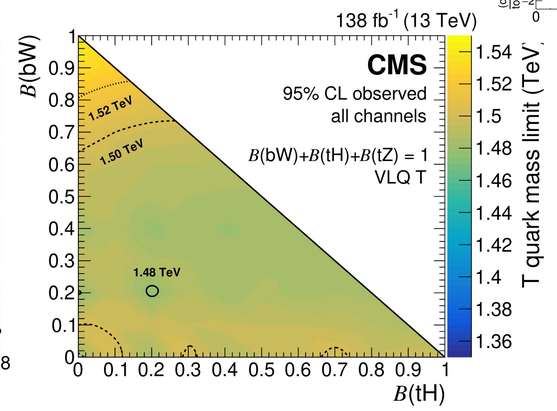


Results

To search for production of T & B quarks, we study the T or B score distribution in each of the event categories. Low purity events are separated based on how many t quark, H boson, or Z boson jets appear. The signal distribution peaks sharply near values of 1, but **data is consistent with the standard model background prediction**. The full search combines single lepton events with same-sign dilepton and multilepton events [3].







6 Bethel student authors!
S. Johnson '19
G. Knefelkamp '19
B. Burgstahler '20
C. Holz '21
E. Scharnick '21
B. Luetke '22

This search excludes VLQ pair production for T quark masses up to 1.54 TeV and B quark masses up to 1.56 TeV, depending on the decay scenario. For *all* decays, T quark masses below 1.48 TeV are excluded. These are the strongest limits to date for T quarks and B quarks that decay to tW!

[1] JINST 15, P06005 (2020). [2] JMLR 12, pp. 2825-2830 (2011). [3] JHEP 07 (2023) 020.

Funding for this project was provided by Bethel University and National Science Foundation Award #1806415.